Temperature and Humidity Profile Retrieval over Land Using Clear-Sky Measurements from the Microwave Humidity and Temperature Sounder on China' s FY-3C Satellite (Postprint)

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Abstract

An one-dimensional variational retrieval system was developed to retrieve the clear sky atmospheric temperature and humidity profiles over land using the measurements of microwave humidity-temperature sounder (MWHTS) on Chinese FY-3C satellite. The system parameters are configured by analyzing the MWHTS channel properties and the climate condition over land. The retrieval results are evaluated by root mean square error (rmse) with respect to European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis data. The validated results show that the maximum root mean square error of temperature and humidity are 2.59K and 11.87%, respectively. The retrieval results, compared with National Centers for Environmental Prediction (NCEP) 6 hour forecast profiles, show that the background profiles can affect the accuracy of retrieval profiles and FY-3C/MWHTS measurements can improve forecast precision of humidity. 2016 IEEE.

Full Text

Retrieval of Temperature and Humidity Profiles Over Land Using Clear-Sky Measurements from the Microwave Humidity-Temperature Sounder on China' s FY-3C Satellite

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1. Introduction

A one-dimensional variational retrieval system has been developed to retrieve clear-sky atmospheric temperature and humidity profiles over land using measurements from the Microwave Humidity-Temperature Sounder (MWHTS) aboard China' s FY-3C satellite. System parameters were configured through analysis of MWHTS channel properties and climatic conditions over land. Retrieval accuracy was evaluated using root mean square error (RMSE) relative to European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis data. The validation results demonstrate maximum RMSE values of 2.59 K for temperature and 11.87% for humidity. Comparisons with National Centers for Environmental Prediction (NCEP) 6-hour forecast profiles reveal that background profiles significantly affect retrieval accuracy, while FY-3C/MWHTS measurements improve humidity forecast precision.

Temperature and humidity parameters play a crucial role in meteorological research, serving not only to assess atmospheric stability and assist in nowcasting convective weather but also to monitor climate change [1]. Numerous studies have investigated retrieving these parameters from satellite measurements [2,3]. Physical retrieval methods, which obtain atmospheric parameters by solving the radiative transfer equation, are considered fundamental and the most effective approach for improving retrieval accuracy. The FY-3C satellite was successfully launched on September 23, 2013, carrying the Microwave Humidity-Temperature Sounder, whose measurements can simultaneously retrieve atmospheric temperature and humidity profiles [4].

This paper first analyzes the parameters of a one-dimensional variational retrieval system that affect retrieval accuracy, then selects optimal parameter combinations for MWHTS. The MWHTS retrieval system uses clear-sky measurements over China to retrieve temperature and humidity profiles, with preliminary results demonstrating high accuracy.

2. One-Dimensional Variational Retrieval System

2.1 System Description

The one-dimensional variational retrieval system employs RTTOV (Radiative Transfer for TOVS) as the forward radiative transfer model to calculate simulated brightness temperatures. The iterative process minimizes the following cost function [3]:

$$J(\mathbf{x}) = \frac{1}{2}[(\mathbf{x}-\mathbf{x}_b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b) + (\mathbf{y}-\mathbf{y}(\mathbf{x}))^T\mathbf{O}^{-1}(\mathbf{y}-\mathbf{y}(\mathbf{x}))]$$

where $\mathbf{x}_b$ and $\mathbf{B}$ are the background state vector and its error covariance matrix, respectively; $\mathbf{x}$ is the parameter vector to be retrieved; $\mathbf{y}$ represents the observations; $\mathbf{y}(\mathbf{x})$ denotes the simulated measurements; and $\mathbf{O}$ is the measurement error covariance matrix, comprising both observation and modeling error components. Minimization of this cost function forms the basis for variational retrieval. The solution is obtained by solving $\partial J/\partial \mathbf{x} = 0$, yielding:

$$\mathbf{x}_{n+1} = \mathbf{x}_n + (\mathbf{B}^{-1} + \mathbf{K}_n^T\mathbf{O}^{-1}\mathbf{K}_n)^{-1}\mathbf{K}_n^T\mathbf{O}^{-1}[\mathbf{y} - \mathbf{y}(\mathbf{x}_n)]$$

where n is the iteration index and $\mathbf{K}$ is the Jacobian matrix (the derivative of $\mathbf{y}$ with respect to $\mathbf{x}$).

2.2 System Parameters

For this study, the retrieval system selects NCEP 6-hour forecast profiles as background fields. The background error covariance matrix $\mathbf{B}$ is generated using ECMWF reanalysis data according to:

$$B_{ij} = \frac{1}{N}\sum_{k=1}^{N}(x_i^k - \bar{x}_i)(x_j^k - \bar{x}_j)$$

where x_i^k represents the k-th element of the i-th profile, $\bar{x}_i$ is the mean value along the i-th dimension, and N is the number of profiles.

To correct biases between observations and simulated brightness temperatures, a statistical regression method is applied pixel by pixel:

$$T_{ij}^* = a_j T_{ij} + b_j$$

where T_{ij}^* and T_{ij} are the corrected and original brightness temperatures, respectively; i is the pixel index; j is the channel index; and a_j and b_j are the slope and intercept coefficients. The measurement error covariance matrix $\mathbf{O}$ is generated from forward model error and channel noise.

2.3 Convergence Check

Convergence is assessed using the following criterion:

$$\frac{|J_{n+1} - J_n|}{J_n} < 0.01$$

Iterations terminate when the relative cost function change falls below 0.01 and the maximum iteration count remains below 10. If convergence fails, the retrieval defaults to the background profiles.

3. Analysis

Root mean square error serves as the standard metric for validating retrievals against ECMWF ERA-Interim reanalysis data. FY-3C/MWHTS data from April and May 2015 were used for detailed comparisons between MWHTS sounding profiles, ECMWF reanalysis profiles, and background profiles. Only clear-sky MWHTS data over Chinese land within 0.5 hours of ECMWF reanalysis data were used for validation.

[Figure 1: see original paper]

Figure 1 illustrates the vertical distribution of RMSE for retrieval profiles and background profiles relative to ECMWF reanalysis data. The retrieval achieves an accuracy of 2.59 K for temperature and 11.87% for relative humidity, demonstrating the system' s high precision. The RMSE of retrieved humidity profiles is smaller than that of background profiles, particularly between 250 hPa and 750 hPa, indicating that humidity retrievals improve upon the NCEP 6-hour forecast background fields.

To assess the impact of background profiles on retrieval accuracy, ECMWF reanalysis data were used as background fields in a separate retrieval experiment. The validation results (Figure 2) show reduced RMSE compared to Figure 1, particularly for humidity profiles, confirming that background profiles—which can introduce significant error—are critical to retrieval system performance.

[Figure 2: see original paper]

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4. Conclusion

This study established a one-dimensional variational retrieval system for FY-3C/MWHTS to retrieve atmospheric temperature and humidity profiles under clear-sky conditions over land. The retrieval system demonstrates high accuracy and improves upon NCEP 6-hour forecast profiles, confirming the significance of FY-3C/MWHTS measurements for numerical weather prediction. Background profiles represent a major error source affecting retrieval accuracy; future research should explore alternative data sources with higher fidelity to the true atmospheric state as background fields to further enhance retrieval performance.

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5. References

[1] Alexander Polyakov, Yurii M. Timofeyev, Yana Virolainen. Comparison of different techniques in atmospheric temperature-humidity sensing from space. *International Journal of Remote Sensing*, vol. 35, no. 15, pp. 5899-5912, 2014.

[2] Fatima Karbou, Filipe Aires, Catherine Prigent. Potential of Advanced Microwave Sounding Unit-A (AMSU-A) and AMSU-B measurements for atmo-

spheric temperature and humidity profiling over land. *Journal of Geophysical Research*, vol. 110, no. D7, pp. D07101, 2005.

[3] Sid-Ahmed Boukabara, Kevin Garrett, Wanchun Chen, et al. MIRS: An All-Weather 1DVAR Satellite Data Assimilation and Retrieval System. *IEEE Transactions on Geoscience and Remote Sensing*, vol. 49, no. 9, pp. 3311-3333, 2011.

[4] Bao J H. The principle of FY-3C satellite microwave humidity-temperature sounder and preliminary analysis on its in-orbit performance. Beijing: National Space Science Center, Chinese Academy of Sciences, 2014.

[5] Jun Li, Walter W. Wolf. Global Sounding of the Atmosphere From ATOVS Measurements: The Algorithm and Validation. *Journal of Applied Meteorology*, vol. 39, no. 8, pp. 1248-1268, 2014.

Note: Figure translations are in progress. See original paper for figures.