Infrared Radiance Spectra for Testing Radiative Transfer Models in Cold and Dry Atmospheres: Test Cases from the Antarctic Plateau

The results from the longwave radiation calculations performed as part of the project on Intercomparison of Radiation Codes used in Climate Models (ICRCCM) (Ellingson and Fouquart 1991) have led to the conclusion that spectral radiance measurements of the real atmosphere are needed to provide standards by which to compare radiative transfer models (Luther et al. 1988; Ellingson et al. 1991). Ideally, spectral radiance data should be measured under the full range of atmospheric conditions from different terrestrial locations. The atmosphere over the Antarctic Plateau is the coldest and driest on earth and thus can serve as a limiting test case. In winter, surface temperatures drop below −70°C, total column precipitable water vapor is as low as 0.3 mm, and the downward longwave flux can be less than 60 W m^{-2}. The surface temperature and humidity conditions over the Antarctic Plateau are similar to those found in the middle and upper troposphere at all latitudes.

A 1-yr field program was conducted at South Pole Station in 1992 to measure the downward infrared radiance spectrum at a resolution of 1 cm^{-1} from 550 to 1500 cm^{-1} using a Fourier transform interferometer. Three clear-sky test cases have been selected from this dataset, one each for summer, winter, and spring. The test cases include radiance data at two viewing zenith angles, 45° and 75°, as well as ancillary data from which model atmospheres have been constructed from radiosondes, ozone sondes, and other measurements (Walden 1995).

Figure 1 shows vertical profiles of temperature, water vapor, and ozone for 1 May 1992 during the South Polar winter. The steep temperature profile in the near-surface inversion layer is corrected for thermal lag of the radiosonde based on an experiment with radiosondes flown on a tethered kite (Mahesh et al. 1997). Humidity in the inversion layer is poorly measured with routine radiosondes, particularly in winter, so several sources are used to construct tropospheric humidity profiles for the model atmospheres: two commercially available radiosonde sensors, a frost-point hygrometer, and ice-crystal precipitation as evidence for saturation. Humidity in the stratosphere and mesosphere is obtained from frost-point hygrometers and satellite observations from the *Upper Atmosphere Research Satellite* (*UARS*). Ozone profiles are obtained from weekly ozone sondes. Continuous surface measurements of CO_2, CH_4, N_2O, CFC-11, and CFC-12 mixing ratios, made by the Climate Monitoring and Diagnostics Laboratory of the National Oceanic and Atmospheric Administration (NOAA–CMDL), are used as tropospheric values; stratospheric mixing ratios of these gases come from *UARS*.

Figure 2 shows the infrared radiance spectrum measured on 1 May 1992. The effect of the strong temperature inversion is seen in the carbon dioxide band between 600 and 700 cm^{-1}. The 9- and 11-μm window regions exhibit very low radiance because of the low total column water vapor amount (0.3 mm of precipitable water). Ozone emission is clearly visible at around 1040 cm^{-1}. Methane, nitrous oxide, and water vapor contribute at wavenumbers greater than 1200 cm^{-1}. The water vapor rotational band from 0 to 550 cm^{-1} is important to the energy balance of the middle and upper troposphere at all latitudes (Clough et al. 1992), but that spectral band was not measured by this instrument.

The total uncertainty (1σ) in spectral radiance varies with wavenumber from 0.2 to 2.5 mW m^{-2} sr^{-1} $(cm^{-1})^{-1}$ in winter, and from 0.2 to 3.0 in summer. Special attention has been given to establishing the accuracy of the temperature and spectral emissivity of the warm calibration source, because uncertainties in those quantities are the major sources of uncertainty in the spec-

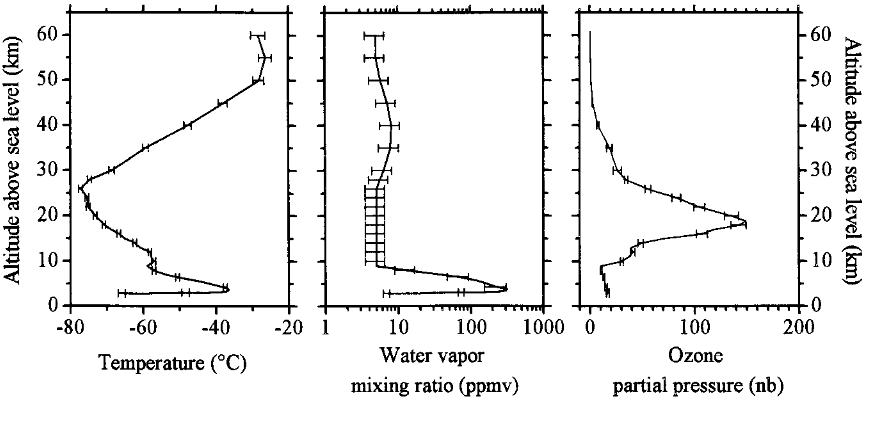

FIG. 1. Vertical profiles of temperature, water vapor mixing ratio, and ozone partial pressure measured over South Pole Station on 1 May 1992. The error bars are the estimated uncertainties (1σ) in the profiles, as discussed by Walden (1995).

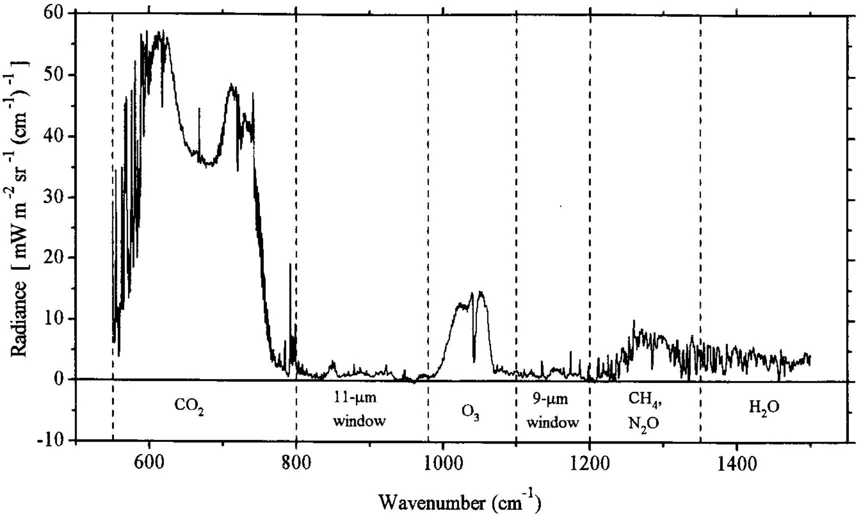

FIG. 2. Spectral radiance measured by the University of Denver's interferometer on 1 May 1992 at a viewing zenith angle of 75°. The vertical dashed lines separate the spectrum into six bands; the primary emitters in each band are indicated. The spurious line at 667 cm^{-1} is due to strong absorption by carbon dioxide where the instrument mostly views its internal temperature.

tral radiances (Walden et al. 1997). A correction has been made to the spectral measurements to remove the effect of the finite field of view of the interferometer. Any residual effect due to the field of view is expected to be less than the radiance uncertainties induced by uncertainties in the temperature and emissivity of the calibration sources.

The model atmospheres created from the ancillary data can be used as input to radiative transfer models. Comparisons of calculations from a line-by-line model with the actual spectral radiance measurements are given by Walden et al. (1997). The atmospheric profiles for the test cases are currently available to any interested modelers through ICRCCM by contacting Robert G. Ellingson (bobe@atmos.umd.edu) or Von P. Walden (vonw@ssec.wisc.edu). Modelers are encouraged to use the atmospheric profiles in their models to calculate spectral radiance, which can then be compared to the measured radiances.

Acknowledgments. We acknowledge the Carbon Cycle, Acquisition and Data Management, and Nitrous Oxide and Halocompounds Divisions of NOAA–CMDL for providing data. We thank the *UARS* project (Code 916) and the Distributed Active Archive Center (Code 902.2) at the Goddard Space Flight Center, Greenbelt, Maryland, for the production and distribution of the *UARS* data, respectively. The *UARS* activities are sponsored by NASA's Mission to Planet Earth Program. We thank the reviewers, S. A. Clough and B. B. Hicks, for their comments on the manuscript. This research was supported by NSF grants DPP-88-18570, OPP-91-20380, and OPP-94-21096.

References

Clough, S. A., M. J. Iacono, and J.-L. Moncet, 1992: Line-by-line calculations of atmospheric fluxes and cooling rates: Application to water vapor. *J. Geophys. Res.*, **97,** 15 761–15 785.

Ellingson, R. G., and Y. Fouquart, 1991: The intercomparison of radiation codes used in climate models: An overview. *J. Geophys. Res.*, **96,** 8925–8927.

——, J. Ellis, and S. Fels, 1991: The intercomparison of radiation codes used in climate models: Long wave results. *J. Geophys. Res.*, **96,** 8929–8953.

Luther, F. M., R. G. Ellingson, Y. Fouquart, S. Fels, N. A. Scott, and W. J. Wiscombe, 1988: Intercomparison of Radiation Codes in Climate Models (ICRCCM): Longwave clear-sky results—A workshop summary. *Bull. Amer. Meteor. Soc.*, **69,** 40–48.

Mahesh, A., V. P. Walden, and S. G. Warren, 1997: Radiosonde temperature measurements in strong inversions: Correction for thermal lag based on an experiment at South Pole. *J. Atmos. Oceanic Technol.*, **14,** 45–53.

Walden, V. P., 1995: The downward longwave radiation spectrum over the Antarctic Plateau. Ph.D. dissertation, University of Washington, 267 pp. [Available from University Microfilms, 300 North Zeeb Rd., P.O. Box 1346, Ann Arbor, MI 48106-1346.]

——, S. G. Warren, and F. J. Murcray, 1997: Measurements of the downward longwave radiation spectrum over the Antarctic Plateau and comparisons to a line-by-line radiative transfer model for clear skies, *J. Geophys. Res.*, in press.

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