Vertical distribution of heating from a suite of mesoscale models over the Asian monsoon region

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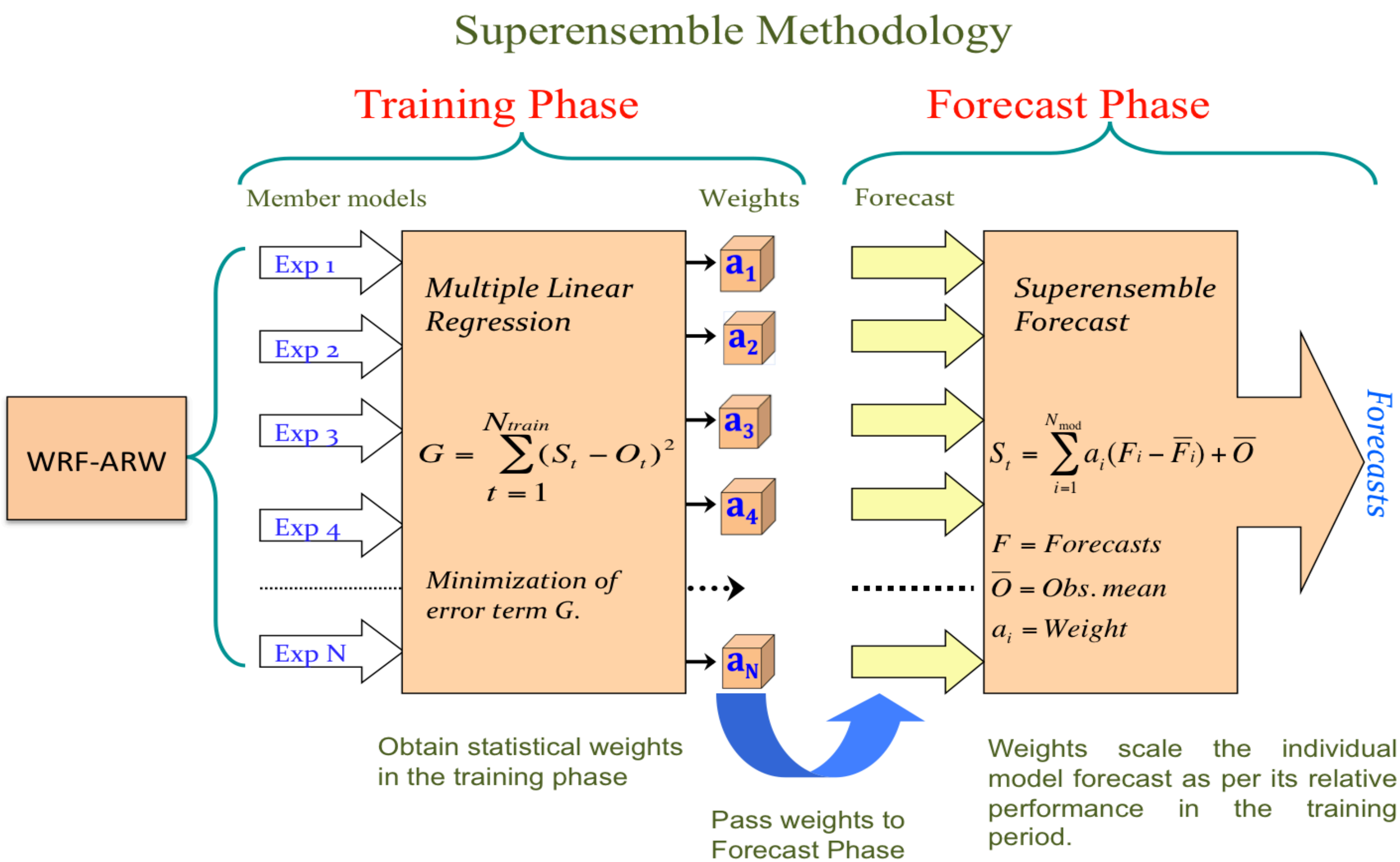
GPM Meeting, Denver Nov 2011

Previously Completed Work

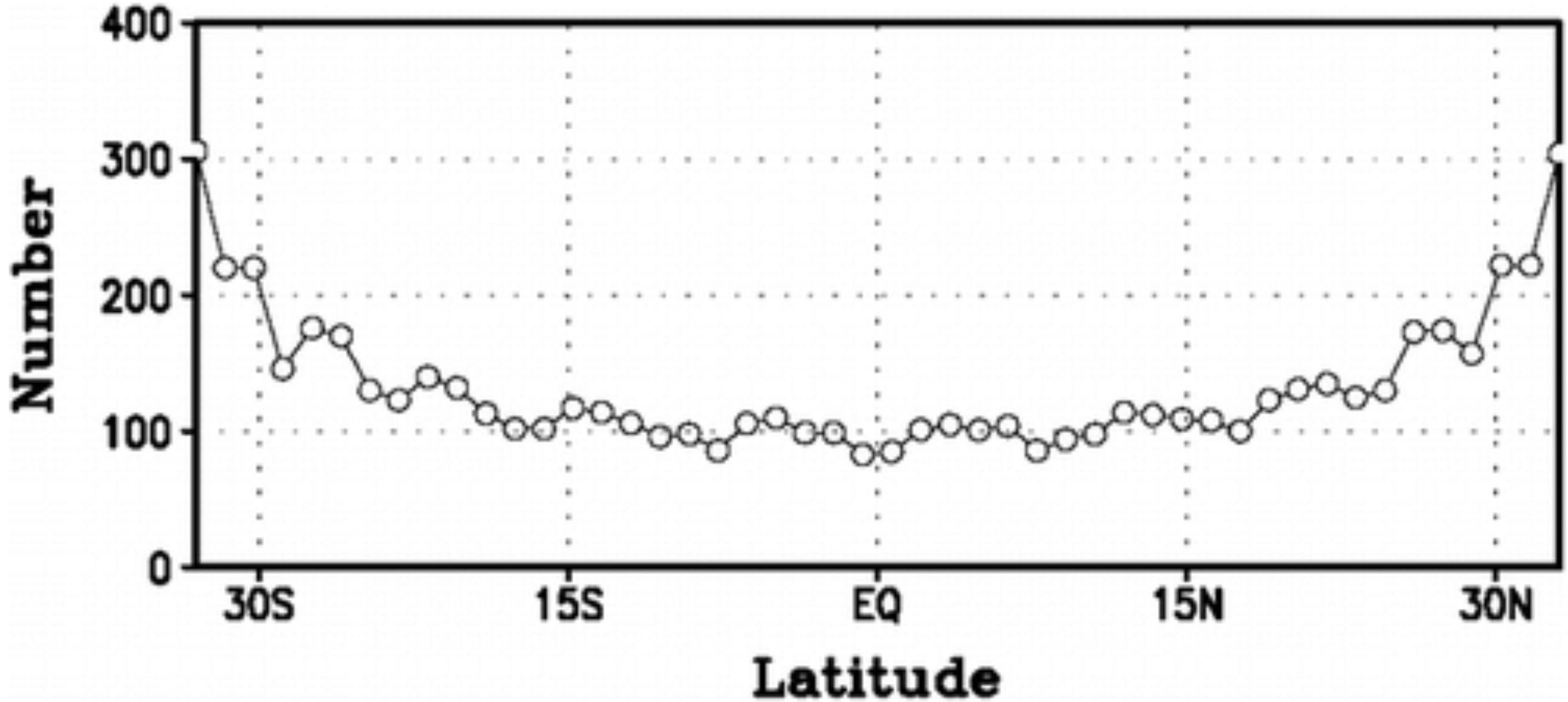
Krishnamurti, T. N., Arindam Chakraborty, A. K. Mishra, 2010: **Improving Multimodel Forecasts of the Vertical Distribution of Heating Using the TRMM Profiles.** ***J. Climate*****, 23, 1079–1094.**

Results based on global models

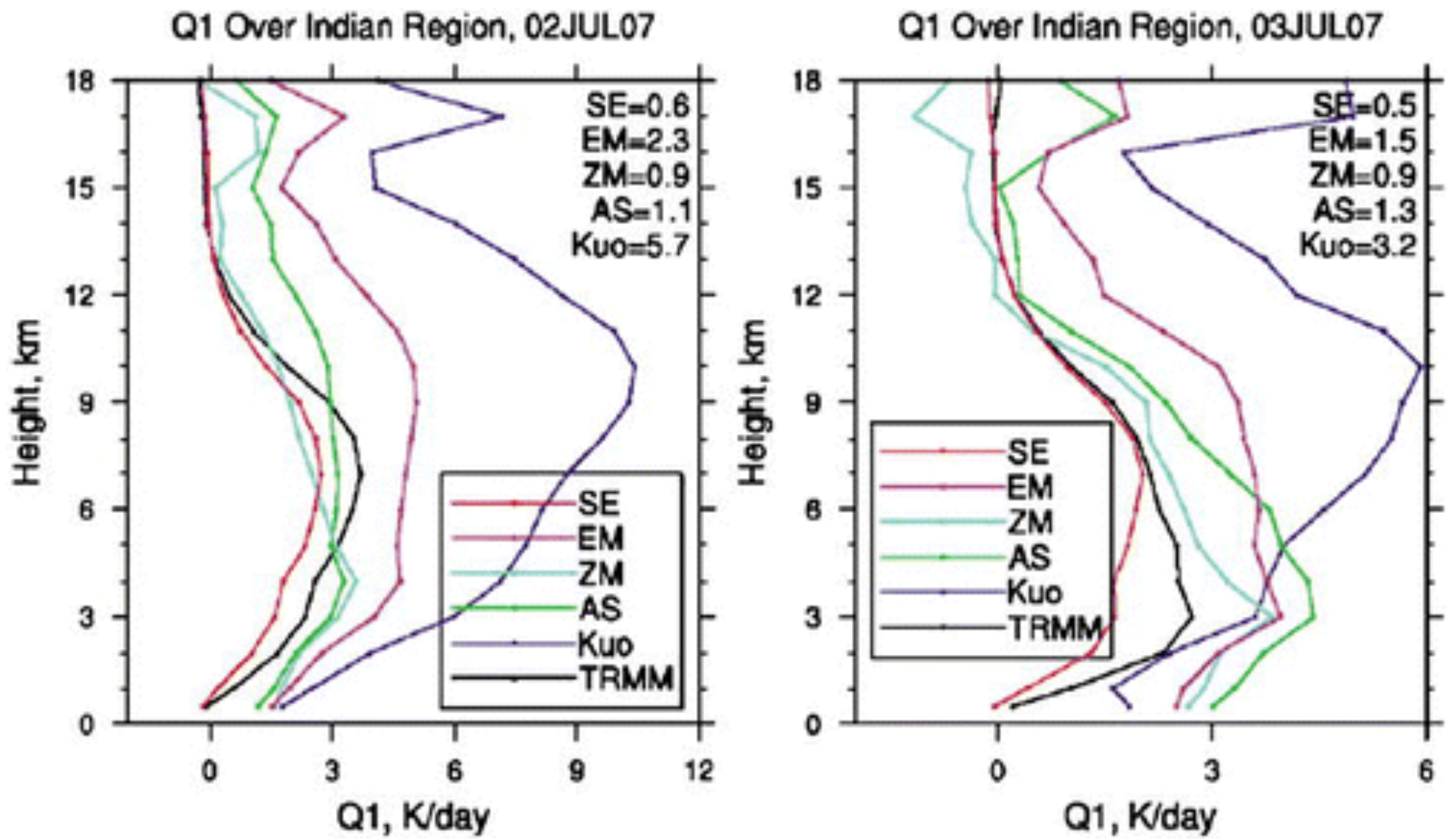
Application of superensemble methodology on Advanced Research WRF



Variation of number of training data points at every 2 × 2 grid box as a function of latitude at 180°. This variation is very similar along all other longitudes.

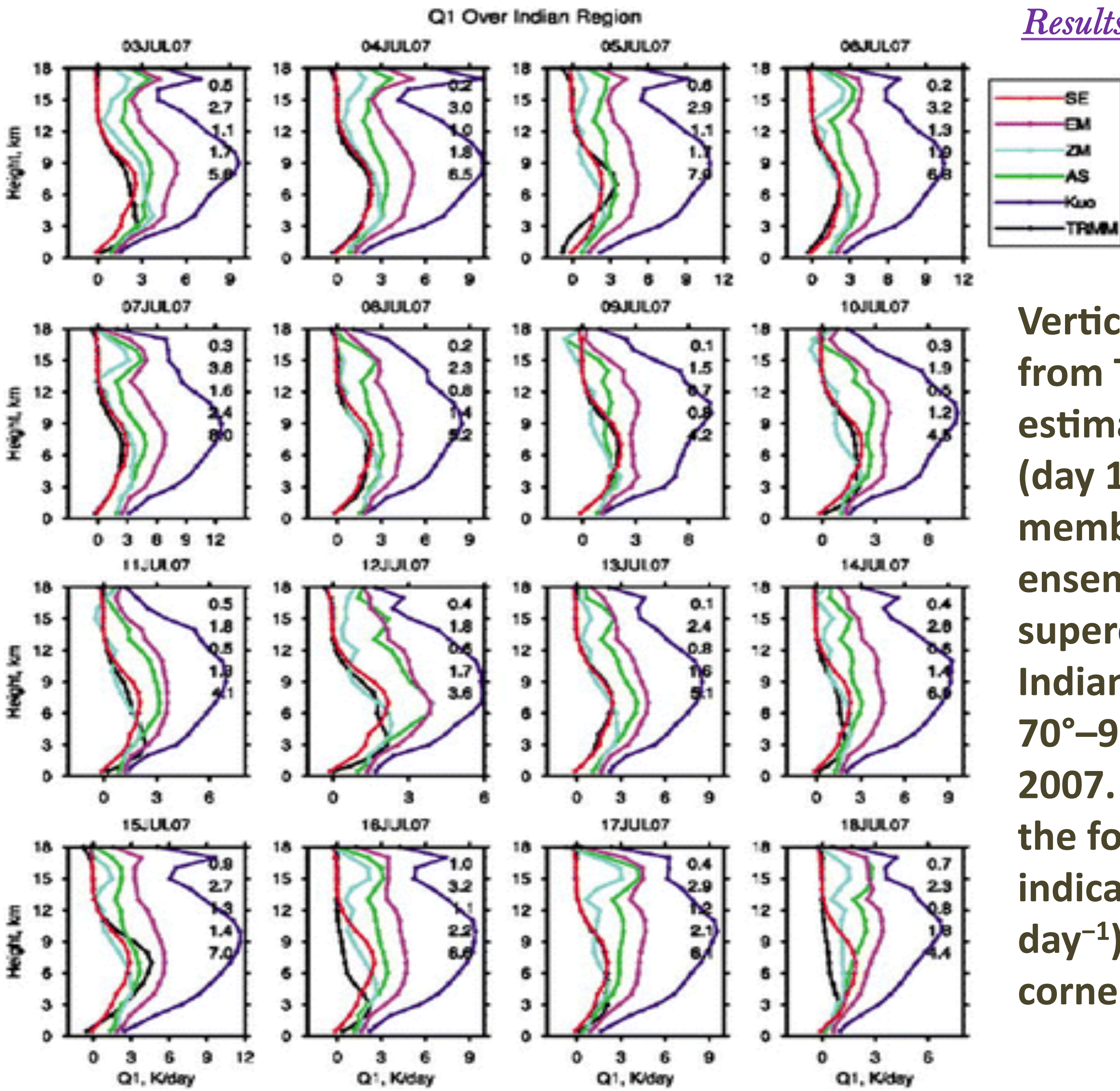


Vertical profile of Q_1 from TRMM PR estimates, and forecasts of three member models, their ensemble mean and the superensemble over the Indian region (5°–25°N, 70°–90°E) during 2 Jul 2007. (left) For 12–36-h forecasts (day 1); (right) for 36–60-h forecasts (day 2). The RMS errors of the forecast fields are indicated as numbers (K day^{-1}) at the top right corner of the panels.



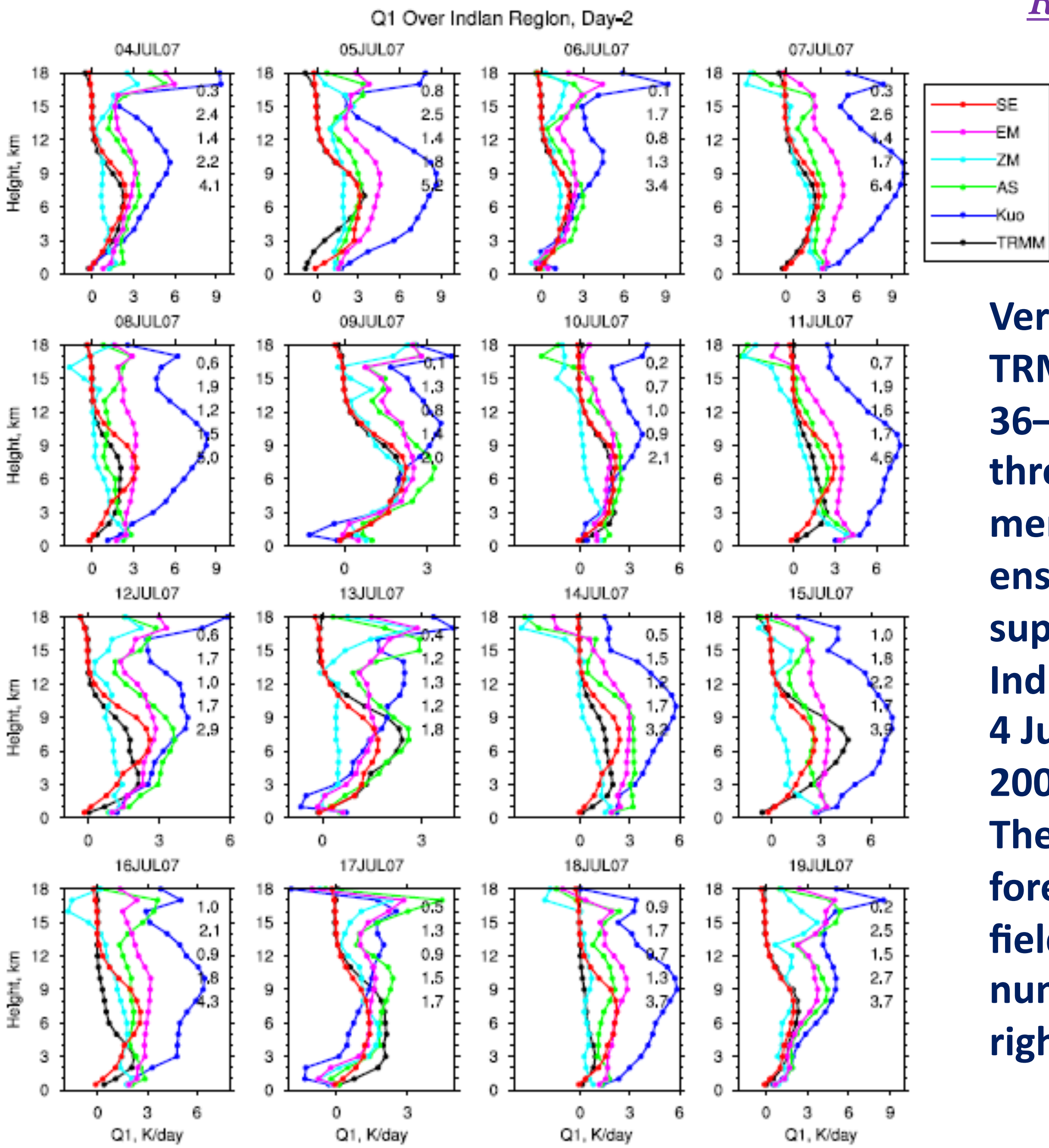
Results based on global models

Results based on global models



Vertical profile of Q1 from TRMM PR estimates, and 12–36-h (day 1) forecasts of three member models, their ensemble mean, and the superensemble over the Indian region (5°–25°N, 70°–90°E) during 3–18 Jul 2007. The RMS errors of the forecast fields are indicated as numbers (K day^{-1}) at the top right corner of the panel.

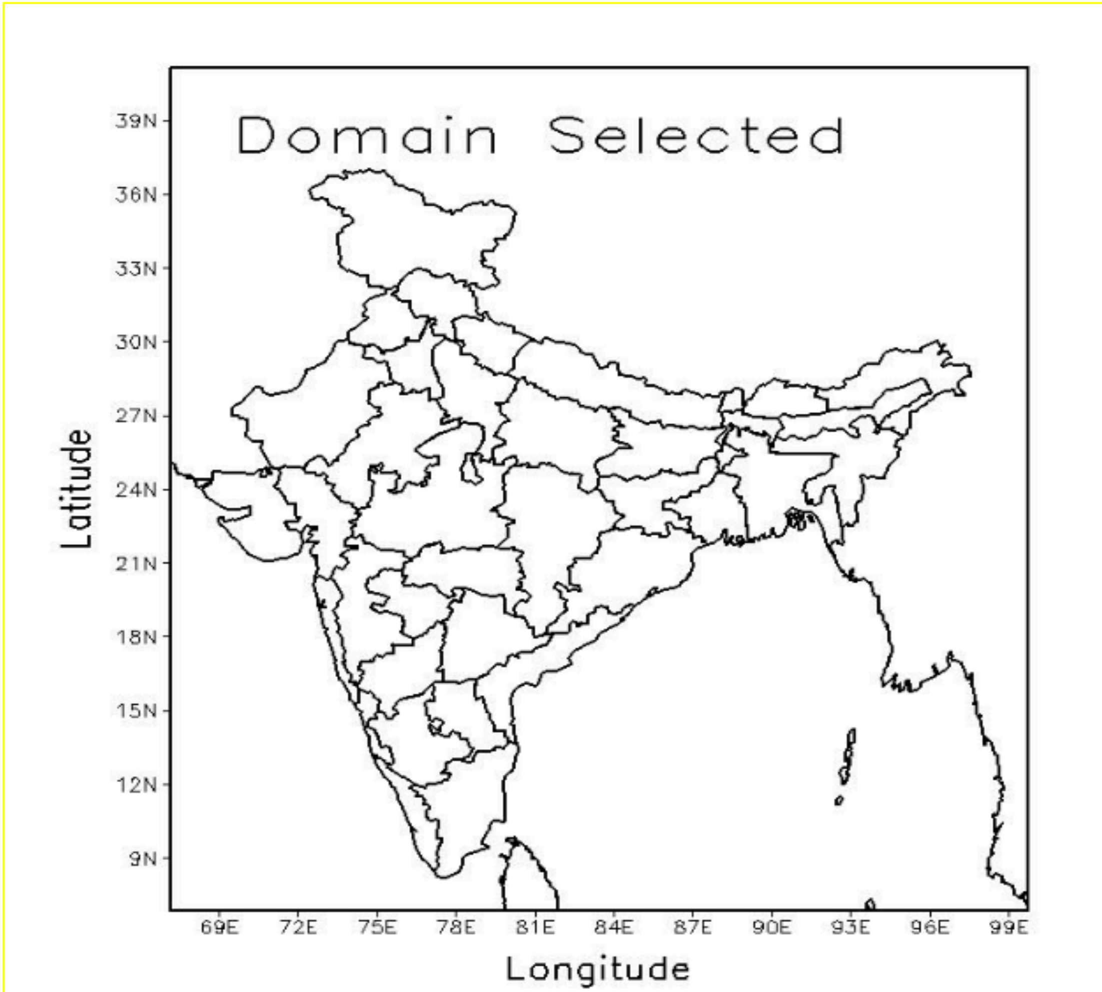
Results based on global models



Vertical profile of Q1 from TRMM PR estimates, and 36–60 hour forecasts of three member models, their ensemble mean and the superensemble over the Indian region during 4 July 2007 through 19 July 2007 for day-2 of forecasts. The RMS errors of the forecast fields are indicated as numbers (K/day) at the top right corner of the panel.

Regional Mesoscale Modeling

Single simulation domain 25 km resolution over Indian Domain (67.13E-99.27E, 6.85N-38.01N).



Model	*NCAR Mesoscale model WRF-ARW*
Dynamics	Non-hydrostatic with 3-D Coriolis force
No. of Vertical levels	28
Horizontal Resolution	25 km
Domain of Integration	67.13E-99.27E, 6.85N-38.01N
Grid Points	134×141
Map Projection	Mercator
Integration Time-Step	100 Sec
Initial and Boundary conditions	FNL $1^{o}\times1^{o}$ Forecast
Boundary conditions updating	12 hourly

Table 1a: Model Configuration

Training phase June, July 2004; June 2005

Forecast phase July, August 2005

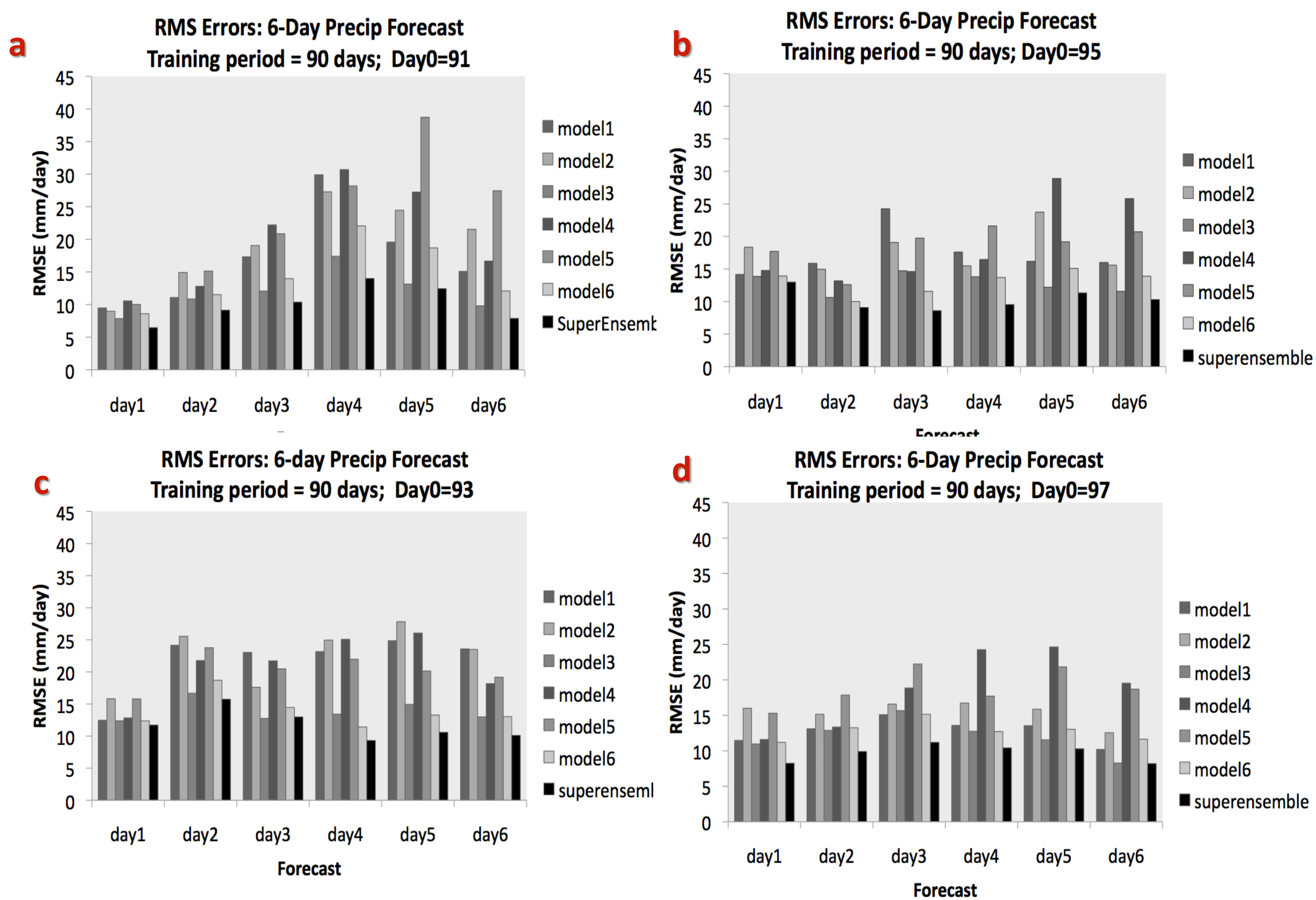
Table 1b: list of physical parameterization schemes used for model simulations

Variable Parameterization	***Fixed parameterization (FP)***
Microphysics (**MP**):	Surface: NOAH LSM (4 subsoil layers)
1. Kessler Scheme (**MP1**)	PBL: YSU Scheme
2. WRF Single Moment 5-class (WSM5) (**MP2**)	Surface layer: Monin-Obukhov Scheme
Cumulus Parameterization (**CP**):	Radiation Parameterizations:
1. Kain-Fritsch Scheme (**CP1**)	1. Short wave (Dudhia)
2. Betts-Miller-Janjic Scheme (**CP2**)	2. Long wave (RRTM)
3. Grell Devenyi ensemble Scheme (**CP3**)	

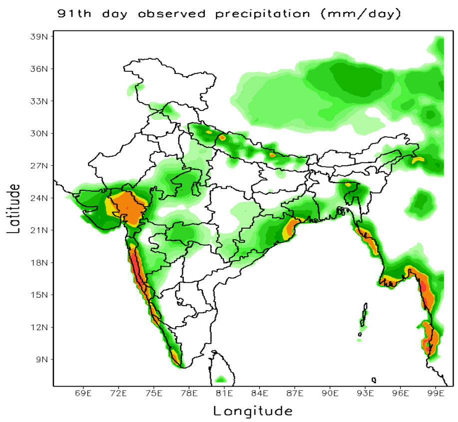
FP +MP1+CP1	Model1
FP +MP1+CP2	Model2
FP +MP1+CP3	Model3
FP +MP2+CP1	Model4
FP +MP2+CP2	Model5
FP +MP2+CP3	Model6

Table 1c: Model Configuration for six experiments.

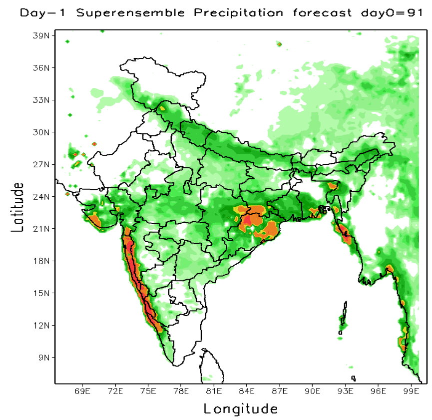
Comparison of RMS error of Superensemble and six models precipitation forecast for 6-Day with initial conditions (a) Day0=91, (b) Day0=93, (c) Day0=95, (d) Day0=97 6-Day RMS Errors for forecast days 91,93,95, and 97 are shown here.



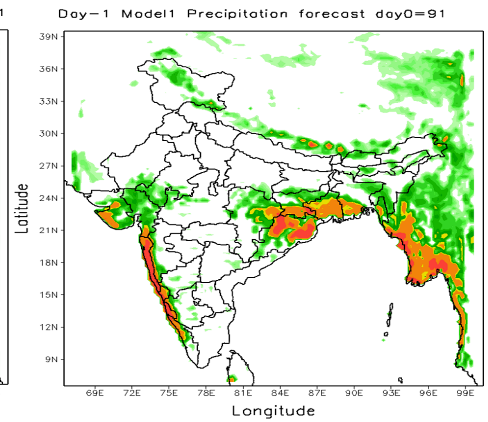
Day -1, Total rainfall (mm/day): (a) Observed Precipitation, (b) Superensemble Forecast, (c) to (h) are Models forecasts based on physical parameterization (Day0=91)



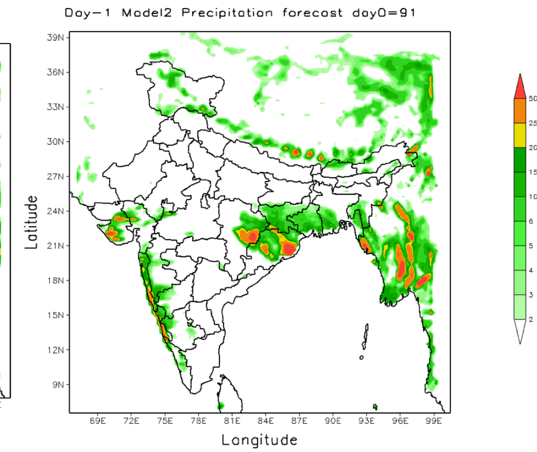
(a) Observed Rainfall (mm/day)



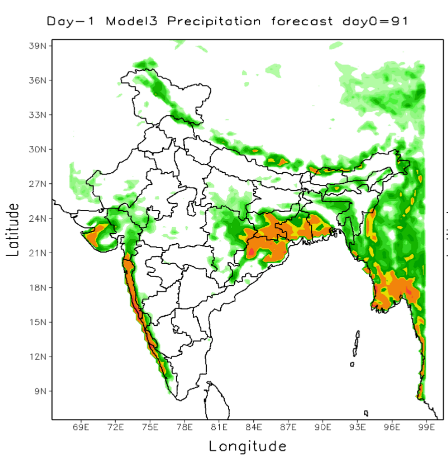
(b) Superensemble Rainfall (CC=0.59)



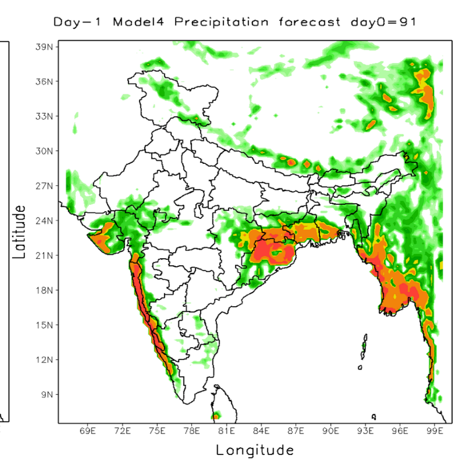
(c) Model1 Rainfall (CC=0.43)



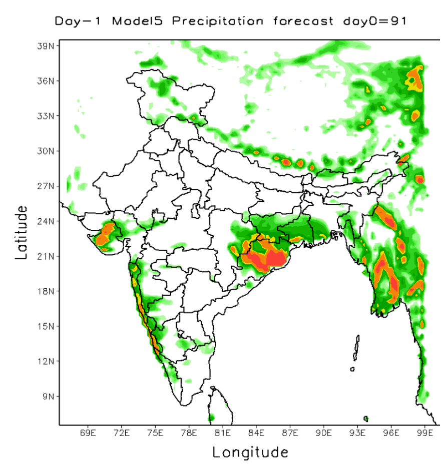
(d) Model 2 Rainfall (CC=0.22)



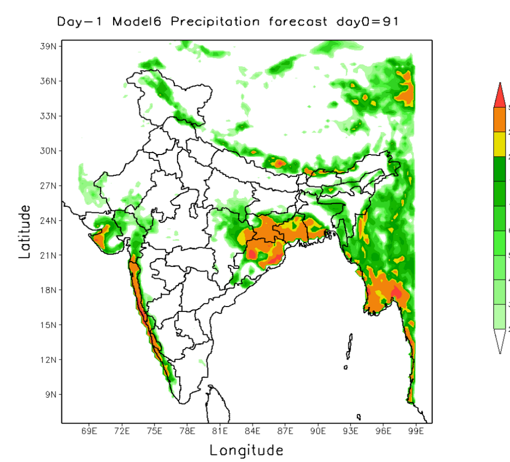
(e) Model3 Rainfall (CC= 0.38)



(f) Model4 Rainfall (CC=0.40)

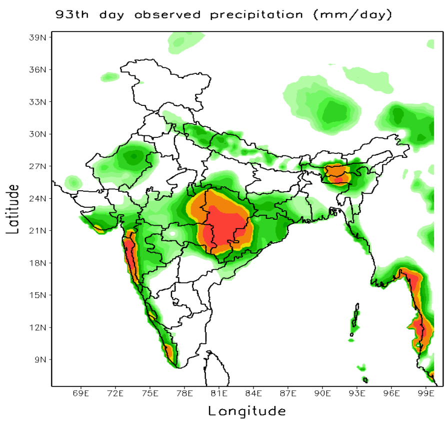


(g) Model5 Rainfall (CC=0.23)

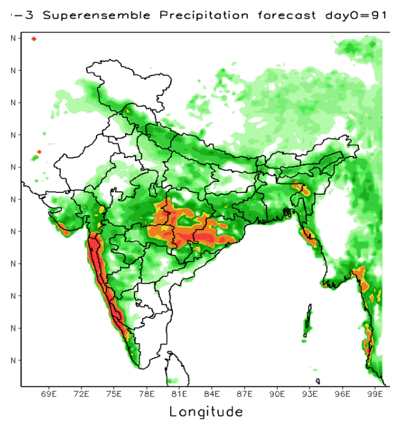


(h) Model6 Rainfall (CC=0.47)

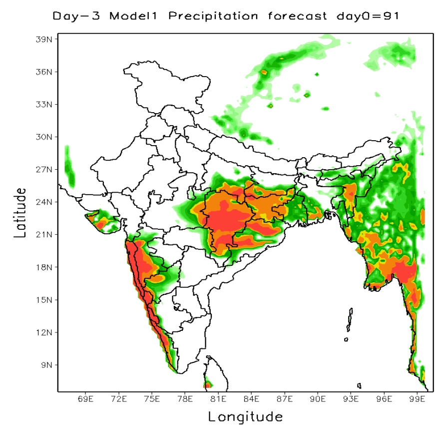
Day -3, Total rainfall (mm/day): (a) Observed Precipitation, (b) Superensemble Forecast, (c) to (h) are Models forecasts based on physical parameterization (Day0=91)



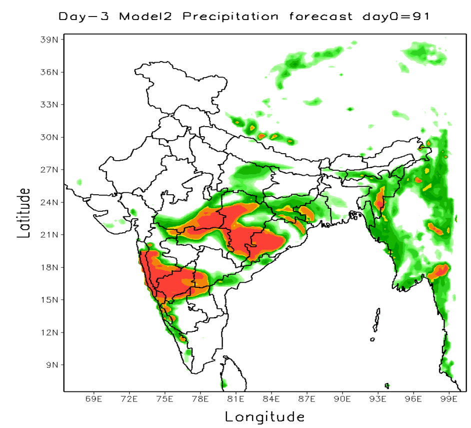
(a) Observed Rainfall (mm/day)



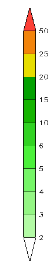
(b) Superensemble Rainfall (CC=0.63)

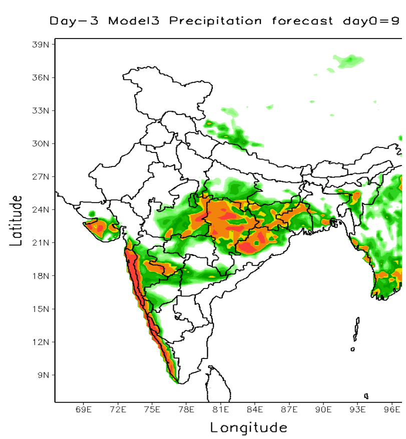


(c) Model1 Rainfall (CC=0.53)

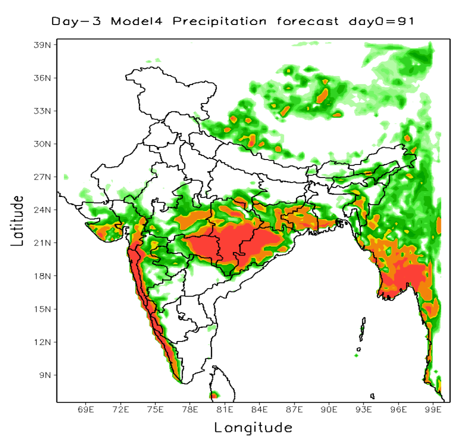


(d) Model 2 Rainfall (CC=0.48)

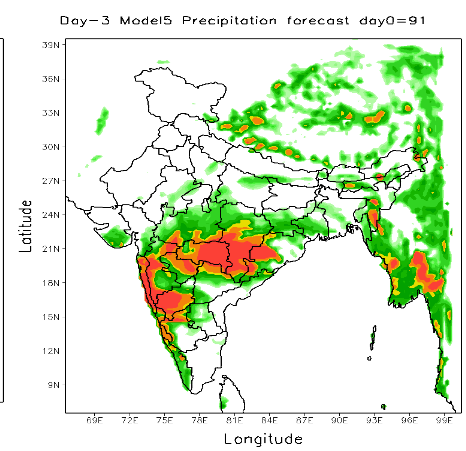




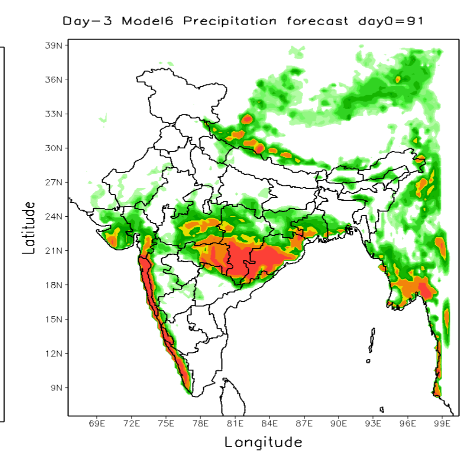
(e) Model3 Rainfall (CC= 0.44)



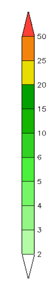
(f) Model4 Rainfall (CC=0.63)



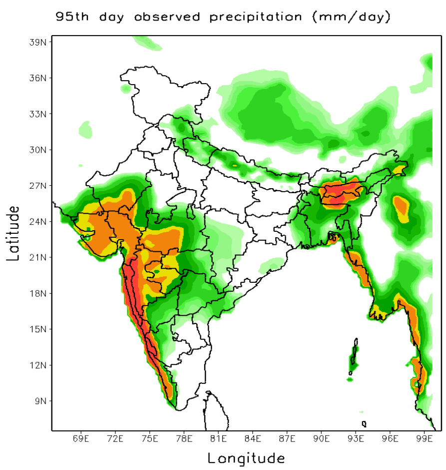
(g) Model5 Rainfall (CC=0.48)



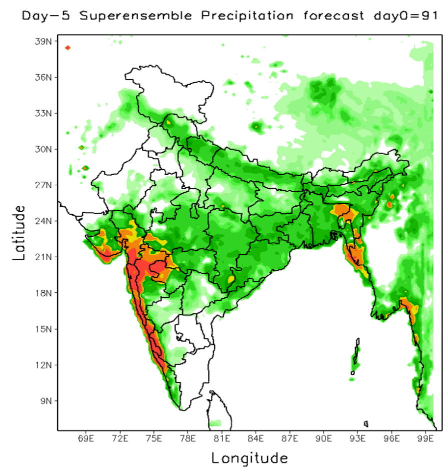
(h) Model6 Rainfall (CC=0.60)



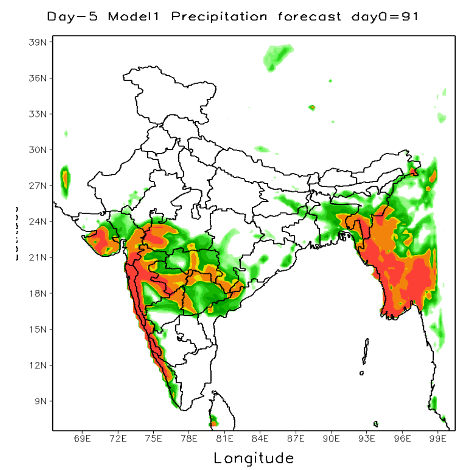
Day -5, Total rainfall (mm/day): (a) Observed Precipitation, (b) Superensemble Forecast, (c) to (h) are Models forecasts based on physical parameterization (Day0=91)



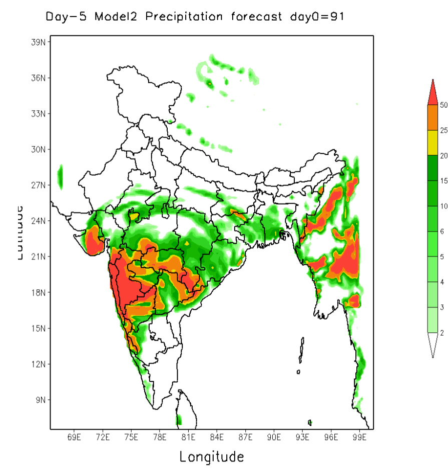
(a) Observed Rainfall (mm/day)



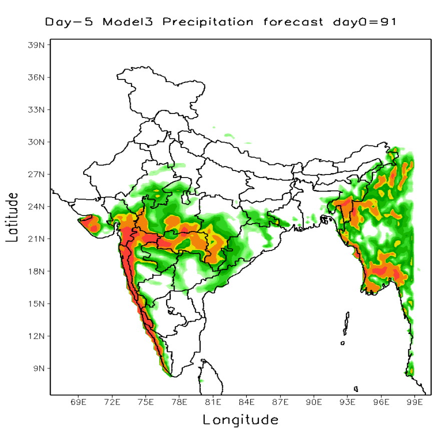
(b) Superensemble Rainfall (CC=0.67)



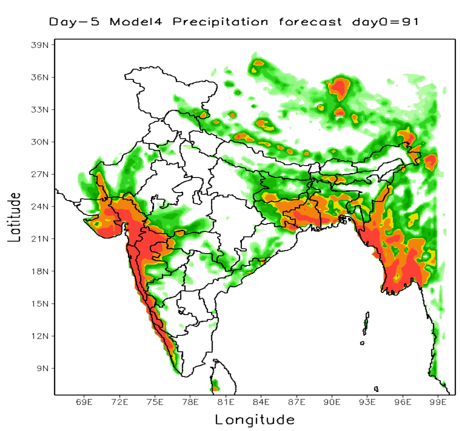
(c) Model1 Rainfall (CC=0.54)



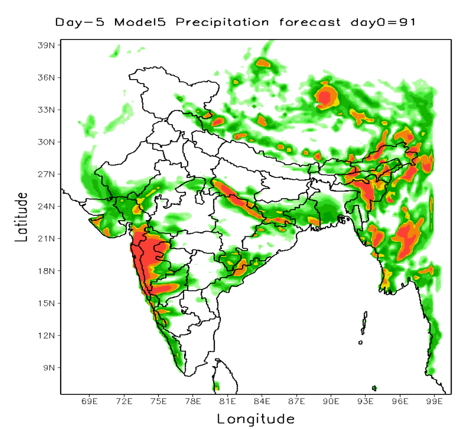
(d) Model 2 Rainfall (CC=0.57)



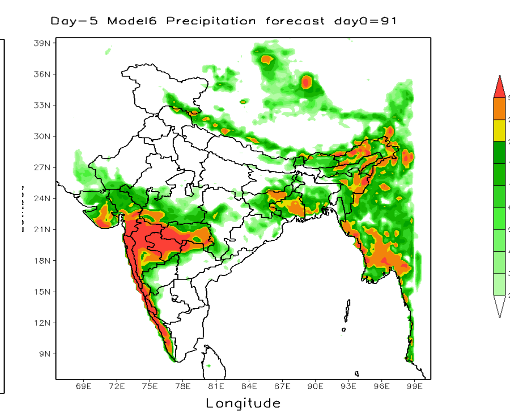
(e) Model3 Rainfall (CC= 0.60)



(f) Model4 Rainfall (CC=0.49)

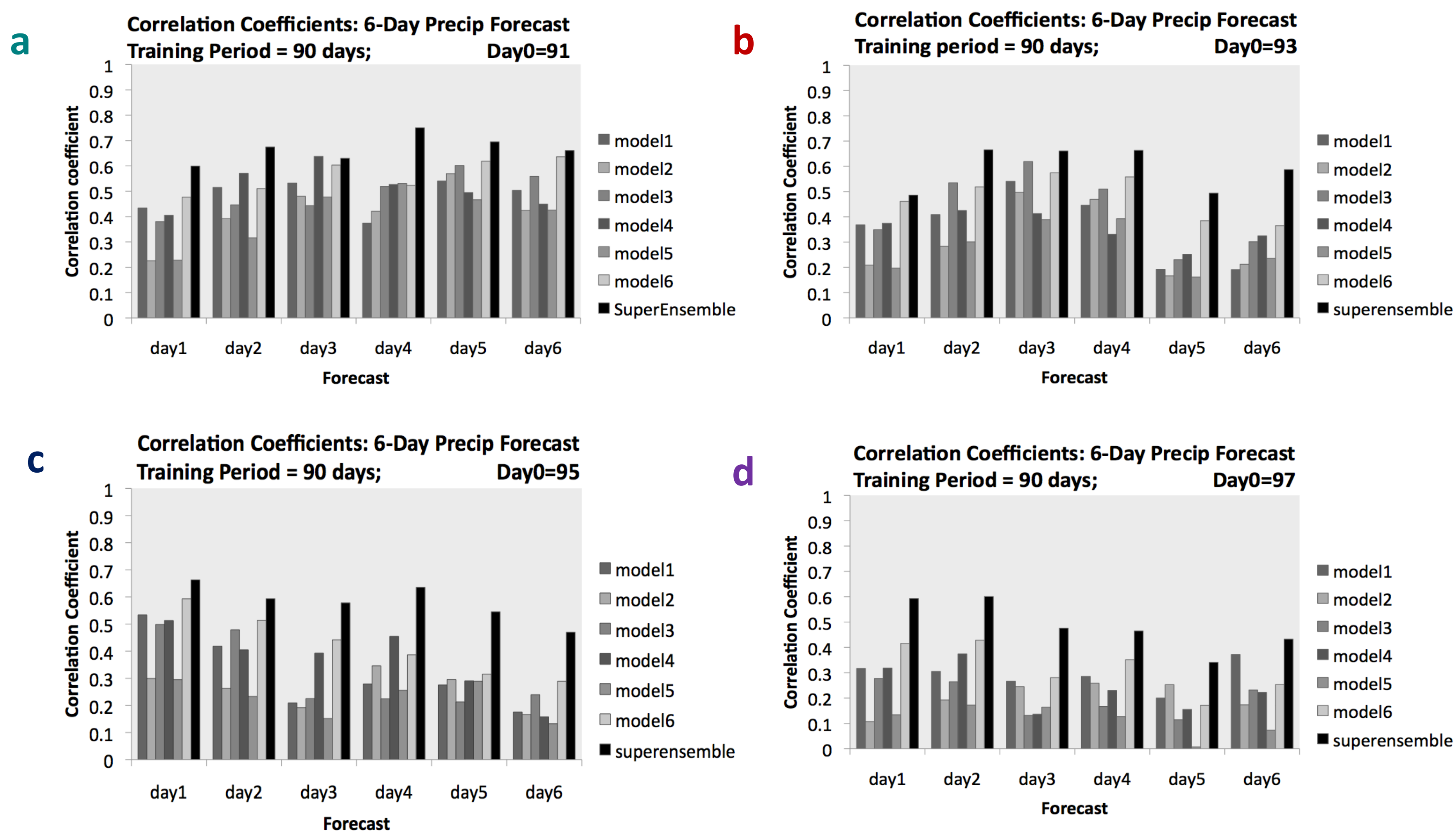


(g) Model5 Rainfall (CC=0.47)

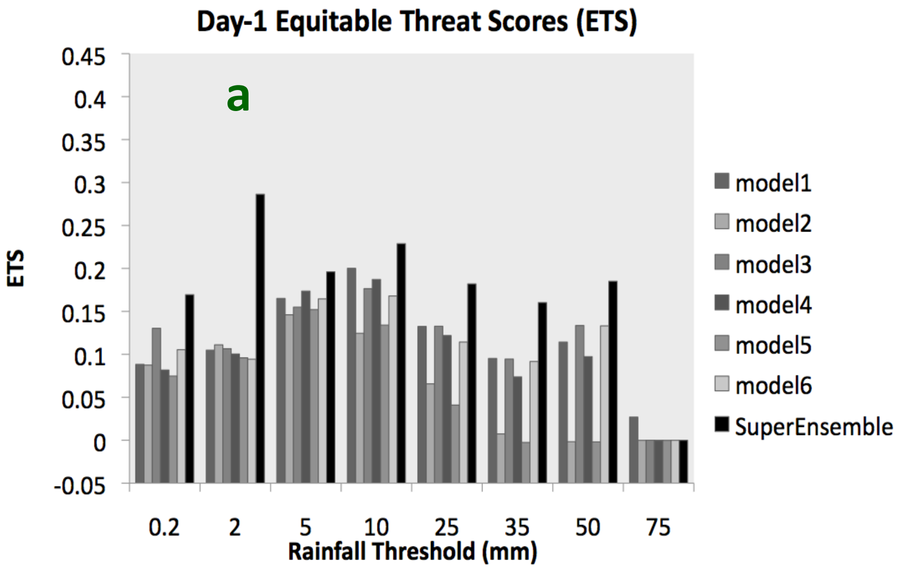


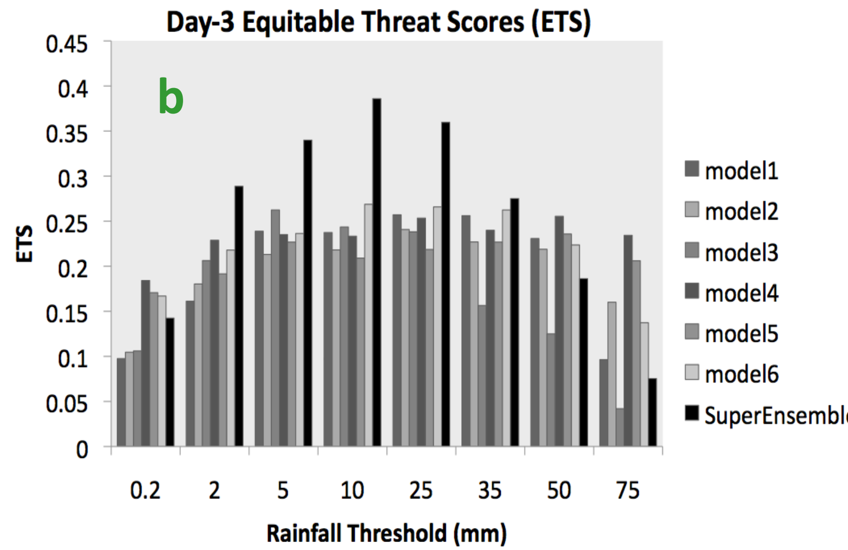
(h) Model6 Rainfall (CC=0.62)

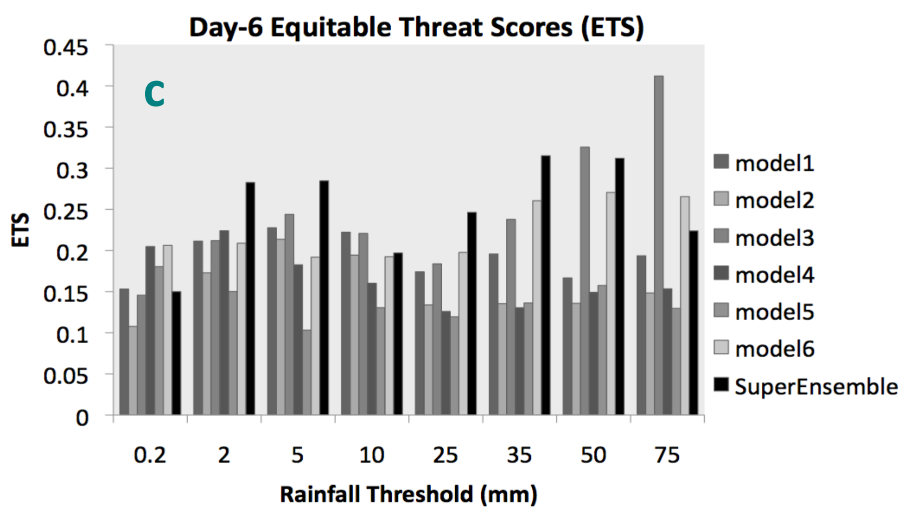
Comparison of Spatial Correlation Coefficients of Superensemble and six Model forecasts from Day 1 to Day 6 with initial conditions (a) Day0=91, (b) Day0=93, (c) Day0=95, (d) Day0=97



Equitable Threat Scores (ETS), (a) Day-1, (b) Day-3, (c) Day-5, (Day0=91)

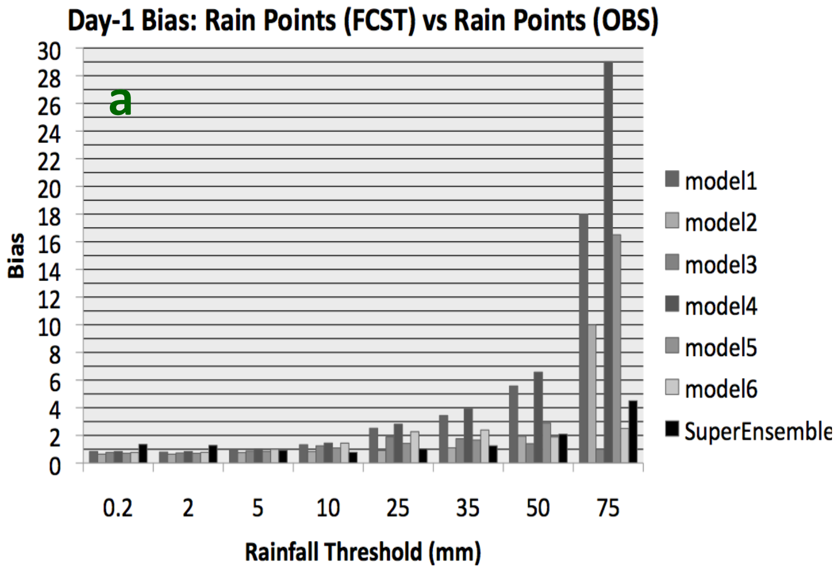


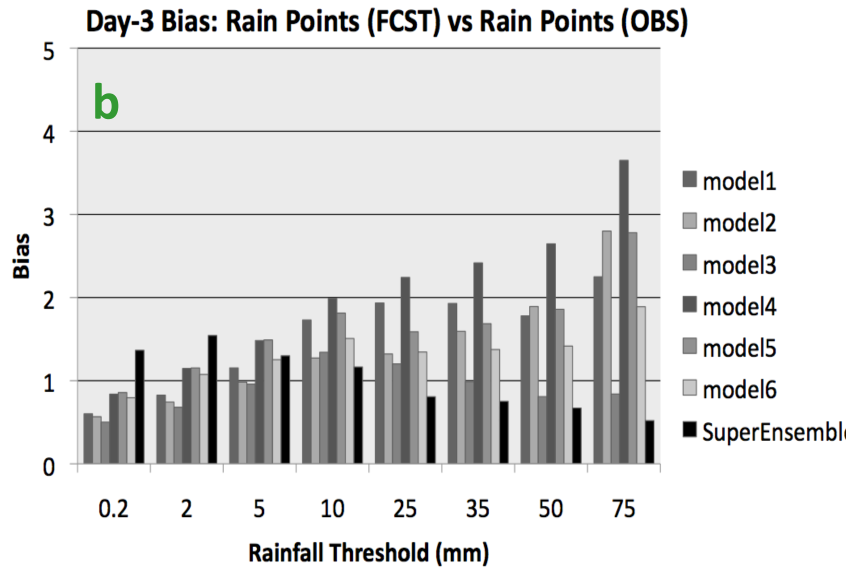


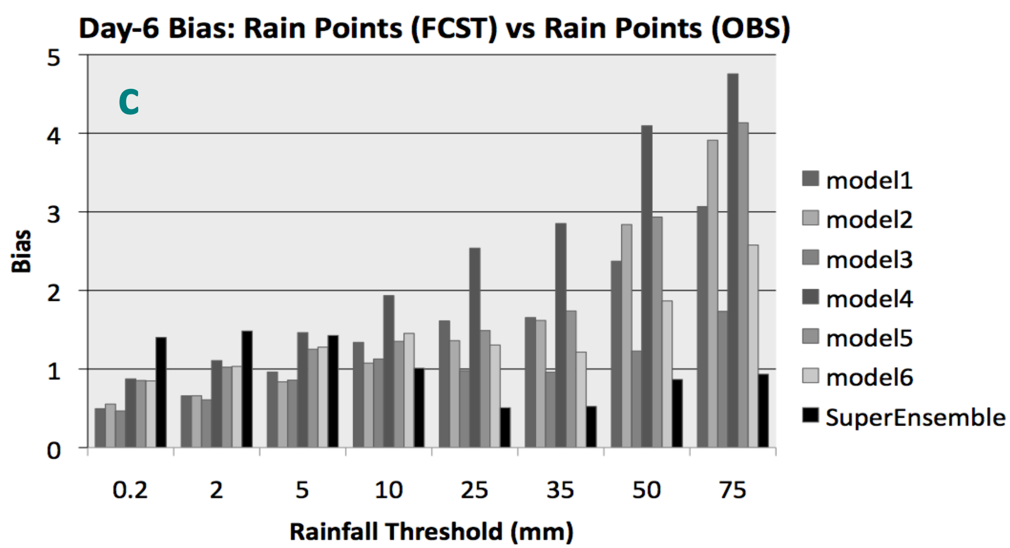


Equitable Threat Scores (ETS-Bias Score),

(a) Day-1, (b) Day-3, (c) Day-5, (Day0=91)







Appendix-1: Definition of statistical parameters

$$RMS\ Error = \left[\frac{1}{N}\sum_{n=1}^{N}(f_n - o_n)^2\right]^{\frac{1}{2}}$$

$$Bias = \frac{N_f}{N_o}$$

$$Equitable\ threat\ score = \frac{H - (F \times \frac{O}{N})}{F + O - H - (F \times \frac{O}{N})}$$

$$Correlation\ Coefficient = \frac{\sum_{n=1}^{N}\left[(f_n - \overline{f})(o_n - \overline{o})\right]}{\left[\sum_{n=1}^{N}(f_n - \overline{f})^2 \sum_{n=1}^{N}(o_n - \overline{o})^2\right]^{\frac{1}{2}}}$$

In these expressions:

N = number of grid points

f_n = forecast value at grid point n

o_n = observed value at grid point

$\overline{f}$ = area mean of the forecasted values

$\overline{o}$ = area mean of the observed values

F = area where event is forecasted

O = area where event is observed

H = hit area, or overlap of areas F and O

N_f = number of grid points where event is forecasted

N_o = number of grid points where event is observed

Appendix-2: Mathematical Derivation of Superensemble methodology

$$G = \sum_{t=1}^{T} (s_t - o_t)^2 \qquad \ldots \qquad (1)$$

$$s_t = \sum_{i=1}^{N_{\mathrm{mod}}} a_i (F_{it} - \overline{F}_{it}) + \overline{o}_t \qquad \ldots \qquad (2)$$

Substituting (2) *in* (1) *and* min*imizing* G.

$$G = \sum_{t=1}^{T} \left[\left(\sum_{i=1}^{N_{\mathrm{mod}}} a_i (F_{it} - \overline{F}_{it}) + \overline{o}_t \right) - o_t \right]^2,$$

$$\frac{\partial G}{\partial a_j} = \sum_{t=1}^{T} \frac{\partial}{\partial a_j} \left[\left(\sum_{i=1}^{N_{\mathrm{mod}}} a_i (F_{it} - \overline{F}_{it}) + \overline{o}_t \right) - o_t \right]^2,$$

$$\frac{\partial G}{\partial a_j} = \sum_{t=1}^{T} 2 \left[\left\{ \left(\sum_{i=1}^{N_{\mathrm{mod}}} a_i (F_{it} - \overline{F}_{it}) + \overline{o}_t \right) - o_t \right\} \sum_{i=1}^{N_{\mathrm{mod}}} \frac{\partial a_i}{\partial a_j} (F_{it} - \overline{F}_{it}) \right], \quad \delta_{ij} = \frac{\partial a_i}{\partial a_j},$$

$$0 = \sum_{t=1}^{T} 2 \left[\left\{ \left(\sum_{i=1}^{N_{\mathrm{mod}}} a_i (F_{it} - \overline{F}_{it}) + \overline{o}_t \right) - o_t \right\} \sum_{i=1}^{N_{\mathrm{mod}}} \delta_{ij} (F_{it} - \overline{F}_{it}) \right],$$

rearranging above terms we get

$$\sum_{t=1}^{T} \left[\sum_{i=1}^{N_{\mathrm{mod}}} a_i (F_{it} - \overline{F}_{it})(F_{jt} - \overline{F}_{jt}) \right] = \sum_{t=1}^{T} \left[(o_t - \overline{o}_t)(F_{jt} - \overline{F}_{jt}) \right],$$

$$\sum_{i=1}^{N_{\mathrm{mod}}} a_i \left[\sum_{t=1}^{T} (F_{it} - \overline{F}_{it})(F_{jt} - \overline{F}_{jt}) \right] = \sum_{t=1}^{T} \left[(o_t - \overline{o}_t)(F_{jt} - \overline{F}_{jt}) \right],$$

If we define

$$P_{ji} = \sum_{t=1}^{T} (F_{it} - \overline{F}_{it})(F_{jt} - \overline{F}_{jt}); \quad q_j = \sum_{t=1}^{T} \left[(o_t - \overline{o}_t)(F_{jt} - \overline{F}_{jt}) \right],$$

$$\sum_{i=1}^{N_{\mathrm{mod}}} a_i P_{ji} = q_j \quad \textit{This form can be expended in the matrix form as:}$$

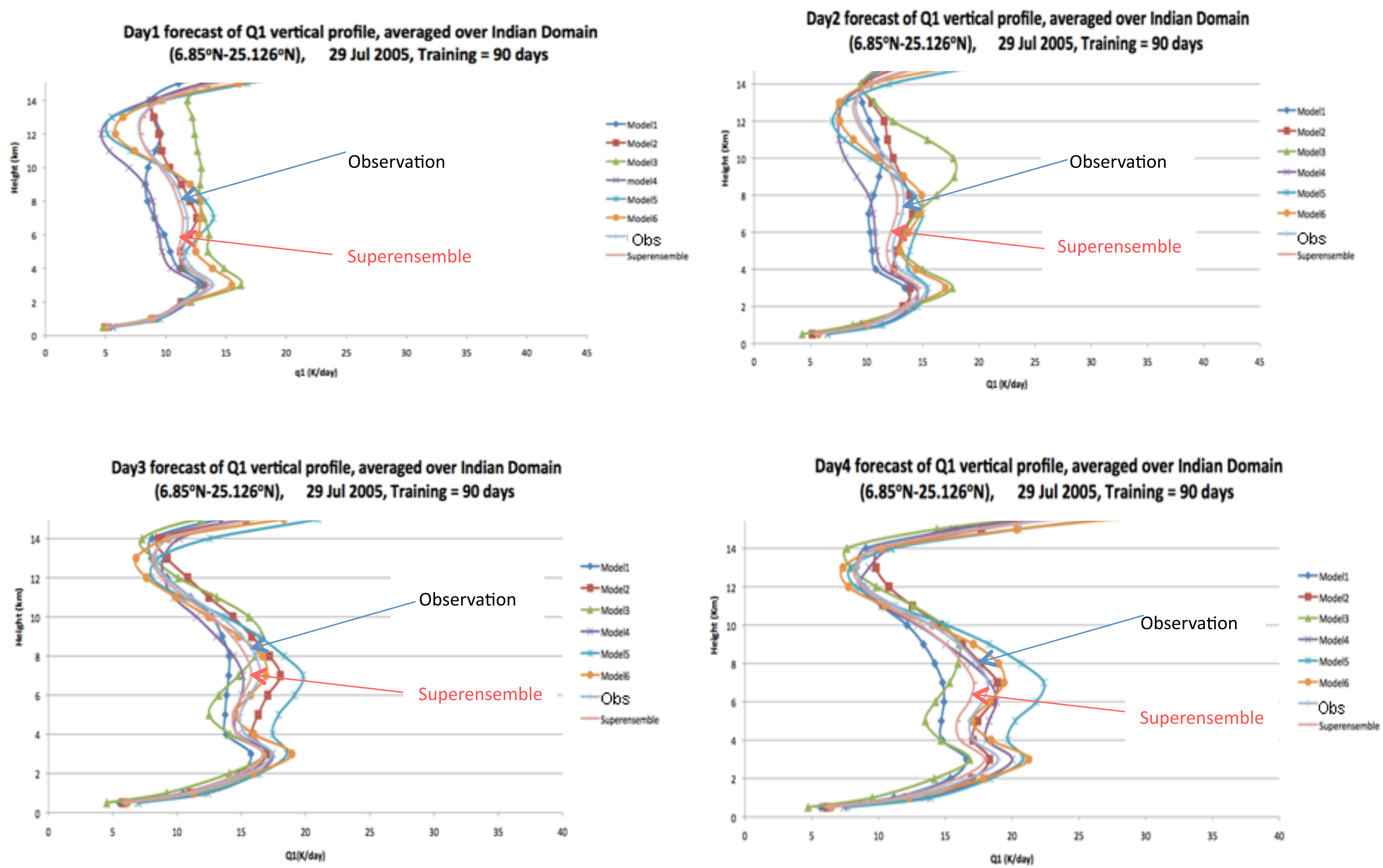
$$\begin{pmatrix} \sum_{t=1}^{T}\left(F_{1t}-\overline{F}_{1t}\right)^2 & \sum_{t=1}^{T}\left(F_{1t}-\overline{F}_{1t}\right)\left(F_{2t}-\overline{F}_{2t}\right) & \dots & \sum_{t=1}^{T}\left(F_{1t}-\overline{F}_{1t}\right)\left(F_{Nt}-\overline{F}_{Nt}\right) \\ \sum_{t=1}^{T}\left(F_{2t}-\overline{F}_{2t}\right)\left(F_{1t}-\overline{F}_{1t}\right) & \sum_{t=1}^{T}\left(F_{2t}-\overline{F}_{2t}\right)^2 & & \vdots \\ \vdots & & \ddots & \vdots \\ \sum_{t=1}^{T}\left(F_{Nt}-\overline{F}_{Nt}\right)\left(F_{1t}-\overline{F}_{1t}\right) & \dots & \cdots & \sum_{t=1}^{T}\left(F_{Nt}-\overline{F}_{Nt}\right)^2 \end{pmatrix} \begin{pmatrix} a_1 \\ \vdots \\ \vdots \\ \vdots \\ a_N \end{pmatrix} = \begin{pmatrix} \sum_{t=1}^{T}\left[(o_t-\overline{o}_t)(F_{1t}-\overline{F}_{1t})\right] \\ \vdots \\ \vdots \\ \sum_{t=1}^{T}\left[(o_t-\overline{o}_t)(F_{Nt}-\overline{F}_{Nt})\right] \end{pmatrix}$$

The equations

$$\sum_{i=1}^{N_{\mathrm{mod}}} a_i P_{ji} = q_j$$

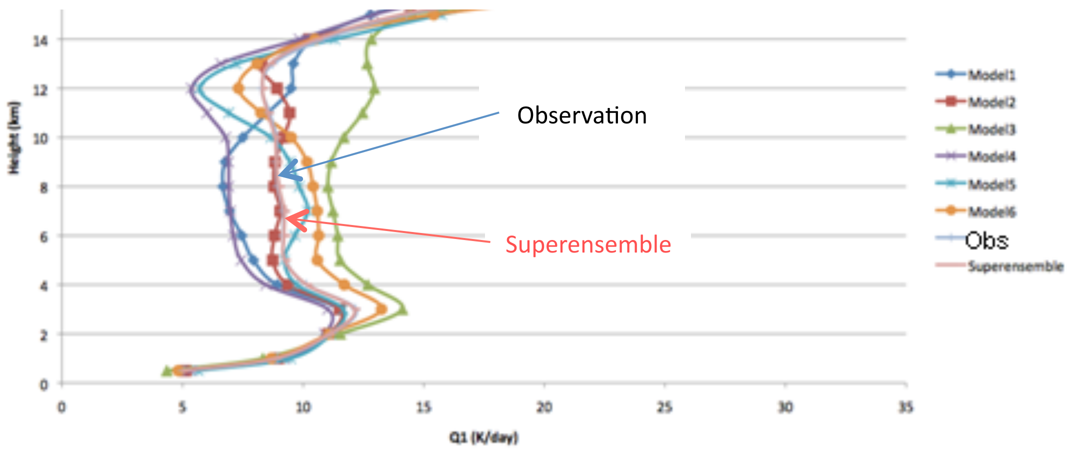
are called the normal equations. The matrix P depends only on the basis functions; it does not involve the values of observed data.

Next we shall look at the multimodel superensemble skills for the apparent heat source Q1 for a suite of mesoscale models

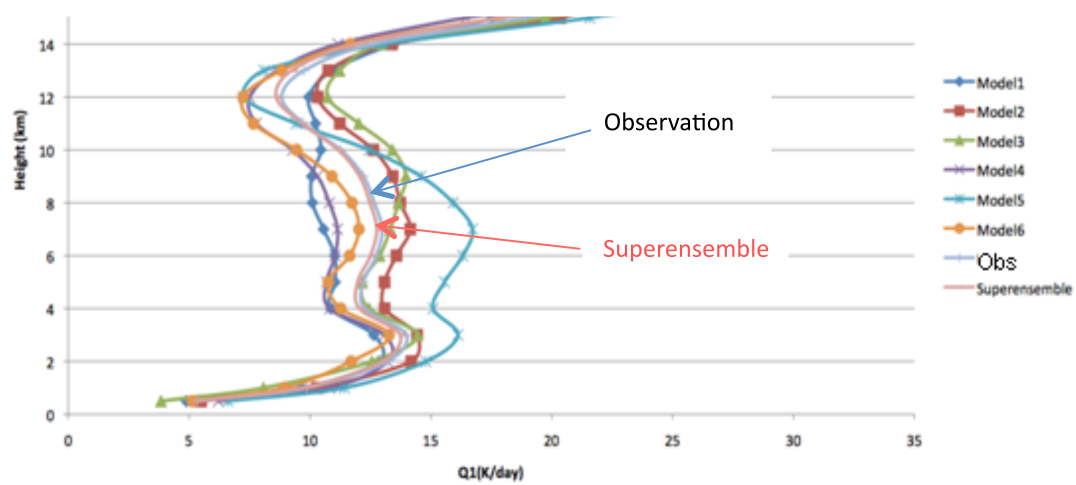


Results based on mesoscale models

Day1 forecast of Q1 vertical profile, averaged over Indian Domain (6.85°N-25.126°N), (97th day or 04 Aug 2005), Training = 90 days

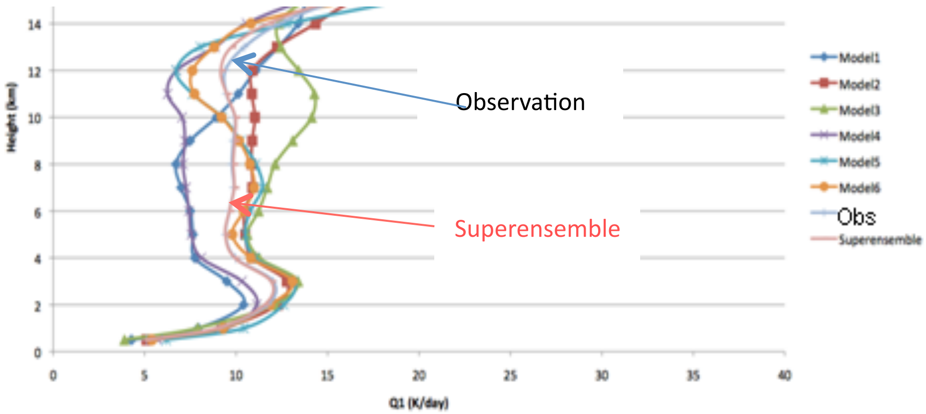


Day3 forecast of Q1 vertical profile, averaged over Indian Domain (6.85°N-25.126°N), (95th day or 02 Aug 2005), Training = 90 days

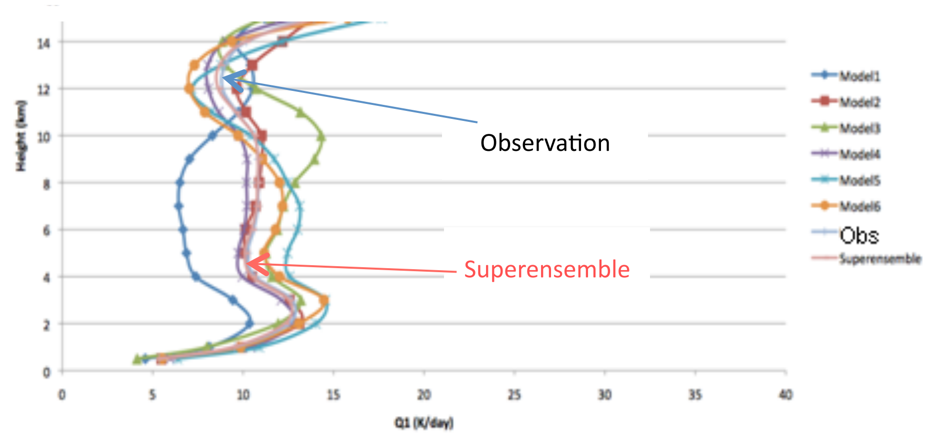


Results based on mesoscale models

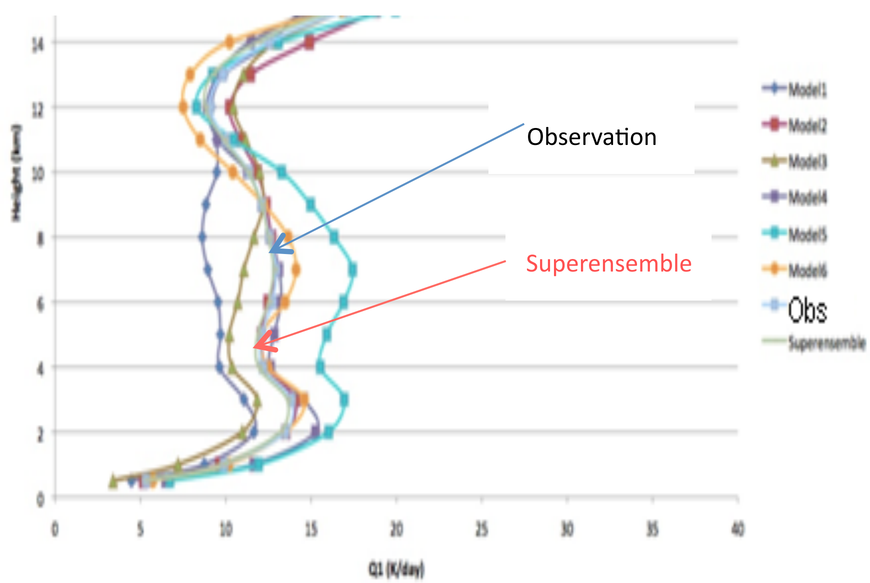
Day2 forecast of Q1 vertical profile, averaged over Indian Domain (6.85°N-25.126°N), (97th day or 04 Aug 2005), Training = 90 days



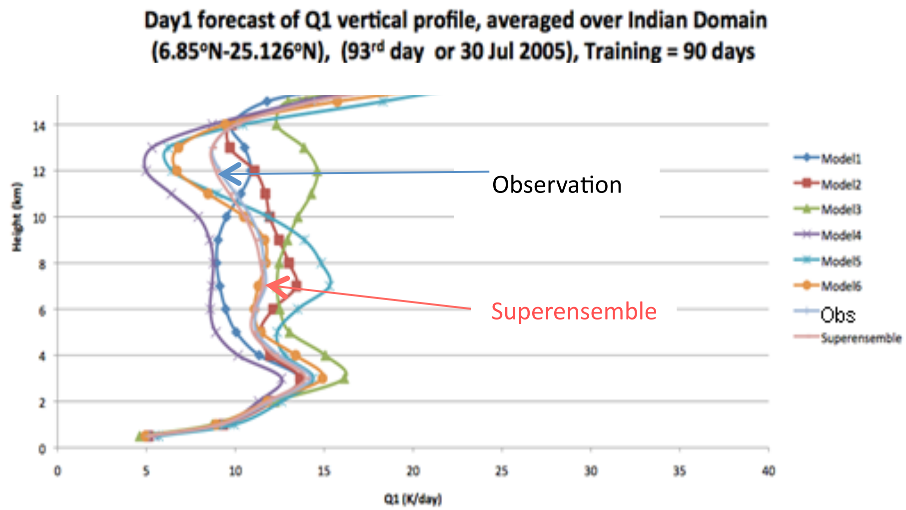
Day3 forecast of Q1 vertical profile, averaged over Indian Domain (6.85°N-25.126°N), (97th day or 04 Aug 2005), Training = 90 days

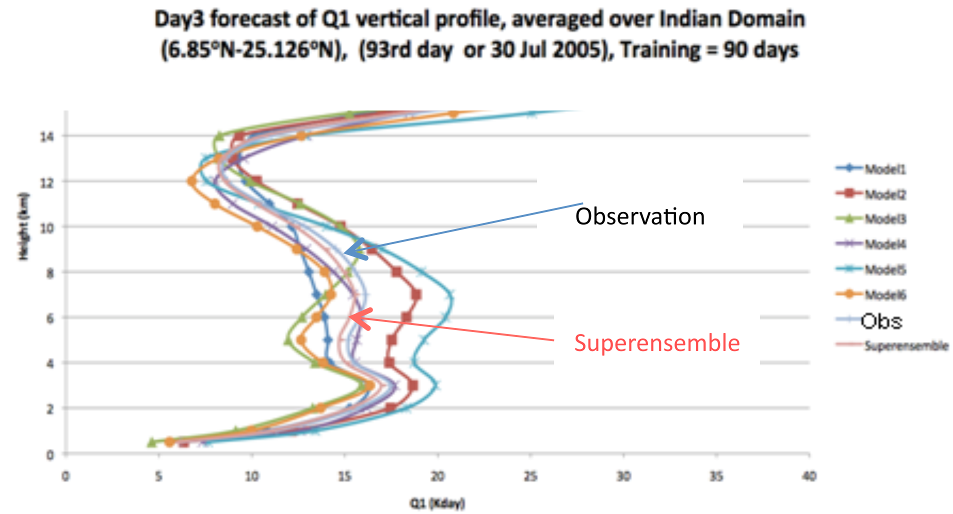


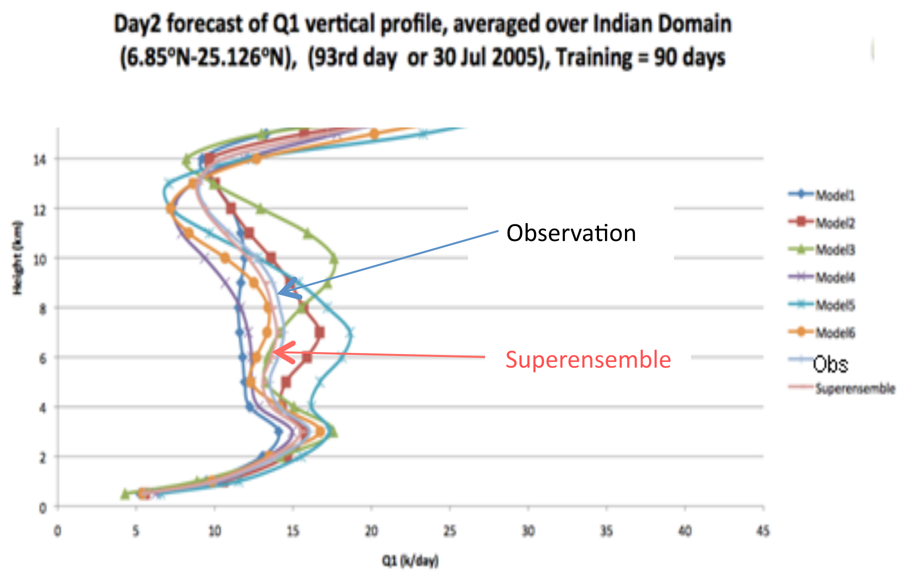
Day4 forecast of Q1 vertical profile, averaged over Indian Domain (6.85°N-25.126°N), (95th day or 02 Aug 2005), Training = 90 days

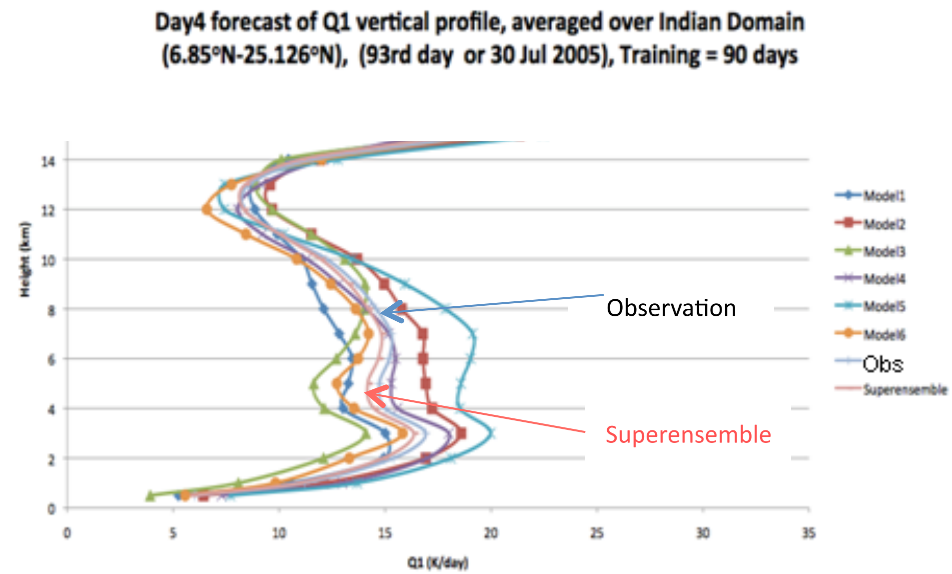


Results based on mesoscale models



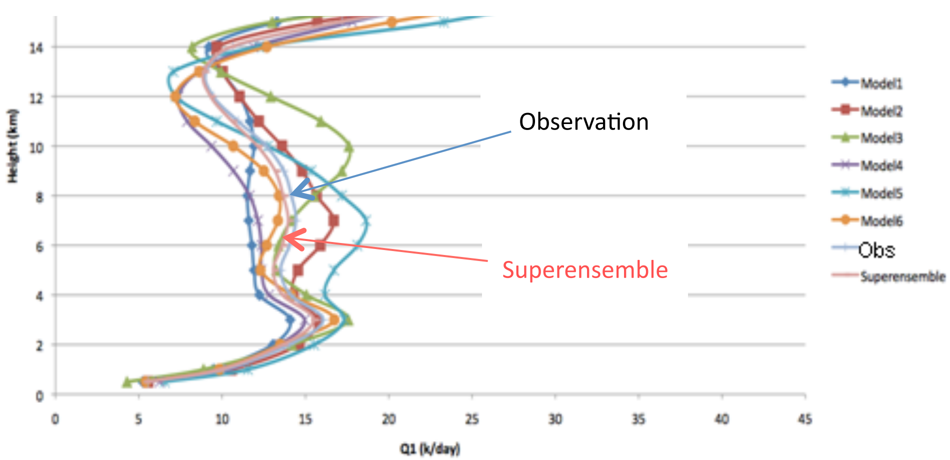




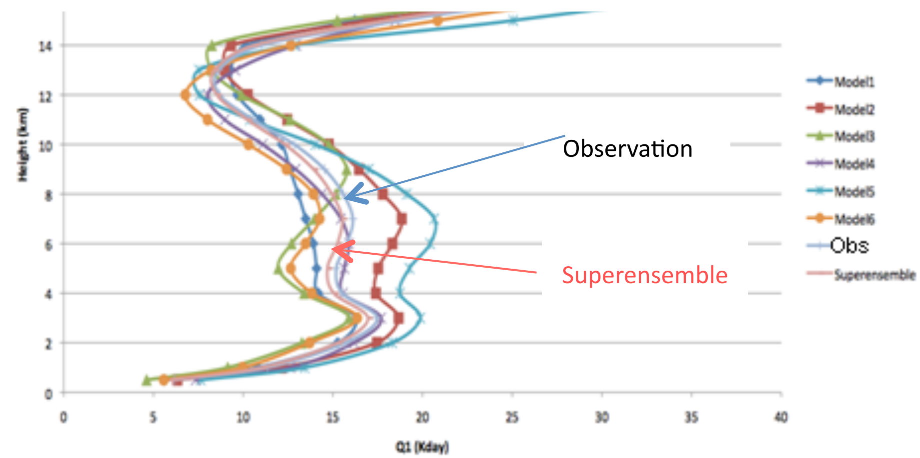


Results based on mesoscale models

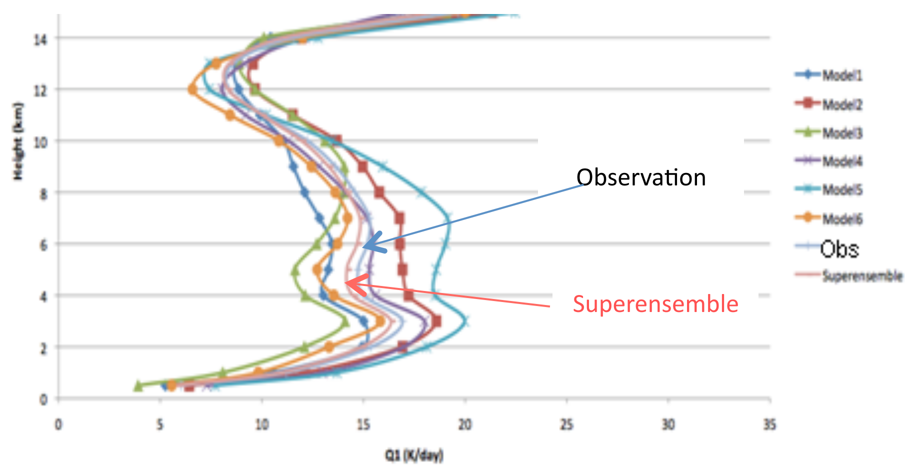
Day2 forecast of Q1 vertical profile, averaged over Indian Domain (6.85°N-25.126°N), (93rd day or 31 Jul 2005), Training = 90 days



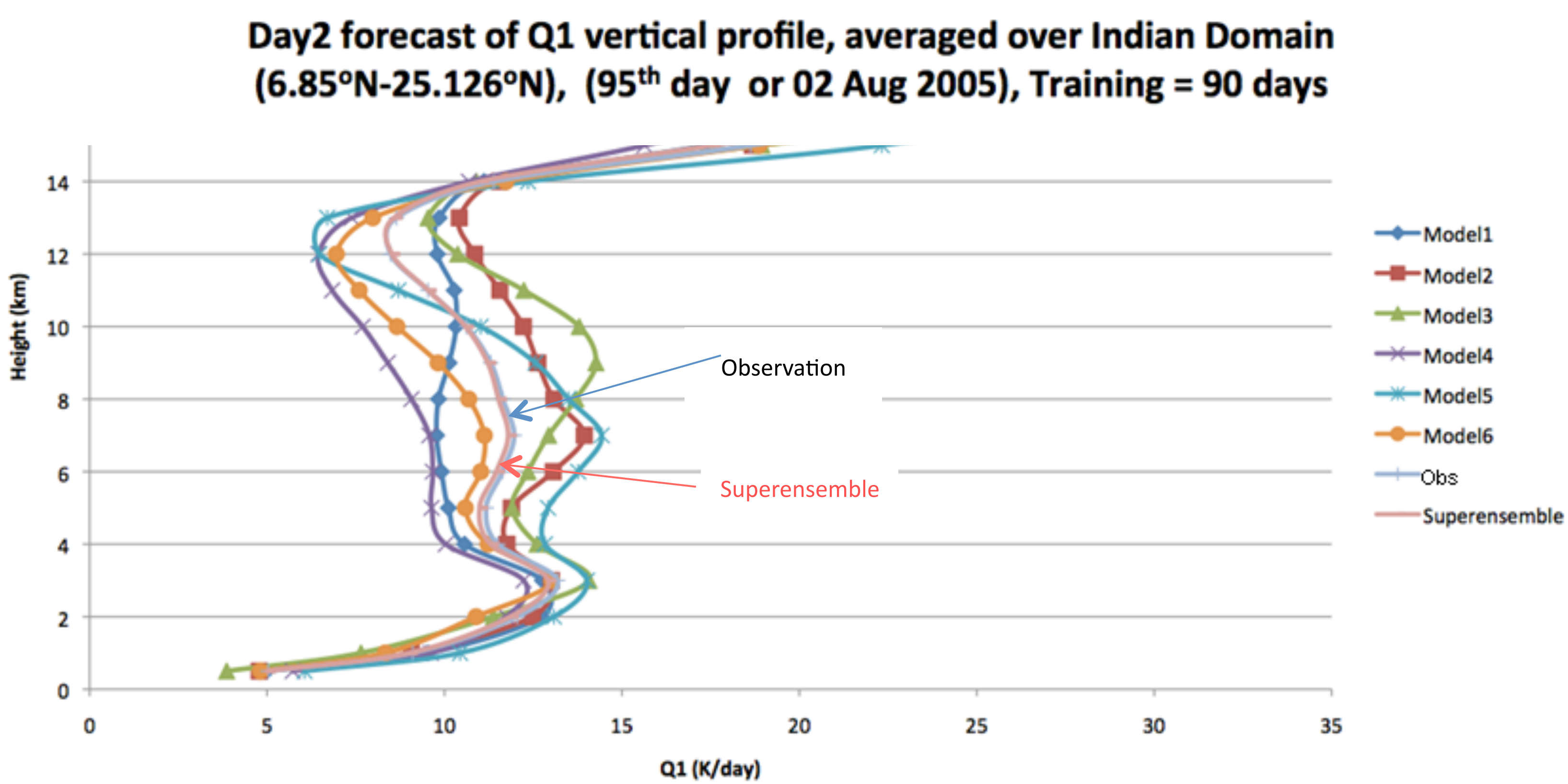
Day3 forecast of Q1 vertical profile, averaged over Indian Domain (6.85°N-25.126°N), (93rd day or 31 Jul 2005), Training = 90 days



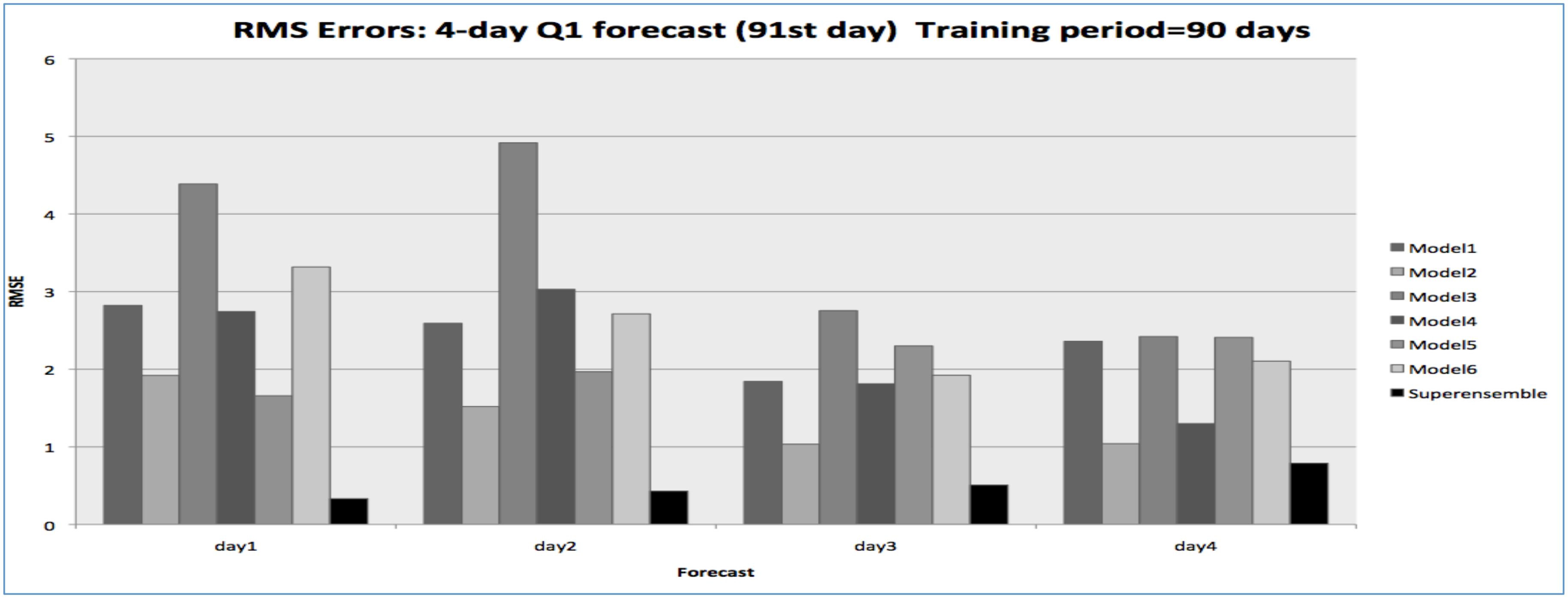
Day4 forecast of Q1 vertical profile, averaged over Indian Domain (6.85°N-25.126°N), (93rd day or 31 Jul 2005), Training = 90 days

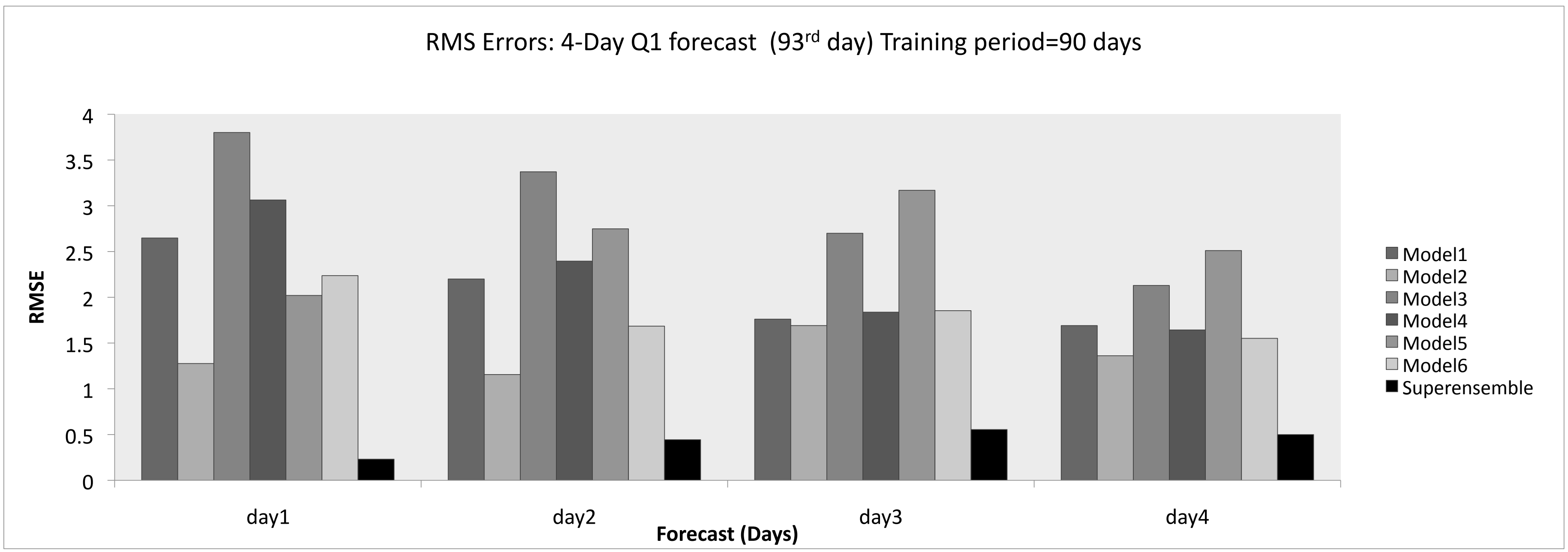


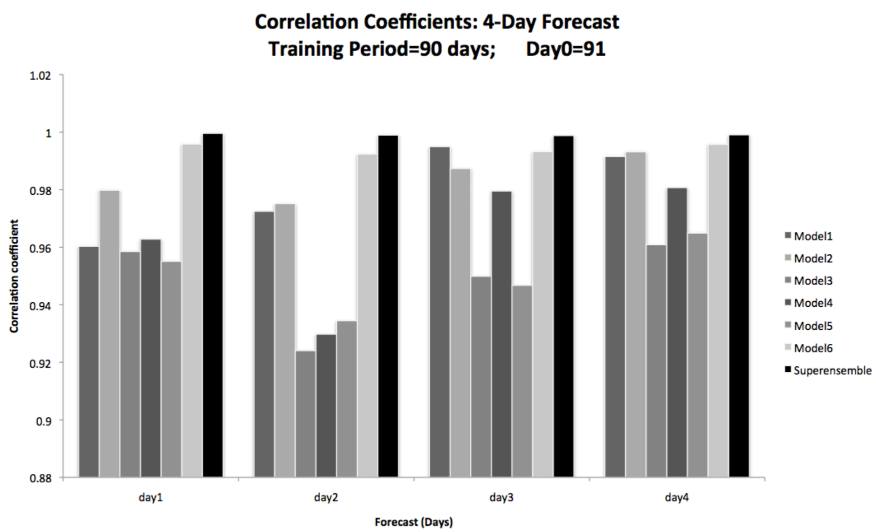
Results based on mesoscale models

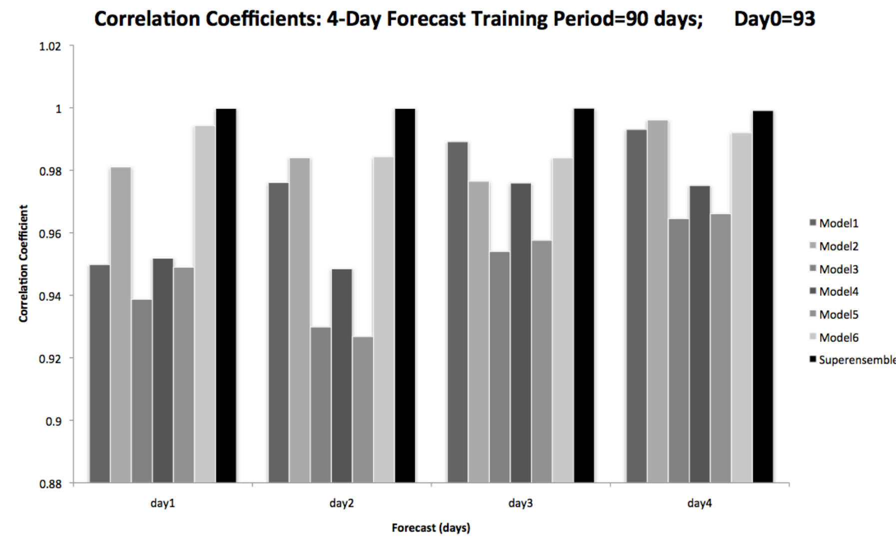


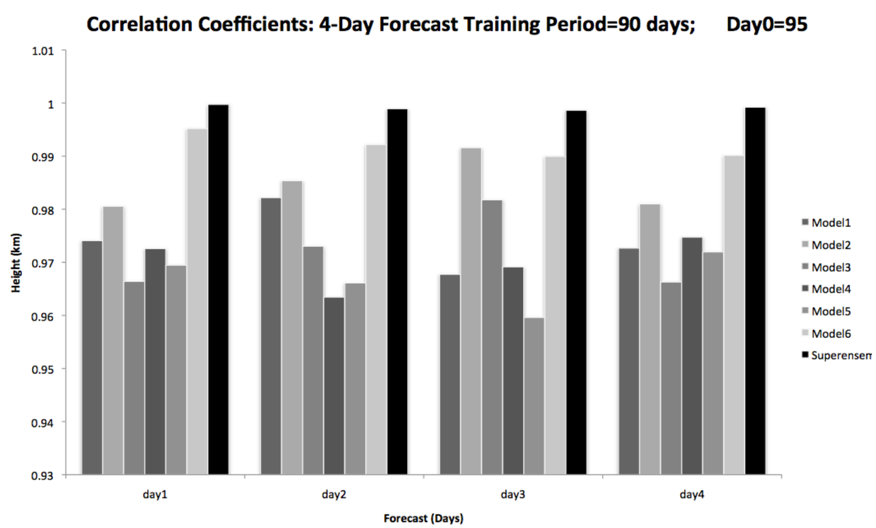
Results based on mesoscale models

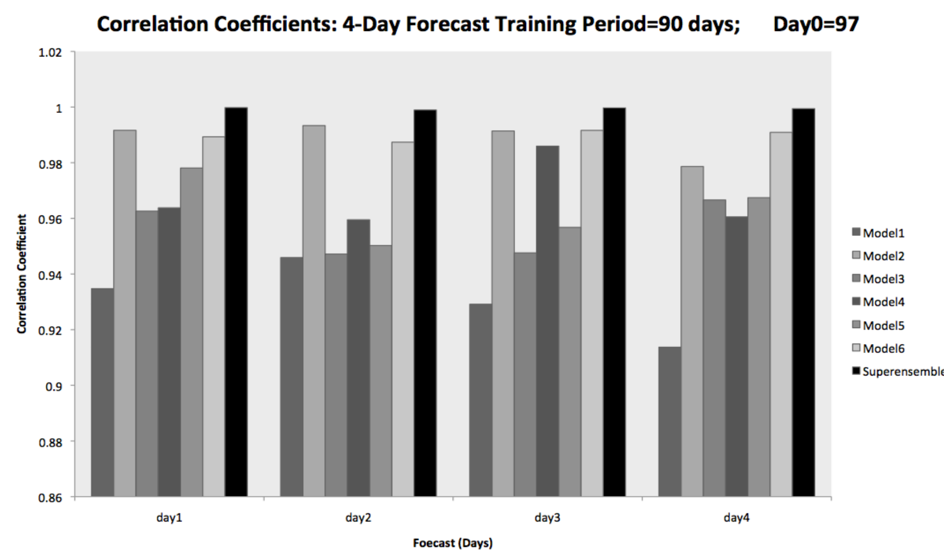

RMS Errors: 4-day Q1 forecast (91st day) Training period=90 days
RMSE
0
1
2
3
4
5
6
day1
day2
day3
day4
Forecast
Model1
Model2
Model3
Model4
Model5
Model6
Superensemble


RMS Errors: 4-Day Q1 forecast (93rd day) Training period=90 days
RMSE
0
0.5
1
1.5
2
2.5
3
3.5
4
day1
day2
day3
day4
Forecast (Days)
Model1
Model2
Model3
Model4
Model5
Model6
Superensemble

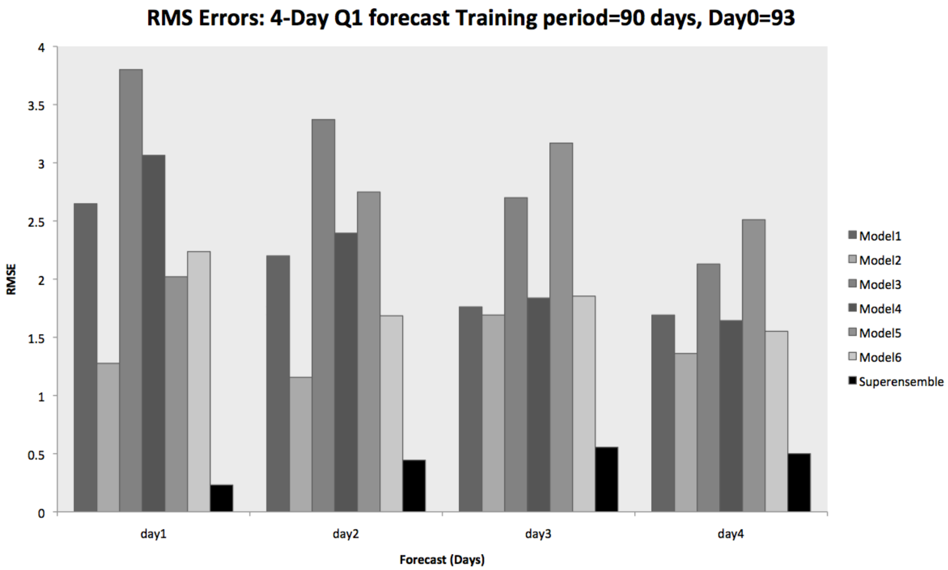


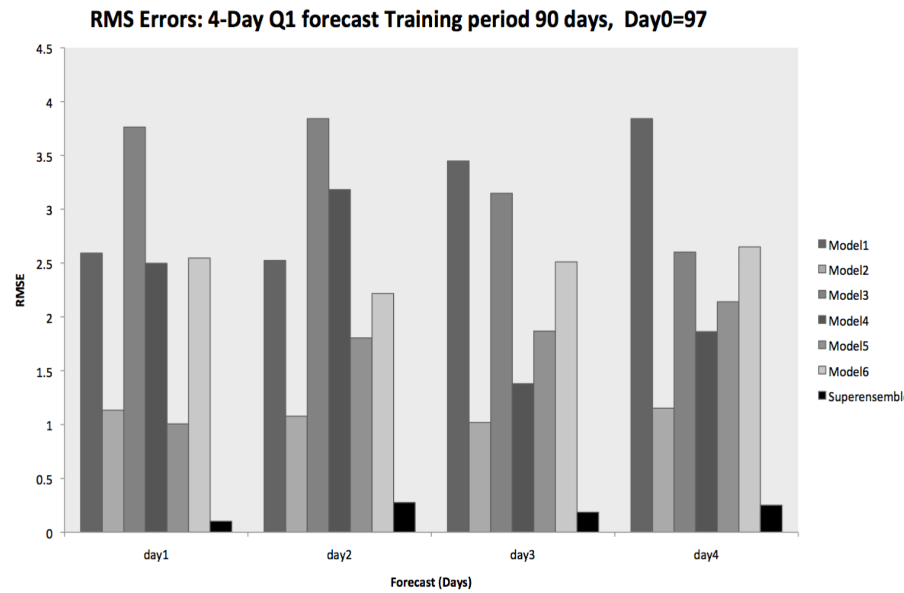


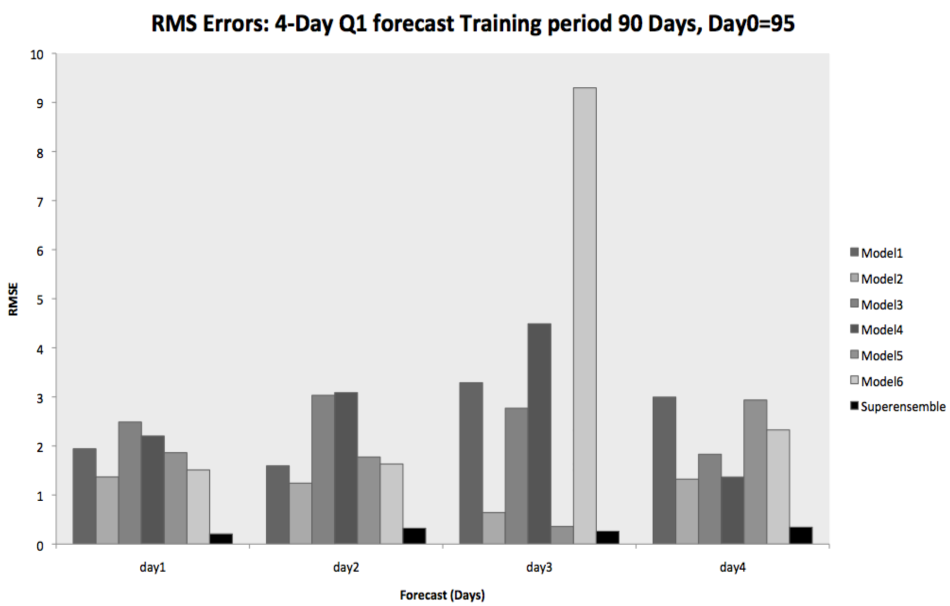




Results based on mesoscale models







Results based on mesoscale models

SUMMARY REMARKS

SUMMER MONSOON FORECASTS OF RAINFALL ARE MUCH IMPROVED FROM THE MULTI MODEL ENSEMBLES OF A SUITE OF MESOSCALE MODELS. THESE IMPROVEMENTS CAN BE SEEN FROM DAY 1 TO DAY 6 OF FORECASTS. FORECASTS SKILLS UTILIZE A MIX OF TRMM AND RAINGAUGE DATA SETS.

IT BECAME POSSIBLE TO CONSTRUCT THE MULTIMODEL SUPERENSEMBLE FOR THE APPARENT HEAT SOURCE FROM ALL THESE MODEL FORECASTS. WE SHOW THAT THE RMS ERRORS AND THE SPATIAL CORRELATIONS OF THE APPARENT HEAT SOURCES ARE VASTLY REDUCED FROM THE CONSTRUCTION OF THE MULTIMODEL ENSEMBLE. THAT IMPLIES THAT MEMBER MODELS CONTRIBUTE TO PERSISTENT SYSTEMATIC ERRORS THAT ARE CAPITALIZED BY THE MULTIMODEL SUPERENSEMBLE.

IT SHOULD BE POSSIBLE TO REDUCE ERRORS IN THE CUMULUS PARAMETERIZATION FROM THE USE OF A ERROR REDUCTION ALGORITHM THAT MAPS THE AMPLITUDE AND SPATIAL DISTRIBUTION OF ERRORS FROM THIS COMPONENT OF MODEL PHYSICS. THIS IS A FUTURE WORK THAT WE ARE CURRENTLY WORKING ON.

THE STUDY ASSUMES THAT THE TRMM BASED HEATING RATES THAT ARE USED AS THE BENCH MARK HERE NEED FURTHER JUSTIFICATION FROM SOME OTHER DIRECT MEANS, WE ARE THANKFUL TO DR TAO FOR HAVING TAKEN ON THIS INITIATIVE TO GENERATE HEATING ESTIMATES FROM SATELLITES.