Impact of the FTH on the clear-sky OLR in the intertropical belt: observations and climate models.

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Abstract

The Free Tropospheric Humidity (FTH) is a key parameter in climate studies. In intertropical regions, it strongly modulates the Clear-sky Outgoing Longwave Radiation (OLRc).

To quantify this radiative impact of this field, a simplified OLRc model was developed for the tropics and validated from the CERES and METEOSAT data.

The construction of this physical and statistical model is based on a classical analytical approach of OLRc enriched with spectral sensitivities studies. It connects the OLR, the FTH and the surface temperature (TS) for the clear sky night-time scenes.

Using this model, the sensitivity of OLRc to the FTH fields at inter-annual time scales is first quickly presented for recent period. Some areas of high sensitivity of OLRc to temporal variability of FTH are identified, whereas the synthetic radiative field is practically insensitive to the variability of TS.

The performance of two global climate models in their reproduction of FTH is presented by performing the same sensitivity experiments. These models represent adequately the variability of FTH and OLRc fields at time scales studied previously.

INTRODUCTION

Tropospheric water vapor plays an important role in climate studies due to a strong positive feedback (Held and Soden, 2000, Sherwood et al, 2009, Allan, 2012). This study focuses on radiative aspects to better understand this feedback, mainly in the infra-red domain.

The intertropical regions are characterized by extended minima of relative humidity above the boundary layer between 800 and 200 hPa.

This free tropospheric humidity, called FTH, is a key parameter for the tropical climate analysis, mainly due to its strong non-linear relationship with the Outgoing Long wave Radiation (OLR).

Modtran simulations (Bernstein et al. 1996; Berk et al. 2000) was performed for a clear sky tropical profile with different values of FTH (Roca et al., 2012). When FTH increases from 1 to 15%, OLR decreases by 23 W/m², while OLR's decreasing is only of 8 W/m² for a moistening from 35% to 50%.

The radiative effect of an increase of FTH is 3 times more important for dry air than for moist conditions.

A SIMPLIFIED MODEL TO COMPUTE CLEAR-SKY OLR

A simplified model of the clear-sky OLR (called OLRc) was built to more easily understand the joint OLR and FTH variability. The OLRc was computed only from the surface temperature (Ts) and from FTH by a bi-linear regression method as follows:

\[ OLRc = aT_s^4 + b \ln(FTH) + c \]  (1)

a, b, c are the bi-linear regression coefficients. The effect of others eventual parameters are included in a residuals term (c).

The first term of equation (1) corresponds to the surface contribution and the second one to the atmospheric contribution to OLRc.
However, this decomposition of two main terms also can be viewed as a spectral separation. Roca et al (2012) showed a spectral decomposition of the OLR sensitivities from MODTRAN simulations of tropical conditions. When only the surface temperature is increased arbitrarily, the OLRc anomalies in the window (8-12µm) are more than 3 times larger than in the other spectral region. When only FTH is increased, the spectral response is more complicated, depending on dry or moist case, but the OLRc in the vibration-rotation band and the Far Infra Red regions are also strongly modified.

The estimation of the a, b, c coefficients is performed with a bilinear regression using colocated satellite data for JJA months from 2002 and 2003.

OLR and Surface Temperatures were estimated with instantaneous SSF CERES (2B edition, FM4/AQUA) data (Geier et al., 2001). FTH was estimated with the algorithm described in Brogniez (2009), from METEOSAT water vapor channel, at the nominal position and over Indian Ocean. These data were colocated in space-time intervals of 1° and 1 hour.

![Figure 1: Scatterplots for 2002-2003 JJA between the CERES measured OLRc and the fitted OLRc during the night for oceans (left), deserts (middle) and non-desert land areas (right)](image)

Bi-linear regressions were performed for three types of surface: ocean, desert and non-desert land areas. The figure 1 presents the comparison between the estimated OLRc as in (1), and the CERES OLRc.

In nighttime scenes, the statistics are satisfying with a relatively weak RMS (about 5 or 6 W/m²) and a high correlation ($R^2$ above or equal to 0.7).

During the day the results (not presented here) are more scattered especially for deserts. This is probably due to a stronger diurnal variability in low levels and also to the difficulty to soil emissivity estimates.

CLIMATOLOGY OF OLR

![Figure 2: DJF (left) and JJA (right) averages of night time OLRc (estimation from 1984-2004 FTH)](image)
The two-parameter model (1) was applied to long time series data sets, in order to explore the interannual and intraseasonal variability.

The figure 2 shows the winter and summer averages of OLRc, calculated as in (1) and using the nominal METEOSAT FTH archive (Picon et al, 2003; Brogniez et al. 2006; Brogniez et al. 2009; Roca et al. 2012), and the ERA-I (Dee et al., 2011) reanalyzed surface temperatures from 1984 until 2004. The left panel of the figure 2 shows the boreal winter average of nighttime OLRc which presents minima over North Africa and maxima over tropical oceans.

For the boreal summer, (Fig. 2.right) the OLRc average presents minima in the ITCZ and maxima over the Eastern Mediterranean and over the Southern Atlantic.

The variances and others statistical moments was also studied but not presented here.

The climate models are essential tools for the climate understanding. They have to well represent in the best way not only the mean radiative fields but also the processes that explain the OLRc variability. For this, the FTH/OLR link has to be also evaluated in climate models. For this preliminary study, three present climate simulations were analyzed: two AMIP runs of, respectively, GISS and IPSL models (IPSL-CM5A-LR et NASA-GISS-ER), with fixed sea surface temperature and a CMIP5 run of the coupled IPSL model (Taylor et al, 2012).

Figure 3: Present Climate simulations of FTH (in %) : AMIP/GISS(left), CMIP5/IPSL (middle), METEOSAT observations (right) – JJA 20 years average .

Synthetic FTH fields were first computed using the RTTOV7 (Matricardi et al, 2004) radiative transfer tool and the temperature and humidity model profiles. Figure 3 shows the comparisons between the METEOSAT FTH climatology and the simulated FTH over about two recent decades for the boreal summer.

The maxima occur over the ITCZ and the minima are located in the subtropics areas.

Figure 4: Present Climate simulations of OLRc (in W/m²) : AMIP/GISS(a), AMIP/IPSL (b), CMIP5/IPSL (c) – JJA 20 years average
The simulated OLRc can be estimated with the same relation (1) as previously, using one profile per night yielding the FTH and TS values. As shown in Figure 4, the three simulated fields are very close. The GISS simulation (Fig 4.left) shows a stronger OLR over land, perhaps due to higher values of land surface temperatures.

**OLR SENSITIVITY EXPERIMENTS TO FTH**

To analyze the OLR variability, sensitivity experiments to Ts and FTH were performed. Only the sensitivity to FTH is discussed here, the Ts sensitivity being very weak at nighttime (R. Guzman, 2012). First, OLRc fields were computed with the whole FTH variability. Then, the FTH time series is replaced by its climatologic mean for the same period. Finally, the OLR differences without and with FTH variability were analyzed.

*Figure 5: Differences of OLRc without and with FTH variability (Wm⁻²)- From 1984-2004 JJA observed fields.*

From the observations (Figure 5), the OLRc anomalies are everywhere negative, indicating that the OLR is weaker when the FTH variability is suppressed. The more sensible areas do not exactly correspond to the driest regions.

The distributions of FTH were analyzed for different values of OLRc anomalies. Two regimes can be identified: the strong OLR differences areas correspond to very asymmetric distribution of FTH, while the weaker OLR anomalies areas correspond to a relatively symmetric FTH PDF.

In the more sensitive areas, the FTH average is not a precise indicator of the OLR sensitivity because the non Gaussian distribution of the FTH fields and due to the strong non-linearity of the OLR/FTH relationship.

The same method was applied to the simulations of the present climate.

The simulated OLRc anomalies (Figure 6) are everywhere negative and present the same magnitude as the observations. The results of the two simulations are similar. However, the GISS/AMIP simulation presents slightly more important OLR anomalies.

*Figure 6: Simulations of OLRc anomalies for AMIP/GISS run (9-a) and for IPSL/CMIP5 run (9-b): Units: Wm⁻²*
CONCLUSIONS

A model was built to compute the clear-sky nighttime OLR. The night OLRc fields can be well reconstructed from two parameters: TS and FTH. A spectral analysis showed that the surface temperature variations explain a great part of the radiative anomalies in the atmospheric window region. In other IR regions, the FTH seems to be the most influential factor. The radiative role of the FTH variability was studied with "FTH sensitivity experiments". Two regimes are identified from 20 years observations:
- the dry regions associated with strong OLR sensitivity present asymmetric FTH distributions.
- the more humid regions with more symmetric FTH distributions present a less OLR sensitivity.

Simulations of present climate show a relevant representation of the OLR sensitivity to FTH, as well as a relatively realistic FTH distribution.

These realistic assessments encourage us to continue our analysis of links FTH / OLRc for climate change simulations.

REFERENCES:


