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Thermodynamic vs Dynamic Control on Radar-observed Diurnal Transition of Congestus into Deep and Overshooting Convection: a reanalysis based time-metric analysis

Abhishek Jha, PhD Researcher, Indian Institute of Tropical Meteorology, Pune

An objective identification for the different tropical cumulus modes is found by examining the occurrence frequency of the 35-dBZ cell top heights and near-ground (at 2.5 km height) rain rates along with area of convective cells using a nine wet-season database of the Kolkata S-band Doppler weather radar. Four cumulus modes were identified, namely a shallow cumulus mode with 35 dBZ tops in the trade inversion layer (1–3 km), a congestus mode with tops in the highly stable middle troposphere (3–7 km), a deep convective mode with tops in the region of free convection (7–15 km), and an overshooting convection mode with tops in the tropical tropopause layer (CTH >15 km). Moreover, the diurnal cycle of different cumulus modes visually suggested that shallow congestus grow into deep that will eventually grow into overshooting convective cells. Using a moisture budget derived from ERA5 reanalysis datasets for the eastern flank of Monsoon Trough region, it is shown that the midtroposphere is moisten prior to deep and overshooting convection by both thermodynamic (congestus moistening) and dynamic processes (large-scale vertical advection). Further, time-metric analysis performed in order to investigate the thermodynamic versus dynamic control on the diurnal transition of congestus to deep and overshooting. The theoretical estimates of transition time between congestus to overshooting deep convection (18-46 h) due to congestus moistening revealed that congestus moistening is too slow to explain observed observed transition time (2-4 h). Our results do not support the thermodynamic viewpoint where atmosphere slowly deepening by local moistening leading to deep convection but rather, it is the large-scale vertical advection helps in congest to deep convection transition on diurnal time-scale over a region.

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High-resolution Weather Simulations with Weather Research and Forecasting Model Over Complex Mountainous Terrain and Comparison with a Micrometeorological Campaign

Dr Alessio Golzio, Department of Physics, University of Turin

Weather forecasts over mountainous terrains are challenging due to the complexities of topography that actual local-area models necessarily smooth. As complex mountainous territories represent 20% of the Earth's surface, accurate forecasts and the numerical resolution of the interaction between the surface and the atmospheric boundary layer (ABL) is crucial. We present an application of the Weather Research and Forecasting model in a truly complex mountainous terrain area located in the north-western Italian Alps, reaching the grid spacing of 0.5 km and high-vertical resolution in the ABL (20 levels below 1000 m a.g.l.). In this region, at a high-altitude plateau (Alpe Veglia 1736 m a.s.l.), a micrometeorological station is installed in September 2018, equipped to measure standard meteorological variables, turbulence and soil properties. The simulation outputs are compared with the observation of nine weather station distributed around Alpe Veglia and with the observations taken at Alpe Veglia. The aim is to test the weather model resolution in complex terrain and its ability to resolve ABL phenomena, such as slope winds and katabatic flows.

Moreover, we wish to test its sensitivity to the boundary condition, number of domains and their dimension, and the nesting ratio. A ready-to-use, reliable and high-resolution weather forecast is a need of the mountainous territories, since these areas are inhabited and used for business, leisure and tourism activities. Furthermore, it is a fragile environment, subject to mass-wasting and weathering processes, and for these reasons, need a more in-depth knowledge of the atmospheric-related processes and their modelling.

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Investigating Boundary Layer Processes in the Met Office Unified Model for Hurricane Maria (2017)
Amethyst Johnson, PhD Student, University of Leeds

The tropical cyclone boundary layer plays a key role in controlling surface fluxes of moisture and heat and while boundary layer friction is a vital part of the storm momentum budget. The boundary layer therefore plays an essential role in cyclogenesis and intensification of tropical cyclones. Despite its fundamental importance, no previous studies have evaluated the performance of the Met Office Unified Model (MetUM) in representing the tropical cyclone boundary layer. Improving forecasts of tropical cyclones is dependent on the representation of the boundary layer. The MetUM has seven boundary layer parameterisation schemes that represent the near-surface structure. However, all of these schemes have been designed for mid-latitude phenomena, which raises the question of whether they are fit for purpose in modelling tropical cyclones. This study aims to assess how well the MetUM represents the boundary layer structure of a recent, high-impact tropical cyclone (Hurricane Maria, 2017) by comparing convection-permitting model simulations with all available observational data, including dropsondes, in-flight radar, ground-based radar, and satellite imagery. Hurricane Maria was a high impact tropical cyclone that experienced rapid intensification, an eyewall replacement cycle, and both weakening and restrengthening following landfall in Puerto Rico and Dominica. Analysing the storm across its entire lifetime will provide a thorough understanding of how the MetUM represents the boundary layer structure during key stages in the lifecycle of the tropical cyclone. These results can help to identify deficiencies in the MetUM, which should point to ways to improve the representation of the tropical cyclone.

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Improving Radar Rainfall Esimation for Urban Flood Risk Using Monte Carlo Ensemble Simulation

Amy Green, PhD Student, Newcastle University

Weather radar is a crucial tool in rainfall estimation, for flood forecasting and urban drainage design, providing a picture of the spatiotemporal distribution of rainfall. Estimates are subject to complex correction procedures as a result of many different error sources e.g. ground clutter, attenuation, the vertical profile of reflectivity and the drop-size distribution. Due to the cumulative nature of errors along a radar beam, and the number of different error sources, correction and calibration is often problematic, relying heavily on ground truth.

During June 2012, the city of Newcastle suffered extensive flooding due to a high-intensity rainfall event; with a month's worth of rainfall falling in just two hours. This event, named the Toon Monsoon, caused traffic chaos and millions of pounds worth of damage. Where there was high-intensity rainfall between the radar and an observation, the radar estimates showed much lower rainfall amounts than ground observations. This dampening of the radar signal, sometimes to such an extent that rainfall 'shadows' occur, causes serious underestimation. The extent and frequency of this signal loss - known as attenuation - are unknown, as the true rainfall field cannot be accurately estimated.

An ensemble of rainfall field snapshots is simulated, corresponding to a realistic 3D generated rainfall field. This satisfies key features of a true rainfall field, namely the spatial correlation structure, marginal distributions and non-zero rainfall proportions. By inverting standard radar processing methods, synthetic attenuated rainfall images are used to investigate shadow effects caused by attenuation. As the true rainfall field is now known, the influence that assumptions placed upon the prescribed error structure have on the estimation process are identified. Inverse transform methods may then be used to reverse this model, to identify which true rainfall field is likely to correspond to existing reflectivity images.

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Improving Regional Rainfall Forecasting Using Video-Based Neural Networks

Andrew Barnes, PhD Student, University of Bath

Monthly variations in rainfall often lead to extreme events causing substantial damage to society. This damage is often caused by droughts and floods. Current sub-seasonal rainfall forecasts are based on large ensemble models using complex numerical predictions which require large amounts of computing power. Despite this, they often fail to capture the extreme events. In this study daily mean sea-level pressure (MSLP) and 2m air temperature (2AT) forecast images across the North Atlantic are used to produce regional, monthly rainfall forecasts for Great Britain. For each month 28 MSLP and 2AT images are derived from the MetOffice GloSEAS5 daily forecasts. The target rainfall is derived from the CEH-GEAR (Centre of Ecology and Hydrology Gridded Estimates of Areal Rainfall) and is used as the benchmark to be aimed for. Three types of convolutional neural networks (CNN) are trialled at combining the image sets into a regional rainfall forecast. These architectures are named slow-fusion, early-fusion and single frame. For each of the three architectures a CNN is developed independently for each region. The CNNs are then evaluated against derived monthly precipitation forecasts from the MetOffice's GloSEAS5 model. Following this, the CNN models are combined with the GloSEA5 forecasts to generate a new ensemble for each region which is then compared to the benchmark rainfall. The results show that the trained CNNs produce errors similarly to the GloSEA5 model with RMSEs of 63mm (Single Frame), 44mm (Slow Fusion) and 37mm (Early Fusion) compared to the GloSEA5 error of 33mm. Ensemble approaches fall closer to this value with the ensemble approaches surpassing it with errors of 32mm (CNN ensemble) and 31mm (post-processing ensemble).

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A Modelling Investigation of Atmospheric Cyanide

Antonio Bruno, PhD Student, University of Leicester

Hydrogen cyanide (HCN) is considered a good tracer of biomass burning, especially for peatland fires. Understanding its physical and chemical nature is important seeing that it is one of the most abundant cyanides in the atmosphere and plays a non-negligible role in the nitrogen cycle. The HCN lifetime varies from 2–5 months in the troposphere to several years in the stratosphere. Biomass burning represents the main source of tropospheric HCN with minor contributions from industry and transport. The main loss mechanism of atmospheric HCN is the oxidation by hydroxyl radicals (OH). Ocean uptake is also important, while in the stratosphere oxidation by reaction with O(1D) needs to be considered.

HCN variability is investigated using an adapted version of the TOMCAT three-dimensional (3-D) chemical transport model (CTM), at a 2.8°x2.8° spatial resolution from the surface to ~60 km for 12 idealised HCN tracers which quantify the main loss mechanisms of HCN, including ocean uptake, atmospheric oxidation reactions and their combinations. The modelled HCN distribution over 2004-2020 has been compared with HCN profiles measured by the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) and with ground-based measurements from NDACC Fourier Transform Infrared Spectroscopy (FTIR) stations and from NOAA network.

The HCN tracers with full treatment of the loss processes generally agree well with ACE-FTS measurements, using recent laboratory values for the atmospheric loss reactions. Diagnosis of the individual loss terms shows that decay of the HCN profile in the upper stratosphere is due mainly to the O(1D) sink. From the comparisons of the model tracers with surface-based observations we also test the magnitude of the tropospheric OH sink and the magnitude of the ocean sink. The implications of our results for understanding HCN and its variability are then discussed.

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Reduced El Niño Variability in the Mid-Pliocene according to the PlioMIP2

Arthur Oldeman, PhD candidate, Utrecht University

The mid-Piacenzian or mid-Pliocene warm period (mPWP, 3.264 – 3.025 Ma) is the most recent geological period to see atmospheric CO¬2 levels similar to the present-day values (~400 ppm). Some proxy reconstructions for the mPWP show reduced zonal SST gradients in the tropical Pacific Ocean, possibly indicating an El Niño-like mean state in the mid-Pliocene. However, past modelling studies do not show the same results. Efforts to understand mPWP climate dynamics have led to the Pliocene Model Intercomparison Project (PlioMIP). Results from the first phase (PlioMIP1) showed clear El Niño variability (albeit significantly reduced) and did not show the greatly reduced time-mean zonal SST gradient suggested by some of the proxies.

In this work, we study ENSO variability in the PlioMIP2 ensemble, which consists of additional global coupled climate models and updated boundary conditions compared to PlioMIP1. We quantify ENSO amplitude, period and spatial structure as well as the tropical Pacific annual mean state in a mid-Pliocene and pre-industrial reference simulation. Results show a reduced ENSO amplitude in the model- ensemble mean, with 15 out of 17 individual models showing such a reduction. Furthermore, the spectral power of this variability considerably decreases in the 3–4-year band. The spatial structure of the dominant EOF shows no particular change in the patterns of tropical Pacific variability in the model-ensemble mean, compared to the pre-industrial. Although the zonal SST gradient in the equatorial Pacific decreases for 14 out of 17 models, there does not seem to be a correlation with the decrease in ENSO amplitude. Lastly, the models showing the most ‘El Niño-like’ mean state, show a similar ENSO amplitude as in the pre-industrial reference.

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Improved Satellite Detection of Volcanic Ash

Cameron Saint, Foundation Scientist, Met Office

I will summarise the spaceborne observations of volcanic ash at the London Volcanic Ash Advisory Centre (VAAC), and my research aimed at refining them. Since the shutdown of significant parts of European airspace during the 2010 eruption of Eyjafjallajökull, there has been significant demand for information on volcanic plumes. Forecasts are obtained with dispersion models, such as the Numerical Atmospheric-dispersion Modelling Environment (NAME) used in the London VAAC, and observations are used in real-time to identify regions with airborne ash.

Geostationary satellites can view the entire plume with high temporal frequency, and several algorithms have been developed to automatically detect ash and retrieve its properties. The Met Office algorithm exploits the observed radiance in three infrared channels (8.7, 10.8 and 12 μm), by considering the brightness temperature difference (BTD) between these channels. The BTD tests are combined with various thresholds on the ratios of effective absorption optical thickness (beta ratios). Based on the above quantities, we assign a confidence level to the volcanic ash detection. I will explain how this data is used in the London VAAC and by developers of the NAME dispersion model. The key improvements that I am researching are achieved through the refinement of detection thresholds and the addition of new tests designed to counter false detections primarily in desert regions, but also other areas such as at high satellite zenith angle. Here, I will show how the results compare to the current operational set-up. The new scheme results in increased correct detection of volcanic ash and a reduction of false positives, as can be seen in examples including imagery of the volcanic plume that followed the June 2019 Raikoke eruption. The improved satellite imagery will be implemented operationally at the Met Office, and the VAAC will benefit from it during future eruptions.

Comparing Different Methods for Detecting Atmospheric Blocking

Charlie Suitters, PhD Student, University of Reading

Atmospheric blocking is the term given to the circulation pattern that describes a persistent, quasi-stationary anticyclone, typically found in the mid- and high-latitudes. Blocks prevent the usual eastward passage of extratropical cyclones and are associated with prolonged periods of suppressed precipitation, weak winds, and often extreme temperature anomalies. Despite their obvious impact on society, the mechanisms contributing to their lifecycle are still not fully understood. This is partly due to the lack of an objective blocking definition and the existence of many methods to identify blocks in reanalysis, numerical weather prediction (NWP) and global climate models (GCMs). Blocks can take on a range of different signature shapes within their lifetime, adding another complexity to their detection. This work explores the representation of blocking using two contrasting methods of detection in reanalysis. Each method demonstrates that climatological blocking activity maxima in the Northern Hemisphere are found over the North Atlantic, Europe, Greenland, and the North Pacific; and that in the hemispheric mean, blocking is most common in winter. However, each blocking detection method varies in the frequency of blocked days in each region, with methods detecting blocking using anomaly fields of 500 hPa geopotential height (Z500) recording around twice as much blocking as a method using meridional Z500 gradient reversals. Case study events are also examined, where it is shown that Z500 blocking signatures can change throughout the event. This dynamic behaviour of blocking leads to discrepancies in detection using each method. This work highlights the shortcomings in using a single detection method when studying atmospheric blocking, suggesting a combination of methods may be better suited to capture a range of different blocking scenarios.

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Meteotsunamis in a changing climate: The future of coastal resilience.

Clare Lewis, PhD Student, University of Reading & Plymouth Marine Laboratory

Coastal zones are subject to an increasing number of issues such as extreme wave and storm events and evolving populations. Amongst these issues is the phenomena of meteotsunami. In the same long wave band as the traditional tsunami (generated by seismic activity), meteotsunami are initiated by sudden pressure changes from moving atmospheric weather systems such as cyclones, squalls, thunderstorms and atmospheric gravity waves. This globally occurring hazard is currently deemed minimal in terms of potential impact by UK coastal managers and Government. The downscaling of this hazard may be due to misidentification and/or infrequent data sampling. This study endeavours to use the current meteotsunami hotspot of Plymouth City, UK as a case study site. It will attempt to highlight the characteristics of a UK meteotsunami by carrying out a reanalysis of three past recorded events. This will then be expanded upon by using GIS mapping to highlight potential impacts and areas of exposure. This will then be followed by an assessment of coastal management strategies in the evaluation of and response to a potential event. Where previous researchers have focused on the wave dynamics of meteotsunami and the detailed post event analysis, this study will place the hazard into the UK environment and into a future context by highlighting how a changing climate may well exacerbate such events and their subsequent impacts. A 0.5m meteotsunami wave might not seem like much of a hazard on its own but couple it with a winter storm, storm surge and/or sea level rise and this promotes a reduction in resilience of both human and green infrastructure. The study subsequently attempts to highlight the need for increased awareness, monitoring and the development of a coastal management strategy to overcome the future exposure factor of events such as meteotsunami.

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Smarter Analysis of Satellite Data for Air Quality Regulators

Daniel Potts, PhD Researcher, University of Leicester

Air quality research has advanced rapidly over the past few decades, driven partly by the advancements in satellite based remote sensing. These missions are able to retrieve concentrations of some of the most threatening pollutants to the environment and public health, with increasingly finer precision. One such mission is TROPOMI, which can measure trace gases such as NO2, SO2, CO, CH4 and O3, as well as aerosols, globally, with a spatial resolution of 3.5km x 5.5km. This step-change in resolution allows us to see large point sources, such as power stations and steelworks. Whilst research in the sector is moving at a rapid pace, satellite data is rarely used in matters of policy and regulation. Working with the UK Environment Agency, work has been done testing a number of “signal sharpening” techniques over major UK industrial sources. Techniques include wind speed and direction conditional aggregation, wind rotation aggregation and emission flux averaging, each designed to combat the UK’s frequent cloud cover and highly variable meteorology. Whilst each has their own unique benefits, wind rotation has shown great promise in its ability to identify an industrial point source, even against polluted backgrounds. It has been able to identify clear plume structure from previously difficult to isolate sources such as Drax power station, due to its proximity to other major sources. This study currently involves 35 major NOx sources, and the technique will be applied to other atmospheric species such as CO and SO2, in an attempt to create the first catalogue of UK regulated sources visible from space. Dispersion modelling of industrial plumes and emission estimates for the most suitable sources will also be generated, to evaluate the performance of TROPOMI for regulation.

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Using Weather Patterns to help the Energy Industry Prepare for Extreme Weather Events.

Eleanor Armstrong, Graduate Trainee, Met Office

Our energy system is highly dependent on the weather, even more so as we move towards a system based on renewable energy sources, such as wind and solar. The ability to prepare for extreme weather events is therefore extremely valuable for the energy industry. Energy systems face multiple challenges during these events, especially during periods of sustained low wind speeds and low temperatures in winter, leading to a lack of energy supply and high levels of energy demand. In this study, forty years of weather dependent energy demand and generation are related to the Met Office’s set of thirty predefined weather patterns, to identify those weather patterns that cause challenging weather conditions for the energy system. A forecast verification is then presented based on these identified weather patterns, providing insight into how many days ahead we can skilfully forecast these important weather conditions for the energy industry. This in turn helps us to tailor Met Office support to help this industry understand how the weather affects their network.

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Symmetries and Asymmetries of The Southern Annular Mode

Elio Campitelli, PhD Student, University of Buenos Aires

The Southern Annular Mode (SAM) is the main mode of the circulation anomalies in the Southern Hemisphere and it has influence over local anomalies of several atmospheric variables such as surface temperature and precipitation. While mostly zonally symmetric, it's spatial structure has also asymmetric characteristics. Since indices used in the literature respond to both aspects, they can lead to difficult interpretations. Here, we propose a straightforward method of creating two indices representing, respectively, the Symmetric and Asymmetric SAM components of variability.

To construct the two indices, we first separate at each level the geopotential height pattern associated with SAM into its zonally symmetric and asymmetric components. After that, observed monthly geopotential height anomalies are projected onto each of the componentes to construct the respective Symmetric SAM (S-SAM) and Asymmetric SAM (A-SAM) monthly index.

Regression patterns of geopotential height based on the S-SAM removing the effect of the A-SAM are almost totally zonally symmetric and vice versa. The asymmetric SAM structure in the troposphere is associated with equivalent barotropic planetary waves 3 and 2, very similar to the Pacific South American Pattern. In the stratosphere it is almost completely dominated by planetary wave 1. We show that positive trend in the SAM index observed in the literature is only detectable in the S-SAM, wich provides further insight about the processes explaining it. On the other hand, there is a statistically significant trend in the variance explained by the A-SAM, which suggest that the SAM is becoming more asymmetric.

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Will Coupling of the Met Office Forecast Model to an Ocean Model Improve Weather Predictions in the Tropics?

Eliza Karlowska, PhD Student, University of East Anglia and Met Office

Numerical weather prediction (NWP) is the main tool behind weather forecasting of meteorological variables. With an ongoing drive to improve models, trials have been conducted to include ocean dynamics and feedbacks with the atmosphere, as is common in models used for climate timescales. These so-called coupled atmosphere-ocean models tend to outperform atmosphere-only systems. In particular, they show improved prediction of the Madden-Julian Oscillation (MJO), an intraseasonal (30 - 90 days) mode of enhanced and suppressed convection in the tropical atmosphere. The MJO is important for global weather prediction, as it influences various weather patterns, including planetary-scale Rossby waves that impact weather in the extratropics. MJO observations show that interactions between sea surface temperature (SST) and tropical convection are crucial during its propagation. Warm SST anomalies lead to increased convection, lowering incoming radiation and increasing upward latent heat fluxes due to strong surface winds. These processes drive cold SST anomalies, leading to suppressed convection. Atmosphere-only NWP models use constant SST for forecasting, which generally results in poorer representation of the MJO. Coupled NWP models benefit from dynamical processes that modulate SST such as heat, moisture and momentum exchange between the atmosphere and ocean. These interactions have been shown to improve MJO prediction. However, it is unclear what mechanisms govern the skill improvement. In this paper, we diagnose the Met Office coupled ocean-atmosphere NWP system, running in near-real time since May 2016. We investigate available MJO events and compare performance in the tropics to the Met Office operational, atmosphere-only NWP system. Bivariate correlation and RMSE values indicate that the coupled NWP model performs better than the operational NWP model, and therefore we perform statistical and process-based analyses of case studies to investigate reasons behind the improvement.

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Detecting and Analysing Early Heatwave Extremes

Emma Yule, PhD Researcher, University of Edinburgh

As extreme heat events are becoming more prevalent globally due to climate change it is becoming increasingly important to understand the mechanisms and impacts of such events on society. This paper focuses on what can be learnt from past extreme heat events over the last 200 years in Europe. A key focus is how past extreme events can be discovered and analysed with the use of reanalysis data sets, station data and historical documentation and how these events can be placed in context with modern extreme events from the past decade. Differing definitions of heatwaves are explored and recommendations made for using past events to help society as a whole adapt and increase resilience towards such extreme events.

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Future Climate Change Impacts on Surface Ozone in the Tropics

Flossie Brown, PhD Student, University of Exeter

Air pollution in remote tropical regions is often overlooked because anthropogenic emissions in these areas are low. However, vegetation can also act as a source and a sink for ozone. Climate change will alter the behaviour of vegetation and this may affect surface ozone concentrations in the tropics. This study explores the impact of climate change on surface ozone concentrations in South America and Africa at the end of the century.

Here, we analyse end of the century climate model predictions from the 6th Coupled Model Intercomparison Project (CMIP6) under scenario SSP 3.70 for simulations which include climate change (ssp370SST) compared to those in which temperatures are fixed to present day values (ssp370pdSST). Four climate models are used to test the robustness of the response to climate change.

Over clean regions, warmer and wetter conditions result in net ozone loss through photochemical destruction whereas, over highly vegetated regions, increased biogenic emissions lead to enhanced ozone production. Deposition of ozone via vegetation represents a major loss pathway which decreases by 10% – 30% due to climate change.

The feedback between climate change and vegetation increases surface ozone in 2100 by 10% in some areas of South America and Africa. This suggests decreased air quality, decreased plant productivity and increased radiative forcing in the tropics by the end of the century unless climate change mitigation strategies are put in place.

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Convection and Circulation in Convection-Permitting Models over West Africa

Francesca Morris, PhD Student, University of Leeds

This work examines the representation of convection-circulation interactions over tropical West Africa in convection-permitting models. Tropical West Africa is not only a region characterised by extremely high-impact weather, in the form of intense and frequent organised convection, but it is also a region of strong baroclinicity and wind shear, and therefore an excellent natural laboratory for examining the connections between mesoscale convection and synoptic circulations. Developing understanding of convection-circulation coupling is crucial to informing development of convection parameterisations and improving regional forecasts of high-impact weather.

We evaluate output from the CP4-Africa convection-permitting configuration of the Met Office Unified Model to investigate links between convective activity and synoptic motions. To illustrate its strengths in representing convection-circulation feedbacks, CP4 output is compared to that from a similar UM configuration which uses a convection parameterisation.

We examine the mean diurnal cycle of circulation during the storm season. Distinct diurnal patterns in circulation tendency are compared to patterns in updraughts and precipitation, which illustrate different forms of convection which can be observed at different points during the day. We illustrate that unorganised and organised convection impact on circulation in different ways with different modes of convection throughout the day, so the diurnal circulation tendencies are linked to the differences in representation of convection in convection-permitting and parameterised simulations.

To explore which physical processes cause changes to circulation in the region, we calculate terms in the circulation tendency equation. Separating these terms into mean and eddy-flux contributions allows us to establish the extent to which mesoscale systems and synoptic structures each influence the diurnal changes to circulation. Understanding these interactions between convection and circulation in the region could be used to inform representation of organised convection in parameterisations.

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Lagrangian Coherent Structures: Kinematical Skeletons of Moisture and Rainfall Bands

Gabriel Perez, PhD Student, University of Reading

Large-scale horizontal turbulence in the atmosphere reshapes the distribution of moisture and other tracers around material skeletons known as Lagrangian Coherent Structures (LCSs). We aim to use the LCS approach to identify the underlying mechanisms generating features such as atmospheric rivers, jets and convergence zones and thus to unify the myriad of region and feature specific criteria typically used to identify them. In this study, we investigate the role of LCSs in the South American Monsoon System (SAMS) employing a reanalysis dataset from 1980 to 2009. We show that the orientation and position of LCSs in the equatorial Atlantic determines the inflow of moisture in South America and anticipate the onset of the SAMS. By computing the moisture flux along LCSs, we identify structures that resemble atmospheric rivers east to the Andes. We show that they play an important role in redistributing equatorial moisture for subtropical latitudes; their intra-seasonal variability explains the well documented rainfall dipole between South and Central South America. We also show that LCSs in Central/Southeast Brazil are associated with cyclones in the South Atlantic; they organise intense and persistent rainfall bands during the austral summer that characterise the South Atlantic Convergence Zone. We believe that the strength of the approach lies in its generality; i.e., by dismissing region specific criteria (e.g., particular cloudiness patterns), we can provide a consistent census of features and attribute rainfall to these features in a non-overlapping way.

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The Interaction Between Cold Fronts and Convection in Germany

George Pacey, PhD Student, University of Berlin

Fronts (~1000km scale) provide an environment favourable for convective initiation (1-10km scale). Convection typically initiates in three locations in frontal environments: ahead of the cold front in the warm sector of the cyclone, directly at the cold frontal boundary and finally behind the cold front. Previous literature has typically focused on each initiation location independently, thus a comprehensive study investigating the link between fronts and convection is currently lacking from literature. This project seeks to better understand the scale interactions and forcing mechanisms of convection at each initiation location (i.e., behind, at, ahead). A secondary motive seeks to understand the feedbacks on the frontal structure in cases of strong convection (e.g., mesoscale convective systems). The project results will improve forecasting of convection in frontal environments and the associated hazards (heavy rain, hail, wind etc).

Automatic front detection methods are applied to reanalysis data and a convective cell-tracking dataset from the German Weather Service is used to build a climatology of fronts and convection between April–September. Convective initiation is frequent in Germany during the warm season, occurring on 78% of days, around half of which days were associated with a weather front, highlighting the importance of fronts on convective initiation in Germany. Convective cells behind the front initiate primarily in the north-west of Germany and exhibit a strong diurnal cycle. On the contrary, cells at and ahead of the front initiate more frequently in southern Germany and exhibit a less prominent diurnal cycle, especially for cells at the frontal boundary. The next stages of research will investigate the relative importance of various forcing mechanisms on the development of convective cells at different cell-front positions.

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Improving Design Storm Hyetographs to Better Represent the Risks from Intense (Convective) Storms in Great Britain

Roberto Villalobos-Herrera, PhD Candidate, Newcastle University

Extreme rainfall often results in damaging pluvial and fluvial flooding. Engineers need reliable rain data to design surface water drainage and flood protection schemes. Our research shows that the two design hyetographs currently in use in the UK misrepresent the behaviour of short duration (< 4 hr) rainfall events. This is problematic as these typically convective storms are predicted to increase in frequency and intensity in the coming years.

Using a sample of over 100,000 independent extreme rainfall events extracted from a large quality-controlled rainfall dataset with sub-hourly resolution for Great Britain we find that rain intensity tends to be highest at the beginning of such events, rather than peaking more gradually in the middle of the storm, as currently understood.

In addition, by assessing the temporal and geographical distribution of rain at sub-hourly intervals, we are providing fresh insight into the significance of intense rainfall bursts embedded within longer duration events. Our approach provides a more accurate representation of rainfall characteristics compared to previous studies that utilised hourly or daily data.

Our ultimate goal is to combine the novel climatological knowledge of rainfall hyetographs with a statistical representation of rainfall extremes in order to improve current design rainfall methods used in the UK. This should ultimately result in improved representations of extreme rainfall intensities and of the peak flows these may generate, facilitating the design of more effective flood mitigation measures.

Statistical Modelling of Surface Solar Radiation for the Identification of Surplus Energy Generation Events to Test the Resilience of a Highly Renewable Future Energy System

Isabel Rushby, Foundation Scientist, Met Office

There is wide agreement that greenhouse gas emissions from the energy sector must be reduced and eventually eliminated if climate change is to be limited to safe levels. With this, an energy system with a growing renewable mix will become increasingly sensitive to weather. Therefore, the National Infrastructure Commission has commissioned the Met Office to produce a set of physically plausible adverse weather scenarios which would be challenging for a highly renewable energy system; for example, a surplus energy event where there is a period of low electricity demand and high wind and solar energy generation

As not all possible events have been realised in the available historical records, the Met Office Decadal Prediction System (DePreSys) was run for 2280 model years, providing a larger dataset of physically plausible forecasts that can be used to identify a greater number of adverse weather events. However, while DePreSys contains most meteorological variables required to comprehensively characterise the energy system, it does not contain solar radiation data, which is an important component of surplus energy events. Here, we describe and validate the statistical methods used to estimate surface solar radiation from DePreSys ensuring consistency between variables. Generalised Additive Models are trained on ERA5 data to quantify the relationship between residual solar radiation (defined as the difference between surface solar radiation and inferred top of atmosphere radiation) and explanatory meteorological and non-meteorological variables.

These models successfully explain a high proportion of the variance in the residual solar radiation, and so can be used to estimate daily surface solar radiation for the DePreSys data. The resulting coherent dataset, including solar values, are used to identify periods of adverse weather allowing energy modellers to test the resilience of a highly renewable future energy system to these events aiding the path to a net-zero sustainable future.

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Monday 28 and 29 June 2021

An Analysis of the Diurnal Cycle of Rainfall over the Maritime Continent using GPM-IMERG Data

Jack Mustafa, Postgraduate Researcher, University of East Anglia

The islands of the Maritime Continent (MC) archipelago, situated in the equatorial Indo-Pacific warm pool, are among Earth's rainiest. Rainfall induces release of latent heat into the troposphere, and this drives worldwide atmospheric teleconnections as this energy propagates away from the equator. Accurate representation of atmospheric dynamics over the MC in weather and climate models offers far-reaching potential benefits, as well as improved forecasting ability concerning local flooding risk. The distribution of MC rainfall in time and space is strongly influenced by a range of phenomena, from the high-frequency diurnal cycle driven by land-sea temperature contrasts, through the intraseasonal Madden-Julian Oscillation (MJO) to the multiannual El Niño Southern Oscillation (ENSO). However, the multitude of interacting phenomena makes accurate representation of regional dynamics challenging.

The diurnal cycle involves development of deep convection over land through the late morning such that diurnal rainfall typically peaks in the afternoon over land, while overnight the rainfall propagates offshore such that diurnal rainfall peaks in the early morning over the surrounding seas. The amplitude of the diurnal harmonic of rainfall and the phase at which it peaks vary systematically according to the states of lower frequency modes of variability. This presentation will cover early progress made in analysing how the diurnal cycle varies according to lower frequency modes of variability, particularly the MJO and convectively coupled equatorial Kelvin waves, as seen in global reanalysis data sets.

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Combined Effects of Global Warming and Ozone Depletion/Recovery on Southern Hemisphere Atmospheric Circulation and Regional Precipitation

Julia Mindlin, PhD Student, Centro de Investigaciones del Mar y la Atmósfera

Ozone depletion has lead to a positive trend in the Southern Annular Mode (SAM) during the end of the 20th century. During the present century, global warming (GW) is expected to contribute to a positive SAM trend, which associated with a poleward shift of the westerly winds, while ozone recovery is expected to act in the opposite direction, contributing to an equatorward shift of the westerly winds. Here, Southern Hemisphere (SH) circulation and regional climate change are studied by applying a methodology that allows the combination of the effects from GW and ozone depletion/recovery and different remote drivers of circulation change. We evaluate a limited number of time dependent storylines that comprehensively represent the uncertainty in the response and the magnitude of the mentioned effects. Our results show that the 'tug-of-war' between ozone and GW occurs in the stratosphere, propagating to the troposphere. We find that at the regional level this 'tug-of-war' is not as relevant as the combined effects of other remote drivers of circulation change, which force different precipitation changes in the SH.

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A Simple Harmonic Oscillator Model for Madden Julian Oscillation with Moisture Feedback.

Kartheek Mamidi, PhD Student, Central University of Kerala.

Despite number of theories existed, the fundamental characteristics of Madden Julian Oscillation (MJO) is still elusive and it has been considered as the “holy grail” of research on the tropical atmosphere. MJO is the planetary-scale intra seasonal eastward propagating variability which as the large impact on other tropical variabilities as well as global weather and climate. MJO is one of the dominant mode of slowly moving equatorial moisture variability, which discovered nearly half a century ago and has large section of theories associated on its observed features.

In this study, we formulated a simple mathematical model using linear shallow water equations with momentum damping in addition with dynamical equation which consist moisture as a prognostic variable. We considered above formulation as a linear harmonic oscillator and the analytical solution explains the fundamental characteristics of observed moisture mode in tropical atmosphere, such as MJO’s planetary scale eastward propagation and growth rate.

The dispersion relation generated from our theory clearly describes the role of moisture in generating the dispersive MJO mode. Here we investigated the role of evaporation wind feedback (E-W) and strength of moisture feedback under the influence of Rayleigh damping. Particularly the moisture process makes the MJO mode unstable at higher wave number values and other high frequency Matsuno modes were damped. The strength of E-W feedback makes the eastward propagating MJO mode to slow down at planetary scale and increases the growth rate.

The model also demonstrates the effect of dissipation and influence of moisture relaxation timescale on dispersion properties of produced MJO mode using the same mathematical framework. Sensitivities of these parameters on the model are also discussed.

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Machine Learning Applications. Numerical Weather Prediction and Dynamic Line Ratings for Overhead Power Lines – A Review

Katie Hodge, Graduate Trainee Scientist, Met Office

Increased renewable energy generation far from demand centres (cities) poses increased pressures on existing network assets such as overhead power lines. To protect lives and preserve the longevity of existing assets, strict current carrying capacity limits (known as the ampacity) are imposed for each circuit. Ampacity is related to the heating and cooling experience by the line, influenced amongst other things by the nearby weather conditions. The rating of a line is calculated to ensure the core temperature of the line remains below manufacturer recommendations and to meet minimum ground clearance limits. Currently, seasonal estimates of the perpendicular wind speed, ambient air temperature and solar radiation are often used to predict a worst-case scenario for the core temperature. This means under certain weather regimes there is underutilised capacity of the overhead lines. Dynamic line rating poses a solution to increase the ampacity of existing assets through dynamically varying the rating using more representative time-varying weather parameters. This talk will review how machine learning methods can be used to learn the relationship between ampacity and numerical weather predictions to forecast dynamic line ratings up to 48 hours ahead. The 24-48 hour forecast horizon is selected as decisions by transmission system operators for planning, maintenance and redispatching are taken one to two days ahead. Finally, the talk will focus on the benefits of using machine learning methods to forecast dynamic line ratings and the next steps for applying machine learning methods to operational systems.

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Climate Model Evaluation of 3 Hourly Compound Precipitation and Wind Extremes Over Europe

Laura Owen, PhD Student, University of Exeter

Extreme precipitation and winds can have a severe impact on society, particularly when they occur at the same place and time. Studies have investigated the frequency of co-occurring extreme precipitation and wind using observational data. Due to the rarity of such events, these results are limited when looking at the risk of very extreme events, since a large number of samples is needed to get robust estimates. Additionally, it is very difficult for estimates based on observations alone to help us understand the risk of future rare or unprecedented events. Using the UNSEEN method (UNprecedented Simulated Extremes using ENsembles) this risk can be estimated from large ensembles of climate simulations. The Met Office's Global Seasonal forecast system version 5 (GloSea5) model ensembles are evaluated against ERA5 reanalysis data to find out how well they represent extreme precipitation, extreme wind and extreme co-occurring events over Europe. This model has not been evaluated in such a way before and this is needed before the model can be used to estimate the likelihood of unprecedented events using the UNSEEN method. We find that although the intensity of precipitation and wind extremes differ between the model and observations (by up to 12 mm and 9 m/s), the frequency of co-occurring events is well represented. However, significant differences in frequency are found around and over some areas of high topography. The model's co-occurring events at individual locations investigated occur with very similar synoptic patterns to ERA5, indicating that the compound extremes are produced for the correct reasons. The model ensembles can then be used to assess the present day likelihood of unprecedented 3 hourly compound precipitation and wind extremes for winter over Europe, and to find out how the North Atlantic Oscillation influences the frequency of co-occurring events over Europe.

Climate Extremes Recorded in Playa Lakes Across Continental Australia Over the Last Millenia

Lea Grunau, PhD Candidate, University of Wollongong

Climate models for Australia still involve high uncertainty, attributed to the limited paleo data available for the Southern Hemisphere, making it difficult to predict climate extremes and landscape responses Australia might face due to global warming. Though efforts have been made to improve the terrestrial record of Australian climate data, there still exists a gap in scientific knowledge, especially on the spatial and temporal scale of extremes and their landscape responses. The project tackles this challenge by utilising paleoenvironmental evidence collected from various ephemeral lakes across the country in areas that are until now un-instrumented. The filling and dry out events of ephemeral lakes are strongly linked to the El Niño-Southern Oscillation and thereby Australia's high susceptibility to extreme climate variability. The terrestrial record from the ephemeral lakes in key quadrants of the country hence, allows the establishment of timing, magnitude, variability, and trend of exceptionally dry and wet periods on a large spatial scale. While previous studies have focused on high resolution at specific locations the large spatial scale of this project enables the analysis of spatial variability and thus will result in an improvement of the understanding of climate patterns across Australia. A timeframe of the last thousand years allows the comparison of frequency and magnitude to inter-annual variability. The paleoenvironmental record further enables analysis of landscape responses to identify climate thresholds and the impact of local and global drivers on the extremes. Ultimately, by comparison of the collected data against global climate simulations model uncertainty can be reduced through observational constraint and future predictions of climate extremes and landscape responses can be improved.

Investigating the Occurrence, Likelihood and Regional Variability of Extreme Ozone Pollution Episodes Across the UK

Lily Gouldsbrough, PhD Student, Lancaster University

Warm summer temperatures provide ideal conditions for the occurrence of extreme ground level ozone pollution episodes. Given the well-established negative impacts of ozone on human and plant health, understanding and attributing these extreme events is of importance to the scientific and wider community, particularly as heatwaves may become more frequent due to climate change. Extreme Value Analysis provides a powerful and flexible framework in which to statistically model unusually large observed values of ozone extracted from historical data. Here, a temperature dependent Peaks-Over-Threshold method based upon the Generalised Pareto Distribution is used to carry out a regional comparison of extreme ozone pollution episodes within the UK. Our analysis uses surface ozone observations from the UK's extensive Automatic Urban and Rural Network. The statistical model was used to quantify the frequency and magnitude of extreme ozone events, including a probabilistic assessment of exceeding UK public health thresholds, conditional on temperature. Return levels are provided for each monitoring site demonstrating the expected future projections of extreme ozone pollution events across the UK. An analysis of the spatiotemporal variability in UK ozone extremes, along with their temperature dependence, will be presented. A particular focus of this analysis will be discussing the effect of heatwaves on extreme ozone events.

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A Methodology for Attributing the Role of Climate Change in Extreme Events: A Global Spectrally Nudged Storyline

Linda van Garderen, PhD Student, Helmholtz-Zentrum Hereon

Extreme weather events are generally associated with unusual dynamical conditions, yet the signal-to-noise ratio of the dynamical aspects of climate change that are relevant to extremes appears to be small, and the nature of the change can be highly uncertain. On the other hand, the thermodynamic aspects of climate change are already largely apparent from observations, and are far more certain since they are anchored in agreed-upon physical understanding. The storyline method of extreme event attribution, which has been gaining traction in recent years, quantitatively estimates the magnitude of thermodynamic aspects of climate change, given the dynamical conditions. There are different ways of imposing the dynamical conditions. Here we present and evaluate a method where the dynamical conditions are enforced through global spectral nudging towards reanalysis data of the large-scale vorticity and divergence in the free atmosphere, leaving the lower atmosphere free to respond. We simulate the historical extreme weather event twice: first in the world as we know it, with the events occurring on a background of a changing climate, and second in a 'counterfactual' world, where the background is held fixed over the past century. We describe the methodology, and present results for the European 2003 heatwave and the Russian 2010 heatwave as a proof of concept. These show that the conditional attribution can be performed with a high signal-to-noise ratio on daily timescales and at local spatial scales.

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Robust Seasonal Forecast Skill for Frequency and Intensity of Winter Windstorms Over Europe Using Different Skill Measures.

Lisa Degenhardt, PhD Student, University of Birmingham

Weather forecasts are one of the main interests in meteorology. Part of the forecasting process is model development and gaining more knowledge about the model's performance. Consequently, forecast skill scores are an essential tool to assess the model capability to predict future weather developments accurately.

This presentation is using different skill measures to assess seasonal winter windstorm forecasts over Europe as provided by the UK Met Office's operational seasonal forecast model, GloSea5, a multi-member ensemble of 63 members for 23 seasons (DJF) from 1993 to 2015. The model skill is validated against re-analysis data (ERA5). Windstorms are tracked based on the exceedance of the 98th percentile of the local 10m wind speeds following Leckebusch et al. (2008). Three different storm parameters are investigated: storm frequency, storm intensity accumulated over all storms per season, and storm-number-normalized storm intensity.

The more general analysis is the ranked Kendal-т_b-correlation, which focuses on the interannual variations between different seasons. The ROC (Relative Operating Characteristics) curves are statistical measures that use classifications, hence focus more on a skilful prediction of a specific class.

The correlation analysis shows a first general pattern of forecast skill with positive and significant correlations over the British Isles and Scandinavia for all 3 storm parameters. The ROC statistic separates the results into the predefined classifications and can be used to identify, in which category the skill is dominant. For the storm frequency, previous studies revealed that forecasts perform best for very low or high storm frequencies classes. Further to this, this study reveals for the storm intensity enhanced forecast skill for the lowest storm intensity seasons over UK and some high and significant skill of high intensity years over Scandinavia.

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Measuring Extinction in the Lower Troposphere with Raman Lidar

M. Stolla

Climate change that we are experiencing strongly depends on the Earth's energy budget. Determining the amount of radiation passing through the atmosphere and being trapped, aerosol and cloud extinction is a very important parameter for the Earth's energy budget. Especially shallow cumulus clouds in the trade wind region have a large impact due to their frequent occurring. Those clouds are relatively small which requires fast measurements and therefore high power systems. The Max Planck Institute's Raman lidar at the Barbados Cloud Observatory fulfills those requirements. Based on the data measured with the Raman lidar during the field campaign EUREC^{4}A that took place in January and February 2020 in the western part of the tropical Atlantic, an algorithm for the extinction retrieval from Raman lidar data has been developed.

Designed as a multipurpose system, the lidar is also dedicated for daytime measurements of relatively weak Raman signals for which the narrow field-of-view detection is implemented. This makes it critical for the extinction retrieval to measure the overlap between the sounding laser beam and the field of view of the receiving telescopes (overlap function). Extensive filtering and data smoothing is applied to calculate a reliable overlap function. As a new approach, the derivative of the overlap function is smoothed, allowing a good degree of noise reducing. Close to the ground where the direct extinction measurement is impossible, it has been estimated from backscatter and the lidar ratio measured with the same instrument. It is shown that the cloud mask derived from extinction data allows avoiding misinterpretation of light drizzle as a cloud that is often the case with the cloud mask calculated from backscatter. Distinguishing between aerosol and cloud extinction allows insights into cloud forming processes.

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Where will we holiday in Europe in the Future? An application of UKCP18 to the Tourism Climatic Index.

Megan Pearce, Scientific Consultant, Met Office

Climate is a common factor that influences the choices of holiday-makers in terms of destination and time of year to travel; both associated with a perceived favourability towards certain conditions and the ‘acceptable comfort level’ of the tourist.

Under future warming scenarios, tourism will undoubtably be impacted by increases in both mean and extreme temperatures, as well as changes in precipitation, humidity and sunshine duration. Here, we look at an approach for assessing the impact of the future climate on tourist destination favourability, through calculation of the Tourism Climatic Index (TCI). This is an established measure that links physical climate with human comfort to assess destination favourability for tourism.

Here, for the first time, we present an overview of the TCI method and its application to UK Climate Projections 2018 (UKCP18) climate model data. In order to capture the range of physical climate impacts on holiday-makers, the TCI is calculated from a variety of meteorological variables, providing a single score that can be used to make objective comparisons. Not all of the required variables are included within these data sets, adding a layer of complexity to the TCI calculation; the approach for the derivation of these variables from the available climate model data is described and explained.

The work provides an update to previous literature studies by using the latest climate projections. Through the application to such climate projections, it is possible to use TCI as an objective comparator between different seasons, geographical regions, warming scenarios and time periods to understand the differences in favourability to tourists. The use of these results are deemed particularly relevant for those responsible for the wider planning of the sector – not limited to those in hospitality, recreation, and transport.

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Effects of Vertical Wind Shear on the Intensities of Mesoscale Convective Systems over West Africa

Michael Baidu, PhD Researcher, ICAS, University of Leeds

Vertical wind shear plays a key role in the intensification of Mesoscale Convective Systems (MCSs). In West Africa, the meridional temperature gradient between the hot Sahel and the humid Gulf of Guinea results in a strong easterly wind at mid-levels and south-westerlies at low-levels leading to a strong vertical wind shear. This strong vertical wind shear is associated with stronger MCSs but the exact mechanism is not thoroughly understood. The effects of vertical wind shear on the intensification of MCSs over sub-regions of West Africa have been investigated using a 10-year (1998 - 2007) MCSs dataset based on brightness temperature from the Cloud Archive User Service (CLAUS). The associated environment and rain-rates of the MCSs were retrieved from ERA-Interim reanalysis and TRMM 3B42 data.

The relationship between the vertical wind shear associated with matured MCSs and the main variables that describe MCS intensity (brightness temperature, lifetime and speed) is investigated. The results show that, a strong vertical wind shear is associated with long-lived, fast moving, large and cold (deep) storms with high rain-rates.

Generally, storms over the oceans could reach their level of neutral buoyancies (LNBs) compared to storms over land. We speculate that entrainment of drier air into land storms prevents them from reaching their LNBs. The difference between the observed brightness temperatures (cloud top heights) and the LNBs of land MCSs is minimised over regions of high vertical wind shear. Strong vertical wind shear results in colder brightness temperatures relative to the temperature at their LNBs. We propose that this happens by increasing updrafts and minimising entrainment. The representation of these processes is important for the accuracy of climate models.

Using Projections from UKCP18's Convection Permitting Model to Increase Understanding of Future Surface Water Flood Risk in Leeds

Molly Asher, PhD Researcher, University of Leeds

Quantifying the severity and regularity of pluvial flood events in future climates is crucial for ensuring that appropriate levels of resilience and protection are delivered. Recently, very high resolution, convection-permitting models (CPM), previously used only in short range weather forecasting, have been run for the first time in national climate scenarios as part of UKCP18. CPMs more accurately represent the convective storms which drive urban surface water flooding, and offer significant potential to increase the accuracy of projections of future pluvial flood risk. This research investigates how the enhanced resolution climate understanding behind UKCP18 2.2km, hourly precipitation projections translates into pluvial flooding impacts and how the new data can best be used in existing flood assessment methods and models.

Using Leeds as a case study, the research begins by validating UKCP18 2.2km precipitation projections locally against 1km gridded estimates of areal rainfall, with particular focus on the model's representation of extreme rainfall events over different time scales. Then, the sensitivity of Leeds urban catchments to storms of various durations are tested in order to determine the characteristics of the storm events which present the greatest pluvial flood risk. Focussing on these critical storm durations, hydraulic flood models of Leeds catchments are used to assess the pluvial flood response to rainfall events in the present climate and the future climate. Comparison is made of the future pluvial flood risk predicted using rainfall events uplifted using national uplift factors currently supplied based on the output of coarser resolution Regional Climate Models and to rainfall events projected to occur locally in the UKCP18 2.2km projections. These results will help to quantify whether the outputs of CPMs predict a significantly different future pluvial flood response.

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The Influence of Stratospheric Meteorology on Forecasting the Movement of Volcanic Ash

Nicola Stebbing, Foundation Scientist, Met Office

Volcanic ash presents multiple hazards to aircraft, from reduced pilot visibility to permanent engine damage. To mitigate the risk of aircraft encounters with ash clouds, the London Volcanic Ash Advisory Centre (VAAC) uses the atmospheric dispersion model NAME (Numerical Atmospheric-dispersion Modelling Environment), driven by numerical weather prediction data, to provide timely information on the location and concentration of volcanic ash in the atmosphere.

We investigate the influence of stratospheric meteorology on the dispersal of volcanic ash from very high (>30 km) eruptions and consider the impact that the vertical resolution of the meteorological data used with NAME has on forecast accuracy. We considered a hypothetical eruption of Öræfajökull (Iceland) during different stratospheric meteorological scenarios, including Sudden Stratospheric Warming (SSW), Vortex Intensification (VI) and Final Stratospheric Warming (FSW) events. Using low resolution meteorological data was found to underestimate the horizontal dispersal of ash perpendicular to the main dispersal path of the ash cloud in every scenario. During events when there was a significant shift in zonal wind direction or speed, such as SSWs, VIs and FSWs, we found that there were differences in the timing of the wind changes affecting the ash dispersal, with the lower resolution meteorology lagging behind the higher resolution meteorology, which greatly affected the distance and direction the ash was dispersed. When stratospheric conditions were more consistent, such as during summer periods, changing the meteorological resolution led to large differences in ash concentrations in the centre of the ash clouds. These results suggest that, depending on the meteorological situation and the plume height of an eruption, stratospheric conditions can have a significant impact on the forecast location and concentration of volcanic ash in the atmosphere and must therefore be adequately represented in operational volcanic ash forecasting.

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Extreme precipitation events and large-scale patterns over the Mediterranean: Connections & predictability

Nikolaos Mastrantonas, PhD Researcher, ECMWF

The Mediterranean region frequently experiences Extreme Precipitation Events (EPEs) with devastating consequences for affected societies, economies and environment. Thus, it is crucial to better understand this natural hazard and its drivers, so we can mitigate associated impacts and increase the resilience of our societies. In fact, one important part of the risk mitigation chain is the sub-seasonal predictability of such extremes, referring to lead times of about 2 weeks up to 2 months. Information at such timescales supports a range of actions, as for example warn decision-makers, and preposition materials and equipment.

In this work, we present a framework for providing skillful information about EPEs occurrences in the Mediterranean in sub-seasonal forecasts. Initially, we analyse the daily atmospheric variability of the low and middle troposphere over the Mediterranean. Using Empirical Orthogonal Function analysis and subsequent K-means clustering, we group the daily weather circulation into 9 classes of distinct atmospheric characteristics. These groups are then used to condition the probability of observing EPEs. It is shown that the derived groups are strongly associated with the preferential occurrence of EPEs at different subregions of the Mediterranean. Taking advantage of these strong connections, we finally assess and quantify the ability of the ECMWF extended-range predictions in correctly identifying the allocated pattern for different lead times.

Initial results show that the model is able to provide skillful information, outperforming climatology and persistence, up to about 13 days lead time. This result is promising for providing useful information at sub-seasonal timescales, as for such lead times, Numerical Weather Prediction models are more skillful in predicting large-scale patterns than localized extremes.

Beyond Probabilities: A Possibilistic Framework To Interpret Ensemble Predictions and Fuse Imperfect Sources of Information

Noémie Le Carrer, Post-doctoral Researcher, Università Ca'Foscari Venezia

Ensemble forecasting is widely used in medium-range weather predictions to account for the uncertainty that is inherent to the numerical prediction of high-dimensional, nonlinear systems with high sensitivity to initial conditions. Ensemble forecasting allows one to sample possible future scenarii in a Monte-Carlo-like approximation through small strategical perturbations of the initial conditions, and in some cases stochastic parameterisation schemes of the atmosphere-ocean dynamical equations. Results are generally interpreted in a probabilistic manner by turning the ensemble into a predictive probability distribution. Yet, due to model bias and dispersion errors, this interpretation is often not reliable and statistical postprocessing is needed to reach probabilistic calibration. This is all the more true for extreme events that for dynamical reasons, cannot generally be associated with a significant density of ensemble members.

In this work we propose a novel approach: a possibilistic interpretation of ensemble predictions, taking inspiration from possibility theory. This framework allows us to integrate in a consistent manner other imperfect sources of information, such as the insight about the system dynamics provided by the analog method. We thereby show that probability distributions may not be the best way to extract the valuable information contained in ensemble prediction systems, especially for large lead times. Indeed, shifting to possibility theory provides more meaningful results without the need to resort to additional calibration, while maintaining or improving skills.

Our approach is tested on an imperfect version of the Lorenz 96 model, and results for extreme event prediction are compared against those given by a standard probabilistic ensemble dressing.

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Can Shooting Stars Can Help Validate Atmospheric Models?

Phoebe Noble, PhD Student, University of Bath & British Antarctic Survey

The layers of the Earth's atmosphere form a coupled system, linking surface weather and climate to the space environment. The Mesosphere and Lower Thermosphere (MLT) at 80-100km above the surface, is critical in the coupling of the middle and upper atmosphere, determining the momentum and energy transfer between these two regions. However, despite its importance, Numerical weather prediction models have only recently been extended to the MLT and as such remain poorly constrained.

We take advantage of the long term dataset available from the meteor radar at Rothera on the Antarctic Peninsula in order to test the Whole Atmosphere Community Climate Model (WACCM). A meteor radar uses the ionised trails left behind by meteors (shooting stars) to evaluate the wind speeds high up in the atmosphere. The Rothera meteor radar has been running continuously since 2005, giving us access to a uniquely long, consistent measure of the winds in the MLT that we can use to investigate long term variability. In this study, we find that although some characteristic features are represented well in the WACCM model, it has considerable biases. In particular, the observations show a ~10m/s eastward wind in Antarctic winter whereas the model predicts winds in the completely opposite direction of ~10m/s westwards. We propose that this is due to the oversimplification of gravity wave representation in the model, in particular the lack of in-situ gravity was sources and the assumption that gravity waves only propagate in the vertical direction.

Recent modelling studies suggest that this region of the atmosphere is also influenced by the 11 year Solar cycle above. Future work will investigate how the Antarctic MLT responds to Solar activity, climate change, El Nino Southern Oscillation (ENSO) events etc. and how well this is represented in WACCM.

Forecasting UK Site Level Air Quality with a Kalman Filtering Approach

Rachael Duncan, PhD Student, Lancaster University

Poor air quality in the UK continues to be considered the UK's biggest environmental threat to health. Despite current efforts to reduce emissions, between 28,000 and 36,000 deaths a year are attributable to poor air quality. Identifying the importance of different drivers through characterisation of the pollutant data is necessary to be able to guide both short and long-term policies to address poor air quality. Here we use a statistical modelling approach to characterise air quality and produce short-term forecasts, using Kalman filters. This approach allows us to combine measurement information with the statistical model to obtain an air quality forecast, using the measurement information to reduce the statistical model errors and improve model results. Kalman filters are a commonly used tool in air quality modelling but are seldom used in a statistic framework that accounts for uncertainty in a principled way. We also consider some of the assumptions of Kalman filters, particularly around the assumption of normally distributed data, and whether this holds for UK air quality data and how this affects the forecasts produced. We explore this approach using air quality monitoring data from the UK Automatic Urban and Rural Network (AURN), which consists of 150 sites focussed mainly in populated areas, leaving large areas unmonitored. AURN is primarily used for compliance reporting against national and European air quality standards and targets. Eventually, our aim is to provide short-term forecasts of pollutant levels from AURN, comparing this against process model forecasts and ultimately providing an optimised combination of process model, statistical model and measurement.

The Urban Heat Island and the Influence of Climate

Sarah Berk, PhD Student, The University of East Anglia

As centres of human activity, just over half the world's population currently lives in cities and this proportion is projected to increase to 68 percent in 2050. The urban heat island (UHI) is a well observed phenomenon, where temperature in a city is warmer than the surrounding rural area. Under the high emissions scenario, the Intergovernmental Panel on Climate Change (IPCC) predicts a global average temperature rise of 2°C relative to pre-industrial levels by 2050. It is important to understand how this warming trend, projected globally, will impact the local environment of our cities and consequently the health and comfort of inhabitants. At present UHI behaviour is difficult to quantify, due to its dependency on the local climate, amongst other factors.

Focusing on two understudied areas, cities in the southern hemisphere and those with a population of less than 1 million, this research explores the relationship between the UHI effect and climate. Cities in different climate zones are selected based on similar characteristics such as population, variation of elevation within the city, and proximity to water bodies. Satellite data, with global coverage, is used to quantify the UHI of the chosen cities using an automated and generalised approach, and the characteristics examined.

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The Relative Contribution of Non-local and Local Moisture Sources To Extratropical Cyclone Precipitation

Sophie Cuckow, PhD Student, University of Reading

In the UK, flooding can lead to economic losses, damage to infrastructure and loss of life, therefore it is imperative that we understand the mechanisms behind such events in order to make accurate forecasts. Long transient corridors of high water vapour called atmospheric rivers, are often linked to flooding via the interaction with orography and the subsequent enhancement of rainfall. However, the relationship between atmospheric rivers and the synoptic-scale precipitation associated with extratropical cyclones is debated in literature. Furthermore, the relation between the synoptic scale precipitation and the microscale process which lead to enhanced precipitation is not fully understood.

In this study, we investigate the relative contribution of non-local and local moisture sources to extratropical cyclone precipitation. Using the European Centre for Medium-Range Weather Forecasts Reanalysis (ERA5) data and an objective method to track cyclones, we develop an identification diagnostic to identify non-local moisture transported by atmospheric rivers and local moisture transported by a low-level airflow, termed the feeder airstream. This diagnostic is applied to a climatology of cyclones with a range of intensities, genesis locations and durations from 1979 to 2019 over the extended winter period. Results demonstrating the contribution of non-local and local moisture sources in this climatology of cyclones will be presented.

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Evaluation of Cloud Resolving Simulations in the Arctic Focusing on Cloud Properties

Theresa Kiszler, PhD Student, University of Cologne

Ny-Ålesund is located on Svalbard which is one of the regions most affected by the accelerated warming in the Arctic region, the Arctic Amplification. Clouds play a role in several of the feedback mechanisms which contribute to this warming but there are still gaps in the understanding of their formation and development. We present findings of a synergetic approach combining high-resolution modelling and cloud observations, to study the capabilities of a model setup in Ny-Ålesund.

We setup daily high-resolution simulations in a region surrounding Ny-Ålesund using the ICON-LEM model. From these ongoing simulations, the period from August to December 2020 was used as dataset. For comparison on the observational side, microwave radiometer and ceilometer data were used. The Cloudnet algorithm which includes further measurements and categorizes clouds, based on the phase of the hydrometeors, was additionally used. Through the Passive and Active Microwave radiativeTRAnsfer tool (PAMTRA), we were able to simulate the radar reflectivity based on the model output and compare it to the cloud radar. The focus of the comparisons lay on features that are relevant for the development and evolution of clouds.

We found that although this region is challenging to simulate due to the heterogenic surface types and pronounced orographic features, the overall representation of cloud structure and occurrence was captured. Nevertheless, there were varying differences between the observed and modelled state. Looking specifically into the liquid water path and integrated water content showed that the differences between model and observations may have a synoptic wind dependency. The wind also could be seen to create standing waves when overflowing the mountains to the South-West of Ny-Ålesund. Some misrepresentations of the cloud microphysical properties in ICON-LEM lead to an underestimation of the reflectivity in certain cases.

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Facilitating Relief from Extreme Weather Events Using Deep Learning-based Remote Sensing

Thomas Chen, Student

Natural disasters ravage the world's cities, valleys, and shores on a monthly basis. Having precise and efficient mechanisms for assessing infrastructure damage is essential to channel resources and minimize the loss of life. Using a dataset that includes labeled pre- and post- disaster satellite imagery, we train multiple convolutional neural networks to assess building damage on a per-building basis. In order to investigate how to best classify building damage, we present a highly interpretable deep-learning methodology that seeks to explicitly convey the most useful information required to train an accurate classification model. We also delve into which loss functions best optimize these models. Our findings include that ordinal-cross entropy loss is the most optimal loss function to use and that including the type of disaster that caused the damage in combination with a pre- and post-disaster image best predicts the level of damage caused. Our research seeks to computationally contribute to aiding in this ongoing and growing humanitarian crisis, heightened by climate change.

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The Impact of Acute Diesel Exhaust Exposure on Executive Brain Function

Thomas Faherty, PhD Student, University of Birmingham

Research suggests that human brain health is harmed by chronic exposure to neurotoxic atmospheric pollutants, probably as a result of neuroinflammatory responses. Previous studies correlated chronic air pollution exposure to children's neurodevelopment and to neurodegeneration in the elderly, without using explicit, focussed cognitive tasks. Although vaccination studies show that acute inflammation can impact attention and social cognition a few hours after vaccination, whether exposure to air pollution could cause similar cognitive dysfunction is unknown. Using an atmospheric chamber, we exposed 81 young healthy adults to diluted diesel exhaust (or clean air) for one hour before completing a facial identification task either immediately or after a four-hour delay period. In the face task, participants made speeded identifications of the gender of a briefly presented target face in the presence of simultaneously presented distractor face (2-face trials) or a scrambled image distractor (1-face trial). Response times (RT) for 2-face trials preceded by a 2-face trial (repeat sequences) versus a 1-face trial (non-repeat sequence) were compared to index reactive attention. Poor control over reactive attention is associated with large differences is such tasks. A significant interaction between sequence type and pollution group was identified, such that reactive attention (non-repeat minus repeated sequences) was 22ms greater for the delayed-diesel compared to the delayed-clean air group, indicating that the former had less efficient adaptive cognitive control. Reactive attention was unaffected by diesel exposure when tested immediately after exposure; response accuracy was similar for all groups arguing against the possibility that speed-accuracy trade-offs could explain the results. These findings provide the first direct experimental evidence that short, city street comparable (8.89μg/m3 PM2.5; 206ppb NO2) diesel exposure can negatively impact attentional executive functioning several hours later. Finding delayed rather than immediate effects support the possibility that such effects stem from neuroimmune, rather than respiratory, responses.

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Development of an Empirical-Statistical Framework for Attributing Fire Weather Extremes to Anthropogenic Climate Change

Zhongwei Liu, PhD Researcher, Coventry University

The occurrence of large wildfire events across the world in recent years has led to greater effort to understand the extent to which climate change may be altering the frequency of fire-conducive meteorological conditions. However, to date, the relative paucity of climate change attribution studies focused on wildfire episodes, coupled with limited observational records, makes it difficult to draw solid and collective conclusions to better inform forest management strategies. The inter-study differences that emerge due to the choice of methodology and event definition are common to many attribution studies, and wildfire attribution is no exception.

Here, we present a framework for the simultaneous attribution of multiple extreme fire weather episodes of using an empirical-statistical methodology. Key to this framework is the development of a common spatiotemporal definition for extreme fire weather events. Firstly, we fit a Generalized Extreme Value (GEV) distribution, scaled by global mean surface temperature, to the annual maxima of a series of reanalysis-derived fire danger indicators. Using global maps of risk ratios and percentage changes, we quantify the influence of recent global warming on the frequency and magnitude of fire weather extremes according to a common 'event type' definition, irrespective of their spatiotemporal occurrence. We subsequently conduct a collective attribution analysis of a series of recent exceptional fire weather events. We conclude with suggestions for further application to climate model ensembles and a discussion of the potential of our findings to inform decision-makers and practitioners.

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What Would Happen if Anthropogenic Methane Emissions Ceased? Exploring a Net-Zero Methane Emissions Future in a Chemistry-Climate Model

Zosia Staniaszek, PhD Student, University of Cambridge

The Paris Agreement highlighted the importance and challenges of limiting global warming to 1.5 degrees above pre-industrial levels. Governments globally have set targets for net-zero carbon dioxide emissions, which are crucial for reducing temperature rise and other climate impacts.

Methane is the second most important greenhouse gas, in terms of radiative forcing. A large proportion of methane is from natural sources, but around 60% of the emissions result from human activity, and there are extensive opportunities for mitigation using existing technologies. Here we explore a net-zero anthropogenic methane emissions future, within the Shared Socioeconomic Pathway 3-7.0 scenario.

We use a new configuration of the UK Earth System Model with the full methane cycle represented, including methane emissions, surface deposition, chemistry and interactive wetland emissions. In a fully coupled atmosphere-ocean experiment, we removed the anthropogenic methane emissions from 2015 onwards, investigating the composition and climate response up to 2050.

Atmospheric methane levels decrease to below pre-industrial levels within 12 years. This has wide-reaching impacts on the earth system, including decreased ozone surface concentration, increased hydroxyl radical (OH) concentration and reduced global mean precipitation. By 2050, the global mean surface temperature is reduced by 0.96 ± 0.09 degrees compared to the baseline scenario, a significant value in the context of the Paris goals.

This experiment shows that atmospheric levels of methane can be rapidly reduced by curtailing emissions, with results seen on a decadal timescale. The resulting reduction in ozone would also lead to improvements in air quality and human health. A substantial proportion of future warming can be attributed to anthropogenic methane, and we show that methane mitigation provides both short-term and lasting benefits.