



## S2D C1-03: Coupled data assimilation and ensemble initialization with application to multi-year ENSO prediction.

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# Observing System Simulation Experiments (OSSE's)

The aim of these Observing System Simulation Experiments (OSSE's) was to

- compare variants of coupled data assimilation (DA) systems based on ensemble optimal interpolation (EnOI) and ensemble transform Kalman filter (ETKF) methods
- to assess the impact of assimilating ocean observations on the atmospheric state analysis update via the cross-domain error covariances from the coupled-model background ensemble.
- examine the relationship between ensemble spread, analysis increments and forecast skill in multi-year ENSO prediction experiments with a particular focus on the atmospheric response to tropical ocean perturbations.
- explore various approaches to generating initial forecast perturbations, either in terms of ETKF or bred vectors

O'Kane, T.J., P.A. Sandery, D.P. Monselesan, P. Sakov, M.A. Chamberlain, R. Matear, M. Collier & L. Stevens (2018) *Coupled data assimilation and ensemble initialization with application to multi-year ENSO prediction* (in review J. Climate)

# Paradigm Model

Paradigm model for ocean-tropical-extra tropical atmosphere coupling (Peña and Kalnay(2004)):

$$\dot{x}_e = \sigma(y_e - x_e) - c_e(Sx_t + k_1) \quad (1a)$$

$$\dot{y}_e = rx_e - y_e - x_e z_e + c_e(Sy_t + k_1) \quad (1b)$$

$$\dot{z}_e = x_e y_e - bz_e \quad (1c)$$

$$\dot{x}_t = \sigma(y_t - x_t) - c(SX + k_2) - c_e(Sx_e + k_1) \quad (2a)$$

$$\dot{y}_t = rx_t - y_t - x_t z_t + c(SY + k_2) + c_e(Sy_e + k_1) \quad (2b)$$

$$\dot{z}_t = x_t y_t - bz_t + c_z Z \quad (2c)$$

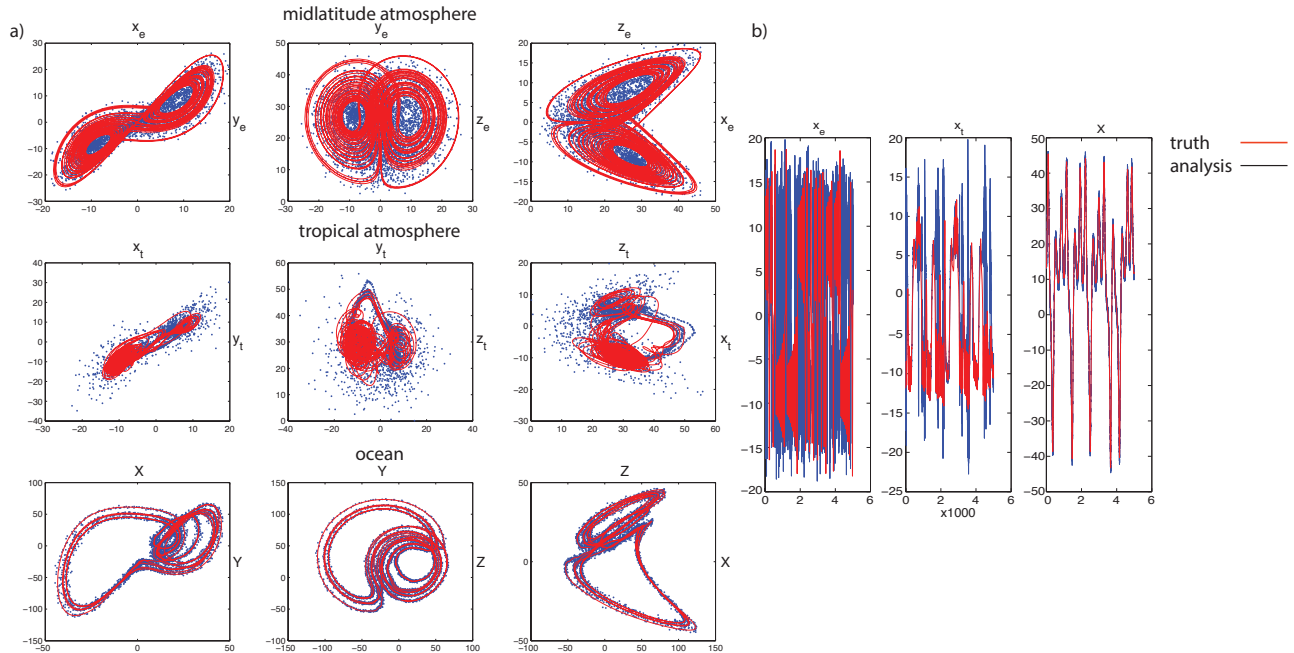
$$\dot{X} = \tau\sigma(Y - X) - c(x_t + k_2) \quad (3a)$$

$$\dot{Y} = \tau rX - \tau Y - \tau SXZ + c(y_t + k_2) \quad (3b)$$

$$\dot{Z} = \tau SXY - \tau bZ - c_z z_t \quad (3c)$$

# Paradigm Model (EnOI)

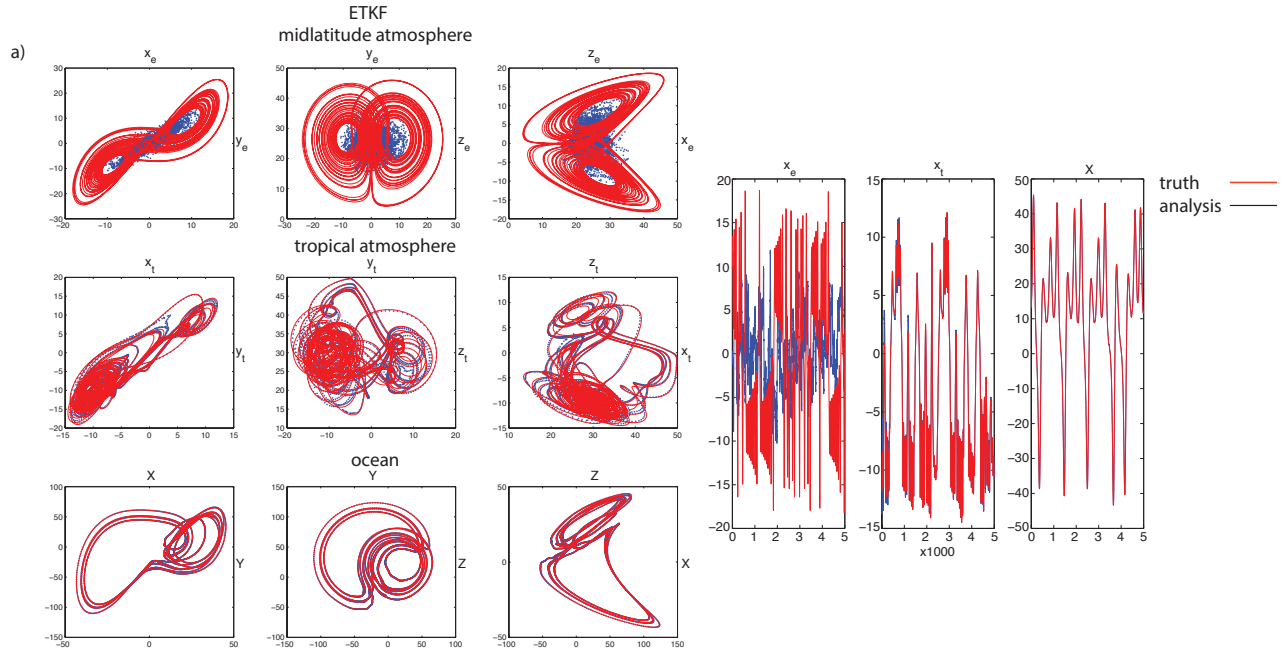
”Ocean” assimilation coupled covariances: Static background covariances (50 mem)  
Analysed tropical atmosphere is on a different attractor. Variance of extra-tropical atmosphere unchanged.





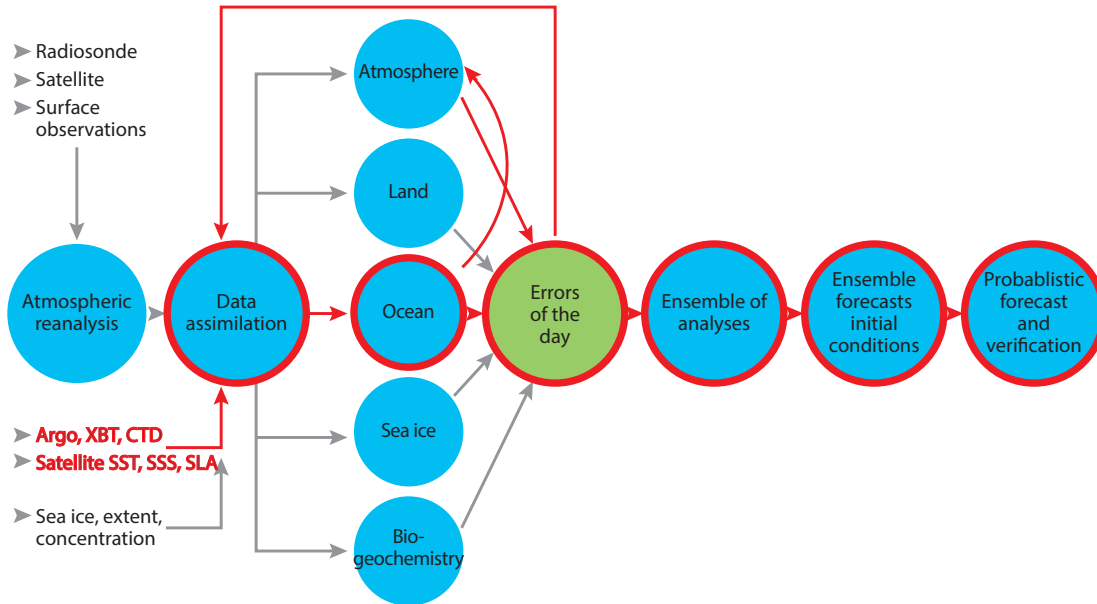
# Paradigm Model (ETKF)

”Ocean” assimilation - coupled covariances: Flow dependent background covariances (10 mem).  
Analysed tropical atmosphere is on the attractor. Variance of extra-tropical atmosphere is suppressed.



# CAFE system design

Schematic of the CAFE system



# Observations assimilated

R-factor to adjust model error variances and K-Factor to adjust observation error variances. ETKF employs SST and SLA bias correction via AR(1) model fit.

TABLE Summary of ocean observations assimilated into the Global Climate Model

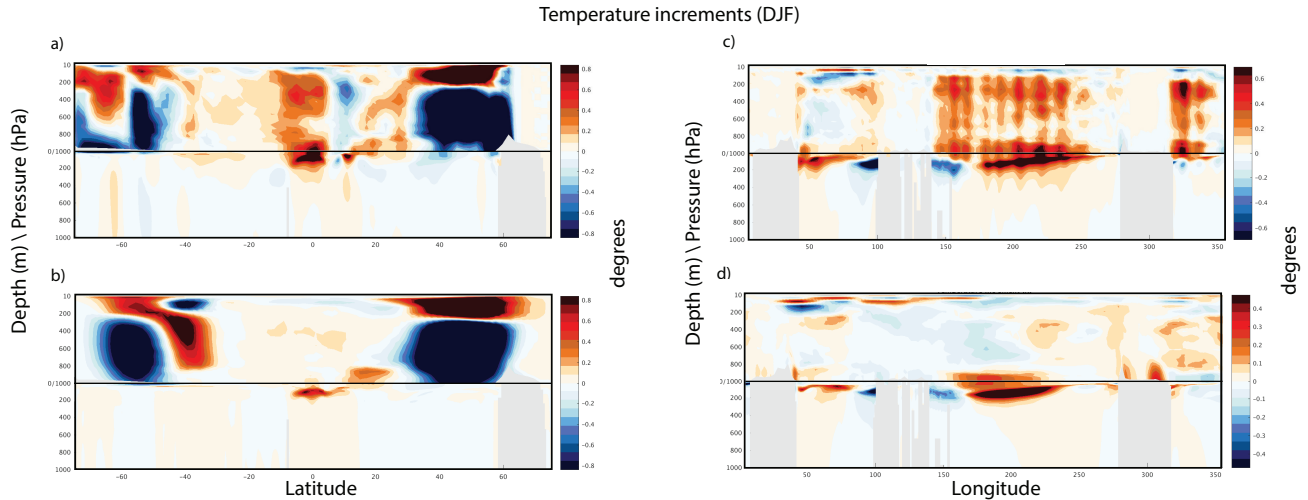
SST	RADS altimetry	SSS	In-situ T/S (WMO GTS)
NAVO-AVHRR	JASON	AQUARIUS	Argo
AMSR-E	CryoSat2	SMOS	CTD
AMSR-2	EnviSat2		XBT
WindSat	Altika		RAMA
PATHFINDER	SARAL		PIRAIA
VIIRS	Sentinel3		TAO-TRITON

TABLE Number of ocean observations and superobs assimilated on 03/2012 & 12/2017

Date	03/2012		
type	# used	# discarded	# superobs
SLA	2249101	122202	245742
SST	19147820	250250	478420
TEM	1341154	14956	298345
SAL	1253298	15470	269894
SSS	2163235	96132	828292
Total	26154608	499010	2120693
Date	12/2017		
type	# used	# discarded	# superobs
SLA	2836923	175817	290120
SST	121295481	1026776	1059509
TEM	10432222	211906	363541
SAL	9452414	285884	337366
SSS	0	0	0
Total	144017040	1700383	2050536

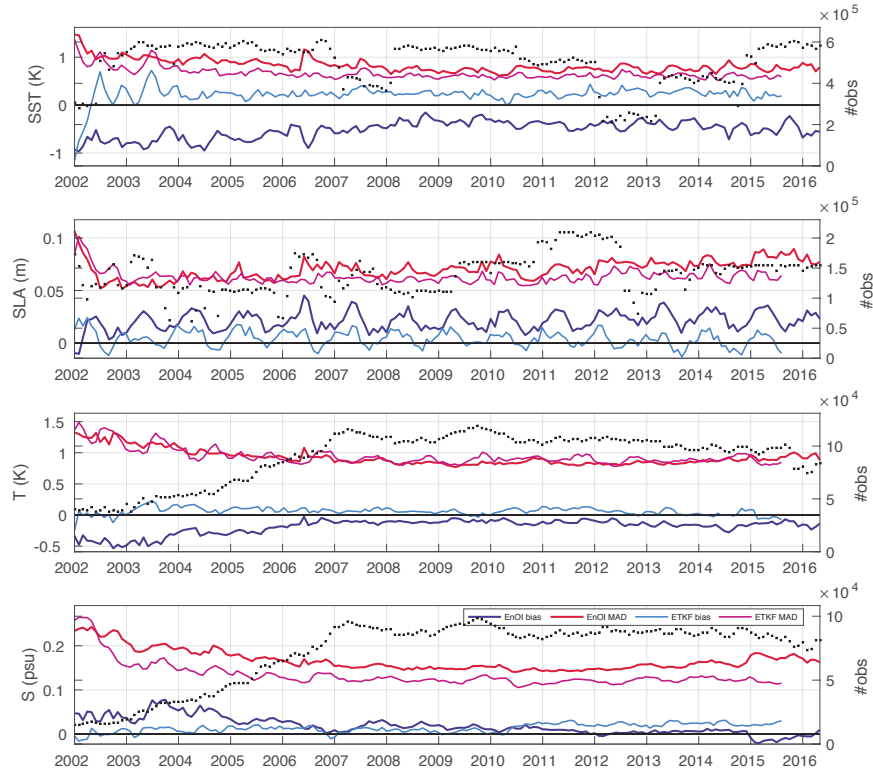
# Tropics-Extra-tropics (seasonal increments)

Comparison of ocean and atmosphere increments averaged over the boreal winter (DJF) along 140°W (ETKF a); EnOI b) and 2°S (ETKF c); EnOI d)



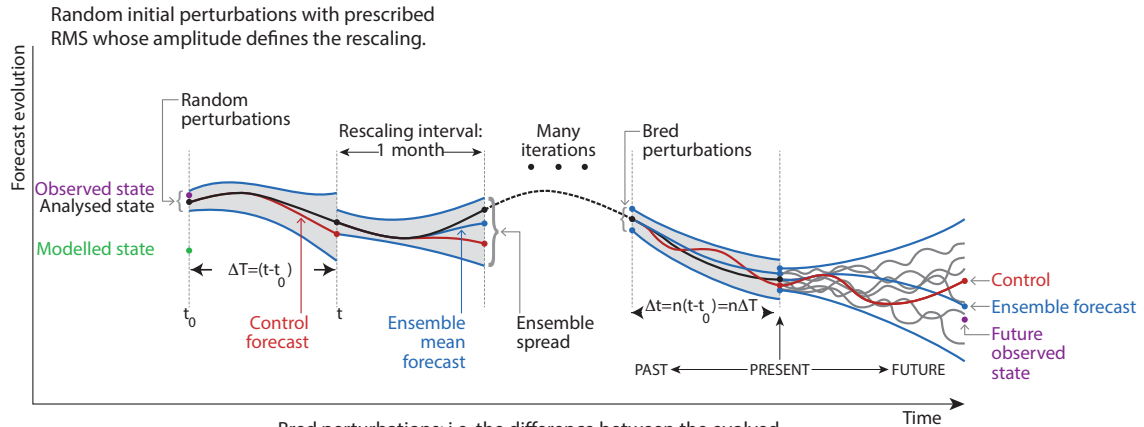
# 3: Assimilation statistics (20°S-20°N)

EnOI (1 analysis, static cov) versus ETKF (96 analyses, flow dependent + SST bias correction)



# Ensemble Prediction System

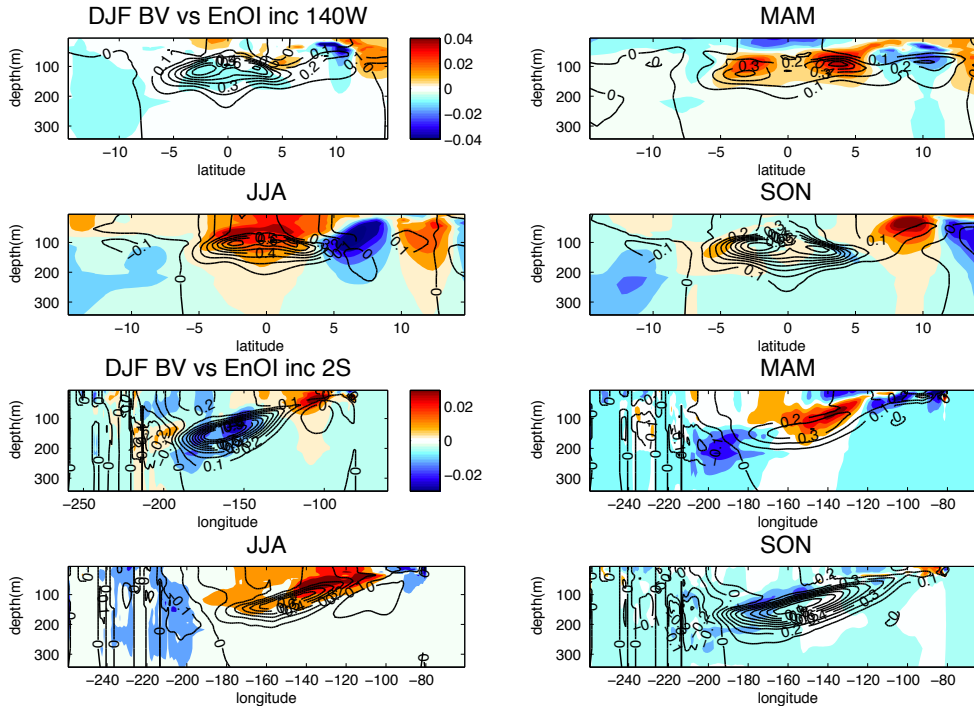
## Bred vector generation



Bred perturbations: i.e. the difference between the evolved perturbed forecasts and the control, renormalised via the norm defined by the RMS of the initial perturbations and the length of the rescaling interval.

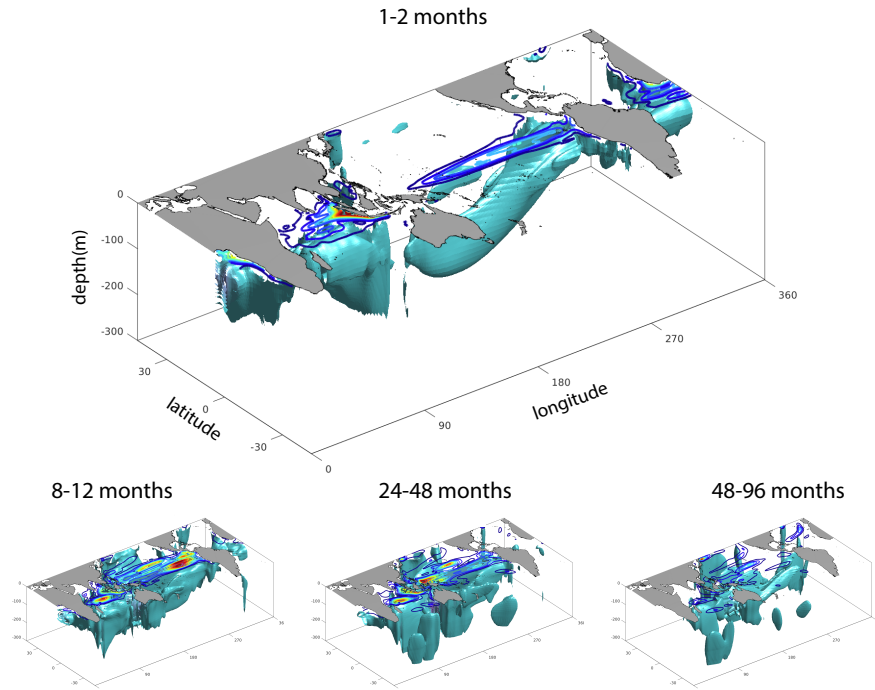
# BV's versus 28 day forecast errors

Comparison of ensemble averaged BV's (shaded) and EnOI/ETKF analysis increment (contour) along sections at 140°W and 2°S.



# Scale selection

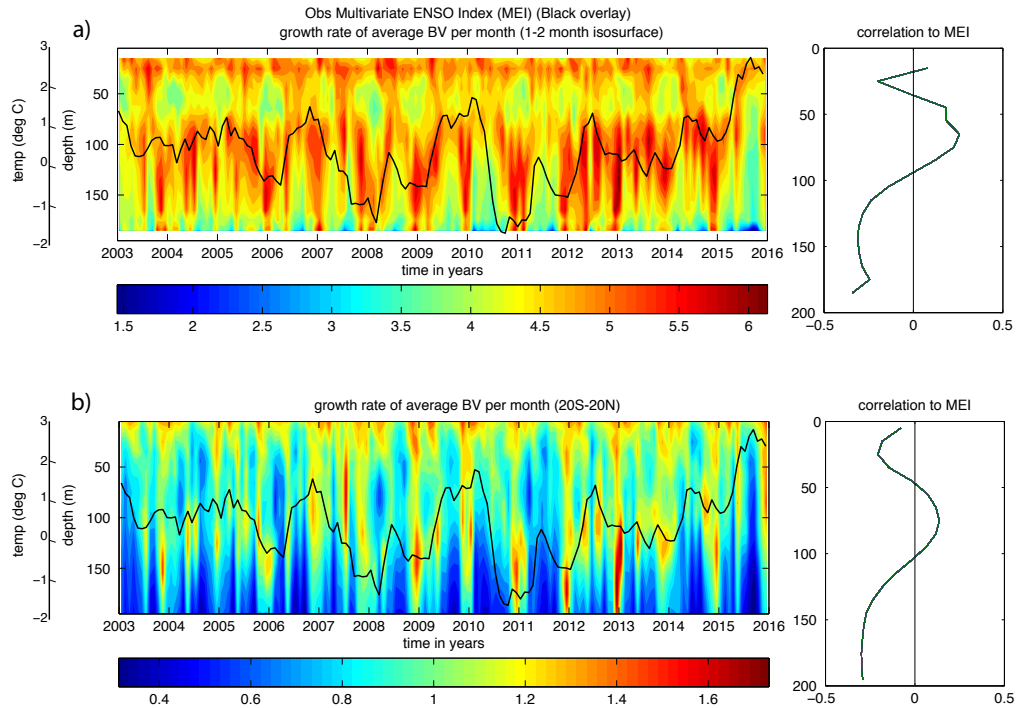
- localisation length scales and adjustment of observation impact factors to "tune" increments to select spatio-temporal scales of relevance to given forecast lead times.
- mask regions of variance relevant to those chosen spatio-temporal scales such as the in band variance for temperature with an appropriate threshold (0.5 RMSE calculated from 500 years of control simulation).





# Error growth rates

isosurface BV growth rates 3 times larger than 20°S-20°N BVs

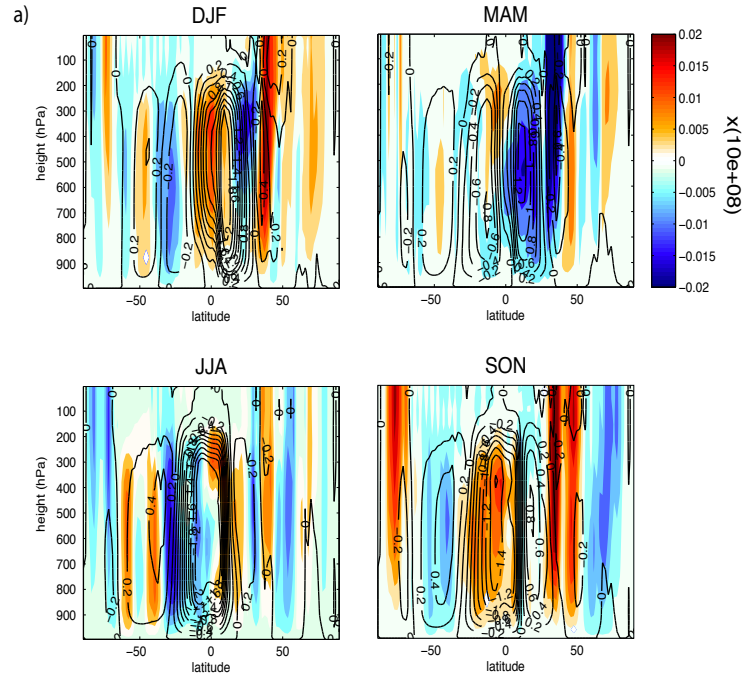


# Tropics-Extra-tropics

Coherent tropospheric response to modulation of tropical convection

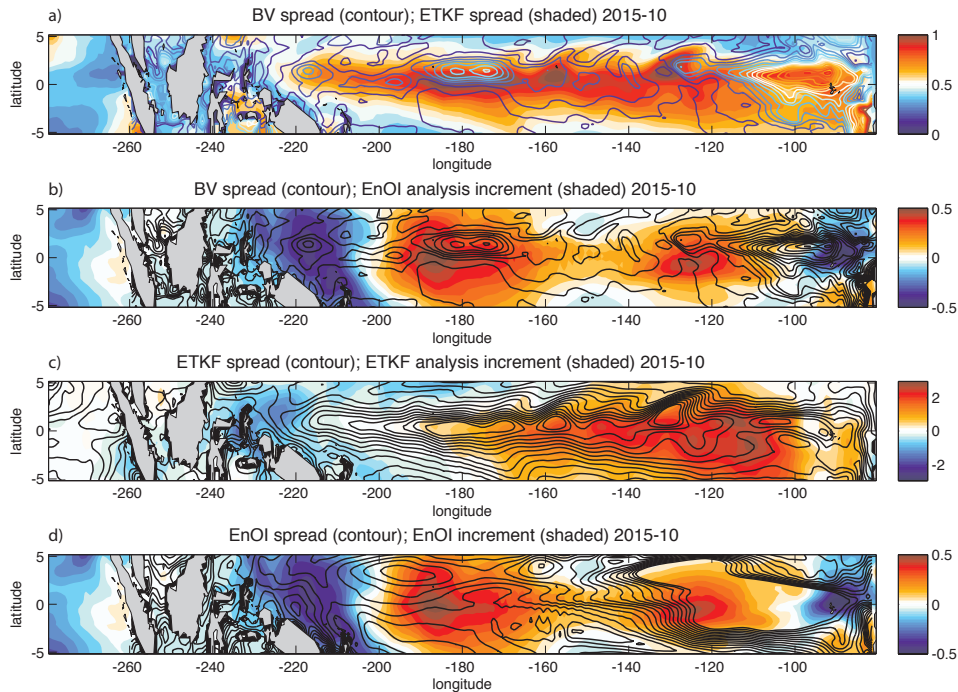
Cntrl (contours) vs BV avg (shaded)

20S-20N



# ETKF versus BVs case study 2016 El Niño

- Ensemble spread versus analysis increment during build up to 2016 El Niño.
- BVs add similar flow dependent structures to ETKF background covariances.

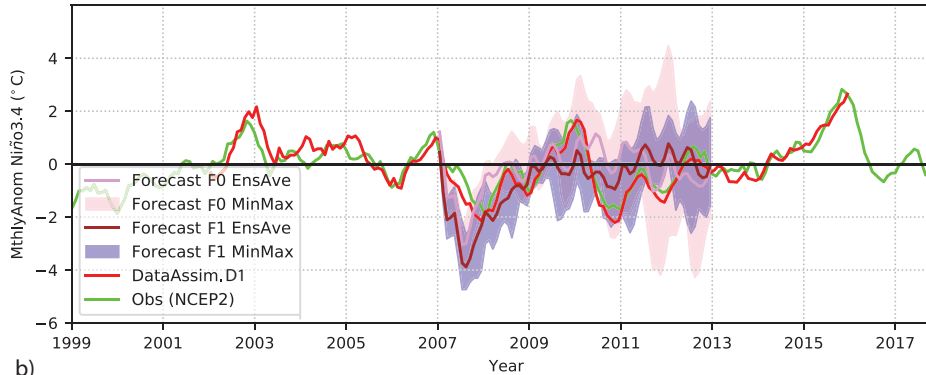


# ENSO Prediction case study

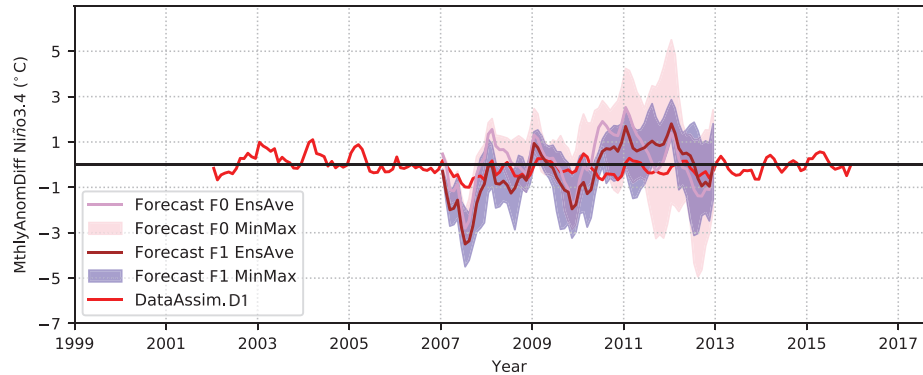
- Ensemble forecasts of NINO3.4 beginning January 2007 comparing isosurface BVs (F1) to BVs generated between 20°N-20°N renormalised to 1% of the background RMSE (F0).
- Spread reduced in isosurface ensemble due to reduced error growth in regions unrelated to the thermocline.
- D1 is the reanalysed state estimates as compared to NCEP reanalysis v2.

Note: no SST perturbations are used in isosurface BVs - predictability comes from thermocline perturbations)

a)

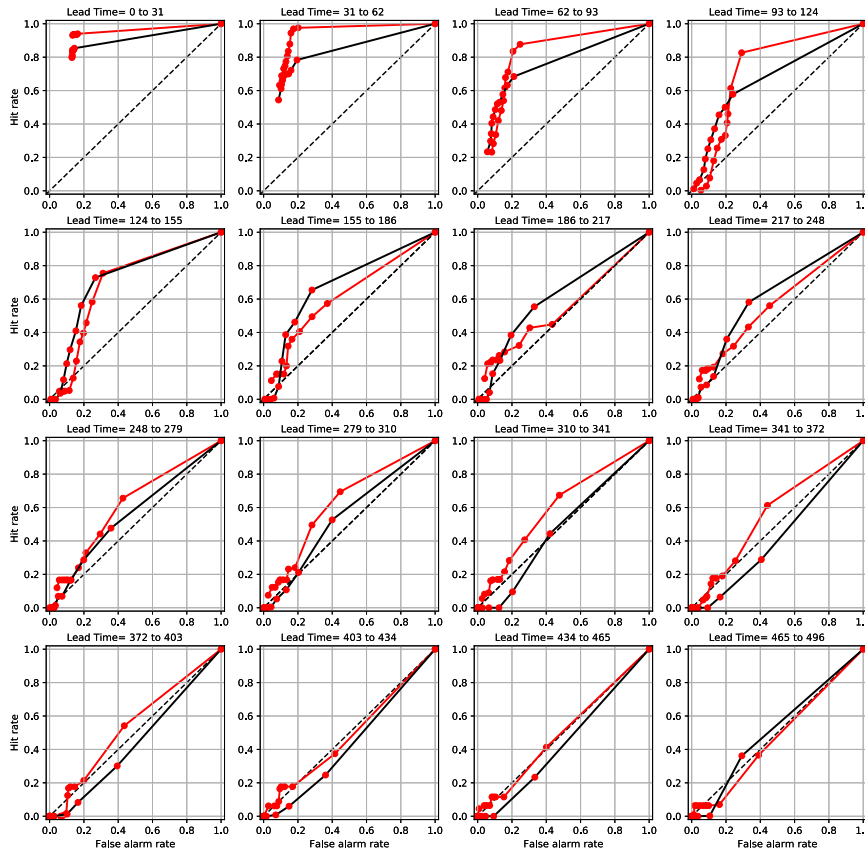


b)



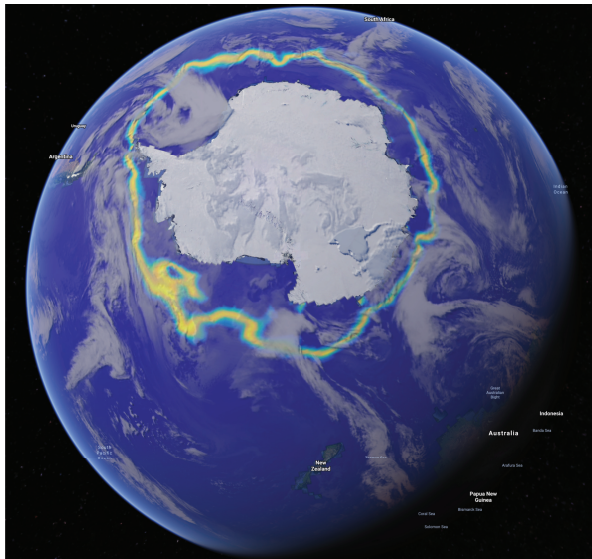
# ENSO Prediction: ROC curves for NINO4

ROC curves of the F0 20°S-20°N (black) and F1 isosurface (red) hindcasts (3960 model years) for NINO4 calculated over a 15 year period (2 year lead-times, 11 members each starting every month over the period 2003 to July 2017)

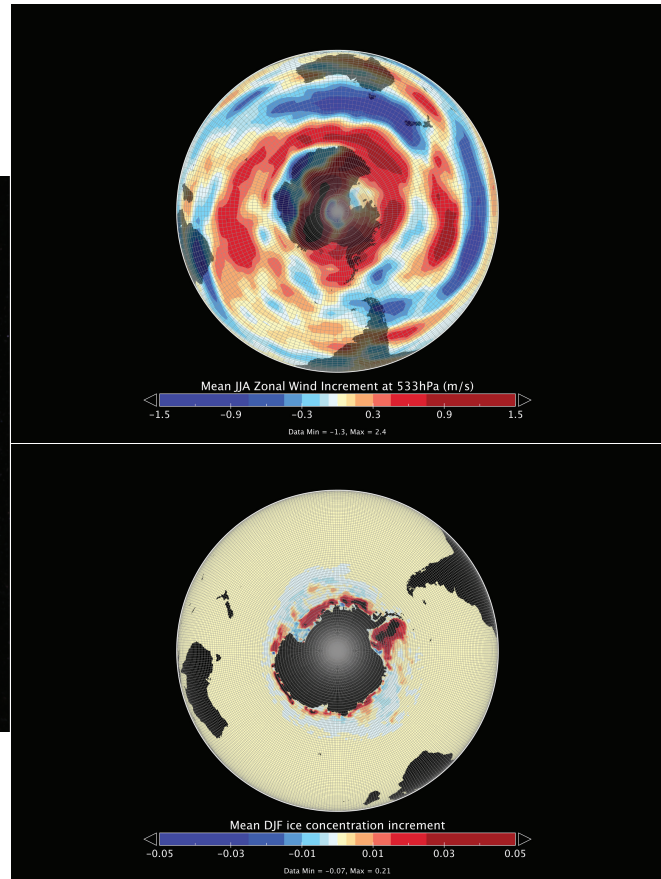


# Current work

- Assimilation of high resolution JRA-55 reanalysis data (hybrid sigma-pressure levels)
- Assimilation of OSISAF sea-ice concentration



ensemble spread 2014-06-06



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## Current work

### Reanalysis and decadal prediction

- 1988-2018 Coupled reanalysis (96 member ETKF)
- 1960 onwards Hindcast / forecast - 5 year leadtime initiated every season - 30 member ETKF + multiscale breeding

### Model configurations and development

- CM2.1 (2 degree atmosphere, 1 degree ocean (MOM5))
- CM2.5 (50km atmosphere (AM2/LM2, 1/4 degree ocean (MOM5))
- CMFLOR (50km atmosphere, 1 degree ocean)
- ACCESS ESM1.5 comparison studies (future model for decadal MIPS)
- KPP ocean surface boundary layer parameterization (CVMix Griffies et al 2015)

# Conclusion

- A properly observed ocean is required to constrain the slow climate "manifold"
- For multi-year forecasting we do not try to track the fast convective or synoptic scales of the atmosphere but rather excite the slow predictable modes coupled to the ocean.
- Optimal perturbations for state estimation are not necessarily optimal for forecasting a given climate mode at a given lead time and should be augmented or replaced by perturbations specific to the phenomena of interest.
- Here we show that it is possible on seasonal timescales to modulate the mid-troposphere jets via targeted perturbations to the tropical thermocline however, how longer timescale memory residing in the subtropical oceans affects the atmosphere and predictability is still unclear.
- The CAFE system is being developed as a tool to target and understand the mechanisms by which coherent variability determines predictability in the climate system in the near term.

## References

- O'Kane, T.J., P.A. Sandery, D.P. Monselesan, P. Sakov, M.A. Chamberlain, R. Matear, & M. Collier (2018) "Coupled data assimilation and ensemble initialization in CAFE with application to near term ENSO prediction." (In review)



# Thank You

**CSIRO Oceans & Atmosphere**

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