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COMPARING DEEP CONVECTIVE SYSTEM EVOLUTION FOR AFRICA AND THE TROPICAL ATLANTIC

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1. INTRODUCTION

Some of the strongest convection found anywhere occurs over the African continent in the summer months, while more weakly buoyant convection is often found over the tropical Atlantic convergence zone. Differences in the radiative, precipitation and lightning properties between these regimes will be investigated as a function of system evolution.

Here, broadband infra-red radiance data from the geostationary Meteosat-8 satellite are used to identify and track convective cloud systems. A multiple threshold detect and spread approach is used to capture all stages of development. The observed system evolution is then used to define the life-cycle stage at each time-step, providing a framework within which other, non-geostationary satellite or in situ data can be used to build up a composite picture of convective system evolution.

As expected from previous studies, Atlantic systems are shallower and have lower albedos, but higher precipitating area fractions than their land based counterparts throughout their lifecycle. TRMM precipitation radar and lightning imager data are used to further investigate and interpret differences in both the mean properties and system evolution for the two regions. We expect the results to provide valuable constraints for the testing of mesoscale updraft and stratiform anvil parameterizations that are currently absent or deficient in GCMs.

2. METHODOLOGY

2.1. *Detection and Tracking of Convective Systems*

Convective systems are identified as continuous regions of cold topped cloud in the broadband thermal flux images from Meteosat-8. As data from the Geostationary Earth Radiation Budget (GERB) experiment are not yet available, GERB-like data, produced using a narrow-band to broad-band conversion of SEVIRI (the Spinning Enhanced Visible and Infra-Red Imager) data, are used here. To ensure that as much of the cirrus anvil associated with the convective cores as possible is retained, a multiple threshold detect and spread approach, similar to that proposed by Boer and Ramanathan (1997) is used. An initial threshold is applied to the flux image to define cold system cores. These are then grown outwards until either the edge of the system at the second, warmer, threshold value is reached, or until another system is encountered. New systems, without a cold core, are also detected at the new threshold. The process is repeated until all systems have been grown to the warmest threshold value. By including warmer anvil cloud surrounding cold cores, and allowing the system to be tracked through stages of development where no cold core is present, this approach provides a more complete picture of the spatial and temporal structure than tracking with a single threshold. The results presented here are for thresholds at 165, 200 and 235 W m^{-2} (approximately 232, 244 and 254 K respectively), however similar results are found for alternative thresholds.

Systems are tracked through their lifecycle using hourly flux data. Tracking is performed iteratively using a maximum area overlap approach. For each system identified in the new image, if the cold core of that system overlaps with more then 50% of the cold core of a system in the previous image they are identified as the same system. If not, or for new systems without cold cores, overlap is calculated at the warmer thresholds. Where two systems merge, the larger, deeper system is considered to continue and the smaller part to terminate. Similarly, where a system splits, the larger fragment is considered as the continuation. All systems present in three or more consecutive images are tracked, but results presented here are only for systems reaching a minimum brightness temperature at some point during their lifetime of less than 220K and a maximum effective radius of more than 300km, which we refer to as 'large deep systems'.

2.2. *Determining Life-cycle Stage*

The evolution of the system radius and minimum brightness temperature is used to define the life-cycle stage. The definition is based on the expected evolution of a convective system, beginning with ver-

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tical growth of a cumulus core, followed by detrainment of a cirrus anvil and subsequent dissipation. For each tracked system a smooth curve is fitted to the radius and temperature data and used to determine the time where the minimum temperature is reached and the time of maximum spatial extent. Before the minimum in brightness temperature the system is growing vertically and is considered to be 'developing'. The subsequent period of horizontal growth is considered to be the 'mature' or 'detraining' stage of the system's development, and the system is considered to begin to dissipate after the maximum radius is reached. The developing and dissipating stages are further divided into 'cold' and 'warm' portions based on the minimum brightness temperature within the cloud. This categorization is illustrated in Figure 1, which shows the temperature and radius data and the resulting life-cycle stage classification for an example African land based storm.

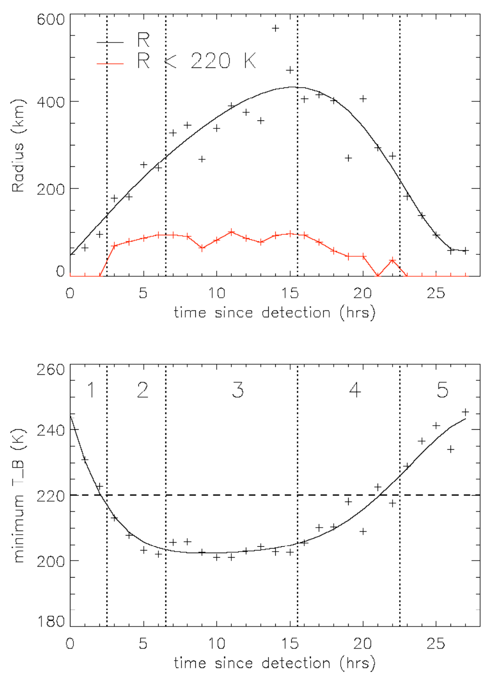

Figure 1: Example of system radius (R) and brightness temperature (T_B) evolution for an African land convective system and the corresponding life-cycle stage classification. Numbers in lower panel give the life-cycle stage: 1. warm developing, 2. cold developing, 3. mature/ detraining, 4. cold dissipating, 5. warm dissipating

This definition of life-cycle stage provides a framework to compare the evolution of African convective systems with oceanic systems in the Atlantic ITCZ (inter-tropical convergence zone). By matching the tracked systems to over-passes of low earth orbiting satellites such as TRMM or to ground based data, these less well sampled datasets can also be evaluated as a function of system evolution.

Plotting results as a function of life-cycle stage rather than simply as against time since formation allows data for systems with a wide range of lifetimes to be combined in a meaningful way and allows results for systems where the complete lifecycle is not tracked (for example where the system forms in a split and hence no developing stage is observed) to be included. This approach is particularly valuable for producing composites from relatively sparse datasets.

3. OBSERVED SYSTEM EVOLUTION FROM GEOSTATIONARY SATELLITE DATA

Figure 2 compares the evolution of the radiative (system averaged outgoing longwave radiation (OLR) and albedo) and precipitation (precipitating area fraction and conditional average rain rate) properties for African land and Atlantic ITCZ systems. Radiative properties are based on hourly GERB-like data and precipitation results are from the three-hourly merged TRMM and geostationary satellites (3B42) dataset for four months (June-September, JJAS) of 2005 for the region 50W-50E, 20S-30N.

Land based systems are deeper and brighter than oceanic systems throughout the life-cycle. However, Atlantic systems show significantly higher precipitating area fractions. The conditional (averaged only over the precipitating portion of the system) rain rates are similar for land and ocean, although oceanic systems remain more heavily precipitating in the dissipating stages. These results are consistent with the presence of larger and more persistent stratiform rain decks over the ocean (Schumacher and Houze 2003).

Overall, a well defined life-cycle is observed for both land and ocean systems, confirming that this approach provides a meaningful framework for the more detailed analysis of the system evolution presented in Section 4 below.

4. MATCHED TRMM PRECIPITATION RADAR AND LIGHTNING IMAGER DATA

4.1. *Differences in Storm Structure*

Figure 3 shows the accumulated (over all observed storms) 2D frequency distribution (FAD) of radar reflectivity from the TRMM precipitation radar (PR) 2A23 dataset for the mature stage of both African and Atlantic storms.

PR data also includes a classification of the observed rainfall as either convective or stratiform

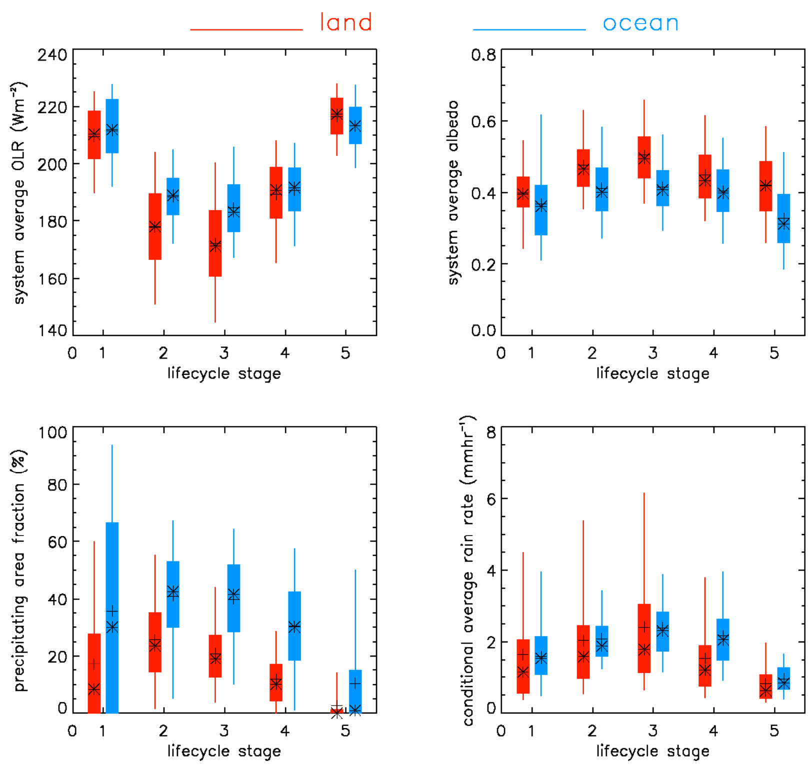

Figure 2: Comparison of the evolution of radiative (OLR, upper left and albedo upper right) and precipitation properties (precipitating area fraction, lower left and conditional average rain rate, lower right) for large deep Atlantic (ocean) and African (land) convective systems. The box covers 25-75th percentile and the whisker 5-95th. + indicates the mean and $*$ the median value. Based on GERB-like and TRMM 3B42 data. Life-cycle stage numbers are defined in Figure 1.

based on the vertical and horizontal structure of the radar echos (Awaka et al. 1997), and this is used to construct median and quartile profiles for reach of the rain types separately. These are also shown in Figure 3 for mature land and ocean storms.

As would be expected, convection is much deeper and, on average, more intense (higher peak reflectivity) over Africa than over the Atlantic. Comparing the FAD with the two sets of profiles also confirms that stratiform rainfall is more dominant over the ocean, producing a strong brightband signature in the distribution. Also apparent (as a decrease in reflectivity towards the surface) is the tendency for re-evaporation of rainfall below the freezing level in the stratiform portion of the land systems, contributing to the lower mean stratiform rain-rate observed (not shown).

4.2. *Differences in Evolution for Land and Ocean Systems*

Figure 4 shows the evolution of the convective and stratiform rain volume fractions for both land and ocean systems. Over land, the expected evolution is observed, with convective rainfall dominating the developing and mature stages of the system evolution, and stratiform rain becoming more important as the systems dissipate. Over ocean, the lifecycle is less well defined, with the stratiform rain fraction essentially constant throughout the life-cycle.

As can be seen in Figure 5, the strength and depth of convection in oceanic systems also shows little variation over the lifecycle (although weaker, shallow profiles are observed in the final warm dissipating stages), while over land the deepest, most intense convection is observed for mature systems.

Differences in system evolution between land and ocean systems are also suggested in the plot of lightning occurrence shown in Figure 6. Lightning occurs where strong updrafts loft large particles into the mixed phase region (Zipser and Lutz 1994) and is therefore associated with active convection and heavy rainfall. Field campaign results suggest that updrafts are significantly weaker over ocean than over land, resulting in the much lower lightning

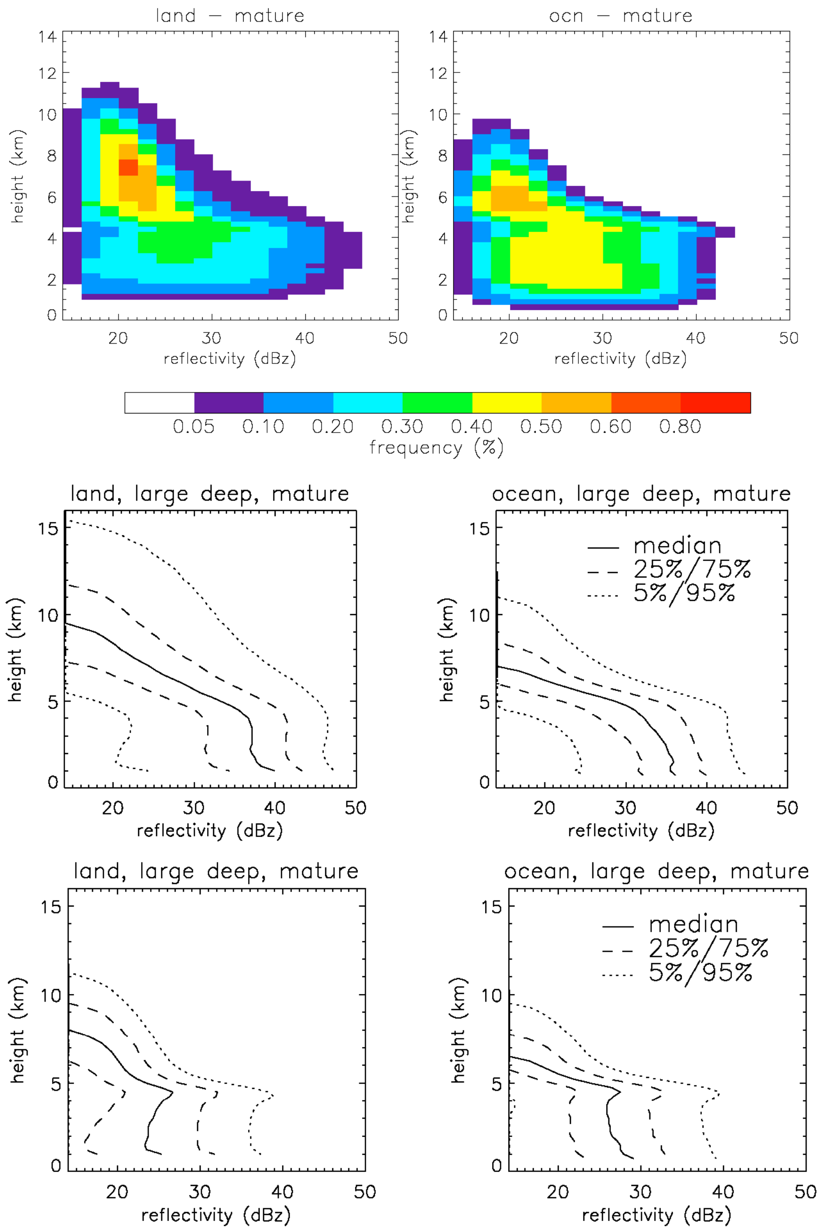

Figure 3: Frequency distribution of radar reflectivity (top) and median and quartile profiles for convective (centre) and stratiform (lower) regions of mature African and Atlantic convective systems.

frequency observed (e.g. Lucas et al. 1994). Consistent with the PR data, lightning occurs most frequently in the convectively active developing and detraining stages over land. Over ocean, however, the peak activity actually occurs during the cold dissipating stage, consistent with the continued occurrence of frequent convection after the peak size is reached.

Together, these results suggest a fundamental difference in the evolution of convective clusters over land and ocean (or at least between the African continent and Atlantic ITCZ). Over land, the evolution observed here is consistent with the classic picture of development of convective towers which then detrain both precipitating and non-precipitating anvil cloud. Once convection ceases, the anvil cloud gradually thins and dissipates.

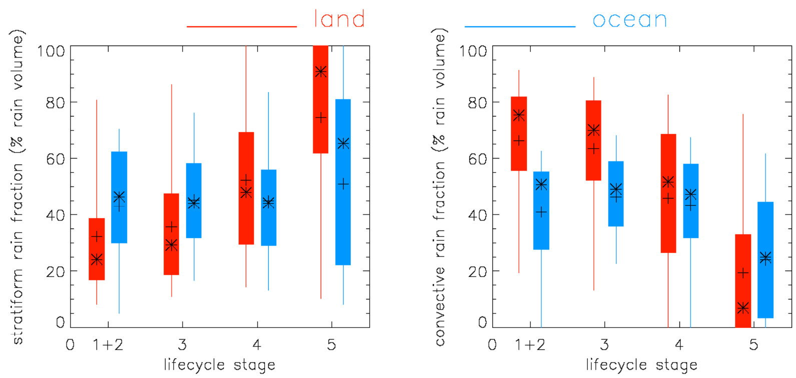

Figure 4: Convective and stratiform rain fractions (% of measured rain volume (rain rate × rain area) flagged as convective etc) as a function of life-cycle stage for large deep land and ocean convective systems. Life-cycle stage numbers are defined in Figure 1.

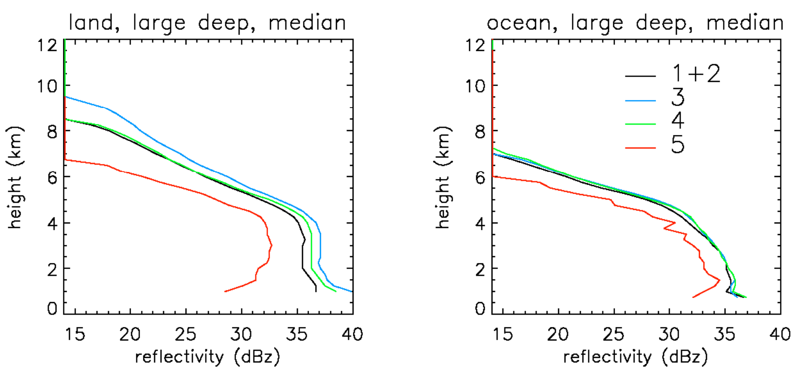

Figure 5: Median convective profiles as a function of life-cycle stage for large deep land and ocean convective systems. Life-cycle stage numbers are defined in Figure 1.

Over ocean, however, the convective rain fraction and strength remain essentially constant as the system grows, deepens and begins to dissipate (as determined from the infra-red signature).

This suggests that, over ocean, new, moderately deep convective cells are continually generated until the instability driving the convection is exhausted and the system decays. The evolution of the system would then be governed by the balance between the formation and dissipation rate for these cells. In contrast, over land, the strong diurnal cycle of surface heating triggers intense, deep convection, which in turn generates a substantial area of cold anvil cloud. However, the nocturnal cooling of the land surface acts to cut off new convective activity, leaving the stratiform anvil which then gradually dissipates.

This higher convective 'sustainability' over ocean has also been postulated by Houze Jr. (2004) as an explanation for the greater stratiform rain fraction observed over ocean than over land, with decaying convective cells contributing to the stratiform rainfall.

5. SUMMARY

The evolution of system size and minimum brightness temperature for convective systems tracked using hourly thermal flux data is used to create a classification by lifecycle stage. This is shown to provide a valuable framework for the analysis of less well sampled datasets, allowing a composite picture of the evolution to be built up. Convective systems over Africa are found to be deeper, with higher albedo and more frequent lightning than oceanic systems over the tropical Atlantic. A larger fraction of the cloud area is however found to be precipitating over the ocean.

As would be expected from the typical picture

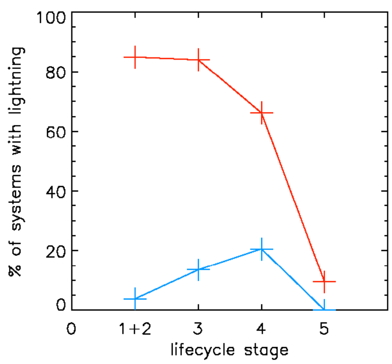

Figure 6: Lightning occurrence (% of sampled systems) as a function of life-cycle stage for large deep land (red) and ocean (blue) systems. Life-cycle stage numbers are defined in Figure 1.

of convective system development, African systems peak in activity early in their development, with rainfall becoming more stratiform in nature as they evolve. In contrast, oceanic systems show little variation in the convective rain fraction over their lifetime, despite a clear evolution in system size, depth and precipitation fraction. Although infrequent, lightning activity is also observed to peak late in the lifecycle, after the peak system size has been reached.

This difference in evolution is postulated to relate to the greater convective sustainability over ocean, with new convective cells being generated throughout the lifecycle, even into the 'dissipating' phase. Over land, the strong diurnal forcing drives intense convection, but also acts as a cut off on the system lifetime, with new cells unlikely to form while the land surface cools strongly at night, leaving a predominately stratiform decaying anvil cloud.

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