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

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Why Climate Model Evaluation?

- None of climate models is perfect; however,
  - Assessing the impact of climate change is crucial for sustainable development.
  - Climate models are the only tool for projecting future climate.

- Regional-scale climate model \([\text{statistical or dynamical}]\) data are particularly important for assessing the impact of climate change on various sectors.
  - Most assessment targets are characterized by strong regional-scale variability.
  - Uncertainties propagate according to model hierarchy:
    - *Climate model errors directly propagate into assessment models.*
  - Model evaluation is the key for *model improvements* and *bias corrections.*
Reference data are the key part of model evaluation

- Typical model evaluation is performed by comparing the simulated and reference data using statistical metrics.
- Reference data are typically obtained through *direct/indirect observations, analysis of observed data* and/or *observation-inferred assimilations*.
- Easy access to quality reference data can facilitate model evaluation efforts.
- The lack of fine-scale reference datasets suitable is among the key difficulties in evaluating today's RCM simulations.

In order to facilitate model evaluation work, especially for easy access to and use of remote sensing data from spaceborne sensors, RCMES has been under development via joint JPL-UCLA efforts in the past 1.5 years

- RMCES is composed by two components:
  - Reference database (Regional Climate Model Evaluation Database: RCMED)
  - Evaluation toolkit (Regional Climate Model Evaluation Toolkit: RCMET)
RCMES
High-level technical architecture

Raw Data:
Various formats, Resolutions, Coverage

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 Tool)
A library of codes for extracting data from RCMED and model and for calculating evaluation metrics
JPL Regional Climate Model Evaluation System (RCMES)

- RCMES is in the prototyping stage

- RCMES will be:
  - Efficient
    - Fast access to the reference datasets
  - User friendly
    - Intuitive and transferrable GUI
  - Flexible
    - Extractors for multiple data formats (netCDF, HDF, Grib, Ascii)
    - Extract partially processed data for users' own analysis
  - Expandable
    - 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.

- Long-term goals include wider utilization of NASA remote sensing products, especially for evaluating fine-resolution climate model data.
The JPL-UCLA team is collaborating with scientists at UCT and Rossby Centre to apply RCMES to the CORDEX-Africa project.

This is the first application of RCMES.

Monthly data from 11-RCM 20-year (1989-2008) hindcast are obtained:
- 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, T2, T2Min, T2Max, Cloudiness

Reference data used:
- Precipitation: TRMM.v6 (1998-present, 0.25deg), CRU (1901-2006, 0.5deg).
- T2, T2Min, T2Max: CRU (1901-2006, 0.5deg).
- Cloudiness: MODIS retrieval (2001-present, 1deg).
### RCMs and Variables Incorporated in the Evaluation Study

<table>
<thead>
<tr>
<th>Institution</th>
<th>Model</th>
<th>Variable</th>
<th>PRECIP</th>
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- Precipitation vs. CRU: 7 RCMs
- T2 fields vs. CRU: 7 RCMs
- Cloudiness vs. MODIS: 5 RCMs
• The CORDEX-Africa domain covers the African continent with a 0.44° resolution horizontal grid mesh.
  • All RCM data are interpolated onto the reference domain

• Six sub-regions are selected for investigating regions of interests.
  1. Western Mediterranean
  2. Western sub-Saharan
  3. Central sub-Saharan
  4. Upper Nile
  5. South-central sub-Saharan
  6. Eastern RSA
[1] Precipitation evaluation
7 RCMs and their ensemble vs. CRU raingauge analysis

- 18 years: 1989-2006 [Limited by the length of the CRU data]
- Overland only
- Annual precipitation climatology
- Interannual variability in terms of temporal standard deviations
Annual overland precipitation climatology for 1989-2006

REF (mm/day): CRU

Bias: Annual-mean precipitation climatology (mm/day)
Most RCMs yield reasonable spatial pattern correlation with the CRU analysis.

- Spatial variability (in terms of standard deviation) varies more widely than correlations.
- The model ensemble compares closely with the CRU analysis.
  - the smallest bias and RMSE (smaller than any model in the ensemble)
  - the highest spatial pattern correlation
  - Spatial variability is smaller than most models, but still comparable to the CRU data.
Precipitation Annual Cycle (mm/day) in the 6 sub-Regions
• Compare the performance of multiple models using "portrait diagram".

• Model performances vary widely according to the region.

• The model ensemble is among the smallest in RMSE and the highest in correlation with the CRU-derived annual cycle.
[2] 2-m air temperature fields evaluation
7 RCMs and their ensemble vs. CRU surface station analysis

- 18 years: 1989-2006
- Overland only
- Annual T2Mean, T2Min, and T2Max climatology
- Interannual variability *in terms of the temporal standard deviations*
Spatial Variability of the T2 Climatology
(vs. CRU: 1989-2006)

The simulated T2 fields compares more closely with CRU than precipitation.

Model ensemble generally performs well compared to individual models.
Annual Cycle RMSE (K)

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Annual Cycle Correlation

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[3] Cloudiness
Six RCMs and their ensemble vs. MODIS retrievals

- 8 years: 2001-2008
- MODIS cloudiness data, $1^\circ \times 1^\circ$, Global coverage
Overland Cloudiness Climatology (2001-2008)

- Model errors range from -17.5% to +20%
- All models generate good spatial pattern (spatial corr. coef. > 0.9 vs. the MODIS data).
- The model ensemble generally agree more closely with the REF data than individual models.
  - the smallest bias and RMSE against the MODIS data.
  - the highest spatial correlation with the MODIS data.
  - Model ensemble does not improve spatial variability.
Cloudiness Annual Cycle Correlation with the MODIS Data

Scaled RMSE: Mean annual cycle

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Correlation: Mean annual cycle

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Summary

- Monthly precipitation, T2's, and cloudiness from RCMs participating in the CORDEX-Africa experiment are evaluated using RCMES.
  - 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.

- Care must be taken in estimating temporal variability using model ensembles
  - Model ensemble may systematically underestimate temporal variability.
  - Model ensemble yields among the highest spatial pattern correlation with REF.

- Use of intuitive visualization tool such as Taylor diagram and Portrait diagram facilitates the evaluation of relative performance of multiple models for multiple properties.
  - Taylor diagrams can present two properties (standard deviation and correlations) widely used to measure variability.

- Future development of RCMES will emphasize the use of remote sensing data for evaluating fine-resolution simulations.