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Study on Hyper-spectral Atmospheric Infrared Sounder Assimilation

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Abstract

Hyper-spectral Atmospheric Infrared Sounder has many channels. Although, it has been carried out channel selection in the actual application process, but compared with the previous detector, the channel also seems more and thus easy to weak correlation between channels, which is not obey classical variational assimilation theory requires observation error is not related. Hyper-spectral sounder covering CO_2 and water vapor absorption band channels, the nonlinear of water vapor channel brightness temperature is strong, the practical application of these channel combinations into the assimilation system together, the brightness temperature information mutual influence and feedback among channels are more complex. Different from the classical variational assimilation that given observation error is not change later, using the observational error re-estimation and robust variational assimilation based on Huber function to study the hyper-spectral sounder brightness temperature assimilation. The ideal experiments show that the observation error re-estimates and robust variational method assimilate hyper-spectral atmospheric infrared sounder can get better assimilation effect than the classical one.

Keywords: *Hyper-spectral, Error re-estimated, Robust variational assimilation*

1. Introduction

Numerical weather prediction (NWP) is an initial/boundary problem. The satellites data can greatly improve data coverage area as well as spatial and temporal resolution. Satellites data assimilation approach can provide accurate initial state as much as possible for the numerical prediction model [1].

Variational assimilation based on linear estimation theory [1], the idea is that the objective functional minimization. Objective functional includes background and observation items. The contribution of observation to the objective functional is regulated by the reciprocal of the channel observation error. The basic assumption of variational assimilation is that observation error not correlation between the channels. Previous instruments, such as AMSU and HIRS [2], due to the some channel and easy to satisfy this assumption. Hyper-spectral sounder has many channels in the same absorption band, it is easy to weak correlation between channels. Variational assimilation of the specific implementation process, the observation errors are generally given and not change later. When actually doing cloud area [3] satellite channel brightness temperature assimilation, showing a strong correlation between the channels. In this paper we used observation error re-estimation method to estimate the observation error, which is provided to the variational assimilation [4].

The hyper-spectral sounder channels covering CO_2 and H_2O absorption band. However, water vapor channels are rather sensitive to humidity variable because of the characteristics of humidity variables. Small perturbations of humidity can have great effects on the brightness temperature, resulting in H_2O absorption band some channel brightness temperature deviation is larger than the CO_2 channel. We adopt robust variational assimilation method based on the Huber function [5, 6], which is coupled with quality control in the process of assimilation, based on the brightness temperature deviation and reduce the contribution rate of the observational data to the objective function when deviation outside the threshold range of fine-tune parameter. Simulated brightness temperature of AIRS is used to carry out ideal experiments [7].

2. Hyper-spectral Sounder Assimilation Theoretical Analysis

2.1 Re-estimated Observation Error

Assuming observation error and background error is irrelevant (both belong to the orthogonal relationship), according to the definition of the variational method, the variational method to seek the analysis of field makes the goal of functional minimum, the variational assimilation analysis of the inverted the distance between the true value, relative to distance between observation and true value and between background and the true value is the shortest, so the difference of analysis and true value is orthogonal to the difference of observation and background, the relationship among three can be described with a triangular geometry [4].

According to the Pythagorean Theorem. We can get

$$(y^o - y^t)^2 = (y^o - y^a) \bullet (y^o - y^b)$$

Among them, y^a , y^b and y^t represent the information of inversion, background and the true value projected onto the observation space respectively. y^o represents the actual observed values. For n observation, re-estimated the observation error is the average error of all observations.

2.2 Robust Variational Assimilation based on Huber function

The objective functional is defined as:

$$J(x,w) = \frac{1}{2}(x - x_b)^T \boldsymbol{B}^{-1}(x - x_b) + \frac{1}{2}\left[H(x) - y\right]^T w(r)\boldsymbol{R}^{-1}\left[H(x) - y\right]$$

Among them, $w(r)$ is the weight function of Huber function of M-estimators. $w(r)$ is a diagonal matrix with the elements $w(r_i)$, $r_i = \left[y_i - H_i(x)\right]/\sigma_i$, $\boldsymbol{y_i}$ is the observed brightness temperature of i channel. $H_i(x)$ is the simulated brightness temperature of i channel, σ_i is square root of the diagonal elements of observation error covariance matrix. It is assumed that each channel is not correlated.

3. Performance Evaluation

3.1 Relevant Model

The variational assimilation system in this paper is a developed one-dimensional variational physical retrieval model based on the EUMETSAT satellite data Numerical Weather Prediction applied research group. On the basis of the original 1D-Var, the following several steps are done: (1) only consider the temperature and humidity;(2) add the program of observation error re-estimated, the specific process needs to meet the conditions established by the Pythagorean Theorem; (3) add the interface program of Huber function.

3.2 Ideal Data Analysis

In the course of ideal experiment, 1D-Var's own profiles are used. Select one of the profiles as real profile and corresponding simulation brightness temperature as true brightness temperature. The profiles are added Gaussian random error and perturbed for 100 times as a background profiles. True brightness temperature is added Gaussian random error and perturbed for 100 times as observed brightness temperature [8].

3.3 Re-estimated Observation Error

In the following adopted 281 channel combinations [9]. Left Figure 1 shows the re-estimated observation error of 281, which are given 100 profiles statistics. Dotted line is error of the original observation error distribution, the solid line is the re-estimated observation error; right figure shows the robust variational assimilation based on Huber function, the first iteration of the Huber function calculated weights allocation for each channel in the minimization process.

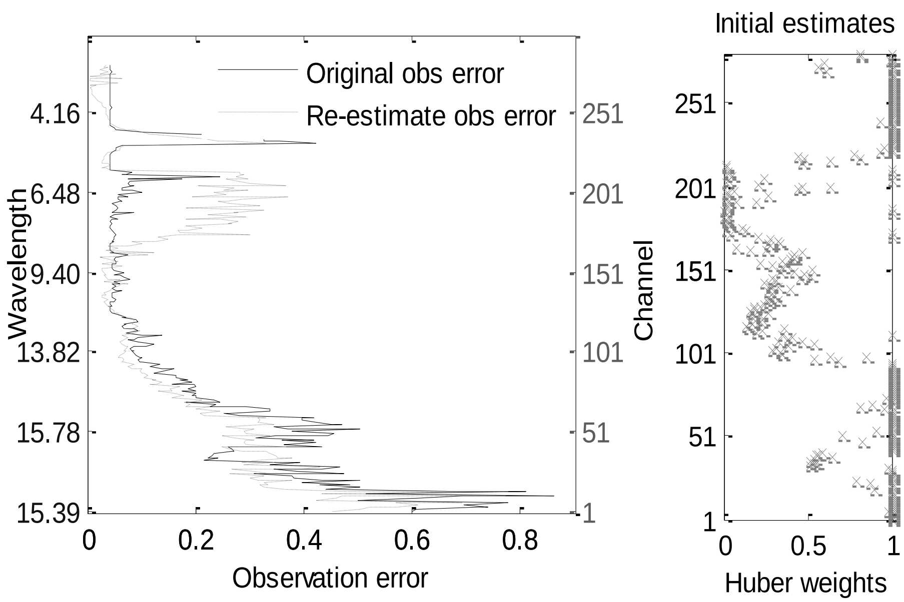
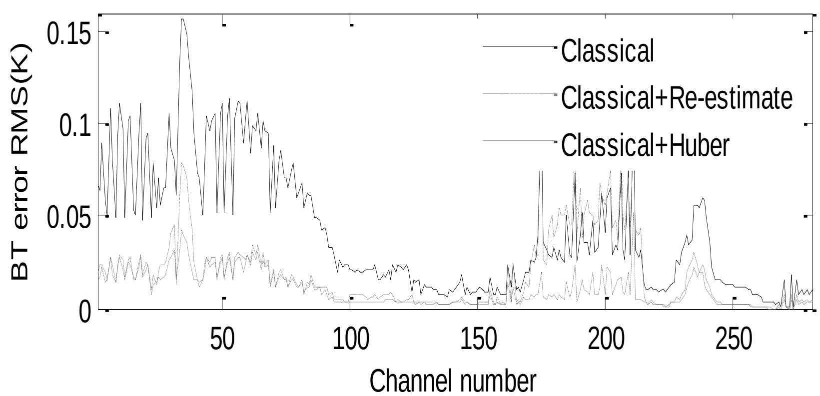


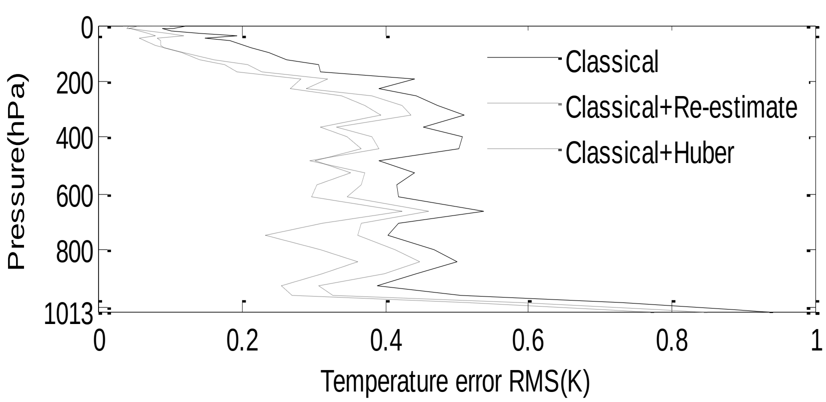
Figure 1. Re-estimated Channel Observation Error and Weight Estimates of Huber Function

Seen from Figure 1 left, AIRS instrument spectral of CO_2 absorption band (center near 15.5 μm and 4.3 μm) channel re-estimated the observation error is smaller than the original observation error, thus re-estimated the contribution rate of CO_2 absorption band channel brightness temperature to the objective functional is increase; water vapor absorption band (the center channel near 6.3 μm) re-estimate the error value is larger, indicating that the contribution rate of water vapor channel brightness temperature to objective functional is reduce; It also can be seen from the right picture, before the first iteration in the minimization process of the objective function, water vapor absorption channel larger brightness temperature deviation assigned smaller weights.

3.4 Different Approach Comparison

When the combined 281AIRS channels are taken into account, the statistics of the analysis error RMS (root-mean-square) of the observation spatial and model spatial are presented in this paper. Figure 2, Classical, Classical+Re-estimate and Classical+ Huber ,which using the classical variational assimilation method, observation error re-estimated and robust variational assimilation based on Huber function respectively to inverted bright temperature(written as: BT), temperature and humidity error. Here given 100 profiles RMS statistics.





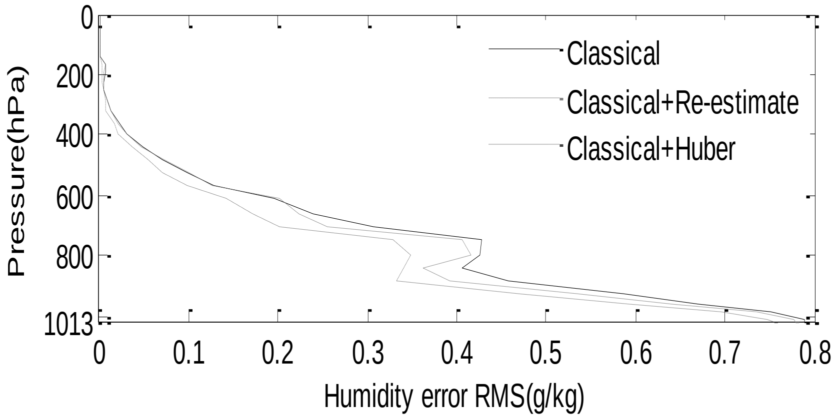


Figure 2. Brightness Temperature (BT), Temperature and Humidity Error RMS Statistics

Seen from Figure 2 about brightness temperature inversion, the effect of robust variational assimilation is best; In addition to, several channel of water vapor absorption band the effect is worse than classic variational, others observation error re-estimated is better than the classic one; Temperature and humidity inversion, the effect of robust is best, the observation error re-estimated is second.

Observation error re-estimated use the information of the classical variational assimilation analysis of field and background field are projected onto the observation space by observation operator, based on linear estimation theory, using the Pythagorean Theorem to get new observation error. The essence of observation error re-estimated to get the information of observation error covariance matrix is not only including diagonal, but also provide non-diagonal information Only consider the diagonal information in this paper. Robust variational method based on Huber function couples quality control in variational assimilation process, the idea is to allocate a smaller contribution rate of channel to objective function, whose channel brightness temperature deviation is exceed the fine-tune parameter.

4. Conclusions

Observation error is provided contribution rate of observation to objective functional. Observation error re-estimation method is used in this paper; Considering non-line of the water vapor channel brightness temperature, we study the robust variational assimilation based on Huber function to assimilate hyper-spectral channel bright temperature, the two methods get better assimilation effect than classical one.

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