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Oral presentations

Extratropical cyclone dynamics and processes (I) — oral session 1

Toward the definition of “Medicane”

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The term Medicane, a portmanteau for Mediterranean hurricane, has been adopted In the scientific literature in different ways, depending on the purpose of the study and the instrument adopted for the analysis. The purpose of the initiative for the definition of "Medicane" is to converge towards a shared definition, which will be able to bring together the numerical and satellite approach, the meteorological and climatological perspectives in a single and complete vision.
Medicanes are generally considered to be baroclinic cyclones that evolve into vortices with structural characteristics similar to tropical cyclones, i.e., axisymmetric, deep warm core with a windless center surrounded by strong winds. The synergy between baroclinic instability and diabatic processes is fundamental for the intensification of Medicanes. Stimulating discussions emerged in some online meetings and in the subsequent debate. While up to now the term Medicane has been used for both cyclones with tropical characteristics and for weaker subtropical cyclones, a certain consensus has been reached in considering the latter category as separate, considering the different convective cloud cover, the fact that a significant part of the energy is received from baroclinic sources and that the area with maximum wind is farther from the center.

A physical descriptor phase space for Mediterranean cyclones.

Juan Jesus Gonzalez Aleman, Michael Sprenger, Heini Wernli

The well-known cyclone phase space (CPS) helps to understand and classify cyclones based on their thermal structure and frontal nature. Extratropical, subtropical, tropical and hybrid cyclones can be then identified in this phase space. However, the CPS is not perfect and many improvements can be developed. For instance, the CPS is limited to only describe the nature of the cyclones without helping us to understand the physical processes occurring in cyclones. Therefore, cyclones with different physical nature can be misidentified.
In this work, we have tried to improve and extend the CPS information by merging it with new information based on a physical phase space (PCA) related to different environmental factors and physical processes that lead to distinct

cyclone nature during the period 1979-2016 in ERA-Interim. First results indicate strong relationship between specific regions in the CPS and in the PCA space, thus helping us to understand the mechanism behind changes in the CPS. This also motivates us to deepen in the analysis of the peculiarities of Mediterranean cyclones, like tropical-like cyclones, medicanes and warm seclusions. In this sense, we aim at creating a novel physical descriptor phase space for Mediterranean cyclones, which could improve overall cyclone classification.

Process-based classification of Mediterranean cyclones using potential vorticity

Yonatan Givon, Shira Raveh Rubin

Mediterranean cyclones govern extreme weather across the basin and into the continents around it, affecting the lives of hundreds of millions. Reliable model prediction and future projections of Mediterranean cyclones (MCs) remain a significant challenge, partly attributed to the large variability among MCs. To this end, past classifications distinguished MCs by their geographical and seasonal occurrence, however, there has been no consideration of a dynamics-based classification, focusing on cyclone genesis and deepening mechanisms. The processes governing cyclogenesis and evolution include diabatic and adiabatic processes, topographic influences, and surface heat anomalies. Here we aim to classify MCs throughout the basin and year-round, according to the potential vorticity (PV) distribution. Based on a combined ('best tracks') MC dataset derived from ECMWF ERA5 from 1979-2020, we classify the tracks based on the upper-level isentropic PV structures relative to the cyclone center at its peak intensity, using the Self Organizing Map (SOM) algorithm. The SOM analysis reveals 9 classes of Mediterranean cyclones, each attributed to a distinct Rossby wave signature. Though classified by upper-level PV, each class shows different PV signatures also in the lower troposphere and different surface anomalies. Each class has distinct cyclone characteristics, associated hazards, and long-term trends. Unique large-scale, thermal, dynamical, seasonal, and geographical features indicate dominant processes in the evolution of each Mediterranean cyclone subset. Furthermore, the tropopause-surface coupling is explored and reveals the importance of topographically-induced Rossby wave breaking to the generation of the most extreme Mediterranean cyclones. These results enhance our understanding of Mediterranean cyclones' predictability, by linking the relatively predictable Rossby wave formations and life cycles to under-predicted cyclonic variability and impact.

Quantifying relationships between measures of extra-tropical cyclone intensity

Joona Cornér, Clément Bouvier & Victoria Sinclair

The intensity of extra-tropical cyclones (ETC) can be quantified with many different measures. These measures include dynamical descriptors, such as vorticity and mean sea level pressure (MSLP) as well as impact-based measures, such as storm severity indices (SSIs). Currently, it is unknown how these intensity measures relate to each other. In this study the relationships between various ETC intensity measures are quantified.
ERA5 reanalysis data from 1979 to 2022 was used to study the ETCs and their intensity measures. The analysis was done for the extended winter season from October to March which is when the strongest ETCs most often occur. ETCs were tracked with values of 850-hPa relative vorticity every three hours as input to the feature tracking software TRACK. To focus on the most relevant ETCs affecting Europe, only tracks in the North Atlantic and Europe were included and stationary and short-lived systems were excluded. The intensity measures were calculated by combining the ETC tracks with parameters from the ERA5 reanalysis. Intensity measures analysed included 850-hPa relative vorticity, MSLP, wind speed at 850 hPa, 925 hPa and 10 m, 10-m wind gust, instantaneous SSI, accumulated SSI and wind footprint. Pearson and mutual information correlations were computed for each combination of the intensity measures. Principal component analysis (PCA) was performed to investigate which intensity measures explain most of the variance of the dataset and sparse PCA was used to design a new reduced feature space.
Vorticity, MSLP and the winds were highly correlated with each other and the wind footprint. The SSIs were correlated weakly with all of the other intensity measures. The wind footprint was found to explain most of the variance in the dataset. Sparse PCA with four principal components indicated that wind speed at 850 hPa connected vorticity with the other wind speed measures. The wind footprint and MSLP appeared as important measures while the SSIs had little to no importance for the performed PCA analysis. Identification of principal components and the

reduction of dimensionality in the set of ETC intensity measures decreases the amount of data needed to comprehensively describe ETCs. It will also guide the choice of input variables to use in a cluster analysis of ETCs.

The Linkage of Serial Cyclone Clustering in Western Europe and Weather Regimes in the North Atlantic-European Region in Boreal Winter

Seraphine Hauser, Sebastian Mueller, Xiaoyang Chen, Ting-Chen Chen, **Joaquim G. Pinto**, Christian M. Grams

Extra-tropical cyclones are an important source of weather variability in the mid-latitudes. Multiple occurrences in a short period of time at a particular location are denominated serial cyclone clustering (SCC), and potentially lead to large societal impacts. We investigate the relationship between SCC affecting Western Europe and large-scale weather regimes (WRs) in the North Atlantic-European region in boreal winter. We find that SCC in low latitudes (45°N) is predominantly associated with the anticyclonic Greenland Blocking WR. In contrast, SCC in mid and high latitudes (55°N, 65°N) is mostly linked to different cyclonic WRs. Thereby, SCC occurs typically within a well-established WR that builds up prior to SCC and decays after SCC. Thus, SCC events are closely associated with recurrent, quasi-stationary and persistent large-scale flow patterns (WRs). This mutual relationship reveals the potential of WRs in forecasting storm series and associated impacts on sub-seasonal to seasonal time scales.

Atmospheric blockings and downstream cyclones in the Euro-Mediterranean sector

Pinelopi Loizou

Weather extremes in Europe and the Mediterranean, namely heatwaves, cold spells, windstorms, and intense rainfall, can significantly affect societies across the region. In a continuously changing climate, their impact, both financially and socially, can worsen with an increase in the frequency and intensity of these extremes. As recent studies have highlighted, some extremes such as heatwaves are connected to atmospheric blocking, while heavy rainfall has been associated with Mediterranean Cyclones (MCs). However, the connection between atmospheric blocking and MCs is still understudied, despite evidence suggesting their mutual importance for exacerbating and synchronizing surface extremes. Here, we aim to systematically investigate how often MCs develop downstream of atmospheric blocks over the Euro-Atlantic region, and how the Atlantic storm track is modulated under such conditions. To this end we employ the combined 'best tracks' MCs dataset with objectively identified blocking features in ERA5 for 1980-2020. We find that in the presence of blocks, MCs that develop downstream tend to be more intense and persistent than other MCs. Moreover, MCs that develop under this scenario form particular subsets of MCs, with preferred seasonality and geographical distribution, compared to all MCs. The results have important implications for predictability of MC impacts in the region on both weather and climate scales.

The upstream downstream connection between North Atlantic and Mediterranean cyclones

Alexander Scherrmann, Heini Wernli and Emmanouil Flaounas

Mediterranean cyclones provide a prominent environmental risk to the region. Their formation is typically triggered by the intrusion of a trough, caused by a preceding Rossby Wave breaking over the North Atlantic. The wave breaking is associated with at least one North Atlantic cyclone, in which warm conveyor belts (WCBs) ascend and amplify the ridge building. So far, there has been only indirect evidence for the connection between an upstream North Atlantic cyclone and downstream Mediterranean cyclones. To fill this gap, we perform semi-idealized simulations with the Weather Research and Forcasting Model, using a climatological atmospheric reference state of different seasons. We perturb the climatological polar jet with a wind anomaly to control the developing dynamics. For the first time, we show and investigate the upstream downstream connection between a North Atlantic cyclone, its WCB and the downstream intrusion of a potential vorticity streamer into the Mediterranean, that triggers cyclogenesis. We will show what characteristics this connection has, how sensitive it is to different atmospheric states, perturbation strengths and locations.

The Eastern Mediterranean - Catastrophic Flash Floods in Antalya-Turkey

Meral Demirta

On 12 December 2022, Finike and Kumluca provinces of Antalya had 253.8 mm and 207.8 mm of rain in 24-hour, respectively, on 12 December 2022. The catastrophic flood damaged 497 vehicles, approximately 100 houses, 920 commercial premises and about 1,200 hectares of greenhouses and farmland. The complex orography surrounding Antalya paves the way for the convergence of low-level atmospheric flows and then the uplift of warm moist air masses that come from the Mediterranean Sea to over the coastal areas, and thereby leading to intense convection. Analysis of atmospheric model products, based on diagnostics and comparison with conventional and remote-sensing observations, indicated that the large amounts of accumulated precipitation were strongly modulated by mesoscale effects induced on the synoptic-scale flow. Numerical experiments are tailored to generate 3-km and 1-km simulations with the Weather Research and Forecasting model with the Advanced Research dynamical core (WRF-ARW). The impact of various microphysics parameterization schemes forced by initial and boundary conditions from the European Centre for Medium-Range Weather Forecasts highlighted the sensitivity to the choice of microphysics parameterization on high-impact rainfall event. Numerical sensitivity experiments are conducted to shed light on the mesoscale aspects of the precipitating structures and their dependence on orography, sea surface temperatures, surface fluxes and latent heating.

Five-year climatology and composite study of precipitation bands associated with extratropical cyclones over the British Isles

Tianhang Zhang and David M. Schultz

A five-year climatology and composite study of precipitation bands associated with extratropical cyclones over the British Isles from April 2017 to March 2022 are constructed. A total of 249 single bands were manually identified from radar network mosaics in association with 167 cyclones identified from surface maps. More bands formed over water near the coast than over inland areas, and most had a meridional orientation. The average lengths of bands at the times of formation and maximum length were 290 and 460 km, respectively; only 20% of bands reached a maximum length exceeding 600 km. The number of bands decreased with increasing duration, with 31% of bands lasting for 2–3 h, with bands lasting more than 10 h uncommon. The bands were classified into six categories, with occluded-frontal bands, warm-frontal bands, and cold-frontal bands being the most frequent. Occluded-frontal and warm-frontal bands commonly occurred west of Scotland and in the east quadrant relative to their parent cyclones. In contrast, cold-frontal bands commonly occurred southwest of Great Britain and in the south quadrant relative to their parent cyclones. Composites for northwest–southeast occluded-frontal and warm-frontal bands west of Scotland, and southwest–northeast cold-frontal bands southwest of Great Britain, show the different synoptic environments that favor bands. The low-level jet transports moisture into the band and is similar to the location and scale of the composite bands, similar to that of an atmospheric river. These results are compared to previous studies on bands from the United States.

Low-level winds jets leading to damaging surface winds in storm Eunice

Suzanne Gray, Ambrogio Volonté, Peter Clark, Oscar Martínez-Alvarado, Duncan Ackerley

Storm Eunice struck the UK with severe gales on 18 February 2022 and then travelled on to impact NW Europe. While Eunice's cyclone structure was well forecast days in advance over the UK, small-scale uncertainty persisted in peak-wind location and strength. Several indications of sting-jet activity were present in observations and model data, and a detailed analysis of Eunice’s airstream structure confirmed its presence during Eunice’s lifecycle. By the time Eunice crossed Wales and Southern England, several other airstreams, including a cold conveyor belt and a dry intrusion, interacted in generating the observed damaging winds. These results illustrate the wind-damage potential of multiple airstreams, including sting jets, in intense cyclones like Eunice, so highlighting the importance of accurate airstream forecasts.

Identification and climatology of high-wind features within European winter storms

Eisenstein Lea, Schulz Benedikt, Pinto Joaquim G., Knippertz Peter

Strong winds associated with extratropical cyclones are one of the most dangerous natural hazards in Europe. These high winds are mostly associated with five mesoscale dynamical features: the warm (conveyor belt) jet (WJ); the cold (conveyor belt) jet (CJ); cold frontal convection (CFC); strong cold-sector winds (CS); and, in some cases, the sting jet (SJ). The timing within the cyclone's life cycle, the location relative to the cyclone core and further characteristics differ between these features and, hence, likely also their associated forecast errors.

We recently introduced the objective and flexible identification tool RAMEFI (RAndom-forest-based MEsoscale wind Feature Identification), which distinguishes between WJ, CFC and CS as well as CJ and SJ combined. RAMEFI is based on a probabilistic random forest trained on station observations of 12 storm cases over Europe. Being independent of spatial distribution, RAMEFI can also be applied to gridded data.

Here, we use RAMEFI to compile a climatology over 19 extended winter seasons (October--March, 2000-2019) based on high-resolution regional reanalyses of the German Consortium for Small-scale Modelling (COSMO) model over Europe. This allows the first-ever long-term objective statistical analysis of the mesoscale wind features, their occurrence frequency, geographical distribution and characteristics. For Western and Central Europe, we demonstrate that the CS is prominent in most winter storms, while CFC is the least common cause of high winds, both in terms of frequency and affected area. However, probably due to convective momentum transport, CFC is on average the cause of the highest gusts after the CJ, and has the highest gust factor. As expected, CFC high-wind areas show high levels of humidity and overcast conditions. In contrast, CS is characterised by sunnier conditions interspersed by patchy cumulus clouds leading to a broader cloud cover distribution than for other features. The WJ produces the weakest winds on average, but affects a larger area than CJ. Central Europe is more strongly affected by WJ and CFC winds, while the CJ usually occurs farther north over the North and Baltic Seas, northern Germany, Denmark and southern Scandinavia. System-relative composites show that WJ and CFC tend to occur earlier in the cyclone life cycle than CJ and CS. Consistently, CS is the most common cause of high winds over Eastern Europe, where cyclones tend to occlude, represented by a narrowing warm sector and weakening cold front. The WJ mostly occurs within the southeastern quadrant of a cyclone bordering with the narrow CFC in the west. However, the location of CFC varies greatly between cases and timing. The CS occurs in the southwestern quadrant, while the CJ appears closer to the cyclone centre, sometimes stretching into the southeastern quadrant.

This objective climatology largely confirms previous, more subjective investigations but puts these into climatological context. It allows a more detailed analysis of feature properties, and provides a solid foundation for model assessment and forecast evaluation in future studies.

A global climatology of sting-jet cyclones

Ben Harvey, Ambrogio Volonte, Oscar Martinez-Alvarado, Suzanne Gray

Sting jets have been identified in some of the most damaging mid-latitude cyclones that have affected the UK since their first identification in 2004 from a re-examination of observations of the 1987 Great October Storm. Sting jets are coherent airflows that descend over a few hours from within the cloud head, a band of cloud that hooks poleward around the centre of intense cyclones. These jets are distinct from the other longer-lived, broader-scale and much better characterised near-surface wind jets. While their wind footprints are typically just 50-100 km across, they can lead to distinct regions of exceptionally strong near-surface winds, and damaging gusts.

Our understanding of the dynamics of sting jets has advanced considerably since their first identification, but mostly through analysis of case studies of cyclones crossing the North Atlantic to affect northwest Europe. A single case of sting-jet activity originating in the Mediterranean has been published, but no published cases exist for other mid-latitude regions and published climatologies only cover the North Atlantic. Despite this, there are no known physical reasons why sting jets should not develop over other oceanic basins and the type of atmospheric instability associated with sting jets has been shown to be widespread over the mid-latitude oceans.

We will present first results from a project to produce the first global climatology of sting-jet cyclones and characterise the differences between these cyclones and cyclones that do not contain sting jets. A sting-jet precursor algorithm has been applied to intense midlatitude cyclones in both hemispheres possessing a warm seclusion at

maturity to identify those that are likely to produce sting jets. This research will reveal whether the hazardous winds that can result from sting jets reaching the ground should be considered by weather forecasters outside the Euro-Atlantic region.

Global analysis of cyclone-induced compound precipitation and wind extreme events

Martina Messmer and Ian Simmonds

Extreme events can have a major impact on society and ecosystems and pose a significant challenge to scientists. The occurrence of extremes in two or more meteorological parameters, so called compound events, add an additional level of complexity, especially when considering the ongoing warming of the Earth's climate. We present a new global climatology of compound events that involve extreme precipitation and extreme wind and that are triggered by low-pressure systems. The analysis employs the 3-hourly ERA5 reanalysis (1979–2018) and two independent cyclone detection and tracking algorithms, both of which provide a quasi-Lagrangian perspective. In the analysis, firstly, spatially large and coherent individual extremes in the accumulated precipitation and maximum 10-m wind gust fields are identified. Then cyclone tracks that have both an extreme precipitation and extreme wind event are considered as compound extremes, and these account for 2–3% of the total number of cyclones. The main areas where compound extremes occur depend on the season but can be summarised as the regions over North America, Japan, the Mediterranean, Australia and regions with high tropical cyclone occurrence. In most of the compound events, either both extremes occur at the same time during the cyclone's lifespan or the precipitation extreme sets in earlier than the wind extreme. There is little difference between the geographic distributions of compound and single precipitation extremes, and a similar comment applies to the wind extremes. However, it is striking that the lifetime of cyclones involved in single precipitation extremes are 48% or 60% and single wind extremes are 64% or 82% of the duration of cyclones associated with compound extremes, depending on the tracking algorithm. The duration of single precipitation extremes is depending on the algorithm 48% or 53% as long as compound extremes, while this number is further reduced to 48% or 51% in wind extremes. This shows that the single precipitation extremes are proportional to the shorter cyclone lifetime, while the duration of wind extremes are disproportionally reduced with respect to the lifetime in single extremes, indicating that especially wind extremes in compound events can profit from the simultaneous presence of precipitation extremes.

Cyclonic compound 'wet' and 'windy' extremes in the Eastern Mediterranean

Assaf Hochman, Eylon Vakrat

Compound extremes, which refer to the co-occurrence of extreme weather events that result in greater socio-economic impacts than the sum of their components, are difficult to predict in advance. We focused on the 'wet' and 'windy' extremes associated with Eastern Mediterranean cyclones in winter. The study provides new insights into the dynamics of compound extremes in the region by combining different analytical techniques, including a synoptic classification algorithm and dynamical systems theory. In summary, the dynamical systems perspective is a valuable addition to comprehending the dynamics of compound extremes in the Eastern Mediterranean. We anticipate that this approach will be beneficially utilized in other regions and for other compound extremes.

A model intercomparison project (MIP) to improve predictions of Mediterranean cyclones

Florian Pantillon and the MedCyclones MIP team

Cyclones are essential elements of the climate system and water cycle but also major natural hazards in the densely populated Mediterranean basin. In the framework of the COST Action "European network for Mediterranean cyclones in weather and climate - MedCyclones", a model intercomparison project investigates the dynamics and predictability of case studies using modelling setups that are not yet available to operational forecasting systems. The intercomparison involves 10 sets of simulations based on 5 mesoscale models and multiple combinations of physical parameterizations. All sets include the same sensitivity simulations to initial and lateral boundary conditions and horizontal resolution.

Here we focus on tropical-like cyclone (Medicane) Ianos that hit Greece in mid-September 2020 and was poorly predicted by operational forecasts. Models systematically perform better when initialized from operational IFS analysis data compared to the widely used ERA5 reanalysis. Reducing horizontal grid spacing from 10 km (convection-parameterized) to 2 km (convection-permitting) further improves the cyclone track and intensity. This highlights the critical organization of convection prior to and during the early cyclogenesis for the phasing with an upper-level jet. Higher resolution enhances convective activity and favorably preconditions the jet, which controls the subsequent cyclone intensification and evolution.

The 10 sets of simulations show robust agreement but also reveal model specificities such as the possible need for a convective parameterization even at 2 km horizontal grid spacing. While they require generalization to other cases of Mediterranean cyclones, the results provide guidance for the next generation of global convection-permitting models in weather and climate.

Enhancement of the predictability of intense Medicane via warmer SST

Claudio Sanchez, Suzanne L. Gray, Ambrogio Volonte, Florian Pantillon, Segolene Berthou

The Mediterranean basin host unique cyclonic systems, termed Medicanes, whose genesis is driven by mid-latitude processes such as baroclinic forcing, but which can develop tropical-like characteristics such as a cloud-free eye and an axisymmetric warm core. Medicane Ianos was one of the most intense Medicanes ever recorded, it transited through the Ionian Sea between 15-18 September 2020 from the Gulf of Sidra to the Greek Ionian Islands where wind gusts above 50 m/s were observed on landfall. Ianos was only well predicted by the ECMWF ensemble system two days ahead of landfall; half of its members missed its intense growth in earlier forecasts.

We investigate the predictability of Ianos using the regional configuration of the MetOffice Unified Model (MetUM) at 2.2 km grid spacing, driven by the IFS-Analysis. Simulations are initialized every 12 hours from 00Z 14 to 00Z 16 Sept. 2020, and run for 5 days. The role of sea-surface fluxes in the development and intensification of Ianos is explored with the use of two additional sets of experiments, with 2K and 2K cooler sea surface temperatures (SSTs). All the simulations with warmer SST are able to simulate Medicane Ianos, whereas those with cooler SST fail to capture it with the exception of the simulation initialised at the latest time. The representation of the convective activity over the Sidra Gulf one day ahead of the cyclonegesis seems critical, as well as its impact on the upper levels via the development of a diabatically-forced low-PV bubble inside the PV streamer. A Semi-Geostrophic inversion model is employed to understand the contribution from diabatic processes, enhanced in the warmer SST simulations, to the formation of the low-PV bubble and Ianos intensification. The role of the low-PV bubble in Ianos's baroclinically-driven genesis and enhancement is explored with the use of a model and Quasi-Geostrophic omega equation.

Extreme weather forecasting at kilometre-scale: insights from two case studies within the Destination Earth Initiative

Estibaliz Gascon, Michael Maier-Gerber, Benoît Vannière, Irina Sandu, Linus Magnusson, Josh Kousal, Inna Polichtchouk, Kristian Mogensen

This presentation will provide some examples of the research conducted at the European Centre for Medium-Range Weather Forecasts (ECMWF) within the Destination Earth initiative of the European Commission. The focus of this initiative is on the development of the global continuous component of the Weather-induced and Geophysical Extremes Digital Twin (Extremes DT) of the Earth, which will provide unprecedented precision in forecasting and monitoring extreme weather events worldwide within a five-day range.
We present here the analyses carried out for two extreme case studies (from 20 cases that have been examined in the period from 2016 to 2022 in the framework of the initiative), namely Medicane Ianos (September 20202) and an Atlantic cyclone with Mediterranean transition (Storm Alex in October 2020). Various model experiments will be used to evaluate the impact of horizontal resolution, ocean-atmosphere coupling, different model versions, and different forecast initializations on the correct prediction of these extreme weather events. At present, the Extremes DT utilizes ECMWF's Integrated Forecasting System cycle 48r1, with a Tco2559 grid (around 4.5 km horizontal resolution). In addition to comparing the performance of these simulations with the current ECMWF's operational deterministic 9km forecasts (and possibly against higher resolution forecasts), the simulations will be validated with high-density observations and model analyses.
This research shows some of the significant benefits of higher resolution in predicting near-surface fields in specific case studies, in particular large precipitation amounts in regions with high orography, as well as the potential for improving medicane forecasts (both location and intensity). Nevertheless, certain variables, such as maximum wind gusts, require additional development (i.e. enhancing data assimilation, reviewing some parametrization formulations, etc.) as well as evaluation using high-density observations. The conclusion of this study suggests that in order to achieve these goals, it is necessary to improve other aspects of the global models along with increasing the resolution. Ultimately, this work offers valuable insights into strategies for evaluating and improving earth system models at kilometre scales.

Investigating the predictability of Mediterranean cyclones and their severity

Benjamin Doiteau, Florian Pantillon, Matthieu Plu, Laurent Descamps, Thomas Rieutord

Cyclones are essential elements of the climate and of the water cycle in the Mediterranean. The most intense of them lead to natural disasters because of their violent winds and extreme rainfall, which can cause significant damages to the territories bordering the Mediterranean (coast and mountain ranges). Reliable cyclone forecasts are therefore essential to anticipate and prevent their societal impact. However, their predictability is often limited by their particularities: smaller cyclones with a shorter life cycle than in the North Atlantic, complex topography, interactions with the relatively warm sea and air masses laden with dust from the Sahara.
We investigate the predictability of Mediterranean cyclones in a systematic framework using an ensemble prediction system. A reference dataset is first obtained by tracking cyclones in the ERA5 reanalysis (1979-2022), using an algorithm developed for the North Atlantic and adapted for the Mediterranean region. The predictability is then investigated using ARPEGE ensemble reforecasts in a homogeneous configuration over 22 years (March 2000 – February 2022).
In a first step the predictability in the reforecasts is quantified using probabilistic scores on cyclone trajectories (along and cross track error) and on intensities (mean sea level pressure and relative vorticity). We show the evolution of predictability with lead time, but also the dependency of the predictability to the cyclone severity using a storm severity index based on wind gusts. In a second step, the cases are divided in several categories following their dynamical context, their intensity and their geographical origin. The predictability in the reforecasts is quantified in each of those categories to link the loss of predictability with particular types of cyclones.
While past studies have been limited by regular updates of operational forecasting systems that do not allow the predictability of cases to be compared with each other, the homogeneous configuration of the ARPEGE ensemble reforecasts makes it possible to systematically identify the limitations to the predictability of Mediterranean cyclones.

Seasonal forecast skill of severe winter windstorms over Europe and assessing the influence of dynamical factors.

Lisa Degenhardt, Adam A Scaife, Gregor C Leckebusch.

A skilful prediction of severe winter windstorms is of great interest especially on a seasonal scale. Previous studies have shown that these extreme events are predictable in terms of storm frequency and intensity over Europe. This study investigates which dynamical factors are the most important for achieving and improving current storm forecast skill.

Our investigation is performed with the seasonal forecast system of the UK Met Office, GloSea, validated with reanalysis, ERA5, for 23 winter seasons.

Windstorms are tracked with an impact-based algorithm, tracking about the top 2% strongest wind events over the North-Atlantic and Europe. The dynamical factors are selected based on their known connectivity to windstorms or cyclones, like the strength of the MSLP gradient, SST, Eady Growth Rate and others.

As expected, the most influential factors for windstorms or cyclones also show the strongest connection to windstorm seasonal forecast skill. MSLP gradient, SST, equivalent potential temperature, and Eady Growth Rate in the upper troposphere are all skilfully forecasted, and a skilful prediction of these dynamical factors increases the forecast skill of severe winter windstorms. Other factors show a connection to windstorms but lack forecast skill in relevant regions. This could be indicative of a pathway for potential improvement of winter windstorms seasonal forecasts over Europe.

Future changes to risk from extratropical wind storms in Europe using Lagrangian feature tracking

Jennifer L Catto, Matthew Priestley, Alex Little

European wind storms are a key cause of socioeconomic losses due to the damage they inflict with their strong winds. Projections of future losses from such storms are subject to uncertainties associated with the projected frequency and tracks of the storms, their intensities and how these are defined, as well as future socio-economic scenarios. Here we use two storm severity indices (SSIs) calculated through application to cyclone foot prints found by Lagrangian objective identification: one based purely on the intensity of the storms, and one weighted by population density. We apply these to cyclones from a multi-model ensemble of state-of-the-art climate models. We consider the impact of mitigation by considering two different future socio-economic scenarios, and consider the impact of adaptation by using both the historical wind thresholds and the future projected wind thresholds.
We find that due to robust increases in storm frequency across parts of northern and central Europe, the storm severity index based only on wind speeds more than doubles over this region. By using future estimates of population consistent with the emissions scenarios, we find the population weighted storm severity index more than triples, due to the projected increases in population. This implies considerable increases in socio-economic impact, especially over the main urban centres of Europe. By adapting to the increasing wind speeds, taken into account by using a future damage threshold, we find that the population weighted storm severity index increases are only partially offset, despite a reduction in the meteorological storm severity through adaptation. Through mitigating projected climate change, the future increase in risk can be reduced, with the population weighted storm severity index increase being more than halved for the lower emissions scenario.

The impacts of European windstorms based on regional climate models and insurance perspective

Inovasita Alifdini, Julia Moemken, Joaquim G. Pinto, Alexandros Georgiadis, and Aidan Brocklehurst

European windstorms are among the natural hazards with the highest economic losses. We investigate the impact of European windstorms under recent and future climate conditions at high spatial resolution. With this aim, we use hourly surface wind speed and gust data at 30 km resolution from ERA5 reanalysis for 1959-2021, and 3-hourly surface wind speed data and daily maximum surface wind gust data at 12.5 km resolution from 60 (wind speed) and 40 (wind gust) different global-to-regional climate model (GCM-RCM) chains from EURO-CORDEX (EUR-11). The windstorm activity is compared in 30-year periods from the historical events (1976-2005) to the future events (under RCP8.5 scenario) at global warming levels (GWL) of +2°C and +3°C. We apply different indices (meteorological index and loss index) to quantify the severity of windstorms and to estimate the corresponding impacts. The rank of top big storms from ERA5 data shows consistency with the rank of storms from Aon Impact Forecasting model. The results from the EURO-CORDEX ensemble show only small changes in windstorm activity between the historical period and the different GWLs, but display considerable decadal variability. Under global warming levels of +3°C, there is a significant decrease in windstorms over Mediterranean, Ireland, the southern UK, and part of France.

Windstorm losses in Europe - What to gain from damage datasets

Julia Moemken, Gabriele Messori, Joaquim G. Pinto

Windstorms are among the major natural hazards affecting Western and Central Europe. Information on associated impacts and losses are essential for risk assessment and the development of adaptation and mitigation strategies. In this study, we compare reported and estimated windstorm losses in five datasets, which belong to one of the following categories: Indices that combine meteorological and insurance aspects, natural hazard databases, and loss reports from insurance companies. We analyse the similarities and differences between the datasets for the period October 1999 to March 2022 in 21 European countries, focusing on reported events, the number of storms per dataset and the ranking of specific storm events. A total of 94 individual windstorms were documented. Only 11 of them were reported in all five datasets, while a large majority (roughly 60%) was solely recorded in single datasets. The results further reveal that the datasets often do not match in terms of the total number of damaging storms and the number of events per winter season. Furthermore, the storm ranking based on reported/estimated losses varies in the datasets. However, these rank differences are usually reduced when computing the ranking relative to storm events that are common in the various datasets. In summary, the datasets provide different views on windstorm impacts. This makes it difficult to define which dataset is good or bad in providing information on windstorm losses. We conclude that a combination of different datasets is crucial to obtain a representative view of windstorm associated impacts.

A framework for understanding the correlation between aggregated losses of compound events.

Toby P. Jones, David B. Stephenson, Matthew D. K. Priestley

The risk from individual natural hazards (such as extratropical cyclones) can be large, but the aggregate loss over yearly timescales is significantly greater. For example, the three major European windstorms in February 2022 caused more than €3.5 billion of insured losses due to wind damage.
This study proposes a random sum modelling framework for understanding the correlation between aggregate risks that occur from compound events. By considering the frequency and intensities of compound events to random variables, the framework provides an expression for correlation between two aggregate losses from compound events.
The framework shows that this correlation will generally increase monotonically towards one as the dispersion (clustering) of the number of events increases. Under certain conditions, the correlation will always monotonically increase with dispersion.
The framework has been illustrated by applying it to annual sums from 1980-2020 using wind speed and precipitation as proxy measures for insured loss. This is calculated from ERA5 reanalysis data which includes 39587 storm events and covers the European region and Atlantic Ocean (from 30°N 100°W to 75°N 40°E).
The framework performs well, capturing the general behaviour of the correlation, with large positive correlation over the N. Atlantic Ocean and weaker correlations over European land regions.

From High Waters to High Stakes, Attributing Acqua Alta Events in Venice to Climate Change and the Efficacy of MoSE adaptation strategy

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This study investigates the attribution of Aqua Alta (flooding) events in Venice to climate change. We use analogues of atmospheric patterns from three most devastating events in the lagoon to evaluate the influence of climate change on these events. Our results provide compelling evidence that climate change is responsible for the increasing frequency and severity of these events. We also evaluate the cost and benefit of the MoSE system, which was designed to protect against flooding. Our analysis shows that the MoSE system has already provided protection against analogues of the most extreme events, which occurred in 1966 and 2018, while for unprecedented events such as 2019 damages can still be important. These findings have significant implications for the future of Venice and other coastal cities facing similar challenges from rising sea levels due to extreme events. This study also provide a pathway to evaluate the effectiveness of adaptation & mitigation strategies against weather extreme events affected by anthropogenic climate change

The cold front identification scheme MedFTS_DT in the Mediterranean and the estimation of related frontal precipitation

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It is well known that extreme precipitation events are frequently connected to the presence or passage of cold fronts. The MedFTS_DT scheme has been developed for the automated and objective identification of cold fronts and it has been verified and optimized for the region of the Mediterranean. It is based on the combination of wind related and thermal criteria. The wind criteria are prerequisites for the identification of Mediterranean cold fronts, while the thermal criteria provide a stricter filter that serves to limit the initial number of identified fronts. The MedFTS_DT scheme appears to be a very effective tool for the identification of individual cold fronts in the Mediterranean and, furthermore, for the generation of an objective full climatology of cold fronts in the Mediterranean. The spatial distribution and frequency of cold fronts are calculated over the Mediterranean on a monthly, seasonal and yearly basis. The spatial distribution of the total precipitation (TP) and the frontal-induced precipitation (FP) are also calculated for the same region and basis. The contribution of cold fronts to the total precipitation (FP/TP) is then calculated. It is observed that, in general the local maxima of FP agree well with the corresponding maxima of frontal activity. It also becomes evident that, contrary to the TP regime, the maxima of FP are not found over the main mountain ranges of the Mediterranean regions, suggesting that orography does not play an important role in the formation of FP.

Return levels of extreme European windstorms, their dependency on the NAO, and potential future risks

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European windstorms experience considerable interannual variability, which makes the quantification of extreme return periods challenging. Estimating 200-year return levels is also complicated by having only ~60 years of comprehensive observational data. Such estimations of return periods are often performed using 'catastrophe models', which use complex calibration and tuning processes. We have developed a reliable statistical model to estimate extreme windstorm gust speed return levels from only a multi-year sample of windstorm footprints without the need for the complexities associated with catastrophe models.
We have also been able to include variations of the NAO in our estimates, allowing for the generation of NAO-dependent return levels. Positive phases of the NAO result in larger return levels across the northwest of Europe. Additionally, the NAO is shown to be especially important for modulating low return period gusts, with the most extreme gusts occurring due to further stochastic processes. Using plausible future states of the NAO we also show that return levels have the potential to increase significantly in the next 100 years to rise well above historical uncertainty levels.

Using seasonal forecasts to enhance our understanding of extreme windstorms

Jacob Maddison and Sandra Hansen

Windstorms pose continual risk to Europe, threatening infrastructure, life and billions of pounds in insured losses. Insurers (and reinsurers) therefore need to prepare for the potential cost of extreme windstorms. Here, the most extreme windstorms that could potentially occur in the current climate are estimated using seasonal forecast data together with a cyclone-tracking algorithm, and their potential losses quantified using a Storm Severity Index (SSI). Nearly 700 extended winter seasons of forecast data are analysed, representing a much larger sample of potential windstorms compared to that available from reanalysis or observational products. This dataset provides a valuable reference for validating and building catastrophe risk models, for understanding worst-case storms, windstorm variability, clustering, cross country correlation, and more. The storm track is reasonably well represented in the seasonal forecast data: spatial features are similar to those in a reanalysis, but there exists a slight poleward bias and underestimation of number of storms per season (maximal underestimation of around 10%). Additionally, distributions of SSI values for several countries in Europe are similar in the forecast data and reanalysis. Together, these features suggest the seasonal forecast data is suitable for analysing windstorm statistics and informing on potential extreme storms.

Impacts of global warming on the development of extratropical cyclones in idealized simulations

Ting-Chen Chen, Hilke S. Lentink, Christoph Braun, Aiko Voigt, Joaquim G. Pinto

This study investigates the impact of global warming on extratropical cyclone development using idealized experiments. We perform baroclinic life cycle simulations using the ICON model with a limited-area, f-plane, and channel setup. Six experiments are conducted with varying initial conditions for a controlled or warmer climates, such as uniformly increasing the atmospheric temperature, increasing both temperature and specific humidity, and changing the meridional temperature gradient (derived from the CMIP6 future projection). Furthermore, two model resolutions of 80 and 2.5 km are tested to assess the impact of resolution and link the high-resolution idealized simulations with the low-resolution global climate model outputs.
To study how various dynamic and thermodynamic processes contribute differently to the deepening of extratropical cyclones among these experiments, we apply the pressure tendency equation (PTE) analysis. As PTE provides a quantitative assessment of effects such as diabatic processes, horizontal temperature advection, and vertical motions, it helps to understand better how extratropical cyclone dynamics and structure may respond to different patterns of global warming.

Unravelling the large scale forcing of projected drying in the Mediterranean region

Benny Keller & Chaim Garfinkel

Which forcings and processes govern the projected future drying of the Mediterranean region as CO_2 concentrations rise, and how do they interact? An intermediate-complexity moist general circulation model is used to investigate the precipitation response to climate change in the Mediterranean region. In particular, we examine stationary wave changes forced by land–sea contrast, zonal heat fluxes in the ocean, and topography, coupled with a quadrupling of initial CO_2 concentrations. Eight different combinations are formed from the three forcings, and the linearity and additivity of the response are investigated. An expected decrease in precipitation over the Mediterranean region is found, accompanied by a strong anomalous ridge, with a significant difference in magnitude between the south-east and north-west of the region, as shown in previous studies. New results suggest that horizontal heat fluxes in the ocean may be a major forcing for future Mediterranean drying, especially over the eastern Mediterranean in winter. The influence of the land-sea contrast is found to be more complex than previously shown, varying from west to east and from north to south of the Mediterranean basin, suggesting further dynamics governing the response in each area. In an attempt to break down the influence of several components of the thermodynamic condition in the Mediterranean, we isolate geographical elements (the Mediterranean, continental Europe, etc.) and examine the precipitation and geopotential height field response, in hope to refine the future projection and better understand the dynamics governing it.