Enabling Regional Climate Model Evaluation: A Critical Use of Observations for Establishing Core NCA Capabilities

RCMES.JPL.NASA.GOV

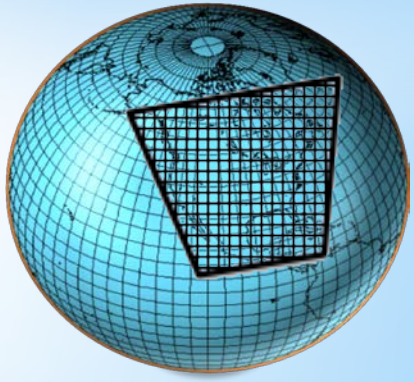
Duane Waliser

Jet Propulsion Laboratory/Caltech

Chris Mattmann, Paul Loikith, Huikyo Lee, **Brian Wilson,** etc, JPL

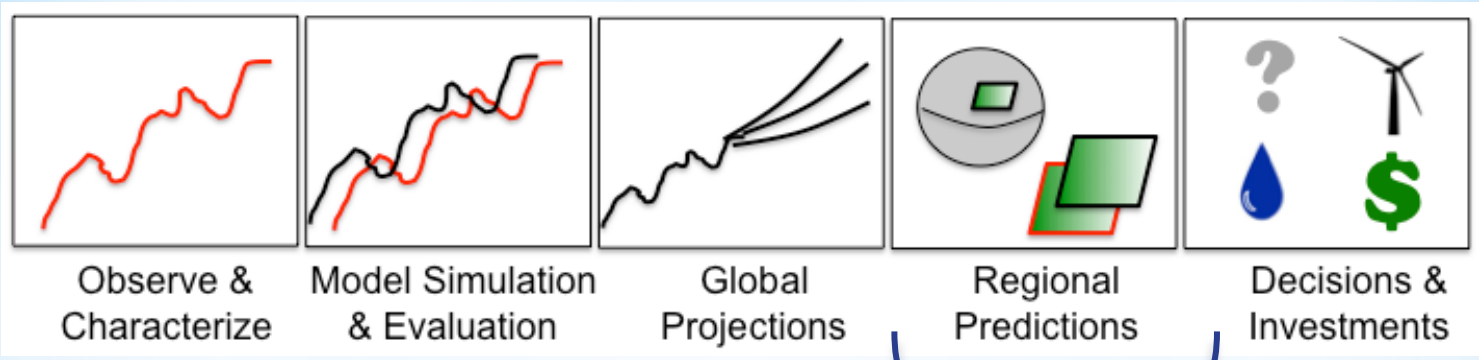
Jinwon Kim, UCLA

& many others, including a number of CORDEX domain working groups



June 2015 Program Review

RCMES Motivation & Goals



From Whitehall et al. 2012, WMO Bull.

GOALS

- Make observation datasets, with emphasis on satellite data, more accessible to the RCM community.
- Make the evaluation process for regional climate models simpler, quicker and physically more comprehensive.
- Provide researchers more time to spend on analysing results and less time coding and worrying about file formats, data transfers, etc.

BENEFITS

- Quantify model strengths/weaknesses for development/improvement efforts
- Improved understanding of uncertainties in predictions

This activity includes three objectives:

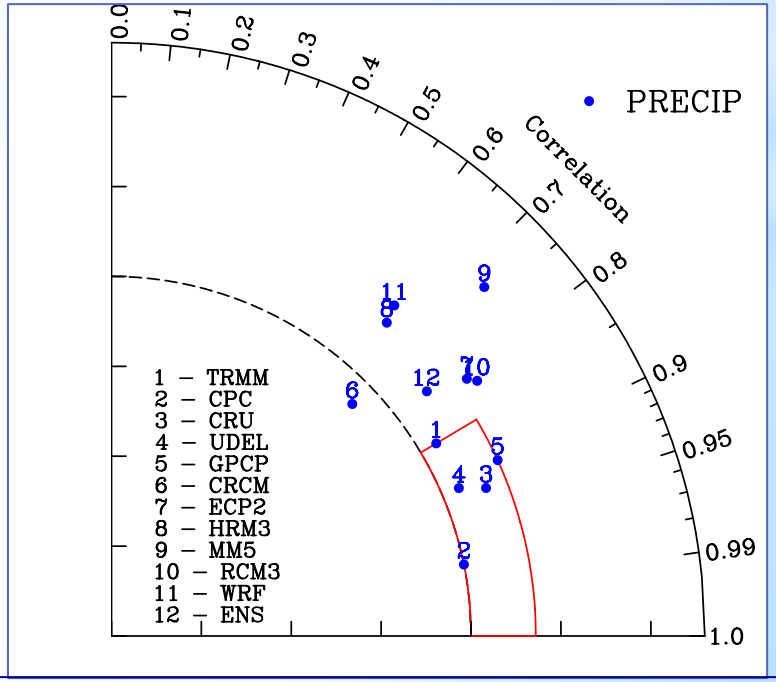
I) Tailoring RCMES for application to the NCA with NASA contribution in mind (e.g. data sets, metrics, visualization)

II) Systematic application of observations to evaluate NARCCAP RCM and CMIP GCM simulations over the U.S./North America.

III) Overall incorporation of model evaluation/assessment results and RCMES infrastructure into the near- and long-term NCA process.

GOAL

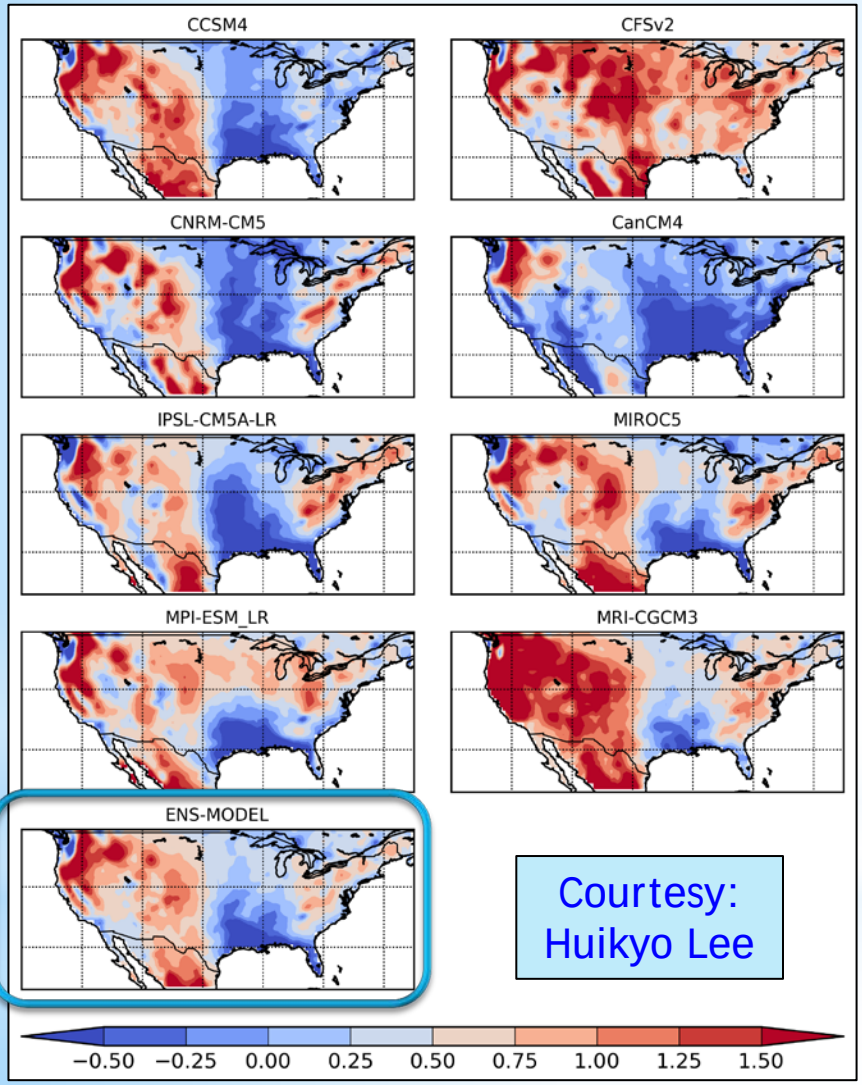
Observation-based model performance metrics for modeling regional climate.



Evaluation of the NARCCAP hindcast precipitation and the uncertainty in precipitation observations for the US region (*Kim et al., 2013, J. Climate.*)

Direct Access to ESGF Now Available: Models & Observations

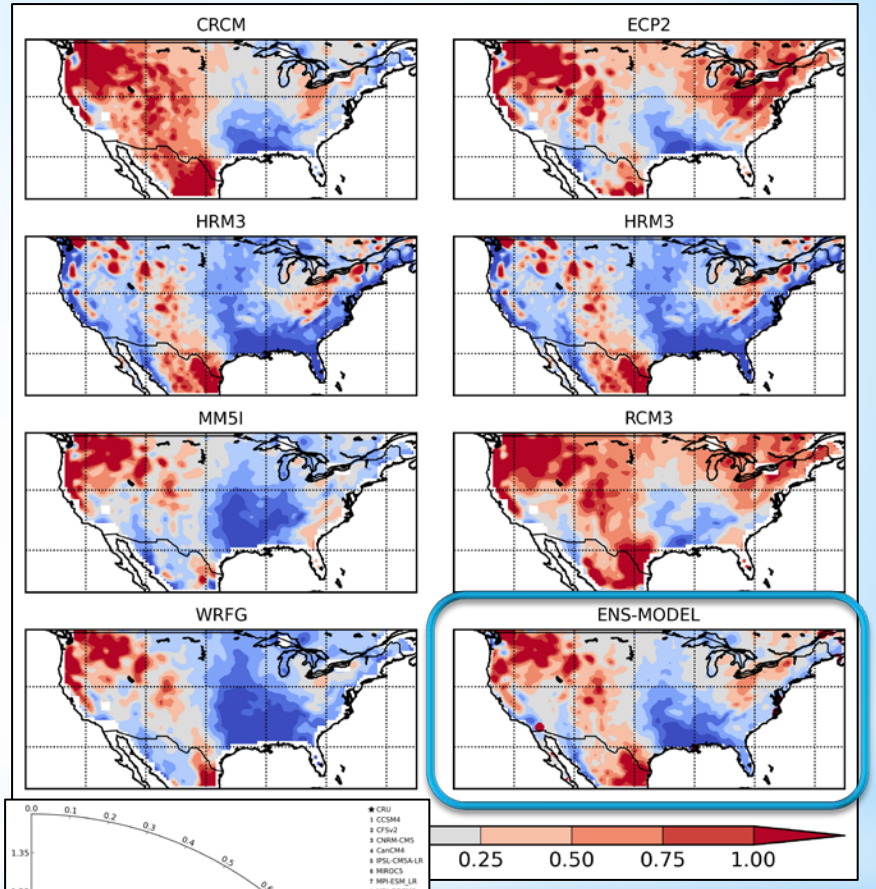
CMIP5 GCMs - observation

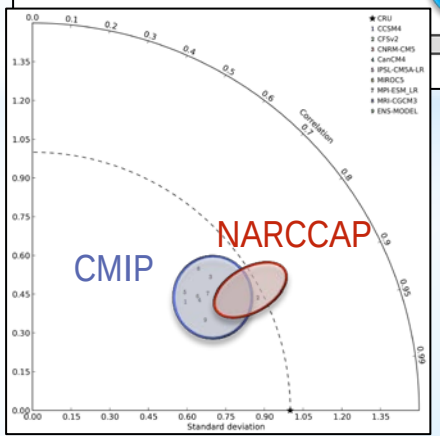


Courtesy: Huikyo Lee

Annual Precipitation Bias

NARCCAP RCMs - observation

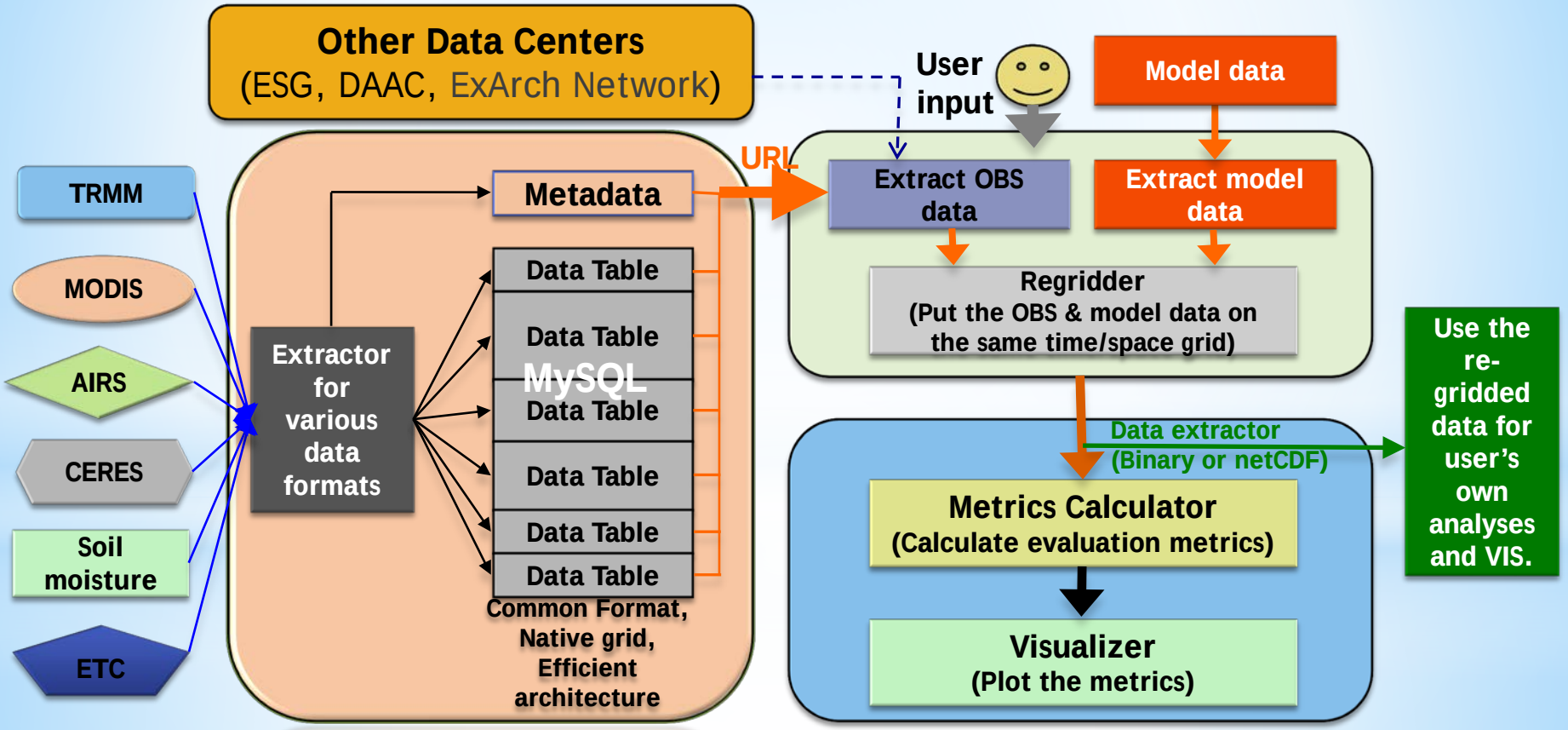




Capability to Perform Regional Evaluation of GCMs

RCMES Motivation & Goals

RCMES – High-Level Architecture – *powered by Apache Climate*



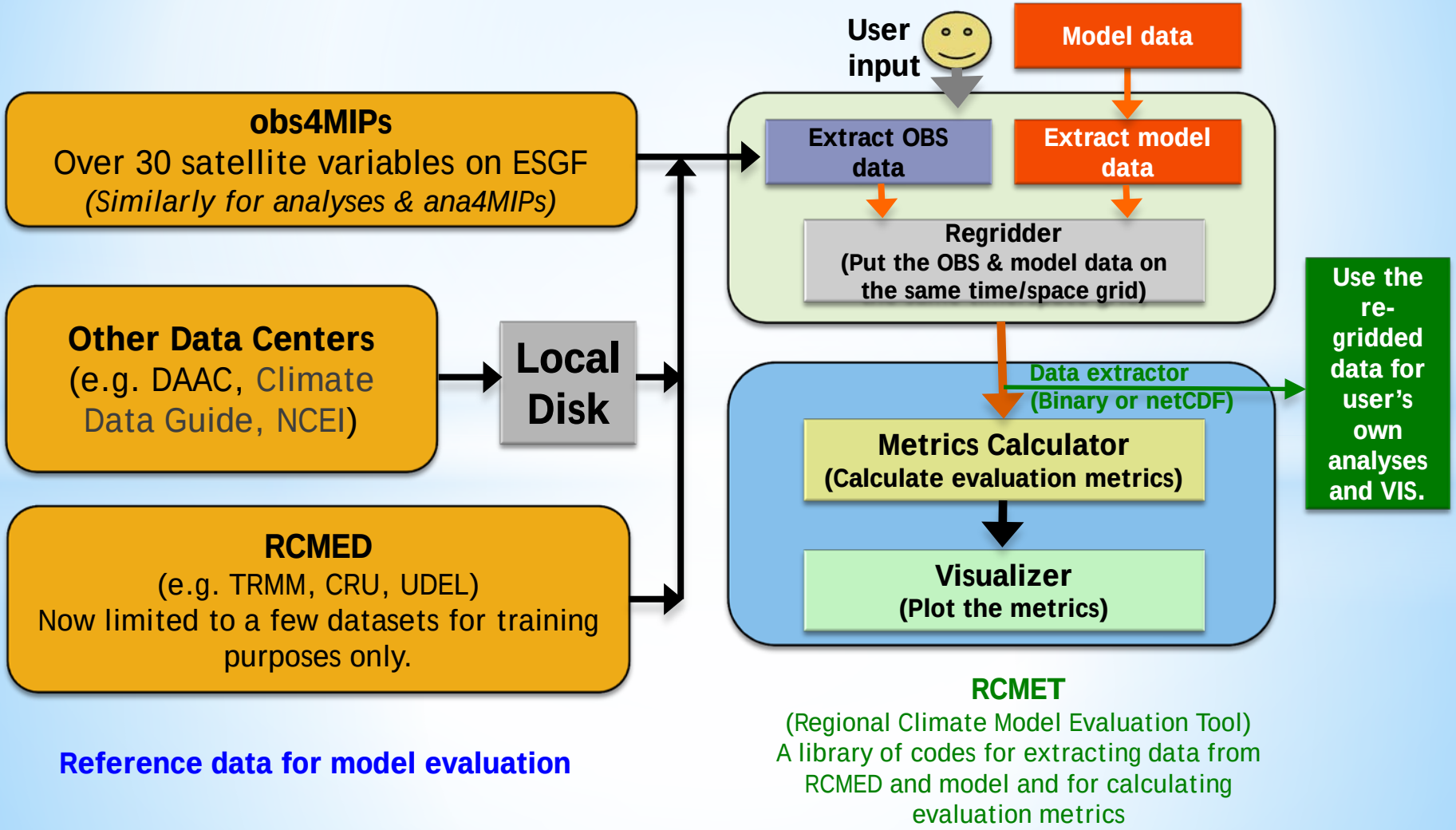
Raw Data:
Various sources, formats, Resolutions, Coverage

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

Changing RCMES Database Approach

RCMES – High-Level Architecture – *powered by Apache Climate*



Reference data for model evaluation

RCMET

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

Education and Training (1)

Student involvement

Jinny Lee – Summer intern; M.S. Student at Cal State Los Angeles in Geology/Hydrology; Web documentation and plans to use RMCES for her M.S. thesis.

Kim Whitehall – Howard University/Prof. G. Jenkins Advisor (**PhD completed; hired at JPL in Data Science**) JPL Intern summer 2012 + 2013; Incorporating RCMES and adding capability for her PhD studies..

Jesslyn Whittell – Previous Marymount HS student and now a undergrad student at UC Berkeley Intern at JPL in summer 2012 + 2013 and worked on RCMES development with the IT staff.

Alexander Goodman – Previous UIUC undergrad, Now a graduate student at CSU, Atmos. Science. Intern at JPL in summer 2013 and improved visualization software.

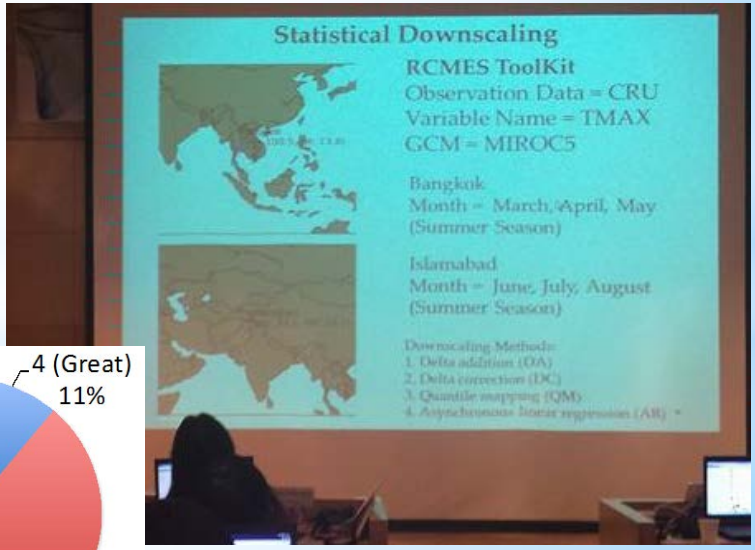
Danielle Groenen – Graduate student at Florida State University, Meteorology W/ V. Misra. Intern at JPL in summer 2014, will work on climate model evalution in N. and C. America.

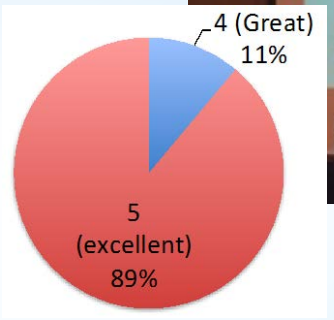
Melanie Cooke – Graduate student at U. Toronto w/ P. Kushner Short term visit to JPL to learn RCMES for research on RCM of Arctic

Training Sessions or Webinars

- CORDEX-Related
  2012-3 Africa, S. Asia, E. Asia
  2014: L. America, RCM Workshop (Sweden)
  2014: MENA Workshop (Cyprus)

- Asia-Pacific Economic Cooperation Climate Center's (APCC) Training Program
  - Busan, S. Korea, August 25-29 2014.
  - Statistical downscaling using RCMES
  - 27 trainees from South Asia, South America and Africa. 24 of them thought that the RCMES tutorial was excellent.

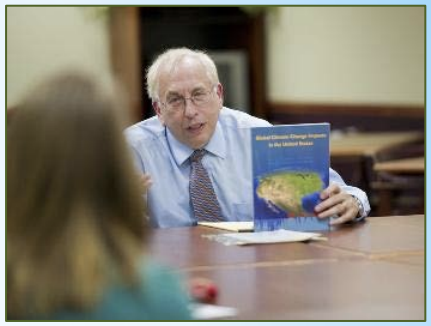




Education and Training (2)

Classroom Instruction

- In 2014 and 2015 spring semesters, Climate Dynamics course at University of Illinois (Prof. Donald Wuebbles) provides RCMES for graduate students who learn about uncertainties in climate models and model evaluation metrics.
  - 2014: 11 students, 2015: 8 students
- RCMES is currently installed on a Linux-based cluster system of the atmospheric sciences department. Using RCMES, even students with no programming background can evaluate GCMs or RCMs over a region of their interests. Incorporated into spring semester homework assignment.



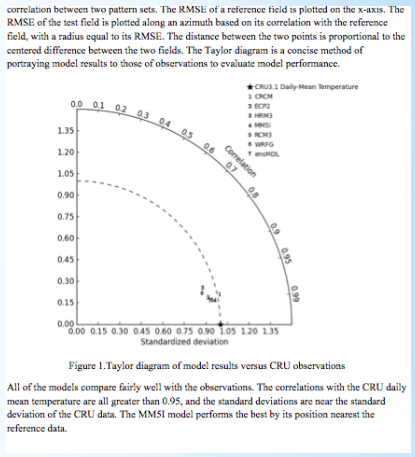

correlation between two pattern sets. The RMSE of a reference field is plotted on the x-axis. The RMSE of the test field is plotted along an azimuth based on its correlation with the reference field, with a radius equal to its RMSE. The distance between the two points is proportional to the centered difference between the two fields. The Taylor diagram is a concise method of portraying model results to those of observations to evaluate model performance.

Figure 1.Taylor diagram of model results versus CRU observations

All of the models compare fairly well with the observations. The correlations with the CRU daily mean temperature are all greater than 0.95, and the standard deviations are near the standard deviation of the CRU data. The MM5I model performs the best by its position nearest the reference data.

captured student's homework

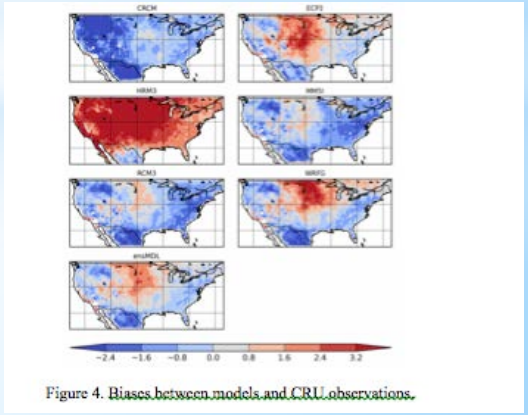
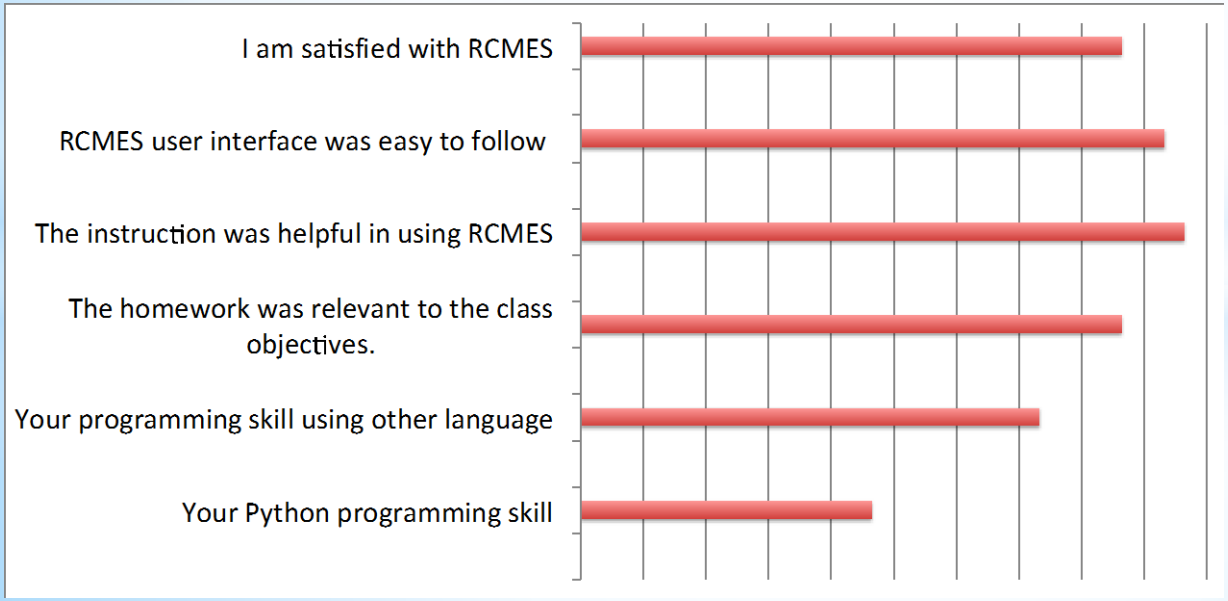


Figure 4. Biases between models and CRU observations.

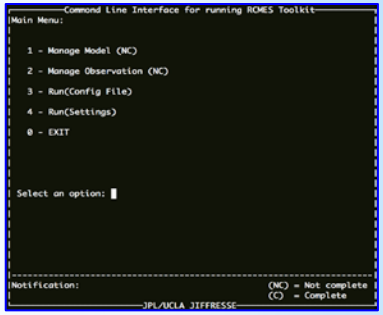


very poor ←----------→ excellent

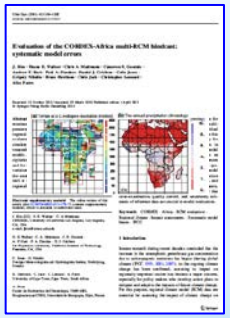
Developing 3 Ways to Learn/Use RCMES

Based on feedback from users/trainings

- **Level 1**: Command line interface (Initial Education/Training)
  - Intuitive but purposely **limited** menu-driven interactive tool.
  - Designed for introduction to RCMES.
  - Performs simple evaluation examples.
  - Outputs configuration file for illustration/further flexibility.

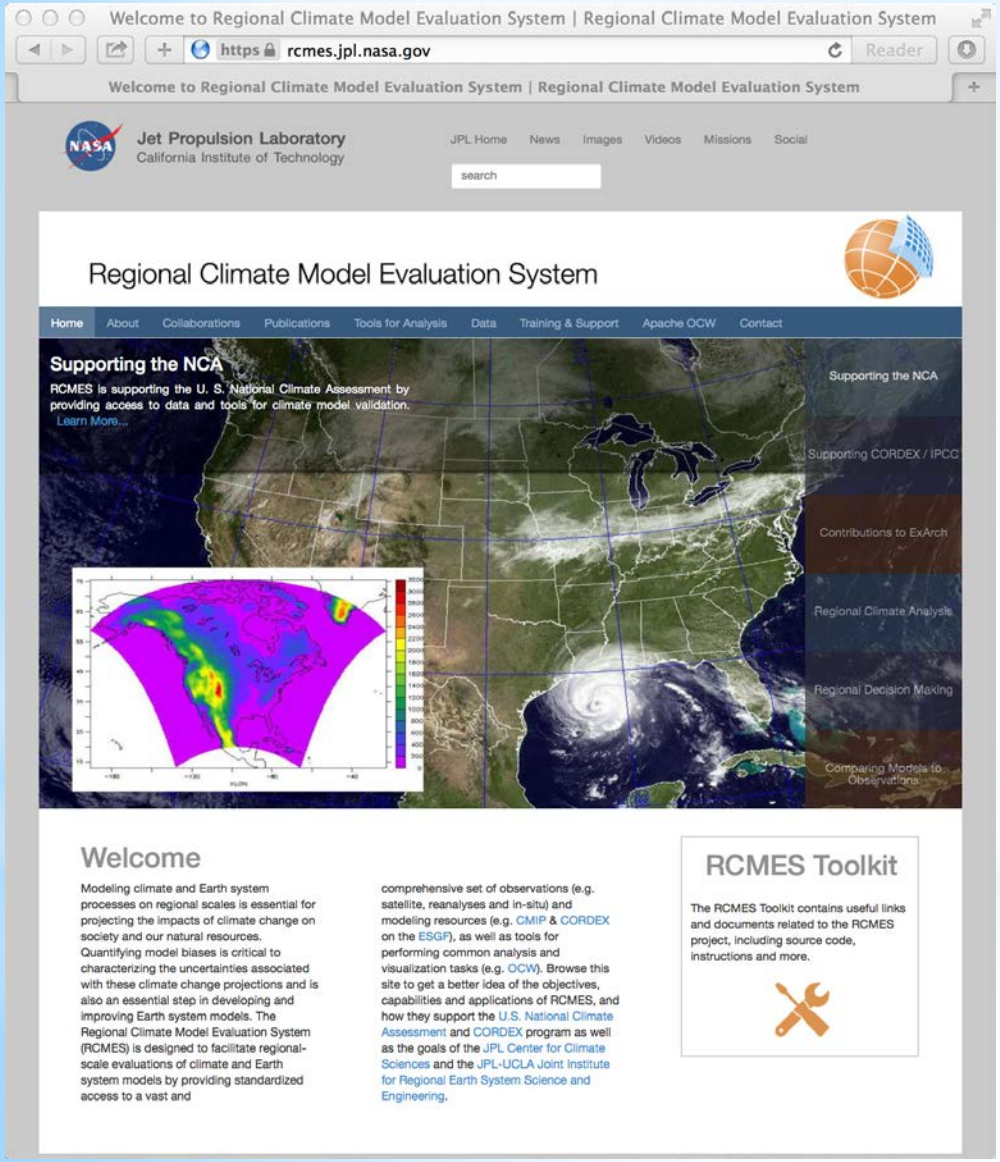


- **Level 2**: Configuration file (Intermediate Education/Training)
  - User provides input to a configuration file template.
  - Execution of configuration file performs evaluation.
  - Allows for more customization than RCMES CLI.
  - Examples for Kim et al. 2013 CORDEX-Afr & 2013 NARCCAP papers.
  - Rerun and illustrate on other CORDEX & N.A. domains



- **Level 3**: Python scripting using Apache OCW library (Advanced Education/Training)
  - Requires installation of Python libraries on user's machine.
  - Requires use of Python and the Open Climate Workbench (OCW) open source library.
  - Most customizable way to use RCMES, allows users to contribute to OCW development.

New RCMES Website (fall'14) & Documentation Development (sum'15)



New Structure & Development Interface

Key Requirement

Readily editable by team members

Summer'15 Objective

Summer intern to develop better documentation for training purposes – particularly the 3 interfaces; and the Kim et al. NCA and CORDEX paper examples, and change in database framework.

Summer intern – Jinny Lee, M.S.

Student at Cal State Los Angeles in Geology/Hydrology; Plans to use RMCES for her M.S. thesis work.

Publications

NARCCAP/NCA

Kim, J., D.E. Waliser, C.A. Mattmann, L.O. Mearns, et al., 2013: Evaluation of the surface climatology over the conterminous United States in the NARCCAP hindcast experiment using RCMES. *J. Climate*, **26**, 5698-5715.

Loikith, P.C., B.R. Lintner, Jinwon Kim, H. Lee, et al., 2013: Classifying reanalysis surface temperature probability density functions (pdfs) over North America with cluster analysis. *Geophys. Res. Lett.*, 40, 3710-3714, doi: 10.1002/grl.50688.

*Lee, H., J. Kim, D. Waliser, P. Loikith, et al., 2014: Using joint probability distribution functions to evaluate simulations of precipitation, cloud fraction and insolation in the North America Regional Climate Change Assessment Program (NARCCAP), *Clim*. Dyn, DOI 10.1007/s00382-014-2253-y.

*Loikith, P C., D. E. Waliser, H. Lee, J. D. Neelin, B. R. Lintner, S. McGinnis, L. O. Mearns, and J. Kim, 2015: Evaluation of Large-Scale Meteorological Patterns Associated with Temperature Extremes in the NARCCAP Regional Climate Model Simulations, Clim Dyn, DOI 10.1007/s00382-015-2537-x.

*Loikith, P. C., D. E. Waliser, H. Lee, J. Kim, J. D. Neelin, B. R. Lintner, S. McGinnis, C. Mattmann, and L. O. Mearns, 2015: Surface Temperature Probability Distributions in the NARCCAP Hindcast Experiment: Evaluation Methodology, Metrics and Results. J. Climate, 28, 978-997.

*Loikith, P., J. Kim, H. Lee, B. Lintner, C. Mattmann, J.D. Neelin, D. Waliser, L. Mearns, and S. McGinnis, 2013: Evaluation of surface temperature probability distribution functions in the NARCCAP hindcast experiment. *J. Climate*, submitted.

Select Related/CORDEX

Kim, J., D. Waliser, C. Mattmann, C. Goodale, A. Hart, P. Zimdars, D. Crichton et al., 2013: Evaluation of the CORDEX-Africa multi-RCM hindcast: systematic model errors. *Clim Dyn*, DOI 10.1007/s00382-013-1751-7.

*Kim, J., J. Sanjay, C. Mattman, M. Boustani, V.S. Ramarao, R. Krishnan, D.E. Waliser, 2015: Uncertainties in estimating spatial and interannual variations in precipitation climatology in the India–Tibet region from multiple gridded precipitation datasets, *Int. J. Clim.*, DOI: 10.1002/joc.4306.

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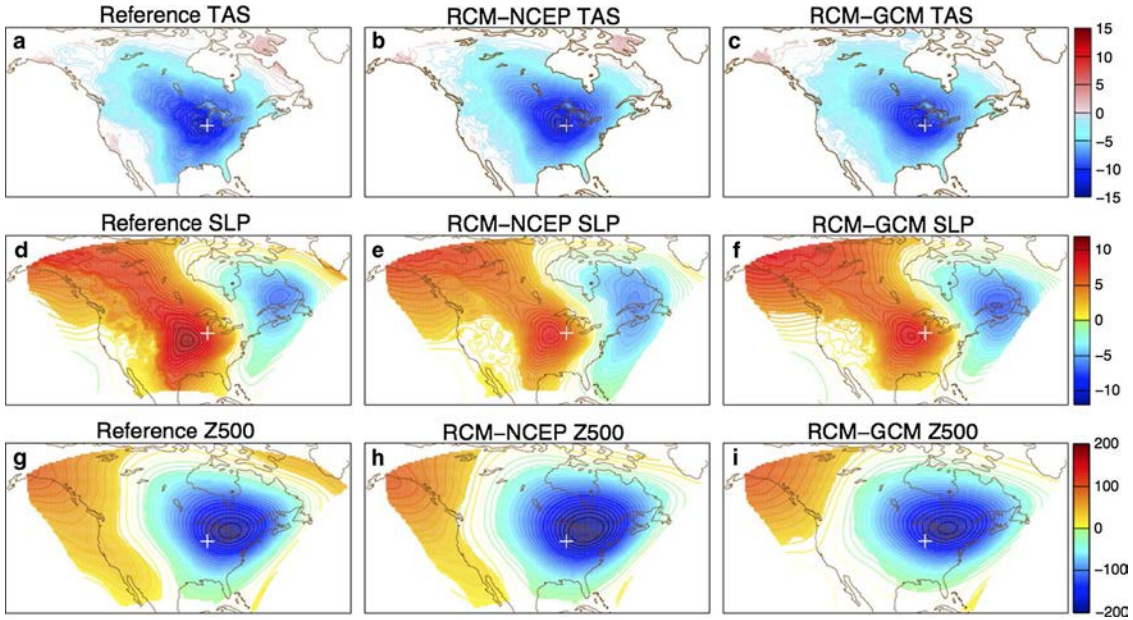
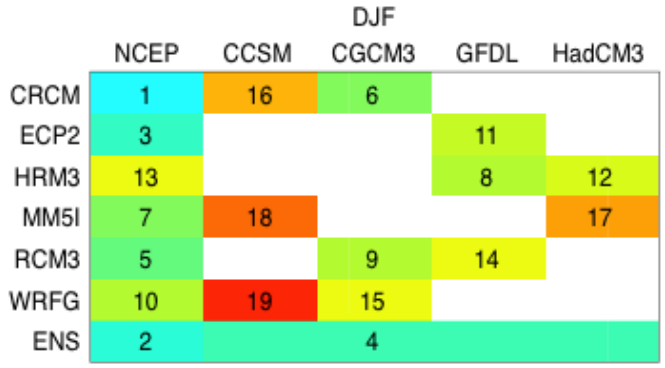
Evaluation of Large-Scale Meteorological Patterns Associated with Temperature Extremes in the NARCCAP Regional Climate Model Simulations

Paul C. Loikith



Model Performance Metric



Problem: Temperature extremes are associated with severe societal impacts and are expected to be affected by climate change. To have confidence in future predictions the skill of climate models to reproduce observed extremes must be measured.

Results: NARCCAP RCM/GCM climate models simulate the observed features relatively well for plausible physical reasons, although in some cases, especially summer, skill is lower and extremes occur for unrealistic reasons.

Loikith, P. C., D. Waliser, H. Lee, J. D. Neelin, B. R. Lintner, S. McGinnis, L. O. Mearns, and J. Kim, 2015: Evaluation of Large-Scale Meteorological Patterns Associated with Temperature Extremes in the NARCCAP Regional Climate Model Simulations. *Clim. Dyn.* , DOI 10.1007/s00382-015-2537-x. Funded by: NASA National Climate Assessment 11-NCA11-0028.

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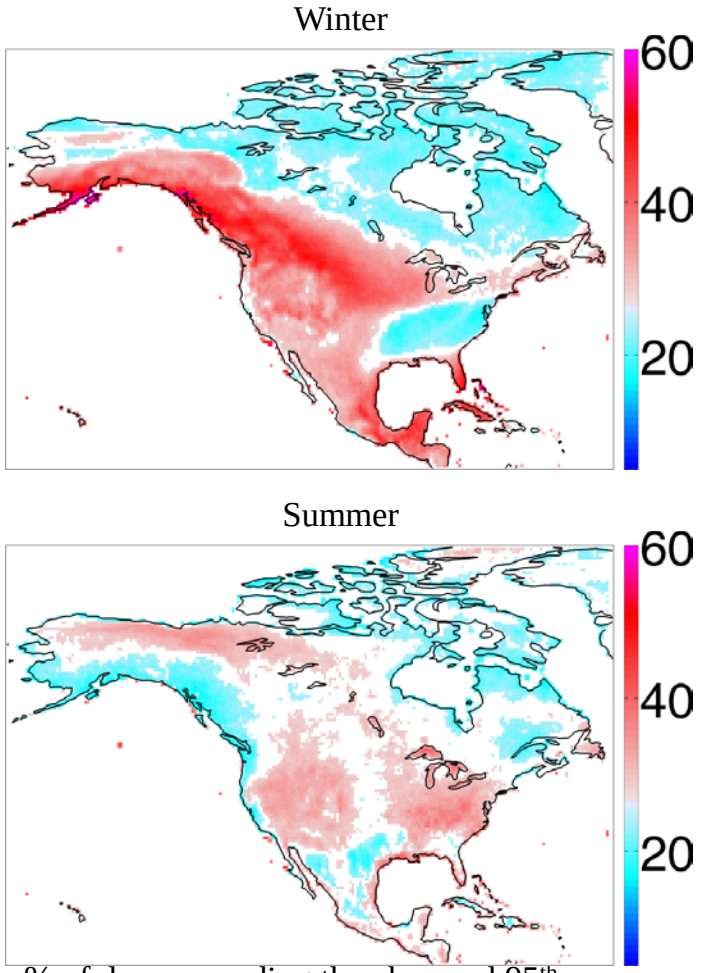
Short-tailed Temperature Distributions over North America and Implications for Future Changes in Extremes

Paul C. Loikith



% of days exceeding the observed 95th percentile of the temperature distribution after a uniform 1 standard deviation warm shift.

Problem: Locations where the temperature distribution has a short warm side tail would experience a greater increase in extreme warm days than a location without a short tail if there were a uniform mean warming across the distribution.

Results: Short warm tails are common in both winter and summer over North America. Some places would see a temperature that is exceeded 5% of the time today as much as 60% of the time due to few degrees of mean warming.

Significance: Places with short warm tails may be more susceptible to increases in extreme warm temperatures in future decades than places with longer tails. These features must be represented in climate model simulations.

Loikith, P. C., and J. D. Neelin, Short-tailed Temperature Distributions over North America and Implications for Future Changes in Extremes, *submitted to GRL*. Funded by: NASA National Climate Assessment 11-NCA11-0028.

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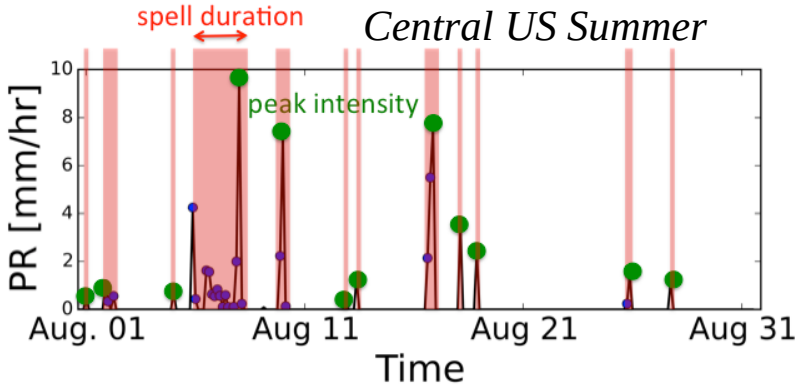
Jet Propulsion Laboratory
California Institute of Technology

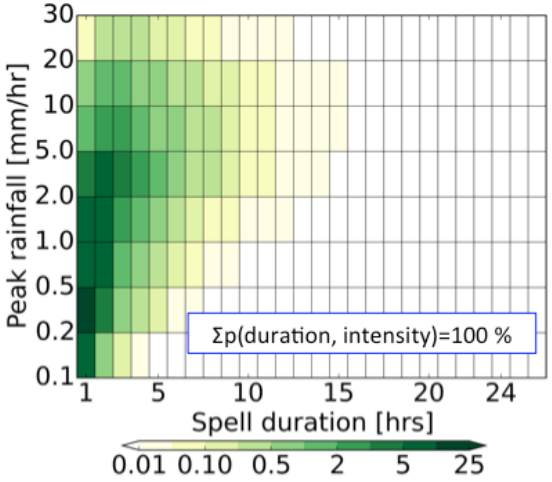
Precipitation Duration/Intensity Distributions

Reference : Stage IV 4km Gridded Observations

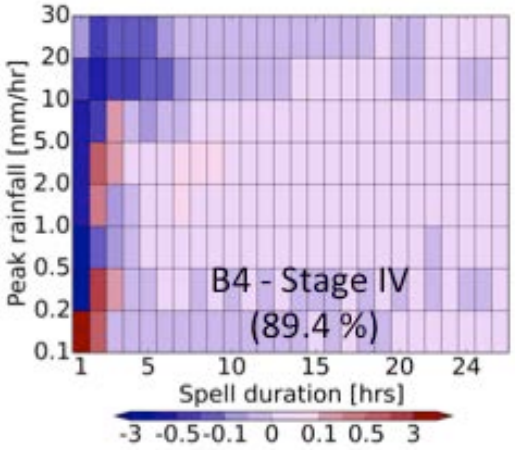


- From a model development as well as climate impacts assessment, the precipitation is important to represent correctly.
- Metrics are needed that limit data transfer or re-gridding needs.

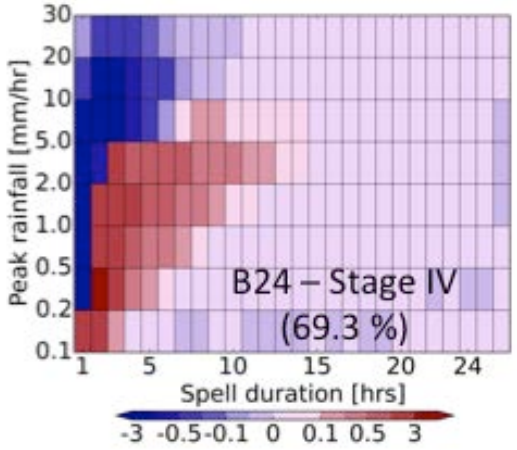
Observations



4km nuWRF



24km nuWRF



- Higher resolution important for realistic precipitation extreme distributions
- Useful information can be obtained from native resolutions

Lee, Waliser, Braverman, 2015: In Prep

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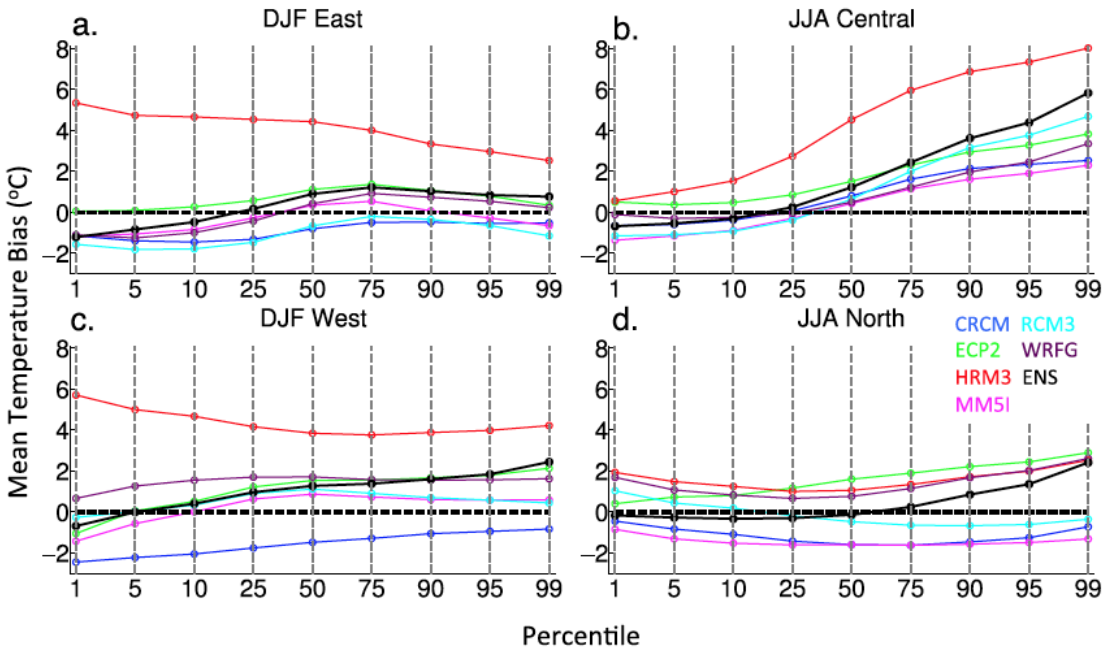
Surface Temperature Probability Distributions in the NARCCAP Hindcast Experiment: Evaluation Methodology, Metrics, and Results

Paul C. Loikith



Difference between model and observed temperature at t percentiles of the frequency distribution averaged over (left) eastern and western North America for winter and (right) over central and northern North America for summer.

Problem: Changes in temperature due to global warming will impact society. Climate models must be able to simulate the observed temperature distribution in order to be trusted to make realistic future predictions.

Results: The climate models evaluated (from the North American Regional Climate Change Assessment Program) were often warmer or colder than observations at all percentiles. Higher moments were mostly simulated well in winter and less so in summer.

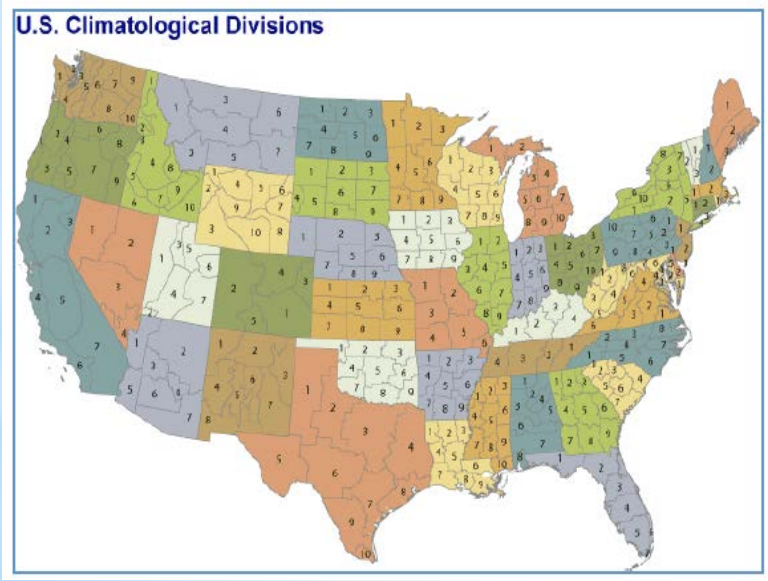
Significance: When the temperature distribution is simulated well, confidence in future projection of temperature is stronger. When the temperature distribution is simulated poorly, models may not be suited for future projections of temperature and temperature extremes. These provide targets for further analysis and model development.

Loikith, P. C., D. E. Waliser, H. Lee, J. Kim, J. D. Neelin, B. Lintner, S. McGinnis, C. Mattmann, and L. O. Mearns, 2015: Surface Temperature Probability Distributions in the NARCCCAP Hindcast Experiment: Evaluation Methodology, Metrics, and Results. *J. Climate*, **28**, 978-997. Funded by: NASA National Climate Assessment 11-NCA11-0028, AIST AIST-QRS-12-0002 and, the NSF ExArch 1125798.

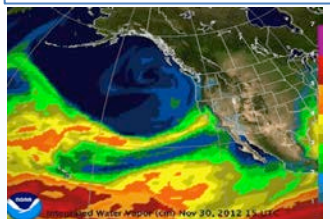
Targeting 2018 / 4th NCA Report

K. Kunkel (NCEI/NOAA) – provided critical analysis/input based on observations to the 2014/3rd report and is interested in providing more analysis/critique of model projection information. We expect this to be the case for 4th report.

We are incorporating their favored "nClimDiv" GHCN-based 5km (temp, prec) dataset into RCMES and are working with them to develop model-based evaluation metrics using RCMES' ESGF interface to CMIP5 and NARCCAP models.



To promote NASA datasets and capabilities into his/this process, we will also leverage metrics developed for extreme weather (i.e. Atmospheric Rivers, NE Storms and MCSs) via the "NASA Downscaling Project", as well as advance and utilize MERRA, LDAS and other obs4MIPs datasets for the model evaluation Kunkel/NCA are interested in exploring.



Personnel Graduations/Changes

Paul Loikith – NCA Postdoc for 2.5+ years, starting faculty position in Dept. of Geography, Portland State University in August.

Huikyo Lee - NCA Postdoc for 2.5+ years, hired at JPL in Data Analysis and Statistics group – still to contribute to RCMES/NCA.

Kim Whitehall – Previous summer intern 2013 and 2014 hired at JPL in Data Sciences group focusing on MISR and other Data Science

New Postdoc? - hoping to hire someone in fall to take Paul's place.

Jinny Lee – CSLA M.S. student and summer (and likely longer) intern.

Computer Science folks – a number of changes

Summary

- Infrastructure changes/improvements – ESGF, database framework, training and interaction tools, website, and TBD documentation developed over 2015 summer.
- The development and application of a number of model evaluation methodologies and model performance metrics pertaining to climate extremes (temperature, precipitation and circulation) has led to ~5-6 peer reviewed journal articles.
- A number of RCMES training/education activities have been undertaken, including workshops, classroom and specific student use.
- FY'16 work will focus on impacting 4th NCA via NCEI collaborator Kunkel and incorporation of above/more metrics into RCMES.

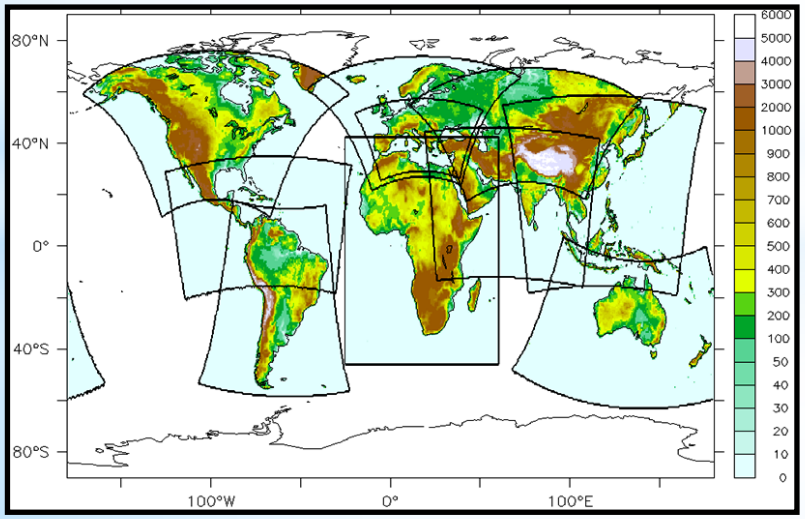
BACKUP

CORDEX Interactions & Support

- **N. America** –NARCCAP via NCAR/Mearns for U.S. NCA
- **Africa** – collaboration with UCT/Hewitson & Rossby Ctr/Jones
- **E. Asia** – exploring collaboration with KMA & APCC, particip. in Sep'11 & Nov'12 mtgs
- **S. Asia** – collaboration with IITM/Sanjay, participated Oct'12 & Sep'13 mtgs.
- **Arctic** – participated in initial Mar'12 mtg, Nov'13 mtg, Jun'14 mtg.
- **Caribbean, S. America** –participated in 1st major mtg Sep'13 and 2nd mtg Apr'14.
- **Middle East – N. Africa** –participating in initial coordinating team and ISSI proposal.

Typically try to support meetings by sending a climate scientist and an IT expert, provide an overview and a tutorial/training.

Have hosted scientists & students at JPL/UCLA

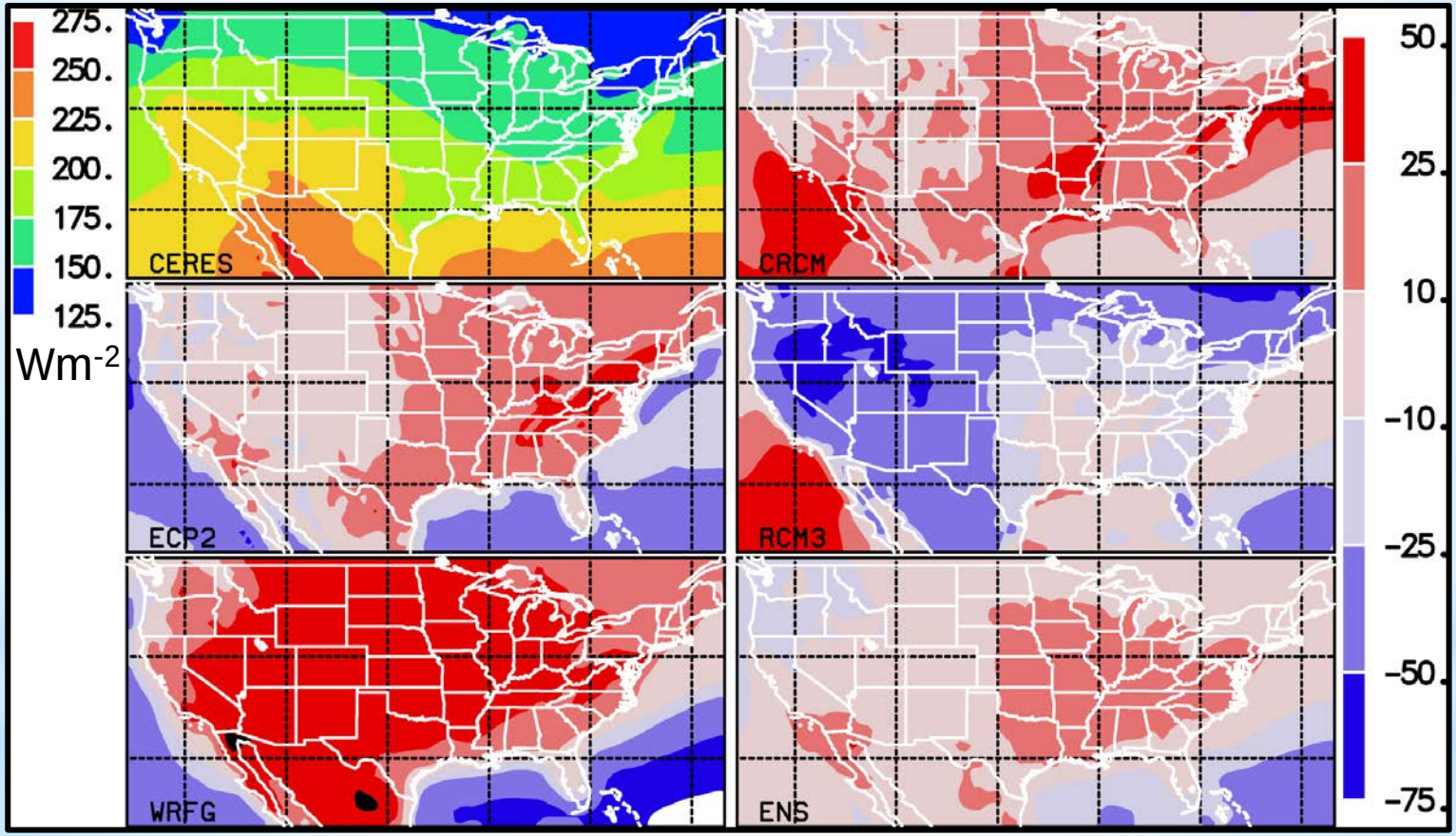


Learning RCM User Needs

Infusing Support into CORDEX

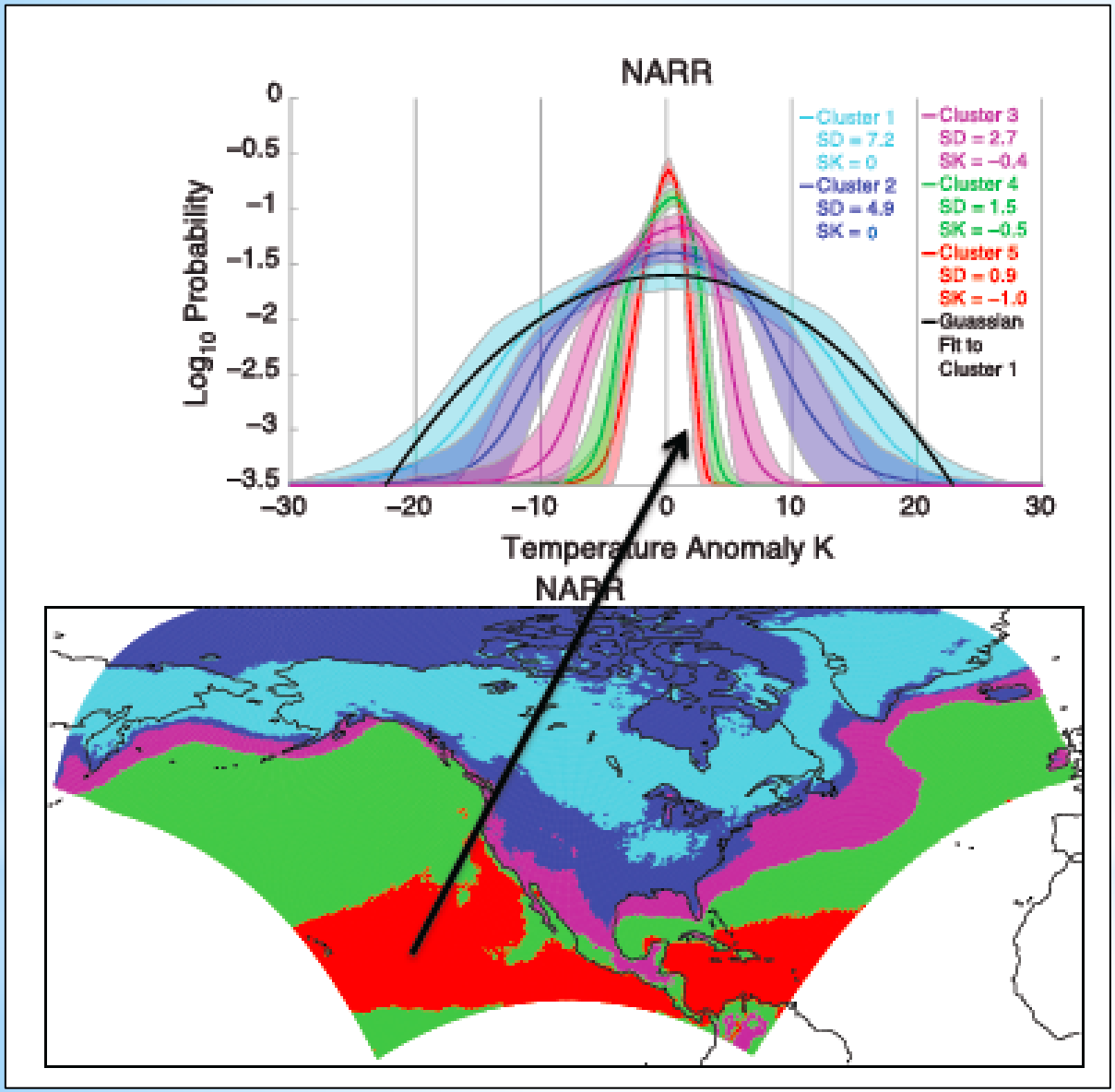
Example: Surface Energy Budget – Shortwave Radiation

NARCCAP RCM biases in surface insolation against GEWEX-SRB



Kim, J., D.E. Waliser, C.A. Mattmann, L.O. Mearns, C.E. Goodale, A.F. Hart, D.J. Crichton, and S. McGinnis, 2013: J. Climate.

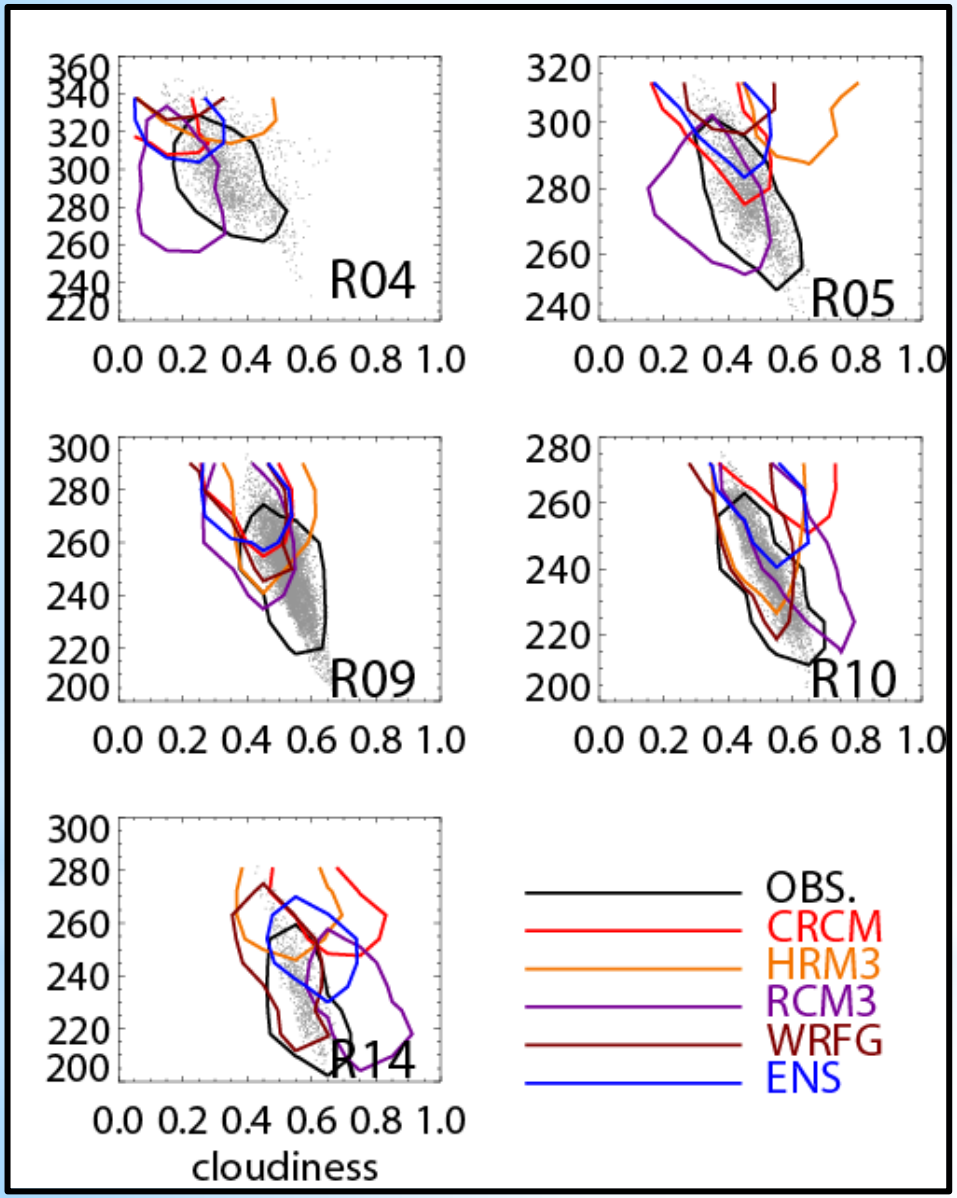
Development : PDFs and Quantifying Extremes



* K-means clustering used to group the January surface temperature PDFs into 5 categories.
* Cluster assignments
  * The red curve is the average of all PDFs shaded in red on map, etc.
  * Clusters primarily reflect variance, with some skewness
* Cluster analysis can provide a basis for identifying regions of common PDF morphology

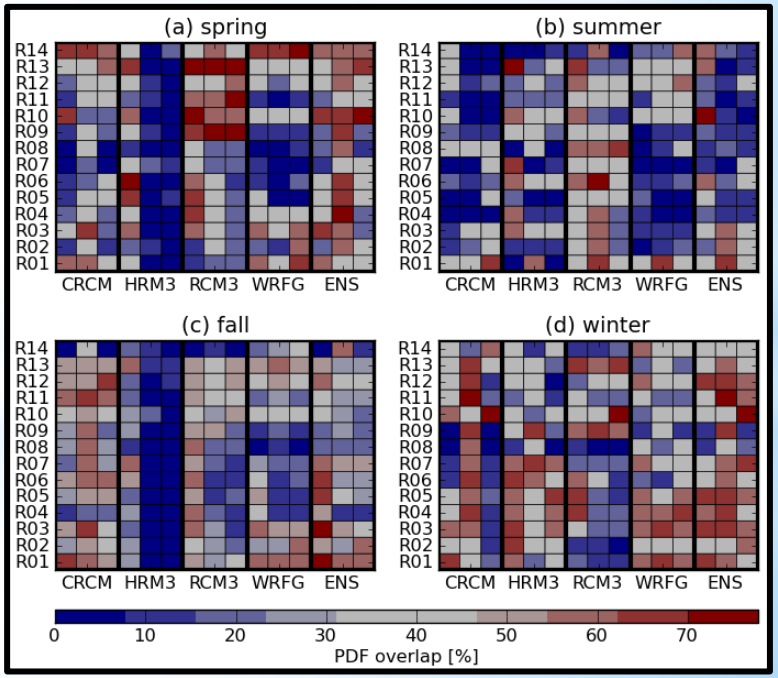
Loikith et al., 2013, *Geophys. Res. Lett.*, 40, 3710-3714.

Development : PDFs and Quantifying Extremes



Bivariate PDF skill score

- Measure models' skill in simulating related variables.
- The example evaluates the cloudiness-surface insolation relationship in the NARCCAP hindcast.
- Results can be visualized using a portrait diagram.



Lee et al., 2013, *J. Geophys. Res.*, submitted.