P1.46

TRADE-OFF STUDY ON VERTICAL RESOLUTION FOR HIGH SPECTRAL RESOLUTION SOUNDER

Fang Wang*, Jun Li*, and Timothy J. Schmit@

*Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison
1225 West Dayton Street
Madison, WI 53706

@Advanced Satellite Products Team
Office of Research and Applications
NOAA/NESDIS
1225 West Dayton Street
Madison, WI 53706

1. INTRODUCTION

The lack of vertical resolution is a concern in the study of atmospheric profile inversion techniques. The poor vertical resolution and associated accuracy of the retrieved profiles limit their use in numerical weather prediction (Bengtsson 1979; Phillips et al. 1979; Smith 1991). Also, the horizontal and temporal resolving power of satellite soundings is closely coupled to the vertical resolving power (Thompson et al. 1989). Consequently, it is one of the most important factors in the design of satellite sounding instruments.

The Hyperspectral Environmental Suite (HES) is currently scheduled to be launched in 2013 on the next generation Geostationary Operational Environmental Satellite (GOES)-R. This high spectral resolution sounder will allow for monitoring the evolution of atmospheric profiles with higher accuracy and will also improve the vertical resolution to approximately 1 km for temperature in the troposphere, which is significantly better than the current GOES sounder (approximately 2 ~ 3 km). The HES will enhance the capabilities for a variety of applications in weather forecasting.

In this paper, trade-off studies on HES spectral coverage, signal-to-noise ratio and spectral resolution are conducted. The combination of the geostationary satellite infrared (IR) sounder and polar orbiting satellite microwave sounding unit for better vertical resolution in temperature sounding retrievals is also investigated.

* *Corresponding author address:* Fang Wang, Atmospheric and Oceanic Sciences Department / Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, 1225 West Dayton Street, Madison, WI 53706; e-mail: fang.wang@ssec.wisc.edu

2. METHODOLOGY

In theoretical vertical resolution studies, various methods have been applied including the FWHM (Full Width at Half Maximum) method, the Backus and Gilbert method (Backus and Gilbert 1968; Conrath 1972), and the data density method (Purser and Huang, 1993; Weisz, 2001). In this study, the data density method is used because it can both avoid the possible error caused by the oscillation slopes in the FWHM method and achieve similar results as the Backus and Gilbert method with its simple and intuitive formula.

The relationship between the measurement vector y and the actual state vector x is described as

$$y = Kx + \varepsilon \tag{1}$$

where K is the linear operator of the forward model as what we call here the weighting function matrix or the Jacobian matrix whose rows reflect the sensitivity of the forward model to incremental changes in temperature, water vapor, ozone, etc and ε is the measurement error whose error covariance matrix is S_ε.

Assuming the background state for the first guess profile is x_{ap} with the prior estimation error covariance matrix S_{ap},

$$\hat{x} = x_{ap} + S_{ap}K^T(K^T S_{ap} K + S_\varepsilon)^{-1}(y - Kx_{ap}) \tag{2}$$

is the retrieved profile which is the optimal estimate of the probability density function (pdf) of y conditioned on x. It is also the minimum variance estimate and the maximum likelihood estimate of the pdf. The estimation error covariance matrix

$$\hat{S} = (K^T S_\varepsilon^{-1} K + S_{ap}^{-1})^{-1} \quad (3)$$

and the gain function

$$G = \frac{\partial \hat{x}}{\partial y} = \hat{S} K^T S_\varepsilon^{-1} \quad (4)$$

is the derivative matrix of the retrieval model with respect to the measurements and, its column reflects how each measurement contributes to the retrieved state. Then the averaging kernel matrix

$$A = \frac{\partial \hat{x}}{\partial x} = GK = \hat{S} K^T S_\varepsilon^{-1} K \\ = (K^T S_\varepsilon^{-1} K + S_{ap}^{-1})^{-1} K^T S_\varepsilon^{-1} K \quad (5)$$

is the matrix of partial derivatives of the retrieval profile with respect to the true state and the rows of A reflect how a true state element is reproduced in the retrieved state.

In the data density method, the vertical resolution r_i is expressed as

$$r_i = \frac{1}{\rho_i} \quad (6)$$

where ρ_i is the data density expressed as

$$\rho_i = \frac{A_{ii}}{\Delta z_i} \quad (7)$$

with Δz_i, the height interval at level i in the profiles and A_{ii}, the diagonal of the averaging kernel matrix A.

3. HES VERTICAL RESOLUTION SIMULATION STUDIES

In this simulation study, the vertical resolutions of temperature, water vapor, and ozone are investigated with the U.S. Standard Atmosphere profile. Measurement error ε is interpolated by wavenumber from the instrument noise specification in the Performance and Operation Requirement Document (PORD). The profile prior errors are assumed to be 1K for temperature, 25% for water vapor, and 15% for ozone.

3.1 SPECTRAL COVERAGE STUDY

In the instrument design, the longwave region (LW, approximately 650-1200 cm^{-1}) is chosen for the temperature, ozone, and surface properties retrievals. Longer middlewave (LMW, approximately 1200-1650 cm^{-1}) and/or shorter middlewave (SMW, approximately 1650-2250 cm^{-1}) are chosen for the water vapor retrieval.

Three simulation experiments are done for temperature and water vapor including LW+LMW, LW+SMW and LW+LMW+SMW with spectral

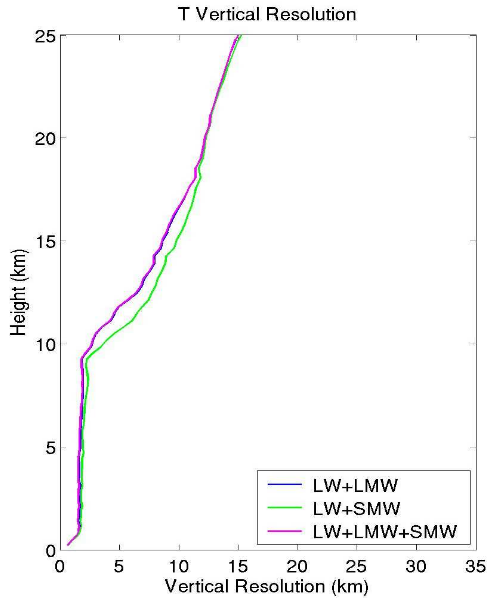

Fig. 1: Temperature vertical resolution of HES with three different spectral coverages.

resolution fixed at 0.625 cm^{-1} and noise factor (NF)=1. Fig.1 shows that LW+LMW+SMW achieves marginally better vertical resolution in the troposphere and obvious improvement (approximately 1km) above the tropopause compared with the LW+SMW scheme. LW+LMW is similar to LW+LMW+SMW for temperature information. However, trace gases such as SO_2, N_2O contamination in LMW region is not considered in the calculation. Considering this point together with the larger data volume, the LW+SMW option is chosen for the following studies.

3.2 SIGNAL-TO-NOISE TRADE-OFF STUDY

In this test, fixing the spectral resolution of 0.625 cm^{-1} and using the spectral coverage of LW+SMW, we compared the noise factors of 0.33, 1 and 2 to investigate the influence of measurement errors on the vertical resolution. As we can see from the temperature results in Fig. 2, the noise factor exerts a very important influence on the temperature vertical resolution: 1~2 km in the troposphere and 5~10 km above the tropopause.

3.3 SPECTRAL RESOLUTION STUDY

A set of spectral resolutions: 0.625 cm^{-1}, 1.25 cm^{-1}, 2.5 cm^{-1}, 5 cm^{-1}, 10 cm^{-1} and 20 cm^{-1} are applied in this study using nominal noise (NF=1.0) and the spectral coverage of LW+SMW. From the temperature and ozone vertical resolution

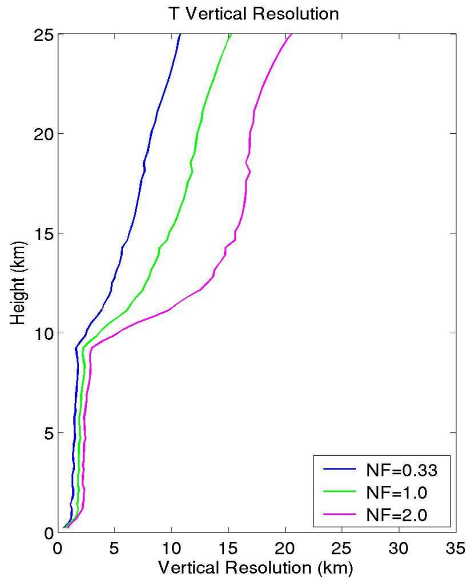

Fig. 2. Noise factor influence on the temperature vertical resolution.

comparisons (Fig. 3), we can see the strong influence of spectral resolutions on the vertical resolutions. To atmospheric temperature, there is a range of 2~3 km difference in the troposphere and 3~15 km difference in upper atmosphere.

3.4 INSTRUMENT COMPARISONS

Infrared (IR) sounders can achieve better resolution in the lower atmosphere while microwave sounding units (for example, Advanced Microwave Sounding Unit – AMSU-A) are more sensitive in the upper atmosphere above the tropopause than the IR sounders. The combination of both of the infrared and microwave sounders can achieve better results throughout the whole atmosphere layer (Li et al. 2004).

This is confirmed in the simulation comparison results (Fig. 4). HES has a better result than both current GOES sounder and the Advanced Microwave Sounding Unit (AMSU-A) in the troposphere while AMSU-A has better vertical resolution above the tropopause. The combination of HES and AMSU-A achieves the best result when compared to either HES or AMSU-A alone. Together with microwave sounding unit data from the Low Earth Orbit (LEO) satellite (for example, ATMS from NPOESS satellites), HES is able to provide detailed atmospheric temperature and moisture structures from the surface to the stratosphere.

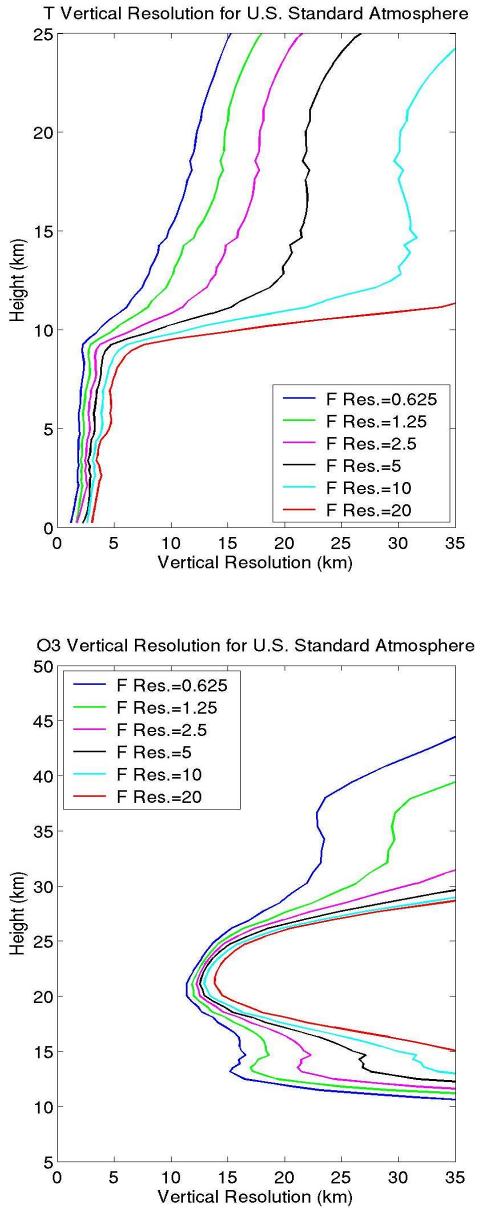

Fig. 3. Spectral resolution influence on temperature (upper panel) and ozone (lower panel) vertical resolutions.

4. SUMMARY

A vertical resolution analysis is performed for HES trade-off studies including spectral coverage, signal-to-noise ratio and spectral resolution. The trade-off studies are focused on the vertical resolution of the atmospheric temperature,

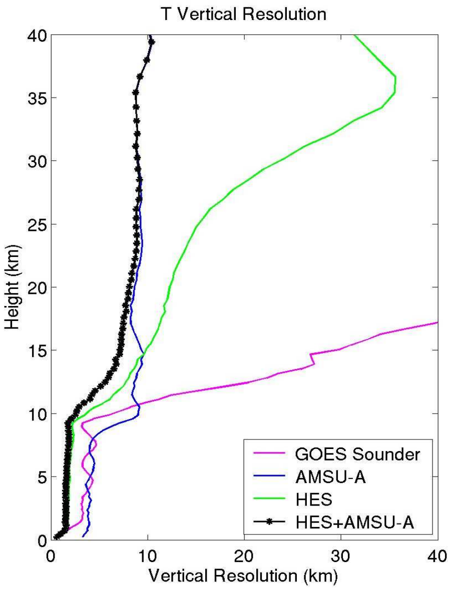

Fig. 4. The temperature vertical resolution from AMSU-A, current GOES Sounder, HES and HES + AMSU-A. The signal-to-noise ratio (SNR) for AMSU-A is assumed to be very good (0.15 K).

moisture, and ozone profiles of HES. A high spectral resolution with a good signal-to-noise ratio is crucial to achieve the high vertical resolution performance according the study. Combination of the GEO IR and LEO microwave data can provide better temperature information from the surface to the stratosphere than that from either instrument alone, demonstrating that synergism of GEO IR and LEO MW is necessary.

ACKNOWLEDGEMENT

This program is supported by NOAA ABI/HES program NA07EC0676 at CIMSS. The views, opinions, and findings contained in this report are those of the author(s) and should not be constructed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

REFERENCES

Backus, G., and F. Gilbert, 1968: The resolving power of gross earth data. *Geophys. J. Roy. Astron. Soc.,* **16**, 169-205.

Bengtsson, L., 1979: Problems of using satellite information in numerical weather prediction. *Proc. Technical Conf., in its use of data from Meteor. Sat.,* Paris, European Space Agency, 87-100.

Conrath, B. J., 1972: Vertical resolution of temperature profiles obtained from remote radiation measurements. *J. Atmos. Sci*., **29**, 1262-1272.

Li, J., F. Wang, T. J. Schmit, W. P. Menzel, and J. Gurka, 2004: Vertical resolution study on the GOES-R Hyperspectral Environmental Suite (HES). *Proceeding of SPIE 5658, Application of Weather Satellites-II*, 8 - 11 November 2004, Honolulu, Hawaii.

Phillips, N. A., L. M. McMillin, D. Wark, and A. Gruber, 1979: An evaluation of early operational temperature soundings from TIROS-N. *Bull. Amer. Meteor. Soc*., **60**, 1188-1197.

Purser, R. J. and H.-L. Huang, 1993: Objective definitions of spectrum-domain information densities for satellite infrared instruments. *8th Symposium on Meteorological Observation and Instrumentation*, Anaheim, CA, January 17-23, 1993.

Smith, W. L., 1991: Atmospheric soundings from satellites-false expectation or the key to improved weather prediction? *Quart. J. Roy. Met. Soc*., **117**, 267-297.

Thompson, O. E. and Y. T. Hou, 1989: Coupling of Horizontal, Vertical and Temporal Resolving Power of a Satellite Temperature Sounder. *J. Atmos. Oceanic Technol.*,**7**, 454-463.

Weisz, Elisabeth, 2001: Temperature profiling by the infrared atmospheric sounding interferometer(IASI): advanced retrieval algorithm and performance analysis. Dissertation, Institute for Geophysics, Astrophysics, and Meteorology, University of Graz, Austria. 124-129.