A variable-resolution CESM case study of the comparative importance of model resolution and microphysics in a mountainous region

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Estimates of Snowpack (SWE) based on:
1) Yearly estimates from DWR April 1st SWE measurements
2) Long-term average from VIC simulations

Dettlinger and Anderson, 2015
Characteristics of Water in the West

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Water stores:
1) 23.5 MAF of storage from reservoirs
2) 17 MAF from April 1st SWE storage (5 Oroville dams) = 72% of additional natural storage from SWE
50% of precipitation in 5-15 days

Dettinger et al., 2011
50% of precipitation in 5-15 days

**Dettinger et al., 2011**

~40% of the Total Snow Accumulation in CA

**Guan et al., 2013**
Global-to-Regional Downscaling Tool to Understand Mountain Hydroclimatology

Variable-Resolution in the Community Earth System Model (CESM)

Benefits:
- Global simulation (atmosphere-ocean teleconnections)
- Increased resolution in specified areas (better topography)
- Decrease in model runtime and data storage (“smaller” server usage)
- Eliminates multi-model dataset needs (bias propagation)
- Merges regional and global modeling communities (scale awareness)
- Glimpse into the future of high-resolution global climate modeling
Global-to-Regional Downscaling Tool to Understand Mountain Hydroclimatology

Pilot VR-CESM project in Chile - column integrated water vapor – figure adapted from Colin Zarzycki
Identify and understand persistent VR-CESM bias associated with changing model resolution and/or sub-grid-scale model parameterizations.

Can VR-CESM realistically represent historical precipitation, snowpack and surface temperature in mountainous regions?
### Experimental Setup and Reference Datasets

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Resolution</th>
<th>Timeframe</th>
<th>Hydroclimate Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR-CESM (CAL_VR) MG1</td>
<td>28 km, 14 km, 7 km*, 3.5 km*</td>
<td>1999-2015</td>
<td>Precipitation, Snow Cover, SWE, Surface Temperature</td>
</tr>
<tr>
<td>VR-CESM (CAL_VR) MG2</td>
<td>28 km, 14 km</td>
<td>1999-2015</td>
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</tr>
<tr>
<td>WRF_VR-CESM MG1</td>
<td>28km, 14km, 7km</td>
<td>1999-2015</td>
<td>Precipitation, Snow Cover, SWE, Surface Temperature</td>
</tr>
<tr>
<td>PRISM</td>
<td>4 km</td>
<td>1999-2015</td>
<td>Precipitation, Surface Temperature</td>
</tr>
<tr>
<td>MODIS</td>
<td>5 km</td>
<td>2000-2015</td>
<td>Snow Cover</td>
</tr>
<tr>
<td>SNSR</td>
<td>90 m</td>
<td>1999-2015</td>
<td>SWE</td>
</tr>
</tbody>
</table>

**Experimental Setup Similarities**

- VR-CESM MG1 and MG2
  - CAM5
  - CLM4 with 5 km year 2000 Surface Datasets
  - Prescribed SST and Sea-Ice

**Differences**

- Horizontal Resolution
- Prognostic vs Diagnostic Treatment of Cloud Hydrometeors

**Morrison and Gettelman microphysics** developed for CESM1 (CESM2) in 2008 (2015) will be referred to as **MG1 (MG2)**

Both MG1 and MG2 are **2-moment schemes** (i.e., mass and number mixing ratio).

*Refinements at nonhydrostatic scales are experimental, targeted over small regions (CA mountain region), mid-latitudes (large-scale dominated), and in DJF (limited convection).*
DJF climate averages for MG1 simulations show a clear windward/leeward mountain precipitation bias which propagates into the other hydroclimate variables. Here the diagnostic treatment of hydrometeors requires precipitation to fall out immediately. DJF seasonal Pearson Pattern Correlations in MG1 were 0.5 to 0.7 across precipitation, snow cover, and SWE and 0.9 for surf. temp., although a systemic cold bias is present.
DJF climate averages for MG2 simulations most closely represented the observed precipitation, snow cover, and SWE results by alleviating bias to within +2% of PRISM, +6% of MODIS, and -5% of SNSR.

**Effects of Prognostic Hydrometeors (MG2) on Mountain Hydroclimatology**

DJF seasonal Pearson Pattern Correlations in MG2 across all of the hydroclimate variables more closely matched observed by +0.12 (0.73) compared to MG1 (0.61).
The least average (range) bias in accumulated PRECT was found for MG2 in the California Mountain Region.
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SWE accumulation cycle closely matched SNSR until the historical peak accumulation months of March to April.
The distributions of PRECT, FSNO and SWE in the windward/leeward of the Sierra Nevada in MG2 was much improved compared with MG1. Too Wet Too Dry

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### Windward/Leeward Ratios

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<th>Ensemble Average MG2</th>
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<tr>
<td>PRECT</td>
<td>2.9</td>
<td>8.79</td>
<td>2.8</td>
</tr>
<tr>
<td>FSNO</td>
<td>1.2</td>
<td>2.67</td>
<td>1.0</td>
</tr>
<tr>
<td>SWE</td>
<td>2.2</td>
<td>10.68</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Conclusions

**Motivation:** VR-CESM is a useful tool to understand resolution and microphysics impacts in CESM, especially in mountains.

**Goals:** Identify and understand persistent VR-CESM bias associated with changing model resolution (28km, 14km, 7km, and 3.5km), sub-grid-scale model parameterizations (28km and 14km), and/or nonhydrostatic dynamical core (28km, 14km, 7km).
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Results in California Mountainous Region:
• Increased refinement in model horizontal resolution to more realistically represent topographic and surface characteristics did not alleviate mountain hydroclimate bias tendencies in VR-CESM
• The use of a nonhydrostatic dynamical core did not alleviate bias in most hydroclimate variables, save for surface temperature. Forcing dataset plays a larger role in mountain hydroclimate bias tendencies in WRF (NCEP vs VR-CESM)
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- The use of a nonhydrostatic dynamical core did not alleviate bias in most hydroclimate variables, save for surface temperature. Forcing dataset plays a larger role in mountain hydroclimate bias tendencies in WRF (NCEP vs VR-CESM).
- The use of a new physics parameterization (MG2) coupled with resolving topography and surface characteristics at 14km resulted in a close approximation to DJF hydroclimate variables with...
  - **Precipitation** = +2% of PRISM (climate), wind/lee distribution 3.0 (2.9 in PRISM), DJF Pearson correlation of 0.77
  - **Snow Cover** = +6% of MODIS (climate), wind/lee distribution 1.1 (1.2 in MODIS), DJF Pearson correlation of 0.80
  - **SWE** = -5% of Landsat-Era (climate), wind/lee distribution 2.0 (2.2 in Landsat-Era), DJF Pearson correlation of 0.69
  - **Surface Temperature** = -2.9 K (climate) needs to be addressed, DJF Pearson correlation of 0.93
- More work is needed to understand the snowpack bias sensitivities to grid resolution and sub-grid-scale microphysics.
Future Work

Case Study Regions (3 water managers from each):
1) Colorado River Headwaters (Colorado)
2) Kissimmee River and South Florida (Florida)
3) Sacramento-San Joaquin Watershed (California)
4) Susquehanna River (Pennsylvania)

http://climate.ucdavis.edu/hyperion
Future Work

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Acknowledgements

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``Multiscale Methods for Accurate, Efficient, and Scale-Aware Models of the Earth System'' project
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**NSF Climate Change, Water, and Society IGERT at UC Davis**
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Benefits associated with proper amounts of total precipitation and windward/leeward deposition location are apparent in MG2 mountain elevation profiles for precipitation and SWE.

However, a systemic cold bias that worsens with elevation is apparent.

A more complete analysis of the processes that impact mountain lapse-rates need to be conducted.

DJF seasonal variability in observed
Effects of a Nonhydrostatic DyCore on Mountain Hydroclimatology

DJF climate averages for WRF_VR-CESM MG1 simulations still show a clear windward/leeward mountain precipitation bias. Snowpack bias is also maintained. Surf. temp. cold bias diminished, but still present in high elevations in mountainous regions.

DJF seasonal Pearson Pattern Correlations in WRF_VR-CESM MG1 were 0.45 to 0.60 across precip., snow cover, and SWE and <0.9 for surf. temp.
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WRF simulations conducted by Zexuan Xu

DJF climate difference in WRF_VR-CESM MG1 vs VR-CESM MG1 Highlights that WRF generally...

- Increases precipitation bias
- Increases average SWE/snow cover
- Warms surface temperatures (save for portions of southern Sierra)

DJF seasonal Pearson Pattern Correlations in WRF_VR-CESM MG1 were 0.45 to 0.60 across precip., snow cover, and SWE and <0.9 for surf. temp.
Accumulated precipitation similar to those seen in VR-CESM results, positive (negative) windward (leeward) bias.

Positive accumulated SWE bias worsened from VR-CESM with increase in resolution.

Surface temperature cold bias halved in DJF, analysis underway to understand why.

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<th>Ensemble Average WRF_NCEP</th>
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<td>10.3</td>
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**WRF simulations conducted by Zexuan Xu**
At what horizontal resolution would MG1 microphysics theoretical assumptions “break”?

**Lateral Transport Time** = \( \frac{dx}{\text{lateral transport velocity}} \)

**Drop Time** = \( \frac{\text{drop distance}}{\text{drop velocity}} \)

*when lateral transport time = drop time, then...*

\( DX = \left( \frac{\text{drop distance}}{\text{drop velocity}} \right) \times \text{lateral transport velocity} \)

**Assume...**

Lateral transport vertical integration = lower 10 levels in atmosphere

drop velocity = maximum, 1.2 m/s (snow) and 9.1 m/s (rain)
drop distance = 5000 m (Morrison and Gettelman)

**Rainfall DX**

Min = 1 km, Max = 6 km

Lower 10 Level Rainfall - dx where lateral transport time = drop time

**Snowfall DX**

Min = 11 km, Max = 47 km

Lower 10 Level Snowfall - dx where lateral transport time = drop time
Historical analysis to evaluate efficacy of VR-CESM as a regional downscaling tool at 28km and 14km

VR-CESM at 28km to evaluate RCP8.5 signal on hydroclimate metrics with comparison to other widely used climate change datasets

VR-CESM CORDEX style grids to evaluate TSA and PRECT over South America/Chile at 28km and 14km

SNOTEL Peak Accumulation Timing (Day 180)

Models have Negative Peak Accumulation Bias

Snowfall decreases with elevation (<2000 m)

SWE decreases with elevation (all elevations)

Freezing line moves upslope by 1000 m


Pilot Project (2017) with the Global Change Center at the Pontificia Universidad Católica de Chile