Suites of physics packages in CFS and GFS

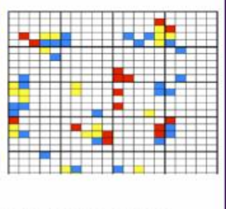
Parameterization and Analyses group

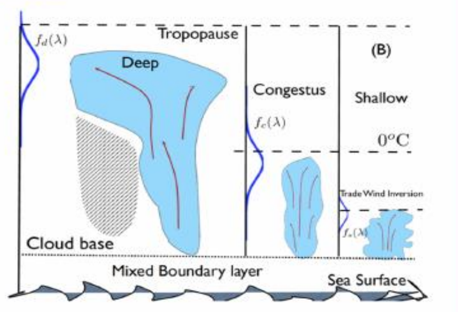
Indian Institute of Tropical Meteorology, Pune, INDIA

The Stochastic MultiCloud Model Parameterization calibrated with radar observation

The framework

By construction, the proposed framework englobes both sallow and deep convection, as well as mid-level congestus clouds. Ideally, the stochastic model is some kind of shell that permits the shallow and deep convection schemes to communicate with each other.





- ❑ A square lattice
- ❑ $N_L \times N_L$ lattice sites
  - ✓ Let z_k be fixed vertical level on the GCM grid
- ❑ $P_{n,m,k}$ the number of plumes that are launched over the lattice site $n; m$, which detrain at an arbitrary level $z_D \geq z_k, 1 < n, m \leq N_L$
- ❑ 4 types of plumes (SC,C,D,S) according to their detrainment levels.
  - ✓ Shallow cumulus detrain near the trade wind inversion,
  - ✓ Congestus detrain above the trade wind inversion and below or near the freezing level
  - ✓ Deep detraining above this level
  - ✓ The cloud types are intentionally allowed to overlap so that each cloud type has its own special distribution of detrainment heights centered around some appropriate level.
- ❑ An order parameter $\sigma_{n,m}$ that takes values $0,1,2,3, or\ 4$ at each site $n; m$
- ❑ For $n; m$ fixed, let P_k be the number of plumes with a detrainment level $z_D \geq z_k$ originating over the lattice site $(n; m)$
- ❑ Let
  - ✓ d_σ be the detrainment level of a random plume of type σ
  - ✓ P_σ be the probability distribution of d_σ
  - ✓ f_σ be the associated density functions

The steady state equation of conservation of moist static energy (h_c) of a rising plume.

$$\frac{dh_c}{dz} = \lambda(h - h_c), z_b \leq z \leq z_D,$$

A quick integration of the above ODE and then using the mean value approximation gives:

$$\lambda = -\frac{1}{\Delta z}\log\left(1 - \frac{h_0 - h^*}{h_0 - h_{\frac{1}{2}}}\right),$$

where $h_{\frac{1}{2}} = h\left(\frac{z_D + z_b}{2}\right)$ and $\nabla z = z_D - z_b$

To complete the definition of the cloud top distributions ($f_j(\lambda), for\ j = sc, c, d\ and\ s$, in the schematic above) we need to specify the means and standard distribution parameters $\lambda_j\ and\ \alpha_j$. To do so we set,

$$\lambda_{sc} = \delta_{sc}\lambda_{lfc}$$
$$\lambda_c = \delta_c\lambda_{lfc} + (1+\delta_c)\lambda_{frz}$$
$$\lambda_d = \delta_d\lambda_{frz} + (1+\delta_d)\lambda_{lnb}$$

And,

$$\alpha_{sc} = \gamma_{sc}\lambda_{sc}$$
$$\alpha_c = \gamma_c(\lambda_{lfc} - \lambda_{frz})$$
$$\alpha_d = \gamma_d(\lambda_{frz} - \lambda_{lnb})$$

Where $0 < \delta_j < 1$ and $\gamma_j > 0$, be a set of parameters.

We have the bulk mass flux equation,

$$M(z) = \Lambda \int_0^{\lambda_z} M_\lambda(z) F(\lambda) d\lambda,$$

where $M_\lambda(z)$ is the mass flux of the plume of type λ, i.e, a plume with a constant entrainment rate λ, given by

$$M_\lambda(z) = \begin{cases} M_b e^{\lambda(z - z_b)}, z_b \leq z \leq z_\lambda \\ 0, otherwise. \end{cases}$$

Here z_b and z_λ represent the level of cloud base and the level at which the type-λ plume detrains and M_b is the cloud base mass flux. $F(\lambda)$ is the plume probability density given by

$$F(\lambda) = \frac{1}{N_L^2}[N_{sc}f_{sc}(\lambda) + N_c f_c(\lambda) + N_d f_d(\lambda)]$$

with f_{sc}, f_c, f_d are plume distributions of shallow cumulus, congestus, and deep cumulonimbus cloud-types, respectively in the schematic above, while λ_z is the entrainment rate of plumes that detrain at level z.

As for the steady state plume model, we assume that the bulk mass flux satisfies the conservation equation

$$\frac{1}{M}\frac{\partial M}{\partial z} = \epsilon(z) - \delta(z),$$

where $\epsilon(z)$ and $\delta(z)$ are the bulk entrainment and detrainment rates, respectively.

To Compute $M(z)$, $\epsilon(z)$ and $\delta(z)$ we assume simple Gaussian shapes for the distributions f_{sc}, f_c, f_d as,

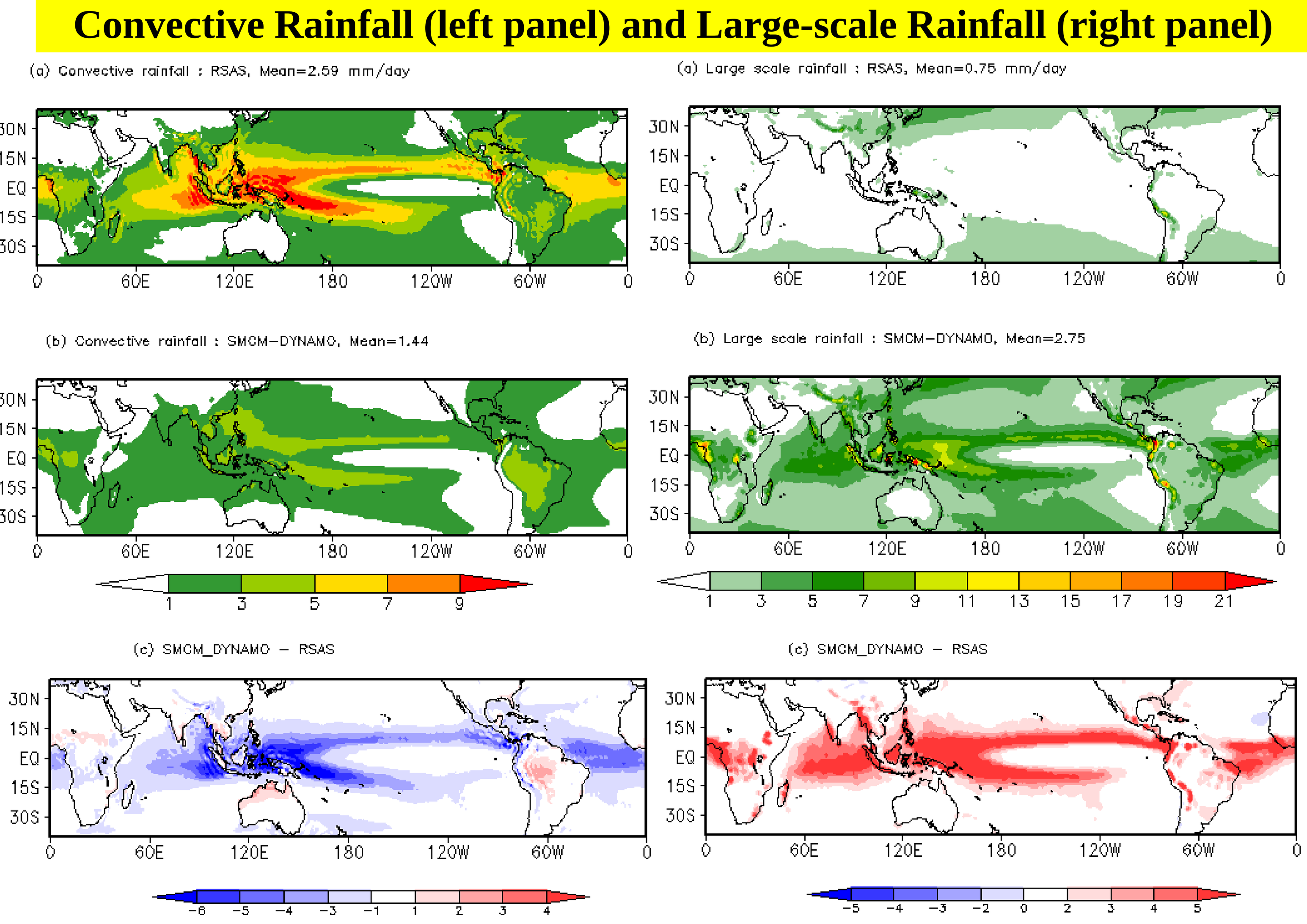
$$f_j(\lambda) = \frac{1}{\sqrt{2\pi}\,\alpha_j} e^{-\frac{(\lambda - \lambda_j)^2}{2\alpha_j^2}}, j = sc, c, d, s$$

Data and Methodology

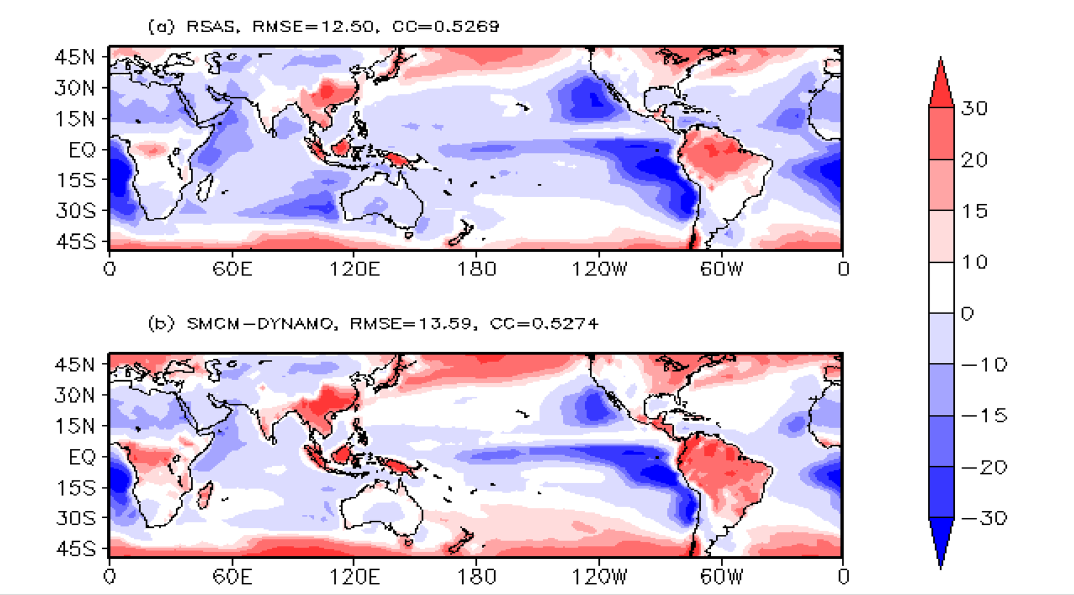
We have trained the model by using Dynamics of the Madden-Julian Oscillation (DYNAMO) radar observations and followed Markov-chain process to generate key parameters like transition probability, required for CFSMCM.

Climate simulations of the CFSMCM is done and 25 year run is made and last 20years are analyzed.

Convective Rainfall (left panel) and Large-scale Rainfall (right panel)



Annual mean bias of Low-level (%)



Summary and Conclusions:

- ➢ Global distribution of low-level cloud is improved and it is also with better agreement with observational analysis, which is inaccurate in RSAS.
- ➢ Convective and Large-Scale rainfall are improved in SMCM as compared to RSAS.

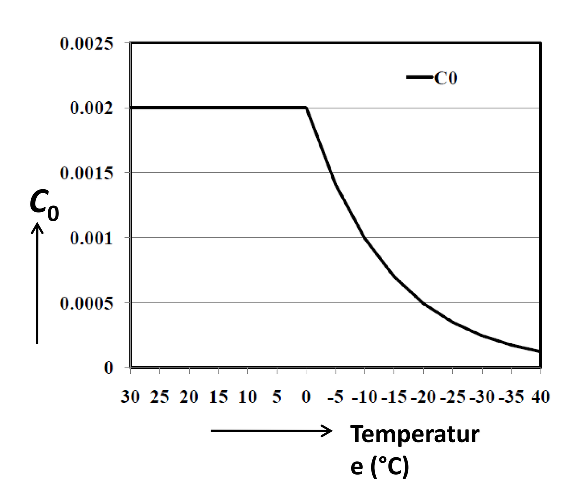
Impact of modified precipitation conversion rate in SAS convection scheme in CFS and GFS

The modified cloud condensate to precipitation conversion parameter (C_0)

Following Lim (2011) and Han et al. (2016)

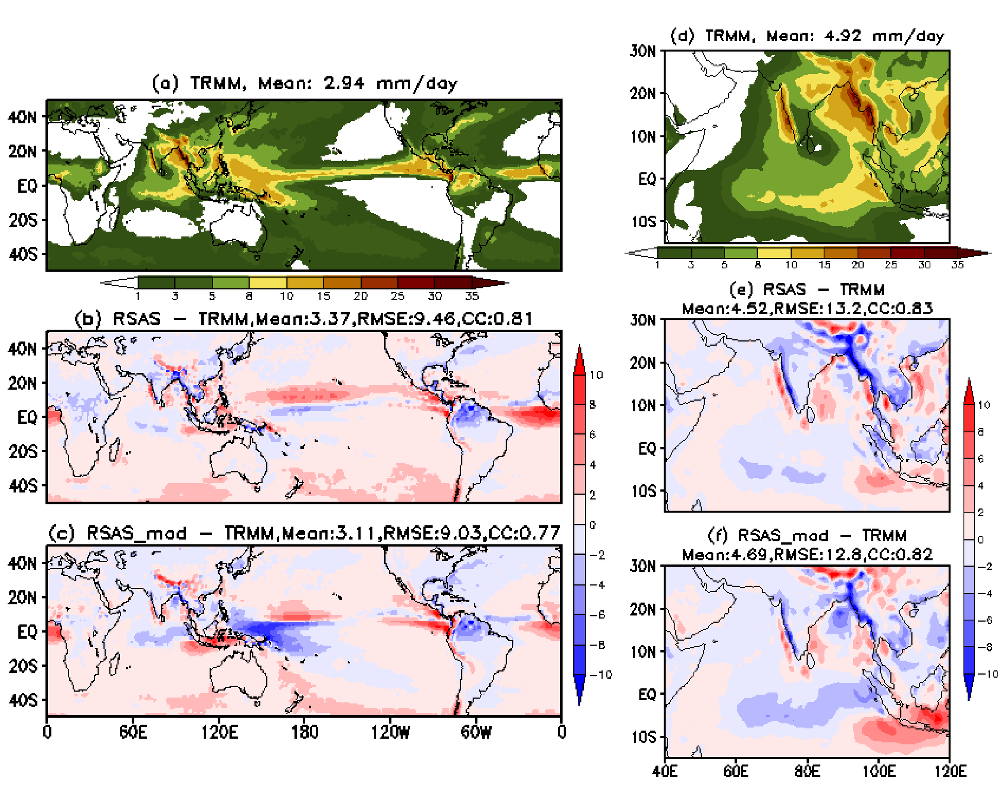
where a = 2.0 x 10^{-3} m^{-1} , is a constant, b = 0.07^O C^{-1} is the exponential decaying rate of C_0 below the freezing temperature T_0 (0^OC).

$$C_0(z) = a\exp\{b[T(z) - T_0]\} \quad \text{for} \quad T \leq T_0$$
$$C_0(z) = a \quad \text{for} \quad T > T_0$$

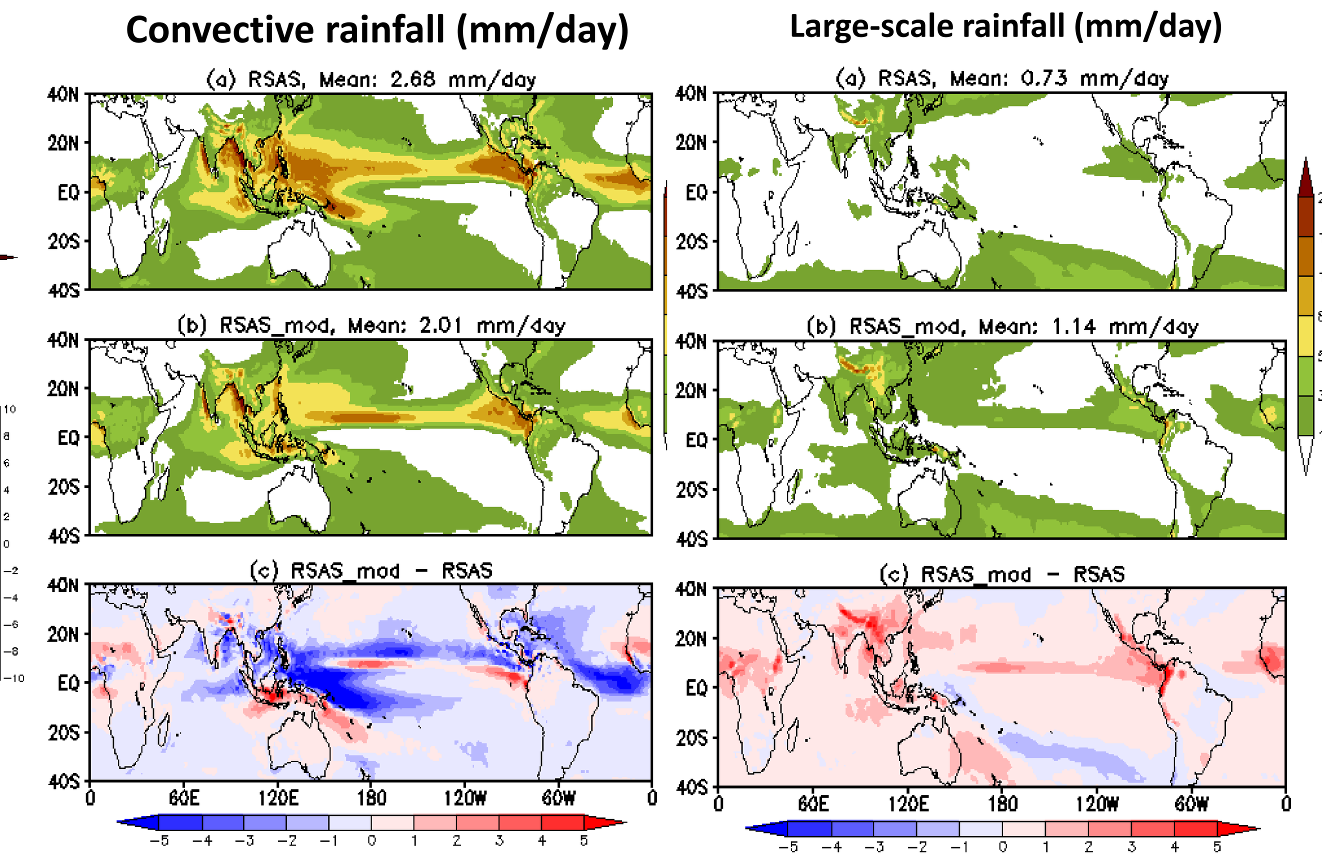


- ❑ **The fraction of cloud ice that is converted to precipitation decreases with height above the freezing level.**
- ❑ **The reduced rate of conversion of cloud condensate to convective precipitation at colder temperatures generally leads to a decrease in precipitation, especially in the category of heavy rainfall.**
- ❑ **The resultant increase of detrained moisture induces moistening and cooling at the top of clouds.**

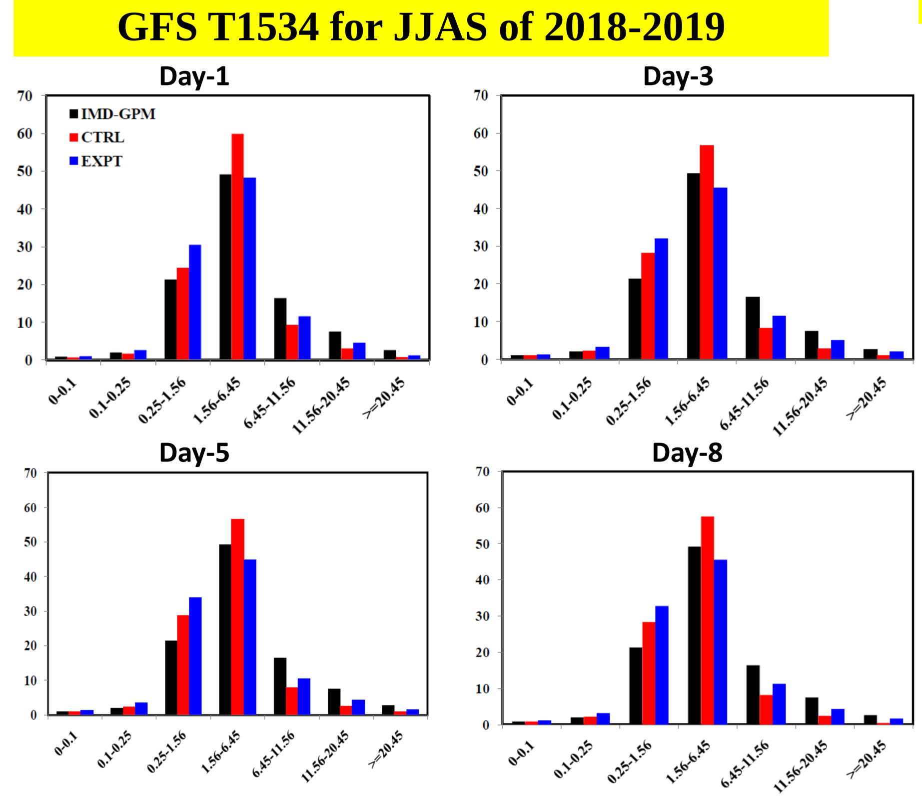
JJAS mean precipitation (mm/day) in CFSv2



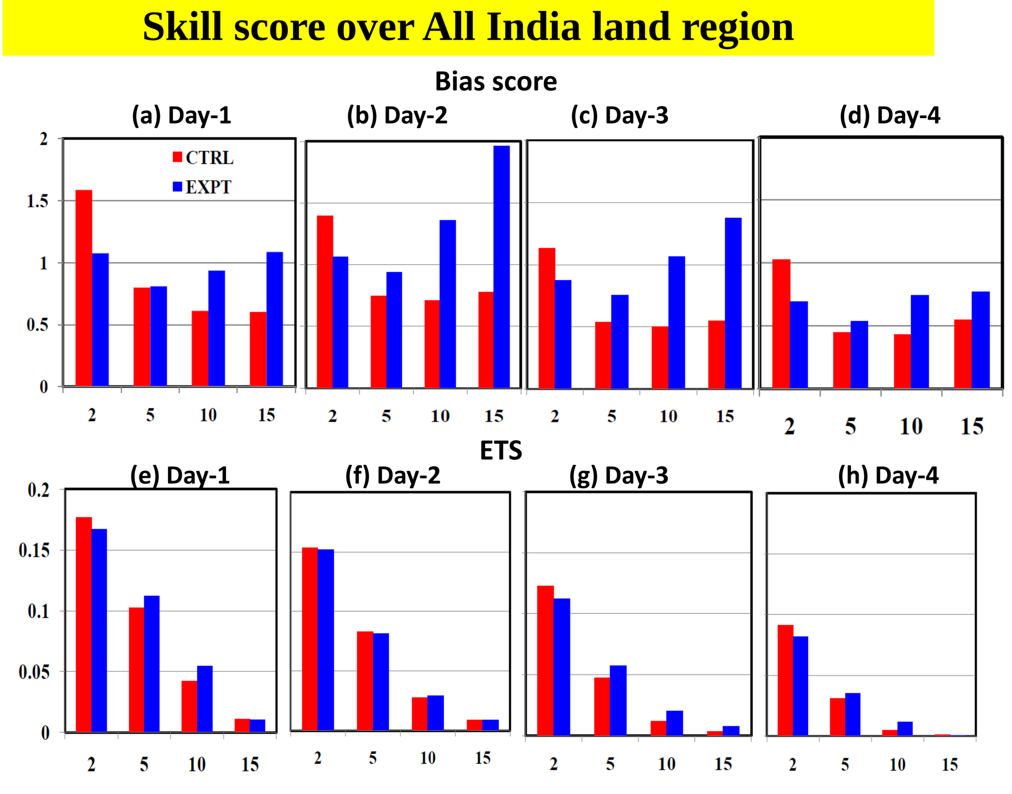
Convective and large-scale rainfall mm/day) in CFSv2



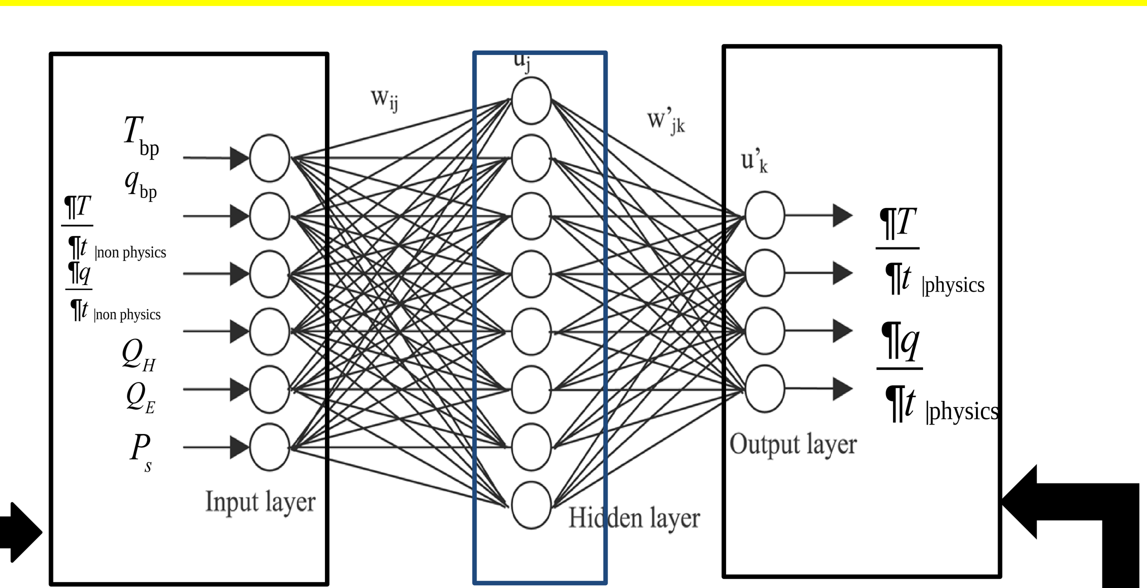
Rainfall PDF (%) over All India land in GFS T1534 for JJAS of 2018-2019



Skill score over All India land region



A new framework of convective parameterization: Artificial Intelligence



Inputs from GFS grid scale

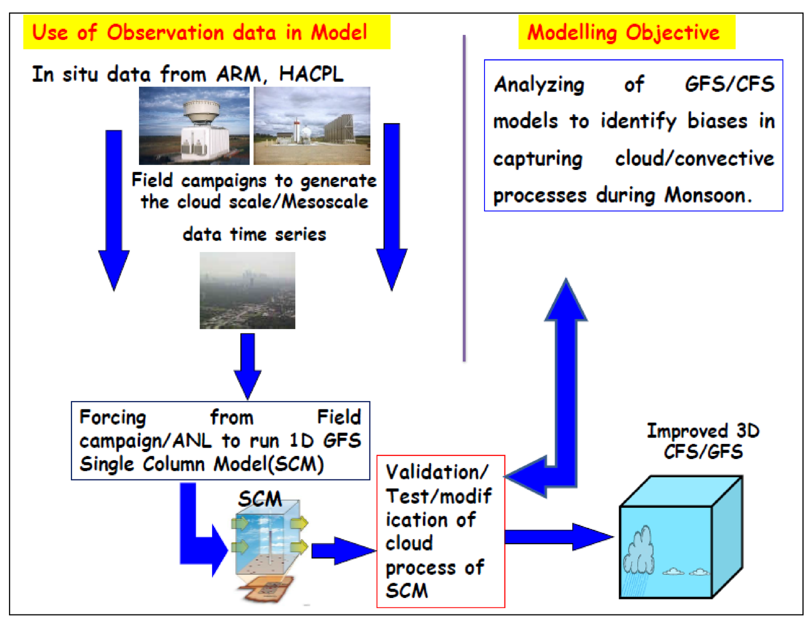
Deep layer trained using the tendencies from the CRMs embedded in SP-GFS

Output at GFS grid scale

GFS Single Column Model (SCM) Set up

Advantages:

- ➢**Computationally cheap.**
- ➢ **Allows to study subset of processes or single process only.**
- ➢**When an SCM is forced with observations, errors must be due to the column physics being tested, or to problems with the observations that are used as input.**
- ➢ **Once a parameterization has passed its SCM tests, it can immediately be used in a true GCM; there is no need to "transfer" it.**
- ➢ **SCM tests cannot detect problems with parameterizations that arise through feedbacks with the large-scale circulation.**



Algorithm Overview

In a nutshell, the SCM code performs the following:

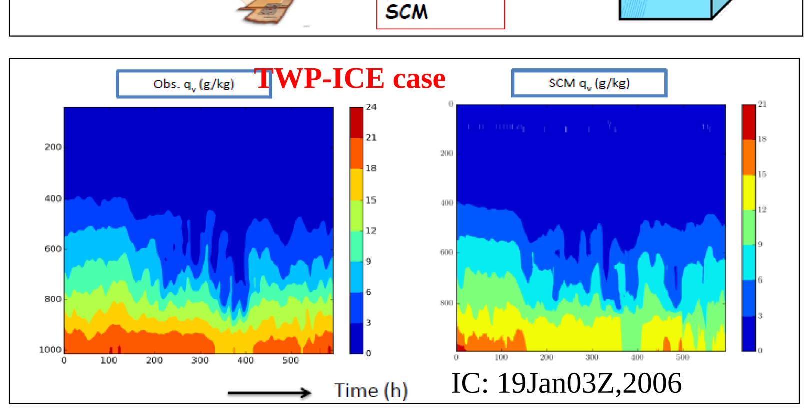
Read in an initial profile and the forcing data

Create a vertical grid and interpolate the initial profile and forcing data to it

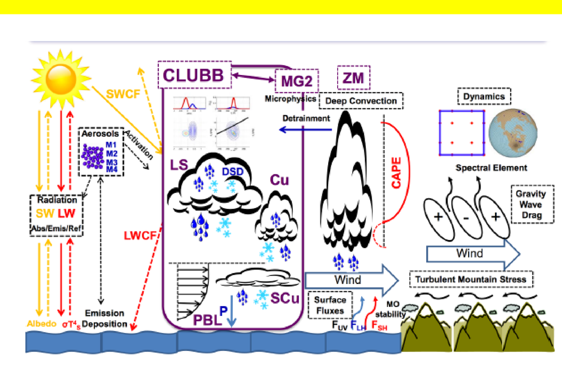
Initialize the physics suite

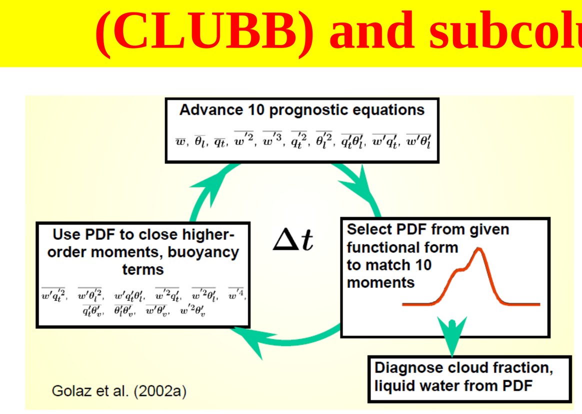
Perform the time integration, applying forcing and calling the physics suite each time step

Output the state and physics data



A unified approach to parameterization using Cloud Layers Unified By Binormals (CLUBB) and subcolumns





Flow of CLUBB-SILHS

Construct the multivariate PDF of subgrid-scale variability (performed by CLUBB)

↓

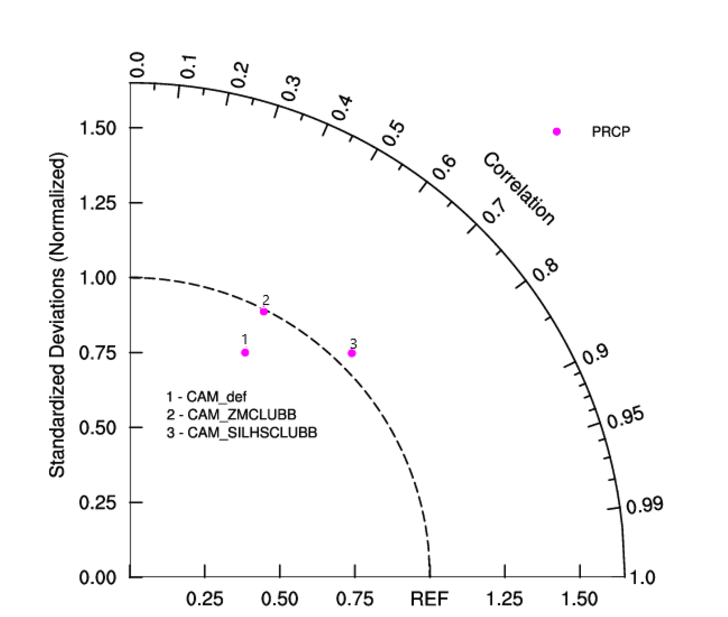
Draw subcolumns from the subgrid PDF (performed by SILHS)

↓

Feed subcolumns into physical parameterizations and compute process rate tendencies (performed by a microphysics scheme)

↓

Average microphysics tendencies from each subcolumn to form a grid box average profile



Taylor Diagram for JJAS climatological mean Rainfall (mm/day)

Acknowledgements: MoES, HPC: Team Pratyush and Mihir support