Ocean state estimation in the under-ice environment

Ian Fenty (JPL)
Matt Mazloff (SIO)
Paul Chamberlin (SIO)

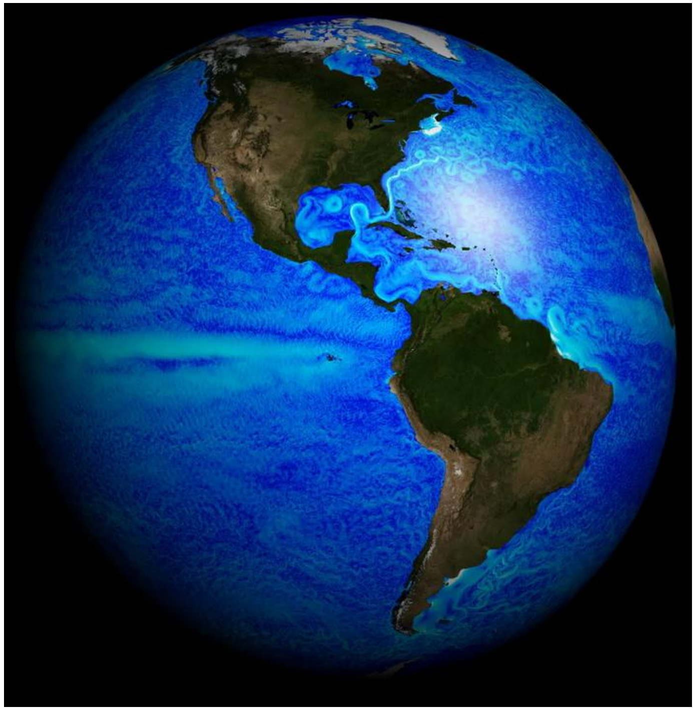
Ocean state estimation in the under-ice environment

- What is ocean state estimation?
- What have we learned so far about data assimilation in the under-ice environment?
- What has been the impact from *in situ ocean hydrographic* observations under ice?
- What are the most important remaining gaps?

Four-Dimensional Model Assimilation of Data

- Four-dimensional (space and time) model assimilation of geophysical data is a method to synthesize **diverse, temporally** and **spatially heterogeneous** observations into a **coherent representation** of an **evolving geophysical system**. The resulting model-data synthesis is referred to as a *state estimate*.

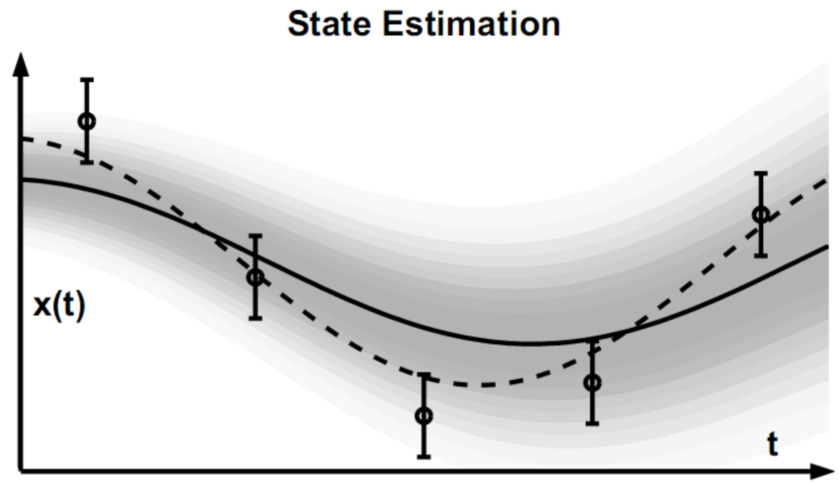
- It is a **systematic, quantitative,** and **objective means** of **inference** and **testing** aimed at advancing understanding and prediction of nonlinear dynamical geophysical systems **where interactions occur continually among relevant physical, chemical, and biogeochemical processes.**



Adapted from the *Panel on Model-Assimilated Data Sets for Atmospheric and Oceanic Research, National Research Council* (1991)

Ocean State Estimation with the Adjoint Method

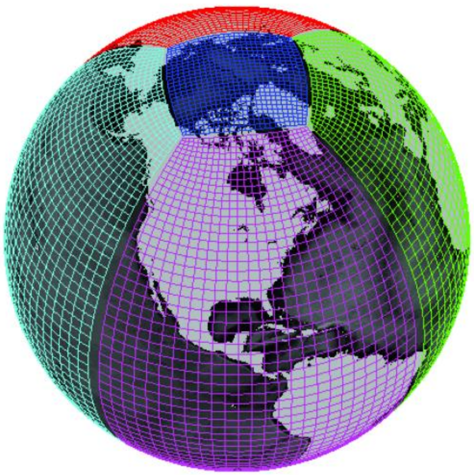
- Goal: reconstruct the three-dimensional time-varying ocean-sea ice system (*ocean-ice state estimate)* with a numerical model constrained by observations.
- Minimize the distance in phase space between a model system trajectory and the observations over some time interval.
- The model system trajectory is brought into a state of consistency with the data in a *least-squares sense* using the adjoint of the numerical model.
- The adjoint provides information about how to correct the model system trajectory via adjustments to first-guess model *initial conditions, atmospheric boundary conditions,* and *other control parameters*.



Circle/bars : observations + uncertainties
Solid : initial state trajectory
Dashed : improved state estimate

Figure from J. Gebbie 2004

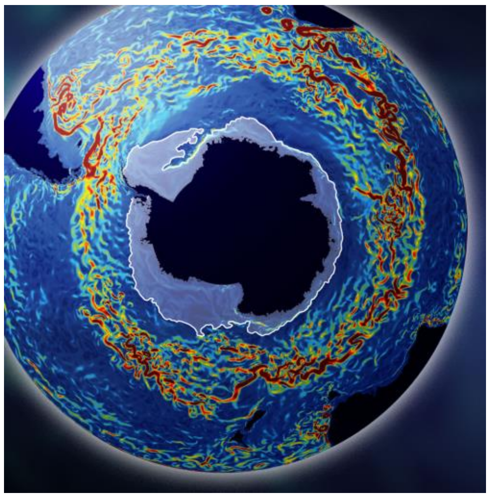
ECCO: Estimating the Circulation and Climate of the Ocean, Version 4



1992-2015
Global
1-degree

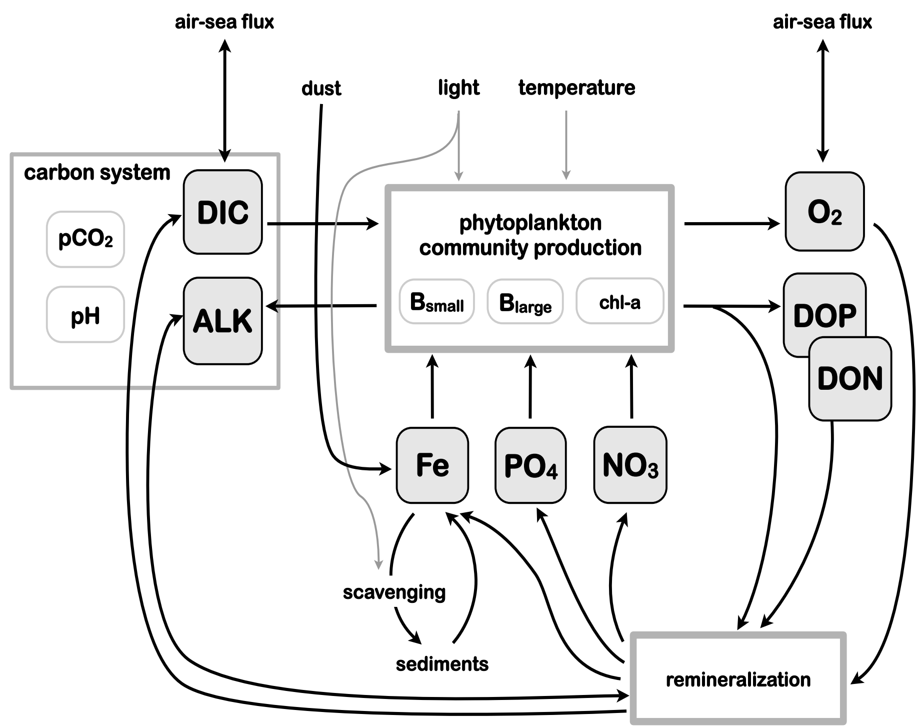
Variable	Observations
Sea surface height	TOPEX/Poseidon (1993-2005), Jason-1 (2002-2008), Jason-2 (2008-2015), Geosat-Follow-On (2001-2007), CryoSat-2 (2011-2015), ERS-1/2 (1992-2001), ENVISAT (2002-2012), SARAL/AltiKa (2013-2015)
in situ temperature	Argo floats (1995-2015), XBTs (1992-2008), CTDs (1992-2011), **Southern Elephant seals as Oceanographic Samplers (SEaOS; 2004-2010), Ice-Tethered Profilers (ITP, 2004-2011)** and other high-latitude CTDs and moorings
in situ salinity	Argo floats (1997-2015), CTDs (1992-2011), **SEaOS (2004-2010),** and other new high-latitude CTDs and moorings
Sea surface temperature	AVHRR (1992-2013), AMSR-E (2002-2010)
Sea surface salinity	Aquarius (2011-2013)
Sea-ice concentration	**SSM/I DMSP-F11 (1992-2000) and -F13 (1995-2009) and SSMIS DMSP-F17 (2006-2015)**
Ocean bottom pressure	GRACE (2002-2014), JPL MASCON Solution

Biogeochemical-Southern Ocean State Estimate: B-OSE (Mazloff and Verde, SIO)



Variable	Observations
pH	Bio-geochemical Argo
NO_3	Bio-geochemical Argo
O_2	Bio-geochemical Argo

2008–2012
Southern Ocean
1/3-degree



The specification of prior uncertainties is a critical component of ocean state estimation

$$J = \Sigma_{i=1}^{n} \left[\frac{(x_i - Hy_i)^2}{\sigma_i^2} \right]$$

model state

observation

prior uncertainty

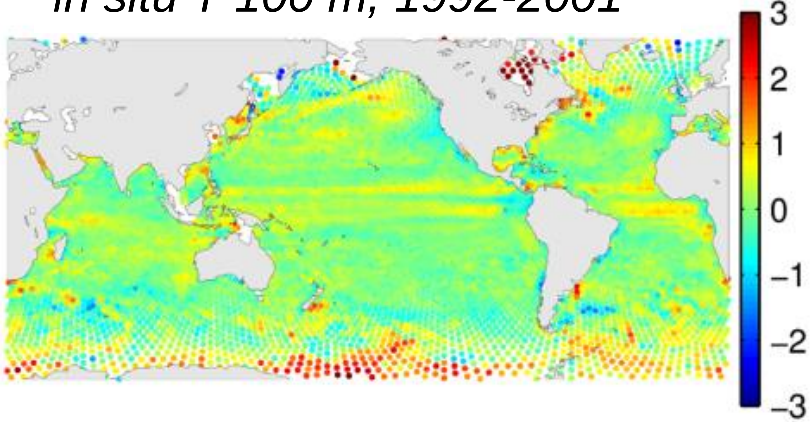
A prior uncertainty is assigned to each observation. Typically, the prior uncertainty is a measure of how well we expect our model to be able to reproduce the observation: the **expected variance** of the **squared model-data residuals.**

Importantly, these prior uncertainties also determine the criteria for determining whether a state estimate is consistent with the data.

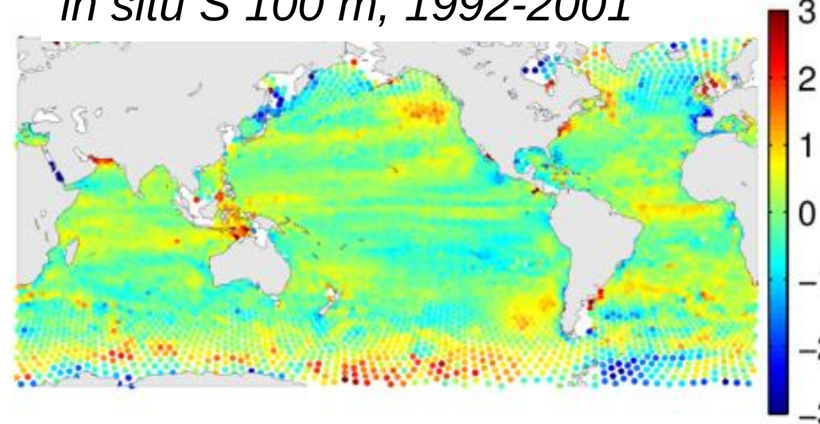
Consistency of the ECCO ocean-ice state estimate with respect to *in situ T and S data*

$$\text{Uncertainty-normalized model-data difference} = \frac{x_i - H y_i}{\sigma_i}$$

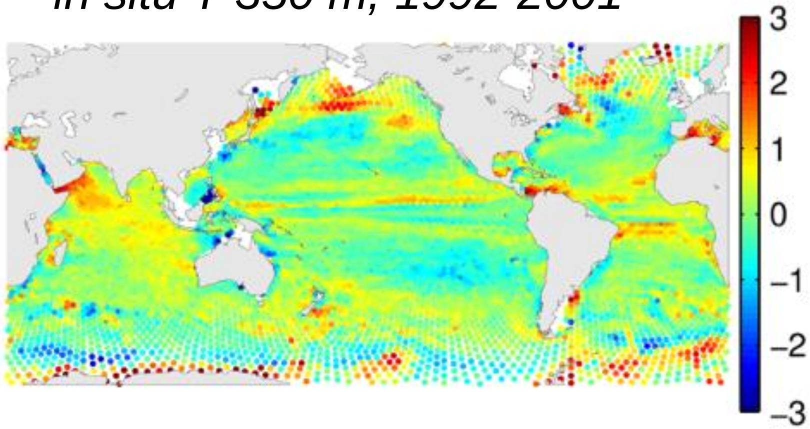
in situ T 100 m, 1992-2001



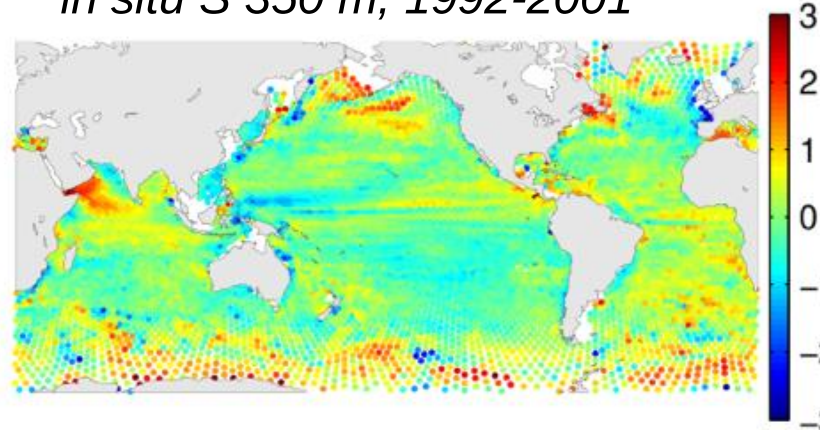
in situ S 100 m, 1992-2001



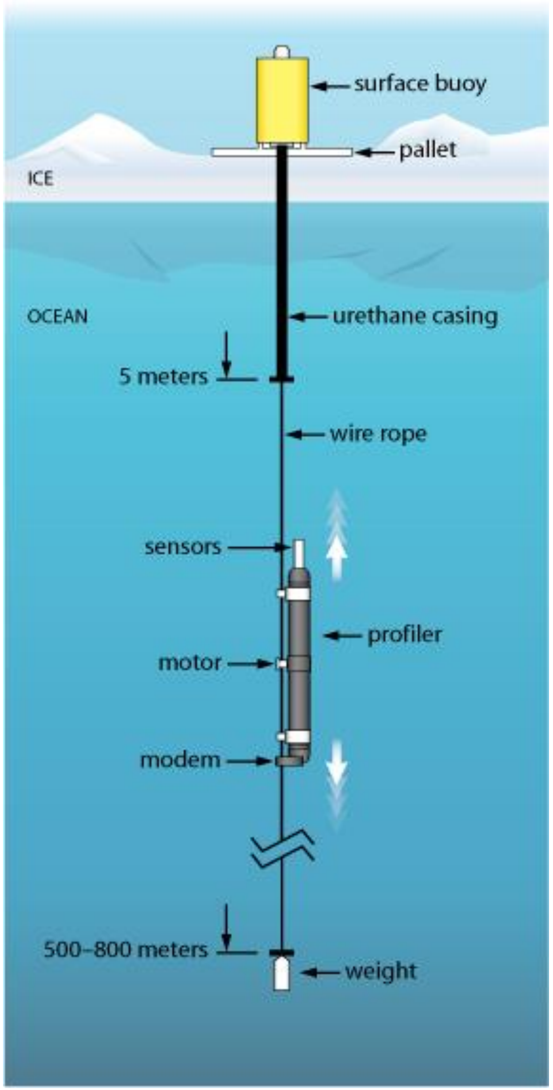
in situ T 350 m, 1992-2001



in situ S 350 m, 1992-2001



What has been the impact from *in situ* ocean observations under ice?

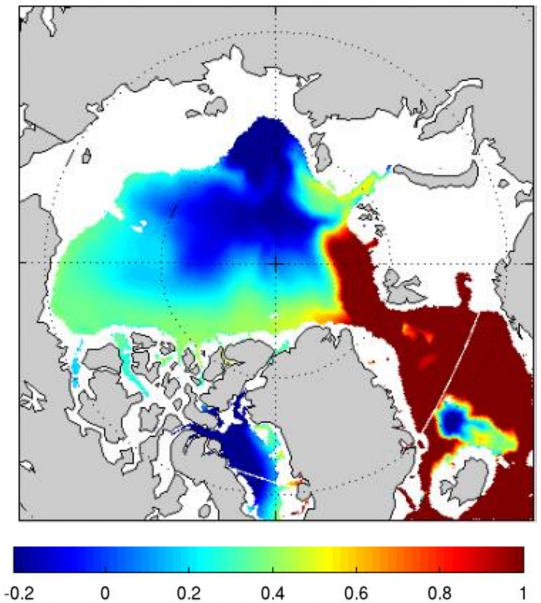


Credit: John Toole/WHOI

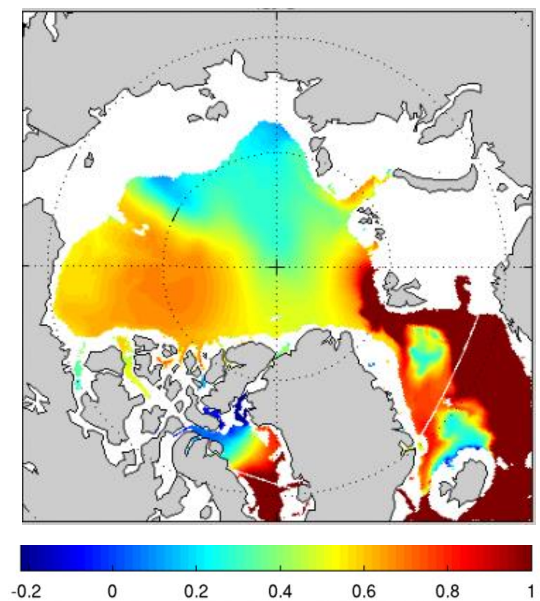
What has been the impact from *in situ* ocean observations under ice?

Ocean T at 220 m, Dec 2012

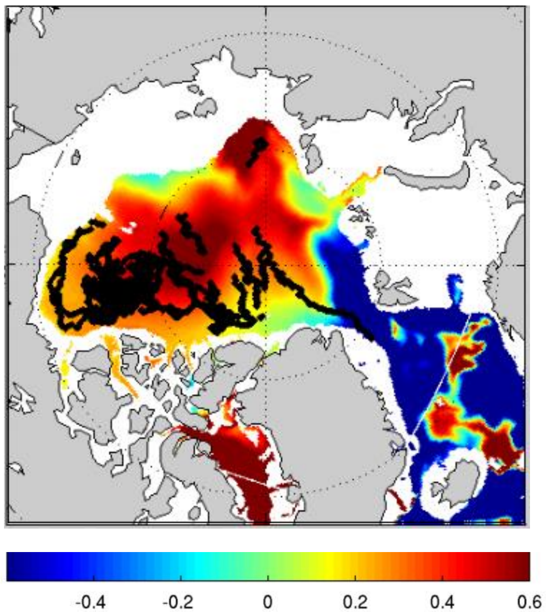
T Difference



Pre ITP data synthesis



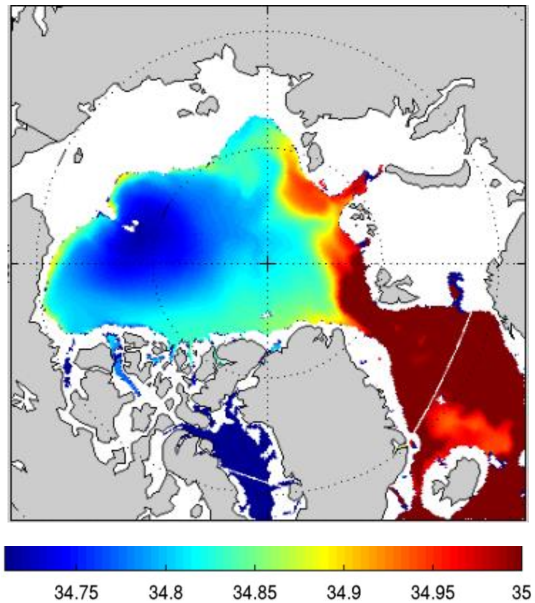
Post ITP data synthesis



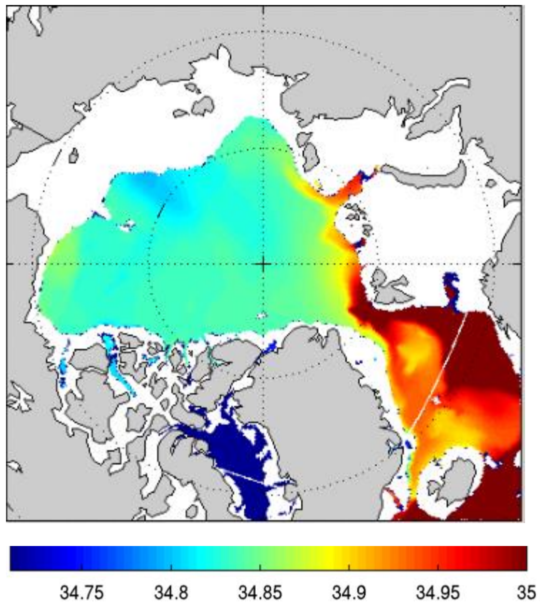
Post – Pre ITP data synthesis

What has been the impact from *in situ* ocean observations under ice?

Ocean S at 220 m, Dec 2012

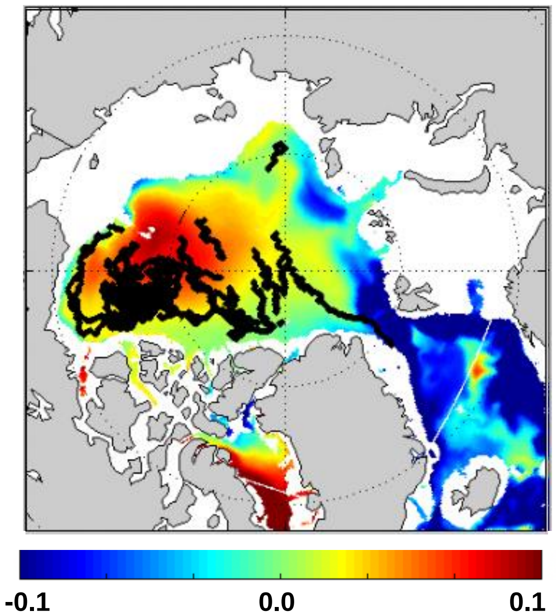


Pre ITP data synthesis



Post ITP data synthesis

S Difference



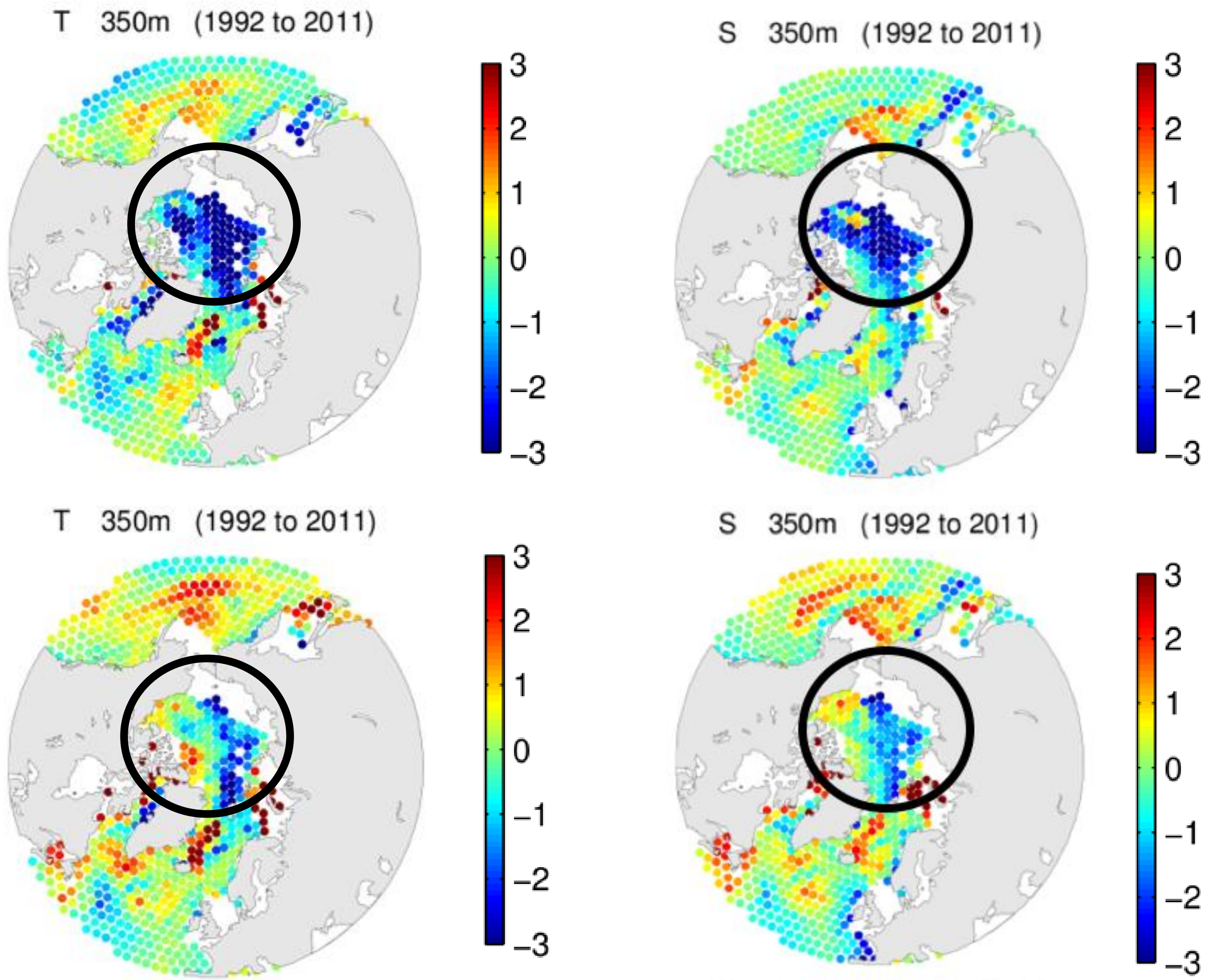
Post – Pre ITP data synthesis

What has been the impact from in situ ocean observations under ice?

Uncertainty normalized model-data in situ T and S differences before and after ITP data constraints

pre-ITP

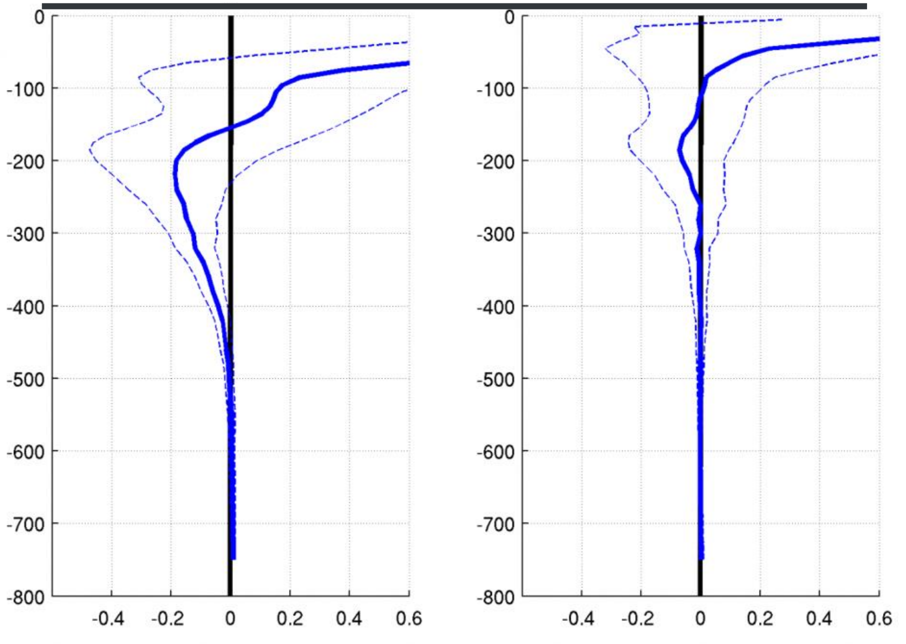
Post-ITP



What has been the impact from in situ ocean observations under ice?

Distribution of model-data T and S differences before and after ITP data synthesis

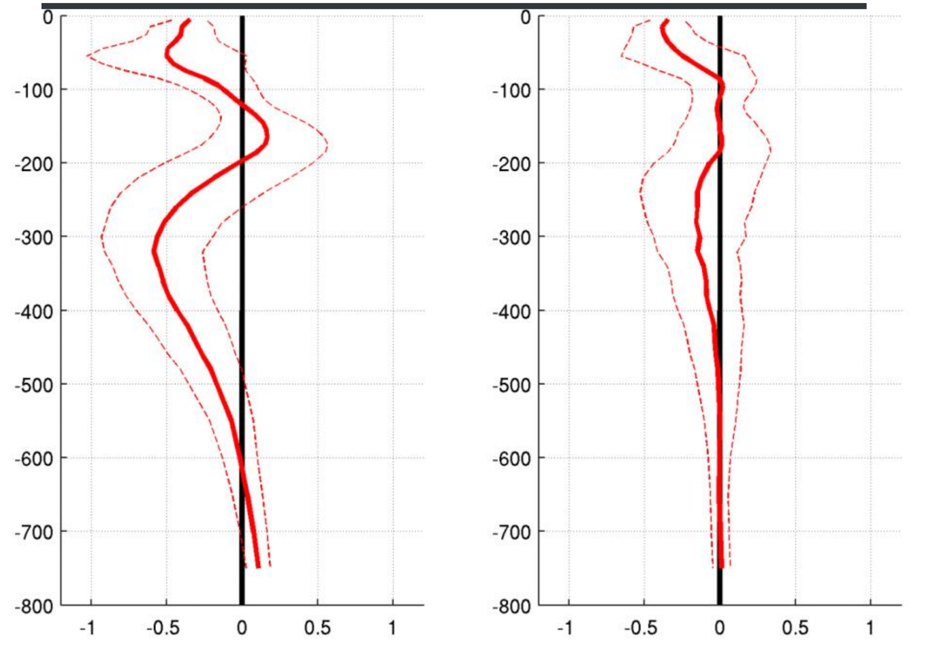
Salinity



pre-ITP

Post-ITP

Temperature

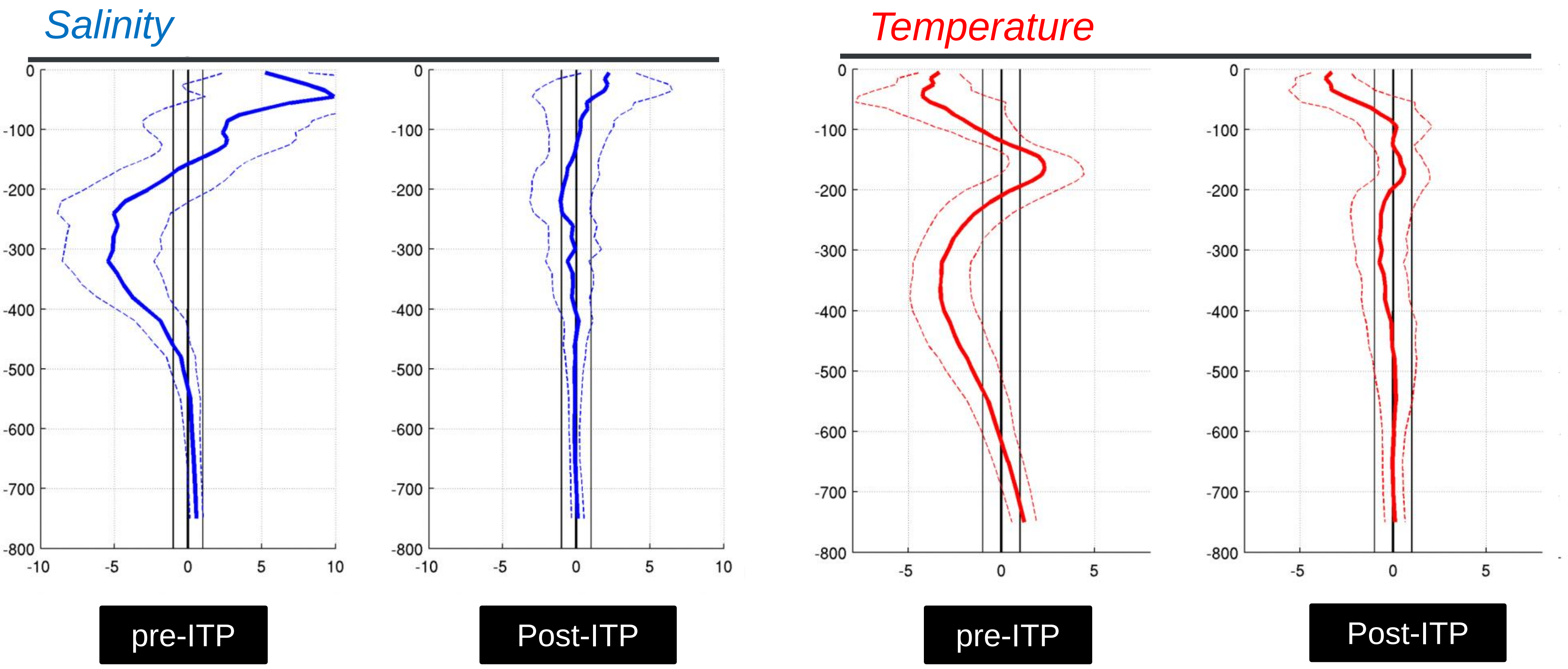


pre-ITP

Post-ITP

What has been the impact from in situ ocean observations under ice?

Distribution of uncertainty-normalized model-data T and S differences before and after ITP data synthesis

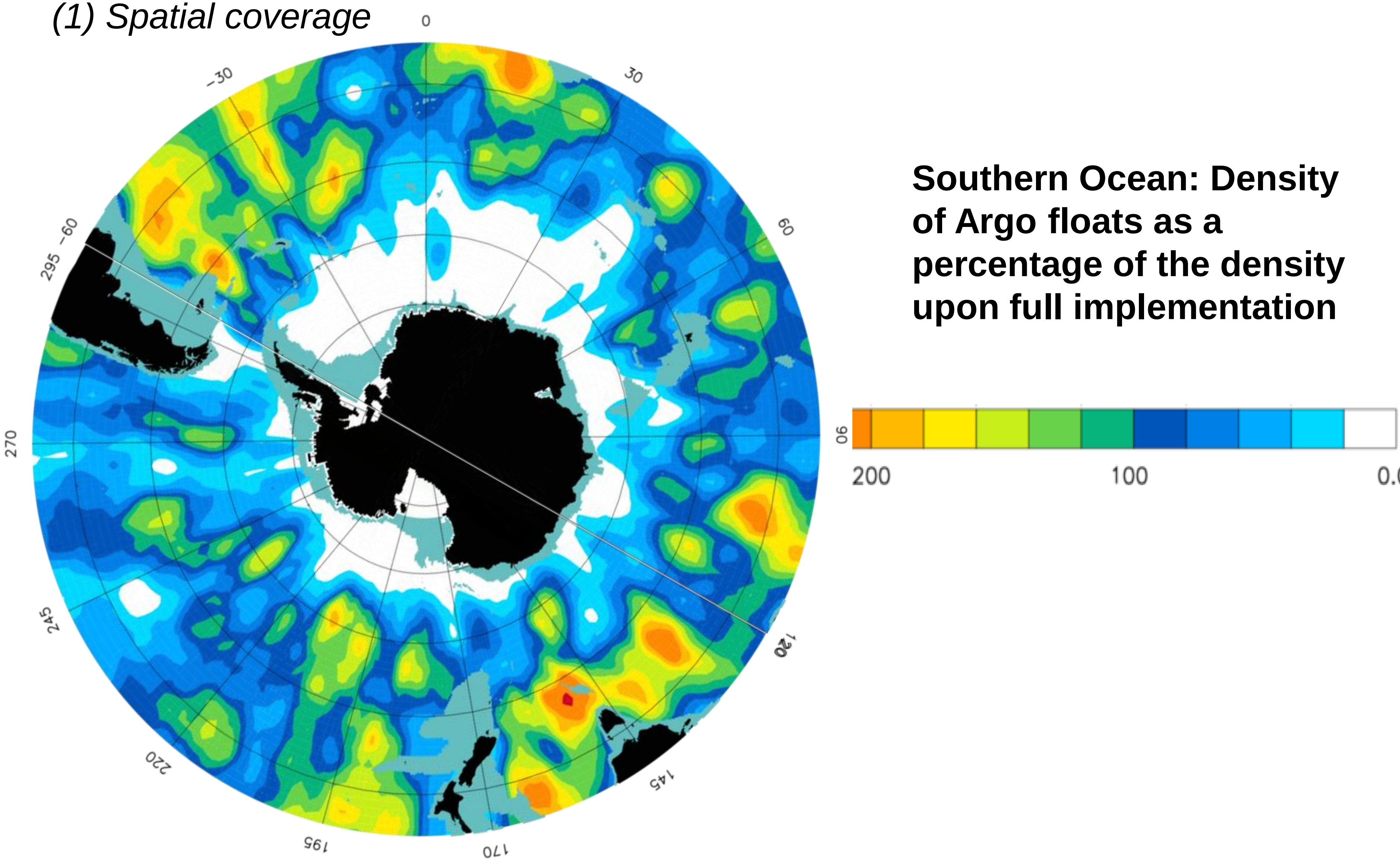


What are the most important remaining gaps?

1. Spatial Coverage
2. Proper specification of prior observation uncertainty for under-ice observations

What are the most important remaining gaps?

(1) Spatial coverage



Southern Ocean: Density of Argo floats as a percentage of the density upon full implementation

http://sio-argo.ucsd.edu/density_so_web.html

Updated 14 Jun 2017 19:26 GMT)

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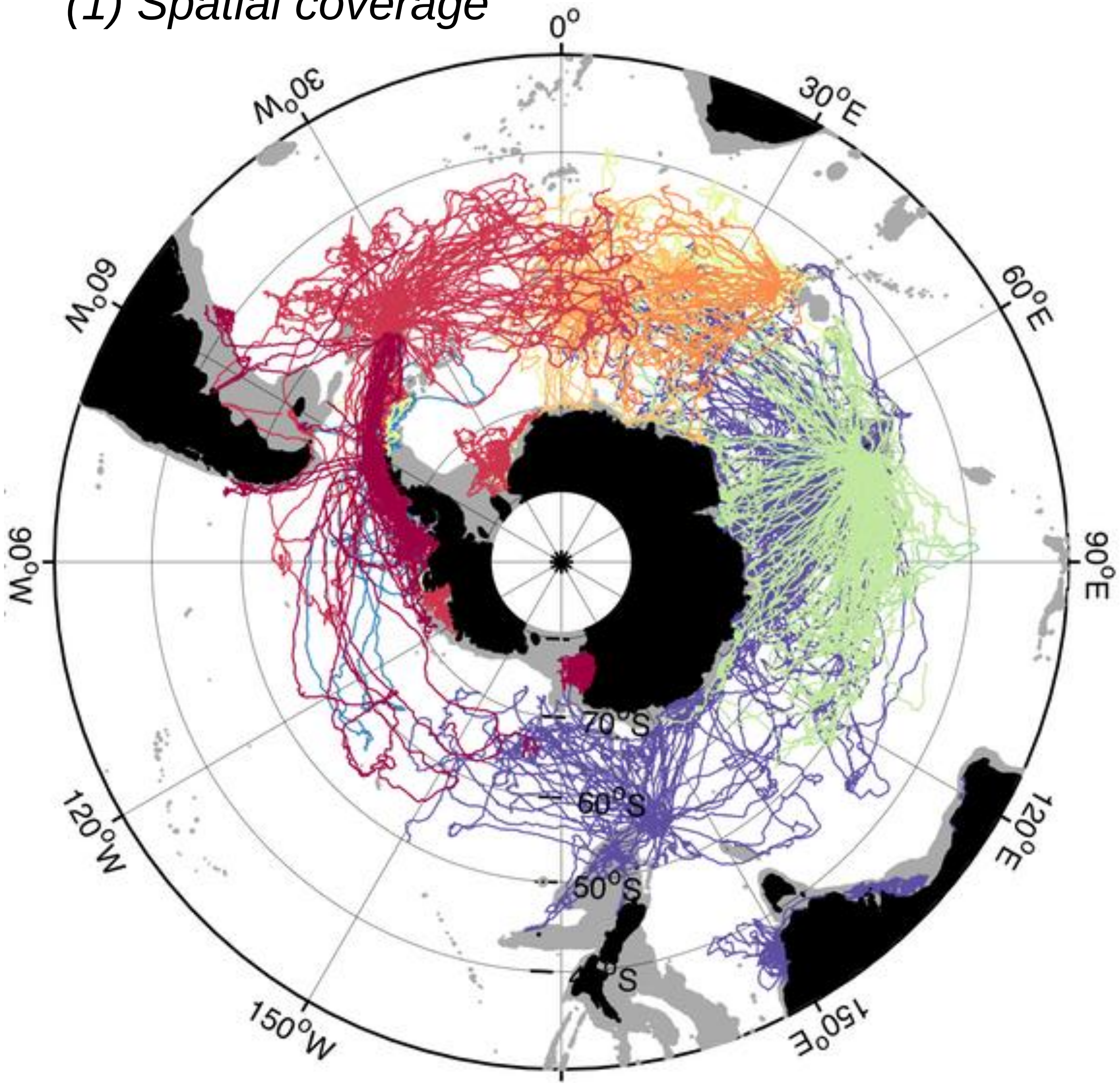
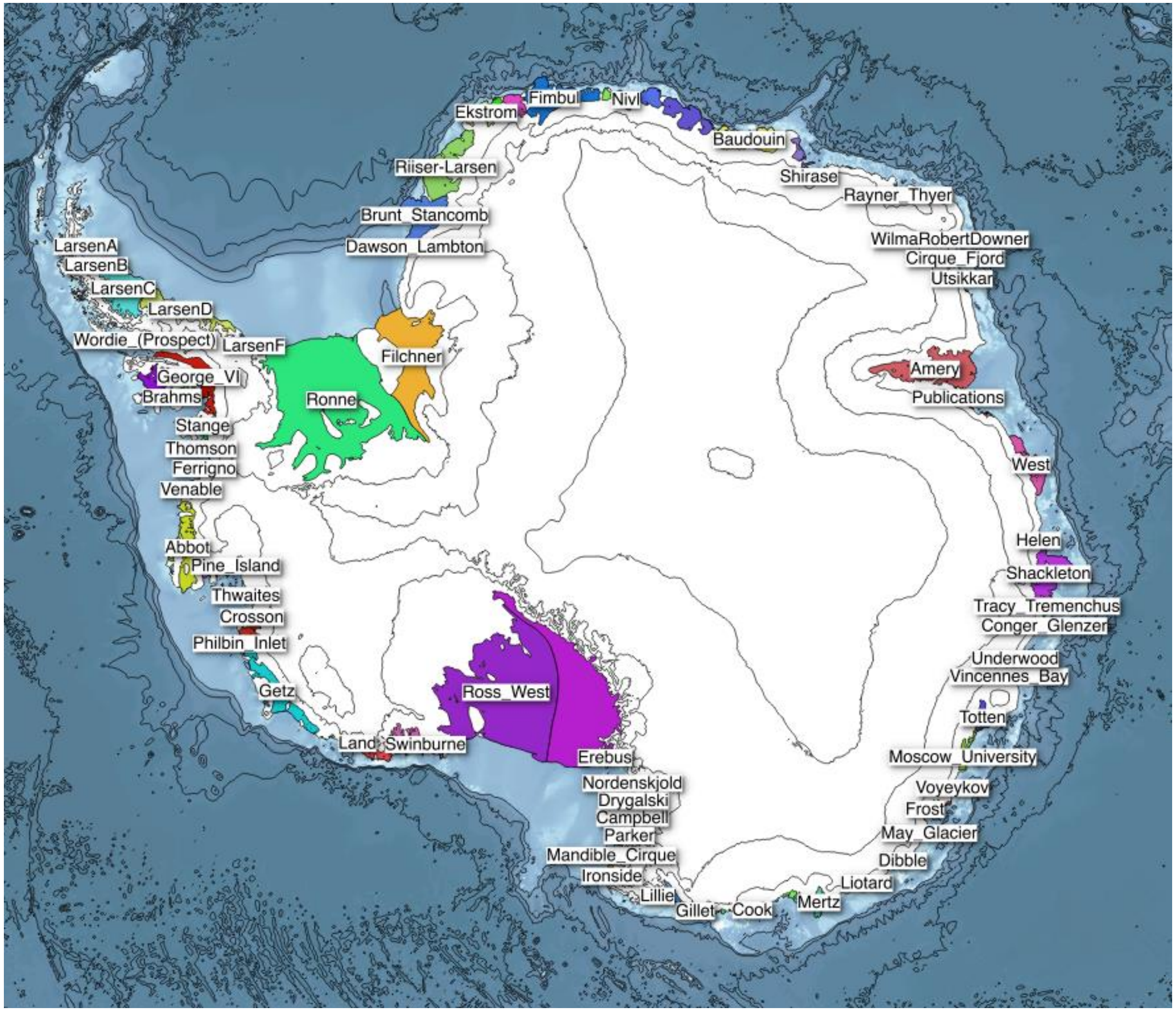
(1) Spatial coverage



MEOP CTD database

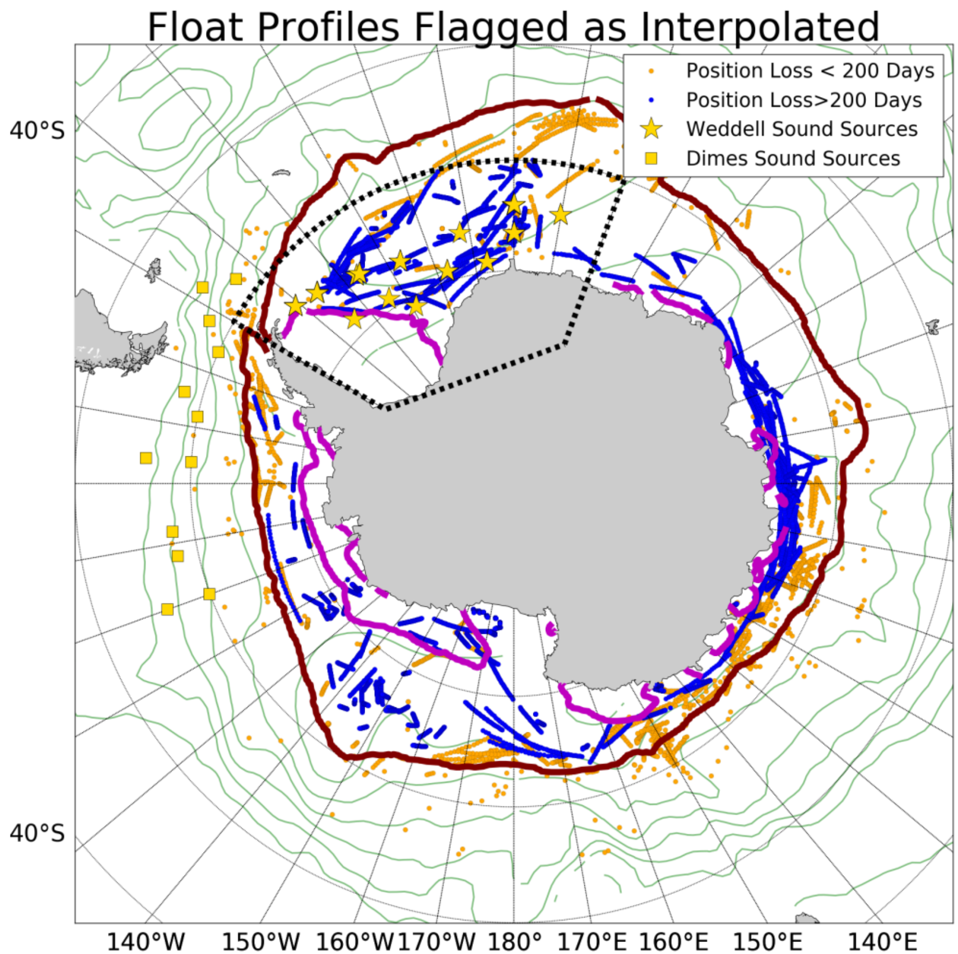
What are the most important remaining gaps?

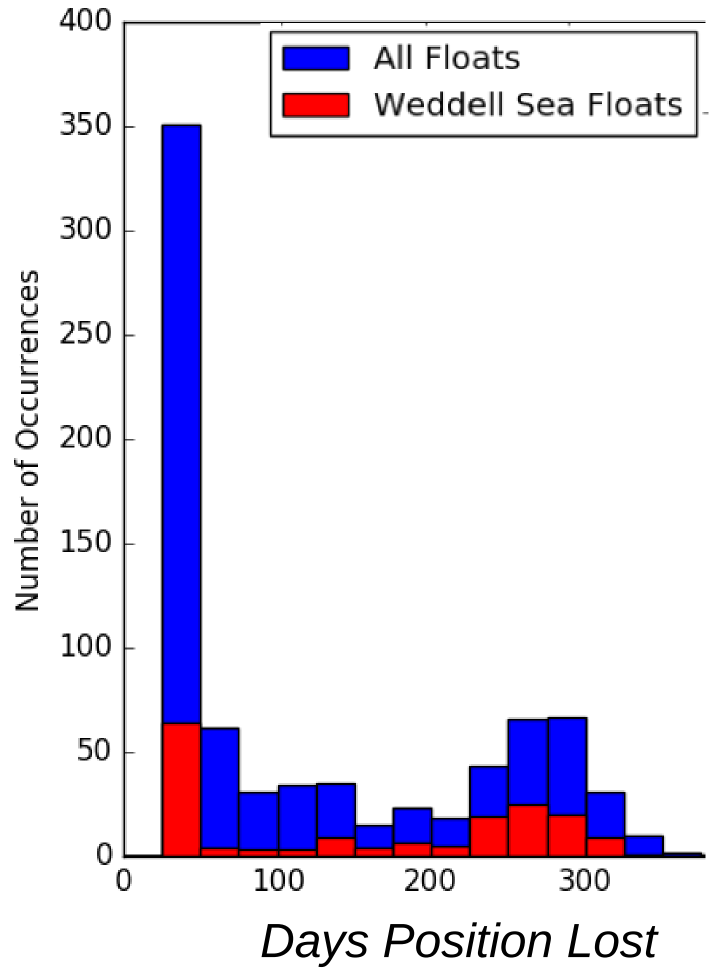
(1) Spatial coverage



What are the most important remaining gaps?

(2) Proper specification of prior uncertainty for under-ice observations





Courtesy Paul Chamberlain

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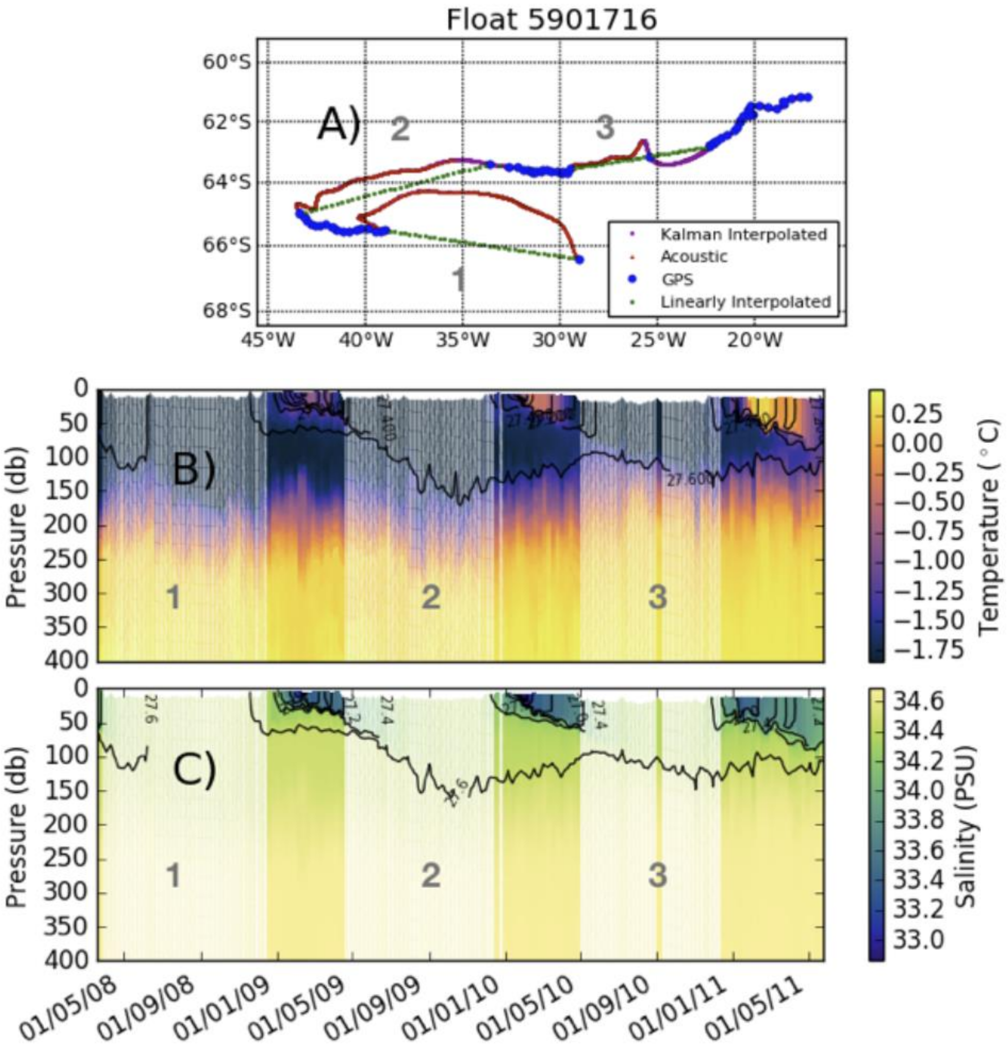
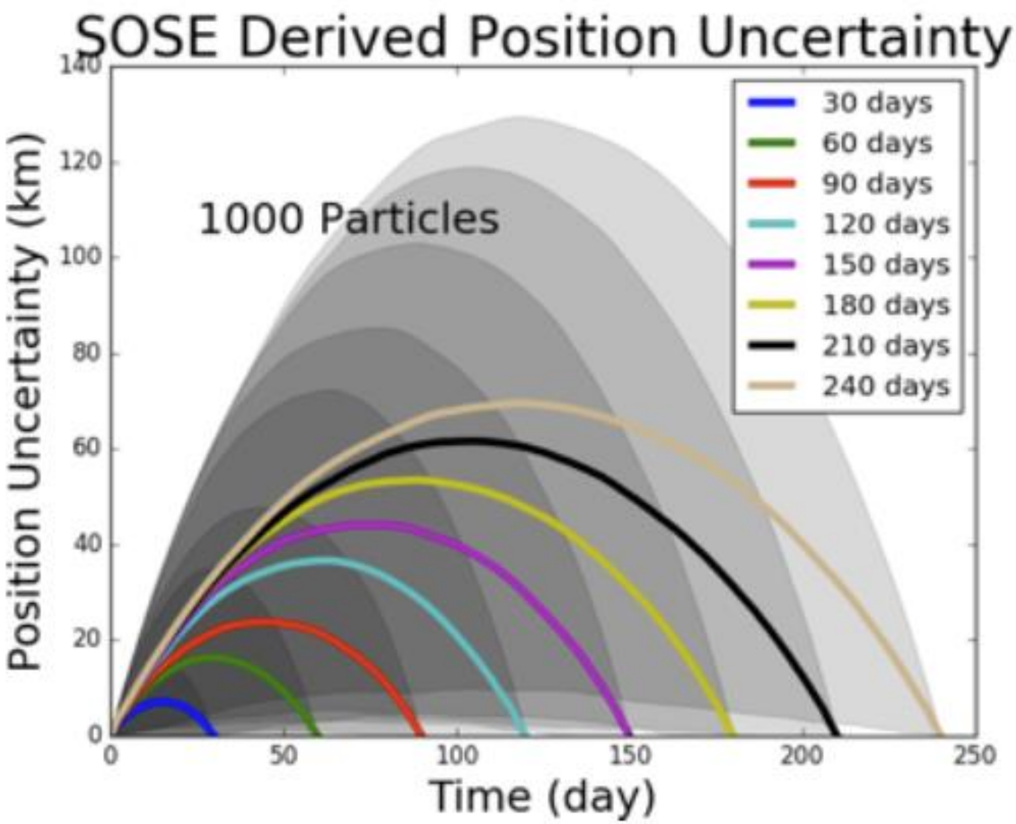


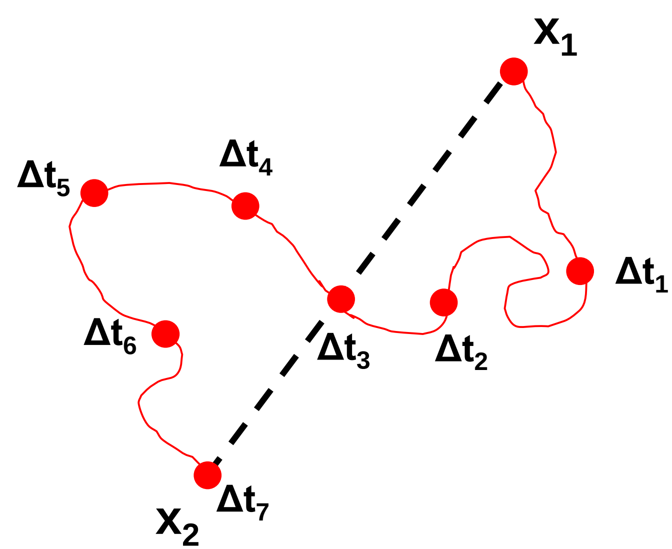
Courtesy Paul Chamberlain

What are the most important remaining gaps?

(2) Proper specification of prior uncertainty for under-ice observations

$$\sigma^2_{total} = \sigma^2_{sensor} + \sigma^2_{location}(x_1, x_2, \Delta t)$$





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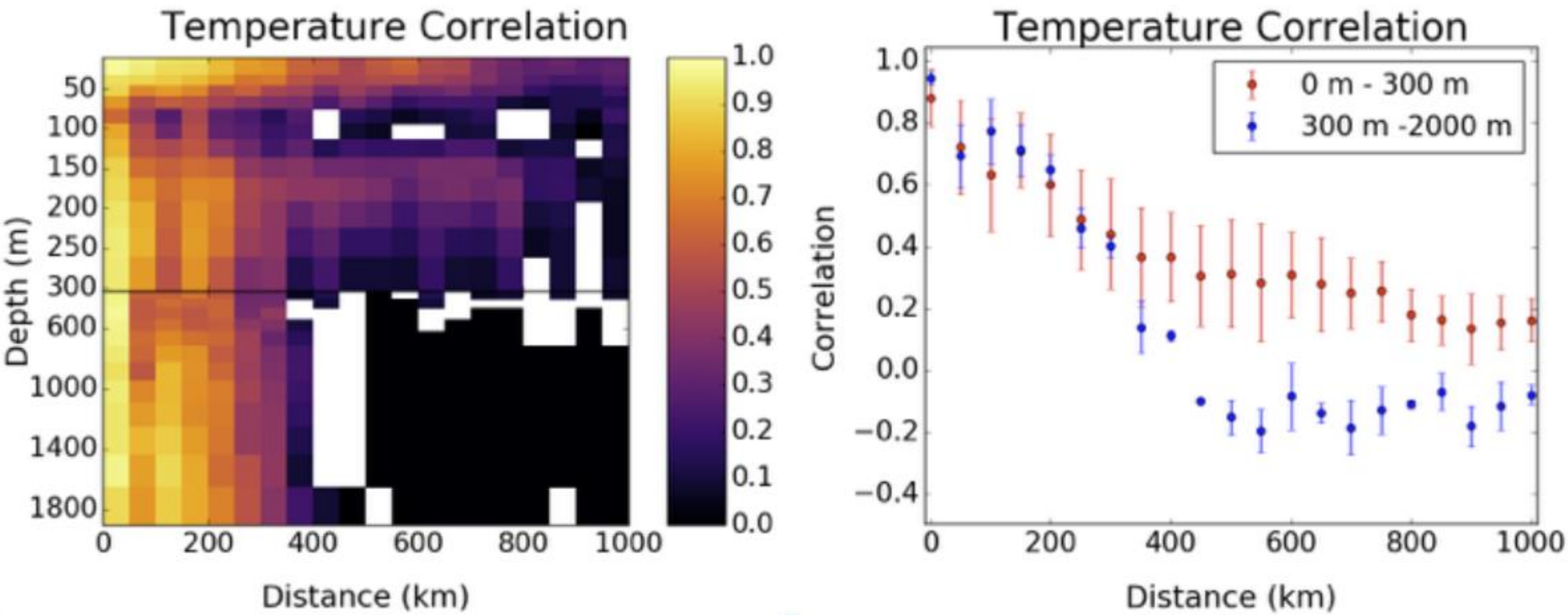

Courtesy Paul Chamberlain

Summary

- The synthesis of in situ T and S observations from Argo and Arctic ice-tethered profiles significantly improves ECCO ocean-ice state estimates.
- Large observational gaps remain in both the Arctic and Southern oceans, especially beneath ice shelves.
- The proper utilization of T and S profiles from floats that survive beneath sea ice for long periods of time requires careful thinking about how to specify their corresponding prior uncertainties as a function of time and space.
- Colleagues at Scripps are currently pursing this important problem with promising results thus far.

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

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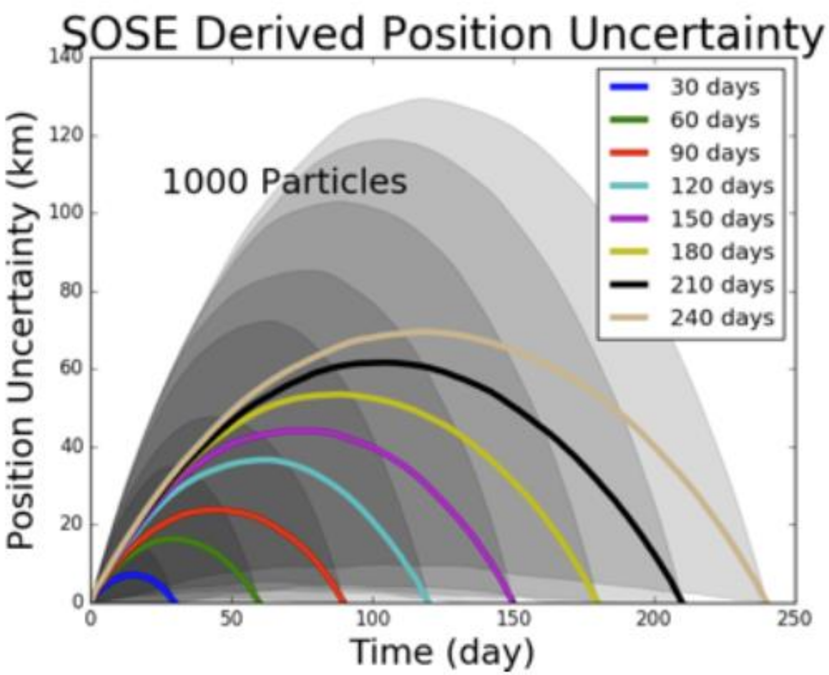
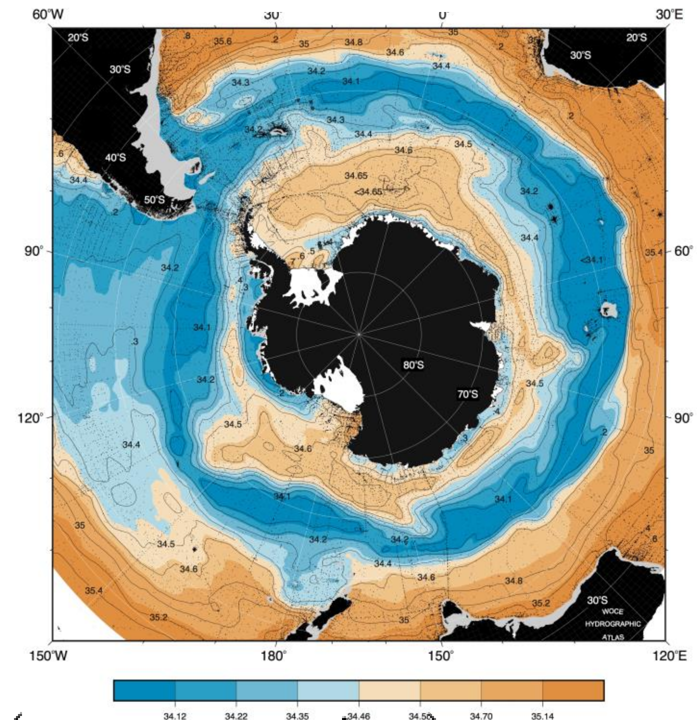
(2) Proper specification of prior uncertainty for under-ice observations



WOCE Atlas Volume 1



$$\sigma^2_{total} = \sigma^2_{sensor} + \sigma^2_{location}(x_1, x_2, \Delta t)$$

Courtesy Paul Chamberlain