NASA Science Mission Directorate
Earth Science Division
Applied Sciences Program

NASA and Glacier Studies

Dan Irwin
SERVIR Director

December 11, 2014

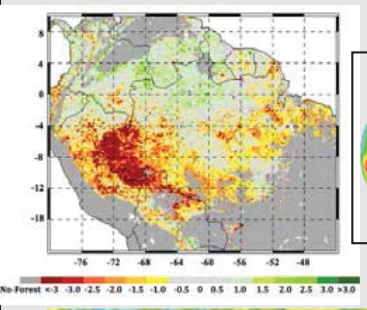
Earth Science Program Overall Strategy

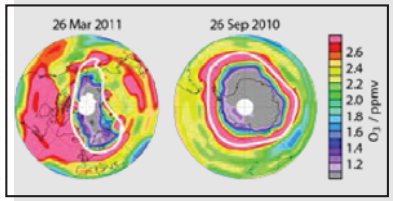
Frellich

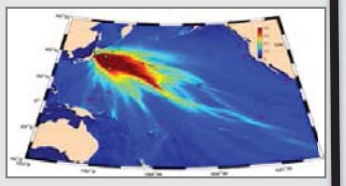
- Maintain a **balanced program** that:
  - **advances Earth System Science**
  - **delivers societal benefit** through applications development and capacity building
  - **provides essential global spaceborne measurements** supporting science and "operations"
  - **develops and demonstrates technologies** for next-generation measurements, and
  - **complements and is coordinated with activities of other agencies and international partners**

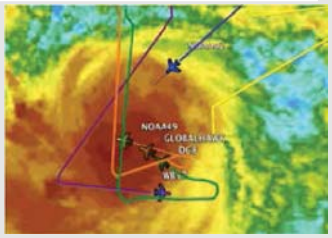
NASA: Advancing Earth System Science to meet the challenges of climate and environmental change

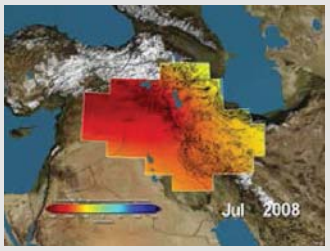
Research

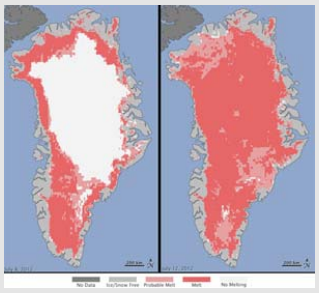




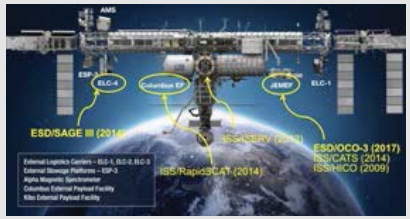




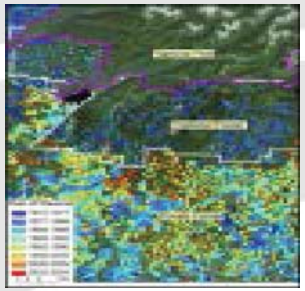


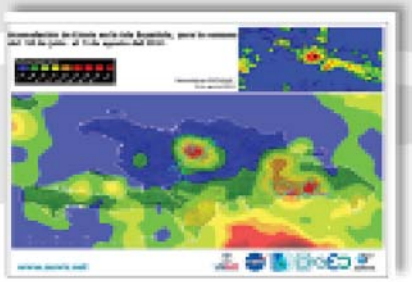


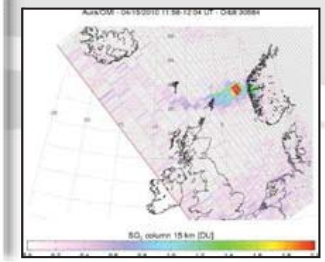
Flight

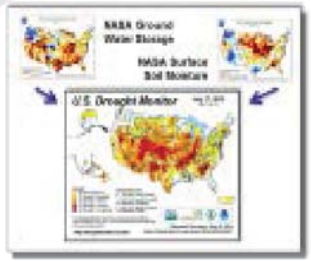


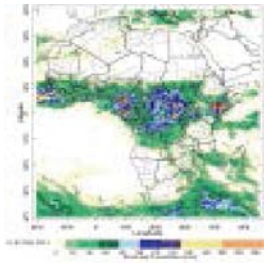
Applied Sciences



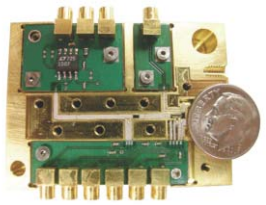








Technology



SMD/ESD Applied Sciences Program

Applications Themes

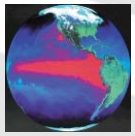

Health


Water


Disasters


Ecosystems

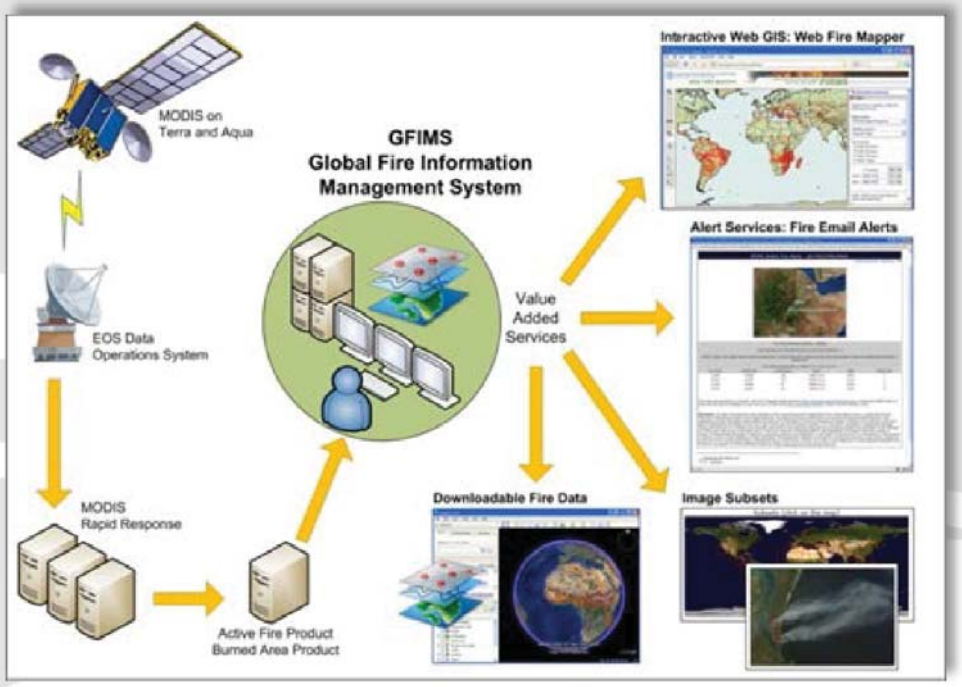

Agriculture


Climate

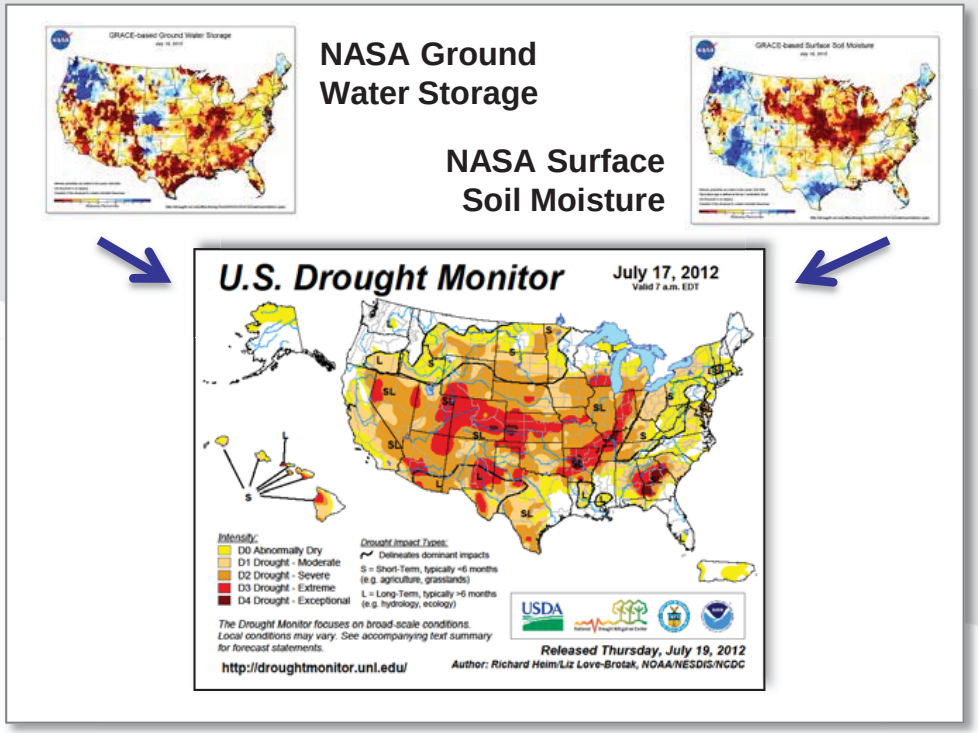
Energy


Oceans


Weather

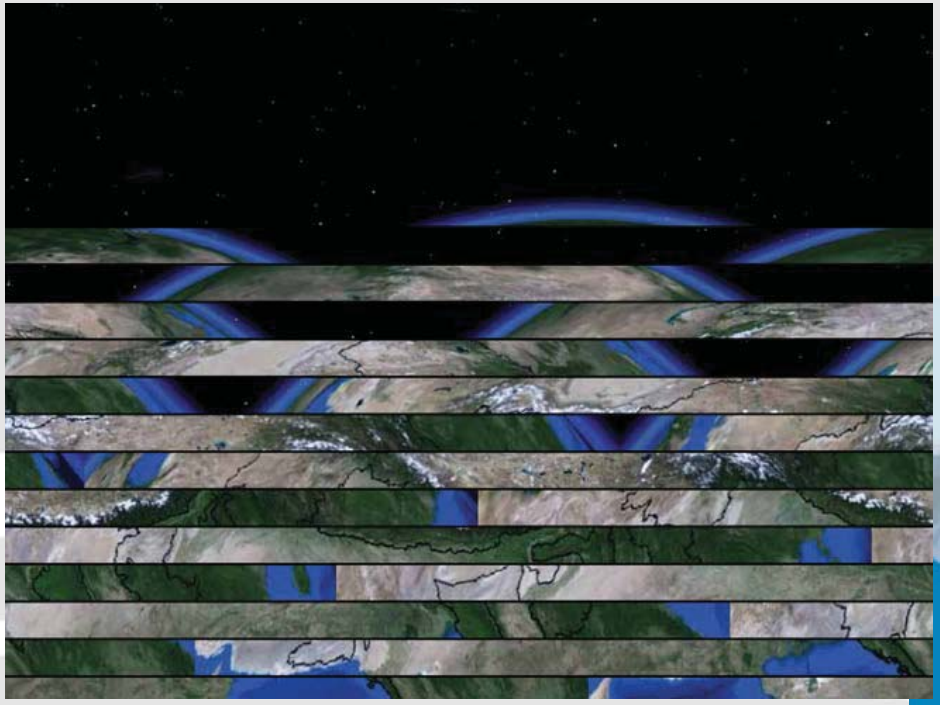


United Nation's system now using data from NASA's Terra and Aqua satellites to identify fires and send alerts to remote areas via SMS and text messages.



USDA/NOAA managed weekly U.S. Drought Monitor now using NASA GRACE data as part of analysis in creation of national and state-level maps..

Importance of Glaciers

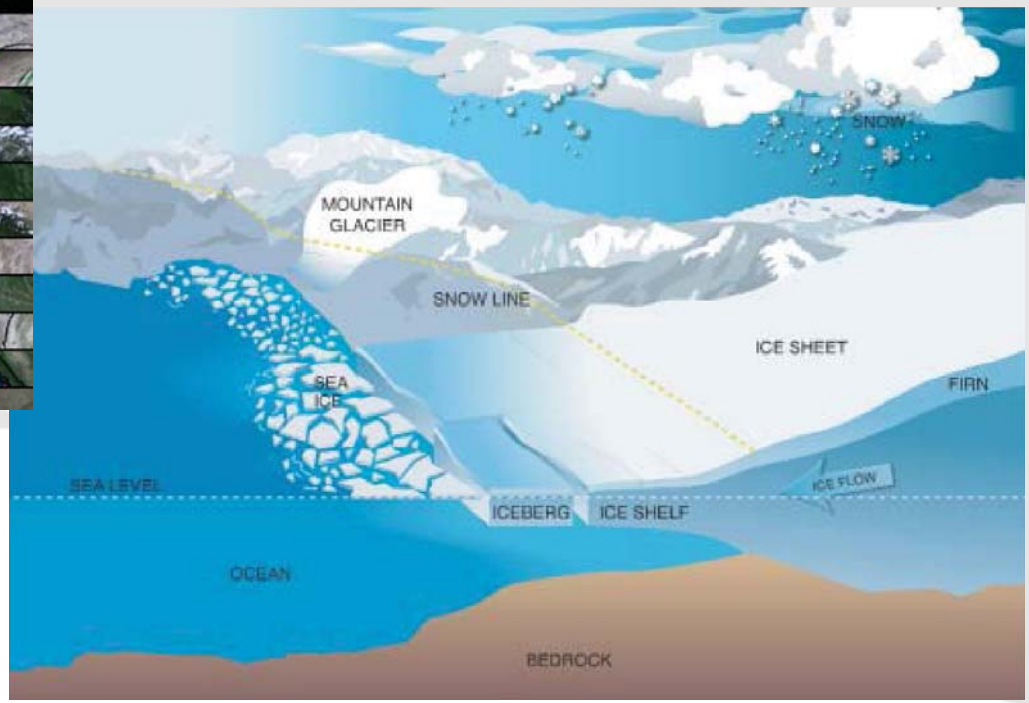


The Hindu Kush-Himalayan range, viewed by satellite imagery.

Photo: ESRI; www.icimod.org

Illustration of ice in the natural environment.

Graphic courtesy of Christopher Shuman, Claire Parkinson, Dorothy Hall, Robert Bindschadler, and Deborah McLean; http://icesat.gsfc.nasa.gov/icesat/science_mission/introduction_to_ice.html



Presentation Objectives

1. NASA Earth Sciences & glacier workshop interests
2. NASA glacier/snow-related missions & airborne campaigns
3. NASA glacier/snow-related research & analysis activities
4. NASA glacier/snow-related applied science activities

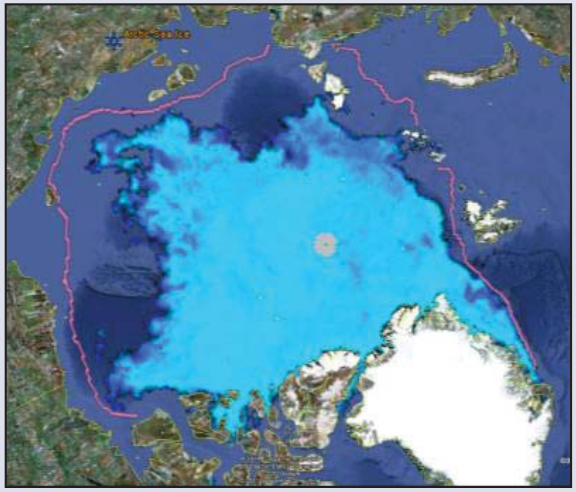
Applicable satellites & airborne missions

- ICESat (Ice, Cloud, & land Elevation Satellite)
  - 2003 – 2009: Ice sheet mass balance, cloud and aerosol heights, land topography and vegetation characteristics
- ICESat-2
  - 2017 launch: Magnitude and causes of ice sheet changes, slope effects vs elevation change
- Operation IceBridge aircraft missions
  - Yearly airborne survey of Earth's Arctic and Antarctic ice sheets, ice shelves, and sea ice
- Airborne Snow Observatory
  - CA snowpack albedo and snow water equivalent (SWE) to understand snowmelt runoff and timing

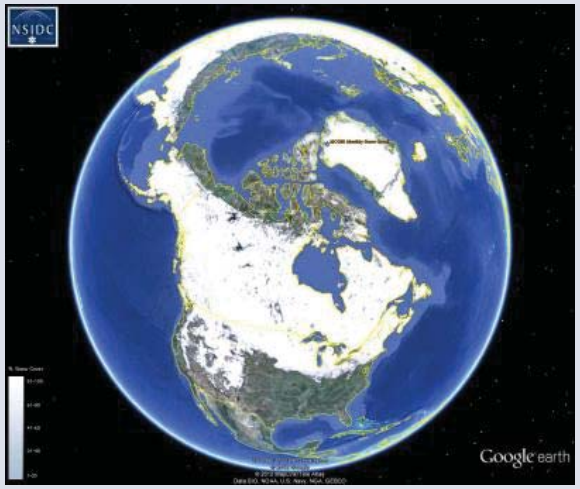
National Snow and Ice Data Center:
A NASA Distributed Active Archive Center (DAAC) for the cryosphere

Hosts a range of datasets from NASA satellites and field programs, including data programs.

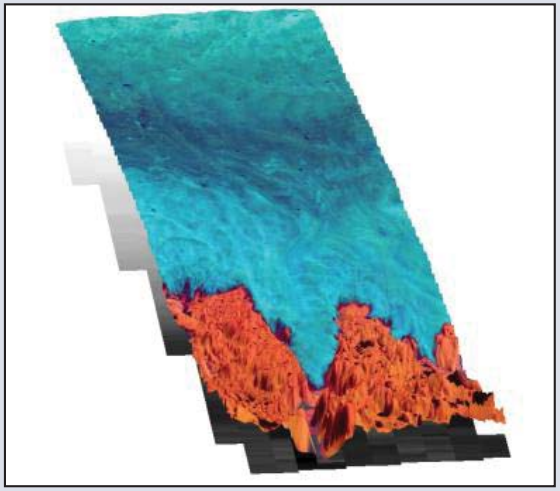
Passive Microwave	VIS/IR Moderate Resolution	Satellite & Airborne Altimetry
• AMSR-E (Aqua) • AMSR (ADEOS II) • SMMR (Nimbus 7) • SSM/I, SSMIS (DMSP series)	• MODIS (Terra/Aqua) snow and ice products • AVHRR polar data (NOAA series)	• IceSAT I/GLAS altimetry and atmospheric lidar data • Digital Elevation Models (DEMs) • IceBridge



AMSR-E 12.5 km Sea Ice Concentration



MODIS Monthly Global Snow Cover



IceBridge ATM Qfit Data on Landsat Image

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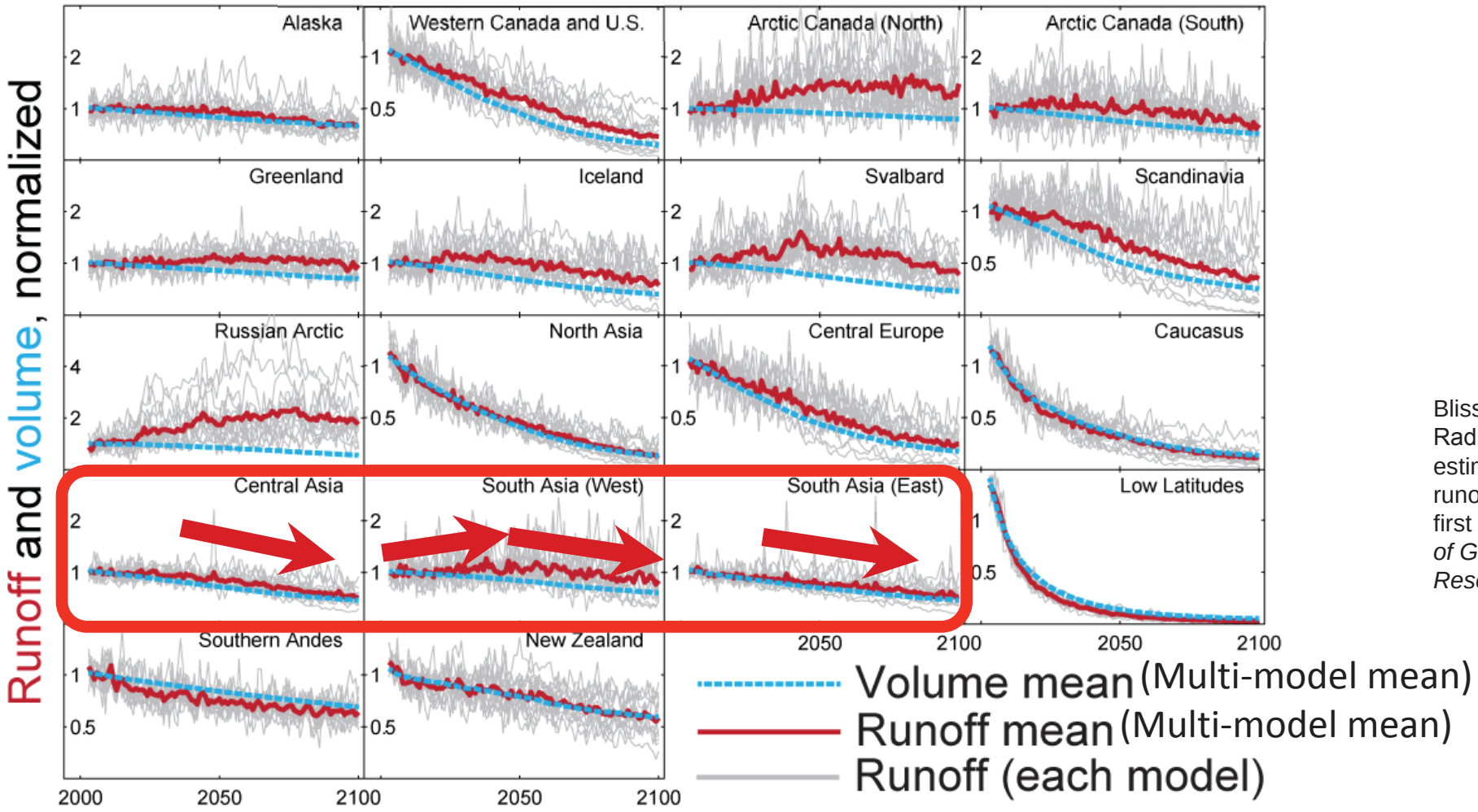
100-year projections of glacier volume and glacier runoff for 18 regions

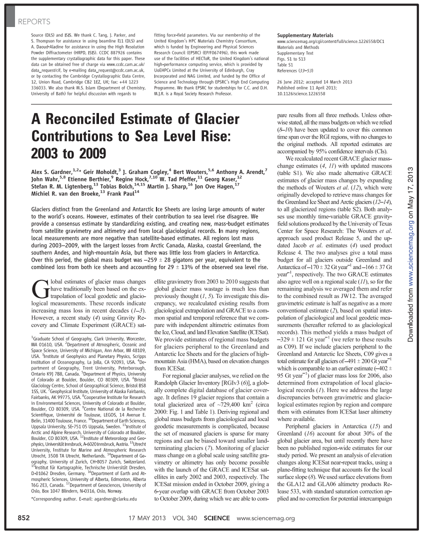
R. Hock,
A. Bliss

NASA grant:
09-IDS09-0114



Bliss, A., R. Hock, V. Radić, 2013. Regional estimates of glacier runoff for the twenty-first century. *Journal of Geophysical Research*, submitted.

- **Reduction in glacier runoff by 2100 coincident with volume reduction in Central Asia and South Asia (East)**
- **Initial increase followed by reduction for South Asia (West)**



REPORTS

A Reconciled Estimate of Glacier Contributions to Sea Level Rise: 2003 to 2009

Alex S. Gardner,[1,2*] Geir Moholdt,[3] J. Graham Cogley,[4] Bert Wouters,[5,6] Anthony A. Arendt,[7] John Wahr,[5,8] Etienne Berthier,[9] Regine Hock,[7,10] W. Tad Pfeffer,[11] Georg Kaser,[12] Stefan R. M. Ligtenberg,[13] Tobias Bolch,[14,15] Martin J. Sharp,[16] Jon Ove Hagen,[17] Michiel R. van den Broeke,[13] Frank Paul[14]

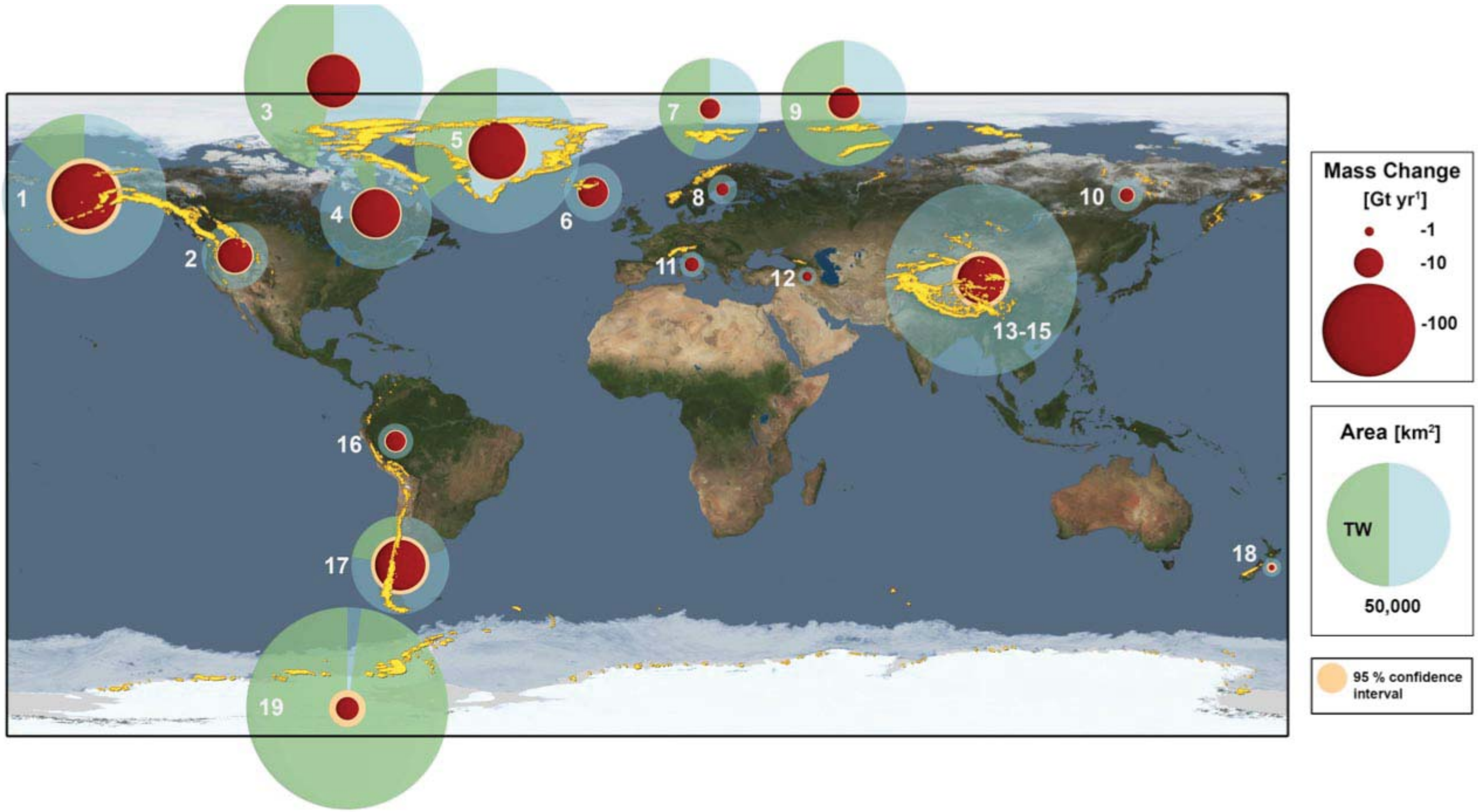
Glaciers distinct from the Greenland and Antarctic Ice Sheets are losing large amounts of water to the world's oceans. However, estimates of their contribution to sea level rise disagree. We provide a consensus estimate by standardizing existing, and creating new, mass-budget estimates from satellite gravimetry and altimetry and from local glaciological records. In many regions, local measurements are more negative than satellite-based estimates. All regions lost mass during 2003–2009, with the largest losses from Arctic Canada, Alaska, coastal Greenland, the southern Andes, and high-mountain Asia, but there was little loss from glaciers in Antarctica. Over this period, the global mass budget was −259 ± 28 gigatons per year, equivalent to the combined loss from both ice sheets and accounting for 29 ± 13% of the observed sea level rise.

Global estimates of glacier mass changes have traditionally been based on the extrapolation of local geodetic and glaciological measurements. These records indicate increasing mass loss in recent decades (1–3). However, a recent study (4) using Gravity Recovery and Climate Experiment (GRACE) satellite gravimetry from 2003 to 2010 suggests that global glacier mass wastage is much less than previously thought (1, 5). To investigate this discrepancy, we recalculated existing results from glaciological extrapolation and GRACE to a common spatial and temporal reference that we compare with independent altimetric estimates from the Ice, Cloud, and land Elevation Satellite (ICESat). We provide estimates of regional mass budgets for glaciers peripheral to the Greenland and ...

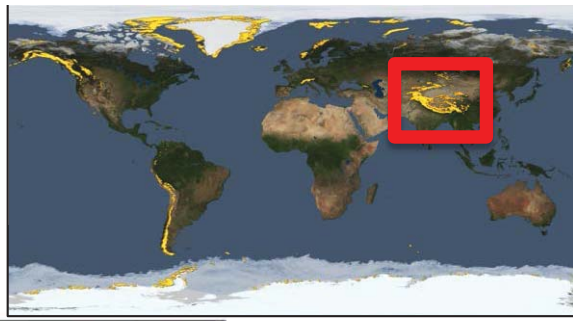
Global glacier loss

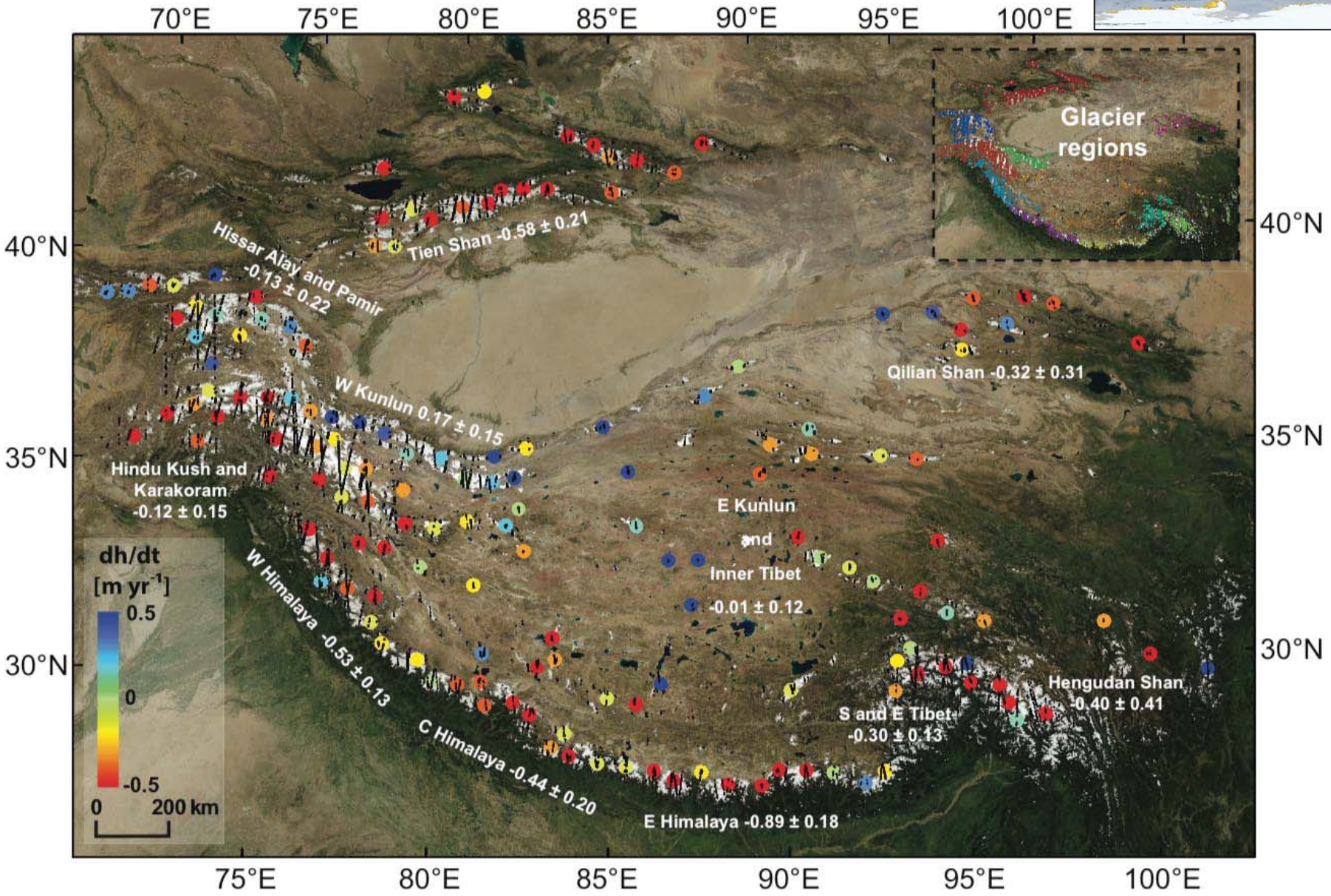
259 ± 28 Gt yr^{-1} for 2003-09

[Gardner et al., 2011 & 2013]



High Mountain Asia





Gardner et al., 2013

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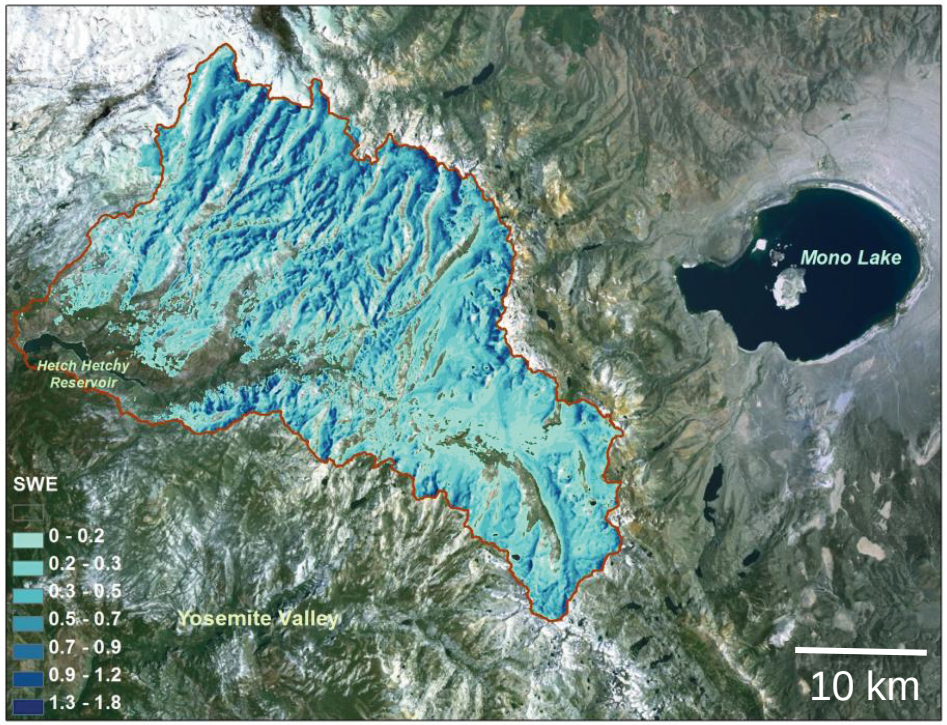
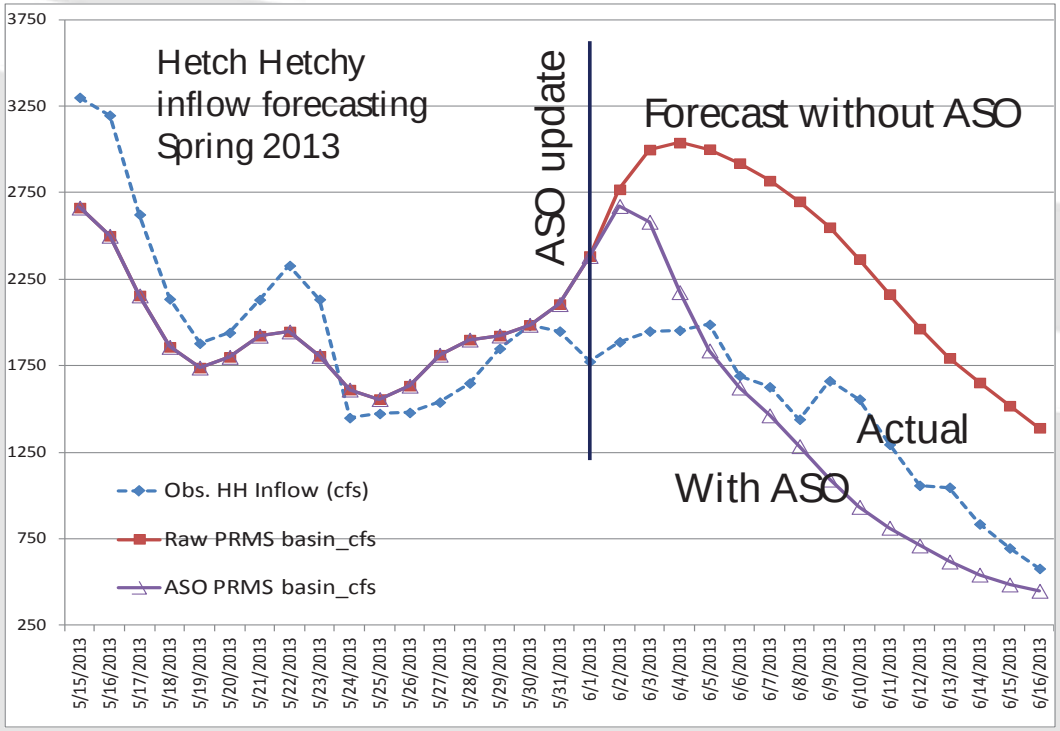
Improved Estimates for Water Management in California

Improved Estimates for California Water Management





AIRBORNE SNOW OBSERVATORY

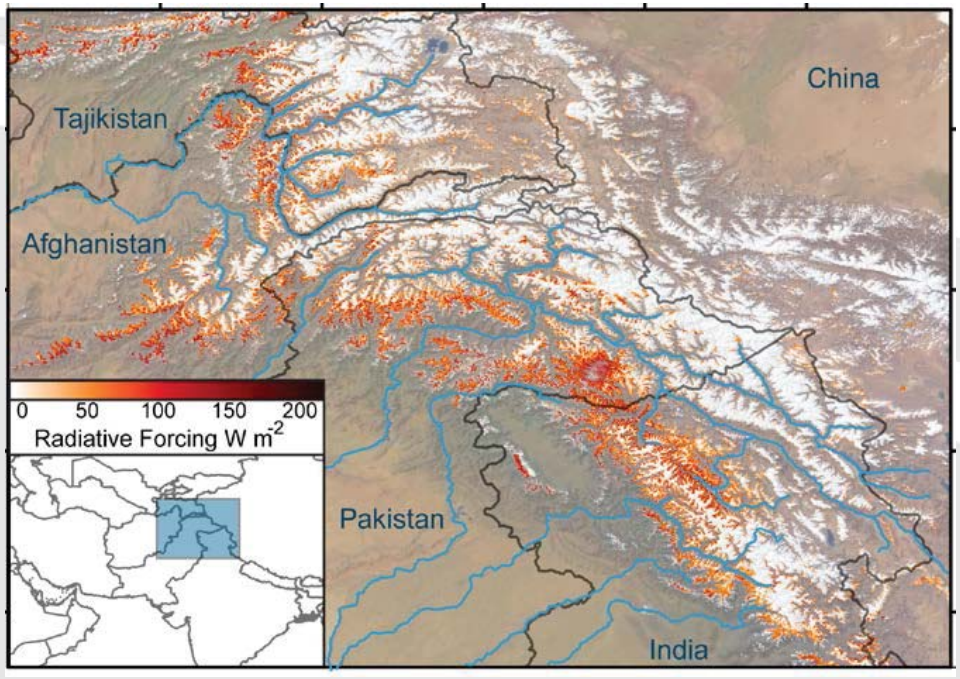
The JPL Airborne Science Observatory (ASO) team and California Dept. of Water Resources (DWR) prediction of water inflow into the Hetch Hetchy Reservoir in thousand acre feet (shown in red) was modified on June 1, 2013 based on snow water equivalent (SWE) data from the NASA/JPL ASO. The new forecast (shown in purple) provided a factor of 2 better estimate of the actual inflow (shown in blue) and enabled water managers to optimize reservoir operations in its first year.

Tom Painter, JPL

Radiative forcing by light absorbing impurities in snow from MODIS surface reflectance data

Painter, Bryant, and Skiles (2012), *Geophysical Research Letters,* doi: 10.1029/ 2012GL052457

- In situ measurements and modeling suggest that dust and carbonaceous particles are accelerating snow and glacier melt in the world's mountains.
- MODIS surface reflectance data offer unique knowledge of the spatial and temporal distribution of aerosol radiative forcing in mountain snow.
- The retrievals facilitate hypothesis building on the aerosol-cryosphere processes and constrain snow/glacier modeling.
- Provides timely, spatially-complete knowledge of the acceleration of snowmelt to water managers and forecasters.



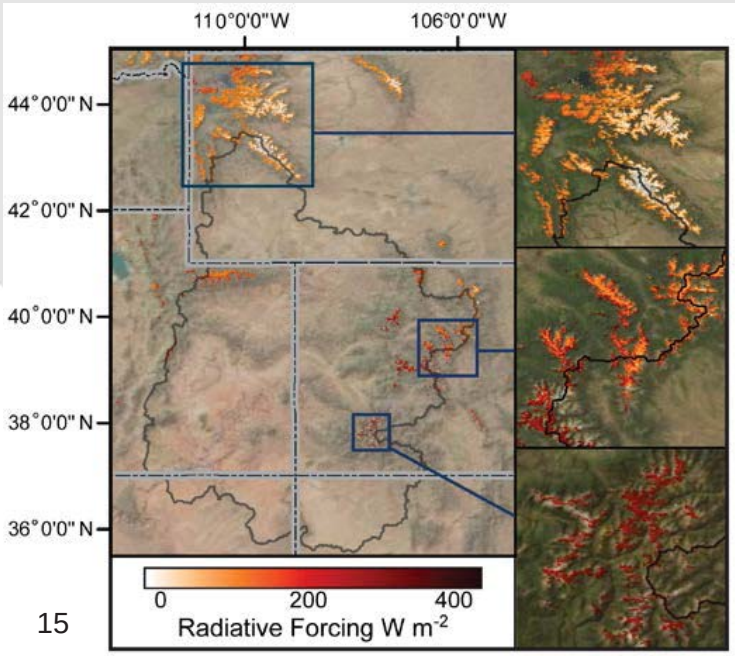


Figure 1: a) Dust radiative forcing in snow for Hindu Kush-Himalaya on June 21, 2010 at time of MODIS overpass, ~05:40 UTC. (b) Dust radiative forcing in snow for eastern half of the Upper Colorado River Basin on May 18, 2009 at time of MODIS overpass, ~17:55 UTC.

NASA's Capacity Building Program

Participation in interagency and global capacity building activities

SERVIR Coordination Office (MSFC)
Building international capacity with hubs in
- East Africa
- Hindu Kush - Himalaya
- Mesoamerica

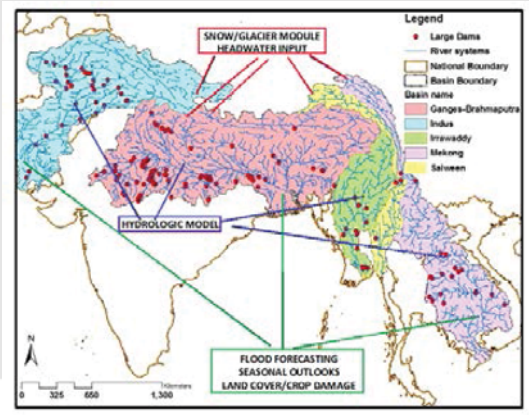
Gulf of Mexico Initiative, GOMI (SSC)
Building Gulf region's capacity for local issues

Applied Remote SEnsing Training, ARSET (GSFC)
On-line and hands on basic/advanced training to build domestic skills

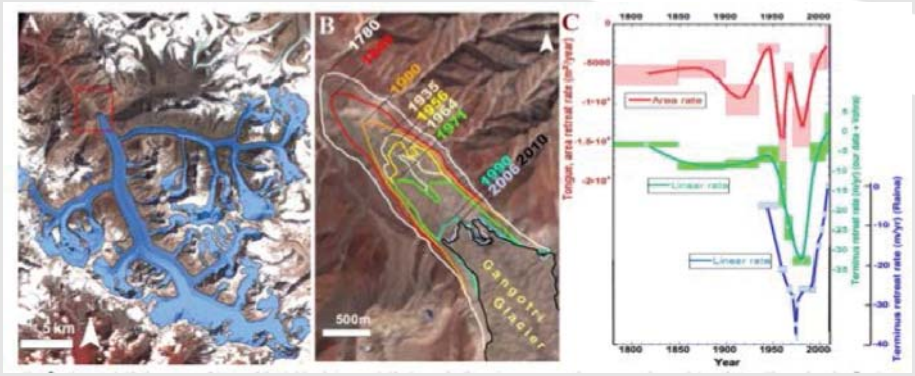
DEVELOP (LaRC national office)
Dual workforce/local government capacity building using collaborative projects

SERVIR Applied Sciences Team – HKH region

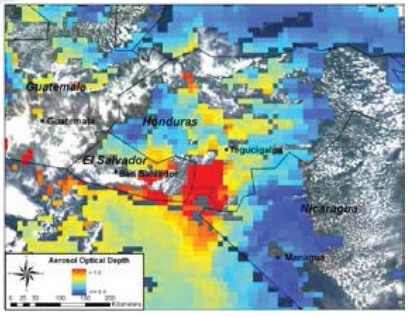
Faisal Hossain (University of Washington)
Web-visualization system that can predict, map and warn of water-related vulnerability issues in Hindu Kush Himalayan region.



Jeff Kargel (University of Arizona)
Identify and study specific alpine systems that will likely develop new hazardous conditions, leading to disasters in the near future.



Huff/Thomas (University of Pennsylvania)
Use NASA satellite EO data for vetting and inclusion in a national Air Quality modeling system for Hindu Kush Himalayan countries



Kirschbaum (GSFC)
To develop a Mesoamerica landslide hazard forecasting system using satellite data to assess regional landslide hazards and explore ways to extend the system to Hindu Kush Himalayan region.

Interdisciplinary science applications to glacier & alpine hazards in relation to development & habitation in the Hindu Kush-Himalaya

Jeff Kargel/University of Arizona

Purpose and Objective

Many disasters in Hindu Kush Himalayas involve ice avalanches, landslides and rockfalls, glacier lake outburst floods (GLOFs), and other active mountain processes. **The objective of this effort aims at identifying and studying specific alpine systems that will likely develop new hazardous conditions, leading to disasters in the near future.**

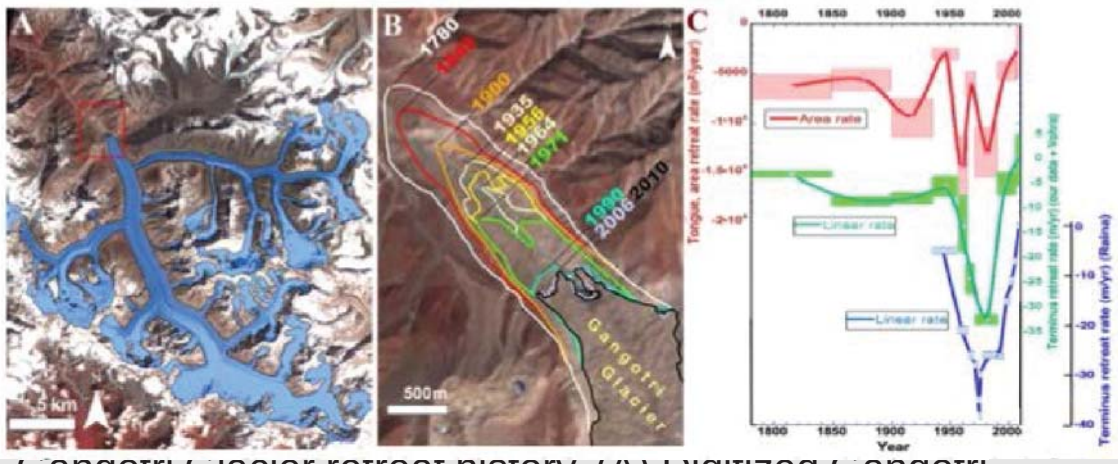
The objective will be accomplished by:

(a) Establishing satellite image time series and assess dynamical evolution of glaciers and glacier lakes;

(b) Applying topographic analysis to assess likely or possible damming points due to landslides into glacier meltwater streams or glacier advances into streams, and assess possible lake areas and volumes;

(c) Modeling the hydrology during typical recent years and verifying it with field work; and

(d) Engaging the appropriate end users through outreach, education.



Gangotri Glacier retreat history. (A) Digitized Gangotri Glacier and tributaries superimposed with ASTER data (B)Retreat history of the glacier tongue using Landsat and ASTER imagery, and © Linear and areal retreat history (green and red curves respectively)

DEVELOP National Program: Alaska Climate - SAR-based Estimation of Glacial Extent and Velocity Fields on Isanotski Volcano, Aleutian Islands

Community Concern & Objectives

Glaciers are a diverse resource for water, energy, ecology, and economy, yet they are sensitive indicators of climatic processes and are receding. This project looked at glacier change near the City of False Pass since they are reliant on glaciers flanking Isanotski Volcano for drinking water, fishing, and possibly future hydroelectric power. The objective of this project was to use NASA UAVSAR data to determine velocity fields of glaciers and compose methods and tutorials of SAR techniques for use by partner organizations and future DEVELOP interns.

Earth Observations Utilized

NASA SRTM

NASA UAVSAR

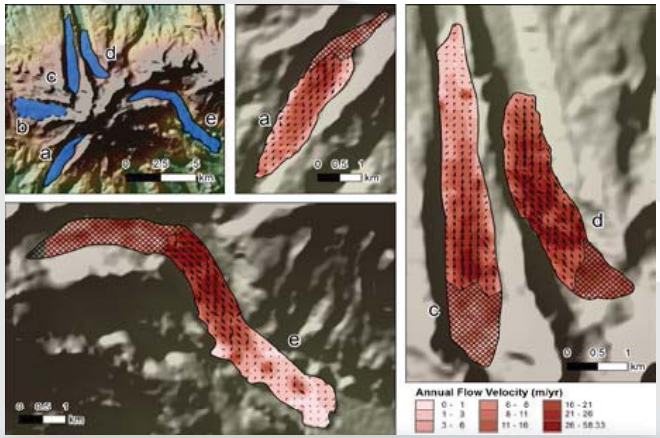
JAXA ALOS PALSAR

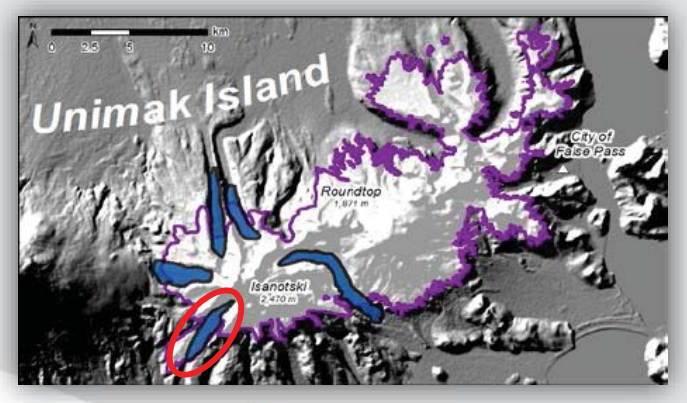
Benefits

Enhances partners understanding of fragile glacier ecosystems and assesses hydroelectric and drinking water resources.

Project End Product

Velocity Field





Methodology & Inputs

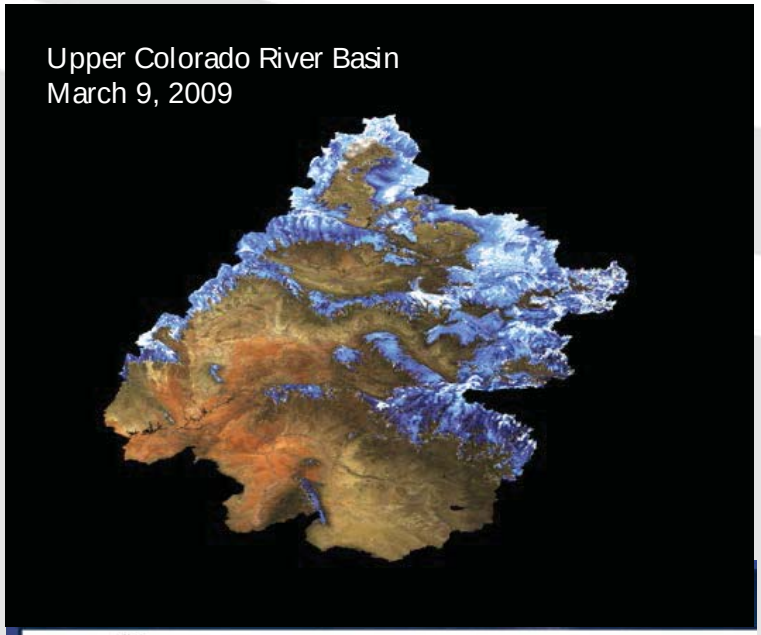
Coherence

Boundary Delineation

Feature Tracking

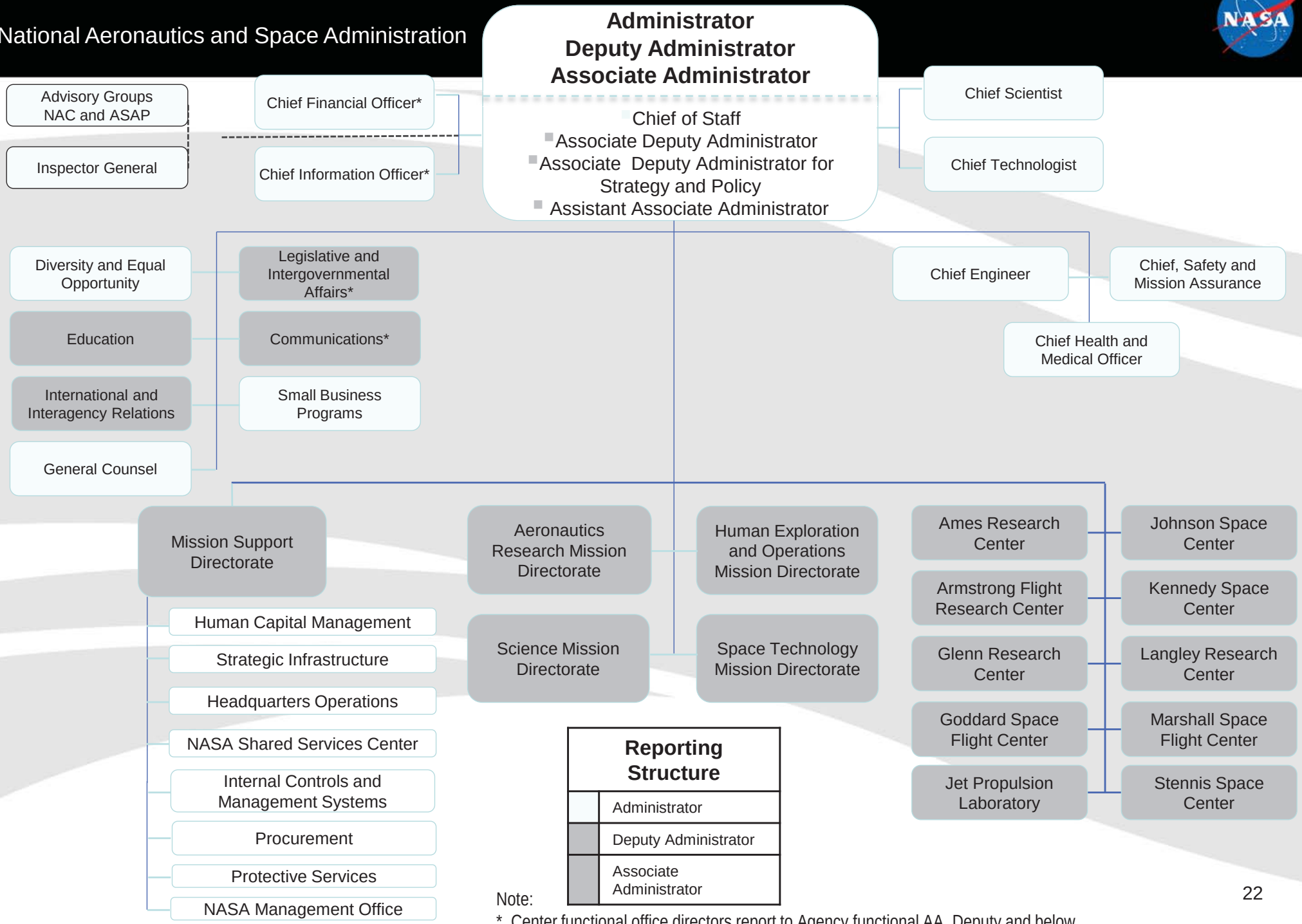
ARSET In-person Training: Snow Applications in California, Feb 10-20, 2014

- Paul Ramirez, Karl, Rittger, Andrew Hart, Tom Painter
- **27 Participants, ½ new to Remote Sensing.**
  - DWR
  - US Water masters, USBR, USACE
  - Irrigation Districts
  - Utilities (PG & E) and other private sector.
  - Hetch Hetchy water reservoir managers.
- **Products and Tools**
  - MODIS snow cover, grain size, albedo, dust radiative forcing, SWE (ASO), and tower data
  - JPL SnowMap server access to products (rated by nearly all as moderately to very useful)
- **Feedback (discussion session) and Surveys:**
  - More interest in 8 day products than daily products, also NRT. Discussion of rolling 8-day composite distributed on Mondays.
  - Interest in a script that generated yearly plots per basin, and use of data products in operational hydrological models.
  - Insufficient hands-on time, instructions.
  - 1/3 stated that training ***Exceeded Expectations;*** strong interest in more courses.



Backup Charts

National Aeronautics and Space Administration

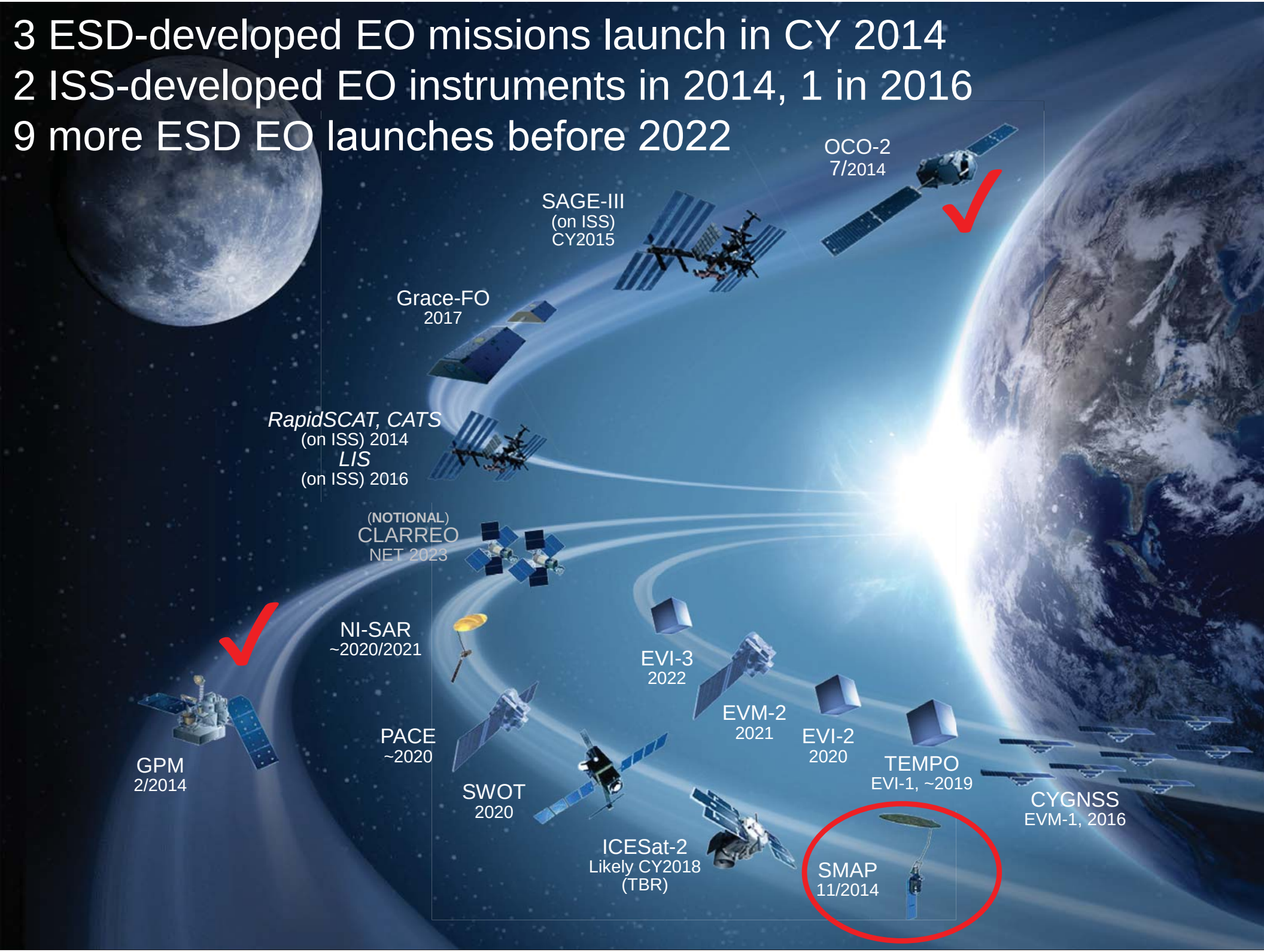


Note:

* Center functional office directors report to Agency functional AA. Deputy and below report to Center leadership.


Formulation
Implementation
Primary Ops
Extended Ops
JPSS-2 (NOAA)
SLI-TBD
Formulation in 2015
RBI
OMPS-Limb
TSIS-2
NI-SAR
PACE
SWOT
TEMPO
GRACE-FO (2)
ICESat-2
CYGNSS
SAGE III (on ISS)
SMAP
OCO-2
TRMM
QuikSCAT
SORCE
EO-1
Landsat-7
(USGS)
ACRIMSAT
Aquarius
Terra
Suomi NPP
(NOAA)
Aqua
CloudSat
Landsat-8
(USGS)
CALIPSO
Aura
GPM
GRACE (2)
OSTM/Jason 2
(NOAA)

3 ESD-developed EO missions launch in CY 2014
2 ISS-developed EO instruments in 2014, 1 in 2016
9 more ESD EO launches before 2022



ICESat

- ICESat - Ice, Cloud, and land Elevation Satellite
  - Measured ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics
  - Operational from 2003 to 2009, decommissioned August 2010
  - ICESat data are distributed by the National Snow and Ice Data Center (NSIDC).

Related polar aircraft missions: IceBridge

Bridge gap in data collection between ICESat & ICESat-2; linking to CryoSat 2; making key measurements for predictive models, run until launch of ICESat 2 in 2016; collaborators: **Australia, France, UK, ESA, CSA, Greenland**

Campaigns completed

Arctic 2009-14; Antarctic 2009-13

Aircraft NASA P3, DC8, B200, Falcon

UT Basler, U. Alaska, NSF GV

Instruments

Lidar

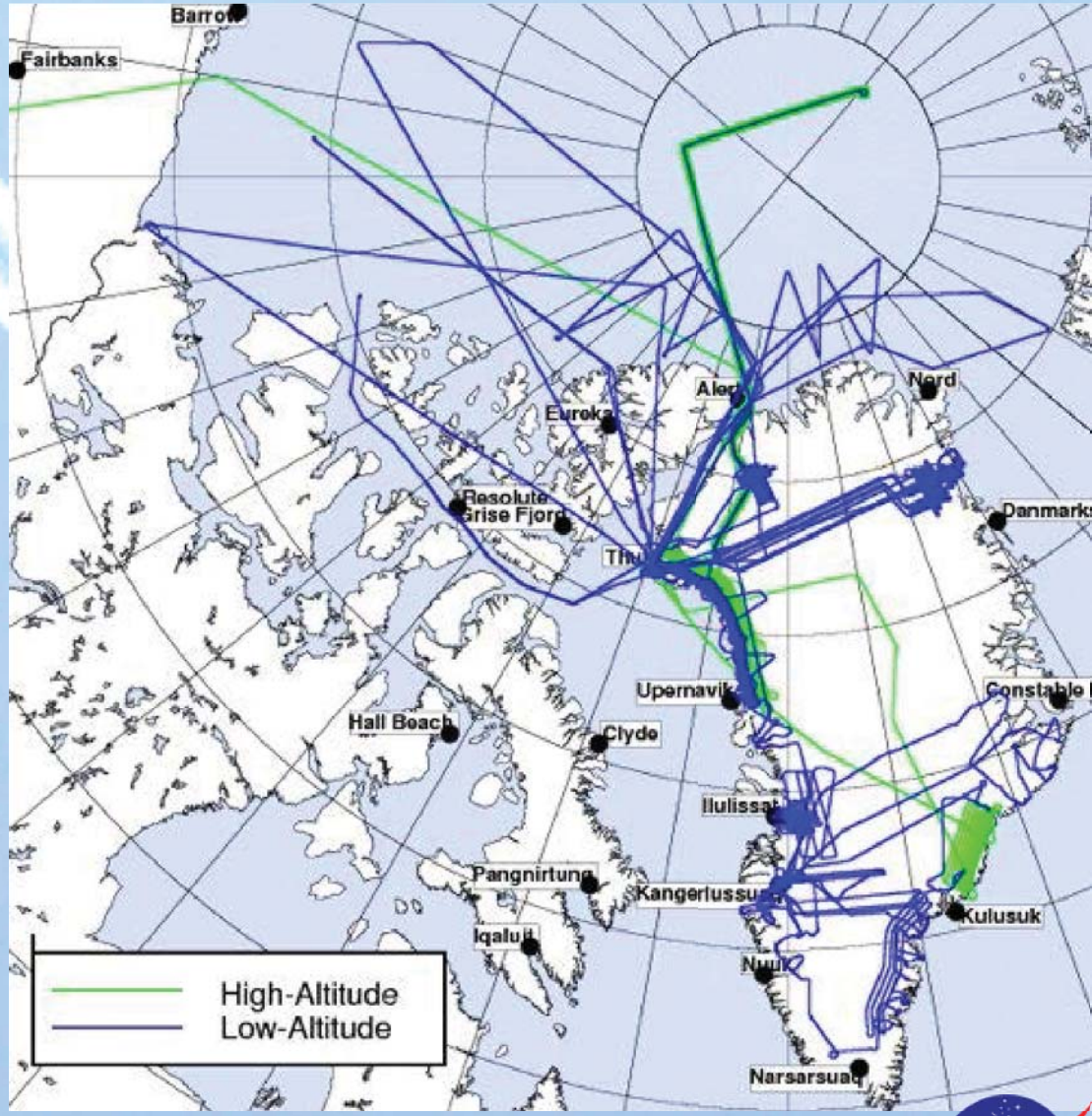
- ATM/NASA-GSFC
- LVIS/NASA-GSFC
- Photon counting/Sigma-U. Texas

Radar

- Accumulation&snow radars/Kansas
- MCoRDS/U. Kansas
- HiCARS&WISE /U. Texas,-JPL

Gravimeter/LDEO & U.Texas

Magnetometer-U. Texas



www.nasa.gov/icebridge

NASA Operation IceBridge-Alaska

C. Larken, E. Burgess, A. Arendt, S. O'Neel

Alaska-wide mass loss

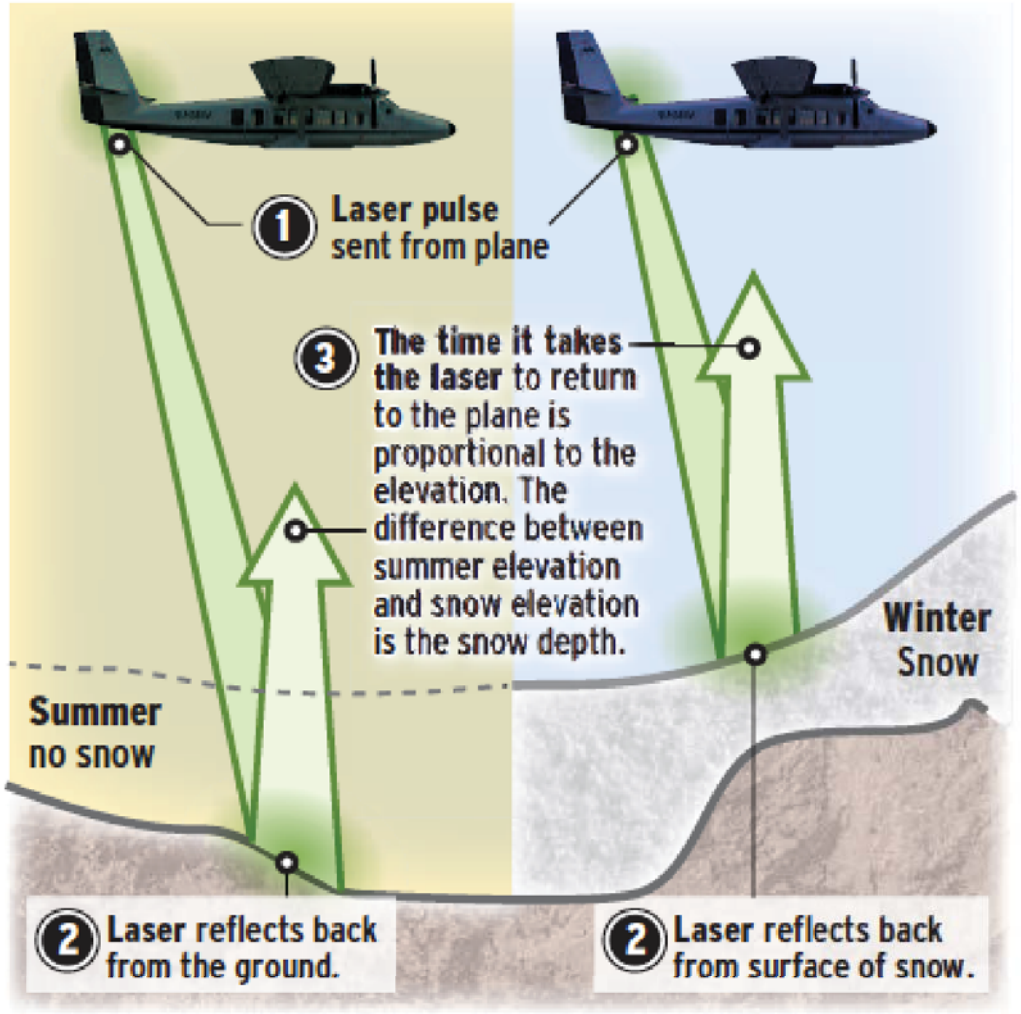
UNIVERSITY OF ALASKA FAIRBANKS

NASA

Airborne Snow Observatory

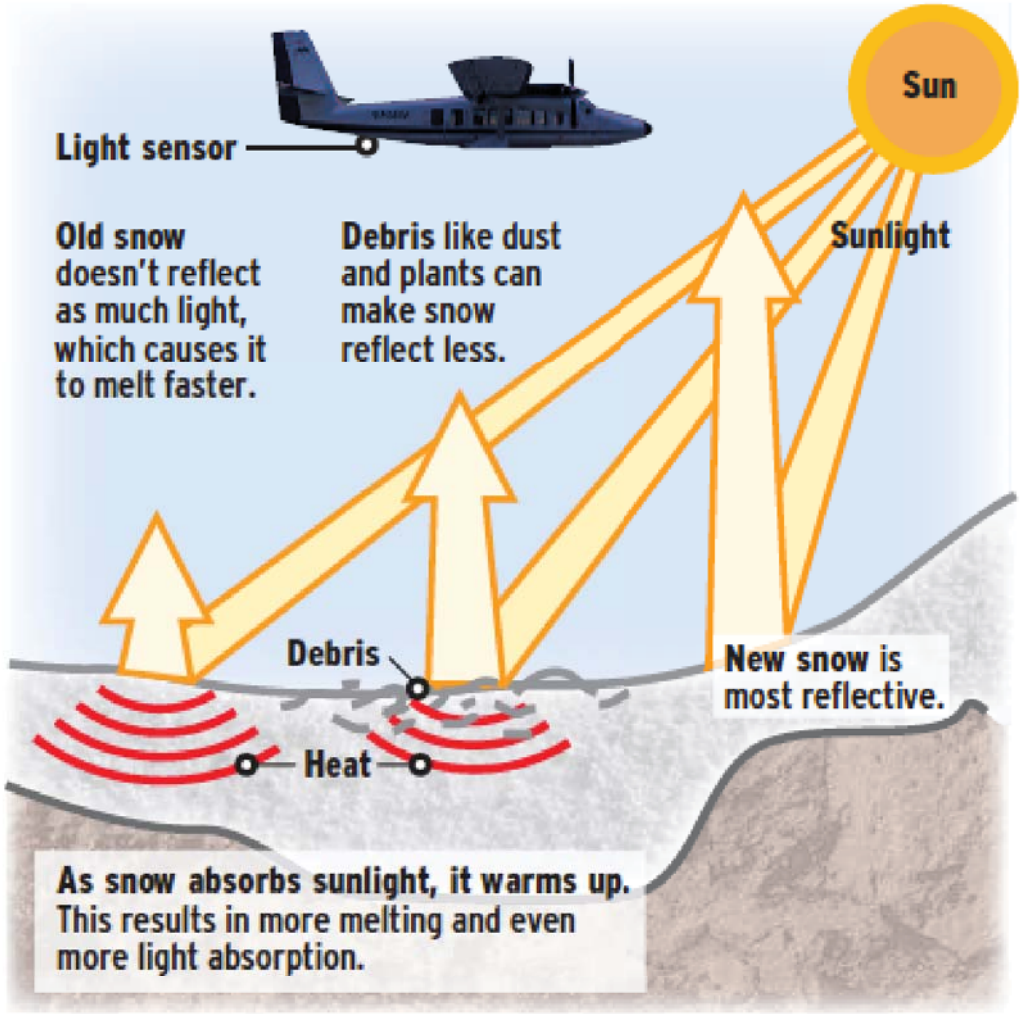
How much snow?

Using laser radar, known as Lidar, researchers measure the depth of snowpack in California.



How will it melt?

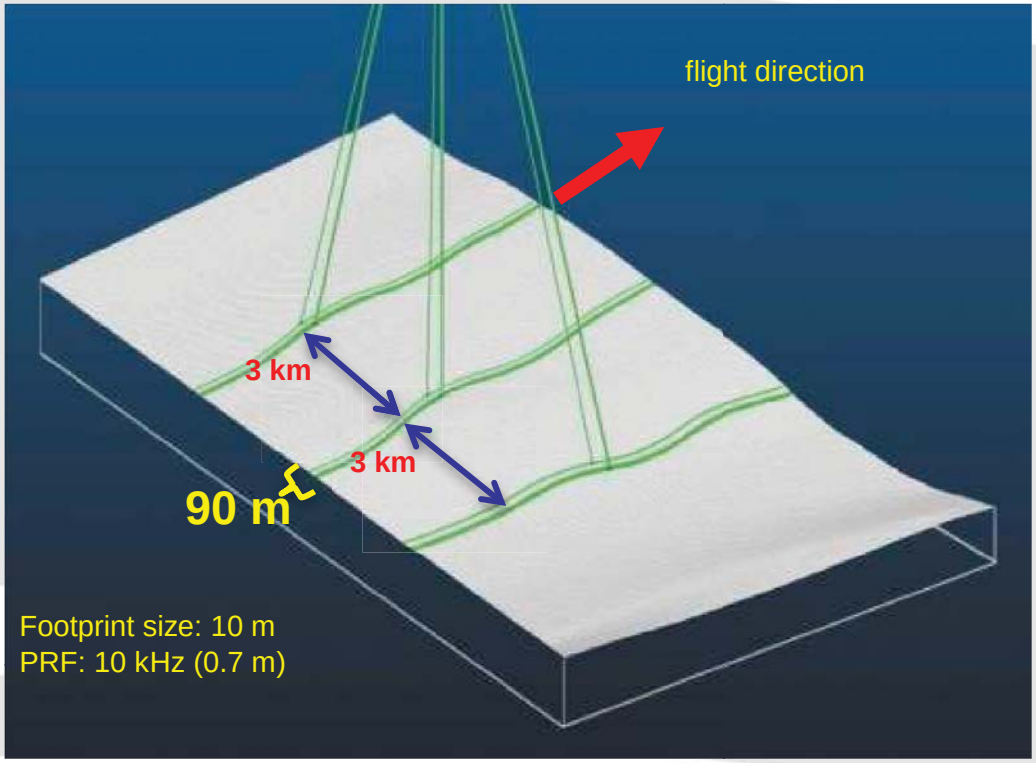
With an advanced light sensor, scientists measure snow's reflectivity – an indicator of how it will melt.

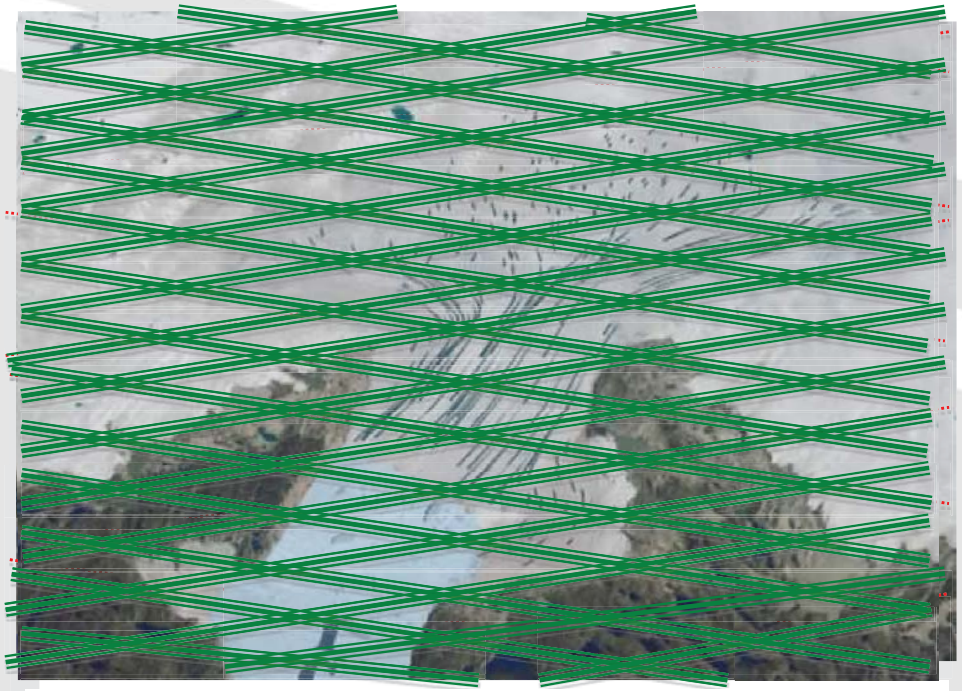


Sources: Thomas Painter, Frank Gehrke, Optech Inc.

Maxwell Henderson / The Register

ICESat-2 measurement concept and coverage





Planned ICESat-2 coverage over outlet glacier (~10 km)

ICESat-2 measurement concept designed to:

- Assess magnitude and causes of ice sheet changes
- Separate slope effects from elevation change on ice sheets
- Produce monthly maps of sea ice freeboard
- Enable determination of global vegetation height

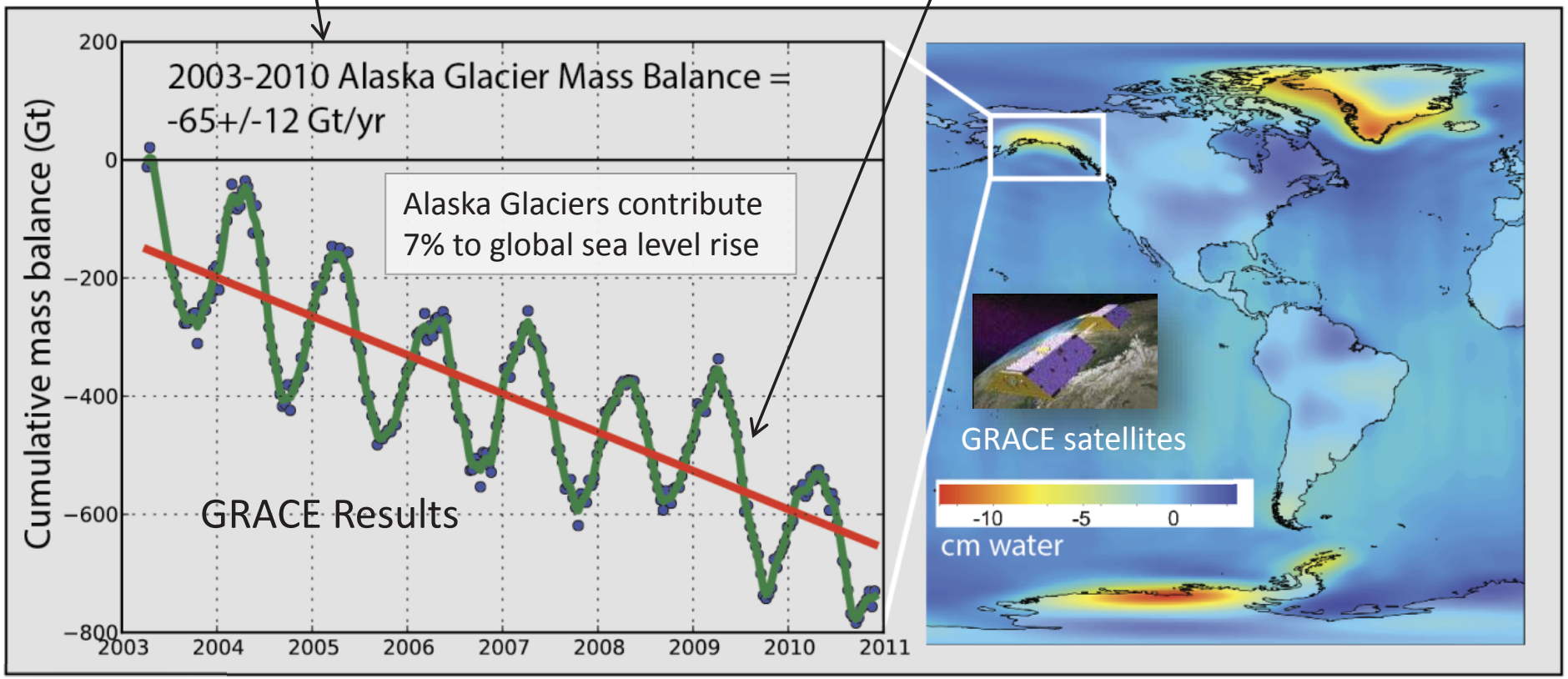
Launch planned in 2017

Recent Results: Loss of ice from Alaska's glaciers

Analysis of a GRACE global mascon solution for Gulf of Alaska glaciers;
Arendt, Luthcke, Gardner, O'Neel, Hill, Moholdt, Abdalati J. Glac. Vol 59 (217), 2013

2003-2010 glacier mass balance calculated by ICESat (-61+/-11 Gt/yr) matches GRACE result

large summer 2009 losses due to volcanic activity (ash on glaciers): confirmed by MODIS surface albedo product

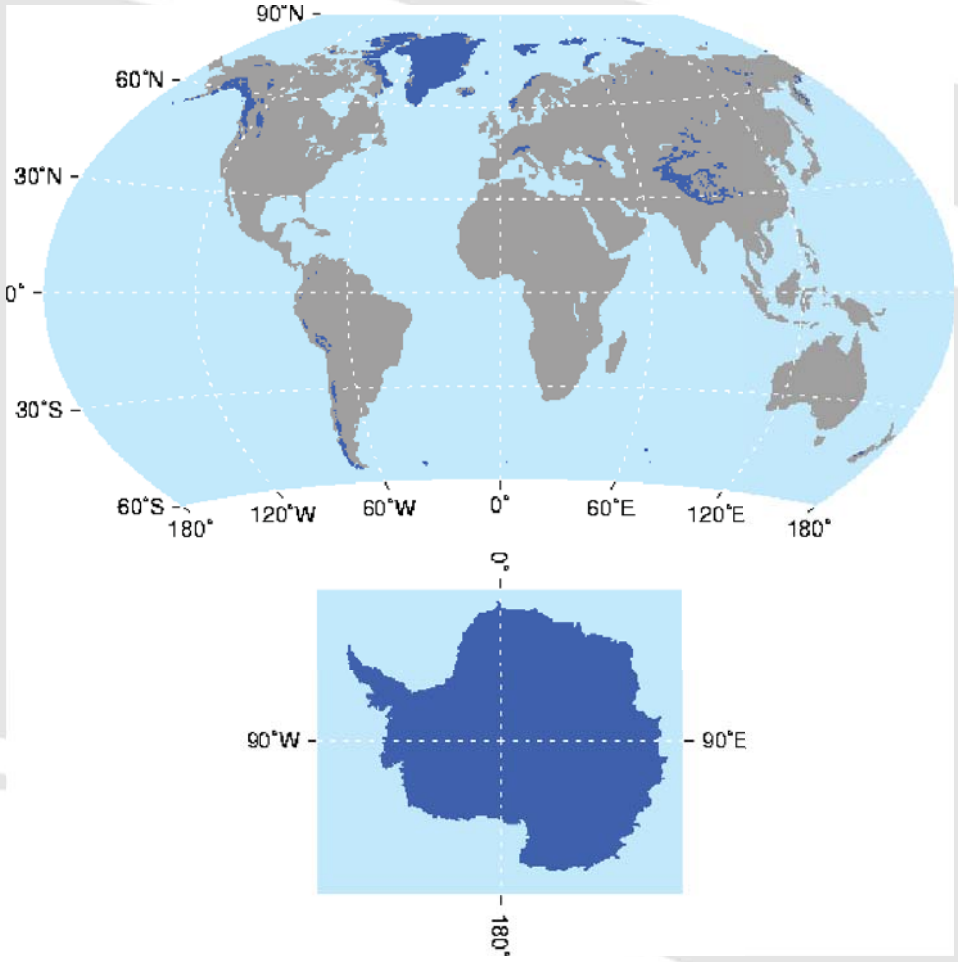


Field observations reveal how well GRACE represents sub-regions of Alaska

MODIS monthly snow-cover product explains interseasonal variability in GRACE data

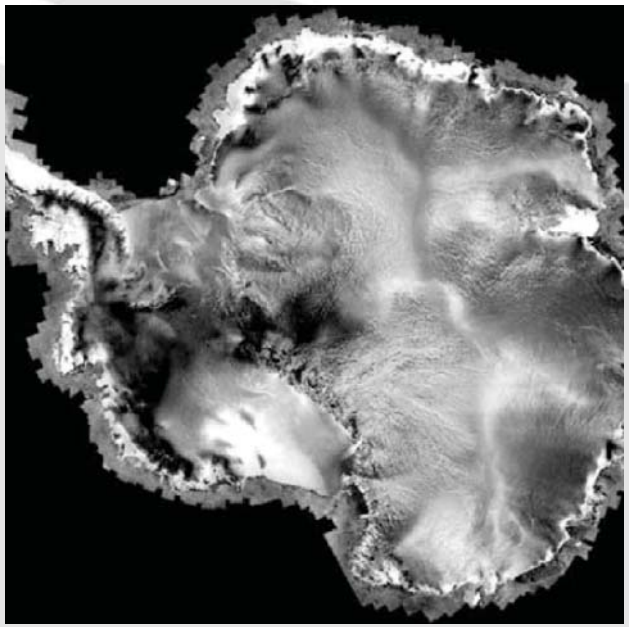
GLIMS Glacier Database

- Global Land Ice Measurements from Space (GLIMS) is a unique glacier inventory at NSIDC storing critical information about the extent and rates of change of the world's estimated 160,000 glaciers.
- Glacier analyses from ASTER and other optical satellite instruments made available using interactive mapping web site.



Alaska Satellite Facility (ASF)

- A NASA Synthetic Aperture Radar (SAR) Distributed Active Archive Center (DAAC) for sea ice, polar processes, geophysics
- Satellite data:
  - Seasat
  - RADARSAT-1
  - Advanced Land Observing Satellite (ALOS) PALSAR
  - European Remote Sensing Satellite-1, -2 (ERS-1 and -2)
  - Japanese Earth Resources Satellite-1 (JERS-1_
- Airborne mission data
  - Airborne SAR (AIRSAR)
  - Jet Propulsion Laboratory Uninhabited Aerial Vehicle SAR (UAVSAR)
- Satellite tracing and ground station capability



32

NASA's new Arctic site to help non-remote sensing scientists place change in context

Satellite records of the critical arctic variables. Some spanning three decades. Site allows users to zoom in to their area or see change across entire Arctic.

- Temperature
- Freeze thaw
- Vegetation change (NDVI)
- Water vapor
- Snow cover
- Sea ice cover
- Others in development

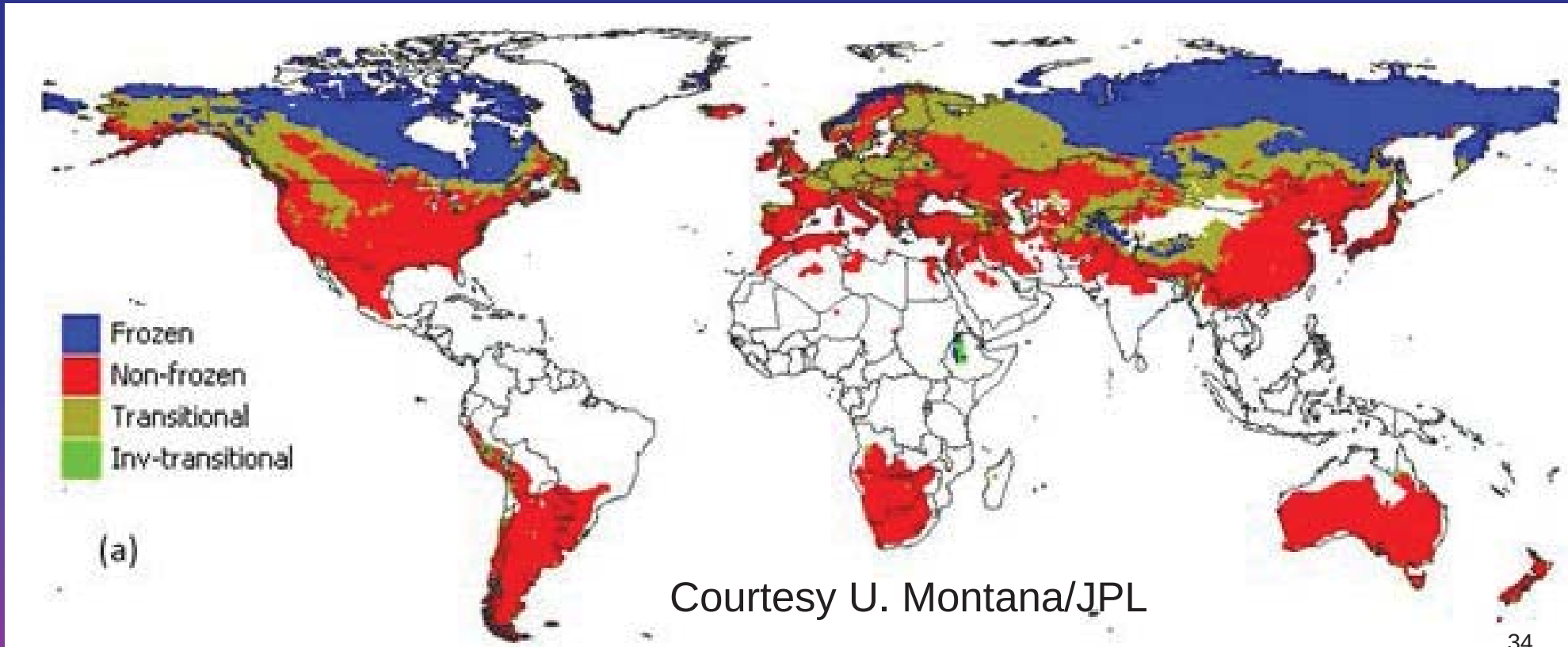
http://nsidc.org/soac

Earth System Data Records: integrating and improving usability for other disciplines

NASA has made major awards to synthesize satellite records critical to polar work, including:

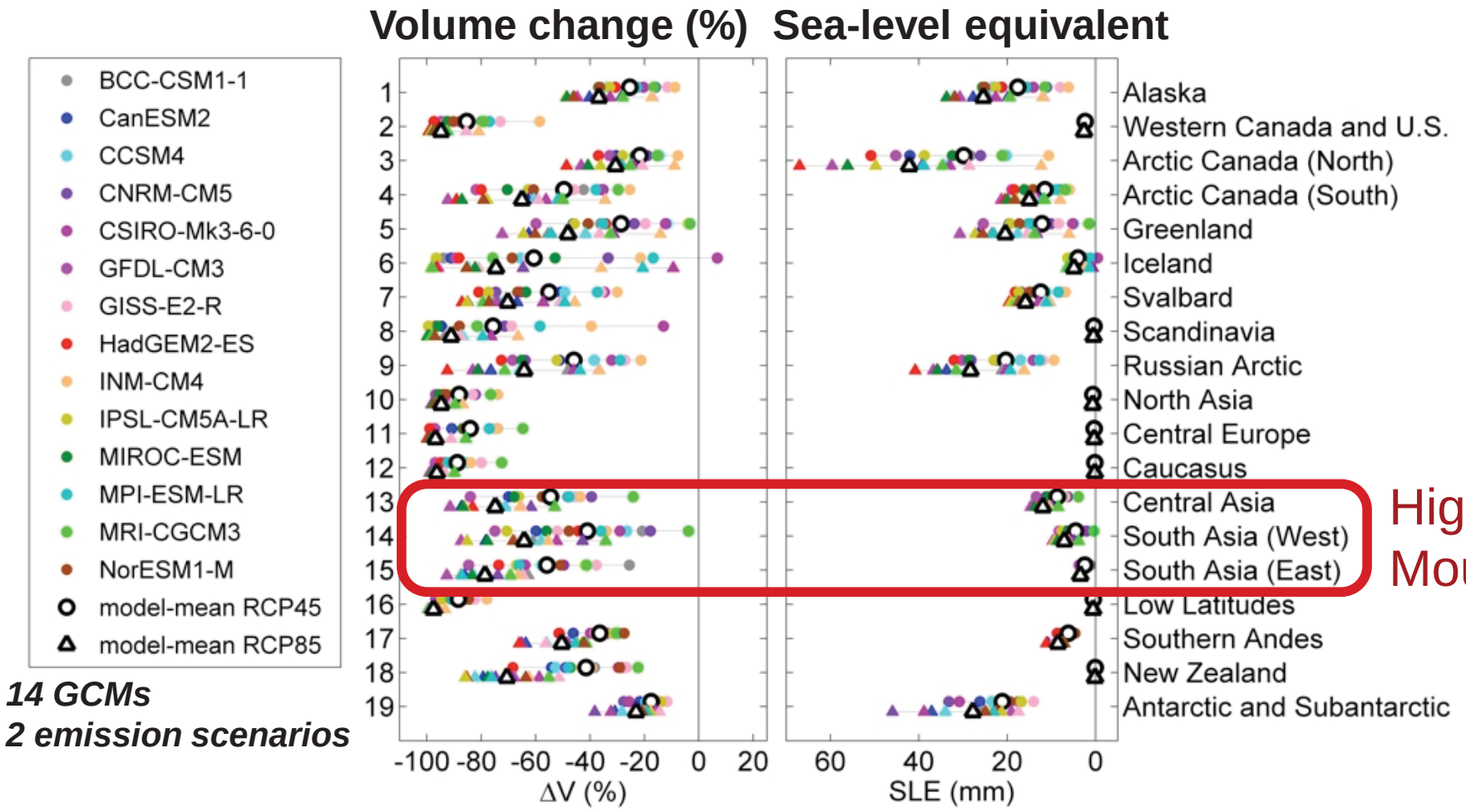
- Greenland ice sheet velocities (InSAR)
- Antarctic ice sheet velocities (InSAR)
- Arctic sea ice kinematics
- Global snow cover (30-yr record)
- Daily freeze-thaw maps (below)

Products at NSIDC



Courtesy U. Montana/JPL

Global glacier volume projections until 2100



14 GCMs
2 emission scenarios

High Asian Mountains

- **Large volume reduction for High Asian Mountain by 2100**
- **But large scatter among the GCMs indicating large uncertainty**

UAF UNIVERSITY OF ALASKA FAIRBANKS

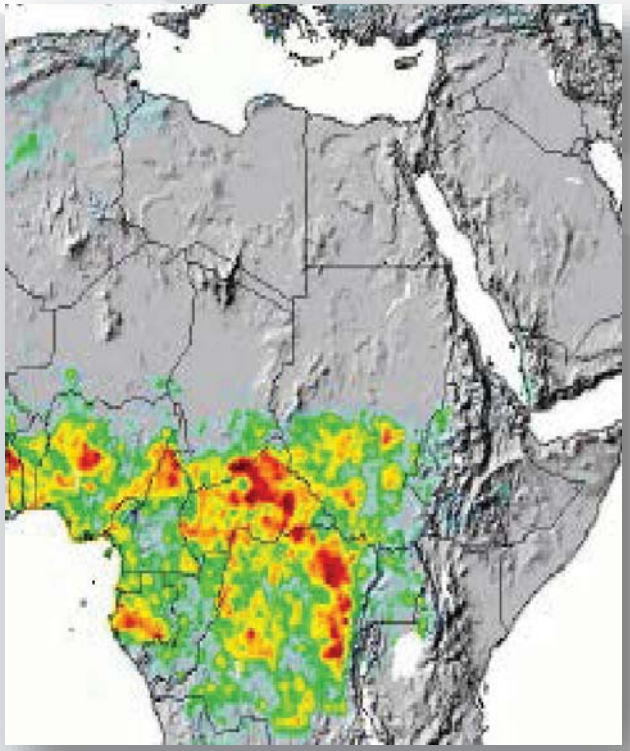
R. Hock,
A. Bliss,
C. Beedlow

NASA grants:
NNX11AF41G
09-IDS09-0114

Radić, V., A. Bliss , A. C. Beedlow, R. Hock, E. Miles and J. G. Cogley, 2013. Regional and global projections of 21st century glacier mass changes in response to climate scenarios from global climate models. *Climate Dynamics*. doi:10.1007/s00382-013-1719-7

SERVIR: What We Do

- Identify needs in SERVIR regions
- Link science products from US institutions to meet those needs through improved access to data, models, online maps, and visualizations
- Build capacity of regional institutions, stakeholders, and young professionals
- Strengthen partnerships and foster collaboration across SERVIR network

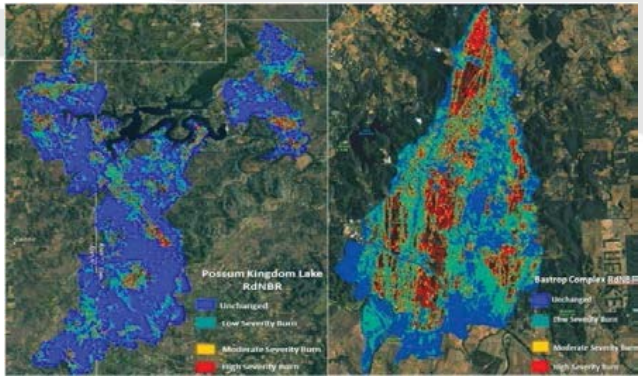


The DEVELOP National Program

The Applied Sciences' DEVELOP National Program addresses environmental and public policy issues through interdisciplinary research projects that apply NASA Earth observations to community concerns around the globe. Under the guidance of NASA and partner organization science advisors, DEVELOP teams work in alignment with local, regional, national and international partner organizations to identify the widest array of practical uses for NASA data to enhance understanding of environmental change. DEVELOP bridges the gap between NASA Earth Science and society, building capacity in both its interns and partner organizations to better prepare them to handle the challenges that face our society and future generations.

Dual Capacity Building

Young Professionals ⬅ **NASA Earth Observations** ➡ Partner Organizations



Applied Remote Sensing Training Program (ARSET)

Online and hands-on courses:

- **Who:** policy makers, environmental managers, modelers and other professionals in the public and private sectors.

  Where: U.S and internationally
- **When**: throughout the year. Check websites.
- Do NOT require prior remote- sensing background.
- Presentations and hands-on guided computer exercises on how to access, interpret and use NASA satellite images for decision-support.

NASA Training for California Air Resources Board, Sacramento