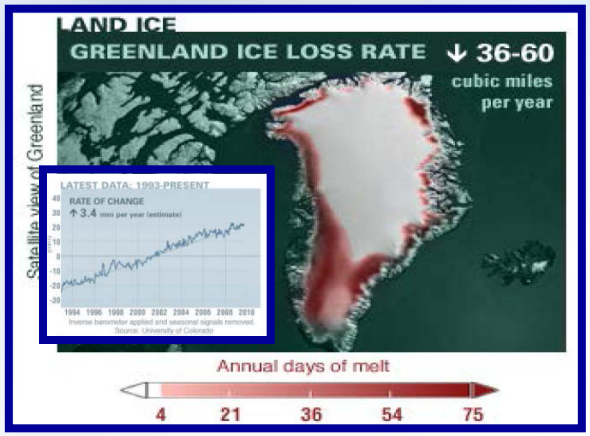
New Measurements for Understanding the Terrestrial Water Cycle

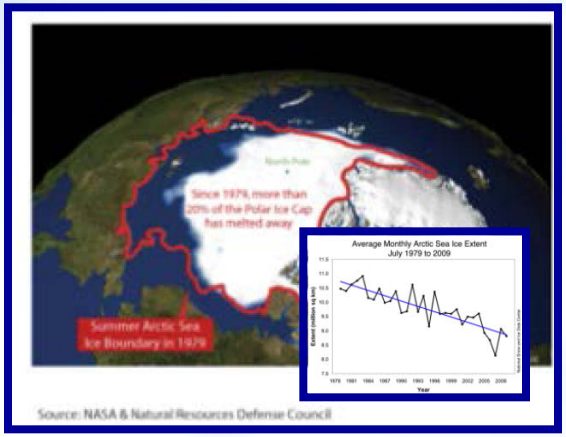
Diane Evans
Director for Earth Science & Technology
Jet Propulsion Laboratory
California Institute of Technology

Central to Key Climate Feedbacks

Ice/Snow Loss & Sea Level

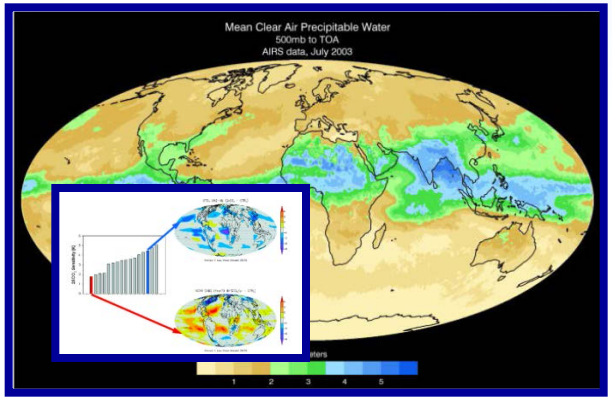


Snow-Ice Albedo Feedback

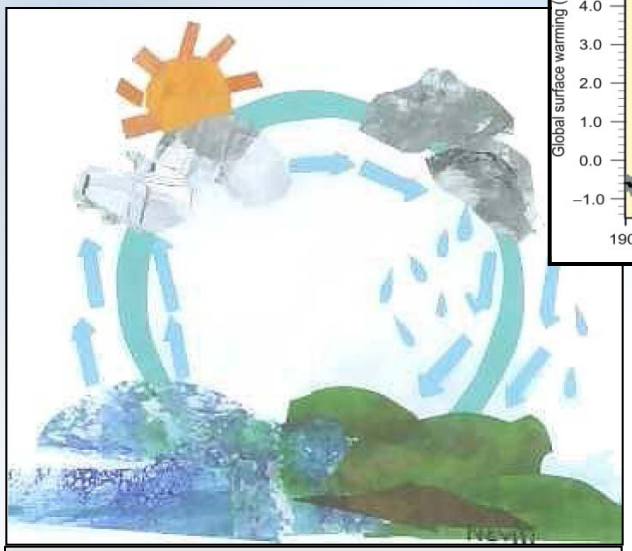


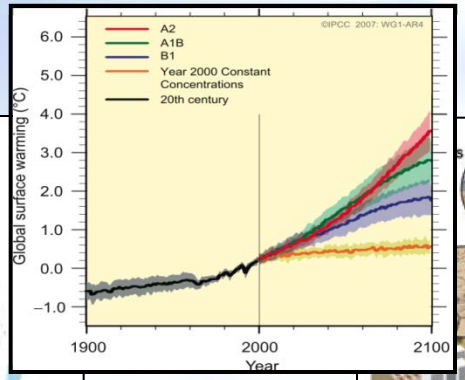
From the standpoint of global change science, monitoring, understanding, predicting and managing our planet's water is essential.

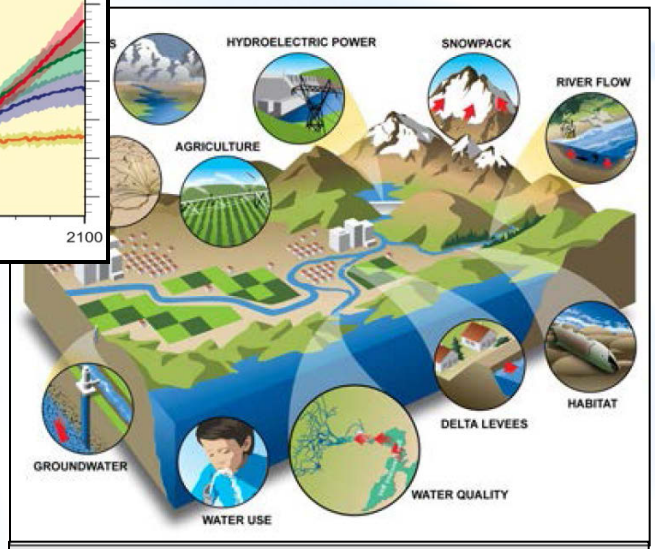
Cloud & Water Vapor Feedback



The Global Water Cycle is Central to Key Global Change Issues







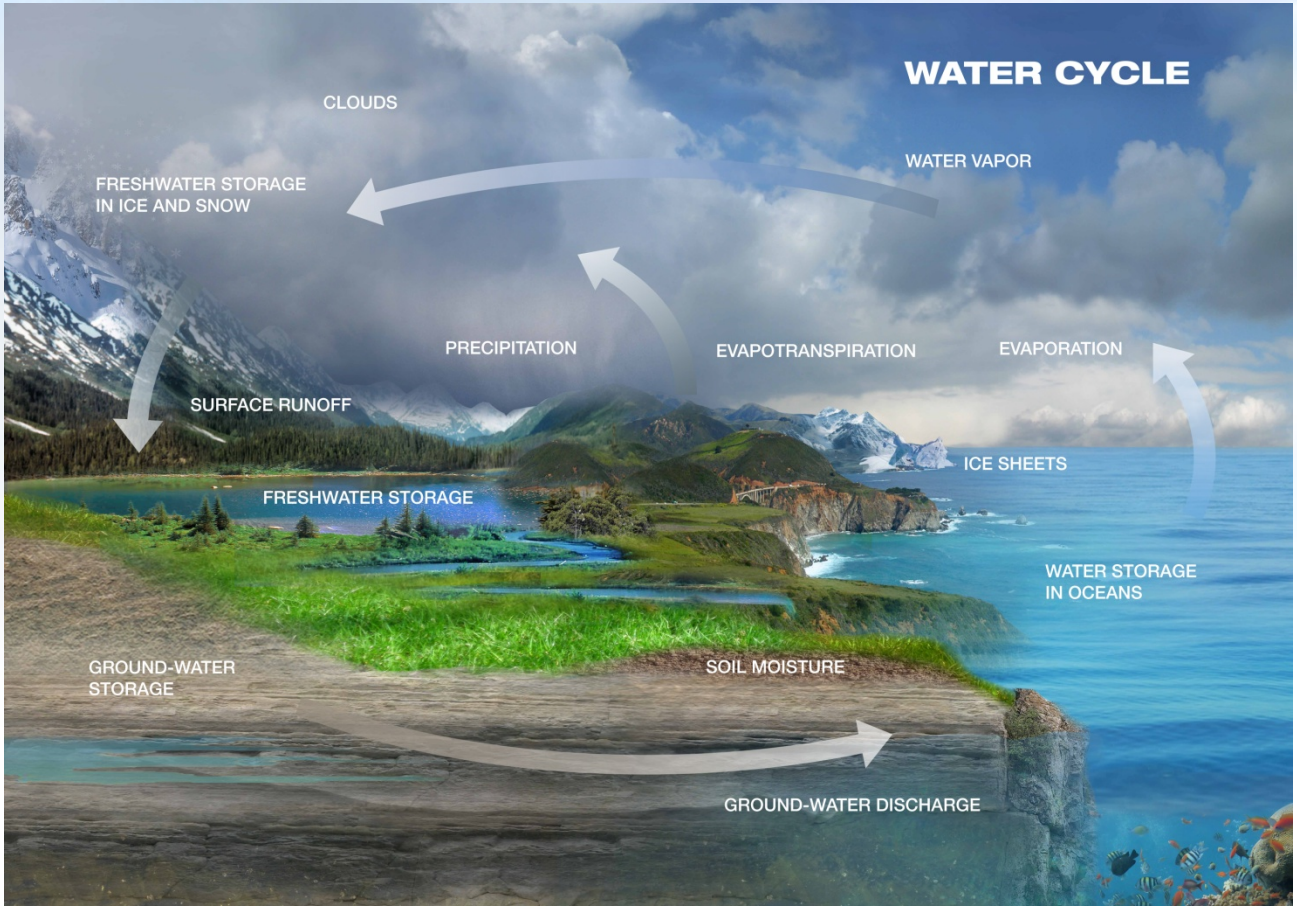
Water Cycle Science

- Water Vapor Feedback
- Cloud Feedback
- Snow/Ice-Albedo Feedback
- Ocean Circulation
- Controls on Carbon Cycle & Vegetation/Land Cover

Water Resource Management

- Fresh Water Supply
- Food Supply
- Security
- Hydroelectric Power
- Sea Level Rise

Water Cycle Observations



GRAVITY
Groundwater, ice sheets, ocean circulation

RADARS
Ice sheets, lake, river & ocean levels, ground water, clouds, precipitation, salinity, soil moisture, winds/fluxes and transport

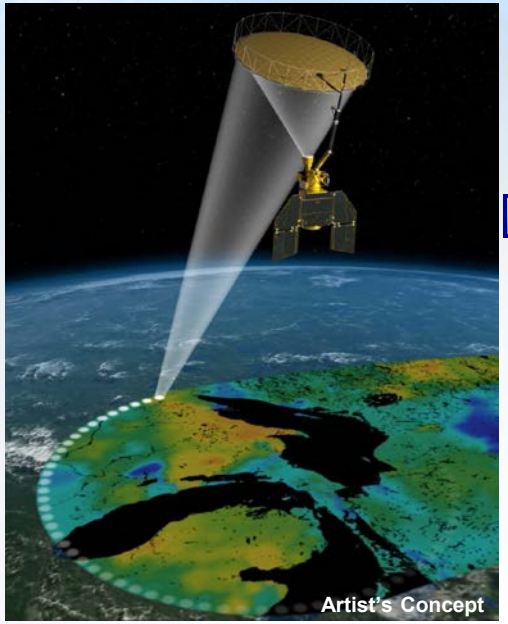
RADIOMETERS
Soil moisture, sea ice, clouds, water vapor, salinity

SPECTROMETERS
Snow, ET

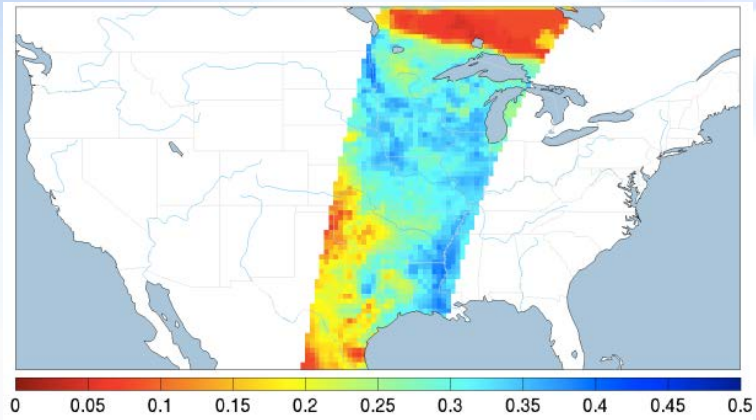
SOUNDERS
Atmospheric water vapor, isotopes, water ice

LIDARS
Ice sheets, winds

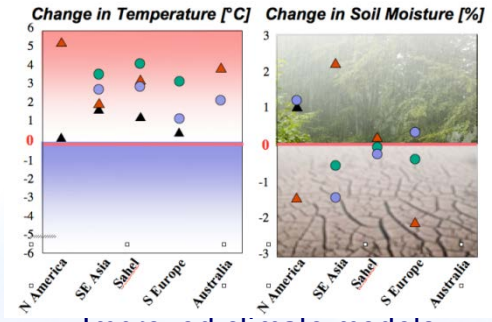
Soil Moisture Active and Passive (SMAP)



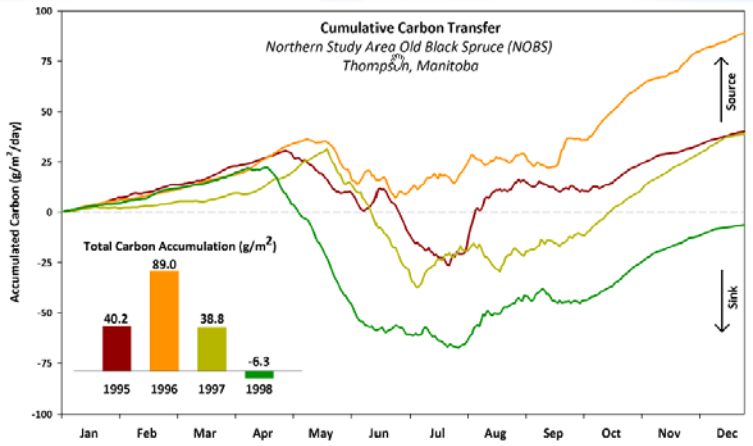
SMAP will use a rotating 6-m deployable mesh antenna shared by an L-band radar & radiometer to map soil moisture and freeze/thaw state and resolution of 10 km every 3 days

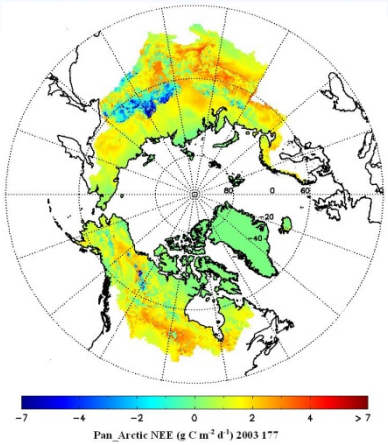


% vol. soil moisture



Improved climate models





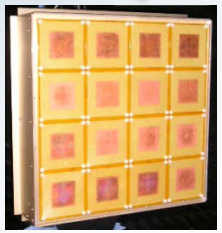
Carbon Storage Estimate

Partner: CSA

Phase C Start: 2012

LRD: 2014

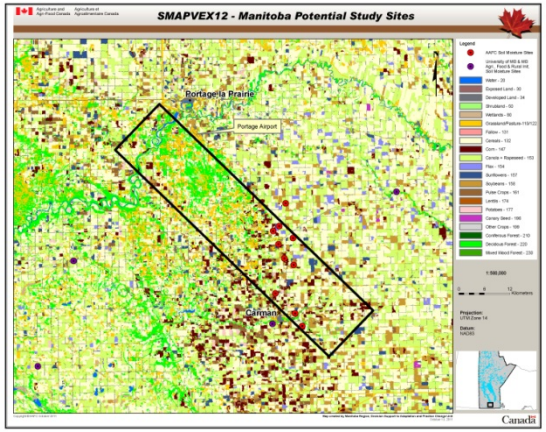
Passive and Active L-band System (PALS) (SMAP Airborne Simulator)



PALS planar active-passive antenna

Front-End Electronics Integrated with Antenna

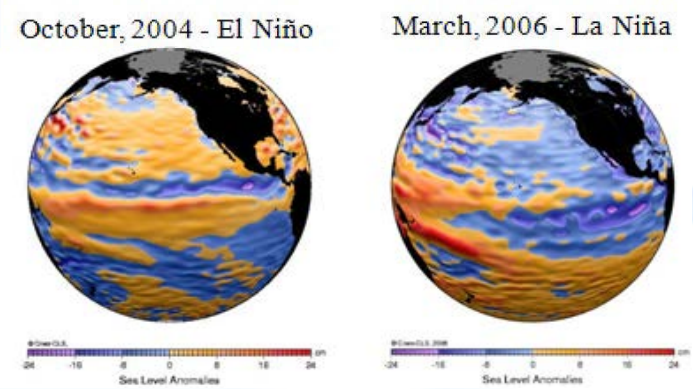
- PALS Characteristics
  - Polarimetric radiometer (1.41 GHz)
    - V, H, +45, and -45 degree polarizations
    - Three noise diode calibration
    - High rate sampling for RFI detection
    - Similar to Aquarius and SMAP design
  - Polarimetric radar (1.26 GHz)
    - VV, HH, VH and HV
    - Parallel V and H receivers

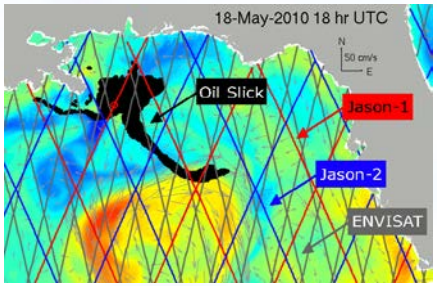


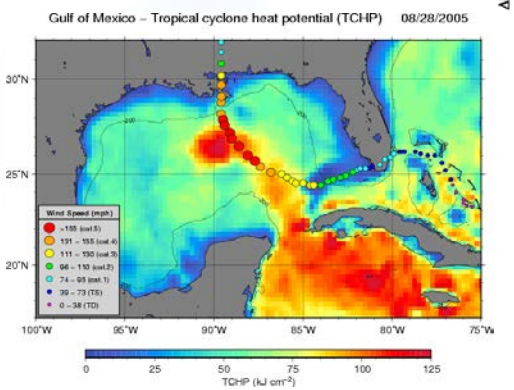
- SMAP plans to use PALS for field campaign near Winnipeg, Canada in Summer 2012
  - Provides active/passive time-series data for pre-launch soil moisture algorithm development under range of soil moisture and vegetation conditions

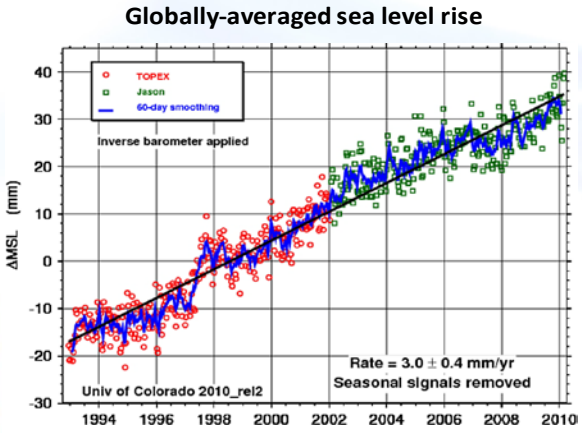
Jason-3* Mission: Altimetry – Going from Research to Operations and Beyond

- **April 14 LRD is pending LV decision.**
- **Four partners: NOAA, EUMETSAT, NASA, and CNES.**
- **JPL deliveries as with Jason-2.**
- Continue the time series of global sea level rise.
- Seasonal, inter-annual and decadal ocean variability.
- Hurricane intensity forecasting.









LRD: 2014 (TBC)

*Proposed Mission

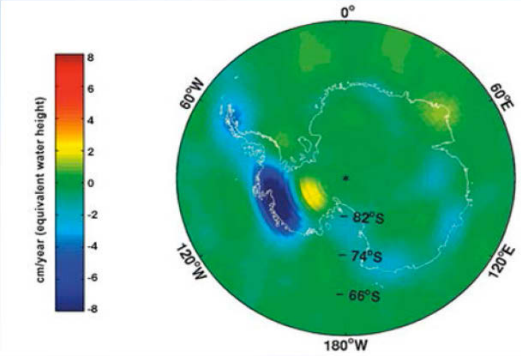
Pre-decisional – for Planning and Discussion Purposes Only

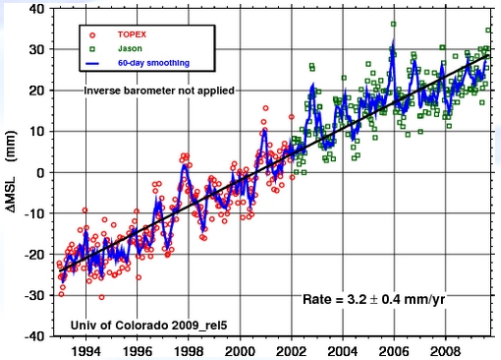
GPS Radio Occultation

- NASA instruments producing data on COSMIC (5 satellites), GRACE and TerraSAR-X
- Next generation instrument would provide improved water vapor profiles in the lower troposphere
  - TriG receiver engineering model ready in September 2012
  - First flight model delivery in October 2013 to USAF
- COSMIC-2* constellation moving forward with initial 6 satellites in low inclination orbit
  - Joint NOAA-USAF-Taiwan-JPL/NASA effort
  - JPL is scheduled to deliver flight model to USAF in October 2013
  - Launch baselined for 2015, launch vehicle (USAF-provided) is identified
  - Second set of 6 polar orbiting satellites baselined for 2017 launch. Plans still under development.

*Proposed Mission

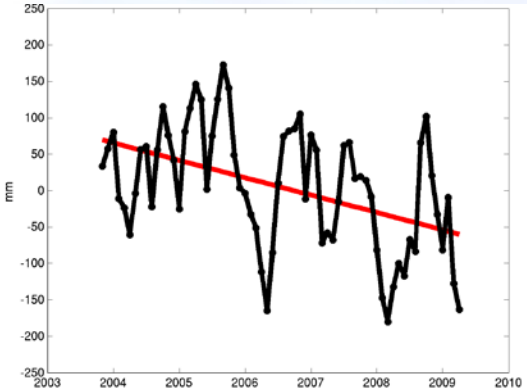
Gravity Recovery and Climate Experiment (GRACE) – Follow-on Mission*





Improved prediction of changes in sea level

GRACE-FO* would use microwave and experimental laser-based satellite-to-satellite ranging, along with precision accelerometers to measure climate related changes in Earth's mass distribution.



Significant loss of stored water in the combined Sacramento-San Joaquin River Basin. (University of California Center for Hydrologic Modeling)

Phase B Start: 2012
LRD: 2017

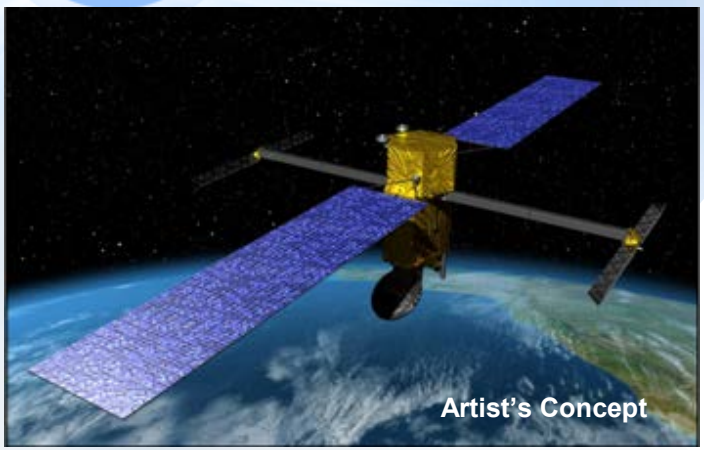
DLR

*Proposed Mission

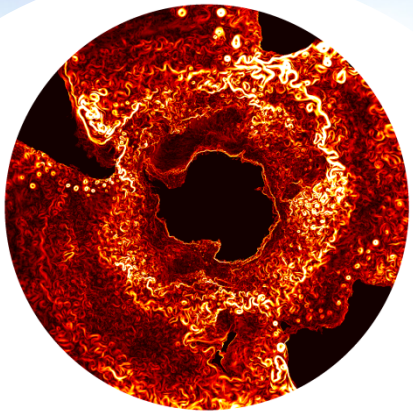
Pre-decisional – for Planning and Discussion Purposes Only

NASA

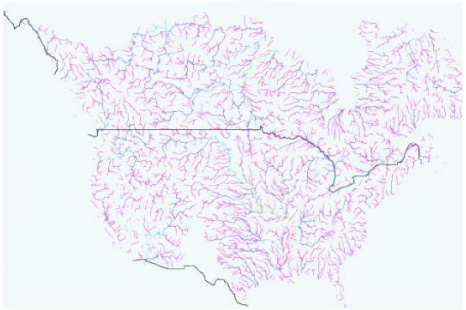
Surface Water and Ocean Topography (SWOT)*



SWOT* would use a Ka-band interferometric SAR with 2 swaths, 60 km each to characterize the ocean circulation at a spatial resolution of 10 km and provide a global inventory of terrestrial water bodies.



Mesoscale Ocean Circulation



Fresh Water Storage And Discharge

SWOT measurements will be critical to determining surface water availability, flooding potential, and the ocean's capacity to absorb heat and carbon from the atmosphere.

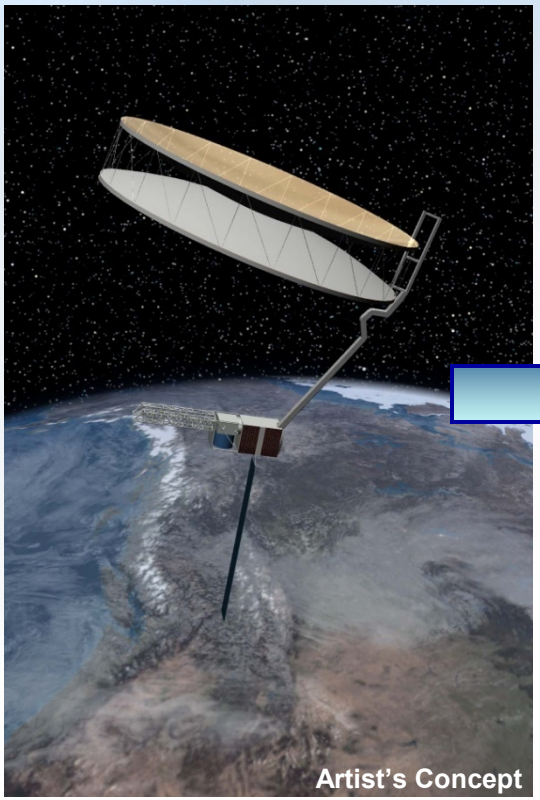
Courtesy Doug Alsdorf

Phase A Start: 2012
LRD: 2019

*Proposed Mission

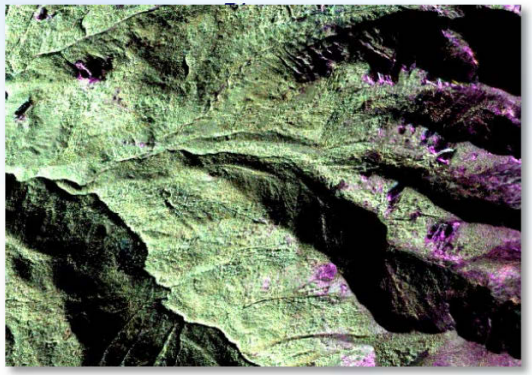
cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

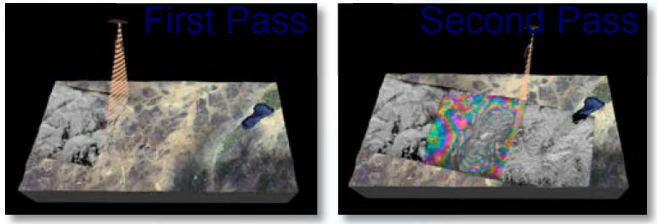
Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI)*



DESDynI* would be an interferometric L-band synthetic aperture radar (InSAR)

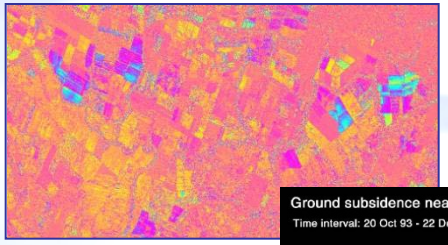
L-band Polarimetric SAR
Primary Objective: Ecosystem Structure



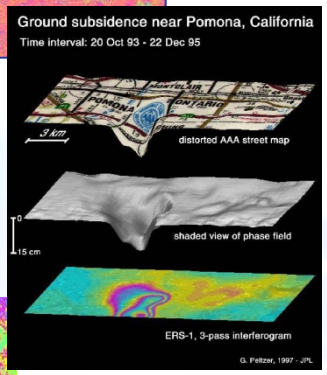


L-band Repeat Pass InSAR
Primary Objectives: Solid Earth Deformation & Cryosphere

Capabilities for Water

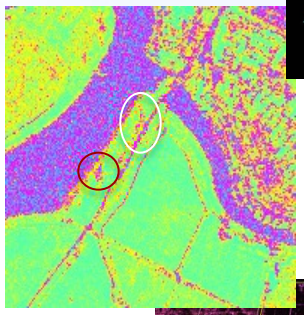


Soil Moisture

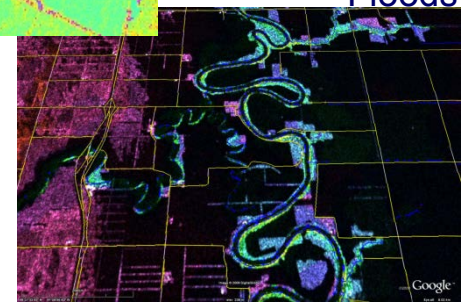


Aquifers

Levees



Floods

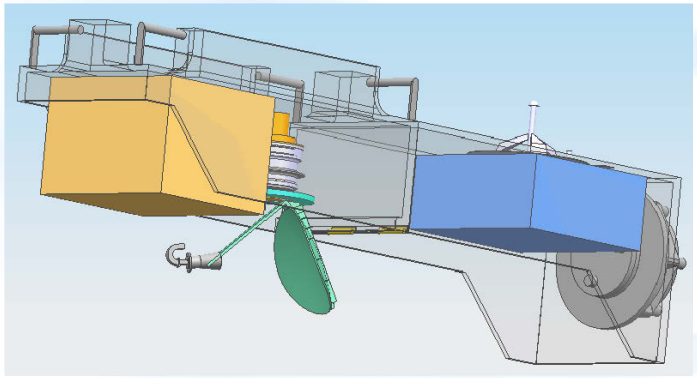


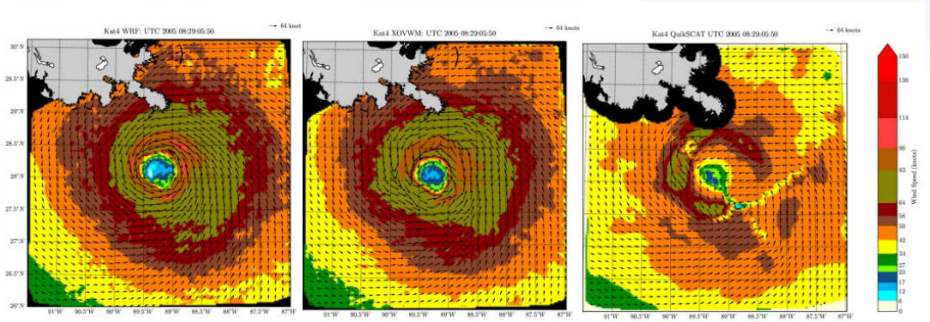
*Proposed Mission

LRD: 2019

Scatterometer

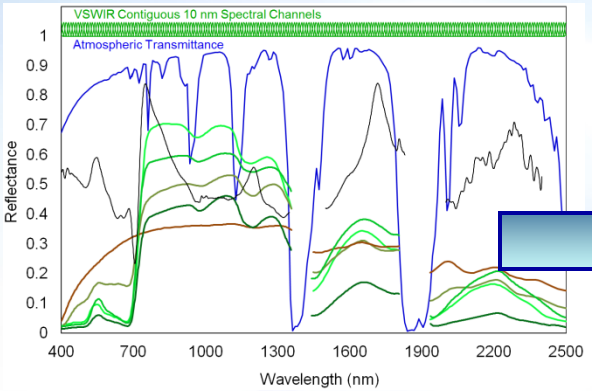
- A dual frequency Extended Ocean Vector Winds Mission (XOVWM) was recommended by the NRC Earth Science Decadal Survey for NOAA to implement.
  - Exchange of heat, carbon, and water between the ocean and atmosphere.
  - Improved prediction of hurricanes, extratropical storms, coastal winds, and storm surge.
- NOAA has been unable to obtain funding for the mission and asked NASA to take responsibility.
- JPL is studying multiple implementation options as part of Earth Radar Missions office.

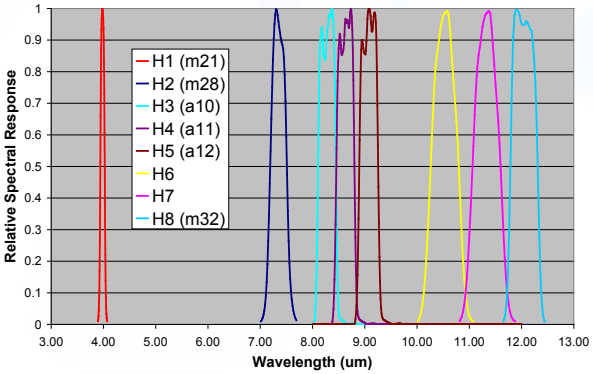




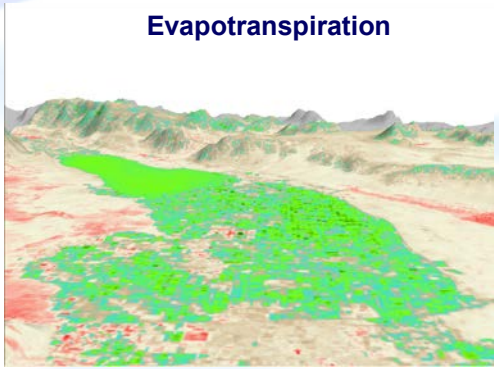
Hyperspectral Infrared Imager (HysplRI)*

HysplRI* would acquire data from 380-2500 nm in 10 nm bands with 60m spatial sampling and 19-day revisit and from 4-12 nm in 8 bands with 5-day revisits (day/night)

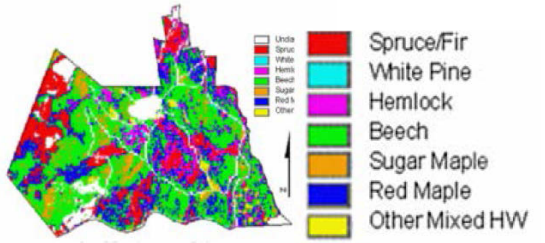




Evapotranspiration



Ecosystems



*Proposed Mission

Pre-decisional – for Planning and Discussion Purposes Only

LRD: 2020

JPL Airborne Instruments (Operational)

MTP
Microwave
Temperature Profiler

LAS-CO_2

JPL Airborne Instruments (Development)

06/12

01/12

05/12

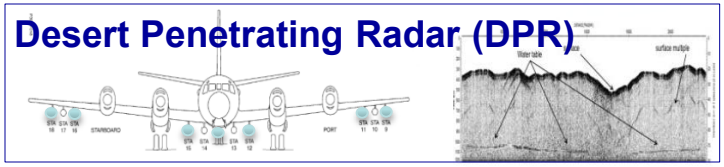
05/12

01/12

01/12

03/12

04/12

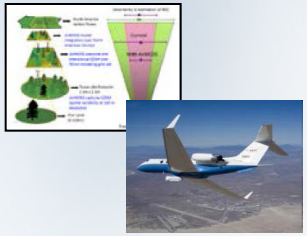


09/14

Earth Venture-1 (Suborbital) Selections

Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) - JPL

Arctic carbon cycling, especially the release of the important greenhouse gases such as carbon dioxide and methane.

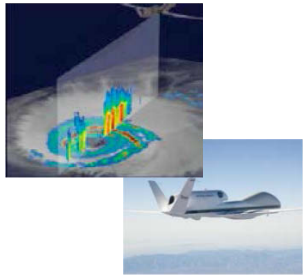


Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) - Univ Mich/JPL

Addresses the uncertainties in existing estimates by measuring soil moisture in the root zone of representative regions of major North American ecosystems.

Airborne Tropical Tropopause Experiment (ATTREX) - ARC

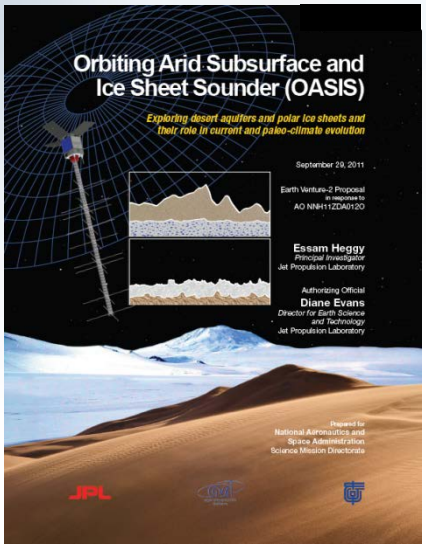
Study chemical and physical processes at different times of year from bases in California, Guam, Hawaii and Australia.

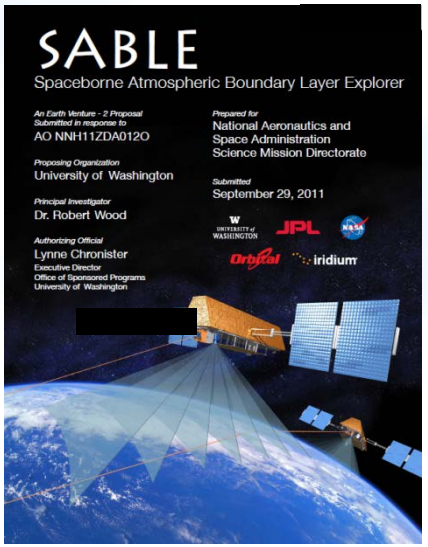


Hurricane and Severe Storm Sentinel (HS3) – GSFC/ARC

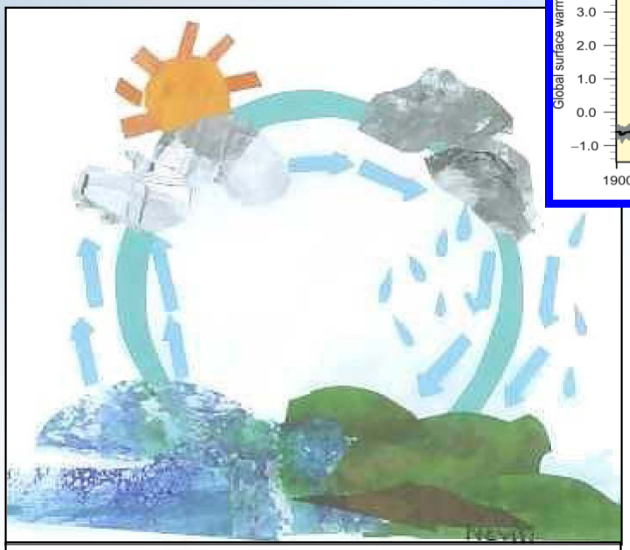
Studying hurricanes in the Atlantic Ocean basin during the 2012-14 Atlantic hurricane seasons.

Earth Venture – 2 (EV-2) Proposals

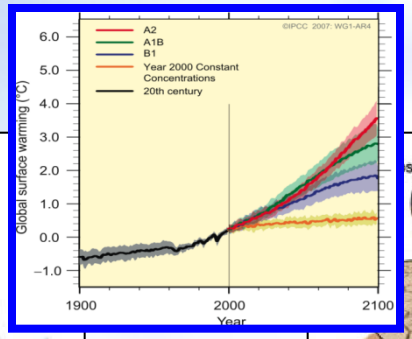


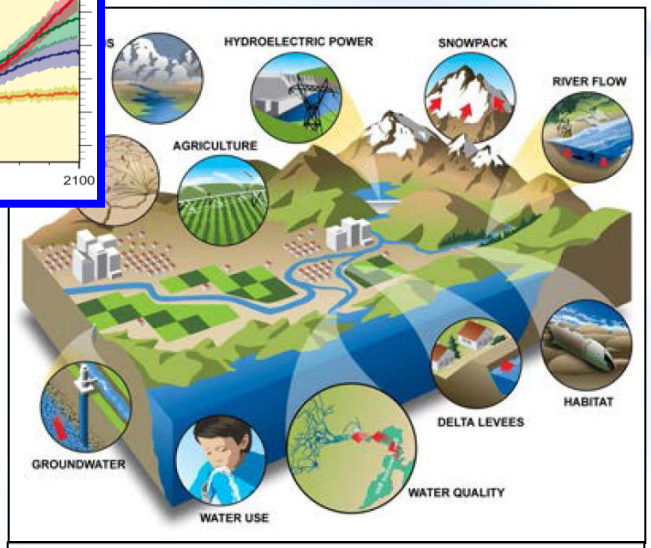


Future Trends



Water Cycle Science



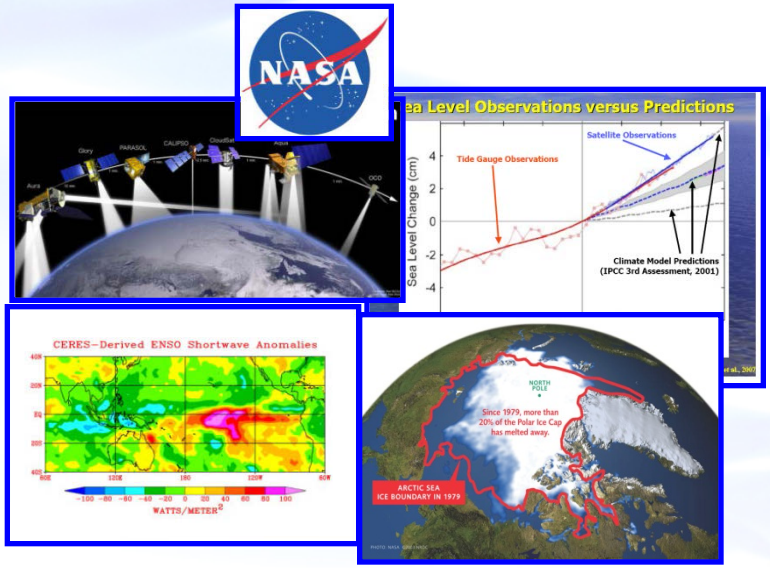


Water Resource Management

- Improved Climate models
  - General Circulation models
  - Intraseasonal to Interannual (ISI) predictions
  - Regional Climate Models (RCMs)
- Integrated Observations

NASA and CMIP/IPCC: Better Linkage

How to bring as much observational scrutiny as possible to the IPCC process?



How to best utilize the wealth of NASA Earth observations for the IPCC process?

ESG Gateway: Side by Side Archive with CMIP*

Earth System Grid

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ESG Gateway hosted by the Program for Climate Model Diagnosis and

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  - > TAMIP2
  - > gfdl_test
  - > obs4MIPs
- Institute
- Model
- Experiment
- Frequency
- Product
- Realm
- Variable
- Ensemble

Welcome to PCMDI

PCMDI

The Program for Climate M
Diagnosis and Intercompar
was established in 1989 at
Livermore National Laborat
located in the San Francisc
Our staff includes research
computer scientists, and di
personnel.

The PCMDI mission is to develop improved methods and tool
diagnosis and intercomparison of general circulation model
simulate the global climate. The need for innovative analysis
climate simulations is apparent, as increasingly more complex
developed, while the disagreements among these simulations
to clim and poorly understo
nature must be accounted
system GCMs for simula
putati

obs4MIPS Project

Status of the CMIP5 Archive

6/3/2011: CNRM-CERFACS decadal hindcast/forecast datasets
available for all realms but sea-ice (10 members already avai
realm ocean, only 3 so far for realms land/atmos/landIce).
6/25/2011: PCMDI CMIP5 data server is back online. The INM
datasets are available.
7/7/2011: NCC datasets are now available to all users.
7/19/2011: PCMDI data server will be down for maintenance
PST. It is expected back online 7/20 17:00 PST.
7/20/2011: PCMDI data server is back online.
7/20/2011: Because of a processing fault affecting the MOHC
rcp85 data from 2080 onwards, this data has been withdrawn
being. They expect to provide us with corrected data in a mat
at which time a new version of these datasets will be publishe
9/7/2011 - 9/9/2011: The BADC ESGF system will be unavaila
September 7th and 8th. As a precaution you should consider
"At Risk" on Friday September 9th.

Earth System Grid

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ESG Gateway hosted at the NASA Jet Propulsion Laboratory

Search: Datasets for: Search Start Over

To conduct a search, select a category from the pull down menu and/or enter free text into the the text box.

Please note that the NASA datasets accessible through this gateway are provided as part of an experimental activity to increase the usability of NASA satellite observational data for the model and model analysis communities. These are not standard NASA satellite instrument products. They may have been reprocessed, reformatted, or created solely for comparisons with the CMIP5 models. Community feedback to improve and validate the dataset for modeling usage is appreciated.

Search Categories

- Project
  - > CMIP5
  - > obs4MIPs
- Institute
- Model
- Experiment
- Frequency
- Product
- Realm
- Variable

AIRS (Atmospheric Infrared Sounder)

AIRS Data Catalog at ESG
Documentation: Air Temperature
Documentation: Specific Humidity
AIRS Home at NASA/JPL

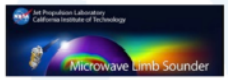
AMSR-E (Advanced Microwave Scanning Radiometer - EOS)

AMSR-E Data Catalog at ESG
Documentation
AMSR-E Home at NSIDC

AVISO

AVISO Data Catalog at ESG
Documentation: Sea Surface Height (SSH)
AVISO Home

MLS (Microwave Limb Sounder)



MLS Data Catalog at ESG
Documentation: Specific Humidity
Documentation: Air Temperature
MLS Home at NASA/JPL

MODIS (Moderate Resolution Imaging Spectroradiometer)

MODIS Data Catalog at ESG
Documentation
MODIS Home

TES (Tropospheric Emission Spectrometer)

TES Data Catalog at ESG
Documentation: Ozone
TES Home at NASA/JPL

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ESG Federation

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BADC Gateway
DKRZ Gateway
NASA JPL Gateway
NCAR Gateway
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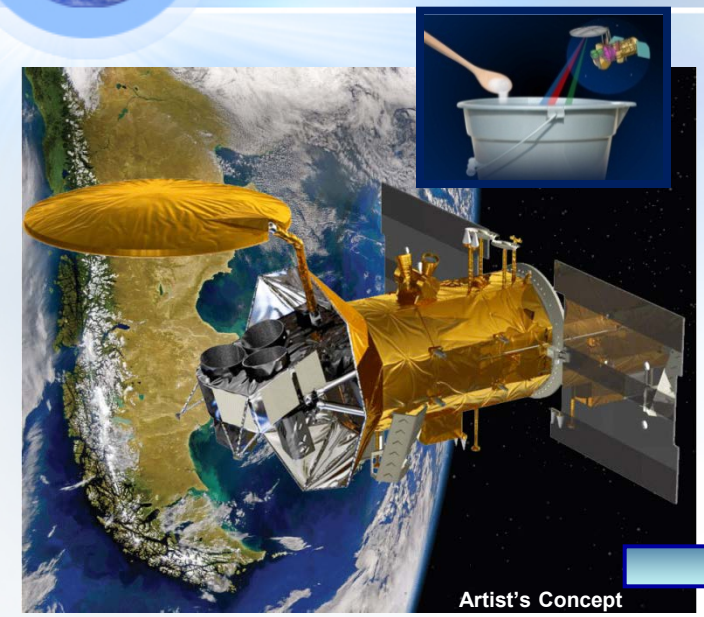
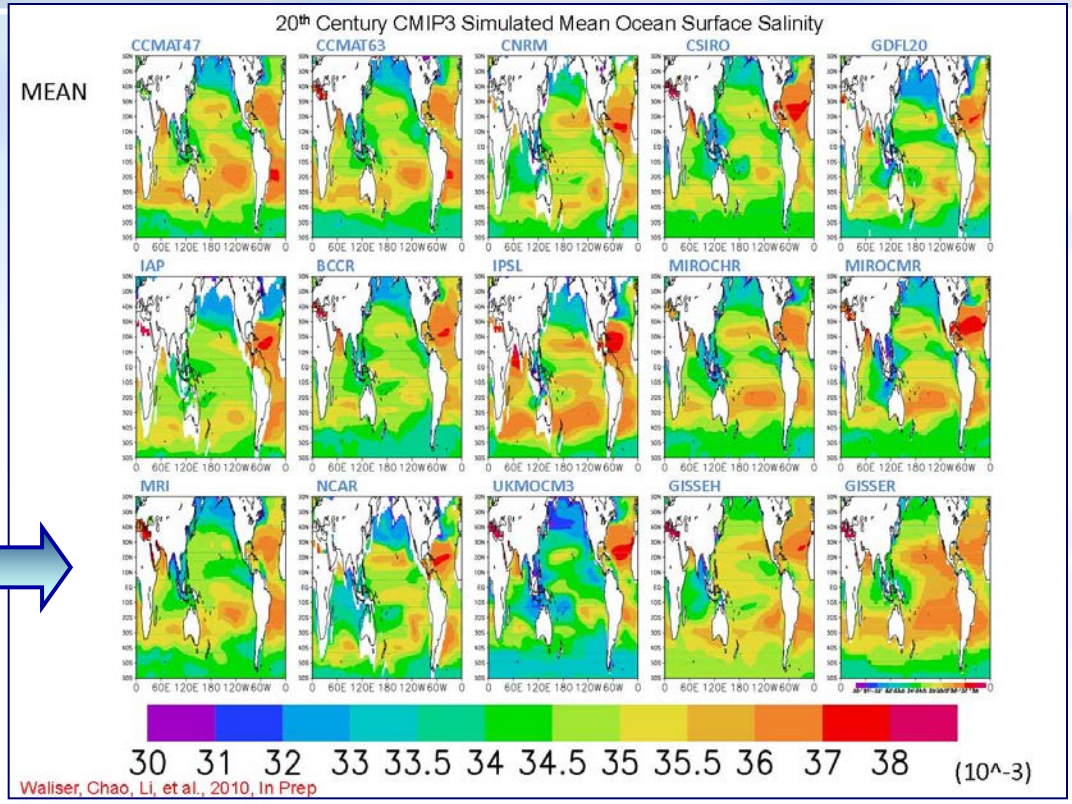
ORNL Gateway
NERSC Gateway

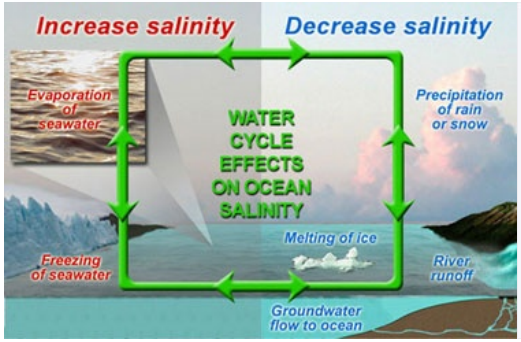
*Coupled model intercomparison project

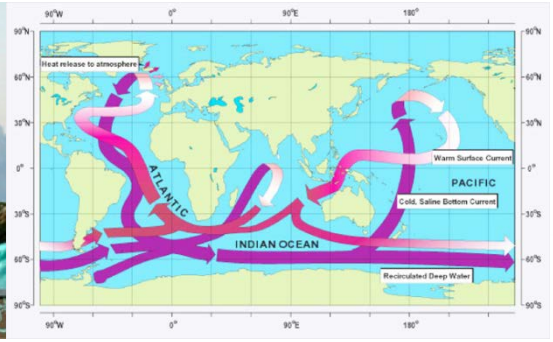
Aquarius



Aquarius uses an L-band radar (JPL) and radiometer (GSFC) to make monthly maps of sea surface salinity with precision of 0.2 PSU (.2 gkg^{-1}) and resolution of 150 x 150 km

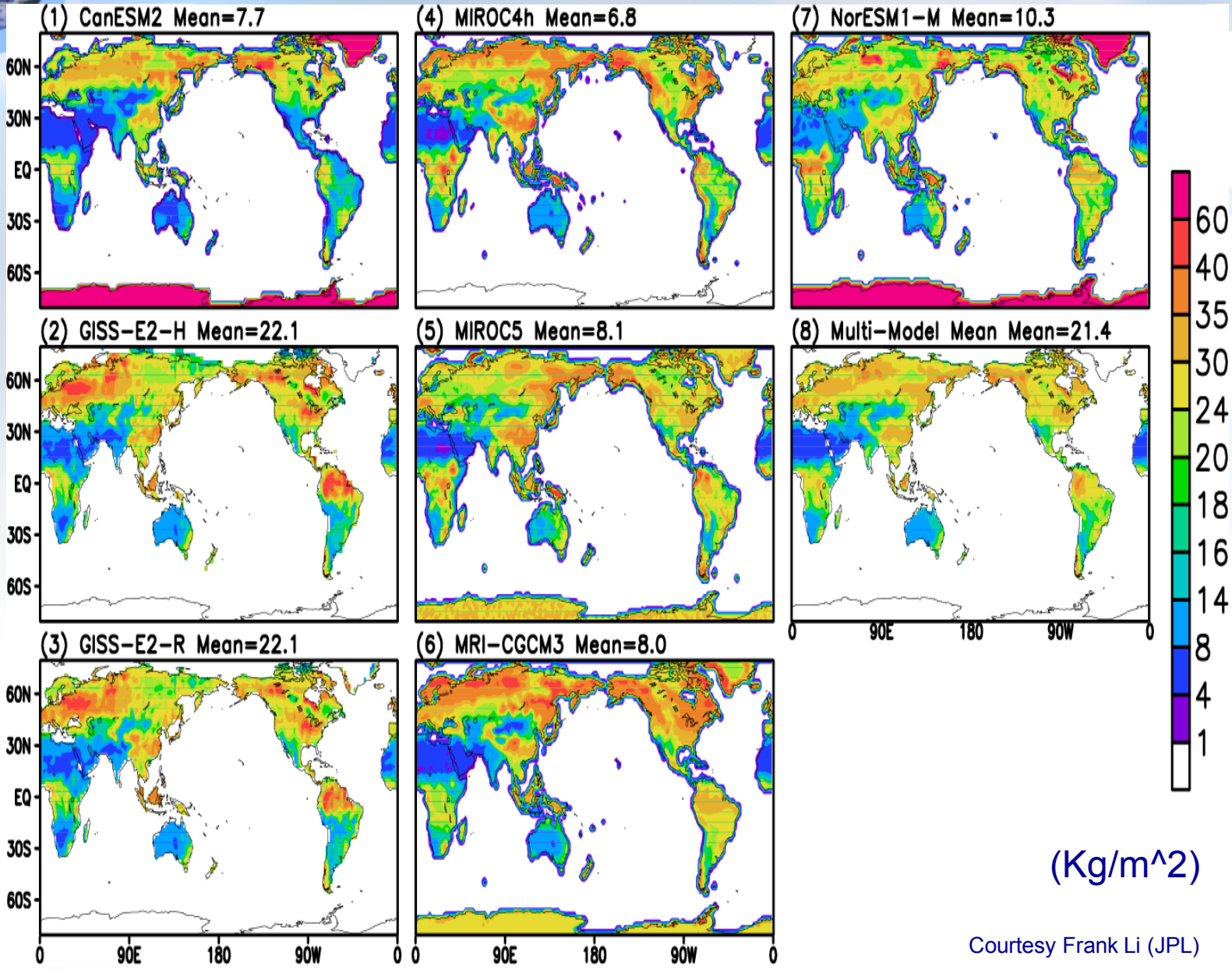






Partners:
CONAE
(INPE, ASI, CNES, CSA)

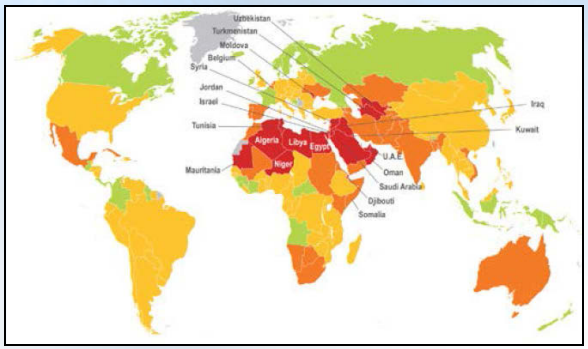
CMIP Present Day (1970-2005) Annual Mean Moisture in Upper 10cm of Soil Column

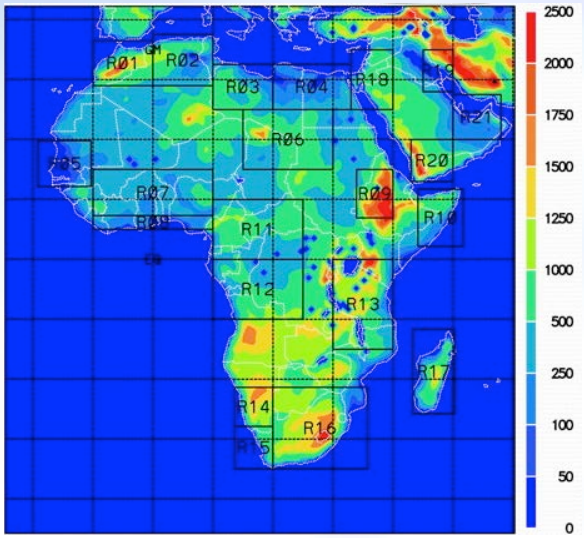


(Kg/m^2)

Courtesy Frank Li (JPL)

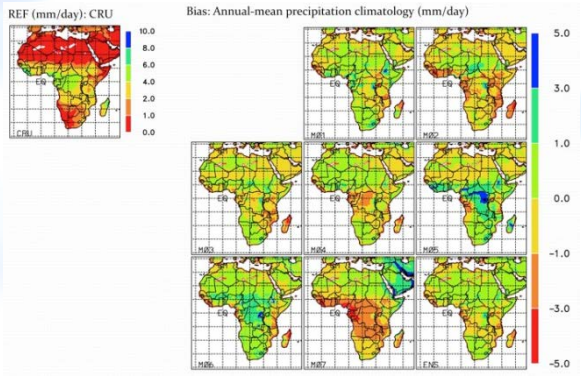
Regional Climate Models





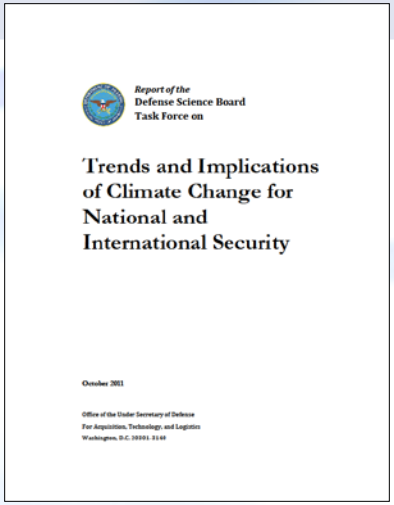
Elevation (m)

COordinated Regional Climate Downscaling Experiment (CORDEX) Domains



All models perform poorly for the E. Mediterranean (R03 & R04), E. Sahara (Ro6) and the three regions in the E. Africa (R10) and southern Arabian Peninsula (R20 & R21)

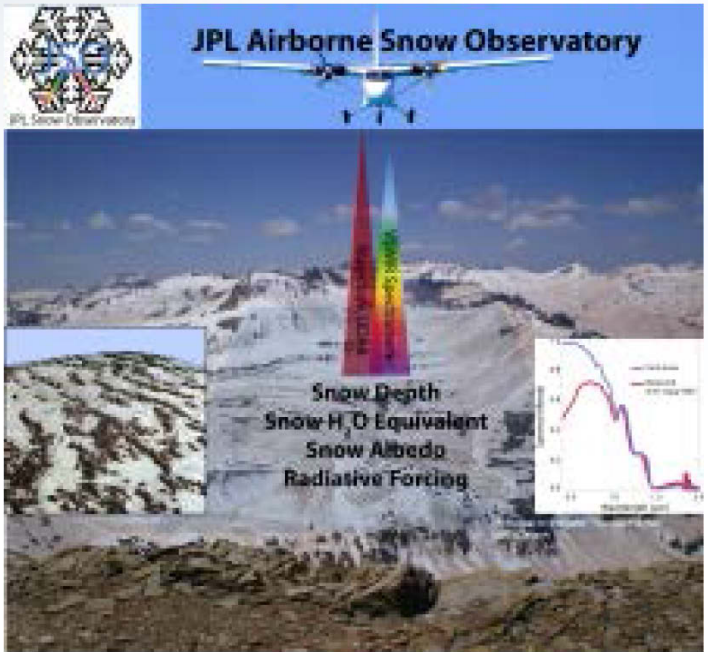
Selected Examples of Recommendations



- …identify approaches and mechanisms for providing sustained, timely, and actionable synthesis assessments focused on developing regions and locales beyond the current US focus.
- …concentrate on the effects of climate change on political and economic developments and their implications for US national security.
- …water and food security and increased storm intensity to regional stability and US national security.
- …climate change adaptation pilot projects in concert with related programs at USAID and other agencies.
- …metrics focused on risk reduction to minimize the impact of climate change on military and support operations, forces, programs, and facilities.

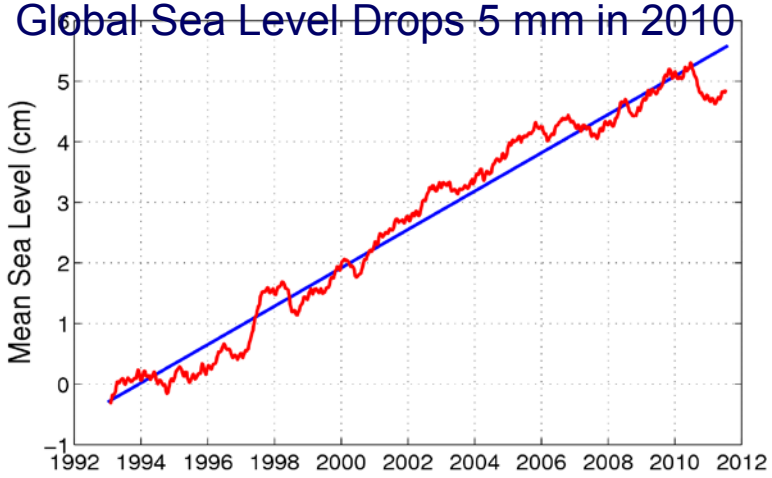
Airborne Campaigns for Water Decision Support

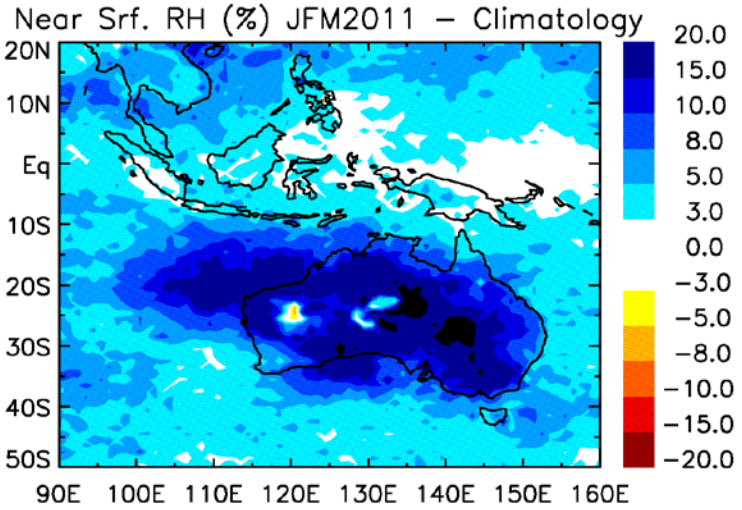
- Airborne Snow Observatory campaign (for Colorado River and Sierra Nevada water resource mgmt.
- US/Mexico Water Sharing Treaty Monitoring System (consumptive use) concept for DOI.



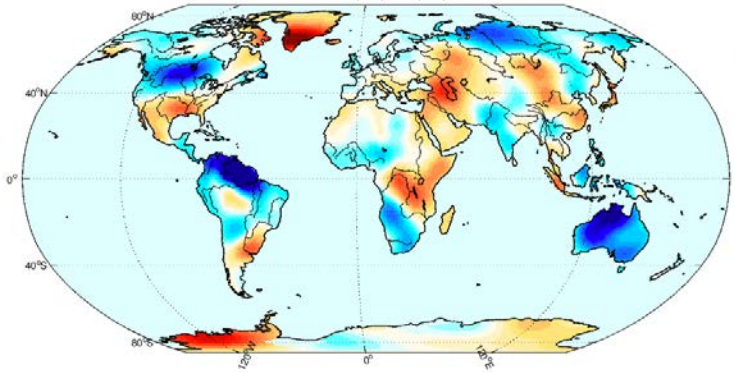
Closing the Water Budget

Global Sea Level Drops 5 mm in 2010



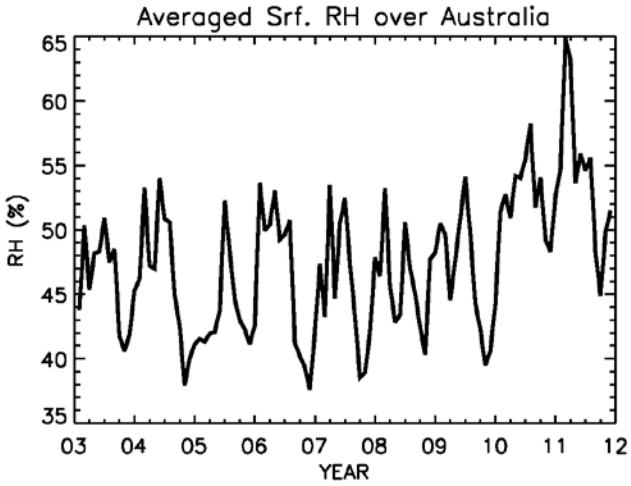


GRACE Shows Change in Water from March 2010 to March 2011



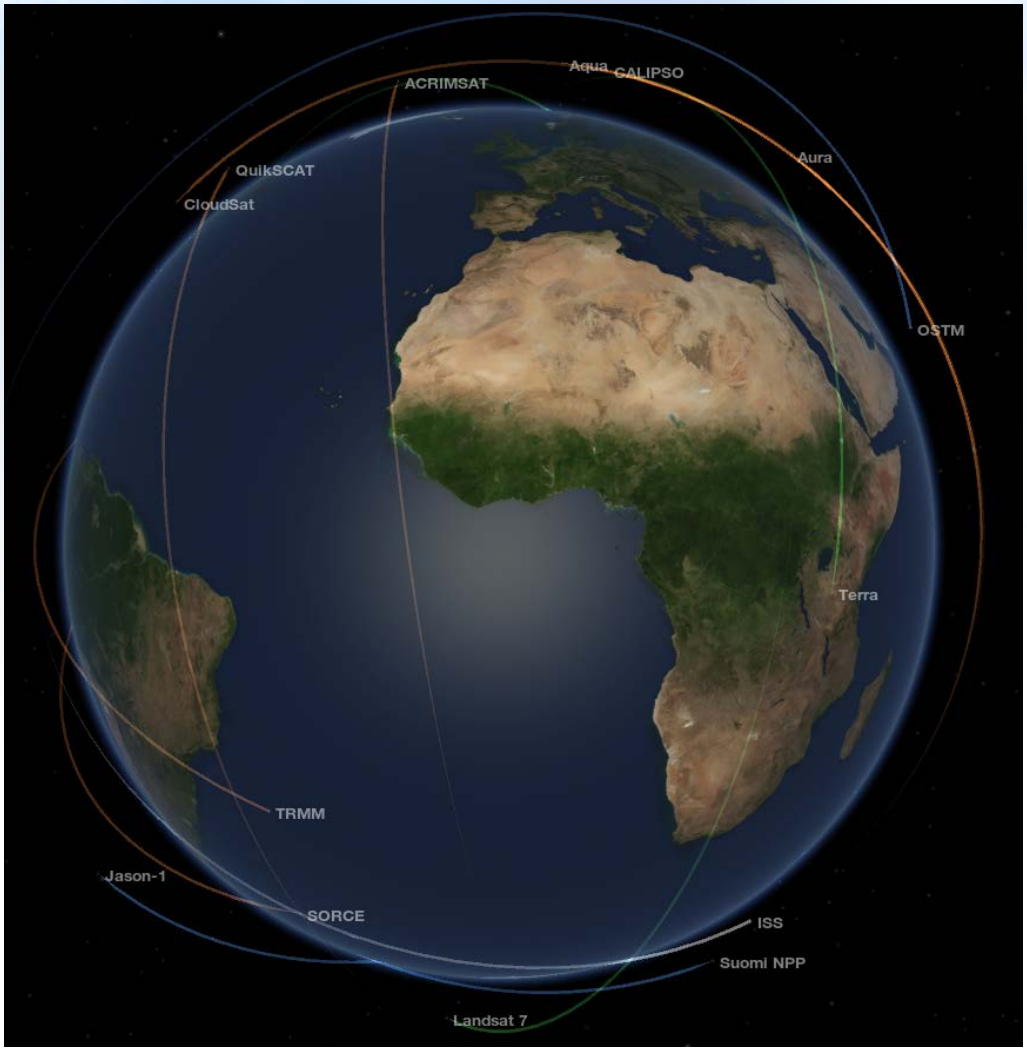
Mass in centimeters of water thickness

From Boening et al., submitted



Courtesy Joao Teixeira

Near Simultaneous Measurements (Next Gen A-Train/ISS)



- Ocean surface atmosphere exchange: SCAT, radiometer, cloud/precipitation radar
- Links between the carbon and water cycles: water vapor isotopes, fluorescence and C02 from near IR and profiling measurements.
- Others?

Summary

- New measurements planned for this decade offer an unprecedented opportunity to study the complete water cycle and provide better constraints on climate models.
- Satellite observations augmented with suborbital and in situ measurements allow for more focus on water resource management.
- Focus should be on integrated multisensor, multidisciplinary approaches.

Back-up

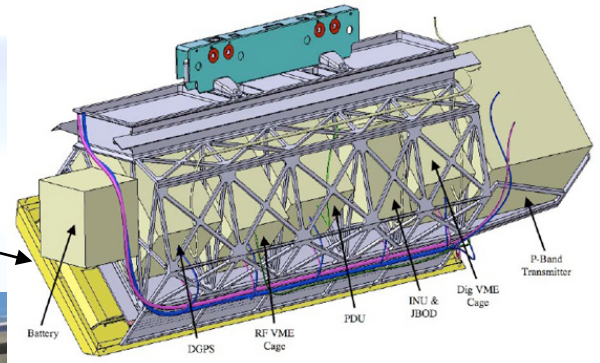
EV-1: Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS)

Science:

- Addresses key questions: 1. How does root zone soil moisture, including its landscape heterogeneity, control the regional carbon fluxes? 2. How is this control quantified via estimates of root zone soil moisture at various spatial and temporal scales?
- MOSS recommended in DS as part of a long term Integrated Water Cycle Observing system, with outstanding challenges in spaceflight accommodation. AirMOSS is both a step towards spaceflight, as well as support for SMAP, DESDynI*, BIOMASS, SMOS.
- NASA programs benefited:
  - TE, THP, Solid Earth

*Proposed Mission

Instrument:

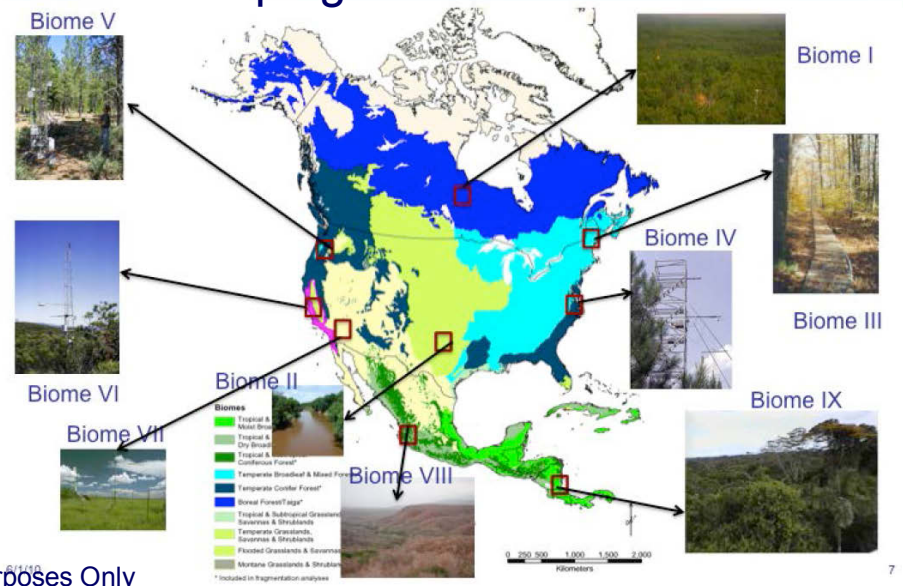


Pod space usage will be similar to that of the L-band UAVSAR

Implementation:

- Polarimetric UHF synthetic aperture radar, 280-440 MHz band capability, 80 MHz total bandwidth (capability for both split spectrum and contiguous)
- UAVSAR electronics and GeoSAR antenna
- Radar to fit inside a G-3 pod
- Integrate algorithms in year 1 using AIRSAR data
- Survey major biomes in North America in years 2-5
- Visit 9 flux tower sites, three times for temperate & boreal sites, twice for arid/semiarid, once for tropical sites; each time complete 3 surveys over 7-10days
- Team: PI Moghaddam (U of Michigan); JPL: Saatchi, Lou, Hensley, Freeman; MIT: Entekhabi; Harvard: Moorcroft; Purdue: Shepson; GSFC: Reichle; USDA: Crow; NSF/OSU: Cuenca

Field Campaigns:



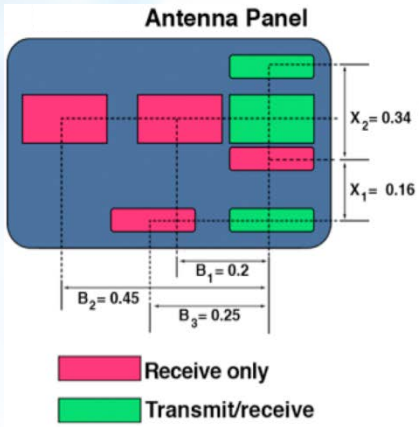
AirSWOT*: the SWOT Cal/Val Platform

PI: Ernesto Rodriguez, JPL

Objective

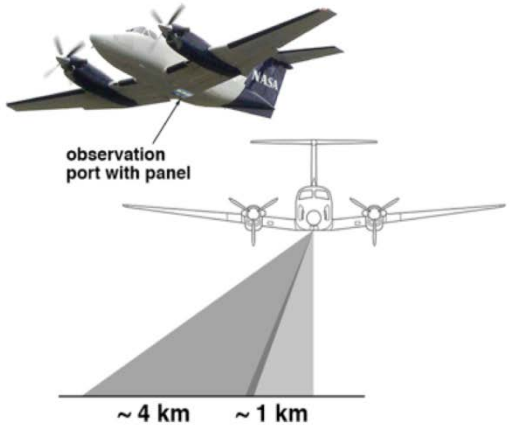
- Develop AirSWOT, the airborne Calibration/Validation (Cal/Val) platform for the Decadal Surface Water and Ocean Topography (SWOT)* mission, by building on subsystems developed under a NASA SBIR
- Demonstrate the performance of AirSWOT by laboratory tests and deployment on a NASA aircraft

*Proposed Mission



AirSWOT cross-track and along-track interferometer antenna configuration for 2 swaths

AirSWOT on NASA King Air B200



AirSWOT 2-swath configuration covers from nadir to 5km cross-track

Approach

- Develop loop-back calibration capabilities
- Develop additional hardware (Control and Timing Unit (CTU), Digital Storage System, Real Time Display) required for the integration of AirSWOT subassemblies
- Conduct functional and performance tests at component and end-to-end levels under laboratory conditions.
- Integrate AirSWOT into a stand-alone package coupled to a high precision inertial measurement unit (IMU) and deploy it on a NASA aircraft (King Air B200)
- Demonstrate performance by engineering flights

Co-Is/Partners:

Delwyn Moller, Remote Sensing Solutions

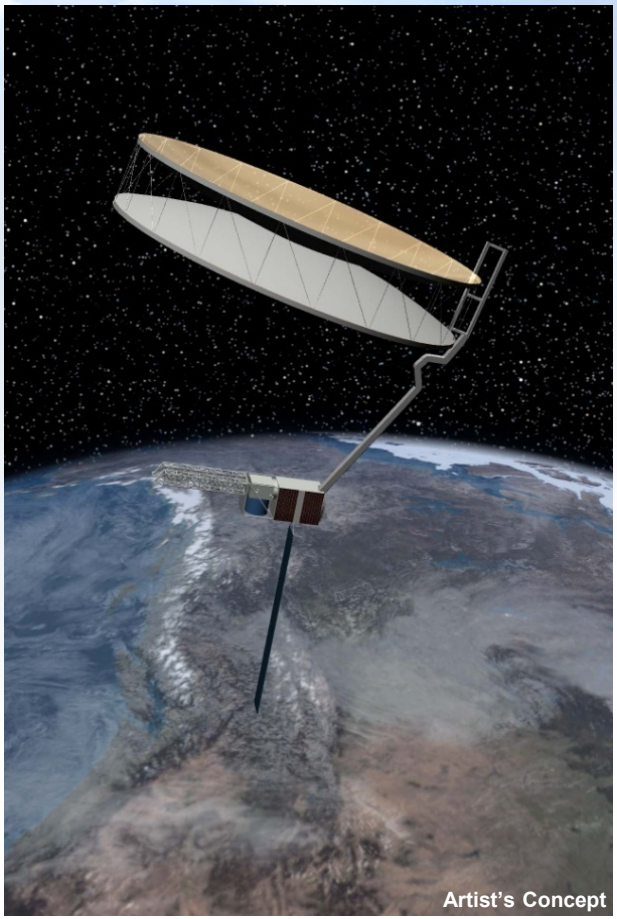
Key Milestones

- Complete mechanical design and airworthiness review 11/11
- Complete subsystem testing (Calibration-loop, CTU, data streaming) 01/12
- Complete full ground system testing 02/12
- Conduct Pre-ship Review 03/12
- Complete engineering test flights 05/12

TRL_{in} = 3 $TRL_{current}$ = 3

ESTO Earth Science Technology Office

Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI)* Status


Artist's Concept

- DESDynI* successfully completed a Mission Concept Review and JPL CMC in January 2011, was to start Phase A in March.
- In February, the President's proposed FY12 budget was released.
  - Lidar was eliminated.
  - NASA was told to come back with a more affordable option for an L-band Radar only mission.
  - Requires a renegotiation of science objectives.
- The past six months have been dedicated to exploring options for partnerships to reduce NASA cost and preserve science.
  - ISRO, CSA, DLR
- NEW Science Definition Team due by January.
- Mission concepts will be presented to NASA in March 2012, for April direction.

*Proposed Mission

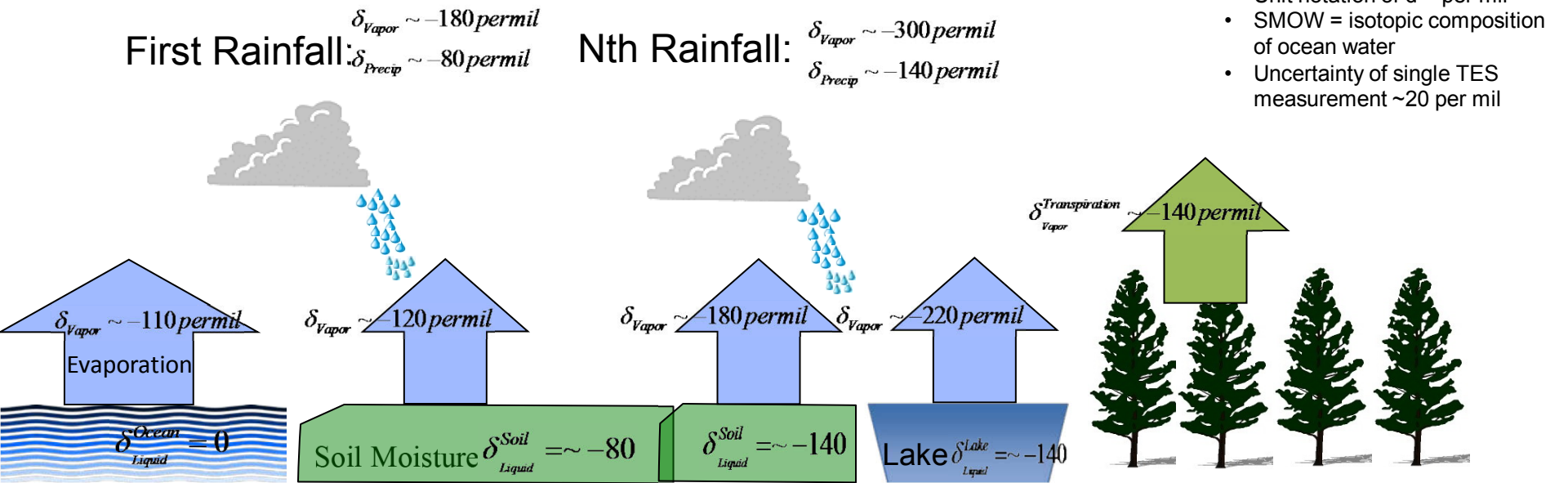
LRD: TBD

Links between the carbon and water cycle: Water vapor isotope profiles from the NASA Aura TES instrument and Fluorescence from the JAXA GOSAT instrument

- The carbon and water cycles are closely linked through uptake and release in the terrestrial ecosystem.
- During photosynthesis, sunlight and CO_2 are absorbed by vegetation, which in turn both "fluoresces" and releases water vapor into the atmosphere
- Water vapor and water vapor isotopes are measured by TES while fluorescence is measured by GOSAT.
- Water vapor isotopes provide a "signature" of water vapor distinguishing vapor released from plants, lakes, soils and oceans.
- Using these two measurements together we can examine the linkages between the water and carbon cycles (see poster by John Worden)
- We are now developing new instruments (e.g. panFTS) that can measure water vapor isotopes, fluorescence, and CO_2 simultaneously to quantify the relationships between the carbon and water cycles

$$\delta = 1000(HDO/H_2O/SMOW - 1)$$

- Unit notation of d = per mil
- SMOW = isotopic composition of ocean water
- Uncertainty of single TES measurement ~20 per mil

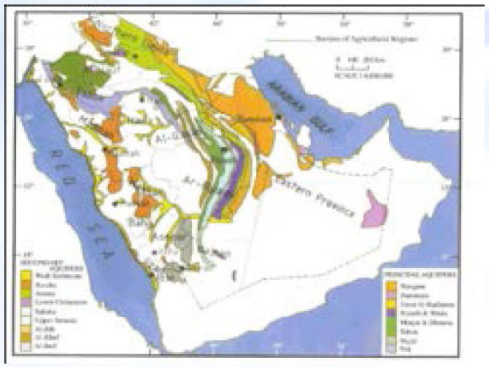


JPL Airborne Radar Sounder Science/Instrument Overview

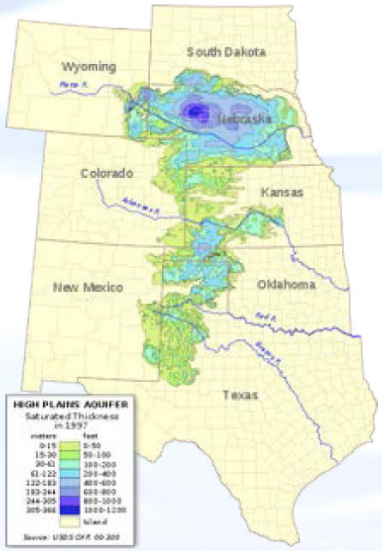
Science Objectives

Construct high-resolution maps of the regional distribution of shallow aquifers in the hyper-arid areas of Earth to better understand desert hydrology and groundwater flow models to provide new insights into recent and past changes in these aquifers and their implications for available water resources.

Science PI: Essam Heggy
Science team: Fadlemwala & Al-Rashed (KISR), Avouac & Lamb (Caltech), Farr (JPL), Sultan (W. Michigan) and Clifford (USRA).



(A. Pensulia Aquifer system, Aderahman, 2006)



(Ogallala, USA, USGS)

Instrument

1. Short pulse sounding radar (< 20 ns) at 40 and 75 MHz center frequencies
2. 20 and 40 MHz bandwidths at 40 and 75 MHz
3. Multiple antennas
4. Platform: Kuwait police Dauphin helicopter and Kuwait Air Force P3

(Nubian Aquifer, Heinl & Brinkmann, 1987)