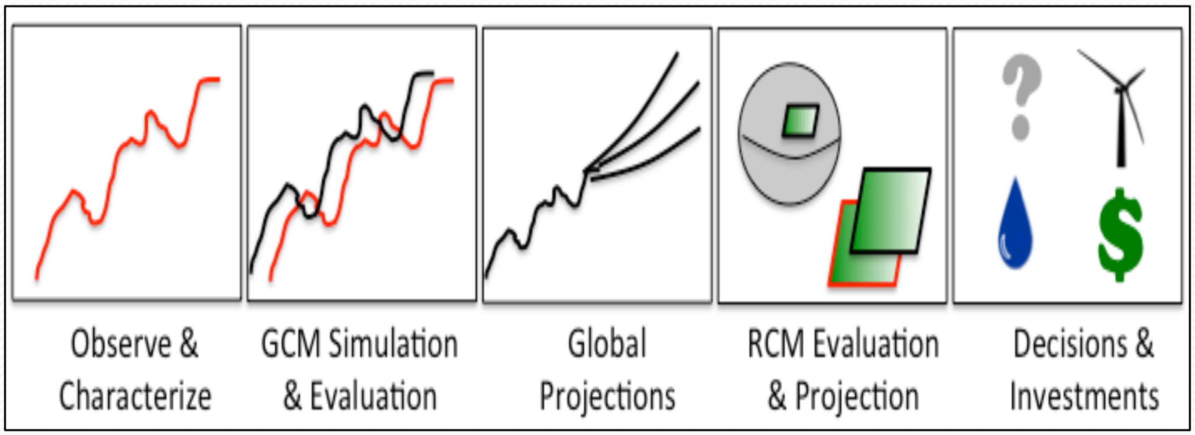
Multi-RCM CORDEX-Africa Hindcast Evaluation using the JPL Regional Climate Model Evaluation System (RCMES)

J. Kim[1], D.E. Waliser[1,2], C. Mattmann[2], C. Goodale[2], A. Hart[2], P. Zimdars[2], C. Jones[3], G. Nikulin[3], B. Hewitson[4], C. Jack[4], C. Lennard[4], and A. Favre[4],

[1]: Joint Institute for Regional Earth System Sci. and Eng./UCLA
[2]: Jet Propulsion Laboratory/NASA
[3]: Rossby Centre, Sweden
[4]: University of Cape Town, RSA

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)

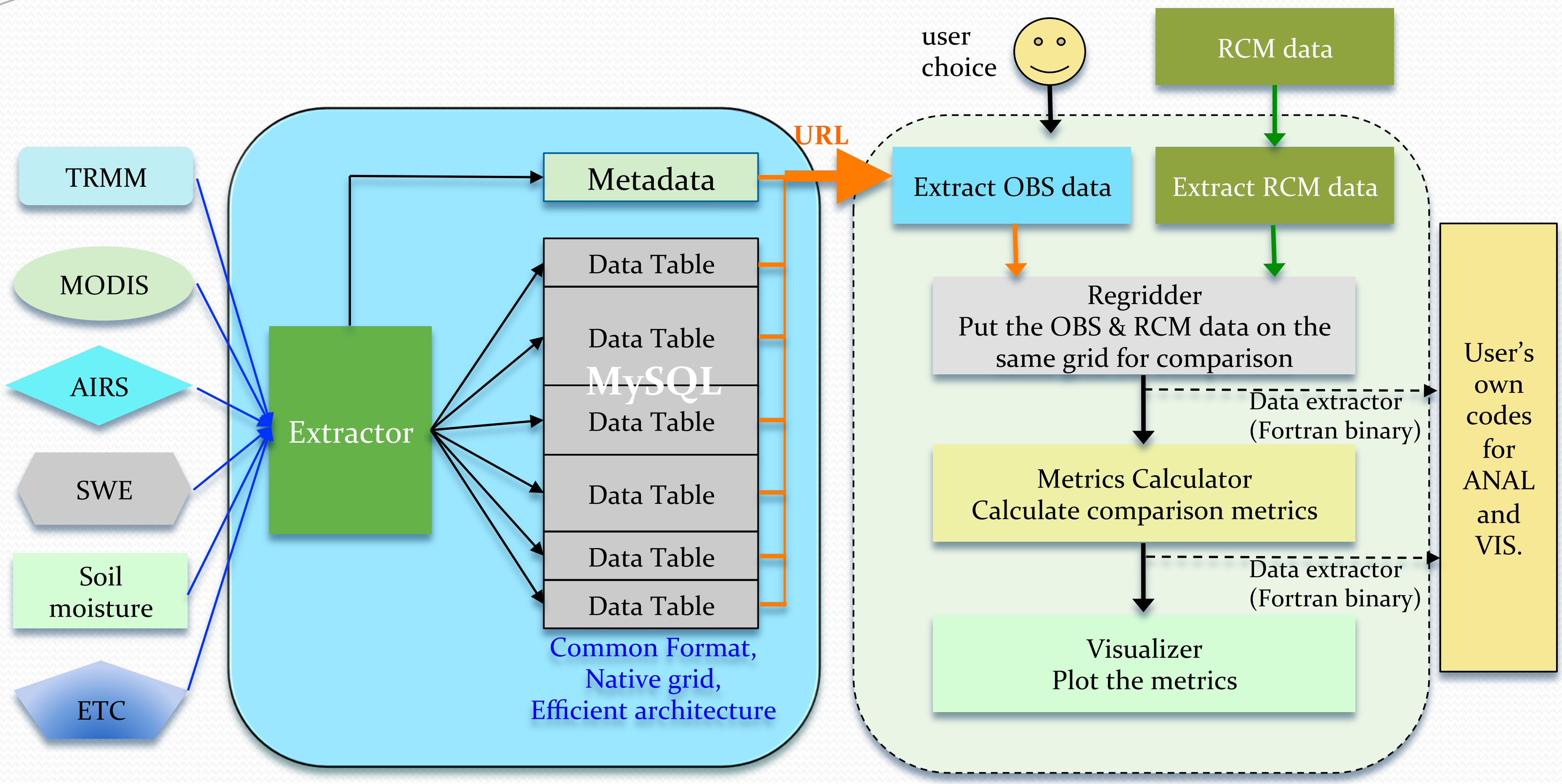
Using Satellite & Other Observations For RCM Evaluation

- *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

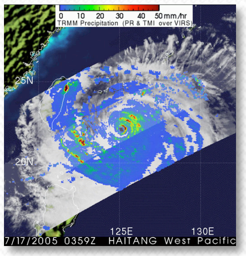


Raw Data:
Various formats, Resolutions, Coverage

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

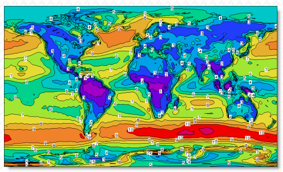
RCMET
(Regional Climate Model Evaluation Toolkit)
A library of codes for extracting data from RCMED and model and for calculating evaluation metrics

RCMES Database (RCMED)
Current & near-future archives



RCMED Datasets (now or near-term):

- MODIS (satellite cloud fraction): [daily 2000 – 2010]
- TRMM (satellite precipitation): 3B42 & version-7 [daily 1998– 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)

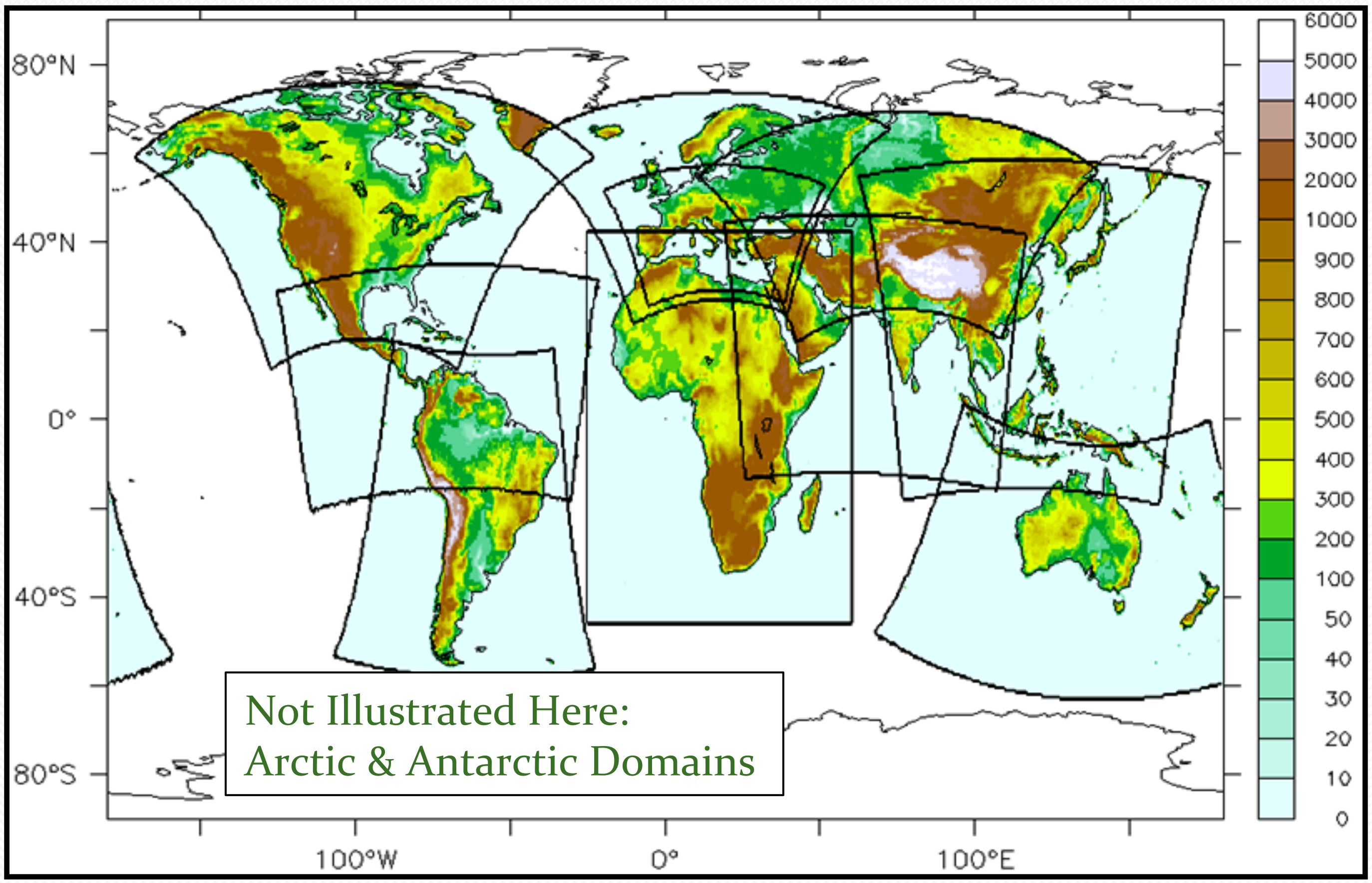
Current status and future development direction

- 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

Ongoing and planned application

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)



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, $T2_{AVG}$, $T2_{MAX}$, $T2_{MIN}$, Cloud Fraction

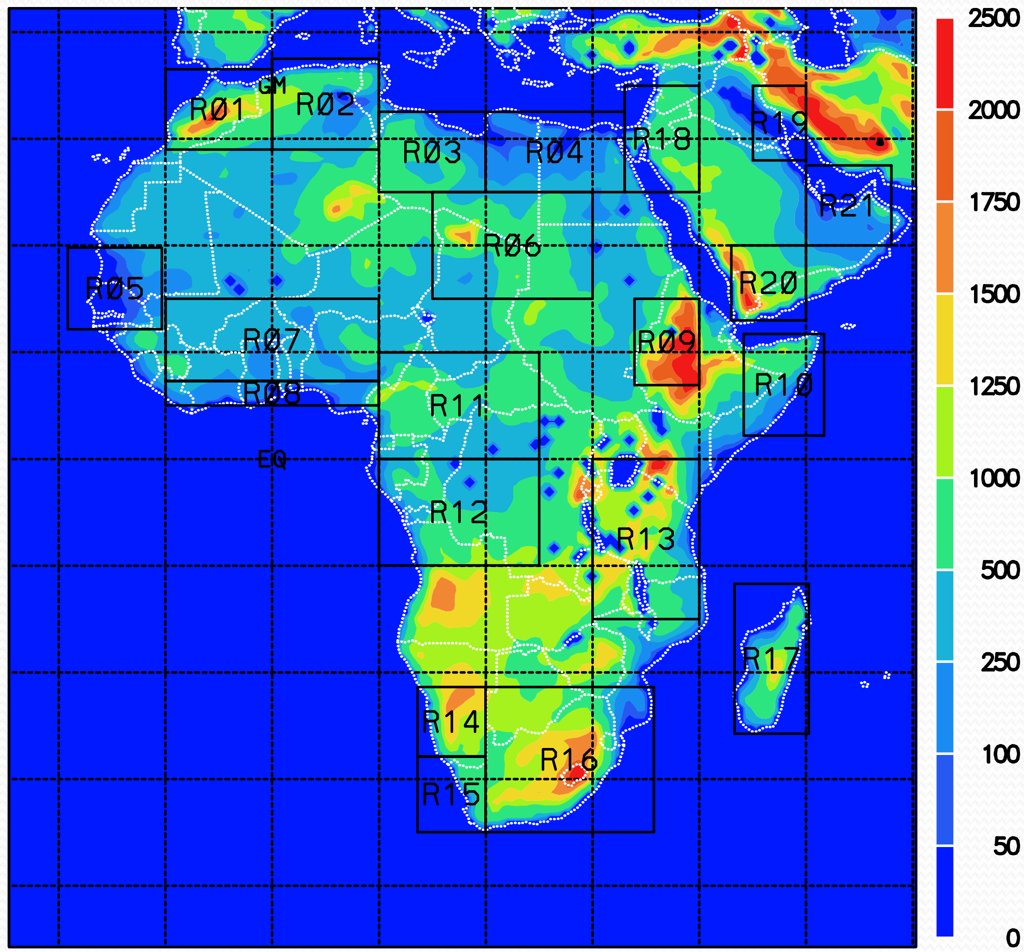
- Reference data used:
  - Precipitation: TRMM.v6 (1998-present, 0.25deg), CRU3.1 (1901-2006, 0.5deg)
  - T2, T2Min, T2Max: CRU3.1 (1901-2006, 0.5deg).
  - Cloud fraction: CRU3.1, MODIS retrieval (2001-present, 1 deg).

RCMs and Variables Evaluated in this Study

ID	Institution	Variable / Model	PRECIP	T_{MEAN}	T_{MIN}	T_{MAX}	Cloudiness
M01	CNRM	ARPEGE51	O	O	O	O	O
M02	DMI	HIRHIM	O	O	O	O	O
M03	ICTP	RegCM3	O	O	O	O	O
M04	IES	CCLM	O	O	O	O	O
M05	KNMI	RACMO2.2b	O	O	O	O	O
M06	MPI	REMO	O	O	O	O	O
M07	SMHI	RCA35	O	O	O	O	O
M08	UCT	PRECIS	O	O	O	O	O
M09	UC	WRF311	O	O	O	O	X
M10	UQAM	CRCM5	O	O	O	O	O
M11	n/a	ENS	O	O	O	O	O

- Precipitation: 10 RCMs
- T2 fields: 10 RCMs
- Cloudiness: 9 RCMs

CORDEX Africa Hindcast/Analysis Domain with 21 subregions



- 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.

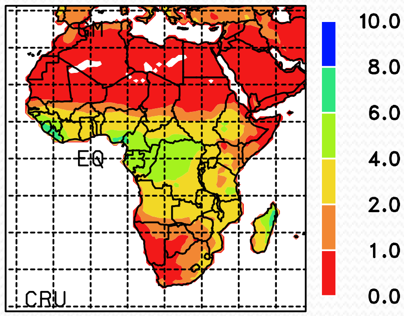
[1] Precipitation evaluation
10 RCMs and their ensemble vs. CRU raingauge analysis

- 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

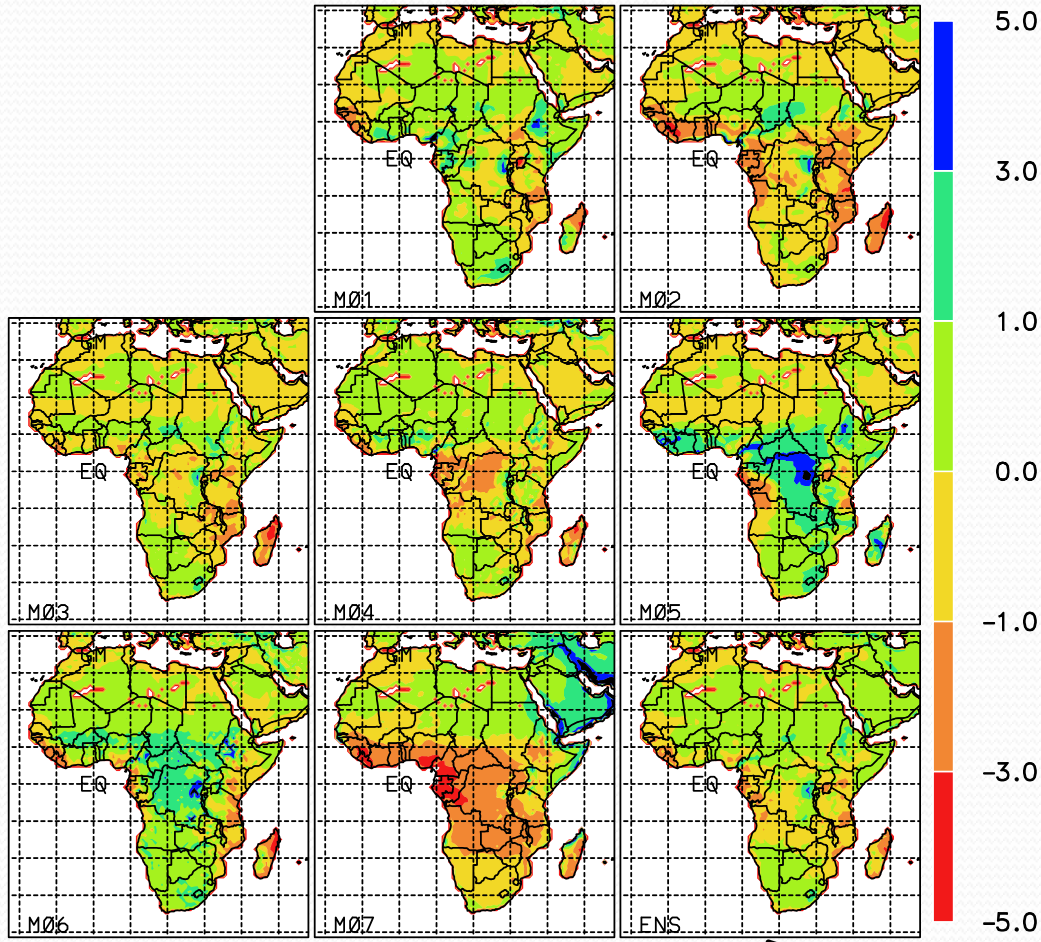
Annual overland precipitation climatology

Climatology

REF (mm/day): CRU

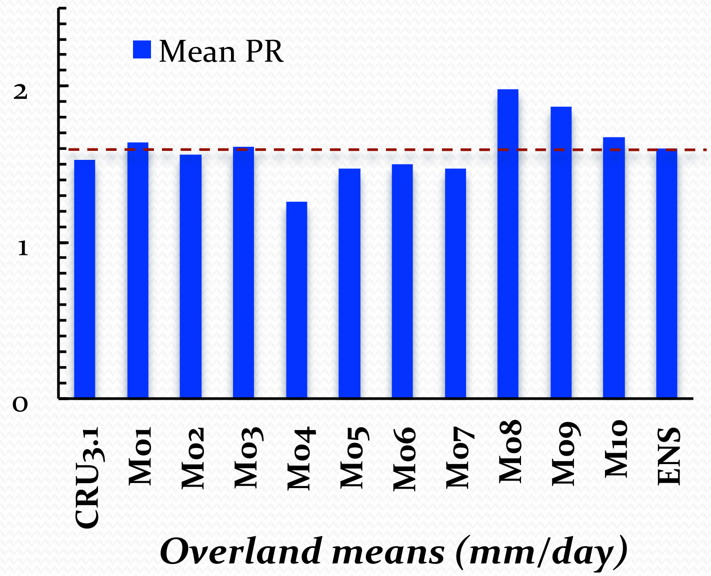


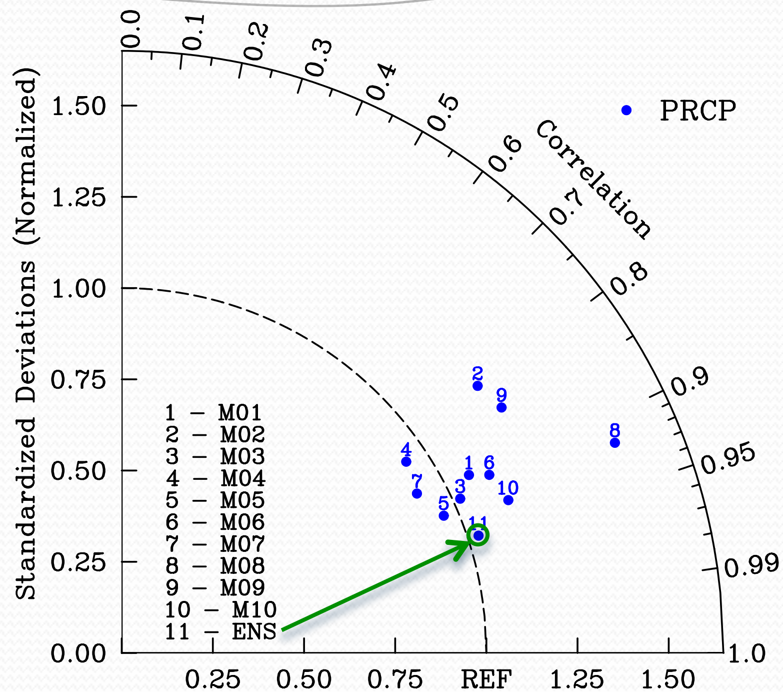
Bias: Annual-mean precipitation climatology (mm/day)



Wet/dry biases in dry/wet regions

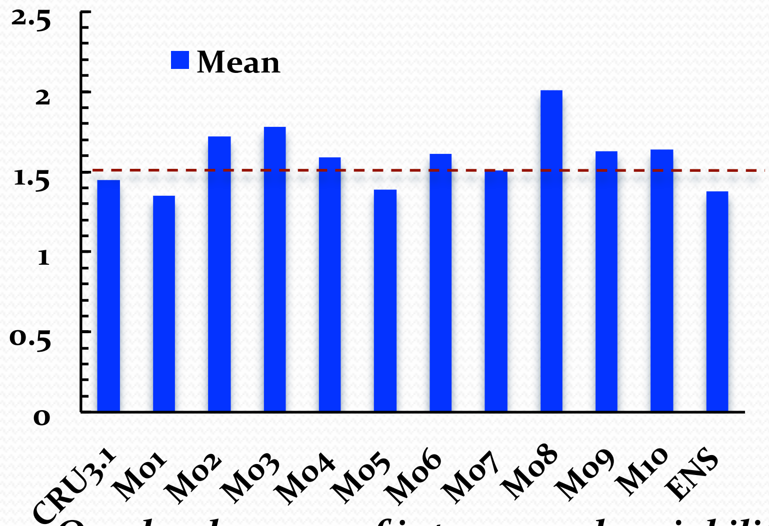
Spatial Variability of the Overland Precipitation Climatology



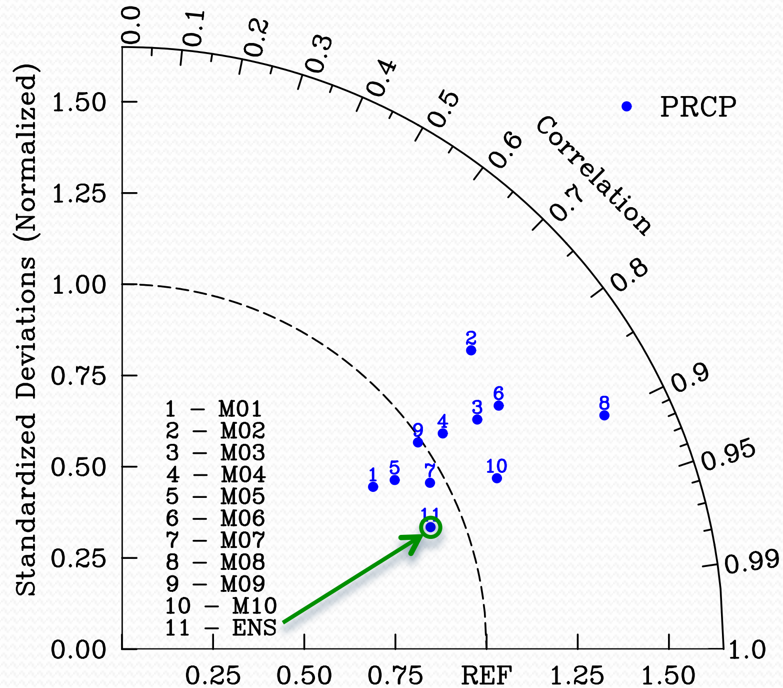


- Attempt to objectively measure the model performances
- Most RCMs simulate precipitation climatology with reasonable *overland totals* and *spatial pattern* compared to the CRU analysis.
- Spatial variability varies widely according to RCMs.
- The model ensemble compares well with the CRU analysis:
    - *smallest in bias and RMSE* and *highest spatial pattern correlation*
    - *Spatial variability is smaller than most models, but comparable to the CRU data.*

Spatial Variations in Overland Prcp Interannual Variability

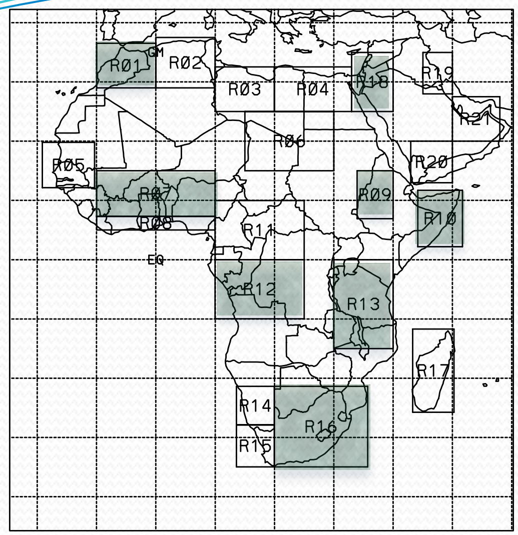


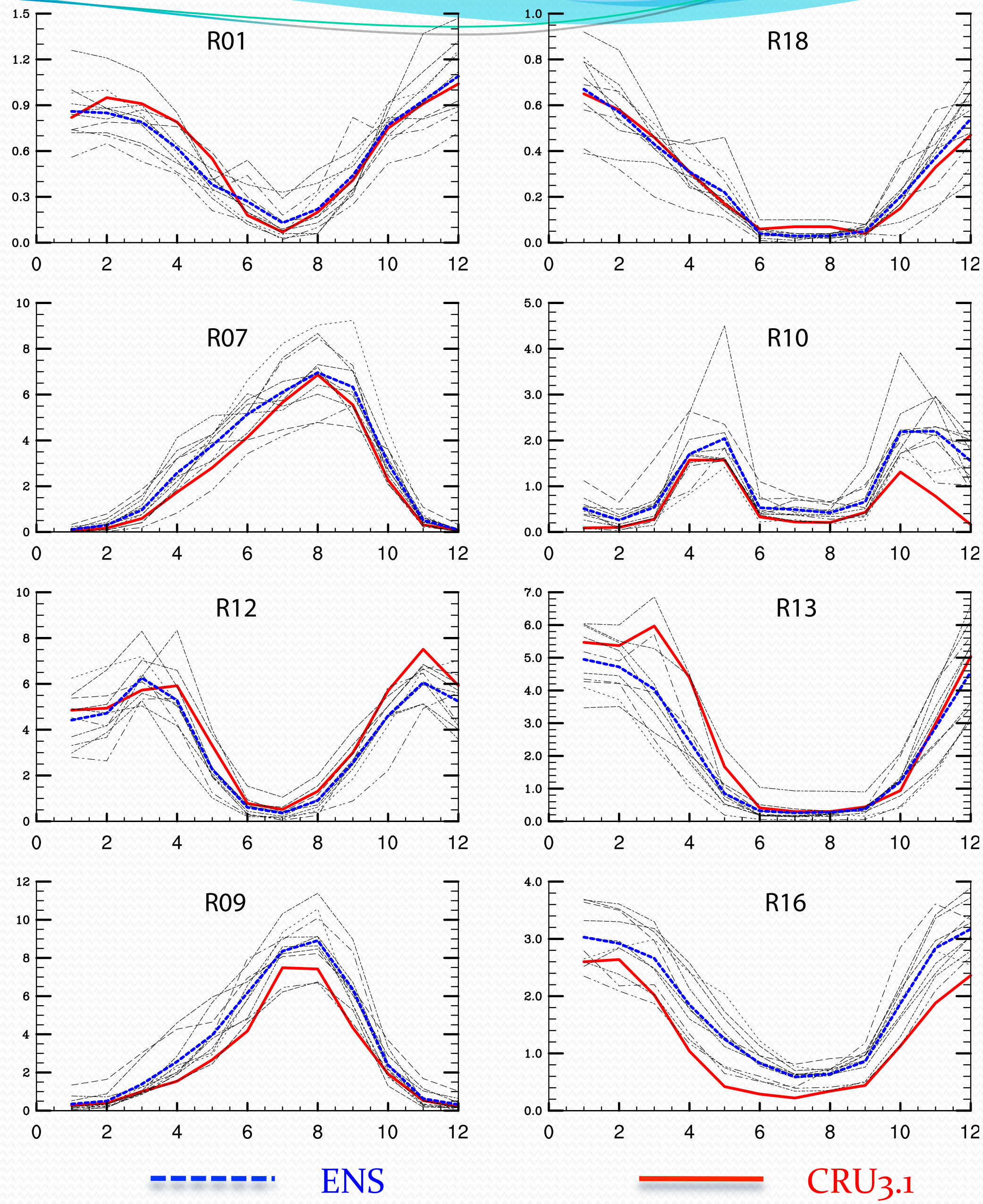
Overland means of interannual variability (mm/day)



- 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*

Precipitation Annual Cycle (mm/day) in 8 subregions

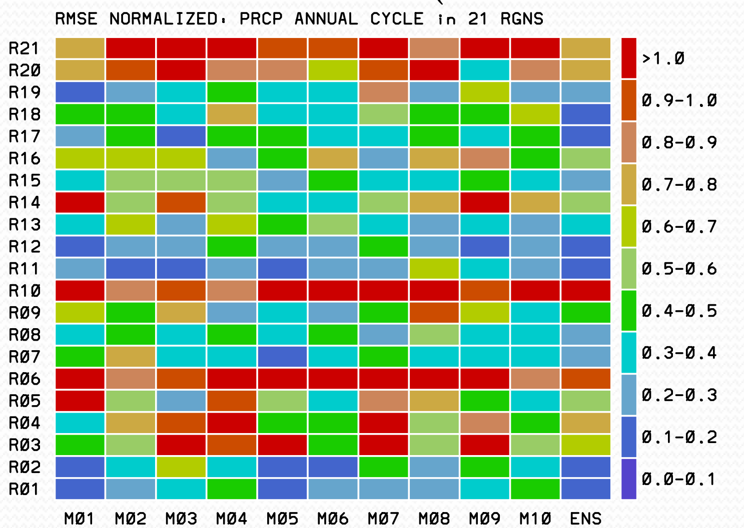




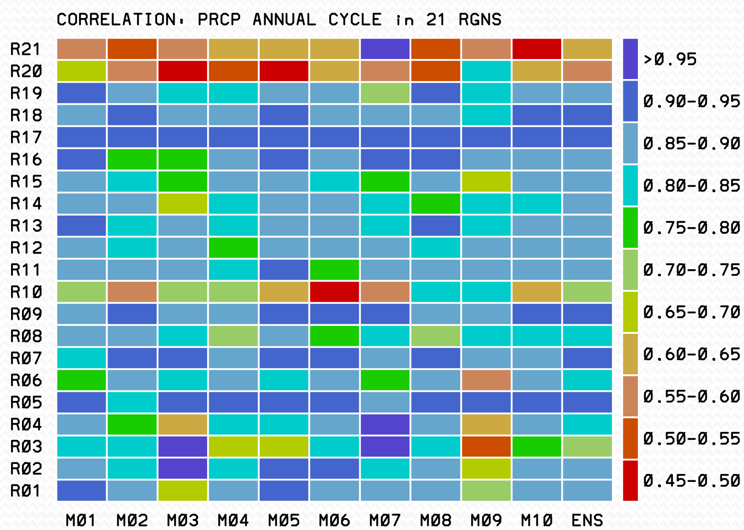
- RCM performance in simulating precip annual cycle vary widely
- *Model ensemble* performs well in a number of regions
  - Mediterranean regions
  - Western AF monsoon
- Systematic biases occur in some regions
  - Eastern RSA (R16) all year
  - Eastern Africa (R13) in austral fall
  - Somalia (R10) in boreal winter

Precipitation Annual Cycle (mm/day) in Subregions

PR: Normalized RMSE (Frac of ann mean)



PR: Corr. with the CRU data

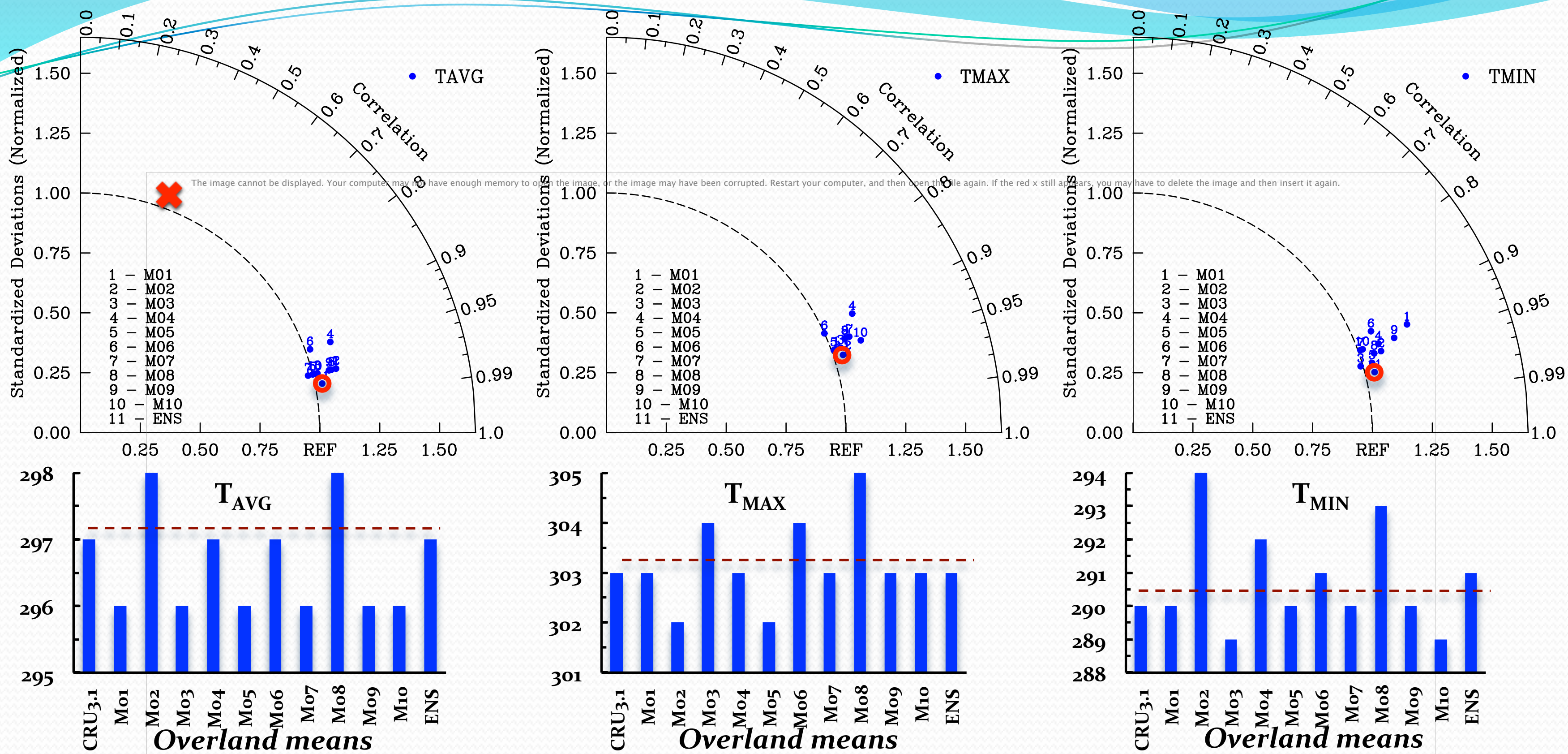


- Compare the performance of multiple models using "*portrait diagram*".
- Model performance varies widely according to regions as well as models.
  - RCMs generally well simulates the precipitation annual cycle in the western Mediterranean coast (R01 & R02), Eq. W. Africa (R11 & R12), and Madagascar (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

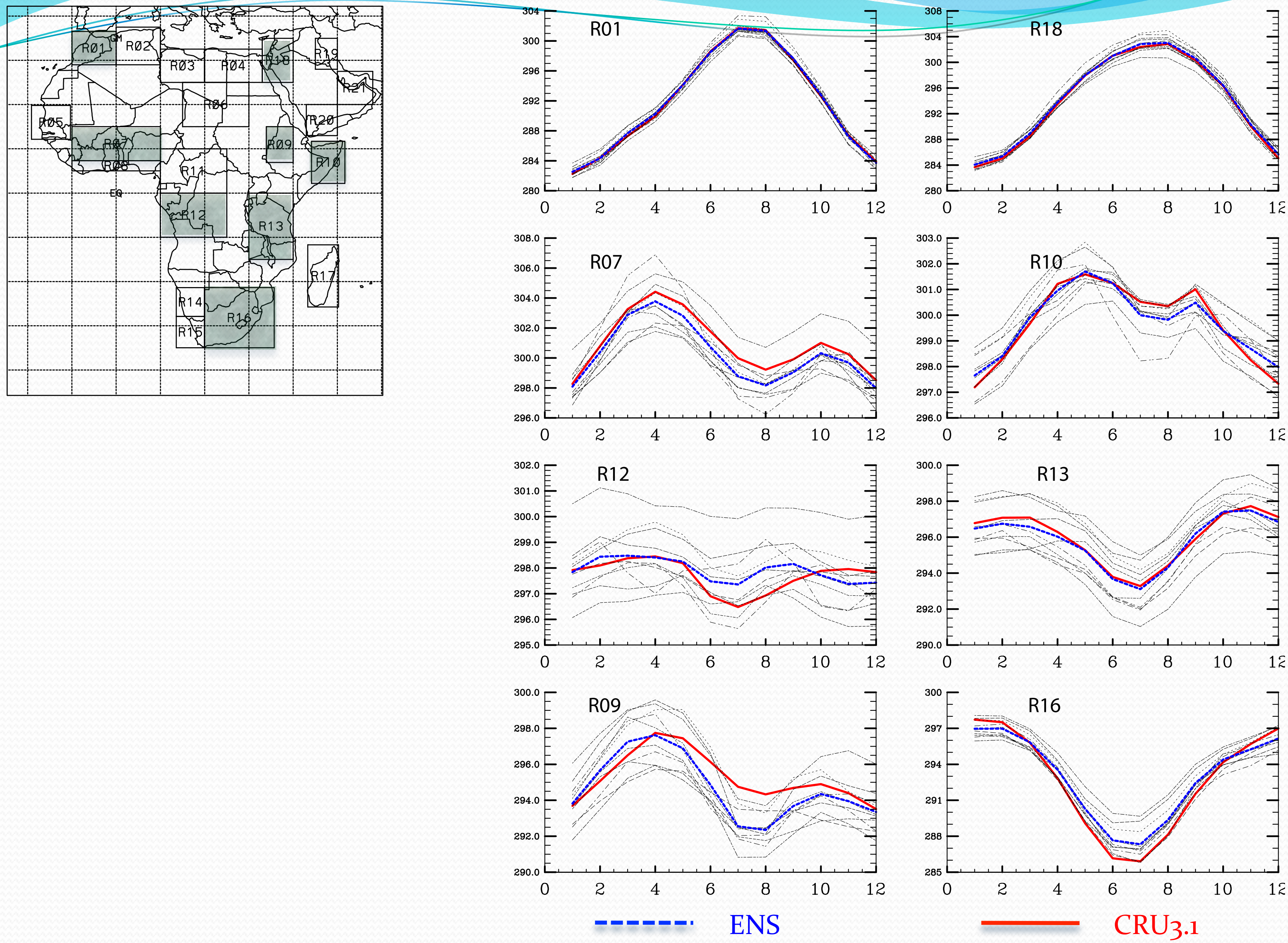
- 18 years: 1990-2007
- Overland only
- Annual T2Mean, T2Min, and T2Max climatology
- Interannual variability *in terms of the temporal standard deviations*
- Annual cycle in subregions.

Spatial Variability of the T2 Climatology

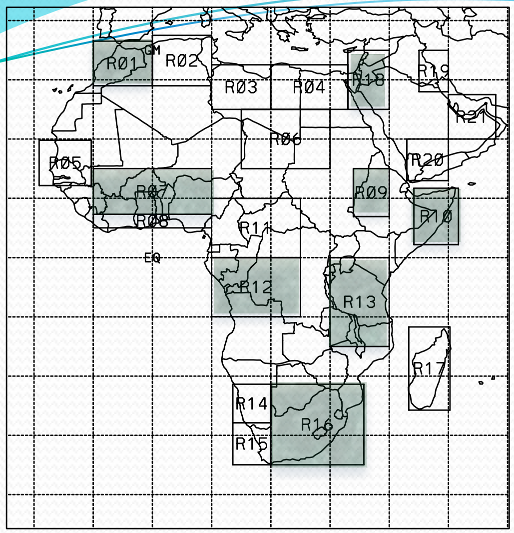


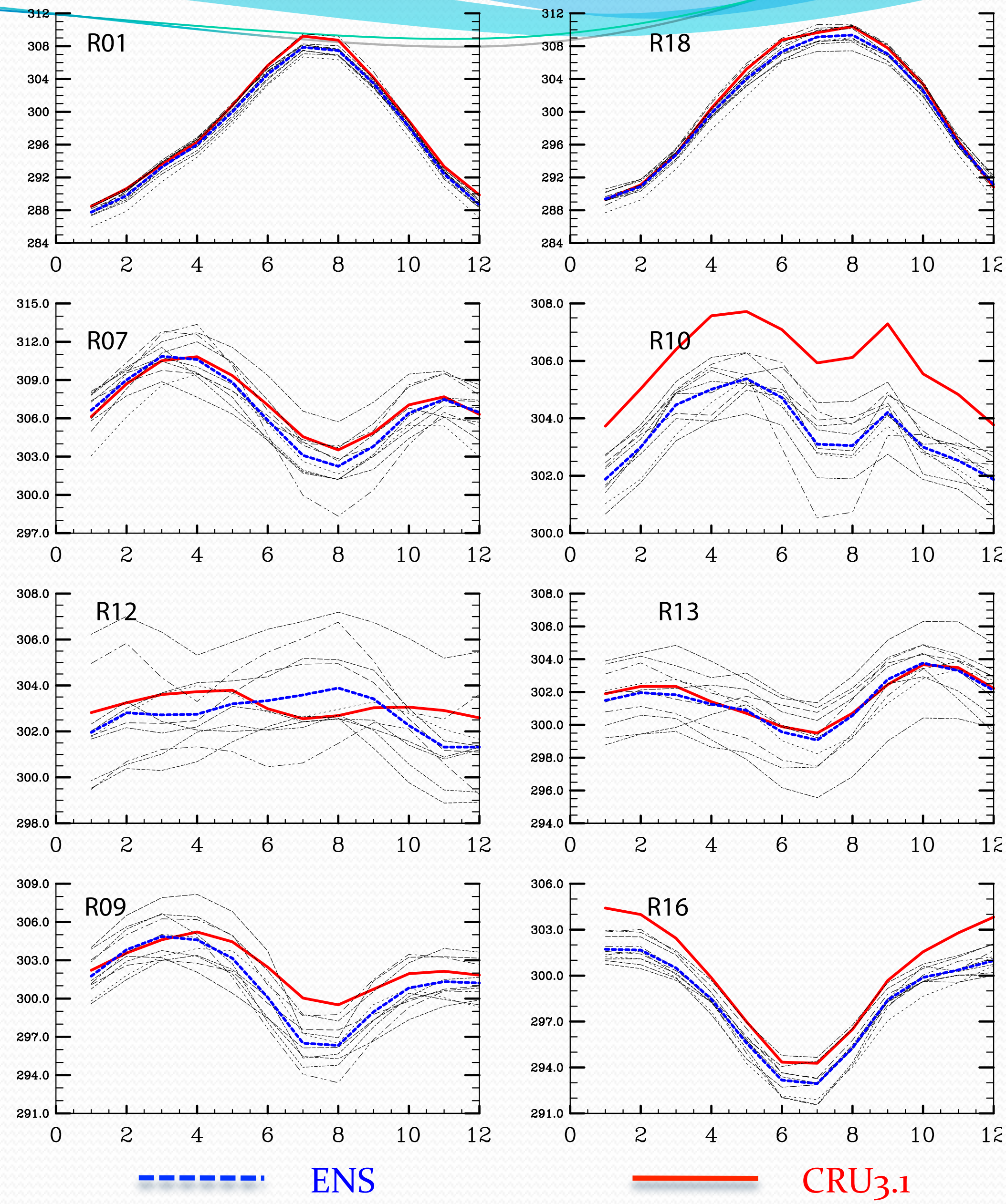
- Model performs somewhat better in simulating the daily means than the daily max/min values
- Inter-RCM variations in the spatial pattern (correlation) and variability (standardized deviation) is much smaller than for precipitation.
- Model ensemble again performs collectively well compared to individual models
    - Smallest RMSE & bias with highest correlation

Spatial Variability of the $T2_{MIN}$ Climatology

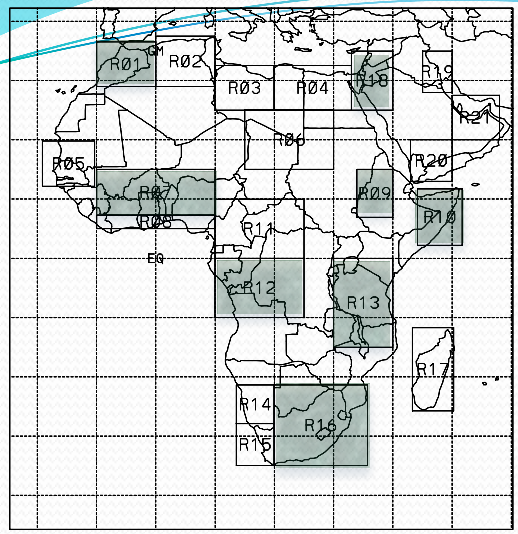


Spatial Variability of the T2$_{MAX}$ Climatology

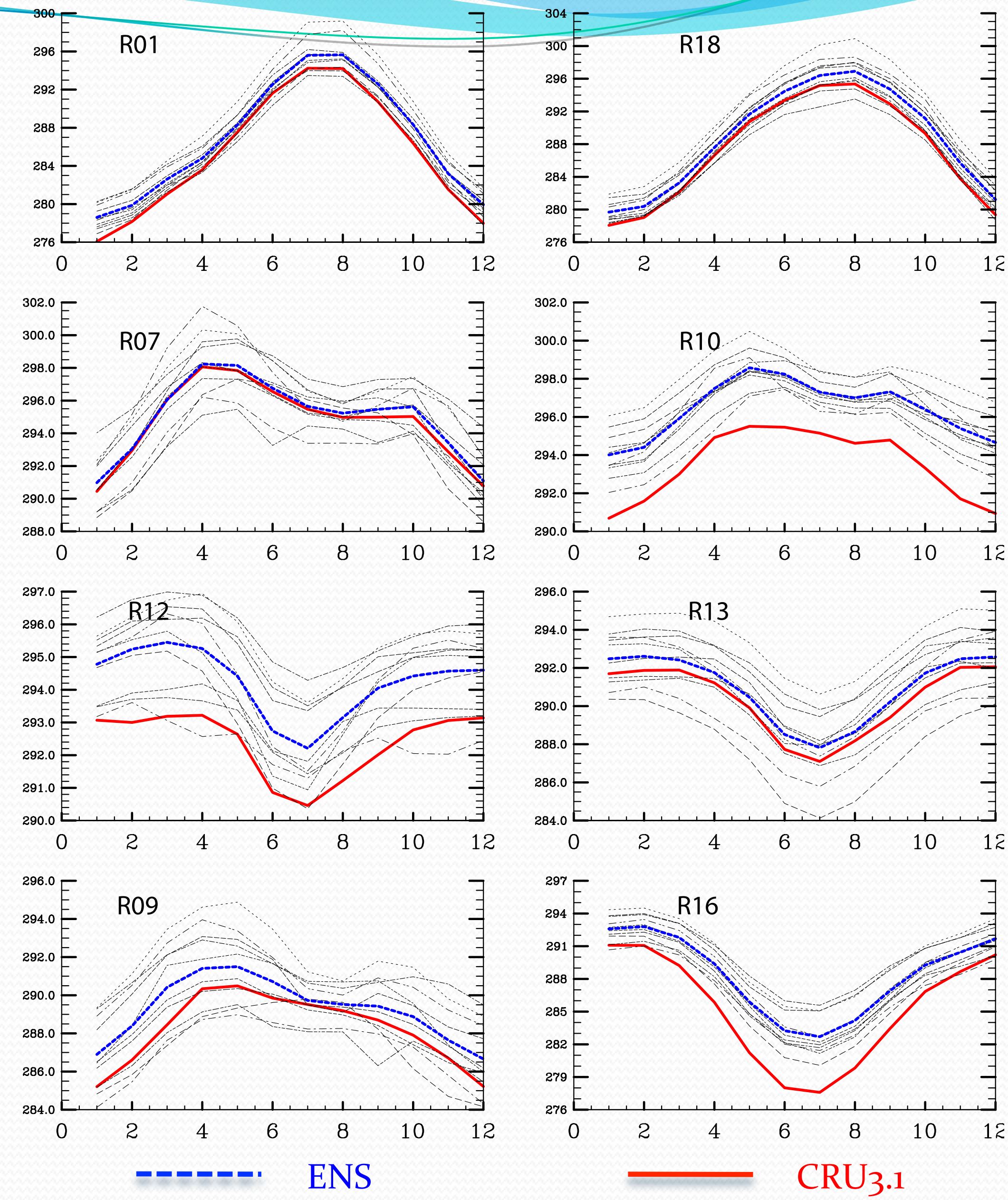




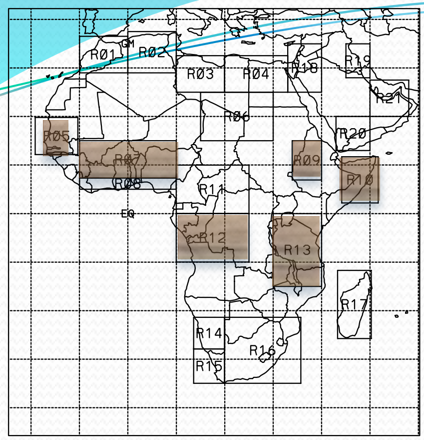
Spatial Variability of the $T2_{MIN}$ Climatology

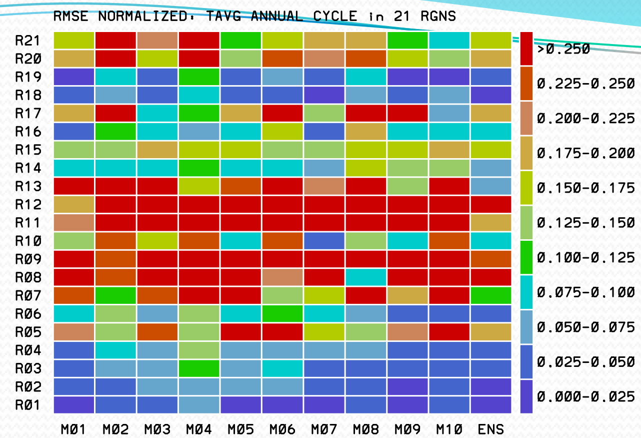


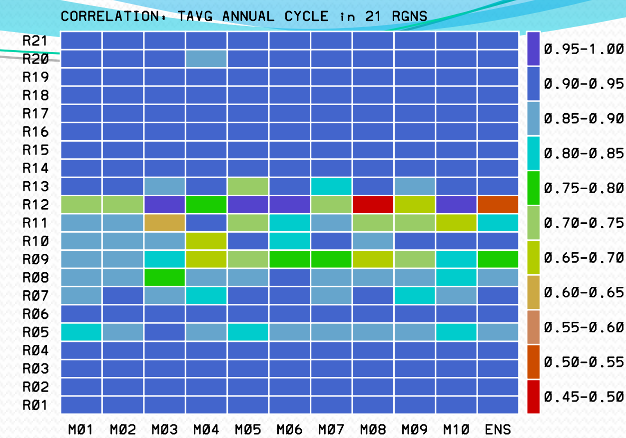
- RCM performance varies widely.
- Performance of *the RCM ensemble* is somewhat better in higher latitude regions than near the Equator for $T2_{AVG}$.
- Performance of *RCMs and their ensemble* are generally lower for daily extremes than daily means.
- Typical bias in the model ensemble is under/overestimation of daily max/min temperatures
    - This bias will result in under-estimation of the amplitude of temperature diurnal cycle.



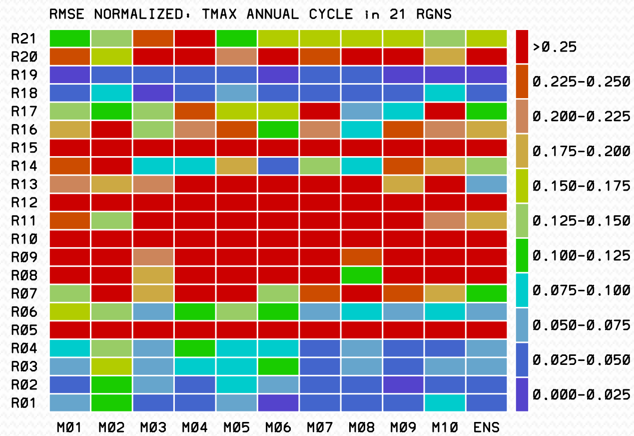
Annual Cycle: Normalized RMSE   Annual Cycle: Correlation

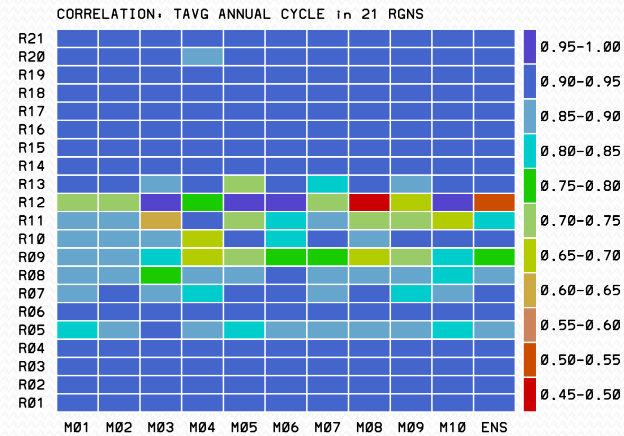






T_{AVG}

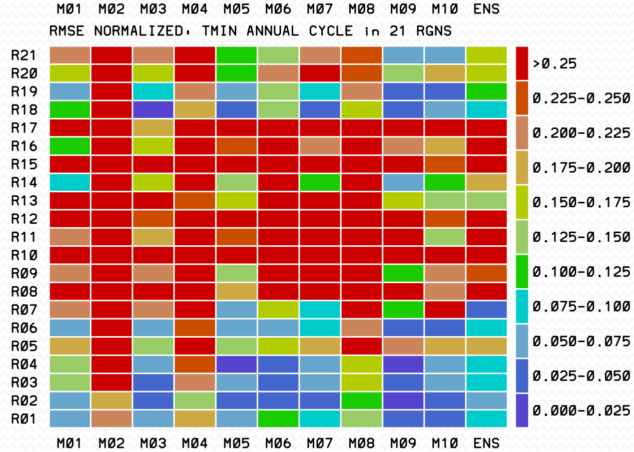


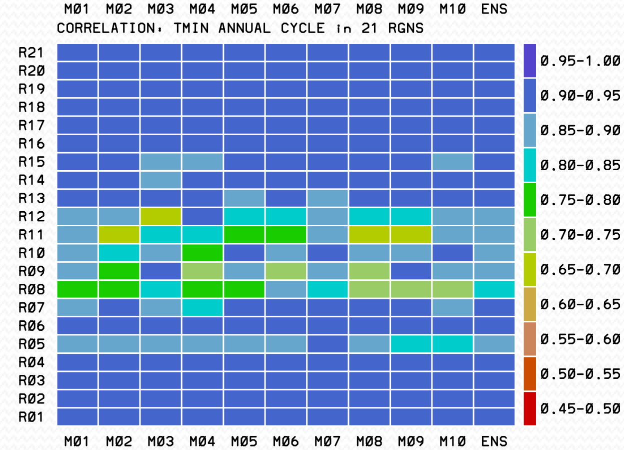


T_{MAX}

Normalization by the annual cycle amplitude of the CRU data

$$NRMSE = \frac{\frac{1}{12}\sqrt{\sum_{m=JAN}^{m=DEC}\left(T_m^{MODEL} - T_m^{OBS}\right)^2}}{\left(T_{\max}^{OBS} - T_{\min}^{OBS}\right)}$$



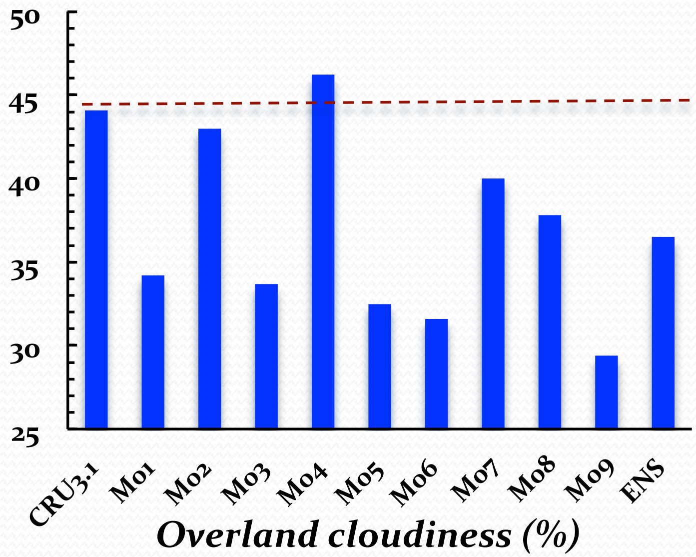


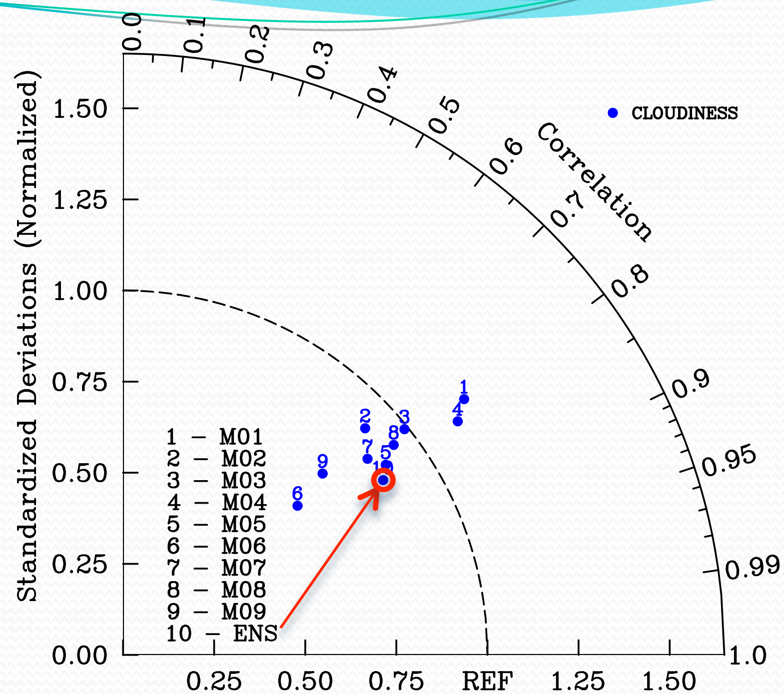
T_{MIN}

[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

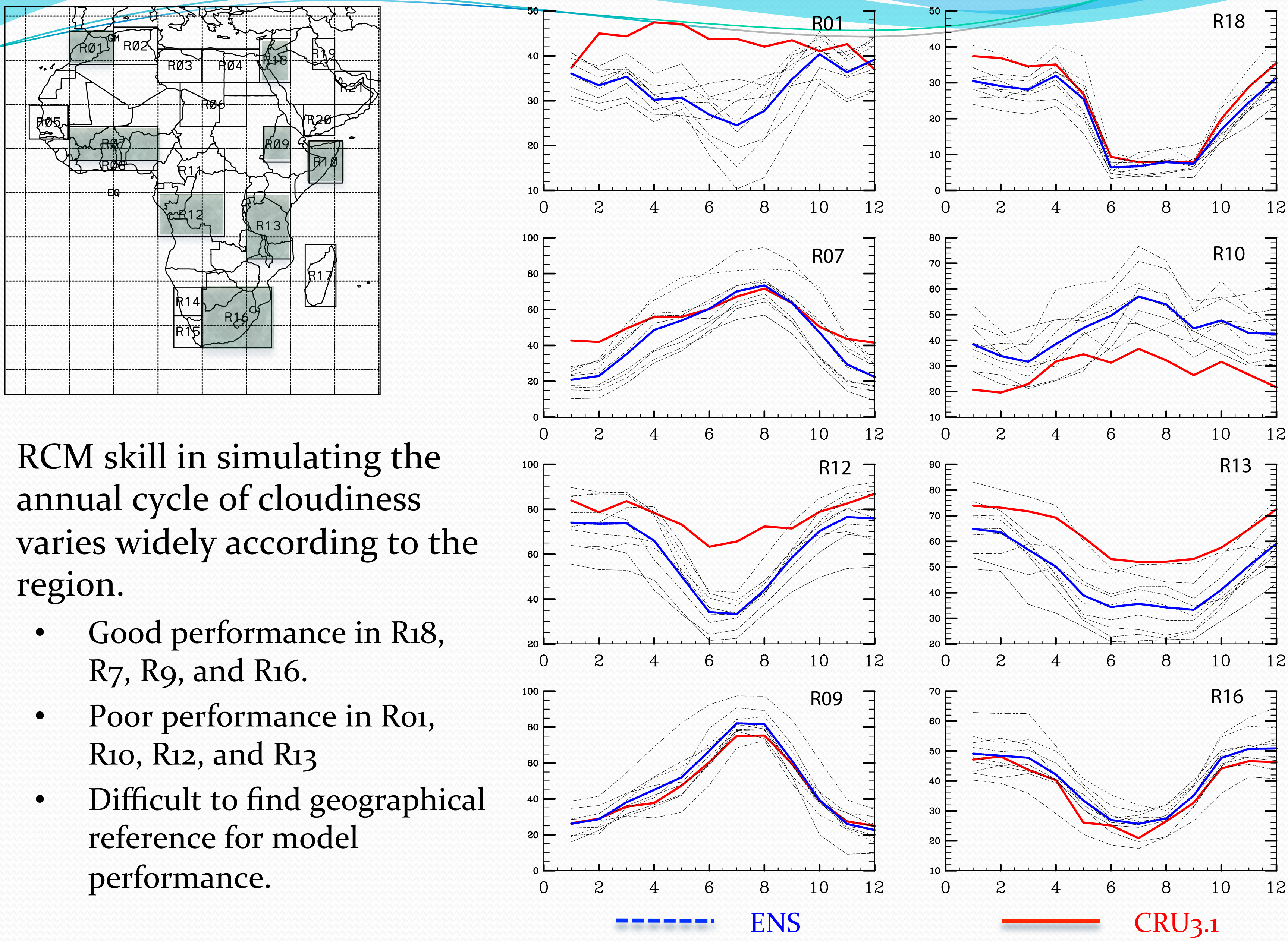
Overland Cloudiness Climatology (1990-2007): RCMs vs. CRU3.1





- 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.

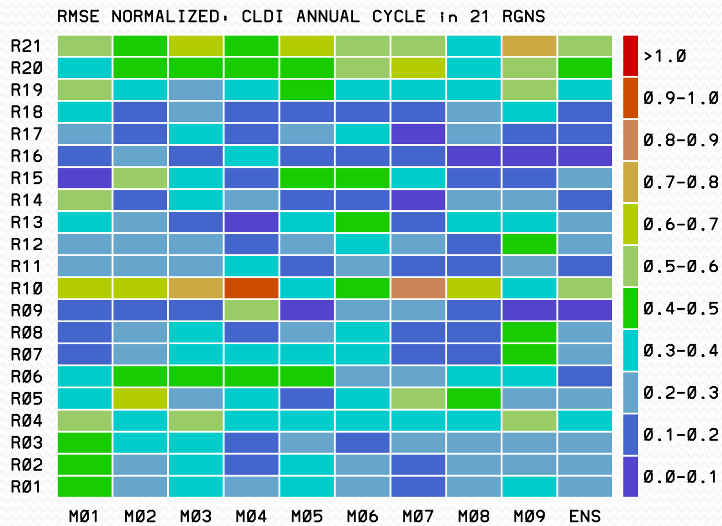
Mean Cloudiness Annual Cycle: CRU vs. RCMs (1990-2007)



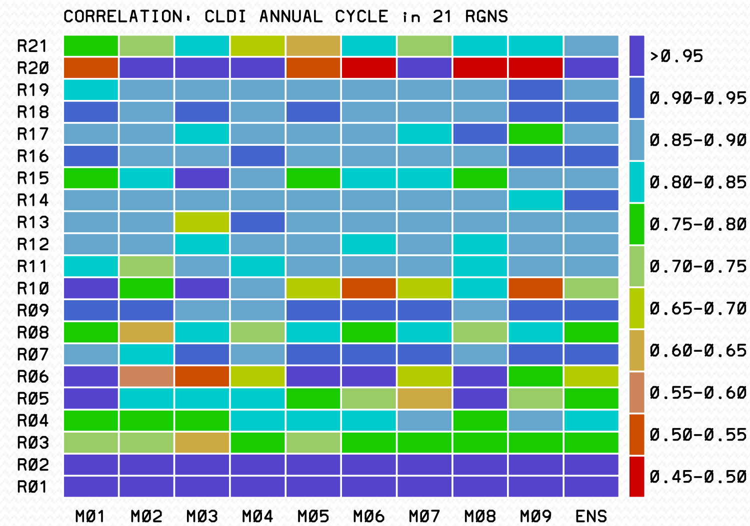
- RCM skill in simulating the annual cycle of cloudiness varies widely according to the region.
  - Good performance in R18, R7, R9, and R16.
  - Poor performance in R01, R10, R12, and R13
  - Difficult to find geographical reference for model performance.

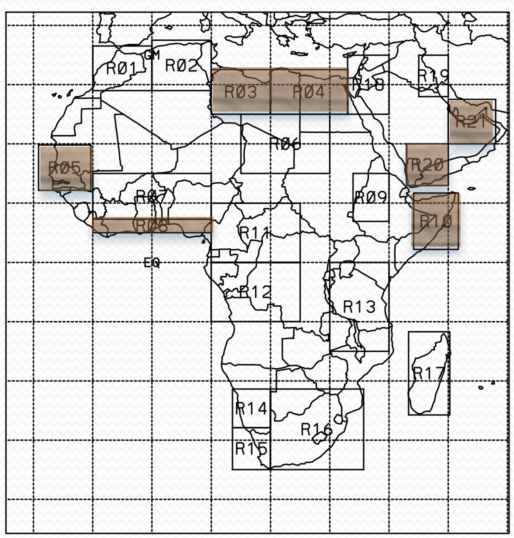
Cloudiness Annual Cycle in 21 Sub-regions

Normalized RMSE



Correlation





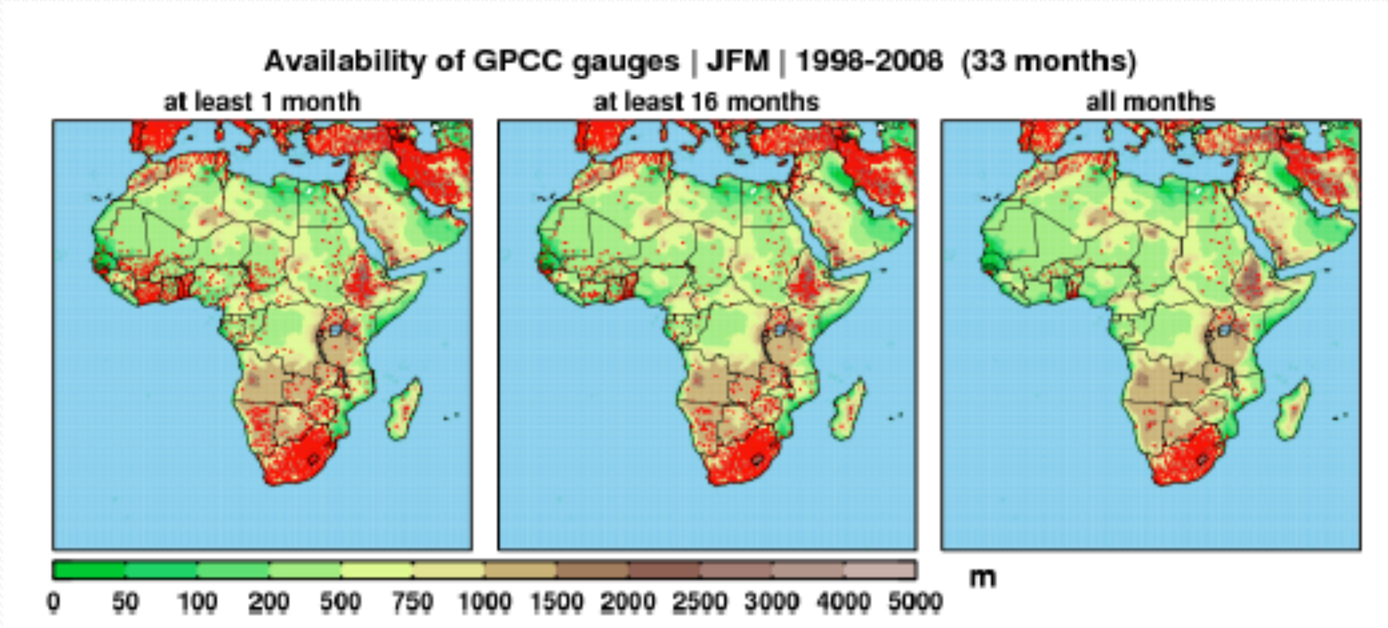
- RCMs may perform better in simulating seasonal cycle, measured in terms of the normalized RMSE and correlation, in the S. hemisphere and equatorial regions than in the N. hemisphere.
- However, it is difficult to link these errors shown in the annual cycle plot (previous page) with these metrics.
  - 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

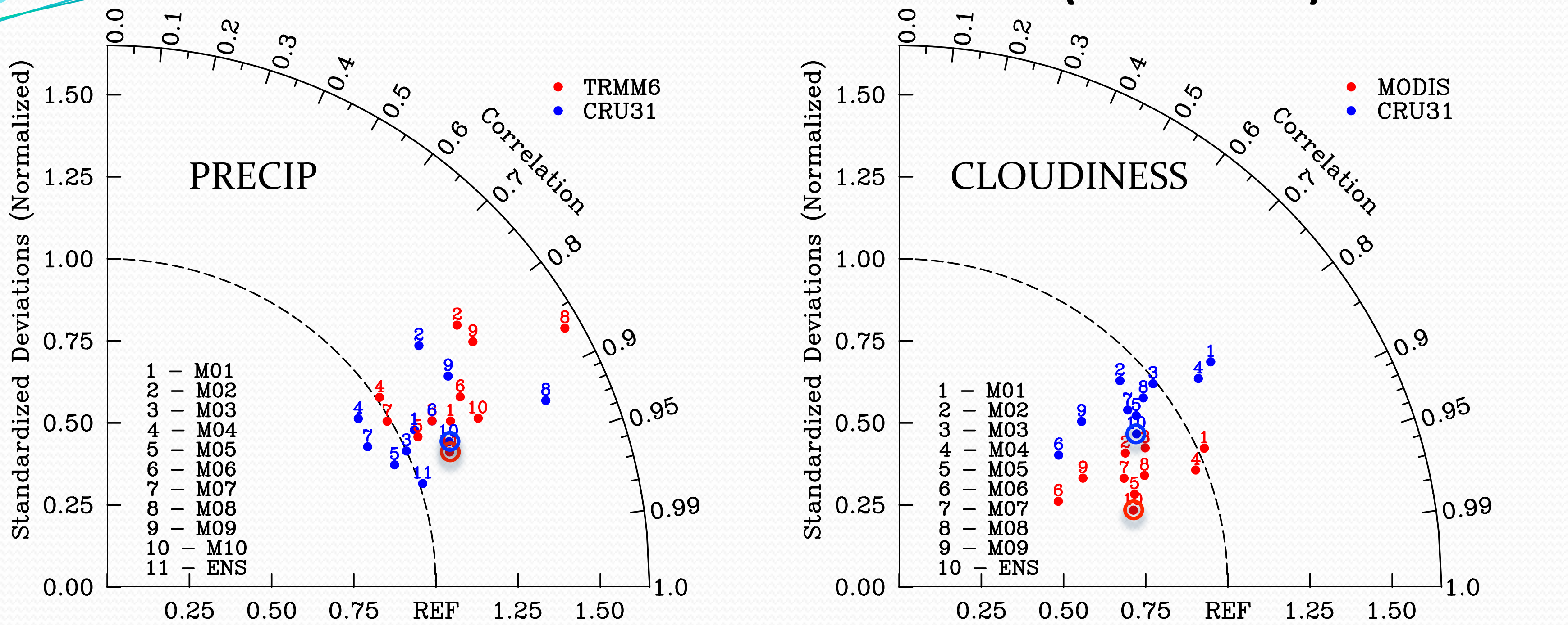
GPCC Gauge Distribution within Africa

(*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

Precipitation : RCMs vs. TRMM & CRU3.1 (1998-2007)
Cloudiness: RCM vs. CRU and MODIS (2001-2007)



- 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.

Summary

- 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.