Seasonal ice forecasting and variational data assimilation with a coupled sea ice-ocean model

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O.A.Sys Ocean Atmosphere Systems

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AWI

Outline:

Description of the system

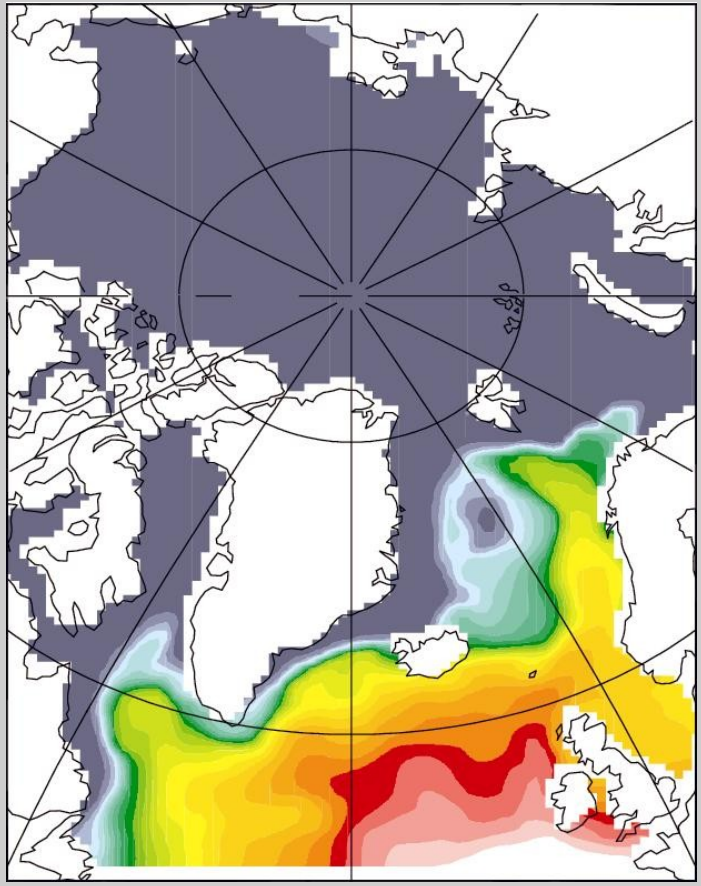
Applications

- **Sea Ice Outlook**
- **IPY state estimation (very briefly)**
- **Effect of Ice Drift Assimilation**

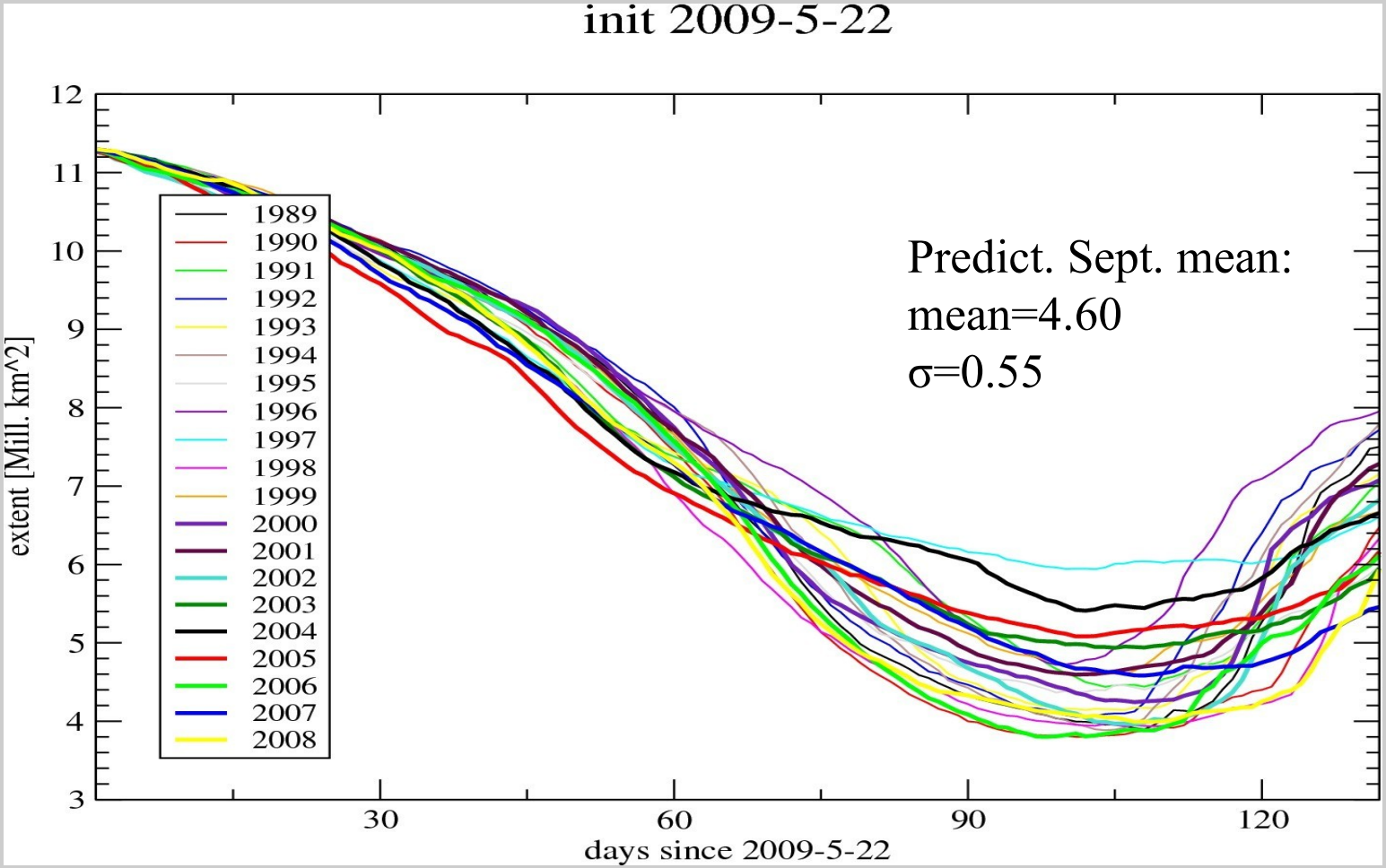
Future projects

Model setup (medium res.)

- Sea Ice/Ocean model (base: NAOSIM)
- Time step: 1/2 hour
- 0.5 x 0.5 degree hor. res., rotated
- 20 vertical layers
- Model domain: north of about 50°N
- Forcing: daily NCEP reanalysis (but also: JRA25, ERAinterim)



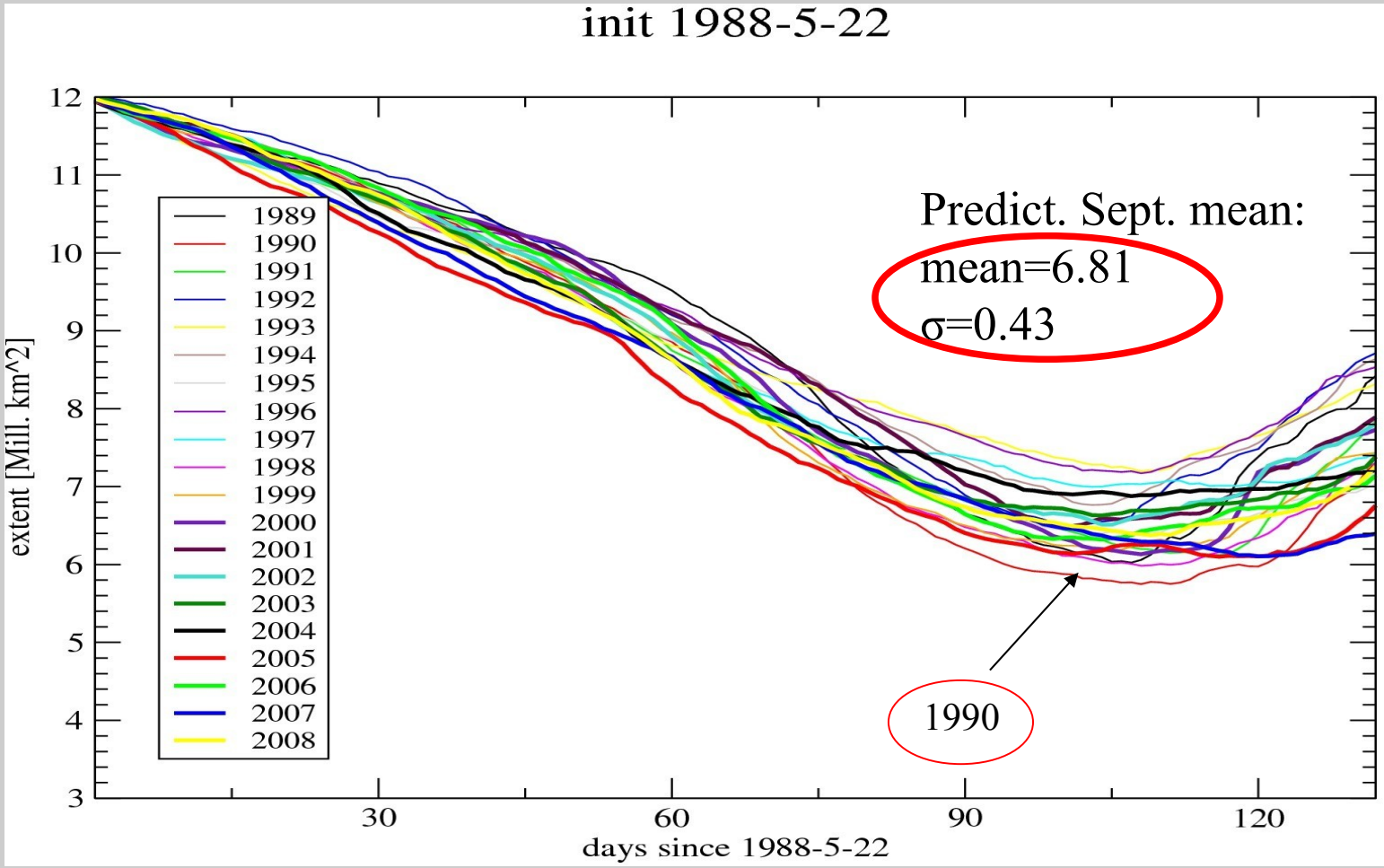
Sea Ice Outlook: Ice extent - start from 22. May 2009



'June' Outlook 2009

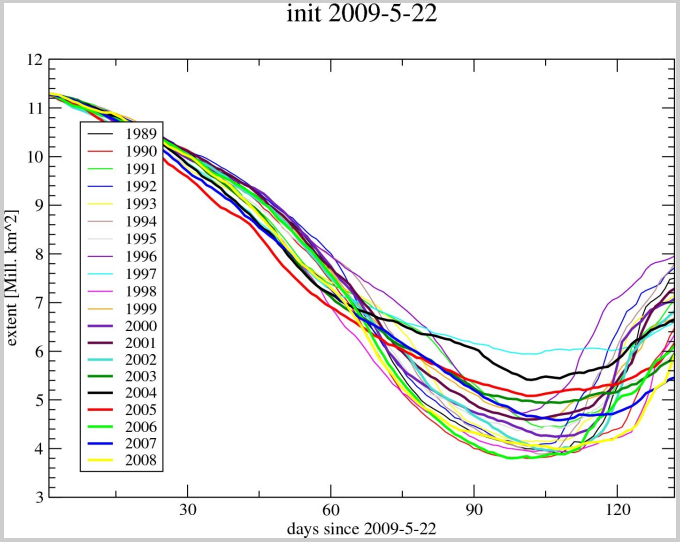
http://www.arcus.org/search/seaiceoutlook

Ice extent - start from 1. June 1988

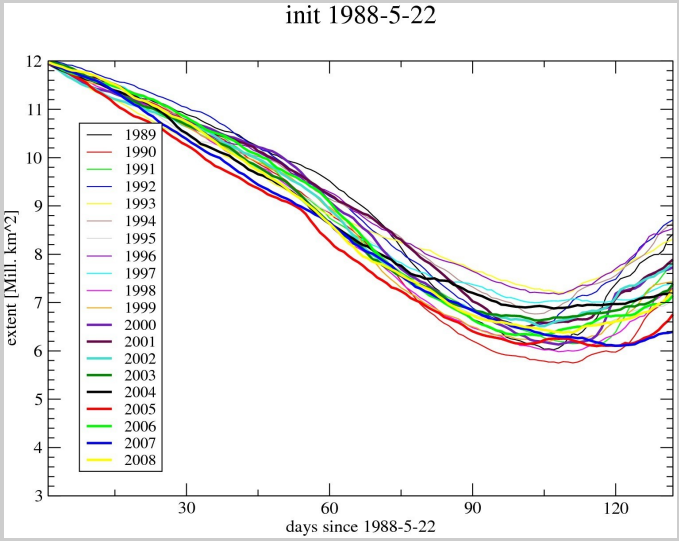


'June' Outlook 2009 with initial state from 1988

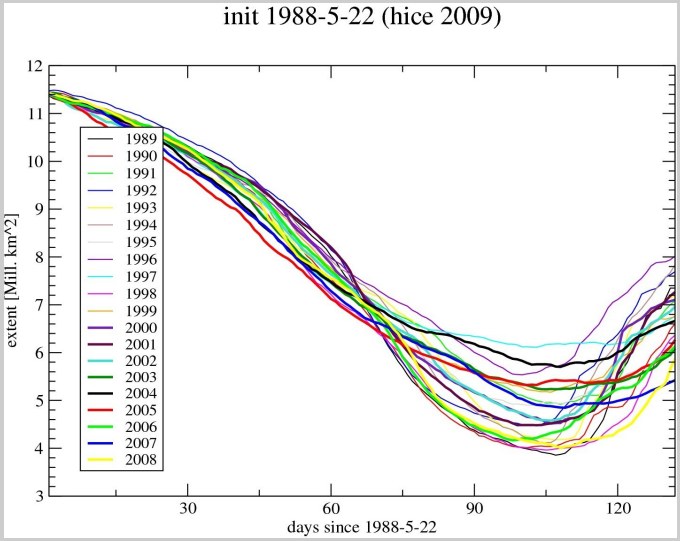
Initial state 2009



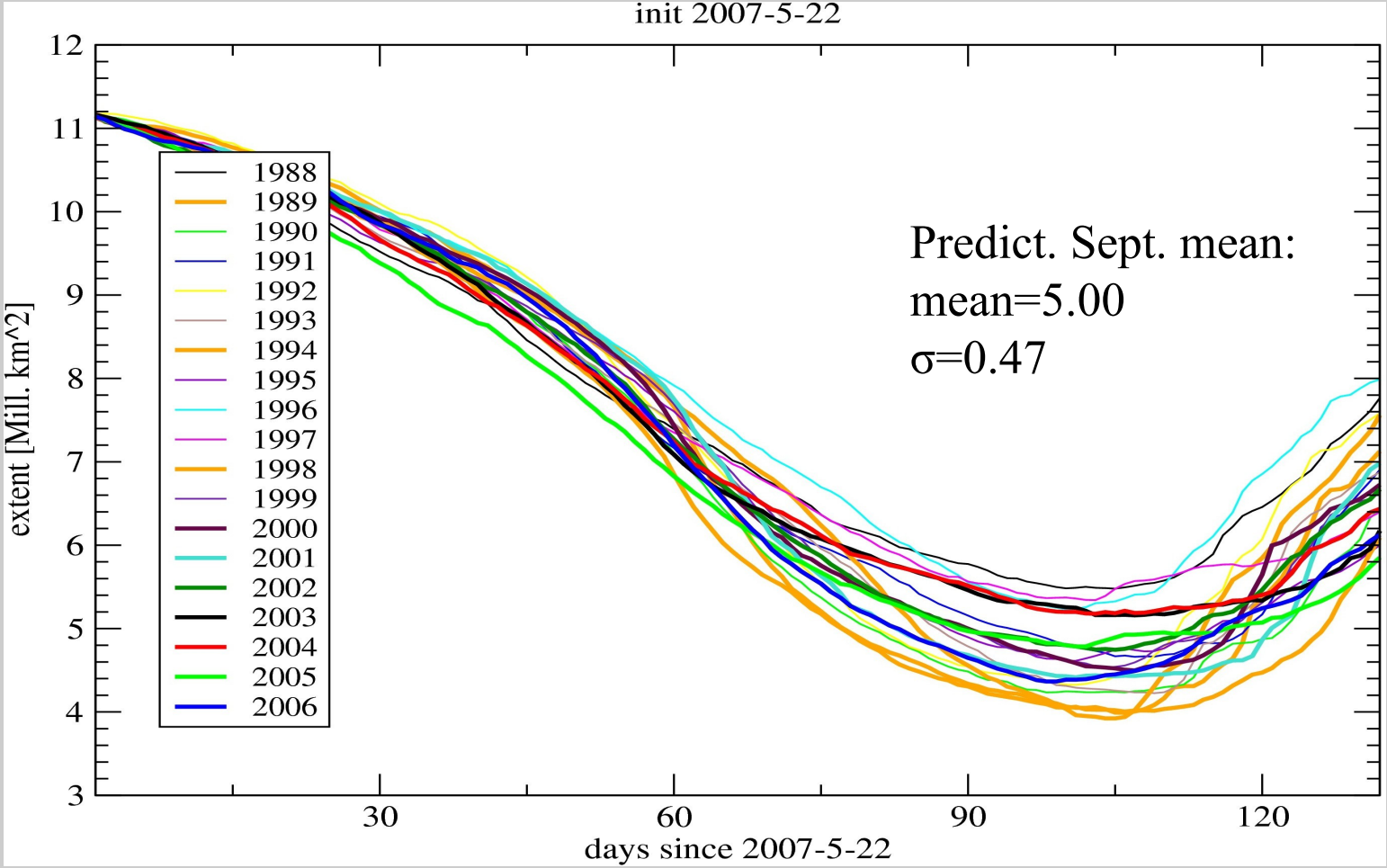
Initial state 1988



Initial state 1988
hice 2009

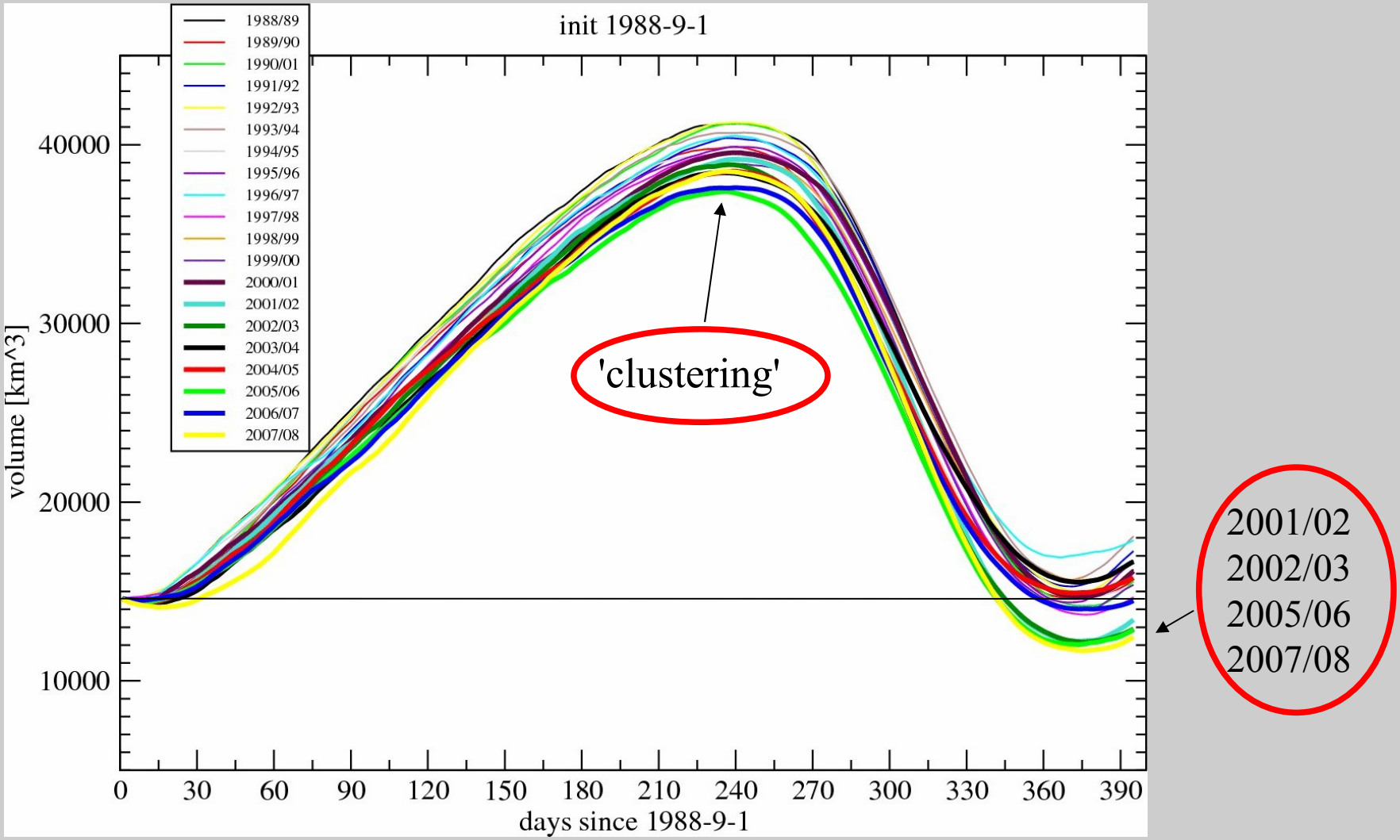


Ice extent - start from 22. May 2007



fictitious 'June' Outlook 2007

Ice volume - start from 1. September 1988

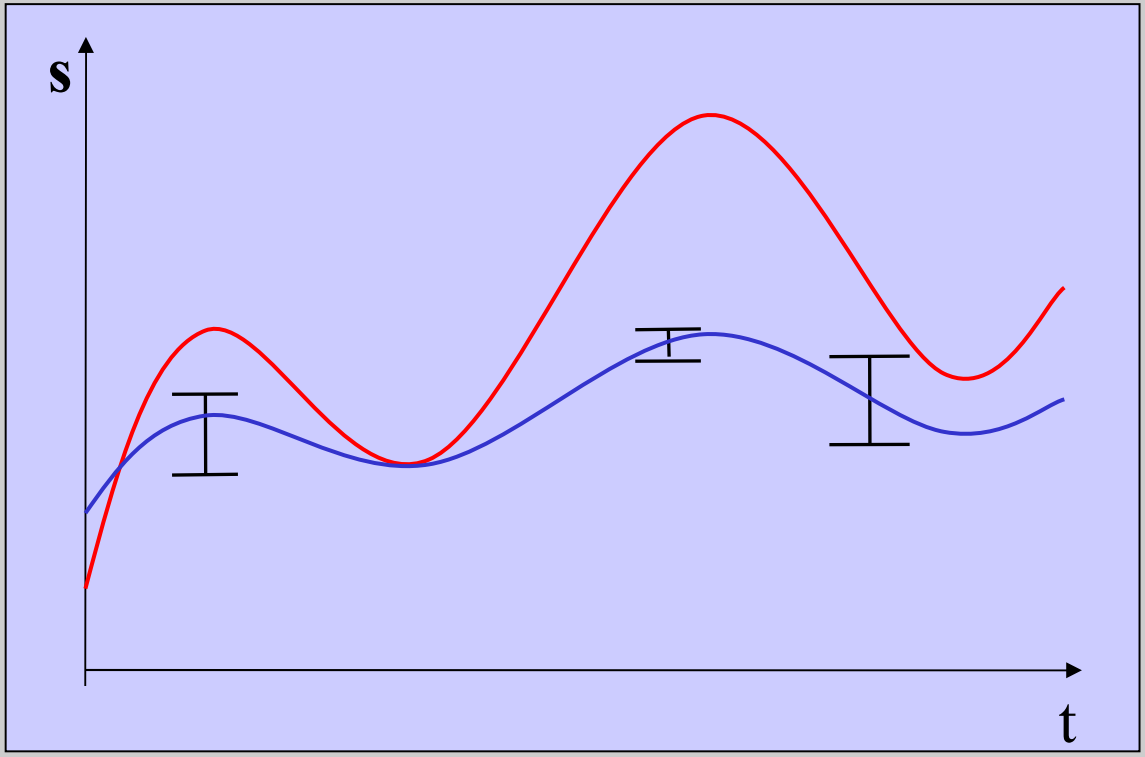


Variational Data Assimilation

Notation:
s : state vector
(ocean: u', v', s, tpot, Φ; ice: h , a, hsn)
t : time
d : vector of observations
σ : vector observational uncertainties

Principle:
•define vector of control variables **x**, e.g.,
- forcing/boundary conditions (**f**)
- Initial state (s0)
- internal model parameters (**p**)

•define quality of fit by cost function:
•minimise J(**x**) by variation of **x**



$$J(x) = \frac{1}{2}((M(x) - d)^T C_d^{-1} (M(x) - d) + (x - p)^T C_p^{-1} (x - p))$$

uncertainty for obs. term

uncertainty for prior term

Minimisation

Efficient minimisation algorithms use J(x) and
the gradient of J(x) in an iterative procedure.
Typically the prior value is used as starting point of the iteration.
The gradient is helpful as it always points uphill.
The adjoint is used to provide the gradient efficiently.

<u>Example: Newton algorithm for minimisation</u>

Gradient: $g(x) = dJ/dx(x)$

Hessian: $H(x) = dg/dx(x) = d^2J/dx^2(x)$

At the minimum, x_{min}: $g(x_{min}) = 0$, hence:

$$g(x) = g(x) - g(x_{min}) \sim H(x)\,(x - x_{min})$$

rearranging yields:

$$(x_{min} - x) \sim - H^{-1}(x)\, g(x)$$

Smart gradient algorithms use an approximation of H(x)

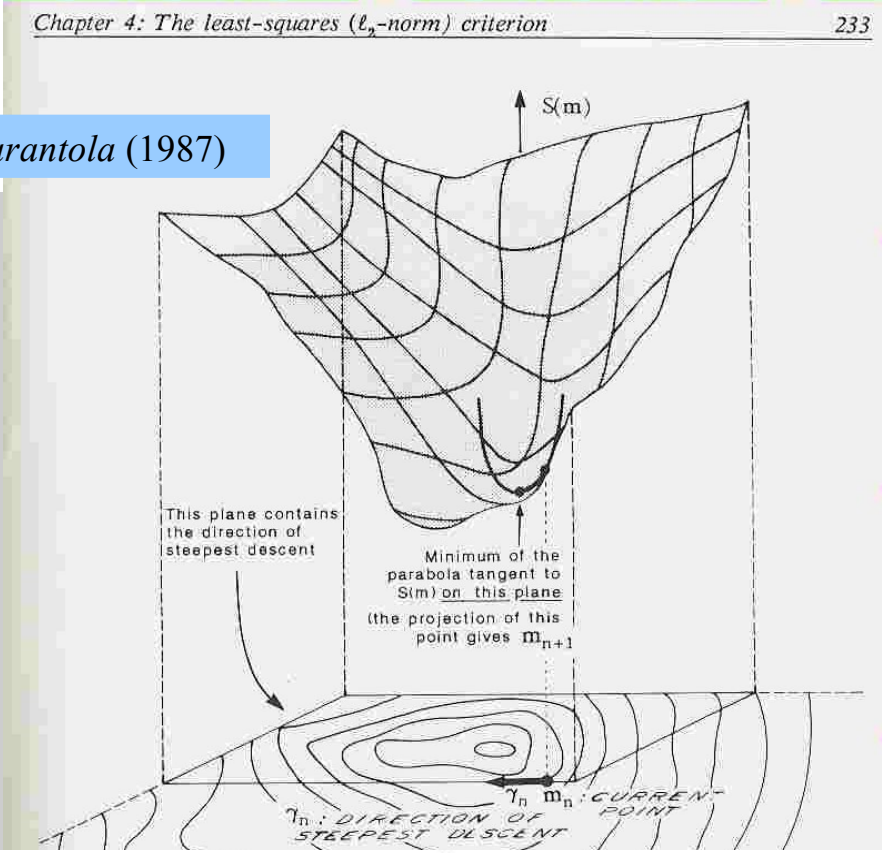


Figure: *Tarantola* (1987)

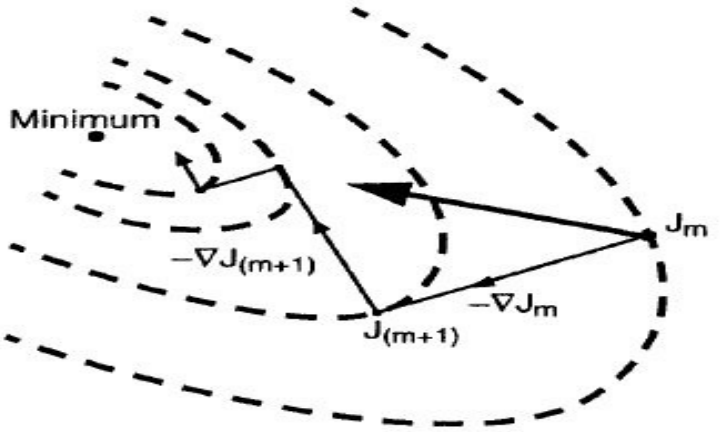


Figure: *Fischer* (1996)

DAMOCLES modeling/assimilation

NAOSIMDAS

- 4 dimensional Variational Assimilation System
- Around coupled ocean sea-ice model NAOSIM
- Adjoint ADNAOSIM by automatic differentiation (TAF)
- Provides a model trajectory (a history of model fields) that is consistent with the model dynamics and the available observational data streams (can be unevenly distributed in space and time)
- Provides 'dynamical' interpolation of the data
- Delivers any field that can be extracted from the model.
- Also delivers updates of model boundary conditions (e.g. Wind, SAT)
- System can also be used to estimate parameters in process model (tuning)
- System is set up for periods up to two years

NAOSIMDAS observational data input

- Prior values of control variables (initial state of ocean and sea ice and surface boundary conditions)
- Hydrographic data from
  - ITPs (www.whoi.edu) deployed as part of several IPY initiatives
  - WODB05 and recent amendments plus additional expedition data (S. Pisarev)
  - ARGO profilers provided by the CORIOLIS data center (www.coriolis.eu.org)
  - Hydrographic Climatology: PHC (psc.apl.washington.edu/Climatology.html)
- Daily mean ice concentration from EUMETSAT Ocean and Sea Ice SAF (www.osisaf.org)
- For some applications: 2-day means of winter ice displacement from OSISAF (Met.no)

Sea Ice Outlook 2009 with optimized initial state

Example **August 2009 Outlook**:

Assimilation window April to July 2009
Assimilated variables: ice concentration (OSI-SAF), T-S (ITPs, Coriolis),
EM-Bird ice thickness (Polar 5 (AWI), Canadian/Alaskan 'coast'),
ice drift (met.no) (April, May – only AMSR-E)

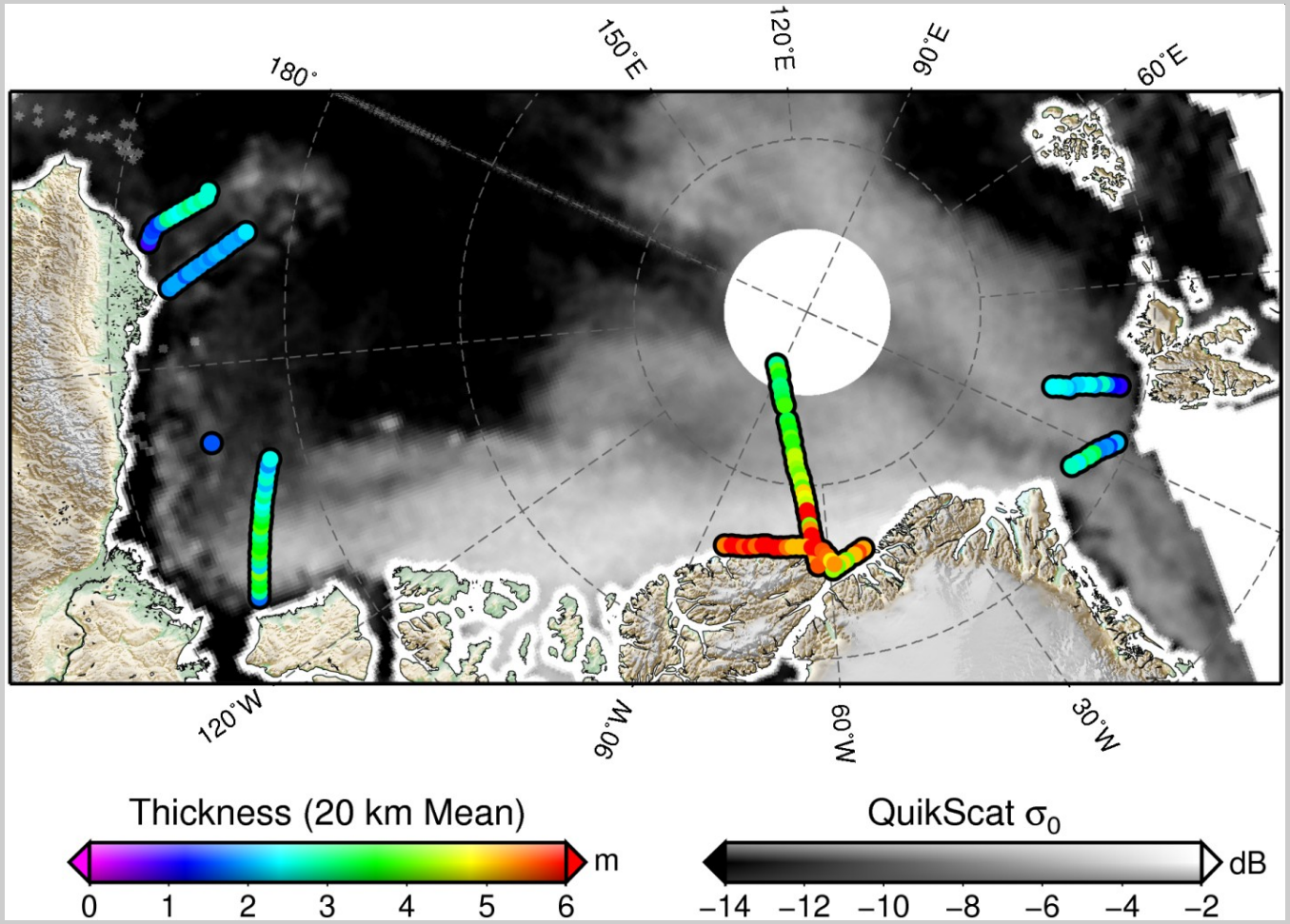
Start outlook at August 1st

'optimized': mean 4.72 million km2
'free run': mean 5.02 (4.42+0.6) million km2

bias correction

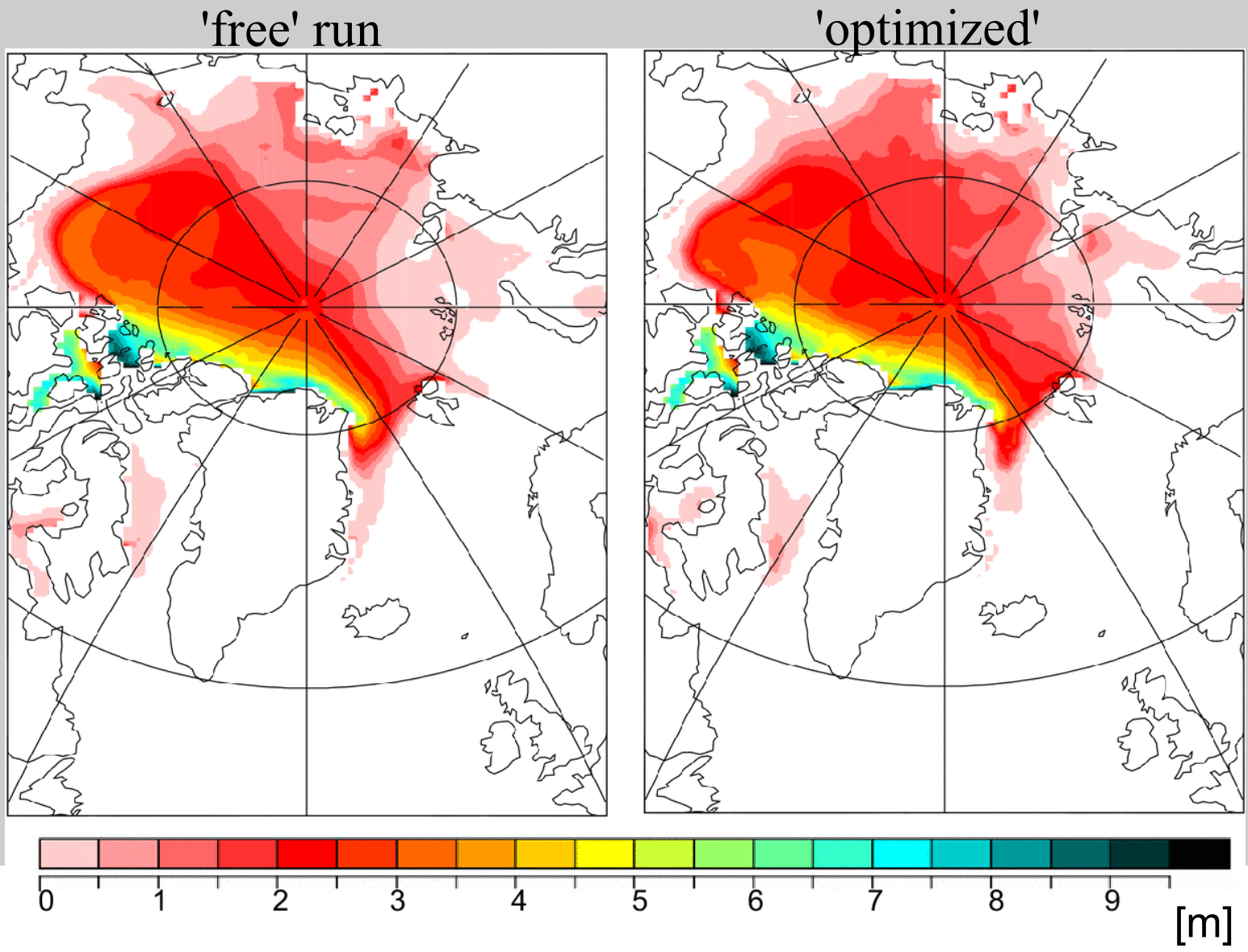
http://www.arcus.org/search/seaiceoutlook

April 2009



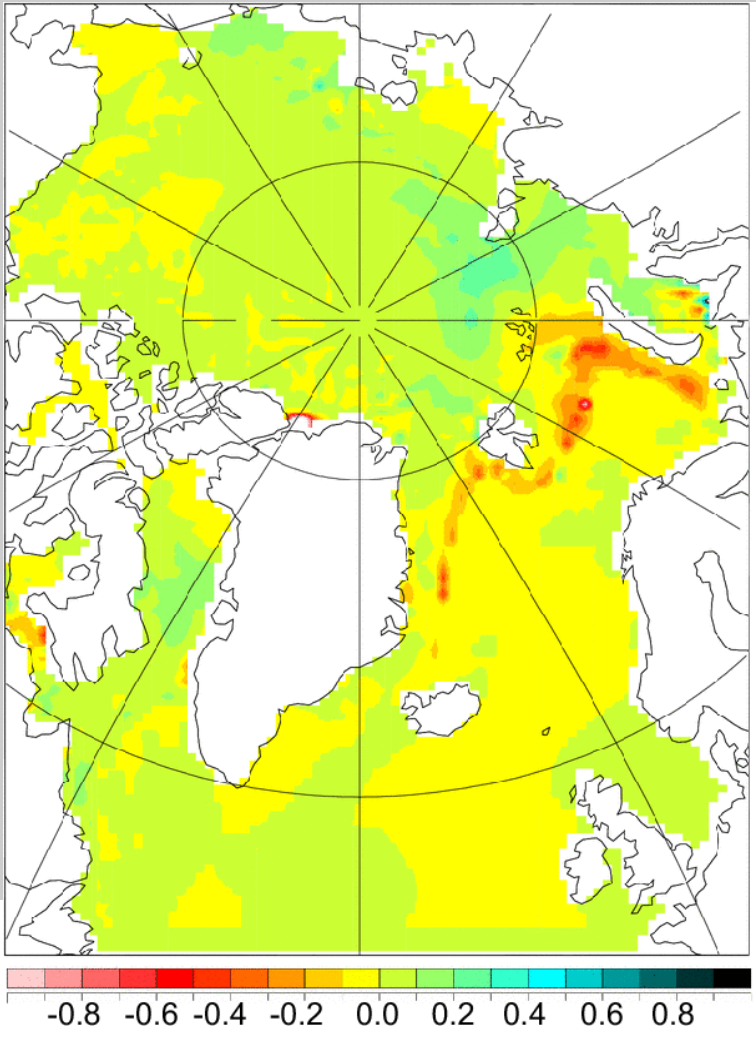
EM-Bird ice thicknesses from the PAM-ARCMIP aircraft campaign in April 2009 with QuikScat backscatter map (pers. comm. Stefan Hendricks, AWI).

Ice thickness mean July 2009

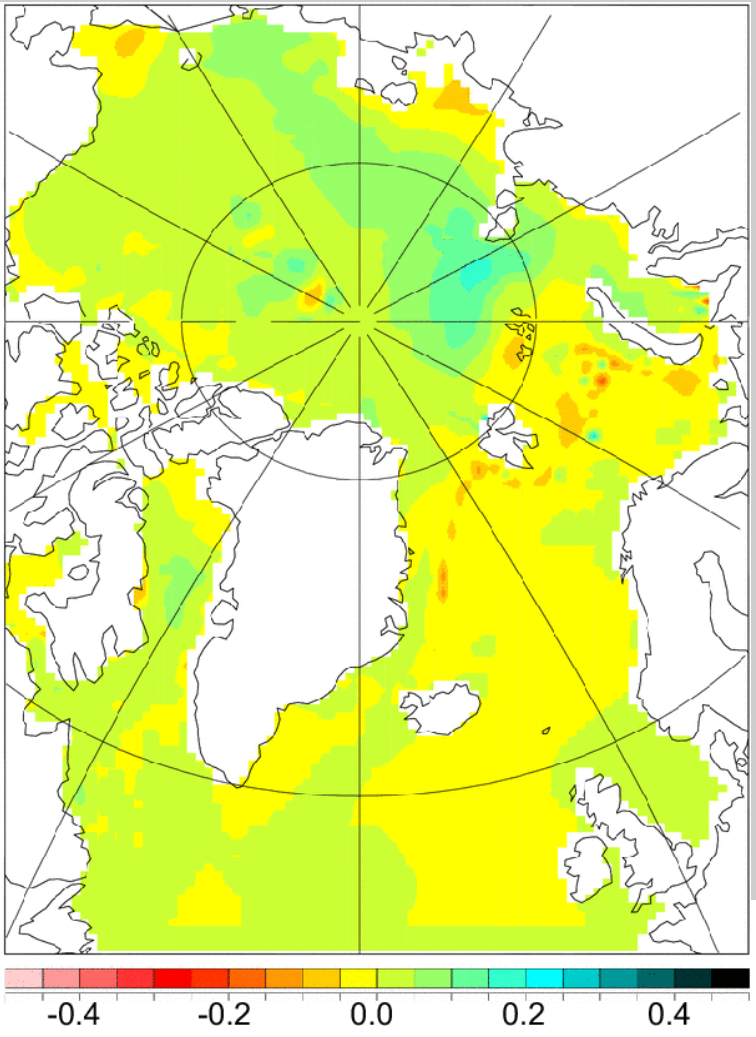


Perturbations (initial state 1.April 2009)

initial ice thickness

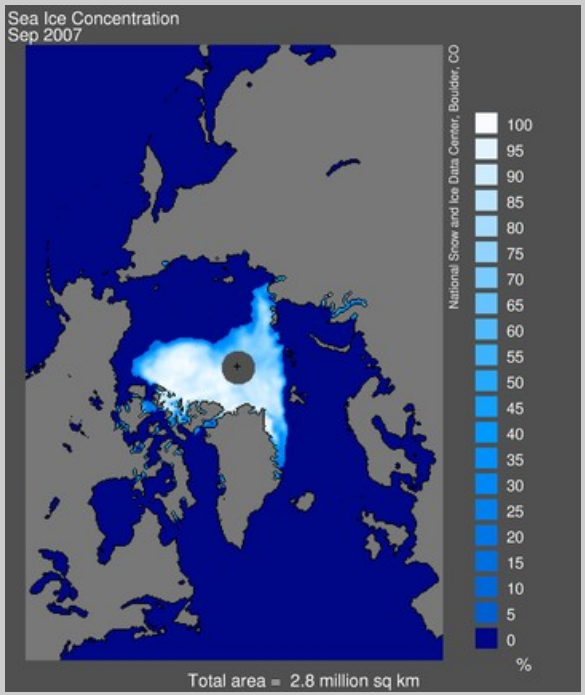


initial snow thickness



Ice thickness Jul/Aug/Sep 2007

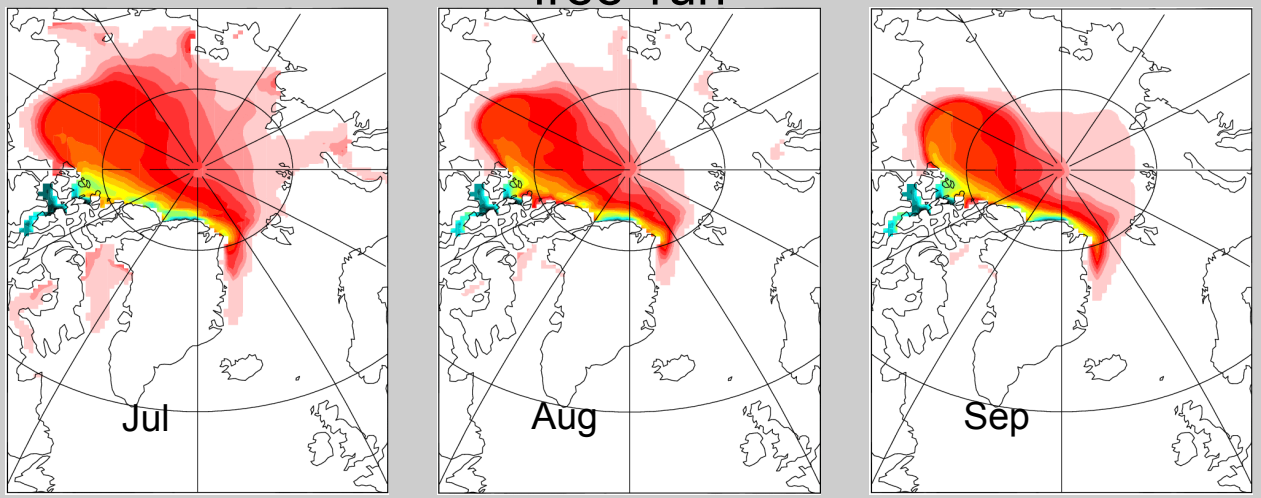
'observed' ice concentration

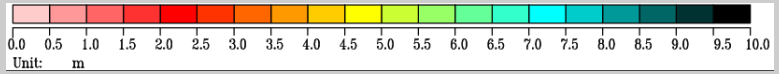


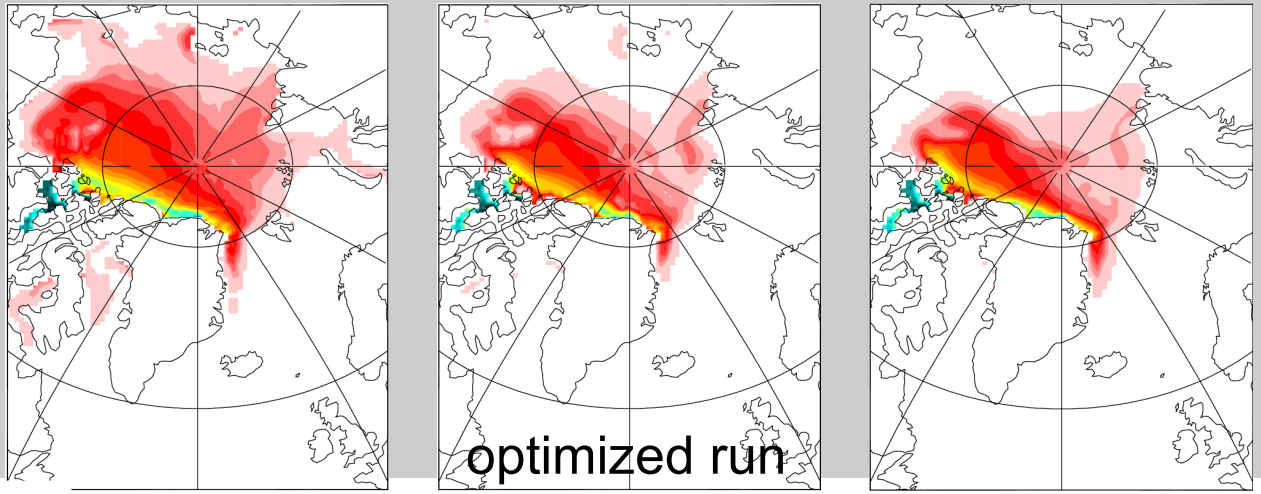
SSM/I-SSMIS EASE-Grid (NSIDC)

Assimilation window 07/2006 - 06/2008

'free' run





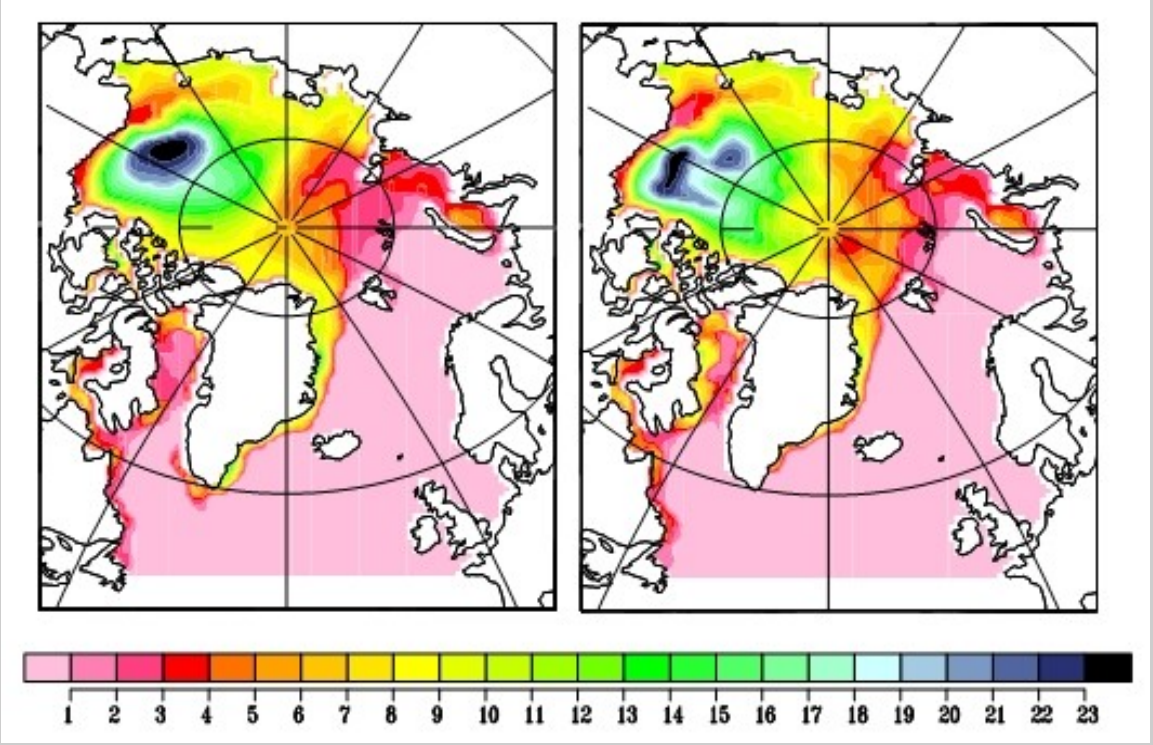


Assimilated variables:
Daily ice concentration: EUMETSAT Ocean and Sea Ice SAF, based on multi-sensor SSM/I analysis
Hydrography (T,S): ITPs from WHOI and ARGO floats from CORIOLIS

2-year state estimation 6/2006 – 7/2008

Freshwater contents (to 34.0, ref 34.8)

September 2007



Free run **Optimized**

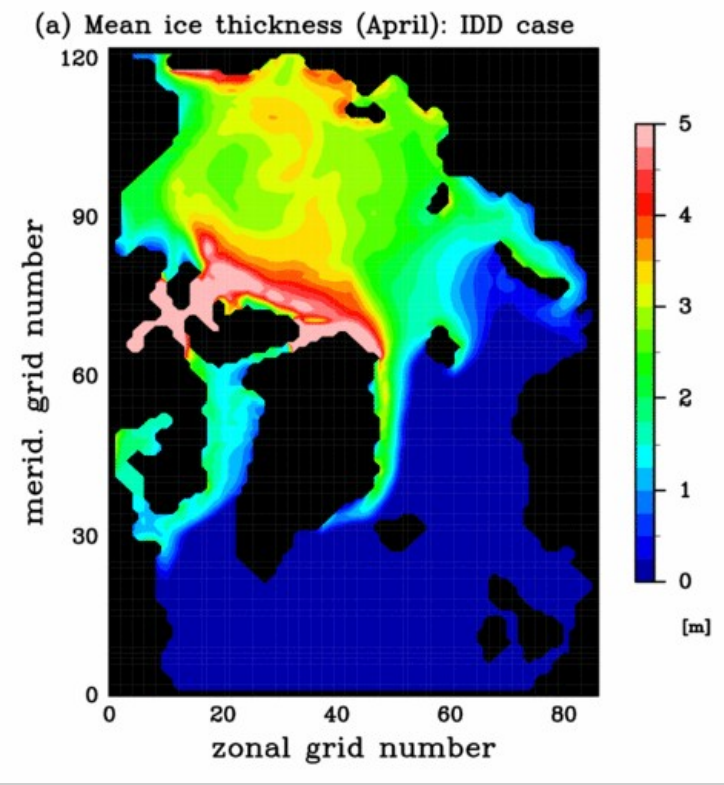
7/2006 to 6/2008 mean difference for Arctic Ocean
approx +1000 qkm

Icedrift Data Assimilation experiment for Mar-May/2010

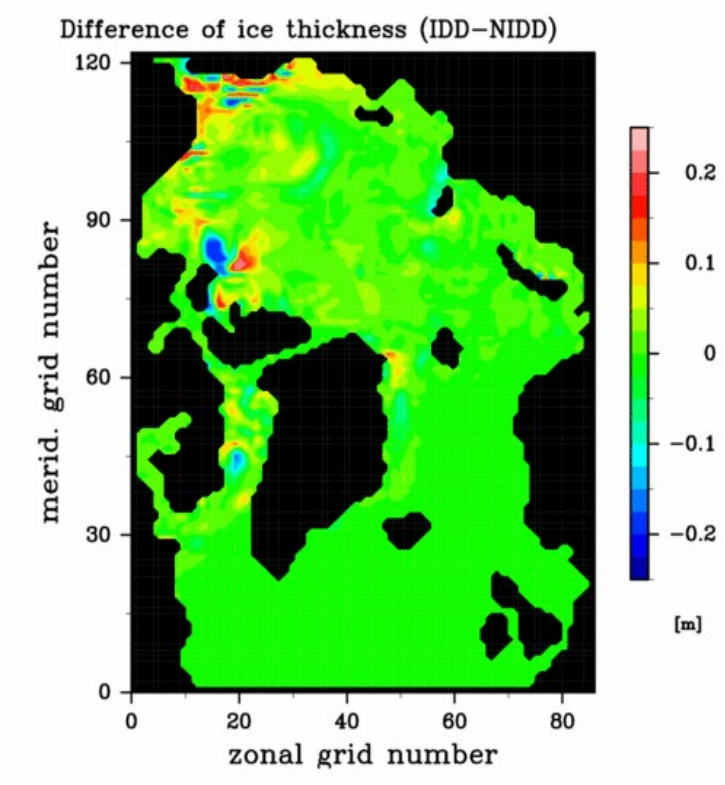
with ice drift (IDD) without ice drift (NIDD)

Mean Ice thickness

IDD



IDD - NIDD

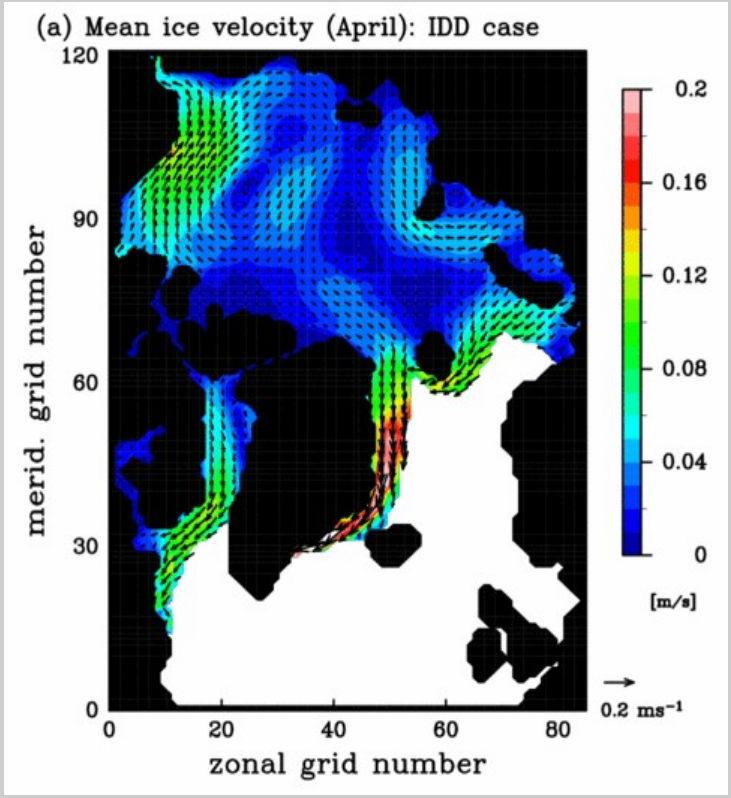


Small changes in sea ice properties

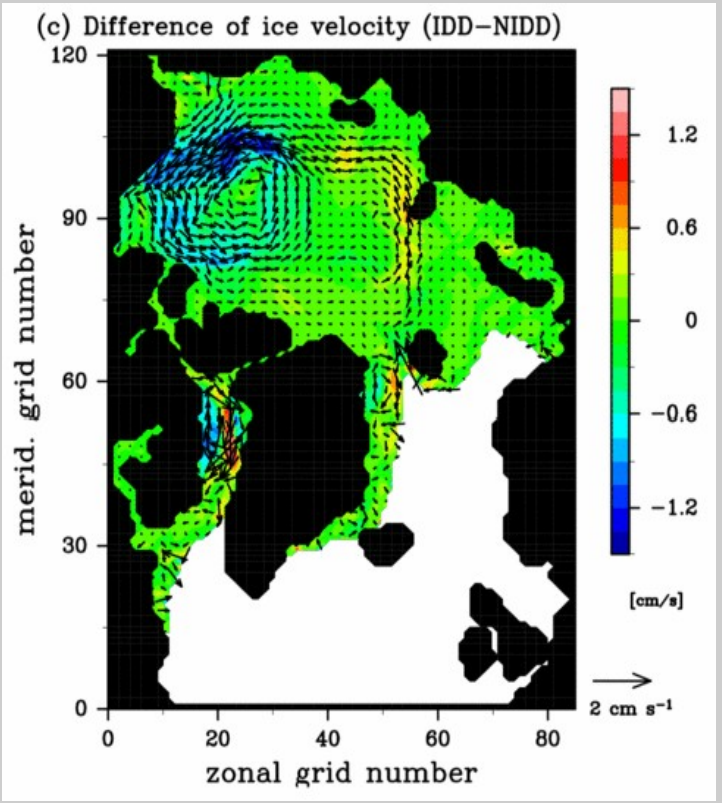
Icedrift Data Assimilation experiment for Mar-May/2010

Mean Ice velocity

IDD



IDD - NIDD

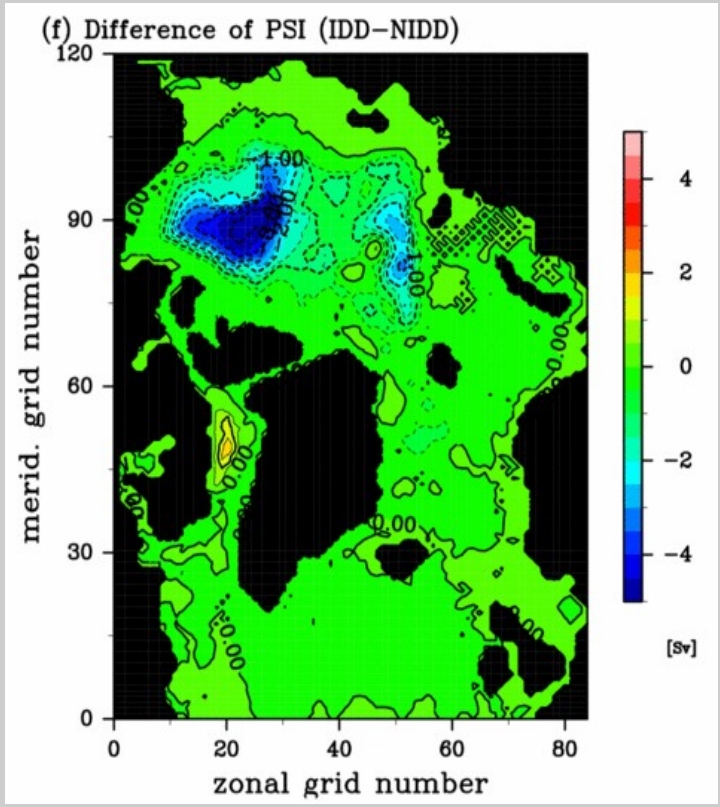


Weakening of Beaufort Gyre in icedrift

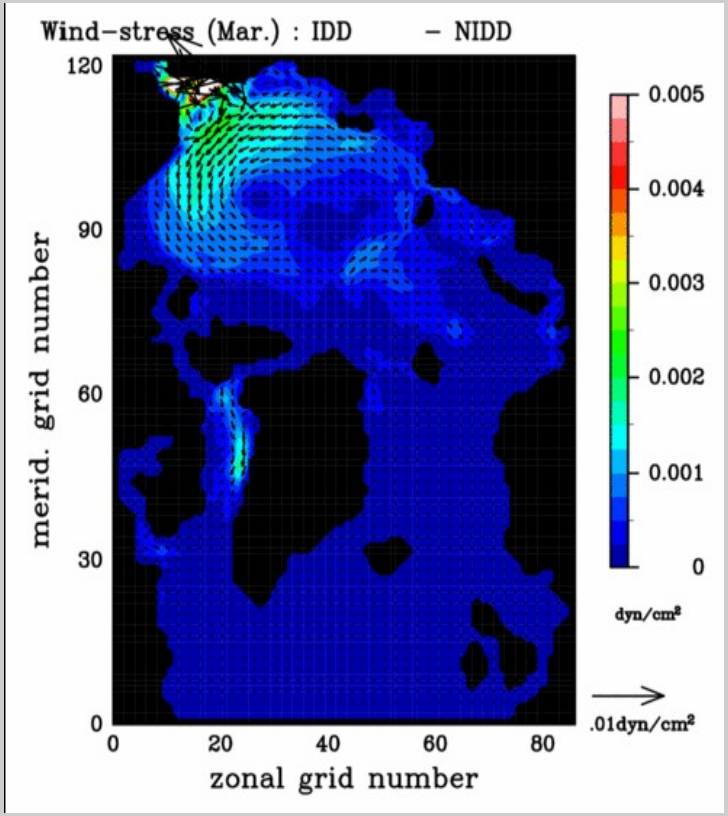
Icedrift Data Assimilation experiment for Mar-May/2010

Mean streamfunction and wind stress

IDD - NIDD

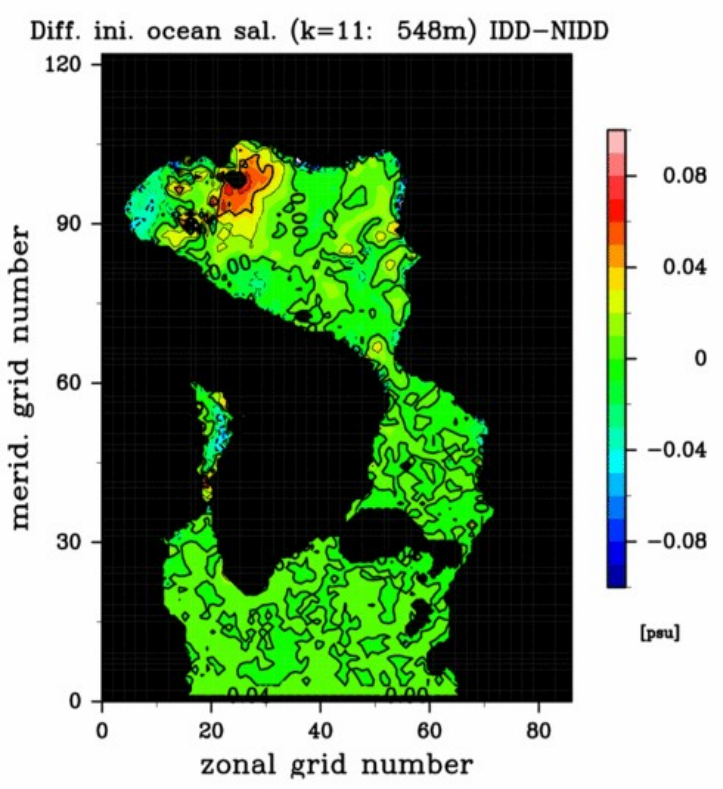


IDD - NIDD



Icedrift Data Assimilation experiment for Mar-May/2010

Initial salinity change (max below pycnocline)
IDD - NIDD



- Strong coupling of ice motion with internal ocean structure

- Salinity field below pycnocline is responsible (verified by perturbed forward experiments)

- See also: AOMIP JGR spec issue 2007:
  - Martin & Gerdes
    - ice drift differences: ocean velocity
  - Zhang & Steele
    - coupling AWL/surf circ: mixing
  - Karcher et al.
    - coupling AWL/BG

NAOSIMDAS to-do list

- 'smooth' adjoint code
- include more data
- reduce uncertainties of uncertainties
- increase resolution
- 'better' surface forcing (JRA25, ERA interim)
- evaluate 'analysed fields'

Summary

- Ice thickness observations (in winter) are very welcome to initialize the SIO system

- (Use of ice age estimates instead)

- (Advanced) data assimilation systems allows you to better understand your system