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Comment on "A reexamination of the 'stratospheric fountain' hypothesis" by A. E. Dessler

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Abstract. Dessler (1998) analyzed 60,000 radiosonde profiles to re-examine an analysis done nearly 20 years earlier by Newell and Gould-Stewart (1981) (hereafter: NGS). Contrary to NGS, Dessler finds that the mean tropical tropopause saturation mixing ratio (SMR) is sufficient to explain stratospheric dryness and that there is no need to assume a seasonal or regional preference for water vapor entering the stratosphere. However, in using the SMR to compute the water vapor amount, he implicitly assumes that the air is saturated, since only under this condition are temperature and water vapor physically connected. If the air is not saturated, the average computed by Dessler will overestimate the amount of water crossing the tropical tropopause ($[H_2O]_e$), while supersaturation and the presence of ice particles will underestimate $[H_2O]_e$. These processes, which are likely to have different regional and temporal distributions, may have fortuitously canceled each other in Dessler's analysis. NGS studied the distribution of tropopause temperatures and focused on the regions and seasons, in which dehydration is more likely to take place. Recent studies indicate that the tropical tropopause has been cooling over the last 25 years and show that the years used by Dessler have the coldest tropical tropopause temperatures. Thus his conclusion may have been different if other years had been studied. These differing viewpoints emphasize the need for a detailed understanding of the stratospheric dehydration mechanism.

Background

The study 'A reexamination of the "stratospheric fountain" hypothesis' by A. E. Dessler (1998) repeats for a different time an analysis done by Newell and Gould-Stewart (1981) (NGS), in which they analyzed radiosonde data to study the tropical tropopause dehydration. NGS found that only in the Western Pacific during the boreal winter and in the Indian Ocean during the monsoon season is the tropopause cold enough to explain stratospheric dryness. NGS surmised that there is a preferential region and a preferential season for air to enter the stratosphere. The limited data used by NGS make a repeat of this analysis highly desirable.

Dessler analyzes 60,000 radiosonde profiles, launched between 1994 and 1997. He correctly points out that, unlike in NGS, the minimum saturation mixing ratio (SMR) of the temperature profile should be used since averaging over the minimum temperature and subsequent application of the Clausius-Clapeyron equation leads to an overestimate of the average SMR at the temperature minimum. He obtains a value of 4.0 ± 0.8 ppmv for the annual and zonal average of the minimum SMR near the tropical tropopause. He compares this value with an estimate for the entry value for water vapor $[H_2O]_e$ of 3.8 ± 0.3 ppmv, which was obtained by an average over various measurements and points out that the annual and zonal average of the minimum SMR is consistent with this estimate for the entry value for water vapor. He concludes that a theory, which assumes a regional and seasonal preference for the entry of air into the stratosphere, is not necessary.

While a study of this kind is highly desirable, the analysis presented by Dessler has some shortcomings, which in our view leave the necessity of a stratospheric fountain as an open issue and show that our knowledge on the detailed mechanism of tropical tropopause dehydration is still limited.

Tropopause saturation

To estimate $[H_2O]_e$ from temperature data it has to be assumed that the air is saturated at the temperature of the minimum SMR. If the air is not saturated then temperature and water vapor content have no direct relationship and temperature cannot be used as a

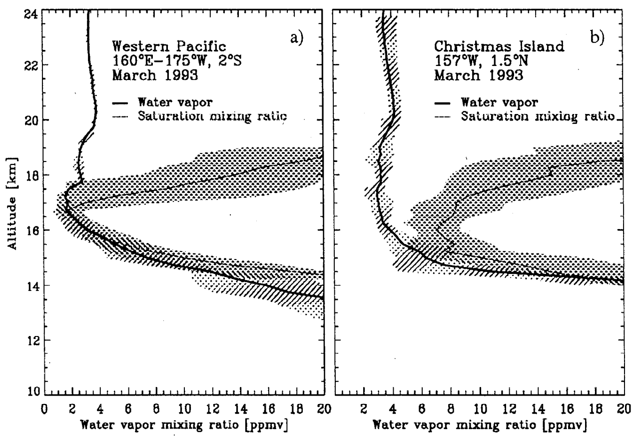

Figure 1. Water vapor and SMR profiles obtained in March of 1993. The solid lines indicate the mean profiles, the shaded areas the minimum and maximum values for the data series. (a) Four profiles in the western Pacific, (b) five profiles in the central Pacific over Christmas Island. While the western Pacific profiles show consistently a nearly saturated tropopause region, none of the profiles over Christmas Island shows saturation, despite a significantly more moist tropopause region.

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proxy for the amount of water vapor. In non-saturated air the SMR is by definition larger than the actual water vapor mixing ratio. Therefore, if a part of the radiosonde observations is not saturated at the minimum SMR, then $[H_2O]_e$ is necessarily overestimated. Operational radiosondes do not measure water vapor at these altitudes and the available water vapor data at these altitudes come from observations onboard high flying aircraft and research balloons. While these data are not sufficient to establish a climatology, they can reveal the processes that control water vapor at the tropical tropopause. Our own measurements using a balloon borne chilled-mirror hygrometer, which is highly suitable for measuring water vapor at the tropopause, indicate that in some cases the cold point temperature in the tropics is saturated, but not in others (Vömel et at., 1995). Figure 1 shows two composites of 5 water vapor profiles in the western Pacific (figure 1a) and 4 profiles in the central Pacific (figure 1b). While most of the western Pacific profiles show saturation at the tropopause, none of the profiles in the central Pacific show saturation at this level. If we average the SMRs of these profiles as a measure of the ambient mixing ratio, we will overestimate the observed amount of water vapor.

On the other hand, if ice particles are present at the minimum SMR and these subsequently evaporate before settling out, then $[H_2O]_e$ is necessarily underestimated, since some amount of water crosses the tropopause in the condensed form, which is not accounted for when calculating the SMR. The same underestimation occurs if the air is supersaturated and water vapor has not yet condensed into ice particles, thus violating the equilibrium assumption, which is implicitly made in calculating the SMR.

Thus there are opposing physical processes, leading to an overestimation of the amount of water vapor in one case and an underestimation in the other. These physical processes, which, as NGS point out, are likely to have different regional and temporal distributions, may by chance cancel out in a zonal average, but there is no reason to expect they should.

The idea presented in NGS was to study the regional and temporal distribution of areas, where dehydration at the tropical tropopause is likely. They avoided computing a zonal and annual average, but instead studied the temporal and geographical distribution of regions, where the SMR is sufficient to explain stratospheric dryness and where it is not. While they had no data of tropical tropopause water vapor, they implicitly assumed that regions with a colder tropopause are more likely to show saturation at the tropopause, than regions with warmer tropopause temperatures. The value of their study was identifying these regions.

Stratospheric and tropopause trends

NGS studied the distribution of 100 hPa temperatures in tropical regions in the 1970's and published their result in 1981. Dessler on the other hand studies cold point temperatures between 1994 and 1997 and uses water vapor measurements from the early 1990s. He makes no statement, whether his conclusion applies to the period studied by NGS, however, he states, that the fountain hypothesis is no longer necessary to explain stratospheric dryness. However, between 1980 and 1995 an increase in stratospheric water vapor has been observed over Boulder, CO (Oltmans and Hofmann, 1995), exceeding the increase which can be explained by the increase in atmospheric methane. Therefore, these two studies cannot be compared directly, without looking at the temperature trend of the tropical tropopause in this time period.

A recent study by Geller et al., (submitted to JGR 1999), indicates that the tropical cold point temperature has cooled by 0.57K/decade, or in terms of SMR by 0.46 ppmv/decade. This temperature trend is directly opposite to what might have been expected from the increase in stratospheric water vapor. They also point out, that the years 1994 through 1997, which Dessler used in his study, were the coldest years in the 25 year record they studied. Thus it appears that the analysis by Dessler could have reached a different conclusion if he had used any other time period.

Measurements of water vapor crossing the tropical tropopause

The estimate of $[H_2O]_e$ used by Dessler is an average derived from different instruments, which show significant disagreement among each other. Assuming the value of each individual instrument we find that the conclusion depends on the instrument used for the study. The value that we have derived from balloon-borne frost-point hygrometers is 3.5 ± 0.5 ppmv, which is in the lower half of the range of data given in table 1 of Dessler's paper. In situ intercomparisons also show that the Harvard instrument, which gives the largest values of $[H_2O]_e$ listed in table 1, gives water vapor amounts that are ~15% larger than those measured by the instrument of NOAA/AL, which is mentioned in the text, but not listed in the table. We have to emphasize the need to resolve the disagreement between the different instruments, since Dessler's conclusion depends strongly on an accurate estimate of $[H_2O]_e$.

Dessler's paper demonstrates the importance of knowing the absolute mixing ratio to a high degree of accuracy. It also demonstrates the need for a detailed understanding of the tropical tropopause dehydration mechanism. Given the current uncertainty among various water vapor measuring instruments it seems that the constraints for a regional and seasonal preference for air passing into the stratosphere from the tropical troposphere remain to be rigorously determined. If a regional and seasonal source of dry air to the stratosphere was required for the period analyzed by NGS and is no longer needed based on the period studied by Dessler, it is important to determine the cause of this change.

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