Exploration of California High Resolution Snowpack Modeling with Realistic Surface-Atmospheric Radiation Physics

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Problem statement

- California water management
  - Urban use: most populous state
  - California is the top state agricultural supplier: 13% of United States produce
  - Large-scale water infrastructure
- Seasonal precipitation
  - Flood risk vs. storage for dry season usage

- Prediction in changing climate
  - Pacific Ocean moisture on orography drives precipitation
  - Mountain snowpack for ~ 30% California water supply
  - Models need to accurately predict snowpack in changing climate

Surface temperature cold bias in California models over mountain region

Radiation Band	Surface Process modeling	Atmospheric process modeling	CESM models
Shortwave	Albedo	Cloud scattering	Yes
Longwave	Spectral emissivity	Cloud scattering	No

- LW surface emissivity in CESM: Arctic surface temperature warming
  - C. Kuo et al, 2018, JGR-Atmos
  - X. Huang et al, 2018, J. Climate
- LW cloud scattering: Significant downward LW surface flux.
  - C.-P. Kuo et al, 2017, JAMES

CESM=Community Earth System Model (National Center for Atmospheric Research, Boulder Colorado, US)

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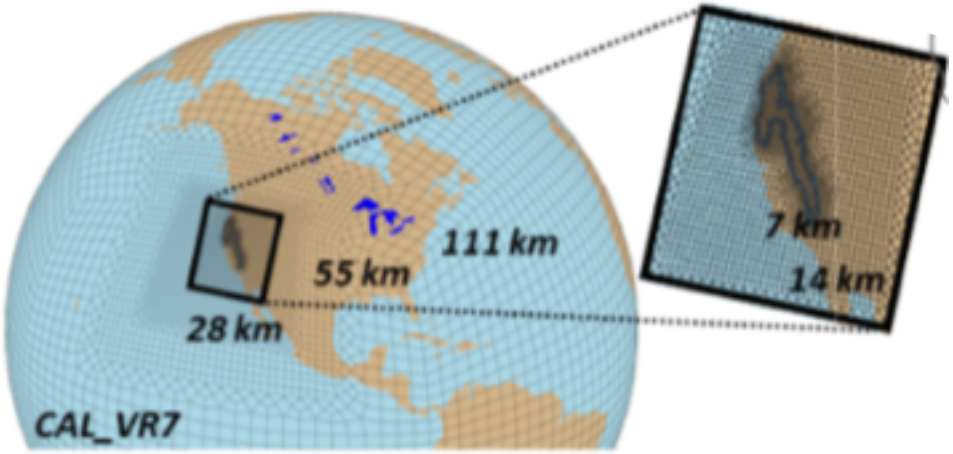
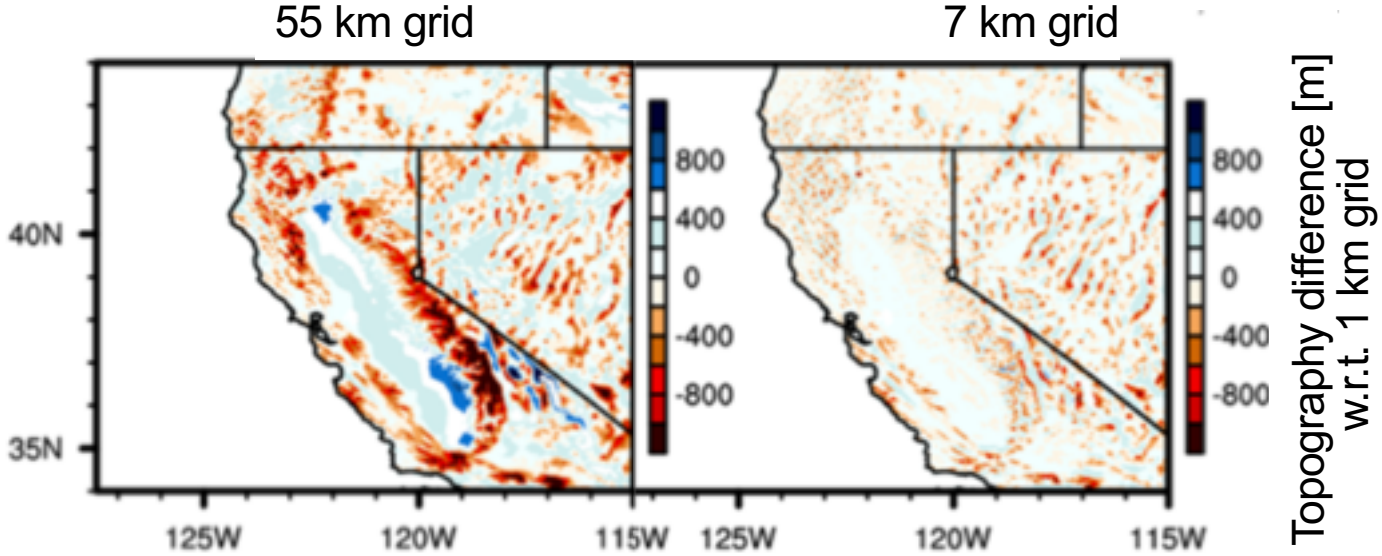
Variable resolution global circulation model captures high resolution topography over California



Atmospheric rivers modeled in general circulation model

Regional high resolution captures orographical-influence on weather

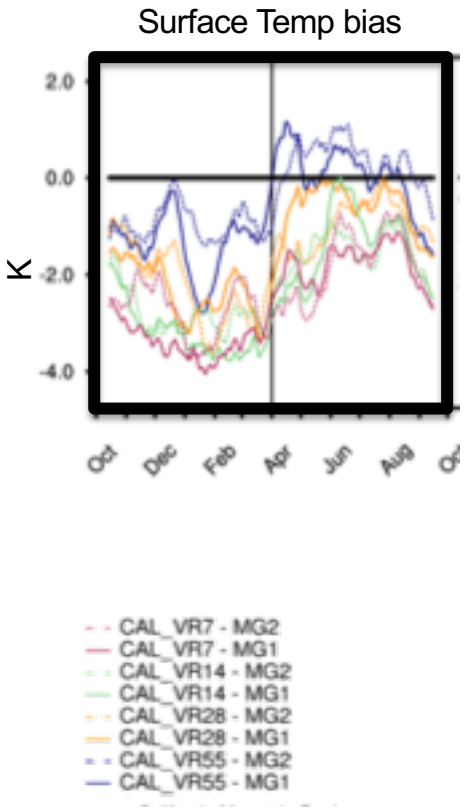


Rhoades et al, 2018, JAMES

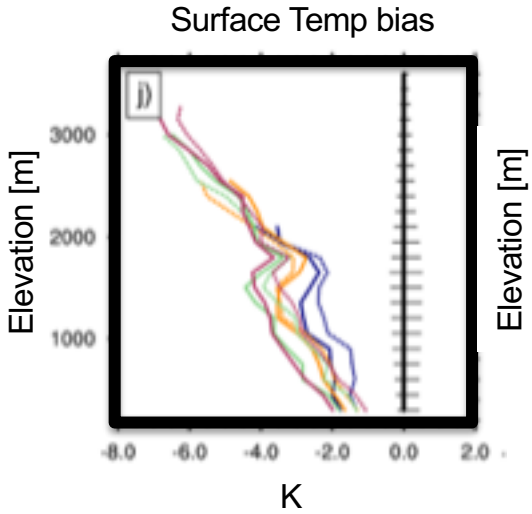
Rhoades et al, 2018, JAMES

Surface Temperature cold bias amplitude increases in dry atmospheres

Seasonal Model Biases
Colder in winter



Altitudinal Model Biases
Colder in elevation



Rhoades et al, 2018, JAMES

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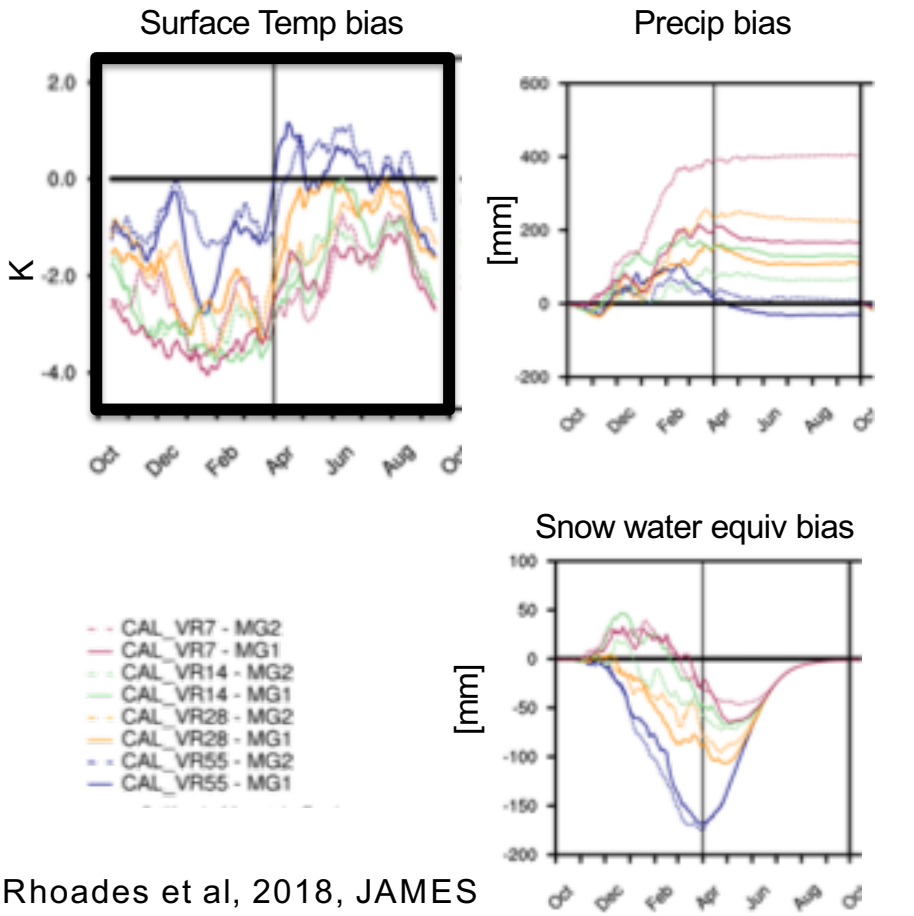

Rhoades et al, 2018, JAMES

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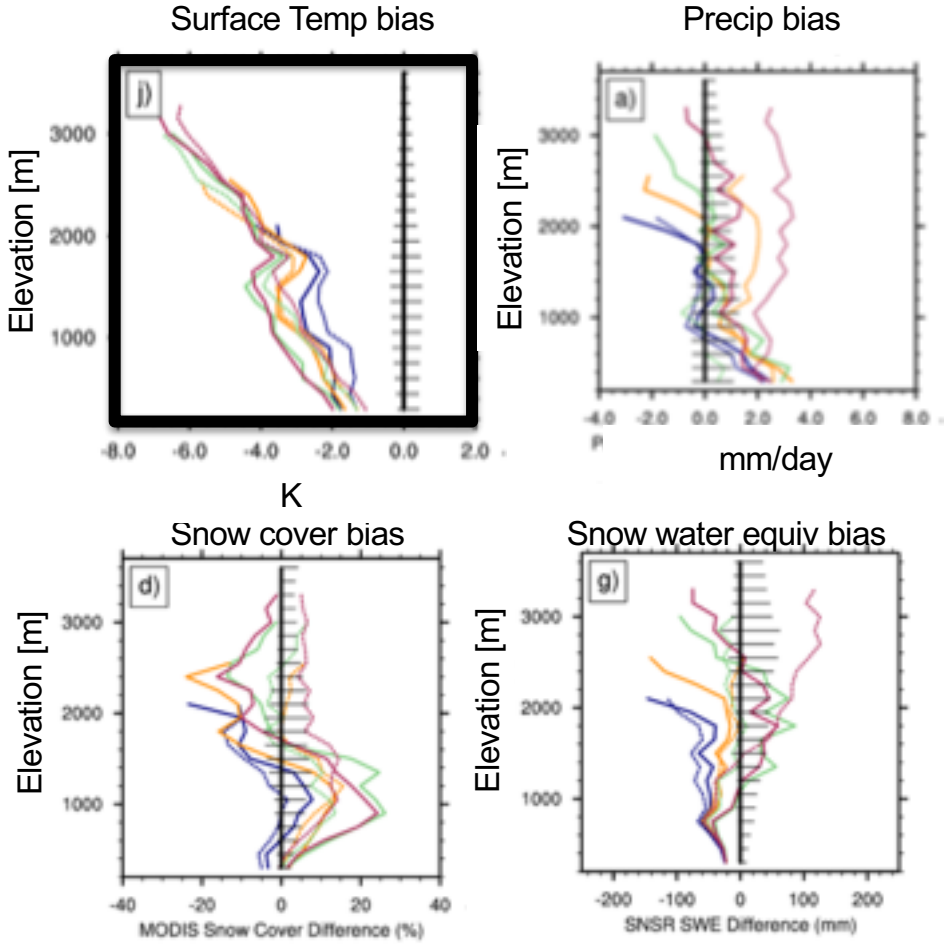

Longwave processes

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Spectral emissivity updates improved surface temperature bias in Arctic.

Applicability to California Mountain Range?

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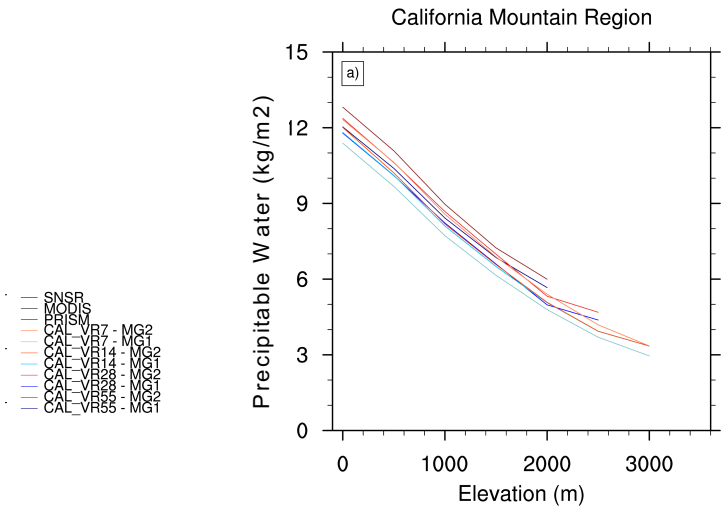
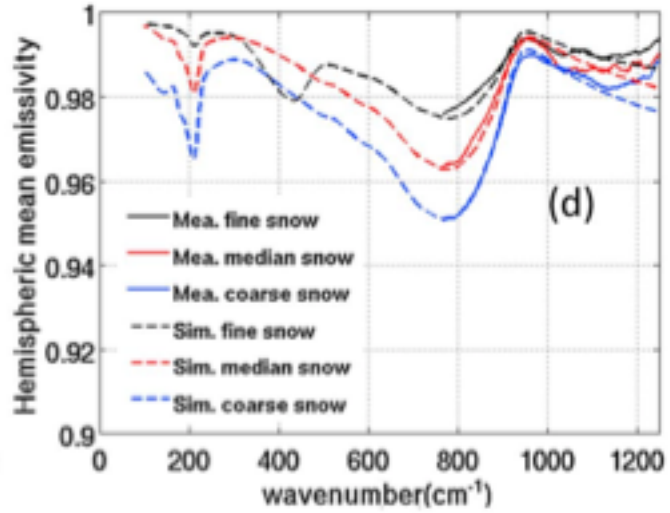


Emissivity implemented in CESM.$\varepsilon(\nu)$



X.Chen et al, 2014,GRL

Surface type	CESM.LME	CESM.$\varepsilon(\nu)$
Land-ice	0.97	0.98
Sea-ice	0.95	0.98

C.Kuo et al,2018,JGR-Atm

Arctic surface temperature bias improved in CESM-$\varepsilon(\nu)$

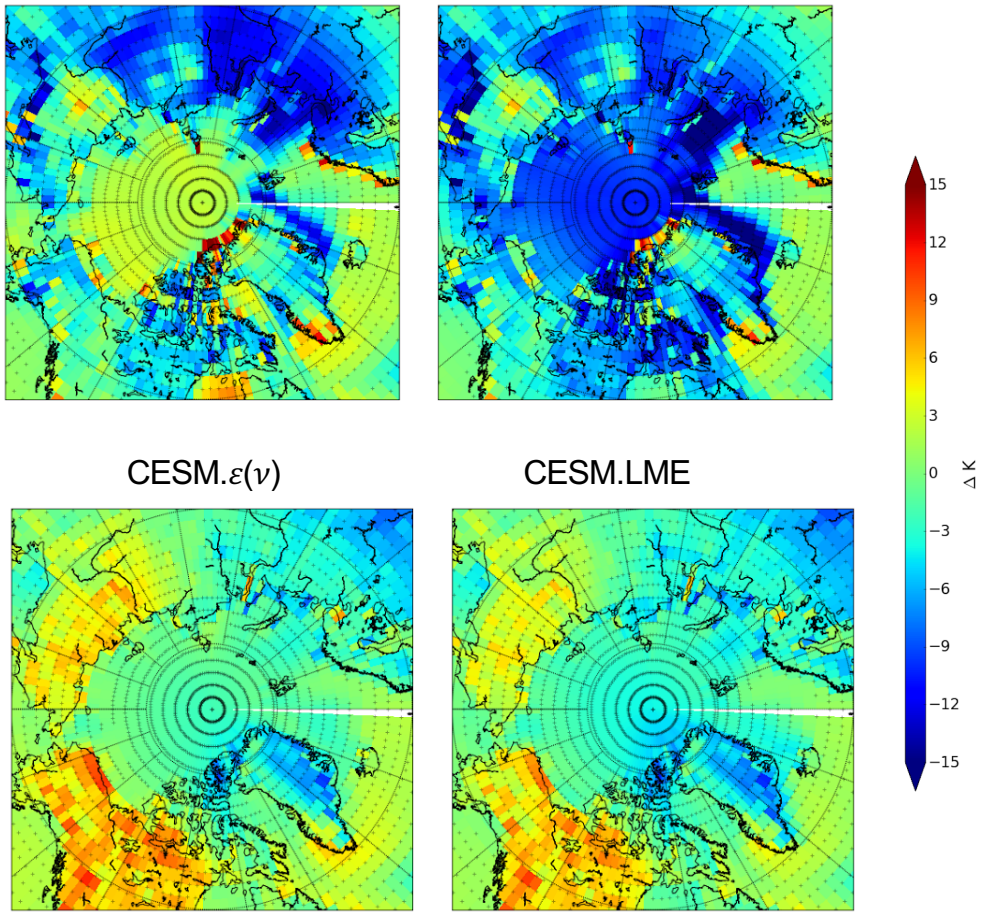
Model TS bias against ERA-Interim, 1979-2005

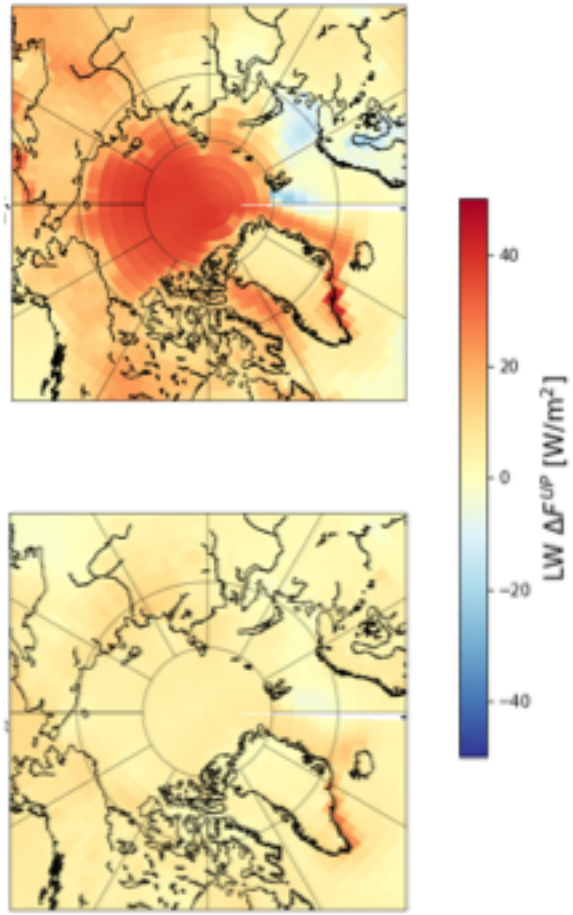
Model Δ Longwave upwelling flux

CESM.$\varepsilon(\nu)$ | CESM.LME | CESM.$\varepsilon(\nu)$ - CESM.LME

DJF

JJA

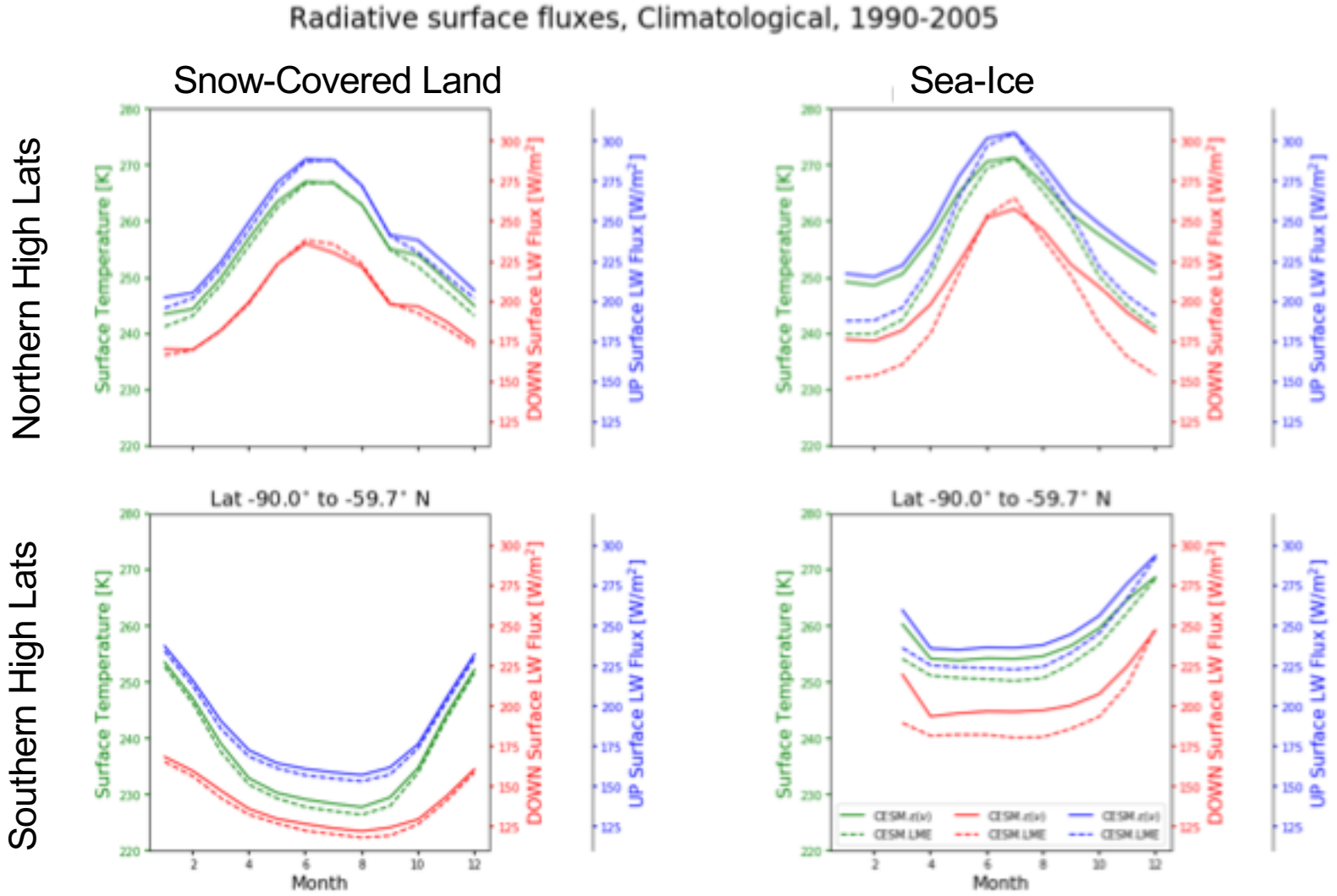




CESM-$\varepsilon(\nu)$: C.Kuo et al,2018,JGR-Atm
CESM-LME: Otto-Bliesner et al, 2016, BAMS

C.Kuo et al, *in prep*

Model surface LW fluxes increases in wintertime for CESM.$\varepsilon(\nu)$ over sea-ice

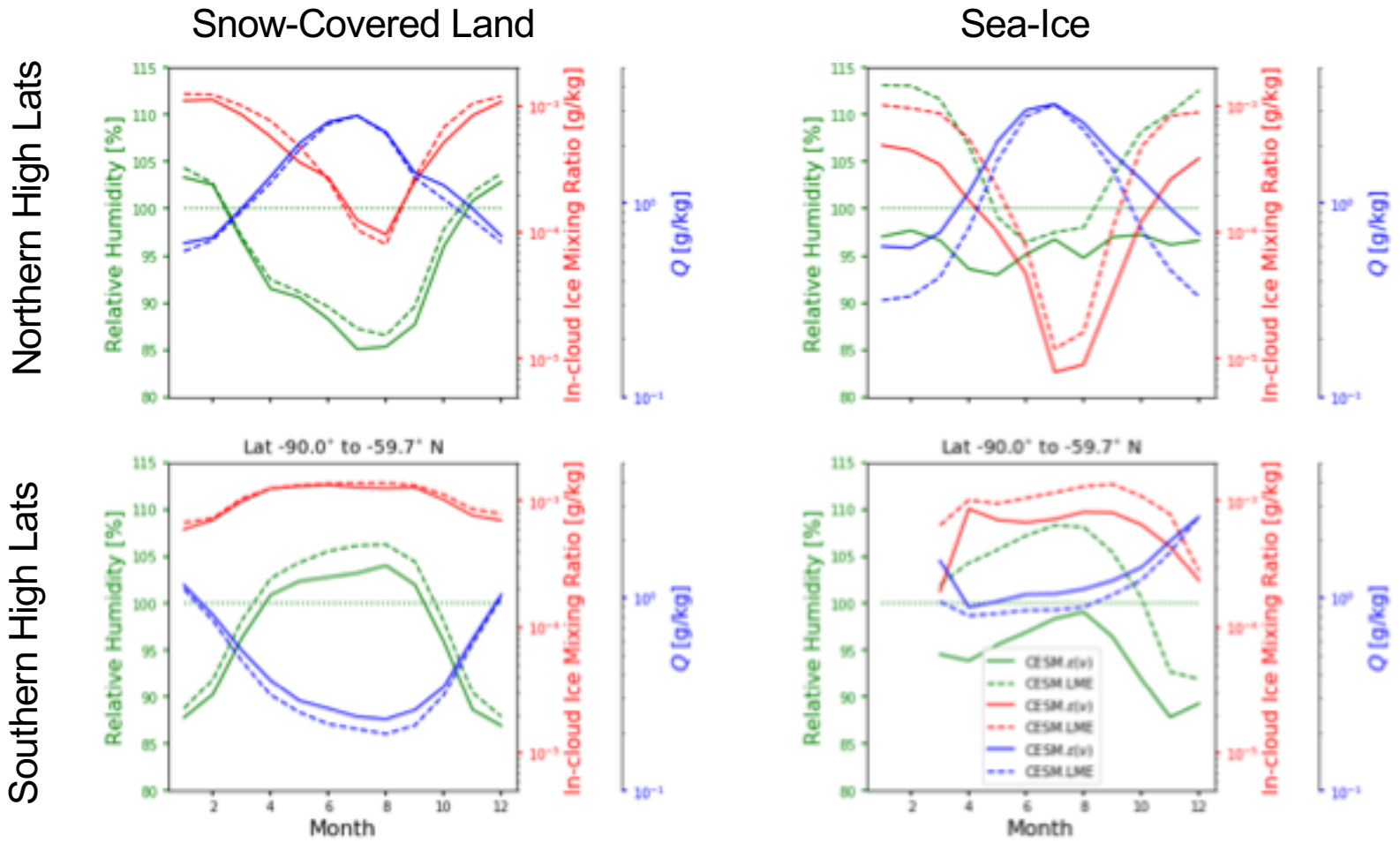


Radiative surface fluxes, Climatological 1990-2005

C.Kuo et al, *in prep*

C. Kuo et al, in prep

Model near surface supersaturation in wintertime removed over sea-ice in CESM.$\varepsilon(\nu)$



Model near-surface ice and liquid mixing ratios, climatological 1990-2005

C.Kuo et al, *in prep*

C. Kuo et al, in prep

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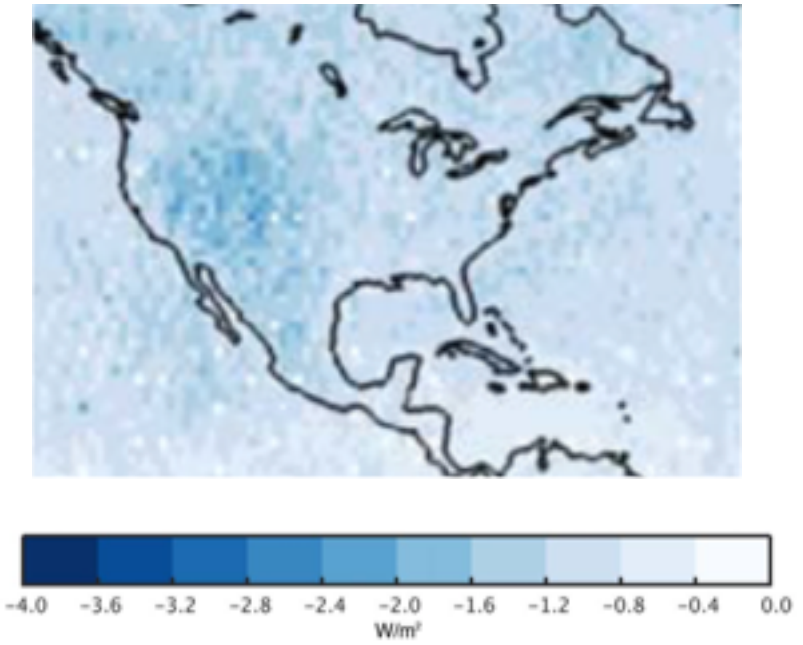
Far-IR multiple scattering in clouds show elevation dependent longwave ice-cloud surface forcing

- MODIS Collection 6 cloud models
- Optical properties:
  - Yang et al, 2013, JAS
- Ice-cloud scattering calculation using RRTMG and DISORT
- Longwave surface downward bias calculated for 2010 in global 1°×1° model.

Longwave surface downward flux bias when scattering is ignored

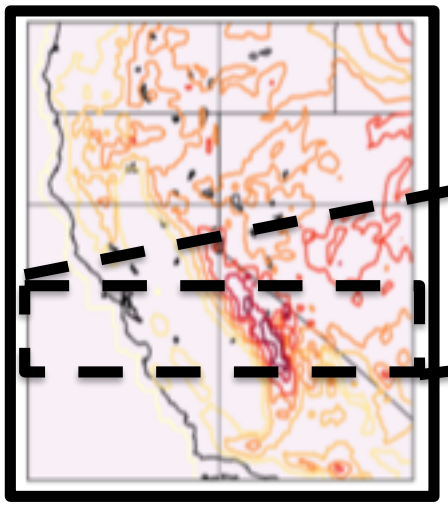


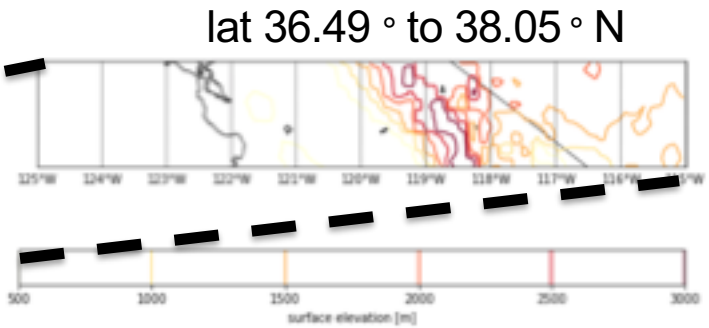
Kuo, C.-P., et al.,2017,*JAMES.* https://doi.org/10.1002/2017MS001117

Ice cloud amount modeled in high resolution grid through tropopause over California Sierra Nevada Mountain region

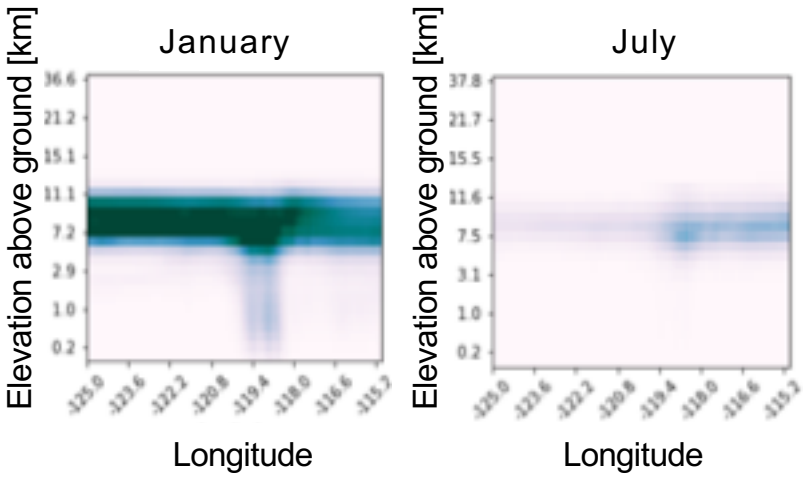
In process calculations:

- Optical properties for rough hollow bullet rosette
  - •Yang et al, 2013, JAS
- Ice-cloud scattering calculation using LBLRTM and CHARTS
- Longwave surface downward bias over high resolution grid cells in Sierra Nevada

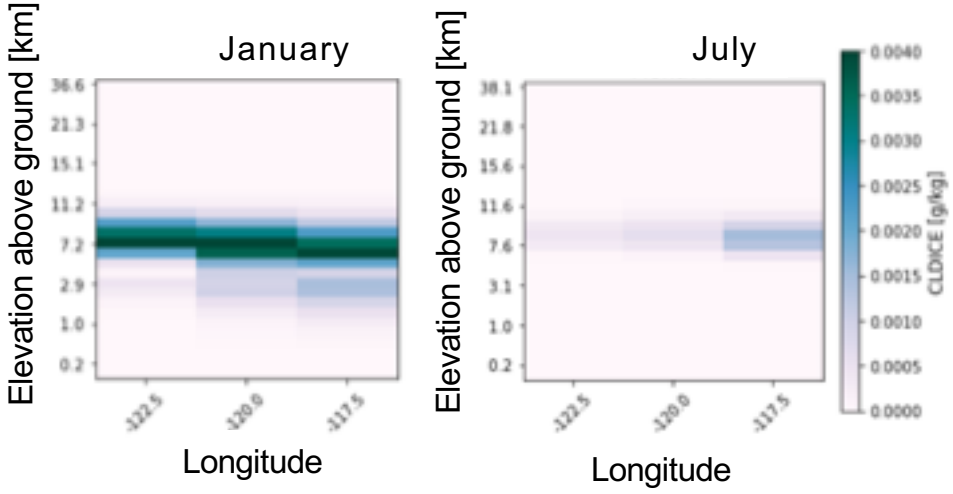




Cloud ice amount, 7km model



Cloud ice amount, 2 deg model



Summary

- California mountain region surface temperature seasonal and altitudinal cold bias is not explained by GCM model processes influencing surface/atmospheric radiative fluxes
  - Shortwave
    - Snow cover biases do not manifest elevation-dependence
    - Precipitation bias occurs at the highest modeled elevations
  - Longwave
    - Spectral emissivity: Mechanism for cold surface temperature bias improvement in Arctic is not indicated for snow-covered land.

- Ice cloud amount in 7 km grid resolution California global circulation model (GCM) has higher contrast through the tropopause than a 2 deg grid resolution GCM over the California mountain region.
  - Cloud scattered longwave surface downward flux is indicated as a missing model component to explain surface temperature cold bias.
  - Offline calculations are continuing.

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