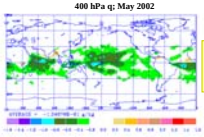
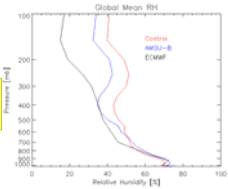
AMSU-B Radiance Assimilation for NOGAPS and COAMPS

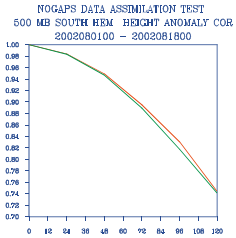
- *Motivation*
  - –NOGAPS and COAMPS use few observations of mid- to upper-tropospheric humidity
  - –Assimilate water vapor profiles from AMSU-B microwave observations
- *Approach*
  - –Observations from from the AMSU-B microwave radiometer on the NOAA-16 polar orbiter.
    - –150 GHz and 183.31±1, 3, and 7 GHz channels
    - –Thinned to every fourth point of every fourth scan (May 2002 runs) or one ob per 2^{n}x2^{n} degree box spacing in tropics (equivalent higher latitudes) for August 2002 runs.
    - –Land, coast, and sea ice are screened out, as are points with high scattering index (Greenwald and Christopher, 2002).
  - – Algorithm is a physical optimal estimation inversion of the observed brightness temperatures (based on Blankenship et al. (2000))
    - –Equivalent to a one-dimensional variational assimilation (1DVAR) of radiances at each observation point.
    - –NOGAPS background (6-hour forecast) humidity profile
    - –Temperature profile, sea surface temperature, and surface wind speed from the NOGAPS forecast (held constant)
    - –Clouds are turned off in this version of the retrieval
    - –No bias correction (known upper tropospheric moist bias in NOGAPS makes traditional bias correction techniques problematic)
    - –Retrievals which failed to converge (usually due to heavy cloud or precipitation in the scene), or which failed gross temperature departure checks were also rejected.
  - – NAVDAS assimilates the 1DVAR profiles of pseudo relative humidity
    - –1DVAR used due to limitations with present NAVDAS configuration
    - –Approximately 45,000 retrievals (5000 for August runs) from the NOAA-16 AMSU-B per 6-hour update cycle are assimilated.
- *Results*
  - – Corrects NOGAPS tendency to be too moist above 500 mb
  - – Enhances humidity gradients in the Intertropical Convergence Zone and South Pacific Convergence Zone
  - – There is also an enhanced humidity gradient at 20º W off the western African coast. The stronger gradient there is consistent with the model's wind field, which indicates that the air mass origin is continental north of 10º N but maritime south of that.
    - –These enhanced gradients are largely maintained out to 4 days

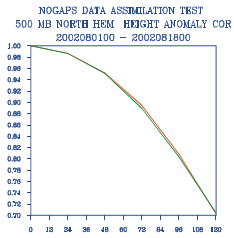
1DVAR AMSU-B minus Control
NOGAPS/NAVDAS Assimilation Tests
400 hPa q: May 2002



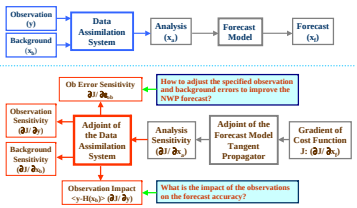
Conclusion: 1DVAR retrieval assimilation dries out NOGAPS in the mid to upper troposphere







NAVDAS Adjoint System



Data Assimilation Adjoint Theory

•Begin with the linear analysis equation

$$\mathbf{x_a} = \mathbf{x_b} + \mathbf{K}(\mathbf{y} - \mathbf{H}\mathbf{x_b}),$$

where

$$\mathbf{K} = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$$

•The sensitivities of the analysis to the observations and background are

$$\frac{\partial \mathbf{x_a}}{\partial \mathbf{y}} = \mathbf{K}^T,$$

$$\frac{\partial \mathbf{x_a}}{\partial \mathbf{x_b}} = (\mathbf{I} - \mathbf{K}\mathbf{H})^T.$$

•Using the chain rule, the sensitivities of the forecast aspect *J* to the observations and background are

$$\frac{\partial J}{\partial \mathbf{y}} = \frac{\partial \mathbf{x_a}}{\partial \mathbf{y}}\frac{\partial J}{\partial \mathbf{x_a}} = \mathbf{K}^T\frac{\partial J}{\partial \mathbf{x_a}},$$

$$\frac{\partial J}{\partial \mathbf{x_b}} = \frac{\partial \mathbf{x_a}}{\partial \mathbf{x_b}}\frac{\partial J}{\partial \mathbf{x_a}} = (I - \mathbf{H}^T\mathbf{K}^T)\frac{\partial J}{\partial \mathbf{x_a}},$$

Baker and Daley (2000)
Doerenbecher and Bergot (2001)

Observation Sensitivity Applications

•Diagnostic (observation taken and forecast error known)
- – Impact of observations on forecast error
- – Tuning of error variances and other parameters

• Targeting (observation and forecast error not known)
- –Test the impact of hypothetical observations
- –Potential benefit of satellite data prior to launch
- –Alternative networks of satellite and in-situ observations

•NRL Core Systems – NAVDAS[1] and NOGAPS[2]

•NRL Predictability Research Group

1. Daley and Barker (2000a,b) 2. Hogan and Rosmond (1991); Rosmond (1997)

Observation Impact on NOGAPS Forecast Error

$$\delta e_{24}^{30} = \left\langle (y - Hx_b), \frac{\partial J_{24}}{\partial y} + \frac{\partial J_{30}}{\partial y} \right\rangle$$

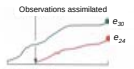
δe_{24}^{30} = adjoint estimate of difference between the 30h and 24h forecast error in global model (scalar)

y = observation vector (~ 250,000 obs)

$\mathbf{x_b}$= background (6h) forecast

•We want an estimate of the impact of the observations on the NOGAPS forecast error in *observation space*

Choice of Cost Function



•Observations are assimilated at 00UTC, creating initial conditions for a new trajectory, which has forecast error *e24*.

• The old trajectory starts from 18UTC (-6h), and has forecast error *e30* . It also provides the background for the analysis at 00UTC.

• Both forecasts verify at time +24h.

•The difference between the errors *e24 – e30* is due solely to assimilation of observations.

•Nonlinear forecast error is given by $\Delta e_{24}^{30} = e_{24} - e_{30}$, where $e_f = \langle (\mathbf{x}_f - \mathbf{x}_t), C(\mathbf{x}_f - \mathbf{x}_t) \rangle$ and **C** is the total (dry) energy-weighted error norm.

•Quadratic measure forecast error (J kg^{-1}) that combines temperature, wind and pressure from ~ 150 hPa to the surface

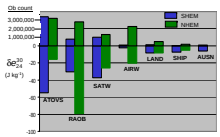
•NOGAPS at T79L30 resolution; verifying analyses produced by NAVDAS

• The impact function δe_{24}^{30} gives an estimate of the contribution of each observation assimilated by NAVDAS in the global domain to a reduction or increase in e_{24}-e_{30}.

• For complete derivation, see Langland and Baker (2003)

•Fourrié *et al.* (2002) and Doerenbecher and Bergot (2001) use similar cost functions

Global Observation Impact (by hemisphere)



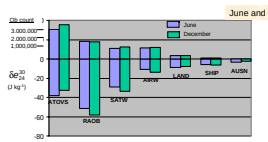
June and December 2002

•Observation impact (δe_{24}^{30} J kg^{-1}) for Southern and Northern Hemispheres, partitioned by instrument type

•Includes all observations assimilated in NAVDAS at 00UTC.

•ATOVS-temperature retrievals, RAOB-rawinsondes, SATW-cloud and feature-track winds, AIRW-commercial aircraft observations, LAND-land surface observations, SHIP-ship surface observations, AUSN-synthetic sea-level pressure data (Southern Hemisphere only).

Global Observation Impact (by season)



June and December 2002

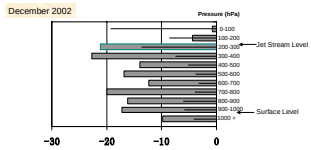
• Global observation impact (δe_{24}^{30} J kg^{-1}) for June and December 2002

•Includes all observations assimilated in NAVDAS at 00UTC.

Acknowledgements

The support of the Naval Research Laboratory, Office of Naval Research and the Space and Naval Warfare System Command through program elements 0603207N, 0601153N, 0602435N and 0601153N is gratefully acknowledged. We thank John Derber of NCEP for suggestions to improve our bias correction scheme, and for incorporating observations over land. We also thank Ed Barker, Tim Hogan, Jim Goerss and Tom Rosmond of NRL for assistance with the NAVDAS and NOGAPS code. The first version of the NAVDAS adjoint was developed by the late Roger Daley.

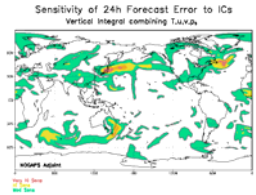
Global Observation Impact (by vertical level)



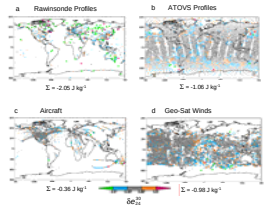
• Global observation impact (δe_{24}^{30}, J kg^{-1}) partitioned by pressure level for December 2002.

•Black solid line within gray bar is proportional to number of observations in each pressure layer

Sensitivity to Initial Conditions
December 10. 2002



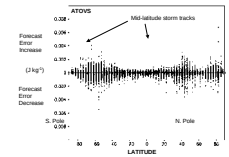
Global Observation Impact (J Kg-1)
00 UTC 10 December 2002



•Green: large reduction in 24h global forecast error. Red: large increase

•Blue: moderate reduction Orange: moderate increase Grey: small reduction or increase

Global Observation Impact for ATOVS



References

Baker, N.L., 2000: Observation adjoint sensitivity and the adaptive observation-targeting problem. Ph.D. dissertation, Naval Postgraduate School, 265 pp. [Available from http://library.nps.navy.mil/uhtbin/hyperion-image/00Dec_Baker.PHD.pdf]

Baker, N.L. and R. Daley, 2000: Observation and background adjoint sensitivity in the adaptive observation-targeting problem. *Quart. J. Roy. Meteor. Soc.*, **126**, 1431-1454.

Blankenship, C.B. and N.L. Baker, 2003: Assimilation of retrieved water vapor profiles into The Navy Operational Global Atmospheric Prediction System (NOGAPS). Preprints, *12th Conference on Satellite Meteorology and Oceanography*, Long Beach, CA., Amer. Meteor. Soc.

Blankenship, C. B., A. Al-Khalaf, and T. T. Wilheit, 2000: Retrieval of water vapor profiles using SSM/T-2 and SSM/I data. *J. Atmos. Sci.*, 57, 939-955.

Campbell, W.F. and N.L. Baker, 2003: A hybrid approach to the bias correction of AMSU-A radiance data. Preprints, *12th Conference on Satellite Meteorology and Oceanography*, Long Beach, CA., Amer. Meteor. Soc.

Cooper, G.A., N.L. Baker and P.A. Durkee, 2003: Variational retrievals within the summertime Eastern Pacific environment using ATOVS with the COAMPSTM mesoscale forecast system. Preprints, *12th Conference on Satellite Meteorology and Oceanography*, Long Beach, CA., Amer. Meteor. Soc.

Cooper, G.A., 2002: Variational retrieval of Eastern Pacific atmospheric boundary layer parameters using ATOVS within the COAMPS mesoscale forecast system. Ph.D. dissertation, Naval Postgraduate School, 244 pp. [Available from http://library.nps.navy.mil/uhtbin/hyperion-image/02Dec_Cooper.pdf]

Daley, R. and E. Barker, 2001. NAVDAS Source Book 2001. Naval Research Laboratory, NRL/PU/7530—01-441.

Daley, R. and E. Barker, 2001: NAVDAS formulation and diagnostics. Mon. Wea. Rev., 129, 869-883.

Doerenbecher, A. and T. Bergot. 2001: Sensitivity of observations applied to FASTEX cases. *Non. Proc. Geophys.*, 8, 467-481.

Greenwald, T. J., and S. A. Christopher, Effect of cold clouds on satellite measurements near 183 GHz, J. Geophys. Res., 107(D13), 4170, doi:10.1029/2001JD000258, 2002.

Gross, A., E.A. Smith, H.S. Chung, M. Ou, B. Sohu, and J. Turk, 2002: Possibilities and Limitations for QPF Using Nowcasting Methods with Infrared Geostationary Satellite Imagery. *J. Appl. Meteor.*, 41, 763-785.

Fourrié, N., A. Doerenbecher, T. Bergot, and A. Joly, 2002: Adjoint sensitivity of the forecast to TOVS observations. *Quart. J. Roy. Meteor. Soc.*, **128**, 2759-2777.

Langland, R.H. and N.L. Baker, 2003: Estimation of observation impact using the NAVDAS Adjoint System. Submitted to *Tellus*.

Rosmond, T.E., 1997: A Technical Description of the NRL Adjoint Modeling System. NRL/MR/7532/97/7230. Available from the Naval Research Laboratory, Monterey, CA., 93943-5502, 62 pp.