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A novel transport assimilation method for the Atlantic meridional overturning circulation at 26°N

Leon Hermanson, Nick Dunstone, Keith Haines, **Jon Robson**, Doug Smith and Rowan Sutton

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JonIRobson

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Atlantic Multidecadal Variability (AMV) and its climate impacts

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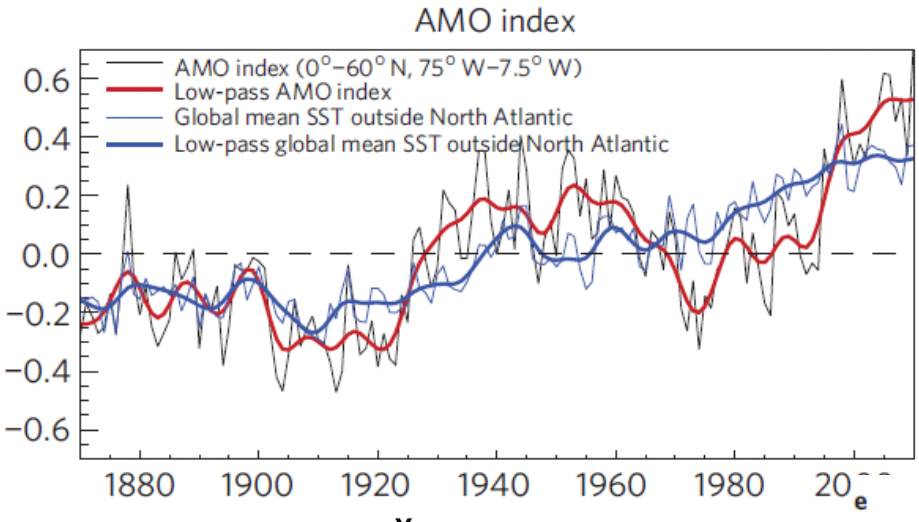
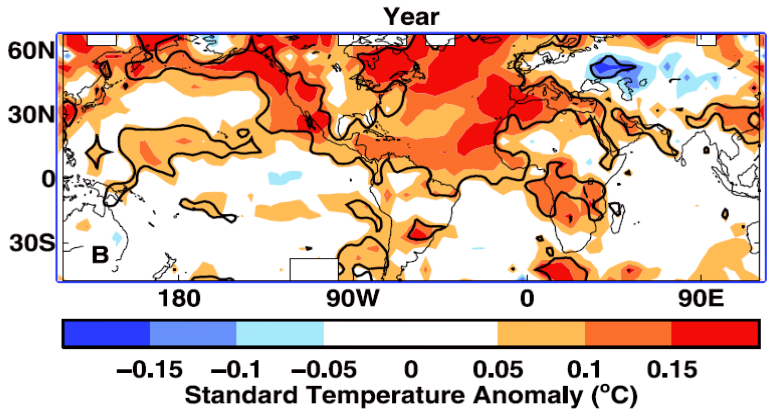
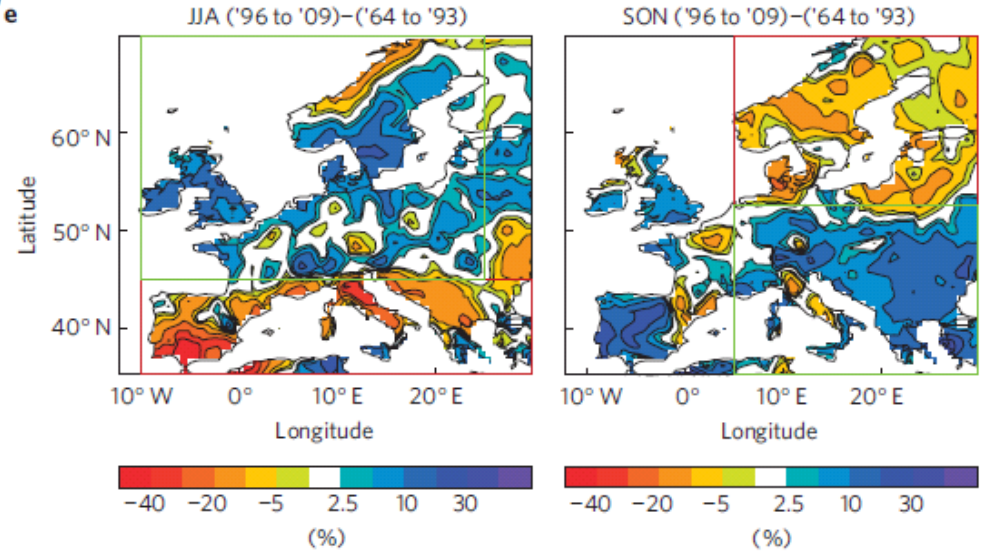




Knight et al, 2005

Evidence that North Atlantic SSTs can affect the surface climate across the Americas, Europe and Africa



Sutton and Dong, 2012

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Can we predict the low frequency variability?

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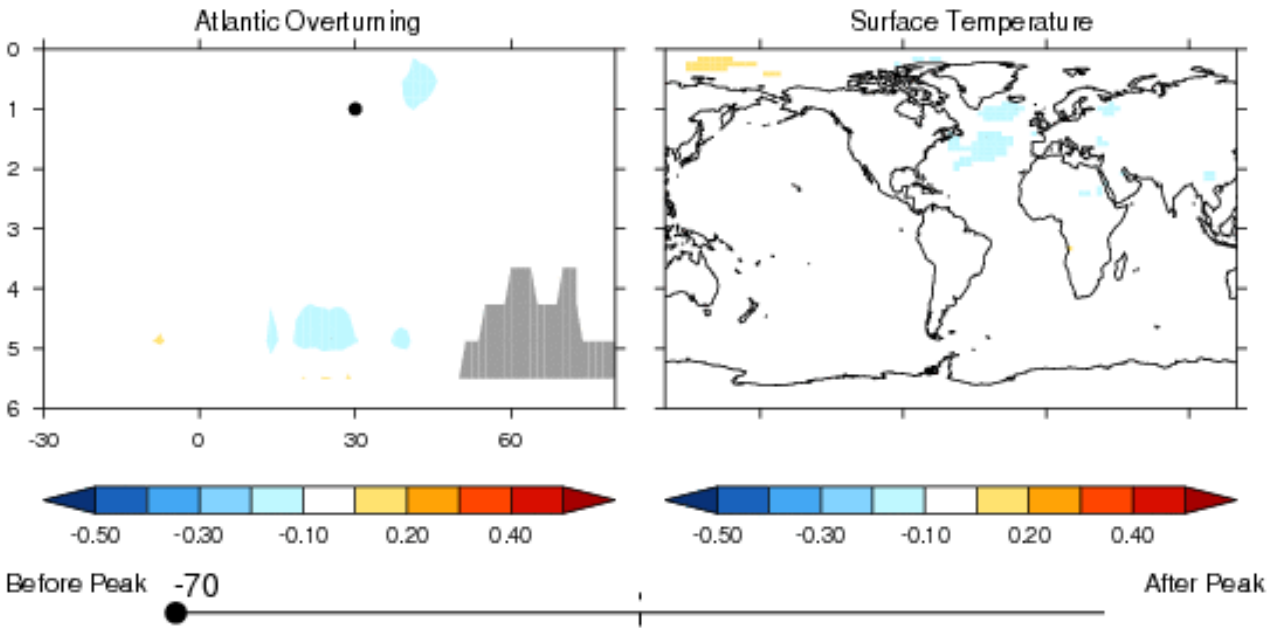
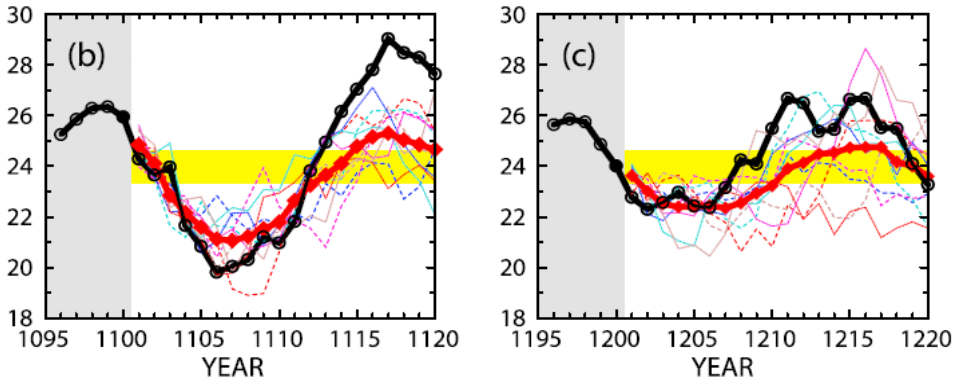


- *Models* suggest that AMV is largely associated with slow changes in ocean circulation (e.g. AMOC) and heat transport
- Could be predictable for up-to a decade ahead

Msadek et al, 2010



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Is there skill in decadal predictions?

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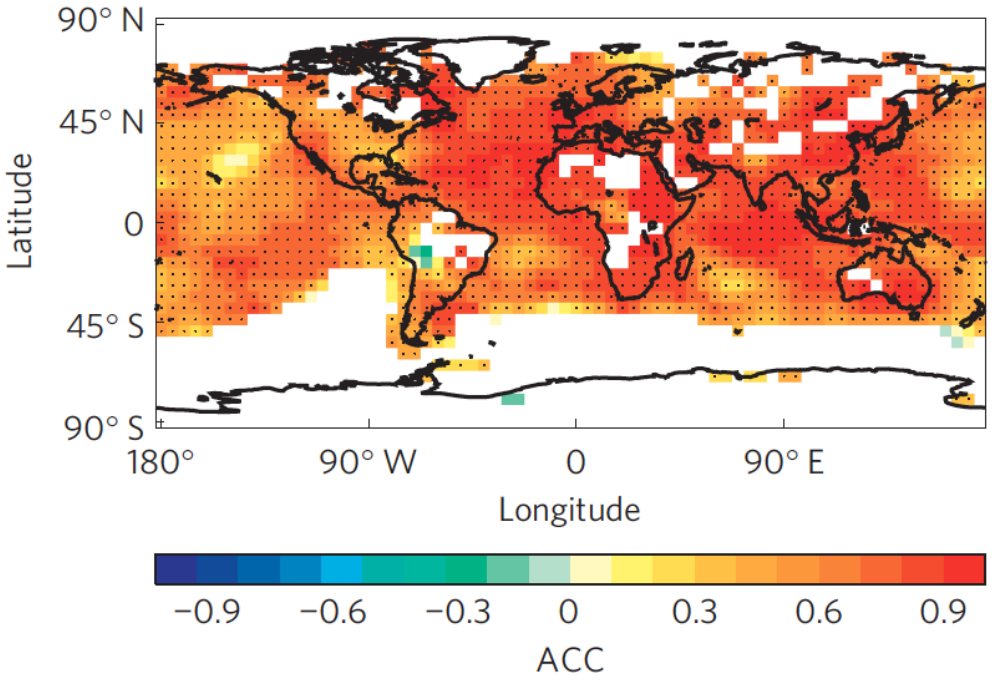
JJASON surface temperature Yrs 1-5 (DePreSys)



(from Smith et al, 2010)

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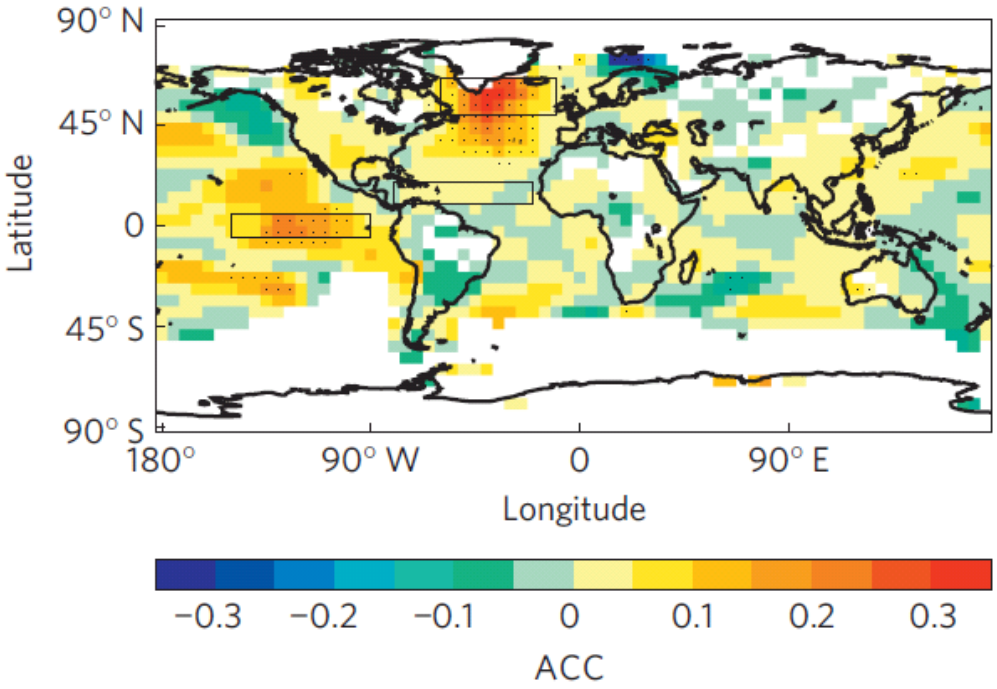
Is there skill in decadal predictions?

JJASON surface temperature Yrs 1-5
(DePreSys – NoAssim)



(from Smith et al, 2010)

- Only “skill” in a few regions
  - Mainly in the North Atlantic – Why?
  - Is the skill just persistence?

1990s North Atlantic warming

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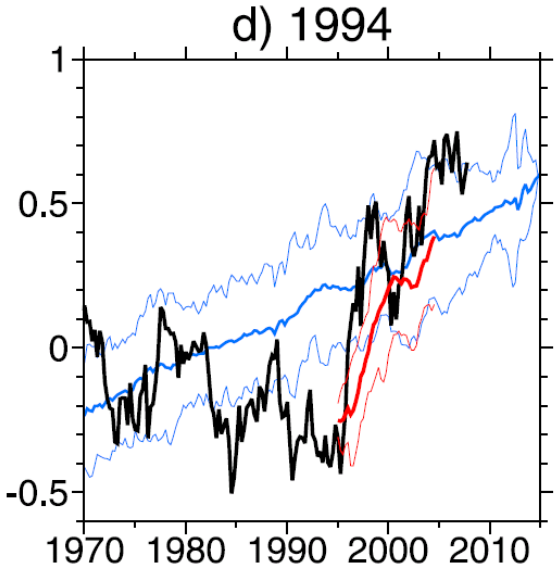
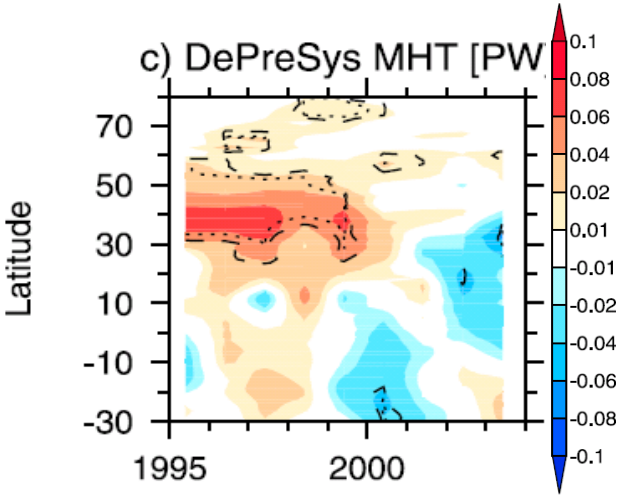
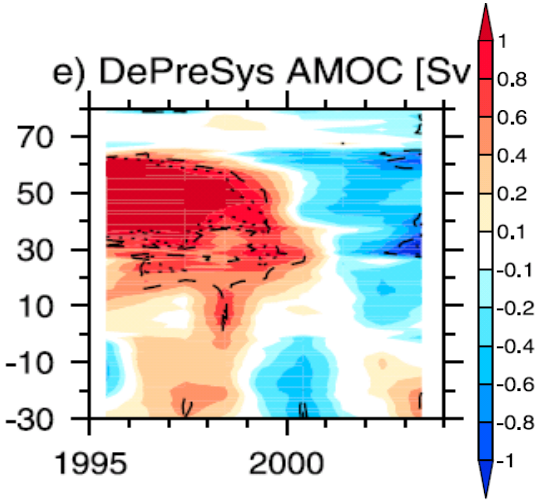
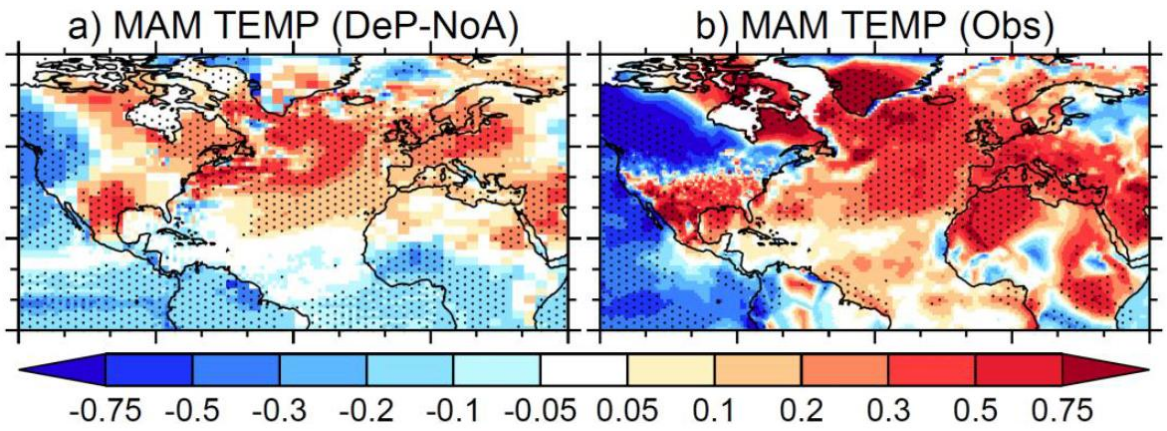


Initialisation of a strong AMOC in DePreSys in the early 1990s key to predict the warming of the North Atlantic subpolar gyre







Robson et al, 2012, J Clim
Robson et al, 2012, GRL
Robson et al, 2013, J Clim

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Measurements of the AMOC

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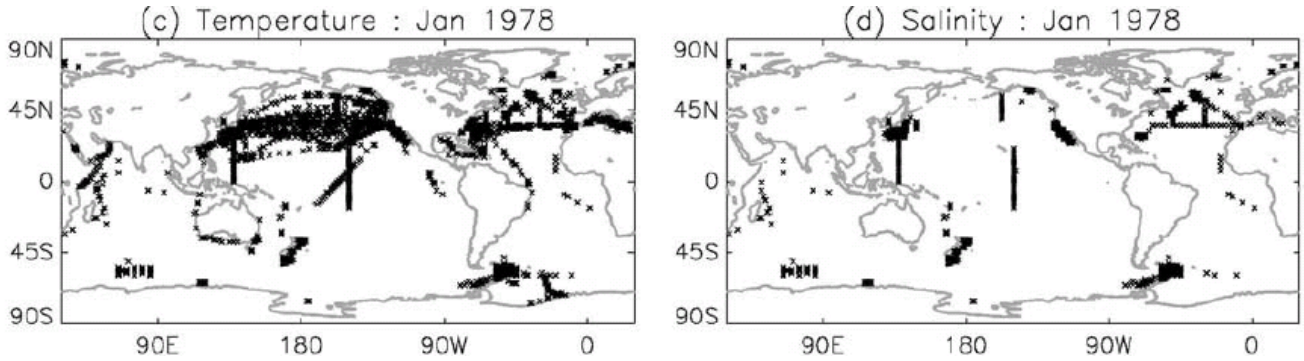
- Initialisation of the AMOC is thought to be essential for skilful mulit-year-to-decadal predictions of the North Atlantic
- But, scarcity of ocean data means estimates of the historical AMOC variability are very uncertain.



- However, since 2004 the first continuous measurements of the AMOC have been taken by the RAPID array
- Key question is whether these new observations can improve ocean state estimation and predictions.

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Met Office Decadal Prediction System

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- Based on HadCM3
  - 1.25° Ocean – 20 levels
  - 3.75 x 2.5° Atmosphere – 19 Levels
- Uses **anomaly assimilation**
  - 3D ocean T, and S
  - atmospheric U,V,T and MSLP (from ERA)
  - Hindcasts initialised every November between 1960-2005
- "Assimilation" is a two stage process
  - First, **Analysis** - object statistical analyses of ocean Temperature and Salinity
  - Second, **Assimilation** - model is relaxed (strongly) towards analysis

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Analysis

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- Statistical Optimal Interpolation
  - Uses global model-derived co-variances to reconstruct T and S anomalies (Smith and Murphy, 2007)
  - Co-variances are derived from 50 years of HadCM3 form a transient run
  - Also uses lagged co-variances to analyse 6 months of data

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Initialisation of DePreSys

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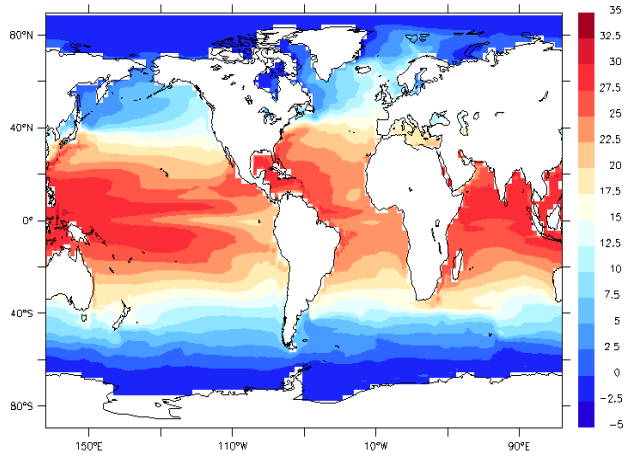
- Seasonal forecasts typically assimilate full fields to initialise the model close to the observed state.
- DePreSys is Initialised close to the *model attractor* by assimilating **anomalies on to the model climate**

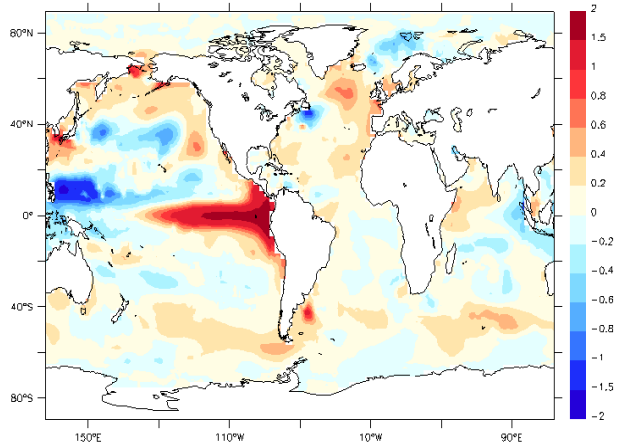
Top 100m average Temperature



Climatology

(Calculated form transient integrations)

+



Observed anomaly

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Measuring the AMOC

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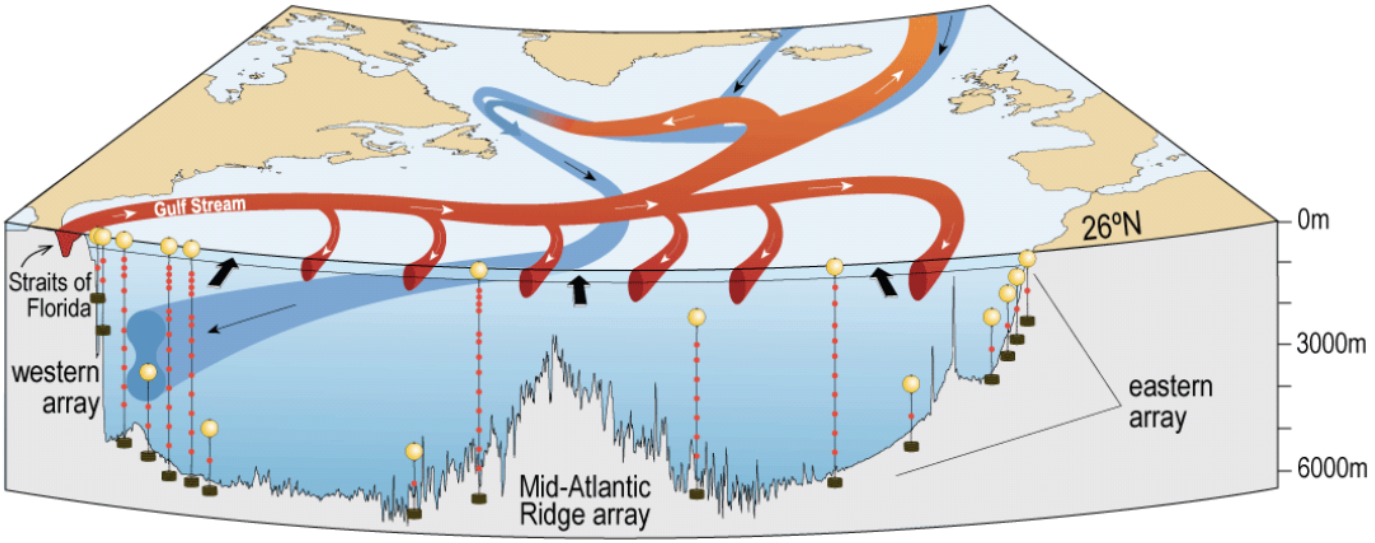

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Measuring the AMOC

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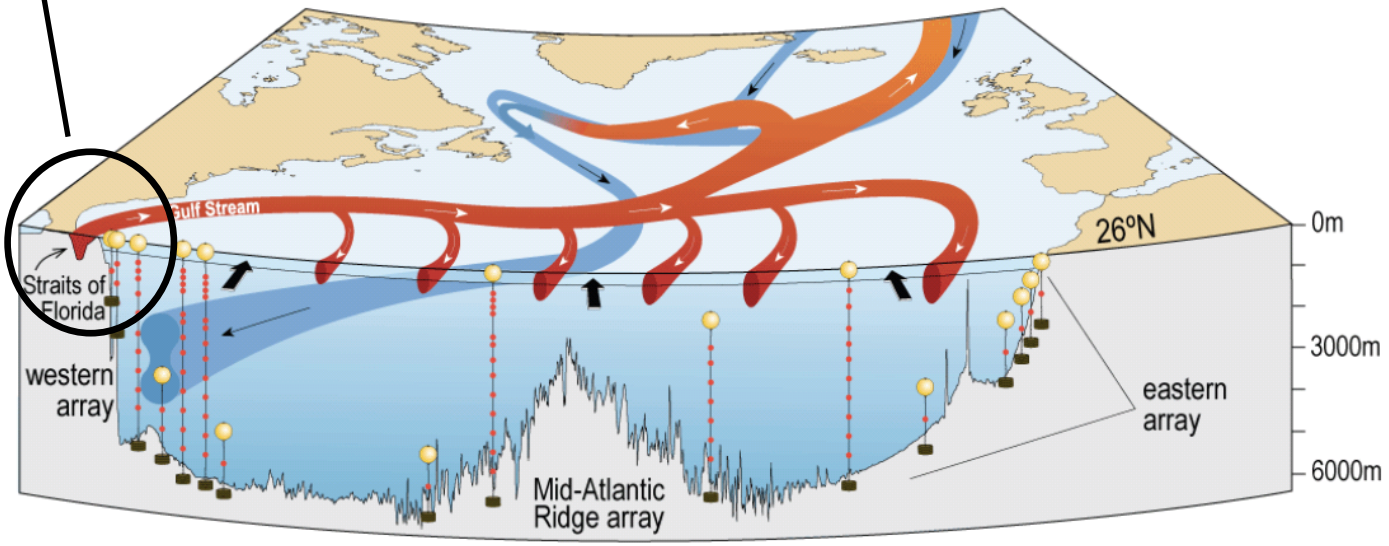
Gulf stream transport
measured by phone line…



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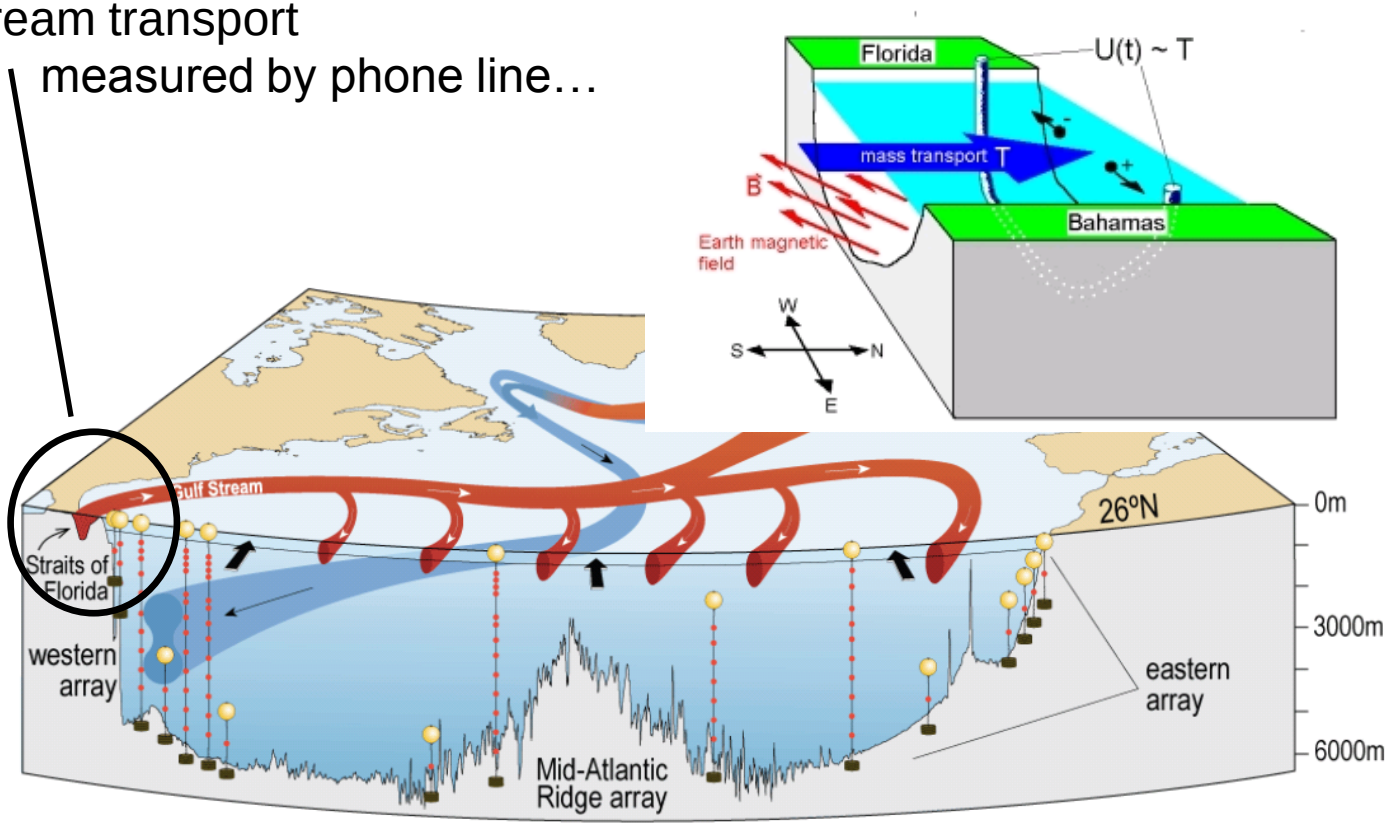

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Measuring the AMOC

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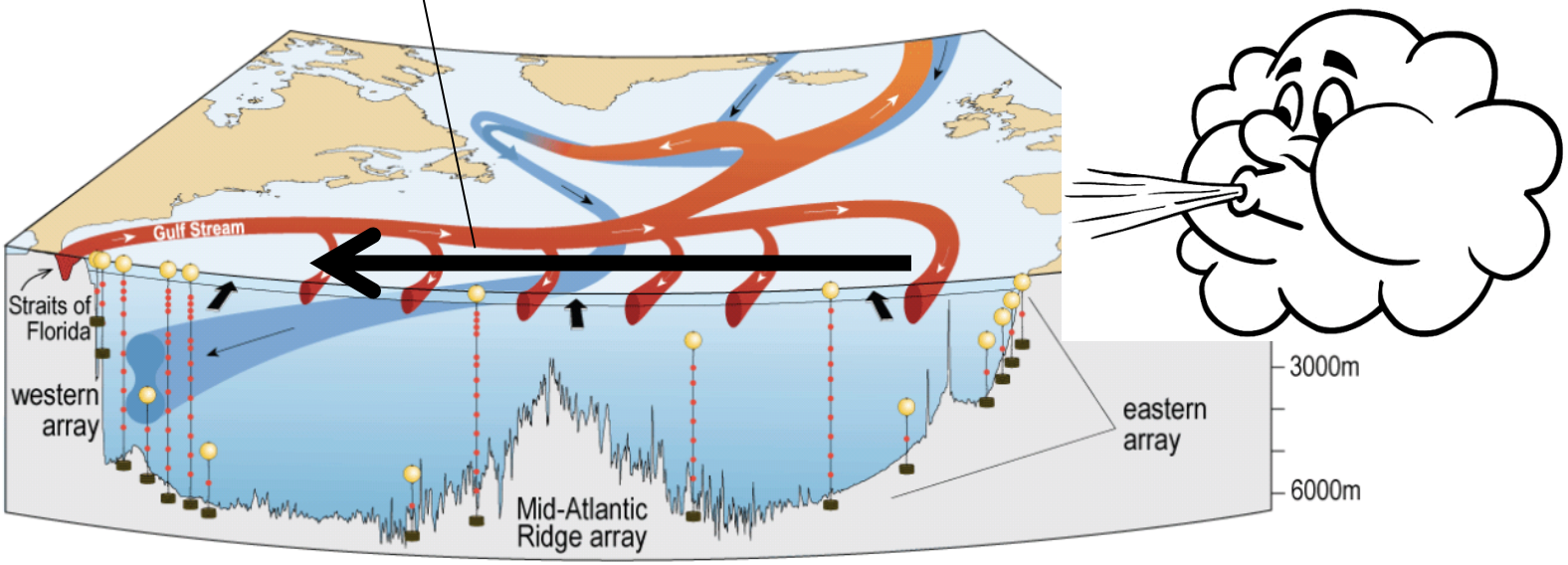
Ekman transports – upper ocean transports act at right angles to wind



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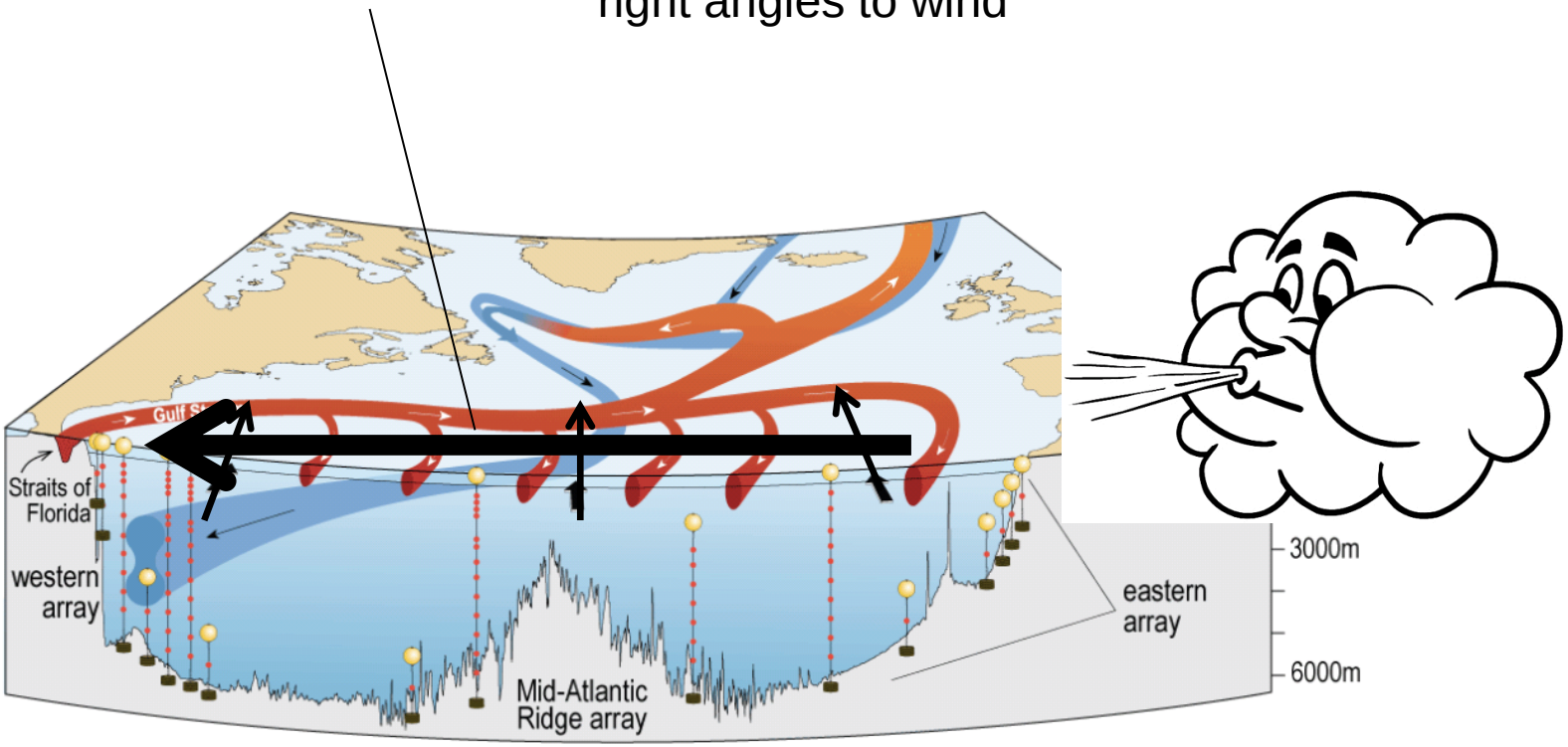

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Measuring the AMOC

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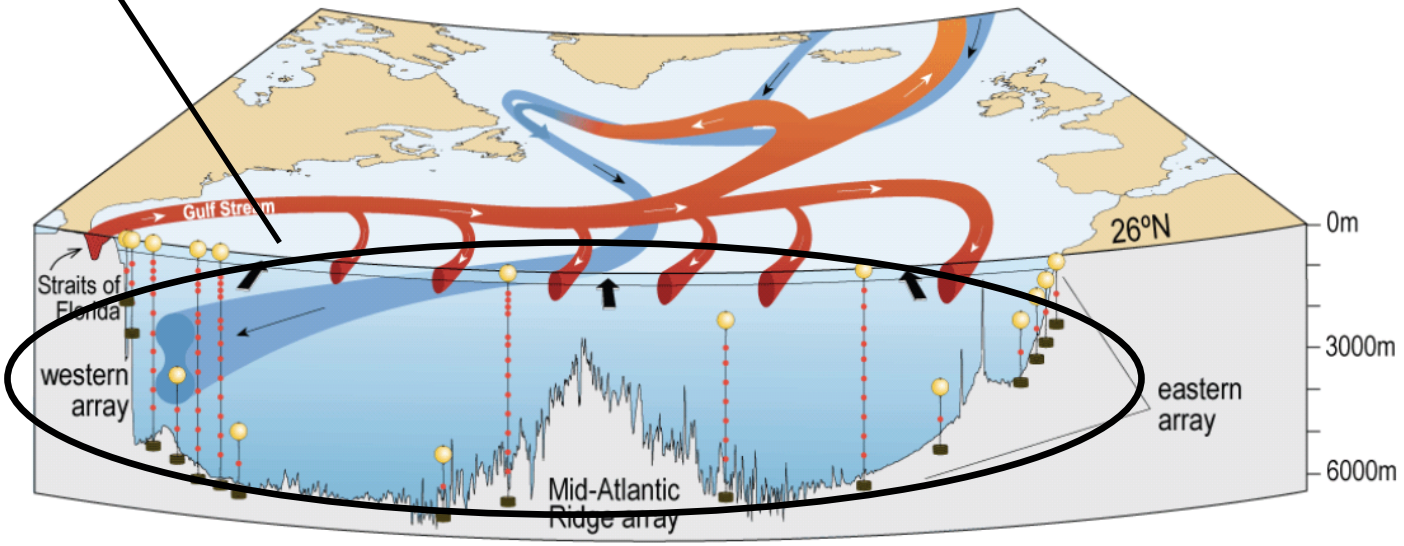
Array of Moorings measuring Temperature and Salinity twice daily
uses thermal wind relationship to deduce geostrophic transport

dv/dz is related to dρ/dx



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RAPID timeseries

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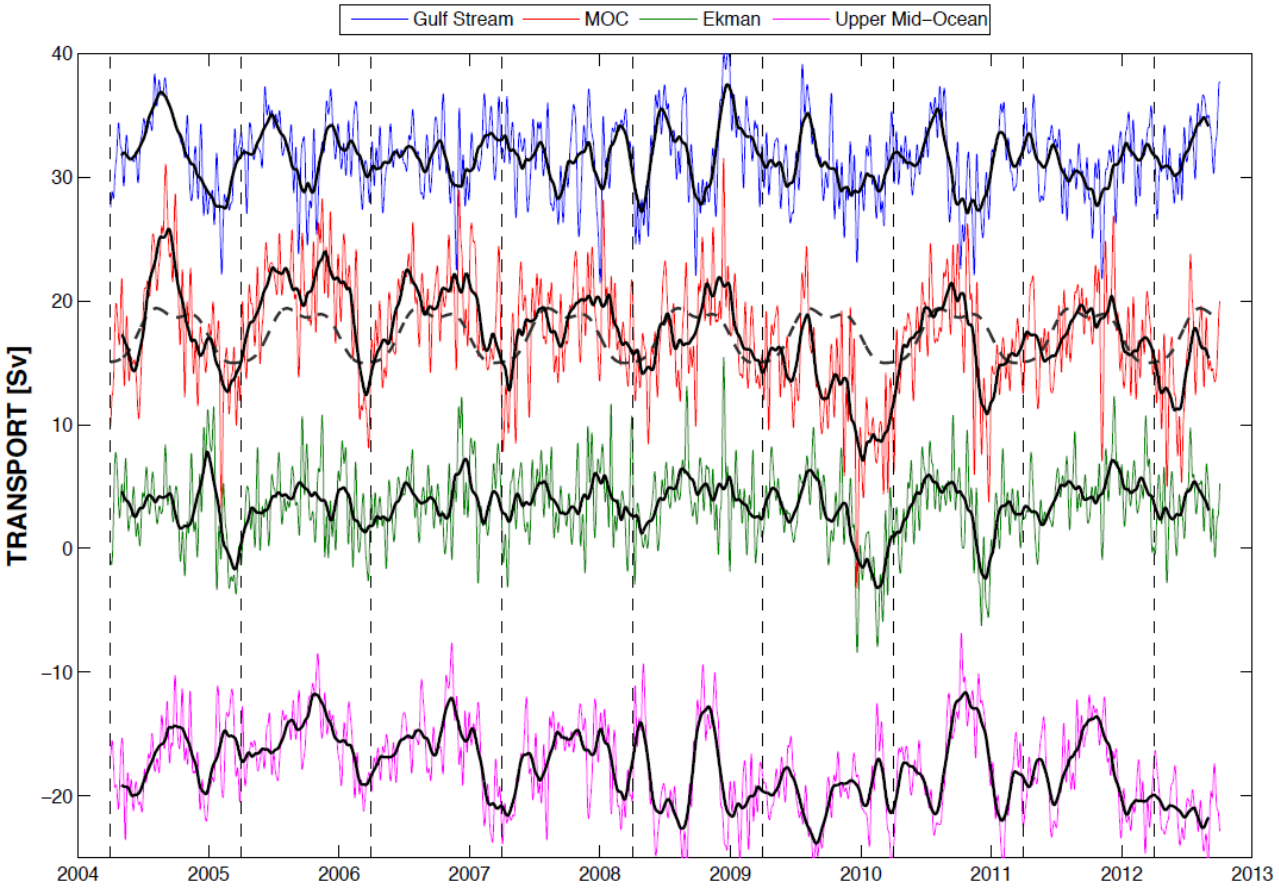

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Assimilating RAPID – What's been done?

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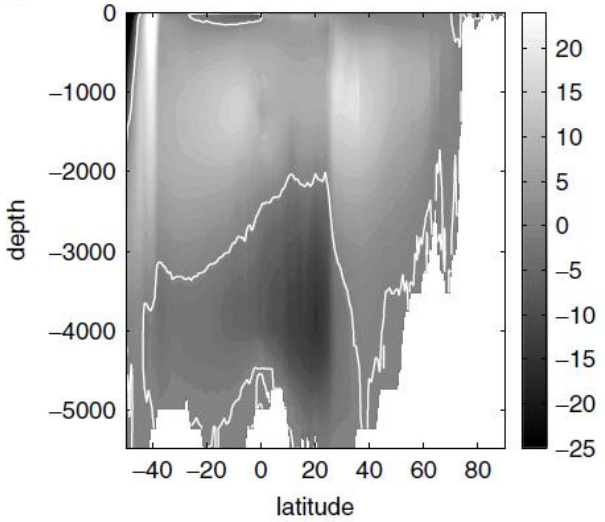
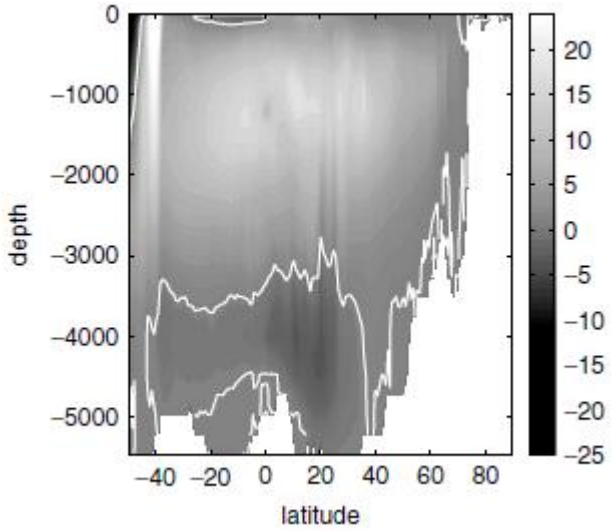
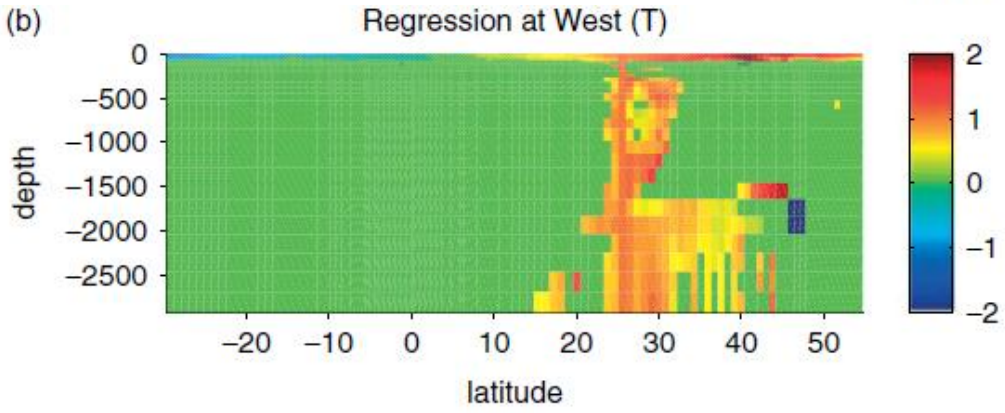
Using conventional covariances



Using boundary covariances





Stepanov and Haines, 2012, *QJRMetS*

Assimilating T&S profiles only can lead to imbalance and thus degrade the simulation

spread the data along the boundary to improve AMOC

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But…. Problems with assimilating RAPID into HadCM3

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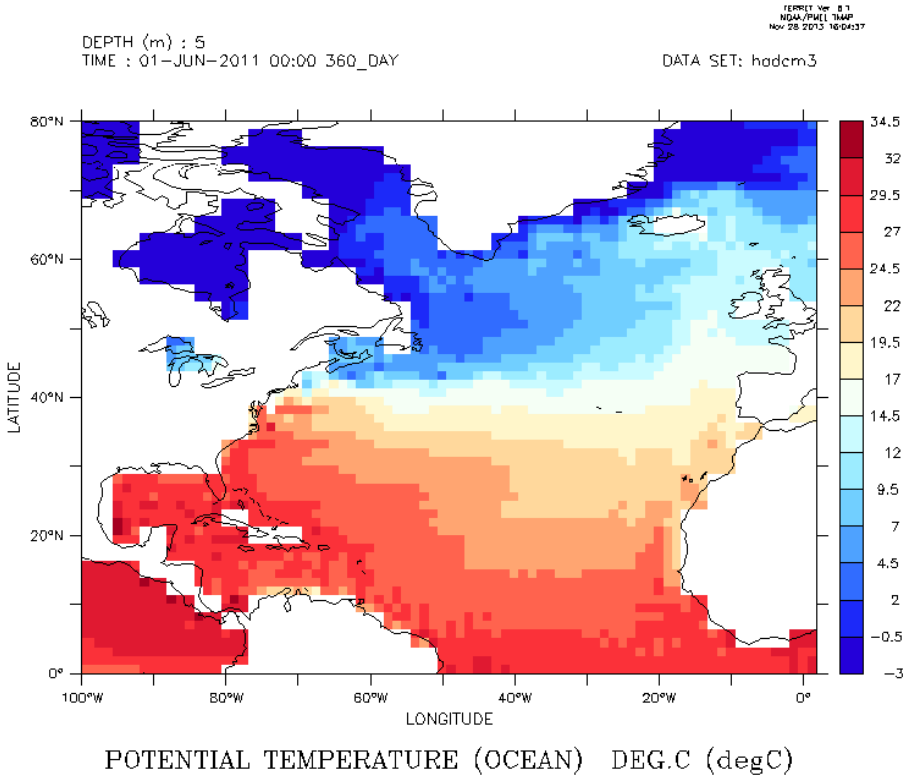
- A significant problem for assimilating into coupled climate models is their very low spatial resolution (HadCM3 1.25 Degree ocean)



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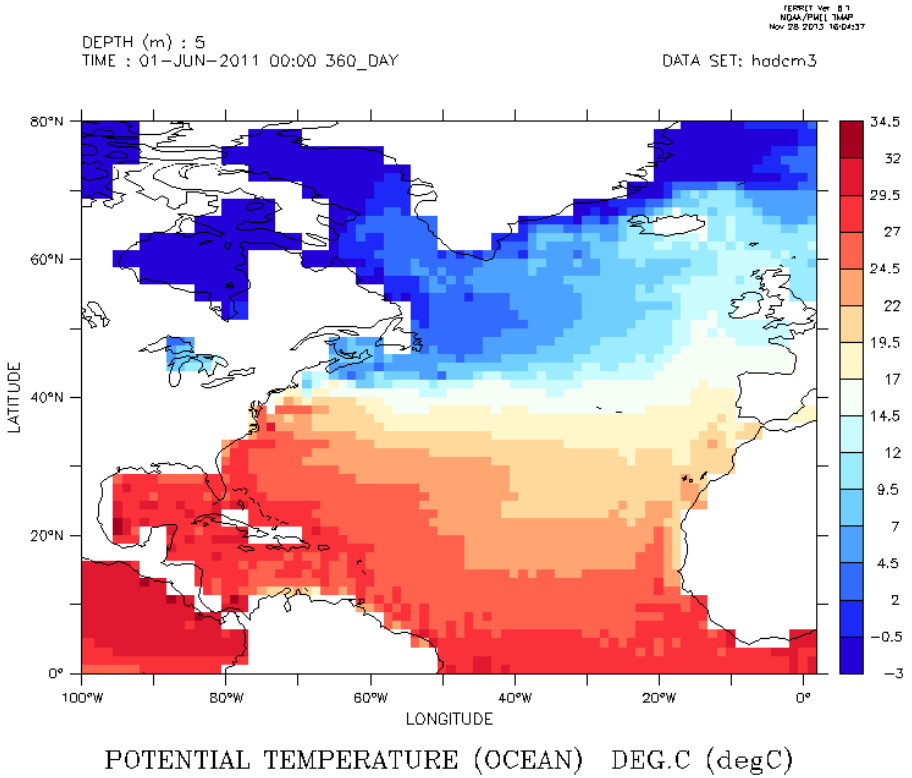

- Not only is there no Florida Straits, *there isn't even a Florida*!
  - The Physics of the problem is not the same between model and real-world

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So how did we decide to tackle the problem?

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- Novel aspects of the assimilation used in DePreSys is actually an opportunity to try something different
- We could assimilate the whole of the RAPID transport and not just temperature and Salinity profiles
- Focus on the covariance of transport with the models 3D Temperature and Salinity fields

- We will focus on MOC-Ekman

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T&S regressed onto MOC-Ekman at 26 N

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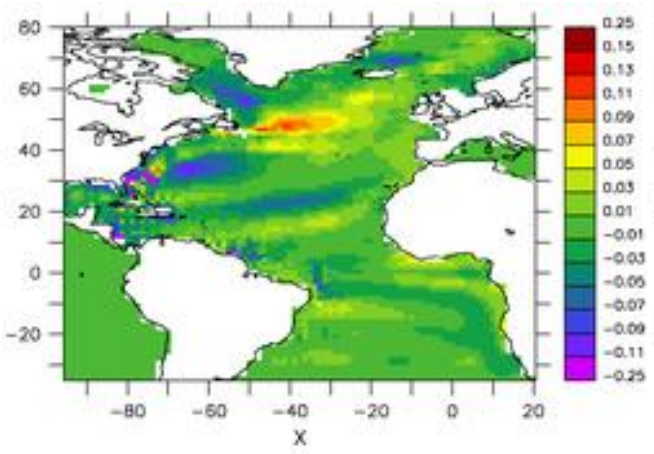
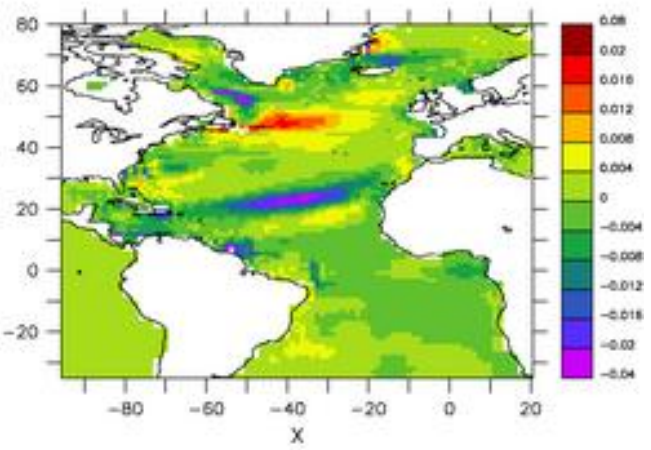
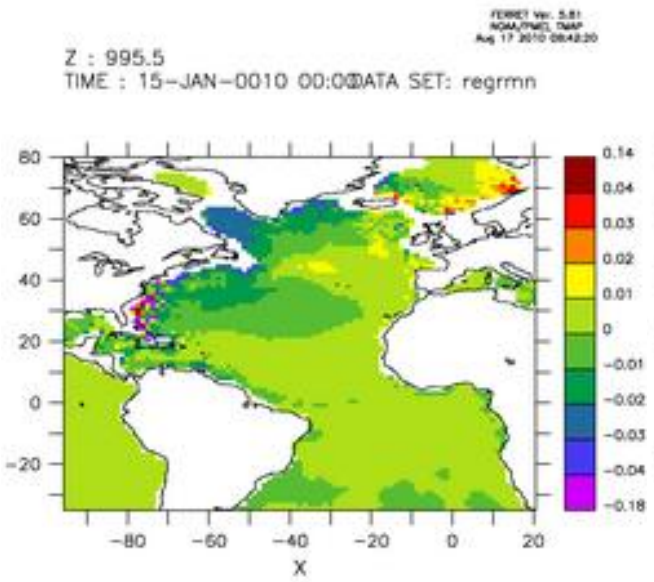
Calculated from the average regression coefficients of ten 48-year sections of control integration removing the seasonal cycle from monthly means



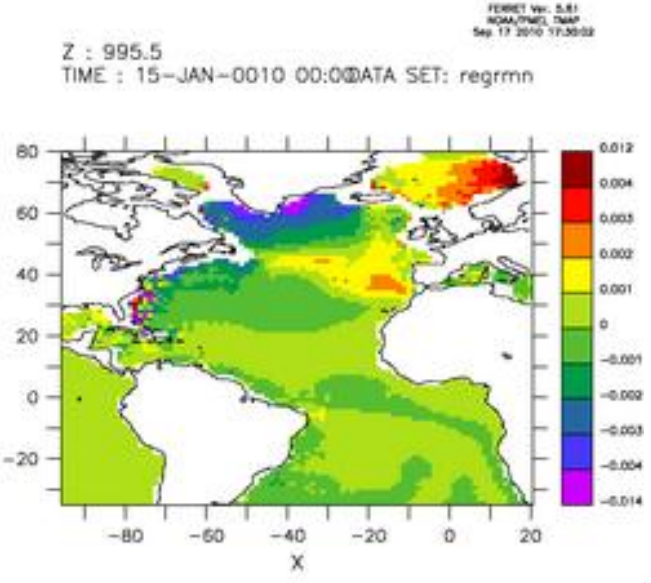
Regression coeff T 200m



Regression coeff S 200m



Regression coeff T 1000m



Regression coeff S 1000m

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Density@1100m related to MOC-Ekman

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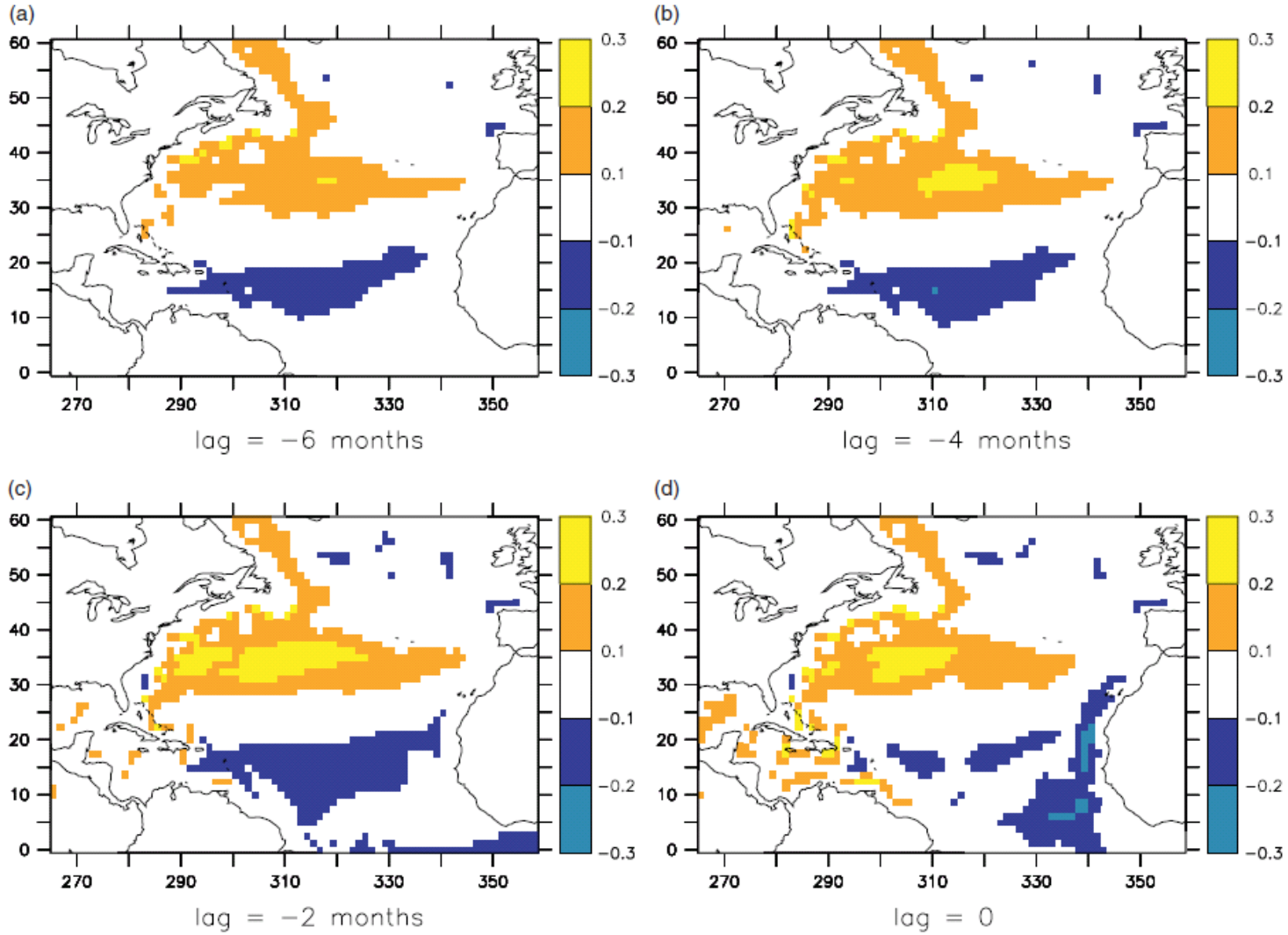

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Assimilating real observations…

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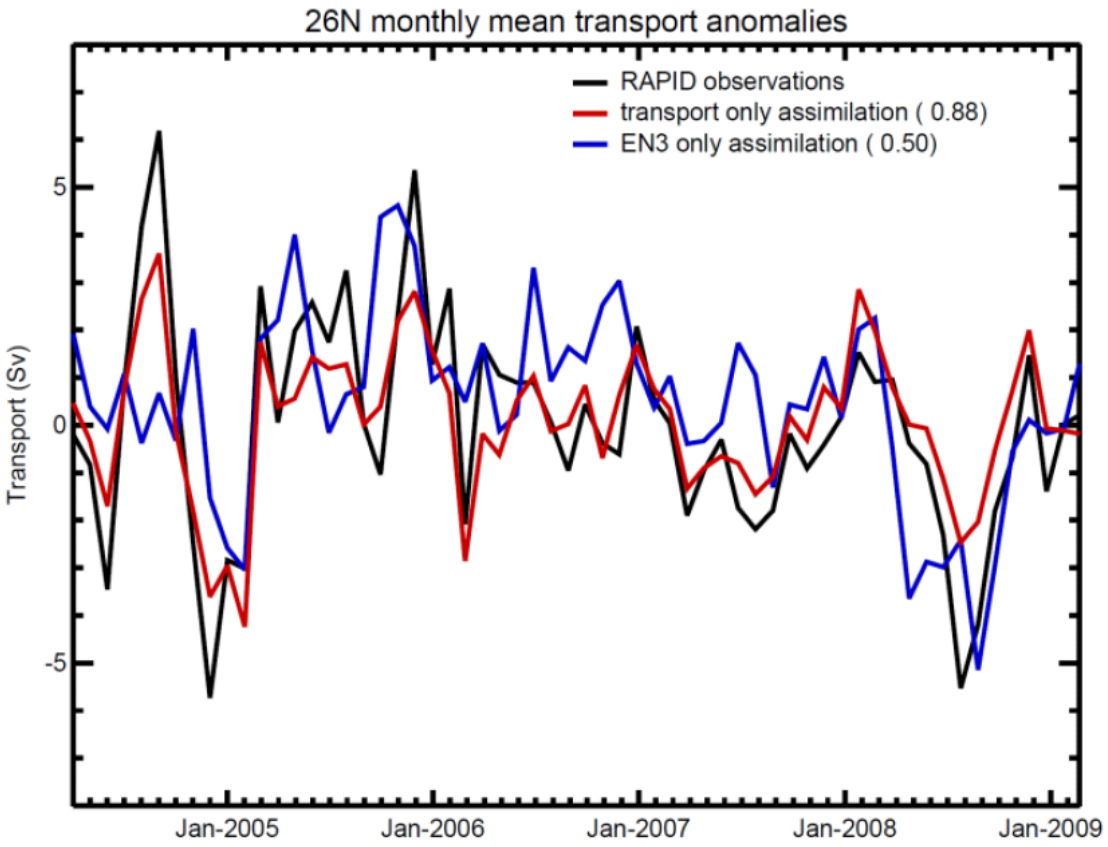

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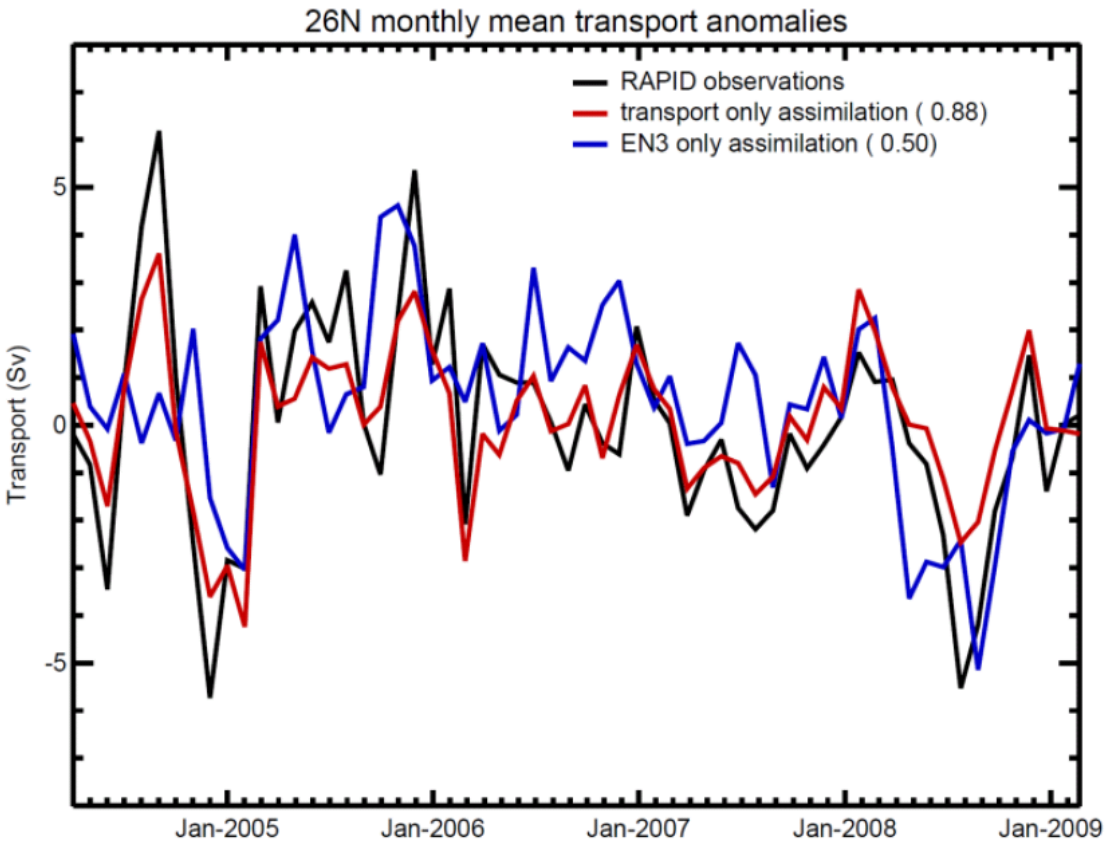

When we assimilated the EN3+transport the skill decreased to 0.38….

Why?

Psuedo-observation experiments

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- An idealised framework to test different analysis and assimilation approaches
- Twin experiment: HadCM3 -> HadCM3
- 10 irregularly spaced start dates within 1000 years of HadCM3 control
- “Observations” of transport, ocean temperature and salinity from one year are analysed & assimilated – We use 2008 EN3 observation mask for profiles of Temperature and Salinity

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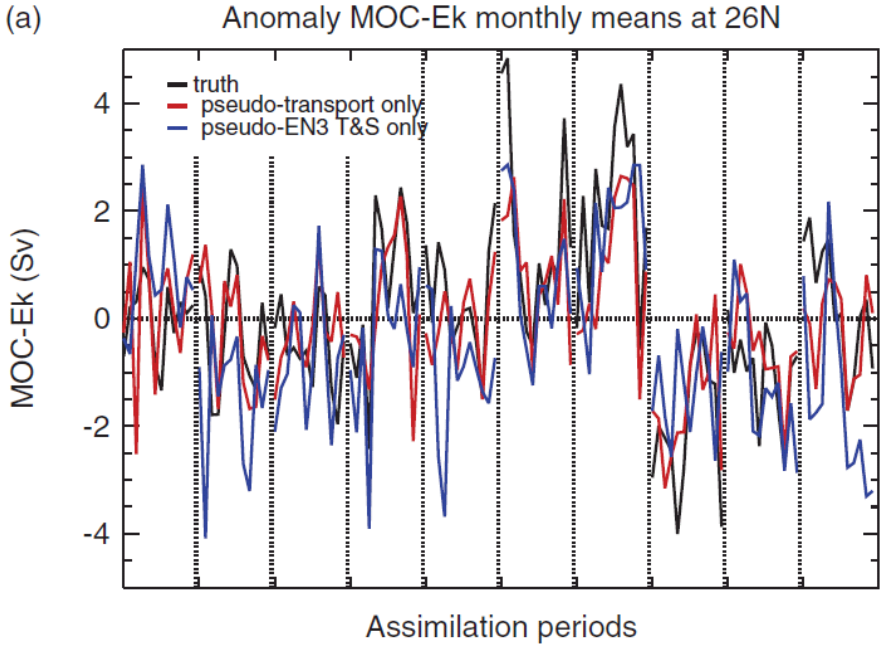
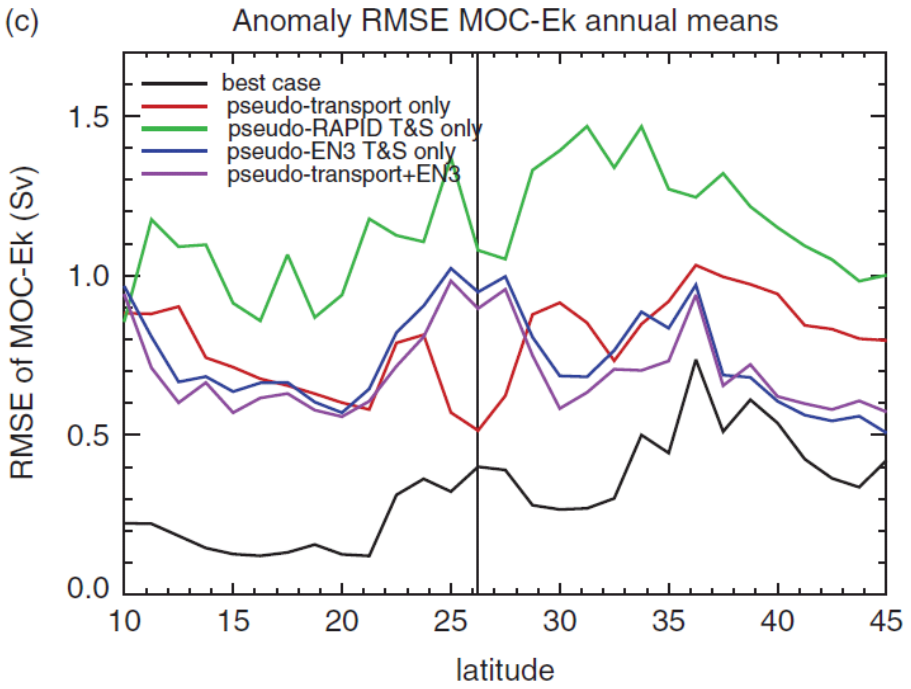

(a)
Anomaly MOC-Ek monthly means at 26N
truth
pseudo-transport only
pseudo-EN3 T&S only
MOC-Ek (Sv)
4
2
0
-2
-4
Assimilation periods


(c)
Anomaly RMSE MOC-Ek annual means
best case
pseudo-transport only
pseudo-RAPID T&S only
pseudo-EN3 T&S only
pseudo-transport+EN3
RMSE of MOC-Ek (Sv)
1.5
1.0
0.5
0.0
10
15
20
25
30
35
40
45
latitude

Validation of density gradient at 26N

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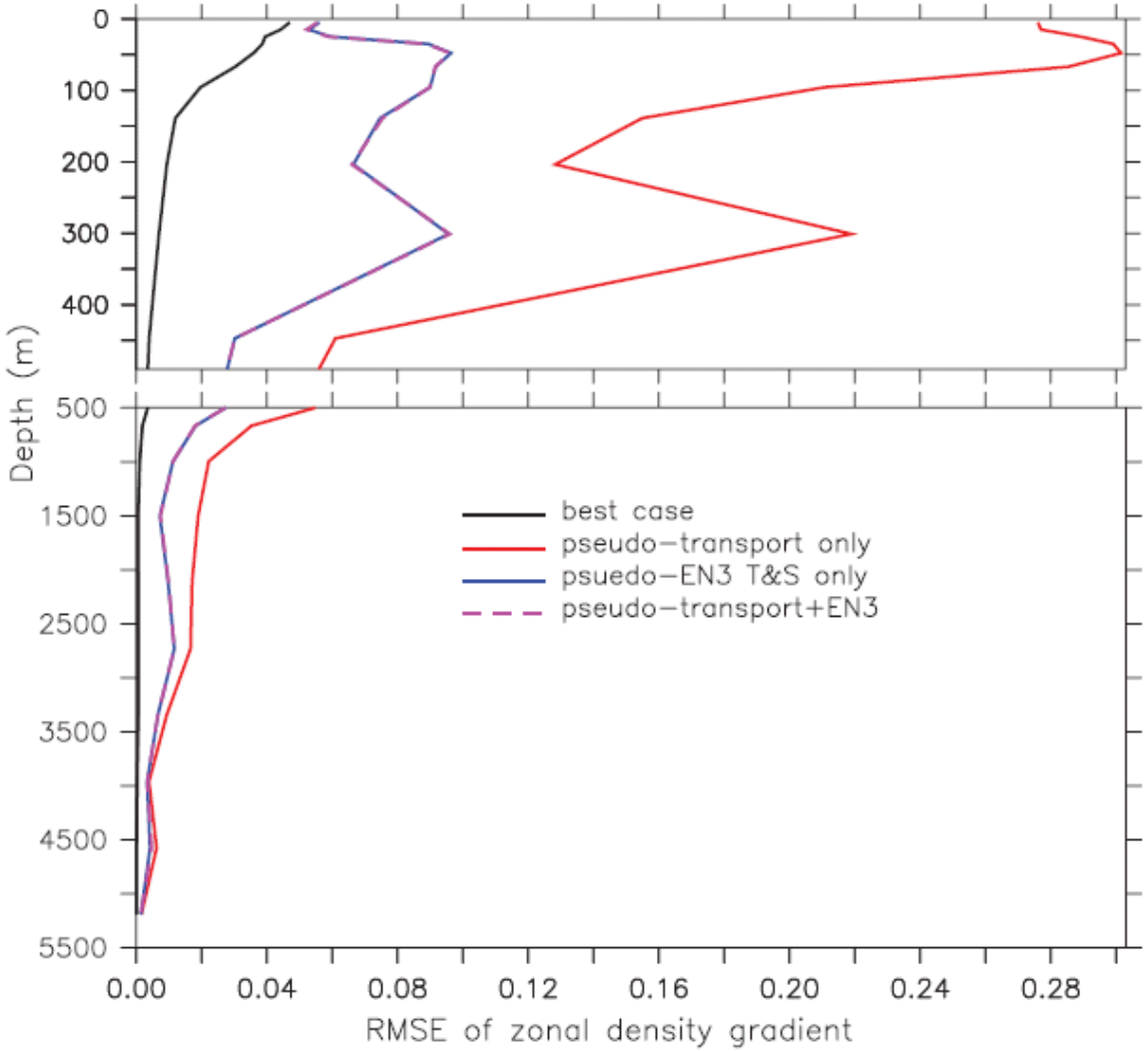

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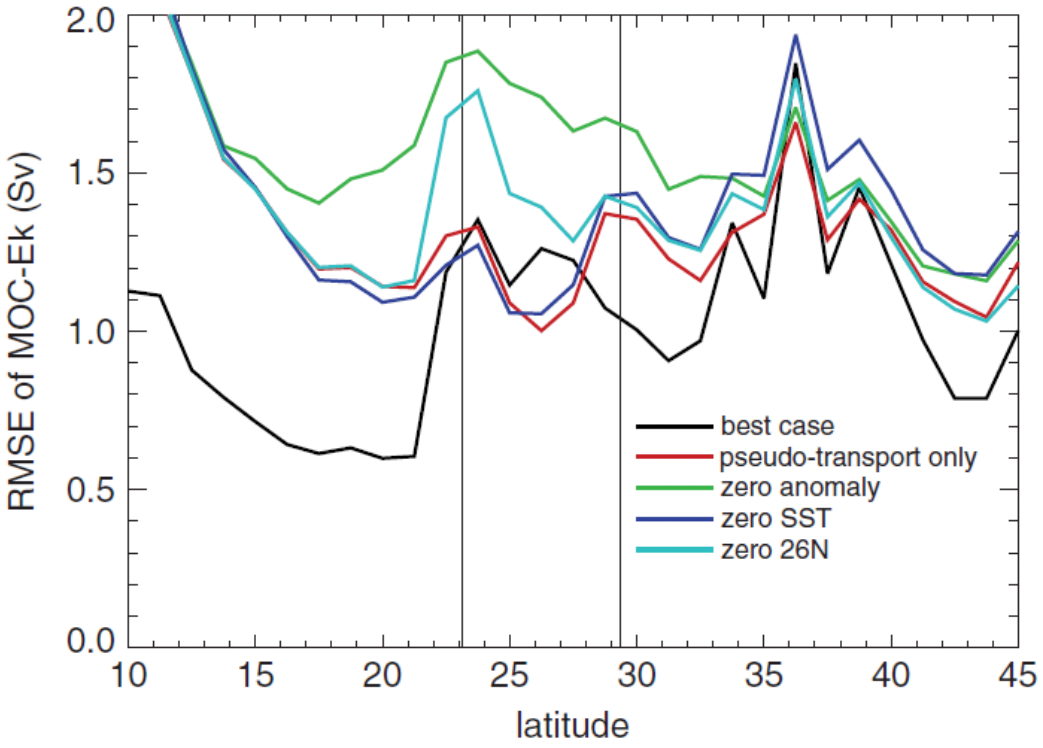
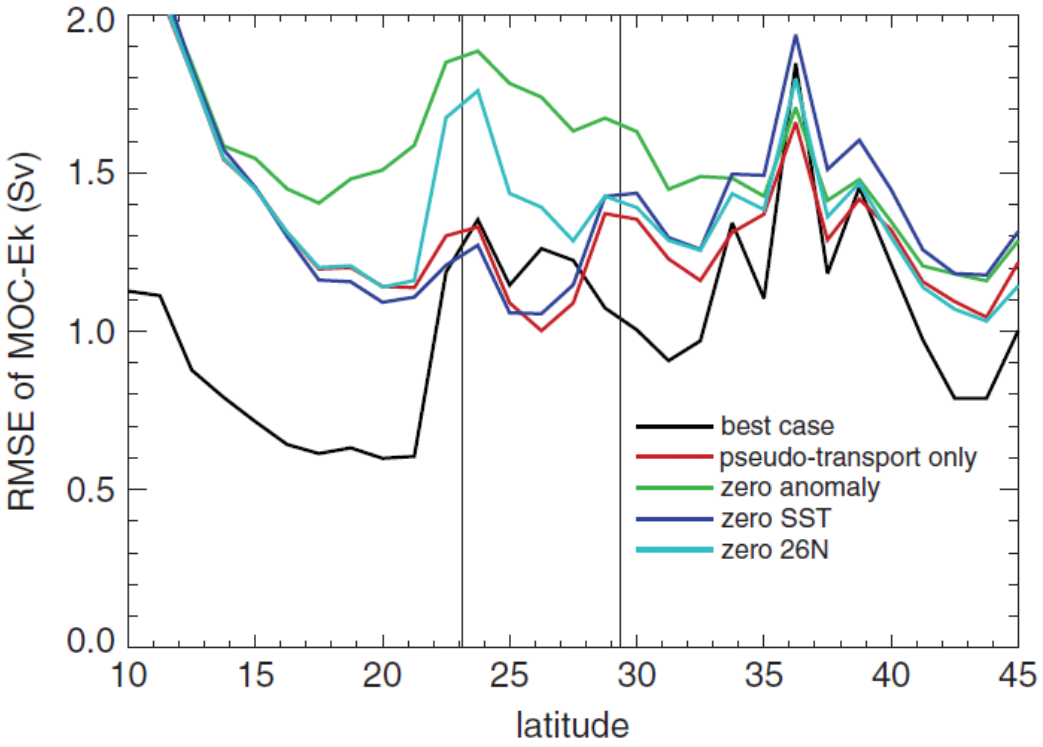
Where is the Skill coming from?



Why is there skill in transport only assimilation?

- Excitation of the MOC by the Atmosphere?
- Non-local density anomalies?

Where is the Skill coming from?



Why is there skill in transport only assimilation?

- ~~Excitation of the MOC by the Atmosphere?~~
- Non-local density anomalies?

High-frequency waves?

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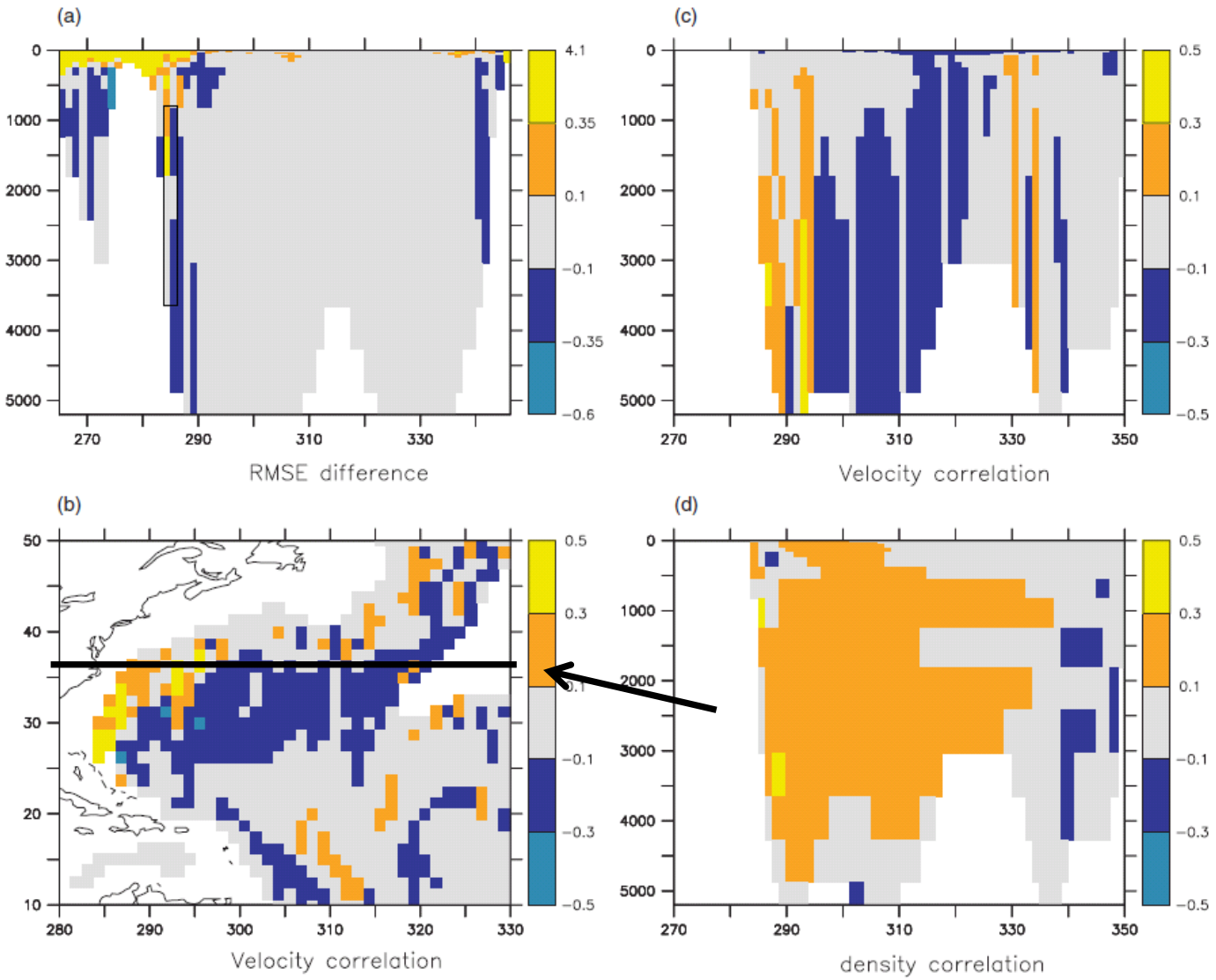

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Summary, and where are we?

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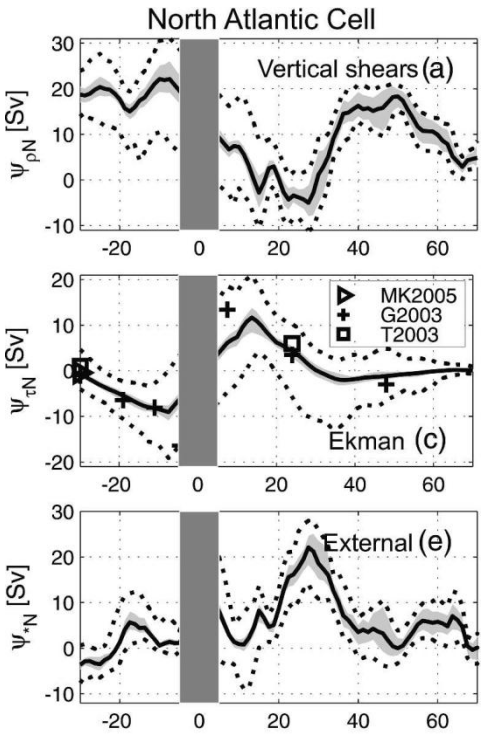
- Transport based co-variances can be used to assimilate the RAPID observations with significant apparent skill
- However, the method doesn't currently work well with other observations….
- Care is also needed to ensure that the method actually works on the mechanism that you intend it too!
- However, there is a lot of room for improvement…



Sime et al, 2006

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How could this be improved?

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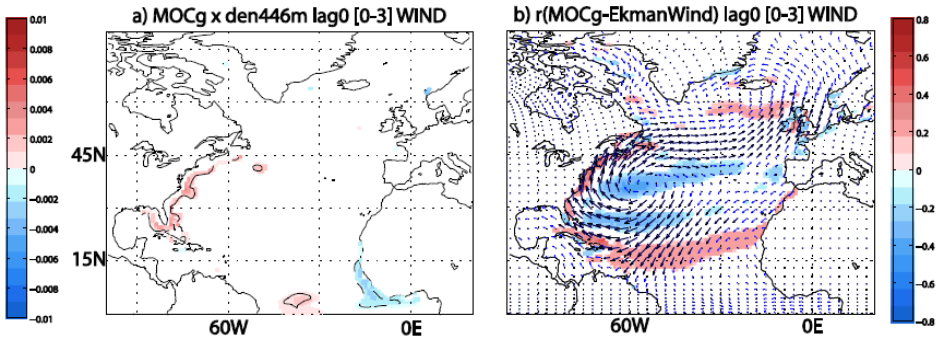
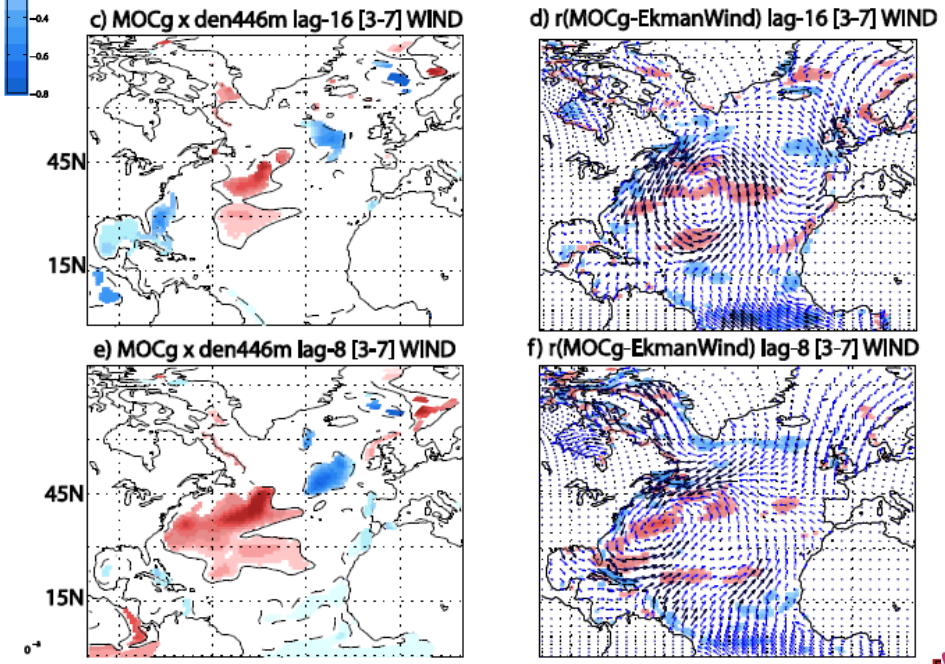
- Covariance's used only focused on the density anomalies that created an average MOC anomaly. But several mechanisms overlap – can we separate them?



- Could include longer lagged covariances
- It's also important to improve the models



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Future of decadal predictions

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- Decadal prediction is a rapidly growing field. Many systems use simple relaxations to produce initial conditions.
- The new Met Office decadal prediction system is moving to the new high-resolution HadGEM3 climate model (N216, ORCA025)
- The current system will still use the same analysis and relaxation method to initialise predictions.
- ***There is a lot of potential for improving the assimilation of data into coupled prediction models!***

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- Thanks!

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