# 2nd MedCyclones & 9th European Storm Workshop

**Centre International de Conférences, Météo-France, Toulouse, France**

**28-30 June 2023**

# Posters presentations

## Forecasts and predictions from weather to climate scales — poster session 2

### Some results on simulation of wind over rugged terrain using OpenFOAM in parallel processing systems

**Neki Frasheri**

Results for simulation of wind over rugged terrain solving Navier-Stokes equations with OpenFOAM software in parallel systems are presented. Terrain in Albania is two-thirds mountainous with mostly narrow valleys, which makes necessary high spatial and temporal resolution of digitized models; as part of Adriatic Sea shoreline the country is subject to strong winds and bad weather. Scalability and calculation times were evaluated and limitations of the method analyzed.

### Mediterranean Cyclones in the IPSL GCM

**Stella Bourdin**, Sébastien Fromang

Recent advances in High-Performance Computing (HPC) enable many modeling centers to perform multi-decadal climate simulations with a horizontal resolution of up to 25 kilometers. The IPSL also benefited from the recent development of the new and highly scalable icosahedral dynamical core DYNAMICO, allowing full advantage of these recent HPC architectures. In this context, the IPSL performed four 65-years long atmosphere-only simulations following the HighResMIP protocol at horizontal resolutions from 200km to 25km.
In this study, we track cyclones occurring in the Mediterranean Sea in these simulations, focusing on warm-core tropical-like cyclones (medicanes).
We had previously shown that the increase in resolution improves tropical cyclones' climatology in our model. Frequency and intensity increase significantly as structures are better resolved. This result holds for medicanes.
In the 25km simulation, our model simulates Mediterranean cyclones with characteristics of medicanes, including symmetrical structure, warm core, and eye. We establish the climatology of these phenomena in our model, focusing on genesis.

### Testing sub-km simulations for Medicane Ianos with HARMONIE-AROME within the context of Destination Earth's on-demand extremes project

**Juan Jesus Gonzalez Aleman**, Javier Calvo, Samuel Viana, Daniel Martin, Carlos Calvo Sancho

Very high-resolution or sub-kilometric simulations are becoming more and more frequent thanks to the increase of modelling knowledge and computational resources. In the Destination-Earth on-demand extremes project we aim at forecasting extreme meteorological events at these resolutions.
Within this context, in this work we try to test this kind of simulations on a specific problem which is highly sensible to increasing resolution: A strongly convective tropical-like cyclone (Medicane Ianos) over the Mediterranean Sea. Ianos was a rare Mediterranean tropical-like cyclone that impacted the eastern Mediterranean on 17 and 18 September 2020, especially Greece, leaving severe damage. Operational forecasts of this event were not highly valuable, thus it is another reason for a highly recommended case study.

### Investigating Ensemble Forecast Simulations of Mediterranean Tropical-Like Cyclones (Medicanes) Using the ECMWF Integrated Forecast System.

**Miriam Saraceni**, Lorenzo Silvestri, Peter Bechtold, Paolina Bongioannini Cerlini

Simulating Mediterranean tropical-like cyclones, "Medicanes" is a difficult task due to the complexity of the processes involved, to the contrast in the density of observations between land and sea, and to the complex orography of the region. Medicanes present a multiscale nature and their track, intensity, and intensification processes have been recognized as very sensitive to different physical parameterizations in multi-physics modeling approaches. Thus, improving the accuracy, and reliability of forecasts for these cyclones is a complex task that requires advances in both large and convective-scale initial condition uncertainty representations, as well as knowledge of the processes involved in their formation and maintenance. This study indeed is aimed at forecast improvement and at understanding medicanes and the physical process involved in using ensemble forecast simulation. The objectives of the work are to investigate the simulation of medicanes intensity, tracks and intensification dynamical and physical processes using the European Centre for Medium-Range Weather Forecast (ECMWF) Integrated Forecast System (IFS) ensemble forecasting system and compare ensembles with the inclusion of the physics uncertainties and ensembles with the inclusion of initial conditions uncertainty. The investigation of the intensification processes is specifically carried out through the analysis of the moist static energy conservation. This way we hope to gain a better understanding of the radiative, convective, and dynamic feedback mechanisms that drive cyclone intensification. Thus, a comparison between three ensemble forecast experiments is set up. One ensemble is run with only initial condition perturbation (Ensemble Data Assimilation, EDA), one is run with the perturbation of physical parameterizations, and one is run with only the convective parameterization perturbations. The physical parameterization perturbation has been carried out employing the Stochastically Perturbed Parametrisations (SPP), a novel but promising scheme developed at ECMWF. The study is carried out for three medicanes, among the strongest in recent years: Ianos, Zorbas, and Trixie. The impacts of the ensemble forecast perturbations on the simulation of the three medicanes, in terms of track and intensity, are presented. It is also found that, in general, the forecasts are accurate at reproducing both the thermal structure and symmetry of the cyclones in comparison to the operational analysis value. The differences between the various experiments in cyclones intensification are underlined and the analysis of the physical processes involved is presented. Given, that the ECMWF ensemble forecasts model can adequately reproduce medicanes with their tropical-like features, this work underlines the potential of using ensemble forecasting to reproduce and analyze these types of Mediterranean cyclones, improve our understanding of them and their physical processes, as well as enhancing the accuracy and reliability of their forecasts.

### Can lightning data assimilation improve the lightning forecast? An application over Italy with WRF.

**Stefano Federico**, Rosa Claudia Torcasio, Martina Lagasio, Barry H. Lynn, Stefano Dietrich

Lightning is a distinctive feature of thunderstorms and is a precise indicator of the location of deep convection. It is a threat to life and property, and it is an important issue for electrical companies, leads to forest fires, and, in general, dangerous for outdoor activities. A lightning forecast could be used to mitigate the impact of lightning threats.

Recently, Federico et al. (2022) showed good performance for the next-day lightning forecast over Italy, and the present study considers the problem of improving short-term forecasts through Lightning Data Assimilation (LDA). Lightning can be assimilated with variational techniques and nudging and has shown its potential in predicting several intense meteorological events over many different countries around the world.

We show the results of a two-seasons experiment with LDA over Italy using a Very Short-Term forecast approach (VSF). In this approach each simulation is divided in two phases with a 6h forecast following a 6h lightning data assimilation phase. Four simulations are required to complete the forecast of a whole day. Two seasons are considered: Summer 2020 and Fall 2021. Summer and fall are the seasons with the largest number of lightning occurrence over Italy.

The nudging method of Fierro et al. (2012), widely applied over Italy in several studies (Torcasio et al., 2021; Federico et al., 2017 for example), is used for lightning data assimilation (LDA), while lightning is forecast by the Lynn scheme ("Dynamic Lightning Scheme;" Lynn et al., 2012) with the WRF model. The model is run at 3 km horizontal resolution and with 50 vertical levels. Lightning data are provided by the LINET network (Betz et al., 2009) that provides high-quality lightning observations over Italy. These data are used for both LDA and for the lightning forecast verification. The analysis is considered for the 0-3h and 3h-6h forecast periods and the impact is analyzed for precipitation and the lightning forecast. Precipitation is verified using more than 4000 rain gauges quite homogeneously distributed over Italy.

Results for the first 3h of forecast after the assimilation phase show the improvement of both precipitation and lightning forecast for Summer and Fall. The improvement of rainfall forecast is up to 80 mm/3h, showing the potential of LDA for a better prediction of high precipitating convective storms, while the improvement of lightning prediction is mainly over the land for summer and mainly over the sea for fall, following the seasonal distribution of lightning. Results for the 3h-6h phase show a negligible of LDA on the precipitation and lightning forecast, limiting the impact of LDA to the first few forecast hours.

### Mediterranean cyclones and severe weather warnings in Sofia, Bulgaria

**Stanislava Tsalova**, Krasimir Stoev, Anastasiya Stoycheva, Guergana Guerova

Mediterranean cyclones are the dominant synoptic scale patterns with a major impact on severe weather phenomena and are associated with 70% of weather related economical losses in Bulgaria. Since 2009 the Bulgarian National Institute of Meteorology and Hydrology (NIMH) has issued 24-36 h ahead severe weather warnings as a contribution to the European Meteoalarm System (www.meteoalarm.org). The NIMH issued around 400 weather warnings only for Sofia for heavy rain with risk of flooding, severe thunderstorms and heat waves for the period 2010-2021. The GNSS derived Integrated Water Vapor (IWV) from the Bulgarian IGS station in Sofia will be used in conjunction with circulation classification types to analyze the water vapor transport for the days with Meteoalarm weather warnings in the region. A monthly climatology for issued warnings with yellow, orange and red codes for Sofia will be prepared and analyzed, devided into warm months (May - September) and cold months (October - April). Two case studies will be presented with synoptic analysis for severe weather in Sofia due to Mediterranean cyclones in both warm and cold season: 1) for rain and wet snow in January 2019 and 2) for heavy rain and thunderstorms in June 2018.

### Assessing the coastal hazard of medicane Ianos through ensemble modelling

**Christian Ferrarin**, Florian Pantillon, Silvio Davolio, Marco Bajo, Mario Marcello Miglietta, Elenio Avolio, Diego S. Carrió, Ioannis Pytharoulis, Claudio Sanchez, Platon Patlakas, Juan Jesús González-Alemán, and Emmanouil Flaounas

On 18 September 2020, medicane Ianos hit the western coast of Greece resulting in flooding and severe damage at several coastal locations. In this work, we aim at evaluating its impact on sea conditions and the associated uncertainty through the use of an ensemble of numerical simulations. We applied a coupled wave-current model to an unstructured mesh representing the whole Mediterranean Sea, with a grid resolution increasing in the Ionian Sea along the cyclone path and the landfall area. To investigate the uncertainty of modelling sea levels and waves for such an intense event, we performed a multimodel ensemble of ocean simulations using several coarse (10 km) and high-resolution (2 km) meteorological forcings from different mesoscale models. The performance of the ocean and wave models was evaluated against observations retrieved from fixed monitoring stations and satellites. All model runs emphasized the occurrence of severe sea conditions along the cyclone path and at the coast. Due to the rugged and complex coastline, extreme sea levels are localised at specific coastal sites. However, numerical results show a large spread of the simulated sea conditions for both the sea level and waves highlighting the large uncertainty in simulating this kind of extreme event. The multi-model / multi-physics approach allows us to assess how the uncertainty propagates from meteorological to ocean variables and the subsequent coastal impact. The ensemble mean and standard deviation were combined to prove the hazard scenarios of the potential impact of such an extreme event to be used in a flood risk management plan.

### GNSS-ZTD data assimilation into the WRF model: impact on precipitable water vapor and precipitation forecast over Italy

**Rosa Claudia Torcasio**, Eugenio Realini, Giulio Tagliaferro, Stefano Dietrich, Stefano Federico

The presence of a warm sea and the complex orography led the Mediterranean area to be particularly exposed to severe weather and deep convective events. Because of the importance of their prediction, such events request Numerical Weather Prediction (NWP) models forecast as accurate as possible. Data assimilation of local observations in NWP plays a key role in the improvement of forecast accuracy.

For example, a good knowledge of water vapor distribution in space and time is a fundamental requirement for improving NWP forecasts of convective and severe weather events. In this context, GNSS – ZTD (Global Navigation Satellite System-Zenith Total Delay) observations, which are directly connected to the knowledge of water vapor content in the atmosphere, can be very useful.

In this work we show an experiment of GNSS-ZTD assimilation, focusing on the impact of data assimilation on the precipitable water vapor and precipitation forecast. The study considers a period covering the whole month of October 2019, which was characterized by both moderate and heavy rainfall events. GNSS-ZTD data assimilation is performed into the WRF (Weather Research and Forecasting) model 4.1.3 using the WRF 3DVar data assimilation system. Simulation followed a Very Short-Term Forecast (VSF) approach. By this approach, we ran four simulation a day, lasting 12 h, with the first 6h used as GNSS-ZTD data assimilation period (one analysis per hour) and the last 6h as free forecast.

Model performance verification, with and without GNSS-ZTD data assimilation, are verified both for water vapor and for precipitation forecast. Water vapor forecast is verified hourly from the 1st to the 6th hour after assimilation, while precipitation prediction is verified for two 3h periods, i.e. the first 3h and the second 3h after assimilation, using rain gauges data over Italy.

Background simulations, without GNSS-ZTD data assimilation, showed an underestimation of the water vapor content. This underestimation is reduced by GNSS-ZTD data assimilation, resulting in a reduction of both BIAS and RMSE statistics. Results for precipitation also confirmed the positive impact of GNSS-ZTD data assimilation on the WRF model forecast.

All in all, GNSS-ZTD data assimilation resulted in a forecast improvement, which lasts at least 6 hours.

### The sensitivity of simulated Mediterranean tropical-like cyclones to the numerical model configuration

**Pytharoulis I.**

The accurate prediction of the Mediterranean tropical-like cyclones, or medicanes, is a challenge for the numerical weather prediction models and the forecasters. This study aims to examine the impact of the model configuration on the simulation of medicanes. The selected cases include cyclone Scott that affected the Levantine sea in October 2019 and Ianos that caused fatalities and significant damages in Greece in September 2020. The main tool of this research work is the non-hydrostatic Weather Research and Forecasting (WRF) model with the Advanced Research dynamic core. Sensitivity experiments are performed using different horizontal resolutions (down to cloud resolving scales), number and distribution of vertical levels and nesting techniques. The vortex-following nesting technique of WRF is employed and tested. The simulated lifetime, track, intensity and thermal structure of the medicanes are analysed and evaluated. The symmetry and warm core structure are determined objectively via phase space diagrams.

**Mediterranean cyclones and Saharan dust transport over Bulgaria – two connected weather stories**

**Anastasiya Stoycheva**, Krasimir Stoev, Ralena Ilieva, Stanislava Tsalova, Guergana Guerova

Mediterranean cyclones are synoptic objects that play important role for forming the weather in Bulgaria. Different trajectories of their centres largely determine the pattern of cloud cover, precipitation, wind and temperatures. Even a small change in trajectory matters and causes a different pattern of extreme weather events. Mediterranean cyclones are also a common cause, especially in spring and early summer, for dusty air masses to move from Sahara to Bulgaria. In 2022, we counted more than 150 days with Saharan dust (from low to high concentrations) all over Bulgaria or over part of the country. This is up to 5 times more than the average for the last ten years.
In our study we analyse two interesting and indicative synoptic situations in 2022 related to the transport of Saharan dust, Mediterranean cyclones and different weather events.
1. On 30-31 March due to cyclonic circulation a combination of Saharan dust transport over Bulgaria and strengthening of southerly winds on the northern slopes of the mountains (gusts reach and exceed 25-30 m/s, in some areas up to 35 m/s) National Institute of Meteorology and Hydrology issued yellow and orange METEOALARM warnings. The strong SW wind and the direct dust transport over Bulgaria are related to the front part of the Mediterranean cyclone and its passage to the northwest from Bulgaria, through Hungary.
2. From 8 to 12 of June 2022 there was direct southwestward transport of dust from Sahara at the beginning of the period. Extreme weather events followed: heavy rain, thunderstorms and hail – all during the passage of Cyclone Genesis through the southern part of the Balkans. How Saharan dust influences the temperature regime and the developing convection is of particular interest for operational practice.

**Predicting European winter storm seasonal activity on different lead times**

**Leckebusch GC**, L Degenhardt, E Barrie, KS Ng, and E Spreitzer

European winter storm season characteristics are increasingly predictable on seasonal timescales. A core question is what is driving the ability to predict skilfully and where would a systematic lead time threshold be? This study expands on previous findings by analysing extended lead times of seasonal forecast into autumn and late summer before the winter season. Hence, in a systematic way, a multi-model ensemble of hindcasts is analysed to evaluate current models' capability to forecast the seasonal activity for initialisations from September to November. First results indicate potential predictability precursors already from the September initialisations for storm frequencies. These results vary from model to model though. The presentation will discuss differences between models as well as lead times for both, storm frequency and intensity and the role of prediction skill of large-scale modes over the North-Atlantic.

**The October 2017 Portuguese wildfires: The influence of Hurricane Ophelia in the extreme atmospheric instability and wind field**

**Luana C. Santos**, Miguel M. Lima, Rita M. Cardoso, Pedro M. M. Soares, Carlos C. DaCamara, Ricardo M. Trigo

In Portugal forest and brush fires occur every summer and are exacerbated when extremely dry weather sets in along with high temperatures. During the 2017 wildfire season, successive heat waves associated with a severe drought affecting Europe compounded in historical periods of high meteorological fire danger that resulted in an excess of 500 000 ha burned.
This unusual season was marked by one of the worst single episodes of wildfire globally, with over 200 000 ha burned in just 24 hours and the tragic toll of 50 fatalities. This episode was exacerbated by the off-shore passage of Hurricane Ophelia, near Portugal, traveling northeast and consequently landfalling in Ireland as a post-tropical cyclone. The closeness to the continent produced a northward circulation that transported dry heat to the country and further aggravating the vegetation stress already severe.
This compound event was modeled with the WRF-ARW v4.4 using a one-way nested setup with a high (5 km) and a medium (1 km) spacing grid. In this simulation 68 hybrid vertical levels are used, the model top is fixed as 20hPa, the first level is set at approximately 15m from the ground. Initial and boundary conditions for the outer domain were extracted from the ECMWF operational analyses, at 6-hourly intervals. Furthermore, we have used different parameterizations to produce a high-quality multi-physics ensemble to best represent the observed conditions over

the region.
The FWI (Fire Weather Index), the CHI (Continuous Haines Index) and the FWIe index (blending of FWI and CHI) were accurately modeled and showed very high values prior and during the fire, which indicates extreme fire danger and the existence of great atmospheric instability that can lead to uncontrollable fires. The improved FWIe index showed an increase of 11 percentage points of the area above the 99th percentile of FWIe compared to FWI, thus allowing us to conclude a preponderant influence of the atmospheric instability due to the intense circulation induced by the close passage of the cyclone.

### What is the best storm severity index for European windstorm losses

**David B. Stephenson**, Donald P. Cummins, Jen L. Catto

This study investigates the performance of various storm severity indices at predicting historical insured losses of the 18 severe European windstorms over the period 1979-2012.
It is found that different SSI formulations often give similar correlations with insured losses, for example, a simple area of wind gust maxima exceeding 30m/s performs almost as well as the more complex cubed exceedance index of Klawa and Ulbrich (2003) (hereafter denoted KU). The area index requires only one threshold choice across the whole of Europe and so is much easier to implement than the KU index.
Similar correlations occur because there exist strong linear associations between pairs of different SSI, despite the indices having different thresholds and different non-linear dependence on wind gust speed. An extreme value theory explanation is proposed for this unexpected linearity whereby exceedances are primarily determined by small variations in the tail scale parameter of a generalised Pareto distribution.

### Cyclones and Safety of Navigation in the Mediterranean Sea

**Kareem Tonbol**, Mohamed Elbawab, Mohamed Rowihil, Amr Moneer Ibrahim, Mahmoud Elbawab

Recent weather events have brought attention to the dangers of extreme weather at sea and underscored the necessity of taking measures to better protect life and property onboard vessels. Also, the cost and safety aspects of the journey are crucial. Every year, the Mediterranean basin is hit by a slew of powerful cyclones, and it is one of the world's busiest seas, accounting for 20% of seaborne trade and 10% of world container throughput. The cyclone's consequences on shipping are barely avoidable without accurate shipping guidance.
Cyclones have a negative impact on maritime logistics and the shipping industry. When a cyclone causes ship delaying, the entire supply chain can be interrupted, affecting thousands of people. Extratropical cyclones at sea have the same potential for harm as hurricanes' high winds and waves. These systems go through the mid-and high latitudes, are frequently bigger in size, and move more quickly ahead than tropical cyclones, which causes sea conditions to alter quickly.
The crucial choice in cyclone avoidance is choosing the precise timing to start the avoidance manoeuvre as well as the appropriate course and speed while maintaining the commercial and economic feasibility of the journey by reducing fuel usage as much as possible when performing the avoidance manoeuvre and preserving the voyage schedule.
Consequently, for ships at sea to successfully carry out a cyclone avoidance manoeuvre in the safest and most time/cost-efficient manner, accurate weather routing data is needed. Such information is currently insufficient. For such navigator guidance to be created, scientific cooperation must be initiated between nautical expertise and metrological scientists to work on a navigation guide for ships sailing in the cyclone areas to save lives, investments, time, and the environment.
Aim:
To ensure safe, timely, and cost-efficient ship navigation within the cyclone areas in the Mediterranean Sea.
Objectives:

1. To provide ships sailing within the Mediterranean Sea with all the needed information about cyclones and extreme weather conditions hitting the region, including but not limited to expected timing ranges, predicted locations, and potential fatality; “Mediterranean Cyclone Atlas”.
2. To provide ships with a complete set of benchmark scenarios for cyclone avoidance, including recommended procedures, action checklists, cyclone surround safe zones, alternative routes, and a list of search and rescue (SAR) centre contact details; “Mediterranean Cyclone Guide for Safe Navigation (MCGSN)”.

### Simple loss model for Windstorms over Europe

**Dhirendra Kumar**, Len Shaffrey, Richard Dixon, Hannah Bloomfield, Paul Bates, John Hillier

European windstorms (EUWS) are a frequent and damaging natural hazard that causes loss to human lives and widespread damage to property every year across the continent. Given the uncertainty in the frequency, intensity and location of EUWS, it is therefore essential to try to model and further understand the present and future risks associated with them. We present a simple loss model to estimate the windstorm losses over Europe. The model comprises of an exposure component based on the countrywide total insured property values, historical population density, and the gross domestic product. The hazard component is derived from the recent ERA5 reanalysis dataset for 1940-2022. The vulnerability component is modelled as a cubic function of wind gust speeds over 20 ms-1 threshold. We evaluate the modeled losses with the available estimates from the XWS catalog and proprietary vendor models. We find that losses are comparable for the Europe-wide average annual losses and most of the individual storms affecting northwestern Europe. However, the model overestimates the losses over the United Kingdom (UK) and underestimates losses in Germany and France. This is predominantly caused by the regional level exposure differences and partly by the hazard component in the model. Although the Europe-wide losses and their return periods are largely unaffected by the choice of the exposure dataset, the regional/countrylevel differences are apparent. The model performance is also limited by the representation of the winds in the ERA5, especially for specific storms such as the Great storm of 1987. We further aim to extend the study to account for future losses under different climate scenarios using high-resolution climate model simulations from the 2018 UK Climate Projections.

### Severe phenomena exposure of socio-economic activity during the warm season in Craiova-Southwestern Romania

**Cristina Burada**, Mihaela Brâncuș

On July 2nd 2022, in Craiova, the biggest city in southwestern Romania, in approximately one hour, a convective storm flooded 34 streets and dozen of buildings, 66 trees and 20 building roofs fell down, damaging 14 cars. This weather event was one of the most severe episodes that occurred in the city in the last 30 years, leading to huge damage both to public and private properties. Convective storms during the warm season (May-September) with the associated phenomena (lightning, hail, squall or strong wind gusts, intense rainfalls) are common for this part of the country. Although the city is not located in an area prone to floodings (e.g., below sea level or mountain area), in the last years problems caused especially by the rainfalls increased. Together with the economic development, people's well-being increased and so did the number and the value of their damaged assets. The necessity of knowing what phenomenon represents a risk for the socio-economic activity in this big city became important either for public authorities, people or companies. The present study analyzes the warm season specific phenomena, except for heat waves, that occured between 1992 and 2021, using observation data recorded at the meteorological weather station located in the eastern edge of the city. No distinction was made between the nature of the convective storms (i.e., frontal or thermal). Due to the large size of the city in contrast with the reduced area where the intensity of a storm is maximum, it is important to note that there were many cases when at the weather station the phenomena were not so intense as in the middle of the city (e.g., for July case, in the center of the city a non-official station recorded about 70 mm and only 10.2 mm at the weather station). It resulted that the highest risks represent intense rainfalls that occur in a very short period of time, overloading the city's sewage network, lightning and wind gusts. For lightning the frequency doubled in the last 10 years, whereas! for wind gusts an increase in the intensity was noted. Hail risk is low, resulting 1case/year in average. Also, installation of urban meteorological stations in big cities will be of great help for stakeholders in planning and supporting their future activities.

### Decadal variability of extreme winds and potential storm losses in Europe using large RCM ensembles

**Jisesh Sethunadh**, Joaquim G. Pinto, Patrick Ludwig, Hendrik Feldmann, Florian Ehmele,

Windstorms (major winter storms) are one of the most important natural hazards in Europe. Despite the large observed socioeconomic losses, the impact of windstorms and its decadal variability is not yet fully understood. This study aims to assess the loss potentials associated with European windstorms and the variability in the wind speed climatology across Europe. We use the 12,500-years LAERTES-EU (LArge Ensemble of Regional climaTe modEl

Simulations for EUrope) RCM ensemble to study the spatio-temporal distribution and variability of windstorms over Europe. LAERTES-EU is validated against reanalysis data (ERA5) and available ground-based station observations. The associated windstorm losses are estimated by computing statistics of extreme wind speeds and related indices. Different loss indices are validated using historical loss data from the insurance sector. The results reveal that the loss index (LI) is a good proxy for the estimation of potential losses associated with windstorms across Europe in winter. The derived statistics of extreme windstorms such as return periods (RP) show hardly any change in the severity and frequency of windstorms during the covered period 1900-2028, but a strong decadal variability is apparent.

### Severe droughts in North Africa: drivers, impacts and management

**M. Tanarhte**, T.Chfadi, A.J. De Vries, G. Zittis

Various parts of North Africa (NAF) have suffered devastating droughts with high socio-economic impacts in the last 50 years. This arid to semi-arid region is one of the most water-scarce areas in the world. In the context of water scarcity, many studies have focused on droughts approaching their impact from different disciplines and perspectives. However, more integrative studies covering both physical and social aspects of drought in NAF are lacking. We review drought's physical and human drivers, the associated socio-economic impacts in NAF countries, actual adaptation and management options.
The analysis of the historical events reveals extensive impacts on agriculture, employment, food security, health and internal migration. The adaptation strategies to drought include irrigation efficiency, groundwater overexploitation and the use of non-conventional water resources such as desalinated water. In NAF, various forms of drought monitoring and early warning operate on several institutional levels under the coordination of different institutions/ministries. An improved understanding of the characteristics of droughts and their impacts in NAF countries is important to guide the transition from emergency response to more proactive policies and long-term planning, but also to assess and identify gaps in drought management capacities.

### Contrasting tail risk in seasonal forecast models

**Richard Dixon**

More and more risk managers are using alternative datasets to complement output from catastrophe models. This study will contrast tail risk as seen in two different seasonal forecast models to understand whether windstorm risk - from the small subset of days within the forecast output that give damaging winds - can differ markedly depending on the forecast provider.

### The Sources of Heavy Precipitation Predictability; The Case of the 'Wet' Red Sea Trough

Assaf Hochman, **Tair Plotnik**, Francesco Marra, Elizabeth-Ruth Shehter, Shira Raveh-Rubin, Leehi Magaritz-Ronen

Heavy precipitation events inflict detrimental socio-economic impacts in the Eastern Mediterranean. These are mainly associated with Mediterranean cyclones or the 'Wet' Red Sea Trough (WRST). The region's weather forecasters consider the second challenging to forecast, even just a few days in advance. Here, we study the dynamic and thermodynamic factors influencing the intrinsic predictability of WRST events. With this aim, we combine insights from traditional atmospheric analysis techniques, Lagrangian air-parcel backward trajectories, and dynamical systems theory. The latter describes atmospheric states via their local dimension (d) and inverse persistence θ), which inform us of the intrinsic predictability of the atmosphere in phase space. We compare WRST events of low (upper decile of d and θ) with high (lower decile of d and θ) predictability. We argue that low-predictability events display a significantly different synoptic pattern.

Moreover, the low-predictability events display significantly higher daily precipitation rates, more extensive spatial spread, and greater precipitation variability among events than more predictable ones. On average, low predictability events are initiated by two distinct moisture sources with different water vapor content. We conclude that the dynamical systems framework may become a valuable tool to improve the forecast of heavy precipitation events associated with the WRST by providing a priori information on their intrinsic predictability. We foresee the successful implementation of such a framework for other extreme weather events and regions such as tropical-like cyclones (Extra-tropical cyclones, Medicanes) in the Mediterranean.

### Dry intrusions in the rear of Mediterranean cyclones govern large-scale dust storms in North Africa

Elody Fluck and **Shira Raveh-Rubin**

Large dust storms in the Saharan desert and the subsequent transport of airborne dust over large distances are a major meteorological hazard. Several mechanisms associated to dust emission, occurring on a range of scales, have been previously documented, notably involving Rossby wave breaking and a low-level jet. However, the mechanistic link between the different features and actual dust concentrations has not been coherently established. Here, using a Lagrangian approach, and the conceptual view of extratropical cyclone airstreams, the role of the dry intrusion (DI) airstream for translating the influence of the upper-tropospheric Rossby wave perturbation to near-surface flow conductive for the highest dust concentrations is examined. To this end, illustrative cases and a climatological set of 325 large-scale dust storms accompanied by dry intrusions in west Africa during 2003-2018 are studied. Data from the Copernicus Atmospheric Monitoring Service (CAMS) are combined with atmospheric data from reanalysis and objectively-identified Lagrangian trajectories of dry intrusions. We find that dry intrusions link Rossby wave breaking in the east Atlantic with the lower-tropospheric dry and cold jets. These conditions favor dust uplift and transport along an arc-shaped cold front trailing from a Mediterranean cyclone. Consequently, the southwest side of the front is characterized by the highest near-surface dust concentrations ahead of the dry intrusion outflow. The northeast part of the front is, however, accompanied by southerly, warm conveyor belt-like flow transporting the dust northward to the Mediterranean, Middle East and/or Europe at mid and upper-tropospheric levels. Climatologically, such dust-DI events occur mostly in late winter and spring, when they are also larger in size and last longer, compared to summer events. When occurring with DIs, dust optical depth is generally higher, compared to events that are not accompanied by DIs. Focusing further on March events, we find coherent large-scale precursors of dust-DI events: a northward jet shift over the North Atlantic with anticyclonic Rossby wave breaking occurring on average 4-5 days prior to the events.

### Where does the precipitation moisture for the Medicane Qendresa come from?

**Patricia Coll-Hidalgo**, Albenis Pérez-Alarcón, Raquel Nieto

The hybrid cyclones formed over the Mediterranean Sea, known as Mediterranean hurricanes (medicanes) or tropical-like cyclones (TLCs), are responsible for hazardous consequences in this region. Remote sources for the

precipitation of medicanes are a open question in the medcyclones field. This work aims to asses  the origin of the precipitation produced by TLCs through a Lagrangian approach based on the analysis of moisture sources for the TLC Qendresa from 6 to 9 November 2014.
We used the global outputs of the FLEXPART model fed by the ERA-5 reanalysis for backtracked the pathways of precipitating particles within the outer radius of the storm up to 10 days. We pinpointed the overall large-scale conditions for the genesis of Qendresa. We found that the moist air parcels described trajectories bordering the extension through the mid-troposphere linked to a branch of a polar jet stream over southwestern Europe. In addition , we amassed the total contribution from moisture sources. In this direction, we highlighted that the atmospheric humidity mainly came from local sources, and the contributions from oceanic (terrestrial) origin represented 62% (38%) of the total moisture gained by the storm. Future studies will focus on a climatological analysis of the origin of rainfall produced by these hybrid cyclones.

### Role of post-tropical cyclones in the hydrological cycle of the northwestern Iberian Peninsula

**Albenis Pérez-Alarcón**, José C. Fernández-Alvarez, Rogert Sorí, Margarida L.R. Liberato, Ricardo M. Trigo, Raquel Nieto, Luis Gimeno

Tropical cyclones (TCs) formed in the North Atlantic (NATL) basin can influence the weather condition in western Europe after recurving northeastward. Generally, these TCs impact the European coast after undergoing an extratropical transition and,  therefore, as post-TCs (PTCs). Recent works have projected a poleward expansion of the genesis area in the NATL basin under global warming. It is then expected an increasing frequency of TCs or PTCs crossing circa or over the western Europe coast. Therefore, this work examines the role of PTCs in the hydrological cycle in the northwestern Iberian Peninsula (NIP) from 1980 to 2018. The information on TCs was extracted from the HURDAT2 dataset from the US National Hurricane Center. The high-resolution Multi-Source Weighted–Ensemble Precipitation dataset was used to quantify the amount of rainfall contributed by PTCs. Our analysis revealed that 30 TCs (~5%) formed within the study period influenced the weather conditions in the NIP region. The monthly frequency showed that October and September were influenced by 13 and 10 PTCs, respectively, while August and November recorded the impacts of 5 and 2 TCs, respectively. The contribution of PTCs to the monthly precipitation totals from August to November accounted for approximately 4.2%. It is important to highlight that September registered the highest PTC rainfall contribution, which accounted for 7.1%. Likewise, the western and northern portions of the NIP recorded the highest PTC-related precipitation totals. TCs can also play a crucial role in the offset of drought episodes. In this line, by using the classification of drought categories for SPI values, we found that PTCs contributed to the ending of ~18% of the dry periods from July to October in the NIP. These findings could be useful for future studies on understanding the possible impacts caused by TCs or PTCs in this region in a warmer climate.

### Convective environments along Mediterranean cyclone tracks: exploring severe surface impacts

**Andrea Angelidou**, Prof. Dr. Olivia Romppainen-Martius, Dr. Raphaël Rousseau-Rizzi, Alice Portal

Mediterranean cyclones may pose significant environmental risks in the form of strong winds, heavy rain and thunderstorms. To better understand the relationship between convective environments along Mediterranean cyclone tracks (Flaounas et al. [2023]), we examine the structural characteristics of different cyclone clusters from a Lagrangian view point. The clusters are defined by a recent classification developed at the Weizmann Institute of Science. Results reveal a connection between the convective parameters, large-scale dynamics and seasonal qualities of the clusters. The time evolution of convective parameters before and after the maximum intensity of the storms are also described. The study further examines the development of severe thunderstorms along cyclone tracks by combining convective parameters, including CAPE and shear, and analyzing their interaction under severe impact thresholds. Understanding how different types of Mediterranean cyclones are associated with convective environments, potentially leading to severe impacts at the surface, is crucial for operational forecasters to issue timely alerts and prepare for potential environmental dangers.

### Relating compound extremes to Mediterranean cyclones

**Alice Portal**, Olivia Romppainen-Martius, Shira Raveh-Rubin and Jennifer Catto

Strong evidence exists regarding the impact of cyclones on the occurrence of extreme weather. Recently, special attention has been devoted to co-occurrence of individual extremes, due to the high societal impacts of compound extremes on infrastructure, transport and health. In this work we attempt to define the impact area of a cyclone, expressly devised for the Mediterranean area (the cyclone tracks are taken from the MedCyclones dataset defined in [1]) and for a range of different extremes (e.g., precipitation, wind and wave extremes), based on a selection of exemplary cyclone tracks. The aim is to identify a causal link between the passage of a cyclone and severe impacts at the surface, by taking into account the former's large-scale features, such as core, cold front, warm conveyor belt and dry intrusion. Based on the definition of impact area resulting from this analysis, we estimate the fraction of compound extremes (e.g., combinations of precipitation, wind and wave extremes) associated with the MedCyclones tracks for every season over the recent climatological period.

[1] Flaounas, E., Aragão, L., Bernini, L., Dafis, S., Doiteau, B., Flocas, H., L. Gray, S., Karwat, A., Kouroutzoglou, J., Lionello, P., Pantillon, F., Pasquero, C., Patlakas, P., Picornell, M. A., Porcù, F., D. K. Priestley, M., Reale, M., Roberts, M., Saaroni, H., Sandler, D., Scoccimarro, E., Sprenger, M., and Ziv, B.: A composite approach to produce reference datasets for extratropical cyclone tracks: Application to Mediterranean cyclones, Weather Clim. Dynam. Discuss. [preprint], https://doi.org/10.5194/wcd-2022-63, in review, 2023.

### The extreme windstorm associated to the landfall of post-tropical cyclone Leslie in Portugal

**Miguel M. Lima**, Luana C. Santos, Rita M. Cardoso, Pedro M. M. Soares, Ricardo M. Trigo

Windstorms in Europe are responsible for more than half of the economic loss associated with natural disasters. In October 2018 a post-tropical cyclone, formerly Hurricane Leslie, made landfall in continental Portugal. This event was characterized by very intense winds, with a record-hitting value of 176 km/h near Figueira da Foz, in the center of the country. A rare dynamic known as a “jet sting” is thought to have caused these extreme winds, usually associated with midlatitude cyclones. Studies modeling this kind of dynamic are few, and in this presentation we present the first successful simulation of this rare dynamic associated with a post-tropical cyclone, in western Europe.

The WRF-ARW model, version 4.4.1, was used to numerically model Leslie as it transitioned from hurricane to post-tropical cyclone. For this simulation, several different parameterizations were used to best represent the event. Two one-way nested domains were used with a medium (5 km) and a lower (1 km) resolution, with 68 hybrid levels (15 m - 20 hPa). The larger domain covers the Iberian Peninsula and a large portion of the Atlantic Ocean nearby while the inner one covers the center and north of continental Portugal. Initial and boundary conditions were retrieved from the GFS operational analysis at 0.25º spacing, in 6-hour intervals. Due to the difficulty modeling this cyclone, nudging was used at the same 6-hour intervals to assure the cyclone would make landfall as close as possible to the real location.

The set of final simulated data reveals a close resemblance to the real event, with parameterized wind gusts presenting a lower intensity, but the largest values impacting approximately the same region of center Portugal. Additionally, several state-of-the-art diagnostics were used to analyze in-depth the “jet sting” associated with Leslie. These diagnostics show a near “text-book” case of this rare dynamic, a novelty considering Leslie had recently undergone post-tropical transition.

### Low-level winds and precipitation associated with subtropical cyclones over the western South Atlantic basin

**Andressa Andrade Cardoso**, Rosmeri Porfírio da Rocha and Natália Machado Crespo

Cyclones influence the synoptic-scale weather with adverse conditions such as precipitation, wind, and gust. Adverse conditions, such as floods, undertows, landslides, etc., may cause a lot of impact on ecosystems and society and, consequently, resulting in economic losses. The main aim of this study is to analyze the subtropical cyclones (SC) impacts on surface wind extremes and precipitation over the western South Atlantic. To do so, two newest reanalysis datasets European Center for Medium-Range Weather Forecast-Copernicus Climate Change Service (ERA5) and Climate Forecast System Reanalysis (CFSR) for the wind at 10 m, and the Tropical Rainfall Measuring

Mission (TRMM) for the precipitation in the period of 1979-2015 were used. The analysis was separated into the cold season (from March to August) and the warm season (from September to February). Two approaches were considered to understand the relationship between SC and synoptic variables (precipitation and wind): the first one is the Lagrangian method, which follows the cyclone center in a 20º x 20º box every 6 hours, and the second one called the Eulerian method, considers the averaged environment during the cyclone life. Additionally, the contributions of SCs for the synoptic environment were analyzed in terms of anomalies. A total of 169 SCs occurred in the warm season (summer and spring) against 87 in the cold one (autumn and winter). In both approaches SCs contributed to a positive anomaly of mean and extreme wind over the east and northeast of the subtropical cyclogenetic region (RG1), which is justified by the intensification of northeastern/eastern winds in the center-east of SCs, while an anomalous anticyclonic circulation south of RG1 induces an eastern circulation that counterbalances the background flow. Furthermore, SCs were responsible for positive precipitation anomalies over the east and inside of RG1 as well as in a northeast-southeast positive anomaly band starting from the continent (Amazon basin) towards the ocean. A negative anomaly (i.e. dry conditions) was found over the south of RG1. The positive precipitation anomalies were associated with an anomalous low pressure, low-level moisture, warm advection at the low level, and divergent flow at the upper level, which contribute to the upward motion at low levels, and consequently convection and intense precipitation related to the cyclone's events.

### The downward transport of strong wind by convective rolls in a Mediterranean windstorm

**Wahiba Lfarh**, Florian Pantillon, Jean-Pierre Chaboureau

The devastating winds in extratropical cyclones can be assigned to different mesoscale air flows.
How these strong winds are transported to the surface is discussed for windstorm Adrian (Vaia), which formed over the northwestern Mediterranean Sea on 29 October 2018 and caused extensive damage in Corsica. A mesoscale analysis based on a kilometer-scale simulation with the Meso-NH model shows that the strongest winds occurring on the southern flank of the cyclone come from a cold conveyor belt (CCB) at lower altitudes. The focus then shifts to a large eddy simulation (LES) for which the strongest winds over the sea are in a convective boundary layer. Convection is organized into coherent structures oriented in the wind direction in the form of convective rolls. It is their downward branches that contribute most to the transport of strong winds from the CCB to the surface layer. On landing, the convective rolls break up because of the negative heat fluxes at the surface and the topographic complexity of Corsica. Sensitivity experiments to horizontal grid spacing (200~m, 100~ m and 50~m) show similar characteristics and organization of boundary layer rolls
across the resolution. A comparative analysis of the kinetic energy spectra suggests that a grid spacing of 200~m is sufficient to represent the vertical transport of strong winds through convective rolls. Contrary to the LES, convective rolls are not resolved in the kilometer-scale simulation, which led to an overestimation of surface winds due to the strong transport of momentum near the surface. These results highlight the need for large eddy simulations to better understand the small-scale processes leading to gust formation in windstorms and to improve their predictions and impacts.

### The role of extratropical cyclones on drought end in the Iberian Peninsula

**Margarida L. R. Liberato**

Extratropical cyclones are known as one of the major natural hazards in mid-latitudes. During recent winters western Europe, and the Iberian Peninsula (IP) in particular, was hit by numerous severe named storms with serious impacts on the environment, economy, and society. The associated impacts of these systems are generally reported as negative, specifically when co-occurring: the effect of heavy rainfall, strong winds, and high waves associated with these systems produce serious damage to the economy, and other irreparable damage due to the loss of human lives.
On the other hand, extensive, long-standing dry episodes are frequent climatic extreme events in the IP. Similar to other Mediterranean regions, droughts represent one of the most frequent damaging natural hazards in the Iberia. In fact, drought events in the IP can induce large socio-economic costs, often with widespread negative ecosystem impacts, namely significant losses of agricultural and hydro-electric production, and an increasing risk of extreme

forest fires.
In this study a comprehensive assessment of the synoptic and dynamic characteristics associated with severe storms during their impact in IP is presented, while assessing the cascading impacts of associated heavy rainfall on the hydrological cycle of mainland Portugal.

### Co-occurring British flood-wind events (1980-2080): Their anatomy & drivers

**Hillier, J. K.**, Bloomfiled, H., Garry, F., Bates, P., Shaffrey, L.

In wintertime, infrastructure and property in NW Europe are threatened by multiple meteorological hazards, and it is increasingly apparent that these exacerbate risk by tending to co-occurring in events that last days to weeks. Impacted by Atlantic storms, Great Britain (GB) is a sentinel location for weather that later tracks into NW Europe.
A recent, dramatic storm sequence (Dudley, Eunice, Franklin) demonstrated the need for a multi-hazard view by bringing a mixture of damaging and disruptive extremes including extreme winds and flooding over 7-10 days in Feb 2022.
This work uses a stakeholder inspired, event-based approach to jointly consider these two hazards.  A wind event set (n = 3,426) is created from the 12km regional UK Climate projections (1981-1999, 2061-2079) to match previously created high-flow events (Griffin et al, 2023). Then, the two hazards' time-series are merged using windows up to a maximum size (Dt = 1-180 days) positioned to maximize the size of the largest events' impact. The uplift in occurrence of the largest events due to inter-hazard dependency is plotted, anatomy of storm sequences (Dt = 21 days) in discussed, and potential drivers of co-occurrence in the multi-hazard sequences (e.g. jet stream position/strength) examined.