Implicit and explicit cross-correlations in coupled data assimilation

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Ensemble correlations between ocean and atmospheric temperature

Motivation:

Balanced initial condition for the coupled forecast of the ocean and atmosphere requires specification of cross-fluid covariances that can synchronize data assimilation updates in two fluids. If known, for example from an ensemble of coupled forecasts, these covariances can be specified explicitly in a strongly coupled data assimilation (DA) system. Alternatively, these covariances can be generated implicitly by utilizing multiple outer iterations of the four-dimensional DA system. The European Centre for Medium-Range Weather Forecasts has recently developed an implicit coupling approach in the CERA reanalysis system, where otherwise uncoupled atmospheric 4DVAR and ocean 3DVAR are synchronized using 3 outerloop iterations. Since this original work on the outerloop coupling, it has been unclear just how closely does the CERA system with implicit coupled covariances. This poster tries to shed light on this question.

(A) Maps of correlation between SST and surface air temperature show strong correlation when the mixed layer is shallow (tropical east pacific and mid-latitudes in the summer hemisphere).

(B) Large flow-dependent correlations are apparent.

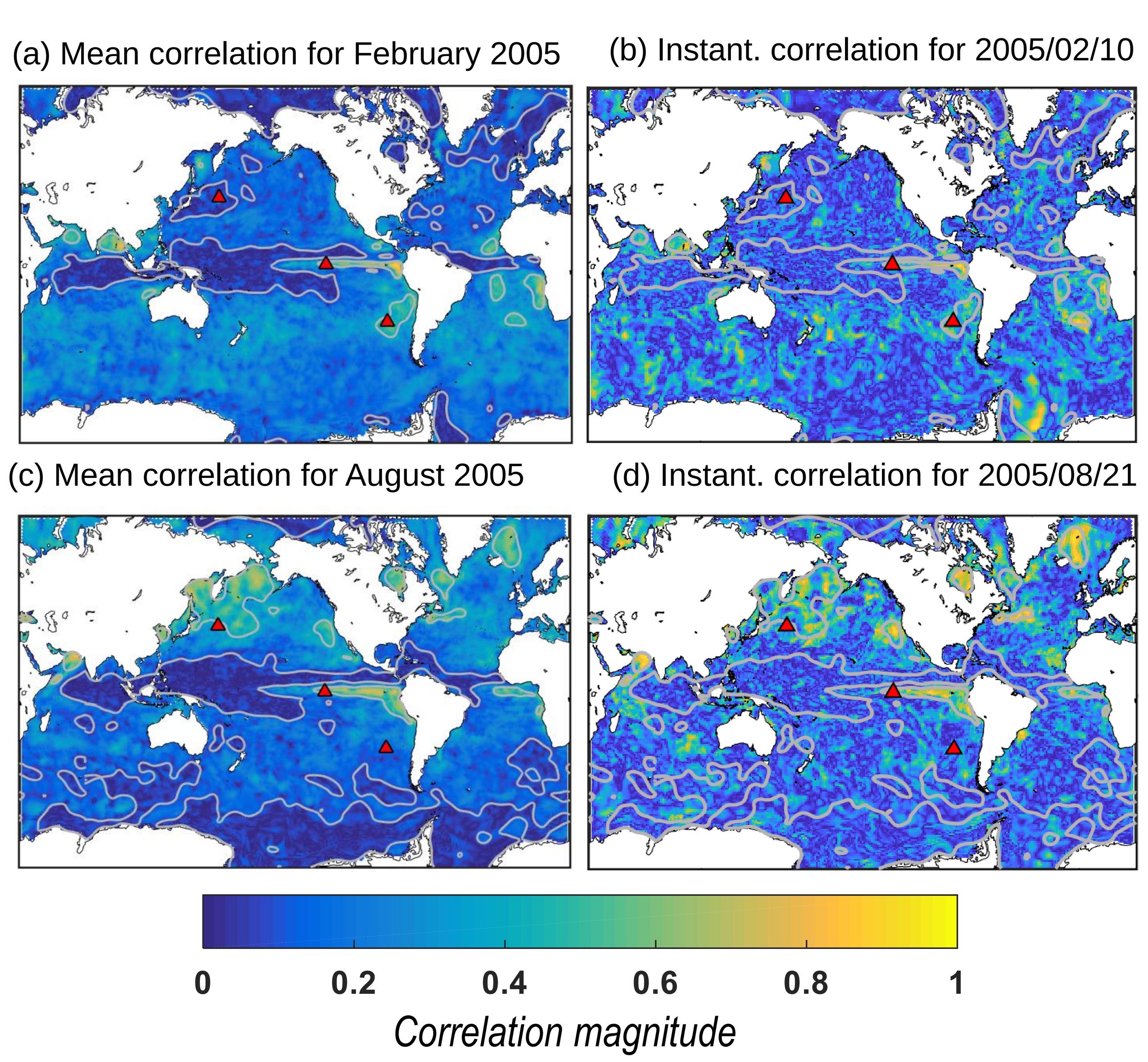

Figure 1: Absolute value of the correlation between SST and surface air temperature computed from 20-members of the CERA coupled reanalsyis. (a) Average of daily correlations for February 2005; (b) daily correlation for 2005/02/10; (c) average of daily correlations for August 2005; (d) daily correlation for 2005/08/21. The isolines of 0.1 and 0.4 monthly average correlations are shown in gray. Red triangles show locations of the single observation experiments.

Methods:

CERA-20C reanalysis (used in this study) reconstructs the past climate and weather over the 20th century (1901-2010) for the atmosphere, ocean, land, ocean waves and sea ice components of the Earth system. CERA-20C reanalysis assimilate only the surface pressure and marine wind observations in the atmosphere, as well as subsurface temperature and salinity profiles in the ocean. The atmosphere has a 125km horizontal grid resolution and the ocean has a one-degree horizontal grid. For this study, we focused on two special periods of the reanalysis when 20 members of the CERA analysis were available.

(C) Ocean surface correlations are correlated to temperatures in the atmospheric boundary layer when the MLD is shallow.

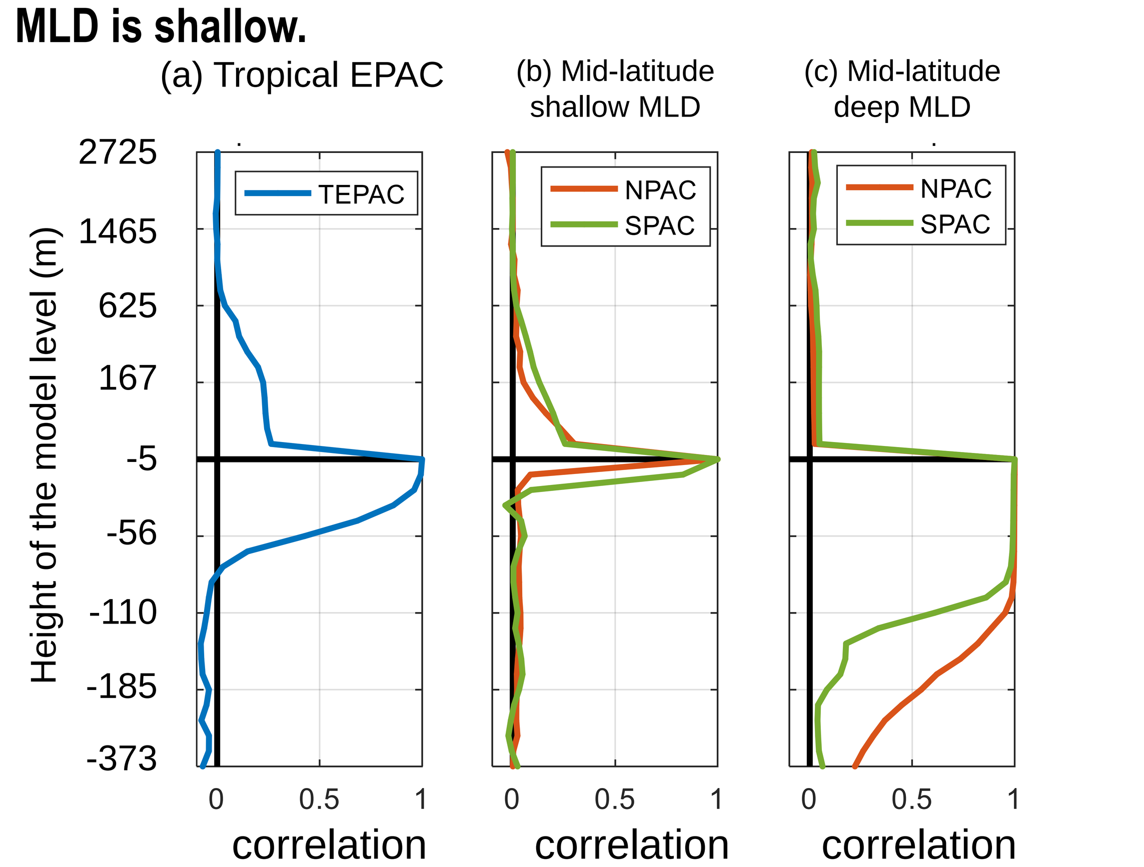

Figure 2: Averaged, localized ensemble correlations between SST and ocean/atmospheric temperatures at the same horizontal location for (a) Tropical East Pacific location; (b) mid-latitude locations when mixed layer was shallow (February for SPAC and August for NPAC locations); (c) mid-latitude locations when mixed layer was deep (August for SPAC and February for NPAC locations).

(D) Localization is essential for removing spurious correlations between ocean variables and free atmosphere.

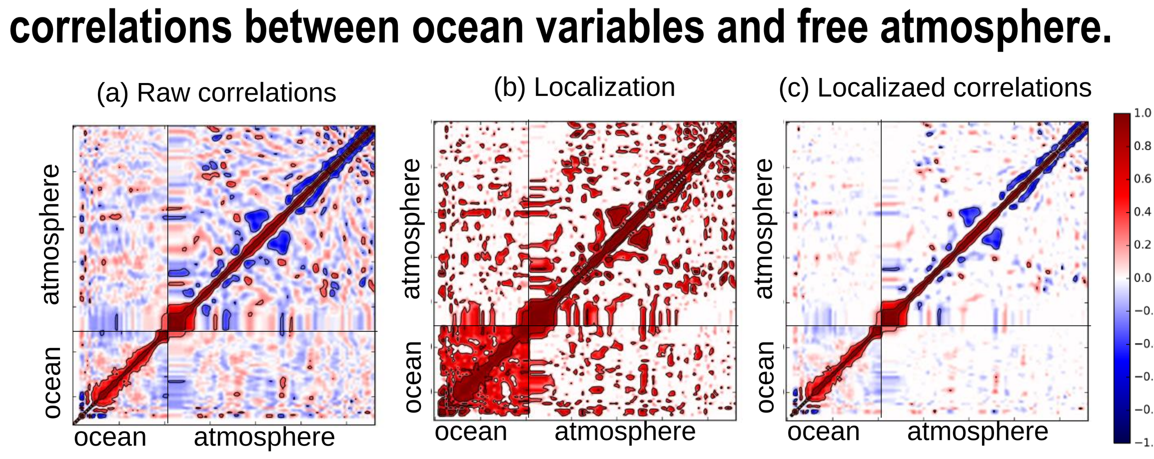

Figure 3: Raw ensemble correlation, localization matrix, and localized ensemble correlation for Tropical East Pacific on August 21st, 2005.

Role of the outer loop in coupled DA

Methods:

A series of single-observation experiments in a perfect twin framework has been conducted to evaluate the effectiveness and the efficiency of the outer loop coupling and the amplitude of the implicit cross-correlations. They are compared against a coupled assimilation system that explicitly specifies cross-correlations from an ensemble of coupled forecasts.

(E) Both the implicit outer loop and the explicit ensemble based methods produce equally skillful estimates of the coupled state in the middle of a 24 hour assimilation window.

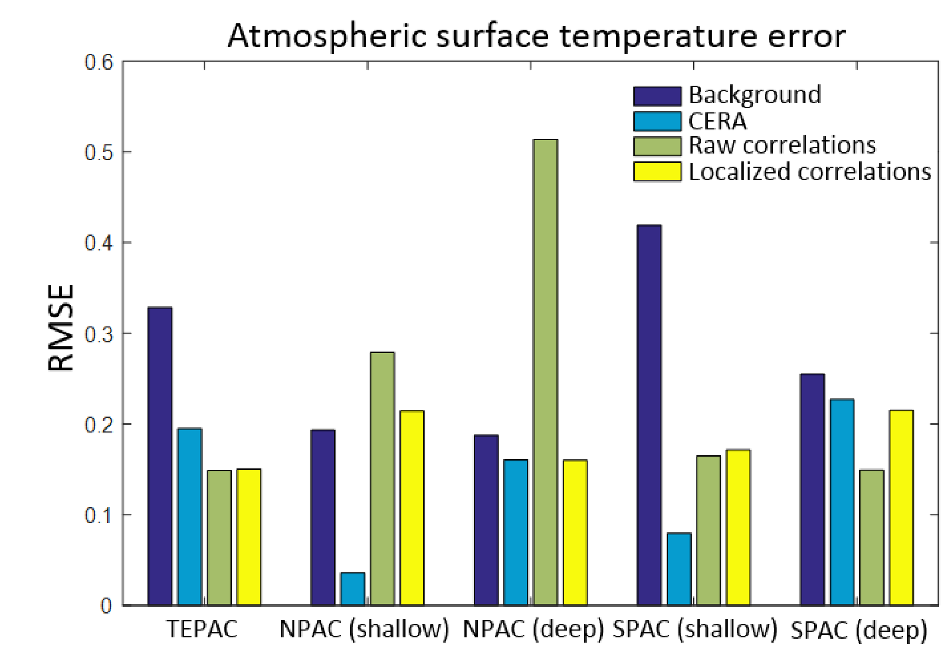

Figure 4: Atmospheric surface temperature RMS error in the middle of the assimilation window (after 12 hours). Errors are sorted by location and season (TEPAC all seasons, NPAC shallow, NPAC deep, SPAC shallow and SPAC deep) and by the type of the estimator (background (dark blue), CERA (light blue), raw explicit cross-correlation (green), and localised explicit cross-corelation (yellow)).

(F) Atmospheric variables of the coupled system require more outer iterations to converge.

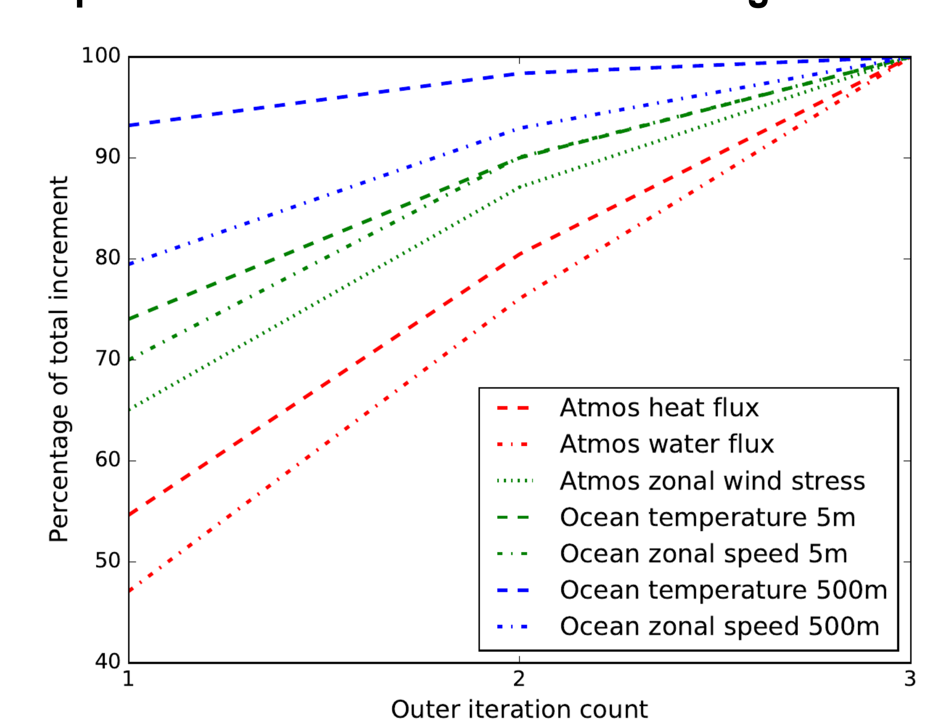

Figure 5: Percentage of the total increment computed at each outer iteration for different geophysical variables

(G) If coupling is present (e.g. when MLD is shallow), the atmospheric and ocean states synchronize within the first 6 to 10 hours of the assimilation window.

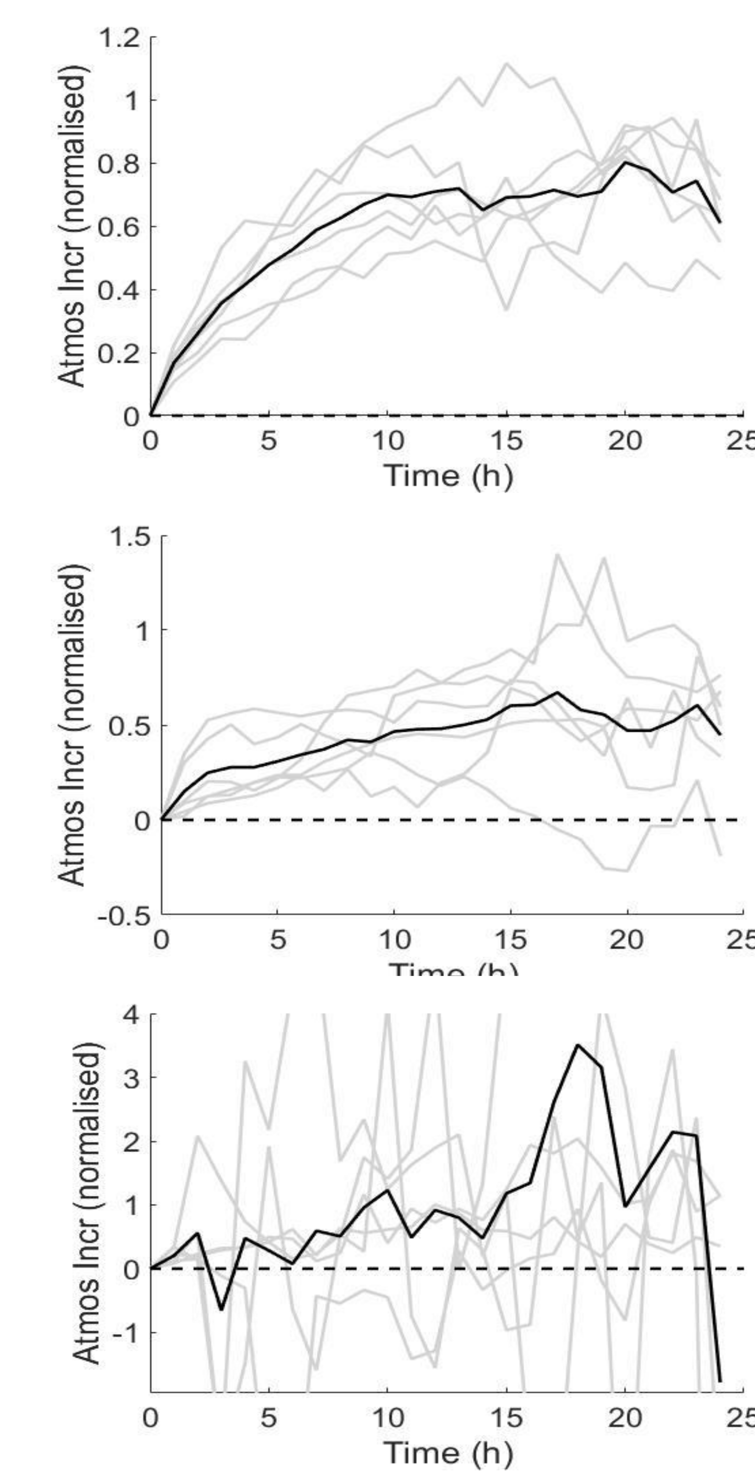

Figure 6: Response time of the atmospheric surface temperature increment to assimilation of the SST observation (Tropical East Pacific (a), shallow mixed layer cases for NPAC and SPAC (b), and deep mixed layer cases for NPAC and SPAC (c)). Plotted is the magnitude of the atmospheric increment in the CERA outer loop normalised by the magnitude of the SST perturbation.

Summary and conclusions:

We find that both the implicit outer loop and the explicit ensemble based methods produce equally skillful estimates of the coupled state in the middle of a 24 hour assimilation window. Our estimates of the speed of the outer loop convergence suggest that atmospheric and ocean states synchronise within the first 6 to 10 hours of the assimilation window. We conclude, that the outer loop coupling is effective when the window is long enough that original imbalances in the atmospheric and ocean increments to synchronise within the length of the assimilation window. On the other hand, we suggest that explicit coupling is preferable for data assimilation systems with short assimilation windows (e.g. 6 hours or less).