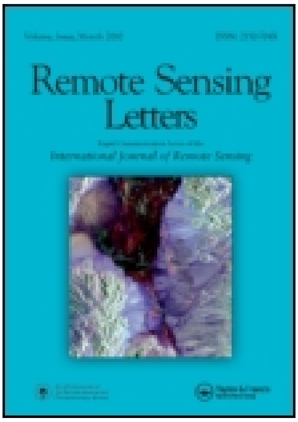

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Improving moisture profile retrieval from broadband infrared radiances with an optimized first-guess scheme

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Improving moisture profile retrieval from broadband infrared radiances with an optimized first-guess scheme

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Variational retrieval of legacy atmospheric moisture profiles needs to begin with a first guess. An optimized first-guess scheme is developed for moisture profile retrieval from broadband infrared (IR) radiances. In this scheme, the non-exponential response of moisture mixing ratio to IR radiance at high temperatures ($>$ 273 K) is considered. It is found that the first guess of low-level (below 550 hPa) moisture profiles is substantially improved after the new scheme. The data collected by Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard the Meteosat Second Generation are used for validation. This scheme provides an important optimization method for the next generation of Geostationary Operational Environmental Satellite (GOES)-R legacy profile retrieval algorithm because the Advanced Baseline Imager (ABI) onboard the GOES-R has very similar configurations to SEVIRI.

1. Introduction

The physical retrieval technique has been employed in moisture profile retrieval with multi-spectral infrared (IR) radiances collected from space-borne sounders for several decades (Smith *et al*. 1979, 1981). However, the next generation of Geostationary Operational Environmental Satellite (GOES)-R will not carry multi-spectral sounders. Instead, a multi-spectral broadband imager named Advanced Baseline Imager (ABI) will be used for sounding purposes (Schmit *et al*. 2009) before the launch of an ultra-spectral IR sounding instrument onboard the geostationary platforms (Smith *et al*. 2009). Using broadband imagers for atmospheric sounding is a big challenge because of the lack of enough vertical resolution. A plausible technique to mitigate such a problem by providing a better first guess of atmospheric profiles using a non-linear regression method rather than the forecast profiles has been applied to the Moderate Resolution Imaging Spectroradiometer (Seemann *et al*. 2003). The same technique is also modified and applied to the Spinning Enhanced Visible and Infrared Imager (SEVIRI) as a proxy for the ABI (Jin *et al*. 2008). Because this algorithm is derived from the one in operational use for current GOES Sounders, it is called the GOES-R legacy atmospheric profile (LAP) retrieval algorithm. Moreover, the

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SEVIRI/ABI has only one CO_2-absorption band at 13.4 μm sensitive to the low-level temperature profile and two/three water vapour-absorption bands between 6.2 and 7.3 μm, so the expectation of the LAP algorithm is that the moisture profile will be improved. In the current version of the LAP algorithm (Jin *et al*. 2008), the first guess of moisture profile is regressed from multiple predictors, including brightness temperatures (BTs) and their squared values, forecast moisture profile between 300 and 1050 hPa and some ancillary parameters such as latitude and local zenith angle.

The water vapour-absorption bands between 6.2 and 7.3 μm are only sensitive to moisture information at upper levels (higher than 700 hPa). Such spectral features indicate that physical retrieval only works well for upper level moisture layers, and the retrieval of low-level moisture to a large extent is determined by the quality of the first guess. Based on a basic concept that IR BTs have exponential responses to the change of atmospheric moisture, the logarithmic form of water vapour mixing ratio is used in the regression. However, this exponential relationship is quite loose and easily demolished by the wild variation of relative humidity. In this study, we present a new method to generate the moisture first guess, considering the demolished exponential relationship between atmospheric moisture and the IR radiance measurements. The algorithm is tested by simulation and validated by SEVIRI radiance measurements.

2. Algorithm description

The relationship between simulated SEVIRI IR BTs and the near-surface moisture is illustrated in figure 1. One-tenth of the randomly selected profiles from a profile dataset consisting of more than 15,700 global profiles of temperature, humidity and ozone (Jin *et al*. 2008) are used in the simulation. The surface variables accompanying each profile, such as surface skin temperature, surface pressure, surface IR emissivities at all SEVIRI IR bands and surface type, are also provided in the database. The radiative transfer model applied here is a fast transmittance model named Pressure-Layer Fast Algorithm for Atmospheric Transmittances (Eyre and Woolf 1988). This fast transmittance model is built upon the transmittance profiles calculated by the line-by-line radiative transfer model based on the high-resolution transmission molecular absorption spectroscopic database HITRAN 2000 (Rothman *et al*. 1998). Pressure-Layer Fast Algorithm for Atmospheric Transmittances is the radiative transfer model (RTM) employed in the current version of GOES-R LAP algorithm. It is clear that the exponential relationship is demolished by the wild variation of scattering plots because of the large change in relative humidity.

In the original regression scheme, the forecast moisture profile between 300 and 1050 hPa is used as a predictor in the logarithmic form. Considering the non-exponential patterns at large mixing ratio, another regression coefficient matrix is generated using the original form of the same forecast moisture profile. In application, two moisture profiles are regressed using different regression coefficients. The next step is to find a threshold to determine which profile is used at a specific height. We finally select 273 K of air temperature at the same height as the threshold. If the forecast air temperature is higher than 273 K, the non-logarithmic result is applied; otherwise, the original result is used. As the forecast air temperature has only small errors below 300 hPa (usually $<$1.5 K), this threshold is quite reliable.

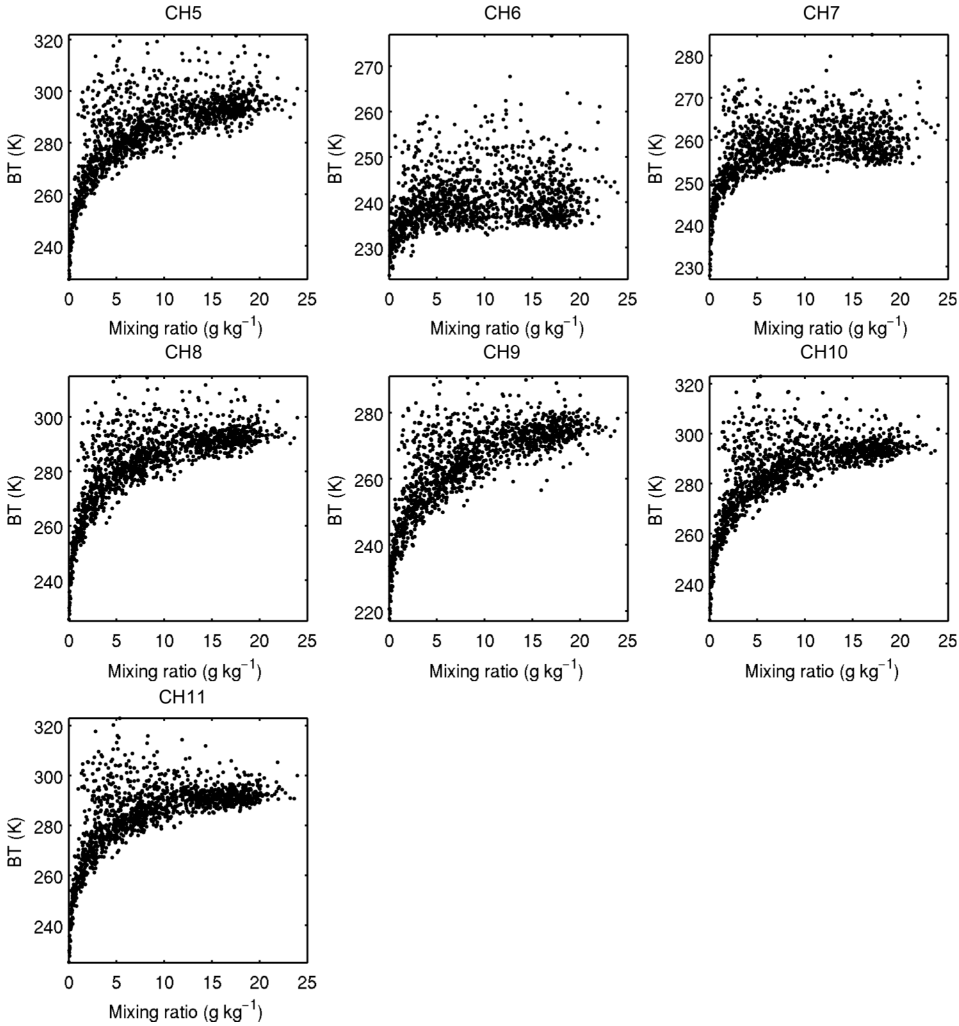

Figure 1. The relationship between brightness temperatures (BTs) and the near-surface atmospheric moisture mixing ratio for seven SEVIRI IR channels (CH5–CH11). The local zenith angle is assumed as 0 and the number of sample is 1443.

3. Numerical test

The same database is used for the numerical test. Ninety per cent of all profiles in the database is used to generate regression coefficients and the remaining 10% is used for retrieval. As the new scheme can only demonstrate its superiority in a humid environment, only those samples with total precipitable water vapour (TPW) greater than 30 mm are selected in the test. The total number of samples is reduced to 491. The local zenith angle is fixed at 0. The regressed and physically retrieved moisture profiles using the new scheme are marked as Reg1 and Phy1 in figure 2, whereas those from the old scheme are marked as Reg2 and Phy2. The forecast is simulated using an eigenvector analysis method (Li *et al*. 2009).

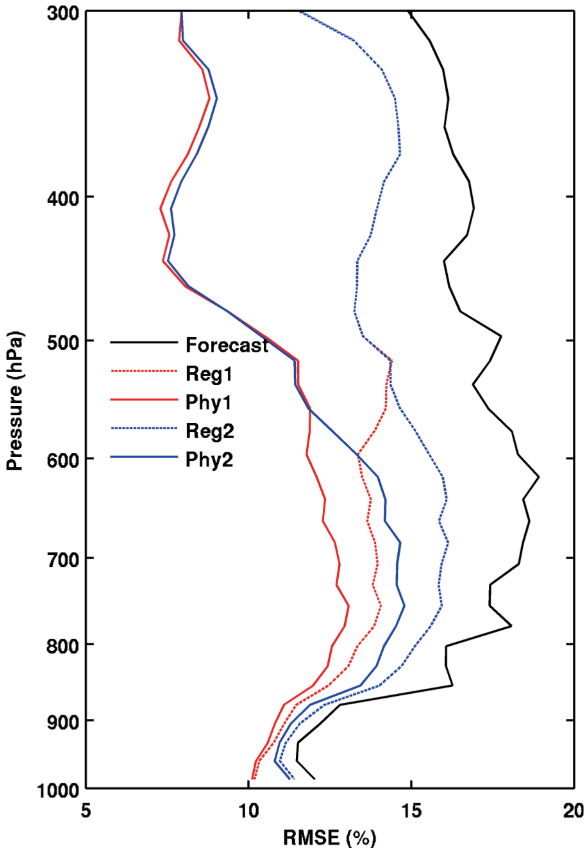

Figure 2. The root mean square error (RMSE) of forecast (black) regressed (colour dashed lines) and physically retrieved (colour solid lines) moisture profiles.

The root mean square errors (RMSEs) are illustrated in figure 2. It is found that the RMSE is substantially decreased below 550 hPa. This is an encouraging result because the physical retrieval from broadband IR radiances is very difficult to improve the forecast moisture profiles at low levels (below 700 hPa).

The quality of TPW and its three components WV1/WV2/WV3 (integrated water vapour between surface and 900 hPa, between 900 and 700 hPa and between 700 and 300 hPa, respectively) is evaluated in figure 3. It is clear that the RMSEs for TPW and for all three components by the new scheme are smaller than those by the old scheme. The best results appear at middle levels (WV2) with increased correlation coefficient *r* (from 0.77 to 0.79), reduced RMSE (from 3.08 to 2.79 mm) and reduced negative bias (from 0.15 to 0.11 mm). This valuable feature makes the new scheme extremely suitable for geostationary satellite-based moisture retrieval because most of the satellite field of view is filled by tropical and sub-tropical areas.

4. Validation with SEVIRI radiances

Four hundred and fifty-seven clear-sky radiosondes in August 2006 over land are collected for evaluating the new scheme. Co-located SEVIRI observations are averaged

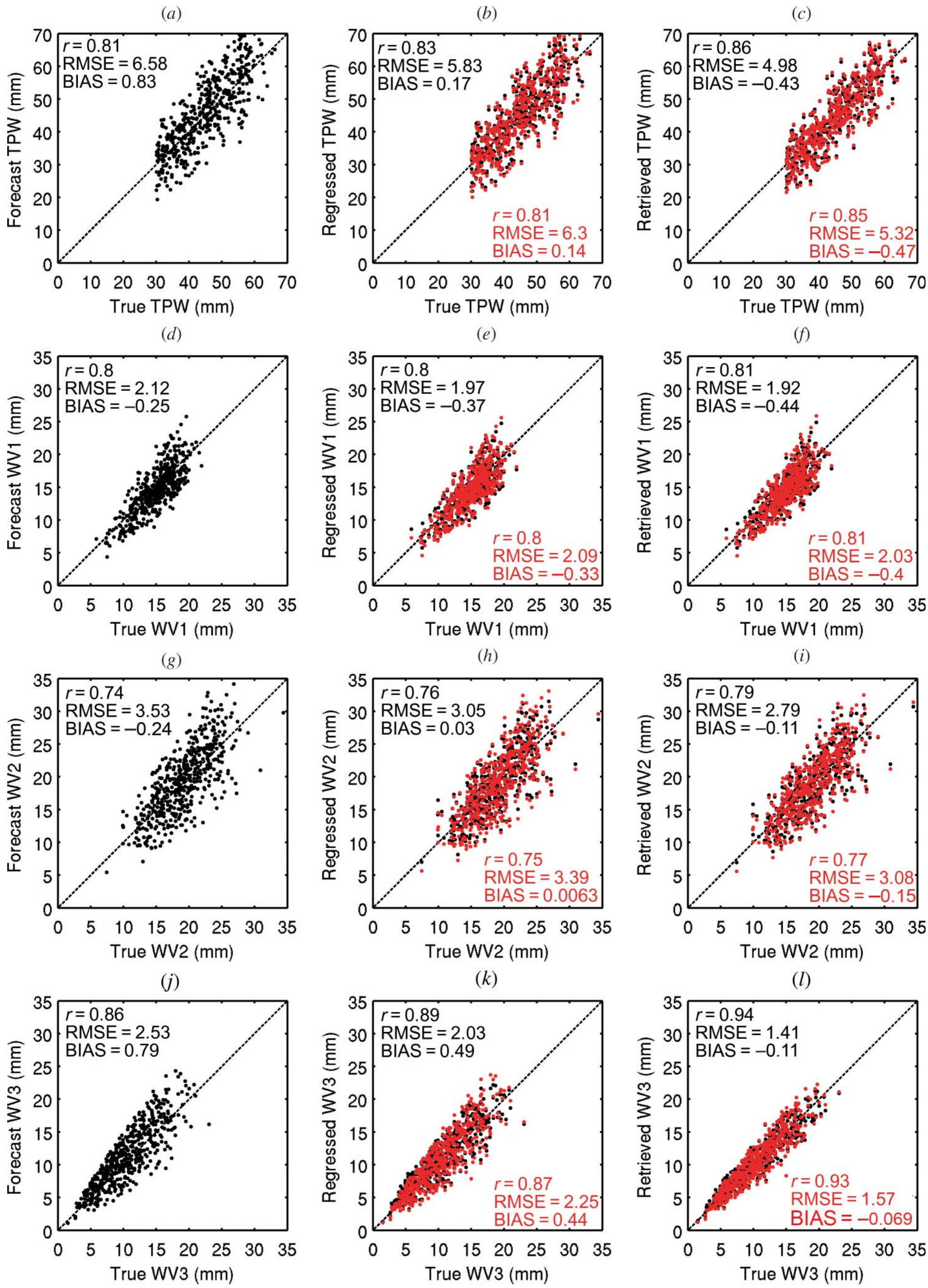

Figure 3. Scattering plots of total precipitable water (TPW) and its three components: WV1/WV2/WV3 (integrated water vapour between surface and 900 hPa, between 900 and 700 hPa and between 700 and 300 hPa, respectively) retrieved by the new (black) and old (red) regression schemes against the true. Panels in the left (*a*, *d*, *g* and *j*) are 'forecast' against 'true', panels in the middle (*b*, *e*, *h* and *k*) are 'regression' against 'true' and panels in the right (*c*, *f*, *i* and *l*) are the physically 'retrieved' against 'true'. In each panel, *r* is the correlation coefficient, RMSE is the root mean square error and BIAS is the mean bias.

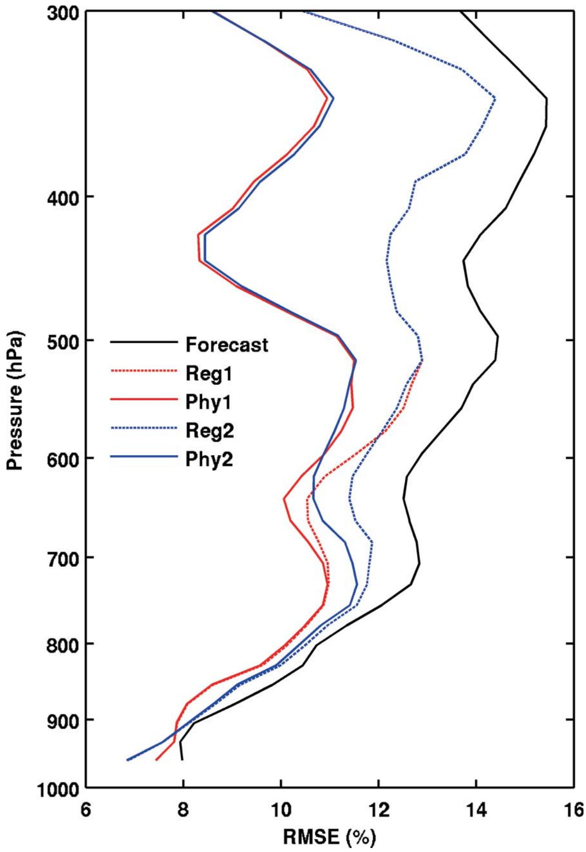

Figure 4. The root mean square error (RMSE) of forecast (black) regressed (colour dashed lines) and physically retrieved (colour solid lines) moisture profiles but using real data.

from clear pixels within each 3 × 3 box. The cloud mask product from the European Organisation for the Exploitation of Meteorological Satellites is used to find clear-sky pixels. The European Centre for Medium-Range Weather Forecasts' 12-hour forecast profiles are used. Figures 4 and 5 are same as figures 2 and 3, respectively, but using real data. The RMSE of retrieved profile below 500 hPa is decently reduced because of the high quality of first guess by the new scheme (figure 4). The TPW retrieval is also improved compared with the old scheme (figure 5). Because most of the samples are located in European areas where humidity is not very high, the improvements shown in figures 4 and 5 are still conservative. More improvements can be expected if this method is applied to IR radiances observed from lower latitude areas.

5. Conclusive remarks

In this letter, an improved scheme of moisture profile first guess for physical retrieval using broadband IR radiances is presented and evaluated by both simulated and real SEVIRI data. Because the wild variation of moisture predictors at high temperature (>273 K) is better treated than a uniform logarithmic form in the linear regression, the new scheme demonstrates its superiority at low-level (below 550 hPa) moisture

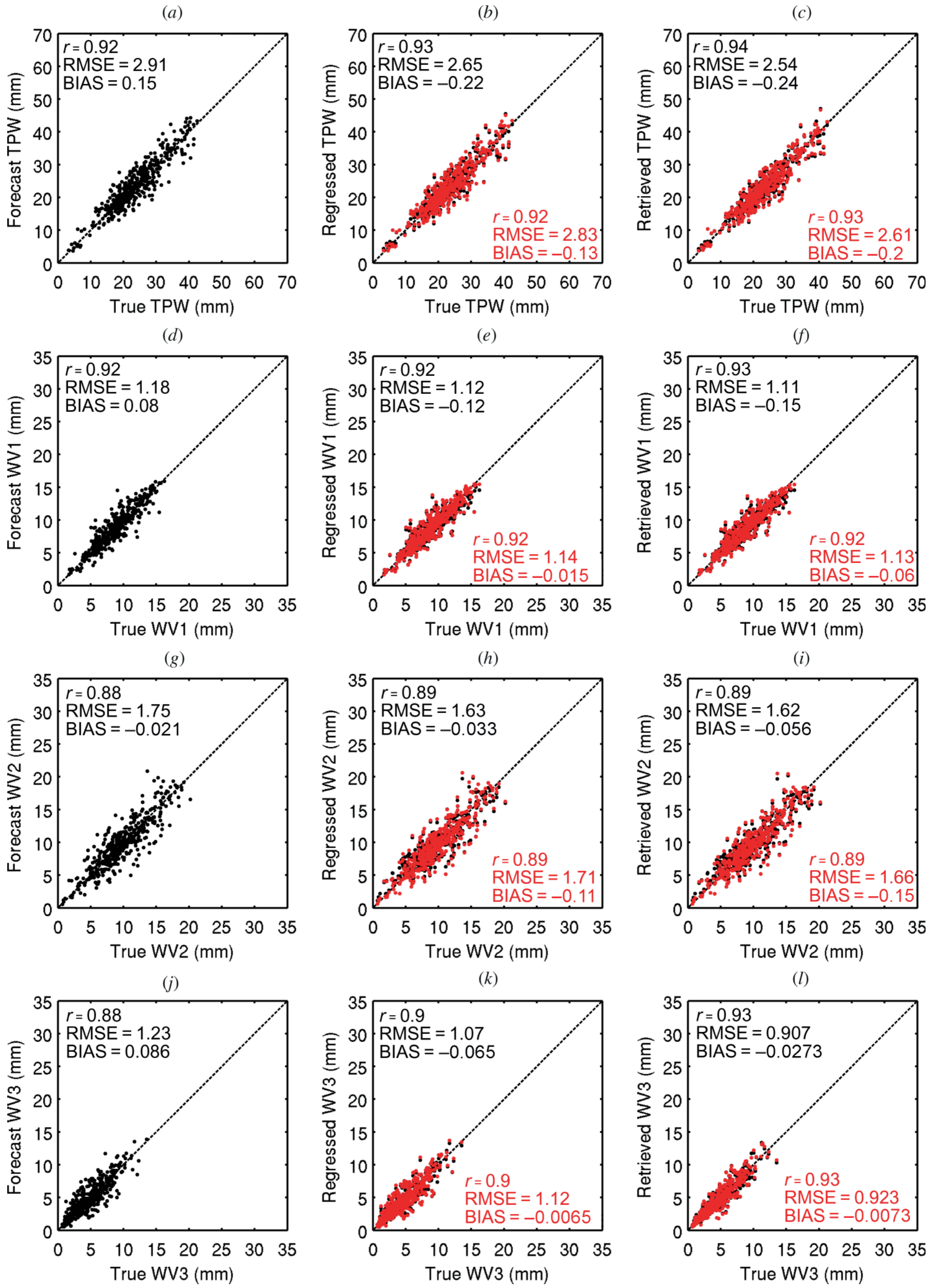

Figure 5. Scattering plots of total precipitable water (TPW) and its three components: WV1/WV2/WV3 (integrated water vapour between surface and 900 hPa, between 900 and 700 hPa and between 700 and 300 hPa, respectively) retrieved by the new (black) and old (red) regression schemes against the true. Panels in the left (*a*, *d*, *g* and *j*) are 'forecast' against 'true', panels in the middle (*b*, *e*, *h* and *k*) are 'regression' against 'true' and panels in the right (*c*, *f*, *i* and *l*) are the physically 'retrieved' against 'true'. In each panel, *r* is the correlation coefficient, RMSE is the root mean square error and BIAS is the mean bias but using real data.

profile retrieval. This feature indicates that the new scheme is particularly suitable for geostationary satellite remote sensing as most of the field of view is filled by warm and humid area.

Acknowledgement
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