An adjoint-based system for real-time monitoring of observation impact in a global forecast system

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NRL- Monterey

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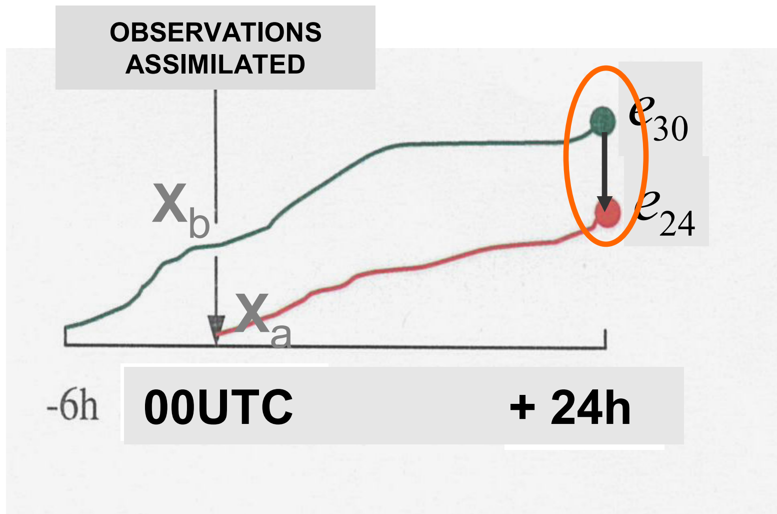
Acknowledgements: Nancy Baker, Gary Love, Ben Ruston, Liang Xu

Observations and forecast trajectories



Note: "e_{30}" is actually a 24hr forecast from $\mathbf{X}_b$

Observations move the model state from the "**background**" trajectory to the new "**analysis**" trajectory

The forecast error difference, $e_{24} - e_{30}$ is due to the combined impact of all observations assimilated at 00UTC

Observation Impact Equation

Innovation (observation-background)

$$\delta e_{24}^{30} = \left\langle (\mathbf{y} - \mathbf{H}\mathbf{x}_\mathrm{b}), \mathbf{K}^\mathbf{T} \left\{ \frac{\partial e_{24}}{\partial \mathbf{x}_\mathrm{a}} + \frac{\partial e_{30}}{\partial \mathbf{x}_\mathrm{b}} \right\} \right\rangle$$

Observation Impact

Sensitivity of forecast error to initial conditions (obtained with adjoint of forecast model)

- Moist total energy forecast error norm (*e*)
- Adjoint versions of NOGAPS and NAVDAS (K^T) are used to calculate the observation impact – NOGAPS adjoint includes large-scale precip.
- The impact of observation subsets (separate channels, or separate satellites) can be easily quantified

Refs: Langland and Baker (Telllus, 2004); Gelaro, Errico, others ….

LESSONS LEARNED SO FAR

- Calculations can be performed in near real-time for operational forecast system – computational cost less than re-run of forecast model and data assimilation procedure (3d-VAR and 4d-VAR)
- Essential to include sensitivity gradients on both the background and the analysis trajectories, for good accuracy
- Accuracy of adjoint-based results ($e_f - e_g$) should be checked in both gridpoint and observation space against truth (difference of actual nonlinear forecast error norms) [~85% for 24hr forecasts]
- System provides much useful information, but interpretation and applications to QC and observation selection may not be simple or straightforward

Use of adjoint to find observation quality problem

Date: Jan-Feb 2006

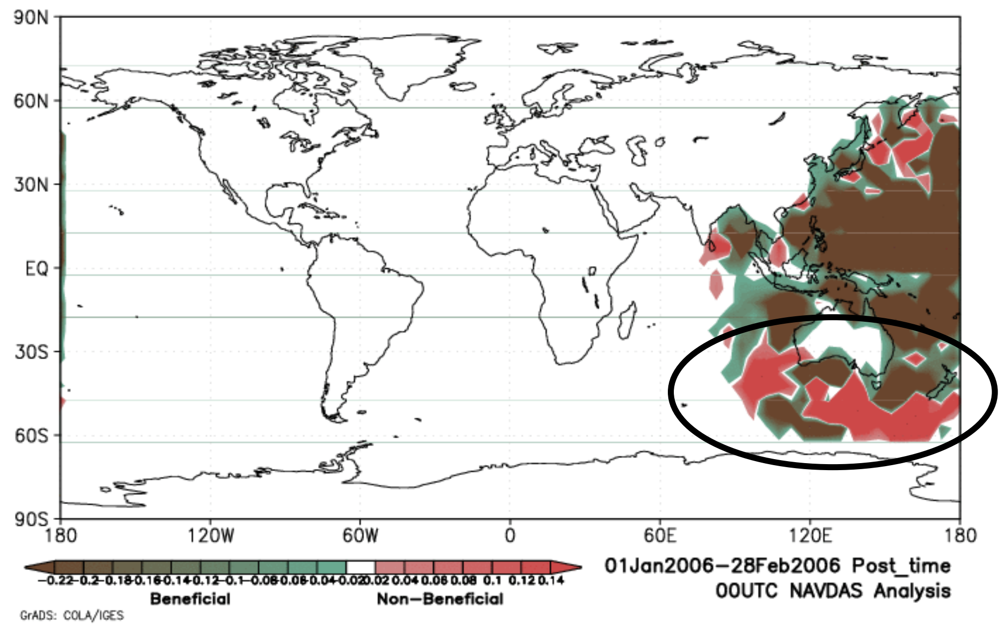
Issue: Large innovations and non-beneficial impact from satellite winds at edge of coverage areas

Action Taken: SATWIND data removed if > 39° from satellite sub-point

Results: 3-hr improvement in SH NOGAPS forecast skill

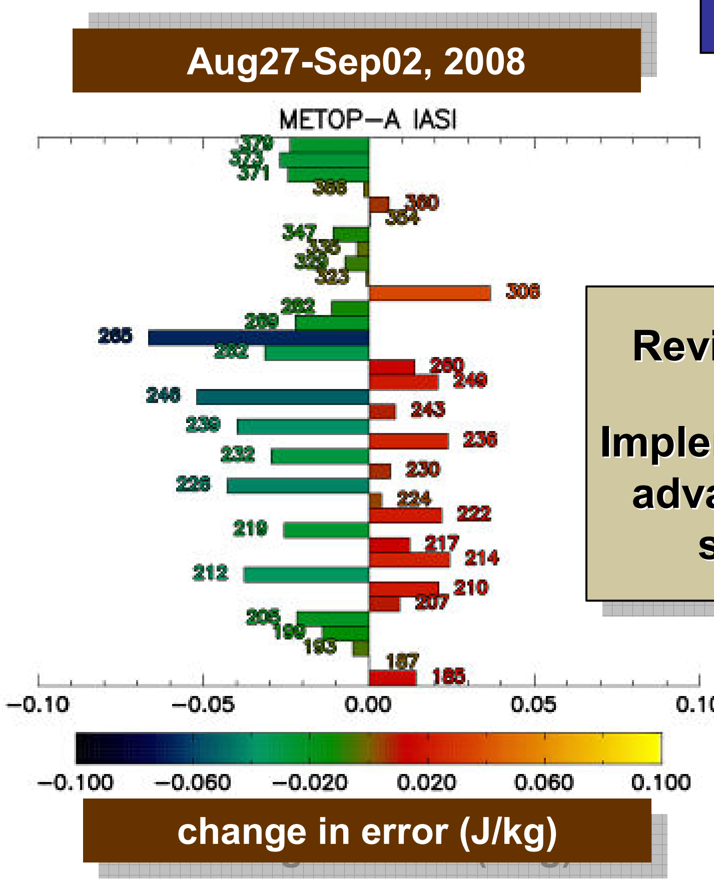
Outcome: reported to CIMSS satwind algorithm team---problem found and corrected

30-day impact of wind observations from geostationary MTSAT

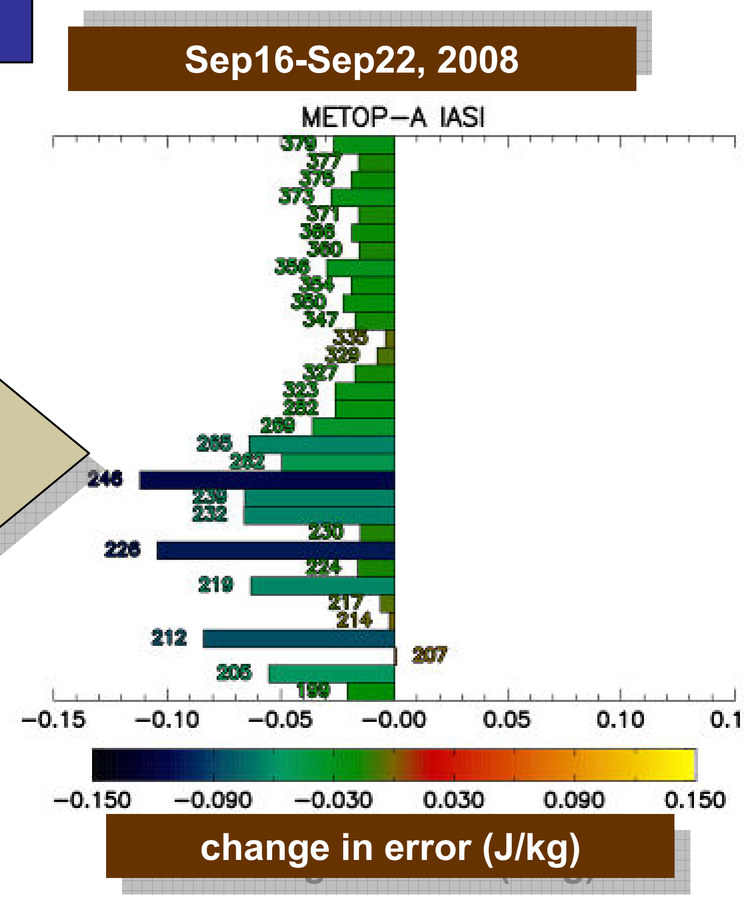


Using adjoint tools for improving satellite assimilation

NAVDAS-AR
Results

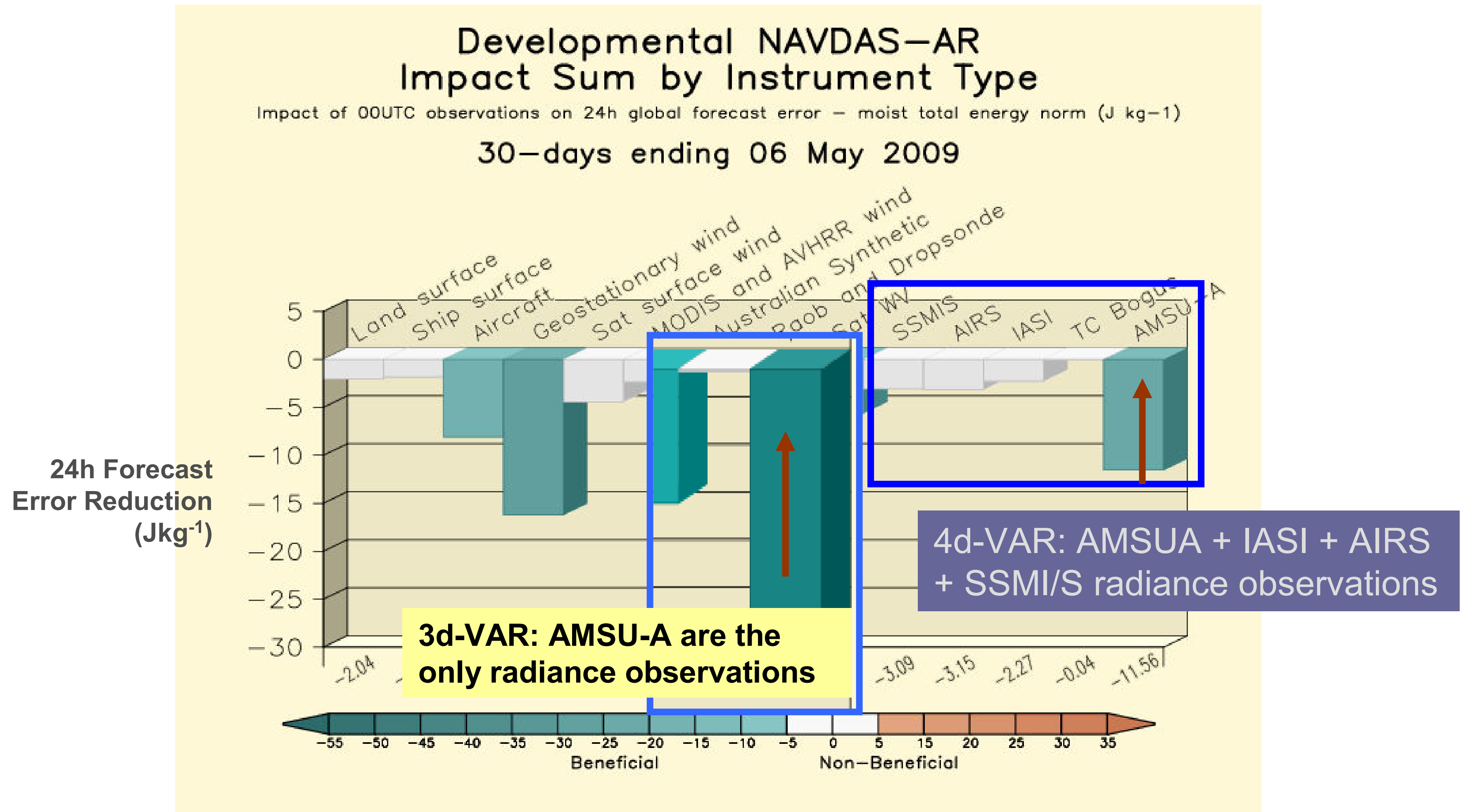


Revise channels
&
Implement ECMWF advanced cloud screening



Adjoint-based observation impact system developed at NRL can be used for operational decision-making – routine monitoring of observations, quality control, satellite channel selection

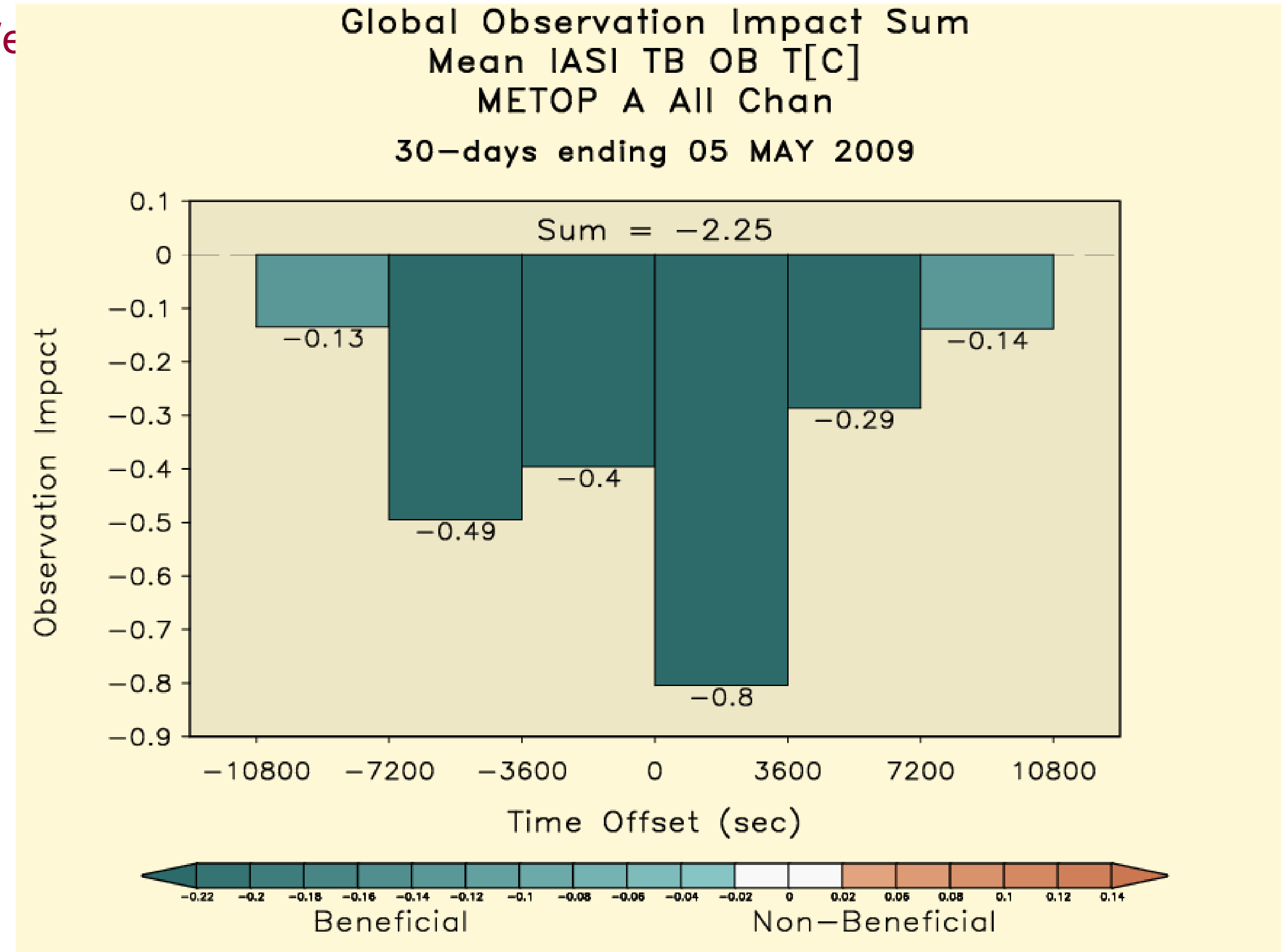
Real-time Observation Impact WEB PAGE



www.nrlmry.navy.mil/obsens/dev/obsens_main_od.html

User-Interactive Plot Capability

We



www.nrlmry.navy.mil/obsens/dev/obsens_main_od.html

Invitation to Compare Observation Impact Results

YOUR RESULTS CAN BE INCLUDED ON OUR WEB PAGE !

WE CAN PROCESS YOUR OUTPUT FILES – OR WE CAN PROVIDE OUR WEB GRAPHICS CODE TO YOU

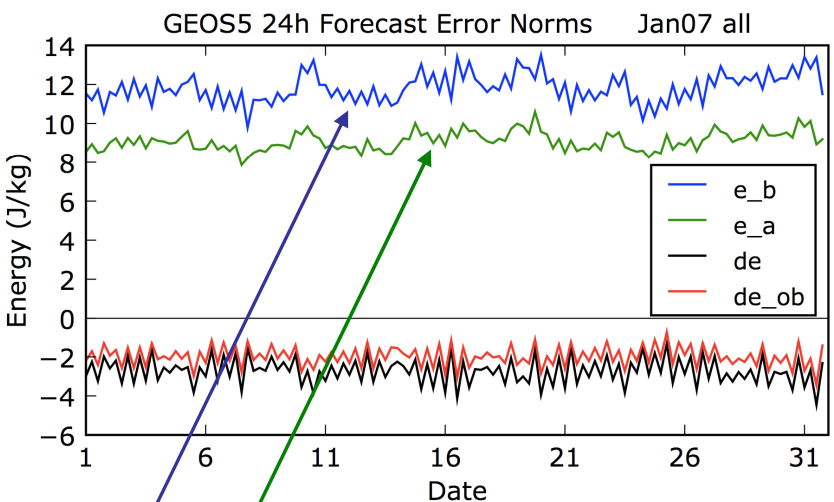
COMPARISON OF OBSERVATION IMPACT IN DIFFERENT FORECAST SYSTEMS ARE VERY USEFUL FOR IMPROVED USE OF OBSERVATIONS

Adjoint-based or Ensemble-based results welcomed

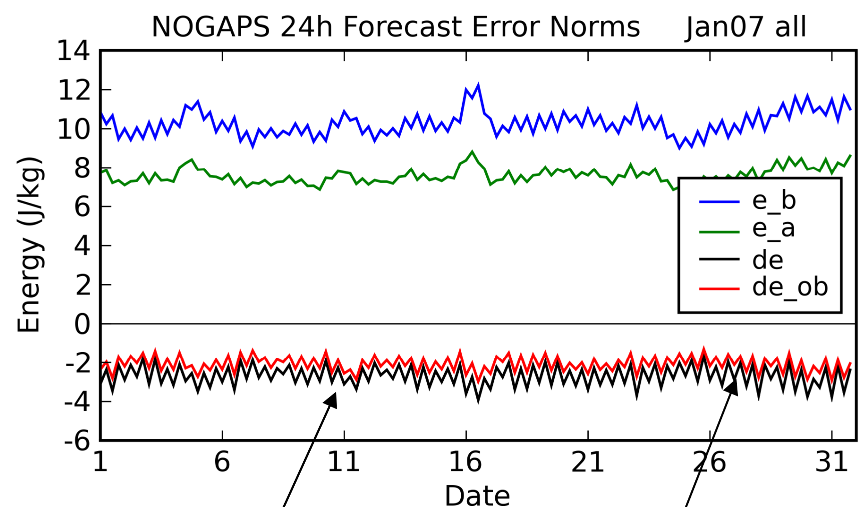
Forecast Error Norm Time Series

global domain

GEOS5



NOGAPS



Forecast error on Background Trajectory (e_g)

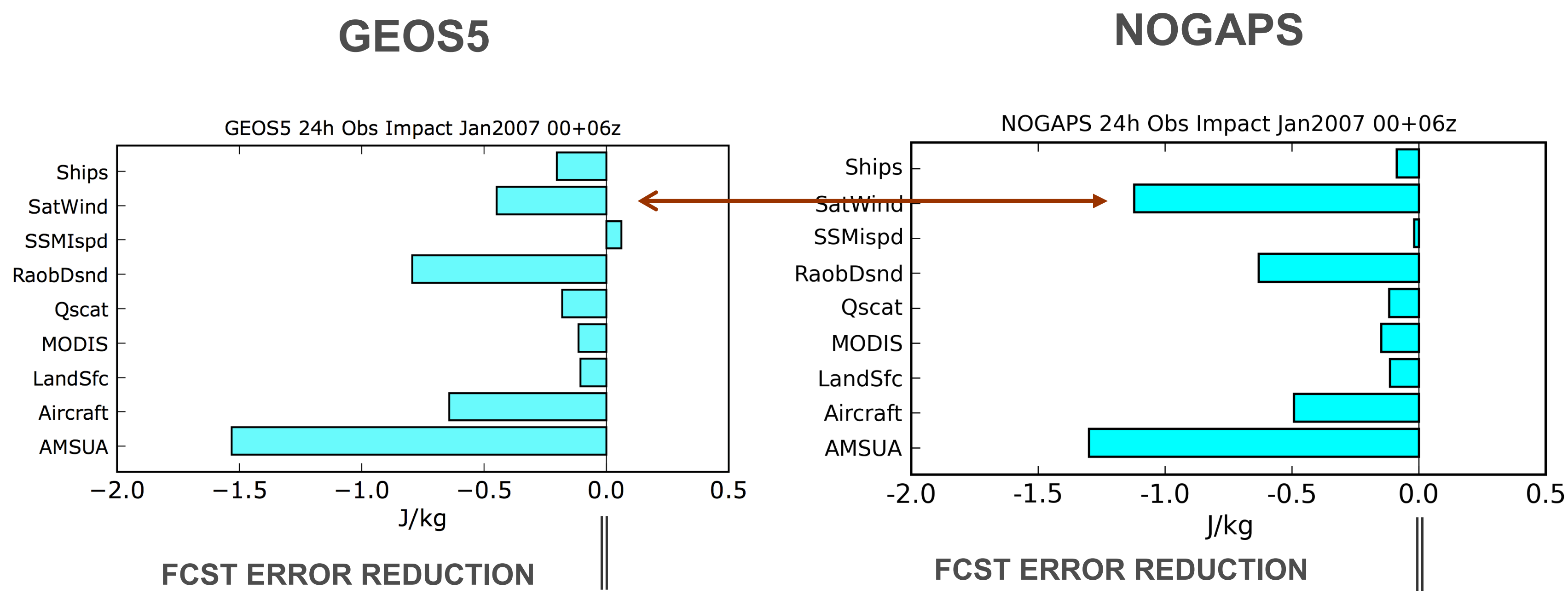
Forecast error on Analysis Trajectory (e_f)

Difference of nonlinear forecast error norms ($e_f - e_g$)

Adjoint-based estimate of ($e_f - e_g$) = global <u>observation impact</u>

Total Observation Impacts

global domain: 00+06 UTC assimilations Jan 2007

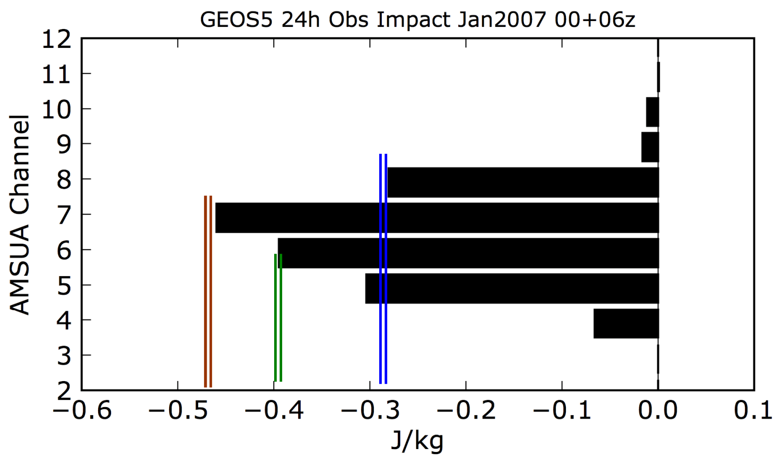


Note: larger impact of satellite winds (AMVs) in NOGAPS

Observation Impacts: AMSUA Ch 4-12

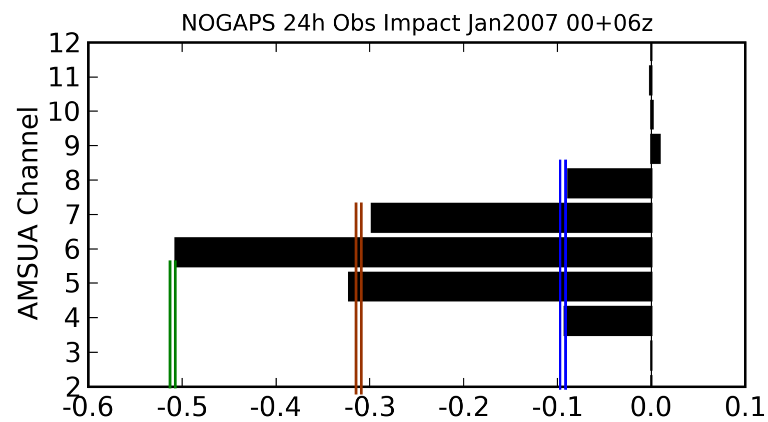
global domain: 00+06 UTC assimilation Jan 2007

GEOS5



FCST ERROR REDUCTION

NOGAPS



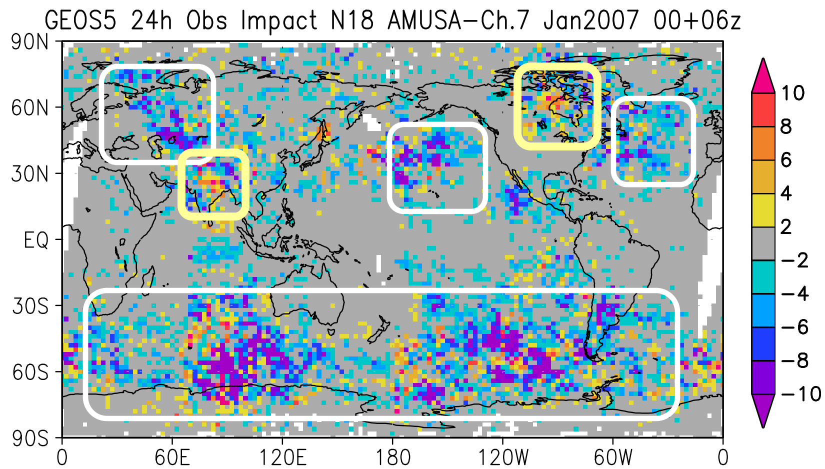
FCST ERROR REDUCTION

Note: GEOS5 has largest impacts from Channels 7-6-8, NOGAPS has larger impact from Channel 6-7-8

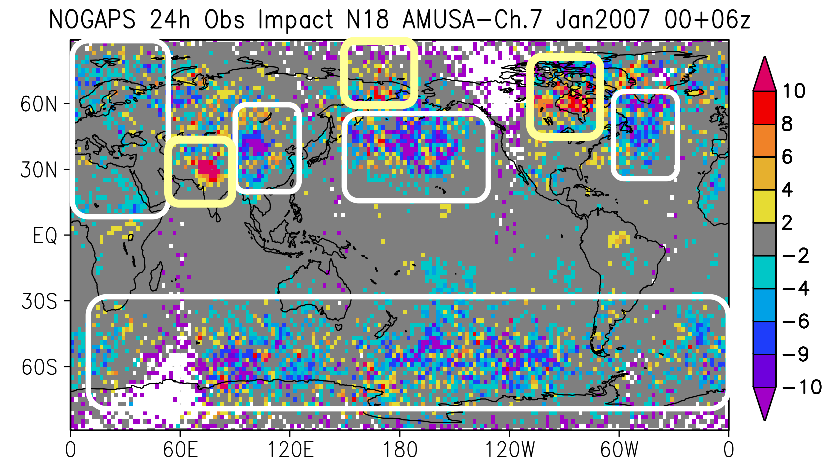
Observation Impacts: N18 AMSUA Ch7

global domain: 00+06 UTC assimilation Jan 2007

GEOS5



NOGAPS



Observations that produce large forecast error reductions

Observations that produce forecast error increases in <u>both models</u> – land or ice surface contamination of radiance data ?

MOTIVATIONS

- Improved accuracy of short-range sensitivity with adjoint
- Adjoint-derived sensitivity in medium-range forecasts
- Possible applications to singular vectors and 4d-Var
- Work in-progress …..

Adjoint sensitivity with correction terms

Example: 48hr sensitivity calculation

$$\left[\frac{\partial J_f^{48}}{\partial \mathbf{x}_f^{36}}\right]^{cor} = \left[\mathbf{L}_f^T\right]_{36}^{48} \left\{ \mathbf{C}\left(\mathbf{x}_f^{48} - \mathbf{x}_t^{48}\right) \right\}$$

$$\left[\frac{\partial J_f^{48}}{\partial \mathbf{x}_f^{24}}\right]^{cor} = \left[\mathbf{L}_f^T\right]_{24}^{36} \left\{ \left[\frac{\partial J_f^{48}}{\partial \mathbf{x}_f^{36}}\right]^{cor} + \mathbf{C}\left(\mathbf{x}_f^{36} - \mathbf{x}_f^{36tlm}\right) \right\}$$

$$\left[\frac{\partial J_f^{48}}{\partial \mathbf{x}_f^{00}}\right]^{cor} = \left[\mathbf{L}_f^T\right]_{00}^{24} \left\{ \left[\frac{\partial J_f^{48}}{\partial \mathbf{x}_f^{24}}\right]^{cor} + \mathbf{C}\left(\mathbf{x}_f^{24} - \mathbf{x}_f^{24tlm}\right) \right\}$$

NOTE: if TLM is "perfect" then correction terms = zero

1. Costfunction is defined at t=48hr using TLM-based correction term
2. Gradient is integrated from t=48hr to t=36hr
3. Correction term is added at t=36hr
4. Gradient is integrated from t=36hr to t=24 hr
5. Continue until gradient at t=0 hr is obtained

TLM-based correction terms

$$\mathbf{x}_f^{24tlm} = \mathbf{x}_t^{24} + [\mathbf{L}_f]_{12}^{24}(\mathbf{x}_f^{12} - \mathbf{x}_t^{12})$$

$$\mathbf{x}_f^{36tlm} = \mathbf{x}_t^{36} + [\mathbf{L}_f]_{24}^{36}(\mathbf{x}_f^{24} - \mathbf{x}_t^{24})$$

$$\mathbf{x}_f^{48tlm} = \mathbf{x}_t^{48} + [\mathbf{L}_f]_{36}^{48}(\mathbf{x}_f^{36} - \mathbf{x}_t^{36})$$

Nonlinear forecasts

Analysis fields

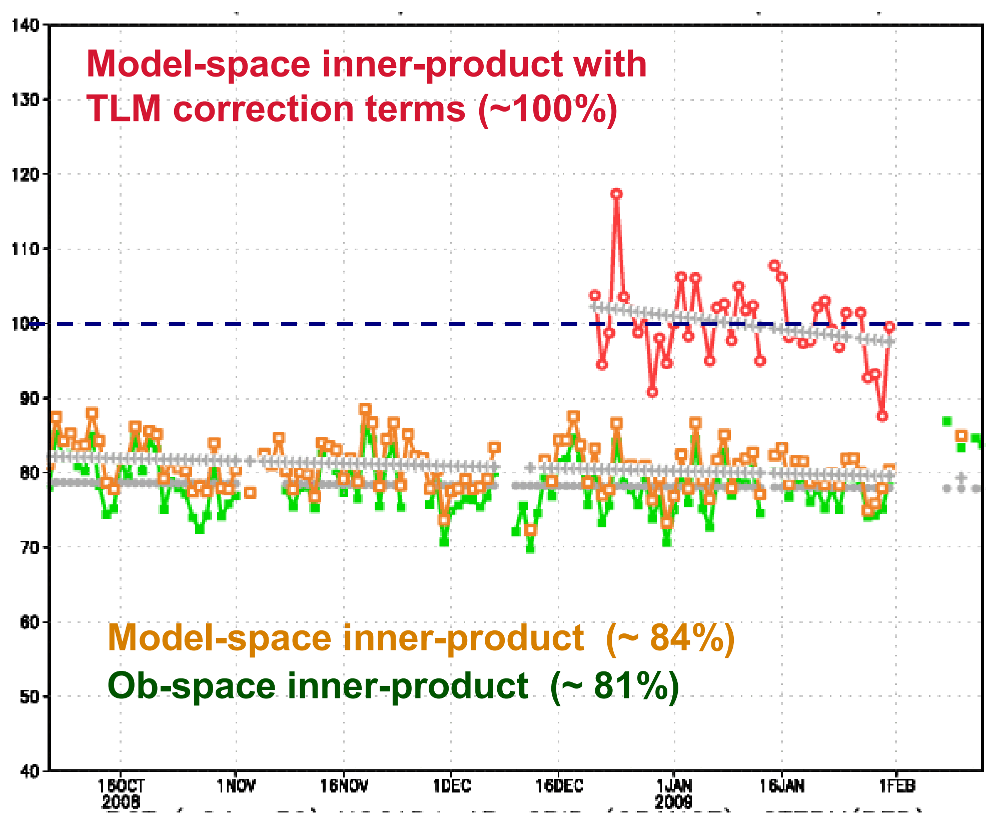
- The TLM is used to calculate forecast vectors in 12-hr <u>segments</u> (other time intervals can be used)
- The **TLM forecasts** are used to define correction terms in the segmented adjoint equations (previous slide)
- The correction terms compensate for error in the adjoint sensitivity calculations (TLM and adjoint have the same error: TLM and NLM forecasts can be used to quantify this error)

Does it work?

NAVDAS-AR observation impact calculations

Percent of actual e_{24}-e_{30} that is obtained with adjoint-based inner products

100% = correct result



END OF TALK

QUESTIONS ?

COMMENTS ?