Climate Science Observations

Remote Sensing Results of NASA and other Missions

Chevron Climate Energy Environment Seminar/Webinar Series

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• Earth satellite remote sensing
• The early challenges and progress in atmospheric chemistry
• The “Golden Age” of EOS
• Progress in carbon cycle science
• Progress in ocean science and sea level rise
• Progress in the hydrologic cycle science
• Progress in severe weather and storms
• What next?
January 31, 1958

Jupiter C rocket carrying Explorer 1

Bill Pickering, James Van Allen and Werhner Von Braun

Atmospheric Science – The ozone story

Stratospheric ozone changes: Northern mid-latitudes 30-60N, 35-45km

SBUV

UARS/HALOE

Odin/SMR

Odin/OSIRIS

• Abundances of Ozone Depleting Substances (ODSs) in the stratosphere are declining
• Long term recovery of stratospheric ozone will take decades
• Climate change - manifests as cooling in the stratosphere - complicates the identification of recovery
• A ‘super-recovery’, i.e., ozone exceeding 1980s levels, is a possibility
NASA Earth Science Missions

- OSTM/Jason 2
- Jason
- QuikScat
- ACRIMSAT
- Landsat-7
- EO-1
- Aqua
- Terra
- SORCE
- TRMM
- GRACE
- ICESat
- CALIPSO
- CloudSat
- Aura
JPL’s Earth Satellite Observations

Atmospheric Infrared Sounder (AIRS) provides monthly global temperature maps

Jason provides global sea surface height maps every 10 days

Gravity Recovery and Climate Experiment (GRACE) provides monthly maps of Earth’s gravity

Quikscat collects data over the polar regions, and supports Cal/Val of India's Oceansat-2

Multi-angle Imaging Spectro Radiometer (MISR) provides monthly global aerosol maps

Tropospheric Emission Spectrometer (TES) provides monthly global maps of Ozone

Microwave Limb Sounder (MLS) provides daily maps of stratospheric chemistry

CloudSat provides monthly maps of cloud ice water content

Aquarius provides monthly maps of sea surface salinity

JPL Earth Science Flight Projects

**Operational**
- QuikSCAT (1999)
- ACRIMSAT (1999)
- Jason-1 (2001)
- ASTER (1999)
- MISR (1999)
- GRACE (2002)
- AIRS (2002)
- TES (2004)
- MLS (2004)
- CloudSat (2006)
- Sea Surface Salinity: Aquarius (2011)

**Formulation/Development**
- OCO-2 (2014)
- GRACE-FO (2017)
- Jason 3* (04/2014)
- Soil Moisture: SMAP (2014)
- COSMIC-2* (2014)

**Mission Studies**
- ASCENDS CO₂ (2020)
- HyspIRI
- Ocean Vector Winds
- GEO-CAPE
- Ventures
- PACE

*NOAA
OCEANOGRAPHY, SEA LEVEL RISE, AND SALINITY
Sea Level Changes - ENSO

Repeating La Nina

Last El Nino

Images and more information can be found at http://sealevel.jpl.nasa.gov/science

Satellite Record

TOPEX
Jason-1
Jason-2

ΔMSL (mm)

Year


Sea level

Courtesy L. Fu

Historical Mean Sea Level Rise

Average Rate $\sim 1.8$ mm/year

$\sim 8$ inches (20 cm)

Courtesy L. Fu

[Church and White, 2006]
Gravity Recovery and Climate Experiment - GRACE

GRACE and GRACE Follow-On provide an original measurement in the shift in water from ice through inundation.

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

Ice Sheet Mass Balance Inter-comparison Exercise for AR5 IPCC Report

- Space methods for recovering ice sheet mass balance report incompatible results: discrepant by sea-level change equivalents of 1 mm/yr

- Result:
  - Space gravimetry & radar altimetry (2003-2011) reconciled to < 0.2 mm/yr (within 1-σ errors)
  - Radar altimetry & Input Minus Output Method (IOM) (involving radar interferometry for output) reconciled to < 0.2 mm/yr after 1995
  - Inter-comparison of all methods (including laser altimetry) are reconciled for Greenland and West Antarctica for the period when all space techniques gather data (2003-2009).

- Space observations provide robust and unambiguous determination of ice mass balance and its change in time.

Change in mass in 2009

Mass change rates 1992 - 2011
The 2011 La Niña: So Strong, the Oceans Fell
Boening et al., 2012a; (GRL, in press).

Global Mean Sea Level dropped by 5 mm

GRACE shows change in land water storage from 2010-2011

1) The problem: Projections of how much the the GMSL will rise in the future are highly uncertain.
2) What was done: Combination of GRACE data, satellite altimetry and ARGO data used to explain sources of sea level drop in 2010/11
3) Main findings: GMSL drop was primarily caused by freshwater exchange between ocean and land.
4) Next step: How do water cycle changes influence sea level?

Aquarius uses an L-band radar and radiometer to make monthly maps of sea surface salinity with precision of .2 PSU and resolution of 150 km.

Changes in salinity impact ocean circulation and precipitation.

Tropical Instability Waves,
early science results from Aquarius
(Lee et al, GRL, in press 2012)
Tropical Instability Waves (TIWs)

- TIWs affect ocean dynamics, climate, biogeochemistry.
- Salinity important to TIWs physics, but limited obs.
- Aquarius fills a significant gap in observing TIWs, complement other obs.
- Captures 17-day period TIWs, an unexpected capability.
- Reveals faster TIW speed near the equator (poorly documented).


CARBON CYCLE, ABOVE GROUND BIOMASS, AND CARBON DIOXIDE
Carbon in the World’s Forests - Above ground biomass

Ruesch and Gibbs

Kellndorf and Walker


The Mystery of the Missing CO₂

- Humans have added >200 Gt C to the atmosphere since 1958
- Less than half of this CO₂ is staying in the atmosphere
  - Where are the *sinks* that are absorbing over half of the CO₂?
    - Land or ocean?
    - Eurasia/North America?
- Why does the CO₂ buildup vary from year to year with nearly uniform emission rates?
- How are variations driven by large scale drivers of atmospheric variability (e.g., ENSO)?
- Can we reduce the uncertainty on each key system within the carbon cycle?
- How will these CO₂ sinks respond to climate change?
Atmospheric CO2 from GOSAT

Chlorophyll fluorescence provides a direct measure of CO₂ uptake by plants, the largest known terrestrial sink.

Frankenberg et al., 2011
WATER CYCLE
CloudSat and TRMM were used in a complementary way to identify how much rain is missed by the current precipitation measuring sensors. It was determined that the quasi-global (60°S-60°N) oceanic mean rain rate is ~3.05 mm/day, considerably larger than that obtained by the current rain products.

obs4MIPs Activity Delivers Satellite Data to Earth System Grid

In Collaboration with PCMDI

Activity resulted in new Roses call: Enhancing the Capability of Computational Earth System Models and NASA Data for Operation and Assessment (Jonathan Jiang, Seungwon Lee)

JPL Data Sets
- AIRS T & Q
- Topex/Jason SLH
- QuikScat Winds
- MLS T & Q
- TES Ozone

Coupled Model Intercomparison Project (CMIP)
Program for Climate Model Diagnostics and Intercomparison (PCMDI)

CloudSat Data Now Available for Model Evaluation and Improvement

CloudSat Total IWP

CloudSat IWP Conditionally Filtered to better approximate/validate GCM-modeled Cloud IWP

Mean Cloud IWP from 16 IPCC Contributions of 20th Century Climate: Color scale ~ log 10: Raises Uncertainty about Model Cloud Representation

Waliser et al. (2009)
SEVERE WEATHER AND STORMS
Hurricane Sandy

10/27/2012 @ 1832 UTC

Light to moderate precipitation
Cumulus cells

Land
Ocean

18:26:19 18:23:08 | Lat 51.5 40.1 | Lon -80.5 -76.3
CIRA CloudSat DPC 2012 Oct 29 (303) 17:22:32 UTC | 1A-AUX | FirstLook 34611

Time
Nine years of Aqua AIRS humidity data encompassing 198 North Atlantic tropical cyclones revealed that:

- Intensifying hurricanes reside in a moister environment than weakening storms.

- Relative humidity (RH) tends to increase with hurricane intensity and intensification rate.
- Substantial azimuthal asymmetry in RH exists at radial distances > 400 km.
- In the front-right quadrant relative to storm motion, intensifying hurricanes are associated with strong radial gradient in upper tropospheric RH.

RESEARCH TO APPLICATIONS
GLOBAL THROUGH REGIONAL TO LOCAL ACTIONS
Airborne Instruments (Operational)

- HAMSR
- ULH
- AVIRIS
- Airborne Visible / Infrared Imaging Spectrometer
- AirMSPI
- Carbon isotope Laser Spectrometer
- UAVSAR
- Uninhabited Aerial Vehicle Synthetic Aperture Radar
- LAS-CO2
- The MODIS/ASTER (MASTER) airborne simulator
- ACR
- Airborne Cloud Radar
- APR-2
- Submillimeter Limb Sounder
- MTP
- Microwave Temperature Profiler
- PALS
- Passive/Active L-band Sensor
- WISE
- Warm Ice Sounding Explorer
- PRISM
- Portable Remote Imaging Spectrometer
- AVIRISng
- Airborne Visible Infrared Imaging Spectrometer
- CARVE
- CARbon in Arctic Reservoirs: Variability, Extent, and Geologic History

http://airbornescience.jpl.nasa.gov
JPL Airborne Snow Observatory

Imaging snow water equivalent and snow albedo

Principal Investigator: Thomas H. Painter

Closing Comments

- Satellite remote sensing has matured from discovery science to monitoring with a range of systems and needs
- Process studies using satellite data fill an important niche in climate change research
- Important long-term trends are emerging from the satellite records
  - Sea level height
  - Summer Arctic sea ice extent
- The frontiers for satellite remote sensing:
  - Can they be sustained and developed to applications in water resource management, food security, and health
  - Can we reduce uncertainty in long-term climate projections