Effects of Spectrally Varying Cryospheric Surface Emissivity on Atmospheric Longwave Radiation

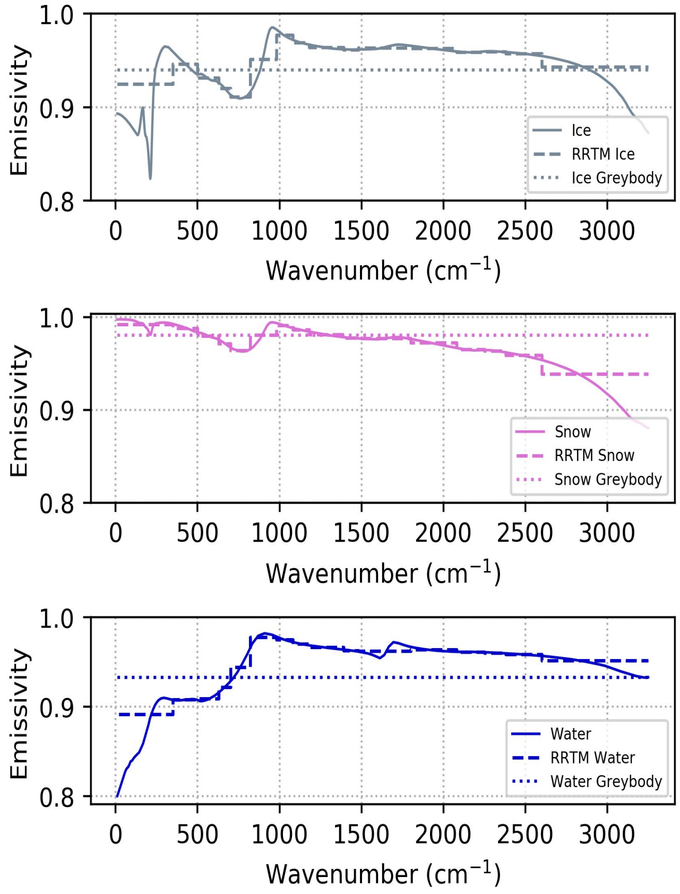
Zachary Wolff and Charles S. Zender
University of California, Irvine, Department of Earth System Science

Cryospheric Surface Emissivity Is Biased in E3SM

- Disconnect in surface emissivity and longwave emission between component models:
  - EAM: Spectrally-resolved emission, blackbody (constant unity) emissivity
  - MPAS-SeaIce/ELM: Broadband emission, greybody (constant non-unity) emissivity.
    - No differentiation of surface types in MPAS-SeaIce for emissivity.
- Few major issues:
  - Emissivity of cryospheric surfaces (Ice, snow, liquid water) have spectral dependence.
  - Surface types in parts of the cryosphere (especially sea ice) is not constant, i.e snow melting from sea-ice/ice sheets.
- Questions: What is the bias in models due to using spectrally resolved emissivity rather than blackbody and how does it change with respect to surface-type and seasonal (temperature, water vapor) changes? How can we bridge the disconnect between surface models and atmospheric models treatment of surface emissivity?

Model Setup

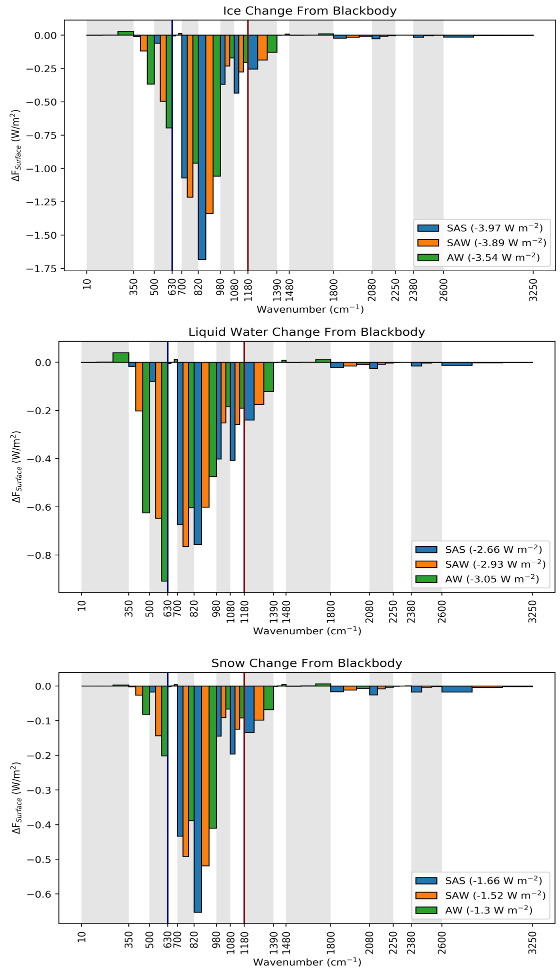
- Offline evaluation with Rapid Radiative Transfer (RRTM) Model
- Three atmospheric profiles
  - Intercomparison of Radiation Codes of Climate Mode (ICRCCM) Subarctic Winter and Summer profiles (SAW, sfc.T= 257 K; SAS, sfc. T= 287 K)
  - Composite clear-sky radiosondes from wintertime from Norwegian Young Ice (NICE-2015) representative of Arctic Winter (AW, sfc. T = 233 K)
- Spectrally-resolved emissivities
  - Ice and Water computed directly through Fresnel equations
  - Snow from Huang et al. (2016) Database
- Evaluation done offline to compare direct difference between surface types
  - Allows us to simulate effect of introducing into surface models.
  - Coupled evaluation shown by Xianlegi Huang for E3SM v2.



Adapted from Wolff and Zender (2020, in review)

Over All Surface-Types and Atmospheric Profiles Surface Emission Significantly Decreases With Spectral Emissivity

- Over all nine cases, emission decreases when using spectral emissivity instead of blackbody assumption.
- Peak of emissivity effects (mostly) in Thermal IR (630-1180 cm^{-1}) region due to largest net surface flux (difference between upwelling and downwelling fluxes)
- Changes due to use of spectrally realistic emissivity range from -1.3 W m^{-2} (Snow AW) to -3.97 W m^{-2} (Ice SAS) at the surface-level and -0.99 W m^{-2} (Snow SAS) and -3.02 W m^{-2} (Ice SAW) at TOA.



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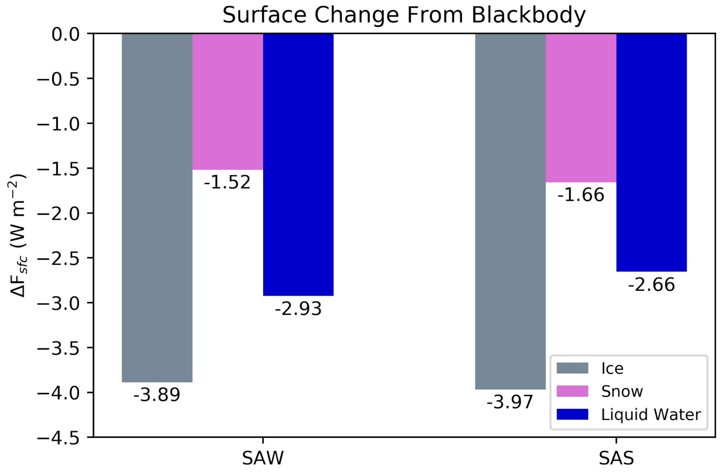
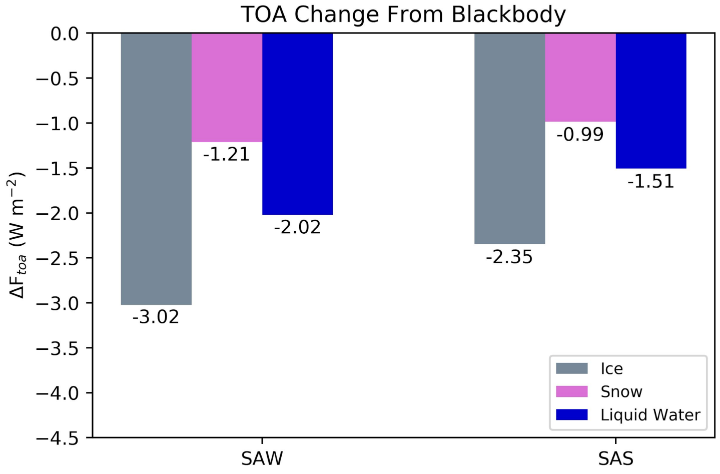
Emission Changes Between Surface-Types Can Be As Large As Initial Change



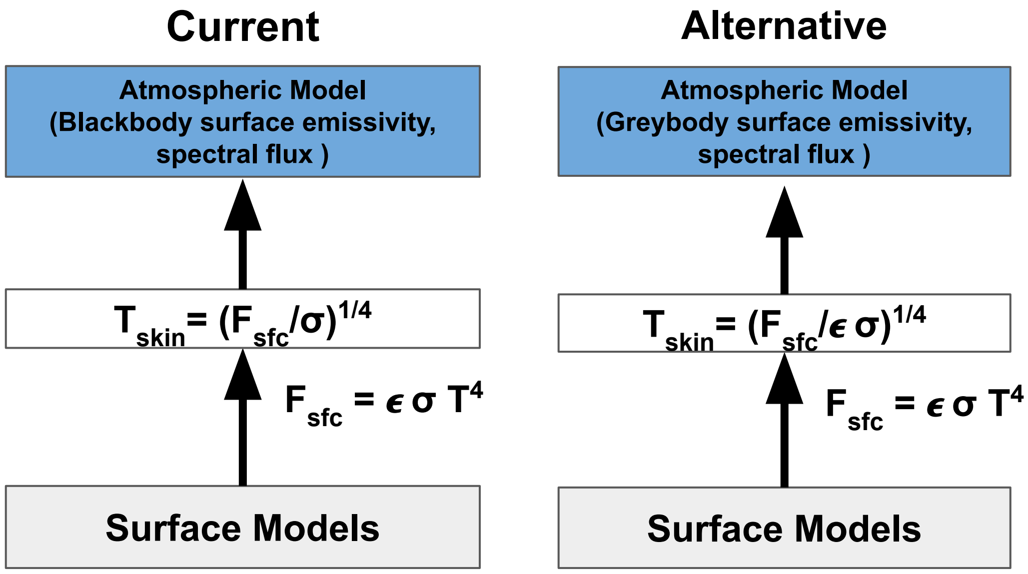


Adapted from Wolff and Zender (2020, in review)

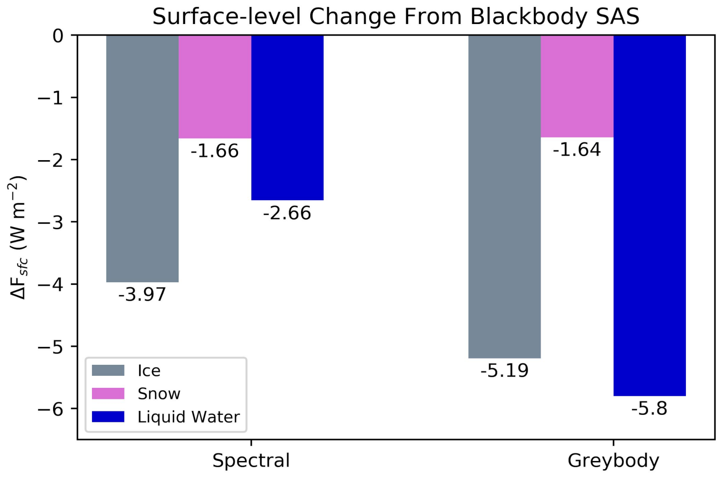
- Smallest change from blackbody is over snow over all 3 atmospheric profiles, largest is over ice in Subarctic Summer and Winter, difference seasonally is small when surface-type is maintained.
- Ice emission is less than snow by between 2.37 W m^{-2} (SAW surface) and 1.81 W m^{-2} (SAS TOA), greater than the decrease between snow and blackbody in each case.

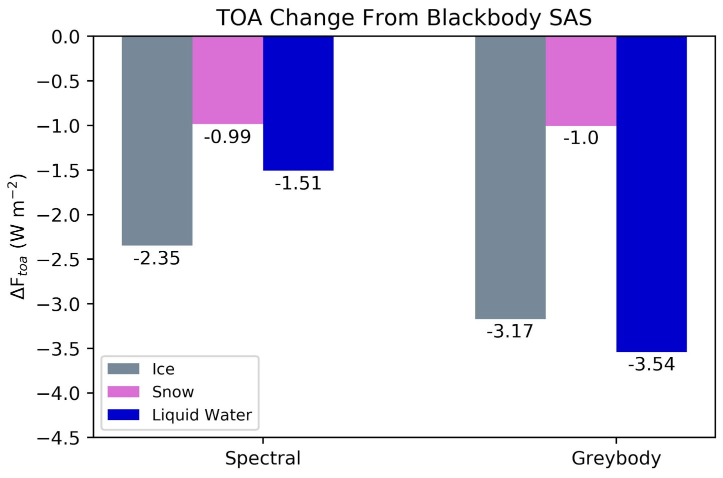
Using Greybody Emissivity To Solve E3SM Emissivity Disconnect?

- E3SM has (not by default) spectrally resolved emissivity option in atmospheric option, only broadband emission and emissivity in surface models.
- Simplified way to connect the two, use physically derived greybody in both models.
    - Advantages: No changes necessary to underlying physics of the models, surface temperature conserved between models.
    - Disadvantages: Ignores spectral variation in emissivity.



Greybody Emissivity Leads to Potential Issues That Makes it Not a Viable Solution





Adapted from Wolff and Zender (2020, in review)

- Average greybody has large emphasis on Far IR (10-630 cm^{-1}) region, due to large percentage of outgoing energy.
- Lower emissivity than Thermal IR region where most of emissivity effects found leads to greybody to be further from blackbody than spectral emissivity.
- SAS liquid water surface-level and top of the atmosphere more than double with greybody.

Summary

- Cryospheric surfaces lead to significant decreases when spectrally resolved emissivity is used rather than blackbody assumption.
- The difference between these surfaces (i.e snow and ice) can be as large as the difference due to assuming blackbody.
- Greybody emissivities can't be used to bridge the gap between surfaces models as it is potentially worse than blackbody assumption.
- Solution requires working across models to:
  - Implement spectrally resolved longwave emission and emissivity in surface models in addition to the atmospheric model for full spectral coupling.
  - Allowing emissivity to change based on modeled surface type (i.e snow or melt ponds on sea-ice)
  - This work has begun to be tested within MPAS-SeaIce.