AMDAR and Climate

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Summary

This note describes the relevance of AMDAR in measuring climate variability and climate change. The sensitivity of climate to variations in water vapour is large when these variations occur at the nominal flight levels of most commercial airlines (9 – 12 km). Therefore AMDAR could potentially have a valuable contribution to our understanding of climate [change] by providing accurate long term records of water vapour at atmospheric altitudes that are difficult to reach by other instruments.

What is the importance of measuring water vapour at high altitudes in the atmosphere?

Carbon dioxide [CO2] and water vapour [H20] are the two most important greenhouse gases in the atmosphere. It is generally assumed that through the anthropogenic emission of CO2 and other Greenhouse gases the atmospheric temperature will increase by 1.5 – 3.5 degrees in the course of this century. An increase in temperature will induce an increase in atmospheric water vapour because a) the capacity of the atmosphere to keep water in its vapour state is direct dependent on temperature [via the well known Clausius-Clapeyron equation, known from thermodynamics] and b) the ocean is an sheer infinite source of additional water vapour. Since the amount of water vapour is dependent on temperature, its concentration is lower in the upper troposphere than near the surface. The influence of water vapour on climate is gauged by its effect on the infrared (IR) spectrum of outgoing radiation. Many water vapour absorption lines in the IR spectrum are saturated for the relatively high amounts of water vapour that are occurring in the lower troposphere. This means that a further increase in water vapour in the lower troposphere will only have an impact on the wings of these absorption lines so that little extra radiation can be absorbed. However, changes in water vapour at higher altitudes have a relatively large impact because they are able to influence the weaker water vapour absorption lines that are not yet saturated. And this, in turn, means that the enhanced greenhouse effect is very much dependent on changes in water vapour at *small* values of this water vapour at *high* altitudes, where fractional changes are significant.

In the last decade several calculations have been made of the sensitivity of the atmospheric IR radiation to changes in water vapour. Figure 1 depicts the mean sensitivity in $Wm^{-2}K^{-1}$ as a function of altitude and latitude. From this figure it emerges that the largest sensitivity is present in the middle and upper troposphere, with a peak region in the sub-tropics and tropics between 200 and 400 hPa. However, tail regions of large sensitivity extend into the moderate latitudes as well, in particular in the altitude range between 300 and 400 hPa. Thus, it turns out that most sensitivity of IR radiation to changes in atmospheric water vapour is present at the nominal flight altitudes of commercial airliners.

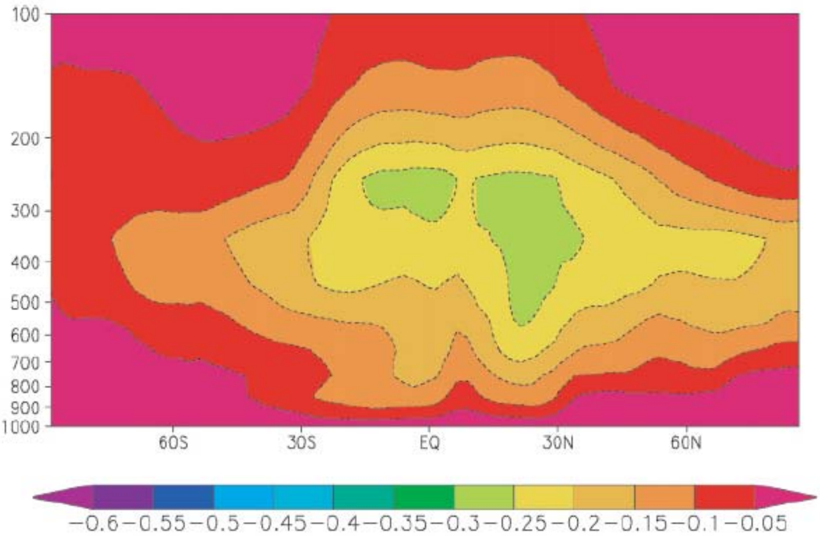

Fig 1: The sensititivity of outgoing IR radiation to changes in water vapour [W m^{-2} K^{-1}] [Figure 9 from *'Water Vapour Feedback and Global Warming'* I. Held and B. J. Soden, Annu. Rev. Energy Environm. 2000, 25:441 – 75]

What are the climate requirements for accuracy of upper tropospheric water vapour?

The ET-GCOS (WMO - 2010) specifies three sets of requirements for accuracy of upper tropospheric humidity measurements so that they become relevant for climate research purposes, namely a target, an optimum and a threshold requirement. Of these requirements, the threshold requirement is the least restrictive and allows a maximum RMS error of 10% in specific humidity between 200 and 400 hPa. This translates into a measurement uncertainty in specific humidity compared to a true and absolute reference value of 20%. At moderate latitudes the specific humidity at 300 hPa has a typical value of 0.1 g kg^{-1} which is expected to double by the year 2100. Therefore, at current levels of the specific humidity the uncertainty requirement for climate purposes is 0.02 g kg^{-1}.

Which techniques are currently used to measure water vapour in the high troposphere?

a) **Operational radiosondes**: Regular radiosonde measurements of water vapour have been made throughout the world for many decades. However, at low temperature and low humidity the measurement uncertainty in specific humidity is too large to construct a climate record of water vapour at high altitudes.
b) **Experimental radiosondes**: Since the 1990's several research groups have been successful in developing new water vapour measurement techniques that are suitable for usage under extreme conditions and that can be launched by radiosondes. There are only a handful of stations that regularly launch these experimental sondes [the so-called Global Reference Upper Atmosphere Network, GRUAN stations, supported by the WMO-GRUAN group]. At this moment there is no universal agreement which of these radiosonde techniques is optimal and comparison studies have revealed biases between instruments that require ad hoc methods to remove. Furthermore, since many instruments are in still under continuous development, daily operational ascents are not possible.
c) **Raman - lidar**: The Raman-lidar technique for measuring water vapour has been available since the early 1970's. Yet it has taken 30 years to overcome important technical obstacles before upper tropospheric water vapour measurements could

be achieved. At this moment there are a few stations that are able to observe water vapour profiles. The technique requires a very high level of expertise of personnel to obtain water vapour measurements that comply with climate standards [only possible at clear skies]. There is no doubt that within 10 years more research groups will achieve tropospheric water vapour observations of very high standards but this technique will remain unsuitable for widespread operational purposes for at least another decade.

d) **Satellite measurements**: Since the 1980's satellite observations have been made of radiative temperature in selected wavelength bands of the IR spectrum that are sensitive to water vapour. Radiative transfer theories have been employed to link the radiative temperature to the mean relative humidity in high altitude tropospheric layers. Some research groups now claim to be able to record a time series with trends of upper tropospheric water vapour. The advantage of this measurement is that it can be made on a global scale. Nevertheless, it is difficult to establish the accuracy of the measurement, for three reasons: 1) There are debatable assumptions in the theory of the conversion of radiative temperature to relative humidity, 2) A stable and absolute calibration of the satellite radiometers is required, and 3) It is often difficult to quantify the effect of changing satellite observing systems and platform on the climate record .
e) **Occultation technique**: This modern technique uses timing signals that are exchanged between GPS satellites. Since timing signals are extremely precise, it is considered an absolute measurement. The timing signals are dependent on the refractive index, which in turn is dependent on temperature and humidity. It is therefore possible to construct temperature and humidity profiles from different occultation constellations on a global scale. However, while refractive index can be used as a fundamental climate record, the relative attribution of this signal to temperature and humidity will always be ambiguous. At this moment it is therefore not yet clear whether upper tropospheric humidity measurements of sufficient accuracy can be obtained with this technique.

Although microwave techniques are also used to measure water vapour as a vertical integrated quantity, water vapour profiles cannot be resolved with appropriate vertical resolution using this technique.

How can AMDAR contribute to climate - quality water vapour measurements?

The use of AMDAR has a number of advantages:

a) The AMDAR water vapour measurement meets the climate requirement now. One system that is currently being evaluated is an optical measurement with a very high accuracy. Laboratory experiments appear to demonstrate that the 0.02 $g\ kg^{-1}$ measurement uncertainty is achieved so that the necessary standard to construct a climate quality record of water vapour is already satisfied.
b) Most AMDAR observations are carried out en-route at altitudes of 200 – 400 hPa. As indicated above observations are these levels are highly relevant for the study / monitoring of the variability and change in water vapour that are key to our understanding of climate change.
c) A uniformly applicable instrumental calibration procedure appears to be available.
d) The instruments are designed as operational measurement systems that are also useful for weather forecasting purposes [in-flight icing].
e) Instruments will be used by a number of different airlines. Since operational flight routes reach many regions of the globe it will be possible to make a near global climate construction of tropospheric water vapour.
f) Software to construct time series of water vapour has already been developed.