RELATIONSHIP BETWEEN MONTHLY MEAN WATER VAPOUR WIND FIELDS AND THE UPPER TROPOSPHERIC HUMIDITY

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ABSTRACT

The paper describes first results of a pilot study investigating the relationship between the monthly mean fields of wind and humidity in the upper troposphere. The wind fields are derived from successive METEOSAT images in the water vapour channel (WV: 5.7 - 7.1 μm) and the upper tropospheric relative humidity (UTH) is inferred from water vapour image data with a physical retrieval scheme.

Quantitative information on the large scale circulation in the upper troposphere can be derived from WV wind fields, since the WV wind vectors are numerous enough to provide a dense spatial coverage, and thus clearly depict the atmospheric flow in the upper troposphere. The monthly mean wind field of January 1992 is employed to estimate the large scale divergence; values are within a range of about $-5 \cdot 10^{-6}\ s^{-1}$ and $5 \cdot 10^{-6}\ s^{-1}$ for a scale of about 1500 km.

The spatial pattern ofthe UTH field closely resembles the divergence of the wind field suggesting that the UTH fields are principally determined by the large scale circulation.

1. Introduction

The water vapour channel of the Meteosat satellites is routinely used for extracting wind fields and the upper tropospheric humidity. Both products are operationally available to users via the Global Telecommunication System (GTS). Apart from the use of both products for numerical weather prediction and model validation it has become evident that they constitute an important source of climatological information. The unique feature of such climatologies is that they are entirely based on large scale observations from a single observing system and, therefore, may serve as truly independent data sets for comparisons with amalgamated climatologies from numerical analyses or other data.

The utility of UTH satellite observations for deriving climatologies (van de Berg et al., 1991, Wu et al., 1993) for comparison with models (Rind et al.,1991; Stephens et al., 1993; Soden and Bretherton, 1993; Schmetz and van de Berg, 1994) has already been demonstrated. The comparisons revealed signficant differences between satellite observations of the UTH and the fields in general circulation models. The importance of an adequate UTH climatology has also been amplified in recent studies on the role of water vapour as the prime greenhouse gas (e.g. Stephens and Greenwald, 1991).

Figure 1 illustrates that all altitude levels of the water vapor profile are important to the water vapor greenhouse effect. A radiative transfer model has been employed to compute the change of the outgoing longwave radiative flux (OLR in Wm^{-2}) at the top of the atmosphere as a function of perturbations of the vertical water vapor profile. The pertubations have been performed on a standard tropical profile at 1, 3, 5, 7, 11, and 13 km altitude, respectively. The sensitivity is then expressed as the ratio of the OLR-change over the change in total precipitable water *PW*, i.e. as *d OLR / d PW*.

Figure 1 shows that this sensitivity varies from about -2.8 $Wm^{-2}/(g\ cm^{-2})$ for a humidity change at 1 km to about -1200 $Wm^{-2}/(g\ cm^{-2})$ for a perturbation at 13 km. That is to say, the greenhouse effectiveness of a single H_2O molecule rapidly increases with altitude. However, this greenhouse potential of a single H_2O molecule needs to be put in a perspective considering the exponential decrease of water vapor with height. A mixing ratio profile typical of a tropical atmosphere is shown in Figure 1 as a dashed curve. The combined effect is that the actual water vapor greenhouse potential in a tropical atmosphere is roughly constant up to an altitude of about 9 km with a minor maximum around 3 km, and a decrease above 9 km. The fact that tropospheric humidity fluctuations are higher between about 700 hPa and 300 hPa than nearer to the surface (e.g. Gutzler, 1992) corroborates the importance of separate observations of the upper tropspheric humidity in addition to low level or total precipitable water observations.

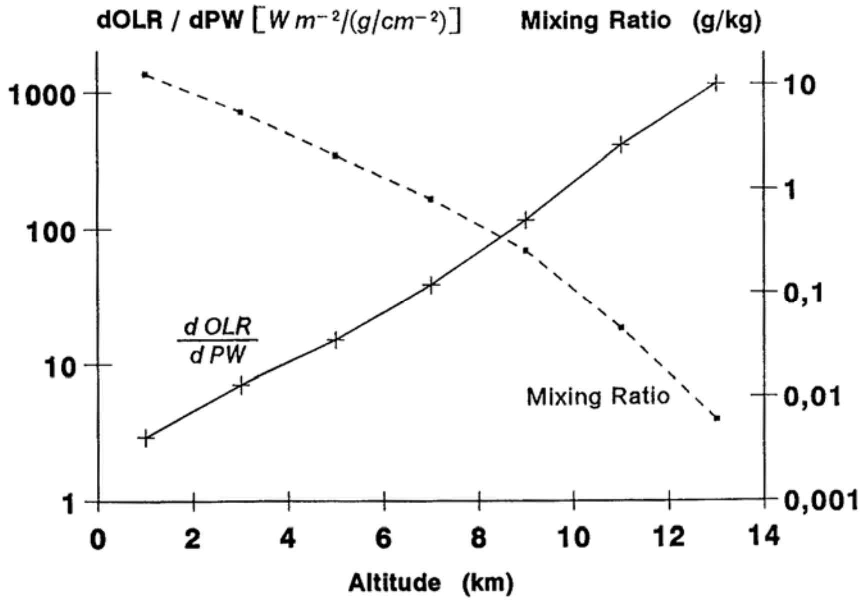

Figure 1. : Sensitivity of the outgoing longwave radiative flux density (OLR in $W\,m^{-2}$) to changes in the total column precipitable water (PW in $g\ cm^{-2}$). PW has been varied at different levels and the sensitivity is expressed as the derivative *d OLR / d PW* (note that values are negative). The dashed curve corresponds to the mixing ratio. The profile is characteristic of a tropical standard atmosphere.

Previous work by Picon and Desbois (1990) indicated that the upper tropospheric humidity field is chiefly determined by the large scale dynamics. Our clear-sky UTH climatology (van de Berg et al., 1991) corroborates this statement as the geographical distribution of monthly UTH fields are reminiscent of the patterns of the Hadley and Walker circulation. In this pilot study we go a step beyond the mere observation of the UTH and combine for the first time monthly mean UTH with large scale wind field observations.

2. Upper Tropospheric Humidity (UTH)

The UTH is inferred from the water vapor channel (WV: 5.7 - 7.1 μm) which has a spatial resolution of 5 km x 5 km. The WV-channel observes the Earth's atmosphere in a strong absorption band and is sensitive to about the upper 3 millimeters of total water vapor; that is, in a clear atmosphere, it typically sees down to a pressure level of 500 - 600 hPa. The exact height allocation of the broad contribution function depends on the

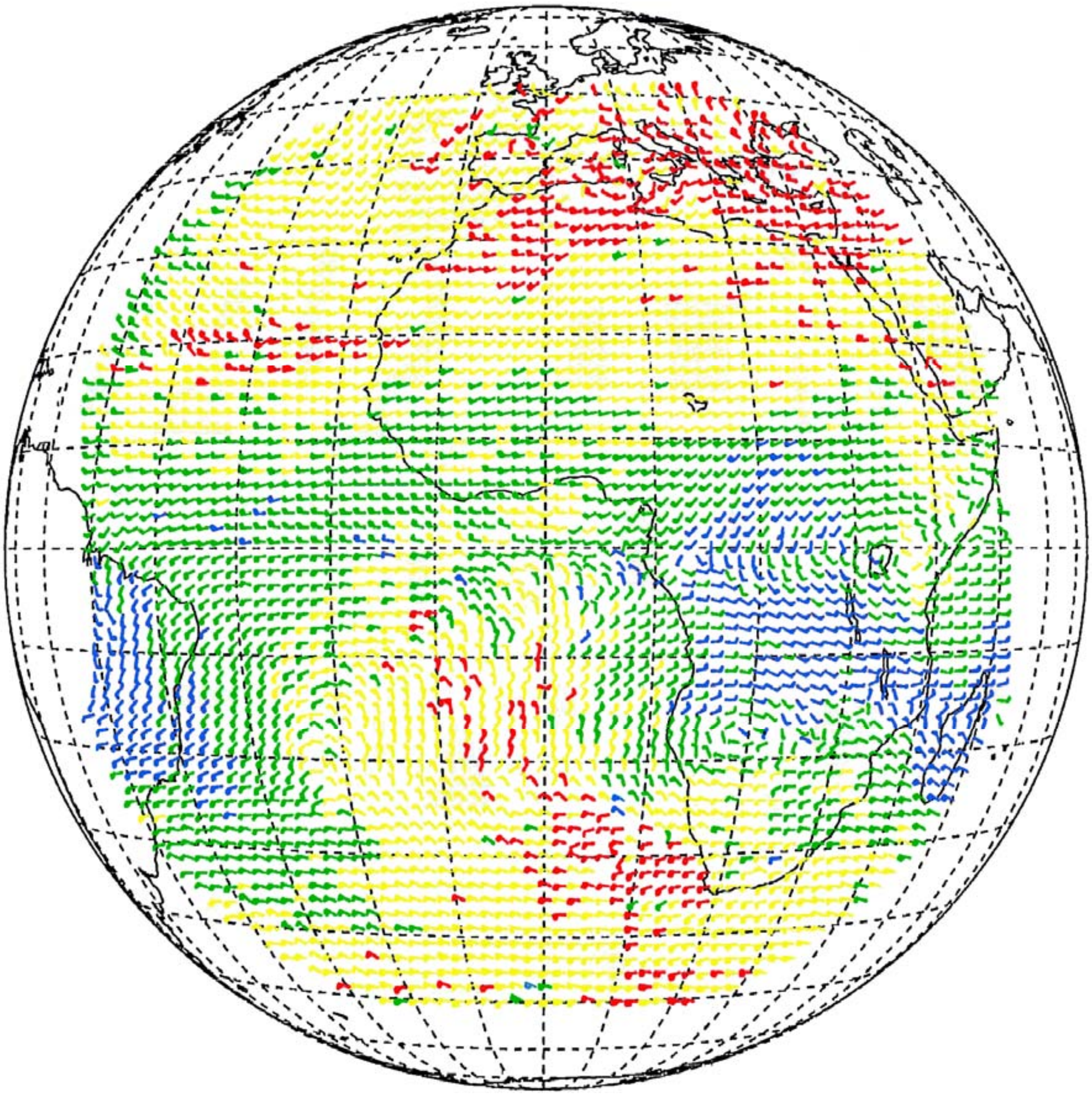

Figure 2. : Monthly mean wind field derived from the Meteosat water vapour channel for January 1992. Colours correspond to the monthly mean height allocation: red: > 350 hpa , yellow: (300, 350] hPa , green: (250,300] hPa , blue: ≤ 250*hpa*

actual profiles of temperature and humidity and the satellite viewing angle (Fischer et al., 1981). The UTH retrieval basically follows the method described by Schmetz and Turpeinen (1988). A significant change is that the retrieval via an interpolation table based on radiative forward calculations has been changed to an iterative scheme where the radiance calculations for a modified humidity profile are repeated until the calculated radiance agrees with the observed radiance.

The basis for this study is a clear-sky radiance data set obtained from a multispectral image classification for areas of 32x32 pixels. Two products per day (1200 and 0000 UTC) are used for computing monthly means of the UTH.

The operational calibration of the Meteosat WV channel is based on radiative transfer calculations with radiosonde profiles and collocated clear-sky WV raw radiances (Schmetz, 1989). It is important to note that a recalibration has been conducted for this study. The revised software yields lower calibration values (see Schmetz and van de Berg, 1994). A comprehensive recalibration campaign of the Meteosat WV channel has been started recently at ESOC and results will be reported in due course.

It should also be noted that the UTH climatology in this study follows a different concept than the study of van de Berg et al. (1991) who confined valid UTH retrievals to segment areas (32x32 pixels) that are free of medium and high level cloud. This ensured that the UTH is representative of the whole segment. Here we extend the retrieval to all clear-sky WV radiances including segments that are partially covered with high and medium level cloud.

Figure 3 shows the monthly mean UTH for January 1992. Highest relative humidities of about 60 to 70 % are observed over the tropical convective zone over South Africa and South America. Note that the relative humdidity values refer to water; at an altitude of 400 hPa the ratio of saturation pressure over ice to that over water is about 0.8.

An interesting feature of the high UTH area over South America is the bifurcation indicating areas of high water vapour transport in the upper troposphere over the North Atlantic in NE direction and over the South Atlantic in SE direction.

3. Monthly Mean Water Vapour Wind Fields

Water vapour winds are operationally prduced at ESOC four times per day. The method of deriving WV winds is described by Laurent (1993) and Holmlund (1994). For this work we use twice daily WV winds (0000 and 1200 UT) for January 1992 to form a monthly mean field by averaging over all wind vectors that are obtained in a given geographical location. The monthly mean height is also calculated by averaging over individual height assignments.

The spatial coverage with wind vectors from the WV channel is dense enough so that it well describes the atmospheric upper level flow, even for a single production cycle (see Figure 7 in Holmlund, 1994). The number of vectors disseminated for use in NWP is smaller since stringent quality control (symmetry and spatial consistency checks) are applied in order to enhance the utility of the WV vectors as single level winds. For a monthly mean field it is advantageous to be less stringent with quality control for the sake of an inreased number of wind vectors.

Nevertheless the number of vectors used to compute a monthly mean at a specific geographic location varies considerably. In cloudy regions more 30 - 50 values (out of 62) are available while in the subtropical subsidence regions the number of observations can be as low as five. The predominantly cloud-free areas with few wind vectors also correspond to areas with the lowest monthly mean altitude (see Figure 2).

Figure 3. : Monthly mean field of the upper tropospheric relative humidity (UTH) derived from the Meteosat water vapour channel for January 1992. Values are in percent and areas moister than 50% are hatched and areas drier than 20% are dotted.

Figure 4. : Monthly mean divergence of the upper tropospheric wind field calculated from Figure 2. A smoothing has been applied by a moving average over 9 by 9 values, which corresponds to an area of about 1500 x 1500 km. Regions with values less than $-5 \cdot 10^{-6}$ (convergence) are dotted and regions with a divergence higher than $5 \cdot 10^{-6}$ are hatched.

4. UTH and Wind Field Divergence

In a first attempt to associate the observed atmospheric circulation with the observed UTH, upper level divergence fields are computed from the monthly mean WV winds. The divergence calculations consider four neighbouring wind vectors following the method described by Davies-Jones (1993). In order to reduce the noise in the divergence field a running average over 9x9 segments, correponding to about 1500 km x 1500 km has been applied. More sophisticated filtering techniques are being developed by one of us (Carlos Geijo) and will provide much smoother fields.

The hatched areas in Figure 4 correspond upper tropospheric divergence with values higher than $5\cdot 10^{-6}$. Those areas should be associated with 'streams' of water vapour emerging from source regions of upper tropospheric moisture which are the deep convective areas. A comparison of Figures 3 and 4 shows that this is indeed the case; especially the bifurcation pattern in the UTH over South America is clearly depicted in the divergence field in Figure 4. This pattern also indicates large water vapour transport in the upper tropsphere. The dotted areas in Figure 4 correspond to upper tropospheric convergence ($\nabla\cdot\bar{v} < -5\cdot 10^{-6}$) over subtropical subsidence regions. The observed divergence appears quite reasonable as the following quick check illustrates: Assuming that the divergence takes place in a layer of about 150 hPa of depth one obtains a subsidence of about 60 hPa d^{-1} which closely corresponds to the observed subsidence in the trade wind regions (Augstein et al., 1973; Betts and Ridgway, 1989).

The congruence of the UTH and WV wind divergence patterns manifests a clear physical relationship between the two fields, which shows that the UTH is largely contolled by upper troposheric dynamics. However the results presented here remain qualitative mainly for the reason that the WV wind field does not represent a single level wind at a specific pressure level. Inspection of Figure 2 reveals that the monthly mean altitude of a WV wind ranges over about 200 hPa. Since wind speed and direction generally vary with height, the change of the monthly mean height could lead to spurious convergence/divergence patterns.

5. Concluding Remarks

Monthly mean fields of the upper tropopsheric relative humidity (UTH) and the water vapour wind field from Meteosat-4 WV have been analysed for January 1992. The fields provide a concise description of the upper tropspheric moisture and flow fields. It is suggested that both data sets are prime candidates for a climate monitoring system. The monitoring of both quantities will be possible on a nearly global basis since future geostationary satellites from China and Japan will also carry WV channels. A joint analysis of UTH and WV winds from the European Meteosat and the American GOES satellites is foreseen for March 1994. Data from Meteosat in its position at 0° latitude are already available for selected months since January 1992.

The comparison of the UTH and WV wind fields in this pilot study shows a close relationship indicating the control of atmospheric dynamics over the upper tropospheric moisture. Since upper tropospheric moisture is an important determinant of the atmospheric greenhouse effect (see Figure 1) the satellite observed data fields of UTH and WV wind fields will also be important for climate model validation. Most of the previous comparisons of climate models with observed moisture fields made use of total precipitable water observations over the oceans. Since low level moisture dominates precipitable water such comparisons do not validate the upper tropospheric moisture fields in models.

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