Using analysis corrections to represent systematic and stochastic model error

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Analysis Correction-based Additive Inflation

- **Goal:** decrease model bias and increase spread in ensemble forecasts

  - Compute $\delta x^F_m = \delta x^a + \alpha [\delta x^a_m - \delta x^a_e]$  

  - Incrementally add $\delta x^F_m / T$ at each time step ($T =$ time steps/6-hr forecast) to $T,U,V,Q,P$

  - Compute/add a new $\delta x^F_m$ over each 6-hr period of the forecast

- Sample from a 1-year archive of analysis corrections

  $$\delta x^a = \text{analysis correction (or increment)}$$  
  $$\delta x^a = x^a - x^f$$  

  *analysis − forecast*

**Crawford et al. 2020 MWR; Bowler et al. 2017 QJRMS**
Structure of average analysis corrections

\[ \delta x^F_m = \bar{\delta x^a} + \alpha [\delta x^a_m - \bar{\delta x^a}] \]

- Example of the mean analysis correction to wind speed
- Illustrates how the DA system is systematically adjusting the background
- In the tropics, represents a slowing of the trade winds

Crawford et al. 2020
Structure of average analysis corrections

- Mean analysis corrections to surface pressure (left) and temperature (right)
- Large dependence on time-of-day
- Average corrections show a clear migration westward between 00Z and 18Z
- We now use analysis corrections relative for the forecast time-of-day to produce the perturbations

Crawford et al. In prep.
Comparison to true estimate of the bias

- Average analysis corrections (blue) verify well against observation based estimates of the bias (red)
- Though corrections tend to be an underestimate of the true bias

Crawford et al. 2020

\[ \text{measured bias } (y - H(x^f)) \]
\[ \text{average correction } -(H(x^o) - H(x^f)) \]
Application to Navy ESPC Ensemble

- 1-year of 45-day ensemble forecasts run once per week (total of 52 forecasts) using Navy ESPC system (Barton et al. 2021)

- Bias scorecard illustrates a largely positive impact to the forecast bias, especially in NE and TR

Crawford et al. In prep.
• While both cases appear degraded, the true biases illustrate that ACAI is able to slow the negative trends

• Though in Z500 (top-right) ACAI tends to over correct the bias at first causing the degradation in the scorecard

_Crawford et al. In prep._
Application to Navy ESPC Ensemble

- Scorecard of spread-skill shows a near across the board improvement in first 3-weeks, with continued improvement in NE and TR out to 45 days

- Some neutral or degraded performance in southern extra-tropics at later leads

\[ \text{Bold outline/gray shading indicates 95\% significant} \]

Verification against ECMWF analyses

Crawford et al. In prep.
Top figures show the reduction of bias in wind speed and moisture by including ACAI in coupled forecasts.

Results in a significant reduction of IVT bias (bottom)

*Reynolds et. al., 2022 MWR*
• ACAI’s reduction in positive TPW bias over Sahel and negative TPW bias over tropical Atlantic.

• In contrast, ACAI has little (slightly negative) impact over western-central tropical Pacific and tropical Indian Ocean.

Reynolds et. al., 2022 MWR
• Hourly coupling in the Navy ESPC will allow cross-component impact of model error techniques

• Tropical SST biases are reduced by the application of the ACAI perturbation to the atmospheric component (NAVGEM)

Crawford et al. In prep.
• Have also explored the use of a moving archive (MA) of analysis corrections vs. a static archive (SA)

• Both methods present a significant improvement over the baseline system, but larger improvement from ACAI_{SA} after ~week-2

• ACAI_{MA} is beneficial in that one does not need to generate a new archive when upgrades are made to the DA or forecast system

_Crawford et al. In prep._
Thanks!