Opportunities to Apply Remote Sensing in Boreal/Arctic Wildfire Management & Science: A Workshop

Supported by NASA Applied Sciences (Wildfire) Program

ALASKA FIRE SCIENCE CONSORTIUM

JOINT FIRE SCIENCE PROGRAM

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Prepared by the Alaska Fire Science Consortium on behalf of the workshop participants

International Arctic Research Center, University of Alaska Fairbanks

May 2019

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AFSC thanks the workshop participants for their enthusiasm and interest, Terrence Cole for his memorable evening presentation, the UAF International Arctic Research Center for supporting catering, Toni Shover and her staff for catering management, Donald Crocker and the UAF Pub staff for accommodating the poster session, and Tina Buxbaum and Dawson Foster for their assistance throughout the workshop.

Contents

Executive Summary

A three-day workshop was held at the University of Alaska Fairbanks April 4-6, 2017. The interagency, international workshop was hosted by the Alaska Fire Science Consortium (AFSC; sidebar page 3) with funding from the NASA Applied Sciences Program to bring science users and producers together to explore new opportunities for applied remote sensing research in boreal and arctic fire management.

Our objectives included fostering co-developed investigations into new management, strategic, and scientific uses of remote sensing data, increasing the scientific foundation and operational efficiency of high northern latitude (HNL) fire management, and improving understanding of climate-induced changes in HNL fire regimes and ecosystem components and potential feedbacks to the global climate system.

We hope the workshop's discussions and outcomes lead to expanded application and use of remotely sensed data for fire management and fire science in HNL countries.

All workshop materials, including the agenda, links to presentation files, and other information are located at https://www.frames.gov/event/426755. Recordings of 36 oral presentations can also be accessed at: https://vimeo.com/album/5021391.

Sunrise over workshop venue on University of Alaska Fairbanks (UAF) campus. UAF is at 64.8° N. (R. Jandt)

Introduction

Climate change is having a profound effect on high northern latitude ecosystems and fire regimes. There are documented impacts to burn extent, seasonality, ignitions, vegetation and soil moisture, and fire behavior; these have consequences for fire risk and danger, successional trajectories, and the legacies of permafrost and carbon stores in high-latitude forests and tundra, as well as for fire protection agencies and communities. Model projections indicate that the northern latitudes will face more extensive and intense fire behavior over much of the boreal forest and tundra (sidebar page 5).

In Alaska, agencies tasked with protection of communities and natural resources have identified a relatively small set of strategies to adapt to the reality of managing a more active fire environment (AFSC workshop Fall 2015) in the face of declining budgets (Congressional Research Service 2017). These include:

- protecting communities at risk by expanding the use of fuels management projects,
- increasing efficiencies in their already lean operations,
- improving the science inputs to their decision-making, and
- expanding their use of data from remotely sensed sources.

Issues of scale and the size and inaccessible nature of many wildfires make remotely sensed data an important and widely applied resource for fire science and management (Lentile et al. 2006). Remotely sensed data can supplement surface weather observations and support models for fire risk and fuel drying used in fire management agency decision-making. Near real-time remotely sensed data—notably MODIS and VIIRS—(sidebar page 8) have been widely adopted to detect and monitor wildfires. Histories from remote sensing libraries, now decades old, can be used to establish fire climatologies, frequencies, and scales of impact.

Alaska Fire Science Consortium

Based at the International Arctic Research Center of the University of Alaska Fairbanks, the Alaska Fire Science Consortium (AFSC) has been funded by the Joint Fire Science Program since 2009 as part of its national Fire Science Exchange Network to accelerate the awareness, understanding, and adoption of wildland fire science information by managers within ecologically similar regions. As part of this collaborative network, AFSC works directly with Alaska's interagency wildland fire management community to support their decisions with the best available science. More information on AFSC is available at akfireconsortium.uaf.edu.

Figure 1. The Alaska Fire Science Consortium is one of 15 members of the Joint Fire Science Program's Fire Science Exchange Network. More information is available at https://www.firescience.gov/

Ambrosia Report

In a report to the Interagency Arctic Research Policy Committee—Wildfires Collaboration Team (WCT), Ambrosia et al. (2014) identified 16 different satellite or airborne sensor systems with utility for fire heat detection. Their report only considered sensor systems with spectral observation capabilities in the visible, near-infrared, middle-infrared and thermal infrared portions of the electromagnetic spectrum. Not included were platforms with active and/or passive radar capabilities like Canada's RADARSAT2 or NASA's recently launched SMAP (Soil Moisture Active/Passive). The European Space Agency and Japan's Aerospace Agency (JAXA) also have sensors with mostly as-yet untapped abilities with regard to boreal fire management. The report is available at https://www.iarpccollaborations.org/uploads/cms/documents/wildfire-sensor-systems_v5.pdf. Materials from the WCT are archived at https://www.iarpccollaborations.org/teams/Wildfires. More information on sensors and missions is available on the NASA website: https://www.nasa.gov/mission_pages/fires/main/missions/index.html.

The availability of remotely sensed data is dramatically increasing with new satellites and sensors (Ambrosia et al. 2014) and enhanced computer data handling and storage capacity. A growing network of Landsat-class instruments which includes new NASA, Japanese, and Canadian satellites and also the European Space Agency's 20-m resolution Sentinel-2a/b Multispectral Instrument and other commercial assets (e.g., Digital Globe's Worldview 3&4) have the potential to transform the way those data are used in routine operations, especially in high latitude regions where observation frequency is improved as a result of satellite orbit convergence. Despite their great promise, these resources have seen limited application in Alaska and other high latitude northern fire management settings to date. These limitations are related to several interrelated issues, which comprise the underlying motivation for this workshop:

Interagency Fire Management in Alaska

The Alaska Wildland Fire Coordinating Group (AWFCG) oversees planning and implementation for interagency fire management statewide. AWFCG charters several interagency committees responsible for issues relevant to the present report, including Fire Modeling and Analysis, Air Quality and Smoke Management, Fire Research Development and Applications, and GIS. More information on AWFCG and its committees is available at https://fire.ak.blm.gov/administration/awfcg.php and https://fire.ak.blm.gov/administration/awfcg_committees.php

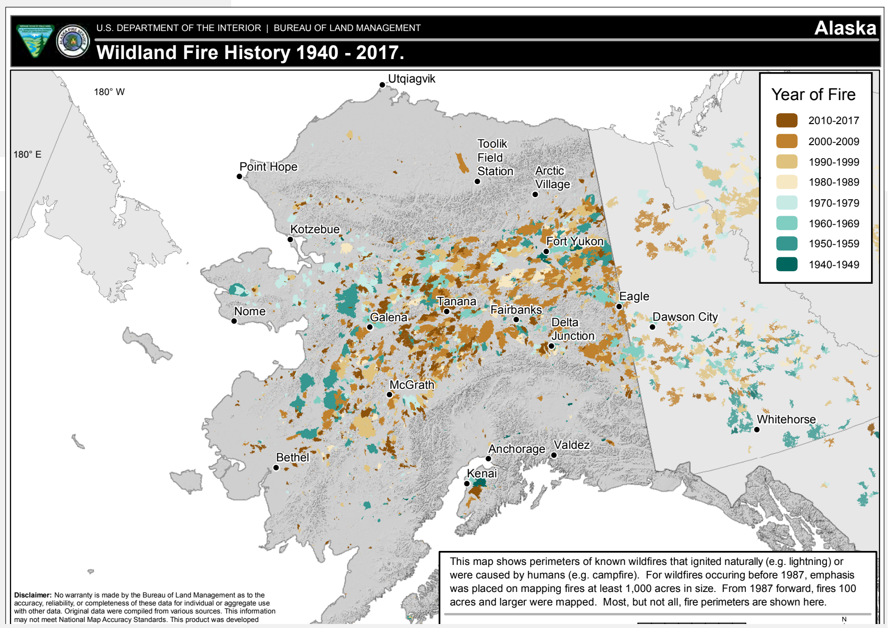


Figure 2. This map shows perimeters of known wildfires that ignited naturally (e.g., lightning) or were caused by humans (e.g., campfire) from 1940-2017. For wildfires occuring before 1987, emphasis was placed on mapping fires at least 1,000 acres in size. From 1987 forward, fires 100 acres and larger were mapped. Most, but not all, fire perimeters are shown here. Image from Alaska Interagency Coordination Center.

The Alaska Interagency Coordination Center (AICC) is the Geographic Area Coordination Center for Alaska. AICC serves as the focal point for initial attack resource coordination, logistics support, and predictive services for all state and federal agencies involved in wildland fire management and suppression in Alaska. AICC agency cooperators include the Bureau of Land Management, State of Alaska Department of Natural Resources, USDA Forest Service, National Park Service, Bureau of Indian Affairs, and the Fish and Wildlife Service.

- Arctic and boreal ecosystems are characterized by specific fuels and hydrologic conditions. Systems designed for environments in other areas such as the western U.S. require additional validation and calibration to extend into these regions (sidebars pages 5, 14, 18);
- The limited national resources for the development and dissemination of remotely sensed tools for wildland fire (chiefly the USDA Forest Service [USFS] Geospatial Technology and Applications Center [formerly the Remote Sensing Applications Center] and NASA Applied Sciences Wildfire Program) have of necessity concentrated on applications for more populous areas;
- The constant flux of remotely sensed systems and technologies makes it difficult for operational users to identify the most appropriate and sustainable tools for their needs.

In 2014 the Implementation Plan for the National Strategy for the Arctic Region (White House 2014) recommended increased attention to wildland fires in high latitudes. In response, the Interagency Arctic Research Policy Committee (IARPC) formed a Wildfires Collaboration Team (WCT), which met regularly from 2014-2017 and developed several products, including an inventory of satellite and airborne sensors that could be applied to wildfire observations (sidebar, page 4).

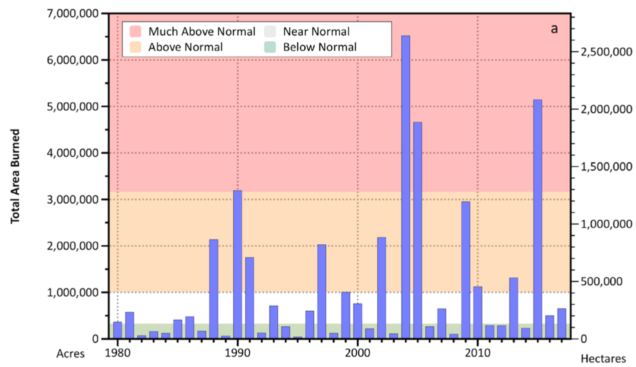


Figure 3. Area burned in Alaska, 1980-2017. Data from Alaska Interagency Coordination Center, figure by Rick Thoman.

Climate Change Impacts on Wildland Fire in High Latitudes

Despite the low annual temperatures and short growing seasons characteristic of northern ecosystems, wildland fire affects both boreal forest (the broad band of mostly coniferous trees that stretches across northern North America and Eurasia, also known as taiga) and adjacent tundra regions. In fact, fire is the dominant ecological disturbance in boreal forest, the world's largest terrestrial biome. Climate is the main driver of fire activity in both boreal and tundra ecosystems. The relationship between climate and fire is strongly non-linear, with the likelihood of fire occurrence within a 30-year period much higher where mean July temperatures exceed 13.4 °C (56°F) (Young et al. 2016). High latitude fire regimes appear to be shifting rapidly due to recent environmental changes associated with the warming climate. Although highly variable from year to year, area burned has increased over the past several decades in much of boreal North America (Kasischke and Turetsky 2006, Gillett et al. 2004). Since the early 1960s, the number of individual fire events and the size of those events has increased, contributing to more frequent large fire years in northwestern North America (Kasischke and Turetsky 2006).

Beyond immediate threats to lives and property, wildland fire has multiple impacts on northern environments and residents. Fire disturbance affects high latitude systems at multiple scales, including direct release of carbon through combustion (Kasischke et al. 2000) and interactions with vegetation succession (Mann et al. 2012, Johnstone et al. 2010), biogeochemical cycles (Bond-Lamberty et al. 2007), energy balance (Rogers et al. 2015), and hydrology (Liu et al. 2005). About 35% of global soil carbon is stored in tundra and boreal systems (Scharlemann et al. 2014) that are potentially vulnerable to fire disturbance (Turetsky et al. 2015). Smoke can be widespread and compromise health, particularly in vulnerable populations (Reid et al. 2016), limit visibility, and constrain aviation operations, including those supporting fire suppression and detection. Black carbon, derived from wildfires, is known to travel considerable distances and accelerate surface melting and thawing of snow and ice (Thomas et al. 2017). Removal of the surface organic layer by combustion has been shown to initiate the development of thermokarst in both boreal and tundra soils, which are rich in permafrost (Jorgenson et al. 2010, Jones et al. 2015). High severity fires have been linked to the disappearance of permafrost, and conversely, thawing soils can result in increased drainage and drier surface layers (Brown et al. 2016).

Kiunnei Kirillina, a PhD student at Keio University in Japan, presented her research on climate effects on boreal forest fires in Siberia (R. Jandt)

Recognizing the issues outlined above, the WCT, in collaboration with the Alaska Fire Science Consortium (AFSC), proposed a workshop to explore opportunities for harnessing remote sensing technologies to advance understanding of the changes in arctic fire ecology and to develop new tools and programs to help fire managers with daily decision-making and management planning. An interagency organizing committee led the workshop proposal and planning process (Appendix C).

This workshop, funded in 2017 by the NASA Applied Sciences Program, focused on three areas as ripe for advancing tools and data for operational and scientific applications by high latitude fire ecology and management communities. The three chapters of this report are organized around these three topics:

I. **Potential fire risk**: Can remotely sensed data (e.g., daily snow extent, soil moisture, land surface temperature, vegetation indices, others) be used to estimate soil moisture (particularly important in spring) and surface and subsurface fuel moisture, and thus provide critical inputs for fire danger rating and fire behavior prediction?

II. **Near real-time fire behavior:** Which remotely sensed data are best and most timely for fire detection, tracking of fire emissions, fire behavior modeling, mapping of flaming fronts, fire intensity, active fire perimeters, and responses for ongoing fires?

III. **Post-fire effects:** Can we develop analytical methods for remotely sensed data to assess fire severity, fuel consumption/CO_2 balance, active-layer changes, and successional trajectories of vegetation communities?

Bud Cribley, BLM State Director, gave an opening welcome address (R. Jandt)

Although this report represents the workshop's proceedings, we have expanded its scope somewhat to include information on follow-up activities and outcomes that occurred in the year following the workshop itself.

One hundred individuals from 5 nations (Canada, China, Japan, U.K., U.S.) registered for the workshop (Appendix C); 16 presenters received travel support. The agenda (Appendix B) included 34 oral presentations, 16 posters, and three panel discussions (Abstracts in Appendix A). The workshop planning included a pre-workshop webinar and other resources on wildland fire management issues in Alaska for participants unfamiliar with this context; 42 individuals accessed these resources before the workshop itself. 57 participants completed a post-workshop evaluation.

The workshop was able to facilitate communication among fire and resource managers and remote sensing scientists and begin to bridge gaps of geography and understanding to focus attention on the needs of decision-makers for new applications and uses of available data. Speakers discussed the utility of promising remote sensing technologies, and key fire management science-users illustrated their uses of data and their needs. Participants acknowledged that multi-scale and multisensory approaches are in the infancy of development for fire management needs and could likely advance the current state of knowledge substantially. More and more, even near real-time applications need to integrate data from multiple platforms, sensors, and derivations to produce meaningful products. These integrations can lead to updated depictions over entire landscapes at frequencies necessary for decision-making. However, raw remote sensing data requires a lot of post-processing to provide anything that is compatible with current surface descriptions of the fire environment (sidebar below).

Consistent with other studies (NSTC 2015), workshop participants identified numerous challenges in current Research to Operations (R2O) processes, also known as the "last mile" and sometimes referred to in jest as the "Valley of Death", a metaphor for the gulf often separating research results from successful transition to operational application. Current R2O processes are largely ad hoc, and adoption of new research tools and findings frequently lags behind due to lack of the last bit of "plumbing" to bring important tools into reliable use by managers. Seeking efficiency, most government agencies have consolidated and centralized their specialties of geospatial applications and information technology—an example would be the USFS Geospatial Technology and Applications Center (formerly Remote Sensing Applications Center, recently merged with the Geospatial Service and Technology Center) in Salt Lake City. National initiatives can be achieved by these centralized centers, but they struggle to maintain communication and local service to the field offices and end-users of the data. The operational weather realm has developed some robust R2O processes, notably NASA's Short-term Prediction Research and Transition Center (SPoRT) and the Joint Polar Satellite System (JPSS) Proving Ground and Risk Reduction (PGRR) program, both represented at the workshop (A-4, A-21). On the receiving end, however, the operational fire workforce is funded seasonally and is ill-equipped to do in-house research and development on the scale necessary to operationalize novel systems. An overarching recommendation from the workshop is that in order to apply all this complex science, more attention needs to be directed to the "last mile"—technology transfer all the way to the end-user.

Research to Operations: The last mile

Discussions at the workshop repeatedly stressed the "last mile" problem, in which research funding agencies are rarely mandated to support tech transfer and ongoing provision of data to end users. For example, supposedly "operationalized" remote sensing tools are in fact underutilized due to gaps in the transition process to pass these tools to end-user groups (sidebar page 33). Ironically, the fact that VIIRS is an "operational" system has limited research funding to explore making it more useful in the fire operations theatre.

Another major barrier to use of RS data in the operational environment is its abundance. With so many channels to look at, there has been little introspective work to identify the most strategic data streams and efficient displays for interpreting this data (e.g., RGB combination displays). There is a need to anticipate and develop a limited set of the most useful and potentially multi-purpose tools in a single "one-stop shopping" location for management accessibility. Convenience is key: as agency fire ecologist Eric Miller said "who wants to lug around a toolbox with 500 kinds of hammers?"

One potential strategy to overcome the difficulty of adopting and integrating new data into wildfire daily operations was the idea of a "chef" or liaison embedded at the regional Coordination Center level with the tech savvy to access and interpret data and help select products for inclusion in the daily decision matrix and provide feedback on user applications, needs, wants, and hurdles back to data providers. Encouraging researchers to involve end-users throughout the research process (co-production), perhaps through the liaison role, is another promising approach.

Big Data

New remote sensing capabilities are leading to improvement in understanding of the earth's surface and atmosphere but also require concomitant expansion of data systems. Increasing spectral, spatial, and temporal resolutions have enabled many more data dimensions and potential applications. Acquisition and storage require infrastructure investments and improved search and share capabilities. Analysis requires new skills and approaches. Simply visualizing what has been collected challenges the capabilities of end-user infrastructure.

The sheer volume of data associated with state-of-the-art remote sensing techniques (hyperspectral imagery, for example) exceeds data storage and processing capabilities of many agency operational environments. The process is more successful where this information is handled and pre-processed by experts for end users to capture as simplified and interpreted results. Without targeted investment and support from advanced capability partners, many of the advanced techniques and high-resolution products will remain unused in operational settings.

MODIS and VIIRS: Use in wildland fire

The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument is a sensor system onboard the Terra (EOS AM) and Aqua (EOS PM) polar-orbiting satellites that is used operationally by U.S. agencies to identify wildfire occurrences on a daily basis. Terra passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the late afternoon. Terra MODIS and Aqua MODIS view the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. Due to orbit and swath width of the sensor system, the MODIS sensor(s) can observe the same feature on the ground from 2–4 times per 24-hour period. Because of the polar-orbit configuration and swath width (2330 km), observation capabilities are increased for high northern (or southern) latitudes, and can afford more frequent observations of fire events during adjacent orbits for polar regions.

Various organizations provide web-based, geospatial wildfire observation maps/data derived from MODIS. The most common service is provided by the USDA Forest Service, which provides wildfire information for the contiguous U.S. (CONUS) and Canada (https://fsapps.nwcg.gov/). The other MODIS channels, particularly the Visible and Near-infrared (NIR) channels can be used to derive historical burned area information, fire intensity information (fire radiative energy), vegetation regrowth following burns, and plant health/vigor using various operational spectral channel indices. Additional information about MODIS can be found at http://modis.gsfc.nasa.gov/about/ or the Ambrosia report (sidebar page 4).

The Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi-NPP satellite is a polar orbiting system launched in 2011 that provides a follow-on, improved spatial resolution to MODIS fire detections (http://npp.gsfc.nasa.gov/viirs.html). The VIIRS is currently in the same orbit as the Aqua satellite (with MODIS aboard), and therefore provides 1–2 observations per 24-hour period of fire occurrences throughout the globe. VIIRS passes over Alaska in mid-afternoon, and comparison studies have shown that orbit is inferior to MODIS as it missed many fire events captured by MODIS (A3, A22). Investigators at the workshop noted the morning orbital pass by MODIS was particularly important to early fire detection. VIIRS data is currently being configured to provide operational fire detections and is being served as a daily fire product for the U.S. from the same USFS Active Fire Mapping Program website as MODIS (https://fsapps.nwcg.gov/). VIIRS represents a continuation of active fire monitoring capabilities started with MODIS on the NASA EOS Terra and Aqua satellites, and also a significant improvement of the current capabilities of the Advanced Very High Resolution Radiometer (AVHRR) on the current NOAA operational polar satellites. A second VIIRS instrument with similar overpass timing launched in 2017 aboard the polar-orbiting NOAA-20 increases available images.

Initial evaluation has provided empirical evidence of the good quality of the VIIRS fire observations, although workshop participants expressed reservations about their ability to replace MODIS for active fire detection (see Chapter 2, Active Fire Detection). Additional VIIRS information can be found at: http://www.jpss.noaa.gov/viirs.html, http://viirsfires.tumblr.com/ or http://npp.gsfc.nasa.gov/viirs.html or in the Ambrosia report (Ambrosia et al. 2014).

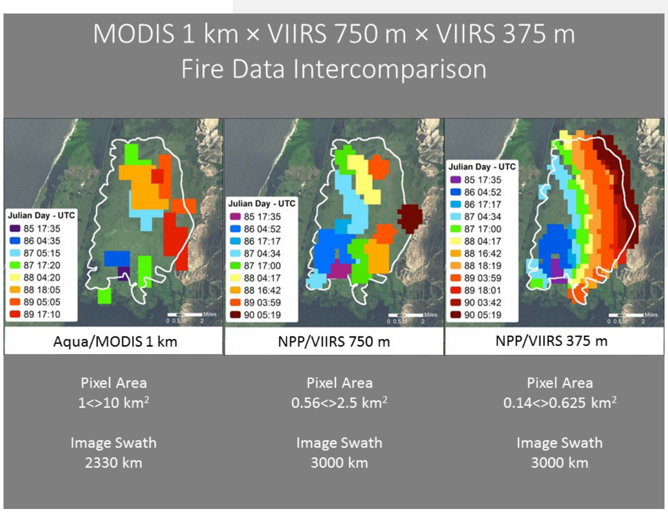


Figure 4. The newly refined VIIRS 375 m product provides 3x more daytime and 20x more nighttime fire pixels than the VIIRS 750 m product, providing additional power to wildfire mapping or fire behavior applications (A-3). However, MODIS has a slightly more desirable overpass timing (morning and late afternoon) for fire detection (A-28) although it has less sensitivity. Figure: W. Schroeder presentation (A-3)

NASA Arctic/Boreal Vulnerability Experiment (ABoVE)

The workshop also contributed to the goals and objectives of the NASA Terrestrial Ecology Program's Arctic-Boreal Vulnerability Experiment (ABoVE). This major field campaign began in 2015 with science objectives broadly focused on

- improving understanding of vulnerability and resilience of Arctic and boreal ecosystems to environmental change, and
- providing the scientific basis for informed decision-making to guide societal responses.

Disturbance from wildfire is one of ABoVE's six science themes. Research for ABoVE links field-based, process-level studies with geospatial data products derived from airborne and satellite sensors, providing a foundation for improving the analysis and modeling capabilities needed to understand and predict ecosystem responses and societal implications.

The workshop's outcomes are expected to increase the operational significance and use of data and analysis products from the ABoVE research efforts. The workshop steering committee included substantial representation of ABoVE scientists toward that objective. More information about ABoVE is available at https://above.nasa.gov/

Tom Maiersperger from USGS presented a poster on the data clearinghouse where ABoVE data is being housed (A-46). More data is being added daily—access the data at the ORNL-DAAC Data Portal, by searching for ABoVE (https://search.earthdata.nasa.gov/portal/ornldaac/). Sample datasets include:

- Fuel Characteristics for Tussock Tundra in Noatak Valley and North Slope, including shrubbiness and biomass
- Thaw Depth at Selected Unburned and Burned Sites Across Alaska, 2016-2017
- Landsat-derived Burn Scar dNBR across Alaska and Canada, 1985-2015
- Last Day of Spring Snow, Alaska, USA, and Yukon Territory, Canada, 2000-2016
- High Resolution Spaceborne Image Digital Surface Models (HRSI DSM) including forest canopy surfaces
- Circumpolar Forest Structure (Calibrated Landsat-7 Tree Canopy Cover, 2010-2015)
- Wildfire Date of Burning within Fire Scars across Alaska and Canada, 2001-2015

Figure 5. The ABoVE study domain is outlined in red and covers most of Alaska and western Canada. Purple outline indicates the extended study domain, where ABoVE observations will be less intensive. Figure courtesy ABoVE.

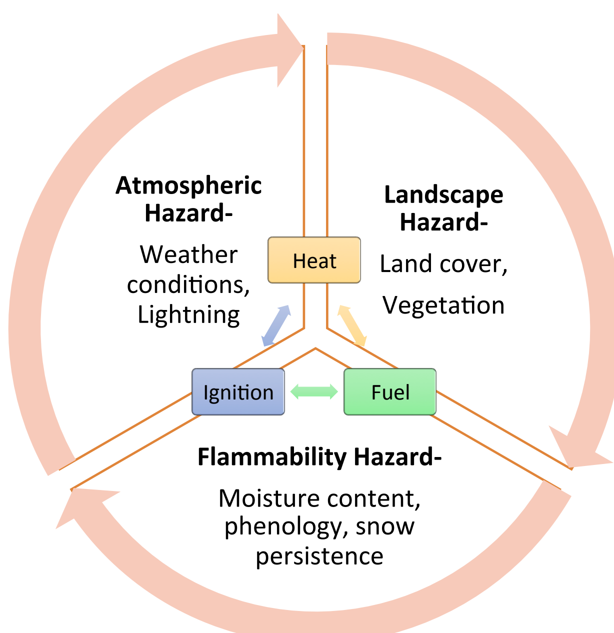
I. Potential Fire Risk

Workshop participants addressed the following question: Can remotely sensed data (e.g., daily snow extent, satellite soil moisture, others) estimate soil moisture and surface and subsurface fuel moisture and fuel conditions, and thus provide critical inputs for fire danger rating and fire behavior prediction?

Wildfire risk assessment brings together estimates of potential wildfire hazards found in the fire environment with the likelihood that wildfire ignitions and growth events will exacerbate them and identifies the values that would be impacted, either positively or negatively, if the wildfire reached them.

In the risk context, remote sensing products primarily provide depictions of existing conditions. There are hazards associated with both predisposing conditions and ongoing wildfires that result in short-term and persistent changes to the landscape. This section will summarize major tools in use by practitioners and focus on ways that remote sensing tools can improve our understanding of the hazards ahead of wildfire events.

Figure 6. Elements of potential fire risk upscale the classic "fire triangle" over space and time. Figure by R. Jandt



Landscape Hazard

Spatial and temporal variability in vegetative cover and condition across the landscape is a critical component when evaluating wildfire potential. Identifying the potential range of flammability in a given area requires depictions of the loading and arrangement of dead fuels, the composition, structure, and cover of living vegetation, and the changes to those "fuelbeds" that come with disturbance (e.g., wind, fire, human activity).

Land Cover. Describing the distribution of fuel characteristics and range of flammability across landscapes provides critical distinctions in wildfire risk assessment. It requires understanding of quantity and arrangement of burnable materials. In most cases, these descriptions are inferred from vegetative cover descriptions applied across those landscapes. Remote sensing products used for these classifications have evolved from aerial photography collected with multiple year return intervals to

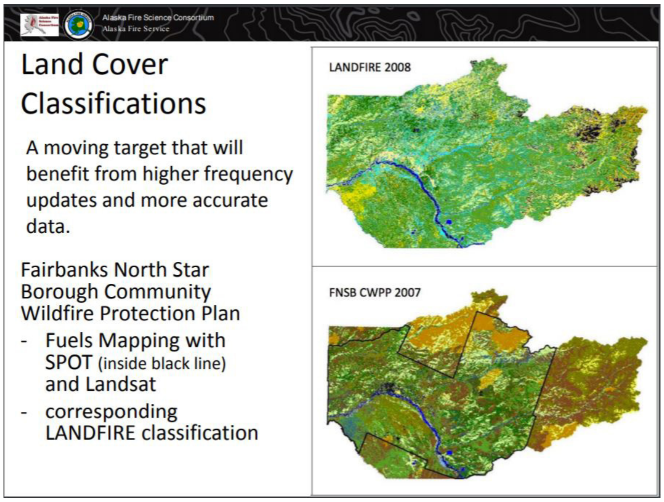


Figure 7. Slide from Jenkins & Ziel presentation illustrating the opportunities for improving the land cover classifications that are available to agencies for fuels mapping and fire behavior modeling work, Figure from Remotely Sensed Data For Alaska: https://vimeo.com/album/5021391/video/216554877.

satellite imagery collected globally with days to weeks return intervals from multiple platforms. It is now possible to update landscape description on a near real-time basis. However, with limited ground verification data, classifications continue to struggle with low accuracy performance.

LANDFIRE vegetation is used as a basis for most agency fire spread modeling and fuel treatment planning, and could be useful for ecological questions, such as trends in forest composition. LANDFIRE (https://www.landfire.gov) first produced classifications of vegetation, fuels, land use, and disturbance using primarily Landsat 7 imagery collected over a couple of years ending in 2000. Since that time, remote sensing of fire disturbance from subsequent Landsat imagery has been augmented by annual reports of disturbances from interested agencies and organizations. With that, classifications have been updated with disturbance and succession assumptions every 2 years. Unfortunately, the Alaska coverage is currently hampered by lack of validation, a paucity of supporting field data, known flaws and inaccuracies (e.g., short-statured taiga spruce forest mapped as "deciduous" or "shrub"), and flaws in the generation of forest successional changes via equation vs detection post-fire. For these reasons it is rarely used for scientific inquiry (and requires much tweaking and adjusting for agency use in modeling). However, USFS has recently begun Forest Inventory and Analysis work in the fire-prone regions of Alaska that will provide much-needed field data and validation (A-26). The launch of Landsat 8 and Sentinel-2 satellites since 2013 provide multispectral land monitoring capabilities that have enabled a comprehensive remap effort initiated in 2016 and more frequent change detection signals as well. Other potential improvements include radar-assisted assessment of canopy structure (Kellndorfer et al. 2010), higher resolution digital elevation model (DEM) data, and partnerships with the ongoing ABoVE field campaign (A-8, A-26). Additionally, LANDFIRE is exploring ways to smooth out mapped data by object-oriented classification techniques, making maps less noisy.

Fuel classifications will continue to be highly subjective, with few objective calibration efforts formally integrated. Most are simply based primarily on expert interpretations of crosswalks from vegetative classifications. Updated products for Alaska are anticipated by 2020. The potential for improving the LANDFIRE vegetation classification is of great interest to management agencies, since it has become institutionalized in their operating tools (e.g., online decision-making tools and fire behavior modeling applications). The participation and cooperation of Department of Interior agencies, State, and tribal agencies is needed to feed point validation from their field monitoring to improve the 2020 remap of LANDFIRE. The importance of completing these improvements to the primary fuels layer data for Alaskan managers cannot be overemphasized because it is integral to decisions in all three areas of fire potential and risk, near real time fire behavior, and post-fire effects. Highlights of technologies currently applied and others that hold promise for informing land cover for the future include:

- Light Detection and Ranging (LIDAR) has always shown promise for mapping vegetative structure (see Stockton 2014, Jones et al. 2015, and A-39 for recent Alaskan examples), though without satellite sensors widespread availability has been lacking. NASA's new Land, Vegetation and Ice Sensor (LVIS) is being tested on airborne platforms with plans to incorporate it into an upcoming satellite launch (A-2, A-25).
- Synthetic Aperture Radar (SAR) products may enhance classifications based in improved depictions of vertical vegetative structure, horizontal vegetation cover, and total biomass distribution. Canada's RADARSAT 3 (planned to launch in May 2019) and the European Space Agency (ESA) Sentinel-1 (operational in 2014) are examples of new data sources that may hold potential for integration and improving landscape and fuels information.
- Hyperspectral imagery records myriad spectral bands of the same pixel and is expected to result in more accurate machine-learning algorithms to distinguish between different classes of vegetation, maybe resulting in much more efficient ways to produce landcover (fuels) maps at higher resolution.
- G-LiHT, a portable airborne imaging system developed at NASA-Goddard Space Flight Center, simultaneously maps the composition, structure, and function of terrestrial ecosystems using LIDAR, imaging spectroscopy, and thermal imaging. G-LiHT provides high-resolution (~1 m) data for tree-level resolution, and can be used to assess productivity of forest stands and individual trees (A-26).

Atmospheric Hazard

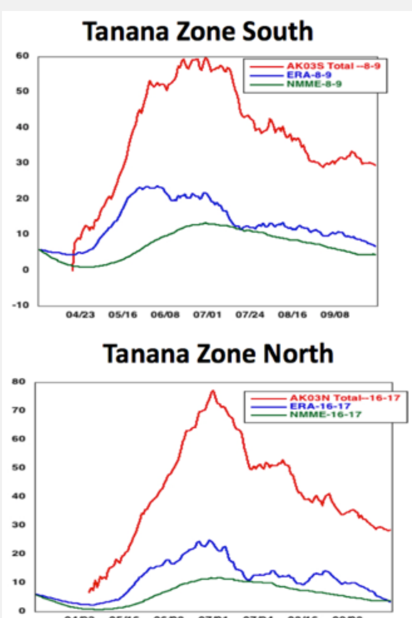
Surface weather observing networks have been the basis of most traditional wildfire risk assessments. Further, they are important resources for calibrating modeled representations of spatial variability in climate reanalysis and gridded weather forecast products. Elements from these surface weather observations are used to infer flammability conditions that are discussed elsewhere in this report. While operational fire behavior modeling systems rely heavily on data from surface observations, new applications of remote sensing capabilities open opportunities for integrating depictions of atmospheric stability, wind fields, cloud cover, and thunderstorm impacts with landscape and flammability characteristics. It may even be possible to leverage this new information with surface observations of temperature, atmospheric moisture, and precipitation to produce spatial and temporal detail for fire models to better inform fire management choices.

Surface Weather Conditions. Both current atmospheric conditions and cumulative atmospheric impacts influence fire hazard and risk. Surface wind, vertical air movement, and accumulated precipitation are primary factors influencing current risk. Atmospheric moisture and cloud cover deter drying. Resources for characterizing weather and climate influences on burnable materials distributed across the landscape are in transition. Investment in ground-based observation networks is challenged by ongoing maintenance costs in a harsh, remote landscape for much of Alaska. As a result, there is a significant lack of good historical reference and near-real time understandings to influence modeled representations and forecast products. New satellite systems show promise for bridging the gap.

Resolution and Calibration for Fire Behavior Models

In the effort to better capture spatial variability of environmental conditions, remote sensing products and modeled estimates from them are capturing and representing factors at a variety of spatial resolutions. Many important products are at sufficiently coarse scales that they cannot fully resolve the variability for some important factors, such as wind and precipitation. Further, there are important discrepancies that arise when comparing the modeled estimates (such as reanalysis climatologies) with surface observation counterparts from a variety of mesonets (e.g., comparing weather station data to gridded reanalysis products). Absolute values and seasonal distributions for these modeled products are difficult to reconcile, especially where the network of surface observations is sparse or not incorporated into processing of results. One problem is that, when used with traditional wildland fire assessment tools that have been calibrated to known variability in surface observation, the differing biases in the modeled and remotely sensed estimates can impair interpretations. Both new assessment tools and bias correction methods need to be employed as remotely sensed data becomes more widely applied. For a brief overview on fire potential assessments in Alaska, see Ziel 2018: https://www.frames.gov/catalog/56814.

Figure 8. Examples of back-casted seasonal trends in Buildup Index (BUI) for 1994-2017, from large management zones in central Alaska. Both climate reanalysis (blue) and ensemble forecast models (green) underestimate trends based on surface observations (red).



Expansion of surface weather observing networks enhance real-time monitoring and climate assessments. Though there are a wide range of station standards, those that include surface observations of temperature, atmospheric moisture, wind speed, and precipitation amounts are generally sufficient. Solar radiation, cloud cover, and smoke density estimates can improve estimates of surface heating and drying. Fire management agencies have maintained a network of Remote Automated Weather Stations (RAWS) for over 25 years. Alaska has augmented those observations with selected stations from the Automated Surface Observing System (ASOS) and the Automated Weather Observing System (AWOS) networks serving at airports. The recent development of the Alaska Fire and Fuels fire weather monitoring system, in partnership with MesoWest and Synoptic Labs (http://akff.mesowest.org), provided greater access to a wide range of observing locations. Among them, a new network of automated seismographic and meteorological recording stations, called the USArray, is providing surface weather observations from 78 remote locations, most of which are in areas previously unmonitored. All told, the fire weather observing network has doubled to approximately 225 stations across the state for the snow-free period from April through September.

Precipitation continues to be difficult to monitor across Alaska, with significant deficiencies in both ground-based and satellite systems that support high resolution assessments in the contiguous U.S. The Next Generation Weather Radar (NEXRAD) system, operated by NOAA, covers less than one third of Alaska, mostly along the southern and western coastline. Key meteorological satellites operate in geostationary orbits, focusing on low- and mid-latitudes. However, new platforms, sensors, and data assimilation techniques (A-16, A-17, A-19) offer promise of greater detail. The Integrated Multisatellite Retrievals for Global Precipitation Measurement (IMERG) provides a unified U.S. algorithm for intercalibrating and combining estimates from a diverse, changing, uncoordinated set of satellites in both near-real and post-real time. IMERG currently provides half-hourly snapshots of precipitation based on merged passive microwave estimates in CONUS, which appear useful during the fire season. It is planned to integrate Alaska into the product (summer season) and time-interpolate these passive microwave data to full half-hourly coverage that provides a record from February 2000 onwards.

The High Resolution Rapid Refresh (HRRR) weather forecast and data assimilation system produces short-term, hourly atmospheric forecasts at 1-3 km resolution out 36 hours, updated every three hours. Since 2015, observations from the USArray have been improving the resolution of barometric pressure grids in the state. Studies are now underway to integrate data from this modality into forecasting weather events that affect fires (A-18).

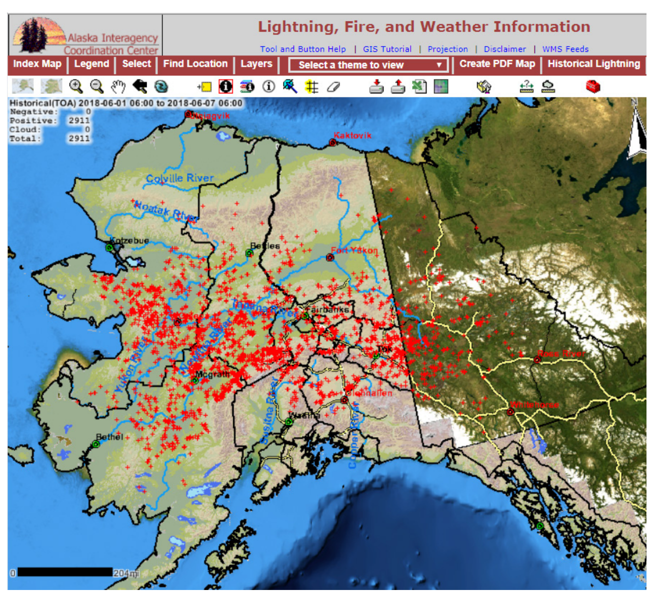
NOAA Unique Combined Atmospheric Processing System (NUCAPS) uses the Cross-track Infrared Sounder (CrIS) and Advanced Technology Microwave Sounder (ATMS), currently onboard the Suomi National Polar-orbiting Partnership (SNPP) satellite and later available from the Joint Polar Satellite System (JPSS-1 and JPSS-2). It is designed to measure infrared and microwave radiances in order to produce vertical profiles of environmental data such as temperature, moisture, and pressure. NUCAPS soundings might be used to predict development of unusual atmospheric conditions hazardous to firefighting or aviation, and work is progressing to integrate this data to support operational forecasting (Berndt 2018).

Lightning Ignition Hazard. None of the other hazards discussed here represent a real risk unless an ignition occurs. Most fires in Alaska, as in other areas of the U.S., are human-caused (78% of the 4,816 fires of known cause between 2004 and 2018, Alaska Department of Forestry data). However, approximately 90% of the area burned in Alaska is ignited by lightning, commonly in remote areas not designated for active suppression, where real-time detection is challenging (over 70% of the state's land area). While lightning plays a dominant role in each fire season (Veraverbeke et al. 2017), its predisposing factors have been difficult to convert into a probability of ignition. Even forecasting strength of lightning-producing storms has proved difficult. Advancements in the detection of lightning-producing storms, real-time detection of lightning occurrence, and modeled representations of co-incident precipitation and fuelbed receptivity all have potential to improve day-to-day risk assessment.

Lightning Detection. The Bureau of Land Management Alaska Fire Service (BLM-AFS) owns and maintains the Alaska Lightning Detection Network (ALDN), which has been operating since 1976. Analogous systems in Canada, the contiguous U.S., and elsewhere have been operating for decades as well. Developments in sensor technology and changes in sensor networks somewhat hamper the ability of these data to be used in long-term trend analysis (Fronterhouse 2012). The GOES-16 Lightning Mapper has the potential to improve continuity and consistency across much of North America. Due to its geostationary orbit, its coverage is limited to 54° N latitude and below, so it does not cover much of Alaska.

Lightning Drivers and Fire Potential. Identifying not only the potential for frequent lightning, but ignition frequency potential is critical as well. NASA's Short-term Prediction Research and Transition Center (SPoRT) currently is combining lightning detection systems with NOAA land information data, vegetation condition, soil moisture, and weather information to provide ignition potential assessment (A-4). With support from NOAA and a new (2019) NSF project, atmospheric scientists

Figure 9. There is not a good satellite sensor for lightning in Alaska. Instead, managers rely on a network of ground-based Time-of-Arrival instruments. An example of output from the AICC website (https://fire.ak.blm.gov/incinfo/aklgfire.php) shows positive strikes during one week (June 1 to 7, 2018).



at UA are attempting to make seasonal predictions of lightning potential, evaluating the quality of climate model elements and factors. U.S. Predictive Services is sponsoring an analysis of lightning occurrence, landscape flammability, and fire occurrence to develop better methods for assessing lightning hazard in a 7-day outlook product.

Flammability Hazard

Snow Persistence. Persistent winter snow cover at northern latitudes effectively limits active wildfire potential and plays a role in extinguishing holdover fires in deep organic fuelbeds. Evaluating the accumulation of winter precipitation provides important insight to the upcoming fire season. The retreat of snow cover in the spring signals the onset of fuelbed response to atmospheric drying, which Alaskan and Canadian managers track using the indices of the Canadian Forest Fire Danger Rating System (sidebar page 18). The CFFDRS system requires identification of a start-up date when the snow has melted and may adjust the Drought Code (DC) depending on over-winter snow conditions. Both these information needs would benefit from near real-time soil moisture and snow cover. At a minimum, integrating spatial assessments of near real-time snow cover would improve methods for specifying the "start-up" date for both gridded representations and the surface observation network. Several existing and potential methods exist:

- The National Snow and Ice Data Center (NSIDC) provides a number of products at coarse resolution, including a climatology of weekly Snow Cover and Sea Ice Extent and Near-Real-Time SSM/I-SSMIS EASE-Grid Daily Global Ice Concentration and Snow Extent at a coarse 25 km resolution.
- MODIS Aqua & Terra Snow Cover Daily L3 Global 500m Grid, Version 6 and VIIRS/NPP Snow Cover Daily L2 Swath 375m, Version 1 datasets provide near real-time coverage that can be integrated into coverage for an entire area of interest (A-21).
- Multi-spectral datasets from Landsat and Sentinel-2 also provide high resolution characterizations of snow and ice cover and with orbit redundancy have increased frequency to approach near real-time frequency. Again, data integration is required to provide effective coverage for entire areas of interest.
- Radar-based (combined C- and X-band) approaches may be able to enhance optical methods for characterizing snow cover, overcoming cloud-cover issues. Again, processing and integrating are major impediments to implementation.

University of Maryland graduate student Dong Chen comments during a discussion at the workshop. Photo by R. Jandt.

Vegetative Phenology. Assessment of "green-up" transition in the spring and current growing-season conditions of green vegetation are important cues to seasonal trends in flammability. Unlike other parts of temperate North America, late season curing is less important in boreal ecosystems than green-up (the spring-time transition from a dead, overwintered fuelbed to live vegetation). This transition signals a significant change in flammability and fire growth potential in both forests and tundra. Monitoring the transition in the ratio of live to dead fuel abundance is an annual need. Further, drought conditions can reduce the heat sink, or fire slowing, influence of green fuelbeds and accelerate curing trends late in the season in graminoid and herbaceous vegetation. Tundra vegetation always includes high volumes of dead fuel—primarily grass/sedge leaf litter—creating unique flammability issues. Greenness assessments commonly employed in other regions may not reflect important transitions in high latitudes.

- Widely used approaches such as Normalized Difference Vegetation Index (NDVI), as well as Normalized Burn Ratio (NBR) and Green Vegetative Fraction (GVF) can detect dormant, green-up, mature, and senescent phenology (A-6, A-11). They have been stitched to produce national assessments on a weekly basis (NWCG 2018). Large portions of weekly depictions can be obscured by cloud cover, reducing their effectiveness, sometime for several successive images.
- The Growing Season Index (GSI) and its rescaled Live Fuel Index (LFI) are weather-based indices of the phenological trends described above. Combining moving averages of daily minimum temperature, vapor pressure deficit, and photoperiod or daylength, they provides day-to-day characterization of the condition of live vegetation through its annual phenology. More testing of greenup and mature trends is needed.
- Synthetic Aperture Radar (SAR) sensors may be able to monitor some aspects of vegetative phenology through changes in structure and complexity. With its advantage in cloud/smoke penetration, it may be able to enhance and augment optical methods highlighted above.
- The Radar Vegetation Index (RVI) is a promising new alternative to NDVI as it correlates with vegetation water content in some biomes. SMAP L-band radar data has been used to generate this index (Szigarski et al. 2018).
- Other types of new RS data (e.g., airborne hyperspectral) may be able to identify areas of stressed vegetation with potentially increased burn susceptibility, in advance of ignitions (A-24).
- Other composite drought indices now being examined include measures of evaporative demand and stress. Three such indices—EDDI, ESI and SPEI—are currently being evaluated for use in Alaska (Ziel, pers. comm.).

Fuel Moisture and Temperature. Wildfire potential assessment has, for nearly a century, focused on fuel moisture as an indicator of flammability. Current fire danger and fire behavior models include fuel moisture as key factors for estimating existing conditions and evaluating trends. Models for converting weather conditions into fuel moisture values have been in place for decades. Direct measurement has been incorporated at surface observing locations. However, remote sensing methods now offer potential for understanding more precisely spatial and temporal variability and the underlying causes. Methods for integrating these tools with traditional drought assessment tools, such as the CFFDRS Drought Code (sidebar page 18), were demonstrated at the workshop.

A unique feature of the boreal spruce forest is its thick organic forest floor. Averaging around 20 cm in much of interior Alaska, this is primarily composed of accumulations of moss, mostly the feathermosses *Pleurozium*

Canadian Forest Fire Danger Rating System (CFFDRS)

The Canadian Forest Fire Danger Rating System (CFFDRS) provides an integrated set of fire danger and fire behavior assessment tools based on a simple set of daily surface weather observations. At its heart, three calculated (not measured) fuel moisture assessments are included in the Fire Weather Index (FWI) system.

- The Fine Fuel Moisture Code (FFMC) offers hourly and daily trends in flammability of available surface fuels (live and dead moss layers in photo);
- The Duff Moisture Code (DMC) keys on drying in the organic fuels just below the surface (upper duff in photo). In addition, it effectively represents the decline in heat sink resistance to fire spread provided by green herbaceous and graminoid fuels in temperate climates;
- The Drought Code (DC) represents cumulative drying over whole seasons and its influence on curing of live fuels, availability of normally unburnable fuels, as well as potential for holdover fires and severe fire effects (lower duff in photo).

The Buildup Index (BUI) combines the DMC and DC into an index of overall flammability for a representative fuelbed. Studies using a 15-year history of MODIS fire detection data (Ziel 2018; York et al. 2018) indicate that BUI is particularly effective in representing temporal changes in landscape receptivity to fire spread and increased burning intensity (see sidebar page 14).

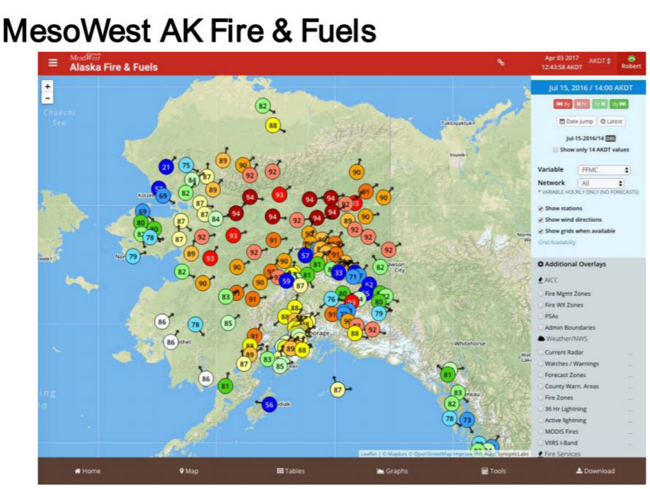


Figure 11. Alaska fire managers have been using the FWI system since 1992 and have compiled a database of daily values dating to 1994 through the Alaska Fire and Fuels website: https://akff.mesowest.org/

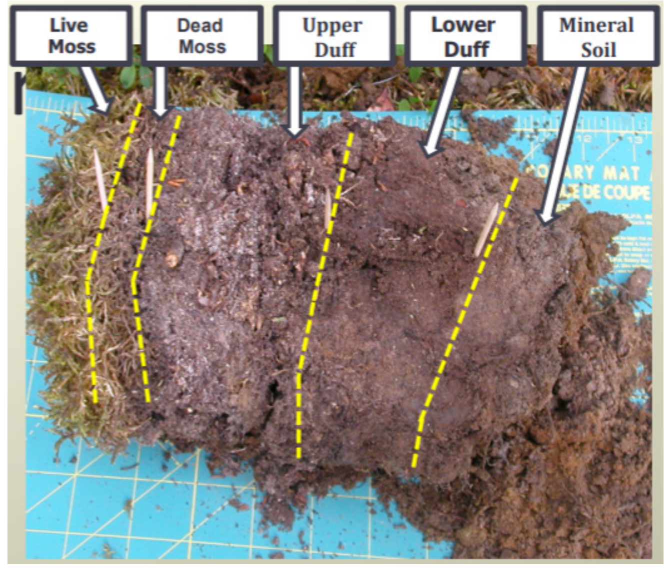


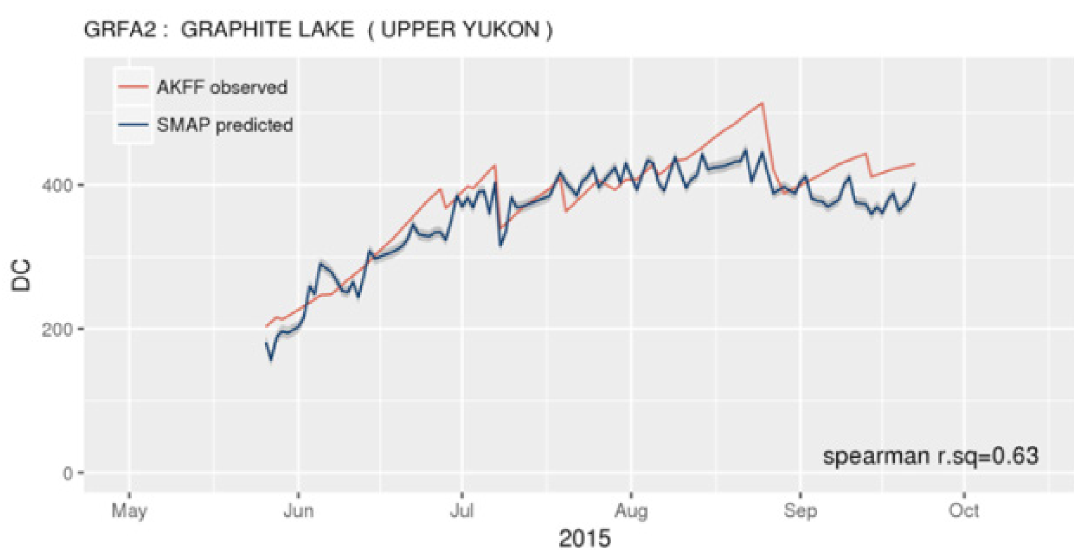
Figure 10. A duff plug dug from an interior Alaska black spruce forest showing the deep organic layers that correspond to the indices of the FWI system. Photo from https://www.frames.gov/documents/alaska/c5/files/barnes_miller_2014_CFFDRS_fuel_moisture.pdf

schreberi (red-stem moss) and *Hylocomium splendens* (stair-step moss; Miller 2010). For fire management purposes a soil profile from a black spruce forest consists of four organic layers: Live Moss, Dead Moss, Upper Duff, and Lower Duff (Figure 10). Despite their moist appearance, these fuels dry rapidly in warm, dry conditions and are the primary fuels that carry fire in northern ecosystems. Thus, although soil moisture data are of interest to the global fire community, they are critically important to Alaska and Canadian fire managers. Managers base seasonal and daily resource allocation decisions on the Fire Weather Indices (FWI) of the CFFDRS, which derived from daily weather data and reflect moisture content of surface and underlying litter, moss, and duff layers. FWI indices—FFMC, DMC, and DC—have been statistically validated by fire behavior analysts as good indicators of day to day variation in flammability, growth, and extreme fire potential. The DC, which reflects deeper drying and equilibrates over weeks, has been more challenging to equate with measured fuel moistures for a variety of reasons (Barnes et al. 2014, Jandt et al. 2005).

Remotely sensed data offer a possible means of validating CFFDRS algorithms for duff drying in Alaska locations with independent data at a meaningful scale. This validation has topped the Alaska Wildfire Coordinating Group's research needs list for over a decade. However, wildfire research and application development in the U.S. is conducted outside of Alaska, where fuels, ignition, and weather differ substantially. For example, most of the U.S. assesses fire risk and danger using regionally relevant drought and downed woody moisture content, estimated by the National Fire Danger Rating System (NFDRS). Similarly, remotely sensed metrics of burn severity provided by the USFS GTAC and Monitoring Trends in Burn Severity program (https://mtbs.gov/) are calibrated to detect varying degrees of mineral soil exposure and crown fraction burned, neither of which are good characteristics for discriminating degrees of burn severity in tundra or in boreal forests with deep organic layers.

Soil Moisture. Developed primarily for agricultural and infrastructure assessments, near real-time estimation of soil moisture using Synthetic Aperture Radar (SAR) sensors and processing models can be directly applied as well as integrated with weather-based fuel flammability assessments to improve spatial representations of current conditions and increase confidence in forecast trends. There is a natural convergence between the fuel moisture codes in the CFFDRS Fire Weather index system and SAR-based methods for directly assessing soil moisture. Further, SAR-derived soil moisture assessment will improve our understanding of the role of permafrost and seasonal active layer changes in surface fuel availability. Already implemented in a variety of applications for CONUS, calibrations for the deep organic fuelbeds of high latitudes show promise for correlating with and improving drought assessments (A-5, A-6). Combinations of satellite platforms and sensors are allowing the integration of C-band and L-Band SAR data. The new Canadian RADARSAT-3 Constellation Mission (expected launch May 2019) may provide open access compact polarimetric SAR data (the primary application is sea-ice mapping) with excellent coverage in the high northern latitudes. The Canadian Space Agency coordinates data ordering and dissemination, and long-term archiving and access to data will be provided by Canada Centre for Mapping and Earth Observation, a division of Natural Resources Canada. European Space Agency's SENTINEL-1 carries a single C-band synthetic aperture radar instrument operating at a center frequency of 5.405 GHz. Their data policy is open access with a simple self-registration (https://sentinel.esa.int/web/sentinel/sentinel-data-access). Moreover, ESA offers an online data toolbox with tools for calibration, speckle filtering, coregistration, orthorectification, mosaicking,

Figure 12. Research presented at the workshop related SMAP-retrieved moisture data to Drought Code (DC) Fire Weather Index at an interior Alaska location. While SMAP soil moisture products can adequately reflect fuel moisture in organic soils at 10-20 cm depth across boreal North America, these estimates can be improved and refined to smaller-scale areas by merging the passive SMAP radiometer data with active radar data (like polarimetric SAR). Much work remains, including calibration with field-deployed moisture sensors, and adding more of the retrieved SMAP data (A-4, A-5, A-27; figure from Bourgeau-Chavez et al. 2018).



data conversion, polarimetry and interferometry. Airborne SAR data products could be useful in downscaling soil moisture derived from SMAP (A-4, A-5) or for surface moisture calibrations, but to date has not transitioned from research into the operational realm (A-27). Calibration and algorithm development is still needed for the C- and L-band tools, especially in deep organic soils of the high latitudes. Airborne and field campaigns may be required. Research on new P-band radar (AirMOSS) being studied by NASA offers another potential tool for near-real-time duff fuel moisture validation (A-25).

Wetland Saturation. For most upland situations, fuel drying starts right after a short period of snowmelt drainage and progresses daily. Poorly drained lowland and wetland communities with high water tables after spring snowmelt take much longer to become available and receptive to wildland fire. Most fire flammability assessments for these situations would be enhanced by a better understanding of soil saturation during the pre-green dormant and transitional green-up period. Most notably, drought assessments that characterize evapotranspiration impacts may overstate drought development in wetland settings (A-11) or may underestimate them in deciduous forest (A-14). Workshop participants repeatedly stressed the importance of have observational data to compare to the DC, especially in the early part of the season. Identifying wetland soils and monitoring/modeling saturation levels is becoming more possible with advances in and availability of SAR technology and processing.

Soil Surface Temperature. Solar radiation and ambient temperature contribute to important short-term changes in surface fuel flammability. Research evaluating AVHRR surface temperature and NDVI showed significant increases in surface temperature in the days before ignition as well as high correlation with Drought Code (DC) estimates (A-6). Surface or soil temperatures are not currently incorporated into fire spread models except indirectly through influence on fuel moisture or indices and may be important in future model development.

II. Near real-time fire behavior

Workshop participants addressed the following question: Which remotely sensed data are best and most timely for fire detection, plume tracking of fire emissions, fire behavior modeling, mapping of flaming fronts, fire intensity, active fire perimeters, and response for ongoing fires?

Because Alaska is so large and many areas are difficult to access, fire agencies rely heavily on aviation-based surveillance and monitoring of remote fire activity and smoke, making the use of remotely sensed data to supplement these methods particularly efficient and economical. Alaska fire agencies are currently using both MODIS and VIIRS as near-real time operational tools for active fire detection, but the workshop identified some issues in the current systems as well as some ways forward (A-1). Ambrosia et al. (2014) identified 16 different satellite or airborne sensor systems that have utility for heat detection. Several new or soon-to-be launched satellites from China, Japan, and European Space Agency have sensors for thermal detection (A-19) and or lightning that would potentially supplement existing data for HNL countries.

Active fire detection

For Alaska fire managers, the Geographic Information Network of Alaska (GINA) currently is the subject matter expert and source of operational VIIRS products (A-1, A-20). Investigators at the University of Maryland (UMD) have also been collaborating with boreal fire managers on their specific needs for active detection now and in the future (Ellicott, pers. comm., also A-3, A-7, A-28). In its current form, VIIRS does not appear to be an adequate replacement for MODIS due to multi-day lags in detection, and issues of data delivery and stability (in spite of potentially higher resolution; A-28). There are basic issues with configuration, wavelength specification, and overpass timing that are not optimized for fire detection (sidebar page 8). In addition, divergence has been noticed in VIIRS data processing/products by NOAA vs. NASA. Official NASA VIIRS datasets were not available to support comparison/validation work by Schroeder or Waigl, for example (A-3, A-22). Despite these issues, Alaska fire managers have been using multiple images per day from VIIRS as part of their routine information gathering for the past few seasons.

The day-night band of VIIRS offers a potentially new data stream for night fire and smoke assessment, but has limited application in high latitudes where peak fire season coincides with summer solstice (A-21). Exploratory studies have indicated the potential for improved detection (earlier and more resolved duration) of fires in HNL with regionally adapted fire detection algorithms, such as UAF VIFDAHL (A-22). GOES-R may provide supplementary fire detection information for Alaska, but the viewing angle is necessarily suboptimal at boreal latitudes (providing resolutions estimated at 8-16 km), and its utility remains to be investigated. If the overpass issues could be solved, having multiple images per day could lead to better understanding about the diurnal burning patterns of large fires.

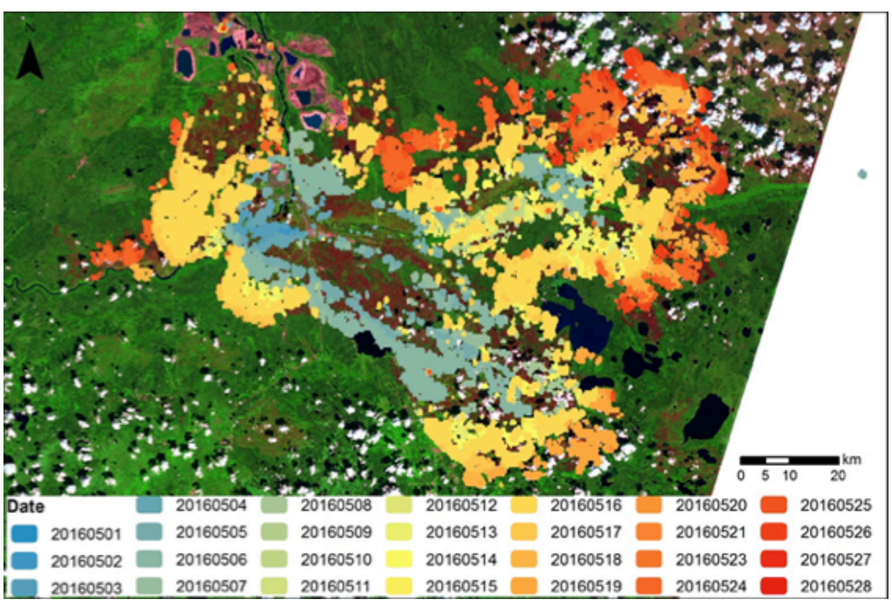
The region's fire and land managers are concerned that the incidence of spring "holdover" fires (fires which reignite from under the snowpack in the spring) appears to be increasing in recent years. Holdover fires can provide ignitions early in the fire season, when protection agency staff and resources may be limited. Some estimates indicate that about one third of the burned area in 2015 in Canada's Northwest Territories could be attributed to holdover fires from the record 2014 season (A-30). Detection of these fires may be feasible with remotely sensed data. The most likely modalities to explore would be VIIRS or MODIS with regionally adapted algorithms (A-22).

Monitoring growth, spread, and behavior

The technique of cumulative pixel mapping with VIIRS data could yield fire perimeters and growth/spread information that would be very useful in remote fire surveillance and monitoring for Alaska, Russia, and northern Canada. This may be a useful data aggregation method that could improve operational efficiencies (A-28). There is also potential to improve fire spread model validation and fire effects information if managers had access to progression maps that were more "real-time", rather than lagged by the time between detection and monitoring flights as they often are currently.

Presently, the duration of fire events (time from first to last detection) is not readily available from agency records, because agencies prioritize monitoring of fires based on threats and workload. Often "out" dates are assigned based on infrequent overflights upon seeing no smokes, or they can be arbitrarily assigned after a "season ending event" on fires that are unstaffed. Research studies have illustrated the potential to use products like MODIS hotspots (A-28, A-13) or Fire Radiative Power (A-17, A-28, A-43) to fill in this data gap and better understand fire behavior relative to environmental conditions (Veraverbeke et al. 2017).

Figure 13. Demonstration of near real-time fire mapping using VIIRS during the Fort McMurray 2016 fire in Alberta, Canada. The figure shows VIIRS 375 m active fire detections (colored dots) from May 1-28 (Oliva & Schroeder, A-23).

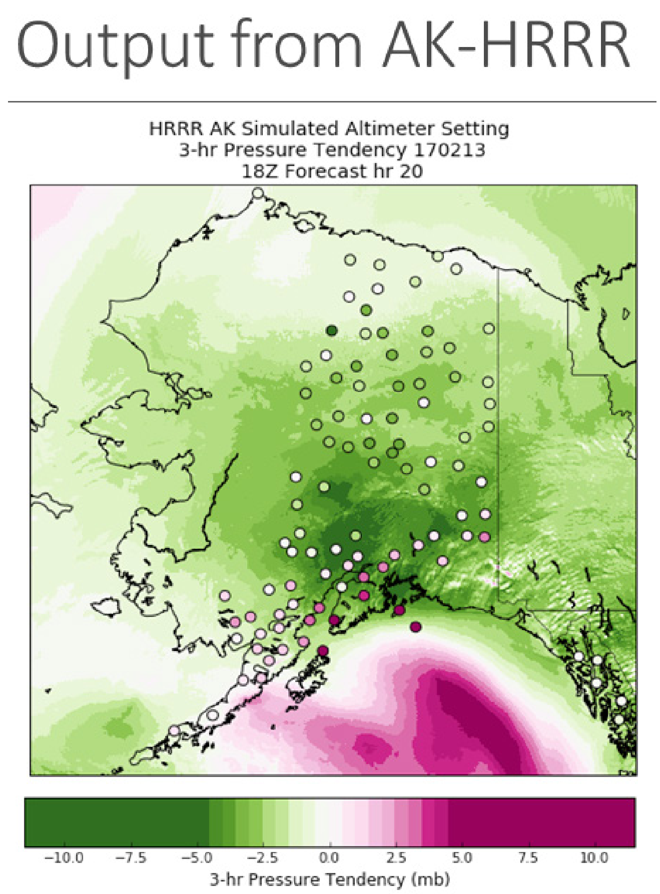


Smoke modeling and monitoring

Alaska has not been considered to have strong interest or needs for NRT smoke modeling, but in fact the needs are critical, related to pre-positioning of firefighting aviation assets, air evacuation of vulnerable populations, health impacts to communities, disruption of commercial activities, and unfavorable impacts on tourism. Real-time air quality smoke monitoring capability is urgently needed in Alaska, but modern transport modeling was not available prior to 2015 when the AirFire group at the U.S. Forest Service Pacific Northwest Research Station produced forecasts for Alaska using the BlueSky modeling framework (https://sites.google.com/firenet.gov/wfaqrp-airfire/data/bluesky). The 2015 smoke product (especially the 12-hour smoke forecast) was valued for many operational decisions, but the model lacks any inputs originating from smoldering combustion and critical chemical interactions, such as ozone formation. There is potential for further work with AirFire at USFS-PNW to refine the model.

There is a need to evaluate which of several available research products providing smoke guidance work best in Alaska's data-poor environment and make these available to the operational agencies, including Alaska Department of Environmental Conservation (ADEC), municipalities, Alaska Fire Service, State of Alaska Forestry, U.S. Forest Service, and the public. One issue with the smoke models is how to operationalize them for year-to-year continuity and the associated costs. The idea of a North America wide approach to smoke modeling was proposed at the workshop, which would make a lot of sense since the impacts of large boreal fires are continental in scale.

Figure 14. Although Alaska encompasses 663,300 mi² and 18% of the U.S. land mass, there are just 158 official automated weather stations supported by the NWS and FAA, generally located at airports. MesoWest collects surface weather conditions at additional remote weather stations maintained by federal and state agencies to aid weather and fire risk forecasting. In 2014, the weather observation network in Alaska was notably expanded with the deployment of EarthScope's USArray Transportable Array with 101 additional stations that continuously measure barometric pressure. Preliminary studies show the additional data may be useful in reducing weather forecasting errors and improving near real-time smoke forecasting (A-17, A-18; McCorkle et al. 2018).



With Alaska's newly available gridded weather products there are new opportunities for research groups to coordinate research projects to achieve advances in NRT smoke models for Alaska. For example, there may be useful synergies between AirFire BlueSky modeling and an experimental regional product called UAFSMOKE (http://smoke.alaska.edu/), a collaboration between UAF and NOAA investigators that uses WRF-Chem. Early testing indicates strong skill at regional predictions, and the model ran daily during the 2018 fire season with good results. The HRRR-Smoke modeling system is an alternative approach to NRT smoke modeling using fire radiative power (FRP) data measured by VIIRS (A-17). Using the FRP data the model predicts fire emissions, fire size, and plume rise. HRRR-smoke, which was run experimentally in 2016, is a fully coupled 3 km resolution online model (WRF-Chem based on the HRRR NWP system) developed to detect convective storms. A University of Colorado group working with NOAA ran HRRR-smoke every 6 hours during the 2017 fire season in both CONUS and Alaska domains. In Alaska in 2018, the same group ran the 13 km RAP-smoke model (https://rapidrefresh.noaa.gov/RAPsmoke/). Quantitative evaluation and verification of the various candidate models remains to be done in Alaska.

There is also potential for use of already existing flux towers (for example the Poker Flat Supersite and NASA CARVE towers in interior Alaska) and airborne campaign data to validate new smoke transport and emissions factors research for its impacts to communities. This is particularly important in terms of recent findings that the contribution of smoldering combustion toward smoke and specific air toxins (like CO) is underestimated by smoke models.

The biggest source of variability in smoke modeling is the representation of the fuel layers and their depth of consumption. Although some studies have compared methods of modeling and tried to assess their accuracy, more research is needed in this area and in efficient ways to characterize fuels (French 2014, A-9).

Panelists discussing the use of remotely sensed data in monitoring near-real time fire behavior and smoke. Left-right: Evan Ellicott, Kent Slaughter, Mike Butteri, Eric Miller, Tom Heinrichs (R. Jandt).

III. Post-fire effects

The problem statement presented to the group for this section was: Can we develop analytical methods for remotely sensed data to assess fire severity, fuel consumption, carbon balance, active-layer changes, and successional trajectories of vegetation communities?

Fire effects studies in Alaska date back before the 1950s, when the U.S. Forest Service Institute of Northern Forestry based at the University of Alaska Fairbanks was a leader of forestry, fire weather, and fire effects research. Methods have evolved through time and with different approaches by different land management agencies. The AWFCG Fire Effects Task Group assembled a brief interagency protocol for post-fire studies in Alaska. Over the years, however, we have found that some of these methods are inadequate to capture the full spectrum of effects on vegetation, active layers, hydrology, etc. It is especially challenging to scale up from plot-scale studies to landscape effects through time. For example, active layer has often been measured pre- and post-burn by measuring depth to ice with tile probes. However, we now realize that these localized methods do not capture wholesale subsidence and lateral migration of the ground surface (Jones et al. 2015), nor changes in bulk density of the organic horizon. Remotely sensed data can provide a much more complete and accurate picture of changes through time over large areas in post-fire effects studies.

Burned areas through space and time

Any assessment of fire effects requires a good map of the burned area. Fire history maps in Alaska are good compared to many other places (Figure 2). Historically, maps were hand-drawn and subject to large errors. Over the past 30 years, with the advent of GPS technology and algorithms to map burned area from satellite images, fire maps have improved dramatically. Reasonably good burned area maps are available for many fires and are open-source shared to the public on Alaska's interagency fire coordination center website (https://fire.ak.blm.gov/).

Although this is a comprehensive dataset, it is not complete. The older data are missing many fire perimeters (including a number of cases where agencies have a record of a fire point of origin, year, and approximate size). For wildfires occurring before 1987, emphasis was placed on mapping perimeters of at least 1000 acres. From 1987 forward, emphasis was placed on mapping wildfires with perimeters of at least 100 acres. From 2016 forward,

Alaska Fire History Database

Mapping of historical fires missing from Alaska's agency-maintained Fire History Database is being conducted by at least 3 different investigators. For optimum usefulness of this data going forward, the entire set of updates has to be incorporated into the agency spatial database (which is the only one funded for maintenance into the future). Discussions at the workshop led to a new process for submitting legacy perimeter data to the interagency coordination center. More information available at https://fire.ak.blm.gov/content/maps/aicc/Data/Data%20Templates%20(zip)/LegacyFirePerimeters_templates.zip.

Rachel Loehman and Sander Veraverbeke during the panel discussion on post-fire effects (R. Jandt).

the dataset has good perimeters for all fires over 10 acres, and there is increasing reliance on satellite data for correcting perimeters. Most of these perimeters include "islands" of unburned vegetation and often waterbodies, both of which can cause overestimation of burned area for consumption and emissions calculations (Walker et al. 2018). In general, actual burned area is approximately 80-85% of what is reported.

Advances in data storage and retrieval technology now allows comparison of the interagency fire database maps with remote sensing imagery, including archival ERS 30m data, using automated data processing. This provides an opportunity to find missing fires to aid all fire ecology research in Alaska (most of which uses this historical fire occurrence map) and to improve algorithms for the future (sidebar page 25).

Tundra fires are known to be underdetected, particularly prior to satellite technology when detection relied exclusively on overflights and pilot reports, but also due to limited human presence in tundra regions (Loboda et al. 2013). The extensive historical archive of ERS-1 and -2, Radarsat-1, and ALOS PALSAR image data now available provides a robust dataset for both pre- and post-fire characterization of fire signatures in the Alaskan tundra (A-15, A-19, A-28, A-37) and is helping characterize deficits and improve future detection of tundra fires. We have discovered that fire disturbance in arctic tundra often results in persistent vegetation and land surface changes (A-39) that can be detected in satellite imagery over 100 years after the event (Jones et al. 2013). Iwahana (2016) has used 2-pass InSAR data from ALOS to quantify post-fire thermokarst in Alaskan arctic tundra.

Remote sensing products analyzed with burned area offer a wealth of new insights into characterization of fire return intervals, the spatial distribution of burning, and how that might be changing over time, particularly with the warming climate (A-12, A-32). Some of the information emerging from these studies has important implications for land management, fire protection, and ecosystem services. For example, Veraverbeke et al. (2017) used MODIS hotspot data to detect an increase in fires near the forest/tundra ecotone. Repeat Landsat data is being applied to detect changing trends in forest structure—the ratio of coniferous forest to deciduous forest has declined by perhaps as much 40% in recent decades in interior Alaska (Beck et al. 2011), and these changes carry important ecological impacts to habitat, future flammability, and hydrology (A-12, A-14). These studies use technology already in process, but other sensor data in development stages may offer as-yet-unknown benefits in boreal forest for refinement and new insight into key questions. Examples include polarimetric spaceborne SAR data (A-6), which could provide improved soil moisture content detection, and a host of airborne sensors being tested in ABoVE experiments (UAVSAR [L-band SAR], AirMOSS-P-band SAR, LVIS full waveform lidar, and AVIRIS-NG [VIS-SWIR] spectral imaging [A-2, A-25]).

Fire Return Intervals

During the 21st century (within the 60-year historical record), 21% of burning occurred in previously burned forest (A-35). The management community needs further insight into disturbance trends and processes for establishing desired future conditions and appropriate fire management strategies. The question of whether fire return intervals are indeed getting shorter, as preliminary spatial analysis and field studies indicate, or whether this is an artifact of record saturation (due to the relatively short 60-year period of record—less than an average boreal forest fire return interval) is particularly important, as this could lead to rapid ecosystem change via threshold changes in active layer depth, drainage, and seedbank availability. Sometimes disturbed communities remain in altered states for persistent periods of time ("recovery failure" [A-35]). One example is the establishment of persistent stands of grasses in former forest that re-burns prior to developing the ability to set seed or in the understory of beetle-killed spruce forest in south-central Alaska. Those ecological tipping points could induce rapid shifts in ecosystem services. Moreover, fire can behave differently in forests under warmer, drier conditions (A-38), and management agencies already have anecdotal evidence for this in Alaska. Additional evidence comes from a large spatial analysis of burn progression during the 2015 fire season, where an unexpected finding was significant fire entry into deciduous stands (normally thought to have high resistant to fire) as well as coniferous forest (Barrett et al. 2016, Jandt 2017).

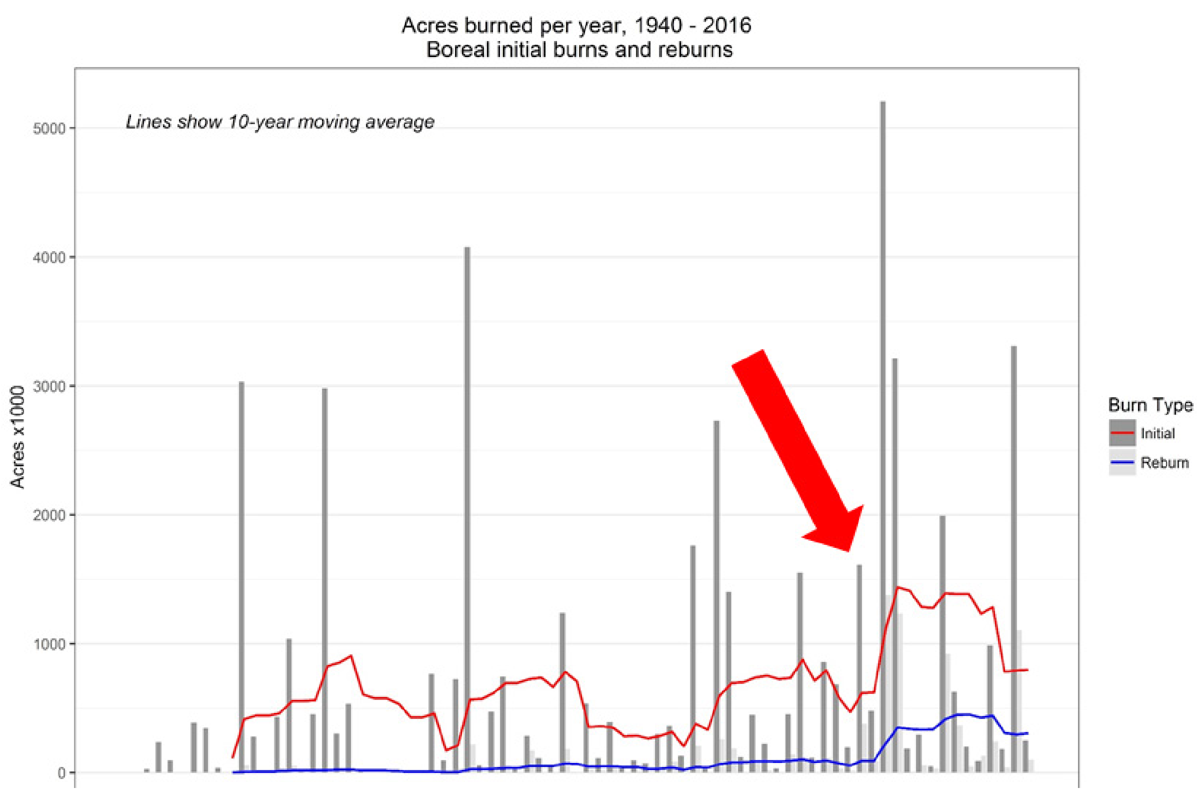


Figure 15. Loehman et al. (A-35) explored the spatial and temporal patterns of initial and reburn fires within Alaska over the past five decades—a topic of significant interest among fire managers in Alaska. There seems to be an increase in "re-burns" in the 21st century, indicated by the red arrow (above); we cannot yet rule out the possibility of an artifact from the relatively short period of record-keeping, however. Figure from A-35).

Local-scale assessment

Recent Structure From Motion post-burn assessments conducted by Northwest Territories and Canadian Forest Service (A-33), and USFWS in Alaska (Laker 2016) yielded relatively low cost products including canopy height and high resolution vegetation.

Impacts to plant and animal communities

The ability to map habitats rich in terricolous lichens has been of particular interest to Alaska fire and resource managers for two decades. These old growth species are important as winter forage for caribou and recover very slowly post fire (Joly et al. 2009). LANDFIRE does not provide an algorithm to detect terricolous lichens, and we still do not have a way to remotely assess and inventory these stands, in spite of their unique spectral characteristics and management importance. Since our workshop, new efforts using combinations of Landsat RGB image mosaics with vegetation height determined from UAS using structure from motion processing have shown great promise in mapping fractional lichen cover (Macander et al. 2018). This is a good example of how combinations of modalities with advanced processing can yield new insights to land managers' ecological questions, and it appears we have only scratched the surface of this new potential.

Fire effects characterization

Burn severity is a much-debated parameter that encompasses a constellation of measurements including depth of consumption, mineral soil exposure, canopy mortality, surface burn severity, and ecological effects of fire at various spatial and temporal scales. In HNL environments, the depth of duff/organic soil consumption is the key determinant of successional trajectory, erosional and thermokarst risk, and vegetation recovery (Johnstone et al. 2010). The first widely adopted algorithms for remotely sensed burn severity (dNBR) were developed in pine forests of the western U.S. (Key and Benson 2006) and are good at discriminating crown fraction burned and mineral soil exposure in dry coniferous forests of the West but less than optimal for nuanced burn severity characteristics in tundra and boreal forest. The dNBR quantifies fire severity from immediate (one season to 1 year) fire-induced changes in near- and shortwave infrared reflectance. Near-infrared reflectance typically decreases after fire due to destruction of live vegetation and deposition of char, while shortwave infrared reflectance increases due to drier substrates, char, and soil. Generally, the dNBR gives a reasonably accurate portrayal of relative burn severity in boreal ecosystems, but it does have shortcomings. For example, severely burned areas can be moister due to permafrost thaw, or greener due to rapid development of liverworts and mosses in sites with mineral soil exposure, and these signals can be misinterpreted by dNBR algorithms (Jandt, pers. comm). Additionally, biases have been shown in different forest types (Rogers et al. 2014) and seasonality—exacerbated by low solar angles in the HNL (Verbyla et al. 2008). New research is identifying algorithms that better separate burn severity levels in other soil types like peatlands. The impacts of fire on the arctic-boreal biome are a major focus of the ABoVE airborne campaign, and we expect that the data they collect on large fires in Alaska and Canada will provide important insights into fire effects (A-25).

Severity and duff consumption

Studies evaluating dNBR alone as a metric for duff consumption show inconsistent results (Allen et al. 2008, Rogers et al. 2014, Verbyla et al. 2008, Murphy et al. 2008, Alonzo et al. 2017). The range of variability is constrained in high severity burns, in forest types with high canopy mortality, and in tundra (Loboda et al. 2013). Severity of re-burns in Alaska registered inaccurately low using dNBR (A-31). Exploratory correlation of duff consumption with newer remotely sensed indices (radar burned ratio, relativized NBR) shows promise but requires validation with airborne and field studies and could be regionally optimized. Use of dNBR together with other predictors of belowground consumption (topography, fire weather) has been shown to capture variation in duff consumption fairly well (Veraverbeke et al. 2015). Several approaches show promise for improving information about the all-important burn severity measure, which influences all other ecological effects, including erosion potential, watershed, wildlife, and infrastructure impacts (A-2, A-10, A-27). This information would also improve emissions models (see below) and carbon balance studies.

Unmanned aerial systems for fire effects mapping

Northwest Territories demonstrated how Unmanned Aerial Systems (UAS) can be very cost-effective and accurate for validation of burn severity and post-fire effects (A-33). Alaska and Canada have employed low-cost digital photogrammetry with Structure From Motion processing with excellent results as well (Fraser et al. 2017, Laker 2016). Alaska fire protection agencies acquired their first low-cost UAS fleets in 2017. Sharing of methods and technology for these cost-effective monitoring approaches could greatly assist agency ability to expand local-scale assessment of burn effects as opposed to fewer studies with costly tools like LiDAR (sidebar, page 28).

Estimating carbon emissions from fires

Carbon emissions from wildfire can be estimated from a variety of global resources, such as Global Fire Emissions Database (GFED; Giglio et al. 2013), the Canadian Forest Service CanFIRE (de Groot et al. 2009) and Fire INventory (FINN; Wiedinmyer et al. 2011), as well as the recent Alaska-centric AKFED (Veraverbeke et al. 2015; https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1341) and the U.S.-level Wildland Fire Emissions Information System (WFEIS; A-9; Figure 16; http://wfeis.mtri.org). Fuel loading and consumption (depth of burn) are the largest sources of uncertainty input to emissions models (A-9, A-29, French 2014). Different models operate at different scales and use different emissions factors. French et al. (2011) compared assumptions and skill of several emissions models on case studies in the U.S. and Canada. The variability in fuel loading in Alaska ecosystems and the diversity of fuel loading data products in use by the science and management communities could benefit from additional field and remote sensing-based calibration efforts. Thermal retrieval, sampling via airborne or UAS sensing, and observational data to validate models and quantify biomass at appropriate scale should continue in parallel with emissions model development. The direct measurement of consumption and emissions with satellite-derived thermal IR Fire Radiative Energy would help determine the relative skill of various different emissions models with widely divergent outputs (A-17). The Global Fire Assimilation System (GFAS) assimilates fire radiative power (FRP) observations from satellites to produce daily estimates of biomass burning emissions, available globally since 2003 from Copernicus (https://atmosphere.copernicus.eu/charts/cams/fire-activity). An example of a validation study in Alaska is the Alaska Fire Emissions Database (AKFED; A-30), which combined spatially explicit calibration and validation with field measurements of combustion for its emission model (sidebar this page). Synergies between various approaches to carbon/emissions modeling need to be explored.

Emissions estimates

Veraverbeke's C emissions database estimator uses Drought Code (from Canadian Fire Weather indices), temperature, pre-fire tree cover, and dNBR as predictors of burn depth (see 'High resolution carbon emissions estimates from boreal wildfires', A-30).

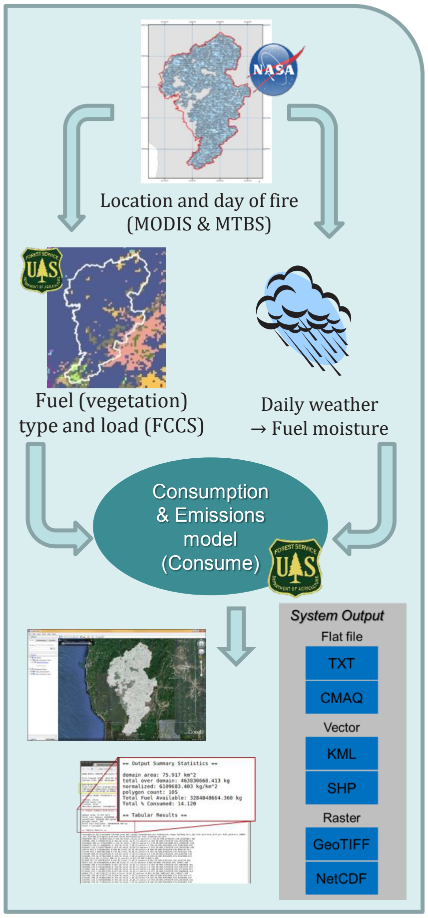


Figure 16. The Wildland Fire Emissions Information System (WFEIS) is a web-based tool that provides a simple user interface for computing wildland fire emissions at landscape to regional scales (1-km spatial resolution). WFEIS is not an inventory of fire emissions, but rather a system that provides open access to the modeling tools needed to quantify emissions from past fires. WFEIS provides access to fire perimeter maps along with corresponding fuel loading data and fuel consumption models to geospatially compute wildland fire fuel consumption and fire emissions for user-specified locations and date ranges. The system currently calculates emissions from fires within the United States from 1984 to 2013. http://wfeis.mtri.org/

An online database with a user-friendly interface for custom query of fire emissions and carbon storage and loss would be useful to land management agencies. Managers are particularly interested in querying carbon loss for specific recent fire events. The on-line emissions calculator designed by Michigan Tech for their Wildland Fire Emissions Information System research product (http://wfeis.mtri.org/) stands out as an example of a highly intuitive tool (French et al. 2014), but it lacks maintenance funding so works only for past fire years. Development of this type of tool for use for post-fire assessment would benefit both research and management efforts in characterizing fire effects, including emissions.

Ecological processes and feedbacks from fire

The science of determining feedbacks to global climate from large-scale boreal wildfires is rapidly evolving. This has national and global importance since Alaskan forests, tundra, and permafrost hold approximately 58% of U.S. carbon stocks. Although snow dependence has recently emerged as the largest single factor influencing post-fire albedo in HNL forests, summer positive feedbacks may be more influential globally (A-37). Continued research on parameterizations for surface forcings are important to complete our understanding of the implications of increased boreal burning on global climate (A-37, A-40, A-41). Carbon trade-offs induced by post-fire vegetation shifts are also little known, but current studies may help identify these relationships and provide improved modeling of carbon budgets on the landscape (A-42, A-43).

The short- and long-term impacts of fire on permafrost vary depending on latitude and the pre-fire impacts of a rapidly warming climate. The changes induced by thawing can include remarkable changes in surface micro-topography (due to accelerated melting of subsurface ice features, A-39) and soil drainage characteristics, which can induce dramatic shifts in vegetation, winter snow cover, and wildlife use. For example, extensive fires in southwest Alaska in the early 1970s and recent years have been preceded by widespread loss of upland lakes and ponds; these aquatic-terrestrial state transitions are potentially exacerbated by active-layer deepening after fire (A-44). The research documenting the persistence and extent of these post-fire impacts is relatively new, and land management agencies seek documentation and models to help them understand the long-term impacts of fire management strategies. Should protection levels be changed in certain cases? Are firefighting tactics involving large backburns to remove fuel always appropriate?

Because of the dual and opposing processes of thawing permafrost and improved sub-surface drainage, the actual soil moisture trajectories post-burn have long been debated in the boreal forest. Historical ground-based studies using probes and thermistor strings help but lack the scale to provide landscape inferences. Radar instruments have rapidly improved, and there is much new data on their ability to estimate landscape-scale soil moisture variance (A-2, A-5, A-6, A-10, A-36), but these techniques have yet to be incorporated into operational fire management use (but see A-4). In particular, we are interested to see the development of boreal vegetation algorithms for the new SMAP satellite (A-27). Alaska and Canada fire managers are engaged directly with research teams working on these and have plans for pro-active technology transfer.

Opportunities & Recommendations

The key opportunity identified by workshop participants was the idea of working smarter to bridge the "last mile" and bring promising science and technology products into use by agencies and stakeholders at multiple scales. Current satellite assets are significantly underutilized in the operational agencies, and the various current fire monitoring activities fall largely in the research domain. To improve operational use of the available information, increasing attention needs to be given to data availability, product accuracy, data continuity, data access, and how the data are being used to provide useful information. A related issue is user saturation for remote sensing products at the operational level, exacerbated by these data being housed at multiple locations.

The sentiment expressed by managers and resource specialists at the workshop was that researchers develop potentially valuable products, but there is no one on the user side to receive and maintain the product in a usable form for fire managers. Field agencies lack fire management "remote sensing specialists" to incorporate the new products into tools. Certainly, from a national perspective, many elements of the necessary systems are in place to enable agencies like NASA to deliver these products for field application. The NASA Applied Sciences Program, of course, sponsored this workshop and facilitates others across the country in various subject areas (see https://appliedsciences.nasa.gov). Twice annual Tactical Fire Remote Sensing Applications Committee (sidebar this page) meetings with NASA, the USFS, and interagency cooperators are helpful to highlight new data and technologies and can be an avenue for development of new programs and initiatives to operationalize technologies to the field. Recent examples include use of UAVs on fires, new forecasting products, and new sensor technology for fire detection and monitoring. NASA's Applied Remote Sensing Training (ARSET) program provides training to acquire and use NASA satellite and model data for decision support via online webinars and in-person workshops.

Everett Hinkley, national remote sensing program manager for the USFS, discussed the operations of working groups established to help bridge the gap between new technology and wildfire management applications (TFRSAC and Thermal Working Group, which deals with classified data). He also summarized national resources for ongoing fires such as the National Infrared Program (NIROPS) aircraft and unmanned aerial systems.

Tactical Fire Remote Sensing Committee (TFRSAC)

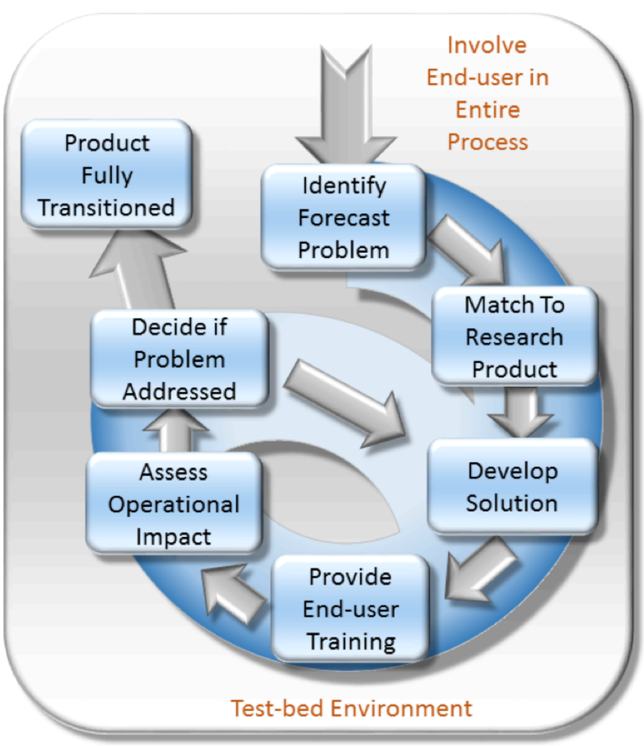
Because NASA's mandate does not usually allow it to put its research results or data directly into practice, applied remote sensing usually requires NASA to partner with another federal agency or nongovernment entity to use the NASA observations for these practical applications (NRC 2007). The Tactical Fire Remote Sensing Applications Committee (TFRSAC) is composed of fire management practitioners, remote sensing scientists, GIS specialists, and industry and university affiliates to formulate a tactical fire information gap analysis and prioritize development and transfer technologies related to those gaps.

TFRSAC convenes twice-yearly meetings; TFRSAC meeting presentations and notes are available at both the USFS GTAC website (https://fsapps.nwcg.gov/nirops/pages/tfrsac) and the NASA Wildland Fire Program website (in the Library section and "past meetings" section: https://appliedsciences.nasa.gov/programs/wildfires-program).

On the agency "receiving" end, the interagency Wildland Fire Management Research, Development & Application is chartered to integrate science, technology, and fire management, but their focus is on the development and support of agency-supported decision support systems. NWCG also has a Geospatial Subcommittee (GSC) to provide national leadership for the integration of geospatial information, technology, and systems into all phases of wildland fire management. This includes the development and promotion of standards and tools; trusted data to support wildland fire operations; training; the development of geospatial capability in the field; and providing geospatial expertise to other wildland fire lines of business. However, most of our field office RS specialists were not familiar with this office.

A few programs offer models for targeted activities to support the successful transition of promising research products to operational systems. These include:

Figure 17. The SPoRT testbed environment. This research-to-operations/operations-to-research paradigm enables the project and its partners and collaborators to provide products that are needed and can be readily used in an operational environment. Keys to this paradigm are active collaboration and communication with end users, formatting experimental data sets for view in end-user decision support systems, creating training materials focused on user needs and applications, and obtaining end-user feedback on the forecaster confidence and operational impact of experimental products.



- The Short-term Prediction Research and Transition Center (SPoRT) based at Marshall Space Flight Center is a NASA and NOAA funded activity to transition experimental satellite observations and research capabilities to the operational weather and disaster response communities. The SPoRT program functions in a testbed environment (Figure 17).
- The Joint Polar Satellite System Proving Ground and Risk Reduction Program was established in 2012. Its primary objective is to develop and enhance user applications of Suomi NPP/JPSS data, algorithms and products. The PGRR supports user demonstration by stimulating interactions between technical experts from the JPSS Program, university partners and key user stakeholders.
- DEVELOP, supported by the NASA Applied Sciences Program, organizes short-term interdisciplinary research projects to apply NASA Earth Observations to specific decision-support contexts.

Based on these and other models discussed at the workshop, participants recommended a number of useful measures to strengthen delivery in "the last mile", including:

- Consolidation of data hosting at "clearing house" websites, or one stop shopping sites. An example is the USGS LP DAAC website (A-45).
- Composite (ex. RGB displays, A-21) and interpreted data products (e.g. fire perimeters, spread) are key. Machine learning could be used to automate product production
- Matchmaking in the form of funding grad students to work with an agency to turn targeted science products into continuously available operational products (NSIDC snow cover was suggested as an example of this). One form this could take would be a remote sensing internship located at (and supported by) Alaska Fire Service.

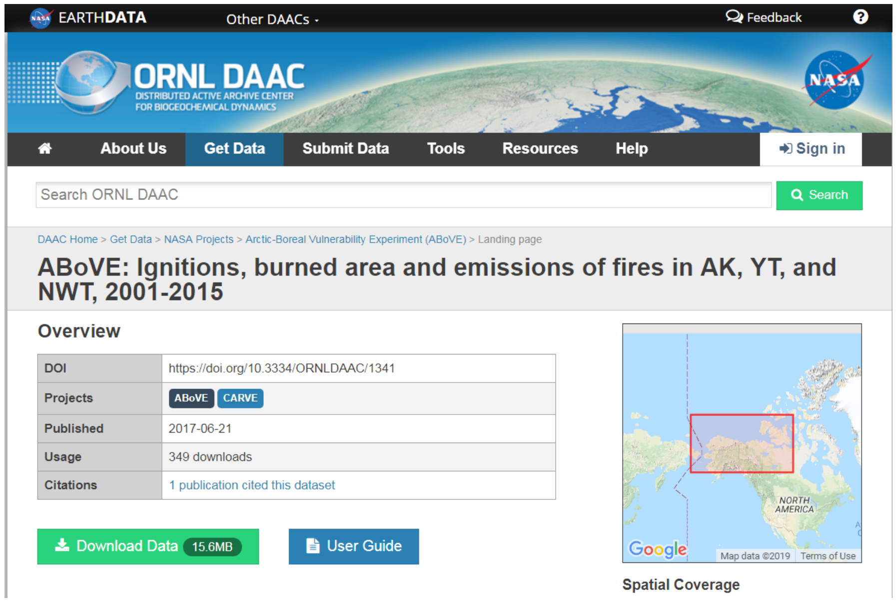


Figure 18. The ORNL DAAC is an example of a data clearinghouse serving research datasets to agencies and the public. In this example, a large data collection of satellite-detected fire ignitions and burned area along with emissions data is provided in downloadable form (Veraverbeke, et al. 2017; A-30, A-45). https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1341

- The National Wildfire Coordinating Group should consider establishing a Remote Sensing committee to reach out to NASA, NOAA and other data providers and better communicate their consolidated needs. Regionally, in Alaska, perhaps the AWFCG Research Committee should have a remote sensing subcommittee or task group to focus on issues and needs.
- Better communication with, and use of existing national and department-level technology bridging efforts at NWCG (for example, Geospatial Subcommittee, TFRSAC). State and field offices need to more effectively use their representation in these efforts and share the information obtained at meetings within their own organizations. They need to provide input to NASA's decadal survey process for earth science needs: the Decadal Survey for Earth Science and Applications from Space. However, 2017 was the most recent year of this survey (recommendations can be viewed at https://www.nap.edu/download/24938). Some of the findings and recommendations are congruent with those identified by this workshop.
- Continuing representation and participation of the Alaska wildland fire community at AGU, NASA Science, and AMS meetings could help improve communications with NOAA and NASA scientists and managers. They also need to identify ways to make their needs known to managers of other observing programs like NOAA GOES-R, EUMETSAT Meteosat and MetOp, JPSS.
- Webinars tailored to educate stakeholders about products. NASA's ARSET courses are a good example of this. A webinar overview of the LP DAAC products that other fire communities are using was suggested. NASA Earthdata has search capability, user resources, data downloads and a helpdesk.
- One idea for inter-coordination included a web-based forum or discussion page, well-known to managers, where tips and trick and locations of data sources could be posted and questions asked. The Alaska Fire Science Consortium was suggested as a possible location for such a page or social media forum.

A major barrier identified to operationalizing new RS technologies is the question of funding. Research funding organizations like NSF, for example, will not fund operationalization of RS products. The question of funding may be why new technologies often do not make it that "last mile" to be adopted by agencies. On the NASA side, SPoRT is a key exception, and the GPM mission has a specific applications focus. Such approaches need to be expanded to meet the need to move promising technologies from research to operations.

User requirements

User requirements—and the challenges associated with communicating them to science and technology providers—cannot be over-stressed here. Understandably, NOAA requirements for weather observations have been driving requirements for NASA developers. The fire community needs to be proactive with communicating to NASA the importance of the products for fire managers. The interagency Tactical Fire Remote Sensing Applications Committee (TFRSAC) is discussing developing a user-requirements matrix for this purpose, and Alaska and Canada should contribute input.

Canadian Wildfire Remote Sensing Workshop

In association with the Earth Observation Summit 2017, a 3-day Wildfire Remote Sensing Workshop was held in Montreal, Canada, June 20-22, 2017. More than 50 people from Canada, U.S., South Africa, U.K., France, and Belgium participated in the workshop, which was co-organized by the Canadian Space Agency and the Canadian Forest Service. The objectives of the Montreal workshop were similar to those of the Alaska workshop, and a few participants attended both meetings.

The Montreal workshop identified 30 needs, challenges, and lessons learned as well as 13 key recommendations in four categories:

- Bridge the gap between research and operations communities,
- Increase the sharing of practices between Canadian provinces and territories and Alaska,
- Improve end-products, and
- Include the airborne industry.

More information on the workshop presentations, findings, and recommendations can be found in the workshop report, available at https://crss-sct.ca/wp-content/uploads/2018/04/EO-Summit-2017-Wildfire-Remote-Sensing-Workshop-Report-2018-04-11.pdf

Outcomes & Updates Since the Workshop

The goal of this workshop was to expand the application and use of remotely sensed data for fire management and fire science in HNL countries, and we hoped to foster co-developed investigations into new management and scientific uses of remote sensing data. Between the workshop and the production date of these proceedings, several positive outcomes, partnerships, and collaborative efforts have already evolved. Descriptions of some follow on projects are provided in the list below, with points of contact for further information:

- Presentations on the workshop outcomes to several audiences:
  - Workshop on The Role of Remote Sensing in Wildfire Management and Research, jointly organized by the Canadian Forest Service (CFS) of Natural Resources Canada (NRCan) and the Canadian Space Agency (CSA) in association with the Earth Observing Summit 2017 (sidebar this page). Report available here: https://crss-sct.ca/wp-content/uploads/2018/04/EO-Summit-2017-Wildfire-Remote-Sensing-Workshop-Report-2018-04-11.pdf (AFSC: York, Ziel)
  - Arctic-Boreal Vulnerability Experiment (ABoVE) 2018 and 2019 Science Team meetings (AFSC: Jandt, York)
  - Interagency Arctic Research Policy Committee Terrestrial Ecosystems Collaboration Team meeting (AFSC: Jandt, York)
- Operationalization of "hot spot" products from GINA to AICC with BLM funding (AICC: Jenkins; https://news.uaf.edu/new-tools-help-fight-wildfire-with-satellite-imagery/)
- A new process for submitting legacy perimeter data to the AICC spatial database (AICC; Jenkins; https://fire.ak.blm.gov/content/maps/aicc/Data/Data%20Templates%20(zip)/LegacyFirePerimeters_templates.zip)
- SPoRT collaboration on extending real-time 3 km Land Information System into Alaska (soil moisture), with plans for a NASA DEVELOP project to support transition of additional products, e.g., evaporative stress index (SPoRT: Schultz, Ziel)
- NOAA DEVELOP project with NCEI on Development of a Snow Melt and Fuel Conditions Monitoring Tool Using NASA MODIS and NOAA Climate Data Records to Aid Wildfire Managers in Alaska. The product is planned for operational use in Spring 2019 (AICC: Strader).
- NASA Short-term Prediction Research and Transition Center (SPoRT) is combining lightning detection systems with NOAA land information data, vegetation condition, soil moisture, and weather information to provide ignition potential assessment (SPoRT: Schultz, Ziel)
- Ongoing investigation to point-validate HRRR with expanded radar data from the Transportable Array and National Weather Service stations in Alaska to quantify the HRRR's ability to forecast the strength and location of surface pressure centers and cloud cover (Univ. Utah: Horel, McCorkle, Ziel).

- Canadian Forest Service (CFS) supported a collaboration with University of New Brunswick, MDA, Michigan Tech Research Institute and CFS using RADARSAT-2 polarimetric and compact polarimetric data to estimate volumetric soil moisture content over boreal forests in Alaska and Ontario (UNB: Leblon).
- An ABoVE project using MODIS burned area and field sampling to quantify carbon consumption by wildfire and long-term changes to albedo to develop maps of net radiative forcings from wildland fire in Alaska and western Canada (WHRC: Rogers).
- 2018 AFSC Research Brief highlighting some of the new data coming out of the NASA ABoVE project that have potential management use (AFSC: Jandt 2018)
- A proposal to support a PhD student to study soil moisture controls on high latitude fires from 2001-2020 (using ESA satellite analog to SMAP data) at the Vrije University Amsterdam (VUA: Veraverbeke).
- Expanded investigations into seasonal forecasts for wildfire in Alaska with strong management collaboration and input (UAF: Bieniek, Bhatt)
- A 2019 high latitude fire project in the Netherlands will study holdover fires, and limitations to fire growth, including Alaska (VUA: Veraverbeke).
- Inclusion of testing hyperspectral imaging to improve evaluations of pre-fire fuel conditions in a newly-funded Alaska EPSCoR project. Improved fuels and enhanced forecasts are to be combined to create fire risk datasets (EPSCoR Fire & Ice 2018; UA: Bhatt, Panda, Stuefer).

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Appendix A: Abstracts of oral and poster presentations

Introduction to the State of the Science

A-1 Warts and All: The Current State of the University of Alaska's Near Real Time Satellite Imagery and Derived Products Available to the Alaska Wildland Fire Community

Eric Stevens, Jay Cable, Carl Dierking, Tom Heinrichs, Dayne Broderson (UAF/GINA), Sharon Alden, Heidi Strader, and Jenn Jenkins (Alaska Interagency Coordination Center)

The Geographic Information Network of Alaska (GINA) at the University of Alaska Fairbanks receives data from a number of polar-orbiting weather satellites. Data from these satellites are used to generate imagery and other derived products (such as the "hotspots" product) that are delivered in near real time to users such as the National Weather Service and Alaska Fire Service.

While there have been many successes over this 13-year-long collaboration, both the quantity and quality of GINA's imagery available at Alaska Fire Service and the Alaska Interagency Coordination Center (AICC) could be improved. Challenges have primarily been rooted in logistical issues that have hindered the ability of fire managers to fully access GINA's imagery.

Examples of GINA's imagery and products currently available at AICC will be presented, with emphasis on the strengths and shortcomings of the imagery. The goal of this talk is to spark a discussion with the assembled experts and stakeholders that guides and prioritizes future enhancements to services.

A-2 Use of New NASA Technologies for Pre-, Active, and Post-Fire Applications

E. Natasha Stavros, Mike Gunson, David S. Schimel (Jet Propulsion Laboratory, California Institute of Technology)

Increasing wildfire size, frequency, and severity, and impacts on a growing wildland urban interface create a need for new technological approaches to study and understand the role of fire in ecological systems (i.e., fire ecology). In November 2015, JPL hosted a study inviting participants from the US Forest Service, National Center for Atmospheric Research (NCAR), and NASA to develop an application traceability matrix relating informational data products useful for pre-, active, and post-fire applications to different platforms that could provide these estimates. Both airborne and spaceborne platforms were considered. In this talk, we will present results from airborne campaigns that have been used for fire applications, present ongoing activities that have the potential for extrapolation to boreal regions with the extensive airborne campaigns as part of the NASA Artic-Boreal Vulnerability Experiment (ABoVE). Specific results will be presented from airborne campaigns over large extents of California. The results derive from use of technologies such as a hyper spectral visual to shortwave infrared Airborne Visual/Infrared Imaging Spectrometer (AVIRIS), high spatial resolution multi-band thermal infrared imaging (MASTER), coupled spectrometer and Light Detection and Ranging (LiDAR) on the Airborne Snow Observatory (ASO), and the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR). This talk will highlight the use of LiDAR to provide 3-dimensional forest structure and biomass, AVIRIS to provide information on forest composition, chemistry, condition, and quantification of fire severity, MASTER to provide very high-resolution fire intensity, evapotranspiration and water-use efficiency maps, ASO to provide forest structure, and UAVSAR to provide estimates of change detection and soil moisture. Because these technologies are either not yet available from satellite, or with limited extent on satellites, research is being conducted to assess their full utility for fire ecology. Although many of these technologies are limited to airborne campaigns currently, that is not true for many of them in the near future. The second part of this talk will focus on describing some of the upcoming missions, specifically NISAR, what the Applications Plan is, how the flight project intends to work with the applications communities, and different information that can be derived (i.e., canopy structure, biomass, change detection, inundation, and fuel moisture) to advance the applications utility of NISAR data. Missions like NISAR have the potential to change the fire management landscape by providing information that is otherwise limited to cloud-free, well-lit (i.e., day time acquisition) areas of the world.

A-3 S-NPP/VIIRS and Landsat-8/OLI global active fire data sets

Wilfrid Schroeder (University of Maryland)

Two spatially-refined active fire data sets have been developed using global multispectral data from the Suomi National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite (S-NPP/VIIRS) and Landsat-8 Operational Land Imager (OLI). The S-NPP/VIIRS 375 m resolution fire detection and characterization product supplements the baseline 750 m fire product, which was built on and therefore provides continuity to the MODIS 1 km resolution Fire and Thermal Anomalies product (MOD14/MYD14). Similar to its coarser resolution siblings, the VIIRS 375 m fire product carries many of the same base layers, including a full-blown fire mask, sub-pixel fire radiative power (FRP) retrievals and file attributes. However, the higher 375 m spatial resolution results in significantly greater response over smaller/lower intensity fires and thermal anomalies, while also delivering improved mapping of larger fire perimeters. Compared to the coincident VIIRS 750 m global fire data, the 375 m product detects, on average, 3x (+20x) more daytime (nighttime) fire pixels of which »45% (»80%) are unique to the product (i.e., show no match in the 750 m data set). Complementing those data, the Landsat-8/OLI global active product delivers 30 m resolution day and (on-demand) nighttime fire detection information albeit at much reduced temporal resolution (16-day nominal interval). The OLI 30 m fire data is the first of its kind to be implemented operationally in support of fire management applications in the U.S. A growing network of Landsat-class instruments which includes ESA's 20 m resolution Sentinel-2a/b Multispectral Instrument (MSI) and other commercial assets (e.g., Digital Globe's Worldview 3&4) have the potential to transform the way those data are used in routine operations, especially at high latitude regions where observation frequency is improved as a result of satellite orbit convergence. Exploring these refined satellite fire products, we demonstrate new data applications supporting routine wildfire mapping and coupled weather-fire behavior modeling.

A-4 Short-term Prediction Research and Transition (SPoRT) Center Datasets and Products for Wildland Fire Potential and Prediction

Christopher Schultz and Anita LeRoy (Short-term Prediction Research and Transition [SPoRT] Center)

Leading up to a wildfire event, land surface and vegetation health are two key components to identifying locations ripe for wildfire occurrence. NASA's Earth Science Division has a number of polar-orbiting satellites that measure land cover characteristics, precipitation, and can even identify active fires and burn scars. These data can contribute to the prediction and monitoring of wildfire occurrence in Alaska through direct use for situational awareness or by integration into modeling tools. This information can provide both short term (0-24 hours) and longer term information valuable to those monitoring for wildfire occurrence. NASA's Soil Moisture Active Passive (SMAP) satellite and the Evaporative Stress Index are vital sources of information on ground moisture and vegetation health. Synthetic Aperture Radar (SAR) measurements, such as those available from the European Space Agency's Sentinel missions, and other high-resolution sensors, such as Landsat-8 can provide additional detail on vegetation stress, active fires and burn scar extent. The Global Precipitation Mission (GPM) provides useful satellite-based precipitation types and rates. The Short-term Prediction Research and Transition (SPoRT) Center at NASA's Marshall Space Flight Center works to transition all of these datasets to operational partners. Additionally, SPoRT currently runs a real-time, high-resolution land surface model based off the NASA-developed Land Information System (LIS), which has capabilities for integrating SMAP and GPM to track land surface, soil and vegetation characteristics for situational awareness and can decipher trends in the land surface characteristics on longer time scales (months, years).

NASA SPoRT and the Earth Science Office at MSFC also has a long standing history of working with ground based and space based lightning for monitoring thunderstorm activity. This includes engineering of instrumentation, intercomparision of lightning datasets from different instruments, development of algorithms to monitor lightning activity and training for end users to maximize the use of the lightning data in the operational framework.

Recently, NASA SPoRT has combined its land surface and lightning expertise to start developing an approach to identify the potential for lightning-initiated fires in real-time. In a small study of 87 lightning-initiated wildfire cases (5300 flashes) statistically significant land surface parameters and lightning characteristics were observed to separate fire starting flashes from non-fire starters. Both the 0-10 cm relative soil moisture content and green vegetation fraction were the two SPoRT-LIS parameters which demonstrated the most utility in identifying lightning flashes which initiate wildfires. Furthermore, the peak magnitude of negative cloud-to-ground flashes were statically different than non-fire starting flashes. For positive flashes, the peak magnitudes were similar, and the underlying land surface that determined if a fire start occurred.

This presentation focuses on specific examples of these datasets and products and demonstrates their utility in the short term prediction and identification of wildfire potential.

Potential Fire Risk : Can remotely sensed data (e.g., daily snow extent, others) estimate spring soil moisture and surface and subsurface fuel moisture and fuel conditions, and thus provide critical inputs for fuel moisture indices used to predict fire danger and risk?

A-5 Assessing Fuel Moisture in Boreal and Arctic Ecosystems with Active and Passive Microwave Satellite Imagery

Laura L. Bourgeau-Chavez, Nancy French, Mary Ellen Miller and Liza Jenkins (Michigan Technological University), Kyle McDonald (City University of New York)

In Alaska and Canada, the Canadian Forest Fire Danger Rating System (CFFDRS) is used to estimate moisture in the organic soil layers of the ground from the surface (nominally 1.2 cm) down to deeper, more compact organic layers of the duff horizons (10-20 cm depth). The moisture status of the organic soil is a key driver of the potential for wildfire and NASA's Soil Moisture Active Passive (SMAP) satellite sensor has potential to provide complementary data to CFFDRS. As a weather-based point source system, CFFDRS has inherent limitations that could be greatly improved with synoptic moisture information from a satellite sensor at high repeat frequency, such as SMAP. Research is underway to assess the utility of the L-band 36 km resolution SMAP moisture products for organic layer fuel moisture monitoring in boreal and Arctic ecosystems for fire danger prediction including: a) comparison to the broadscale network of weather-based CFFDRS fuel moisture estimates; b) soil moisture databases; c) the Canadian Land Data Assimilation System (CaLDAS) modeled root zone and near-surface soil moisture; and d) the actual occurrence of wildfire. In addition, a comparison of the passive SMAP data with high-resolution SAR imagery is being evaluated to: a) address the impact of scene heterogeneity and surface water on SMAP results; and b) investigate methods for downscaling SMAP to a finer resolution (0.2 to 3 km) soil moisture product through development of hydrological modeling and integration of high resolution SAR data from Sentinel-1 and/or PalSAR-2. The overall investigation will yield a more complete understanding of the relationship between field measurements, the CFFDRS Fire Weather Index, CaLDAS moisture models, SAR and SMAP soil moisture. A key goal of this project is the development of a refined assessment of fire danger for boreal and Arctic regions. With 2 day repeat, synoptic coverage, and an observation-based enhancement to the weather-based CFFDRS codes, SMAP has potential to provide essential, complementary data to the weather data that provides the basis for current fire danger and behavior assessment system used in Alaska and Canada. The outcomes of this project will be valuable for fire management and prediction across the vast region where weather-based information is scarce. While the research is focused on improving modeling of fire danger to understand spatial and temporal patterns of organic soil moisture in HNL ecosystems, something that has not been able to be monitored synoptically before now, the impact of this research extends beyond fire decision-making into needs for ecosystem modeling and monitoring climate change impacts.

A-6 An overview of twenty years of research at the Faculty of Forestry and Environmental Management, University of New Brunswick, Canada on fuel moisture estimation using optical, thermal infrared and radar remote sensing in boreal forests in Alberta, the Northwest Territories, and Alaska

Brigitte Leblon, S. Oldford, L. Gallant, G. Strickland, K. Abbott (University of New Brunswick, Canada), L. Bourgeau-Chavez (MTRI, USA), J. R. Buckley (Royal Military College, Canada), M.E. Alexander (Canadian Forest Service, Canada), M. Flannigan (University of Alberta, Canada), G. Staples (MDA, Canada)

This paper presents an overview of 20 years of research at the Faculty of Forestry and Environmental Management, University of New Brunswick, Canada, on fuel moisture estimation using optical, thermal infrared and radar remote sensing in the boreal forests of Alberta, the Northwest Territories, and Alaska. In collaboration with Canadian Forest Service (CFS), the first studies tested the use of NOAA-AVHRR NDVI and surface temperature images over the boreal forests of the Northwest Territories and Alberta. Over the boreal forests in the Northwest Territories, we observed that mean surface temperature values increased as ignition dates approached and high fire weather index (FWI) areas corresponded to high surface temperature values (Oldford et al. 2003). A modelling approach showed that FWI was related to the ratio between actual and potential evapotranspirations estimated from NOAA-AVHRR images (Strickland et al.. 2001). Over boreal forests in Alberta, significant relationships were established between the drought code (DC) and NOAA-AVHRR NDVI and surface temperature images, Satellite-based DC estimations were more reliable than weather station-based DC in the detection of fire starts (Oldford et al.. 2006). More recently, SAR images from ERS-1 C-VV (Leblon et al.. 2002) and RADSARSAT-1 C-HH (Abbott et al.. 2007) were tested over forests in the Northwest Territories for the estimation of fuel moisture codes such as DC and FWI. Relationships with foliar moisture content (FMC) were also established. These studies also showed that biomass and canopy had an influence on the moisture code or FMC estimation. Finally, over a chronosequence of Alaskan boreal black spruce ecosystems (recent burns, regenerating forests dominated by shrubs, open canopied and moderately dense forest cover), RADARSAT-2 and ALOS-PALSAR polarimetric images were tested to assess DC variations (Bourgeau-Chavez et al.. 2013 a, Bourgeau-Chavez 2013). Several polarimetric variables from a multi-date RADARSAT-2 C-band image sequence that were acquired across a range of soil moisture conditions were used to develop empirical algorithms to estimate volumetric soil moisture maps over the Alaskan boreal test area (Bourgeau-Chavez et al.. 2013b). A mean error of 6.7 % between observed and estimated values was achieved through a regression model that used the C-VH backscatter intensity, the maximum of degree of polarization (dmax) and the maximum of the completely unpolarised component (Unpolmax) as independent variables. The model also showed improvement from 27% to 33% in the accuracy of the soil volumetric moisture content retrieval by comparison with a model that used only single polarized C-HH data. By providing information on surface roughness and/or biomass, dmax appeared to be helpful for extracting surface soil moisture from SAR data. So far, only empirical relationships have been established and a more deterministic approach still needs to be developed. The various studies were funded by NSERC. RADARSAT-1 and-2 images were provided by the Canadian Space Agency.

A-7 Lightning Distribution and Wildland Fire Occurrence in Alaska tundra (Poster)

Jiaying He, Tatiana Loboda (University of Maryland)

Wildland fires can cause dramatic changes in vegetation, soil and water properties of ecosystems in a short period of time, leading to strong impacts on ecosystem functions and services. Though wildland fires are relatively rare in Alaskan tundra ecosystems compared to forest regions, they release vast below-ground carbon stores, affect biogeochemical cycles and alter biophysical properties, leading to consequences from local to global. Recent studies indicate that small fires are quite common and climate warming has the potential to increase wildland fire frequency and area burned in the tundra biome in future. However, the drivers and mechanisms of wildland fire occurrence and spread in Alaskan tundra area are still poorly understood. To enhance the understanding of wildland fire activities in Alaskan tundra, this study aims to explore the interactions between lightning and wildland fire as well as the mechanisms of lightning activities, utilizing remote sensing data and circulation models. In this study we build quantitative relationships between lightning as recorded by the Alaska Lightning Detection Network and ignition points for wildfires in Noatak Nature Preserve during the large fire season of 2010 extracted from the Moderate Resolution Imaging Spectroradiometer (MODIS) active fire detection data. We further examine the spatiotemporal distribution patterns of lightning and fires, and the potential relationship between those patterns with a focus on understanding the factors, derived from MODIS observations of the atmospheric column, and atmospheric processes that drive the lightning activities and distribution in Alaskan tundra. Finally, we quantify fuel state that supports lightning-based ignition using 1km Daymet meteorology and the Canadian Forest Fire Danger Rating System weather indices. The results of the analysis are combined in a spatially-explicit fire ignition model that delivers daily wall-to-wall projections of ignition probability for Alaskan tundra ecosystems.

A-8 LANDFIRE Remap: opportunities for incorporating new remotely sensed data into vegetation and fuels characterization across Alaska

Kurtis Nelson (US Geological Survey, Earth Resources Observation and Science Center, Sioux Falls, SD)

The LANDFIRE program has produced and distributed consistent and comprehensive vegetation, fuels, and fuel regime data across the United States for over 10 years. LANDFIRE data are used for strategic wildfire and natural resource management planning, tactical wildfire incident response, and a diverse array of other ecological applications. LANDFIRE data are regularly updated, from the circa 2001 base layer, to account for vegetation and fuel changes in response to landscape disturbance and vegetation succession. LANDFIRE is now embarking on its first ever update to the base vegetation and fuel layers. The LANDFIRE Remap effort will utilize newly available field data and remotely sensed data sources to create more current versions of the LANDFIRE data layers, from which future updates can be based. Improvements are being made to the product legends, mapping methods, and input data sources, and collaborations with partner organizations are being created or enhanced.

To prepare for the LANDFIRE Remap, a series of prototyping efforts are ongoing to test different product definitions, algorithms, and ancillary data sets. The prototyping work in CONUS is currently wrapping up with a production kickoff anticipated in early 2017. Prototyping activities in Alaska are now being defined and started. One of the specific collaborations being pursued, as part of LANDFIRE Remap prototyping in Alaska, is with the ABoVE program. The goal is to integrate as many of the ABoVE data sets and processes as are applicable into the LANDFIRE base layers to improve quality and currency. Other remotely sensed datasets being evaluated include Landsat, Sentinel, airborne and spaceborne lidar, and synthetic aperture radar. Given the paucity of field data in large parts of Alaska, and the complexity of some ecosystems, the hope is that more recently available remotely sensed datasets will provide valuable information on which to base the new LANDFIRE layers.

The LANDFIRE Remap effort is expected to take 3-4 years and will produce data for all 50 states and associated insular areas. More information about the Remap prototyping and production efforts can be found on the program website at www.landfire.gov.

A-9 Improving fuel characterization and maps useful for emissions modeling

Nancy French (Michigan Tech Research Institute), Susan Prichard (University of Washington Seattle), Michael Billmire (Michigan Tech Research Institute), Maureen Kennedy (University of Washington Seattle) Don McKenzie, Roger Ottmar (USFS Pacific Northwest Research Station, Seattle, WA)

In developing new approaches to mapping fire emissions, data on the heterogeneity of fuels and variability in fuel loading is a fundamental factor to be considered. For regionally specific approaches to emissions modeling, fuels classification maps are valuable tools to account for landscape heterogeneity. Underlying fuel classifications, however, is variability in fuel loadings that is not acknowledged, much less quantified. The best practice for producing emissions estimates from data with inherent spatial variability is to represent the underlying uncertainty in the base fuels map. This measure of uncertainty can then be used in understanding the reliability of the fuel-loading estimates and also to evaluate how that uncertainty translates to variability in emissions estimates. The goal of the JFSP-funded project is to develop a geospatial database of fuels that enables best practices modeling of national- and regional-scale emissions. Best practices include fuel layers that characterize variability of fuel loading for a specific type, and that have been validated by field sampling. The presentation will review progress on our efforts to characterize the distributions of fuel loadings by strata for standard FCCS fuelbeds of the Contiguous US and Alaska. The presentation will also review the sensitivity analyses underway to quantify fuel loading impacts on emission estimates, and the information system we will be building to help serve out the complex fuel loading data. The value of and status of advanced methods for quantifying fuel loadings will also be reviewed, as planed within the Fire and Smoke Model Evaluation Experiment (FASMEE). We envision a set of data that will have value to emissions modeling at regional scales and that will provide a statistically accurate characterization of representative fuelbeds and loadings for national emissions inventories and other broad-scale applications.

A-10 Improving Remote Sensing Capability for Assessing Wildfire Effects in North American Boreal Peatlands

Laura Bourgeau-Chavez, Liza Jenkins, Sarah Endres, Michael Battaglia, Evan Kane, Nancy French (Michigan Technological University), William de Groot, Chelene Hanes (Canadian Forest Service), Eric Kasischke (University of Maryland), Merritt Turetsky (University of Guelph), Brian Benscoter (Florida Atlantic University)

Wildfire is a natural disturbance factor in high northern latitude (HNL) ecosystems occurring primarily through lightning ignitions. However, there is evidence that frequency of wildfire in both boreal and arctic landscapes is increasing with climate change. Higher temperatures and reduced precipitation is leading to widespread seasonal drying in some HNL landscapes, thereby increasing wildfire hazard. In 2014 Northwest Territories (NWT) Canada had a record breaking year of wildfire, burning over 3.4 million hectares of upland forests, peatlands, and even emergent wetlands. Fire activity occurred across seasons (spring, summer, and fall) in the Taiga Shield and Boreal Plains ecozones. Similar large fire years have occurred in boreal Alaska in 2004 and 2015. Under NASA ABoVE and other efforts, North American boreal peatlands of Alaska and Canada are the focus of both field and remote sensing studies to better understand their vulnerability and resiliency to wildfire. Landsat and radar satellite imagery is being used to develop remote sensing algorithms specific to peatlands to map and monitor not only burn severity but also organic soil moisture, peatland type (e.g. bog vs. fen) and biomass form (herbaceous, shrub, forest dominated). Through integration with CanFIRE (a carbon emissions and fire effects model), this spatial information allows for better quantification of the landscape heterogeneity of peatlands and fire effects, thus providing new insights to landscape scale changes and allowing improved understanding of the implications of increasing wildfire in HNL ecosystems. This presentation will focus on results from several current and previous NASA-funded projects focused on characterizing wildfire vulnerability and resiliency in North American boreal peatlands.

A-11 Hydrological and phenological monitoring of wildfire potential in boreal and taiga wetlands: remote sensing approaches

Dan Thompson, Peter Englefield, Brian Simpson, Marc Parisien (Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta, Canada)

Regionally, the boreal forest of North America contains between 10-30% wetland area, often as a mosaic alongside upland forest. These wetland complexes vary widely in their vegetation structure and susceptibility to wildfire, ranging from treeless sedge fens to forested black spruce bogs. During large fire years featuring widespread and persistent drought, the rate of hydrological response of these wetland types varies by wetland type. Moreover, contrasting vegetation structure among wetland types in both the surface and the overstory leads to variable flammability via deciduous phenology. Here we outline a method of monitoring flammability across the range of boreal wetlands via remote sensing techniques and applications of the Canadian Fire Weather Index system. In order to discriminate between the various wetland types, we describe the use of integrated remote sensing and forest inventory data products in order to predict the distribution of sedge-dominated (fens) and moss-dominated (bogs) surface fuels and their respective abundance of larch and spruce tree cover. With this spatial knowledge of the distribution of sedge wetlands, a simple MODIS-based NDVI monitoring scheme currently used in the Canadian Wildland Fire Information System (CWFIS) for sedge wetland greenup and senescence is shown. The gap-filling scheme used to produce nowcasts of sedge wetland greenup is also shown. In order to distinguish between flammable (i.e. cured) sedge wetlands with high and low water tables, a reanalysis of historic water table measurements across western Canadian non-permafrost wetlands is used to predict water table depths using the Drought Code of the Canadian Fire Weather Index system. We show how a simple Drought Code scheme by wetland type can effectively map areas where low water tables allow for sufficiently dry surface fuels to carry fire spread. Lastly, a case study of this framework in a fire management context is shown during the drought-driven fires of 2015 in Wood Buffalo National Park, Alberta. This ecologically-informed monitoring framework allows for an improved estimation of fire spread potential in areas of abundant wetland cover, and offers a contribution towards improved modelling of smoke emissions, carbon loss, and overwintering fire potential in these often data-limited and remote areas of North America.

A-12 Burn, grow, repeat: Toward an improved understanding of causes and consequences of shortened fire return intervals in northwest boreal forests

Rachel Loehman (Alaska Science Center, U.S. Geological Survey, Anchorage, AK), Jessica Walker (Western Geographic Science Center, U.S. Geological Survey, Tucson, AZ), Jennifer Barnes, Jennifer Hrobak (National Park Service, Fairbanks, AK), Jennifer Jenkins (Alaska Fire Service, Bureau of Land Management, Ft. Wainwright, AK), Erana Loveless (Western Geographic Science Center, U.S. Geological Survey, Tucson, AZ), Lisa Saperstein (Alaska Region, U.S. Fish and Wildlife Service, Anchorage, AK),, Robert Ziel (Alaska Fire Science Consortium, Fairbanks, AK)

The boreal region of Alaska and Canada is warming approximately twice as fast the global average, and above-average temperatures and prolonged drought over the last half century are thought to have increased regional fire frequency in recent decades. Over the past 11 years Alaska has seen the largest (2004), second largest (2015), third largest (2005), and sixth largest fire years (2009) since 1940, and observed increases in area burned in Canada during the last four decades are linked with warming summer season temperatures and attributed to human-induced climate changes. Changes in wildfire frequency have been identified as a "tipping element" likely to seriously impact boreal forest and woodland integrity. To the surprise and concern of fire and resource managers some of these fires burned across fire scars from the previous decade or decades (i.e., were much more frequent "reburns"), an uncharacteristic phenomenon in boreal forests. This dynamic is significant in terms of management - past fires serve as fire breaks that are factored into active fire planning for protection of life, infrastructure, and resources - and ecology, because changes in fire frequency and severity can alter successional trajectories, species composition, critical wildlife habitat, and long-term carbon balance. However, there are few studies in northwest boreal forests that provide information on the weather, climate, and fuels factors associated with short-interval fires, or on their ecological impacts. We use geospatial datasets of fire history, land cover and fuels, weather, climate, fire danger indices, and fire progression from MODIS/VIIRs to address the following questions: 1) Under what climatic, weather, topographic, and vegetation (fuels) conditions do fires reburn recently burned areas? 2) What characteristics allow older fires to act as fuel breaks for new fires? 3) Is fire behavior or fire severity different in reburned areas? 4) What are the effects of changing fire regimes on northwest boreal ecosystem processes such as carbon storage, stand dynamics, vegetation biomass and composition, wildlife habitat, and subsistence? Project results provide improved understanding of potential changes in fire regimes and fuels that impact ecology and management of northern boreal forests.

A-13 Synoptic-scale fire weather conditions in Alaska (Poster)

Hiroshi Hayasaka (Fire Science Division, NPO Hokkaido Institute of Hydro-climate), Hiroshi L. Tanaka (Center for Computational Sciences, University of Tsukuba), Peter A. Bieniek (International Arctic Research Center, University of Alaska Fairbanks)

Recent concurrent widespread fires in Alaska are evaluated to assess their associated synoptic-scale weather conditions. Several periods of high fire activity from 2003 to 2015 were identified using Moderate Resolution Imaging Spectroradiometer (MODIS) hotspot data by considering the number of daily hotspots and their continuity. Fire weather conditions during the top six periods of high fire activity in the fire years of 2004, 2005, 2009, and 2015 were analyzed using upper level (500 hPa) and near surface level (1000 hPa) atmospheric reanalysis data. The top four fire-periods occurred under similar unique high-pressure fire weather conditions related to Rossby wave breaking (RWB). Following the ignition of wildfires, fire weather conditions related to RWB events typically result in two hotspot peaks occurring before and after high-pressure systems move from south to north across Alaska. A ridge in the Gulf of Alaska resulted in southwesterly wind during the first hotspot peak. After the high-pressure system moved north under RWB conditions, the Beaufort Sea High developed and resulted in relatively strong easterly wind in Interior Alaska and a second (largest) hotspot peak during each fire period. Low-pressure-related fire weather conditions occurring under cyclogenesis in the Arctic also resulted in high fire activity under southwesterly wind with a single large hot-spot peak.

A-14 Deciduous trees are a large and overlooked sink for snowmelt water in the boreal forest (Poster)

Jessica Young-Robertson, W. Robert Bolton, Uma S. Bhatt, Jordi Christobal (University of Alaska Fairbanks)
Richard Thoman (National Weather Service)

The terrestrial water cycle contains large uncertainties that impact our understanding of water budgets and climate dynamics. Water storage is a key uncertainty in the boreal water budget, with tree water storage often ignored. The goal of this study is to quantify tree water content during the snowmelt and growing season periods for Alaskan and western Canadian boreal forests. Deciduous trees reached saturation between snowmelt and leaf-out, taking up 21–25% of the available snowmelt water, while coniferous trees removed <1%. We found that deciduous trees removed 17.8–20.9 billion m^3 of snowmelt water, which is equivalent to 8.7–10.2% of the Yukon River's annual discharge. Deciduous trees transpired 2–12% (0.4–2.2 billion m^3) of the absorbed snowmelt water immediately after leaf-out, increasing favorable conditions for atmospheric convection, and an additional 10–30% (2.0–5.2 billion m^3) between leaf-out and mid-summer. By 2100, boreal deciduous tree area is expected to increase by 1–15%, potentially resulting in an additional 0.3–3 billion m^3 of snowmelt water removed from the soil per year. This study is the first to show that deciduous tree water uptake of snowmelt water represents a large but overlooked aspect of the water balance in boreal watersheds. The water content of deciduous vegetation may have impacts for understanding fire dynamics in the boreal forest.

A-15 Effects of weather and climate on forest fire behaviour: Case study of Northern boreal forest in Republic of Sakha (Yakutia), Russia (Poster)

Kiunnei Kirillina, Elham Goumehei, Wanglin Yan (Graduate School of Media and Governance, Keio University), Natalia Serditova (Tver State University)

Modern climate change in the northern regions, including Russia, has been greater than in most of the rest of the world. Climate change is projected to be even greater in the future and the changes even faster than in the past. Study area, Yakutia has unique geographic and climate characteristics that makes the examination of climate change and its implications urgent and very important. In republic, climate changes over the past 40 years are in part responsible for the rise in economic losses from extreme weather events, stresses on water supply, worsening air quality and related health and economic effects. Extreme events and rising temperatures are becoming more damaging as recent strong summer forest fires and thawing permafrost have demonstrated. This research is devoted to evaluation of the relative role of different weather conditions in explaining occurrence and burned area for Sakha Republic in historical period (1955-2014) and preparation predictions of future forest fire risk. Other study goals are (2) assessment of historical trends of forest fires, (3) determine which part of the republic had highest forest fire rick in the past and how this risk will be changed under influence of climate change and (4) examine how climate conditions varied historically and how they can change between present and 2100 according to the predictions from set of modern climate models. Six different climate models were used to predict future climate changes which effects on number and the area of forest fires, extent of their impact on forest ecosystems in the republic. This study used GIS environment to map the present and future climate change variables across Yakutia and historical spatial distribution of forest fires. Information from 85 meteorological stations was selected to interpolate temperature and precipitation data for the entire of the Sakha Republic. Interpolation of climate data and forest fires statistics had done using Kriging method. Predicted climate data based on tested climate models shows increase of temperature during forest fire season. But this increase is not the same for all area, as maps present more changes of temperature is for western part of the study area. Western part of republic, which had the highest fire risk in the past, will have the most risk based on predicted data.

A-16 APRFC Produced QPE and QPF grids (Poster)

Arleen Lunsford (NOAA/NWS/APRFC)

The Alaska-Pacific River Forecast Center (APRFC) produces Quantitative Precipitation Estimation (QPE) grids for synoptic 6-hour periods and for the 12Z-12Z (4am-4am AKDT) 24-hour period daily during the open water season, generally late April through early November. The QPE grids are also produced during the cold season, with grids produced daily Monday through Friday (excluding holidays), and the grids for Saturday and Sunday are produced on Monday. The APRFC also produces 6-hour Quantitative Precipitation Forecast (QPF) grids out to 7 days.

This presentation will describe the input data and the programs used in producing these grids, as well as some of the factors to be aware of when using these grids. We will also discuss why the grids are produced when they are, as well as other gridded products currently produced at the APRFC, and products that might be available in the future.

Near Real-Time Fire Behavior: Which remotely sensed data are best and most timely for fire detection, plume tracking of fire emissions, fire behavior modeling, mapping of flaming fronts, fire intensity, active fire perimeters, and response for ongoing fires?

A-17 High-Resolution Rapid Refresh with Smoke (HRRR-smoke) modeling system for experimental smoke forecast guidance

E. James, R. Ahmadov (Cooperative Institute for Research in Environmental Sciences, University of Colorado), G. Grell (NOAA ESRL/GSD), S. Freitas (USRA/GESTAR & NASA Goddard Space Flight Center), G. Pereira (Federal University of Sao Joao del-Rei), I. Csiszar (Center for Satellite Applications and Research, NOAA/NESDIS), M. Tsidulko (I.M. Systems Group, Inc.), B. Pierce (Advanced Satellite Products Branch, Center for Satellite Applications and Research, NOAA/NESDIS), C. Alexander (NOAA ESRL/GSD), S. Peckham (Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers), S. Benjamin (NOAA ESRL/GSD)

Wildfires can have a huge impact on air quality and visibility over large parts of the contiguous US and Alaska. In this talk we describe a fully coupled meteorology-chemistry modeling system (HRRR-Smoke) run in real time for the CONUS and Alaska domains. The HRRR-Smoke modeling system uses fire radiative power (FRP) data measured by the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on the Suomi National Polar-orbiting Partnership satellite. Using the FRP data the model predicts fire emissions, fire size and plume rise.

The HRRR-Smoke model is run in real time since the summer of 2016 on a 3km horizontal grid resolution over the CONUS and Alaska domains by NOAA/ESRL Global Systems Division (GSD). The model simulates advection and mixing of fine particulate matter (PM2.5 or smoke) emitted by calculated fire emissions. The fire emissions include both smoldering and flaming fractions. Fire plume rise is parameterized in an online mode during the model integration.

The HRRR-Smoke real-time runs use meteorological fields for initial and lateral boundary conditions from the experimental real-time HRRR(X) numerical weather prediction model also run at NOAA/ESRL/GSD. The model is initialized every 6 hours (00, 06, 12 and 18 UTC) daily using newly generated meteorological fields and FRP data obtained during the previous 24 hours. The model then produces a meteorology and smoke forecast for the next 36 hours. The smoke fields are cycled from one forecast to the next one. Predicted near-surface and vertically integrated smoke concentrations are visualized online on a web-site: http://rapidrefresh.noaa.gov/HRRRsmoke/

In this talk, we discuss the major components of the HRRR-Smoke modeling system and its potential applications for air quality forecasting.

A-18 Verification of the Experimental High Resolution Rapid Refresh in Alaska using the USArray Transportable Array Network

Taylor A. McCorkle, John D. Horel (University of Utah)

Alaska's expansive size, dynamic weather, and abundance of remote regions make it the ideal location for innovative atmospheric and environmental observation platforms. In 2015, EarthScope began deploying its USArray Transportable Array (TA) stations across the state of Alaska at an average spacing of 85 km. The USArray was originally designed as an in-situ seismic monitoring network, but later was retrofitted with atmospheric sensors to expand the platform's scientific reach. This high resolution network, known for its research quality instruments and measurements, allows for a rich dataset of pressure observations to be taken across Alaska. These TA observations will be used in an effort to validate an experimental version of the High Resolution Rapid Refresh (HRRR) being run in Alaska by the National Oceanic and Atmospheric Association's (NOAA) Earth System Research Laboratory (ESRL). The experimental Alaska HRRR is a 3 km convection-permitting model that is initialized every 3 hours and produces hourly forecast grids out to 36 hours. The verification process will use data collected during the 2015-2016 cold season (October – March) and focuses on how the HRRR handles rapidly intensifying surface lows and storm tracks. Point verification of the HRRR with TA and National Weather Service stations in western Alaska will serve to quantify the HRRR's ability to forecast the strength and location of surface pressure centers in the state of Alaska. In addition to validating the HRRR's surface pressure forecasts, the model will likely be compared to satellite imagery. The satellite data will be used to verify the HRRR's ability to model cloud cover, which will be useful not only in the cold season, but as a parameter for fire weather forecasting.

A-19 Applications of Chinese FY series meteorological satellites in boreal forest fire management

Fengjun Zhao (Research Institute of Forest Ecology, Environment & Protection, Chinese Academy of Forestry), Yongqiang Liu (Center for Forest Disturbance Science, USDA Forest Service)

Wildfire is a major forest disturbance in the forests in northeastern China. Fires in this region have extraordinary environmental and social impacts because it's location close to densely populated regions in China and other northeastern Asian countries. This study describes the applications of Chinese satellite products in forest fire management in northeastern China. China has launched a total of 14 Fengyun (FY) (Chinese words meaning wind and cloud) meteorological satellites since 1988, seven for each of polar-orbiting and geostationary types. Half of them are in service currently. Besides weather, FW satellites provide extensive products for forest fire management, including fuel classification, fire detection, fire spread and smoke transport monitoring, damage estimate, and post-fire recovering assessment. Fuels are classified based on FY NDVI products combined with techniques such as principal component analysis and GIS. Fire detection and monitoring is the most important application of FY products. The catastrophic fires occurred in the Daxinganlin Mountains region in May, 2006, for example, were monitored by the FY satellite remote sensing throughout the entire burning period, providing the information necessary for planning and implementing fire suppression. The time resolution of the FY polar-orbiting satellite products has continued to increase, from one hour in 1997 with FY-2A/B to about one minute now and near future with FY-4A/B, leading to dramatic increase in the capacity of fire detection and monitoring. Meanwhile, the FY geostationary satellite products improved from one hour with normal scan to 6 minutes with region rapid scan, increasing the accuracy in estimating burned areas, fire intensity, and smoke. Nine more satellites will be added to the FY series from 2016-2011, which will provide more powerful remote sensing products for fire management in the boreal forests in China.

A-20 Challenges and Opportunities: Using the University of Alaska's Near Real Time Satellite Imagery to Support Alaska Wildland Fire Community

Eric Stevens, Jay Cable, Carl Dierking, Jiang Zhu, Tom Heinrichs, Dayne Broderson (UAF/GINA)

The Geographic Information Network of Alaska (GINA) at the University of Alaska Fairbanks receives data from a number of polar-orbiting weather satellites. Data from these satellites are used to generate imagery and other products that are delivered in near real time to users such as the National Weather Service and Alaska Fire Service. Examples of satellite imagery useful in monitoring and forecasting weather that impacts the behavior of wildfires in Alaska will be presented, with a special emphasis on newer multispectral products. Plans for the future will also be addressed, including a description of some of the challenges that must be overcome if these satellite products are to be of maximum benefit to Alaska's wildfire community.

A-21 VIIRS Imagery Applications for Fire Weather Monitoring

Curtis J. Seaman and Steven D. Miller (CIRA, Colorado State University, Fort Collins, CO)

The Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi National Polar-orbiting Partnership (NPP) satellite has been producing high-quality imagery since its launch in October 2011. Additional VIIRS instruments will be launched on subsequent JPSS satellites (1-4). The 22 bands on VIIRS include 5 high-resolution imagery channels (~375 m resolution at nadir), 16 moderate resolution channels (~750 m resolution), and the Day/Night Band (~742 m resolution), which collectively range in wavelength from 0.412 μm to 12.01 μm. These channels offer a wide range of imagery applications that are useful for monitoring the fire weather environment. For example, VIIRS has 5 bands in the near and shortwave IR that useful for detecting hot spots. The Day/Night Band is sensitive to the light emissions from fires at night, as well as the smoke (given sufficient moonlight). In addition to these individual VIIRS bands, there are many multispectral applications including red-green-blue (RGB) composites of these channels that are useful for detecting fires, smoke, vegetation health, snow and ice coverage, and even flooding. Specific RGB applications include: True Color for detecting/monitoring smoke; Natural Color for detecting snow cover, vegetation health and burn scars; the Fire Temperature RGB composite for monitoring fire activity; and the Snow/Cloud Discriminator product, which utilizes the Day/Night Band to improve the discrimination of snow and clouds at night. An introduction to these RGB composites and an overview of these applications will be discussed.

A-22 Improved operational approaches to high and low-intensity fire detection in Alaska using the VIIRS I-band Fire Detection Algorithm for High Latitudes (VIFDAHL)

Christine F. Waigl, Martin Stuefer, Anupma Prakash (Geophysical Institute, UAF), Charles Ichoku (NASA Goddard Space Flight Center, Greenbelt, MD)

Fire products from Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) provide near real-time information for wildfire detection, monitoring, and characterization. Using data acquired during Alaska's 2015 extreme fire season, we analyzed the performance of the MODIS-based MOD14/MYD14, and the more recent VIIRS I-band operational active fire products. A comparison with the fire perimeter and properties data published by the Alaska Interagency Coordination Center (AICC) shows that both MODIS and VIIRS fire products successfully detect all fires larger than approximately 1000 hectares. For smaller fires, the VIIRS I-band product offers higher detection likelihood, but overall still misses one fifth of the fire events. To map both low- and high-intensity burn areas in Alaska, we developed the VIIRS I-band Fire Detection Algorithm for High Latitudes (VIFDAHL), which we applied to selected study regions of known Alaskan boreal forest fires. VIFDAHL more accurately captures the fire spread, can differentiate well between low- and high-intensity fires, and can detect 20-70% more low-burning fire pixels compared to the MODIS and VIIRS global fire products. It also offers avenues to further fire characterization via sub-pixel temperature and fractional active fire area retrieval.

A-23 Near real-time estimation of burned area in boreal forest using VIIRS 375 m active fire product

Patricia Oliva (Department of Geographical Sciences, University of Maryland, College Park)

Every year, thousands of hectares of boreal forest are affected by fires, causing significant ecological and economic consequences, and associated climatological effects as a result of fire emissions. In recent decades, burned area estimates generated from satellite data have provided systematic global information for ecological analysis of fire impacts, climate and carbon cycle models, and fire regimes studies, among many others. However, many of the operational products are delivered with a time lapse which ranges from weeks to months. There is an urgent need of near real-time burned area estimations to assess the impacts of fire, estimate smoke plume transport, and biomass burning emissions. The enhanced characteristics of the Visible Infrared Imaging Radiometer Suite (VIIRS) 375 m on board the Suomi National Polar-orbiting Partnership (S-NPP) make possible the use of near real-time active fire detection data for burned area estimation. The VIIRS 375 m active fire detection product offers higher sensitivity to smaller and low-intensity fires. In addition, the higher frequency of image acquisitions due to VIIRS long swath makes possible to obtain more than four acquisitions per day in high latitudes (> 40 degrees). The reception of multiple images per day allows the monitoring of fire growth and burned area estimation. In this study, consecutive VIIRS 375 m active fire detections were aggregated to produce the VIIRS 375 m burned area (BA) estimation over Canada, Russia, and Alaska. The accuracy of the BA estimations was assessed by comparison with Landsat-8 supervised burned area classification. The results showed good agreement with the reference fire perimeters proving that the VIIRS 375 m BA estimations can be used for near real-time assessments of fire effects.

A-24 Airborne hyperspectral remote sensing in the real-time detection and management of wildfire (Poster)

Keshav Dev Singh (College of Agricultural and Environmental Sciences, University of California, Davis)

Hyperspectral airborne remote sensing has capable sensors for the early detection of boreal or arctic wildfire even before visible symptoms become apparent. It integrates conventional imaging and spectroscopy knowledge to attain both spectral and spatial information from an object. Imaging spectroscopy provides detailed signatures (such as reflectance) of the biological samples due to interaction between the electromagnetic radiation and contact material. It is a powerful tool in studies of wildfire triggering due to abilities to assess woodland health via reflectance profiling. I am studying various wildfire sites in California (e.g. Davis-Sacramento area: Boys Fire, Willow Fire, Bell Fire; Eldorado National Forest: Mokelumne Fire, Emerald Fire; Napa Valley: Creek Fire; Yuba City: Butte Fire) to characterize relationship between field composition and abiotic stress induced by different factors. The abiotic stresses are due to drought (water deficit), excessive erosion, extreme temperatures, salinity (sodicity) and hydrocrabon presence. For this study, the hyperspectral data of referred field sites are acquired using an airborne "true push-broom" hyperspectral camera [OCI Imager (OCI-UAV-D1000), BaySpec Inc.; 116 bands from 470-980nm] mounted on a drone (S1000 Premium Octocopter). The acquired images are generally affected by solar light intensity, source-sensor geometry, and scattering, so a ground-based spectrometer is used for continuous white calibration of these datasets. The bi-directional reflectance was corrected using radiative transfer based Hapke's model, which addresses non-linear factors arises due to multiple scattering. The stresses negatively impact growth, development, and yields of green woodland. The narrowband/hyperspectral indices shows that it is possible to pinpoint the areas covered by abiotic stress (drought, and other deficiencies) on woodland prior to fire spread over whole field. It prevents surrounding areas from being threatened, smoky or fire outbreaks. It also reduces the time, cost of fire retardant and poisonousness in our biosphere. The whole study shows that the airborne remote sensing technology has major importance in the real-time detection and management of wildfire for suppression.

Post-Fire Effects: Can we improve analytical methods for remotely sensed data to assess fire severity, consumption/CO_2 balance, active-layer changes, and successional trajectories of high latitude vegetation communities?

A-25 An Overview of the 2017 Airborne Campaign for NASA's Arctic Boreal Vulnerability Experiment (ABoVE)

C. Miller (Jet Propulsion Laboratory), S. Goetz (Northern Arizona University), P. Griffith (NASA Goddard/SSAI), H. Margolis (NASA HQ), E. Kasischke (University of Maryland), and the ABoVE Science Team

ABoVE envisions major airborne campaigns in 2017 and 2019 with the potential for less comprehensive bridging activities in 2018. Airborne research during the 2017 ABoVE airborne campaign (AAC) will link field-based, process-level studies with geospatial data products derived from satellite remote sensing, spanning the critical intermediate space and time scales that are essential for a comprehensive understanding of scaling issues across the ABoVE Study Domain and extrapolation to the pan-Arctic. The impacts of fire on the Arctic-boreal landscape are a central feature of the 2017 AAC. ABoVE aircraft and field teams will explore fires spanning a broad range of landscapes, burn intensities, and burn histories in Alaska and northwestern Canada, with particular emphasis on areas burned in the Northwest Territories during 2014 and Alaska during 2015. We will also conduct extensive measurements over the ~1200 km^2 2007 Anaktuvuk River fire scar on the North Slope, in the Yukon-Kuskokwim Delta, and on the Seward Peninsula.

The observing strategy involves Foundational Measurements made with the NASA facility instruments UAVSAR (L-band SAR), AirMOSS (P-band SAR), LVIS (full waveform LiDar) and AVIRIS-NG (VIS-SWIR spectral imaging). These will provide domain-wide sampling and coverage of ABoVE field sites. Additional measurements will be made by AirSWOT (Ka-band radar) and CFIS (solar induced fluorescence) with an emphasis on higher resolution coverage over specific field sites or portions of the experimental domain. The strategy will seek to leverage complementary NASA airborne activities such as ICEBridge and SnowEx, pre-launch airborne acquisitions for NISAR, HyspIRi and ASCENDS, as well as activities sponsored by partner agencies. Coordination with ongoing or planned Canadian airborne remote sensing (eg LiDar-based boreal forest inventories) is key to this approach.

A-26 A USFS-NASA partnership to leverage advanced remote sensing technologies for forest inventory

Hans-Erik Andersen (USDA Forest Service), Chad Babcock (University of Washington), Robert Pattison (USDA Forest Service), Bruce Cook (NASA Goddard), Doug Morton (NASA Goddard), and Andrew Finley (Michigan State University)

The boreal forests of interior Alaska cover approximately 110 million acres, and appear to be changing rapidly in response to warming temperatures. The status and trends of these forests are poorly understood due in part to the lack of a comprehensive inventory. In 2014 the United States Forest Service's Forest Inventory and Analysis (FIA) program in conjunction with the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center carried out a pilot test of an interior Alaska inventory design. The pilot inventoried the forests of the Tanana Valley State Forest (TVSF) and the Tetlin National Wildlife Refuge (TNWR) in the Tanana River Valley of interior Alaska, covering 2.5 million acres. In order to increase the precision of the inventory estimates, the relatively sparse FIA field plot sample collected in Tanana Valley State Forest and Tetlin NWR was augmented with sampled airborne remotely-sensed data acquired with the G-LiHT (Goddard-Lidar/Hyperspectral/Thermal) system to increase the precision of inventory parameter estimates. G-LiHT is a portable, airborne imaging system, developed at NASA-Goddard Space Flight Center, that simultaneously maps the composition, structure, and function of terrestrial ecosystems using lidar, imaging spectroscopy, and thermal imaging. G-LiHT provides high-resolution (~1 m) data that is well suited for studying tree-level ecosystem dynamics, including assessment of forest health and productivity of forest stands and individual trees. In addition G-LiHT data support local-scale mapping and regional-scale sampling of plant biomass, photosynthesis, and disturbance. The data is accurately georeferenced and can be matched very precisely with field plot data that are georeferenced using high-accuracy (dual-frequency, GLONASS-enabled) GPS.

A-27 Rapid response tools and datasets for post-fire modeling in boreal and arctic environments

Mary Ellen Miller, M. Billmire, Laura Bourgeau-Chavez (Michigan Technology Research Institute, Michigan Technological University), W. J. Elliot and P. R. Robichaud (U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station)

Preparation is a key component to utilizing Earth Observations and process-based models in order to support post-wildfire mitigation. Post-fire flooding and erosion can pose a serious threat to life, property and municipal water supplies. Increased runoff and sediment delivery due to the loss of surface cover and fire-induced changes in soil properties are of great concern to resource managers. Remediation plans and treatments must be developed and implemented before the first major storms in order to be effective. One of the primary sources of information for making remediation decisions is a soil burn severity map derived from Earth Observation data (typically Landsat) that reflects fire induced changes in vegetation and soil properties. Slope, soils, land cover and climate are also important parameters that need to be considered. Spatially-explicit process-based models can account for these parameters, but they are under-utilized relative to simpler, lumped models because they are both difficult to set up and require spatially-explicit inputs (digital elevation models, soils, and land cover). Our goal is to make process-based models more accessible by preparing spatial inputs before a wild fire, so that datasets can be rapidly combined with soil burn severity maps and formatted for model use. We have built an open source online database (http://geodjango.mtri.org/geowepp /) for the continental United States that allows users to upload soil burn severity maps into the database. The soil burn severity map is then rapidly combined with land cover and soil datasets in order to generate the spatial model inputs needed for hydrological modelling of burn scars. We believe our database could be expanded internationally to support other countries that face post-fire hazards.

This summer we worked with the University of Alberta to model potential erosion from the Fort McMurray fire. We utilized Lidar based DEM, Canadian weather data, Canadian Soil Landscape data, pre and post-fire Landsat imagery, and the Alberta Biodiversity Monitoring Institute land cover map in our modeling. We were able to demonstrate that process based models could be rapidly applied for modeling post-fire effects in Canada. The datasets and modeling developed for the Fort McMurray fire will be refined and utilized under a new NASA SMAP program to help improve Canadian Forest Fire Danger Rating System predictions with SMAP soil moisture data. Data fusion techniques will be used to combine modeled predictions of soil moisture with SMAP observations with the goal of improving the spatial resolution of SMAP.

A-28 Evaluating characterization of fire extent and fire spread in boreal and tundra fires of North America from coarse and moderate resolution MODIS and VIIRS data

Tatiana Loboda, Kelley O'Neal, Varada Shevade, Khashayar Dehkordi (University of Maryland College Park)

Satellite observations of fire occurrence, extent, and spread have become a routine source of information for fire scientists and managers worldwide. In remote regions of arctic and boreal zones, satellite observations frequently represent the primary and at times the only source of information about fire occurrence. While a large suite of observations have been shown to provide beneficial and important information about fire occurrence, coarse and moderate resolution data from polar orbiting satellites in optical and thermal ranges of the electromagnetic spectrum provide the most widely-used observations that characterize on-going burning processes and consistent estimates of fire-affected areas. The reliance of the global community on active fire detections and burned area estimates delivered from the Moderate Resolution Imaging Spectroradiometer (MODIS) raises concerns about the continuity of the data record beyond the lifetime of this mission. The Visible Infrared Imaging Radiometer Suite (VIIRS) operated by National Oceanic and Atmospheric Administration (NOAA) represents the future of satellite fire monitoring within US-designed and operated missions. While some advancements have been introduced into the VIIRS fire detection capabilities, including enhanced spatial resolution of spectral bands aimed at active fire detection, the reduced number of orbital overpasses (only one VIIRS instrument is currently in orbit compared to two MODIS instruments) and other differences in data acquisition open the potential for substantial differences in future fire monitoring and mapping capacity and long-term record compatibility between MODIS and VIIRS observations. This study aims to assess and quantify the differences in characterization of on-going burning processes (including in time of detection, spatial fidelity and extent of fire detection coverage, fire spread rate, and fire radiative power) and post-fire extent within fire events (i.e. burned area mapping) in boreal forests and tundra regions of North America delivered by the MODIS Terra and Aqua collection 6 and VIIRS 750m and 375m active fire products and derived burned area maps. Since VIIRS standard data suite does not include burned area estimates, we used VIIRS and MODIS collection 6 surface reflectance products to generate an annual burned area record using the Regionally Adapted Burned Area algorithm developed specifically for high northern latitudes. Our initial results indicate that despite higher spatial resolution of VIIRS observations, the MODIS record (even from a single satellite) delivers a more comprehensive coverage of on-going burning within the large fire events of the 2014 fire season in the Northwest Territories, Canada. However, while substantial differences in fire characterization exist between the satellite data, there is strong potential for calibration of the data records (particularly for the burned area and fire radiative power estimates) for the two instruments necessary to achieve a consistent long-term record of fire occurrence in the high northern latitudes that would support long-term scientific studies and management decision-making processes.

A-29 Decades of Change in the Former Soviet Union: Current Assessment and New Possibilities

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The Former Soviet Union (FSU) is a distinct and crucial region because it has the physical size necessary to effect regional and global climate, and it lies in the northern hemisphere upper latitudes where climate-driven change is already evident. The circumboreal zone contains the largest stock of terrestrial carbon on Earth, and Russia holds 2/3 of that carbon pool. Recent climate change data and models agree that temperature increases in Russia have been and will be among the greatest on the planet, leading to longer growing seasons, increased evapotranspiration, and increased extreme fire weather, all of which are altering fire regimes and the carbon balance in ecosystems.

Fire is an integral natural process that serves to alter landscapes and their carbon balance and is largely under the control of weather and climate. Estimating the amount of biomass burned or available fuel during fire events is challenging, particularly in remote and diverse regions, like those in Russia. Historically, we have typically assumed 25 tons of carbon per hectare (tC/ha) is emitted across boreal landscapes, however depending on the ecosystem and severity, biomass burning emissions can range from 2 to 75 tC/ha. Ecosystems in the FSU span from the tundra through the taiga to the forest-steppe, steppe and desserts and includes the extensive West Siberian lowlands, permafrost-lain forests and agricultural lands. Excluding this landscape diversity and fire severity results in inaccurate emission estimates and incorrect assumptions in the transport, deposition, and feedbacks of these emissions.

In this work, we present two beta products that will enhance long-term understanding of Russian environments. First, we will introduce a hybrid ecosystem map of the Former Soviet Union (FSU) that contains explicit estimates of fuel or biomass. Specifically, the ecosystem map is a fusion of satellite-based data, a detailed ecosystem map, and Alexeyev and Birdsey carbon storage data, which is used to build carbon databases that include the forest overstory and understory, litter, peatlands and soil organic material for the FSU. We provide a range of potential carbon consumption estimates for low-, medium- and high-severity fires that can be driven with fire weather or fire danger indices to more accurately estimate fire emissions. Additionally, a team of scientists has been working to estimate historic large-burned areas in Siberia using historic Advanced Very High Resolution Radiometer (AVHRR) Global Area Coverage data that is expected to span from 1980 through 1995. Paired with satellite-based products from Sukachev Institute of Forest, MODIS, and VIIRS, we can expect a large-fire burned area database that spans almost 40 years for Siberia.

A-30 High resolution carbon emissions estimates from boreal fires

Sander Veraverbeke (University of California, Irvine and Vrije Universiteit Amsterdam), James Randerson, Elizabeth Wiggins (University of California, Irvine), Brendan Rogers (Woods Hole Research Center)

Boreal forests and arctic tundra store approximately 35 % of global soil carbon. Many of these organic soils are vulnerable to combustion during wildfires. Carbon combustion rates are high latitude ecosystems and vary greatly depending on environmental conditions.

Several research teams associated with NASA's Arctic-Boreal Vulnerability Experiment have been conducting field measurements in recent fires in Alaska and Canada. This is resulting in a growing database of field measurements of carbon combustion in boreal and arctic ecosystems, which will increase our ability to estimate and forecast fire carbon emissions. Effective use of these field measurements with remotely sensed and other geospatial datasets allows for spatially and temporally explicit estimates of pyrogenic carbon combustion. We explored relationships between field measurements and remotely sensed estimates of burn severity, tree cover and topography, and meteorological variables from reanalysis. A multiplicative regression model produces carbon emissions estimates with uncertainties of approximately 20 %. We combined this model with remotely sensed daily burned area maps at 500 m resolution to develop a spatially and temporally explicit carbon emissions inventory.

The model has been successfully applied in Alaska between 2001 and 2015 resulting in the Alaskan Fire Emissions Database (AKFED). We are currently expanding the model into Canada. The daily temporal resolution of the emissions combined with regional air transport models has already led to an improved understanding of emission factors. In addition, applications over the large fires years in the Northwest Territories in 2014 and in Alaska in 2015 provided critical insights in the environmental drivers of fire spread and emissions. We estimated emissions of 164 ± 32 Tg C in the Northwest Territories in 2014 and 59 ± 14 Tg C in Interior Alaska in 2015.

Our daily ignitions, burned area and carbon emissions products are of interest to land and fire managers who may benefit from spatially explicit inventories for decision-making. Our products can further provide a first step towards the inclusion of carbon accounting in fire management.

A-31 Improving remotely sensed multispectral estimations of burn severity in western boreal forests

Ellen Whitman (University of Alberta), Marc-André Parisien, Dan K. Thompson, Ronald J. Hall, Rob S. Skakun (Canadian Forest Service), Mike D. Flannigan (University of Alberta)

Burn severity (fire-induced changes to vegetation and soils) is assessed following wildfires to estimate ecological impacts, and to plan postfire mitigation and management. The Monitoring Trends in Burn Severity (MTBS) program provides Landsat-based remotely sensed burn severity products of the differenced Normalized Burn Ratio (dNBR) and the Relativized dNBR (RdNBR) for all large fires in the United States (including Puerto Rico). Although dNBR is a widely-adopted metric it does not accurately represent burn severity where prefire vegetative biomass is low, and in very severe burns, and thus it is often correlated to prefire imagery. The RdNBR was developed to address these limitations, but the equation can fail and may produce extreme values. Researchers have expressed longstanding concerns over modelling ecologically meaningful burn severity in the boreal forests of North America using multispectral remote sensing products, because relationships between remotely sensed burn severity and field measurements are often site-specific in northern environments. Despite known limitations, the use of Landsat-based fire severity metrics in the boreal forest persists due to their widespread availability and documented relationships to some field measures of fire severity.

The Relativized Burn Ratio (RBR) is a Landsat-based fire severity metric that presents an alternative to both dNBR and RdNBR, providing a reduced correlation to prefire imagery, while overcoming the mathematical limitations of RdNBR. We compared the relationship between field observations taken one year postfire and the three aforementioned remotely sensed measures of burn severity, collected in several fires, various ecosites, and both wetlands and uplands that burned in 2014 in the Northwest Territories and Wood Buffalo National Park (n = 51). Postfire field measurements include the Crown Fire Severity Index (CFSI), Composite Burn Index (CBI), percent overstory mortality, exposed mineral soil and organic soil depth, as well as prefire forest stand structure and composition. We produced significantly better model fits between field measurements of burn severity and RBR than with dNBR and RdNBR, suggesting that RBR may be preferable for future spatial analysis of burn severity in the boreal forest, when using multispectral imagery. Partitioning of the data by ecosite type and drainage produced different relationships between field and remotely sensed severity metrics, emphasizing the importance of the use of normalized and relativized data when quantifying burn severity across multiple fires.

As fire weather and burn rates in the boreal forest escalate under climate change, reburning over fuel-limited recently-burned areas is increasingly a reality. The successful estimation of severity in reburns where the cumulative impacts of multiple fires may be ecologically severe, but represent a small change in biomass, requires the adoption of relativized metrics of burn severity. Although new alternatives for assessing burn severity exist using other spectral satellites, UAVs, and radar, Landsat imagery provides a unique opportunity to revisit historical wildfires and a long time series. Improved models relating observed severity in northern environments to Landsat burn severity measures enable us to examine the variability in past burn severity, providing enhanced baselines from which to measure future change and guide management.

A-32 Changing fire frequency and carbon consumption in Alaskan black spruce forests (Poster)

E. Hoy (NASA Goddard/Global Science and Technology, Inc.), K. Barrett (University of Leicester), T. Loboda (University of Maryland), M. Turetsky (University of Guelph), E. Kasischke (University of Maryland)

Changes to the fire regime in the boreal forests of Alaska have included increases in burned area and fire frequency over recent decades. These fire regime changes alter carbon storage and emissions, especially in the thick organic soils of black spruce (Picea mariana) forests, but there is uncertainty in the overall vulnerability of these landscapes to burning, especially in stands that burn while they are still immature (~<60 years old). A better understanding of both the vulnerability of immature stands, and of the carbon emissions impact of immature stands burning, is needed. In the research presented here we first assessed geospatial and remote sensing datasets from 167 interior Alaskan fire events between 2002 and 2008 to analyze the relationship of fractional burned area (representative of the total burned area within a fire perimeter) with fire-free interval (a measure of fire frequency), vegetation, topography and the seasonal timing of burning. We then analyzed how fire frequency impacts carbon consumption in Alaskan boreal forests using a modeling framework. Interestingly, it was found that the fraction of burned area differed between mature forested areas and immature non-forested areas within the analysis. Results showed that considerable burning in interior boreal regions occurs in stands not yet fully recovered from earlier fire events (~20% of burned areas are in immature stands). These newly determined results were then incorporated into the modeling framework through adding an immature black spruce fuel type and associated ground-layer carbon consumption values. This alteration to the model lead to higher ground-layer carbon consumption (and thus total carbon consumed) for areas that burned in two years with high total burned area in Alaska (2004 and 2005). These new results provide insight into the fire-climate-vegetation dynamics within interior Alaskan boreal forests and can be used to both inform and validate modeling efforts to better estimate soil carbon pools and emissions in interior Alaskan boreal forests.

A-33 Assessing Boreal Forest Burn Severity using UAS-based Photogrammetric Mapping

Robert H. Fraser (Canada Centre for Mapping and Earth Observation, Natural Resources Canada), Jurjen van der Sluijs (Government of the Northwest Territories), Ronald J. Hall (Canadian Forest Service, Natural Resources Canada)

Wildfires are a major disturbance to boreal forests where in North America, there is often considerable variability in the severity of burns. Estimating and mapping boreal forest burn severity is important for understanding ecological response to fires, assisting rehabilitation efforts, and predicting post-fire vegetation successional patterns. Burn severity has been measured at plot scales using field techniques such as the Composite Burn Index (CBI), while a range of remotely sensed data and methods have also been applied to measure severity at landscape to regional scales. One common approach for regional-scale mapping of boreal burn severity is to quantify the empirical relationship between CBI plot values and change in the Normalized Burn Ratio (NBR) computed from Landsat satellite imagery. These relationships can then be used to convert the relative NBR spectral index into a numerical field-based rating of burn severity. Some limitations with applying this calibration approach include the subjective and qualitative nature of CBI measurements, a limited ability to measure consumption of surface organic material, and a complex mechanistic relationship between CBI's multiple, integrated measures of severity and spectral reflectance changes. Our study investigated the potential to map two simple attributes of boreal burn severity (residual green vegetation and charred organic surface) in NWT, Canada at very high (3 cm) resolution using color orthomosaics and vegetation height models derived from Unmanned Aircraft System (UAS)-based photographic surveys. These attributes were scaled to 30 m resolution Landsat pixel footprints so they could be compared to the NBR and other Landsat-based spectral vegetation indices. We found that the 30 m fractions of green vegetation and charred organic surfaces were both highly related (R2 > 0.80) to Landsat spectral indices and that these relationships were stronger than those between CBI and Landsat indices. Follow-on research will conduct higher resolution UAS mapping of burns to quantify more complex metrics of burn severity from which to better characterize post-burn vegetation structure. Overall, these initial results provide a proof-of-concept for using low-cost UAS photogrammetric mapping to derive key measures of boreal burn severity at landscape scales, which can be used to calibrate Landsat spectral indices for mapping severity at regional scales.

A-34 Post-fire vegetation index recovery patterns in the taiga-steppe ecotone of southern Siberia

Kirsten Barrett, Joerg Kaduk (University of Leicester), Robert Baxter (Durham University), Heiko Balzter, Kevin Tansey (University of Leicester)

Wildfire disturbance in the light conifer forests of southern Siberia is a common occurrence, with an average fire return interval on the order of 50 to 100 years. In the ecotone between steppe vegetation to the south, and taiga to the north, vegetation type is determined by topographic position, with forests dominating areas of higher elevation. Wildfires can reduce the resilience of forest ecosystems, making them vulnerable to recovery failure post-fire, particularly when these occur on south-facing slopes or in areas affected by multiple fires in short succession. Remotely sensed vegetation indices are sensitive to the signal of forest loss post-fire, and can provide an estimate of the disturbed area that experiences recovery failure in the region. We apply the bfast method for detecting disturbances in southern Siberia in 2000 using remotely-sensed vegetation indices, and study the variability of post-fire recovery patterns using rgrowth. We find that a fraction of the disturbed area appears to experience recovery failure, and that the post-disturbance conditions have persisted in these sites for 1.5 decades. The loss of southern boreal forests as a result of wildfire is consistent with other studies highlighting the vulnerability of these forests globally, which is likely to offset boreal expansion to the north.

A-35 Wildfire reburn dynamics within Alaska, 1970–2015 (Poster)

Jessica Walker (Western Geographic Science Center, U.S. Geological Survey, Tucson, AZ), Rachel Loehman (Alaska Science Center, U.S. Geological Survey, Anchorage, AK), Jennifer Barnes, Jennifer Hrobak (National Park Service, Fairbanks, AK), Jennifer Jenkins (Alaska Fire Service, Bureau of Land Management, Ft. Wainwright, AK), Erana Loveless (Western Geographic Science Center, U.S. Geological Survey, Tucson, AZ), Lisa Saperstein (Alaska Region, US Fish and Wildlife Service, Anchorage, AK), Robert Ziel (Alaska Fire Science Consortium, Fairbanks, AK)

Climate is the primary driver of fire regimes in Alaskan boreal forests, where warmer and drier conditions are implicated in the contemporary trend towards larger, more severe, and more frequent fires. Resource and fire managers have also reported a contraction of reburn intervals, as a growing number of fires burn across existing fire scars in anomalously short periods of time. The deviation of reburn frequencies from historical norms can disrupt stable cycles of postfire vegetation succession, resulting in critical landscape-scale shifts in boreal forest structure, function, and species composition. To substantiate and understand reburn observations, we explored the spatial and temporal patterns of initial and reburn fires within Alaska over the past five decades. We examined fire incidence on a statewide and local level using the dataset of historical fire perimeters produced by the Alaska Interagency Coordination Center (AICC), the 2016 vegetation classification map published by the Alaska Center for Conservation Science (ACCS) (University of Alaska, Anchorage), and higher-resolution vegetation classification maps, where available, for more localized investigations in individual National Parks, National Wildlife Refuges, and ecological zones of interest. To focus on the time period of most consistent fire documentation and to exclude minor and intentional burns, we subset the perimeter dataset to non-prescribed fires that burned from 1970 to 2015 and were larger than 400 hectares. Our analysis links metrics of burn seasonality, extent, geographic location, and proportion and configuration of reburn area with coarse-level landcover categories to assess fire dynamics and trends across broad ecosystem types. Our results elucidate reburn characteristics within the context of the evolving nature of Alaskan fire regimes under altered climate conditions.

A-36 Satellite Synthetic Aperture Radar detection of soil moisture condition and associated post-fire physical and ecological changes in single and repeated burning in North American tundra (Poster)

Liza Jenkins (Michigan Tech Research Institute, Michigan Technological University), Tatiana Loboda (University of Maryland)

The all-weather imaging capabilities of Synthetic Aperture Radar (SAR) satellite systems provide significantly more data looks than electro-optical systems in high northern latitudes. The extensive historical archive of ERS-1 and -2, Radarsat-1, and ALOS PALSAR image data available provides a robust dataset for both pre- and post-fire characterization of fire signatures in the Alaskan tundra. Our analysis shows that a strong statistically significant relationship between burning and increase in soil moisture immediately after the burning event and a statistically discernable change in backscatter that persists for 4-5 years (Jenkins et al.. 2014). Ecologically in peer-reviewed literature this increased moisture at burn sites has been linked to the reduction in SOL depth and subsequent redistribution of moisture across a smaller duff layer leading to pooling of water on the surface (Rocha and Saver 2011). However, duff accumulation in tundra occurs extremely slowly and thus the relatively quick (5-10 year) recovery observed in SAR imagery is not likely to be related to accumulation of SOL to pre-burn layers. An alternative explanation could be presented by the subsequent considerable increase in the active layer depth allowing for more even distribution of surface moisture through the soil column. A rapid increase in vascular plant cover with the subsequent increase in evapotranspiration could present another viable alternative for the observed change in electro-magnetic radiation signature with very different ecological implications. We will summarize the initial findings from our satellite-based and in-situ analysis of soil moisture condition as a function of active layer depth and vegetation fractional composition and above ground biomass using in-situ data from four field campaigns in burned areas in the Alaskan tundra.

A-37 An Investigation of Impacts of Large Wildland Fires on Land Surface Properties in Alaska by Combining Satellite Remote Sensing and In-situ Measurements

John J. Qu, Xianjun Hao, and Ray Motha (Global Environment and Natural Resources Institute & Department of Geography and GeoInformation Science, George Mason University), Yongqing Liu (USDA Forest Service, Southern Research Station), Zhiliang Zhu (U.S. Geological Survey)

Wildland fire is a natural phenomenon and influential force of the Earth's climate system. During the past decades, increased large wildland fire activities, longer wildland fire durations, and longer wildfire seasons in the United States have received more and more attention because of increasing extreme weather and climate events. While there is no significant trend of fire numbers, the burned area apparently increased during the recent decade, which implies increase of large fires. Early studies have demonstrated dramatic changes of surface dynamic, radiative, vegetative, thermal and hydrological properties caused by large wildland fires and significant impacts of wildland fires on ecosystem and regional climate. Wildland fires may lead to either warming or cooling at regional scale. The net impacts of wildland fires depend on the integrated effects of many factors, such as fire emissions, changes in surface albedo, and carbon deposition. Previous studies about the climatic impacts of large wildland fires mainly focused on western region, especially in Alaska and found both positive and negative implications for climatic feedbacks. It's also important to investigate and compare the impacts of large fires over other regions.

To further understand wildland fire trends, forest recovery patterns, and fire-climate interactions, it is essential to quantitatively characterize various changes caused by wildland fires, such as atmospheric composition, cloud cover, surface albedo, soil composition and moisture etc. Providing global coverage and repetitive observations, satellite remote sensing has emerged as an advanced technique for land and climate study. The satellites of Landsat series (Landsat 1-8) have been providing continuous and consistent measurements of the earth from early 1970s to now. Landsat data have been playing important role in wildland fire study, including fuel and burned area mapping. Landsat imagery is the foundation of the LANDFIRE's vegetation and disturbance data layers. From 2000, the launch of NASA's EOS platform with a series of polar-orbiting satellites provided the opportunity for systematic observation and study of the Earth's surface and atmosphere. Especially, the Moderate-resolution Imaging Spectroradiometer (MODIS) data products are available since 2000. With plenty of products and consistent records over 15 years, MODIS has improved our understanding of global dynamics and processes occurring on the Earth's surface, and provides the potential for further investigation of fire-climate interactions.

This presentation will focus on results from our investigating land property changes in Alaska by combining using satellite remote sensing and in-situ measurements. The preliminary results include: an integrated spatiotemporal database in Alaska since 1982, including fire information, time series of land surface properties, as well as climate/weather data; post-fire land surface properties changes of burned areas spatially and temporally; and the impacts of large post-fires on regional climate in Alaska.

A-38 Wildfire Consumption of Deciduous Stands during Large Fire Years (Poster)

Maija Wehmas and David Verbyla (Department of Natural Resources Management, University of Alaska Fairbanks)

A shift in Alaska's fire regimes has included an increase in the severity of wildfires. Previous research suggests that the increased fire severity favors a shift towards deciduous forest stands. A vegetation shift is likely to lead to future boreal landscapes with lower flammability due to a landscape shifting from spruce to deciduous stands. How resilient are these broadleaf stands to burning during large fire years? In the study, we used Landsat imagery to map pre-fire deciduous stands and track their fate inside burned perimeters that occurred during large fire years of 2004, 2009, and 2015. We categorize deciduous stands by patch size, topographic position, and timing of wildfire to address the potential effectiveness of deciduous stands as "fire breaks" during large fire years.

A-39 Remotely sensing post-fire land surface changes in the Arctic using repeat airborne LiDAR (Poster)

Benjamin M. Jones (Alaska Science Center, U.S. Geological Survey), Eric Miller (Bureau of Land Management Alaska Fire Service), Carson A. Baughman (Alaska Science Center, U.S. Geological Survey), Daniel Mann (University of Alaska Fairbanks Department of Geosciences), Benjamin V. Gaglioti (Columbia University Lamont-Doherty Earth Observatory), Guido Grosse (Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research), Christopher Larsen (Geophysical Institute, University of Alaska Fairbanks)

Wildfire disturbance in northern high latitude regions is an important factor contributing to ecosystem and landscape change. The impact of fires on permafrost-influenced terrain in Boreal Forest regions is well documented; however the role of fires in initiating thermokarst development in Arctic Tundra regions is poorly understood. Rapid climate change at high latitudes has increased interest in the spatial and temporal dynamics of thermokarst and other permafrost thaw-related features in diverse disciplines including landscape ecology, hydrology, engineering, and biogeochemistry. As a result, there is an urgent need to develop new techniques and tools to observe and quantify changes to near-surface permafrost terrain. Remote sensing provides a means for documenting and quantifying many of the changes now occurring on arctic landscapes. In particular, application of multi-temporal airborne LiDAR allows for the detection of terrain subsidence caused by thermokarst. LiDAR elevation model differencing provides a direct measure of land surface elevation changes over time. In this study, we compare two airborne LiDAR datasets covering ~400 km2, acquired in the aftermath of the large and severe Anaktuvuk River tundra fire that occurred in 2007 in northern Alaska. Digital terrain models (DTMs) at 1 m spatial resolution were developed from the LiDAR datasets that were acquired two years and seven years post-fire. These datasets were differenced using the Geomorphic Change Detection tool to quantify thermokarst development in response to the tundra fire disturbance. Results show permafrost thaw subsidence (> 0.2 m) occurring across 34% of the burned tundra area studied, compared to < 1% in similar undisturbed, ice-rich tundra terrain. Ice-rich, yedoma upland terrain was most susceptible to thermokarst development following the disturbance, accounting for 50% of the areal and volumetric change detected, with some locations subsiding more than five meters in the first seven years following the disturbance. Calculation of rugosity, or surface roughness, in the two datasets showed a doubling in microtopography on average across the burned portion of the study area, with a 340% increase in yedoma upland terrain. An additional LiDAR dataset was acquired in April 2015 to document the role of thermokarst development on enhanced snow accumulation and subsequent snowmelt runoff within the burn area. Our findings will enable future vulnerability assessments of ice-rich permafrost terrain as a result of shifting disturbance regimes. Such assessments are needed to address questions focused on the impact of permafrost degradation on physical, ecological, and socio-economic processes.

A-40 Differences in wildfire induced land-surface changes between cold and warm U.S. eco-regions detected by satellite remote sensing (Poster)

Yongqiang Liu (USDA Forest Service/Center for Forest Disturbance Science, Athens, GA), Xianjun Hao and John Qu (Global Environment and Natural Resources Institute, College of Science, George Mason University, Fairfax, VA.)

Wildfires can impact the earth systems by modifying not only atmospheric radiation transfer and cloud microphysics through emitting smoke particles but also the land-air heat and water fluxes through changing land-surface properties. Both mechanisms would lead to changes in local and even regional climate. This study detected the changes in land-surface properties induced by large wildfires in the United States with a focus on the differences between cold and warm eco-regions. More than a dozen of large fires with information provided from the Monitoring Trends in Burning Severity (MTBS) dataset were examined. Satellite remote sensing tools including MODIS and Landsat were used to quantitatively evaluate the land-surface changes. The temporal changes were obtained by comparing properties of the burned area between the periods before and after a fire for both fire year and prior year. Spatial changes were obtained by comparing properties between the burned area and a nearby control area with same vegetation cover and very close albedo. The results indicate that land-surface changes are remarkable only if land coverage meets the thresholds of NDVI greater than 0.5 or LAI greater than 1. NDVI and LAI reduce by about 30-70% after burning and large changes exist over 4-10 years. Albedo is reduced by 15-25% shortly after fires, but increase from the second year due to removed vegetation. Day time temperature increases as many as 7-8 K in first 1-2 years during summer. Large changes in cold eco-regions occur mainly in winter and last longer than those in warm eco-regions. These changes and eco-region dependence provide useful guidance to the development of parameterization scheme of wildfire induced land-surface changes for simulating the climate impacts of wildfires through land-air interactions in the earth system models.

A-41 Fire-induced surface forcing of the Siberian larch forests since 2000 in the context of climate change (Poster)

Dong Chen, Tatiana V. Loboda, Tao He, Shunlin Liang (Department of Geographical Sciences, University of Maryland)

The Siberian larch forests are a major component of the global boreal biome with wildfire being the most important disturbance agent. However, due to their unique characteristics and remote location, coupled with a limited record of remotely sensed datasets, we know little about the post-fire albedo dynamics in the region as well as the associated climatic impact, especially over a relatively longer temporal span. This is unfortunate as it has been suggested that the climatic effect of the fire-induced albedo change may have a pivotal role in controlling the net climatic impact of the boreal forests. Utilizing a 30-m 24-year stand age distribution map of the Siberian larch forests, combined with the MODIS albedo product and a series of climate datasets produced through the NCEP/NCAR Reanalysis project, this study quantified the fire-induced surface forcing of the Siberian larch forests over 2000-2015. The results show that the post-fire larch forests in the region has a cooling effect lasting for more than 25 years, and the magnitude of the cooling is much larger than previously expected. In contrast, the forests that remained unburned since 2000 show a considerable warming effect, which is largely attributable to the earlier snow-melt in the region. These results together indicate that wildfire may play a much bigger role in modulating the climatic impact of the Siberian larch forests than we previously thought, but this role is likely weakened by the considerable warming in the region, thus needs to be evaluated in the context of global climate change. In addition, the consistent net warming effect of the region, coupled with its large expanse, making the Siberian larch forests a significant contributor to the global warming since 2000.

A-42 Carbon exchange rate in burned black spruce forest in interior Alaska (Poster)

Yongwon Kim (International Arctic Research Center (IARC), University of Alaska Fairbanks)

The Boreal black spruce forest is highly susceptible to wildfire, and postfire changes in soil temperature and substrates have the potential to shift large areas of such an ecosystem from a net sink to a net source of carbon. In this study, we examine CO_2 exchange rates (e.g., NPP and Re) in juniper haircap moss (*Polytrichum juniperinum*), 10-year old younger black spruce, and microbial respiration in no-vegetation conditions using an automated chamber system in a burned black spruce forest of interior Alaska during the growing season. Mean ± standard deviation microbial respiration and NEP (net ecosystem productivity) of juniper haircap moss were 0.27 ± 0.13 and 0.28 ± 0.38 $gCO_2/m^2/hr$, respectively. CO_2 exchange rates and microbial respiration showed temporal variations following fluctuation in air temperature during the fall season, suggesting the temperature sensitivity of juniper haircap moss and soil microbes after fire. During the 45-day fall period, mean NEP of *P. juniperinum* moss was 0.49 ± 0.28 MgC/ha following the five-year old forest fire. On the other hand, simulated microbial respiration normalized to a 10 °C temperature might be stimulated by as much as 0.40 ± 0.23 MgC/ha. These findings demonstrate that the fire-pioneer species juniper haircap moss is a net C sink in the burned black spruce forest of interior Alaska.

A-43 Environmental controls on regional trace gas variability and emission factors in Alaska (Poster)

Elizabeth Wiggins, Jim Randerson (UCI), Charles Miller (NASA JPL), Arlyn Andrews, Colm Sweeney (NOAA)

We examined environmental controls on fire emissions and trace gas variability using three distinct conceptual models of fire emissions that draw upon different types of remote sensing information. The three approaches were derived from satellite-derived observations of active fires, satellite-derived estimates of fire radiative power, and daily emissions estimates from the Alaska Fire Emissions Database model (AKFED). In our analysis, we assessed the relative importance of different climate variables and fire weather indices in explaining the temporal variability of satellite-detected fire thermal anomalies and emissions within the state of Alaska during the summer of 2013. We evaluated the performance of each emissions model using trace gas observations from the CARVE (CRV) tower in Fox, Alaska. In our approach we used an inverse atmospheric transport model, the coupled Weather Research and Forecasting/Stochastic Time-Inverted Lagrangian Transport (WRF-STILT) model, to link the fire emissions with the trace gas observations. MISR plume observations were used to inform the injection height distribution in WRF-STILT and CRV-derived estimates of CO/CO_2 emission ratios were used to convert modeled carbon emissions into trace gas fluxes. Local climate variables had varying levels of influence on fire dynamics in interior Alaska, with vapor pressure deficit and temperature explaining the most variability. Combined use of the emissions products and WRF-STILT allowed us identify fire contributions to the CRV time series on a daily basis, and to isolate contributions from individual fires that had different temporal dynamics and interactions with atmospheric transport. Using this approach, we were able to identify individual fire contributions to emission factors calculated from CRV trace gas observations. Environmental conditions including hourly weather, soil moisture, and fractional tree cover were defined for individual fires and correlated with emission factors. The findings from this study could be used to build a dynamic emission factor model that responds to pre-existing environmental conditions.

A-44 Ecosystem Dynamics and Fate of Warm Permafrost after Tundra Wildfire and Lake Drainage on the Yukon-Kuskokwim Delta (Poster)

Gerald V. Frost, Matthew J. Macander (Alaska Biological Research, Inc. Fairbanks, AK), Rachel Loehman (USGS Alaska Science Center, Anchorage, AK), Lisa Saperstein (USFWS Regional Office, Anchorage, AK), Kristine Sowl (Yukon Delta NWR, Bethel, AK), Uma S. Bhatt, Peter Bieniek (UAF)

The Yukon-Kuskokwim Delta (YKD) encompasses the southernmost, warmest parts of the arctic tundra biome and is renowned for its high biological productivity and large subsistence-based human population. Ice-rich permafrost currently is widespread and strongly influences terrestrial and aquatic habitats, including local topography, vegetation, soil hydrology, and the water balance of lakes. Ground temperatures are near the freezing point, however, and widespread loss of permafrost is projected to occur by the end of this century. Tundra wildfire is a common ecological pulse disturbance and a potent permafrost stressor on the YKD. Permafrost-affected uplands are extensive in inland parts of the YKD and have one of the most active fire regimes in the circumpolar tundra biome. Large episodes of fire in the early 1970s and recent years have been preceded by widespread loss of upland lakes and ponds; these aquatic-terrestrial state transitions are potentially exacerbated by active-layer deepening after fire, and have secondary impacts associated with increased landscape vulnerability to fire. Here we present a suite of mapping products derived from Landsat 1–8 indicating spectral dynamics related to fire severity and ecosystem recovery, and long-term changes in surface water regime in the inland YKD (Izaviknek Uplands) since 1972. Dense time-series acquired by the Multispectral Scanner (MSS) aboard Landsat 1–3 provide foundational observations of vegetation and aquatic-terrestrial hydrologic state before and after large fires in the early 1970s at 60 meter resolution. The MSS archive has been comparatively little-used because of spectral and calibration limitations, but it is a useful resource for observing land-cover changes with a stark spectral signature such as wildfire and lake drainage. Observations by later Landsat satellites provide more detailed information on post-fire ecosystem dynamics since the mid-1980s using indices that require a short-wave infrared band (e.g., Normalized Burn Index). The landscape-scale remote sensing products presented here will inform the design of a field campaign planned for July 2017 aimed at determining impacts and trajectories of YKD vegetation, soils, and permafrost along gradients of wildfire age and intensity. Findings from field-based and remote sensing components will be used to model changes in landscape vulnerability to future fire resulting from lake drainage and post-fire shifts in vegetation and soil organic stocks. The products of this work will inform YKD resource managers and local stakeholders on the dynamics and trajectories of terrestrial and aquatic habitats and subsistence resources (e.g., berry-producing shrubs associated with permafrost soils) following tundra wildfire. This work leverages logistical and scientific synergies with ongoing research funded by NASA's Arctic Boreal Vulnerability Experiment and USFWS long-term monitoring of breeding birds that depend on upland tundra habitats.

A-45 LP DAAC Products and Services for the Wildland Fire Community (Poster)

Tom Maiersperger (Land Processes Distributed Active Archive Center (LP DAAC), U.S. Geological Survey, Earth Resources Observation & Science (EROS) Center)

Established in 1990 in partnership with the U.S. Geological Survey, the Land Processes Distributed Active Archive Center (LP DAAC) is 1 of 12 DAACs within the National Aeronautics and Space Administration (NASA) Earth Observing System Data and Information System (EOSDIS). The LP DAAC ingests, archives, processes, and distributes NASA Earth science land processes data. The LP DAAC holds more than 2 petabytes (2,000 terabytes) of remotely sensed land data that are available to the public at no charge. The LP DAAC holds data collected by satellite sensors that observe the Earth's land surface. Currently, data archived by the LP DAAC are collected by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Moderate Resolution Imaging Spectroradiometer (MODIS) sensors onboard the Aqua and Terra satellites, as well as a variety of other datasets from NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) and community programs that are generated by selected science investigators. For more information about data products at the LP DAAC, please visit https://lpdaac.usgs.gov/.

Appendix B: Workshop Agenda

Opportunities to Apply Remote Sensing in Boreal/Arctic Wildfire Management and Science

April 4-6, 2017 | University of Alaska Fairbanks

Organized by the Alaska Fire Science Consortium (AFSC) with support from the NASA Applied Sciences Program.

All sessions in Regents' Conference Room (109 Butrovich)

Tuesday, April 4 ***Day Organizer: Kristi Bulock*** ***Facilitator: Vince Ambrosia***

0730 Registration and coffee

Introductory Session

0800 Alison York: *Welcome, Introductions (name and affiliation)*

Randi Jandt: *What we hope to get out of this workshop*

Jenn Jenkins, Randi Jandt, Robert Ziel: *Overview: Current Uses of Remote Sensing for Wildland Fire in High Latitudes*

Keynote presentations

0910 Bud Cribley, BLM Alaska State Director: *A View from the Bridge: Why Alaska's Management Agencies Need Science*

0930 Everett Hinkley, USDA Forest Service – National Remote Sensing Program Manager: *Remote Sensing Support to Interagency Fire Management*

0950 BREAK

Introduction to the State of the Science

1010 Anita LeRoy: *Short-term Prediction Research and Transition (SPoRT) Center Datasets and Products for Wildland Fire Potential and Prediction*

1030 Wilfrid Schroeder: *S-NPP/VIIRS and Landsat-8/OLI global active fire data sets*

1050 E. Natasha Stavros: *Use of New NASA Technologies for Pre-, Active, and Post-Fire Applications*

1110 Eric Stevens: *Warts and All: The Current State of the University of Alaska's Near Real Time Satellite Imagery and Derived Products Available to the Alaska Wildland Fire Community*

1130 Discussion

1145 LUNCH (on your own)

Potential fire risk: Can remotely sensed data (e.g., daily snow extent, others) estimate spring soil moisture and surface and subsurface fuel moisture and fuel conditions, and thus provide critical inputs for fuel moisture indices used to predict fire danger and risk?

1330 Laura Bourgeau-Chavez: *Assessing Fuel Moisture in Boreal and Arctic Ecosystems with Active and Passive Microwave Satellite Imagery*

1350 Brigitte LeBlon: *An overview of twenty years of research at the Faculty of Forestry and Environmental Management, University of New Brunswick, Canada on fuel moisture estimation using optical, thermal infrared and radar remote sensing in boreal forests in Alberta, the Northwest Territories, and Alaska*

1410 Kurtis Nelson: *LANDFIRE Remap: opportunities for incorporating new remotely sensed data into vegetation and fuels characterization across Alaska*

1430 BREAK

1445 George J. Huffman (by phone): *NASA Precipitation Datasets for High-Latitude Applications*

1505 Nancy French: *Improving fuel characterization and maps useful for emissions modeling*

1525 BREAK

1545 Ignite Session with Wednesday's Poster Session Presenters (4 min/2 slide intros to people and their projects)

1730 ADJOURN

Evening Buffet Dinner at Pike's in the Binkley Room: UAF history professor Terrence Cole will speak on the history of forestry and fire in Interior Alaska

Wednesday, April 5 ***Day Organizer: Nancy French*** ***Facilitator: Vince Ambrosia***

Potential fire risk, continued: Can remotely sensed data (e.g., daily snow extent, others) estimate spring soil moisture and surface and subsurface fuel moisture and fuel conditions, and thus provide critical inputs for fuel moisture indices used to predict fire danger and risk?

0800 Welcome back

0810 Laura Bourgeau-Chavez: *Improving Remote Sensing Capability for Assessing Wildfire Effects in North American Boreal Peatlands*

0830 Dan Thompson: *Hydrological and phenological monitoring of wildfire potential in boreal and taiga wetlands: remote sensing approaches*

0850 Panel on Potential Fire Risk: moderated discussion of how to advance capabilities to estimate conditions associated with high fire danger. Robert Ziel, moderator.

Managers: Kristi Bulock, Jay Wattenbarger, Larry Weddle

Researchers: Laura Bourgeau-Chavez, Brigitte Leblon, Dan Thompson

0930 BREAK

Near Real-Time Fire Behavior: Which remotely sensed data are best and most timely for fire detection, plume tracking of fire emissions, fire behavior modeling, mapping of flaming fronts, fire intensity, active fire perimeters, and response for ongoing fires?

0945	Robert Ziel: *Near-real Time Fire Behavior: A Personal History*
1005	Eric Stevens: *Challenges and Opportunities: Using the University of Alaska's Near Real Time Satellite Imagery to Support Alaska Wildland Fire Community*
1035	Curtis Seaman: *VIIRS Imagery Applications for Fire Weather Monitoring*
1055	BREAK
1110	Chris Waigl: *Improved operational approaches to high and low-intensity fire detection in Alaska using the VIIRS I-band Fire Detection Algorithm for High Latitudes (VIFDAHL)*
1130	Patricia Oliva: *Near real-time estimation of burned area in boreal forest using VIIRS 375 m active fire product*
1150	LUNCH (on your own)
1330	Eric James: *High-Resolution Rapid Refresh with Smoke (HRRR-smoke) modeling system for experimental smoke forecast guidance*
1350	Taylor McCorkle: *Verification of the Experimental High Resolution Rapid Refresh in Alaska using the USArray Transportable Array Network*
1410	Fengjun Zhao: *Applications of Chinese FY series meteorological satellites in boreal forest fire management*
1430	Panel Discussion on Near Real-Time Fire Behavior: moderated discussion of how to advance capabilities in active fire applications. Jenn Jenkins, moderator.
	Managers: Mike Butteri, Mike Roos, Kent Slaughter
	Researchers: Evan Ellicott, Tom Heinrichs, Chris Waigl
1515	BREAK and relocate
1530	Poster Session: Special Topics in Wildfire & Remote Sensing (UAF Pub)
	Peter A. Bieniek (presenting for Hiroski Hayasaka): *Synoptic-scale fire weather conditions in Alaska*
	Elizabeth Hoy: *Changing fire frequency and carbon consumption in Alaskan black spruce forests*
	Maija Wehmas: *Wildfire Consumption of Deciduous Stands during Large Fire Years*
	Jiaying He: *Lightning Distribution and Wildland Fire Occurrence in Alaska tundra*
	Jess Walker: *Burn, grow, repeat: Toward an improved understanding of causes and consequences of shortened fire return intervals in northwest boreal forests*
	Kiunnei Kirillina: *Effects of weather and climate on forest fire behaviour: Case study of Northern boreal forest in Republic of Sakha (Yakutia), Russia*
	Arleen Lunsford: *APRFC Produced QPE and QPF grids*
	Keshav Dev Singh: *Airborne hyperspectral remote sensing in the real-time detection and management of wild-fire*
	Eric Miller (presenting for Benjamin Jones): *Remotely sensing post-fire land surface changes in the Arctic using repeat airborne LiDAR*
	Yongqiang Liu: *Differences in wildfire induced land-surface changes between cold and warn U.S. eco-regions detected by satellite remote sensing*
	Dong Chen: *Fire-induced surface forcing of the Siberian larch forests since 2000 in the context of climate change*
	Tatiana Loboda (for Liza Jenkins): *Satellite Synthetic Aperture Radar detection of soil moisture condition and*

	associated post-fire physical and ecological changes in single and repeated burning in North American tundra
	Yongwon Kim: *Carbon exchange rate in burned black spruce forest in interior Alaska*
	Elizabeth Wiggins: *Environmental controls on regional trace gas variability and emission factors in Alaska*
	J.J. Frost: *Ecosystem Dynamics and Fate of Warm Permafrost after Tundra Wildfire and Lake Drainage on the Yukon-Kuskokwim Delta*
	Tom Maiersperger: *LP DAAC Products and Services for the Wildland Fire Community*
1730	ADJOURN

Thursday, April 6 **Day Organizer: Jen Hrobak** **Facilitator: Vince Ambrosia**

Post-fire effects: Can we improve analytical methods for remotely sensed data to assess fire severity, consumption/CO_2 balance, active-layer changes, and successional trajectories of high latitude vegetation communities?

0800	Welcome back
0810	Mary Ellen Miller: *Rapid response tools and datasets for post-fire modeling in Boreal and Arctic Environments*
0830	Tatiana Loboda: *Evaluating characterization of fire extent and fire spread in boreal and tundra fires of North America from coarse and moderate resolution MODIS and VIIRS data*
0850	Amber Soja: *Decades of Change in the Former Soviet Union: Current Assessment and New Possibilities*
0910	Sander Veraverbeke, Elizabeth Wiggins: *High resolution carbon emissions estimates from boreal fires*
0930	Ellen Whitman: *Improving remotely sensed multispectral estimations of burn severity in western boreal forests*
0950	BREAK
1005	Jurjen van der Sluijs: *Assessing Boreal Forest Burn Severity using UAS-based Photogrammetric Mapping*
1025	Kirsten Barrett (by phone): *Post-fire vegetation index recovery patterns in the taiga-steppe ecotone of southern Siberia*
1045	Rachel Loehman: *Spatial, temporal, and ecological trends in repeat fires within Alaska, 1940-2016*
1105	Yongqiang Liu: *An Investigation of Impacts of Large Wildland Fires on Land Surface Properties in Alaska by Combining Satellite Remote Sensing and In-situ Measurements*
1125	Panel Discussion on Post-Fire Effects: moderated discussion of how to advance capabilities to assess post-fire conditions. Rachel Loehman, moderator.
	Managers: Jennifer Hrobak, Eric Miller, Lisa Saperstein
	Researchers: Elizabeth Hoy, Tatiana Loboda, Sander Veraverbeke
1210	LUNCH (on your own)

Partnerships: can we leverage other data collection and analysis efforts to advance our objectives?

1400	Elizabeth Hoy: *An Overview of the 2017 Airborne Campaign for NASA's Arctic Boreal Vulnerability Experiment (ABoVE)*
1420	Hans-Erik Anderson: *A USFS-NASA partnership to leverage advanced remote sensing technologies for forest inventory*
1440	Charge to breakouts: Next steps to synthesize and advance our objectives
1500	BREAK and breakouts

1615	Report out
1715	Wrap up and evaluation
1730	ADJOURN

Appendix C: Workshop organizers and participants

Members of the workshop organizing and writing committees are in bold type

Name	*Affiliation*
Sharon Alden	Alaska Interagency Coordination Center (AICC)-Predictive Services
Vince Ambrosia	NASA Applied Sciences Program HQ
Hans Andersen	USDA Forest Service
William Archer	Bureau of Land Management (BLM) - Alaska Fire Service
Scott Arko	University of Alaska Fairbanks
Kirsten Barrett	University of Leicester
Carson Baughman	U.S. Geological Survey
Peter Bieniek	University of Alaska Fairbanks
Casey Boespflug	BLM - Alaska Fire Service
Laura Bourgeau-Chavez	Michigan Technological University
Amy Breen	University of Alaska Fairbanks
Kristi Bulock	U.S. Fish and Wildlife Service
Michael Butteri	BLM - Alaska Fire Service
Tina Buxbaum	University of Alaska Fairbanks
Jay Cable	University of Alaska Fairbanks
Dong Chen	University of Maryland
Jessica Cherry	University of Alaska Fairbanks
Eirik Christensen	Imperial College London
Melanie Colavito	University of Alaska Fairbanks
Matthew Coyle	Government of the Northwest Territories
Bud Cribley	Bureau of Land Management
Sheila Dufford	U.S. Fish and Wildlife Service
Evan Ellicott	University of Maryland
Mike Flannigan	University of Alberta
Dawson Foster	University of Alaska Fairbanks
Nancy French	Michigan Tech Research Institute
Gerald (JJ) Frost	Alaska Biological Research, Inc.
Randy Fulweber	University of Alaska Fairbanks
Helene Genet	University of Alaska Fairbanks
Daniel Griggs	BLM - Alaska Fire Service
Michael Hatfield	University of Alaska Fairbanks
Jiaying He	University of Maryland
Tom Heinrichs	University of Alaska Fairbanks
Everett Hinkley	USDA Forest Service
Lisa Holsinger	USDA Forest Service
Kato Howard	BLM - Alaska Fire Service
Elizabeth Hoy	NASA Goddard/Global Science and Technology, Inc.
Jennifer Hrobak	National Park Service
George Huffman	NASA Goddard
Hannah Huhman	University of Alaska Fairbanks
Go Iwahana	University of Alaska Fairbanks
Eric James	University of Colorado
Randi Jandt	University of Alaska Fairbanks
Jennifer Jenkins	BLM - Alaska Fire Service
Anne Johnson	Alaska Department of Natural Resources
Cathleen Jones	Jet Propulsion Laboratory, California Institute of Technology
Yongwon Kim	University of Alaska Fairbanks
Kiunnei Kirillina	Keio University, Japan
Brigitte Leblon	University of New Brunswick

Anita LeRoy	NASA Short-term Prediction Research and Transition Center (SPoRT)
Tyler Lewis	U.S. Geological Survey
Yongqiang Liu	USDA Forest Service
Tatiana Loboda	University of Maryland
Rachel Loehman	U.S. Geological Survey
Arleen Lunsford	NOAA/National Weather Service
Tim Lynham	Canadian Forest Service
Tom Maiersperger	U.S. Geological Survey
Jingqiu Mao	University of Alaska Fairbanks
Taylor McCorkle	University of Utah
Amber Jean McCullum	NASA Applied Remote Sensing Training
Franz Meyer	University of Alaska Fairbanks
Eric Miller	BLM - Alaska Fire Service
Mary Ellen Miller	Michigan Tech Research Institute
Kurtis Nelson	U.S. Geological Survey
Patricia Oliva	University of Maryland
Branden Petersen	BLM - Alaska Fire Service
Amy Pocewicz	U.S. Fish and Wildlife Service
Anupma Prakash	University of Alaska Fairbanks
Kathryn Pyne	Alaska Division of Forestry
Michael Roos	BLM - Alaska Fire Service
Scott Rupp	University of Alaska Fairbanks
Eyal Saiet	University of Alaska Fairbanks
Lisa Saperstein	U.S. Fish and Wildlife Service
Jennifer Schmidt	University of Alaska Anchorage
Cindy Schmidt	NASA Applied Remote Sensing Training
Wilfrid Schroeder	University of Maryland
Curtis Seaman	Colorado State University
Ben Seifert	BLM - Alaska Fire Service
Hilary Shook	BLM - Alaska Fire Service
Keshav Dev Singh	University of California, Davis
Kent Slaughter	BLM - Alaska Fire Service
Amber Soja	NASA Applied Sciences Program HQ
E. Natasha Stavros	Jet Propulsion Laboratory, California Institute of Technology
Eric Stevens	University of Alaska Fairbanks
Matthew Stevens	Alaska Division of Forestry
Martin Stuefer	University of Alaska Fairbanks
Dan Thompson	Canadian Forest Service
Sarah Trainor	University of Alaska Fairbanks
Jurjen van der Sluijs	Government of Northwest Territories
Sander Veraverbeke	University of California, Irvine/Vrije Universiteit Amsterdam
David Verbyla	University of Alaska Fairbanks
Christine Waigl	University of Alaska Fairbanks
Jessica Walker	U.S. Geological Survey
Jay Wattenbarger	BLM - Alaska Fire Service
Larry Weddle	National Park Service
Maija Wehmas	University of Alaska Fairbanks
Ellen Whitman	University of Alberta
Elizabeth Wiggins	University of California, Irvine
Philip Williams	National Park Service
Alison York	University of Alaska Fairbanks
Jessica Young-Robertson	University of Alaska Fairbanks
Fengjun Zhao	USDA Forest Service/Chinese Academy of Forestry
Robert (Zeke) Ziel	University of Alaska Fairbanks

APPENDIX D: Acronyms and initialisms

ABoVE	Arctic-Boreal Vulnerability Experiment
ADEC	Alaska Department of Environmental Conservation
AFS	Alaska Fire Service
AFSC	Alaska Fire Science Consortium
AGU	American Geophysical Union
AICC	Alaska Interagency Coordination Center
AirMOSS	Airborne Microwave Observatory of Subcanopy and Subsurface
AirSWOT	Air Surface Water and Ocean Topography
AKFED	Alaska Fire Emissions Database
ALDN	Alaska Lightning Detection Network
ALOS	Advanced Land Observing Satellite
AMS	American Meteorological Society
APRFC	Alaska-Pacific River Forecast Center
ARSET	Applied Remote Sensing Training
ASOS	Automated Surface Observing System
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATMS	Advanced Technology Microwave Sounder
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AWFCG	Alaska Wildland Fire Coordinating Group
AWOS	Automated Weather Observing System
BLM	Bureau of Land Management
BUI	Build Up Index
C	Carbon
CARVE	Carbon in Arctic Reservoirs Vulnerability Experiment
CFFDRS	Canadian Forest Fire Danger Rating System
CFS	Canadian Forest Service
CO	Carbon monoxide
CO_2	Carbon dioxide
CONUS	Contiguous United States
CrIS	Cross-track Infrared Sounder
CSA	Canadian Space Agency
DAAC	Distributed Active Archive Center
DC	Drought Code
DEM	Digital Elevation Model
DMC	Duff Moisture Code
dNBR	Difference Normalized Burn Ratio
DOI	U.S. Department of the Interior
DSM	Digital Surface Model

EASE-Grid	Equal Area Scalable Earth Grid
EDDI	Evaporative Demand Drought Index
EOS	Earth Observing System
ERS	European Remote Sensing
ESA	European Space Agency
ESI	Evaporative Stress Index
FFMC	Fine Fuel Moisture Code
FRP	Fire Radiative Power
FWI	Fire Weather Index
GFAS	Global Fire Assimilation System
GINA	Geographic Information Network of Alaska
GIS	Geographic Information System
G-LiHT	Goddard's LiDAR, Hyperspectral, and Thermal Imager
GOES	Geostationary Operational Environmental Satellite
GPM	Global Precipitation Measurement
GSI	Growing Season Index
GTAC	Geospatial Technology and Applications Center
GVF	Green Vegetative Fraction
HNL	High Northern Latitudes
HRRR	High Resolution Rapid Refresh
HRSI	High Resolution Spaceborne Image
InSAR	Interferometric Synthetic ApertureRadar
IARPC	Interagency Arctic Research Policy Committee
IMERG	Integrated Multisatellite Retrievals for Global Precipitation Measurement
IR	Infrared
JAXA	Japan Aerospace Exploration Agency
JPSS	Joint Polar Satellite System
LAI	Leaf Area Index
LANDFIRE	Landscape Fire and Resource Management Planning Tools
LFI	Live Fuel Index
LiDAR	Light Detection and Ranging
LVIS	Land, Vegetation and Ice Sensor
MODIS	Moderate Resolution Imaging Spectroradiometer
MTBS	Monitoring Trends in Burn Severity
NASA	National Aeronautics and Space Administration
NBR	Normalized Burn Ratio
NDVI	Normalized Difference Vegetation Index
NEXRAD	Next Generation Weather Radar
NFDRS	National Fire Danger Rating System
NG	Next Generation
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration

NPP	National Polar-orbiting Partnership
NRT	Near Real Time
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NUCAPS	NOAA Unique Combined Atmospheric Processing System
NWCG	National Wildfire Coordinating Group
NWP	Numerical Weather Prediction
ORNL	Oak Ridge National Laboratory
PALSAR	Phased Array L-band Synthetic Aperture Radar
PGRR	Proving Ground and Risk Reduction
PNW	Pacific Northwest Research Station
QPE	Quantitative Precipitation Estimate
QPF	Quantitative Precipitation Forecast
R2O	Research to Operations
RAP	Rapid Refresh
RAWS	Remote Automated Weather Stations
RGB	Red/Green/Blue
RSAC	Remote Sensing Applications Center
RVI	Radar Vegetation Index
SAR	Synthetic Aperture Radar
SMAP	Soil Moisture Active/Passive
SNPP	Suomi National Polar-orbiting Partnership
SPEI	Standardized Precipitation-Evapotranspiration Index
SPoRT	Short-term Prediction Research and Transition
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager/Sounder
TFRSAC	Tactical Fire Remote Sensing Applications Committee
UAF	University of Alaska Fairbanks
UAV	Unmanned Aerial System
UAVSAR	Unmanned Aerial Vehicle Synthetic Aperture Radar
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite
VIS-SWIR	Visible-Shortwave Infrared
WCT	Wildfires Collaboration Team
WRAP	Wildfire Research and Applications Partnership
WRF	Weather Research and Forecasting Model