



## ARSET

Applied Remote Sensing Training

<http://arset.gsfc.nasa.gov>

 @NASAARSET

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# Applications of Remote Sensing to Soil Moisture and Evapotranspiration

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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](mailto:erika.podest@jpl.nasa.gov)
  - Amita Mehta: [amita.v.mehta@nasa.gov](mailto:amita.v.mehta@nasa.gov)

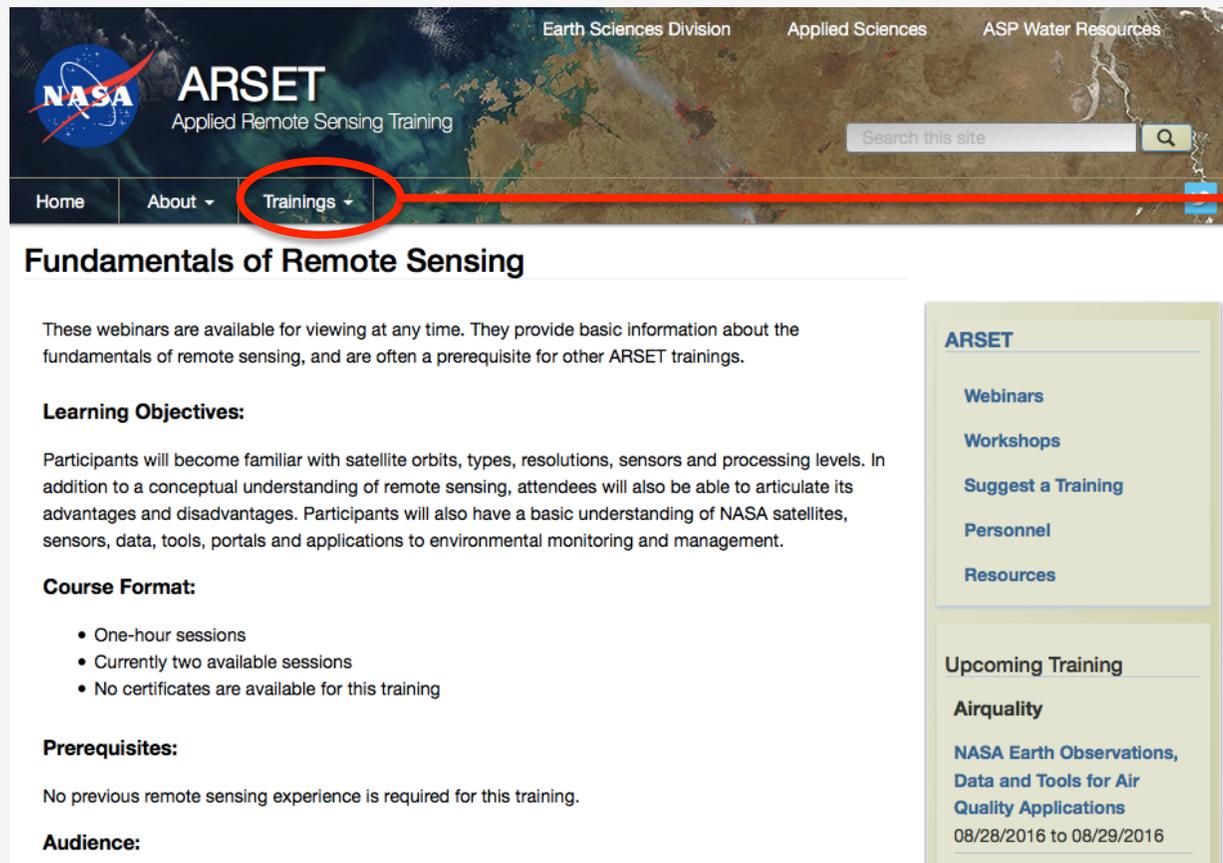
# Homework and Certificate

- 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](mailto:marines.martins@ssaihq.com))

# Prerequisite

## Fundamentals of Remote Sensing

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



Earth Sciences Division Applied Sciences ASP Water Resources

**NASA ARSET**  
Applied Remote Sensing Training

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Home About **Trainings**

### Fundamentals of Remote Sensing

These webinars are available for viewing at any time. They provide basic information about the fundamentals of remote sensing, and are often a prerequisite for other ARSET trainings.

**Learning Objectives:**

Participants will become familiar with satellite orbits, types, resolutions, sensors and processing levels. In addition to a conceptual understanding of remote sensing, attendees will also be able to articulate its advantages and disadvantages. Participants will also have a basic understanding of NASA satellites, sensors, data, tools, portals and applications to environmental monitoring and management.

**Course Format:**

- One-hour sessions
- Currently two available sessions
- No certificates are available for this training

**Prerequisites:**

No previous remote sensing experience is required for this training.

**Audience:**

**ARSET**

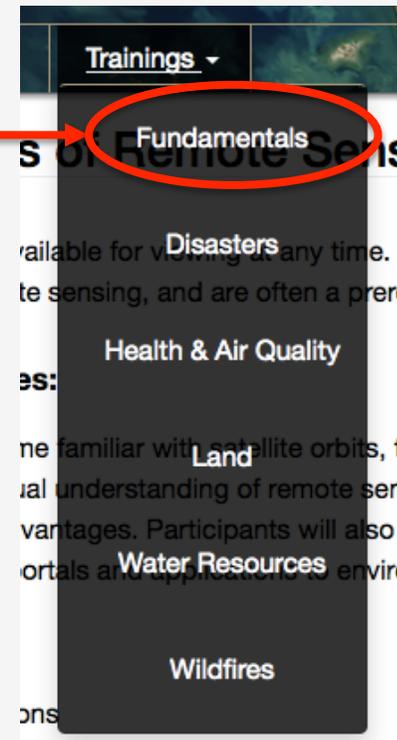
- Webinars
- Workshops
- Suggest a Training
- Personnel
- Resources

**Upcoming Training**

**Airquality**

NASA Earth Observations,  
Data and Tools for Air  
Quality Applications

08/28/2016 to 08/29/2016



**Trainings**

- Fundamentals**
- Disasters
- Health & Air Quality
- Land
- Water Resources
- Wildfires

# Course Material

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

The screenshot shows the ARSET website with a header for 'Applied Remote Sensing Training' and navigation links for 'Home', 'About', and 'Trainings'. The main content area features a large image of a satellite map with blue and yellow patches, representing soil moisture and evapotranspiration data. Below the image, the course title is displayed, followed by the dates (Thursday, September 1, 2016 to Thursday, September 29, 2016) and times (11:30 a.m.-12:30 p.m. or 6:00-7:00 p.m. EDT (UTC-4)). A brief description states that previous ARSET trainings focused on water resources and remote sensing measurements of precipitation, but this course also covers the SMAP satellite mission. A sidebar on the right lists 'Water Resources' (Water Webinars, Water Workshops, Applications), 'Upcoming Training' (Air Quality), and 'The Practical Use of Satellite Observations for Visibility and Air Quality Analysis'.

The screenshot displays the 'Course Agenda' section of the website. It lists five sessions with their respective dates: Session One (September 1, 2016), Session Two (September 8, 2016), Session Three (September 15, 2016), Session Four (September 22, 2016), and Session Five (September 29, 2016). Each session title is followed by a brief description of the topics to be covered. Below the sessions, the 'Application Area' is listed as 'Water', and 'Available Languages' are listed as 'English'. The 'Instruments/Missions' section lists Aqua, GPM, Landsat, MODIS, NPP, SMAP, Terra, TRMM, and VIIRS. The 'Keywords' section lists Model Intercomparisons, Satellite Imagery, and Tools. At the bottom of the page, there is a NASA logo, the last updated date (Aug. 15, 2016), the NASA Official (Kenneth Pickering), and links for 'Contact Us' and 'Site Map'.

# Course Objectives

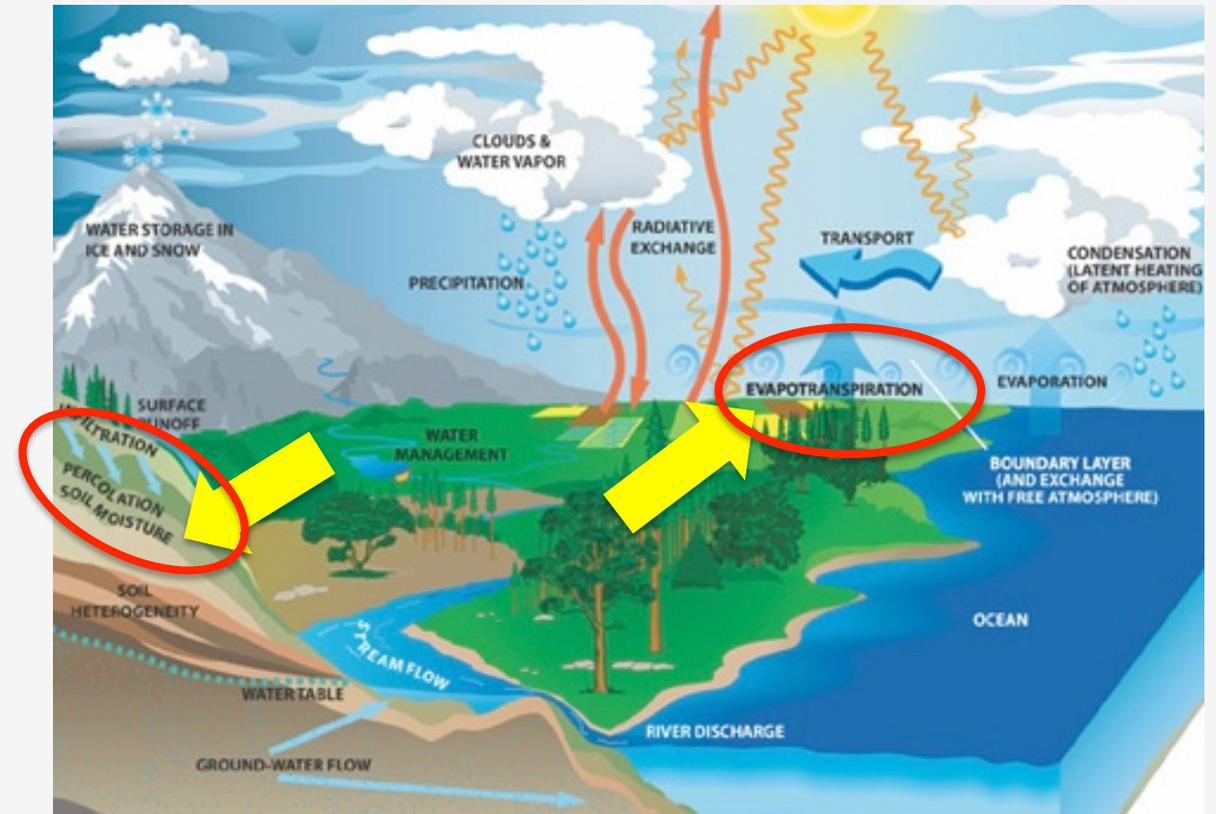
- Learn about NASA Earth observation resources (data and tools) available for water resource applications, including:
  - how evapotranspiration and soil moisture are included in the water cycle
  - how to access and visualize these data products
- Become familiar with soil moisture and evapotranspiration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



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

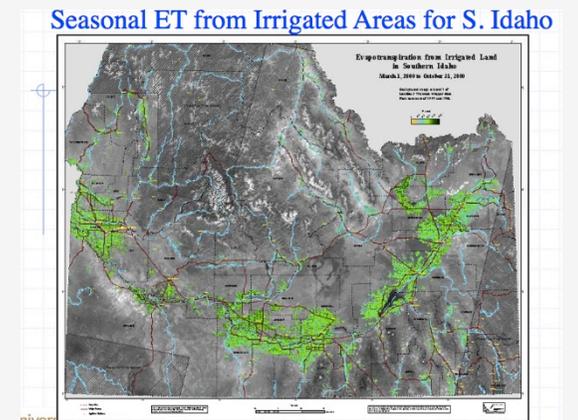
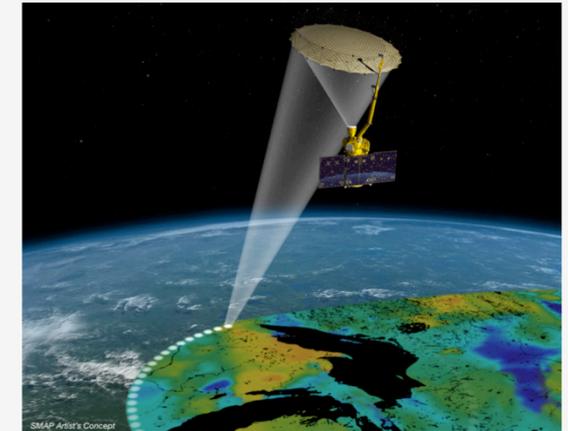
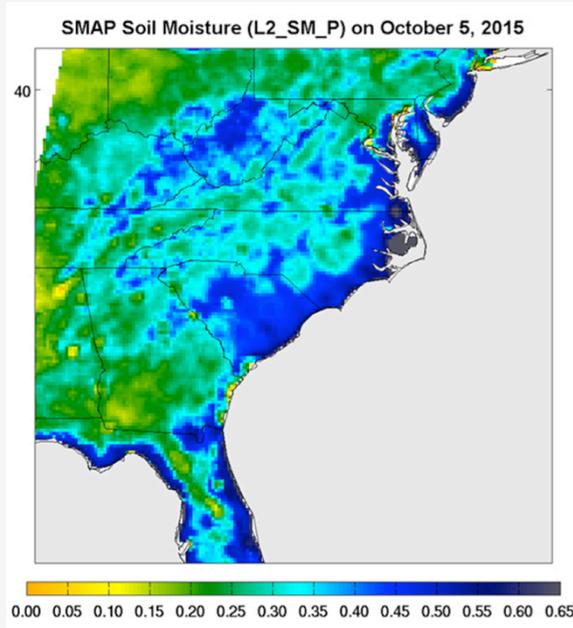
# The Water Cycle

- 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 (EEFlux) 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

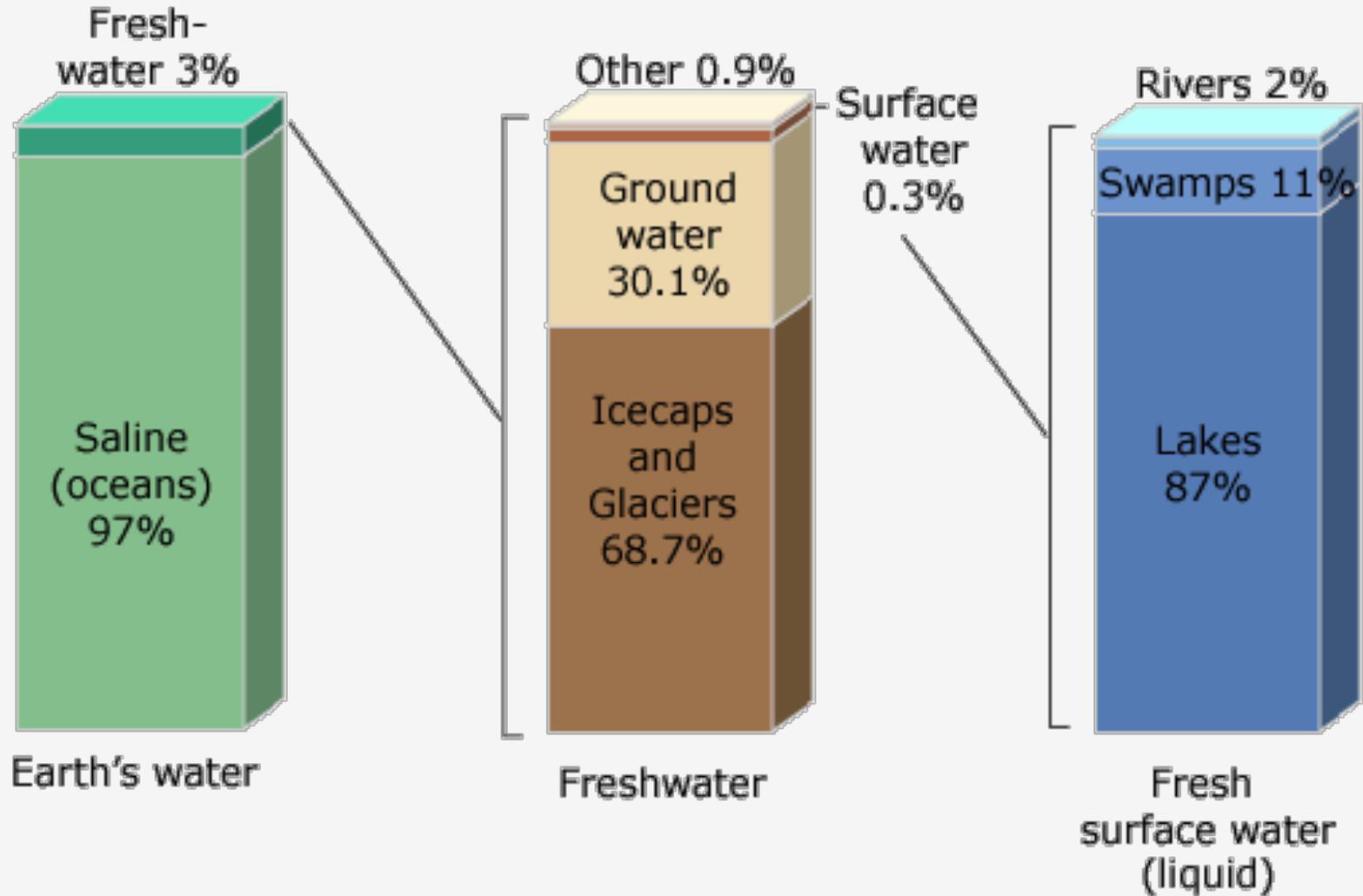
# Agenda: Week 1

- 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

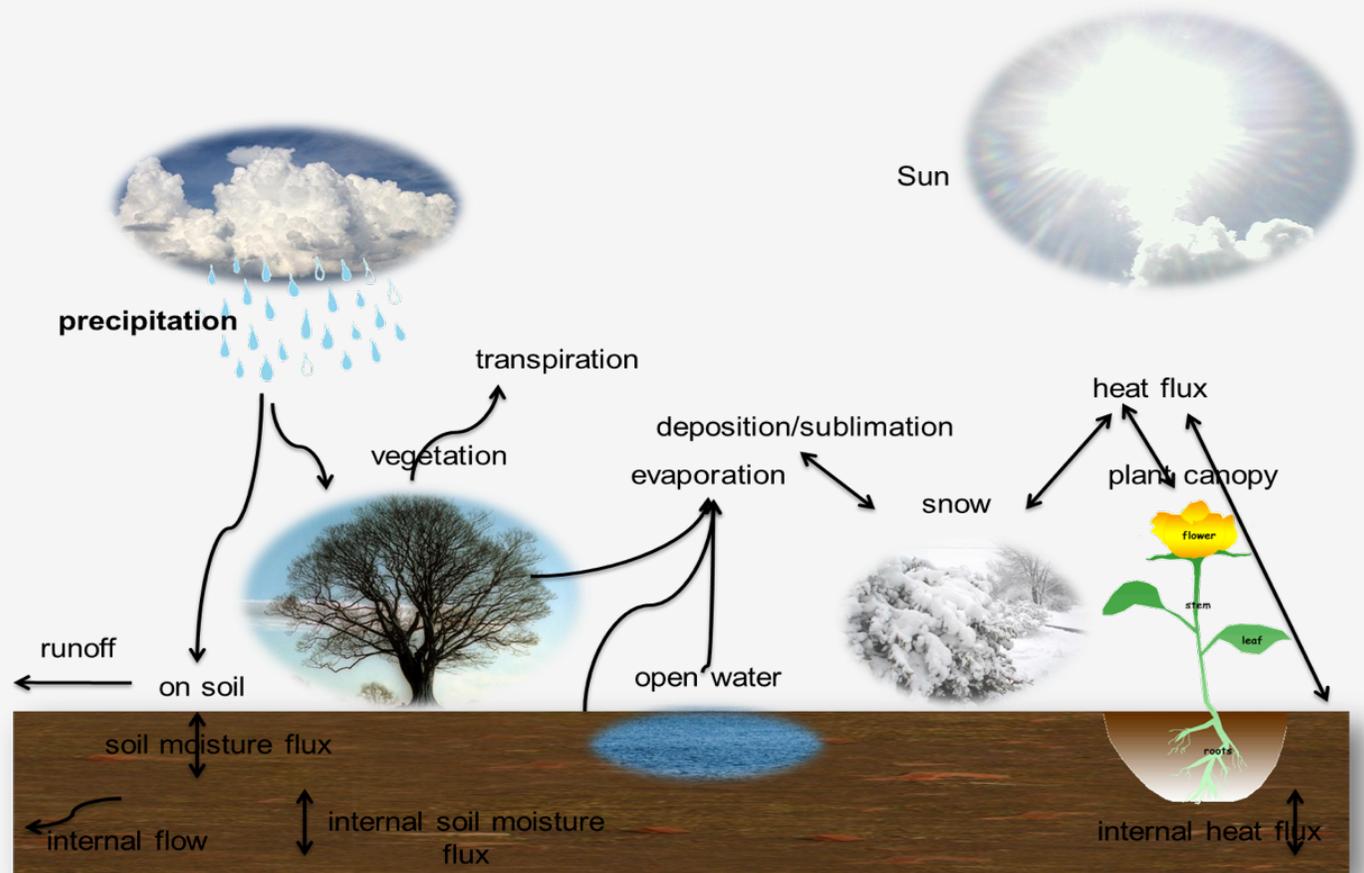
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# Water Distribution on Earth



# Importance of Soil Moisture

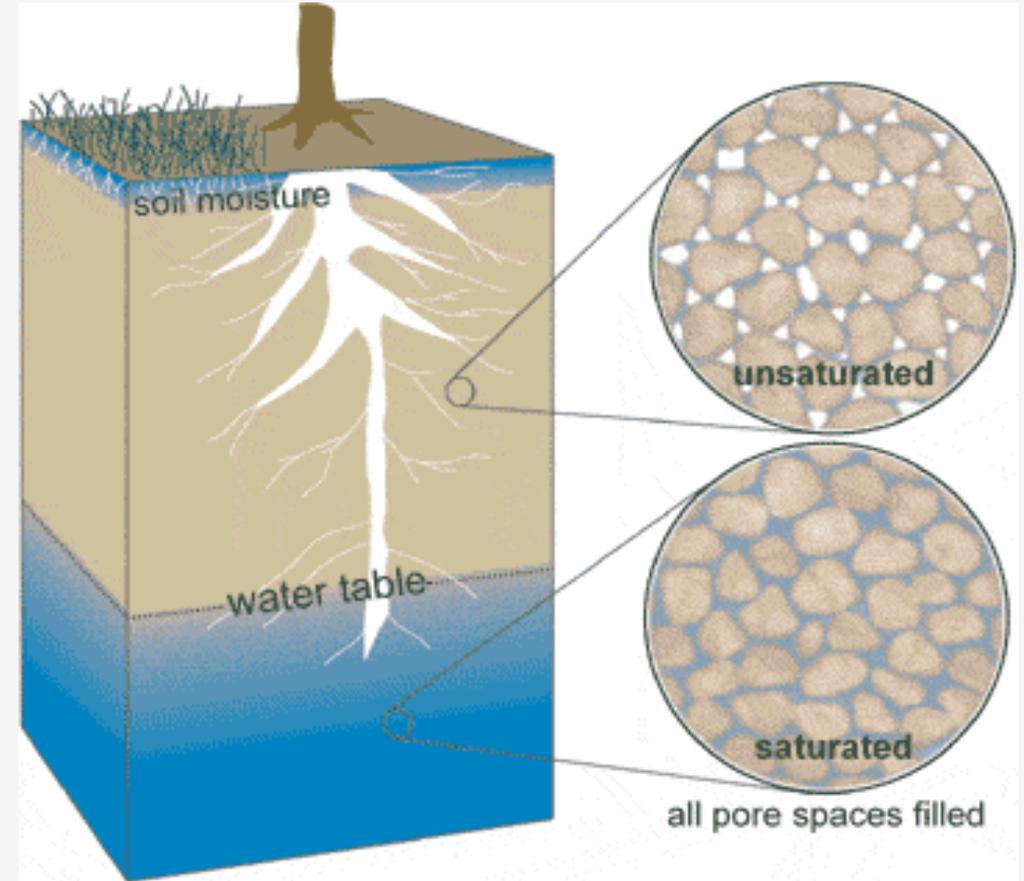
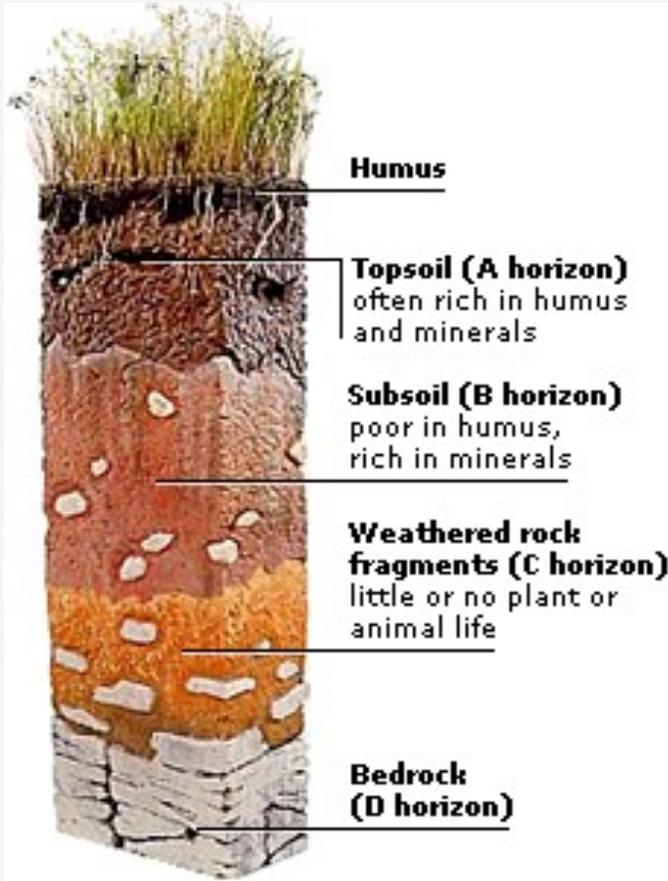
- For each kilogram of water on earth, only 1 milligram is stored as soil moisture
- Soil moisture exerts significant control over:
  - Hydrological Processes
  - Ecological Processes
  - Meteorological Processes



\* 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



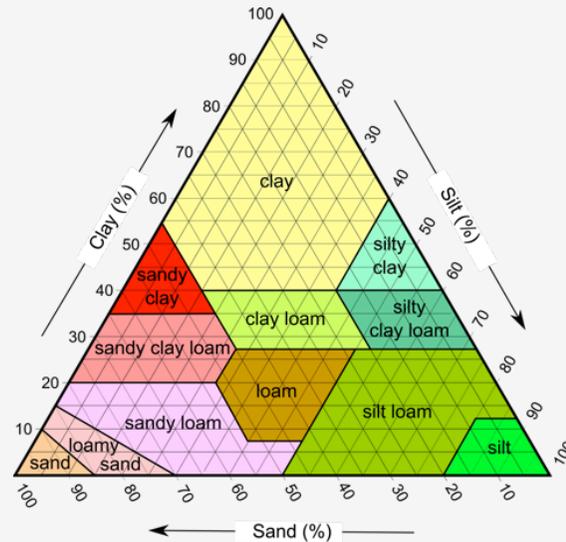
# Factors Influencing Soil Moisture

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

## Rainfall



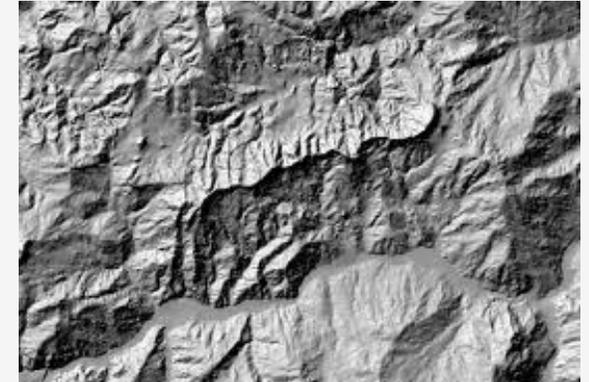
## Soil Texture



## Vegetation



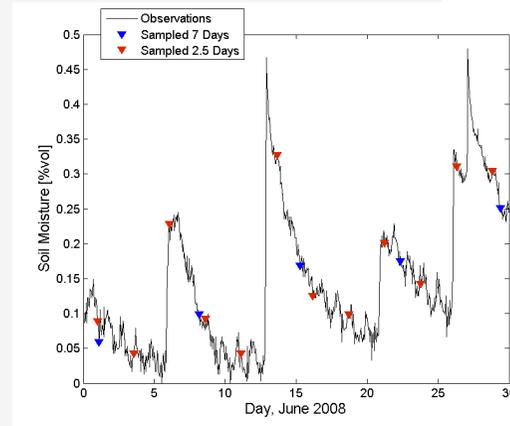
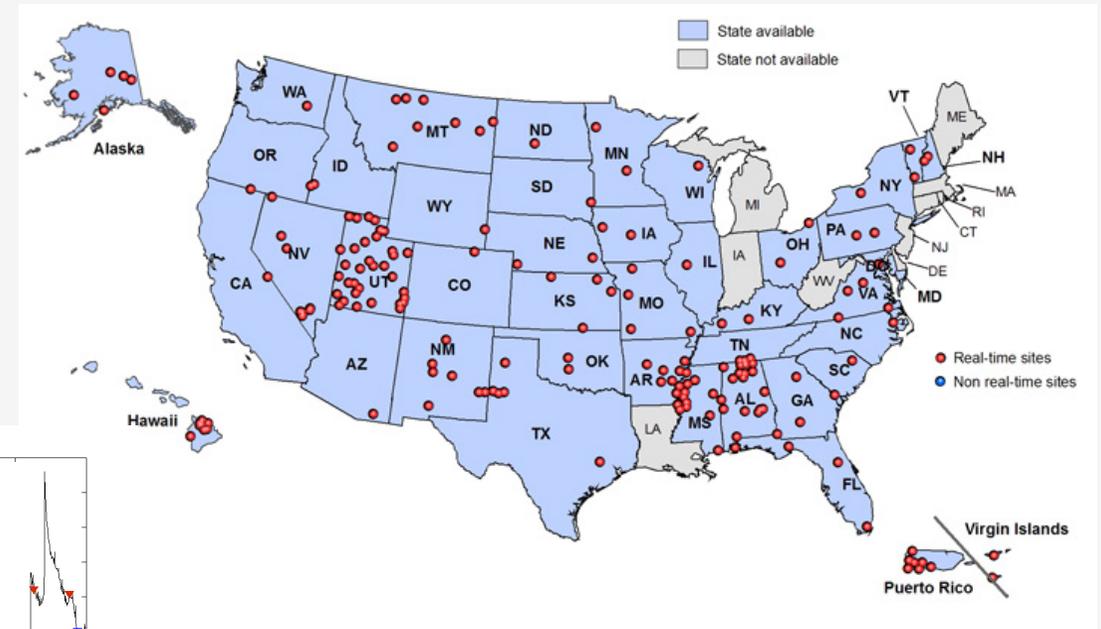
## Topography



# 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  $0.04\text{m}^3/\text{m}^3$



## 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



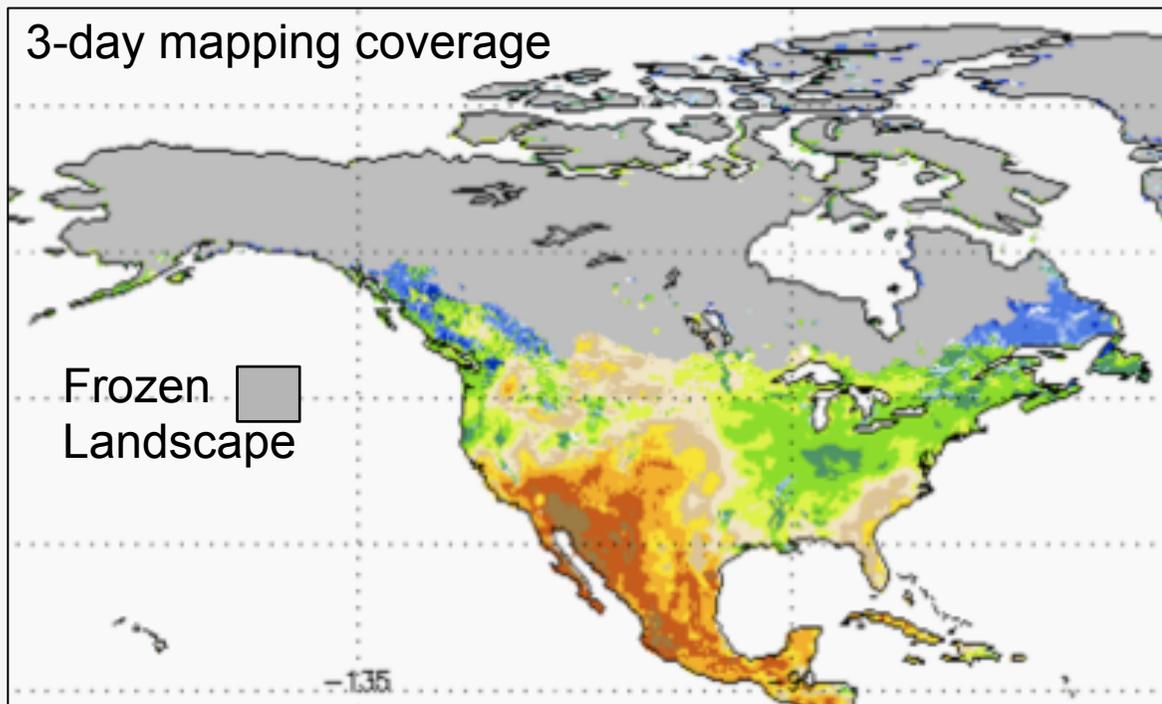
Human health and vector borne diseases



Drought monitoring and early warning

# Primary Objectives of SMAP

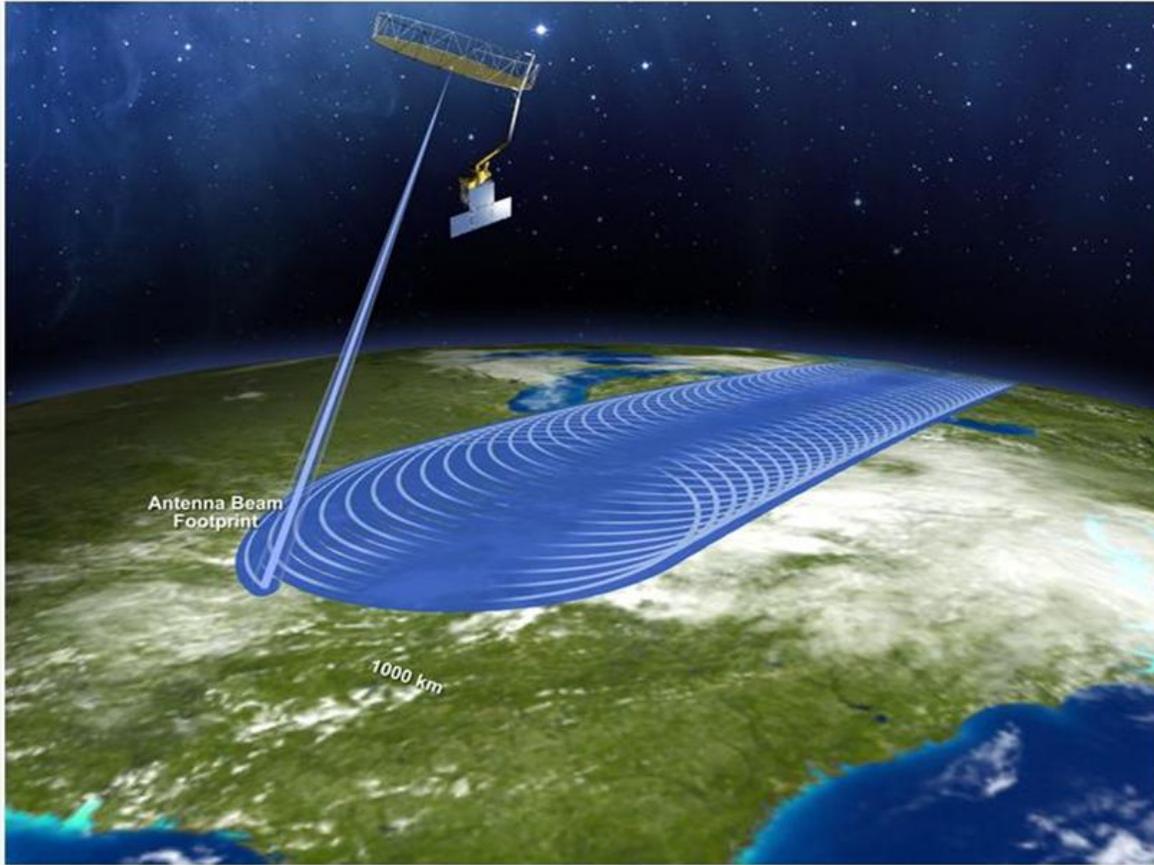
- Measure the moisture in the top 5 cm of the soil globally every 3 days



- 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)**

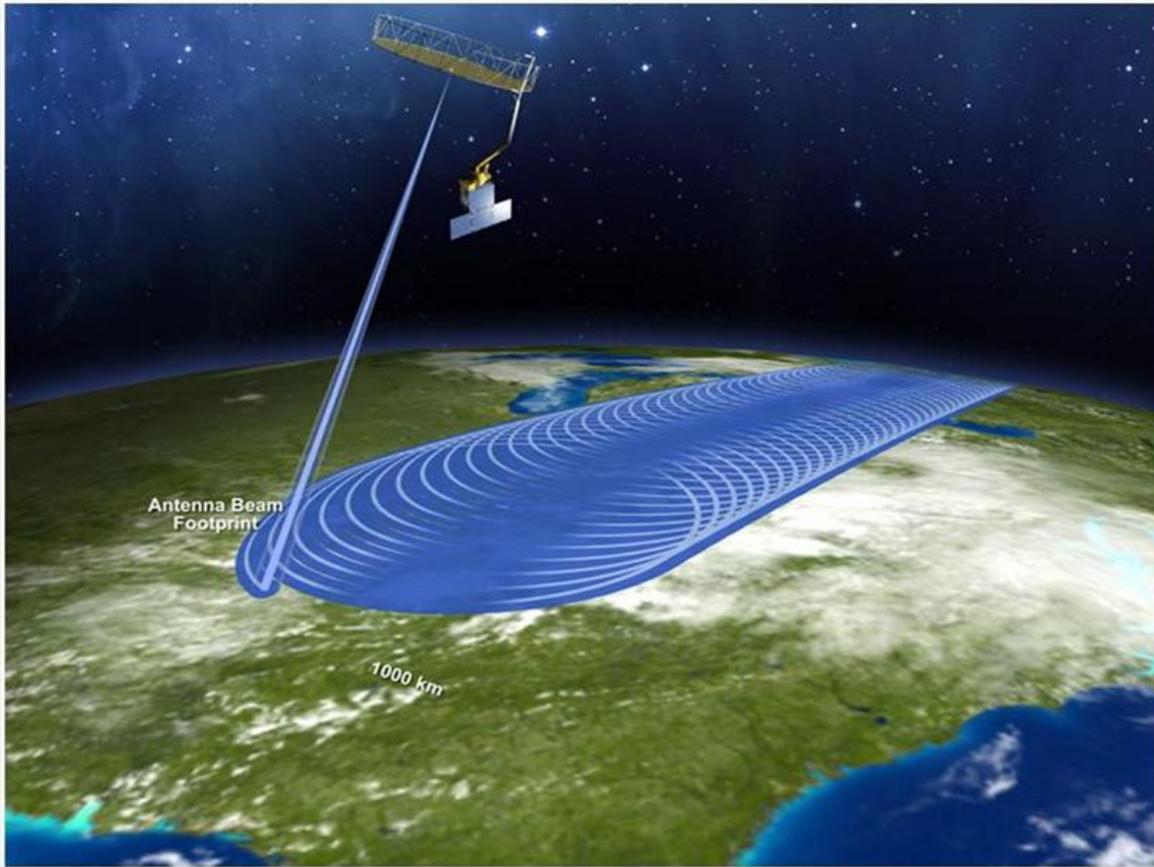
- Frequency: 1.26 GHz
- Polarization: VV, HH, HV
- Resolution: 3km
- Relative Accuracy: 1.0 dB (HH and VV), 1.5 dB (HV)

### **Radiometer**

- Frequency: 1.41 GHz
- Polarization: H, V, 3<sup>rd</sup> & 4<sup>th</sup> 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

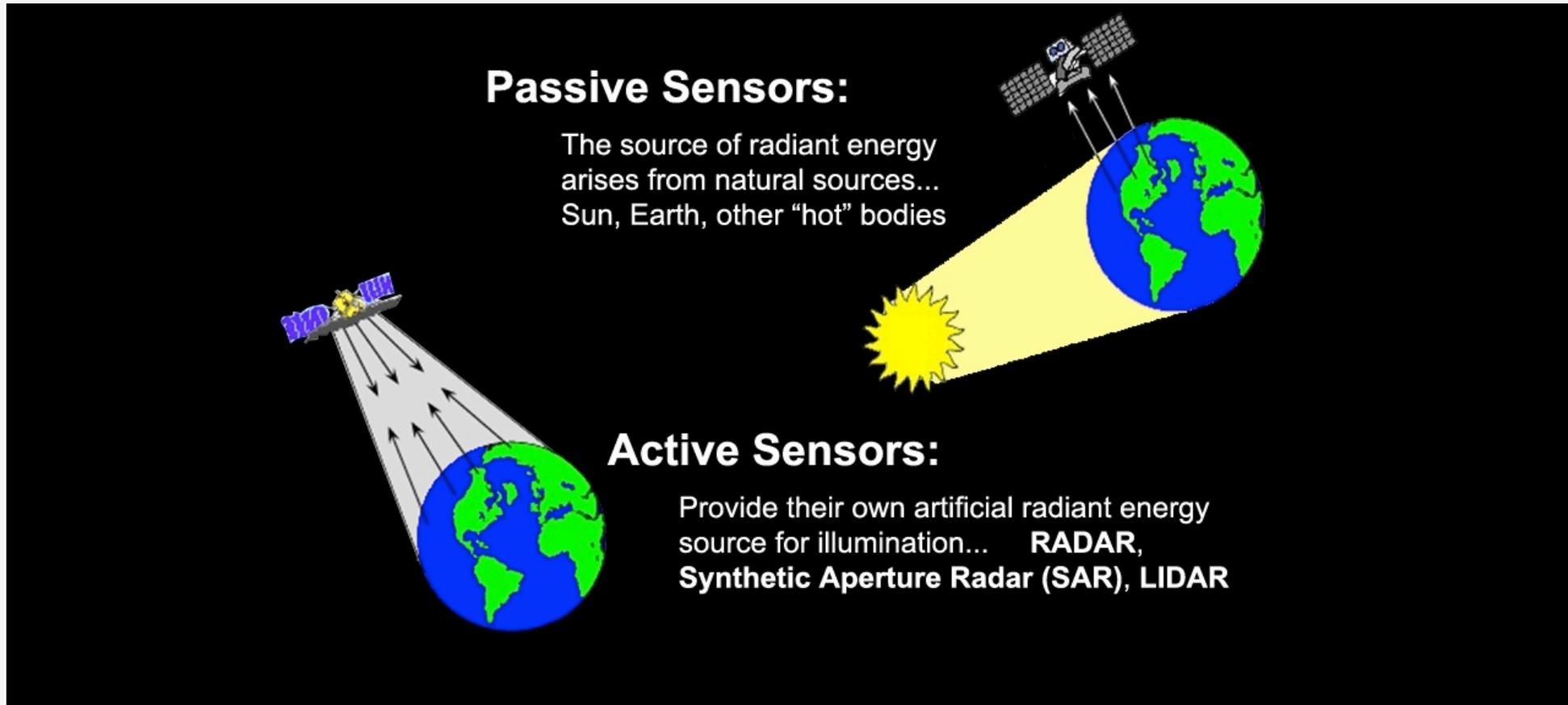
### Orbit

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

**Mission Duration: 3 yrs**

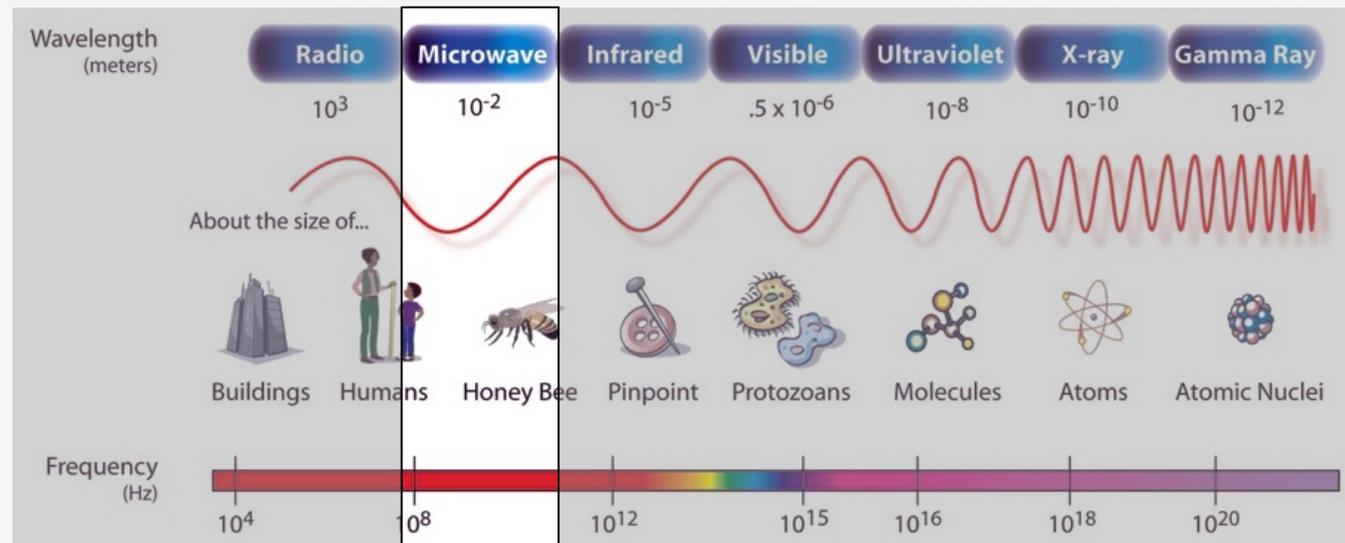
# Passive and Active Remote Sensing

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

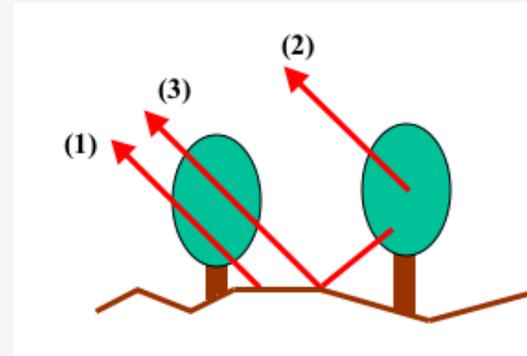


# Measurement Approach

- 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

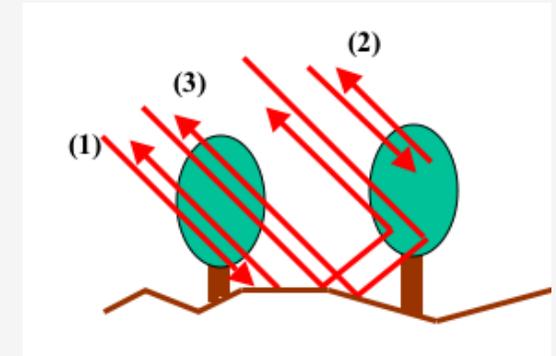
## Emission

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



## Backscatter

$$\sigma_{pq}^t = \sigma_{pq}^s L_{pq}^2 + \sigma_{pq}^v + \sigma_{pq}^{sv}$$

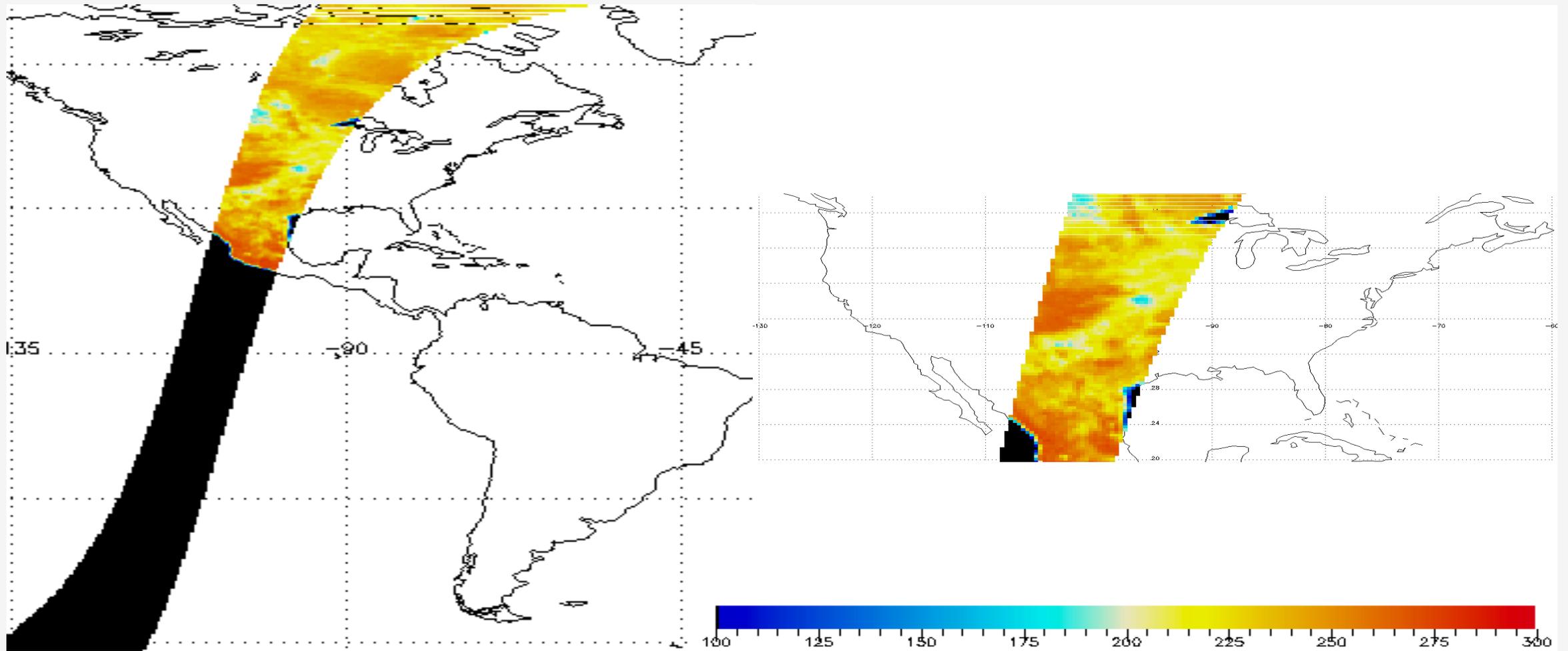


<b>Data Product Short Name</b>	<b>Description</b>	<b>Grid Resolution</b>	<b>Granule Extent</b>
<b>L1A_Radar</b>	<b>Parsed Radar Instrument Telemetry</b>		<b>Half Orbit</b>
<b>L1A_Radiometer</b>	<b>Parsed Radiometer Instrument Telemetry</b>		<b>Half Orbit</b>
<b>L1B_S0_LoRes</b>	<b>Low Resolution Radar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

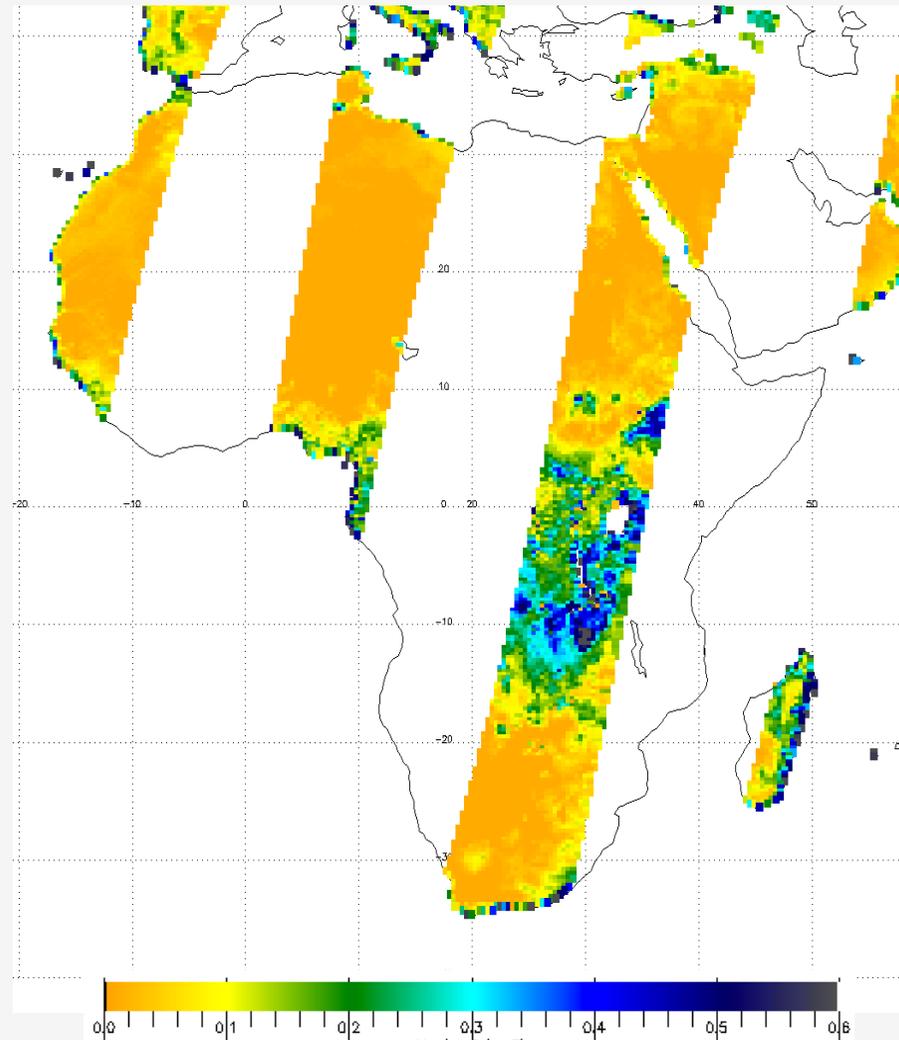
# SMAP Status

- 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

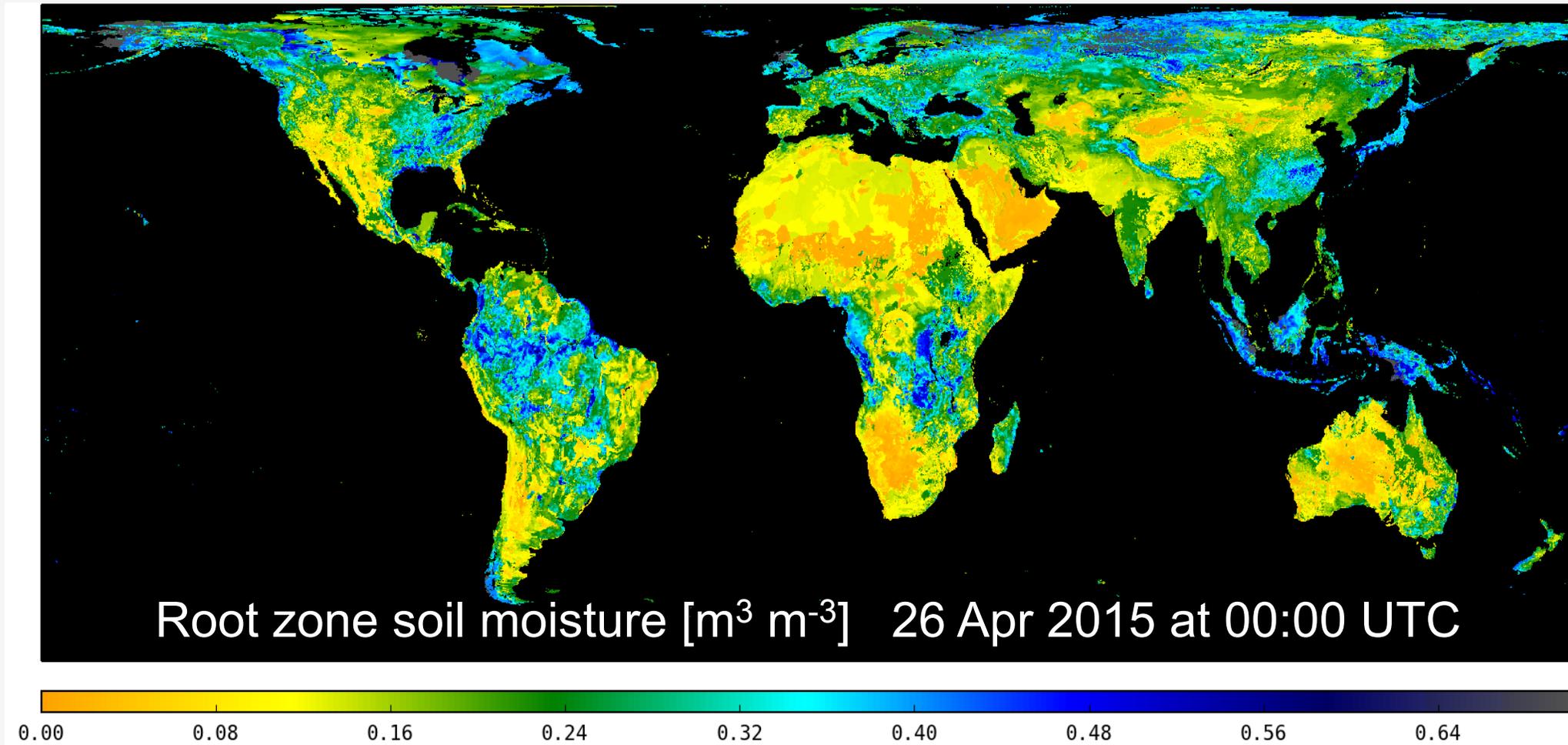
# Radiometer Data – Level 1C



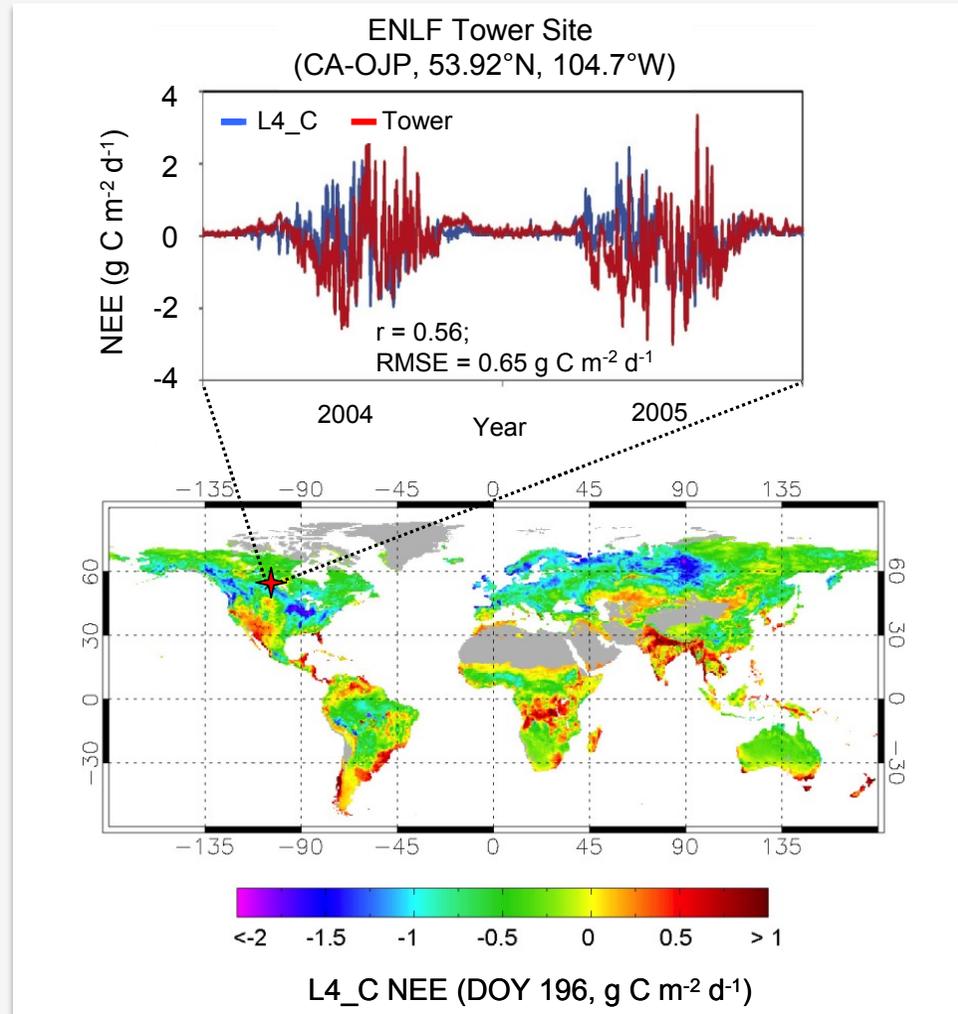
# Soil Moisture Derived from the Radiometer- Level 3



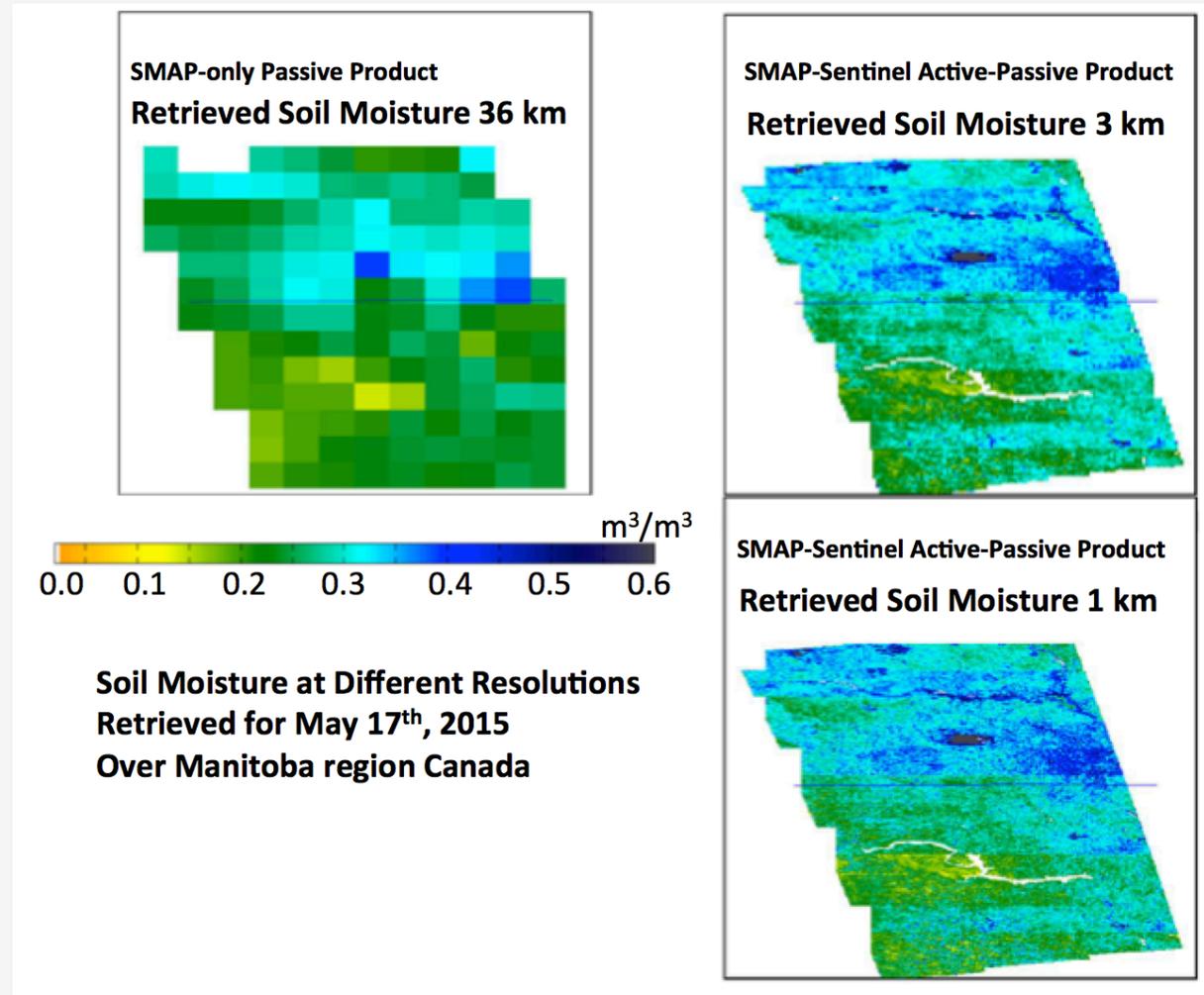
# Surface and Root Zone Soil Moisture- Level 4



# Net Ecosystem Carbon Exchange- Level 4



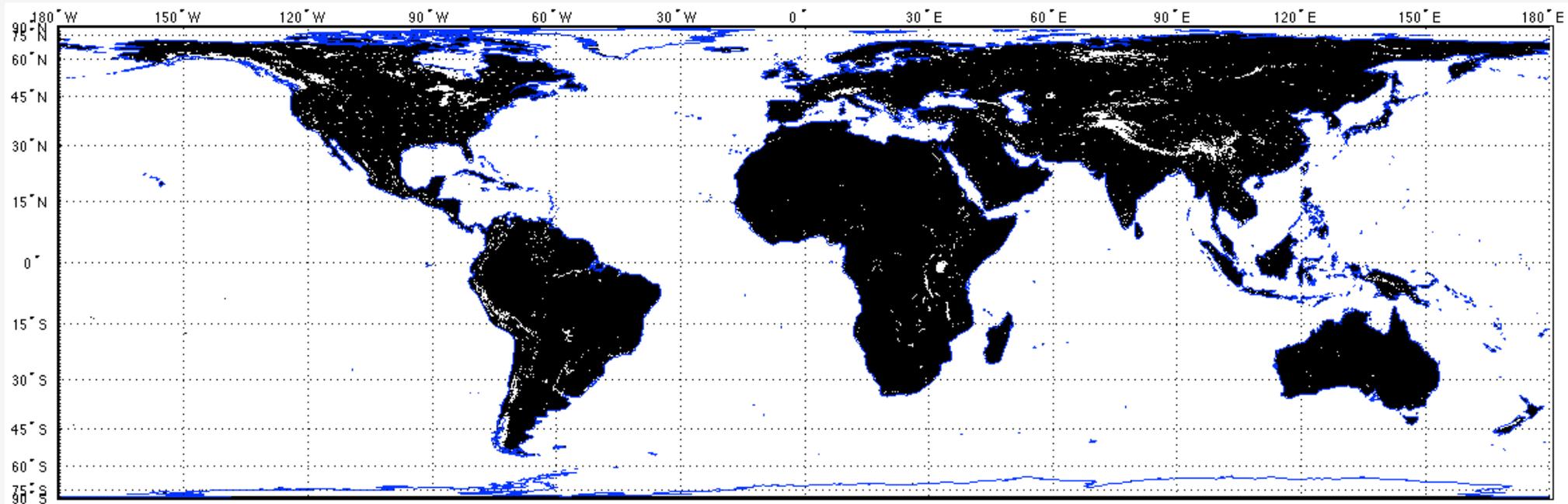
# SMAP Enhanced Active-Passive Product Using Sentinel



Source: Narendra Das

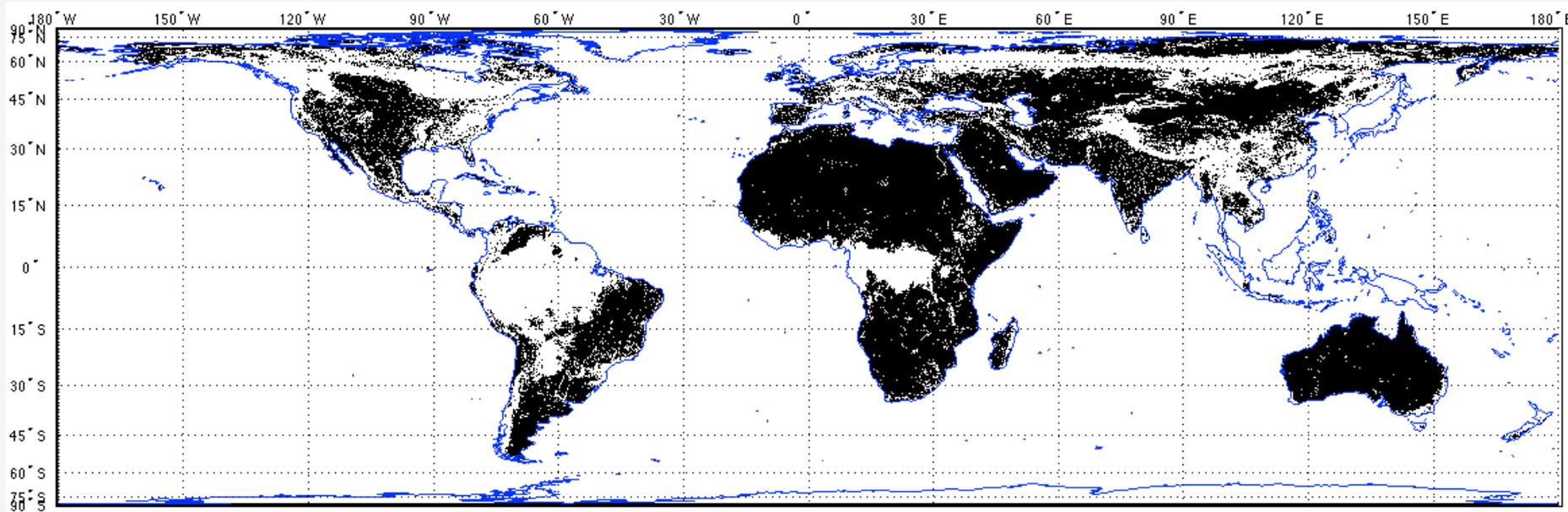
# Soil Moisture Retrieval Map

- 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  $\leq 5 \text{ kg/m}^2$
  - Urban Fraction  $\leq 0.25$
  - Water Fraction  $\leq 0.1$
  - DEM Slope Standard Deviation  $\leq 3 \text{ deg}$



# Access to SMAP Data: NSIDC

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

NSIDC National Snow & Ice Data Center

DATA RESEARCH NEWS ABOUT

SEARCH Web pages

NASA Distributed Active Archive Center (DAAC) at NSIDC

**SMAP Data**  
Soil Moisture Active Passive Data

Overview

Data Sets

[SMAP Data](#)

[Validation Data](#)

**Overview**

The National Snow and Ice Data Center (NSIDC) and the Alaska Satellite Facility (ASF) will jointly manage SMAP science data on behalf of the [NASA ESDIS Project](#). Currently, NSIDC distributes

**Measuring Soil from Space**

SMAP is a NASA Earth science mission that uses microwave radar and radiometer instruments to measure soil moisture from space.

[Read more ...](#)

**RELATED RESOURCES**

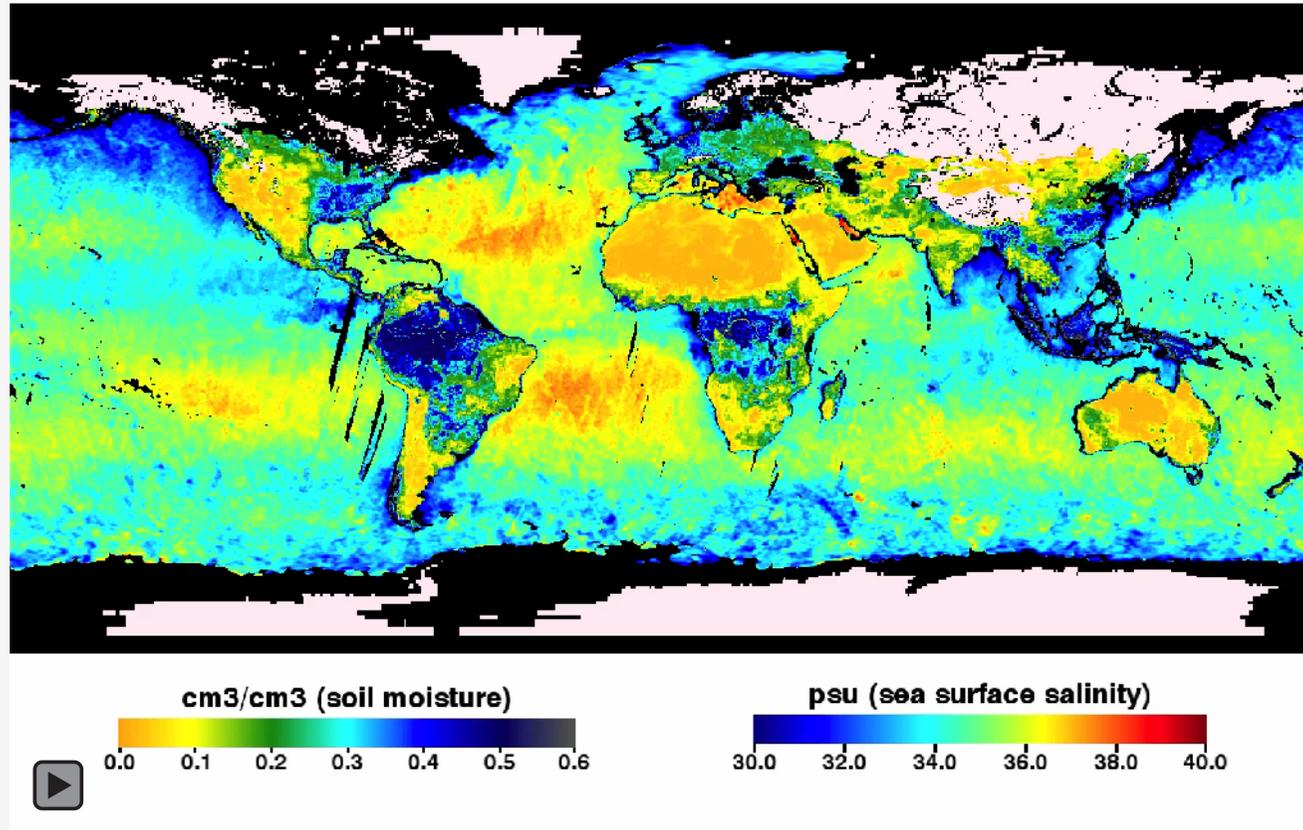
[SMAP Handbook](#)  
Essential information on the programmatic, technological, and scientific aspects of SMAP data and the mission.

[SMAP Radar Data at ASF](#)

[SMAP Information at NASA](#)

# Global Soil Moisture Animation

## SMAP: Soil Moisture + Sea Surface Salinity Mar 29 - Apr 05, 2015

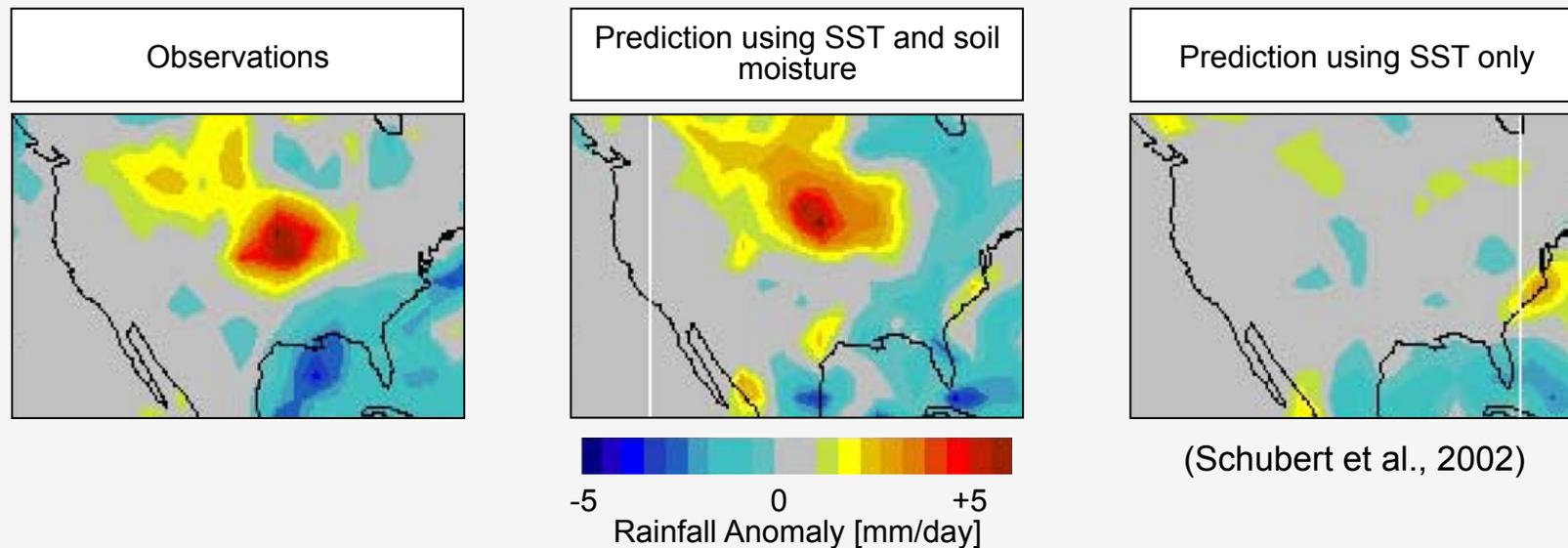


# Value of Soil Moisture Data to Weather and Climate

## 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

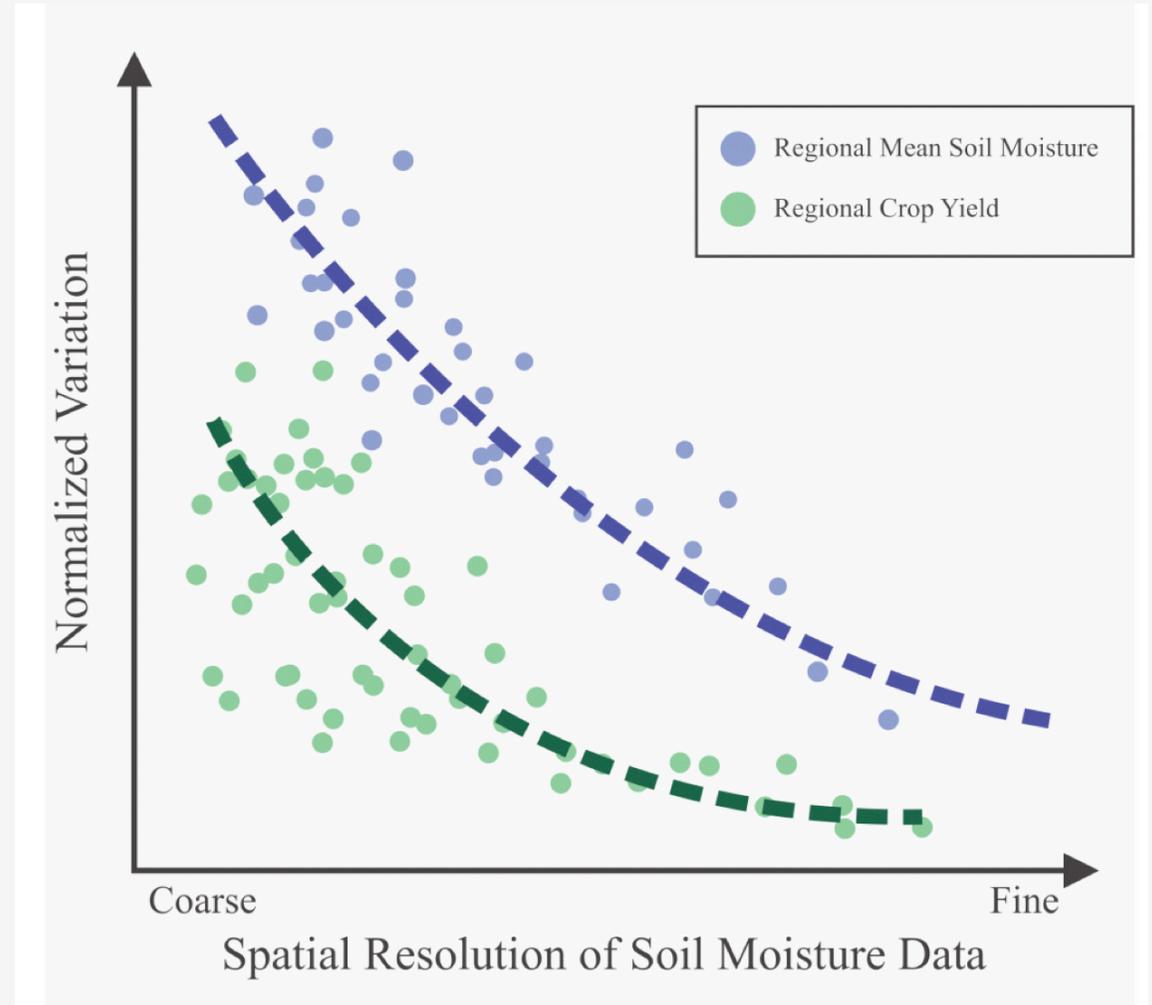




# Crop Yield Modeling

- 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
<b>Weather and Climate Forecasting</b>	
* <b>Stephane Bélair</b> , Meteorological Research Division, Environment Canada (EC); SMAP Contact: <b>Stephane Bélair</b>	Assimilation and impact evaluation of observations from the SMAP mission in Environment Canada's Environmental Prediction Systems
* <b>Lars Isaksen and Patricia de Rosnay</b> , European Centre for Medium-Range Weather Forecasts (ECMWF); SMAP Contact: <b>Eni Njoku</b>	Monitoring SMAP soil moisture and brightness temperature at ECMWF
* <b>Xiwu Zhan, Michael Ek, John Simko and Weizhong Zheng</b> , NOAA National Centers for Environmental Prediction (NCEP), NOAA National Environmental Satellite Data and Information Service (NOAA-NESDIS); SMAP Contact: <b>Randy Koster</b>	Transition of NASA SMAP research products to NOAA operational numerical weather and seasonal climate predictions and research hydrological forecasts
* <b>Michael Ek, Marouane Temimi, Xiwu Zhan and Weizhong Zheng</b> , 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: <b>Chris Derksen</b>	Integration of SMAP freeze/thaw product line into the NOAA NCEP weather forecast models
* <b>John Galantowicz</b> , Atmospheric and Environmental Research, Inc. (AER); SMAP Contact: <b>John Kimball</b>	Use of SMAP-derived inundation and soil moisture estimates in the quantification of biogenic greenhouse gas emissions
◇ <b>Jonathan Case, Clay Blankenship and Bradley Zavodsky</b> , NASA Short-term Prediction Research and Transition (SPoRT) Center; SMAP Contact: <b>Dara Entekhabi</b>	Data assimilation of SMAP observations, and impact on weather forecasts in a coupled simulation environment
◇ <b>Steven Quiring</b> , <i>Texas A&amp;M University</i> ; SMAP Contact: <b>Dara Entekhabi</b>	Hurricane power outage prediction

## Droughts and Wildfires

* <b>Jim Reardon and Gary Curcio</b> , US Forest Service (USFS); SMAP Contact: <b>Dara Entekhabi</b>	The use of SMAP soil moisture data to assess the wildfire potential of organic soils on the North Carolina Coastal Plain
* <b>Chris Funk, Amy McNally and James Verdin</b> , USGS & UC Santa Barbara; SMAP Contact: <b>Susan Moran</b>	Incorporating soil moisture retrievals into the FEWS Land Data Assimilation System (FLDAS)
◇ <b>Brian Wardlow and Mark Svoboda</b> , Center for Advanced Land Management Technologies (CALMIT), National Drought Mitigation Center (NDMC); SMAP Contact: <b>Narendra Das</b>	Evaluation of SMAP soil moisture products for operational drought monitoring: potential impact on the U.S. Drought Monitor (USDM)
◇ <b>Uma Shankar</b> , The University of North Carolina at Chapel Hill – Institute for the Environment; SMAP Contact: <b>Narendra Das</b>	Enhancement of a bottom-up fire emissions inventory using Earth observations to improve air quality, land management, and public health decision support
◇ <b>Javier Fochesatto</b> , University of Alaska; SMAP Contact: <b>John Kimball</b>	Soil moisture in Alaskan ecosystem soils
◇ <b>Amir AghaKouchak</b> , University of California, Irvine; SMAP Contact: <b>Dara Entekhabi</b>	Integrating SMAP into the Global Integrated Drought Monitoring and Prediction System: Toward near real-time agricultural drought monitoring
◇ <b>Renato D'Auria</b> , ALTEC S.p.A; SMAP Contact: <b>Randy Koster</b>	Satellite soil moisture accuracy evaluation for hydrological operative forecasting (SMAHF)
◇ <b>Rong Fu</b> , University of Texas; SMAP contact: <b>Randy Koster</b>	Using SMAP data to improve drought early warning over Texas and the U.S. Great Plains

## Floods and Landslides

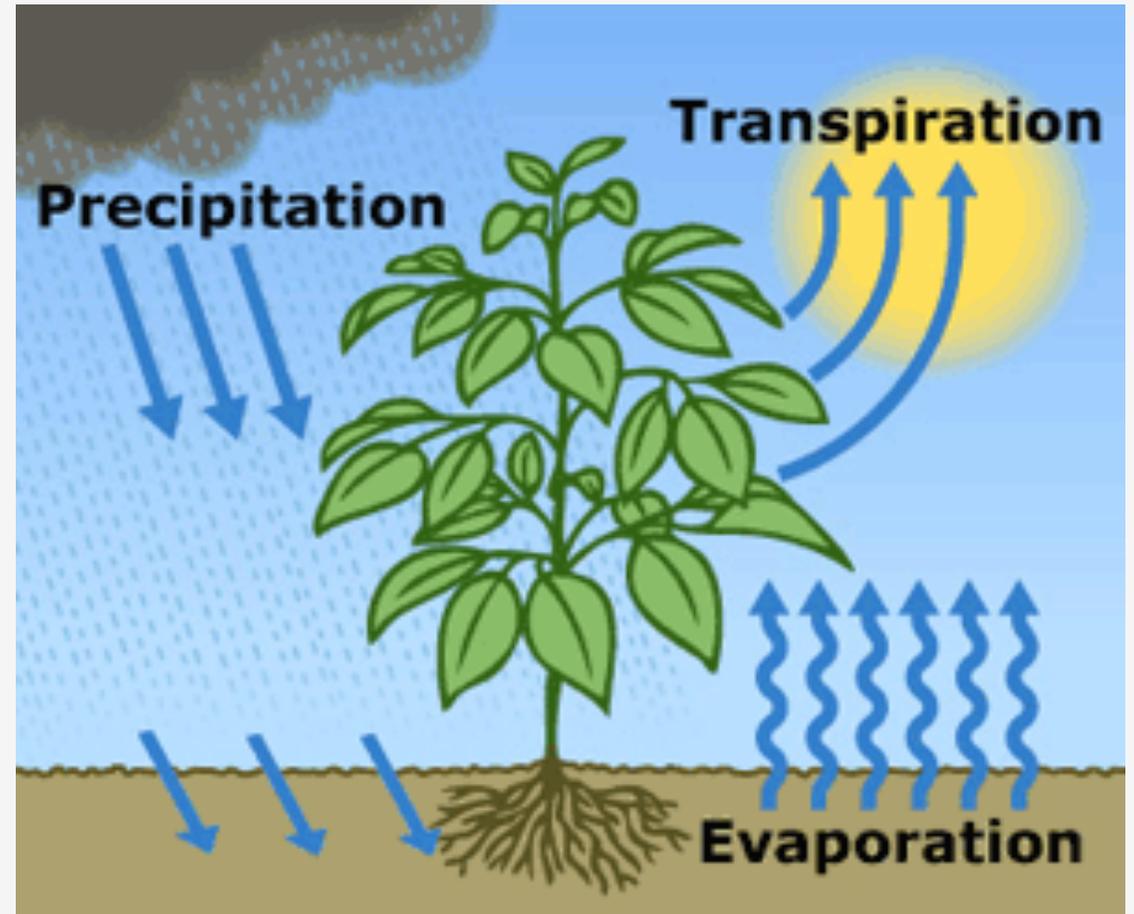
* <b>Fiona Shaw</b> , Willis, Global Analytics; SMAP Contact: <b>Robert Gurney</b>	A risk identification and analysis system for insurance; eQUIP suite of custom catastrophe models, risk rating tools and risk indices for insurance and reinsurance purposes
* <b>Kashif Rashid and Emily Niebuhr</b> , UN World Food Programme; SMAP Contact: <b>Eni Njoku</b>	Application of a SMAP-based index for flood forecasting in data-poor regions
◇ <b>Konstantine Georgakakos</b> , Hydrologic Research Center; SMAP Contact: <b>Narendra Das</b>	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
◇ <b>Luca Brocca</b> , Research Institute for Geo-Hydrological Protection, Italian Dept. of Civil Protection; SMAP contact: <b>Dara Entekhabi</b>	Use of SMAP soil moisture products for operational flood forecasting: data assimilation and rainfall correction
◇ <b>Jennifer Jacobs</b> , University of New Hampshire; SMAP contact: <b>Narendra Das</b>	Satellite enhanced snowmelt flood predictions in the Red River of the North Basin

The background of the slide is a microscopic image of plant tissue, likely showing stomata and epidermal cells. A semi-transparent blue rectangular box is overlaid on the image, containing the title text. The text is in a black, sans-serif font and is underlined with a thin black horizontal line.

# 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)



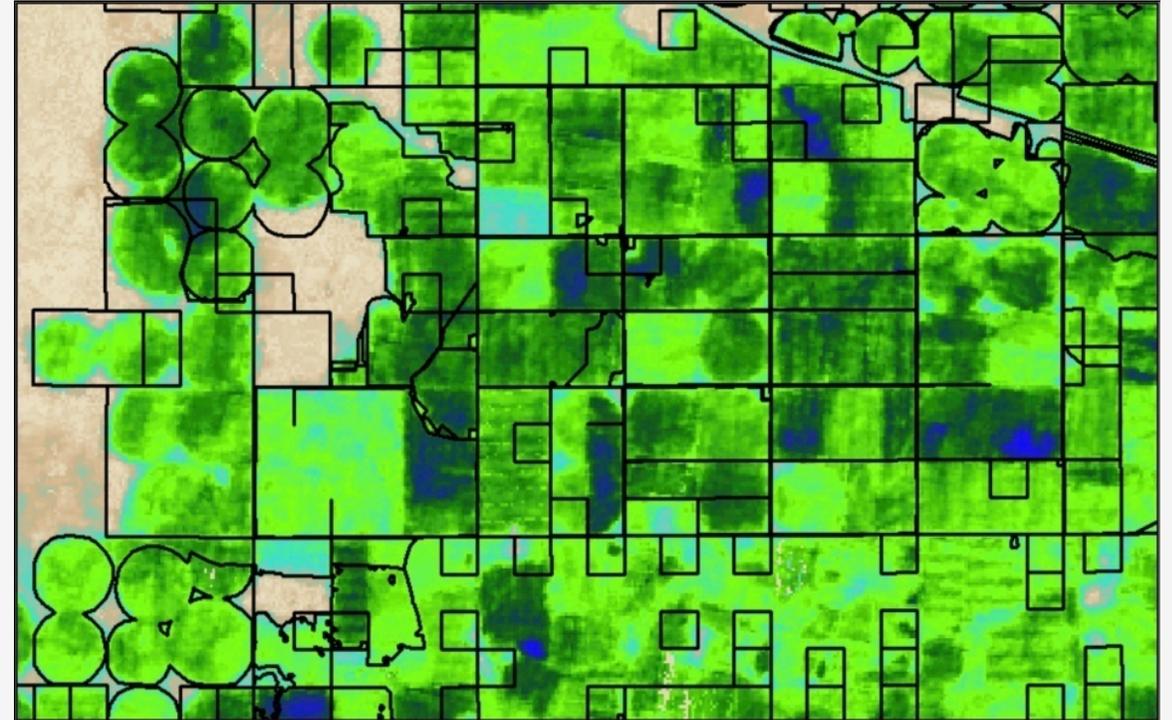
\* Image Credit: USGS

# 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



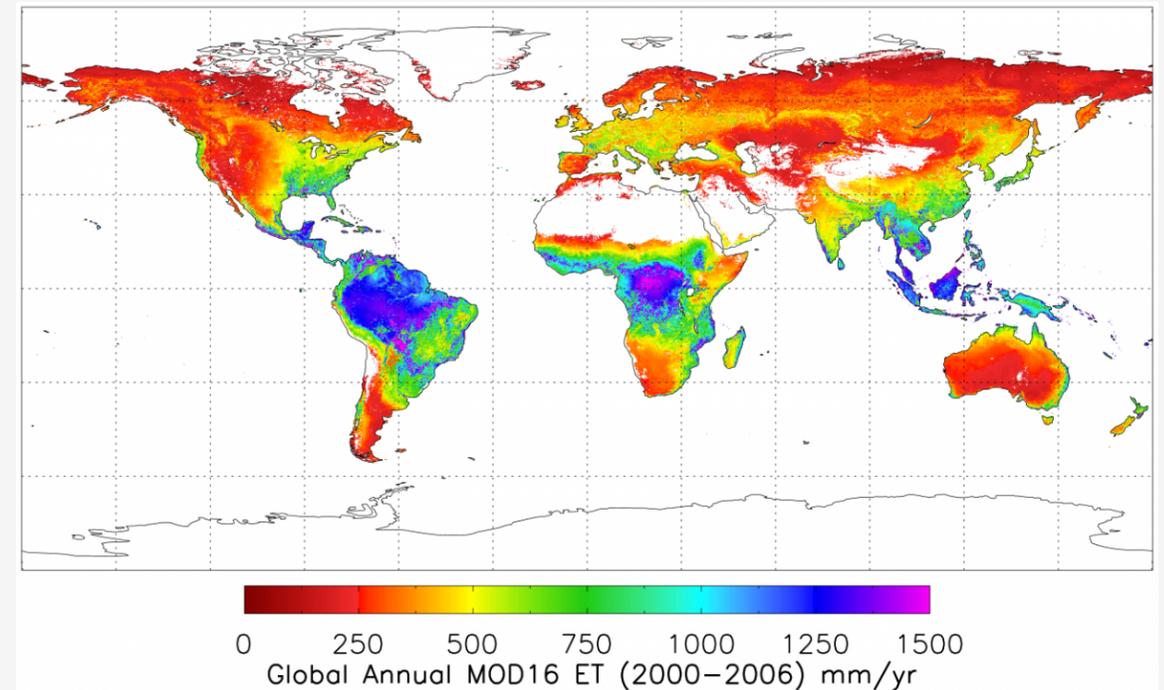
Lysimeters

\* Image Credit: Rick Allen, University of Idaho

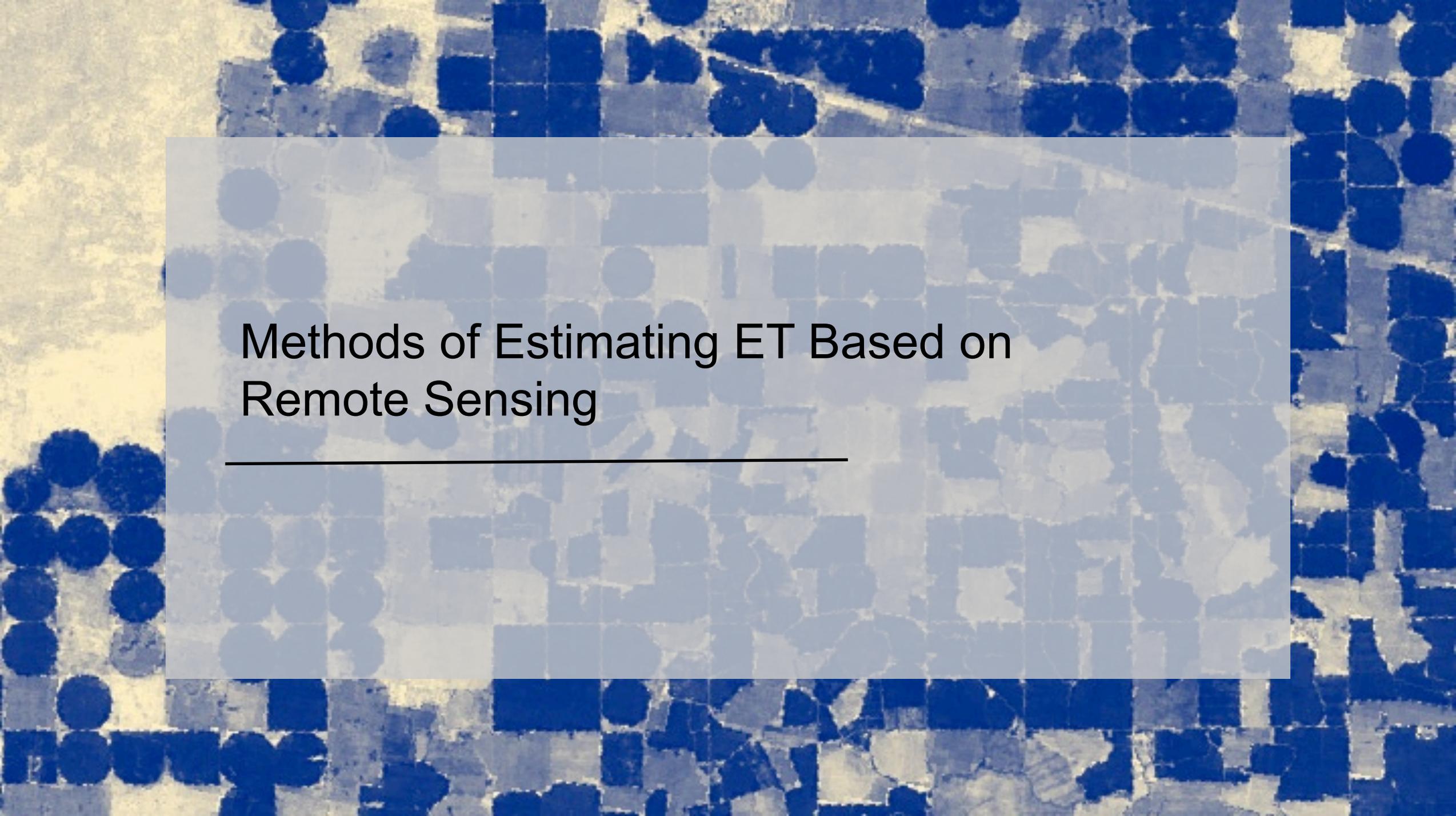
# Benefits of Estimating ET from Remote Sensing Data

- 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

The background of the slide is a satellite or aerial photograph of a field, showing a grid-like pattern of crops or plots. The colors are primarily green and brown, with a semi-transparent blue overlay in the center where the text is located.

# Methods of Estimating ET Based on Remote Sensing

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# Remote Sensors and Observations for ET

Satellite	Sensor	Parameter
Terra and Aqua	MODIS	<ul style="list-style-type: none"><li>• Normalized Difference Vegetation Index (NDVI)</li><li>• Leaf Area Index (LAI)</li><li>• Albedo (fraction of surface solar radiation reflected back)</li></ul>
Landsat	OLI, ETM+, TIRS	Spectral Reflectance, Thermal Emission

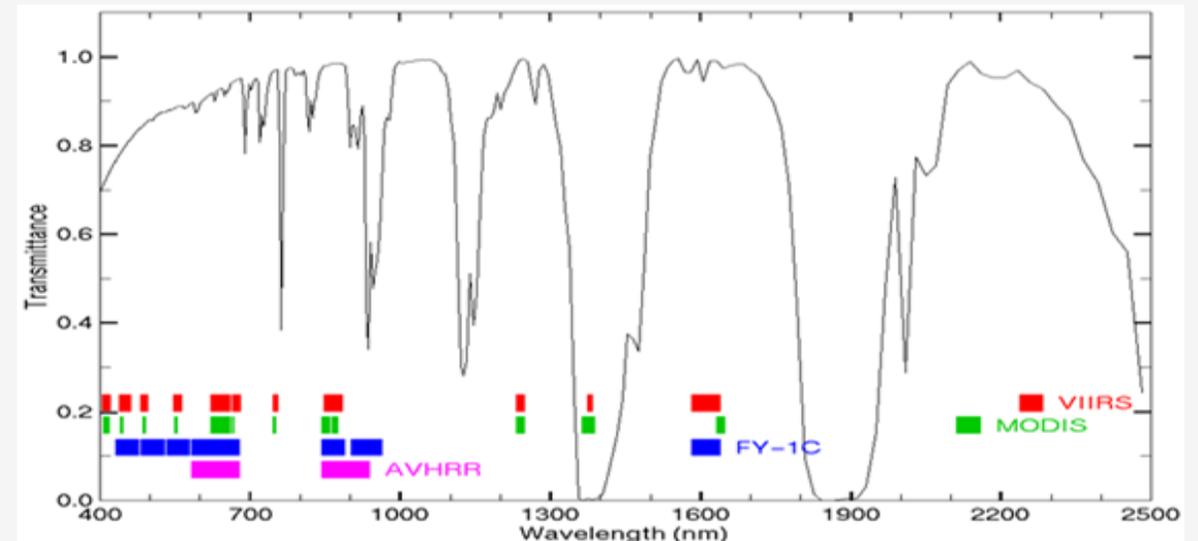
# MODerate Resolution Imaging Spectroradiometer (MODIS)

<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

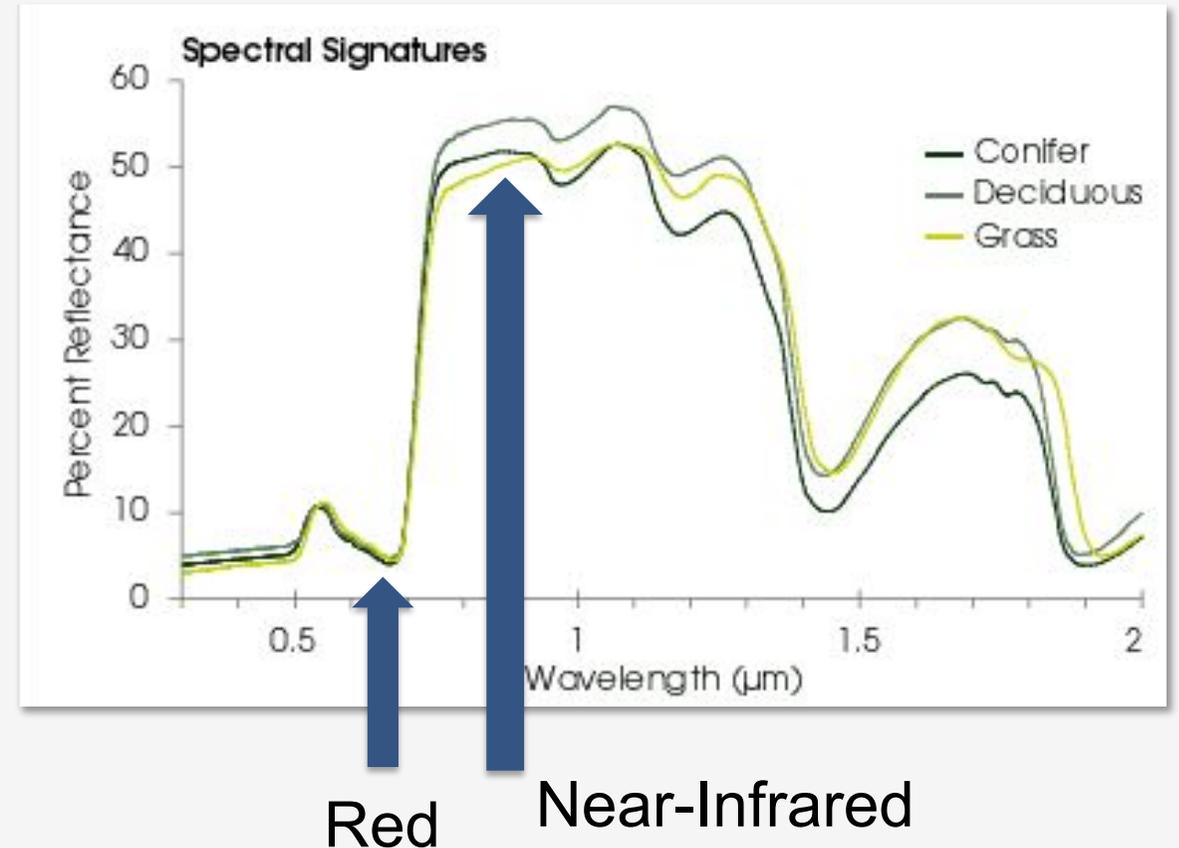
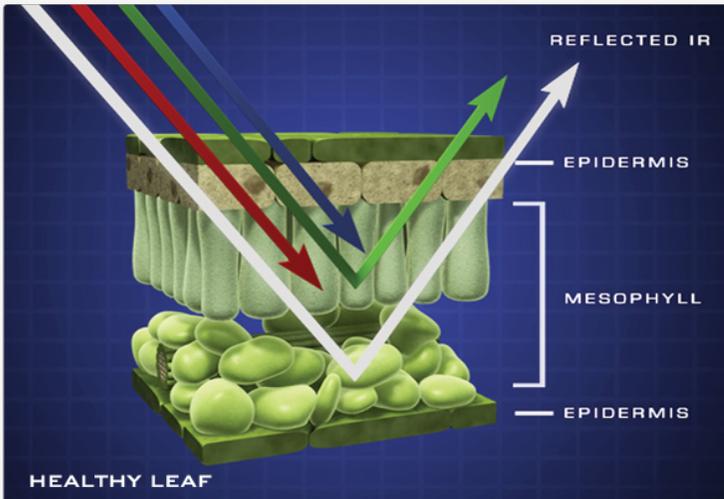


\* Image Credit: Cooperative Institute for Meteorological Satellite Studies,

# 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

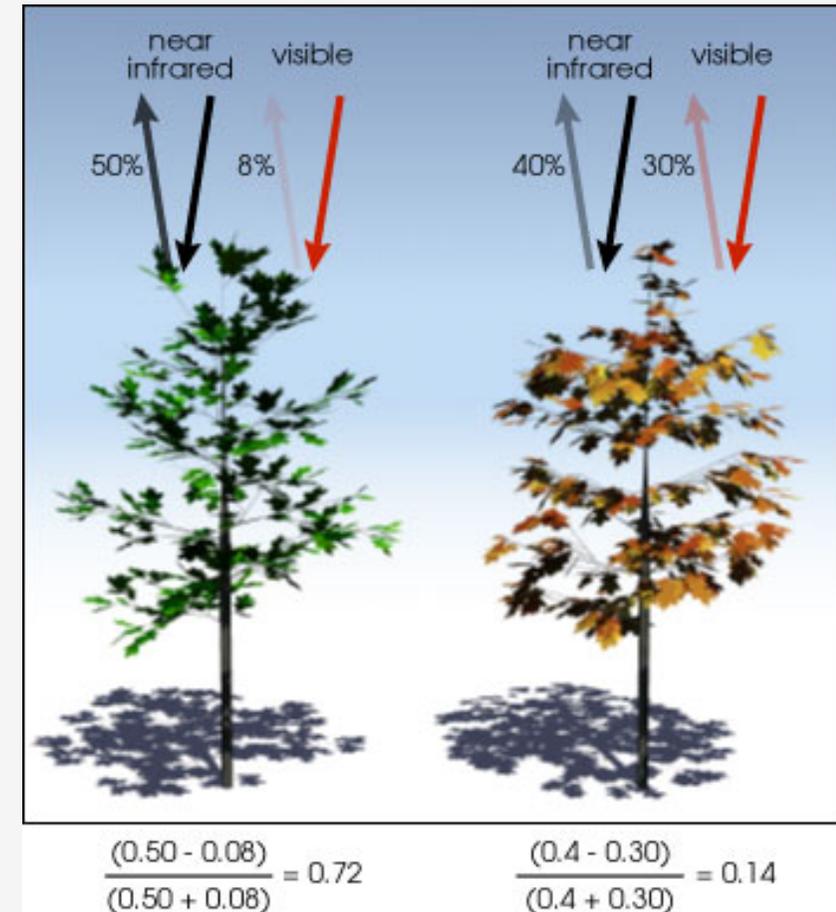


\* Image Credit (left): NASA/Jeff Cerns

# NDVI Formula

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

- $NDVI = \frac{\text{Near-Infrared} - \text{Red}}{\text{Near-Infrared} + \text{Red}}$
- 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](http://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table)



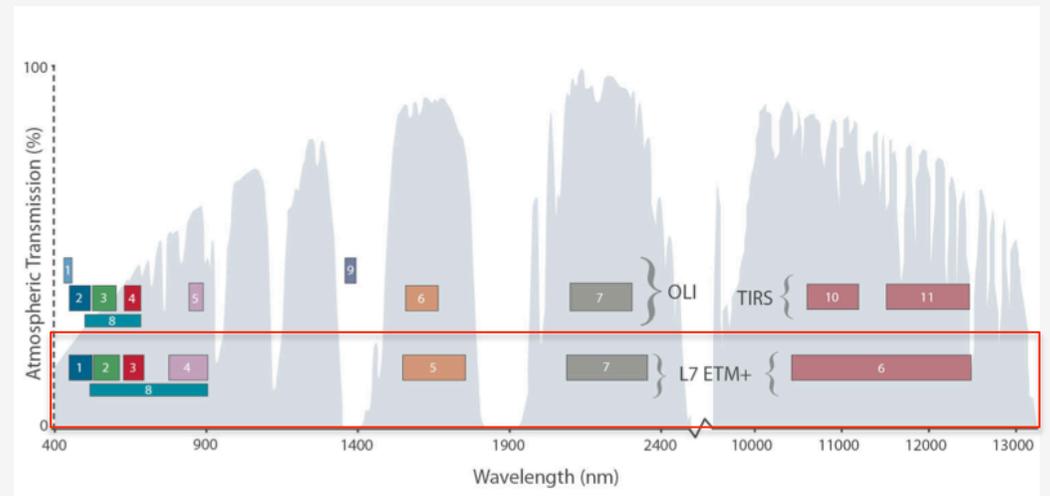
# Enhanced Thematic Mapper (ETM+)

<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



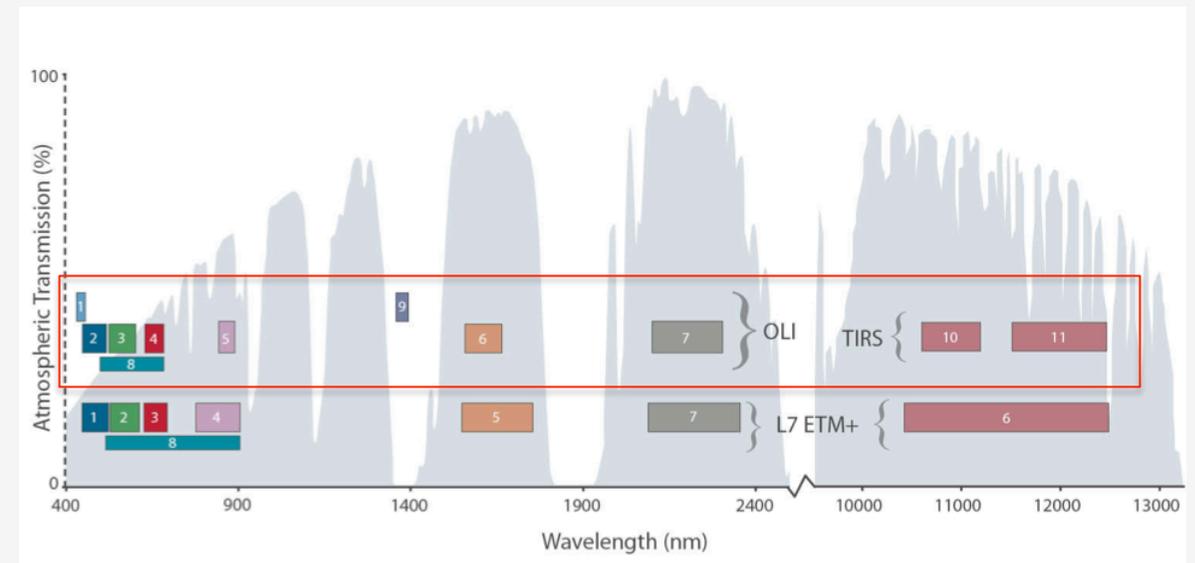
# Operational Landsat Imager (OLI)

<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

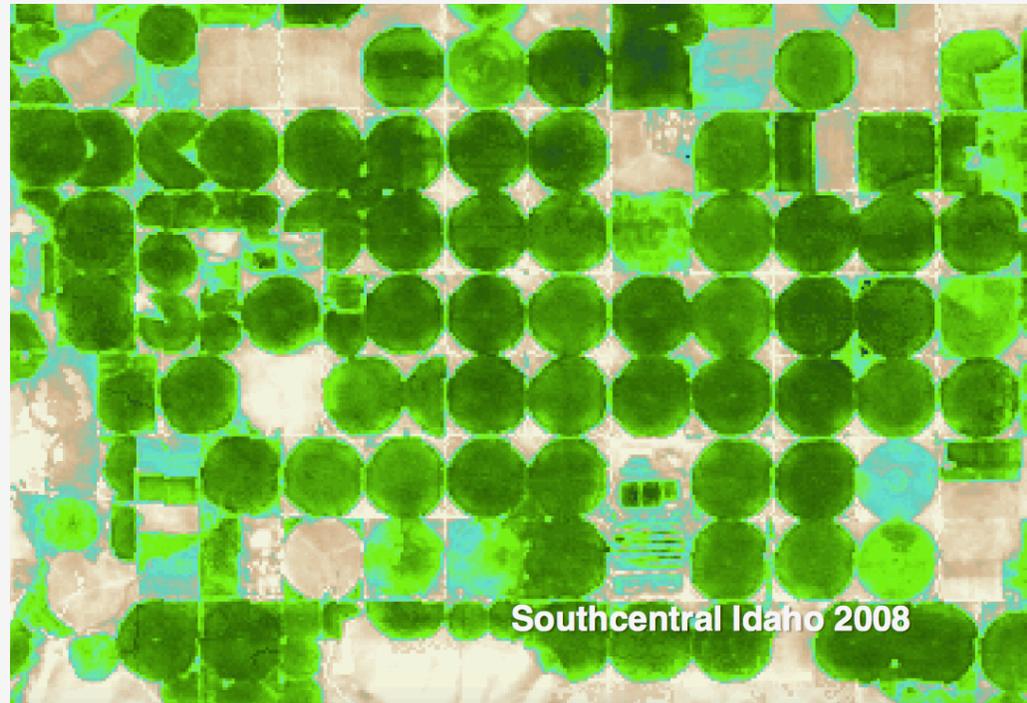
## Spectral Bands

- 2 bands centered at
  - 10.9  $\mu\text{m}$
  - 12.0  $\mu\text{m}$



## 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
    - $ET = \text{Precipitation} + \text{Irrigation} - \text{Runoff} - \text{Ground Water} + \text{Vertical Water Transport} \pm \text{Subsurface Flow} \pm \text{Soil Water Content}$
  - Surface Energy Balance
    - $ET \text{ (Latent Heat Flux)} = \text{Net Surface Radiation} - \text{Ground Heat Flux} - \text{Sensible Heating Flux}$
  - 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

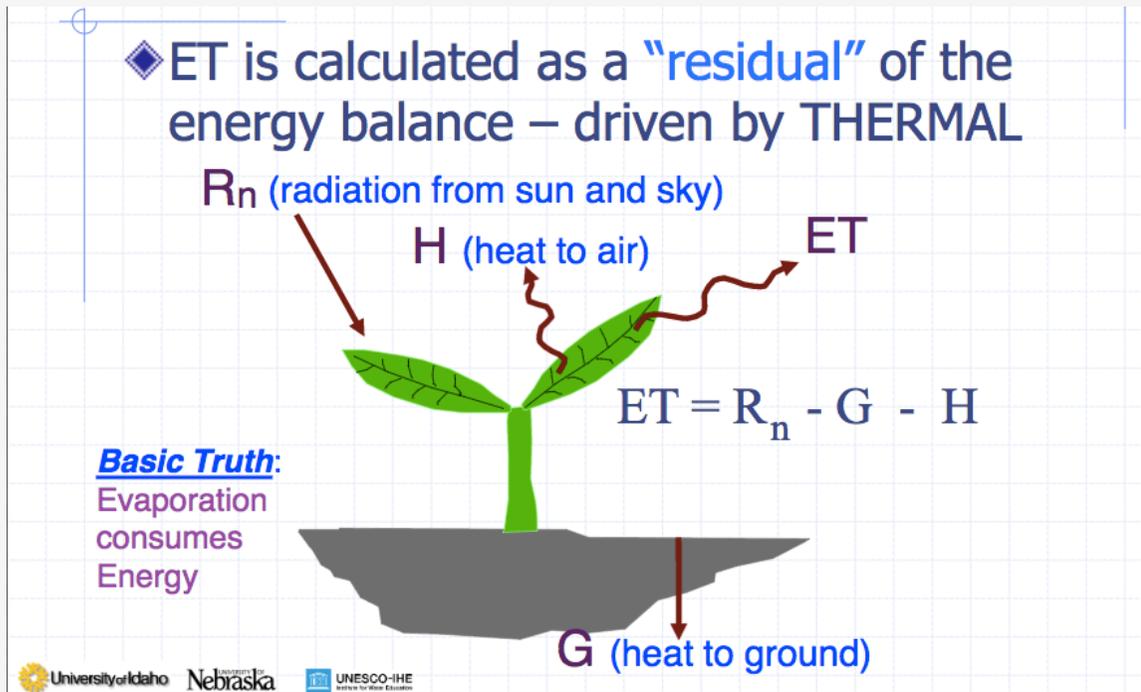
## Remote Sensing Inputs

- 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

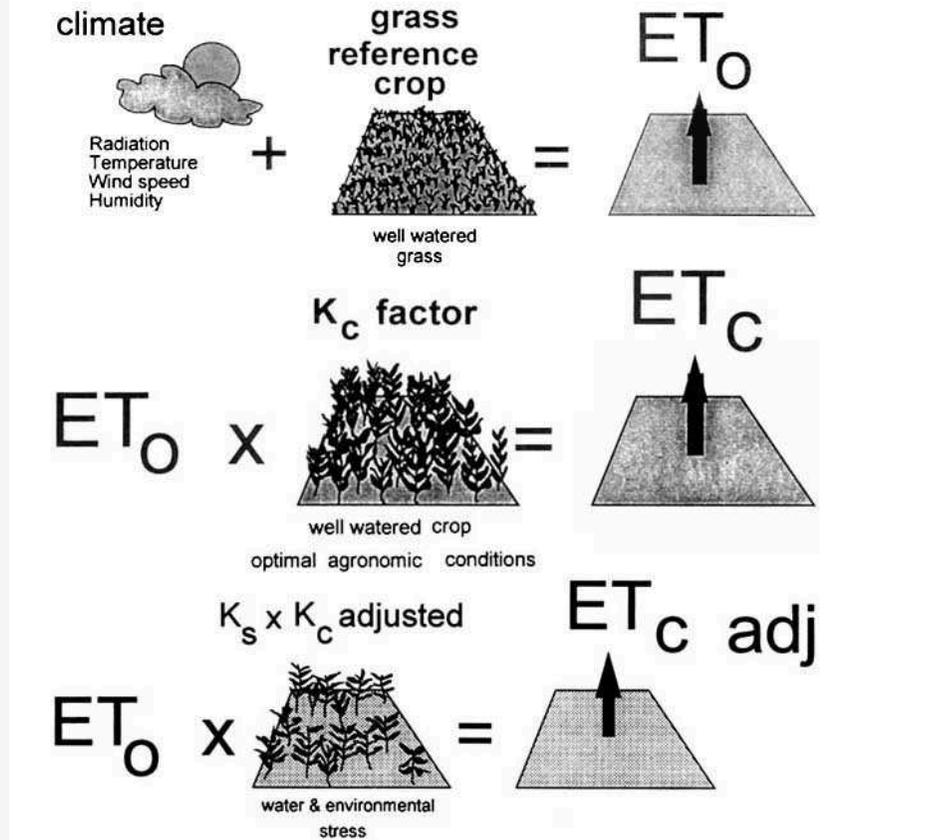


- Used by multiple groups to develop ET products
- Uses MODIS & Landsat
  - land surface temperatures
  - land cover

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

# ET Estimation from Vegetation and Crop Information

## 4. Reference ( $ET_0$ ), crop evapotranspiration under standard ( $ET_c$ ) and non-standard conditions ( $ET_{c\ adj}$ )



\* Image Credit:

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

- $ET_0$ : 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

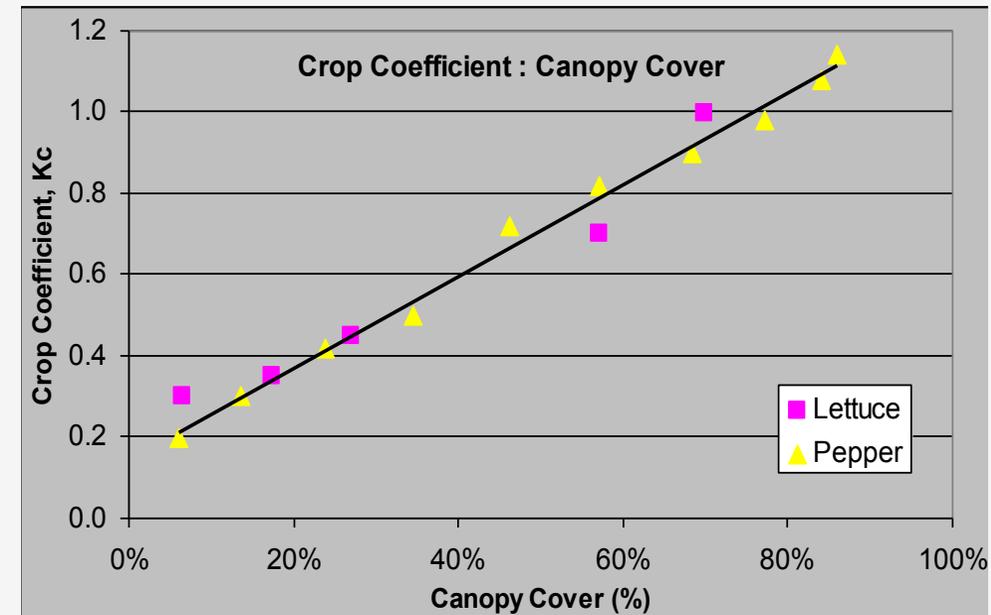
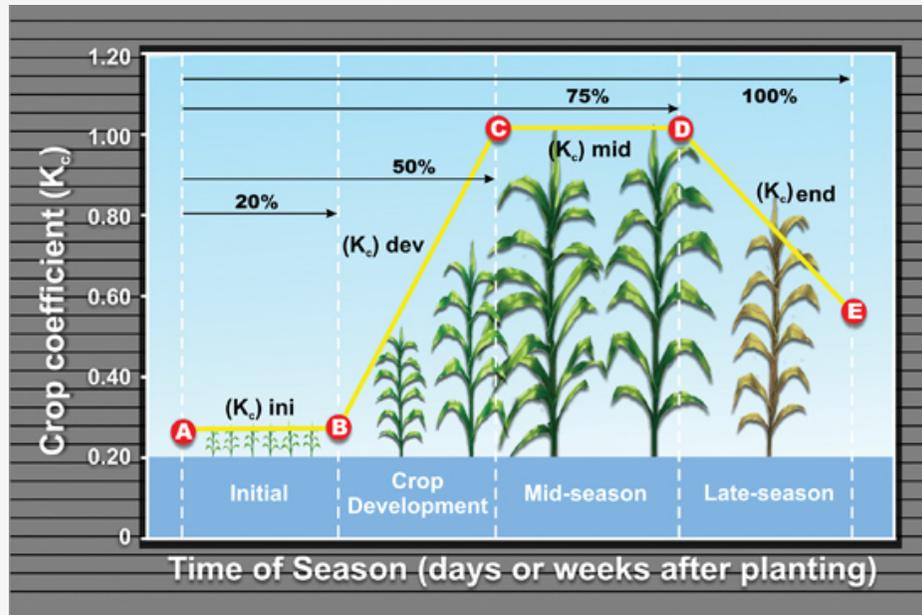
$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left( 1 + \frac{r_s}{r_a} \right)}$$

- $R_n$ : net surface radiation
- $G$ : ground heat flux
- $(e_s - e_a)$ : vapor pressure deficit
- $r_a$  &  $r_s$ : aerodynamic & surface resistance
- $\gamma$ : psychrometric constant
- $\lambda$ : 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

The background is a high-resolution aerial satellite image of agricultural fields. The fields are arranged in a grid-like pattern, with various shades of green, brown, and tan representing different crops and land uses. A semi-transparent blue rectangular overlay covers the central portion of the image, serving as a background for the text.

# ET Data Products Based on Remote Sensing

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# ET Data Products Based on Remote Sensing Observations

## Global Products

- MOD16: MODIS Global Evapotranspiration Project
  - <http://ntsg.umd.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_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_S2-5_Kilic.pdf)
  - [https://c3.nasa.gov/water/static/media/other/Day1\\_S3-3\\_Allen.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](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](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](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](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	<ul style="list-style-type: none"> <li>• Land Surface Model</li> <li>• Water and Energy Balance</li> </ul>	<ul style="list-style-type: none"> <li>• TRMM &amp; Multi-Satellite Precipitation</li> <li>• MODIS and AVHRR Land Cover</li> <li>• Landsat Topography</li> </ul>
MOD16	<ul style="list-style-type: none"> <li>• Normalized Vegetation Index (NDVI)–Based Model</li> </ul>	<ul style="list-style-type: none"> <li>• MODIS</li> </ul>
METRIC	<ul style="list-style-type: none"> <li>• Energy Balance</li> </ul>	<ul style="list-style-type: none"> <li>• Landsat</li> </ul>
ALEXI	<ul style="list-style-type: none"> <li>• Energy Balance</li> </ul>	<ul style="list-style-type: none"> <li>• MODIS</li> <li>• Landsat</li> <li>• GOES</li> </ul>

## Summary: Publicly Available Global ET Products

ET Sources	Spatial/Temporal Resolutions	Data Source	Availability
MOD16	<ul style="list-style-type: none"> <li>• 1km (Global)</li> <li>• 8-day, Monthly</li> <li>• 2000 – 2014 (will be extended to present)</li> </ul>	<ul style="list-style-type: none"> <li>• University of Montana</li> </ul>	<ul style="list-style-type: none"> <li>• <a href="http://ntsg.umt.edu/project/mod16">http://ntsg.umt.edu/project/mod16</a></li> </ul>
METRIC (Week 4)	<ul style="list-style-type: none"> <li>• 30m (Global)</li> <li>• 2011 – March 2016</li> </ul>	<ul style="list-style-type: none"> <li>• Google Earth Engine Evapotranspiration Flux (EEFlux)</li> </ul>	<ul style="list-style-type: none"> <li>• <a href="http://eeflux-level1.appspot.com">http://eeflux-level1.appspot.com</a></li> </ul>

## Summary: Publicly Available Global ET Products

ET Sources	Spatial/Temporal Resolutions	Data Source	Availability
GLDAS (Week 5)	<ul style="list-style-type: none"> <li>• 1/8<sup>th</sup>-1 degree (Global)</li> <li>• 3-hour, monthly</li> <li>• 1979 – May 2016</li> <li>• 1979 – 2010</li> </ul>	<ul style="list-style-type: none"> <li>• NASA/NOAA</li> <li>• Mirador</li> <li>• Giovanni</li> </ul>	<ul style="list-style-type: none"> <li>• <a href="http://mirador.gsfc.nasa.gov">http://mirador.gsfc.nasa.gov</a></li> <li>• <a href="http://giovanni.gsfc.nasa.gov/giovanni">http://giovanni.gsfc.nasa.gov/giovanni</a></li> </ul>
ALEXI (Week 5)	<ul style="list-style-type: none"> <li>• 8km (will be available globally from MODIS)</li> <li>• Daily, 2-12 week composites</li> </ul>	<ul style="list-style-type: none"> <li>• NOAA</li> </ul>	<ul style="list-style-type: none"> <li>• <a href="http://www.ospo.noaa.gov/Products/land/getd/index.html">http://www.ospo.noaa.gov/Products/land/getd/index.html</a></li> </ul>

# Coming Up Next Week

## Week 2: Applications of SMAP Data





Thank You

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