Community Modeling and Long-Term Predictions of the Integrated Water Cycle

1. Multi-Scale Behaviors of the Water Cycle
5. Prediction, Analysis, and Uncertainty Quantification of Water Cycle Mean & Extremes

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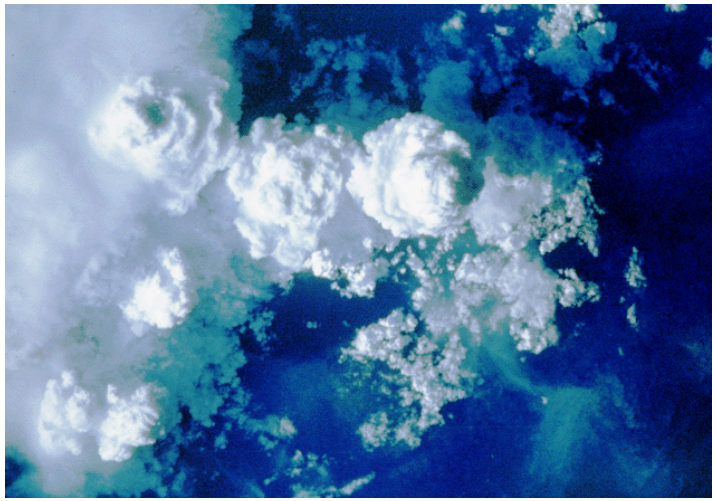
Synthesizing Models and Measurements across Scales

- How does the water cycle vary across scales, and do global models capture this variation?
- What are the factors governing the statistics, especially the tails, of rainfall distributions?
- How does skill in modeling multiscale effects and bounding uncertainty affect end users?



Multiscale Properties of Water Vapor from AIRS

- Atmospheric Infrared Sounder (AIRS) retrieves vertical profiles of water vapor:
  - *50km nadir resolution*
  - *Near global coverage*
  - *Twice daily sampling*

- Water vapor variability as function of scale changes with pressure altitude.

500 hPa

925 hPa

3 0

$\log\left(q_v / \max(q_v)\right)$

(Pressel and Collins, 2012)

Analysis of Scaling and the Hurst Exponent (H)

- Structure functions relate statistics of spatial fluctuations to length scale:

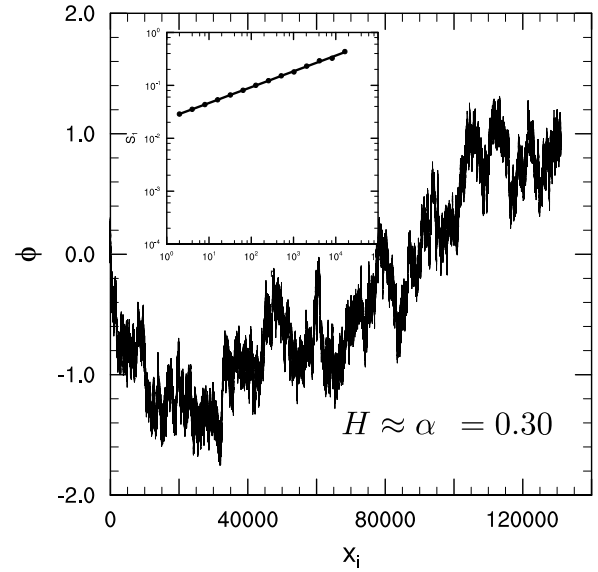
$$S_q(r) = \langle |\phi(x_i + r) - \phi(x_i)|^q \rangle$$

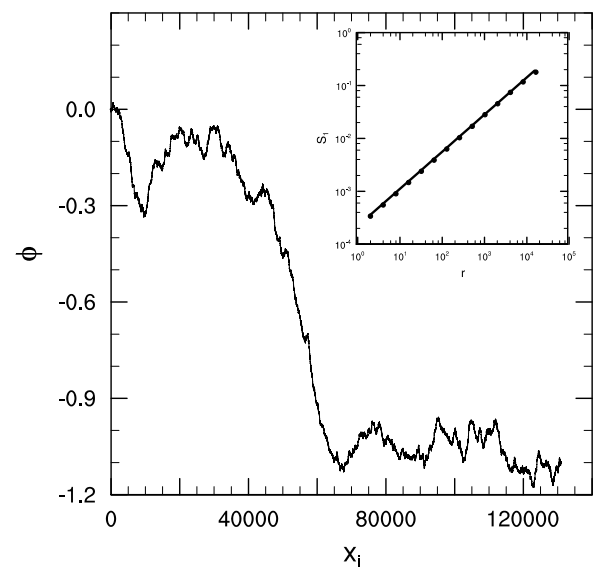
- **Power law behavior (scaling) in distance is indicative of statistical scale invariance.**

- Power law scaling exponent of the 1st order structure function is the Hurst exponent (H):

$$S_1(r) \sim r^H$$

- **H characterizes persistence of fluctuations:**
  - **H < ½ : anti-persistence**
  - **H > ½ : persistence (long range correlations)**





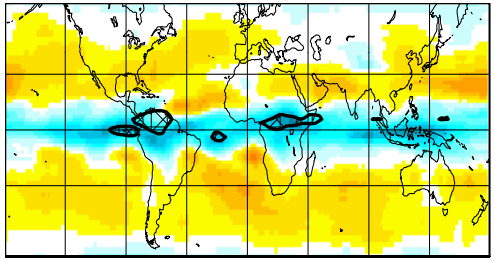
Scaling Properties of Water Vapor from AIRS

- Structure functions are computed from AIRS over scales between 50km and 500km.

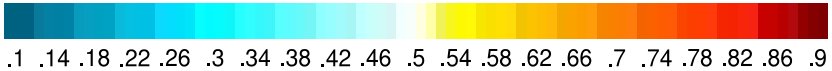
- Nearly ubiquitous scaling is observed in the extratropics:
  - **H < ½ in lower troposphere (925 hPa): anti-persistence**
  - **H > ½ in middle troposphere (500 hPa): persistence**

925 hPa *500 hPa*

Ascending



Descending



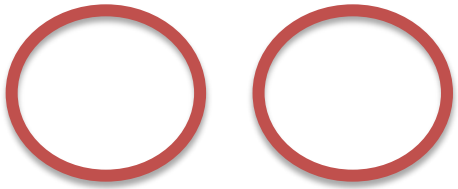
(Pressel and Collins, 2012)

AIRS vs. Aqua-planet CAM

AIRS

- In the extratropics, there is a transition between H < ½ and H > ½ at 850hPa.
- Equatorial regions have H < ½ at all levels.
- CAM scaling exponents agree well with AIRS in tropics and extratropical free troposphere.
- **CAM exponents differ significantly from observed exponents in the PBL.**

Aqua Planet

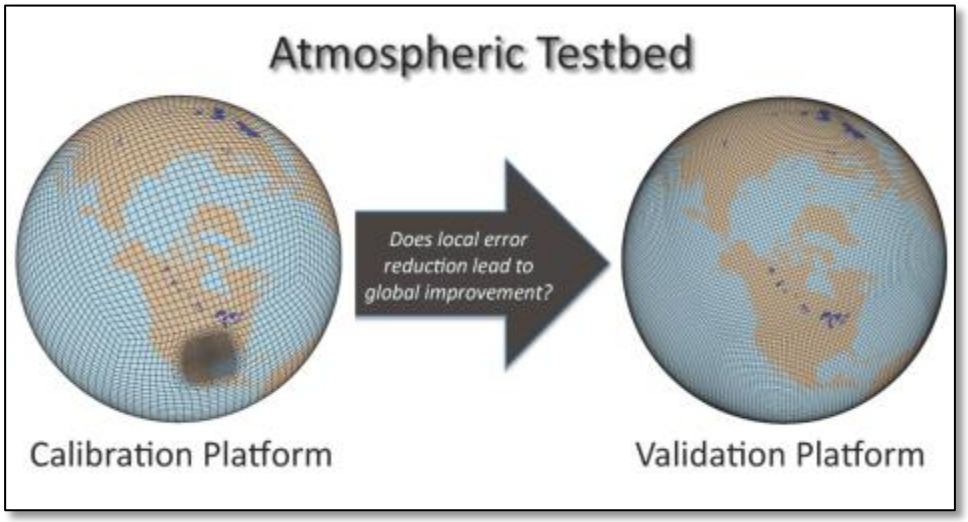


8 .85 .9

(Pressel and Collins, 2012)

Uncertainty Quantification of Water Across Scales

- ***Goal:*** Use *in situ* and satellite water cycle observations to calibrate the model across scales.
- ***Method:*** Do so in a systematic and reproducible way using techniques developed by the UQ community.



Robust Sensitivity Analysis with Response Models

CAM5 Response Models:

- Multiple response models have been compared for predicting global and zonal aggregated CAM5 responses.

Initial Conclusions:

- **Response models show high fidelity for large scale fields.**
- **Results are insensitive to choice of response models.**

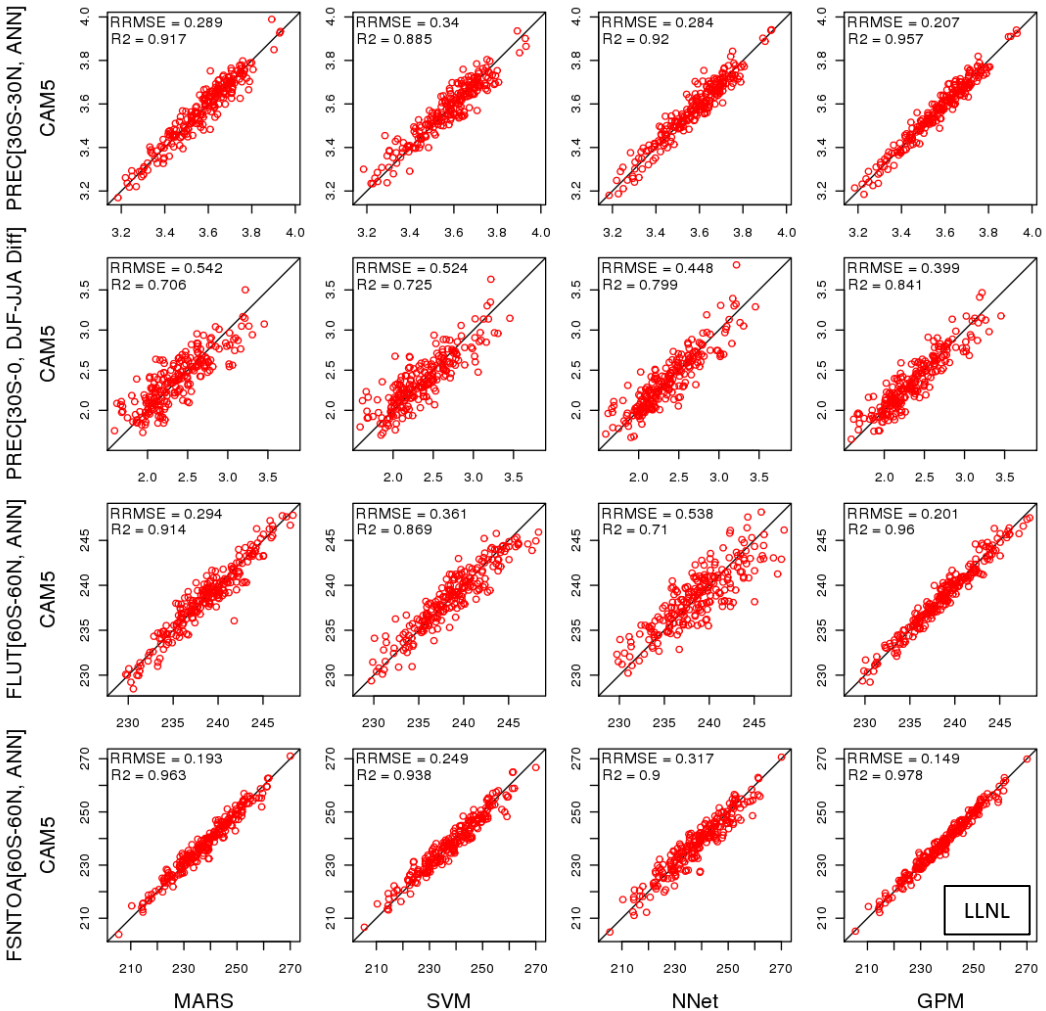


Figure: Validation plot of actual CAM5 responses plotted versus predicted responses for four type of response models (columns) in predicting four CAM5 statistics (rows). Each response model is trained on 440 CAM5 simulations and validated on 220.

PREC[30S-30N, ANN] = Total annual precipitation in the tropics
PREC[20S-0, DJF-JJA, Diff] = Winter/summer precipitation diff in the south tropics
FLUT[60S-60N, ANN] = Annual outgoing longwave radiation from 60°S to 60°N
FSNTOA[60S-60N, ANN] = Annual shortwave radiation from 60°S to 60°N

Robust Sensitivity Analysis (SA) with Surrogate Models

The Impact of Response Models on CAM5 Sensitivity Analysis:

- Multiple response models have been used to determine fraction of variance controlled by each free parameter.

Initial Conclusions:

- **The orderings of parameters by fraction of variance are relatively robust.**
- **Same parameters are important for multiple fields.**

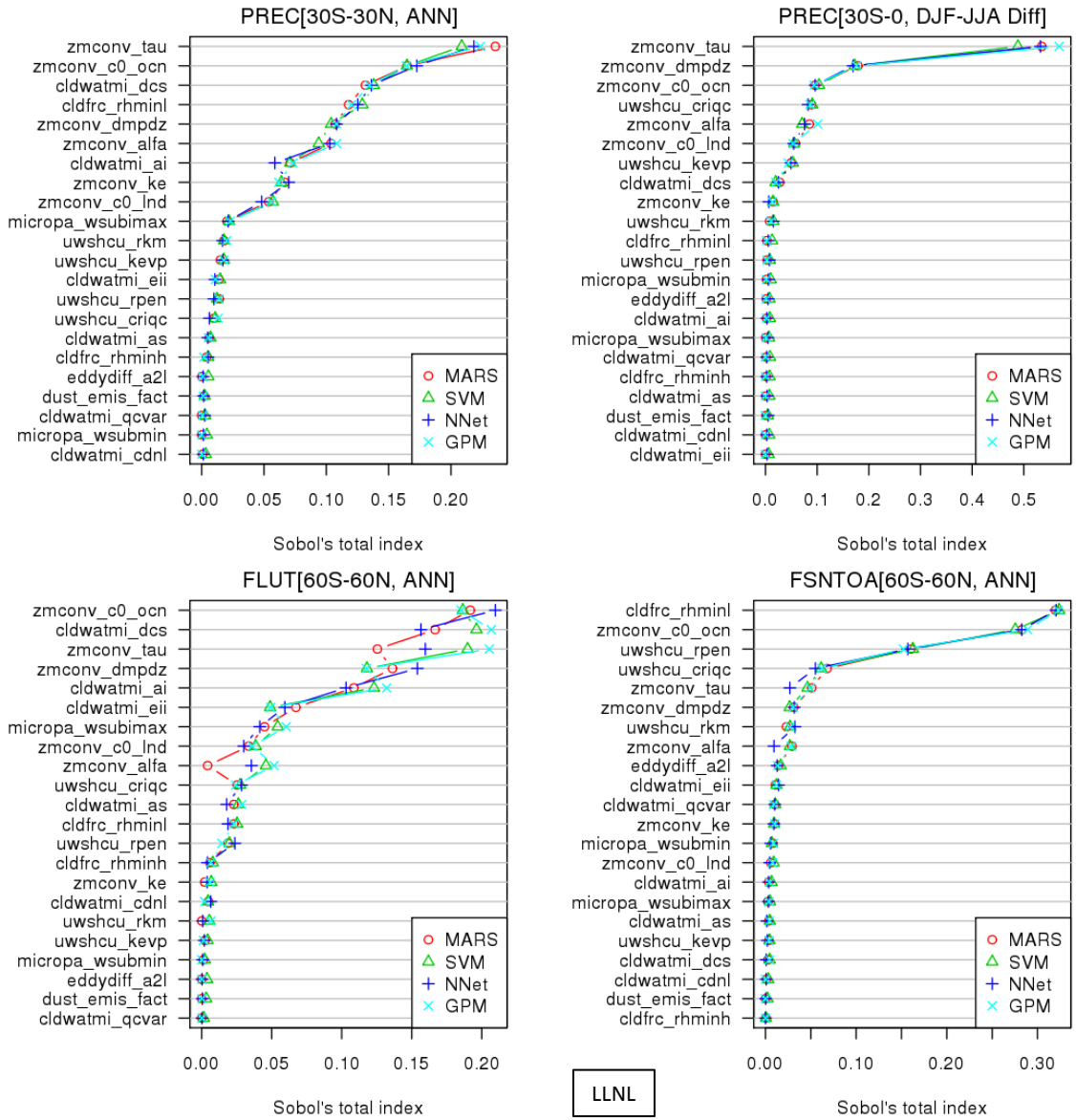


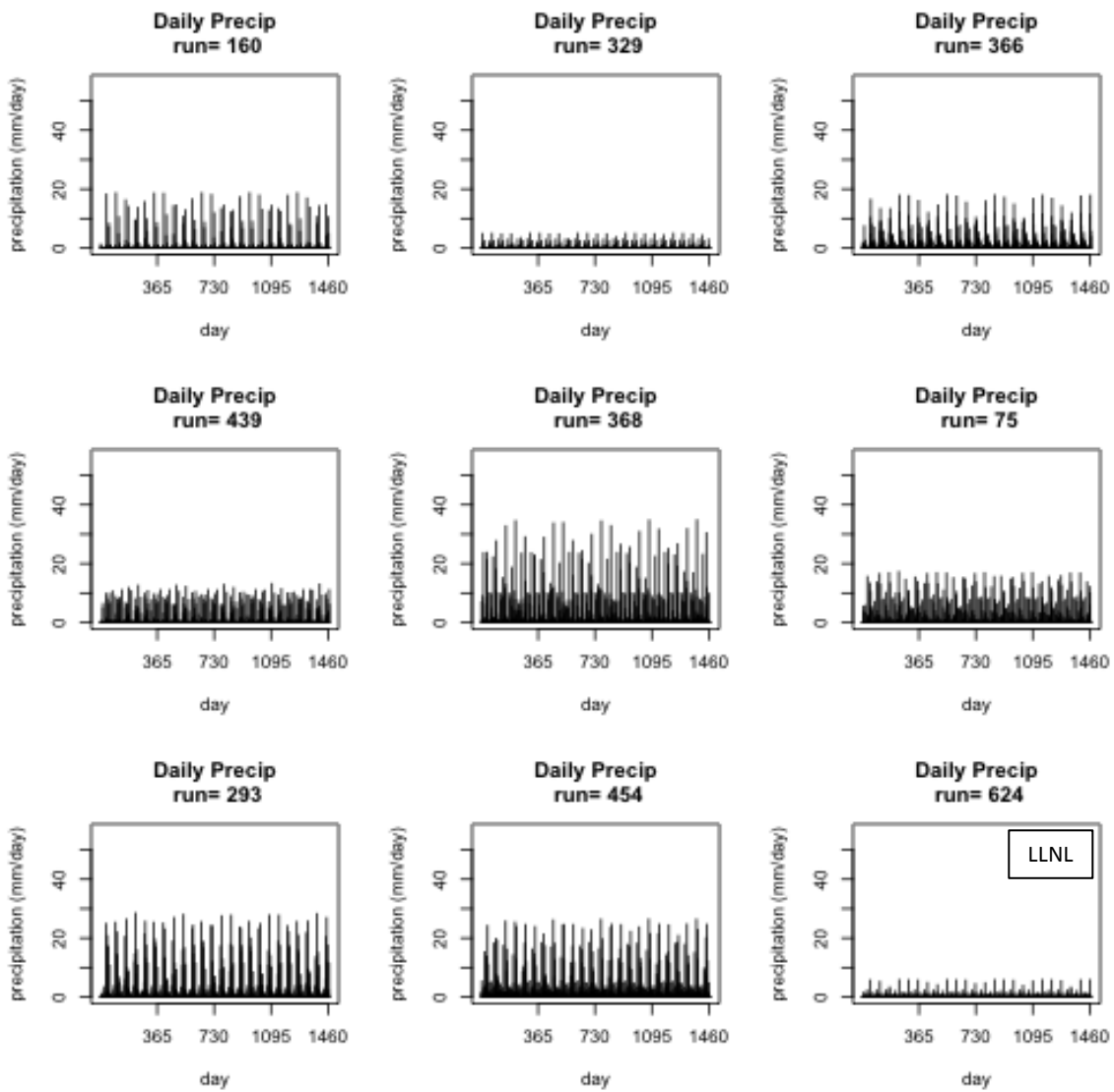
Figure: Each plot shows an estimate of the Sobol's Total Sensitivity Index for a given aggregated output quantity using four different response models.

LLNL

Robust Sensitivity Analysis (SA) with Surrogate Models

From Large-Scale to Regional and Hourly Rainfall Statistics.

- Daily rainfall in CAM5 grid-box over Central ARM site has been simulated using a PPE.
- ***Daily statistics vary strongly with parameter perturbations.***



Robust Sensitivity Analysis (SA) with Surrogate Models

CAM5 Response Models:

- Multiple response models have been compared in predicting hourly rainfall statistics.

Initial Conclusions:

- Different response model show **similar fidelity in predicting various rainfall statistics.**

- **But large natural variability prevents any response model to produce accurate prediction.**

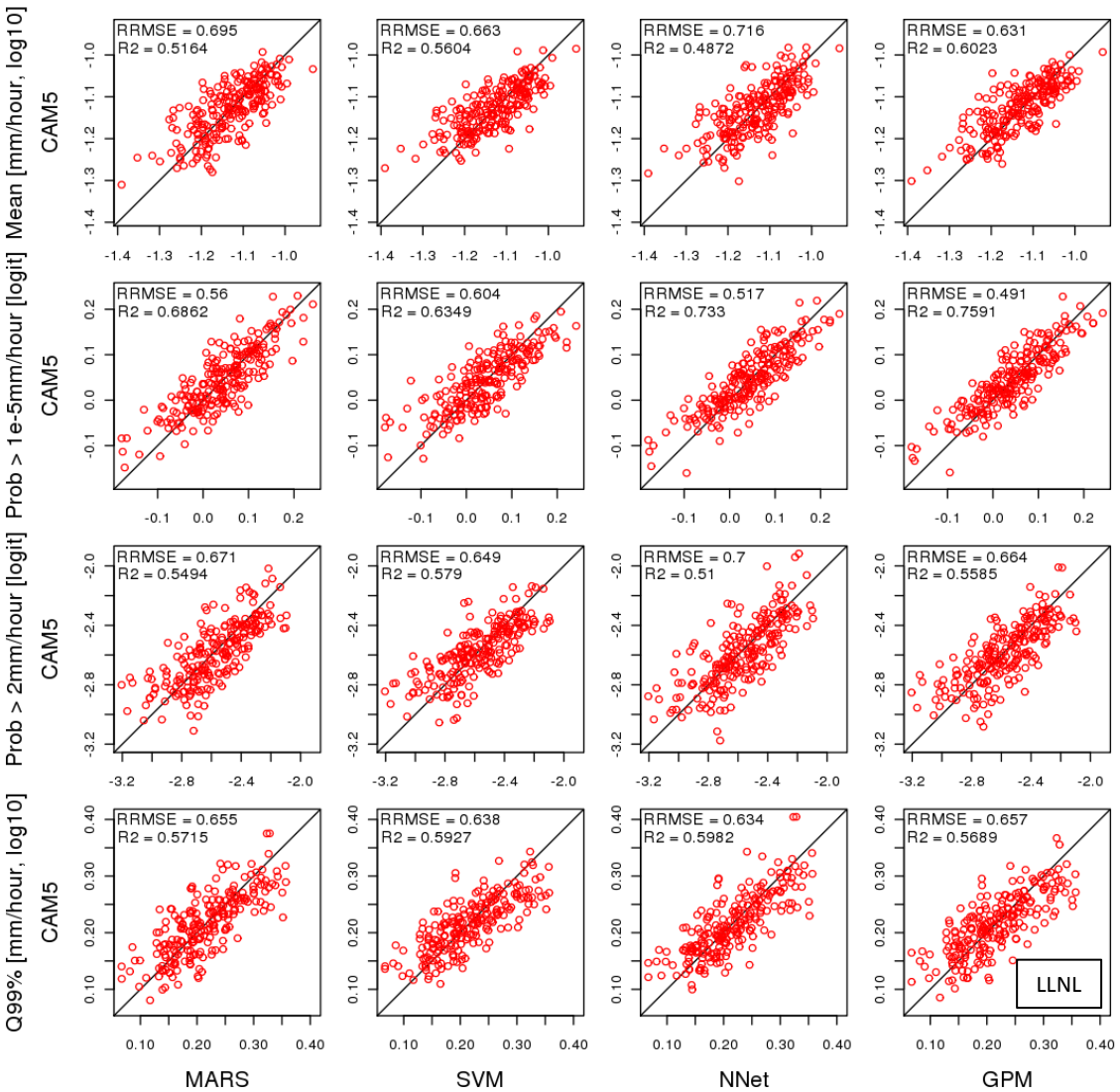


Figure: Validation plot of actual CAM5 responses plotted versus predicted responses for four type of response models (columns) in predicting four CAM5 hourly rainfall statistics (rows). Each response model is trained on 440 CAM5 simulations and validated on 220.