ATMOSPHERIC CORRECTION OF AVIRIS DATA OF MONTEREY BAY CONTAMINATED BY THIN CIRRUS CLOUDS

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1. INTRODUCTION

Point source measurements (e.g. sun photometer data, weather station observations) are often used to constrain radiative transfer models such as MODTRAN/LOWTRAN7 when atmospherically correcting AVIRIS imagery. The basic assumption is that the atmosphere is horizontally homogeneous throughout the entire area. If the target area of interest is located a distance away from the point measurement position, the calculated visibility and atmospheric profiles may not be characteristic of the atmosphere over the target.

AVIRIS scenes are often rejected when cloud cover exceeds 10 percent. However, if the cloud cover is determined to be primarily cirrus rather than cumulus, in-water optical properties may still be extracted over open ocean. High altitude cirrus clouds are non-absorbing at 744 nm (Reind, *et al*, 1992). If the optical properties of the AVIRIS scene can be determined from the 744 nm band itself, the atmospheric conditions during the overflight may be deduced.

2. STUDY SITE

AVIRIS imagery of Monterey Bay, CA (Figure 1) was acquired 4 September 1992 at 14:00 PDT in support of a larger experiment which involved shipboard measurements of photosynthetic pigment concentrations. Monterey Bay, a designated National Marine Sanctuary, is an ecologically important area that has been the subject of intense research for over 15 years due to the diversity of underwater habitats, increased bioproductivity from upwelling coastal waters and anthropogenic impact.

3. *IN-SITU* MEASUREMENTS AND PROCESSING

The Monterey Bay Aquarium Research Institute (MBARI) maintains a permanent mooring, M1, in the Bay. The mooring includes Biospherical Instruments MER-2020 underwater spectroradiometers at depths of 10 and 20 m which measured downwelling irradiance and upwelling radiance at six wavelengths and a surface sensor which measured surface irradiance at five wavelengths. A GPS is deployed on the mooring giving exact geographic coordinates at the time of the overflight. The MER-2020 data at 10 and 20 m were converted to water-leaving radiance at each of the five wavelengths. Instrumentation problems prevented use of the surface irradiance values.

Cloud profiling was performed simultaneously with Reagan sun photometer measurements at the Presidio in Monterey, CA, over 20 km away from the mooring location. The sky was characterized by an increasing coverage of stratocirrus and cirrus clouds from sunrise to the time of the overflight. A halo was detected around the sun indicating ice crystals at an altitude of approximately 12 km. The sun photometer data was reduced using a modified Langley approach (Bruegge, *et al*, 1990), yielding a calculated visibility of 36 km and atmospheric water profiles. Ancillary meteorological data were supplied by the Naval Post Graduate School's Doppler radar wind profiler (wind speed and wind direction) and the NPGS weather station (surface pressure and temperature).

4. ANALYSES AND RESULTS

A correction factor was applied to the radiometrically corrected AVIRIS data based on the ratio of the in-flight calibration to the laboratory calibration (Robert O. Green, JPL, personal communiqué). The 557 and 1382 nm bands of the corrected, calibrated AVIRIS scene were used to determine cloud type (Gao and Goetz, 1992). Cumulus clouds (low elevation water clouds), if present, will be visible in the 557 nm scene but will not be detected in the 1382 nm scene, where the observed radiance results only from the scattering by the cirrus clouds. The cloud cover, estimated at 20 percent, was entirely cirrus.

Apparent reflectance, ρ_{app}, of the cirrus clouds was calculated as

$$\rho_{app} = \frac{L_{AV_{744}}}{L_{TOA_{744}}} \quad (1)$$

where $L_{AV_{744}}$ is the radiance from AVIRIS 744 nm band and $L_{TOA_{744}}$ is the solar radiance at 744 nm above the top of the atmosphere (Iqbal, 1983).

Since the cirrus clouds are non-absorbing at 744 nm and the reflectance of the ocean surface is negligible at this wavelength, the radiance measured represents mainly the scattering of the ice crystals and the ocean aerosols. Transmission at 744 nm may then be approximated as

$$T_{AV_{744}} = 1.0 - \rho_{app} \quad (2)$$

and represents transmission of solar energy in the presence of aerosols.

MODTRAN was iteratively run at visibilities ranging from 30-100 km. The total optical depth at each visibility was separated into the individual components of Rayleigh [scattering], Mie [scattering] and ozone. At 70 km visibility, the MODTRAN predicted total aerosol optical depth matched within 2.55% the calculated optical depth from the AVIRIS 744 nm image.

A 50 x 50 pixel area at the location of M1 mooring was atmospherically corrected to water-leaving radiance with MODTRAN and incorporated a continuum interpolated band ratio (CIBR) correction for water vapor, an ozone correction factor and a visibility of 70 km (Davis, *et al*, 1993). The resulting spectrum demonstrates closer agreement with the calculated water-leaving radiance from the mooring data than L_w from 36 km visibility (Figure 2). The negative and low values between 400-450 nm are due to the insensitivity of AVIRIS to detect radiance values from dark [ocean] targets in these wavelengths.

In the absence of near-surface profiling measurements of the underwater light field, the mooring data represent a crude approximation when computing water-leaving radiance values. Profile measurements are typically binned to 1 m intervals. The depth-rate of spectral attenuation is fit with a polynomial, extrapolated to just below the surface, and transformed to a value just above the surface using an empirical relationship. With measurements only at 10 and 20 m, the attenuation curve is highly skewed toward lower attenuation values due to the fact that most of the absorption and scattering affecting water-leaving radiance occurs in the uppermost optical depth. This leads to artificially high calculations of water-leaving radiances.

C. Mobley's radiative transfer model (Mobley, 1989) was initialized with the irradiance calculated by MODTRAN, the vertical profile of chlorophyll-a concentration at mooring M1, the solar zenith angle and the recorded wind speed at the time of the AVIRIS overflight. The calculated water-leaving radiance at the six MER wavelengths (Figure 2) was rescaled by a factor of 0.4. This factor may be associated with the uncertainties in the irradiance calculated by MODTRAN, the absorption and scattering coefficients calculated for the open ocean versus coastal waters and the method of converting *in situ* MER measurements at 10 and 20 m to water-leaving radiance. The radiance distribution calculated by the radiative transfer model depends both on the inherent optical properties of the water column and on the sea state and sky radiance distribution. The model is applicable to general ocean waters. In these model runs, the absorption and scattering coefficients were calculated as functions of wavelength and chlorophyll using empirical relationships developed for clear ocean waters (Morel, 1988). In view of the fact that these relationships are not specific to Monterey Bay, the results are encouraging.

The above outlined method of retrieving atmospheric parameters from an AVIRIS scene demonstrates that there are caveats for using point source measurements for initializing MODTRAN and that AVIRIS scenes contaminated by optically thin cirrus clouds may still be atmospherically corrected.

5. ACKNOWLEDGEMENTS

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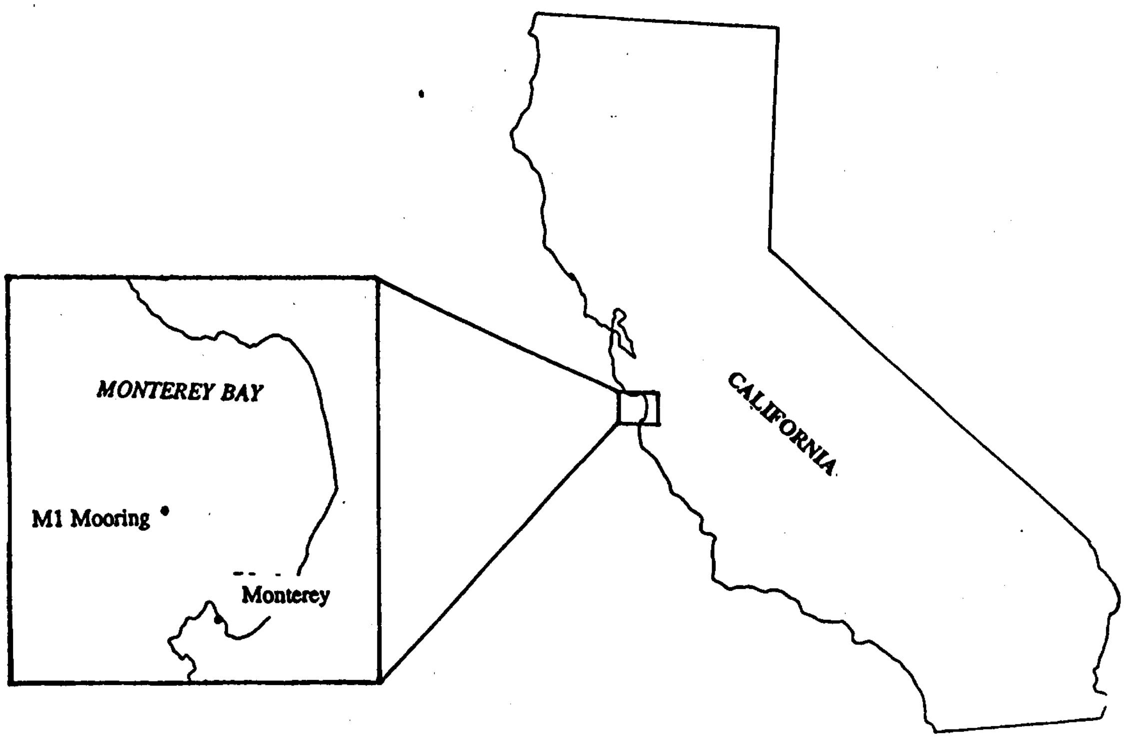

Figure 1. Study Site

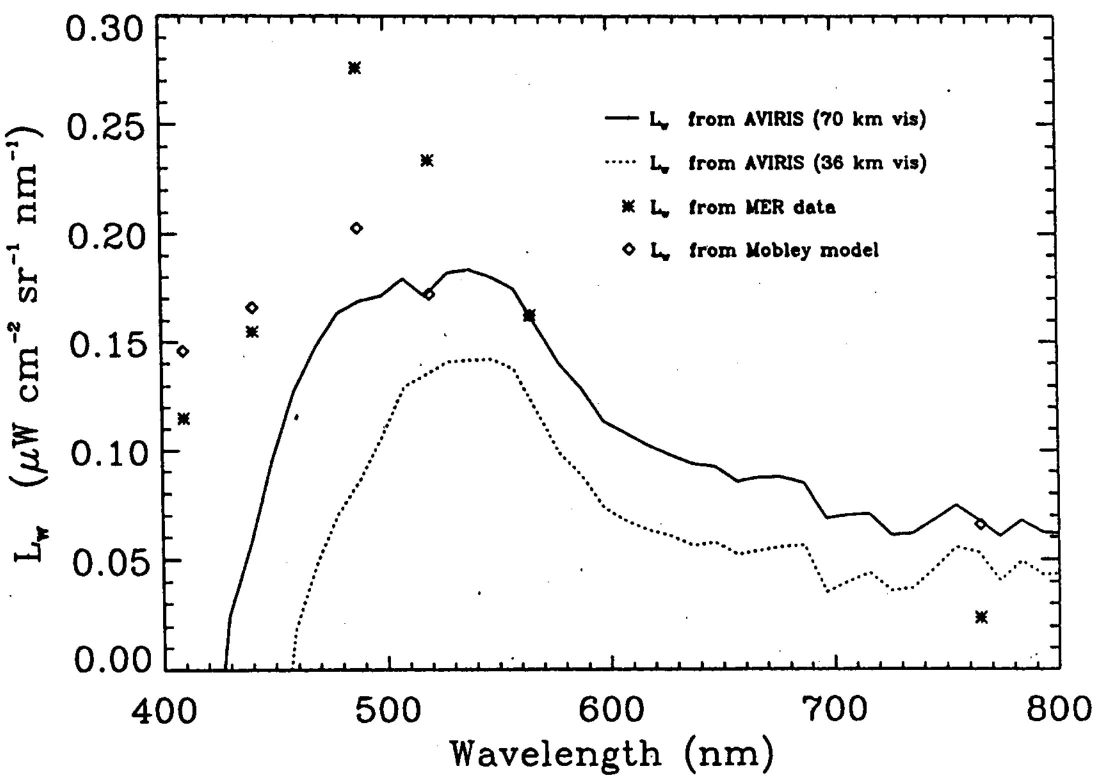

Figure 2. M1 Water-Leaving Radiance