Coupled data assimilation and ensemble initialization with application to multi-year ENSO prediction.

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Data Assimilation Experiments

The aim of these Experiments 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

CAFE system design

Schematic of the CAFE system

Data assimilation
- Radiosonde
- Satellite
- Surface observations

Atmospheric reanalysis
- Argo, XBT, CTD
- Satellite SST, SSS, SLA
- Sea ice, extent, concentration

Errors of the day

Atmosphere

Land

Ocean

Sea ice

Biogeochemistry

Ensemble of analyses

Ensemble forecasts initial conditions

Probabilistic forecast and verification
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.

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<th>Summary of ocean observations assimilated into the Global Climate Model</th>
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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)

Temperature increments (DJF)
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

Random initial perturbations with prescribed RMS whose amplitude defines the rescaling.

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

![Graph showing growth rate of average BV per month (1-2 month isosurface) and correlation to MEI](image)
Coherent tropospheric response to modulation of tropical convection

Cntrl (contours) vs BV avg (shaded)

20S-20N

DJF

MAM

JJA

SON
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 (no bias correction) of Niño3.4 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.
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)
Lagged auto-correlation coefficients of monthly Nino SST based on 100 years of control simulation

Projection onto only those disturbances relevant to the Eq. Pacific thermocline enhances long range ENSO prediction
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

Thank You

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