Addressing the Temperature Dependence of Water within the CRTM Infrared Sea Surface Emissivity (IRSSE) Model

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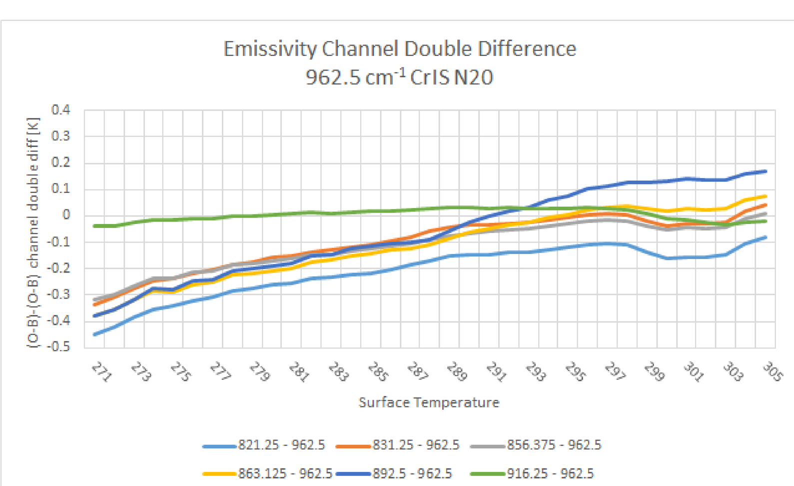
Relevance

- For satellite IR remote sensing applications, the **surface emissivity** must be specified with a high degree of absolute accuracy
- **0.5%** uncertainty ⇒ **≈0.3–0.4 K systematic error** in LWIR window channels
- For operational processing, fast-model efficiency is still of the essence

Temperature Dependence Found in Global Data

- Recent findings (*Liu et al.* 2019) show a **significant systematic bias** (order of **0.5 K**) **on a global scale**
- The **CRTM IR sea surface emissivity (IRSSE) Model** has thus been undergoing upgrades to account for *T*-dependence in the IR optical constants and atmospheric diffusivity



Currently Available Temperature Dependent IR Optical Constants

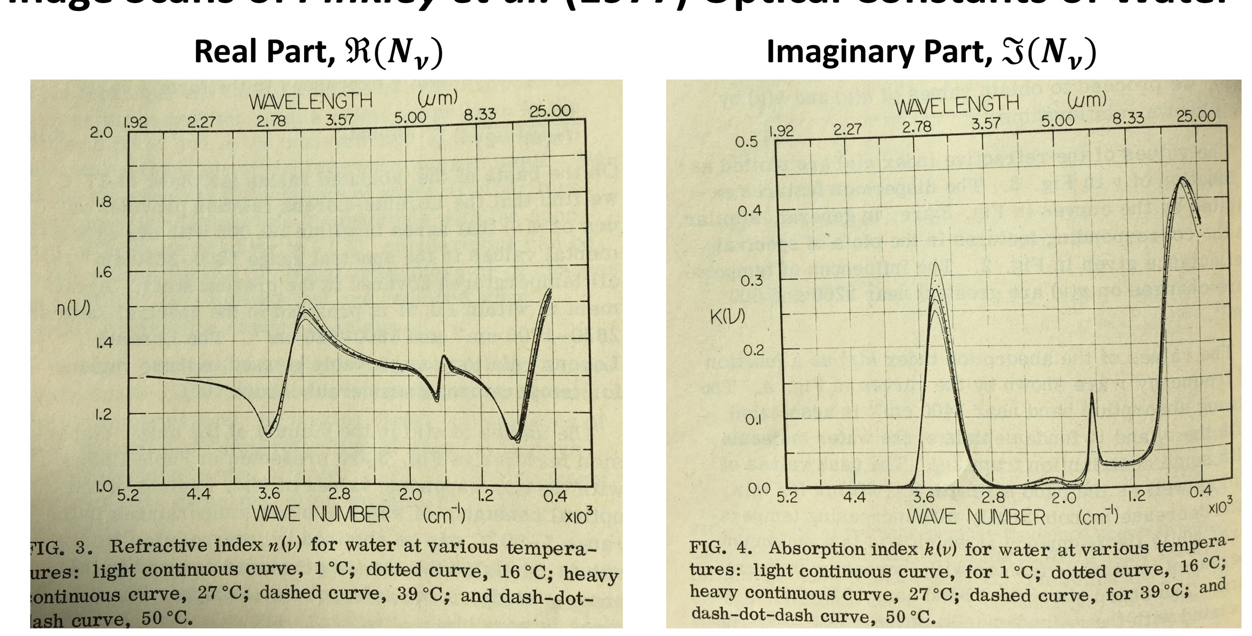
- **Existing measurements** of temperature-dependent IR optical constants for water are sparse
- ***Pinkley et al.* (1977)** are based on laboratory measurements of water reflectance
  - However, they only published in a table a very small subset of the IR spectrum, severely truncated to only 3 significant digits
  - They also provided their optical constants and reflectance-ratios within a couple of monochrome figures
  - We attempted to contact the Pinkley authors, but were unsuccessful (the authors may be deceased)
- ***Newman et al.* (2005)** derived their data experimentally from low-flying aircraft
  - Their data are currently used by RTTOV, but are limited to the LWIR
- ***Rowe et al.* (2020)** recently published data for supercooled water
  - Derived at supercooled water temperatures: 240, 253, 263, 273 K
  - The intended primary application of these data was for cloud droplets

Model Development and Testing

Preliminary Attempts to Account for Temperature Dependence

- The first upgrade attempt (v2.0) in 2019 utilized *ad hoc* digitized image scans of *T*-dependent data plotted by *Pinkley et al.* (1977)
  - This approach was ultimately suboptimal
- **Subsequent merged datasets** with ***Rowe et al.* (2020)** were developed and experimented with; however
  - The Rowe data are for **supercooled water**, with only one useful datapoint (273 K), from which a large interpolation was needed with independent datasets taken at room temperature
  - Thus, this approach was also ultimately suboptimal

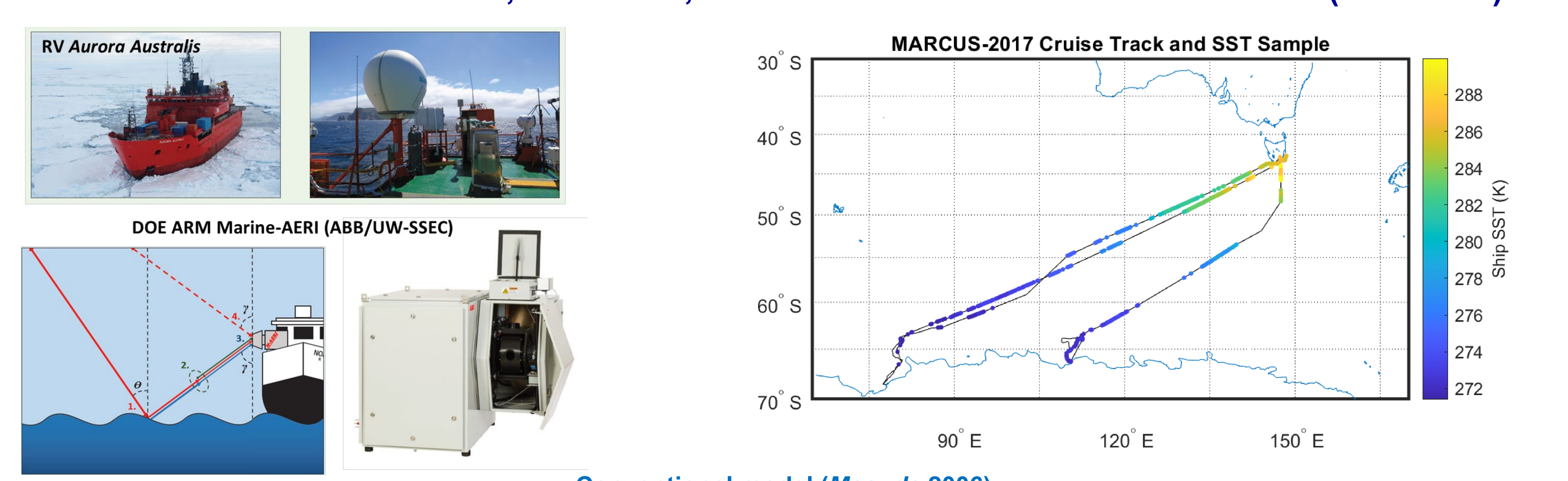
Inage Scans of *Pinkley et al.* (1977) Optical Constants of Water



Results

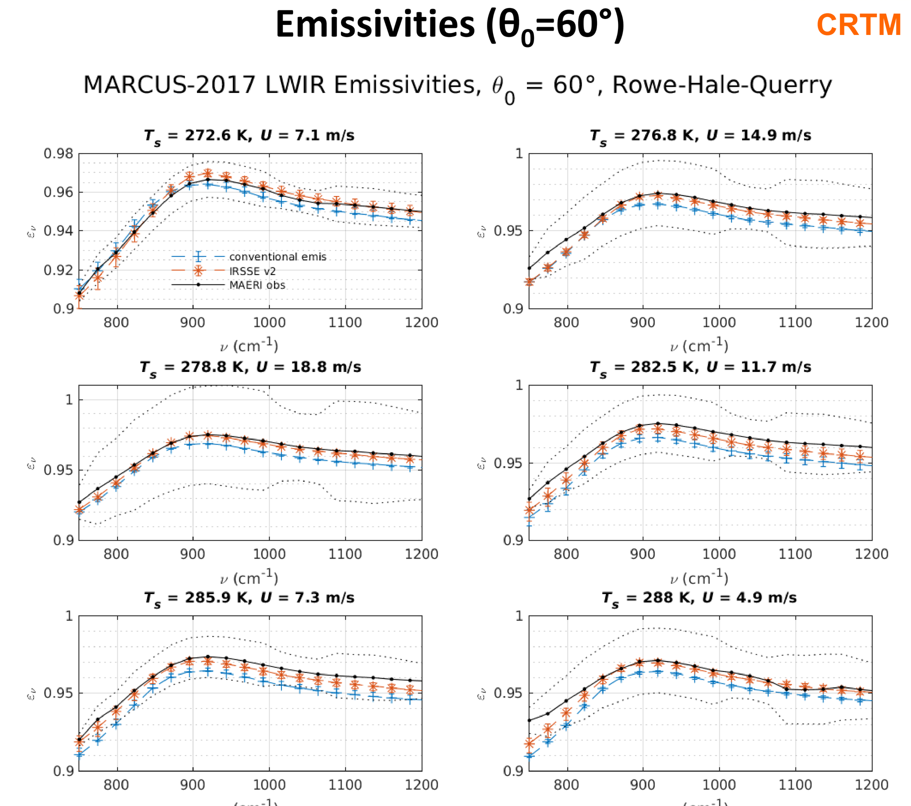
- **4-D lookup tables (LUT)** including temperature dimension have been generated and have undergone testing
  - **Field testing** of the adjusted LUT has been conducted versus 2 ship-based campaigns
    - **MARCUS 2017** campaign (Southern Ocean, cold water)
    - **CSP 1996** campaign (Tropical Western Pacific Warm Pool; *Post et al.* 1997)
  - NOAA operational **CRTM GSI assimilation testing** and **impact studies**
  - **UMBC kCARTA testing** (with DeSouza-Machado and Strow)
  - The results show improved agreement of *calc* with *obs*, but some residual spectral biases remain (e.g., see figure below)

Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean (MARCUS)

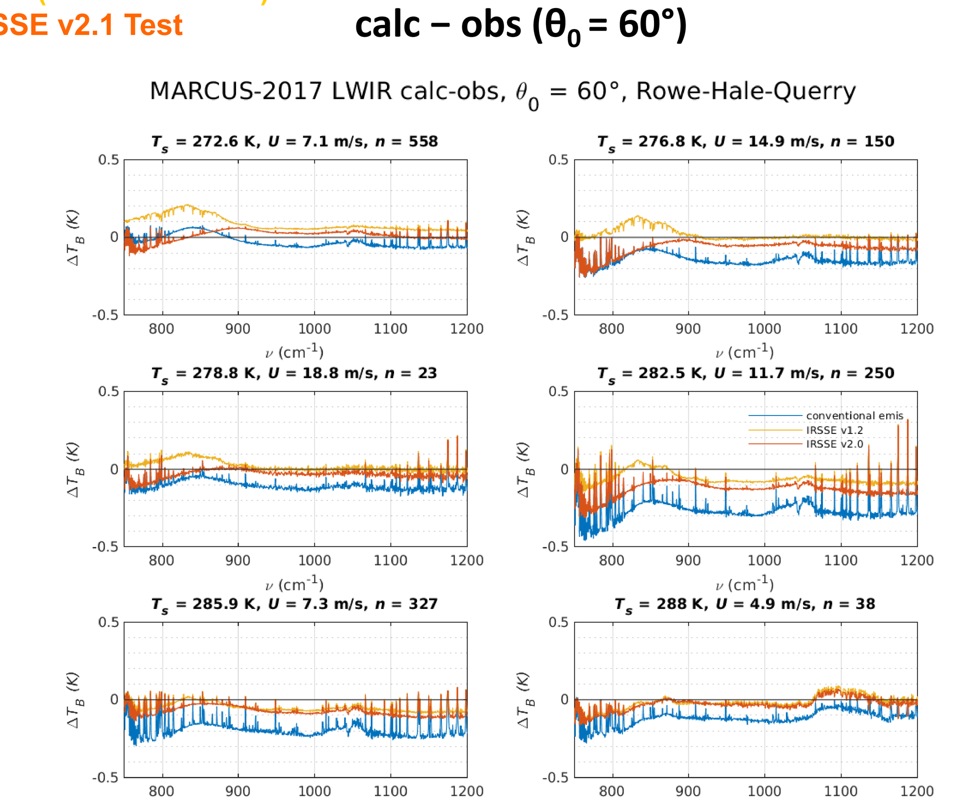


Conventional model (*Masuda* 2006)
CRTM IRSSE v1.2 (*Nalli et al.* 2008)
CRTM IRSSE v2.1 Test

Emissivities (θ_0=60°)



calc – obs (θ_0 = 60°)

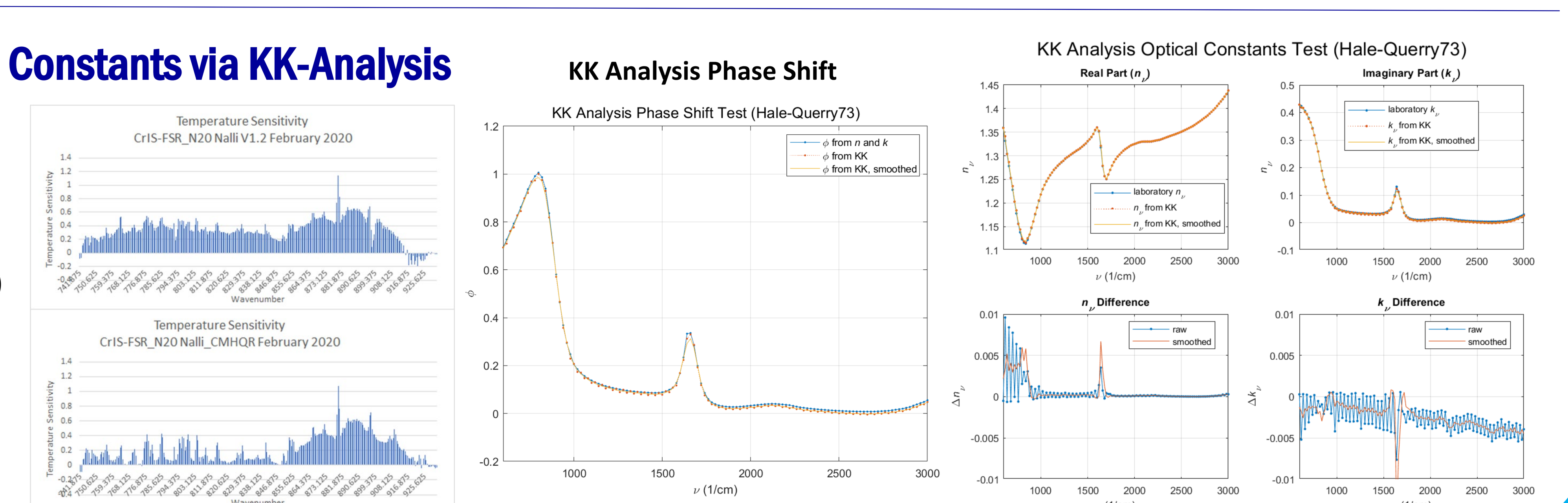


Deriving Temperature-Dependent IR Optical Constants via KK-Analysis

- Because of the sub-optimal approaches described above (leading to residual spectral biases; see leftmost figure), we are now employing a rigorous approach via digitization of **Pinkley's reflectance measurements** and **Kramers-Kronig (KK) analysis** (e.g., *Stegmann et al.* 2017)
- We are currently in the process of generating optical constants for all published datasets, then implementing within the IRSSE model
- This also provides us the methodology and experience for deriving a new laboratory set given a funding source

KK Analysis Phase Shift

KK Analysis Optical Constants Test (Hale-Querry73)



Summary and Future Work

- The **IRSSE test LUT** exhibit improved agreement with the MAERI observations at over the range of surface temperature and windspeeds
  - Systematic spectral biases (≈0.1–0.5 K) associated with SST dependence and the ocean BRDF have been reduced vs MAERI observations
- Additional testing and optimizing the model within NOAA operational GSI assimilation and SARTA implementation is ongoing
- A **new set of laboratory-measured IR optical constants** of water is desirable for this effort (we would employ our **KK-analysis** method)
  - Responsive to **ITSC-22 ITSP-WG Action RTSP-5**

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