A comparison of EnKF, 4DVar and E4DVar for a case of tropical cyclogenesis: more than just forecast results

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Coupling EnKF and 4DVar

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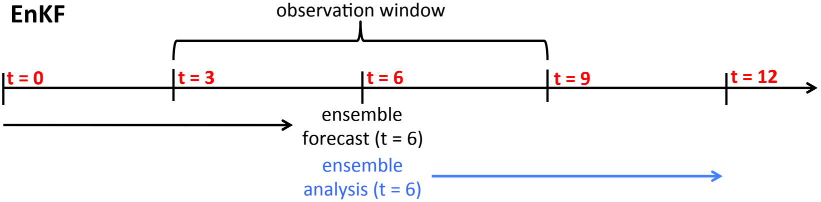
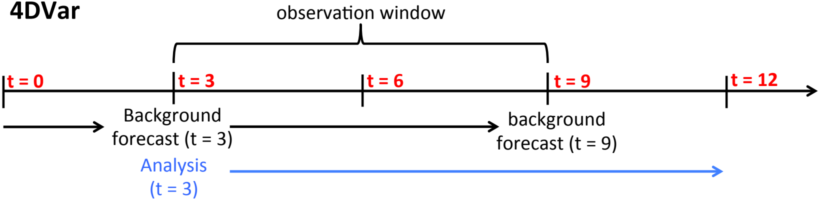
EnKF



4DVar



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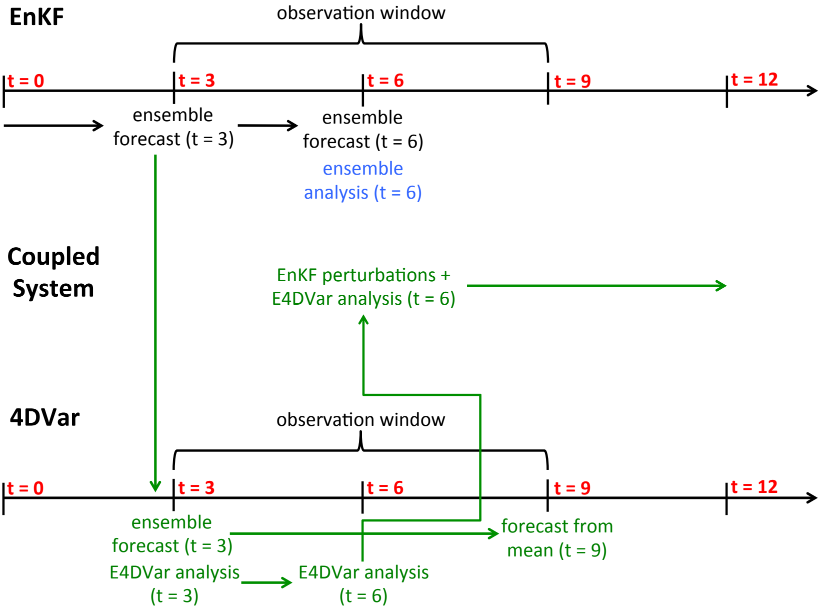
Coupling EnKF and 4DVar



E4DVar

To find the analysis at time t ($\mathbf{x_t^a}$), the standard 4DVar method seeks an increment ($\delta\mathbf{x_t}$) from a background state ($\mathbf{x_t^b}$)

$$\mathbf{x_t^a} = \mathbf{x_t^b} + \delta\mathbf{x_t}.$$

The $\delta\mathbf{x_t}$ is found by minimizing the cost function

$$J(\delta\mathbf{x_t}) = J_b(\delta\mathbf{x_t}) + J_o(\delta\mathbf{x_t}).$$

E4DVar

In E4DVar, the $\delta\mathbf{x_t}$ is split into two parts

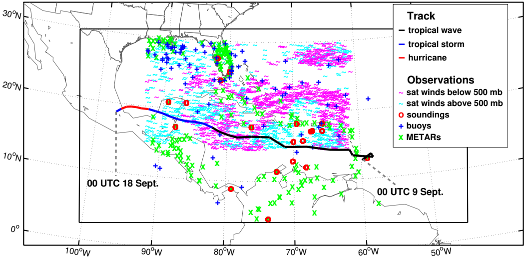
$$\delta\mathbf{x_t} \;=\; \delta\mathbf{x_t^c} + f(\alpha).$$

The cost function is then minimized with respect to two sets of control variables ($\delta\mathbf{x_t^c}$ and α)

$$J(\delta\mathbf{x_t^c}, \alpha) \;=\; \beta_1 J_b(\delta\mathbf{x_t^c}) + \beta_2 J_e(\alpha) + J_o(\delta\mathbf{x_t^c}, \alpha),$$

(Lorenc, Q. J. R. Meteorol. Soc, 2003)

Case study: Hurricane Karl (2010)



Hurricane Karl (2010) developed from a broad low-pressure system that initiated near the northern coast of South America on 8 Sept., and became a tropical depression on 18 UTC 14 Sept.

- Pre-genesis Karl was targeted during the Predepression Investigation of Cloud Systems in the Tropics (PREDICT) field campaign.
- This study uses the WRF model to perform a set of cycling data assimilation experiments over the entire life cycle of Karl.

Data assimilation configuration

EnKF:

- 13.5-km horizontal grid spacing and 34 vertical levels
- 60 ensemble members
- 80% covariance relaxation to the prior
- 900 km radius of influence

Data assimilation configuration

4DVar:

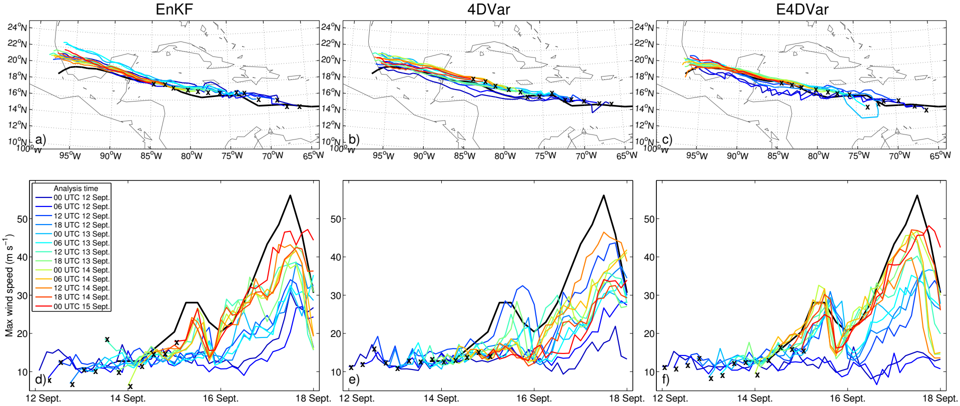
- Multi-incremental version with 13.5-km grid spacing outer loops and 40.5-km grid spacing inner loops
- WRF CV5 control variables
- Default length scales and amplitudes from month-long climatological covariance estimate

Data assimilation configuration

E4DVar:

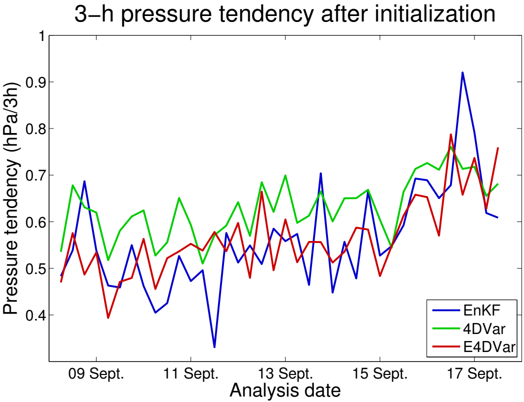
- EnKF component uses the previously mentioned setup
- The ensemble (α) control variables are preconditioned for localization using a 900-km radius of inluence
- The hybrid analyses use 80% of the ensemble increment and 20% of the climatological increment

Deterministic track and intensity forecasts



Forecasts are run from each analysis time to 00 UTC 18 Sept. using a 4.5-km nested domain.

Balance



- Domain-averaged dry surface pressure tendency is used to quantify imbalance following each data assimilation cycle.
- Pressure tendencies in the E4DVar simulations are comarable to EnKF, both of which perform better than 4DVar.
- The E4DVar system appears to be the most stable, with fewer spikes in pressure tendency.

Cost

- Solutions to 4DVar and E4DVar are found by searching down gradient of the cost function (e.g., conjugate gradient method).
- These methods require many iterations to adjust the control variables using information from the gradient of J.
- Each iteration requires the integration of the tangent linear and adjoint model (can be very expensive).

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Inner-loop iterations are averaged over the 40 cycles:

	4DVar	E4DVar
Mean iterations	37.5	25.6

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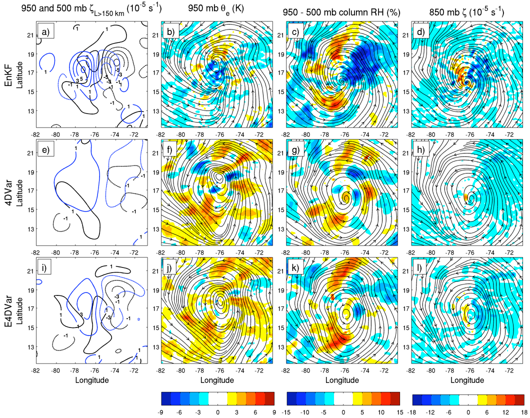
EnKF, 4DVar and E4DVar analysis increments



- The EnKF produces the largest vorticity increments at all levels to move the vortex farther westward.
- The length scale of the 4DVar increments is limited mostly by the parameters used to specify the covariance in J_b.

- Moisture is not included as a control variable in 4DVar (using CV5), so increments to θ_e and column RH must come from T and P, or adjustements to specific humidity using the adjoint.

Conclusions

- An E4DVar data assimilation system outperformed the standalone methods for a case of tropical cyclogenesis.
- Coupling EnKF with 4DVar improves the initial condition balance over multi-incremental 4DVar.
- The use of ensemble information in 4DVar speeds the minimization of the cost function.
- Introducing ensemble perturbations into the 4DVar cost function can yield analysis increments that are far different from EnKF and 4DVar.