Developing Modeling Techniques Applicable for Simulating Future Climate Conditions in the Carolinas

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- **Global Climate Models (GCMs)**
  - Global coverage at century-long timescales
  - Typical grid cell is ~ 1° latitude/longitude

- **Regional Climate Models (RCMs)**
  - Limited-area model used over monthly to decadal periods

**Downscaling:** GCM projections used to drive RCM
Computational Expense

• Users can obtain future climate projections at higher spatial resolution & temporal frequency, within limitations of computing resources.

• Running & storing dynamically downscaled simulations is often computationally expensive.
  – Example: 12-km RCM output covering eastern U.S. produces \(~5 \text{ GB/day} \rightarrow 1.6 \text{ TB/year}\)

• Implications for users:
  – Prioritize spatial resolution, output frequency, ensembles of GCMs, etc. Communicate necessities to modelers.
Developing Downscaling Methods

• Simulate historical period using coarse dataset of observations as a proxy for a GCM

  – NCEP-DOE AMIP-II Reanalysis (R2)
    • “Reanalysis”: combination of observations with numerical model to form comprehensive representation of atmosphere
    • 1.875° at equator. Similar to several currently-used GCM, but note that some GCMs use finer resolution
Developing Downscaling Methods

• R2 is dynamically downscaled to 36- & 12-km grids using the Weather Research & Forecasting (WRF) model as an RCM.

• Here, the utility of downscaling as a tool illustrated by comparing R2 with a 12-km downscaled WRF run.
Representation of Topography

• RCMs have sufficient resolution to represent land features & can simulate their impacts
  – Shorelines → land-sea breeze
  – Lakes → lake-effect precipitation
Representation of Topography

- Mountainous terrain significantly better resolved. Enables simulation of:
  - Rainfall with upslope flow
  - Cold air damming events
- Statistical models can adjust temperatures. Not true for winds, humidity, & other variables.
Monthly Precipitation: Southeast

- WRF captures precipitation in the Carolinas & Georgia, but with much more detail than R2.

- Better agreement with high-resolution MPE observations.
Monthly Precipitation: Carolinas

- WRF produces too much precip in central NC and along coasts
- R2 has high bias throughout NC & SC
Regional Averages

- During period of previous plot, monthly rainfall amounts are similar when spatially-averaged over all of southeast U.S.
- *Utility of downscaled data is in representation of spatial variability, extremes.*
  - Downscaled data loses potential value (relative to existing GCM simulations) when aggregated up to large spatial & temporal scales.

![Graph showing mean monthly precipitation in Southeast Land points, 2006](chart.png)

- **Mean Monthly Precipitation in Southeast**
  - University of Delaware obs, plotted with WRF & R2 precip

- June 2006
Customization

- GCMs are tasked with global coverage. *Choices of model configuration in RCMs allows improvement in regional areas or specific variables needed for application.*

- Evaluation by downscaling group at EPA & collaborators at UNC Inst. for Environment:
  - Temperature & precipitation extremes (Otte et al. 2012, *J. Climate*)
  - Hurricanes as “drought busters” (Talgo et al., In Preparation)
  - Location of Bermuda High & moisture flow into southeast (Bowden et al. 2013, *Clim. Dynam.*)
  - Lake temperatures & ice cover (Mallard et al., *J. Geophys. Res.*, In Review)
Lake Temperatures

- Large error in near-surface temperature around Great Lakes.
  - WRF reliant on GCM to provide water temps. R2 poorly resolves lakes.

- Solution: Coupled WRF with lake model.
  - Improvement in temps, ice cover & lake-effect snow

2-m temperature mean absolute error [K], Summer 2006, computed against NOAA Meteorological Assimilation Data Ingest System (MADIS) observations.
Summary

• Benefits of downscaling are in representing smaller scale features, extremes.

• Not all downscaled datasets are created equal. Downscaling methods are often different among groups of modelers. Some RCMs and model configurations perform better in specific regions.
Slides Prepared for Questions
Regional Climate Modeling at EPA

- Downscaling multiple GCMs from IPCC 5th Assessment Report to 36-km WRF grid.
  - NASA/GISS MODEL-E2
    - Downscaled for historical period and decadal time slice centered on 2030 with RCP 6.0 scenario.
    - Community Multi-Scale Air Quality (CMAQ) model runs driven with downscaled projections & present-day emissions to examine effect of “climate penalty” on ozone and particulate matter concentrations (Nolte et al., 2013, CMAS).
  - NCAR CESM
    - Also downscaled for 2030 period (RCP 8.5) & used to drive CMAQ
    - Plan to simulate mid-century period and use additional RCPs
    - Ongoing work to also downscale NOAA GFDL CM3
Lake Temperatures

- Interpolation of water temps from R2 used oceanic values in eastern lakes
- In 12-km runs, WRF is coupled with a lake model that provides temperatures & ice cover

Hourly surface temperatures valid 15 Jun 2006
2-m Temp: Bias in Carolinas

2-m Mixing Ratio: Bias
Impacts of introducing KF Cloud-Radiation Interactions
Surface Precipitation for Southeast U.S. using 36 km grids in the WRF model

Wet bias from Kain-Fritsch CPS is largely eliminated

Alapaty et al., 2012, GRL; Herwehe et al. (2014), JGR – in PRESS
June-August 2006 MPE Precipitation

June-August 2006 PRISM Precipitation

June-August 2006 WRF Case 1 Precipitation

June-August 2006 WRF MSKF Precipitation

12km WRF

WRF Modified
Annual number of days with 2-m temperature greater than 90° F (gray) and less than 32° F (white) from 20-year 36-km runs where R2 is downscaled. Boxes are drawn from 25th to 75th percentiles with 50th percentile shown in center of each box, and whiskers at minimum and maximum values.