Western Resources Committee
Western States Water Council Meeting

NASA Missions and Water Resource Program

Michael Freilich, NASA
Director, Earth Science Division

9 July 2015, Lake Tahoe, NV

Earth Science Missions and Instruments

- Formulation
- Implementation
- Primary Ops
- Extended Ops

Altimetry-FO (Formulation in FY16; Sentinel-6/Jason-CS)

Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS, GEDI,
CLARREO-PF

Landsat 9, TIR-FF
PACE
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
ISS
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(NOAA's DSCOVR)
QuikSCAT
EO-1
Landsat 7
(USGS)
SMAP
Terra
Suomi NPP
(NOAA)
Aqua
Landsat 8
(USGS)
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

Earth Science Missions and Instruments

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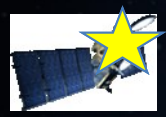
Implementation
Primary Ops
Extended Ops



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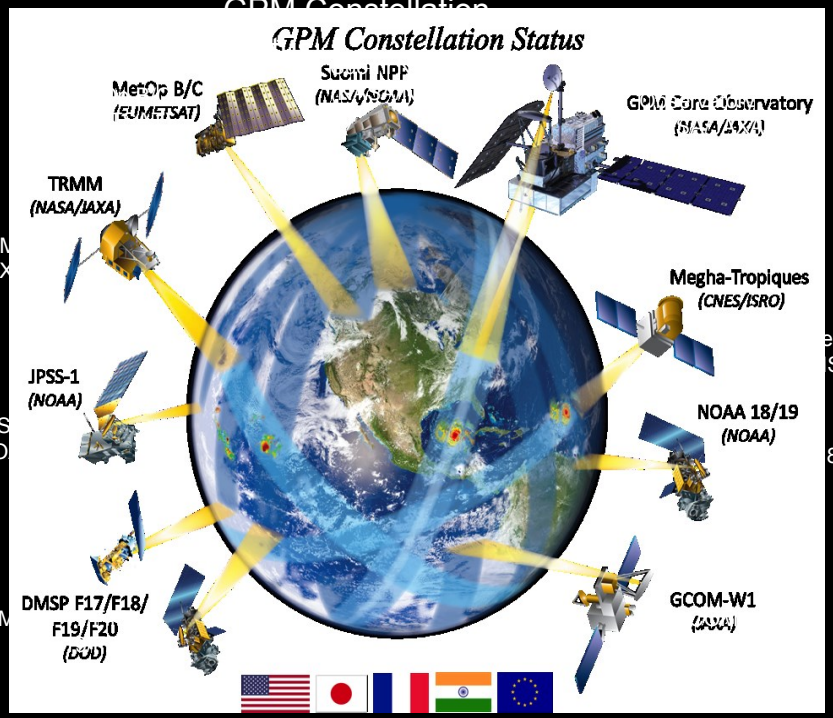
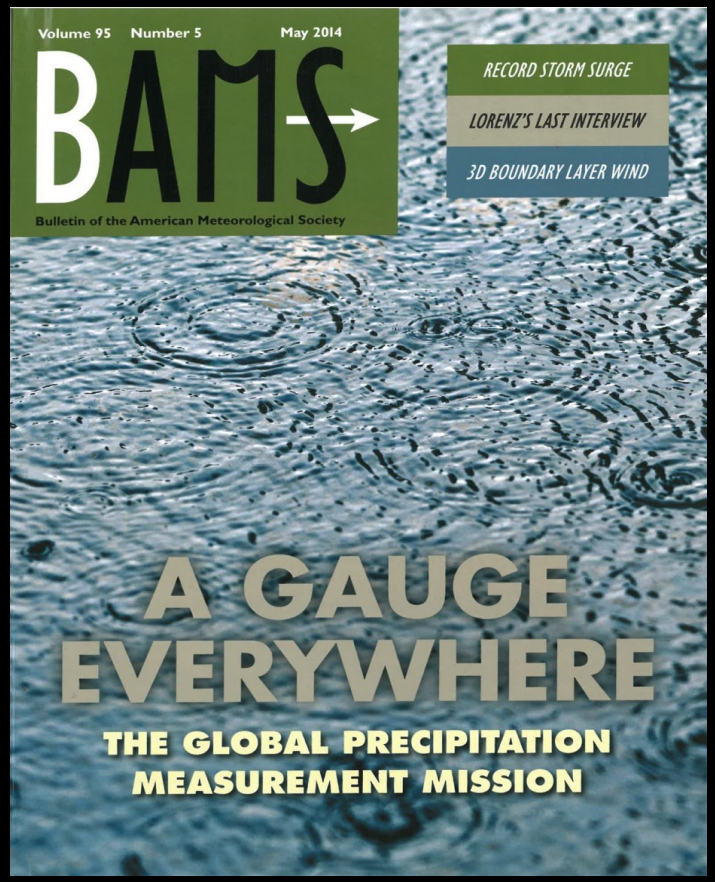
Contributing to Water Cycle Studies

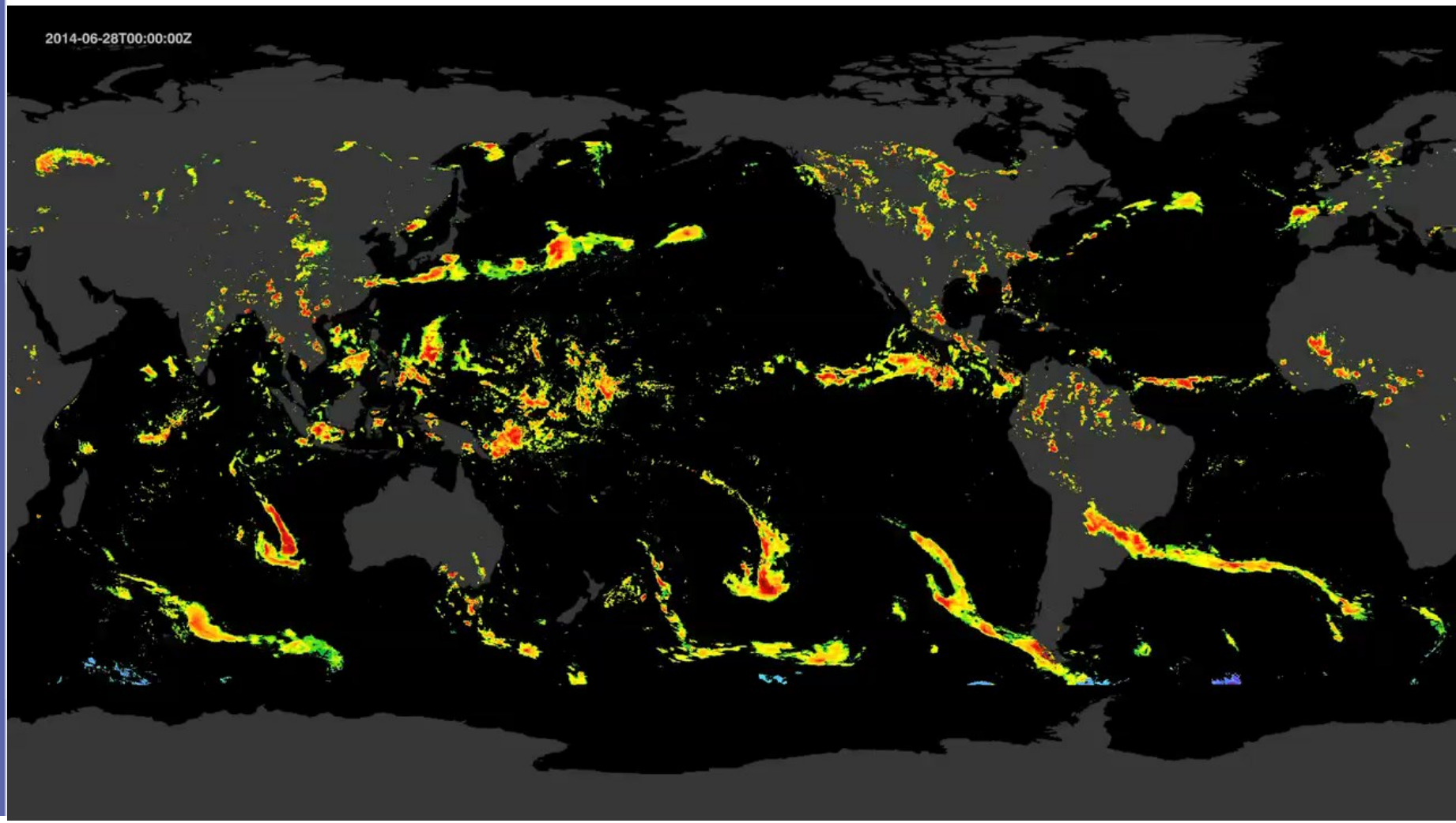
Global Precipitation Measurement Mission





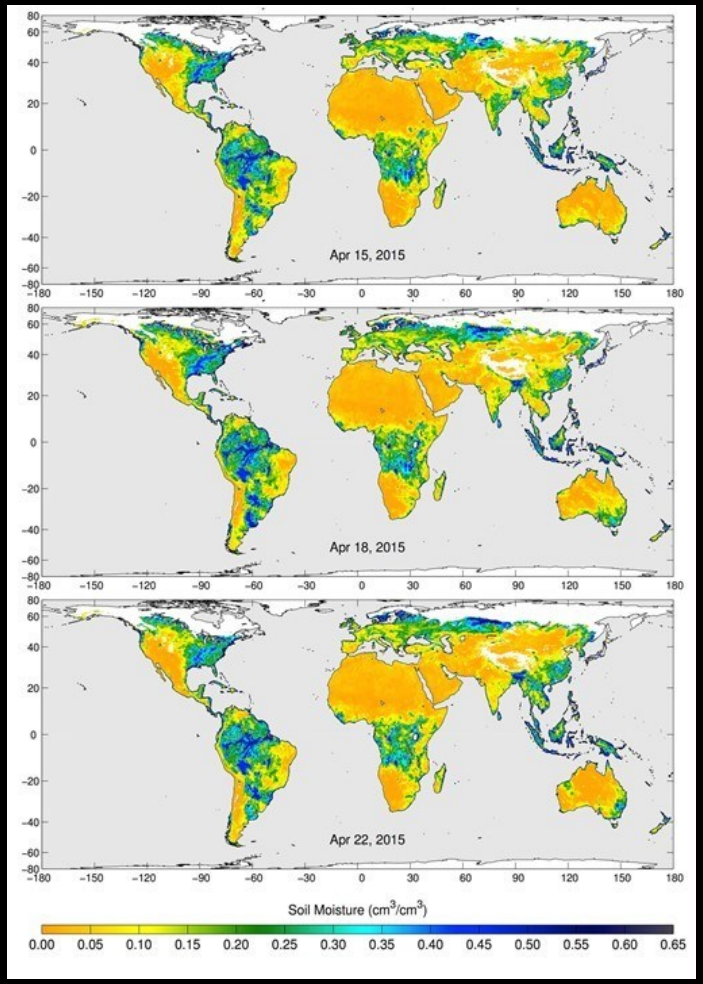
Active Joint Projects (19 PI's from 13 countries)

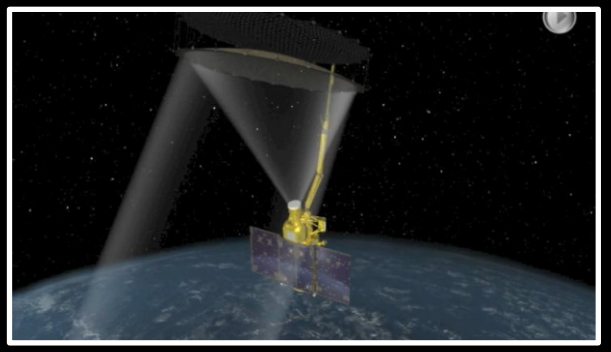
IMERG: Integrated Multi-satellitE Retrievals for GPM

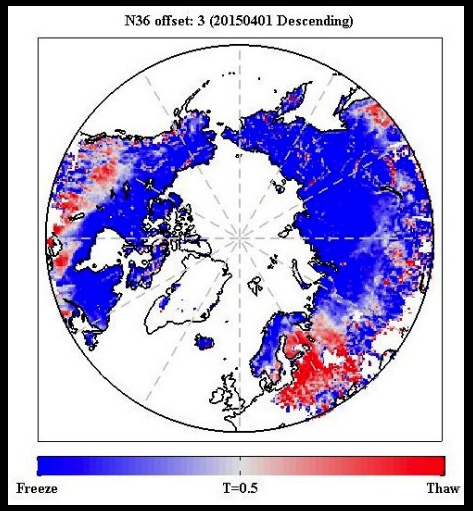


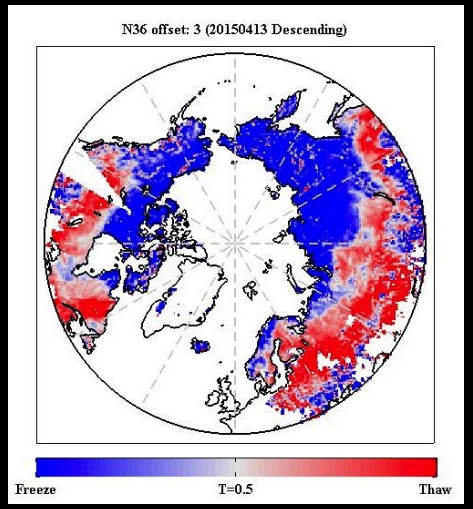
SMAP Measurements

- SMAP is providing moisture content in the top 5 cm of soil, at 10 km resolution, globally every 3 days





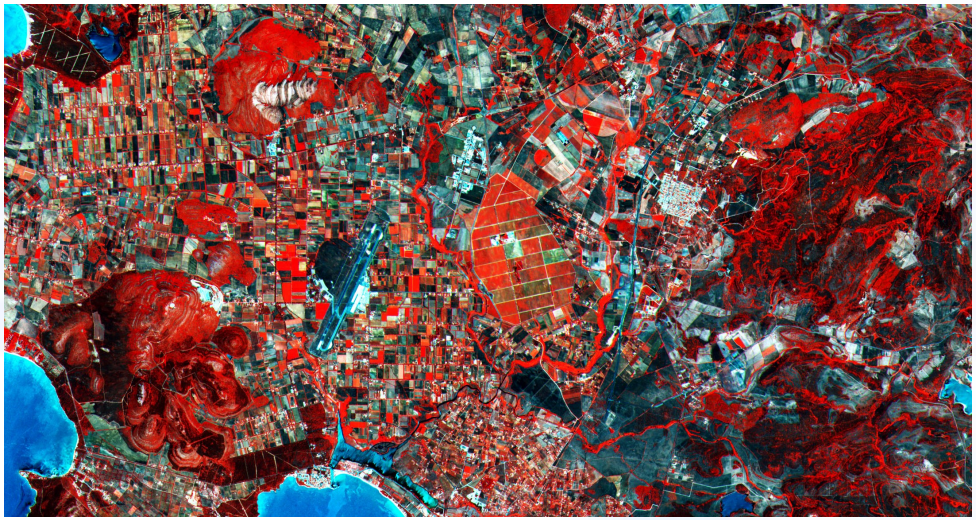




SMAP measurements of soil moisture address a wide range of water cycle research and science applications, including weather prediction, drought/flood monitoring, and food production

Sentinel-2 – European Multi-Spectral Land Imaging

- Sentinel-2A launched successfully 23 June 2015
  - 13 spectral bands (Landsat-8 bands plus…) – ***NO THERMAL INFRARED***
  - 10 m resolution, 280 km swath – 10-day, single-satellite repeat
  - First imagery and processed products received 27 June 2015
  - Sentinel-2B on schedule for mid-2016 launch – 5-day system repeat

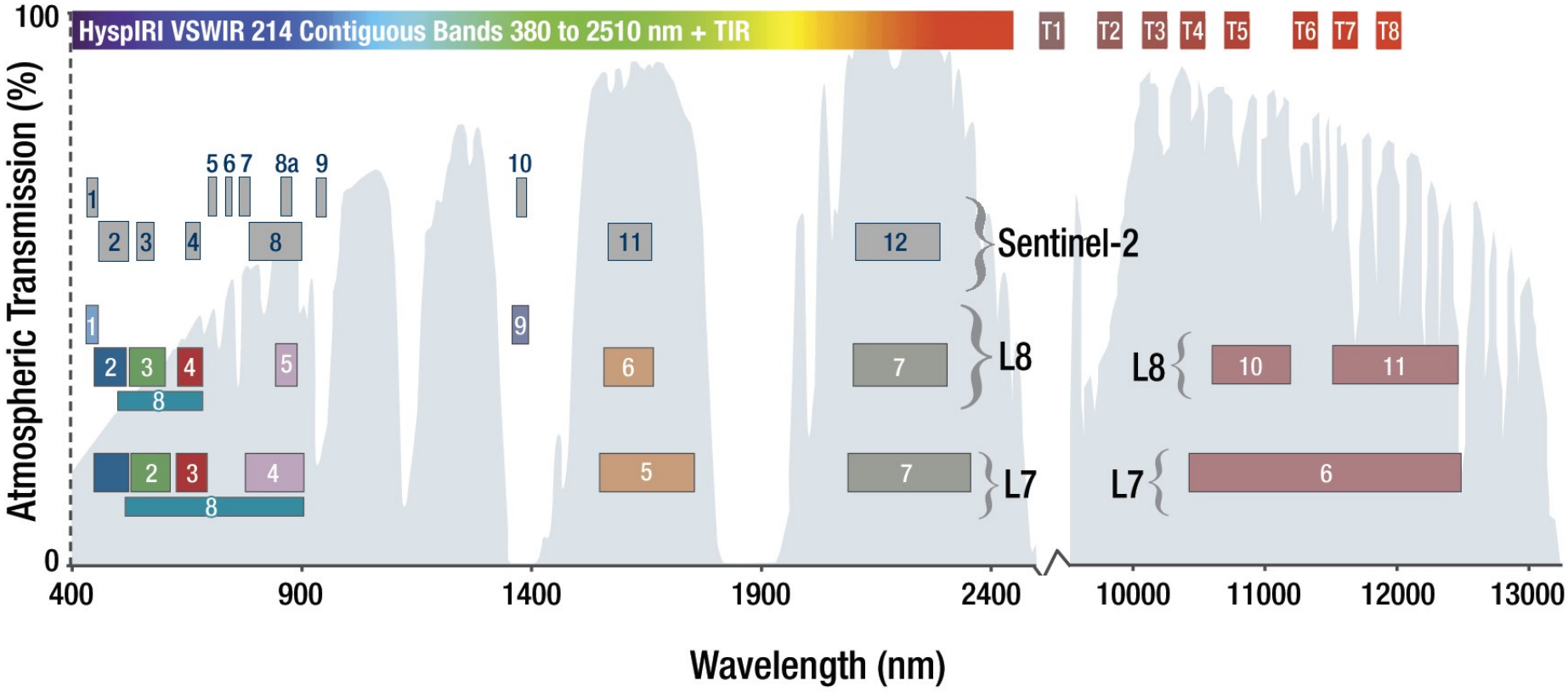


Northwest Sardinia

So. France, No. Italy

- Open data availability agreement w/EU in final stages: NASA, NOAA, USGS; State Dept. signs
- NASA has solicited and selected research investigations for multi-system data fusion products

Land Imaging Sensor Spectral Ranges/Bands



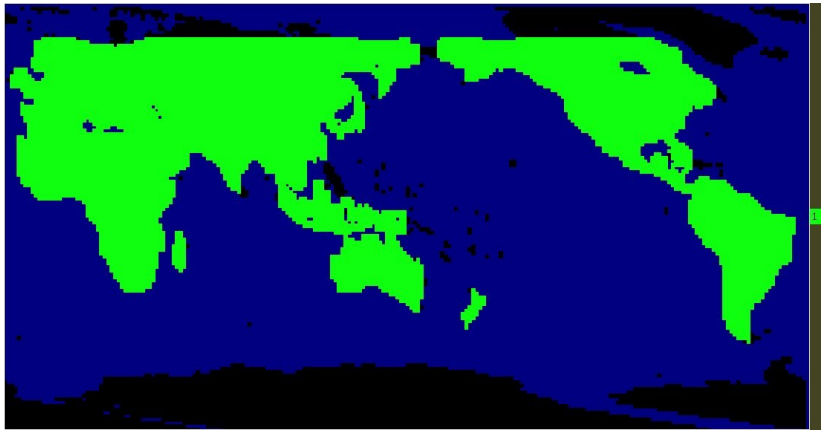
Sentinel-2 and other planned international missions do not acquire Thermal IR measurements

Landsat On-Orbit Status

- Landsat 7
  - Launched in 1999
  - Scan Line Corrector instrument hardware failure in 2003 resulted in a loss of 22% of each Landsat 7 scene
  - Collecting ~475 scenes per day; ~22% of pixels missing per scene (faulty scan-line corrector)
  - L7 collection strategy modified to concentrate on continental coverage (L8 capturing islands and reefs)
  - Expected to be decommissioned in 2020 (potential extension by an additional 24 months beyond 2020 if science is still valuable from data acquired earlier than 0930 MLT)
- Landsat 8
  - Launched in February 2013
  - Operational Land Imager (OLI; the 30m resolution, multi-spectral instrument) operating superbly
  - Thermal Infrared Sensor (TIRS) experiencing a stray light problem in one of two channels; also now operating on redundant hardware
  - Currently collecting 725 scenes/day (exceeding the requirement of 400 scenes/day)
  - Fuel could last ~20 years based on operational consumption to date

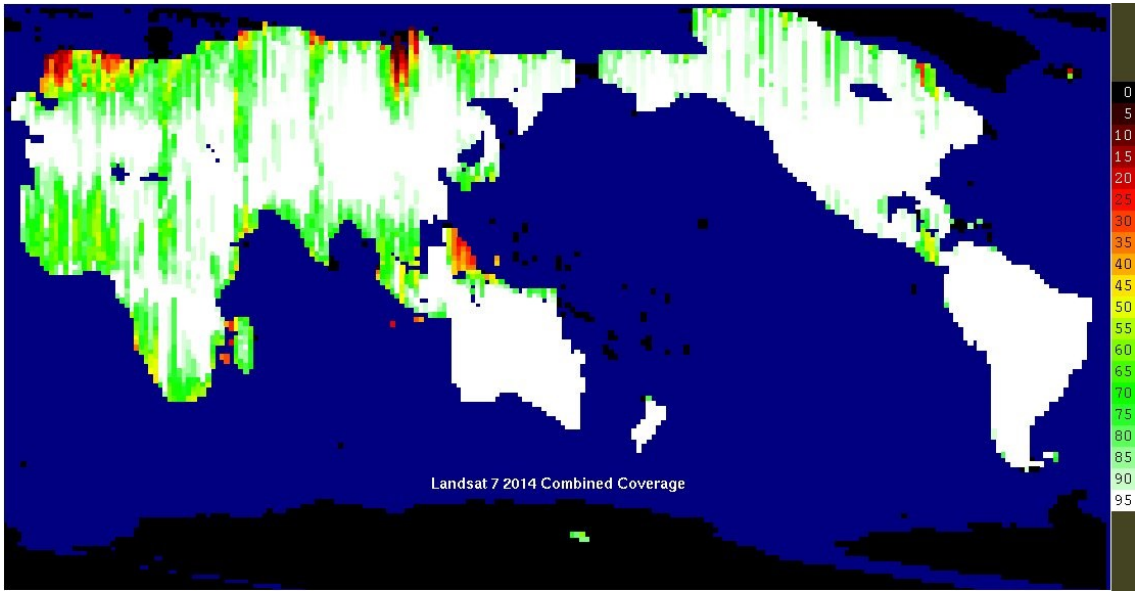
Landsat 7 Current Status

- **Acquire only continental land masses**
  - Minimize revisit time
  - Maximize interval lengths
  - Exclude many islands, Antarctica, Greenland, and row 9 and above



- **No daily limits**

Currently acquiring ~470 scenes/day!

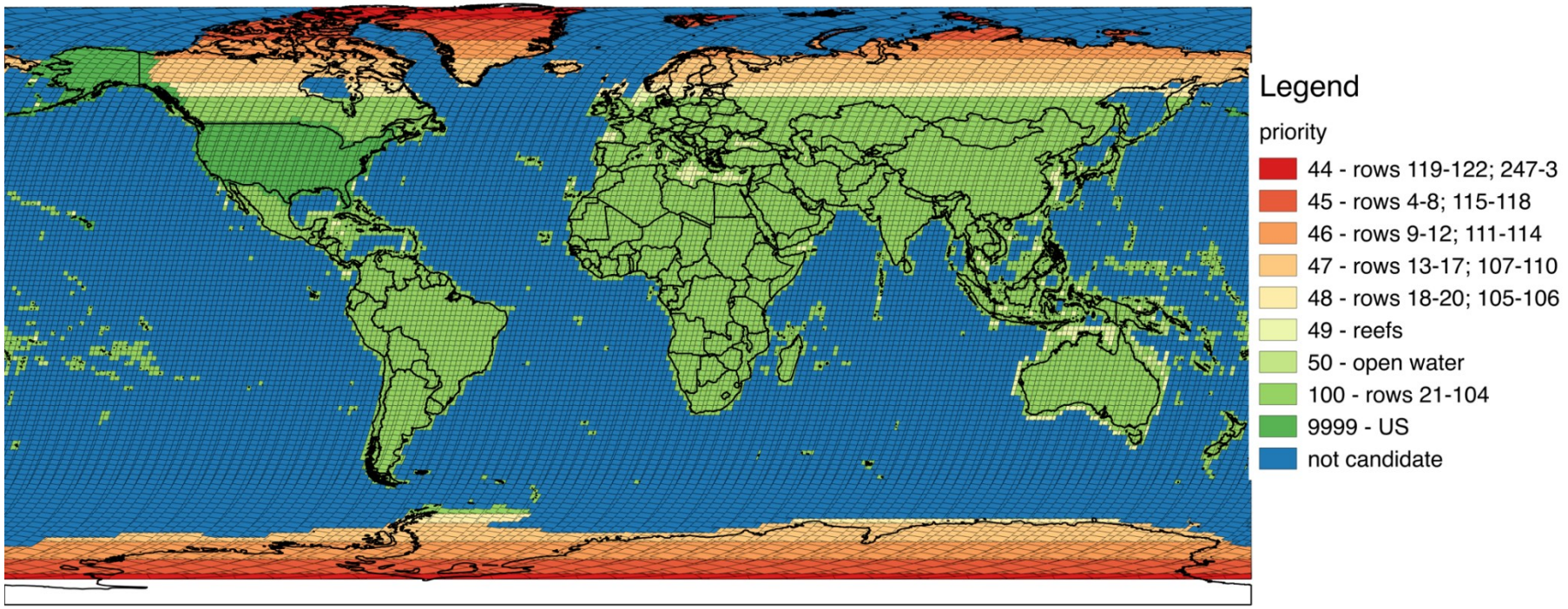


Fraction of CY2014 acquisitions

USGS

Landsat 8 – Acquisition Priorities

Seasonality 6 May 2015

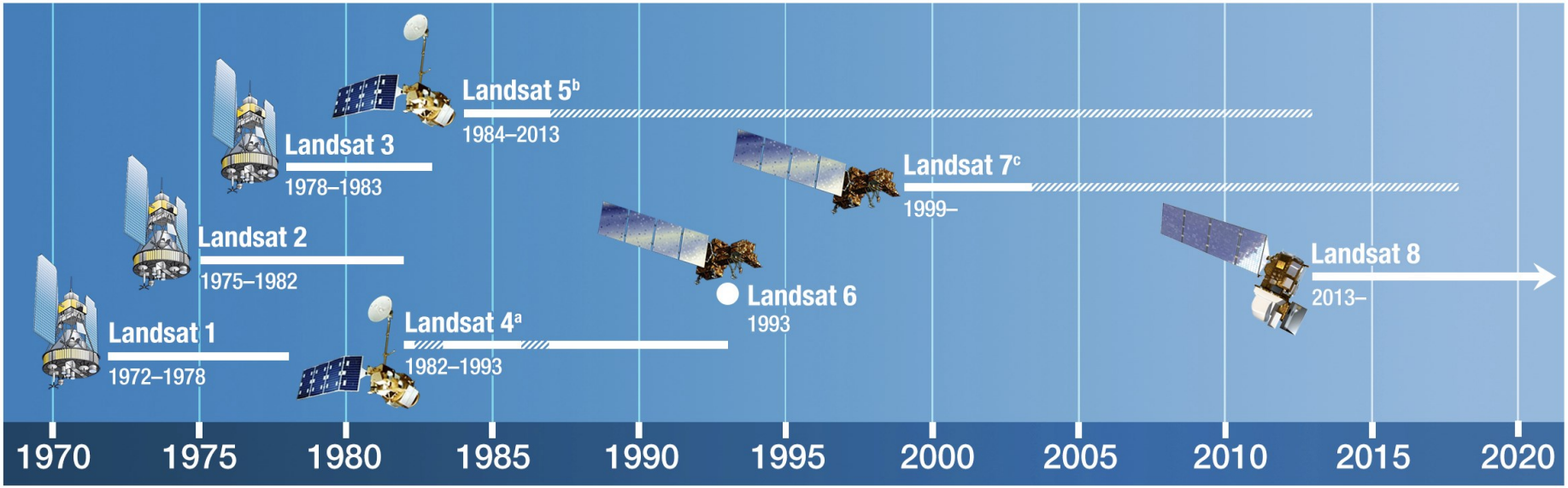


USGS

Sustainable Land Imaging 2016 - 2035

FY14, FY15 President's NASA budgets called for design and initiation of an affordable, ***sustained,*** Land Imaging Satellite System (with USGS) to extend the Landsat data record for decades – not just the "next mission"

NASA (w/USGS) Sustainable Land Imaging report produced 9/2014



[a]Limited data due to transmitter failure soon after launch. Only 45,172 Landsat 4 Thematic Mapper scenes from 1982–1993 available for science users—~10 scenes/day (vs 725 scenes/day from L8)

[b]Data coverage limited to Continental US (CONUS) and International Ground Station sites after a transmitter failure in 1987; Multispectral Scanner turned off in August 1995

[c]Degraded Performance due to Scan Line Corrector failure in May 2003

SLI in FY16 President's Budget Submit

- A 3+1 part program to ensure a world class, sustainable, and responsible land imaging program through 2035:

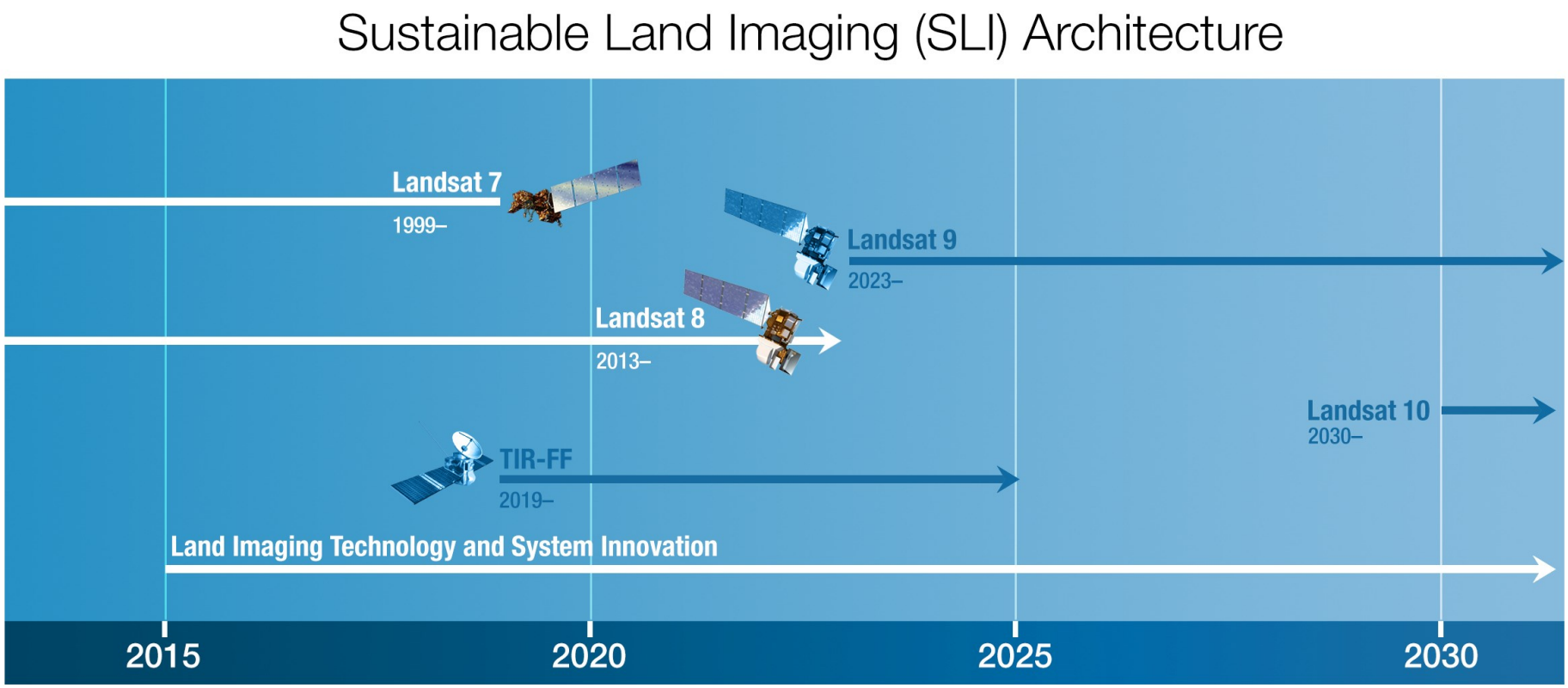
1. **Class D Thermal Infrared Free Flyer** (TIR-FF) to launch ASAP (NLT 2019) and to fly in constellation with a reflective band imager
   - Low cost mitigation against an early loss of the Landsat 8 Class C TIRS, while demonstrating feasibility of constellation flying

2. **Landsat 9** (fully Class-B rebuild of Landsat 8) to launch NLT 2023
   - Low programmatic risk implementation of a proven system with upgrades to bring the whole system to Class B

3. **Land Imaging Technology and Systems Innovation**
   - Hardware, operations, and data management/processing investments to reduce risk in next generation missions

4. **Landsat 10**, Class B full spectrum, to launch ~2030
   - Mission architecture to be informed by the technology investments (2015-), leading to definition ~2020

Landsat Future – FY16 Budget Submit



SLI: Congressional Action/Status

- FY15 ***Appropriation*** allocated $64.1M for initiation of Landsat-9
  - Called for Landsat-9 as a lower cost Landsat-8 "copy," 2020 launch date
  - "*The* [Conference] *does not concur with various administration efforts to develop alternative "out of the box" approaches to this data collection — whether they are dependent on commercial or international partners.*"

- NASA request to initiate both TIR-FF (2019 LRD) and Landsat-9 (2023 LRD) in FY15, consistent with President's FY16 budget submit, was denied by both House and Senate - focus on L-9 (Tech. Dev. activities underway)

- FY16 Appropriations Mark-Up: House
  - Rejected President's budget proposal to develop TIR-FF beginning in FY16
  - $32.9M in FY16 (added to significant carryover from FY15) for L-9 development for launch in **2023**

- FY16 Appropriations Mark-Up: Senate
  - Rejected President's budget proposal to develop TIR-FF beginning in FY16, directs no launch of TIR-FF prior to launch of L-9
  - $100M in FY16 (added to significant carryover from FY15) for L-9 development for launch in **2020**

SLI: NASA Present Status, FY15

- Landsat-9 Project has been initiated with $60M in FY15 funds
  - Directed to NASA's Goddard Space Flight Center (GSFC)
  - Project Office established and substantially staffed
  - OLI Instrument procurement actions in work
  - Earliest possible launch date is 2021 – consistent with FY15 funding level

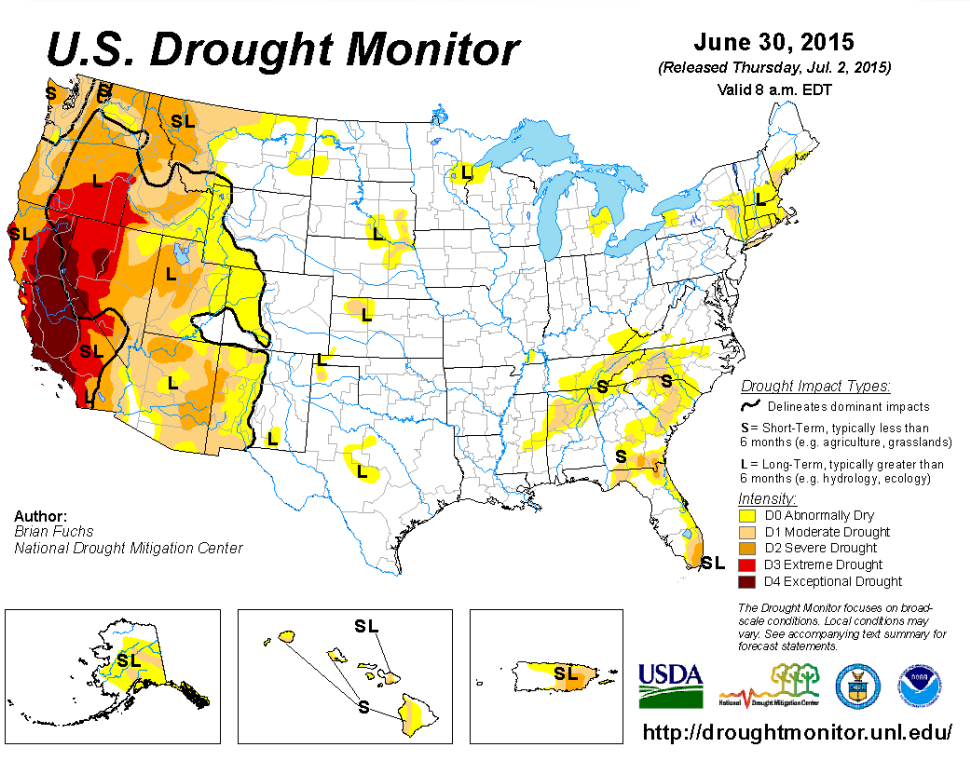
- Technology studies underway
  - Detector component development
  - Overall instrument size reduction using advanced technologies

- NASA has solicited, selected, and initiated science investigations focused on construction of multi-system fusion data sets ("Multi-Source Land Imaging Science"
  - "…[W]e solicit for efficient use and seamless combination with Landsat, of satellite sensor data from international Landsat-type moderate resolution (~30 m ground resolution), multispectral sources on continental to global scales. A primary focus is on developing algorithms and prototyping products for combined use of data from Landsat and Sentinel-2 toward global land monitoring. However, we also welcome proposals combining Landsat with other sources of moderate resolution data, such as IRS and/or CBERS…"
  - 7 investigations selected
  - $1.3M/year total, 3-year studies

NASA Water Resource Applied Sciences

The NASA Water Resources Program Element:

The Water Resources Program Element addresses concerns and decision processes that are related to water availability, water forecast, and water quality. The goal of the Water Resources Program Element is to apply NASA satellite data to improve the Decision Support Tools (DSTs) of user groups that manage water resources. Implementation requires close and enduring partnerships with Federal agencies, academia, private firms, and international organizations.



Water Resources Projects:

Projects are tactical implementations led by Principal Investigators, driven by water management challenges, and ultimately sustained by water resource information stakeholders.

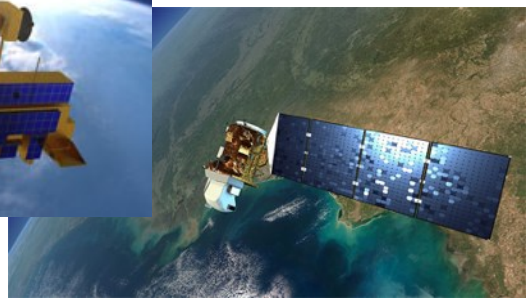
Programmatic Activities:

National and international activities to improve skills, share data and applications, and broaden the range of users who apply satellite data and Earth science in water resource decisions.

NASA Satellite Irrigation Management Support: Mapping Crop Water Requirements to Assist Growers in Optimizing Water Use

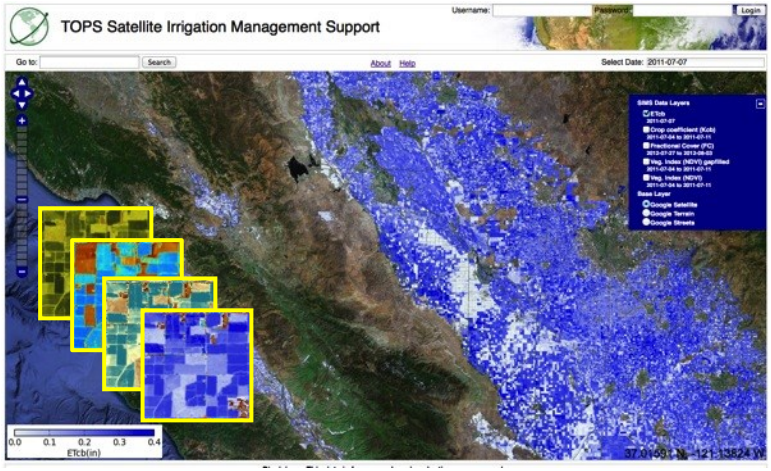
PROJECT TEAM: NASA Ames Research Center, California Dept. of Water Resources, Western Growers Association, California State University, Univ. of California Cooperative Extension, Desert Research Institute, USDA Ag. Research Service, USGS, Booth Ranches, Chiquita, Constellation Wines, Del Monte Produce, Dole, E & J. Gallo, Farming D, Fresh Express, Pereira Farms, Ryan Palm Farms

Terra Satellite



Landsat 8

California agricultural sector produced $46.4b In 2013

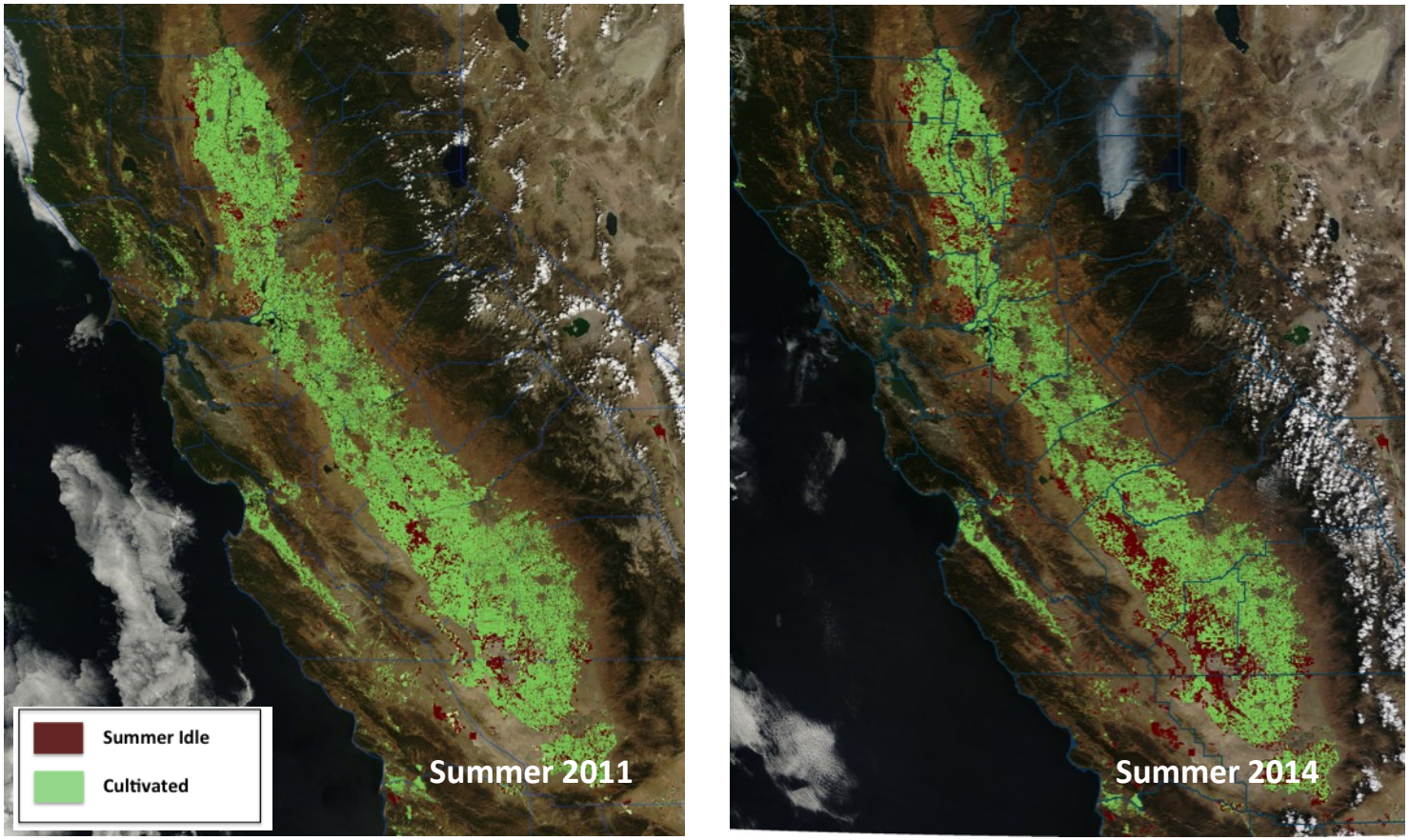


NASA SIMS web and mobile data services puts irrigation demand across 8 million acres of farm land directly into the hands of farmers and water managers

Students work hand in hand with growers to validate the system and quantify benefits

For more information, contact forrest.s.melton@nasa.gov, or visit https://c3.nasa.gov/water/projects/1/

Determining the Extent of Fallowed Land with Satellite Imagery



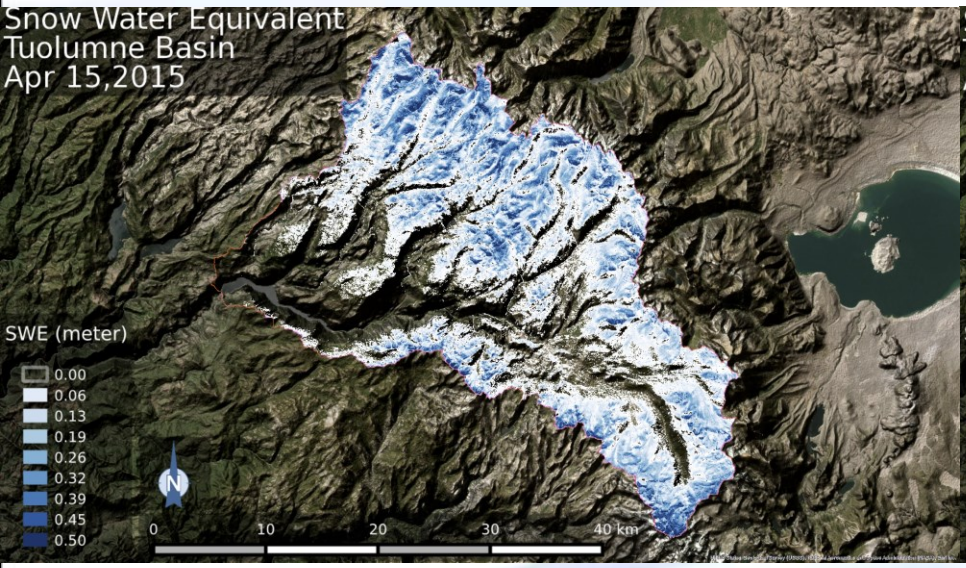
The maps above are based on data from the Landsat 5, Landsat 7, Landsat 8, and Terra and Aqua satellites and show changes in crop cultivation and idle agricultural lands in California in the summers of 2011 and 2014. Brown pixels depict farms and orchards that have been left fallow or "idled" since June 1st in each year. Green pixels are lands still being farmed during the summer growing season. Using 2011 as a baseline, a total increase of 500,000 acres were idled during the summer of 2014 during the drought.

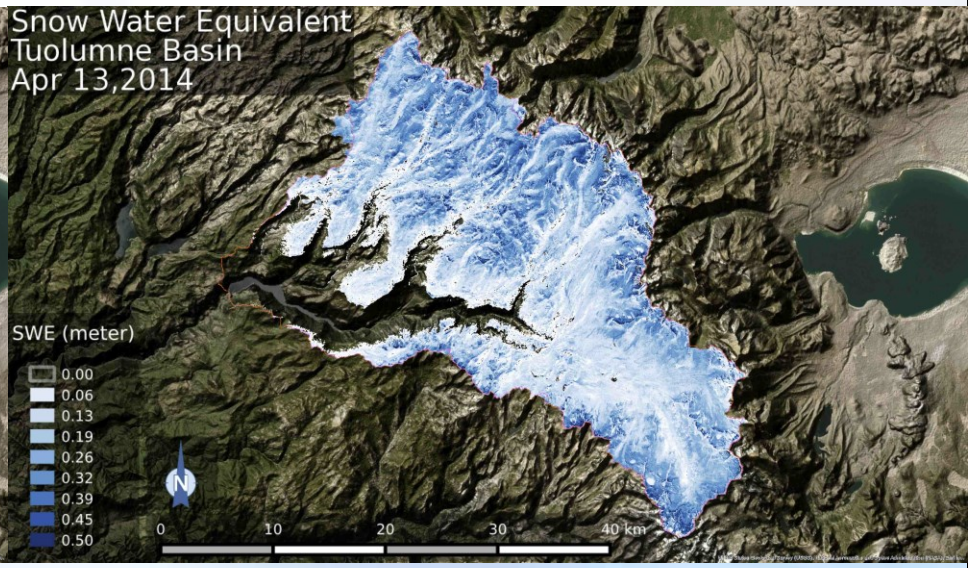
Forecasting Snowmelt Inflow and Timing Airborne Snow Observatory (LiDAR & spectrometer)

Airborne Snow Observatory: fusion of imaging spectrometer and scanning lidar for studies of mountain snow cover

Snow Water Equivalent and albedo at meter-scale resolution for a 300k acre watershed with 24hr latency

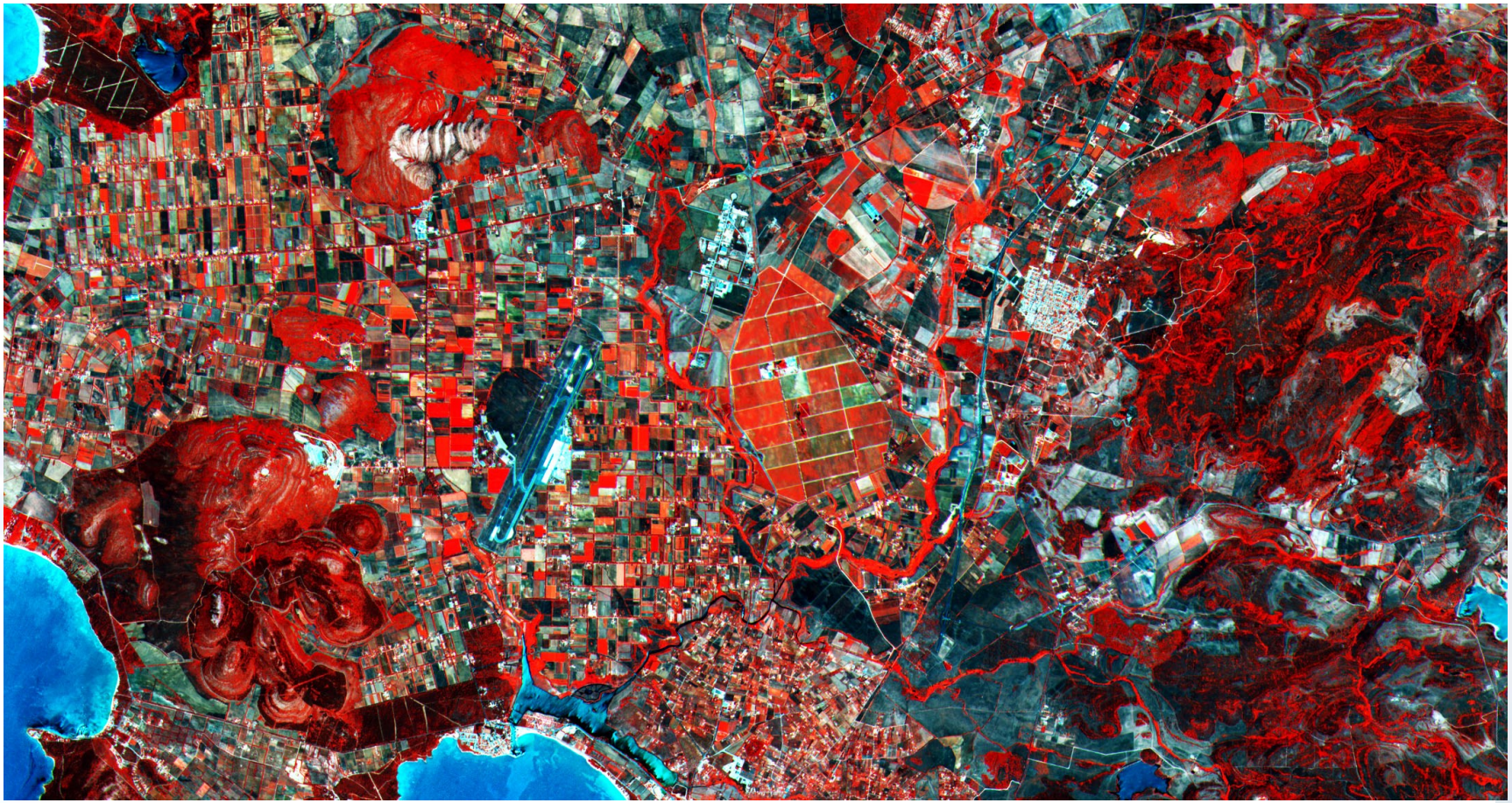
California Tuolumne Snowpack 40 Percent of Worst Year

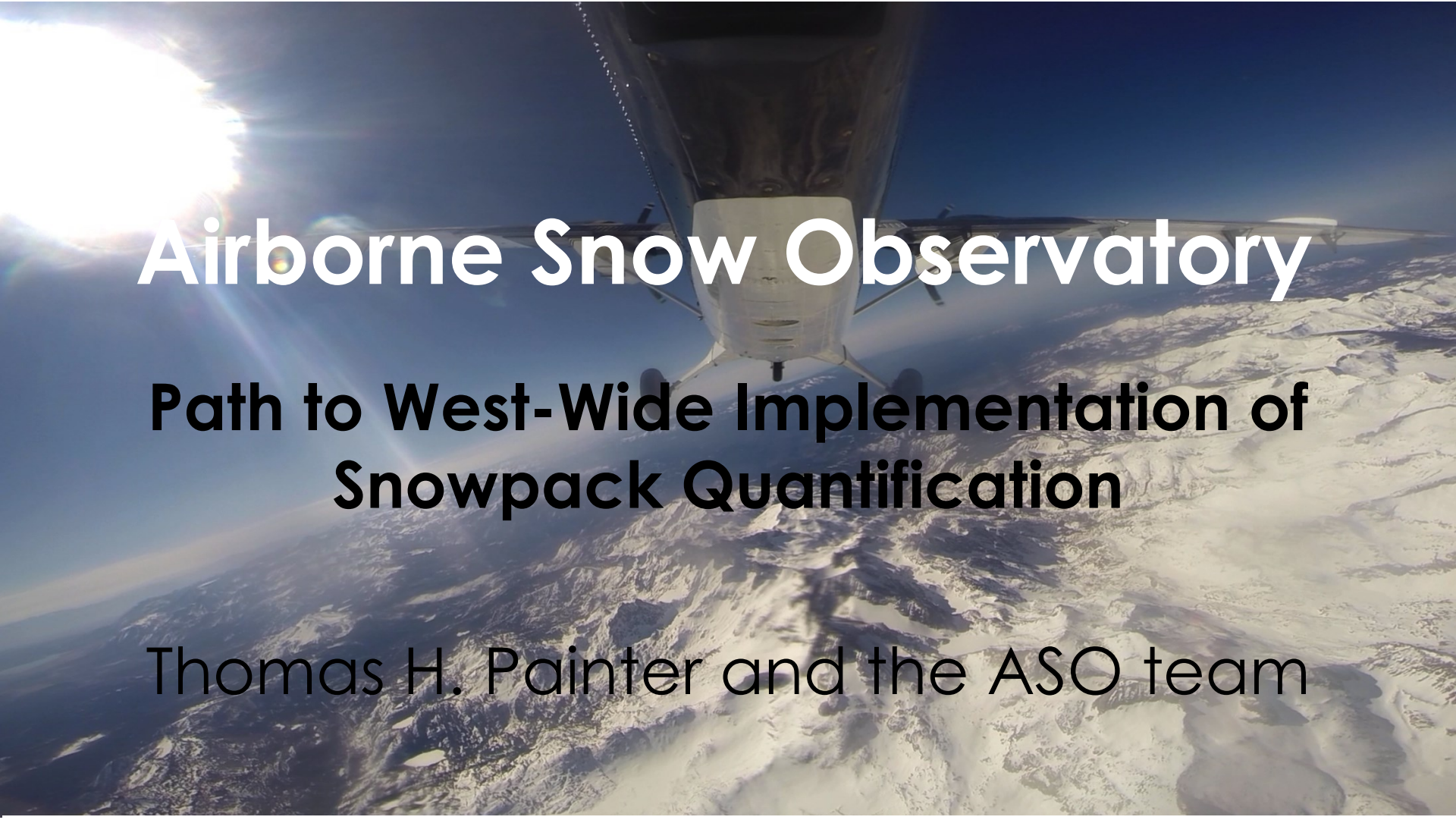




Tom Painter, JPL

Sentinel-2A: Sardinia, 27 June 15





Airborne Snow Observatory

Path to West-Wide Implementation of Snowpack Quantification

Thomas H. Painter and the ASO team

Jet Propulsion Laboratory
California Institute of Technology


Knowing the magnitude and timing
of snowmelt runoff requires
knowing
SNOW WATER EQUIVALENT and
SNOW ALBEDO

Snow Water Equivalent

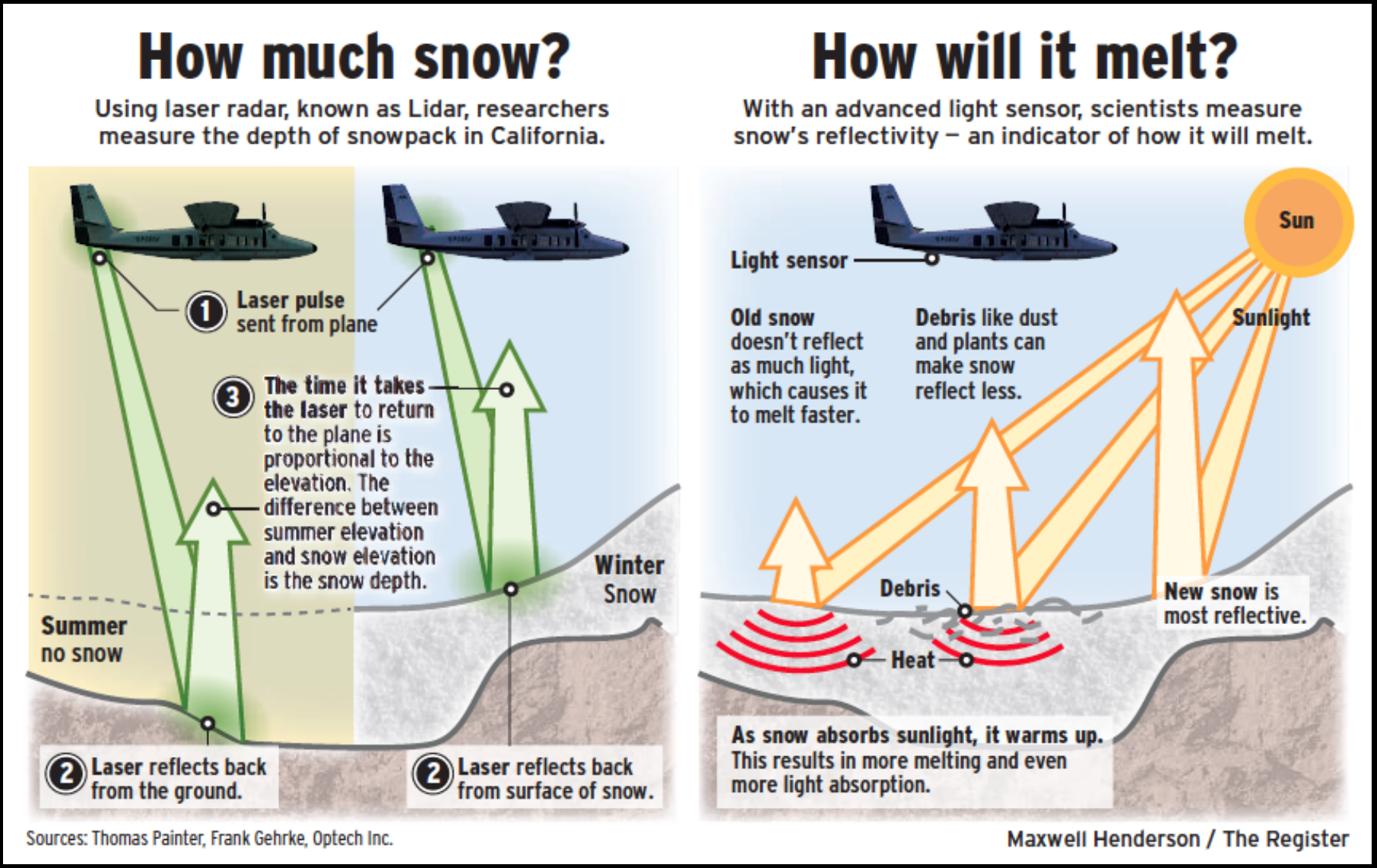
Riegl Q1560 3D Scanning lidar
1064 nm, canopy penetration
1 m spatial resolution

Albedo

CASI-1500 Imaging Spectrometer
0.35-1.05 µm
2 m spatial resolution from 4000 AGL

- < 24 hour turnaround of products
- Quantification of snow volume
- Quantification of snowmelt timing
- Quantification of snowfall
- Much improved allocations
- Much improved runoff forecasting

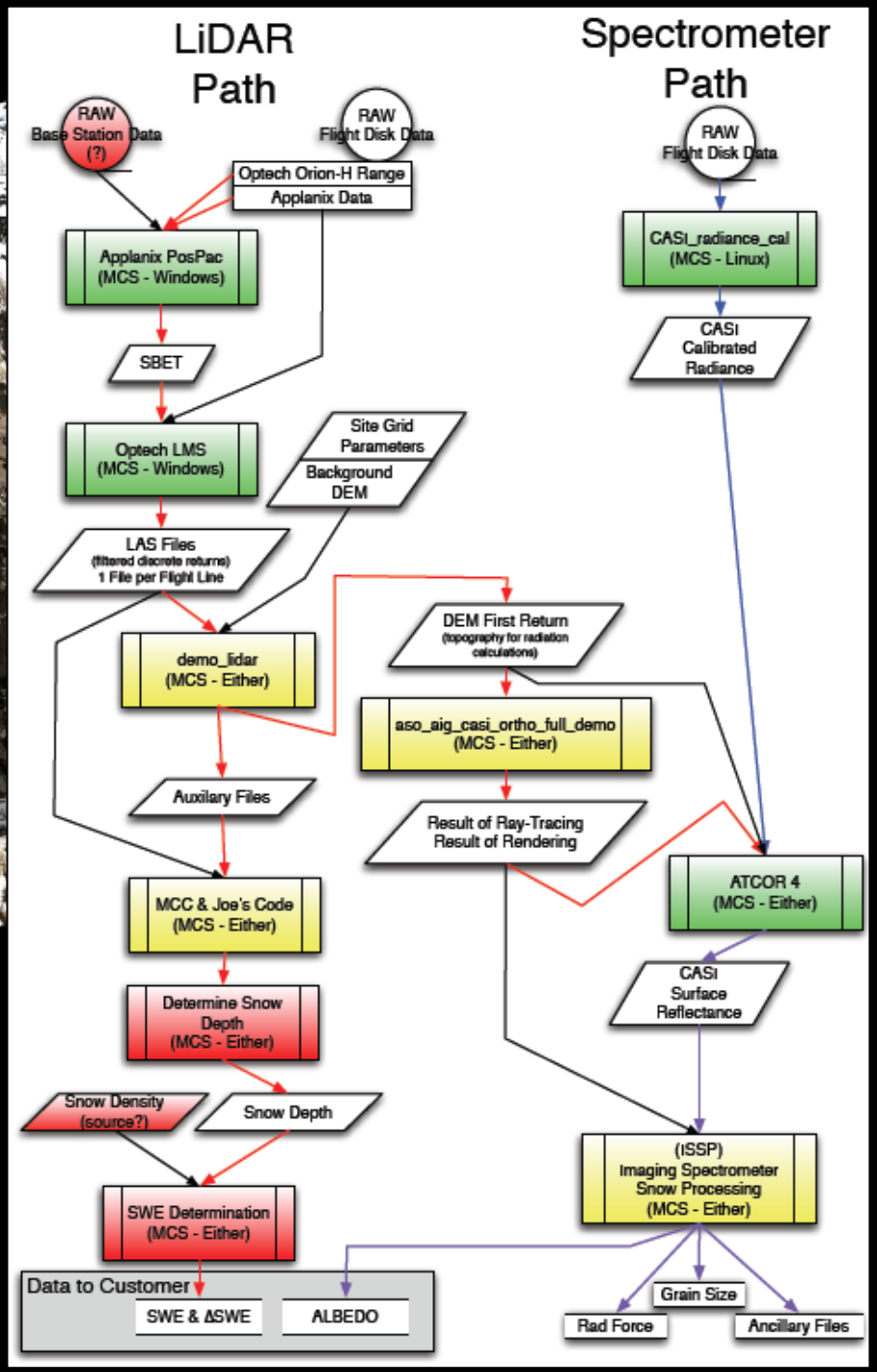
How ASO works



ASO Compute System

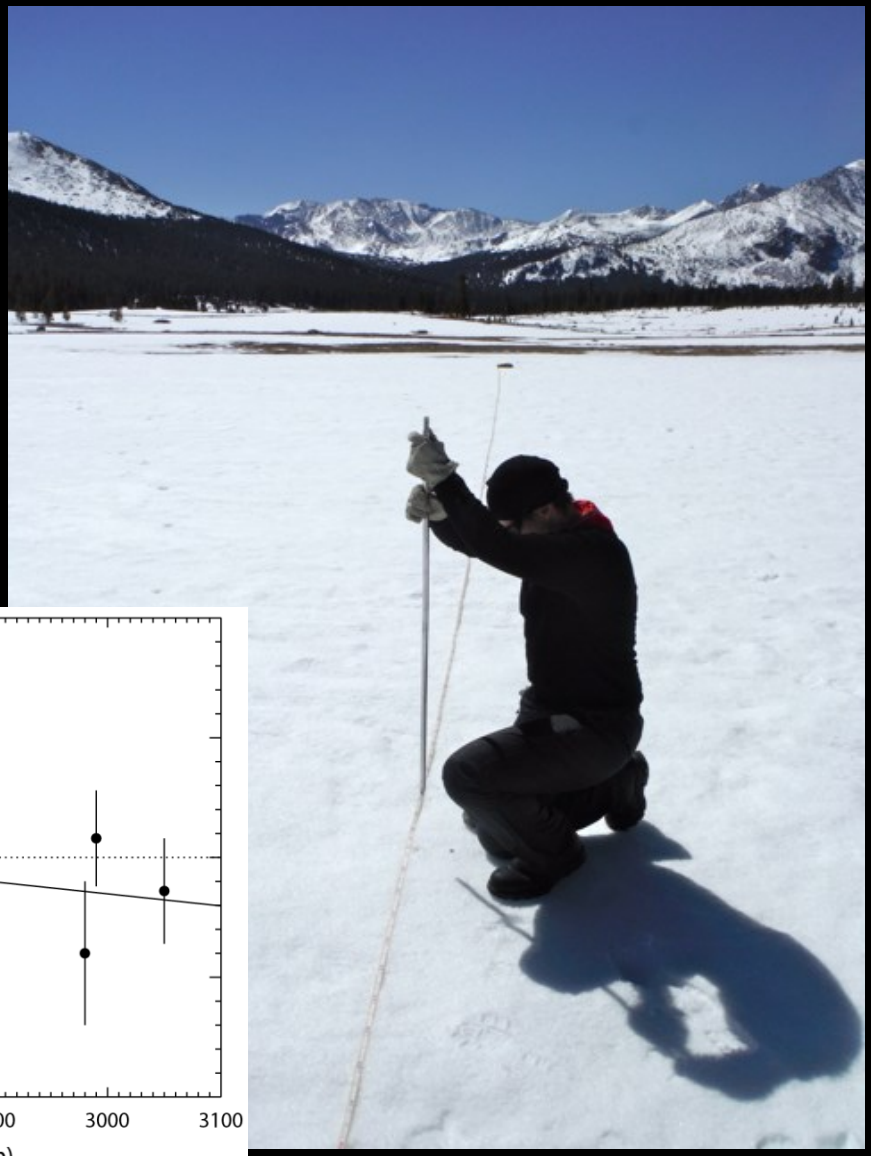
operational products

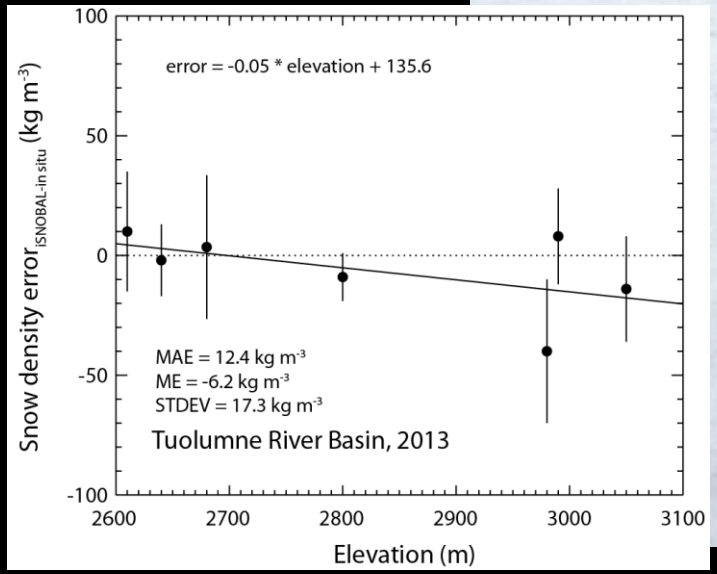
- 24-hour turnaround
- maps of:
  - snow depth
  - SWE (using snow pillow densities)
  - albedo
- aggregated to operational model resolution (PRMS HRUs)



How accurate?

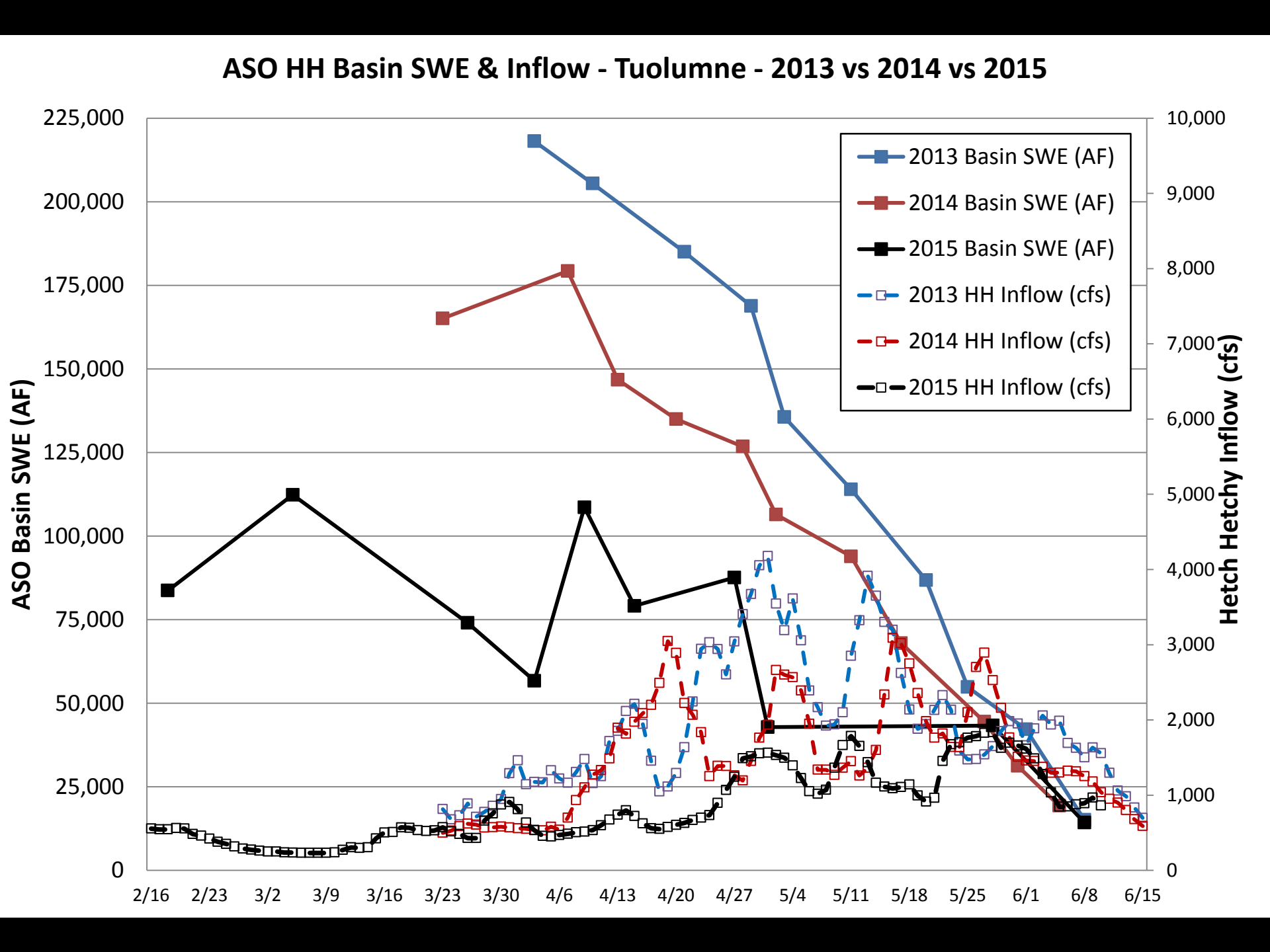
Validation showing:
snow depth from ASO have uncertainties of:
2±1 cm (or about ¾")
Snow density uncertainties of < 20 kg/m^3
Snow water equivalent is < 5% for 2 m depth and 300 kg/m^3 density





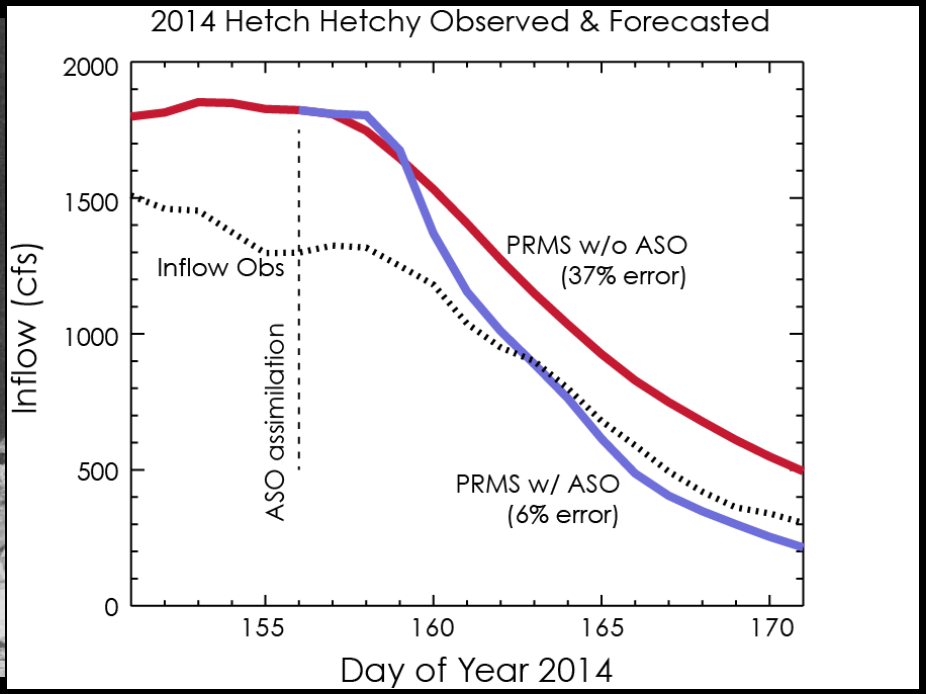
Tuolumne River Basin
Water supply to SFO and other cities

2013


ASO HH Basin SWE & Inflow - Tuolumne - 2013 vs 2014 vs 2015
ASO Basin SWE (AF)
Hetch Hetchy Inflow (cfs)
225,000
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
0
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
2/16
2/23
3/2
3/9
3/16
3/23
3/30
4/6
4/13
4/20
4/27
5/4
5/11
5/18
5/25
6/1
6/8
6/15
2013 Basin SWE (AF)
2014 Basin SWE (AF)
2015 Basin SWE (AF)
2013 HH Inflow (cfs)
2014 HH Inflow (cfs)
2015 HH Inflow (cfs)

Runoff Forecasting

Hetch Hetchy – Tuolumne River Basin



Snowmelt runoff forecasting with USGS Precipitation/Runoff Modeling System (PRMS)

How well can ASO predict inflow

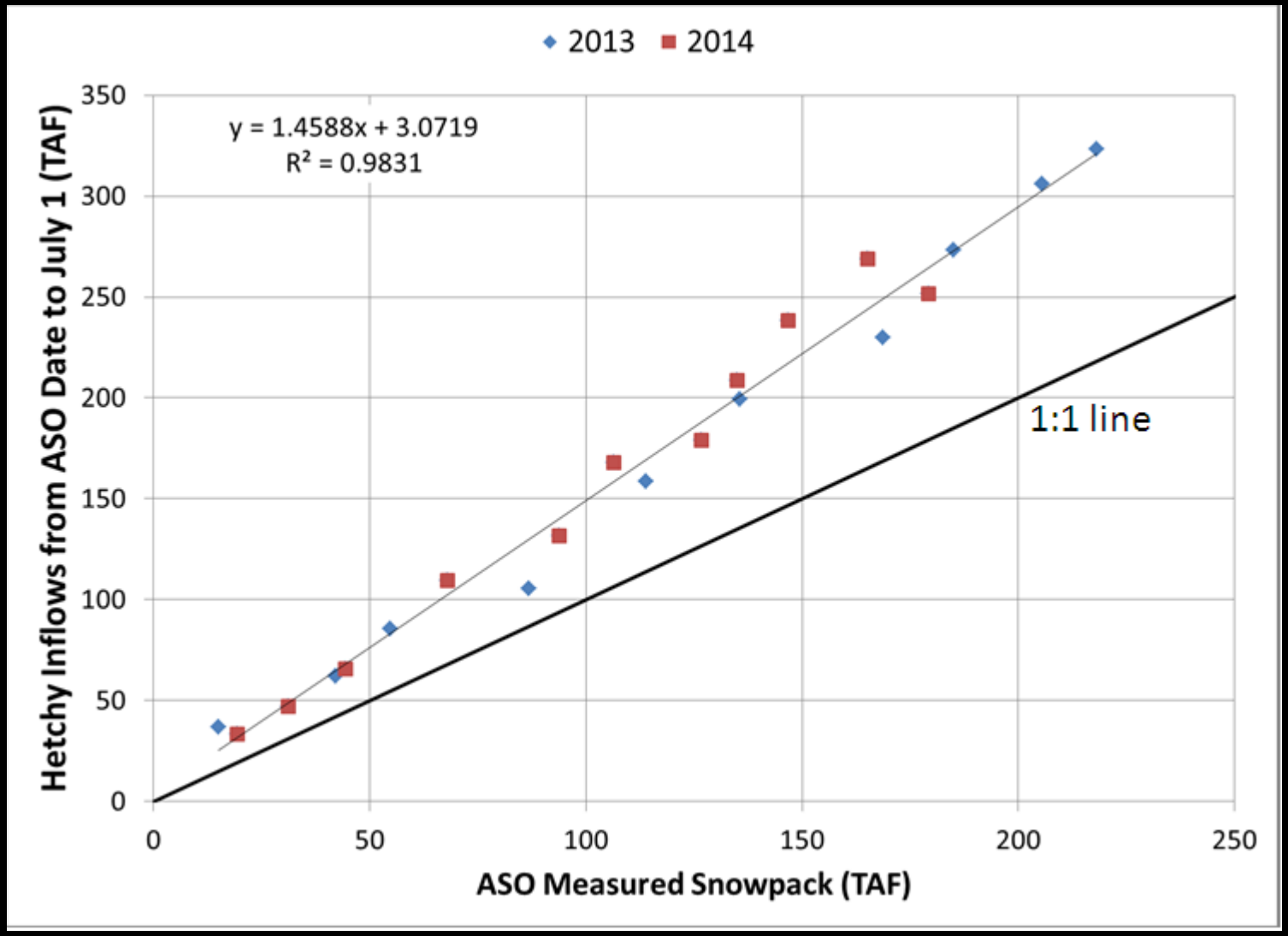


Image courtesy: Chris Graham (HH)

URL – aso.jpl.nasa.gov

Spacecraft Status: L7 Summary

≈ 15 years of on-orbit operations

Power Subsystem

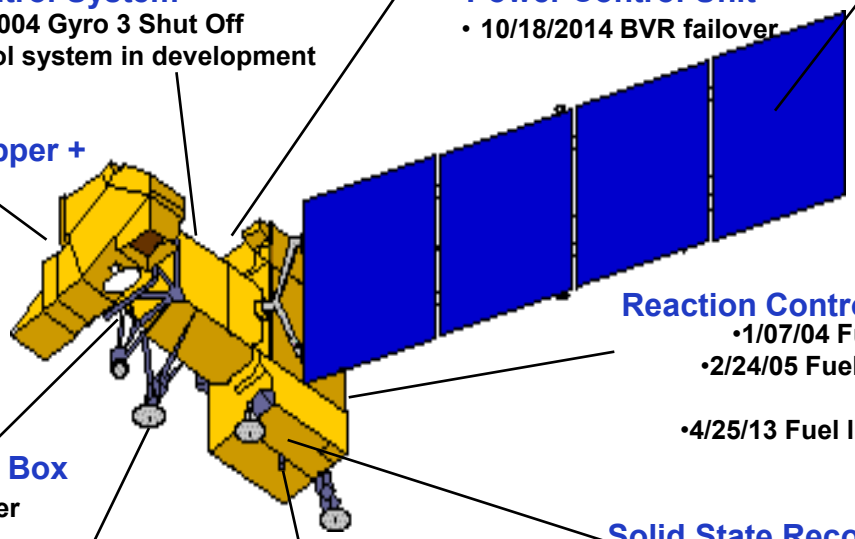
Batteries
Performance nominal

Solar Array
- 5/14/2002 Circuit #14 Failure
- 5/16/2005 Circuit # 6 Failure
- 8/13/2008 Circuit #14 partial recovery
- 14 circuits remain operating
- no impact to ops

Power Control Unit
- 10/18/2014 BVR failover

Attitude Control System
- 05/05/2004 Gyro 3 Shut Off
- 1-gyro control system in development

Enhanced Thematic Mapper +
- 5/31/2003 SLC Failure
- 4/01/2007 Bumper mode



Reaction Control System
- 1/07/04 Fuel line #4 thermostat #1a failure
- 2/24/05 Fuel line #4 thermostat failure; Primary heater circuit disabled
- 4/25/13 Fuel line #2 thermostat failure; Redundant heater circuit disabled

Remote Tlm Cmd (RTC) Box
- 09/27/2014 RTC A Failover

Solid State Recorder
- 11/15/1999 SSR PWA #23 Loss
- 02/11/2001 SSR PWA #12 Loss
- 12/07/2005 SSR PWA #02 Loss
- 08/02/2006 SSR PWA #13 Loss
- 03/28/2008 SSR PWA #22 Loss
- 09/03/2008 SSR PWA #23 Recovered
- 10/12/2013 SSR PWA #11 Loss
- Each PWA is 4% loss of launch capacity
- Boards are likely recoverable

X-band System
Performance nominal

S-band System
Performance nominal

*** No new spacecraft issues to discuss.*

USGS

An Evolving Scheduling Paradigm

- Landsat 7
  - Maximize repeat coverage of continental land masses
  - Maximize health and safety of mission
  - Coordinate acquisitions with Landsat 8
  - Increase ground station contacts and relax duty cycle constraints to maximize acquisitions between now and end-of-mission
- Landsat 8
  - Continue with 725 limit
    - All encompassing - includes special requests

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