IRISS: InfraRed In situ Sea Skin Skin Temperature Measurements for USVs and Buoys

Use of an Optimal Spectral Band

Andy Jessup
Applied Physics Laboratory , University of Washington
Richard Jenkins and David Peacock
Saildrone, Inc.

R/V Oceanus
October 2021

Saildrone

Acknowledgements
NSF Ocean Technology and Interdisciplinary Coordination Program
Elizabeth Thompson, NOAA PSL
Mike Reynolds, RMR
Tom Farrar, WHOI
Peter Minnett, Miami
Bob Knuteson, Wisconsin

ISFRN Workshop 2022

Challenges Limiting T_{skin} Measurements to Ships

- Need for *in situ* two-point calibration using precision blackbodies
- Separate sky measurement to correct for reflected downwelling radiance
- Uncertainty in emissivity, which depends on incidence angle and roughness

- Improved radiometer stability allows simplified 1-pt calibration
- Optimal Spectral Band approach may:
  - Eliminate need for sky measurement via modeling using Tair and RH
  - Reduce emissivity effects

Outline

- Part 1: Simplified Calibration with Separate Sky Measurement
- Part 2: Optimal Spectral Band: Preliminary Results

Part 1: Design and Testing Strategy

Design

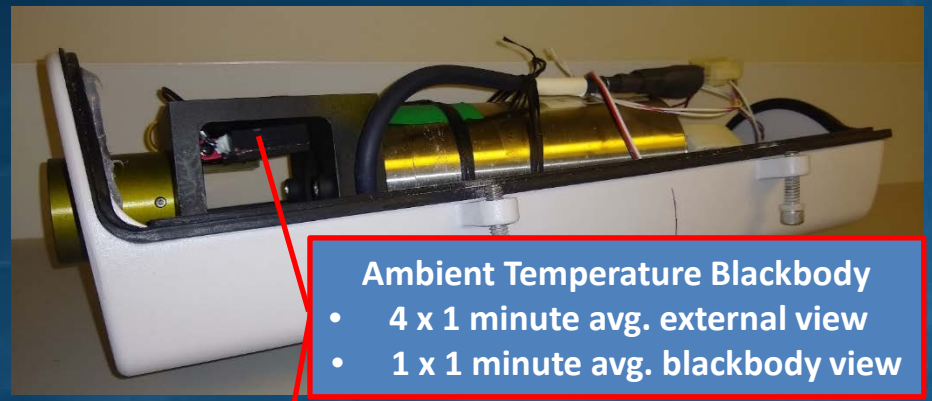
- Up and down IR sensors
  - Eliminates mirror
  - Protects down lens
  - Rain guard for up sensor
- Simplified calibration
  - Lab characterization
  - 1-pt ambient in situ cal.

Testing

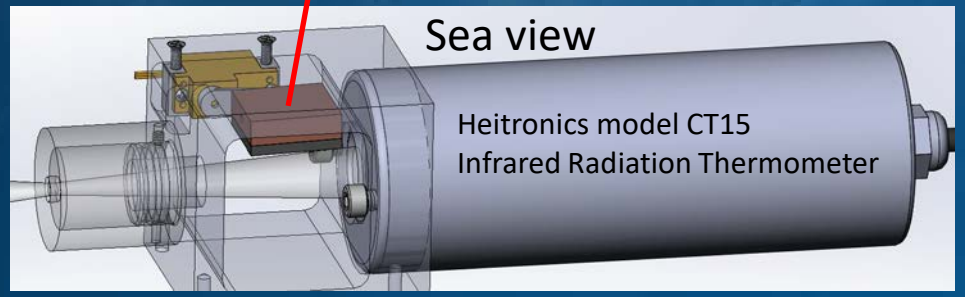
- Ship Measurements
  - 2 x ROSR – reference
  - IRISS prototypes
- Saildrone
  - Add uplooking sensor
  - Shadow with ship

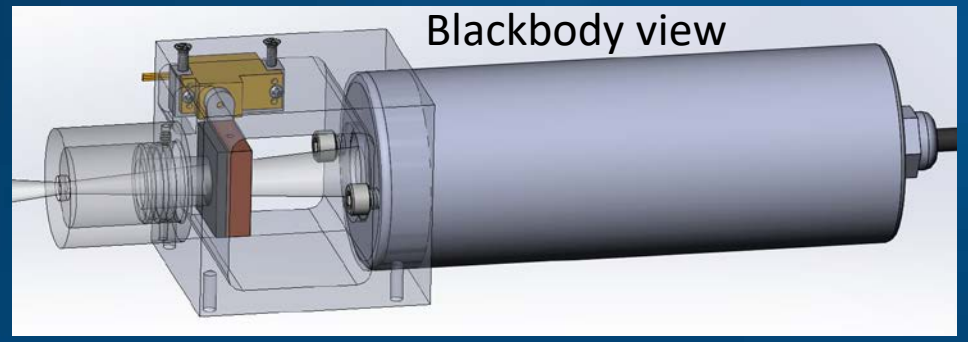
IRISS Prototype Design

Downlooking

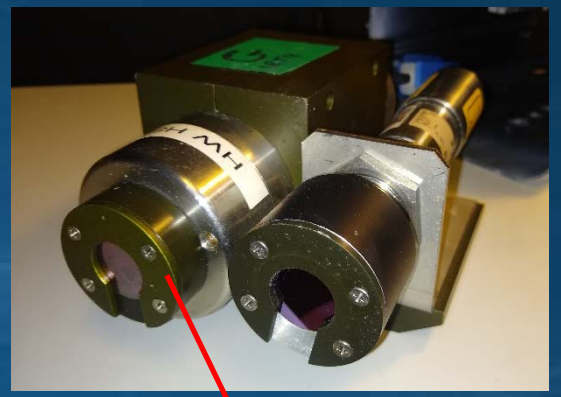


Ambient Temperature Blackbody
- 4 x 1 minute avg. external view
- 1 x 1 minute avg. blackbody view

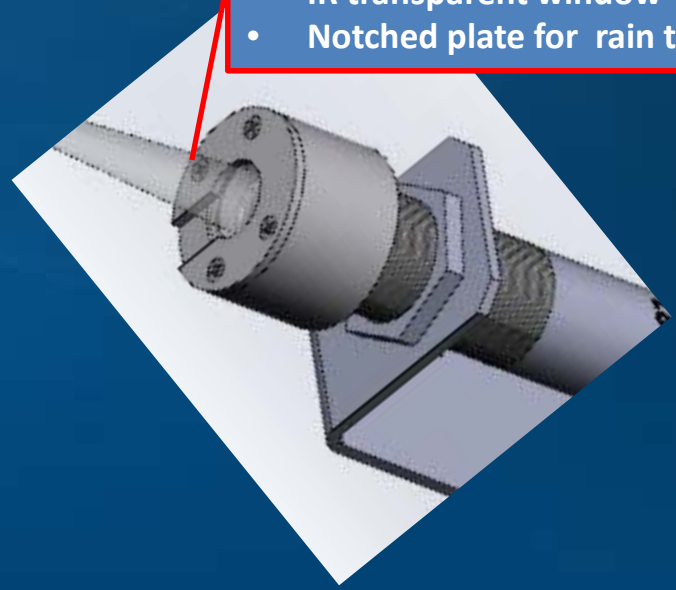




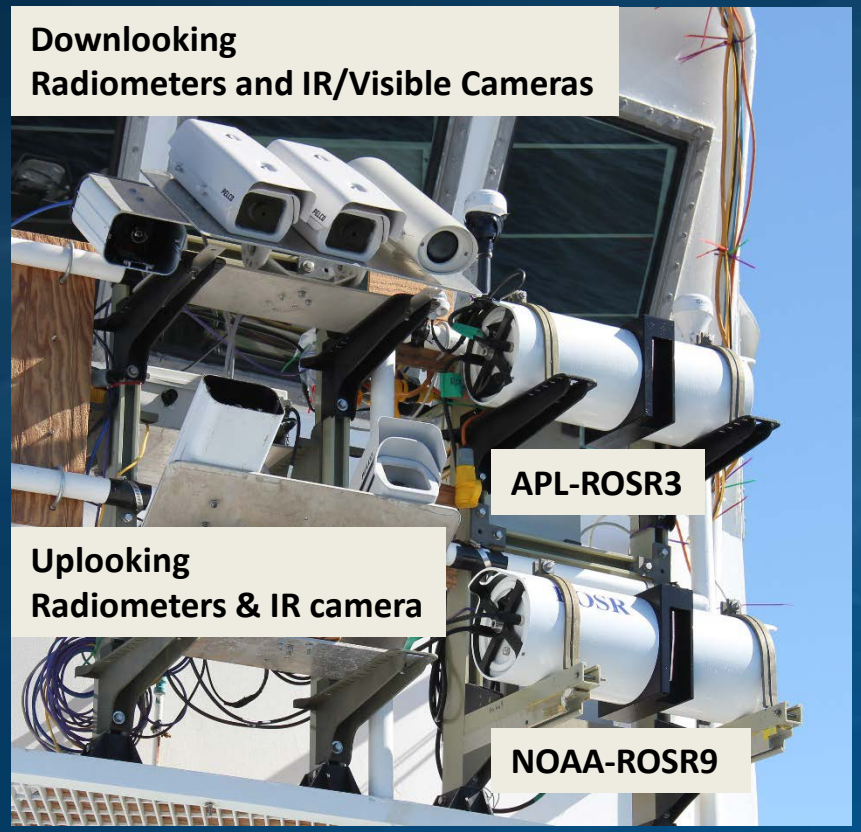
Uplooking



Rain Guard
- IR transparent window
- Notched plate for rain to drain

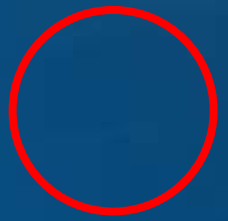


R/V Oceanus October 2021



2 x ROSR
3 x Uplooking radiometers
2 x Downlooking radiometers
2 x sea snake T sensors

WakeCam



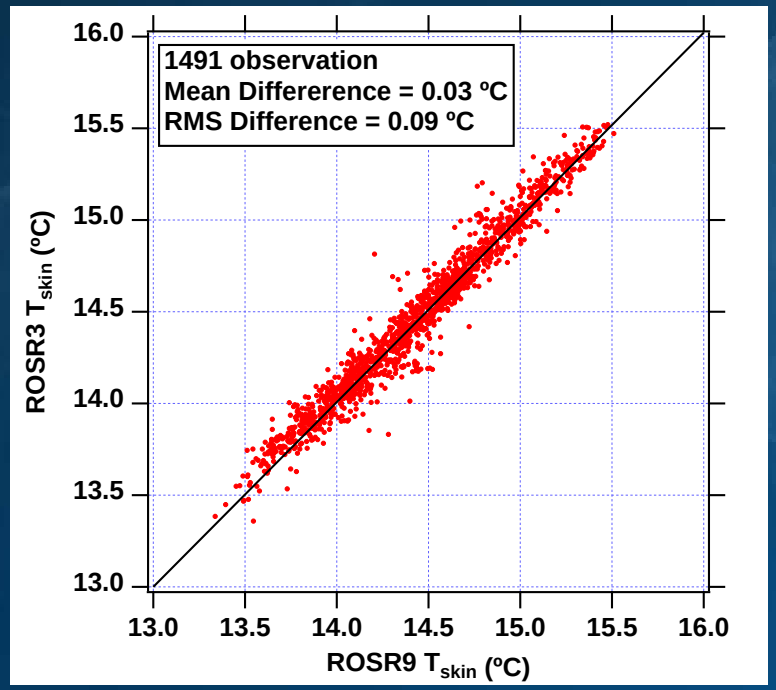
Infrared

Good data for ship speed less than 5 knots

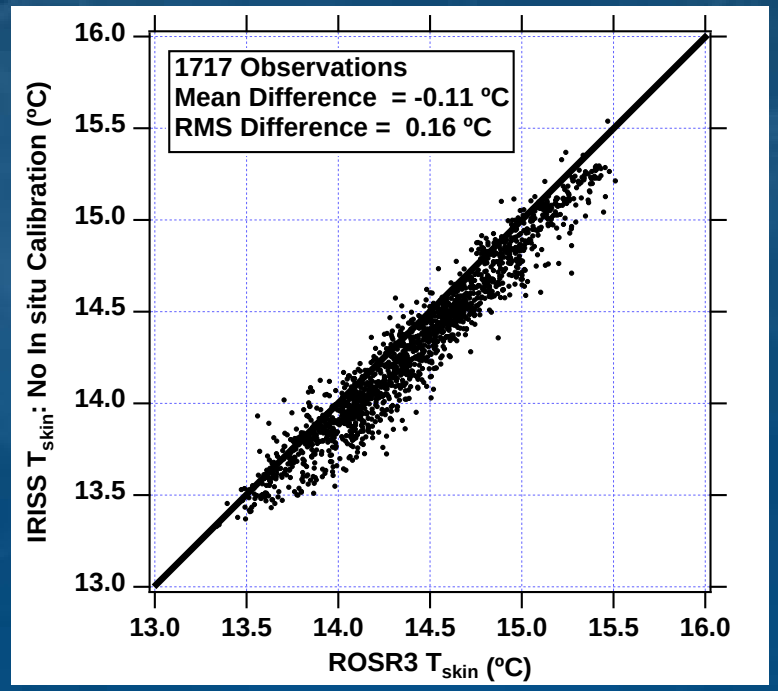
Oceanus 2021

ROSR/ROSR and ROSR/IRISS Comparison

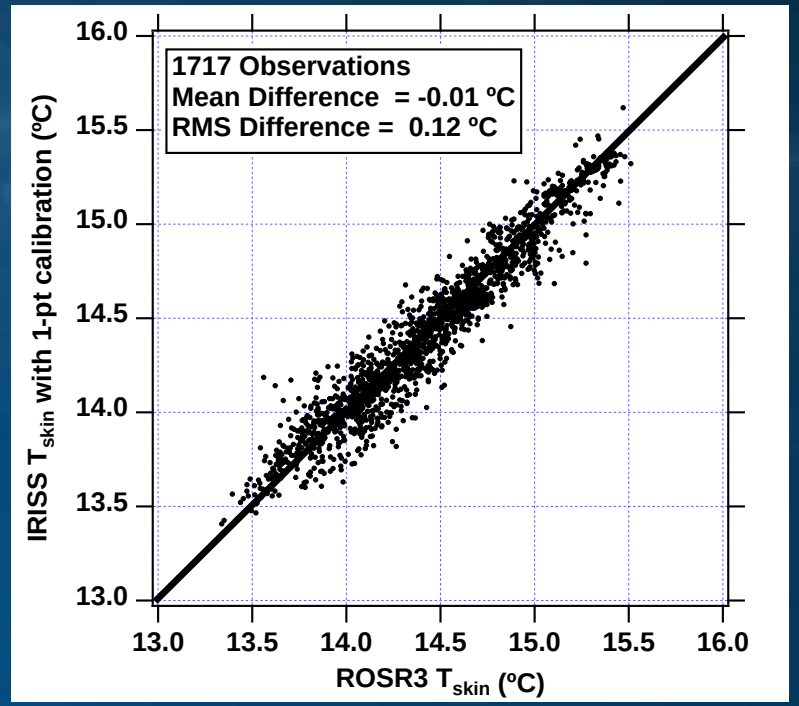
APL-ROSR3 vs NOAA-ROSR9



IRISS vs ROSR3 without 1pt cal.



IRISS vs ROSR3 with 1-pt cal.

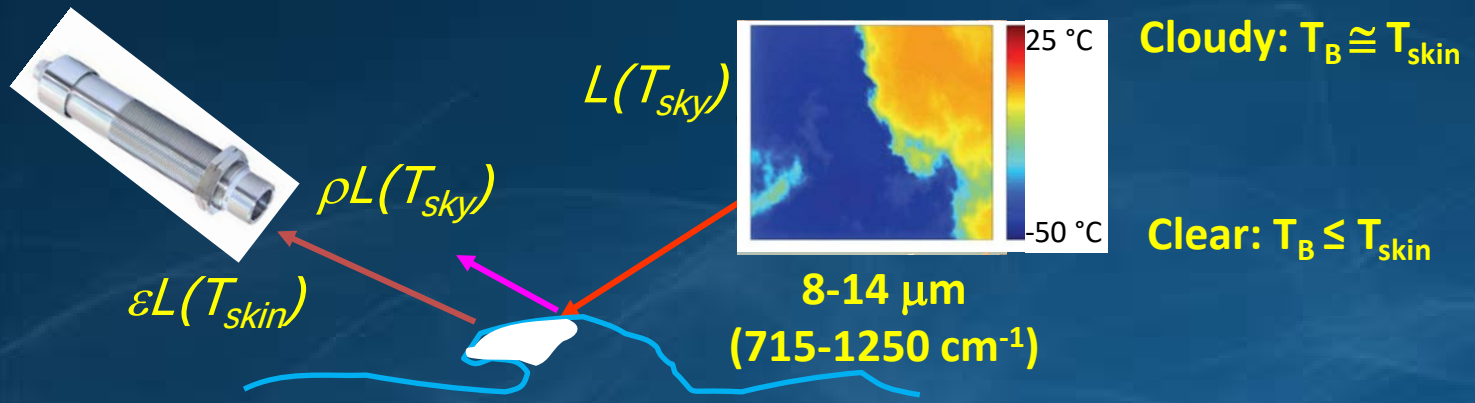


Quantity	Mean	Std dev	Min	Max
$T_{ISAR} - T_{CIRIMS}$	0.00	0.13	−0.64	0.52
$T_{ISAR} - T_{MAERI}$	−0.08	0.15	−0.84	1.01
$T_{MAERI} - T_{CIRIMS}$	0.08	0.15	−1.15	1.10

[*Branch et al.*, 2008]

Ship-based IRISS w/ 1-pt in situ cal. has accuracy comparable to ROSR

Part 2: Optimal Spectral Band



Cloudy: $T_B \cong T_{skin}$

Clear: $T_B \leq T_{skin}$

$$L(T_B) = \varepsilon L(T_{skin}) + \rho L(T_{sky})$$

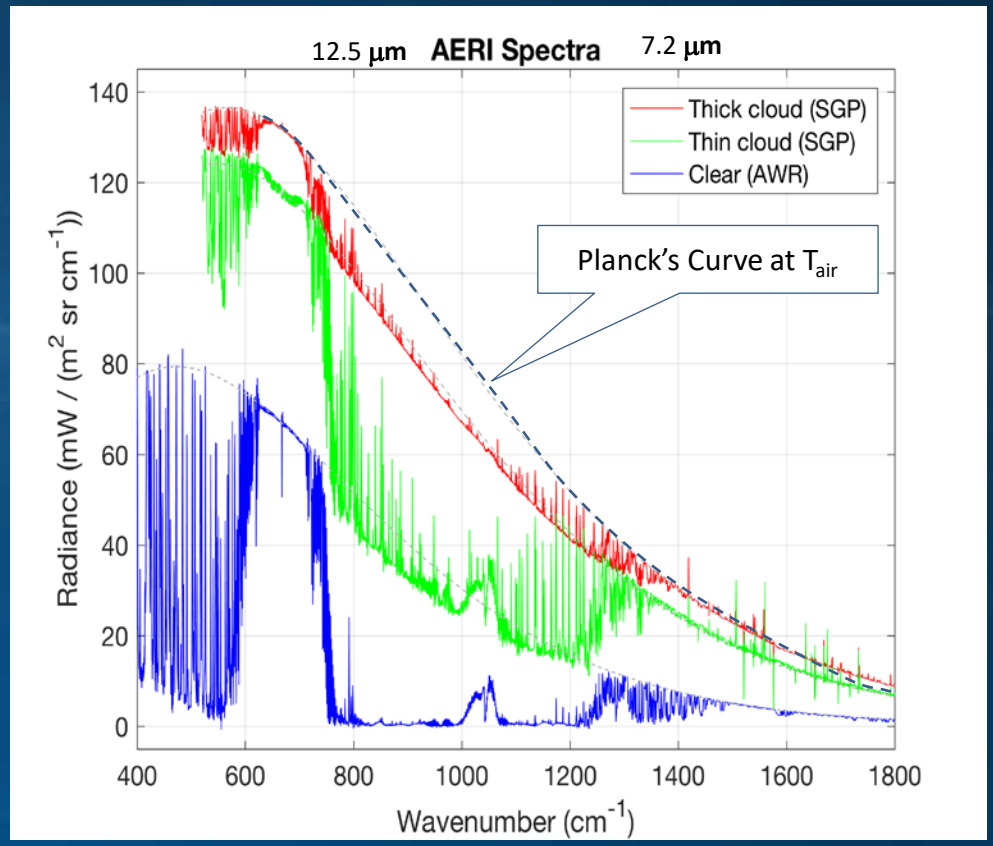
Range of T_{sky} depends on spectral band

Optimal Spectral Band

- **optical depth from the ocean to top of the atmosphere is large**
- **reflected sky radiance is from 1-2 km of the ship**
- **relatively invariant because it is not affected by clouds**

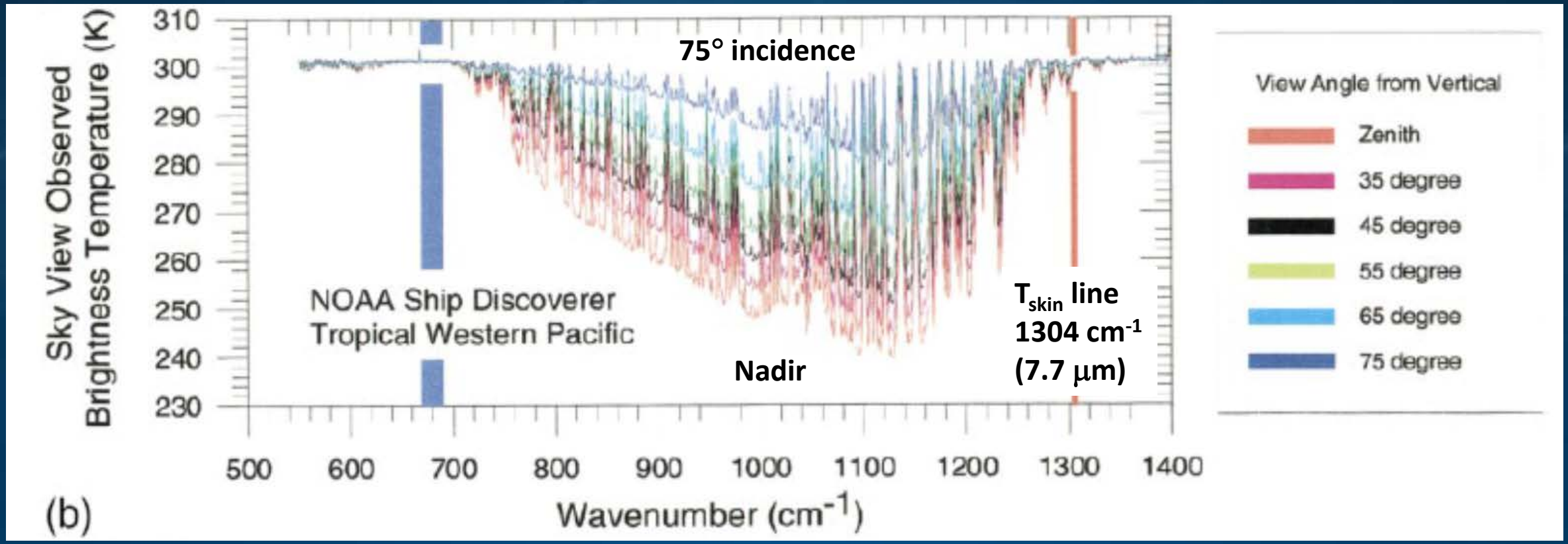
[*Smith, Knuteson, et al.*, 1996]

Downwelling Sky Radiance Spectra



[https://www.ssec.wisc.edu/aeri/]

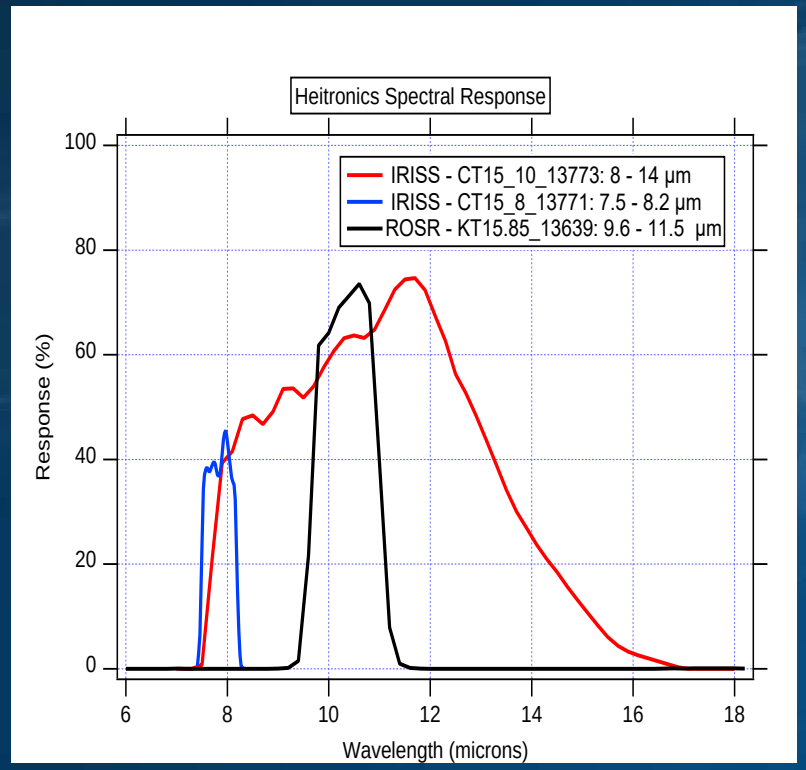
M-AERI Clear Sky Brightness Temperature Spectra



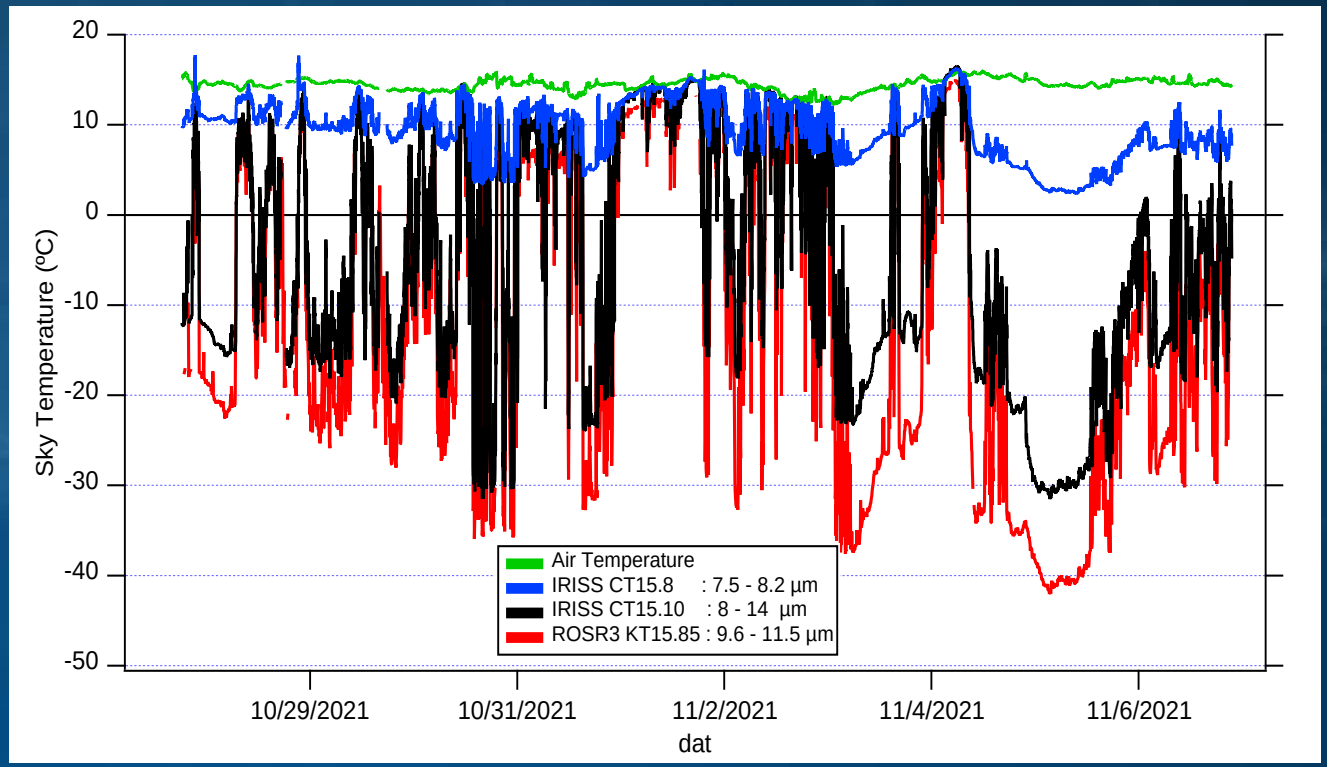
[*Minnett et al.*, 2001]

R/V Oceanus Spectral Bands

Spectral Responses



Sky and Air Temperature Time Series



Heitronics

- CT15.10: 8-14 µm
- KT 15.85: 9.6-11.5 µm
- CT15.8: 7.5-8.2 µm (centered on M-AERI band)

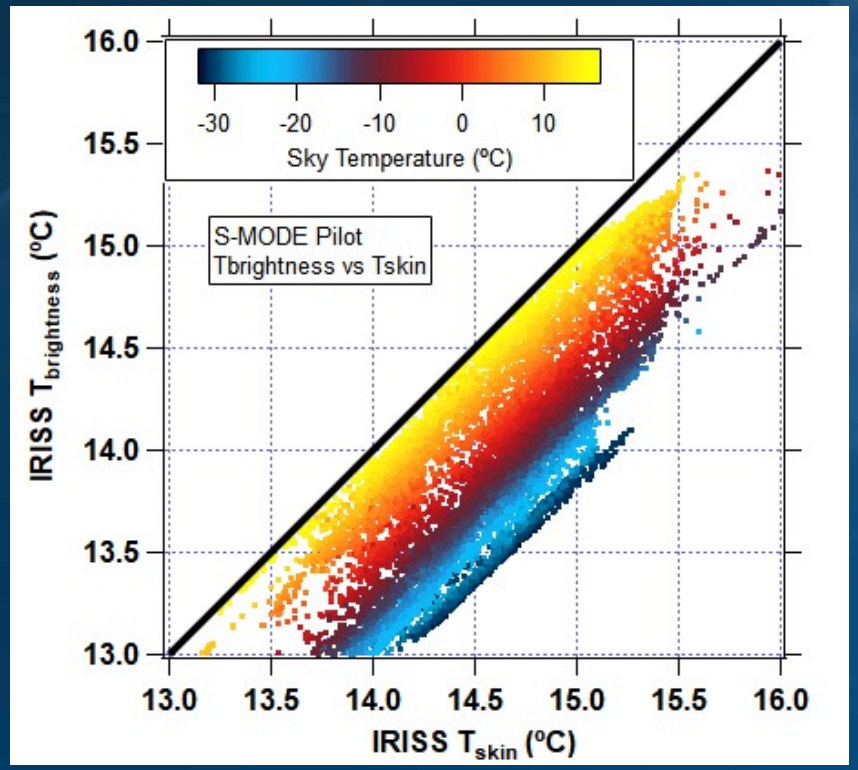
Cloudy: All T_{sky} comparable to T_{air}

Clear:

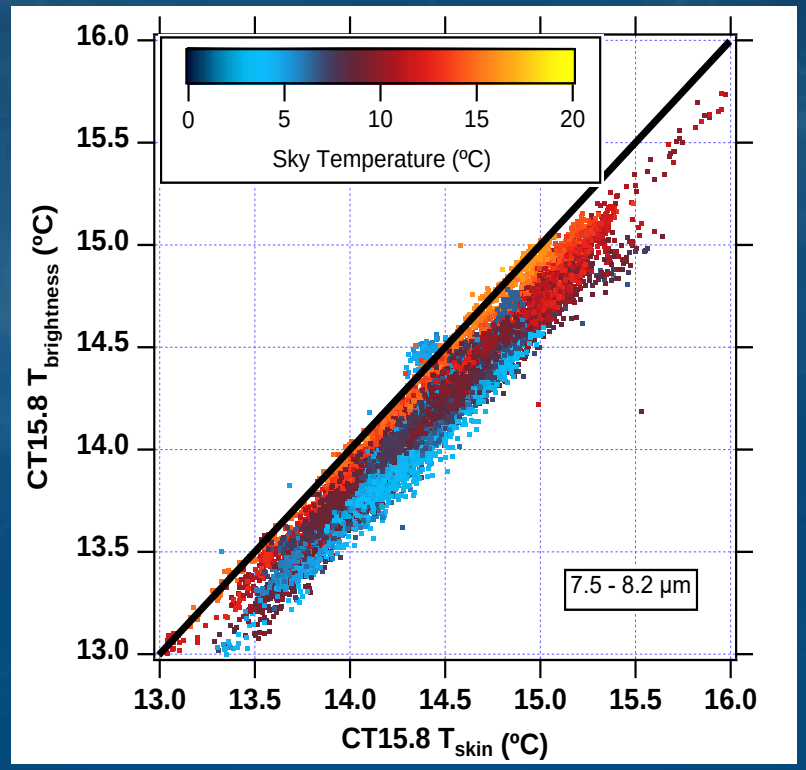
- Broad bands have wide T_{sky} range
- Narrow band has significantly reduce T_{sky} range

$T_{Brightness}$ vs T_{skin} Color Coded by T_{sky}

CT15.10: 8-14 µm

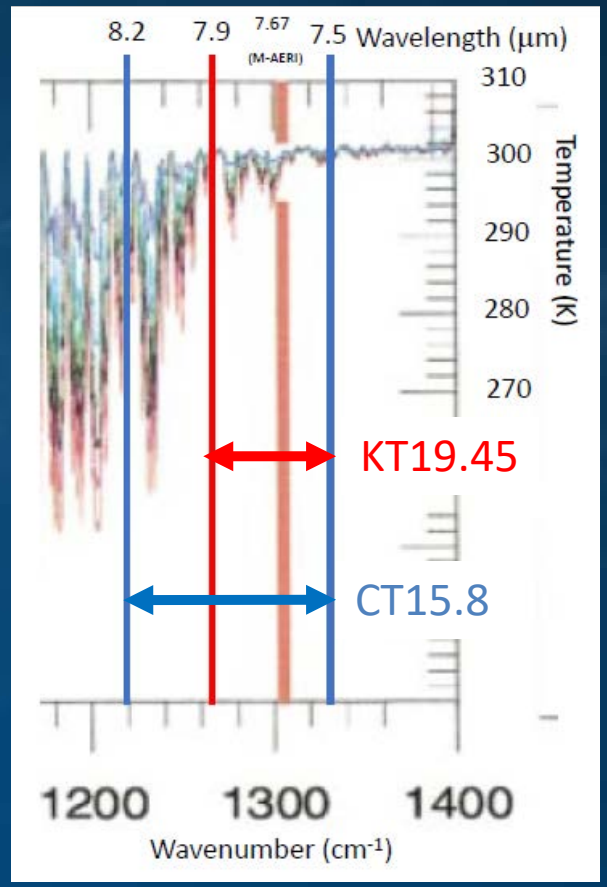


CT15.8: 7.5-8.2 µm



Encouraging results suggest trying narrower band

M-AERI Sky Radiance Spectra

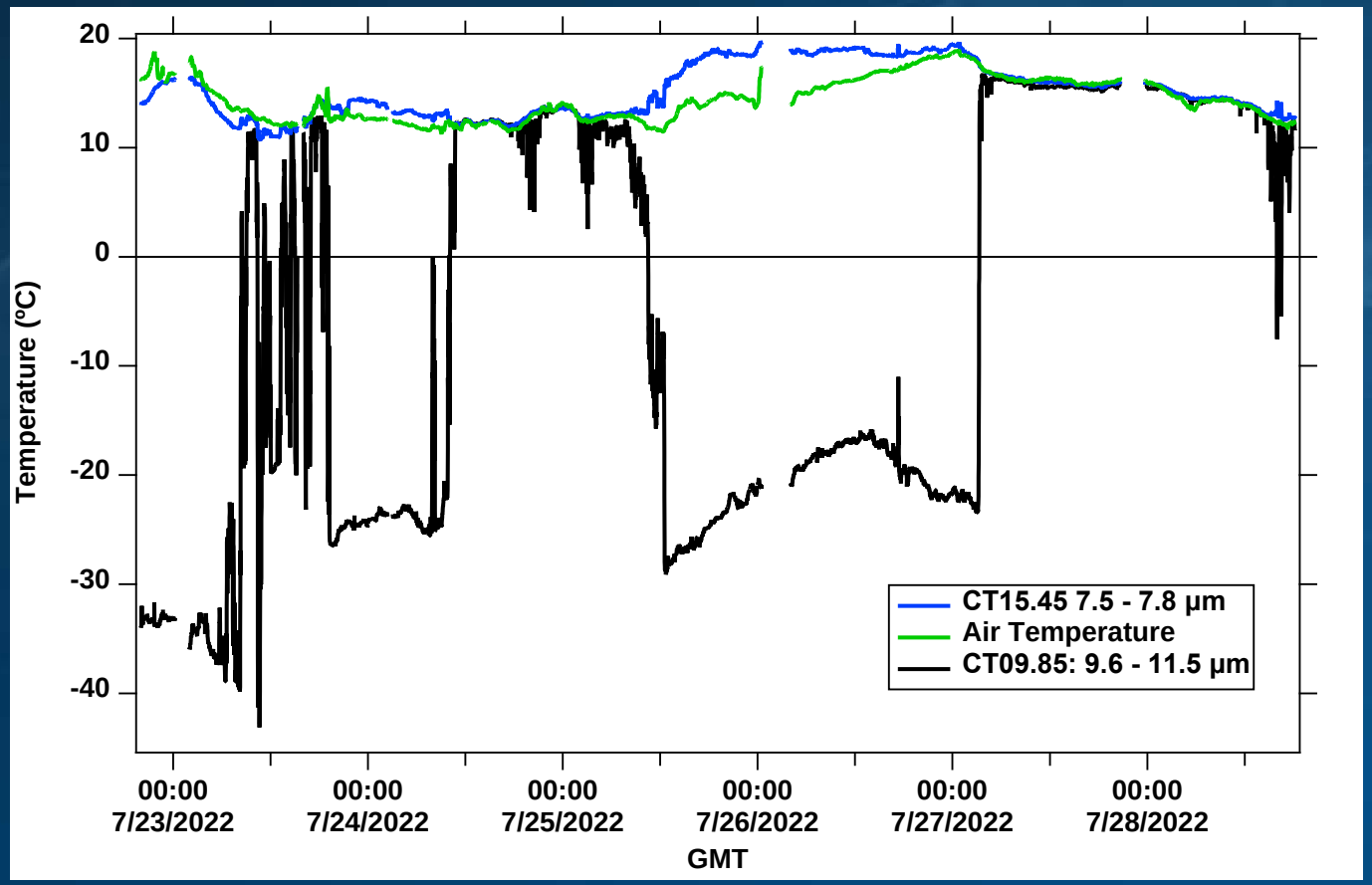


Candidate: KT19.45: 7.5-7.8 µm

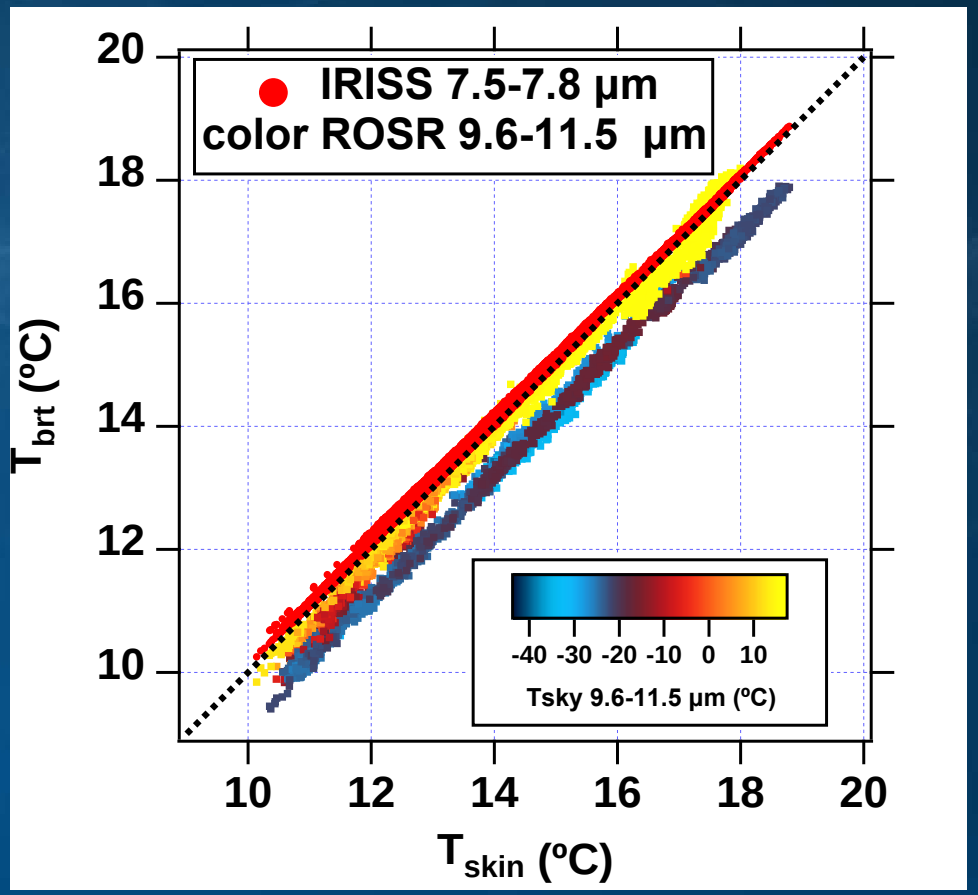
- **Retrofit CT15.8 → CT15.45**

R/V Rachel Carson July 2022

Sky and Air Temperature Time Series



T_{brt} vs T_{skin} Color Code by T_{sky}

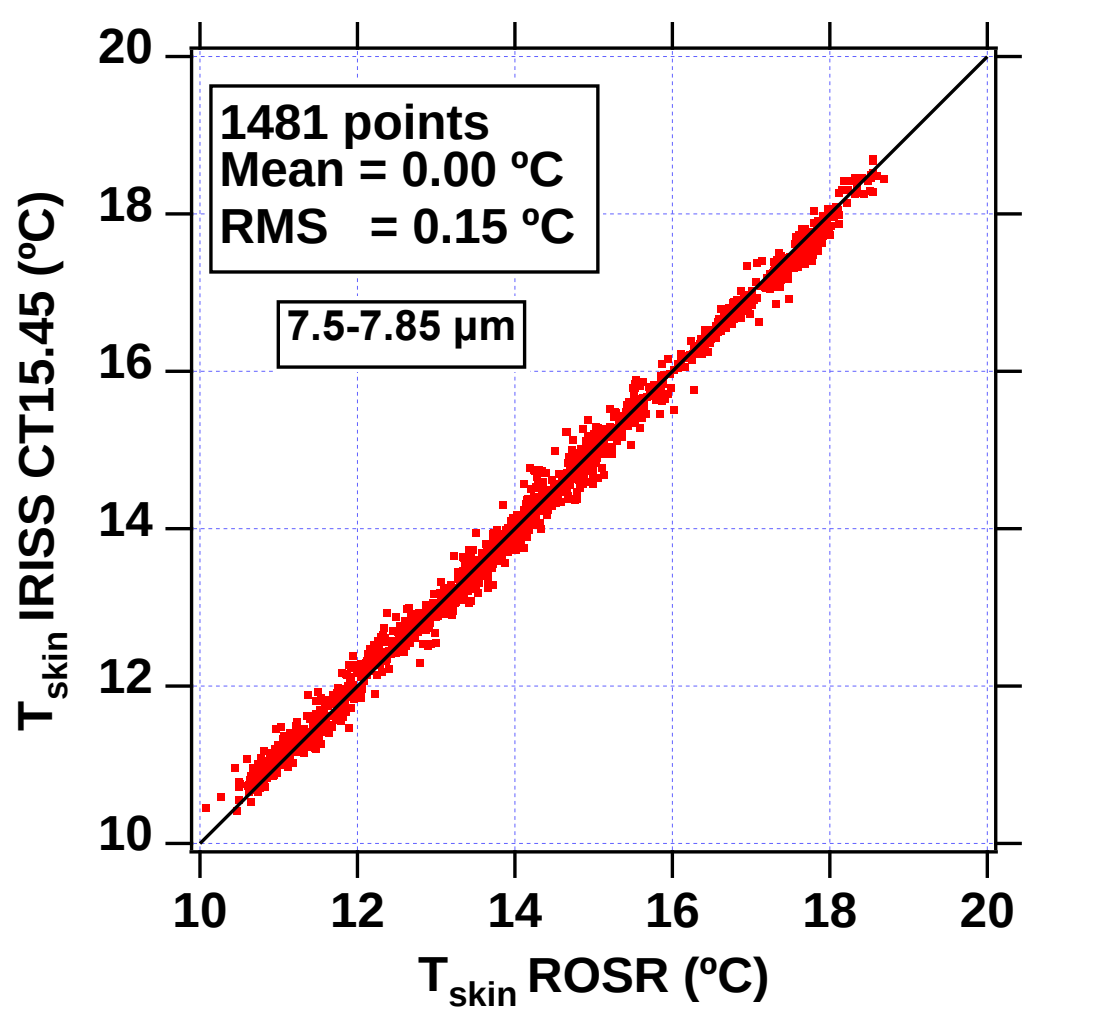


Preliminary Result

- No 1-pt calibration
- Light QC on IRISS and ROSR

IRISS CT15.45 T_{skin} vs ROSR T_{skin}

T_{skin} computed using uplooking CT15.45



Preliminary Result

- No 1-pt calibration
- Light QC on IRISS and ROSR

Anticipate reduction in RMS with more analysis

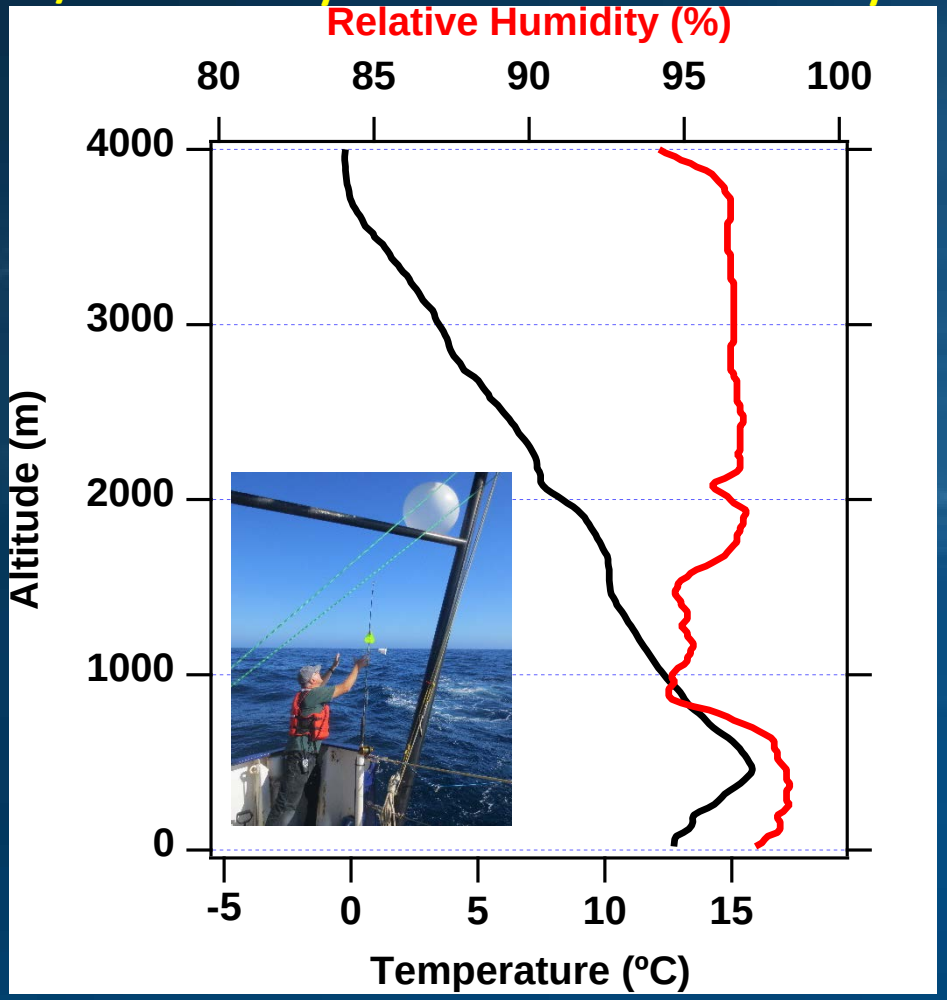
Next Steps

Model sky radiance based on T_{air} and RH

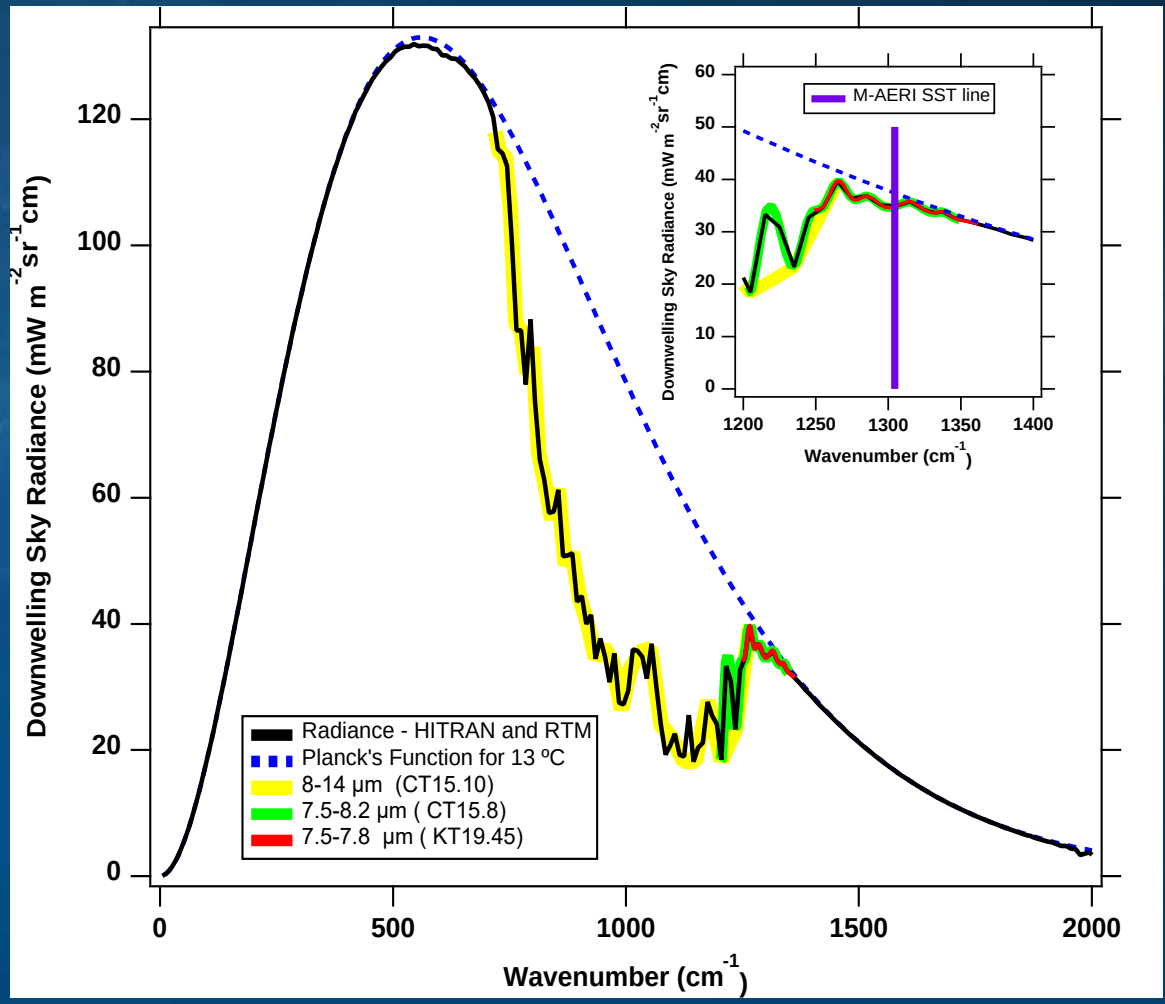
- Radiosondes
- MODTRAN

Radiosondes + MODTRAN

R/V Carson July 2022: 10 sondes over 4 days



Sky Radiance: Mid-Latitude Summer Standard Atmosphere



Conclusions and Future Work

- **Ship-based IRISS w/ 1-pt in situ cal. has accuracy comparable to ROSR**
- **Preliminary results from Optimal Band radiometer show promise**

- **R/V Bold Horizon Cruise October 2022**
  - **30 days off San Francisco**
  - **250 radiosondes**
  - **Rendezvous with four saildrones**
    - **2 x CT15.85 (9.6-11.5 μm) with sky measurements**
    - **1 x CT15.45 (7.5-7.8 μm)**
    - **1 x CT15.10 (8-14 μm)**

SWIFT Drifter w/ CT15.45
R/V Carson Cruise July 2022