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Ensemble-based Experimental Atmospheric Reanalysis Using a Global Coupled Atmosphere–Ocean GCM

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To enhance the capability of the local ensemble transform Kalman filter (LETKF) with the Atmospheric general circulation model (GCM) for the Earth Simulator (AFES), a new system has been developed by replacing AFES with the Coupled atmosphere–ocean GCM for the Earth Simulator (CFES). An initial test of the prototype of the CFES–LETKF system has been completed successfully, assimilating atmospheric observational data (NCEP PREPBUFR archived at UCAR) every 6 hours to update the atmospheric variables, whereas the oceanic variables are kept unchanged throughout the assimilation procedure.

An experimental retrospective analysis–forecast cycle with the coupled system (CLERA-A) starts on August 1, 2008, and the atmospheric initial conditions (63 members) are taken from the second generation of AFES–LETKF experimental ensemble reanalysis (ALERA2). The ALERA2 analyses are also used as forcing of stand-alone 63-member ensemble simulations with the Ocean GCM for the Earth Simulator (EnOFES), from which the oceanic initial conditions for the CLERA-A are taken.

The ensemble spread of SST is larger in CLERA-A than in EnOFES, suggesting positive feedback between the ocean and the atmosphere. Although SST in CLERA-A suffers from the common biases among many coupled GCMs, the ensemble spreads of air temperature and specific humidity in the lower troposphere are larger in CLERA-A than in ALERA2. Thus replacement of AFES with CFES successfully contributes to mitigate an underestimation of the ensemble spread near the surface resulting from the single boundary condition for all ensemble members and the lack of atmosphere–ocean interaction.

In addition, the basin-scale structure of surface atmospheric variables over the tropical Pacific is well reconstructed from the ensemble correlation in CLERA-A but not ALERA2. This suggests that use of a coupled GCM rather than an atmospheric GCM could be important even for atmospheric reanalysis with an ensemble-based data assimilation system.

1. Introduction

Ensemble-based data assimilation techniques have been rapidly growing because of their advantages of the on-the-fly estimation of analysis and forecast errors, relative ease of implementation, and efficiency with parallel computers.

Miyoshi and Yamane [2007] applied the local ensemble transform Kalman filter (**LETKF**) to an atmospheric general circulation model (GCM), **AFES**, to construct the AFES–LETKF ensemble data assimilation system (**ALEDAS**). Miyoshi et al. [2007] performed one and a half years of AFES–LETKF experimental ensemble reanalysis (**ALERA**) using observational dataset of the Japan Meteorological Agency operational system. Currently the second generation of ALERA (**ALERA2**) is underway with the latest version of AFES and LETKF (**ALEDAS2**), assimilating observational data of the National Centers for Environmental Prediction (NCEP) global data assimilation system (PREPBUFR) [Enomoto et al., 2013].

In ensemble data assimilation systems based on atmospheric GCMs (including ALEDAS), however, surface boundary conditions such as sea surface temperature (SST) and sea-ice distribution are the same among all ensemble members, which leads to an underestimation of the ensemble spread (an overestimation of the forecast accuracy) near the surface. Additionally air–sea coupled phenomena, e.g., lead–lag relationship between SST and precipitation over the tropics, are not well reproduced in such systems. To overcome these problems, we replace AFES with a coupled atmosphere–ocean GCM, **CFES**, to develop the CFES–LETKF ensemble data assimilation system (**CLEDAS-A**).

2. CFES–LETKF Ensemble Data Assimilation System

The resolution of the atmospheric component of CFES used in the system is **T119** (~100 km) in the horizontal and **48 layers** in the vertical, the same as in ALERA2. The oceanic component has a resolution of **1/2°** (~50 km) in the horizontal and **54 levels** in the vertical, and is coupled with the atmospheric component every hour.

An experimental retrospective analysis–forecast cycle with CLEDAS-A (63 members) is conducted from August 1 to September 30, 2008, assimilating the atmospheric observational data (NCEP PREPBUFR archived at UCAR) every 6 hours to update the atmospheric variables, whereas the oceanic variables are kept unchanged throughout the assimilation procedure. The result is referred to as **CLERA-A**.

The 63-member initial conditions of the atmospheric component are taken from ALERA2. The initial conditions of the oceanic component are made by stand-alone ensemble ocean simulations (**EnOFES**) forced by each member of ALERA2 after 60-year spin-up integration.

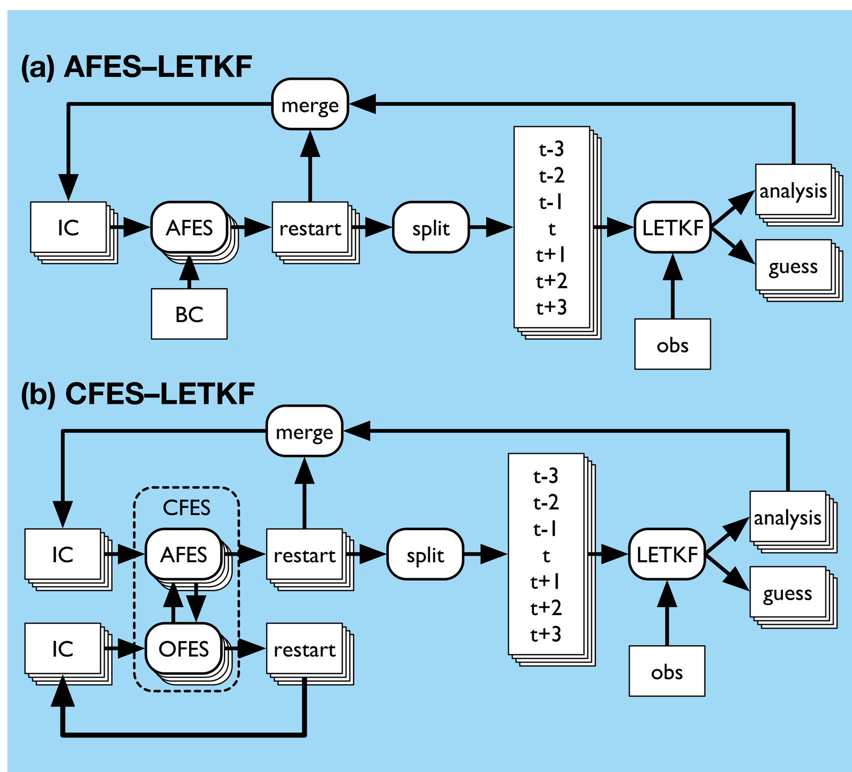

Figure 1: The data flow charts of an analysis–forecast cycle for (a) ALEDAS2 and (b) CLEDAS-A. Rectangles represent input/output data, and round rectangles represent processes.

3. Results

3.1. Comparison of ALERA2 and CLERA-A

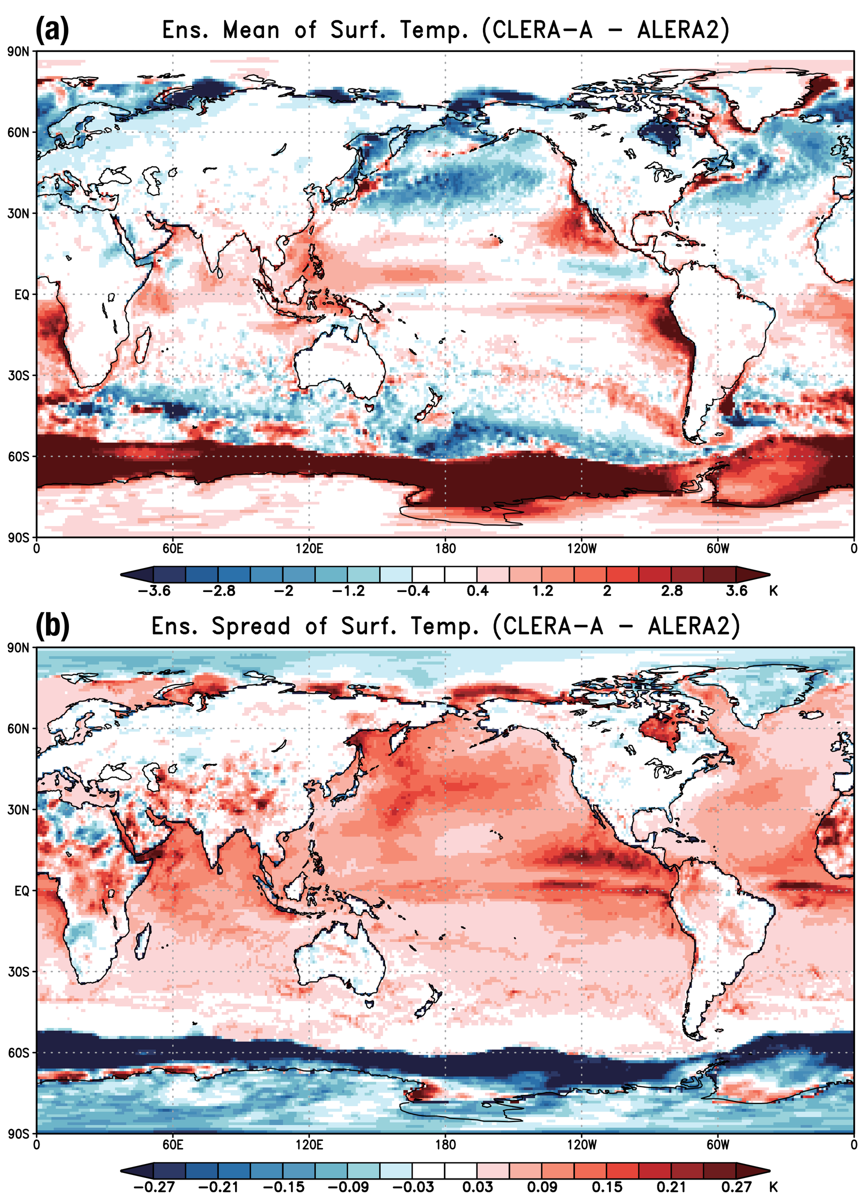

Figure 2: Difference (CLERA-A minus ALERA2) in (a) ensemble mean and (b) spread of forecasted surface temperature (unit in K) averaged over the experimental period.

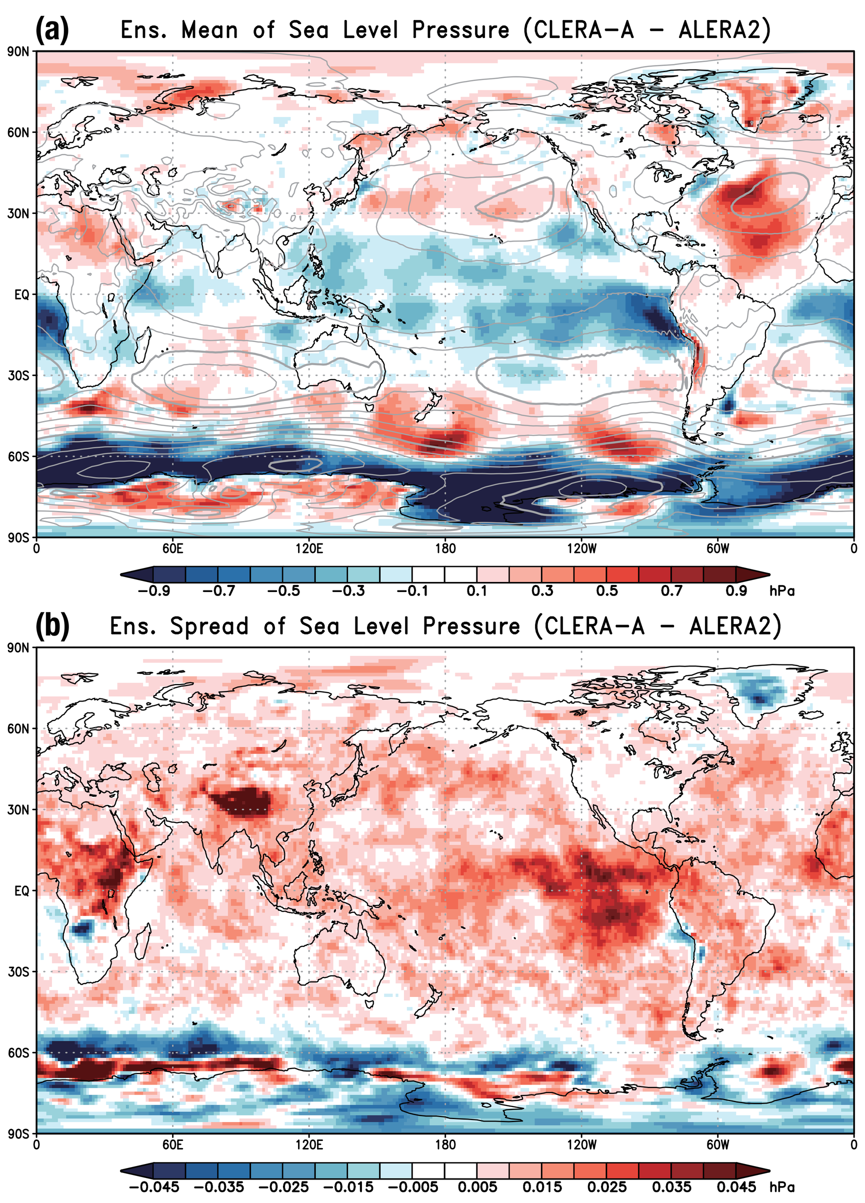

Figure 3: Same as in Figure 2 but for analyzed surface pressure (unit in hPa).

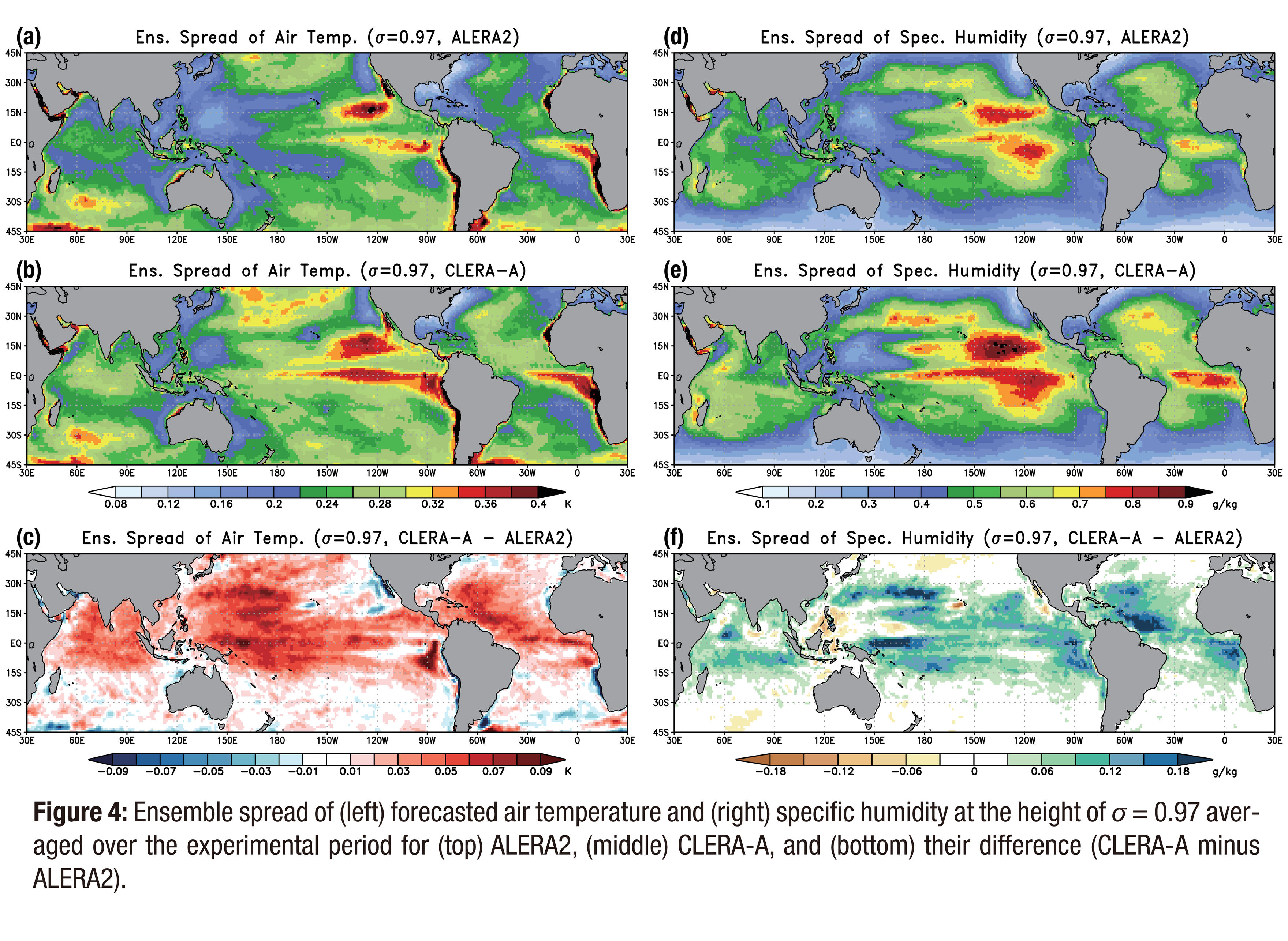

Figure 4: Ensemble spread of (left) forecasted air temperature and (right) specific humidity at the height of $\sigma = 0.97$ averaged over the experimental period for (top) ALERA2, (middle) CLERA-A, and (bottom) their difference (CLERA-A minus ALERA2).

3.2. Ensemble Covariance and Correlation

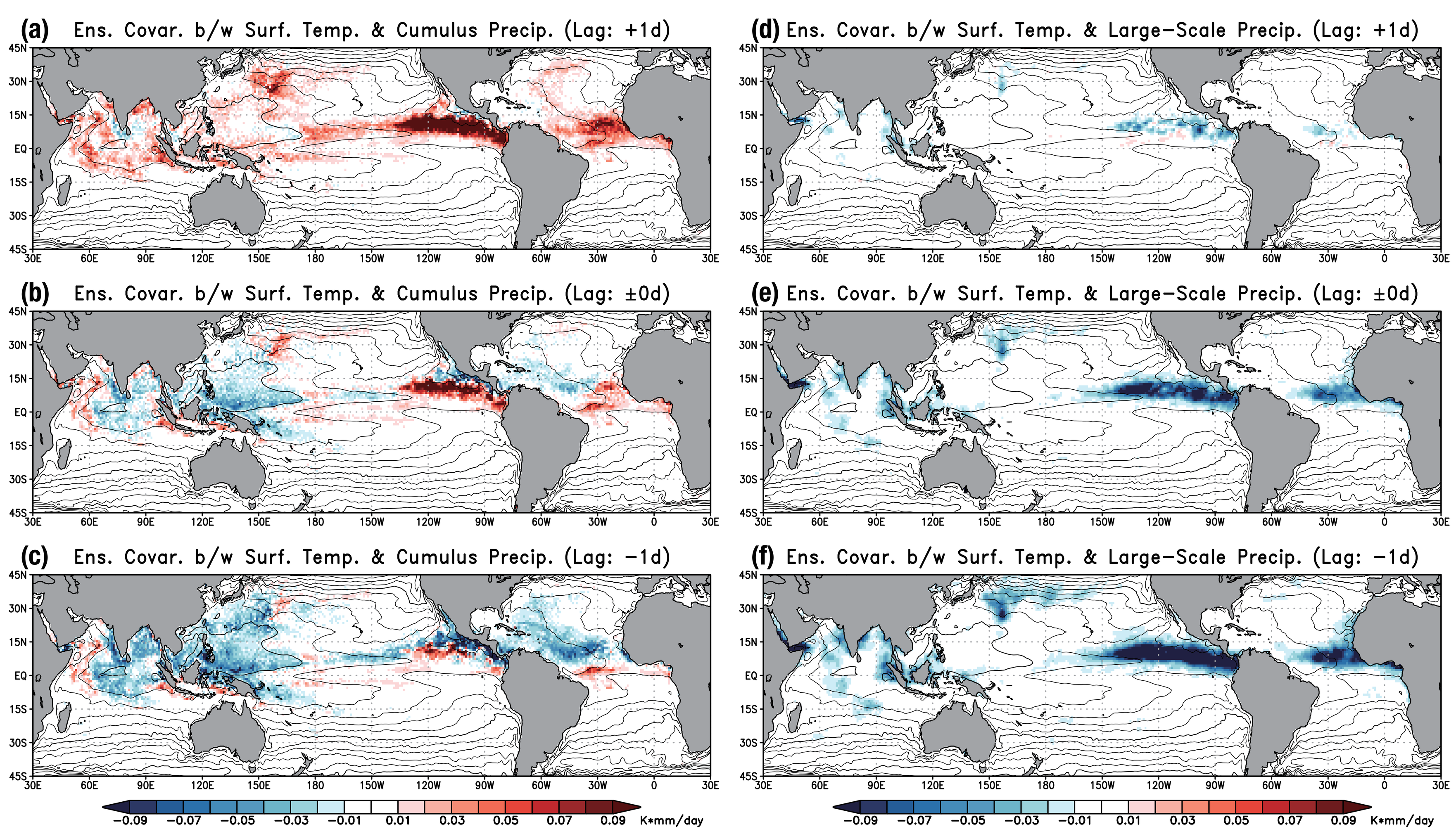

Figure 5: Lag ensemble covariance between forecasted SST and precipitation induced by (left) cumulus convection and (right) large-scale condensation in CLERA-A. (Top) SST leads precipitation 1 day, (middle) simultaneous, and (bottom) precipitation leads SST 1 day.

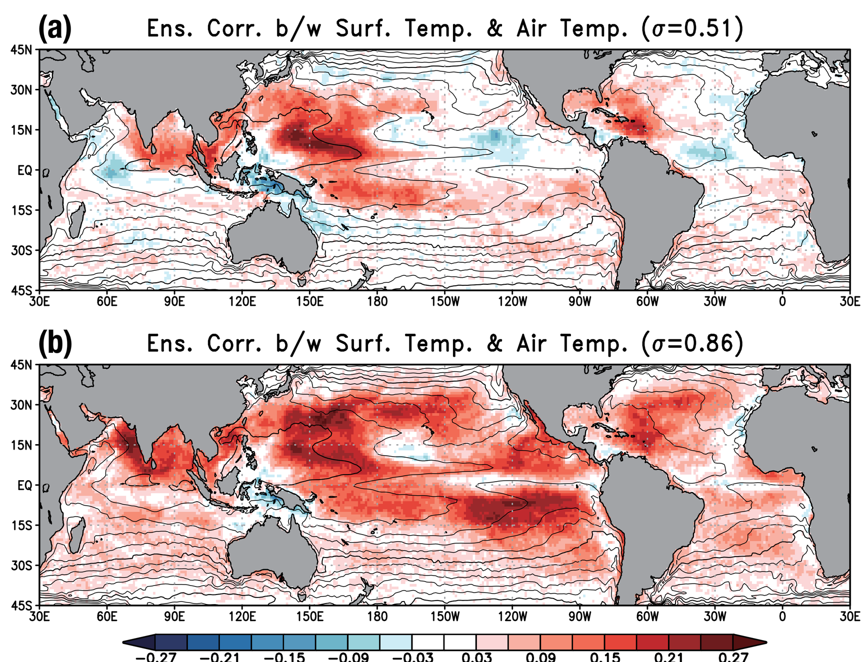

Figure 6: Vertical ensemble correlation between forecasted SST and air temperature at the height of (a) $\sigma = 0.51$ and (b) $\sigma = 0.86$ in CLERA-A averaged over the experimental period.

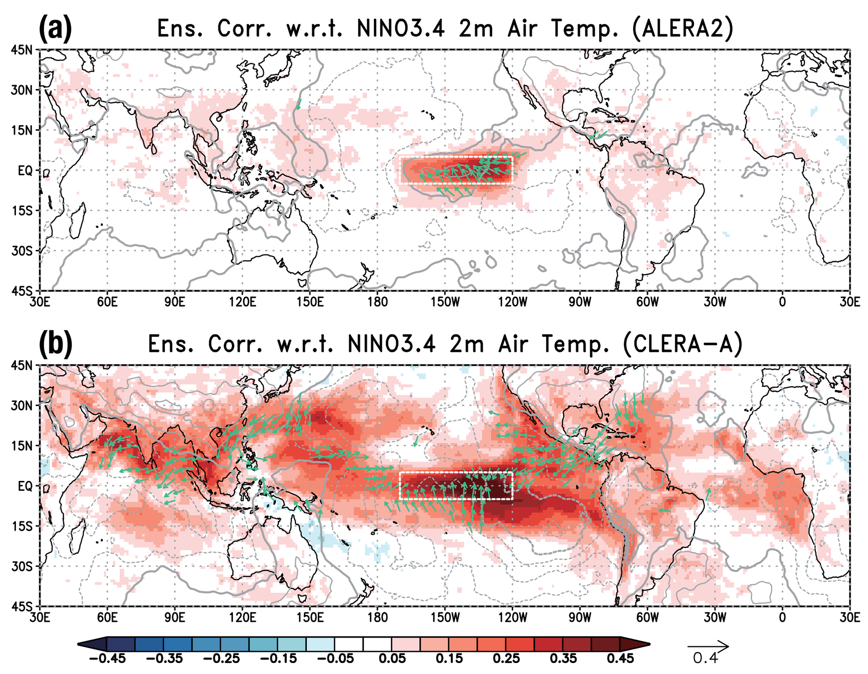

Figure 7: Ensemble correlation of forecasted 2-m air temperature (color), 10-m winds (green arrows), and surface pressure (gray contour) with respect to 2-m air temperature in the NINO3.4 region (indicated by a white rectangle) averaged over the experimental period for (a) ALERA2 and (b) CLERA-A.