ICAR: A Simplified Atmospheric Model for Climate Applications

NCAR Day of Networking and Discovery 2017
Ethan Gutmann, Idar Barstad, Trude Eidhammer, Martyn Clark, Roy Rasmussen, Jeff Arnold, and others
Water security

- Mountain Snowpacks Supply Water to Reservoirs

- The U.S. Army Corps of Engineers, the Bureau of Reclamation want to use the latest in climate & hydrology modeling to understand risks to water security.

- Scientific understanding of the weather-water-climate nexus is critical!

- Advances enable water agencies to develop strategies to modernize and maintain their infrastructure
Climate Model Native Resolution and Application Resolution

Topography

Precipitation

WRF Ens002 (4km)
A dichotomy of downscaling options

• Statistical downscaling based on rescaling GCM outputs
  – BCSD, BCCA, AR

• “Dynamical” downscaling using simple weather models

• Dynamical downscaling using state-of-the-art RCMs
Intermediate Complexity Atmospheric Research model (ICAR)

Identify the key physics and develop a simple model
GOAL: >90% of the information for <1% of the cost
ICAR Simulations

- ICAR mean climate looks like WRF

ICAR (30 member average)
CESM Large Ensemble

• Tremendous, chaotic, variability
ICAR Simulations

- Cool Season Climate change signal looks similar to WRF.

- Use ICAR to expand a downscaled ensemble.
ICAR 30 Member Ensemble
Using ICAR to Diagnose Physics Parameterizations

• Many parameters in RCMs are highly uncertain, and have a significant impact on climate change signals.

• ICAR can be used to test some parameter sensitivities.

• Land surface models contain many simplifications ICAR can test.

\[
\begin{align*}
\rho: & \quad \left( \frac{\partial u_\rho}{\partial t} + u_\rho \frac{\partial u_\rho}{\partial r} + \frac{u_\theta}{r} \frac{\partial u_\rho}{\partial \theta} + \frac{u_\phi}{r} \frac{\partial u_\rho}{\partial \phi} - \frac{u_\rho^2 + u_\phi^2}{r} \right) = -\frac{\partial p}{\partial r} + \rho g + \\
\mu: & \quad \frac{1}{r^2} \left( \frac{\partial}{\partial r} \left( r \frac{\partial u_\rho}{\partial r} \right) + \frac{u_\theta}{r} \frac{\partial u_\rho}{\partial \theta} + \frac{u_\phi}{r} \frac{\partial u_\rho}{\partial \phi} - \frac{u_\rho^2 + u_\phi^2}{r^2} \right) = -\frac{1}{r^2} \left( \frac{\partial p}{\partial r} + \rho g + \right) \\
\phi: & \quad \frac{1}{r} \left( \frac{\partial}{\partial r} \left( r \frac{\partial u_\theta}{\partial r} \right) + \frac{u_\phi}{r} \frac{\partial u_\theta}{\partial \phi} + \frac{u_\theta}{r} \frac{\partial u_\theta}{\partial \theta} + \frac{u_\phi}{r} \frac{\partial u_\phi}{\partial \phi} - \frac{u_\theta^2 + u_\phi^2}{r^2} \right) = -\frac{1}{r^2} \left( \frac{\partial p}{\partial r} + \rho g + \right) \\
\theta: & \quad \frac{1}{r} \left( \frac{\partial}{\partial r} \left( r \frac{\partial u_\phi}{\partial r} \right) + \frac{u_\theta}{r} \frac{\partial u_\phi}{\partial \theta} + \frac{u_\phi}{r} \frac{\partial u_\phi}{\partial \phi} + \frac{u_\rho}{r} \frac{\partial u_\phi}{\partial \rho} - \frac{u_\theta^2 + u_\phi^2}{r^2} \right) = -\frac{1}{r^2} \left( \frac{\partial p}{\partial r} + \rho g + \right)
\end{align*}
\]

\[
M(H^8) = \pi \left( \frac{1}{137} \right)^8 \sqrt{\frac{hc}{G}}
\]

\[
3987^{12} + 4365^{12} = 4472^{12}
\]

\[
\Omega(t) > 1
\]
Snow Albedo Feedback in the Mountains

Temperature Change in May
Mountains in the Real World

• Spatial Heterogeneity

• Rock is Always Exposed – Even when there is >1-5m of snow "on average"
Snow Depth Distributions

- Airborne Lidar Surveys
- Mean Snow Depth
  \(~1.5\) m
- Min = 0, Max > 15 m!
- Particularly important in melt season
1-2°C difference!

“Alpine” Snowpack

Standard Snowpack

Alpine - Standard delta T

1-2°C difference!
Uncertainty within Cloud Physics parameterizations

Thompson et al. (2008)
Ideal Hill Case

- But with varying cloud physics parameters...
- (Some of these may be unrealistic...)
Ideal Change Signal

- These changes affect a climate change signal strongly as well (2°C warming)
Summary

- Water managers want downscaled climate products. We would prefer they were based on physical understanding.
- ICAR provides a quasi-dynamical downscaling option consistent with dynamical downscaling.
- ICAR provides the ability to explore uncertainty in climate (or weather forecasts).
ICAR Users / Applications
Snow Covered Area the Noah LSM

- SCA = f(swe, LC)

- Above Treeline
  - SWE=2cm, SCA=1!

- Should be closer to
  - SWE=1m, SCA=0.5
Importance of Uncertainty on Apparently Certain signals

Increasing Precipitation (Ens. 2)

Decreasing Precipitation (Ens. 30)

Highly uncertain changes in total precipitation can modify what appear to be high certain
Summary

• New Physics + new infrastructure

• Exploring Variability with CESM
  – and other CMIP 5 models

• Exploring Climate sensitivity due to Physics parameterizations
## Uncertainty in Microphysics

<table>
<thead>
<tr>
<th>Parameter Name</th>
<th>Description</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ntc:</td>
<td>Droplet number concentration</td>
<td>50 cm(^{-3}) – 1000 cm(^{-3}) Clean air - Polluted</td>
<td>Related to Aerosol concentration</td>
</tr>
<tr>
<td>TN0:</td>
<td>Cloud ice number concentration parameterization</td>
<td>0.5 to 50</td>
<td>Vary deposition ice nucleation with a factor of 100.</td>
</tr>
<tr>
<td>(a_v, b_v, f_v):</td>
<td>Snow fall speed parameters</td>
<td>Original Mitchell and Heymsfield (2005). Test: Locatelli and Hobbs (1974) used in other microphysical schemes.</td>
<td></td>
</tr>
<tr>
<td>(c_{\text{cube}}):</td>
<td>Capacitance (ice, graupel and snow)</td>
<td>Original: 0.5 Test: 0.25 (Lin 2008)</td>
<td>Deposition and sublimation dependent on capacitance. Reduced (c_{\text{cube}}) based on Lin (2008)</td>
</tr>
<tr>
<td>Bigg:</td>
<td>Droplet freezing</td>
<td>0 : Some aerosol types(?) -5 : Default (most aerosol types) -10 : Relatively clean air (some aerosol types)</td>
<td>Change the temperature for where droplet freezing occur</td>
</tr>
<tr>
<td>Ef_sw_l:</td>
<td>Snow collecting cloud water.</td>
<td>Original: efficiency &lt; 1 Test: efficiency = 1 (used in many microphysical schemes)</td>
<td>Variable collection efficiency based on median volume diameter of snow and cloud water.</td>
</tr>
</tbody>
</table>
ICAR Simulations with Modified SCA-SWE

- 8 Year Simulation (Oct 2000 – Oct 2008)
- NARR Boundary Forcing
- Noah LSM
- “PGW” warming simulations – Boundary conditions perturbed with climate change signal from CCSM4
Effects on Runoff

- **More** late season snowmelt and runoff
- **Less** early spring runoff
  - Less surface area to melt
  - And less to evaporate/sublimate
- ~2% more runoff in total
Effects on Climate Change Signal

- **Less** increase in early spring runoff
- **Less** decrease in mid-season melt and runoff
- **More** decrease in late-season runoff
- Smaller, longer Change signal (might be easier to manage)
- Slightly smaller change in total runoff (–0.5mm vs –4mm)
Is there a Signal in Cool Season Precipitation?
Snow Albedo Feedback

February Temperature Change