Thirty Years of Work on Heating Rates in Tropical Anvils

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Tom Ackerman Retirement Seminar

Heating Rates in Tropical Anvils

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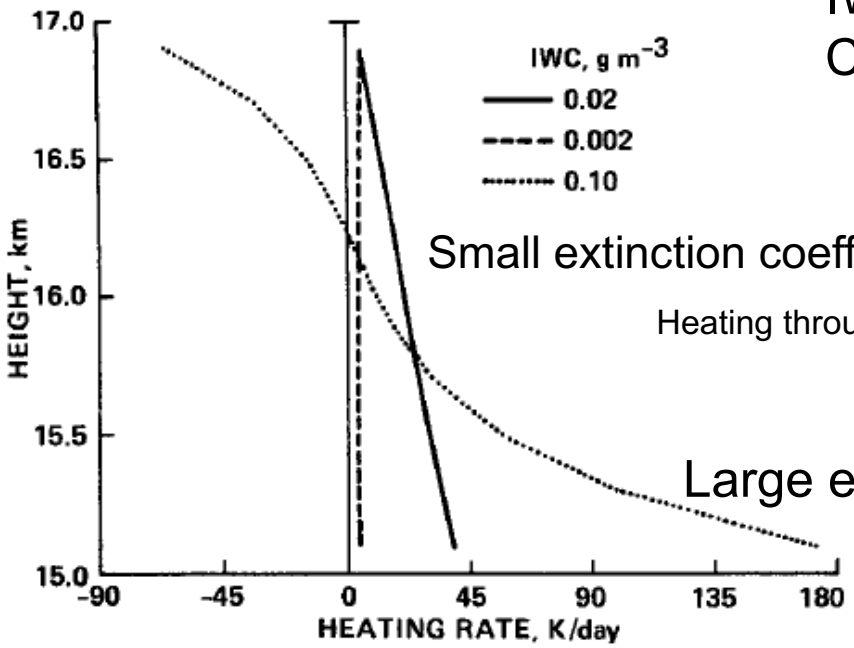
ABSTRACT

The interaction of infrared and solar radiation with tropical cirrus anvils is addressed. Optical properties of the anvils are inferred from satellite observations and from high-altitude aircraft measurements. An infrared multiple-scattering model is used to compute heating rates in tropical anvils. Layer-average heating rates in 2 km thick anvils were found to be on the order of 20 to 30°K day^{-1}. The difference between heating rates at cloud bottom and cloud top ranges from 30 to 200°K day^{-1}, leading to convective instability in the anvil. The calculations are most sensitive to the assumed ice water content, but also are affected by the vertical distribution of ice water content and by the anvil thickness. Solar heating in anvils is shown to be less important than infrared heating but not negligible. The dynamical implications of the computed heating rates are also explored and we conclude that the heating may have important consequences for upward mass transport in the tropics. The potential impact of tropical cirrus on the tropical energy balance and cloud forcing are discussed.

Processes responsible for the difference



IWC: Ice Water Content

Small extinction coefficient

Heating throughout the layer (heated by warm surface)

Large extinction coefficient

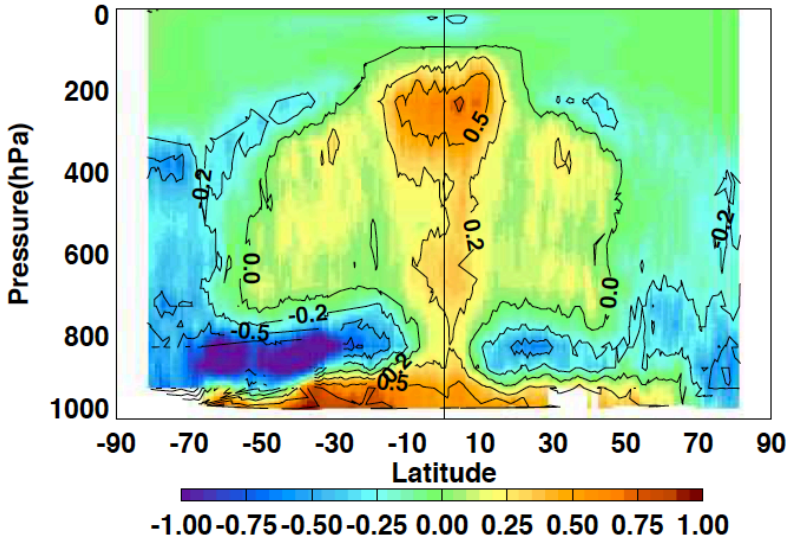
Cloud top cooling
Cloud base heating

FIG. 6. In-cloud heating rates as a function of height for three constant ice water contents: 0.02 g m^{-3} (solid curve), 0.002 g m^{-3} (dashed), and 0.10 g m^{-3} (dotted). (Note the horizontal scale of this figure is substantially compressed relative to other figures.)

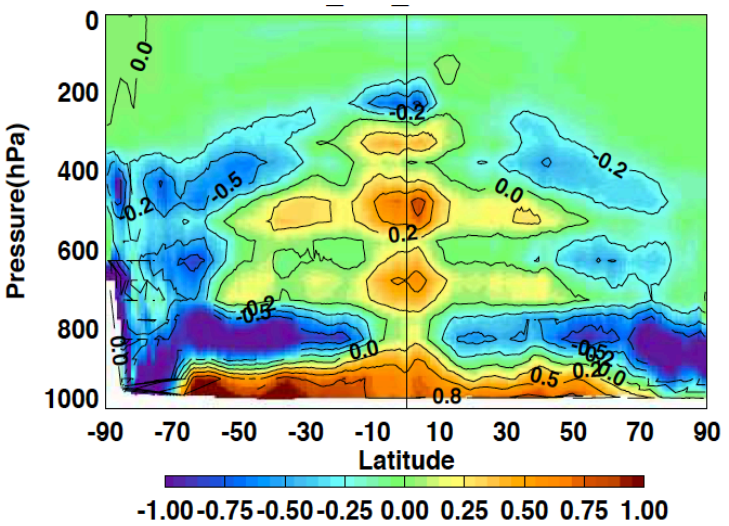
Ackerman et al. 1988

Longwave cloud effect comparison (April 2011)

CALIPSO, CloudSat, and MODIS
(active + passive)



MODIS and GEOs
(passive only)



Passive only heating rates have large cloud top cooling and the heating maximum is too low.
Cloud extinction distributed in the atmospheric column when active sensors are used.
Cloud optical thickness for a given cloud layer is too large when only passive sensors are used.
As a consequence, cloud top cooling and cloud base warming is too large.

Clear-sky surface shortwave irradiance comparison in 1996

Obs. - model

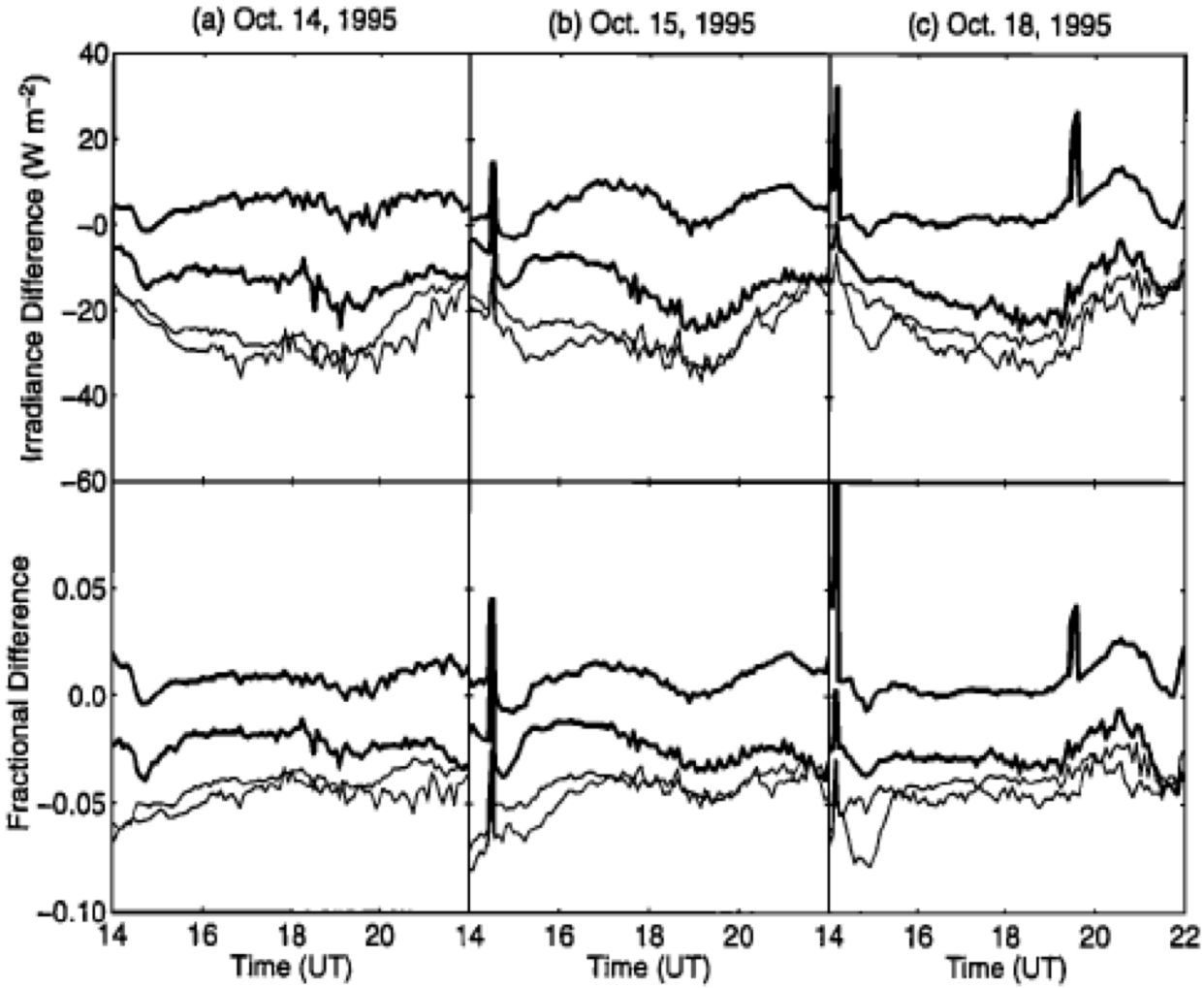


Figure 2. The absolute and fractional differences of the measured downward shortwave irradiances at the surface relative to the irradiances measured by the BR unshaded pyranometer. The thick lines represent reconstructed irradiances (see text); the reconstructed irradiance from the BR data set is always greater than that from the SIROS data set at given time. The upper and lower thin lines represent measured irradiances by the SIROS and NASA unshaded pyranometers, respectively.

1996

Uncertainties in modeled and measured clear-sky surface shortwave irradiances

Seiji Kato,[1] Thomas P. Ackerman,[1] Eugene E. Clothiaux,[1]
James H. Mather,[1] Gerald G. Mace,[1,2] Marvin L. Wesely,[3] Frank Murcray,[4]
and Joseph Michalsky[5]

measured by a multifilter rotating shadow-band radiometer. Therefore, in order for instrumental error to account for the diffuse field discrepancy, three independent measurements of the diffuse field irradiance must be biased low by at least 40%. For an aerosol to account for this discrepancy, it must be highly absorbing with a single-scattering albedo as low as 0.3. The unlikelihood of instrumental errors of 40% and aerosol single-scattering albedos of 0.3 suggests a third possibility: the neglect of some gaseous absorption process at visible wavelengths.

Gas-X was born

Wiscombe 1996

Fate of gas-x

On the Use of Pyranometers in the Study of Spectral Solar Radiation and Atmospheric Aerosols

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15 February 1977 and 13 February 1978

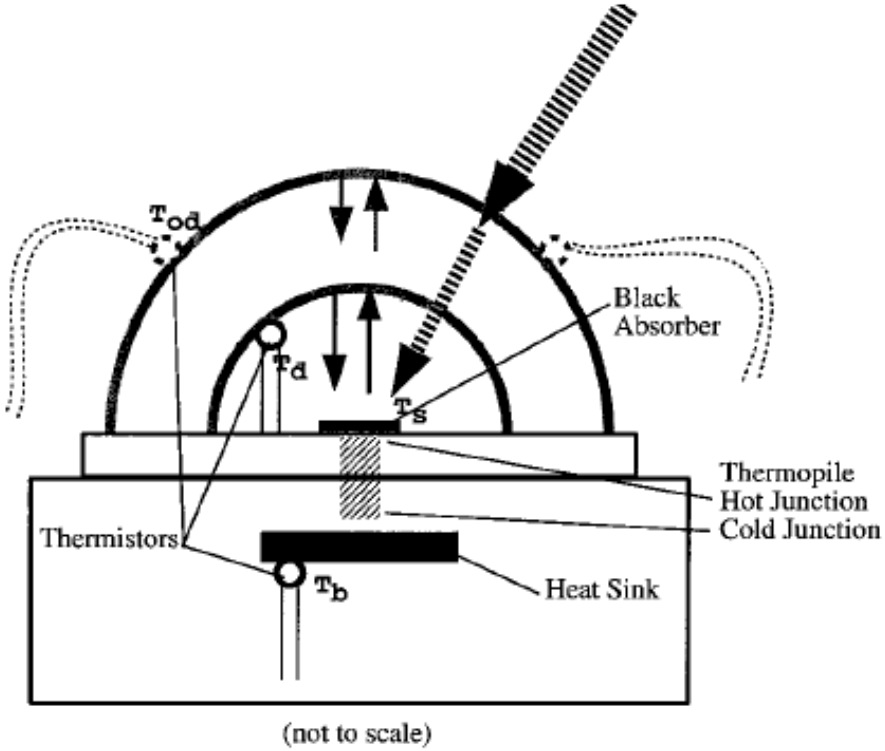
ABSTRACT

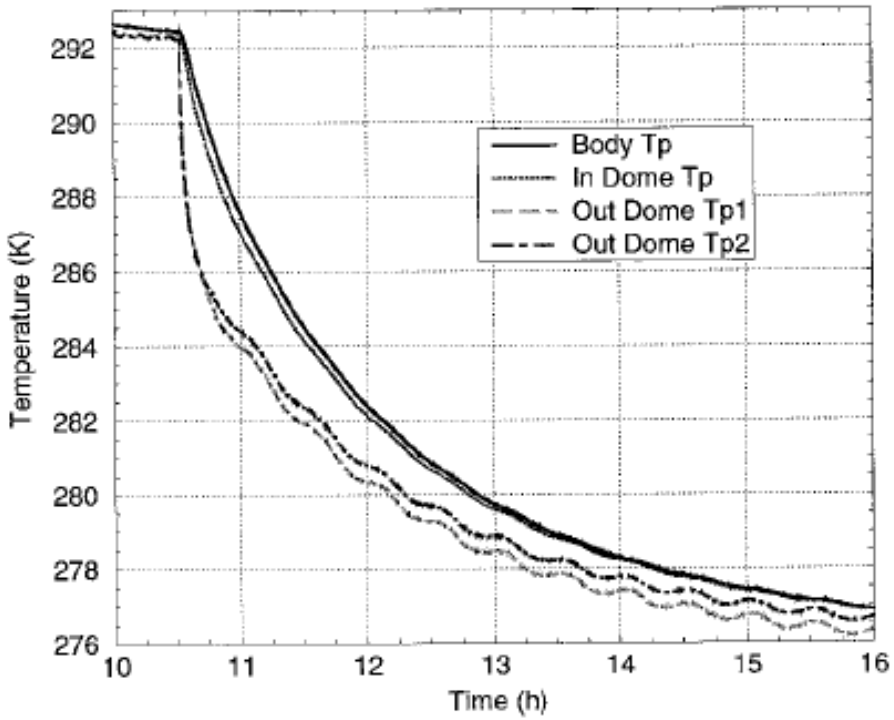
The zero-point deviation of Eppley precision spectral pyranometers is considered for different types of Schott filter glass hemispheres. It is found that the zero-point deviation may significantly affect the measurements of spectral global and diffuse fluxes, and may also lead to considerable errors in the estimates from pyranometer data of the influence of atmospheric aerosols on shortwave radiative transfer. When the zero-point deviation is properly corrected for, however, precision spectral pyranometers may yield precise measurements of even very low spectral irradiances.

Journal of Applied Meteorology 1978

Eppley precision spectral pyranometer (PSP)

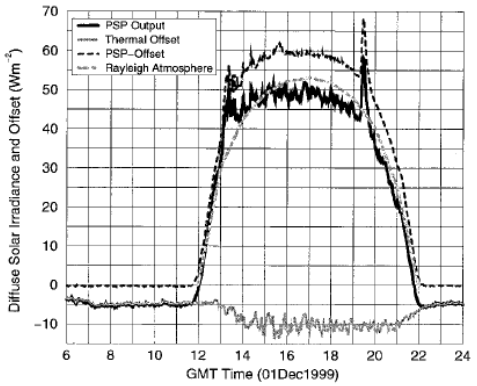
Internal temperature gradient

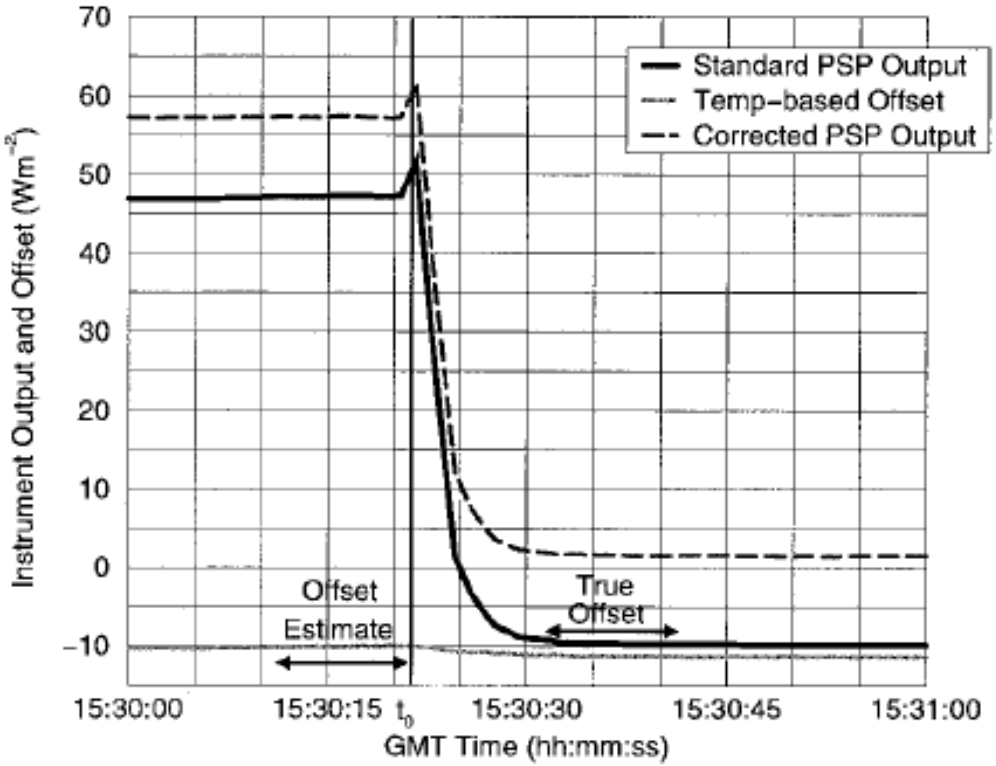




Haeffelin et al. 2001

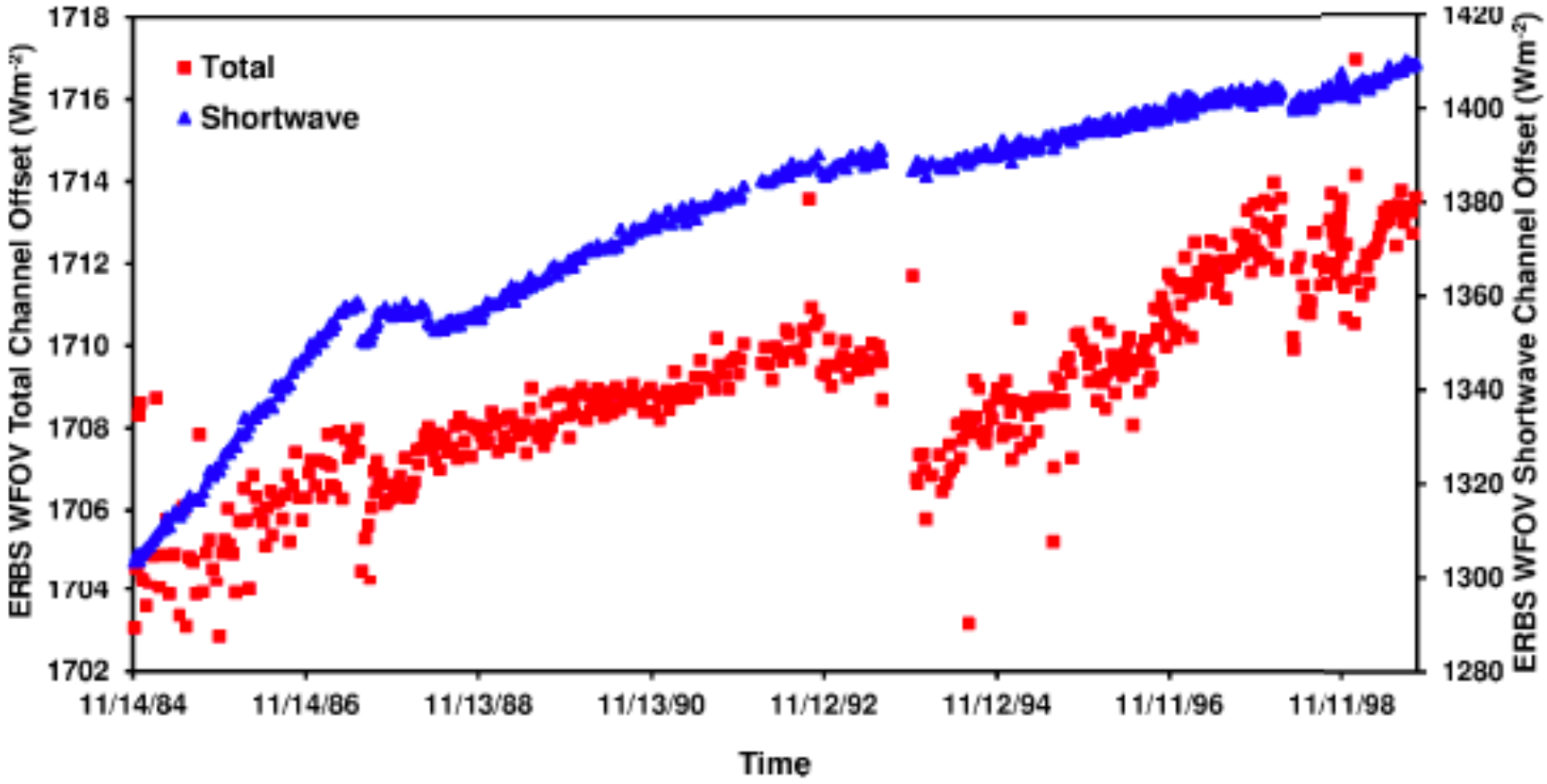
Estimating offset by a capping experiment





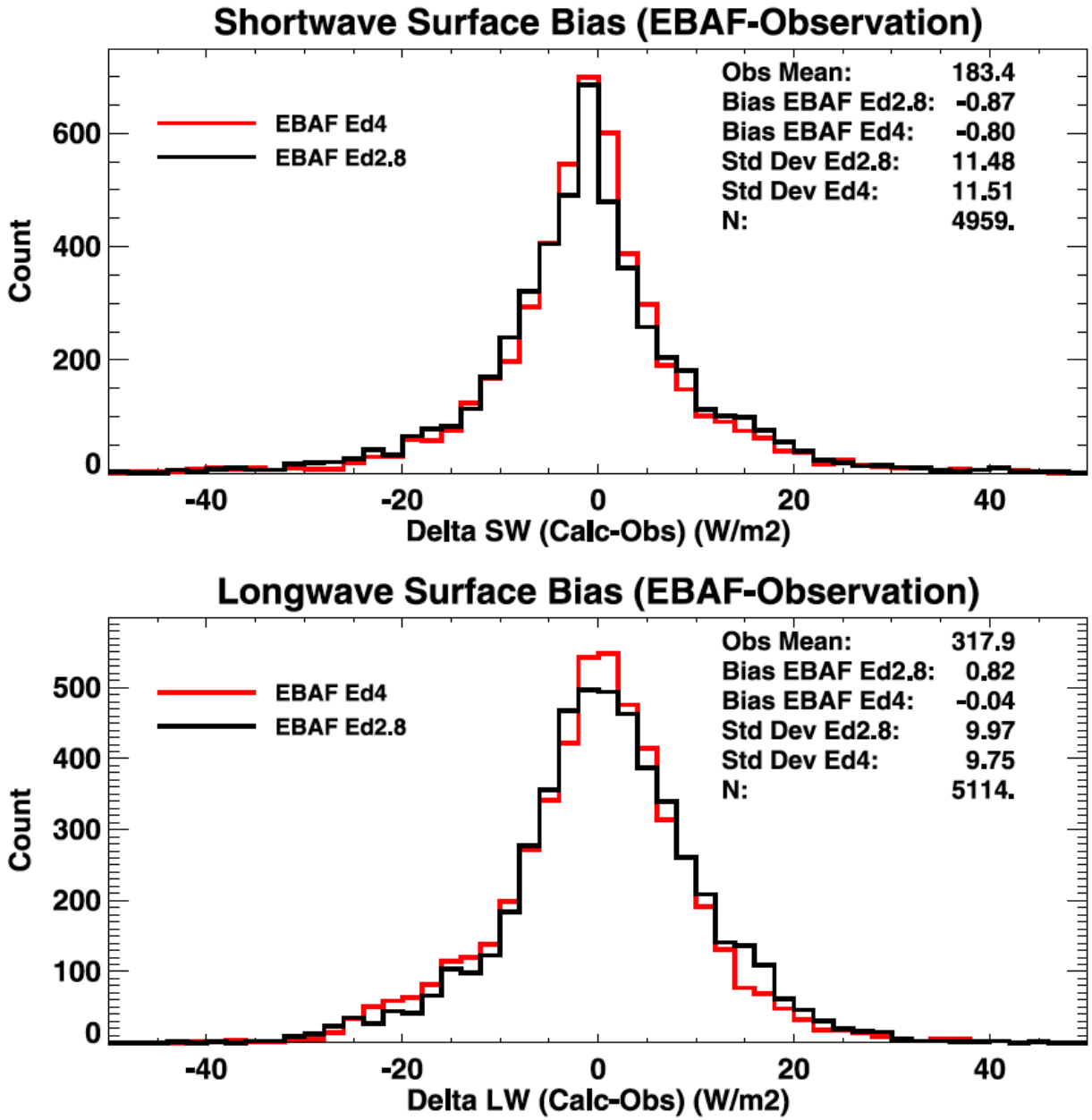
10 Wm^{-2} offset

ERBE nonscanner offset



Lee et al. 2002; Wong et al. 2018

2018 (all-sky over land)



Kato et al. 2018

Summary

- It took 30 years to compute anvil heating rates correctly using satellite observations after Tom published the heating rate paper in 1988.
- Work I did under Tom during my graduate school provides a solid foundation of what I do today.