A quasi-global analysis of the mean relative humidity of the upper troposphere

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ABSTRACT

The meteorological satellite Tiros III measured the upwelling infrared radiation in the spectral intervals from 5.8 to 6.8 microns and from 8 to 13 microns simultaneously. According to a method developed by Möller (1962) and Raschke (1965) the relative humidity of the upper troposphere and surface temperature of the ground and/or of clouds were determined. Results for one day (July 12, 1961) are presented in a quasi-global distribution.

The mean relative humidity appears to be lower than 10 % in the subtropical anticyclones on both hemispheres, while it is higher than 60 % in the cloudy regions of the tropics and at higher latitudes.

Introduction

The Tiros III satellite carried a five-channel medium resolution radiometer for measurements of thermal radiation and reflected solar radiation emerging from the Earth and its atmosphere (Bandeen *et al.*, 1964). The measured values of the infrared radiation in the spectral region between 5.8–6.8 microns (channel 1), which covers the center of the 6.3 micron-band of water vapor, are a measure of the mean relative humidity of the upper troposphere between about 200 and 500 mb (Möller, 1962; Raschke, 1965). The radiation originating below 500 mb cannot penetrate the atmosphere. If clouds are present in layers above 500 mb, however, channel 1 also receives radiation emitted from their surfaces. Therefore other data are needed, which give information on the temperature of the cloud surface. These data are given by channel 2 of the five-channel radiometer, whose spectral response is between 8–13 microns, where atmospheric absorption is very weak.

Evaluation method

Möller (1962) developed a method, by which the relative humidity and the surface temperature are determined by comparing measurements by channel 1 and channel 2 with calculated intensities from model atmospheres. This method has been discussed in detail by Raschke (1965), and was used to determine the present results. A tropical atmosphere was used between 40 N and 40 S latitude, and the U.S. standard atmosphere was used poleward of 40 degrees. Some parameters of these models are summarized in Table 1.

The absorbing mass of water vapor has been determined assuming a constant relative humidity in the troposphere and a mean distribution derived by Gutnick (1962) for the stratosphere. Ozone profiles for tropical and middle latitudes were determined from the vertical cross-section of Paetzold & Piscalar (1961) and the carbon dioxide was assumed to have a constant mixing ratio of 0.03% by volume.

The largest uncertainties in the evaluation are due to the assumption of homogeneous cloud surfaces within the field of view of the radiometer. The cloud surfaces are assumed to have unit emissivity.

Since values in only two spectral regions are available, only two parameters in the model atmospheres can be varied: (1) the value of the relative humidity of the troposphere above the surface of the ground or clouds and (2) the temperature of the underlying surface.

All calculations of the infrared radiation intensities were performed with radiation diagrams which were constructed for the filter functions of both channels (Raschke, 1965).

Table 1. *Parameters of the temperature profiles used for calculations of the upward infrared radiation.*

	Tropical atmosphere	U.S. standard atmosphere
Temperature of the air adjacent to the ground	+35.0°C	+15.0°C
Temperature gradient ($-\partial T/\partial z$) in the troposphere	6.5°C/km	6.5°C/km
Temperature and height of the tropopause	−75.0°C at 16.9 km (constant up to 17.9 km)	−56.5°C at 11.0 km (constant up to 25.0 km)
Temperature gradient ($-\partial T/\partial z$) in the stratosphere	−3.0°C/km	−3.0°C/km

To take into account the nadir angle dependence of the measurements, all data with nadir angles $0° \leqslant N \leqslant 25°$ were evaluated with values of the vertical intensity, those measured in the range $26° \leqslant N \leqslant 35°$ with values calculated for $N = 30°$, and those measured between $36° \leqslant$ and $\leqslant 45°$ with values calculated for $N = 40°$. All data measured with nadir angles higher than 45° were rejected.

Results

The detectors in the radiometer showed a remarkable decrease in sensitivity six days after launch (Bandeen *et al.*, 1963). Therefore, only data from the first five days (July 12–16, 1961) were evaluated. The degradation of the sensors during the first five days was small and was not taken into consideration.

The relative humidity and the surface temperature were determined from the data of each individual orbit. Maps of the results of launch day (July 12, 1961) are shown in Figs. 1 and 2. Additional results for the other days are given in a Final Report to the National Aeronautics and Space Administration (Raschke & Tannhäuser, 1965).

In the map of the surface temperature (Fig. 1) cold areas occur over cloudy areas of the tropics (primarily over Central Africa and the Western Pacific), which belong to the intertropical convergence zone. Surface temperatures lower than −30°C indicate cloud tops higher than 10 km. The areas south of 40 S latitude appear to be completely overcast with cloud tops higher than 10 km. Temperature values determined over clear ocean regions correspond closely to sea surface temperatures. An exact check of the temperature values is not possible due to the lack of precise observations of such factors as sea surface temperature and atmospheric dust layers.

Pronounced dry regions (Fig. 2) were found over the subtropical anticyclones at both hemispheres. The relative humidity is higher over the intertropical convergence zone and at higher latitudes. This agrees with the results of Telegadas & London (1954) and Manabe *et al.* (1965). All areas indicated in Fig. 2 with N.I. (no interpretation) designate areas where either the cloud tops were so high that channel 1 measured primarily their surface temperature, or the upper troposphere and lower stratosphere were colder and/or moister than was assumed in the models. Thin cirrus layers near the level of the tropopause cause additional absorption of infrared radiation emitted from below (Zdunkowski *et al*, 1965). Therefore an interpretation with the model assumptions described above leads to values of the relative humidity which are higher than 100%.

The systematic geographical distribution of the mean relative humidity, which is primarily due to the general circulation in the Earth's atmosphere (e.g. Manabe *et al.*, 1965) is somewhat disturbed over the Western Pacific by cyclones which cause high cloudiness in this region. Therefore, zonal averages of the mean relative humidity determined for the first five days after launch (July 12–16, 1961) are higher over the Northern Hemisphere than over the Southern Hemisphere as shown in Fig. 3.

A comparison of the humidity values with conventional radiosonde measurements is not yet possible, since radiosondes do not measure humidity accurately at high altitudes.

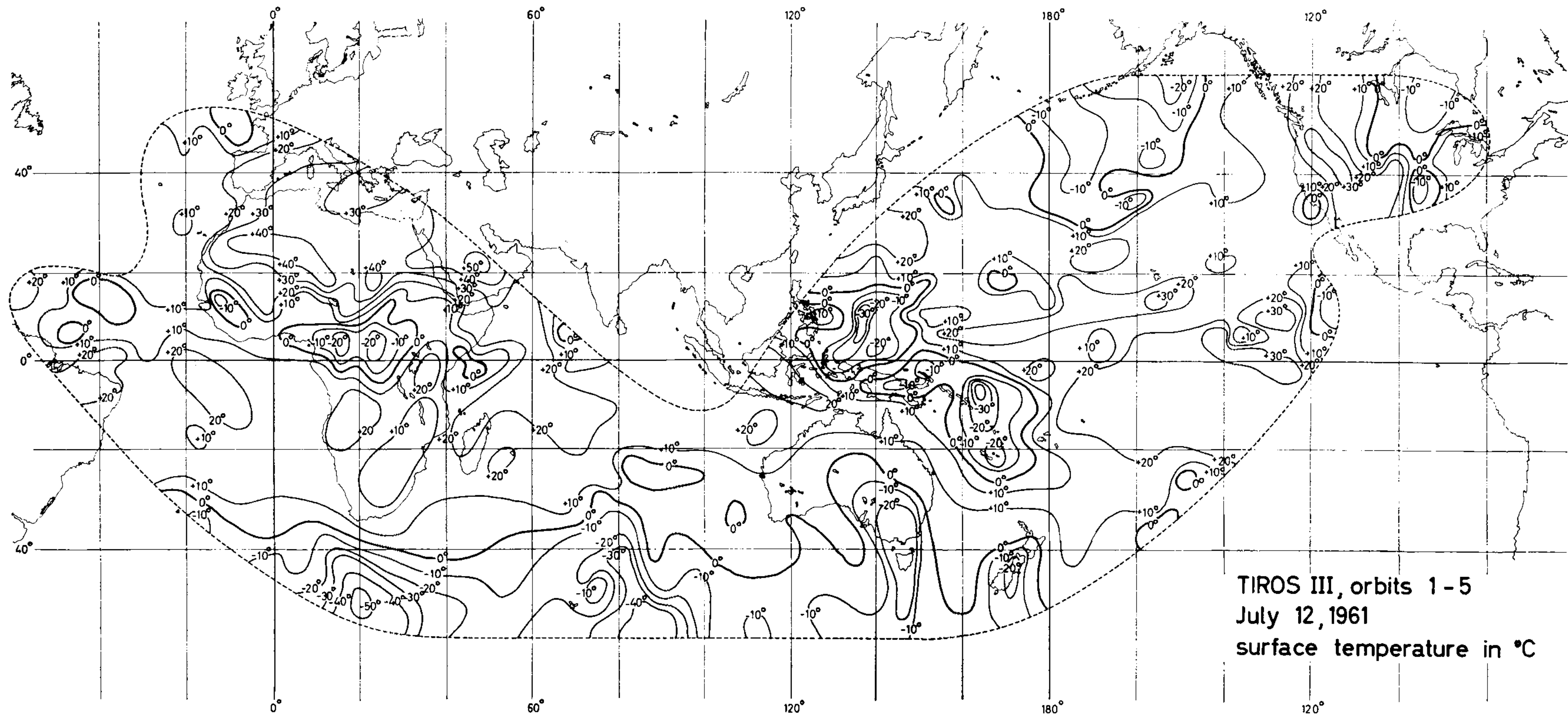

Fig. 1. Temperature of the underlying surface as evaluated from infrared measurements of Tiros III during orbits 1–5 on July 12, 1961.

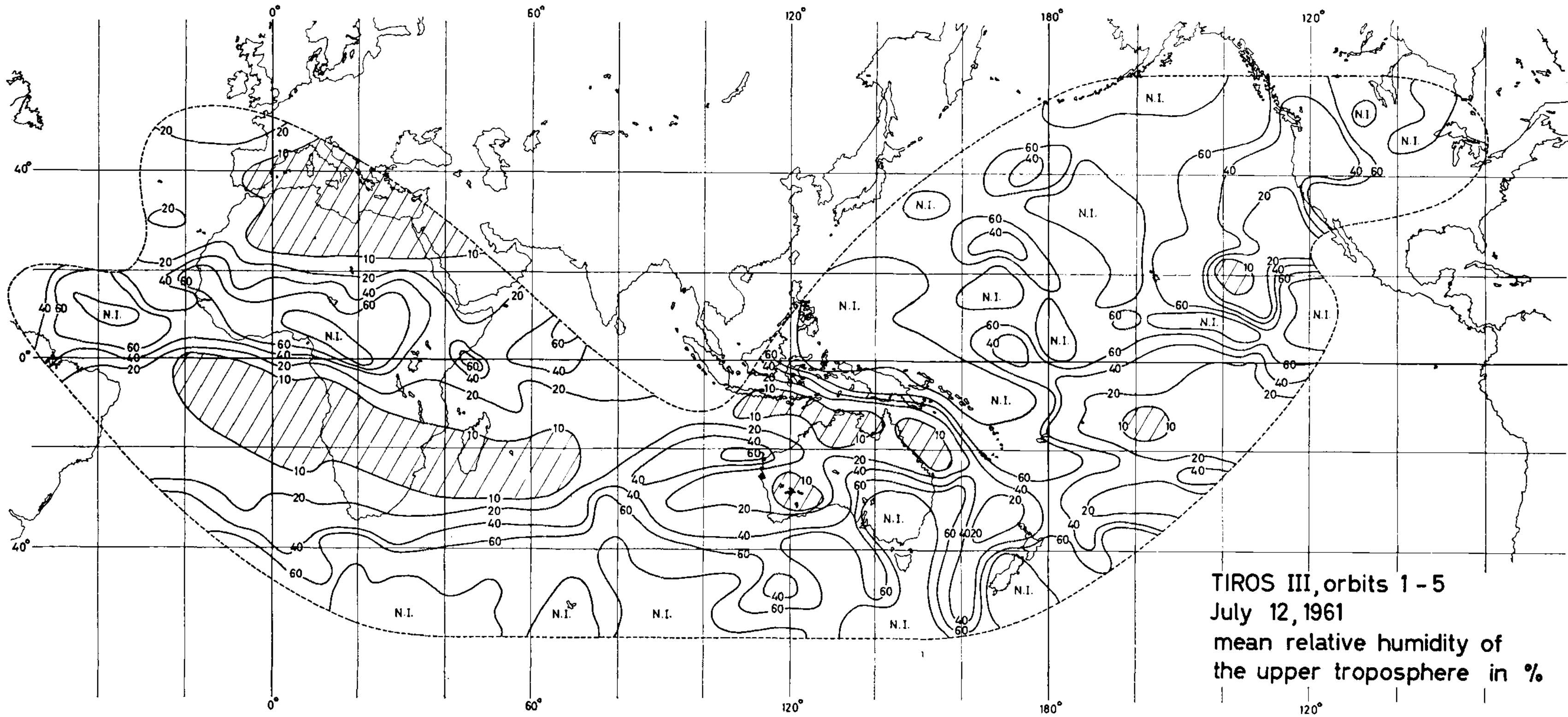

Fig. 2. Mean relative humidity of the upper troposphere as evaluated from infrared measurements of Tiros III during orbits 1–5 on July 12, 1961.

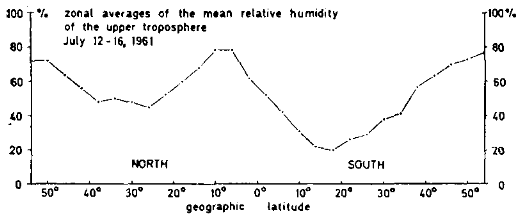

Fig. 3. Mean relative humidity of the upper troposphere; zonal averages for 5 days, July 12–16, 1961.

Conclusions

The mean relative humidity of the upper troposphere as determined from satellite infrared radiation measurements, has a geographical distribution which agrees with results of other authors. The quantitative values, however, contain errors which are primarily due to deviations of the actual atmospheric structure from the assumed models and by the inaccuracy of the radiation measurements. More accurate measurements should be possible with radiometers aboard the Nimbus satellites. Final checks of the evaluation method used above will then be possible when the actual atmospheric structure over a certain area is known. Therefore, vertical moisture, dust and the temperature distribution in the troposphere and stratosphere and surface temperatures should be measured simultaneously when the satellite flies over the test area.

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КВАЗИГЛОБАЛЬНЫЙ АНАЛИЗ СРЕДНЕЙ ОТНОСИТЕЛЬНОЙ ВЛАЖНОСТИ В ВЕРХНЕЙ ТРОПОСФЕРЕ

Метеорологический спутник ТАЙРОС Ш измерял восходящую инфракрасную радиацию одновременно в спектральных интервалах $(5{,}8 + 6{,}8)\ \mu$ и $(8 + 13)\ \mu$. По методу, развитому Мёллером (1962) и Рашке (1965), были определены относительная влажность в верхней тропосфере и температура поверхности Земли и (или) облаков. Представлены в качестве квазиглобального распределения результаты для одного дня (12 июля 1961 г.).

Оказалось, что средняя относительная влажность меньше 10% в субтропических антициклонах в обоих полушариях, тогда как в тропических областях, занятых облаками, она выше 60%.