Satellite data relevant to Polar Prediction and Climate Studies

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Introduction

Many processes involving the cryosphere remain poorly represented in current models

Challenges:

- To improve representation of polar processes in models using measurements of cryosphere relevant geophysical parameters at sub grid-scale
- To assess their sensitivity on different scales to ocean and atmosphere coupling
- To detect elements of predictability in the cryosphere and associated high-latitude processes over a range of time (diurnal – decadal) and space scales (sub km – global)
- To use this knowledge to increase predictive skill in models - for the benefit of improved polar prediction

Addressing the Challenges:

- Spatially detailed, and precise observations/monitoring of elements of the polar cryosphere, atmosphere and ocean by satellite remote sensing
- Support improvement and verification of modelled cryosphere processes by use satellite remote sensing data
- Incorporate improved cryosphere processes in coupled models
- Use satellite data assimilation tools to guide models

Disclaimer

- In the slides that follow it is simply not possible to show a complete overview, nor all available relevant data types/products that are useful for polar prediction
- I will show a thematic cross-section and selection of products
- The presentation is biased by my perspective

Basic Principles Underlying Use of Sat. Data in Polar Prediction

- Need coordinated, sustained satellite observations of a set of cryosphere-relevant parameters to better predict the polar component of Earth system
- Need to produce consistent, stable, robust, error-characterised, gridded satellite data products
- Need to fulfill specifications for short data latency (i.e. sensing to product generation/ delivery), and routine operational production to be relevant to NWP

General Product Attributes

- *Well calibrated, and Quality Flagged/screened (i.e. QA process implemented)*
- *Level 2 products shall have uncertainties characterised and error specification at a pixel level (also bias, precision, long-term stability)*
- *Product validation assessment report*

For Model data Assimilation

- *Near-real time (latency 3-5 hours), > 95% availability*
- *easy access in standard data format*
- *Data shall be truly operational (i.e. routine, robust, 24/7 availability)*

ESA Climate Change Initiative (CCI)

- Satellites **essential** for Climate Change monitoring
- **30 years** of EO data archived
- **20 new satellites** launched over next 10 years

Essential Climate Variables (ECVs)	ERS-1 / -2	Envisat	GOCE	SMOS	CryoSat-2	ADM-Aeolus	EarthCARE	MSG	MTG	MetOp	S-1	S-2	S-3	S-4	S-5	S-5p	Jason CS
Ozone	•	•								•				•	•	•	
Greenhouse Gases	•	•							•	•				•	•	•	
Cloud Properties	•	•				•	•	•	•	•			•	•	•	•	
Aerosol Properties	•	•				•	•	•	•	•			•	•	•	•	
Fire disturbance	•	•						•	•			•	•				
Land Cover	•	•					•	•	•	•	•	•	•				
Glaciers		•			•						•	•					
Ocean Colour		•											•				
Sea Surface Temperature	•	•						•	•	•			•				
Sea Level	•	•	•		•								•				•
Sea Ice	•	•		•	•						•		•				

CCI: to systematically generate and distribute long-term series of **"Essential Climate Variables" (ECV)** to meet needs of UNFCCC and IPCC

http://www.esa-cci.org/

NOAA Climate Data Records (CDR)

- NOAA systematically generates and quality controls a series of operational CDRs
- Public posting of the dataset, the source code used to generate the CDR, and supporting documentation on NCDC webpage:
  - Fundamental CDRs
    - sensor data (e.g. calibrated radiances, brightness temperatures) that have been improved and quality controlled over time, together with the ancillary data used to calibrate them
  - Thematic (Atmospheric, Oceanic, and Terrestrial) CDRs
    - geophysical variables derived from the FCDRs
    - generated by blending satellite observations, in-situ data, and/or model output
- Operational Thematic CDRs
  - Atmospheric (Mean layer atmos. Temperatures; Aerosol Optical Thickness; Outgoing Longwave Radiation)
  - Oceanic (Sea ice concentration; Sea surface temp)

http://www.ncdc.noaa.gov/cdr/

Sea ice

- Extent and Concentration (new developments)
- Ice drift (large-scale low res. & small scale high res.)
- Ice thickness (CryoSat & SMOS)

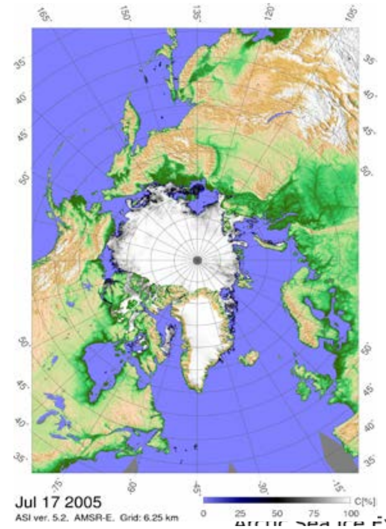
AARI Ice Camp on 13 Aug. 2007

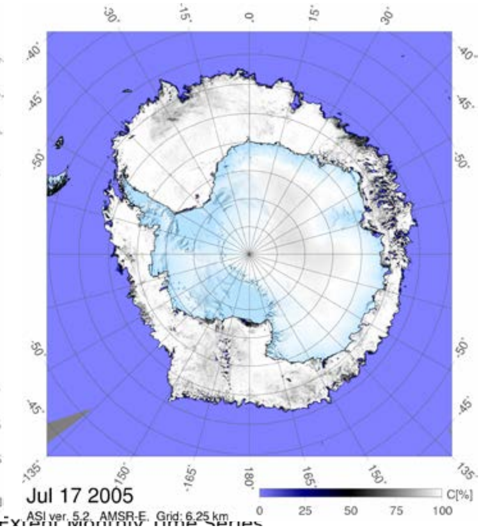
Sea Ice Goals

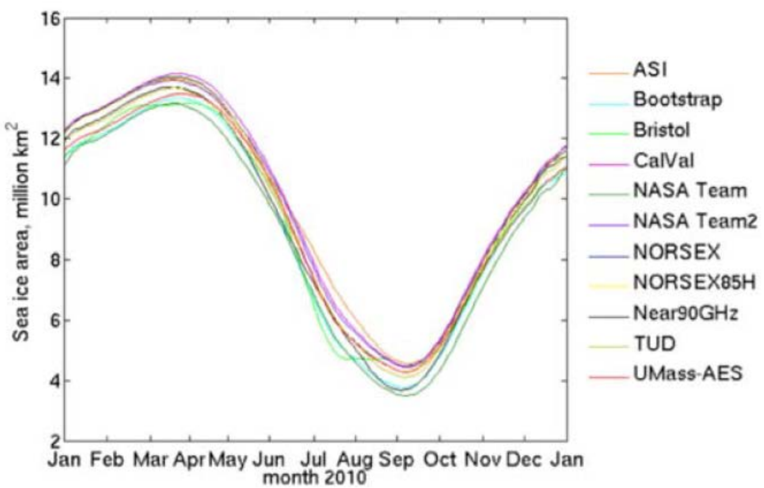
- To obtain an accurate representation of the distribution of ice and water as a constraint to ocean-ice-atmosphere heat/moisture fluxes and to the energy balance
- To combine ice extent, fractional area, and thickness to constrain thermodynamics and to compute the volume of freshwater stored in sea ice
- To measure the dynamics of sea ice to map freshwater transport and its contribution to ice thickening
- To use the thermodynamic and dynamic constraints to better understand sea ice mass balance variability on seasonal to interannual to decadal time scales

Sea Ice Extent/Concentration

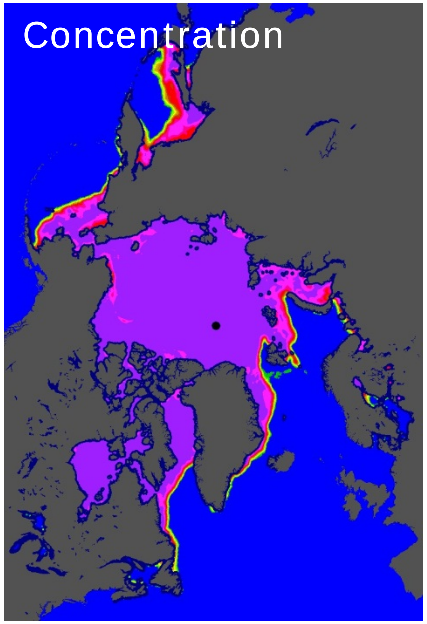
- Multi-freq. Passive microwave sea ice extent/concentration products from SMMR, SSM/I, AMSR-E (Aqua), AMSR2 (GCOM-W)
- Grid spacing 25km or 12.5km depending on algorithm
- Comparison of 21 algorithms reveals differences of up to 1 Mill km^3 ice area at end summer (see opposite), 10% in concentration, 3%/decade in area and concentration trends
- ESA Sea ice CCI (SICCI) goal is to provide the bipolar algorithms with the best possible accuracy and error estimates
- NSIDC/NOAA combined algorithm Sea ice CDR with error estimates available
- Multisensor Analysed Sea Ice Extent (MASIE) http://nsidc.org/data/masie/index.html

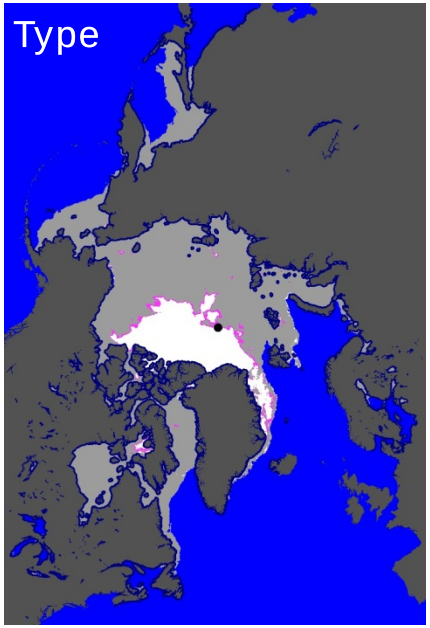


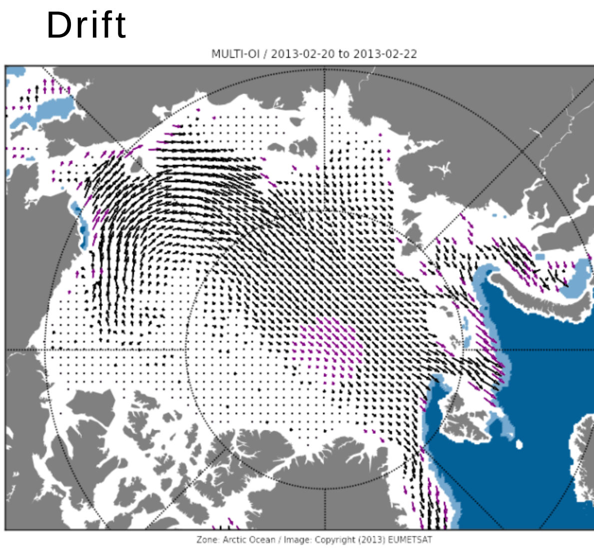




Self-Consistent Sea ice Products



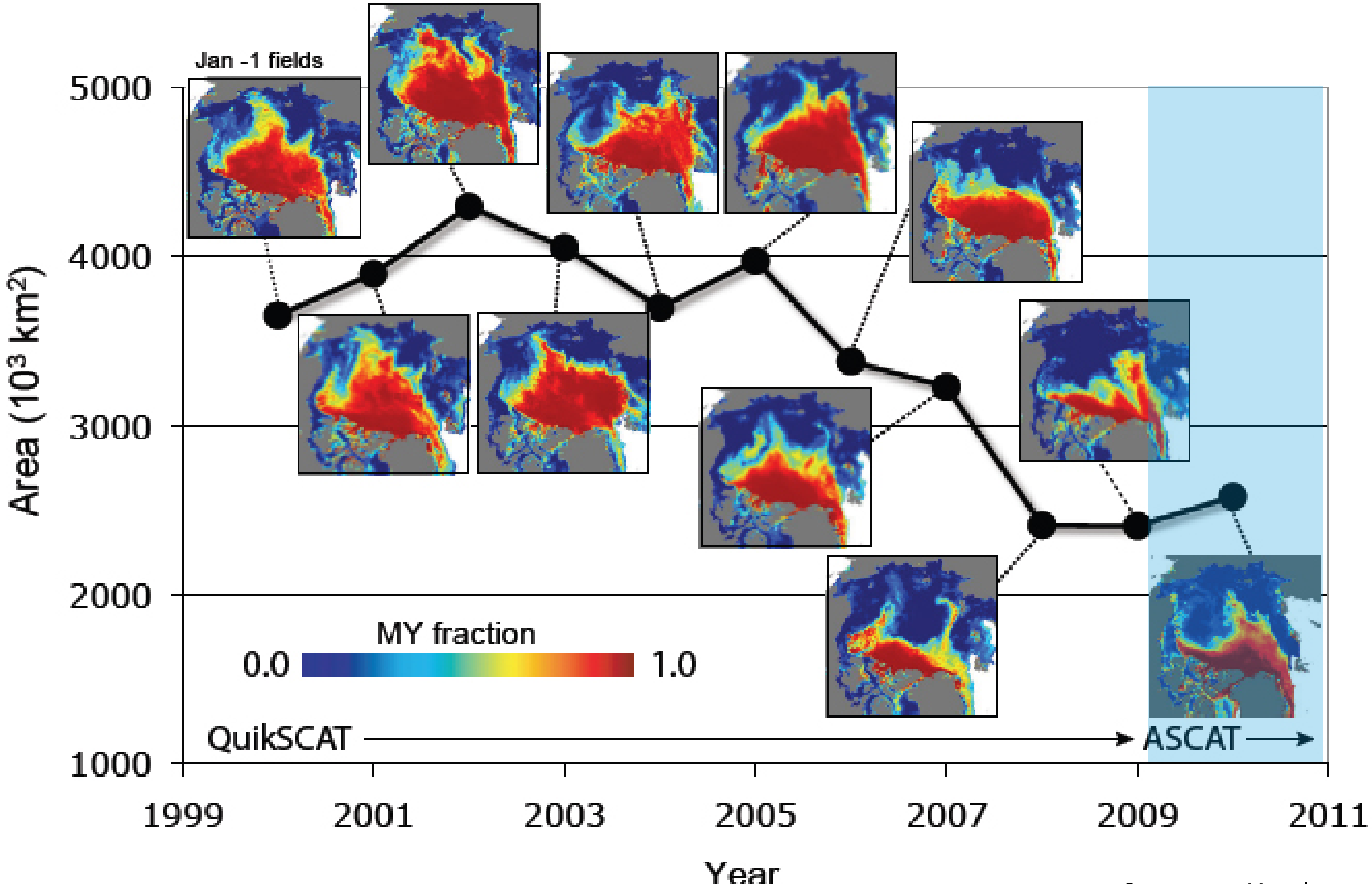




- EUM OSI-SAF Passive microwave + Scatterometer Products – since 2005
- Operational daily mean products on 10km grid (optimal estimation)
- Ice drift on 62.5km grid over 2d interval
- Product validation reports available

- EUMETSAT Ocean and Sea Ice SAF data access: http://www.osisaf.org

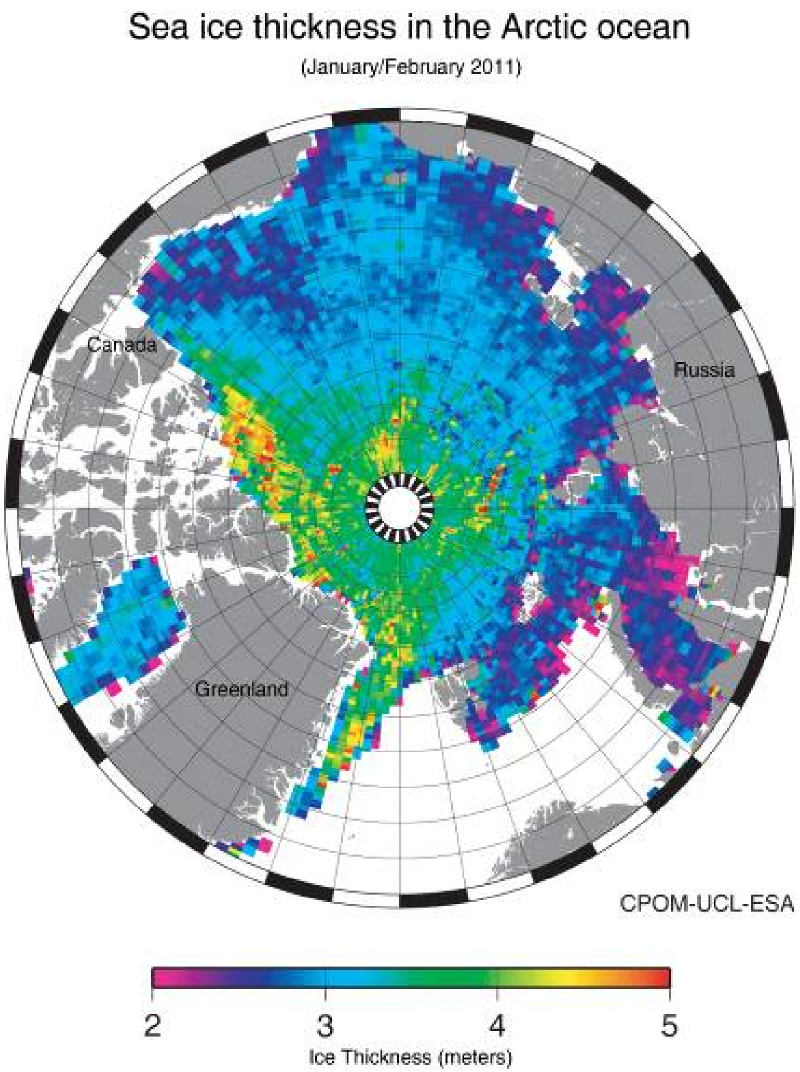
Decline in Perennial Ice Area

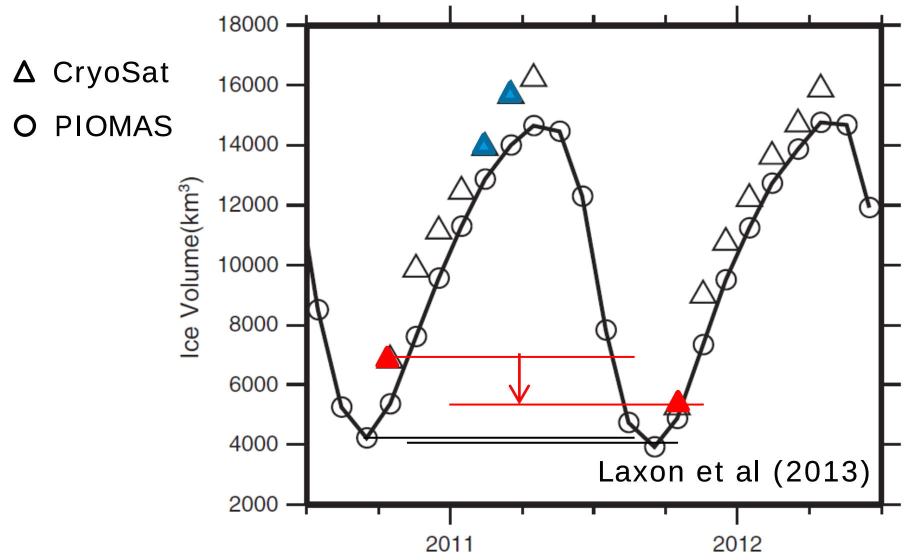


Courtesy Kwok et al. (2009)

See Scatterometer Climate Record Pathfinder data at: http://www.scp.byu.edu/

CryoSat: Arctic sea ice thickness

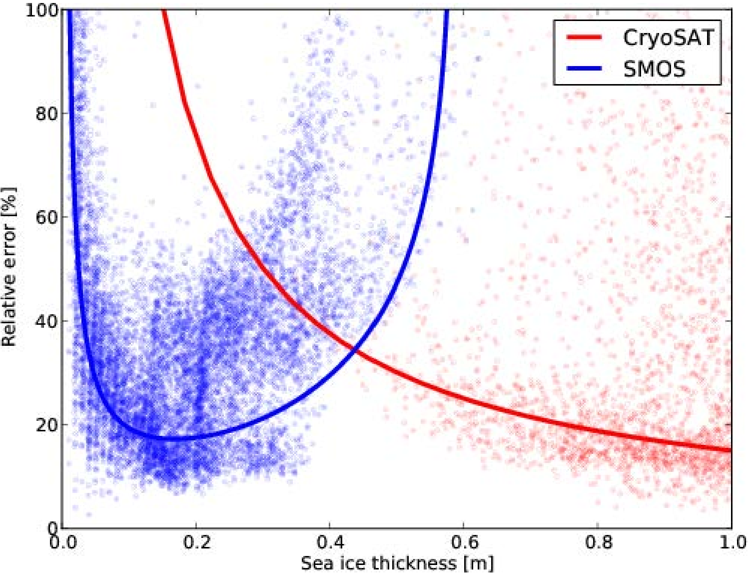




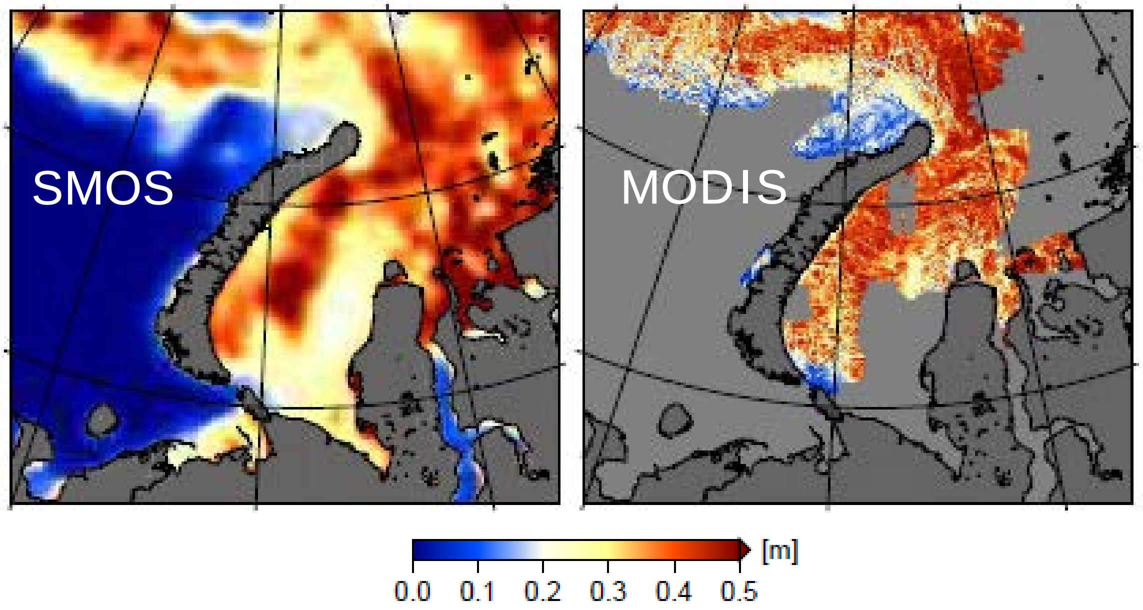
- Jan – Feb. 2011 used to generate Arctic map (▲ LEFT) as the sea ice approached annual max extent
- Variations in sea-ice thickness observed (ABOVE) for 2010-11 and 2011-12
- CryoSat delivers new insight into the seasonal-interannual variation in winter growth cycle

SMOS: Measuring Ice Thickness

- ESA's Soil Moisture and Ocean Salinity (SMOS) being used to derive estimates of seasonal sea ice thickness up to 0.5m, complementing CryoSat measurements of thick ice.
- Products being transferred to operations: i.e. systematic products in ESA SMOSIce Project



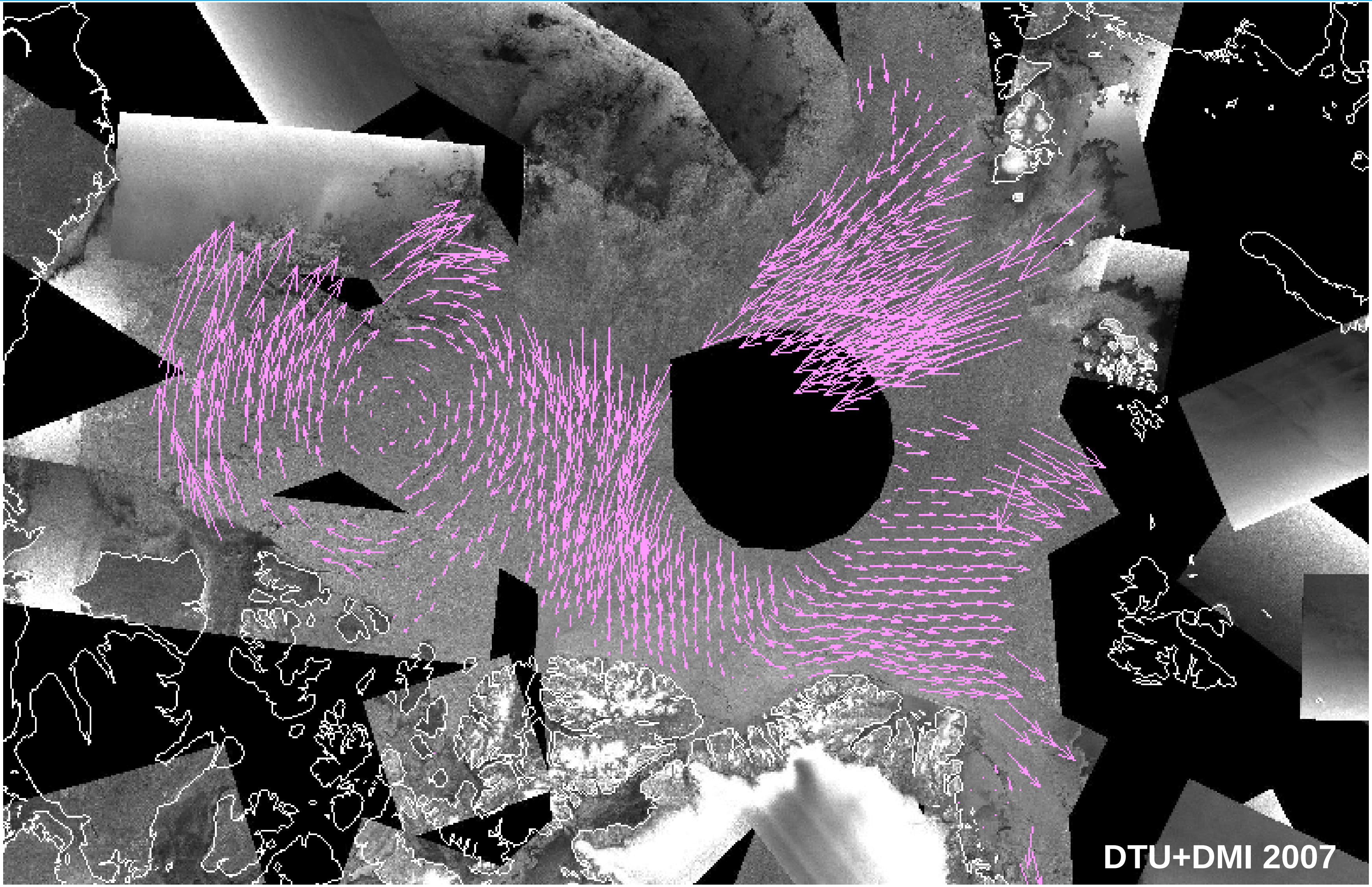
Relative error in sea ice thickness for both SMOS and Cryosat (pers. Comm Kaleschke)



Thin sea ice thickness derived from SMOS (<0.5) on 26 December 2010 Kaleschke et al., (2012)

MODIS thickness product (courtesy J. Key)

ENVISAT wide swath 3-day ice drift
October 16-19, 2007

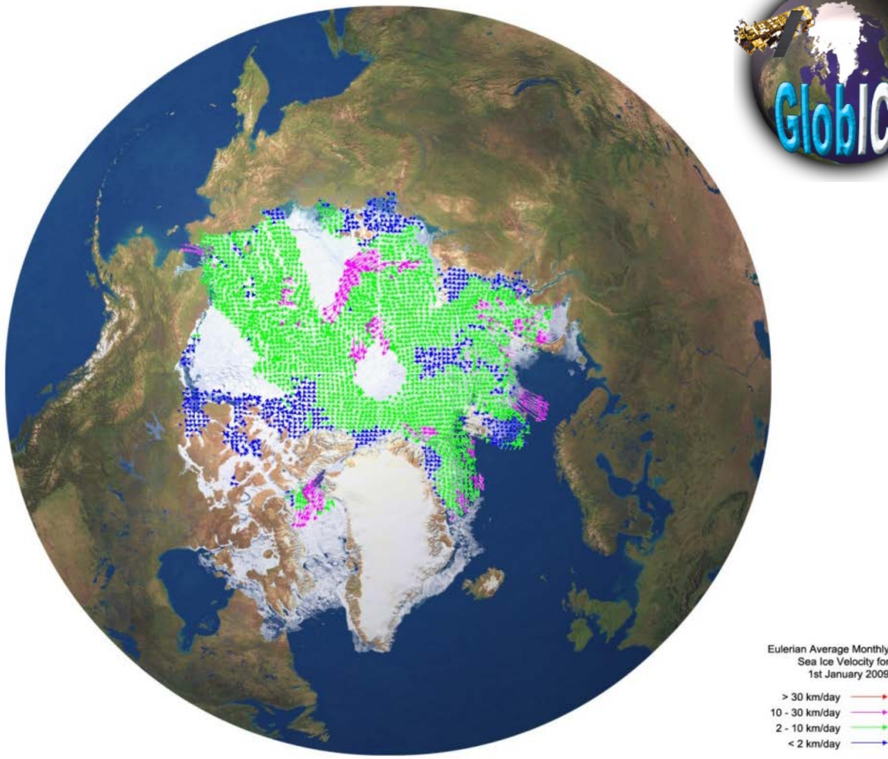


GlobIce: Sea Ice Dynamics

Objectives:

- All-weather, high res. (space/time) sea ice motion and deformation mapping from SAR image data
- To resolve seasonal-interannual variability in sea ice dynamics in the Arctic
- Long-term changes in the cryosphere e.g. extent, volume and flux of sea ice, based on 18 year archive of ERS and ENVISAT (more than 500,000 SAR scenes)

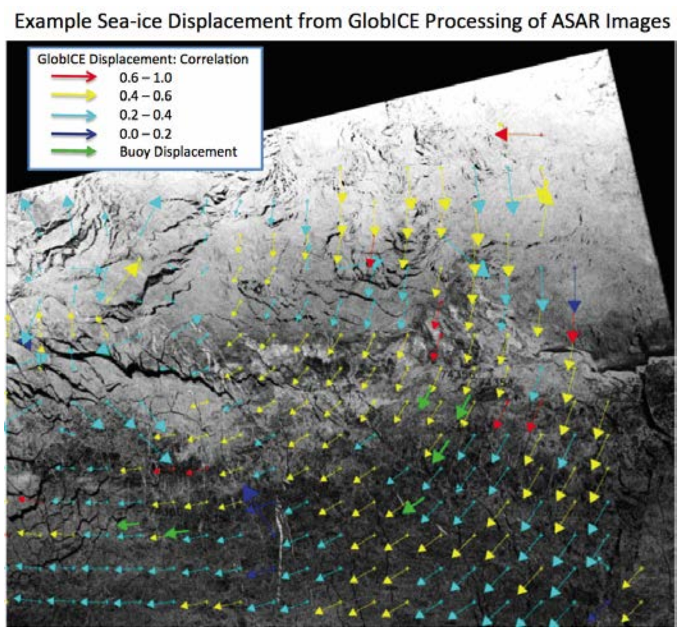
http://www.globice.info

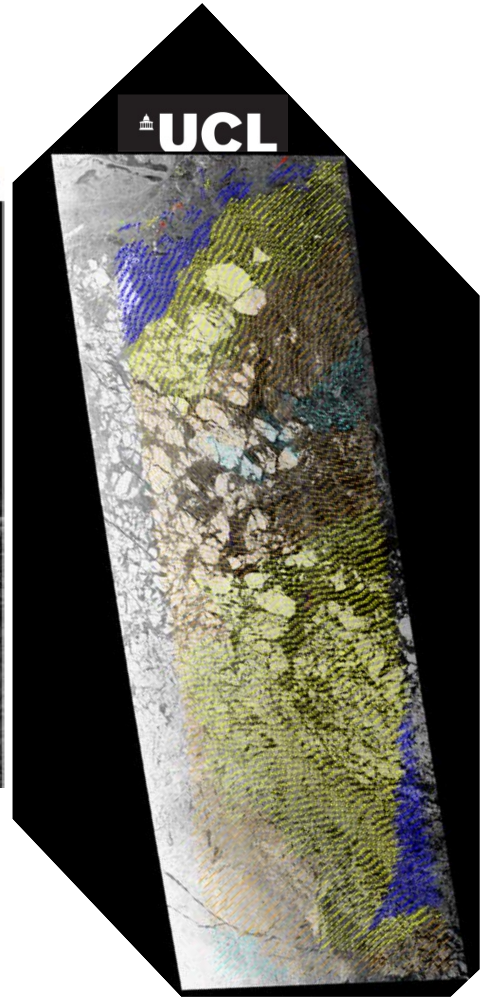


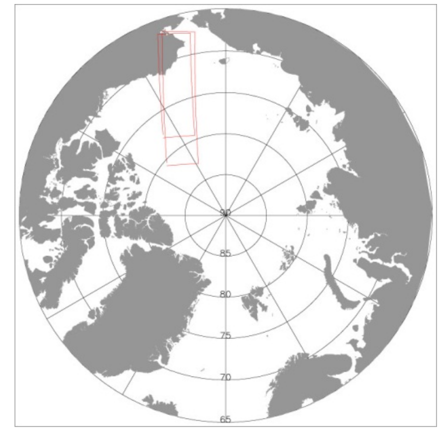
Team:

- UCL (Prime)
- Kongsberg Spacetec, UK Met Office, AWI, IFREMER, JPL, Planetary Visions

GlobIce: ASAR Tracking:
SEDNA Ice Camp - April 2008







Sedna IPY ice camp

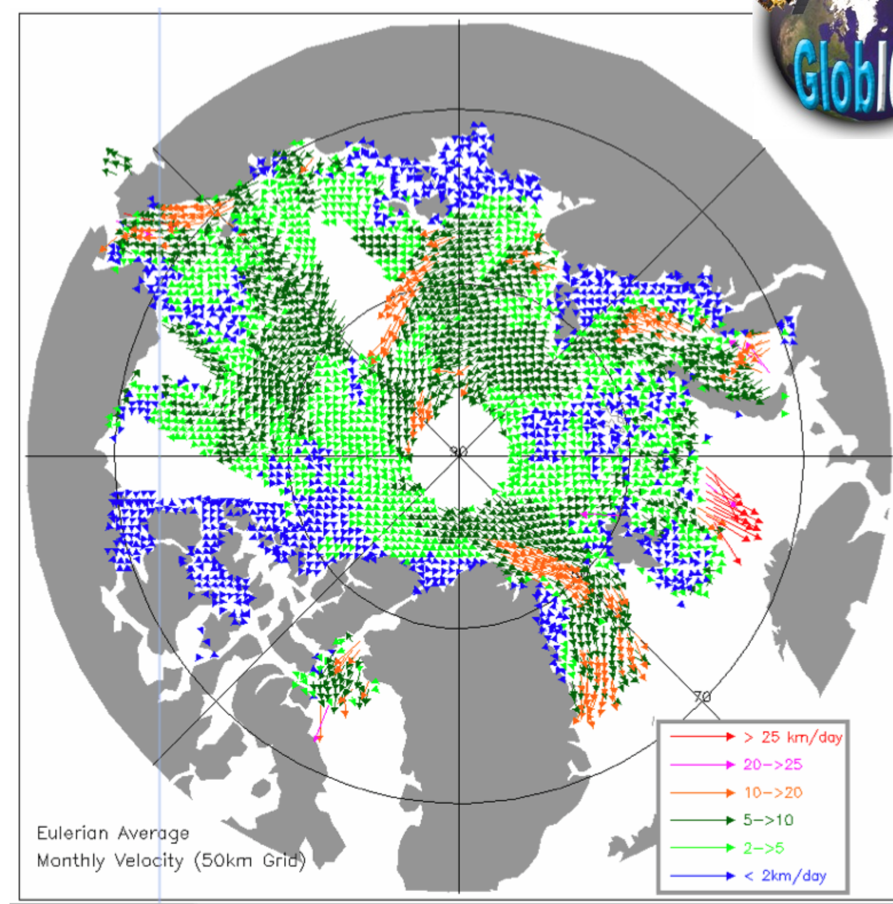
JPL

Drift products validated using GPS buoy/ice camp data

GlobIce: Arctic Products

- GlobICE processed all Envisat ASAR-WS image pairs from winter Arctic from 2004 to 2011.
- Sea ice displacement and velocity
    - 3d and monthly average at 5km spacing
- Higher level products
    - Lagrangian motion
    - Sea ice deformation
    - Open water fraction
    - Ice Mass flux
- Product grid spacing: 5, 20, 50, 100km

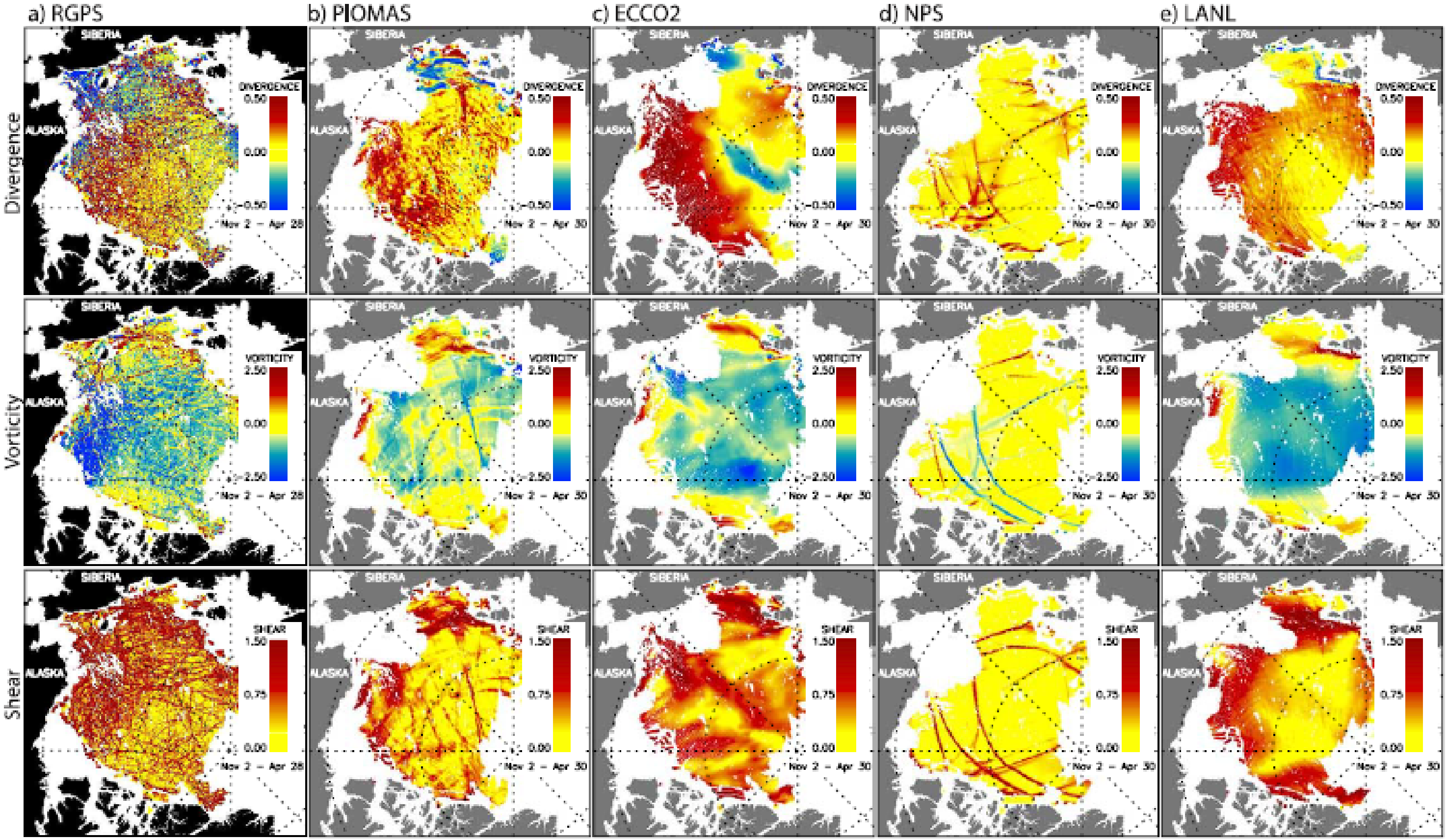
**Prototype Antarctic ice drift products also available



http://www.globice.info

Arctic Comparison: RGPS and Models

- RGPS produces ice drift, deformation, age and thickness from RADARSAT SAR Arctic snapshot products from 1997–2002 on 3d intervals at 10km gridscale

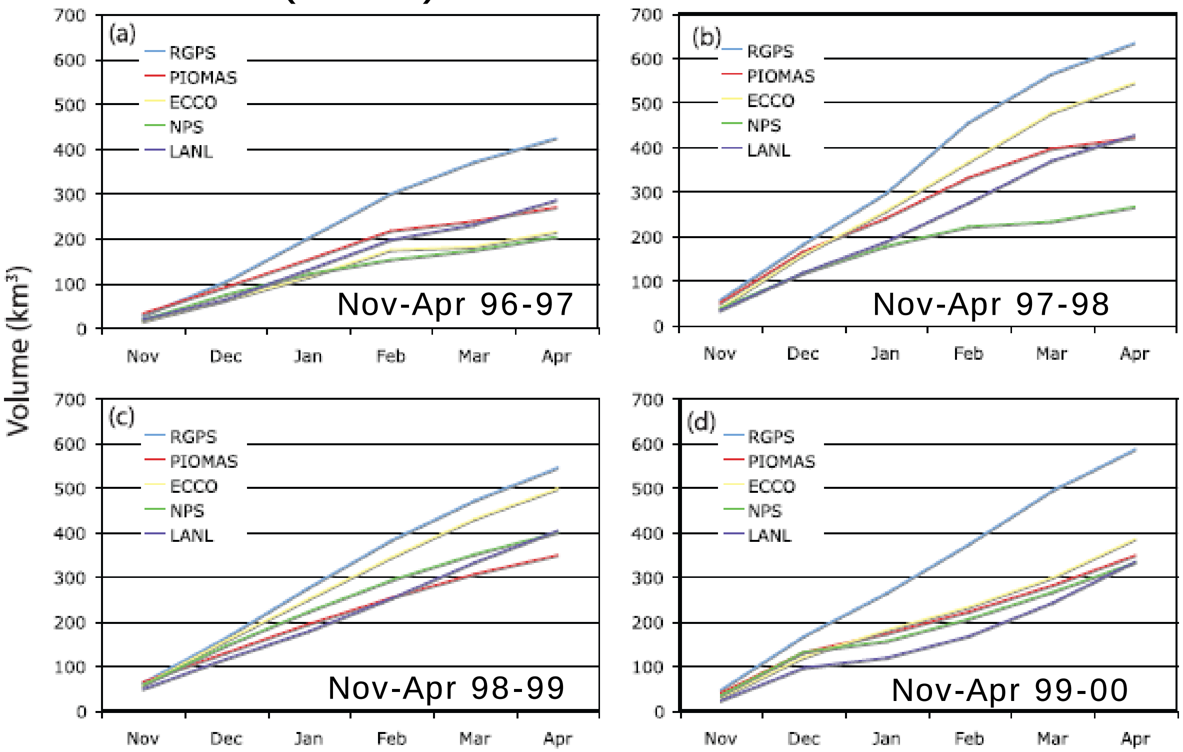


Contrast between the net winter deformation (divergence, vorticity, and shear) from a) RGPS ice drift and model simulations: (b) PIOMAS (UW); (c) ECCO2 (JPL); (d) NPS; and (e) LANL (strain rate units: d^{-1}).

Kwok et al (2008)

Sea Ice growth cycle representation

Kwok et al (2008)



Deformation-related sea ice volume production in 4 successive seasons

Laxon et al (2013)

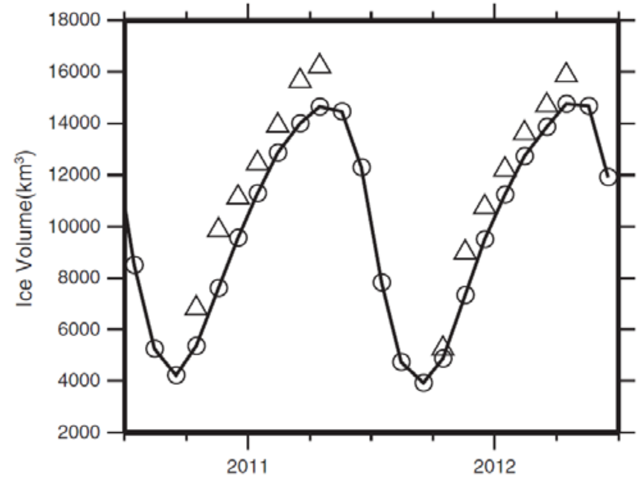
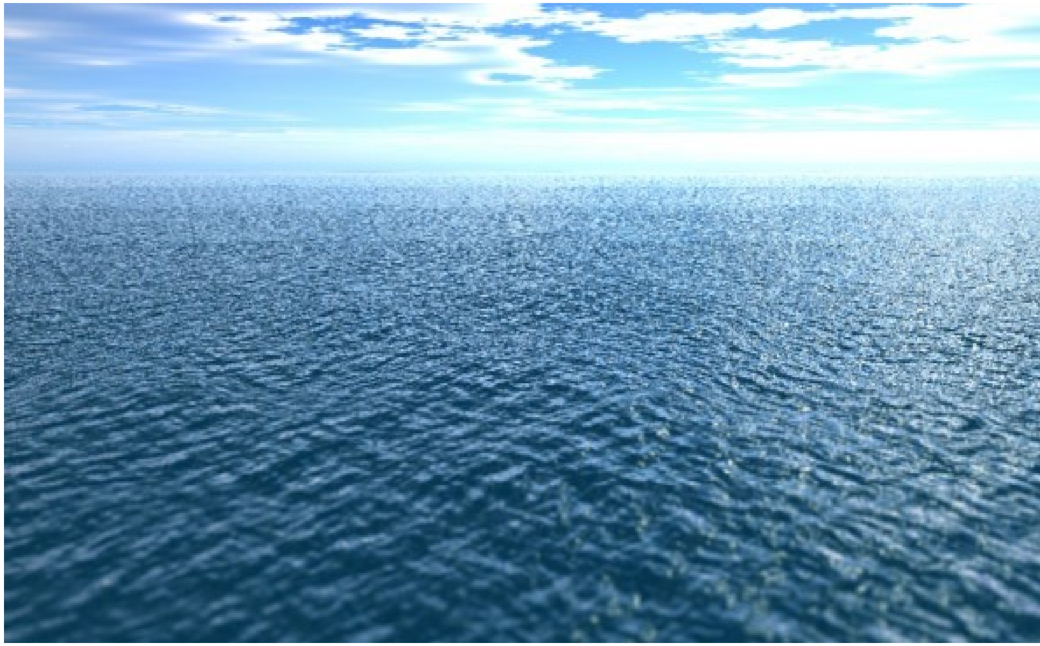


Figure 3. Timeseries of monthly Arctic sea ice volume from CS-2 (triangle) and from PIOMAS (solid line and circle) for two winter growth periods (October–April).

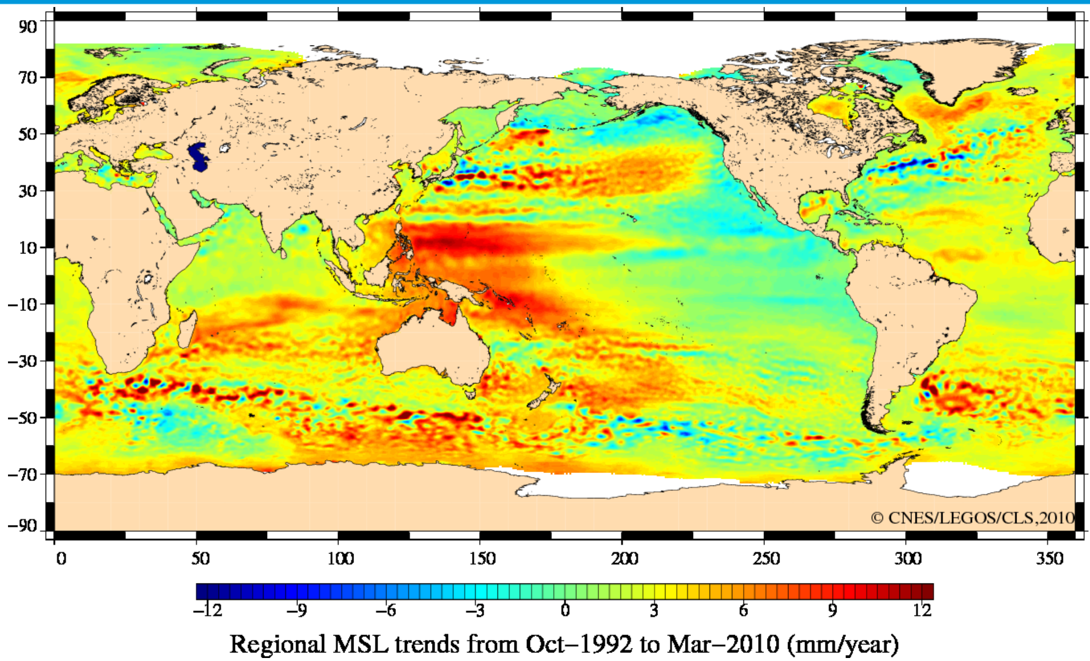
- Models underestimate seasonal ice volume increase production owing to poor representation of deformation/ridging
- Too little deformation = too little volume of ice produced

Ocean

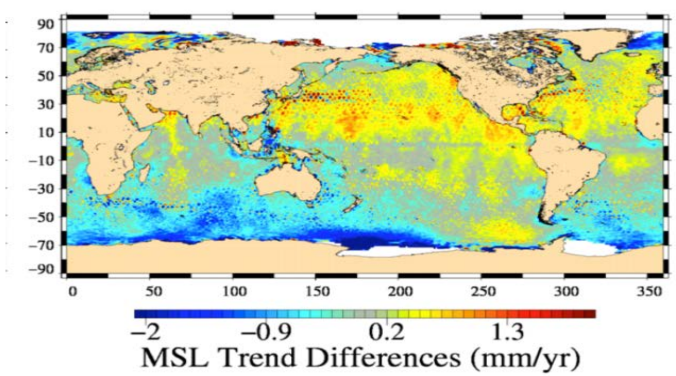
- Sea Level
- Ocean Dynamic Topography
    - CryoSat



18 Years of Sea Level Trends from Radar Altimetry



Improvements of SLCCI project on regional MSL trends



ESA CCI Sea Level ECV

18 year reconstruction sea level topography and trends

Sea Level CCI project: refined processing algorithms, and selected most accurate ones

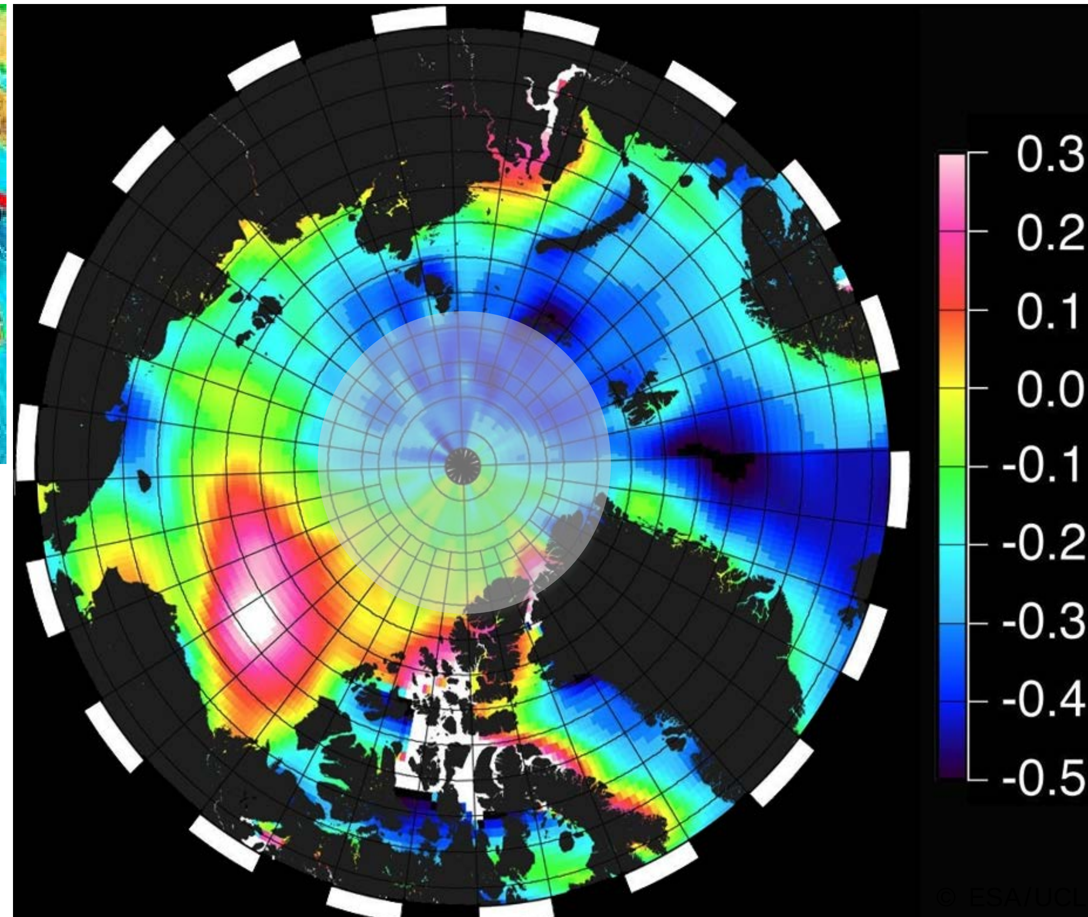
Global maps of regional Sea level trends reveal interannual variability can be detected in the sea level trends signal

Data Used: ERS-1, -2, Envisat, T/P, Jason-1, -2 (and CryoSat) Radar Altimetry

Dynamic Ocean Topography

CryoSat has acquired first complete picture of ocean dynamic topography in the Arctic Ocean and reveals freshwater dome in Canada basin (i.e. storage within Beaufort Gyre)

Ocean circulation patterns



First map of Dynamic Ocean Topography of the Arctic region
(up to 88° deg. N)

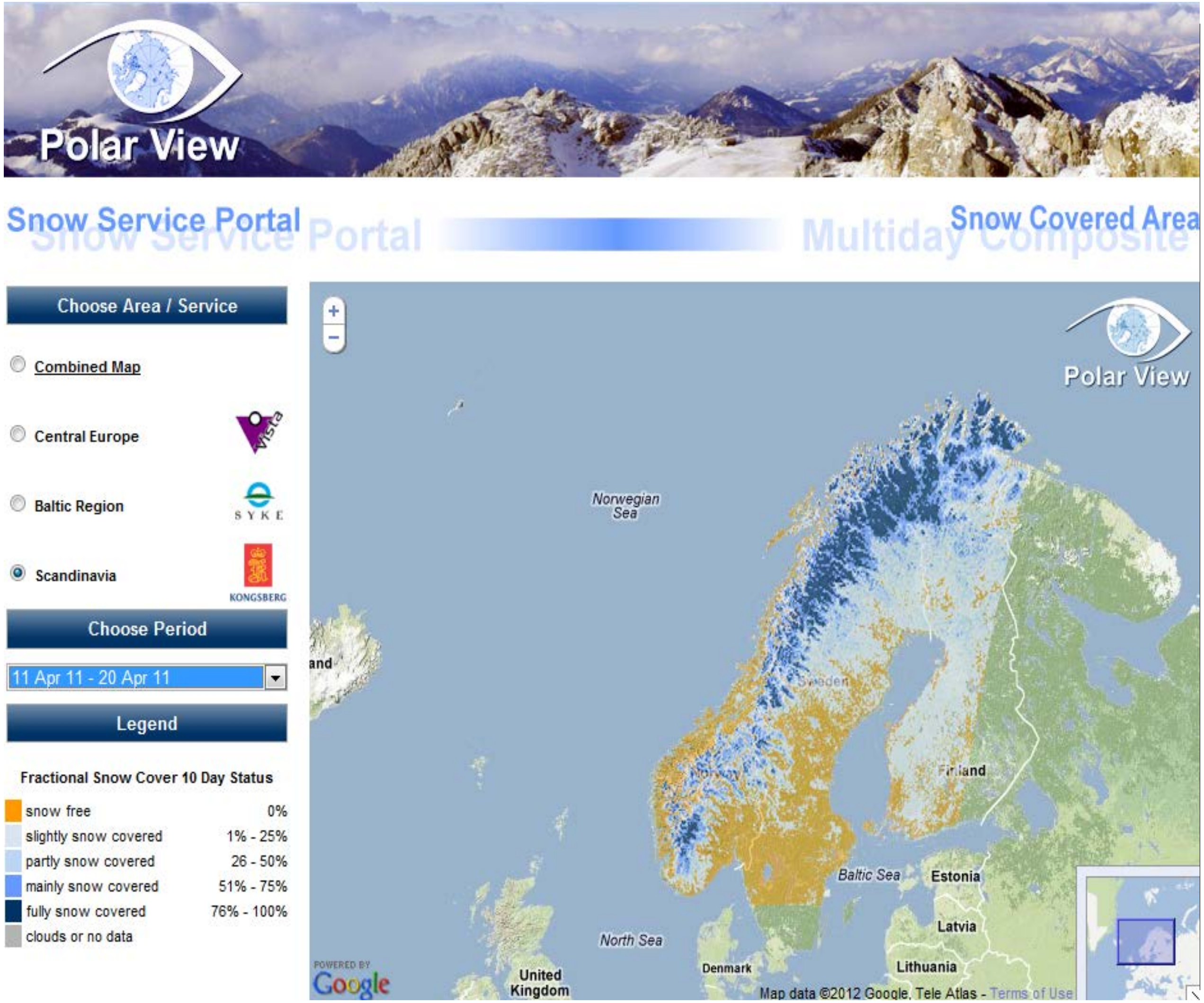
Snow

- Traditional Snow Cover extent
- GlobSnow
- Snow trends

Operational Monitoring of Snow Cover

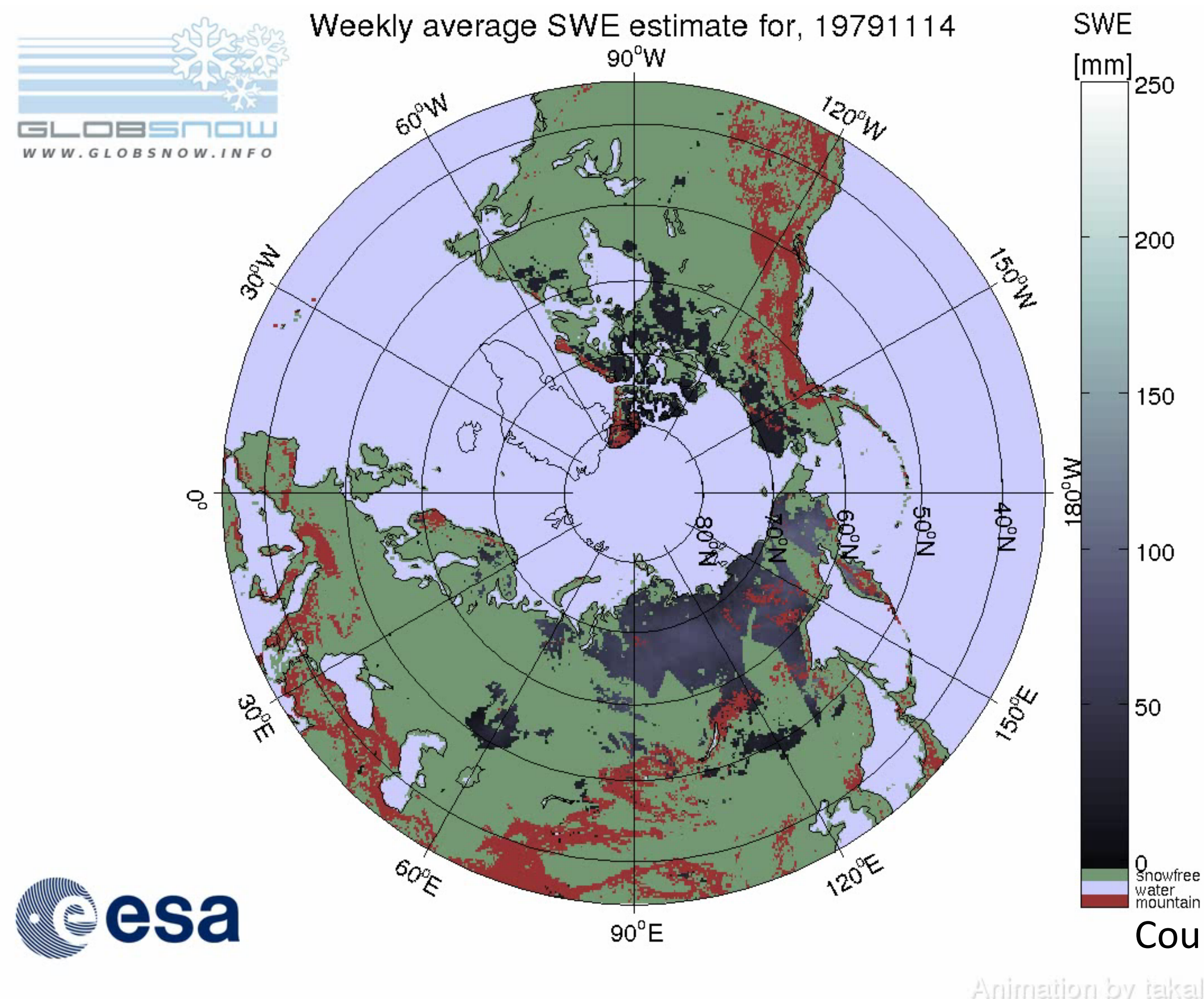
Seasonally –varying snow covered Area/ Extent important for regulating high lat energy balance and hydrological cycle and for flood forecasting

Optical Satellites used in combination with radar instruments



http://www.vista-geo.de/snowportal

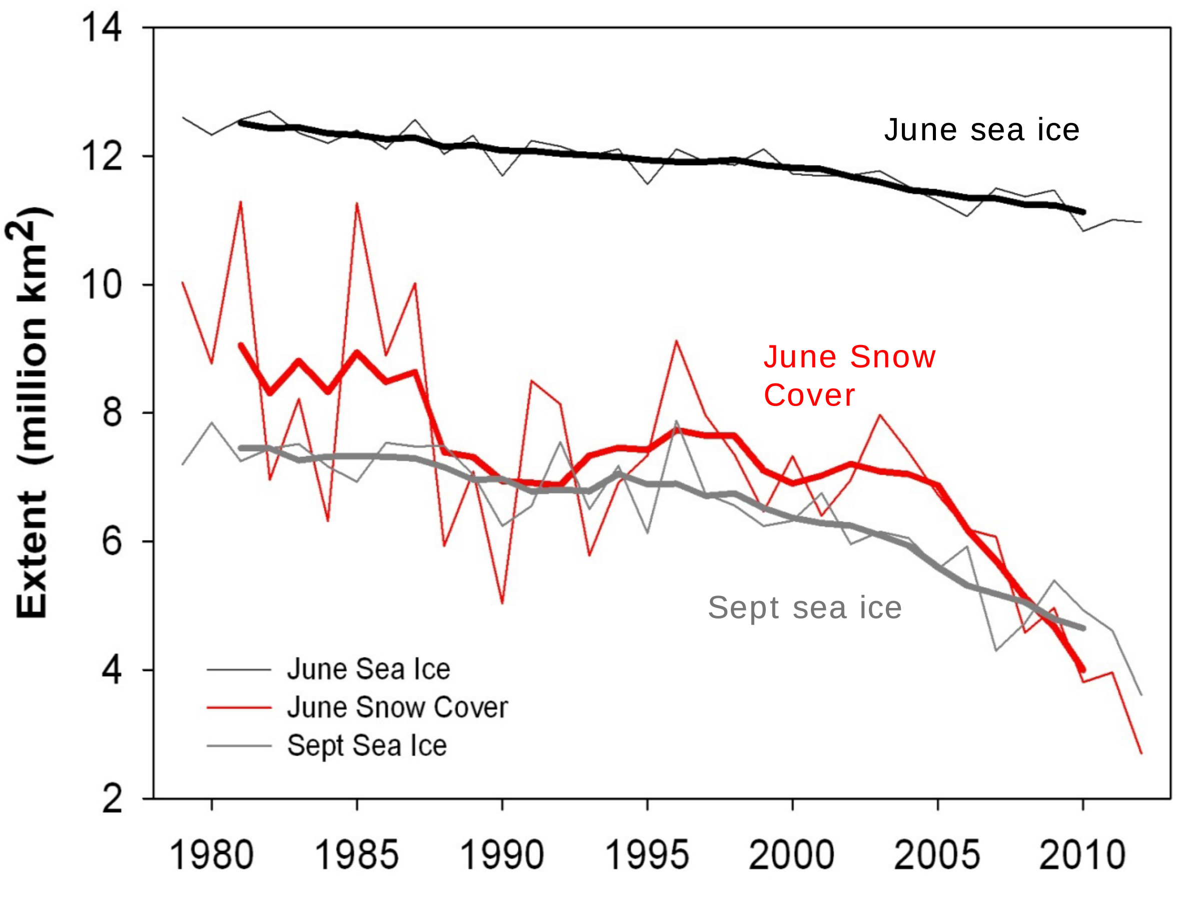
GlobSnow - Global Snow Water Equivalent



Courtesy K. Luojus (FMI)

http://www.globsnow.info

GlobSnow: Trends in Northern Hem. June Snow & Sea Ice Extent

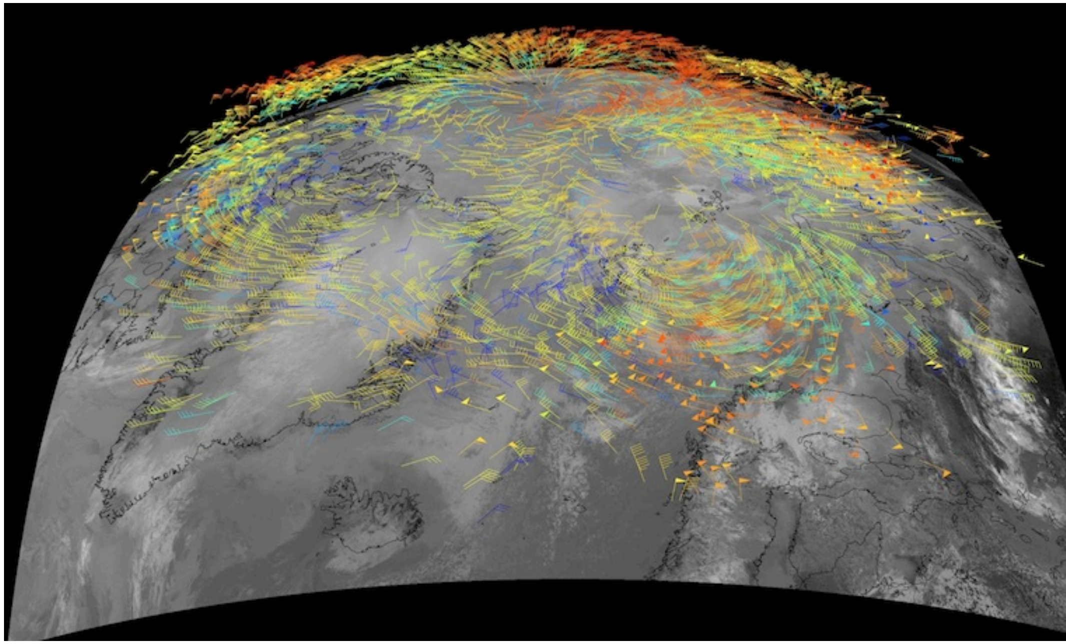


Courtesy: C. Derksen & R. Brown, Environment Canada

- 30 year timeseries of June Snow & Sea Ice, and Sept sea ice
- Bold lines denote 5 year running means
- Relative to 1979-2000 baseline, June snow extent declined by 17.6% by contrast to 13% decline in Sept. sea-ice

Atmosphere

- Sounder Data
- Clouds and Radiation
    - EarthCARE
- Atmospheric Dynamics
    - ADM-Aeolus
- Radio Occultation



Sounder data (MW and IR)

Passive sounding instruments in the microwave and IR regions like ATOVS instruments (NOAA), ATMS(NPP), or CrIS (NPP) and IASI (MetOp) - used to measure Brightness temperatures , or IR Radiances from which the following profile quantities derived:

- Temperature
- Moisture

IASI also derives total columnar amounts of:

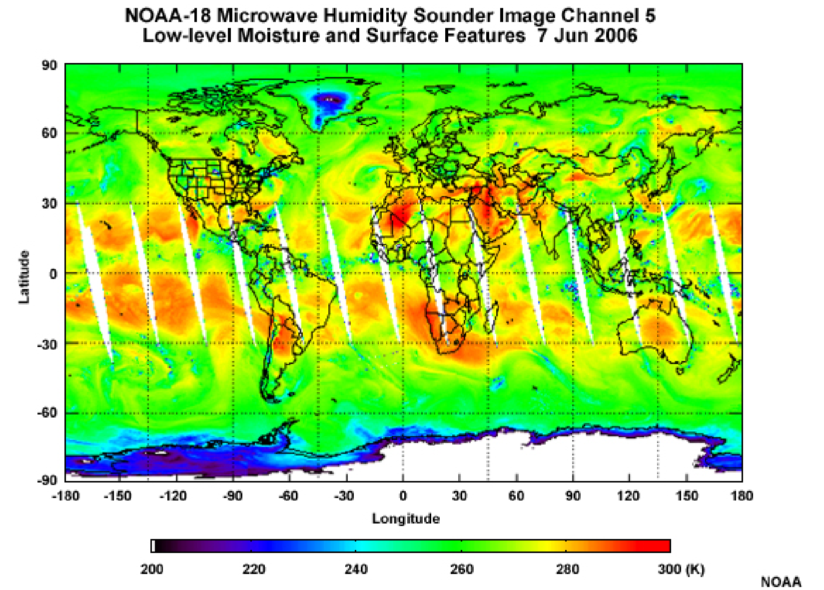
- 0_3, CO_2, CH_4, and N_2O

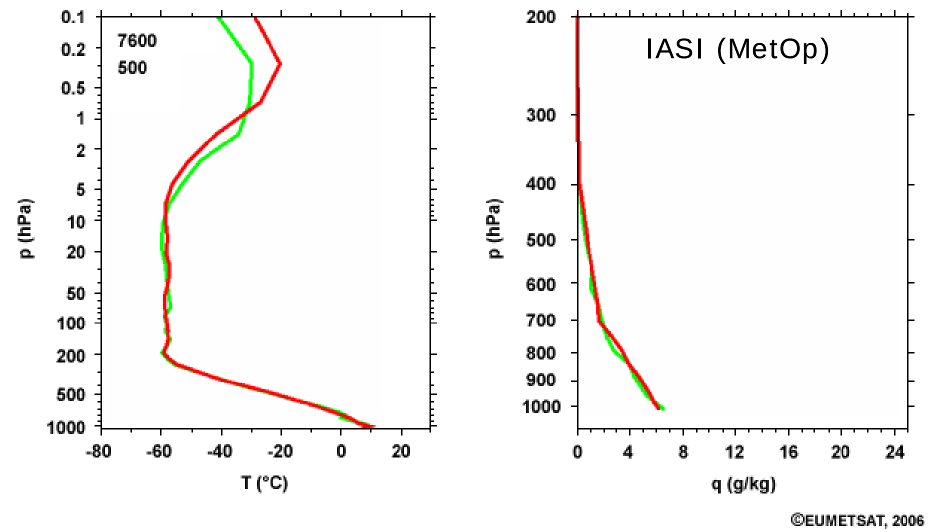
Sounders are mature and deliver significant operational benefits

IASI made a revolutionary advance by measuring IR energy emitted by the earth-atmosphere system in high spectral resolution (8461 "channels")

Issues still to be resolved:

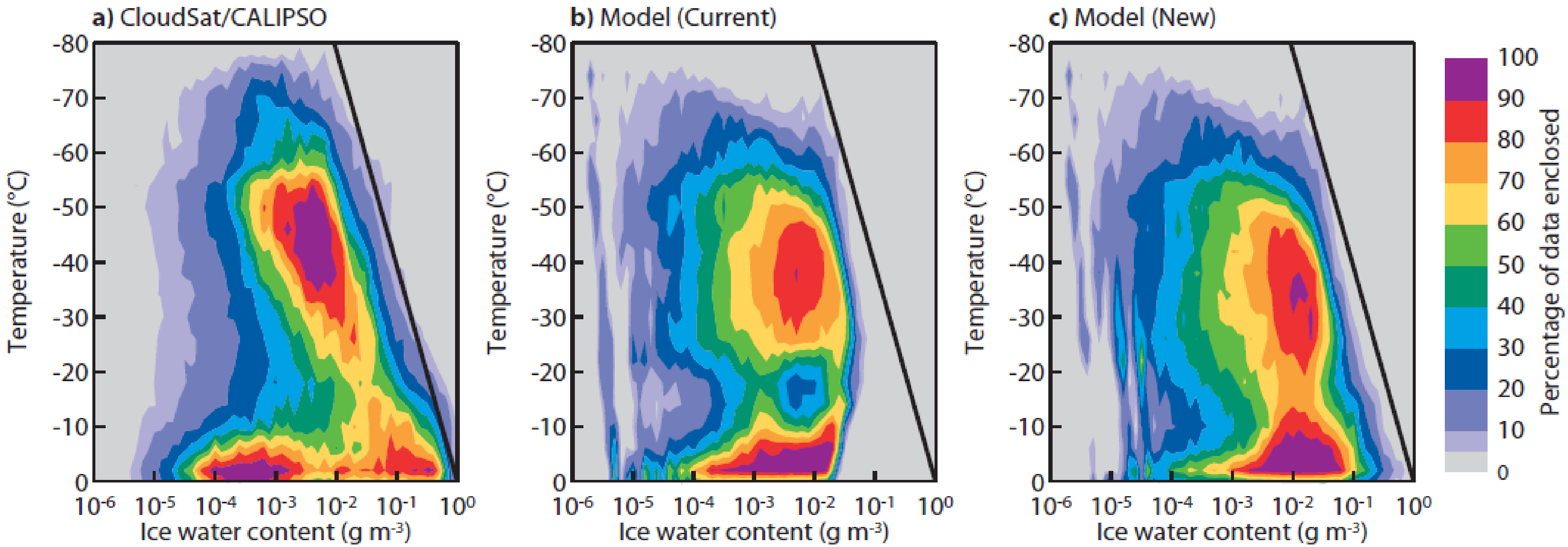
- Surface emissivity
- impact of summer surface melt
- Full exploitation of IASI/CrIS data





Combined lidar and radar profiling: CloudSat+CALIPSO → EarthCARE

ESA *QUARL* Study to prepare for ESA's EarthCARE mission. CloudSat radar and CALIPSO lidar data verify improvement of new ECMWF precipitation scheme:



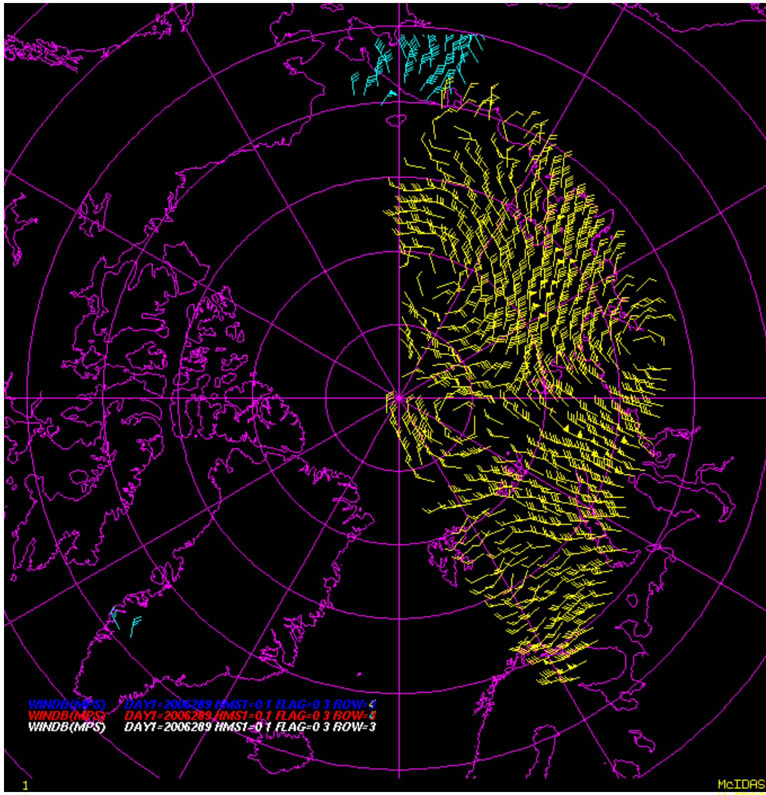
Comparison of cloud ice water content vs. temperature for July 2006 for N. Hem (30-60deg N). Black indicates slope of observed distribution to highlight differences

EarthCARE data assimilation preparations ongoing at ECMWF

Atmospheric Motion Vectors (AMVs)

- 1km – 4km Vis-IR polar orbiting sat. images used to track atmospheric features (AVHRR (NOAA; MetOp), MODIS (Terra; Aqua); VIIRS (NPP); OLCI (Sentinel-3), JPSS
- Water Vapour channel (6.7 micron) and IR Cloud channel (11 micron) used for clear/cloudy sky respectively
  - AVHRR & VIIRS (NPP) no WV channel Cloud top pressure sets alt. range
- Data returned by retransmission from direct broadcast sites in Arctic/Antarctic
  - Images available every ~100 mins, delivered within ~100 minutes, with > 13 polar images/day
- AMVs distributed by GTS or EumetCAST

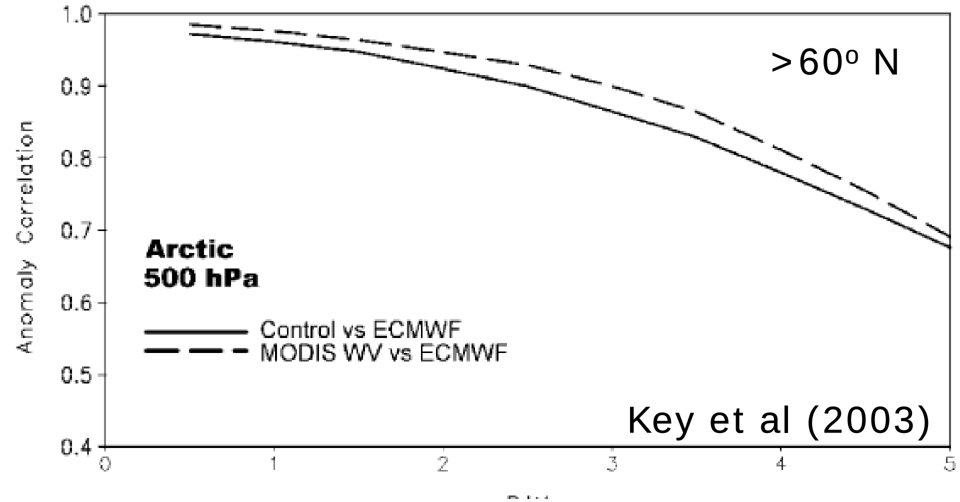
Courtesy J. Key (NOAA)

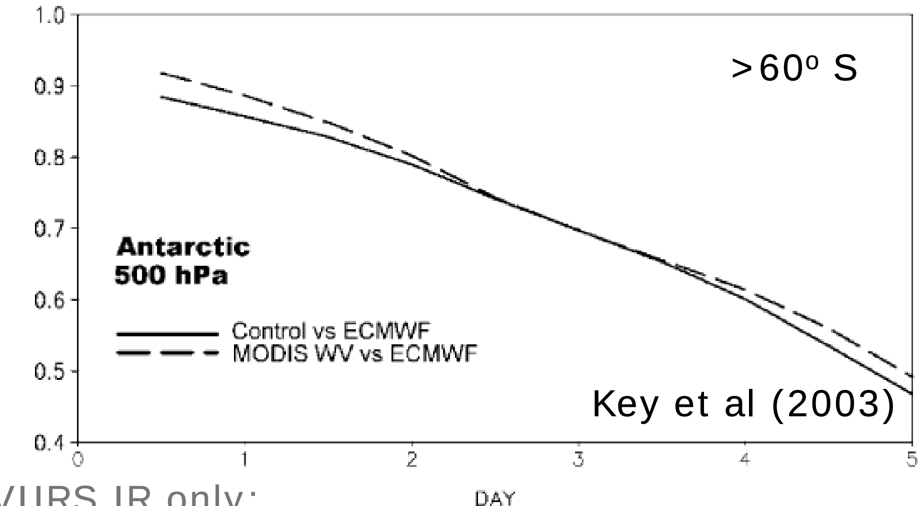


Daily Composites: Terra: cyan, Aqua: yellow, NOAA-15: green, NOAA-16: red, NOAA-17: blue, NOAA-18: white

AMV Products

- WV channel gives more complete sampling
- WV AMVs only attainable at mid- and upper-tropospheric levels, while IR images yield lower level cloud vectors
- Benefits:
  - Forecast improvements in NWP models in both poles and extratropics
  - ~30 year record from AVHRR
- Limitations:
  - Cloud top pressure localisation (errors in vector height assignment)
  - Biases in height assignment revealed in comparisons with CALIPSO/CALIOP lidar data
  - Lack of WV channel on VIIRS (NPP and JPSS)





- Future AMVs secured by NPP VIIRS → JPSS VIIRS IR only; Sentinel-3 (OLCI+SLSTR); MetOp (AVHRR) → MetOp-SG (MetImage)

See: http://stratus.ssec.wisc.edu/projects/polarwinds/polarwinds.html

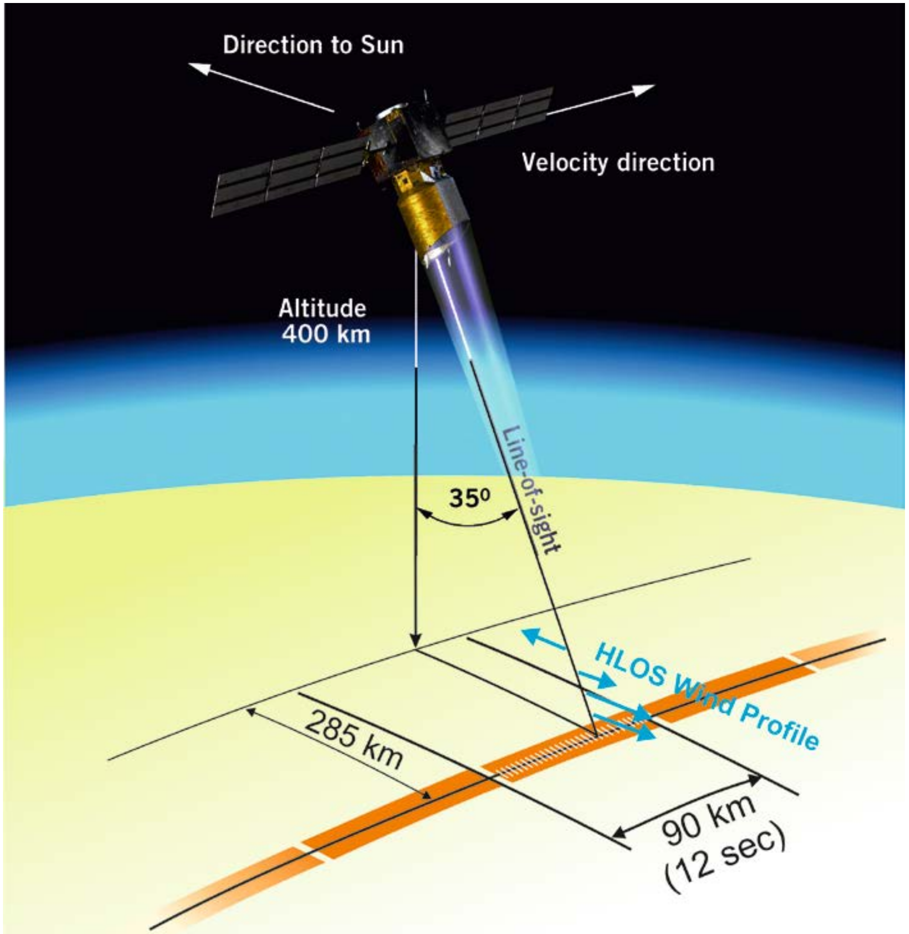
Future Lidar Missions

- ADM-Aeolus (Doppler wind Lidar) wind profiling mission

ESA's ADM-Aeolus: Doppler Wind Lidar

ECMWF "Impact Study" to:

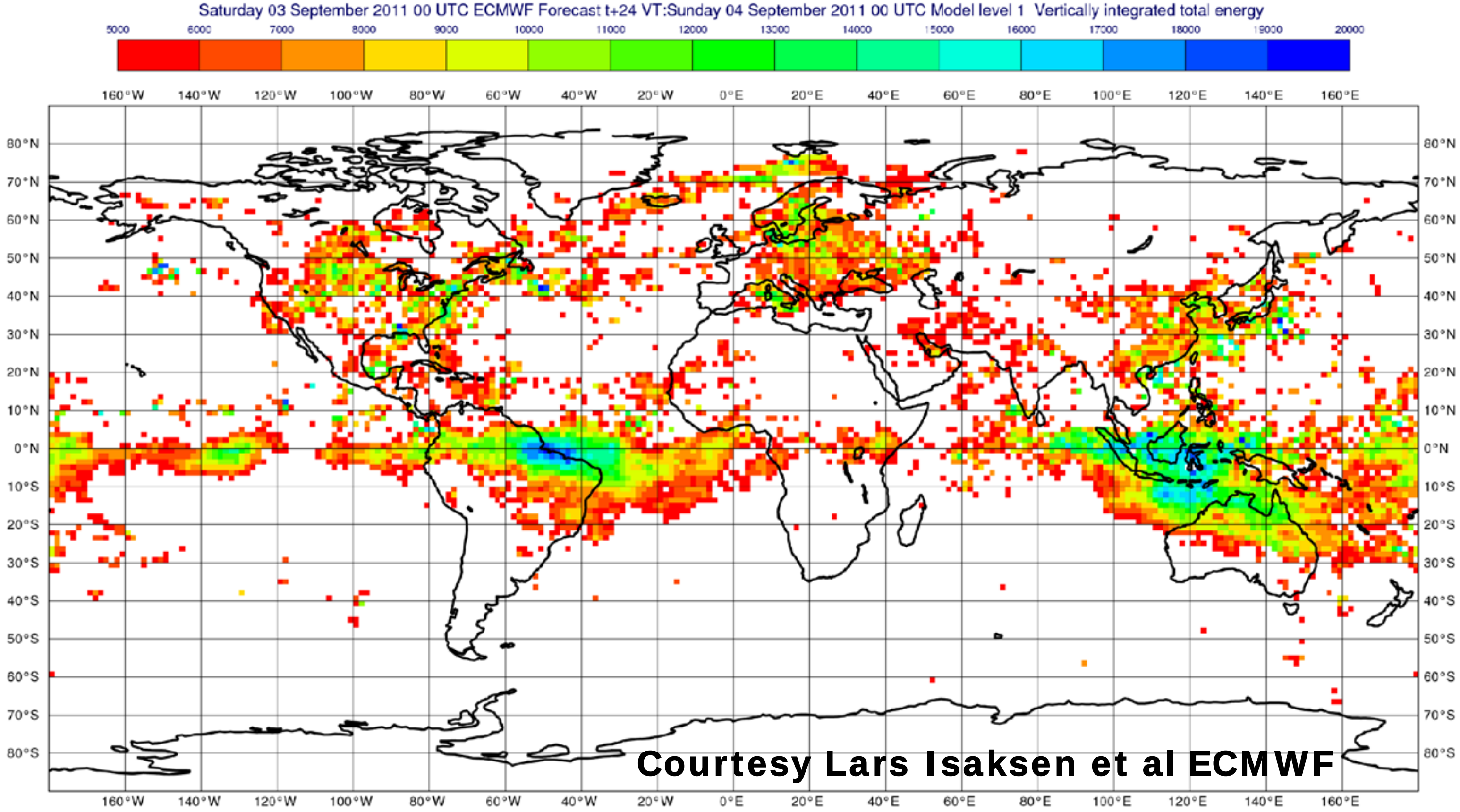
- Provide recommendations on the Aeolus sampling strategy and OSE's to evaluate merit of observations in terms of NWP impacts
- Investigated impact of HLOS wind data on ECMWF assimilation system



- UV lidar (355 nm) with Mie and Rayleigh receivers
- Doppler shift used to retrieve Horizontal Line of Sight (HLOS) component of wind velocity

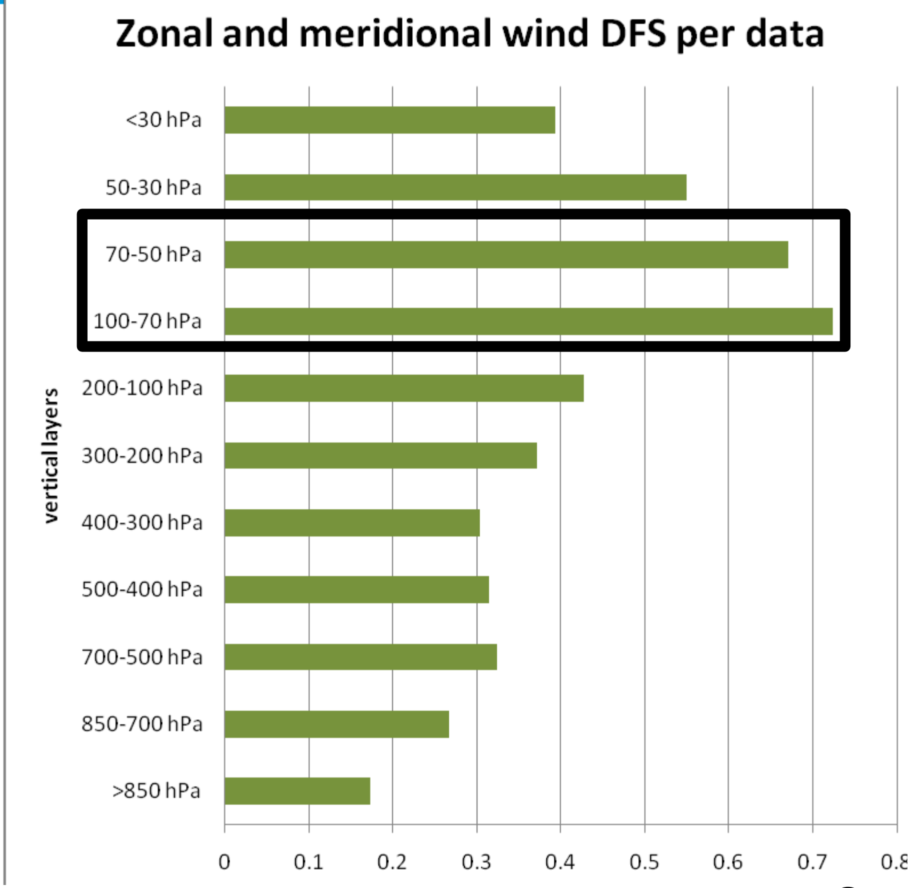
OSE: impact of ADM on ECMWF model

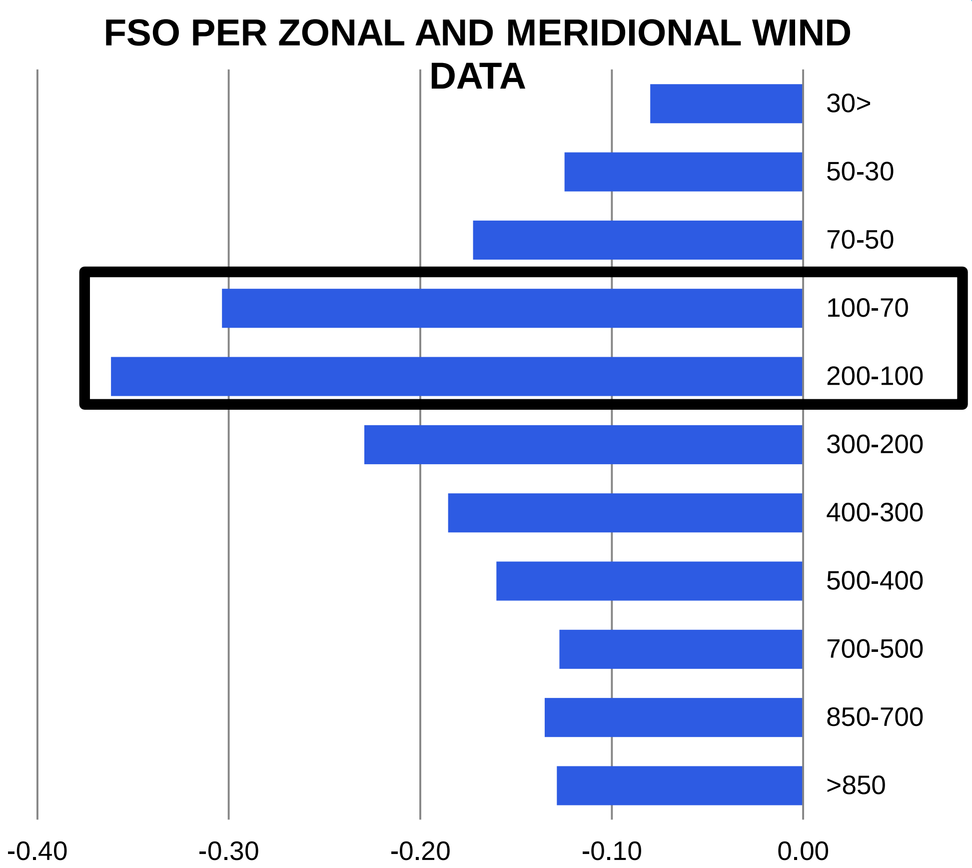
→ Stronger impact



- HLOS assim. decreases 24h total forecast error (truth=op. IFS analysis)
- Most consistent improvements in the tropics and N. Hemisphere

HLOS Wind impact on ECMWF model

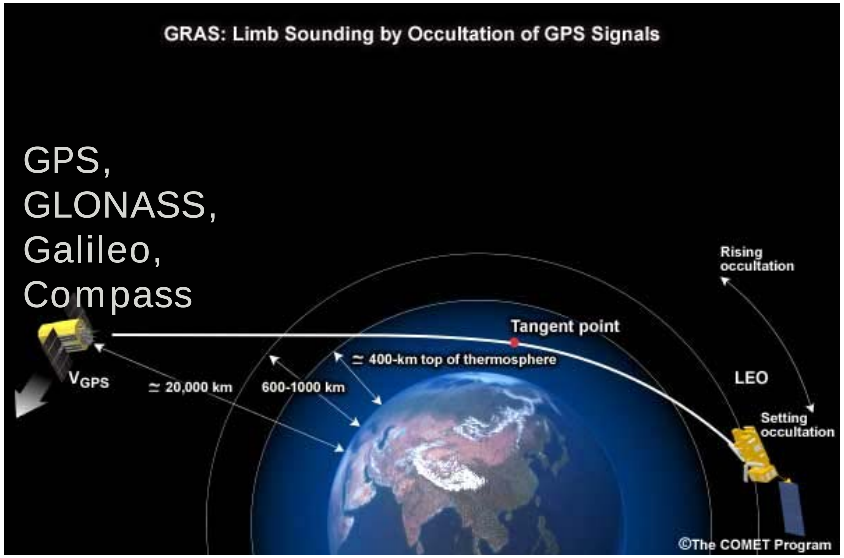


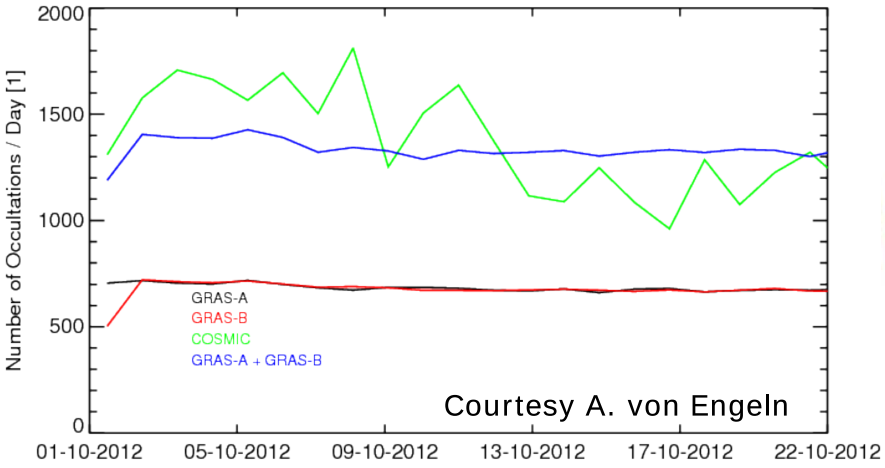


Courtesy Lars Isaksen et al ECMWF

HLOS wind information is most important for the analysis at 50-100 hPa, and for the forecast at 100 - 200 hPa

Radio Occultation (RO) using GNSS satellites





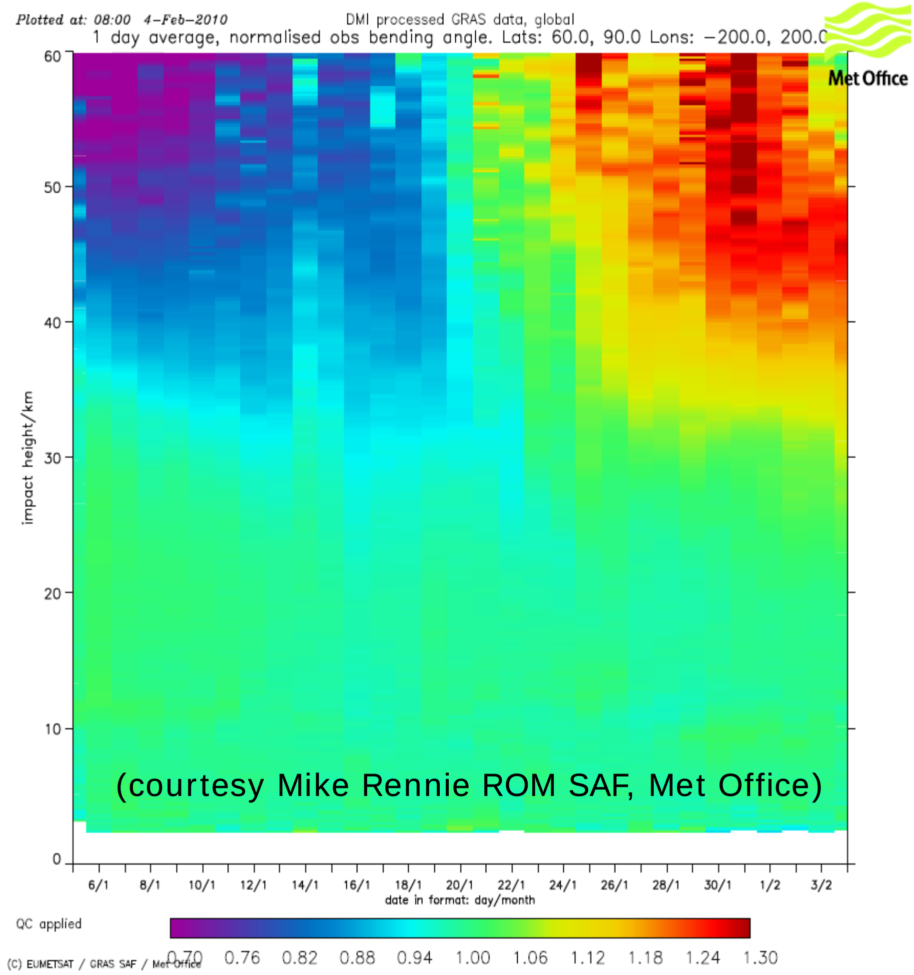
- RO principle used on e.g. CHAMP, COSMIC, GRAS on MetOp-A, -B and missions
- RO advantages: all-weather capability and good vertical resolution
- RO can in principle deliver better height resolved temperature and water vapour than traditional passive atmospheric sounders
- RO provides unbiased bending angles (refractivity) measurements for assimilation into NWP models; there are 2 primary effects of this in the assimilation:
  - bending angle converted to temperature and pressure, or water vapour (approx. < 8km altitude)
  - data an anchor point for other bias-affected radiances

For climate application, the unbiased nature has relevant features:

- different RO instruments can be combined without inter-satellite calibration
- no trends in the biases in the data (although solar cycle impact on ionospheric correction still needs to be assessed for higher altitudes)

RO Polar Impact: Sudden Stratospheric Warming (SSW)

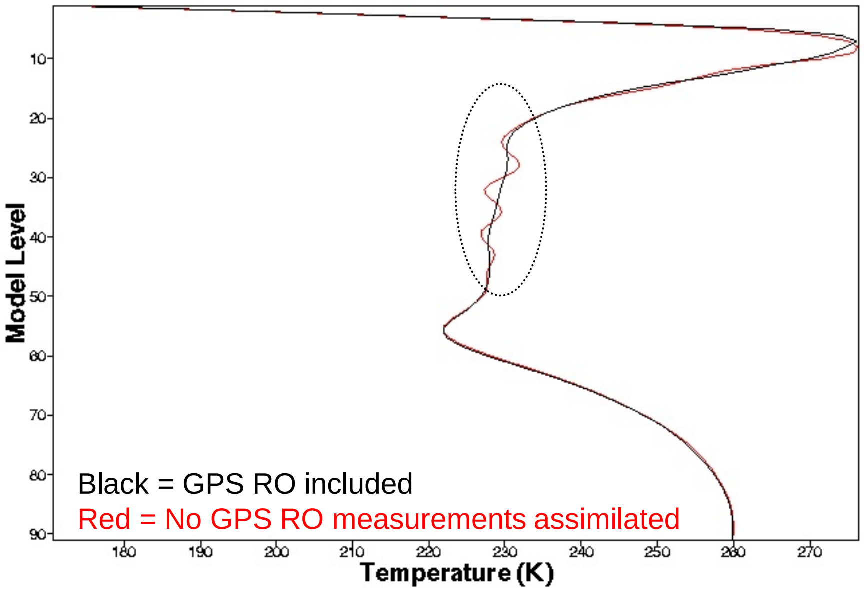
Deviation to the average monthly bending angle from MetOp-GRAS data



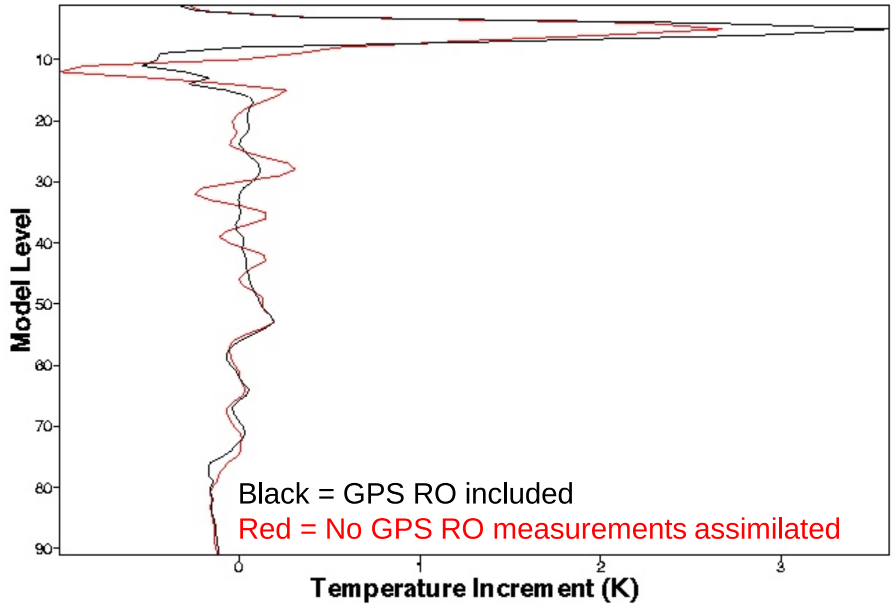
- For polar regions, RO provides temperature, pressure information, in addition to information on gravity waves
- Arctic 2010 SSW event clearly observed by GRAS
- A direct impact of the availability of RO data over Antarctica is shown on the slide after.

RO: Mean analysis/increments over Antarctica for Feb. 2007

Mean analysis



Mean temperature increment

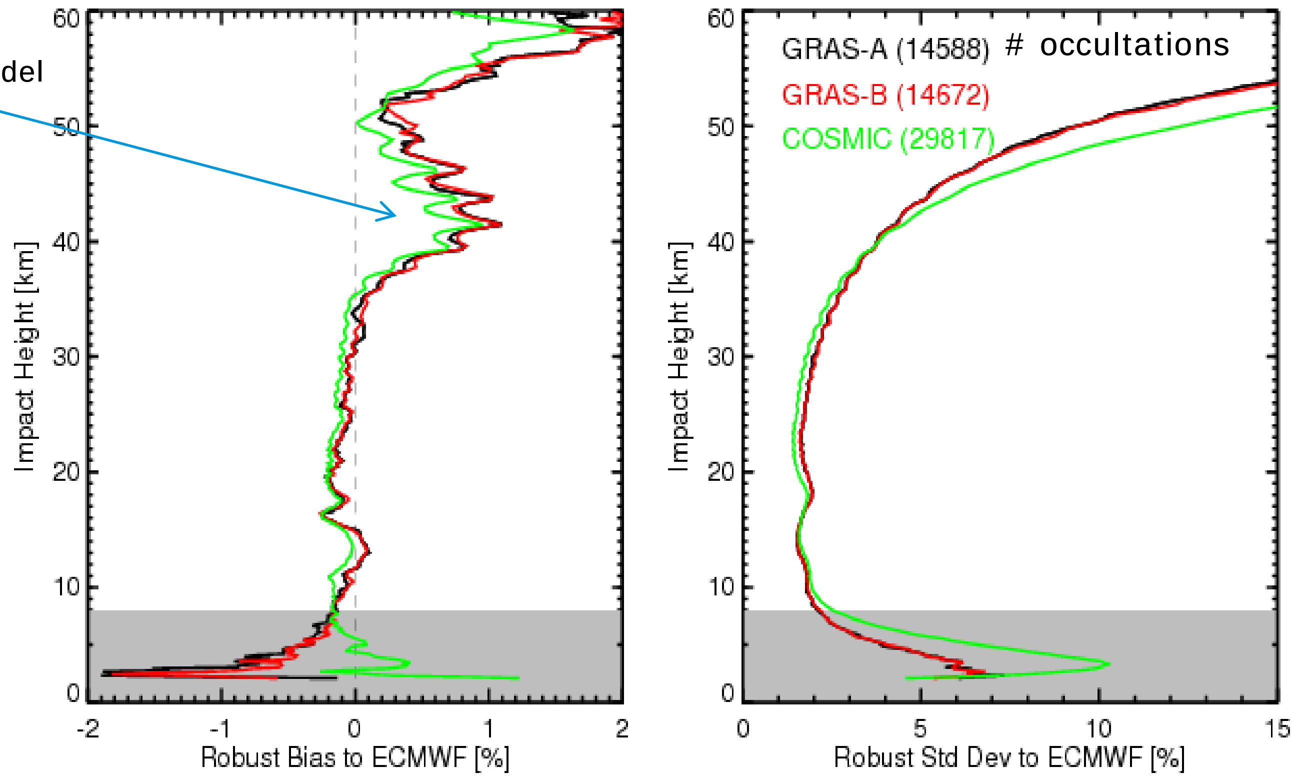


- GPS RO demonstrated to correct model ringing errors in stratosphere – in range where satellite radiances don't have benefit
- But GPS RO cannot solve all issues: at higher altitudes the bending angle depends on Density (ρ) & Temperature (T), and which if both quantities change similarly, the bending angle remains unchanged

Courtesy S. Healy (ECMWF), M.Rennie (UKMO), A. von Engeln, EUMETSAT

Metop-A / -B Val: against ECMWF

biases in the model are visible at around 40km



- Global, robust statistics of GRAS and COSMIC data versus ECMWF forecast model (from 3 weeks data)
- Very similar performance found on Metop-A and -B with respect to ECMWF
- Error of 1% in bending angle is ~1K in temperature (if one simplifies by neglecting impact of water vapour)

Courtesy S. Healy (ECMWF), M.Rennie (UKMO), A. von Engeln, EUMETSAT

Active Temperature, Ozone and Moisture Microwave Spectrometer
Courtesy R. Kursinski

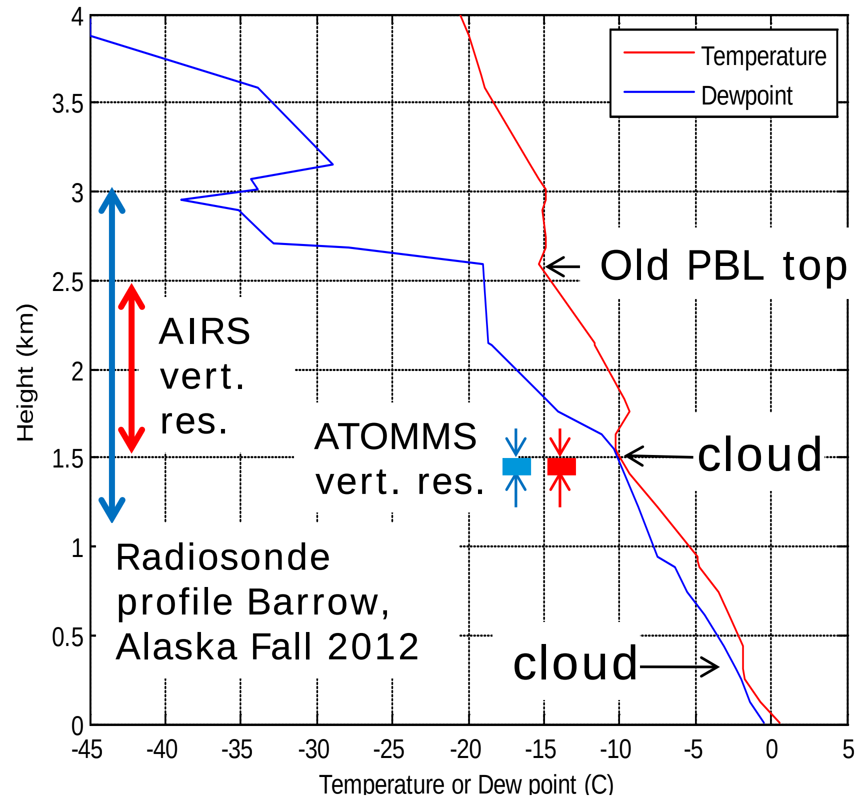
- New concept for satellite-to-satellite radio occultation (RO) system
  - Extends GPS RO by probing cm and mm wavelength H_2O & O_3 lines (22, 183 & 195GHz)
  - Enables *simultaneous* profiling of atmospheric temperature (~0.4K), pressure (~10m) and water vapor (1-3%) (which GPS RO cannot do)
  - profiles turbulence and in clouds, and is insensitive to surf. emissivity (unlike passive sounders)

⇒ **Unique radiosonde-like profiling from orbit**

High latitude Applications

- Large spread among sea ice forecasts
  - Linked to differences in modeled clouds & energy fluxes
  - Need to minimise obs. uncertainties
  - Need precise vertical observations because convection, sensible & latent heat fluxes, clouds & radiative transfer linked to vertical atmospheric structure, particularly near to surface

ATOMMS has a combination of features to determine true profile, expose biases and constrain processes, in the manner needed to improve models



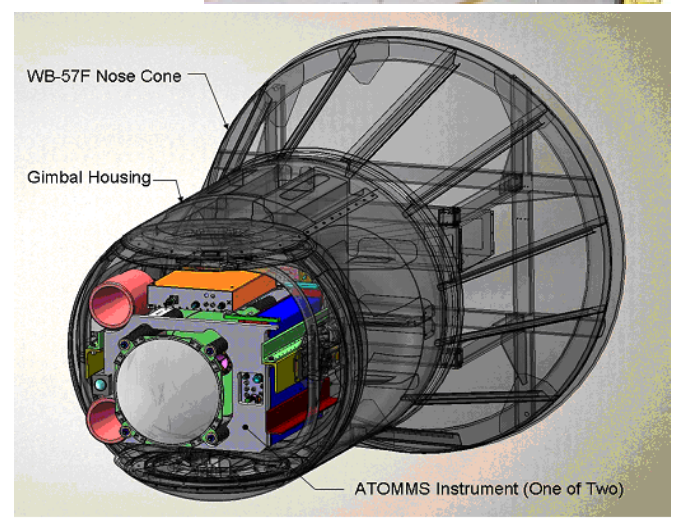
Additional uses

- Measure stability from orbit
- Constraints to help understand cloud formation conditions; complement Cloudsat, Calipso, EarthCARE like measurements
- Horizontal pressure structure driving winds
- Measure Fronts
- Assimilate ATOMMS data into NWP Analyses to initialize forecasts
- Determine climate trends
- Constrain Processes
- Build up statistical database for processes and climatology

Instrument Development Status

- Ongoing prototype demonstrations between mountaintops Next steps: aircraft-aircraft occultations, then LEO-LEO constellation of small satellites
- Aircraft to aircraft capability for field campaigns, process studies and satellite cal/val

Challenge: funding (as ever)!



Conclusion

- Broad range of satellite data products exist that can be used to help improve polar prediction capabilities
- New datasets, stimulated by the International Polar Year, can help to improve process parameterisations in models
- Future augmentations to existing observing infrastructure may deliver improvements in sampling and new types of measurements
    - ADM-Aeolus & EarthCARE
    - Robust basis data set available from MetOp and MetOp-SG and GMES Satellites for another 20 years or more
- A number of datasets available can be used for model validation or data assimilation
- The Polar Space Task Group (PSTG) has been formed amongst Space Agencies to coordinate future satellite acquisitions over the polar regions and cryosphere
    - PSTG solicits consolidated observation requirements for WWRP PPP and the WMO's Global Integrated Polar Prediction System to coordinate future observations