ing material, and possibly montmorillonite have been made. These results indicate that there is an excellent potential for future narrowband, spectral imaging systems for mineralogical mapping from orbital platforms.

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References and Notes

1. The SMIRR instrument (Fig. 1) consists of a coaligned radiometer and two 16-mm cameras for positioning information. The radiometer consists of a reflecting telescope, spinning filter wheel, two thermoelectrically cooled HgCdTe detectors, and associated timing and signal conditioning electronics. Data were recorded on the shuttle payload tape recorder. The data were received from a 100-m-wide swath under the spacecraft. Field-of-view location within the camera frames is ±100 m. Data from the radiometer are oversampled so that sequentially obtained filter measurements can be resampled to provide spatially coincident data for all ten channels (A. F. H. Goetz, M. L. Brownell, J. C. Mahoney, D. B. Vane, in preparation).
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10. We thank Jet Propulsion Laboratory personnel M. Brownell and C. Mahoney and the other members of the SMIRR engineering team for their support in building, calibrating, and integrating SMIRR; H. Paley for her many years of work with the preparation, flight planning, and flight operation of SMIRR; and J. Reimer and E. Abbott for data reduction support. We thank F. El Baz and R. Said for contributions to the interpretation of the data. The research described here was carried out by Jet Propulsion Laboratory under contract with the National Aeronautics and Space Administration and by the U.S. Geological Survey.

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Carbon Monoxide Measurements in the Troposphere

Abstract. *During the second flight of the space shuttle, the measurement of air pollution from satellites (MAPS) experiment in the OSTA-1 payload acquired approximately 35 hours of radiometric measurements of the carbon monoxide mixing ratio in the middle troposphere, upper troposphere, and lower stratosphere. A gas filter radiometer operating in the 4.67-micrometer band was used to acquire the data over the region from 38°N to 38°S during both daytime and nighttime. The performance of the measurement system was excellent. The data reduced to date indicate the presence of significant gradients in the middle tropospheric carbon monoxide mixing ratio with both latitude and longitude over the North Atlantic, the Mediterranean Sea, and the Middle East. On the basis of comparisons with directly measured values, the accuracy of the measurements is approximately 15 percent. Comparisons of data taken on successive orbits over the same geographic region indicate that the repeatability of the measurements is approximately 5 percent.*

This report summarizes preliminary results obtained by the measurement of air pollution from satellites (MAPS) experiment during the second flight of the space shuttle. The major objectives of this experiment are to measure the mixing ratio of carbon monoxide in the middle and upper troposphere as a function of latitude, longitude, and season; to define the operational characteristics of the instrumentation system as part of an orbiting spacecraft; and to evaluate and refine the method of data inference. The MAPS science team (*1*) established that these objectives could be accomplished if a single measurement of ±20 percent accuracy were obtained in at least half of the 10° latitude by 10° longitude grid squares that underlie the orbital track on each of four seasonally spaced flights of the experiment. The flight aboard STS-2 was the first of the series.

The instrument employed is a nadir-viewing gas filter radiometer that operates in the 4.67-μm region of the CO fundamental band with a passband from 2080 to 2220 cm^{-1}. At the surface the instantaneous field of view is approximately 20 by 20 km. The instrument is similar to the selective chopper radiometer (*2*) in that it measures the difference in the upwelling radiation as seen through a vacuum cell and as seen through a cell of fixed pressure and path length containing the gas of interest. Implementation is very different, however, in that the MAPS signal balance between vacuum and gas path legs is continually maintained electronically by an automatic gain control circuit. The instrument evolved as a result of analytical and laboratory studies and aircraft flight tests (*3–7*). The instrument flown on STS-2, which is similar to that described by Ward and Zwick (*8*), is described in detail by Hesketh *et al.* (*9*). It has two 1-cm-long gas cells at different pressures, one containing pure CO at 76 torr and the other pure CO at 266 torr, and a single vacuum cell. This allows the measurement to be made in two broad atmospheric layers, one centered in the middle troposphere (the higher pressure cell) and the other centered in the upper troposphere and lower stratosphere (the lower pressure cell). Since the primary radiation source for the measurement is thermal radiation emitted by the earth's atmosphere, the experiment operates equally well during the daytime or the nighttime and over land or water.

Data from the experiment were formatted and stored on a tape recorder contained within the experiment package. In addition, a 35-mm camera with false-color infrared film acquired overlapping pictures of the daylight portions of the subsatellite track for use in evaluating the effects of the underlying surface and cloud cover.

The scheme for inferring the CO mixing ratio from the calibrated radiometric signals is based on the use of a regression approximation to line-by-line calculations of the atmospheric transmission (*10*). Operationally, line-by-line calculations are made for a set of model atmospheres that is representative of the range of temperature and humidity conditions that existed during the period of the measurements. These calculations yield predicted signal strengths as a function of CO mixing ratio and surface temperature. Regression coefficients, generated from these results for each model atmosphere, yield CO mixing ratios as a direct function of the observed radiometric signals. Actual conditions of atmospheric temperature and humidity along the orbital track are used to select the appropriate blend of coefficients. The actual conditions are obtained from either the U.S. Fleet Numerical Oceanographic Center or the NOAA National Meteorological Center analysis. This method allows the data for cloud-free fields of view to be reduced rapidly and at low cost. Fields of view containing middle-altitude or high clouds require that more highly refined methods be applied.

Correlative measurements were made during the mission. The primary test site was over the eastern United States, where a NASA Learjet carrying an aircraft version of the MAPS radiometer

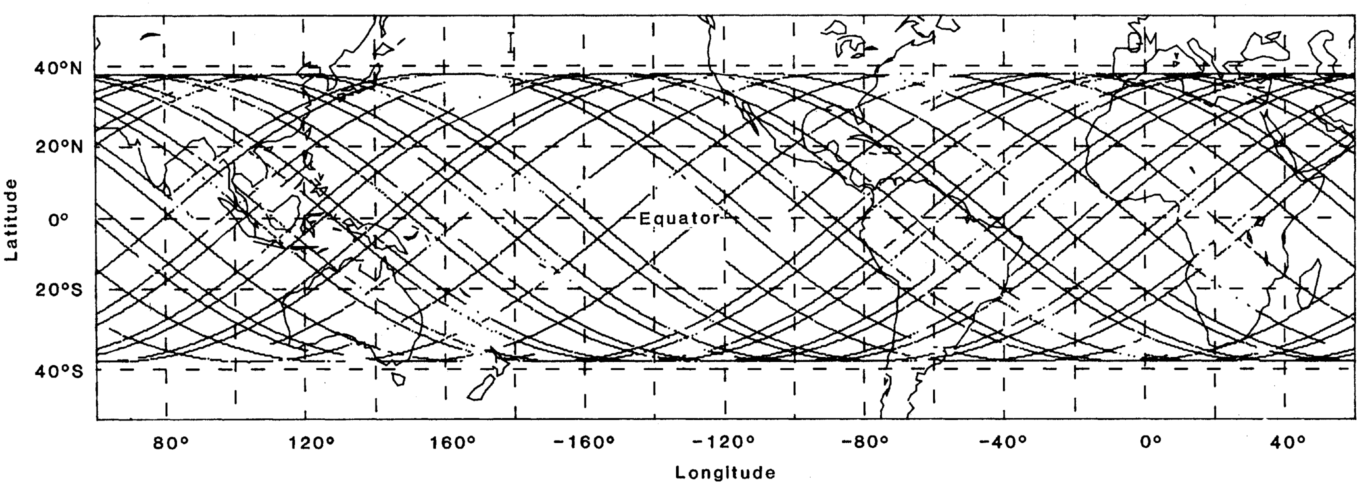

Fig. 1. Geographic coverage achieved by the MAPS experiment during the flight of STS-2, 12 and 13 November 1981. Open portions of tracks indicate periods when either the spacecraft was out of attitude or the instrument was being calibrated.

and gas sample bottles underflew orbit 18 over south-central Virginia and orbit 21 over Key West. This aircraft gathered data over the altitude range 12.5 to 0.3 km. The second test site was over the eastern Pacific Ocean approximately 600 miles west of San Francisco. There, NASA Convair 990 gathered air samples and meteorological data over the altitude range 10 to 0.3 km under orbits 21 and 22. The third test site was northwest of Melbourne, Australia, where air samples were taken from an altitude of 4 km to the surface for a 5-day period spanning the mission. In addition, special ozone sondes were flown from Wallops Island, Virginia.

The MAPS experiment operated for a total of 42.5 hours. During that period it acquired approximately 35 hours of potentially usable nadir-viewing data and underwent five in-flight calibrations. The ground tracks associated with these 35 hours are shown in Fig. 1. The geographic coverage was good even though the mission was abbreviated. In general, the higher latitudes were more heavily sampled than the equatorial regions. The only large region of sparse coverage was the central Pacific Ocean; hence, the requirement for high-quality measurements in 50 percent of the 10° by 10° grid squares may have been satisfied.

Radiometer and camera operation were nominal during the entire operating period. Large fluctuations in the temperature of the spacecraft's coolant loop (resulting from a combination of the effects of spacecraft radiator deployment angle, flash evaporator malfunction, and off-nominal payload coolant pump operation) have somewhat complicated the data reduction and have necessitated certain postflight instrument tests. However, these effects are not expected to seriously affect the quality of the final results. The instrument signal-to-noise ratio was approximately 150 to 1, which was higher than predicted. Zero and gain stability were excellent.

Initial efforts to reduce the data concentrated on comparisons among results obtained by the satellite-borne radiometer and the aircraft-borne radiometer and direct measurements over Farmville, Virginia. The results from the aircraft-borne radiometer and the directly measured profile agreed to within 10 percent; however, the satellite measurements indicated a substantially (approximately 50 percent) higher value for the CO mixing ratio. When the calibrated radiometric signals from the satellite-borne and aircraft-borne radiometers were compared, it was found that the discrepancy resulted from an error in the measurement of the upwelling radiance as seen through the vacuum cell. (After correction for atmospheric absorption, this is a measure of the radiance emitted by the underlying surface. The emitted radiance is used in the data reduction process.) Whether the discrepancy resulted from an instrument calibration problem or from an error in the calculation of atmospheric absorption above 12.5 km is not yet known.

While awaiting the results of an instrument calibration in a vacuum chamber, we have taken an empirical approach to the calibration of the surface radiance measurement. Specifically, we have selected a number of cloud-free sites over open ocean areas (to minimize surface temperature gradients) for as wide a range of surface temperatures as possible. The temperatures, as determined from Navy data, range from approximately 28°C in the Red Sea to 15°C in the Yellow Sea. Using the temperature data and a calculation of atmospheric absorption, we have been able to define a correction for the surface temperature measurement as inferred from the satellite data. This correction has been applied to the orbital data from the Virginia and Australia test sites. (The Pacific test site was under poor meteorological conditions at the time of the underflight.) The inference of the CO mixing ratio at these two sites with the empirical instrument calibration is now within 15 percent of the values recorded by the direct measurements. This is acceptable, since it is within the ± 20 percent accuracy sought by the science team. Completion of instrument recalibration in a vacuum chamber and refinement of the atmospheric model should further improve these results.

The data set for orbit 15 has been reduced by using the correction for the surface radiance calibration and atmospheric temperature models derived from the Fleet Numerical Oceanographic Center's meteorological analysis. Relatively simple methods were applied to remove some of the apparent noise associated with the effects of clouds passing through the instrument's field of view. Figure 2 shows the middle tropospheric CO mixing ratio for orbit 15 plotted as a function of longitude. These data begin at approximately 317 days, 11 hours, 51 minutes (Greenwich mean time). Most of the data for the Southern Hemisphere were not acquired on this orbit because the spacecraft was rolled out of earth-viewing attitude while the inertial platform was being aligned. The large apparent noise level in the data is an effect of clouds passing through the field of view. Clouds tend to cause an upward spike in the data. (The instrument noise level is somewhat less than the width of the "line" in the data over the Arabian Sea. The line is a series of one-per-second data points.) Also easily seen in the data over the Arabian Sea is an oscillation having a period of about 45 seconds. This oscillation results from the approximately ± 1°C variation in the instrument's reference blackbody temperature. Steps are now being taken to account for the actual time-dependent temperature of this blackbody in the data reduction, and to remove this oscillation.

If one takes instrument-induced oscillation and cloud effects into account, the best representation of the CO mixing ratio would be a smooth curve drawn through the data near the trace's lower edge. This curve would begin near the equator and 110°W at about 70 ppb (by volume) and rise smoothly to about 115 ppb at 30°N, 35°W, then fall again to 90 ppb at 37°N, 10°W. This is in qualitative agreement with the data of Seiler and Fishman (*11*). From this point, the orbital track is oriented nearly east and west along the length of the Mediterranean Sea, and the CO mixing ratio rises to a maximum value of 140 ppb just south of Cyprus. The track then turns southeastward and the CO mixing ratio falls rapidly to about 80 ppb over the Persian Gulf. This value is maintained across the Arabian Sea to near the southern tip of India. It can be seen from the data obtained on this one orbit that the experiment clearly shows the latitudinal and longitudinal variations in CO. With reduction of the total data set, it will be possible to separate these variations.

The repeatability of the experiment has been assessed by comparing the measurements taken over the same location on two different orbits. The ground tracks for orbits 15 and 16 cross near the southern end of the border between Spain and Portugal. The time separation is approximately 90 minutes. The weather was cloudy in the area for both passes, with the surface showing through the clouds in only scattered areas. The measurements for the two orbits agree to better than 5 ppb at a value of approximately 90 ppb, or to within about 5 percent.

From the data that have been reduced it is apparent that the MAPS experiment was highly successful. The instrument operated very well in spite of rather large, spacecraft-induced fluctuations in instrument temperature. The method of inferring the CO mixing ratio by means of regression coefficients works well, providing good accuracy at a relatively low cost. The accuracy of the experiment, when compared to direct measurements with gas chromatography, is approximately 15 percent, and the repeatability of the measurement is about 5 percent. This repeatability and accuracy, combined with the extensive geographical coverage, will allow both the scientific and technological objectives of the experiment to be achieved.

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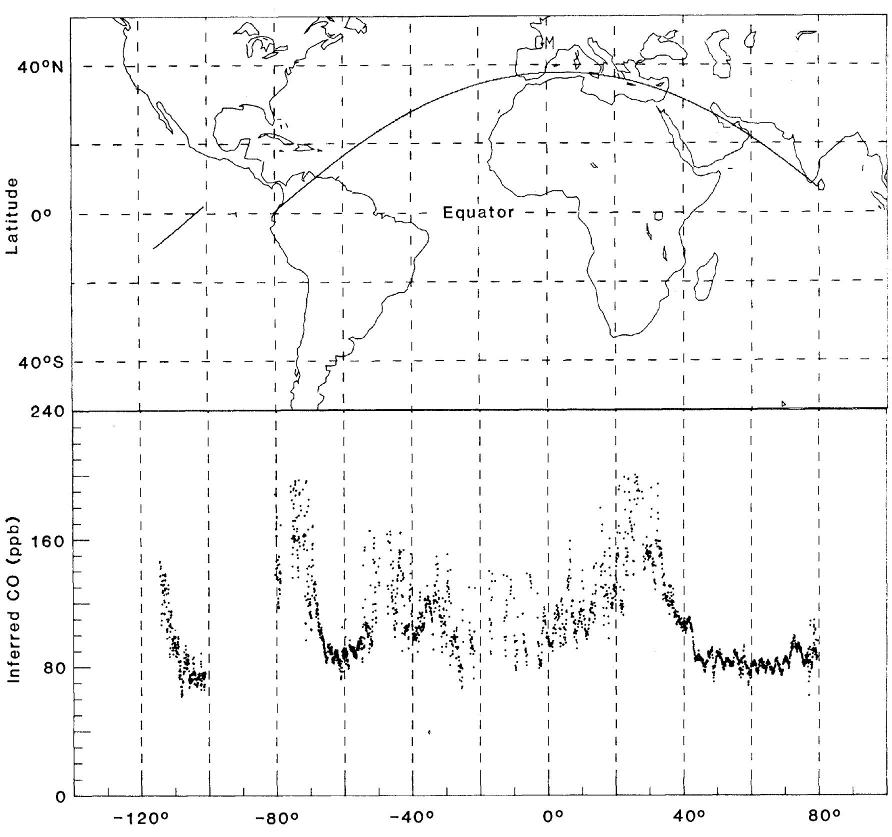

Fig. 2. Inferred middle tropospheric CO mixing ratio and corresponding ground track for orbit 15. Inferences are at 1-second intervals.

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