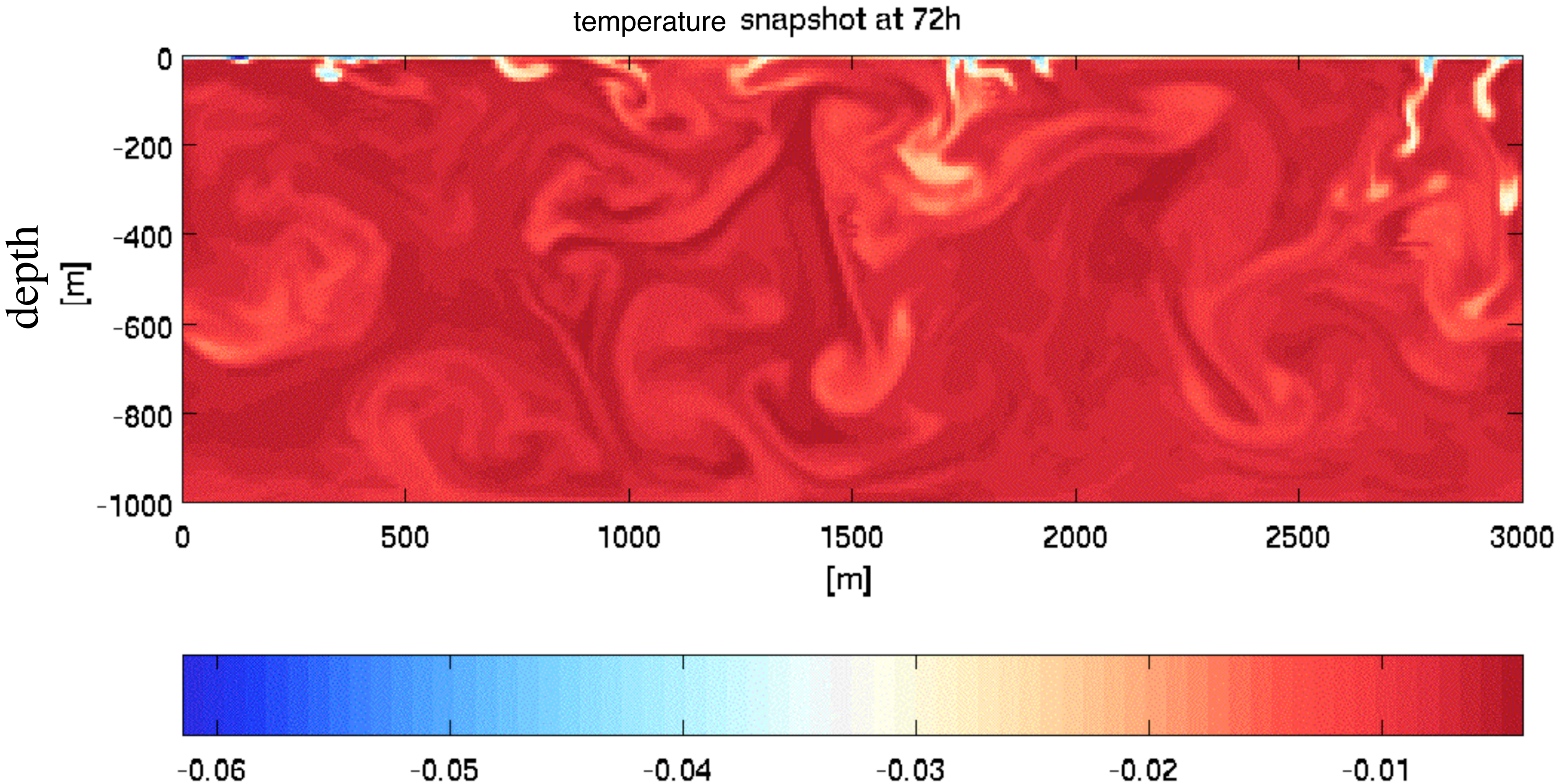
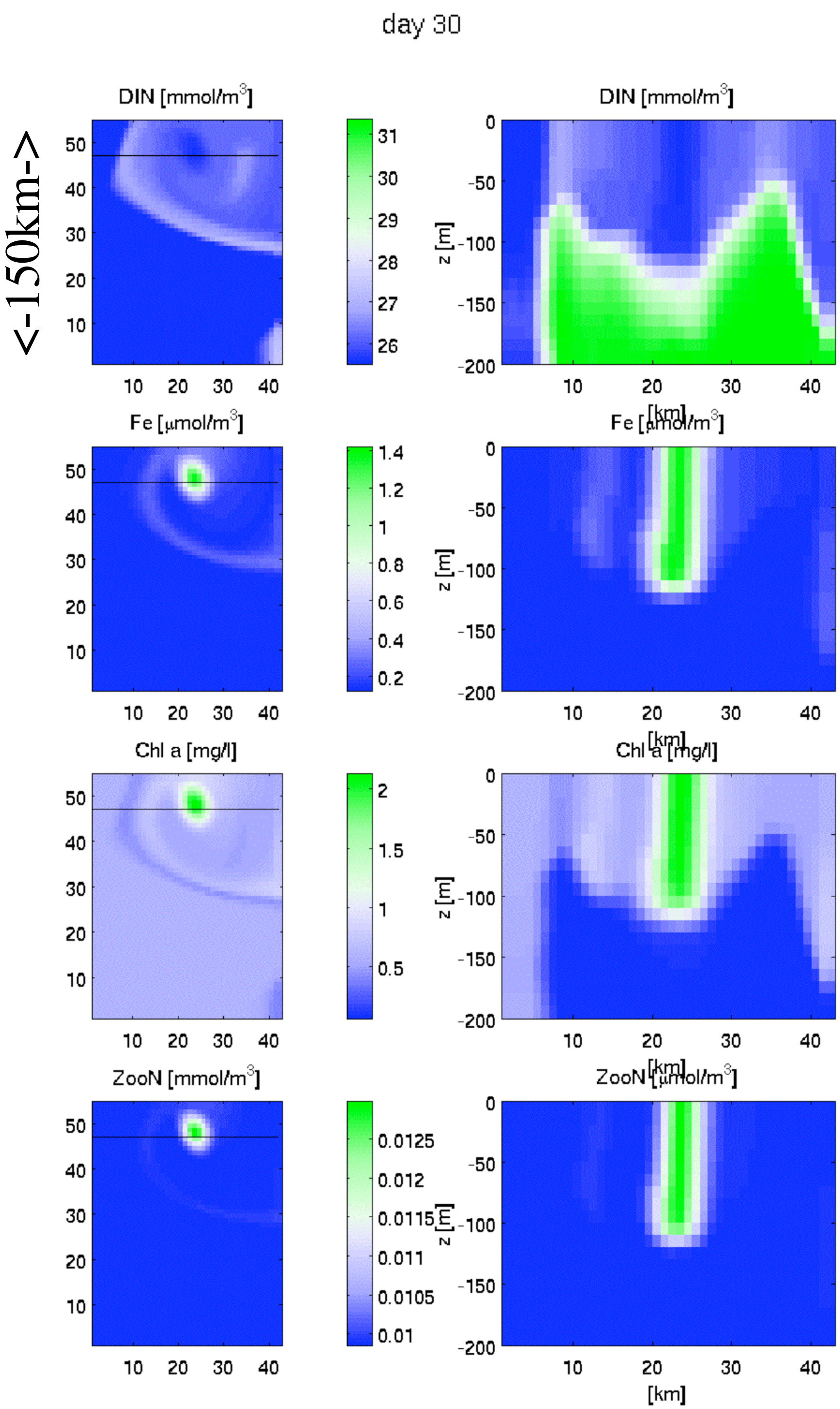
- Very accurately measures gravity, geoid, SSH
- serves as place holder for other high accuracy data
- Are ocean models up to this challenge?

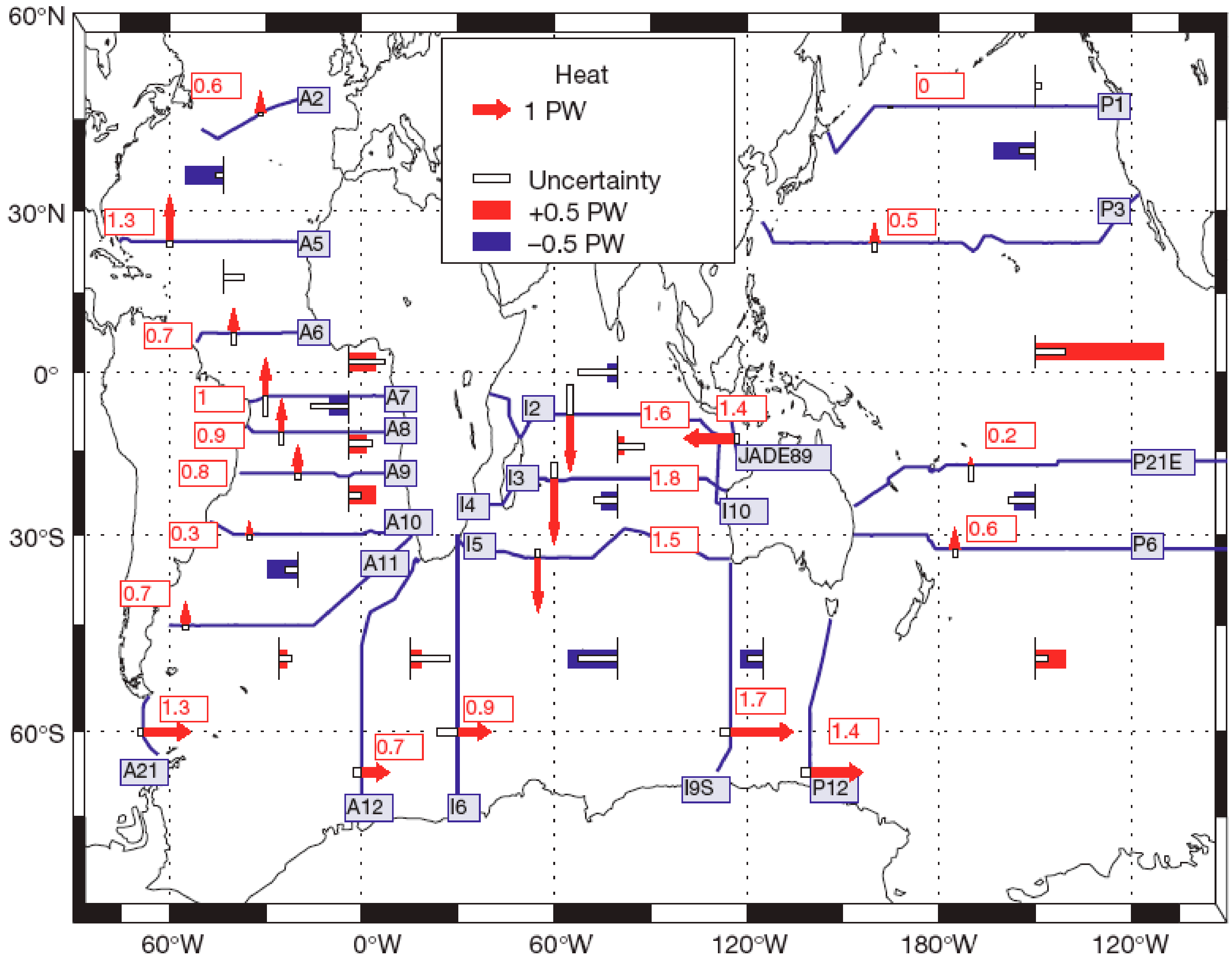
LES, vertical mixing



with V.Gryanik

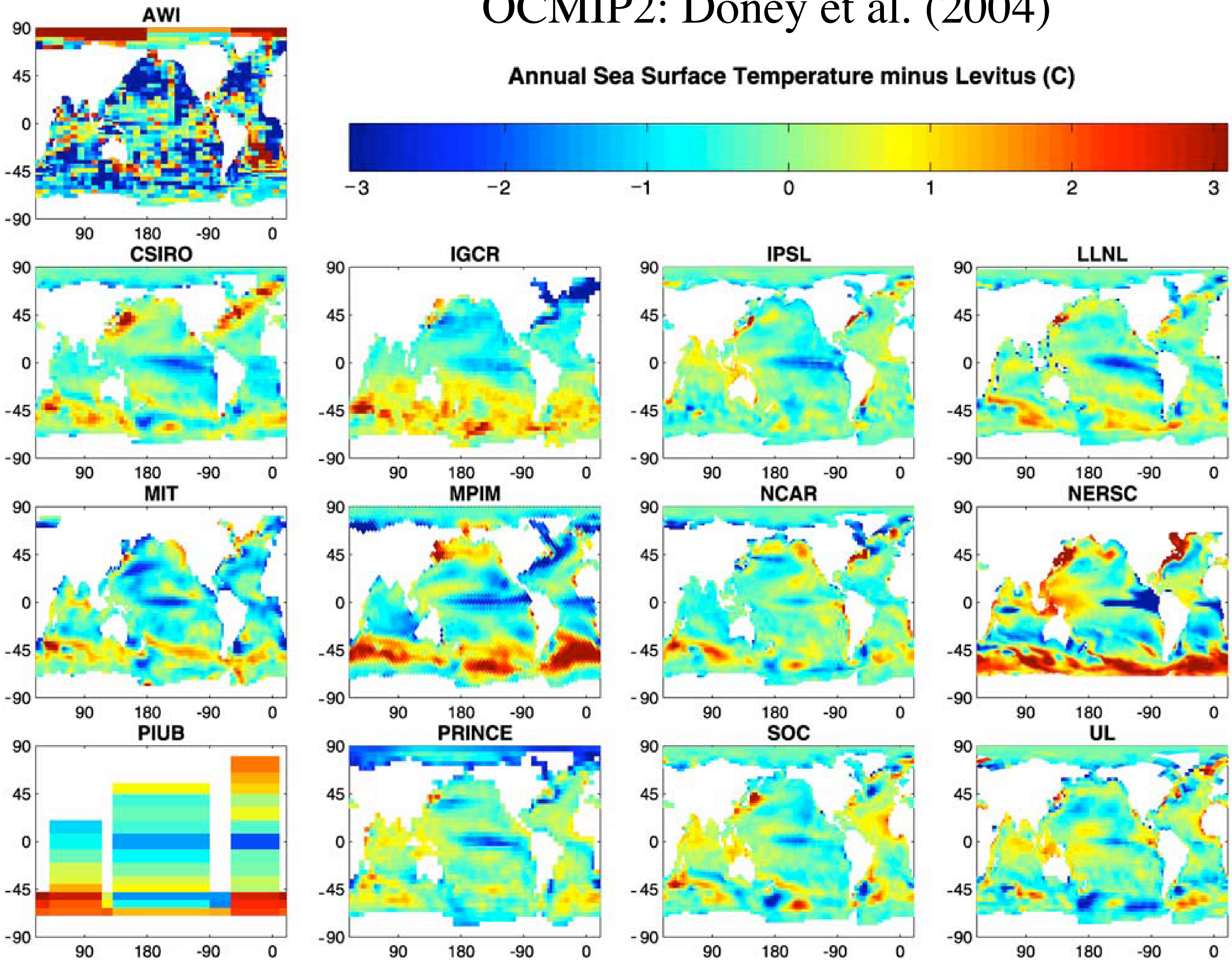


Regional model in the Antarctic Polar Frontal Zone: EIFEX analysis with MITgcm and REcoM (with M. Schartau, V. Strass)



Ganachaud and Wunsch (2000)

OCMIP2: Doney et al. (2004)



Estimating the accuracy of ocean circulation models

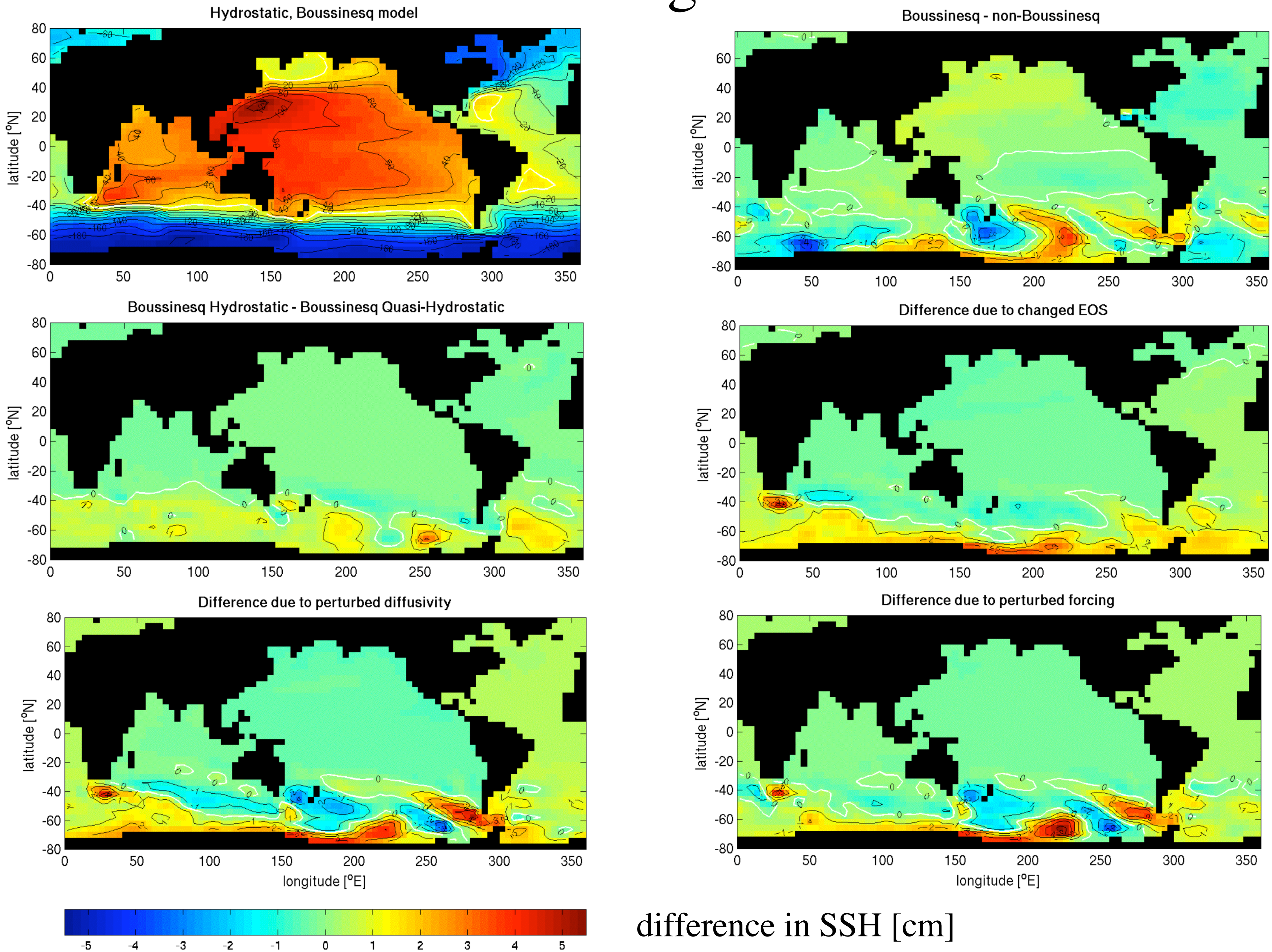
Martin Losch

- To what extend can we trust ocean model-based estimates?
- random errors -> parameter perturbation, adjoint sensitivity
- systematic errors (very hard to assess) -> comparison to measurements; leads to state estimation with formal error estimates

A. perturbation experiments ("brute force")

- perturb 1 parameter, observe effect
- perturb next parameter, etc.
  - Problem: very costly, if systematic
- ensemble methods, Monte Carlo methods
  - choose ensemble of experiments and compare ensemble members, determine spread of solutions
  - Problems: what is the optimal ensemble size, how do you choose the ensemble?
- Example: Losch, Adcroft, and Campin (2004)

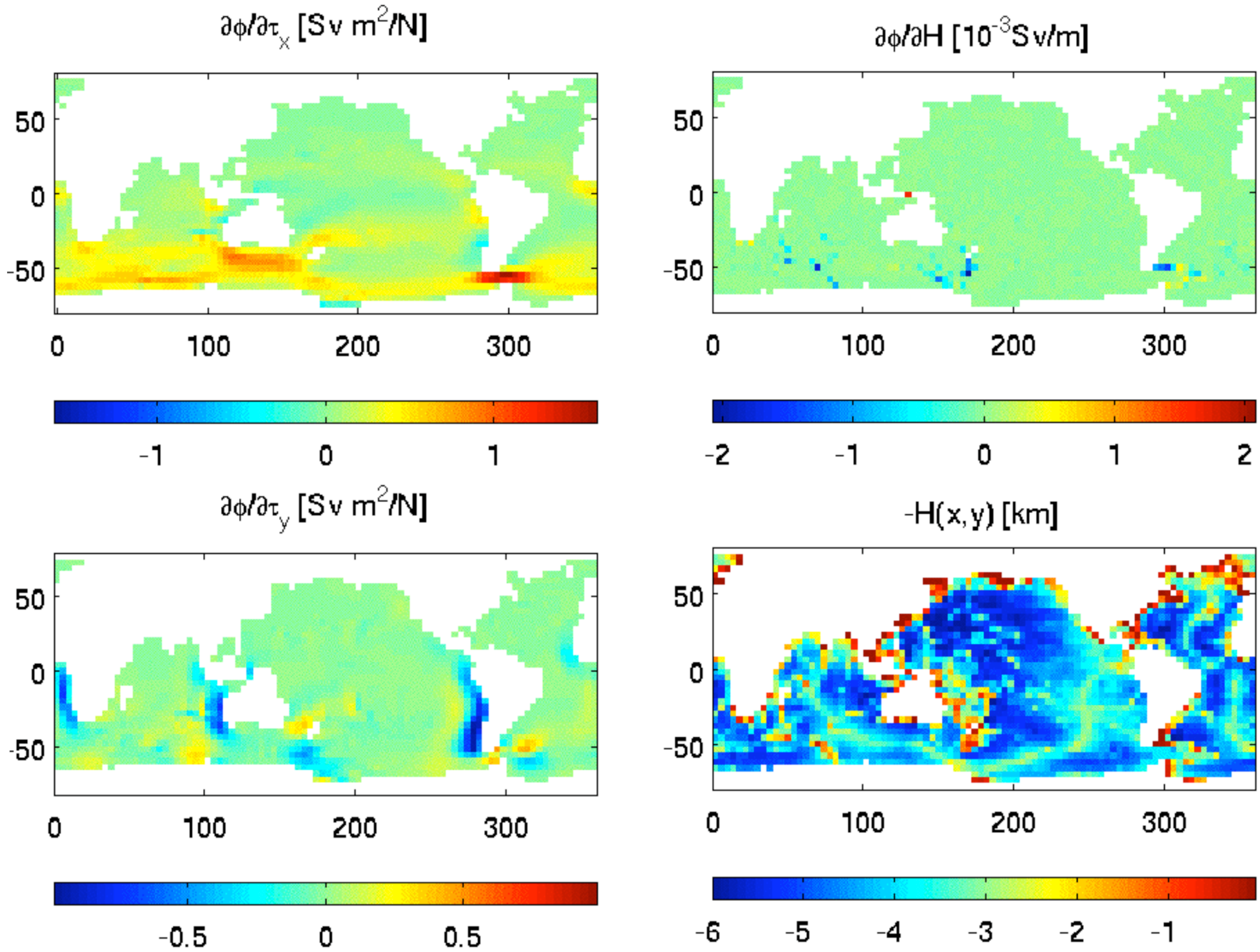
Mean SSH and changes to mean SSH



B. (linear) adjoint sensitivity

- choose observable, objective function (OF)
- compute exact derivative of OF with respect to "control variables", *d(*OF)/*dx* by means of the adjoint model.
- very elegant, needs only 1 forward and 1 backward integration
- Problem: requires gradient code of ocean model, always involves linearization
- Example: OF = transport through Drake Passage, control variables: wind stress (conventional), bottom topography (unconventional), (with P. Heimbach, MIT)

adjoint sensitivities



with P. Heimbach, MIT

C. Systematic comparison to observations:

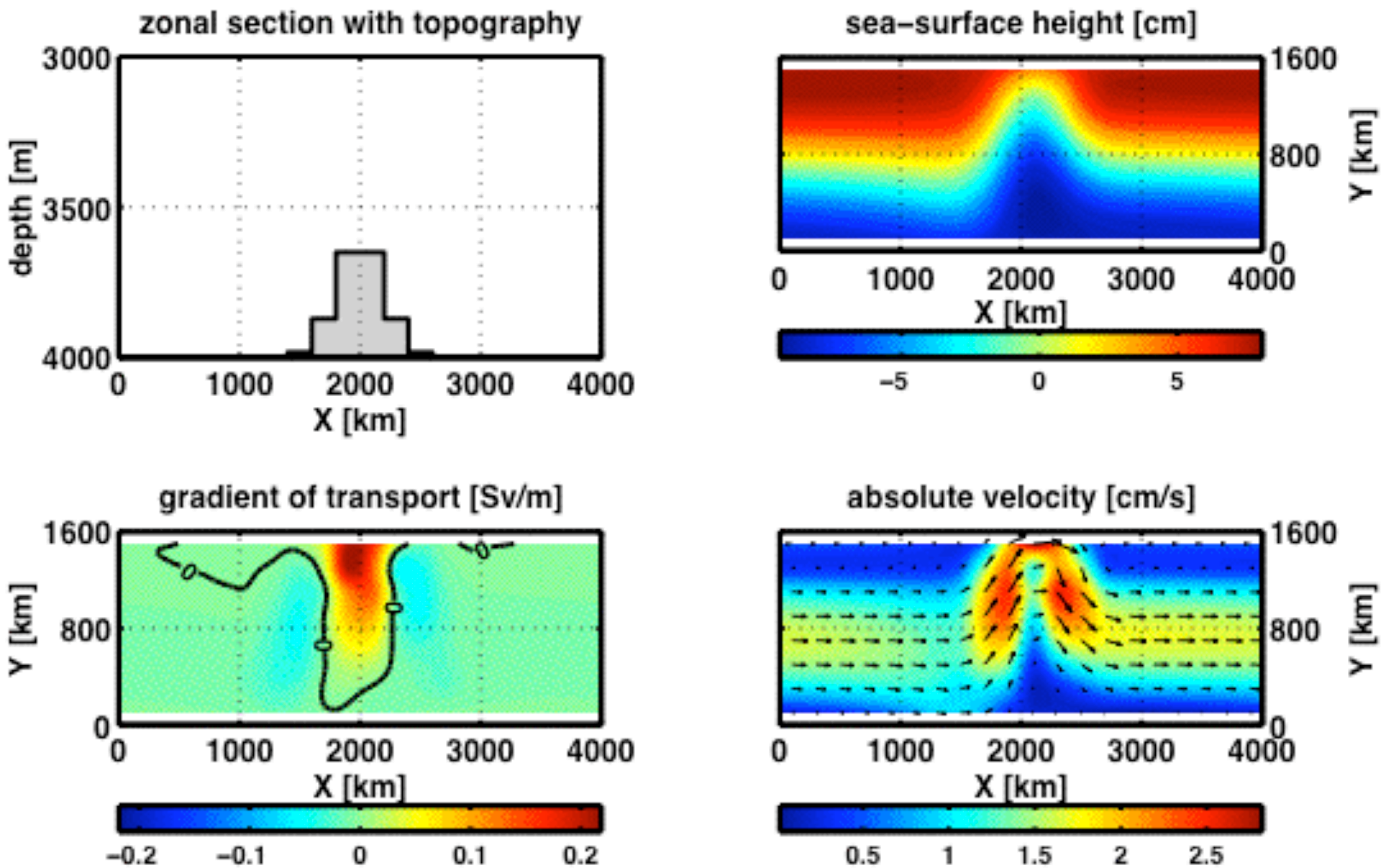
- Data assimilation, state estimation, with error analysis
- different techniques
- variational/adjoint methods use gradient information (previous slide)
- example: ECCO-consortium (Stammer, Fukumori, Wunsch, and many others)
- large computational effort

C. Systematic comparison to data: error analysis

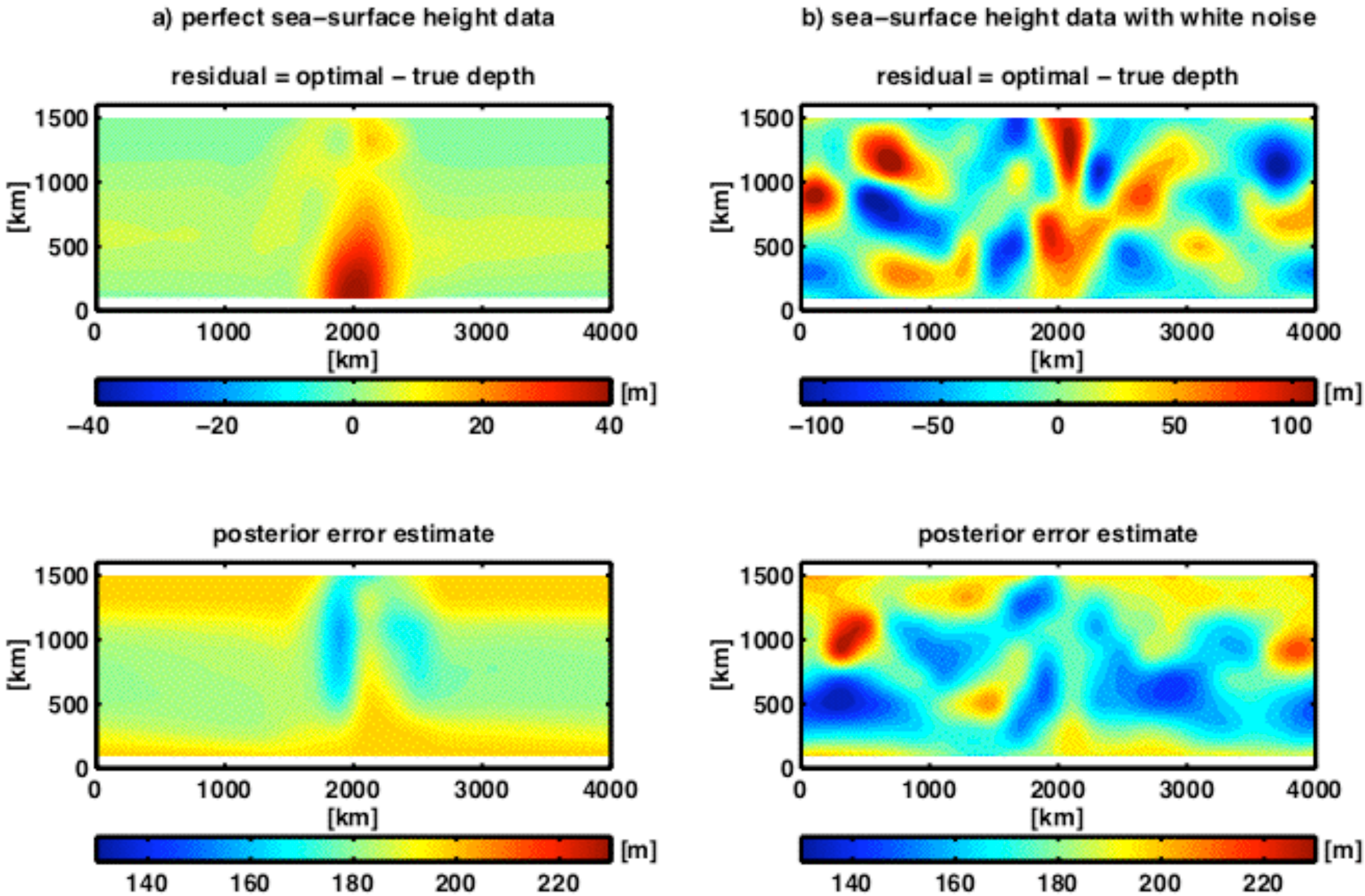
- cost function $$J = \frac{1}{2}\left(d - m(x)\right)^T W \left(d - m(x)\right)$$
- error covariance $$C_{xx} = H^{-1} = \left(\frac{\partial^2 J}{\partial x_i \partial x_j}\right)^{-1}$$
- error analysis is almost always computationally prohibitive, but yields “best estimate” with error estimate
- example: Losch and Wunsch (2003) and FEMSECT

linear shallow water model

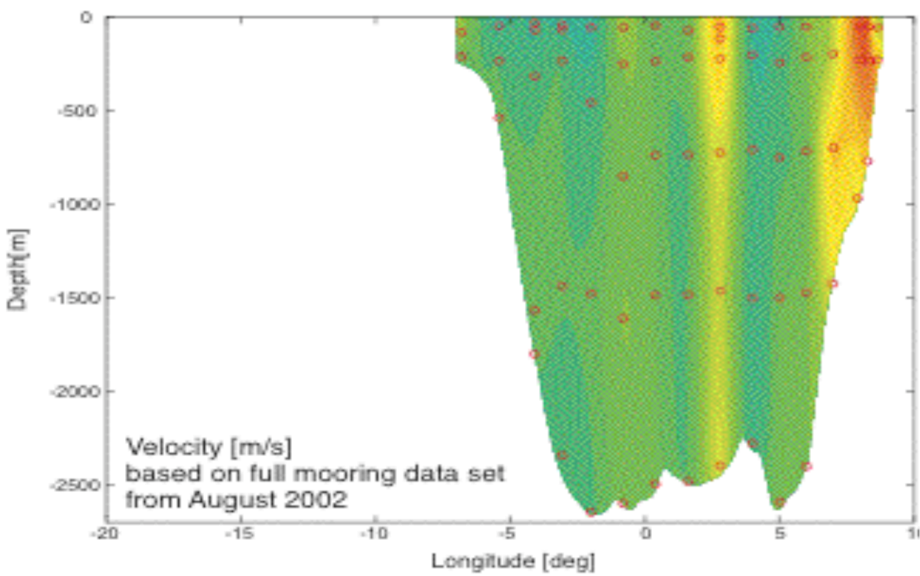
Losch and Wunsch (2003)

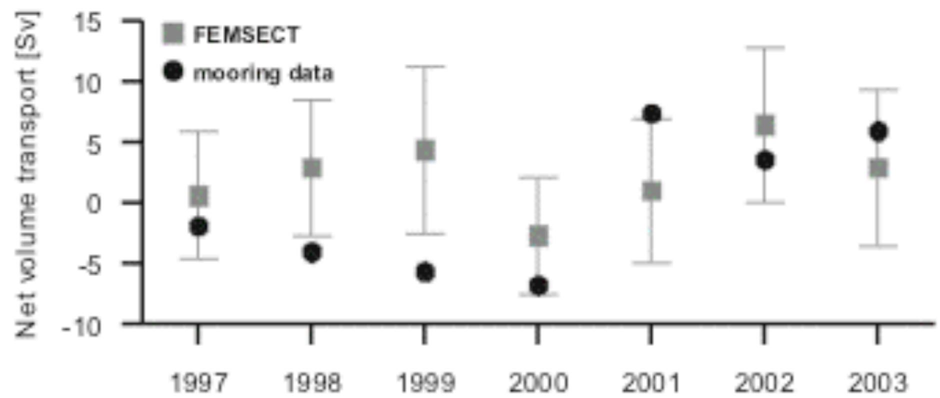


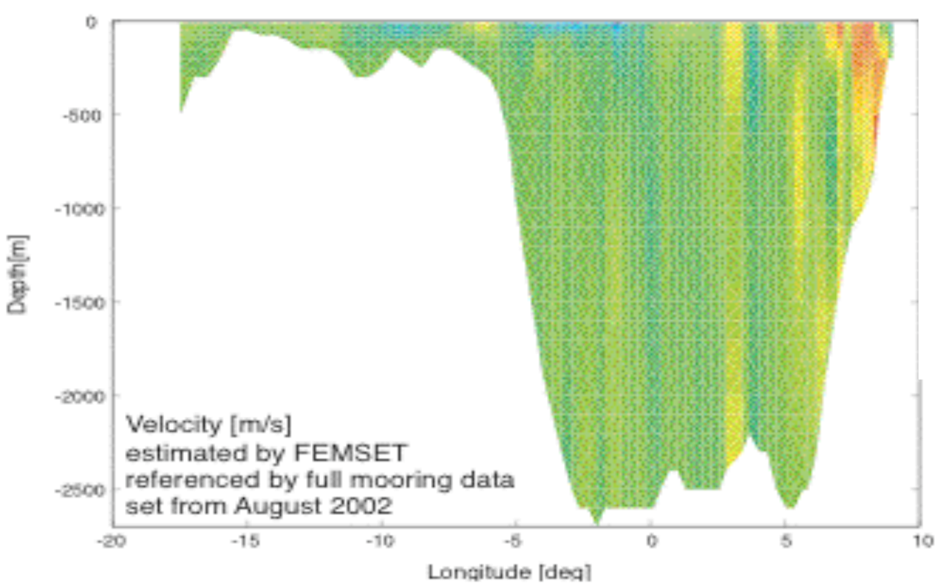
linear SWM: optimized solution

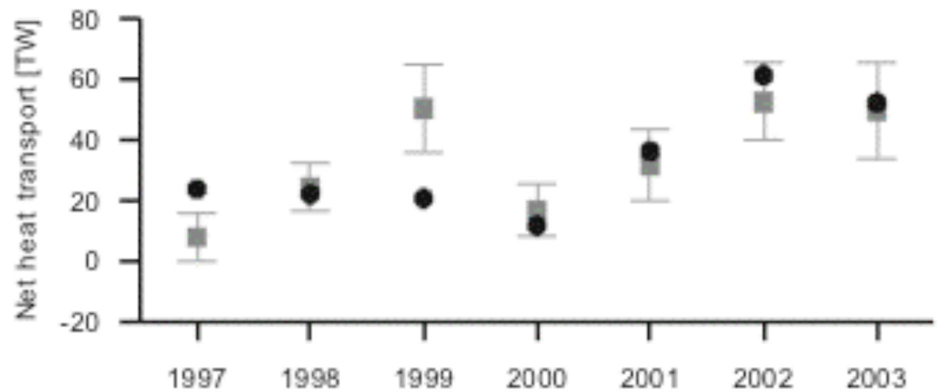


FEMSECT: finite element inverse section model. Application to Fram Strait









with D. Sidorenko, A. Beszczynska-Möller

Well, and how do you to estimate the accuracy of ocean circulation models?

a list with increasing complexity:

- “brute force” perturbation/ensemble methods, but very expensive
- adjoint sensitivity
- comparison to observations; data assimilation/state estimation with error estimates

to do

- explore unconventional control parameters in ocean models:
  - topography, diffusivity, lateral boundary conditions, ...
  - revise parameterization of the above
- state estimation with (coupled) ecosystem models (very nonlinear), to improve flux estimates of, e.g., CO_2