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

Xin-Zhong Liang

Department of Atmosphere & Ocean Science
Earth System Science Interdisciplinary Center
University of Maryland, College Park

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Collaboration with NOAA

Julian X.L. Wang (Air Resource Laboratory)
Vernon Morris, Everette Joseph, Tsann-Wang Yu (NCAS/Howard University)

Earth System Model (EaSM)
Research & Development Laboratory
ESSIC, University of Maryland
Collaboration Began in 1999

- **Climate, Air Quality and Impact Modeling System (CAQIMS)**
  - predict climate & air quality variations at scales crucial to human activities and natural resources

- **Regional Climate Impact & Air Quality Experiments (CIAQEX)**
  - downscale GCM climate simulations
  - simulate the surface ozone and particle levels
  - perform scenario experiments on regional scales
Collaboration Expands

- Sustained supercomputing supports
- Research grant awards
  - Orographic effect (2004-2007)
  - Vegetation deep-root effect (2006-2009)
  - Seasonal climate prediction (2008-2011)
  - Ensemble prediction optimization (2008-2011)
  - Cloud-radiation interaction (NCAS, 2000-2006)
  - CWRF physics development (NCAS, 2006-2011)
- U.S.-China Bilateral Activities
  - Visiting scientists assisting model development
EPA STAR 2003-2011

FOCUS

Consolidate O₃

Elaborate PM

Explore Hg

EPA STAR 2009-2012

FOCUS

Nutrients

Pathogens

Bacteria

Sediments

Agriculture

Urban

Global Climate Projection

- GCM (250-150km): high
- FDLR CM2.1: high
- NCAR CCSM3: low

IPCC SRES Emissions Scenarios

- A1FI (high)
- A2 (medium)
- B1 (low)

NA Climate Downscaling

CWF

NA Air Quality

CMAQ

SMOKE Emissions

IPCC SRES Land use changes

Imposed on the baseline with
NLCD2001 USA & Canada (2001)

NO₃⁻, NH₄⁺ Depositon

Observations

- USDA crop yield, livestock
- NASA snow cover, vegetation
- NOAA temperature, precipitation
- NADP deposition, air pollution
- USGS streamflow, water table depth, in-stream nutrients, dam, tillage

Validation

Climate & Terrestrial Hydrology

Canopy & Terrestrial Hydrology

Impacts Assessment

Future climate & CO₂ changes

with present crop distributions &
best agriculture management

Future agricultural adaptation
areas growing crops for food
(soybeans, corn, wheat, cotton) &
biofuel (switchgrass, sorghum)

Future total no-till agriculture

Future increased urbanization

Nitrogen Cycle

Non-Cultivated Land

Urban

Upland

Bedrock

Channel/Flood Plain

Dammed

Cultivated Land

HUMAN

climate change
urban development
crop & biofuel growth
atmospheric deposition
fertilizer & pesticide use
irrigation, tillage, dam control

FOCUS

water yield & supply
streamflow, surface runoff
soil moisture, groundwater recharge
nutrients, pathogens, bacteria, sediments
EaSM R&D Thrusts

- **System Integration & Improvement**
  - Physical schemes; research => operation

- **Seasonal-Interannual Ensemble Prediction**
  - Ensemble optimization; data assimilation

- **Climate Change & Impacts Projection**
  - Quantify & narrow uncertainty range

- **Interactive Climate-Human System**
  - Adaptation, Mitigation, Policy & Decision Making
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
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

NOAA
2008-2011

CWRF Downscaling Seasonal Climate Prediction over the U.S.
Ensemble Global Forecast System

⇒ ICs, SSTs, LBCs

NCEP
ECMWF

OP DASs
⇒ ICs

NOAA CFS
NASA GEOS

Bias corrections

NOAA GFS
NCAR CAM
IRI ECHAM

AGCMs
⇒ LBCs

OP CGCMs
⇒ SSTs
NCEP/AMIP II vs ECMWF-Interim Reanalysis
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).
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
OBS NOAH CSSP

T2m Bias (summer 1993)

Rainfall (summer 1993)

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
    - **Forcing:** linear relaxation in 4 grids (MM5I, HRM3) domain spectral nudging (ECP2, CRCM)
  - **NARCCAP IA correlations differ largely due to the strength of forcing integrated**
- **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
Choi 2006; Choi et al. 2007; 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)
CWRF
Climate-Ocean Interaction
Multilevel Upper Ocean Model
UOM
CWRF MLO (upper 300m ocean)

- Transient sea-air interactions
- Significant diurnal cycle
- Crucial for hurricane/typhoon
- Cost-effective

Modeled and Observed
July SST diurnal cycle

Modeled and Observed
SST 2005
Hurricane Katrina August 23-30, 2005
CWRF Physics Options

Diffusion
- Upper
- Eddy
- Const DIF
- L2.5 TKE
- L2 3D DEF

RadExt
- Orbit
- Gases
- Aerosols

SfcExt
- VEG
- SST
- OCN

Cumulus
- BMJ
- NKF
- SAS
- GD
- G3
- UW
- ZML
- CSU
- GFDL
- MIT
- ECP

Microphysics
- Kessler[2]
- Thompson[7]
- Lin[6]
- Hong[3]
- Zhao[2]
- Tao[5]
- Morrison[10]

Surface
- Urban
- Land
- Ocean
- PBL

http://cwrf.umd.edu
Cloud-Aerosol-Radiation Ensemble Model

http://car.umd.edu

Cloud

- (10^10)
- 10^18 configurations

Aerosol

- (10^8)

Radiation

- (10^2)

Cloud-Radiation-Aerosol

Ensemble Model

GSFCLXZ
CCMA
CAM
FULIOU
GFDL
RTMG
CISIO
ETA
RTMLW
GSFCLXZ
CCMA
CAM
FULIOU
GFDL
RTMG
CSIO
ETA
GSFCSW
SWRAD

Earth orbit
Radiative gases
Surface characteristics

Infrared

(9)

Solar

(10)

Topographic effect

DOE 2009-2011
CAR Ensemble Flux Frequency Distribution
Optimized Physics Ensemble

Increasing predictive skill

Quantifying uncertainty
Optimized Physics-Ensemble Prediction

KF Climate Mean (mm/day)

GR

MGR

OBS

ECb

EOP

Legend:

0.5 1.5 2.5 3.5 4.5 5.5 6.5 7.5 8.5
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.
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