Assessing the saturated and unsaturated air relative contributions to tropical convective momentum transport

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Motivation

To analyze cumulus convection, it is useful to separate the contributions from saturated air (air within the clouds) and unsaturated air (air outside or between clouds, or free air) because these often have different underlying mechanisms. The core assumption made in all Convective Momentum Transport (CMT) parameterizations is that CMT mainly occurs within vigorous cumulus clouds updrafts and downdrafts, i.e. CMT is dominated by large horizontal velocity anomalies in the cumuli. *Unsaturated updrafts and downdrafts are not taken into account, therefore they aren't considered as subject of research.* CMT parameterizations evolved, over time, in a particular direction where it is assumed that cloudy updrafts have the strongest signature on CMT leading to a slower investigation of saturated downdrafts. These are not fully explored, no saturated downdrafts parameterization is established so far. Consequently, understanding the roles played by the saturated and unsaturated air is of vital importance to aid the development of an appropriate parameterization of convective momentum fluxes within general circulation models.

Model & Data

✶ The simulations available to perform this study are provided by the System for Atmospheric Modeling (SAM, Version 6.3), a **C**loud-**R**esolving **M**odel (CRM) developed by M. Khairoutdinov at CSU(2003).

✶ The model solves non-hydrostatic and anelastic equations for a 3-Dimensional, rectangular, cartesian horizontal grid (C-grid) over a flat and homogeneous surface, and it uses a single-moment bulk microphysical parameterization and has prognostic equations for liquid–ice static energy, total non-precipitating water (vapor/cloud) and precipitating water.

✶ The CRM uses three types of thermodynamic forcings and the radiation scheme is provided by the **C**ommunity **A**tmosphere **M**odel (CAM), which is a GCM from NCAR.

✶ 3D and statistics data files from a 120-day simulation (the full TOGA COARE time period from Nov 1st 1992 to Feb 28th 1993), for a small (64 x 64 horizontal grid point) doubly-periodic domain, 1 km horizontal resolution and 96 vertical levels between the sea surface and 30 km of height are used.

✶ An additional 256x256x96 large-domain simulation was performed for a 10 day subperiod (Dec 16 to 25, 1992) with strong convection combined with substantial mean vertical zonal wind shear, conditions favourably for strong CMT.

✶ Case-study: cumulus-scale characteristics of convective momentum transport during a specific deep convective episode - the late December westerly wind burst, 1992.

Binning Method

✶ Definition of saturated and unsaturated updrafts and downdrafts grid points (Gregory et al. 1997) - Table 1.

✶ Vertical-velocity binning approach is applied to the 3D small domain hourly data set for Julian day 358, but first tested on a single tridimensional CRM volume.

✶ Bin sizes of 512, 256, 128 and 64 elements are tested.

✶ Binned fields: zonal velocity perturbation (*Up* in m/s), the density temperature (T_d in K) and the buoyancy acceleration (*By* in m/s^2).

✶ Binning is very helpful method because the correlations of horizontal and vertical velocity perturbations that create CMT are relatively weak, 0.1 or less at many vertical levels, and binning *w* filters out most of the noise, isolating the correlated part of the variability without assuming a particular (*e.g.* linear) structure for this variability, providing clarification of the mechanisms involved in the CMT.

Results

Table 1. Definition of saturated and unsaturated up-and-downdrafts. W is the vertical velocity (m/s) and QN is the non-precipitating condensate mixing ratio (g/kg).

	QN	W	
Saturated Unsaturated	> 0.001 0	≥ 1	Updraft
Saturated Unsaturated	> 0.001 0	≥ 5	Strong Updraft
Saturated Unsaturated	> 0.001 0	≤ -1	Downdraft

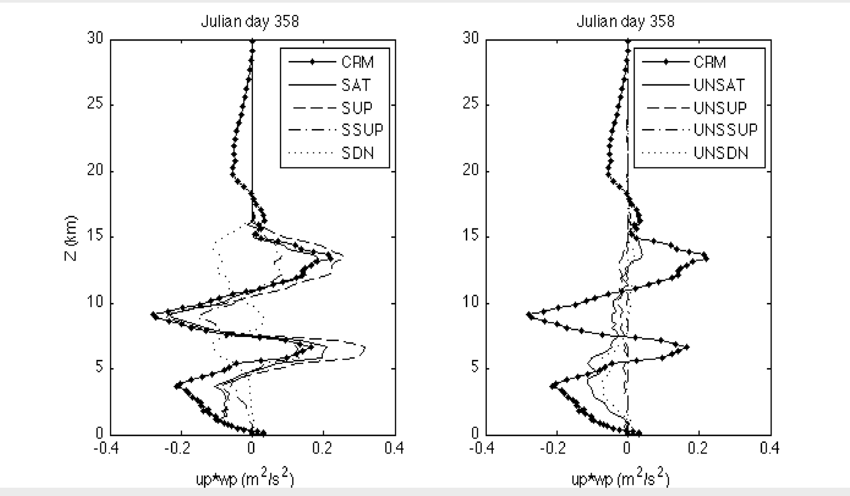

Fig.1 Vertical profiles of the CMT for the whole CRM spatial domain, contributed by saturated and unsaturated up-and-downdrafts domains.

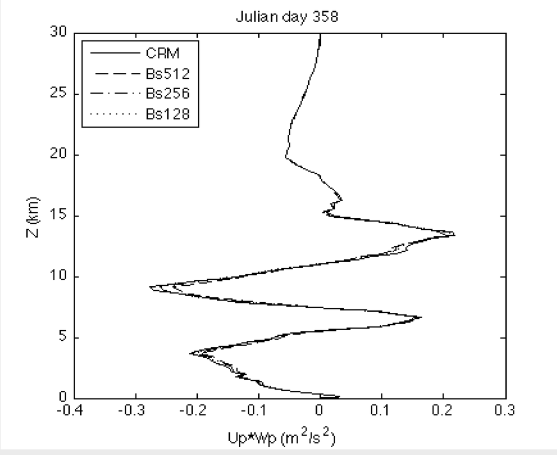

Fig.2 Vertical profiles of the binned CMT for the whole CRM spatial domain.

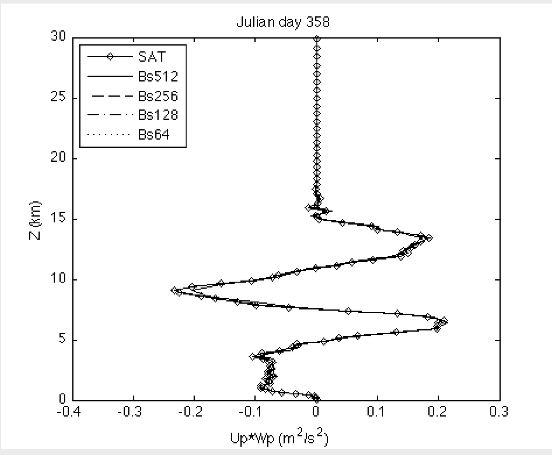

Fig.3 Vertical profiles of the binned CMT for the saturated CRM domain.

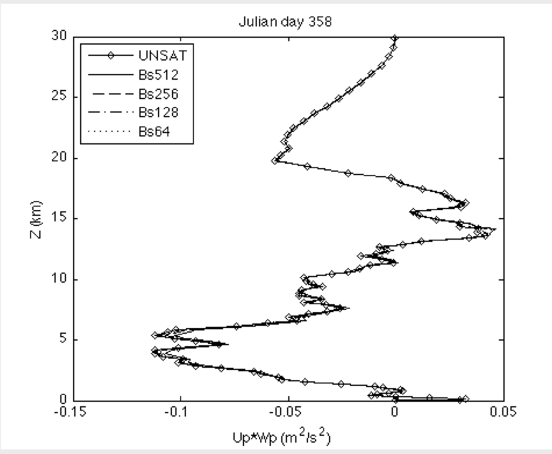

Fig.4 Vertical profiles of the binned CMT for the unsaturated CRM domain.

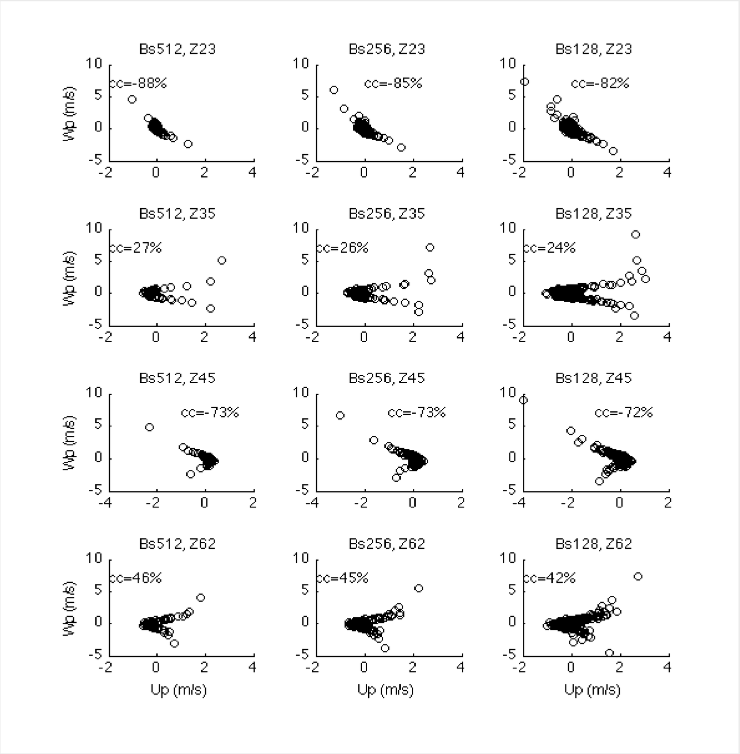

Fig.5 Scatter plots of binned u' (Up) and w' (Wp), for specific bin sizes of 512, 256 and 128 elements, at vertical levels of Z23 (3.625 km), Z35 (6.625 km), Z45 (9.125 km) and Z62 (13.375 km), with the correspondent correlation coefficient values (in %) .

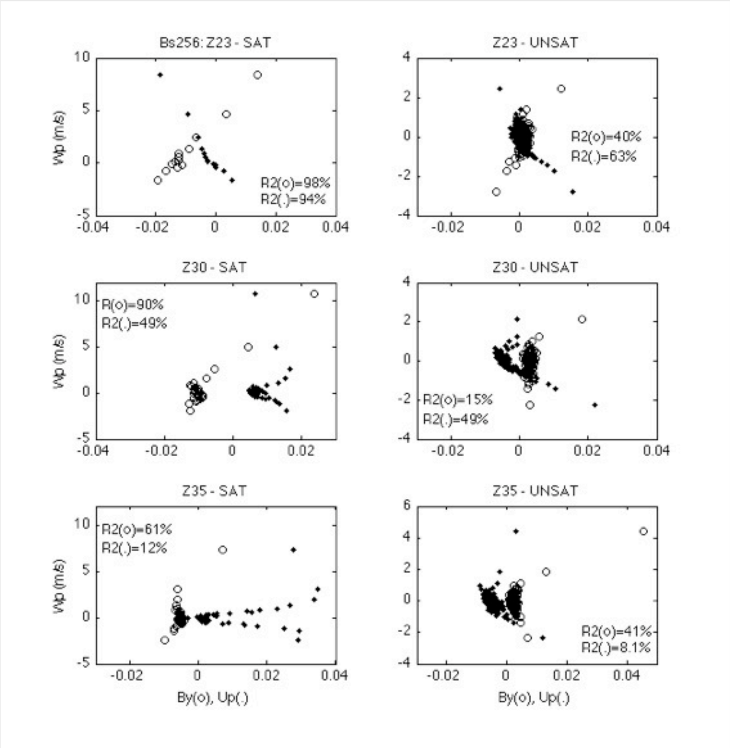

Fig.6 Scatter plots of binned saturated and unsaturated Buoyancy (By - circles), u' (Up/100) and w' (Wp), for the bin size of 256 elements, at vertical levels of Z23 (3.625 km), Z30 (5.375 km) and Z35 (6.625 km), with the correspondent correlation coefficient squared (in %).

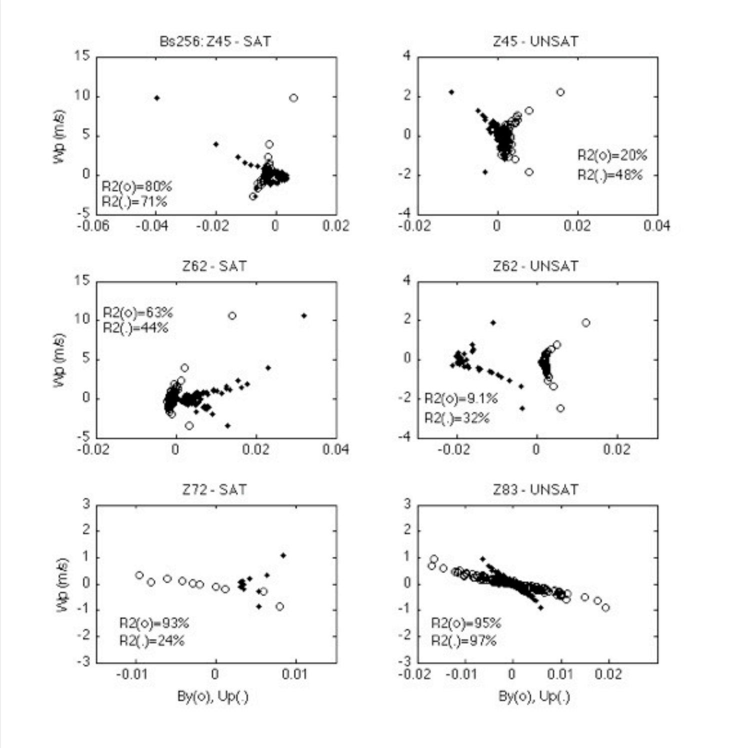

Fig.7 Scatter plots of binned saturated and unsaturated Buoyancy (By), u' (Up/100) and w' (Wp), for the bin size of 256 elements, at vertical levels of Z45 (9.125 km), Z62 (13.375 km), Z72 (16.281 km) for saturated bins and Z83 (21 km) for unsaturated bins only, with the correspondent correlation coefficient squared (in %).

Conclusions

➡ The CMT contributions from saturated and unsaturated air have different vertical profiles, and although the CRM CMT holds a strong saturated air signature, the unsaturated air also significantly shapes it, within the lower-levels and above tropopause, via downdrafts.

➡ The bin-mean total, saturated and unsaturated CMT compares well to the exact correspondent CMT simulated by the model -> little information relevant for CMT has been lost by binning.

➡ Binning *Up* and *Wp*, without partitioning into saturated and unsaturated air, exposes a strong linear correlation between the bin-averages.

➡ Mid and upper troposphere are dominated by a C-curve structure with little linear correlation in every binned saturated and unsaturated fields -> strong interaction with environmental air can be the cause?

➡ The saturated air holds a strong correlation between buoyancy acceleration and vertical velocity perturbation (*Wp*), which is expected for buoyancy-driven convective drafts.

➡ The unsaturated air exhibits poor correlation between buoyancy and *Wp* in many tropospheric levels, except in the stratosphere, however there are some levels, within mid and upper troposphere, where buoyancy is almost zero for all *Wp* bins -> internal gravity waves driving unsaturated air?

➡ In future CMT parameterizations, downdrafts and unsaturated air must be considered in order to accurately resolve cumulus convection in GCM models.

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