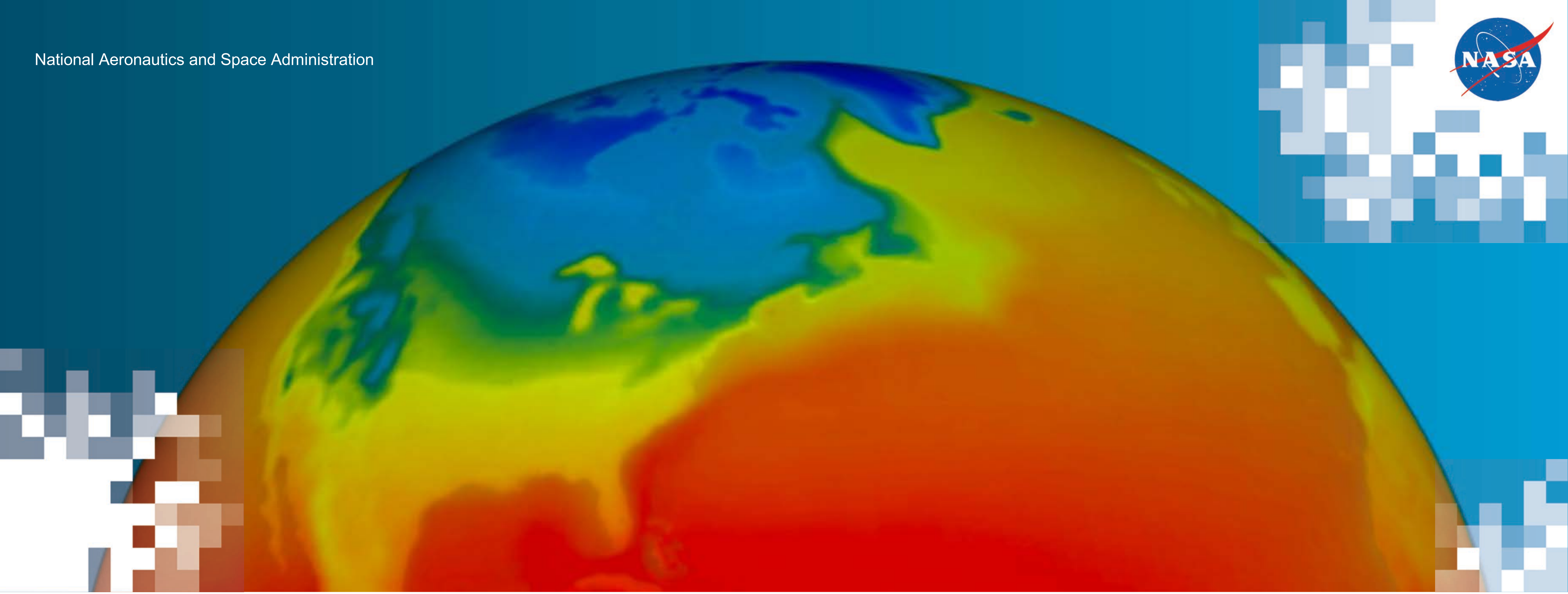


Part 2: Using NASA Products for a More Climate Resilient Energy Sector

June 8, 2021

Training Outline

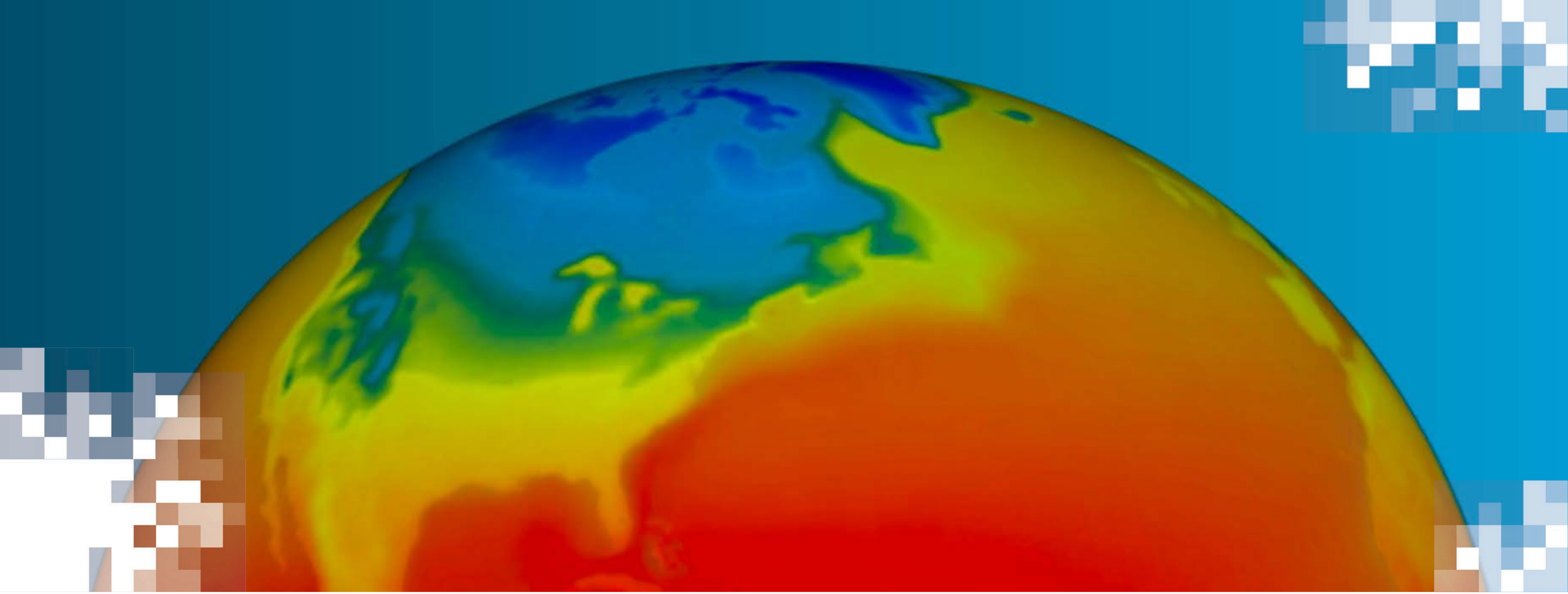
- Part 1: Introduction to Earth Observations (EOs) for Energy Management
  - June 1
- Part 2: Using NASA Products for a More Climate Resilient Energy Sector
  - June 8
- Part 3: NASA Resources for Renewable Energy and Building Energy Efficiency Applications
  - June 15
- Part 4: Data Access: the NASA Prediction of Worldwide Energy Resources (POWER) Project
  - June 22

Course Logistics

- Four 1-hour presentations with Q&A
  - Course recordings will be available on the training webpage
- **Homework:**
  - One homework assignment given after Part 4
  - Answers must be submitted via Google Forms
  - **HW Deadline: Tuesday, July 6**
- **Certificate of Completion:**
  - Attend all four live parts
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately three months after the completion of the course from: marines.martins@ssaihq.com
- **Prerequisites:**
  - Fundamentals of Remote Sensing

Part 2 Outline

- Present climate resilience and environmental threats to the energy sector
- Present real-world examples:
  - Near-real time wildfire potential and preventing impacts on energy infrastructure and provision of services
  - Satellite-based assessment of electricity restoration efforts in PR after Hurricane Maria
  - Hydropower reliability monitoring in Malawi using satellite data and machine learning



Climate Resilience and the Energy Sector

The Importance of Resilience

- **Resilience:** The ability to prepare for, respond to, and recover from disruptions.
  - *"Power sector resilience refers to the ability of the power sector to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions."*
- **Effects of climate change** will necessitate hardening of energy infrastructure to mitigate service disruption.
  - There are likely to be more frequent and intense hazards for longer duration.
  - Energy infrastructure is increasingly vulnerable, even if built to withstand historical conditions.
- **Resilience efforts** benefit an energy company financially (planned, gradual spending vs. unplanned, large spending during an event).
  - Ancillary benefits also exist, such as improved reliability and diversity of energy supply.

Vulnerabilities

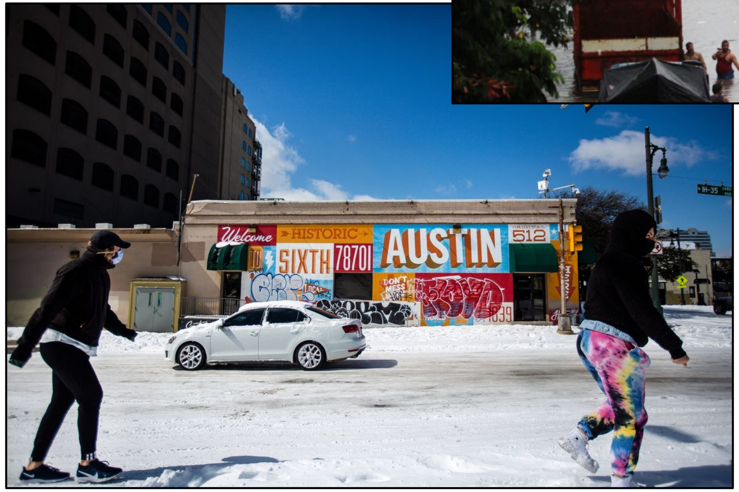
- **Infrastructure:**
  - Aging infrastructure built to withstand historic hazards and trends (not adequate for current trends and future projections associated with hazards)
  - Lack of cooling water
  - Vegetation or weather/climate leading to outages
  - Infrastructure design (lack of redundancy, bottlenecks, lines in high wind/high temp environments)
  - Infrastructure located in areas increasingly susceptible to climate-related hazards
- **Inadequate supply** for generation demand, especially during peak-demand loads (e.g., heatwaves, extreme cold) resulting in brownouts or blackouts
- **Shortages of staff** (and staff trained in disaster response and emergency preparedness) to respond to emergencies
  - Compounded events complicate preparedness and response

Climate-Related Threats to the Energy Sector

- **Catastrophic Events**
  - Landslides, wildfires, hurricanes, monsoons, tornados, flooding, storms (including snow or ice)
- **Gradual Changes**
  - Changes in the water table, sea level rise, precipitation patterns
    - Availability of cooling water
  - Air and water temperature increase
    - Increased demand at hot temperatures, cooling water too warm
  - Wind changes
    - Wildfire, wind energy

Source: Getty Images

Source: Getty Images

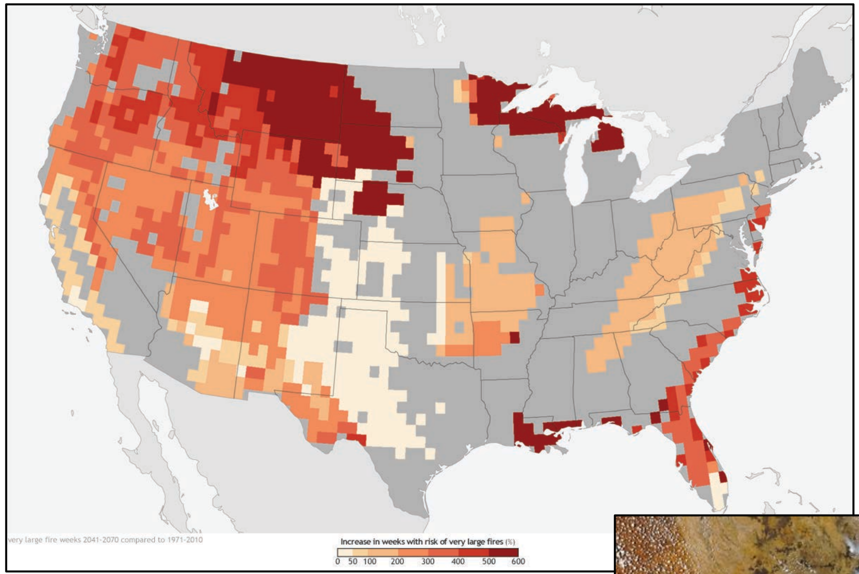


Pedestrians walk along a snow-covered street on February 15, 2021, in Austin, Texas. Source: *Montinique Monroe/Getty Images*

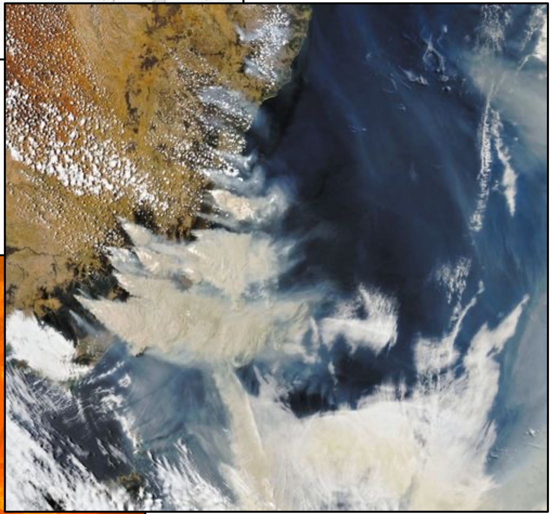
Threats to the Energy Sector

Example: Wildfires or Bushfires

- In many regions of the world, wildfires projected to burn longer over wider areas as climate becomes warmer and drier with shifting wind patterns
  - Fire seasons starting earlier, accidental anthropogenic fires spread rapidly
  - Fire occurring in previously rural areas that have seen population growth
  - Global insured losses from wildfires hit $20bn USD in 2018
- Mitigators:
  - Vegetation management, covered conductors, drones, resilience planning, reinsurance, improved land use planning



Risk of very large fires could increase sixfold by mid-century in the US.
Source: NOAA Climate.gov



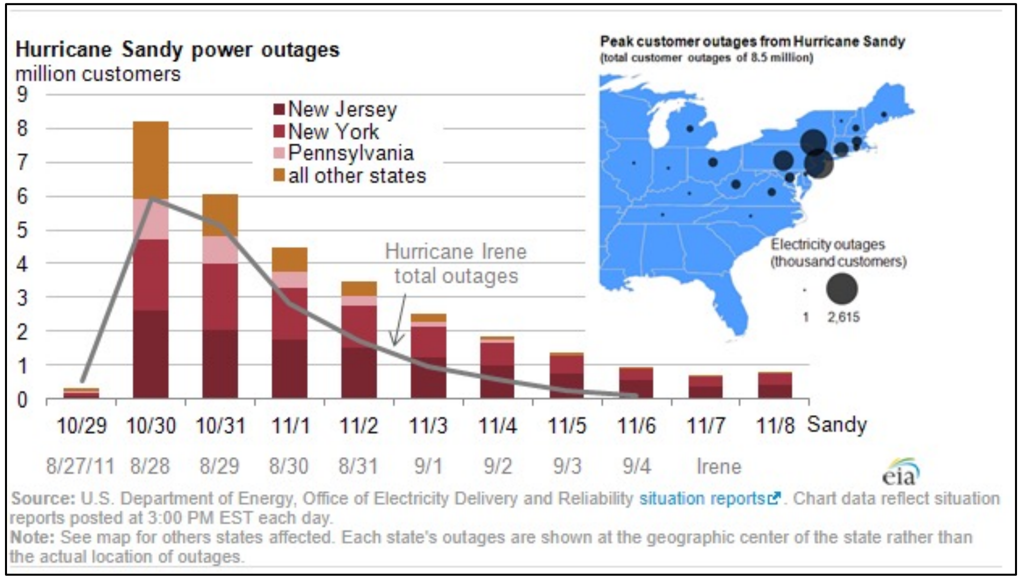
Smoke over Australia.
Source: Physics Today (NASA image)

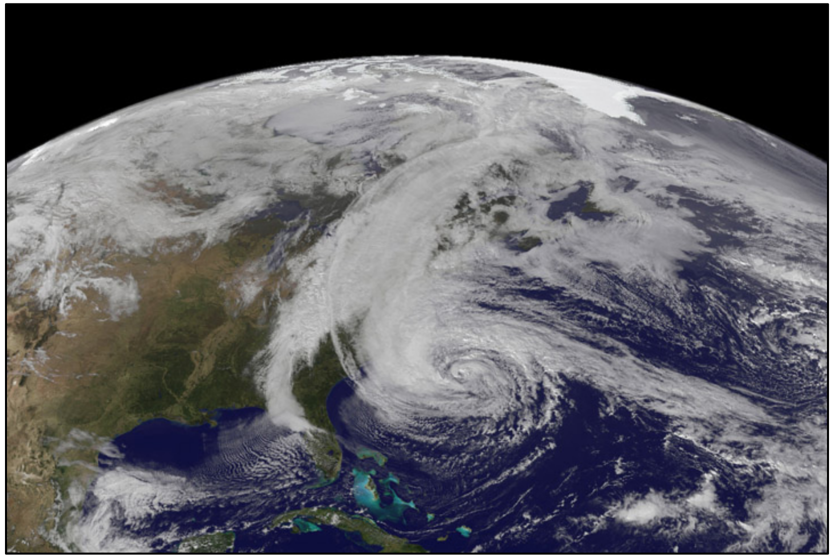
Source: New York Times, December 10, 2020

Threats to the Energy Sector

Example: Hurricanes (e.g., Superstorm Sandy, U.S.)

- Proportion of Category 4 and 5 storms is doubling or tripling depending on the region
  - Winds, flooding, and storm surge damaging infrastructure and interrupting service
- Hurricane Sandy
  - Storm impacted an estimated 8.5 million customers across the Mid-Atlantic, Northeast, and Ohio Valley
  - Flooding, especially in New York City (where most lines are underground), demonstrated that underground transmission and distribution infrastructure not immune to damage
- Mitigators:
  - Submersible equipment
  - Conversion to underground lines
  - Smart switches





Hurricane Sandy above the Eastern seaboard of the U.S. Source: NASA, GOES-13.

Threats to the Energy Sector

Example: Sea Level Rise & Storm Surge

- Sea level rise and flooding from storm surges both expected to increase in magnitude and severity
  - Recent NASA study projects average sea level rise of 65 inches by 2100
- Low-lying power plants and coastal infrastructure at increased risk
  - More than 100 U.S., European, and Asian nuclear power stations built just a few meters above sea level
  - Threatened by serious flooding caused by accelerating sea-level rise and more frequent storm surges
- Mitigators:
  - Storm surge barriers
  - Shore protection structures
  - Microgrids

FIGURE 3. U.S. Electricity Facilities Less than Four Feet above Local High Tide

Nearly 100 electricity facilities in the contiguous United States, including power plants and substations, are within four feet of high tide—and are therefore vulnerable to rising sea levels.

SOURCE: ADAPTED FROM CLIMATE CENTRAL 2012.

The Doel Nuclear Power Station in Antwerp, Belgium.
Source: Hakai Magazine, August 21, 2018.

Threats to the Energy Sector

Example: Severe Winter Weather

- In addition to increased prevalence and severity of catastrophic events, geographic range will expand
  - February 2021: Historic snowfall and ice across Texas, leaving millions without power and resulting in loss of life due to frigid conditions
  - In Winter 2017: Europe faced electricity load shortages after extreme cold that increased residential demand
- Mitigators:
  - Linking Texas's grid with others in the Midwest
  - Maintaining a diverse energy portfolio (e.g., in Europe)
  - Winterizing equipment to withstand freezing temperatures

Source: CBS, Dallas/Fort Worth, 2021.

An Oncor crew works to restore power after the winter storm in Texas. Source: Smiley N. Pool/Staff Photographer/Dallas Morning News

Threats to the Energy Sector

Example: Drought and Aridification in Africa

- Hydropower: Average of 17% of the electricity generation in Africa; over 80% in certain countries
- Southern and Eastern Africa expected to more than double hydropower capacity by 2030
  - Impacts to water availability → increased potential for blackouts and shortages
  - Example: Cape Town water shortages for drinking and power generation from 2015-2018
- Mitigators:
  - Soft Measures – Regulations for improved water resource management, incentivized reliance measures, use of models to predict changing weather and climatic conditions in planning, and financing new projects
  - Hard Measures – Increased reservoir capacity, sediment control, increased dam height

The Soubre hydroelectric dam in the Ivory Coast. Source: The Independent, August 30, 2018

Low water levels in Theewaterskloof Dam, South Africa. Source: University of Birmingham

Threats to the Energy Sector

Example: Monsoons and Typhoons in Asia

- Typhoons intensifying 12 to 15 percent in the past 40 years, which impact renewable and fossil fuel energy generation
  - Flooding/precipitation to increase 10% in some areas by 2030
- In India, monsoons impact energy generation and energy demand
  - Monsoon Season – High winds, heavy rainfall, lower temperatures → lower energy demand + lower solar energy generation, higher wind energy generation
  - Dry Season – Low wind, higher temperatures → high energy demand + higher solar, lower wind generation
- Mitigators:
  - Soft Measures: Use of models to predict changing weather and climatic conditions in planning supply/demand, incentives and regulations to improve management
  - Hard Measures: More diverse generation mix – power sources that track with demand to maintain supply/demand balance (renewables combined with other sources), dewatering pumps for hydropower, spillway gate inspections, use of batteries to store energy

Monsoon flooding in Bangladesh. Source: Phys.org, July 14, 2020.

Solar panels installed in Mumbai, India. Source: Getty Images.

Threats to the Energy Sector

Example: Landslides in Latin America

- Latin America closing the energy access gap, but facing new challenges due to climate change
  - Extreme storms, hurricanes, and heavier rainfall causing increased risk for landslides and flooding, which impact energy infrastructure such as power lines or hydroelectric sites
  - Other parts of Latin America facing drought, with other impacts to energy infrastructure such as water shortages for hydroelectric power generation
- Mitigators:
  - Soft Measures: Use of models to predict landslide/drought risk and identify at risk infrastructure
  - Hard Measures: More diverse energy source portfolio, including renewables

Colombia's US $4bn Ituango hydroelectric project was hit by two significant landslides in 2018. Source: bnamericas, May 28, 2018.

Landslides after Storm Eta in Guatemala. Source: The Guardian, November 7, 2020.

What does resilience look like?

- Flexibility to reallocate resources (staff, money, supplies)
- Preparation (via infrastructure and equipment, staffing, training, cash reserves, etc.) for catastrophic events and gradual changes over time
- Generation mix diversification, via source type and location
- Microgrids
- Underground distribution lines and strengthening of overhead lines
- Elevating substations

Portable flood-mitigation equipment surrounds a Duke Energy Corp. substation in North Carolina following Hurricane Florence. Duke Energy

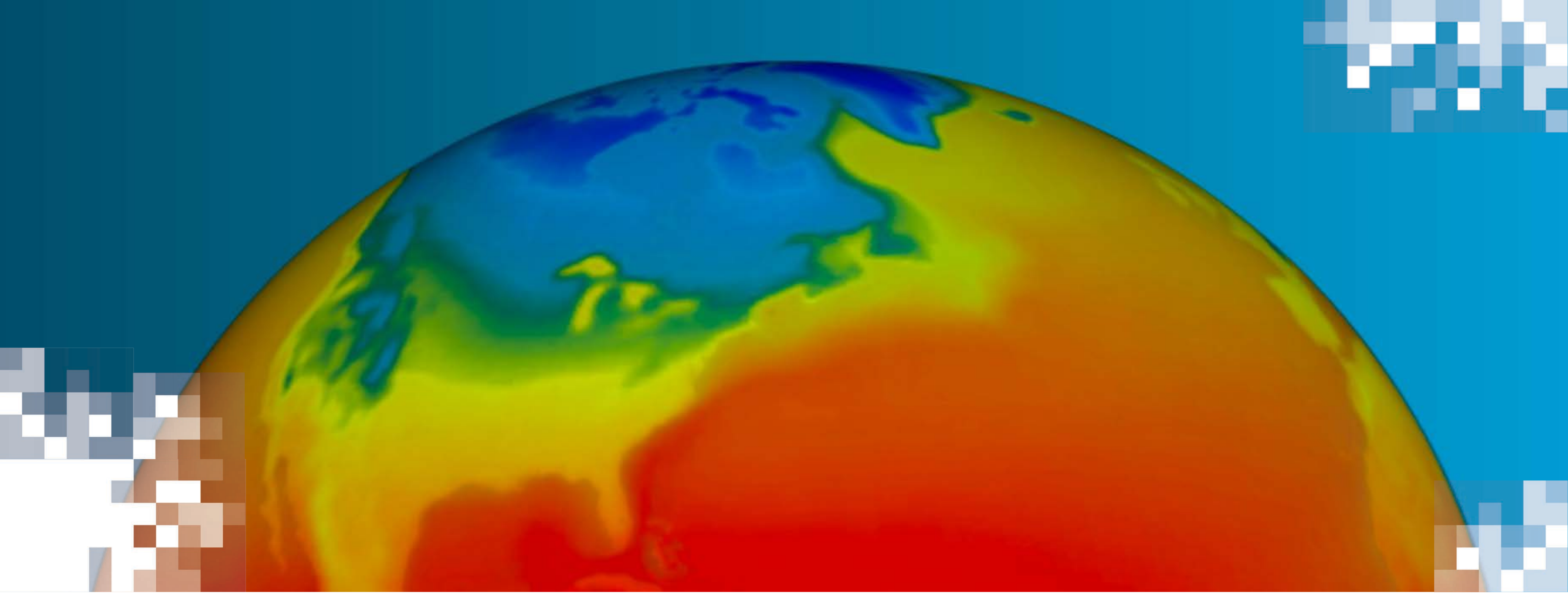
Entergy Corp. elevated a substation in Texas that was damaged during Hurricane Harvey. Entergy

Climate Resilience Efforts in the Energy Sector

- Grid Hardening
  - ConEd - $1 billion in storm hardening after Hurricane Sandy
  - Florida Power & Light (FPL) – Strengthened infrastructure after Hurricane Wilma in 2005
- Non-Wire Options
  - Changes in generation (FPL)
  - Batteries
  - Microgrids and distributed energy
  - Environmental management – wetlands
- Wildfire Mitigation
- Increased access to financing for green energy infrastructure
- ***Available, accessible, and actionable data to inform climate resiliency decision-making***

Hornsdale Wind Farm, AUS, Source: Consolidated Power Projects

AES Huntington Beach natural gas power plant. Photo by Paul Bersebach, Source: Orange County Register/SCNG



How can NASA Tools Promote Energy Resilience?
Illustrative Examples

Utilities' Use of Earth Observation Data

- **PG&E:** Measure land subsidence in service area
- **India Lights:** Nighttime lights (NTL via DMSP-OLS), rural electrification planning, historical data
- **Power Grid Company of Bangladesh:** Planning route of transmission line
- **Powerhive East Africa, Ltd.:** Microgrid site selection
- **India Central Electricity Authority:** Land use and geology information
- **Isagen Productive Energy:** Landscape restoration
- **Kenya Electricity Generating Company:** Geothermal hotspots
- **Central American Electrical Interconnection System:** Environmental impact and geotechnical studies
- **Energisa:** Vegetation management, weather conditions
- **Empresa de Transmisión Eléctrica S.A.:** Weather forecasting

Near-Real Time Wildfire Potential and Preventing Impacts on Energy Infrastructure and Provision of Services

- **Problem:**
  - Fire detection system to mitigate line faults (abnormal current)
- **Solution:**
  - Mobile fire alert system started in 2004 in South Africa
  - Data:
    - MODIS (NASA Aqua and Terra Satellites)
    - 1-hour latency, high spatial resolution, 4x daily
    - Can detect flaming and smoldering fires <1 sq. km
  - Spinning Enhanced Visible and Infrared Imager (SEVERI) sensor (Meteosat 2nd Gen)
    - Data every 15 minutes, poor spatial resolution
  - Ground-based data on infrastructure

Figure 1: A cane fire causes a flashover on an electricity transmission line in South Africa [photo courtesy of R. Evert, Eskom]

Near-Real Time Wildfire Potential and Preventing Impacts on Energy Infrastructure and Provision of Services

- **Solution:**
  - A fire notification sent via SMS to Eskom field supervisors
  - High credibility of the fire alerts, although a few misdetections were noted when fire detection algorithm was in its beginning stages
    - Sometimes fires were not detected – fire was too small, too cool, burned outside of MODIS' temporal window
  - MSG data was found to be more helpful, since temporal resolution was greater
    - Unique cases where fire was not detectable – cane fires that start in the early morning hours
  - Stakeholder Input – Eskom supervisors and landowners
- Benefit – EOs can be used to monitor wildfires in near-real-time

Example of a cell phone text message delivered in South Africa. Source: Davies et al., 2008

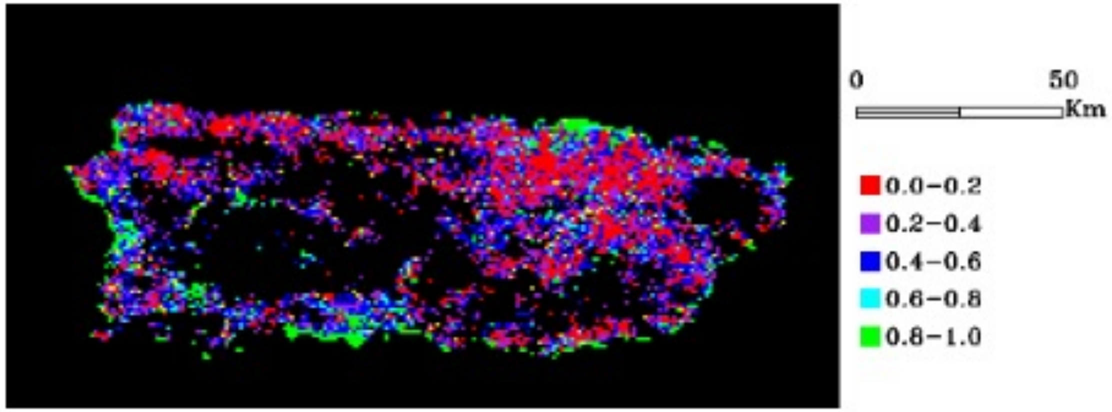
Satellite-Based Assessment of Electricity Restoration Efforts After Hurricane Maria

- **Problem:**
  - Need for timely and accurate monitoring of outages and power restoration in Puerto Rico (PR) after Hurricane Maria in 2017
- **Solution:**
  - Use of nighttime lights (NTL) data to monitor electricity restoration efforts
  - Data & Tools:
    - Black Marble NTL product, neighborhood-level imagery
    - Day/Night Band sensor of Visible Infrared Imaging Radiometer Suite (VIIRS), etc.
      - Extraneous light and biases minimized

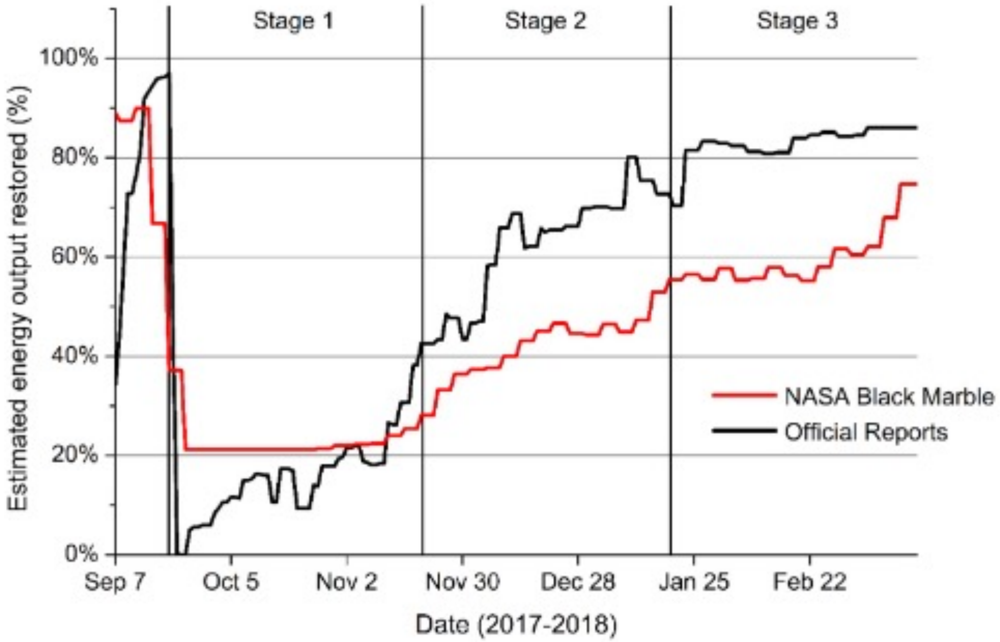
A man walks past destroyed homes in Catano, Puerto Rico, on Sept. 21, 2017. Hector Retamal / AFP - Getty Images file

Satellite-Based Assessment of Electricity Restoration Efforts After Hurricane Maria

- Observations from monitoring power restoration via Black Marble
  - 80% reduction in NTL after Hurricane Maria
  - In 90% of municipalities, PR followed the recovery protocol
  - Long duration outages (>120 days) occurred more frequently in rural areas
  - Differences in power restoration in the same urban areas, impacted by housing density, per recovery plan
- Post-Hurricane Recovery:
  - NTL tracked the timing of electricity restoration reported by state utility



The percent of normal NTL power outage spatial extent. The NTL on September 30 is used for post hurricane. Source: Román et al., 2019



Satellite-derived NTL products agree with official records of total electricity generation following Hurricane Maria in PR (R=0.839, SE=0.1601, P<0.0001. n=195 days. Source: Roman et al., 2019

Satellite-Based Assessment of Electricity Restoration Efforts After Hurricane Maria

- In addition to Black Marble standard product, high-definition (HD) product in the works
  - HD imagery will be viewable on Google Earth Engine, release date TBD
- Separate ARSET Training on Black Marble available here
- Benefit – Black Marble can be used to monitor power restoration over large area, complementing on-the-ground efforts

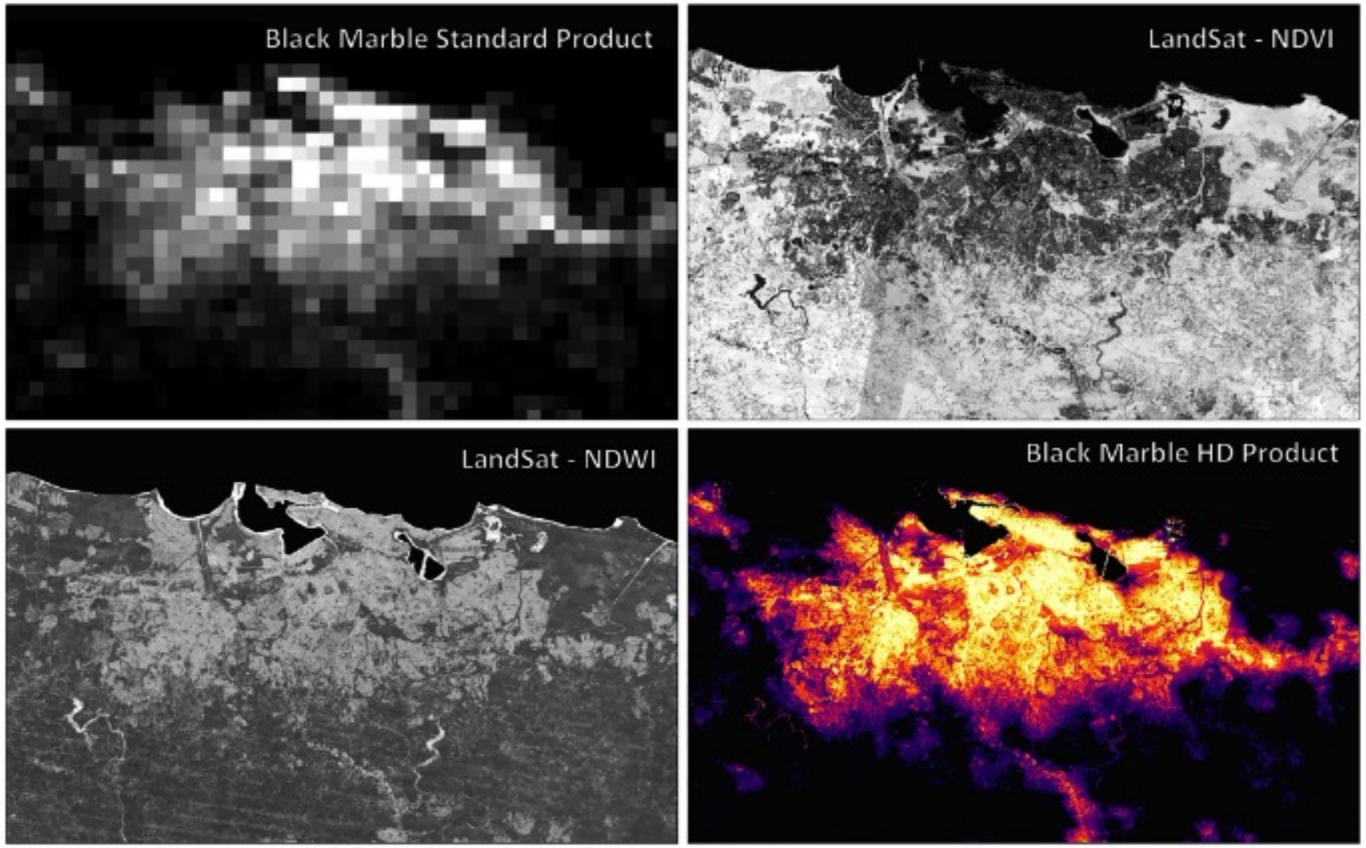


Fig 1. Data inputs for the production of the Black Marble HD Product to measure Puerto Rico neighborhood level electricity access. (Top right) 500m Black Marble VNP46 product (Top left) Landsat 8/Sentinel 2 NDVI (Bottom left) Landsat 8/ Sentinel 2 NDWI (Bottom right) Black Marble HD 30m Product.

Source: Roman et al., 2019

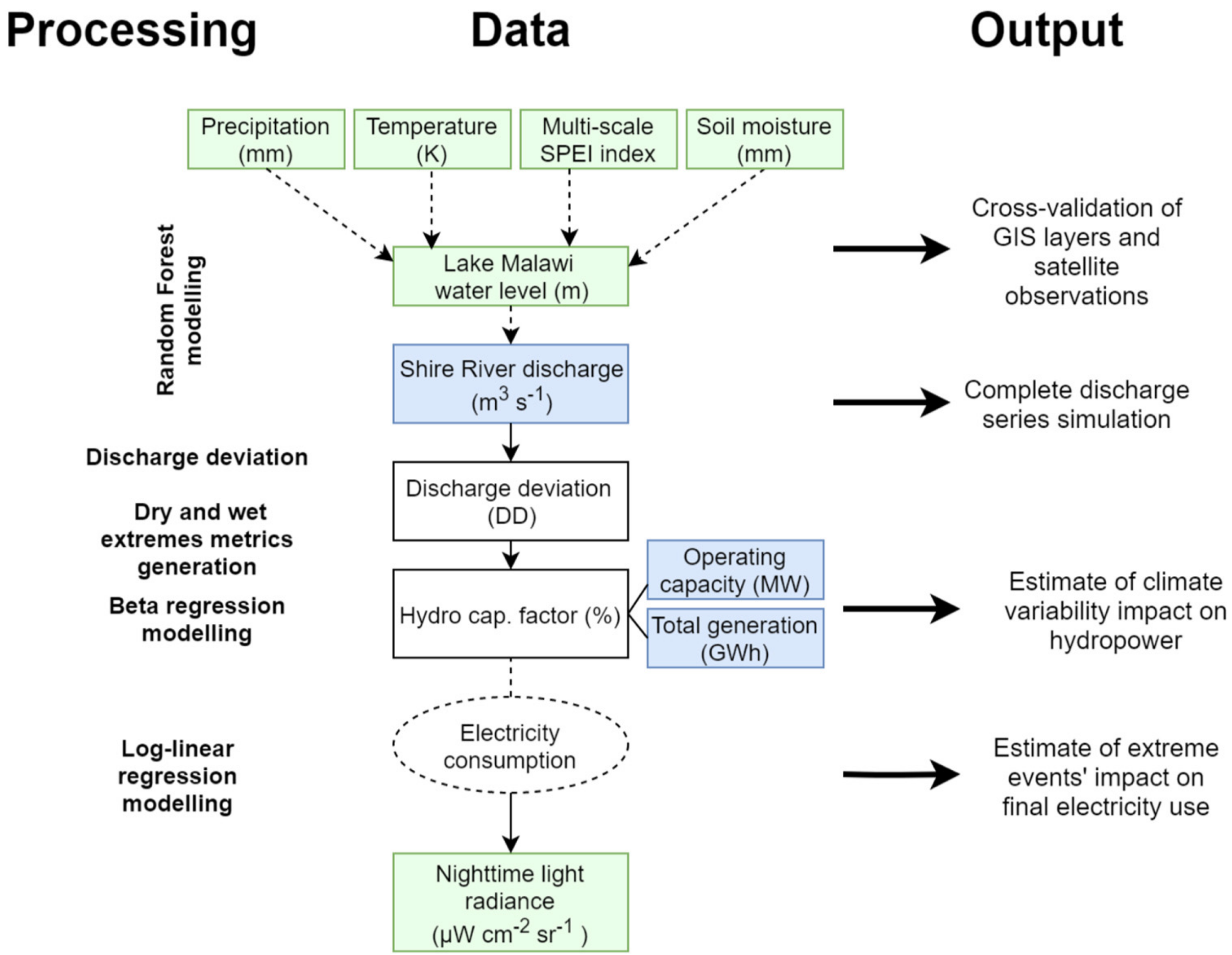
Hydropower Reliability Modelling in Malawi using Satellite Data and Machine Learning

- **Problem:**
  - Almost exclusive reliance on hydropower and hydro-climatic extremes (delay in the rainy season, drought, flooding) lead to brownouts, blackouts, and load shedding
- **Solution:**
  - Energy-climate-water framework that includes remote sensing data, field observations, and machine learning
  - Model to understand dry/wet extremes impact on electricity use
  - Use of machine learning and satellite imagery to fill data gaps
  - Data (accessed via Google Earth Engine):
    - TOPEX/POSEIDON
    - OSTM/Jason, VIIRS, MODIS, TMPA, AMSR-E
    - Nighttime lights (NTL)

Map of hydropower resources in Malawi.
Source: Falchetta et al., 2020

Hydropower Reliability Modelling in Malawi using Satellite Data and Machine Learning

Green shading denotes remotely-sensed or geo-processed openly-available and regularly updated datasets; blue shading denotes field gauge variables, which are used to validate the model; white shading refers to variables calculated through a combination of the data input sources; dashed arrows denote a simulation process carried out to fill gaps in the time series, while dashed boxes represent unobserved, proxied variables.

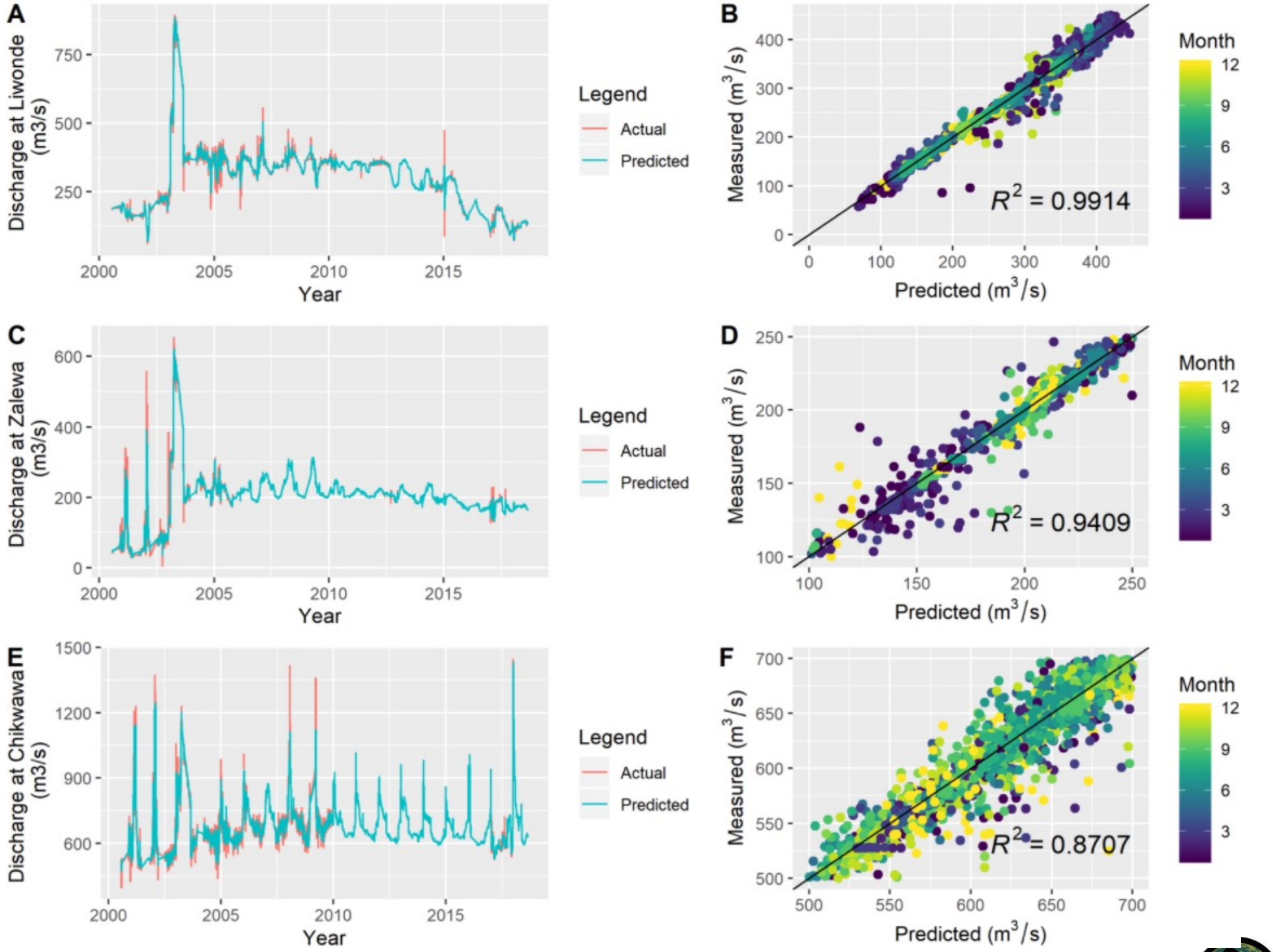


Falchetta, G., Kasamba, C., & Parkinson, S. C. (2020). Monitoring hydropower reliability in Malawi with satellite data and machine learning. Environmental Research Letters, 15(1).

[R code for processing the workflow is available here.]

Hydropower Reliability Modelling in Malawi using Satellite Data and Machine Learning

- Notable findings from the model:
  - Satellite data had almost full explanatory power of water level in Lake Malawi
  - Dry extremes found to reduce NTL in urban areas by 31%, and up to 150% in some areas of Malawi
    - Hydropower capacity factor reduced by 9.4% during dry extremes
    - Wet extremes not associated with a reduction in NTL
- Benefit – Modelling and EOs can be used to accurately fill gaps in data

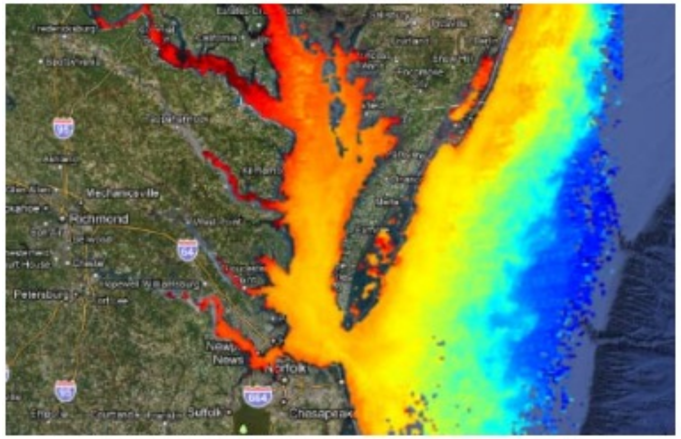


Comparison and statistical evaluation of modelled and gauged discharge at Liwonde (a), (b), Matope (c), (d), and Chikwawa (e), (f). Left hand side panels: time-series representation. Right hand side panels: scatter-plot and R^2 results from the random forests regression analysis. Source: Falchetta et al., 2020

Future Trends in EOs for Energy Management

- Open, easier data access and greater interoperability
- Hyperspectral imagery
- Machine learning/AI
- Increase in private EO satellites and services
  - Drones in data collection
- Use of EOs to monitor green energy/renewables
  - Decreasing impact of energy sector on climate change

Source: Igor Ivanov, AgFunder, 2017

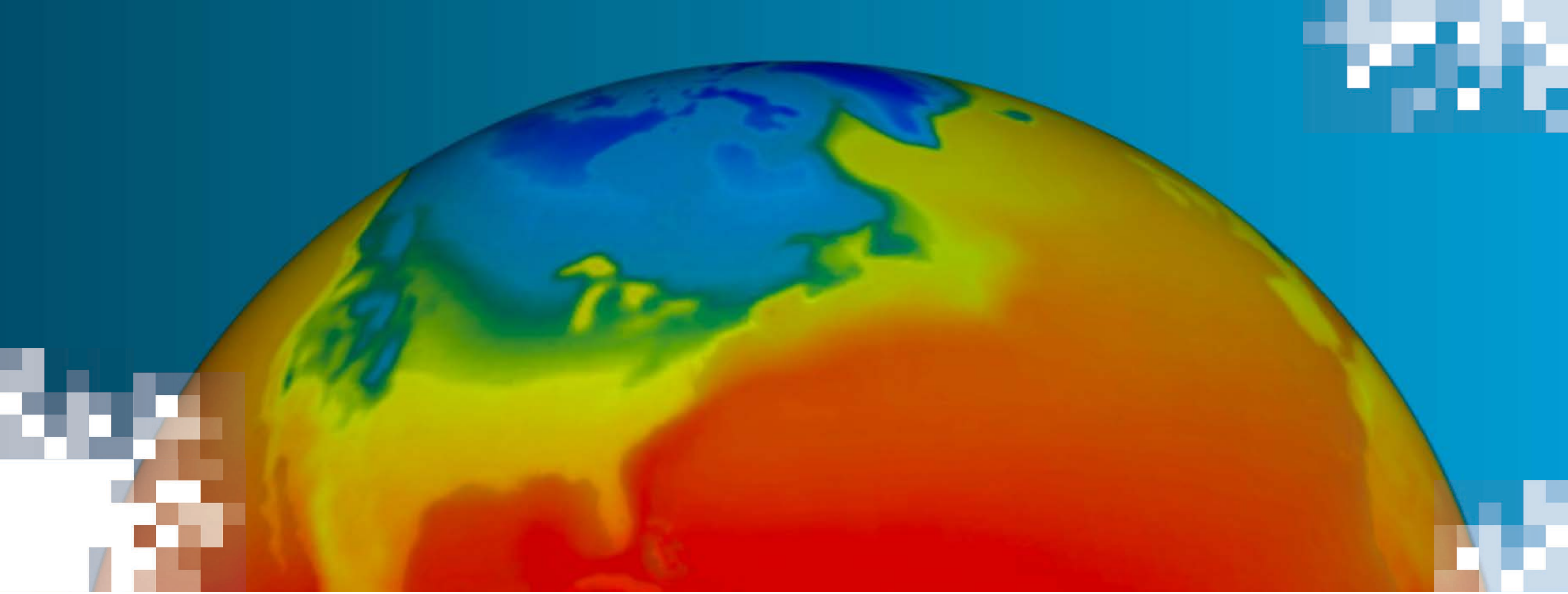


Hyperspectral Imagery of U.S. East Coast (by NOAA)

Courtesy of Brandi Jewett, Grand Forks Herald

Data Gaps and Limitations for Energy Management Decision-Making

- More real time data and forecast modelling needed
  - Ideally, models going out 100 years
- Tools that predict risk (fire, debris flow)
- Finer resolution, lower latency, higher frequency
- Products for vegetation management (tree health, dead trees, encroachment)
- For data that is not open-source, cost may be prohibitive
  - Creating algorithms takes resources within utility or via third-party servicer
- Tutorials to incorporate NASA EOs into utility models or decision-making for energy management or resilience



Closing

Summary

- Need for resilient energy infrastructure and planning will increase as climate changes
  - Electrical grid should be adapted to gradual changes in climate, as well as severe weather events
- Vulnerabilities of the energy sector include lack of cooling water, staffing shortages, aging infrastructure, and more
- Many ways a utility can prepare themselves for extreme conditions, including elevating substations, storm hardening, and generation diversification
- Researchers and utilities have used NASA data to understand how to make the electricity supply more reliable/less prone to outages

Contact Information and Further Resources

- Battelle Study Team
  - Natasha Sadoff, Amy Leibrand, Meredith Fritz, Tanya Maslak
  - sadoffn@battelle.org

- ARSET
  - Ana Prados and Brock Blevins
  - aprados@umbc.edu, brock.blevins@nasa.gov

- StoryMap with NASA resources for energy utilities

- Electric Power Research Institute (EPRI)
  - Eyes in the Sky: Satellite Remote Sensing and Data Analytics for Electric Utilities

Case Study References

- Davies, D. K., Vosloo, H. F., Vannan, S. S., & Frost, P. E. (2008, February). Near real-time fire alert system in South Africa: from desktop to mobile service. In *Proceedings of the 7th ACM conference on designing interactive systems* (pp. 315-322).
- Falchetta, G., Kasamba, C., & Parkinson, S. C. (2020). Monitoring hydropower reliability in Malawi with satellite data and machine learning. *Environmental Research Letters*, *15*(1), 014011.
- Román, M. O., Stokes, E. C., Shrestha, R., Wang, Z., Schultz, L., Carlo, E. A. S., ... & Enenkel, M. (2019). Satellite-based assessment of electricity restoration efforts in Puerto Rico after Hurricane Maria. *PloS one*, *14*(6), e0218883.
- Wang, Z., Román, M. O., Sun, Q., Molthan, A. L., Schultz, L. A., & Kalb, V. L. (2018). Monitoring disaster-related power outages using NASA black marble nighttime light product. *ISPRS Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci*, 1853-1856.

Other References

- In the Wake of the Great Winter Storm, How Can Texas Create a More Resilient Power Grid?
  - https://news.utexas.edu/2021/03/12/in-the-wake-of-the-great-winter-storm-how-can-texas-create-a-more-resilient-power-grid/
- Texas Winter Storm: What to Know
  - https://www.nytimes.com/2021/02/20/us/texas-winter-storm-explainer.html
- 'We know this is hard': 1.7 million homes remain dark as ERCOT continues to restore power
  - https://www.dallasnews.com/news/weather/2021/02/17/widespread-power-outages-continue-as-north-texans-endure-second-winter-storm-warming/
- Entire State Of Texas Under Winter Storm Warning, Federal Emergency Declaration Approved
  - https://dfw.cbslocal.com/2021/02/14/entire-state-of-texas-under-winter-storm-warning/
- How Wildfires Have Sparked Change In The Power Industry
  - https://theonebrief.com/how-wildfires-have-sparked-change-in-the-power-industry/
- Out of Control: The Impact of Wildfires on our Power Sector and the Environment
  - https://www.energypolicy.columbia.edu/research/testimony/out-control-impact-wildfires-our-power-sector-and-environment
- Power Sector Resilience Guidebook
  - https://www.nrel.gov/docs/fy19osti/73489.pdf
- Hornsdale Wind Farm Battery Energy Storage System
  - http://www.conpower.com.au/our-projects/hornsdale-wind-farm-battery-energy-storage-system
- Coastal power plants get dramatic upgrades, but how do they fit with California's renewable energy future?
  - https://www.ocregister.com/2018/12/06/coastal-power-plants-get-dramatic-upgrades-but-how-do-they-fit-with-californias-renewable-energy-future/

Other References

- Pacific Gas and Electric Company Climate Change Vulnerability Assessment and Resilience Strategies
  - https://www.pgecurrents.com/wp-content/uploads/2016/12/PGE_climate_resilience_report.pdf
- Texas Musicians on How They're Making It Through the Deep Freeze
  - https://www.rollingstone.com/music/music-country/texas-musicians-winter-storm-freeze-power-1130593/
- California wildfires have burned an area almost the size of Connecticut
  - https://www.cnn.com/2020/09/14/us/california-wildfires-monday/index.html
- Soaked substations trip up post-hurricane power restoration
  - https://www.eenews.net/stories/1060100456
- Regulations and standards: What it takes for utility vegetation managers to comply with state, county and municipal laws
  - https://www.tdworld.com/vegetation-management/regulations-standards
- Raytheon will Build NASA's First GEO Hyperspectral Imager
  - https://www.satellitetoday.com/imagery-and-sensing/2019/08/26/raytheon-will-build-nasas-first-geo-hyperspectral-imager/
- Workshop explores potential of machine learning for Earth observation and prediction
  - https://www.ecmwf.int/en/about/media-centre/news/2020/workshop-explores-potential-machine-learning-earth-observation-and
- Remote Sensing Market Map: 20 Remote Sensing Startups and the Varied Data That Fuels Them
  - https://agfundernews.com/remote-sensing-market-map.html
- Why, and how, utilities should start to manage climate-change risk
  - https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/why-and-how-utilities-should-start-to-manage-climate-change-risk#

Questions?

Thank You!