An Overview of the NARCCAP WRF Simulations

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What is WRF

► WRF is a supported “community model” that stands for Weather Research and Forecasting model – a free and shared resource with distributed development (NCAR, NOAA, AFWA, FAA, NRL, …) and centralized support (NCAR)

► Since version 2.1 (2005), WRF has two dynamical cores: ARW and NMM – both non-hydrostatic, Eulerian mass, with terrain following vertical coordinates

► The NARCCAP WRF simulations are based on WRFV2.0.1 (ARW dynamical core) (also used in the NRCM tropical channel simulations)

► Features added to WRFV2.0.1 (now mostly available in WRFV3.1+):
  - CAM3 radiation (prescribed spatially uniform aerosol concentrations and monthly/latitudinally varying ozone concentration)
  - Background surface albedo changes between summer/winter seasons
  - Prescribed seasonal changes in vegetation cover
  - Updating SST and sea ice in the lower boundary condition
  - Cloud fraction following Xu and Randall (1996) instead of 0/1
What is WRF

► Features added to WRFV2.0.1 (cont’d):

- Output accumulated instead of instantaneous fluxes for budget analysis (plus added clear sky / total sky fluxes)
- Prognostic deep soil temperature based on Salathé et al. (2008), where $\alpha = 0.6$ and $n = 140$

$$T_{soil} = \alpha \langle T_{skin} \rangle_{365} + (1 - \alpha) \langle T_{skin} \rangle_n$$

- Use of linear-exponential functional form for the nudging coefficients in the relaxation boundary conditions with a 10-grid point wide buffer zone
- $\text{CO}_2$ concentration temporally interpolated from time series of annual mean $\text{CO}_2$ concentration based on the GCM scenarios
- For downscaling CCSM – used 365 day calendar

► Most “climate” implementations are incorporated in the standard WRFV3
WRF configurations:

- **Physics options:**
  - Radiation: CAM3 for both shortwave and longwave
  - Boundary layer turbulence: A nonlocal scheme based on YSU
  - Cloud microphysics: mixed phase (wsm4) – water, ice, snow, rain
  - Cumulus convection: Grell-Devenyi scheme (WRFG)
    - Also used Kain-Fritsch for a simulation driven by reanalysis (WRFP)
    - For consistency with the GCM downscaled runs, WRFG should be used as the “standard”
  - Land surface model: Noah LSM; No lake model
    - Lake surface temperature prescribed based on reanalysis/GCM SST linearly interpolated from coast to coast to the locations of lakes
    - In the CCSM driven future climate run, lake temperature was inadvertently prescribed based on skin temperature from CCSM, which is only representative of temperature of larger lakes simulated by CLM

- **Grid resolution:** 50 km (155x130); vertical levels: 35
- **Time step:** Between 120s and 150s
WRF initialization:

► For the reanalysis driven runs:
  - Initial atmospheric and land surface conditions are based on global reanalysis
  - Simulations were initialized on 9/1/1979 (only 3 months of model spinup)
  - Lateral and lower boundary (SST and sea ice) conditions are updated every 6 hours based on the global reanalysis

► For GCM driven runs:
  - Initial atmospheric conditions are based on GCMs; initial land surface conditions are based on global reanalysis
  - Lateral and lower boundary conditions updated every 6 hours based on GCMs
  - Allow 2 years of model spinup (e.g., 1/1/1968 – 12/31/1969)
WRF Simulations:

- Completed two simulations driven by NCEP/DOE global reanalysis for 1979/9/1 – 2004/12/31 using GD (WRFG) and KF (WRFP)
- Completed two simulations driven by the CCSM control (1968/1/1 – 1999/12/31) and future (2038/1/1 – 2069/12/31) using GD
- Completed two simulations driven by the CGCM control (1968/1/1 – 2000/12/31) and future (2038/1/1 – 2070/12/31) using GD
- WRF writes two kinds of model outputs:
  - The standard wrfout* files are written every 3 hours (include both 2D and 3D fields) (~ 600 MB/day)
  - Auxiliary output files (aux*) are written every hour (include only some 2D fields) (~ 28 MB/day)
- Model outputs have been postprocessed to generate data for the various NARCCAP tables – data that have undergone checking for missing/bad values are posted on ESG
- Additional variables added to Table 3 for April – September (e.g., CAPE, wind shear, LLJ cat (Bonner), u/v moisture transport, virtual potential temp, pbl mixing ratio)
Analysis of WRF simulations

- Atmospheric river induced heavy precipitation and flooding in the western US


Source: Neiman et al. 2008

Ralph et al. (2005)

Source: Neiman et al. 2008
GCM simulated AR changes in the future climate

The number of AR days increases by 27% and 132%, respectively, based on the CCSM and CGCM simulations of current (1970-1999) and future (2040-2069) climate.

CCSM projected larger increase in AR frequency in the north compared to CGCM.

There is a 7 – 12% increase in column water vapor and water vapor flux, with little change in wind speed.
Changes in AR precipitation and runoff

Change in total AR precip
AR Total Precip Diff (mm/yr) Future–Current

WRF-CCSM

AR Total Precip Diff (mm/yr) Future–Current (cgcm)

WRF-CGCM

Change in total AR runoff
AR Total Runoff Diff (mm/yr) Future–Current

WRF-CCSM

AR Total Runoff Diff (mm/yr) Future–Current (cgcm)

WRF-CGCM
Analysis of WRF simulations


- The northward seasonal migration of precipitation from the southern Great Plains to the Midwest is well captured in WRF, but not CCSM, which provided the large-scale boundary conditions for the WRF simulation.
Changes in severe weather environment under climate change

- The northward seasonal migration of mesoscale convective complex (MCC) (and the associated severe weather) is reproduced in the simulation.
- The model simulated a general increase in the north and reduction in the south for severe weather environment.


WRF simulated frequency of MCC-like precipitation objects

WRF simulated changes in frequency of MCC-like precipitation objects between 2040-2070 and 1970-2000