WCO5 - 5th Workshop on Convective Organization | (SMR 4191)

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T01

Immediate flash extent density applied to access the convective cores severity.

Reinaldo Pereira Nobre[1], Ana Teena Bulcão dos Santos[1], Domingo Cassain Sales[1], Francisco Agustinho de Brito Neto[2], Lucas Alberto Fumagalli Coelho[1], Rafaela dos Santos Gomes[1], Bruno Dias Rodrigues[1], Frank Bruno Baima de Sousa[1], Vinicius Oliveira[1], Anthony Carlos Silva Porfirio[1], Arthur Costa Tomaz de Souza[1], Enrique Vieira Mattos[3], Weber Andrade Gonçalves[4], Cristiano Prestrelo de Oliveira[5], Samuel Amorim Silva[5] and Evandro Moimaz Anselmo[1]

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5 - Universidade Federal do Rio Grande do Norte – UFRN

The Funceme is a regional meteorological center in operation at Ceará State of Brazil, and has been making efforts to improve the weather monitoring in the field of nowcasting, especially in the immediate identification of conditions potentially associated with severe weather conditions. These advancements have been supported by the National Council for Scientific and Technological Development (CNPq) project granted 446256/2023-4. The convection intensity is evaluated based on the lightning activity. The data (lightning flashes) from Geostationary Lightning Mapper (GLM) GOES-19 were used to identify convective cores realtime monitoring. The GLM flash area extent was calculated and the convective cores were found based on the lighting flash extent density in the last 30 minutes and last 15 minutes. The last 30 minutes flash extent gridded was made in each step of 5 minutes between January 1st, 2023 and July 1st, 2023 and the flash area density probability of occurrence was studied over the Ceará state to define four categories of severity levels (Low, Moderate, High and Extreme). In the last 30 minutes flash extent gridded, the median of probability of occurrence was 5 flashes per grid point (~64 km²) and the extreme (90th percentile) was 25 flashes. The last 15 minutes flash extent gridded in each step of 5 minutes was important to evaluate the lightning cluster movement, when the TATHU[1] tracking was used to access the propagation statistics of lightning cores and the time evolution of flash rate in each lifetime.

[1] UBA, D. M.; NEGRI, R. G.; ENORÉ, D. P.; COSTA, I. C.; JORGE, A. A. S. **TATHU - Software para rastreio e análise do ciclo de vida de sistemas convectivos**. São José dos Campos: INPE, 2022. 39 p. IBI: <8JMKD3MGP3W34T/47AF772>. (sid.inpe.br/mtc-m21d/2022/07.20.15.45-NTC). Disponível em: <http://urlib.net/ibi/8JMKD3MGP3W34T/47AF772>.

T02

One cold pool in five models, ten runs, and one campaign

N. Antary[1,2], J. Kazil, M. Ahlgrimm[3], M. Janssens[4,5], G. N. Raghunathan[6], T. Yanase[7,8], R. Vogel[1], and the CP-MIP community.

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Cold pools play an important role in determining the structure and properties of the marine boundary layer in the subtropics. Cold pools are precipitation-driven downdrafts that reach the surface and spread concentrically, leading to cloud suppression inside the cold pool and an active gust front at the perimeter, where converging winds often trigger new convection. Although their importance has long been recognised, the net effect on cloud amount, organisation and radiative effects is still not fully clear.

Before we can trust large-eddy simulations to study these aspects, we need to better understand the dependency of simulated cold pools on the chosen model and set-up. Here we analyse outputs from ten runs from five models simulating a cold pool observed during the EUREC4A campaign. All runs were performed as part of the Cold Pool Model Intercomparison Project (CP-MIP).

Our goal is to assess the trustworthiness of LES and understand the origin of model differences. We focus on differences related to the following research questions: What conditions lead to the formation of the cold pool? How does the cold pool expand and eventually recover? What is the internal moisture and temperature structure?

Our first results show that most runs produce a single strong cold pool. While large differences in the onset time are caused by the speed of moisture aggregation and the microphysical model, the growth rate is rather consistent across most runs. Furthermore, we show that the internal structure can differ greatly between runs that differ only in their microphysical schemes. While some runs produce a single cold pool that eventually spreads to a size exceeding 100 km, other runs initially create more than ten individual cold pools that all collide and form a super cold pool of comparable size. The EUREC4A observations show a growth rate and timing that fall within the inter-model spread. Measurements of the early stage of the cold pool reveal an almost homogeneous internal structure rather than multiple events. As demonstrated, this unique setup allows not only for a comparison of the runs but also for validation of relevant processes with observations.

T03

Causes of aggregation and disaggregation in reanalysis

Larissa E. Back[1], Vijit Maithel[1], Victor Mayta[1] and Ángel Adames-Corraliza[1]

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The amount of convective organization in the nature and some idealized simulations varies with time and as different types of systems, like convectively coupled waves, develop and dissipate. Hence, both convective aggregation and disaggregation processes occur over time in nature. These aggregation and disaggregation processes likely have impacts for high-impact phenomena like precipitation extremes, which some studies suggest are more likely to occur in aggregated conditions. Thus, predicting and simulating aggregation variations with time correctly is important for numerical models to correctly simulate high impact tropical weather and climate.

In this work, we diagnose the processes that lead to aggregation and disaggregation cycles from the perspective of a phase space diagnostic that makes use of the moist static energy variance budget [1]. We find that the horizontal advection of MSE plays the primary role in determining when ocean-basin scale domains aggregate and disaggregate in ERA5 reanalysis data. This is consistent with the processes described in Adames-Corraliza and Mayta's recent theoretical work [2]. We also find that vertical advection tends to enhance aggregation anomalies at shorter time-scales, but becomes less important at longer timescales, consistent with previous work that suggests less tilted vertical motion structures at longer time-scales compared to shorter time-scales.

We will also briefly discuss new theoretical analysis on the reasons why horizontal advection is so much more important than other processes in the column moist static energy variance budget in determining how tropical water vapor evolves over time.

[1] Back, Larissa and Maithel, Vijit, Journal of Climate. **37**, 6751 (2024).
[2] Mayta, Víctor C and Adames Corraliza, Ángel F, Journal of Climate **37**, 1981 (2024).

T04

Evaluations of the sensitivity of the shallow-to-deep convective transition in the Amazon to the vertical distribution of humidity using two numerical models

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Deep convection is the primary influence on weather and climate in tropical regions. However, understanding and simulating the shallow-to-deep (STD) convective transition has a challenge for a long time [1]. Here, we assess the environmental controls in convective development through idealized high-resolution numerical simulations using the System of Atmospheric Model (SAM) [2] and the Advanced Research WRF (WRF-ARW) [3] at 500m horizontal resolution. The models consistently reproduce the GoAmazon observations for precipitation, moisture, and surface fluxes of radiation, latent and sensible heat. Next, we perform sensitivity experiments to evaluate the relative importance of moisture and vertical wind shear role in controlling convection. The experiments consist on perturbing the vertical profile of humidity or wind shear before the sun rises, and integrating the model for the rest of the day to observe the consequences on the STD transition. Our results show that deep convection over the Amazon is particularly sensitive to low-level environmental conditions. Notably, early morning low-level preconditioning is vital to daytime convection and precipitation. On the other hand, only unrealistically dry conditions in the free troposphere significantly inhibit deep cloud development [2, 3]. The low-level wind shear facilitates the late afternoon STD transition when the jet width is broadened, and with a moderate strength peaking from approximately 2 to 4 km. A more intense upper-level jet negatively affects the development of the deep clouds and substantially reduces the anvil [2]. While low-level preconditioning is a necessary condition for deep convection, free troposphere humidity and vertical wind shear only modulate the late afternoon STD convection transition in the Amazon.

[1] L. A. M. Viscardi, G. Torri, D. K. Adams, H. M. J. Barbosa, Atmos. Chem. Phys., 24, 8529–8548 (2024)
[2] L. A. M. Viscardi, G. Torri, D. K. Adams, H. M. J. Barbosa, J. Adv. Mod. Earth Sys., 17, e2024MS004238 (2025)
[3] C. Gurung, X. Li, H. B. Gomes, G. Torri, D. K. Adams, H. M. J. Barbosa, in prep (2025)

T05

Representing Convective Organization and Memory in NOAA's Unified Forecast System

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As global numerical weather prediction models achieve higher resolution and shorter time steps, traditional assumptions in cumulus parameterizations, such as steady state and statistical equilibrium, break down. Convection can evolve across multiple time steps and occupy a significant fraction of the grid box, particularly when organized.

This talk presents recent advances in the Unified Forecast System (UFS) global applications used for NOAA's operational forecasting (GFS/GEFS and SFS) to better represent convective organization through convective memory, three-dimensional structure, and stochasticity. A new prognostic closure evolves convective area fraction and updraft velocity, while a cellular automata framework captures subgrid and cross-grid organization.

Case studies show that this approach improves Madden-Julian Oscillation (MJO) prediction, yielding more realistic amplitude, phase, and propagation. The improvements appear linked to stronger coupling between moisture flux convergence and MJO activity, including enhanced preconditioning over the western and central Pacific that supports eastward propagation across the Maritime Continent.

T06

Storm Dynamics-based Attribution to the Valencia's deadly floods

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Cut-off lows are, and will be in the future, one of the main threats related to severe weather in the Iberian Peninsula, especially in the eastern Mediterranean fringe. Cut-off lows are often accompanied by heavy precipitations in a short time promoting flash-floods, as well as hail, severe straight-line winds and tornadoes.

On the week of October 27th – November 4th, 2024, a cut-off low affected the Iberian Peninsula with impactful socio-economic consequences- in several Spanish regions and, especially, in the Valencia area. The severe weather phenomena on the surface have differed depending on the region: large hail (5-7 cm), several tornadoes, strong wind gusts and, above all, extreme precipitations. The most severe day was October 29th in the Valencia region, with rainfall accumulations higher than 300 mm in a notable area and locally registering 771 mm in 24 hours. In addition, the Turís official weather station recorded numerous national records for rainfall intensity. Moreover, the convective system developed 11 tornadoes (two of them with intensity IF2) and large hail (~ 5 cm). The social impact of the floods in Valencia was very high, with more than 16.5 billion euros of damage to infrastructure (roads, railways, etc.), housing and croplands, as well as 225 fatalities.

In this survey, we focus on Valencia's floods on October 29th. Here, by performing model simulations with the WRF-ARW model and employing a storyline approach, we find a 21% increase in the 6-hour rainfall intensity, a substantial 55% increase in areas with extreme accumulated rainfall exceeding the 180 mm threshold, and a 19% increase in total rainfall volume over the Jucar River catchment—attributable to current anthropogenic climate conditions compared to preindustrial conditions. Moreover, the enhanced available water vapor content played a central role, while CAPE, diabatic heating, and stronger vertical velocities boosted convective processes. A deeper warm cloud layer and elevated graupel concentration reveal microphysical mechanisms that enhanced precipitation volumes in a warmer climate, exceeding Clausius-Clapeyron scaling.

This study highlights the growing risks in the Mediterranean area and the urgent need for effective adaptation in urban planning to reduce the hydrometeorological extremes due to the human-induced climate change.

T07

A New Concept for Comparing Satellite Observations and km-Scale Atmospheric Simulations using Self-Supervised Machine Learning

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Clouds affect the distribution of moisture, heat, and momentum in the atmosphere and therefore strongly shape Earth's hydrological and radiative balance. Even as storm-resolving global models begin to simulate deep convection with remarkable fidelity, they still differ substantially in how they represent cloud processes at mesoscale and sub-mesoscale levels. These differences are difficult to diagnose with traditional evaluation tools, which tend to rely on coarse, aggregated statistics that smooth out the fine-scale structures critical to understanding physical processes underlying convective evolution.

This work is the first to develop an evaluation framework that compares observations and simulations in a shared latent representation learned from a large-scale, self-supervised model trained on Meteosat Second Generation satellite data. By emulating satellite radiances at the 10.8 µm channel from simulations using the regional ICON-EU and ECMWF's kilometre-scale IFS at spatial resolutions comparable to the satellite sensors, we bring both models and observations into the same physically grounded space for process-level comparison.

We then develop latent space dynamical diagnostics that compare the evolution of cloud regimes in km-scale simulations with observations in a quantitative manner. Using the latent trajectory structure, we assess persistence, transition behaviour, and regime evolution rates. We further derive metrics that translate latent-space behaviour into physically interpretable tendencies, such as latent velocity, indicating on a diurnal basis when modeled cloud evolution proceeds faster or slower than observed. Additionally, a latent maturity index that characterizes convective life-cycle stages and exposes systematic progression biases. Together, these metrics demonstrate how learned representations can expose process-level model biases that are otherwise difficult to detect.

T08

Impact of Cold Pools on the Intermittence of Precipitation in a General Circulation Model

Maxime Colin [1,2,3] , **Jean-Yves Grandpeix** [3] , **Sandrine Bony** [3] , **Steven Sherwood** [2]

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Simulation of precipitation intermittence/frequency remains a long-standing challenge for atmospheric General Circulation Models (GCM): rainfall usually occurs too often. This study aims at testing the hypothesis that improving cold pool properties in a prognostic cold pool parameterization can alleviate the precipitation frequency bias in GCMs.

We hereby test this hypothesis using LMDZ, the atmospheric component of the IPSL GCM, which includes a prognostic parameterization of cold pools. It assumes the cold pool number density (number of cold pools per unit area) is a fixed parameter globally, so that cold pools are not numerous enough over oceans. We first increase the cold pool number density in the GCM to a value more representative of cold pools over tropical oceans, in a 1D Single-Column Radiative-Convective Equilibrium (RCE) framework, using Cloud-Resolving Model (CRM) simulations as a guide. Cold pool thermodynamic anomalies become much weaker, which reduces cold pool ability to maintain convection. We then perform 3D simulations with the modified parameter and show that it improves the intermittence of convective precipitation: convective precipitation becomes significantly more sporadic, in particular over oceans. There is a monotonous sensitivity of convective rainfall intermittence to cold pool number density, while it does not affect mean precipitation, which is promising for GCM tuning.

This work shows that a better representation of cold pools in GCMs can help alleviate the precipitation frequency bias.

T09

Tropical CO_2-Exchange Across Convective Regimes in ECMWF-IFS

Vincent S. de Feiter[1], Martin Janssens[1], Alessandro Savazzi[2], Chiel C. van Heerwaarden[1], Anna Agusti-Panareda[2], and Jordi Vilà-Guerau de Arellano[1]

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The diurnal cycle and vertical exchange of CO_2 are governed by interacting surface and atmospheric processes operating across a wide range of spatial and temporal scales. Over tropical regions such as the Amazon rainforest, distinct shallow-to-deep convective regimes are anticipated to significantly influence how CO_2 is exchanged laterally over the rainforest and vertically between the surface and the free troposphere. Yet, the role of organised convection in modulating the diurnal cycle and transport of CO_2 over the Amazon remains poorly understood and insufficiently quantified. Accurately representing these multi-scale dynamics is essential for improving global estimates of CO_2 exchange for the Amazon rainforest under a changing climate.

In this study, we evaluate the relative contribution of these multi-scale dynamics to the atmospheric CO_2 exchange over the Amazon rainforest by examining how these processes are represented within the Integrated Forecasting System (IFS) of the ECMWF. More specifically, we assess three IFS configurations (horizontal resolutions of 25 km, 9 km (current operational resolution), and 4.4 km) to quantify how parametrised to explicitly resolving organised convection affects the simulated diurnal and vertical CO_2-exchange. To this end, we construct a sensitivity framework in which we decompose diurnal CO_2 tendencies into contributions from turbulent diffusion, convective transport, and large-scale dynamics, isolating the role of (organised) convection. We further formulate an analytical expression grounded in well-mixed theory to quantify local sensitivities of parametrised versus resolved representations across resolutions. The framework is evaluated using comprehensive observations and large-eddy simulations (DALES) from the 2022 dry season, first under clear-to-shallow convective conditions at the ATTO and Campina supersites, and subsequently across shallow-to-deep convective regimes over the Amazon.

Our findings show that under clear-to-shallow convective conditions at ATTO, three diurnal regimes can be distinguished and that shallow clouds actively organise the vertical turbulent exchange at cloud scales, ventilating CO_2 to altitudes up to twice the boundary-layer depth and modulating its vertical distribution until late afternoon. The IFS reproduces the diurnal evolution and vertical structure of temperature, humidity, and wind across resolutions. However, larger uncertainties remain in the representation of CO_2 exchange near the surface, at the boundary layer top and during the morning transition. These discrepancies highlight the sensitivity of simulated CO_2 to the timing and organisation of convection, motivating ongoing efforts to disentangle the multi-scale and role of convective processes in the transport of CO_2 over the Amazon rainforest.

T10

An analysis of intense convective wind gusts and their environments in the Brazilian Amazon

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Deep moist convection in the Amazon Basin has been studied for decades, but the documentation and understanding of convective storms that reach severe intensity in this region are still limited. Advancing this field of study is important, given that severe storms typically producing extreme rainfall and/or damaging winds can significantly affect forest structure, ecosystem functioning, carbon dynamics, and the safety and well-being of local communities and cities. This study investigates intense convectively induced wind gusts (≥20 ms^{-1}) across the Brazilian Amazon using hourly WMO-compliant observations from the network of surface weather stations operated by Brazil's National Meteorological Institute (INMET) from 2000 to 2024. The analysis reveals that gust events are widespread across the region, with more frequent occurrences in the southeastern and southern Amazon, particularly along the forest–cerrado transition zone. Intense wind gusts occur during the wet, dry, and transition seasons, but are most frequent during the dry-to-wet transition months of September and October, with a pronounced peak in the mid- to late afternoon. These gusts are accompanied by temperature drops and pressure rises consistent with the formation of surface mesohighs and cold pools. Temperature drops were sharper during the dry and transition seasons, whereas pressure increases were smaller and relatively uniform across seasons. The atmospheric environments associated with the intense wind gusts are analyzed using the fifth-generation atmospheric reanalysis (ERA5) from the European Centre for Medium-Range Weather Forecasts (ECMWF). The results indicate that thermodynamic factors dominate gust generation, with environments during the dry and transition seasons being more favorable for strong downdrafts and intense wind gusts, characterized by higher DCAPE, steeper lapse rates, and more elevated LCLs, particularly in the southern Amazon.

T11

Assessing Microwave Signatures of Hail in Southeastern South America

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Southern South America is a well-known global hotspot for strong deep moist convection. The environmental conditions across this region frequently favor the development of organized convective systems capable of producing severe weather hazards, including hail. Due to the widespread socioeconomic impacts of hail – which can severely affect agriculture, infrastructure, and public safety – improving its detection and characterization remains crucial for developing accurate climatologies and enhancing risk assessments. Although many remote-sensing techniques are available, the task remains challenging, as each approach presents inherent limitations in how hail signatures are detected.

In this context, microwave observations are particularly valuable because they are sensitive to hail scattering signatures. Bang et al. (2029, hereafter BC19) trained a passive microwave hail retrieval by pairing TMI (TRMM Microwave Imager) observations with surface hail reports from the United States to produce a global hail climatology. As expected, Southeastern South America (SESA) emerges as a hotspot for hail occurrence in their results. However, their retrieval exhibits some differences when compared with available ground-based hail reports in Argentina. While the highest hail frequencies are typically observed in the regions of Mendoza, Córdoba, and Misiones, the BC19 climatology instead highlights a pronounced hotspot over northeastern Argentina.

To assess the potential factors responsible for these discrepancies, we investigate a set of regional case studies where the BC19 probability of hail exceeded 50%. For each event, we analyze polarimetric weather radar observations and a hydrometeor identification algorithm (HID). To ensure that the HID can be reliably used as a hail proxy, we include an independent evaluation of its performance against hail reports from the South American Meteorological Hazards and their Impacts (SAMHI) database.

In addition to these observational analyses, we discuss ongoing work—including high-resolution WRF simulations and preliminary radiative-transfer experiments—to better understand the microwave signatures associated with hail-producing storms in SESA.

Collectively, these analyses provide new insights into the processes shaping microwave hail retrievals in this region and help clarify the origins of the hotspot identified by BC19.

T12

Projected Changes in Mesoscale Convective System Frequency and Intensity over South America in a Future km-scale Climate Scenario

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In tropical and subtropical South America, mesoscale convective systems (MCSs) produce over half of total precipitation in summer months. They are also almost exclusively related to hourly precipitation extremes in some subtropical regions of the continent. As such, MCSs dominate the South American hydrological cycle in both rainfall volume and intensity, and future changes to these systems should be explored to analyse potential hazards to the local ecosystem and population. Here, we utilize km-scale climate simulations over South America to assess changes to MCS frequency in a warming climate and isolate the MCS rainfall response from total rainfall. MCSs are identified using a cloud-tracking algorithm applied to regional convection-permitting climate model simulations run by the UK Met Office for a present-day and an RCP8.5 end-of-century scenario. Despite a 20% domain-wide, annual mean reduction in MCS frequency in response to warming, there is a small yet significant increase in the MCS contribution to total rainfall of +5%. There are, however, sub-regional and seasonal variations to this mean. In contrast, there is an undoubtedly consistent MCS intensification signal across South America, where mean and maximum MCS rain rates increase near year-round across all sub-regions. We find that the most extreme (P_{99}) MCS rain rates increase the most under warming, with a domain-wide annual-mean increase of 41%, and that the probability of present-day intense (P_{95}) MCS events occurring in the future climate scenario increases sixfold. In addition, MCSs in the future scenario produce, on average, 37% more rainfall over their lifetime. These results partly explain the increase in MCS rain fraction despite the reduction in storm frequency. Consistent with the total precipitation response to warming, total MCS precipitation shows large regional and seasonal variability, unlike the MCS intensity signal. Yet, where the sign of total rainfall and MCS rainfall are the same, changes to MCS rainfall can explain 33% of changes to total rainfall. These results highlight the continued importance of MCSs to the South American hydroclimate despite the mean frequency reduction under future warming, yet also emphasise the continent-wide increase in both the frequency and intensity of extreme MCS events that would place the population at greater risk of floods and other rain-ralated hazards.

T13

WCO5 - 5th Workshop on Convective Organisation

Convective Organisation and Rainfall in the African Tropics

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Tropical convection organises into coherent structures across a range of spatial and temporal scales. Recent studies, including those using satellite data and idealised climate simulations, have found links between the degree of convective organisation and extreme precipitation [1, 2]. It has been suggested that the degree of convective organisation could be an important mechanism driving changes in tropical rainfall patterns and extremes in a warming climate. However, traditional climate models (with parameterised convection) struggle to represent physical structures of convective storms and their spatial organisation.

In this work, we explore how convective organisation is represented in the first ever ensemble of pan-African km-scale climate simulations (CP4-Africa), which explicitly represent convection. We investigate three regions: West Africa, Central Africa, and Southern Africa, using the L_{org} metric to quantify organisation [3]. Results during the wet season demonstrate that more intense hourly rainfall is associated with the most organised convective scenes, in all regions. Future changes in convective organisation and the impacts on rainfall are also considered. Results suggest that, with warming, convection is likely to become more organised in the future, but that the relationship between organisation and extreme rainfall remains. These results differ between African regions, making the investigation into regional drivers of climate dynamics an important next question. It is hoped that understanding how convective organisation changes with warming will allow us to better understand future changes in extreme rainfall events across Africa.

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T14

Hidden Order Under Sparse Trade Cumulus

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Non-precipitating marine trade cumulus clouds often appear sparse, suggesting weak cloud to cloud interaction and localized plume-triggered, formation. We show that, beneath this apparent disorder, the flow organizes into a dense lattice of steady, thermally driven convective cells that tile the domain.

These cells form the dynamical backbone of the cloud field. Their lifetimes are comparable to the field's lifetime, and their updraft walls act as persistent launch points for plumes that initiate clouds.

Using a Lagrangian framework, we recover an almost fixed cellular pattern in space and time that predicts where clouds recur despite strong intermittency aloft. This reframes sparse trade cumulus cloud field. Rather than cloud formation associated with isolated responses to local perturbations, they express a deterministic organization imposed from below. The results provide a physically grounded basis for linking steady convective dynamics to cloud occurrence and for improving organization-aware parameterizations.

T15

Bimodal Evolution of Vertical Motion in Tropical Precipitation Extremes

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This study examines the evolution of "top-heaviness" in tropical convection during extreme precipitation events. Top-heaviness describes the extent to which ascent peaks in the upper (top-heavy) versus lower (bottom-heavy) troposphere. Reanalysis vertical velocity profiles are projected onto two sinusoidal basis functions, representing the first and second baroclinic modes, that together characterize top-heaviness. Two distinct modes are found following the peak in rainfall: stratiform decay and convective decay. Stratiform-decay events transition rapidly from bottom-heavy to top-heavy to stratiform-like ascent profiles and experience sharp reductions in instability, moisture and precipitation after the peak of the event. In contrast, convective-decay events sustain bottom-heavy ascent profiles with a gradual decline in instability and moisture and prolonged precipitation; they contribute over 55% of the rainfall during extreme events. These findings emphasize the significant role of convective decay in shaping extreme precipitation compared to conventional stratiform decay.

T16

A Phase-Space Framework for Characterizing the Evolution of Organized Tropical Convection Using 35 Years of Global Geostationary Tracking Data

Z. Johnny Luo

Using the ISCCP H-Series Pixel-Level Grid data (HXG; 10-km and 3 hourly) and the Tracking and Object-Based Analysis of Clouds (tobac) package, we developed a global, geostationary infrared (geoIR)-based convection tracking (CT) database spanning July 1983 to June 2017. From the geoIR-CT perspective, two parameters are key to characterizing tropical convective systems (CSs): the CS size, representing its horizontal extent, and the minimum brightness temperature (minTB), reflecting its convective intensity. We construct a size-minTB histogram as a phase space, where each snapshot of a CS is represented by a point. A dynamic element is added by plotting vectors that trace the temporal evolution of CSs through this phase space. Composites on the size-minTB phase space reveal distinct evolutionary trajectories of organized tropical convection, including regional differences and land-ocean contrasts. Finally, we explore extending this framework from two to multidimensional phase space, incorporating additional CS attributes such as eccentricity and the fraction of overshooting cores. While geoIR-CT data are commonly used to provide life-cycle context for snapshot observations from other satellites (e.g., CloudSat, GPM, and the upcoming INCUS mission), the phase-space framework presented here offers a new perspective for depicting the temporal evolution of tropical convective systems.

T17

Deep cell organization over Congo vs. Amazon in obs vs. models

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We study organization in terms of maps of the probability of occurrence of deep convective cells, conditional on a cell at a central location. These are estimated from data as frequencies of occurrence, suitably normalized. We bracket various definitions of a "cell". Our common definition is that cells are a 1 (Boolean True) pixel at every local minimum of a smoothed IR brightness field which is also colder than a threshold. Watershed methods are also easy to try.

Diurnal organization development is compared between tropical Africa and South America, with these conditional probabilities expressed in terms of local clock hours. We also compare satellite observed data to OLR fields from explicit-convection or "storm resolving" models, both regional and global.

These different conditional-probability structures are used as inputs to a Monte Carlo simulation, akin to a Cellular Automaton model for neighbor interactions. This iterated view of the probability structure can amplify subtle differences into distinct phenomenological outcomes. Those iterated-probability model outputs can be compared to the input data to see how much of the essence is captured; or treated as synthetic data to see how well a probability kernel structure can be recovered from its iterated outputs. In this way, the mapping between phenomenology and the underlying probability structure can be mapped and understood. That understanding can find final utility in stochastic convection schemes.

T18

Energetics of Southern African Monsoon Onset

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Predictability of the Southern African monsoon is a topic which spans the weather-climate interface on the subseasonal-to-seasonal scale. Forecasting the first rains is a key decision-making tool which combines meteorological, hydrological, and agroeconomic principles. However, onset is a nonlinear process: while classical theory argues that it is a consequence of the seasonal progression of the angular-momentum-conserving Hadley cell, it often manifests as an abrupt increase in frequency of smaller-scale organised convection such as mesoscale convective systems (MCSs). For example, MCSs have been shown to dominate the energetics of the South Asian Monsoon onset [1]. In the case of the Southern African monsoon, significant precipitation events also take the form of tropical-extratropical cloud bands (TTTs) which contribute substantially to intraseasonal and interannual variability in rainfall totals, and are generated by the interactions between synoptic-scale Rossby waves and subtropical convection [2]. Crucially, the intraseasonal variability in rainfall in Southern Africa is not fully understood [3], despite a distinct drying trend emerging in models [4]. This study analyses the contribution of MCSs and TTTs to the rainfall onset.

The properties and behaviour of organised convection such as MCSs are represented more faithfully in high-resolution convective-scale simulations, while in single realisations of large-domain regional convective-scale climate models, even planetary-scale circulations can deviate significantly from their driving models [5]. Therefore, to robustly understand the scale interactions that control seasonal rainfall onset from the meso- to the planetary scale, we examine large-domain convective-scale ensembles at kilometre-scale resolution for a duration of three months. We track MCSs and TTTs in these simulations (using well-characterised algorithms [6], [7]) and quantify the respective energetic contributions of the different modes of organisation to the onset of the Southern African monsoon in 2022.

We explore mechanisms driving MCS and TTT energetic contributions in this region, connecting with other established controls on rainfall onset such as Congo Air Boundary breakdown [8] and large-scale planetary motions such as the overturning Hadley circulation [9]. We further examine MCS interactions with the land-surface, examining modelled responses in the context of observed trends [10]. Our results offer unique insights into the processes driving onset of rainfall in the Southern African monsoon season, providing key understanding for improving user-relevant first rains forecasts.

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T19

Measuring updraft strength from successive radar scans during the WesCon and KASBEX field campaigns

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Convective updrafts are integral to mesoscale convective systems (MCSs), with the release of energy driving a vertical transport that leads to the production of large anvil clouds surrounding the MCS convective cores. However, direct observation of updrafts is difficult. We build on the delta-Z method [1], in which successive radar scans are differenced to identify the characteristic signal of updraft strength and cloud growth. We make use of thousands of scans from the Wessex Convection Experiment (WesCon) field campaign in southern England [2, 3] to build a statistical picture of the delta-Z method for the first time from observations. We further use information from the Ka- and S-band Experiment (KASBEX) to characterize the differences of the delta-Z method between these two radar frequencies. We track clouds using the UK Met Office's operational rainfall product, RadarNet [4], and match this information to growth and updraft strength from the delta-Z method.

Our work stands alone, but also informs the upcoming INvestigation of Convective UpdraftS (INCUS) satellite mission [5], which will use the delta-Z method from three satellites flown in a tight convoy. This will provide a tropics-wide estimate of updrafts for the first time. In particular, the statistical information we produce, the matching of the delta-Z signal to cloud lifecycle, and the characterization of the differences between S-band and Ka-band radars help to understand the delta-Z method from observations in more detail.

The work forms part of the UPFLO (Improving understanding and modelling of convective UPdraFts and anvil cLOuds) project, by allowing us to diagnose updraft strength from radar reflectivity alone. It contributes to the wider Advancing the Frontiers of Earth System Prediction (AFESP) programme, a 15-year programme hosted at the University of Reading [6], with collaboration from ECMWF, the UK Met Office, and the National Centre for Atmospheric Science (NCAS).

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Targeted probabilistic trigger for the representation of organized deep convection in a global forecasting ensemble

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Representing organized convection in atmospheric models that are too coarse to explicitly simulate it remains a major challenge. A novel class of stochastic parametrization scheme representing an underlying atmospheric phenomenon is described. The effects of mesoscale convective systems (MCSs) are represented in a targeted manner, based on probabilistically triggering an MCS scheme in regions of enhanced environmental total column water vapour, where there is a high likelihood of MCS occurrence. In combination with the probabilistic trigger, patterns with appropriate spatiotemporal scales determine where and when the scheme is active. Our scheme builds on the multiscale coherent structure paramtrization (MCSP) [1, 2, 3], which represents the top-heavy heating structure associated with MCSs and their attendant anvil clouds.

The stochastic scheme is compared with a control and vanilla MCSP to determine the space and time correlation statistics of precipitation. Results with the stochastic trigger are closer to observations when compared to the control, and the new scheme performs well over larger spatial and temporal separations, although it does not perform as well as the default MCSP at reproducing the spatial correlations at small (near grid scale) separations. When tropical spread-error statistics of geopotential at 500hPa are analysed in an ensemble, we find that our scheme marginally boosts spread compared to the default MCSP as expected, improving the underdispersion of the ensemble. The improvement in spread is clearer for precipitation, and the stochastic scheme improves the spread with little degradation in the error compared to MCSP.

The work was carried out as part of the Mesoscale Convective Systems: PRobabilistic forecasting and upscale IMpacts in the grey zonE (MCS:PRIME) project, a collaboration between the University of Reading, the University of Oxford and the UK Met Office.

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T20

A New Ground-Based IR Dataset for Convection-Resolving Model Evaluation in the Amazon

Theotonio Pauliquevis[1], **Elion Daniel Hack**[1], **Rodrigo Augusto Ferreira de Souza**[2], **Jaidete Monteiro de Souza** [2], **Kemely Araújo Pereira** [2], **Cauã Medeiros de Oliveira**[2], **and Jair Max Furtunato Maia**[2]

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Sub-grid cloud variability and the associated shallow-to-deep convective transition remain key sources of uncertainty in numerical simulations of Amazonian convection. Coarse horizontal resolutions (tens of kilometers) inhibit the explicit representation of small-scale vortices and shallow cumulus fields that regulate moisture preconditioning and delay the onset of deep convection. To provide observational constraints for this problem, we introduce a new ground-based infrared hemispheric imaging system designed to characterize the macroscopic properties of clouds throughout the diurnal cycle in the central Amazon.

The system consists of a fisheye absolutely calibrated IR camera operating in four spectral bands (CH1: 8–9 μm; CH2: 10–11 μm; CH3: 11–12 μm; CH4: 10–12 μm), with full-sky images acquired at 90-s intervals. Pixel-level spectral radiances enable robust cloud detection [1, 2]. Brightness temperatures derived through inversion of Planck's law provide a proxy for cloud-base temperature and, consequently, cloud base height when combined with near-surface thermodynamic profiles. This yields a high-temporal-resolution reconstruction of the evolving three-dimensional cloud field geometry as seen from the surface.

In this talk we aim to present the processing framework, quality control methodology, and initial climatological statistics of cloud-base distribution and cloud-field morphology. The resulting dataset offers a unique, high-frequency observational reference for evaluating high-resolution and convection-permitting simulations over the Amazon, particularly regarding the representation of shallow morning cumulus, moisture preconditioning, and the timing of the convective onset. This work establishes a new experimental pathway for validating the diurnal cycle of convection and associated sub-grid processes in numerical models.

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T21

Measuring tropospheric gravity waves over stratocumulus cloud decks

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Tropospheric internal gravity waves, often originating from jets, fronts, or deep convection, leave subtle but discernible imprints on the vast stratocumulus decks that cover subtropical oceans. These waves represent a non-negligible, yet poorly quantified, interaction between the free atmosphere and the marine boundary layer. This presentation introduces a robust, two-pass methodology using 2D continuous wavelet transforms (CWT) on geostationary satellite imagery (GOES-16) to objectively detect, track, and characterize these wave packets. The core of our framework is its ability to precisely separate the intrinsic wave propagation signal from the dominant, large-scale advective flow of the cloud field.

Our method quantifies the primary physical signature of these waves: the modulation of cloud-top brightness caused by vertical displacements at the boundary layer inversion. By tracking these propagating brightness patterns, our algorithm identifies individual wave packets as dynamically evolving objects and measures their physical properties, including wavelength, propagation speed, and direction. To validate the method, we generate synthetic satellite imagery by superimposing the signatures of hypothetical wave fields (with known properties such as wavelength, speed, and direction) onto realistic, advected cloud scenes. This process allows us to confirm the method's ability to faithfully retrieve the initial parameters and to characterize its measurement uncertainties.

We then apply this validated methodology to a real-world case study from 12 October 2023 over the Southeast Pacific. The analysis successfully isolates a coherent wave packet with a ~150 km wavelength and tracks its dynamic evolution.

Potential applications are numerous, including the construction of wave climatologies, the study of wave-cloud interactions, the analysis of their role in organizing shallow convection, and the assessment of their long-range predictability. The tool, made available as open-source software, is intended to facilitate a systematic exploration of these key, yet often hidden, components of the climate system.

T22

Cold pools in realistic cloud-resolving simulations, and confrontation to idealized cold pool models

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This paper aims to evaluate the robustness of a conceptual model of density currents developed by Rochetin et al. (2021), using a 30-day storm-resolving simulation over the Tropical Atlantic with realistic boundary forcings. Density currents are defined as active cold pools, identified as cold pools associated with gusts. First, the assessment is conducted through a detailed examination of their bulk morphological, thermodynamical, and dynamical properties. Second, the analysis of these properties across transects of the density currents provides a pioneering 3D composite structure of these currents. Third, a simple model for the top entrainment of density currents is discussed. Overall, the targeted density currents are approximately ~ 2.3 K colder, ~ 0.7 g.kg−1 moister, and release about ~ 16 W.m−2 more sensible heat at the surface compared to the neighboring planetary boundary layer (PBL). No clear anomaly is observed in terms of latent heat flux, and the density currents have a similar depth (around ~ 600 m) to the adjacent convective PBL. Finally, as they approach the center of divergence, density currents become deeper, drier, colder, less gusty, and more subsiding.

T23

Evaluation of deep convection and cold pool representation in MONAN for simulating a major agricultural Haboob in Southeast Brazil

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This study investigates the critical role of deep convection and resultant convective cold pools in generating the intense winds responsible for a massive "haboob" dust storm in the agricultural region of São Paulo state, Brazil. The main objective is to evaluate how the representation of these convective processes influences the modeling of dust-generating winds. The simulation utilizes Brazil's Unified Earth System initiative MONAN (Model for Ocean-laNd-Atmosphere PredictioN) to reproduce the "haboob" dust storm event. The haboob, which swept the region on September 26, 2021 (extending up to 200 km and increasing PM10 to 200µg/m3), was directly caused by strong outflow winds emanating from a convective system combined with very dry soil conditions. To specifically model the gust front forcing, the physically based Leung et al. (2024) dust emission scheme is used, driven by MONAN meteorology. The study incorporates the Freitas et al. (2024) cold pool edge parameterization; a physics scheme incorporated into the MONAN physics to explicitly test the influence of the gust front on the dust emission mechanism. Simulations are run at multiple spatial resolutions (10, 30, and 60 km) to examine the sensitivity of the modeled cold pool structure and resultant winds. By comparing the modeled meteorological results with satellite imagery, surface observations, and weather radar data, this work assesses the efficacy of convective cold pools deep representations within MONAN. The findings provide crucial insights into the requirements to accurately predict and forecast extreme wind-driven dust events like the haboob dust storm seen in Sao Paulo countryside.

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T24

Organization of deep convection into squall lines

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The organization of deep convection into squall lines is not represented in global climate models, despite being among the biggest storms on Earth and having a huge impact on precipitation and extremes in tropical regions such as the Sahel or the Amazon [1, 2]. The overarching goal of this project is to parameterize the occurrence of squall lines in the general circulation model LMDZ, and their impact on their environment. Since the interaction between wind shear and cold pools is essential in squall line formation and maintenance [3], we plan to take advantage of the cold pool scheme [4] already implemented in LMDZ.

Regarding the occurrence of squall lines, we hypothesize that it can be predicted based on the domain-mean wind profile and the cold pool properties, diagnosed from the cold pool scheme. Regarding the impact of squall line in their environment, we hypothesize that squall lines impact the vertical profile of diabatic heating [5], either through entrainment in convective updrafts [6] or through the rate of rain evaporation [7]. We also hypothesize that the larger rate of rain evaporation strengthens cold pools favoring more likely and more intense convection [8]. Entrainment and rate of rain evaporation can be varied in the convective scheme of LMDZ [9] through tunable parameters.

To test these hypotheses, we analyse simulations from the cloud-resolving model SAM in radiative-convective equilibrium configuration with various wind shear and large-scale ascent conditions.

Ultimately, the representation of squall lines should improve the simulation of precipitation distribution, variability and extremes in tropical regions such as the Sahel or the Amazon.

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T25

Representation of Marine Cloud Mesoscale Organisation by models operating in the Grey Zone.

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This paper reports on simulation results of nine atmospheric models with horizontal resolutions ranging from 150 meter to 2.5 km of shallow cumulus convection such as observed over the subtropical Atlantic Ocean during the EUREC4A Field campaign from January-February 2020.

More specifically, the results concentrate around answering the questions how models across this resolution range

- reproduce the observed atmospheric mean state, cloud statistics and energy and heat budgets as well as their temporal variability.
- reproduce the observed horizontal spatio-temporal mesoscale cloud organization.
- Couple their cloudiness to the model dynamics.

Finally, this paper provides an open invitation for further exploration of the model simulation data gathered as part of this present EUREC4A-MIP project [1,2].

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T26

Expansion of tropical ascent in kilometer-scale mock-Walker circulations

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Model simulations and limited observations indicate that regions of tropical ascent and precipitation contract in response to surface warming. This response has well-studied implications for the width of the Intertropical Convergence Zone, but its applicability to the Pacific Walker circulation remains unknown. Here, we investigate the impact of warming on the area of large-scale ascent in kilometer-scale, mock-Walker simulations with both fixed and interactive surface temperatures. Contrary to the "wet-gets-wetter" paradigm of precipitation change and the expected reduction in ascent area, the simulations show a "wet-gets-drier" response to warming in which the ascent region becomes larger and, on average, drier. We attribute these changes to the rapid weakening of the circulation in response to warming, which limits the transport of moisture into the ascent region. To meet the growing moisture demand for precipitation, local evaporation within the ascent region must increase rapidly, and the ascent region expands to draw moisture from a larger surface area. We link the circulation slowdown to increases in gross moist stability, which are driven by changes in the vertical structure of the circulation. These results indicate that modest changes in circulation structure can have upscale impacts on large-scale forms of convective organization and their associated precipitation patterns. They also suggest that hydrological change associated with the Walker circulation may differ substantially from that associated with the Hadley circulation, which does not weaken as rapidly in response to warming.

If results are ready in time, this presentation will also discuss the vertical structure of convectively driven overturning in yearlong simulations with seven global storm-resolving models (GSRMs). Special attention will be paid to differences in the vertical structure of ascent in the Eastern and Western Pacific, and whether the GSRMs improve on GCM representations of the observed bottom-heavy ascent in the Eastern Pacific.

T27

Impacts of Land Cover on Cloud Organization Across Amazonia

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Clouds can be organised across a wide range of spatial and temporal scales. For example, warm cumulus clouds may range from just a few metres in size to squall lines extending thousands of kilometres across the Amazon. Each scale is associated with distinct dynamics and interacts directly with radiative, hydrological, and energy balances. Across this spectrum, clouds exhibit notable organisational patterns. The effective radius of a cloud cluster is almost linearly related to its lifetime, and the cloud life cycle is typically divided into three phases: initiation, maturity, and dissipation. The initiation–maturity phase features the greatest area expansion, rainfall production, and lightning activity. During dissipation, convective activity weakens, although the cloud deck may continue to expand before eventually breaking down. This study evaluates the characteristics of cloud organisation over the Amazon Basin under different land-use conditions. IMERG data were used to identify rain cells (defined as areas with a rain rate greater than 0.1 mm h^{-1}) across the basin at 30-minute intervals from 1988 to 2022. Py-ForTracc was applied to describe the morphological properties of all rain cells with radii exceeding 11 km. These data were combined with land-use information from MapBiomas, resampled to match the IMERG resolution (10 × 10 km^2). For each IMERG pixel, the percentages of forest and pasture cover were calculated, producing a dataset that links land-use characteristics with cloud organisation metrics. This merged dataset enables investigation of how land use influences cloud-cluster size, life-cycle duration, intensity, and normalised area expansion (a proxy for vertical motion), along with several other morphological attributes. The results where split in life cycle phase and reveal clear differences in rain-cloud characteristics as a function of forest and pasture cover. For example, cloud size varies substantially: larger rain cells and cloud clusters are more prevalent in areas with higher forest cover. These and additional findings will be discussed in detail.

T28

Abstract for presentation on “Will Fish clouds reduce global warming rates?”

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The largest uncertainty of climate sensitivity resides with the shallow cloud feedback, where shallow trade-wind cumulus clouds cover around 20% of the oceans. They tend to organize in mesoscale (10-1000 km) patterns, which have different properties, such as cloud-radiative effects (CRE) [1]. Therefore, mesoscale cloud organizations might change under global warming leading to a changed CRE of shallow trade-wind cumulus.
Since the patterns have different properties, we hypothesize different physical processes underlying these patterns and we lack dedicated processes studies on large patterns formed by imposed variability in convective forcing, such as Fish clouds [2]. Therefore, we have created a 500 by 500 km idealized LES simulation in the Dutch Atmospheric LES (DALES) with a horizontal resolution of 100 m [3]. The simulation is initialised with a moisture perturbation. Due to self-aggregation, this moisture perturbation grows to a 300-400 km long cloud structure. This self-aggregation is caused by convective heating in WTG leading to a circulation on the cloud scale (300-400 km). This circulation is similar to the Shallow Mesoscale Overturning Circulation (SMOC) previously found in observations and a realistic LES [4,5]. On a smaller scale (8 by 8 km), the cloud is organized in cold pool regions and SMOC like regions. Each (8 by 8 km) location in the cloud alternates between these two modes, where the cold pool mode takes on average 2 hours and the SMOC mode 4 hours. The moisture perturbed simulation has a larger domain averaged CRE compared to a control case. This emphasizes the importance of mesoscale (100-400 km) shallow convective forcing in cloud feedbacks.

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T29

Climatology of Amazonian Squall Lines derived by Algorithmic Detection and Tracking of Coherent Features

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The Amazon basin, with its abundant moisture and energy, is particularly favorable for deep convection. Semi-objetive detection methods have estimated that around 100 squall lines form annually near the Amazon River delta, about half dissipating near the coast, while roughly 20% penetrate more than 400 km inland and some travel up to 3000 km (Rickenbach, 2004; Alcântara et al., 2011). Although there are no systematic, long term reports on squall line frequency and characteristics further inland, previous authors have suggested that long-lived coastal and inland squall lines can undergo regeneration, either weakening overnight and re-intensifying in the early morning (Rickenbach, 2004) or dissipating and re-forming the next day further along their track (Anselmo, Machado, et al., 2021), processes likely linked to the Amazonian low-level jet (Anselmo, Schumacher, et al., 2020).

Existing cloud detection and tracking schemes are not tailored to the often discontinuous structure of squall lines and recent studies still rely on subjective identification (Oliveira and Oyama, 2019; Sousa et al., 2021). Here we designed a new algorithm using the Density Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm (Ester et al., 1996) applied to GOES-16 10,33 µm brightness temperatures, combined with feature- and track-based filtering (e.g., length, area, aspect ratio, and minimum cloud-top temperature) to extract squall lines embedded within larger convective cloud decks and to build a multi-year squall-line track climatology over the Amazon basin.

Here we present a multi-year climatology of Amazonian squall lines, documenting their spatial and temporal distribution, typical durations, sizes, peak cloud-top brightness temperatures, and other properties. The results are consistent with previous statistics of Amazonian convective systems, while highlighting the particularities of squall lines. Squall line regeneration, following partial or complete dissipation, is found to occur frequently over the Amazon, especially under an easterly wind regime.

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Cloud–Forest Coupling:
Insights from Amazon Observations and Multiscale Modelling

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Forests and clouds are central to Earth's carbon and water cycles, yet they are rarely studied as a coupled system. Recent observations reveal concurrent shifts in forest CO_2 uptake and cloud regimes across tropical, temperate, and boreal biomes, signaling changes in forest–atmosphere coupling with profound implications for convective organization and climate feedbacks. While rising CO_2 may enhance forest assimilation, declining trends in low cloud cover alters radiative fluxes and amplifies warming, potentially modifying forest photosynthesis, turbulence, and biogenic volatile organic compound emissions. In turn, these forest processes by controlling the canopy turbulent fluxes, influence boundary-layer dynamics and cloud formation, yet current Earth system models largely overlook these cross-scale interactions.

To address this gap, and focusing on the Amazonia basin, we combine field observations from CloudRoots-Amazon22 field campaign (including remote sensing) with new large-eddy simulations and high-resolution global models. CloudRoots-Amazon22, conducted at the ATTO/Campina supersites during August 2022 dry season, investigated the diurnal evolution of the clear-to-cloudy transition in the Amazon. High-frequency observations revealed that stomatal conductance responds to cloud optical thickness, that canopy–cloud radiative perturbations regulate sub-diurnal carbon and water exchange, and that turbulent fluxes and vertical transport adjust within minutes to cloud passages. Collocated surface fluxes, profiles of state variables, and carbon dioxide further established causal relationships between biophysical canopy processes and cloud mass fluxes.

Building on these insights, I will present how we currently integrate high-frequency observations with turbulence-resolving simulations embedded in global storm-resolving models to quantify emergent shifts in cloud–forest coupling under changing climates. This integrated framework advances our understanding of how convective organization and photosynthesis co-evolve—bridging the gap between leaf-level processes and cloud-scale dynamics essential to improve climate predictions.

T31

Organization in a toy model for convection at kilometre-scale resolution

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We develop a simple kilometre-scale convection model in which it is assumed that convective updrafts are sub-grid, while the convective fractional area can grow to grid scale. This separation is achieved by modelling the convective updraft velocity and the convective cloud cover as distinct components. The updraft velocity is diagnosed from a simple function of convective available potential energy and cloud cover, whereas the cloud cover is predicted using a prognostic equation based on mass conservation. The model assumes a stochastic distribution of cloud-base mass flux (M_b), which serves as the source of convective cloud cover. Three cloud types—shallow cumulus, congestus, and cumulonimbus—are represented, each characterized by its cloud-top height and governed by its own prognostic equation. A reaction–diffusion equation is used to model column-integrated relative humidity, following Ref. [1], but with the detrainment from each cloud type acting as the local moisture source. Congestus and cumulonimbus clouds are assumed to generate cold pools, which suppress convection locally while enhancing the cloud-base mass flux in neighbouring grid cells. The model produces both random and aggregated convective states, depending on the choice of parameters and boundary conditions. Smaller diffusion coefficients favour clustering, consistent with Refs. [1,2], whereas in the absence of cold pools, aggregation emerges only for very small diffusion and large cloud-base mass flux, in agreement with earlier findings [2]. We further show that M_b plays a key role in aggregation: higher mass flux leads to more rapid clustering, while for small M_b aggregation occurs only when diffusion is extremely weak. These results demonstrate that this simple toy model can capture essential features of full-physics cloud-resolving models, and with further development, it may provide the basis for a new stochastic parameterization suitable for the convective grey zone.

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T32

Self-aggregation of deep convection in a moisture model with nonlocal coupling

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Convective self-aggregation (CSA) emerges spontaneously in radiative–convective equilibrium but lacks a unified theory connecting onset and scale selection. We analyse an idealised moisture model under the weak temperature-gradient framework in which the only prognostic variable is column-integrated water vapour. The key ingredient is nonlocal coupling in the thermodynamic balance, causing each column to interact with its filtered neighbourhood. This coupling yields bistability between moist and dry equilibria, while diffusion damps small-scale anomalies. Although the spatially uniform state is linearly stable, finite-amplitude perturbations reduce the effective precipitation damping and can trigger aggregation. An effective growth-rate analysis reveals two regimes: with global (domain-wide) coupling, the most unstable disturbances are the longest available, approaching infinite-wavelength solutions; with nonlocal coupling, a finite preferred wavelength emerges, set by the coupling length and moderated by diffusion. Numerical diagnostics and theory consistently reproduce inter-cluster distances of order 10^3 km, with maximal growth near a few thousand kilometres for plausible parameters. This framework unifies reaction–diffusion perspectives with scale-aware coupling and clarifies similarities between CSA and moisture-mode dynamics.

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T33

Deep Learning the Sources of MJO Predictability: A Spectral View of Learned Features

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The Madden-Julian oscillation (MJO) is a planetary-scale, intraseasonal tropical rainfall phenomenon crucial for global weather and climate; however, its dynamics and predictability remain poorly understood. Here, we leverage deep learning (DL) to investigate the sources of MJO predictability, motivated by a central difference in MJO theories: which spatial scales are essential for driving the MJO? We first develop a deep convolutional neural network (DCNN) to forecast the MJO indices (RMM and ROMI). Our model predicts RMM and ROMI up to 21 and 33 days, respectively, achieving skills comparable to leading subseasonal-to-seasonal models such as NCEP. To identify the spatial scales most relevant for MJO forecasting, we conduct spectral analysis of the latent feature space and find that large-scale patterns dominate the learned signals. Additional experiments show that models using only large-scale signals as the input have the same skills as those using all the scales, supporting the large-scale view of the MJO. Meanwhile, we find that small-scale signals remain informative: surprisingly, models using only small-scale input can still produce skillful forecasts up to 1–2 weeks ahead. We show that this is achieved by reconstructing the large-scale envelope of the small-scale activities, which aligns with the multi-scale view of the MJO. Altogether, our findings support that large-scale patterns—whether directly included or reconstructed—may be the primary source of MJO predictability.