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

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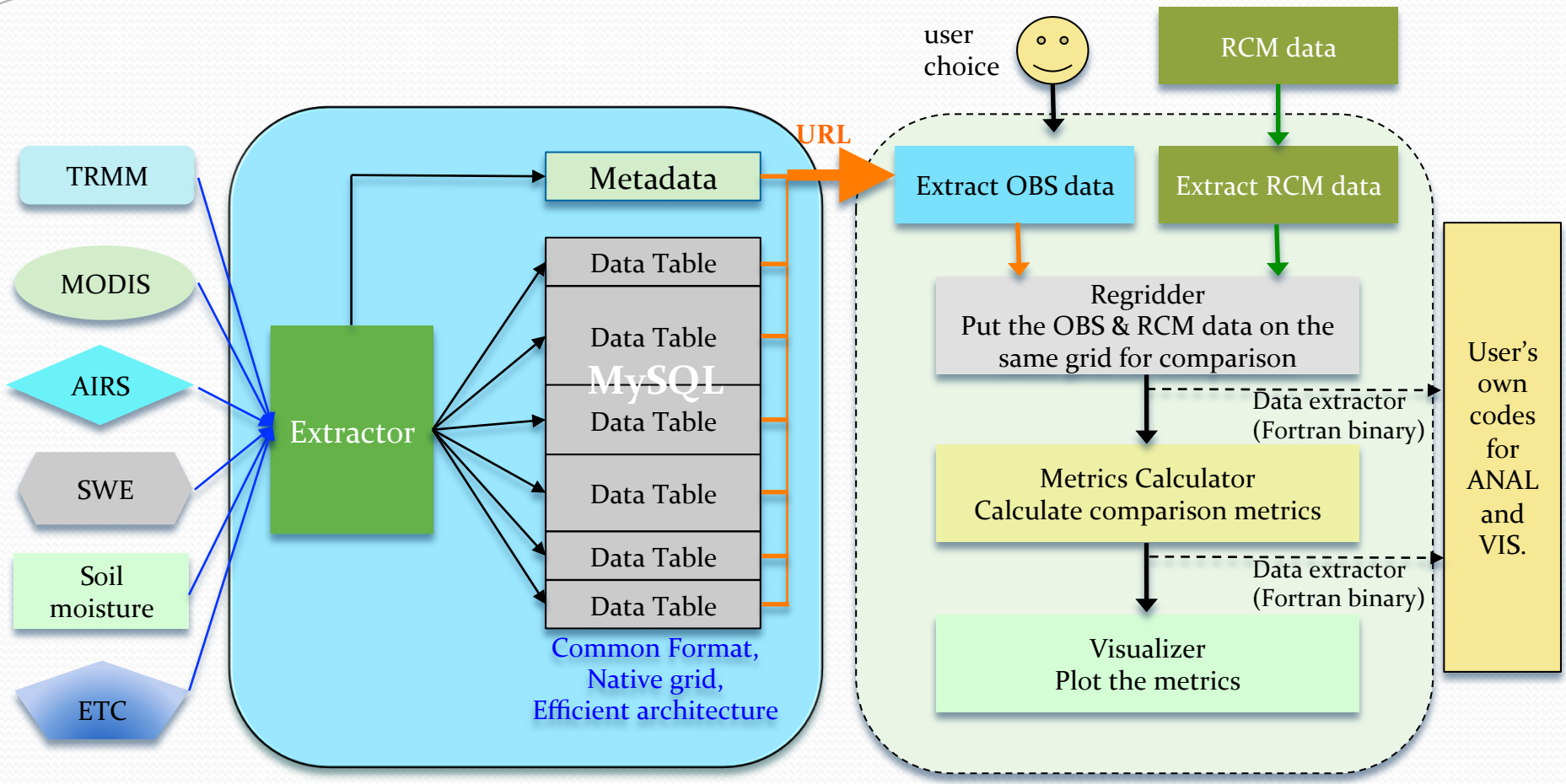
# Why Climate Model Evaluation?

- 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 [*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.

# JPL Regional Climate Model Evaluation System (RCMES)

- 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.

# Evaluation of the CORDEX-Africa Multi-RCM Hindcast

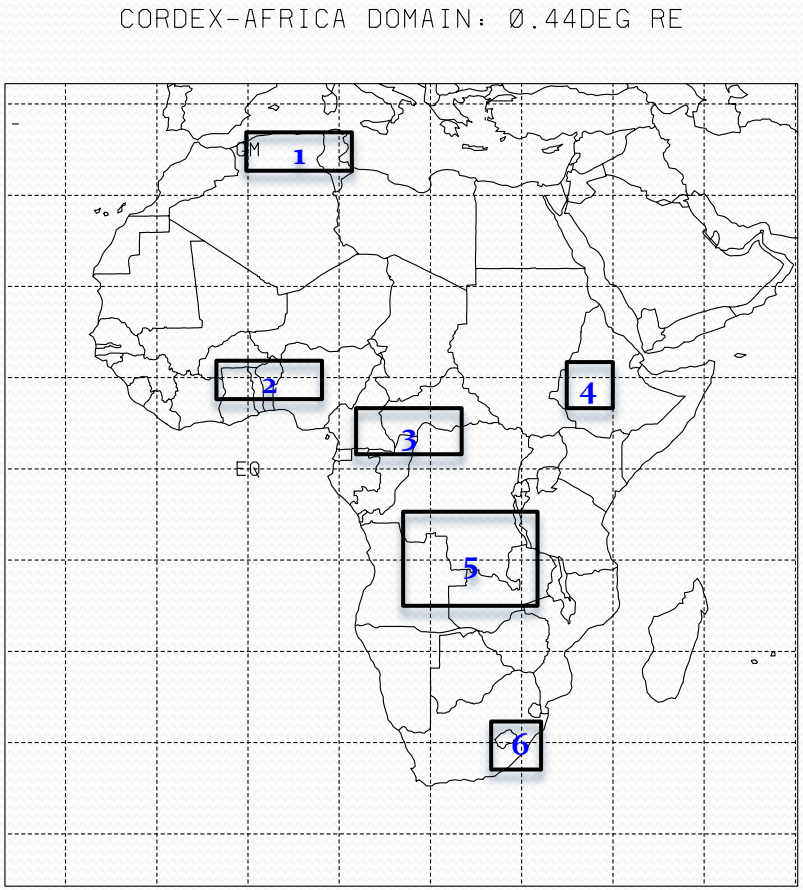
- The JPL-UCLA team is collaborating with scientists at UCT and Rossby Centre to apply RCMES to the CORDEX-Africa project
- This is the first application of RCMES
- Monthly data from 11-RCM 20-year (1989-2008) hindcast are obtained
  - Some models are excluded due to incomplete/missing data.
  - Evaluation 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

| Institution | Model \ Variable | PRECIP | $T_{MEAN}$ | $T_{MIN}$ | $T_{MAX}$ | Cloudiness |
|---|---|---|---|---|---|---|
| CNRM | ARPEGE51 | X | X | X | X | X |
| DMI | HIRHIM | | | | | X |
| ICTP | RegCM3 | | | | | |
| IES | CCLM | X | X | X | X | X |
| KNMI | RACMo2.2b | X | X | X | X | X |
| MPI | REMO | | | | | |
| SMHI | RCA35 | X | X | X | X | X |
| UCT | PRECIS | X | X | X | X | |
| UC | WRF311 | X | X | X | X | |
| UM | MM5 | X | X | X | X | |
| UQAM | CRCM5 | | | | | |
| n/a | ENS | X | X | X | X | X |

- Precipitation vs. CRU: 7 RCMs
- T2 fields vs. CRU: 7 RCMs
- Cloudiness vs. MODIS: 5 RCMs

# CORDEX-Africa Hindcast Domain



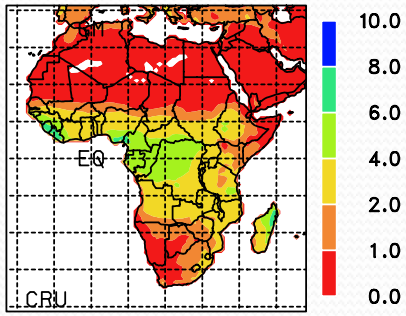

- The CORDEX-Africa domain covers the African continent with a 0.44° resolution horizontal grid mesh.
  - All RCM data are interpolated onto the reference domain
- Six sub-regions are selected for investigating regions of interests.
  1. Western Mediterranean
  2. Western sub-Sahara
  3. Central sub-Sahara
  4. Upper Nile
  5. South-central sub-Sahara
  6. Eastern RSA

## [1] Precipitation evaluation
## 7 RCMs and their ensemble vs. CRU raingauge analysis

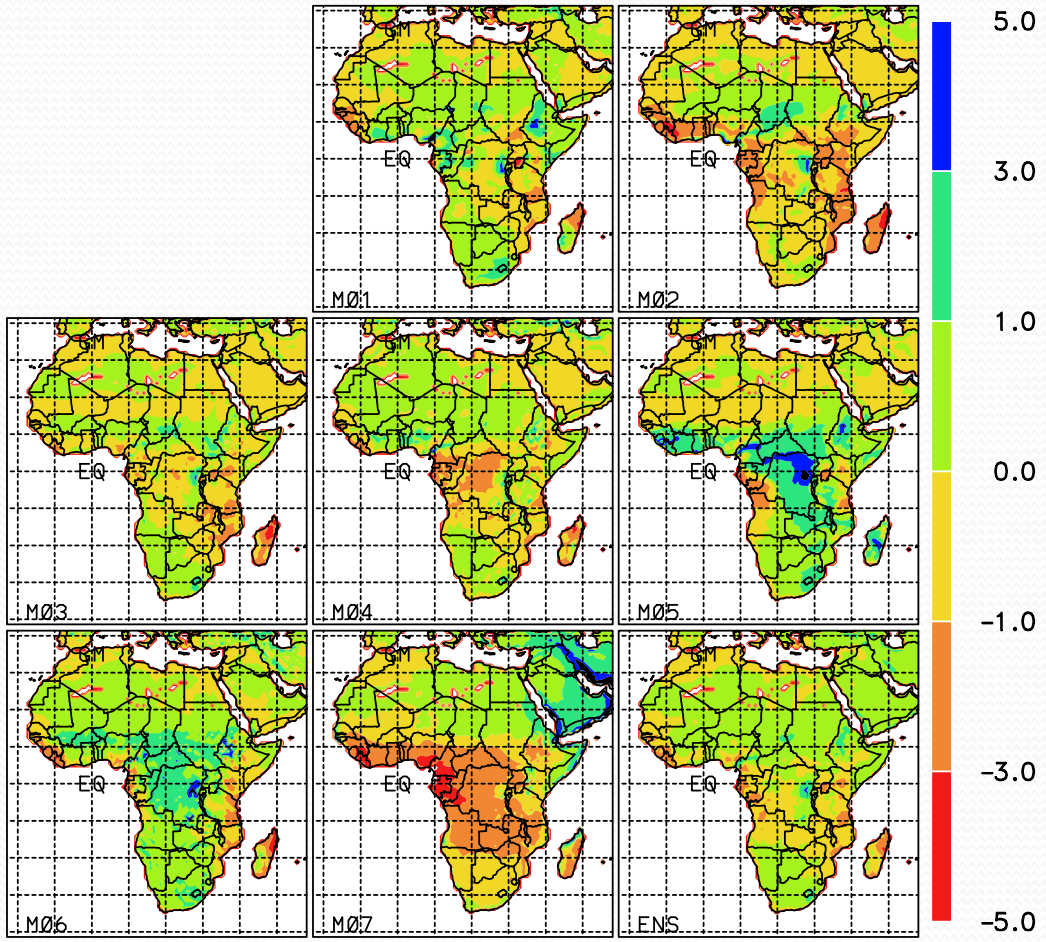
- 18 years: 1989-2006 [Limited by the length of the CRU data]
- Overland only
- Annual precipitation climatology
- Interannual variability *in terms of temporal standard deviations*

# Annual overland precipitation climatology for 1989-2006

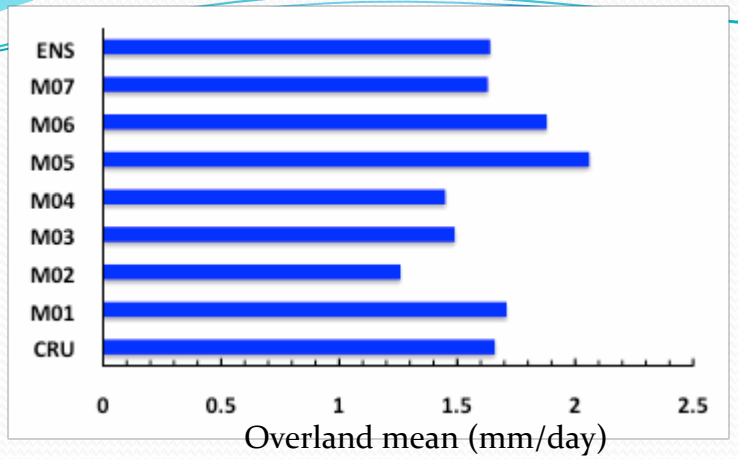
REF (mm/day): CRU

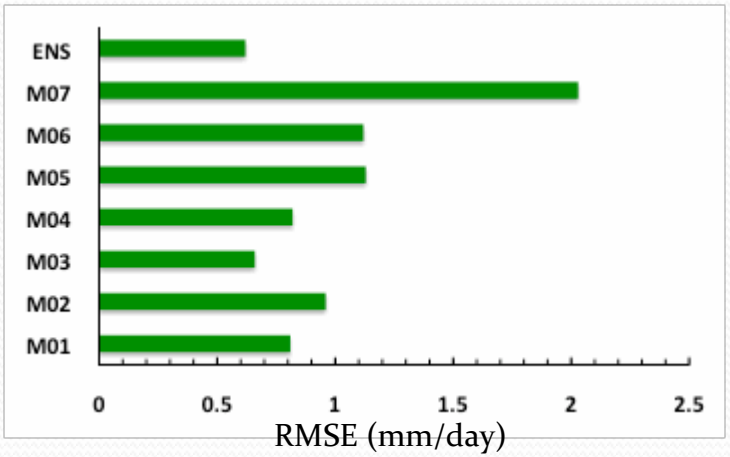


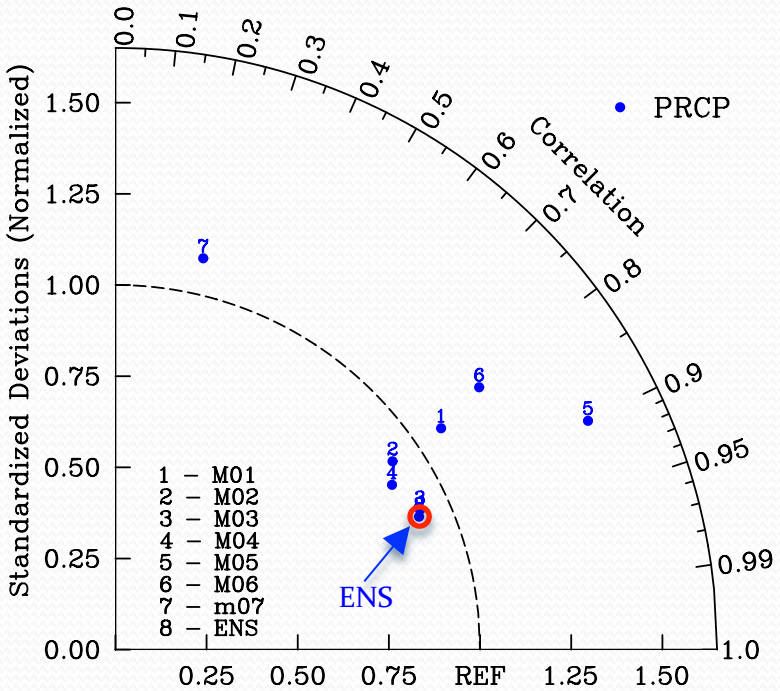

Bias: Annual-mean precipitation climatology (mm/day)



# Spatial Variability of the Overland Precipitation Climatology

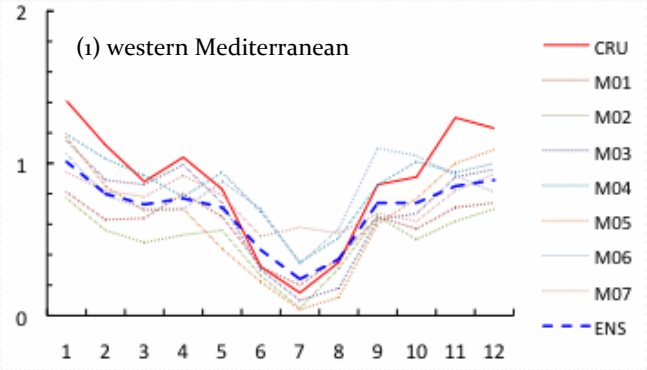


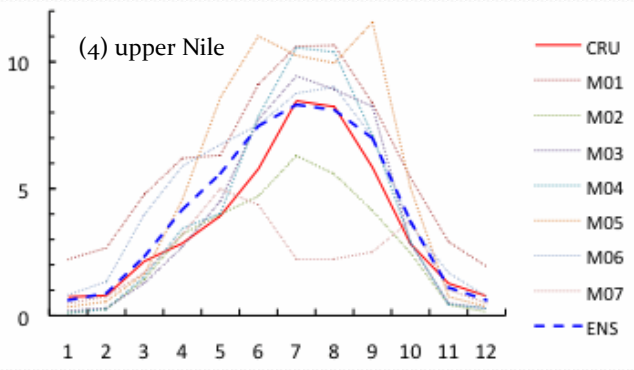



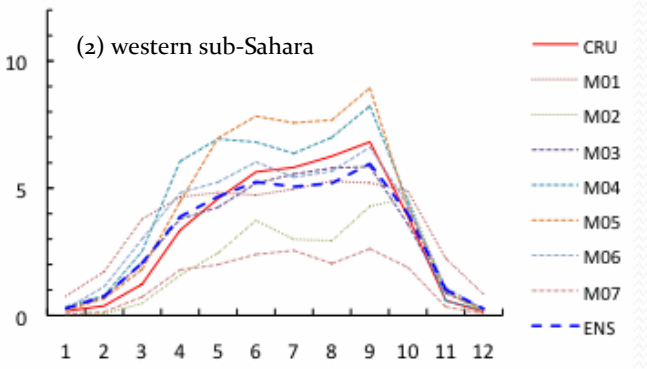



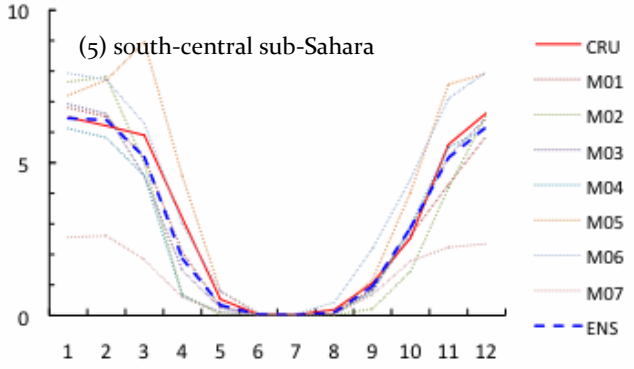

- Most RCMs yield reasonable spatial pattern correlation with the CRU analysis.
- Spatial variability (*in terms of standard deviation*) varies more widely than correlations.
- The model ensemble compares closely with the CRU analysis.
  - the *smallest bias and RMSE* (smaller than any model in the ensemble)
  - the *highest spatial pattern correlation*
  - *Spatial variability is smaller than most models, but still comparable to the CRU data.*

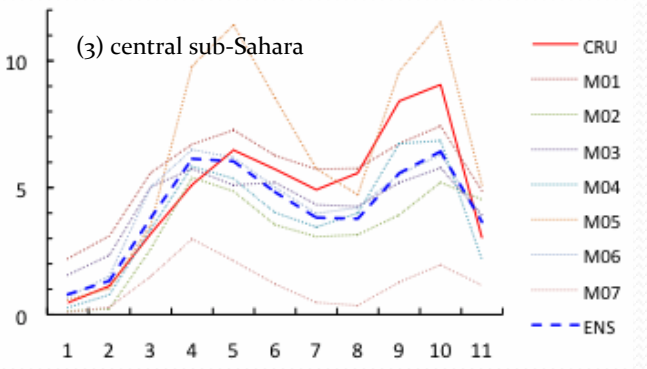
# Precipitation Annual Cycle (mm/day) in the 6 sub-Regions

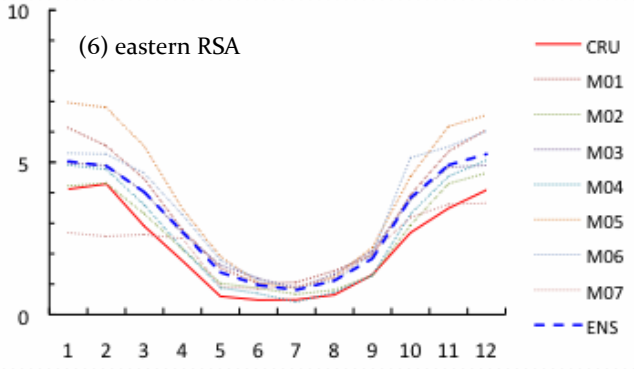


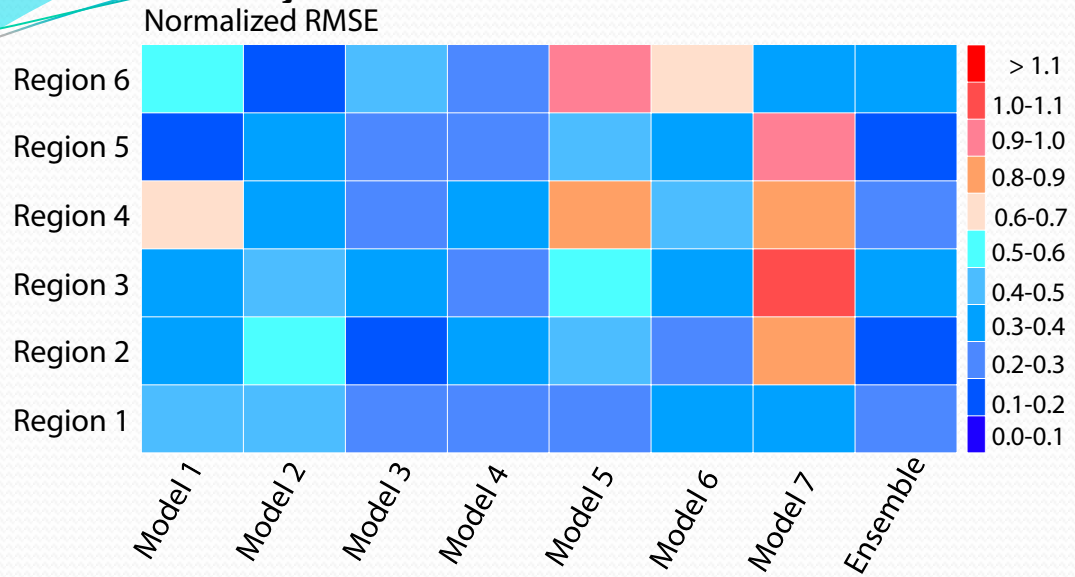



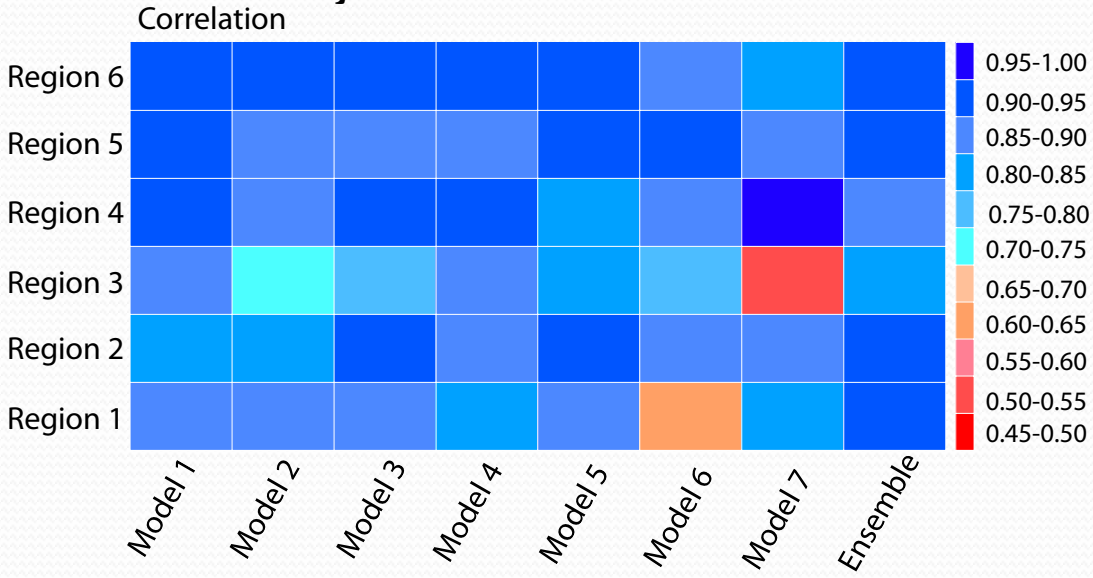



## PR Ann Cycle: Normalized RMSE ($RMSE/MEAN_{CRU}$)




## PR Annual cycle: Correlation with the CRU data

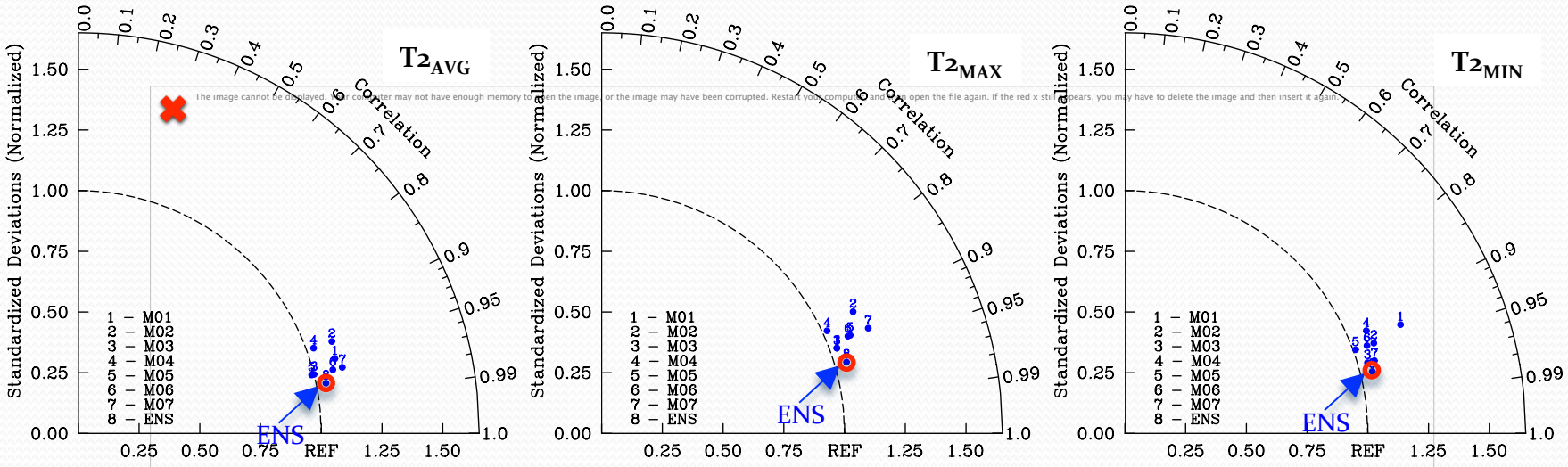



- **Compare the performance of multiple models using "portrait diagram".**
- Model performances vary widely according to the region.
- The *model ensemble* is *among* ***the smallest in RMSE*** and ***the highest in correlation*** with the CRU-derived annual cycle.

## [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*

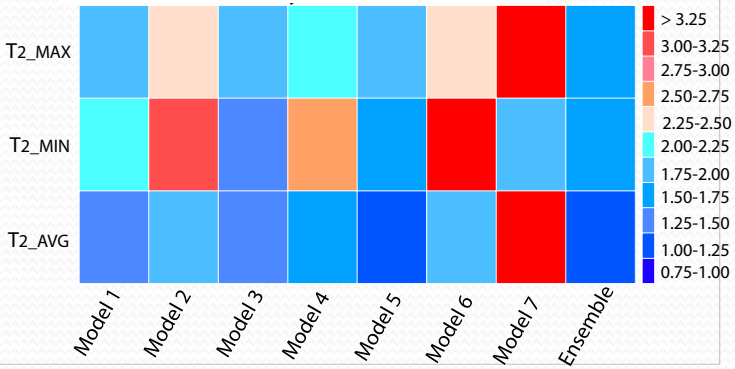
# Spatial Variability of the $T_2$ Climatology
## (vs. CRU: 1989-2006)




**Overland-means (K)**

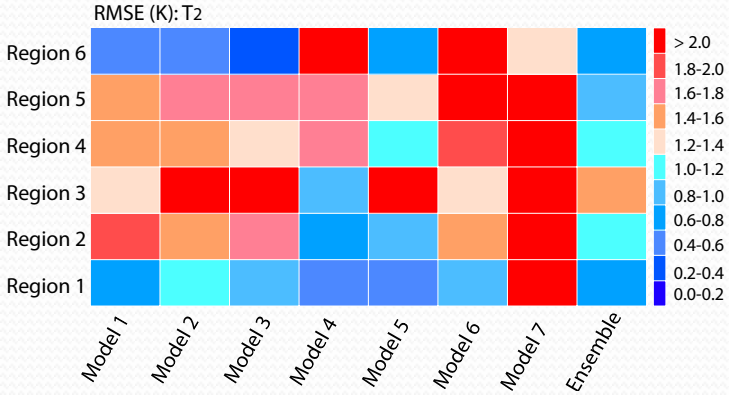
| Data | T2_AVG | T2_MIN | T2_MAX |
|---|---|---|---|
| CRU | 297 | 290 | 303 |
| M01 | 296 | 290 | 303 |
| M02 | 297 | 292 | 303 |
| M03 | 296 | 290 | 302 |
| M04 | 297 | 291 | 304 |
| M05 | 296 | 290 | 303 |
| M06 | 298 | 293 | 304 |
| M07 | 293 | 288 | 298 |
| ENS | 296 | 290 | 302 |

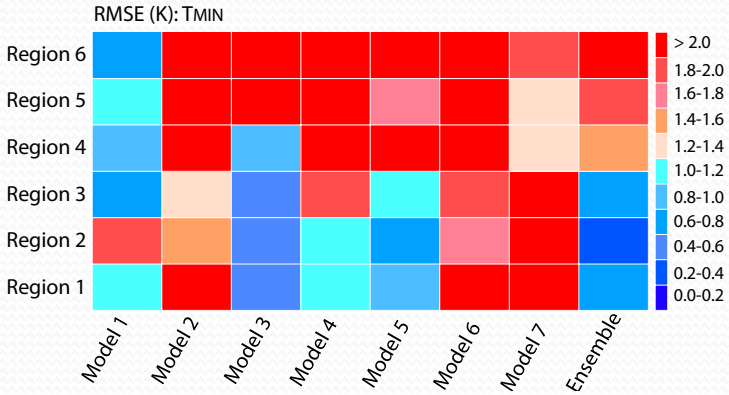
**RMSE (K): Overland only**

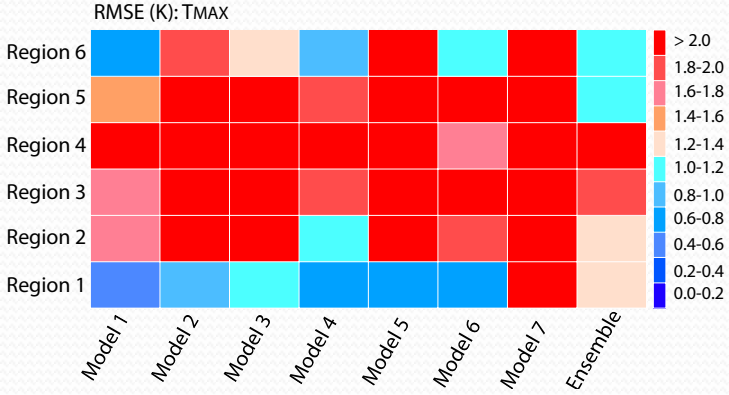



- **The simulated T2 fields compares more closely with CRU than precipitation**
- **Model ensemble generally performs well compared to individual models.**

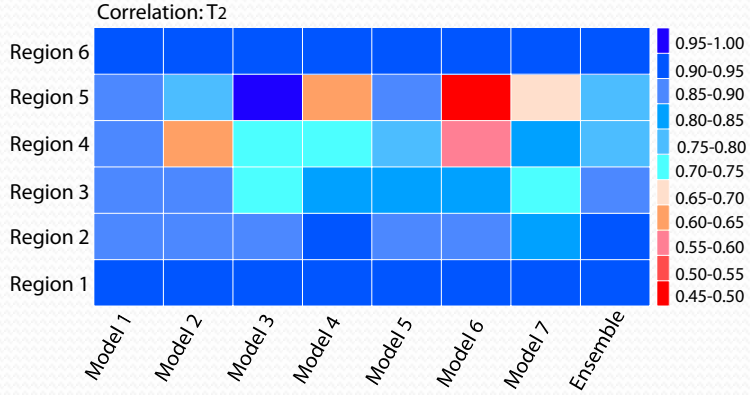
# Annual Cycle RMSE (K)

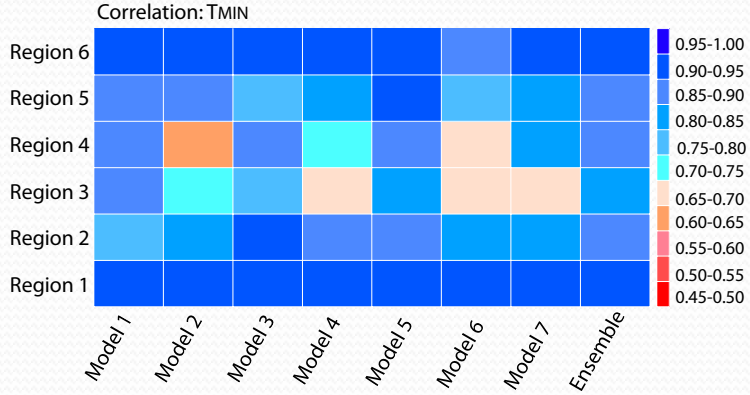


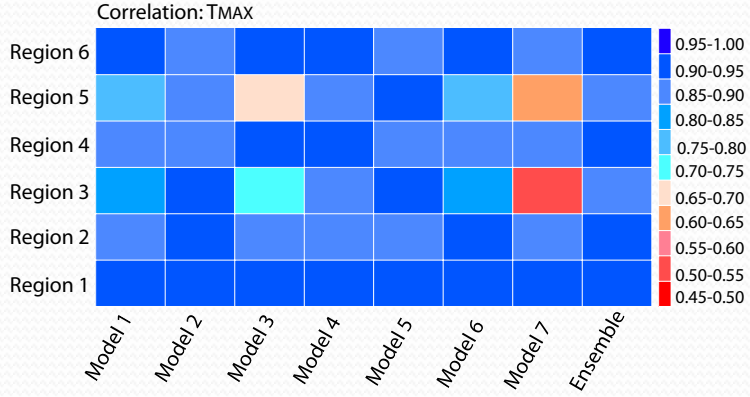




# Annual Cycle Correlation



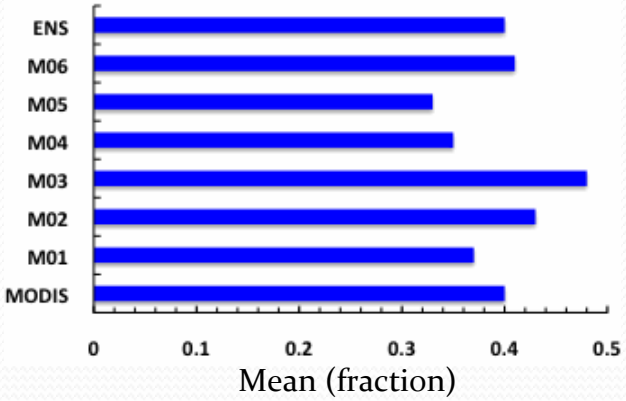



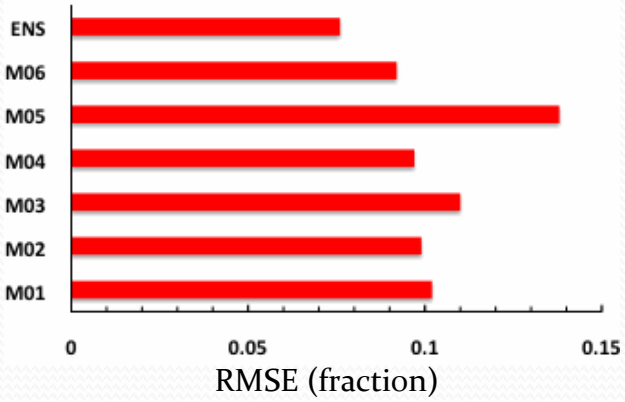



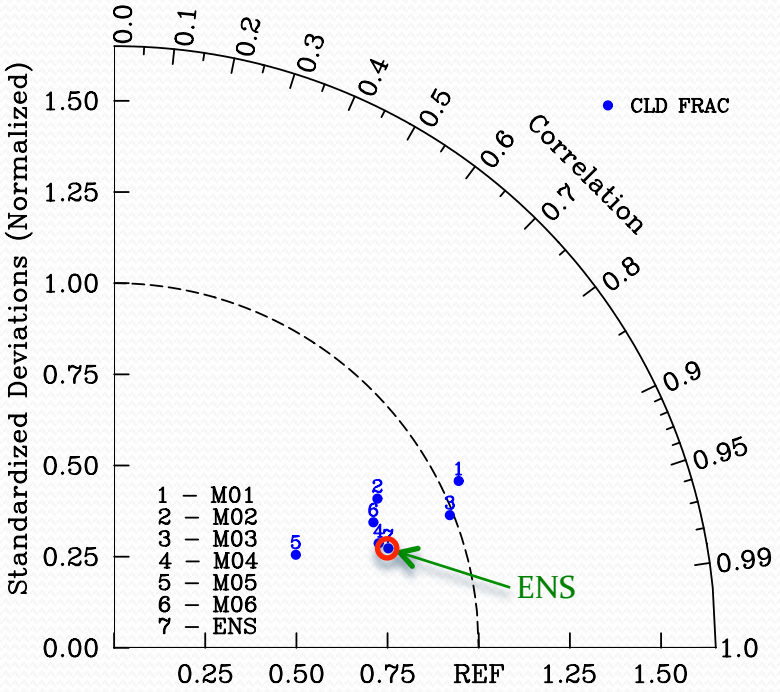
## [3] Cloudiness
## Six RCMs and their ensemble vs. MODIS retrievals

- 8 years: 2001-2008
- MODIS cloudiness data, $1^{o}$x$1^{o}$, Global coverage

# Overland Cloudiness Climatology (2001-2008)

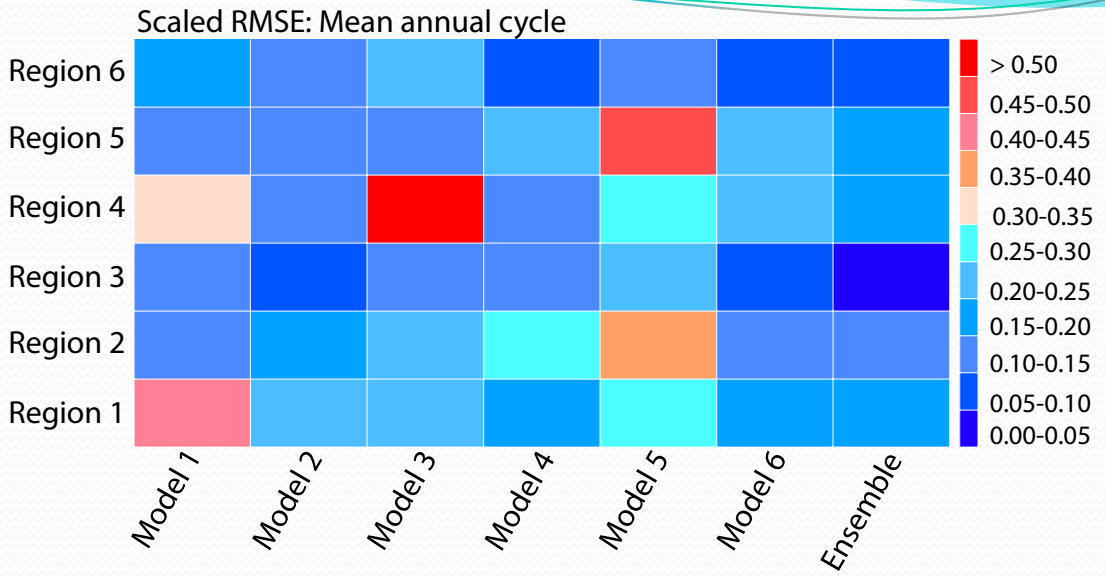


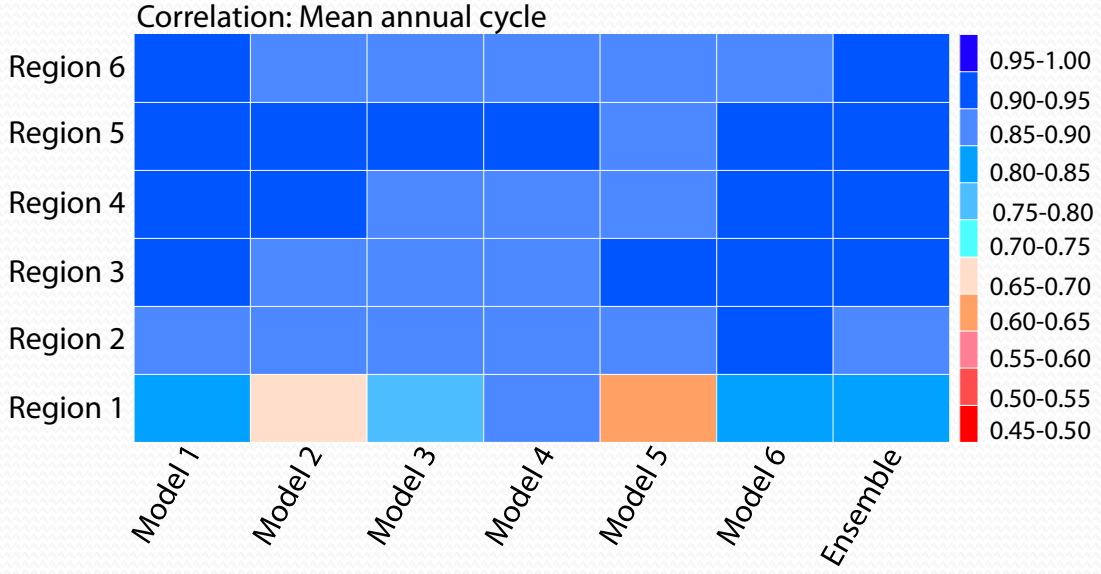




- Model errors range from -17.5% to +20%
- All models generate good spatial pattern (spatial corr. coef. > 0.9 vs. the MODIS data).
- The model ensemble generally agree more closely with the REF data than individual models.
  - the smallest bias and RMSE against the MODIS data.
  - the highest spatial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

# Cloudiness Ann Cycle Normalized RMSE ($RMSE/MEAN_{MODIS}$)




# Cloudiness Annual cycle Correlation with the MODIS data



# Summary

- Monthly precipitation, $T_2$'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.