Ensemble Kalman filter in sea ice modeling

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The 2012 sea ice kiss: two pending challenges

Observed summer sea ice extent [Comiso & Nishio, 2008]

Million km²

September - Arctic

February - Antarctic
Challenge 1
Expanding Antarctic sea ice

- Mostly **areal** observations

- **GCMs are of limited utility** because of biased mean state and variability [Zunz et al., 2013]

- **Several interpretations proposed**
  - Changes in winds [Holland and Kwok, 2012]
  - Changes in hydrological cycle [Zhang, 2007; Bintanja et al., 2013]
  - Unforced variability [Polvani & Smith, in rev.]
  - …

[data: Comiso and Nishio, 2008]
Challenge 2
Summer Arctic sea ice predictability
Challenge 2
Summer Arctic sea ice predictability

**September Arctic sea ice extent**

**Quadratic fit**

**1 million km²**
Challenge 2
Summer Arctic sea ice predictability

Never rely on your first intuition for complex systems!

September Arctic sea ice extent simulated by a CMIP5 model

Quadratic fit

1 million km²

1950 2000 2050 2100
Data assimilation and ensemble Kalman filter

Reconstructing Antarctic sea ice changes

Is there an added value from sea ice initialization?
The ensemble Kalman filter is a multivariate data assimilation method

\[
\mathbf{x}^a = \mathbf{x}^f + K \cdot (d - H \mathbf{x}^f)
\]

[Evensen, 2003]
The ensemble Kalman filter is a multivariate data assimilation method.

Example of an update in sea surface salinity:

- Analysis saltier than forecast
- Analysis fresher than forecast
The ensemble Kalman filter relies on ensemble simulations.

\[
K = P H^T \left( H P H^T + R \right)^{-1}
\]

- **$K$**: Filter gain matrix.
- **$P$**: Model error covariance matrix (from 25 members).
- **$H$**: Observation operator.
- **$R$**: Obs. error covariance matrix (diagonal for now).
The ensemble Kalman filter is a forecast-analysis method.

- At time $t$, perturbed winds and $T2m$ are used.
- $t+1$ is the observed time step.
- $t+2$ is the future time step after the analysis.
Ensemble spread, restartability and limitations

The distribution of ensemble members should reflect the full model uncertainty

- 25 members with perturbed atmospheric forcing (winds/2m-air temperature)
- Localization [Sakov and Bertino, 2010]
- Use of perturbed observations [Burgers et al., 1998]
Ensemble spread, restartability and limitations

A «sanity check» for the model is necessary because gaussianity assumption is rarely fulfilled.

- Reset negative ice concentrations/thickness to zero
- Bound total ice concentration by 1
- Ice thickness stays within category bounds
Data assimilation and ensemble Kalman filter

Reconstructing Antarctic sea ice changes

Is there an added value from sea ice initialization?
Improved sea ice extent variability

Trend in sea ice extent in the Southern Ocean

assim

free

obs+/- 2std

%/decade

Weddell  Indian  Pacific  Ross  Am. – Bell.  Antarctica
Improved simulated sea ice thickness

Mean bias in simulated thickness against ASPeCt data [Worby et al., 2008]
Weak, regionalized and noisy increase in Antarctic sea ice volume

1980-2008 trend in sea ice volume [km³/decade]
Mechanisms for Southern Ocean sea ice variability

The global increase in volume should be analyzed at the regional scale first.

Regional signed responses are a result of regional dynamical and thermodynamical processes.

- Changes in winds [Holland and Kwok, 2012]
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- …
Data assimilation and Ensemble Kalman filter

Reconstructing Antarctic sea ice changes

Is there an added value from sea ice initialization?
The predictive skill from a model may depend on
> The metrics used to measure it
> The model used
> The data assimilation method used
Antarctic ocean/sea ice initialization efforts

Initialization of 3-D ocean does not significantly improve sea ice predictability

Winter SH sea ice extent correlation with observations

[Zunz et al., 2013]
Arctic sea ice initialization efforts

The onset, timing and amplitude of large sea ice anomalies are hardly predictable

[adapted from Tietsche et al., 2013]
Arctic sea ice initialization efforts

Arctic sea ice extent [million km²]

Year 2007

FREE RUN

Initialization March 2007
Conclusions

Arctic & Antarctic sea ice data assimilation

Useful for sea ice state reconstruction

Marginal improvements for sea ice predictability

Prospects for joint state/parameter estimation
Thank you

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