Coupled data assimilation

in climate analysis and forecasting

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The GFDL CM2.1 climate model, an ensemble Kalman filter data assimilation system and ocean and atmospheric observational data is used to explore strong and weakly coupled data assimilation (CDA). Predictability and sensitivity of the cross-domain ocean-atmosphere covariances is illustrated through comparison of forecast innovation errors and seasonal mean increments for all possible cases (Table 1).

Method

- 96 member EnKF data assimilation system.
- Coupled state vector includes ocean temperature, salinity, sea-level anomaly, velocity, sea-ice concentration and thickness categories, atmospheric pressure, temperature, humidity and winds.
- Experiments based on 7-day asynchronous assimilation of ocean observations and assimilation of one day of JRA55 data on analysis day.
- System run as a sequence of 7-day coupled forecasts allowing evolution of coupled model cross-covariances.
- SST and SLA bias correction.
- Sea-ice assimilation is carried out by comparing ice concentration in the forecast model to satellite observations. The five thickness categories in the ice model are added to the state vector to initialize the ice model.
- Sea-ice assimilation is strongly coupled to the ocean. It is left on in the control (enkf-016).
- All 16 cases are run over the same period.
- The initial conditions are the same for all experiments and initially based on multi-century runs of the model then converted to an ensemble state representing the last 20 years of data assimilation using all available observations.

Observational Data

- Wind, temperature, humidity and surface pressure from JRA55 atmospheric reanalysis data.
- Sea surface temperature from NAVO-AVHRR, AMSR2, WindSat, Pathfinder, VIIRS.
- Sea surface salinity from SMOS, SMAP version L2OS REO5.
- Temperature and salinity from Argo, XBT, CTD, TAO, PIRATA and RAMA sourced from WMO GTS, CORIOLIS, USGODAE, processed to Bureau MMT and CSIRO CARS.
- Sea level anomalies from the Radar Altimeter Database System (RADS) including SARAL, ALTIKA, JASON1-3, ENVISAT, CRYOSAT, TOPEX-POSEIDON.
- OSISAF sea-ice concentration.

FIGURE 1 Example of 7-day forecast innovations from data assimilation system for SST, SLA, 500hPa air temperature and zonal velocity.

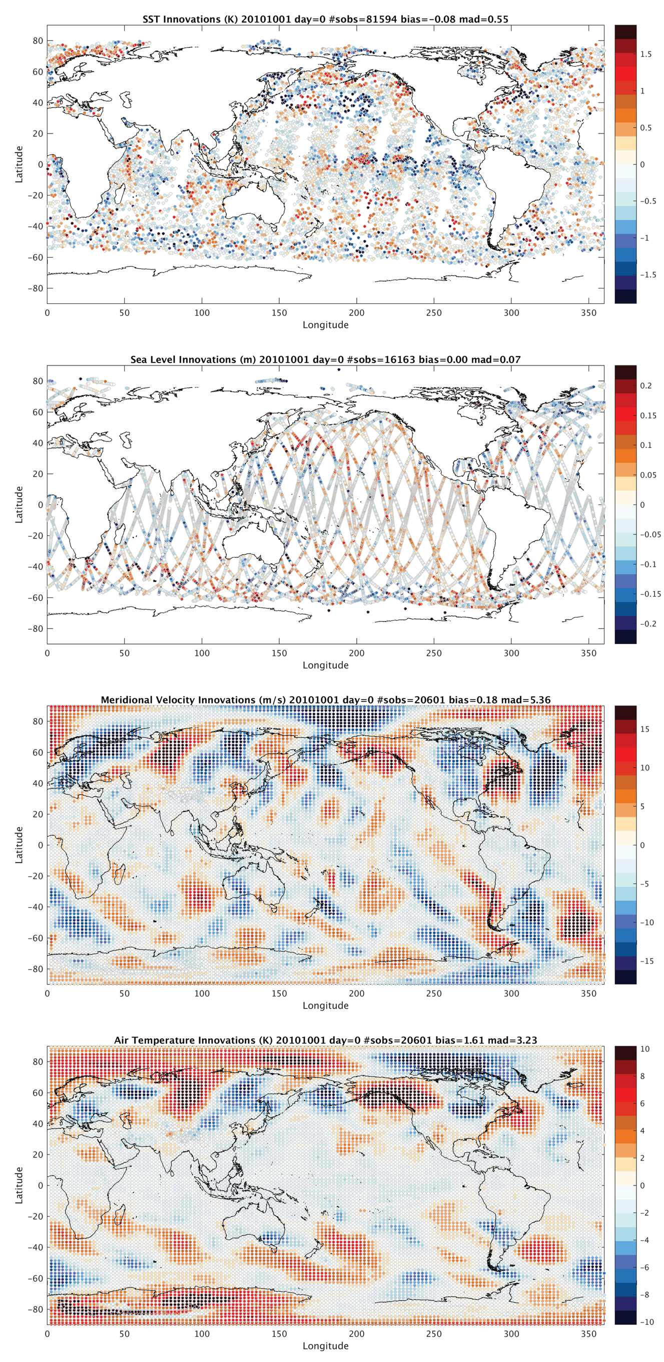


FIGURE 5 Ensemble, observation and forecast error spread distributions for SST in 2010.

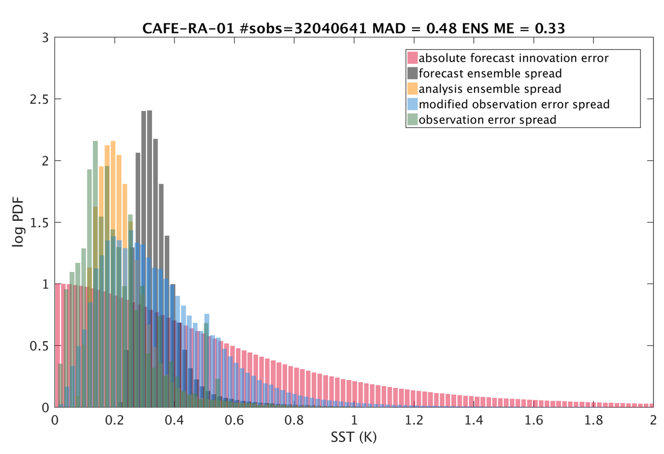


FIGURE 2 Global mean 7-day forecast errors.

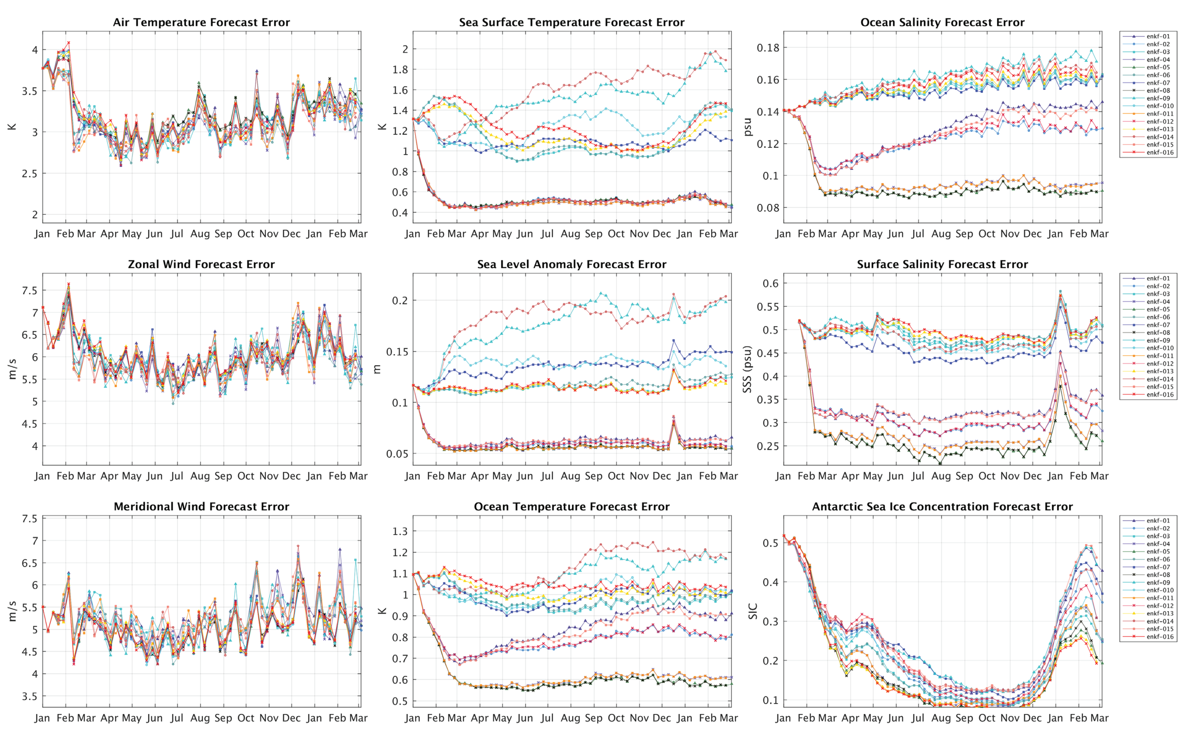


TABLE 1 All ocean-atmosphere weakly and strongly coupled cases. Strongly coupled is any case where either ATM-OCN or OCN-ATM cross covariances are used to calculate coupled analysis.

EXP	ATM–ATM	ATM-OCN	OCN-OCN	OCN-ATM	Atmospheric increment	Ocean increment
enkf-001	1	1	1	1	atmospheric and ocean observations	atmospheric and ocean observations
enkf-002	0	0	1	1		atmospheric and ocean observations
enkf-003	1	1	0	0	atmospheric and ocean observations	
enkf-004	1	0	1	0	atmospheric observations	ocean observations
enkf-005	0	0	1	0		ocean observations
enkf-006	1	0	0	0	atmospheric observations	
enkf-007	0	1	0	1	ocean observations	atmospheric observations
enkf-008	0	1	1	0	ocean observations	ocean observations
enkf-009	1	0	0	1	atmospheric observations	atmospheric observations
enkf-010	0	0	0	1		atmospheric observations
enkf-011	1	1	1	0	atmospheric and ocean observations	ocean observations
enkf-012	0	1	1	1	ocean observations	atmospheric and ocean observations
enkf-013	0	1	0	0	ocean observations	
enkf-014	1	1	0	1	atmospheric and ocean observations	atmospheric observations
enkf-015	1	0	1	1	atmospheric observations	atmospheric and ocean observations
enkf-016	0	0	0	0		

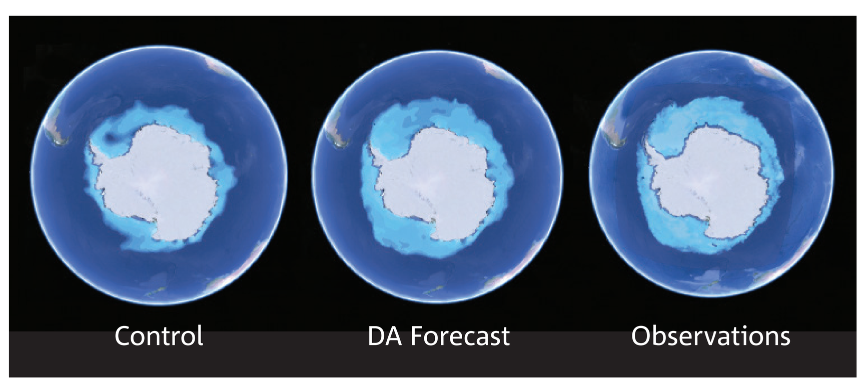
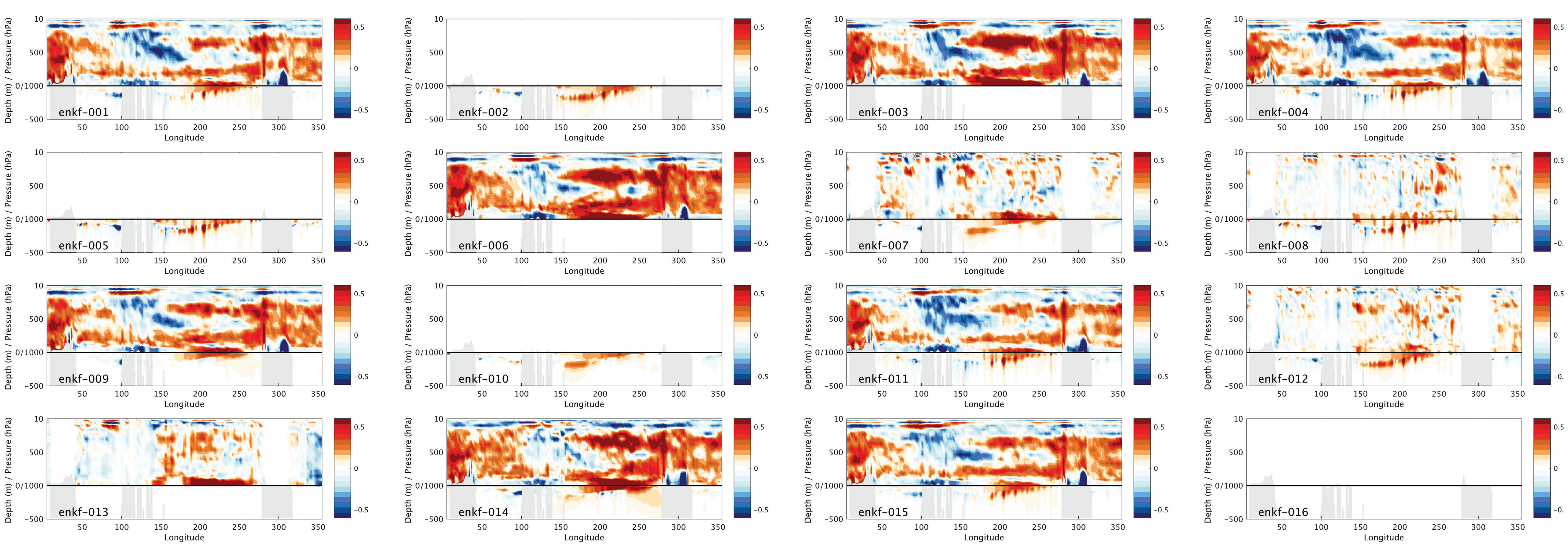


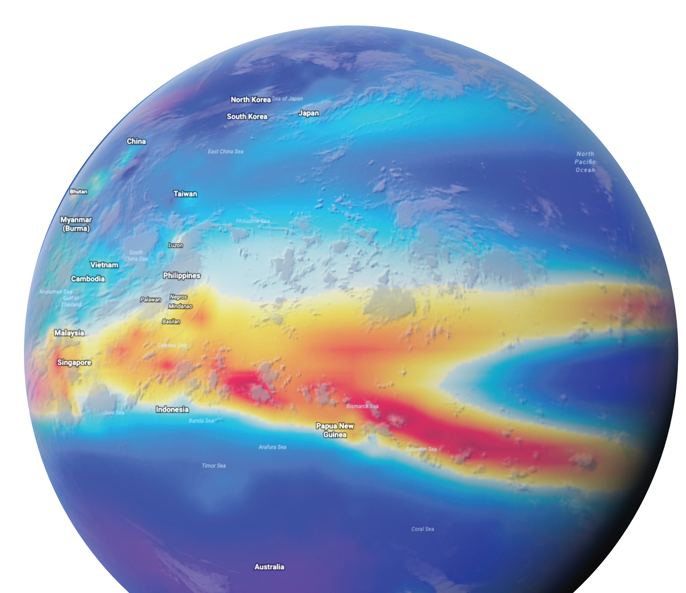
FIGURE 3 Antarctic sea-ice concentration on 1st July 2010.

FIGURE 4 Seasonal mean temperature increments for DJF for zonal sections through 2 degrees south of equator.



Results

- The forecast innovations (Figure 1) are used to calculate global 7 day forecast error (mean absolute deviation) using forward unassimilated independent observations (Figure 2). At 7 days lead time forecast errors in the atmosphere are nearly saturated. Ocean errors appear to stratify into classes of predictability.
- Figure 3 shows an example of sea-ice data assimilation for 1st July 2010.
- The weakly coupled experiment enkf-004 performs best overall for the coupled data assimilation system.
- The strongly coupled experiment enk-001 had deleterious affect on ocean subsurface.
- In strongly coupled data assimilation cross-covariances are more sensitive to spurious correlations and model deficiencies. This can be seen in some of the strongly coupled cases in Figure 4.
- In enkf-007 atmospheric observations drive ocean increment and ocean observations drive atmospheric increment. This is an extreme case of strong CDA that highlights scale separation away from the planetary boundary layer in the tropics between ocean and atmosphere (Figure 4).
- The tropical marine and atmospheric boundary layers are where air-sea interactions are tightly coupled.
- CDA experiments imply this particular system would benefit from vertical localization.
- Figure 5 contrasts ensemble, observation and forecast error spread distributions for a reanalysis based on idealized settings generated from this study.
- Larger ensemble and improved model may be required for strong CDA to be effective.



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