NATURAL ENVIRONMENT RESEARCH COUNCIL

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

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Motivation

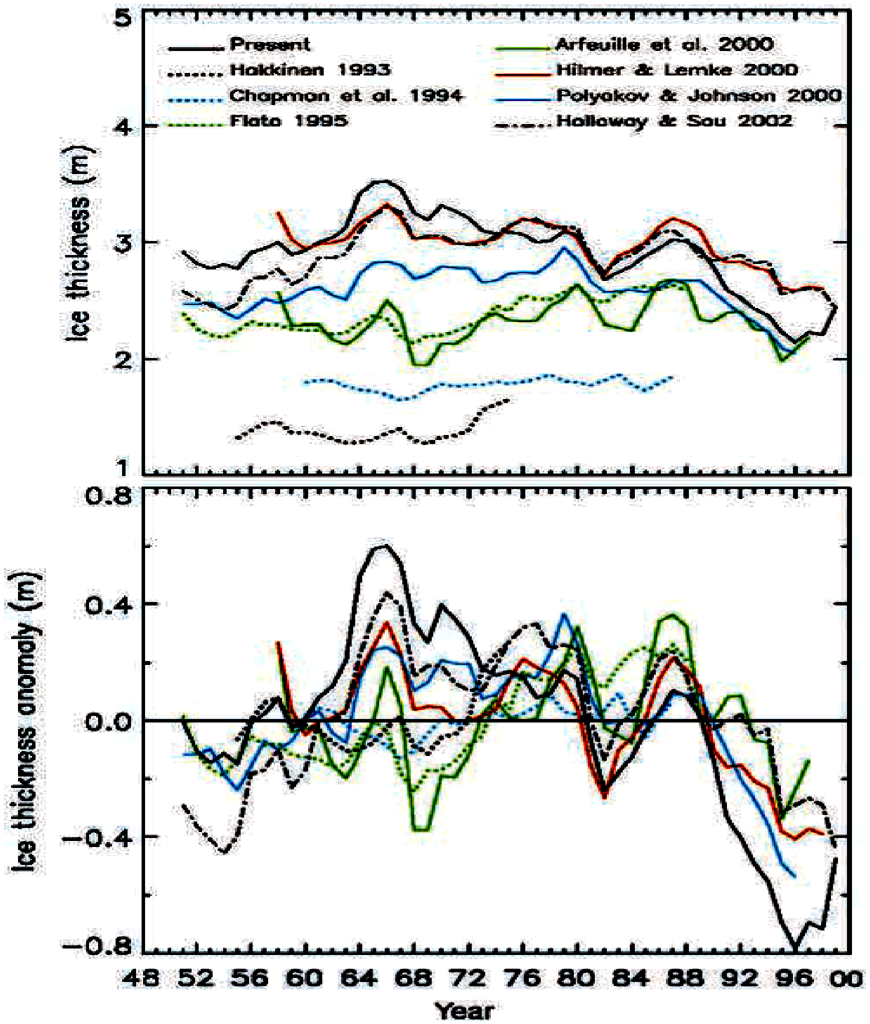
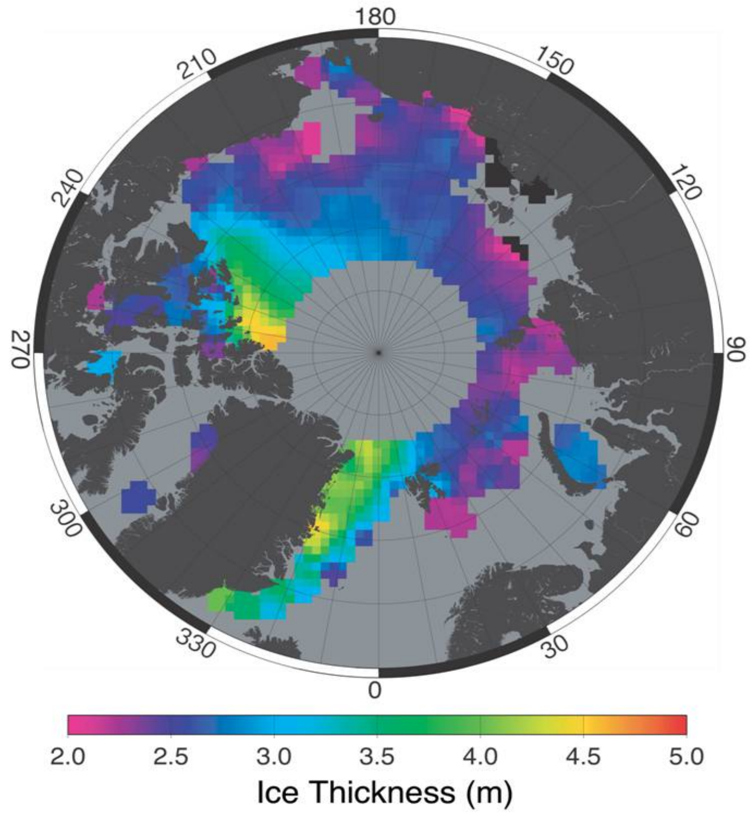


Figure 12. (Upper) Annual mean thickness from several ice models during the period 1951 to 1999. (Lower) The thickness difference from the mean over each simulation.

- ***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

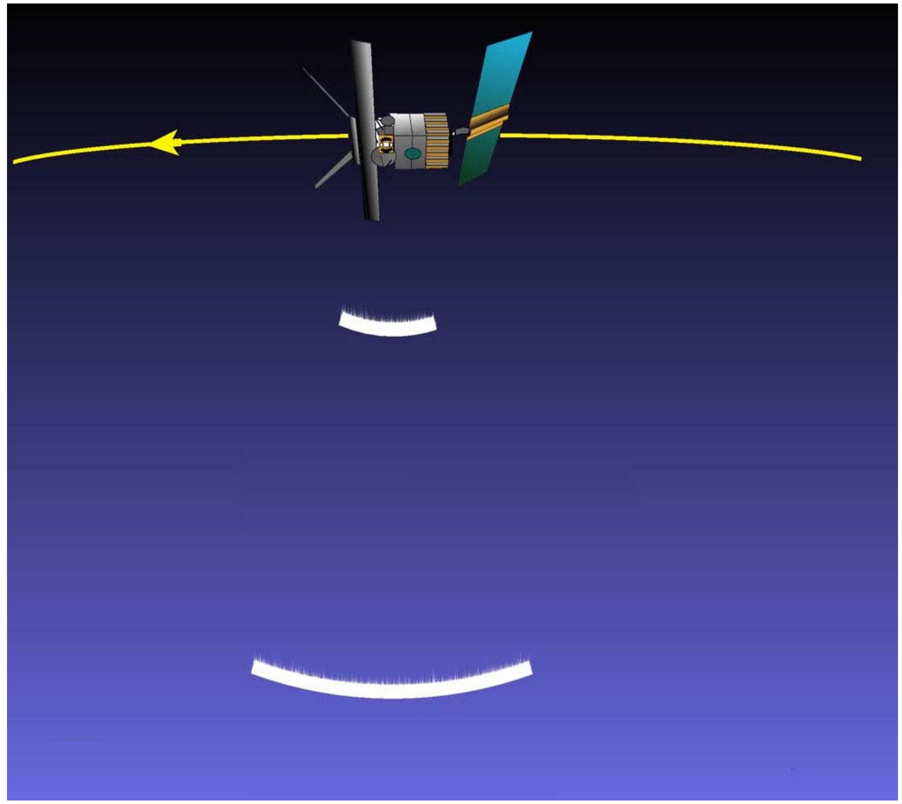
- Use the Los Alamos sea ice model, **CICE**, and force it with ERA-40 & POLES data
- Optimise and validate the model using a comprehensive range of sea ice observations:
  - Sea ice **velocity**, 1994-2001 (SSM/I + buoy + AVHRR, *NSIDC*)
  - Sea ice **extent**, 1994-2001 (SSM/I, *NSIDC*)
  - Sea ice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

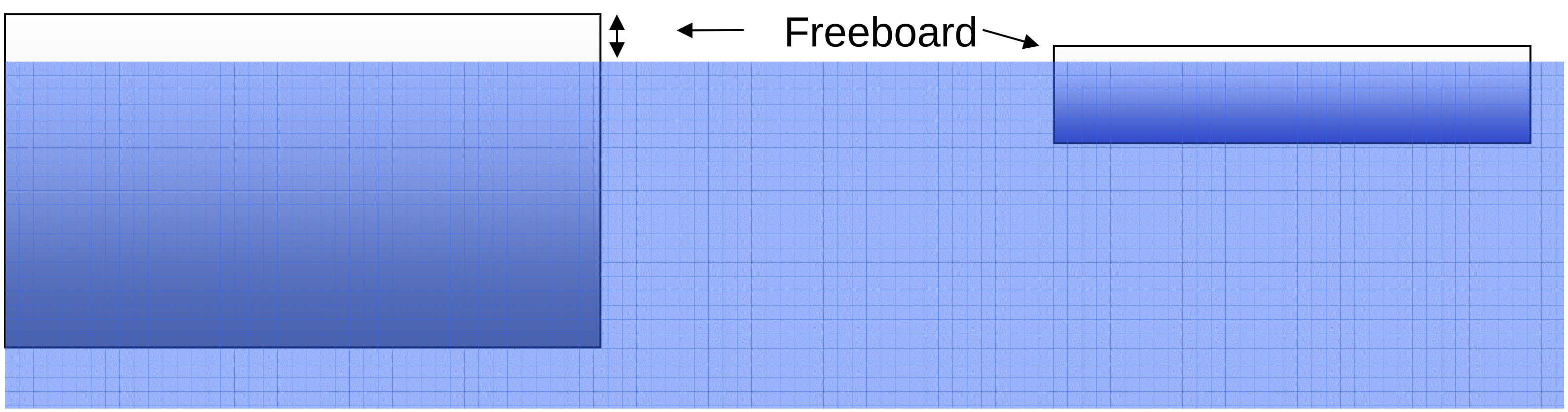


We used this model and forcing to reduce uncertainty surrounding sea ice model parameters

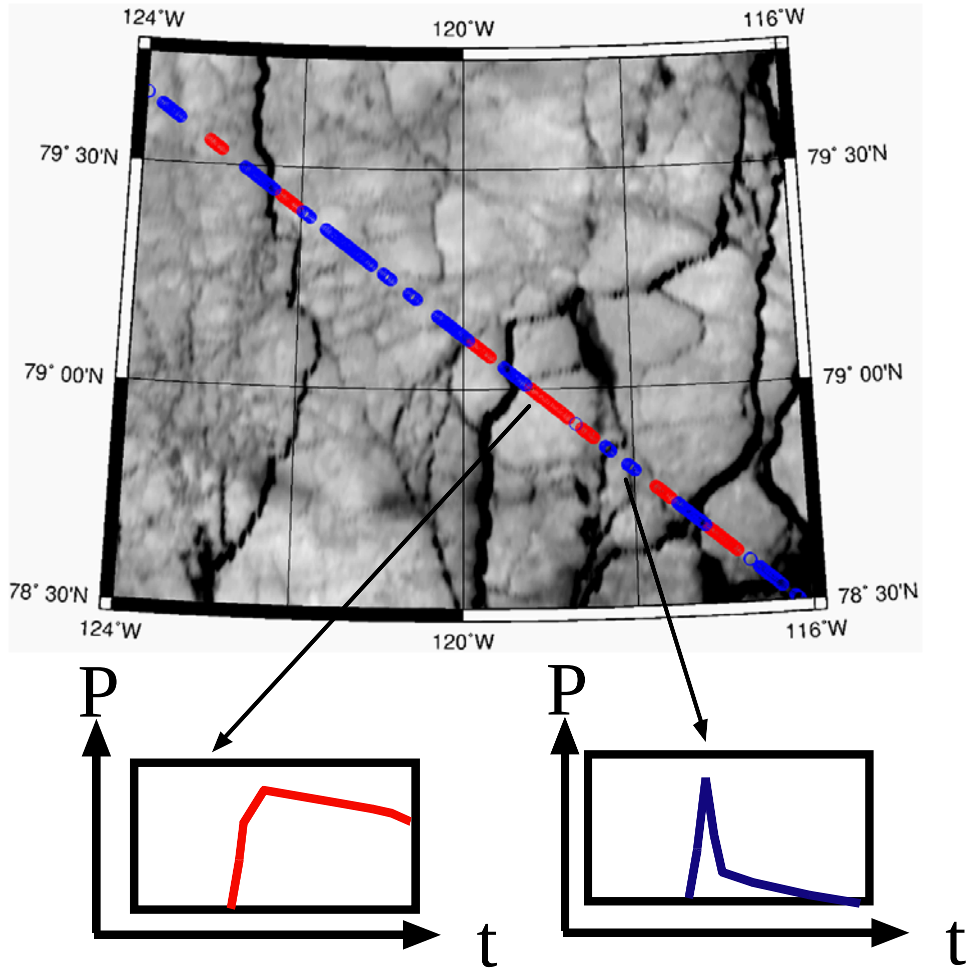
Satellite Altimetry - Measurement Principle

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



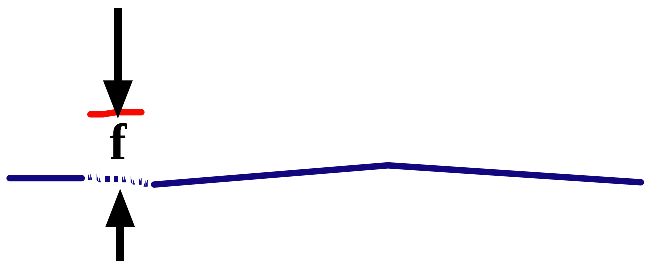


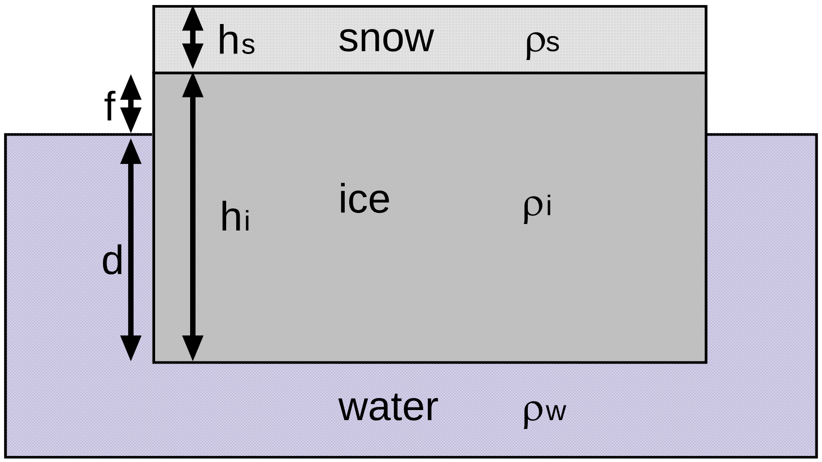
Origin of Radar Altimeter Sea Ice Echoes - ERS



- 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

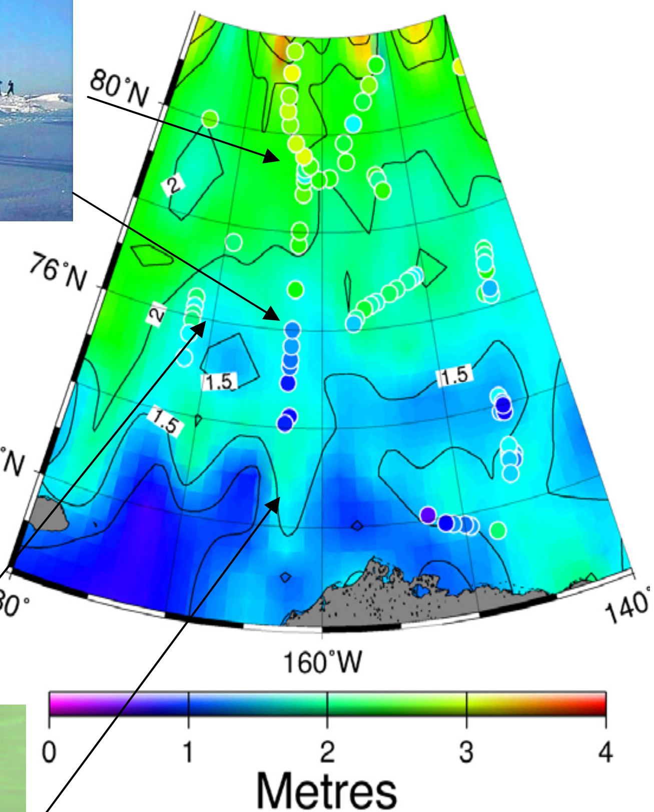


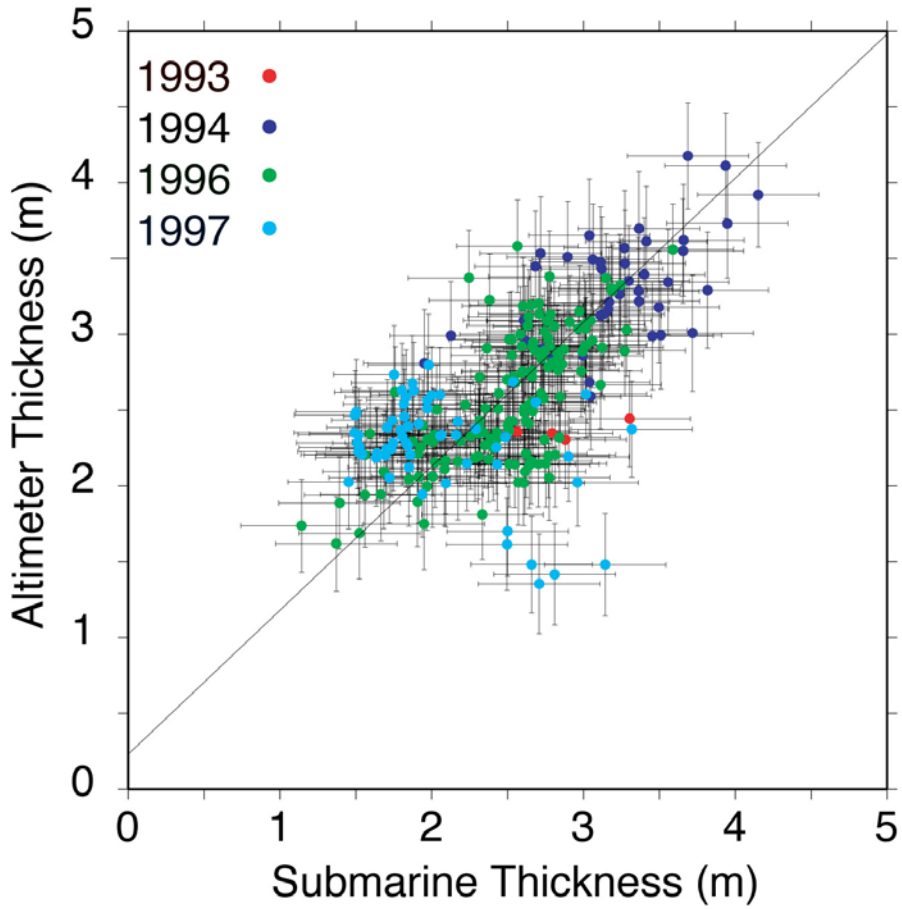


- Conversion assumes reflection from the ice/snow interface
- Conversion to thickness uses climatology of snow depth/densities
  (*Warren et al.*, J. Climate 1999)

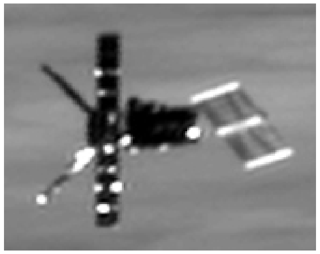
$$h_i = f\frac{\rho_w}{(\rho_w - \rho_i)} + \frac{h_s \rho_s}{(\rho_w - \rho_i)}$$

ERS Altimeter Ice Thickness Validation

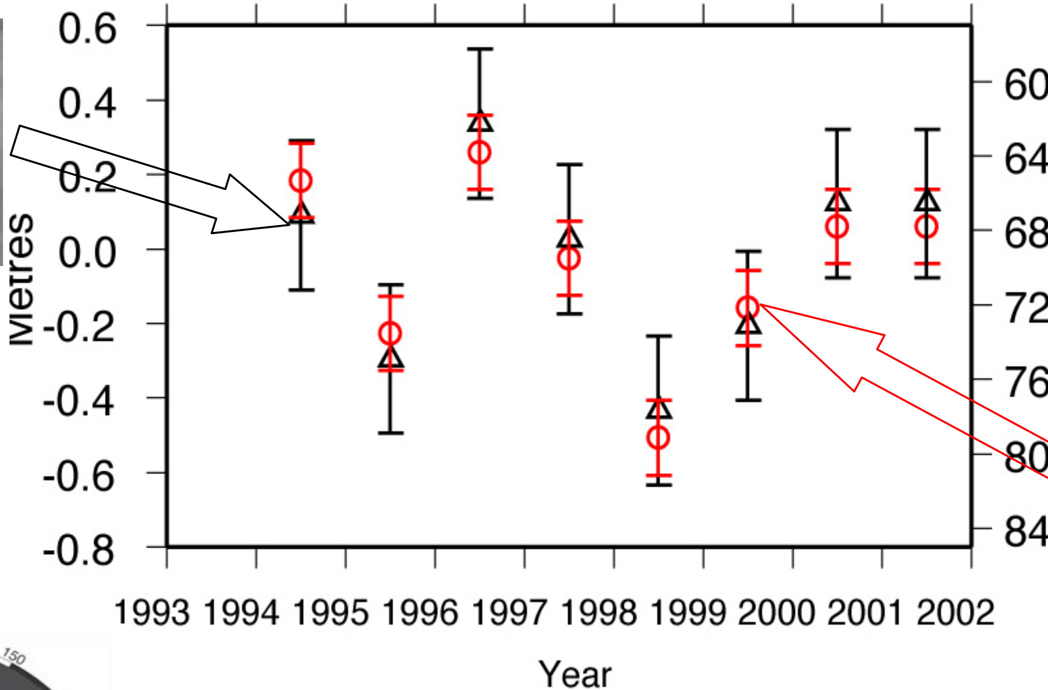




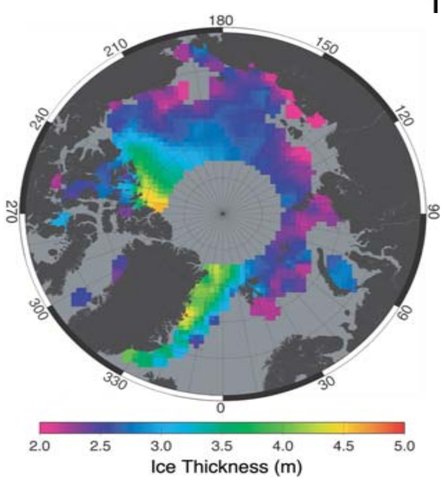
Ice Thickness - Summer Melt



Sea Ice Thickness Change



Melt Season Length (*Smith,* GRL, 1998)



22 NEWS

THE INDEPENDENT
Thursday 30 October 2003

Vanishing ice may destroy polar bears' habitat

By Steve Connor
Science Editor

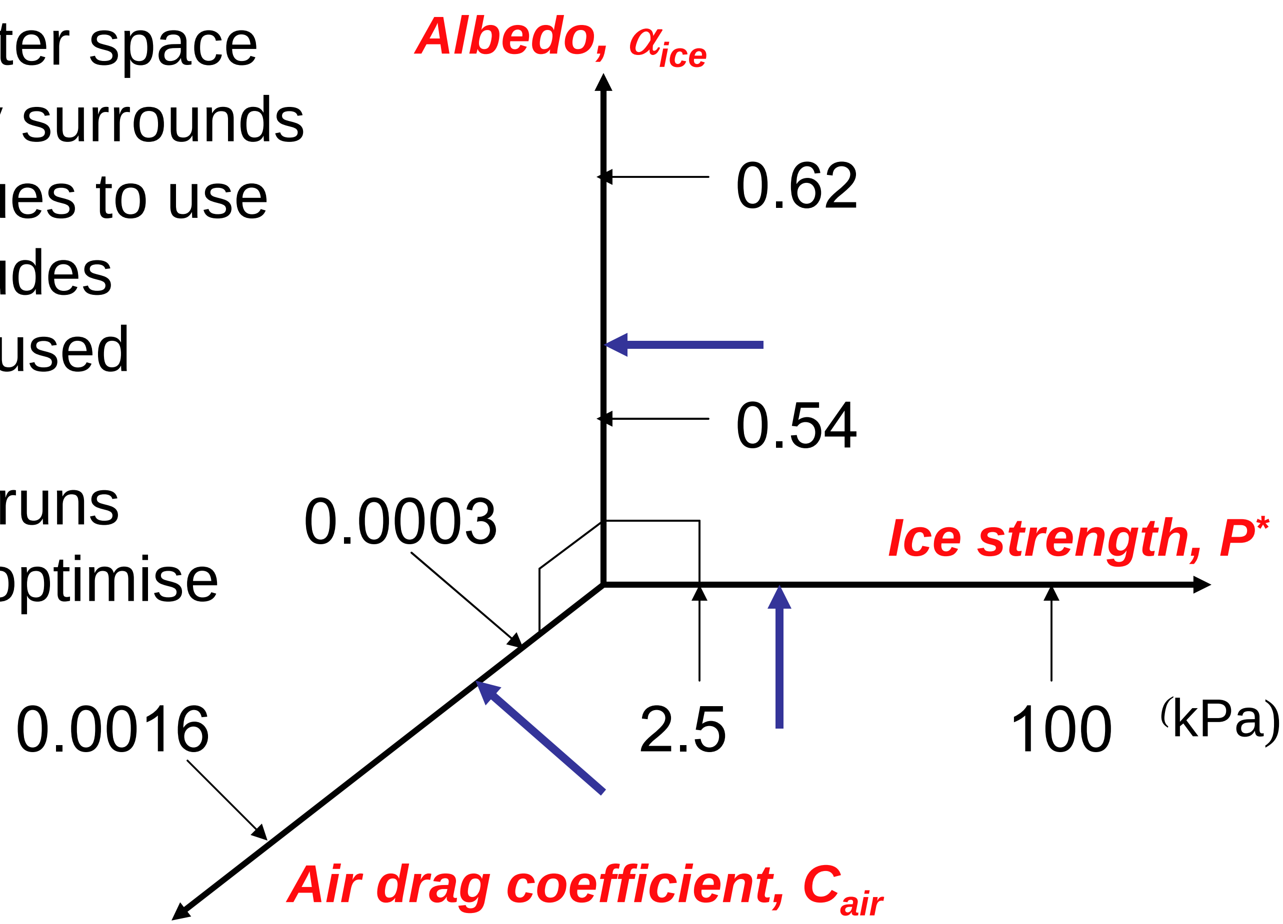
A study predicts there will be little ice left in a century for polar bears to hunt on

***Laxon et al.,* Nature, 2003**

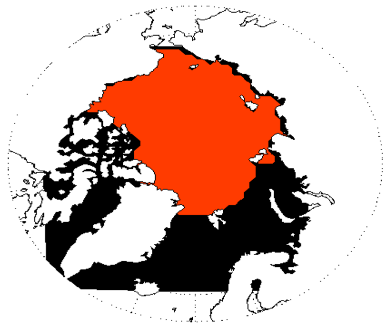
Parameter Space

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

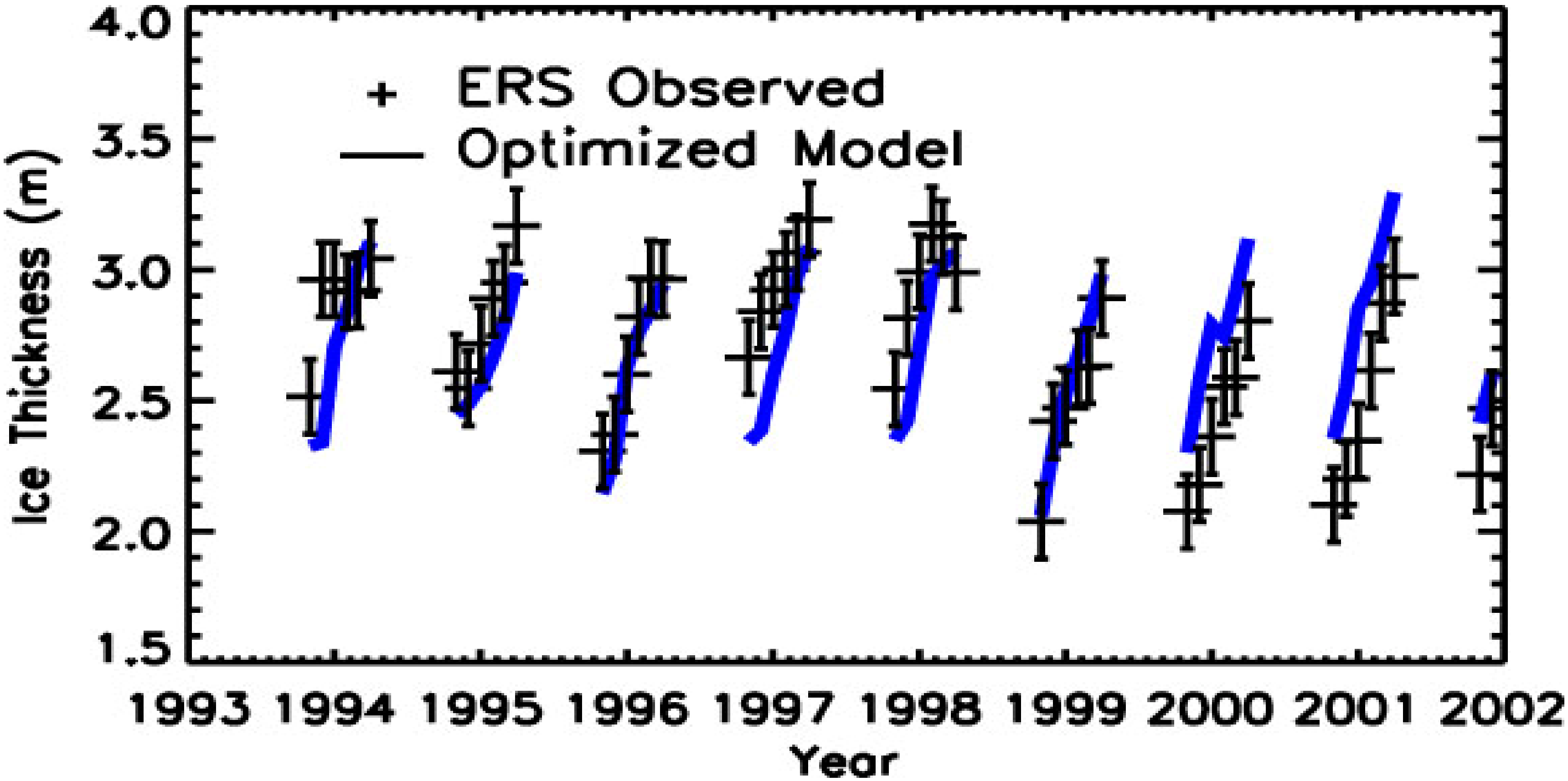
- 3D parameter space
- Uncertainty surrounds correct values to use
- Space includes commonly-used values
- 168 model runs needed to optimise model



Arctic Basin Ice Thickness



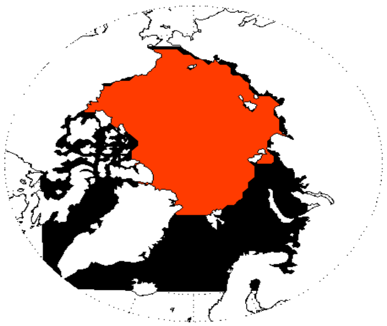
{α_{ice}, C_{air}, P} = {0.56, 0.0006, 5 kPa}*

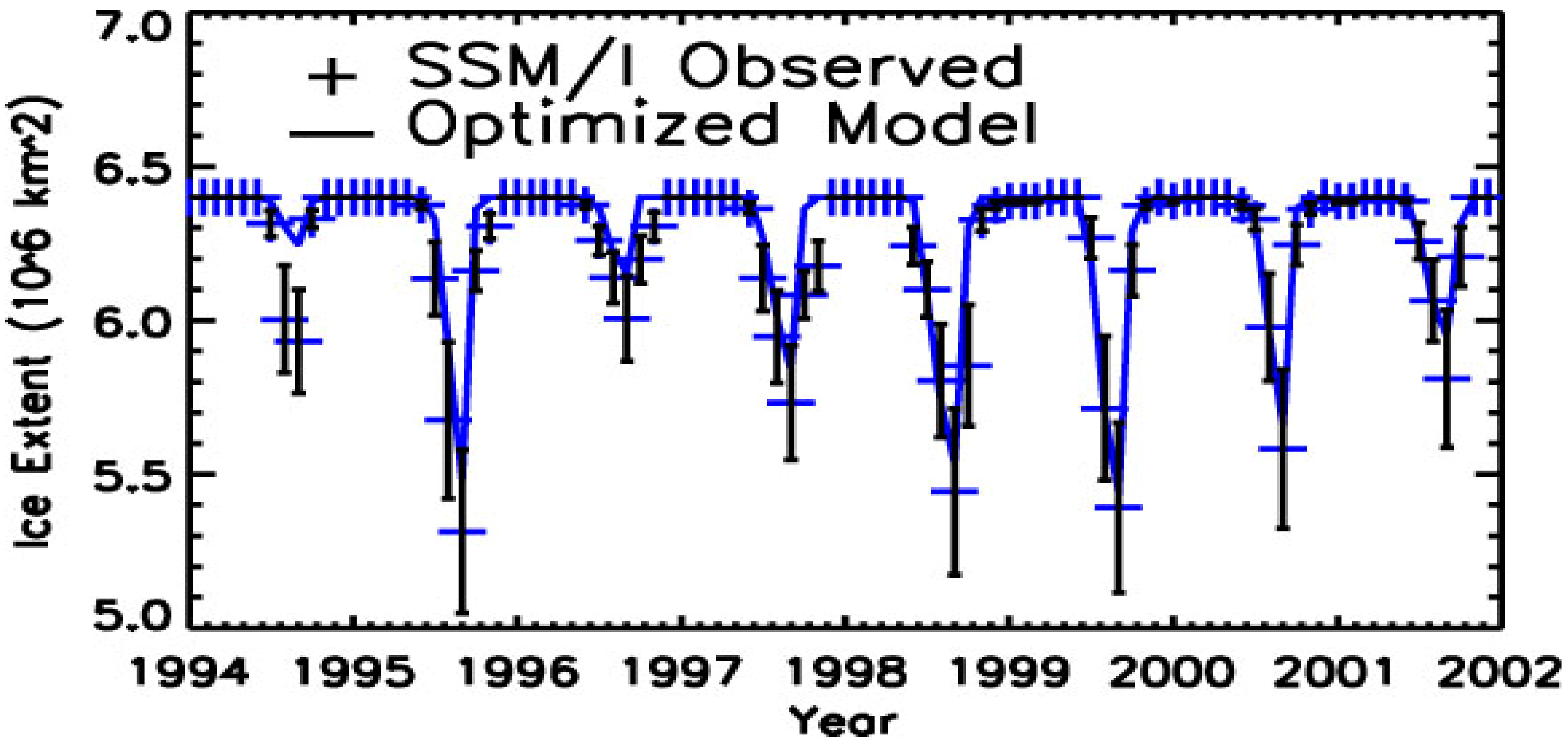


***Miller et al.*, J. Climate, submitted**

Arctic Basin Ice Extent

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

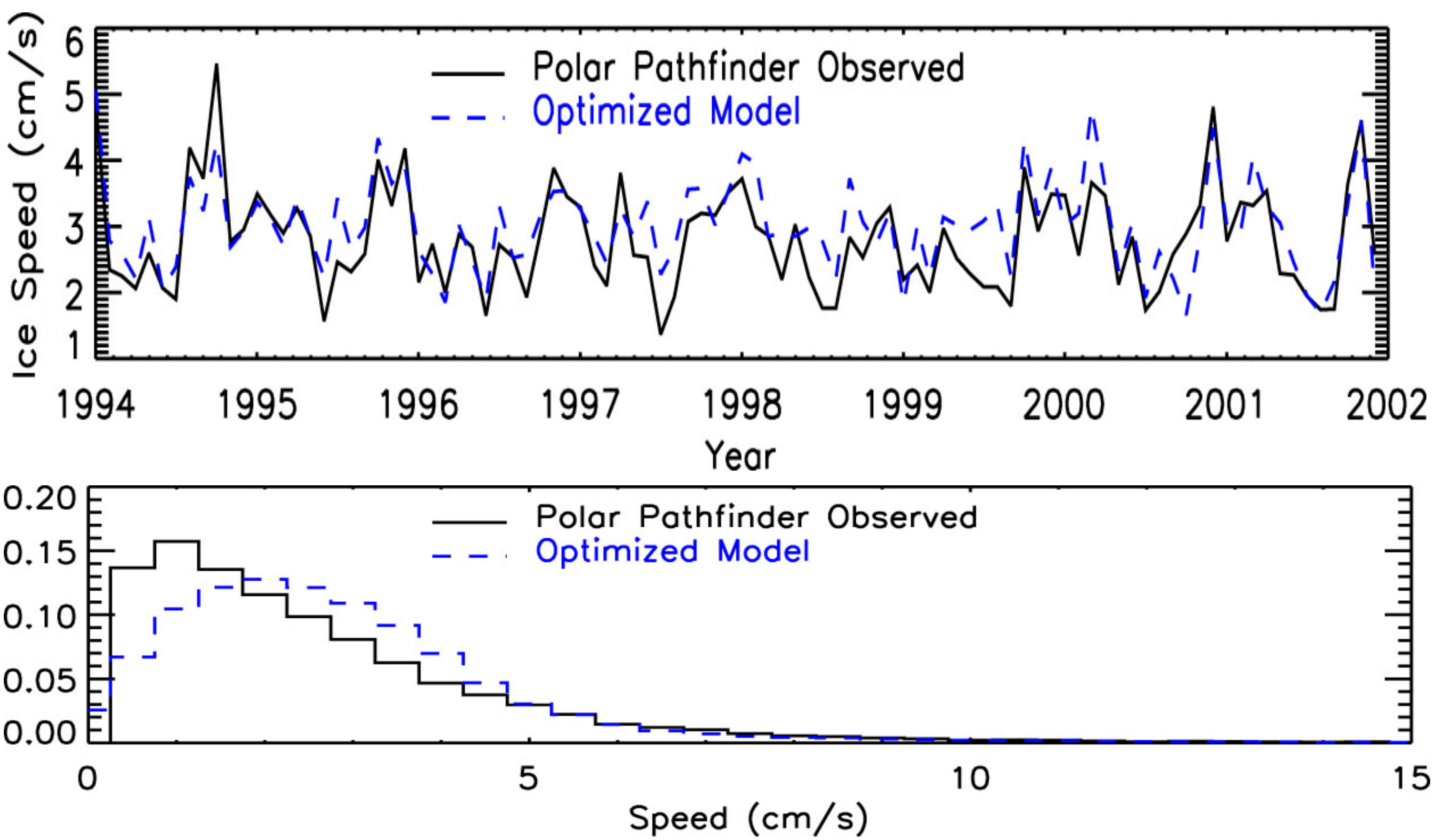




***Miller et al.*, J. Climate, submitted**

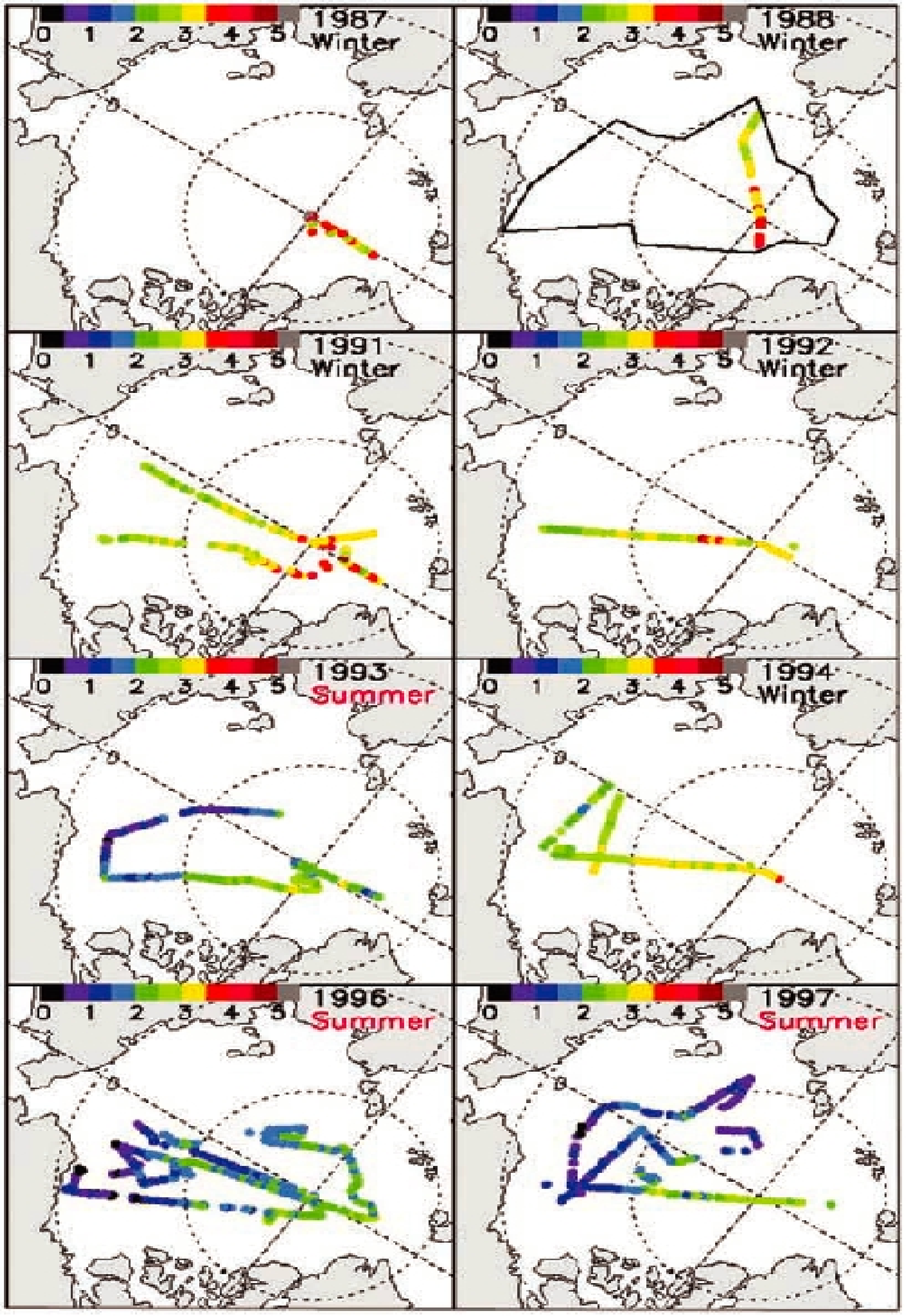
Arctic Basin Ice Speeds

{α_{ice}, C_{air}, P} = {0.56, 0.0006, 5 kPa}*

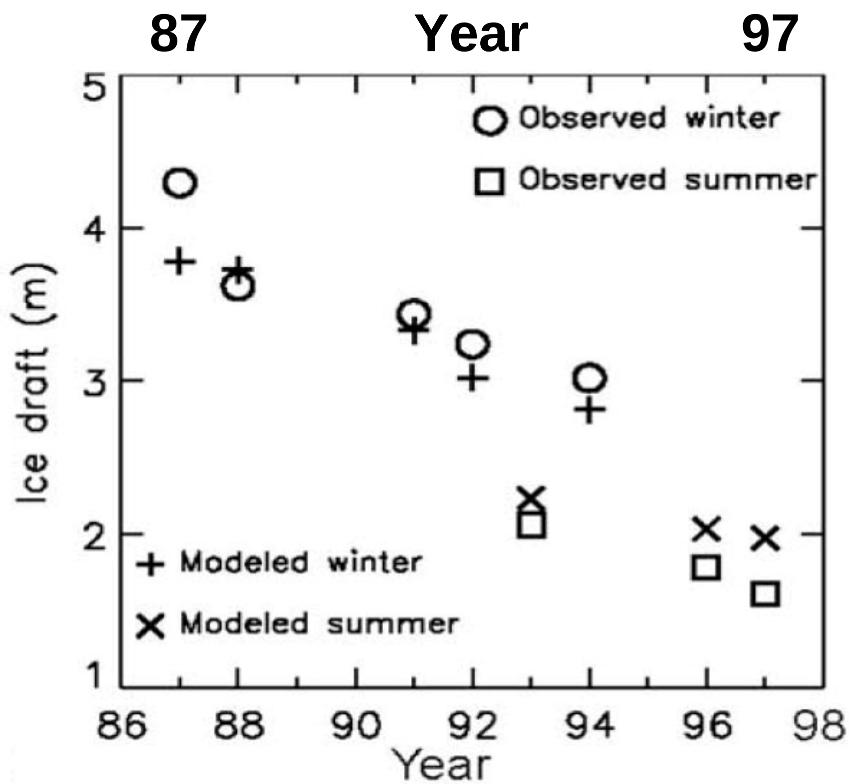


***Miller et al.*, J. Climate, submitted**

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**

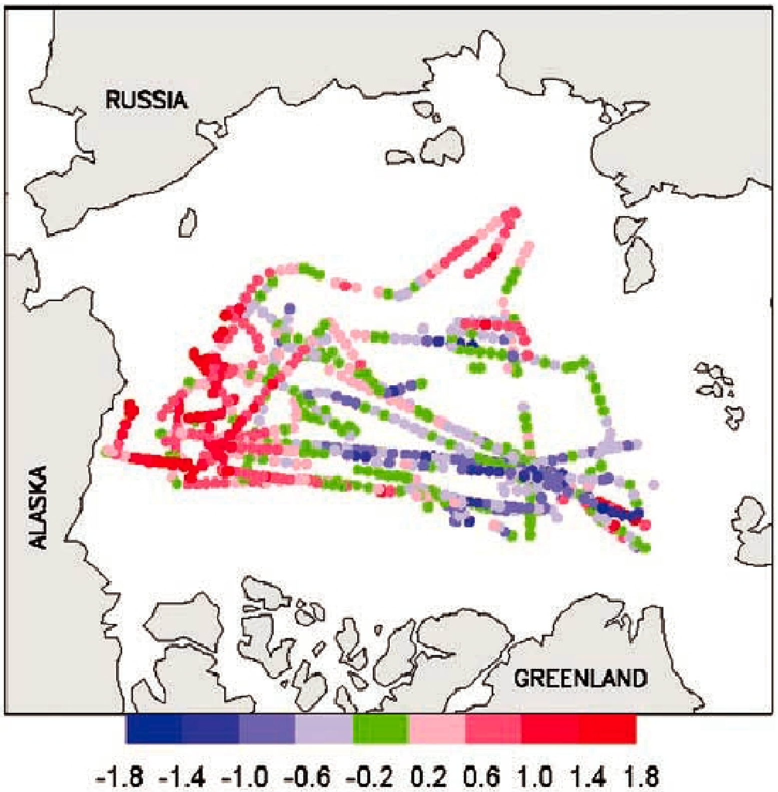
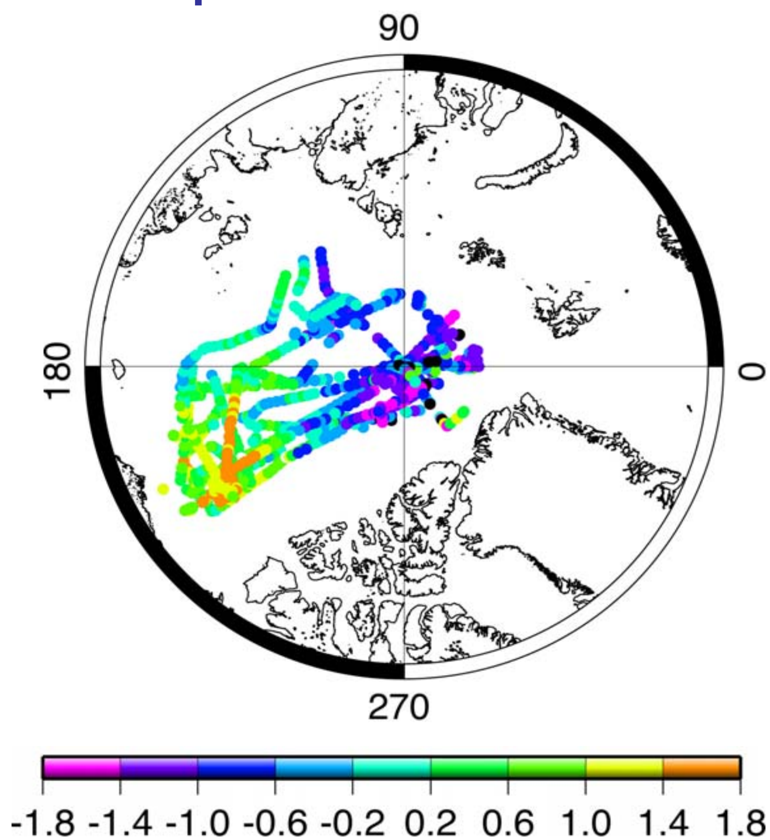


Figure 9. Modeled minus observed mean draft (m) along cruise tracks from 1987 to 1997.

Optimised CICE Model



Model - ULS Observed Draft (m)

Improved Spatial Distribution

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

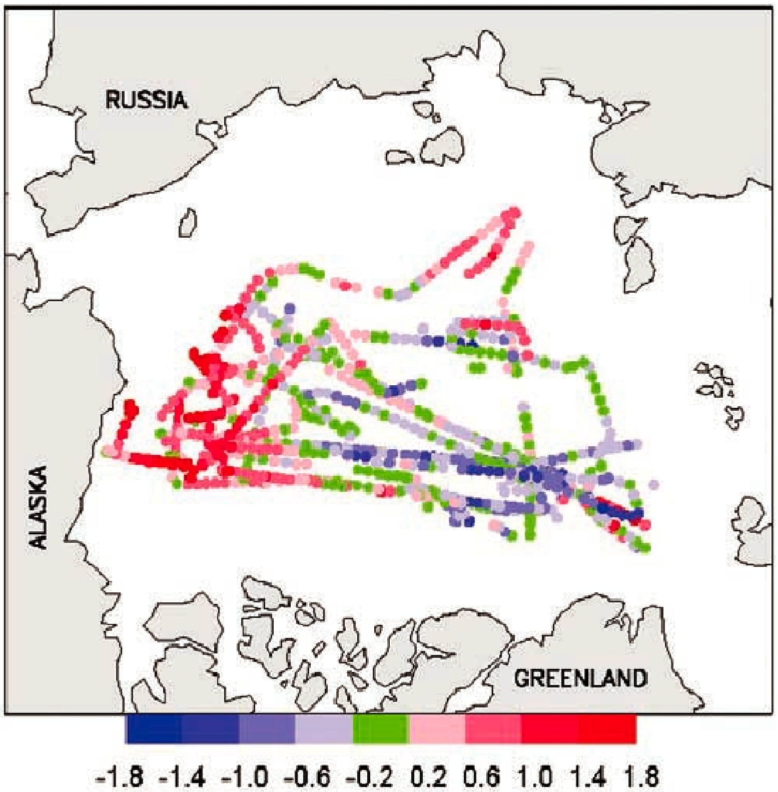
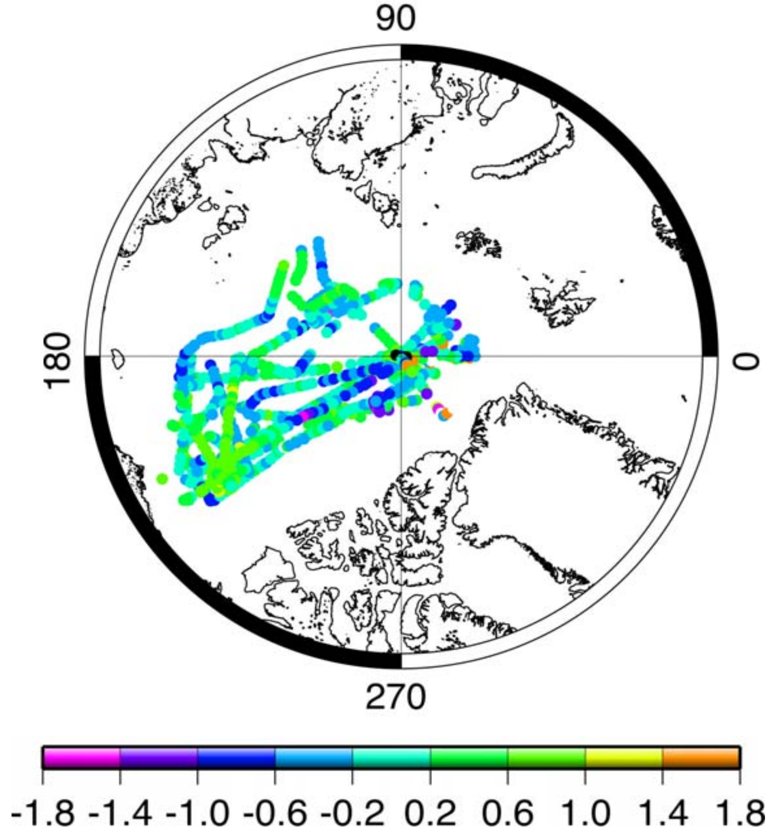


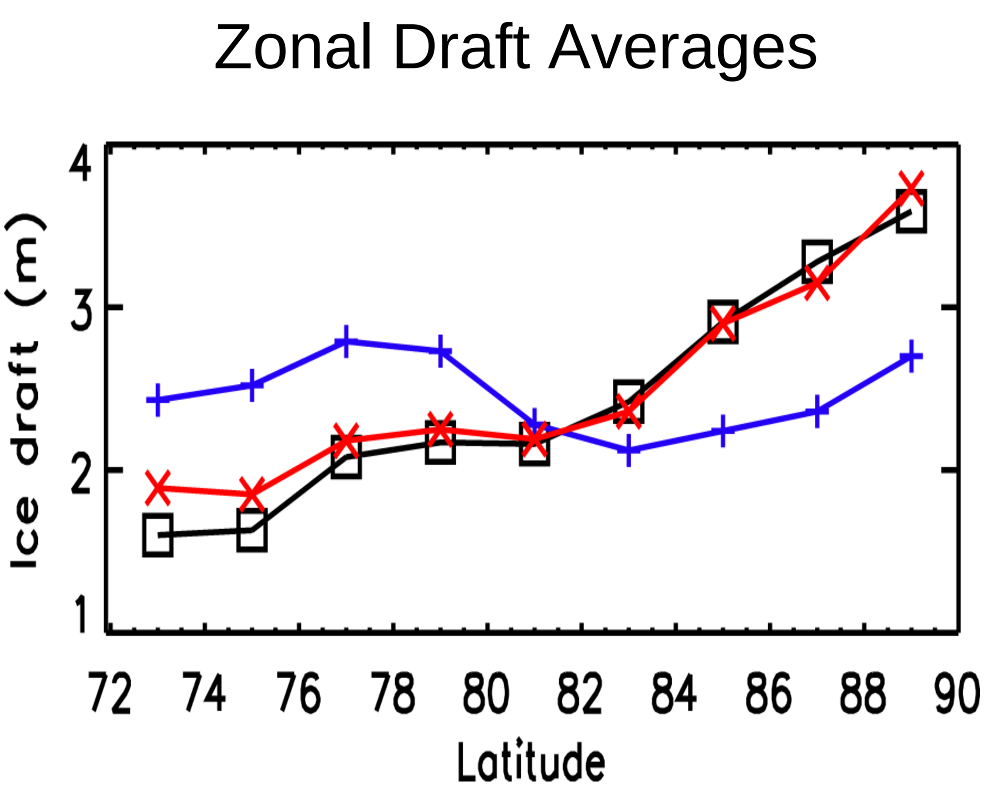
Figure 9. Modeled minus observed mean draft (m) along cruise tracks from 1987 to 1997.

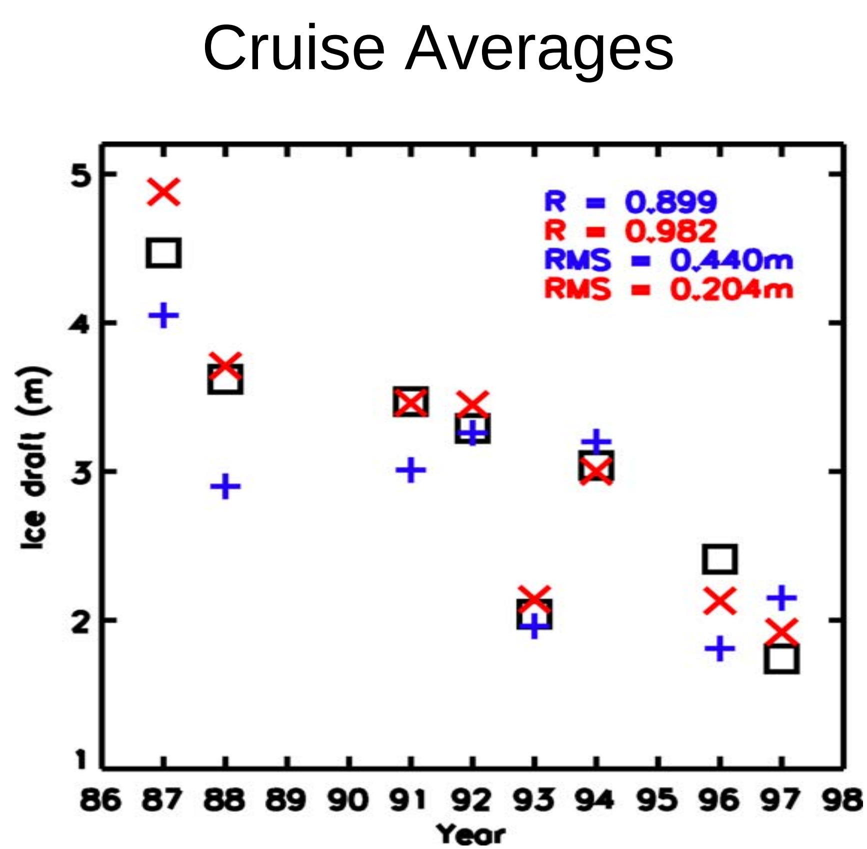
CICE, *e* = √*.5*



Model - ULS Observed Draft (m)

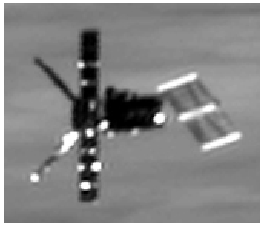
Zonal and Interannual Variability



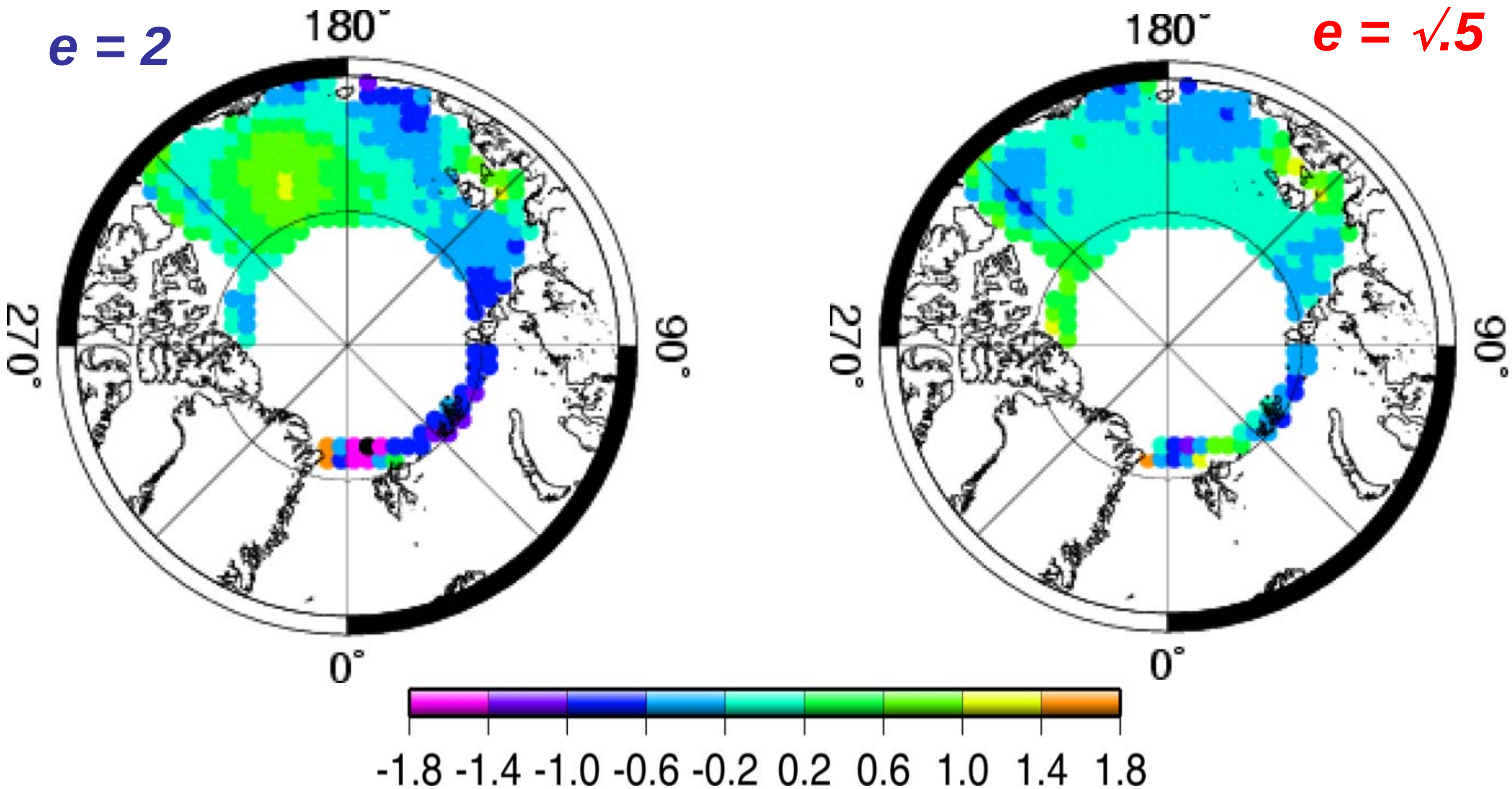


� - Observed ***e = 2*** ***e = √.5***

***Miller et al.*, GRL, submitted**

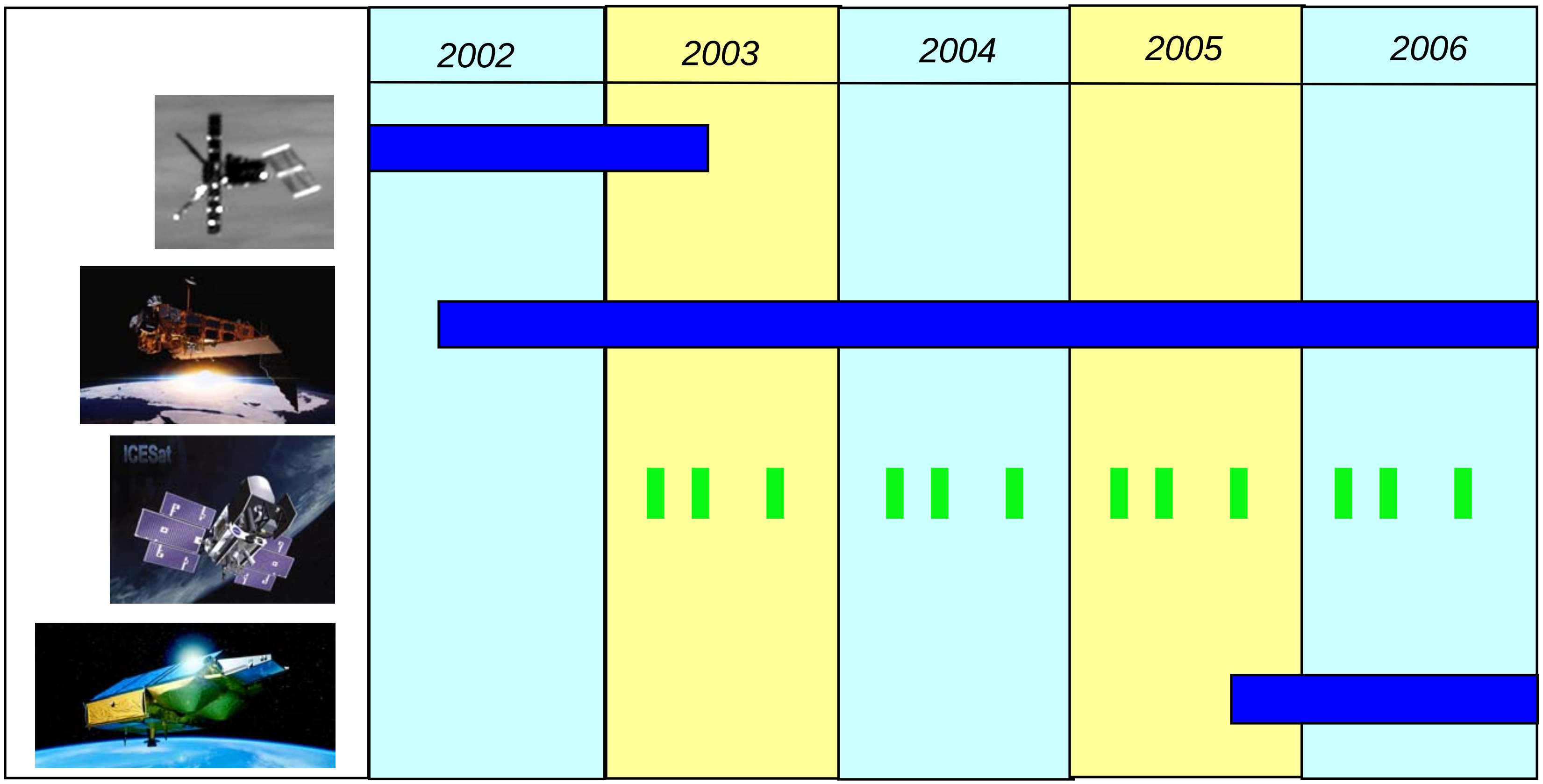


Model vs ERS Mean Winter Ice Thickness

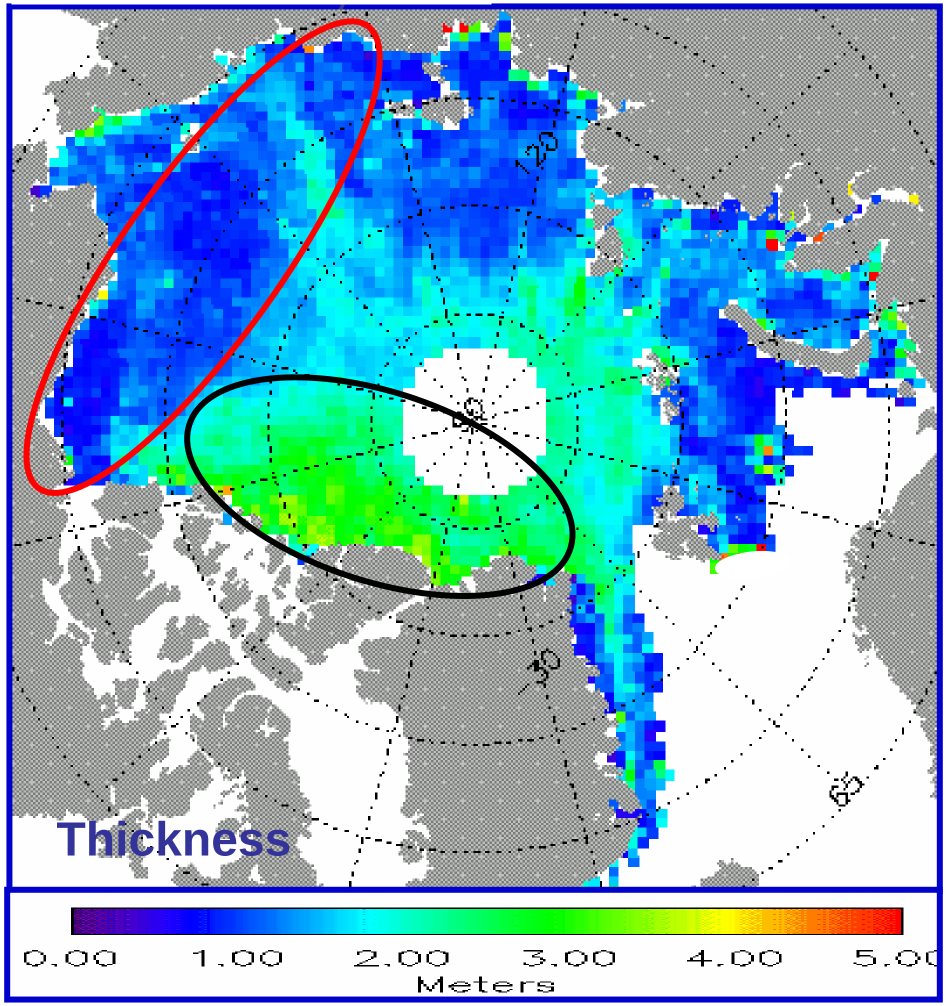


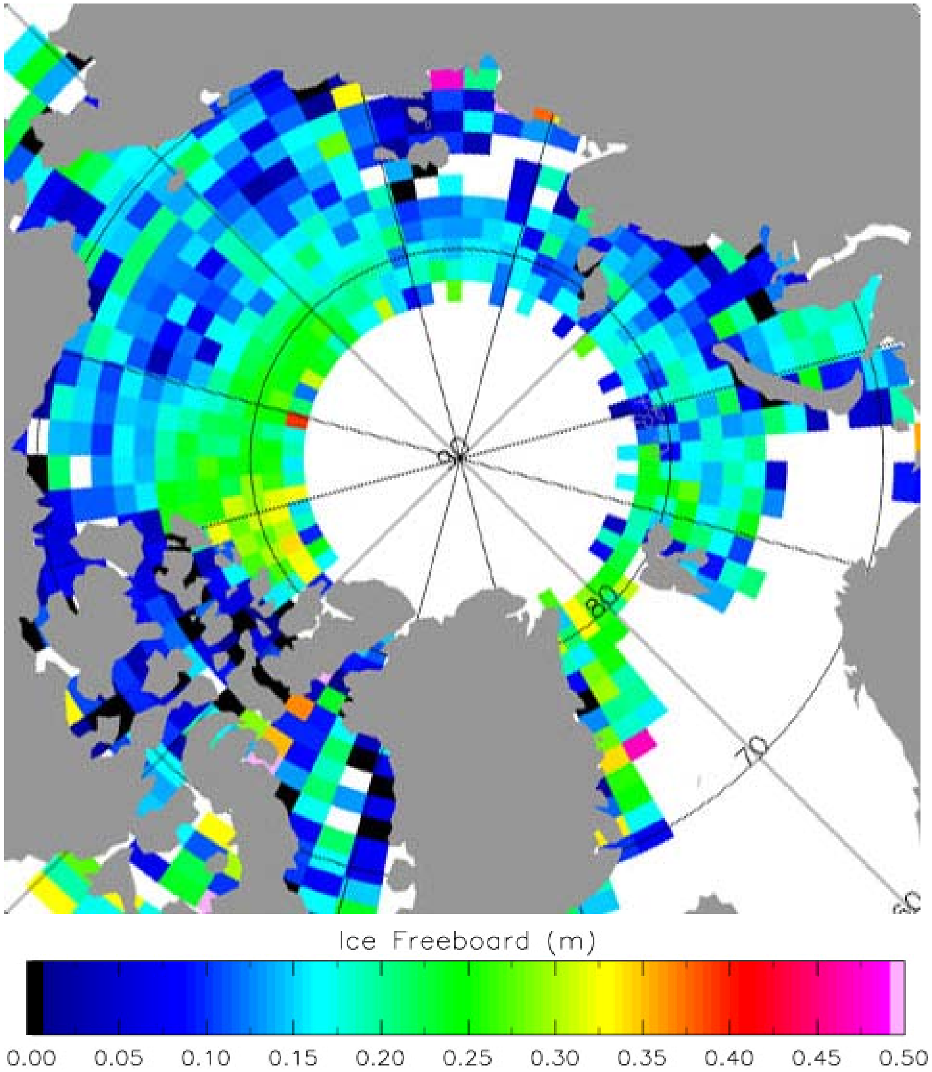
Model - Satellite Thickness (m)

Satellite Altimeter Missions 1993 -



IceSat vs Envisat RA-2 March 2003

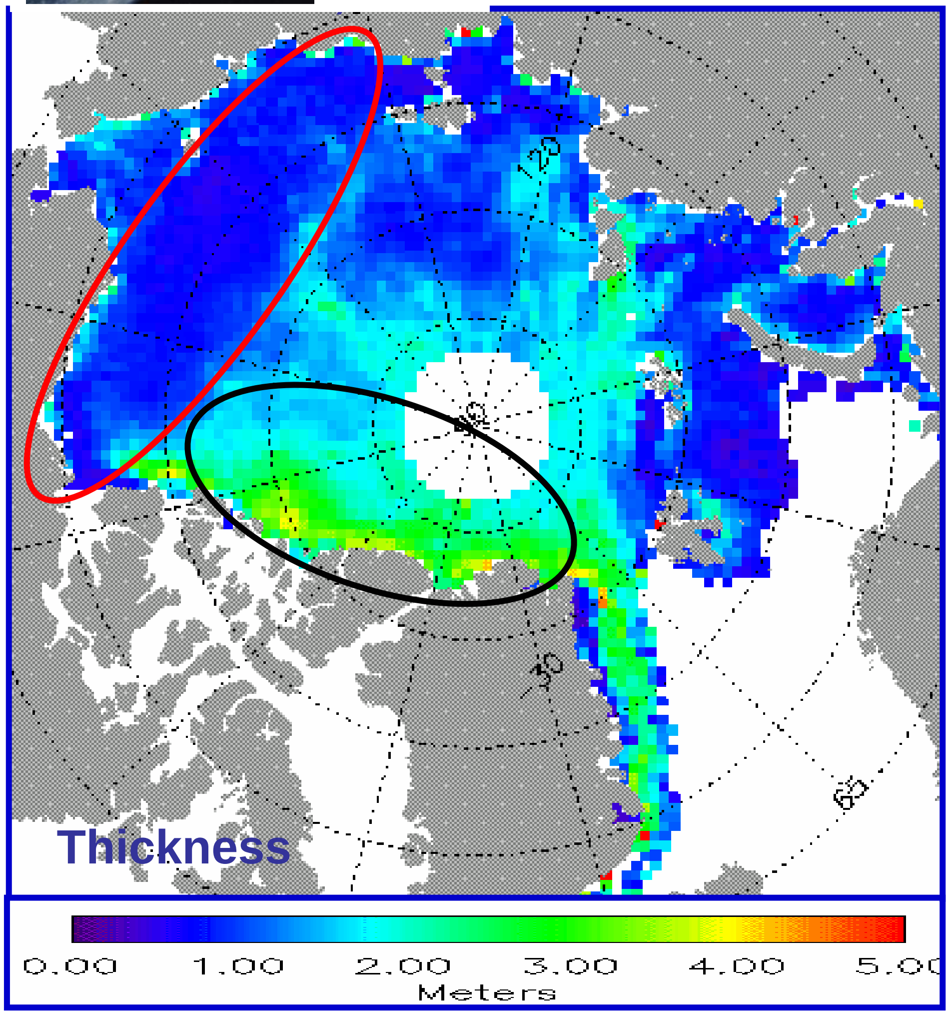


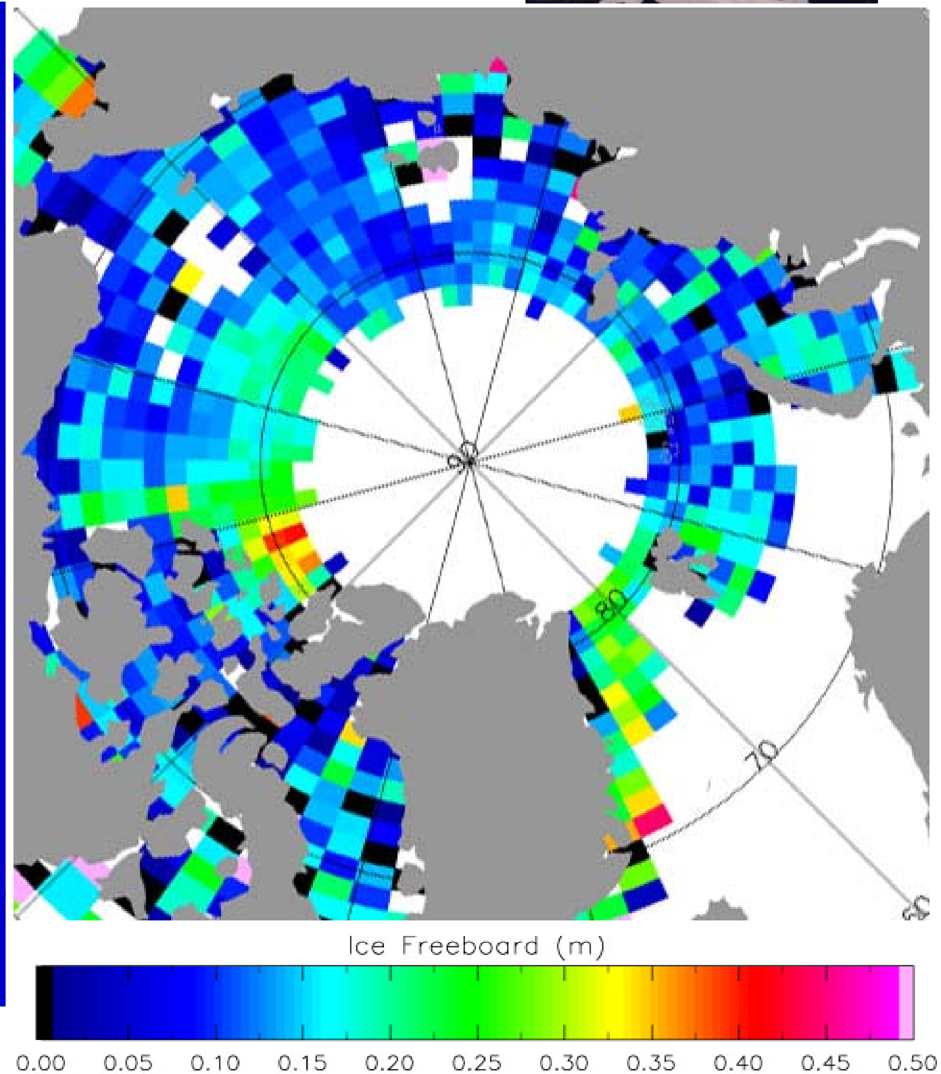


[Courtesy J. Zwally]

[Courtesy Andrew Ridout, CPOM]

IceSat vs Envisat RA-2
March 2004

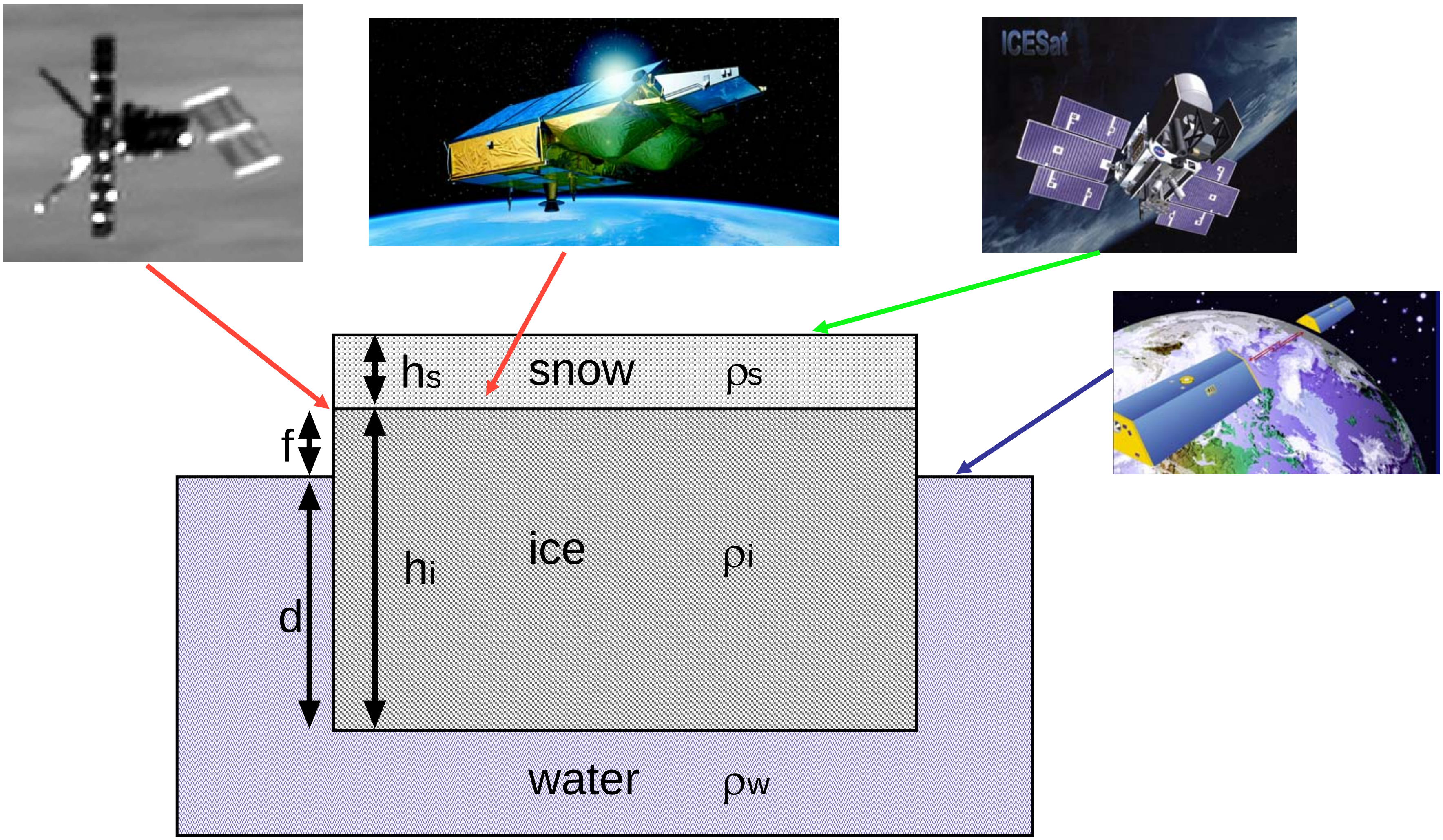




[Courtesy J. Zwally]

[Courtesy Andrew Ridout, CPOM]

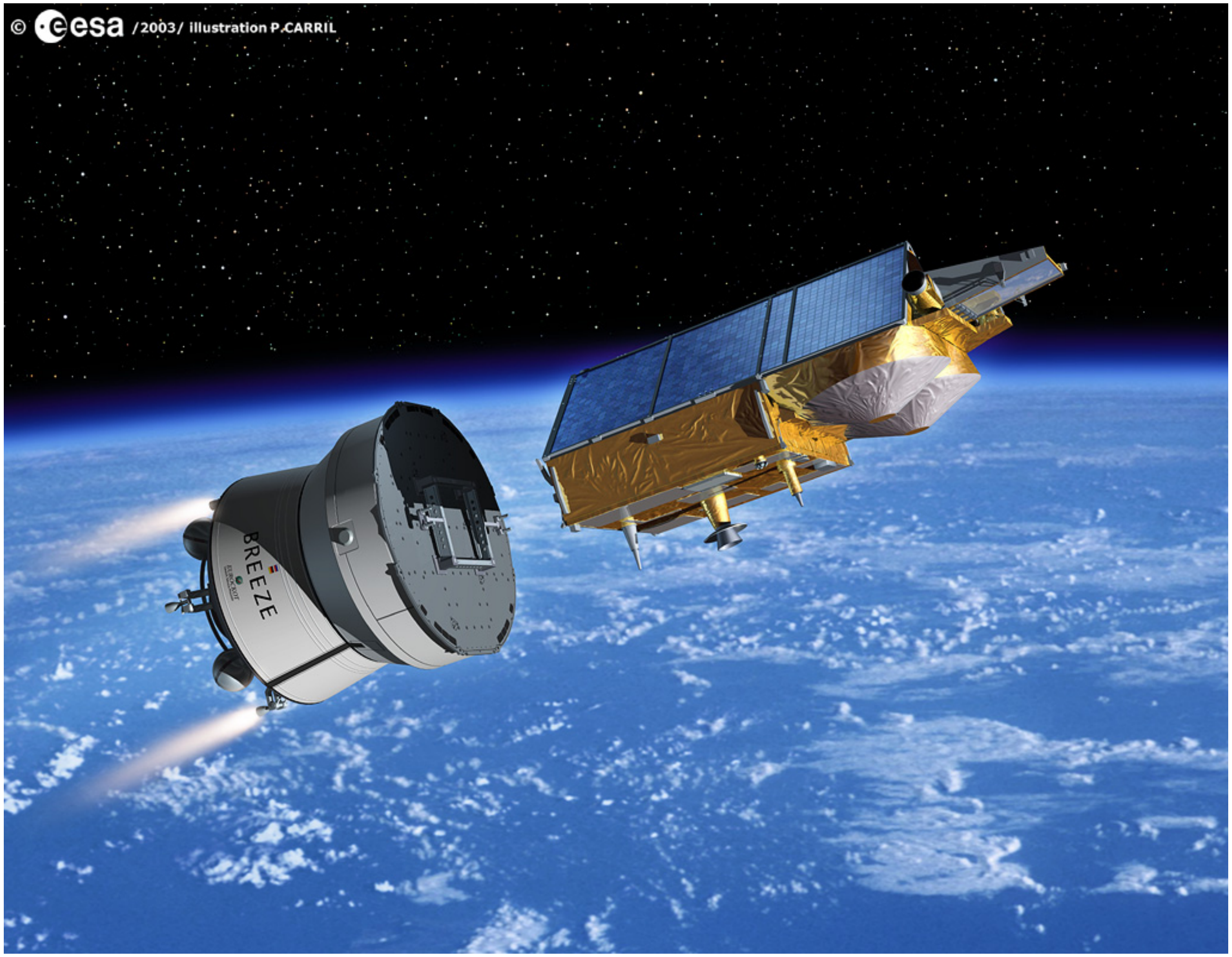
The Future: Combining Radar/Laser Altimetry



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
- These 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

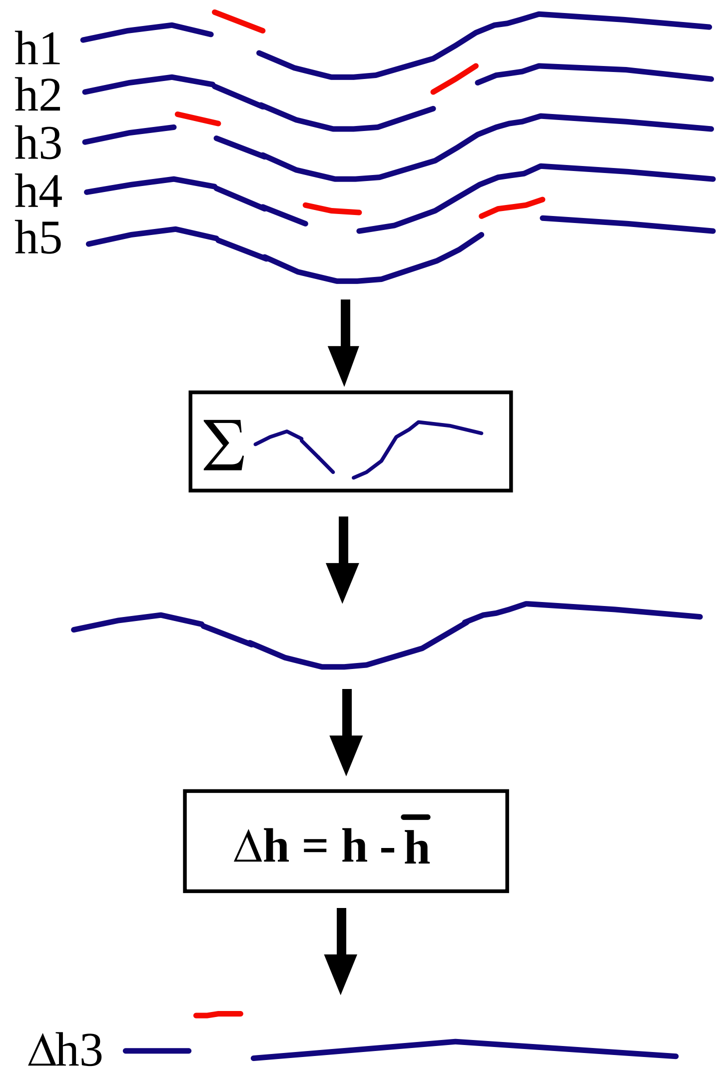
Summer 2005?



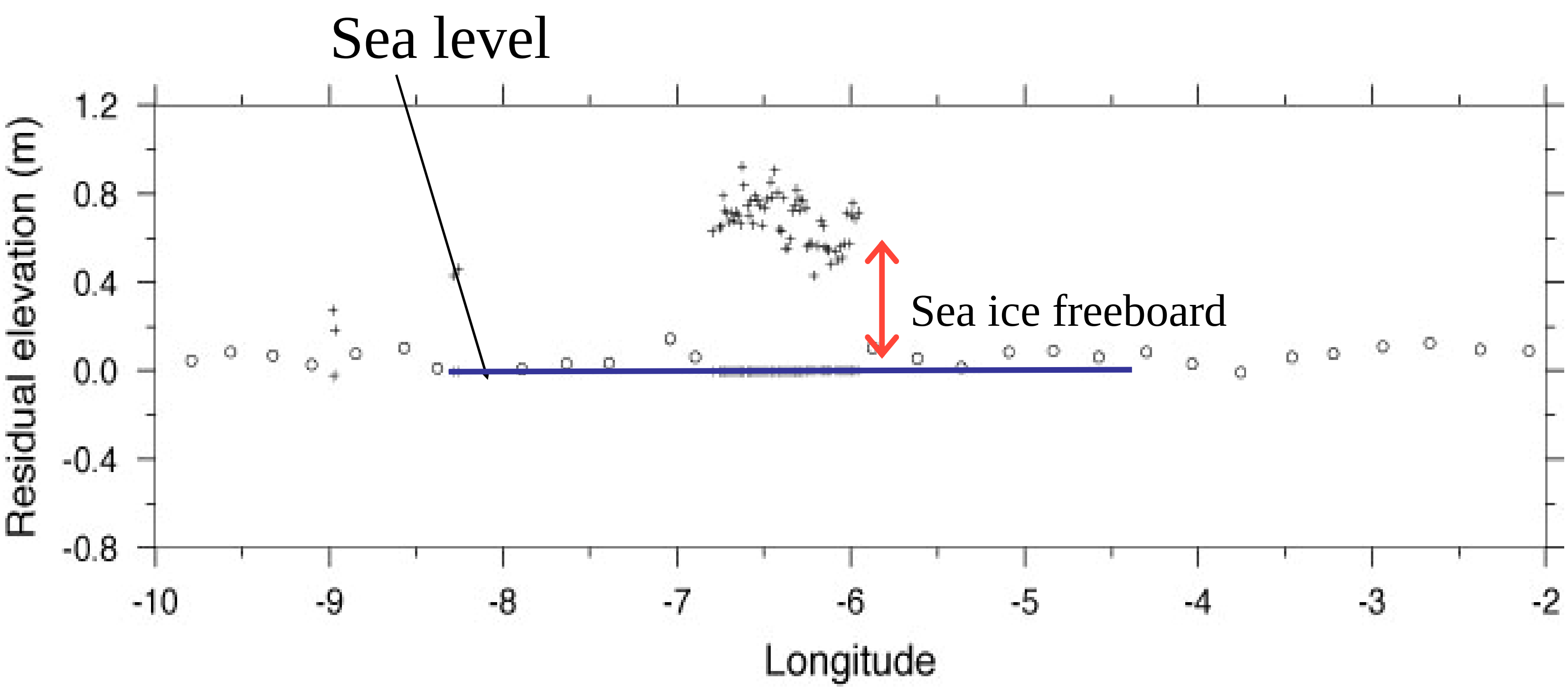
www.esa.int/esaLP/cryosat.html

Repeat Profile Analysis

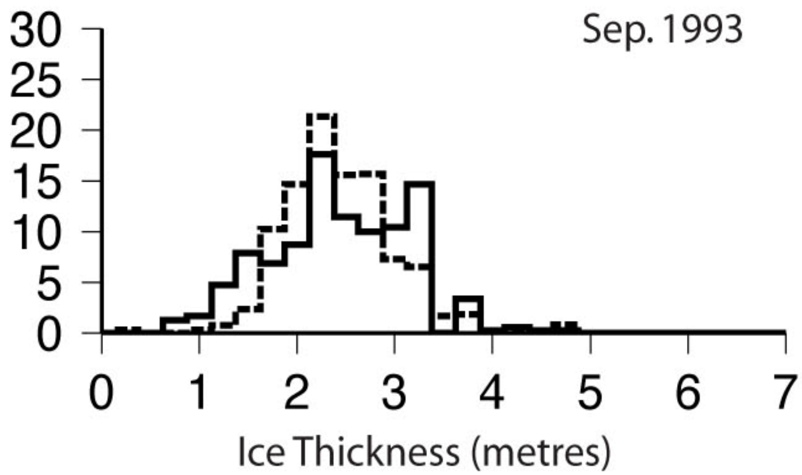
- Up to 60 repeat profiles are analysed along each of the 501 orbit tracks
- Ocean returns are used to construct a mean sea surface profile
- Residual height profiles are used to determine ice freeboard

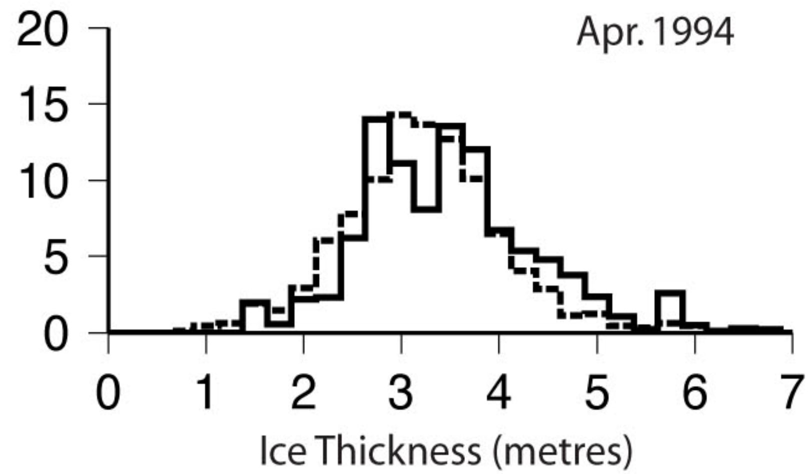


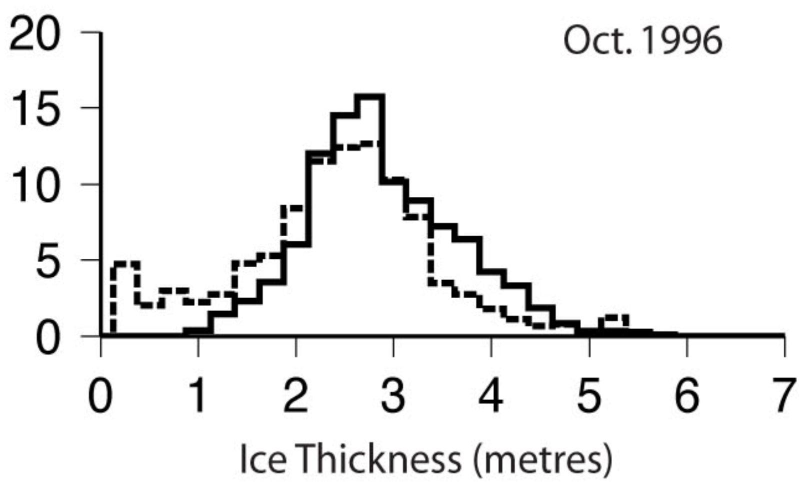
Altimeter Elevation Profile

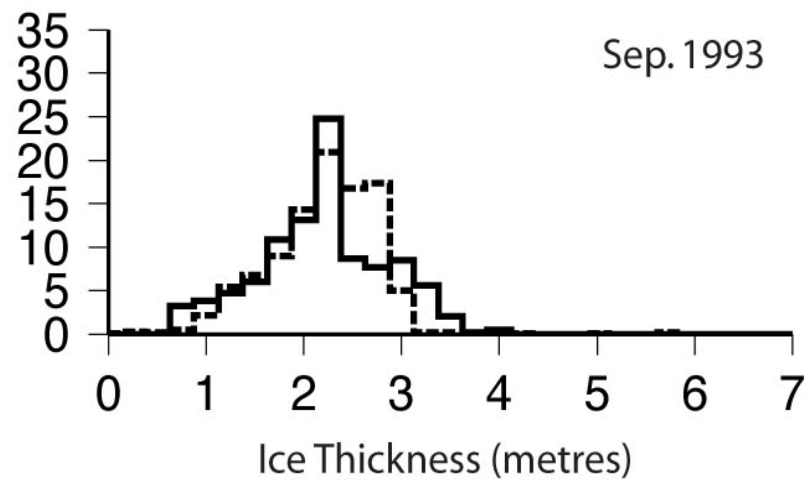


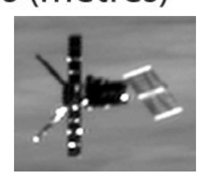
Comparison of Submarine and Altimeter Thickness PDF



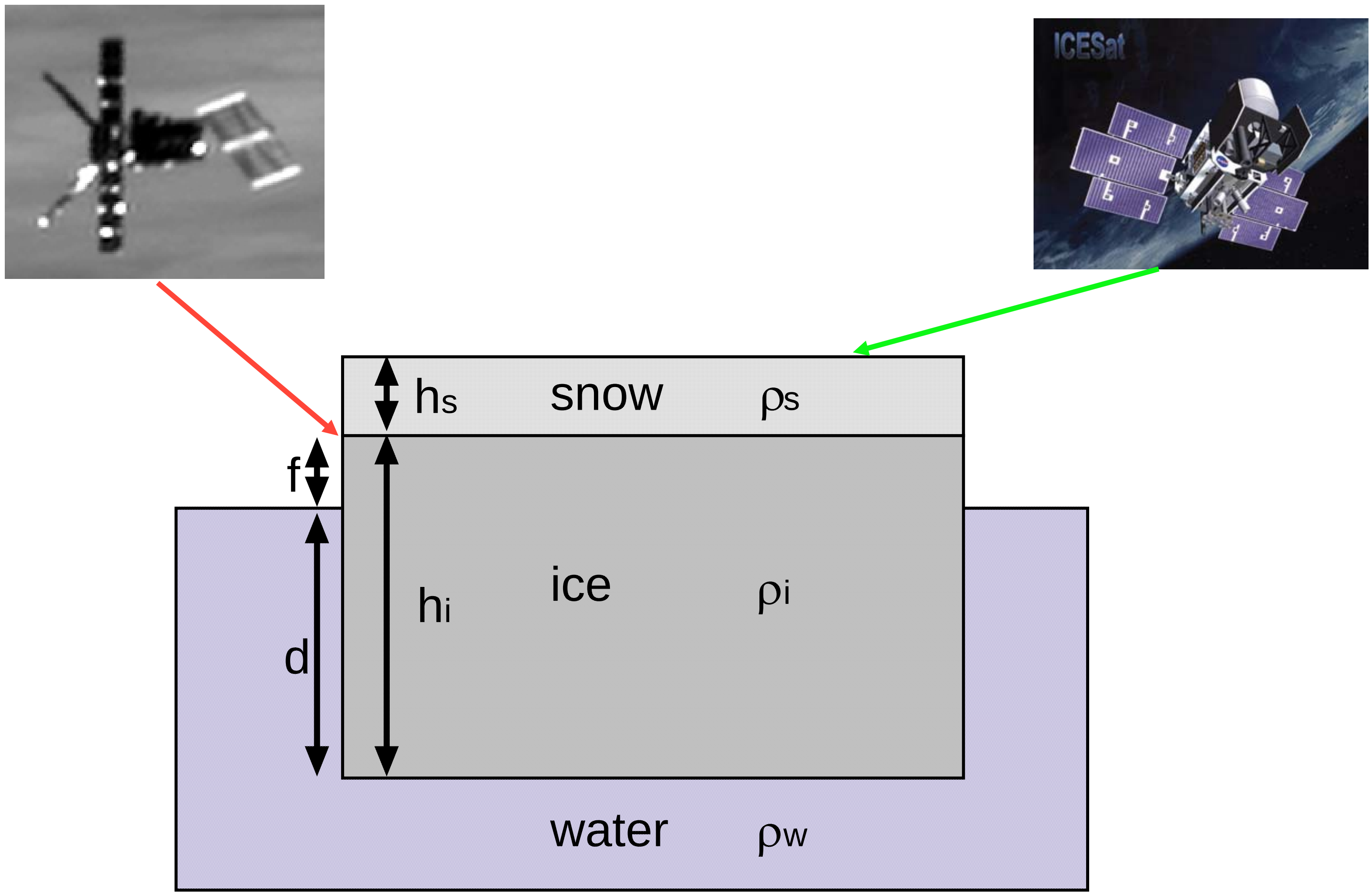






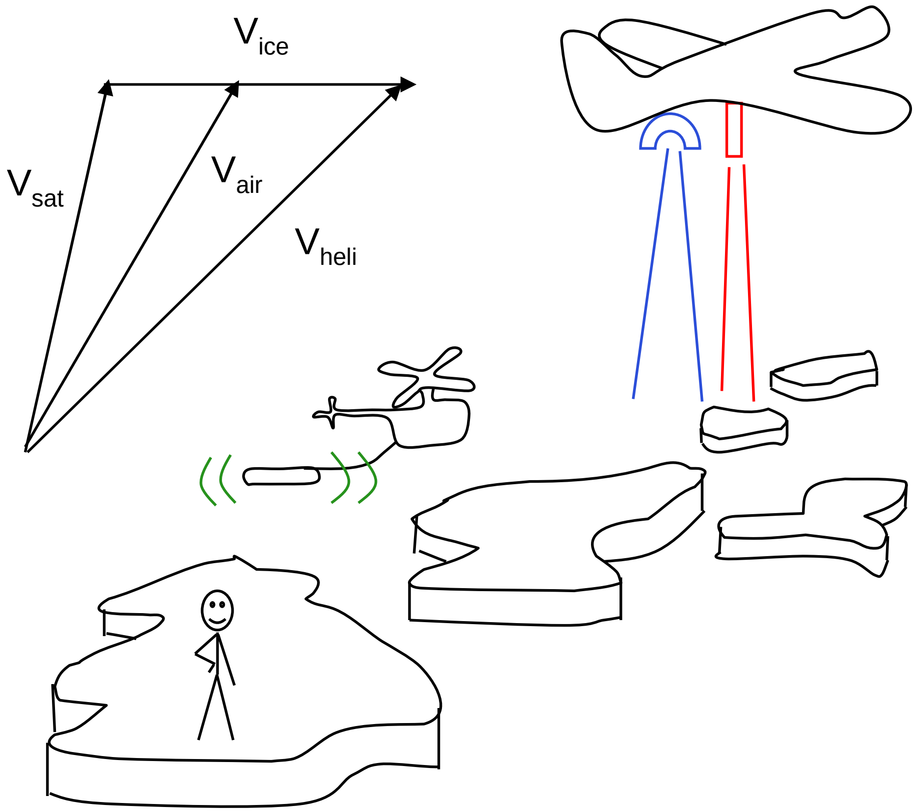


Combining Radar/Laser Altimetry



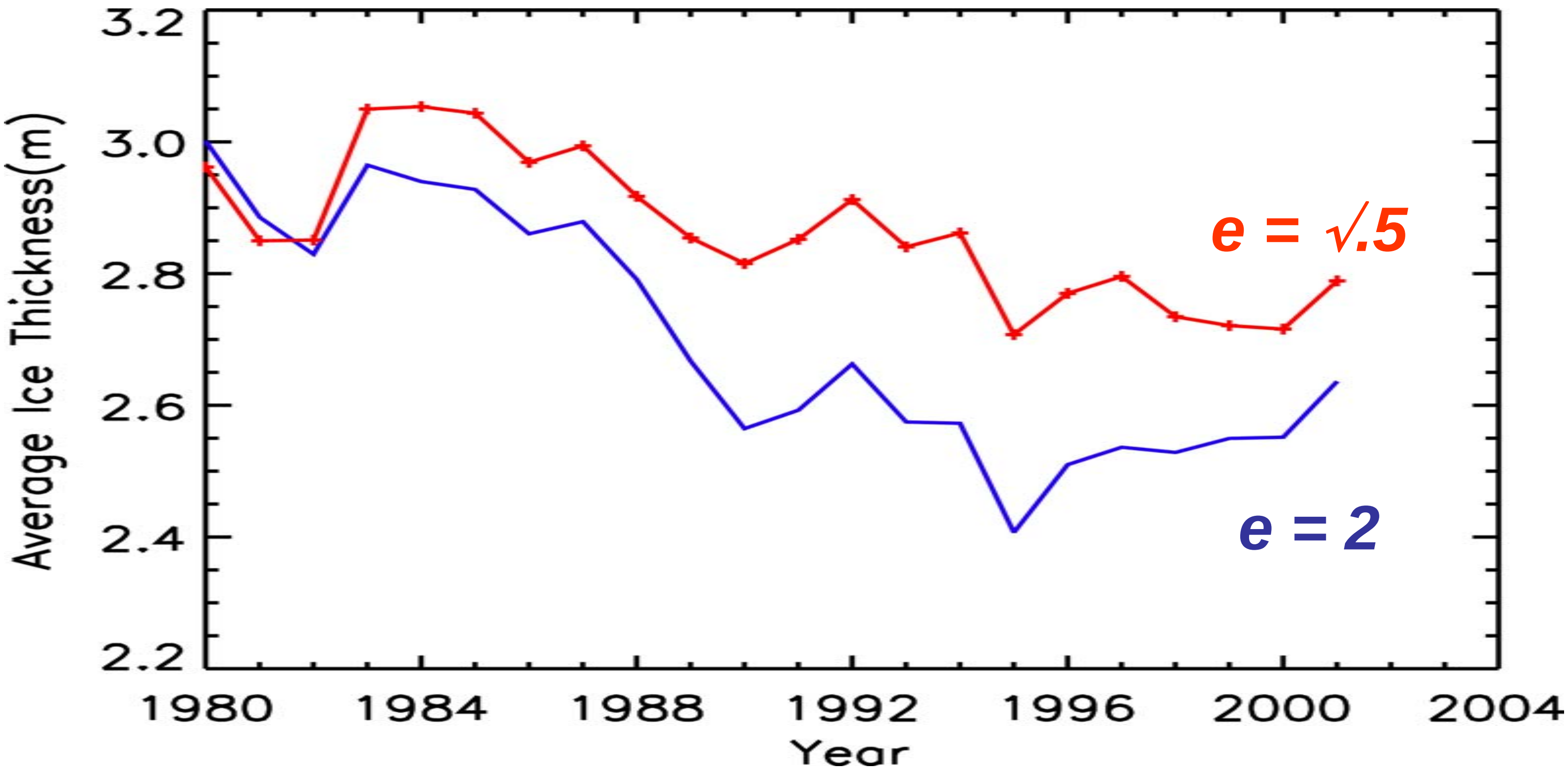
Conceptual Experiment Design

Example: Level 2 Sea ice geometric and penetration model error



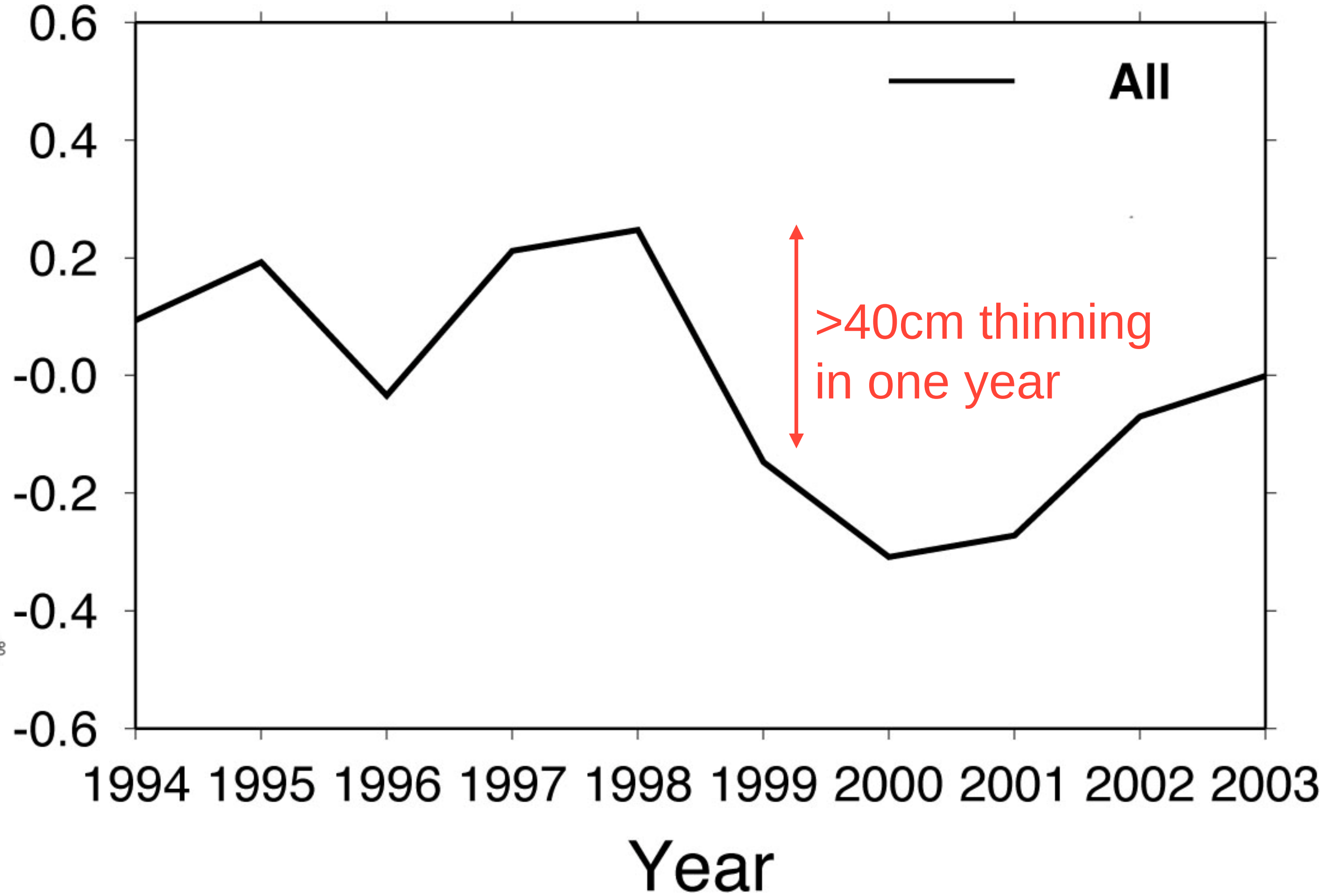
- Assess practicality and identify missing capability *e.g.* ASIRAS.
- Identify and contact important groups and planning time-scales *e.g.* Alfred Wegener Institute; 2-3 year planning horizon for polar activity.
- Identify practical locations *e.g.* Arctic Ocean N. and W. of Greenland is accessible 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.

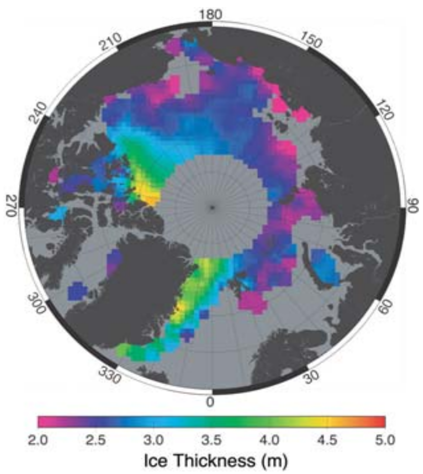
Arctic Basin Ice Thickness Since 1980



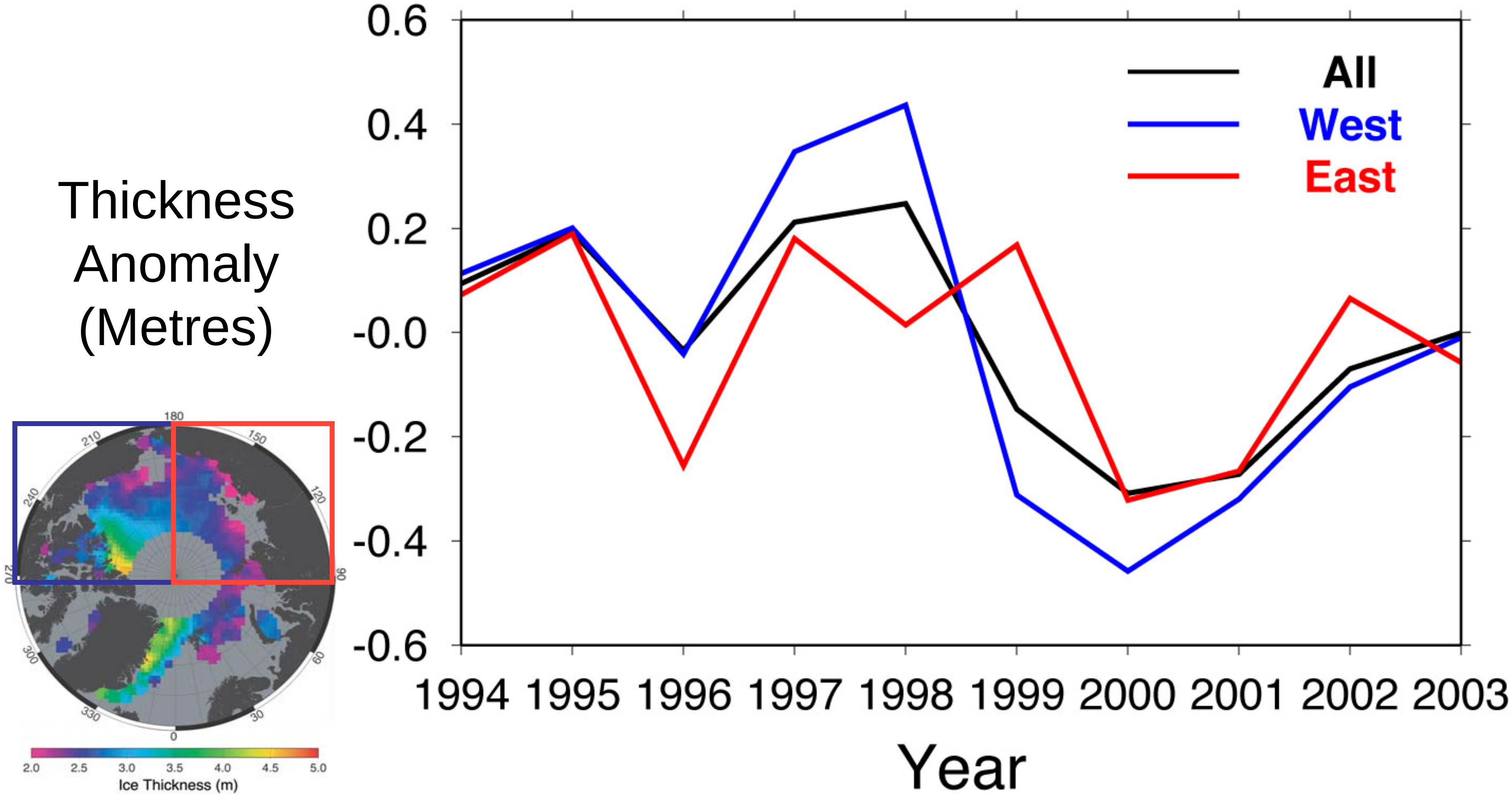
Annual mean Arctic sea ice thickness has been in decline since the mid-1980s

Ice Thickness Anomalies 1993-2003





Regional Ice Thickness Anomalies 1993-2003



Sources of Uncertainty