# MILLIMETER RADIOMETRIC SENSING OF THE LOWER ATMOSPHERE

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ABSTRACT

One of the most rewarding results of the mid-century development of high-sensitivity passive microwave spectrometers, of which the Dicke radiometer was a key enabling element, has been the advent of scientific and operational sounding of the lower atmosphere by passive microwave techniques on both local and global scales. Strong microwave spectral features of oxygen and water vapor permit ground and space-based sensors to determine the altitude profiles of atmospheric temperature and humidity with an accuracy not obtainable by comparable infrared sensors. Clouds and precipitation, as well as numerous stratospheric and mesospheric constituents, can also be measured.

## ORIGINS OF THE FIELD

The origins of millimeter radiometric sensing of the atmosphere lie principally in optical and radio astronomy and their use of spectroscopic techniques to measure properties of the atmospheres of stars and planets. It had been demonstrated that both atmospheric compositions and temperatures could be measured remotely by virtue of the temperature-dependent intensity of atmospheric black-body radiation, and the composition-specific frequencies at which they emit. Such techniques had also exploited the pressure-dependencies of spectroscopic line widths, and mathematical techniques of estimation to yield altitude distributions of these parameters. Additional temperature information results from the relative temperature-dependencies of the line absorptions corresponding to different molecular states. Doppler shifts can also yield wind velocity information.

A second essential element was the development of sensitive microwave radiometers, the first one appropriate to microwave atmospheric sensing being reported by Dicke (1) and demonstrated in atmospheric sensing by Dicke, Beringer, Kyhl, and Vane (2). Such systems had the ~1K accuracies necessary to sense small atmospheric changes.

The third element comprised the mathematical techniques necessary to estimate with minimum error the desired atmospheric temperatures despite the fact that the relation between the observed spectrum and atmospheric parameters is non-linear and involves non-stationary statistics and unobserved factors, which therefore contribute noise. The observations furthermore are insensitive to rapid spatial variations in parameter values. They can also be related to the atmosphere in non-unique ways; quite different atmospheres can sometimes yield identical spectra. These data interpretation techniques have their origins in estimation theory.

## HISTORY

Ground-based observations by Dicke *et al.* (2) at 1.0, 1.25, and 1.5-cm wavelength revealed the effects of the water vapor absorption line centered near 1.35-cm wavelength, and the non-resonant microwave absorption by clouds. Subsequent measurements of the oxygen absorption band led to formulation of plans for earth-orbiting satellites to yield global data sets even in the presence of cirrus and other clouds which had hampered infrared observations.

The first satellite to observe microwave water vapor and cloud emission was Cosmos 243 in 1968 (3), and the first to observe oxygen emission and the associated atmospheric temperature profiles was Nimbus 5 in 1972 (4). Over 17 different satellite passive microwave sensors have now monitored the earth. Most frequently flown is the MSU 4-channel sensor sounding the 5-mm wavelength oxygen band on operational NOAA polar satellites. MSU is scheduled to be replaced by a much improved 20-channel sensor, AMSU, in the mid 1990's.

## APPLICATIONS

Satellites can yield excellent measures of integrated atmospheric water vapor over ocean and acceptable measures of tropospheric water vapor profiles everywhere, with somewhat less accuracy near land surfaces where the thermal contrast is less. Altitude resolution is several kilometers, limited by the scale height of the atmosphere; in the tropics perhaps 3 or 4 points on a vertical profile might be usefully measured. Above the tropopause limb-scanning configurations yield superior vertical resolution, say ~3 km, by virtue of geometric effects and the use of very thin pencil antenna beams. Altitudes to the mesosphere can be sounded in this way. Horizontal resolution of AMSU-B, the water vapor and cloud sounding portion of AMSU, will be ~15 km near nadir, and nearly full earth coverage will be provided every 12 hours from each such satellite in operation.

Temperature profiles can be sounded to the mesosphere with rms accuracies of ~1-4 K at full vertical resolution, the errors being dominated by vertical structure in the atmospheric temperature profile too fine to be resolved by the oxygen channel response functions (weighting functions); these weighting functions have widths on the order of a scale height, ~8 km. Long-term average temperatures in broader altitude bands can be determined in principle with accuracies of hundredths of a degree, limited principally by the calibration accuracy of the sensor. Recent concern about long-term global warming has heightened interest in the use of microwave sensors for monitoring such changes on a global scale. The horizontal resolution of AMSU-A is ~50 km near nadir; it also scans to yield nearly full global coverage every 12 hours. Such sensors should respond to most meteorological events of interest, and have demonstrated an ability to monitor hurricane intensities by virtue of their strong horizontal temperature gradients at fixed pressure levels near the core.

Clouds and precipitation have strong signatures, particularly over ocean or when convective activity thrusts substantial ice aloft. These signatures over land are usually cold spots, sometimes dropping below 100K when ice aloft scatters radiation shorter than 3-mm wavelength. Over ocean their signatures are often warm and can rise 100K or more above the cold ocean background that results from its high reflectivity, approximating 50 percent or more over much of the millimeter-centimeter wavelength spectrum.

In conclusion, the advent of the Dicke radiometer permitted the opening of the microwave spectrum to many practical and scientific uses in the remote sensing of the lower terrestrial atmosphere.

## ACKNOWLEDGEMENT

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