Model Errors in Precipitation, Cloudiness, and Radiation in the NARCCAP Hindcast Experiment

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Introduction

- Precipitation, clouds and surface insolation are among the most crucial variables in shaping the energy and water cycle, especially in the surface climate.
- These variables directly affect agriculture, water resources, snowpack, and natural ecosystems that are key targets in a number of climate change impact assessment studies for practical applications.
- Thus, estimating model errors in simulating precipitation, clouds and insolation are an important concern in climate simulations and their application to energy/water cycle analyses and impact assessments – especially for multi-model ensemble and bias correction.
- The relationship between the model errors in these variables may provide clues *for the source of model errors* and/or *for improving climate model performance*.

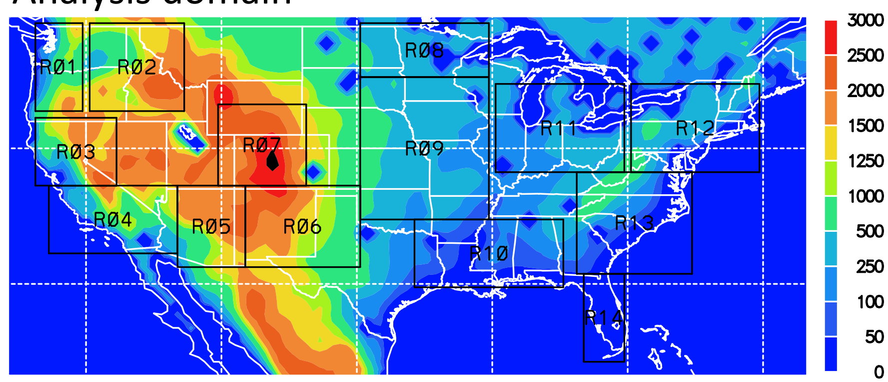
Experiment

- We examined the relationship between the model biases in precipitation, cloudiness, and surface insolation over the conterminous United States in the NARCCAP multi-RCM climate hindcast data for 1984-2003.
  - Cloudiness is selected to represent "*cloud effects*".
  - Cloud effects are determined by, in addition to cloudiness, the content, size distribution, and phase of cloud particles.
- Data from 4 RCMs and their *ENS* are used (Table).
- Reference datasets include the *station-based* CRU3.1 for precipitation and *satellite-based* Clouds and the Earth's Radiant Energy System (CERES) datasets for cloudiness and surface insolation.
  - The JPL Regional Climate Model Evaluation System (RCMES) is used to access and process the reference and model data in this study.

Table: RCMs incorporated in this study

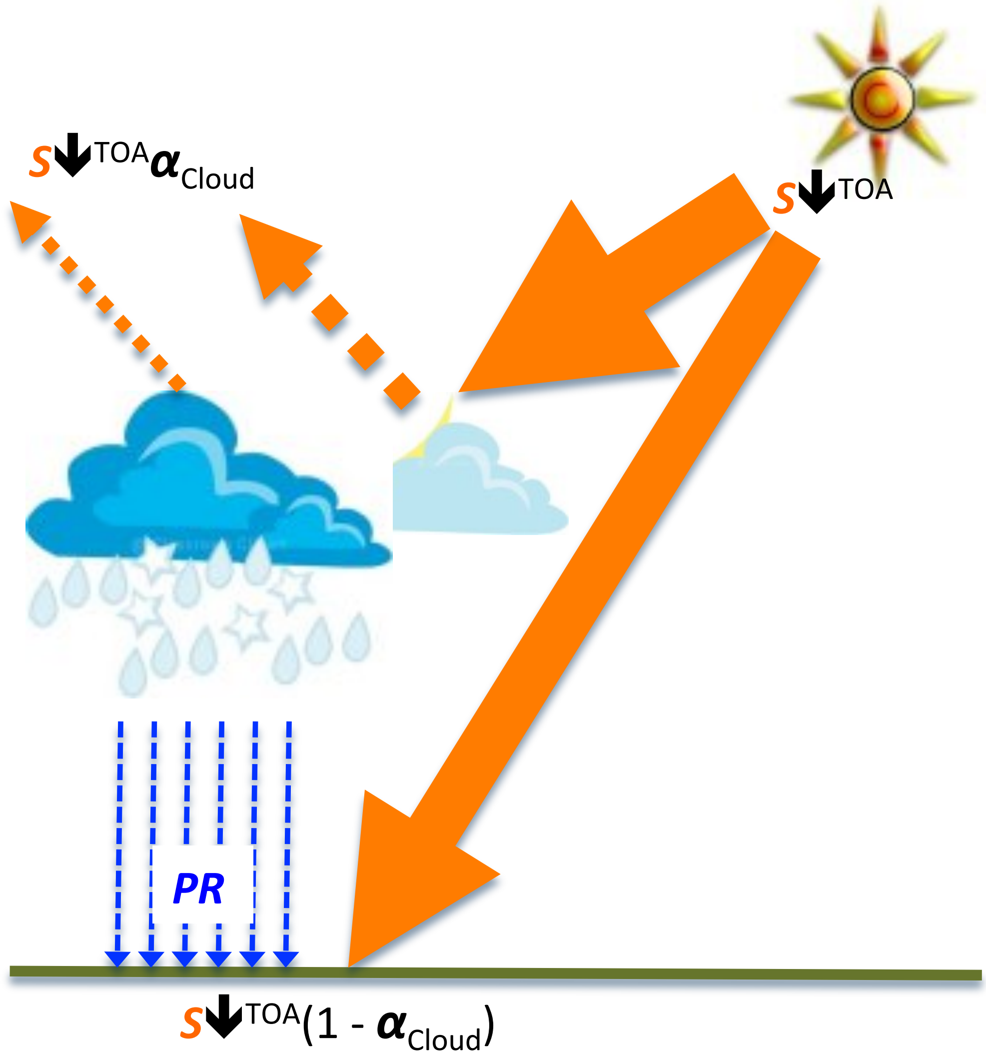
ID	Model Name
CRCM	Canadian Regional Climate Model
HRM3	Hadley Center Regional Climate Model
RCM3	ICTP Reg. Climate Model 3 (run by UCSC)
WRFG	Weather Research and Forecast Model
ENS	Uniform-weighted multi-model Ensemble

Analysis domain

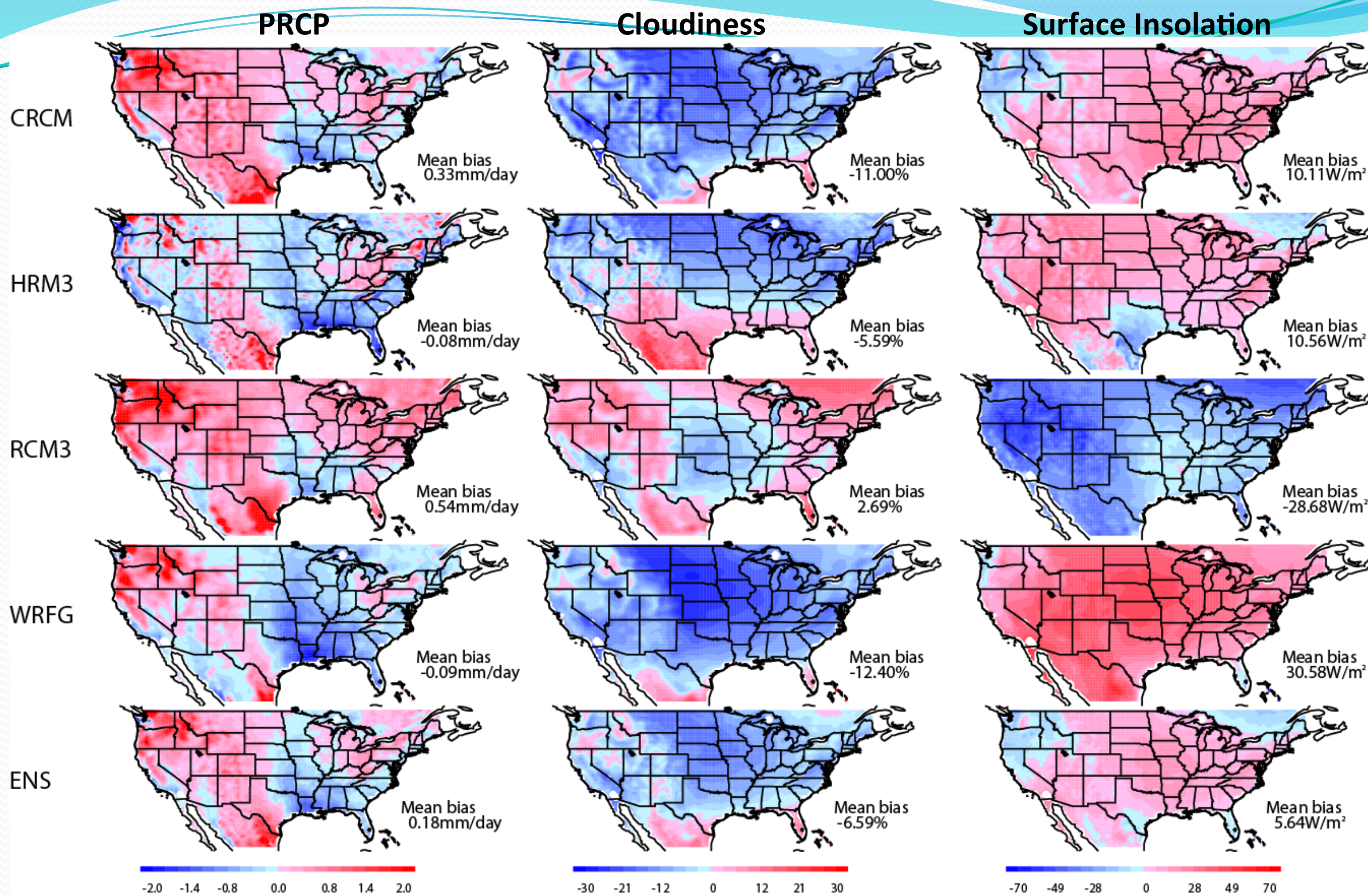


Precipitation, Surface Insolation, and Clouds

- Precipitation and surface insolation are related via clouds.
- Calculations of these three fields are among the most uncertain components in today's climate models.
- *Working Hypothesis*:
    1. Model biases in *precipitation* and *cloudiness* are positively correlated,
    2. The biases in *surface insolation are* negatively correlated with the biases in *cloudiness* (*and thus precipitation*).

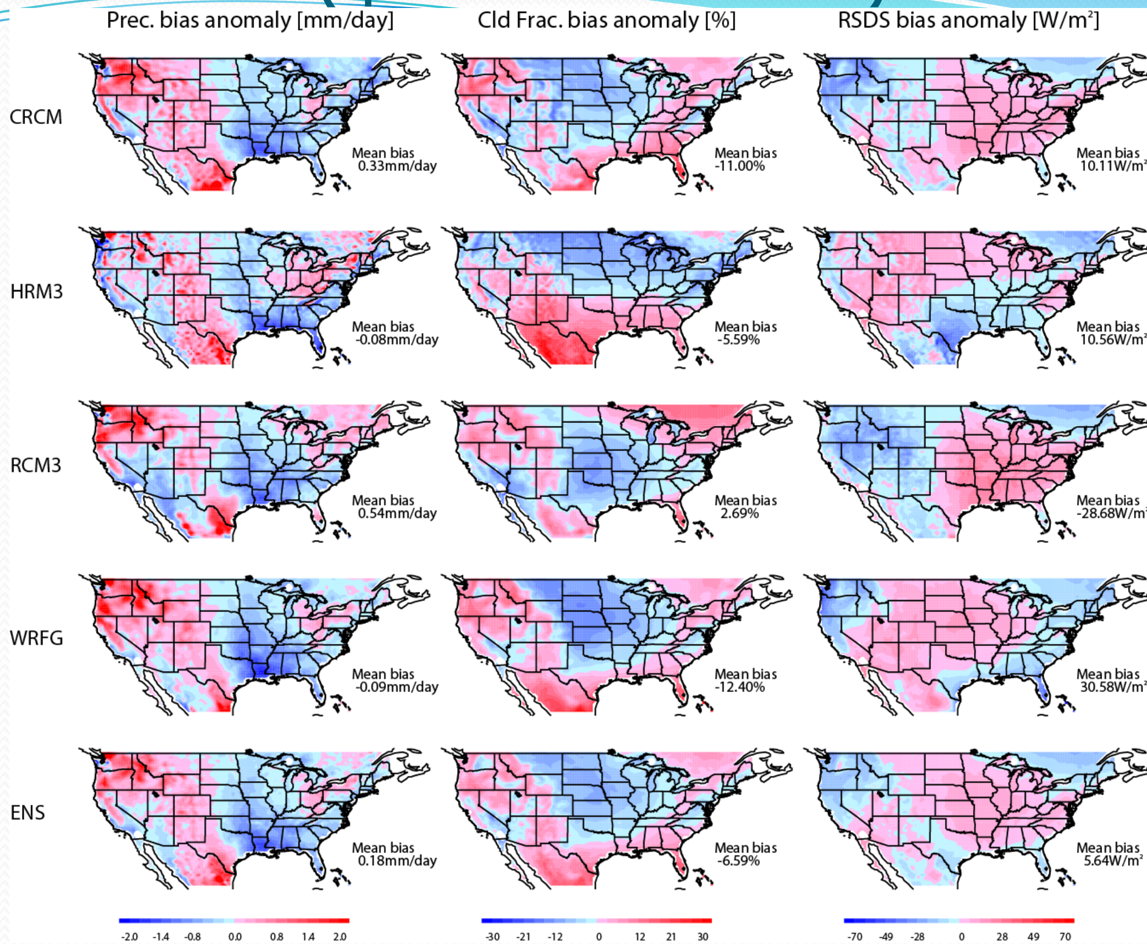


Biases in Annual-mean precipitation, Cloudiness, and Insolation



- Model biases show regionally systematic variations. E.g.,
  - Wet/Dry biases in the western US/Gulf of Mexico
  - Overall negative cloudiness biases in the US
  - General positive biases in insolation except in the Pacific NW
  - RCM3 is an outlier among the four RCMs in the cloudiness & insolation biases.
- The expected relationship between these three bias fields is not clear.

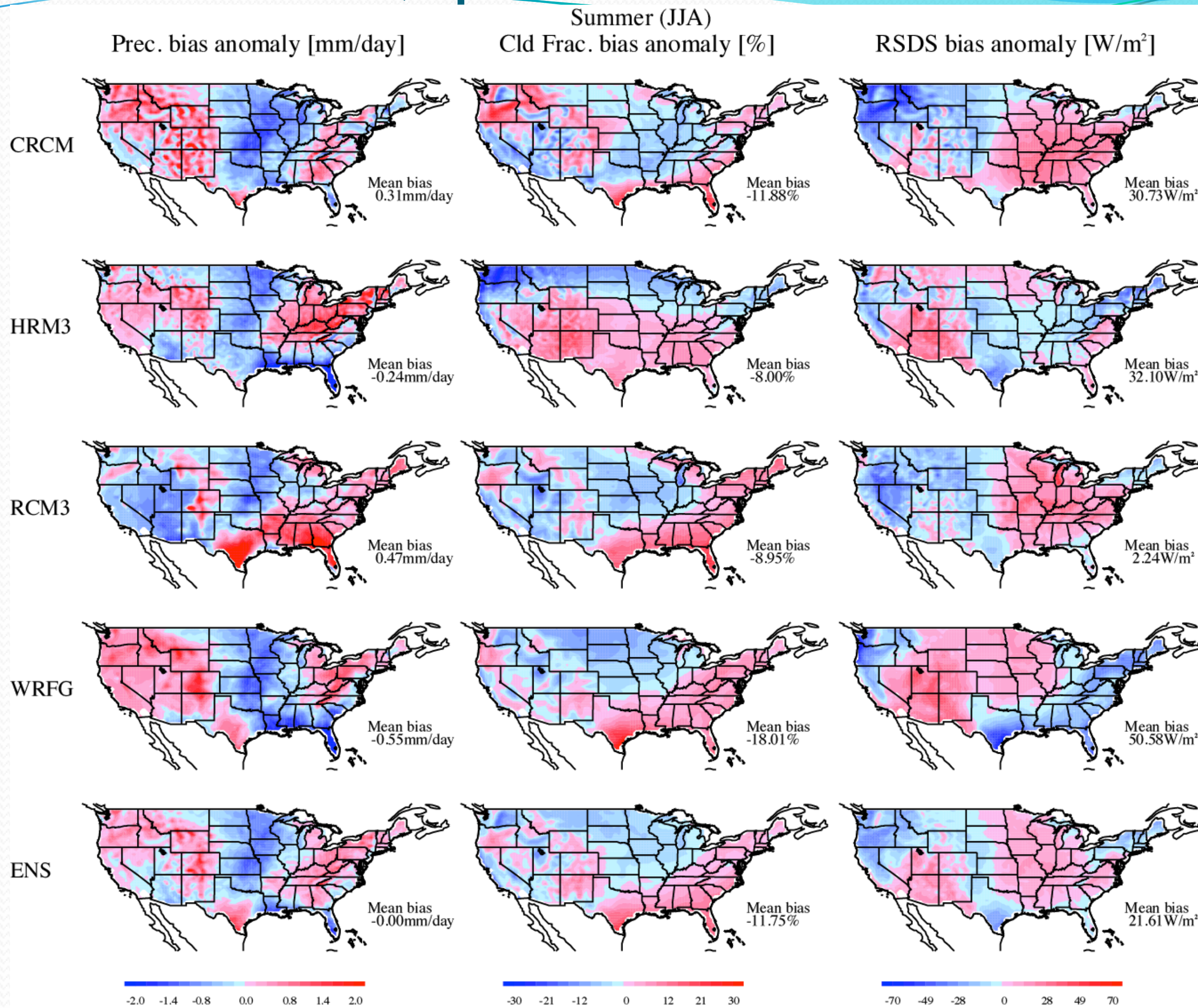
Biases in Annual-mean precipitation, Cloudiness, and Insolation (Spatial mean removed)



- Spatial anomalies of model biases show more systematic patterns
  - Most RCMS show positive/negative precipitation bias anomalies in WUS/EUS, most notably in the Pacific NW/Gulf of Mexico-Atlantic coast regions.
  - Positive/negative cloudiness bias anomalies in WUS/EUS.
  - Positive/negative insolation bias anomalies in EUS/WUS.

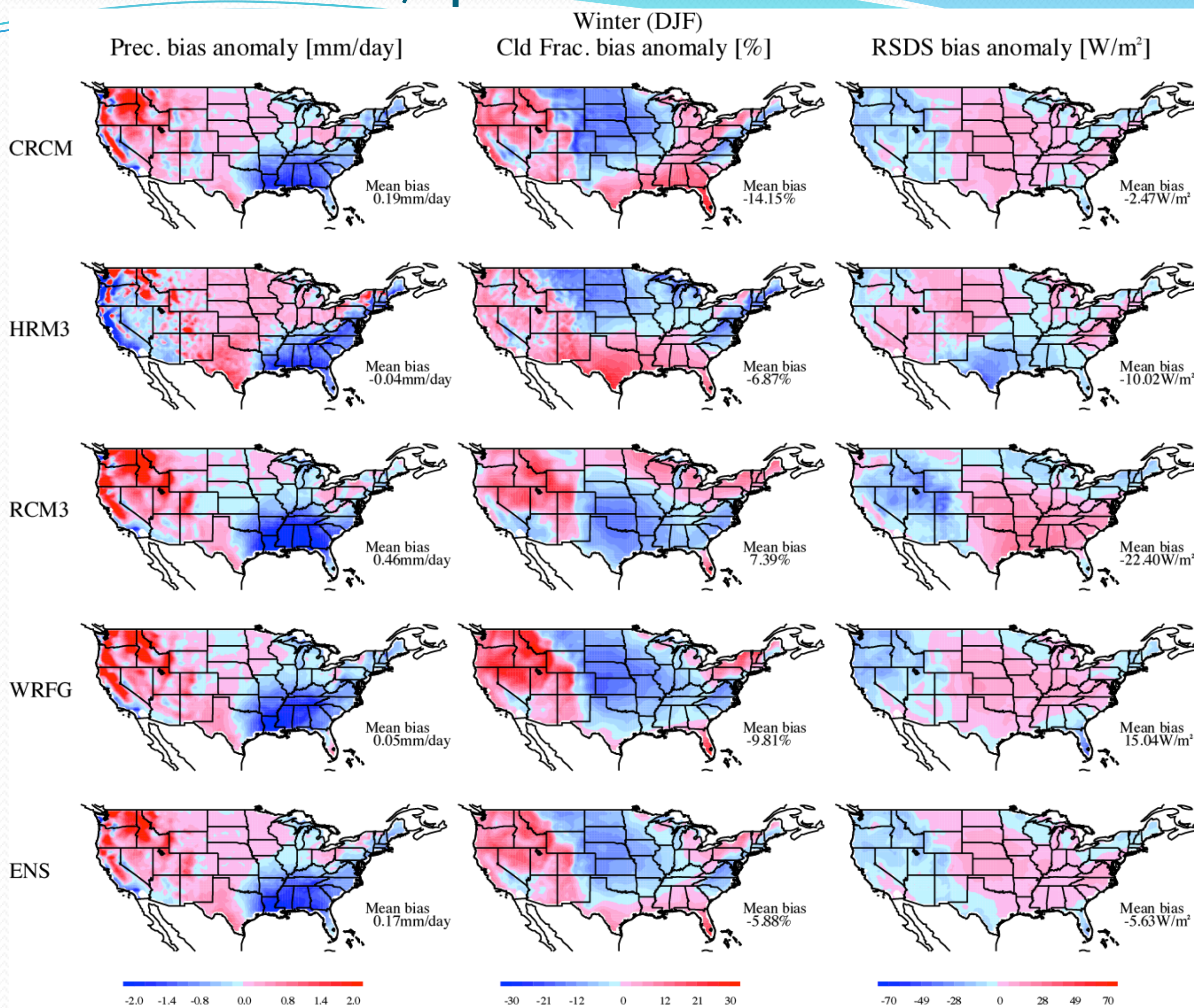
- These patterns show the expected relationship between the three error fields.

Biases in Annual-mean precipitation, Cloudiness, and Insolation: Summer, Spatial mean removed



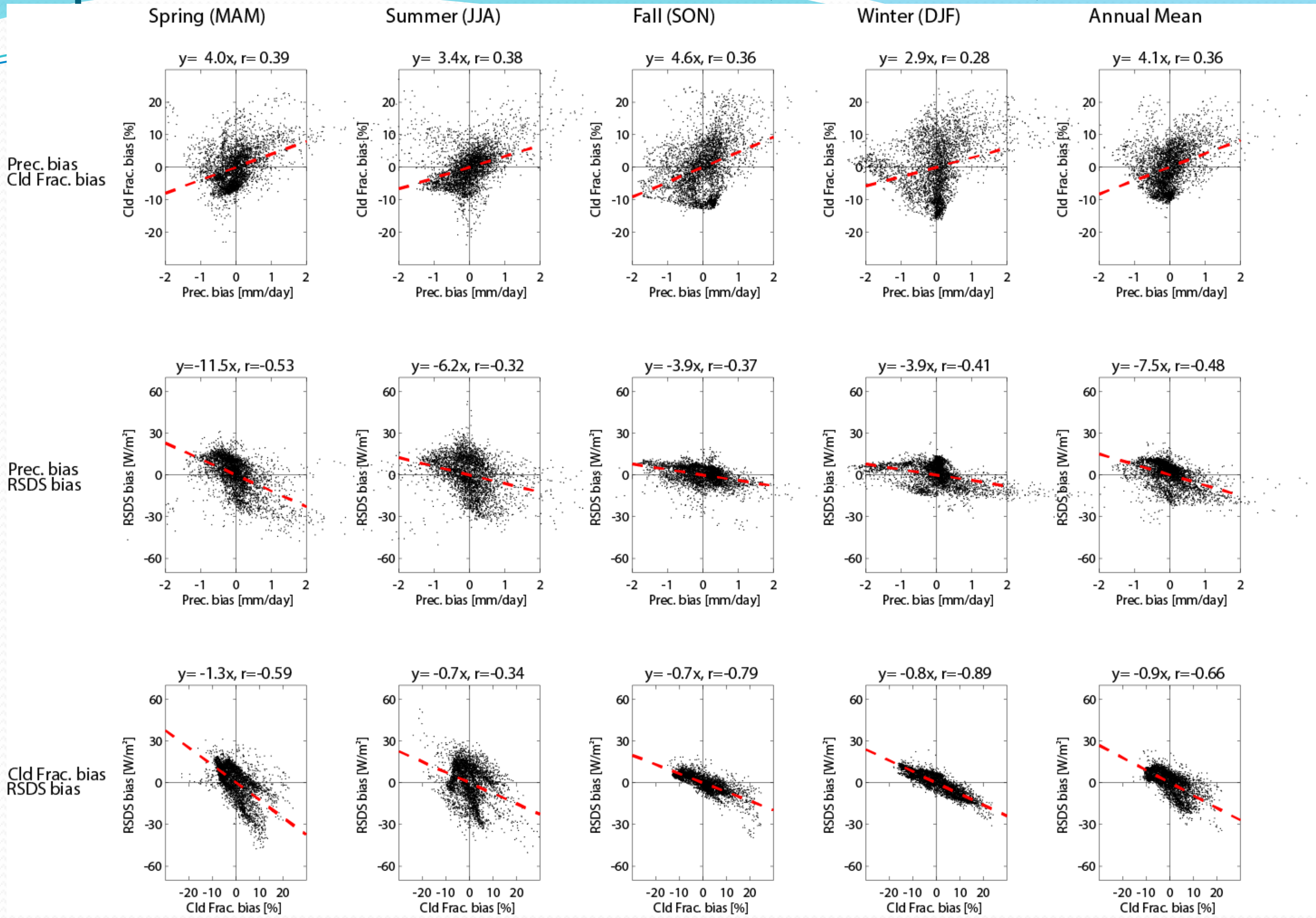
- The negative correlation btn cloudiness & insolation bias is well established.
- The positive correlation btn rainfall & cloudiness bias varies geographically
  - Well established in the EUS region
  - Not clear in the WUS region (most WUS is very dry during summer)

Biases in Annual-mean precipitation, Cloudiness, and Insolation: Winter, Spatial mean removed



- The negative correlation btn cloudiness & insolation bias is well established.
- The positive correlation btn rainfall & cloudiness (negative with insolation) is generally established, especially for the WUS region
  - WUS winter precipitation is mostly related with stratiform clouds.

Relationship between the model bias in PR, Cloudiness, and Insolation: *ENS*



- The bias anomalies of multi-model ensemble shows consistent relationship between precipitation, insolation, and cloudiness for season totals as well as annual totals.
  - Positive correlation: PR vs. Cloudiness
  - Negative correlation: PR vs. Insolation & Cloudiness vs. Insolation
- The strongest correlation between cloudiness and surface insolation; the weakest for precipitation and cloudiness.

Biases in Precipitation, Cloudiness, and Insolation

Overland Means

	Model	PR (mm/day)	Cloudiness (%)	Insolation (W/m2)
All Year	CRCM	0.33	-11.0	10.1
	HRM3	-0.08	-5.6	10.6
	RCM3	-0.54	2.7	-28.7
	WRFG	-0.09	-12.4	30.6
	ENS	***0.18***	***-6.6***	***5.6***
Spring	CRCM	0.60	-12.8	10.7
	HRM3	0.22	-5.7	-43.5
	RCM3	0.96	5.5	-26.7
	WRFG	0.23	-12.9	35.6
	ENS	***0.50***	***6.5***	***-6.0***
Summer	CRCM	0.45	-11.7	29.9
	HRM3	-0.18	-7.9	31.0
	RCM3	0.62	-7.4	-28.1
	WRFG	-0.44	-16.9	49.6
	ENS	***0.11***	***-11.0***	***20.6***
Fall	CRCM	-0.04	-6.9	3.9
	HRM3	-0.51	-3.9	66.6
	RCM3	0.01	3.1	-32.9
	WRFG	-0.34	-11.9	23.5
	ENS	***-0.22***	***-5.1***	***15.2***
Winter	CRCM	0.32	-12.6	-3.8
	HRM3	0.16	-5.1	-11.6
	RCM3	0.57	8.8	-27.0
	WRFG	0.16	-8.0	14.3
	ENS	***0.31***	***-4.3***	***-7.0***

- The overland-mean values of the model biases in precipitation, cloudiness, and surface insolation do not show the relationship expected from the physical processes except for fall.
- This may suggest problems in the formulations related with precipitation, clouds, and insolation in the RCMs examined in this study.

Biases in Precipitation, Cloudiness, and Insolation

Spatial Anomalies

Season	Model	PR vs. Cloudiness	PR vs. Insolation	Cloudiness vs. Insolation
All Year	CRCM	0.24	-0.48	-0.46
All Year	HRM3	0.29	-0.30	-0.51
All Year	RCM3	0.47	-0.49	-0.64
All Year	WRFG	0.36	-0.22	-0.60
All Year	*ENS*	*0.36*	*-0.48*	*-0.66*
Spring	CRCM	0.30	-0.43	-0.45
Spring	HRM3	0.36	-0.43	-0.49
Spring	RCM3	0.59	-0.52	-0.75
Spring	WRFG	0.39	-0.26	-0.75
Spring	*ENS*	*0.39*	*-0.53*	*-0.59*
Summer	CRCM	0.42	-0.35	-0.58
Summer	HRM3	0.00	-0.33	0.03
Summer	RCM3	0.59	-0.07	-0.22
Summer	WRFG	0.22	-0.14	-0.56
Summer	*ENS*	*0.38*	*-0.32*	*-0.34*
Fall	CRCM	-0.06	-0.34	-0.50
Fall	HRM3	0.40	-0.36	-0.58
Fall	RCM3	0.53	-0.61	-0.57
Fall	WRFG	0.40	-0.40	-0.44
Fall	*ENS*	*0.36*	*-0.37*	*-0.79*
Winter	CRCM	0.08	-0.28	-0.72
Winter	HRM3	0.27	-0.35	-0.75
Winter	RCM3	0.37	-0.49	-0.82
Winter	WRFG	0.38	-0.41	-0.79
Winter	*ENS*	*0.28*	*-0.41*	*-0.89*

- The spatial pattern correlation coefficients between the spatial anomalies of the model biases in the three fields show the expected relationship between the three fields.
- The presence of the expected relationship between the spatial anomalies of these model biases may imply some consistency in simulating these variables within RCMs – a subject that needs further exploration.

Summary

- Relationships between model biases in simulating precipitation, insolation, and cloudiness over the conterminous US region are examined for the NARCCAP hindcast experiment data.
- The relationship between *the domain-averaged* model bias based on a simple physical model are not well established, but
- The *spatial anomalies* (*i.e., domain mean is subtracted*) *of model biases* show consistent relationships between precipitation-and-insolation (negative), cloudiness-and-insolation (negative), and precipitation-and-cloudiness (positive) for all seasons and for (nearly) all models.
  - *Cloudiness vs. Insolation bias relationship is most clearly established.*
- Mean biases in precipitation, clouds, and insolation in these RCMs are not well related; *however*,
  - The spatial anomalies of these model biases show the expected relationship.
  - *This indicate that model sensitivity may possess useful skill*.
- *Cloudiness may not be the right choice for quantitative representation of cloud effects on precipitation* – may need to examine more directly related fields such as the content, phase and size distribution of cloud particles.
  - We are currently developing key reference datasets especially from satellite-based remote sensing and methodologies *for more thorough examinations/evaluations of model precipitation-cloud-radiation interaction in terms of more detailed cloud structures and hydrometeor concentrations*.

Related publications

- Kim, J., D. Waliser, C. Mattmann, L. Mearns, C. Goodale, A. Hart, D. Crichton, S. McGinnis, H. Lee, P. Loikith, and M. Boustani, 2013: Evaluation of the surface air temperature, precipitation, and insolation over the conterminous U.S. in the NARCCAP multi-RCM hindcast experiment using RCMES. *J. Climate,* Submitted.

- Li, J., D. Waliser, W. Chen, B. Guan, T. Kubar, G. Stephens, H. Ma, M. Deng, L. Donner, C. Segman, and L. Horowitz, 2012: An observationally based evaluation of cloud ice water in CMIP3 and CMIP5 GCMs and contemporary reanalyses using contemporary satellite data. *J. Geophys. Res.*, 117, DOI: 10.1029/2012JD017640.

- Waliser, D., J. Li, T. L'Ecuyer, and W. Chen, 2011: The impact of precipitating ice and snow on the radiation balance in global climate models. *Geophys. Res. Lett.*, 38, L06802, doi: 10.1029/2010GL046478.