Preliminary Results Cycling GEOS-JEDI with GSI-based Background Errors

Ricardo Todling(1), D. Holdaway(1), B. Menetrier(2), Y. Tremolet(3), A. Shlyaeva(3), F. R. Diniz(3), R. Treadon(4), C. Thomas(4), W. Gu(5), J. Jin(5), A. Sewnath(5), M. Sienkiewicz(5), Y. Zhu(1), R. Gelaro(1), D. F. Parrish(4), J. C. Derber(4), R. J. Purser(4) & D. T. Kleist(4)

9th International Symposium on Data Assimilation

Bologna, Italy, 16-20 Oct 2023

GMAO

Global Modeling & Assimilation Office

Poster number?

Prolegomenon

The first phase of transitioning the NASA GMAO GEOS atmospheric data assimilation capabilities to JEDI involves the replacement of the Grid-point Statistical Interpolation (GSI) with a corresponding JEDI analysis. This includes taking JEDI's Unified Observation Operator (UFO), its underlying dependencies, and the JEDI solver that enables a hybrid 4DEnVar strategy similar to what is used in the current GEOS-GSI system.

Variational analysis involves at least two main components associated with the observation and background cost function terms. The first is directly related to the UFO, which is being carefully validated in a joint collaboration between GMAO and NCEP to demonstrate consistency with corresponding observations usage in GSI. The second component is the background term, which in a hybrid system involves the ability to set up both a climatologically-based term and an ensemble-based term. JEDI provides the means to implement both terms through its BUMP component. Use of BUMP would require a complete re-tune of both climatological and ensemble, which is a non-trivial exercise we would prefer to avoid. As an alternative, the work here studies the results of interfacing the GSI-background error capability (GSIBEC) into JEDI through SABER. With this, the exact same background error covariance formulation used in GSI can be employed in JEDI without need for re-tuning.

This brief summary covers the work done to interface GSIBEC into JEDI and shows preliminary results where the background error covariances of the control (GEOS-GSI) and experiment (GEOS-JEDI) are identical in corresponding cycling experiments. The cycling exercise is obviously preliminary and so much can be expected from GEOS-JEDI when compared to GEOS-GSI. There is still a number of features that need closer attention and although in some cases in principle ready to cycle have been intentionally either turned off or not fully exercised (e.g., VarBC is applied but not cycled). Other features are still pending implementation, one such example is the implementation of the Tangent Linear Normal Mode Constraint. Still, results are quite encouraging as hopefully the discussion here illustrates.

Adding GSI-Background Error Covariance capability to SABER

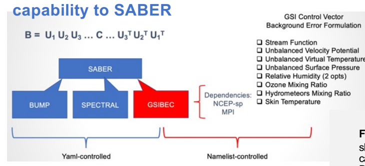


Fig. 1: A Schematic showing added SABER capability to use GSI Background Error Covariance (BEC) formulation.

Status of Available Var Flavors

	BUMP	GSIbec
3DVar; 4DVar	Climatological	N/A
3DVar; 4DVar	N/A	Climatological
3DEnVar	Ensemble	N/A
3DEnVar	N/A	Ensemble
4DEnVar	Ensemble	N/A
4DEnVar	N/A	Ensemble
Hybrid 3DVar	Ensemble	Climatological
Hybrid-3DVar	Climatological	Ensemble
Hybrid 4DEnVar	Ensemble	Climatological
Hybrid 4DEnVar	Climatological	Ensemble

- With exception of options invoking 4D ensemble capability through GSIbec, all other options work to good extent.
- GSIbec will never be model agnostic, if nothing else, because its formulation is highly dependent on its regular grid.
- Climatological B capability works for both GEOS and fv3GFS.
- Work is in progress to bring back fv3GFS ensemble handling in the context of GSIbec.
- Is it recommended for people to start cycling with GSIbec? Not just yet.

We have added capability in SABER to invoke the same background error covariance formulation as used in GSI – indeed the covariance software of GSI has been made into an independent library which can be loaded to JEDI to allow for GSI-like background errors to be used in the variational procedures (see **Fig. 1**)

A number of systematic stand-alone analysis tests and experiments have been performed comparing increments from GSI with those from JEDI in various configurations of the variational covariance and observing systems. From analyzing simple single observations of different types, to using conventional observations such as radiosondes (**Fig. 2**), to ozone sources, to radiance observations. Most tests show reasonable match of increments; some care to moisture still pending.

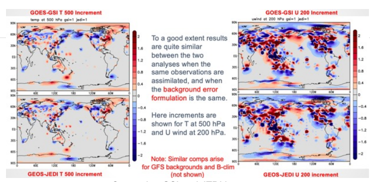


Fig. 2: Comparing GSI and JEDI increments when both exercise the same background error covariance formulation in a 3DVar setting.

Table: Cycling experiments using the augmented GEOS ADAS Workflow

	ca. Fall 2021	ca. Fall 2022	ca. Fall 2023	ca. Fall 2023
Algorithm & BEC	3DEnVar-BUMP	3DVar-GSIBEC	3DVar-GSIBEC	Hyb4DEnVar-GSIBEC
Model/Ana Resolution	c90/c90	c90/c90	c360/c180	c360/c180
Outer/Inner Loops	1/30	1/30	1/100	1/50
VarBC	N/A	N/A	YES (From-CTL)	No
Correlated IR Rad Channels	N/A	N/A	NO	NO
CTL experiment	Downgraded GSI	Downgraded GSI	Regular GSI	Regular GSI
Experiment Period	Dec 2020	Apr 2022	Dec 2021	Dec 2021
Aircraft	NO	NO	YES	YES
AIRS Aqua	NO	NO	YES	YES
AMSR2 GCOM W1	NO	NO	NO	NO
AMSU-A Metop-B	NO	NO	YES	YES
AMSU-A Metop-C (for consis. w/ CTL)	NO	NO	YES	YES
AMSU-A N15	NO	NO	YES	YES
AMSU-A N18	NO	NO	YES	YES
AMSU-A N19	NO	NO	YES	YES
ATMS N20	NO	NO	YES	YES
ATMS NPP	NO	NO	YES	YES
AVHRR Metop-B	NO	NO	YES	YES
AVHRR N18	NO	NO	YES	YES
AVHRR N19	NO	NO	YES	YES
CrIS-FSR N20	NO	NO	YES	YES
CrIS-FSR NPP	NO	NO	YES	YES
GNSS RO	NO	NO	NO	NO
GMI GPM	NO	NO	NO	NO
IASI Metop-B (operator not ready)	NO	NO	YES	YES
IASI Metop-C (for consistency w/ CTL)	NO	NO	YES	YES
MHS N19	NO	NO	NO	NO
MLS55 Aura	NO	NO	NO	NO
OMI Aura (Not available over exp period)	YES	YES	NO	NO
OMPNM NPP (operator not ready)	YES	YES	NO	NO
Pibal	NO	NO	NO	NO
Sat Wind	NO	NO	YES	YES
Land Obs	NO	NO	YES	YES
Marine Obs	NO	NO	YES	YES
Radiosondes	YES	YES	YES	YES
SSMIS F17	NO	NO	YES	YES

GSI-aided, JEDI-based GEOS ADAS Workflow

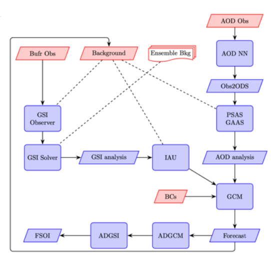


Figure 3: Current (left) and enhanced (right) Workflow of Deterministic component of the Hybrid 4DEnVar of GEOS Atmospheric DAS.

The enhanced Workflow allows for the JEDI Var components (green) to run in parallel to GSI-based system. The option to have either the GSI or the JEDI analysis feedback to the GEOS model as IAU tendencies (red) allows for on-the-fly comparison of the two variational systems.

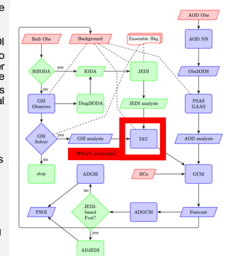
Cycled attempts thus far:

Circa mid-2021: BUMP-BEC 3DEnVar, Sondes only & ozone.

Circa Fall-2022: GSI-BEC 3DVar, Sondes & ozone.

Fall 2023: GSI-BEC 3DVar; near full observing system (see Table 1).

Fall 2023: GSI-BEC Hyb-4DEnVar; near full observing system (not quite going yet)



GMAO is adopting a phased transition to JEDI. The first phase preserves the present DA Workflow. This is illustrated in the schematic above: on the left, the current workflow shows how GSI analysis feeds its results to the GCM using the Incremental Analysis Update (IAU); on the far right, the diagram shows an enhanced version of the Workflow with components needed to run a variational analysis using JEDI are accounted for. The Workflow handles 3DVar, 3D/4D-EnVar, and Hybrid 3D/4D-EnVar, regardless of which analysis is ultimately passed along to the model.

This first phase deals only with the deterministic part of the (operational) hybrid system, leaving the ensemble DA Workflow unchanged. A further revision of the first phase enhanced Workflow is being considered to accommodate a JEDI-LETKF option, as a possible first phase addition.

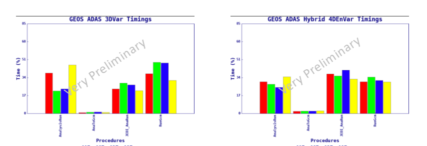


Fig. 4: The figures above display percentage timings derived from a day of cycling 3DVar and Hybrid 4DEnVar. Unfortunately, the experiments have been running during a time when our computers have been going through an upgrade that, while still at works, drastically affects disk access. Still the preliminary timings serve to illustrate the fact that the cost of running JEDI is not much higher than that of running GSI – though the GSI integrations use 2 middle loops and invoke one extra call to the observation operators.

It has been about two years that some cycling with JEDI using the enhanced GEOS Workflow above has been first tried. The initial configuration used what was available then, 3DEnVar using (poorly tuned) BUMP background errors and radiosonde observations. Since then, a few other configurations have been cycled. The various attempts, including presently ongoing ones, are summarized in the **Table** (left). The introduction of GSIBEC avoids (or postpones) need to tune a completely new covariance using BUMP; use of GSIBEC allows effort to concentrate aspects of integration other than doing work that's already done. This capability allows for 3DVar to be readily cycled and tested, hybrid 3DVar is also readily available, and aside from some details being sorted out in the JEDI cost function, 4DEnVar is also available and near ready for testing in cycled mode.

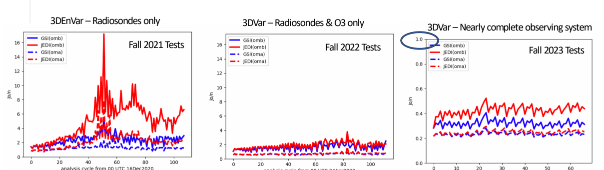


Fig. 5: Illustration of the behavior of the initial and final cost functions for three cycling configurations of GEOS-JEDI and corresponding control experiments. The initial 3DEnVar experiment (left) illustrate the poor attempt of mildly tuning BUMP-based ensemble covariances (blame on first author only). The second and third experiments, using 3DVar with radiosondes and ozone only, and a near full observing system (right), respectively, show way more reasonable results, with Jo(b) and Jo(a) being relatively close between the two experiments Although in the most recent 3DVar the analysis seem to fit the observations as seen in the control, the fits to the background are not as good – further experimentation is necessary. The two 3DVar experiments benefit from using well established GSI background errors, with no need for re-tuning; the same error covariances are used in the controls and JEDI experiments.

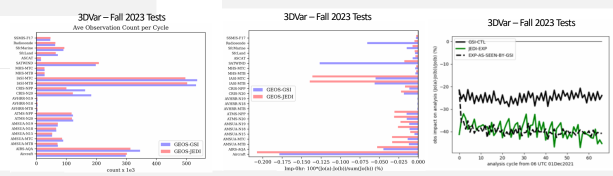


Fig. 6: Closer look at the most recent 3DVar experiment, when a near complete observing system. It provides evaluation of observation-space diagnostics comparisons between GEOS-JEDI and the control GEOS-GSI. Left: observation count for assimilated instruments. Middle: reduction in Jo fits. And right: time series of relative reduction in Jo fits. The counts compare reasonably well, with slightly less hyperspectral IR data being taken in the JEDI case. When it comes to the contribution of individual instruments to reduce the cost function (middle), aircrafts shows as a major player in both systems, however, radiosondes and satellite winds play a much larger role in GEOS-GSI than in GEOS-JEDI. Reversely, most of the MW instruments and hyperspectral IR are seen to contribute more to GEOS-JEDI. Results for the latter must be interpreted with caution since GSI treats these data as correlated in channel-space, whereas JEDI (here) is not yet using this feature. Overall, the impact of observations in reducing errors in the analysis is much larger in the JEDI system (right), a clear consequence of the results displayed in the last panel of **Fig. 5**.

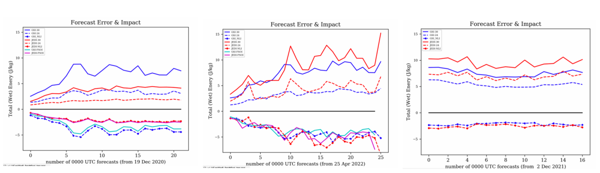


Fig. 7: Day-one self-verified forecast RMS errors (expressed as global linearized total moist energy) show "low errors" in the poorly tuned 3DEnVar experiment; in a self-verified measure, low errors are an indication of the model not listening to the analyses (also seen in **Fig. 5 & 6**). The 3DVar experiment carried out ca. Fall 2022 shows rather reasonable agreement in the day-one errors and their corresponding nonlinear impact (negative curves). In the more recent Fall 2023 experiment with a nearly complete observing system forecast errors from GEOS-JEDI seem to lag about 6-hours from those of GEOS-GSI. This is not bad for a first GEOS-JEDI experiment using nearly 4 million observations in each 6-hour cycle. A much closer evaluation is now beginning to try to understand nuances of the differences in the latest control and experiment.

Closing Remarks

The implementation of the GSI background error capability in JEDI is now available for testing. The implementation supports both the climatological and hybrid formulations just as GSI does. Preliminary tests cycling with a 3DVar (climatological) configuration produce quite reasonable results, tough some puzzles in the treatment of some key observing types must be resolved. We have experimented cycling the hybrid 4DEnVar configuration, but this has been done simply as an engineering test to exercise the Workflow; there are known issues with the 4D-Ens-Var cost function in JEDI with GSIBEC that need to be addressed before any serious cycling begins - this is a source of intense work being done at the time of this writing.

Additionally, there are still a number of details that need to be tackled in GSIBEC: (i) the moisture control variable is not being handled as in GSI; (ii) a reproducibility issue across different number of PEs has found (there are no reproducibility issues for fixed number of PEs); and (iii) the need for some form of dynamical balance, e.g., the GSI Tangent Linear Normal Mode Constraint needs to be brought into JEDI.

Beyond GSIBEC work is being done to: (a) bring the GMAO-GSI GNSSRO operator into UFO; (b) perform consistency check in geophysical fields needed in observation operators between GSI and JEDI; (c) complete implementation of varBC for aircraft observations; (d) fully cycle varBC; (e) exercise channel correlation capability for handling hyperspectral IR observations in the same way as done in GSI; (f) add JEDI's First-Guess at the Appropriate Time capability to the test experiments; and (e) make sure that JEDI's multiple middle loop capability can be exercised properly when GSIBEC is used.

Work-in-progress: it was found while this poster was being put together that some UFO filters were not quite properly set, and that errors assigned to AMSU-A and Hyperspectral IR were not consistent with those from GSI. A re-run is on the way.

GODDARD EARTH SCIENCES

E-mail: ricardo.todling@nasa.gov | *Web:* gmao.gsfc.nasa.gov

(1) NASA/Global Modeling and Assimilation Office
(2) Norwegian Meteorological Institute
(3) Joint Center for Satellite Data Assimilation
(4) NOAA/National Centers for Environmental Prediction
(5) Sciences Systems and Applications Inc./GMAO

National Aeronautics and Space Administration