Estimate of land surface temperature from Chinese second generation polar orbit FengYun meteorological satellite (FY-3) data

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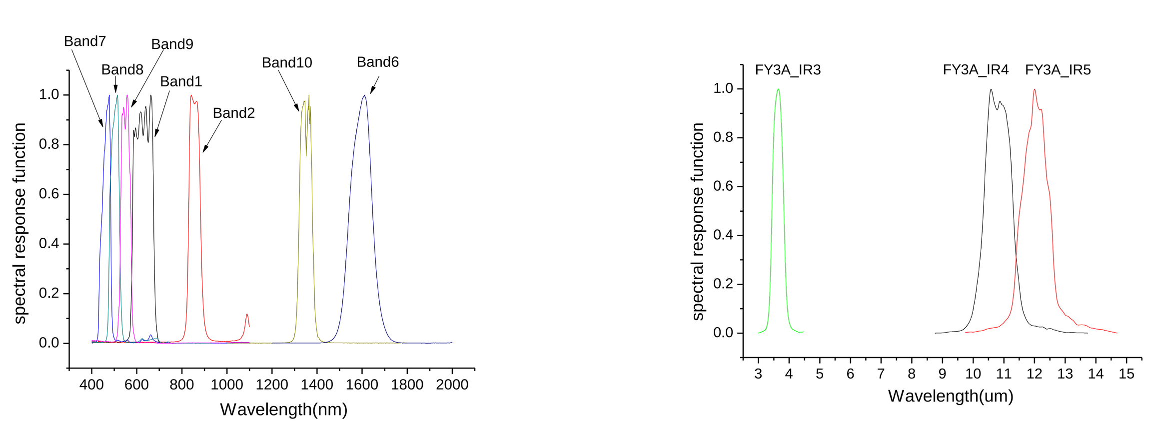
Abstract: This paper addressed the estimate of LST from the second generation of Chinese polar orbit FengYun-3 (FY-3) meteorological satellite data in two thermal infrared channels 4 (wavelength centred at 10.8 mm) and 5 (wavelength centred at 12.0 mm), using a split-window algorithm developed by Sobrino et al. (1993). The LST, mean emissivity, and atmospheric Water Vapor Content (WVC) were divided into several tractable sub-ranges with little overlaps to improve the fitting accuracy. The experimental results showed that the Root Mean Square Errors (RMSEs) are proportional to Viewing Zenith Angles (VZAs) and WVC, and they are less than 1.0 K for the sub-ranges with VZA less than 30° or for the sub-ranges with VZA less than 60° and the atmospheric WVC less than 3.5 g/cm², provided that the Land Surface Emissivity (LSE) are known. In addition, a preliminary test, by taking into account a simulated dataset different from that one used to obtain the algorithm, had been done with the proposed LST split-window algorithm over a wide range of atmospheric and surface conditions. The results showed that the split-window algorithm is capable of producing LST from FY-3 satellite data with RMSE less than 1.0 K.

Introduction

Land Surface Temperature (LST) is one of the key parameters in the physics of land surface processes at regional and global scales. It is, consequently, crucial to have access to reliable estimates of LST over large spatial and temporal scales, such as the satellite observations in the Thermal Infra-Red (TIR) channels.

FengYun-3 (FY-3), the second generation of Chinese polar orbit meteorological satellite, was launched into an 807-kilometer-high sun-synchronous orbit on 27 May 2008. It is an advanced earth observation satellite which carries ten payloads aboard of optical and microwave sensors to collect a range of remote sensing data, including temperature, humidity, air pressure, clouds, and radiation, through all-weather, multi-spectrum, three dimensional, and quantitative means. One of the major payloads onboard FY-3 is the Visible and InfraRed Radiometer (VIRR), which consists of seven visible and near infrared channels, and three infrared channels.



(a) (b)

Fig.1. Spectral response functions of FY-3 VIRR channels (a: visible and near-infrared channels; b: infrared channels)

The present work in this paper aims to obtain the LST from FY-3 VIRR satellite data in two thermal infrared channels 4 (wavelength centred at 10.8 μm) and 5 (wavelength centred at 12.0 μm) by using a split-window technique.

Algorithm development for FY-3 VIRR

So far, there is no available database of in situ LST measurements in coincidence with the FY-3 overpasses. Therefore, to determine LST from the data of VIRR onboard FY-3, we used synthetic data. To this end, the atmospheric radiative transfer model MODTRAN 4 was used to simulate at-sensor radiance with the latest version of the Thermodynamic Initial Guess Retrieval (TIGR) database TIGR2002, a variety of appropriate LSTs and LSEs change, as well as thermal infrared channel response function of the VIRR.

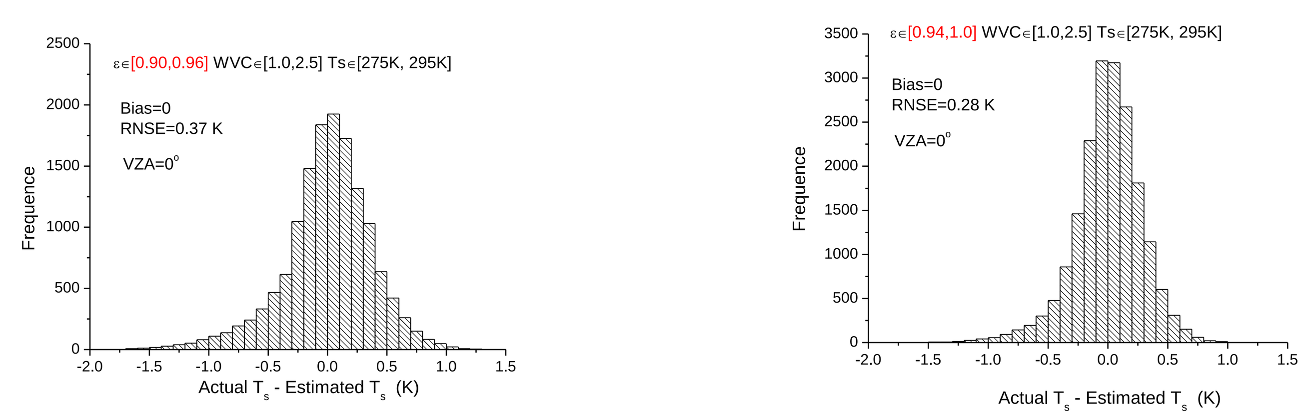
For different simulated values of the numerical experiments mentioned above, as done by Wan and Dozier (1996), the averaged emissivities are divided into two groups: one varies from 0.90 to 0.96 and the other ranges from 0.94 to 1.0. The atmospheric WVCs are divided into six sub-ranges with an overlap of 0.5 g/cm²: [0, 1.5], [1.0, 2.5], [2.0, 3.5], [3.0, 4.5], [4.0, 5.5], and [5.0, 6.5] g/cm². The LSTs, , are divided into five sub-ranges with an overlap of 5 K: Ts ≤280 K, 275≤Ts≤295 K, 290≤Ts≤310 K, 305≤Ts≤325 K, Ts≥320 K. We then propose to retrieve the LST according to the split-window algorithm developed by Sobrino et al. (1993) as follows

$$T_s = b_0 + b_1 * T_4 + b_2 * (T_4 - T_5) + b_3 * (T_4 - T_5)^2 + b_4 * (1-\varepsilon) + b_5 * \Delta\varepsilon$$

where b_0-b_5 are coefficients, which can be obtained through statistical regressions method for each VZA and each sub-range. ε is the mean emissivity, and Δε is the emissivity difference between VIRR channels 4 and 5. .

Results and analysis

Figure 2 shows, for an example, the histogram of the difference between the actual Ts and the Ts estimated with the coefficients corresponding to the sub-range WVC∈[1.0, 2.5], and Ts ∈[275K, 295K] for two different emissivity groups and VZA=0°, respectively. The Root Mean Square Errors (RMSEs) between the actual and estimated Ts is 0.37 K for the emissivity group ε∈[0.94, 1.0], and 0.48 K for the other emissivity group ε∈[0.90, 0.96]. Similar results are obtained for the other VZAs.



(a) (b)

Fig.2. Histogram of the difference between the actual and estimated Ts for the sub-range with WVC ranging from 1.0 g/cm² to 2.5 g/cm², and LST from 275 K to 295 K for VZA=0°. (a) for ε∈[0.90, 0.96] and (b) for ε∈[0.94, 1.0].

The total maximum error associated with the present algorithm itself (σ_{RMSE}), the error related to the instrumental noise (σ_{noise}), the error with respect to LSE (σ_ε), and the error caused by the uncertainty of atmospheric WVC (σ_{WVC}) is calculated by $\sigma_{total}^2 = \sigma_{RMSE}^2 + \sigma_{noise}^2 + \sigma_\varepsilon^2 + \sigma_{WVC}^2$.

As the sub-range ε∈[0.94, 1.0], WVC∈[1.0, 2.5], and Ts ∈[275K, 295K] for an example, the retrieval accuracy of LST related to the algorithm itself is affected by 0.28 K. The errors caused by the instrumental noise, LSE, and the uncertainty of atmospheric WVC are 0.21, 0.97, and 0.24 K, respectively. Finally, the total error associated to the LST retrieval is about 1.1 K.

Application to actual FY-3 data

i) Determination of LSEs

An NDVI-based threshold method is used to determine the LSEs for FY-3 VIRR channels 4 and 5. The spectral databases provied by the University of California Santa Barbara (UCSB) spectral database (http://www.icess.ucsb.edu/modis/EMIS/html/em.html) and the Johns Hopkins University (JHU) (http://speclib.jpl.nasa.gov/) spectral database are used to simulate the VIRR reflectances for visible and near-infrared channels and emissivities for infrared channels. The channels emissivities are determined by taking into account the characteristics of the soil present in each pixel and by identifying it as bare soil pixel, mixed pixel, and fully vegetated pixel, respectively.

ii) Determination of WVC

Taking into account that the WVC is used to determine the optimal coefficients in the LST algorithm, accurate WVC is not required, provided that the estimated WVC is within the same sub-range as the actual WVC. The method proposed by Li et al. (2003) is used, which utilizes the transmittance ratio of two VIRR split-window channels 4 and 5 to derive the WVC.

$$WVC = d_1 + d_2 \times \frac{\tau_j}{\tau_i}$$

iii) Estimation of LST

Figure 3 gives an example of the map of LST estimated from FY-3 VIRR satellite data on December 1, 2010 for China. The model input are the TOA brightness temperatures, VZA, LSEs, and WVC. All of these variables are extracted or derived directly from VIRR satellite data. From this figure one can see that the values of LST in the South and Easter China are higher, while those in the West and North China are relative lower.

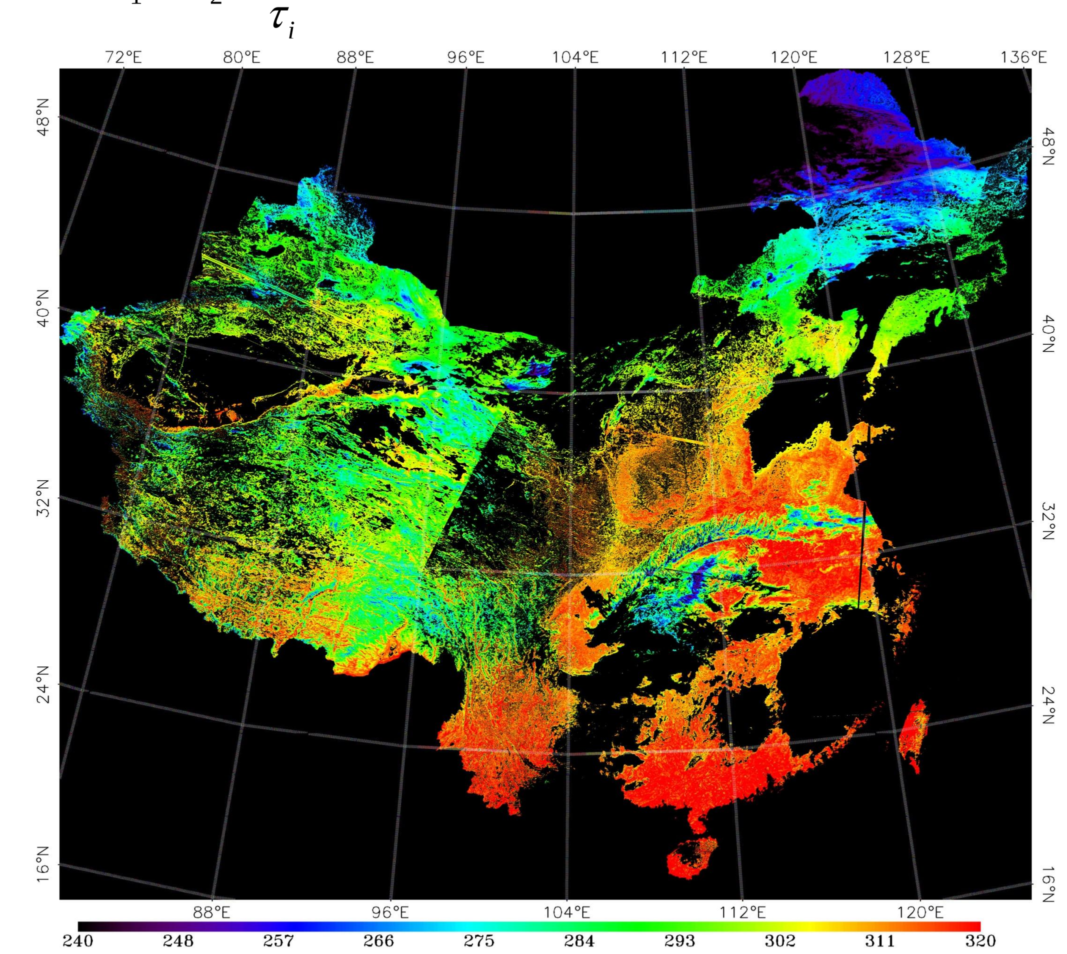


Fig.3. Map of the LST estimated from FY-3 VIRR data on December 1, 2010 for China

Conclusions

In this paper, an operational split-window algorithm was developed to retrieve Land Surface Temperature (LST) from the second generation of Chinese polar orbit FengYun-3 (FY-3) meteorological satellite data in two thermal infrared channels 4.

Sensitivity and error analyses in term of the instrumental noise, the uncertainty of LSE and the atmospheric WVC showed that, given an instrumental noise NEΔT=0.2 K and the uncertainties of and around 1%, the total error associated to the LST retrieval is about 1.1 K.

A comprehensive validation between the estimated LST and the in-situ measurements or validated LST products such as MODIS LST will be done in the near future.

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