Comparison of Ground-Based Observations of Water Vapor and Cloud Liquid in Mid-Latitudes and the Tropics

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Introduction

Microwave radiometers have become indispensable for research into the role of clouds and cloud-radiation feedback mechanisms affecting climate and global change. The National Oceanic and Atmospheric Administration's (NOAA) Environmental Technology Laboratory (ETL) has participated in several research campaigns in which microwave radiometers have made continuous observations of precipitable water vapor and cloud liquid. Measurements were made at several diverse locations ranging from continental and coastal regions of the United States to ships and islands in the North Atlantic Ocean and the tropical western Pacific Ocean. In this paper, we review the characteristics of the radiometric instrumentation used in ETL and compare vapor and liquid measurements in the tropics with observations at mid-latitudes.

Radiometric Instrumentation

NOAA/ETL microwave radiometers are typically two- or three-channel, independent receivers coupled into a common antenna system. The antennas are designed so that each frequency employs an equal beamwidth, usually 2.5 deg. Two-channel systems operate at either 20.6 or 23.87 GHz near a water vapor rotational absorption line and at 31.65 GHz, which is sensitive to liquid water. In the ETL three-channel system, a third frequency at 90 GHz is used; the latter channel is sensitive to both water vapor and liquid water but is about five times more sensitive to liquid water than the 31.65 GHz frequency. The radiometers are switching types that compare incoming radiation from the atmosphere with the emission from a temperature-controlled resistive load. Radiometer gain is monitored by measuring the noise power difference between two temperature-controlled loads. Corrections for gain changes are made in the data acquisition software. Linear statistical retrieval techniques are used to retrieve water vapor and liquid water amounts from the radiometric brightness temperatures. Based upon extended comparisons with radiosonde water vapor measurements, the accuracy of the radiometric vapor measurements is ~ 0.5 mm. The estimated accuracy of the liquid measurement is approximately 20%. Details of the radiometric systems and retrieval methods for measurement of water vapor and cloud liquid are given in Hogg et al. (1983).

Radiometric Data Base

From 1987 to 1996, NOAA/ETL participated in six measurement campaigns; the location, approximate latitude and elevation of the measurement site, and duration of the measurements are listed in Table 1. Data taken during the long-term observations are not discussed in this extended abstract.

Comparison of Data as Function of Location

Precipitable Water Vapor

Statistics of precipitable water vapor (PWV) observed at mid-latitudes and the tropics are given in Tables 2 and 3. Although the mean PWV at Coffeyville is less than at San Nicolas I., the variance is greater by about a factor of two. This is a result of the wider variety of air masses passing over the continental inland location at Coffeyville than at San Nicolas I., located about 80 km west of Los Angeles, California. The North Atlantic locations show similar means, but a larger variance is observed for measurements taken from the R/V *Malcolm Baldridge*. This is caused in part by the large region of the ocean (28 to 38 deg N, 22 to 30 deg W) sampled by the ship during the cruise.

For the tropical Pacific Ocean data, PWV mean values exceed mid-latitude values by about a factor of two. As in the North Atlantic, the ship data show a larger variance than observed at the Kavieng, New Ireland Island, location. Again this

Table 1. Measurement campaigns employing NOAA/ETL surface-based microwave radiometers.

Campaign	Location	Latitude (deg)	Elevation (m)	Duration
FIRE[a]I	San Nicolas I.	33.2 N	20	1-19 July 1987
FIRE II	Coffeyville, KS	37.1 N	227	13 November to 8 December 1991
ASTEX[b]	Porto Santo I.	33.1 N	97	1-28 June 1992
ASTEX	R/V[c] *Malcolm Baldridge* N. Atlantic Ocean	28 to 38 N	6	8-28 June 1992
Long-term Obs.	Porto Santo I.	33.1 N	97	12 July 1992 to 17 June 1993
TOGA-COARE[d]	Kavieng, Papua New Guinea	2.6 S	3	15 January to 28 February 1993
CSP[e]	R/V Discoverer Tropical Western Pacific Ocean	11 S to 15 N	6	15 March to 11 April 1996

(a) First International Satellite Cloud Climatology Project Radiation Experiment
(b) Atlantic Stratocumulus Transition Experiment
(c) Research Vessel
(d) Tropical Ocean Global Atmosphere-Coupled Ocean-Atmosphere Regional Experiment
(e) Combined Sensor Program

Table 2. Summary of precipitable water vapor measurements at four mid-latitude locations.

Campaign	Location	Latitude (deg)	Mean vapor (cm)	Std. deviation
FIRE[a]I	San Nicolas I.	33.2 N	1.922	0.553
FIRE II	Coffeyville, KS	37.1 N	1.642	0.868
ASTEX[b]	Porto Santo I.	33.1 N	2.268	0.375
ASTEX	R/V[c] *Malcolm Baldridge* N. Atlantic Ocean	28 to 38 N	2.458	0.557

(a) First International Satellite Cloud Climatology Project Radiation Experiment
(b) Atlantic Stratocumulus Transition Experiment
(c) Research Vessel

is caused by the large area sampled by the Discoverer (15 deg S to 15 deg N, 172 deg W to 145 deg E.). However, if the ship data are sorted into latitude intervals, the variance is reduced as shown in Table 4.

CSP data in Tables 4 and 6 were recorded at a 30 sec rate. The duration of measurements in each latitude interval can be determined from the number of points. The small number of points in the -15 to -10 deg interval is caused by a

Table 3. Summary of precipitable water vapor measurements at two tropical locations.

Campaign	Location	Latitude (deg)	Mean vapor (cm)	Std. deviation
TOGA-COARE[a]	Kavieng, Papua New Guinea	2.6 N	5.227	0.429
CSP[b]	R/V *Discoverer* (Tropical Western Pacific Ocean)	15 S to 15 N	4.952	0.936

(a) Tropical Ocean Global Atmosphere - Coupled Ocean - Atmosphere Regional Experiment
(b) Combined Sensor Program

Table 4. Precipitable water vapor as a function of latitude interval during combined sensor program cruise at R/V *Discoverer*. Data are for clean and cloudy skies. Negative latitudes are south of the equator.

Latitude interval (deg)	Mean (cm)	Std. deviation (cm)	Percent cloud cover	No. of point
-15 to -10	6.031	0.173	100.0	171
-10 to -5	5.520	0.636	55.6	1933
-5 to 0	5.031	0.883	37.6	55353
0 to 5	4.894	0.518	25.6	2747
5 to 10	3.964	0.929	29.7	3223
10 to 15	3.324	0.412	58.5	752
15 to 20	2.445	0.169	67.2	454

wet synoptic event with frequent precipitation at the start of the cruise. Data recorded when precipitation is detected at the surface have been discarded.

Similarly, integrated liquid amounts that exceed 2 mm are considered to be caused by precipitation aloft and have been discarded.

Liquid Water

Table 5 presents statistics of liquid water observed at the three mid-latitude locations. At Coffeyville, cloud types varied from stratus with typical drop diameters of several µm to cumulus congestus with drop diameters of 100 µm or larger. As a result, both mean and variance are considerably larger than at the other two mid-latitude locations. Cloud types observed in the North Atlantic at Porto Santo Island and R/V *Malcolm Baldridge* varied from stratus to cumulus. Liquid water amounts at Porto Santo Island are therefore greater than in the predominantly marine stratocumulus environment at San Nicolas Island. The mean liquid at Porto Santo Island is slightly greater than observed by the ship. The variance is also larger for the island data. Whether the larger mean and variance in liquid water are a consequence of being on the island is unclear. However, similar findings in the tropical data, discussed below, may be evidence that island locations result in larger amounts of liquid water than found in the open ocean.

Table 5. Integrated liquid water measured at three mid-latitude locations. Data averaging times are 30, 60, and 120 s for Porto Santo I., San Nicolas I., and Coffeyville, respectively.					
Location	**Latitude (deg)**	**Mean (cm)**	**Std. deviation (cm)**	**Percent cloud cover**	**No. of points**
Porto Santo I.	33.1	0.142	0.129	32.5	25,600
San Nicolas I.	33.2	0.111	0.092	64.4	15,562
Coffeyville, KS	37.1	0.256	0.357	41.2	7,031

Statistics of liquid water observed during the CSP cruise of the R/V *Discoverer* and at Kavieng, Papua New Guinea are given in Table 6. The ship data are sorted by latitude interval. Note that the mean liquid water at Kavieng is about two times greater than for the *Discoverer* data. Part of the reason for the difference is the larger area observed during the cruise of the *Discoverer*. It is also possible that updrafts from the island land mass (or a greater concentration of cloud condensation nuclei) contribute to formation of clouds with greater liquid water contents than found over the open ocean.

Summary

Significant differences in precipitable water vapor are observed in the mid-latitude and tropical regions. Amounts of PWV in the tropics exceed those in mid-latitudes by a factor of 2.5. Liquid water amounts do not show a systematic behavior as a function of latitude except in the region near the equator where clouds were less frequent that at higher latitudes. The data suggest that greater amounts of cloud liquid are generated over islands than in the open ocean. While these data do not represent true climatologies, it is believed they are of sufficient duration to reveal meaningful trends. Therefore, one can use the averages shown here quantitatively, provided that one properly acknowledges the representativeness issue.

Reference

Hogg, D. C., F. O. Guiraud, J. B. Snider, M. T. Decker, and E. R. Westwater, 1983: A steerable dualchannel microwave radiometer for measurement of water vapor and liquid in the troposphere, *J. Climate Appl. Meteorol.*, **22**, 789-606.

Table 6. Liquid water as a function of latitude Interval during combined sensor program cruise of R/V *Discoverer,* and at Kavieng, Papua New Guinea. Negative latitudes are south of the equator.				
Latitude interval (deg)	**Mean (mm)**	**Std. deviation (mm)**	**Percent cloud cover**	**No. of points**
-15 to -10	0.538	0.331	100.0	171
-10 to -5	0.153	0.159	55.6	1,074
-5 to 0	0.112	0.202	37.6	20,798
0 to 5	0.217	0.271	25.6	703
5 to 10	0.132	0.237	29.7	957
10 to 15	0.071	0.091	58.5	440
15 to 20	0.044	0.010	67.2	305
-2.6 Kavieng, PNG	0.223	0.341	41.9	51,581