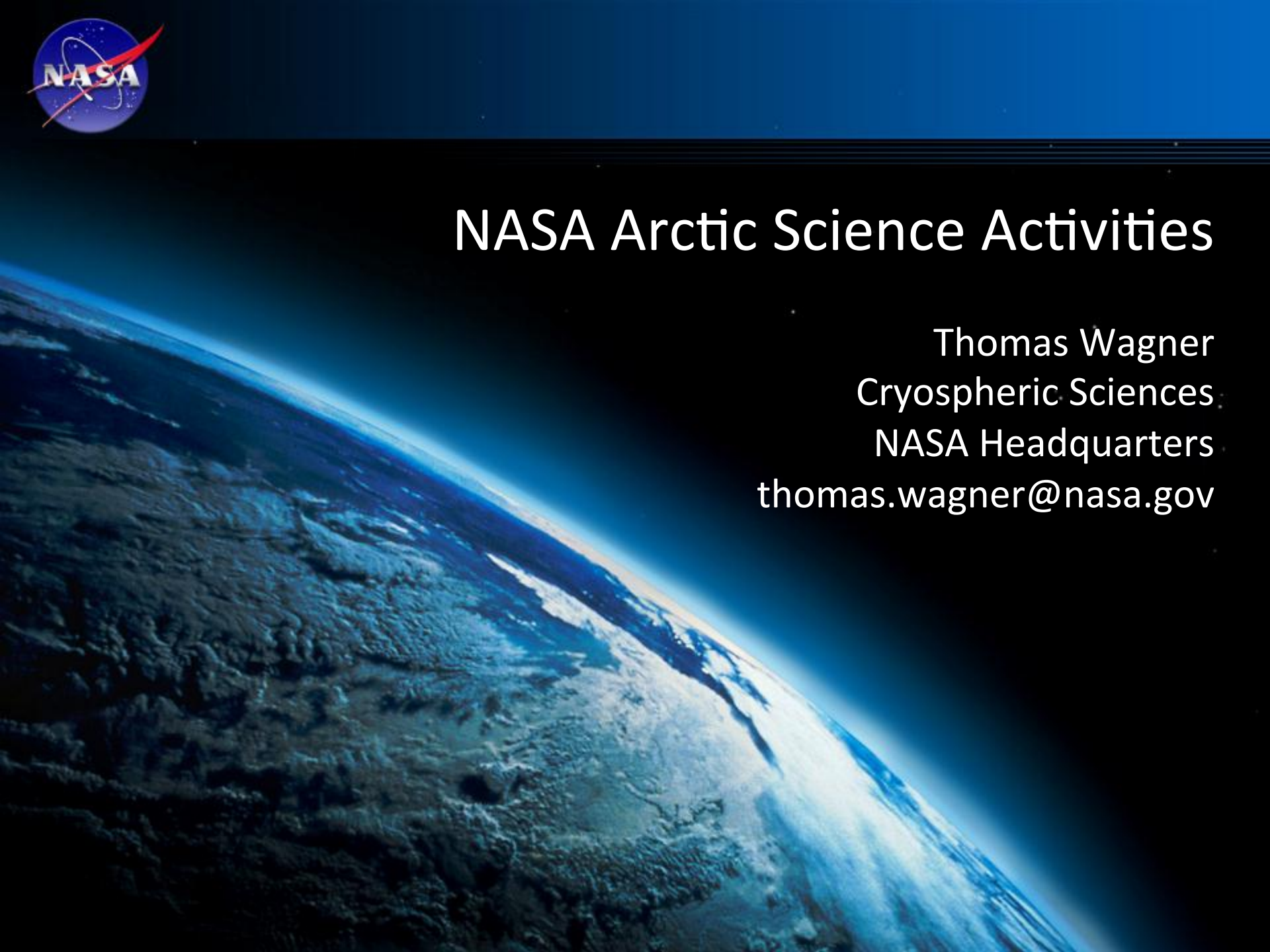
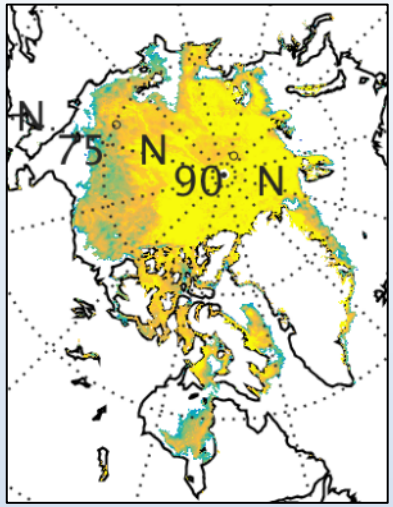


NASA Arctic Science Activities

Thomas Wagner
Cryospheric Sciences
NASA Headquarters
thomas.wagner@nasa.gov

Satellite mapping of sea ice

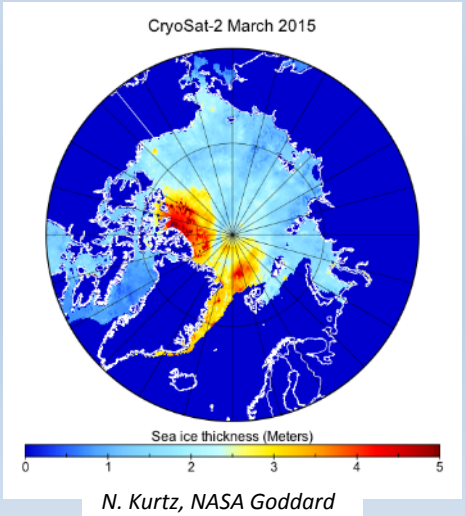


- AMSR2 products (w/ JAXA)
- Combined-sensor products (w/ ONR)
- Long-term time series continuity
- Aquarius/SMAP (thin ice)

Airborne observations of the Arctic

- IceBridge
- ARISE: Arctic Radiation – IceBridge Sea&Ice Experiment
- Sea ice and radiation, cloud, aerosol interactions
- Aug-Oct 2014
- Summer-fall transition period

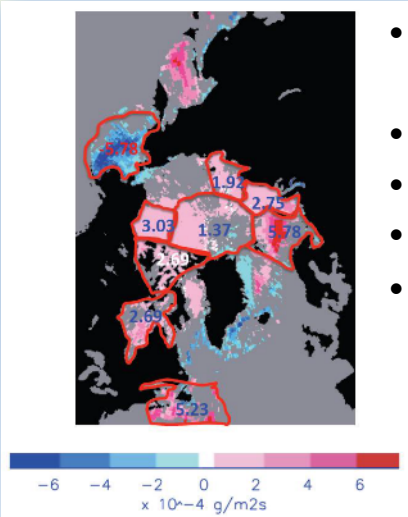
Observations linked to models



N. Kurtz, NASA Goddard

- Sea Ice Outlook
- Obs4MIPs (WCRP)
- Sea Ice MIP (CliC)
- PM extent
- CS-2/IB thickness

Atmosphere – Sea Ice Interactions



- Sea ice – atmospheric feedbacks
- Melt onset
- Moisture flux trends
- AIRS data
- MERRA reanalysis for sea ice

2003-2013 moisture flux trends
Boisvert et al., JGR, 2015


Formulation
Implementation
Primary Ops
Extended Ops
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

National Aeronautics and Space Administration

Airborne Science Program

Observing Platforms for Earth System Science Investigations

ER-2

WB-57

Global Hawk

G III

DC-8

Learjet

Ikhana

P-3

S-3B

B-200

Twin Otter

SIERRA

www.nasa.gov


IceBridge Flight Lines
Aircraft lidar mission to bridge the gap between ICESat altimetry missions (2009-2019)
North Pole
Barrow
Prudhoe Bay
Fairbanks
Alert
Eureka
Thule AB
Resolute
Kangerlussuaq
2009
2010
2011
2012
2013
2009 - 2013

Critical questions for America addressed by NASA's polar work:

- How much will sea level rise as the Earth's polar regions melt? What mitigation strategies do our coasts need?
- Will continued loss of the Arctic sea ice cap change our weather? Will it cause more drought?
  Can we inform planners now?
- What is causing such dramatic polar change? How does global climate change affect polar regions, and how, in turn does polar change influence global climate?

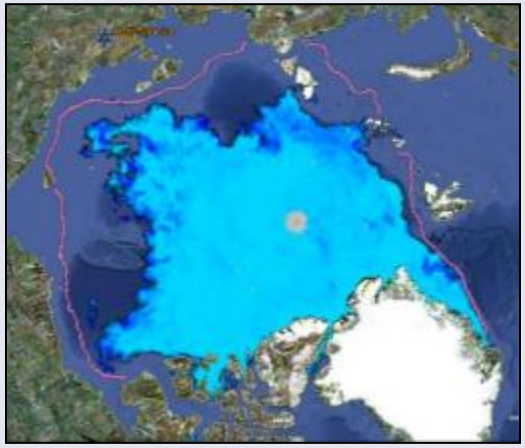
For the US, NASA makes many of the most important observations to answer these questions through satellites and aircraft

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

- **Hosts >100 Tb of data, and distributes more than double that each year**
- **Includes Earth System Data Records: integrated, multi-year to decadal datasets that improve usability for other disciplines, e.g. freeze-thaw, temp, sea ice motion**

Passive Microwave

- AMSR-E (Aqua)
- AMSR (ADEOS II)
- SMMR (Nimbus 7)
- SSM/I, SSMIS (DMSP series)



AMSR-E 12.5 km Sea Ice Concentration

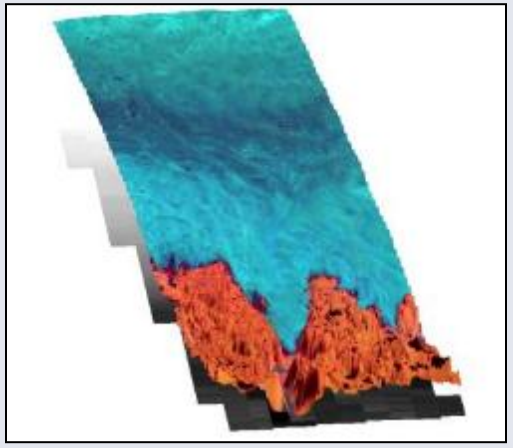
VIS/IR Moderate Resolution

- MODIS (Terra/Aqua) snow and ice products
- AVHRR polar data (NOAA series)

MODIS Monthly Global Snow Cover

Satellite & Airborne Altimetry

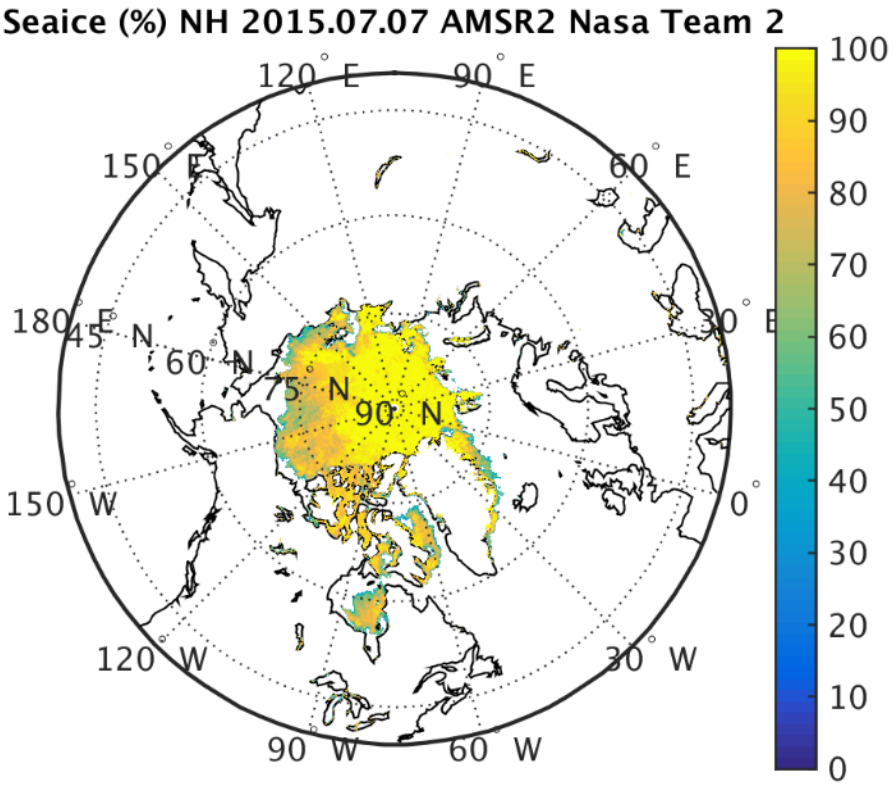
- ICESat I/GLAS altimetry and atmospheric lidar data
- Digital Elevation Models (DEMs)
- IceBridge



IceBridge ATM Qfit Data on Landsat Image

NASA AMSR2 Sea Ice

- AMSR2 launched by JAXA in May 2012, data from August 2012
- Successor to AMSR-E (operational performance ceased October 2011)
- NASA Science Team developing NASA products for continuity with AMSR-E products
- Intercalibration of sea ice concentration via comparisons with limited AMSR-E overlap data and SSMIS estimates
- Soon to be implemented in NRT in NASA LANCE system
- Version also being implemented by NOAA NESDIS for operations; now being run in preliminary mode at NOAA CIMSS/Univ. Wisconsin



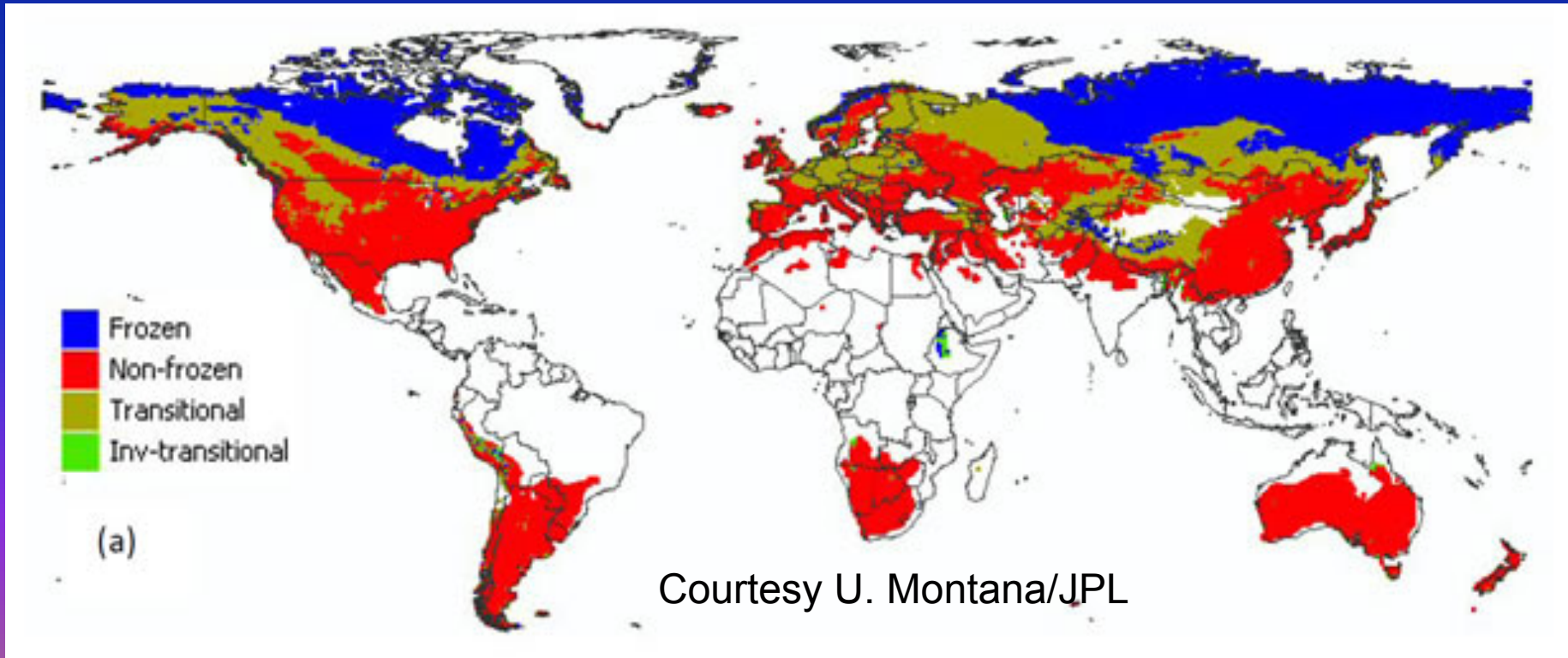
From J. Key and Y.-K. Lee
NOAA NESDIS/Univ. Wisconsin
http://stratus.ssec.wisc.edu/cgi-bin/amsr2snow_main

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)

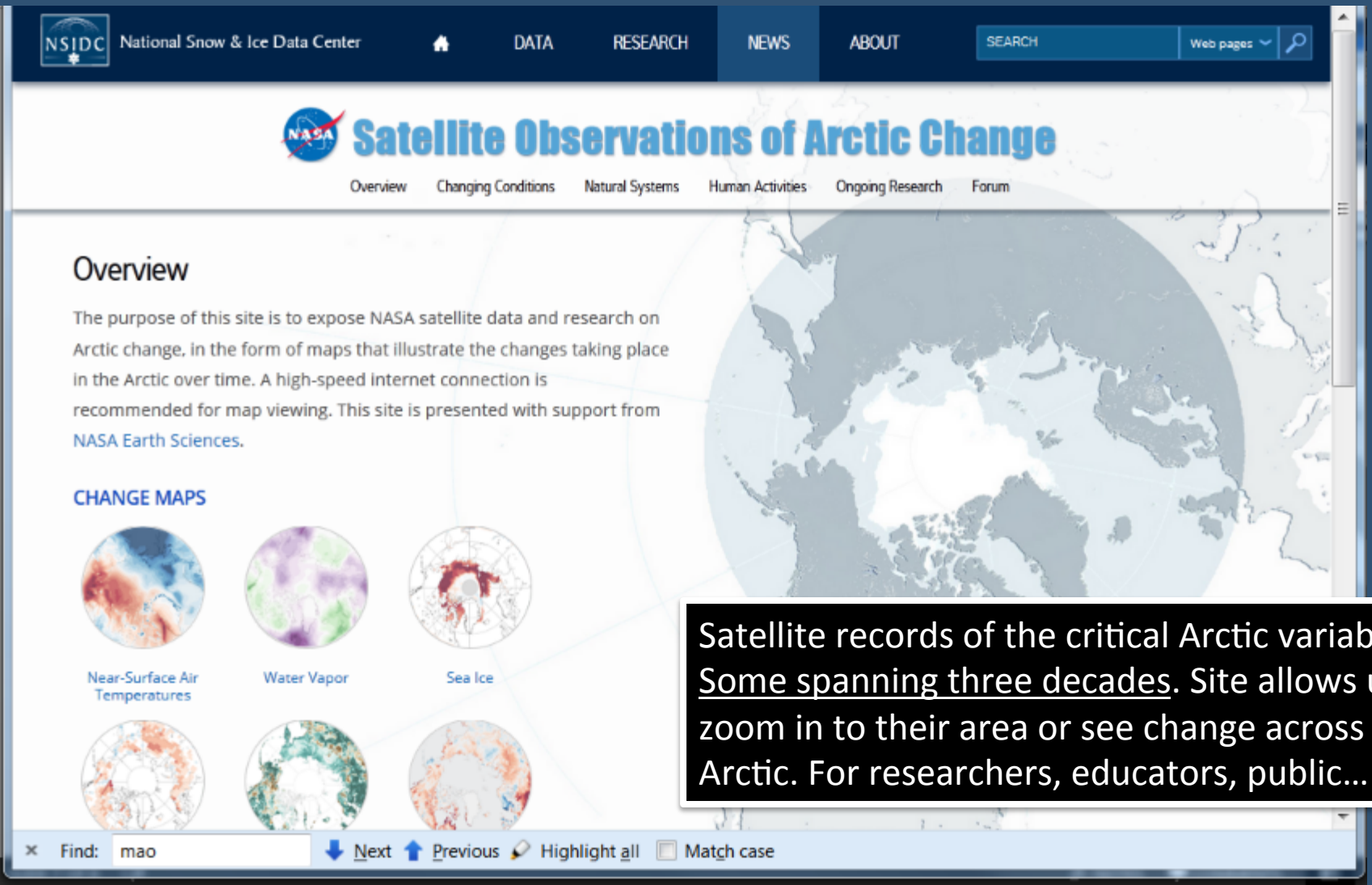
Products at NSIDC



Courtesy U. Montana/JPL

Putting change in context: nsidc.org/soac

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



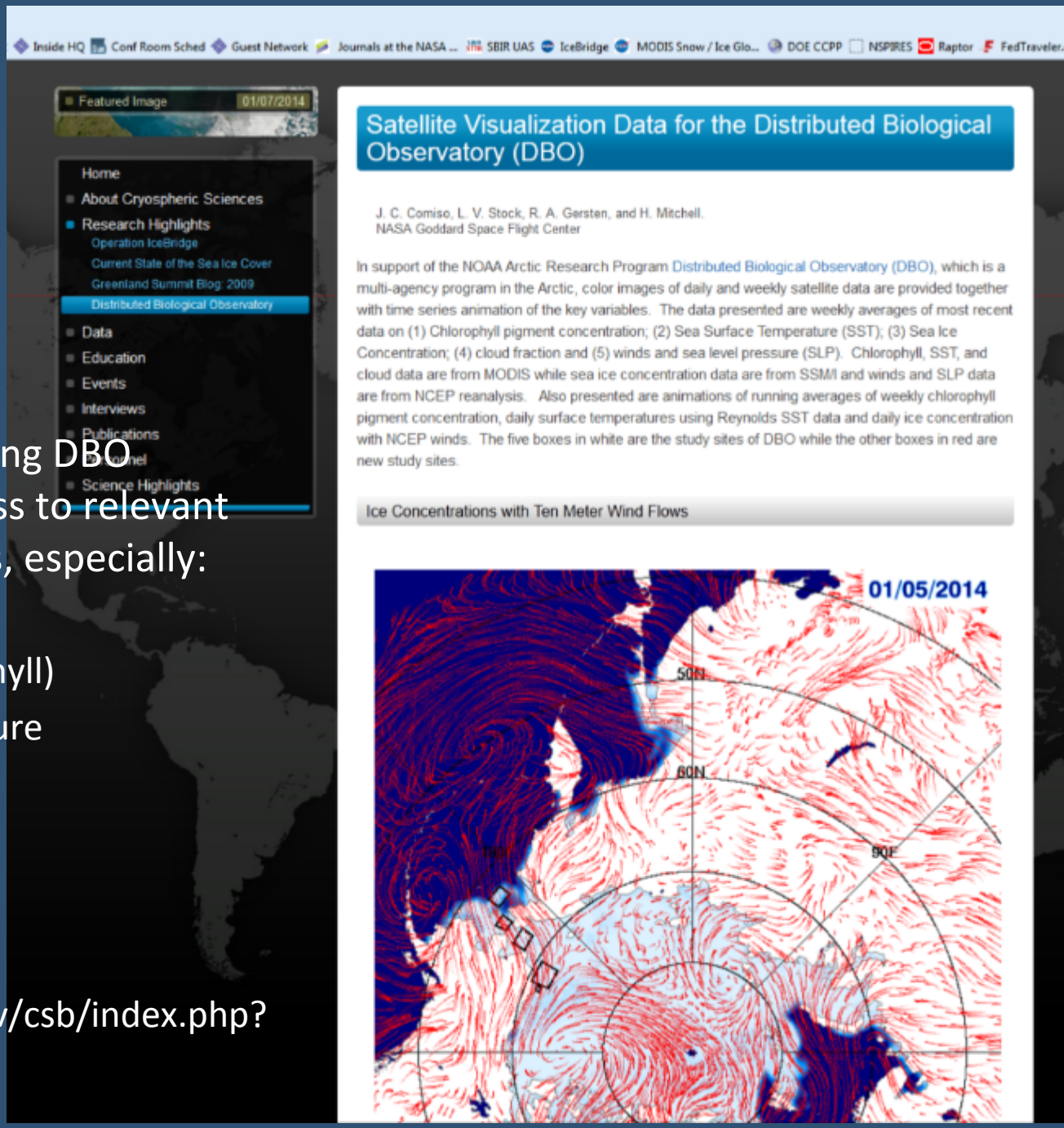
Satellite records of the critical Arctic variables. Some spanning three decades. Site allows users to zoom in to their area or see change across entire Arctic. For researchers, educators, public…

NASA's new site to support the Arctic *Distributed Biological Observatory (DBO)*

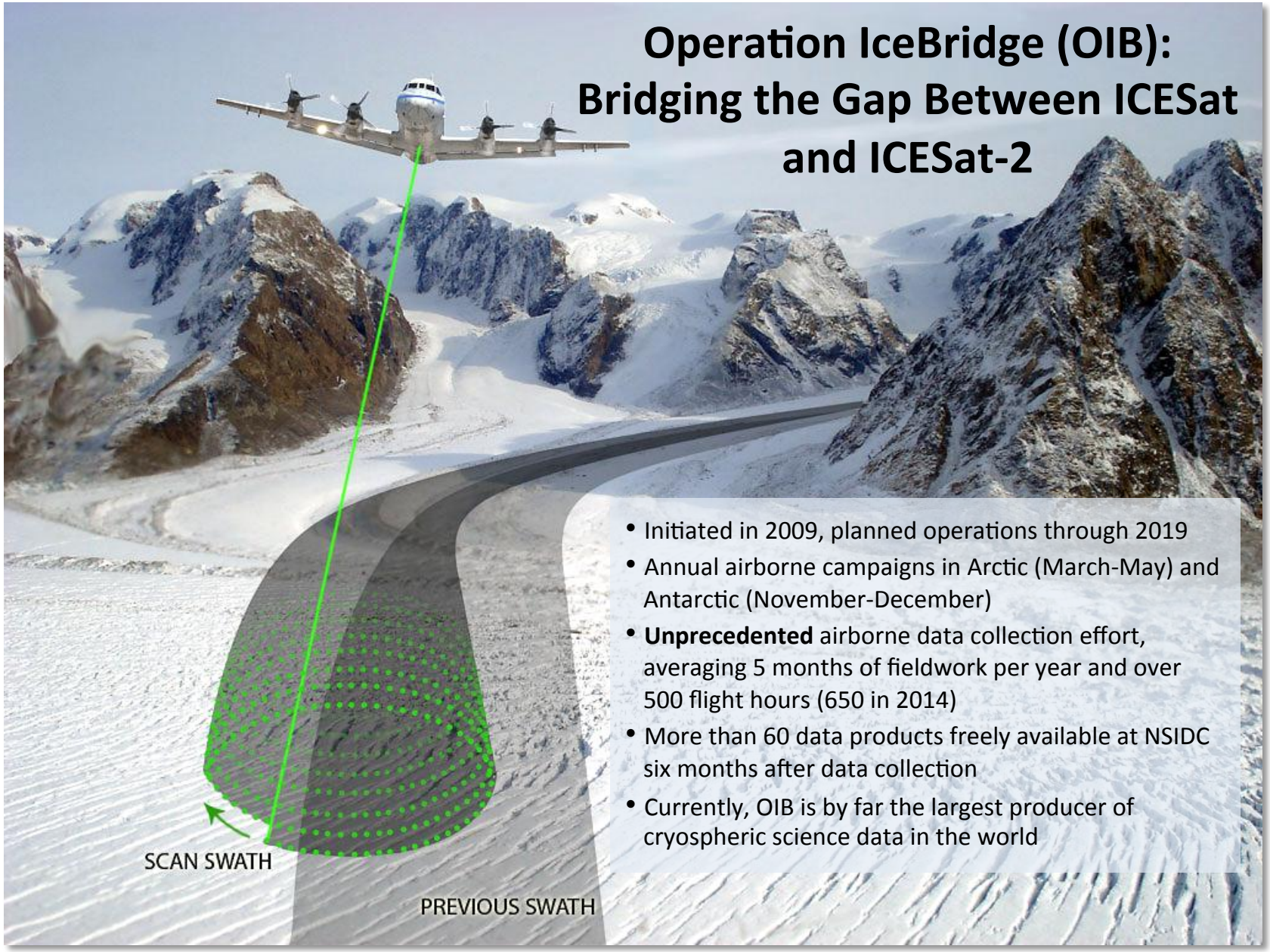
Allows researchers making DBO observations quick access to relevant remote sensing datasets, especially:

- Windspeed
- Ocean color (Chlorophyll)
- Sea surface temperature
- Sea ice concentration
- Cloud cover
- Surface pressure

http://neptune.gsfc.nasa.gov/csb/index.php?section=270



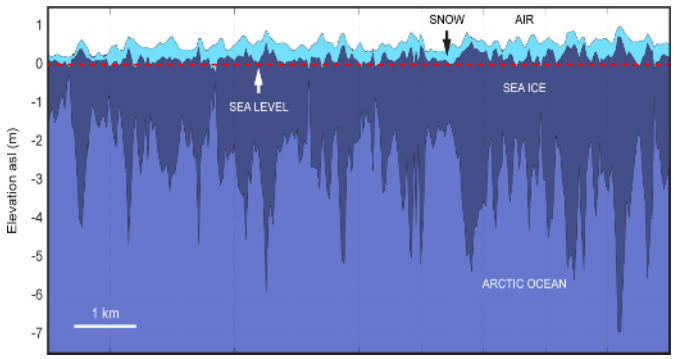
Operation IceBridge (OIB): Bridging the Gap Between ICESat and ICESat-2



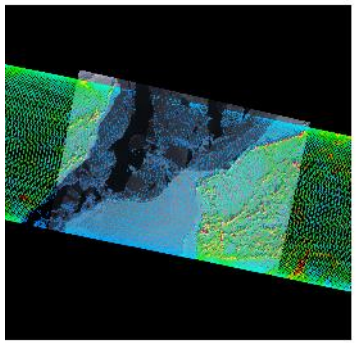
- Initiated in 2009, planned operations through 2019
- Annual airborne campaigns in Arctic (March-May) and Antarctic (November-December)
- **Unprecedented** airborne data collection effort, averaging 5 months of fieldwork per year and over 500 flight hours (650 in 2014)
- More than 60 data products freely available at NSIDC six months after data collection
- Currently, OIB is by far the largest producer of cryospheric science data in the world

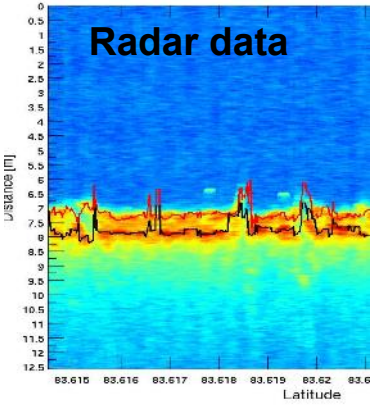
Operation IceBridge 2009-present

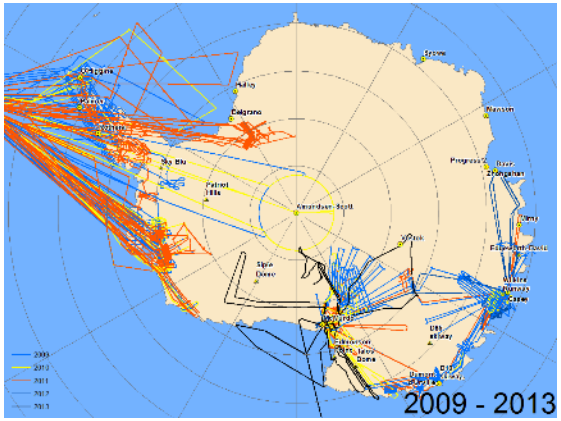
- Snow surface freeboard data from ATM and LVIS laser altimeter systems to bridge the gap between ICESat and ICESat-2 missions
- CReSIS snow radar for measuring snow thickness
- High resolution visible imagery from DMS camera system
- New surface temperature measurements from KT-19 pyrometer and high resolution thermal IR camera, new spectrometer for determine albedo
- Results: First maps of snow thickness over Arctic sea ice; annual measurements of sea ice thickness
  - Science flights with multiple platforms (P-3, DC-8, B-200, HU-25, Basler BT-67, Single Otter, GV, C-130); more than 19 instruments
  - Total science flights: 498
  - Total science flight hours: 2400+

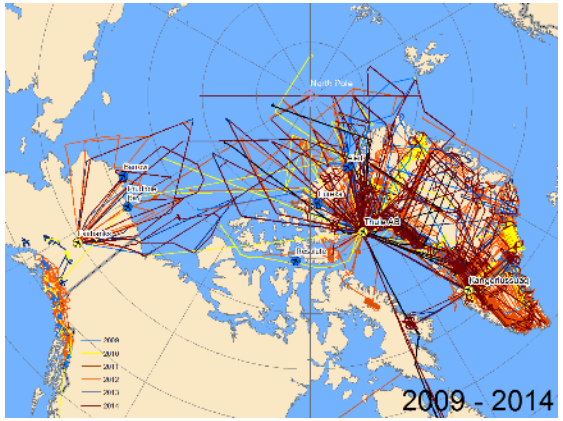


Imagery and lidar data



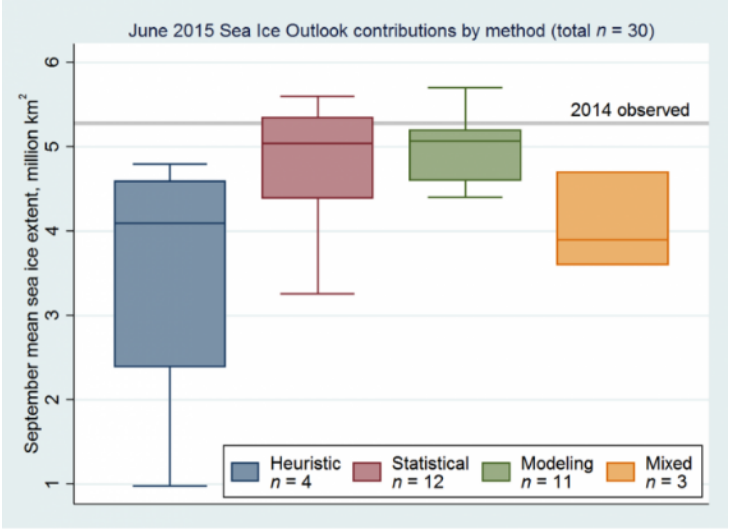






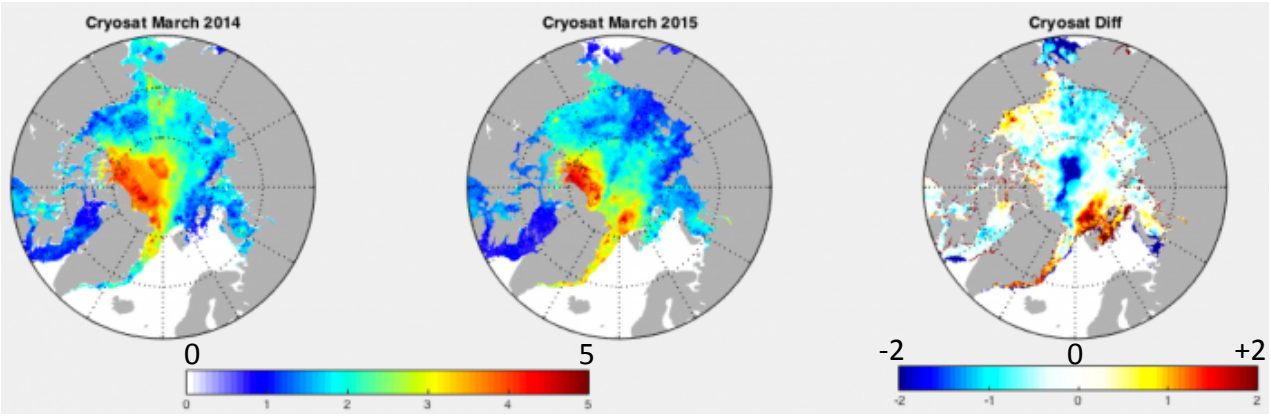
Sea Ice Prediction Network

- Sea Ice Outlook June report published 24 June
- 32 contributions
- NASA sea ice thickness estimates for March/April 2015 from CryoSat-2 and IceBridge provided at end of May for initialization



Distribution of contributions (2 late contributions not included)
http://www.arcus.org/sipn/sea-ice-outlook/2015/june

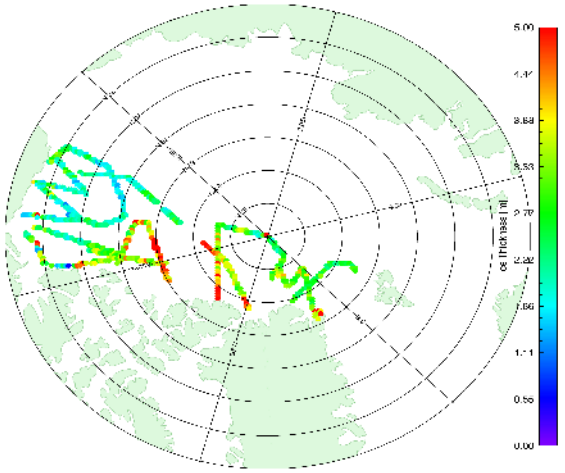
CryoSat-2 sea ice thickness
N. Kurtz (NASA Goddard)
http://nsidc.org/data/docs/daac/icebridge/evaluation_products/cryosat-2-sea-ice-frebrd-thick-snowdepth-quicklook-index.html



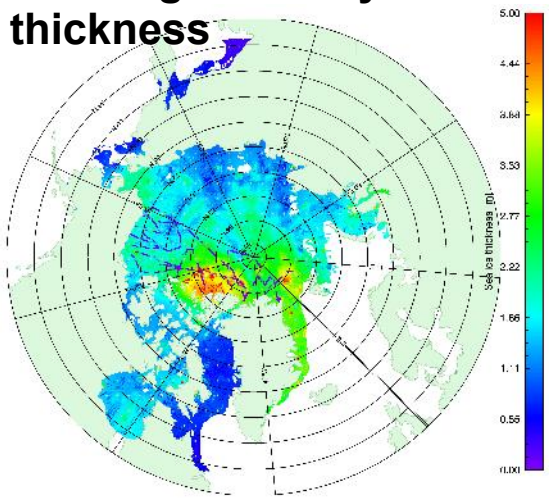
Availability of near real-time Arctic sea ice thickness results from IceBridge and CryoSat-2

March 2015 Results

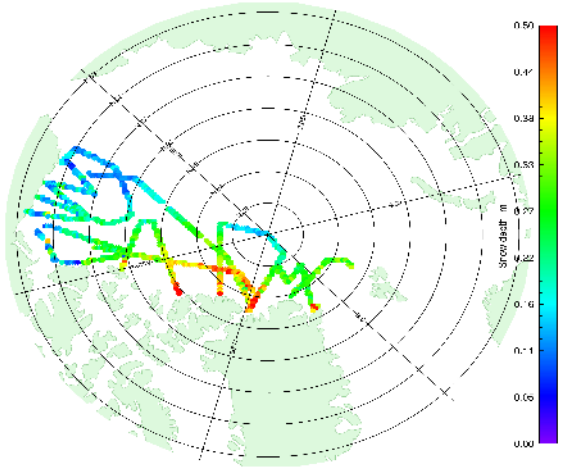
IceBridge sea ice thickness



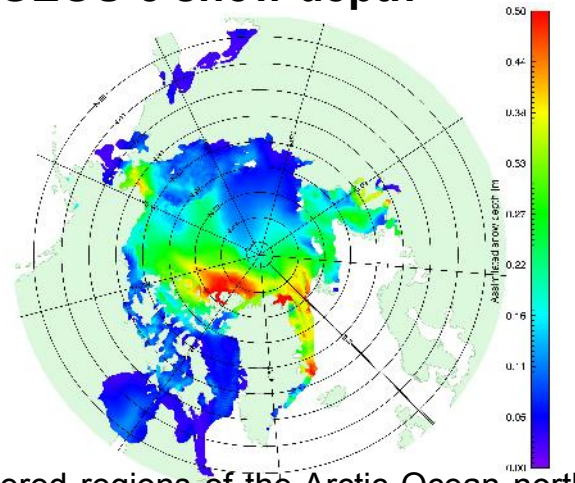
IceBridge and CryoSat-2 sea ice thickness



IceBridge snow depth



Assimilated IceBridge and GEOS-5 snow depth

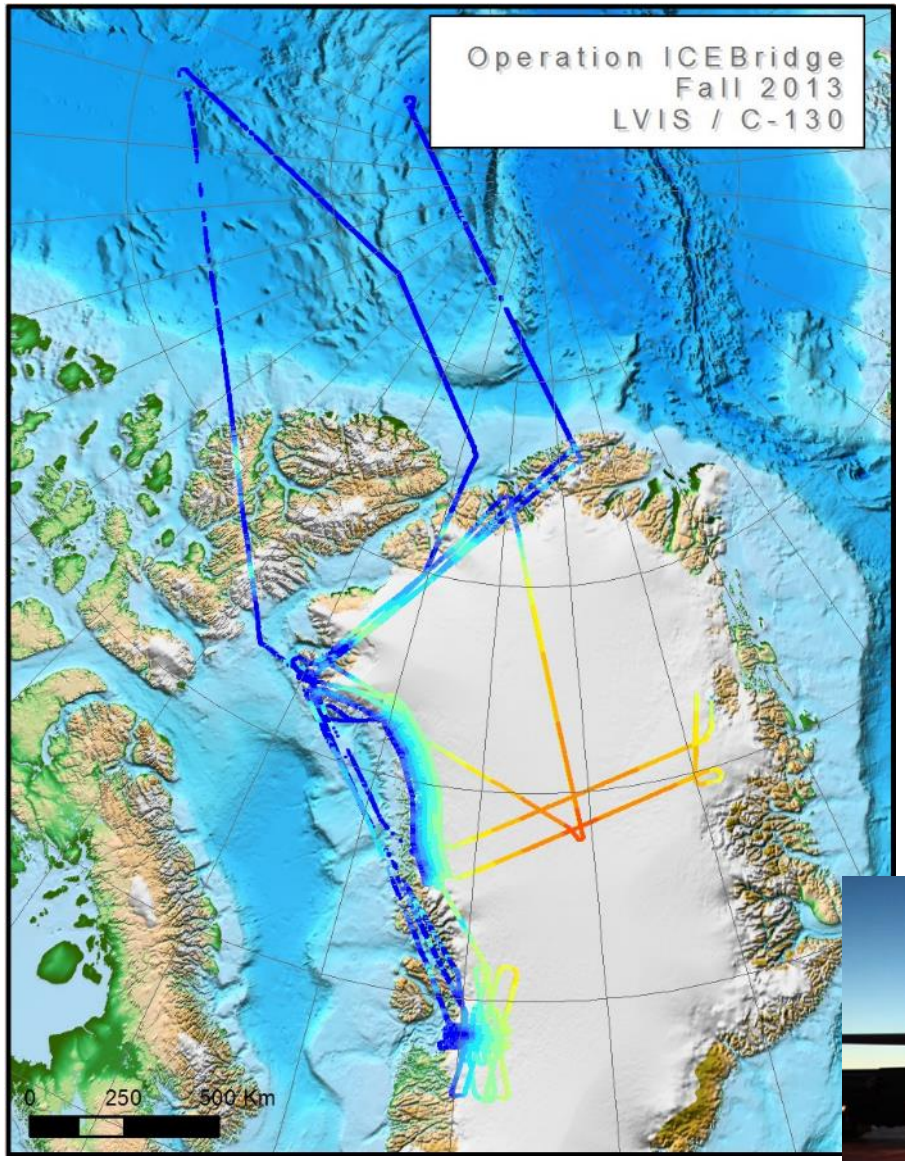


Combined IceBridge and CryoSat-2 sea ice thickness and snow depth fields available in May of each year to support seasonal prediction efforts:

http://nsidc.org/data/icebridge/evaluation-products.html

Thick ice can be seen in the perennially covered regions of the Arctic Ocean north of Greenland and Canada, while thinner seasonal ice surrounds the perennial ice regions and extends outward from the Arctic Ocean. The dashed purple lines in the central Arctic Ocean are the flight tracks of the Operation IceBridge campaign which was collecting data during the same time period. The two data sets provide complementary input and quality assurance of the final derived sea ice thickness data set.

OIB Arctic Melt Season Campaign: October-November 2013



- Fall 2013 LVIS/C-130 Greenland mission completed in mid-November.
- 3 week mission, based out of Thule in Greenland.
- 9 science flights (2 sea ice, 7 land ice)
- Collected 68,000 km^2 of elevation data.
- Two instruments (LVIS and LVIS-GH) were flown, measuring partially overlapping swaths to increase coverage.
- Study marked the first time a single season of melting has been measured for OIB, as well as providing baseline measurements for future satellite missions.

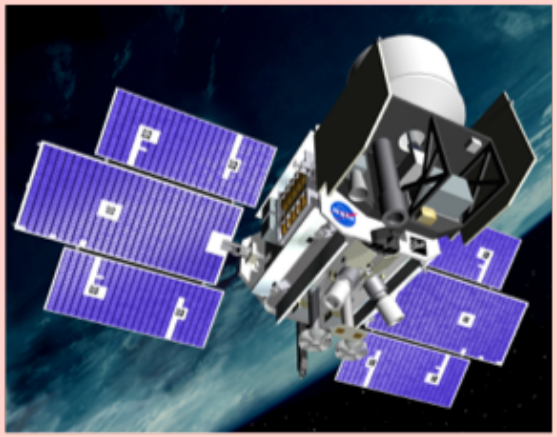
Summer/Fall 2015-Spring/Summer 2016

- Simultaneous deployments to Northern and Southern Hemisphere.
- Arctic LaRC HU-25C Falcon deployment out of Thule AFB, Greenland.
  - ATM, DMS
- Antarctica NCAR G-V based out of Punta Arenas, Chile.
  - LVIS, DMS
- Spring deployment on WFF C-130 for snow and sea ice thickness measurements
- Seasonal 'melt' deployment tentatively scheduled for WFF C-130 July/August 2016.
  - Large-scale melt pond measurements: area, depth?
  - Ice thickness and surface temperature measurements to determine the role of oceanic and atmospheric forcings
  - Provide baseline data set for ICESat-2 melt season measurements

ICESat-2: Next Generation Laser Altimetry from Space

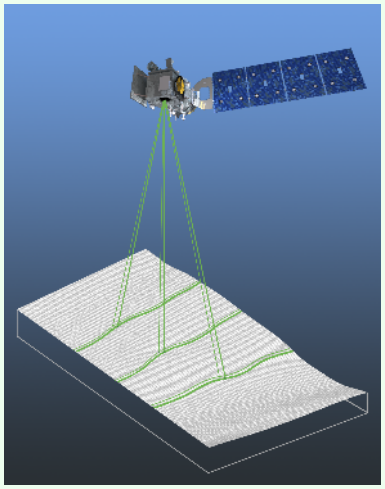
Ice, Cloud and land Elevation Satellite (ICESat)

- Operated 2003-2010
- Near-polar orbit, ~600 km altitude
- 94-degree inclination (max latitudes of +/- 86 degrees)
- 33-day campaigns, 2-3 times per year



Geoscience Laser Altimeter System (GLAS)

- Single beam, 1064 nm (near-infrared)
- Laser fired 40 shots per second
- Spots on surface 70 m in diameter, 170 m separation
- Full waveform receiver
- Campaign-mode + single beam limited slope determination



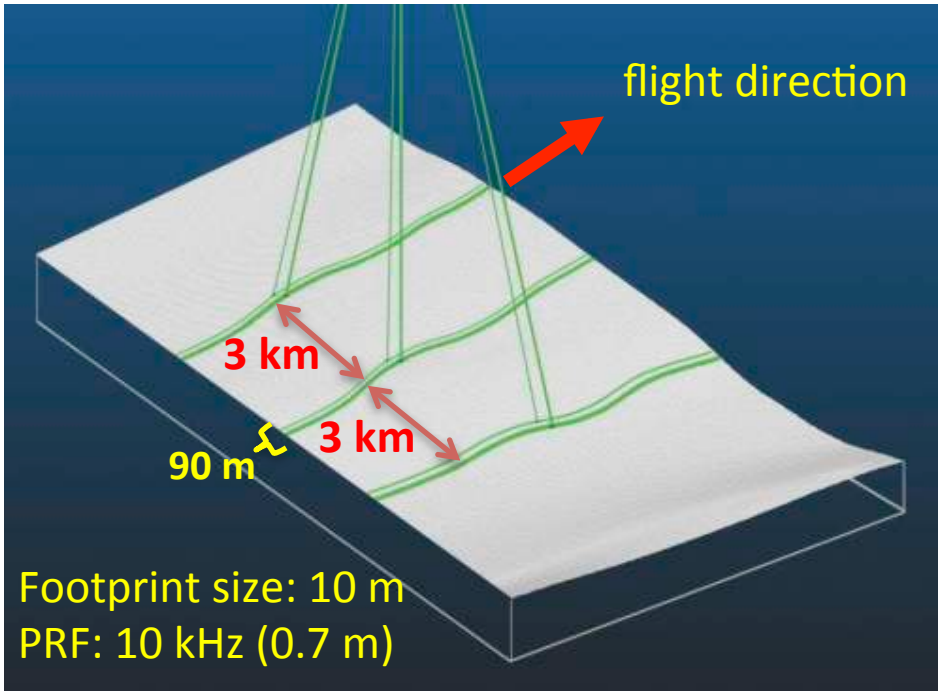
ICESat-2

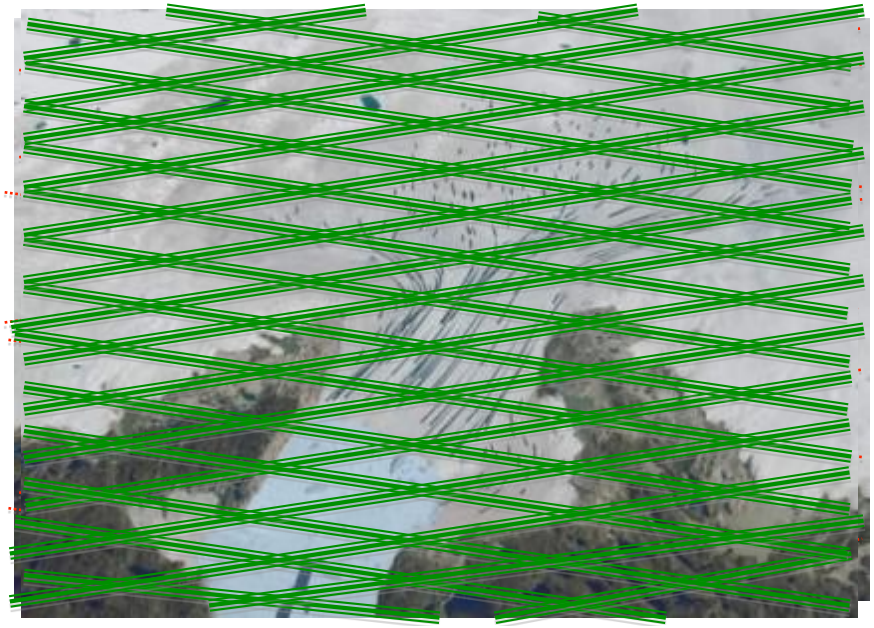
- Scheduled for launch in 2017
- Near-polar orbit, ~500 km altitude
- 92-degree inclination (max latitudes of +/- 88 degrees)
- Year-round operation planned

Advanced Topographic Laser Altimeter System (ATLAS)

- Six beams, 532 nm (green)
- Single laser fires 10,000 shots per second, split into six beams
- Spots on surface 17 m in diameter, 70 cm separation
- Photon-counting detectors
- Beam pairs allow direct local slope determination

ICESat-2 measurement concept and coverage





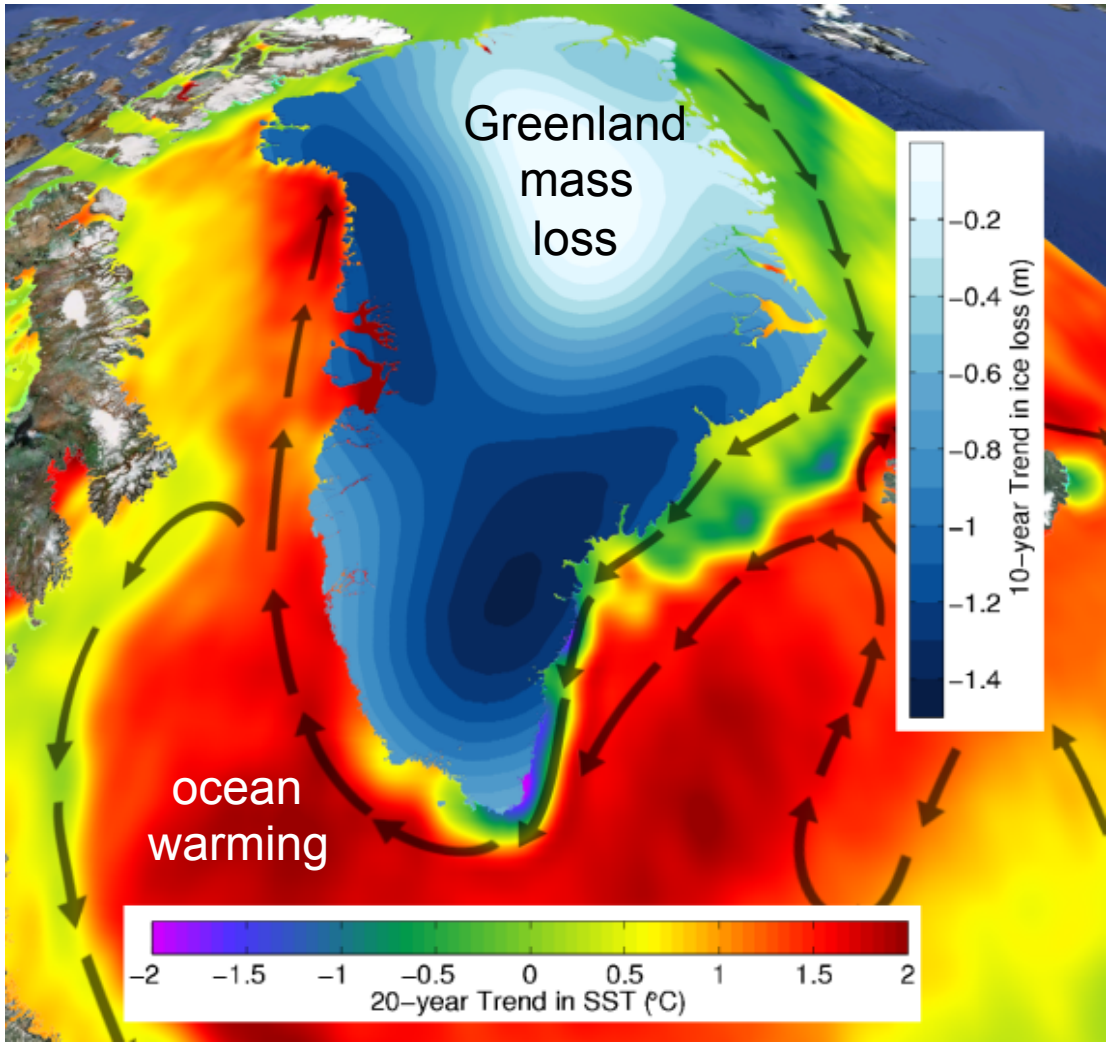
Planned ICESat-2 coverage over outlet glacier (~10 km)

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

OMG: Oceans Melting Greenland

How much are the Oceans Melting the Greenland Ice Sheet?



Sub-surface warm water melts glaciers that reach the oceans

Ocean Obs: Track spread of warm water

Can we relate these?

Ice Obs: Quantify glacier loss

OMG: Oceans Melting Greenland

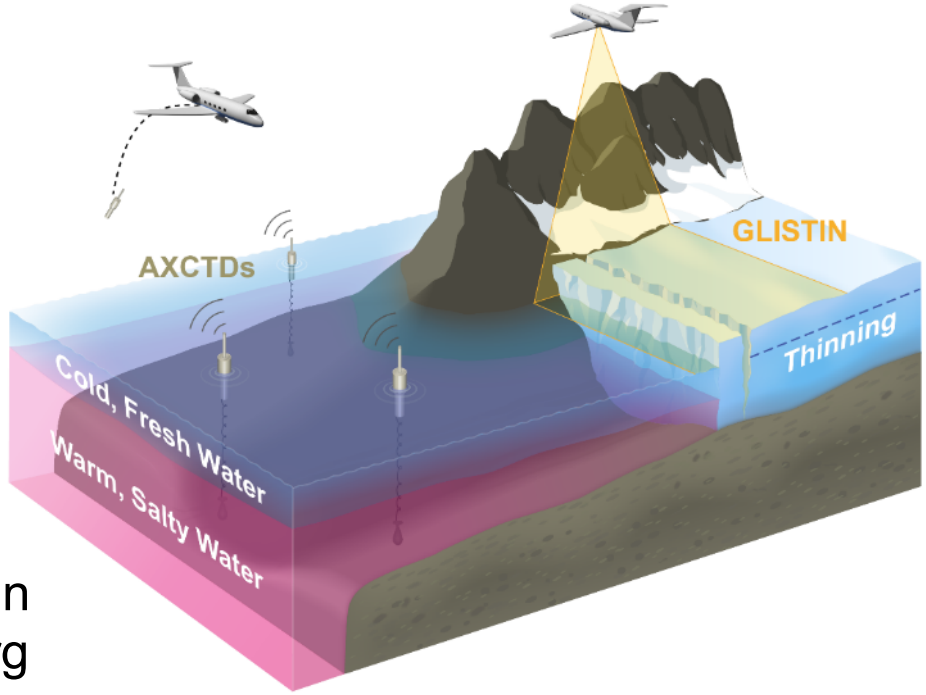
Josh Willis (PI)

Deputy PI: Eric Rignot
Proj. Manager: Steve Dinardo

Ocean: Ian Fenty, Jamie Morison, David Holland, Ichiro Fukumori, Andrew Thompson

Ice: Ala Khazendar, Delwyn Moller

Bathymetry: Michael Schodlock, Martin Jakobsson, Kristy Tinto, René Forsberg



$30 M over 5 years will fund 4 observational campaigns:

Ocean	Ice	Bathy	Bathy
• 5 years • ~250 AXCTDs/yr	• 4 years • GLISTIN radar: 10 km swath at terminus of 90% of all MTG	• One time • Ship survey with multibeam sonar for key, unmapped fjords	• One time • Airborne gravity survey of shelf

Questions:

- How do we encourage broader use of remote sensing and modeling for polar science?
- How do we develop as a community of Arctic scientists to support national and scientific needs?
- How do we approach the next great questions polar science?

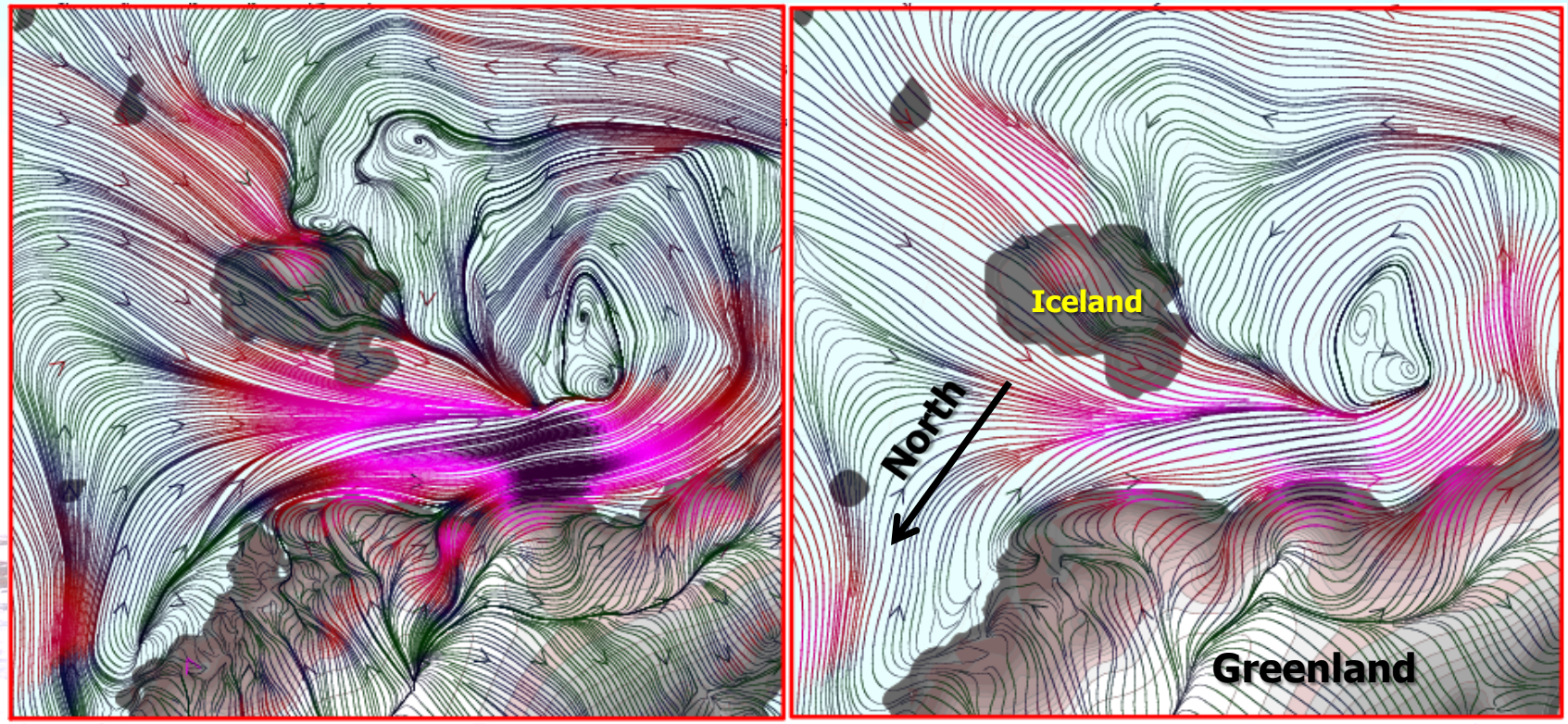
Improving Arctic Forecasts: The Role of Reanalysis

The Need

- The IARPC collaboration teams and the AESC gap analysis are highlighting the urgency of improved forecasts.
- Reanalyses (e.g. NOAA/NCEP's CFS, NASA's MERRA) merge observations and physics through models to describe past weather/climate.
- Products from reanalyses provide pan-Arctic insight on critical properties—e.g. temperature, wind, precipitation—that are poorly measured in situ. They are used by both operational and research agencies to aid in forecasts of everything from risk to weather to ice mass change.
- Arctic reanalyses suffer from a lack of both data and insight into physical processes, such as cloud formation and properties. A goal of improving reanalyses could guide Arctic observations.

ASR Data Assimilation Result: 10 m Wind

Intense Barrier Wind in Denmark Strait @ 15 km



ASR 15km **ASR 30km**

Wind Speed
m/s

3 6 9 13 16 20 23

03UTC Mar 03, 2007

Recommended Actions from IARPC

IARPC develop a limited term, cross-cutting team called SIRTA: Systematic Improvements to Reanalyses of The Arctic

- Chaired by NOAA and NASA; DOE, NSF, ONR engaged
- Composed of key members of the following IARPC CTs: AOS-Atmo-Modeling-Sea Ice
- Other agencies invited to send representatives as interested

SIRTA's tasks:

- Evaluate the state, utilization, limitations and potential utility of the current Arctic reanalyses
- Inventory and assess the currently planned operational and experimental observations of the Arctic system to improve reanalyses
- Examine reanalyses products and forecast models for potential improvement
- Assess the potential utility of YOPP and CMIP6 as focal points to facilitate progress

SIRTA outcomes to be reported to the IARPC principals for routing to the AESC

In Situ Cloud Measurements During ARISE

- In situ cloud measurements using three cloud probes mounted to the aircraft fuselage during ARISE (Fig. 1).

- Data currently available for all flights and all instruments, though some minor revisions still needed before the data are finalized.

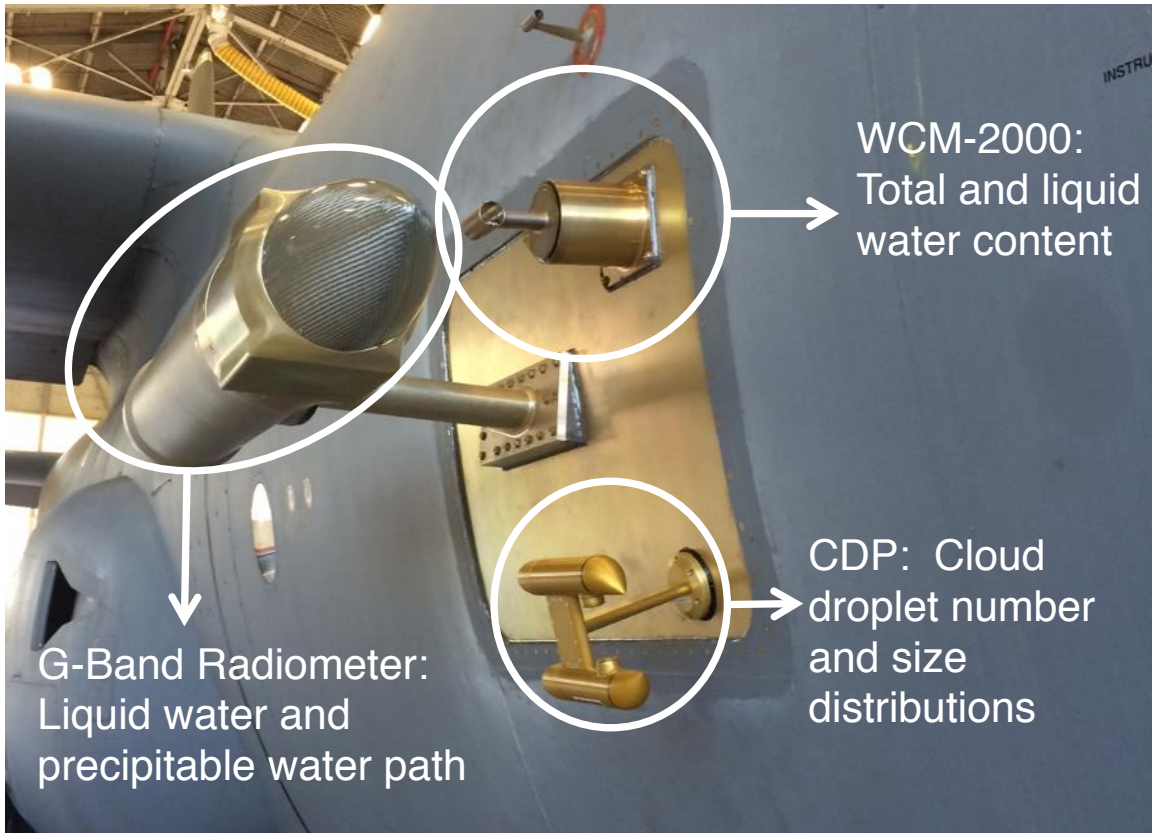
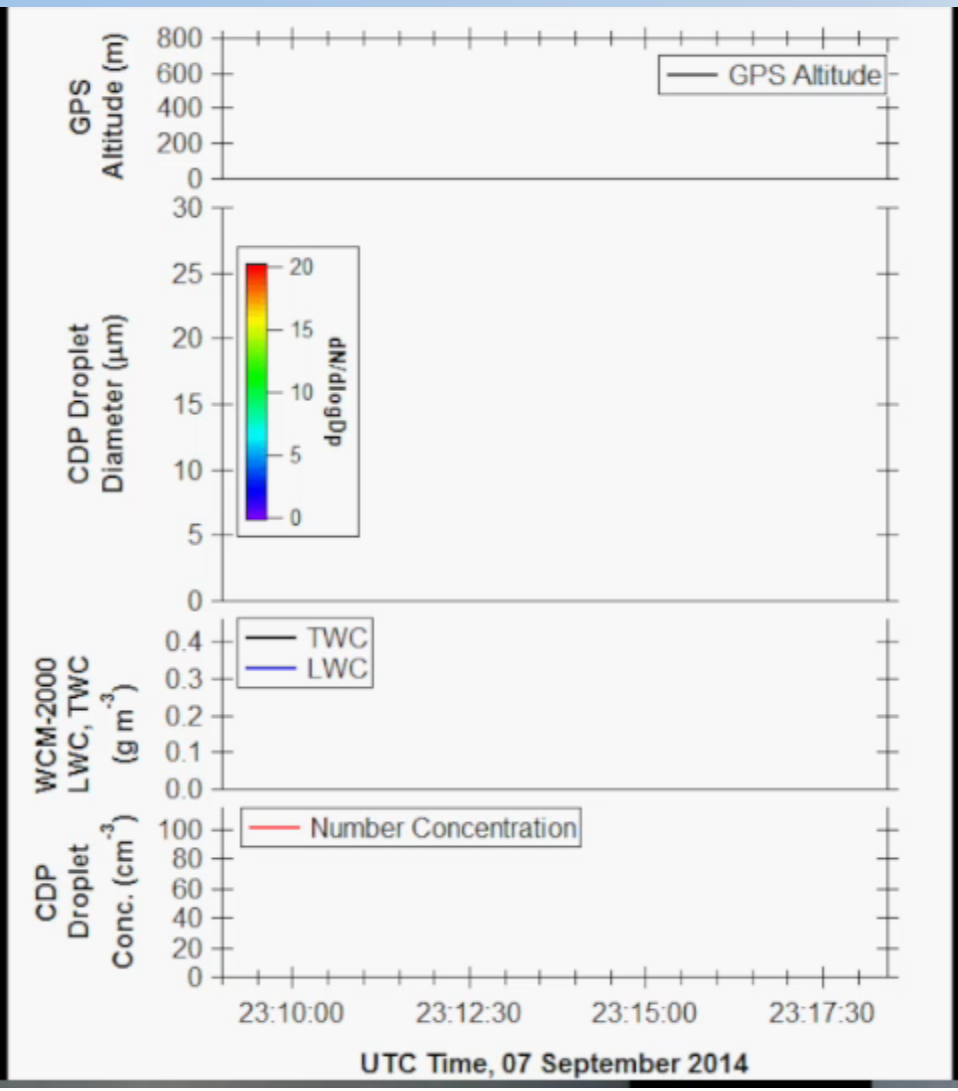
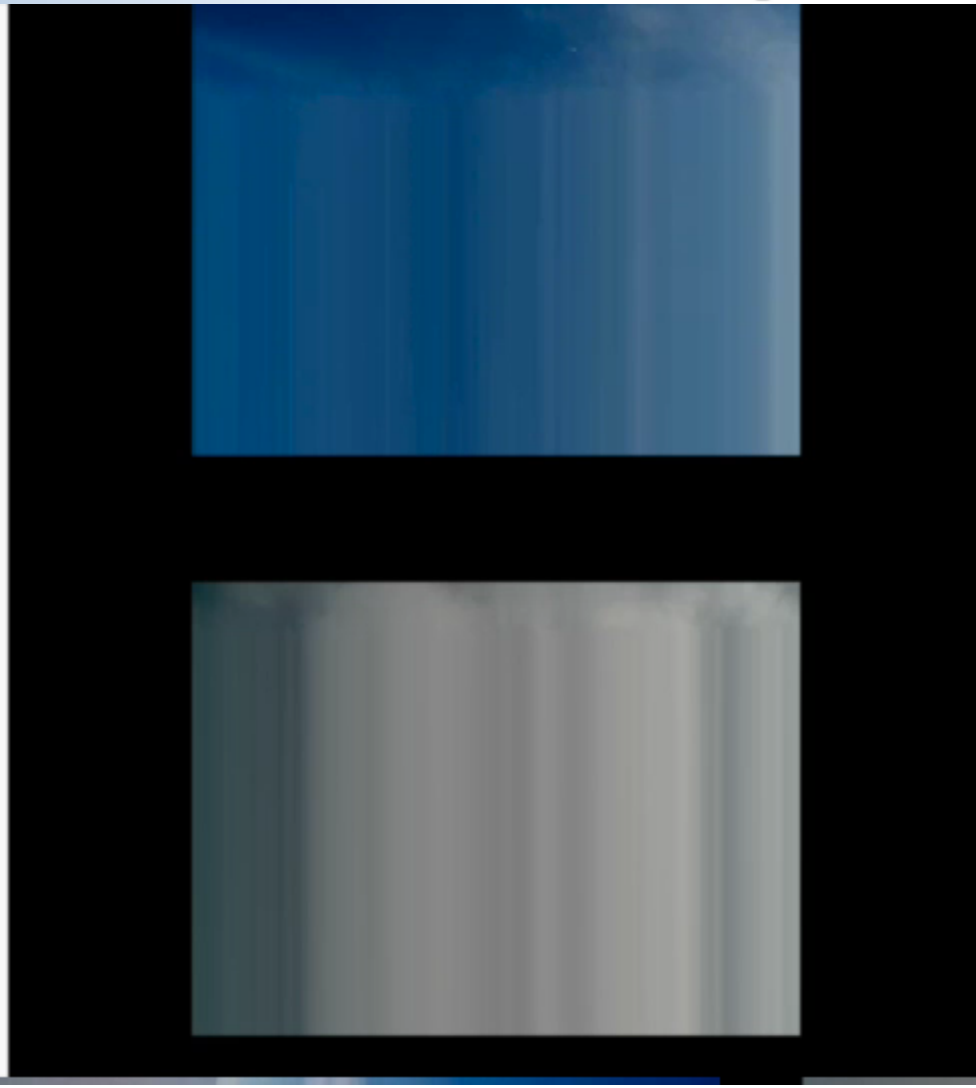


Figure 1. Cloud probe instrumentation and data products. Probes were mounted to the C-130 fuselage.

- Interesting horizontal and vertical variability in clouds detected with probes → useful for validating retrievals of cloud properties (7 Sept flight example).

September 7th Flight





Preliminary data, such as that shown above, suggest clouds encountered during ARISE were mostly liquid-phase though some mixed-phase clouds were also present.