Early Career & Student Conference

The Met Office

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BOOK OF ABSTRACTS

CONTENTS

Decadal Predictability of Surface Variables Over Europe and Relevance for the Energy Sector

Ben Hutchins (he/him), PhD Student, University of Reading

Session 1 : Weather and Climate Predictions

The timescale of decadal climate predictions, from a year-ahead up to a decade, is an important planning horizon for stakeholders in the energy-sector. With power systems transitioning towards a greater share of variable renewable energy sources, these systems become more vulnerable to the impacts of both climate variability and climate change. As decadal predictions sample both the internal variability of the climate and the externally forced response, these forecasts can provide useful information for the upcoming decade.

There are two main ways in which decadal predictions can benefit the energy-sector. Firstly, they can be used to try to predict how a variable of interest, such as average temperature, may evolve over the coming year or decade. Secondly, a large ensemble of decadal predictions can be aggregated into a large synthetic event set to explore physically plausible extremes, such as winter wind droughts.

For decadal predictions to prove useful, however, they must demonstrate skill during the hindcast (retrospective forecast) period. As a result, the initial phase of this PhD project has involved evaluating the skill of decadal predictions for surface variables, including temperature, wind speed, solar irradiance, and mean sea level pressure. We find high skill for decadal predictions (forecast years 2-9) for temperature, wind speed and solar irradiance over the UK and Northern Europe during the boreal winter (DJFM). These decadal predictions demonstrate skill at predicting the internal variability of the climate, capturing the variability around externally forced trends. From this, we demonstrate the potential for skillful decadal predictions for the energy-sector.

Exploring Physics-Dynamics Coupling with Moist Shallow Water Models

Nell Hartney (she/her), PhD student, University of Exeter

Session 1 : Weather and Climate Predictions

The dynamical core is the name given to the part of a weather forecast model that computes solutions to the fluid equations describing the behaviour of the atmosphere. Any processes that aren't dealt with by the dynamical core are known as physics. For example, physics incudes processes that happen on scales too small to be resolved by the dynamical core, and non-fluid dynamical processes such as radiation. Physics processes have a significant effect on the overall dynamics, and so need somehow to be coupled to the dynamical core so that they can influence the solution correctly. The implementation of this physics-dynamics coupling can have a significant impact on the effectiveness of a model and there are many challenges associated with it, including how best the dynamics and physics should be advanced in time.

An ideal context to look at some of these physics-dynamics coupling questions is in a moist shallow water model. The traditional shallow water equations retain many pertinent features of the atmosphere but are simple and computationally cheap. Incorporating moisture into the shallow water equations introduces physics into the model, giving an inexpensive framework with a physics process and simple (but reasonably realistic) dynamics.

This presentation will discuss our implementation of a flexible, unifying moist shallow water model which encompasses three different approaches to moist shallow water modelling. Our implementation is in the dynamical core toolkit Gusto, which follows a compatible finite element approach like that of the next-generation UK Met Office model. We will demonstrate moist shallow water test cases in each of the three models using our unifying formulation in Gusto, and describe progress towards using our model and test cases to investigate questions about time-stepping with physics.

Seasonal Forecasting of the European North-West Shelf Seas: Limits of winter and summer sea surface temperature predictability

Jamie Atkins (he/him), PhD Student, University of Exeter

Session 1 : Weather and Climate Predictions

The European North-West shelf seas (NWS) – shallow and variable waters encompassing the North Sea, Irish Sea and Celtic Sea regions – support economic interests and provide environmental services to adjacent countries. With the expansion of offshore activities, such as renewable energy infrastructure, aquaculture, and growth of international shipping, there will be increasingly complex demands on the marine environment over the coming decades. Skilful forecasts of NWS physical properties on seasonal timescales will help to effectively manage these activities. Here we quantify the skill of an operational large-ensemble ocean-atmosphere coupled global forecasting system (namely the Met Office's "GloSea" system), as well as benchmark persistence forecasts, for predictions of NWS sea surface temperature (SST) at 2-4 months lead time in winter and summer. We identify sources of and limits to SST predictability, considering what additional skill may be available in the future. We find that GloSea NWS SST skill is generally high in winter and low in summer. GloSea outperforms simple persistence forecasts by adding information about atmospheric variability, but only to a modest extent as persistence of anomalies in the initial conditions contributes substantially to predictability. Where persistence is low – for example in seasonally stratified regions with a thin surface mixed layer – GloSea forecasts show lower skill. GloSea skill can be degraded by model deficiencies in the relatively coarse global ocean component, which lacks dynamic tides and subsequently fails to robustly represent local circulation and mixing. However, "near perfect atmosphere" tests show potential for improving predictability of currently low performing regions if atmospheric circulation forecasts can be improved. This underlines the importance of coupled atmosphere-ocean model development for NWS seasonal forecasting applications.

Wave and Wind Ensemble Forecasting with a Regional Coupled System

Vivian Fraser-Leonhardt, Industrial Placement - Regional Coupled Modelling, Met Office

Session 1 : Weather and Climate Predictions

The United Kingdom (UK), situated on the Western European continental shelf (NWS), exhibits a diverse range of ocean, atmosphere, and wave conditions. The shallow sea and complex coastline mean that the assumption of equilibrium state at the air/sea interface is not valid in this area and coupled modelling becomes important, especially as individual model components reach greater accuracy.

Recent research shows that coupling has significant impact on both atmospheric and marine forecast in the NWS, particularly during storms. In this project, we analyse winter and summer storm case studies from 2023 to assess the accuracy of the Regional Coupled Suite (RCS-UKC4) in forecasting significant wave height and wind speed over the NWS.

The RCS-UKC4 is the latest regional coupled configuration over the NWS, coupling the Unified Model (UM), NEMO and WaveWatchIII. Our findings suggest promising skills in ensemble wave forecasts with RCS-UKC4 during storms compared to current operational wave ensembles (uncoupled, coarser resolution). We show that the choice of coupling frequency influences the timing of wave growth and decay. We also investigate coupling 10-meter neutral winds instead of 10-meter winds and adjusting the wave growth parameter (Betamax).

How does the Met Office Knowledge Integration Team get Climate Science into Government?

Rebecca Sawyer (she/her), Foundation Climate Scientist, Met Office

Session 2: Applications

In order for climate science to be integrated into policy decisions made in government, the information needs to be accessible to the people who need to use it i.e. policy makers. This issue has been acknowledged by government stakeholders through the funding of the Met Office Hadley Centre Climate Programme (MOHCCP) which aims to provide government stakeholders with scientific evidence that is timely and policy-relevant. This evidence supports climate action to help avoid the worst impacts of climate change for future generations.

The Met Office Knowledge Integration (KI) team works to understand the needs of government stakeholders and exploit the science and expertise in the MOHCCP to ensure the science is useful and usable. To do this, the KI team has secondees which are integrated into government departments such as Department for Energy Security and Net Zero (DESNZ) and Department for Environment, Food and Rural Affairs (Defra). This secondee network acts as a bridge between the government and the Met Office, helping to facilitate dialogue to guide the MOHCCP and ensure maximum impact for its outputs. Secondees also help deliver teach-ins (interactive webinars) and briefings to government teams and senior civil servants on specific topic requests, with input from expert scientists across the Met Office.

In this talk, I will highlight the most successful methods for engaging and communicating climate science to policy makers I have found whilst being a secondee into DESNZ and highlight the remaining challenges. The people attending this talk will leave having a better understanding of how best to engage in the policy landscape, to make their climate science useful and usable to policy makers.

Modelling the Carbon Sequestration of the UK Afforestation Under Future Climate using JULES-RED

Hsi-Kai Chou, Research Associate, University of Exeter

Session 2: Applications

Global warming and climate change caused by greenhouse gas (GHG) emission is projected to have multiple impacts on the forest ecosystems. To mitigate these impacts, the UK Government has set a goal of net zero emissions of GHG by 2050. One core strategy is to use afforestation and forestry management to implement large-scale Greenhouse Gas Removal (GGR). However, the effectiveness of afforestation as a GGR strategy is difficult to fully evaluate with standard empirical models due to the complexities of environmental conditions under a changing climate. Alternatively, process-based land surface models (LSM), such as the Joint UK Land Environment Simulator (JULES), are increasingly being used to evaluate forest growth within a national GGR context as they are driven by environmental drivers. By coupling the Robust Ecosystem Demography (RED) model with JULES, we model the forest dynamic and carbon sequestration among a set of Representative Concentration Pathway (RCP) projections geographically across the UK up to 2080. Our results demonstrate the capability of mapping the potential GGR across the UK while also accounting for the changing environment and risks of climate change, which can provide an effective tool for national-scale afforestation evaluation toward the 2050 net-zero targets.Global warming and climate change caused by greenhouse gas (GHG) emission is projected to have multiple impacts on the forest ecosystems. To mitigate these impacts, the UK Government has set a goal of net zero emissions of GHG by 2050. One core strategy is to use afforestation and forestry management to implement large-scale Greenhouse Gas Removal (GGR). However, the effectiveness of afforestation as a GGR strategy is difficult to fully evaluate with standard empirical models due to the complexities of environmental conditions under a changing climate. Alternatively, process-based land surface models (LSM), such as the Joint UK Land Environment Simulator (JULES), are increasingly being used to evaluate forest growth within a national GGR context as they are driven by environmental drivers. By coupling the Robust Ecosystem Demography (RED) model with JULES, we model the forest dynamic and carbon sequestration among a set of Representative Concentration Pathway (RCP) projections geographically across the UK up to 2080. Our results demonstrate the capability of mapping the potential GGR across the UK while also accounting for the changing environment and risks of climate change, which can provide an effective tool for national-scale afforestation evaluation toward the 2050 net-zero targets.

Global Distribution of "Dark Doldrums"

Tabea Rahm (she/her), Doctoral Researcher, GEOMAR Helmholtz Centre for Ocean Research Kiel

Session 2: Applications

Transitioning towards renewable energy sources is a crucial step in mitigating climate change.

However, renewable power production is affected by weather variability and climate change, raising the question of how the potential for wind and solar energy might change in the future.

One of the challenges faced by power grids with a high share of renewable energies is the occurrence of "dark doldrums", i.e., periods of simultaneously low wind speeds and irradiance. These events confine the reliability and stability of renewable power production and are therefore essential for impact assessments for renewable power.

We analyse climate model output from phase 6 of the Coupled Model Intercomparison Project (CMIP6) and ERA5 reanalysis data.

CMIP6 collects global climate projections from different modelling centres following a joint experiment protocol.

The same experiments were also used by the Intergovernmental Panel on Climate Change (IPCC) for their Sixth Assessment Report.

In the first step, we investigated the present-day global occurrence of low wind speed events in ERA5 reanalysis data.

Reanalysis data is a globally complete and consistent blend of available observations and a forecasting model and is perceived as the best guess of past weather and climate.

Our initial findings indicate a seasonally and regionally different occurrence of dark doldrums.

Secondly, we evaluated a multi-model mean of historical CMIP6 simulations from 28 models against the ERA5 climatology of dark doldrums. By comparing to ERA5, we determined differences and similarities for the seasonal cycle in the regional occurrence of dark doldrums.

Our first results hint towards a systematic under-representation of the occurrence of low wind speed events in the CMIP6 multi-model mean.

Our next steps involve including anomalies in irradiance and ultimately evaluating future projections for the occurrence of dark doldrums under different climate scenarios.

An Examination of Climate Sensitive Diseases - A Case of Malaria In Ghana

Ekuwa Adade (she/her), Doctoral Researcher, Brunel University London

Session 2: Applications

In this era of climate change, diseases affected directly by weather patterns such as malaria are predicted to either increase or decrease in prevalence or be found in geographic settings where the disease may have never existed.

The National Malaria Control Program in Ghana has, since its inception, planned and implemented various strategies for the control and eradication of malaria. Amongst these, little attention has been paid to the influence of climate change on the disease's transmission and prevalence.

This study aims to analyse the impact of climate change on Malaria in Ghana by exploring datasets of climate variables (temperature, rainfall, humidity) and malaria. The data will be statistically analysed to first establish the correlation between the climate variables and malaria. This will be followed by an in-depth investigation into novel statistical models to identify predictive relationships between malaria incidence and meteorological and climatological characteristics. The ultimate aim is to make predictions about future changes in the disease prevalence in Ghana using climate projections.

Advanced knowledge of this interrelationship will be a platform that informs decisions on measures to put in place to promote policies and activities which reduce the impact of climate change on malaria.

Influence of Weather Regimes on European Winter Energy Demand and Renewable Generation

Emmanuel Rouges (he/him), Postdoctoral Research Assitant, University of Reading

Session 2: Applications

In the context of climate change, countries are increasing their proportion of renewable energy generation, such as wind and solar. The integration of renewable energy sources into the current energy network is a challenging task, as these sources are highly dependent on weather. The main challenge is to balance energy demand and supply, as both are now weather dependent.

During the winter season, cold temperatures lead to high demand. If these cold conditions coincide with periods of low winds, renewable generation becomes low at the same times as energy demand is high. These periods of high demand and low generation have gained a lot interest in the scientific literature and are defined as periods of high energy shortfall.

Recent studies have highlighted the influence of weather regimes or large-scale circulation patterns on both renewable energy generation and energy demand and shortfall.

In this research, the influence of weather regimes on energy shortfall days is investigated across 28 European countries during the winter. To this end, modelled energy data is analysed with respect to a weather regime classification.

The results show how blocking type regimes such as the Scandinavian Blocking, the Atlantic Ridge and the negative North Atlantic Oscillation, are most likely to favour periods of high shortfall. Additionally, large regions of Europe, and therefore multiple countries, are most likely to experience high shortfall during the same regime. This would suggest that multiple countries can simultaneously experience high shortfalls. In these circumstances, connection between the energy networks of multiple countries might not be sufficient to mitigate such high energy shortfall. The coldest winter (1962-1963) of the 20th century is used to highlight worst case scenarios, for which current and future energy networks need to be prepared.

Clouds and Seasonality on Terrestrial Planets with Varying Rotation Rates

Daniel A. Williams (he/him), PhD Student, University of Exeter

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Session 3: Atmospheric Dynamics

Clouds have been observed on Venus, Mars and Titan, and a growing number of exoplanets, yet the connection between planetary rotation rate and cloud distribution has not previously been extensively investigated. Using an idealised climate model incorporating seasonal forcing, we investigate the impact of rotation rate on the abundance of clouds on an Earth-like aquaplanet, and the resulting impacts upon albedo and seasonality. We show that the cloud distribution varies significantly with season, depending strongly on the rotation rate, and is well explained by the large-scale circulation and atmospheric state. Planetary albedo displays non-monotonic behaviour with rotation rate, peaking around one half of Earth's rotation rate. Clouds reduce the surface temperature and total precipitation relative to simulations without clouds at all rotation rates, and reduce the dependence of precipitation on rotation rate. Clouds also affect the amplitude and timing of seasonality, in particular by modifying the width of the Hadley cell at intermediate rotation rates. The timing of seasonal transitions varies with rotation rate; the addition of clouds further modifies this phase lag, most notably at Earth-like rotation rates. Our results may inform future characterisation of terrestrial exoplanets, in particular informing estimates of planetary rotation for non-synchronous rotators.

Exploring the Dynamics of UK Summertime Convective Storms: Insights from the Wessex Convection Experiment (WesCon) 2023

Aoife McQuaid (she/her), Industrial Placement, Met Office

Session 3: Atmospheric Dynamics

Stereotypical British summertime has bouts of sunny spells followed by torrential downpours. Surface heating can transport warm, moist air upwards where condensation releases latent heat, further lifting the air. The resulting "fair-weather" cumuli may develop into towering convective clouds called cumulonimbus: severe, localised storms associated with thunder, lightning, heavy rain, hail, strong winds and sudden temperature changes. As sub-grid phenomena, these storms are challenging for the current generation of numerical weather prediction (NWP) models to represent. Observational data to understand the processes in real convective storms is critical to better resolve convection in the next generation of NWP.

The Wessex UK Summertime Convection Experiment (WesCon) 2023 supplied detailed observations of UK summertime convective storms to determine how well they are represented and to understand the processes that drive them. For the first time, UK convective storms were targeted with coordination between aircraft (Facility for Atmospheric Airborne Measurements (FAAM) BAE-146 aircraft) and Doppler radar (Chilbolton Advanced Meteorological Radar (CAMRa)). A second aircraft, a motor glider managed by Jade Hochschule called DIMONA HK36, probed the convective boundary layer and pre-convective environment.

Here, we analyse high resolution (<5m) in-situ aircraft data to characterise the vertical velocity structure of convective storms; investigating the factors that influence radial variability from cloud edges to convective cores and potential differences amongst a population of clouds. This can be used to inform model development at 100m "urban" and 1km global scales. This work is part of a wider project, ParaChute (Parametrizing Convective [turbulence] at Hectometric [and larger] scales, and Understanding the Turbulent Environment).

Quantifying Risk of a Noise-Induced AMOC Collapse

Ruth Chapman (she/her), PhD Student, The Met Office

Session 3: Atmospheric Dynamics

The Atlantic Meridional Overturning Circulation (AMOC) exerts a major influence on global climate. There is much debate about whether the current strong AMOC may collapse as a result of anthropogenic forcing and/or natural variability. Here, we ask whether internal decadal variability could affect the likelihood of AMOC collapse. We examine natural variability of basin-scale salinities and temperatures in four CMIP6 pre-industrial runs. The variability is weak and its processes inconsistent among the CMIP6 models considered. Based on the CMIP6 variability levels we find that noise-induced AMOC collapse is unlikely in the pre-industrial climate, but plausible if external forcing has shifted the AMOC closer to a threshold. However the CMIP6 models may systematically underestimate current Atlantic Ocean variability, and we find that substantially stronger variability would increase the likelihood of noise-induced collapse. We also consider an approximation of the potential landscape for the model, and how this can inform the understanding of tipping in this system.

Tracking Mesoscale Convective Systems Over South America in Convective-Permitting Model Simulations

Harriet Gilmour (she/her), PhD Student, University of Exeter

Session 3: Atmospheric Dynamics

South America is highly vulnerable to storms and extreme precipitation. Mesoscale Convective Systems (MCSs), a prevalent storm type in tropical and subtropical South America, are particularly damaging due to their organised, deep convection that fuels heavy precipitation over wide areas. Future warming will likely bring changes to MCS characteristics and precipitation extremes across the region. However, the coarse horizontal resolution of current regional climate models fails to explicitly resolve convective processes, making any future changes uncertain. Here, cutting-edge convection-permitting regional climate model simulations over South America (SA-CPRCM), run by the UK Met Office, are used to simulate MCSs in both a present and future climate. These ten-year simulations are compared with satellite observations using a cloud tracking algorithm (tobac) to generate storm track datasets and assess differences in storm representation. Comparisons are based on storm characteristics such as track density, initiation time and seasonality. We find that the SA-CPRCM simulations resolve, and successfully capture, the structure of MCSs over South America when compared to satellite observations. The SA-CPRCM simulations perform well at capturing the spatial frequency, seasonal cycle and total accumulated precipitation of MCSs. However, the simulations produce too many storms compared with observations, and they struggle to capture nighttime initiation. Due to a lack of high-resolution observational precipitation datasets, it is hard to compare precipitation metrics. We tentatively conclude that the CPM produces MCSs with heavier rainfall than observations, but that a smaller proportion of the MCS cloud shield is raining at a given time. Here, an overview of MCSs over South America will be presented, as well as cloud tracking methods and results that compare MCSs in the SA-CPRCM simulations with satellite observations.

Idealised Modelling of Vertical Transport by Convective Overshoots in the Tropical Tropopause Layer

Charles Powell (he/him), PhD Student, University of Cambridge

Session 3: Atmospheric Dynamics

We use large-eddy simulations to study the penetration of a buoyant plume carrying a passive tracer into a stably stratified layer with constant buoyancy frequency. This simple fluid dynamical problem is relevant to many geophysical problems in both the atmosphere and ocean. An important example is the tropical upper troposphere and lower stratosphere, where convective plumes generated by strong thunderstorm complexes can penetrate through the tropical tropopause layer into the lower stratosphere. The contribution of these events to vertical transport of trace gases is not well understood. We consider the distribution of volume in buoyancy-tracer space and develop a method for objectively partitioning buoyancy-tracer space into three regions which correspond to coherent structures of the plume in physical space. Specifically, we identify a source region where undiluted plume fluid enters the stratified layer, a transport region where much of the transition from undiluted to mixed fluid occurs in the plume cap, and an accumulation region corresponding to the radially spreading intrusion. This method enables quantification of different measures of turbulence and mixing within each of the three regions, including potential energy and turbulent kinetic energy dissipation rates, an activity parameter, and the instantaneous mixing efficiency. We find that the most intense buoyancy gradients are found in a thin layer at the cap of the penetrating plume, where mixing between the plume and environment exhibits the greatest mixing efficiency. In the radially spreading intrusion that forms, turbulence is relatively weak, but a substantial volume of environmental fluid is entrained. However, the `strongest' entrainment is in the plume cap where the most buoyant environmental fluid is entrained. The quantitatively different mixing statistics within each region suggest that they should be parameterised separately in models of convective penetration events.

Evaluating Disparities in Air Pollution as a Function of Ethnicity, Deprivation and Sectoral Emissions in England

Nathan Gray (he/him), PhD Student, University of York

Session 4: Atmospheric Chemistry

The emissions of pollutants that affect health are often distributed in a way that places vulnerable groups at a disadvantage. This can lead to poorer health outcomes and propagate disparity and inequality further. To address this problem, evidence of its extent and cause is needed. Here we evaluate surface emissions of NOx and primary PM2.5 in England, and how these intersect with area deprivation and ethnicity. Lower Layer Super Output Areas (LSOAs), geographic domains containing ~1600 people, were linked to emissions by overlaying their boundaries on a 1 × 1 km grid from the National Atmospheric Emissions Inventory with emissions grouped by source. The average emissions for each were calculated as the mean emissions within the space occupied. Demographic data such as area deprivation and 2021 census data is available for LSOAs, allowing linking of emissions to demographic factors. A strong association between deprivation and emissions of NOx from all major sources was observed, with the most deprived 10% of the population experiencing more than double the average emissions of the least deprived 10%. Minoritised ethnic groups, including minoritised white groups such as Roma and Gypsy or Irish Traveller, were shown to experience higher emissions of NOx and PM2.5 than the majority "White: English, Scottish, Welsh or Northern Irish" group at all levels of deprivation. There was considerable variation in the average deprivation and emissions of the groups under umbrella categories e.g. Black, White, Asian, suggesting that these generalisations can obscure key information. The observed disparities were shown to be affected by all major source sectors, and not solely road transport. By directly quantifying contributing sources impacting on disparities, more directed interventions may be designed to address the problem.

Gas Ash-particle Separation and the Role of Aggregation in Volcanic Plumes

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Session 4: Atmospheric Chemistry

Ash ejected during an explosive volcanic eruption can pose serious hazards near and far from its origin. In the event of an explosive eruption, the aviation industry relies on ash forecasts to guide flight paths and on-ground procedures to ensure passenger safety and minimise damage to equipment and infrastructure. The eruptions of Eyjafjallajökull (2010) and Grimsvötn (2011) highlighted that operational forecasting models could not adequately quantify atmospheric ash concentrations or correctly predict ash fallout in instances of plume phase separation. A decade on, these issues remain outstanding. One reason for this developmental lag is an inadequate appreciation of small-scale processes and interactions between plume particles in numerical models, resulting in errors and uncertainties in the eruption source parameters used to initialise operational dispersion models. Of these processes, particle aggregation is commonly neglected or considerably simplified. However, many field studies have reported the presence of ash aggregates in fallout regions, and its importance in stripping fine ash from eruption clouds is widely acknowledged. This project aims to add an improved ash aggregation module to the three-dimensional plume model ATHAM and run novel simulations of well-observed explosive volcanic eruptions; integrating findings from these simulations into current one-dimensional plume models aims to improve the capabilities of operational ash forecasting models to capture, predict, and forecast the multiphase nature of volcanic plumes.

Novel Approaches to Observationally Constrain Aerosol Effects in Climate Models

Léa Prévost (she/her), PhD Student, University of Leeds

Session 4: Atmospheric Chemistry

Aerosol play a crucial role in shaping the climate. Despite their significance, aerosol are still not accurately represented in climate models due to the complexity of their microphysical interactions and the scale of their impact. This introduces uncertainty into long-term climate predictions which has endured for over 40 years and influenced global temperature estimates. The goal of my research is to address and reduce uncertainty in aerosol climate modelling. Specifically I aim to develop new methods to distinguish between structural model uncertainties (originating from choices made while building the model) and parametric uncertainties (associated with uncertain input parameters). My project will make use of perturbed-parameter ensembles (PPEs) together with extensive aerosol observations from the Global Aerosol Synthesis and Science Project (GASSP) to disentangle these uncertainties.

Has Imposing Stricter Limits on Marine Fuels Inadvertently Boosted Global Warming?

George Jordan (he/him), Foundation Scientist, Met Office

Session 4: Atmospheric Chemistry

In January 2020, the International Maritime Organization (IMO) imposed stricter rules on the sulphur content of fuels used by maritime shipping vessels to improve air quality and public health. By tightening the global limit on the maximum allowed sulphur mass content in exhaust gases from 3.5% to 0.5%, annual sulphur dioxide (SO2) emissions from shipping are estimated to have reduced by 8.5 Mt of SO2. Equating to roughly a 10% decline in annual global SO2 emissions, this reduction may have unwanted consequences on the climate. Once oxidised in the atmosphere, SO2 forms sulphate aerosol, which overall has a cooling effect on the climate and helps partially offset the warming effect of greenhouse gases. By using cleaner fuels, this offset has been weakened, effectively accelerating global warming. Here we employ a state-of-the-art Earth system model, UKESM1, to explore the climate impacts caused by the IMO 2020 shipping regulations, particularly in relation to the notable spike in sea surface temperatures observed in 2023.

Using Unsupervised Machine Learning to Understand Drought Severity in Urban Vegetation

Naya Desai (she/her), PhD Student, University of Birmingham

Session 5: AI and Statistics

Urban vegetation plays a crucial role in alleviating the impacts of climate change such as extreme heat. Trees provide shade, open green space allows advective cooling at night, and when there is sufficient water, trees and other green infrastructure provide localised cooling via evapotranspiration. This is particularly important in urban areas are more susceptible to high temperature due to the urban heat island effect, and where there is high population density. However, extreme heat is often occurs with drought and low precipitation, which negatively affects tree health and evapotranspiration rates. Thus, it is imperative to investigate the effects of drought on urban vegetation. This study presents a novel unsupervised machine learning approach to investigating drought severity on urban vegetation to support resource management. Remote sensing enables large areas of trees and green infrastructure to be surveyed rapidly in comparison to in-person ground inspections. Seven parks in London were selected for the use of this study such as Hyde Park, Regent Park, Green Park, Richmond Park, Wimbledon, Osterley Park, and Kew Gardens. These seven parks provide a spectrum of differing vegetation. Sentinel-2 monthly composites from 2018-2022 were leveraged through Google Earth Engine (GEE), and spectral vegetation indices such as Normalised Difference Vegetation Index (NDVI) and Normalised Difference Moisture Index (NDMI) were utilised to explore vegetation health. The analysis of Spearman’s correlation between the two indices showed that NDVI and NDMI were strongly correlated during drought years ($\rho = 0.93$). Applying a k-means algorithm to NDVI, NDMI, NDVI/NDMI stacked, and NDVI/NDMI merged composites suggests NDMI composites to be the optimal choice for predicting drought severity. Convolutional autoencoders and k-means were then applied to classify all monthly composites to discern severe drought months. The study built two different models, a baseline and maxpooling model, and ran NDVI and NDMI composites on them separately. The results showed that all models, except the baseline autoencoder with NDMI, were able to cluster out June and July of severe drought years. Next steps include comparing the spatial variability in drought severity with ground-based tree observations, ultimately to prioritise decisions related to tree maintenance, such as watering.

Emulation of Sub-Grid-Scale Atmospheric Turbulence in a Large Eddy Simulation Using Deep Learning

Sambit Kumar Panda (he/him), PhD Student, University of Reading

Session 5: AI and Statistics

Large Eddy Simulation (LES) is an important tool for atmospheric research, enabling computationally tractable simulations of turbulent flows. However, unresolved sub-grid scale (SGS) processes necessitate parameterization, introducing uncertainties and potentially hindering model accuracy and performance. Deep learning (DL) is emerging as a promising alternative for representing SGS processes, capturing complex relationships between the resolved flow features and SGS stresses. Our work showcases the development of such a DL based model to represent the dynamics of SGS turbulence within the LES framework.

The proposed approach leverages 3-D diagnostics data from the Met Office Natural Environment Research Council Cloud model (MONC), for idealistic atmospheric conditions over a small domain. MONC is a highly scalable, user friendly 3-D LES/cloud model, which is based on the legacy Met Office Large Eddy Model (LEM). It includes parametrizations for sub-grid turbulence, cloud microphysics and radiation. One of the key aspects of our investigation is the selection and evaluation of different DL architectures (Convolutional Neural Networks, Recurrent Neural Networks, etc.) to emulate the SGS physical parameterization, aimed at predicting the SGS tendencies, and the associated components.

We further investigate the feasibility and effectiveness of DL for SGS representation in LES, by rigorously evaluating the results against established parameterizations within MONC for varied atmospheric conditions. This data-driven approach is an initial attempt at successfully emulating the simple versions of the parameterizations, potentially leading to more efficient and adaptable DL based SGS parameterizations aimed at much more complex scenarios which could be computationally expensive for traditional methods.

Machine Learning Sub-Grid Variability to Perturb Parameterisations

Helena Reid (she/her), Modelling Scientist in Machine Learning, Stochastic Physics & Ensembles, Met Office

Session 5: AI and Statistics

Atmospheric simulations divide the world into a grid, with the grid box typically ranging in size between 100 km and 10 km for a global simulation, depending on whether it is multi-decade long climate simulation, a short 5-day weather forecast, or something in between such as a seasonal forecast. Parameterisation schemes represent unresolved processes but must work with data available to them at the grid scale. However, if we could reliably estimate properties on the sub-grid scale then there is the potential to improve parameterisations with this information.

We have developed a machine learning model to predict the covariance matrix of sub-grid temperature. Initial experiments with this model use it to add stochastic physics to an existing parameterisation scheme. We use its outputs to generate profiles of temperature which are plausibly representative of the sub-grid distribution. These plausible alternative profiles are passed as inputs to a convection scheme. Thus, at each timestep, rather than seeing the mean temperature in the grid box, the scheme effectively sees a random profile from within the box.

Data from control and experiment single column model ensembles of radiative-convective equilibrium cases so far clearly demonstrate greater inter-ensemble differences than intra-ensemble ones. More detailed analysis and experiments are underway, with the goal of experiments in a full 3D atmospheric simulation.

A Graph Neural Network Emulator for Greenhouse Gas Emissions Inference

Elena Fillola Mayoral (she/her), PhD Student, University of Bristol

Session 5: AI and Statistics

Inverse modelling systems relying on Lagrangian Particle Dispersion Models (LPDMs) are a popular way to quantify greenhouse gas emissions using atmospheric observations, providing independent evaluation of countries' self-reported emissions. For each GHG measurement, the LPDM performs backward-running simulations of particle transport in the atmosphere, calculating source-receptor relationships ("footprints"). These reflect the upwind areas where emissions would contribute to the measurement. However, the increased volume of satellite measurements from high-resolution instruments like TROPOMI cause computational bottlenecks, limiting the amount of data that can be processed for inference. Most existing approaches to speed up footprint generation revolve around interpolation, therefore still requiring expensive new runs. In this work, we present the first machine learning-driven LPDM emulator that once trained, can approximate satellite footprints using only meteorology and topography. The emulator uses Graph Neural Networks in an Encode-Process-Decode structure, similar to Google's Graphcast [1], representing latitude-longitude coordinates as nodes in a graph. We apply the model for GOSAT measurements over Brazil to emulate footprints produced by the UK Met Office's NAME LPDM, training on data for 2014 and 2015 on a domain of size approximately 1600x1200km at a resolution of 0.352x0.234 degrees. Once trained, the emulator can produce footprints for a domain of up to approximately 6500x5000km, leveraging the flexibility of GNNs. We evaluate the emulator for footprints produced across 2016 on the 6500x5000km domain size, achieving intersection-over-union scores of over 40% and normalised mean absolute errors of under 30% for simulated CH4 concentrations. As well as demonstrating the emulator as a standalone AI application, we show how to integrate it with the full GHG emissions pipeline to quantify Brazil's emissions. This method demonstrates the potential of GNNs for atmospheric dispersion applications and paves the way for large-scale near-real time emissions emulation.

[1] Remi Lam et al.,Learning skillful medium-range global weather forecasting. Science 382,1416-1421 (2023). DOI:10.1126/science.adi2336

Correlation of Wind and Precipitation Annual Aggregate Severity of European Cyclones

Toby P. Jones (he/him), PhD Student, University of Exeter

Session 5: AI and Statistics

The yearly cost of wind and flooding from European cyclones frequently reaches billions of euros. This study has investigated the correlation between wind gust and precipitation annual aggregate severity arising from extra-tropical cyclones over the Europe-Atlantic region using ERA5 reanalysis from 1980-2020.

Simple annual aggregate severity indices have been constructed by aggregating exceedances above chosen damage thresholds of wind gust speed maxima and precipitation totals for all storms in a year. At low thresholds, there is a strong positive correlation between wind and precipitation aggregate severity, likely induced by the common dependence on the total number of storms.

However, at higher thresholds, where the severity indices are expected to be a better reflection of wind and flood losses, negative correlations start to appear especially over western Europe. A correlation of -0.22 is observed between aggregate severity indices over France at thresholds of 20 m/s and 20mm. Furthermore, regions that experience positive correlation at these thresholds exhibit negative correlation values for sufficiently high thresholds.

This suggests that aggregate wind and flood losses in Europe should not be assumed to be either independent or positively correlated, and that there is a potential for risk diversification.

A framework has been developed to better understand the negative correlation occurring at high thresholds. Only the mean and variance of the severities and counts of storms are used to estimate the correlation between aggregate severities. A reduction in error occurs once the framework is modified to reflect how atmospheric conditions can lead to stormier or calmer years. The overall trend of the correlation being more positive over the ocean and closer to zero (and negative) over land is well captured by the framework.

Towards a Blended Satellite-Station Sunshine Duration Dataset for the UK

Josh Blannin (he/him), Foundation Climate Observation Scientist, Met Office

Session 6: Observations

In the UK the number of weather stations recording Sunshine Duration (SD) decreased by approximately two-thirds between 1983-2022, leading to increased SD uncertainties in the Met Office gridded SD dataset (“HadUK-Grid”).

The objective of this study is to produce a blended satellite-station SD dataset for the UK, with the aim of producing improved SD estimates. Satellite based SD estimates (SDsat) can provide daily, high-resolution, spatially-complete fields. This study uses the CM SAF SARAH-3 dataset to provide SDsat between 1983-2022. Station observations are retrieved from the Met Office’s MIDAS-Open, which contains SD from traditional Campbell-Stokes (CS) devices and more modern Kipp-Zonen (KZ) recorders.

This study initially compares SDsat with quality-controlled CS and KZ measurements to guide the identification of suspect stations which are excluded from subsequent blending. The blending procedure has two steps; first a generalised linear model (GLM) estimates station measurements from co-located SDsat, and second a Gaussian Process (GP) is trained on the GLM residuals to produce a correction field.

SDsat have a high correlation with station measurements (≈0.93), but the mean difference between SDsat and CS (0.1 hours) is slightly smaller than with KZ (0.5 hours). Therefore, a conversion is performed to map KZ to CS and produce a unified SD representative of CS measurements (CSuni). Three GLM models are trialled with different combinations of explanatory variables: SDsat only, SDsat & latitude, and SDsat & latitude & SDsat-squared. A 15-fold cross-validation found that all models have a similar root mean square error (RMSE: 1.4 hours), residual mean (μ: 0.2 hours) and residual standard deviation (σ: 1.4 hours). After training a GP on the daily GLM residuals and then revising the GLM estimates, the updated validation results showed an improvement in the blended SD estimates (RMSE: 1.2, μ: 0.0, σ: 1.2). However, improvements may be larger than this locally.

Improving Hydrological Forecasts Along The Nile: An In-depth Analysis Of The Different Satellite Precipitation Products Over Uganda For The Period 2018-2022

Douglas Mulangwa (he/him), PhD Researcher; Hydrologist, University of Reading, UK and Assessment, Directorate of Water Resources Management, Ministry of Water and Environment, Uganda

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Session 6: Observations

Globally, 70% of the most impactful natural hazards are hydrometeorological events, that disproportionately affect developing countries like Uganda. According to the World Bank, floods impacted 21.5% of the population in Uganda between 1980 and 2020. The 2019 and 2022 floods disrupted livelihood for over one million people in the country. The World Meteorological Organisation through its strategy of 'living with floods' recommends flood forecasting as a valuable way to reduce vulnerability and manage flood risk. However, functional flood forecasting systems are limited in Uganda. In the absence of functional national flood forecasting systems, global distributed hydrological forecasting systems such as the Global Flood Awareness System (GloFAS) can be harnessed to provide information on future floods which can be used to facilitate preparedness actions. While GloFAS has been successfully used to provide interim flood forecasting information over parts of Africa such as in Mozambique for the floods that happened after cyclones Kenneth and Idai in 2019, it overestimates discharge when compared with observed river discharge over Uganda. Whereas this mismatch has not been categorically attributed to any of the forcings used in GloFAS, we have embarked on investigating the source of the bias starting with comparing the ERA5 precipitation data used within GloFAS with other satellite precipitation products (CHIRPS, TAMSAT) that have been found to give good rainfall estimates over East Africa. Preliminary results show large discrepancies between ERA5 and the other precipitation products which could be driving this bias in the GloFAS reforecast. These results ascertain the need to bias correct ERA5 data to improve accuracy of GloFAS flood forecasts and thus early warning across Uganda and downstream countries such as South Sudan.

Automated Weather Impact Data Collection

Lucy Seabourne (she/her), Weather Impacts Industrial Placement, Met Office

Session 6: Observations

Impact-based Forecasts and Warnings aim to help stakeholders better understand the potential consequences of hazardous weather events, rather than simply forecasting the weather itself. This increased awareness improves the actionability of warnings produced and highlights the importance of collecting weather impact data to improve situational awareness and verify impact-based warnings. However, collecting this data manually is a laborious task and inevitably susceptible to temporal bias with fewer impact reports being recorded overnight and at weekends. For this reason, it is advantageous to collate an automated weather impact database.

At the Met Office our automated workflow involves scraping websites that reliably report global socio-economic weather impact data such as deaths, injuries and buildings damaged. Where websites report impacts from events that are not always relevant, a machine learning model is used to filter out those irrelevant reports. Tabulated statistics are extracted directly, and natural language processing is applied to extract numerical information from free text descriptions. This data is then stored in our impact database and visualized on a map displaying weather impacts globally over the past seven days.

We are currently working on producing a similar weather impact database focusing specifically on UK impacts. This database will allow us to identify affected areas on a more detailed scale, thereby enhancing the verification of UK Impact-based Forecasts and Warnings.

This talk will provide an overview of our automated impact data collection methodology and the steps we are taking to adapt this approach for collecting UK-specific impacts.

Indonesia's Extreme Rainfall: A Sub-Daily, Observational Analysis of Spatio-Temporal Patterns

Imaduddin S. Faalih (he/him), PhD Student, Newcastle University

Session 6: Observations

Indonesia has complex topography, landscapes and climate systems. This tropical country frequently faces severe natural disasters, especially those triggered by extreme rainfall events. This study aims to understand more about the spatial and temporal characteristics of extreme rainfall on sub-daily timescales. A rigorous quality control will be performed on rainfall data collected between 2015 and 2023 from 1,188 observation sites. These sites consist of 375 sites of Automatic Weather Stations (AWS), 709 sites of Automatic Rain Gauges (ARG), and 104 sites of Automated Agricultural Weather Stations (AAWS), all operated and managed by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) featuring a 10-minute observational time resolution. Several 'extreme' definitions will be tested to obtain a comprehensive perspective on sub-daily extreme events in the last 9 years of observations. The study will focus on the variability of extreme rainfall event timing, compare their typical durations, both spatially and temporally, allowing a deeper understanding on the behaviour of these extreme events.

Emerging River Flow and Hydrological Drought Trends in Great Britain

Wilson Chan (he/him), Hydroclimatologist, UK Centre for Ecology & Hydrology

Session 7 : Hazards

Hydrological drought frequency and severity is projected to increase for the UK. However, there is not yet robust observational evidence for decreasing river flows and increasing hydrological drought severity. This lack of evidence may stem from short observational records, human influences on river flows and internal climate variability. As a result, river flow trends in the past and in the near-term may be different to the trend induced by long-term climate change. This lack of congruency poses significant challenges for decision-makers faced with uncertain future projections on the one hand and an apparent lack of observed changes on the other: underscoring the need for approaches that bridge this gap. Single-Model-Initial-Condition-Large Ensembles (SMILEs) provide an ideal opportunity to reconcile past observations and future projections as they isolate the effect of internal climate variability. Here, we use the 50-member CRCM5 12km SMILE to drive GR6J catchment hydrological models for 190 catchments across Great Britain. Results show that observed trends in precipitation and river flows are within the spread of the large ensemble, which includes both robust wetting and drying trends over the historical period that could have arisen from internal climate variability. We further estimate the time of emergence for each catchment, i.e. the decade at which river flow changes exceed natural climate variability. Winter river flows increase with warming and are estimated to exceed natural climate variability before the 2050s for many catchments, with implications for flood risk. Summer river flows are estimated to reduce with warming, including hotspots in southwest Britain with an early time of emergence, exacerbating existing pressures on water resources. Autumn flows for catchments in southeast England are estimated to decrease but are not estimated to exceed natural climate variability until late 21st century. Establishing water management and adaptation strategies is crucial well in advance of catchments reaching their time of emergence (i.e. before a statistically significant trend is detectable). These results highlight the potential to use SMILEs to explore plausible alternative realisations and explore storylines of low-likelihood, high-impact hydrological extremes.

Transitions in UK Hydrological Extremes

Rachael Armitage (she/her), Hydrological Analyst, UK Centre for Ecology & Hydrology (UKCEH)

Session 7 : Hazards

Rapid transitions between droughts and floods can exacerbate the impact of the individual drought or flood events, and present a complex challenge for water resource management. Despite the potentially severe consequences of these transitions, their characteristics are not as comprehensively understood as those of the individual drought or flood events . To understand transitions in UK hydrological extremes over the historic period, we use rainfall and streamflow observations from the UK Benchmark Network (UKBN2) catchments. For investigating the transitions in the future climate, we use the enhanced future Flows and Groundwater (eFlaG) dataset based on the UKCP18 projections.

Transition events are identified by using a threshold method to extract flood and drought events in both streamflow and precipitation to evaluate both meteorological and hydrological transitions. In this study, both types of transitions are considered; wet-to-dry and dry-to-wet. Transitions in the hydrological extremes are characterised based on their magnitude, duration, intensity and frequency.

Through this work, we aim to assess the spatial distribution of transitions in the UK, with a view to being able to identify any ‘hotspots’ of transitions, over both a historical period and in future climate projections. Results from this study will be beneficial to water resource managers and decision makers, aiding them in improving preparedness for both droughts and floods.

Statistical and Deep Learning Approaches to Identifying Dry Intrusion Outflows

Owain Harris (he/him), PhD Student, University of Exeter

Session 7 : Hazards

Weather in the mid-latitude regions, which includes the UK, is largely dictated by the presence of fronts and extratropical cyclones. Often associated with these weather systems, dry intrusions (DIs) are descending airstreams originating from the upper troposphere or lower stratosphere that are linked to extreme surface conditions such as severe winds and heavy precipitation. To identify these low-level DI outflows, 3D wind field data are required at high spatial and temporal resolution to track trajectories from their origins towards the surface. This is a costly process that cannot be easily applied to climate projections, due to a lack of available necessary data. Therefore, in our changing climate, we do not currently know how these objects are likely to behave in the future. Motivated by the needs for adaptation to and mitigation of extreme weather events, this work will present an exploration of statistical and machine learning methods as alternate approaches to identifying DI outflows. Specifically, the success of logistic regression and convolutional neural network models will be compared on their ability to identify DIs from various meteorological fields, including potential temperature and relative humidity, and their ability to reproduce known DI climatologies. In addition, this presentation will discuss how new information about DIs can be derived from these models and the decisions they make, what has been learnt so far, and how this may help unlock insight on how these airflows may behave in the future.

Characterising Cold-Wet and Cold-Dry Compound Events in the United Kingdom

Kanzis Mattu (she/her), PhD Candidate, University of Strathclyde

Session 7 : Hazards

Despite a warming climate, extreme cold weather events still occur that result in costly damages and severe disruption to affected regions. Cold events impact a range of sectors from energy and agriculture to transport and health. The impacts of these cold events have been amplified by the ‘compounding’ effect of another meteorological variable, such as whether precipitation is present or not, with subsequent socio-economic impacts dependent on the nature of the cold event. For example, for road maintenance, a cold-wet event would require snow ploughs, whereas a cold-dry event would require gritters to spread salt. In this study, we define these cold events as multivariate compound cold-wet and cold-dry events. We use daily gridded observations from HadUK-Grid at a 5 km resolution to explore the frequency and spatial distribution of multivariate compound cold-wet and cold-dry events, using the UK as a case study. We use a percentile-based approach with monthly rolling percentiles for an extended winter period from October to March to produce a catalogue of cold-wet and cold-dry events from 1960-2022. The results show a clear west-east divide across the UK with a higher frequency of place-based cold-wet events in the east, and of cold-dry in the west. The Met Office’s Decider forecast tool, which characterizes 30 UK-focused weather patterns based on clustering mean sea level pressure, was then used to identify the predominant weather patterns present at the time of these compound cold events. Initial results indicate that cold-wet events in northeast Scotland are influenced by north-westerly weather patterns, whereas cold-dry events in this region are influenced by Scandinavian high weather patterns. This talk will present results showing the occurrence of observed weather patterns and establish the regimes that drive cold-wet and cold-dry events. The results of this study will produce a useful insight into compound cold events for future early warning systems and initiatives such as Early Warnings for All, with valuable information on cold weather event hazard characterisation and their associated impacts across varying timescales.

Convective Environment of Severe Hail and Tornado Producing Storms in the United Kingdom

Henry Wells (he/him), Doctoral Researcher, Loughborough University

Session 7 : Hazards

Costly impacts from severe hail and tornadoes in the UK are currently rare, but events such as the November 2023 Jersey storm demonstrate that high-end events do occur. Recent studies seek a ‘recipe’ of local convective parameters that can statistically predict the occurrence of convective hazards globally, although the most relevant parameters are known to vary regionally. Is the ‘recipe’ for severe hail or tornadoes in the UK, a ‘peripheral’ country for severe convective storms, the same or different to the USA and central Europe?

Using a combined database of UK severe hail and tornado events – radar-verified since 2004 – and a large set of convective parameters from ERA5 reanalysis, we analyse the environments producing these convective hazards in the UK. Initial results indicate that severe hail environments fall generally within the pan-European parameter space, but very large hail may occur with stronger deep layer shear and lower CAPE. We previously found that most very large hail in the UK is caused by supercells. Compared to the USA, mid-tropospheric lapse rates appear most relevant over a lower layer. Similar analysis of tornado environments is in progress, and we also intend to investigate the larger-scale flow through a preliminary analysis of Met Office weather patterns on large hail and tornado days.

In summary, the optimal local conditions for high-impact convective events appear slightly shifted in the maritime climate of the UK. Adding this variability into statistical models of convective hazards derived from global ‘hotspots’ should enable better assessments of current and future risk. Our results may also have relevance for operational forecasting of convective hazards in the UK.

Exploring the Importance of Representing Chemistry when Modelling the Atmospheric Transport and Dispersion of Volcanic SO2 using NAME

Lucy King (she/they), Earth Observation Foundation Scientist, Met Office

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Poster Board Number: 1
Theme: Atmopsheric Chemistry & Air Quality

Volcanic sulphur dioxide (SO2) and its oxidation products pose a potential hazard to public health and aviation. SO2 released by volcanoes is removed from the atmosphere by several processes, including deposition and chemical reactions. The Met Office's Numerical Atmospheric-dispersion Modelling Environment (NAME) can be used to forecast the atmospheric transport and dispersion of volcanic SO2, and thereby provides a tool to mitigate the hazards associated with these emissions. An important consideration when using NAME to model volcanic SO2 emissions is the representation of chemical reactions, particularly the oxidation of SO2 to sulphate, since this will influence the modelled concentrations. Since using the chemistry scheme significantly increases model run time, the choice of whether to use it involves a compromise between computational cost and model accuracy. It may therefore be valuable to assess the extent to which the chemistry scheme impacts model results. This has been explored here by conducting volcanic SO2 simulations with and without using the chemistry scheme and comparing the output in the form of timeseries of the masses of SO2 and sulphate. The results suggest that the impact of the chemistry scheme is highly dependent on altitude. At lower altitudes in the atmosphere, not using the chemistry scheme can result in a significant overestimate of the amount of SO2 present compared to when the chemistry scheme is used, particularly in the first few days following a release of SO2. In contrast, at higher altitudes, the chemistry scheme only begins to have a significant impact on the results of the simulation around a week or longer after the release. This poster will describe the results of this study, using case studies to explore the importance of using a chemistry scheme in atmospheric transport and dispersion models to represent oxidation of volcanic SO2 for hazard forecasting.

Large-Ensemble Simulations of Volcanic Impacts on Climate Throughout the Last 9000 Years

Magali Verkerk (she/her), PhD student, University of Exeter

Poster Board Number: 2

Theme: Atmopsheric Chemistry & Air Quality

Large explosive volcanic eruptions are one of the most important drivers of climate variability and result in global cooling. Our understanding of their impact is based either on proxy reconstructions or on climate model simulations. These two methods tend to present discrepancies, with a stronger cooling in the simulations than in the reconstructions.

To address this problem, we quantify how uncertainties on eruption source parameters, uncertainties on aerosol and climate models and natural climate variability affect the simulated surface temperature response to large eruptions for the last 9000 years. As the computational cost of full-blown Earth System models is prohibitive to quantify uncertainties for such long simulations, we use simple models instead. We first use ice-core derived estimates of Holocene volcanic stratospheric sulfur emissions and a simple aerosol model (EVA_H) to obtain volcanic aerosol optical properties and radiative forcing. This volcanic forcing and forcing from greenhouse gases, ice sheets, land use and the Sun are then used to run a simple climate model (FaIR) providing global mean surface temperatures. Thanks to the inexpensive nature of the model used, Monte Carlo simulations are used to propagate uncertainties at each step of our modelling framework.

Our results show a time averaged cooling of -0.2 ± 0.1°C over our nearly 9000-year studied time period, the volcanic induced cooling reach -2.0 ± 1.1°C for the strongest eruption in our database. Our simulations show excellent agreement with the latest tree ring-based reconstructions since 750 CE on the mean temperature response to volcanic eruptions. On a millennial scale, we obtain a good agreement with the state-of-the-art Last Glacial Maximum reanalysis.

The models we used only predict climate impacts in terms of global mean surface temperatures. The next step would be to extend their capability to predict regional scale impacts on a diverse range of climate metrics.

Simulating Martian CO2 Ice with the Unified Model

Alex McGinty (he/him), Master's student, University of Exeter

Poster Board Number: 3

Theme: Atmopsheric Chemistry & Air Quality

Mars has been a target for crewed space exploration for decades. As governmental and private enterprises increase their efforts to explore the planet, a working weather model is of paramount importance. To achieve a working weather model decades of observations from a range of rovers, orbiters and landers have been combined to develop increasingly accurate Global Circulation Models (GMCs) capable of simulating long-term climates and weather. We present an adapted version of the Met Office’s Unified Model (UM), an industry-leading Earth GCM. We are adapting the UM to the Martian atmosphere by including the key processes driving the Martian weather. Firstly, Mars has an eccentric orbit when compared to other solar system planets (e~0.093, compared to Earths~0.017) this leads to yearly pressure fluctuations (up to 20%) caused by differential freezing/sublimination rates of CO2 ice in the polar regions. Similar GCMs prescribe this pressure variation throughout the year, but this does not allow for the model to dynamically portray localised pressure variations, which in turn leads to less accurate models. We include an updated prognostic CO2 ice scheme to calculate formation rates and the corresponding atmospheric mass changes. We show how capturing the change in atmospheric CO2 mass improves our representation of Mars’ climate – through better representation of surface pressure patterns and thus the surface winds. In our poster, we show how capturing this change in atmospheric CO2 mass improves our representation of Mars’ climate. This work is a crucial step in accurately simulating a Martian climate and weather predictions using GCMs.

Key words: Polar, Modelling, Land Surface, Climate Science

Accurate Modelling of CMIP6 ESM Carbon Cycles

Alex Romero Prieto (he/him), PhD Student, University of Leeds

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Poster Board Number: 4

Theme: Atmopsheric Chemistry & Air Quality

Accurate simulation of climate dynamics is essential to develop effective mitigation and adaptation strategies to avoid the worst impacts of climate change. State-of-the-art Earth System Models (ESM) stand as our best computational representation of the climate system. Yet, they are too resource-intensive to be run for every single research question. Simple Climate Models (SCM) aim to solve this problem by offering fast simulations while retaining accuracy in their results. This is usually achieved via a substitution of explicit process simulations with simpler parameterised versions. The new parameters are then calibrated to emulate output from ESMs. A particular area of interest in current climate modelling research is the land carbon cycle, which has been identified as an important source of uncertainty in future atmospheric CO2 concentrations. Indeed, discrepancies

in CO2 atmospheric concentration between ESMs have been attributed to a large extent to differences in their land carbon uptake. In this study, we present an efficient simple carbon cycle model that is able to accurately emulate the behaviour of carbon cycles from twelve ESMs in one-percent-CO2-compound-increase scenarios. We will discuss the simple carbon cycle model itself, as well as its calibration and future plans to integrate it with FaIR, a simple climate model. This integration brings two main benefits. First, it will enable FaIR to produce future climate projections with a higher level of detail, providing a series of carbon-cycle relevant properties. Additionally, it is also expected to improve the flexibility and accuracy of the model.

A Scale-Aware Method for Parametrizing Dispersion by Unresolved Motions in the Atmopshere

Vibha Selvaratnam, PhD student/Atmospheric Dispersion Scientist, The Met Office

Poster Board Number: 5

Theme: Atmopsheric Chemistry & Air Quality

Atmospheric dispersion models employed for regional and global transport typically rely on meteorological data from Numerical Weather Prediction (NWP) forecast models, usually archived at intervals ranging from 1 to 12 hours. Nevertheless, the atmosphere experiences high-frequency variability due to mesoscale and microscale flows, including orographic flows, sea breezes, frontal circulations, boundary layer turbulence and moist convection. These processes generate rapid changes in wind speed, direction, cloud formation, and rainfall, which may not be adequately captured in archived meteorological data due to the coarse temporal and spatial resolutions of NWP output, but still play a large role in atmospheric dispersion. To circumvent the challenge of generating and storing extensive NWP output, an alternative approach involves representing transport processes occurring at unresolved temporal and spatial scales within the dispersion model itself. The influence of sub-grid processes on the larger scale can be statistically accounted for in dispersion model parameterizations. It is important that these parameterizations cover the correct scales of motion such that all scales are represented through either parameterization or the NWP data, but that no motions are both resolved and parameterized.

A spectral analysis method is used to compare NWP data with boundary layer observations to determine the scales of motion unresolved in the NWP data. Velocity variances and Lagrangian timescales of the unresolved motions are calculated and the relationship between these parameters and the spatial and temporal resolution of the NWP model is investigated. These parameters can then be used to inform the parameterizations for the unresolved motions in the UK Met Office’s operation dispersion model, NAME (Numerical Atmospheric-dispersion Modelling Environment).

Novel Approaches to Observationally Constrain Aerosol Effects in Climate Models

Léa Prévost (she/her), PhD student, University of Leeds

Poster Board Number: 6

Theme: Atmopsheric Chemistry & Air Quality

Aerosol play a crucial role in shaping the climate. Despite their significance, aerosol are still not accurately represented in climate models due to the complexity of their microphysical interactions and the scale of their impact. This introduces uncertainty into long-term climate predictions which has endured for over 40 years and influenced global temperature estimates. The goal of my research is to address and reduce uncertainty in aerosol climate modelling. Specifically I aim to develop new methods to distinguish between structural model uncertainties (originating from choices made while building the model) and parametric uncertainties (associated with uncertain input parameters). My project will make use of perturbed-parameter ensembles (PPEs) together with extensive aerosol observations from the Global Aerosol Synthesis and Science Project (GASSP) to disentangle these uncertainties.

Evaluating Ensemble Forecasts of Atmospheric Dispersion Events

Ben Joyce, Atmospheric Dispersion Scientist Placement, The Met Office

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Poster Board Number: 7

Theme: Atmopsheric Chemistry & Air Quality

With the increasing adoption of ensemble forecasting within the Met Office, evaluating the performance of probabilistic forecasts derived from ensembles has become of fundamental interest. This study, which is a part of my industrial placement at the Met Office, focuses on assessing the accuracy of probabilistic forecasts generated by the Met Office's 'Numerical Atmospheric Dispersion Modelling Environment' (NAME) for large SO2 dispersion events, using comparisons with TROPOMI satellite retrievals.

We have made utilised metrics such as the Brier Skill Score, Rank Probability Skill Score and Fractions Skill Score, and more diagnostic graphical representations of performance, such as Reliability Diagrams and Verification Rank Histograms. Our findings indicate that probabilistic forecasts drawn from true ensembles consistently outperform than those derived from spatial neighbourhoods. However, these forecasts still experience intrinsic issues that must be addressed, particularly in forecasting high event probabilities at greater lead times of dispersion events, due to increasing spatial uncertainty.

Future research within this project (and beyond my tenure at the Met Office) will focus on developing neighbourhood processing techniques to help account for spatial uncertainty and enhance the reliability of these probabilistic forecasts. By addressing these highlighted challenges, we aim to increase effectiveness of ensemble-based forecasting for atmospheric dispersion events.

Keywords: forecasting, dispersion, ensembles, model evaluation, satellite retrievals

Key-theme: Ensemble forecasting evaluation

Multidecadal Atmospheric Circulation Trends and Their Drivers

Melissa Seabrook, Scientist, The Met Office

Poster Board Number: 8

Theme: Atmopsheric Dynamics

Recently several long-term atmospheric circulation trends have been identified but their drivers, impacts on extreme weather events, and representation in climate models are still poorly understood. One potential driver of atmospheric circulation is Pacific sea surface temperature variability, where in recent decades there has been a cooling trend in the east and a warming trend in the west Pacific and a strengthening of the Walker circulation. However, climate models struggle to capture this pattern and understanding why is critically important for reducing uncertainties in future projections.

By using large ensembles of single forcing experiments, driven by changes only in a single forcing while all other forcings are held at pre-industrial values, we assess the causal influence of external forcings, both natural and anthropogenic, on historical trends. We begin by looking at the atmospheric response of the Aleutian Low, and how this differs between models and across experiments with different forcings. We also find surprising non-additivity between different forcing experiments of key quantities including the Aleutian Low and North Atlantic Oscillation and aim to explain why these occur.

Tipping Mechanisms in a Conceptual Model of the Atlantic Meridional Overturning Circulation

Ruth Chapman (she/her), PhD student, The Met Office

Poster Board Number: 9
Theme: Atmopsheric Dynamics

The Atlantic Meridional Overturning Circulation (AMOC) forms an essential component of the global ocean circulation. Paleo-climate records indicate the AMOC's capability to tip between different states that resulted in large global climate impacts. Using an AMOC box-model, re-calibrated against a Global Circulation Model, HadGEM3, we present a new bifurcation analysis and showcase mechanisms that may lead the AMOC to tip from its current `on' state to a collapsed `off' state under climate change. We find that bifurcation- and noise-induced tipping remain viable tipping mechanisms as in previous calibrations, while rate-induced tipping only occurs for specific parameter configurations of this model.

Interactions Between Arctic Cyclones and Sea Ice in Summer

Xueqing Ling, PhD Student, University of Reading

Poster Board Number: 10

Theme: Atmopsheric Dynamics

Sea ice cover in the Arctic has reduced significantly during summer over the past few decades, leading to the opening up of Arctic shipping routes. Sea ice and cyclone are two most important phenomenon in Arctic region. However, the prediction of cyclone, which plays an important role in shipping safety, still has room for improvement. Cyclones interact with the underlying sea ice leading to potential modification of the sea ice through advection and melting as well as modification of the cyclone through changes in the fluxes of heat, moisture and momentum into the atmospheric boundary layer from the sea surface. Therefore, further understanding of the interaction between sea ice and the structure and lifecycle of cyclones in the Arctic region is crucial to improving forecasts. In this presentation a case study, the third cyclone observed in summertime Arctic cyclones field campaign in 2022, is discussed, to find out the relationship between the structure and characteristics of the cyclone and surface heat fluxes. Cyclone3 lasted 13 days and travelled from Greenland Sea, across the North Pole, to the Laptev Sea before returning to the Greenland sector. Because of its long lifetime and moving track, we can find its property changes with different type sea ice cover. Ensemble forecasts from ECWMF are used to analyse the sensitivity of cyclone to the sea ice heat fluxes, to understand how the prediction of cyclone evolution, including the track and intensity of the cyclone, changes above the sea ice.

Equatorial Waves in Global Kilometre-Scale Model Simulations

Elliot McKinnon-Gray, PhD Student, University of Reading

Poster Board Number: 11

Theme: Atmopsheric Dynamics

Equatorial waves coupled with deep convection are modes of variability that propagate along the equatorial waveguide and contribute a significant amount of variability in winds, precipitation and energy fluxes in the tropical region. Despite their impact on the weather in the tropics, they are poorly simulated in current NWP systems, and the performance of forecasts in the tropics as a whole suffers partially as a result of poorly represented equatorial waves. A well-known reason for comparatively poor forecasting in the tropics is because of the parameterisation of convection in current NWP systems. The use of a high-resolution convection-permitting model should allow for better simulation of convectively coupled equatorial waves, and by extension, the tropics as a whole. The 3D structure and propagation characteristics of equatorial waves are evaluated in a suite of convection-permitting simulations and compared to current operational convection-parameterising simulations. This will allow for the elucidation of the gains made by using a global convection-permitting NWP model, and provide a rationale for its use in the tropics. Preliminary results show that these high-resolution models are able to simulate the propagation characteristics of equatorial waves and their long lifetime compared to the current predictability horizon in the tropics. If the findings are robust, then the use of convection-permitting models in the tropics and understanding of equatorial waves can be a source of extended predictability in this region, which may in turn improve predictability of weather in other latitude regions. Future work will investigate further the energetics of the tropics in convection-permitting simulations, and the spread of realisations achievable through the use of a global convection-permitting ensemble.

Serial Clustering of Cyclonic Windstorms Over Europe on Intra-Seasonal Timescales

Sophie Feltz (she/her), PhD student, University of Birmingham

Poster Board Number: 12
Theme: Atmopsheric Dynamics

Extreme mid-latitude winter windstorms cause environmental damage and economic loss over

Europe. These impacts are magnified when windstorms cluster in time (seriality), where the occurrence of multiple storms over a fixed location occur in quick succession in a given

timespan. To understand in more detail the sources and occurrences of serial clustering, however, spatial clustering analysis in combination with time-clustering can form a new

perspective on our understanding of main drivers of clustering on different time scales. Here, employing the wind-based tracking algorithm WiTRACK (Leckebusch et al., 2008), impact

relevant storm footprints are detected for the core winter season (DJF), in the period 1981-2016 from ERA5 reanalysis.

To quantify the magnitude of clustering we use the well-established dispersion statistic from Mailier et al. (2006). Serial clustering on 45- and 30-day timescales has been analysed.

Crucially shorter reference periods of 30-, 20-, 15- and 11-days of the time development of clustering are also examined. While our findings suggest greater clustering in the latter half of the winter season on 45- and 30-day timescales, temporal variability within this is recognised. Preliminary findings suggest further 2 distinct peaks of increased clustering on shorter timescales (<30 days) at the middle and end of the core winter season depending on location.

Investigating the Eddy Feedback Processes Between Zonal Wind and Wave Sources Using an Idealised Model

Charles Turrell (he/him), Postgraduate Researcher, University of Exeter

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Poster Board Number: 13

Theme: Atmopsheric Dynamics

Rising temperatures due to increased CO_2 concentrations are likely to increase the equator-to-pole temperature gradient in the upper troposphere and decrease it in the lower troposphere, causing the jet streams to shift from their natural positions. It is uncertain whether these jet shifts will be equatorward due to rapid polar warming, or if the shift will be poleward due to the rise of temperatures around the equator and tropics.

Recent studies on the response of the eddy-driven jet streams to polar warming have shown a link between the amount of equatorward shift seen in a given model, and the strength of the ’eddy feedback parameter’ (Smith et al. 2022; Screen et al. 2022). In these studies, the eddy feedback parameter (EFP) is defined to be the correlation between zonal-mean zonal wind and the divergence of the northward component of the Eliassen-Palm flux, in an effort to assess the eddy feedback processes between the jet stream winds and the sources of energy that are driving them.

Despite the apparent usefulness of the EFP, understanding the processes that determine its strength is a challenge. In this work we delve deeper into the processes that determine the strength of this feedback. Starting with various reanalyses data, we explore whether certain formulations are representative, or advantageous, over the original quantity, and how these formulations differ. Furthermore, we find supporting evidence of the observed eddy feedback parameter being sensitive to the chosen time domain of the reanalysis data.

In addition to the data analysis part of the study, we have explored the EFP in simulations with an idealised model (Isca), using the Polvani-Kushner setup (Polvani and Kushner 2002), in order to further understand the connections between the EFP and previous theoretical work on eddy feedbacks. We have investigated which components are important in the EFP, and whether disregarding time-lagged relationships is characteristic of eddy feedback processes.

RMetS Royal Meteorological Society
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A Source of Clear-Air Turbulence? Tracking gravity wave formation in inertially unstable regions.

Timothy Banyard (any/all), Postdoctoral Research Associate, University of Manchester

Poster Board Number: 14

Theme: Atmopsheric Dynamics

Turbulence was responsible for 71% of all weather-related aviation accidents and incidents in the US between 2000–2011 [1], leading to structural damage, injuries and US$200 million in unforeseen costs for airlines each year [2]. With only 14% of turbulence encounters being attributable to convection [3], clear-air turbulence (CAT) is a leading cause of these encounters and thus poses a major risk to travellers. A variety of dynamical mechanisms can be responsible for CAT, including shear instabilities, inertial instabilities and gravity waves; however, differentiating between the distinct roles of each mechanism when more than one is present remains difficult. In fact, it is the precise evolution of these atmospheric instabilities and waves, and their potential for generating CAT, which remain uncertain in our current scientific understanding.

In this study, investigate the relationship between CAT and gravity waves, with a specific focus on tracking the formation of these waves around regions of inertial instability. Previously, [4] showed the emission of inertia–gravity waves following the release of inertial instability using idealised model simulations. Here, we use the WRF model to consider some real-world examples of where regions of low potential vorticity (PV) in the vicinity of the jet stream are associated with inertia–gravity waves. We track the waves as they propagate and investigate whether the causal link found by Thompson and Schultz can be observed in more realistic simulations.

We present results from several case studies exhibiting this behaviour, identifying the sources of the gravity waves observed in simulations. The characteristics of these waves will be compared to those in the idealised model simulations, and gravity-wave parameters will be calculated. Finally, we widen our analysis by examining the broader upstream pattern that contributes to the development of the initial inertial instabilities and explore the different regimes under which these phenomena occur.

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Minimal Moisture Models in Convective Penetration of a Stably Stratified Layer

Charles Powell (he/him), PhD Student, University of Cambridge

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Poster Board Number: 15

Theme: Atmopsheric Dynamics

In the tropical upper troposphere and lower stratosphere, convective plumes generated by strong thunderstorm complexes can penetrate through the tropical tropopause layer into the lower stratosphere. Tropospheric air predominantly enters the stratosphere in the tropics, thereby largely setting stratospheric composition. There is an ongoing debate on the importance of convective penetration in this transport, particularly with respect to water vapour. Numerical simulations of convective penetration events have been performed using realistic and complex meteorological models containing many physical processes, but these are computationally expensive and challenging to interpret. We attempt to gain insight into this process by considering a simple fluid dynamical problem representative of the environment, in which a region of strong stable stratification is penetrated by a turbulent buoyant plume generated in a region with weak or zero stratification. The stable layer is also subject to large-scale shear and we neglect latent heating effects. We present results from a minimal moisture scheme which captures the aspects of moist convection that are thought to be essential to the irreversible transport of water vapour. We consider the fast autocondensation limit in which two moisture species exist, represented a condensate and vapour tracer. Moisture is converted between species via condensation and sublimation, in the limit where these processes are fast relative to the dynamics. The condensate tracer is further subject to sedimentation. We consider 9 simulations in which the effects of condensation/sublimation, sedimentation, and shear are each strong, weak and small. We compare the final hydration profile of the stable layer in each simulation and use a buoyancy-tracer volume distribution to analyse the mixing processes in each regime.

Effect of Seasonal Drivers on the Life Cycle of Boreal Summer Intra-seasonal Oscillation (BSISO)

Indrakshi Mukherjee, PhD Student, University of Reading

Poster Board Number: 16
Theme: Atmopsheric Dynamics

The Asian summer monsoon is a major part of the hydrological cycle and directly impacts one third of the global population. Accurate prediction of monsoon rainfall has great socio-economic importance since it has a critical influence on agricultural planning, water management and irrigation, ecosystems and on human health.

Monsoon precipitation shows large-scale variations on a range of spatial and temporal scales, presenting a huge challenge for sub-seasonal to seasonal (S2S) prediction. Active and break phases of the monsoon, which represent the extremes of intra-seasonal variability broadly occur with a period of 30-60 days. S2S prediction has been considered a ‘desert of predictability’ for a long time, since it falls at a time range that is too long to be influenced purely by initial conditions and too short to be influenced only by slowly-varying lower boundary conditions. The boreal summer intra-seasonal oscillation (BSISO) is known to provide some predictability at the S2S scale, but skillful prediction of BSISO in operational models is limited to 10-15 days. The current state of prediction indicates difficulty in simulating precipitation patterns associated with the BSISO, and the amplitude of the BSISO is underestimated with increasing lead time.

This study is part of a project that will explore ways in which S2S prediction skill can be improved and if the prediction of monsoon intra-seasonal variability can be extended to one-month lead time. S2S prediction has a strong dependence on the background mean state. Our aim here is to investigate how slowly varying seasonally persisting components such as the El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Quasi-Biennial Oscillation (QBO) will modulate the background seasonal mean state through which the BSISO propagates. It will also assess how the spatial patterns and amplitude of the BSISO change under different phases of ENSO, IOD and QBO.

Keywords: monsoon, sub-seasonal to seasonal (S2S), boreal summer intra-seasonal oscillation (BSISO), El Niño-Southern Oscillation (ENSO)

Key theme: sub-seasonal to seasonal (S2S) prediction

An Idealised Model of Martian Polar Vortex Dynamics

Stephen Hughes (he/him), PhD student, University of Exeter

Poster Board Number: 17

Theme: Atmopsheric Dynamics

The time averaged winter polar vortex on Mars has been found to have an annular structure, with a potential vorticity (PV) local minimum at the pole and a surrounding region of higher PV. By contrast, Earth’s polar vortex has PV increasing monotonically towards the pole. The annular structure is barotropically unstable and thought to be maintained by latent heat release from CO_2 condensation, which as the main constituent of Mars’s atmosphere has a much larger effect than any latent heat released by H_2O condensation on Earth. Studies show that instantaneously, Mars’s polar vortex can have a patchy structure with regions of higher and lower PV within the annulus. This patchiness may have important implications for the transport of dust and trace gases within Mars’s atmosphere.

Here we present an analysis of the PV structure of Mars’s polar vortices using reanalysis data and numerical modelling of the moist shallow water equations. Comparisons are made between two reanalysis data sets and corresponding model simulations to investigate the prevalence of instantaneous anomalous patches of PV within the polar vortex. Moist shallow water modelling is implemented in Gusto, a finite element model with adaptive resolution, allowing fine-scale features to be resolved. We investigate how differing implementations of latent heating can affect the vortex structure and dynamics, with a focus on how spatially varying latent heat release can affect vortex patchiness. Eddy enstrophy is used as a measure of vortex patchiness, to quantify comparisons between different data. The implications of vortex patchiness are discussed in relation to the transport of dust to polar regions, contributing to the polar layered deposits.

Developing and Evaluating Cyclone Tracking Algorithms to Detect and Track Polar Lows

Alice Miller (she/her), Deployable Project Scientist, The Met Office

Poster Board Number: 18

Theme: Atmopsheric Dynamics

Polar lows are short-lived, intense mesoscale low-pressure systems that occur over the oceans at high latitudes, in regions adjacent to sea ice and cold landmasses. They develop rapidly, bringing hazardous weather conditions including strong winds and heavy precipitation to coastal communities and those operating offshore. Their small size and short lifespans make forecasting polar lows particularly challenging. Inconsistent identification criteria and a lack of observational data also hinder research in this area. However, having an ability to forecast them is crucial for keeping Arctic users safe, particularly as the reduction in sea ice due to climate change will likely result in an increase in marine activity.

This study investigates the skill of two cyclone tracking algorithms, TRACK and TempestExtremes, at detecting and tracking polar lows in the Barents and Norwegian Seas. While TRACK uses spectrally filtered vorticity to detect cyclones, TempestExtremes uses sea level pressure. Both algorithms are run using Met Office operational forecast data across a selection of dates and case studies, with a variety of polar low identification criteria applied. Outputs from the algorithms are compared to one another and statistically with tracks observed via satellite imagery.

This research will contribute to the development of a demonstrable forecast tool for key stakeholders, allowing them to view polar low tracks and associated hazardous weather, and make optimal operational decisions.

Investigation of Graupel Hydrometeor Spatial and Temporal Size Distribution in Deep Convective Cloud

Ezri Alkilani-Brown (she/they), PhD student, The Met Office

Poster Board Number: 19

Theme: Atmopsheric Dynamics

Omnipresent, cloud feedback contributes the largest uncertainty in equilibrium climate sensitivity forecasts. Alongside the implications for radiation and precipitation, the fiend that troubles numerical weather prediction is the sub-scale microphysics, which controls the extent and behaviour of clouds, but cannot be explicitly represented. Instead, practical cloud microphysics schemes that parameterise cloud processes are implemented into models; bulk microphysics is quickly becoming commonplace in forecasts, as seen with the Cloud Aerosol Interaction Microphysics (CASIM) being added to the Unified Model. Nonetheless, despite the advances in cloud representation, mixed phase and ice processes have been notoriously challenging to constrain, especially for individual hydrometeors. Alongside this, convection has been a longstanding problem in modelling, due to its sporadic nature and small-scale processes such as turbulence, mixing and entrainment, but is likewise extremely important in cloud formation. Couple these things together, and you have the basis of the The Deep Convective Microphysics Experiment (DCMEX); a culmination of ground based and flight observations, investigating deep convective clouds over the Magdalena Mountains in New Mexico. From DCMEX in-situ observations of ice crystal images, and exploring machine learning techniques, this project aims to investigate ice processes in deep convective clouds, focusing on the graupel hydrometeor. Results from this investigation, via the categorisation and clustering of ice crystal images with other simultaneous measurements will aid to address underlying uncertainties in CASIM, such as the spatial and temporal particle size distribution of graupel.

Results from a Climatology of Large-Scale Atmospheric Gravity Waves

Peter Berthelemy (he/him), PhD Student, University of Bath

Poster Board Number: 20
Theme: Atmopsheric Dynamics

Atmospheric gravity waves are one of the main drivers of vertical energy & momentum transport through the atmosphere, yet are still often under-represented in global climate models. This poster will present the main findings of a new method for detecting large scale gravity waves, and will compare these findings to those from older methods of gravity wave detection. These results can then be used to better parameterise gravity waves in GCMs.

Study of Extreme Precipitation Events Characteristics in West Java Indonesia

Yan Firdaus Permadhi, PhD Student/Climatologist, University of Exeter

Poster Board Number: 21
Theme: Hazards

Climate change is causing a significant increase in extreme precipitation events in Indonesia, making the country more vulnerable to hydrometeorological disasters. Rainfall patterns are changing, with dry seasons lasting longer and wet seasons becoming shorter and more intense. Moreover, there has been an increase in extreme rainfall in certain areas of Indonesia. This is also explained in the report of the World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC) on the impact of climate change on extreme events.

To deal with climate change, it is crucial to understand past climate states and apply the knowledge gained about patterns, spatiotemporal distributions, and the relationship to atmospheric events to climate change adaptation and mitigation action plans. Hence, to minimize the adverse impacts of climate change, adequate preparedness and planning, along with research to respond to climate variability and change, are necessary.

In this contribution, we will present the statistical factors of extreme rainfall, as well as their spatiotemporal distribution, using Generalized Extreme Value (GEV) analysis.

We will use precipitation data from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) from 1991 to 2020 that incorporates 0.05o resolution satellite information with station observations. Relevant indices from the Expert Team on Climate Change Detection and Indices standard will also be presented for the wet season period of December–January–February (DJF) calculated from the CHIRPS data to investigate the frequency of extreme precipitation events across West Java and present them as spatial and temporal patterns of extreme precipitation.

Future work will use the UNprecedented Simulated Extremes using ENsembles (UNSEEN) approach to examine the risk of unprecedented rainfall events in the current climate and the large-scale drivers of such events. For the UNSEEN approach, we will use precipitation data from either the Decadal Prediction System or the GloSea5 global seasonal forecasting system.

A Multi - Hazard Risk Assessment for RemoteTransport Infrastructure Exposed to Precipitation Induced Hazards Under Future Climate Projections

Rachel Doley (she/her), PhD Student, University of Birmingham

Poster Board Number: 22

Theme: Hazards

Climate change is increasing the frequency and magnitude of extreme rainfall in the United Kingdom. This causes concern when considering the role of extreme precipitation in triggering both hydrometeorological and geophysical hazards. Of particular concern are multi–hazards, which are hazard events that occur in proximity to; or interacting with one another. These have the potential to destroy and impede critical infrastructure systems, such as transportation. Many transport systems within the United Kingdom are exposed to both flooding and land sliding events. A key example of this being Rest and Be Thankful, a mountain pass in the Scottish Highlands which has recorded over 70 landslide events since 2003. This has led to recurrent road closures costing around £80,000 per day. As our climate warms and extreme precipitation increase in frequency and magnitude, it follows that these events will become more frequent. This project is considering the risk of multi-hazard events triggered by extreme precipitation in order to improve infrastructure resilience in the Scottish Highlands. It is utilising computer modelling and Geographical Information Systems to recreate past hazardous events, explore potential future scenarios, and better understand the risks multi-hazard events pose to transportation in this area. This work seeks to model the areas in which land sliding will occur and the extent to which these landslides will spread. Additionally, analysis of rainfall will determine how these geomorphic events have changed flood regimes of this region. Early results indicate that under future projections land sliding and flooding in this region is to become more common and extreme, further worsening the risks posed to transportation.

Quantify the Drivers of Humid Heat Extremes over Africa

Jack Law (he/they), PhD student, University of Leeds

Poster Board Number: 23
Theme: Hazards

Extreme humid heat events pose a significant health threat to humans through heat stress brought on by sweating becoming inefficient at high humidity level. In Africa, the Western Sahel and East African coastal plains are especially susceptible to these events, experiencing the highest wet-bulb temperatures on the continent. However, there is very little understanding of the dynamical drivers of humid heat events. Africa has a limited ground observational network, therefore, satellite retrievals are an opportunity to quantify the key characteristics and drivers. Here, we use Clouds and the Earth's Radiant Energy System to quantify the surface radiative balance and Moderate Resolution Imaging Spectroradiometer to quantify the radiative effects of clouds and aerosols. We also use both Atmospheric Infrared Sounder and Advanced Microwave Sounding Unit onboard the Aqua satellite to measure precipitable water vapour and Integrated Multi-satellite Retrievals for Global Precipitation Measurement for precipitation. These retrievals are combined to characterise the combined role of clouds, water vapour, rainfall and aerosols in water and energy budget a sub-daily timescale prior to and during extreme humid heat events, so as to understand the operating thermodynamics. The results bear importance in risk management and adaptation measures such as the development of early warning systems as the population is expected to rise rapidly in Africa and climate change will worsen heat extremes.

Seeing Extreme Winds: Video innovation for precise extreme wind assessment

Sai Kulkarni (she/her), Doctoral Researcher (first year), Loughborough University

Poster Board Number: 24

Theme: Hazards

This study addresses the need for precise, localized wind velocity measurement, particularly in the insurance industry, where understanding and managing losses due to extreme winds is paramount. Windstorms, while resulting in relatively few casualties, stand out as the costliest type of natural disaster in north-west Europe. Achieving dense and comprehensive coverage with traditional instrumentation for wind velocity data collection is costly, and has logistical hurdles, posing challenges, especially in urban areas.To overcome this challenge and improve hazard estimation for industrial and commercial property owners, we propose using the innovative concept of 'Seeing the Wind' (Cardona et al. 2019). This approach harnesses short video clips of trees as proxy indicators for wind speed, eliminating the need for specialized equipment like anemometers, to create high-resolution wind hazard maps.To test this approach to creating a localized understanding of wind hazards, a pilot study was conducted at a domestic property comprising 147 video clips (3 to 20 seconds long) captured on a mobile phone. The videos analyzed showed a pear tree and two cup anemometers (mounted at 0.8m and 1.6m) each beside a chequered flag. The chequered flags are a common test in machine vision approaches, the anemometers allow comparison with actual wind speeds, and the combination may allow for correlation between the methods to be assessed. This study aims to systematically evaluate the effectiveness of various methods for wind velocity estimation from the video source, assess the accuracy of the estimates, and explore the potential limitations of this video-based wind velocity estimation method.The findings of this study will pave the way for a site-scale study at Loughborough University, where our wind speed estimates will be integrated with campus weather station data for accurate downscaling. Insurers can utilize the resulting precise wind hazard maps to adjust parameters more closely aligned with the actual risk.

An Early Warning System for Humid Heat Extremes Over the Maritime Continent

Anistia M. Hidayat (she/her), PhD student, University of Leeds

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Poster Board Number: 25
Theme: Hazards

The World Meteorological Organization (WMO) has confirmed that 2023 stands as the warmest year ever recorded worldwide. Moreover, heat stress over the Maritime Continent (MC) is increasing in frequency, duration, and intensity, particularly evident in the increase of wet-bulb temperatures compared to dry-bulb temperatures. While extensive research exists on the factors contributing to heatwaves in midlatitude regions, there is a significant lack of studies addressing this phenomenon over MC, especially for humid heat. This underscores the critical need to determine its atmospheric drivers and develop early warning systems for heatwaves in this region. Initially, the focus is on the April to May 2023 heatwave events, during which cases of heat-related deaths was reported in Malaysia. A 10-year, pan-MC Met Office Unified Model, convective-scale simulation accurately captures moist processes is used to statistically evaluate the factors contributing to humid heatwaves. Processes at the synoptic, regional, and local scale are investigated. Results will eventually be used to explore the potential for a humid heat early warning system.

Weather Patterns and Antecedent Conditions Driving Extreme Floods in UK Benchmark Catchments

Emma Ford (she/her), Doctoral Researcher, University of Oxford

Poster Board Number: 26
Theme: Hazards

Extreme fluvial floods pose severe socioeconomic and environmental risks across the UK. This paper addresses the critical need to identify the most influential features driving extreme flood events, including atmospheric circulation patterns, and land-surface antecedent conditions, through the integration of datasets from ERA5-Land, CAMELS-GB, and the Met Office Weather Patterns (MO30). Understanding the interplay between atmospheric circulation patterns and antecedent conditions as drivers of flood extremes remains a significant research gap. This paper addresses this gap through employing machine learning techniques (random forest models) to assess the relative importance of daily synoptic scale weather patterns, large scale weather regimes and antecedent land-surface conditions as predictor variables for the target variable of extreme flood magnitudes within the UK's most 'natural' catchments (UKBN2). Findings reveal cyclonic types with deep lows, very windy types, the North Atlantic Oscillation positive phase (NAO+) and southwesterlies as key drivers of the top 1% flood magnitudes. Our analysis also reveals further regional and seasonal variations in the dominance of these drivers. These insights highlight the necessity for further investigation on how driver relationships with extreme floods vary spatially, temporally, and under future climate changes.

The Diurnal Cycle of Gravity Waves in GNSS-RO Data

Emily Lear (she/her), PhD student, University of Bath

Poster Board Number: 27

Theme: Observations

Atmospheric gravity waves impact the atmospheric circulation and understanding gravity wave processes is important for the improvement of weather and climate models. Convection, which is a source of gravity waves, is known to have a diurnal cycle, so it is expected that convective gravity waves should also follow a diurnal cycle. However, although this cycle can be simulated in models and observed in ground based data at fixed locations, it is difficult to observe in global satellite observations, due to their low time resolution, particularly since most gravity wave resolving instruments have sun-synchronous orbits and therefore always observe the same local solar time. In this study, Global Navigation Satellite System Radio Occultation (GNSS-RO) data are used to investigate whether a diurnal cycle in gravity wave amplitudes can be seen in the stratosphere using these observations. Radio occultation uses GNSS signals received by a satellite that measures the bending angles and phase delay, due to these signals passing through the atmosphere. Temperature profiles can then be retrieved from the measurements. These measurements are randomly distributed in local solar time and have the high vertical resolution required to accurately resolve gravity waves. Specifically, in this work, GNSS-RO dry temperature data are used from multiple satellite missions, including COSMIC 1 and 2, Metop-A, -B and -C, and CHAMP. Wave amplitudes are found using the 1D S-Transform and the amplitudes are then binned in local solar time and averaged for each month, using all available data from the years 2001-2023. Consistent with theoretical observations, a diurnal cycle in gravity wave activity can be seen in the results and comparisons to convection data sets suggest this is strongly linked to convection. These results are also compared to wind data, which will affect the generation and filtering of the waves.

Investigating Observations from Ground-Based Far-INfrarEd Spectrometer

Sophie Mosselmans (she/her), PhD Student, Imperial College London

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Poster Board Number: 28

Theme: Observations

The ground-based instrument FINESSE (the Far-INfrarEd Spectrometer for Surface Emissivity) was taken on its first field campaign in November 2023, deploying to the ALOMAR ground station in Andoya, Norway. FINESSE measures upwelling and downwelling radiation with a flexible resolution (maximum $0.5\ cm^{-1}$) and a range of 6.25×10^{-4} to 25×10^{-4} cm (Warwick, 2023b). I will be presenting data from this campaign and comparing these observations to the outputs of LBLRTM simulations. The aim is to produce column water vapour retrievals from Andoya and possibly combine the cirrus cloud measurements radiative signatures with the micro-physical cloud properties.

Assimilating NASA Deep Blue VIIRS AOD Observations into the UK Met Office NWP Global Model

Patrycja Siwek (she/her), Earth Observation Foundation Scientist, The Met Office

Poster Board Number: 29
Theme: Observations

The Met Office (MO) Numerical Weather Prediction (NWP) 10km Global Model (GM) produces a dust forecast which is of interest to customers such as those in aviation, and for giving guidance on potential impacts to human health and air quality from dust transport episodes. Aerosols play an important role in atmospheric processes and the interactive dust aerosols in the GM affect other forecast variables such as surface temperature. The modelled transport and amount of dust in the forecast is improved with Data Assimilation (DA). The premise of DA in NWP is to adjust initial conditions of forecast parameters in NWP models, by updating the previous model forecast with real-time observations. The NASA 10km resolution Deep Blue and Dark Target combined Aerosol Optical Depth (AOD) products at 550nm for the MODIS instrument, onboard NASA's Aqua and Terra polar satellites, are assimilated into the GM. AOD shows the total column loading of (optically active) aerosols present in the atmosphere and can be derived for different aerosol types using their unique spectral signatures. The total AOD is filtered for mineral dust in the assimilation. However, MODIS is operating long past its expected lifetime, so we are investigating NASA's Deep Blue algorithm (version 2) for the follow-on instrument mission VIIRS onboard NASA's polar satellites S-NPP and NOAA-20. We present a statistical analysis comparing VIIRS AOD against AERONET (in-situ) and MODIS AOD measurements to assess the data quality and any biases that may be important to consider for DA. Lastly, we show preliminary results from experimental NWP trials assimilating the new data into our system, to assess whether we get a positive impact on the whole NWP forecast.

Monitoring the UK climate in the National Climate Information Centre at The Met Office

Emily Carlisle (she/her), Scientist - UK Climate Monitoring, The Met Office

Poster Board Number: 30
Theme: Observations

Observational data underpins meteorological and climatological research and is vital for operational meteorology. The UK has an extensive station network with weather stations providing daily, hourly and/or sub-hourly observations. The National Climate Information Centre (NCIC) uses these observations to provide monitoring and analysis products for a wide range of government and commercial customers, researchers, meteorologists, and the interested public. Here I will present an overview of NCIC products and datasets, with the aim to facilitate building connections with researchers and Met Office staff who can make use of the team's products and knowledge. I will discuss several key datasets maintained and developed within the NCIC, all of which are publicly available. The NCIC team delivers monthly, seasonal and annual weather reports for the UK and its constituent regions, and near real-time maps and charts of recent weather across the UK. Many of these can be found on the Met Office public website, and further enquiries can be directed to the NCIC team. Monitoring the UK climate is of great importance for understanding and adapting to the changing climate, and the resources and products provided by the NCIC are invaluable for this.

Quantifying the Underestimation of Rainfall by Rain Gauge Networks: Significance, implications & recommendations

Ruth Dunn (she/her), Doctoral Student, Newcastle University

Poster Board Number: 31
Theme: Observations

Accurately measuring precipitation is notoriously difficult. Traditionally, precipitation at the Earth's surface is measured using catching-type rain gauges, and many countries have national networks and historical records spanning multiple decades. Large datasets of such longevity enable the study and detection of non-stationarity trends and extremes, providing a means of investigating climate change and its impacts from either natural or anthropogenic forcings. While remote sensing techniques are becoming increasingly popular, indirect measurements often rely on rain gauges for calibration and validation, underscoring the continued importance and relevance of rain gauge data. Unfortunately, precipitation data collected by rain gauges is infamously unreliable due to a multitude of errors. Improving the accuracy of rain gauge records will enable us to better observe and understand climate variability and climate change effects on precipitation, facilitating improved design storm estimation and contributing to the construction of more effective and resilient infrastructure systems. Additionally, as rainfall data serves as the primary input for most hydrological models, enhancing the accuracy of this data will result in more reliable flood simulations, aiding in the identification and mitigation of flood risks, and fostering a greater understanding of the mechanisms operating within a catchment. Furthermore, if applied at real-time, more accurate rainfall data will also aid in the effective monitoring of and response to evolving situations. This research aims to investigate rain gauge undercatch in a British context, utilising synthetically generated rainfall fields, and experiments with a rainfall simulator. The primary objectives include identifying the applications most sensitive to undercatch and establishing the relationship between undercatch extent, rain gauge type, and meteorological conditions. Through this investigation, a correction methodology will be developed to enhance the accuracy and reliability of both historic and future rainfall datasets. Moreover, the study will establish the contexts where the application of this correction methodology is most crucial. The outcomes of this research hold significant implications for understanding climate change effects, improving flood simulations, and designing resilient infrastructure. By addressing the challenges associated with rain gauge data accuracy, this study contributes to greater climate awareness and more informed decision-making and infrastructure design.

Quality Control of the Gridded Radar Precipitation Dataset

Xiaobin Qiu (he/him), PhD Student, Newcastle University

Poster Board Number: 32

Theme: Observations

Gridded precipitation datasets (such as radar rainfall dataset) are widely used in climate and flood risk research. And the quality control is extremely important prior to their application. There are always rainfall overestimation (such as radar malfunction, ground clutter, random noise.) and underestimation (such as radar beam blockage, radar signal attenuation) problems in the radar rainfall.

Current approaches of quality control are based on the radar reflectivity which is familiar for radar experts but not for hydrologists. In this research, we explore the new methods for the quality control of the gridded radar dataset (based on the rainfall field continuity assumption) and propose a quality control framework for the radar rainfall dataset. For radar beam blockage, the Differential Excitation (DE) Method is proposed to detect the blocked area. Then the Minimum Difference Method is used to recover the rainfall in the blockage, with error less than 3%. Besides, there are Maximum Difference Method, Robust Score Method, Zero Difference Method, High-ranking Method, Isolated Rainfall Method, and Normal Rainfall Field Protector. These methods are moving window based and only take rainfall data as input, using the relationship between the local pixel and its neighboring pixels. They can identify the abnormal rainfall from the radar rainfall fields and solve the overestimation issue to some extent. After the error identification, the Gauss Interpolation Method is applied to recover the missing/problematic rainfall.

Towards a Blended Satellite-Station Sunshine Duration Dataset for the UK

Josh Blannin (he/him), Foundation Climate Observation Scientist, The Met Office

Poster Board Number: 33
Theme: Observations

In the UK the number of weather stations recording Sunshine Duration (SD) decreased by approximately two-thirds between 1983-2022, leading to increased SD uncertainties in the Met Office gridded SD dataset (“HadUK-Grid”).

The objective of this study is to produce a blended satellite-station SD dataset for the UK, with the aim of producing improved SD estimates. Satellite based SD estimates (SDsat) can provide daily, high-resolution, spatially-complete fields. This study uses the CM SAF SARAH-3 dataset to provide SDsat between 1983-2022. Station observations are retrieved from the Met Office’s MIDAS-Open, which contains SD from traditional Campbell-Stokes (CS) devices and more modern Kipp-Zonen (KZ) recorders.

This study initially compares SDsat with quality-controlled CS and KZ measurements to guide the identification of suspect stations which are excluded from subsequent blending. The blending procedure has two steps; first a generalised linear model (GLM) estimates station measurements from co-located SDsat, and second a Gaussian Process (GP) is trained on the GLM residuals to produce a correction field.

SDsat have a high correlation with station measurements (≈0.93), but the mean difference between SDsat and CS (0.1 hours) is slightly smaller than with KZ (0.5 hours). Therefore, a conversion is performed to map KZ to CS and produce a unified SD representative of CS measurements (CSuni). Three GLM models are trialled with different combinations of explanatory variables: SDsat only, SDsat & latitude, and SDsat & latitude & SDsat-squared. A 15-fold cross-validation found that all models have a similar root mean square error (RMSE: 1.4 hours), residual mean (μ: 0.2 hours) and residual standard deviation (σ: 1.4 hours). After training a GP on the daily GLM residuals and then revising the GLM estimates, the updated validation results showed an improvement in the blended SD estimates (RMSE: 1.2, μ: 0.0, σ: 1.2). However, improvements may be larger than this locally.

Atmospheric Response to Mesoscale Ocean Eddies in Southeast Asia

Ashar Aslam (he/they), PhD Student, University of Leeds

Poster Board Number: 34
<u>Theme: Oceans</u>

Mesoscale ocean eddies contribute to the mixing and transport of water properties all over the global ocean. Surface signatures associated with these eddies have been noted to potentially influence the stability of the atmospheric boundary layer. Southeast Asia, despite being a region known for the genesis of mesoscale ocean eddies, remains understudied with respect to eddy-associated air-sea interactions. In fact, this is the case for the entire Tropics.

Here, using a sea surface height-based algorithm, we detect and track eddies over a large domain including southeast Asia. Consistent with other studies, we observe distinct differences in eddy characteristics between the Tropics and extratropics, such as in number, duration and amplitude. This contrast is also visible in the surface signatures of, and atmospheric response to, these eddies. Surface heat flux, wind divergence and rainfall anomalies are significant in an extratropical case study region, and largely insignificant in selected regions in southeast Asia, relative to the background environment.

We find these results are likely to be linked to a latitudinal gradient in sea surface temperature anomalies associated with mesoscale ocean eddies. We additionally explore the potential role of background environmental characteristics in modulating the observed signals in southeast Asia.

Simulating Regional Marine Cloud Brightening (MCB) in the UKESM1 Climate Model

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Poster Board Number: 35
<u>Theme: Oceans</u>

Marine Cloud Brightening (MCB) is a potential climate intervention strategy where sea-salt particles are sprayed into marine clouds to increase the reflectivity of the clouds. This is a solar radiation management (SRM) strategy with the potential to cool the Earth's surface by reflecting more solar radiation. SRM is controversial and more research is needed to understand the consequences of any such intervention. In this study, we research simulations of MCB in the UK Earth System Model (UKESM1) across 14 different regions. Each experiment injects sea-salt at a rate of 50 Tg/yr over the open-ocean parts of a given region, and the impact on effective radiative forcing (ERF), surface temperature, precipitation and net primary productivity (NPP) are studied. The annual and seasonal impacts will be researched, investigating how effective MCB is in the different regions and seasons, as well as comparing the direct and indirect effects of the aerosols in the simulations. Potential combinations of the experiments to mitigate regional impacts will also be explored.

The Inian Ocean : Understanding the biases in The Met Office Global Coupled Climate Model (GC5).

Aparna Anitha (she/her), PhD Student, University of East Anglia

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Poster Board Number: 36
Theme: Oceans

The Indian Ocean plays a vital role in modulating the global weather and climate systems and is a source of regional and global variability. However, many state-of-the-art climate models still struggle to accurately represent the complex and dynamic coupled climate of the Indian Ocean. The primary focus of this study is to locate the sources of coupled biases in the Indian Ocean basin in Met Office forecast models, spanning both numerical weather prediction (NWP) forecasts at 15–30 daytime scales and seasonal (1-6 month) forecasts using the GloSea suite. Previous studies on the Met Office coupled model showed that the biases develop during the initial days of the model simulation and then persist up to climate time scales. Here we analyse a set of forecasts initialised in June 2019 and found that the SST biases intensified over time showing significant biases across the Indian Ocean. we perform a mixed-layer heat budget analysis to understand the relative contributions of the various parameters which might be driving this variability in the SST.

Developing a Coupled Model to Explore Antarctic Ice Sheet - Climate feedbacks in the past and future

Laura Byrne (she/her), PhD student, University of Exeter

Poster Board Number: 37

Theme: Polar

Although the largest contribution to sea level rise at present is through thermal expansion, the Antarctic Ice Sheet has the potential to dramatically increase sea level. Estimates of Antarctic Ice Sheet contribution to sea level by the end of this century are uncertain, ranging from a few millimetres, to over 1m. One obstacle in producing these projections is that most climate models do not include interactive ice sheets. Climate models can be used to drive separate ice sheet models, however this method ignores subsequent feedbacks between ice sheets and climate, leading to simulations that may under-estimate potential sea level rise. Some model simulations that do include ice sheet-climate feedbacks show future warming may result in increased Antarctic Ice Sheet mass loss and sea level rise for lower values of ocean warming, though other studies report a negative feedback. Both positive and negative feedbacks occur between Antarctic Ice Sheet and the climate system and it is not known which is currently dominant or will be in the future.

This study builds upon current knowledge of the interactions between the Antarctic Ice Sheet and the climate system by investigating feedbacks between the Antarctic Ice Sheet and climate using an offline coupling process. A climate model will be used to drive an ice sheet model of Antarctica. The ice sheet in the climate model will be modified to match the ice sheet model, then the climate model simulation continued with this new ice sheet. Changes in the climate will then be updated in the ice sheet model and the process repeated. This method allows for feedbacks to occur that are normally missing from climate models. The new model will be used to investigate Antarctic Ice Sheet and sea level under the warm climate conditions of the middle Miocene and projections of future climate.

Assessment of the Met Office’s Coupled and Ocean-Only Systems in Predicting Arctic Sea Ice and Ocean Conditions

Jessica Diamond (she/her), Deployable Project Scientist, The Met Office

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Poster Board Number: 38
Theme: Polar

Over the past 50 years, Arctic sea ice has significantly declined in both extent and thickness, a trend projected to continue into the future. This decline has enabled increased maritime activity in the region, necessitating accurate forecasts of sea ice and ocean conditions to support the growing maritime operations. Historically, the Met Office has concentrated its model development and verification efforts in mid-latitudes. However, with the changing dynamics of the Arctic, there is now a pressing need to enhance forecasting capabilities for this region.

Therefore, this study evaluates the performance of the Met Office's current short-range operational forecasting systems in predicting crucial ocean and sea ice variables. The investigation specifically focuses on assessing the Forecast Ocean Assimilation Model (FOAM) and the Coupled Numerical Weather Prediction (NWP) system, with a primary emphasis on their ability to accurately forecast two essential variables for ship navigation: the position of the ice edge and the thickness of sea ice.

This assessment involves comparing model output with independent observations and subsequently calculating statistics to evaluate the accuracy of these predictions. For the ice edge position, the integrated ice edge error statistic is calculated, while for sea ice thickness predictions, Root Mean Square Error and mean difference statistics are computed. The findings from this study should pinpoint areas where current forecasting systems fall short of customer requirements, offering insights to guide future development priorities and efforts aimed at improving the Met Office's Arctic forecasting capability. These findings are pivotal for meeting the escalating demand for reliable services in this vital region.

Developing the Met Office’s Regional Arctic Atmospheric Modelling Capabilities

Eloise Matthews (she/her), Deployable Project Scientist, The Met Office

Poster Board Number: 39

Theme: Polar

Under a changing climate, there is increasing interest in the Arctic region and the role of the poles in influencing wider global climate. This project is developing a regional, atmosphere-only model over the North Pole, which fills a gap in current Met Office capabilities. It will be important for purposes such as safety while following new shipping routes, as well as providing further basis for understanding the Arctic’s elevated response to climate change. This project uses the Met Office’s Regional Ancillary and Regional Nesting Suites, the former to generate surface data (“ancillaries”) for the chosen domain, to input into a nested model alongside driving lateral boundary conditions from a global model. Many technical difficulties are encountered when generating the ancillaries over a pole, which are requiring much attention to embed fixes into the model configuration that could go operational, building on previous work by Met Office colleagues.

The model domain was selected such as to be scientifically and technically relevant to current work and future applications, including covering areas where observation data is available to facilitate future model verification. There is outlook for eventually coupling the model, such as to oceans and sea ice, and running it operationally, producing ensemble forecasts which will increase forecast confidence and thus the safety of Arctic transits, alongside deepening our understanding of the Arctic environment.

Exploring Mechanisms for Model-Dependency of the Stratospheric Response to Arctic Warming

Regan Mudhar (they/them), PhD Student, University of Exeter

Poster Board Number: 40

Theme: Polar

Recent studies propose that Arctic sea ice loss and associated warming influence wave propagation into the stratosphere, affecting the winter polar vortex. Through stratosphere-troposphere coupling, this may perturb the winter jet stream and affect surface weather. But the “stratospheric pathway” linking Arctic variability to midlatitude weather extremes is not well understood. For example, studies such as the Polar Amplification Model Intercomparison Project (PAMIP) have not found a robust stratospheric response to Arctic sea ice loss, in strength nor sign. Previous work suggests that atmosphere-only GCMs likely underestimate the depth and strength of sea ice loss-induced atmospheric warming, and that the Arctic amplification link to midlatitude weather is sensitive to the vertical extent of polar heating. We therefore explore the dependency of the stratospheric response to polar heating on characteristics of the heating itself, as well as the stratospheric state.

We use an idealised atmospheric modelling framework (Isca) to better understand mechanisms and uncertainties in the stratospheric response to Arctic amplification. We use Newtonian relaxation of temperature to a specified equilibrium temperature to simulate northern hemisphere winter, then alternatively force the model with an adjustable polar heating and modify the stratospheric state by adjusting polar vortex strength. Consistent with previous work, the imposed polar heating consistently increases upward wave propagation into the polar stratosphere, but with a notable dependency on heating depth and strength; vortex variability and sudden warming frequency reduces with increasing depth of heating. We also find that the sign and magnitude of the polar vortex response is highly sensitive to the basic state. We further show an analysis of stratospheric responses in PAMIP simulations, and propose that our idealised model results help to explain some of the significant model-dependency driving the range of simulated responses.

Adaptively Implicit Time Stepping for Atmospheric Transport

Amber Te Winkel (she/her), PhD Student, University of Reading

Poster Board Number: 41

Theme: Weather and Climate Prediction

Next-generation numerical weather prediction models are moving away from the widely-used semi-implicit semi-Lagrangian scheme due to its undesired non-conservation. Solutions include the conservative, flux-form semi-Lagrangian scheme and Eulerian finite-volume methods. The latter are limited in their time step for stability, resulting in a loss of efficiency. In this research, we present a one-dimensional hybrid advection scheme that removes time step restrictions by implementing implicit time stepping adaptively, i.e., for high Courant numbers where an explicit scheme is rendered unstable. It is applied to a vertical column, where strong updraughts can lead to instability. Numerical properties of the scheme such as conservation, boundedness, stability, and accuracy are discussed. The implicit scheme reduces local accuracy, but, importantly, stability is ensured. A compromise is reached between efficiency and accuracy over the entire domain.

Can Air-Sea Coupling Solve the Signal-to-Noise Paradox in Climate Predictions?

Yvonne Anderson (she/her), PhD Student, University of Leeds

Poster Board Number: 42

Theme: Weather and Climate Prediction

Climate models underestimate predictability in the North Atlantic region, for several variables across multiple timescales. Here, the predictable component in models is lower than in observations, a phenomenon known as the 'signal-to-noise paradox'. Several studies have explored possible causes of the signal-to-noise paradox, but no consensus on the source or a solution for the problem has been determined. The signal-to-noise problem is prevalent in regions of eddy-activity, which are characterised by strong energy exchange between the ocean and atmosphere. This energy exchange is an important driver of large-scale atmospheric signals, which can offer a source of predictability in climate models. This work aims to test the hypothesis that model underestimation of predictability is a result of poor representation of air-sea interactions. The analysis will compare the nature of air-sea coupling in satellite observations and models, with a focus on turbulent fluxes in the Gulf Stream region. The comparison aims to identify missing features that may amplify predictable signals, resulting in low signal-to-noise ratios in models.

Implementation of Regional Idealized Tests in the Met Office Next Generation Atmosphere Model

Declan Healy, Industrial Placement, The Met Office

Poster Board Number: 43

<u>Theme: Weather and Climate Prediction</u>

We present the implementation and results of regional idealized tests conducted in the Met Office's LFRic atmosphere model, a next-generation model developed for high-resolution weather and climate simulations. By running these idealized tests, we aim to deepen our understanding of the behaviour of atmospheric dynamics in regional setups. The tests encompass a range of scenarios, including radiative convective equilibrium (RCE) and the Atmospheric Radiation Measurement (ARM), and thus cover a varying range of climates and model complexity. Many of these tests necessitated additional model capabilities, such as time-varying surface fluxes of moisture and heat, that were added to LFRic in order to perform this work. Through comparison with theoretical expectations and relevant academic literature, we assess the model's ability to accurately represent key atmospheric phenomena, particularly the representation of convection and accuracy of transport schemes that are important in governing organised convection. We include results from single column models and larger domains, such as long channel biperiodic domains which permit the formation of organised convection. Our findings contribute to ongoing efforts in model development and verification, enhancing the reliability and robustness of LFRic for weather and climate forecasting.

WRF Model Utilized for Tropical Cyclone Prediction (Case Study: Tropical Cyclone Anggrek)

Fazrul R. Sadarang (he/him), Master's Student, University of Birmingham

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Poster Board Number: 44

Theme: Weather and Climate Prediction

Tropical cyclones (TC) cause enormous losses due to their derivative impacts, namely increased rainfall and maximum wind speed. TC Anggrek, which hit the southern region of Indonesia, is proof that even though it is at the equator, Indonesia cannot escape the impacts caused by tropical cyclones. Utilizing numerical weather prediction (NWP) for TC predictions will be very helpful, especially in mitigation efforts. The weather research and forecasting (WRF) model that applies NWP is a model that has been widely used to predict meteorological events, including tropical cyclones. This research will test the sensitivity of the cumulus and microphysics parameterization of the WRF model for predicting TC Anggrek.

Informing the Unification of a Single Cloud Scheme in Met Office's Unified Model

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Poster Board Number: 45

Theme: Weather and Climate Prediction

Cloud representation in weather and climate models significantly influences model performance. Currently, the Met Office employs two approaches for sub-grid cloud representation in its global model and regional model: a prognostic cloud scheme, considering the evolution of cloud over time, and a diagnostic scheme, focusing solely on the present state. However, it would instead be beneficial to have one unified large-scale cloud fraction scheme. To inform this unification, we assess the effects of various combinations of cloud, microphysics and convection scheme configurations on several key variables.

We investigate both the prognostic and diagnostic cloud fraction approaches, alongside single-moment and double-moment microphysics schemes. Additionally, we examine two convection schemes: one employing multiple plume models for different convection types, and another utilising one unified plume model.

High-resolution (300m) simulations are performed across multiple global domains, centred around Atmospheric Radiation Measurement (ARM) sites, such as the Southern Great Plains for a continental case and the Tropical Western Pacific for an oceanic case. Additional sites to look at UK summertime convection and stratocumulus cloud are also explored. Through the evaluation of various variables, we aim to identify the configuration that best aligns with observations, thereby informing the development of a unified cloud scheme.

Identifying Forecast Busts Events in Recent Years Over European Region

Kaustubh Mittal , PhD Student, University of Reading

Poster Board Number: 46
Theme: Weather and Climate Prediction

Due to chaos, probabilistic weather forecasts cannot be very sharp, but it is important for users that they are reliable. Despite progress in Numerical Weather Prediction, poor representation of uncertainties in the model may sometimes cause periods of very large errors, referred to as ‘forecasts busts’. Atmospheric flows such as those caused by the influence of Mesoscale Convective Systems (MCSs) on the upper-tropospheric Rossby Waves, contribute to the growth of model uncertainties. The subgrid-scale nature of MCSs genesis highlights the role of convection errors in the busts. Over Europe, forecast busts are often defined in terms of errors in the prediction of the height of the 500-hPa pressure surface and can be linked to MCSs forming over the continental US. Previous research, using forecasts made within the Interim European Centre for Medium-Range Weather Forecast (ECMWF) Re-Analysis system (ERA-Interim), identified 584 bust cases for 6-day predictions over Europe over 22 years (1989-2010). Our aim is to update the record of bust events for more recent years using the newer ECMWF Reanalysis V5 (ERA5). A comparative study is made between the two datasets based on the number of bust events and the usability of the forecast bust definition for the current ERA5 datasets. The findings will provide an opportunity to study individual bust cases and potential links to MCSs over the US and subsequently determining paths for improving global weather and climate models.

Keywords: Forecasts, NWP, Mesoscale, Forecast errors

Key Theme: Forecast Busts

Developing Mountain Ancillary Fields for Next Generation Modelling Scheme

Callum Dinnett (he/him), Foundation Scientist - Atmospheric Processes and Parametrizations (Orographic Processes), The Met Office

Poster Board Number: 47
Theme: Weather and Climate Prediction

The introduction of the Met Office's new forecasting model, LFRic, has required redevelopment of how several values are calculated and used. Included in this is generation of ancillary fields, which contain additional information needed for the model system. Particularly, we develop the ancillary fields which account for the representation of mountains (orography) in the model. Methods used in the Unified Model relied on the structured grid system, so new methods need to be developed and tested. In this project, effects of 'local' filters are tested on idealised orography and compared to methods used in the Unified Model on similar idealised orography for similarities in effect. We also investigate and evaluate generation of sub-grid fields, statistical data that is used to tune atmospheric gravity wave and drag effects, and which are affected by the filtering methods used in the wider dataset. These tests are used to help evaluate different filtering effects on model dynamics stability and determine which option provides the optimal representation for our purposes.

A Cloud-Based Platform for Scientific Post-Processing Workflows

Thomas Harry Mansfield, Foundation Scientific Software Engineer, The Met Office

Poster Board Number: 48
Theme: Weather and Climate Prediction

For many years, the Met Office has created separate streams of post-processing on platforms related to the teams creating the workflows, so that each team could manage releases and provide support. This has resulted in different standards and investment levels, and has proved to be a barrier for implementing innovative post-processing science. The Enhancing Post Processing project (EPP) is an ongoing project that aims to create a new solution for running post-processing on public cloud-based platforms using Amazon Web Services.

The EPP project will allow the Met Office to replace these existing science post-processing workflows, support the development of future post-processing enhancements, enable more use of current post-processing and ensemble exploitation, and also enable the re-use of existing post-processing modules by enhancing discoverability and useability. When implemented, this will speed up the operationalisation of data pipelines and improve the overall post-processing and analysis capability. We also hope to further enhance reusability by implementing a post-processing reusability framework to provide policy and guidance for the creation of new post-processing modules, to enforce a common standard.

This presentation will describe the ideas behind EPP, the achieved goals and aims of the project, and provide explanations of example workflows that have already been implemented.

Detecting Arctic Polar Lows Using Deep Learning

Jack Hill (he/him), Deployable Project Scientist, The Met Office

Poster Board Number: 49

Theme: AI & Statistics

Polar Low (PLs) are high-latitude mesoscale cyclones that appear as comma-shaped clouds in satellite imagery. They form over sea during cold air outbreaks and are short-lived but intense. The risks posed by these systems include gale-force winds, poor visibility, high precipitation, large waves and rapid ice accumulation on ships. Their small size, rapidity of formation and short lifetime mean that PLs are challenging to predict and track. Typically, physical models have been the method of choice for detecting and tracking PLs in reanalyses and observational data. This project investigates the capability of machine learning techniques, particularly neural networks, to detect PLs. The first step, a convolutional neural network (CNN) constructed to classify satellite images as containing PLs or not, has already shown good performance. The next steps will be adding object detection, so that the model can say which part of an image (or other geographic dataset) contains PLs, and training a recurrent neural network (RNN) using sequential data to train the model to predict formation conditions. Also of interest are Bayesian methods, which can be integrated into a model to provide probability distributions for its guesses on test data, rather than discrete class choices. The main challenge so far have been acquiring enough usable data to make a tool that is accurate, given that PL data is scarce and deep learning models require sample sizes of several orders of magnitude to be successful. Also, identifying the data types the model will have to be receptive to, and, accordingly, giving the model the necessary capabilities, will also be a key consideration.

Causal Approach to Cloud Development Along Trajectories

Geoff Pugsley (he/him), PhD reseacher, Imperial College London

Poster Board Number: 50
Theme: AI & Statistics

Aerosols affect the climate both through scattering and absorption of incoming solar radiation (direct effect) as well as acting as cloud condensation nuclei and hence changing clouds microscopic and macroscopic properties (indirect effect). The indirect aerosol effect is the most uncertain contribution of the climate response from anthropogenic forcing. Aerosols offset the warming caused by greenhouse gasses. Since the magnitude of this offset is uncertain, this leads to large uncertainties in projections for climate change under different carbon dioxide emission scenarios. (Andreae et al. 2005). Hence, it is crucial to better characterise aerosol-cloud interactions in order to more tightly constrain the aerosol effective radiative forcing (ERFaer) so that climate policy can set carbon targets that will keep global mean surface temperatures within safe limits (UNFCCC 2015).

When compared to observations, climate models exhibit biases in the representation of cloud processes due these processes having to be parameterized and therefore not perfectly capturing the underlying physics (Malavelle et al. 2017). In particular the liquid water path (LWP) response to an aerosol perturbation exhibits a bias when models are compared with observations (Michibata et al. 2016). For the observations the sign of the response was observed to change over a range of different meteorological conditions, however the models predicted a monotonic increase in LWP with aerosol loading (Fons et al. 2023).

Clouds are time dependant and the cloud response to an aerosol perturbation occurs on a range of different timescales. However, satellite data is typically static, just capturing the cloud at a single instance in time. Better observations of cloud temporal development will allow us to identify causal relationships between cloud properties, for example through Granger causality (Pearl 2000), which have previously been challenging to identify due to complex feedbacks (Gryspeerdt et al. 2022). The shortest timescale is the Twomey effect whereby an increase in aerosols leads to an increase in cloud droplet number concentration (Nd), an effect that can be most easily observed with ship tracks. Changes to the LWP and cloud fraction (CF), measures of cloud vertical and horizontal extent respectively, occur on longer time scales and are often referred to as the ‘cloud adjustments’ (Forster et al. 2021).

This work uses a causal approach combined with high resolution geostationary data to understand cloud development along trajectories, combined with the physical processes driving the clouds development. It seeks to understand the effect of the clouds development on the initial conditions and subsequent changes in the meteorology.

Enhancing Radar-Based Precipitation Nowcasting through Deep Learning: A case study with Rainymotion

Daniel O'Brien (any/all), Student, Maynooth University

Poster Board Number: 51
Theme: AI & Statistics

This study presents an advanced approach to precipitation nowcasting by integrating deep learning models, specifically Convolutional Neural Networks (CNNs), with the rainymotion Python package. The conventional methods of radar-based precipitation forecasting, such as optical flow techniques and simple advection, have shown considerable success in short-term rainfall prediction. However, the complexity of advection and convection patterns in the lower atmosphere demands more sophisticated models to enhance accuracy and reliability. Our project extends the traditional numerical methods and statistical modeling in rainymotion by developing and implementing deep learning algorithms which are trained from historical radar data across the UK and Ireland.

We explore the integration of dense and sparse optical flow methods with CNNs to capture the dynamic and complex nature of precipitation dynamics. By training these models on a comprehensive dataset of radar images, we aim to better understand intricate patterns of advection and convection that are critical for accurate rainfall nowcasting. The evaluation of our model's performance utilizes various statistical and error metrics, including Root Mean Squared Error and correlation coefficients, ensuring a rigorous assessment against observed rainfall data.

Preliminary results demonstrate that deep learning-enhanced rainymotion models significantly outperform traditional methods in terms of forecasting accuracy and reliability over short periods. This advancement holds promising applications within hydrometeorology, offering a more effective tool for flood management, agricultural planning, and emergency response. This study also contributes to the emerging area of data-driven forecasting, and showcases the potential of combining machine learning with traditional meteorological methods for improved nowcasting.

Improving Vertical Detail in Simulated Temperature and Humidity Data Using Machine Learning

Joana Rodrigues (she/her), AI Aided Hybrid Modelling Scientist, The Met Office

Poster Board Number: 52

Theme: AI & Statistics

Numerical models are used to predict the weather and make projections about future climate by discretizing the atmosphere into a grid. There are, however, atmospheric phenomena that occur at scales smaller than the size of those gridboxes. The formation of low level clouds due to temperature inversions in the vertical is an example of this. This is because inversions are generally very thin in comparison with the vertical resolution of our models at those heights, leading to the models underestimating or even missing these clouds. This can have negative effects for example on the radiative transfer. Another example is convective inhibition, for which thin layers might be missed due to this, affecting the development of convection in our weather forecasting and climate models. While increasing vertical resolution is likely to improve the representation of some atmospheric processes, this would also increase the computational cost drastically. Therefore, this project aims to keep the current resolution of these models while improving the vertical detail where it is most needed. For that, Machine Learning models were trained to refine the thermodynamical profiles of Temperature and Specific Humidity, using radiosonde data. Physics Informed Machine Learning models were used and compared against traditional Machine Learning models, with the results showing an improvement in the final Cloud Fraction profiles calculated from its predictions. Overall, the predictions from our models, surpassed the benchmarks and proved that this technique might be useful in improving the representation of the effect of subgrid processes in the vertical. The next step will be to couple the model to a Cloud Scheme in the Met Office's Unified Model and test its online performance

Identifying Precipitation Types over China using a Machine Learning Algorithm

Yi Wang (she/her), PhD student, University of Exeter

Poster Board Number: 53

Theme: AI & Statistics

In the context of global warming, changes in extreme weather events may pose a larger threat to society. Therefore, it is particularly important to improve our climatological understanding of high impact precipitation types (PTs), and how their frequency may change under warming. In this study, we use MIDAS (the Met Office Integrated Data Archive System) observational data to provide our best estimate of historical PTs (e.g. liquid rain, freezing rain, snow etc.) over China. We use machine learning (ML) techniques and meteorological analysis methods applied to data from the ERA5 historical climate reanalysis data to find the best variables for diagnosing PTs, and formed training and testing sets, which were input into ML training. We evaluate the diagnostic ability of the Random Forest Classifier (RFC) for different PTs. The results show that using meteorological variables such as temperature, relative humidity, and winds to determine different PTs, ERA5 grid data and MIDAS station data have good matching ability. Comparing the feature selection results with Kernel Density Estimation, it was found that the two methods have consistent results in evaluating the ability of variables to distinguish different PTs. RFC shows strong robustness in predicting different PTs by learning the differences in meteorological variables between 1990 and 2014. It can capture the frequency and spatial distribution of different PTs well, but this capture ability is sensitive to the training methods of the algorithm. In addition, the algorithm finds it difficult to identify events such as hail that are very low frequency in observations. According to the results of testing for different regions and seasons in China, models trained using seasonal data samples have relatively good performance, especially in winter. These results show the potential for combining a RFC with state-of-the-art climate models to effectively project the possible response of different PT frequencies to climate warming in the future. However, the training method of ML algorithm should be selected with caution.

Can we Accelerate Fluid Dynamics Solvers in Atmospheric Models using Machine Learning?

Benjamin Buchenau (he/him), Student, University of Edinburgh

Poster Board Number: 54

Theme: AI & Statistics

Global coupled climate model (GCM) biases thought to stem from parametrisations of unresolved physical processes have led to calls for a step-change in the resolution of GCMs, from currently around 100km to about 1km.

To facilitate this increase in resolution, GCMs need to become much cheaper to run. This work takes aim at accelerating the solution of large systems of linear equations arising in semi-implicitly time stepped models by using machine learning (ML) methods. ML models can be very cheap at the inference stage, but may become unreliable when encountering scenes not included in their training data. Therefore, the idea to implement an ML model as the preconditioner to the linear solver - i.e., an approximate solve that helps the actual solve to converge quickly - is natural, promising significant speed-up over traditional iterative preconditioners while not affecting the solution.

We provide an overview of potential ML methods for Geophysical fluid dynamics solvers. We identify the most promising approaches as well as potential pitfalls through theoretical considerations and numerical experiments on idealised equation sets and test cases.

Hydra-LSTM: A semi-shared machine learning architecture prediction across catchments

Karan Ruparell (he/him), PhD Candidate, University of Reading

Poster Board Number: 55
Theme: AI & Statistics

The prediction of river discharge across multiple catchments using Long Short Term Memory (LSTM) models has significantly enhanced the ability to capture extreme flow events and perform well under varying climatic conditions. However, these models require uniform data availability across all catchments, preventing the utilization of additional data that may be available in some catchments. Currently there are no methods in river discharge prediction that allow a machine learning model to learn to use additional information that was not considered in the initial creation of the model. To address this limitation, we propose the Hydra-LSTM, a novel two-tier model. The first tier, known as the LSTM Body, processes the data common to all catchments. The second tier utilizes the encoded output from the LSTM Body, optionally integrating additional data to predict river discharge for individual catchments. We apply this methodology to 3-day ahead river discharge prediction in the Western US. We obtain state of the art performance, while also having the unique advantage of being able to efficiently train the model to use additional data as they become available in different catchments, without the need for prior specification of what those variables may be.

Identification of Cumulonimbus Clouds from Radar Imagery Using a Convolutional Neural Network

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Poster Board Number: 56

Theme: AI & Statistics

AutoCB is a Met Office aviation product which automates the detection of cumulonimbus (CB) and towering cumulus (TCu) clouds at a number of major UK airports, including Heathrow and Manchester. This information is then used to inform Meteorological Aerodrome Reports (METARs) to pilots, giving an indication of the present weather at and around the airport. AutoCB currently implements a K-nearest neighbour clustering algorithm on the latest radar data for the given airport, using radar reflectivity thresholds to determine whether a CB is present. However, this approach leads to a high false alarm ratio as the algorithm is often unable to distinguish between intense frontal rain and CBs. A convolutional neural network (CNN) has therefore been investigated in place of the current radar clustering method by treating automated detection as a binary image classification problem; the aim being that a deep learning approach can capture spatial correlations in the radar imagery and improve the false alarm ratio. The CNN was trained on 2023 radar images at three UK airports and then integrated into the AutoCB software to test for the year 2022. This was then compared with the operational AutoCB output for 2022.

Reducing Errors In The UK Sea Level Forecast Using Gradient Boosted Random Forests

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Poster Board Number: 57
Theme: AI & Statistics

Atmospheric conditions such as pressure can cause the coastal sea level to be higher or lower than one would expect based only on the tide. This is known as “surge residual” and can lead to flooding, especially during storms, with the potential to cause damage to infrastructure and loss of life.

The Met Office produces an ensemble forecast of the residual surge based on the “Nucleus for European Modelling of the Ocean" (NEMO) model for ports across the UK 4 times a day.

Over the course of six months, I developed an error correction scheme for this forecast, utilising a machine learning technique called Histogram Gradient Boosted Decision Trees. Several input variables are provided to the machine learning model based on physical processes, such as atmospheric conditions, as well as based on known factors that correlate with model error, such as the moon phase. The aim of the machine learning model is to predict the error of the physical model’s prediction, calculated as the difference between the mean of the ensemble forecast and in-situ buoy observations, so that it can be corrected. It is trained on data from August 2016 to December 2020 and tested on data from 2021.

Across the testing period, the machine learning model reduces the absolute error of the ensemble mean by more than 20% on average across the UK, as well as reducing the percentage of the time that the error is more than 20 cm by more than 35% on average. It performs especially well in the south and south-east of the country, making it a good candidate for improving the forecast provided to the London Port Authority.

Overall, the machine learning model reduces the physical model’s errors for the majority of UK ports, and could help provide more accurate forecasts.

Toward the Use of Ensemble Sensitivity Analysis for Monitoring Precursors to Extreme WeatherEevents

Daniel Etheridge (he/him), Deployable Project Scientist, The Met Office

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Poster Board Number: 58
Theme: AI & Statistics

Ensemble forecasting provides a wealth of insights on top of those provided by traditional deterministic numerical weather prediction. One method of analysis that could exploit these insights in an operational capacity is Ensemble Sensitivity Analysis. This involves analysing correlations between a variable representing a weather event in an area of interest with variables at positions in a wider area at times leading up to the event, to identify and track sensitive areas. In theory this sensitivity analysis could be used to help inform decision making around extreme weather events by operational meteorologists.

The use and usefulness of Ensemble Sensitivity Analysis in an operational context has yet to be explored in full, and the Met Office is beginning a collaborative project to research its potential. In this project we aim to report on the use and usefulness of Ensemble Sensitivity Analysis for monitoring precursors of extreme weather events and how this could be used by operational meteorologists. Using data from the Met Office's Global and Regional Ensemble Prediction System – Global (MOGREPS-G), Ensemble Sensitivity Analysis is being carried out for a collection of historic use cases, covering extreme weather events in the UK including named storms. The same analysis will be carried out in near real time, providing a prototype tool for meteorologists. From this we will work to refine and explore the usefulness of the technique and report on its benefits.

Machine Learning Subgrid Variability to Perturb Parameterisations

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Poster Board Number: 59

Theme: AI & Statistics

Atmospheric simulations divide the world into a grid, with the grid box typically ranging in size between 100 km and 10 km for a global simulation, depending on whether it is multi-decade long climate simulation, a short 5-day weather forecast, or something in between such as a seasonal forecast. Parameterisation schemes represent unresolved processes but must work with data available to them at the grid scale. However, if we could reliably estimate properties on the sub-grid scale then there is the potential to improve parameterisations with this information.

We have developed a machine learning model to predict the covariance matrix of sub-grid temperature. Initial experiments with this model use it to add stochastic physics to an existing parameterisation scheme. We use its outputs to generate profiles of temperature which are plausibly representative of the sub-grid distribution. These plausible alternative profiles are passed as inputs to a convection scheme. Thus, at each timestep, rather than seeing the mean temperature in the grid box, the scheme effectively sees a random profile from within the box.

Data from control and experiment single column model ensembles of radiative-convective equilibrium cases so far clearly demonstrate greater inter-ensemble differences than intra-ensemble ones. More detailed analysis and experiments are underway, with the goal of experiments in a full 3D atmospheric simulation.

Global Stilling: The importance of high-resolution wind speed data.

Kathryn Vest (she/her), PhD Student, Lancaster University

Poster Board Number: 60

Theme: Applications

Global stilling is the observed reduction of wind speeds due to climate change. This is highly important as society is becoming increasingly reliant on wind power which could be impacted by significant global stilling. Using the record of wind speed and wind power generation data from the Hazelrigg Meteorological Station and wind turbine, we performed trend analyses and assessed the rate of change across several sampling rates. The 10-minute data for Lancaster shows decreasing wind speeds (-0.2m s-1) and estimated wind power (-20kW) in the last decade, similarly daily run of wind data suggests decreasing wind speeds and a total decrease in estimated wind power generation by approximately 350kW between 1985 and 2022. To assess the importance of high-resolution data in wind power analysis we transformed the 10-minute wind speed and daily run of wind data to estimated wind power generation, this allowed for comparison between equivalent data. The opposing patterns shown by this estimated wind power generation data highlight the importance of using high resolution wind speed data for global stilling research due to the large spatial and temporal variability of wind speeds.

A New Model for Rail Surface Temperature Prediction

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Poster Board Number: 61
Theme: Applications

Continuous welded rails, which are used as standard on the UK railway network, are optimised to withstand a specified temperature range centred around a given "stress-free temperature" (SFT). A higher SFT allows the track to handle hotter temperatures before expanding and potentially buckling, but too high an SFT causes brittleness and cracks in cold temperatures. Although rare, derailment caused by buckling can result in catastrophic consequences. Therefore, blanket speed restrictions are currently imposed when the forecast air temperature exceeds a set threshold.

However, these blanket speed restrictions assume that rail surface temperature will be a constant value above the air temperature. This is in contradiction with observation data, which does not show a simple linear correlation between the two. Accurate and reliable modelling of rail surface temperatures would enable the application of more precise, locally-targeted speed restrictions and preventative measures, a need amplified as climate change increases the frequency of occurrence of extreme high temperatures in the UK.

Therefore, the Met Office is currently developing a new rail surface temperature model. This is centred on the Joint UK Land Environment System (JULES), a community model used as the land-surface component of the Met Office Unified Model (UM), but which can also be used – as we do here – as a stand-alone land-surface model. By adapting JULES to model the energy balance of the rail, we are able to produce forecasts of rail surface temperatures.

Output from the rail surface temperature model has been compared to observation data collected at 40 locations across Northern Ireland. Results of this initial analysis will be presented comparing the new model with traditional forecasting methods based on linear relationships with air temperature. This new model has the potential to significantly improve heat-related hazard forecasting across the UK railway network, thus improving the safety and efficiency of the network.

Exploring mathematical formulations for a next-generation compatible finite element dynamical core

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Poster Board Number: 62
Theme: Applications

Compatible finite element methods are attractive for modelling geophysical fluids because they can replicate many of the desirable properties of the Arakawa C-grid, such as good wave dispersion. Compatible finite elements also facilitate alternative grid structures which avoid the clustering of grid points at the poles without the associated downsides these grids have with a finite difference scheme. For this reason compatible finite element methods are used in the Met Office's next-generation dynamical core, GungHo. The mathematical formulation used in GungHo is designed to be similar to that used in the Met Office's previous dynamical core, ENDGame. For instance, GungHo uses an advective form of the momentum equation and the lowest-order finite element spaces

We present an investigation into formulation options, carried out in Gusto, a geophysical fluid toolkit built upon Firedrake, an automated code generation framework for solving PDEs via finite element methods. Gusto shares the same fundamental compatible finite element formulation as GungHo but provides greater flexibility to investigate other choices

Specifically, we investigate the effects of increasing the finite element order on the model. Due to the flexibility of Gusto, we can consider a generally higher order model as well as separately altering the horizontal and vertical orders. We evaluate the impacts of these choices by conducting several test cases considering the short-term fluid dynamics and long-term statistical climate properties.

Dansgaard-Oeschger Events: Challenges of Predicting abrupt Shifts in Multiscale Systems

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Poster Board Number: 63

Theme: Applications

The last glacial period (110-10 kya) was highly unstable, punctuated by millennial-scale climate oscillations termed Dansgaard-Oeschger (DO) events. A DO event is characterised by a rapid increase in temperature (10-16°C in high northern latitudes) over decadal timescales, followed by cooling over extended periods of centuries to millennia. Unlike the anthropogenic climate change we are experiencing today, DO events are quite unique. While the high northern latitudes rapidly warmed, there was simultaneous cooling over large portions of the Southern Hemisphere. Understanding how Earth’s climate was able to undergo these natural ‘tipping points’ is crucial to gaining a greater knowledge of the stability of our current climate under the pressures of global warming. The precise cause of these abrupt shifts is still subject to debate. Building upon the low-dimensional model presented by Boers et al. (2018), we present a stochastic nonlinear model that can induce self-sustaining oscillations through feedbacks between sea ice and the Atlantic Meridional Overturning Circulation. Here, transitions between stadial (cold) and interstadial (warm) states result from bifurcations in an underlying fast subsystem connected to sea ice extent. Changes in the subsurface water temperature in the North Atlantic modulate the duration spent in stadial conditions, with canard trajectories offering explanations for interesting behaviour for sustained stadial periods and smaller transitions that do not trigger full DO events. Our model, therefore, uses a combination of noise and bifurcation in a multiscale system and finds tipping in the fast subsystem. This approach suggests that if early warning signals are present, they may be hard to detect in the timescale of the slower subsystems.

N. Boers, M. Ghil, D.D. Rousseau, Proceedings of the National Academy of Sciences of the United States of America 115, 47 (2018)

Climate Action Co-Benefits and Trade-Offs: How a decision-support tool can be used to assist in understanding the evidence on climate action co-benefits and trade-offs and its application to UK climate policy

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Poster Board Number: 64
Theme: Applications

The University of Leeds in collaboration with the Met Office have produced an online tool to help communicate the co-benefits of climate actions. The tool, known as the Climate Co-benefits Portal, enables the impacts of climate interventions to be explored, highlighting the co-benefits and trade-offs across the economy, ecosystems, energy, health and socio-cultural categories. The co-benefits portal brings together the available scientific evidence to provide an assessment of the impacts associated with 40 different mitigation and adaptation measures at global and continental scales.

The Met Office Knowledge Integration team have produced an information pack to support policy makers using the Portal. The information pack introduces the Climate Co-benefits Portal, provides an overview of information from the portal relevant to UK climate adaptation and mitigation policy, and explores a few example interventions which aim to illustrate the impacts in more detail.

Astroclimes: A synthetic transmission spectra code for measuring atmospheric CO_2

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Poster Board Number: 65
Theme: Observations

Measurements of the atmospheric abundance of greenhouse gases such as CO_2 are crucial to understand and model their effects on climate change. Besides in situ observations that can be taken either day or night, column-averaged measurements of CO_2 are also carried out by satellites such as NASA's OCO-2 and OCO-3 and JAXA's GOSAT-2, as well as by ground-based networks such as the Total Carbon Column Observing Network (TCCON).

Column-averaged measurements are done by analysing the solar spectra in the near-infrared (NIR). When light passes through the Earth's atmosphere, it is left with an imprint based on which gases are present in the atmosphere. This imprint comes in the form of absorption lines, and the absorption lines left by molecules in the Earth's atmosphere are called telluric lines. Each gas absorbs light at specific wavelengths, so their spectral lines can be identified and by measuring the intensity of their spectral lines, the abundance of said gas can be obtained. The aforementioned satellites and network, however, rely on sunlight, so their measurements can only be taken during the day.

Here, we describe a novel method for measuring the column abundance of CO_2 that aims to bridge this gap. Our measurement approach is similar to that of OCO-2 and TCCON, but instead of using sunlight, we analyse the spectra of stars taken by ground-based telescopes. The selected sample of stars is known as telluric standard stars, usually O, B or A type stars that are called telluric standards because they are very hot, thus have very few spectral lines, and rotate very fast, thus the few lines that they do have are broadened, making the stellar lines easy to distinguish from the narrower telluric lines.