

# Assimilation of AMSU-A Microwave Radiances with an Ensemble Kalman Filter (EnKF)

Herschel L. Mitchell, P. L. Houtekamer, Gérard Pellerin,  
Mark Buehner and Bjarne Hansen

Meteorological Service of Canada (MSC),  
Dorval, Québec, Canada

## Overview of the presentation:

- description of the EnKF,
- experimental environment,
- assimilation of AMSU-A microwave radiances,
- results,
- conclusion.

The **Kalman filter** provides the optimal (minimum variance) solution to the 4D data-assimilation problem in the case of small errors with Gaussian distribution.

The **ensemble Kalman filter (EnKF)** is a close approximation to the Kalman filter. It uses a Monte-Carlo ensemble of short-range forecasts to estimate the covariances of the forecast error. The approximation to the Kalman filter becomes more accurate as the ensemble size increases.

The EnKF is conceptually simple. It does not depend strongly on the validity of hypotheses about the linearity of the model dynamics and requires neither a tangent linear model nor its adjoint. In addition, it parallelizes well.

## EnKF equations

For ensemble member  $i$ ,

$$\Psi_i^f(t + 6) = M(\Psi_i^a) + q_i$$

$$\Psi_i^a = \Psi_i^f + K(o_i - H(\Psi_i^f))$$

where

$\Psi^f$  : first-guess (forecast) field,

$\Psi^a$  : analysis field,

$M$  : full (nonlinear) forecast model,

$q_i$  : representation of model error,

$o_i$  : vector of (perturbed) observations,

$H$  : interpolation operator (may be nonlinear),

$K$  : gain matrix (the same for all ensemble members).

## The Gain Matrix

$$K = P^f H^T (H P^f H^T + R)^{-1}$$

where

$$P^f H^T \equiv \frac{1}{N-1} \sum_{i=1}^N [\psi_i^f - \overline{\psi_i^f}] [H(\psi_i^f) - \overline{H(\psi_i^f)}]^T$$

$$H P^f H^T \equiv \frac{1}{N-1} \sum_{i=1}^N [H(\psi_i^f) - \overline{H(\psi_i^f)}] [H(\psi_i^f) - \overline{H(\psi_i^f)}]^T$$

Note:  $R$  is the observational error covariance matrix.

A random ensemble is used to estimate error covariances.

Since  $H$  is applied to each background field individually (rather than to the covariance matrix  $P^f$ ), it is possible to use nonlinear operators. For example,  $H$  can be a radiative transfer model if radiance observations are available.

## Localization

To filter covariances at long distances, we use a Schur product (i.e., a point-wise product of two matrices):

$$P^f(r_i, r_j) = P_{ensemble}^f(r_i, r_j) \rho(r, L).$$

This leads to a positive definite matrix  $P^f$  (Gaspari & Cohn 1999).

As we get bigger ensembles, we can make  $L$  longer.

Covariances are localized in the vertical in a similar way.

## EnKF configuration.

**model:** the Canadian Global Environmental Multiscale (GEM) model. Similar to the version used to produce the higher resolution medium-range deterministic forecast at CMC.

horizontal grid:  $144 \times 72$  or  $240 \times 120$

28 levels in the vertical.                      model top: 10 hPa.

vertical coordinate:  $\eta \equiv \frac{p - p_{top}}{p_{surface} - p_{top}}$ .

timestep: 60 minutes.                      model variables:  $u, v, T, q$ , and  $p_{surface}$ .

### observations:

Our approach with the EnKF has been to use those observations accepted by the CMC operational global 3D-Var.

In this way, we are making use of the operational:

- “background check” and QCVAR,
- TOVS monitoring and bias correction, and
- horizontal thinning of TOVS observations.

## EnKF configuration. cont'd

Currently the EnKF assimilates:

- radiosondes:  $u, v, T, q, p_{surface}$
- aircraft:  $u, v, T$
- satellite: cloud track winds  $u, v$ , and AMSU-A microwave radiances
- surface observations:  $T, p_{surface}$

For the calculation of simulated radiances from a model state vector, the EnKF (like the CMC 3D-Var procedure) uses the RTTOV radiative transfer model.

Our implementation of RTTOV is very much based on its use in the operational 3D-Var (Chouinard, Hallé).

Note: we don't need either the tangent linear or adjoint of this operator.

The EnKF uses the same observational error statistics as the 3D-Var.

The vertical localization forces covariances to zero in 2 units of ln (pressure).

Results shown here are from data assimilation cycles over a 2-week period in May-June 2002.

# Channel Selection - AMSU-A

## Channel selection - AMSU-A

Channel	Open Ocean	Land/Ice
3	√	
4	√	
5	√	
6	√	√ if topo. < 250m
7	√	√ if topo. < 2000m
8	√	√
9	√	√
10	√	√

Also: Horizontal thinning at 250 km



Environment Canada  
Canadian Meteorological Centre

Environnement Canada  
Centre météorologique canadien

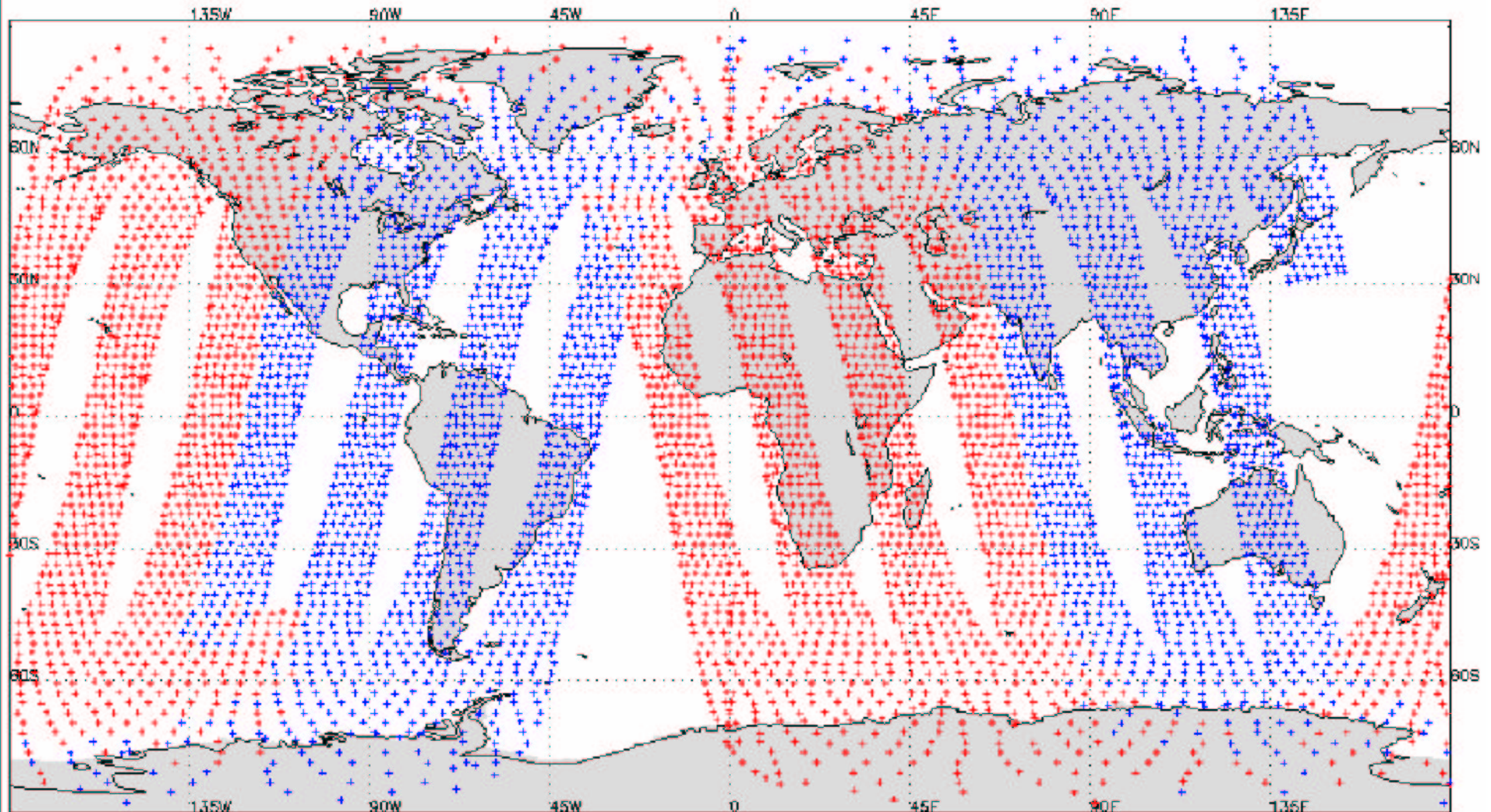


# ATOVS (amsua) Data after Thinning

ATOVS Observations after thinning

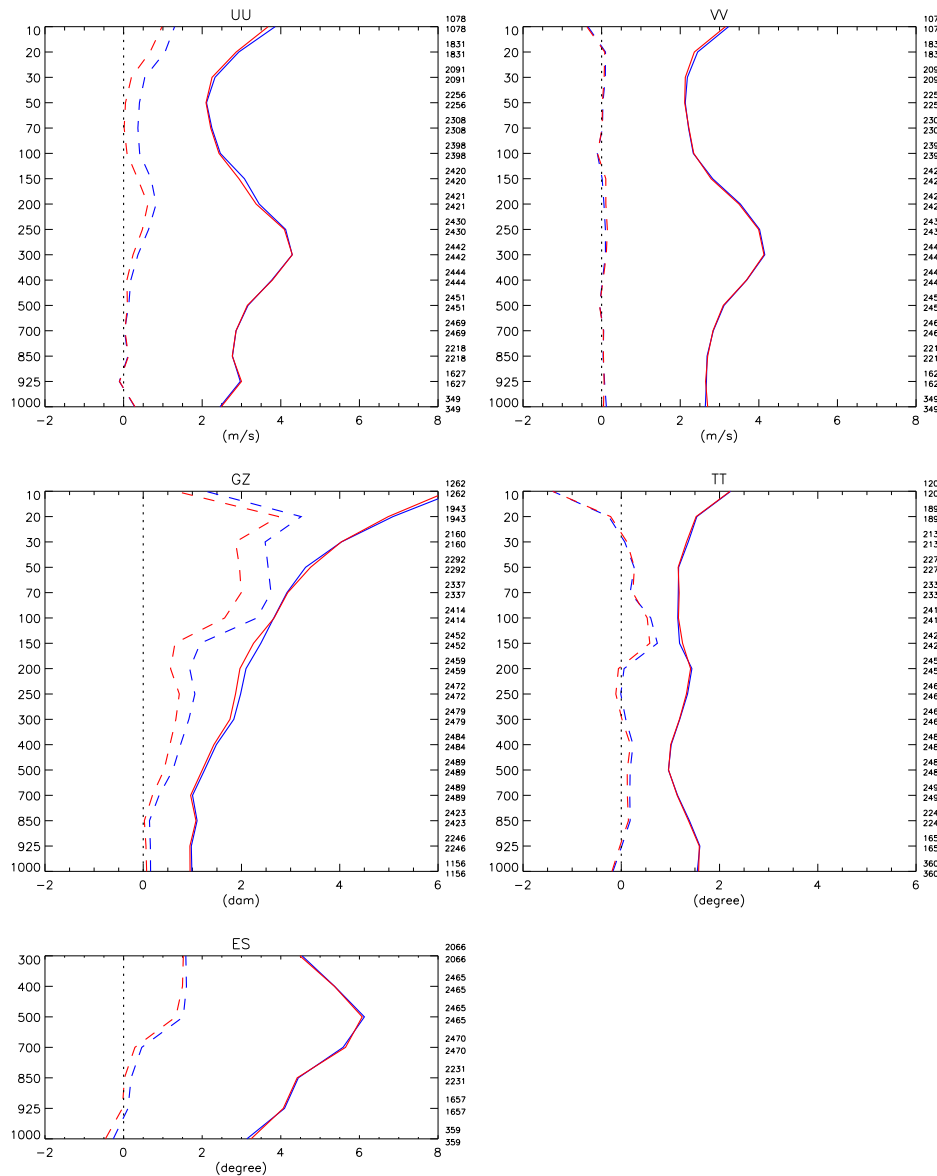
3026 NOAA16

2866 NOAA15



Date 2002050812

0-P6hr



## TOVS/NoTOVS Exp. (NH)

Verification of 6-h forecasts vs radiosonde observations.

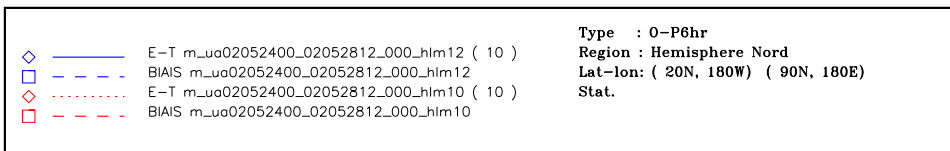
Evaluation over a 5-day period (after a 5-day spin-up).

horizontal grid:  $144 \times 72$  ;

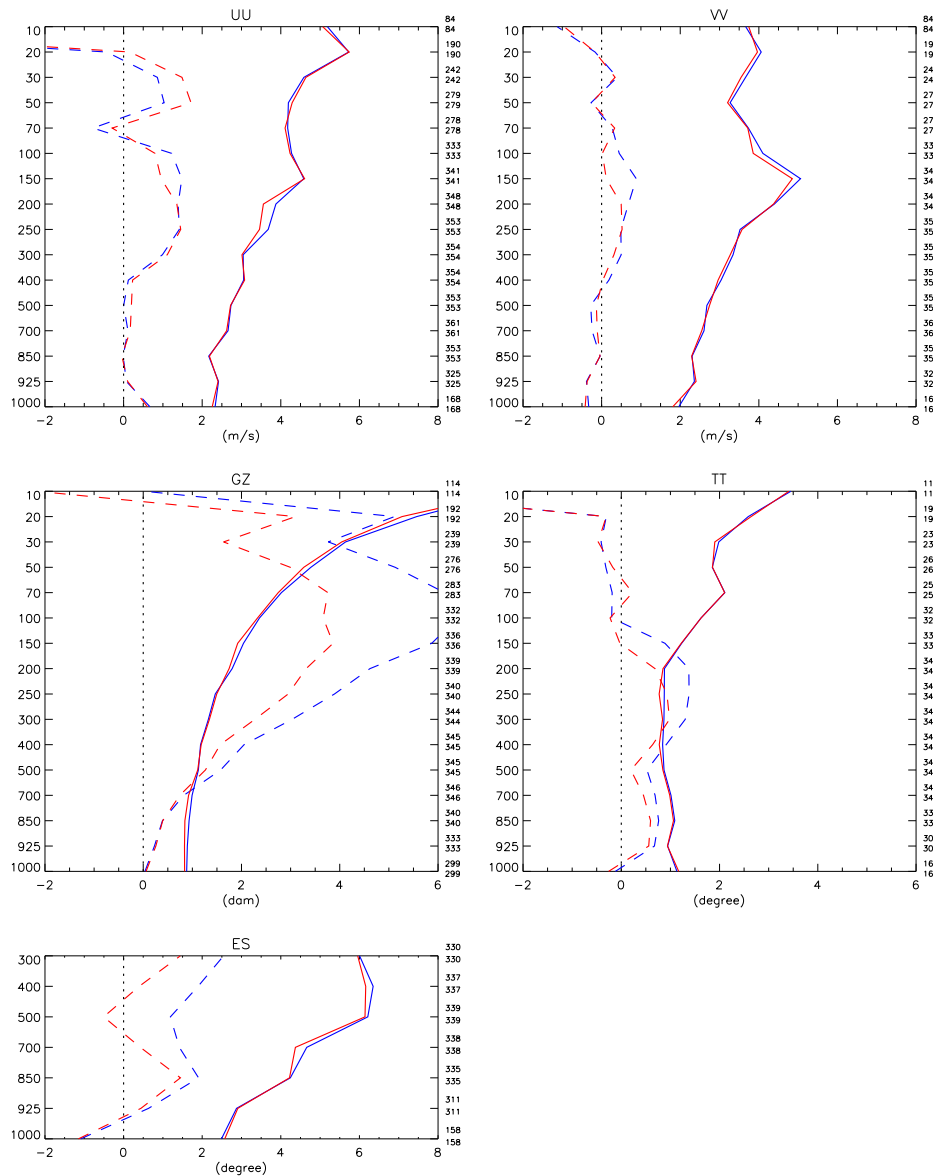
$2 \times 48$  ensemble members.

The correlation function used for localization falls to zero at 2300 km.

These results are for the Northern Hemisphere ( $20 - 90^\circ$  N).



0-P6hr



# TOVS/NoTOVS Exp. (trop)

Verification of 6-h forecasts vs radiosonde observations.

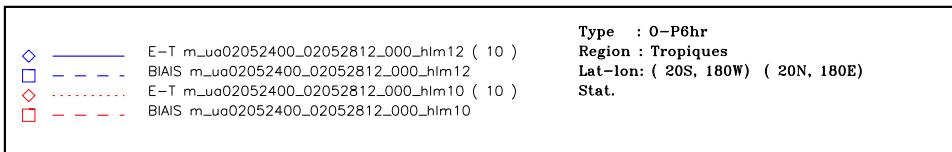
Evaluation over a 5-day period (after a 5-day spin-up).

horizontal grid:  $144 \times 72$  ;

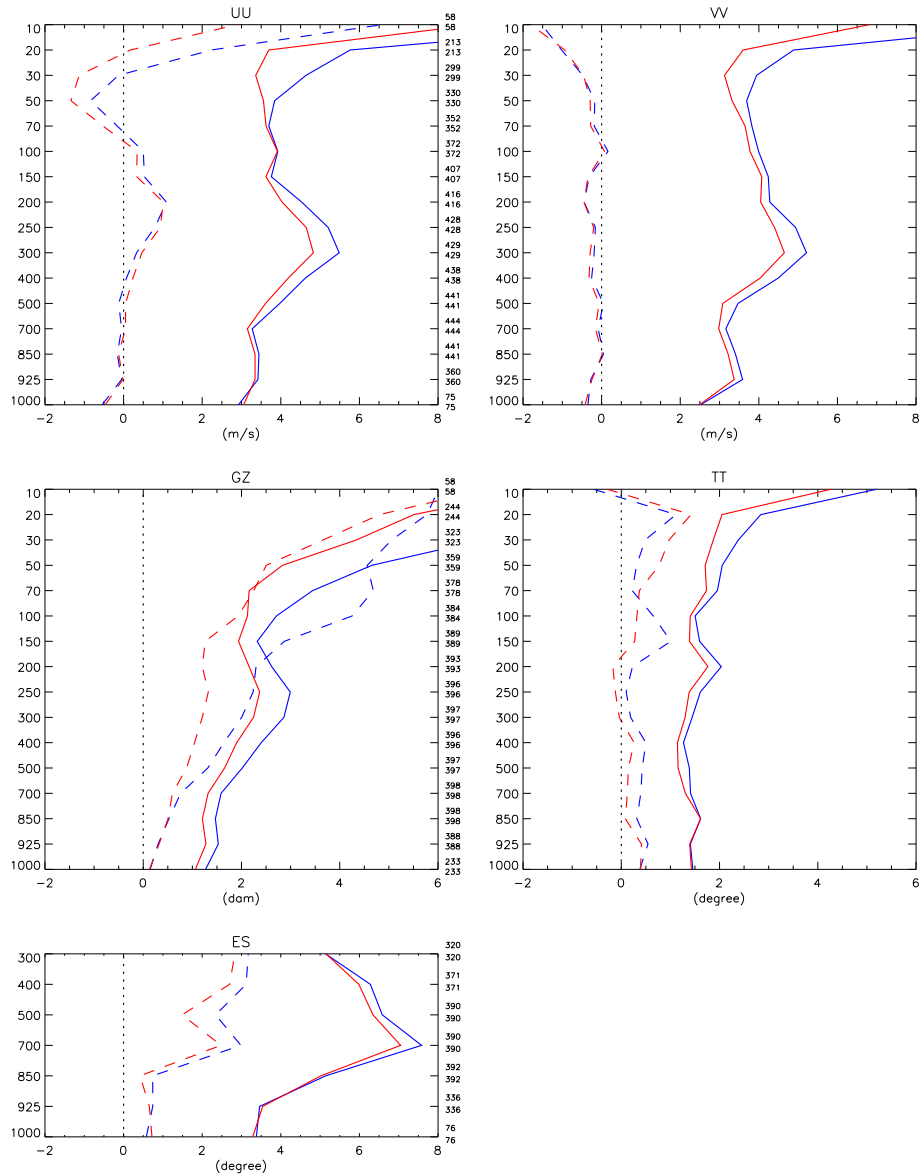
$2 \times 48$  ensemble members.

The correlation function used for localization falls to zero at 2300 km.

These results are for the tropics ( $20^\circ$  S to  $20^\circ$  N).



0-P6hr



## TOVS/NoTOVS Exp. (SH)

Verification of 6-h forecasts vs radiosonde observations.

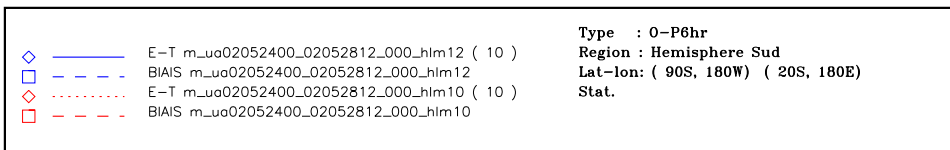
Evaluation over a 5-day period (after a 5-day spin-up).

horizontal grid:  $144 \times 72$  ;

$2 \times 48$  ensemble members.

The correlation function used for localization falls to zero at 2300 km.

These results are for the Southern Hemisphere ( $20 - 90^\circ$  S).



## 3D-Var/EnKF Comparison.

The 3D-Var and EnKF have been used to assimilate exactly the same set of (quality-controlled) observations, using the same observational error statistics. The same forecast model (resolution, physical parameterizations, etc.) has been used for both methods.

horizontal grid:  $240 \times 120$  ;

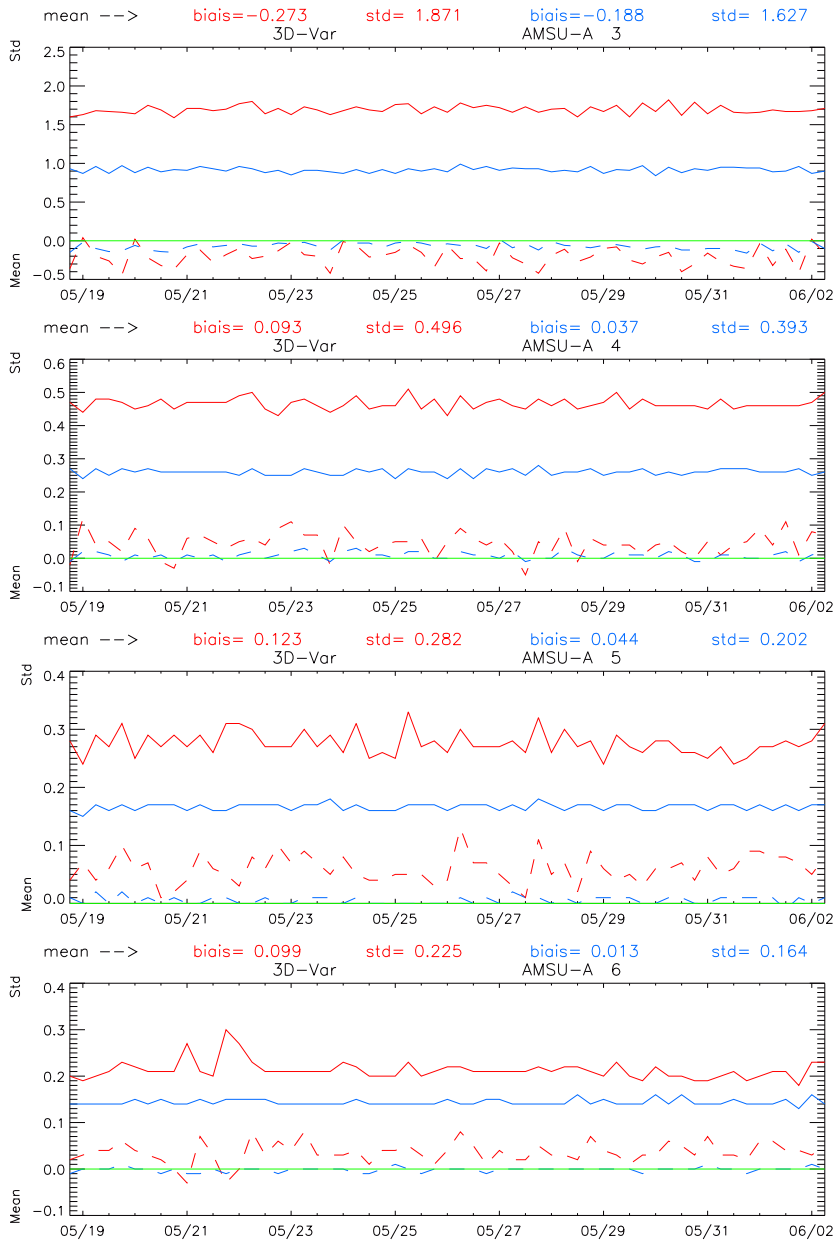
the EnKF uses  $2 \times 64$  ensemble members.

The correlation function used for localization in the EnKF falls to zero at 2800 km.

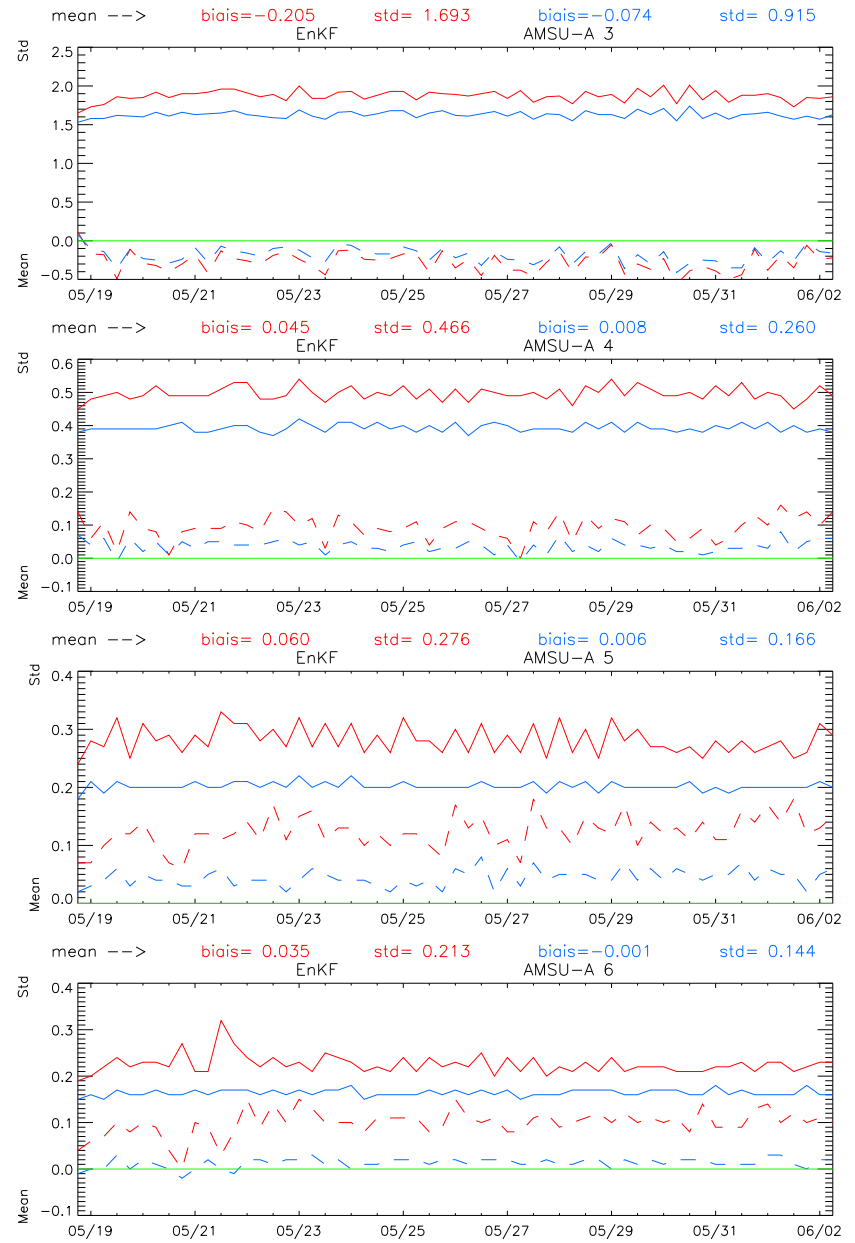
O - P and O - A statistics are computed for each AMSU-A radiance channel.

These plots were produced by Chantal Côté.

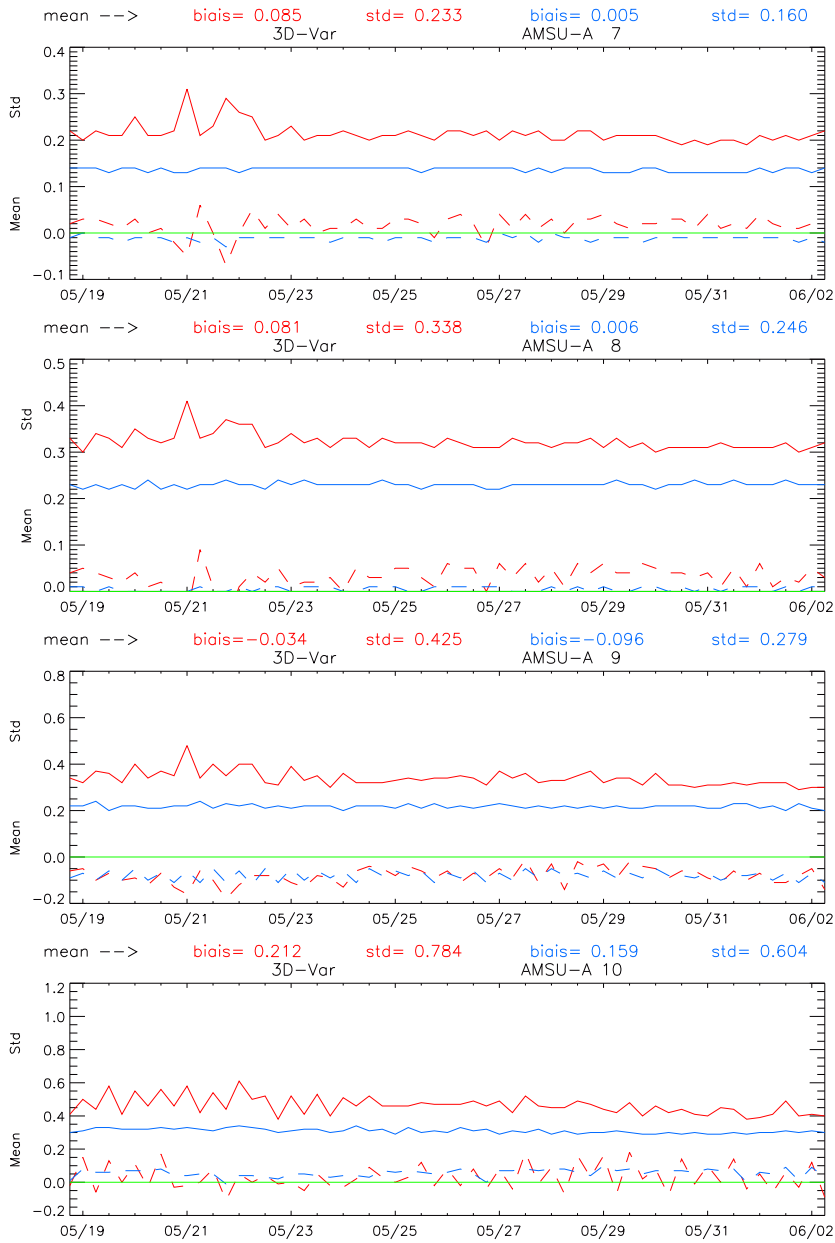
# Brightness Temperature O-A



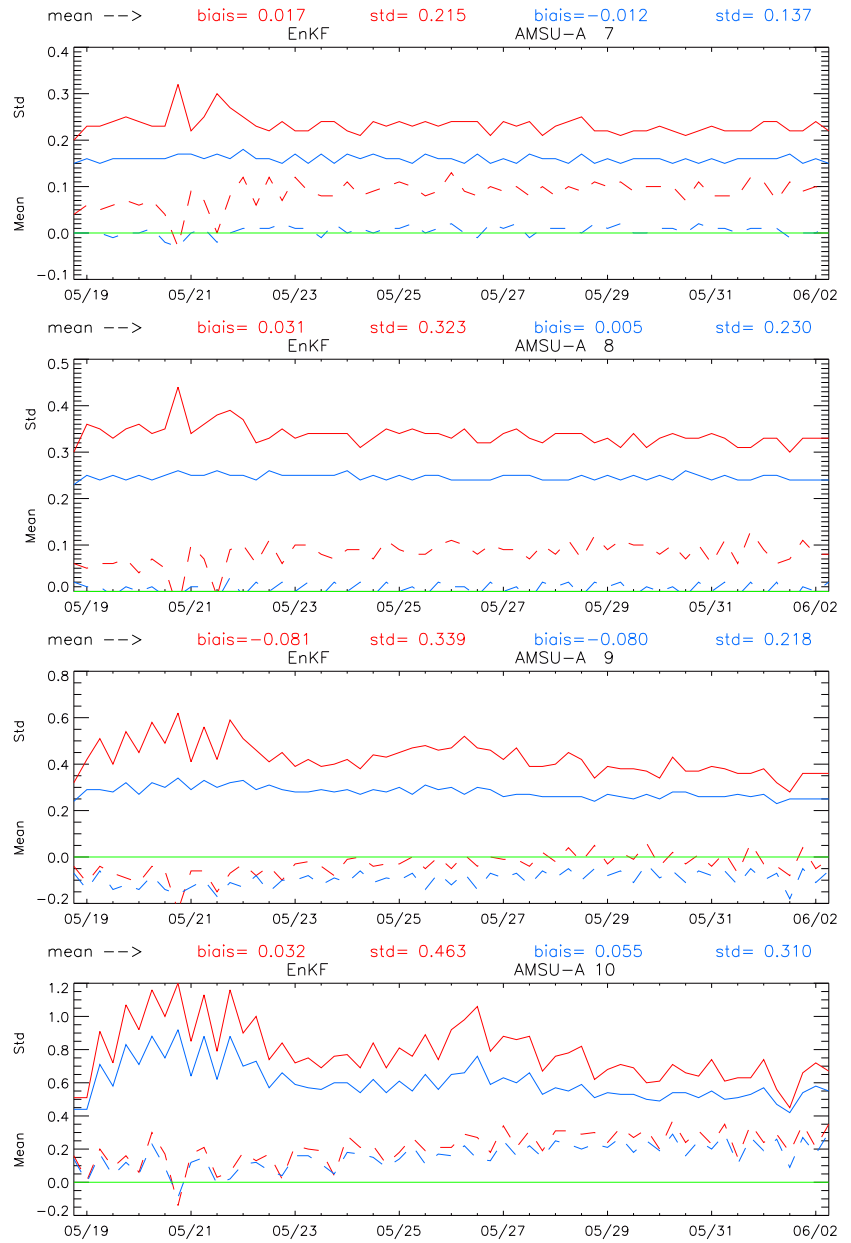
# O-P NOAA 16 globe



# Brightness Temperature O-A



# O-P NOAA 16 globe



## Conclusions

An EnKF has been developed for atmospheric data assimilation. It is to be used as the data assimilation component of the CMC operational medium-range Ensemble Prediction System. Results with real observations indicate that the EnKF can be used to assimilate AMSU-A microwave radiances.

### Areas for further related work

- impact of AMSU-A radiances;
- effect of vertical/horizontal localization;
- EnKF-specific (a) QC, (b) monitoring, and (c) bias correction;
- adjust observation errors (especially for channels 9 & 10);
- possible inclusion of observation-error correlations;
- improved treatment of the time dimension;
- assimilate other types of satellite data, e.g., AMSU-B.