Uncertainties in Climate Projections: Evaluating RCM Skills

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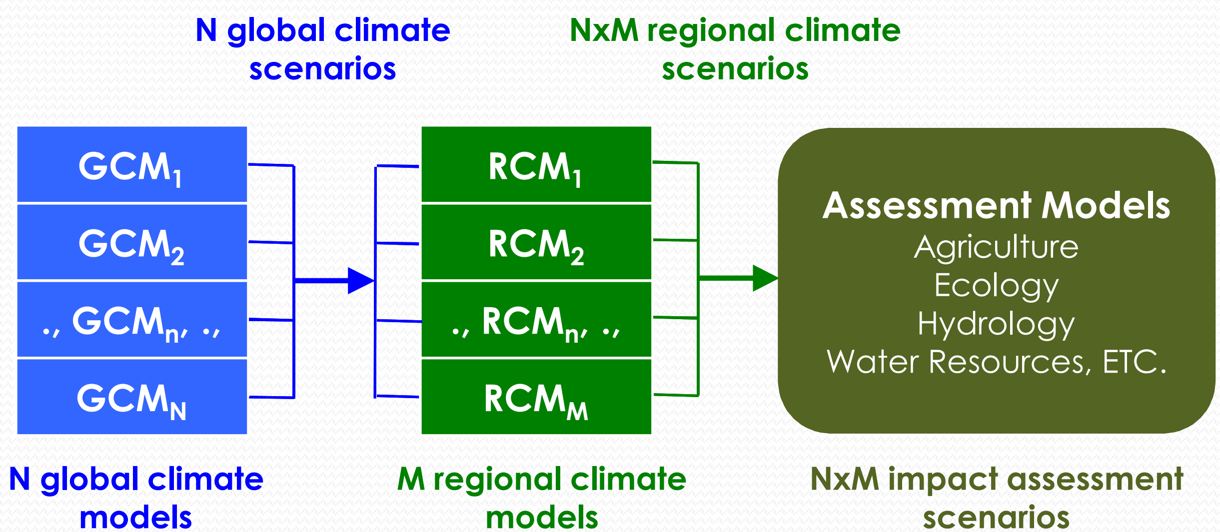
Climate change and impact assessments

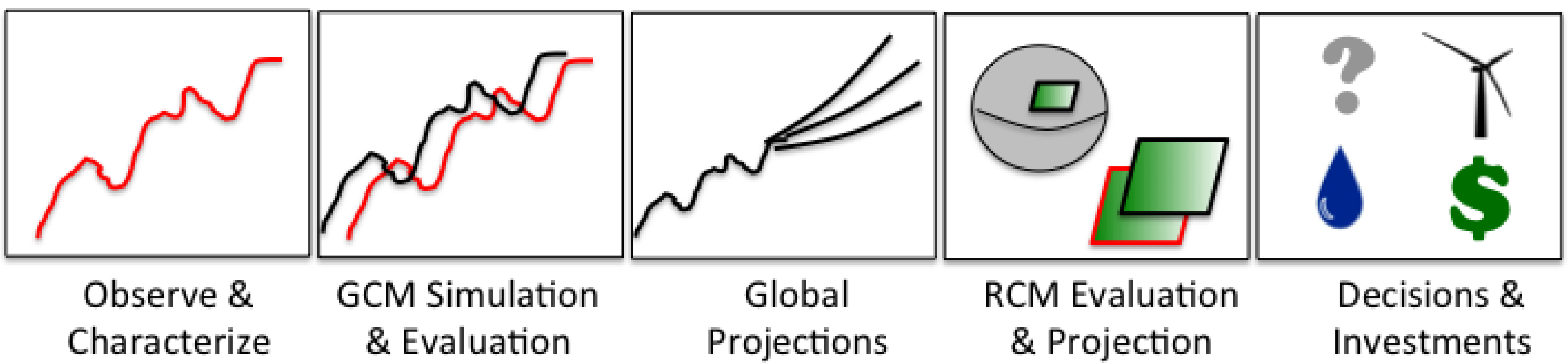
- Intense research in the last three decades has concluded *with high confidence* that *the increase in atmospheric GHG due to anthropogenic emissions has begun altering global climate*.
- As the global climate change of anthropogenic origins has been confirmed, *assessing the impact of climate change on regional sectors* has become an important concern.
- Climate change impact assessment is based on nested modeling in which information flows hierarchically.



A schematic illustration of information flow in assessing climate change impacts on regional sectors

Climate model evaluation

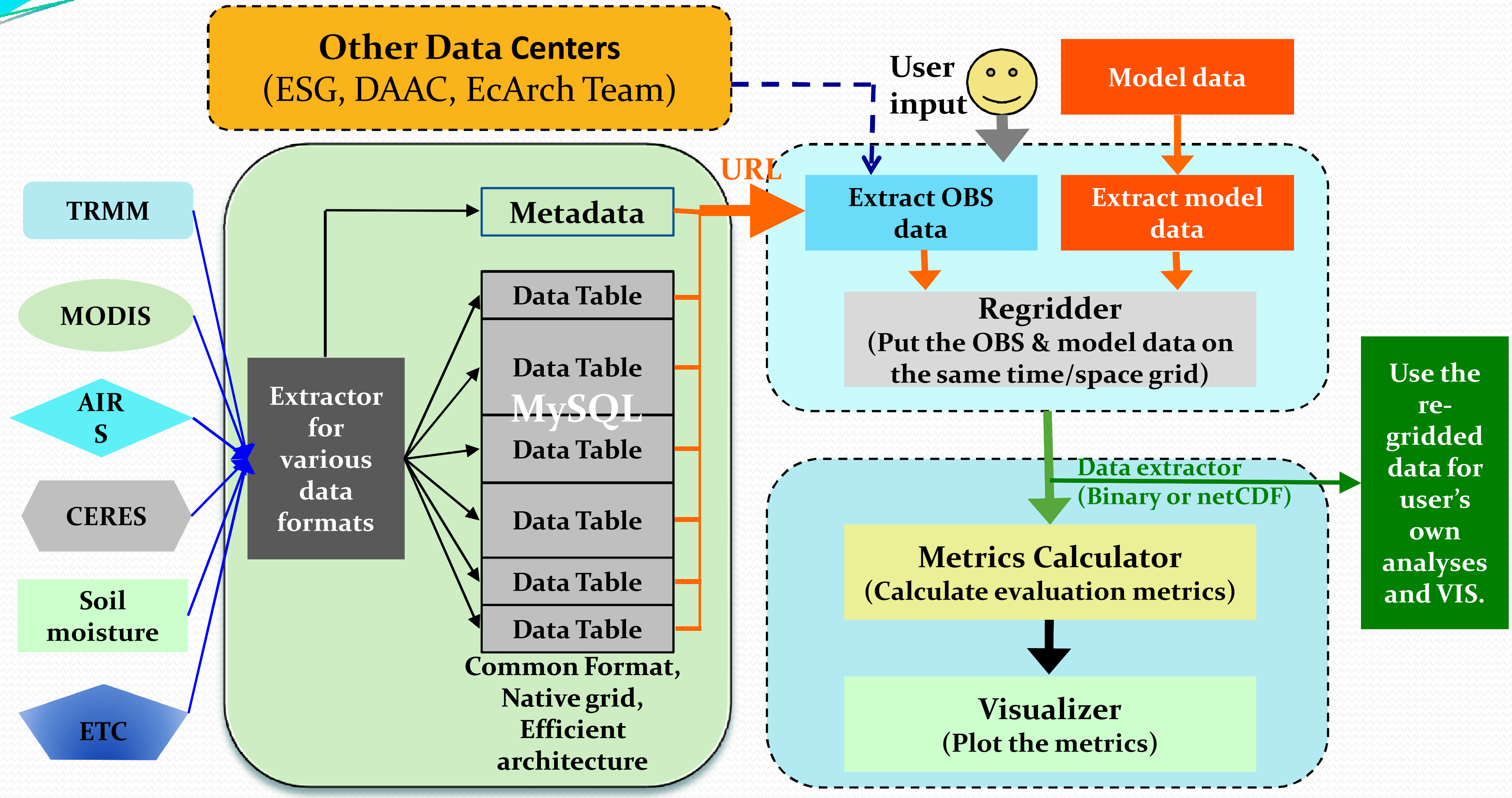
- Model errors are an important concern in climate change impact assessments.
- To deal with model errors in climate projection and impact assessments, we usually rely on *bias correction*or*multi-model ensemble*, or (*typically*)*both*.
- Model evaluation is the key step for bias correction and multi-model ensemble, in addition to model improvements.
- Observational data plays a key role in this process.



Schematic showing in red where observations play a key role in the assessment process; typically carried out from left to right, with the goal of a thoroughly informed process on the far right.

RCMES2.0

Initiated as a JPL-UCLA joint project – Ready for open access and wider collaboration



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

This study

- Examines the RCM skill in simulating variables fundamental in surface climate.
- Takes advantage of the RCM datasets generated in the CORDEX-Africa Hindcast Experiment:
  - A large number (9-10) of RCMs provide simulation data
  - Closely coordinated experimental design
- Focuses on:
  - The presence of model biases common to multiple RCMs
  - The effect of observational uncertainties in model evaluation

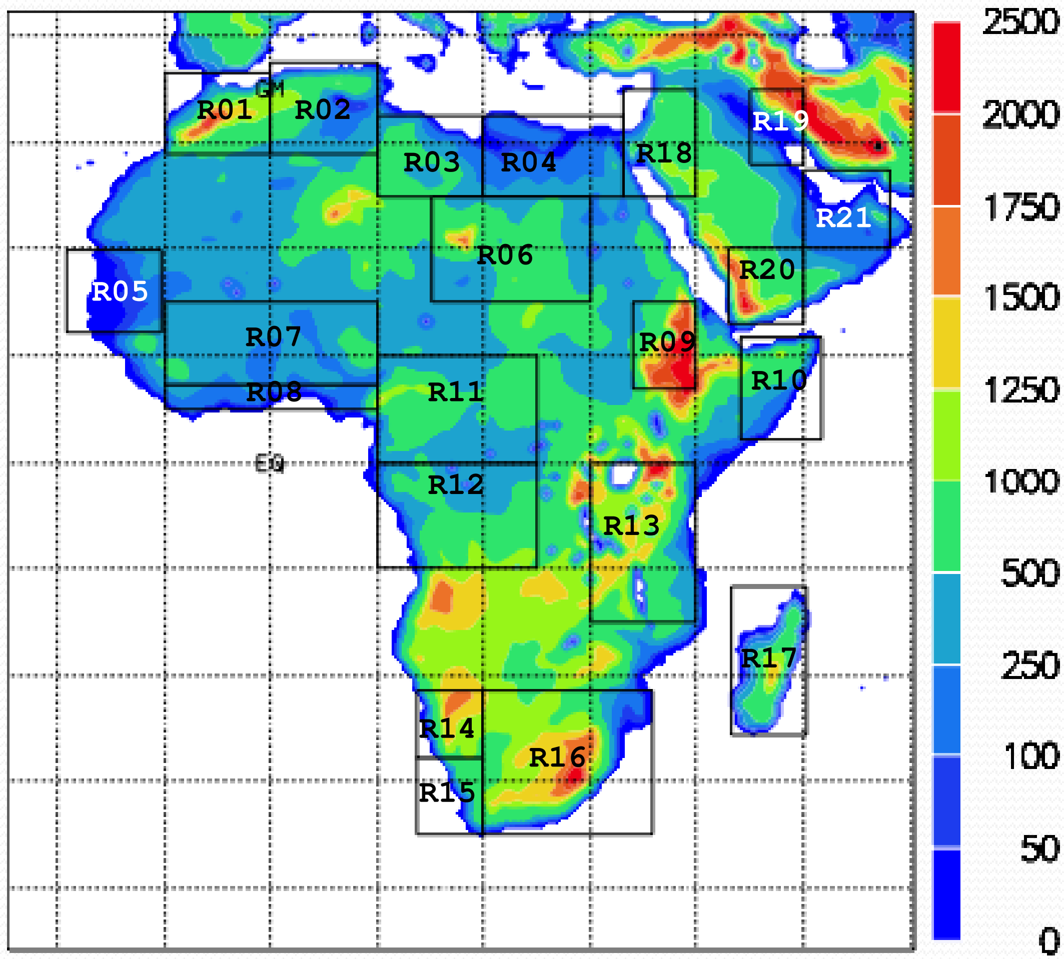
RCMs and variables evaluated in this presentation

Institution/Model	PR	Cloudiness
CNRM/ARPEGE5.1	x	x
DMI/HIRHAM5	x	x
ICTP/RegCM3	x	x
IES/CCLM4.8	x	x
KNMI/RACM02.2b	x	x
MPI/REMO	x	x
SMHI/RCA35	x	x
UCT/PRECIS	x	x
UC/WRF3.1.1	x	
UQA/CRCM5	x	x
ENS	10 RCMs	9 RCMs

Daily mean, max, and min surface air temperatures have been also evaluated , but not included in this presentation.

CORDEX-Africa analysis domain

- Regularly spaced at 0.44 degree resolutions
- All RCM data are interpolated prior to the evaluation onto the domain by SMHI.
  - 21 subregions are introduced to examine RCM skill in varied geography



Observational data and data processing

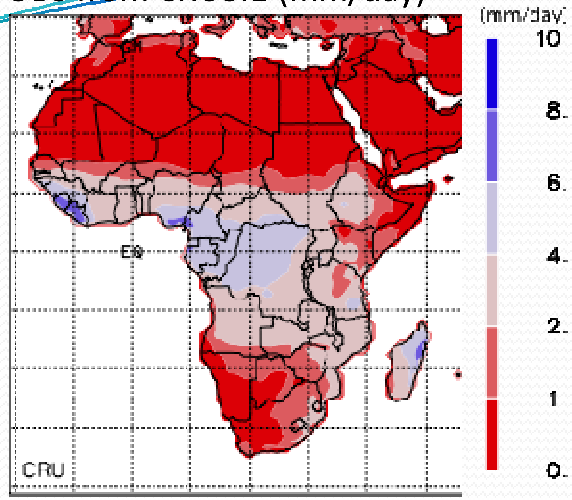
- Baseline evaluations utilize the *CRU* surface station analysis data, *version 3.1*:
  - 1901-(near) present
  - 0.5deg horizontal resolution
  - Global, land-surface only
  - Monthly-mean values only
  - Major source of uncertainties is the density of observational stations
- Spaceborne remote sensing data for sensitivity investigation:
  - TRMM precipitation
  - MODIS cloudiness
- The Regional Climate Model Evaluation System (RCMES) has been utilized to process the observational and model data for evaluation.
  - RCMES combines observational database and analysis toolkit to facilitate the access to and analysis of observational datasets for model evaluation.
  - Details of RCMES has been presented by Paul Ramirez at JPL in the morning session.

[1] Precipitation evaluation
10 RCMs and their ensemble vs. CRU monthly raingaugeanalysis

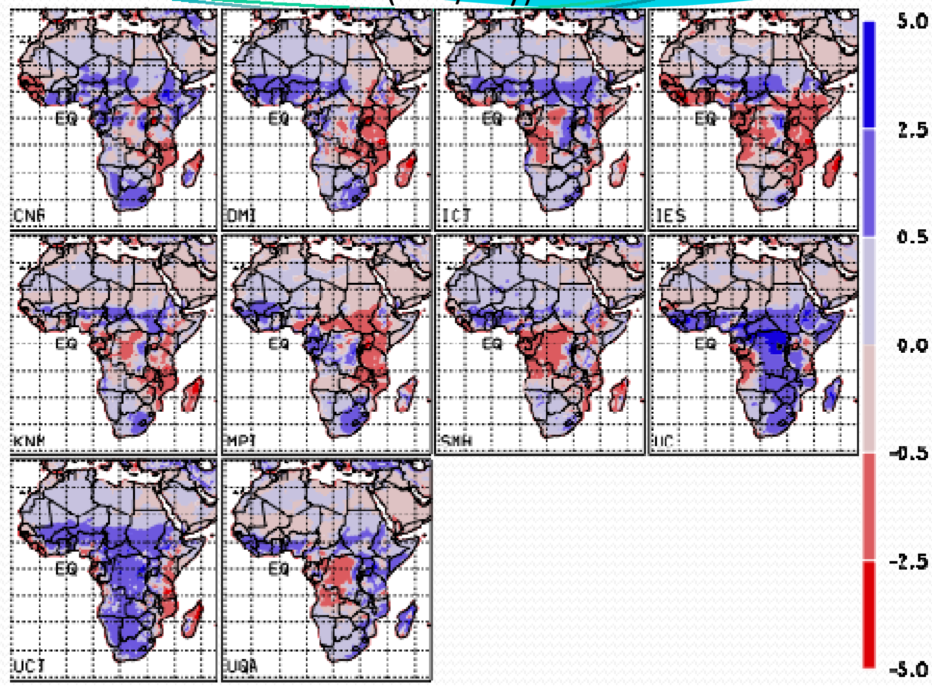
- 18 years: 1990-2007
- Overland only – *Limited by the coverage of the CRU analysis*
- Spatial variability of the annual-mean precipitation
- Annual cycle
- Interannual variability of wet-season precipitation in the western sub-Sahara and Nile headwater basin (Ethiopian Heights).

Annual-mean precipitation for 1990-2007

OBS from CRU3.1 (mm/day)



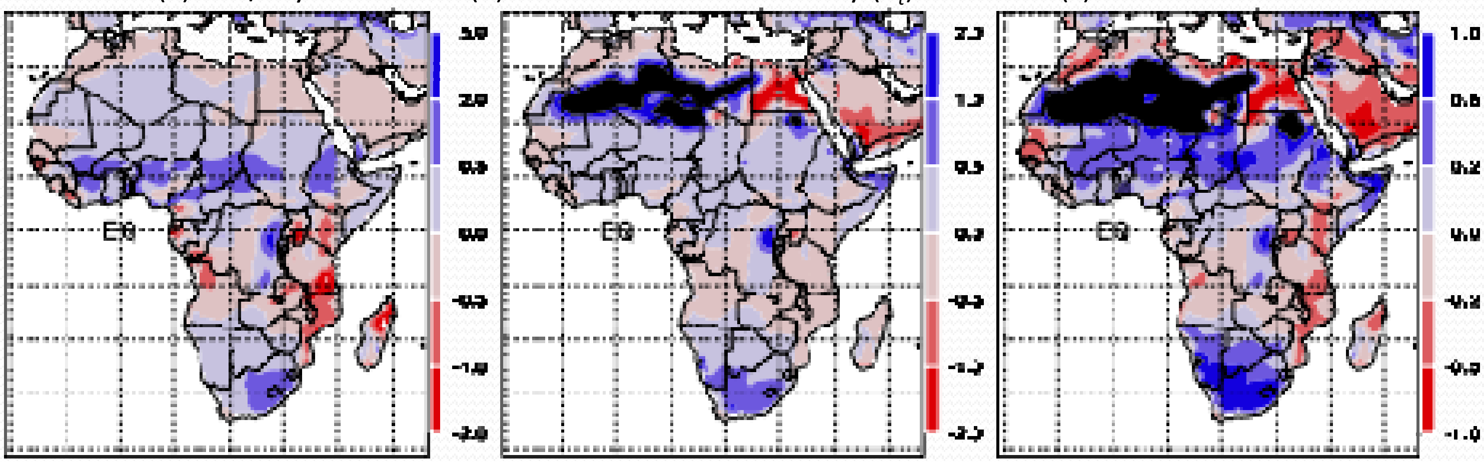
Model bias from CRU3.1 (mm/day)



- All RCMs reasonably simulate the annual-mean precipitation inAfrica
- Model biases vary widely among RCMs.
  - Tropical western Africa, Horn of Africa
- There also exist model biases common to all or a majority of RCMs
  - Wet biases in South Africa, eastern sub-Sahara
  - Dry biases in eastern Africa coastal regions, interior of the Arabia Peninsula

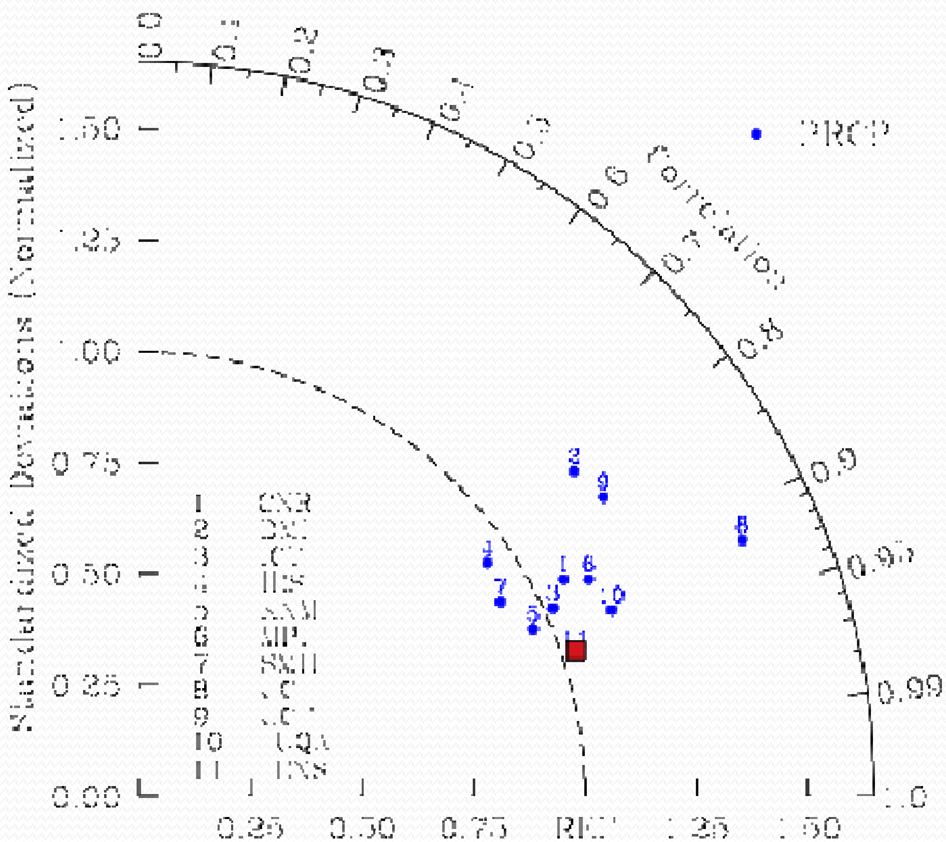
Multi-model ensemble (ENS) precipitation bias

(a) mm/day (b) Frac. interannual variability (σ_t) (c) Frac. annual mean



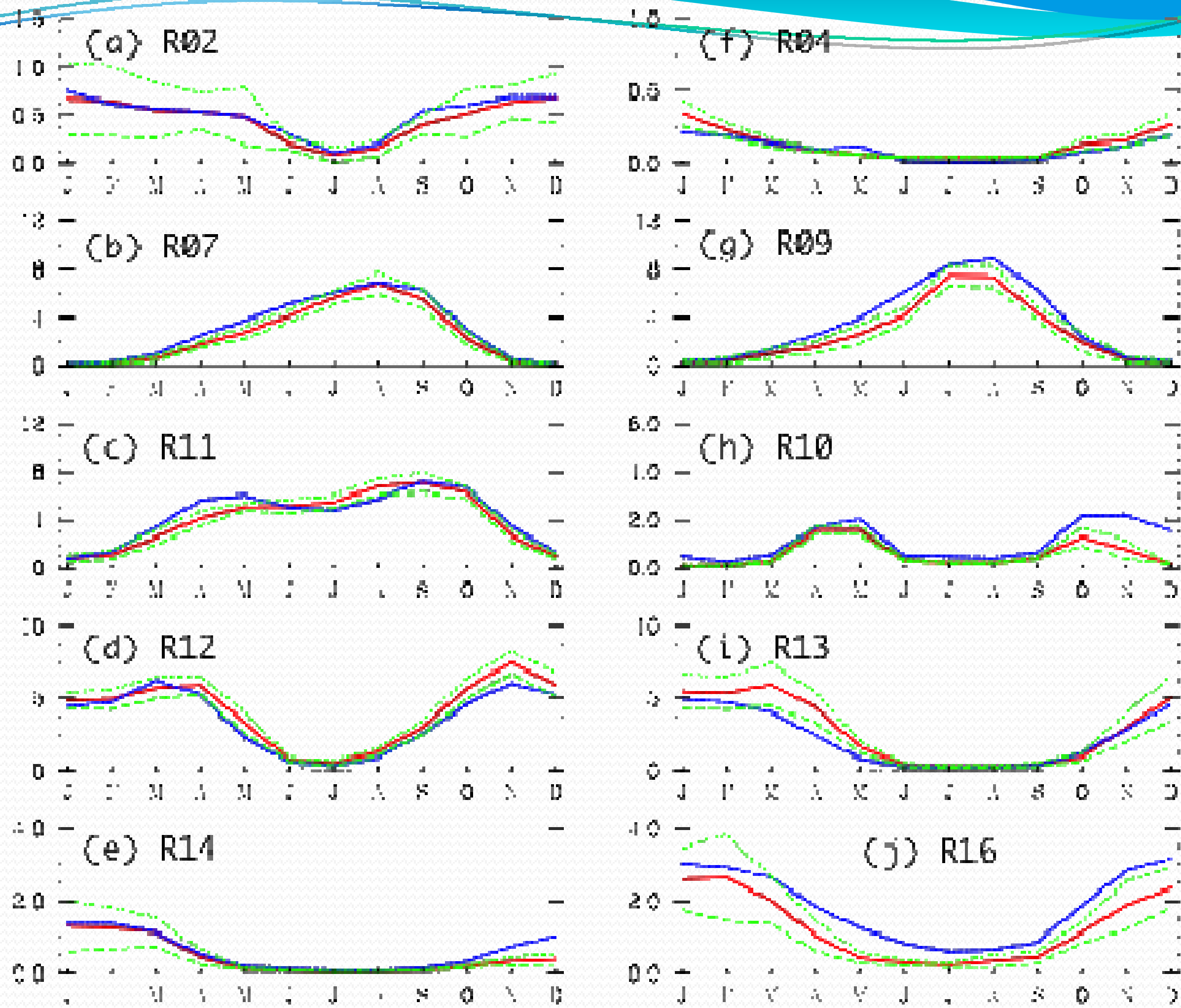
- (a)The ENS bias is characterized by wet/dry biases in the dry/wet regions
- (b) The ENS bias is well within the $\pm 1\sigma_t$ range for most of the region except in the regions W. Sahara, central Egypt, and southeastern Arabia Peninsula.
- (c) With respect to the observed annual mean, the ENS bias is smallest in the tropics (wet) and large in dry regions.
- The ENS bias shows that:
  - The ENS precipitation may not be useful in the dry northern Sahara & Arabia Peninsula regions where the ENS bias is significantly large compared to the interannual variability ($|Bias/\sigma_t|>1$) or the annual mean.

Spatial variation of the annual-mean precipitation



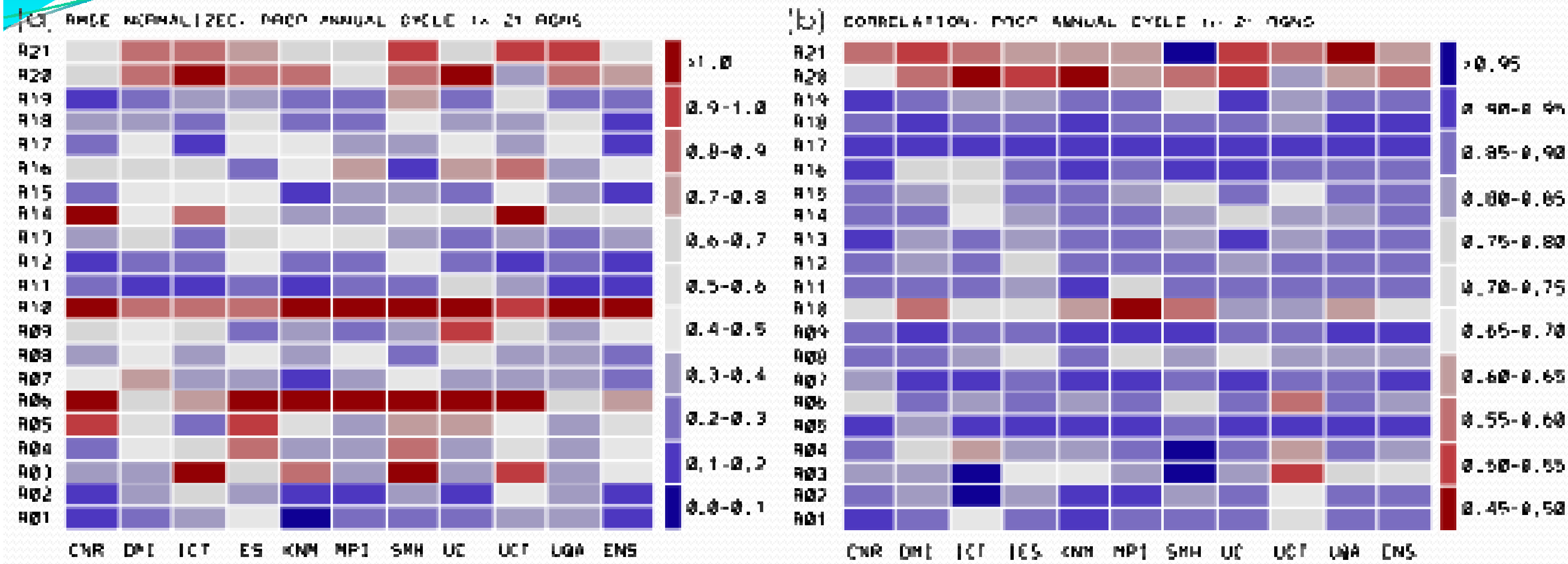
- All RCMs have simulated the observed spatial pattern of the annual-mean precipitation reasonably well.
- The simulated spatial variability varies more widely than the pattern.
- ENS (red square) outperforms individual models within ENS.
  - *Smallest RMSE* (smaller than any model in the ensemble)
  - *Highest spatial pattern correlation*
  - *Spatial variability is smaller than most models, although comparable to the CRU data.*

Precipitation annual cycle simulation skill – Regional variations



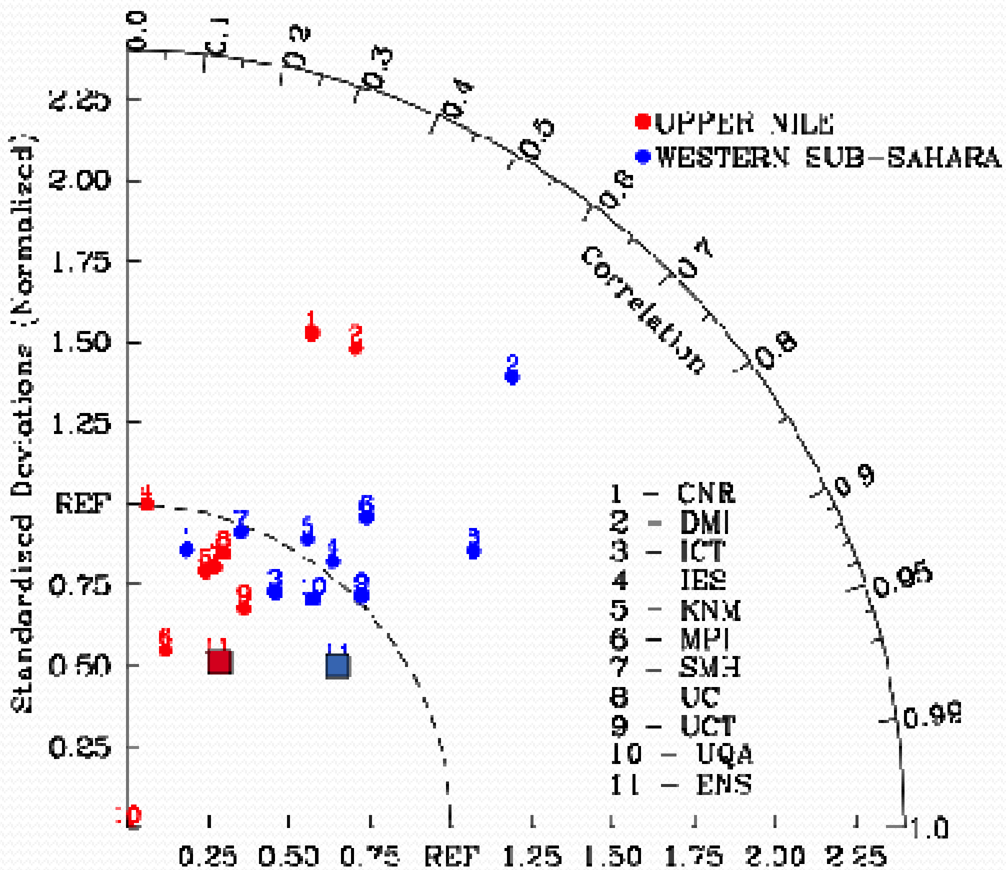
- All RCMs simulate the observedannual cycle reasonably well, at least its phase.
- Models generally perform better for the West Africa region than the East Africa region:
  - ENS is within ±1σ range from the CRU data for the Mediterranean and West Africa regions.
  - ENS is generally out of the ±1σ range for the north-central and East Africa regions.

Precipitation annual cycle simulation skill – Regional variations



- Most models well simulate the phase of the annual cycle (in terms of the correlation coefficient) in most regions, except the eastern Arabia Peninsula (R20, R21) and the Horn of Africa (R10) regions.
- The RMSE in the simulated annual cycle also indicates similar regional variations. In addition to the regions of poor phase simulation, the RMSE is large in the dry regions of western & eastern Sahara (R05, R06) and the central Mediterranean (R04).

Interannual variability of the wet-season precipitation
Western sub-Sahara (R07) vs. Nile River Headwater basin (R09)

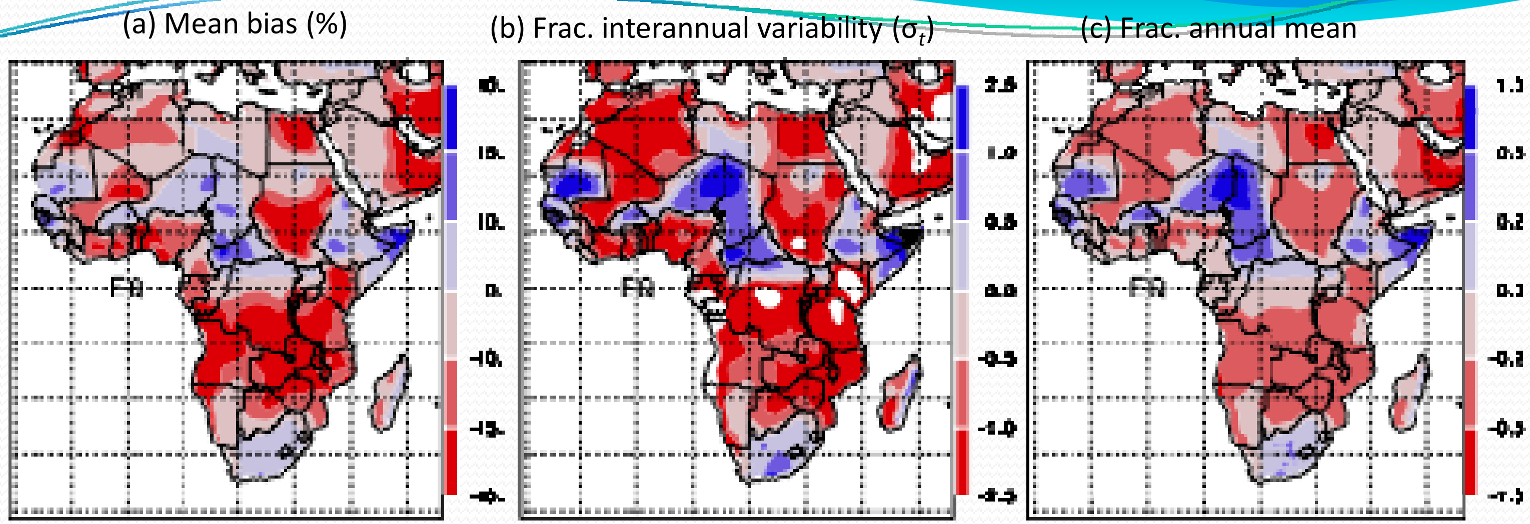


- RCM skill in simulating the interannual variability of the wet-season rainfall is generally higher for the W. sub-Sahara (blue) than the Nile headwater region (red).
- This also suggests that RCMs perform systematically more skillfully for the western Africa regions than the eastern regions as shown in the seasonal cycle simulations.

[2] Cloudiness
Nine RCMs and their ensemble vs. CRU analysis

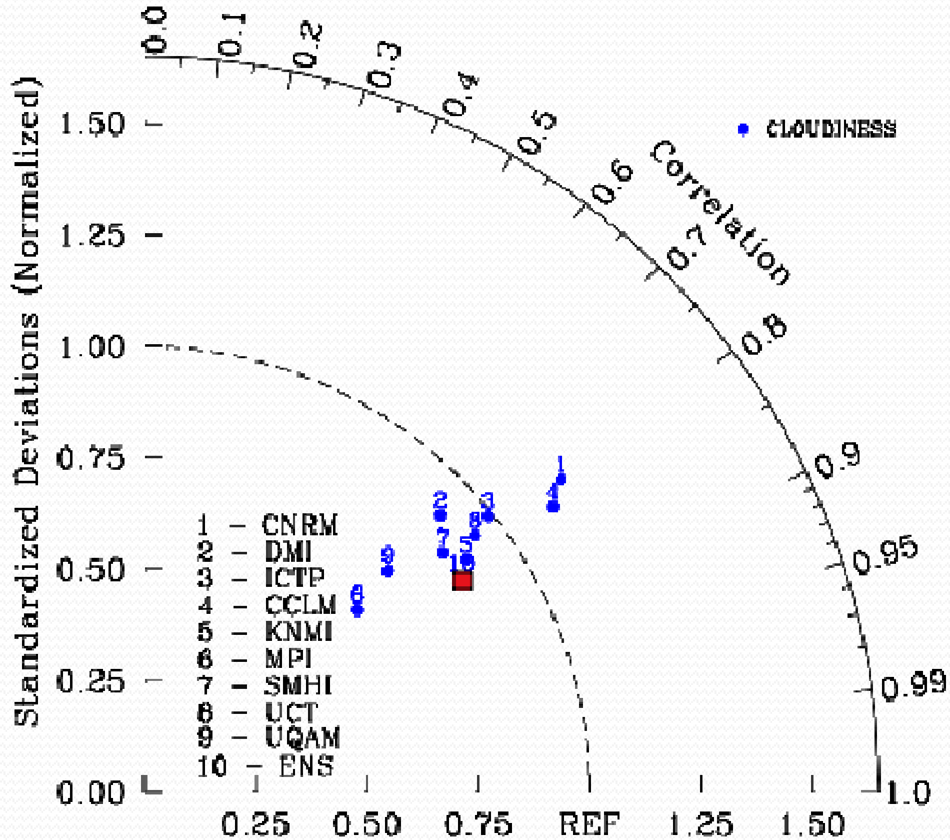
- 18 years: 1990-2007
- CRU monthly mean cloudiness analysis
- Overland only

Multi-model ensemble (ENS) cloudiness bias



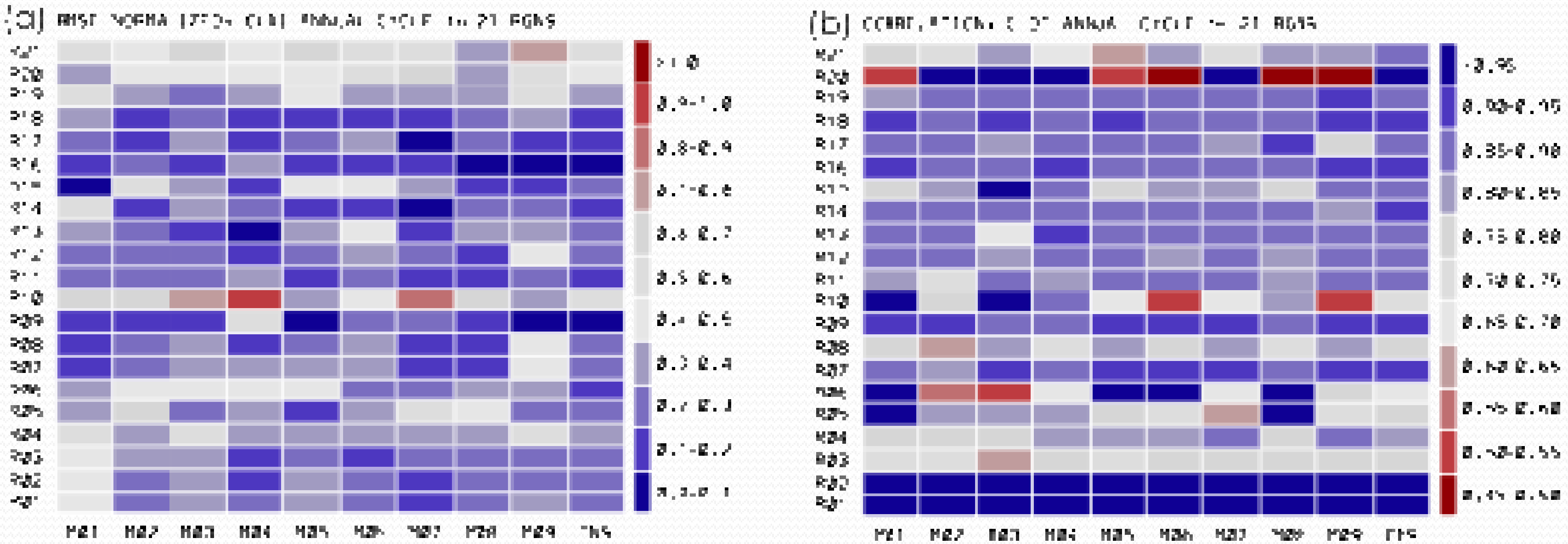
- (a)ENS underestimates the CRU cloudiness over most of the land surface, especially in the Southern Hemisphere subtropics, eastern Arabia Peninsula,northwestern Sahara, southern Sudan, and northern Egypt.
  - Positive bias is most noticeable over the Ethiopia/Horn of Africa region, western Sahara coast, central tropical Africa, and South Africa.
- (b) The ENS bias is outside the $\pm 1\sigma_t$ range in most regions but the South Africa region.
- (c) With respect to the observed annual mean, the ENS bias is smallest in the tropics (wet) and largest in dry subtropics.
- The ENS cloudiness bias resembles that of precipitation. The most notable exceptions are in the western sub-Sahara and southern Sudan region.

Spatial distribution of the annual-mean cloudiness (2001-2008) Baseline evaluation against CRU3.1



- All RCMs show similar skill in simulating the spatial pattern of the annual-mean cloudiness with the spatial correlation coefficient of ~0.8 with the CRU analysis.
- RCM performance in simulating the spatial variability varies widely - the standardized deviation varies from 0.6 to >1.25.
- The model ensemble shows the highest spatial correlation and smallest RMSE.

Cloudiness annual cycle simulation skill – Regional variations

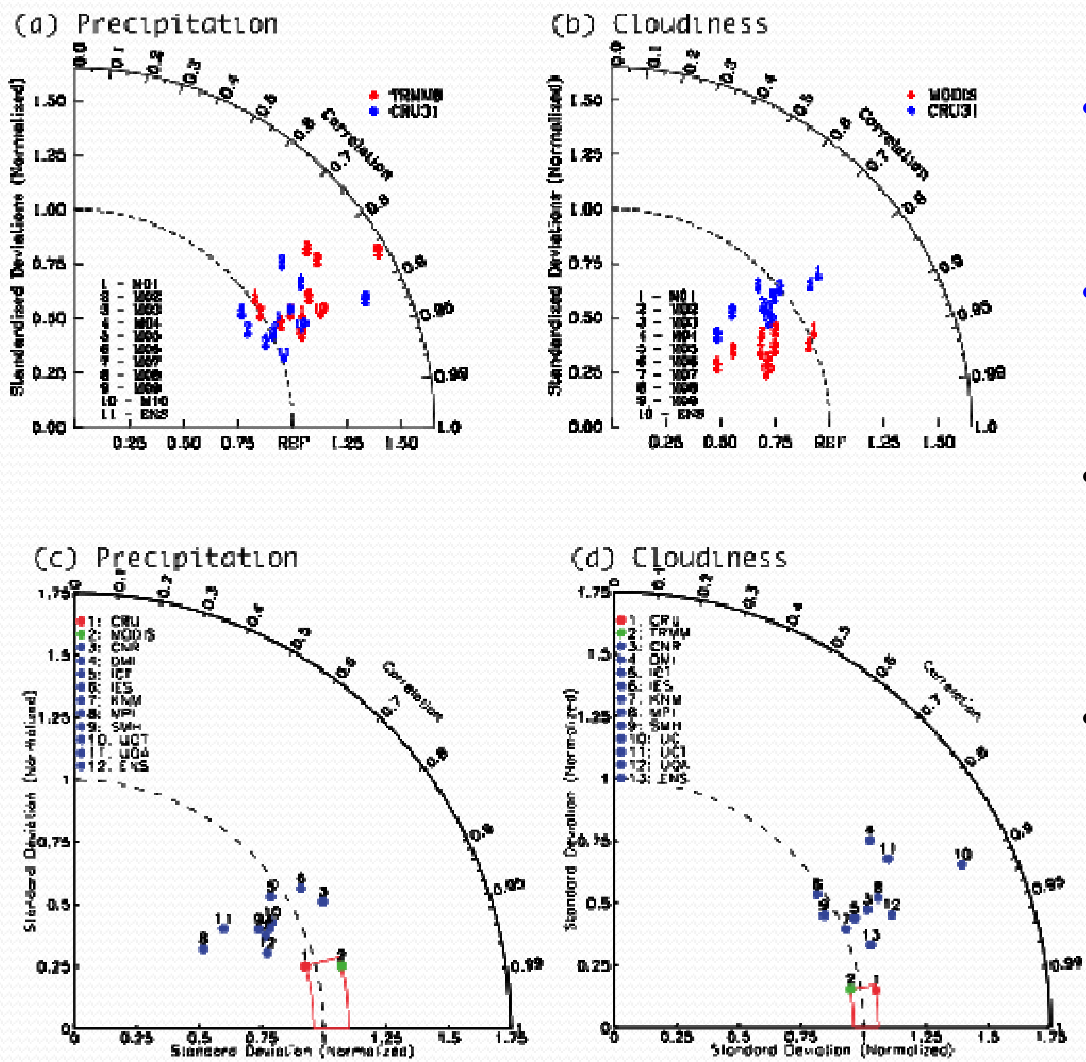


- The *normalized RMSE* and *correlation coefficients* show that RCM skill in simulating the annual cycle is generally lower or highly variable in the eastern Mediterranean (R03, R04), eastern Sahara (R06), Somalia (R10), and eastern Arabia Peninsula (R20, R21) regions.
- The regions of large RMSE tend to coincide with those of smaller correlation coefficients.

[3] Uncertainties related with observational datasets

- Precipitation evaluation against CRU (0.5^ox0.5^o) and TRMM (0.5^ox0.5^o)
- Cloudiness evaluation against CRU (0.5^ox0.5^o) and MODIS (1^ox1^o)

Annual-mean precipitation & cloudiness evaluation vs. 2 REF datasets



- (a) Evaluation of the annual-mean precipitation is not very sensitive to the reference data
- (b) The simulated cloudiness evaluates better against the MODIS than CRU data
- None of the RCMs, even their ENS, is within the range of uncertainties defined by multiple reference datasets (c&d).
- Cross-examination and evaluation of reference data is important for reliable model evaluations.

Summary and Conclusions

- Climate model evaluation is a fundamental step in projecting climate change and assessing their impacts.
- Monthly-mean precipitation 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.
  - Multi-model ensemble generally performs better than individual RCM.
- Differences between REF datasets can be a significant source of uncertainties.
  - REF datasets need to be cross-examined and independently evaluated in order to minimize uncertainties in measuring model performance.
- *There exist model biases common to a majority of RCMs*
  - *These systematic biases vary regionally as well as for different metrics and variables*.
  - *This makes defining a single index to define overall model performance difficult*.
  - *Multi-model ensemble construction based on model performance may be performed separately for individual regions, variables, and seasons*.

Next steps

- RCMES will be further developed with new datasets, metrics, and visualization.
- We plan to closely collaborate with the CORDEX community in future RCMES developments.
  - Metrics calculations and visualization to support multiple CORDEX domains, most immediately *South Asia*, *East Asia* and *Arctic*, in addition to ***Africa***&***North America***.
  - Data collection will focus on obtaining fine-resolution reference datasets suitable for RCM evaluations, *with special emphasis on the spaceborne remote sensors*.
  - Develop data processing to support the application of regional climate projection data to impact assessments for various regions and sectors – inputs from regional assessment community are crucial for the success in this activity.
- CORDEX-South Asia application.
  - Processing of several sample data files has been successful.
  - RCMES version 1.0 Virtual Machine has been successfully tested by CCCR/IITM
    - *A prototype RCMES version 2.0 has been delivered to CCCR/IITM*.
  - Use of formalism in variable names and file-naming convention will facilitate handling multiple model data files as has been done for the CORDEX-Africa data.
  - Identifying *local stakeholders* and *issues* will allow us to develop specific metrics and visualization suite to support specific local uses – *this is among the most crucial part of climate modeling projects*.