

Assimilation of SSM/I radiances in the NCEP global data assimilation system

Kozo Okamoto* and John Derber**

**Japan Meteorological Agency (JMA) visiting National Centers for Environmental Prediction (NCEP), Tokyo, Japan*

*** National Centers for Environmental Prediction (NCEP), Camp Springs, MD, USA*

Abstract

A technique for the assimilation of Special Sensor Microwave Imager (SSM/I) data in the National Centers for Environmental Prediction's (NCEP's) global data assimilation and forecast system is described. Because the radiative transfer (RT) model used here does not yet allow for cloud/rain effects, it is crucial to properly identify and exclude (or correct) cloud/rain-contaminated radiances using quality control (QC) and bias correction procedures. Both procedures require an accurate estimate of the total column cloud liquid water (CLW). The CLW is used in a frequency dependent cloud detection component of the QC and as a predictor in the bias correction algorithm.

A two-month data assimilation experiment from July to August 2004 using the Gridpoint Statistical Interpolation (GSI) analysis system and the NCEP operational forecast model reveals that SSM/I radiance assimilation has significant positive impact on the analyses and forecasts. It adds moisture in the NH and tropics, and slightly reduces the moisture in the mid- to high-latitudes of the SH. Although the moisture added appears to be slightly excessive in the tropics, it reduces model spin-up of precipitation and substantially improves the dynamic fields. In addition, it improves forecast skill globally, especially in measures of the 200hPa vector wind error in the tropics. In terms of hurricane track, the SSM/I radiance assimilation produces more cases with smaller errors and reduces the average error. No disruption of the Hadley circulation is found by introducing the SSM/I radiance data.

1. Introduction

In the operational global data assimilation system (GDAS) at the National Centers for Environmental Prediction (NCEP), most satellite data are assimilated as radiances into the Spectral Statistical Interpolation (SSI) 3DVar analysis system (Parrish and Derber 1992; Derber and Wu 1998). The radiances are assimilated using the Community Radiative Transfer Model (CRTM) with Optical Path Transmittance (OPTRAN) algorithm (Kleespies et al. 2004) and surface emissivity models, such as FASTEM (English and Hewison 1998) for microwave instruments over the ocean. The SSI will be replaced by Gridpoint Statistical Interpolation (GSI, Wu et al. 2002) analysis scheme which is used in this study. For Special Sensor Microwave Imager (SSM/I), precipitation and ocean surface wind-speed estimates are assimilated operationally (Treadon et al. 2002; Yu et al. 1997). However,

no atmospheric moisture information from SSM/I in rain-free areas is utilized in the GDAS. Past attempts to assimilate retrieved total column water vapor (TCWV) disrupted the Hadley circulations by moistening the lower troposphere in the tropics (Treadon et al. 2002). The direct assimilation of SSM/I radiance has three advantages over the TCWV and wind speed retrieval assimilation; 1) better handling the vertical observation information by accounting for weighting functions in radiative transfer (RT) calculation, 2) processing the moisture and wind signals consistently through RT and ocean surface emissivity model, and 3) simplifying description of observation errors. The inclusion of the cloud condensation in forecast variables (Moorthi et al. 2001) has made the model climatology more consistent with the SSM/I data response in the assimilation system. This paper describes the processing and results of the SSM/I direct assimilation.

2. Quality Control

SSM/I pixels over land or sea-ice are removed because of the relative difficulty in estimating an accurate surface emissivity, skin temperature and CLW. Identification of sea-ice is based upon a daily sea-ice analysis at NCEP. Pixels are used only when all observed brightness temperatures (TBs) range between 70 to 320 K and $TB_v + 2 \text{ K} < TB_h$, where TB_v (TB_h) is vertically (horizontally) polarized TB. Also, a rain check from Ferraro (1997) excludes any pixels with a scattering index over 10.

Cloud-contaminated channels are identified and removed when CLW retrieval values from Weng et al. (1997) exceeds predefined criteria (clw_0) depending on its frequency. The clw_0 are determined so that amount of liquid water absorption, which is proportional to CLW under the Rayleigh approximation, is equal at every frequency. When CLW threshold of English et al. (2000), 0.1 kg/m^2 , is applied to the SSM/I 37-GHz channels, clw_0 criteria listed in Table 1 are obtained. Table 1 shows that channels at higher frequency are more likely rejected by the cloud-QC. Finally, a gross check screens out outliers by rejecting channels if $|O-G| > \sigma_o$ or 6.0 K, where O , G and σ_o are observed TB, first-guess TB, observation error, respectively. σ_o , listed in Table.2, is calculated from the standard deviation of $O-G$, and modified based on Chouinard and Hallé (1999).

Table.1: The criteria (clw_0) of cloud-QC for each channel

Channel	19V,H	22V	37V,H	85V,H
$clw_0 \text{ (kg/m}^2\text{)}$	0.35	0.27	0.10	0.024

Table.2: Observation error σ_o assigned to SSM/I.

Channel	19V	19H	22V	37V	37H	85V	85H
$\sigma_o \text{ [K]}$	1.60	2.26	2.01	1.48	2.28	1.43	2.33

3. Bias Correction

The bias correction for SSM/I is implemented using the operational bias correction scheme in GDAS

(Derber and Wu 1998). The scheme consists of a slowly varying component and an air-mass dependent component. The former is intended to remove the bias across a scan, and is computed at each scan position from QC-ed *O-G* differences accumulated for the latest 30 days. The air-mass dependent component is expressed as a linear equation with five predictors: a constant, the scan angle path (always set to zero for SSM/I), the CLW, the integrated lapse rate over the simulated weighting functions and the square of the integrated lapse rate. The regression coefficients are included as analysis variables and are determined globally along with other analysis variables. Figure 1 illustrates the clear dependency of *O-G* residuals on CLW over the ocean, suggesting that CLW predictor plays an important role in the bias correction. The integrated lapse rate is integration over all model levels of the lapse rate dT multiplied by the difference of vertically adjacent transmittance $d\tau$, which contains moisture information for SSM/I. An attempt to include apparently more moisture-related variables, such as TCWV itself or TCWV weighted by $d\tau$, has not outperformed the operational combinations of the predictors. The frequency histogram of *O-G* in Fig.2 shows that *O-G* residuals for all channels are clearly reduced by the bias correction scheme.

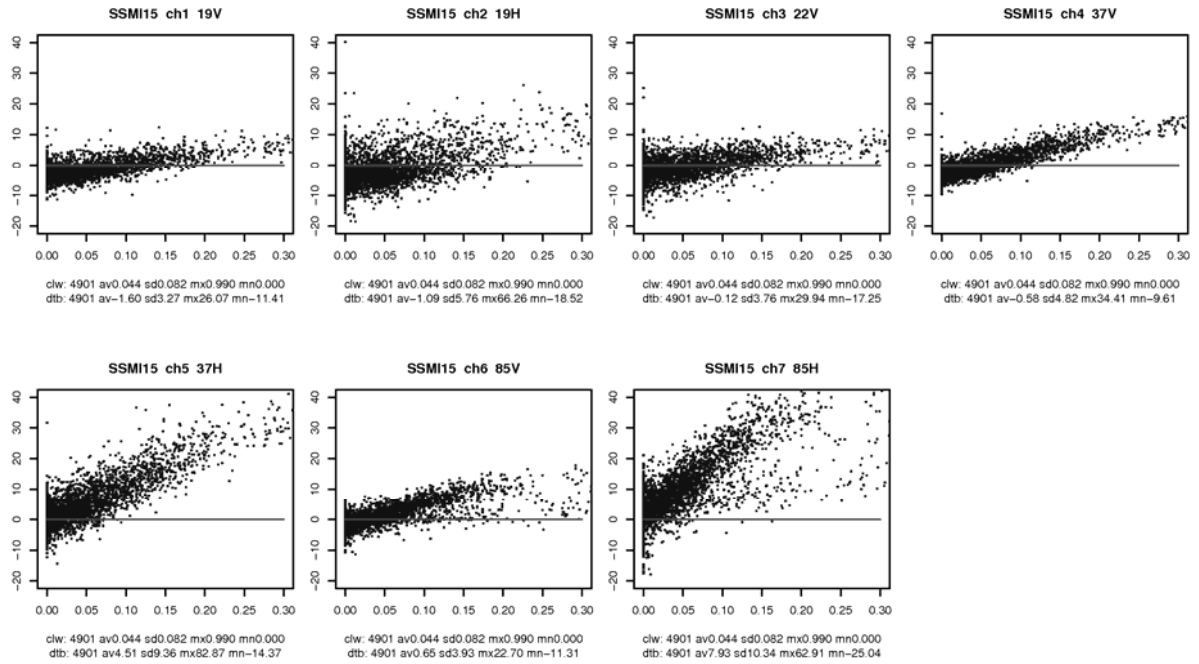


Fig.1: Dependency of observed-minus-guess brightness temperature difference (*O-G*, units are K) on CLW (kg/m^2) over the ocean. Data shown is from DMSP-15 SSM/I at 00UTC on 1 July.

4. Forecast and Analysis Impacts of the SSM/I Radiance Assimilation

Two assimilation experiments were carried out from 1 July to 31 August 2004 in order to assess the impact of the SSM/I radiance assimilation on forecasts and analyses. The configuration of the data usage is as follows:

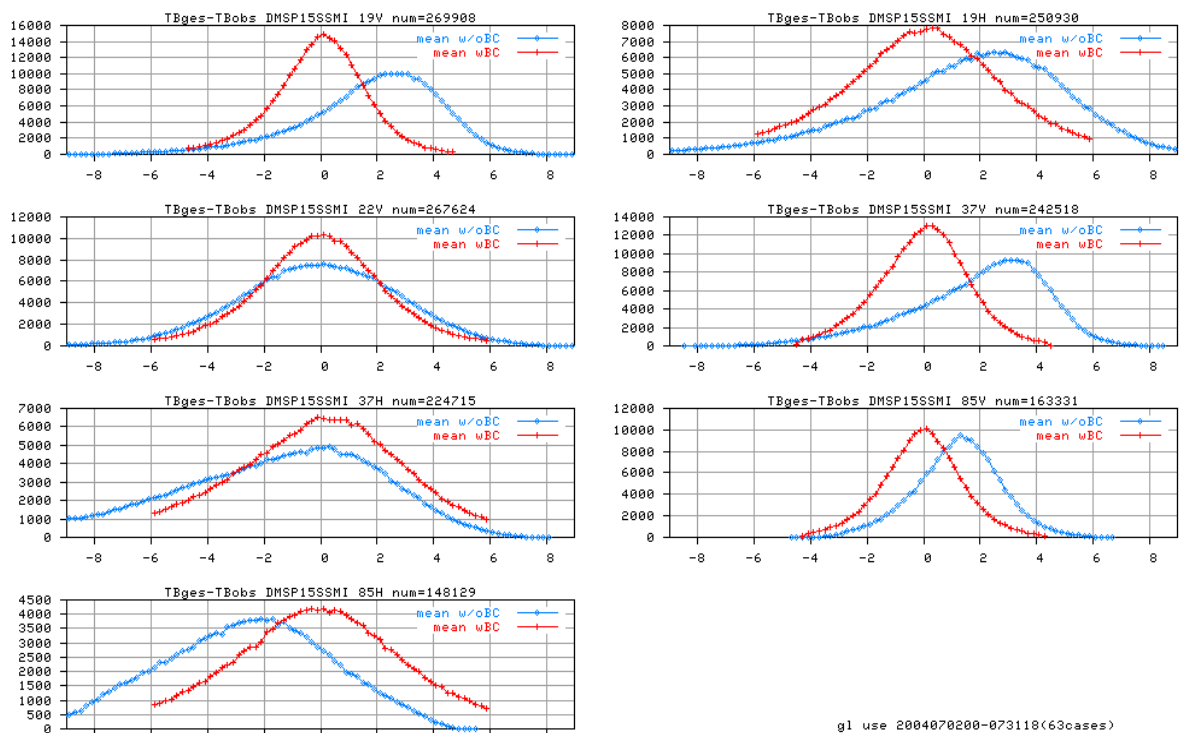


Fig.2: Frequency histograms of O-G before (blue lines) and after (red lines) bias correction. They are produced from all data which pass all QC procedures from DMSP-15 SSM/I for 15 days in July 2004. The units for O-G are K

CNTL: identical to the operations one, where moisture-related observations are rawinsondes, ships, buoys, HIRS/AMSU-A/AMSU-B/MSU radiances onboard NOAA14-17, GOES sounder radiances, and precipitation estimates from SSM/I and TMI.

TEST: SSM/I radiances from DMSP-13, 14 and 15 satellites are added to CNTL. SSM/I retrieved wind-speeds are removed.

The inclusion of the microwave emissivity jacobian with respect to wind allowed the extraction of the surface wind information from MW radiances and made the use of retrieved wind-speed redundant. The resolution of the forecast and analysis model is T254L64, and is reduced to T170L42 beyond 84-hours.

Figure 3 shows zonal mean difference at the first analysis time for the specific humidity between TEST and CNTL. The SSM/I radiance assimilation adds moisture in the tropics and NH, and decreases mid- to high-latitudes of the SH, while only small temperature differences are seen (not shown). On average over the 2-month period, TCWV rises by 0.43 and 1.01 kg/m² in the NH and tropics, respectively, while it decreases by 0.22 kg/m² in the SH. The absolute value of the monthly O-G residual for AMSU-A1, which is sensitive to TCWV, is decreased over the ocean by the SSM/I radiance assimilation (Fig.4), suggesting that the SSM/I radiance assimilation improves the moisture

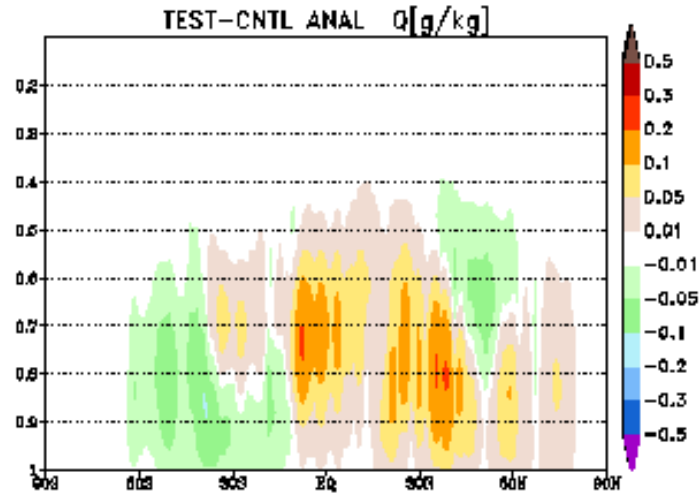


Fig.3: Zonal mean of 1st analysis difference between TEST and CNTL for specific humidity. Vertical axis indicates a sigma level from 1.0 to 0.1, and horizontal axis is 90S (left) to 90N (right).

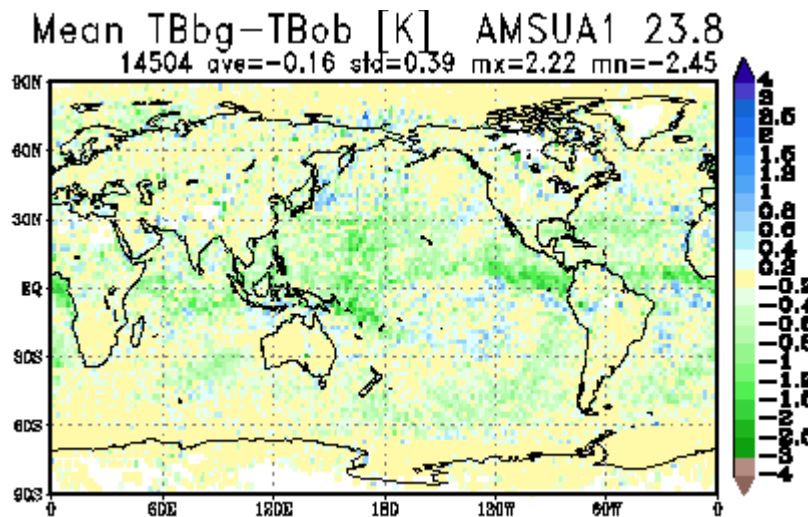


Fig.4: Monthly averaged TEST-minus-CNTL of absolute O-G for AMSU-A1. Green shade indicates that TEST reduces O-G residuals.

field. The higher levels of moisture are retained for 7 or more days in the forecast for the tropics and NH, indicating that the moisture field is compatible with the model physics. Moreover, it reduces model spin-up at the beginning of the forecasts in the tropics.

Figure 5 shows the Root Mean Square Error (RMSE) and bias of the temperature analysis and 6 hour forecast verified against rawinsonde observations. There is reduction in both RMSE and bias for the TEST experiment at almost all levels and regions. In particular, the reduction in the tropics is significant. The vector fit of wind is also improved (not shown), but not as significantly as for

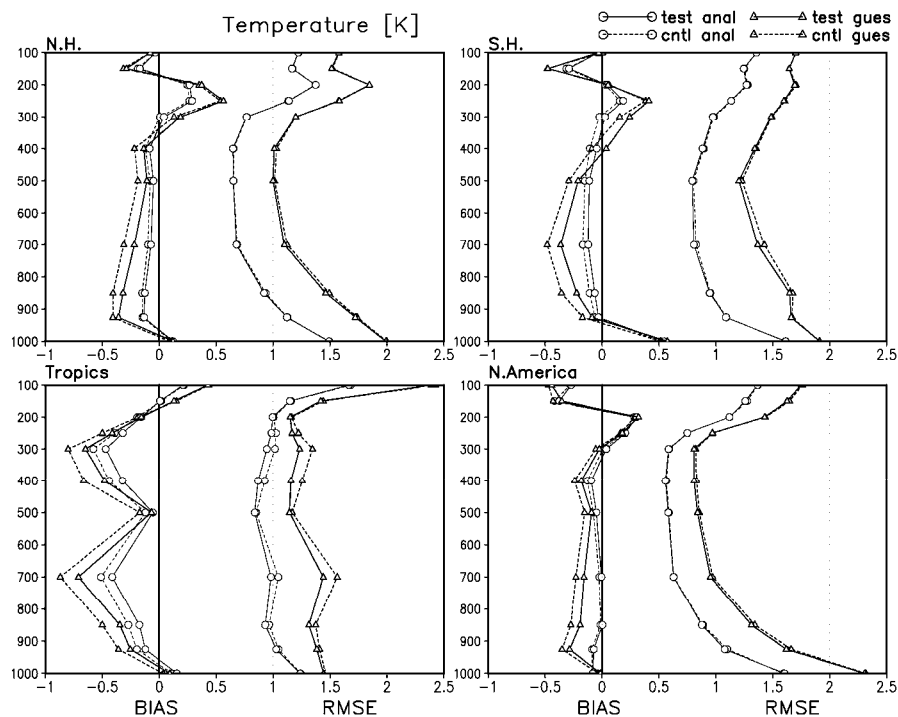


Fig.5: Root mean square error (RMSE) and bias of analysis and first-guess for temperature (K) verified against rawinsonde observations. The statistics are computed for 7 July - 31 August 2004.

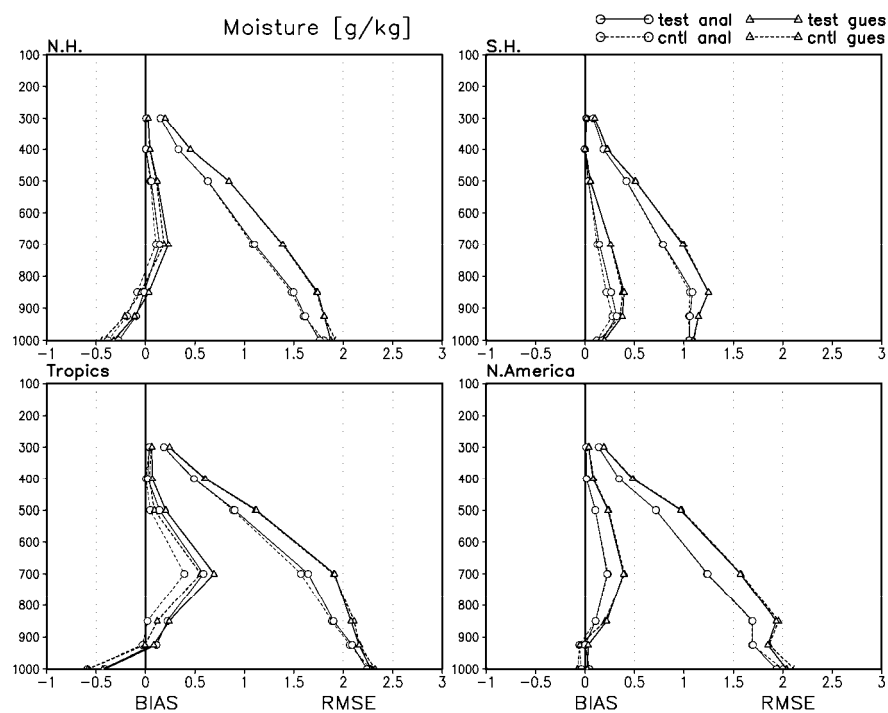


Fig.6: The same as Fig.6 except for moisture (g/kg)

temperature. The moisture bias is increased in both the analysis and first-guess, especially at 700-850 hPa in the tropics (Fig.6). This wet bias may be associated with misrepresentation of the moisture field due to insufficient model resolution or/and background errors. The increased moisture over the ocean in the tropics may be incorrectly extrapolated over the land where most rawinsondes are located. Indeed, an increase of the spatial resolution from T62 to T254 in preliminary experiments reduced the bias in the tropics for TEST.

Averaged forecast scores of 500Z in the extra-tropics and wind vector in the tropics are shown in Fig.7. There is slight improvement in the anomaly correlation (AC) in the NH, and significant improvement in other regions. In particular, the 200 hPa vector wind RMSE in the tropics is substantially reduced for the whole forecast range. In addition, a reduction in the track error of hurricanes and tropical storms over the North Atlantic Ocean is more frequently found in TEST (not shown). Monthly

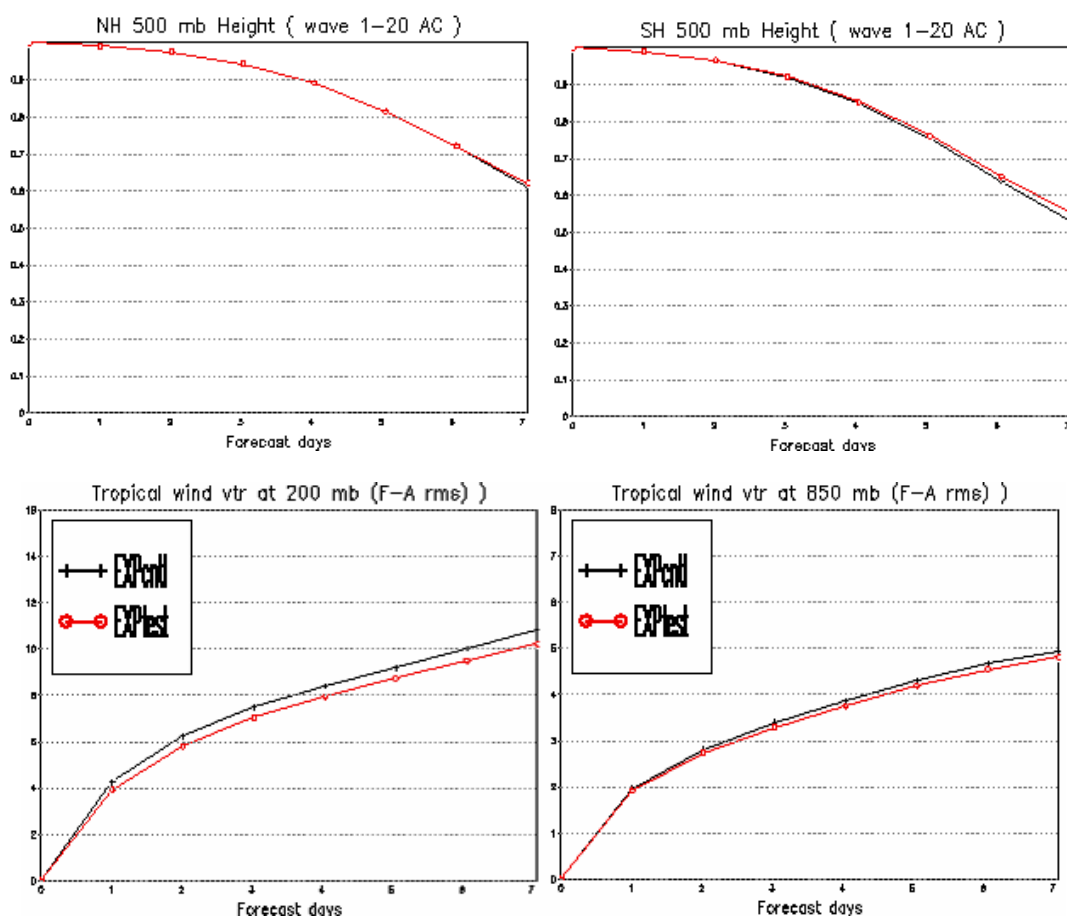


Fig.7: Average anomaly correlation scores for 500Z in the NH and SH (upper two panels) and vector wind RMSE in the tropics at 200 hPa and 850 hPa (lower panels). TEST and CNTL scores are plotted by red and black lines, respectively, and are computed for 7 July - 31 August 2004.

averaged zonal means of the vertical and meridional wind for the second month of the experiments (August 2004) shows no significant difference between TEST and CNTL (not shown), suggesting that the Hadley circulation is not disrupted by the SSM/I radiance assimilation.

5. Summary

A scheme to assimilate SSM/I clear or thin-cloud radiances over the ocean has been developed. QC and bias correction procedures have been developed using an accurate and robust CLW retrieval algorithm. Results from a 2-month assimilation/forecast experiment, from July to August 2004, indicate the SSM/I radiance assimilation moistens the NH and tropics while dries the mid- to high-latitudes of the SH. The moisture added in the tropics may be excessive. However, it reduces the model spin-up of precipitation in the tropics and substantially improves the mass and wind fields. Average forecast scores are improved slightly in the NH and substantially in the tropics and SH. Contrary to earlier results using TCWV, no disruption of the Hadley circulation was found for the SSM/I direct assimilation.

References

- Chouinard C., and J. Hallé, 1999: The impact of TOVS radiances in the CMC 3D variational analysis. *Proceedings of the 10th International TOVS Study Conference*, Boulder, CO, February. 1999, 92-98.
- Derber, J.C., and W.-S Wu, 1998: The use of TOVS cloud-cleared radiances in the NCEP SSI analysis system. *Mon. Wea. Rev.*, **126**, 2287-2299.
- English, S.J. and T.J. Hewison, 1998: A fast generic millimetre wave emissivity model. *Microwave Remote Sensing of the Atmosphere and Environment Proc. SPIE*, **3503**, 22-30.
- English, S.J., R. J. Renshaw, P. C. Diben, A. J. Smith, P. R. Rayer, C. Poulsen, R. W. Saunders, and J. R. Eyre, 2000: A comparison of the impact of TOVS and ATOVS satellite sounding data on the accuracy of numerical weather forecasts. *Q. J. R. Meteorol. Soc.*, **126**, 2911- 2932.
- Ferraro, R. R., 1997: Special sensor microwave imager derived global rainfall estimates for climatological applications. *J. Geophys. Res.* **102**, 16, 715-16,736.
- Kleespies, T. J., P. V. Delst, L. M. McMillin, and J. Derber, 2004: Atmospheric Transmittance of an Absorbing Gas. 6. OPTRAN Status Report and Introduction to the NESDIS/NCEP Community Radiative Transfer Model, *Applied Optics*, **43**, 3103-3109
- Moorthi, S., H.-L. Pan, and P. Caplan, 2001: Changes to the 2001 NCEP operational MRV/AVN global analysis/forecast system. *NWS Technical Procedures Bulletin*, **484**, pp14. [Available from <http://www.nws.noaa.gov/om/tpb/484.htm>]
- Parrish, D. F. and J. C. Derber, 1992: The National Meteorological Center's spectral statistical interpolation analysis system. *Mon. Wea. Rev.*, **120**, 1747 - 1763.
- Treadon, R. E., H.-L. Pan, W.-S. Wu, Y. Lin, W. Olson, and R. Kuligowski, 2002: Global and regional moisture analyses at NCEP. *Proc. ECMWF/GEWEX Workshop on Humidity Analysis*, Reading, United Kingdom, ECMWF, 33-47. [Available from European Centre for Medium Range

Weather Forecasts, Shinfield Park, Reading RG2 9AX, United Kingdom.]

- Weng, F., N.C. Grody, R.R. Ferraro, A. Basist and D. Forsyth, 1997: Cloud liquid water climatology from the special sensor microwave imager. *J. Climate*, **10**, 1086-1096.
- Wu, W. -S., R. J. Purser, and D. F. Parrish, 2002: Three-Dimensional Variational Analysis with Spatially Inhomogeneous Covariances. *Mon. Wea. Rev.*, **130**, 2905-2916.
- Yu, T.-W., M. Iredell, D. Keyser, 1997: Global Data Assimilation and Forecast Experiments Using SSM/I Wind Speed Data Derived from a Neural Network Algorithm. *Weather and Forecasting*, **12**, 859-865.