Multi-RCM CORDEX-Africa Hindcast Evaluation using the JPL Regional Climate Model Evaluation System (RCMES)

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Regional Climate Model Evaluation

- Studies have confirmed with high level of confidence that the emissions of anthropogenic greenhouse gases have induced the ongoing global warming trend.
- Assessment of the impacts of global climate change on regional sectors (e.g., water resources, agriculture, and ecosystems) have become an important concern.
- Assessing climate change impact on regional sectors requires fine-scale climate data.
- Regional climate models (RCMs) are key to downscaling GCM projections to the spatial scales relevant for regional impact assessments to support decision making.

- Evaluating climate models against "observations" is a key for model improvements and developing the methodology for applying model projections to impact assessments.
- Systematic evaluations of GCMs have been undertaken for some time (e.g., AMIP, CMIP); this is not the case for RCMs.
**JPL Regional Climate Model Evaluation System (RCMES)**

Using Satellite & Other Observations For RCM Evaluation

- NASA can provide critical and unique observational and technological resources to facilitate RCM evaluations and thus make key contributions to the climate-change impact assessment processes.

- Observational data are a key part of model evaluation
  - Typical model evaluation is performed by comparing the simulated and reference data in terms of statistical metrics.
  - Reference data are obtained from *direct/indirect observations, analysis of observed data* and/or *assimilations based on observed data*.
  - Easy access to *quality reference data* can facilitate evaluation efforts.
  - The lack of *fine-scale observations* is among the key difficulties in evaluating today’s RCM simulations.

- To facilitate RCM evaluation, especially for *easy access to remote sensing data*, RCMES has been under development via joint JPL-UCLA efforts.
**RCMES**

**High-level technical architecture**

**RCMED**
(Regional Climate Model Evaluation Database)
A large scalable database to store data from variety of sources in a common format

**RCMET**
(Regional Climate Model Evaluation Toolkit)
A library of codes for extracting data from RCMED and model and for calculating evaluation metrics

**Raw Data:**
Various formats, Resolutions, Coverage

**Metadata**
Data Table
Data Table
Data Table
Data Table
Data Table

**MySQL**
Data Table

**Extractor**

**URL**

**Extract OBS data**

**Extract RCM data**

**Regridder**
Put the OBS & RCM data on the same grid for comparison

**Metrics Calculator**
Calculate comparison metrics

**Visualizer**
Plot the metrics

**Data extractor (Fortran binary)**

**User's own codes for ANAL and VIS.**

**TRMM**

**MODIS**

**AIRS**

**SWE**

**Soil moisture**

**ETC**
RCMED Datasets (now or near-term):

- **MODIS** (satellite cloud fraction): [daily 2000 – 2010]
- **AIRS** (satellite surface + T & q profiles) [daily 2002 – 2010]
- **ERA-Interim** (reanalysis): [daily 1989 – 2010]
- **NCEP CPC Raingauge analysis** (gridded precipitation): [daily 1948 – 2011]
- **CRU**: 3.0 & 3.1, prcp, $T_{AVG}$, $T_{MAX}$, $T_{MIN}$, cloud frac. [monthly 1901 – 2006]
- **Snow Water Equivalent**: NOHRSC, JPL [daily & monthly 2000-2010]
- **NASA MERRA Land Surface Assimilation** [daily, 1979-2008]
- **........CERES-radiation, CloudSat, MISR/MODIS-aerosol, etc**

RCMET Metrics & visualization:

- Bias
- RMS error
- Anomaly Correlation  (e.g., spatial patterns)
- PDFs (likelihoods, extremes and their changes)
- Statistical Tests
- User-defined regions  (e.g. watershed, airshed, desert, sea, political)
- Maps, Taylor Plots & Portrait Diagrams (overall model performance)
• RCMES is in the prototyping stage
• RCMES development is focused on:
  • **Efficiency**
    • Fast access to the reference datasets
  • **User friendliness**
    • Intuitive and platform-transferrable GUI
  • **Flexibility**
    • Extractors for multiple data formats (netCDF, HDF, Grib, Ascii)
  • **Expandability**
    • Easy to add new data and/or analysis tool
    • **Apache Hadoop** and **MySQL** are used to provide scalable storage solution
    • Cloud-based architecture for storage and user interface is explored
Near-term applications to WCRP’s CORDEX for IPCC

- **Africa**: Collaboration & analysis ongoing (UCT, Rossby Centre)
- **N. America**: Funded via NASA for U.S. NCA (NCAR, NARCCAP)
- **Arctic**: Exploring collaboration (J. Cassano, March 2012 Workshop)
- **E. Asia**: Exploring collaboration (KMA, APCC)

Not Illustrated Here: Arctic & Antarctic Domains
Evaluation of the CORDEX-Africa Multi-RCM Hindcast

- The JPL-UCLA team is collaborating with scientists at UCT and Rossby Centre to apply RCMES to evaluating the multi-RCM CORDEX-Africa hindcast experiment.

- Monthly data from 11-RCM, 20-year (1989-2008) hindcast on a common grid are obtained from the Rossby Centre.
  - Some models are excluded due to incomplete/missing data.
  - Evaluation periods are limited due to the coverage of reference datasets.

- Evaluations are performed for the monthly values of:
  - Precipitation, T$_{2\text{AVG}}$, T$_{2\text{MAX}}$, T$_{2\text{MIN}}$, Cloud Fraction

- Reference data used:
  - Precipitation: TRMM.v6 (1998-present, 0.25deg), CRU3.1 (1901-2006, 0.5deg)
  - T$_2$, T$_{2\text{Min}}$, T$_{2\text{Max}}$: CRU3.1 (1901-2006, 0.5deg).
### RCMs and Variables Evaluated in this Study

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<tr>
<th>ID</th>
<th>Institution</th>
<th>Model</th>
<th>Precip</th>
<th>T&lt;sub&gt;Mean&lt;/sub&gt;</th>
<th>T&lt;sub&gt;Min&lt;/sub&gt;</th>
<th>T&lt;sub&gt;Max&lt;/sub&gt;</th>
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- Precipitation: 10 RCMs
- T2 fields: 10 RCMs
- Cloudiness: 9 RCMs
• The domain covers the African continent with a 0.44°-resolution grid mesh.
• All RCM data have been interpolated onto the same domain by SMHI.
• 21 sub-regions (R01-R21) are selected to investigate regions of interests.
[1] Precipitation evaluation
10 RCMs and their ensemble vs. CRU raingauge analysis

- 18 years: 1990-2007
  - 1989 & 2008 are dropped to include the maximum number of RCMs
- Overland and sub-regions
- Annual climatology
- Interannual variability in terms of temporal standard deviation
- Annual cycle in each subregion
Bias: Annual-mean precipitation climatology (mm/day)

Climatology
REF (mm/day): CRU

Wet/dry biases in dry/wet regions
• Attempt to objectively measure the model performances
• Most RCMs simulate precipitation climatology with reasonable overland totals and spatial pattern compared to the CRU analysis.
• Spatial variability varies widely according to RCMs.
• The model ensemble compares well with the CRU analysis:
  • smallest in bias and RMSE and highest spatial pattern correlation
  • Spatial variability is smaller than most models, but comparable to the CRU data.
The interannual variability of overland precipitation is measured in terms of temporal standard deviation over the 18-yr period. RCMs generally overestimate the interannual variability in the CRU data. Model ensemble is among the few that underestimate the interannual variability. The model ensemble compares well with the CRU analysis for the estimation of the interannual variability. It yields:

- *Smallest RMSE* (smaller than any model in the ensemble)
- *Highest spatial pattern correlation*
• RCM performance in simulating precip annual cycle vary widely

• Model ensemble performs well in a number of regions
  • Mediterranean regions
  • Western AF monsoon

• Systematic biases occur in some regions
  • Eastern RSA (R16) all year
  • Eastern Africa (R13) in austral fall
  • Somalia (R10) in boreal winter
Metrics and Visualization

Precipitation Annual Cycle (mm/day) in Subregions

**PR: Normalized RMSE (Frac of ann mean)**
- Compare the performance of multiple models using *portrait diagram*.
- Model performance varies widely according to regions as well as models.
  - RCMs generally well simulates the precipitation annual cycle in the western Mediterranean coast (R01 & R02), Eq. W. Africa (R11 & R12), and Madagascar (R17).
  - All models perform poorly for the E. Mediterranean (R03 & R04), E. Sahara (R06) and the three regions in the E. Africa (R10) and southern Arabian Peninsula (R20 & R21).
- The region dependence suggests systematic biases either in *large-scale forcing data* or *model formulations* or both.
- The **model ensemble** is among the **best performers**
  - smallest in RMSE and highest in corr.
[2] 2-m air temperature fields evaluation
10 RCMs and their ensemble vs. CRU3.1 surface station analysis

- 18 years: 1990-2007
- Overland only
- Annual T2Mean, T2Min, and T2Max climatology
- Interannual variability in terms of the temporal standard deviations
- Annual cycle in subregions.
• Model performs somewhat better in simulating the daily means than the daily max/min values
• Inter-RCM variations in the spatial pattern (correlation) and variability (standardized deviation) is much smaller than for precipitation.
• Model ensemble again performs collectively well compared to individual models
  • Smallest RMSE & bias with highest correlation
Spatial Variability of the $T_{2\text{MIN}}$ Climatology
Spatial Variability of the T2_{MAX} Climatology
• RCM performance varies widely.
• Performance of the RCM ensemble is somewhat better in higher latitude regions than near the Equator for T$_{2\text{AVG}}$.
• Performance of RCMs and their ensemble are generally lower for daily extremes than daily means.
• Typical bias in the model ensemble is under/overestimation of daily max/min temperatures
  • This bias will result in underestimation of the amplitude of temperature diurnal cycle.
Normalization by the annual cycle amplitude of the CRU data

$$NRMSE = \frac{1}{12} \sqrt{\frac{\sum_{m \in \{\text{Jan}, \ldots, \text{Dec}\}} (T_{\text{obs}}^m - T_{\text{model}}^m)^2}{(T_{\text{max}}^m - T_{\text{min}}^m)}}$$
[3] Cloudiness
Nine RCMs and their ensemble vs. CRU3.1 analysis

- 18 years: 1990-2007
- CRU3.1 cloudiness data, 0.5°x0.5°, Global overland coverage
Most RCMs underestimate the cloudiness in the CRU analysis
- Model errors range from -14.7% (or -33% of CRU) to +5.1% (or +11.6% of CRU)
- All models generate consistent spatial pattern with spatial corr coef > 0.8.
- Most RCMs underestimate spatial variability (only M01 and M04 exceed the CRU value).
- The model ensemble generally agree more closely with the REF data than individual models.
  - among the smallest in bias and RMSE against the CRU data.
  - the highest spatial correlation with the CRU data.
  - Model ensemble is among those which underestimate the spatial variability most.
• RCM skill in simulating the annual cycle of cloudiness varies widely according to the region.
  • Good performance in R18, R7, R9, and R16.
  • Poor performance in R01, R10, R12, and R13.
  • Difficult to find geographical reference for model performance.
RCMs may perform better in simulating seasonal cycle, measured in terms of the normalized RMSE and correlation, in the S. hemisphere and equatorial regions than in the N. hemisphere.

However, it is difficult to link these errors shown in the annual cycle plot (previous page) with these metrics.

- Model errors are large, but
- The seasonal cycle is in phase with the obs
- The RCMs generally yields larger annual cycle amplitudes than the CRU data.
[4] Uncertainties related with observational datasets

• Precipitation evaluation against TRMM and CRU analysis
GPCC Gauge Distribution within Africa
(Nikulin et al., under preparation)

- Gauge density and distribution is a key concern for the accuracy of the reference data
- The density and observation length of gauges vary substantially according to geopolitical regions within Africa.
- Gridded station data (e.g., CRU) suffer directly from the lack of gauges
- Remote sensing data (e.g., TRMM, GPCP) also suffers from the lack of gauges because remote sensing data are calibrated using the gauge values.
- This problem necessitates the use of multiple reference datasets in model evaluations
The simulated precipitation & cloudiness is evaluated against two REF data.

TRMM and CRU31 result in similar evaluation of precipitation.
  - The simulation shows similar spatial correlations with CRU & TRMM
  - Systematically larger spatial variability w.r.t. the TRMM than CRU

Cloudiness evaluation varies systematically according to the reference data:
  - Systematically higher spatial correlation with the MODIS data than the CRU data
  - Scaled STD is larger with the CRU than MODIS.

Inter-comparison of reference data may be necessary.
Evaluation of climate models is a fundamental step in projecting climate variations and change and assessing their impacts.

- RCMES has been under development at JPL to facilitate RCM evaluation
  - User friendly, flexible, and expandable
- Monthly precip, 2-m air temperatures and cloudiness from multiple RCMs participating in the CORDEX-Africa experiment are evaluated.
  - All RCMs successfully simulate qualitative features of the observed climatology.
  - Performance of individual models vary widely.
  - Ensembles of all RCMs are generally closer to the reference data than individual RCM, especially in the climatological means, with small biases and large pattern correlations.
  - Evaluation of cloudiness is difficult to quantify.
- Care must be taken in estimating variability using model ensembles
  - Model ensemble may systematically underestimate temporal variability.
- Differences between REF datasets may be a source of uncertainties.
  - REF datasets need be cross-examined.
- Use of intuitive visualization tool such as Taylor diagram and Portrait diagram facilitates the evaluation of relative performance of multiple models for multiple properties.