Data Assimilation Research for improving monsoon simulation and forecast

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Objectives

- To study the impact of temperature profiles Assimilation on the dynamical and thermodynamical characteristics of Indian Summer Monsoon.
- To produce a multi-year downscaled regional reanalysis of the ISM using the NCEP operational analyses and AIRS temperature and moisture retrievals in a regional frame work.
- Evaluate the impact of AIRS profiles on prediction of Indian summer monsoon using WRF 3D-variational data assimilation system
- Study the predictability of monsoon intra-seasonal oscillations in a regional model with and without data assimilation

Outcome

- Improved simulation of ISM circulation in WRF model by assimilating temperature profiles from AIRS due to elimination of asymmetric (north–south) SLP bias; larger error reduction in winds; temperature (at boundary layer and mid-troposphere); vertical wind shear and WVMR.
- Demonstrated improvement in all the predicted fields associated with the ISM, consequent to the month long assimilation of AIRS profiles, is an innovative finding with large implications to the operational seasonal forecasting capabilities over the Indian subcontinent.
- Improvement in the predictability of circulation and precipitation associated with MISO is found when the initial state is produced by assimilating AIRS retrieved temperature and water vapour profiles in WRF model.

Four dimensional Data Assimilation (FDDA) for simulation

- The FDDA is a continuous dynamic data assimilation method that relaxes the model state toward observed state.
- In the analysis, Newtonian relaxation term is added to the prognostic equation

$$\frac{dT}{dt} = M(T,x,t) + G(T).W_s.W_t.\varepsilon(T,x)(y^\circ - HT)$$

- T is a prognostic variable (i.e., temperature), M represents model which includes the physical processes, x represents the independent variables, and t is time. y° is the observation vector, H is the observation operator that transforms or interpolates the model forecast variable to the observation variable and location, G is the nudging magnitude matrix, and W_s, W_t are the spatial and temporal nudging (or weighting) coefficients.
- The nudging strength is specified to be 3×10^{-4} s^{-1} and ε denotes observation quality factor.
- Each observation is ingested into the model at its observed time and location with proper space-time weights and the model spreads the information in time and space according to the model dynamics. Raju et al., 2014, TAAC

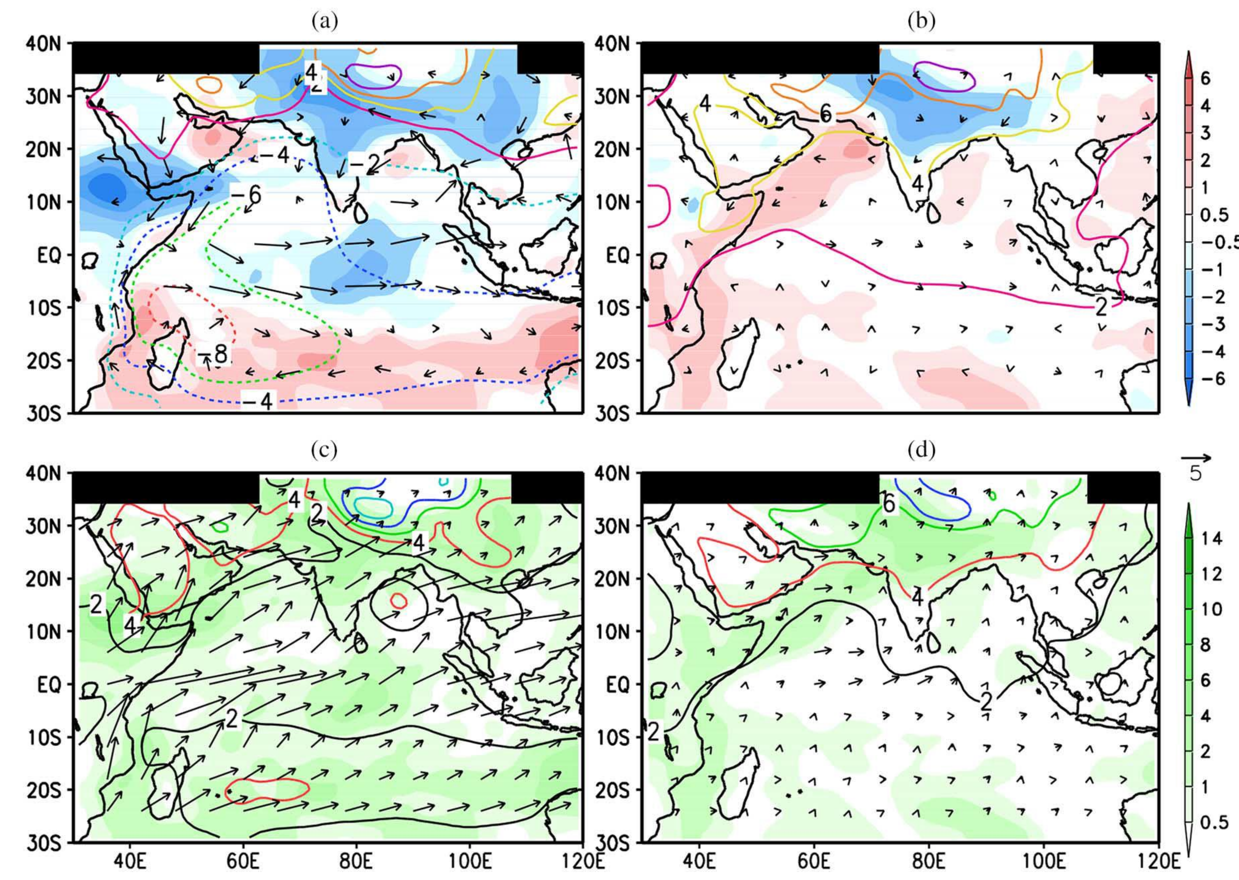
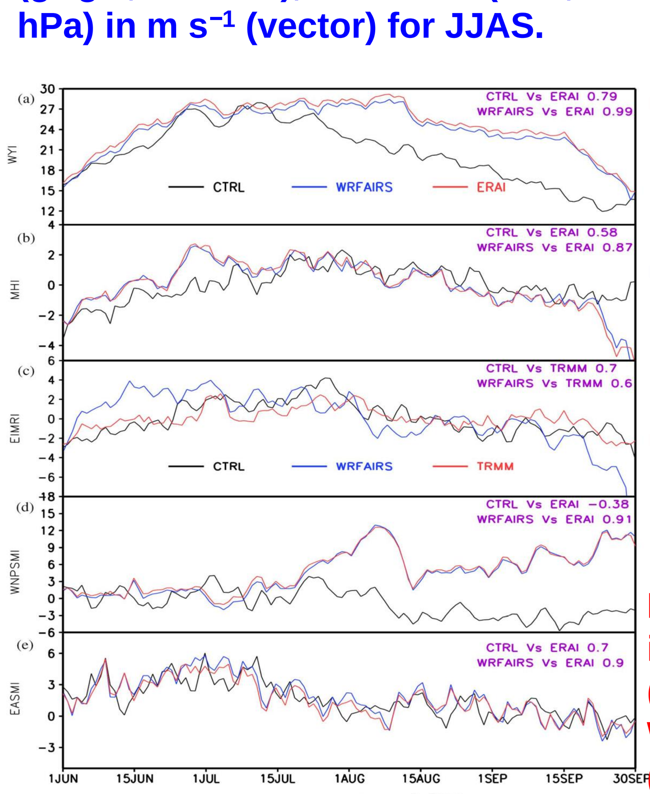


Fig. 1. Spatial distribution of bias (a) CTRL and (b) WRFAIRS and RMSE (c) CTRL and (d) WRFAIRS with respect to ERAI for WVMR (gKg^{-1}; shaded), and SLP (hPa; contours), low level winds (a) at 850 hPa) in m s^{-1} (vector) for JJAS. Raju et al., (2015) IEEE-JSTAR



- Eliminate the asymmetric SLP bias resulted better circulation.
- Reduction in T biases at the lower & mid-troposphere
- Monsoon Indices are simulated better in WRFAIRS than CTRL

Fig. 2. Time series of monsoon indices (a) WYI (ms^{-1}) (b) MHI (ms^{-1}) (c) EIMRI (mmday^{-1}) (d) WNPSMI (ms^{-1}) and (e) EASMI (ms^{-1}).

Reanalysis of the ISM: FDDA of AIRS T & Q

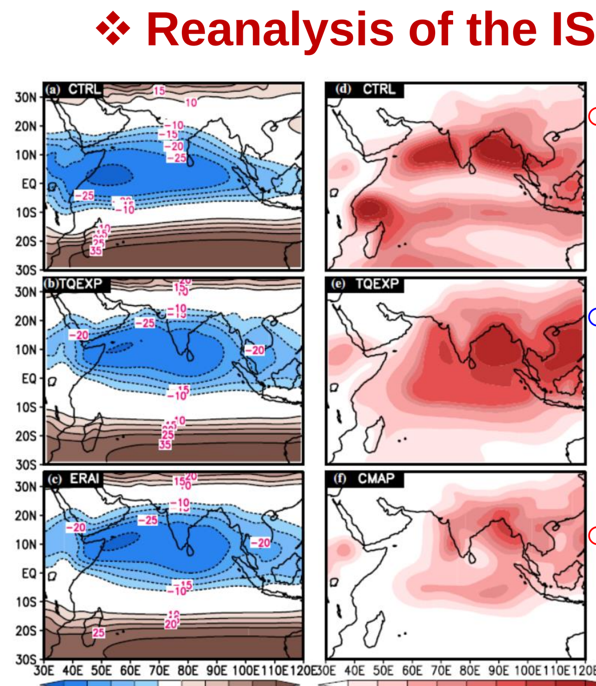


Fig. 3 JJAS mean spatial distribution of vertical shear of the zonal winds (U200–U850) (a-c, ms^{-1}) and precipitation (d-f,mmd^{-1}) Raju et al., (2017), Clim Dyn

- Better representation of strength and location of monsoon elements,
- Disappearance of the unrealistic double ITCZ like rainfall pattern due to proper monsoon circulation,
- Better representation of the meridional distribution of temperature, water vapour, MSE and wind shear,
- Proper vertical structure of moisture, vorticity, divergence and vertical velocities.

3D-Var for the seasonal forecast

- The WRF 3DVar data assimilation system [Skamarock et al., 2008] is used in this study.
- Two assimilation experiments are performed, one with conventional data and the other with both conventional and AIRS profiles. These experiments are in addition to the control run where no assimilation is performed.
- Six-hourly assimilation cycles is performed with ±3 h time window for the entire month of May 2010, until 00:00 UTC, 1 June 2010.
- Model is initialized at 00:00 UTC, 1 June 2010, and gives the forecast for 1 June to 30 September 2010.
- Conventional observations are assimilated, such as surface synoptic observations (SYNOP); Meteorological Aerodrome Report (METAR); buoy, ships, aircraft and Special Sensor Microwave Imager (SSMI) wind speed; and total perceptible water and satellite-observed cloud motion vectors from GTS during May 2010. It includes surface station reports as well as upper air observations.
- In the third experiment, AIRS-retrieved T and Q profiles (more than 43% of observations) are assimilated along with the conventional data. level 2, version 6 AIRS atmospheric profiles are used. The T (Q) profiles are available at 28 (14) standard pressure levels between 1000 and 0.1 hPa (1000hPa to 50hPa). Raju et al., (2015), JGR

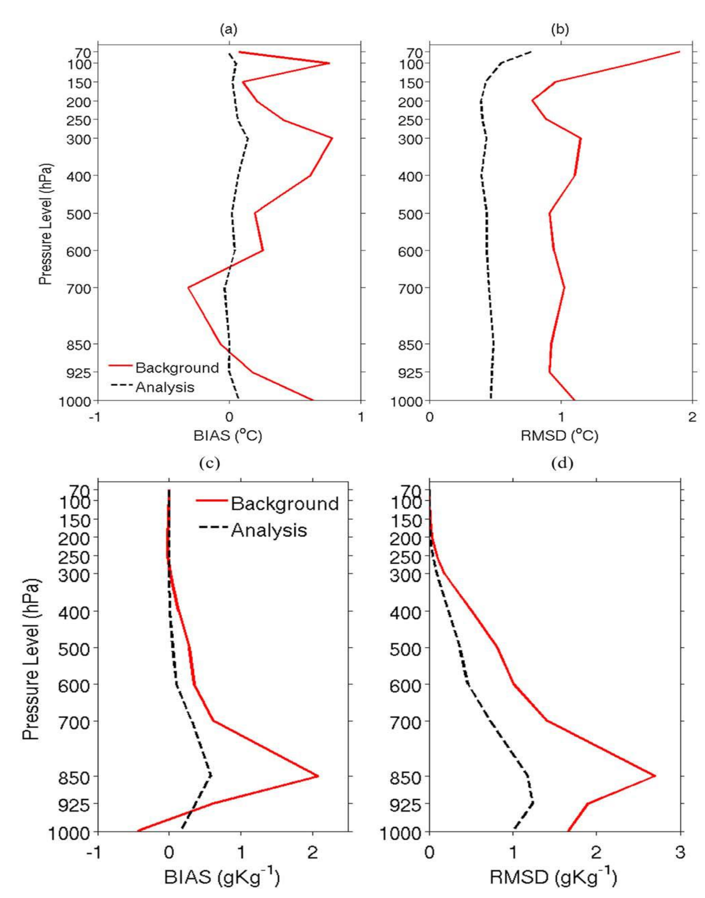


Fig. 4 Vertical profile of BIAS and RMSD of (a and b) temperature (K) and (c and d) WVMR (gkg^{-1}) in WRF first guess and analysis.

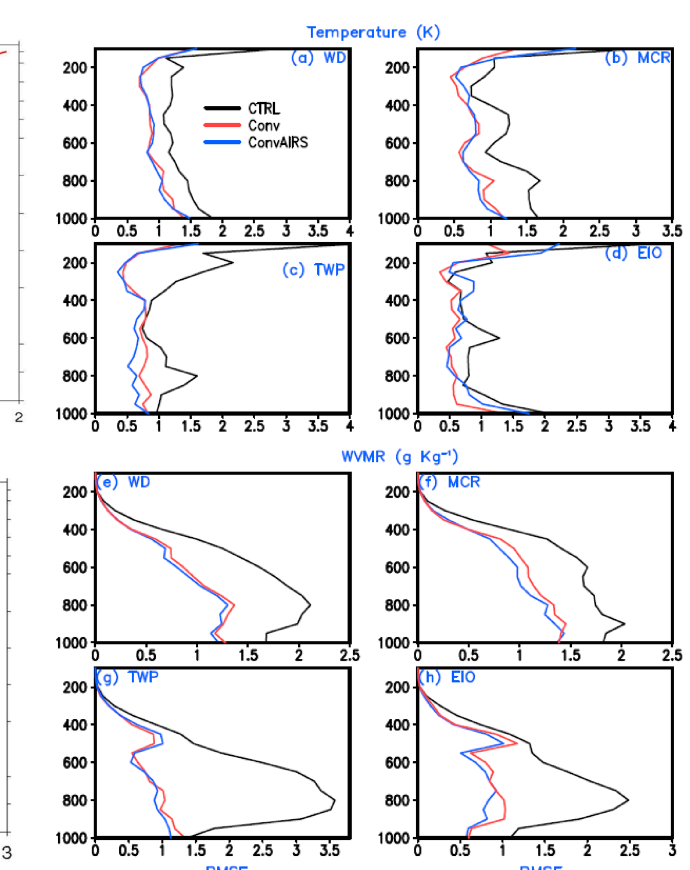


Fig. 5 Vertical profile of RMSE for (a–d) T (K) and (e–h) WVMR (g kg^{-1}) from CTRL, Conv & ConvAIRS at 00:00 UTC on 1 June 2010.

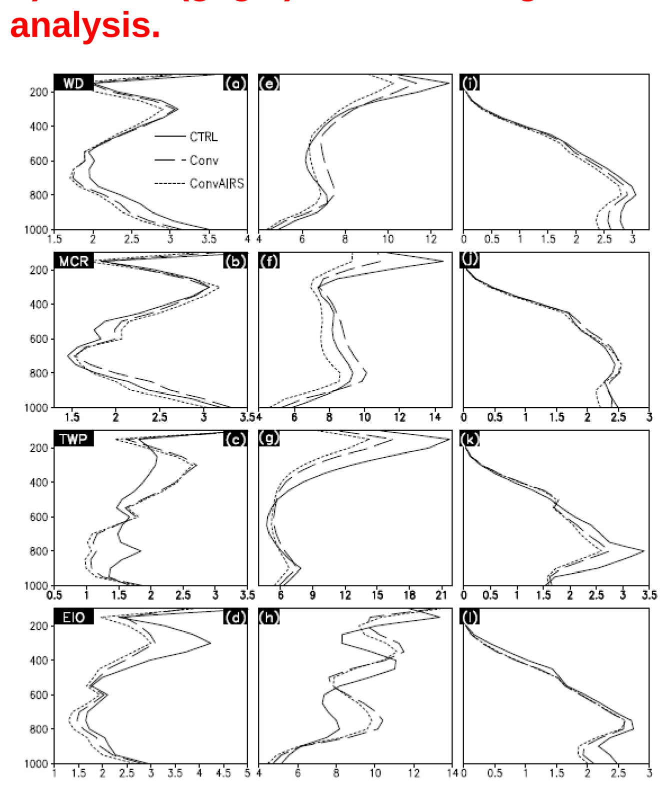


Table 2. Pattern Correlation for Mean Sea Level Pressure, Zonal Winds, Tropospheric Temperature, Vertical Averaged Specific Humidity, and Rainfall Over the Whole Domain From CTRL, Conv, and ConvAIRS Experiments Against Observations During Monsoon 2010

Variable	CTRL	Conv	ConvAIRS
Sea level pressure	0.78	0.86	0.94
Low (upper) level zonal wind	0.75 (0.94)	0.80 (0.96)	0.87 (0.97)
Tropospheric temperature	0.69	0.79	0.79
Vertical-averaged specific humidity	0.85	0.89	0.92
Rainfall	0.30	0.42	0.47

Fig. 6 Vertical profiles of RMSE for (a-d) T (K), (e–h) zonal wind (ms^{-1}), & (i-l)WVMR (g kg^{-1}) for CTRL, Conv, & ConvAIRS during monsoon 2010.

- Assimilation of AIRS profiles has significant impact on predicting the seasonal mean monsoon characteristics such as tropospheric temperature, low-level moisture distribution, easterly wind shear, and precipitation.
- The vertical structure of the RMSE is substantially affected by the assimilation of AIRS profiles, with smaller errors in temperature, humidity, and wind.
- The consequent improved representation of moisture convergence in the boundary layer (deep convection as well) causes an increase in precipitation forecast skill.
- This finding has large implications to the operational seasonal forecasting capabilities over the Indian subcontinent.

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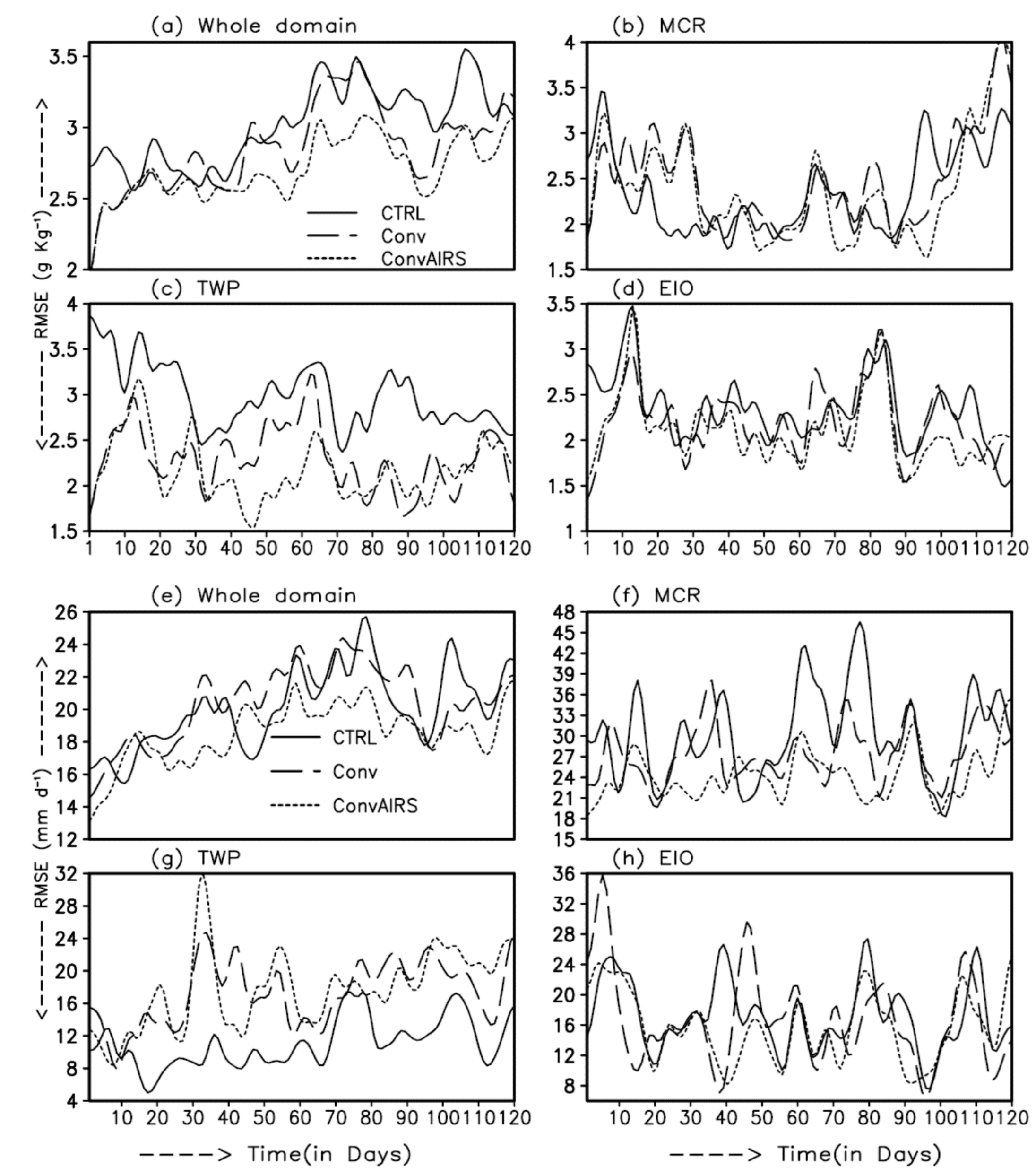

Fig. 7 Temporal variation of RMSE of the predicted (a–d) WVMR (g kg^{-1}) and (e–h) precipitation (mm d^{-1}) against ERAI/GPCP during monsoon 2010.

FDDA and perturbation methodology for the MISO predictability study

- This study reports the improvement in the predictability of circulation and precipitation associated with MISO when the initial state is produced by assimilating (AIRS) retrieved T and Q profiles in WRF model.
- Two separate simulations are carried out for 2003 to 2011 . In the first simulation, forcing is from NCEP (CTRL) and in the second, apart from NCEP forcing, AIRS T & Q profiles are assimilated (ASSIM).
- Ten active and break cases are identified from each simulation.
- Three dimensional T states of identified active and break cases are perturbed using twin perturbation method and carried out predictability tests. (Parekh et al., 2017)

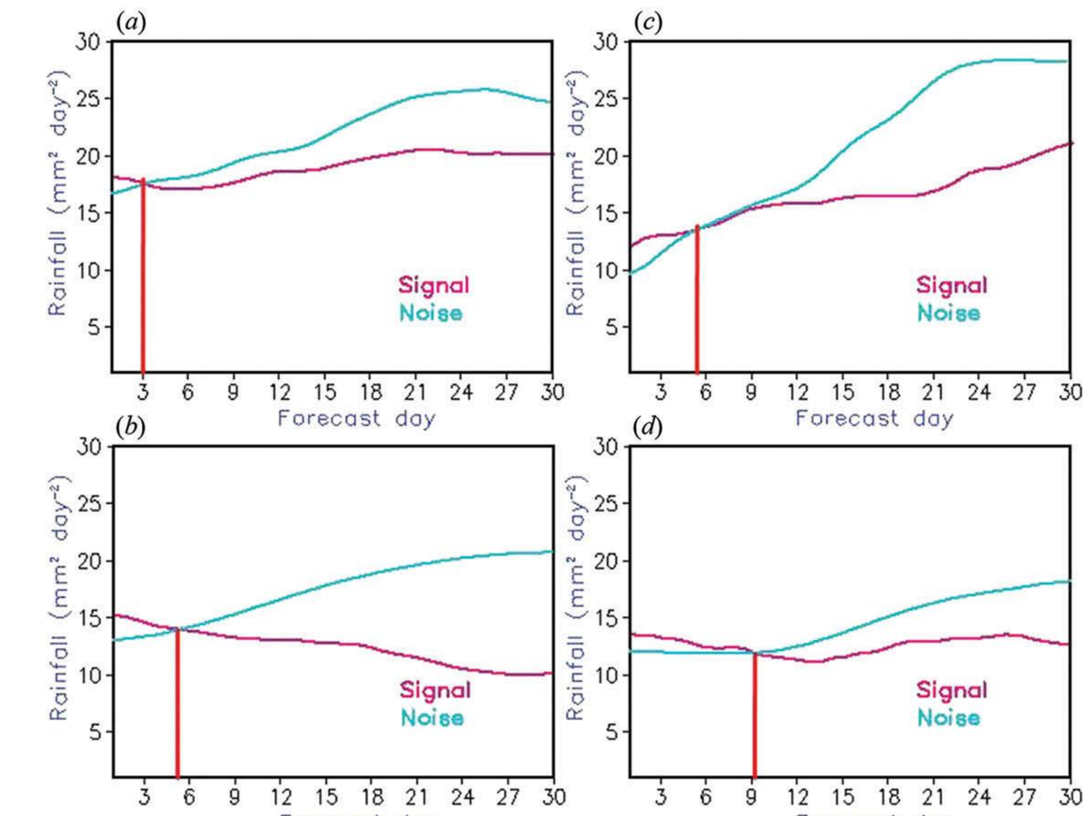

Fig. 8. Time evolution of signal & noise of rainfall (mmd^{-1}) over MCR for active (a-b) and break (c-d) phases from CTRL (upper panel) and ASSIM (bottom panel). Vertical red lines are indicating predictability limit where signal and noise intersects each other.

- Analysis reveals that the limit of predictability of low level zonal wind is improved by four (three) days during active (break) phase. Similarly the predictability of upper level zonal wind (precipitation) is enhanced by four (two) and two (four) days respectively during active and break phases.
- More realistic baroclinic response and better representation of vertical state of atmosphere associated with monsoon enhance the predictability of circulation and rainfall.

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