Global Precipitation Measurement (GPM) Mission

Dalia Kirschbaum
Associate Deputy Project Scientist for GPM
Goddard Space Flight Center
- Launched in 1997 to measure tropical rainfall, ended in 2015
- TRMM has a 17-year record of precipitation from latitudes ~35°North to 35°South
- Partnership between NASA and the Japan Aerospace Exploration Agency (JAXA)
- Data at http://trmm.gsfc.nasa.gov

GPM instrument enhancements and improved retrievals estimate light rainfall and snow typically found in higher latitudes

Rainfall Accumulation from Tropical Cyclone Giovanna, triggering deadly floods in Madagascar
Dual-frequency Precipitation Radar (DPR): Ku-Ka bands
Two different radar frequencies look at precipitation in 3-D, similar to a CT scan

GPM Microwave Imager (GMI):
10-183 GHz
13 channels provide an integrated picture of the energy emitted by precipitation, similar to an X-ray
Global Precipitation Measurement (GPM)
Multi-Satellite Precipitation Data (30 min, 10km by 10km)

IMERG: Integrated Multi-satelliteE Retrievals for GPM

2016/07/21 00:00:00

Liquid Precipitation Rate

mm/hour

0.1 0.2 0.3 0.5 1.0 2.0 3.0 5.0 10 20 50

Frozen Precipitation Rate

mm/hour

0.1 0.2 0.3 0.5 1.0 2.0 3.0 5.0 10 20 50
Societal Benefit Areas

Extreme Events and Disasters
- Landslides
- Tropical cyclones
- Floods
- Re-insurance

Water Resources and Agriculture
- Famine Early Warning System
- Water Resource management
- Drought
- Agriculture

Weather, Climate & Land Surface Modeling
- Numerical Weather Prediction Modeling
- Land System Modeling
- Global Climate Modeling

Public Health and Ecology
- Disease tracking
- Food Security
- Animal migration
TRMM & GPM provides rain accumulation and distribution data at high resolution to advance predictions of high-impact natural hazard events.

Dozens dead after flash floods and landslides in Nepal

4 hours ago

Dozens of people have died in Nepal as flash floods and landslides, caused by monsoon rains, have swept through villages.

Amateur video from Butwal in Nepal’s Rupandehi District shows water pushing through flood defences.
Famine Earth Warning System (FEWS) relies on TRMM and other satellites to anticipate poor growing seasons.

Rainfall Estimates

http://farmlandgrab.org

http://earlywarning.usgs.gov

www.climatecentral.org
For more information on the TRMM and GPM Missions:


www.nasa.gov/gpm

Movies at: http://svs.gsfc.nasa.gov/

Twitter: NASA_Rain (11K followers) Facebook: NASA.Rain (>20K)
## GPM Data Products

<table>
<thead>
<tr>
<th>Product Level</th>
<th>Description</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1B GMI, GMI-2, Level 1C GMI, GMI-2&lt;br&gt;&lt;br&gt; <em>Latency ~ 1 hour</em></td>
<td>Geolocated Brightness Temperature and intercalibrated brightness temperature</td>
<td>Swath, instrument field of view (IFOV)</td>
</tr>
<tr>
<td>Level 1B DPR</td>
<td>Geolocated, calibrated radar powers</td>
<td>Swath, IFOV (produced at JAXA)</td>
</tr>
<tr>
<td>Level 1C, partner radiometers</td>
<td>Intercalibrated brightness temperatures</td>
<td>Swath, IFOV</td>
</tr>
<tr>
<td>Level 2 GMI, GMI2&lt;br&gt;&lt;br&gt; <em>Latency ~1 hour</em></td>
<td>Radar enhanced (RE) precipitation retrievals</td>
<td>Swath, IFOV</td>
</tr>
<tr>
<td>Level 2 partner radiometers</td>
<td>RE precipitation retrievals from 1C</td>
<td>Swath, IFOV</td>
</tr>
<tr>
<td>Level 2 DPR&lt;br&gt;&lt;br&gt; <em>Latency ~3 hours</em></td>
<td>Reflectivities, Sigma Zero, Characterization, DSD, Precipitation with vertical structure</td>
<td>Swath, IFOV (Ku, Ka, combined Ku/Ka)</td>
</tr>
<tr>
<td>Level 2 combined GMI/DPR&lt;br&gt;&lt;br&gt; <em>Latency ~3 hours</em></td>
<td>Precipitation</td>
<td>Swath, IFOV (initially at DPR Ku swath and then at GMI swath)</td>
</tr>
<tr>
<td>Level 3 Latent Heating (GMI, DPR, Combined)</td>
<td>Latent Heating and associated related parameters</td>
<td>0.5 x 0.5 daily and monthly grid</td>
</tr>
<tr>
<td>Level 3 Instrument Accumulations</td>
<td>GMI, partner radiometers, combined and DPR</td>
<td>0.1 x 0.1 daily and monthly grid</td>
</tr>
<tr>
<td>Level 3 Merged Product</td>
<td>Merger of GMI, partner radiometer, and IR</td>
<td>0.1 x 0.1 hourly grid</td>
</tr>
<tr>
<td>Level 4 Products</td>
<td>Model assimilated data</td>
<td>Fine temporal and spatial scale TBD</td>
</tr>
</tbody>
</table>
SMAP: Soil Moisture Active Passive
31 January 2015

Instruments
- Radar (1.26 GHz)
  - High resolution, moderate accuracy
- Radiometer (1.4 GHz)
  - Moderate resolution, high accuracy

Shared antenna
- Constant incident angle: 40 degrees
- 1000 km wide swath

Orbit
- Sun-synchronous
- 6 am (Descending) / 6 pm (Ascending)
- 685 km altitude
- Global coverage every three days

---

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
<th>Gridding (Resolution)</th>
<th>Latency**</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1A_Rad</td>
<td>Radar Data in Time-Order</td>
<td>-</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1A_Rad</td>
<td>Radar Data in Time-Order</td>
<td>-</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1B_TB</td>
<td>Radiometer $T_b$ in Time-Order</td>
<td>(36×47 km)</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1B_S0_LoRes</td>
<td>Low-Resolution Radar $\alpha_s$ in Time-Order</td>
<td>(5×30 km)</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1C_S0_HiRes</td>
<td>High-Resolution Radar $\alpha_s$ in Half-Orbits</td>
<td>1 km (1-3 km)$^2$</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1C_TB</td>
<td>Radiometer $T_b$ in Half-Orbits</td>
<td>36 km</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L2_SM_A</td>
<td>Soil Moisture (Radar)</td>
<td>3 km</td>
<td>24 hrs</td>
</tr>
<tr>
<td>L2_SM_P</td>
<td>Soil Moisture (Radiometer)</td>
<td>36 km</td>
<td>24 hrs</td>
</tr>
<tr>
<td>L2_SM_AP</td>
<td>Soil Moisture (Radar + Radiometer)</td>
<td>9 km</td>
<td>24 hrs</td>
</tr>
<tr>
<td>L3_FT_A</td>
<td>Freeze/Thaw States (Radar)</td>
<td>3 km</td>
<td>50 hrs</td>
</tr>
<tr>
<td>L3_SM_A</td>
<td>Soil Moisture (Radar)</td>
<td>3 km</td>
<td>50 hrs</td>
</tr>
<tr>
<td>L3_SM_P</td>
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<td>50 hrs</td>
</tr>
<tr>
<td>L3_SM_AP</td>
<td>Soil Moisture (Radar + Radiometer)</td>
<td>9 km</td>
<td>50 hrs</td>
</tr>
<tr>
<td>L4_SM</td>
<td>Soil Moisture (Surface and Root Zone)</td>
<td>9 km</td>
<td>7 days</td>
</tr>
<tr>
<td>L4_C</td>
<td>Carbon Net Ecosystem Exchange (NEE)</td>
<td>9 km</td>
<td>14 days</td>
</tr>
</tbody>
</table>

---

Level-3 (L3) soil moisture
Passive only product
Spatial Coverage: N: 85.044, S: -85.044, E: 180, W: -180
Spatial Resolution: 36 km x 36 km
Temporal Coverage: 2015-03-31-present
EASE-Grid, Version 2.0
SMAP launched on January 31, 2015 into a sun-synchronous 6 am/6 pm orbit
-- routine science operations began on March 31, 2015
-- the L band radiometer continues to work well; the L band radar transmitter failed on July 7, 2015
-- validated L1 instrument data and beta versions of all L2-L4 products were released to the DAACs by November 1, 2015
-- validated versions of the L2-L4 products are due to be released in May, 2016
-- the SMAP Freeze/Thaw team is currently testing a passive-only algorithm for the SMAP L3_FT product given the demise of the SMAP radar
-- the SMAP Project is currently investigating:
  (a) several resolution enhancement approaches for the SMAP radiometer data
  (b) possible use of Sentinel-1 C-band radar to replace the SMAP L-band radar in the active/passive disaggregation approach for the L2_SM_AP product

Example of Passive-Only SMAP Soil Moisture (L3_SM_P)


Courtesy of Peggy O’Neill / NASA GSFC Code 617
• The second part of the SMAPVEX16 cal/val campaign started on July 10 in Manitoba, Canada
• SMAP science and algorithm teams completed algorithm updates and validated Levels 1-4 data products for public release available at NSIDC and DAACs (May, 2016).
Pairing Precipitation and Soil Moisture to Illustrate ‘Precipitation Memory’
SMAP: Soil Moisture Active Passive
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Instruments
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Example of Passive-Only SMAP Soil Moisture (L3_SM_P)

SMAP SM in m³/m³

Courtesy of Peggy O’Neill / NASA GSFC Code 617
- The second part of the SMAPVEX16 cal/val campaign started on July 10 in Manitoba, Canada.
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Pairing Precipitation and Soil Moisture to Illustrate ‘Precipitation Memory’
Satellite-Based Remote Sensing of Water Resources

Matt Rodell, Ph.D.
Chief, Hydrological Sciences Laboratory
NASA Goddard Space Flight Center
Greenbelt, MD
Inadequacy of Surface Observations

Global Telecommunication System meteorological stations. Air temperature, precipitation, solar radiation, wind speed, and humidity only.

Eight countries make groundwater data publicly available through the Global Groundwater Monitoring Network.

River flow observations from the Global Runoff Data Centre. Lighter circles indicate greater latency in the data record.

USGS Groundwater Climate Response Network.

Issues include coverage gaps, delays, measurement continuity and consistency, data format and QC, political restrictions.
Highly relevant to hydrology

Earth Science Instruments on ISS:
- RapidScat, CATS,
- LIS, SAGE III (on ISS), TSIS-1, OCO-3,
- ECOSTRESS, GEDI,
- CLARREO-PF
Conventional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column. GRACE is unique in its ability to monitor water at all levels, down to the deepest aquifer.
Gravity Recovery and Climate Experiment (GRACE)

- Two identical satellites flying in tandem, near-polar orbit, ~200 km apart, 500 km initial altitude
- Distance between satellites tracked by K-band microwave ranging system
- Launched 17 March 2002
Terrestrial Water Storage Variations

TWS variations are dominated by:
- Soil moisture in temperate regions;
- Snow in polar and alpine regions;
- Surface water in wetlands.

Top: 23 year time series of snow, soil moisture, and groundwater storage in Illinois, USA (right)

Updated from Rodell and Famiglietti, WRR, 2001
Emerging Trends in Terrestrial Water Storage from GRACE

Best fit linear rate of change of TWS (cm/yr), 2002-2015.

- Data from http://grace.jpl.nasa.gov/data/get-data/jpl_global_mascons/
- Which apparent trends are real and likely to continue?
Exploitation of Water Resources

Percentage of Irrigated Area

Source: FAO and University of Frankfurt

Groundwater Depletion Rate (ca. 2000)

Wada et al. (2010)

Equivalent height of water (mm/yr)

Net Consumptive Use of Ground and Surface Waters, 1998-2002

Döll et al. (2011)

Equivalent height of water (mm/yr)

Terrestrial Water Storage “Trends” from GRACE

Equivalent height of water (cm/yr)

Net Consumptive Use of Ground and Surface Waters, 1998-2002

Equation: Equivalent height of water (mm/yr)

Döll et al. (2011)

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Döll et al. (2011)

Net Consumptive Use of Ground and Surface Waters, 1998-2002

Equivalent height of water (mm/yr)

Terrestrial Water Storage “Trends” from GRACE

Equation: Equivalent height of water (cm/yr)
Groundwater continues to be depleted in the Indian states of Rajasthan, Punjab, and Haryana by about 16.0 km$^3$/yr, reduced slightly from our previous (2002-08) estimate of 17.7 ±4.5 km$^3$/yr (Rodell, Velicogna, and Famiglietti, 2009).

Trends in terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE during 2002-15.
Emerging Trends in Global Freshwater Storage

Trends in terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE during 2002-15

Rate of change of water storage (cm/yr)

Growth of Irrigation in Saudi Arabia

Landsat images prepared by Aries Keck, NASA/GSFC
Preliminary estimate of groundwater depletion rate: 2.6 km$^3$/yr.
This includes the impact of a persistent drought in the region, as indicated by the soil water time series.
Emerging Trends in Global Freshwater Storage

Rates of change of terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE* during 2002-15

*JPL GRACE Mascon hydrology product

- Greenland’s ice sheet has been thinning at a rate of 142 km³/yr
- Russian droughts in 2010 and 2012
- Groundwater is being depleted across northern India at a rate of about 54 km³/yr due to pumping for irrigation
- Overexploitation of freshwater resources in the North China Plain
- Return to normal after wet years in early 2000s
- Drought recovery and flooding in east Australia
- Depletion of water resources in Middle East, exacerbated by drought
- Return to normal in the Okavango Delta after drought ended in 2007

- Alaska’s glaciers have been melting at 84 km³/yr
- Recent droughts in California and Texas
- Recovery from 2004-05 drought in the Amazon
- 2010 Chile earthquake and drought in southern Argentina
- Patagonian glacier melt
- The western Antarctic ice sheet has been thinning at a rate of 65 km³/yr

GRACE observes changes in water storage caused by natural variability, climate change, and human activities such as groundwater pumping
Summary and Future Prospects

• Due to the incompleteness of ground-based observations, space-based observation of global freshwater resources is critical.

• NASA’s GRACE satellite mission is unique in its ability to monitor all forms of water at all depths, including groundwater.

• Emerging trends in terrestrial water storage observed by GRACE can be categorized as natural variations, climate change impacts, or direct consequences of human activities, particularly irrigation.

• The value of GRACE and other satellite data for applications such as drought monitoring can be enhanced by combining them within a land surface model.

• The GRACE Follow-On mission is scheduled to launch by February 2018.

• Commencing in June, the National Research Council’s 2017 Decadal Survey in Earth Sciences will set the priorities for NASA’s 2020-2030 Earth observing satellite missions.
The ICESat-2 Mission
Inland Water Height Data Product

Michael Jasinski
NASA GSFC
Science Team Lead for
Inland Water Data Product

USGS Interagency Mtg
ACWI/SOH
July 28, 2016
ICESat-2/ATLAS Instrument

Instrument
- Advanced Topographic Laser Altimeter System (ATLAS)
- Micro-pulse instr w/single-photon sensitive detection
- 6 beams, arranged in 3 pairs (25/100 μJ)
- 10 kHz pulse repetition rate
- 14m footprint
- spaced 0.7m along-track
- 532nm wavelength

Orbit: 500 km, non-sun-synch, 92° inclination
Repeat: 91 day exact repeat, ~30 day subcycle
Launch Date: ~Nov/Dec 2017
Lifetime: 3 years, with consumables for 7
Partners: GSFC, Orbital Sciences, ULA, KSC

Status: Built and in Thermovac Testing!
# ICESat-2 Data Products

<table>
<thead>
<tr>
<th>ATBD</th>
<th>Lead</th>
<th>Affiliation</th>
<th>ATLAS Science Data Products</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision Pointing Determination (PPD)</td>
<td>Bob Schutz / Sungkoo Bae</td>
<td>UTCSR</td>
<td>ancillary data</td>
<td>Precise laser pointing solutions input to all level 2 and higher level products</td>
</tr>
<tr>
<td>Precision Orbit Determination (POD)</td>
<td>Scott Luthcke</td>
<td>GSFC</td>
<td>ancillary data</td>
<td>Precise orbit solutions input to all level 2 and higher level products</td>
</tr>
<tr>
<td>Level 1A</td>
<td>John DiMarzio</td>
<td>SGT/GSFC</td>
<td>ATL01</td>
<td>Conversion and reformatting of Level 0 data</td>
</tr>
<tr>
<td>Level 1B</td>
<td>Rob Jones / Tony Martino</td>
<td>GSFC</td>
<td>ATL02</td>
<td>Apply necessary corrections from housekeeping data, e.g. calibrated ranges</td>
</tr>
<tr>
<td>Level 2A</td>
<td>Tom Neumann</td>
<td>GSFC</td>
<td>ATL03</td>
<td>combine elevation corrections, geolocation information, laser spot location (which requires preliminary surface finding) with L1B product</td>
</tr>
<tr>
<td>Ice Sheet</td>
<td>Ben Smith</td>
<td>UW</td>
<td>ATL06, 11, 14, 15</td>
<td>Define ice sheet products and parameters</td>
</tr>
<tr>
<td>Sea Ice</td>
<td>Ron Kwok</td>
<td>JPL</td>
<td>ATL07, 10, 20, 21</td>
<td>Define sea ice products and parameters</td>
</tr>
<tr>
<td>Land/Vegetation</td>
<td>Amy Neuenschwander</td>
<td>U. Texas</td>
<td>ATL08</td>
<td>Define land and vegetation products and parameters</td>
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<tr>
<td>Ocean</td>
<td>James Morison</td>
<td>UW</td>
<td>ATL12, 19</td>
<td>Along track SSH and Significant Wave Height;</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Steve Palm</td>
<td>SSAI/GSFC</td>
<td>ATL04, 09, 16, 17</td>
<td>Atmosphere products and parameters and the calibrated backscatter</td>
</tr>
<tr>
<td>Inland Water</td>
<td>Mike Jasinski</td>
<td>GSFC</td>
<td>ATL13</td>
<td>Along track height distribution, ~ 100m segments (variable), cross track max slope and aspect.</td>
</tr>
</tbody>
</table>
Inland Water Data Products

Along track water surface height, standard deviation and slope

Water body maximum slope and aspect between neighboring strong beams
Testing ICESat-2 Inland Water Algorithm w/MABEL Prototype

- 2014 Fairbanks, AK
- 2013 Mojave, CA
- 2013 Langley, VA
- 2012 Keflavik, Iceland
- 2012 Wallops, VA
- 2012 Dryden, CA
- 2011 Dryden, CA
- 2010 Dryden, CA
E.g. MABEL flight over Lake Mead

Lake Mead
Feb 24, 2012
11 PM local time
20 km AGL

Similar profiles expected from ICESat-2

SWOT combines surface water hydrology with physical oceanography.
1. The Problem

In-situ cannot measure this

2. The Question

What is the spatial and temporal variability of freshwater stored in the world’s terrestrial water bodies?

Floods are the number one hazard

3. Measurements Required

Maps of h, which give maps of dh/dt and dh/dx

4. The Solution

KaRIN: Ka-band Radar Interferometer. SRTM, WSOA heritage. Maps of h globally and ~weekly (over a 120 km wide swath at 1km resolution)
1. The Problem  Altimeters miss considerable ocean area.

2. The Question  What are the energy dissipation, ocean circulation, and climate implications from oceanic eddies which contain 90% of the kinetic energy, but are ~10 km scale in cross-stream direction, e.g. Gulf Stream, Kuroshio.

3. Measurements Required  Maps of \( h \), which give maps of \( \frac{dh}{dt} \) and \( \frac{dh}{dx} \) allowing derivation of velocity, vorticity, and stress tensor.

4. The Solution  KaRIN: Ka-band Radar Interferometer. SRTM, WSOA heritage. Maps of \( h \) globally and ~weekly.

bprc.osu.edu/water
Snow Missions

Edward Kim
NASA/GSFC
ed.kim@nasa.gov
301-614-5653

snow.nasa.gov
The Importance of Snow

• Snow is important both as a water resource and as a control on surface energy balance.

• For 1/6 of Earth’s population 50-100% of runoff results from snowmelt\(^1\), affecting about a quarter of the global GDP.

• In large parts of the western US, up to 90% of renewable water comes from snow. The current CA drought is mainly due to low snow.

• 9 of the top 20 US floods during 1900-2000 were snow-related.

• Snow is a major source of spring soil moisture for agriculture.

Snow is important, yet simple questions like ‘how much snow is there?’ and ‘when will it melt?’ are still difficult to answer; there are large uncertainties using remote sensing or models.

\(^1\)Barnett et al, Nature (17), Nov 2005
Snow missions

- Must address *global* snow
- Therefore must include multiple sensors (community consensus)
  - e.g., Active & passive microwave, lidar, multi-spectral VIS/IR
  - Recent snow mission proposals were single-sensor & algorithms were not robust enough ➔ proposals not selected
- Need mature sensor technology and algorithms
  - Strengths & limitations of various sensors not well characterized vs. each other
  - Very little work on multi-sensor algorithms used w/great success elsewhere
  - Little existing work on snow retrievals in forest areas (50% snow covered area)
- Satellites are expensive; multi-sensor missions are more expensive
  - Must leverage existing assets (e.g., passive microwave and multispectral)
  - But some satellite assets might go away (passive microwave)
- International partnering is the key to
  - Leveraging technology and algorithm development investments
  - Spreading costs
- Societal benefits and science return already strong

Need multi-sensor field data to perform mission concept trade studies
Snow Measurement Capabilities

• Recent snow remote sensing community consensus: no single sensing technique works well across a wide variety of snow types and conditions.

• What is the optimum combination of sensing techniques to measure
  • regional (global) SWE?
  • global snow melt/energy balance (where, when, how fast)?

• Candidate sensors: radar, lidar, passive microwave, VIS/IR multispectral, BRDF

• Groups in US & Europe are exploring satellite concepts

Need a multi-sensor field campaign to compare techniques, to quantify when each ‘breaks’ and to understand why.

snow.nasa.gov
SnowEx airborne campaigns

• Year 1 led by NASA GSFC with help from whole snow community

• Will collect a multi-sensor dataset for mission trade studies and algorithm development

• Year 1 focus: snow in forests

• Sites selected for 2016-17
  • Primary: Grand Mesa, CO
  • Secondary: Senator Beck basin, CO

• Airborne sensors
  • Radar: SnowSAR (ESA)
  • Passive mw: AESMIR (GSFC)
  • BRDF: CAR (GSFC)
  • Lidar+ hyperspectral: ASO (JPL)
  • Thermal IR: TBD
  • Photography: TBD

• Year 1 Deployments
  • Sep/Oct 2016 lidar only no-snow background;
  • Feb 2017: with-snow; all sensors
  • Summer 2017: radar only no-snow background

• Ground truth
  • Traditional & new measurements
  • Snow & trees & soil

• SnowEx schedule:
  • Year 1 = 2016/17 dedicated campaigns
  • Year 2 = 2017/18 **no** campaign
  • Year 3 = 2018/19 dedicated campaigns
  • Year 4 = 2019/20 dedicated campaigns
  • Year 5 = 2020/21 dedicated campaigns
  • Locations for years 3,4,5 TBD

snow.nasa.gov -> snowex
GLOBAL MAPPING OF EVAPOTRANSPIRATION

Thomas R. H. Holmes
Hydrological Sciences Lab, Code 617
ET at the Hydrological Sciences Lab

Importance
• Evapotranspiration (ET) is the link between the energy, water, and carbon cycles
• Accounting for up to 60% of the return of precipitation to the atmosphere, it plays a key role in climate, meteorology, and agriculture.
• ET is also one of the most unconstrained components of the hydrological cycle.

ET at the Hydrological Sciences Lab
• Use remotely sensed ET as a diagnostic observation for model improvement and/or assimilation;
• Concept development for remote sensing missions to estimate evapotranspiration (ET) at diverse spatial domains (e.g. Decadal Survey)

Challenge
• Evaporative flux does not leave a direct electromagnetic fingerprint that can be exploited by satellite retrievals
Energy balance approach: ALEXI
Applications with Thermal Infrared

General Method
- Interprets temporal gradients in Surface Temperature as one of the most direct diagnostics of ET
- Atmosphere Land Exchange Inverse (ALEXI: Anderson et al., 1997, 2007)

Thermal Infrared (TIR) implementations (USDA/NOAA)
- Using TIR-LST allows to integrate measurements from field to continental scales depending on application:
  - **Field Scale**: crop water use
  - **Regional scale**: early indicator of agricultural drought
  - **Continental to global scales**: Confronting LSM with observations
- MODIS-LST implementation (Chris Hain, NOAA). Global 5km, 7-day product 2001-Present

Microwave LST implementation (NOAA/NASA/USDA)
- In evaluation. Test run: Global 0.25 degree, 7-day product 2003-2013

Multi-scale ET maps using land-surface temperature from various satellites
Microwave Implementation of ALEXI
3-month totals

Cumulative - Clear Sky - Evapotranspiration (mm)

Cloud issues in TIR
LST result in low ET values in tropics:
MW looks more consistent

TIR-ALEXI underestimates ET over
Ethiopian highlands:
MW looks more realistic

TIR-ALEXI
MW-ALEXI
Anomaly analysis with MW-ALEXI ESI 12week moving window

ESI = standardized anomalies in ET/RefET
Anomaly analysis with MW-ALEXI
ESI 12week moving window

ESI = standardized anomalies in ET/RefET
Mission Development

• **ThermaSat (PI: Alicia Joseph, Code 617)**
  • Propose to fly a thermal instrument with (SWIR) Shortwave Infrared band in same orbit with European Space Agency’s (ESA’s) Sentinel 2 mission. This will afford the near-simultaneous collection of Visible (VIS)/Near Infrared (NIR)/SWIR and TIR data for ET retrievals at a consistent time of day, with 10-day revisit time.

• **NRC Decadal Survey:**
  • Joseph et al 2016: “Characterizing evapotranspiration, ecosystem productivity and water stress to address global food and water security”, *whitepaper in response to ESAS 2017 Request for Information #2*
  • Our vision for combining thermal (high res), with microwave (cloud tolerant), and hyperspectral (ecosystem physiological responses) into a mission to estimate ET and its source components for Agricultural, Weather and Climate applications.
Land Surface Modeling and Data Assimilation

http://lis.gsfc.nasa.gov

Sujay V. Kumar

Hydrological Sciences Laboratory
NASA Goddard Space Flight Center
Remote sensing data for land data assimilation

- **Surface soil moisture**: (SMMR, TRMM, AMSR-E, SMOS, Aquarius, SMAP)
- **Snow water equivalent**: (AMSR-E, SSM/I, SCLP)
- **Land surface temperature**: (MODIS, AVHRR, GOES, ...)
- **Precipitation**: (TRMM, GPM)
- **Radiation**: (CERES, CLARREO)
- **Snow cover fraction**: (MODIS, VIIRS, MIS)
- **Water surface elevation**: (SWOT)
- **Terrestrial water storage**: (GRACE)
- **Vegetation/Carbon**: (AVHRR, MODIS, DESDynI, ICESat-II, HyspIRI, LIST, ASCENDS)
How do we combine the information from satellite observations and models?

Data assimilation is the method used to incorporate observational data into model forecasts.

Like a “sleepy-driver” scenario
Land Data Assimilation Systems

- NASA develops remote sensing and modeling techniques to improve our understanding of stocks (soil moisture, snow) and fluxes (evaporation, runoff) of the water cycle through the development of Land Data Assimilation Systems (LDAS)

- Land Information System (LIS; lis.gsfc.nasa.gov)
  - Flexible software that enables LDAS instances
  - Multiple data assimilation options
  - Used for operational/routine land modeling support at 557th Weather Wing USAF, NOOA NCEP, NOAA NOHRSC, USAID, among others.

- Global scale (GLDAS), North America (NLDAS and the National Climate Assessment NCA-LDAS), Africa (FLDAS)


http://lis.gsfc.nasa.gov
http://ldas.gsfc.nasa.gov
http://disc.sci.gsfc.nasa.gov/hydrology
Multivariate assimilation of satellite-derived remote sensing datasets in the National Climate Assessment LDAS

The concurrent, multivariate assimilation of various terrestrial hydrological datasets (soil moisture, snow depth, snow cover, terrestrial water storage, irrigation intensity) has been demonstrated for the NCA LDAS.

Multivariate assimilation of satellite remote sensing datasets are helpful in improving water budget components, including streamflow.

Impact of LDA on drought estimates (Sep, 2012).

Kumar et al. (2014): Assimilation of remotely sensed soil moisture and snow depth retrievals for drought estimation, J. Hydromet., 10.1175/JHM-D-13-0157.1
Summary

Land Data Assimilation Systems have been developed for central North America (NLDAS, NCA-LDAS), Africa (FLDAS) and the globe (GLDAS)

The common goal of these projects is to integrate all relevant data in a physically consistent manner within sophisticated land surface models to produce optimal estimates of hydrological states (e.g. soil moisture, surface temperature) and fluxes (e.g. runoff, evapotranspiration)

The Land Information System (LIS) is an efficient and configurable software that can be used to specify an instance of LDAS

LDASs have been used for water availability applications including drought/flood monitoring, agricultural management, weather and climate initialization.
Global NRT MODIS and Landsat Flood Mapping/
NRT Flood Extent and Impact Assessment in S.E. Asia

Fritz Policelli, NASA GSFC
John Bolten, NASA GSFC
Aakash Ahamed, USRA/ GSFC
Colin Doyle, UT Austin
Jessica Fayne, U. South Carolina
Dan Slayback, SSAI/ GSFC
Bob Brakenridge, U. Colorado
Joe Nigro, SSAI/NASA GSFC

July 28, 2016
Original MODIS product distribution system: http://oas.gsfc.nasa.gov/floodmap

- Continental tile index
- Specific tile
  - Date selector
  - Available product/format downloads
Image Services Approach: Example display / query online w/ ArcGIS Server. Zoom to detail, change of basemap layer, viewing date, etc.

- Landsat water
- MODIS flood
Automated MODIS Flood Map Production System

- Fully automated (since Nov 2011)

- 223 10x10° tiles x 3 products (2-day, 3-day, 14-day) = 669 daily product suite generated

- 1-day composite production mode

- Product suites include: geotiffs, shapefiles, KML (Google Earth), and graphic maps (png)

- Products typically available within 6 hours of Aqua overpass (~ 8:00 PM local time)

- Delivery via web download, and (from June 2014) via live ArcGIS Image Services
Working on Sentinel-1, -2 Flood Mapping Capability

Sentinel-1  Lake Chad

Sentinel-2  Southern Europe
NRT Flood Extent and Impact Assessment in SE Asia
J. Bolten (GSFC), A. Ahamed (USRA/GSFC), J. Fayne (USC/GSFC), C. Doyle (UTA)

<table>
<thead>
<tr>
<th>Capability</th>
<th>Data / Method / Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional flood extent</td>
<td>250m LANCE – MODIS + NDVI change detection algorithms <a href="http://nrt1.modaps.eosdis.nasa.gov">http://nrt1.modaps.eosdis.nasa.gov</a></td>
</tr>
<tr>
<td>Web Interface (in dev.)</td>
<td><a href="http://mekongflood.appspot.com">http://mekongflood.appspot.com</a></td>
</tr>
<tr>
<td>Historic analysis tool</td>
<td>Analyze historic events for product validation</td>
</tr>
</tbody>
</table>

Submitted Publications:
Comments/ Questions ?
Pakistan Flooding – Sept 2014
Landsat Water Product

Features:

• 30 m resolution can provide useful detail when available (MODIS is at 250 m)
• Additional spectral bands improve water detection (we use a multi-index algorithm)
• Automated processing of Landsat 7 and 8 imagery when available from USGS (typically several hours after 10:30AM local time acquisition for Landsat 8)
• Processing triggered only for targeted scenes of interest
  – Scenes targeted based on flood alerts (Stuart Frye’s geoBPMS system)
Example: MODIS flood product + Landsat water product
Example: MODIS flood product for one tile, 17-Sep-12 (Pakistan event)

Landsat footprint
~ 185 x 185 km
Selection of end users
Applied Sciences Portfolio at GSFC

Mission Applications
- GPM
- SMAP
- ICESat-2
- GRACE FO/2
- PACE
- LIST
- 3D-Winds

Applications Areas
- Disasters
- Ecological Forecasting
- Health and Air Quality
- Water Resources
- Wildfires

Capacity Building
- ARSET
- SERVIR
- DEVELOP

Global Initiatives
- Food Security
- Water Availability
- Disaster Response
- Water and Energy Cycle
- Terrestrial Hydrology
- Cryospheric Science
- Land Cover/Land use

Mission Applications
- NASA/HQ Applied Sciences & R&A Programs
- Technology
- Reimbursable Projects

Data systems, Decision Support Tools, technology development programs

Agreements with: Air Force, Army, DOE, Academia, NOAA, USAID, USFS, among others
Disaster Response

- Disaster application science answering questions and supporting decisions transforming EO data and research results into environmental intelligence
- Coordination and collaboration informing brokers, managers, and responders with critical products and services
- Creation and leverage of partnerships strengthening and enabling effective response throughout the disaster lifecycle
Examples of Daily NASA Products Provided to FEMA via the U.S Hazard Data Distribution System for Disaster Response.

**Top L.** NASA’s Integrated Multi-satellite Retrievals for GPM (IMERG) showed historic rainfall in the Carolinas.

**Top R.** NASA’s Land Information System running operationally at MSFC using NOAA Stage IV precipitation and other forcing inputs produced analyses and short term forecasts of soil moisture and other parameters (SpORT)

**Bottom R.** VIIRS nighttime environmental products provided for detection of technological failures (power outages and infrastructure damage).
Water Resources

Focus Areas

**Drought**
The Water Resources Application Area provides support for efforts to integrate remote sensing and other NASA technologies into decision support systems for drought monitoring, impact assessment and mitigation. Additional funding ...

**Streamflow and flood forecasting**
The Water Resources Application Area provides support for efforts to integrate remote sensing and other NASA technologies into decision support systems for monitoring and forecasting of streamflow and flood risk. ...

**Evapotranspiration and irrigation**
The Water Resources Application Area provides support for efforts to integrate remote sensing and other NASA technologies into decision support systems for monitoring and forecasting of evapotranspiration and irrigation demand. ...
NASA Remote Sensing Observations for Flood Management

**Dates:** Monday, June 8, 2015 to Monday, June 29, 2015  
**Registration Closes:** Friday, March 18, 2016

This training introduces remote sensing resources available for monitoring extreme precipitation and flooding, as well as flood mapping tools for flood management and planning.

**Course Format:**
- Four, one-hour sessions  
- Introductory Webinar - no remote sensing experience necessary
Technology

EOSDIS: Earth Observing System Data and Information System

- *EOSDIS* is designed as a distributed system, with major facilities at *Distributed Active Archive Centers* (DAACs) located throughout the United States.

LANCE: Land, Atmosphere Near Real-time Capability for EOS

- Provide near real-time (NRT) data products within 3 hours of observation to meet the timely needs of applications users.

AIST: Advanced Information Systems Technology (AIST)

- The objectives of the AIST program are to identify, develop and (where appropriate) demonstrate advanced information system technologies.
Mission Applications

Flood Response using ICESat-2*

- ICESat-2 will provide along track water body height, slope and roughness
- Flood event monitoring, flood mapping & forecasts
  ICESat-2 with any latency could be used for historic analysis, re-analysis and calibration/validation studies at regional to global scales
- Near real-time monitoring of seasonal and flash floods
  ICESat-2 is expected to improve subsurface water storage change measurements due to its accuracy and dense along/cross-track resolution; Combined with other observations, ICESat-2 will be used to build a global surface water monitoring system especially valuable for river basins that lack in situ data.

* Based on ICESat-2 Proposed Early Adopter Research. For more information, visit: http://icesat-2.gsfc.nasa.gov/applications
Goals for Applied Science Activities

1. Identify core capabilities across GSFC and other NASA Centers related to the applied sciences portfolio

2. Promote and expand the reach of NASA data, products, models, technology and within end user communities

3. Foster and expand partnerships with other NASA centers, government agencies, NGOs, commercial and private sectors

4. Establish two-way feedback channels to communicate potential opportunities to the NASA and end user communities