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Validation of a cirrus parameterization with Meteosat Second Generation observations

Jean-Pierre Choubeureau¹ and Jean-Pierre Pinty¹

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[1] A brightness temperature difference (BTD) technique is used to constrain the ice to snow autoconversion threshold, a tunable parameter of a bulk microphysical cloud scheme in a regional meteorological model. The technique based on a contrasted absorption property of ice crystals at two wavelengths within the atmospheric infrared window is applied to 3-hourly Meteosat Second Generation (MSG) observations in the 8.7- and 10.8- μm bands over southern Brazil. The cirrus coverage presents a diurnal cycle associated with tropical deep convection peaking at 1800 local solar time (LST). A similar signal is obtained from the regional model when the ice to snow autoconversion threshold is reevaluated using the BTD data. The improved diurnal cycle furthermore better captures the observed upper-tropospheric humidity (UTH) maximum that lags the cirrus cover by 12 hours.

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1. Introduction

[2] Cirrus clouds, covering more than 30% of the globe, play a major role in the earth's radiative budget. Their complex microphysics associated with a variety of ice crystals make their radiative impacts still uncertain [e.g., Kristjánsson *et al.*, 2000]. About half of the tropical cirrus are originated from deep convection [Comstock and Jakob, 2004] by detrainments of condensates formed in cumulus and mesoscale updrafts to the anvils. Tropical cirrus can last more than one day and can be advected over distances larger than the grid box of current general circulation models (GCM). Thus, a modeling of cirrus requires a prognostic equation with a convective source and a horizontal transport term. This combination makes its representation as a subgrid-scale process difficult.

[3] The accuracy of satellite data themselves is too low to directly constrain the models as pointed out by [Zhang *et al.*, 2005] in reporting a four-fold difference in high cloud occurrence between 10 GCMs, for example. The difficulty may be overcome by adopting a model-to-satellite approach, in which satellite brightness temperature (BT) images are directly compared to BTs computed from predicted model fields. This approach is especially powerful in identifying discrepancies of cloud cover forecasts [Choubeureau *et al.*, 2002]. The present paper shows how

a BTD technique associated with the model-to-satellite approach can constrain a critical parameter in a bulk cloud scheme.

[4] The BTD technique is often used for examining microphysical properties of cirrus clouds, such as the size, shape and orientation of ice crystals [e.g., Inoue, 1985]. The technique is based on a contrasted absorption property of ice crystals at two channels located within the atmospheric infrared window. More specifically, brightness temperature difference (BTD) between the 8.7- and 10.8- μm bands tends to be positive for ice clouds that have infrared optical thickness greater than 0.5 [Baum *et al.*, 2003]. This information obtained from Meteosat Second Generation (MSG) is used here for the first time to evaluate a time series of cirrus cover forecasts.

[5] The BTD technique is applied to daily forecasts performed during the Tropical Convection, Cirrus and Nitrogen Oxides (TROCCINOX) experiment. After the first campaign in February–March 2004, an evaluation of the model forecasts was conducted using GOES infrared imagery. This evaluation led us to include a subgrid cloud scheme in the model [Choubeureau and Bechtold, 2005]. During the second campaign in January–February 2005, MSG observations were available in near real time, allowing us to test the BTD technique. Here, instead of inferring microphysical properties more directly, BTD was adopted as a proxy for cirrus clouds as in the work by Roskovensky and Liou [2003]. The overestimation of the cirrus cover found during the course of the campaign leads us to rerun the model and to perform an additional set of simulations but with a modified microphysical scheme. Section 2 presents the model and the satellite observations. Section 3 provides an analysis of the cirrus cover and discusses the diurnal cycle of various components of the tropical convection. Section 4 concludes the study.

2. Model and Satellite Observations

[6] The Meso-NH model [Lafore *et al.*, 1998] is adopted as a non-hydrostatic regional model. The vertical grid spacing in the free troposphere is set to 600 m with the horizontal grid spacing 30 km. The model includes a 1.5-order turbulence scheme, an interactive radiation and a prognostic microphysical scheme for 5 precipitating and non-precipitating liquid and solid water categories [Pinty and Jabouille, 1998]. The model includes a parameterization for shallow and deep subgrid-scale convective transport and precipitation [Bechtold *et al.*, 2001]. Subgrid cloud cover and condensate content are parameterized as a function of the normalized saturation deficit by taking into account both turbulent and convective contributions [Choubeureau and Bechtold, 2005].

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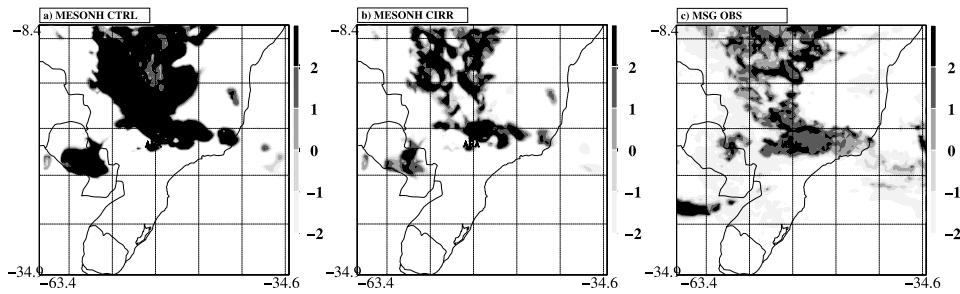


Figure 1. BTD (K) between 8.7 and 10.8 μm bands at 2100 UTC 4 February 2005 (1800 LST) obtained from (a) the CTRL simulations, (b) the CIRR simulations, and (c) the MSG observations.

[7] The present TROCCINOX simulations were performed for tropical conditions at a relatively low resolution (30 km). Thus, the deep convection scheme was essential in reproducing convective clouds and the associated vertical transport. Cloud ice are detrained from parameterized deep convection at high altitudes (above 8 km), whose subsequent evolution is predicted by the microphysical scheme. The detrained condensate is made of non-precipitating pristine ice (with a mixing ratio r_i). The microphysical evolution of cirrus-like clouds, as seen at the resolved scale, is governed by the deposition of water vapor and the autoconversion of the small ice crystals to precipitating snow, which further depletes the pristine ice crystals by aggregation during the snow fall. The formation of snow by autoconversion is dictated by the deposition growth of selective large crystals [Harrington *et al.*, 1995]. Here, as in other numerous models [e.g., Fowler *et al.*, 1996; Hong *et al.*, 2004], this process is parameterized by a Kessler-type scheme, originally developed for the coalescence of cloud droplets, mostly for simplicity. Thus, the autoconversion rate is given by:

$$R_{iauts} = k_{is} \max(0, r_i - r_i^*). \quad (1)$$

[8] The autoconversion is activated only when r_i is greater than the critical pristine ice mixing ratio r_i^* , and it is dictated by the inverse timescale $k_{is} = 10^{-3} \exp[0.015 \times (T - 273.16)]$. Clearly r_i^* , along with k_{is} , is a key parameter in defining ice cloud cover: a high (low) value may lead to an excessive (underestimated) cirrus sheets. In the current model version, an assigned value is $r_i^* = 2 \times 10^{-5} \text{ kg kg}^{-1}$ as deduced from an extended thick cloud regime over Atlantic [Chaboureau *et al.*, 2002].

[9] A wide range of values for r_i^* is found in the literature, ranging from $1.8 \times 10^{-4} \text{ kg kg}^{-1}$ [Hong *et al.*, 2004] to $1 \times 10^{-5} \text{ kg kg}^{-1}$ [Fowler *et al.*, 1996]. Thus, in order to apply the formulation to several ice cloud types Ryan [2000] parameterizes r_i^* as a function of the air temperature, T . This suggestion may be incorporated into the original model setting as an adjustment for low temperature limits, which leads to:

$$r_i^* = \min\left(2 \times 10^{-5}, 10^{0.06 \times (T - 273.16) - 3.5}\right). \quad (2)$$

[10] This parameterization is believed to be better for controlling thin cold cirrus sheets, in which ice content decreases with temperature [Wang and Sassen, 2002].

Equation (2) is tested through a regional climatological study of cloud systems observed during TROCCINOX-2. During this campaign, from 27 January to 24 February 2005, a total of 28 daily 48-hour (CTRL) forecasts were run over a domain of $3000 \text{ km} \times 3000 \text{ km}$ covering São Paulo State of Brazil. The individual forecasts were initialized with 12-h ECMWF forecasts based on the 1200 UTC ECMWF analyses. The initial and boundary conditions of the numerical experiments are provided for the horizontal wind, the temperature, and the water vapor. Clouds are not initialized, so the mixing ratios of the liquid and ice water species build themselves during the course of the simulations. The control (CTRL) runs were performed using the standard constant value for r_i^* , whereas additional simulations (CIRR) were run using equation (2).

[11] Brightness temperatures (BT) corresponding to the MSG observations are computed using the Radiative Transfer for Tiros Operational Vertical Sounder (RTTOV) code version 8.5 [Saunders *et al.*, 2005]. Hexagonal columns are assumed with radiative properties taken from Baran and Francis [2004] and with an effective dimension diagnosed from the ice water content [McFarquhar *et al.*, 2003]. The surface emissivity is given by the Ecoclimap database but without dependence on the wavelength [Masson *et al.*, 2003]. The Moderate Resolution Imaging Spectroradiometer (MODIS) data suggest differences of emissivity up to $\pm 3\%$ (not shown). Also, MSG viewing angles are large over southern Brazil, where the RTTOV limit angle of 63.6° is reached. As a result, spectral and angular effects lead to a BT bias, roughly estimated to 2 K. This constant is removed when computing BTDs from the simulation series.

3. Results

[12] The BTD technique is illustrated at 2100 UTC 4 February 2005, the “golden day” of the TROCCINOX-2 campaign. Observed positive BTDs roughly correspond to the locations of the deep convective systems (Figure 1c). BTD larger than 1 K found at the cloud borders are interpreted as the anvils of convective outflows. Figures 1a and 1b present the BTD images resulting from the CTRL and CIRR simulations after 21 h of model run. Simulated BTD fields larger than 1 K are present in the same locations, suggesting a good forecast capacity of the model. However, BTD from the CTRL image are clearly excessive resulting in a correlation coefficient of 0.57 with the observations. In contrast, the differences between the observations and the CIRR simulation are significantly lower. Areas with BTDs

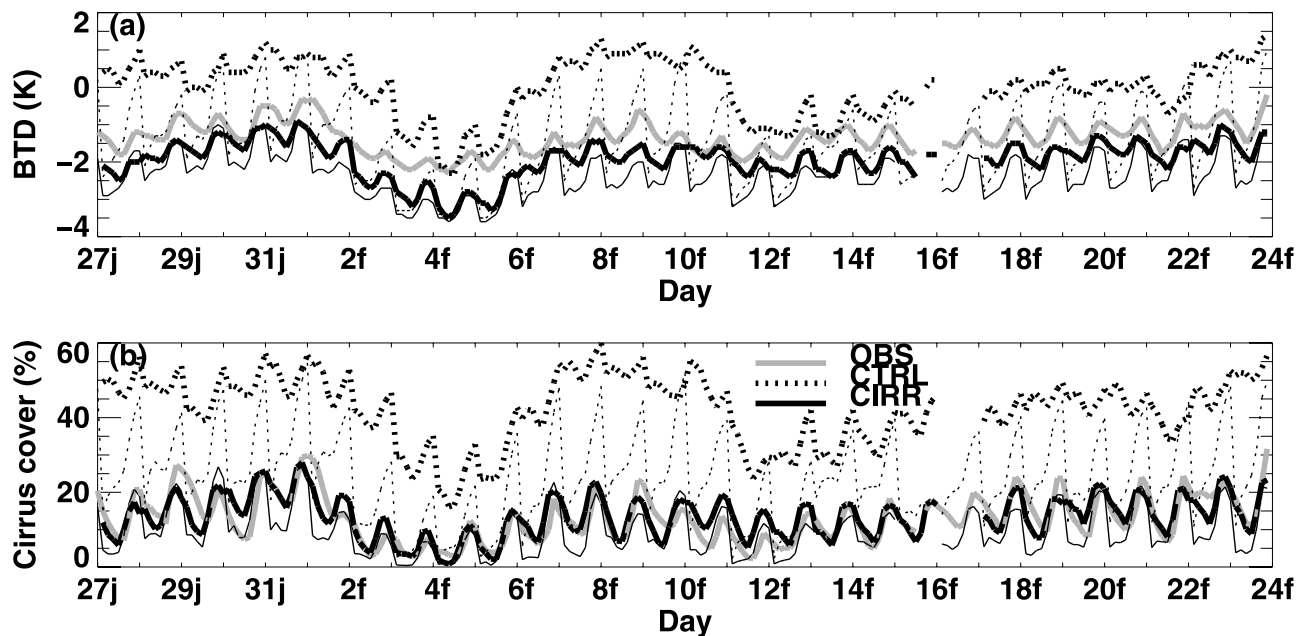


Figure 2. Time evolution of BTD (K) between $8.7 \mu\text{m}$ and $10.8 \mu\text{m}$ bands obtained from the observations (grey line), the CTRL (dotted line), and the CIRR (solid line) simulations: (a) BTD averaged over the domain, (b) the percentage of gridpoints within the domain simulation with BTD larger than 1 K. Results from the 3–24 h (27–48 h) forecasts are displayed with thin (thick) lines. The time axis is indicated by the day; j, January; f, February.

larger than 1 K are comparable to those observed. A correlation coefficient is increased to 0.63.

[13] The BTM technique applied to the MSG observations also allows us to monitor the cirrus cover in near real time during the campaign (Figure 2a). Observed BTM averaged over the domain presents a diurnal cycle superimposed on a lower frequency variability. The weather passed three regimes during the campaign. During the first regime from January 27 to February 1, the south Atlantic convergence zone is placed over the São Paulo state. It is followed by the second regime with less organized convection lasted until February 15. Finally the circulation is characterized by southernward frontal incursions during the last regime. The simulations mimic this low-frequency variability reasonably well.

[14] However, the CTRL simulation presents a BTM increasing dramatically with the forecast time. In contrast, the diurnal amplitude of the BTM in the CIRR simulations is much lower, without noticeably increasing with the forecast time. The cirrus cover over the domain is deduced from the BTM fields by taking an arbitrary threshold of 1 K (Figure 2b). The cirrus cover oscillates between 5 and 25% in the observations. The CTRL simulations greatly overestimate this value with a maximum greater than 60%. The CIRR simulations find the cirrus cover less ubiquitous with good matches for both first-day (thin-solid) and second-day (thick-solid) forecasts.

[15] Further statistics are obtained by averaging all the CTRL and CIRR simulations over the 48-h forecast cycle and the observations over a diurnal cycle (Figure 3). Figure 3a compares the (mostly convective) simulated precipitation rates to the Tropical Rainfall Measurement Mission (TRMM) 3B42 product. Both simulations and observations present a clear diurnal cycle, with a maximum of around 10 mm day^{-1} at 1500 LST (1800 UTC). A similar

signal is observed over the whole tropical land by [Tian *et al.*, 2004]. The afternoon convective peak is followed by a maximum of cirrus cover about 3 hours later in the observations (Figure 3b). Both phase and magnitude of the CIRR cirrus cover cycle compare favorably with the observations while that of CTRL is definitely out of scale. Finally, the mean clear-sky BT at $6.2 \mu\text{m}$ is converted into upper-tropospheric humidity (UTH) following Tian *et al.* [2004] (Figure 3c). The maximum of UTH is observed at 0600 LST, with a 12-h phase lag with the cirrus cover, in agreement with Tian *et al.* [2004]. Apart from the 5% bias, the amplitude of the CIRR UTH cycle (2%) corresponds well to the observed UTH. Furthermore, in contrast to CTRL, the CIRR UTH contains no dry trend. This shows that moistening of the upper-troposphere associated with a decay of cirrus is better reproduced by the model when a portion of ice crystals grown by deposition precipitates out as snow particles.

4. Conclusion

[16] A BTM technique is applied to MSG observations between the 8.7- and $10.8\text{-}\mu\text{m}$ bands in order to monitor the cirrus cover during the TROCCINOX-2 campaign. When it is combined with the model-to-satellite approach, the BTM technique gives a specific constraint to the ice to snow autoconversion threshold of the microphysical scheme in the mesoscale model Meso-NH, as used here for forecasts at regional scales. Moreover, the model result shows a positive impact on a cirrus cloud cover in the simulated diurnal cycle of tropical deep convection.

[17] In near future, the BTM technique coupled with lidar observation from space will give further constraints on cloud models as shown by Chiriaco *et al.* [2004]. Furthermore, the next generation of operational models will operate with

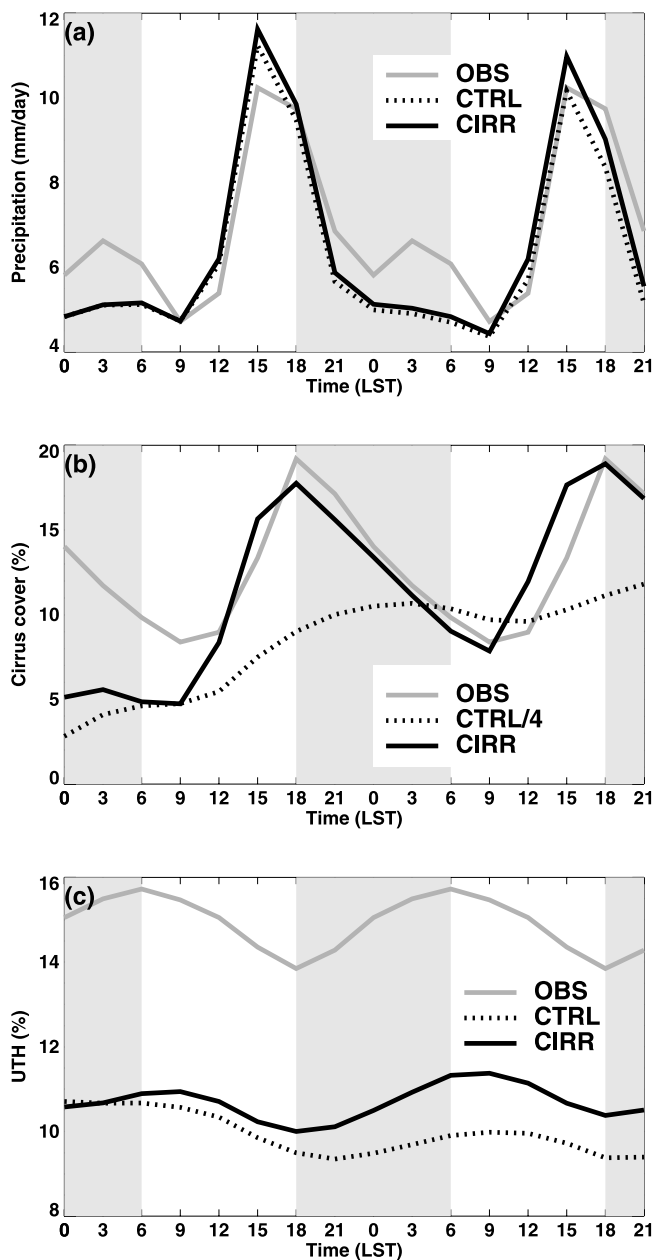


Figure 3. Bi-diurnal cycle of (a) precipitation (mm day^{-1}), (b) cirrus cover (%), and (c) UTH (%) from the observations (repeated twice; grey line) and the 3–48 hour forecasts with the CTRL (dotted) and CIRR (solid) simulations. In Figure 3b, the CTRL cirrus cover is divided by a factor of 4.

explicit bulk cloud schemes to be run at mesoscale with typical grid size of a few kilometers. A systematic evaluation with MSG observations, up to every 15 minutes, by the present approach would lead to substantial progress in cirrus modelings. Finally, this approach also offers guidances to climate models for introducing more sophisticated microphysical schemes in carrying out the water vapor budgets.

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