Angular Dependence of Ocean Infrared Emissivity Derived from Marine-AERI observations during the ACAPEX Campaign

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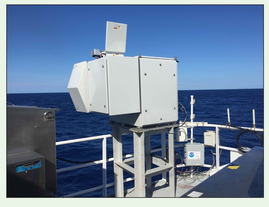
Marine-AERI

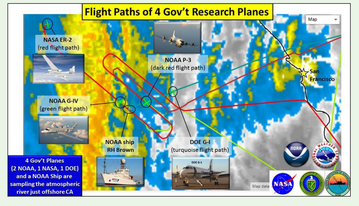
- A new ship-based Fourier transform spectrometer has been developed to measure the atmospheric downwelling and reflected infrared radiance spectrum at the Earth's surface with high absolute accuracy.
- This instrument was designed and built by ABB Inc., based on the heritage of the Atmospheric Emitted Radiance Interferometer (AERI) designed by the University of Wisconsin Space Science and Engineering Center (UW-SSEC) for the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program.
- Uplooking surface observations can be used to obtain vertical profiles of tropospheric temperature and water vapor, as well as measurements of trace gases (e.g. ozone, carbon monoxide, methane) and downwelling infrared spectral signatures of clouds and aerosols.
- Downlooking reflected observations can be used to obtain ocean skin temperature and surface emissivity. Both quantities are important in satellite meteorology. Marine-AERI observations can be used to test and validate existing models of sea surface emissivity, which in turn can lead to more accurate satellite meteorological observations.

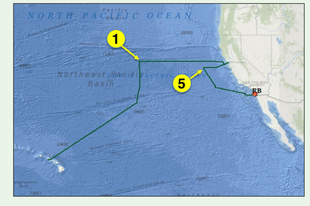
ACAPEX / CalWater 2 Field Campaign



For its maiden voyage, the new M-AERI was deployed in the Pacific Ocean on the NOAA Ship *Ronald H. Brown*, the flagship and largest vessel in the NOAA fleet, as part of the DOE ARM Second Mobile Facility (AMF-2) during the ARM Cloud Aerosol Precipitation Experiment (ACAPEX) / NOAA CalWater 2 campaign in Jan-Feb 2015.

The primary goal of the campaign was to study atmospheric rivers (AR), which transport moisture from the tropics to the mid-latitudes, and are responsible for the majority of precipitation on the U.S. west coast. Two significant AR events were encountered over the course of the campaign. The M-AERI dataset from ACAPEX contains a wider range of observation angles than previous emissivity studies, and will allow ocean emissivity models to be tested under new conditions.





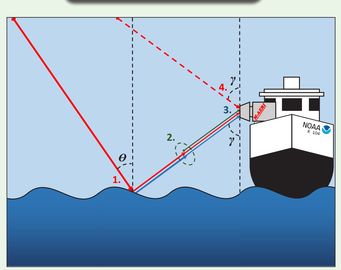
Emissivity and Temperature Retrieval

Surface Emissivity and Temperature are retrieved using an application of the radiative transfer equation:

$$R_\nu(\gamma) = [\varepsilon_\nu(\gamma)B_\nu(T_s) + (1-\varepsilon_\nu(\gamma))S_\nu(\Theta)]\,\tau_\nu(\gamma) + E_\nu(\gamma)$$

- $R_\nu(\gamma)$ is upwelling radiation observed by the M-AERI at wavenumber ν and nadir viewing angle γ.
- $\varepsilon_\nu(\gamma)$ is the emissivity of the ocean surface.
- B_ν is the Planck Radiation emitted by the ocean surface at temperature (T_s).
- $S_\nu(\Theta)$ is the downwelling radiation emitted by the atmosphere at zenith angle Θ that is reflected by the ocean's surface.
- $\tau_\nu(\gamma)$ and $E_\nu(\gamma)$ are the atmospheric transmittance and emission along the optical path between the M-AERI and the sea surface.
- All quantities besides $\varepsilon_\nu(\gamma)$ can be accurately measured or modelled, which allows a solution for emissivity

M-AERI View Angles

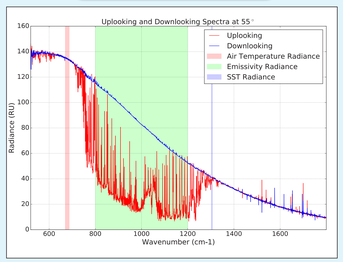


The various radition sources observed by the M-AERI:

1. Incoming atmospheric radiation at incidence angle Θ reflected at angle γ by the ocean surface (red). Radiation emitted by the ocean surface (blue).
2. Atmospheric emissiton (green) and transmitance.
3. The M-AERI measures all incoming infrared radiation at nadir angle γ.
4. The M-AERI measures incoming atmospheric radiation at zenith angle γ (red, dashed). A ratio function is applied to approximate incoming atmospheric radiation at angle Θ.

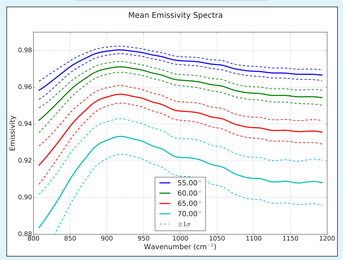
M-AERI Results

Observed Spectra



Upwelling ocean view radiance (blue) and downwelling sky view radiance (red) measured directly by the M-AERI. Shaded areas indicate the spectra regions used to retrieve air temperature (red), ocean skin temperature (blue), and ocean surface emissivity (green).

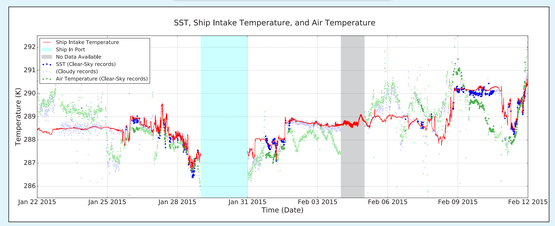
Emissivity vs. Angle



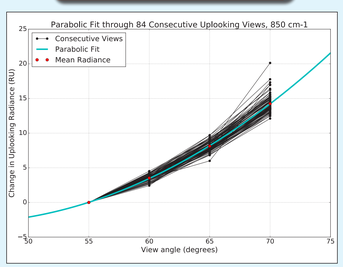
Left: Summary of emissivity results in the window region, averaged over the campaign, for four observing angles, with 1σ uncertainties.

Right: Time series of skin temperature (blue), air temperature (green) and ship intake temperature (red).

Retrieved Temperatures

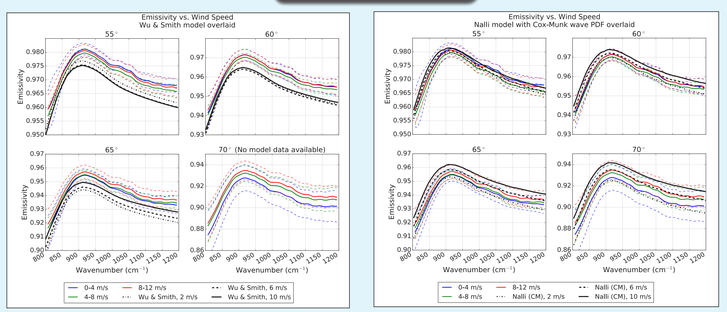


Uplooking Ratio Function



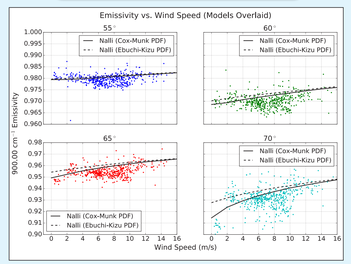
Consecutive uplooking sky view radiances (black) measured by the M-AERI at 55, 60, 65, and 70 degrees off-zenith. A parabolic least-squares fit (blue) through the mean radiance (red) at each view angle is used to approximate reflected sky radiance at angle of incidence Θ.

Emissivity Models



Emissivity results, sorted by wind speed and observing angle, as compared to the Wu & Smith model (left) and the more recent Nalli model (right). The recent model is in better agreement with the observations.

Emissivity vs. Windspeed



Scatterplot of 900 cm^{-1} emissivity vs. wind speed, for four observing angles, as compared to the recent recent Nalli models.

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