Data assimilation & initialization in CM2.1

or

The atmospheric response to coherent upper ocean disturbances

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Aims: To characterize multi-week to multi-year predictability

Assumptions / approach:

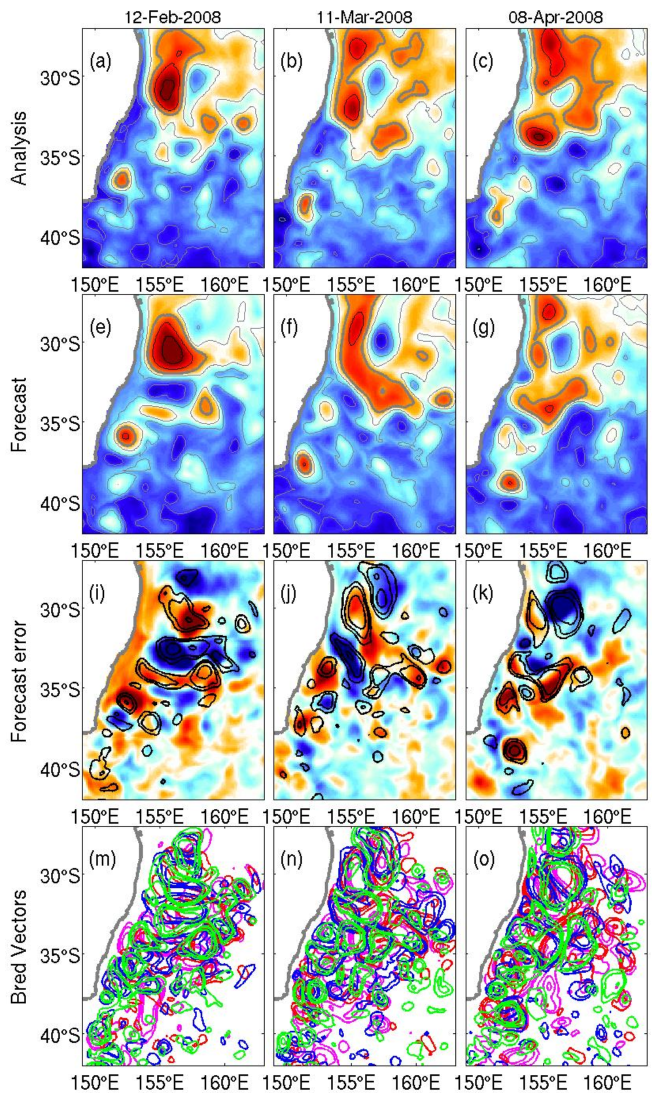
1. Memory on the appropriate timescales resides in the upper ocean.
2. Atmospheric memory resides on much shorter timescales therefore it is the coupled response that is of relevance.
3. Ocean data assimilation – long windows required to constrain the relevant modes and allow time for disturbances to grow i.e. coherent response in the atmosphere.
4. Random perturbations – grow too slowly (unorganized) and do not capture relevant disturbances - require a very large sample size to even resolve variances.
5. Computational expense of running large ensemble (EnKF) prohibitive – however relatively small ensemble sampling regions of instability on the relevant spatio-temporal scales i.e. Ensemble to sample low dimensional subspace of dynamically relevant growing modes.
6. Ensemble perturbations can be used to augment static background covariances with appropriate weighting.

Computational Framework: A relatively computationally cheap system that can be used to search for the relevant predictable modes/disturbances on any spatio-temporal scale of interest.

Ensemble initialization is an extension of approach due to:
Nadiga & O'Kane (2016) Nonlinear & Stochastic Climate Dynamics, Cambridge University Press
Sandery & O'Kane (2014) QJRMS
O'Kane, Oke & Sandery (2011) Ocean Modelling
O'Kane & Frederiksen (2008) J. Atmos. Sci.

DA builds on
O'Kane, Monselesan & Maes (2016) JGR-Oceans,
Sloyan & O'Kane (2015) JGR-Oceans,
Maes, Reul, Behringer & O'Kane (2015) Geoscience Letters,
Maes & O'Kane (2014) JGR-Oceans
O'Kane et al (2014) J. Comp. Phys.
O'Kane & Frederiksen (2008) entropy

1/10th degree ocean forecasting - 1 month rescaling – surface height



O'Kane, Oke & Sandery Ocean Modelling (2011)

Tropical cyclone prediction – Coupled initialization

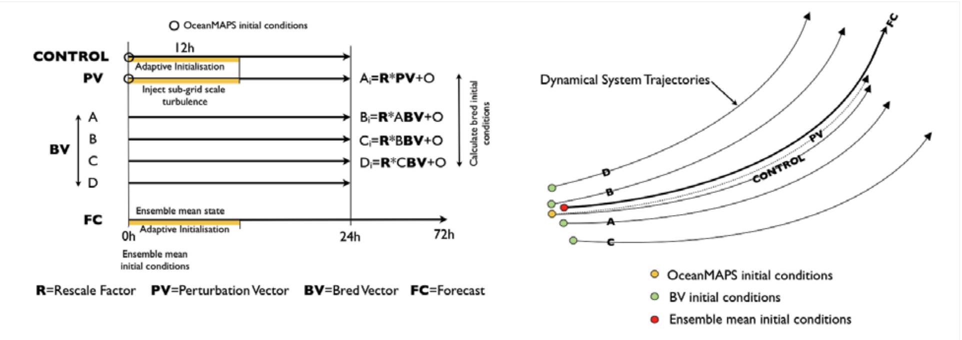


FIGURE 1 Diagram illustrating the cyclic bred vector ensemble method.

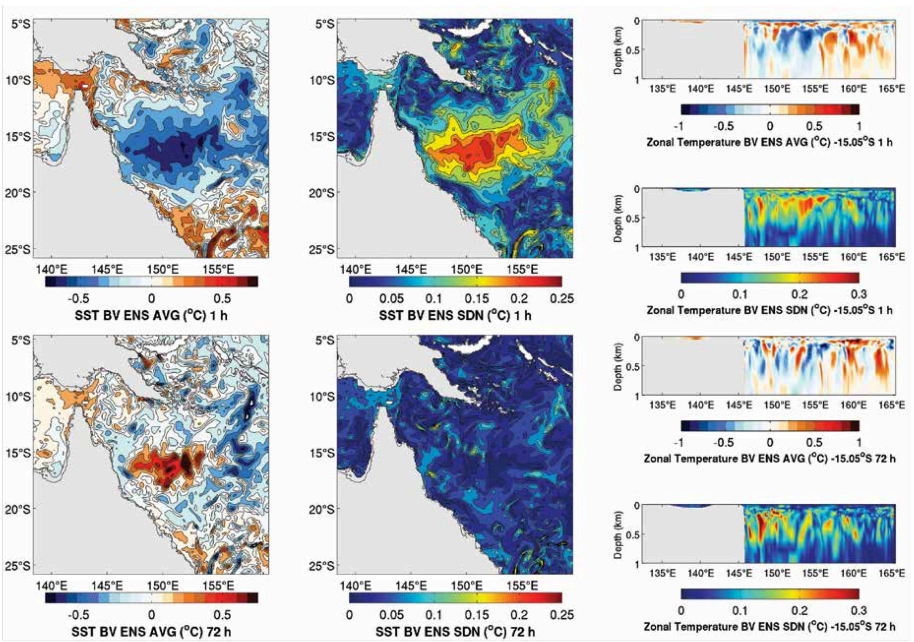


FIGURE 2 Ensemble average (AVG) and standard deviation (SDN) of SST bred vectors (BV) for initialized perturbations at the beginning of the forecast (1 h) and evolved perturbations at the end of the forecast (72 h). Corresponding temperature zonal sections though 15.05oS are also shown.

Sandery & O'Kane QJRMS (2014)

Configuration:

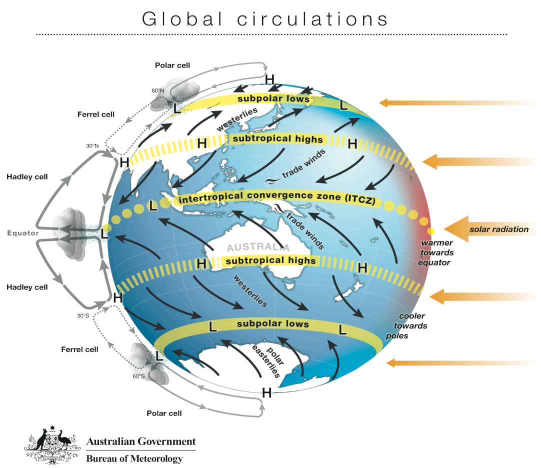
- Model used is CM2.1 on the ACCESS-O grid (ocean)
- Initial state after 700 year spinup
- EnOI using EnKF-c code (Sakov) – large ensemble 432 members.
- Static ensemble taken from both CORE2 forced 60 year ocean control simulation and from 20 year ocean only data assimilation – same ocean configuration as in coupled experiments.
- Centered 30 day observation window – superobs for satellite products. No overlap between windows. Choice of window arrived at through observation of the atmospheric response – e.g. stationary Rossby waves in troposphere or vacillation of Hadley Cell.
- Tuning of DA parameters e.g. r-factor (obs errors), etc completed.
- Observations restricted to between 65S & 65N – could be relaxed if ice observations assimilated.
- Restoring below 2000m with 1 year relaxation timescale
- SSS restoring with 90 day relaxation timescale – progress toward replacing this with SMOS/Aquarius data (Maes, Reul, Behringer & O'Kane, Geoscience Letters 2015)
- Ensemble perturbations – initial perturbation is random with amplitude 10% of background RMS. Full state vector (u,v,eta,T&S) and all levels in upper 2000m perturbed. Systematic renormalization every 30 days produces nonlinear finite time generalizations of the Lyapunov vectors – identifies nonlinearly evolving local disturbances on manifolds spanning a subspace of the pdf.
- Ice and atmosphere free to respond to ocean perturbations.

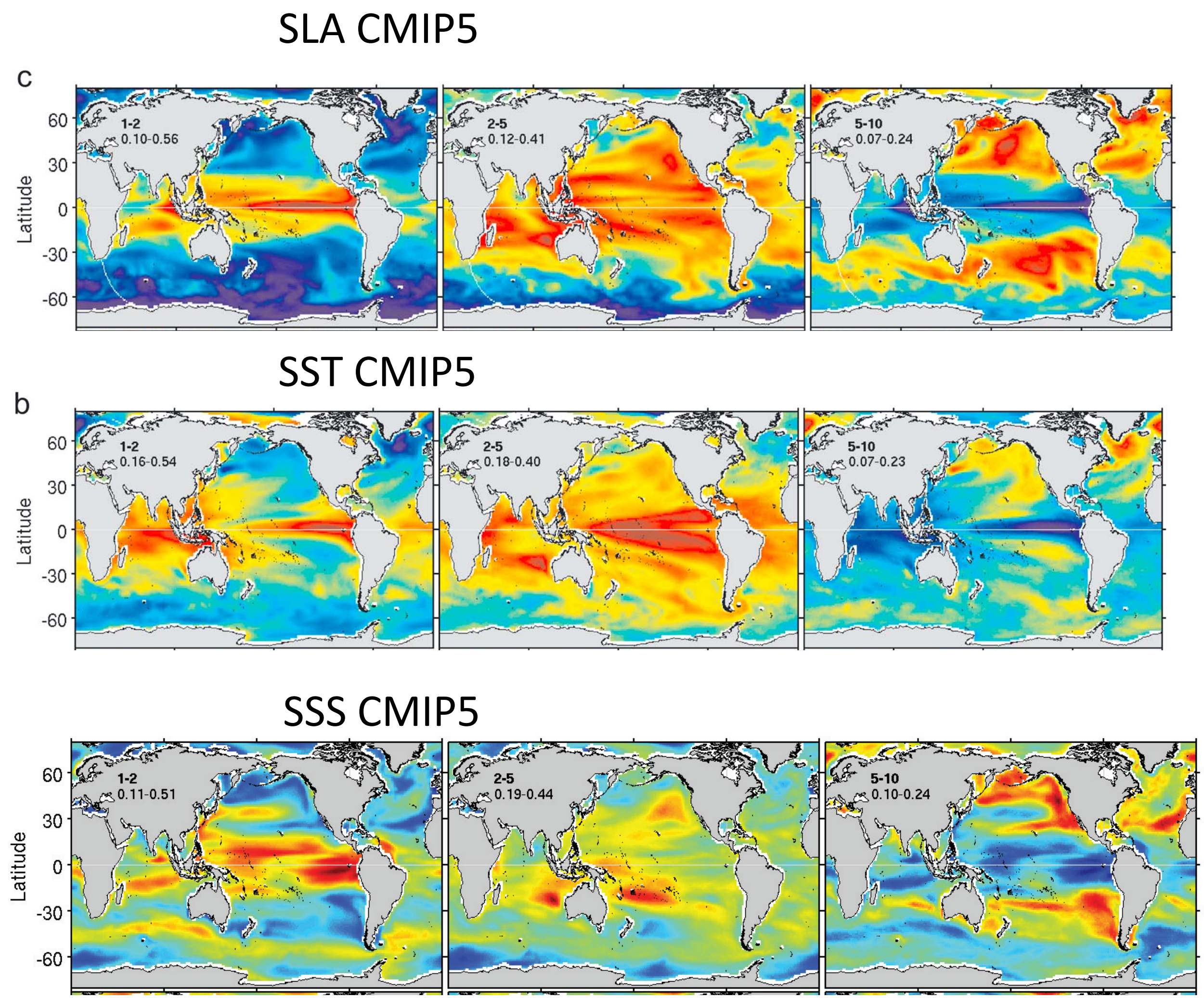
Progress to date:

- 10 year data assimilation experiment (2004-2014) with all available ocean observations (Argo, XBT, CTD, satellite SST, altimetry) apart from SMOS.
- Multiple 10 year ensemble runs (control + 4 members) with ocean perturbations restricted to various zonal bands consistent with large scale atmospheric cells i.e. Hadley Cell etc.
- No systematic bias in salinity but small bias in temperature observed after 1st year of assimilation.

Coupled model seems to be free of several difficulties experienced in ocean-ice only data assimilation.

Multi-week – 2 years: coherent atmospheric response to tropical disturbances

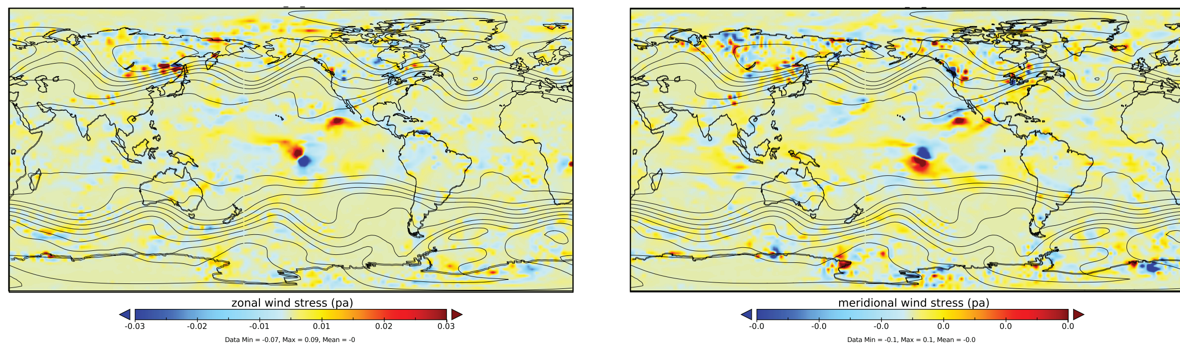




O'Kane, Monselesan & Maes (2016) JGR-Oceans
Monselesan, O'Kane, Risbey & Church (2015) GRL

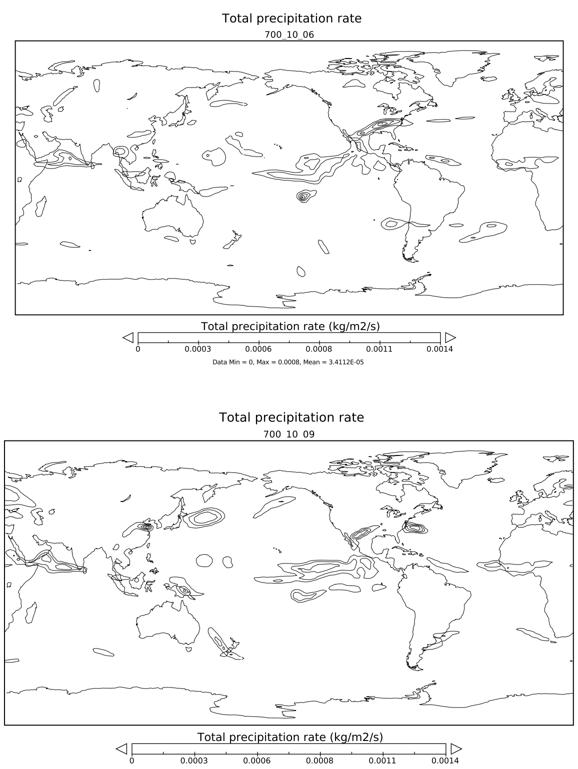
day 3 - wind stress anomalies at surface (shaded)
control Z_500mb (contours)

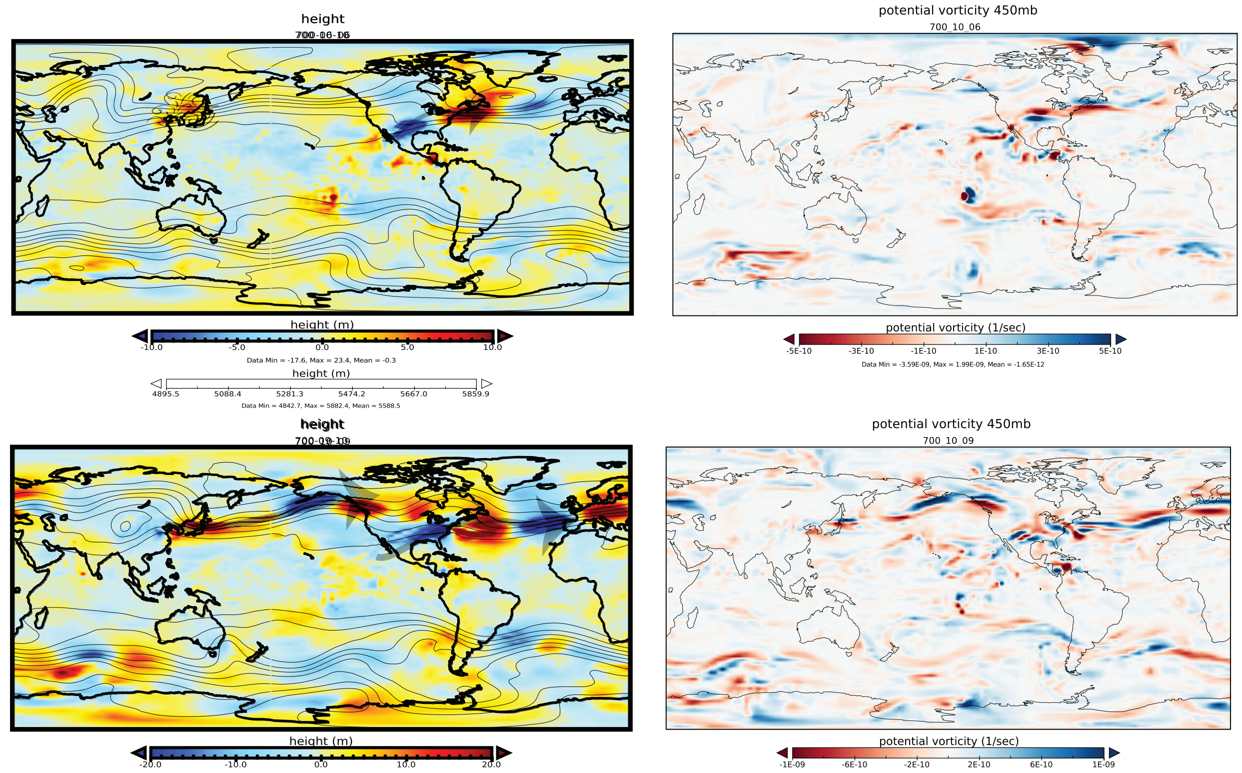
Case 1: Coherent atmospheric response to
upper ocean BVs out to 2 weeks
dependent on disturbances getting
into the midlatitude jets.



days 6 & 9 control precipitation

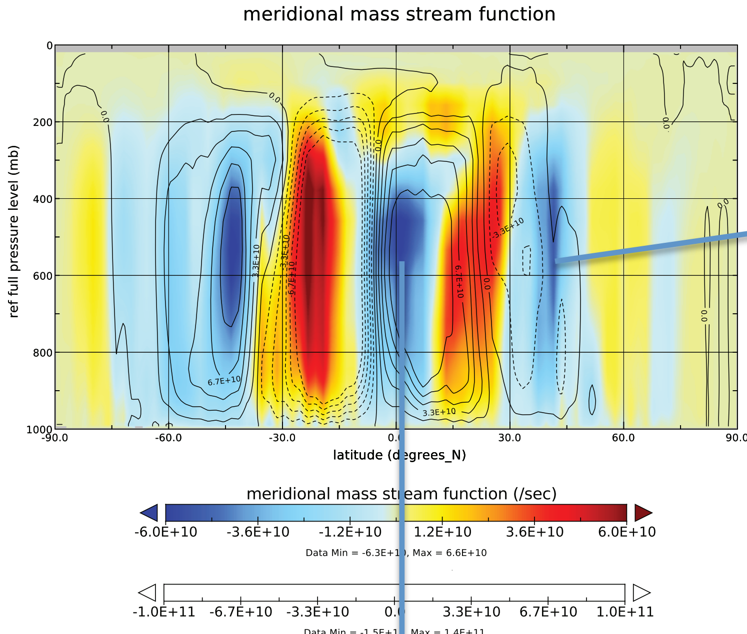
days 6 & 9 anomalous Z_500mb & PV at 450mb (shaded)
control Z_500mb (contours)



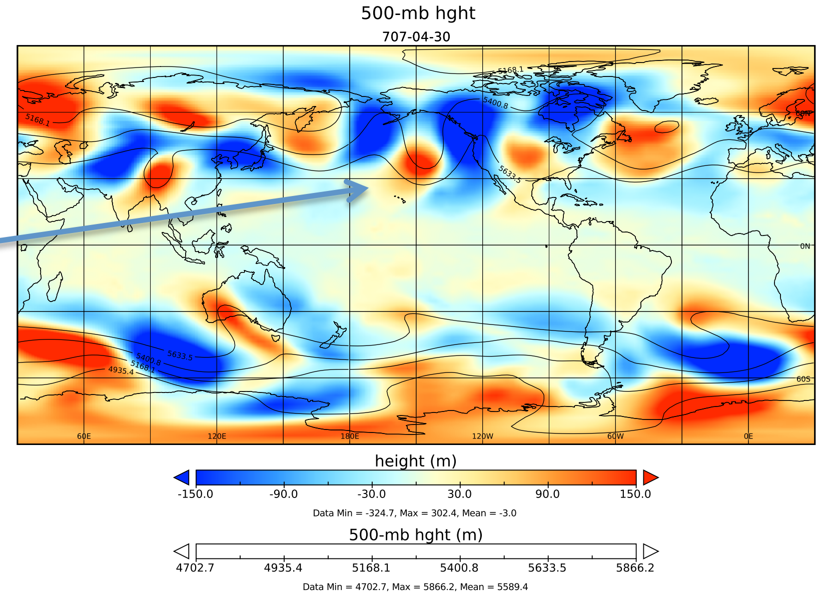


Case 2: At 1 month (30^{th} April year 7)

Ensemble mean of perturbation vectors (shaded)
Control (contours)

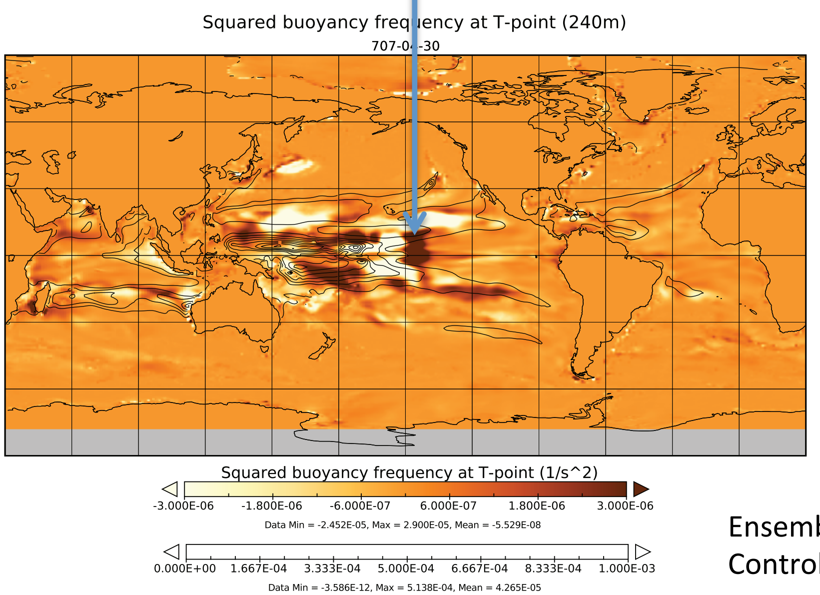


Ensemble mean of perturbation vectors (shaded)
Control (contours)



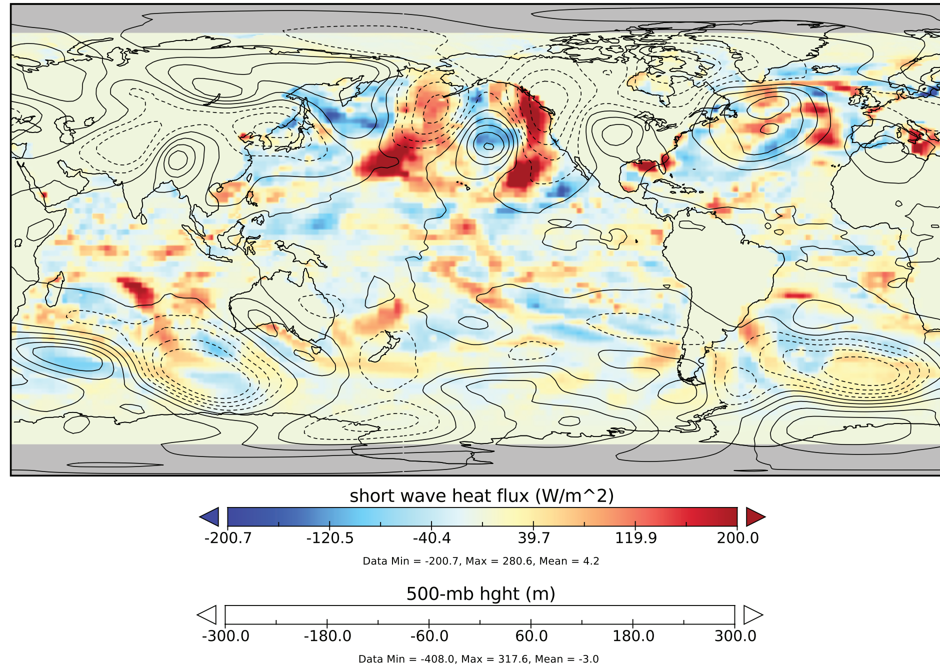
Note: we have projected onto the tropical ocean but there is a significant coherent response in the troposphere at the NH midlatitudes via modulation of the Hadley Cell.

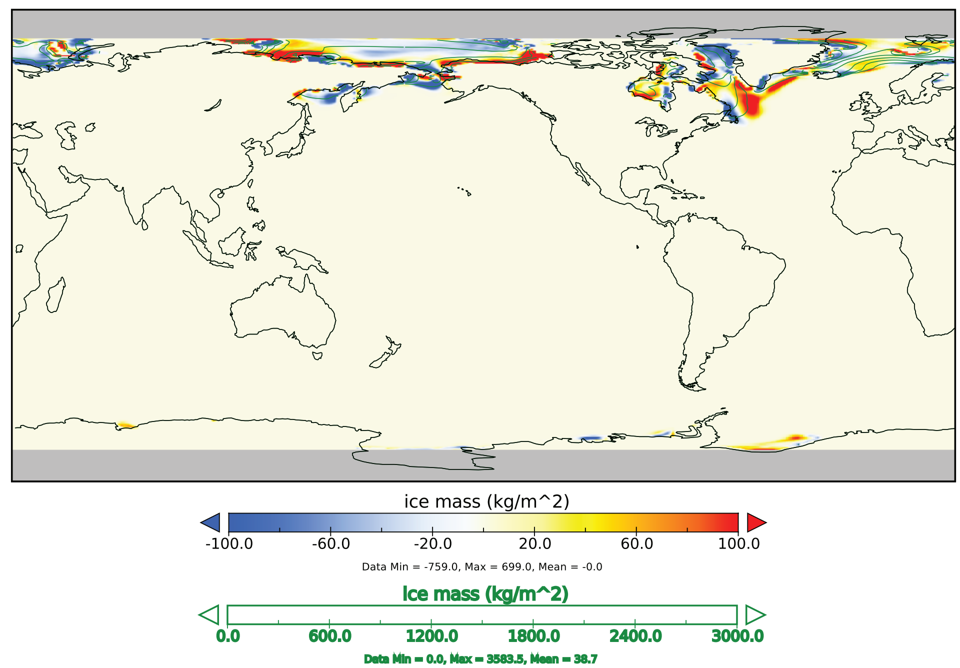
Potential for longer timescales via Rossby wave breaking on PNA etc.



Ensemble mean of perturbation vectors (shaded)
Control (contours)

Ice response





Thanks