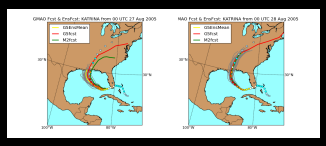
Preliminary Studies to Configure the NASA GMAO Hybrid-4dEnVar System



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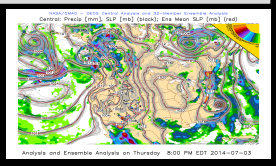


Introduction

The present work is a preliminary study on establishing an adequate configuration for the upcoming upgrade of NASA GMAO's near-real time system from its hybrid 3dVar to hybrid 4dEnVar.

Combined with analysis from the Gridpoint Statistical Interpolation (GSI) system, GMAO has used the incremental analysis update (IAU) procedure of Bloom et al. (1996) as its 3d assimilation methodology. In updating to 4d it is natural to implement a 4dIAU strategy (e.g., Lorenc et al. 2015).

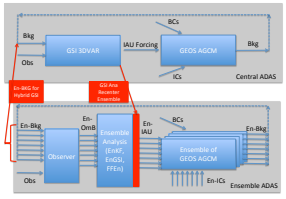
The upcoming hybrid 4dEnVar upgrade will also be accompanied by an increased horizontal resolution taking the present 25 km system to 12.5 km.

The series of experiments examined here include a mix of various configurations and resolutions. Most of the configuration studies have been done using the 25 km system; we explicitly indicate as appropriate when the 12.5 km system is used.

The GMAO DAS

The GMAO data assimilation is composed of two data assimilation systems running side-by-side. The primary component is a hi-resolution system that uses GSI for its main analysis, configured to solve either a hybrid 3dVar or a hybrid 4dEnVar minimization problem.

The secondary component is composed of a lower resolution system that uses a Square-Root Ensemble Kalman filter (EnKF) to analyse the members of an ensemble of model forecasts.



Schematic representation of the two-system GMAO atmospheric DAS. The primary hi-resolution system (top) produces a single deterministic forecast from either a hybrid 3dVar or a hybrid 4dEnVar analysis. This latter makes use of an ensemble of background states generated by the secondary assimilation system (bottom). The two systems are coupled by the hi-resolution system providing the analysis to recentre the members of the ensemble about, and by the low resolution system providing the ensemble of backgrounds to the central analysis (see Todling and El Akkraoui 2013).

DAS Configuration

Configurations of the present (black) and upcoming (red) GMAO DAS are shown in the table below.

	Primary System	Secondary System
Model	25 km 12.5 km	32 x 100 km 32 x 50 km
GSI : hyb3dVar: 2 x100 hyb 4dEnVar: 2x TBD	50 km 25 km	N/A
EnKF (3D)	N/A	32 x 100 km
IAU	3D 4D	3D 3D

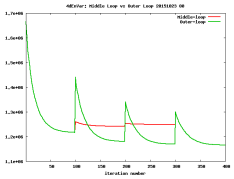
Alternative configurations of the system are tested for the present resolution settings of the DAS with the twists in the table below.

	GSI-outer-loop	GSI: middle and inner loops
Default	1	2: 100 + 100
Reduced	1	2: 50 + 25
Legitimate	2	1: 50 1: 25

Configuring the Minimization

Misleading Ob Fit from Middle-Loop

Before going into comparing the experiments above we test the Hybrid 4dEnVar system and the reliability of the outer loop and compare it to the middle-loop strategy.



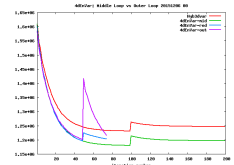
Left: *The illustration shows how in actuality the middle-loop gives a misleading estimate for how well the background really fits the observations.*

By choice, we stop the middle loop case after 3 iterations; the outer loop case is let to iterate 4 times.

Configurations of the middle, inner and outer loops

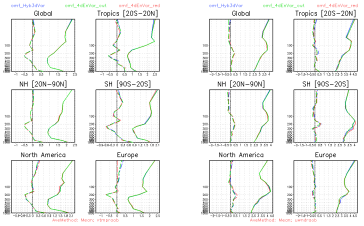
The present Hyb3dVar system uses the middle-loop strategy to better assimilate satellite radiances. In going to 4d, reducing the number of iterations in the inner loop helps contain computational cost; this becomes even more important when replacing the middle-loop with a legitimate outer loop.

Right: *Illustration shows total cost function for a given cycle of experiment ran with different configurations of the middle-, inner, and outer loops. The idea is to try to find configurations in which the quality of the fit to obs remains comparable..*



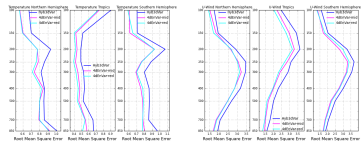
Preliminary Results

Observation Residual Statistics: RAOB OmB

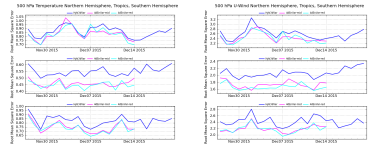


Above: *Comparison of observation-minus-background residual statistics show little to no appreciable difference among different configurations of the ensemble-based assimilation system, be it 3d or 4d. The figure shows radiosonde residuals: T (left) and U (right) for Hyb3dVar, and Hyb4dEnVar with 2 minimization middle-loops using 100+100 (4dEnVar-mid) and 50+25 (4dEnVar-red) inner iterations.*

Forecast Skill Scores: 36-hr RMSE

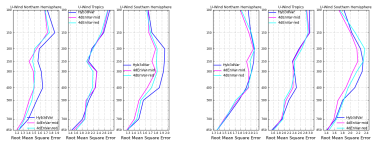


Most improvement in the ensemble-based system in going from 3d to 4d is seen in forecast skill scores. Above: *RMS error for T (left) and U (right) in 36 hour forecasts over NH, Tropics, and SH. We see that configuring the hybrid 4dEnVar system with 50+25 iterations leads to similar improvements over 3dEnVar configured with 100+100 inner iterations.* Below: *Time-series of 36 hour forecast RMS error for T (left) and U (right) for same three experimental settings.*



Comparing with ECMWF analysis

In addition to self-verifying the forecasts from GMAO, we also compare with ECMWF and NCEP forecasts. Here we show a verify with ECMWF analyses and we corroborate that the improvements from Hyb4dEnVar over Hyb3dVar seem to hold still.

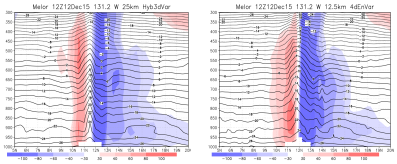


Above: *RMS error in zonal wind for 0 hr assimilation and 12 hr forecast calculated with respect to ECMWF analyses. Benefit from Hyb4dEnVar is seen from the start and are still noticeable in the short-range forecasts.*

4dEnVar: From 25 km to 12.5 km

GMAO's current 25 km DAS uses an approach to relocate the position of tropical cycles (TCs) in the model background fields whenever the cyclone position in the background differs somewhat from the observation location available at the centre-time of the 6-hour assimilation window. In the Hyb3dVar, 25 km system this procedure is helpful in analysing TCs. For multiple reasons, however, it would be desirable to move away from this somewhat ad-hoc and largely outdated procedure.

In the Hyb4dEnVar, 12.5 km system we find that TCs are analysed with enough fidelity not to require the background TC relocation procedure. The upcoming high resolution system also produces TCs with considerably better-defined vertical cores.



Above: *Illustration of vertical structure of Typhoon Melor at around its peak intensity time as captured by the GMAO 25 km Hyb3dVar (left) and the upcoming 25km Hyb4dEnVar. Though only a single example is shown here, many months of cycling have obtained plenty of evidence that the higher resolution Hyb4dEnVar system is considerably better than the present system; the upgrade also simplifies and removes the ad-hoc relocation of the background storm.*

Conclusion

Preliminary results from the search to find a configuration for the upcoming 12.5 km hybrid 4dEnVar GMAO data assimilation system have been shown here. The indications are that a middle-loop strategy might be acceptable for a first implementation, using 50+25. This choice keeps cost reasonable with no deterioration in quality. Ultimately, this author believes a legitimate outer loop strategy should bring further improvements. This ongoing research is expected to determine the best configuration.

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References

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- Lorenc, A. C., N. E. Bowel, A.M. Clayton, and S. R. Pring, 2015: Comparison of Hybrid-4DEnVar and Hybrid-4dVar data assimilation methods for global NWP. *Mon. Wea. Rev.*, **143**, 212-229.
- Todling, R., and A. El Akkraoui, 2013: The GEOS Hybrid Ensemble-Variational Atmospheric Data Assimilaton System, GMAO Note [available upon request].