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CloudSat and CALIPSO cloud composites for the Madden-Julian Oscillation

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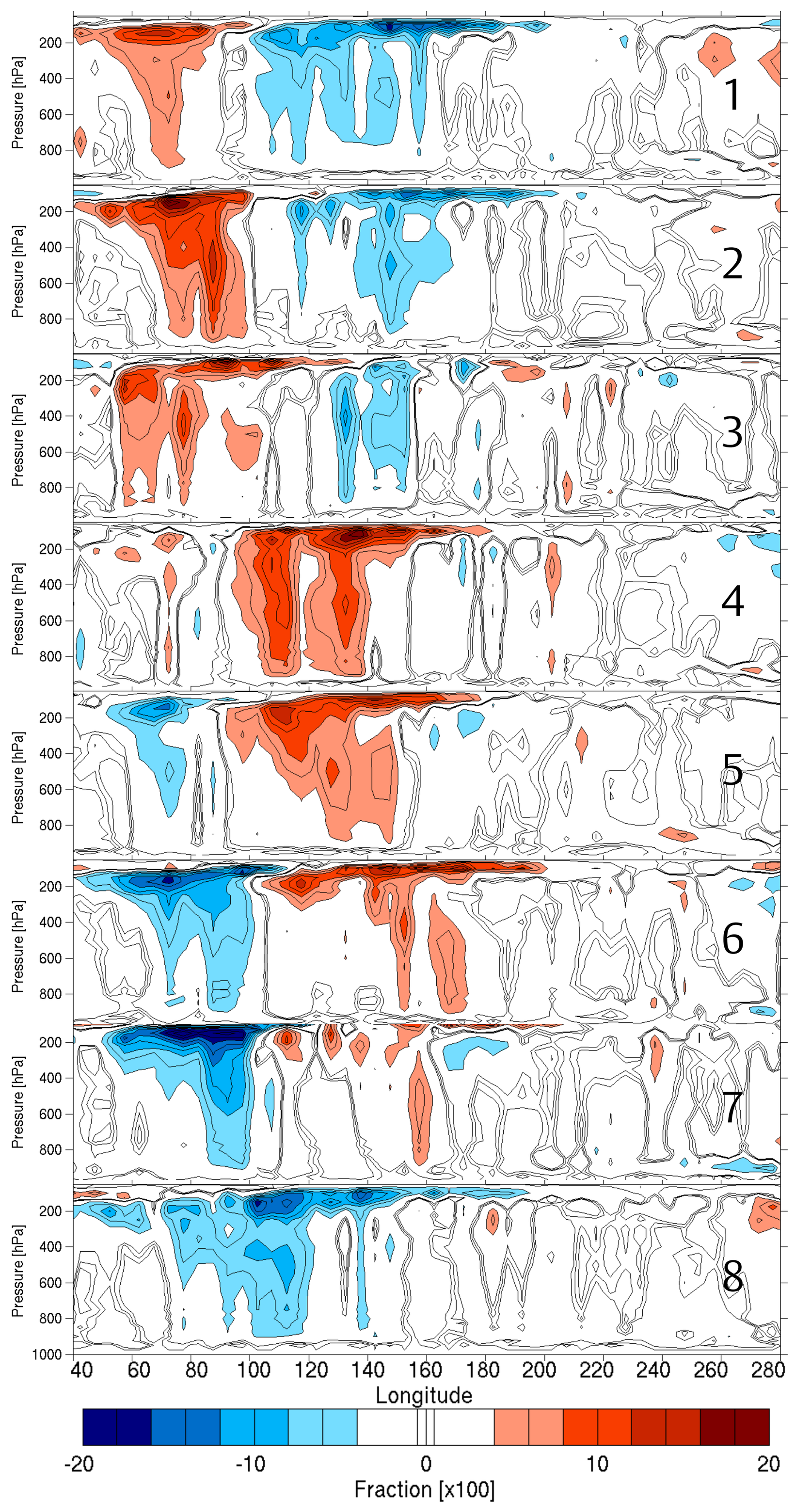
Introduction

We use three years of collocated CloudSat and CALIPSO data (Delanoë and Hogan, 2010) to study the vertical cloud structure associated with different phases of the Madden-Julian Oscillation (MJO). The combination of the CloudSat radar and the CALIPSO lidar allows us to observe all cloud from optically thin cirrus to deep convection. ERA-Interim data are used to compare anomalies in observed cloud structures with anomalies in temperature, zonal wind and relative humidity from reanalysis.

Mean vertical cloud structure

CloudSat and CALIPSO observations of cloud and precipitation are averaged along the equator over 5° longitude and across the equator from 10°S to 10°N.



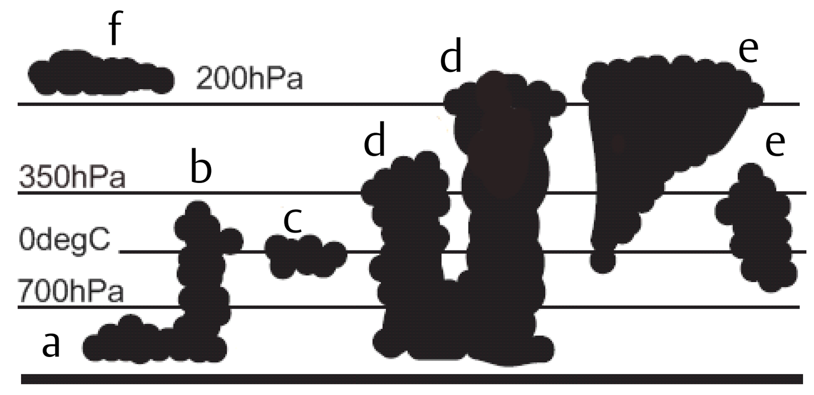
The mean vertical cloud-and-precipitation structure can be decomposed into the structures associated with each individual phase of the MJO, where we use the Wheeler and Hendon (2004) index when the MJO amplitude is larger than 1.

To the left we show the anomalous cloud-and-precipitation fraction compared to the mean, per phase, which clearly shows the progression of the deep convective signal with the eastward propagation of the MJO.

Information on less extensive cloud types such as shallow cumulus is masked by the strong anomalies from deep convection.

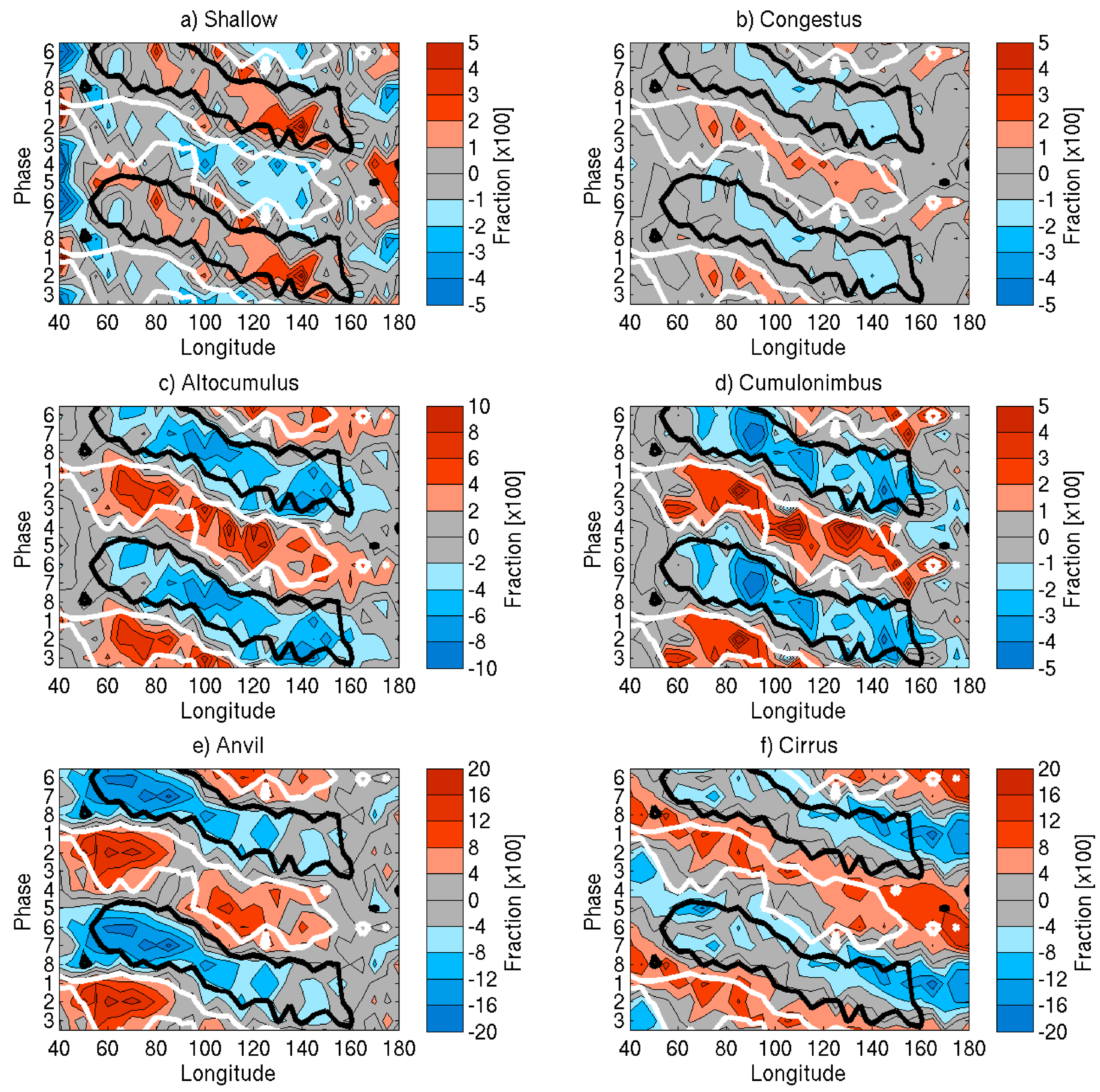
Cloud classification

For every individual CloudSat-CALIPSO profile we use pressure levels to distinguish between six different cloud types, indicated on the right.



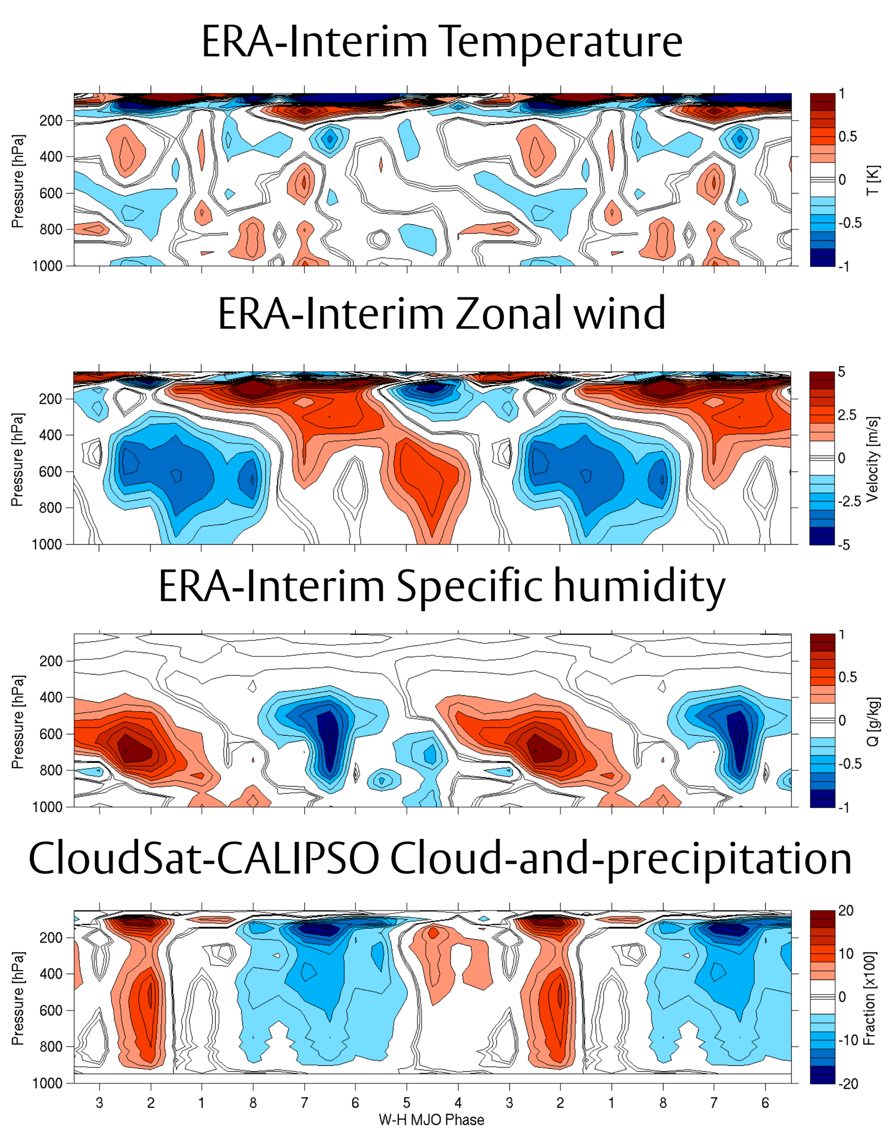
a. Shallow
b. Congestus
c. Altocumulus
d. Cumulonimbus
e. Anvil
f. Cirrus

Below, we compare the probability of a each cloud type per profile for a given phase and location with the mean probability of that cloud type at that location. Black and white contours indicate OLR anomalies of +7.5 and -7.5 W/m² respectively. Enhanced shallow convection is now observed during the suppressed phase of the MJO, whilst the congestus signal is weak and timed with cumulonimbus. Cirrus is on the cusp of positive and negative OLR anomalies.



ERA-Interim analysis associated with CloudSat-CALIPSO observations

ERA-Interim reanalysis data are interpolated to every 3 hours and averaged to 2.5 degrees, then sampled when the CloudSat-CALIPSO track crosses a 2.5x2.5 degree grid box within 1.5hr. To the right, we show the anomalies of temperature, zonal wind, and specific humidity, averaged between 90°E and 100°E (west of Sumatra), with phase ("time") reversed on the x-axis to highlight the westward tilt with height of these anomalies at this location. The cloud-and-precipitation anomaly in the lower panel clearly occurs after low-level moistening and is followed by westerly wind anomalies in the lower troposphere. Cooling can be seen to co-occur with cirrus ahead of the MJO, associated to a Kelvin wave response by Virts et al. (2010).



Conclusions

- **CloudSat-CALIPSO composites confirm the MJO as an eastward propagating signal of deep convection**
- **Cirrus and shallow cloud are enhanced ahead of the MJO active phase but no strong congestus signal is observed**
- **Initial comparison with re-analysis suggests CloudSat-CALIPSO composites are suitable to study cloud response to the atmosphere**