Decadal Climate Forecasting Project

- Project leader: Richard Matear

3 Key activities:

1. Data Assimilation, Climate Modelling and Ensemble Prediction (Leader: Terry O'Kane)
2. Processes and Observations (Leader: Bernadette Sloyan)
3. Verification and Application (Leader: James Risbey)

CLIMATE ANALYSIS FORECAST ENSEMBLE system

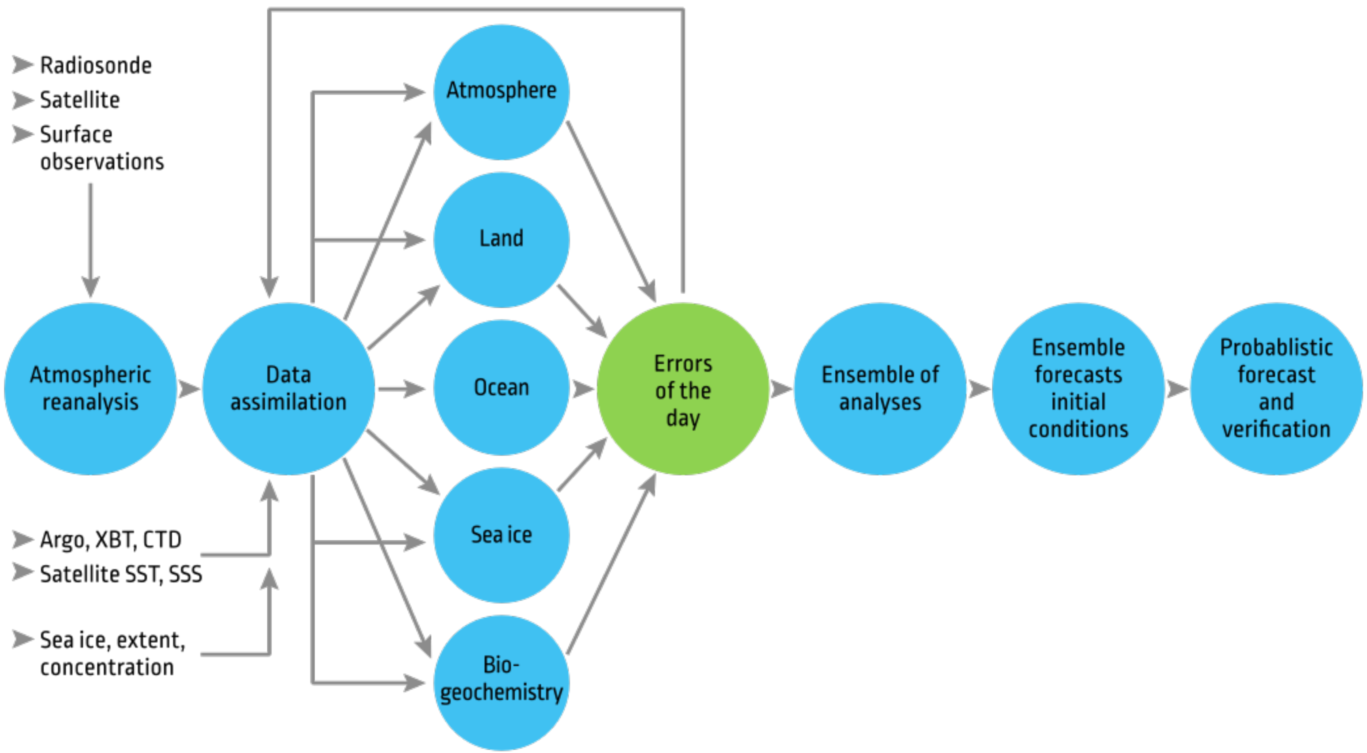
Climate Analysis Forecast Ensemble (CAFE) System

- ***The work presented here is due to the efforts of the data assimilation, climate modelling & ensemble prediction team***

Paul Sandery, Pavel Sakov, Matt Chamberlain, Didier Monselesan, Vassili Kitsios, Lauren Stevens, Mark Collier

CLIMATE ANALYSIS FORECAST ENSEMBLE system

CAFE System


Radiosonde
Satellite
Surface observations
Atmospheric reanalysis
Data assimilation
Argo, XBT, CTD
Satellite SST, SSS
Sea ice, extent, concentration
Atmosphere
Land
Ocean
Sea ice
Bio-geochemistry
Errors of the day
Ensemble of analyses
Ensemble forecasts initial conditions
Probablistic forecast and verification

The EnKF system runs a 96 member ensemble on a 30 day sequential cycle

- System carries out coupled data assimilation
- Members are initialised directly to their own analysis
- Reanalysis starts 1st January 2002
- Initial ensemble is derived from restarts taken from 1st of January from different years

Features

Asynchronous data assimilation

- The model is compared to the observations each day within the cycle and this information is used to calculate the analysis increments
- All metrics-statistics are forecast errors derived asynchronously in observation space - This provides a good indication of system performance

SST bias correction

- An ensemble of SST bias fields is added to the state vector
- A time-space varying SST bias is detected for each member based on differences between itself and the observations via fitting a linear stochastic model
- The bias is subtracted from the innovation vector for SST and the mixed layer before calculating increments
- The ensemble mean SST forecast and analysis bias fields are calculated each analysis cycle

Dynamic ice mask for the DA

- A composite ensemble ice mask is generated using ice concentration
- This composite is based on all members and all days within the cycle
- Its purpose is to limit the assimilation of observations to ice-free areas only

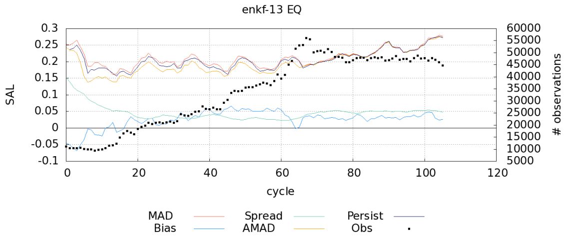
Observations

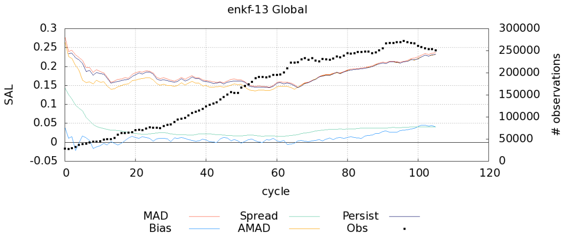
The following ocean and surface observations are used for assimilation and verification

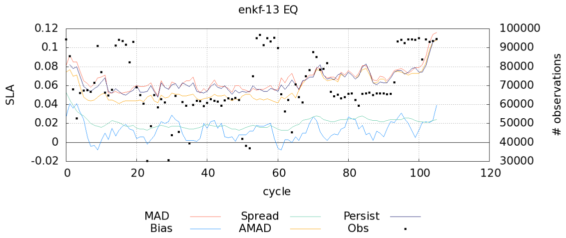
- RADS altimetry
- SST - NavOceano, AMSRE, AMSR2, PATHFINDER + VIIRS and Himaware-8 from 2016
- SSS - AQUARIUS, SMOS
- In-situ T/S - ARGO, CTD, PIRATA, TAO from CARS31 (CSIRO) and MMT (BoM NRT)

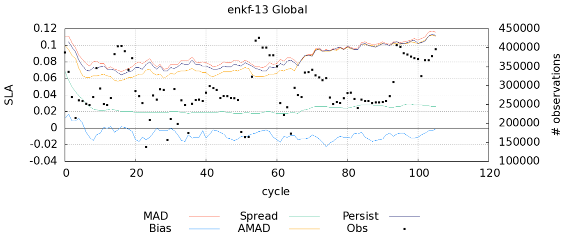
Atmospheric reanalyses from NCEP v1 and JRA-55 are employed either as fields to relax the atmospheric state vector (zonal and meridional winds, temperature, specific humidity and surface pressure) or are directly assimilated.

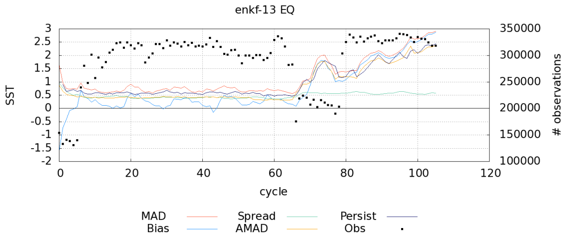
Direct verification of (ocean) assimilation and forecast against observations

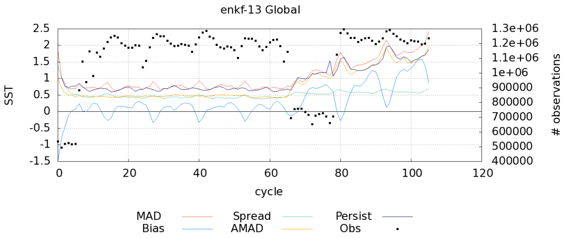


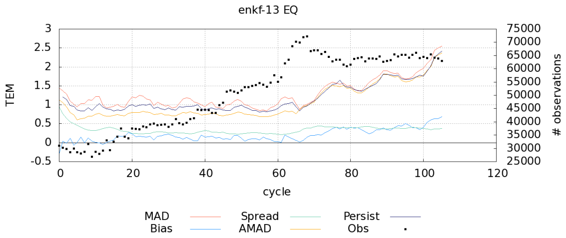


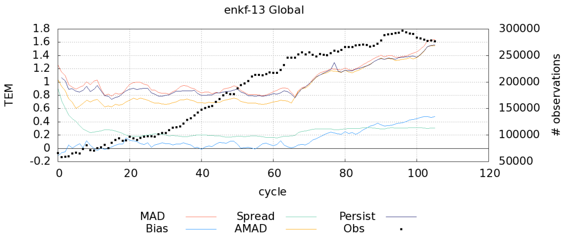




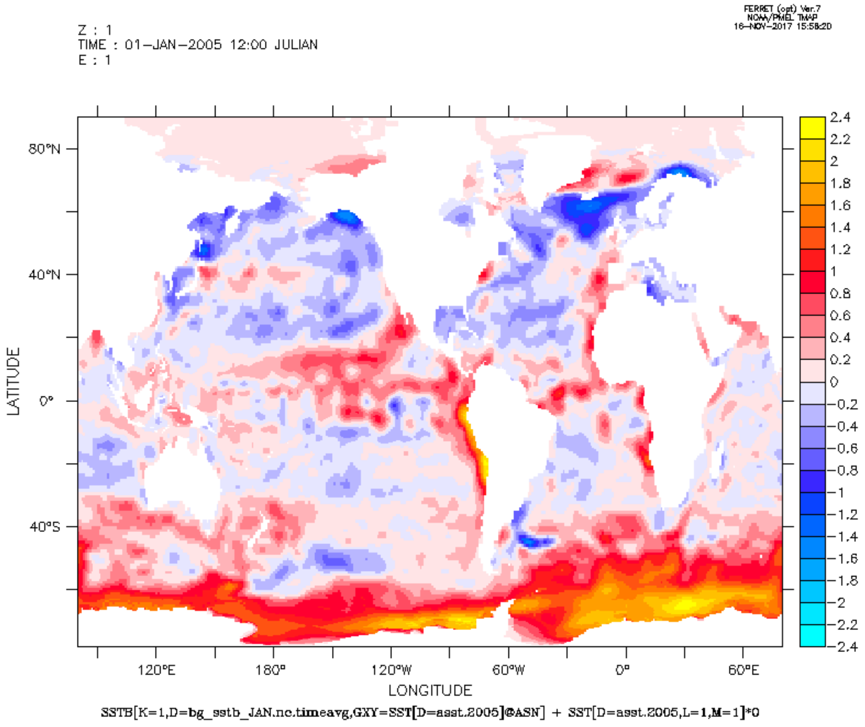


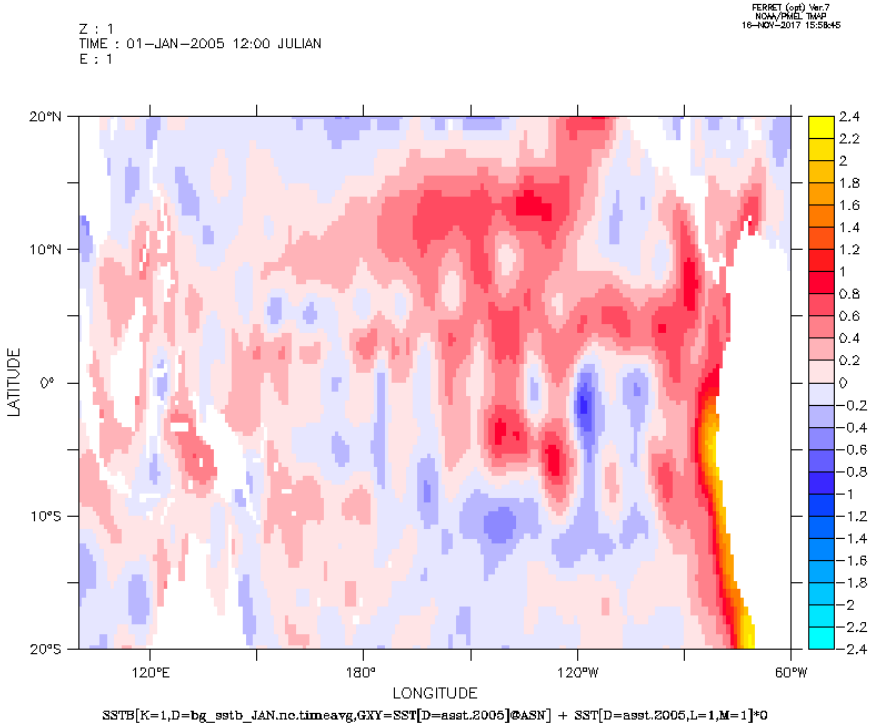




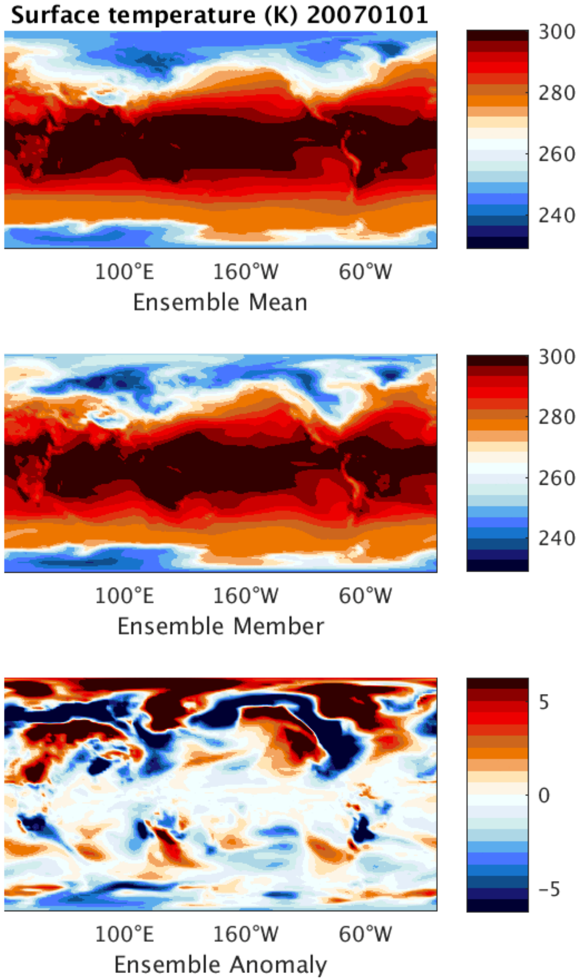


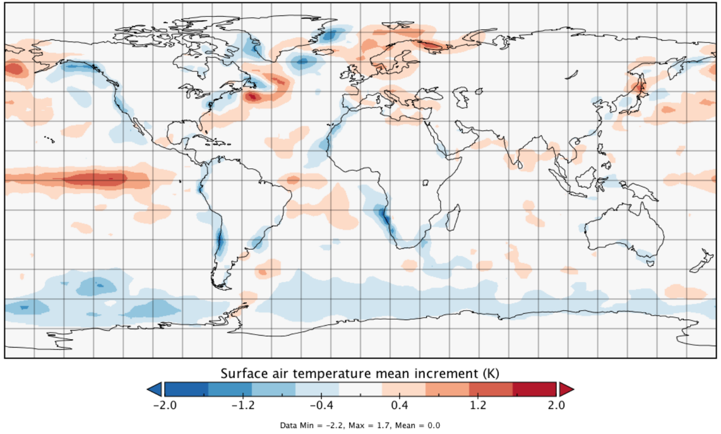
Spatial pattern of analysis SST biases w.r.t. HadISST (January 1st 2005)

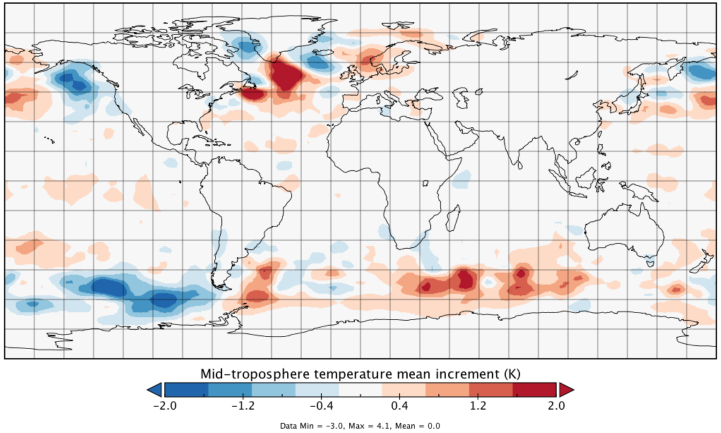




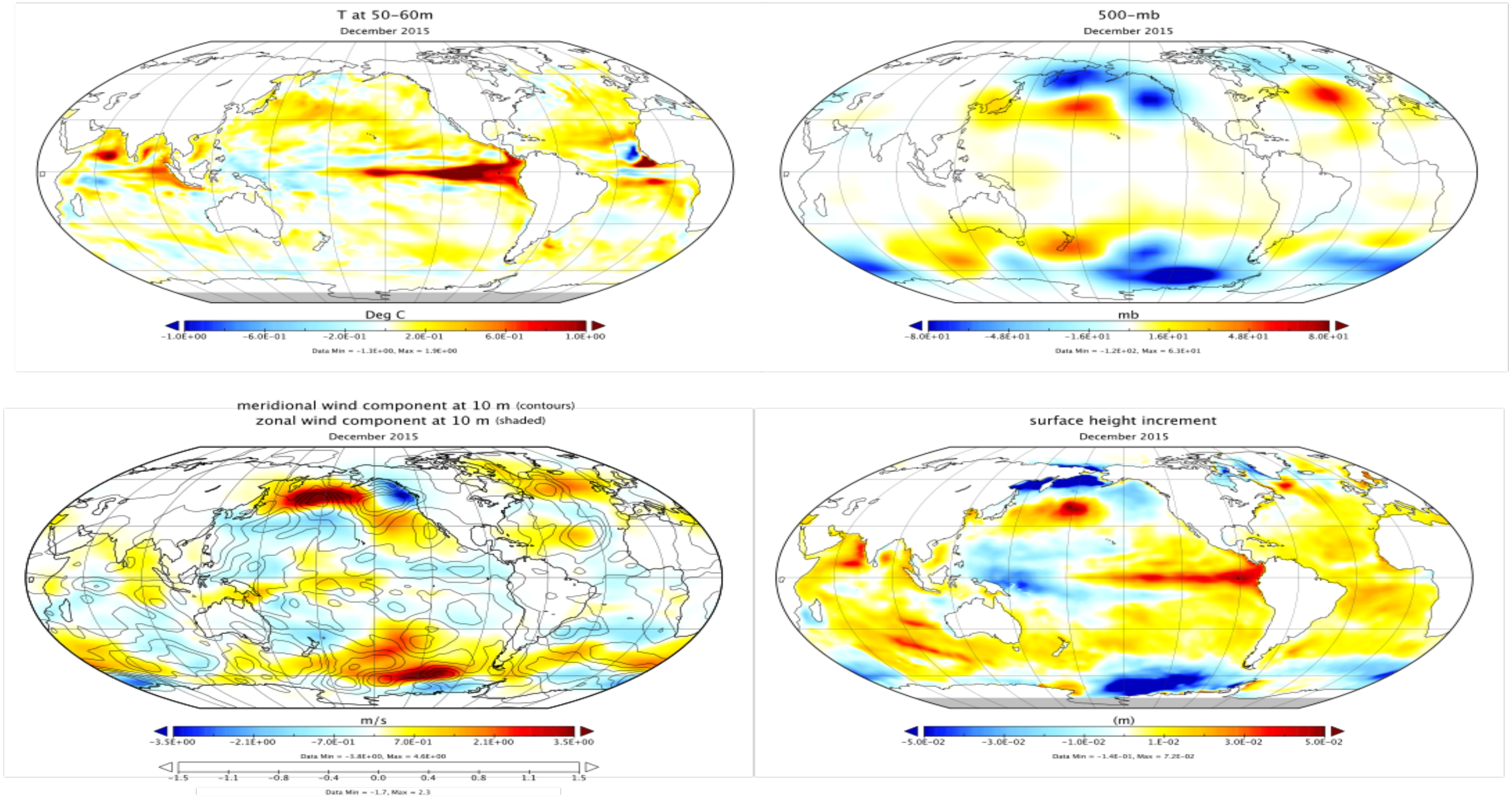
Coupled ocean-atmosphere assimilation:
Identifies where ocean observations covary and project onto atmospheric variables (and vice versa)



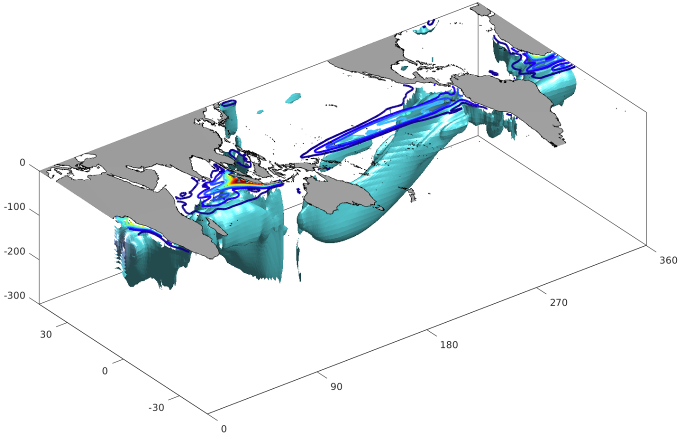




Adjusting DA increments derived from ocean and coupled covariances Dec 2015 (localization radius: 4000km atmosphere, 750km ocean)

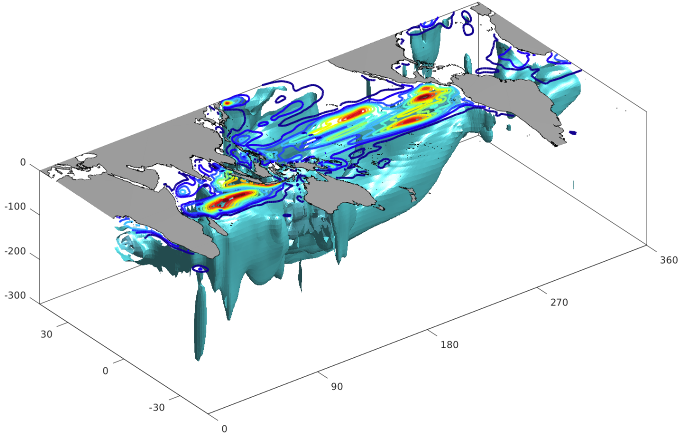


Band: 1-2 months



mat/gfdl_control_temp_ocean_month_000101-050012.anom.periodgram.welch.mat

Band: 6-8 months



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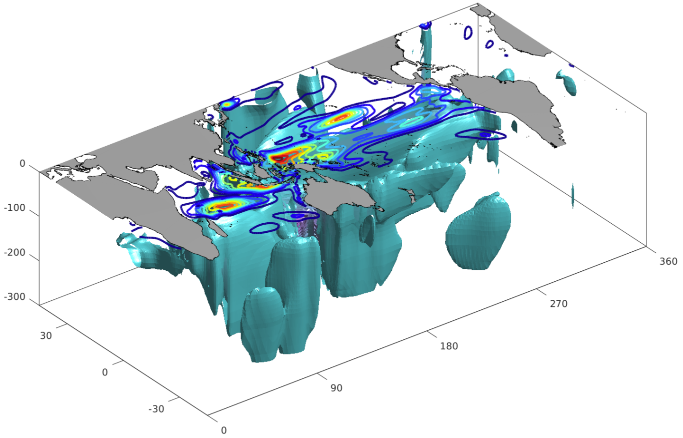
Band: 24-48 months



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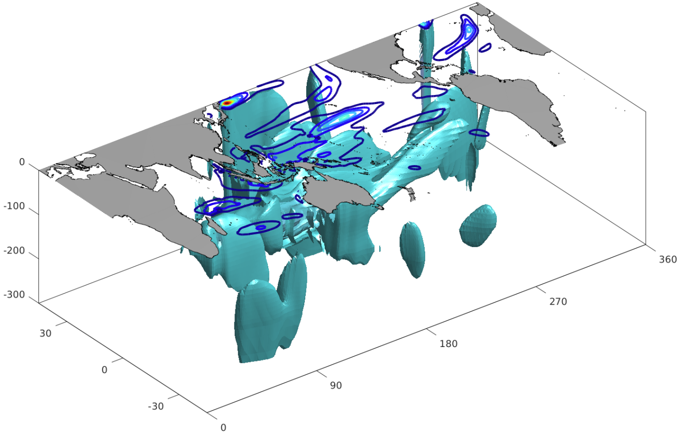
Band: 48-96 months



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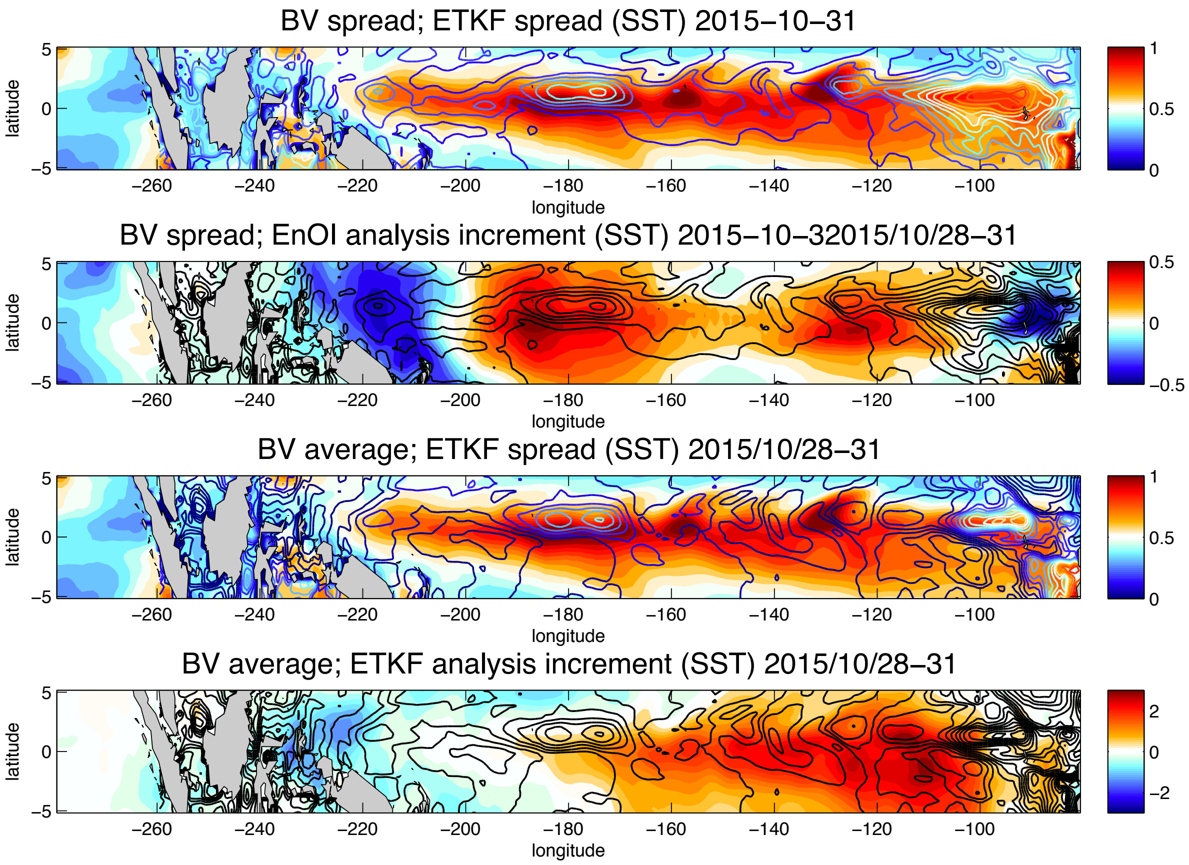
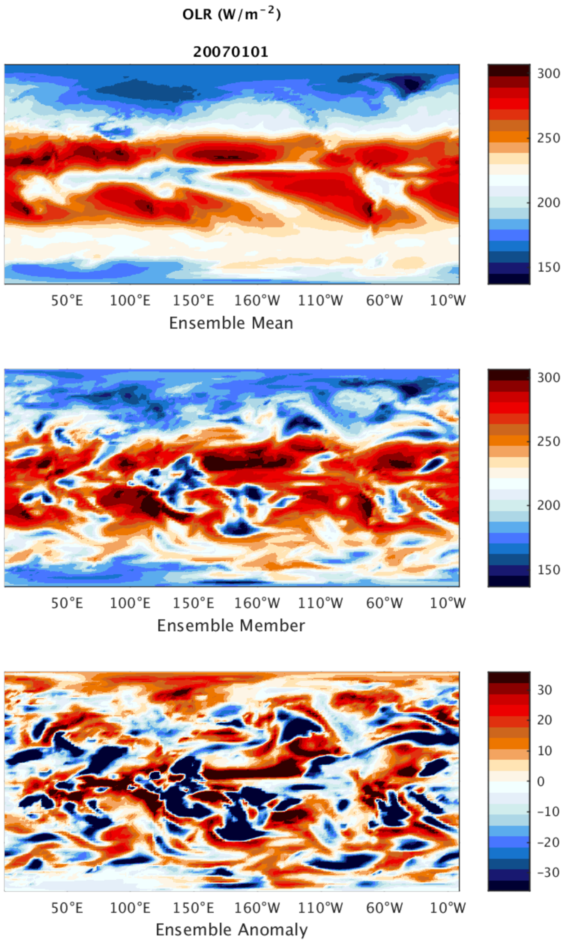
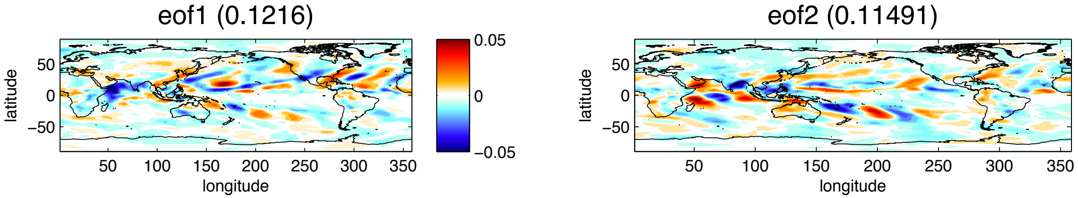
Ensemble spread - forecast error: EnOI + BVs (10) versus ETKF (96)



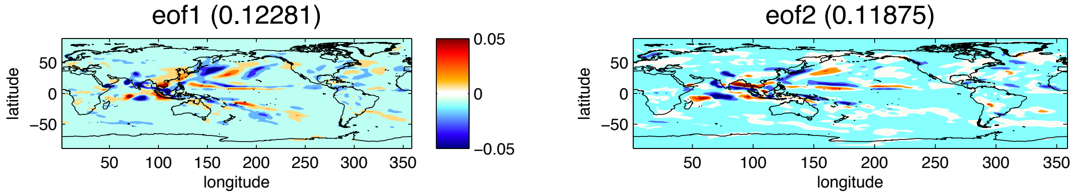
Assimilation OLR



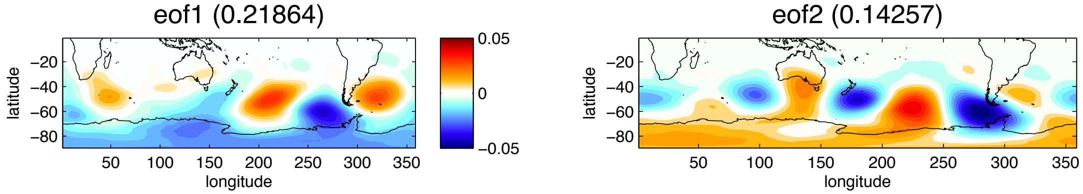
BV OLR October



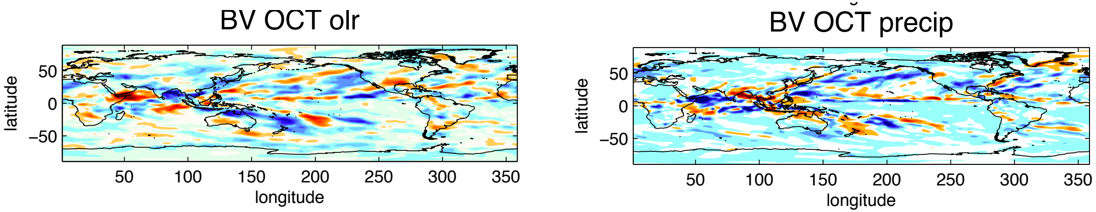
BV Precipitation October



BV 500mb October

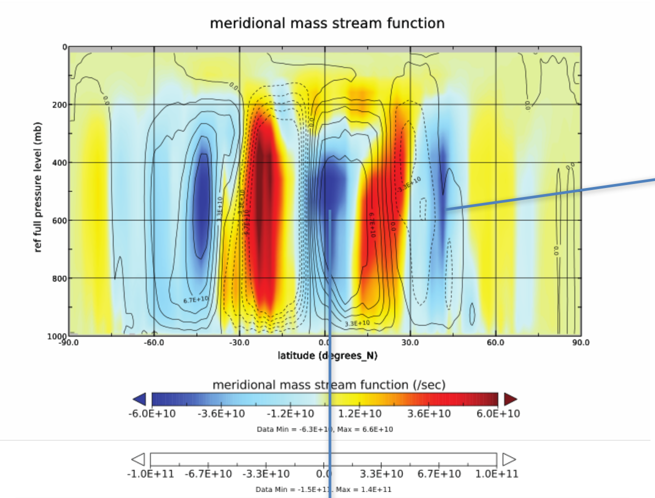


Time mean

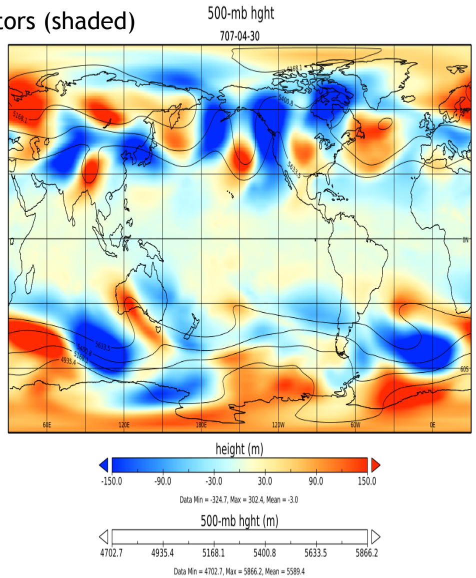


Case 2: At 1 month (30th April year 7)

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

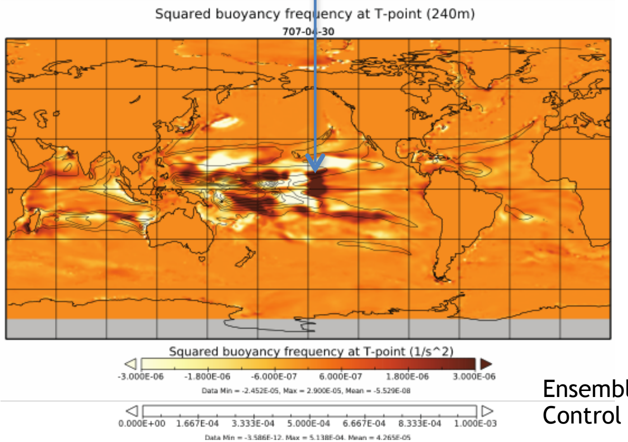


Ensemble mean of perturbation vectors (shaded)
Control (contours)



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.

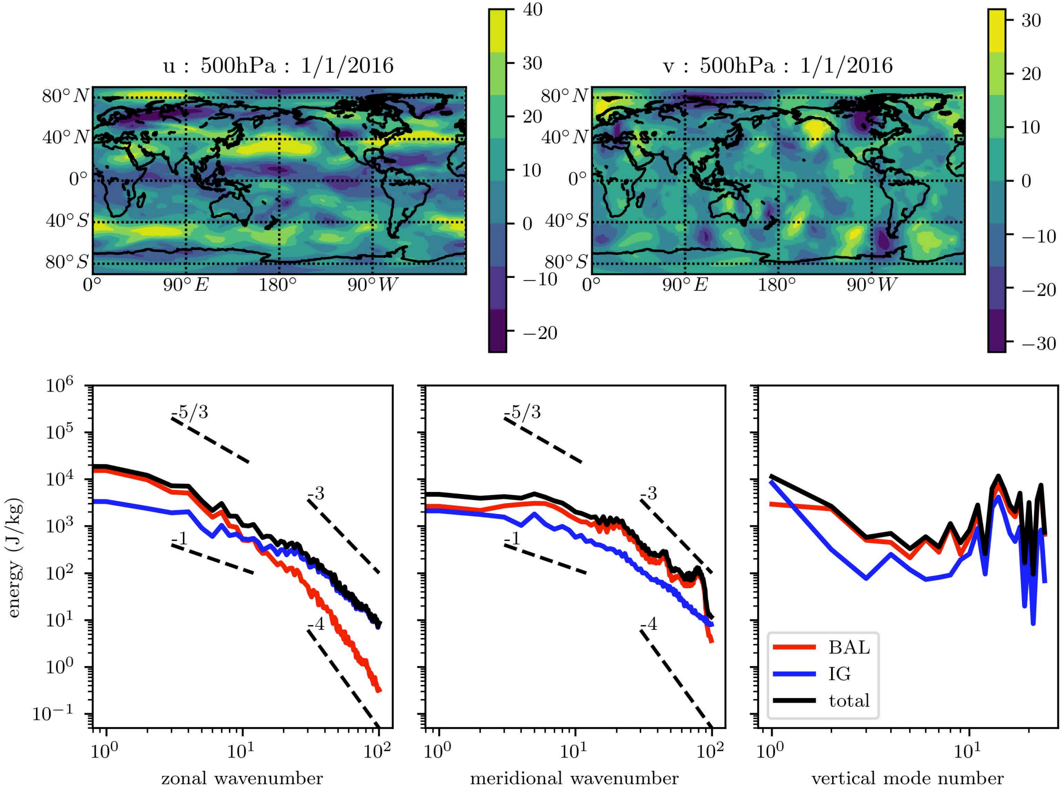
Potential for longer timescales via Rossby wave breaking on PNA etc.



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

Balance

- ***Covariance localisation and the addition of increments due to coupled covariances can lead to imbalance in the analysed atmospheric state. We apply NMI to reduce initialisation shock and as a diagnostic tool. Here NMI is applied to the JRA reanalysis.***

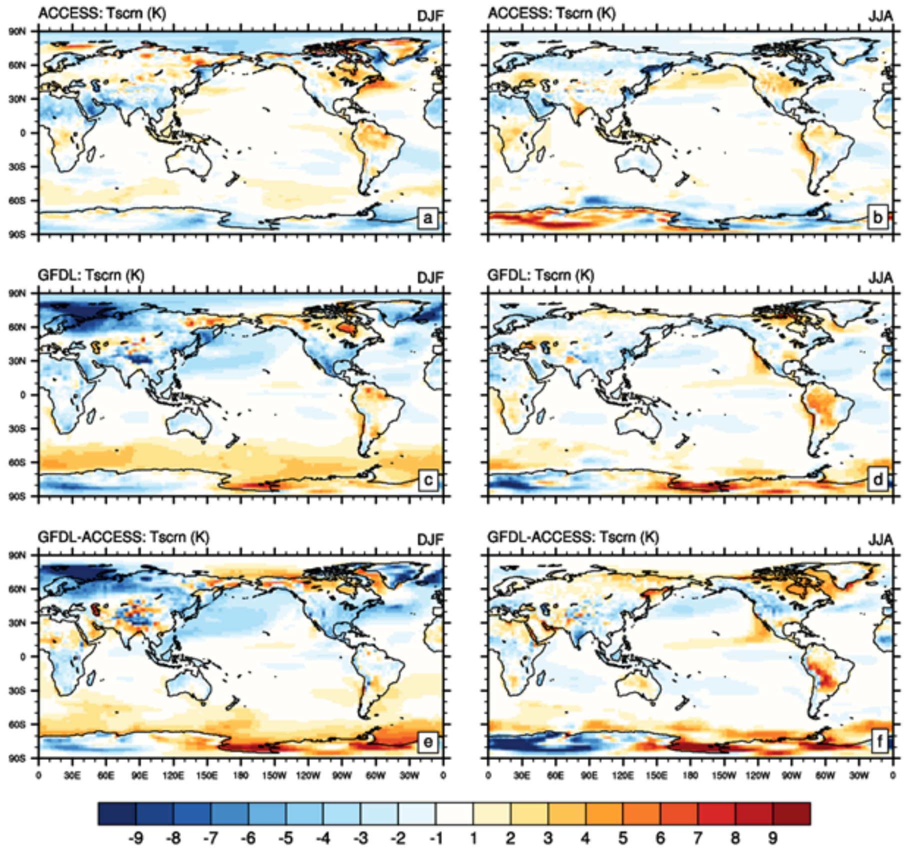


BIASES compared to ERA-Interim

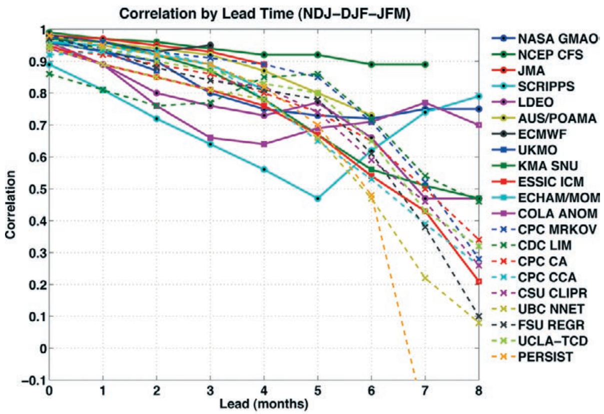
ACCESS amip: v1.4, vaoyb, 10 years; GFDL: control v2, 300-309,10years

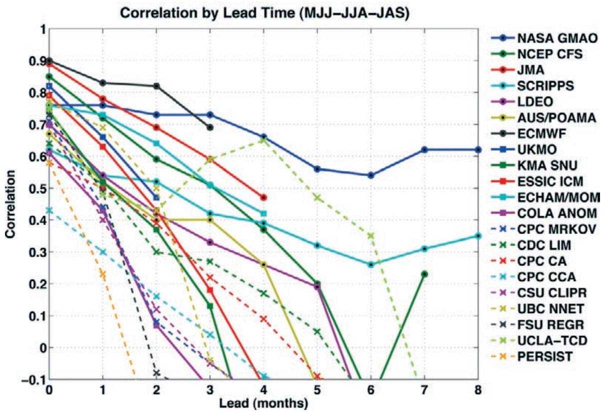
Models:
GFDL: AM2, LM2, SIS, MOM5,WOMBAT (BGC)
(upgrading to AM3 & LM3)

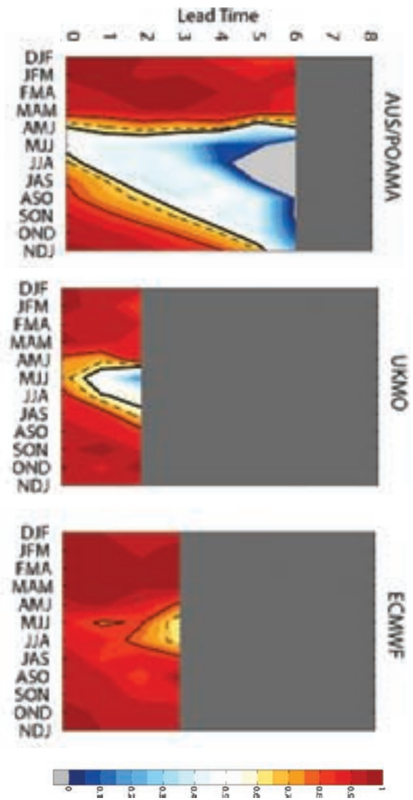
ACCESS ESM1.5:
UM7.3, CABLE, CICE, MOM5, WOMBAT

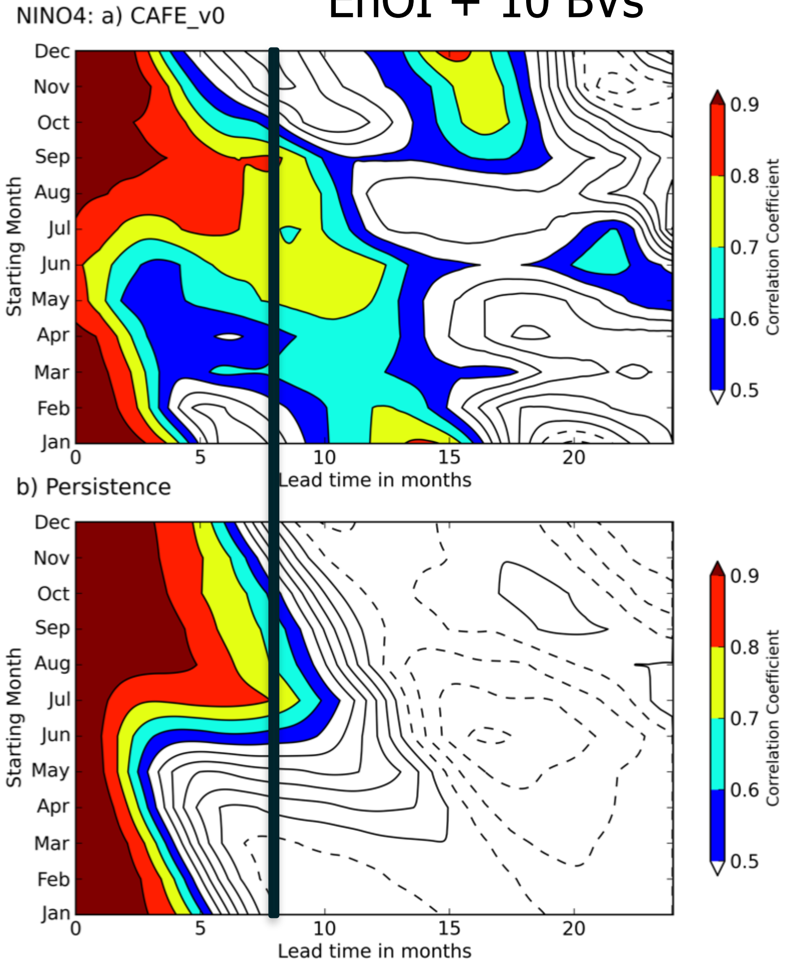


EnOI + 10 BVs





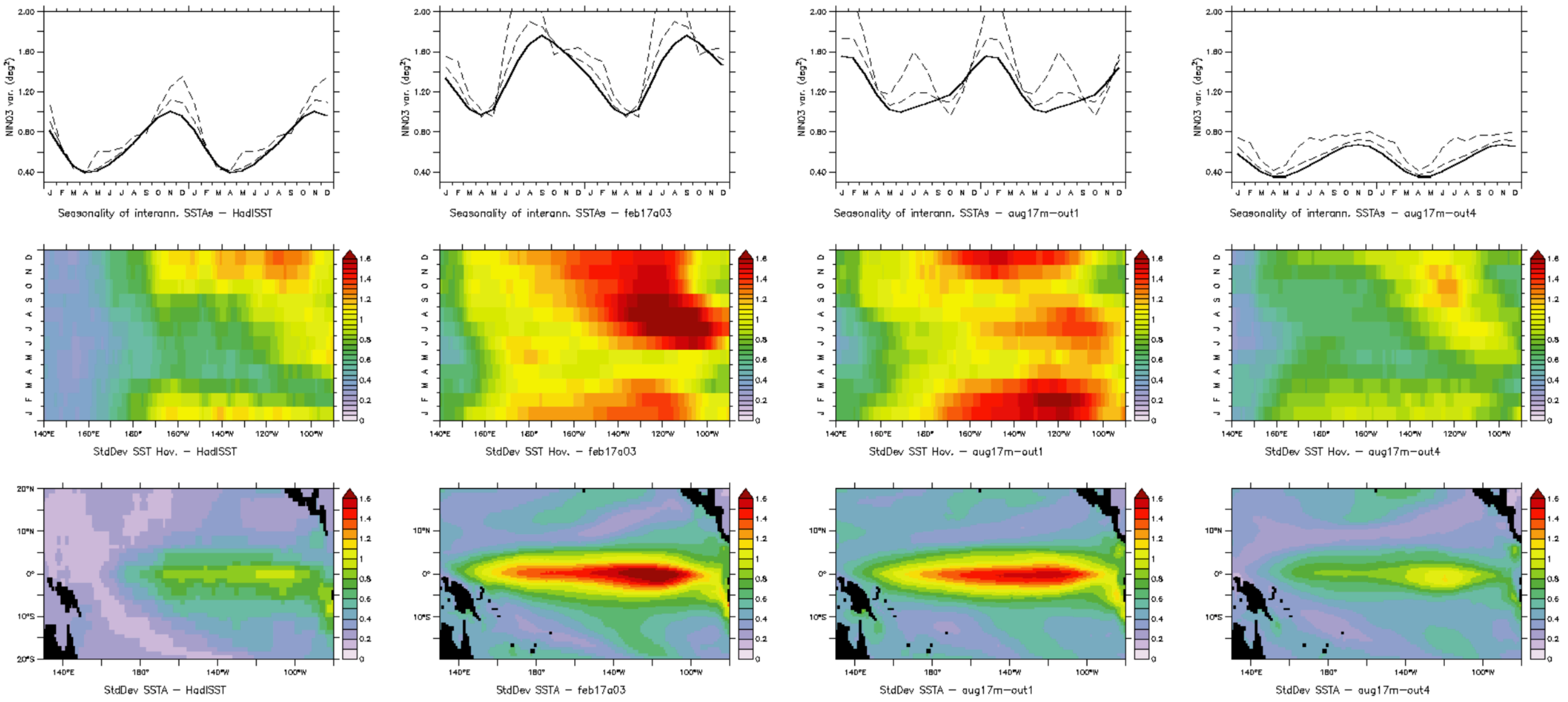




Barnston et al BAMS May 2012
Skill of real-time ENSO model predictions during 2002-2011

Improving ENSO: playing with horizontal friction and vertical mixing

Observations | CAFE v1 | ACCESS – ESM1 | CAFE with ACCESS-ESM



CURRENT STATUS OF HINDCAST / FORECAST DATA SETS AND NEAR FUTURE

v0

2yr or 5yr forecasts of months from Feb 2002 to May 2016 using bred_vectors as IC

NOTE: this run has a bug in the initialization of the atmosphere and so initial (t=0) atmospheric states do not correspond to any particular date.

v1

2yr or 5yr forecasts of months from Feb 2002 to May 2016 using corrected data assimilation and bred_vectors as IC.

Data assimilation is EnOI with fixed but seasonally evolving background covariances. Only ocean observations are assimilated and the atmosphere is relaxed to interpolated monthly mean NCEP v1 reanalysis fields.

Bred Vectors are generated each month about the analysed ocean state from the data assimilation. Member 1 is the control (unperturbed) and members 2-11 have anomalies added between 20S-20N in the upper 2000m of the ocean perturbed.

v2

Hindcast using approach based on Meehl et al. (2016) Nat. Comms.

Ocean restarts from ocean experiment forced with JRA-55, atmospheric restarts from different years of control simulateon

Hindcasts from Januarys of 2000 to 2017.

v3

Early 2018:

- 96 member EnKF
- Normal mode initialisation
- SST and SLA bias correction in the assimilation
- Assimilation of atmospheric (JRA-55 reanalysis) data
- Combined Bred Vector and EnKF initial forecast observations
- Improved climate model (corrected ENSO phase locking, improved summertime Antarctic sea ice and reduced southern ocean SST biases)

External Website

- https://research.csiro.au/dfp/

Theory

Simple Climate Model - coupled attractor with fast, medium and slow dynamics

Extratropical Atmosphere

$$\dot{x}_e = \sigma(y_e - x_e) - c_e(Sx_t + k_1)$$
$$\dot{y}_e = rx_e - y_e - x_e z_e + c_e(Sy_t + k_1)$$
$$\dot{z}_e = x_e y_e - bz_e$$

Tropical Atmosphere

$$\dot{x}_t = \sigma(y_t - x_t) - c(SX + k_2) - c_e(Sx_e + k_1)$$
$$\dot{y}_t = rx_t - y_t - x_t z_t + c(SY + k_2) + c_e(Sy_e + k_1)$$
$$\dot{z}_t = x_t y_t - bz_t + c_z Z$$

Ocean - slow dynamics

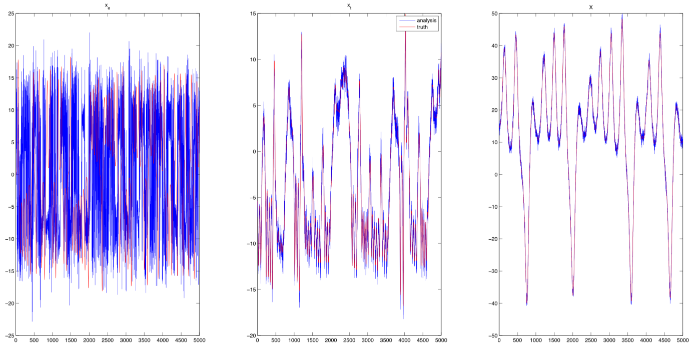
$$\dot{X} = \tau\sigma(Y - X) - c(x_t + k_2)$$
$$\dot{Y} = \tau rX - \tau Y - \tau SXZ + c(y_t + k_2)$$
$$\dot{Z} = \tau SXY - \tau bZ - c_z z_t$$

The lowercase x, y and z represent the fast modes, with the *e* and *t* subscripts designating the quickly varying, small amplitude "extra tropical" and "tropical" variables, respectively. The uppercase X, Y and Z represent the slowly varying, large amplitude "ocean" variables. Here the extra-tropics and tropics are weakly coupled in the horizontal (c_e = 0.08) and vertical (c_t = 0.08) directions while the tropics and ocean are fully coupled in the horizontal and vertical directions ($c = c_z = 1$). tau and S are temporal and spatial scaling factors, respectively, for the ocean variables.

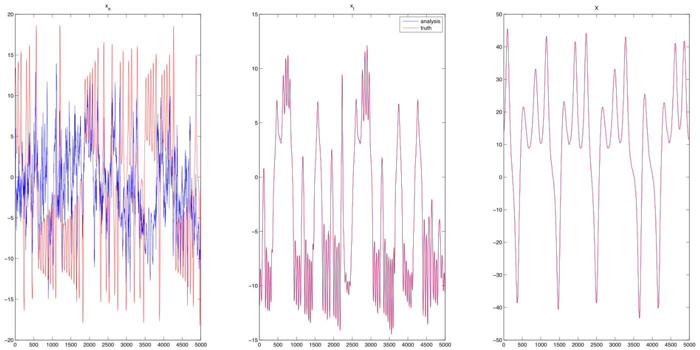
EnOI versus ETKF – the role of flow dependant covariances

Assimilation of ocean (slow) and mid-latitude atmosphere (medium) observations. Fast tropics are unconstrained.

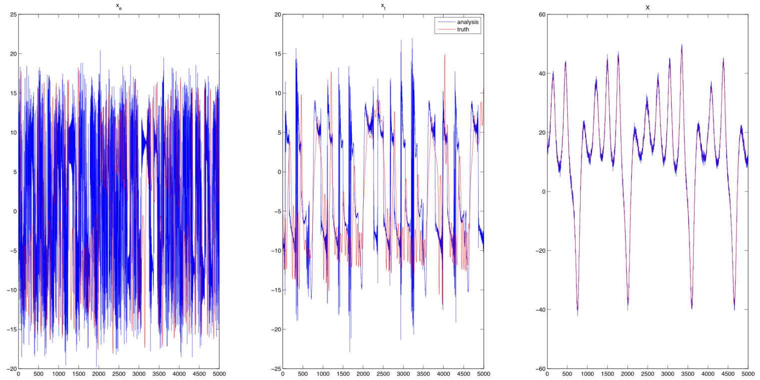
EnOI (static background covariances)

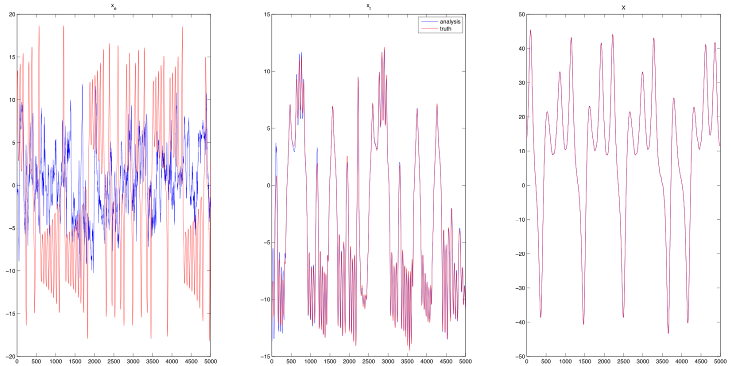


ETKF (flow dependent background covariances)



Assimilation of ocean (slow) observations only





Conclusions:

A properly observed ocean is required in order to constrain the slow “climate” manifold.

For multi-year forecasting we do not try to track the fast convective (stochastic) scales but rather the slow predictable modes.

To do this for the attractor model, the EnOI system requires both the ocean and extra-tropical atmospheres to be observed. This mirrors our present forecast system where we assimilate into the ocean and relax to reanalysed large scale atmospheric state.

In the case of the ETKF it is sufficient to assimilate only ocean observations but generate coupled covariances between ocean and extra-tropical atmosphere.

We are now examining whether this holds in a ETKF variant of our forecast system.