



Using Remote-sensed Sea Ice Thickness, Extent and Speed Observations to Optimise a Sea Ice Model

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Motivation

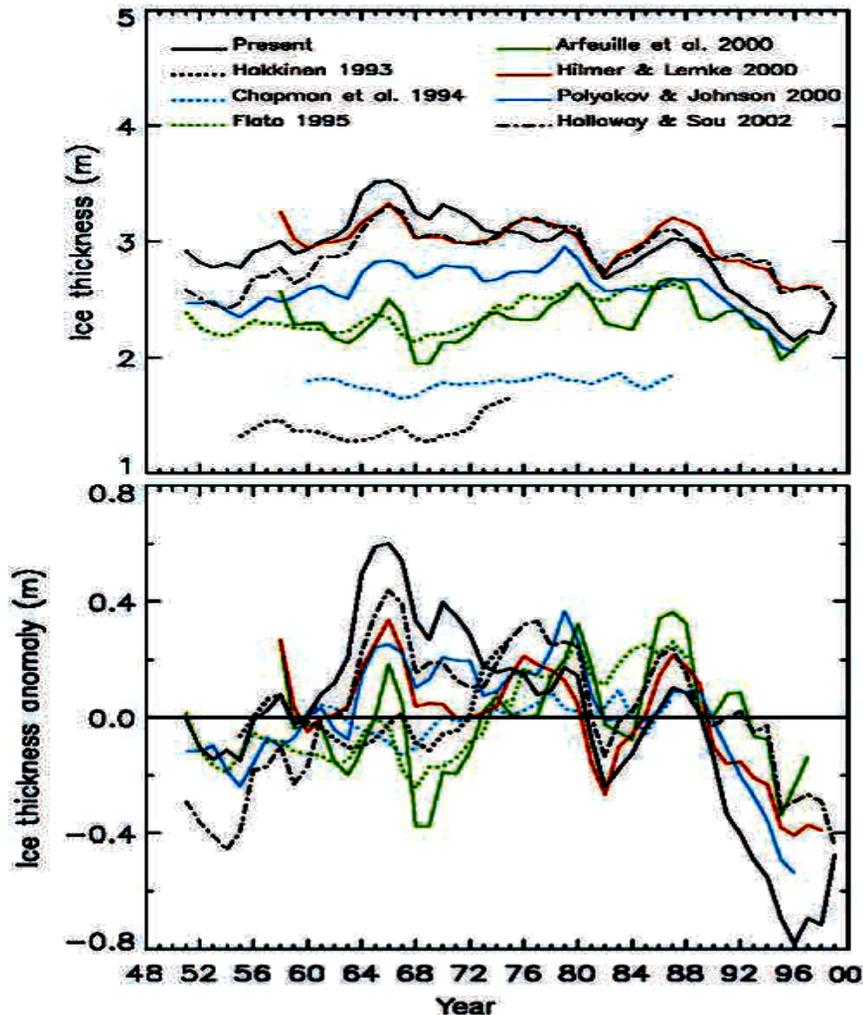
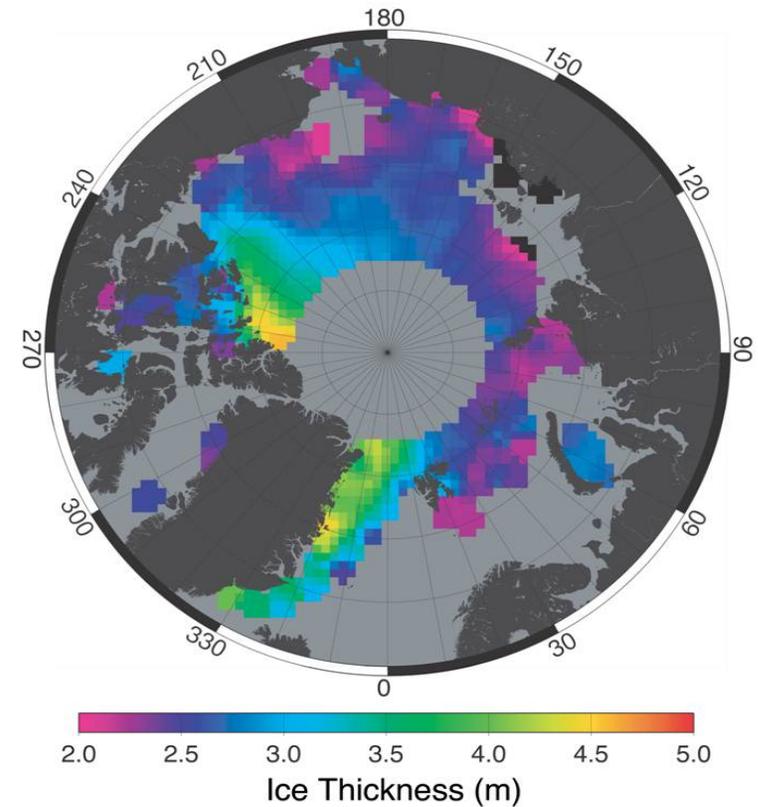


Figure 12. (Upper) Annual mean thickness from several ice models during the period 1951 to 1999. (Lower) The thickness difference from the mean over each simulation.

- ***Rothrock et al., (JGR, 2003)*** illustrated the significant differences, in both means and anomalies, between model simulations of recent Arctic ice thickness
- Reasons for differences not well understood, but there is both parameter and forcing uncertainty
- How can we reduce this uncertainty and increase our confidence in conjectures based on model output?

Reducing Parameter Uncertainty in Sea Ice Models

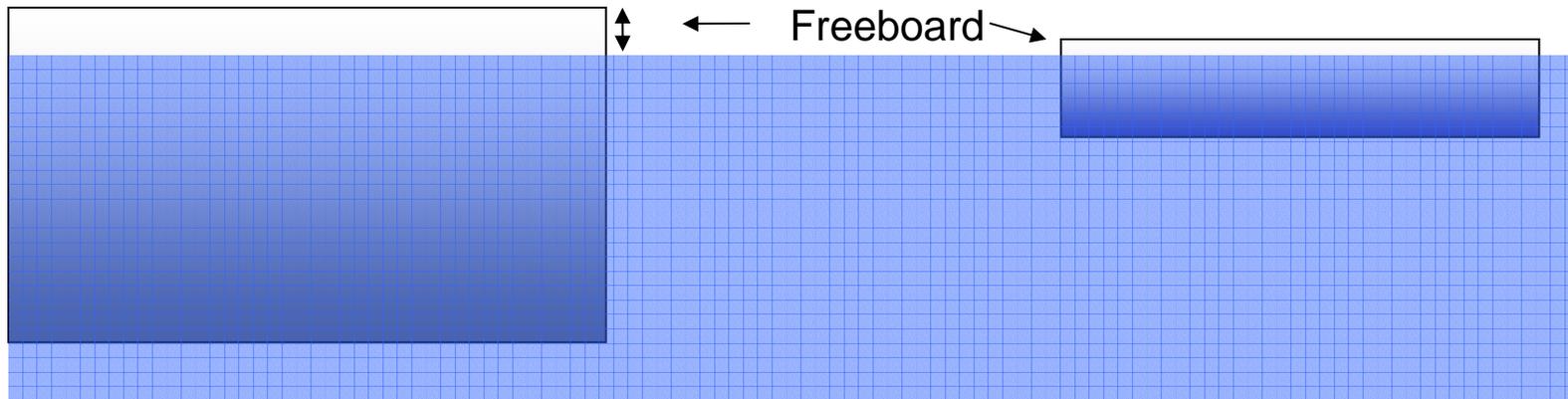
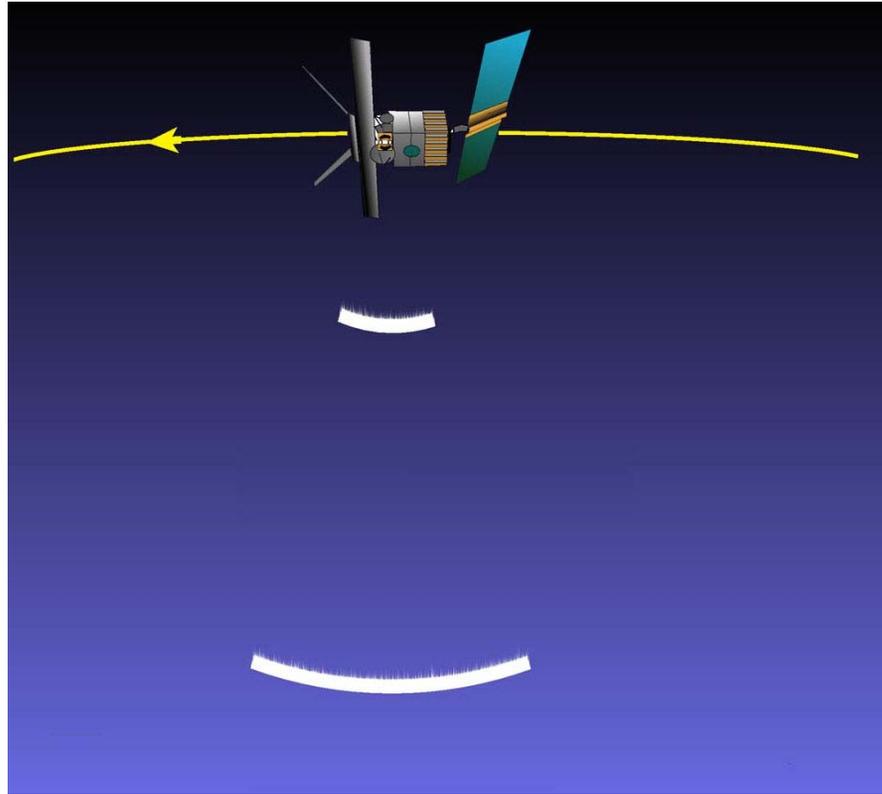
- Use the Los Alamos sea ice model, **CICE**, and force it with ERA-40 & POLES data
- Optimise and validate the model using a comprehensive range of sea ice observations:
 - Sea ice **velocity**, 1994-2001 (SSM/I + buoy + AVHRR, *NSIDC*)
 - Sea ice **extent**, 1994-2001 (SSM/I, *NSIDC*)
 - Sea ice **thickness**, 1993-2001 (ERS radar altimeter, *Laxon et al., Nature, 2003*)



We used this model and forcing to reduce uncertainty surrounding sea ice model parameters

Satellite Altimetry - Measurement Principle

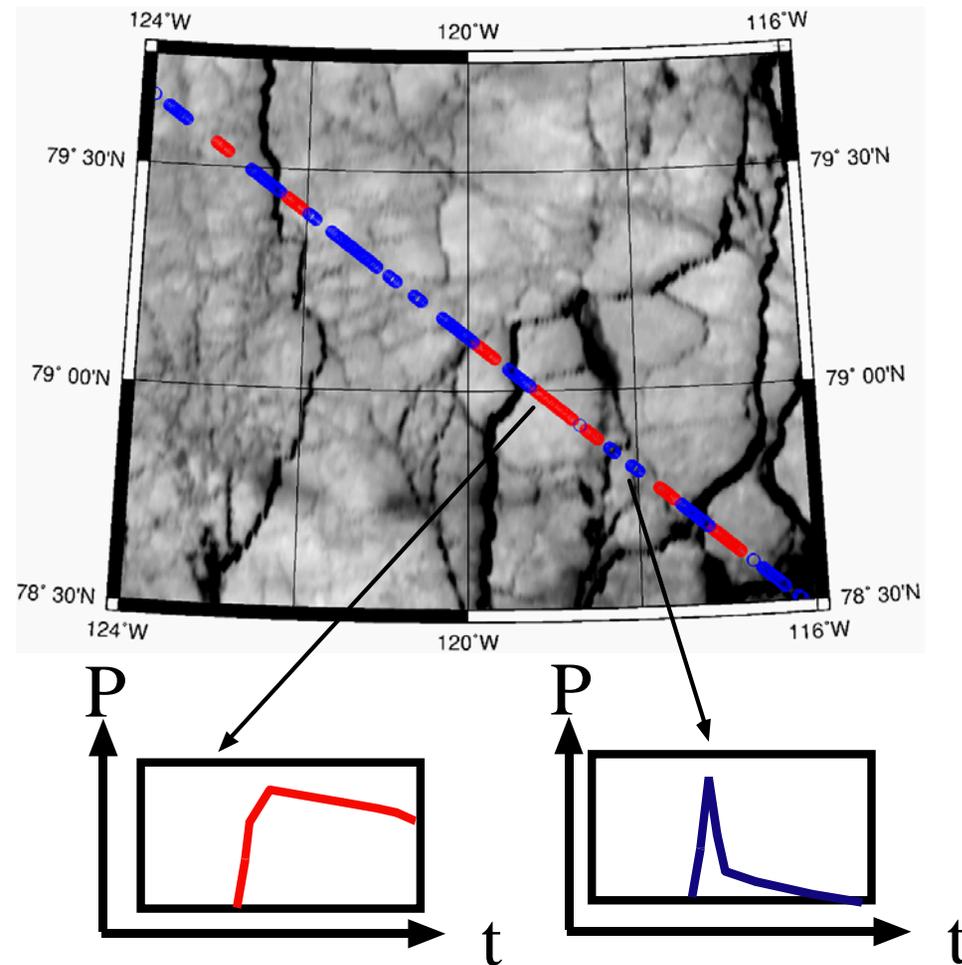
$$h = \frac{ct}{2}$$



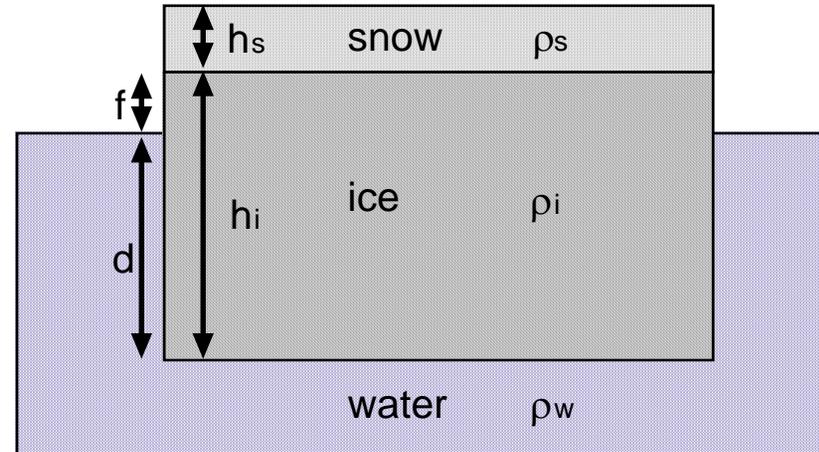
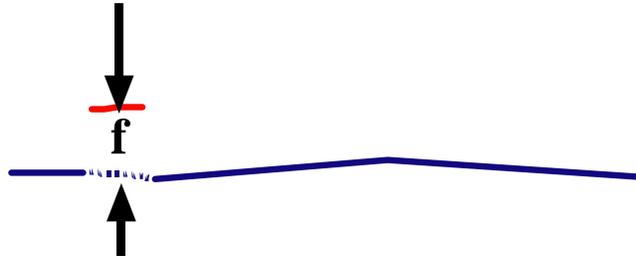
Origin of Radar Altimeter Sea Ice Echoes - ERS



- Co-incident ATSR imagery reveals the origin of **Diffuse** and **Specular** echoes over sea ice
- **Diffuse echoes originate from ice floes**
- **Specular echoes originate from leads**
- Gaps are caused by Complex echoes which are excluded



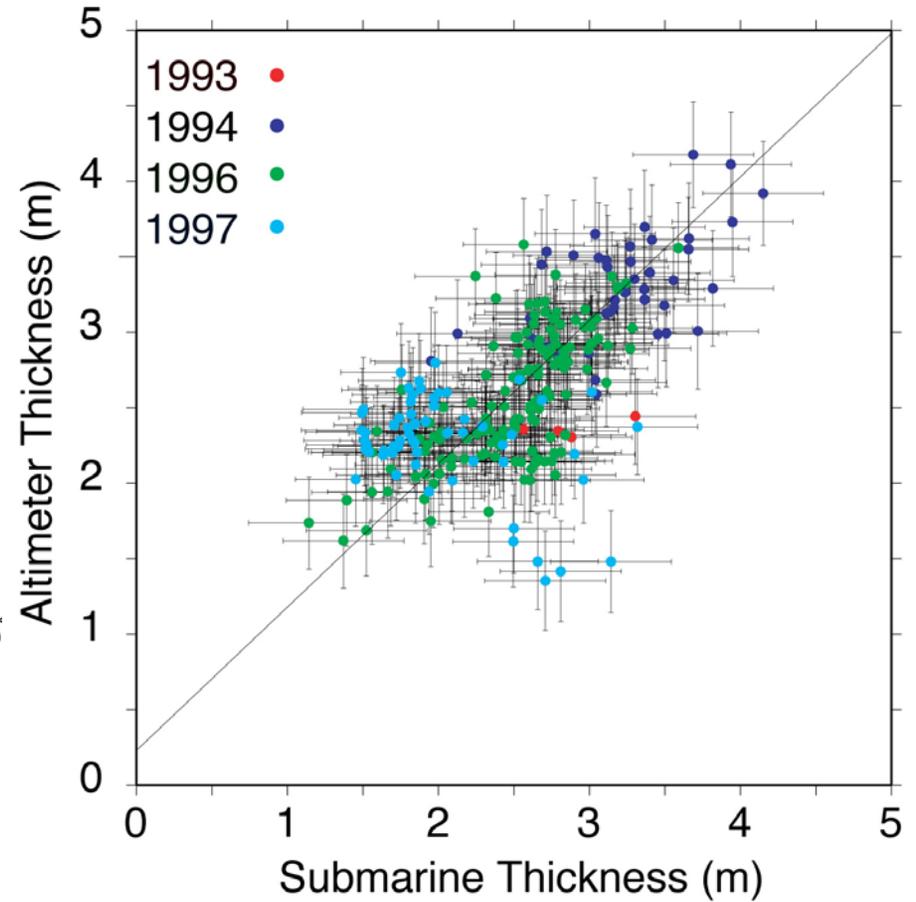
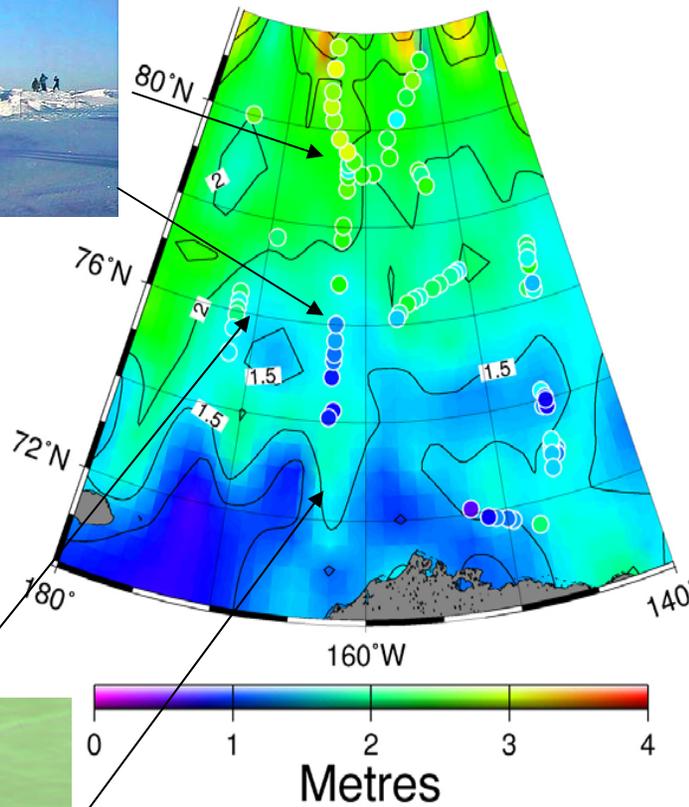
Freeboard to Thickness Conversion



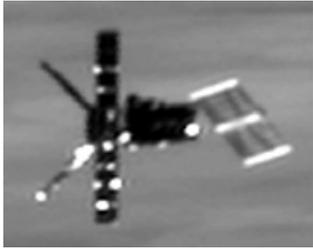
- Conversion assumes reflection from the ice/snow interface
- Conversion to thickness uses climatology of snow depth/densities
(Warren et al., J. Climate 1999)

$$h_i = f \frac{\rho_w}{(\rho_w - \rho_i)} + \frac{h_s \rho_s}{(\rho_w - \rho_i)}$$

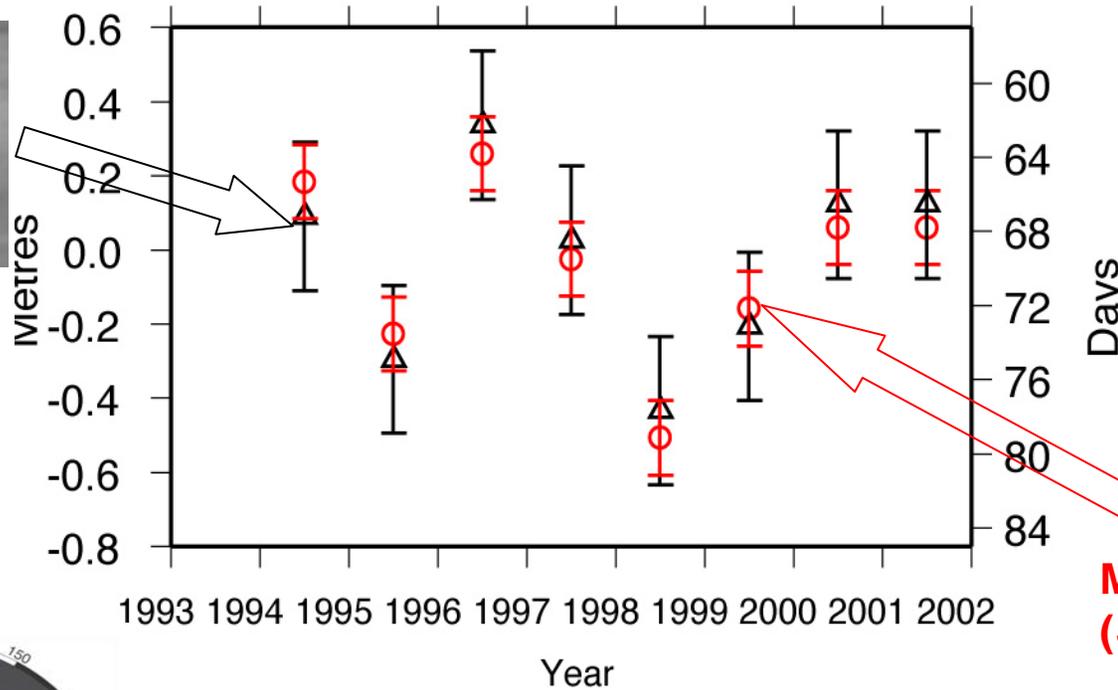
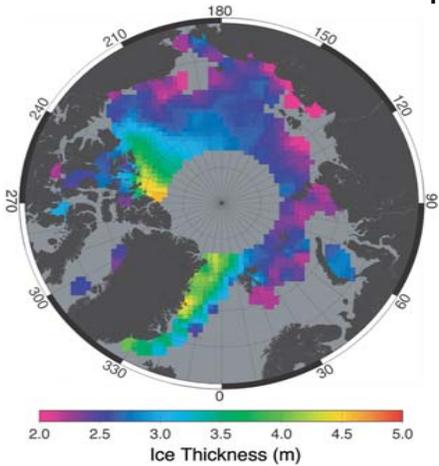
ERS Altimeter Ice Thickness Validation



Ice Thickness - Summer Melt



Sea Ice Thickness Change



Melt Season Length (Smith, GRL, 1998)

22 NEWS

Vanishing ice may destroy polar bears' habitat

BY STEVE CONNOR, Science Editor

A SKETCHY thinning of sea ice across the Arctic region has been confirmed for the first time by a satellite study which predicts the imminent demise of the only natural habitat for the polar bear. Climate scientists said yesterday they had established an unambiguous link between the melting of the Arctic and rising temperatures caused by global warming. There will be little or no ice left for the polar bear to use as its vital hunting ground within 100 years, if trends continue, the researchers say. Previous studies on the extent of the Arctic sea ice have had to rely on sporadic measurements taken by the sonar instruments of military submarines. Those studies showed that, in some regions, the ice had thinned by about 40 per cent between the 1960s and the early 1990s, but there was a suspicion that the ice might simply have been blown from one region to another. The latest study published in the journal *Nature*, uses a far



A study predicts there will be little ice left in a century for polar bears to hunt on

the thickness of the ice from space across the entire Arctic and for the first time we've made a clear link between longer Arctic summers, rising temperatures and the thinning of the ice. The sea ice in the Arctic is about 2.7 metres (nine feet) thick on average and has thinned by about 1.3 metres in the past 30 years. The latest study shows that, in the eight years to 2001, the ice thinned by a further 50cm.

Ice-cover in the Arctic goes through dramatic changes over the yearly cycle, freezing during the winter months and melting during the long summer days. A previous satellite study revealed that the length of the Arctic summer - the period from when the ice begins to melt to when it begins to freeze again - had gradually lengthened in the past 20 years, with summer getting longer by about five days every decade, Dr Laxon said. In the winter months, and especially in the early spring, polar bears need the ice to hunt for seals, Bernard Stonehouse, from the Scott Polar Research Institute in Cambridge, said that as the ice retreated, there was their opportunity to find food. "The ice varies a great deal from year to year. The most likely consequence of this is that there will be more bad ice years

THE INDEPENDENT Thursday 30 October 2003

than good ones. It's also more likely to affect the seals who live on the ice," Dr Stonehouse said. Dr Laxon said that the disappearing sea ice in the Arctic could affect ocean currents, in particular the warm Gulf Stream, which keeps winters in Britain relatively mild.

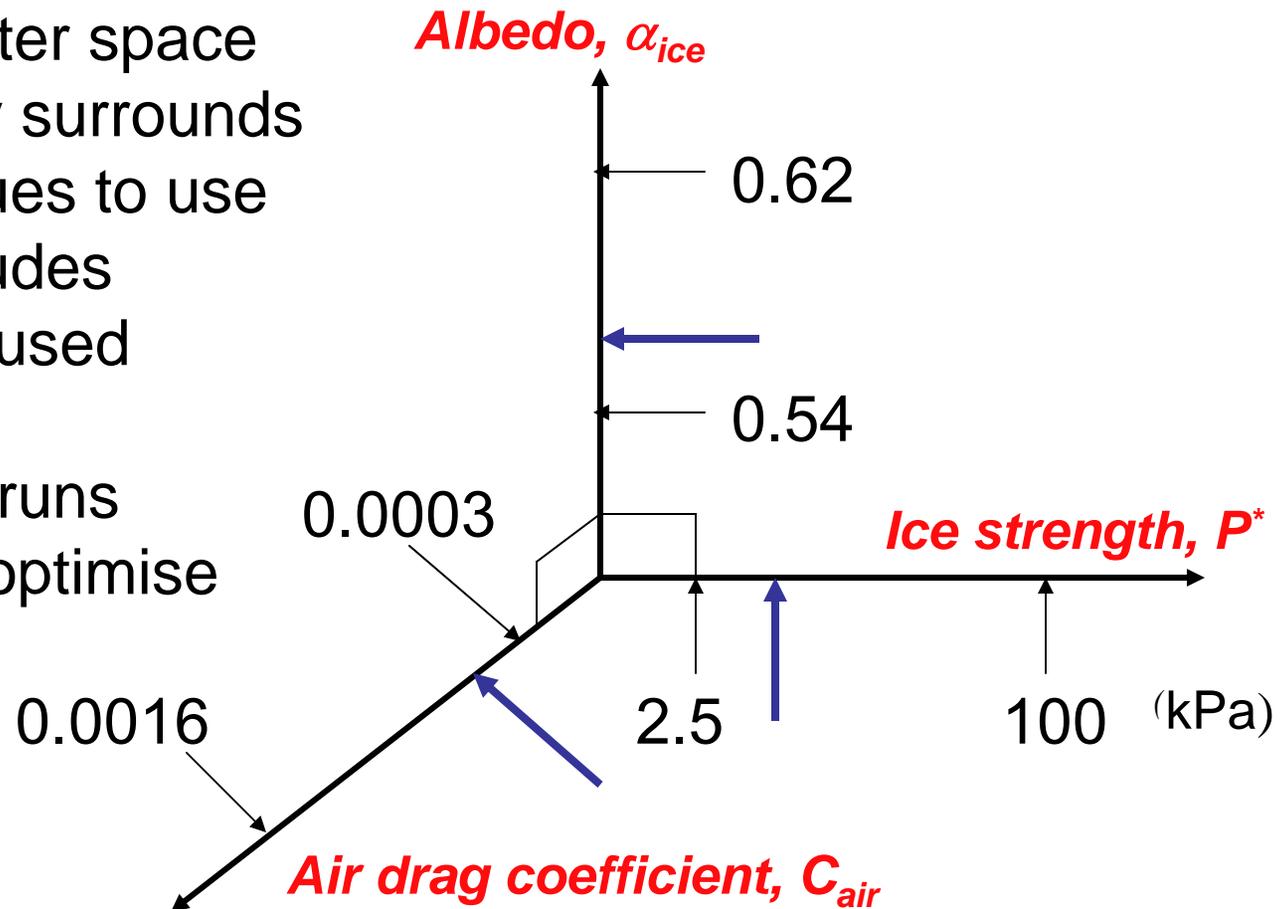


Laxon et al., Nature, 2003

Parameter Space

We explored the model's multi-dimensional parameter space to find the best fit to the observational data

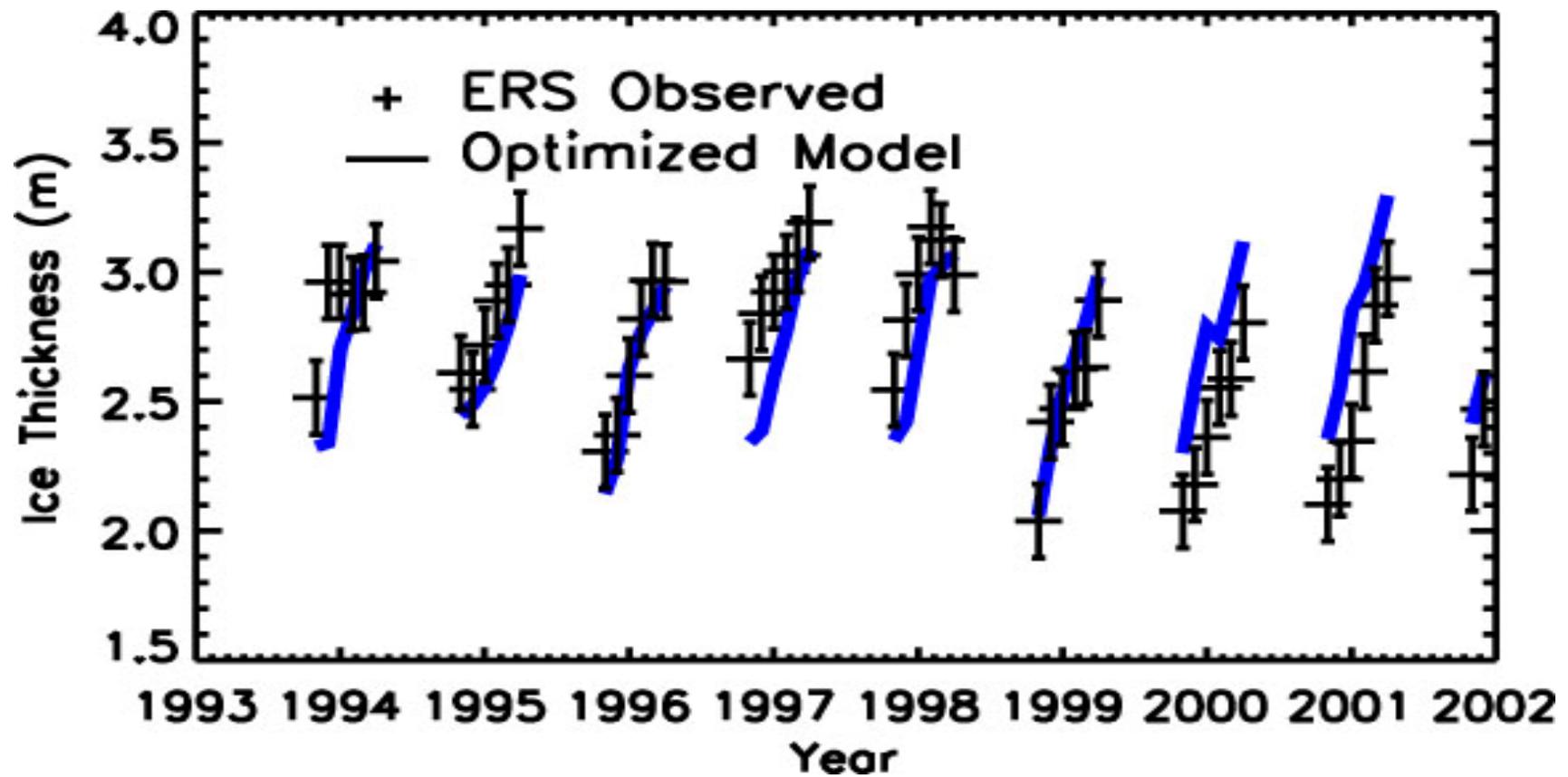
- 3D parameter space
- Uncertainty surrounds correct values to use
- Space includes commonly-used values
- 168 model runs needed to optimise model



Arctic Basin Ice Thickness

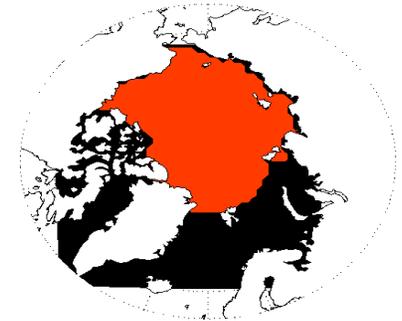


$$\{\alpha_{ice}, C_{air}, P^*\} = \{0.56, 0.0006, 5 \text{ kPa}\}$$

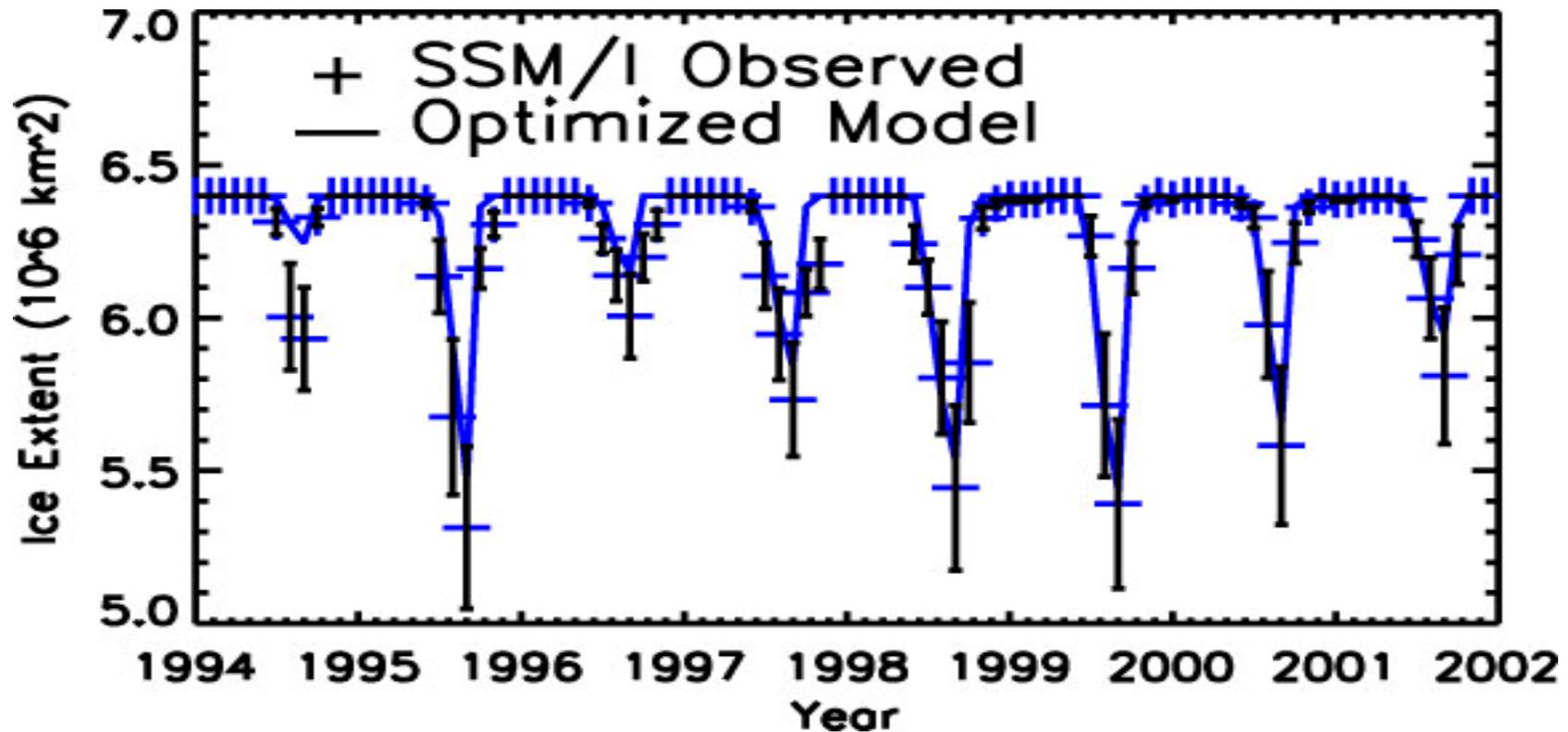


Miller et al., J. Climate, submitted

Arctic Basin Ice Extent



$$\{\alpha_{ice}, C_{air}, P^*\} = \{0.56, 0.0006, 5 \text{ kPa}\}$$

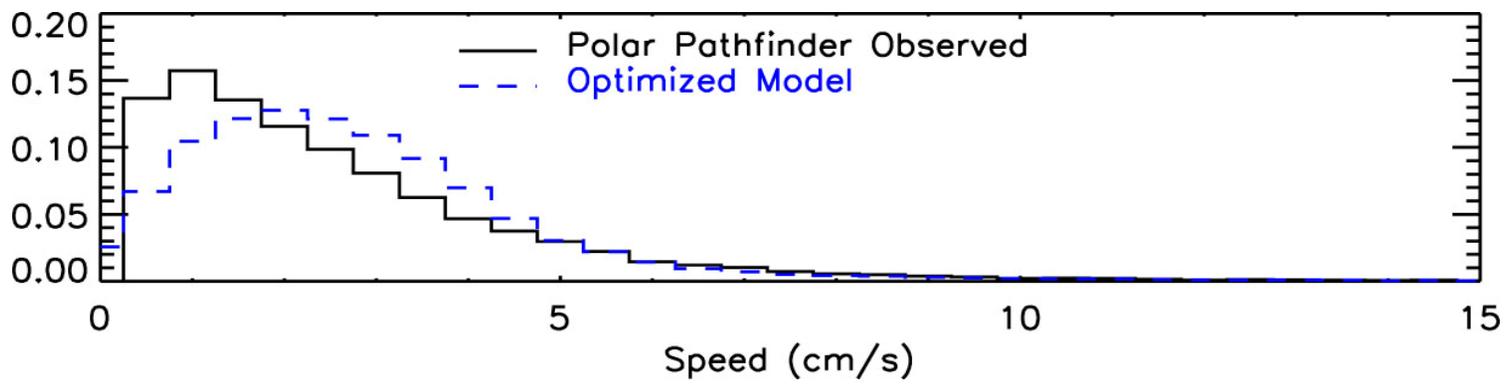
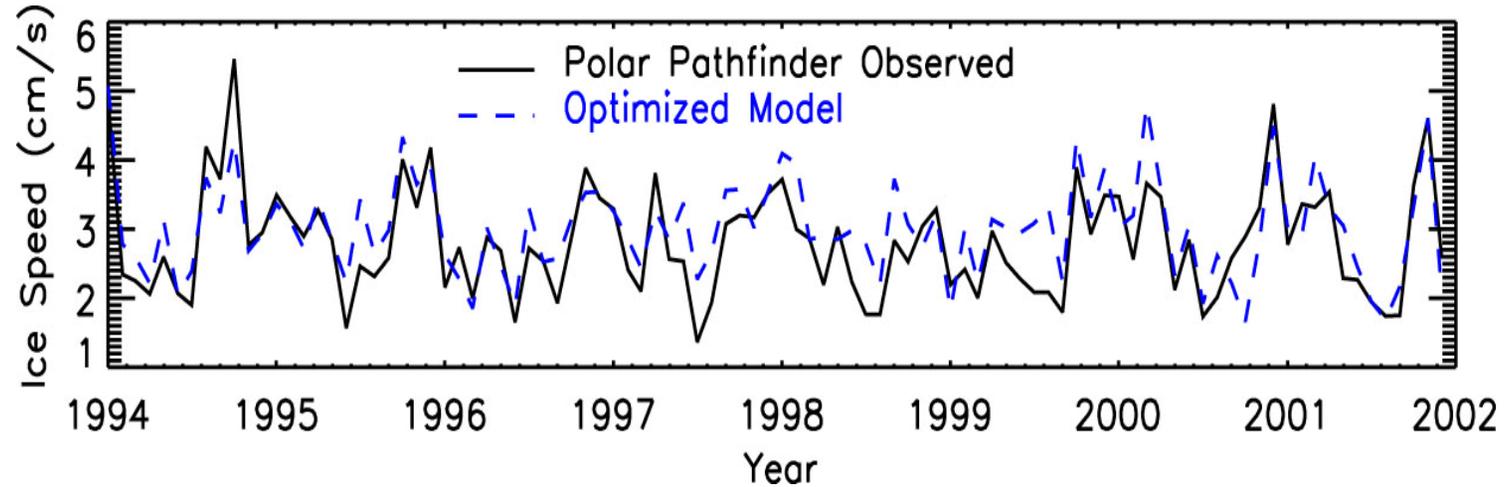


Miller et al., J. Climate, submitted

Arctic Basin Ice Speeds

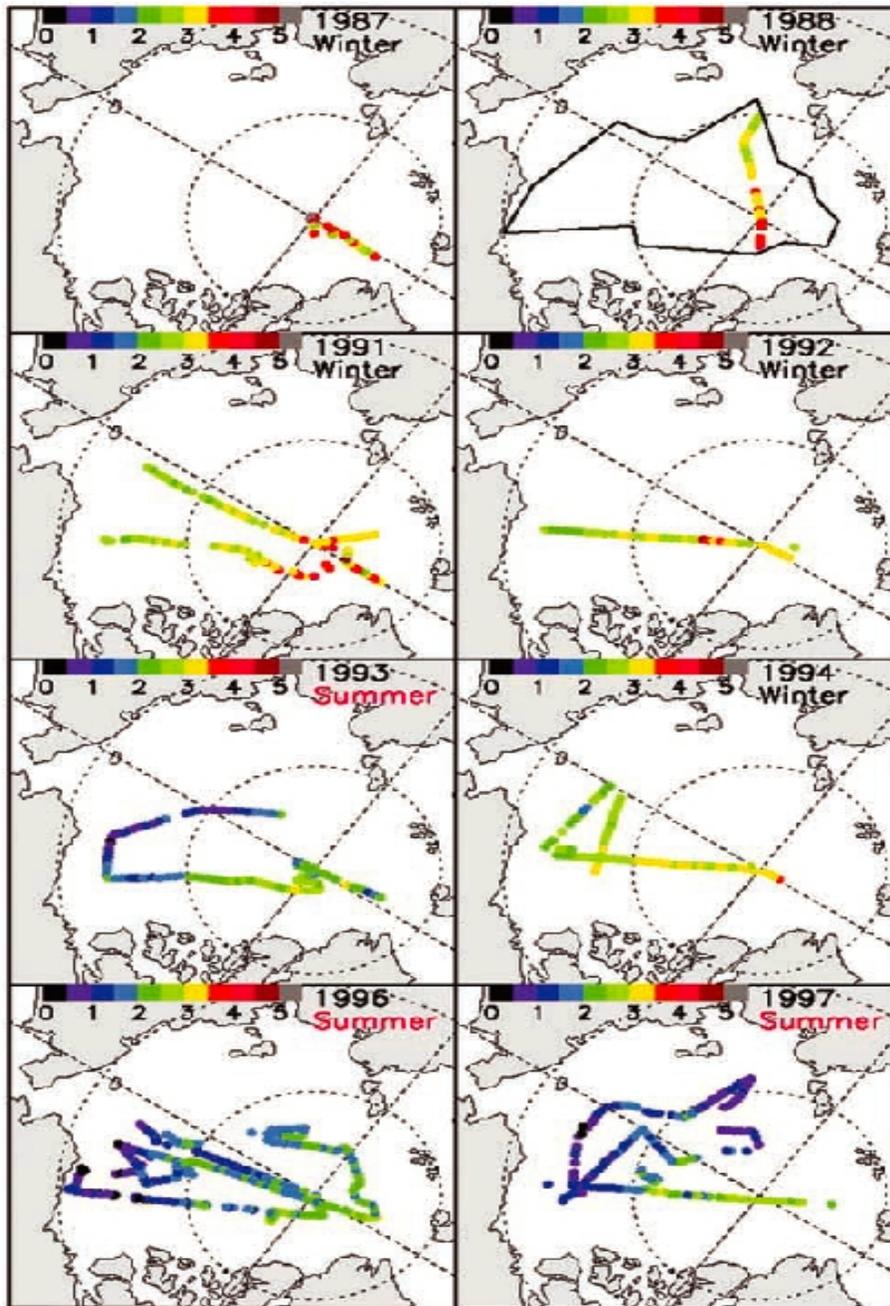


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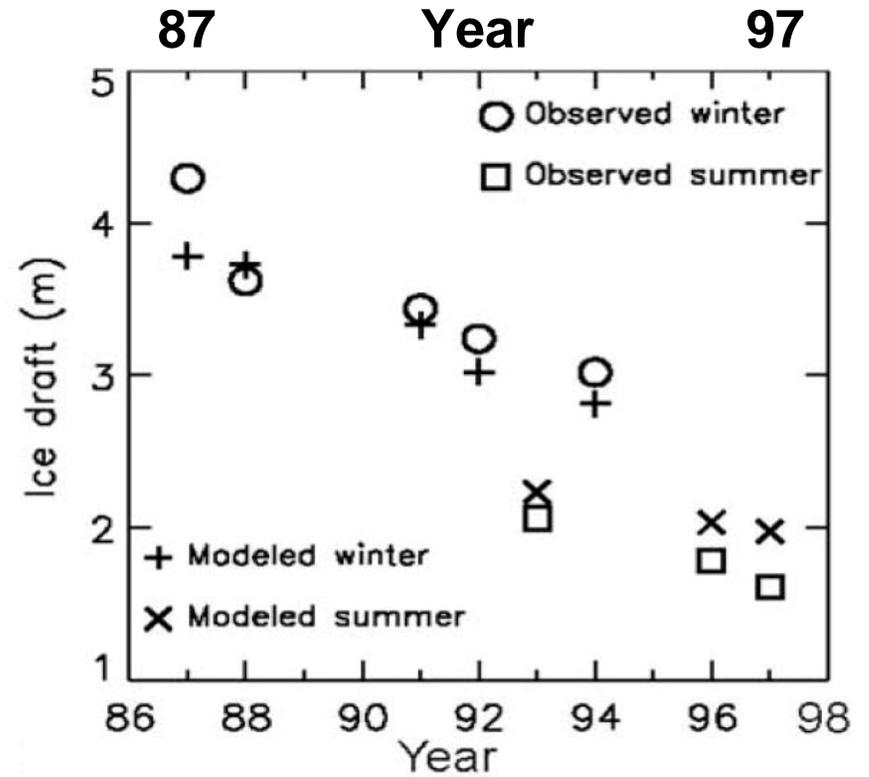


Miller et al., J. Climate, submitted

Rothrock et al., 2003, JGR, 108(C3), 3083



Validation With ULS Draft Data



$R = 0.98$

RMS difference = 0.28m

Spatial Draft Discrepancy

Rothrock et al., JGR, 2003, 108(C3), 3083

Optimised CICE Model

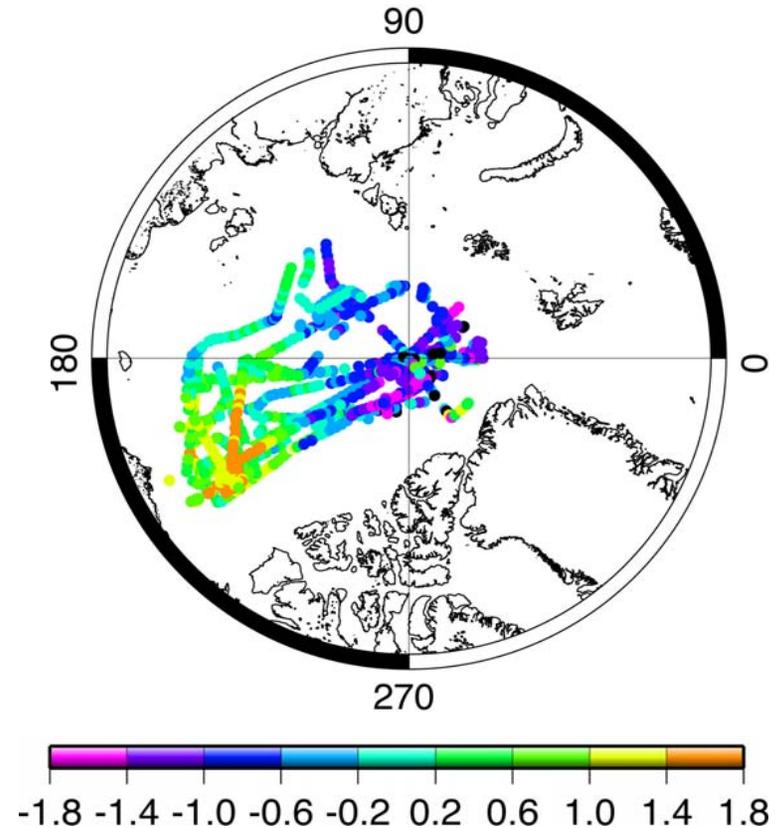
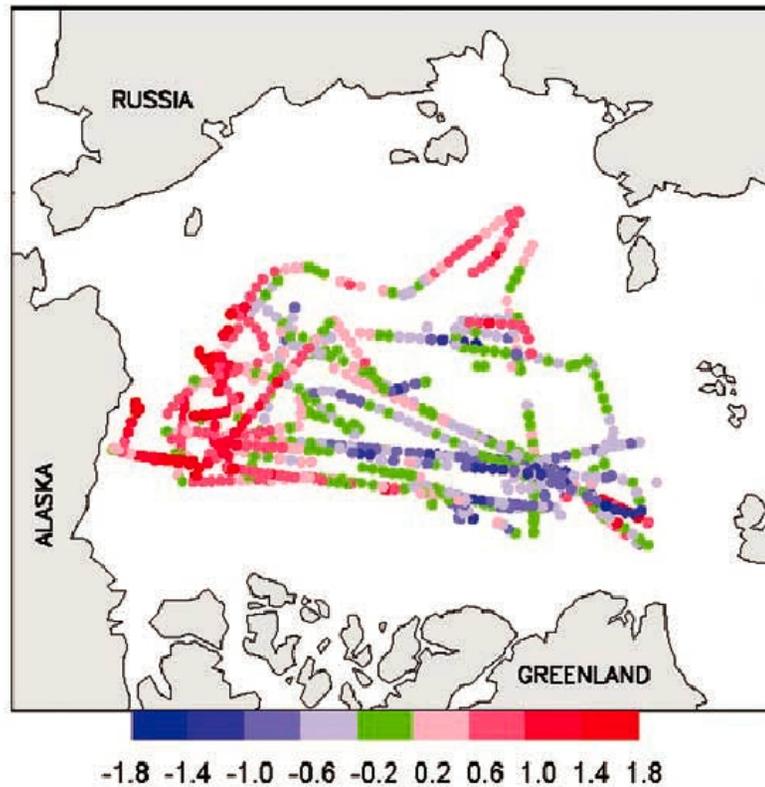


Figure 9. Modeled minus observed mean draft (m) along cruise tracks from 1987 to 1997.

Model - ULS Observed Draft (m)

Improved Spatial Distribution

Rothrock et al., JGR, 2003, 108(C3), 3083

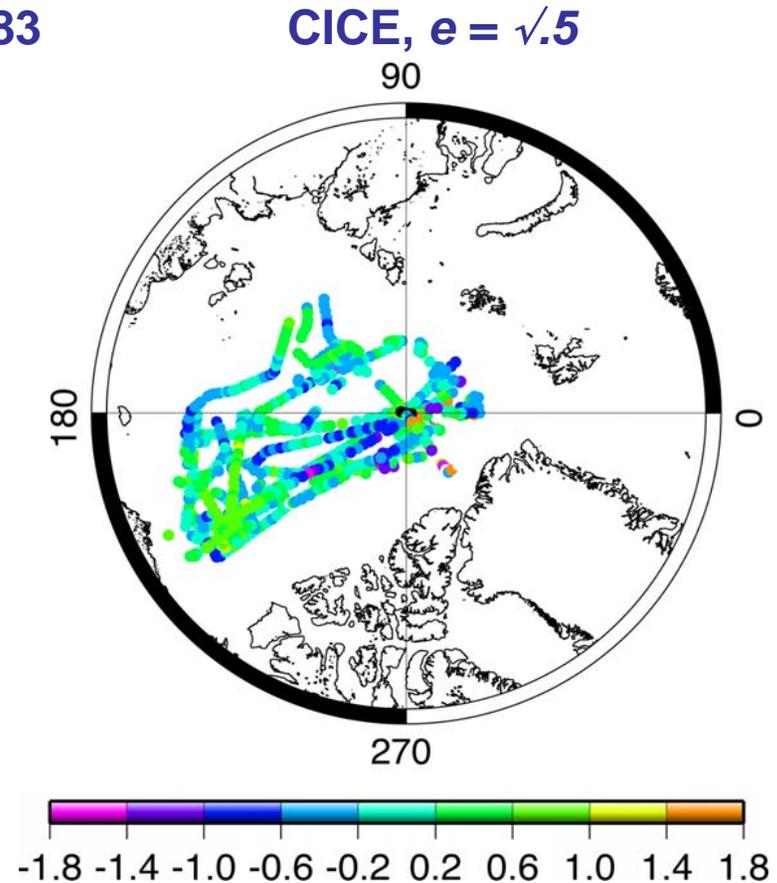
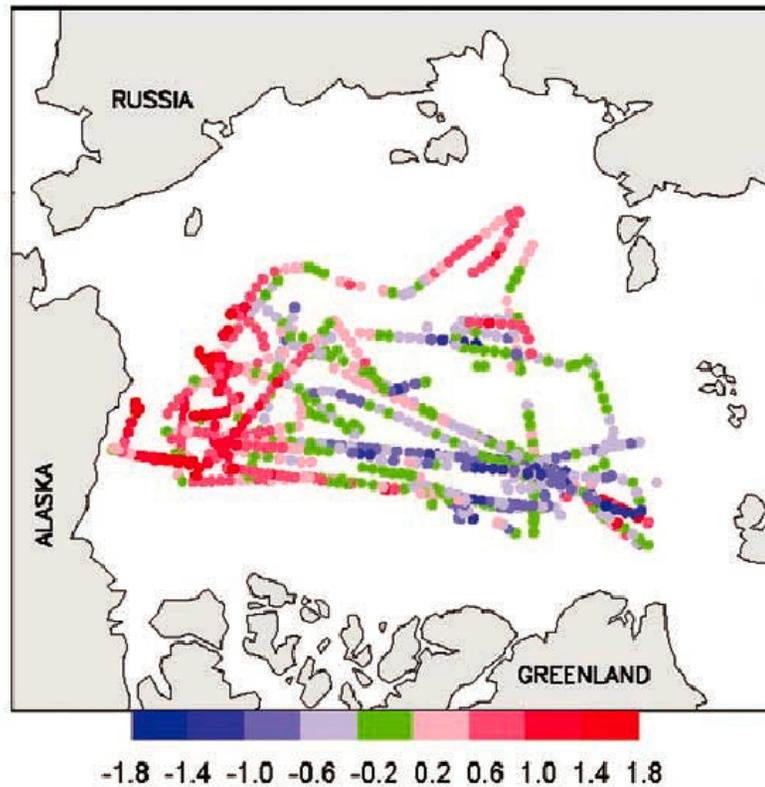
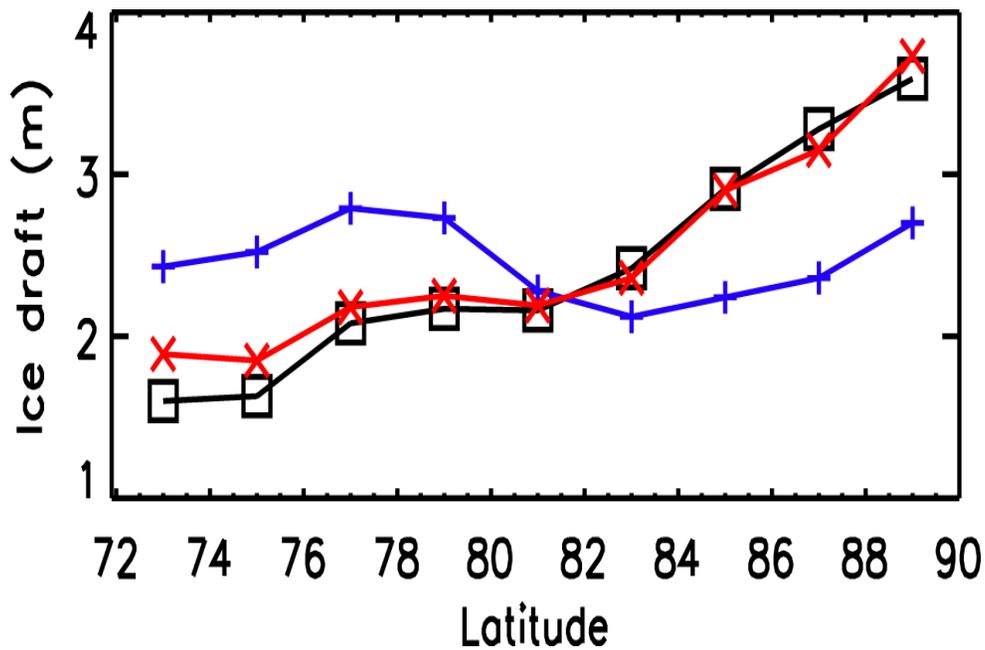


Figure 9. Modeled minus observed mean draft (m) along cruise tracks from 1987 to 1997.

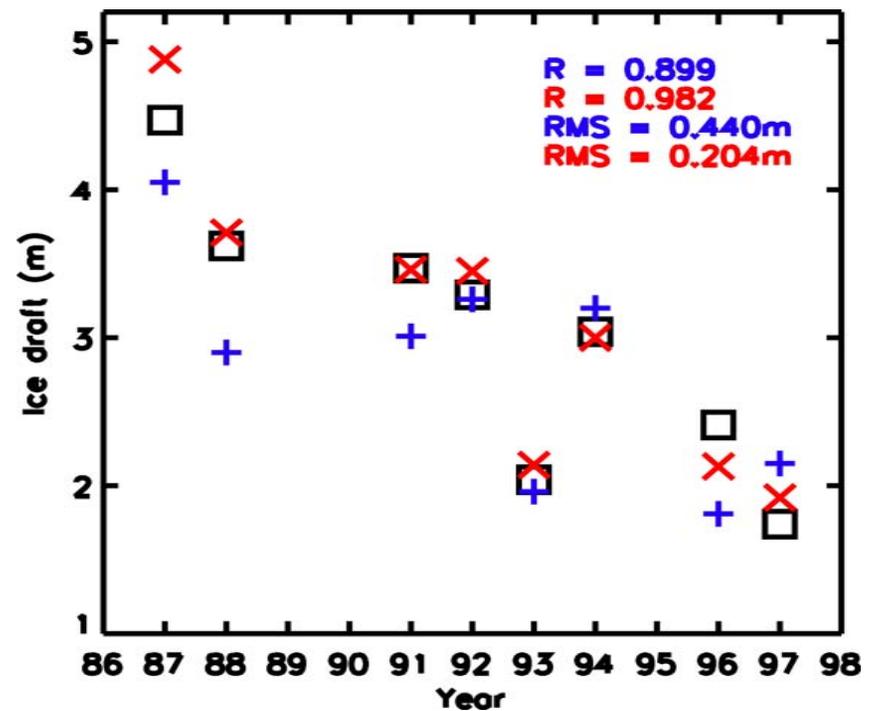
Model - ULS Observed Draft (m)

Zonal and Interannual Variability

Zonal Draft Averages

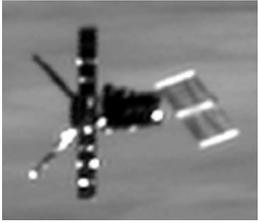


Cruise Averages

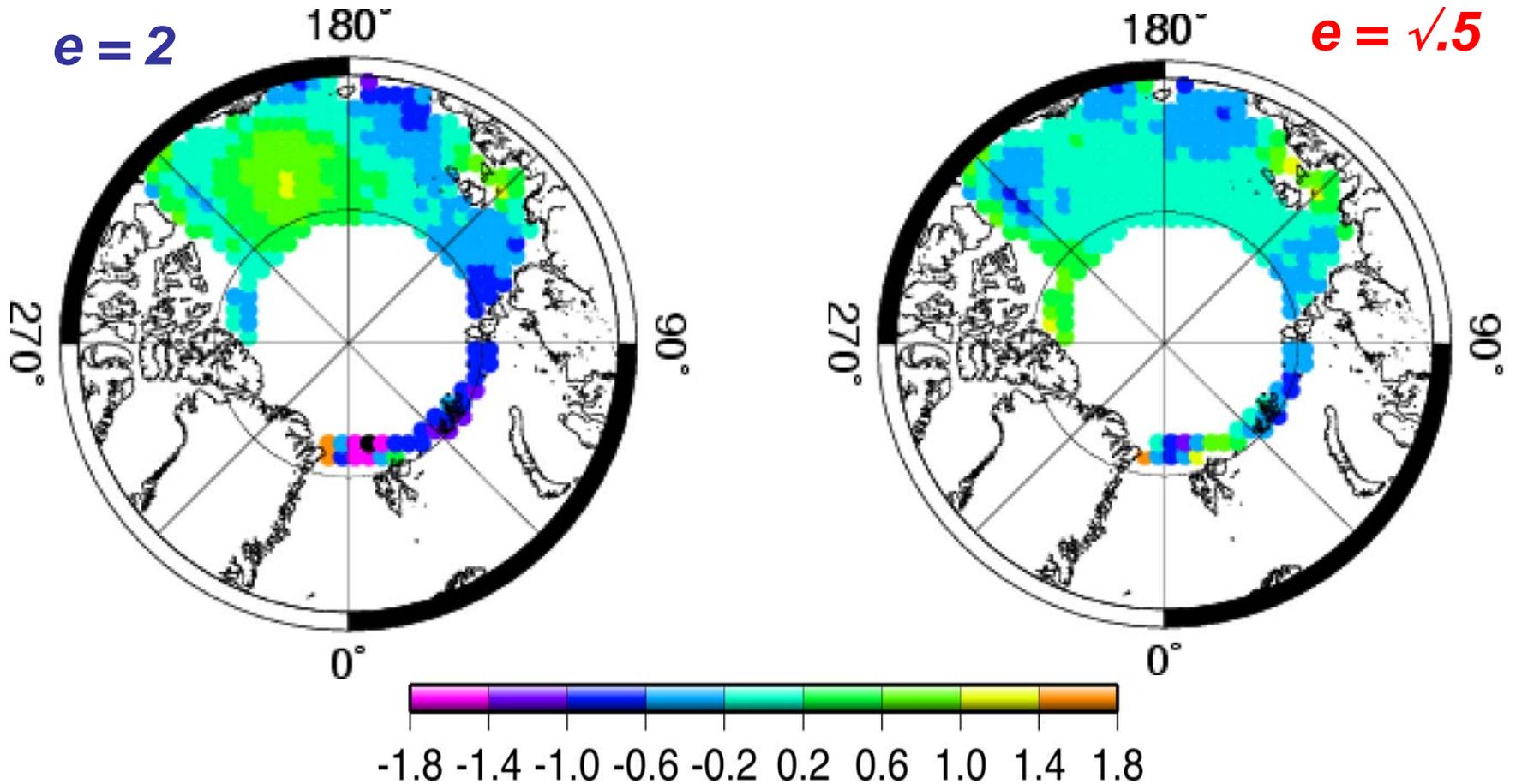


◆ - Observed $e = 2$ $e = \sqrt{.5}$

Miller et al., GRL, submitted

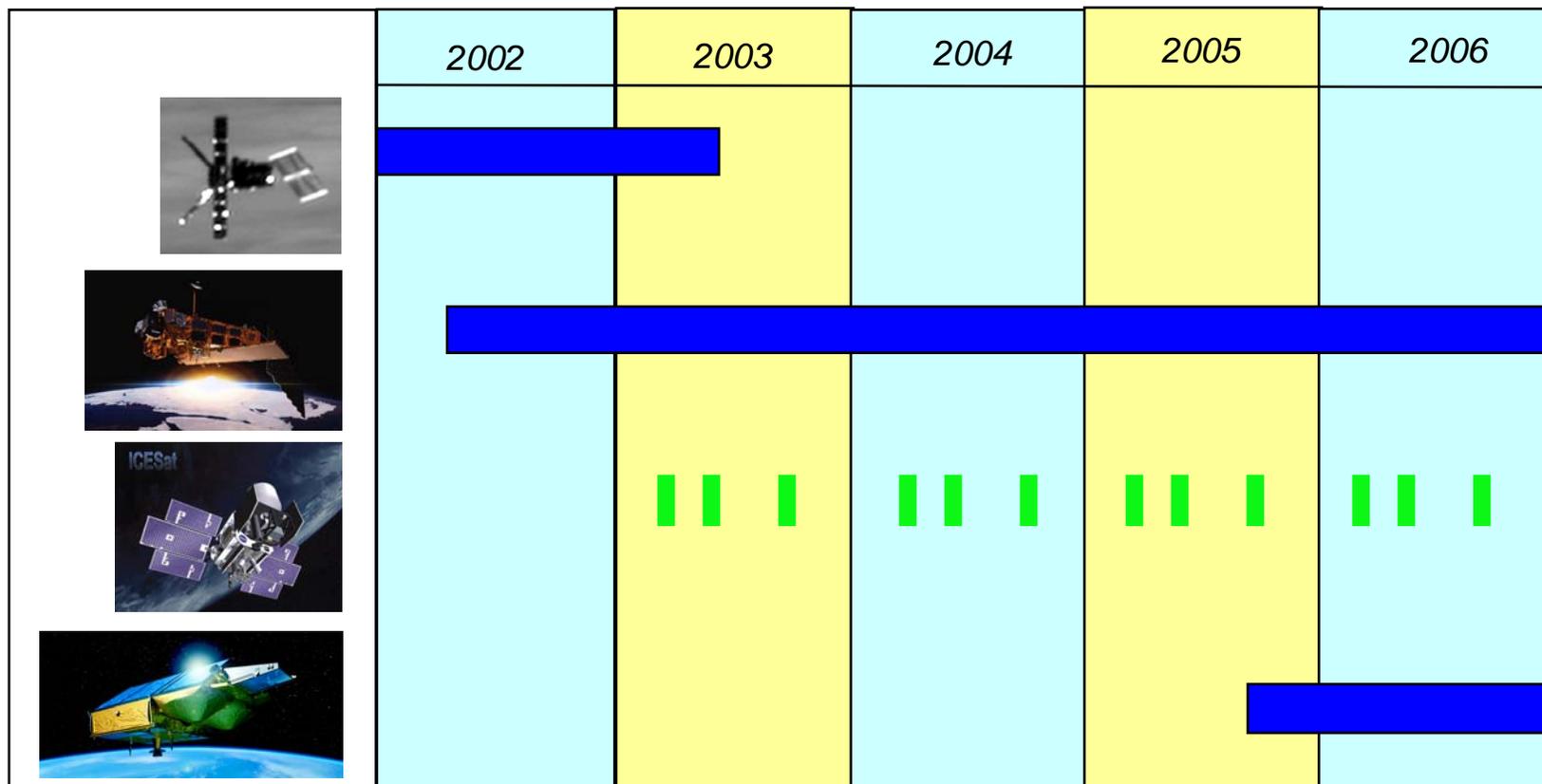


Model vs ERS Mean Winter Ice Thickness



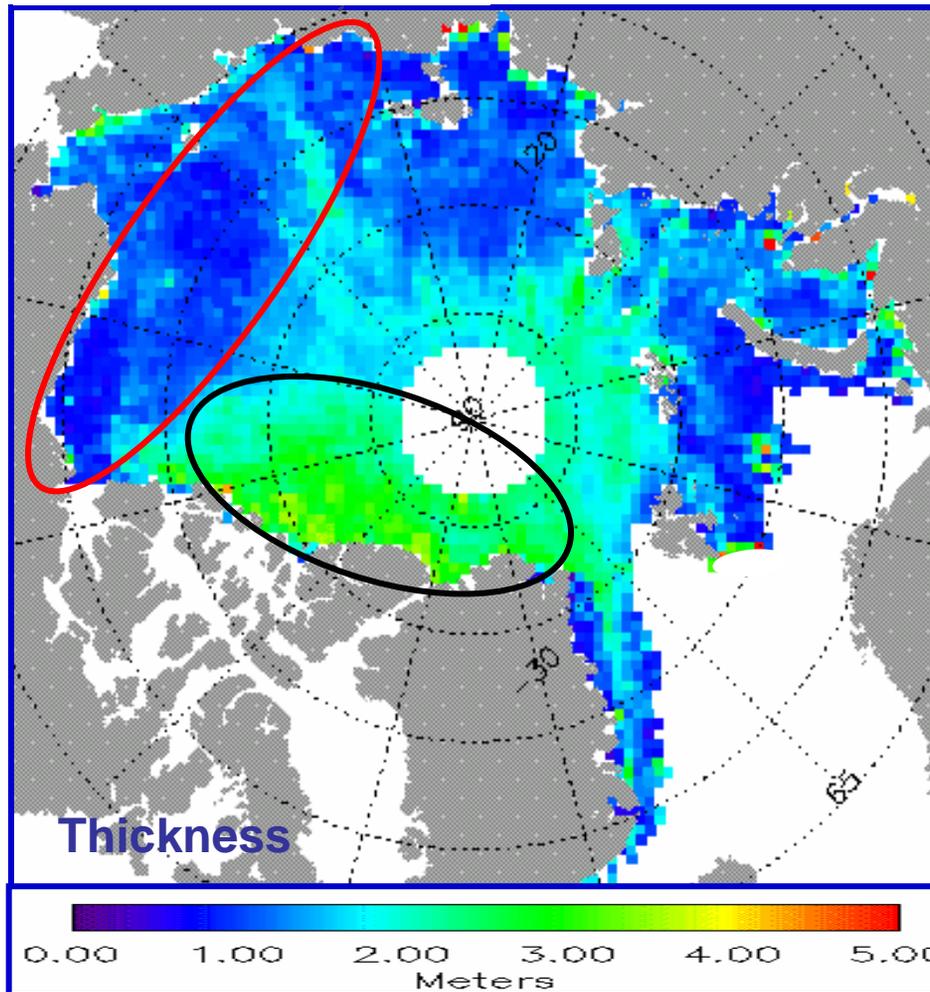
Model - Satellite Thickness (m)

Satellite Altimeter Missions 1993 -

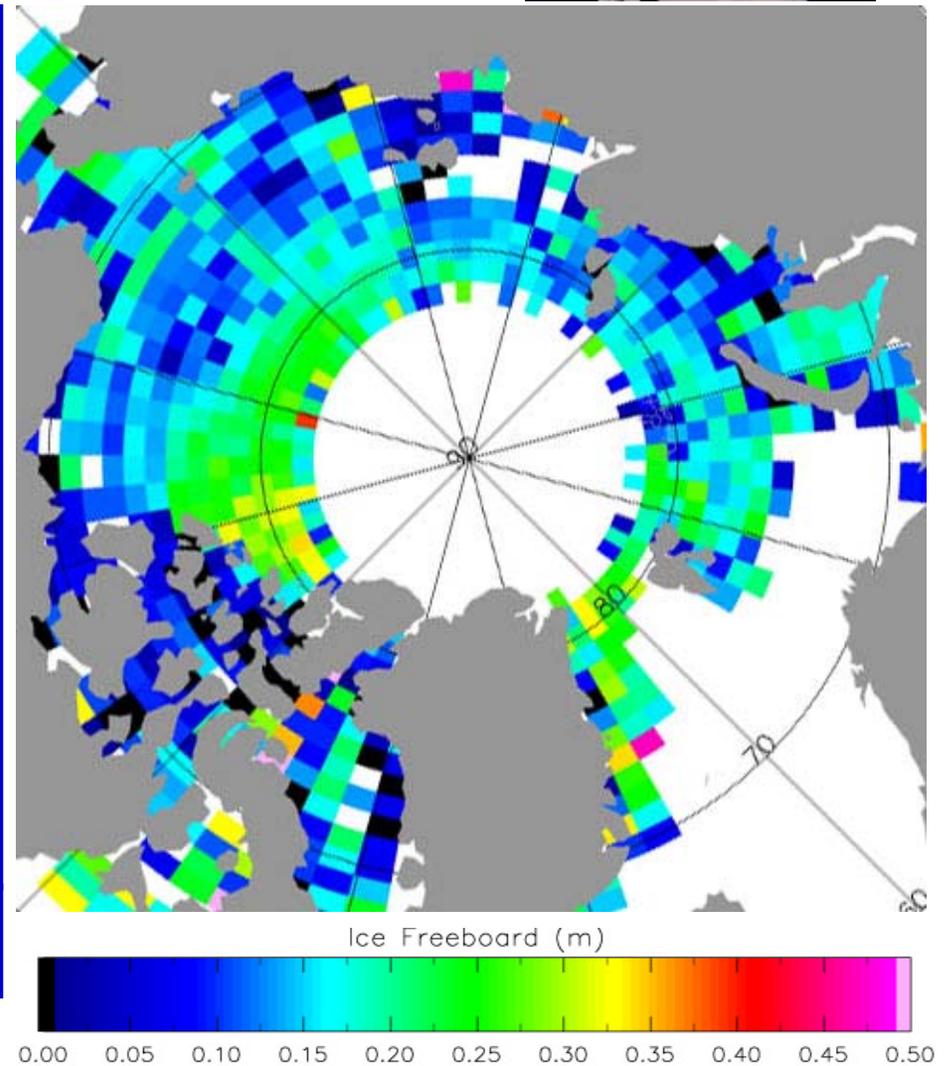




IceSat vs Envisat RA-2 March 2003



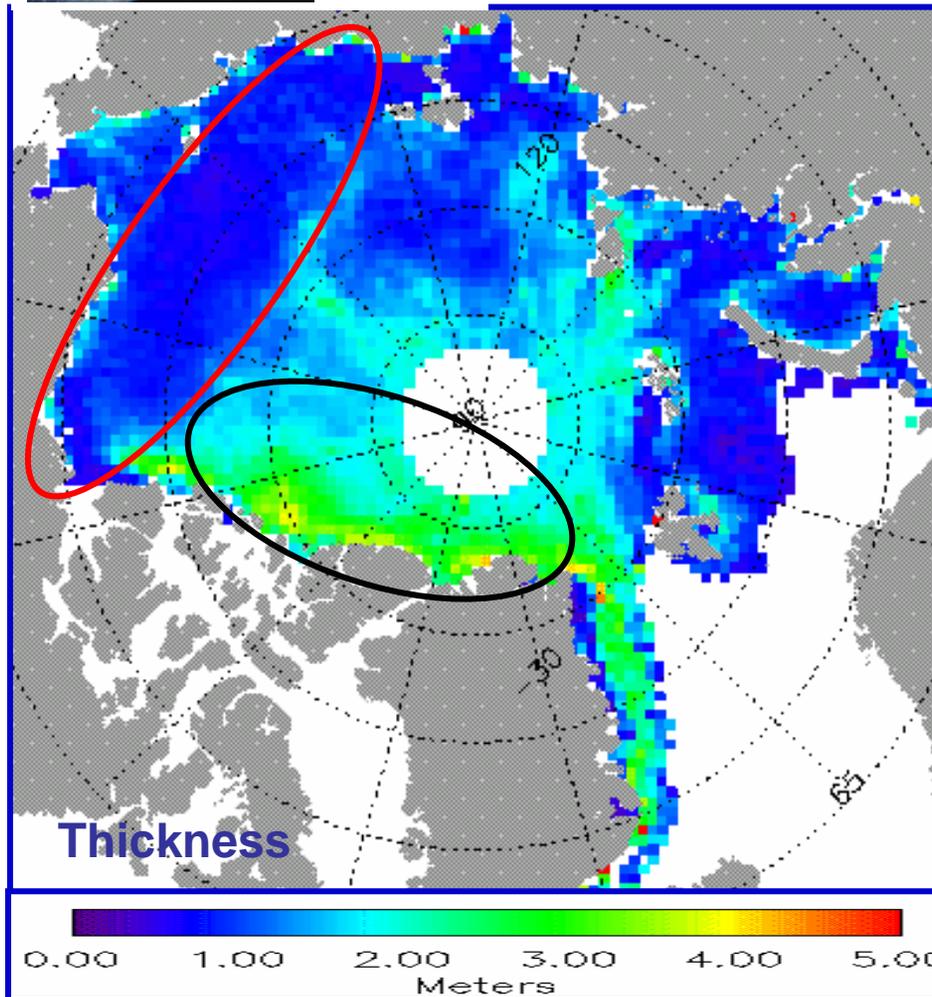
[Courtesy J. Zwally]



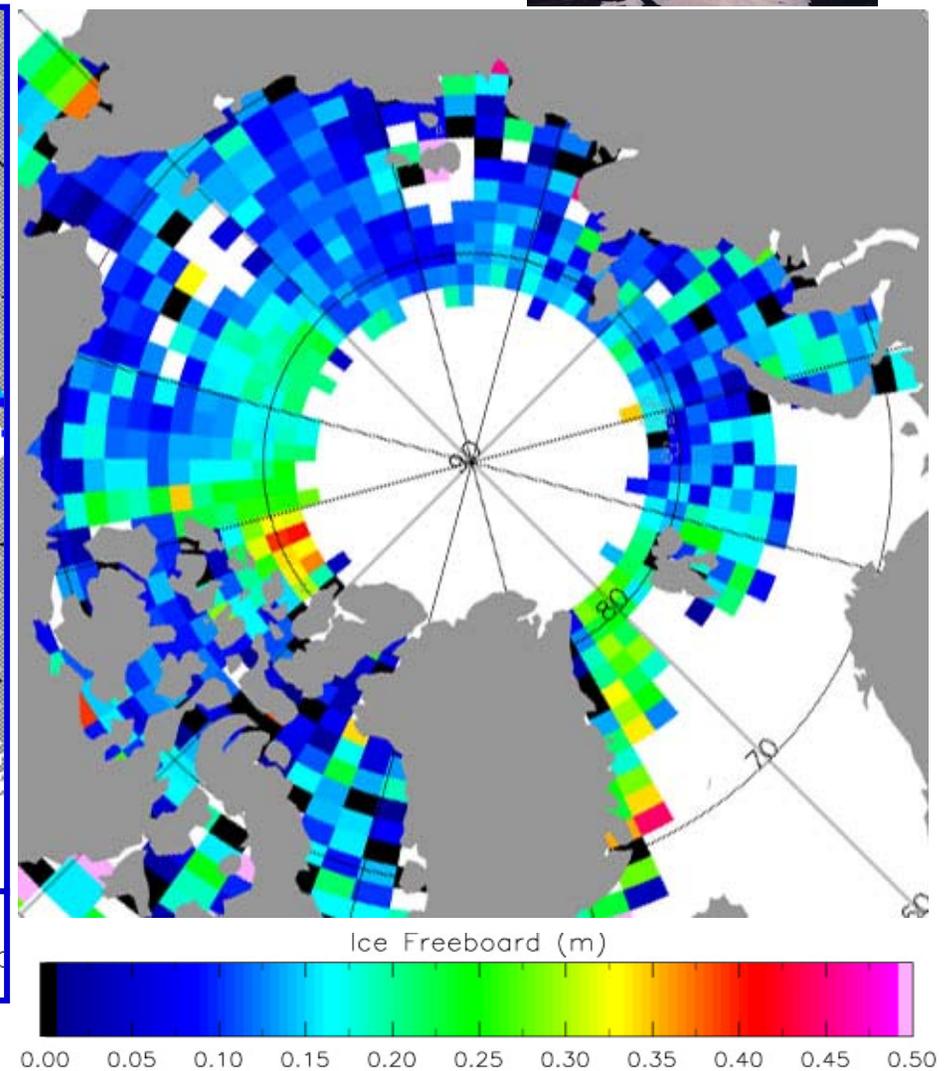
[Courtesy Andrew Ridout, CPOM]



IceSat vs Envisat RA-2 March 2004

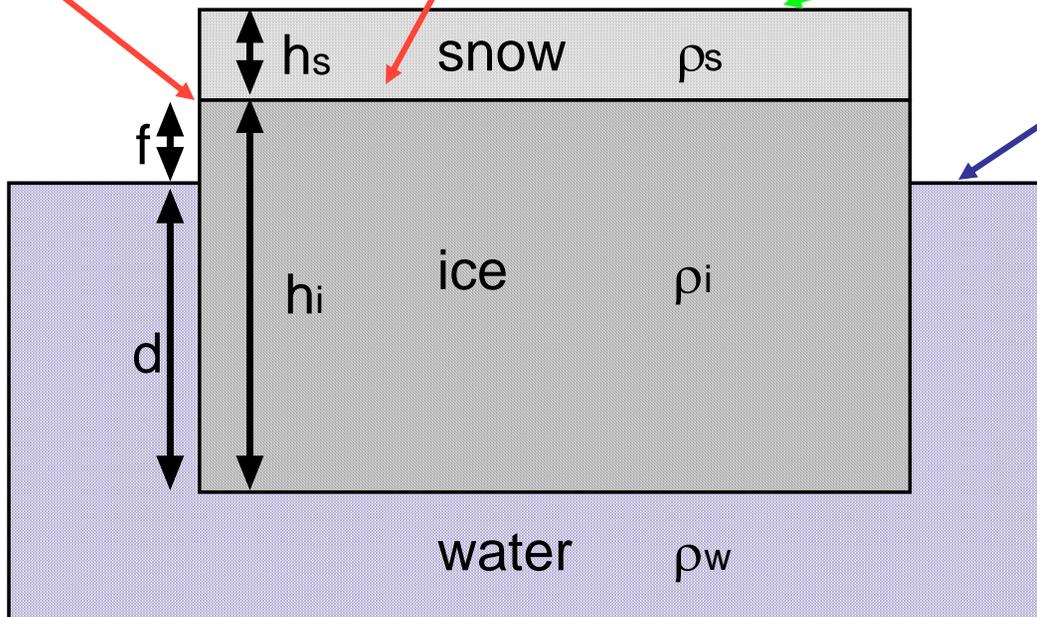
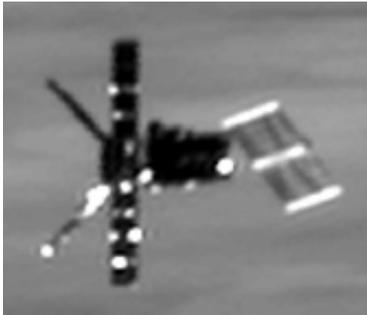


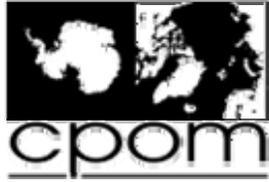
[Courtesy J. Zwally]



[Courtesy Andrew Ridout, CPOM]

The Future: Combining Radar/Laser Altimetry





Summary



- Remote-sensed sea ice data are vital for the optimisation and validation of sea ice models, and for reducing parameter uncertainty
- We have optimised CICE using remote-sensed thickness, extent and speeds, as well as ULS draft data
- Combining radar and laser data has the potential to significantly reduce uncertainties in snow loading
- Comparisons with submarine data suggest that our satellite thickness errors are considerably less than discrepancies between different model simulations
- There is still much work to do to fully understand these uncertainties. In particular, CryoSat will be a particular focus for a \$15m validation campaign, post-launch (land ice and sea ice)
- www.esa.int/esaLP/cryosat.html

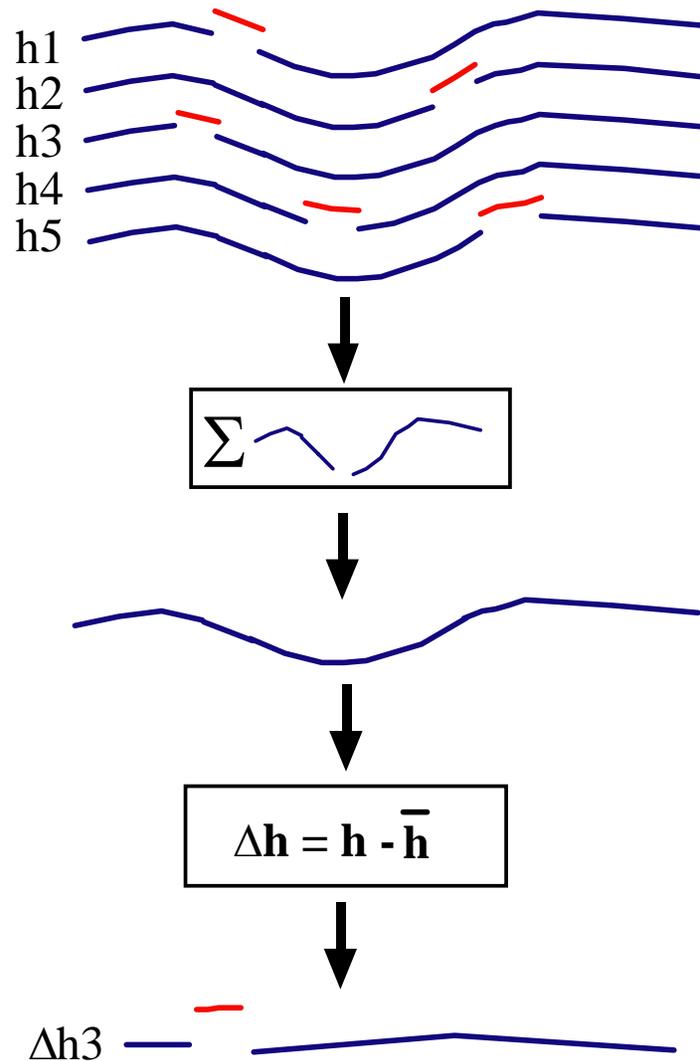
Summer 2005?



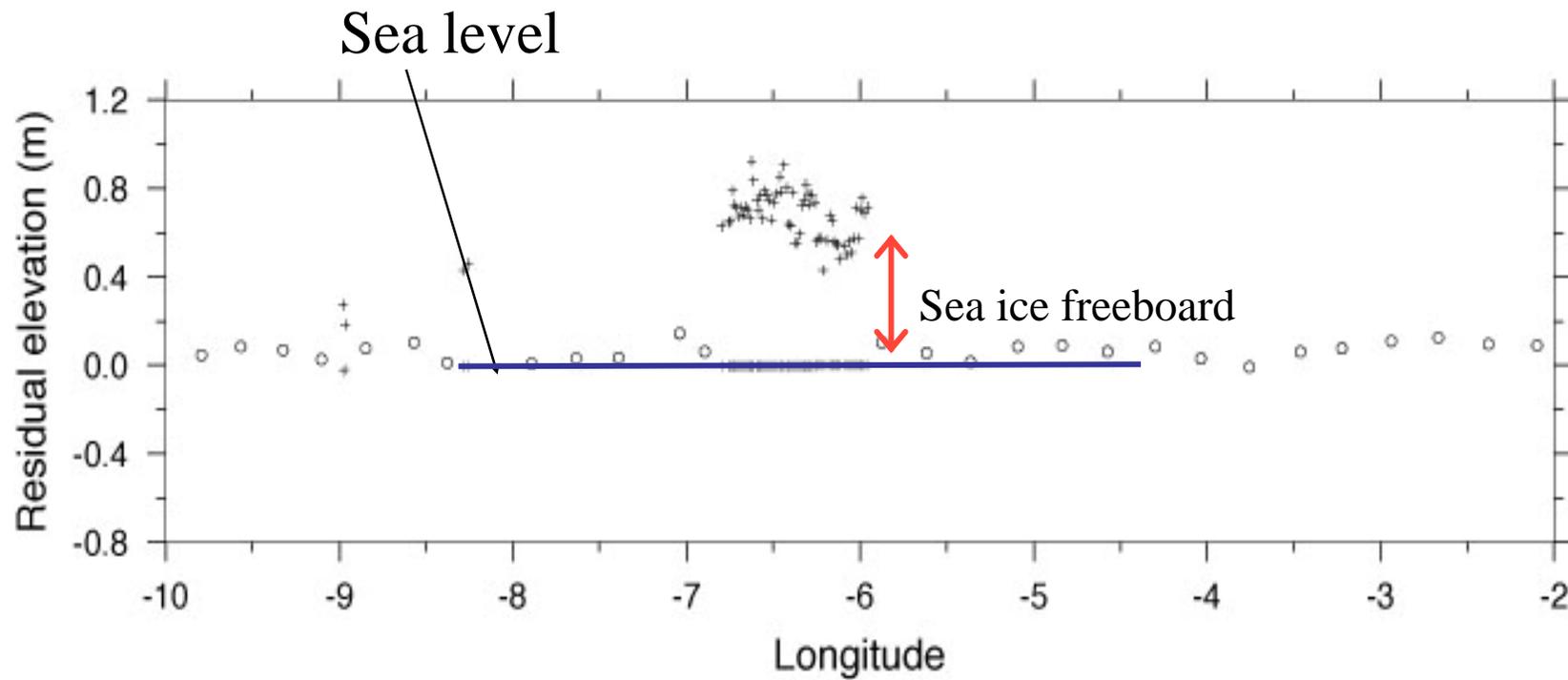
www.esa.int/esaLP/cryosat.html

Repeat Profile Analysis

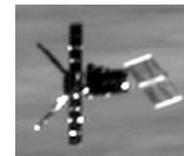
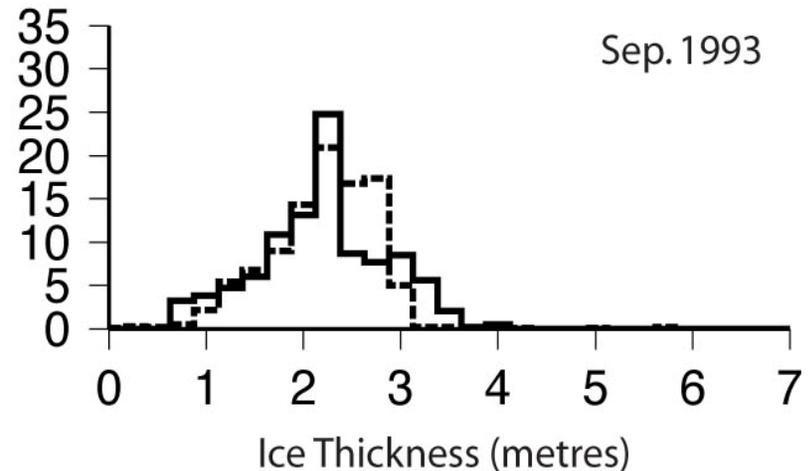
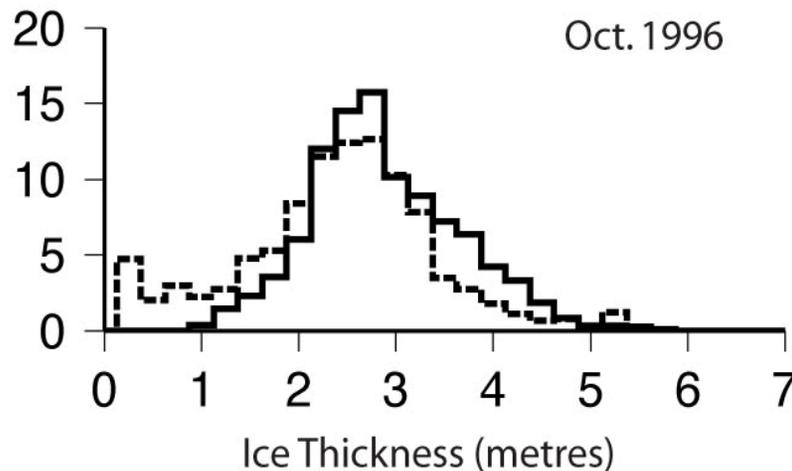
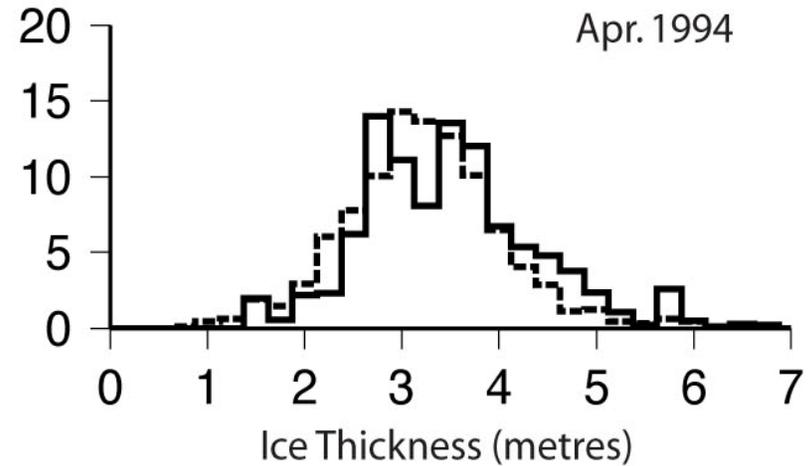
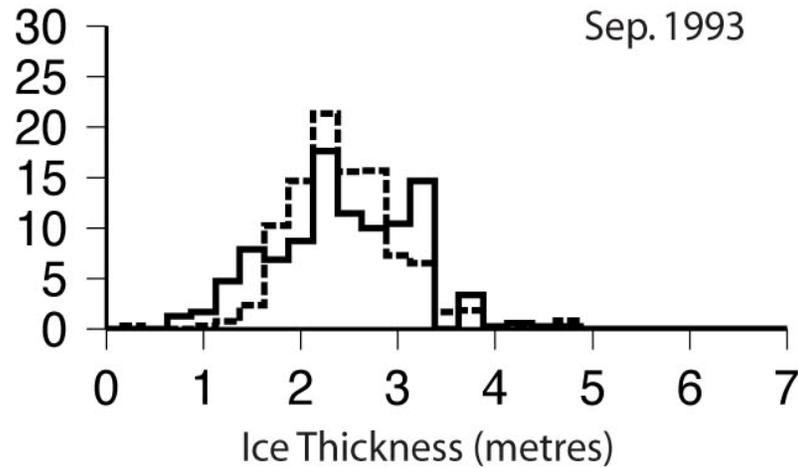
- Up to 60 repeat profiles are analysed along each of the 501 orbit tracks
- Ocean returns are used to construct a mean sea surface profile
- Residual height profiles are used to determine ice freeboard



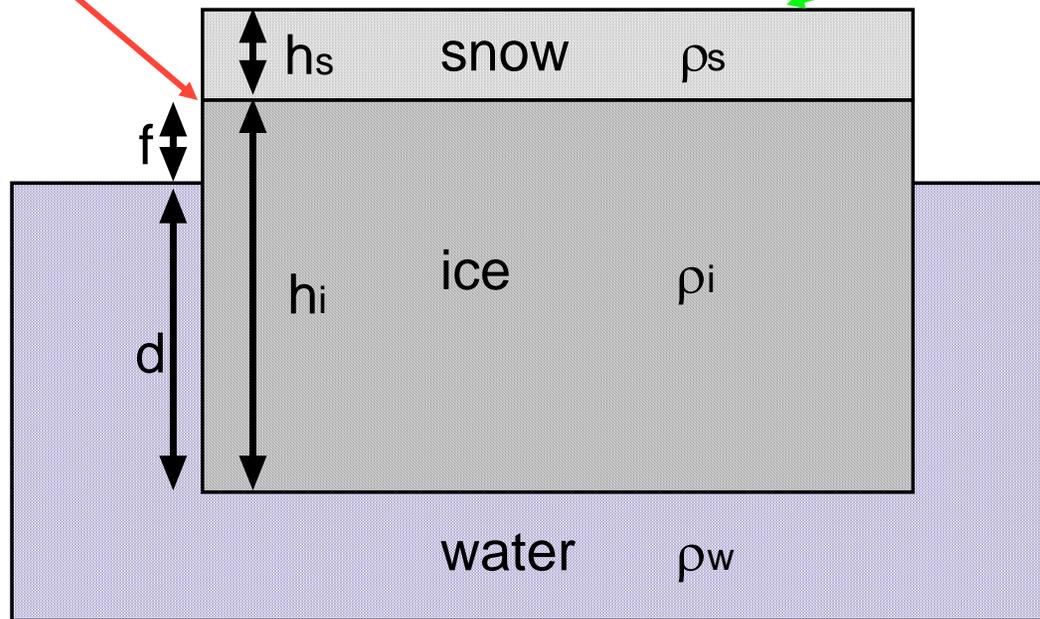
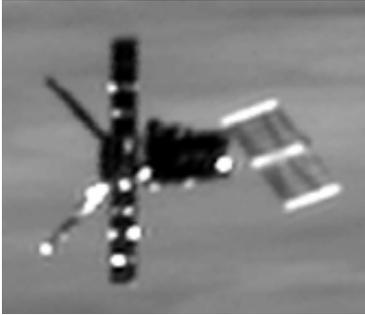
Altimeter Elevation Profile



Comparison of Submarine and Altimeter Thickness PDF

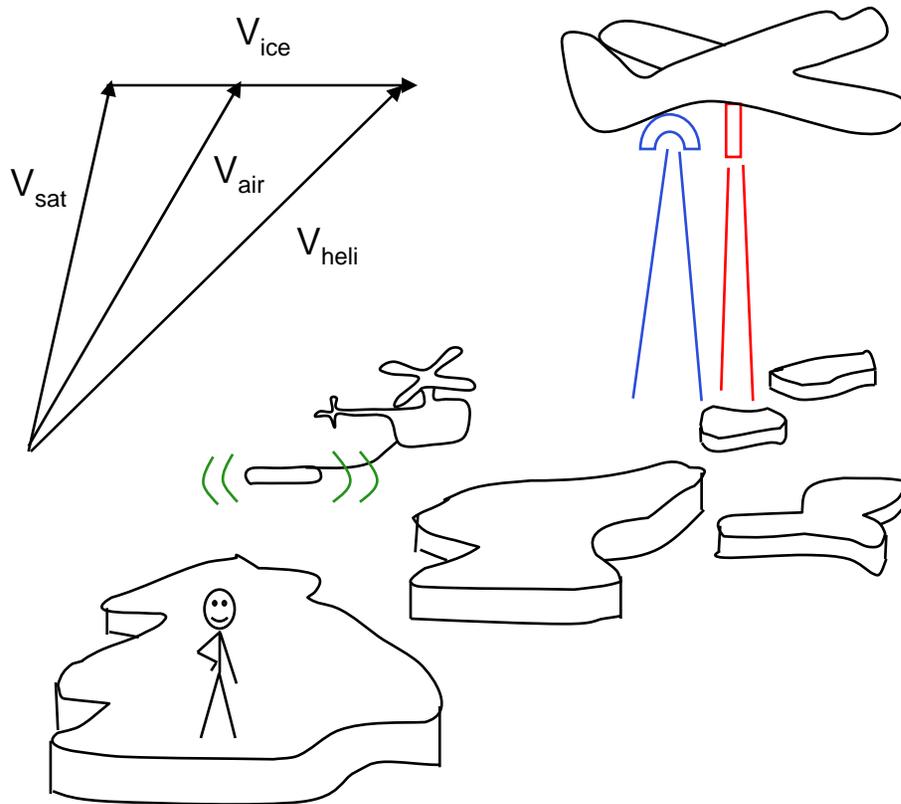


Combining Radar/Laser Altimetry



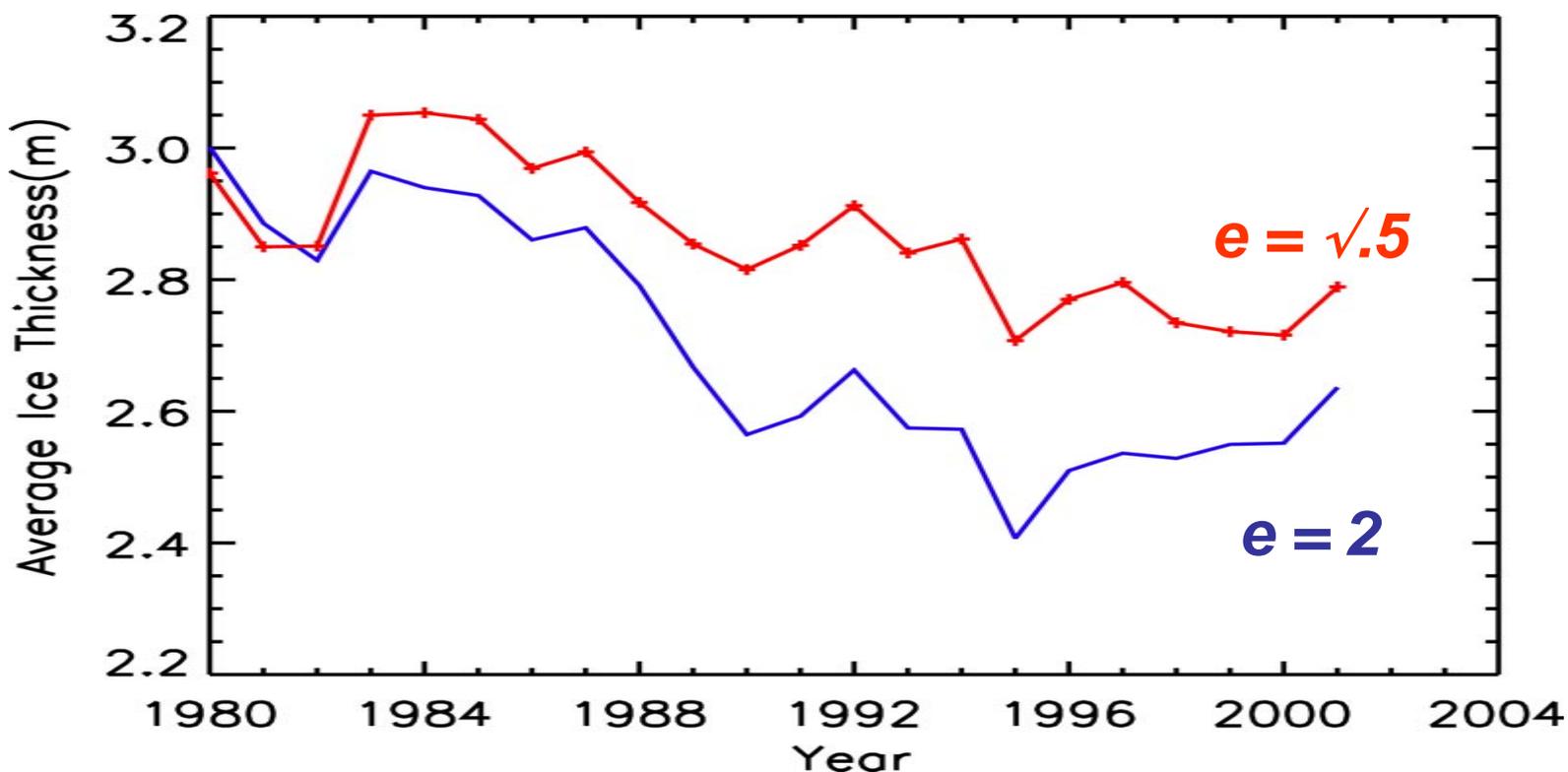
Conceptual Experiment Design

Example: Level 2 Sea ice geometric and penetration model error



- Assess practicality and identify missing capability *e.g.* ASIRAS.
- Identify and contact important groups and planning time-scales *e.g.* Alfred Wegener Institute; 2-3 year planning horizon for polar activity.
- Identify practical locations *e.g.* Arctic Ocean N. and W. of Greenland is accessible and gives access to strong ice concentration variations.
- Identify experimental complexity and novelty and assess need for pre-launch trials *e.g.* LARA (2002) and CryoVEx (2003) campaigns.
- Identify and implement requirements on ground-segment capability.

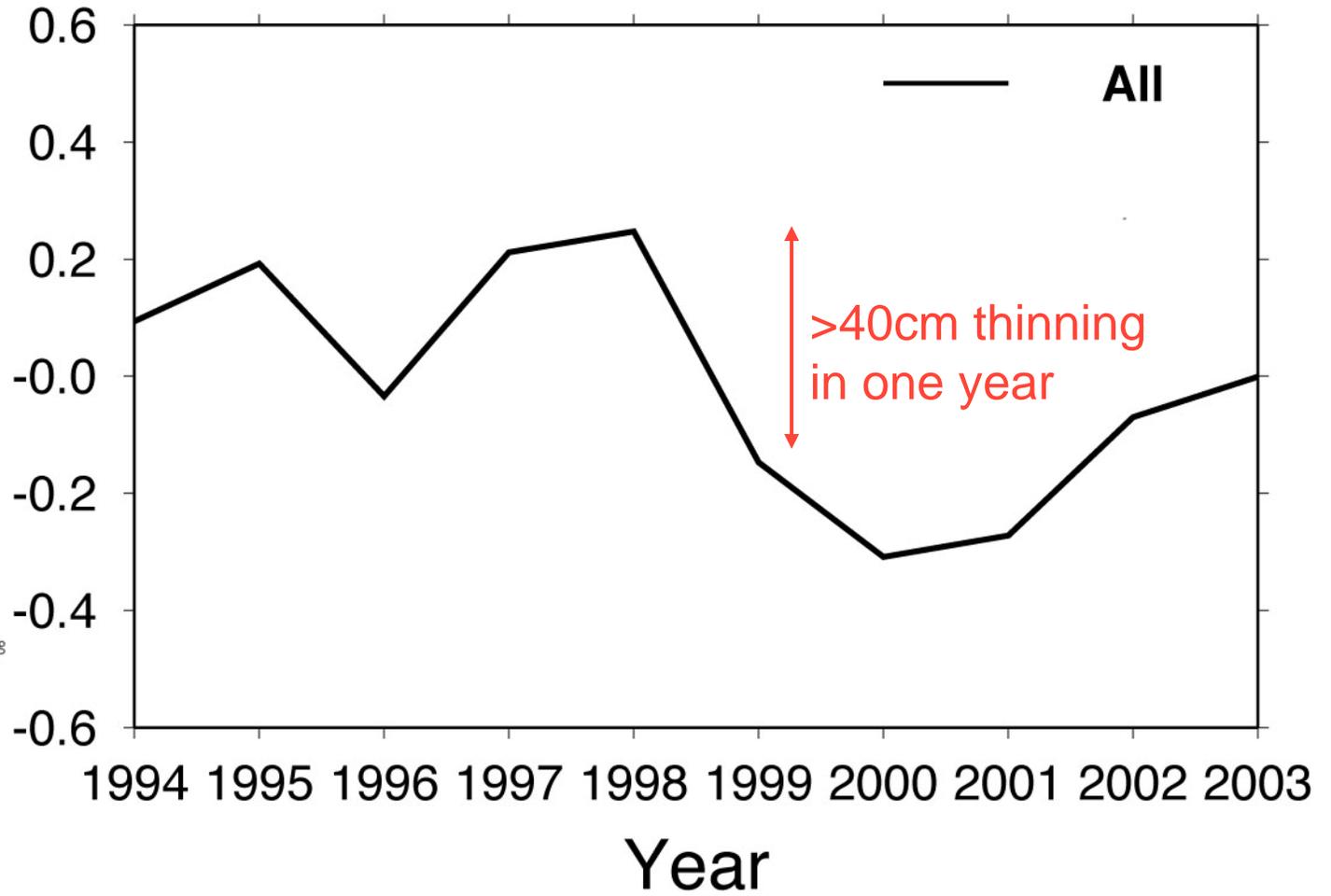
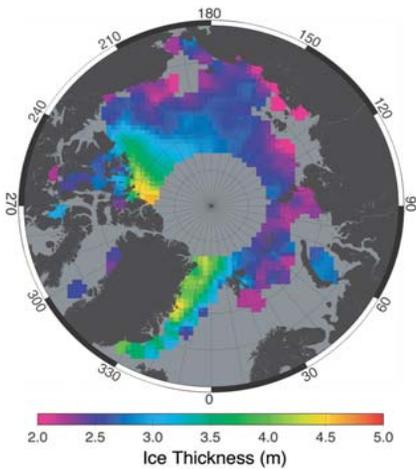
Arctic Basin Ice Thickness Since 1980



Annual mean Arctic sea ice thickness has been in decline since the mid-1980s

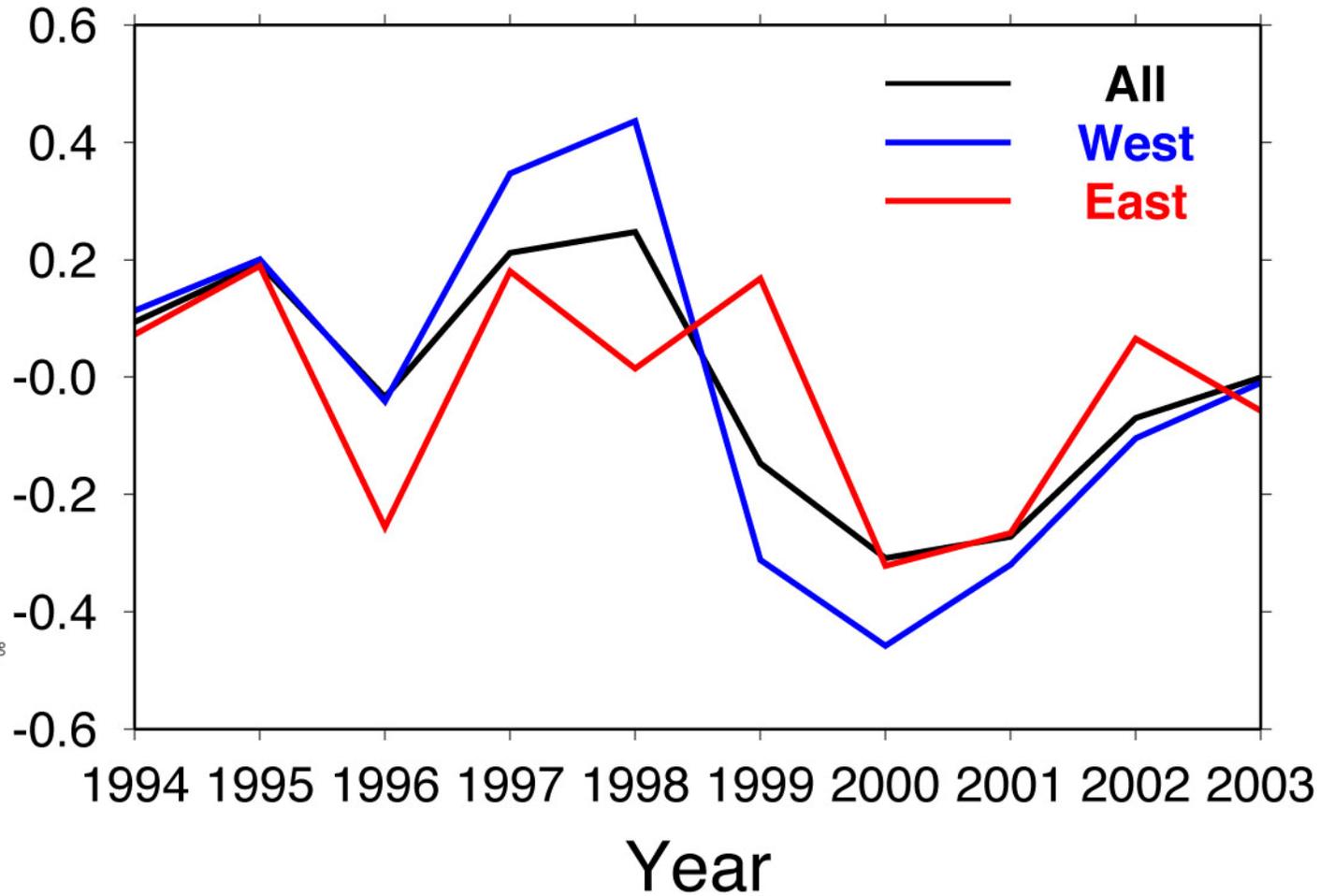
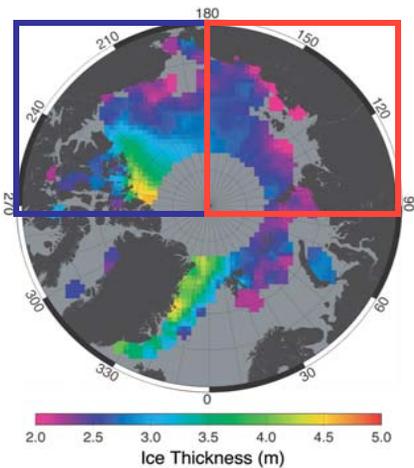
Ice Thickness Anomalies 1993-2003

Thickness Anomaly (Metres)



Regional Ice Thickness Anomalies 1993-2003

Thickness
Anomaly
(Metres)



Sources of Uncertainty

