P1.12

Using time continuity for sounding retrieval from GOES data

***Zhenglong Li*[@], *Jun Li*[@], *and W. Paul Menzel*[#]**

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

Office of Research and Applications
NOAA/NESDIS
1225 West Dayton Street
Madison, WI 53706

1 INTRODUCTION

The current Geostationary Satellite-12 (GOES-12) was launched on 23 July 2001, and became operational (Replaced GOES-8) on April 3, 2003. The Sounder onboard is a 19-channel discrete-filter radiometer that senses vertical atmospheric parameters, such as temperature, water vapor and ozone. Among these 19 spectral bands (7 longwave (LW), 5 midwave (MW), 6 shortwave (SW), and 1 visible, see Table 1), the first 15 infrared (IR) bands are usually taken for retrieval due to the affect of solar radiation on near IR and visible channels. The IR channels measure radiances emitted from layers from surface to lower stratosphere. Hourly-retrieved temperature and water vapor profiles have been routinely generated at CIMSS/University of Wisconsin-Madison.

There are usually two main parts of the retrieval program using sounder data. The first is to provide the first guess, which is usually obtained through linear regression (Li et al 2000) or directly from forecast data (Ma et al 1999). And the second part is the physical retrieval, which will adjust the first guess according to the differences between the measured radiances and the calculated radiances for all channels used. In the regression algorithm the temperature, water vapor, ozone, skin temperature and IR surface emissivities are regressed against the radiances as well as some other related predictors. The algorithm was described in detail in Smith et al. (1970). In case the regression retrieval is not better than forecast, forecast data can be used as the first guess. In the early stage of physical retrieval development, linearized algorithms were used to solve the simultaneous retrieval (Smith 1983, Hayden 1988). The methods were focused on better cloud detection, better water vapor basis functions, and better bias adjustment scheme (Hayden 1994; Hayden and Schmit 1994, 1995). However, since the radiative transfer equation (RTE) is highly nonlinearly-dependent on temperature and water vapor, the linearization method still leave room for improvement. In recent years, nonlinear physical retrieval algorithms are being developed (Ma et al. 1999; Li et al. 2000; Seemann 2003). These algorithms use a nonlinear Newtonian iterative method to find the optimal solution to the nonlinear inverse of the radiative transfer equation. Both the linear and nonlinear algorithms highly depend on the precision of the first guess. Usually, a better first guess will result in a better physical solution.

The method in this paper includes two parts: regression for first guess and a nonlinear physical retrieval method. Effort has been made in order to improve the retrieval both on regression and physical retrieval.

2 REGRESSION

Regression is used for first guess of temperature and water vapor instead of forecast in recent years (Li et al, 2000; Seemann et al. 2003). Technically, there is no big difference among different regression methods. The main difference is what predictors are used and how they are used. The primary predictors are GOES radiances. In this method, four types of predictors are used: (1) the radiances; their quadratic and interactive terms(2) surface pressure, local zenith angle and latitude; (3) hourly surface temperature and moisture observations, and (4) the forecast temperature and moisture profiles. All those predictors make a significant improvement on the first guess (forecast) used in the current GOES Sounder operational processing.

In order to generate the regression coefficient, the time and space collocation radiosonde observations (RAOB) and GOES Sounder radiance measurements are used. An alternative way is to generate synthetic regression using the profiles of temperature, moisture and ozone, and the surface emissivities. A radiative transfer model is used to calculate the simulated GOES Sounder radiances. In such a way, there is no time and space collocation bias, but the model uncertainty brings new bias (forward model bias) and error (forward model error). Also, because the profiles of ozone are difficult to obtain, the ozone profiles in the training data set may have impact on temperature and moisture sounding retrieval. In this paper, both the matchup-based and the synthetic-based regressions are used. The former is used for the temperature, moisture profiles and skin temperature, the latter for the ozone and surface emissivity. There are also the forecast data from NCEP ETA forecast model in the matchup file. In order to test the regression retrieval accuracy, the randomly-selected 90% of the matchup data is used as training set for regression coefficients, while the other 10% are used as validation (Figure 1). The red lines are root mean square error (RMSE) between forecast (use as first guess in current operational GOES Sounder processing) and RAOB, the blue lines are for the retrieval RMSE from GOES-12 Sounder alone (all predictors except forecast data), while the green lines are our new results. When including the forecast data as predictors, the retrieval is improved at all levels over the GOES Sounder alone. For temperature, the improvement is larger than 0.5 K almost at all levels. While for water vapor, the improvement is mainly at levels between 700 and 900 hPa. Also, the improvement over the forecast is obvious. Near the surface, because the hourly surface temperature/moisture observations are included as predictors, the retrieval is much better than the forecast.

3 NONLINEAR PHYSICAL RETRIEVAL

The nonlinear physical retrieval algorithm here is based on regularization method (Li et al. 2000). A penalty function (Rodgers 1976) is defined as

$$J(X) = \left\| Y^m - Y(X) \right\|^2 + \gamma \left\| X - X_0 \right\|^2 \qquad (1)$$

Where X is the atmospheric parameters to be retrieved, X_0 is the first guess, Y^m is the vector of the observed radiances, Y(X) is the calculated vector of the satellite radiances with the atmospheric parameters X, γ is the regularization parameter that can be determined by the discrepancy principle (Li and Huang 1999; Li et al. 2000). The minimum variance solution to (1) is the nonlinear physical retrieval solution. Because the surface emissivities are difficult to retrieve, constant values are usually used for physical retrieval (Ma et al. 1999). In this paper, to take advantage of a new training that contains physically realistic surface skin temperature and IR emissivities, regressively-retrieved surface emissivities are used in the physical retrieval. Instead of using the other 10% matchup data for validation, CART SITE data are used to demonstrate the capabilities of the physical algorithm over the regression one. Figure 2 are the total precipitable water (TPW) from different methods. The blue dots are microwave radiometer measured TPW, the blue line is forecast TPW, the red line is the regressed TPW (first guess), and the magenta line the physical retrieved TPW. The x-coordinate represents time (0Z-23Z), and the y-coordinate represents the TPW (mm). Obviously, both the regression and the physical have better results than forecast. And during most of the time of this day, the physical has better results than regression. Near 7-8Z and after 18Z, the retrieval is probably affected by the failure detection of clouds. This is only one day case. More data are now being processed at CIMSS/University of Wisconsin-Madison. The results will be shown at AMS meeting. We believe the physical retrieval will show more evidently better results than the regression.

4 SPATIAL FILTERING FOR BETTER SOUNDINGS

When implementing the retrieval algorithms on the real GOES-12 sounder data, one of the important issues is noise impact. Currently, the routinely-running GOES-12 sounder processing uses linear averaging over a 3x3 box for all the channels. This spatial smoothing can reduce the gradient of the retrieved TPW, which are caused by the noise. However, this uniform spatial smoothing is not physically perfect. For channel 1, 2, 3 and 15, whose weighting functions peak very high, the radiances are spatially homogenous. Thus, the 3x3 filtering is not large enough to remove the noise. For channel 7 and 8 (window channels), most of the gradients of the radiance are caused by the signal itself. 3x3 filtering might overly smooth the noise effects. Thus, a better smoothing scheme is needed.

Unlike the spatial average smoothing above, which filters the noise in spatial domain, the Fourier transfer filtering (FTF), which is an effective digital image processing method in reducing the noise, filters the noise in frequency domain (Gonzalez and Woods, 2002). Through 2-D Fourier transferring, most of the signals are located in the center in the frequency domain because the signals are low frequency variant. There are various kinds of noise in the radiance data, with the most important of random noise and scanning strip noise. The random noise is high-frequency variant. Thus, in the frequency domain, through retaining the frequencies near the center, one may filter out the random noise. For random noise, the fundamentals behind the FTF are almost the same as the spatial smoothing above. However, the difference is that the FTF can set the size of the smoothing box to any size, while the normal spatial smoothing can only do it within integer-size box. One cannot use a 2.5X2.5 box to do the averaging. Thus, we can set a very large box for channel 1, 2, 3 and 15, and set very small box for channel 7 and 8. One of the important advantages of FTF is its effectiveness on scanning strip noise. One may show the scanning strip has a feature of a pair of bright spots, symmetrical around the origin in frequency domain. Thus it is very simple to filter out the scanning strip noise: just remove the pair of the bright spots.

Figure 3 shows the effect of FTF on the retrieval. The left columns are before filtering, and the right ones are after filtering. (a) - (d) are regression. (e) - (h) are physical. (a), (b), (e) and (f) are the retrieved image of TPW. (c), (d), (g) and (h) are the corresponding gradient image.

Comparing the images of TPW before and after filtering, it is obvious the filtering is effective on removing the noise. After the filtering, the image is very smooth. The same conclusion can be drawn from the images of the gradients. Random noise has a feature of randomly-located on the gradient image, as can be seen in (c) and (h). After the filtering, most of these features are gone. And, some of the gradients are retained. These are the response to natural spatial change of the TPW.

5 TIME CONTINUITY

Taking the fact that temperature is more spatially and temporally stable than the water vapor, we can use 3 by 3 FOV area's GOES Sounder radiance measurements from two continuous time steps to retrieve one temperature sounding and 18 water vapor soundings. In such a way, 18 times of GOES Sounder radiance measurements will be simultaneously used in the retrieval procedure for one temperature sounding and 18 moisture soundings, the retrieval procedure has the advantage of over determinacy. As the core of the time continuity, the physical retrieval algorithm is now being developed. This includes two stages. The first is the new physical retrieval algorithm based on spatial continuity. The second is the new physical retrieval algorithm based on time continuity. These results will be shown at AMS meeting.

6 SUMMARY

With the new retrieval algorithms (regression and physical) and the new filtering method, the GOES-12 sounder is able to provide better products of temperature and moisture profiles retrieval. More promising improvement will be made based on time continuity.

Acknowledgements
This work was funded by NOAA GIMPAP program NA07EC0676. The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

REFERENCES

Gonzalez, R. C. and R. E. Woods, 2002: Digital Image Processing , Addison-Wesley Pub. Co., New York, (2nd edition)

Hayden, C. M., 1988: GOES–VAS simultaneous temperature–moisture retrieval algorithm. *J. Appl. Meteor.,* **27,** 705–733.

Hayden, C. M., 1994: *GOES-I* sounder, pre-launch investigations in simulation.Preprints, *Seventh Conf. on Satellite Meteorology and Oceanography,*Monterey, CA, Amer. Meteor. Soc., 484–488.

Hayden, C. M., and T. J. Schmit, 1994: *GOES-I* temperature moisture retrievals and associated gradient wind estimates. Preprints, *Seventh Conf. on Satellite Meteorology and Oceanography,* Monterey, CA, Amer. Meteor. Soc., 477–480.

Hayden, C. M., and , 1995: Initial evaluation of the *GOES-8* sounder. Preprints, *Ninth Symp. on Meteorological Observations and Instrumentation,* Charlotte, NC, Amer. Meteor. Soc., 385–390.

Li, Jun and H.-L. Huang, 1999: Retrieval of atmospheric profiles from satellite sounder measurements by use of the discrepancy principle. *Appl. Optics,* **38,** 916–923.

Li, Jun, W. Wolf, W. P. Menzel, W. Zhang, H.-L. Huang, and T. H. Achtor, 2000: Global soundings of the atmosphere from ATOVS measurements: The algorithm and validation. *J. Appl. Meteor.,* **39,** 1248–1268.

Ma, Xia L., Schmit, Timothy J., Smith, William L. A Nonlinear Physical Retrieval algorithm—Its Application to the *GOES-8/9* Sounder Journal of Applied Meteorology 1999 38: 501-513

Rodgers, C. D., 1976: Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. *Rev. Geophys. Space Phys.,* **14,** 609–624.

Seemann, S., J. Li, W. P. Menzel, and L. Gumley (2003). Operational Retrieval of Atmospheric Temperature, Moisture, and Ozone from MODIS Infrared Radiances. *Journal of Applied Meterology*, 42, 1072-1091

Smith, W. L., H. M. Woolf, and W. J. Jacob, 1970: A regression method for obtaining real-time temperature and geopotential height profiles from satellite spectrometer measurements and its application to *Nimbus 3* ‘‘SIRS’’ observations. *Mon. Wea. Rev.,* **98,** 582–603.

Smith, W. L, 1983: The retrieval of atmospheric profiles from VAS geostationary radiance observations. *J. Atmos. Sci.,* **40,** 2025–2035.

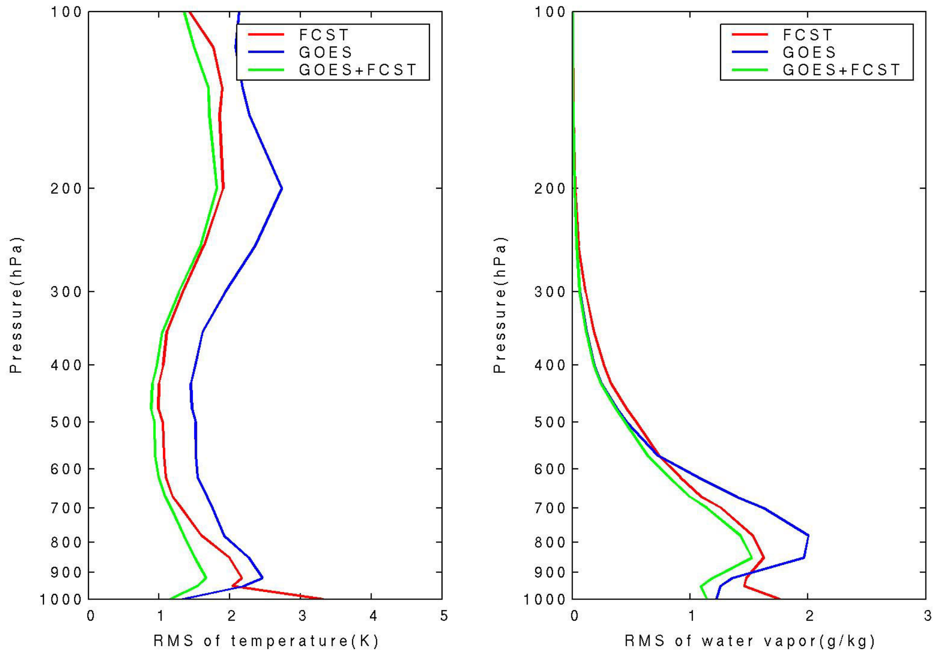

Figure 1. Temperature and water vapor RMSe compared to RAOB. The red lines are forecast, the blue lines are GOES alone, and the green lines are new regression.

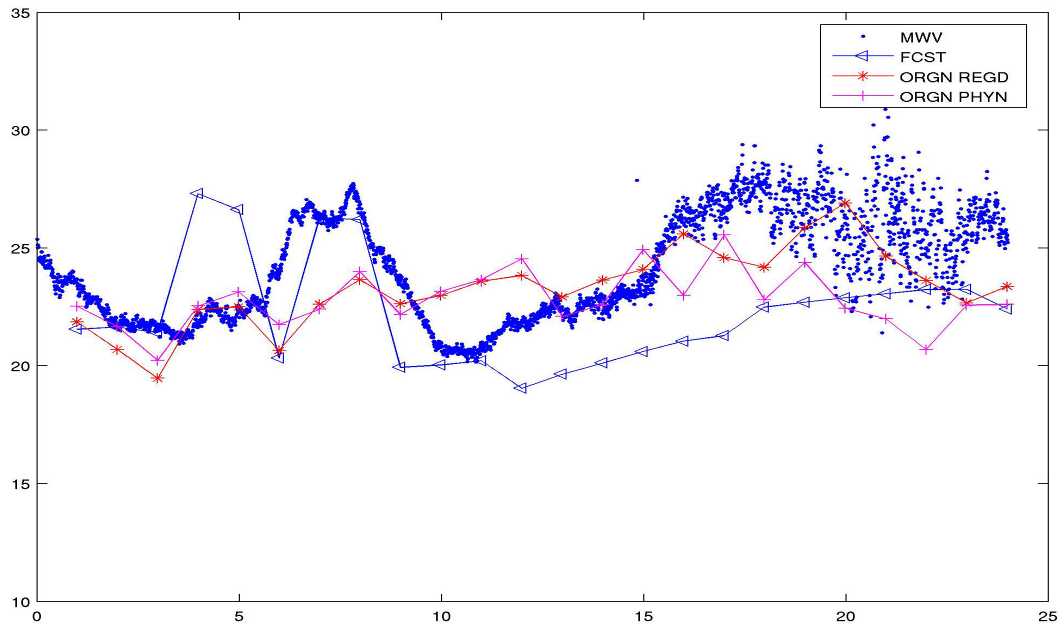

Figure 2. TPW from different retrieval methods

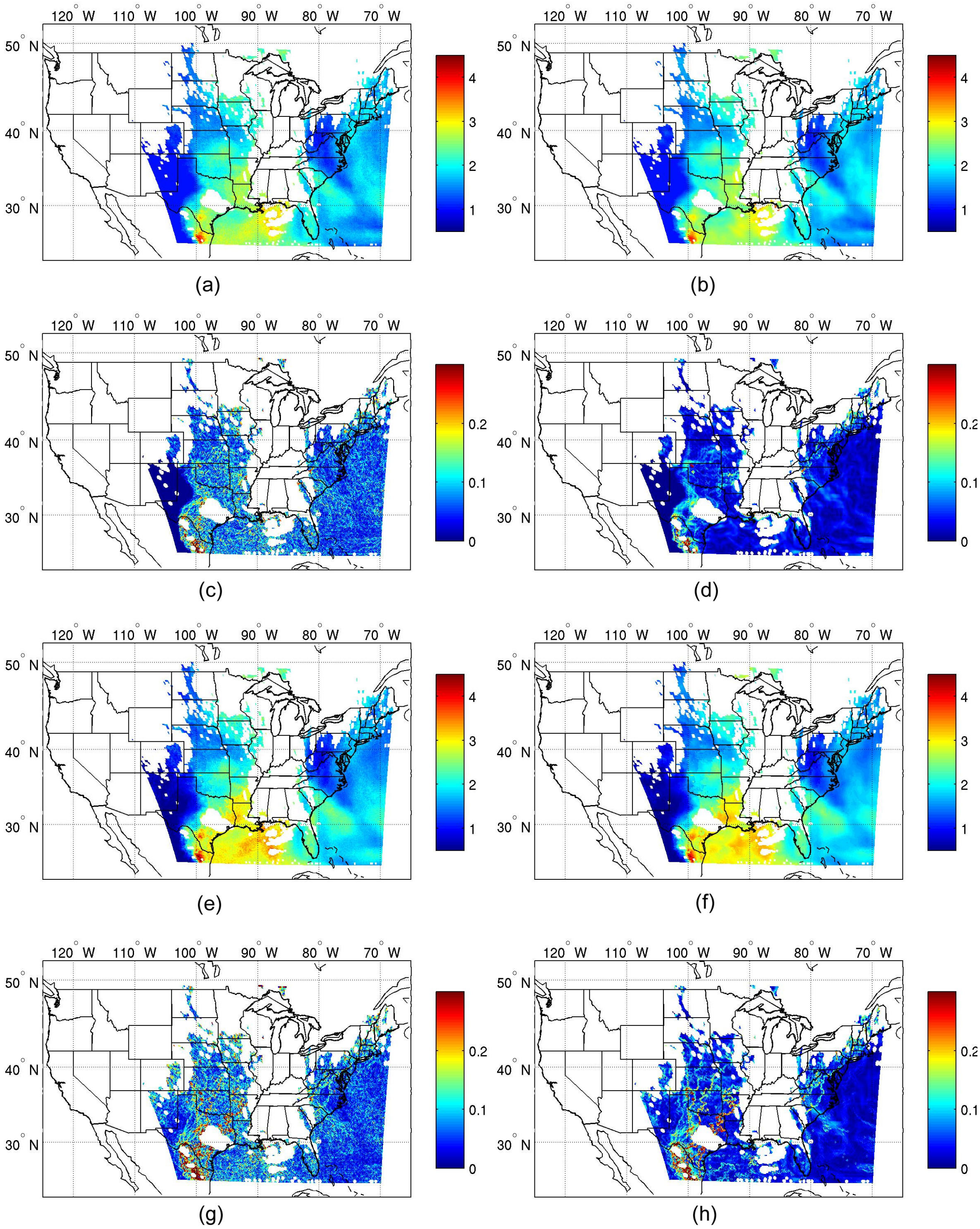

Figure 3. The effect of the Fourier transfer filtering on retrieval. The left are before filtering, and the right are after filtering. (a) - (d) are regression, (e) -(h) are physical. (a), (b), (e) and (f) are retrieved image of TPW. (c), (d), (g) and (h) are corresponding gradient image.

Wave Range	Channel Numbers	Wavelength(μm)	Band	Purpose: T-temperature W-Water vapor
Long wave IR	1	14.71	Carbon Dioxide	Stratosphere T
	2	14.37	Carbon Dioxide	Tropopause T
	3	14.06	Carbon Dioxide	Upper-level T
	4	13.64	Carbon Dioxide	Midlevel T
	5	13.37	Carbon Dioxide	Low-level T
	6	12.66	Water Vapor	Surface T, W
	7	12.02	Window	Surface T, W
Medium wave IR	8	11.03	Window	Surface T
	9	9.71	Ozone	Total Ozone
	10	7.43	Water Vapor	Low-level W
	11	7.02	Water Vapor	Midlevel W
	12	6.51	Water Vapor	Upper-level W
Short wave IR	13	4.57	Carbon Dioxide	Low-level T
	14	4.52	Carbon Dioxide	Midlevel T
	15	4.45	Carbon Dioxide	Upper-level T
	16	4.13	Nitrogen	Boundary-layer T
	17	3.98	Window	Surface T
	18	3.74	Window	Surface T, W
Visible	19	0.70		

Table 1. GOES I-M (GOES 8-12) Sounder Instrument Characteristics