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

<table>
<thead>
<tr>
<th>Radiation Band</th>
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<th>CESM models</th>
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<td>Shortwave</td>
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<td>Spectral emissivity</td>
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- 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)
## Surface temperature cold bias in California model over mountain region

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CESM=Community Earth System Model (National Center for Atmospheric Research, Boulder Colorado, US)
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
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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## 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. $\varepsilon(\nu)$

![Graph showing emissivity and precipitable water vs elevation](image)

X. Chen et al, 2014, GRL

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<th>Surface type</th>
<th>CESM.LME</th>
<th>CESM. $\varepsilon(\nu)$</th>
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<td>Land-ice</td>
<td>0.97</td>
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<td>Sea-ice</td>
<td>0.95</td>
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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 $\Delta$ Longwave upwelling flux

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

Snow-Covered Land

Southern High Lats

Northern High Lats

Sea-Ice

Radiative surface fluxes, Climatological 1990-2005

C. Kuo et al, in prep
Model near surface supersaturation in wintertime removed over sea-ice in CESM.\(\varepsilon(\nu)\)

**Northern High Lats**

**Snow-Covered Land**

**Sea-Ice**

**Southern High Lats**

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

C.Kuo et al, in prep
Longwave processes

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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 $1^\circ \times 1^\circ$ model.

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
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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- Chia-pang Kuo, Texas A&M
- Charles Koven, Lawrence Berkeley National Laboratory

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