

Looking Inside the Ocean Skin:
Differential absorption techniques to sense the interface temperature gradient
Walt McKeown, Code 7340, Naval Research Laboratory
Stennis Space Center, MS 39529
mckeown@nrlssc.navy.mil 601-688-5456 FAX 601-688-4149

The crucial role the air/sea interface plays in heat and gas transfers and satellite sea surface temperatures is well known. A full understanding of interface effects is delayed by the difficulties of making measurements inside this thin (~1.0 mm) and erratically moving zone.

Atmospheric sounding interferometers have been developed which use the frequency variations in atmospheric absorption to retrieve the temperature profiles (Smith et. al, 1983)). Using a similar strategy, such instruments have "sounded" the interface temperature gradient. Frequency variations of water's absorptive properties have been used to measure the temperature gradient inside the interface (McKeown, 1995). The measurement extends less than 1.0 mm. into the water; however, it is precisely this zone that is the most relevant to heat and gas transfers and the most difficult to sample. This technique also avoids the problems of thinness and erratic motion that plague mechanical measurements.

The water molecule has quantum resonance features which cause the optical properties to vary with frequency. For example, the absorption coefficient drops 7 orders of magnitude from infrared to optical frequencies. A useful parameter is the inverse of the absorption coefficient, called the effective optical depth or EOD. EOD quantifies the range of depths in which a frequency's radiation originates. Figure 1 shows EOD variations in 2 - 5 μm region (5000 - 2000 wavenumbers)

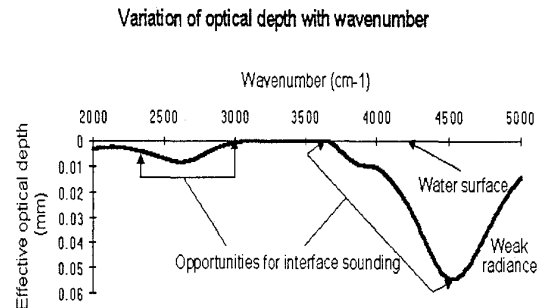


Figure 1. Variations of effective optical depth for water 2.0 - 5.0 μm (5000 - 2000 wavenumbers) Ref: Wieliczka, Weng & Querry, 1989

Since the radiant flux of a 300 K ocean is weak at 2.2 μm , the 3.8 μm region is the most practical for existing instruments. To explore the technique, the radiance spectrum emitted from a small well known water body was measured in a laboratory setting. Temperature change over time measured by thermistors allowed calculation of the interface heat flow and the gradient required by that flow (required gradient) to be known.

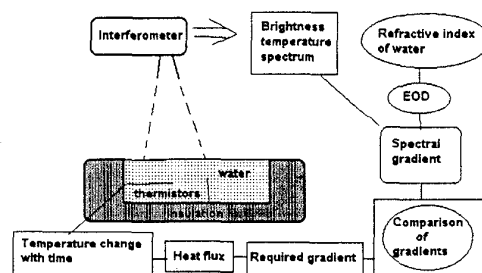


Figure 2. Experimental configuration

Since gradient measurement is the goal, the brightness temperature spectra were plotted at a frequency's EOD rather than the frequency itself. This plot, called a "spectral gradient", facilitates comparison of two gradients. Figure 3 shows the result.

Close agreement between radiometric and independently-measured gradients indicates that the interface gradient was observed. The instrument's high spectral resolution ($\lambda/\Delta\lambda=1000$) translated into unprecedented detail (900 measurements within 0.065 mm). The "overlap" feature is caused by different frequencies with the same optical depth. The overlap feature, consistently seen in many spectra, is internal evidence that interface gradients were being observed.

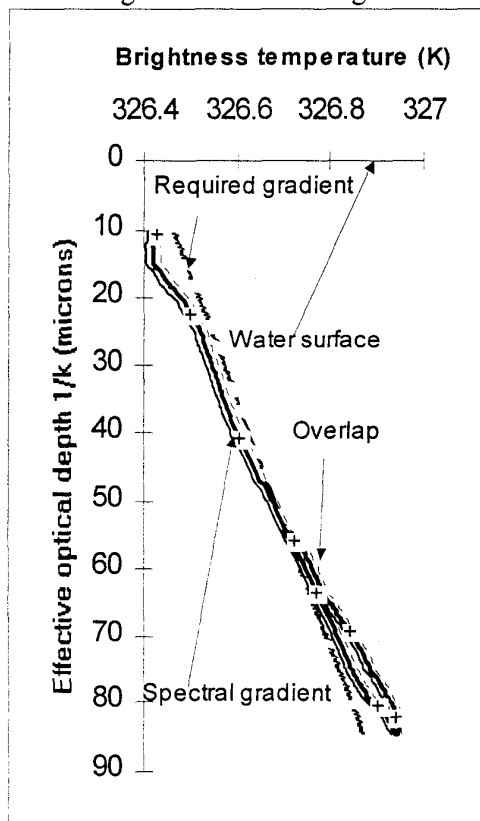


Figure 3. Comparison of spectral and required gradients. Thin parallel lines are measurement error limits

This capability applied to gas transfer was explored theoretically in order to supplement the expensive and labor-intensive shipborne measurements now needed (McKeown & Asher 1997). Heat is used as a proxy tracer for gas to sense the thickness of the zone in which heat moves primarily by conduction. Scaling arguments using a ratio of the thermal and molecular diffusivities are employed to relate the conduction zone thickness to the thickness of the zone in which gas is transferred primarily by diffusion. Laboratory experiments to investigate this approach are planned.

Another differential absorption technique images water with a low-noise (NETD = 0.025 K) infrared camera. Images are made in frequencies which have different absorptive properties: 3.817 and 4.514 μm . The difference of two images with different EOD carries information about the interface gradient. When properly calibrated, a capability to map heat flux variations on waves was shown at NRL (McKeown and Leighton, 1998). The experimental configuration is seen in Fig. 2; the camera replaces the interferometer. Fig. 4 shows the heat flux profile over a small 10 cm. wave.

Detecting these small signals requires effective noise suppression, thorough error analysis and advanced low-noise instrumentation. If ever used from aircraft or satellites, atmospheric effects must be minimized. While this may be considered from low altitude, a geosynchronous sounder may be needed to repeatedly measure the atmospheric profile. Averaging the soundings would allow surface signals to be reconstructed and a two-frequency technique applied. This strategy was simulated with Chris Sisko of the University of Wisconsin, using representative retrieval errors in

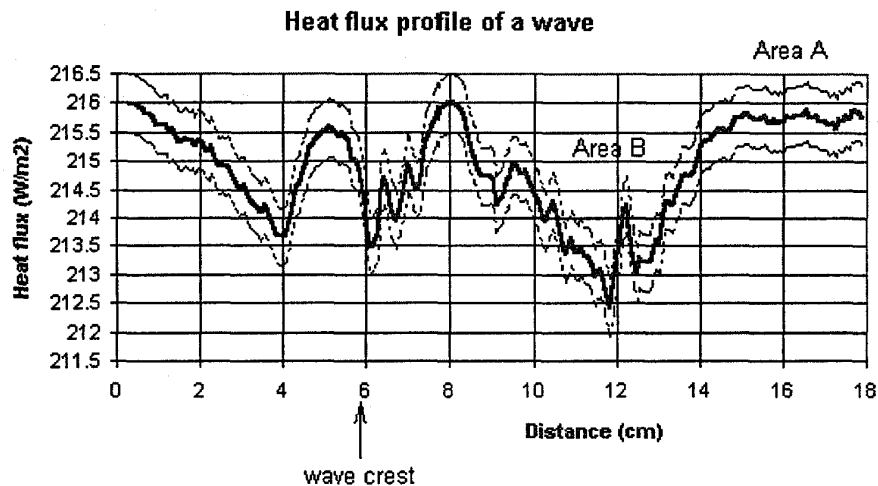


Fig. 4 Heat flux profile on 10 cm. wave

atmospheric temperature and specific humidity (McKeown & Sisko, 1998).

The results of the simulation indicate that averaging 5 soundings from 900 mb. would measure heat flux to within 20 W/m² RMSE. Satellite use would require averaging at least ten soundings to reach 15 W/m². The uncertainties in the retrieval process make it currently unknown how much error is random and can be averaged out or how much of the error is systematic.

No surfactant effects have been used in these experiments or simulations. While a monomolecular surface film may affect capillary wave behavior, it is unclear at present if such films have significant radiative effects.

Let there be no illusions: these are difficult measurements. The small signals become clear and useful only with advanced low-noise instrumentation which is well-calibrated and radiometrically stable.

However, differential absorption techniques look at water in a new way. Considering the importance of heat and gas transfer to climate change, looking inside the planet's largest homogenous

surface is a critical opportunity, difficult or not. If carefully employed, differential absorption techniques are the only know way to look inside this thin puzzling membrane, the top millimeter of the ocean.

References

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