Reports

The Short-Term Temporal Spectrum of Precipitable Water Vapor

Abstract. *Short-term power spectra of the fluctuations in the precipitable water vapor measured with a dual-channel microwave radiometer are presented. The spectra, taken over 34-hour sampling periods, encompass periodicities from 1 day to about 10 minutes. The fluctuation power is associated with the average precipitable water vapor for the sampling period. The background noise spectrum of the radiometric instrument is also discussed.*

The amount of atmospheric water vapor above a given site on the earth's surface, the precipitable water vapor (PWV), varies greatly with time. For synoptic weather forecasting, one obtains this quantity by integrating in situ measurements from balloon-borne radiosondes conventionally launched every 12 hours; but the periodicities of the variations span a wide scale. For example, seasonal and yearly changes are significant, especially in temperate zones. Likewise, large air masses on the synoptic scale produce variations with periods of the order of a week. On the other hand, weather fronts give rise to variations on the order of hours. In addition, there are cloud-sized patches of vapor that produce periods of minutes, as well as very-small-scale patches, caused by turbulence, that move with the wind and can give rise to periods on the order of seconds. The variations are of interest in systems relying on measurement of the phase of radio waves, such as very-long-baseline interferometry and geodetic metrology, as well as in meteorology.

Recent developments in dual-channel microwave radiometers (*1*) have afforded continuous observation of the PWV. This type of instrument is well calibrated and reliable; extensive field tests show that it yields measurements that compare closely with PWV measured by radiosondes of the U.S. National Weather Service (NWS). The minimum time constant of the instrument is about 1 second. In addition, the instrument measures the vertical line-integral of cloud liquid (*2*) independently but simultaneously with the PWV.

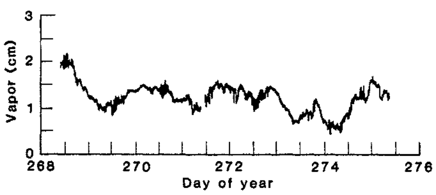

Fig. 1. Microwave radiometric measurement of the total PWV for a 7-day period in 1978 at the Weather Service Forecasting Office, Denver, Colorado.

Figure 1 is a time series that shows, to some extent, how the PWV varies during time intervals of less than a week. For example, on day 273, the PWV decreased to half value from midnight to midday and then regained half of that decrease by evening. Periods of much less than an hour are observed on several occasions; for example, the fine-grained low-amplitude fluctuations near noon of day 269. The time constant of the instrument is 2 minutes for these data. An analysis of very-short-term fluctuations is given by Orhaug (*3*).

A 2-year test of a dual-channel radiometric instrument has been performed at the radiosonde launch site of the Weather Service Forecasting Office of NWS, Stapleton Airport, Denver, Colorado. The main objectives of the test were evaluation of reliability under continuous unattended operation and direct comparison with data from the radiosondes (launched every 12 hours). The test showed that the accuracy of PWV measured by the radiometers is ≤ 0.8 mm (root-mean-square) in the long term, with a short-term sensitivity of 0.08 mm. During this period, the 2-minute averages of PWV were recorded on the disk of a minicomputer. Thus, by analysis on a computer, one can obtain spectra of PWV that extend to periods as short as several minutes.

Examples of spectra are shown in Fig. 2; curve a corresponds to the time series of Fig. 1, about a 7-day period. The abscissa is in frequency units (F) of cycles per day; therefore, $F = 10^2$, for example, applies to a period of about 15 minutes. The length of the individual data samples was 34 hours, and five of these were averaged to produce the spectrum of curve a. The weather was clear with broken clouds; the average PWV for the 7-day period was about 1.2 cm, and the average wind was about 8 m/sec. We detrended the time-series data by taking first differences before removing the mean. The spectrum, computed by Fourier transform, is adjusted by taking into account the effect of differencing the time series. Differences between the spectra of the detrended data and data with only the mean removed are only observed at the lowest frequencies for nonstationary samples.

Another spectrum, taken under much drier conditions, is curve b in Fig. 2; three 34-hour data samples were averaged. Visual comparison indicates that this power spectrum is lower by almost a factor of 10 than curve a.

It is instructive to integrate these spectra of Fig. 2 to obtain the variances; these are 0.66 and 0.04 cm^2, respectively, for curves a and b. The variance for curve a is larger by more than a factor of 10 than the variance for curve b, a result

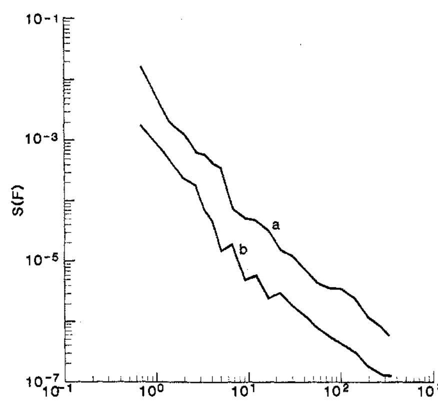

Fig. 2. Curve a is an example of the spectrum of PWV measured at the Weather Service Forecasting Office, Denver, Colorado, over five 34-hour periods during a week; the average PWV for the period is 1.2 cm. Curve b is the corresponding spectrum for a drier condition over three 34-hour periods; the average PWV is 0.35 cm. The units of the ordinate are square centimeters per cycle per day.

similar to that obtained by visual inspection of Fig. 2. Since the average PWV over the respective periods was 1.2 and 0.35 cm, we conclude that the fluctuation power varies considerably more rapidly than the average PWV, approximately as the square.

A matter of considerable interest in the theory of atmospheric structure is the slope of the power spectrum. Although the shape is found to change considerably with weather conditions, one can fit the slopes of spectra such as those in Fig. 2 with relationships of the form $S(F) = KF^{-x}$. However, it is clear by visual inspection of Fig. 2 that the curves can be more satisfactorily represented by two straight lines rather than one. Such being the case, the behavior of the PWV spectrum appears to change at about $F = 10$, corresponding to a period of about 2.5 hours.

A concern in power spectra measurements is the signal-to-noise ratio over the frequency range of interest. Low-frequency noise in a microwave radiometric instrument is generated by effects such as changes in the temperatures of components, gains of amplifiers, and lack of stability in power supplies. To determine the noise performance of the dual-channel system, the microwave antenna (which normally is permanently attached to generate a beam in the zenith) is disconnected and replaced by an enclosed microwave termination of known temperature. Under these conditions, the radiometer is operated over a long period of time, and data are recorded in the usual way. The spectrum of the background noise of the instrument is then obtained by the same technique, and length of interval, as that used in generating the PWV spectra. The result (Fig. 3) shows that the most objectionable noise components occur at the lower frequencies, near two to three cycles per day. A comparison of curve a of Fig. 2, the moist condition, with the noise spectrum of Fig. 3 shows that the data spectrum exceeds the noise spectrum by two orders of magnitude over most of the frequency range. In curve b of Fig. 2, the dry condition, the signal-to-noise ratio is sometimes less than 10 dB, especially at the high frequencies.

Although not yet applied, spectra of water vapor such as those discussed here are known to be of interest in areas other than meteorological research on short-term weather prediction. They may also have impact on the choice of the optimum time constant in the design of microwave radiometers, in the spacing of very-long-baseline radio interferometers, and in the design of metrology instruments that rely on radio phase, such as those of a global positioning system for monitoring the motion of the crust of the earth. The latter applications arise because the fundamental limit on phase fluctuation in such systems is set by the variation in the water vapor in the troposphere.

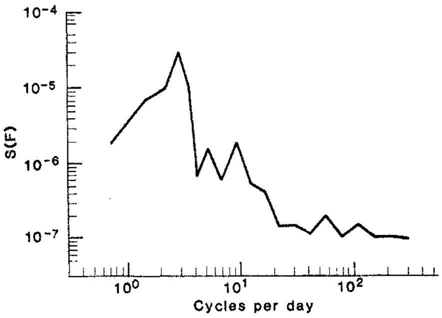

Fig. 3. A 34-hour measurement of the spectrum of the background noise of the dual-channel microwave radiometric system; the ordinate is lower by a factor of 10^3 than in Fig. 2. The units of the ordinate are square centimeters per cycle per day.

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References and Notes

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Detection of Overflow Events in the Shag Rocks Passage, Scotia Ridge

Abstract. *During an almost yearlong period of observations made with a current meter in the fracture zone between the Falkland Islands (Islas Malvinas) and South Georgia, several overflow events were recorded at a depth of 3000 meters carrying cold bottom water from the Scotia Sea into the Argentine Basin. The outflow bursts of Scotia Sea bottom water, a mixing product of Weddell Sea and eastern Pacific bottom water, were associated with typical speeds of more than 28 centimeters per second toward the northwest and characteristic temperatures below 0.6°C. The maximum 24-hour average speed of 65 centimeters per second, together with a temperature of 0.29°C, was encountered on 14 November 1980 at a water depth of 2973 meters, 35 meters above the sea floor.*

In historic (*1*) and recent (*2*) descriptions of the position of the Polar Front (Convergence) in the Drake Passage and the Scotia Sea, its most meridional component seems to be situated between the Falkland Islands and Shag Rocks (Fig. 1). As in similar cases in the Pacific (*3*), the associated Antarctic Circumpolar Current seems to be guided there by the local bottom topography. The topographic chart from the Scotia Sea area shows a discontinuity at the site where, on the average, the Circumpolar Current leaves the Scotia Sea with a strong equatorward component.

Several investigators have emphasized the significance of this fracture zone—henceforth called Shag Rocks Passage (SRP)—for water exchange between the Pacific and Atlantic (*4–6*). Analyzing potential temperature and dissolved oxygen data from higher southern latitudes between 20°W and 170°W, Gordon (*6*) deduced the circulation patterns of Antarctic bottom water. He showed that the circumpolar bottom flow originates from the Ross Sea, passes through the Drake Passage, and mixes with Weddell Sea water in the eastern Scotia Sea. He calculated strong (> 20 cm sec^{-1}) currents transporting bottom water through the SRP into the Argentine Basin. His arguments have since been supported by bottom photographic observations indicating murky water in the deep layers of the SRP associated with abundant evidence for strong contour currents (*7*).

During the German Antarctic Expeditions of 1979–1980 and 1980–1981 with research vessels *Polarsirkel* (*8*) and *Meteor* (*9*), I had the rare opportunity to obtain an almost yearlong direct observation of bottom current speed, direction, and temperature from the SRP.

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