National Academies Workshop
Future Use of NASA Airborne Platforms to Advance Earth Science Priorities

Session on Coupling of the Water and Energy Cycles

Overview

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Gratefully Acknowledging Past and Present Group Members:
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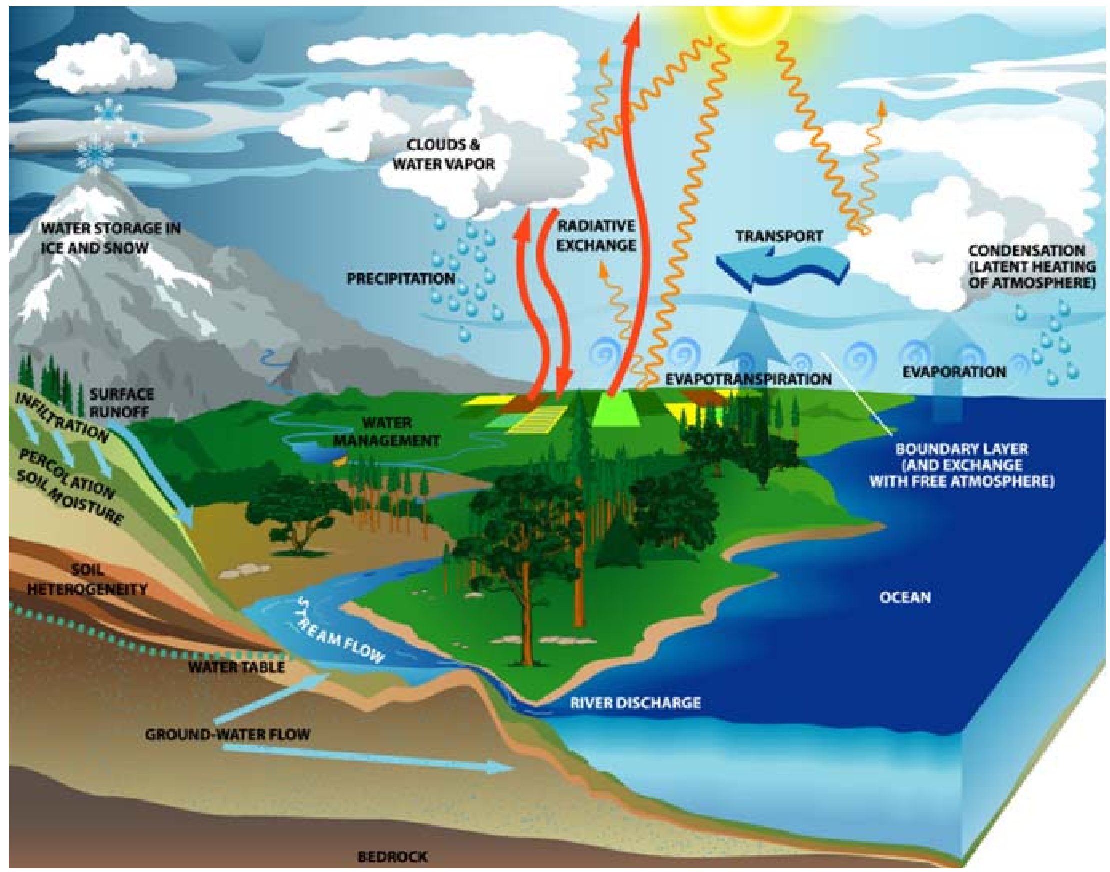
MiXIL Microwave Systems, Sensors and Imaging Lab

Water and Energy Cycle

Components of the water and energy cycle that must be quantified:

- Surface-to-depth profiles of soil moisture
- Evaporation/transpiration
- Ground water
- Recharge
- Precipitation and clouds
- Ice and snow
- Surface water: river, lake, wetland
- Etc.

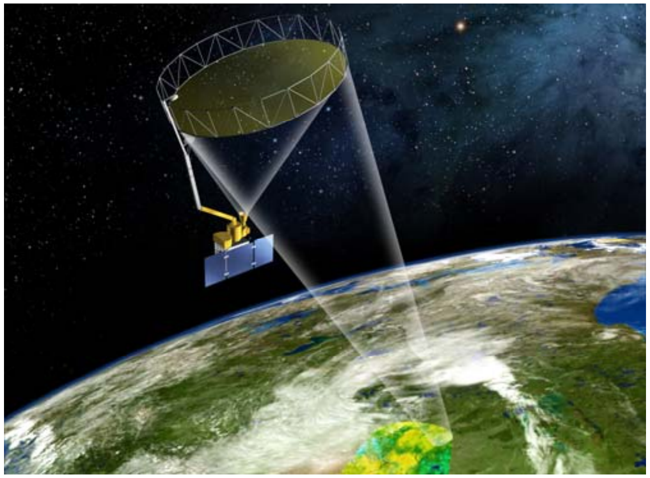
Conceptualization of Global Water Cycle



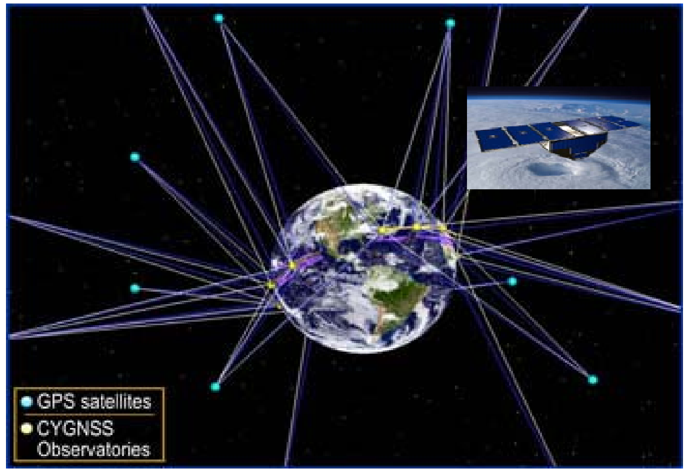
http://www.usgcrp.gov/usgcrp/images/ocp2003/

Envisioned Observation Strategy: in-situ, UAV, airborne, spaceborne, SoOP

Conventional satellite sensors



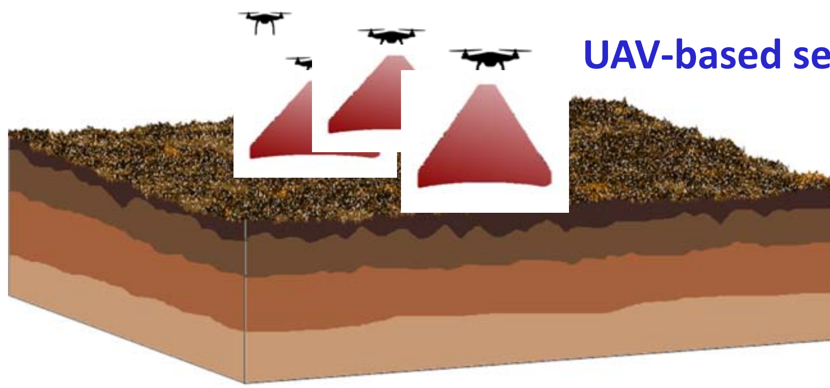
Signals of Opportunity (SoOPs)



Airborne sensors

In-Situ sensor networks

UAV-based sensors



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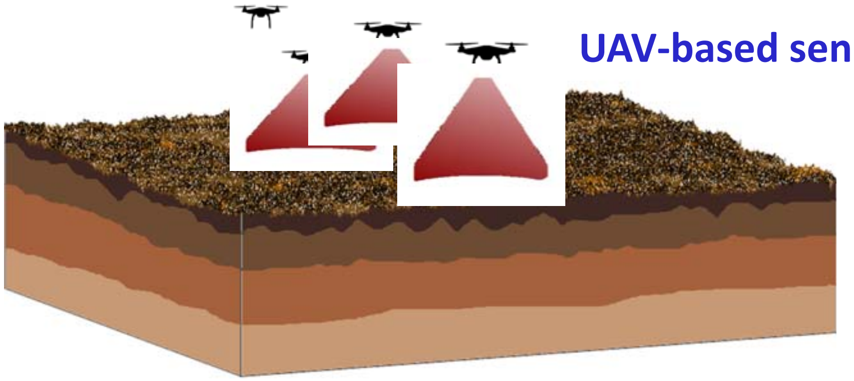
Envisioned Observation Strategy: in-situ, UAV, airborne, spaceborne, SoOP

Airborne sensors

- Airborne observations, both high-altitude and drone-based, are needed for multi-scale observations of terrestrial water puzzle components

- They are also needed as technology testbeds for spaceborne instrument development



UAV-based sensors

Excerpts from 2017 Decadal Survey

Two top-level water cycle questions:

(H-1) Water Cycle Acceleration. How is the water cycle changing? ……space-time distribution of rainfall, snowfall, evapotranspiration….frequency and magnitude of extremes such as droughts and floods

(H-2) Impact of Land Use Changes on Water and Energy Cycles. How do …changes in climate, land use, water use, and water storage interact and modify the water and energy cycles …..?

Priority observations identified as towards:

- Estimating fluxes of evaporation and evapotranspiration (ET)
- snow and glacier extent
- soil moisture
- atmospheric water vapor
- Clouds
- Precipitation
- terrestrial vegetation and oceanic chlorophyll
- water storage in the subsurface

Excerpts from 2017 Decadal Survey

Integrating Theme	Targeted Observable Contribution
Water and Energy Cycle	• *Aerosols:* Radiative forcing and feedbacks, aerosol cloud interaction • *Atmospheric Winds:* Role of winds in energy transport and evapotranspiration • *Clouds, Convection, and Precipitation:* Forcings and feedbacks, thermodynamic processes • *Greenhouse Gases:* Contributions of various greenhouse gases in Earth's energy balance • *Ice Elevation:* Ice-sheet contributions to the water cycle, modulation of ocean/atmosphere energy exchanges by sea ice • *Mass Change:* Movement of water throughout the Earth, ocean heat content • *Ocean Surface Winds and Currents:* Ocean/atmosphere energy and moisture exchanges, ocean energy transport • *Planetary Boundary Layer:* Energy and moisture exchanges in the boundary layer, cycling of water through evaporation and precipitation • *Snow Depth and Snow Water Equivalent:* Storage and distribution of water, latent energy associated with snowmelt, insulation modulating land/atmosphere energy exchanges, surface radiative balance associated with snow cover • *Surface Topography and Vegetation:* Cycling of water and energy through evapotranspiration, carbon uptake, soil moisture • *Terrestrial Ecosystem Structure:* Cycling of water and energy through evapotranspiration, carbon uptake, soil moisture

Long list, many observables

Today we will focus on terrestrial/fresh water

Some Perspective on Fresh Water

- About 2.5% of terrestrial water is fresh water; needed to sustain life
  - ~68.7% in glaciers, snow, and icecaps; melting glaciers ➔ freshwater joins saltwater
  - ~30.1% in ground water
  - ~1.2% in surface water (ground ice, permafrost, lakes, soil moisture, rivers, lakes, etc.) – small fraction, but very important in partitioning of the water cycle, feeding the world, and influencing the carbon cycle
- Our knowledge of how much water is where and details of its dynamics are sketchy
- Microwave remote sensing can play a big role to provide quantitative info: it is primarily sensitive to presence of water

Sharpening the focus
Remote Sensing of Terrestrial Water

- Microwaves are highly sensitive to water content in the natural landscape because water content is a first-order determinant of dielectric constant, and dielectric constant is a primary property of matter impacting electromagnetic scattering

- Pieces of the global fresh water puzzle currently poorly quantified:
  - Snow water equivalent
  - Soil moisture
  - Ground water
  - Several others, e.g., rivers and lakes, wetlands, ice, glaciers, vegetation

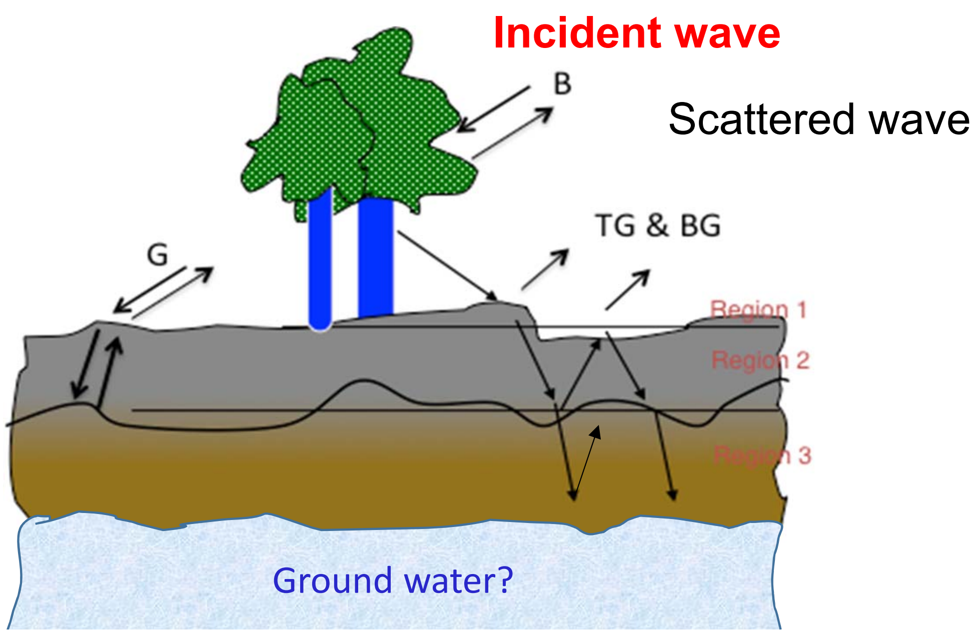
Decreasing microwave frequency ↓

Increasing opacity: difficulty of detection ↓

- Most popular sensors for high-resolution mapping are airborne and spaceborne microwave instruments, including synthetic aperture radars (SARs), and radiometers

The Way It Works…

- "Scattering mechanisms" are at play that carry information about the scene
- Example shows signal paths for vegetated ground: direct ground, direct vegetation volume, branch-ground, trunk-ground
- For longer wavelengths, scattering from ground includes scattering from subsurface layers and their water content profiles, and even down to the water table



Current NASA Airborne Instruments and Platforms For Terrestrial Water
(list may be incomplete)

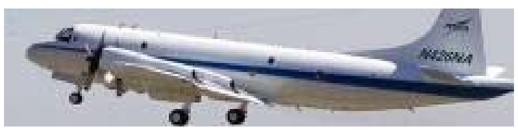
Surface and Root Zone Soil Moisture

G3: AirMOSS
P-band SAR

G3: UAVSAR
L-band SAR

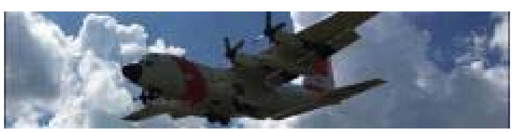
DC-8
PALS, PSR/CX, PSR/A

P-3
ESTAR, GPSRS, PALS, RadSTAR, 2D-STAR, PSR



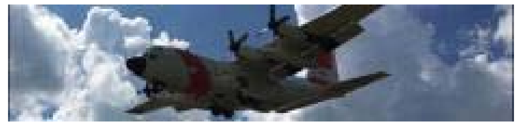
Twin Otter
PALS

C-130
PALS

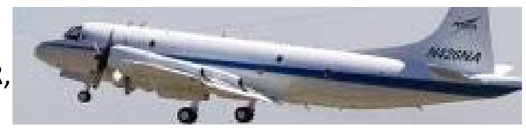


Snow and Ice

C-130
AESMIR



P-3
AESMIR, FMCW



DC-8
FMCW

G3:
GLISTIN
Ka-band SAR

Ground Water

G3: UAVSAR
L-band SAR

Indirect – InSAR surface subsidence

A Quick Personal Perspective

airmoss.jpl.nasa.gov

Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS)
EVS-1

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Elaine Chapin (System Engineer, JPL)

Science Team (in alphabetical order):
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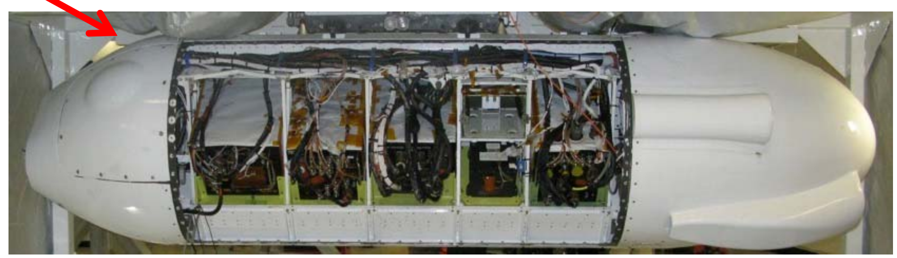
Scott Henlsey (JPL), Dave Hollinger (Collaborator, USDA/UNH)
Paul Moorcroft (Harvard), Rolf Reichle (GSFC)
Sassan Saatchi (JPL), Paul Shepson (Purdue)
Steve Wofsy (Collaborator, Harvard)

Application Example: NASA AirMOSS Radar

Front side of pod: antenna



Back side of pod: electronics

- AirMOSS: Airborne Microwave Observatory of Subcanopy and Subsurface Earth Ventures Suborbital 1 (EVS-1) mission
- P-band frequency ensures we can observe soil water content below vegetation & surface
- The “pod” contains radar electronics and antenna
- P-band radar (420-440 MHz), polarimetric

AirMOSS Flight System: Inside the JSC G-3

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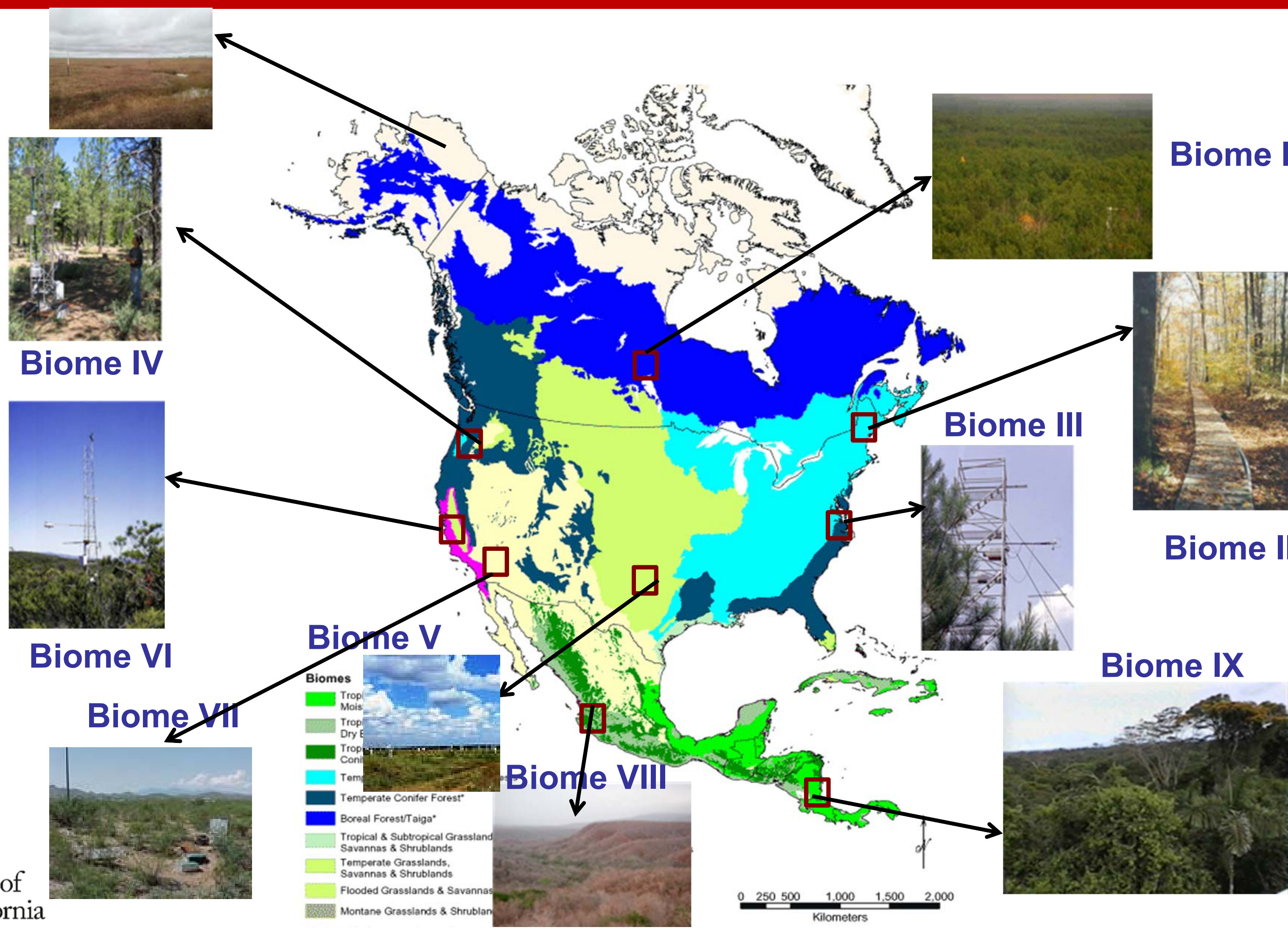
AirMOSS EVS-1 Data Collected at Several North American Ecosystems



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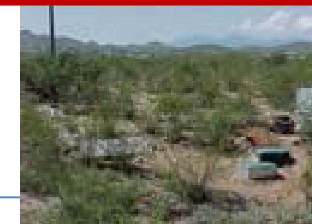
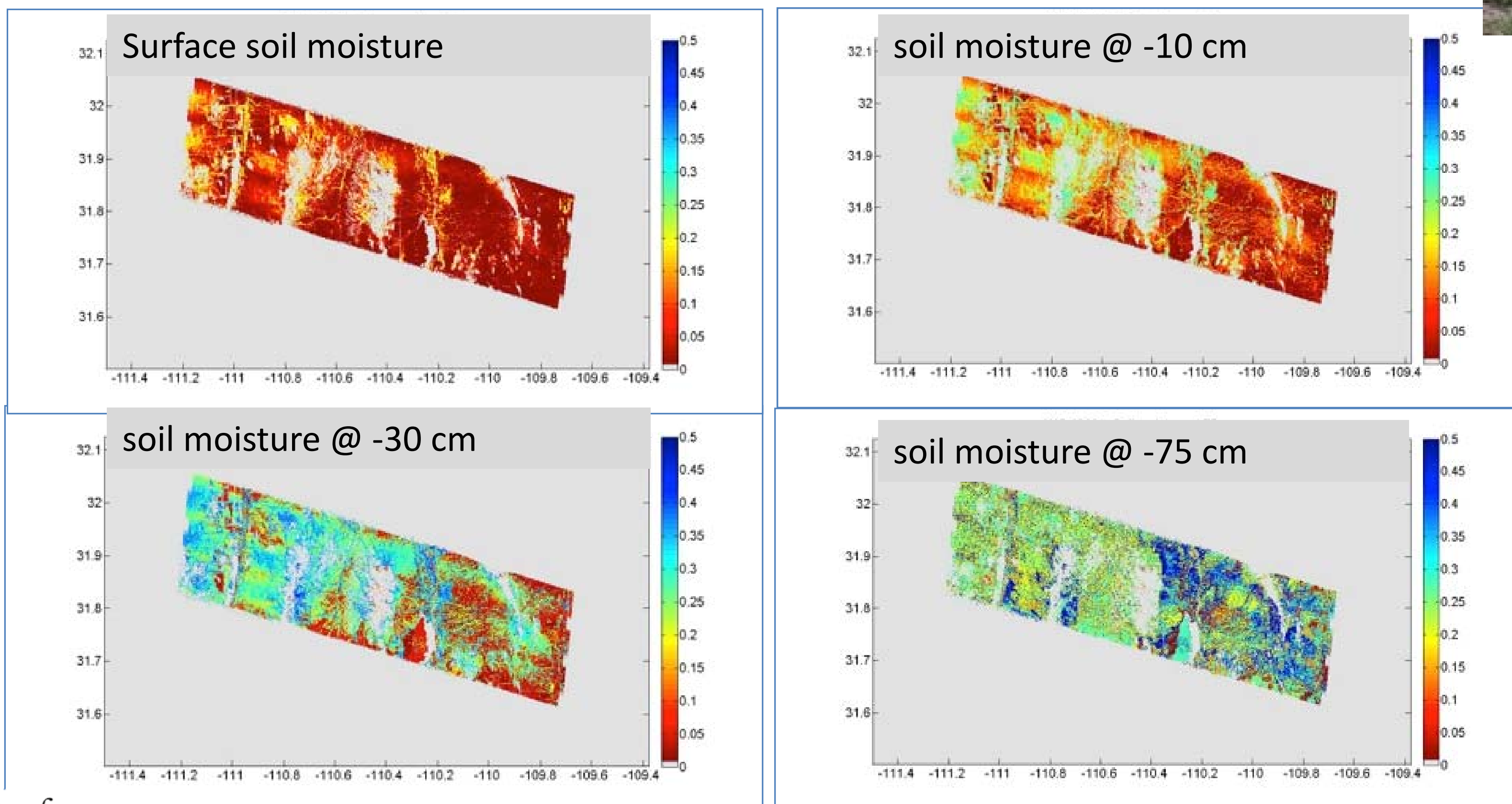
AirMOSS Soil Moisture Retrieval Example: Arizona (1)

Walnut Gulch, AZ

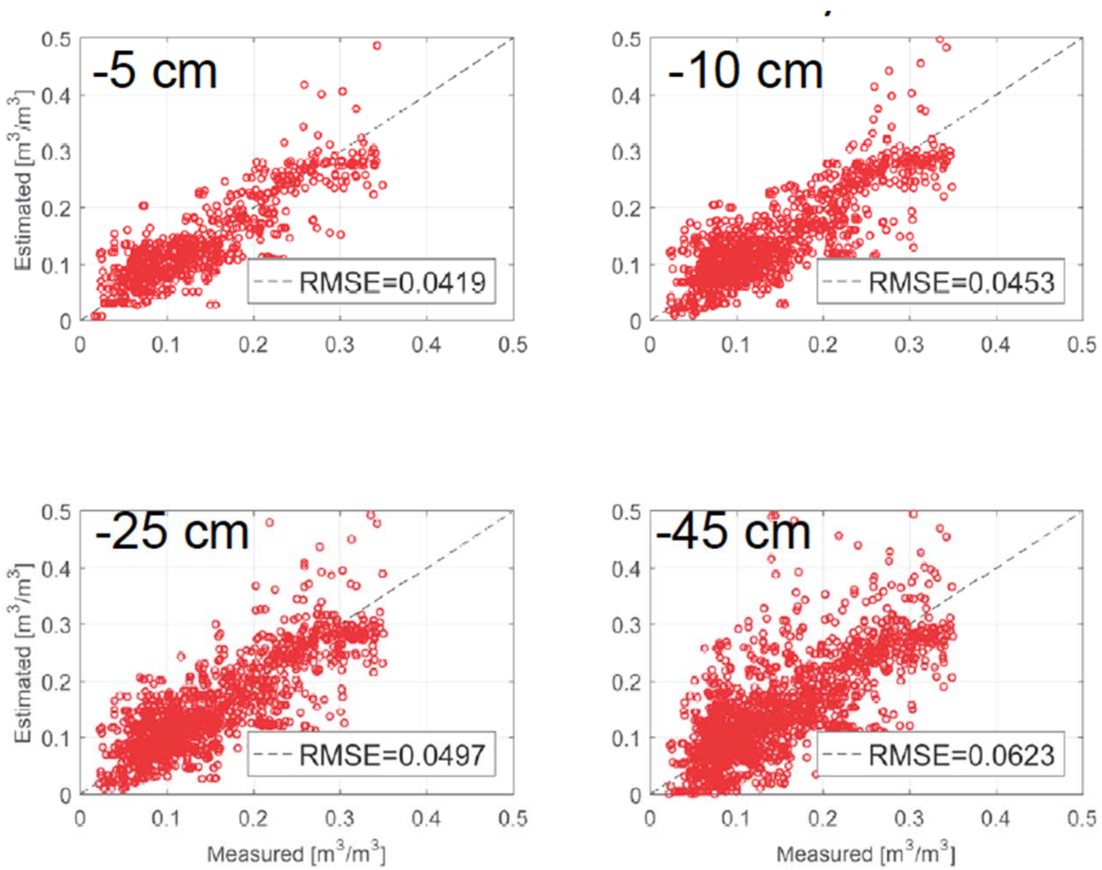
AirMOSS Soil Moisture Retrieval Example: Arizona (2)



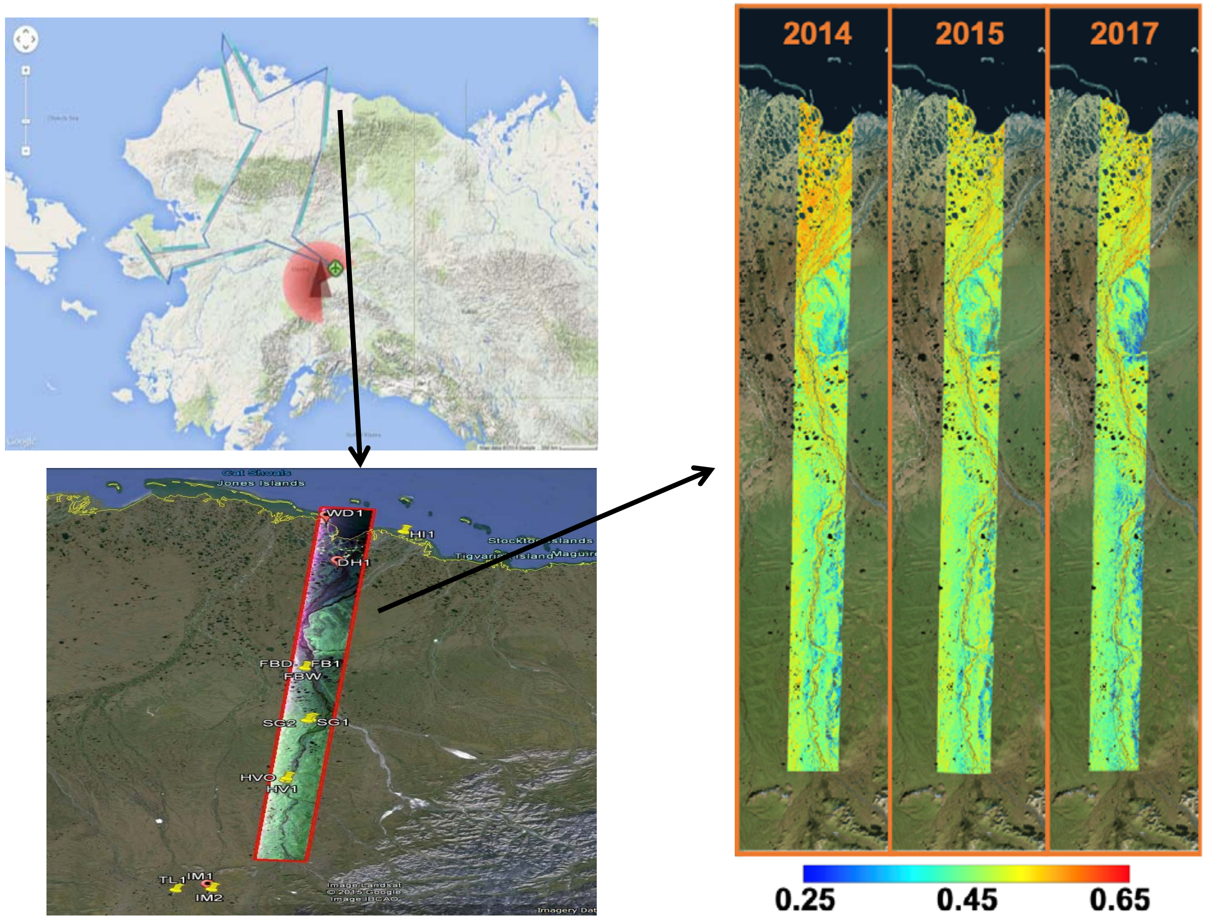


Soil Moisture Retrieval: Overall Error Assessment

Retrieval errors at all sites in 4 years (> 1000 AirMOSS flight hours)



Characterizing Permafrost Soil Moisture and ALT with AirMOSS



Permafrost Active Layer Thickness (m)

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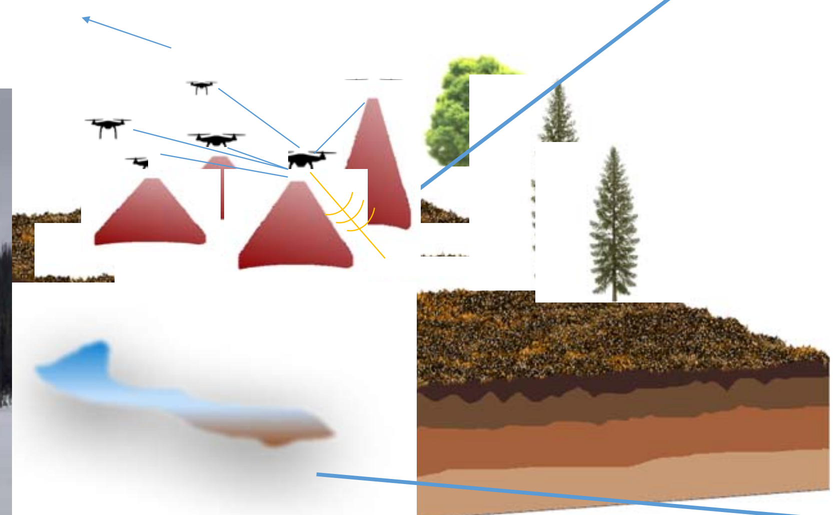
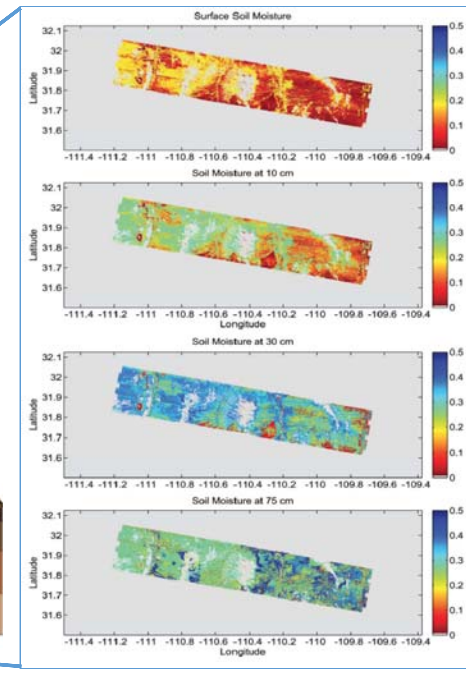
New System Concepts: UAV-based radars

- Currently, observation scales between in-situ point scale and high-altitude airborne maps are not addressed
- UAVs can address the gap
- Software defined Radars on UAVs can address the lack of a number of high-resolution observations, e.g.,
  - Ground water table
  - SWE





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Earth Science Technology Office

Where Do We Go From Here?

Components of the water/energy cycle change fast with space and time

- We will always need airborne observations that span large areas quickly
- Large-area coverage means high-power instruments: heavy lift capability, especially for radars
- Therefore high-altitude aircraft such as Gulfstream, DC-8

- Retrievals of soil moisture, SWE, water-table depth involve many unknowns; they need multiple frequencies for unique and accurate results (remember AIRSAR?)
- We need multi-frequency microwave instruments
- This further justifies the need for heavy-lift aircraft

On the other hand, we also need more rapid-development, low-cost, on-demand experimental systems, such as those onboard UAVs