Regional Climate-Weather Research and Forecasting (CWRF) Model Development & Application

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2011 / 09 / 29
EPA STAR 2003-2011

FOCUS

Consolidate O₃

Elaborate PM

Explore Hg

EPA STAR 2009-2012

FOCUS

Nutrients

Pathogens

Bacteria

Sediments

Agriculture

Urban
RCM Better Resolves Extremes

Northeast U.S. Assessment

Propagation of GCM Present Climate Biases into Future Change Projections: Temperature
Outline

- What is RCM – the EaSM core?
- What are values added by RCM downscaling?
- What are CWRF advances over other RCMs?
- What are needed to make a credible RCM run?
- What challenges face RCM development?
  - Scale dependence
  - Physics configuration selection
  - Optimized physics ensemble
  - System uncertainty
NOAA 2008-2011

Urban and Built-up
Dryland Cropland and Pasture
Irrigated Cropland and Pasture
Cropland/Grassland Mosaic
Cropland/Woodland Mosaic
Grassland
Shrubland
Mixed Shrubland/Grassland
Savanna

Deciduous Broadleaf Forest
Evergreen Broadleaf Forest
Evergreen Needleleaf Forest
Mixed Forest
Water Bodies
Wooded Wetland
Barren or Sparsely Vegetated
Wooded Tundra
Mixed Tundra
RCM Downscaling is Science + Art

- Do NOT take an RCM off the shelf (localization)
- Domain Design (integrating planetary forcing)
- Physics Configuration (regime & scale dependence)
- Verification or Evaluation (obs. data & added values)
- Ensemble Approach (prediction skill & uncertainty)

Doing details is the key to success!
Ensemble Global Forecast System

⇒ ICs, SSTs, LBCs

- NCEP
- ECMWF
- OP DASs
  ⇒ ICs

- NOAA CFS
- NASA GEOS
- Bias corrections
- OP CGCMs
  ⇒ SSTs

- NOAA GFS
- NCAR CAM
- IRI ECHAM
- AGCMs
  ⇒ LBCs
NCEP/AMIP II vs ECMWF-Interim Reanalysis
Recent Advances
Comparing with Other RCMs

Ability to reproduce observations

- All driven by the same reanalysis
- Result comparison on
  - Seasonal variations
  - Interannual anomalies
  - Extreme events
Summer 1993 U.S. Midwest Record Flood

OBS

WRF

CWRF

Rainfall (mm d\(^{-1}\))

WRF

CWRF

T2m Bias (°C)

CWRF has made significant improvements.
Surface Temperature Biases

All driven by NCEP/DOE AMIP II Reanalysis
Surface $SW_d$ Biases

All driven by NCEP/DOE AMIP II Reanalysis
Understanding Biases

- **WRFG & CMM5**: SWd are too large, while T2m biases are relatively small.
- **HRM3**: SWd is quite realistic, while T2m is substantially overestimated.
- **CRCM**: SWd is fairly realistic, but T2m has notable cold biases.
- **RCM3**: SWd is substantially underestimated, yet T2m is reasonable.
- **CWRF**: SWd and T2m both are quite realistic.
- **Conclusion**: SWd seems not the dominant factor that cause T2m biases; the latter may largely result from deficiencies in the water cycle.
Interannual CORR over USA
Why Do RCM Results Differ?

- **Domain:** U.S. + Adjacent for CWRF & CMM5, Extended North America for NARCCAP
- **Resolution:** 30 km for CWRF & CMM5, 50 km for all other NARCCAP RCMs
- **Forcing:** linear-exp relaxation in buffer zones of 14 (CWRF, CMM5), 10 (WRFG) grids, linear relaxation in 4 grids (MM5I, HRM3) domain spectral nudging (ECP2, CRCM)
- **Physics:** CWRF is much better than CMM5, being identical in all other settings

Different dynamics may also contribute.
Physics Representation

Evaluating Skill under Correct Forcing Conditions
Scale Dependence

Model physics representation and predictive skill depend on spatial scale
CWRF Terrestrial Hydrology

Choi 2006; Choi et al. 2007, 2011; Choi and Liang 2010; Yuan and Liang 2010; Liang et al. 2010d
Illinois Soil Moisture Simulations Driven by NARR

Yuan and Liang 2011 (J. Hydrometeorology)
Cloud-Aerosol-Radiation Ensemble Model

Cloud \(10^{10}\)  \(\rightarrow\)  10\(^{18}\) configurations  \(\rightarrow\)  Aerosol \(10^6\)  \(\rightarrow\)  Radiation \(10^2\)

- types (13)
- vertical profiles (8)
- optics (1152)
- indirect effects (18)
- cover (360)
- radius (42)
- water (3)
- optics (137088)
- mosaic (9)
- geometry (9)
- infrared (9)
- solar (10)
- topographic effect

Earth orbit: radiative gases, surface characteristics

Observation: in situ & satellite

Petascale computing: optimization

DOE 2009-2011

gsfclxz  cccma  cam  fulliou  gfdl  rrtmg  csiro  eta  rrtmlw  gsfclxz  cccma  cam  fulliou  gfdl  rrtmg  csiro  eta  gsfcsw  swrad
CAR Ensemble Flux Frequency Distribution
Optimized Physics Ensemble

Increasing predictive skill

Quantifying uncertainty
Optimized Physics-Ensemble Prediction
Optimized Physics Ensemble Prediction of Precipitation In summer 1993

The physics ensemble mean substantially increases the skill score over individual configurations, and there exists a large room to further enhance that skill through intelligent optimization.

Spatial frequency distributions of correlations (top) and rms errors (bottom) between CWRF and observed daily mean rainfall variations in summer 1993. Each line depicts a specific configuration in group of the five key physical processes (color). The ensemble result (ENS) is the average of all runs with equal (Ave) or optimal (OPT) weights, shown as black solid or dashed line.
CWRF
Seasonal-Interannual Climate Prediction
Nested with NOAA Operational CFS

a) Spatial frequency distributions of root mean square errors (RMSE, mm/day) predicted by the CFS and downscaled by the CWRF and b) CWRF minus CFS differences in the equitable threat score (ETS) for seasonal mean precipitation interannual variations. The statistics are based on all land grids over the entire inner domain for DJF, JFM, FMA, and DJFMA from the 5 realizations during 1982-2008. From Yuan and Liang 2011 (GRL).
CWRF improves predictions at regional-local scales

- CWRF includes advanced physics schemes crucial to climate
- CWRF couples essential components directly linking to impacts
- CWRF builds upon a super ensemble of alternative physics schemes for skill optimization and uncertainty quantification
- CWRF has greater capability & better skill than CMM5, WRF...
- CWRF downscaling improves CFS precipitation predictions
Faculty & Student

- **Research**
  - Develop, test, evaluate physics parameterization
  - Improve weather forecast, climate prediction
  - Project climate change and impacts
  - Understand process, mechanism

- **Thesis**
  - Develop new schemes
  - Compare schemes
  - Diagnose processes

- **Fun**