Environnement Canada
Environment Canada

Canada

Assimilation of AMSU-A Radiances in an EnKF Column Environment

Herschel Mitchell, Pieter Houtekamer, Sylvain Heilliette

8th EnKF Workshop
7-10 May 2018
Mont Gabriel
Québec, Canada

Motivation and objective

AMSU-A is important data source. Impact in operational EnKF?

Two EnKF-4D-Var intercomparison studies concluded that satellite radiances have smaller impact in EnKF systems [Miyoshi et al 2010, Bonavita et al 2015].

Using the same EnKF-generated background fields to calculate background-error covariances, an EnVar system produced better deterministic forecasts than the EnKF system (Buehner et al, 2010). Why?

A series of EnKF experiments at EC aimed at improving the assimilation of AMSU-A radiances yielded unsatisfying results.

Objective : Use a simpler (i.e., column) environment to understand the underlying issues.

Experimental method

Perform a single data assimilation step many times, i.e., use different realizations of sets of simulated observations and of ensembles of bkgd profiles to produce many realizations of an analysis ensemble.

Each result is based on 20,000 realizations of the analysis procedure.

For each experiment, EnKF performance is evaluated by examining

- the rms error of the ensemble mean,
- the rms spread in the ensemble.

The column EnKF -

- based on the global EnKF,
- analysis variable is temperature,
- 81 analysis levels between 1013.25 and 0.1 hPa (≈ 65 km),
- uses RTTOV (v12.1) to assimilate AMSU-A channels 4 - 14.

Experimental set-up A

Large ensemble size (384 members).

No localization. No covariance inflation or covariance relaxation.

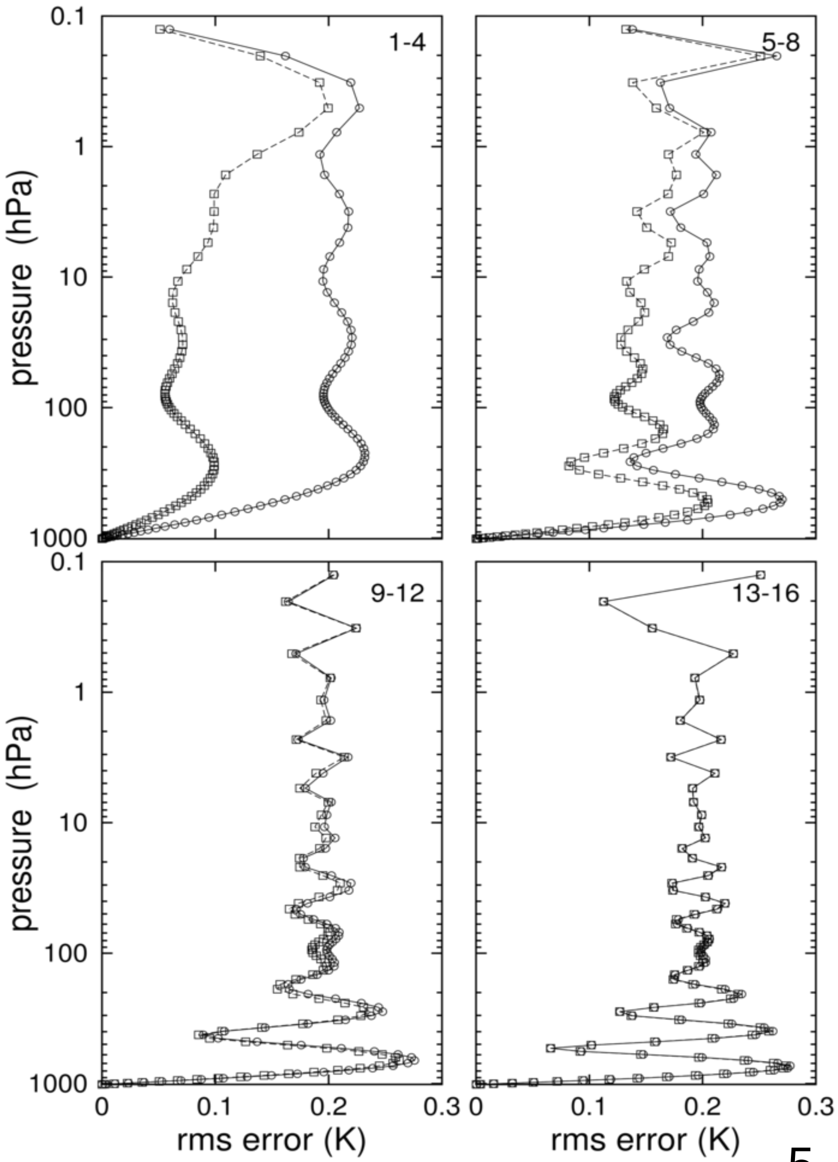
AMSU-A obs errors obtained from global EnKF/EnVar.

Background temperature perturbations specified w.r.t. to a reference T profile, i.e., U.S. Standard Atmosphere.

Experiments A.

- bkgd-error perturbations in terms of analytical modes,
- $B_n(Z) \sim \sin nZ \exp(Z/2H)$, where H is scale height and $Z = -H \ln(p/p_s)$,
- $\varepsilon(Z) \sim \Sigma\, r_n\; b_n\, B_n(Z)$, where $r_n \sim N(0,1)$ and spectra b_n are hypothetical.

Effect of bkgd-error vertical structure



Profiles of rms error of the ensemble mean for the bkgd and analysis.

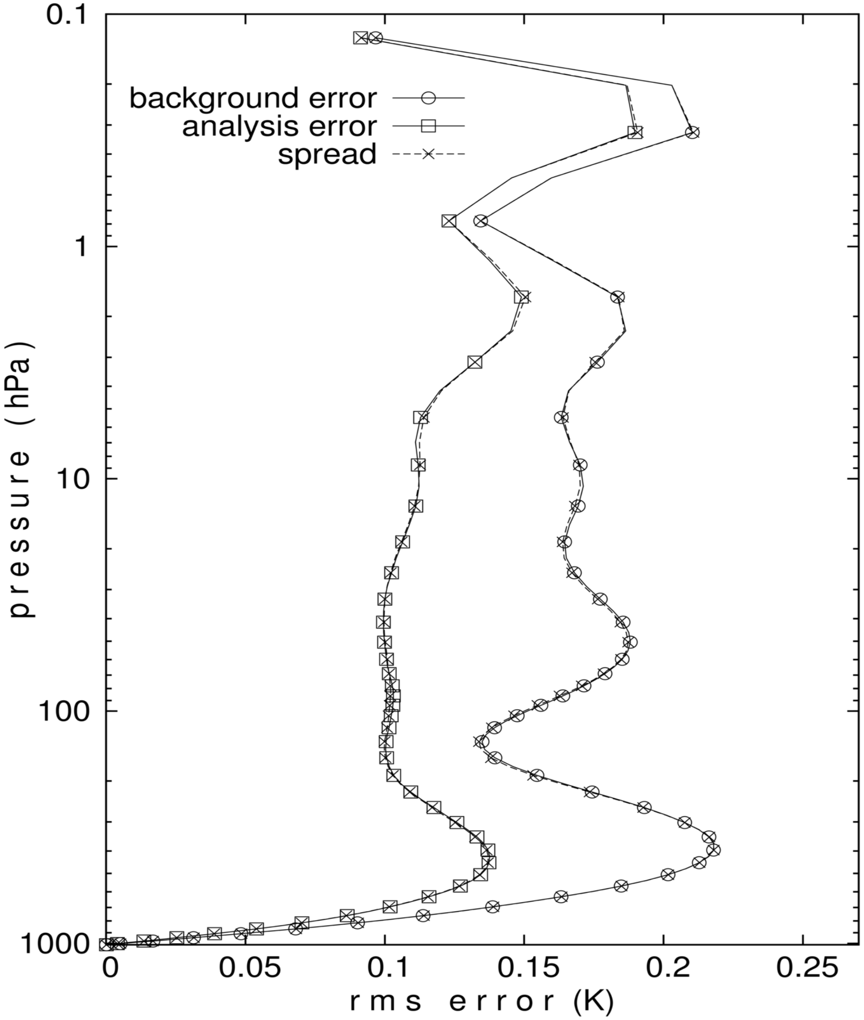
In each panel, the background consists of four vertical modes, as indicated.

As wavenumber of the modes in the bkgd increases, the error reduction due to AMSU-A assimilation shrinks rapidly.

Conclusion:

AMSU-A radiances can only reduce bkgd error in deep vertical modes (e.g., Rodgers 2000).

A broader bkgd-error spectrum



Bkgd-error consists of modes 1 to 24, peaking at modes 4 and 5.

Assimilation of the AMSU-A radiances results in a substantial reduction of error (except above ≈ 2 hPa).

A diagnostic: the trace of HPH^T

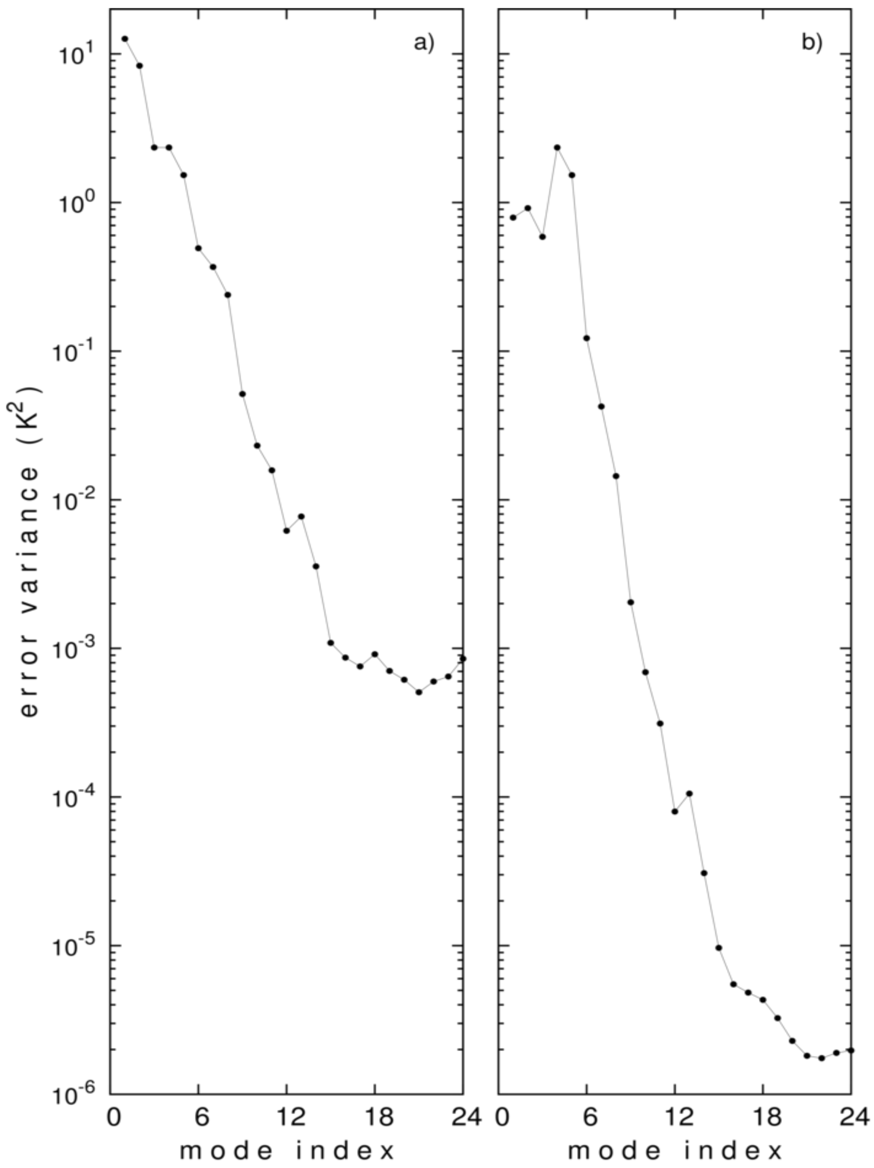
Almost every occurrence of the bkgd in the EnKF algorithm involves it first being acted upon by the forward interpolation operator, H.

Consequently, we will consider how our different backgrounds appear through the prism of the RT model.

To do this, we consider the matrix HPH^T and focus on its trace.

Note that HPH^T can be expressed as $(Hx)(Hx)^T$, where x is a vector.

Spectrum of tr(HPH^T) for expts A



Left-hand panel: spectrum of HPH^T if the bkgd-error is defined using analytical modes all having the same amplitude.

Right-hand panel : spectrum of HPH^T for the bkgd-error spectrum peaking at modes 4 and 5.

Conclusion: If tr(HPH^T) for a given bkgd mode is less than 0.1 K^2, AMSU-A obs will be ineffective in reducing that error variance.

Experimental set-up B

The global EnKF has 256 ensemble members and the top of the R&D version is at 0.1 hPa.

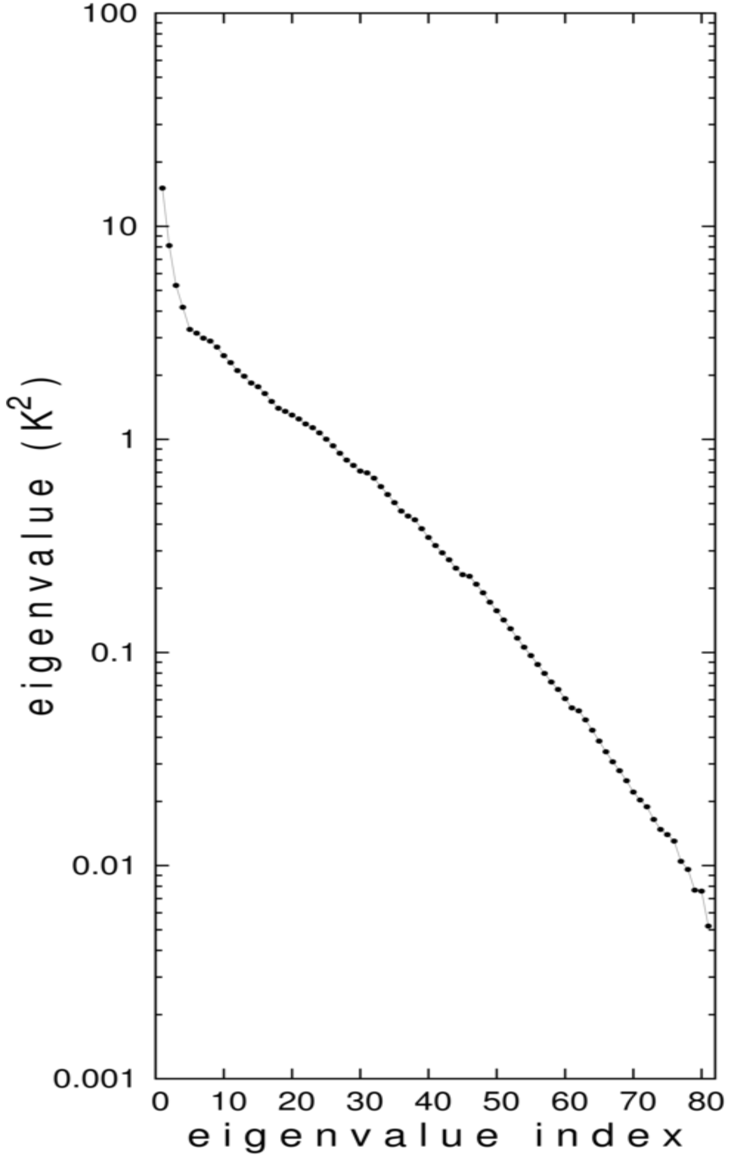
After 2 weeks of cycling the R&D EnKF, a global average of the 256 ensemble members for T, is used to compute an 81x81 vertical covariance matrix for T.

Perform an eigen-analysis of this covariance matrix.

Experiments B.

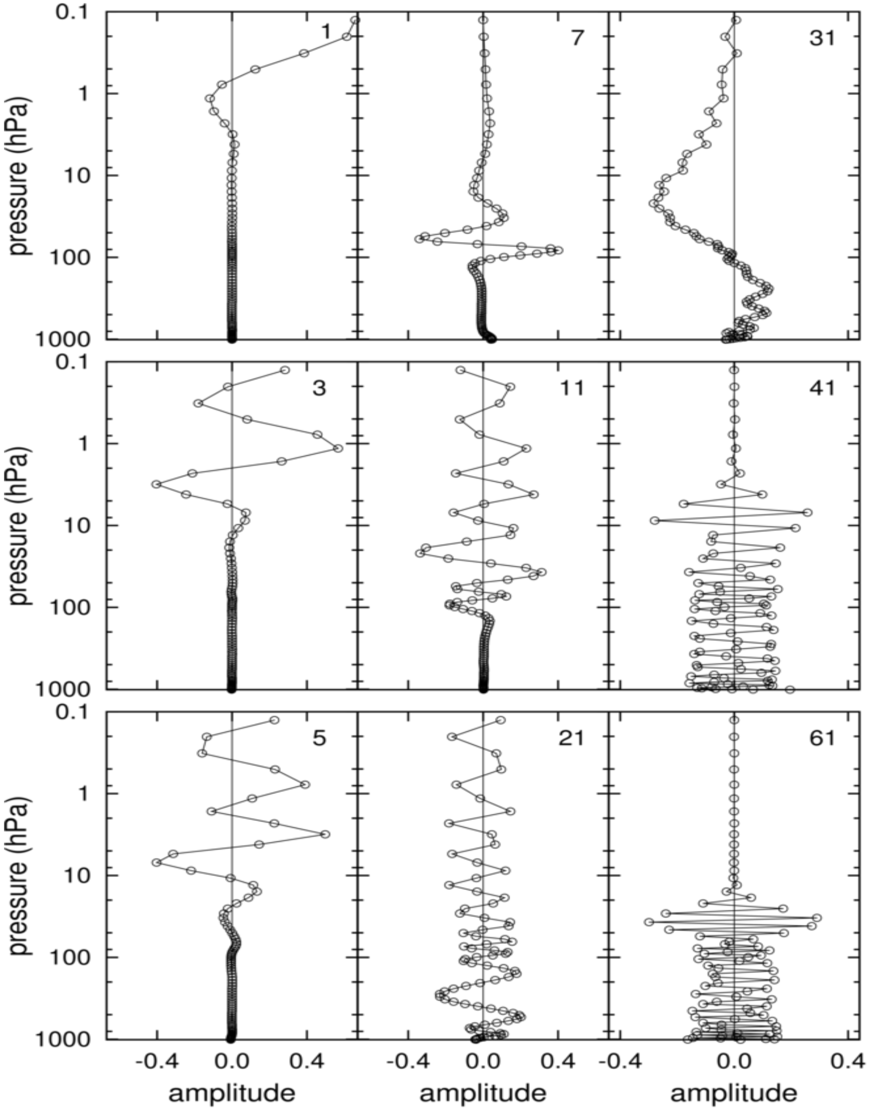
- bkgd-error perturbations in terms of these eigenmodes,
- $\varepsilon(Z) \sim \Sigma\, r_n\, b_n\, B_n(Z)$, where $r_n \sim N(0,1)$, $b_n = \mathrm{sqrt}(\lambda_n)$ and $B_n(Z)$ is nth eigenmode.
- As before, U.S. Standard Atmosphere is used as reference T profile.

Spectrum of P



Define P to be the 81x81 bkgd-error covariance matrix for T obtained from the global EnKF.

Structure of some eigenmodes of P



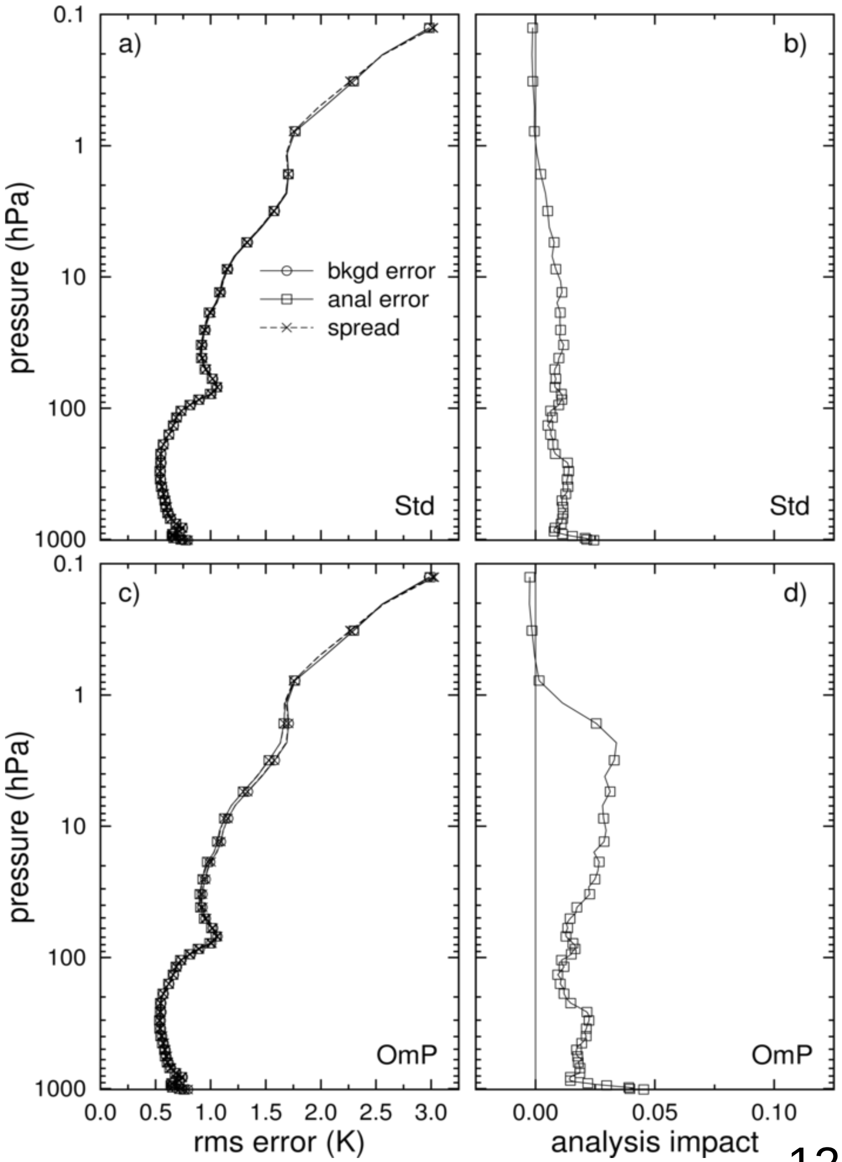
Modes 1 – 5 are stratospheric modes.

Mode 31 is notable as the deepest mode.

Inclined to consider modes 41 etc to be noise.

Paucity of deep modes.

Experimental set-up B: Results



Left-hand panels: rms error of the ensemble mean for the bkgd and analysis.

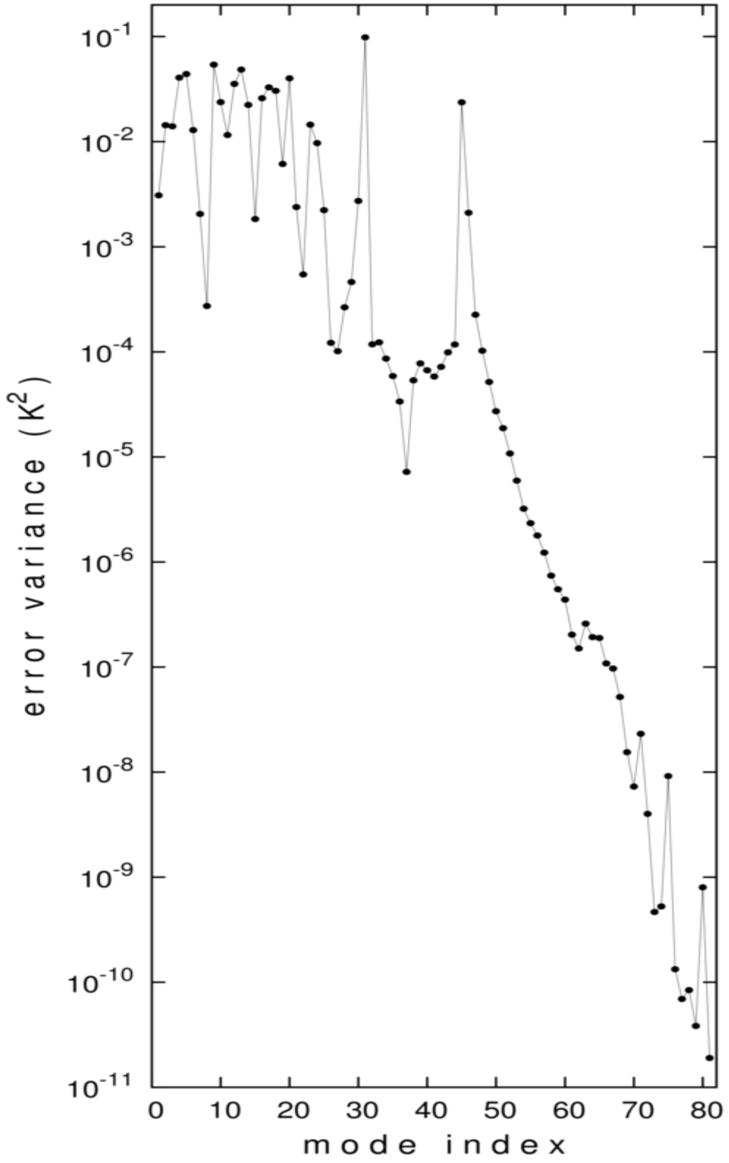
Right-hand panels show the same results in terms of analysis impact.

Upper panels use operational obs-errors, lower panels use reduced obs-errors.

Conclusion:

Assimilation of AMSU-A radiances has no substantial impact.

Spectrum of tr(HPH^T) for expt B



Here P is the 81x81 bkgd-error covariance matrix for T obtained from the global EnKF.

tr(HPH^T) is a maximum for mode 31 for which its value is just below 0.1 K^2.

This is consistent (i) with the ineffectiveness of the column EnKF with the bkgd profiles from the global EnKF and (ii) with the general unresponsiveness of the global EnKF to attempts to increase the impact of AMSU-A radiances.

Conclusions

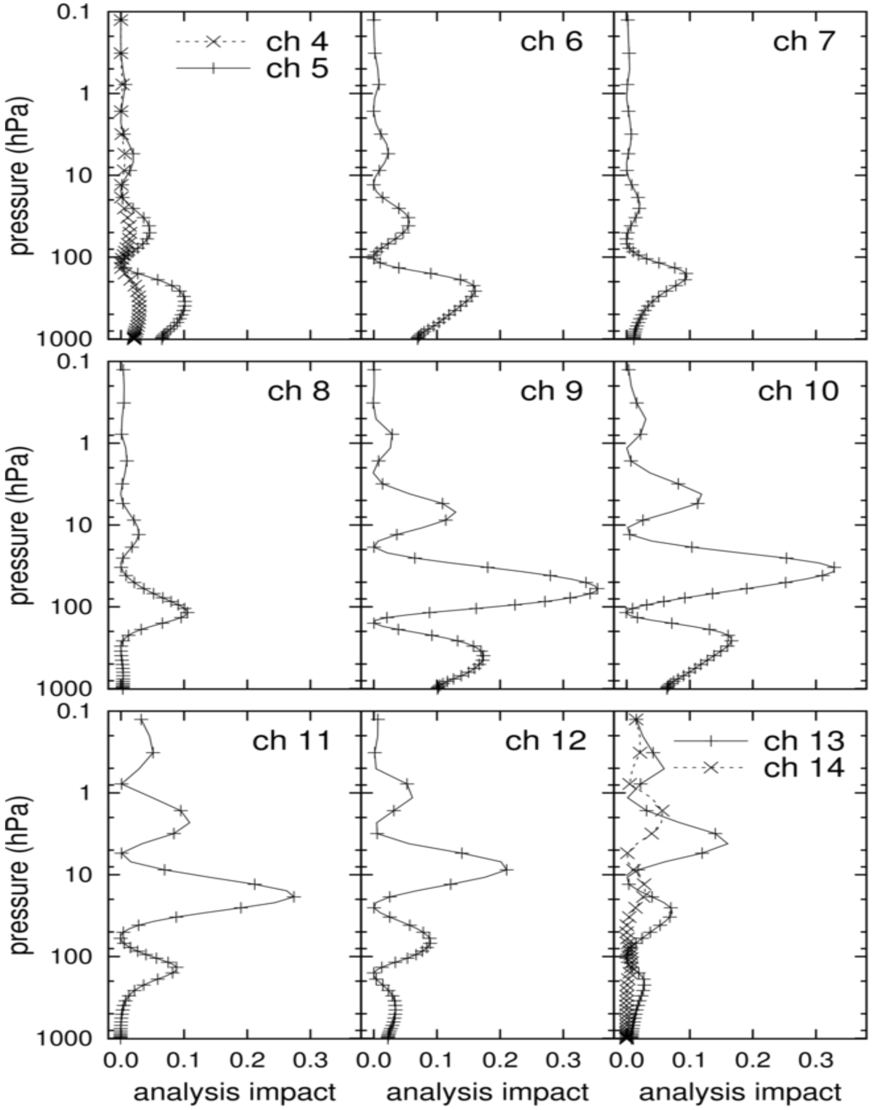
The problems relating to the assimilation of AMSU-A radiances stem from the vertical structure of the bkgd-error profiles (not the use of small ensembles or the way localization has been implemented).

After two weeks of cycling, it seems that the global EnKF has virtually eliminated all bkgd-error structures that can be ˝seen˝ by the AMSU-A radiances.

Raises questions about utility of assimilating ever larger volumes of AMSU-A (or ATMS) radiance profiles in operations.

Or, perhaps there are error sources relating to deep modes that need to be explicitly sampled in the EnKF, e.g., relating to the bias correction for AMSU-A radiances.

Impact of each AMSU-A channel



Bkgd-error is as before, i.e., consists of modes 1 to 24, peaking at modes 4 and 5.

Figure shows **analysis impact** [= (B_{ERR} – A_{ERR}) / B_{ERR}] for each AMSU-A channel.

Conclusion:

Only channels 9 – 12 have a substantial analysis impact.
(This is largely due to the specified obs errors).