High Resolution Regional Climate Simulations of the Water Cycle over CONUS Including Potential Climate Change Scenarios

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Sponsored by NCAR Water System Program

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Science Objectives of the CONUS Project

• To assess future changes of snowfall/snowpack and associated hydrological cycles

• To examine precipitation changes under the CMIP5 projected global warming, including extremes, warm-season precipitation in central US and hurricanes

• To provide the community a dataset for high resolution studies of regional climate change and impact studies
Numerical Approach

- WRF model with a 4-km-spacing $1360 \times 1016 \times 51$ points!

- Physics parameterizations:
  1. Thompson aerosol-aware microphysics
  2. Noah-MP LSM
  3. YSU PBL
  4. RRTMG radiation
  5. Weak spectral nudging

- 2000-2013 (ERA-I) Forcing
- Future forcing using “PGW”
  - Pseudo-Global Warming
  - CMIP5 (19) model ensemble mean change
  - (2071-2100) – (1975-2005)
    - Eliminates the internal variability problem
What is PGW approach?

- Compute 30-year CMIP5 19 model ensemble monthly mean
- Compute mean changes – T, U, V, Qv, GPH
- Add change signal to the 6-hrly ERA-I data

- No change in storm tracks.
- Same transient spectra. (weather)
Efforts to improve WRF high-resolution climate simulations

1. Computing requirements
   - NCAR Strategic Capability proposals with a total award of 42M core hours
2. WRF model improvements for CONUS project made over last two years
   - Significant model deficiencies found in test runs

<table>
<thead>
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<th>Improvements</th>
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<tr>
<td><strong>Noah-MP LSM</strong></td>
<td>1. Rain-snow partitioning</td>
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<td>2. vegetation-dependent snow fraction/melt curves</td>
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<td>3. Allowing snow to be present at above 0°C</td>
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<td>4. heat advection by precipitation</td>
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<td></td>
<td>5. Bug fix for canopy snow unloading and snow density</td>
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<td><strong>Microphysics</strong></td>
<td>Aerosol emission refinement</td>
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<td><strong>lake water</strong></td>
<td>Based on a combination of SST &amp; skin temperature</td>
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<td>temperature**</td>
<td>testing and parameter adjusting</td>
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<td><strong>spectral nudging</strong></td>
<td>skin-temperature based approach for PGW</td>
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<td><strong>sea ice/SST</strong></td>
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Efforts to improve WRF high-resolution climate simulations

3. Bug fix in WRF model associated with long-term high-resolution integrations

- deficient treatment of lateral boundary conditions
- bug in diagnosis module
Winter cold biases from test runs
Compared to PRISM observations

December 2000
Results after LSM improvement: vegetation-dependent snow fraction/melt curves

December 2000
Comparison of monthly precipitation between WRF and PRISM for 2008
PRISM observations averaged over 2001-2008

Precipitation (mm/day)

Precipitation bias (mm/day)

Courtesy of Andreas Prein
PRISM observations averaged over 2001-2008

2 m temperature (°C)

2 m temperature bias (°C)

Courtesy of Andreas Prein
Model Evaluation at SNOTEL Sites

SNOTEL site at Brooklyn Lake, WY

1: Pacific Northwest
2: Sierra Nevada
3: Blue Mts
4: Idaho/w. MT
5: NW WY–S. MT
6: Utah
7: Colorado

Snow gauge
Snow pillow
SNOTEL vs WRF at SNOTEL sites: 9-year climatology

1: Pacific Northwest (105)
2: Sierra Nevada (31)
3: Blue Mnts (28)
4: ID, W. MT (110)
5: NW WY, S. MT (102)
6: UT (95)
7: CO (130)

All SNOTEL sites (816)

PRCP bias: -2% – 9%
SWE bias: -10% – -40%
Preliminary results from ongoing PGW simulation

- Seasonal/annual surface temperature changes
- Seasonal/annual precipitation/rainfall changes
- Snowfall and Snowpack changes over western mountains
8-year Climatology of Surface Temperature Change (PGW – CTRL)

JAN-MAR

APR-JUN

JUL-SEP

OCT-DEC
Annual Precipitation

CTRL Annual 8-yr climatology

PGW Annual 8-yr climatology

Percent Change : Annual 8-yr climatology

PGW - CTRL : Annual 8-yr climatology
Snowfall and Rainfall Climatology

CTRL

PGW

PGW - CTRL

Snowfall

Rainfall

CTRL

PGW

PGW - CTRL

Annual Total (mm)

PGW – CTRL (mm)
IKE
Wind: Curr=41.1m/s PGW=45.7m/s
Radius: Curr=133.9km PGW=140.4km
Summary

• Four CONUS simulations
  • ERA-I forced & PGW
  • two CMIP5-forced runs.

• Unique features including
  • 10+ yrs Continental scale convection-permitting integrations, and
  • use of CMIP5 model ensemble mean forcing.

• Efforts to improve model skills.

• Impressive performance for precipitation and temperature
  • except for dry and warm bias in Central US.

• PGW shows
  • increasing annual precipitation/rainfall over most of CONUS
  • reduced snowfall/snowpack
  • suppressed summer convection in central US.
Thank you.

Questions?
SWE underprediction from test runs

- capability for snow being present at above 0°C
- microphysics-based rain-snow partitioning
Overprediction of lake precipitation due to warm water temperature from test runs

October 2000
Result after lake temperature fix:
used daily mean skin-temperature for lake water

October 2000
Summer warm biases from test runs

August 2001
Results with spectral nudging plus default option changes in LSM

August 2001
8-year Climatology of Surface Temperature Change

( PGW – CTRL )

Annual Temperature Change
Seasonal Precipitation: Jan – Mar
Seasonal Precipitation: Apr – Jun

CTRL AMJ 8-yr climatology

PGW AMJ 8-yr climatology

Percent Change : AMJ 8-yr climatology

PGW - CTRL : AMJ 8-yr climatology
Seasonal Precipitation: Jul – Sep

CTRL JAS 8-yr climatology

PGW JAS 8-yr climatology

Percent Change: JAS 8-yr climatology

PGW - CTRL: JAS 8-yr climatology
OUTLINE

1. Overview of the Project
   - Motivation & objectives
   - Methodology
   - Numerical Experiments
   - Challenges and efforts

2. Preliminary Results
   - 9-yr control simulation
   - 8-yr PGW simulation

3. Ongoing Work and Future Plan
**Numerical Experiments**

- **EXP1**: Retrospective/Control simulation
  - forced with ERA-I reanalysis
  - Completed March 2016

- **EXP2**: Pseudo-Global Warming (PGW) simulation
  - forced with ERA-I plus climate perturbation
  - $\Delta_{\text{RCP8.5}} = \text{CMIP5}_{2071-2100} - \text{CMIP5}_{1976-2005}$
  - 13-year integration
  - Completed April 2016