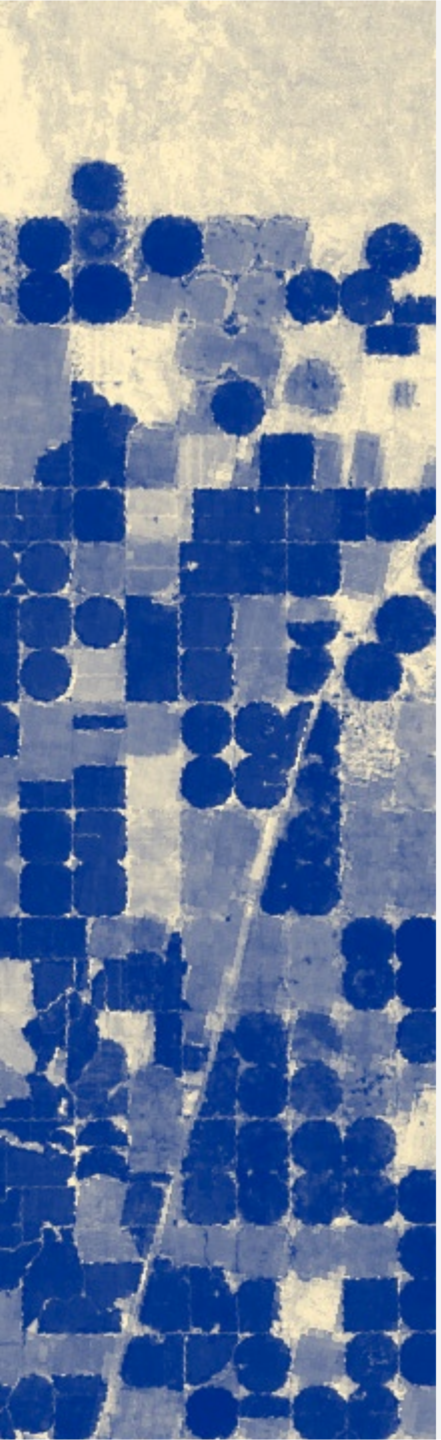


National Aeronautics and
Space Administration

ARSET
Applied Remote Sensing Training
http://arset.gsfc.nasa.gov
@NASAARSET

Applications of Remote Sensing to Soil Moisture and Evapotranspiration

Speakers:
Erika Podest
Amita Mehta

Course Structure

- One session per week on September 1, 8, 15, 22, 29
  - 11:30 a.m. – 12:30 p.m. EDT (UTC-4)
  - 6:00 p.m. – 7:00 p.m. EDT (UTC-4)

- Homework Assignments
  - Given on Sept 15 and 29
  - Both due by October 31, 2016

- Q&A following each session, or by email to:
  - Erika Podest: erika.podest@jpl.nasa.gov
  - Amita Mehta: amita.v.mehta@nasa.gov

Homework and Certificate

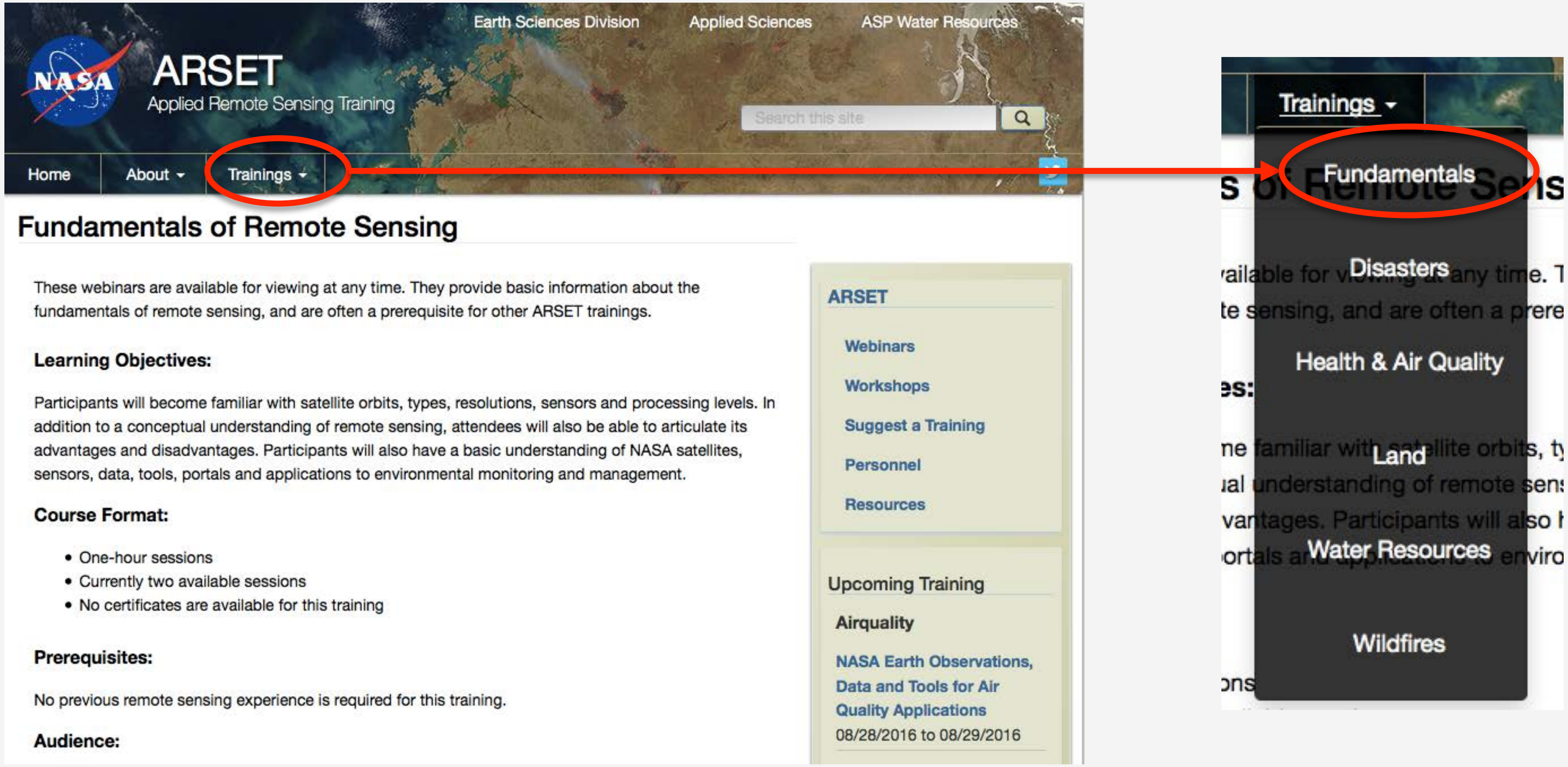
- Homework
  - Submit answers to homework questions via Google Form
  - Will be available at http://arset.gsfc.nasa.gov/water/webinars/apps-et-smap

- Certificate of Completion
  - Attend all 5 webinar sessions
  - Complete both homework assignments by due date
  - Certificates will be emailed approx. 2 months after the course finishes by Marines Martins (marines.martins@ssaihq.com)

Prerequisite

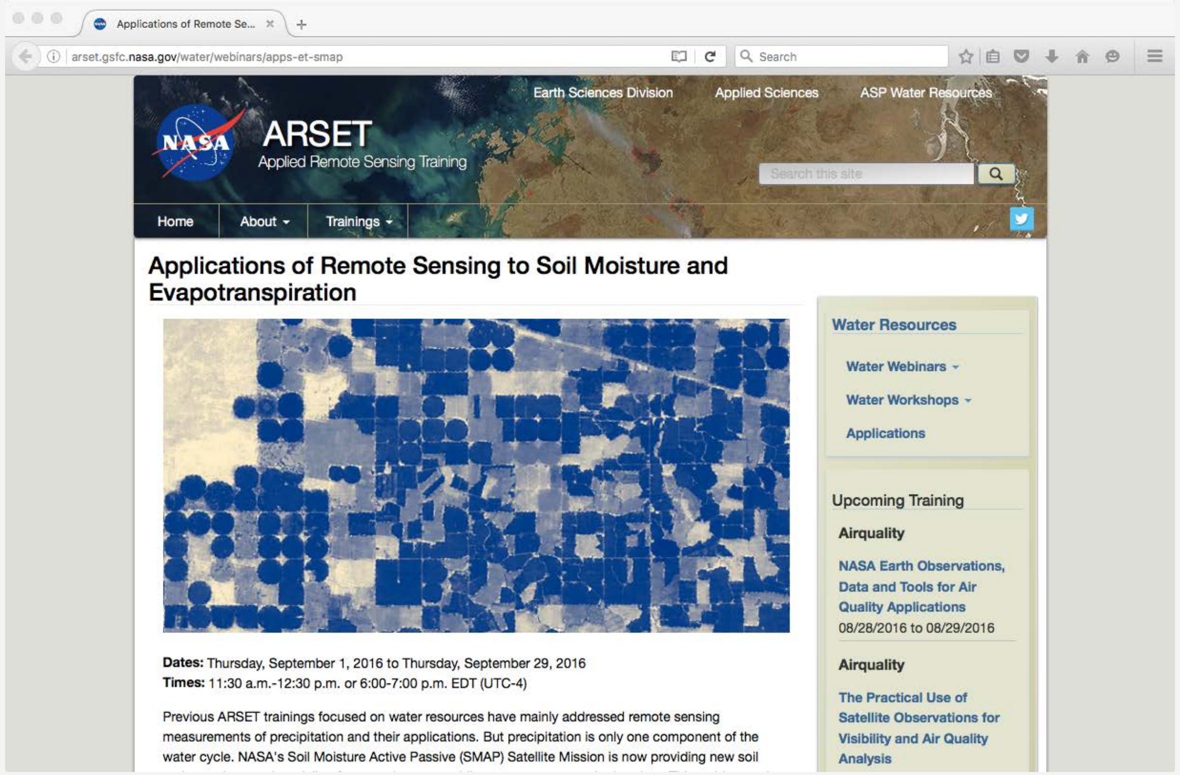
Fundamentals of Remote Sensing

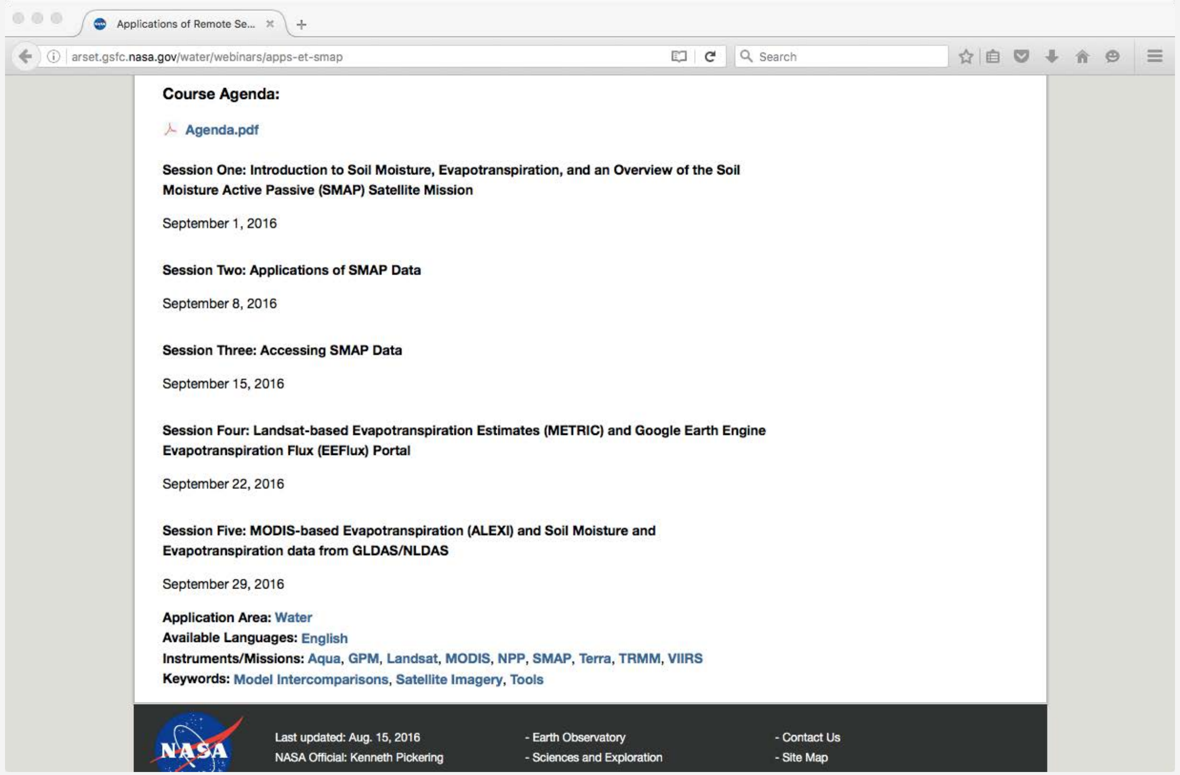
http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing/



Course Material

http://arset.gsfc.nasa.gov/water/webinars/apps-et-smap





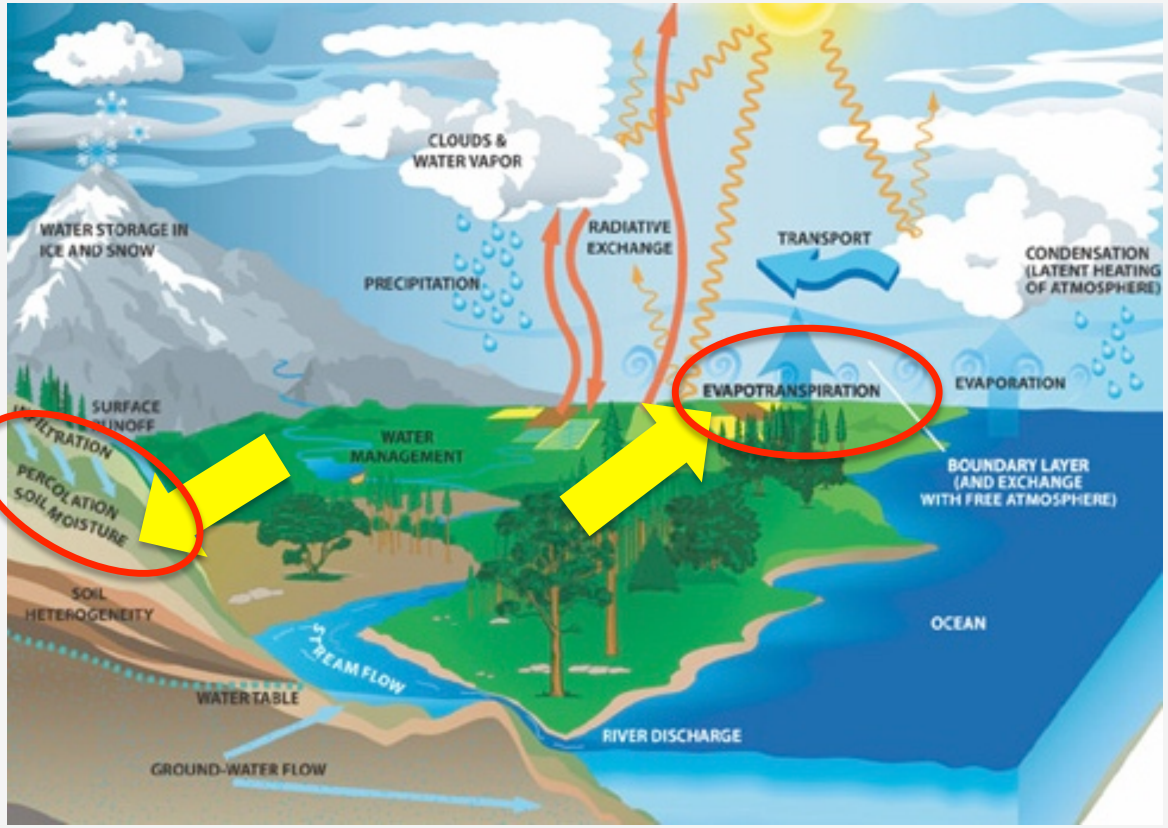
Course Objectives

- Learn about NASA Earth observation resources (data and tools) available for water resource applications, including:
  - how evapotranspiration and soil moisture are included in the water cycle
  - how to access and visualize these data products
- Become familiar with soil moisture and evapotranspiration data applications

* Image Credit: http://smap.jpl.nasa.gov/science/applications/

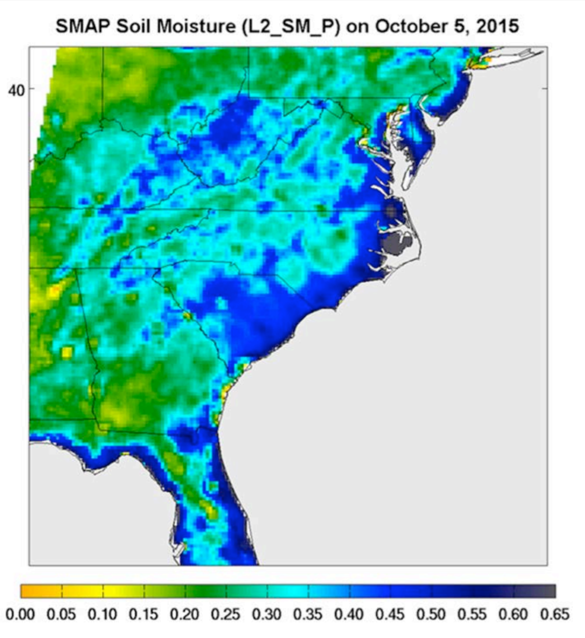
The Water Cycle

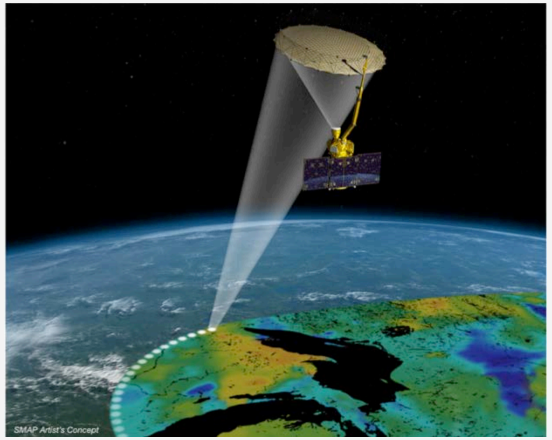
- For sustainable water management, it is critical to have accurate estimates of water cycle components
- Soil moisture (SM) and evapotranspiration (ET) are major components of global and regional fresh water budgets
- SM & ET data have applications in:
  - Water resources management
  - Flood and drought monitoring and management
  - Agriculture

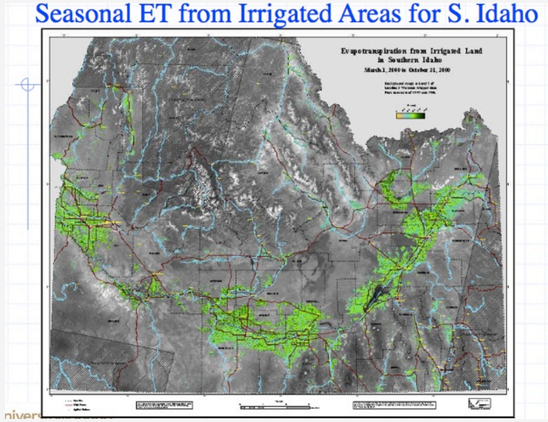


Course Outline

- **Week 1:** Intro to Soil Moisture, Evapotranspiration (ET), and an Overview of the Soil Moisture Active Passive (SMAP) Mission
- **Week 2:** Applications of SMAP Data
- **Week 3:** Accessing SMAP Data
- **Week 4:** Landsat-Based ET Estimates and Access via Google Earth Engine ET Flux (EEEFlux) Portal
- **Week 5:** MODIS-Based ET Applications and Soil Moisture and ET Data from GLDAS/NLDAS







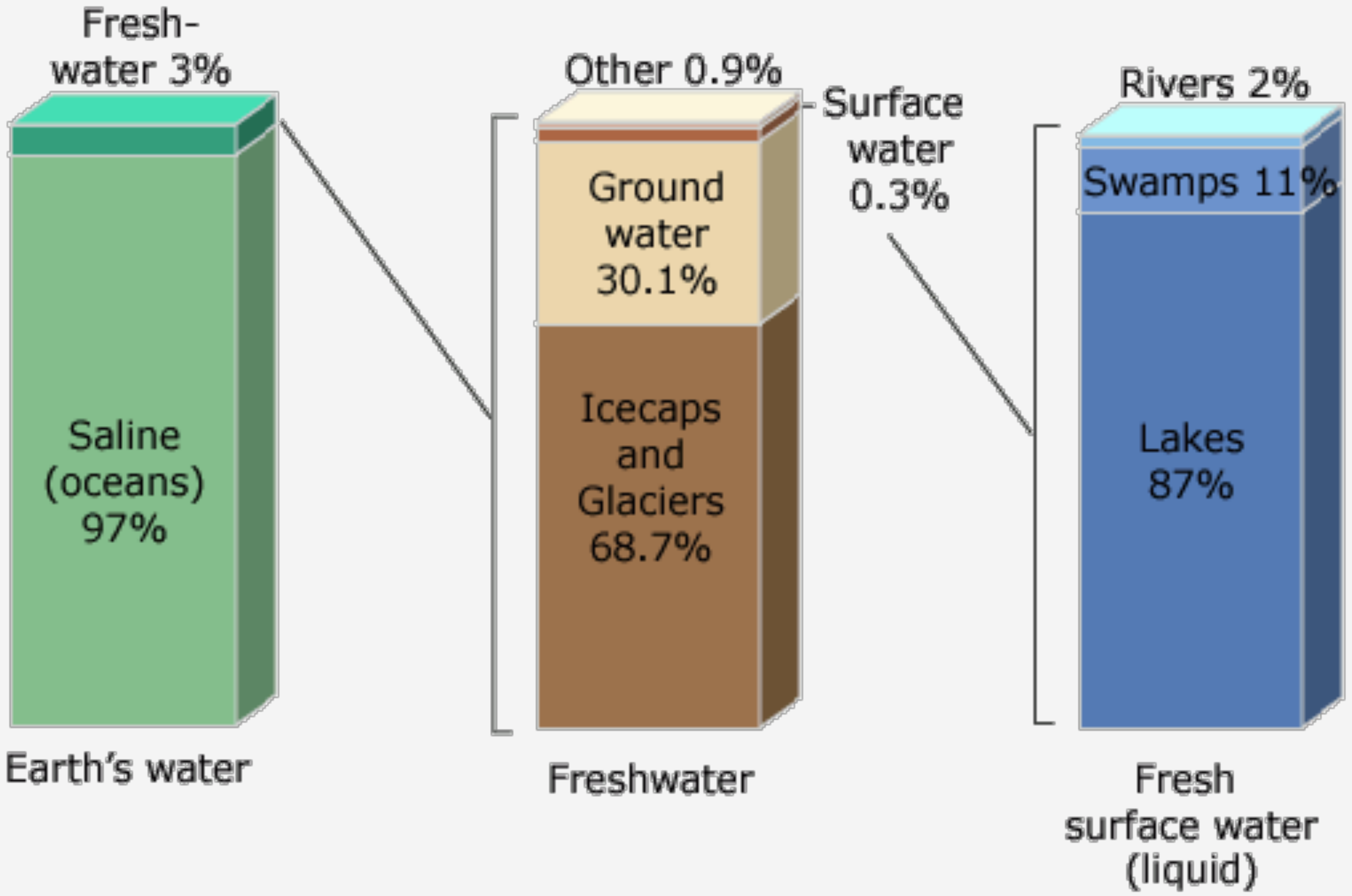
* Image Credits:
Left: JPL; Top Right: JPL; Bottom Right: California Department of Water Resources

Agenda: Week 1

- SMAP
  - Overview of SMAP
  - SMAP Products
- Evapotranspiration
  - Overview of Evapotranspiration
  - Methods of Estimating ET Based on Remote Sensing
  - ET Data Products Based on Remote Sensing

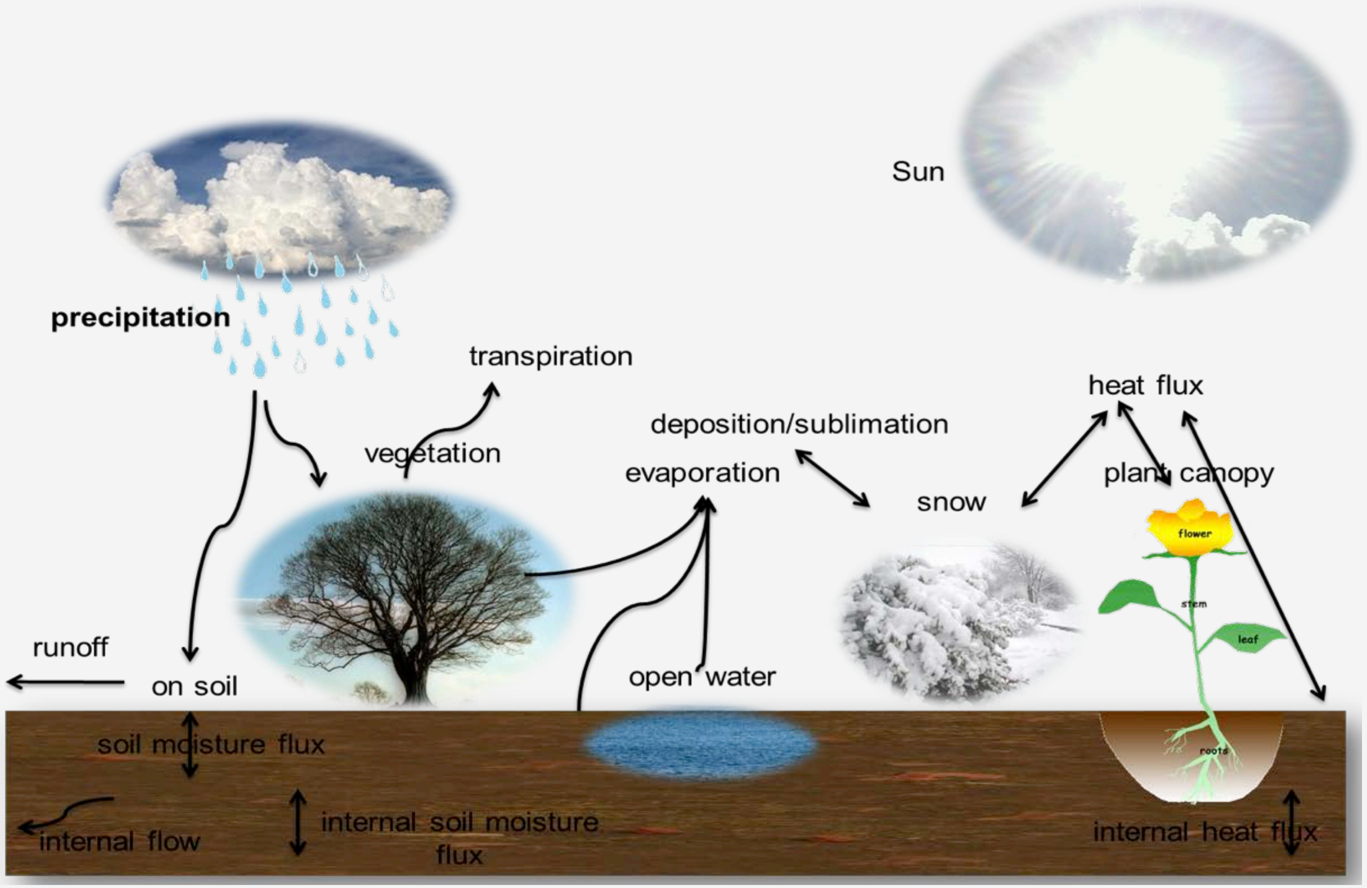
Overview of SMAP

Water Distribution on Earth



Importance of Soil Moisture

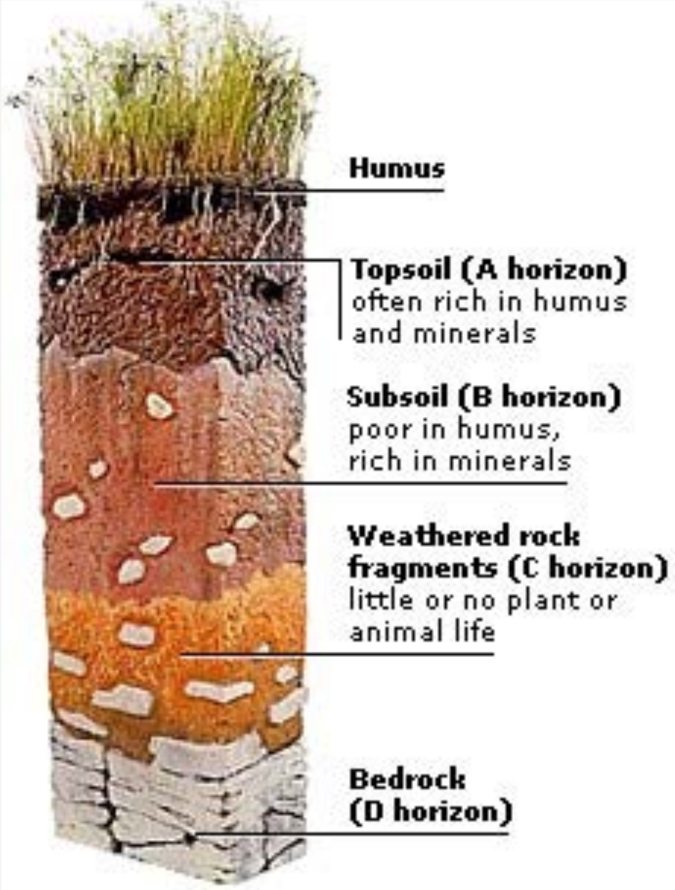
- For each kilogram of water on earth, only 1 milligram is stored as soil moisture
- Soil moisture exerts significant control over:
  - Hydrological Processes
  - Ecological Processes
  - Meteorological Processes

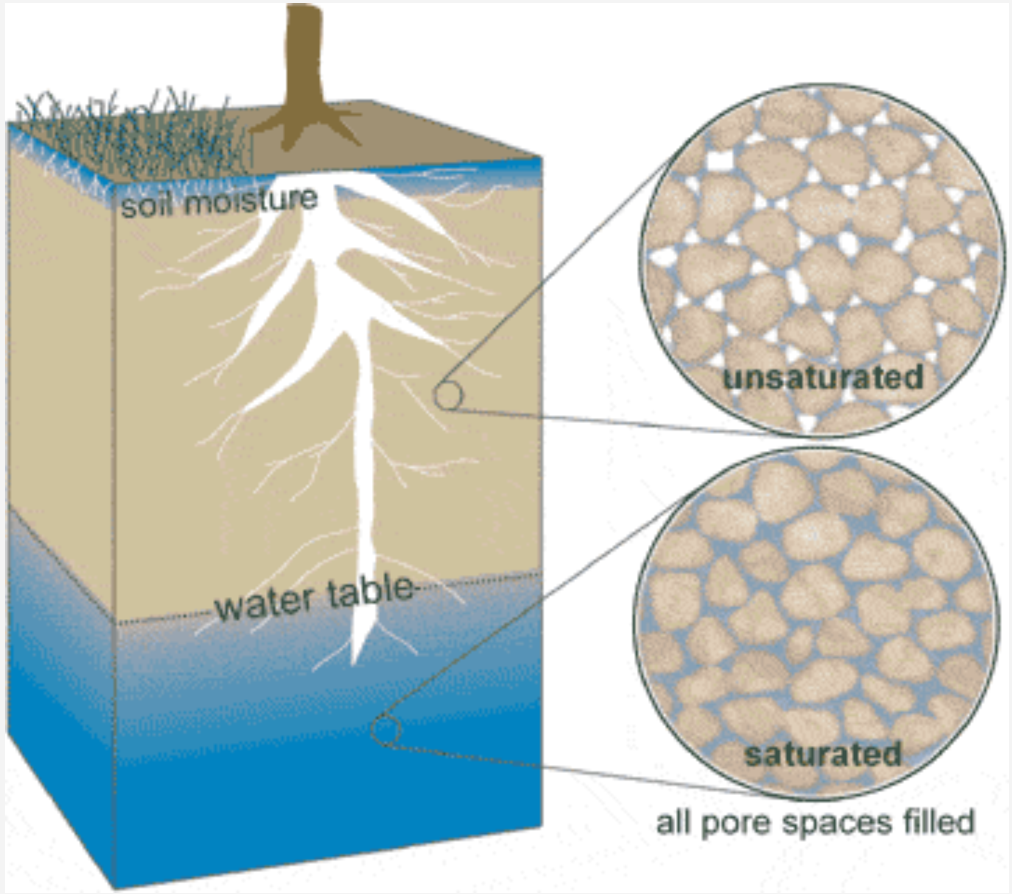


* Source: Pachepsky, Y., Radcliffe, D. E., & Selim, H. M. (2003). *Scaling methods in soil physics*. Boca Raton, FL: CRC Press.

* Image Credit: Chen et. Al. 1996, 1997; Chen and Dudhia, 2001; Ek et. Al. 2003; Koren et. Al. 1999

Soil Profile



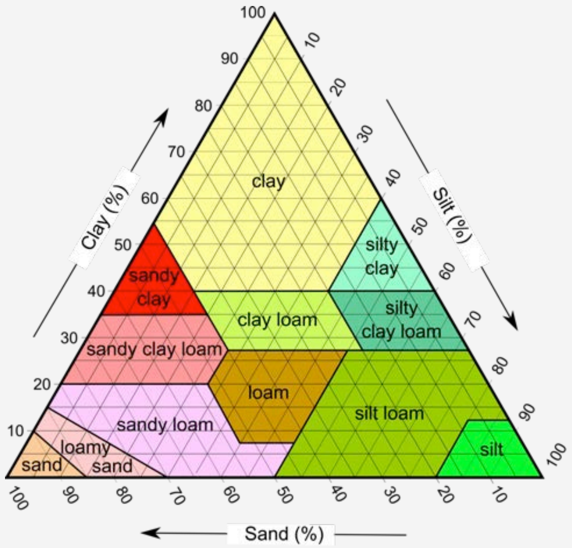


Factors Influencing Soil Moisture

- Soil moisture varies with space and time
- Primary factors that influence distribution of soil moisture:

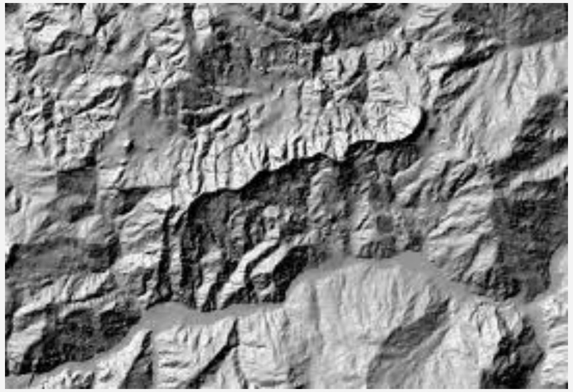
Rainfall

Soil Texture



Vegetation

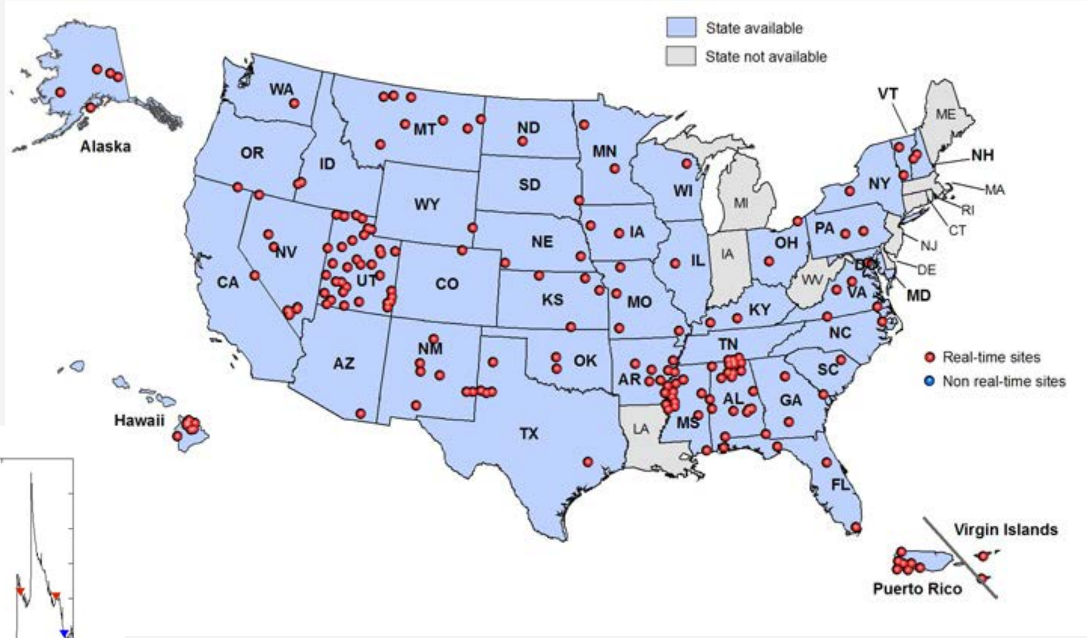
Topography

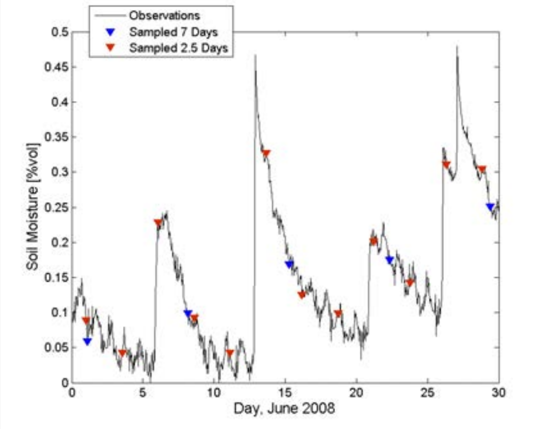


Why Measure From Space?

SMAP provides a capability for global observations of soil moisture and its frozen or thawed state with high spatial resolution and frequent temporal revisits

- Current ground measurements of soil moisture are sparse and have limited coverage
- Previous space missions have relatively low soil moisture accuracy, resolution, & coverage
- **SMAP provides**
  - 10-40 km spatial resolution
  - 3 day global revisit
  - Accuracy of $0.04 m^3/m^3$





Inter-Storm Soil Moisture Dry-Down

Average inter-storm period implies 3 day sampling or better is required to resolve SM variability

Source: Sun et. al, 2006, How often does it rain? *J. Climate,* **19**

Applications in Soil Moisture

Enhanced weather & climate forecasting

Flood monitoring and prediction

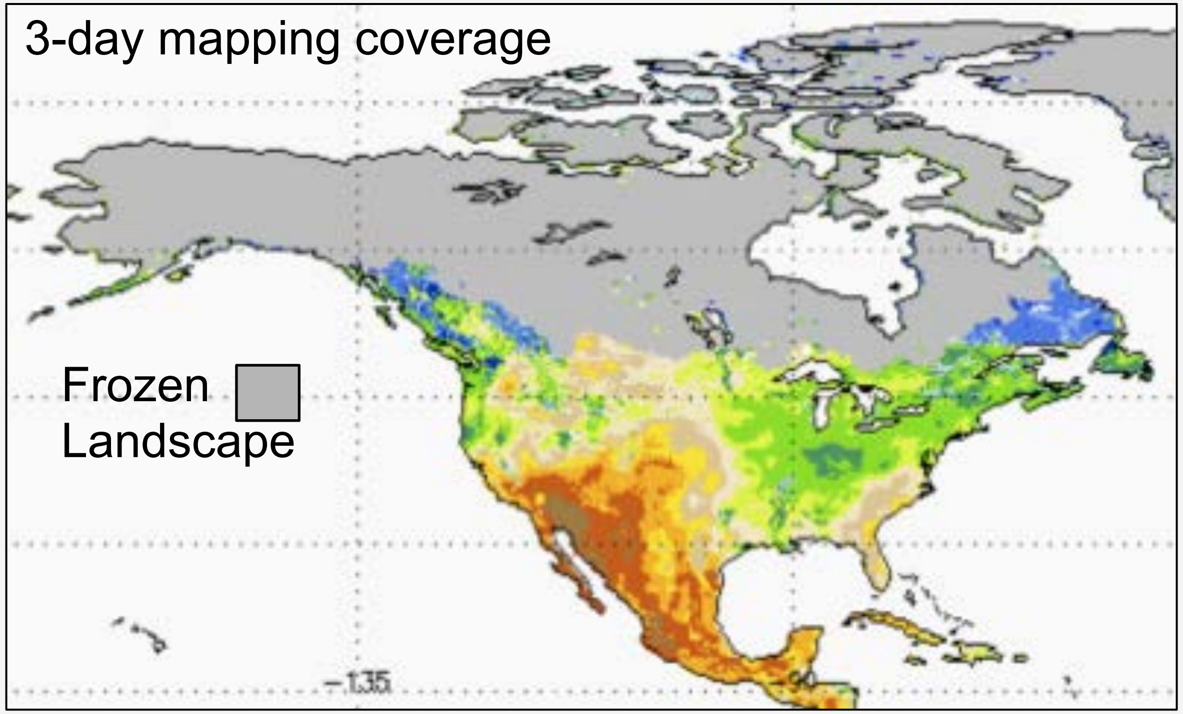
Improved agricultural productivity and crop yield predictions

Human health and vector borne diseases

Drought monitoring and early warning

Primary Objectives of SMAP

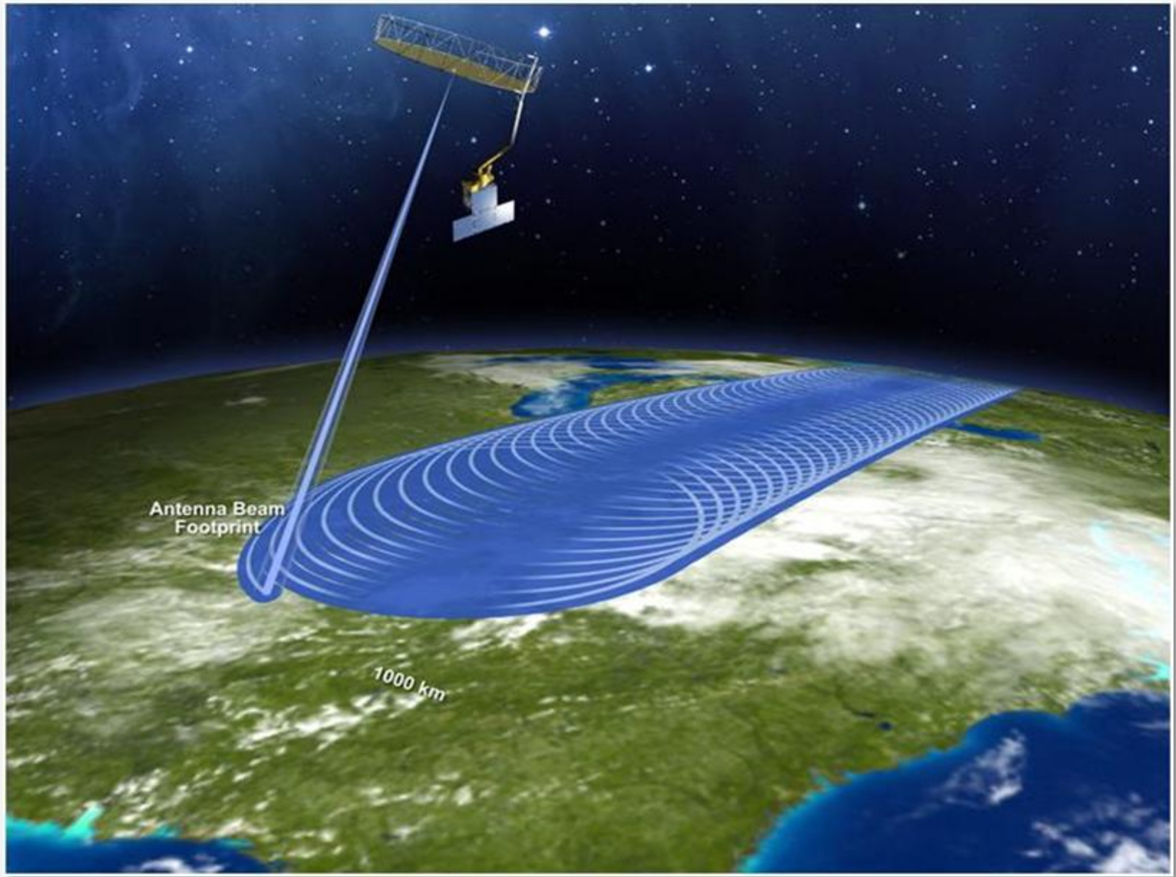
- Measure the moisture in the top 5 cm of the soil globally every 3 days



- SMAP supported science and applications
  - Understand processes that link the terrestrial energy, water, and carbon cycles
  - Estimate global water and energy terrestrial fluxes
  - Quantify net carbon fluxes in the northern high latitudes

SMAP Overview

Instruments



Launched Jan 31, 2015

Radar (no longer working)

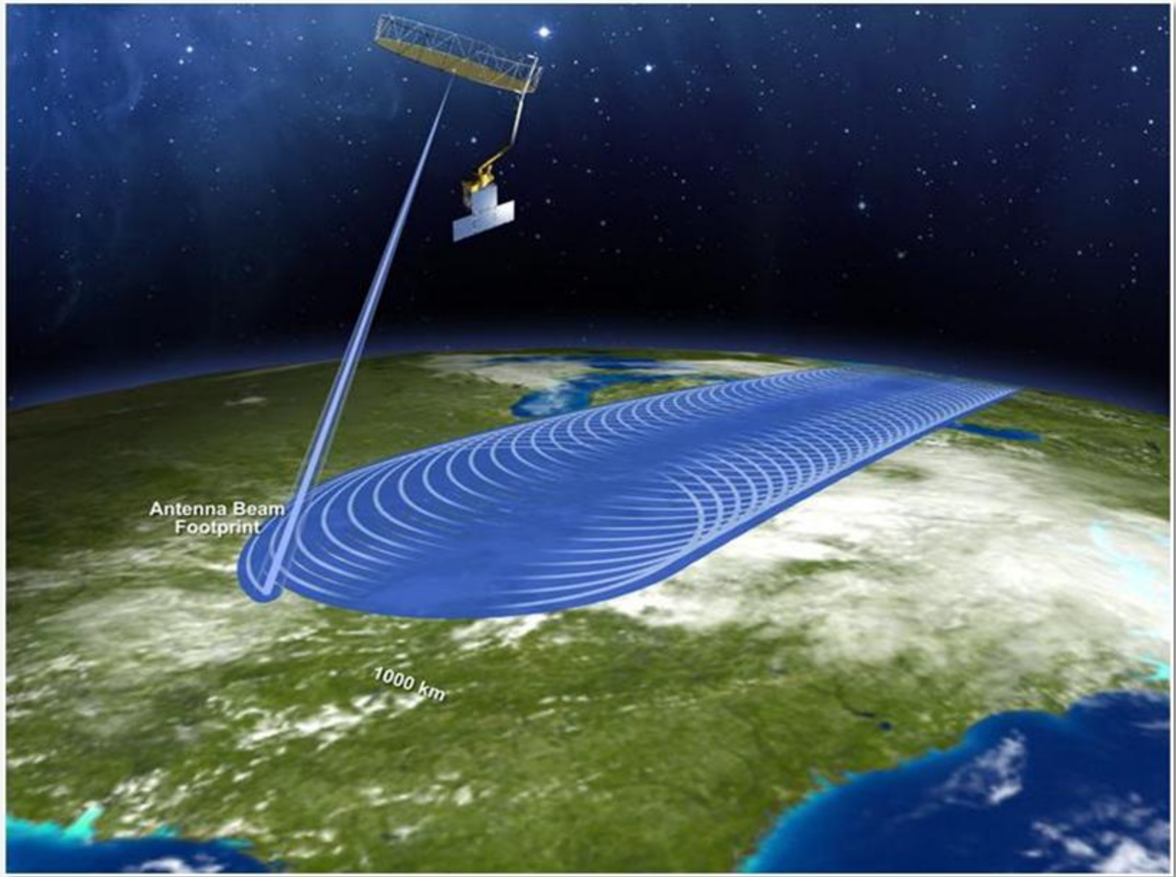
- Frequency: 1.26 GHz
- Polarization: VV, HH, HV
- Resolution: 3km
- Relative Accuracy: 1.0 dB (HH and VV), 1.5 dB (HV)

Radiometer

- Frequency: 1.41 GHz
- Polarization: H, V, 3rd & 4th Stokes
- Resolution: 40km
- Relative Accuracy: 1.3K

SMAP Overview

Instruments



Shared Antenna

- 6 m diameter
- Conical scanning at 14.6 r.p.m.
- Constant incidence angle: 40 deg
- Swath: 1,000 km wide
- Swath and orbit allow global coverage every 2-3 days

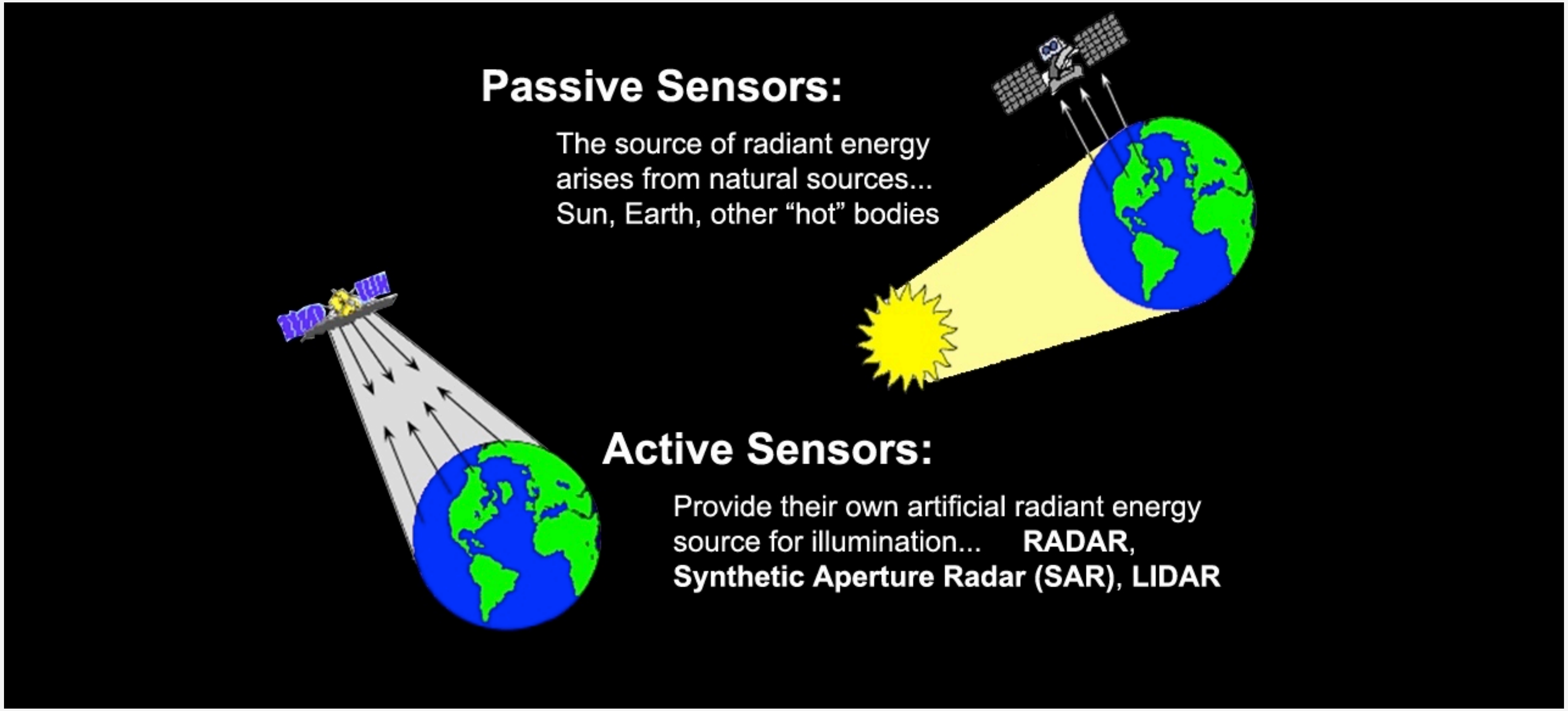
Orbit

- Sun synchronous, 6 am/pm orbit
- 685 km altitude

Mission Duration: 3 yrs

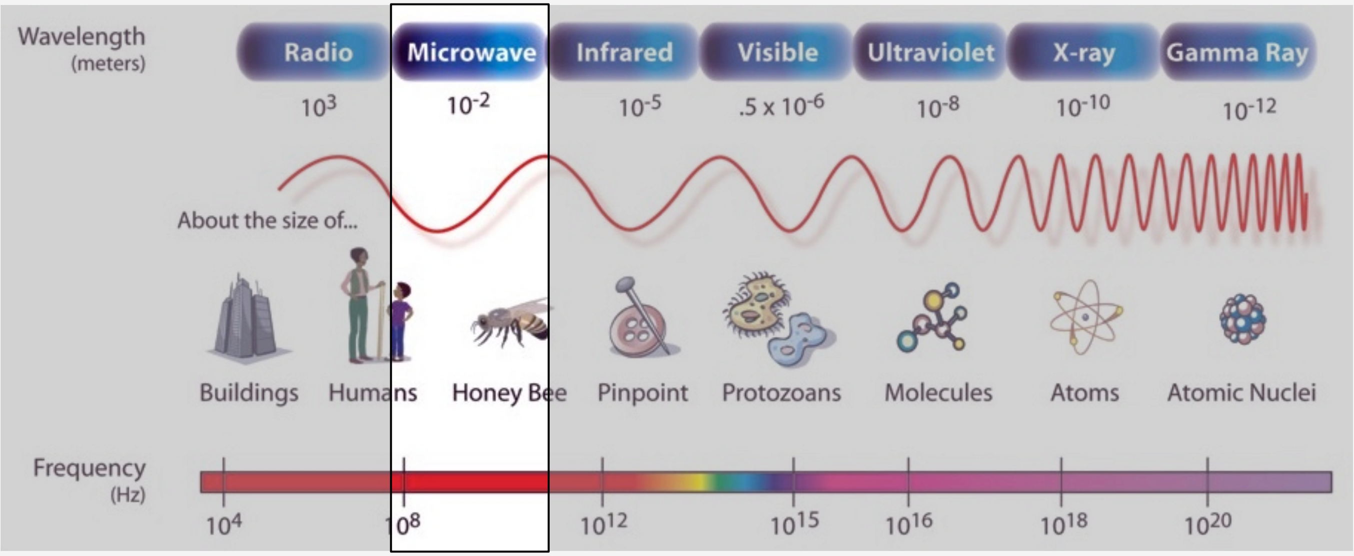
Passive and Active Remote Sensing

SMAP uses active and passive sensors to measure soil moisture



Microwave Remote Sensing

- Soil is masked by clouds and vegetation for visible and infrared sensors
- Optical sensors operate by measuring scattered sunlight and are “daytime only”
- Microwaves can penetrate through clouds and vegetation, operate day and night, and are highly sensitive to the water in the soil due to the change in the soil microwave dielectric properties

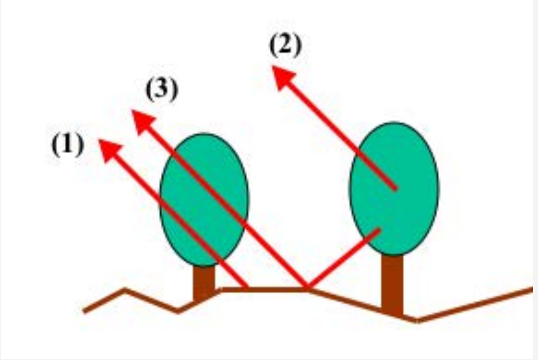


Measurement Approach

- p = H, V (radiometer)
- pq = VV, HH, HV (radar)
- Contributions from: soil, vegetation, and soil-vegetation interaction
- Soil moisture is the dominant contributor to the signal
- Soil moisture measurements are corrected for the effects of vegetation, surface roughness and temperature

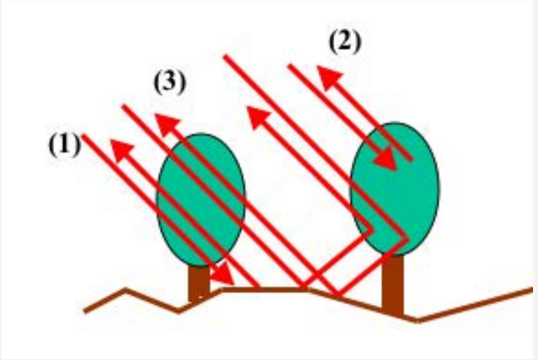
Emission

$$T^{t}_{Bp} = T^{s}_{Bp} L_p + T^{v}_{Bp} + T^{sv}_{Bp}$$



Backscatter

$$\sigma^{t}_{pq} = \sigma^{s}_{pq} L^{2}_{pq} + \sigma^{v}_{pq} + \sigma^{sv}_{pq}$$



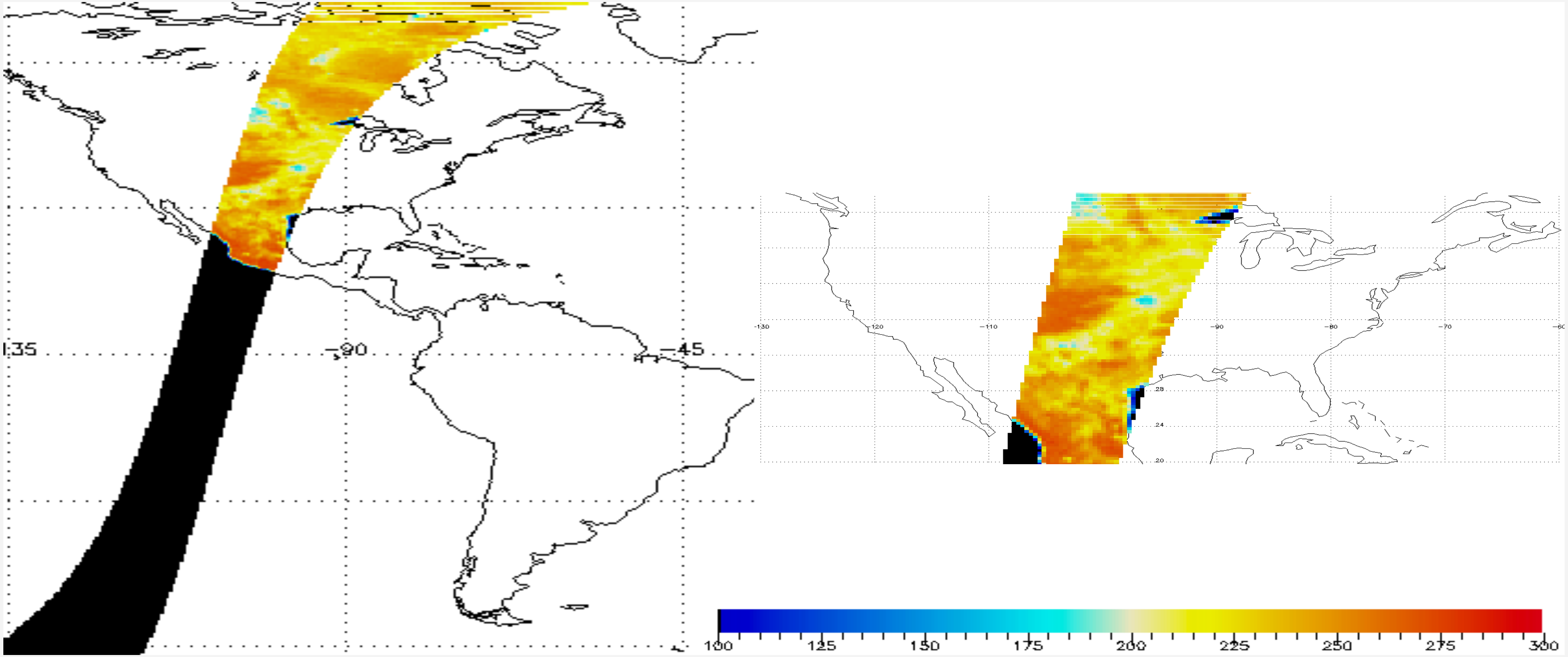
Data Product Short Name	Description	Grid Resolution	Granule Extent
L1A_Radar	Parsed Radar Instrument Telemetry		Half Orbit
L1A_Radiometer	Parsed Radiometer Instrument Telemetry		Half Orbit
L1B_S0_LoRes	Low Resolution Radar σ_o in Time Order	5x30 km (10 slices)	Half Orbit
L1C_S0_HiRes	High Resolution Radar σ_o on Swath Grid	1 km	Half Orbit
L1B_TB	Radiometer T_B in Time Order	39x47 km	Half Orbit
L1C_TB	Radiometer T_B	36 km	Half Orbit
L2_SM_A	Radar Soil Moisture (includes Freeze-Thaw)	3 km	Half Orbit
L2_SM_P	Radiometer Soil Moisture	36 km	Half Orbit
L2_SM_AP	Active-Passive Soil Moisture	9 km	Half Orbit
L3_FT_A	Daily Global Composite Freeze/Thaw State	3 km	North of 45° N
L3_SM_A	Daily Global Composite Radar Soil Moisture	3 km	Global
L3_SM_P	Daily Global Composite Radiometer Soil Moisture	36 km	Global
L3_SM_AP	Daily Global Composite Active-Passive Soil Moisture	9 km	Global
L4_SM	Surface & Root Zone Soil Moisture	9 km	Global
L4_C	Carbon Net Ecosystem Exchange	9 km	North of 45° N

SMAP Status

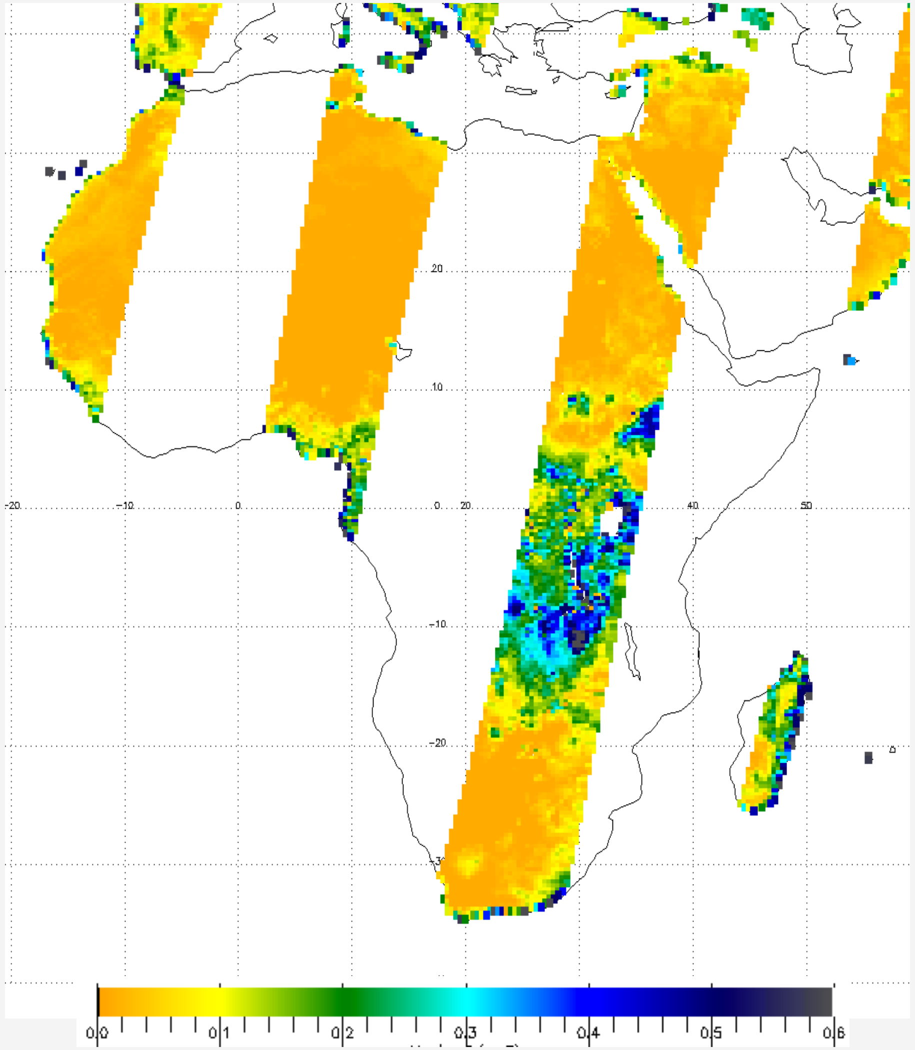
- Loss of the SMAP Radar
  - On July 7 2015 the SMAP radar suddenly stopped operating (after having collected data for 2.5 months)
  - A team was formed to determine the cause
  - The high power amplifier was identified as the cause
  - Efforts were made to configure the system in different ways with no success

- Implications for SMAP
  - Surface freeze/thaw state product at 3 km will not be produced
  - Soil moisture products at 9 km will not be produced

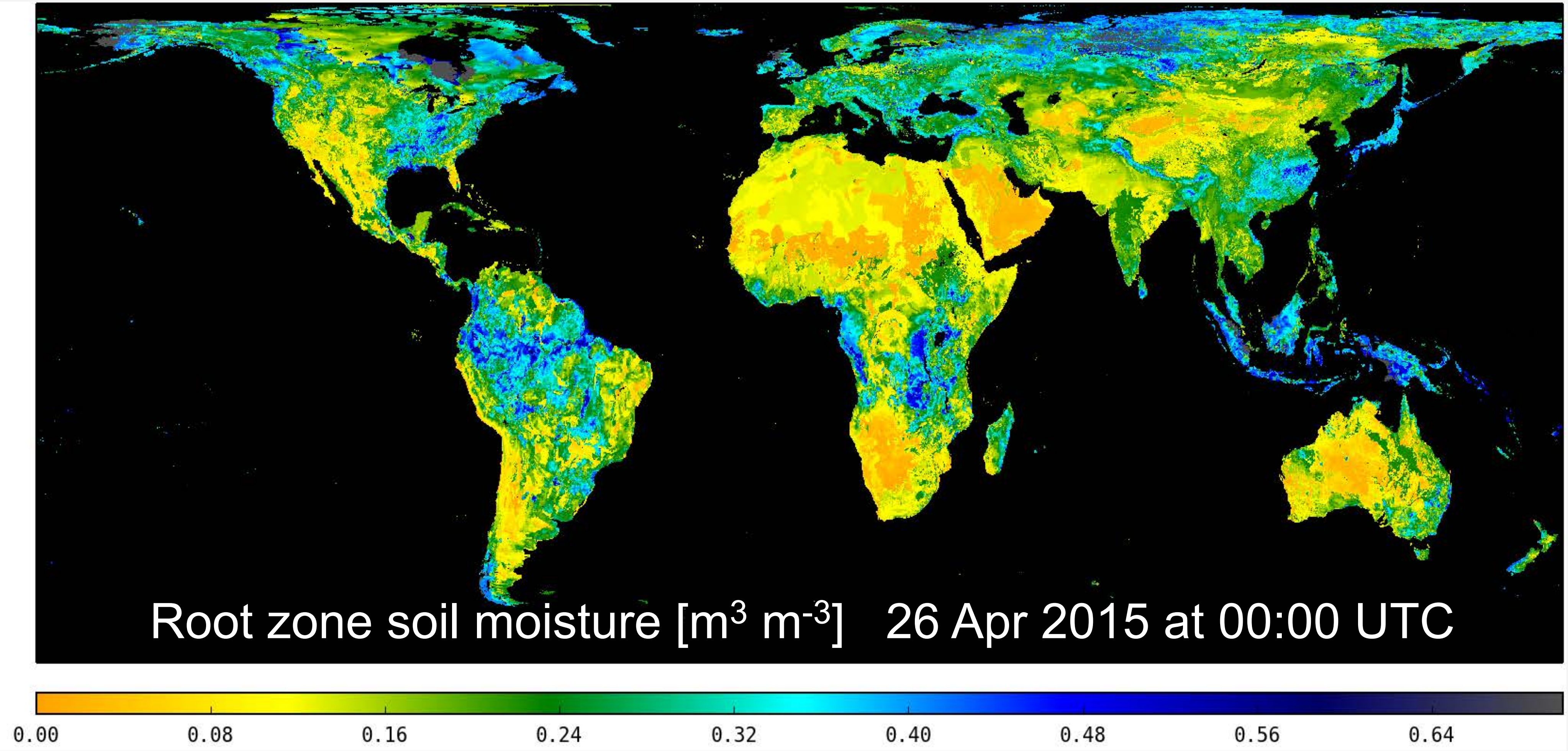
Radiometer Data – Level 1C



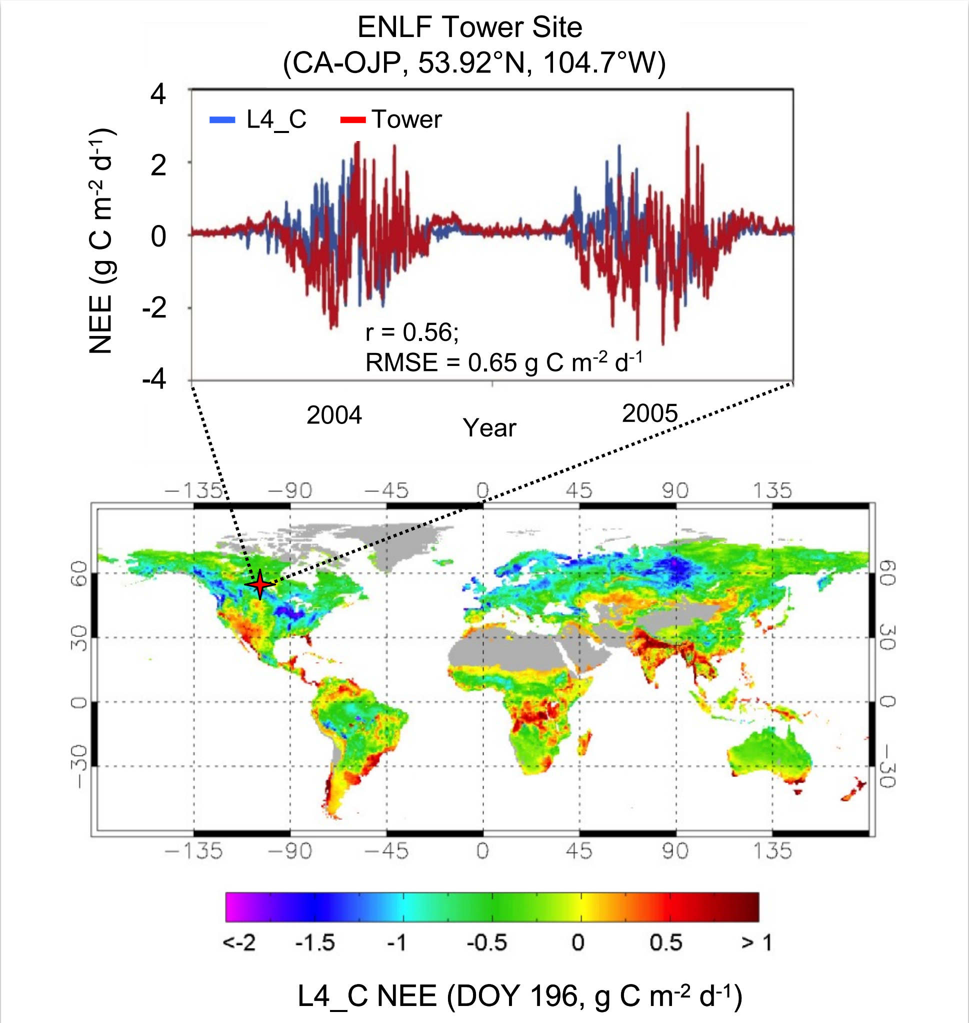
Soil Moisture Derived from the Radiometer- Level 3



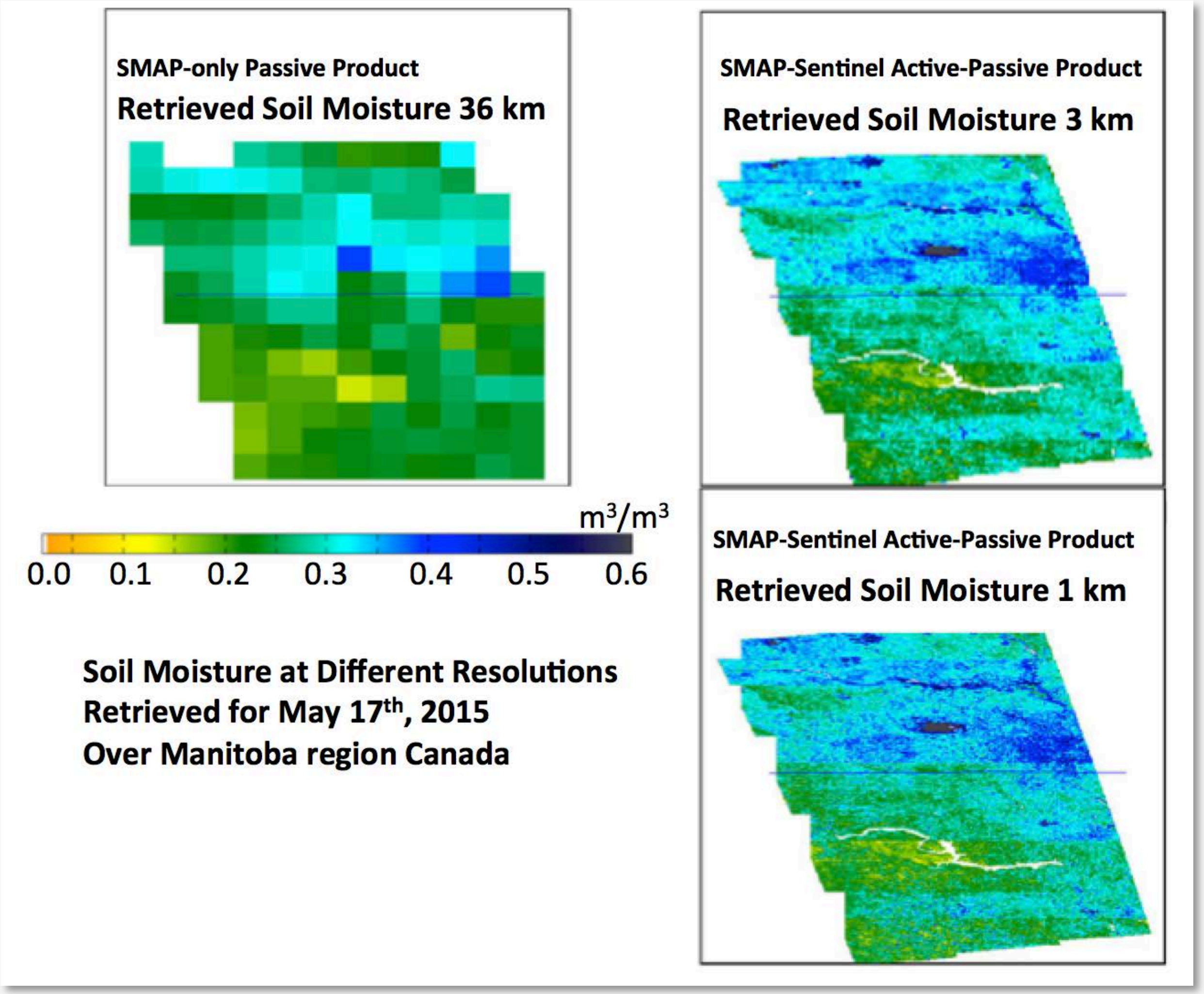
Surface and Root Zone Soil Moisture- Level 4



Net Ecosystem Carbon Exchange- Level 4



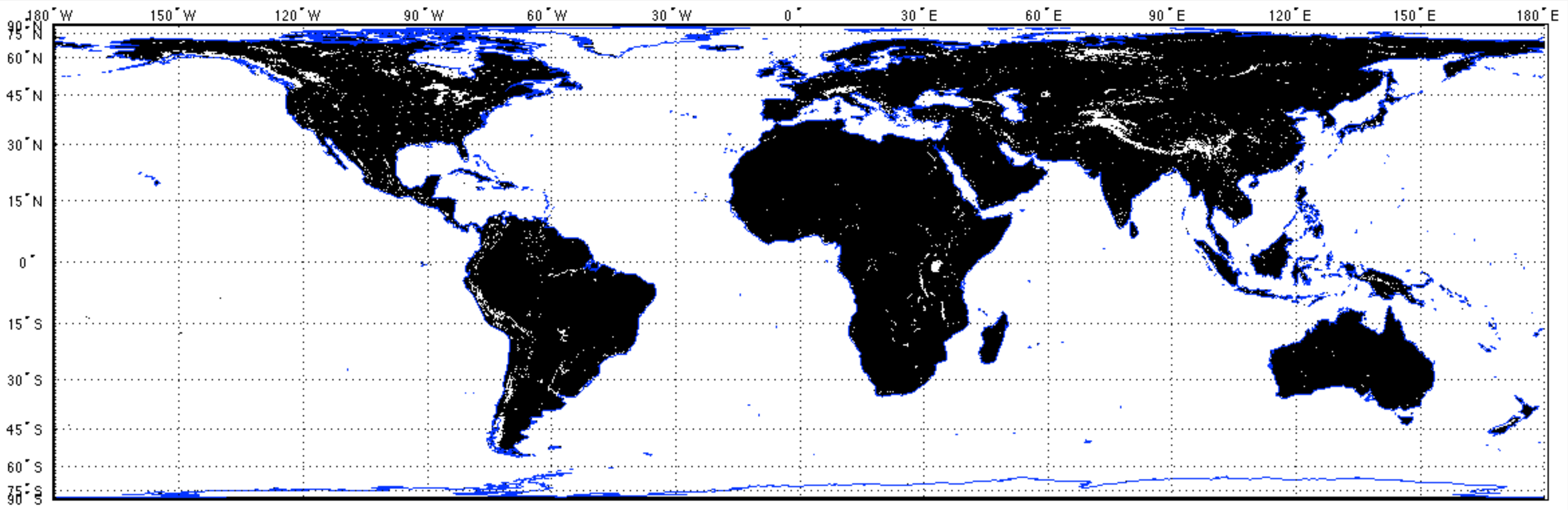
SMAP Enhanced Active-Passive Product Using Sentinel



Source: Narendra Das

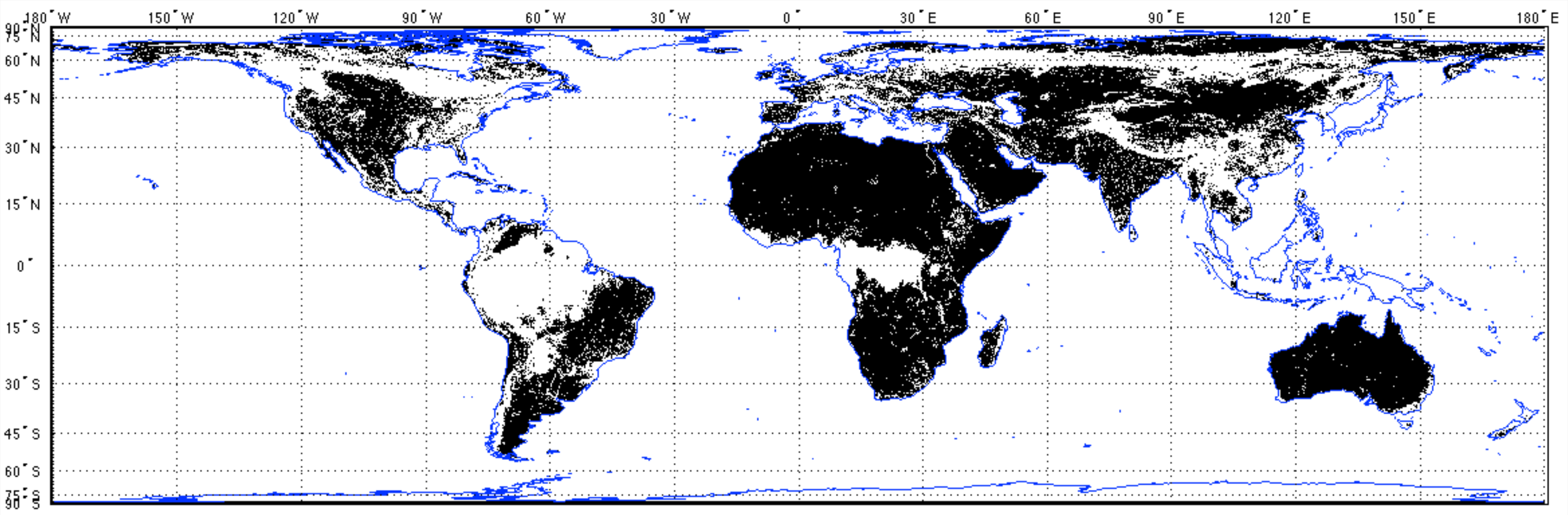
Soil Moisture Retrieval Map

- Retrievable Mask (Black Colored Pixels):
  - Urban Fraction < 1
  - Water Fraction < 0.5
  - DEM Slope Standard Deviation < 5 deg



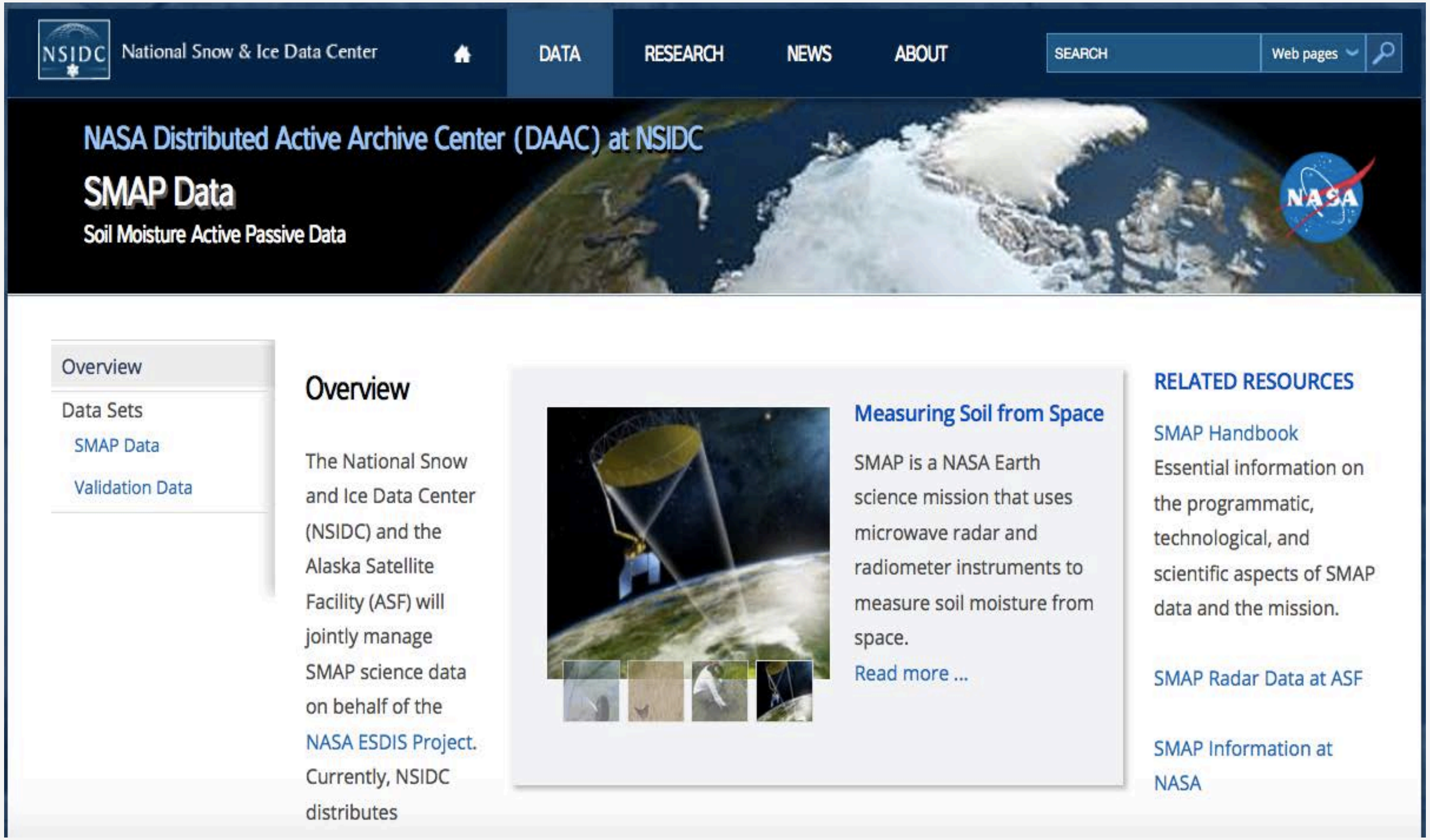
Soil Moisture Expected Accuracy

- Retrieval Expected Quality Mask (black colored pixels indicate good quality)
  - Vegetation Water Content ≤ 5 kg/m^2
  - Urban Fraction ≤ 0.25
  - Water Fraction ≤ 0.1
  - DEM Slope Standard Deviation ≤ 3 deg

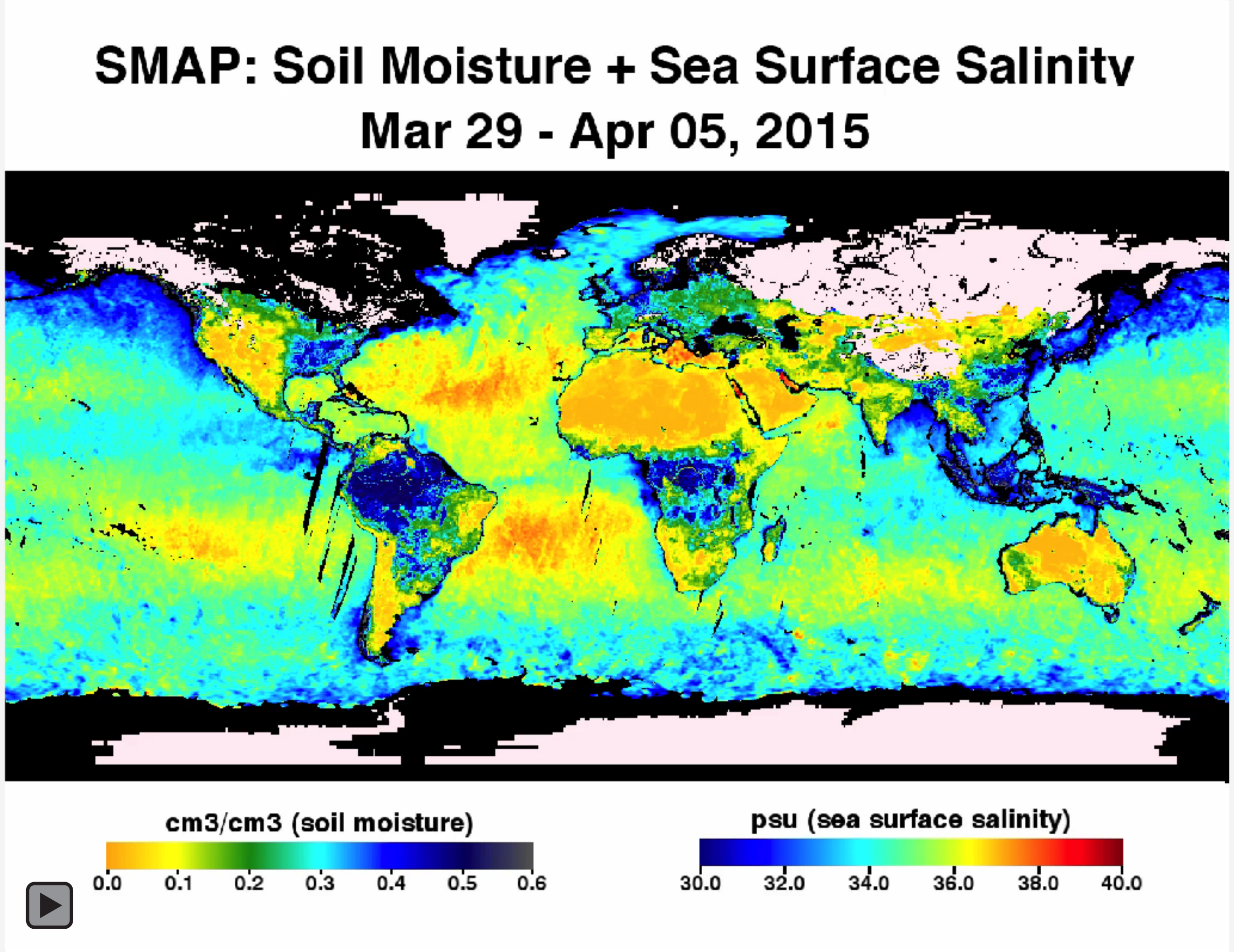


Access to SMAP Data: NSIDC

http://nsidc.org/data/smap/



Global Soil Moisture Animation

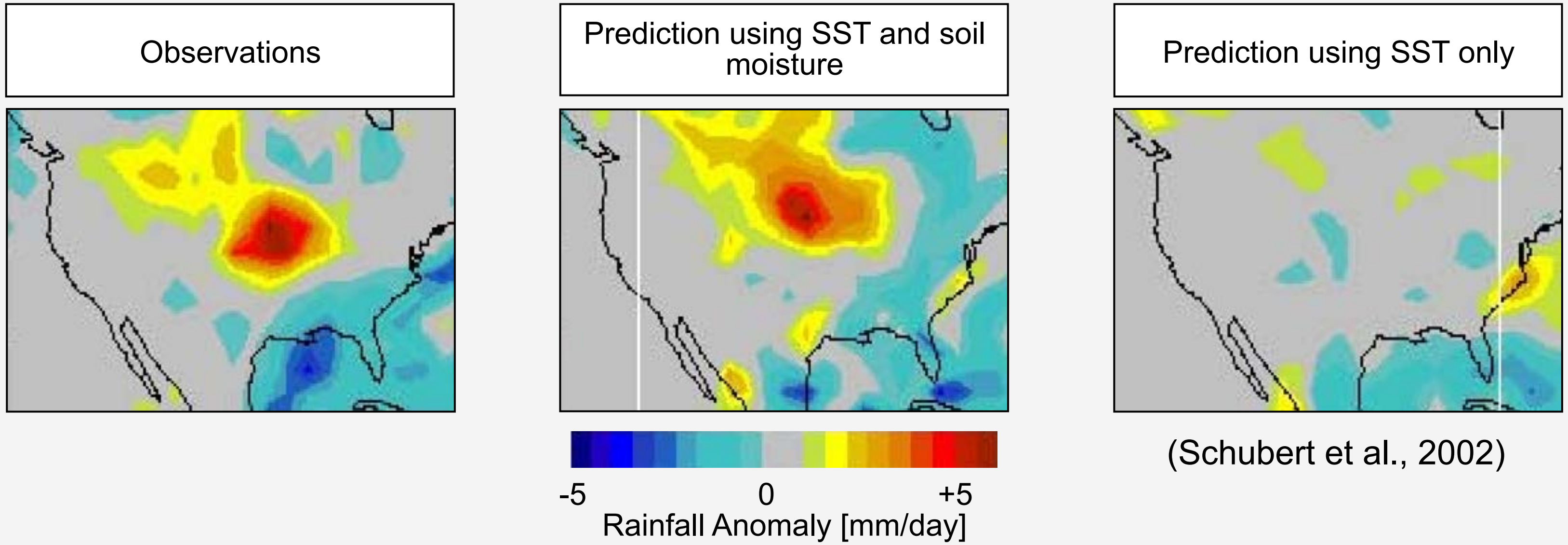


Value of Soil Moisture Data to Weather and Climate

Seasonal Climate Predictability

*Predictability of **seasonal climate** is dependent on boundary conditions such as sea surface temperature (SST) and soil moisture – **soil moisture** is particularly important over continental interiors*

Rainfall

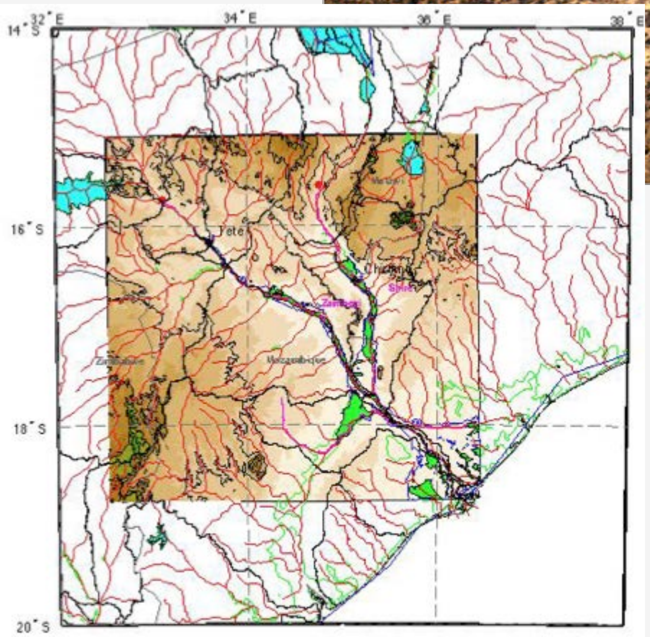


(Schubert et al., 2002)

Flood Example

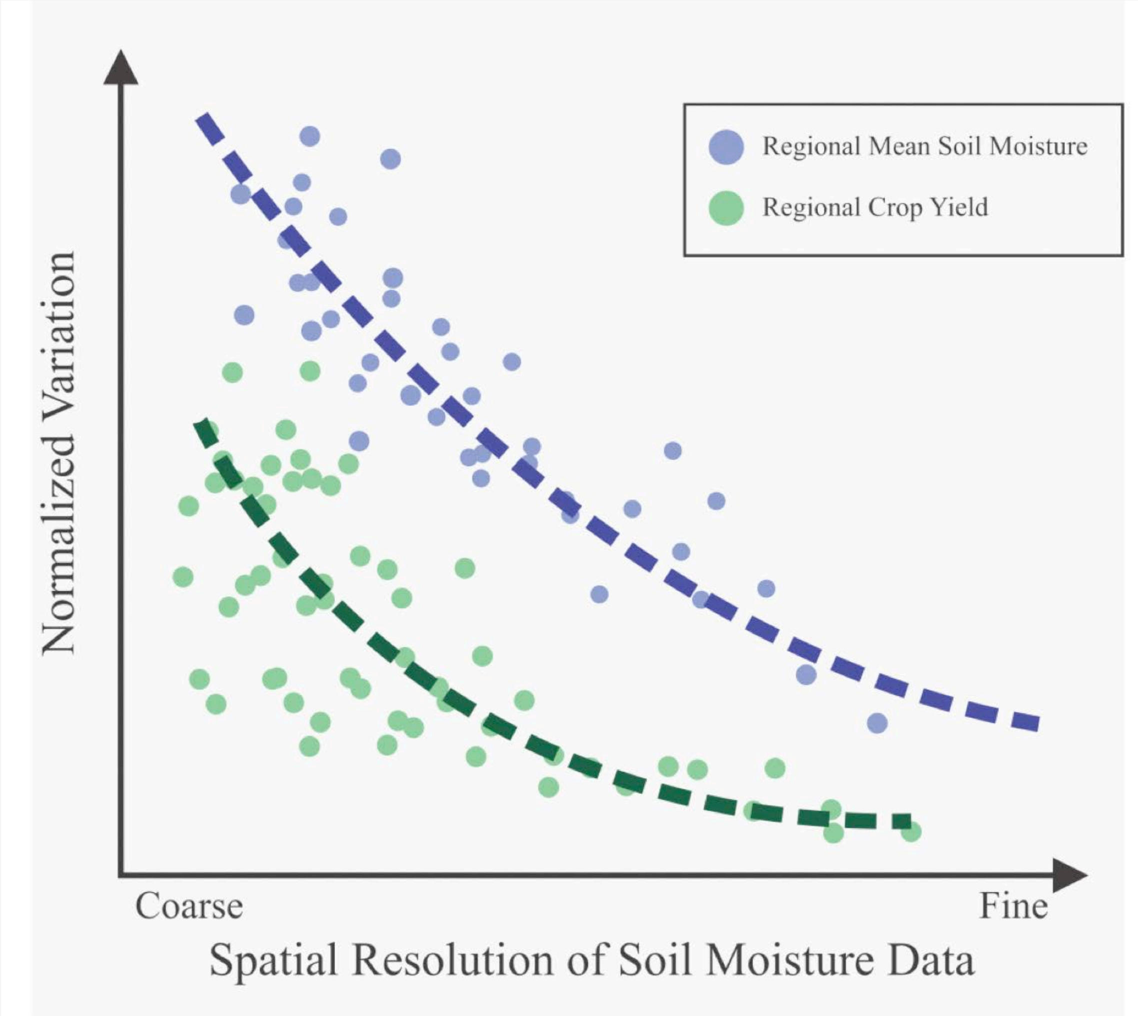
Application of a SMAP-based index for flood forecasting in data-poor regions

- Current Capability
  - UN-WFP uses satellite derived flood maps to locate floods and map delivery routes to affected areas
- Enhanced Capability
  - Use SMAP to expand current flood database with look-up information that produces flood indices for a given rainfall forecast (ECMWF) and soil moisture condition (SMAP)
- Study Area
  - Zambezi basin and delta in Mozambique



Crop Yield Modeling

- Agricultural models have been developed to predict the yield of various crops at field and regional scales
- The diagram (right) relates variation in regional domain-averaged soil moisture to variation in total crop yield
- Statistical analysis would lead to the development of probability distributions of crop yield as a transformation of the probability distribution of domain averaged soil moisture at the beginning of the growing season



Source: http://smap.jpl.nasa.gov/resources/54/

Predicting Vector-Borne Diseases

SMAP Early Adopters

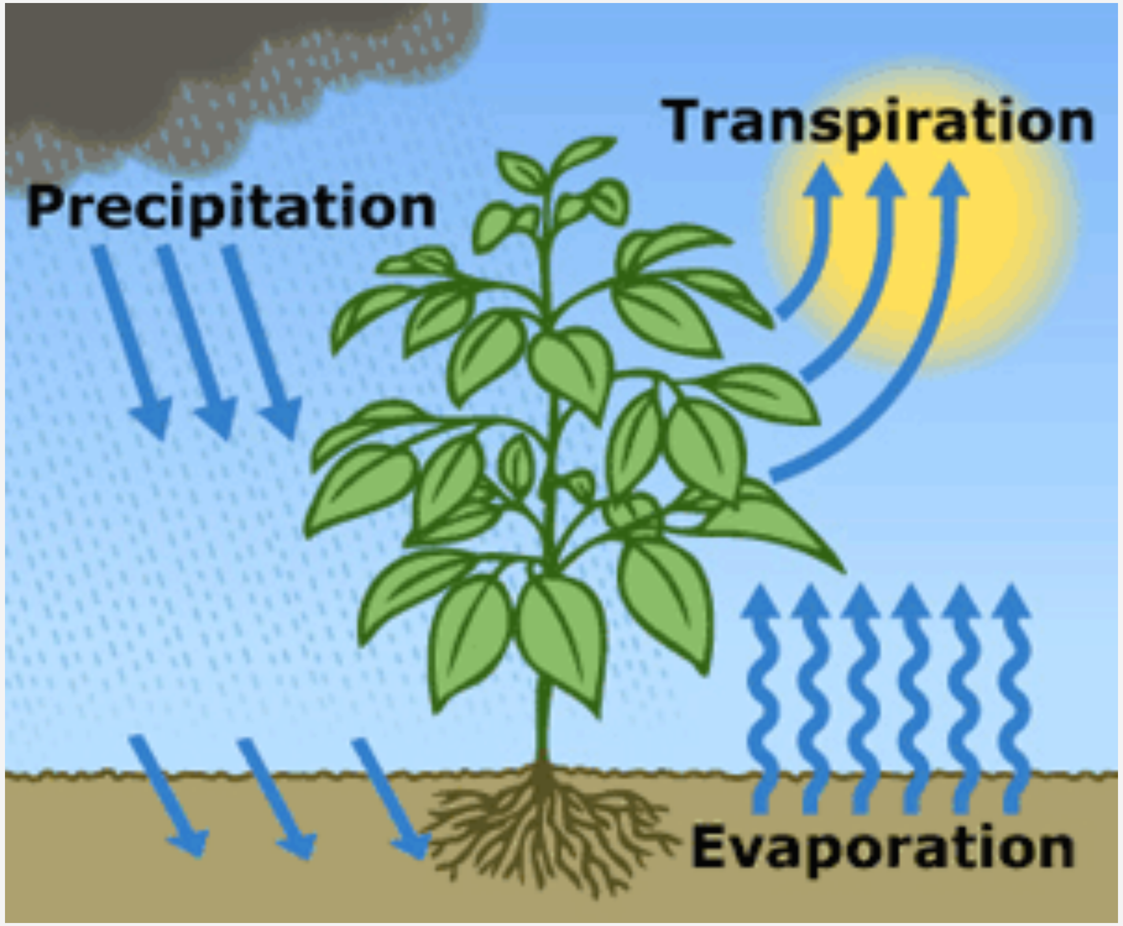
SMAP Early Adopters†, SMAP project contacts, and applied research topics. Many Early Adopters cross multiple applications.

Early Adopter PI and institution SMAP Contact	Applied Research Topic
Weather and Climate Forecasting	
*** Stephane Bélair**, Meteorological Research Division, Environment Canada (EC); SMAP Contact: **Stephane Bélair**	Assimilation and impact evaluation of observations from the SMAP mission in Environment Canada's Environmental Prediction Systems
*** Lars Isaksen and Patricia de Rosnay**, European Centre for Medium-Range Weather Forecasts (ECMWF); SMAP Contact: **Eni Njoku**	Monitoring SMAP soil moisture and brightness temperature at ECMWF
*** Xiwu Zhan, Michael Ek, John Simko and Weizhong Zheng**, NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS); SMAP Contact: **Randy Koster**	Transition of NASA SMAP research products to NOAA operational numerical weather and seasonal climate predictions and research hydrological forecasts
*** Michael Ek, Marouane Temimi, Xiwu Zhan and Weizhong Zheng**, NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS), City College of New York (CUNY); SMAP Contact: **Chris Derksen**	Integration of SMAP freeze/thaw product line into the NOAA NCEP weather forecast models
*** John Galantowicz**, Atmospheric and Environmental Research, Inc. (AER); SMAP Contact: **John Kimball**	Use of SMAP-derived inundation and soil moisture estimates in the quantification of biogenic greenhouse gas emissions
◊ Jonathan Case, Clay Blankenship and Bradley Zavodsky, NASA Short-term Prediction Research and Transition (SPoRT) Center; SMAP Contact: **Dara Entekhabi**	Data assimilation of SMAP observations, and impact on weather forecasts in a coupled simulation environment
◊ Steven Quiring, *Texas A&M University*; SMAP Contact: **Dara Entekhabi**	Hurricane power outage prediction
Droughts and Wildfires	
*** Jim Reardon and Gary Curcio**, US Forest Service (USFS); SMAP Contact: **Dara Entekhabi**	The use of SMAP soil moisture data to assess the wildfire potential of organic soils on the North Carolina Coastal Plain
*** Chris Funk, Amy McNally and James Verdin**, USGS & UC Santa Barbara; SMAP Contact: **Susan Moran**	Incorporating soil moisture retrievals into the FEWS Land Data Assimilation System (FLDAS)
◊ Brian Wardlow and Mark Svoboda, Center for Advanced Land Management Technologies (CALMIT), National Drought Mitigation Center (NDMC); SMAP Contact: **Narendra Das**	Evaluation of SMAP soil moisture products for operational drought monitoring: potential impact on the U.S. Drought Monitor (USDM)
◊ Uma Shankar, The University of North Carolina at Chapel Hill – Institute for the Environment**;** SMAP Contact: **Narendra Das**	Enhancement of a bottom-up fire emissions inventory using Earth observations to improve air quality, land management, and public health decision support
◊ Javier Fochesatto, University of Alaska**;** SMAP Contact: **John Kimball**	Soil moisture in Alaskan ecosystem soils
◊ Amir AghaKouchak, University of California, Irvine**;** SMAP Contact: **Dara Entekhabi**	Integrating SMAP into the Global Integrated Drought Monitoring and Prediction System: Toward near real-time agricultural drought monitoring
◊ Renato D'Auria, ALTEC S.p.A**;** SMAP Contact: **Randy Koster**	Satellite soil moisture accuracy evaluation for hydrological operative forecasting (SMAHF)
◊ Rong Fu, University of Texas; **SMAP contact: Randy Koster**	Using SMAP data to improve drought early warning over Texas and the U.S. Great Plains
Floods and Landslides	
*** Fiona Shaw**, Willis, Global Analytics; SMAP Contact: **Robert Gurney**	A risk identification and analysis system for insurance; eQUIP suite of custom catastrophe models, risk rating tools and risk indices for insurance and reinsurance purposes
***Kashif Rashid and Emily Niebuhr**, UN World Food Programme; SMAP Contact: **Eni Njoku**	Application of a SMAP-based index for flood forecasting in data-poor regions
◊ Konstantine Georgakakos, Hydrologic Research Center; SMAP Contact: **Narendra Das**	Development of a strategy for the evaluation of the utility of SMAP products for the Global Flash Flood Guidance Program of the Hydrologic Research Center
◊ Luca Brocca, Research Institute for Geo-Hydrological Protection, Italian Dept. of Civil Protection; SMAP contact: **Dara Entekhabi**	Use of SMAP soil moisture products for operational flood forecasting: data assimilation and rainfall correction
◊ Jennifer Jacobs, University of New Hampshire; SMAP contact: **Narendra Das**	Satellite enhanced snowmelt flood predictions in the Red River of the North Basin

Overview of Evapotranspiration

What is evapotranspiration (ET)?

- The sum of evaporation from the land surface plus transpiration from plants
- ET transfers water from land surface to the atmosphere in vapor form
- Energy is required for ET to take place (for changing liquid water into vapor)



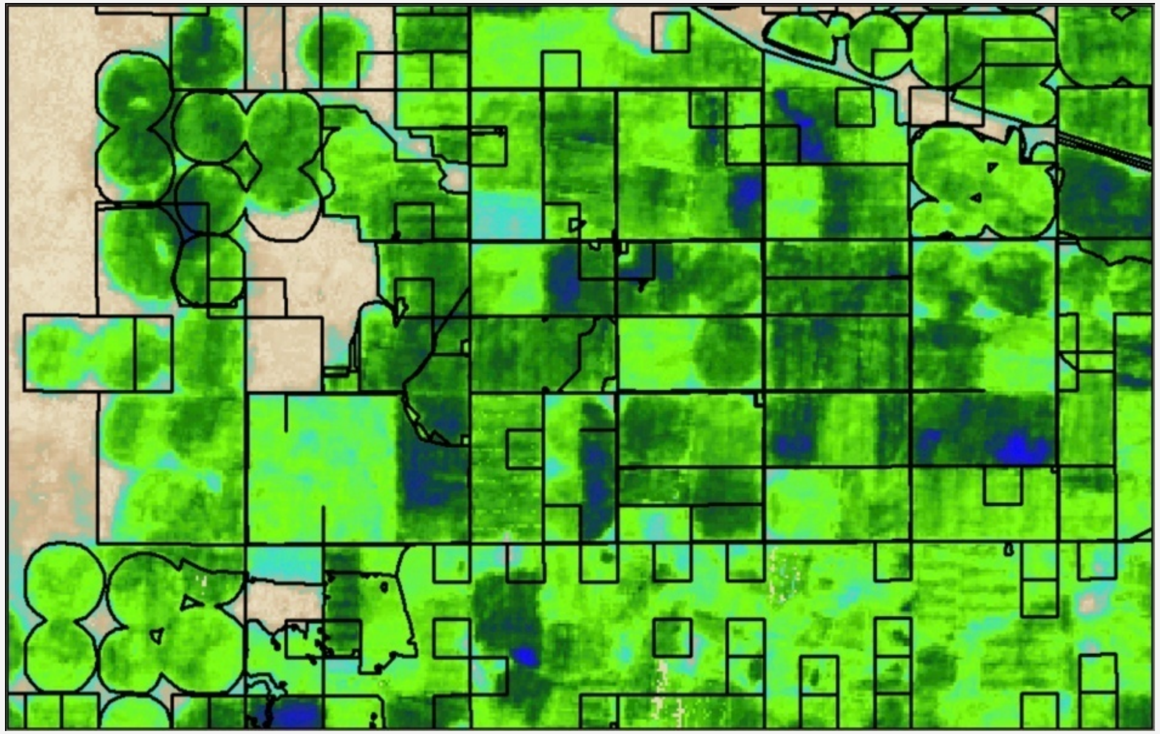
* Image Credit: USGS

Importance of ET

- Critical component of the water and energy balance of climate-soil-vegetation interactions
- Useful for:
  – determining agricultural water consumption
  – assessing drought conditions
  – developing water budgets
  – monitoring aquifer depletion
  – monitoring crops and carbon budgets

Challenges in Measuring ET

- ET depends on many variables:
  - solar radiation at the surface
  - land and air temperatures
  - humidity
  - surface winds
  - soil conditions
  - vegetation cover and types
- Highly variable in space and time



ET Ground Measurements

- Limitation
  - They are point measurements and cannot capture spatial variability

Eddy Covariance System

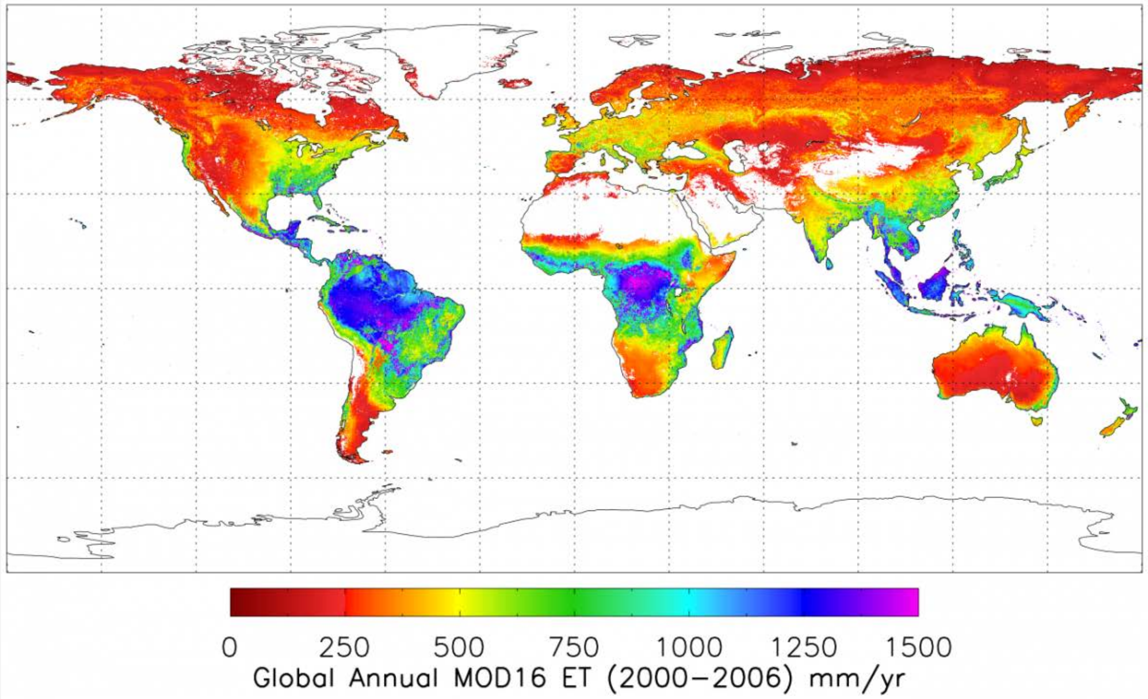
Lysimeters

* Image Credit: Rick Allen, University of Idaho

Benefits of Estimating ET from Remote Sensing Data

- Provide relatively frequent and spatially continuous measurement of biophysical variables used in estimating ET at different spatial scales including:
  - – radiation
  - – land surface temperatures
  - – vegetation coverage and density
  - – precipitation
  - – soil moisture
  - – weather and climate variables

Global ET Based on MODIS Averaged over 2000-2006



* Source: University of Montana, Numerical Terradynamic Simulation Group

Methods of Estimating ET Based on Remote Sensing

Remote Sensors and Observations for ET

Satellite	Sensor	Parameter
Terra and Aqua	MODIS	• Normalized Difference Vegetation Index (NDVI) • Leaf Area Index (LAI) • Albedo (fraction of surface solar radiation reflected back)
Landsat	OLI, ETM+, TIRS	Spectral Reflectance, Thermal Emission

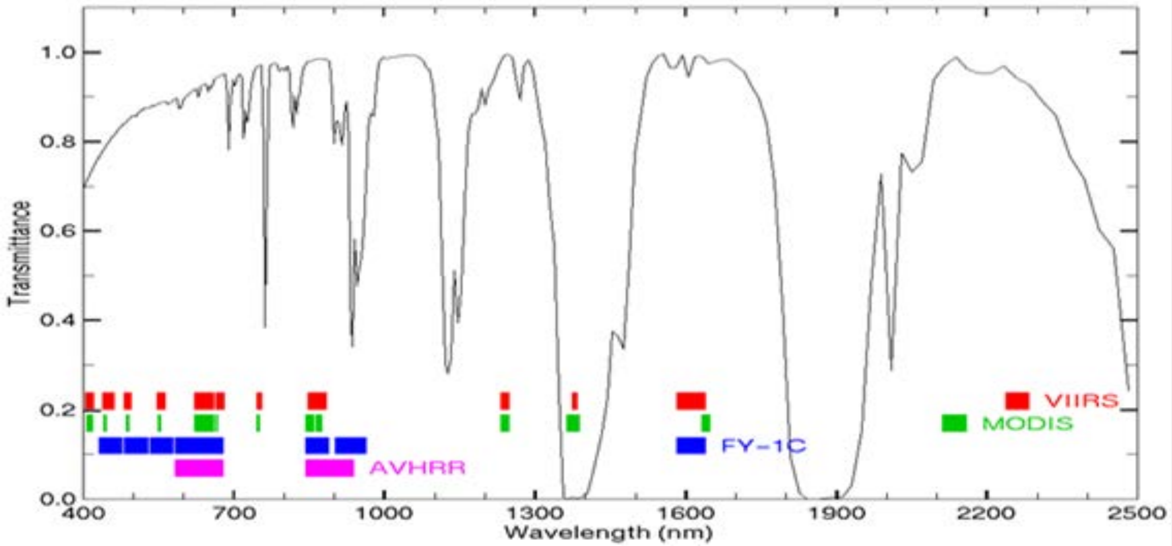
MODerate Resolution Imaging Spectroradiometer (MODIS)

http://modis.gsfc.nasa.gov

- Onboard Terra and Aqua
- Designed for land, atmosphere, ocean, and cryosphere observations
- Spatial Coverage and Resolution:
  – Global Coverage
  – Swath: 2,330 km
  – Spatial Resolution Varies: 250 m, 500 m, 1 km
- Temporal Coverage and Resolution:
  – 2000 – present, 2 times per day

Spectral Bands

- 36 bands (red, blue, IR, NIR, MIR)
  – Bands 1-2: 250 m
  – Bands 3-7: 500 m
  – Bands 8-16: 1,000 m

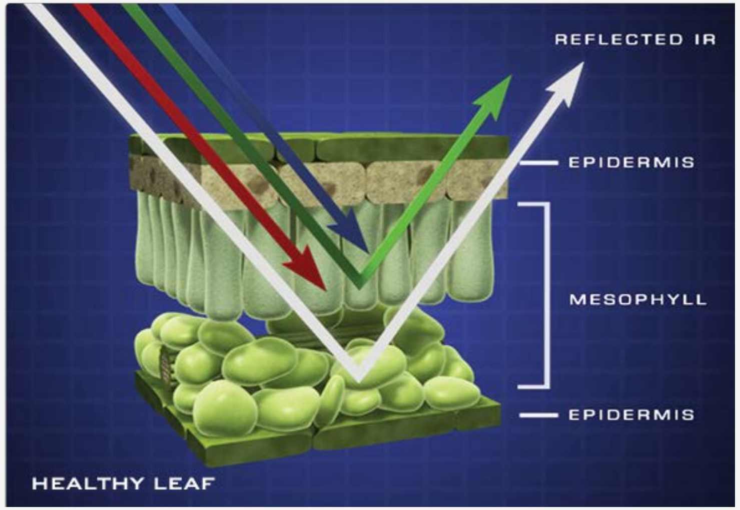


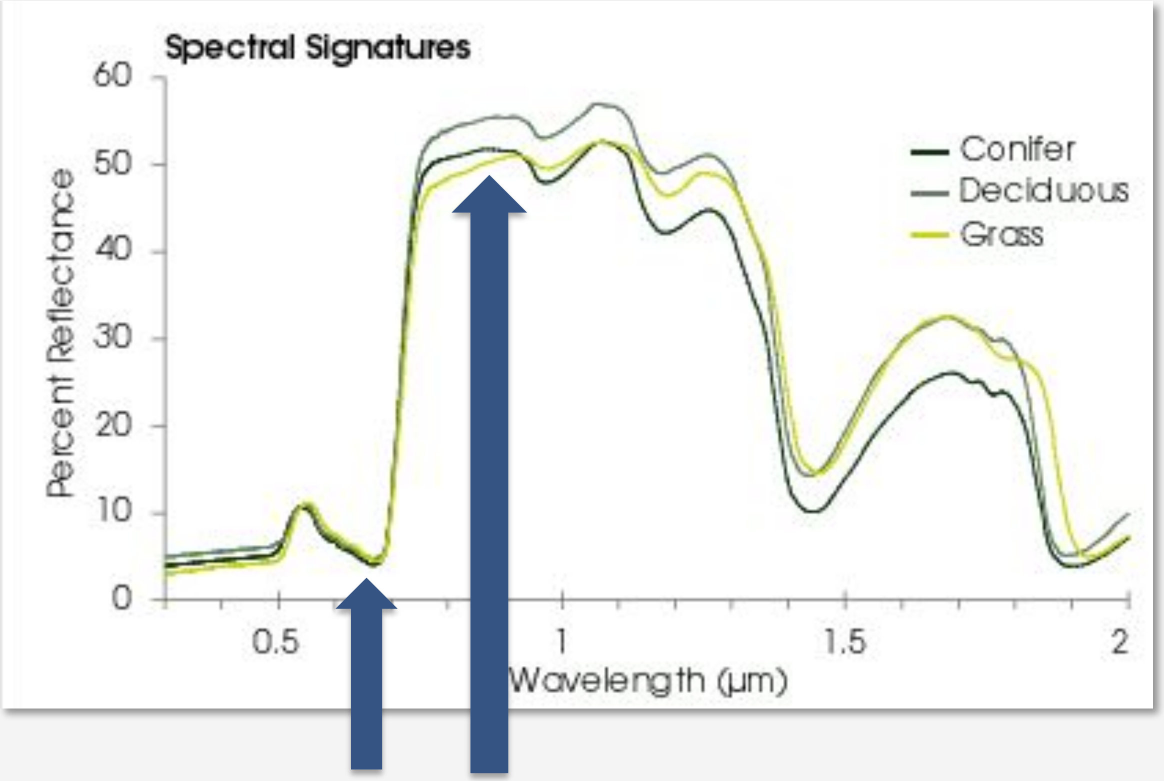
* Image Credit: Cooperative Institute for Meteorological Satellite Studies,

MODIS Normalized Vegetation Index

http://arset.gsfc.nasa.gov/land/webinars/advancedNDVI

- Based on the relationship between red and near-infrared wavelengths
  - chlorophyll strongly absorbs visible (red)
  - plant structure strongly reflects near-infrared





Red

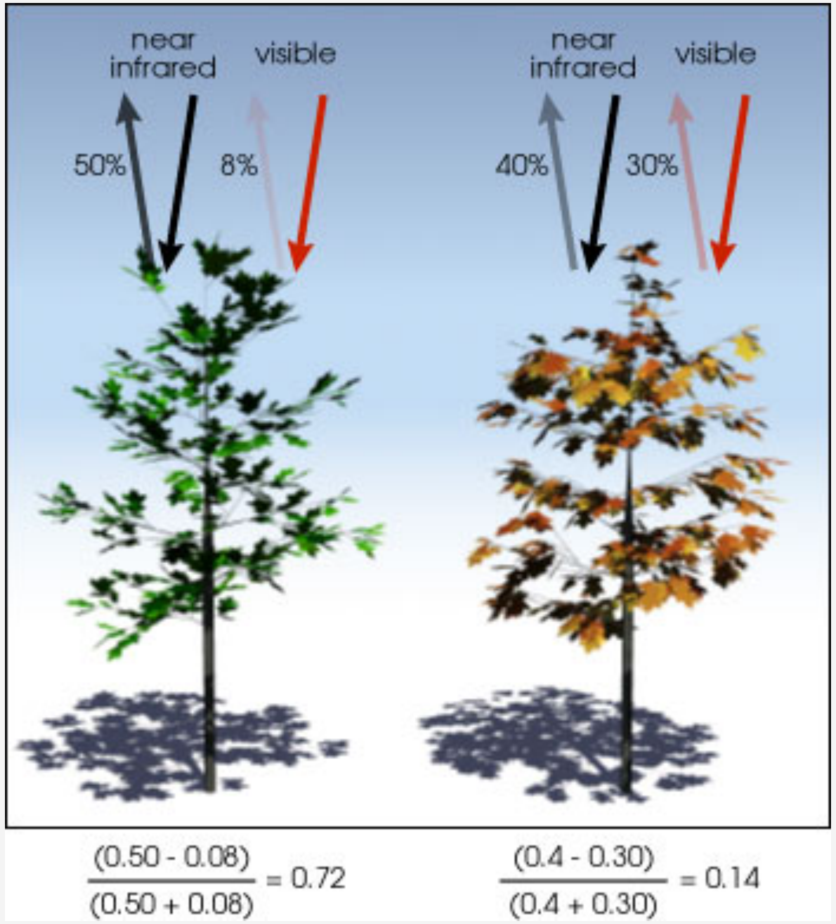
Near-Infrared

* Image Credit (left): NASA/Jeff Cerns

NDVI Formula

http://earthobservatory.nasa.gov/Features/MeasuringVegetation

- $\text{NDVI} = \dfrac{\text{Near-Infrared - Red}}{\text{Near-Infrared + Red}}$
- Values range from -1.0 – 1.0
  - Negative values – 0 mean no green leaves
  - Values close to 1 indicate the highest possible density of green leaves
- Other relevant MODIS products:
  - Leaf Area Index
  - Land Cover
  - Albedo
  - More info: http://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table



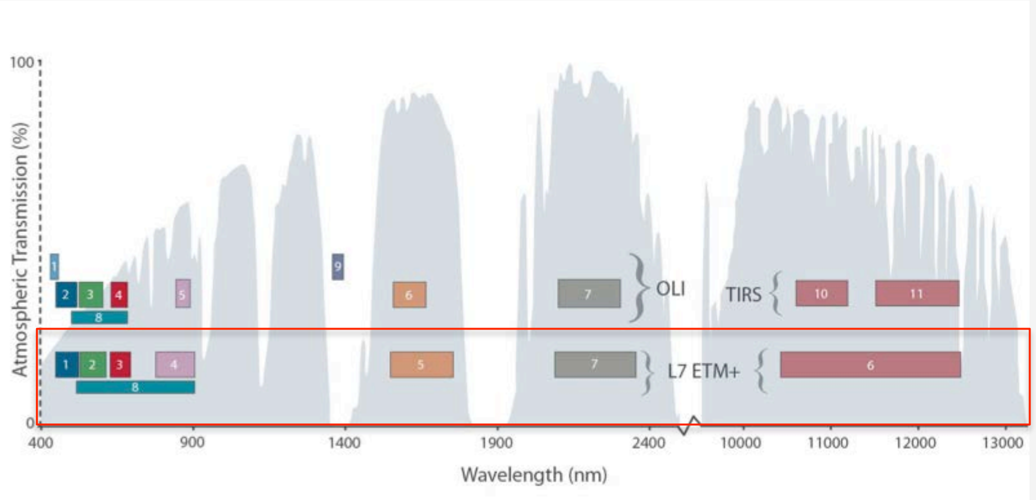
Enhanced Thematic Mapper (ETM+)

http://geo.arc.nasa.gov/sge/landsat/7.html

- Onboard Landsat-7
- Polar Orbiting Satellite
- Spatial Coverage and Resolution:
  - Global Coverage
  - Swath: 185km
  - Spatial Resolution: 15m, **30m**, 60m
- Temporal Coverage and Resolution:
  - April 15, 1999 – present
  - 16 day revisit time

Spectral Bands

- 8 bands (blue-green, green, red, reflected & thermal IR, panchromatic)
  - Bands 1-5, 7: 30m
  - Band 6: 60m
  - Band 8:15m



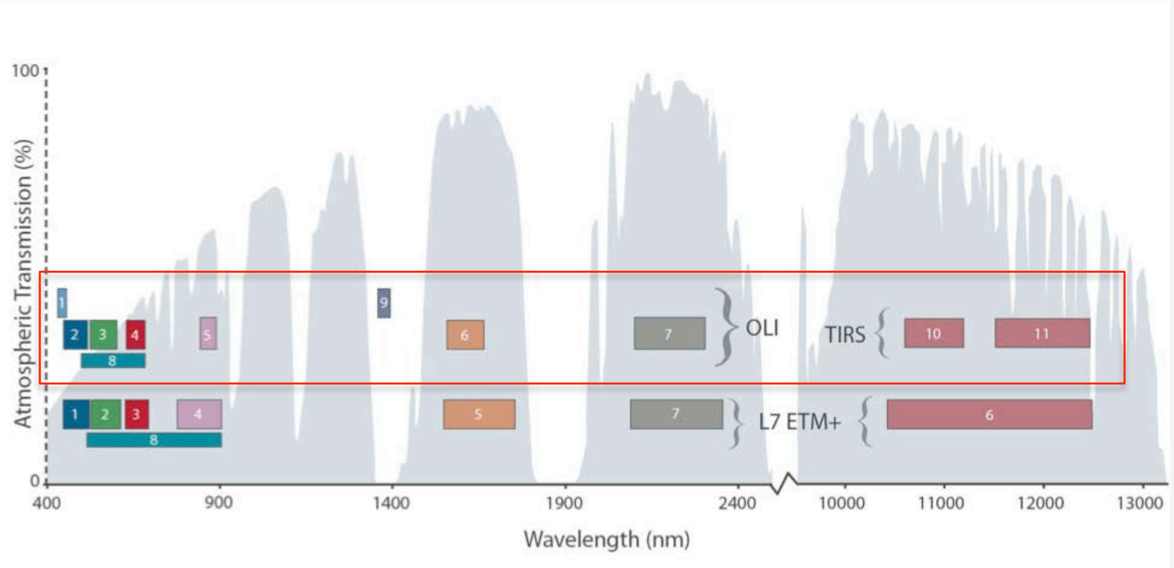
Operational Landsat Imager (OLI)

http://landsat.usgs.gov/landsat8.php; http://landsat.gsfc.nasa.gov/?p=5779

- Onboard Landsat-8
- Polar Orbiting Satellites
- Spatial Coverage and Resolution
  - Global Coverage
  - Swath: 185 km
  - Spatial Resolution: 15 m, **30 m**
- Temporal Coverage and Resolution
  - Feb 11, 2013 – present
  - 16 day revisit time

Spectral Bands

- 9 bands (blue-green, green, red, near IR, shortwave, and thermal IR)
  - Bands 1-7, 9: 30 m
  - Band 8: 15 m



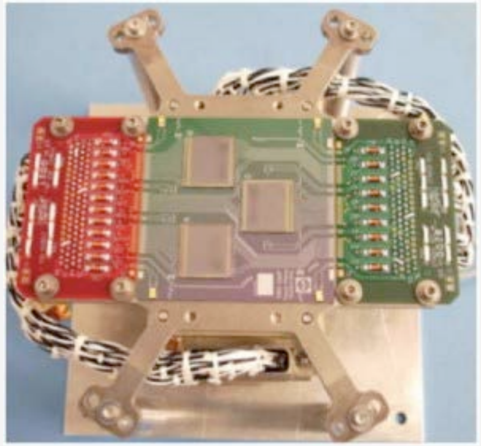
Thermal Infrared Sensor (TIRS)

http://landsat.gsfc.nasa.gov/?p=5474

- Onboard Landsat-8
- Polar Orbiting Satellites
- Spatial Coverage and Resolution
  - Global Coverage
  - Swath: 185 km
  - Spatial Resolution: 100 m
- Temporal Coverage and Resolution
  - Feb 11, 2013 – present
  - 16 day revisit time

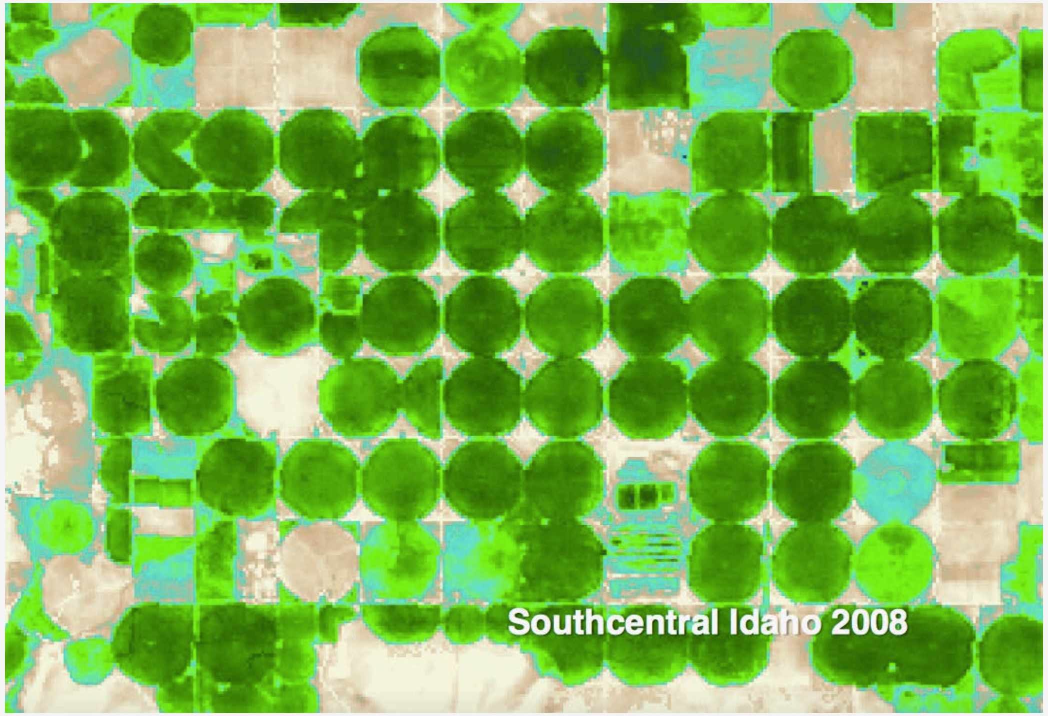
Spectral Bands

- 2 bands centered at
  10.9 µm
  12.0 µm



Importance of Landsat for ET

- Allows field-level ET (30 m resolution) – much higher resolution than MODIS-based ET (1 km)
- Has a thermal band that is important for some ET approaches



* Image Credit: Richard Allen, University of Idaho

Estimation of ET – not easy!

- ET can be derived primarily from:
  - Surface Water Balance
    - ET = Precipitation + Irrigation – Runoff – Ground Water + Vertical Water Transport ± Subsurface Flow ± Soil Water Content
  - Surface Energy Balance
    - ET (Latent Heat Flux) = Net Surface Radiation – Ground Heat Flux – Sensible Heating Flux
  - Meteorological and Vegetation/Crop Data (Penman-Monteith Equation)

*Reference: http://www.fao.org/docrep/X0490E/x0490e04.htm#determining%20evapotranspiration

ET Estimation by Land Surface Models

Global Land Data Assimilation System (GLDAS): http://ldas.gsfc.nasa.gov

Integrate satellite and ground observations within sophisticated numerical models based on water and energy balance methods

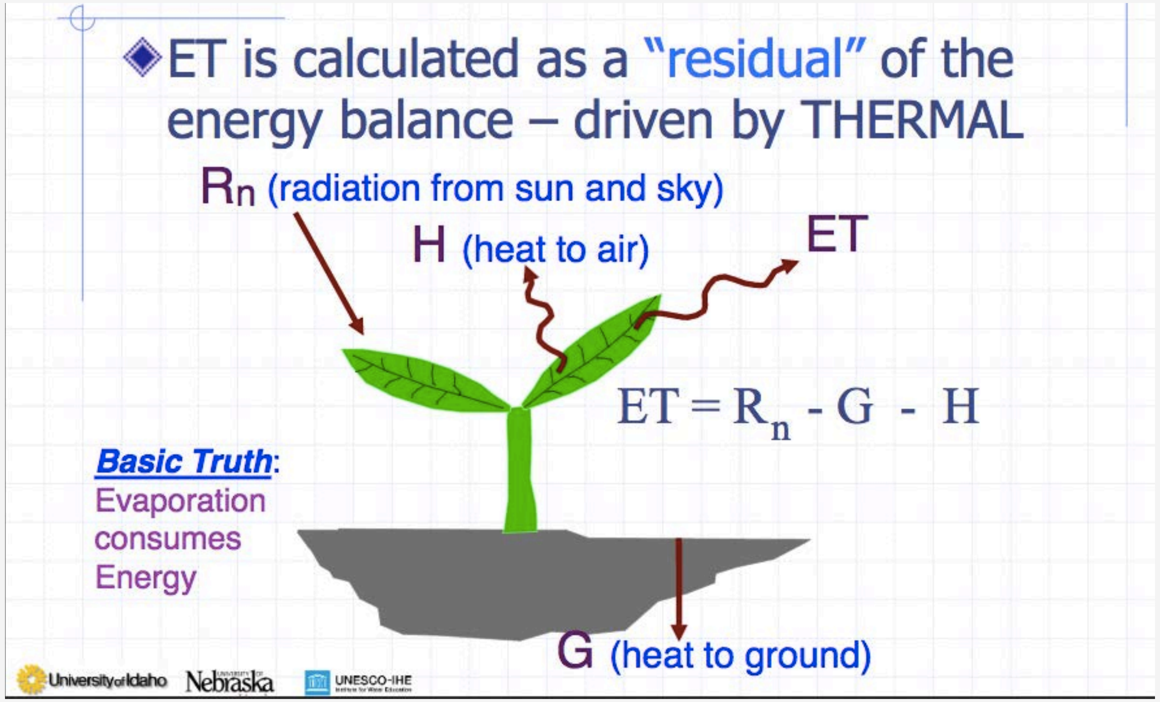
Remote Sensing Inputs

- Surface Solar Radiation
  – from atmospheric models with satellite data assimilation
- Precipitation (TRMM and Multi-Satellites)
- Vegetation Classification & Leaf Area Index (MODIS & AVHRR)
- Topography (Landsat)

Integrated Outputs

- Soil Moisture
- Evapotranspiration
  – Surface/Sub-Surface Runoff
  – Snow Water Equivalent

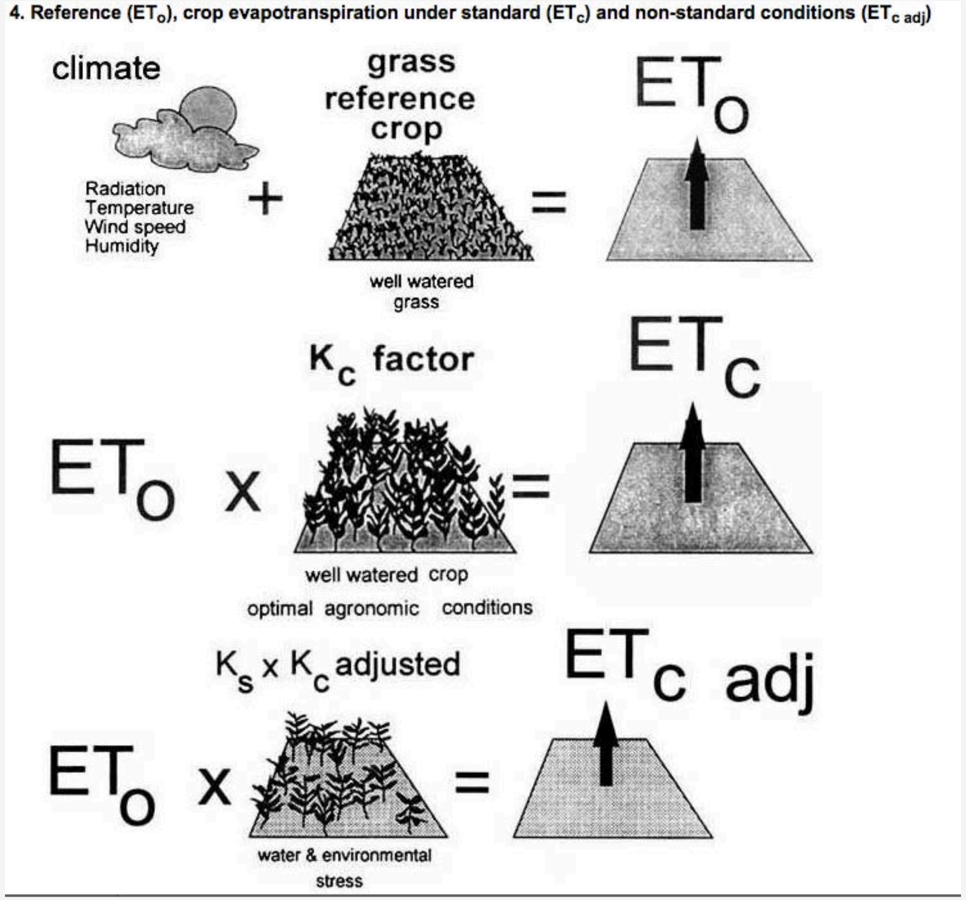
ET Estimation by Surface Energy Balance



- Used by multiple groups to develop ET products
- Uses MODIS & Landsat
  - land surface temperatures
  - land cover

* Image Credit: Rick Allen, *Additional ET Observation Platforms: Towards an Integrated Observation Capability*

ET Estimation from Vegetation and Crop Information



* Image Credit: http://www.fao.org/docrep/X0490E/x0490e04.htm#determining%20evapotranspiration

- ET_o: reference ET for well-watered grass reference (Penman-Moneith Equation)
- ET_c: crop ET for standard crop conditions:
  - disease free, well fertilized, grown in large fields, optimum soil water conditions, achieving full production under given climatic conditions
- $ET_{c\ adj}$: adjusted for non-standard crop conditions
- K_c: crop coefficient

Penman-Monteith Equation for ET

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

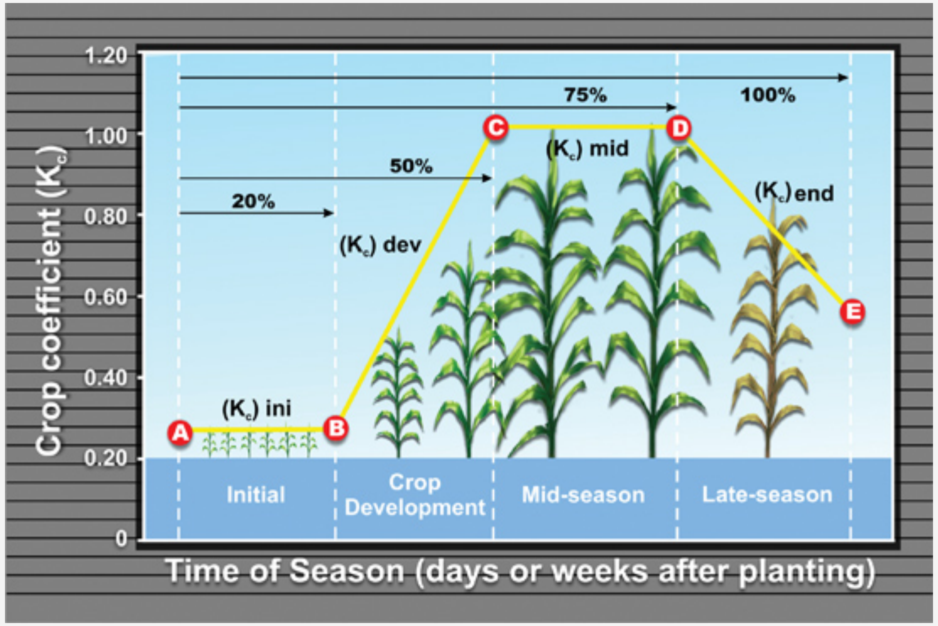
- R_n: net surface radiation
- G: ground heat flux
- (e_s-e_a): vapor pressure deficit
- r_a & r_s: aerodynamic & surface resistance
- γ: psychrometric constant
- λ: latent heat constant
- c_p: specific heat constant

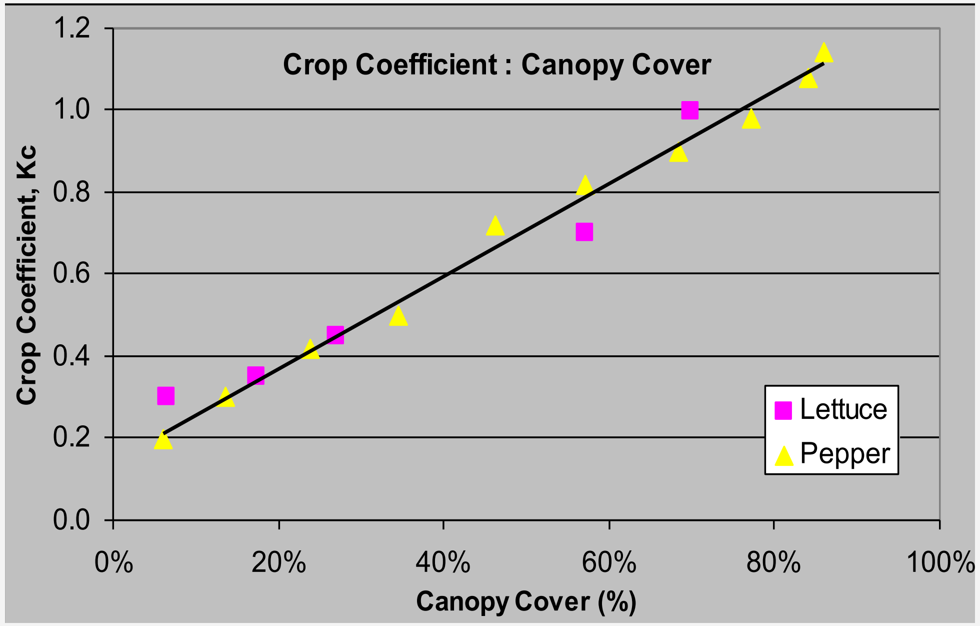
- Requires climate and crop information
- r_a & r_s depend on Vegetation Height, Leaf Area Index (LAI)
- R_n depends on the fractional solar radiation reflected back from the surface (albedo)
- LAI and albedo are both available from MODIS

*Reference: http://www.fao.org/docrep/X0490E/x0490e06.htm#penman%20monteith%20equation

Crop Coefficient (K_c) and Normalized Vegetation Index (NDVI)

- K_c is related to light interception (ground cover)
- There is a direct relationship between K_c and NDVI
  – available from MODIS





* Image Credits: Tom Trout, USDA

ET Data Products Based on Remote Sensing

ET Data Products Based on Remote Sensing Observations

Global Products

- MOD16: MODIS Global Evapotranspiration Project
  - http://ntsg.umt.edu/project/mod16
- METRIC: Mapping EvapoTranspiration with high-Resolution with Internalized Calibration
  https://c3.nasa.gov/water/static/media/other/Day1_S1-3_Allen.pdf

https://c3.nasa.gov/water/static/media/other/Day1_S2-5_Kilic.pdf

https://c3.nasa.gov/water/static/media/other/Day1_S3-3_Allen.pdf

- ALEXI: Atmosphere-Land Exchange Inverse Model
  - https://c3.nasa.gov/water/static/media/other/Day1_S1-4_Anderson.pdf
  - http://www.ospo.noaa.gov/Products/land/getd/index.html
- GLDAS: Global Land Data Assimilation System
  - http://ldas.gsfc.nasa.gov/gldas/

ET Data Products Based on Remote Sensing Observations

Regional Products: can be adapted for other regions

- SIMS: Satellite Irrigation Management Support (California)
  - https://c3.nasa.gov/water/static/media/other/Day1_S2-2_Melton.pdf
- NLDAS: North American Land Data Assimilation System (North America)
  - http://ldas.gsfc.nasa.gov/nldas
- SSEBop: Operational Simplified Surface Energy Balance (US & Africa)
  - http://www2.usgs.gov/climate_landuse/lcs/projects/wsmartet.asp
- ETWatch: Multi-Satellite Based Energy Balance Model (China)
  - https://c3.nasa.gov/water/static/media/other/Day2_S1-4_Wu_2.pdf

Summary: Publically Available Global ET Products

ET Source	Method	Remote Sensing Observations
GLDAS	• Land Surface Model • Water and Energy Balance	• TRMM & Multi-Satellite Precipitation • MODIS and AVHRR Land Cover • Landsat Topography
MOD16	• Normalized Vegetation Index (NDVI)–Based Model	• MODIS
METRIC	• Energy Balance	• Landsat
ALEXI	• Energy Balance	• MODIS • Landsat • GOES

Summary: Publicly Available Global ET Products

ET Sources	Spatial/Temporal Resolutions	Data Source	Availability
MOD16	• 1km (Global) • 8-day, Monthly • 2000 – 2014 (will be extended to present)	• University of Montana	• http://ntsg.umt.edu/project/mod16
METRIC (Week 4)	• 30m (Global) • 2011 – March 2016	• Google Earth Engine Evapotranspiration Flux (EEFlux)	• http://eeflux-level1.appspot.com

Summary: Publicly Available Global ET Products

ET Sources	Spatial/Temporal Resolutions	Data Source	Availability
GLDAS (Week 5)	• 1/8th-1 degree (Global) • 3-hour, monthly • 1979 – May 2016 • 1979 – 2010	• NASA/NOAA • Mirador • Giovanni	• http://mirador.gsfc.nasa.gov • http://giovanni.gsfc.nasa.gov/giovanni
ALEXI (Week 5)	• 8km (will be available globally from MODIS) • Daily, 2-12 week composites	• NOAA	• http://www.ospo.noaa.gov/Products/land/getd/index.html

Coming Up Next Week

Week 2: Applications of SMAP Data

Thank You