Insight and evidence motivating the simplification of dual-analysis hybrid systems into single-analysis hybrid systems

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Contributions from F. L. R. Diniz, L. L. Takacs, and M. J. Suárez

Outline

Originally we were planning to provide insight in trying to answer the question:

Can a reliable hybrid procedure be build without an ensemble analysis?

But we are postponing it to another time, and presenting on Recentering-IAU instead.

Topics under consideration

- Insight I: Can EFSOI serve as proxy for FSOI in hybrid systems?

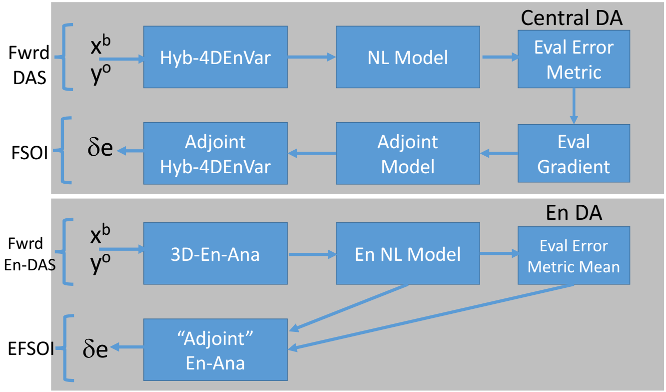
The first discussion examines the tentative by some to assess the impact of observations in hybrid variational-ensemble systems by using EFSOI instead of FSOI.

- Insight II: A cautionary tale on Ensemble Recentering & IAU.

The second discussion comes from a serendipitous realization that Ensemble Recentering is partially analogous to what we call Analysis Replaying, that when combined with an Incremental Analysis Update initialization strategy can have rather undesirable consequences.

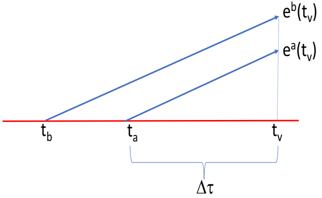
Insight I: Can EFSOI serve as proxy for FSOI in hybrid systems?

Schematic Representation of a DA Scheme and its Forecast Sensitivity and Observation Impact (FSOI) Tool



- Throughout this presentation Center & Deterministic are used interchangeably.

Forecast Sensitivity and Observation Impact (FSOI)



Forecast error:

$$e^s(t_v|t_0) = < [\mathbf{x}^f(t_v|t_0) - \mathbf{x}^v(t_v)]^T \; \mathbf{T} \, [\mathbf{x}^f(t_v|t_0) - \mathbf{x}^v(t_v)] >$$

The impact of observations is typically evaluated by studying how an error measure such as the above changes as a consequence of assimilating observations. Whether based on adjoint or ensemble techniques, the impact requires evaluation of an expression of the form:

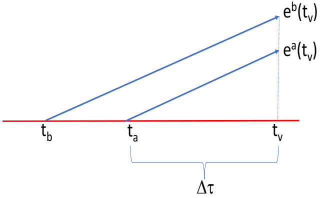
$$\delta e \;\approx\; < \mathbf{d}^T \mathbf{K}^T \mathbf{g}_0 >$$

with **d** and **K** being the background residual vector and the analysis gain matrix, and **g** amounting to a forecast sensitivity vector whose approximation leads to all kinds of formula.

	AD-Solver ($\mathbf{K}^T$)	Forecast Sensitivity ($\mathbf{g}_0$)	Forecast Error	Source
VA-FSOI	Var	ADM	e^f	Langland & Baker (2004)
EE-FSOI	En	En	$\bar{e}^f$	Liu & Kalnay (2008)[1]
VE-FSOI	Var	En	e^f	Buehner et al. (2018)
EA-FSOI	En	ADM	$\bar{e}^f$	Why not?

[1] Simpler approach in Kalnay et al. (2012)

Forecast Sensitivity and Observation Impact (FSOI)



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EA-FSOI	En	ADM	$\bar{e}^f$	Why not?

[2] Simpler approach in Kalnay et al. (2012)

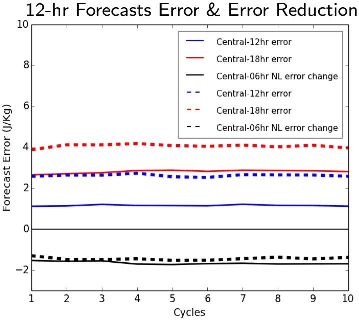
Two conditions to satisfy for EFSOI to be a viable proxy for FSOI in hybrid systems:

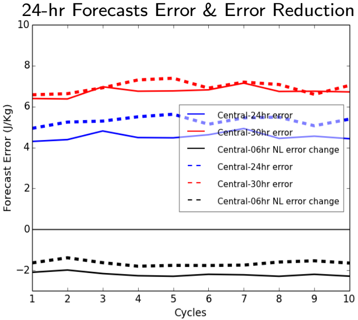
1. Forecast error reduction of Ensemble Mean forecasts must be representative of those in the driving Deterministic System.
2. Treatment of observations between Hybrid and Ensemble analyses must be consistent.

	Resolution (km) of Hybrid Componenets	
	Near-Real Time System	Experimental System
NLM	12.5	25
ADM	25	50
Fwd/Bwd Hyb-4D-EnVar	25	50
En-NLM	50	100
EnSRF	50	100
	Average Observation Count per 6 hours (million)	
Central-Var	4	4
EnSRF[3]	1	1
	Observation Impact on Forecast	
FSOI	25	50
EFSOI	50	100

Can the conditions above be met in the present of such differences in resolution and use of observations between the deterministic and ensemble components?

[3] Similarly set in both GMAO & NCEP systems.





- Forecast errors above are calculated wrt to assimilated fields (not analyses); though choice of verification does not affect error reduction levels.
- Similarity of error reductions between (central) deterministic and ensemble mean forecasts deteriorates with increased forecast lead-time.

> *With some loss, one could make the case that error reductions from ensemble mean forecasts are reasonable proxy for error reductions from deterministic forecasts.*
> *Condition 1: OK.*

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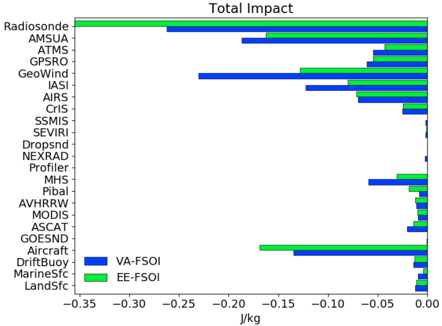
To make comparison more fair . . .

	Components Resolution (km)	
	Experimental System	Rev Exp System
NLM	25	25
Fwd Hyb-4D-EnVar	50	50
ADM	50	100
Bwd 4D-EnVar	50	50
Ens-NLM	100	100
EnSRF	100	100

- Examination of impacts reveals considerable differences in Radiosonde and satellite winds (GeoWind).
- Differences are non-negligible for MW and IR satellite radiances too.

Question: Why are there such differences between FSOI & EFSOI?



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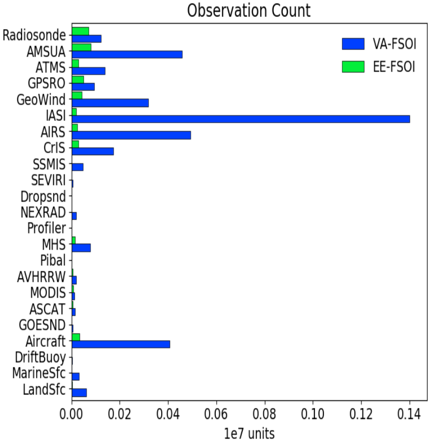
Answer:

- Because of difference in treatment of observations between central and ensemble analyses.
- Because of cost of serial obs-processing, EnSRF criteria for converge are very forgiving.
- Even with the ideal DFS-based criterium (chosen here), the EnSRF ignores more than 2/3 of all observations.

Condition 2: Fails.

Conclusion: Current operational EnSRF settings prevent EFSOI from serving as proxy for FSOI.



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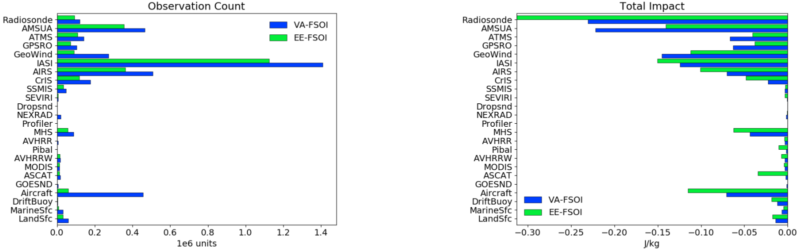
Question: What happens when EnSRF is re-configured to take as many obs as possible?

	Typical Observation Count per 6 hours (million)	
	Experimental System	Rev Exp System
Hyb-Var	4	4
EnSRF	1	4



- There is more similarity in the observing systems of the Central and Ens DAS.
- There are still significant differences, such as seen for aircraft.
- Nonetheless, it is now plausible to accept EFSOI results as reasonable, but . . .

In hybrid DA, it is still hard to accept EFSOI as proxy for FSOI.

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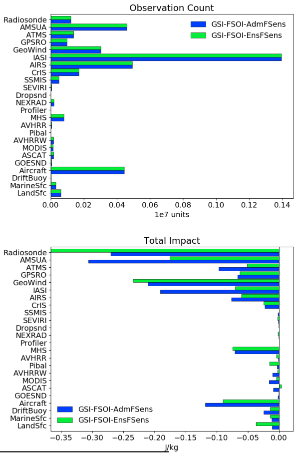
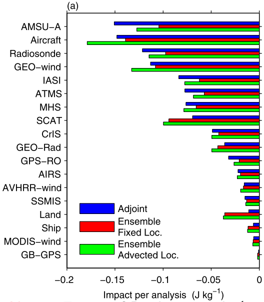
Fortunately, in hybrid DA, there is no reason to have to rely on EFSOI . . .

Impacts on 12-hour forecasts

- Buehner et al. (2018) blend Var and Ens procedures into a VE approach to bypass the ADM.
- Within Var, observations counts are consistent whether using VA or VE approaches.
- GMAO results (left) comparing VA- and VE-derived FSOI shows slightly larger differences between procedures than found in Buehner et al. (right) for 12-hour impacts.
- With advection of localizations, it is possible to extend results to 24 hours but differences between VA and VE procedures increase (see Buehner et al.). .





Above: Fig 5. of Buehner et al. (2018).

Right: GMAO results for Jan 2017.

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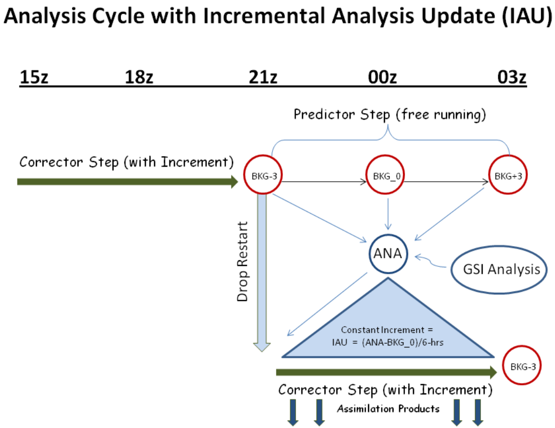
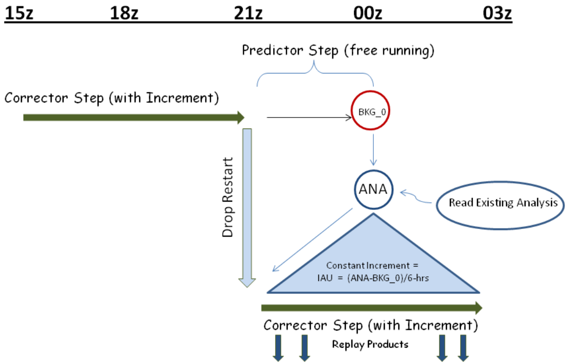
Insight II: A cautionary tale on Ensemble Recentering & Incremental Analysis Update

Schematic of (3D) IAU



GMAO IAU-based Replay Strategy used in, say, dynamical downscaling of the analyses

Replay Cycle with Incremental Analysis Update (IAU)



Note: By construction, in a Replay Strategy the cycle never changes the analysis it replays to.

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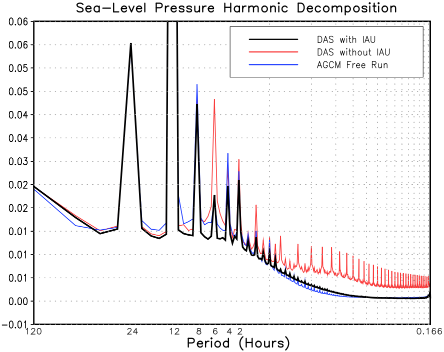
Harmonic analysis of 30S-30N SLP tendency due to dynamics in three contexts:

1. Assimilation with IAU
2. Assimilation without IAU
3. Free-running model

Clearly the motivation for IAU (Bloom et al. 1996).



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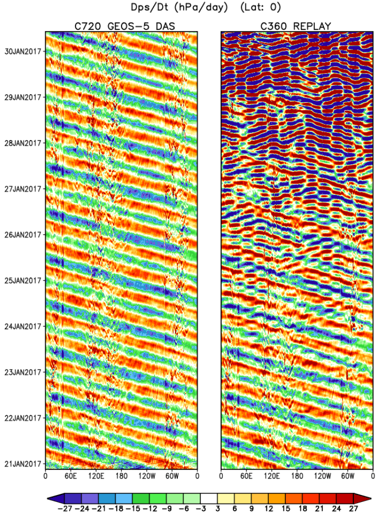
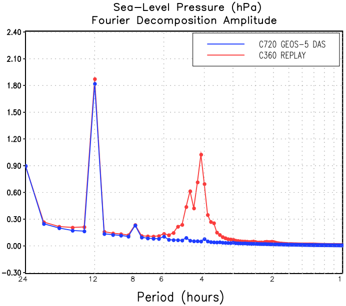


Below: Harmonic analysis of 30S-30N sea-level pressure (SLP) from last 5 days of DAS and REPLAYED integrations on the right.



Left: Hovmöller of PS tendency of DAS and REPLAYED model.

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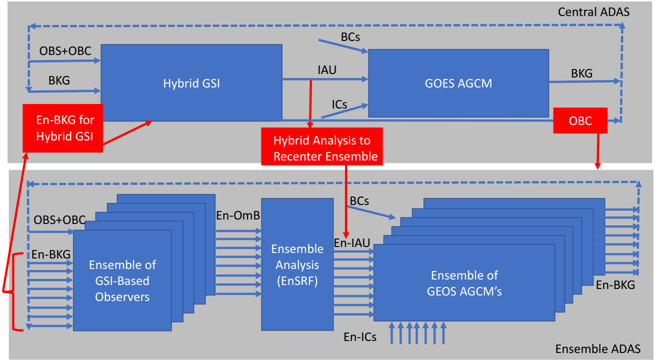
Schematic of the GEOS Hybrid Atmospheric Data Assimilation System

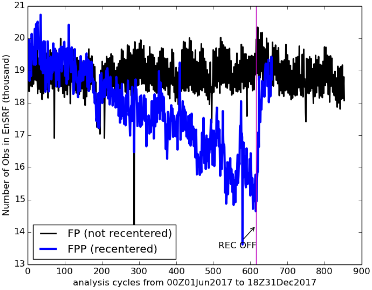


Remarks:

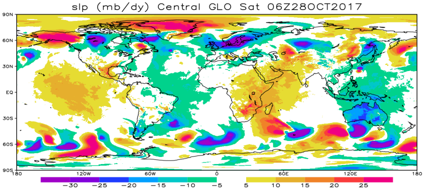
- Deterministic Hybrid (Central) ADAS uses as so-called Nudged-4D-IAU
- Ensemble ADAS uses traditional (3D) IAU

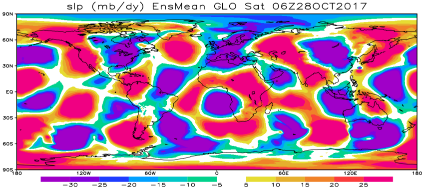
Manifestation of the instability in a high-resolution Hybrid 4D-EnVar System

Below: PS Obs count in EnSRF for over six months of assimilation in the GMAO Forward Processing (FP) (non-recentered) System and its replacement candidate FPP (recentered).



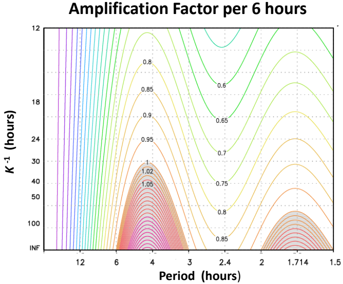
Note: As soon as recentering is turned off in FPP the obs count jumps up.

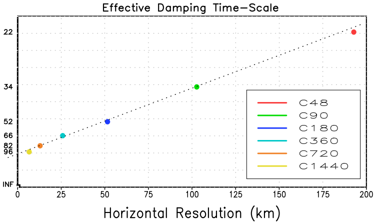




Above: SLP tendency in DAS at give time: Central (top) and Ensemble Mean (bottom).

Below: Amplification factor for given idealized analysis gain as a function of period and damping time scales.





Above: Estimate of effective damping time scales for different GEOS model resolutions from roughly 200 km (C48) to roughly 6 km (C1440).

Implications: For most GEOS model resolutions, use of traditional IAU to replay to existing analyses leads to eventual development of instabilities.

Amusing: Most our tests in research mode run one resolution coarser than in GEOS FP; the C90 ensemble of research mode is right at the stability point thus, thus in research mode the instability never manifests itself.

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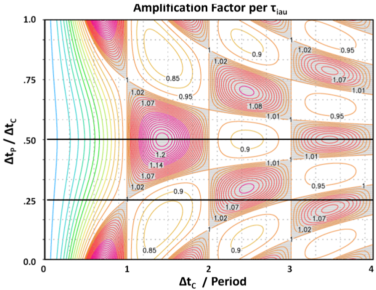
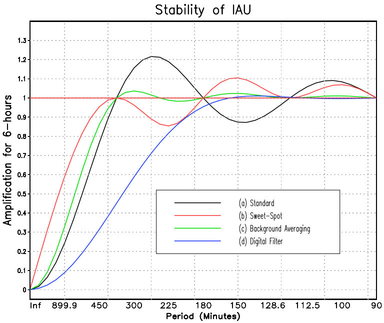
The theoretical study points to the following strategies to avoid the IAU instability:

1. Sweet spot (in the stability diagram)
2. Background averaging
3. Modulation by Digital Filter (DF; Polavarapu et al., 2004)



Above: Amplification factor for a Replay of length τ_{iau} (for given analysis gain) as a function of normalized frequency and ratio of Predictor-to-Corrector duration.



Above: Amplification factor for 6-hour IAU Corrector with difference strategies to avoid instability; traditional 3-hour Predictor shows as Standard (black curve).

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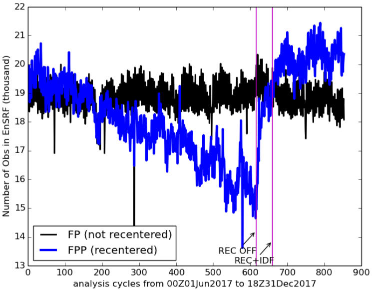
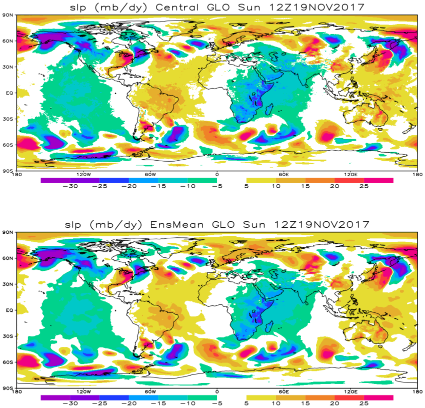
Digital Filter modulation of IAU for in En-ADAS

Below: With a DF modulation of IAU, recentering can now be turned back on in FPP with no risk of an instability developing.



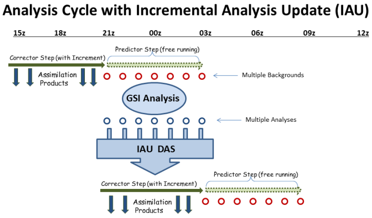
Remark: With this, we get an increase in the number of accepted observation by the Ensemble.



Above: with the Digital Filter modulation of IAU, recentering can be turned back up and the system remains stable.

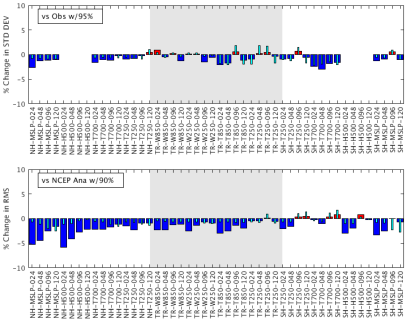
Digital Filter + 4D-IAU in Hybrid 4D-EnVar

Question: Is there an advantage in using DF to modulate 4D-IAU?



Left: Score cards comparing GMAO's present Nudged-4D-IAU settings with the DF-modulated 4D-IAU. Blue colors indicate improvement by new over current settings.

Answer: Yes, certainly over Nudged-4D-IAU.



Note: Our 4D-IAU implementation might be similar to that of Lorenc et al. (2015).

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Closing Remarks

EFSOI

In hybrid DA, EFSOI is generally not a good proxy for FSOI:

1. though ensemble mean forecast error reductions are reasonable proxies for deterministic forecast error reductions,
2. ensemble analysis typically use a reduced observing system, and
3. are performed at reduced resolution.

→ In hybrid DA, it is best to rely on FSOI.

→ When an adjoint model is unavailable, FSOI can employ a Var-Ens alternative.

Recenter+IAU

1. This study has consequences to downscaling and any application employing IAU.
2. Ensemble Recentering can be seen as a form of Replay.
3. Recentering combined with IAU lead to a potential for instabilities to arise in the ensemble, especially in a dual resolution framework, and when the effective damping in the model is not enough to prevent instabilites from forming.
4. The study here finds that one of three approaches prevents these instabilities from arising: (i) sweet spot; (ii) background averaging; and (iii) modulation of IAU increments with a Digital Filter.
5. In particular, the Digital Filter solution is the preferred approach and leads to potential benefit when applied in the context of 4D-IAU.