# The NAOSIM Data Assimilation System (NAOSIM-DAS)
# Project aims and first obstacles

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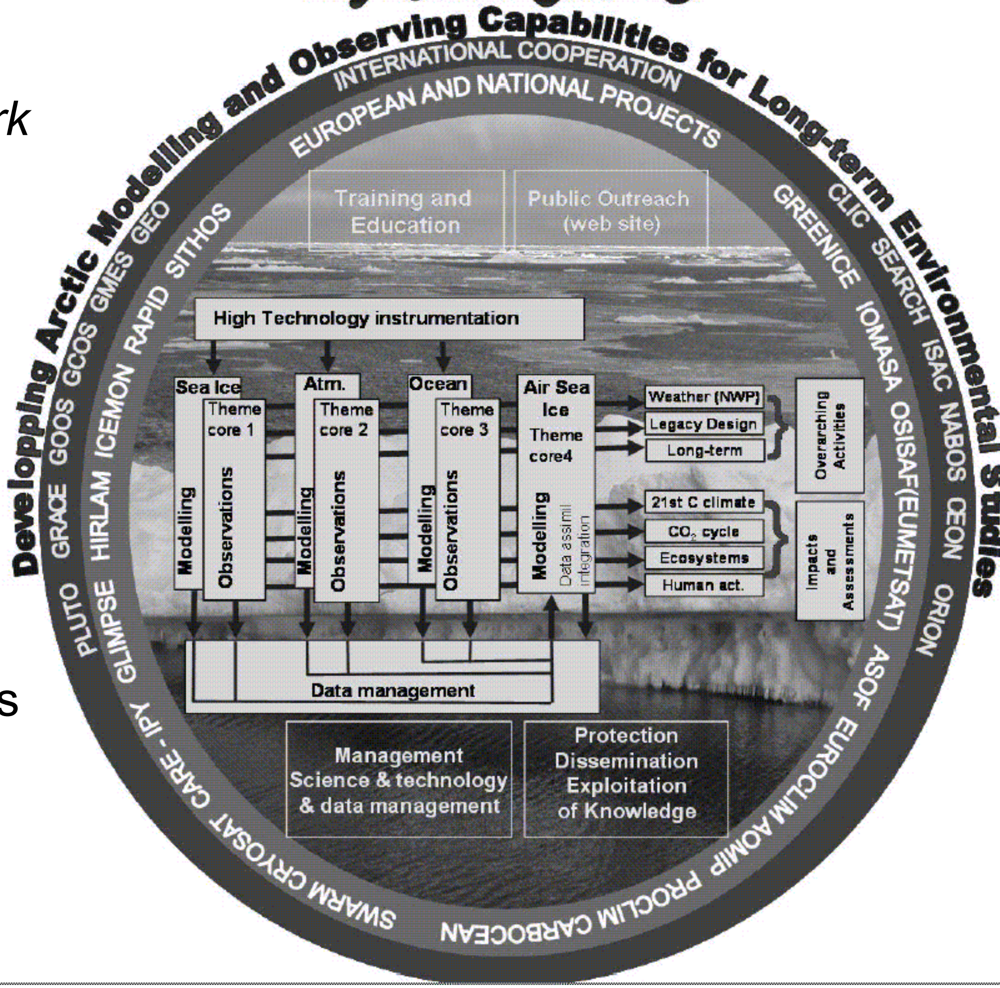
## OUTLINE

- Brief description of the EU-Project DAMOCLES
- The role of NAOSIM in the project
- Presentation of a finite-difference experiment with NAOSIM

*DAMOCLES: An Integrated Project in the 6th Framework of the European Commission from (2006 to 2009 ???)*

Consortium:
48 partners
(including 9 SMEs)
from 12 EU contries

# DAMOCLES




Organized in
4 Core Themes, 3 over-arching activities and 5 impact activities:

**CT 1-3:** Observation of sea-ice, atmosphere, ocean and forward modelling

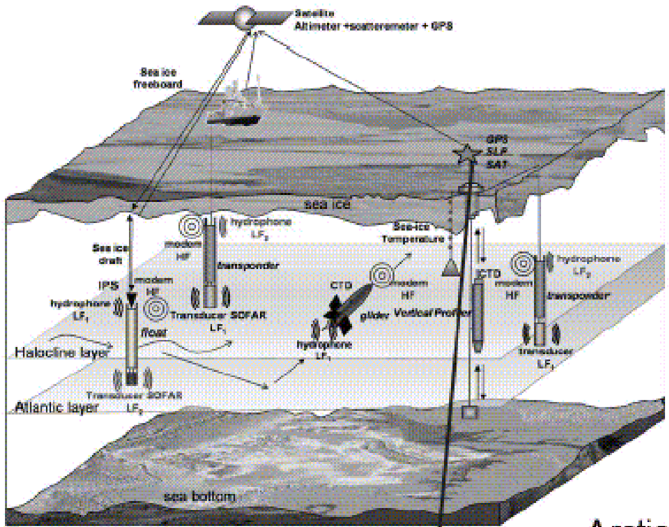
**CT 4:** Integration: Sensitivities, and data assimilation

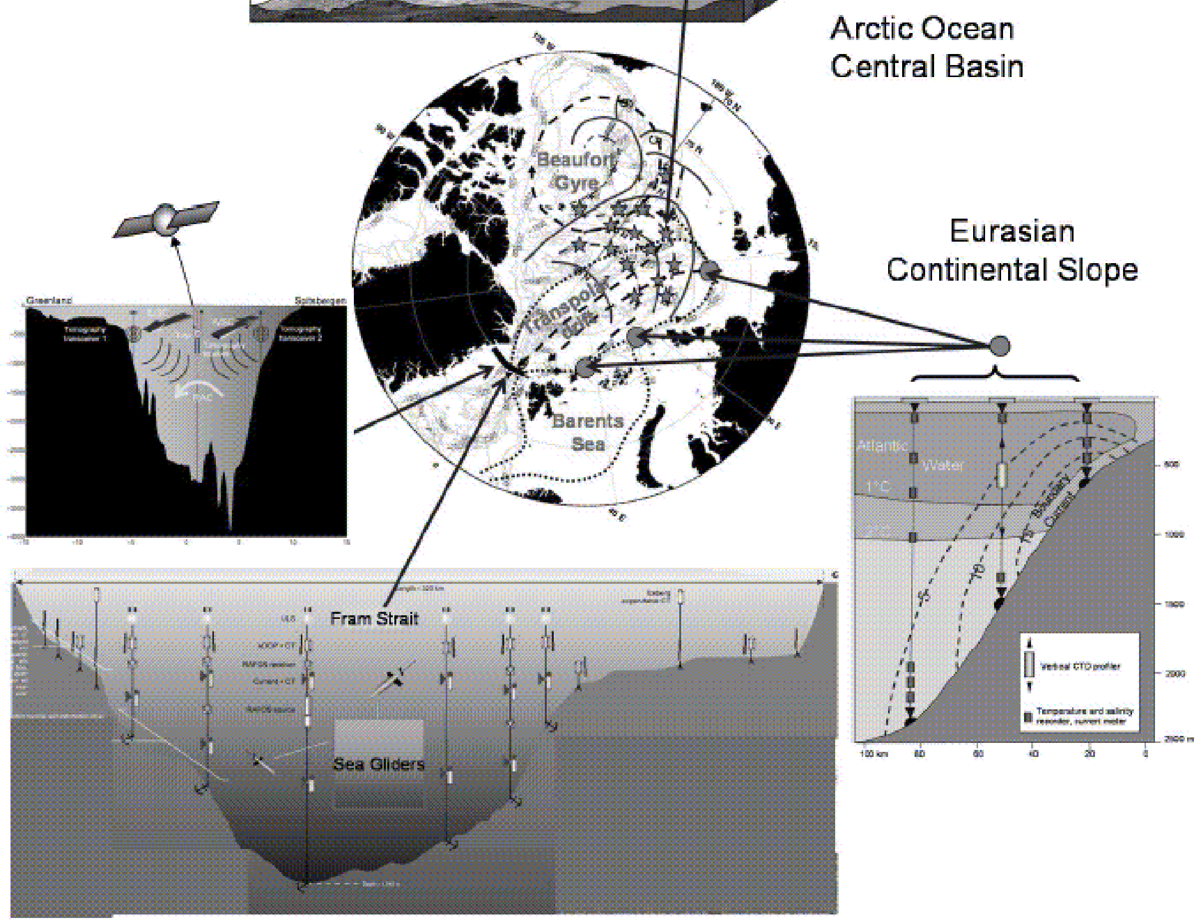
**OA 1-2:** Forums on NWP and climate time-scales (AMOC)

**OA 3:** 4D analysed fields

**IA 1-4:** Impact on the physical environment, the ecosystem, and on human activities

**Overall Goal and Mission:**
DAMOCLES aims at reducing the uncertainties
in our understanding of climate change in the Arctic and their impact. ... DAMOCLES is specifically concerned with the potential for the significantly reduced sea ice cover, and the impacts this might have on the environment and on human activities, both regionally and globally.




## Summary of the technological objective:

The main technological objective of DAMOCLES is to develop a prototype for an Arctic Ocean Observing System including major innovations and breakthrough in High Technology instrumentation ...

### (Selected topics)

- Satellite radar altimetry, Scatterometers, passive microwave radiometers, SAR imagery
- Sea-Gliders measuring 1000s of slanted profiles of T and S along transects between ITPs and moorings equipped with acoustic transponders
- Neutrally buoyant floats drifting at constant depth and equipped with Upward Looking Sonars to measure Sea-Ice draft
- Ice Tethered Platforms equipped with vertical CTD profilers for taking daily profiles of T and S versus depth
- Acoustic Doppler profilers measuring vertical profiles of horizontal currents
- Tomography for measuring T along vertical sections

## Core theme 4: Integration and data assimilation in large-scale modelling and forecasting

Aims to integrate observations and modelling by combining output from the observation- and process-oriented themes 1-3 (and IPY and non-DAMOCLES observations) with dedicated regional and global scale numerical modelling.

A hierarchy of global coupled atmosphere-sea ice-ocean (AOGCM, BCM), regional AOCGM (RCAO, ORCM, HIRLAM/HIROMB), regional coupled sea ice-ocean models (TOPAZ, NAOSIM) to 1D vertical column models, will be used to

- Calculate model sensitivities (in case of NAOSIM with the adjoint ADNAOSIM), and to improve the models themselves

- Quantify predictability with the help of ensemble runs and data assimilation
    1. ...
    2. ...
    3. ...
    4. NAOSIM-DAS: Improved prediction skill is estimated by comparing the skill in a period with data assimilation with a the skill within the same period without data assimilation

- The overall goal is to produce a set of consistent atmospheric, oceanic and sea ice fields (analysed fields) for the DAMOCLES period

# Variational Data Assimilation

**Notation:**

$\underline{\mathbf{s}}$ : state vector
(ocean: u',v',s,tpot,ψ ; ice: h,a,age,hsn)

t : time

$\underline{\mathbf{d}}$ : vector of observations

$\underline{\sigma}$ : vector observational uncertainties

**Principle:**

•define vector of control variables $\underline{\mathbf{x}}$, e.g.,

- •initial state ($\underline{\mathbf{s}}_0$)
- •forcing/boundary conditions ($\underline{\mathbf{f}}$)
- •internal model parameters ($\underline{\mathbf{p}}$)

•define quality of fit by cost function:

$$J(\mathbf{x}) = 1/2 \ \Sigma \ (\underline{\mathbf{d}}_i - \underline{\mathbf{s}}_i(\mathbf{x}))^2 / \underline{\sigma}_i^2$$

•minimise J(**x**) by variation of **x**

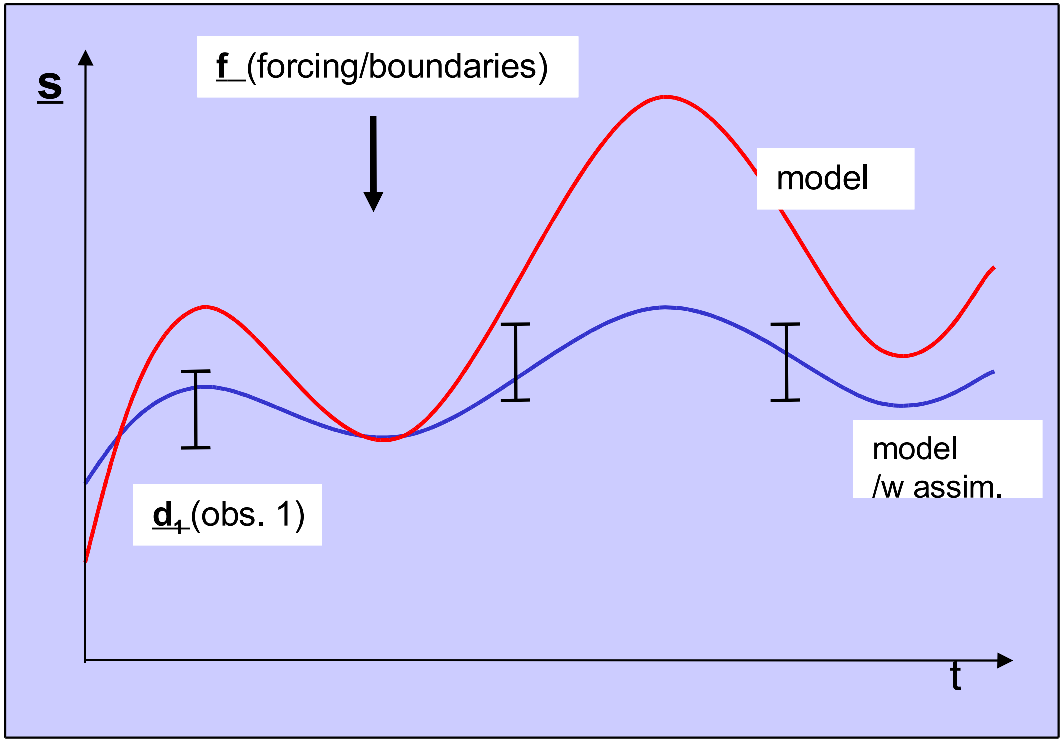
**Remarks:**

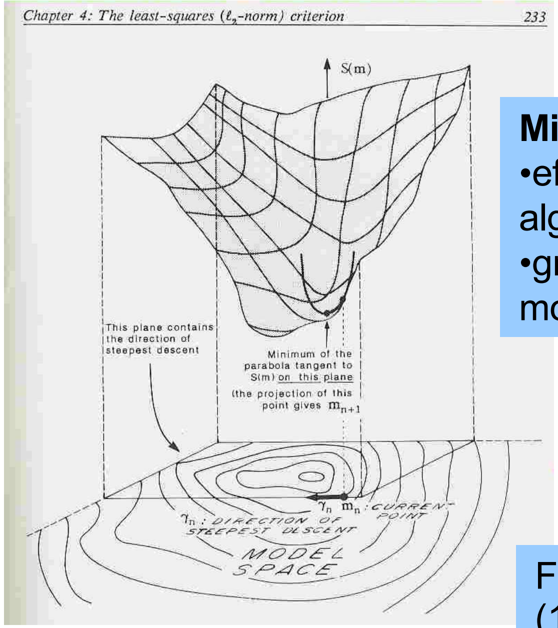
•can handle ***any*** observation that can be computed from the model state

• in numerical weather prediction (NWP) 4DVar usually variation of initial state ($\underline{\mathbf{s}}_0$) only

•can also include uncertainties from model error and correlated uncertainties

•can include more constraints in J, next slide...




**Minimisation:**

•efficient minimisation algorithms use gradient of J

•gradient provided by adjoint model

Figure: *Tarantola* (1997)

# The ECCO costfunction – observational elements

$$
\begin{aligned}
\mathcal{J} \;=\; & (\bar\eta - \bar\eta_{TP})^t\, \mathbf{W_{geoid}}\, (\bar\eta - \bar\eta_{TP}) && \text{TOPEX absolute SSH} \\
& + \left(\eta - \eta'_{TP}\right)^t \mathbf{W_{TP}} \left(\eta - \eta'_{TP}\right) && \text{TOPEX SSH anomalies} \\
& + \left(\eta - \eta'_{ERS}\right)^t \mathbf{W_{ERS}} \left(\eta - \eta'_{ERS}\right) && \text{ERS SSH anomalies} \\
& + \left(\bar T_{surf} - \bar T_{Reyn}\right)^t \mathbf{W_{SST}} \left(\bar T_{surf} - \bar T_{Reyn}\right) && \text{Reynolds SST} \\
& + \left(\bar T - \bar T_{Lev}\right)^t \mathbf{W_{T_{Lev}}} \left(\bar T - \bar T_{Lev}\right) && \text{Levitus clim.} \\
& + \left(\bar S - \bar S_{Lev}\right)^t \mathbf{W_{S_{Lev}}} \left(\bar S - \bar S_{Lev}\right) && \text{Levitus clim.} \\
& + \left(\tau_x - \tau_{x,NCEP}\right)^t \mathbf{W}_{\tau_\mathbf{x}} \left(\tau_x - \tau_{x,NCEP}\right) && \text{zonal wind stress} \\
& + \left(\tau_y - \tau_{y,NCEP}\right)^t \mathbf{W}_{\tau_\mathbf{y}} \left(\tau_y - \tau_{y,NCEP}\right) && \text{merid. wind stress} \\
& + \left(H_Q - H_{Q,NCEP}\right)^t \mathbf{W_{H_Q}} \left(H_Q - H_{Q,NCEP}\right) && \text{NCEP heat flux} \\
& + \left(H_F - H_{F,NCEP}\right)^t \mathbf{W_{H_F}} \left(H_F - H_{F,NCEP}\right) && \text{NCEP freshwater flux}
\end{aligned}
$$

**ECCO costfunction**
**courtesy: Patrick Heimbach (MIT)**

**setup for assimilation into MIT ocean general circulation model**

Currently added:

- Jason-1 altimetry (sea surface height)
- WOCE hydrography, XBT, TAO buoys
- PALACE/ARGO tracer profiles and drift velocities
- surface drifter velocities
- NSCAT/QuickScat surface wind stress fields
- TRMM/TMI tropical surface temperature fields

# TAF
# Transformation of Algorithms in Fortran

- Source-to-source translator for Fortran-77/90/95
- forward and reverse mode
- scalar and vector mode
- full and pure mode
- efficient Hessian code by applying TAF twice (e.g. forward over reverse)
- command line program with many options
- TAF-Directives are Fortran comments
- extensive and complex code analyses (similar to optimising compilers)
- generated code is structured and well readable

# TAF
## More features

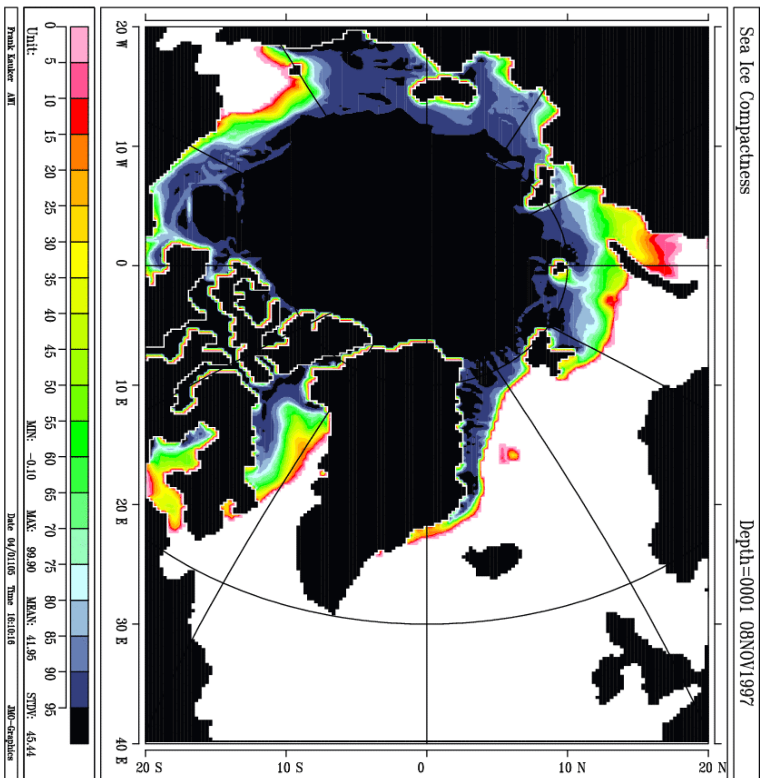
- Generation of flexible store/read scheme for required values triggered by TAF init and store directives
- Generation of simple checkpointing scheme (Griewank, 1992) triggered by combination of TAF init and store directives
- Generation of efficient adjoint (Christianson, 1996, 1998) for converging iterations triggered by TAF loop directive
- TAF flow directives for black-box routines,
  or to include user provided derivative code
  (exploit linarity or self-adjointness, MPI wrappers, etc...)
- Automatic Sparsity Detection
- Basic support for MPI and OpenMP
- supports interrupting and restarting adjoint ('divided adjoint')

## Finite-difference experiment (proposed by D. Menemenlis, JPL)

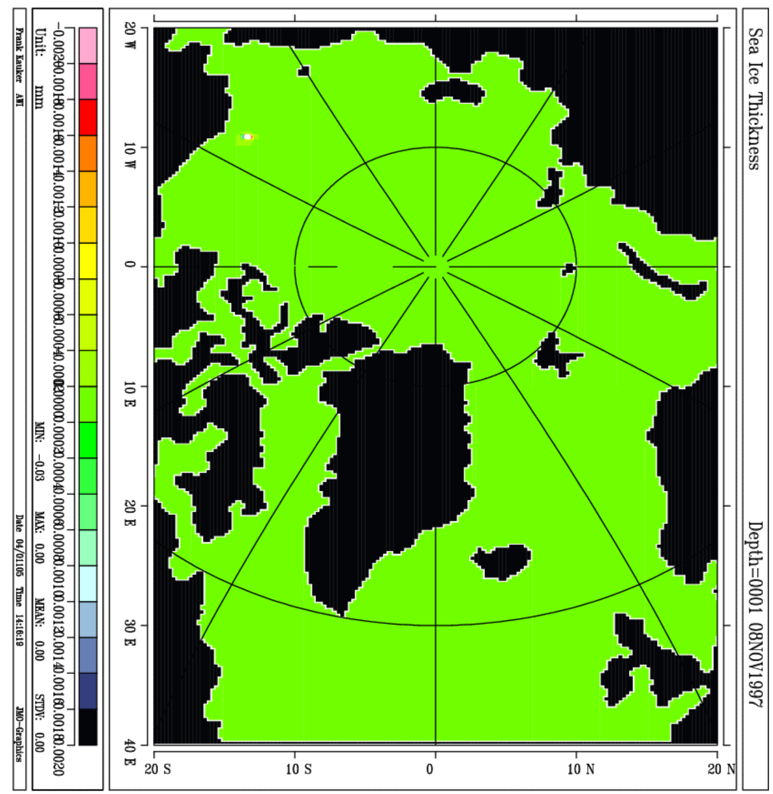
• Disturb the 2m-temperature at ONE grid point with marginal sea ice by +0.01K and -0.01K for 7days.

• Is the response weakly or strongly non-linear?

Sea ice concentration at the start (11/8/1997)

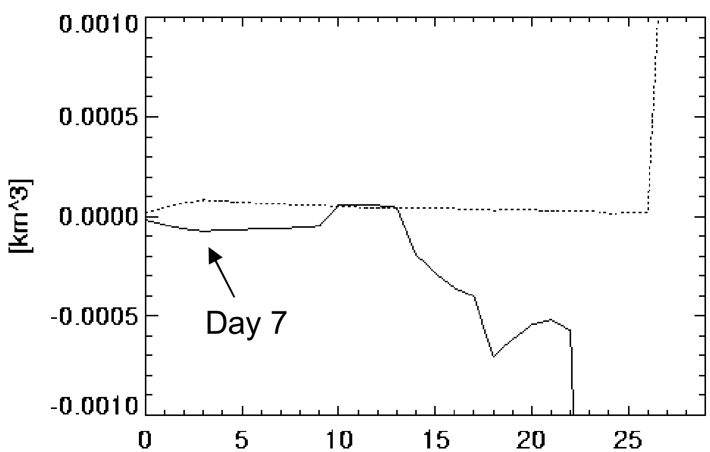


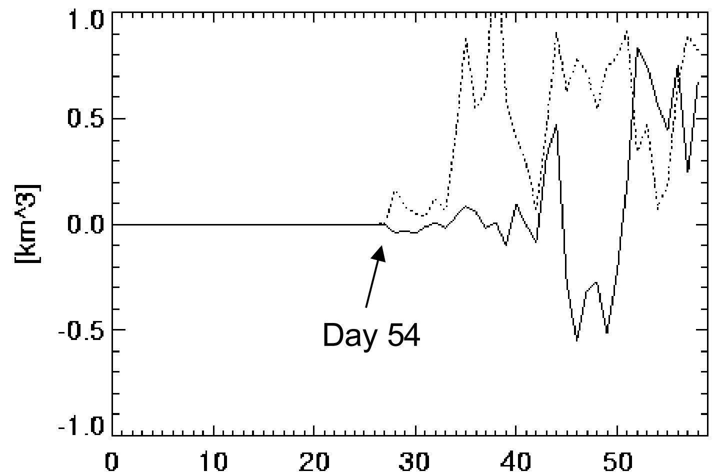

First response after 2 days in sea ice thickness



## Finite-difference experiment:

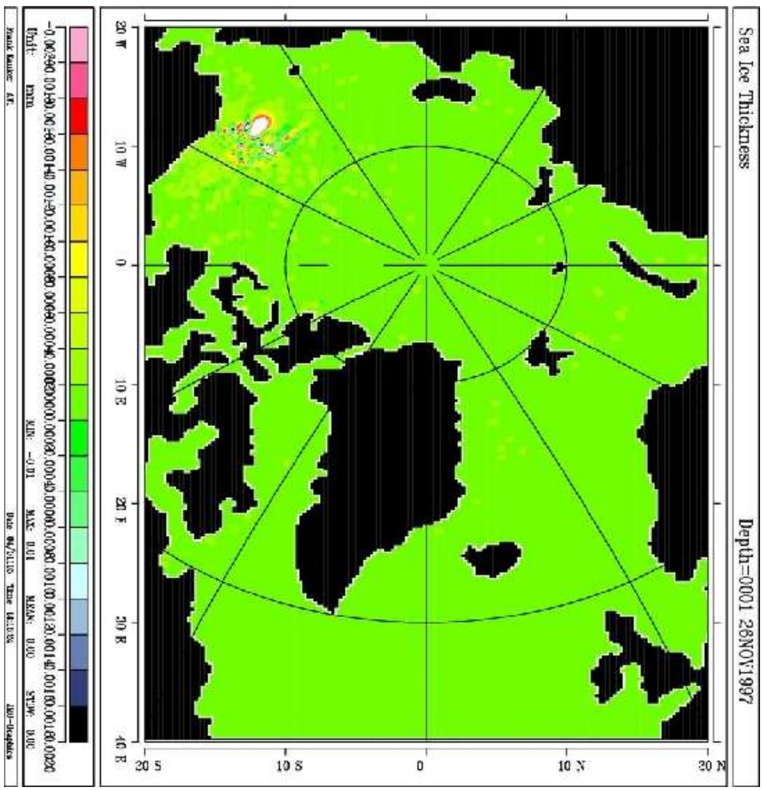
- Look at some integral quantity: sea ice volume in the Arctic [km**3]
- Difference +0.01K-ctrl (straight) and -0.01K-ctrl (dashed)



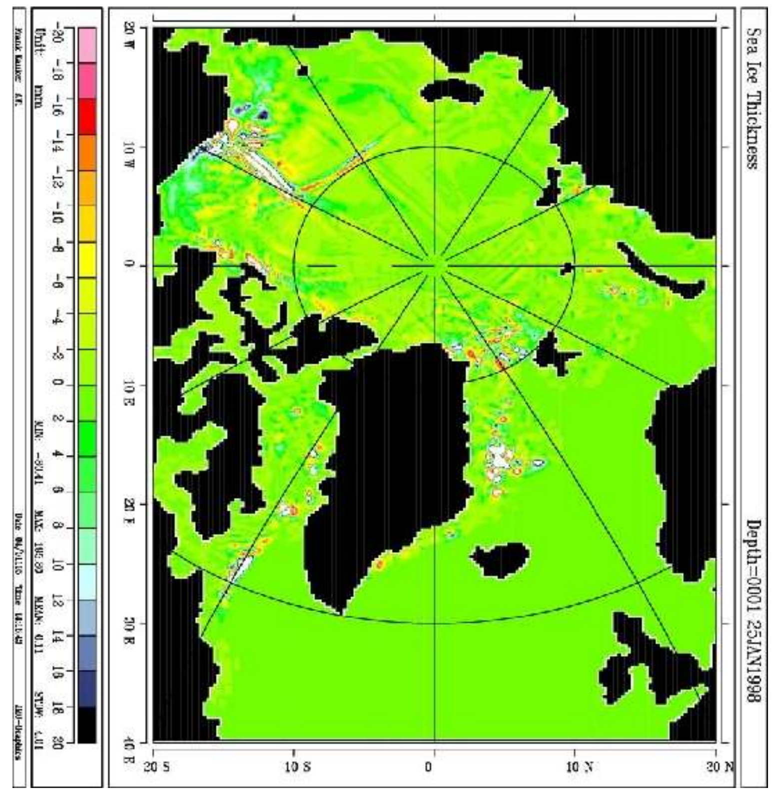



# Finite-difference experiment:

Sea ice thickness diff after about 20 days

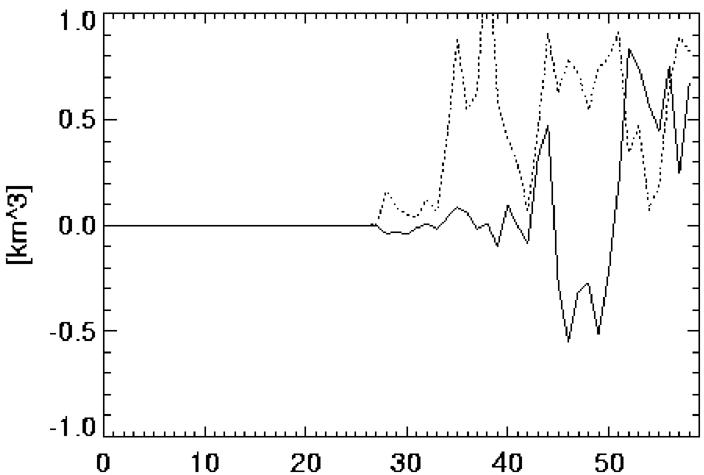


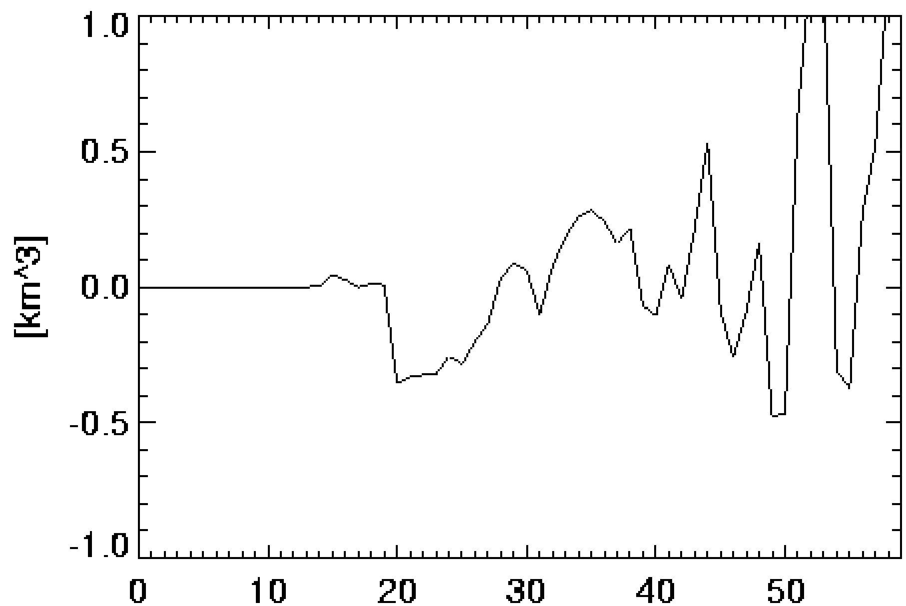

Sea ice thickness diff after about 50 days



## Finite-difference experiment:

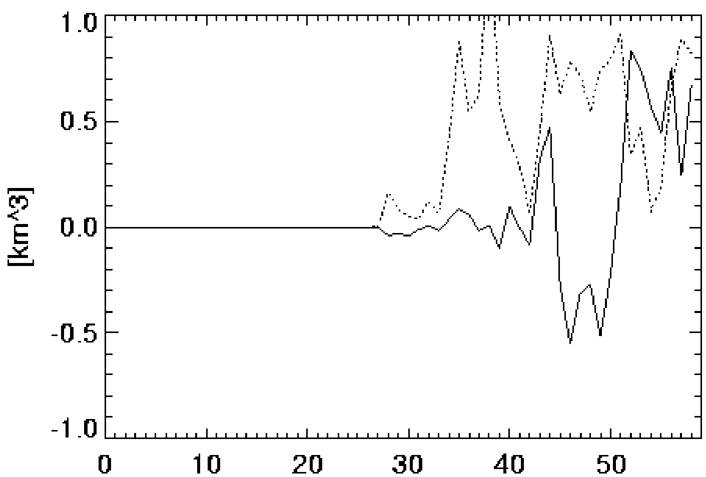
• Look at some integral quantity: sea ice volume in the Arctic [km**3]
(mean 20000 to 30000km**3)
• amasmin=1.e-6m---> 1.e-8m
(if ice thickness lower amasmin free drift solution is applied)

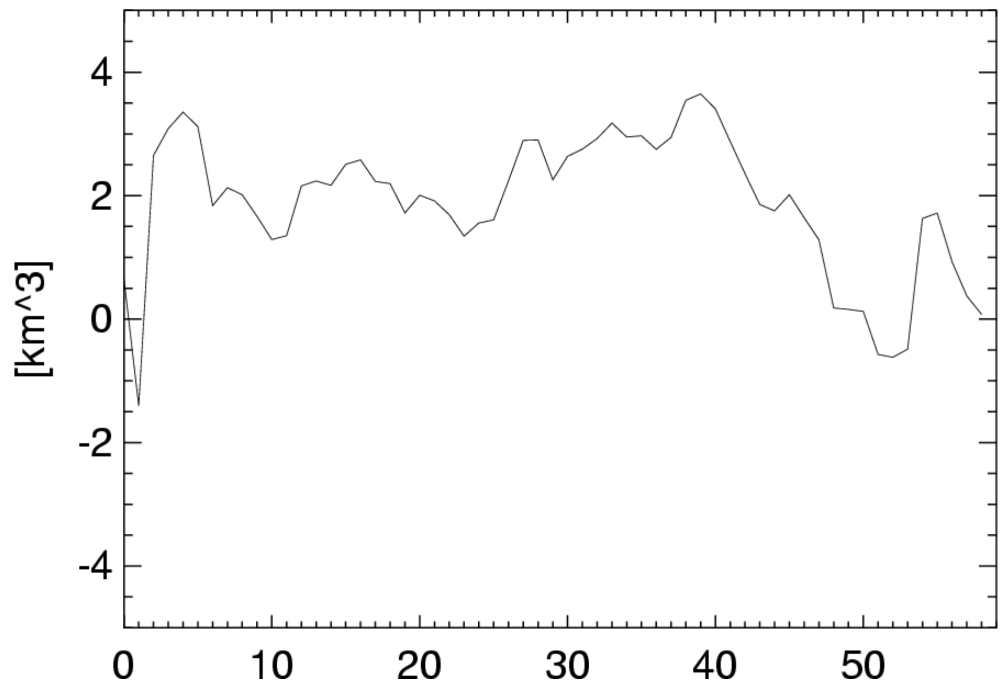


## Finite-difference experiment:

• Look at some integral quantity: sea ice volume in the Arctic [km**3]
• vrmax=1.e-4m/s ---> 5.e-5m/s
(if the global maximum of the drift change in the iteration is lower vrmax stop iteration)



## Questions finite-difference experiment:

- Strong non-linear behaviour due to the numerical formulation or the real physics?
- Hibler and Bryan (1986) stress coupling?
- Is EVP more well behaved?