Regionally Enhanced Global (REG) Data Assimilation

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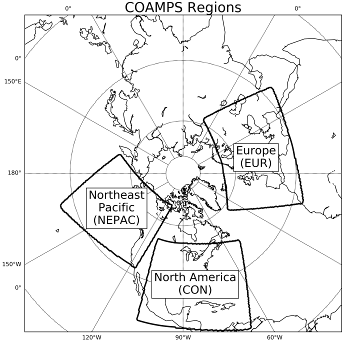
General idea: Assume a forecast center that prepares both global and limited area analyses. Let's prepare the global and limited area analyses of the center valid at the same time by a single computational process (Merkova et al. 2011; Yoon et al. 2012; Kretschmer et al. 2015)

Illustration for 3 limited area domains:



Potential benefits of the approach

- Reduced development, maintenance, and computational cost
- The limited area analysis is informed about the large scale flow and may benefit from observations outside of the limited area domain
- The limited area analysis may benefit from the direct use of satellite radiance observations
- The global analysis may benefit from the availability of higher resolution model information in the interior of the limited area domain

REG DA is the latest algorithmic implementation of the general idea from my research group (Michael Herrera and Adam Brainard) and our collaborators (Craig Bishop and Dave Kuhl from NRL)

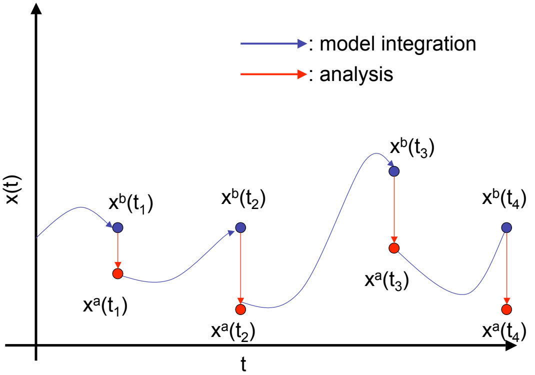
Recall My Favorite Quote from Last Year

"*The sciences do not try to explain, they hardly even try to interpret, they mainly make models. By a model is meant a mathematical construct which, with the addition of certain verbal interpretations, describes observed phenomena. The justification of such a mathematical construct is solely and precisely that it is expected to work."*– John von Neumann

Sequential DA–Extended Kalman Filter (EKF):

$$\mathbf{x}^a = \mathbf{x}^b + \delta\mathbf{x}^a, \qquad \delta\mathbf{y} = \mathbf{y}^o - \mathcal{H}\left(\mathbf{x}^b\right),$$

The analysis increment $\delta\mathbf{x}^a$ is computed by $\delta\mathbf{x}^a = \mathbf{K}\delta\mathbf{y}$, where $\mathbf{K} = \mathbf{P}^b\mathbf{H}^T\left(\mathbf{H}\mathbf{P}^b\mathbf{H}^T + \mathbf{R}\right)^{-1}$ or a 4D-Var



An Issue: Good Observations May Shock the Forecast Model

- A (flow-dependent) **background bias** $\mathbf{b}\left(\mathbf{x}^b\right)$ leads to a biased prediction $\mathcal{H}\left(\mathbf{x}^b\right)$ of the observations, which in turn leads to a large innovation $\delta\mathbf{y} = \mathbf{y}^o - \mathcal{H}\left(\mathbf{x}^b\right)$
- There are two alternative strategies to deal with this situation:
  1. **Strategy 1:** Pushing $\mathbf{x}^a$ closer to $\mathbf{y}^o$, (further away from $\mathbf{x}^b$)
  2. **Strategy 2:** Keeping $\mathbf{x}^a$ closer to $\mathbf{x}^b$, (further away from $\mathbf{y}^o$)
- **Strategy 1** works when the resulting large analysis increment $\mathbf{x}^a$ does not lead to a **strong adjustment process** (in my experience, a real but rare situation)
- **Strategy 2** is advantageous when the original increment $\mathbf{x}^a$ would lead to a **strong adjustment process** (in my experience, the typical situation)

Two Ways to State the Problem

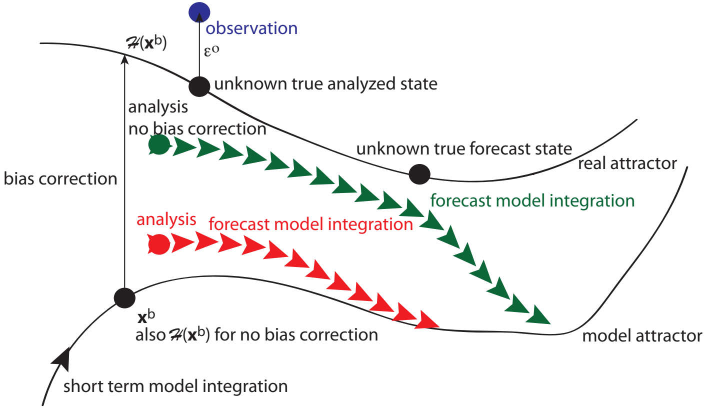
1. The background $\mathbf{x}^b$ is a state on (or very near to) the **model attractor.** The observation $\mathbf{y}^o$ observes a state on the **attractor of the true atmosphere.** When there is a substantial difference between the two attractors, forcing the analysis near to the true attractor leads to a "jump" of the state to the model attractor (strong adjustment process)
2. By definition, the **observation function** should satisfy

$$\mathbf{y}^o - \mathcal{H}\left(\mathbf{x}\right) = \varepsilon^o, \tag{1}$$

   for any value of $\mathbf{x}$, where the observation error ε^o is a random variable with mean $\mathbf{0}$ and covariance matrix $\mathbf{R}$

$\mathcal{H}\left(\mathbf{x}\right)$ should include all corrections necessary to satisfy Eq. (1)

Schematics Illustration for a 2-dimensional State Space



Examples for the Correction of $\mathcal{H}(\mathbf{x})$

- **Observation bias correction** (e.g., for radiance observations) is a correction of $\mathcal{H}\left(\mathbf{x}^b\right)$ rather than $\mathbf{y}^o$
- For instance, adjusting the surface pressure to the model orography should be done in $\mathcal{H}(\mathbf{x})$ rather than correcting $\mathbf{y}^o$
- $\mathcal{H}\left(\mathbf{x}^b\right)$ can be biased because
  - $\mathcal{H}(\cdot)$ is biased, and/or
  - $\mathbf{x}^b$ is biased
- **REG DA** is an attempt to account for the bias in $\mathbf{x}^b$ in the computation of $\mathcal{H}\left(\mathbf{x}^b\right)$:

$$\mathbf{x} = (c-1)\mathbf{x}_g + (c)\mathbf{x}_\ell \qquad 0 < c < 1.$$

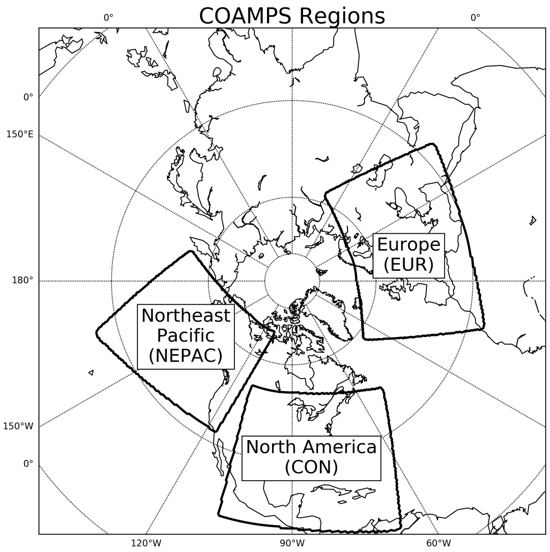
where c is the blending coefficient, $\mathbf{x}_g$ is the global model state and $\mathbf{x}_\ell$ is the limited area model state, but the data assimilation updates the **global background** $\mathbf{x}_g^b$

Implementation on the Navy Model Suite

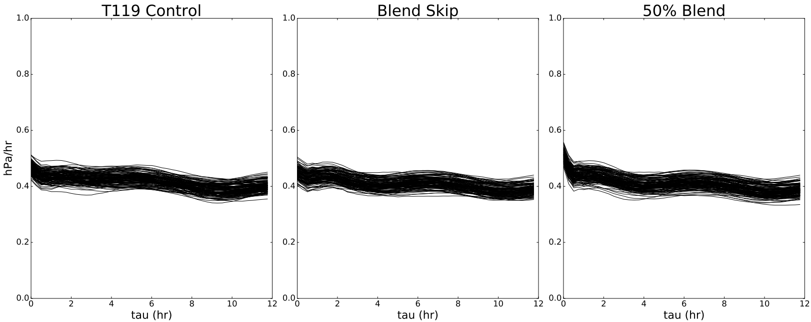
Manuscripts: Herrera et al. 2017 and Brainard et al. 2017

- **Global model:** NAVGEM T119
- **Limited area model:** COAMPS with 32 km
- **Data Assimilation:** NAVDAS-AR with TLM at resolution T119
- **Blending Grid, $\mathbf{y}^o - \mathcal{H}(\mathbf{x})$:** T319 Gaussian Grid
- **Blending Coefficient:** $\alpha = 0.3, 0.5, 1.0$
- **Number of limited area domains:** 3
- **Test Period:** from 0000 UTC, October 1, 2012 to 0000 UTC, November 1, 2012 (includes Hurricane Sandy)
- **Limited Area Analysis:** Interpolated global analysis (using the standard interpolation routines)
- **Verification:** ECMWF analyses (NAVGEM, COAMPS), RAOB (COAMPS)

Configuration: Limited Area Domains

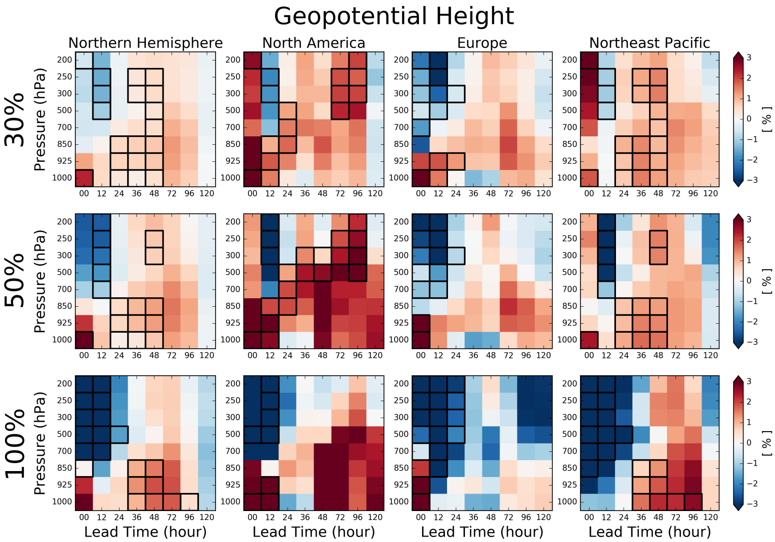


Atmospheric Balance in NAVGEM



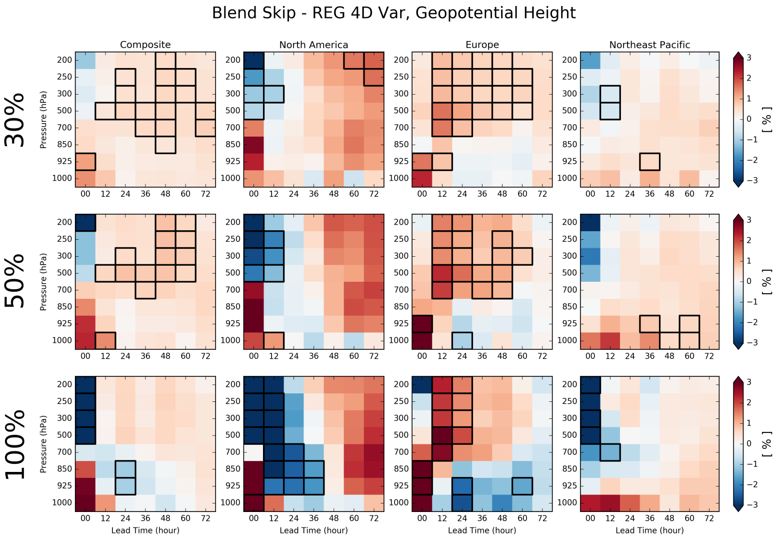
Geopotential Height: NAVGEM Forecasts

Red: Improvement Blue: Degradation



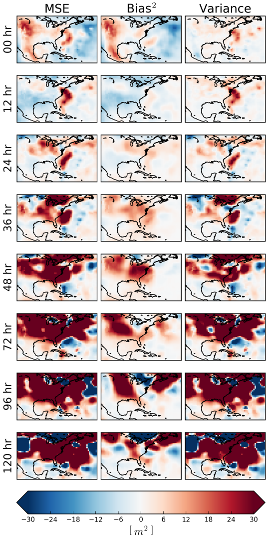
Geopotential Height: COAMPS Forecasts

Red: Improvement Blue: Degradation



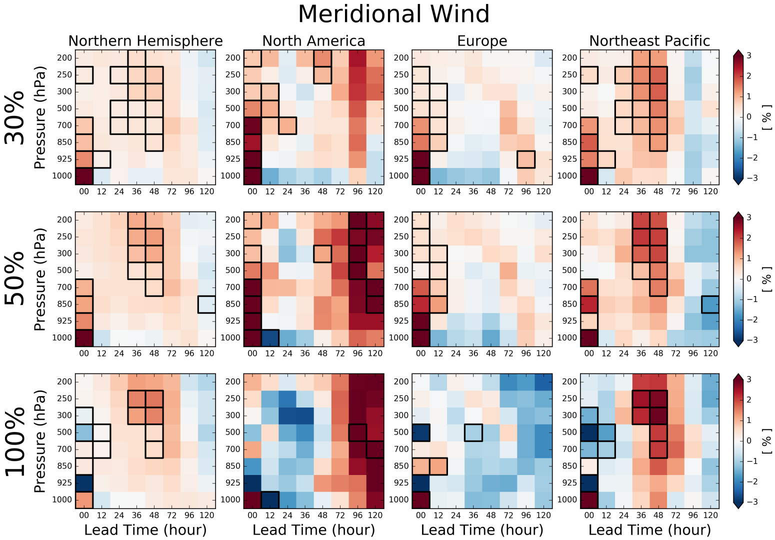
Geopotential Height: NAVGEM Forecasts

Red: Improvement Blue: Degradation



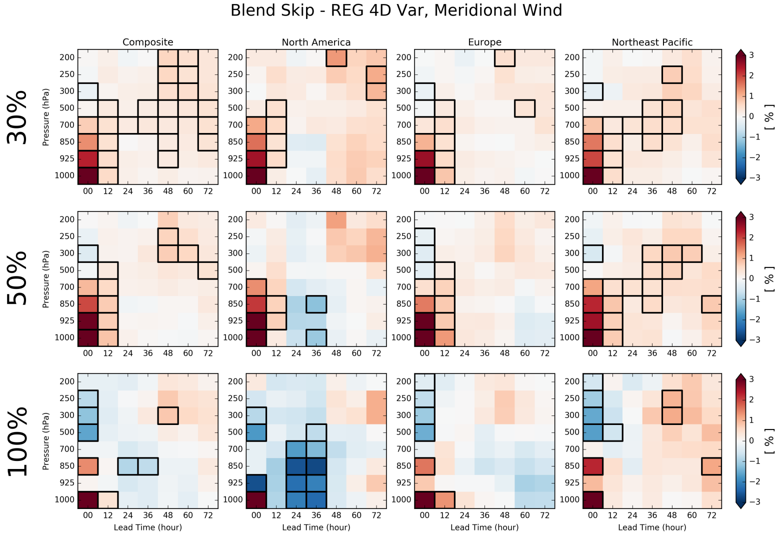
v-wind: NAVGEM Forecasts

Red: Improvement Blue: Degradation

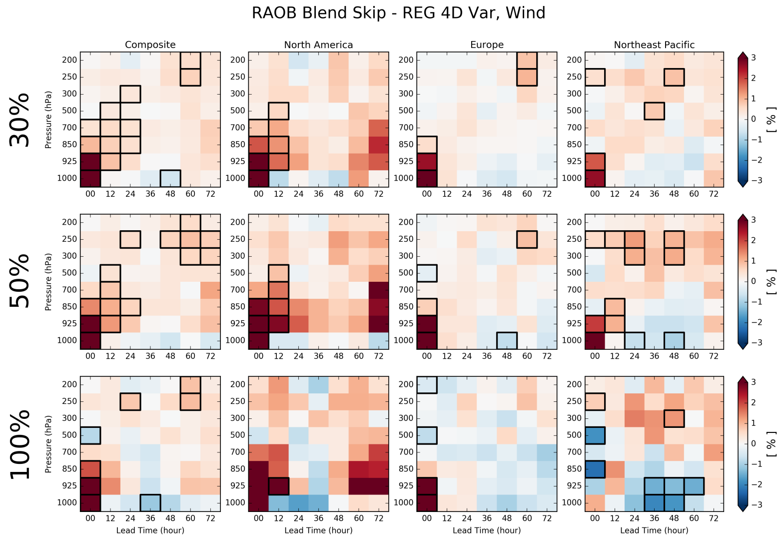


v-wind: COAMPS Forecasts

Red: Improvement Blue: Degradation

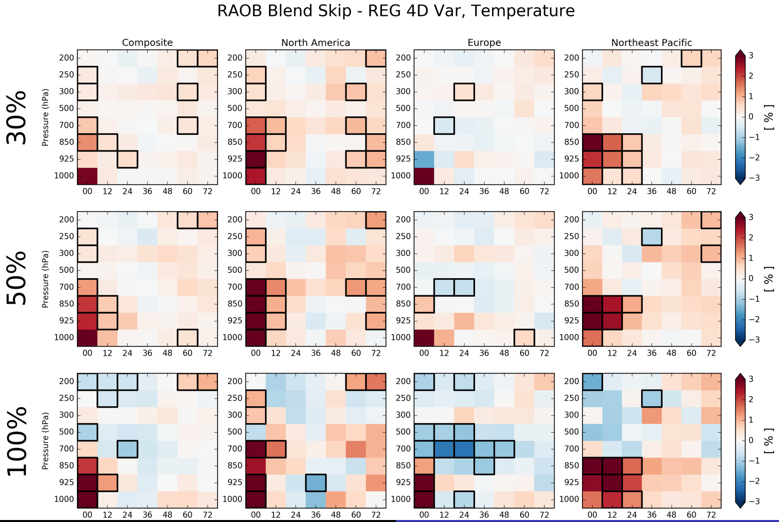


Red: Improvement Blue: Degradation



Air Temperature: COAMPS Forecasts (RAOB verification)

Red: Improvement Blue: Degradation



Concluding Remarks

- Results with prototype REG 4D-Var system at reduced resolutions are promising
- **Ongoing and Future Efforts** (Max Gavryla's thesis research):
  - Implementation of a different approach for the preparation of the limited area analyses
  - Analysis/forecast experiments at operational resolution
  - Replacement of 4D-Var by the Local Ensemble Transform Kalman Filter (LETKF)–Development of REG LETKF