Using the stochastic multicloud model to improve tropical convective parameterization: A paradigm example

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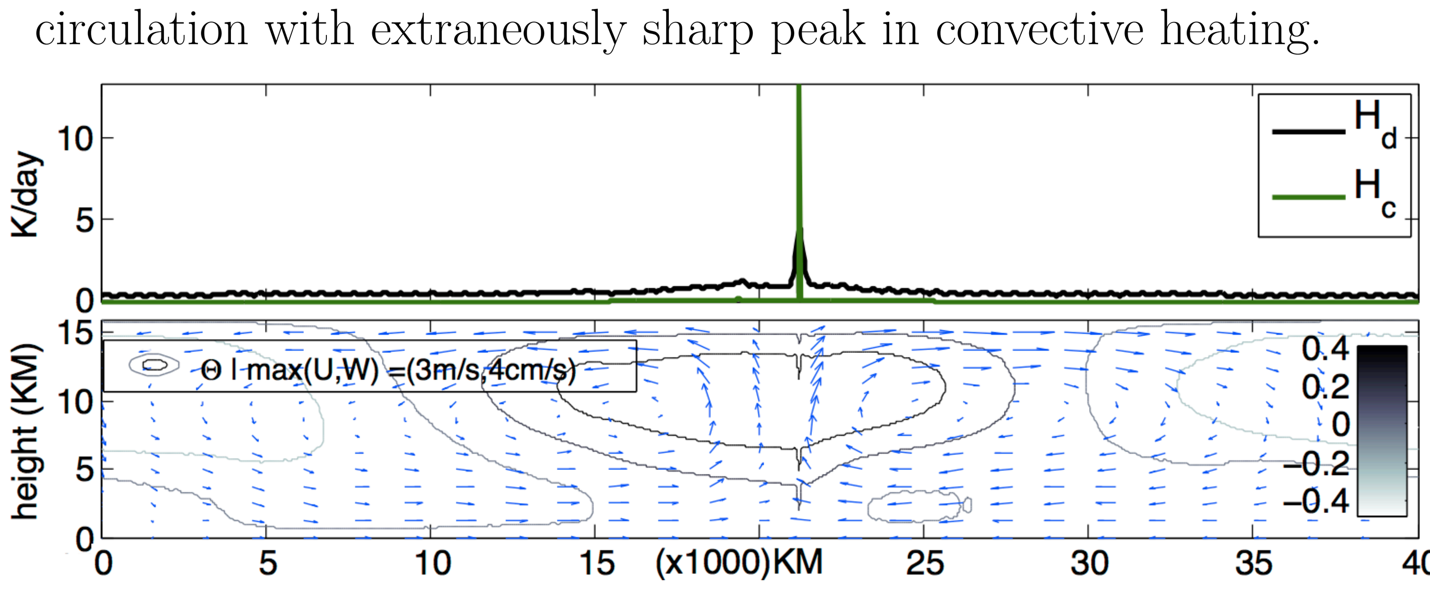
Motivation

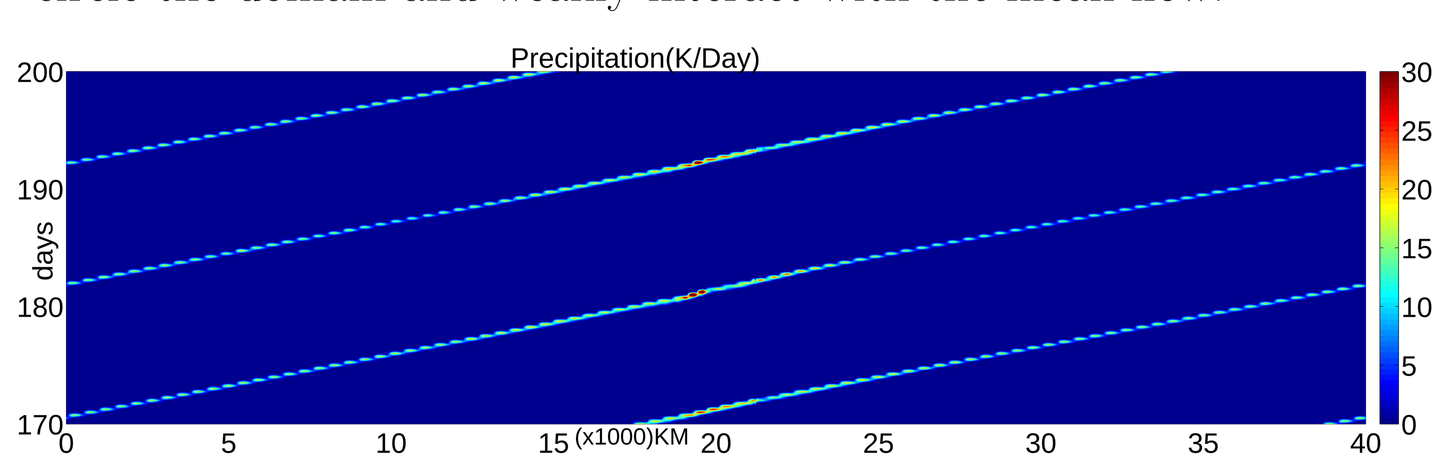
- Despite the continued research efforts by the climate community, the present coarse resolution GCMs, used for the prediction of weather and climate, poorly represent variability associated with tropical convection.
- The convectively coupled waves (CCW) captured by the models often lack important features, such as front-to-rear vertical tilt which is of immense importance for the convective momentum transport. Furthermore, the mean structure of large-scale circulations may not be physical.
- It is believed that the deficiency is due to inadequate treatment of cumulus convection. All of the above shortcomings will be corrected by the stochastic parameterization considered here.

An analog of deterministic GCM convective parameterization with clear deficiencies.

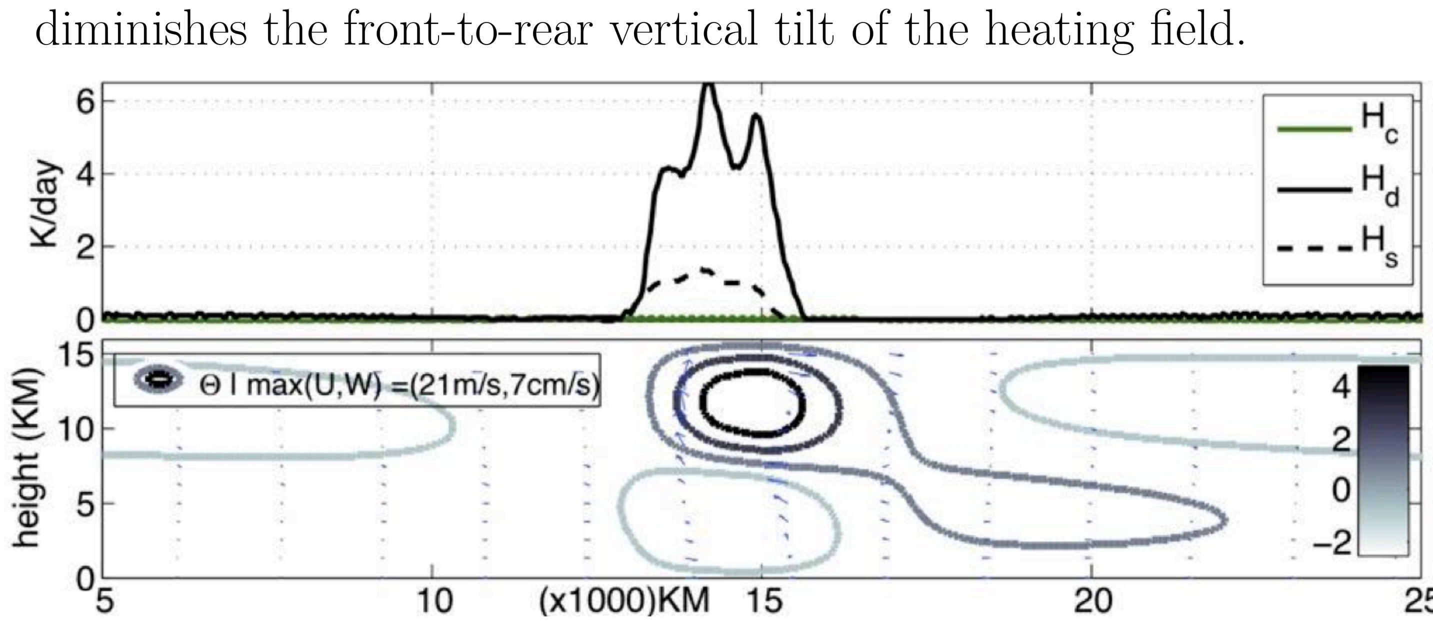
- Here deterministic multicloud parameterization [4] in a suboptimal regime is used to provide a reference point that roughly corresponds to the behavior of a paradigm GCM parameterization with clear deficiencies.
- Time-averaged zonal structure of the heating fields of Walker circulation with extraneously sharp peak in convective heating.



- Precipitation corresponding to CCWs. The extremely stable waves circle the domain and weakly interact with the mean flow.

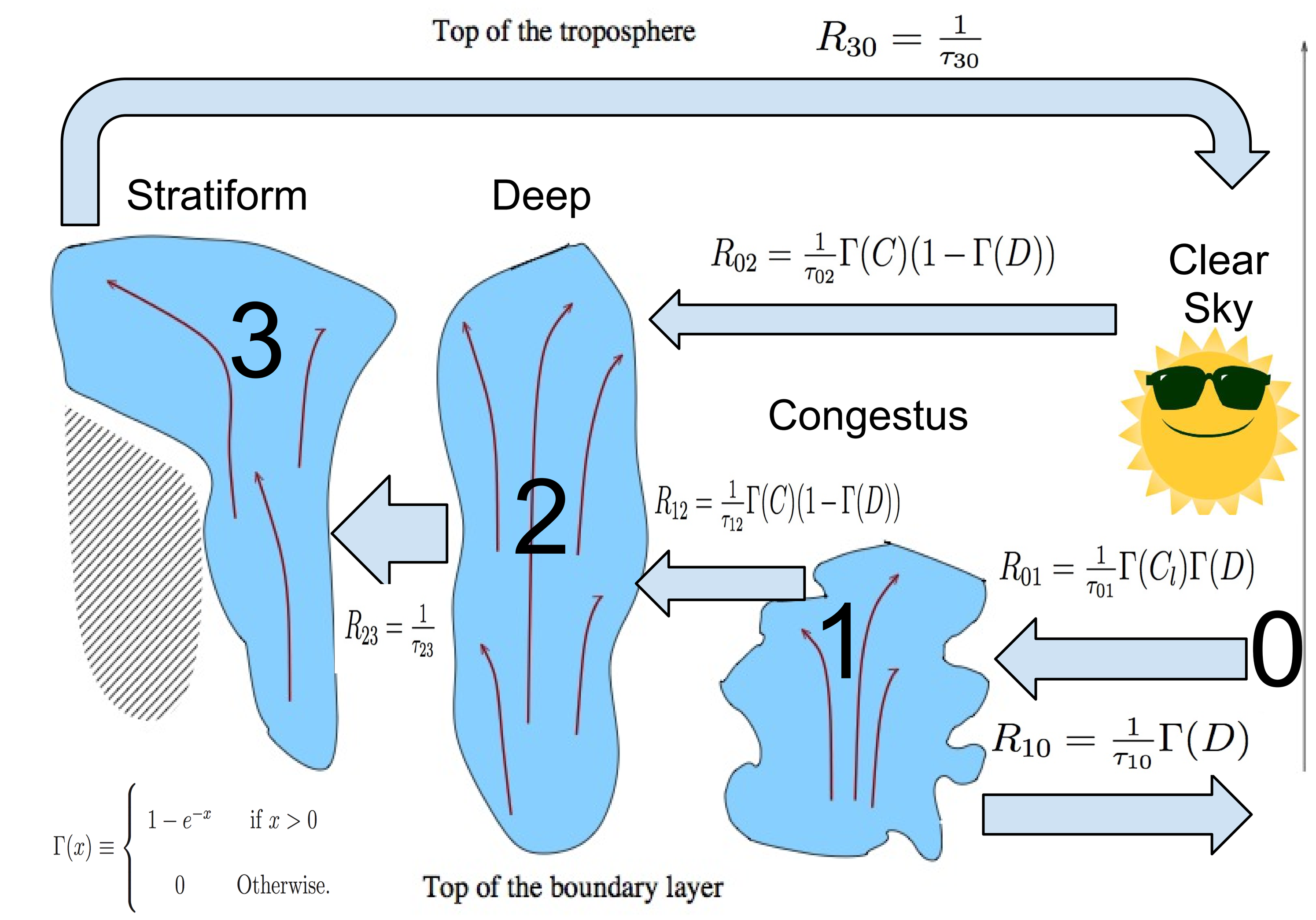


- Eastward propagating CCW. The lack of congestus heating diminishes the front-to-rear vertical tilt of the heating field.



Stochastic Multicloud model

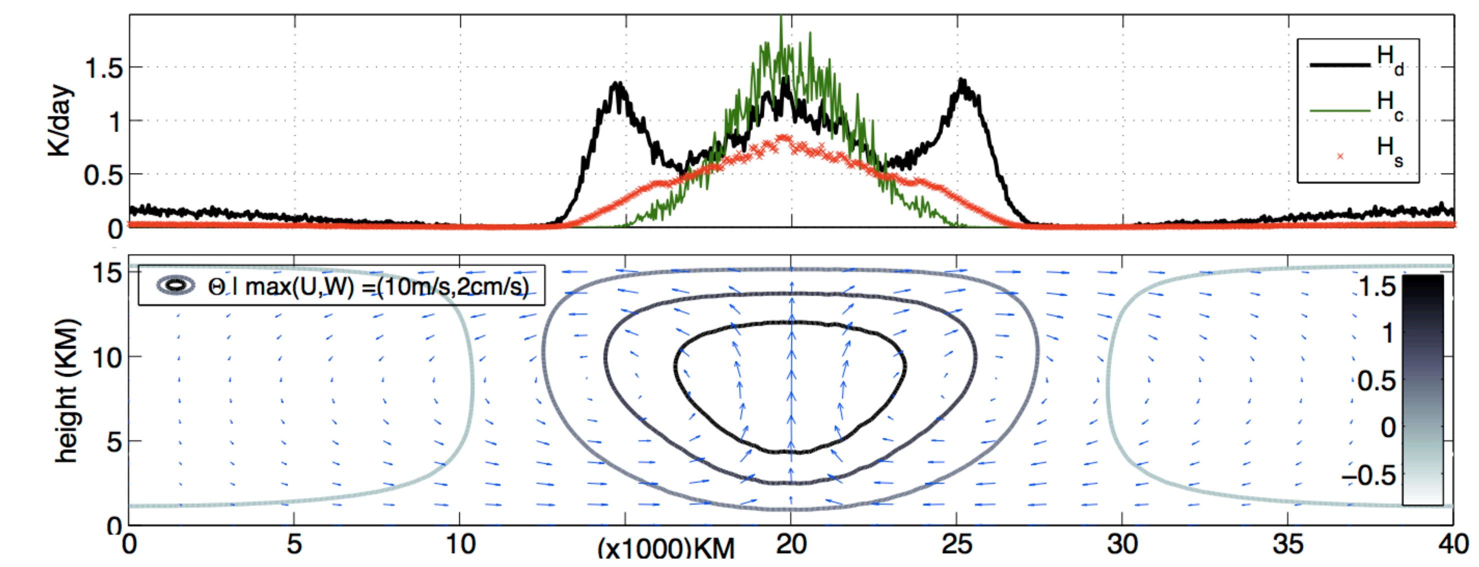
- The multicloud parametrization framework assumes three heating profiles associated with the main cloud types that characterize organized tropical convective systems : cumulus congestus clouds that heat the lower troposphere and cool the upper troposphere, through radiation and detrainment, deep convective towers that heat the whole tropospheric depth, and the associated lagging-stratiform anvils that heat the upper troposphere and cool the lower troposphere, due to evaporation of stratiform rain [4,5,6].



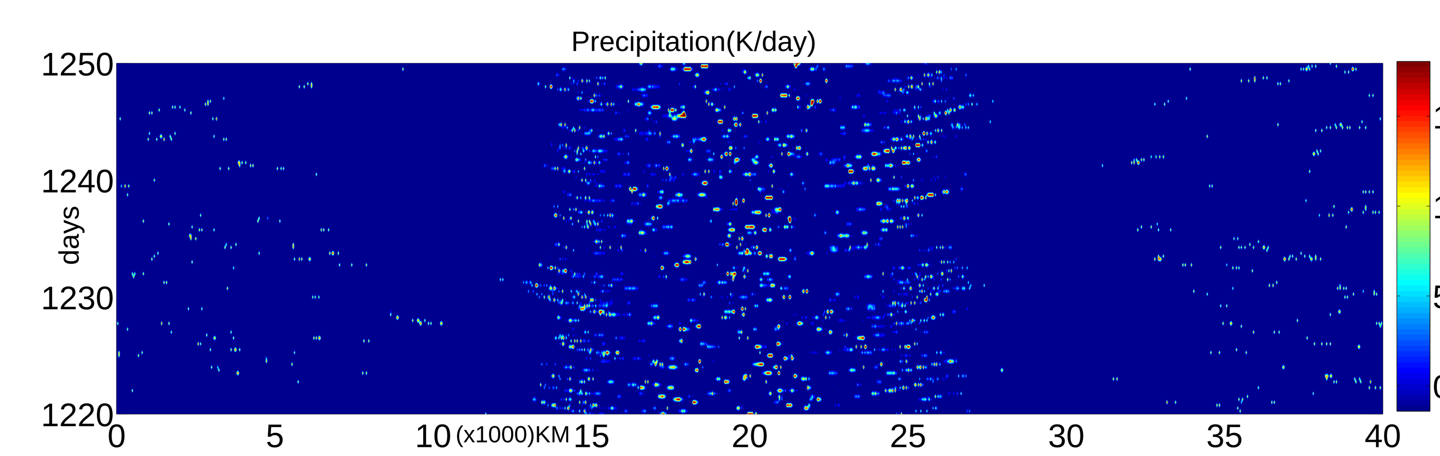
- A clear site turns into a congestus site with high probability if low level CAPE (C_l) is positive and the middle troposphere is dry (D). A congestus or clear sky site turns into a deep convective site with high probability if CAPE (C) is positive and the middle troposphere is moist. A deep convective site turns into a stratiform site with high probability [4,5]. These rules are formalized by transition rates, R_{ik}.
- A four state continuous time stochastic process is then defined by allowing the transitions for individual cloud sites. All cloud sites in a GCM grid box are assumed to be identical. This simplification makes it easy to derive, through a coarse-graining technique [3] ,the stochastic dynamics for the grid box cloud coverages alone. The resulting birth-death Markov system is easily evolved in time using Gillespie's exact algorithm[1].
- The equations are coupled to momentum and potential temperature equations for the first and second baroclinic modes of vertical structure, that are directly forced by deep convection and both congestus and stratiform clouds, respectively. The multicloud model also carries equations for the vertically averaged moisture and bulk boundary layer dynamics.

Results

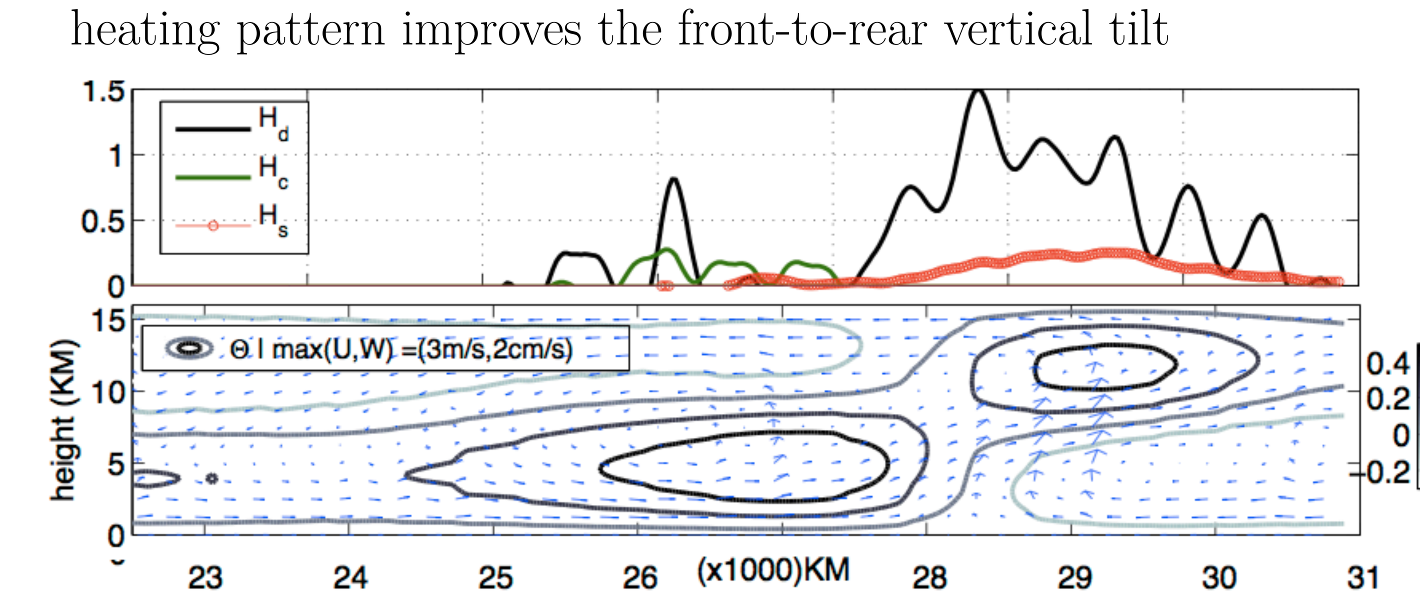
- Improved mean structure of Walker circulation



- Intermittent coherent structures contribute to higher variability.



- Westward propagating CCW, note congestus to deep to stratiform heating pattern improves the front-to-rear vertical tilt



Conclusions

- The stochastic model produces **realistic mean Walker-cell circulation** and **dramatically improves the variability of tropical convection**. This increase in **variability comes from intermittent coherent structures such as synoptic and mesoscale convective systems, analogs of squall lines and convectively coupled waves seen in nature whose representation is improved by the stochastic parameterization.** Both the structure of the mean circulation and waves are comparable to the results of CRM simulations [2].

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References

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