A Statistical View of the Large-Scale Properties of Tropical Convection

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Motivation

The International Satellite Cloud Climatology Project (ISCCP) D1 dataset provides joint-histograms of cloud top pressure and optical thickness for 280 km × 280 km equal-area grids globally. Applying cluster analysis[1] to **35°S to 35°N** from **1985 to 2007** yields **eight cloud regimes** (Fig. 1).

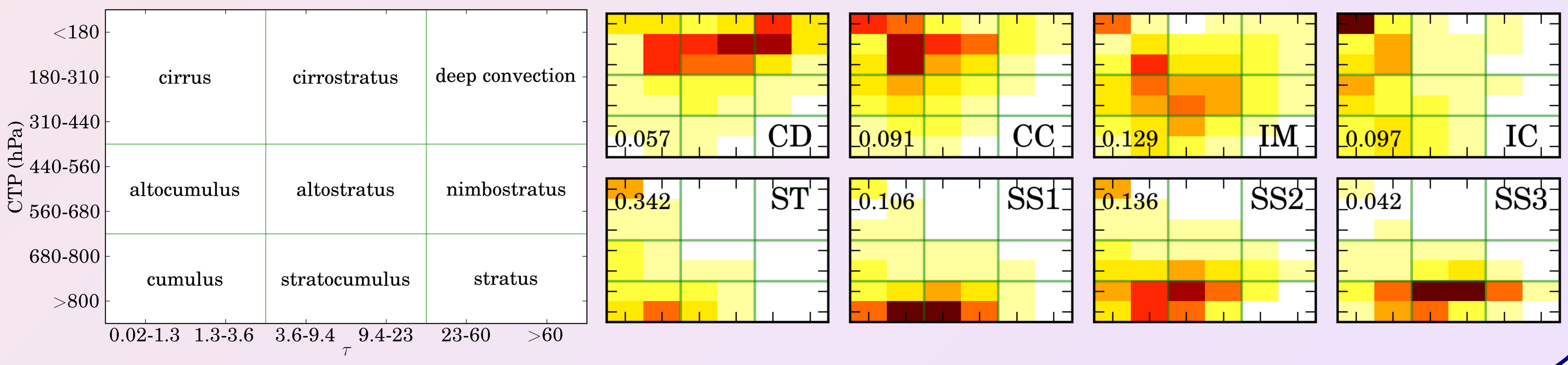
The goal of this study is **to investigate the atmospheric conditions in which the regimes occur** and **to determine whether they provide a more useful description of the character of tropical convection** than more traditional measures such as OLR and precipitation.

Fig. 1 (right). Mean optical thickness (x-axis) versus cloud top pressure (y-axis) frequency distributions for each of the eight tropical cloud regimes[2]. The abbreviated regime name and its relative frequency of occurrence in indicated in the sub-figures. See table below for the full regime names based on convective state and dominant cloud type.

	Convectively-active	Intermediate	Suppressed
Dominant cloud type	Deep stratiform (CD)	Mixture (IM)	Trade cumulus (ST)
	Cirrus (CC)	thin Cirrus (IC)	Stratocumulus (SS; 3 types)

Dataset

- ISCCP Flux Data: **outgoing longwave radiation** (OLR) at top of atmosphere
- Global Precipitation Climatology Project: **daily precipitation**
- ECMWF Re-Analysis (ERA-Interim):
  - **saturation ratio** r, the ratio of the vertical integral of humidity to that of saturated humidity
  - **lower tropospheric stability** LTS, defined as the difference in dry potential temperature between 700 hPa and the surface
  - **vertical velocity** ω



Relationship of Atmospheric Properties of Regimes

The convectively-active regimes are wet, unstable and mostly exist in ascending motion. The suppressed regimes are dry, stable and mostly exist in descending motion. The intermediate regimes show both convective and suppressed characteristics, indicating their transitional nature. The regime CD stands out as the wettest and most strongly ascending atmospheric state.

The regime occurrence distributions (Fig. 3) separate best in vertical motion and saturation ratio for the convectively-active regimes and in lower tropospheric stability for the suppressed regimes. According to the Kolmogorov-Smirnov two-sample test, the distributions of each regime are distinct.

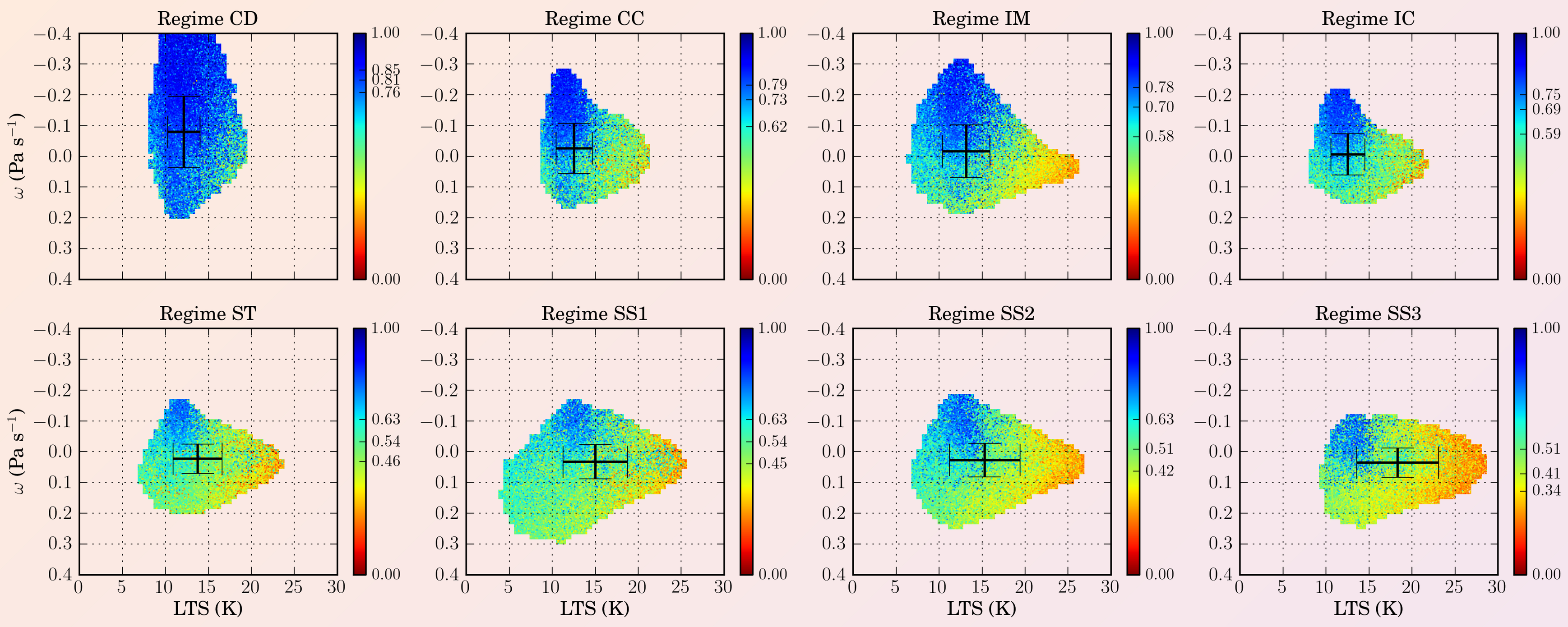


Fig. 2. Scatter diagram of the relationship between lower tropospheric stability (x-axis), vertical motion (y-axis) and saturation ratio (colour) for each regime. Points lying outside the 0.95 contour line of the density of points are discarded. Black crosses indicate the median and interquartile range, also shown for saturation ratio in the colour bar.

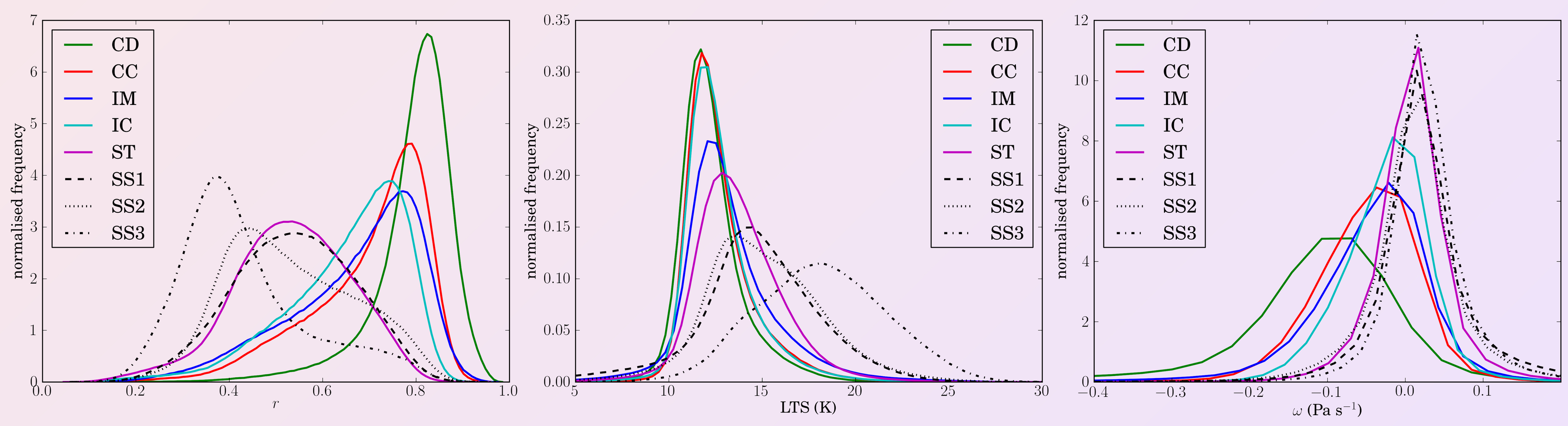
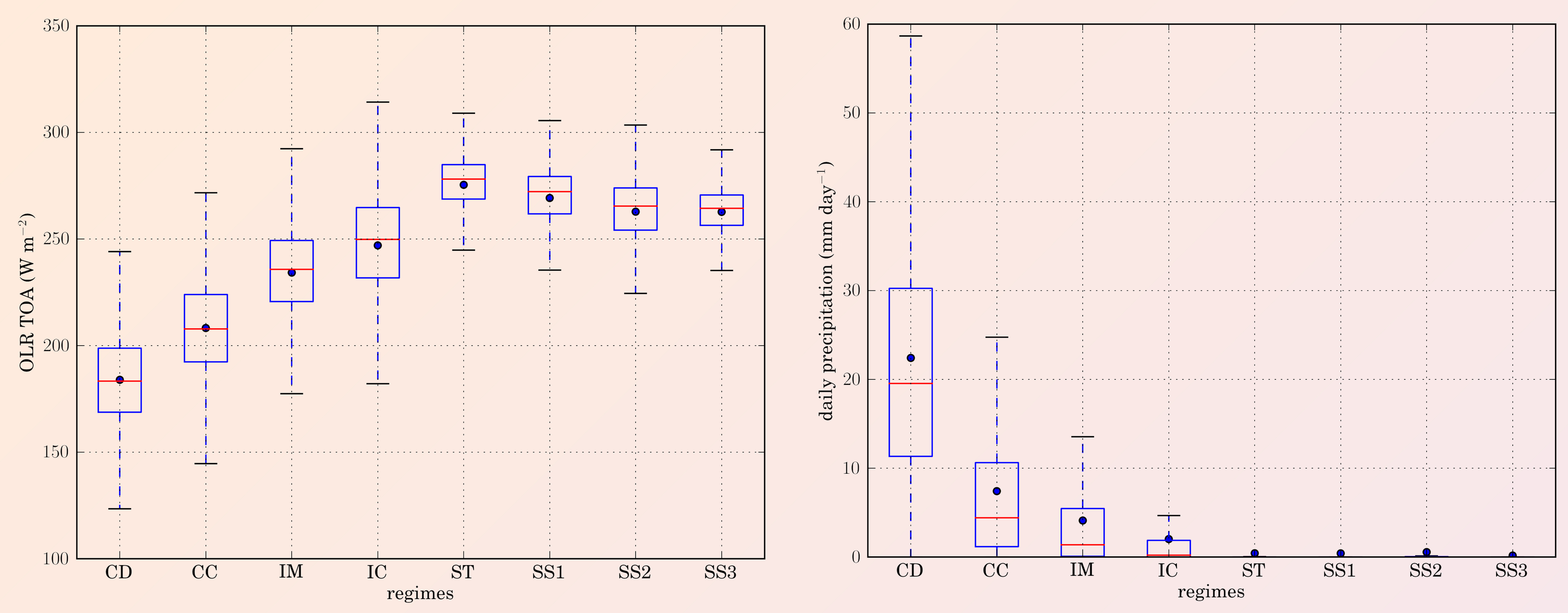
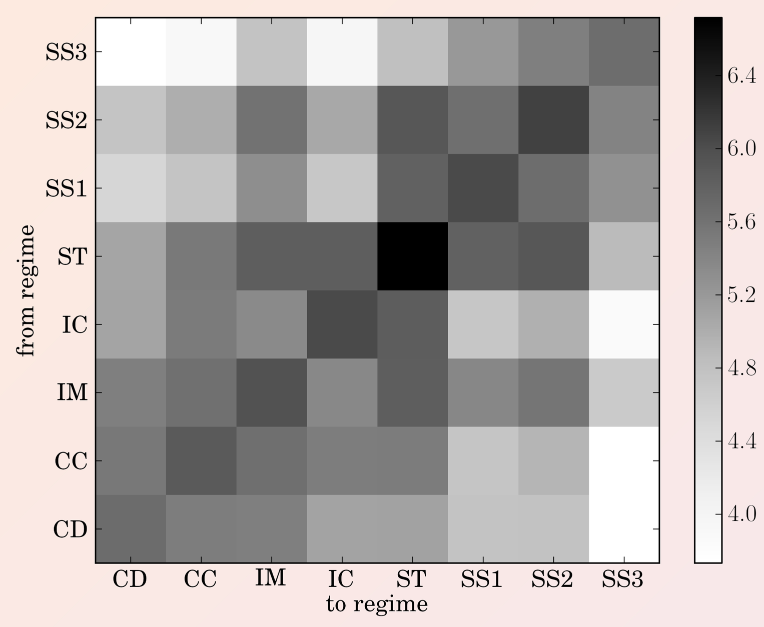


Fig. 3. Normalised distributions of the regime frequency of occurrence as a function of r, LTS and ω. A Kolmogorov-Smirnov two-sample test rejects the hypothesis that any of the distribution comes from the same population.





(Top) Fig. 4. Box-whisker diagrams of OLR at TOA (left) and precipitation (right) for the tropical cloud regimes.

(Left) Fig. 5. Number of transitions between regimes at the same grid points for the entire period. The scale of the colourbar is logarithmic (base 10). Keep in mind that the transition counts are influenced by the regimes' frequencies of occurrence (FOC); to illustrate this, compare transitions from ST (FOC = 34%) and SS3 (FOC = 4.2%): $N_{ST\to CD} = 12 \times 10^4 > N_{SS3\to IM} = 6.0 \times 10^4$ even though the latter transition is more likely ($p_{ST\to CD} = 1.4\% < p_{SS3\to IM} = 6.2\%$).

Regimes, OLR, and Convection

Two conventional measures of convective strength, OLR and rainfall, are composited with the regimes in Fig. 4. The regimes, in particular the convectively-active and intermediate regimes, exhibit **different OLR and rainfall statistics**. Therefore, the regimes can be utilised as a **measure of convective strength**.

Regimes offer several advantages over OLR and rainfall as a proxy for convection because:

1) the regimes provide a **more informative distinction of the type of convection**, such as strong stratiform components (CD) and a prevalence of congestus type convection (IM);
2) the regimes allow a **clearer identification of the type of suppressed conditions**, which are indistinguishable in OLR and precipitation; and
3) the regimes, being empirical archetypes of recurring cloud patterns, offer a **more complete representation of atmospheric conditions**.

The transition counts between regimes (Fig. 5) lend further support to this idea of a convective measure. First, the transition counts are roughly symmetric (e.g. $N_{CC\to CD} \approx N_{CD\to CC}$). Second, transitions between regimes of similar convective strength are more frequent (e.g. $N_{CD\to CC} > N_{CD\to ST} > N_{CD\to SS3}$). Both facts imply the **existence of various stages of convection**, especially the intermediate states which mediate transitions between the convectively-active and suppressed regimes.

Conclusions

1) The eight tropical regimes identified from ISCCP data exist in distinct large-scale atmospheric conditions, making them a **good descriptor of the tropical and subtropical atmosphere**.
2) The convectively-active regimes can serve as an **empirically-derived measure of convective strength in the atmosphere** and possess several advantages over traditional measures such as OLR and rainfall.

1 Jakob, C., and G. Tselioudis (2003), Objective identification of cloud regimes in the Tropical Western Pacific, *Geophysical Research Letters*, **30**, 2082, doi:10.1029/2003GL018367.

2 Cloud morphology of ISCCP joint-histograms adapted from http://isccp.giss.nasa.gov/cloudtypes.html.

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