Sensitivity of snowpack simulation associated with snow-related model physics

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Related publications:

Kim et al., 2008: A projection of the cold season hydroclimate in California in mid-twentieth century under the SRES-A1B emission scenario. California Climate Change Center Report, in press.

Waliser et al., 2008: Simulating the Sierra Nevada snowpack: The impact of snow albedo and multi-layer snow physics. California Climate Change Center Report, in press.

International Conference on Water Scarcity, Global Changes, and Groundwater management responses, December 3, 2008, University of California, Irvine

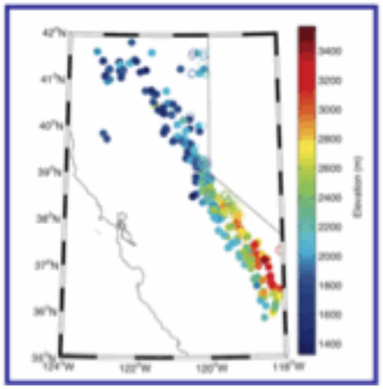
Importance of snowpack and its simulation in California climate research

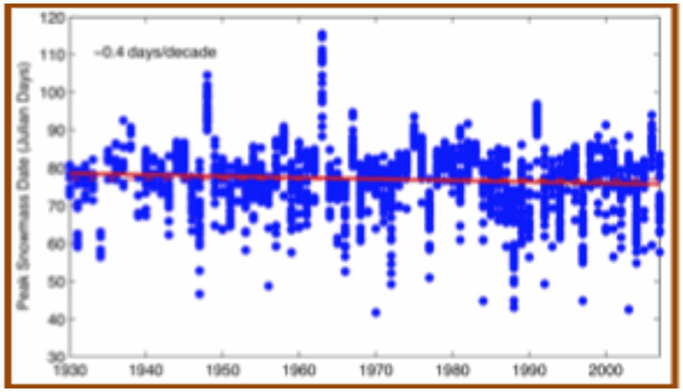
- High elevation snowpack accumulated during the course of a cold season is the major source of water supply during the following dry warm season for California and the western United States.
  - Precipitation in California and most of the western United States is highly seasonal; a wet cold season is followed by a dry warm season.
  - Snowpack in high elevation regions plays a role of a natural reservoir that stores water during the cold season and gradually releases it during the warm season.

- Snowpack is among the most sensitive components in California's hydroclimate to global climate change.

- Thus, reliable projection of high elevation snowpack is crucial for planning water resources management in California and the western United States in the presence of global climate change.

Motivation

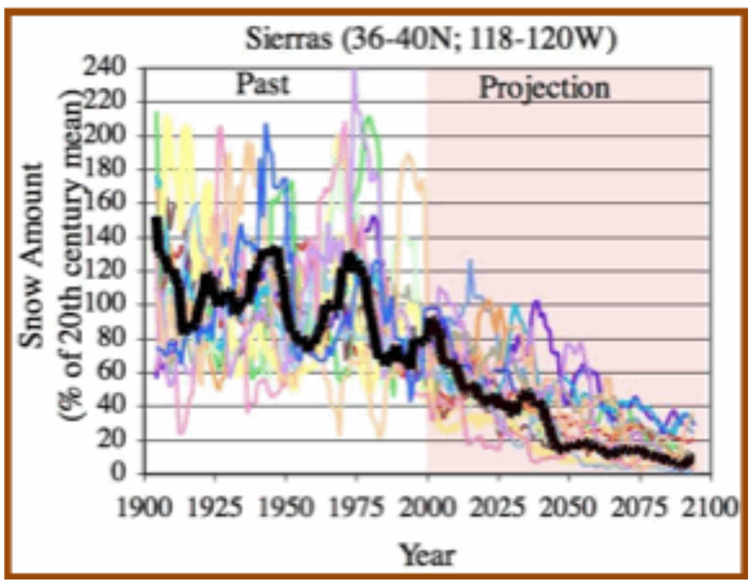




- ✓ Ongoing climate change is affecting snow in the Sierra Nevada.
- ✓ Observed snow-water equivalent (SWE) for 1930-2007 show that the date of peak snow mass occurs earlier by 0.4 day per decade.

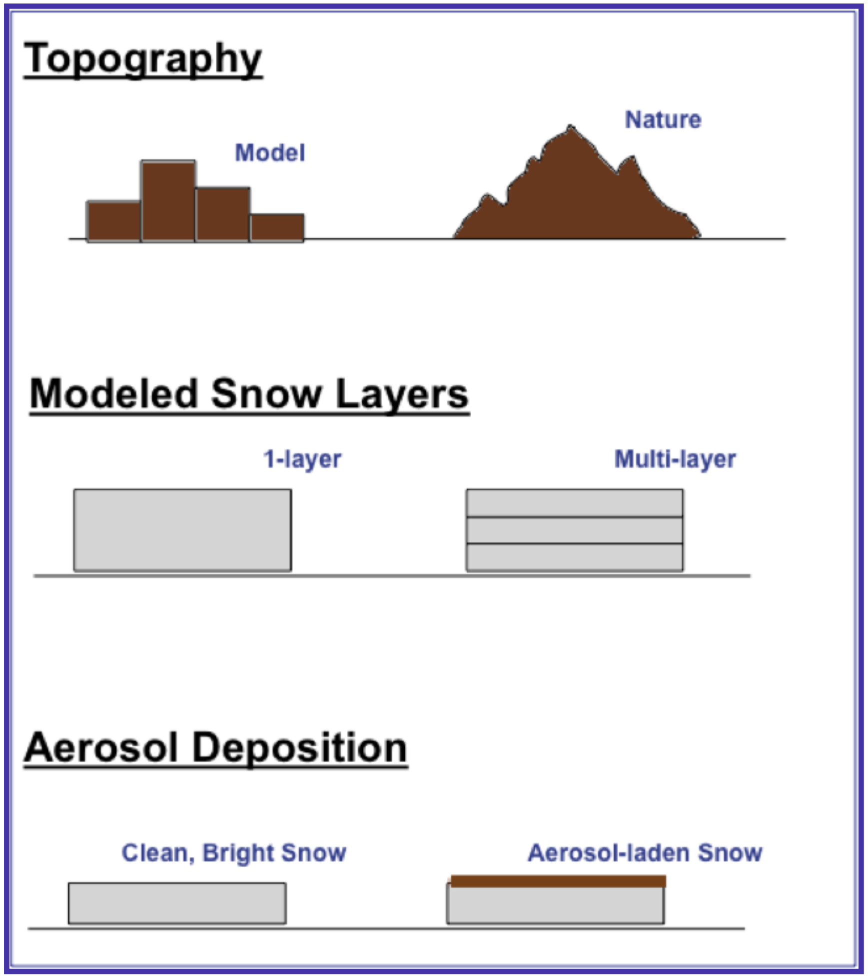
Based on this study and considerations of temperature projections, the date of peak snow mass would be expected to occur 3-9 days earlier by the end of the 21 century (Kapnick et al. 2008).

Uncertainties in the currently available projections of future SWE is large



- ✓ All GCMs used in IPCC-AR4 project a continued decrease in SWE in the Sierra Nevada.
- ✓ Their projections, however, vary widely among these GCMS.
- ✓ Such large uncertainties make it difficult to develop policy for effective mitigation of the climate change impact on the SWE and water resources in California.

California Snowpack Projections: Model Uncertainties



Model calculation of snowpack is directly affected by low-level air temperature and surface energy budget.

- For a region of complex terrain, representation of terrain elevation varies, in general, according to a model resolution. This in turn can cause systematic biases in calculating snowpack.
- Representation of internal snow physics can also be a source of model biases.
- Aerosol deposition on snow can alter snow albedo and, consequently, snowmelt.

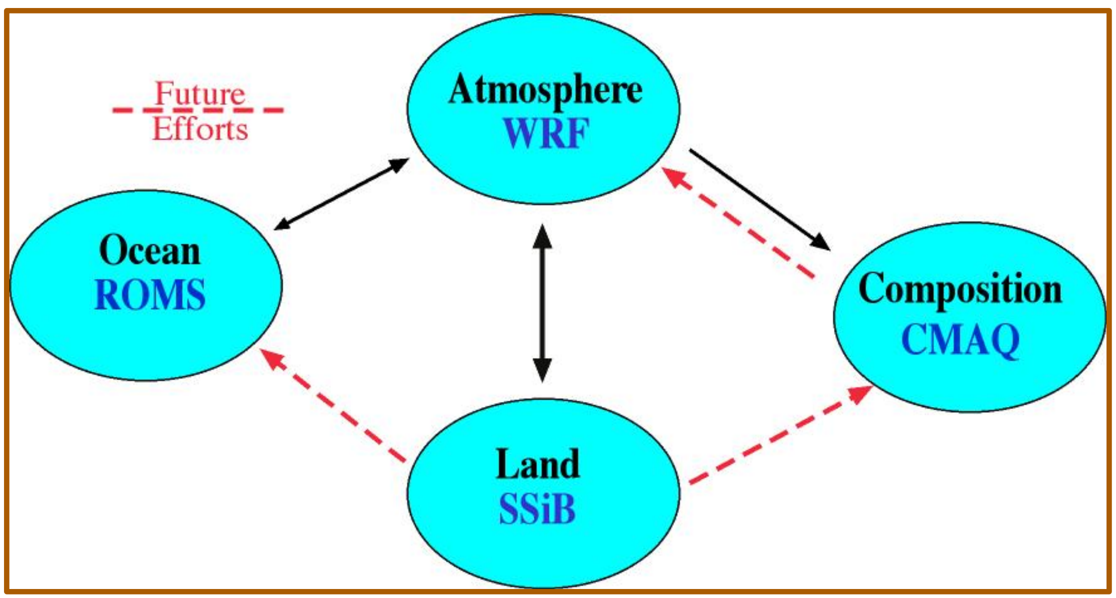
- **We investigate the uncertainties in simulating snowpack associated with these three aspects in regional climate modeling using the JIFRESSE RESM.**

JIFRESSE RESM

UCLA and JPL established the Joint Institute for Regional Earth System Science and Engineering (JIFRESSE) to promote and engage UCLA (Modeling) and JPL (Observations*)* in cutting edge Earth System science research.

The Regional Earth System Model (RESM) is being developed on the basis of limited-area *atmospheric* (WRF), *Ocean* (ROMS), and *Air quality* (CMAQ) models. These models are being improved with an inclusion of advanced physics schemes

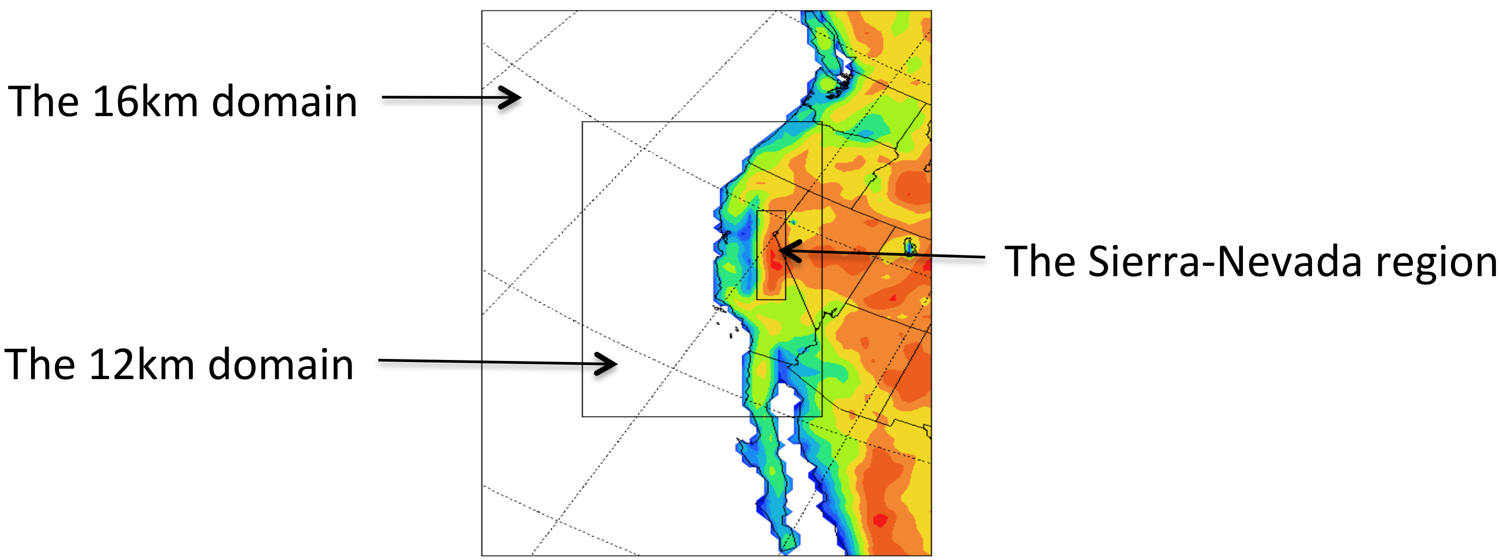
(e.g., Fu-Liou Delta/4-stream radiation scheme, SSiB land-surface, aerosol effects).

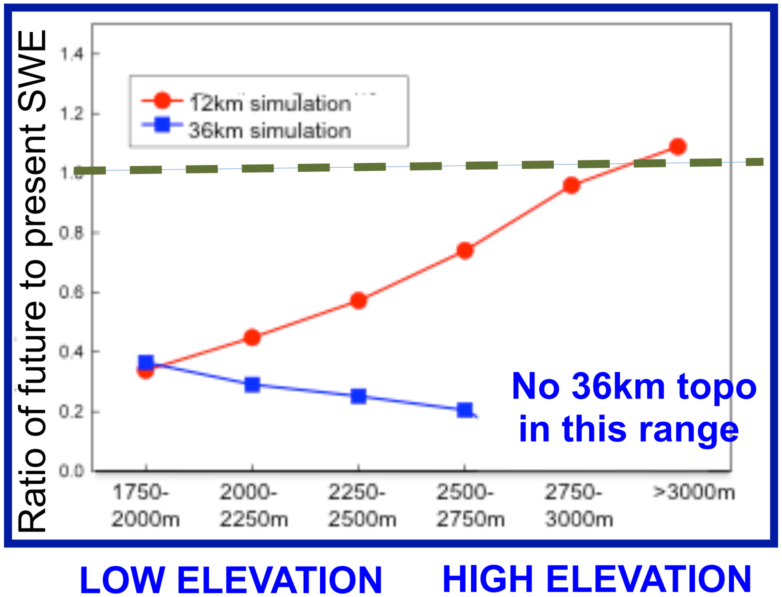


JIFRESSE Regional *Earth System Model* (RESM)

The impact of Model Resolution

- The impact of model resolution on projecting the climate change signal in SWE in the Sierra Nevada region is investigated.
- Two sets of climate change signals in SWE between late 20th century (1971-1980) and mid-21st century (2045-2054) were calculated at 36km and 12km simulations.
    - The 12km domain is one-way nested within the 36km domain.
- The large-scale climate forcing data were obtained from a NCAR-CCM3 climate scenario based on the IPCC SRES-A1B emission scenarios.





The projected SWE signals

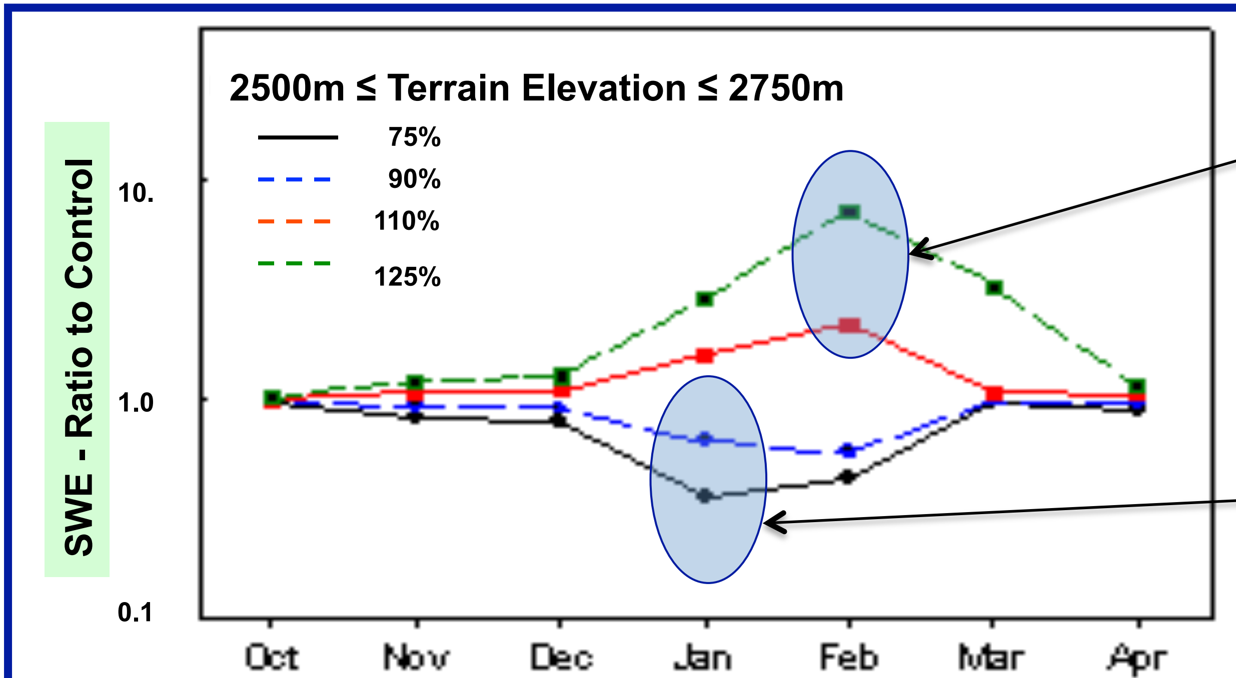
- Both runs project decreases in SWE in future climate.
  - Sensitivities are calculated in terms of percent changes.
- The 36km run projects much larger SWE sensitivities than the 12km run.
- The 36km resolution does not represent the Sierra Nevada terrain above 2500m.

- Further investigations show that the differences in the SWE sensitivity are:
  - not explained by the differences in snowfall sensitivity.
  - more directly related with the snowfall amounts in the two runs.
    - Snowfall in the 36km run is somewhat less than in the 12km.
    - Smaller snowfall in the 36km run resulted in smaller SWE that is subsequently amplified through snow-albedo feedback.
- The 12km run generates larger SWE decreases in lower elevations; this also supports that the SWE climate change signal is amplified via snow-albedo feedback.

The Impact of Snow Albedo/Aerosol Deposition

Role of Emissions?

- The 12km simulation for 2045 winter is rerun with varying snow albedo values:
  - **Control**: The default snow albedo values provided with WRF and Noah LSM.
  - **Increased emission**: Snow albedo is decreased by 10 and 25% from the control (blue and black)
  - **Reduced emission**: Snow albedo is increased by 10 and 25% from the control (red and green)



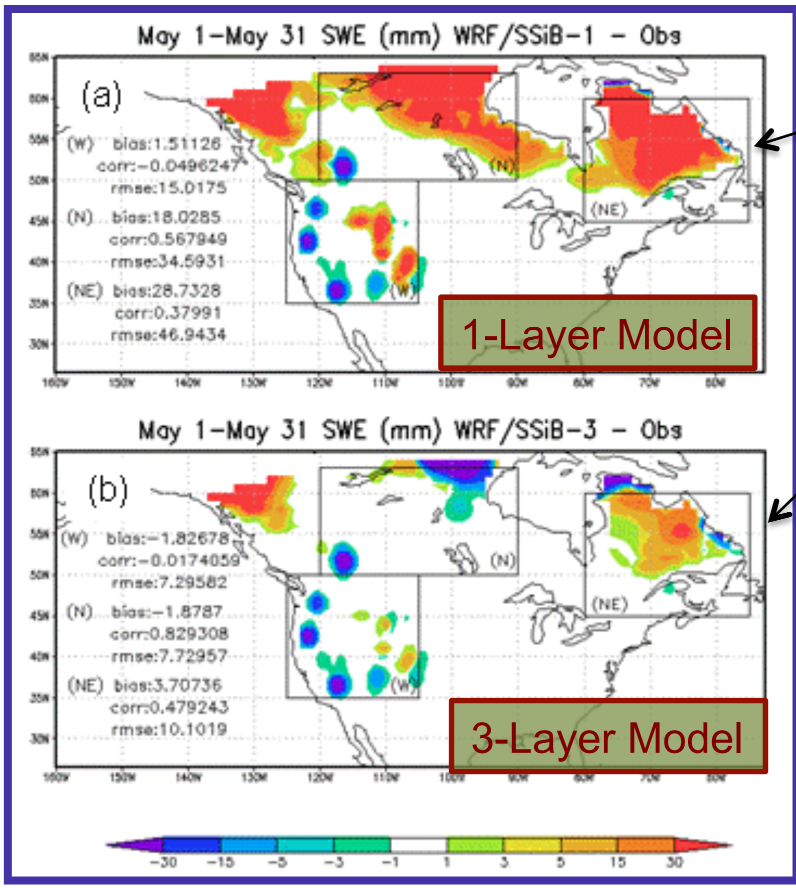
Modest increases in snow albedo lead to significant increases in SWE later in season

Modest decreases in snow albedo lead to significant decreases in SWE earlier in season

Reducing emissions will improve air quality; it may also improve water resources.

Impact of Snow Layer Physics Representation

- We compare spring SWE simulated with a single layer snow model against a multi-layer representation.
- The WRF model coupled with the SSiB land-surface scheme has been used.
- The simulation was performed for May 1998, a major snow ablation season.



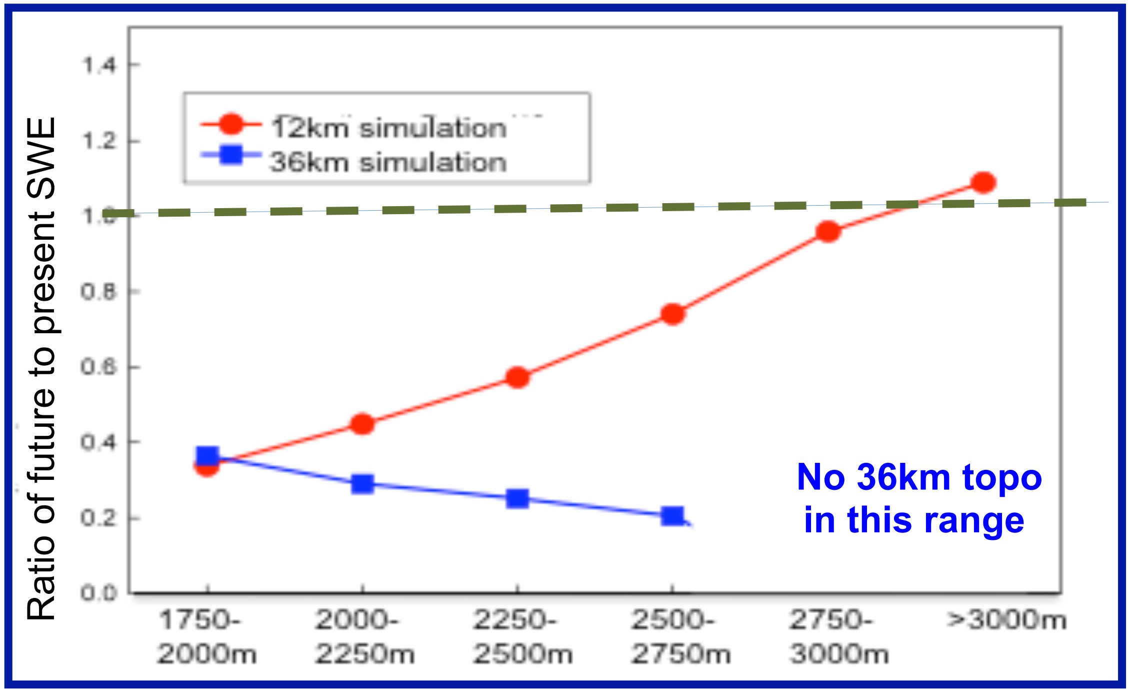
A single-layer snow model significantly overestimates SWE, especially in Canada and the Rockies.

A 3-layer snow model could reduce the biases noticeably. The negative SWE bias over the Sierra Nevada and the Cascades in the single-layer run is not affected by the three-layer model.

This result shows that more detailed treatment of the physical processes within snowpack is essential in climate simulations for snow-sensitive regions.

Summary and Conclusions

- High elevation snowpack plays a crucial role in California's hydroclimate related with water resources.
- Snowpack simulations suffer significant uncertainties due to model resolution, snow albedo changes [associated with aerosol deposition], and the level of details in representing snow physics:
  - Coarse resolution simulations cannot adequately resolve complex terrain. The resulting differences in snowfall can be amplified via snow-albedo feedback to result in significant uncertainties in the simulated SWE.
  - A modest increase or decrease in snow albedo, possibly due to aerosol deposition, can alter snow accumulation and ablation substantially during the course of a cold season.
    - Increased snow albedo significantly increases SWE in late cold season.
    - Decreased snow albedo significantly decreases SWE early in cold season.
  - Multi-layer representation of the physical processes within snowpack may be necessary for improving snowpack simulations.
    - A single layer snow model may overestimate snowpack during snow melt season.
    - A multi-layer snow model could alleviate the biases in single-layer model results.
- It is important to improve snow model physics for reducing uncertainties in projecting the impact of climate change on snowpack and cold-season climate:
  - E.g., The aerosol deposition-snow albedo relationship is not well quantified.



LOW ELEVATION HIGH ELEVATION

Winter season snowfall climate change sensitivity