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Evaluation of the West African monsoon vertical cloud structure in the UM using CloudSat

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Motivation

This work forms part of the NERC funded **Cascade** project, in which we study the development and organization of **tropical convection** at increasing **model resolution**, using the Met Office Unified Model (UM).

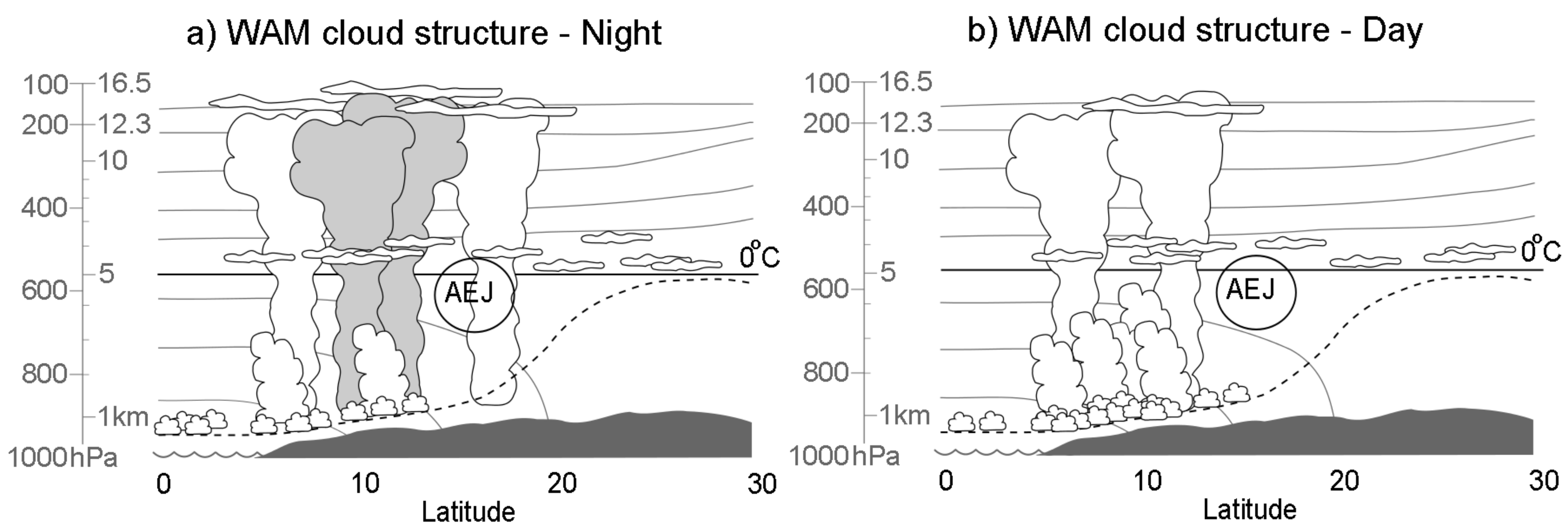
The **West African monsoon** is a region of large uncertainty in climate model prediction of precipitation and provides a **test bed** to evaluate model capability to represent different cloud types.

CloudSat and CALIPSO provide detailed information on **cloud vertical structure** around the globe, with the **lidar** observing cloud tops and thin cirrus, and the **radar** penetrating anvil and deep convection.

Observed Vertical Cloud Structure

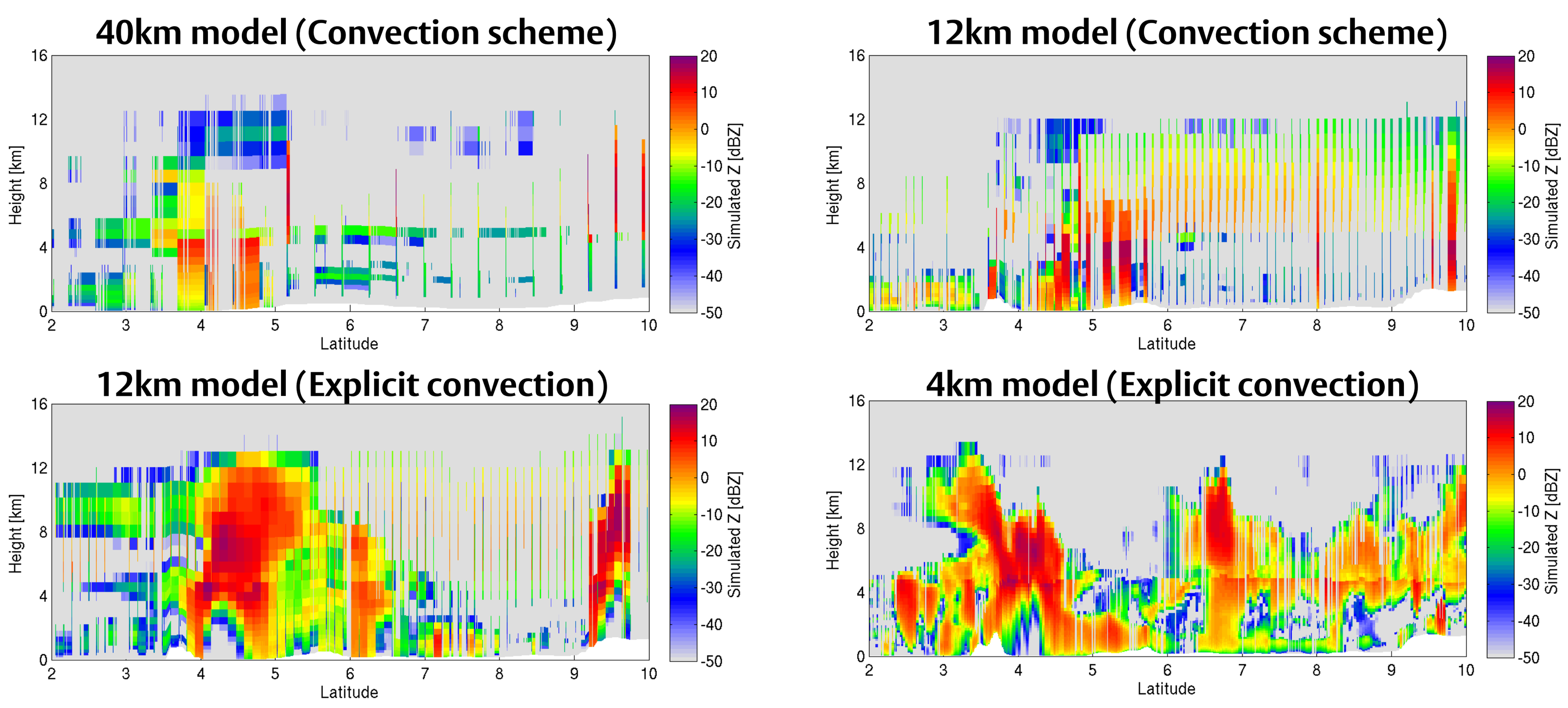
A four-year climatology of the **zonal mean** vertical cloud structure of the West African monsoon has been constructed using data from CloudSat and CALIPSO [1]. The results from cloud fraction, frequency, and mean amounts are depicted schematically below and can be summarised as follows:

1. **Deep convection and anvil** are confined to a region between 5°N and 15°N, with higher mean amounts when present at night.
2. **Cirrus** is located in the same region as deep convection, with higher amounts towards the north.
3. A layer of **altocumulus** extends north from 5°N over the Sahara, situated above the freezing level and normally topped by supercooled liquid.
4. **Congestus** are frequently observed in the early afternoon up to 12°N.
5. Low-level cloud extend further north in the early afternoon, indicative of the advance of the **monsoon layer**, whilst nocturnal stratus is evident over the Atlantic.



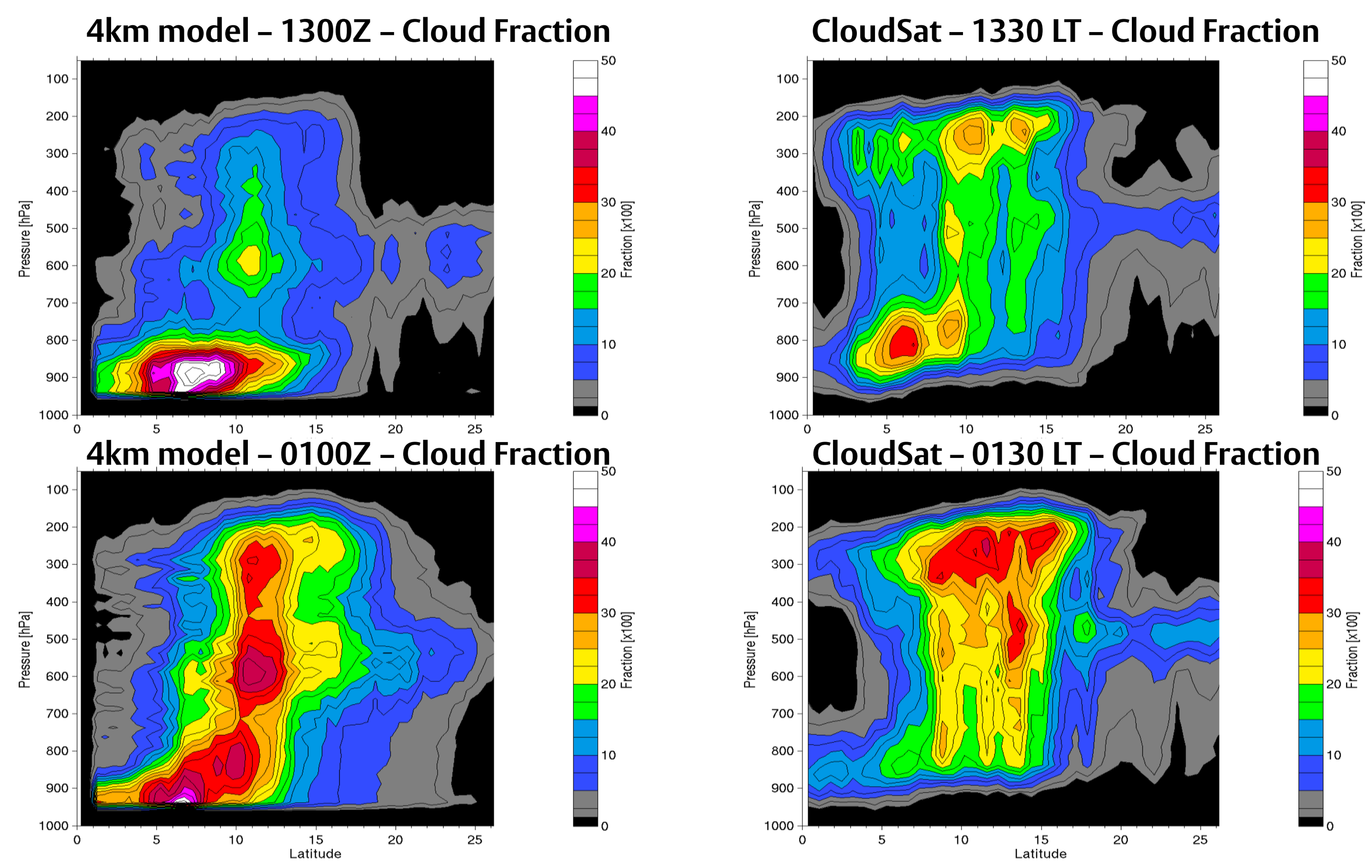
Model Setup and CloudSat Simulator

To provide a like-with-like comparison between model and observations, we use the Quickbeam radar simulator [2], part of the COSP satellite simulation package [3]. Using the model cloud and precipitation fractions and the maximum-random cloud-overlap assumption, subgrid hydrometeor profiles are produced in COSP, for which Quickbeam then calculates the CloudSat radar reflectivities using the model microphysical parameters for rain, snow, liquid, and ice. Below, we show simulated reflectivity profiles for different model configurations for the same longitude and hourly output. Due to the infrequent sampling by CloudSat of the same region, we evaluate the model statistics against the mean observed cloud structure for August 2006-2009. For a given hourly output, 20 latitude-height simulated reflectivity swaths are taken from the 4km-model at random longitudes to produce the statistics shown.



References

1. Stein et al., 'The vertical cloud structure of the West African monsoon: A four-year climatology using CloudSat and CALIPSO', *J. Geophys.Res*, 2011, doi:10.1029/2011JD016029
2. Haynes et al., 'A multipurpose radar simulation package: Quickbeam', *Bull. Amer. Meteor. Soc.*, 88 (2007), pp. 1723-1727
3. Bodas-Salcedo et al., 'Satellite simulation software for model assessment', *Bull. Amer. Meteor. Soc.*, 92 (2011), pp. 1023-1043



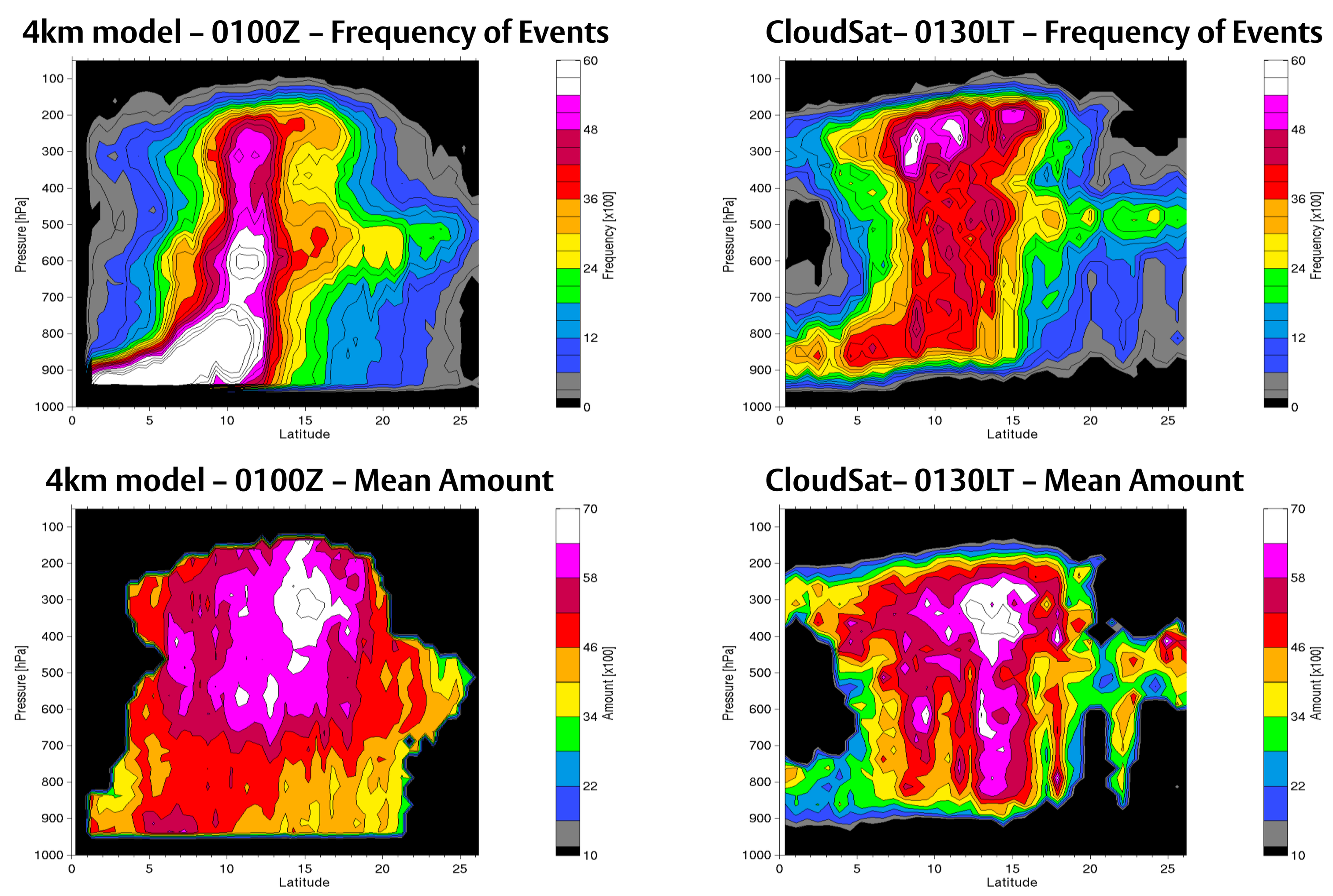
Results on Model Performance

The panels above show the zonal mean cloud fraction between 10°W and 10°E on a latitude-pressure grid. We pick up on three main differences:

1. **Too much low-level cloud in the model**: This abundance is not observed by CloudSat and this model bias may be due to too much precipitation from low-level cloud.
2. **Deep convection distribution too "normal"**: Observations indicate variation in the location of deep convection, possibly linked to African Easterly Waves, whilst the model may fail to respond to these dynamic features.
3. **Mid-level detrainment too low:** The model tends to detrain right around the freezing level, whereas observed altostratus are regularly observed to temperatures down to -25°C.

Frequency of Events and Mean Amount when Present

Mean cloud fraction obscures the contribution from smaller but perhaps frequent cloud types to favour organised systems. For the night-time evaluation we calculate the frequency of events (event is 10% cloud fraction over 0.5deg and 25hPa) and the mean amount for these events. The low-level cloud abundance comes from both a high frequency and a larger mean amount. The frequency and mean amounts of altostratus and deep convection are comparable to observations.



Summary and Outlook

CloudSat and CALIPSO enable us to construct **climatologies** of vertical cloud structure to test climate model performance and study cloud feedback.

Satellite **simulators** allow for a like-with-like comparison between observations and models, although differences in sampling strategy need to be studied further.

At 4km resolution, an adjustment of model **microphysics** to include a drizzle mode may reduce the overestimate of low-level cloud using simulated reflectivities.

A study of **energetics** of African Easterly Waves in the model may explain the low variability in latitudinal position of deep convection.

Study of the **thermodynamic** profiles for mid-level cloud is expected to explain their low position in the model.