EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Brussels, 24 March 2020

COST 012/20

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "European network for Mediterranean cyclones in weather and climate" (MEDCYCLONES) CA19109**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action European network for Mediterranean cyclones in weather and climate approved by the Committee of Senior Officials through written procedure on 24 March 2020.

Funded by the Horizon 2020 Framework Programme of the European Union

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA19109
EUROPEAN NETWORK FOR MEDITERRANEAN CYCLONES IN WEATHER AND CLIMATE (MEDCYCLONES)

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. "Rules for Participation in and Implementation of COST Activities" (COST 132/14 REV2);
b. "COST Action Proposal Submission, Evaluation, Selection and Approval" (COST 133/14 REV);
c. "COST Action Management, Monitoring and Final Assessment" (COST 134/14 REV2);
d. "COST International Cooperation and Specific Organisations Participation" (COST 135/14 REV).

The main aim and objective of the Action is to coordinate the efforts of researchers and professionals involved in Mediterranean weather and climate to make research results directly applicable to cyclones prediction, tailor novel services to stakeholder needs, harmonise and advance weather and climate prediction capabilities in Europe and increase public awareness of cyclone environmental and socio-economic impacts. This will be achieved through the specific objectives detailed in the Technical Annex.

The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 116 million in 2019.

The MoU will enter into force once at least seven (7) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14 REV2.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14 REV2.

OVERVIEW

Summary

Cyclones are the main weather modulators in the Mediterranean region and constitute a major environmental risk, often producing windstorms and heavy rainfall. Moreover, cyclones play a key role in the regional climate variability by controlling the oceanic circulation and regional water cycle, and by mobilizing and transporting large amounts of dust from North Africa.

Despite the recent achievements of the scientific community to provide deeper insight into the atmospheric processes and impacts associated with Mediterranean cyclones, there are still unaddressed scientific challenges that require a coordinated approach. In addition, the lack of direct interaction between academic researchers and weather/climate prediction scientists working in operational centres inhibits the efficient exploitation of fundamental research results to improve atmospheric models in a tangible way. Therefore, it is undeniable that there are potentially large societal benefits from improving cyclone predictions for weather and climate timescales.

Efficient networking between stakeholders, operational weather forecasters and researchers is timely and essential to address both challenges of research coordination and operational implementation of scientific results into weather and climate services. This Action will coordinate the activities of researchers in meteorology and climatology and scientists from weather/climate services with the main aims to provide a deeper understanding of Mediterranean cyclones and to improve significantly the European capacity to predict their environmental and climate impacts. In this context, the network will identify, and involve in the network, relevant stakeholders with different backgrounds (e.g. civil protection, re-insurance companies) and co-develop cyclone prediction products tailored to their needs.

Areas of Expertise Relevant for the Action	**Keywords**
● Earth and related Environmental sciences: Meteorology, atmospheric physics and dynamics ● Earth and related Environmental sciences: Climatology and climate change	● Mediterranean cyclones ● Numerical weather prediction ● High impact weather ● Climate prediction

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination

● Delineate the role of the more typical and unique for the Mediterranean atmospheric processes, for cyclogenesis and cyclone intensification;
● Determine the relationship between these processes and the performance of the models in representing them on time-scales relevant for weather and climate prediction;
● Establish priorities for model development aimed at improving the representation of the formation, movement, and intensity change of Mediterranean cyclones.
● Develop common protocols for assessing the quality of Mediterranean cyclone simulations by weather forecasting and climate models;
● Foster the application of these common protocols to enhance timely and direct exchange between European weather and climate prediction centres when high-impact weather is imminent;
● Identify and set a scientific agenda for addressing new and poorly understood research questions related to socio-economic and environmental impacts of Mediterranean cyclones;
● Share observations between different countries commonly affected by Mediterranean cyclones;
● Increase public awareness of cyclone-related high-impact weather by maintaining a website, social media channels and newsletter;

● Improve stakeholders' understanding of cyclone-related high-impact weather and of relevant uncertainties regarding prediction on weather and climate time-scales;

Capacity Building

● Engage researchers with a background in atmospheric physics, meteorology and climatology, and professionals providing weather/climate services, in order to encourage a transfer of knowledge between subdomain experts that will advance our collective understanding of the processes occurring in Mediterranean cyclones;
● Train early career academic researchers, weather/climate prediction professionals and stakeholders on the new scientific advancements in the field of Mediterranean cyclones, as well as on the new evaluation tools and prediction methods that are outcomes of this Action
● Promote exchange of scientific and modelling expertise between weather and climate prediction and research centres located around the Mediterranean and in other European countries. Special focus will be given on improving high-impact weather prediction.
● Promote collaboration between researchers, prediction centres and stakeholders to co-design and tailor research outcomes and services to the needs of the latter.

TECHNICAL ANNEX

1 S&T EXCELLENCE

1.1 SOUNDNESS OF THE CHALLENGE

1.1.1 DESCRIPTION OF THE STATE-OF-THE-ART

The Mediterranean is a unique region, lying between the arid zone of North Africa and the North Atlantic storm track. It possesses a complex geography characterized by a relatively narrow and nearly closed sea surrounded by high mountains and abrupt land-sea transitions. In this relatively small region, cyclogenesis (the formation of cyclones) is frequent, with cyclones producing the majority of high-impact weather in the basin. In fact, several of these Mediterranean cyclones have attained wind intensities comparable to those of named Atlantic hurricanes. The recent storms "Rolf", "Qendresa" and "Zorbas" – tropical-like cyclones that occurred in November 2011 to the south of France, in November 2014 in Malta and Italy and in September 2018 in Greece, respectively – caused fatalities and severe damage due to strong wind gusts, high sea waves, and heavy rainfall that locally reached in all cases exceptionally high accumulated values. Beyond their primary impact on local weather extremes, Mediterranean cyclones influence the regional and global climate. These systems are responsible for mobilizing and transporting large amounts of dust from North Africa towards Europe, as well as for significantly contributing to the marine and atmospheric water budgets of the Mediterranean basin. As such, Mediterranean cyclones pose major environmental risks and act as climate modulators that affect more than 480 million people on three continents.

On the understanding and modelling of Mediterranean cyclone dynamics: In the scientific literature there is a general consensus regarding the main processes essential for the life cycle of cyclones, although they act in different measures for different classes of events: (a) baroclinic instability, (b) air-sea interaction, (c) moist convection, (d) orographic interaction, (e) direct and indirect effects of aerosols, and (f) tropical/subtropical transition of baroclinic lows (i.e. the synergy of convection with baroclinic instability that may turn a Mediterranean cyclone into a tropical-like storm). Among these processes, baroclinic instability is the fundamental mechanism of cyclone formation and intensification in the Mediterranean, typically enhanced by latent heat release in clouds associated with the developing cyclone. Indeed, intense cyclones are preceded by upper-tropospheric disturbances that intrude into the Mediterranean, such as troughs and cut-offs. After cyclogenesis takes place, cyclone dynamics is influenced by a set of atmospheric processes that is unique to the region, compared to hurricanes or other extratropical cyclones that develop over the larger ocean basins. Moisture availability is limited, constrained by the relatively narrow Mediterranean Sea, while dry and warm air from North Africa, rich in dust, is often transported to the centre of cyclones. High mountains surrounding the Mediterranean Sea play a key role in the occurrence of lee cyclogenesis, and further influence cyclone dynamics via frictional forces and wind steering. These unique dynamics act in synergy with the "more typical" cyclone-related atmospheric processes of large-scale condensation, convection and air-sea interaction. The complexity of the interactions between all these atmospheric processes over different temporal and spatial scales leads to a broad range of categories of cyclones, each of them associated with different cyclogenesis mechanisms and different spatial and seasonal distributions in the Mediterranean basin (Lionello et al., 2012). For instance, Mediterranean cyclones may occasionally transition from initially baroclinic to tropical-like systems. The relative contributions of the different thermo-dynamical processes to the triggering of cyclogenesis, the intensification of Mediterranean cyclones and the promotion of tropical transition remain uncertain, while the impacts of dust and mountains on the life cycle of

Mediterranean cyclones has not yet been adequately investigated. Especially in climate studies, uncertainties in resolving these processes may lead to significant divergence of cyclone climatologies among models (e.g. Gaertner et al., 2018). This is a major issue for climate studies in a region that is highly responsive to climate change (Giorgi, 2006) and where risk related to cyclones is expected to significantly increase in the future (e.g. Romero and Emanuel, 2013).

On the impacts of Mediterranean cyclones on regional climate: Mediterranean cyclones have been shown to modulate indirectly different aspects of the regional climate. However, these cyclone-related impacts are currently only poorly understood by the scientific community. For instance, it is only recently that the community started to investigate dust transport associated with Mediterranean cyclones and its relationship to severe particulate matter pollution episodes (e.g. Rizza et al., 2018). This lack of research is in contrast to the recently revealed leading role of Mediterranean cyclones for the mobilization and transport of dust from North Africa, the world's primary source of atmospheric dust (Knippertz and Todd, 2012). Furthermore, an improved understanding of convective overshooting and the associated moistening of the lowermost stratosphere, which often occurs in the vicinity of Mediterranean cyclones (Bedka, 2011), is a timely issue that needs to be addressed by the scientific community. These storms also appear to modulate the Mediterranean Sea water budget (Flaounas et al., 2016), formation of deep water (Romanski et al., 2012) and marine biology (Kotta and Kitsiou, 2019). Mediterranean cyclones have a potentially strong impact on the marine and atmospheric water cycle; however, this effect is still far from being quantified or analysed in detail. Therefore, research activities on Mediterranean cyclones need to prioritize the development of new understanding of processes including: (a) transport of dust from North Africa towards Europe; (b) troposphere-stratosphere interactions, especially through the convective overshooting associated with Mediterranean cyclones; (c) impacts of cyclones on the Mediterranean Sea circulation and deep water formation; and finally, (d) cyclones' impact on the regional water cycle and transport of water into and out of the Mediterranean. Especially themes (a) and (b) concern processes of high importance for global climate, as they have been identified as major sources of uncertainties in future climate projections.

On the effective operational and climate prediction of Mediterranean cyclones: The complex regional geography and broad spectrum of atmospheric processes involved with Mediterranean cyclones render the accurate simulation of these storms by means of atmospheric models a very challenging task. This limited predictability has important implications for both weather forecasters and climatologists. Significant contributors to this problem are the complex atmospheric thermo-dynamical processes, as described above, that occur across multiple spatial and temporal scales. Each of these need to be realistically reproduced by the models for accurate predictions, as do the significant nonlinear interactions between them. It is currently an open question whether one or more cyclone-related processes are more challenging to be reproduced by forecasting and climate models. And if so, it is also uncertain what is the impact of the "misreproduced" process to the overall model performance. Delineating the importance of each atmospheric process to the credible reproduction of a cyclone is a crucial step for understanding model performance. This aspect is a currently missing fundamental step of the state-of-the-art required for the credible prediction of high-impact weather or climate extremes. Regardless the time scales considered, major modelling issues include spatial resolution, atmospheric model coupling with an oceanic and/or chemistry model, and the choice of physical parameterisations. Moreover, numerical weather prediction also needs to address the issue of assimilating observations, while climate prediction needs to address issues of internal climate variability. Therefore, optimising model performance is not straightforward and it depends on the scales and specifics of the processes to be reproduced (e.g. depending on model resolution a certain process may be parameterised rather than explicitly resolved). For instance, a complete representation of the direct and indirect effects of dust is prohibitively computationally expensive and theoretically yet not well described for climate simulations – but is realizable in the simulation of a specific cyclone for weather predictions. The state-of-the-art of modelling Mediterranean cyclones suffers from a lack of coordinated research on the accurate reproduction of the atmospheric processes responsible for cyclone development.

On the socio-economic interest in Mediterranean cyclones: The understanding and accurate prediction of cyclones is an issue that is of significant interest to the general public and stakeholders (e.g. civil protection agencies and re-insurance companies), since cyclones affect a large variety of socio-economic activities. Nevertheless, providing the most relevant information to stakeholders and the general public is a complex and currently under-addressed challenge. For instance, products showing the probability of the occurrence of explosive cyclogenesis (rapidly developing storms) and the resulting cyclone trajectory and effects (winds, waves) are difficult to generate and need to be defined in detail so that their usefulness can be optimized for e.g. shipping transports (a simple weather chart is not sufficient). A coordinated interaction between researchers and stakeholders in order to co-design in

detail and to refine the cyclone-related products of weather/climate prediction centres is currently missing. This is one of the major issues of the state-of-the-art (World Weather Research Programme Implementation Plan of WMO for 2016-2023), which has not been effectively addressed so far despite increasing public interest in cyclones. Indeed, the general public is only occasionally informed about Mediterranean cyclones by the mainstream media, usually using superficial or scientifically inaccurate language. A coordinated dissemination of information by a European network of researchers, forecasters and climatologists would be exceptionally beneficial for the quality of common knowledge about high-impact weather and climate extremes.

1.1.2 DESCRIPTION OF THE CHALLENGE (MAIN AIM)

Challenges addressed by the Action: Realizing the great societal benefits of accurately forecasting high-impact weather and predicting regional climate variability and extremes largely relies on the accurate modelling of cyclone-related physical processes. This is a fundamental issue regardless of the specific time scale considered, i.e. from weather forecasts to seasonal and decadal predictions and eventually climate projections. However, the recent efforts of the scientific community to understand the atmospheric processes that govern Mediterranean cyclone dynamics lack coordination and the focus needed to improve cyclone predictions in a tangible way. In addition to scientific issues, all these research results have to be of interest to end users and stakeholders, including public and private entities (e.g. civil protection and private entities such as insurance companies). *Therefore, this Action tackles the overall challenges of (1) coordinating scientific efforts, (2) making research results directly applicable to cyclone prediction, (3) enabling novel services tailored to stakeholder needs and (4) increasing public awareness of cyclone environmental and socio-economic impacts.*

Relevance and timeliness: In recent decades, the major scientific achievements in the field of Mediterranean cyclones have been attained through coordinated international programmes, mostly endorsed by the World Meteorological Organization (WMO). Such programmes brought together meteorological researchers and forecasters (e.g. ALPEX in the 80s; MAP and MCP in the 90s; and MEDEX in 00s). More recently, research interest has moved towards longer time scales (e.g. MedClivar, Med-CORDEX) that are of direct relevance to climate scientists. At present, a coordinated international effort to exploit the synergistic potential of bringing together different research activities in the field of Mediterranean cyclones is missing. Instead, projects are organized at the national level and are thematically relatively narrow. In addition, the latest research progress has been largely achieved in an uncoordinated way, through the use of a large variety of modelling and/or observation-based approaches, mostly applied to case studies. It is thus of no surprise that the direct implementation of the diverse results into atmospheric models is a rather difficult task, and currently cannot meet the constant demand from weather and climate centres for credible cyclone predictions. It is the lack of scientific coordination that inhibits the advancement of applied science for the benefit of society, economy and civil protection. The current strategy does not do justice to the importance of Mediterranean cyclones in producing weather extremes and modulating the regional climate.

Beyond scientific research, cyclone prediction is not equally effective among the different European institutions (e.g. Bertotti et al., 2012). The origin of this inequality may be related to differences in infrastructures and/or human resources, but also to unbalanced expertise and use of state-of-the-art numerical tools or modelling approaches. Therefore, networking between European institutions is a timely proposition and the ideal means for fostering the exchange of numerical tools and expertise in order to achieve improvements in performance with no additional infrastructure costs. Such a network can produce added value through both intra-Mediterranean collaboration, and collaboration with weather and climate centres across Europe. Indeed, the relatively small community of scientists dedicated to Mediterranean cyclones may benefit hugely from the expertise of different communities working on different cyclone categories outside the Mediterranean (e.g. tropical cyclones, extratropical storms, polar lows, and diabatic Rossby waves). Moreover, Mediterranean cyclones are relevant also for countries outside the Mediterranean basin, since they significantly influence weather and climate in central Europe (e.g. by triggering heavy precipitation and major flood events in Central Europe, such as the Elbe flood in 2013), and parts of Africa and Asia (e.g. due to dust or water vapour transport).

The current lack of international coordination and public awareness in this important field, and the need to channel new and already acquired knowledge to prediction models, together with the exploitation of new datasets (such as the new ERA5 reanalysis and CMIP6 climate simulations) make this Action exceptionally timely for harmonising and advancing weather and climate prediction capabilities in Europe and for enhancing the excellence of European research. Most important, this Action is designed to contribute significantly to four out of five priorities (except improving infrastructures) for weather and

climate research, which have been agreed by more than 50 countries and will be announced at the 2019 World Meteorological Congress: deliver science for services, build seamless models, nurture a diverse workforce, and share ideas with stakeholders (Hov et al., 2017).

1.2 PROGRESS BEYOND THE STATE-OF-THE-ART

1.2.1 APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE-OF-THE-ART

To address the four main challenges (section 1.1.2), this Action will provide a nucleus around which knowledge from European experts concerning Mediterranean cyclones can coalesce. It does so by *bringing together researchers specialized in meteorology and climatology, as well as professionals involved in weather and climate predictions, within a structured network.* This network will benefit from the participation of international experts specialised in other cyclonic systems such as polar lows, midlatitude storms and tropical/subtropical cyclones. Therefore, this Action will function as an ideal platform for weather and climate centres to exchange modelling skills, expertise and observations as well as to foster a continuous dialogue with end users (stakeholders and the general public). It will also manage short-term scientific missions (STSM) and training schools to ensure long-lasting collaborations between the different participating communities.

The atmospheric thermo-dynamical processes associated with Mediterranean cyclones have been well identified (Section 1.1.1). On the other hand, their interactions and relative importance to cyclogenesis, storm motion and intensity changes remain open questions. This Action will address this issue through the coordination of research activities already being carried out by its participants. One avenue of research will focus on case studies identified by the forecasters as being the most challenging ones to be reproduced by models. In particular, well documented case studies will be commonly simulated by the participants with different models, but with unified boundary conditions, derived from ensemble forecast members, and will be compared with observations. Beyond the research outcomes of such a joint community effort, results will offer benchmark for current and future model development efforts and will be helpful for outreach activities. In addition, this Action will also focus on climatological datasets in order to understand models' uncertainties in reproducing the climatology of Mediterranean cyclones, their morphologies and life cycles. Complementary use of both case studies and climatologies will provide a considerable advancement to the state-of-the-art in understanding and predicting the dynamics of Mediterranean cyclones. Particular scientific innovations brought by this Action are the following:

1) Provide for the first time a methodology that can be applied systematically in order to breakdown the dynamics of cyclones into individual atmospheric (thermo-)dynamical processes, such as baroclinic instability, air-sea interaction etc., each with a well-defined impact on storm development. Gathering existing methodologies and developing new ones will lead to the development of an assessment toolkit for the diagnosis of forecast and climate model simulations that will categorise cyclones with respect to their driving processes. These methodologies will be equally applied to weather forecasting and climate models, providing thus a common framework for the diagnosis of uncertainties in the representation of cyclone processes at different time-scales. Such a common framework is expected to facilitate transferability of improvements on the reproduction of Mediterranean cyclone dynamics from weather to climate models and vice versa.

2) By decomposing cyclones into processes, provide for the first time the criteria that qualify convectively -dominated cyclones in the region as so-called medicanes (storms that have completed tropical transition), an outcome of high interest for weather forecasting centres (e.g. for issuing warnings).

3) Results from a process-based assessment of how well models reproduce cyclones will provide an essential basis for the partners to develop innovative joint research proposals on the development of numerical model parametrisations, atmosphere-ocean-aerosol coupled modelling, and seamless prediction approaches including regional applications on weather forecasting and climate prediction.

4) Provide new methods and assessment tools based on ensemble forecasts. These will be the core basis for the development of new cyclone forecasting protocols that will function as common technical language among weather forecasting centres. This facilitates international cooperation and represents one of the major innovative aspects of this Action: establishing a framework for improving the prediction of an important class of high-impact weather events through the added-value produced by collaboration of operational forecasting centres.

5) The challenges related to the impact of cyclones on regional climate have only vaguely been identified so far (as outlined in Section 1.1.1) and thus further coordinated research is needed to understand how Mediterranean cyclones modulate the regional and global climate. The first steps in this direction will be brainstorming, reviewing literature, identifying the resources/observations needed for research, and eventually specifying the questions that need to be addressed. Therefore, new climate research objectives and perspectives are expected to emerge from this Action that advance the state-of-the-art and improve our understanding of the Mediterranean climate. To reinforce and achieve innovation in this direction this Action hosts a dedicated WG.

6) Beyond fulfilling research objectives, this Action is expected to promote the applicability of scientific advancements to the needs of weather/climate prediction centres and other stakeholders. Indeed, the model assessment toolkit, documentation and modelling guidelines for predicting cyclones at different time scales will be tailored to the needs of all Action participants aiming in particular at improving the effectiveness of prediction centres and enhancing a three-way collaboration between stakeholders, researchers and forecasting experts. Bringing together these communities to co-design weather/climate relevant services for mutual benefit has no precedent and is one of the core-objectives of this Action.

1.2.2 OBJECTIVES

1.2.2.1 Research Coordination Objectives

The overall challenges of this Action (outlined in Section 1.1.2) will be best tackled by performing a lateral exchange of models, tools, datasets and expertise among researchers and weather/climate prediction professionals. This Action will address the following research coordination (RC) objectives:

1) delineate the role of the "more typical" and "unique for the Mediterranean" atmospheric processes, as outlined in Section 1.1.1, for cyclogenesis and cyclone intensification, including medicanes;

2) determine the relationship between these processes and the performance of the models in representing them on time-scales relevant for weather and climate prediction;

3) establish priorities for model development aimed at improving the representation of the formation, movement, and intensity change of Mediterranean cyclones. Focus will be given on physics parameterisation, model coupling capabilities (ocean/dust interactions with atmosphere) and on adapting these priorities to the modelling particularities of weather forecasting and climate prediction;

4) develop common protocols for assessing the quality of Mediterranean cyclone simulations by weather forecasting and climate models;

5) foster the application of these common protocols to enhance timely and direct exchange between European weather and climate prediction centres when high-impact weather is imminent;

6) identify and set a scientific agenda for addressing new and poorly understood research questions related to socio-economic and environmental impacts of Mediterranean cyclones, especially those outlined in Section 1.1.1;

7) share observations between different countries commonly affected by Mediterranean cyclones;

8) increase public awareness of cyclone-related high-impact weather by maintaining a website, social media channels and newsletter;

9) improve stakeholders' understanding of cyclone-related high-impact weather and of relevant uncertainties regarding prediction on weather and climate time-scales;

The number of joint and international peer-reviewed publications will serve as a metric of the COST Action advancement in RC objectives 1 to 2. RC objectives 3 to 6 will be achieved through dedicated reports/documents publicly available and distributed through the Action website and/or peer-reviewed publications. The fulfilment of RC objective 7 will be measured by the number of available catalogues of observational dataset for common use within the network. Finally, the number of website visits and subscriptions, as well as the number of stakeholders that join the network, will be a metric of the achievements for RC objectives 8 and 9. Mediterranean cyclones and atmospheric modelling are of interest to –but not the core focus of– other international projects such as HyMeX (see section 2.1.1). However, this Action tackles the unique and unprecedented challenge to provide an integrated scheme

of straightforward interaction between scientific research, its application to weather/climate prediction and stakeholder needs in cyclone-prediction products.

1.2.2.2 Capacity-building Objectives

The capacity building (CB) objectives of this Action focus on the application of scientific knowledge to prediction models and on the effective dissemination of the outcomes of this Action, mainly composed by the RC objectives, as well as on the consolidation of long-lasting collaboration between research, weather and climate prediction centres. In particular this Action aims to do the following:

1) engage researchers with a background in atmospheric physics, meteorology and climatology, and professionals providing weather/climate services, in order to encourage a transfer of knowledge between subdomain experts that will advance our collective understanding of the processes occurring in Mediterranean cyclones;

2) train early career academic researchers, weather/climate prediction professionals and stakeholders on the new scientific advancements in the field of Mediterranean cyclones, as well as on the new evaluation tools and prediction methods that are outcomes of this Action. This objective will be further promoted through the website, which will function as a prototype for cyclone forecast dissemination with contributions from the involved partners.

3) promote exchange of scientific and modelling expertise between weather and climate prediction and research centres located around the Mediterranean and in other European countries. Special focus will be given on improving high-impact weather prediction. The involvement of North African partners will be pursued by looking for specific programs at universities or projects at weather and climate prediction centres whose inclusion in the network would be of mutual benefit.

4) promote collaboration between researchers, prediction centres and stakeholders to co-design and tailor research outcomes and services to the needs of the latter. For instance, the building of consistent databases of numerical products (e.g. a cyclone tracks inventory), adapted to the needs of re-insurance companies for infrastructure resilience or of civil protection for population exposure to natural hazards, is a major step forward for further development of collaborations between the participating communities and fostering common projects;

Achievement of all CB objectives will be measured by the number of participants to the Action and the number of attendances to (i) open summer schools, (ii) STSMs and (iii) workshops.

2 NETWORKING EXCELLENCE

2.1 ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

2.1.1 ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

This Action is expected to complement and extend current international initiatives and projects that focus on the Mediterranean climate, cyclone systems and extreme weather:

• the Hydrological cycle in the Mediterranean Experiment (HyMeX, Drobinski et al., 2014) provides the largest active consortium devoted to Mediterranean climate. HyMeX focuses on the hydrological cycle in the region and hosts more than 160 participants at its annual meetings;
• EGU Plinius Conference on Mediterranean Risks, MetMed Conference and MedClivar network are Mediterranean forums to which the Action will contribute;
• the WMO World Weather Research Programme (WWRP) High Impact Weather (HIWeather) coordinates research activities and the dialogue with stakeholders related to severe weather impacts (e.g. winter weather and severe windstorms associated with cyclones);
• the Cyclone Workshop, an international workshop designed to promote discussions and interactions between researchers and operational meteorologists in the field of synoptic and mesoscale meteorology, held every other year and open to participants from any institution or organization in the world;

This Action will collaborate with these research projects and initiatives in order to promote complementary activities that provide a meteorological dimension to the climate extremes and new agendas for climate impact research. Moreover, this Action will benefit from related projects that issue model outputs for scientific research, in particular:

• the WMO World Climate Research Programme (WCRP) COordinated Regional climate Downscaling Experiment (CORDEX) hosts a wide variety of regional climate simulations performed at different resolutions, forced by reanalysis and by global circulation models operated in the context of CMIP5. In particular the Med-CORDEX initiative (Ruti et al., 2016) is especially focused on Mediterranean climate;
• the European Centre for Medium-Range Weather Forecasts' (ECMWF) offers new ERA5 global reanalyses with unprecedented high horizontal (of the order of 30 km) and temporal (hourly) resolutions;
• the International Grand Global Ensemble (TIGGE) corresponds to a database of ensemble forecasts of different lead times from many weather prediction centres;
• the Subseasonal-to-Seasonal (S2S) WMO project, provides an extensive database of (sub)seasonal forecasts and hindcasts from operational centres;
• the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) is a platform that offers real-time dust forecasts since 2011 with a focus on Europe and North Africa. Large datasets of dust forecasts are available to assist research in understanding dust-cyclone interactions.

This Action will function as an end-user of these datasets in order to produce ground-breaking research. These datasets will also help to establish development priorities that will improve the representation of Mediterranean cyclones in the modelling systems that will be used to produce future reanalysis and reforecast products. Therefore, this Action shows great complementarity and high potential for collaboration with international initiatives on dataset production.

2.2 ADDED VALUE OF NETWORKING IN IMPACT

2.2.1 SECURING THE CRITICAL MASS AND EXPERTISE

The developed network brings together researchers and prediction experts from many countries with different scientific background and modelling expertise including cyclone-related dynamics and diagnostics, forecasting methodologies and climate modelling experience. Concentrating this multi-disciplinary knowledge and the skills and expertise from both the research and prediction (weather and climate) communities is an unprecedented approach, not only for Mediterranean cyclones, but generally for high-impact weather. In fact, the added value of such a structured and focused network represents one of the major innovative aspects of this Action: establishing a framework for improving the prediction of an important class of high-impact weather events.

The network has been built to balance the participation of universities and research institutions and environmental agencies, including forecasting centres, covering the Mediterranean region and contiguous areas that are regularly affected by Mediterranean cyclones. Moreover, participants from countries outside the Mediterranean will share in the network their expertise on other cyclonic systems such as midlatitude storms and tropical cyclones, thus favouring the mutual exchange of tools, diagnostics, and forecasting experience. Exchange of knowledge will be ensured through workshops, training schools and STSMs.

The secondary proposers from both Mediterranean and central/northern European countries already represent a suitable critical mass needed to address issues concerning cyclone-related process understanding and the forecasting of Mediterranean cyclones at different time scales. However, the Action's intention is to actively foster the participation of a larger number of researchers and to enlarge the network with stakeholders from both public and private entities (e.g. civil protection, energy and insurance companies). A Steering Committee (SC) composed by the MC chair and vice-chair, and working group (WG) leaders will be in charge of enlarging the network and reaching out to stakeholders.

2.2.2 INVOLVEMENT OF STAKEHOLDERS

Several European countries possess large prediction centres, with active and renown research departments -mainly national weather meteorological services-, while others, especially in eastern Europe, mainly focus on operational weather forecasting and do not have clear research-oriented activities. This Action takes into account this diversity of organisational structures of weather and climate centres in Europe and also the diversity of their prediction capacities. As a result, weather and climate prediction centres will act as stakeholders by benefiting of the outcomes of this Action and thus

improving their services, but also will act as contributors by promoting research within the network and by further engaging end-users.

Beyond weather and climate prediction centres and due to the importance of Mediterranean cyclones to the regional weather and climate, including extreme events, this Action will actively pursue the direct involvement of all potential stakeholders that make use of the forecasts. This entails stakeholders at both public and private entities. Specific public entities include the European environmental agency, government policy makers of different sectors and levels, from ministry divisions to municipalities, with interest in agriculture, tourism, energy, migration and urban planning, as well as civil protection, especially fire-brigades and national disaster management agencies. Specific private companies from the socio-economic sector, charged with weather and climate predictions, mainly include insurance, risk assessment and energy production as well as, land and marine transport companies.

It is the innovation of this Action to already involve stakeholders in its network from weather and climate prediction centres across Europe, as well as from private entities with a commercial background. Therefore since an early stage of this Action, stakeholders will have an unprecedented opportunity to co-design, together with researchers, the cyclone-related prediction products that address their end-user needs. This will be further pursued through Action workshops, including joint presentations, dedicated solicited talks and round tables, but also through training actions and STSMs that will favour exchange between researchers, weather and climate professionals and stakeholders. This Action seeks to have maximum visibility and to be highly appealing for a diverse spectrum of end-users and thus it is within its interest to maintain a balance in stakeholder participation between public and private entities so that the research and applied science outcomes will tilt in either direction.

Involvement of more stakeholders will be actively pursued by this Action. Each WG is organized along three axes (see Section 4), one of them being dissemination. This structure aims at optimal communication at national level, where each WG will identify and involve stakeholders in collaboration with the Management Committee (MC) members. Inclusion of stakeholders will be achieved generally through invitations, periodic newsletters and calls published on the Action website; however, this process will also proceed through personal invitation from MC members to highly qualified persons, and through presentations at project meetings and international conferences with the specific aim of disseminating Action outcomes. Finally, in order to attract relevant stakeholders, the outcomes of this Action will be presented through already-established networks, such as the different WMO groups (e.g. WWRP HIWeather Project, WCRP and Hydrology and Water Resource (HWRP) Programmes) that deal with high-impact weather, climate variability, and water resources and through networks focusing on the assessment of climate change and its impacts in the Mediterranean basin (e.g. MedECC).

2.2.3 MUTUAL BENEFITS OF THE INVOLVEMENT OF SECONDARY PROPOSERS FROM NEAR NEIGHBOUR OR INTERNATIONAL PARTNER COUNTRIES OR INTERNATIONAL ORGANISATIONS

The participation of the WMO will facilitate interactions with many of the relevant programs described in Section 2.1.1 and the worldwide dissemination of the Action outcomes. The WMO will also support the effort of involving North African countries. On the other hand, Action topics are well in line with WMO science summit priorities (Section 1.2.1) and directly relevant for the objectives of the WMO HIWeather project. Participation of the International Centre for Theoretical Physics will enable a fruitful sharing of modelling and diagnostic tools, knowledge and regional climate predictions specifically addressing the Mediterranean basin and climate extremes.

3 IMPACT

3.1 IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1 SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

In terms of research, the field of Mediterranean cyclones will first greatly benefit from the involvement of scientists and institutions from other European countries that focus on the larger and more developed research fields of tropical and extratropical cyclones. In fact, the new results, modelling and diagnostic approaches are transferable and thus will be of great benefit not only to the Mediterranean cyclone

community, but also to communities interested in cyclones in other regions. In addition, the results of this Action will provide, for the first time, an integrated approach to tackle the challenge of understanding Mediterranean cyclones in an atmospheric process-based framework. This includes physical processes whose impact on cyclone behaviour is relatively unexplored (e.g. dust and ocean interaction with the atmosphere). The development of methods that decompose cyclones into processes (see section 1.2.1) will be applied to both specific cyclone cases simulated by forecasting models, as also to outputs from climate models. This approach allows a straightforward comparison on the basis of (thermo-) dynamical processes between models operated at different spatial resolutions and integration periods, highlights their advantages and disadvantages, is transferable to other cyclonic systems and opens new perspectives for seamless prediction. Finally, new research lines are expected to emerge with focus on interdisciplinary approaches and applications, while environmental impacts of cyclones will be specifically addressed through a dedicated WG (e.g. dust transport, effect on the marine environment and sea state).

In terms of socioeconomic benefits, this Action addresses the constant demand for accurate, reliable and useful weather and climate predictions. This is a crucial issue for populations in vulnerable areas, as well as for the economic sector in the Mediterranean region. An expected but unprecedented impact of this Action is thus to improve and harmonise high-impact weather prediction between European countries. This will be of great benefit especially for research centres in less research-intensive countries and in countries with limited operational forecasting capacities. To this end, this Action will foster direct collaboration between weather and climate prediction centres through the development of a common vocabulary, and shared comparison and assessment tools. This enhanced cooperation is expected to be solidified through STSMs and training schools, and through opportunities for collaboration among scholars, practitioners and experts in the field. Therefore, this Action is expected in the coming years to contribute to the improvement of the readiness of civil protection on the European level with regard to high-impact weather, and to assist the economic growth of both public and private sectors, e.g. in tourism, agriculture, energy and shipment. Especially to for the latter, this Action will vividly pursue the inclusion of stakeholders (see section 2.2.2).

In terms of outreach activities, this Action will increase public awareness of high-impact weather associated with Mediterranean cyclones, as well as of the future of cyclones in the context of climate change. To support and increase the Action's visibility, the dedicated website and social media feeds will largely publicise contributions (also for advertising the Action) from the international network (e.g. in case of imminent intense cyclone development). The end goal of this component of the Action is to prepare a prototype/experimental cyclone-devoted forecasting service similar to that used for tropical cyclones by the National Oceanic and Atmospheric Administration (NOAA) in the USA (nhc.noaa.gov), with naming, predicted trajectories, intensity and categories of Mediterranean cyclones.

In the long term, after the end of the Action, the improved ability of numerical models to simulate Mediterranean cyclones and their impacts on the environment, for both weather and climate predictions, will be an important legacy of the Action, including benchmark model intercomparison for common case studies. Methodologies and tools will remain available for continuous upgrading and exchange between weather and climate prediction centres. Moreover, guidelines on the exploitation of new observations and on monitoring network requirements will be distributed to the responsible agencies, while tests of novel observation strategies will foster dedicated field campaigns (possibly joining experiments supported by funded projects). Finally, the Action's STSMs and training schools will promote the training of a new generation of weather and climate professionals (academic and non-academic) who will carry on the legacy of this Action as part of an international cross-sectorial community devoted to Mediterranean weather and climate.

3.2 MEASURES TO MAXIMISE IMPACT

3.2.1 KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

Beyond bringing together academics and professionals from services with backgrounds in meteorology and climatology, this Action will benefit from the experience of scientists and forecasters from across the Mediterranean region. This will enable a valuable transfer of knowledge between communities that have often worked separately in the field of Mediterranean cyclones. In addition, considerable advancements in both scientific understanding and high-impact weather prediction are expected through the inclusion of researchers and forecasters from countries outside the Mediterranean region, specialised in other cyclonic systems such as midlatitude storms and tropical cyclones. It is undeniable that international coordination of efforts between western and eastern Mediterranean countries and

northern European countries will produce significant added value aimed at improving our understanding of Mediterranean cyclones and their environmental and socio-economic impacts. As envisaged by this Action, interactions and collaborations between the members will be mutually beneficial. Overall, the mutual benefit to weather and climate prediction centres and stakeholders is expected to be exceptionally high. The former will increase the visibility and application of their products, while the latter will acquire products tailored to their needs. The mutual benefit to researchers and weather/climate prediction centres is also expected to be high because the cornerstone of this Action is the acceleration and facilitation of the application of core science to cyclone prediction. In particular, the participants from different communities through mutual benefit will have a unique opportunity to develop new knowledge and to transfer existing expertise, as well as to significantly develop their careers.

This network will allow **academic researchers** to:
• enhance their research through synergetic approaches that include meteorology and climatology and through the development of new scientific objectives related to cyclone impacts on regional climate;
• gain access to a plethora of observations enabling a coordinated effort to understand the atmospheric processes involved in Mediterranean cyclones;
• gain a unique opportunity to cooperate in an interdisciplinary and international framework;
• be exposed to services of applied science and thus broaden their career development options, an element that is of special interest to the early career scientists;
• have a unique opportunity to communicate their results to the general public and to profit from bridging scientific research with public awareness of cyclone systems.

This network will allow **professsionals and model developers at weather/climate centres** to:
• profit from and acquire new tools for diagnostics, intercomparison of forecasts, and numerical analyses
• establish priorities for improving their forecasting systems, with focus on the simulation of cyclones;
• build new and enhance existing collaborations across weather prediction centres;
• profit from inputs from stakeholders in order to make their products more useful;
• acquire new evaluation tools for investigating climate simulation and addressing their uncertainties;
• find a stimulating environment to set the agenda for new research questions on climate impacts;
• increase their visibility to the general public on issues that are relatively poorly understood such as uncertainties in predicting future climate.

Finally, this network will allow **stakeholders** to:
• experience how academic research reaches towards and interacts with operational applications in weather and climate predictions;
• develop an in-depth understanding of the challenges and uncertainties associated with the prediction of Mediterranean cyclones;
• develop collaborations with academic sector and prediction centres;
• co-develop, acquire and exploit tools and datasets, tailored to their needs;
• enlarge their international network, where private entities will facilitate their access to new markets, especially to the emerging economies of southern and eastern Europe;

3.2.2 PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

The MC will appoint eight members, two from each WG and two from the MC as the Communication Team. This group will coordinate the dissemination of the Action's results and ensure internal and external communication, including the Action website and social media feeds. The dedicated website and social media channels will provide constantly updated information about the Action activities, meeting/workshop reports and presentations. Reports of results and activities will be regularly disseminated during the Action, with emphasis during each formal meeting (MC or annual workshops). These products will be adapted and tailored to four specific target groups:

Scientific community: it is necessary to provide news on Action results in order to better coordinate and steer the research activities of the Action participants, as well as to promote collaborations and further involvements in the network. Peer-reviewed papers (a list of which will be maintained on the Action website) and international conference presentations (possibly made publicly available) will provide an up-to-date overview of the results of this Action. Participation in WMO working groups (e.g. WWRP, WCRP and HWRP) will further spread the results to the scientific community. Results will be summarized in annual workshops, and for the final workshop a special issue of a peer-reviewed journal will be prepared, collecting the main Action results. A scientist-in-residence program will be pursued,

looking for external scientists (possibly on sabbatical) available to stay at one of the participating institutions. This would bring expertise and further promote the visibility of the Action.

Weather and climate prediction centres: the knowledge developed and the modelling progress made during the Action will be transferred mainly through annual workshops, and further supported by documentation and user-guides published on the website, advertised by a newsletter and, especially to early-career professionals, provided through planned training schools. Also, the Action will strongly recommend academic scientist STSMs to operational centres to ensure an efficient uptake of the research results emerging from the Action.

Relevant stakeholders: one specific activity of each WG will be devoted to the identification and invitation of stakeholders (see Section 2.2.2). Moreover, promotional and information material (web-based advertisements, presentations, leaflets, brochures, posters) will be produced to meet the needs of a broad target audience. Presentations to local authorities or to specific groups of stakeholders will be also encouraged. Annual workshops will be open to stakeholders and round tables will be organised for optimizing interactions with Action participants.

General public: here the need is to disseminate results in a suitable manner and in a non-technical language through popular science articles, website and social media, interviews and presentations. A joint press release will be prepared during the kick-off meeting among the largest possible number of countries involved. Moreover, getting in touch with national meteorological or climate societies will build a bridge between academic research and the general public. In case of severe Mediterranean cyclones, the Communication Team will take care of a special effort to promote forecasting products, graphical output and also post-event visualization and information to attract the attention of the general public.

4 IMPLEMENTATION

4.1 COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1 DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

The core RC and CB objectives (outlined in Section 1.2.2) can be synthesised to form three main axes, corresponding to the overall challenges of this Action (Section 1.1.2): (1) international coordination of research, (2) implementation of the scientific knowledge into forecasting and climate prediction services, and (3) effective dissemination of outcomes of this Action to stakeholders and the general public. However, depending on the time scale considered, there are different scientific questions of interest regarding Mediterranean cyclones, and different modelling issues involved in cyclone prediction. The needs of stakeholders may also largely depend on the considered time scales, e.g. stakeholders interested in the timely and accurate forecast of imminent high-impact weather or stakeholders interested in the future climatology of Mediterranean cyclones. The same is also valid for the objective of increasing the general public awareness, where interest may range from the explanation of single catastrophic events to the future of cyclone-related environmental risks. Therefore, the Action's main challenges and objectives are addressed through three WGs, each of them organised along the three aforementioned axes. Annual workshops of the Action will specifically address the work of the three WGs, where scientific presentations, training actions and round tables will foster the exchange between researchers, weather/climate professionals and stakeholders (CB objectives 3 and 4, Section 1.2.2.2).

WG1: Process-based understanding of Mediterranean cyclones at weather time scales

Coordination of research: WG1 will mainly address RC objectives 1 and 2 (described in Section 1.2.2.1). Coordinated research will be largely based on the analysis of a large number of cyclone case studies, from the early stages of cyclogenesis until dissipation. These case studies will be identified in collaboration, involving researchers and forecasters from both the eastern and western Mediterranean, giving priority to cases where forecasts failed to reproduce the cyclone properties (e.g. intensity, track or morphology) and/or the associated extreme weather phenomena (e.g. heavy rainfall, wind storms and dust transport). Research efforts will focus on identifying why the models failed in the reproduction of specific processes (outlined in Section 1.1.1). A particular effort will be made to gain a better understanding (i) of processes that are particularly relevant to Mediterranean cyclones but still poorly understood, and (ii) of the complex interaction among different mechanisms in a large variety of Mediterranean cyclones. This will be done through the use of (1) coordinated model sensitivity experiments, (2) state-of-the-art coupled models (ocean/chemistry/atmosphere), and (3) observations.

Operational implementation: WG1 will address RC objectives 3 to 5 as well as CB objectives 1 and 2 (Section 1.2.2). This will be done through the development and application of common protocols for assessing forecasting models, by proposing priorities for improving atmospheric modelling and operational forecasting procedures, and by applying protocols and assessment tools to past forecasts of Mediterranean cyclones. Studies will be performed using common datasets provided by the participants (observations and model outputs), while proposed priorities for forecasting improvements will be continuously updated (given the constant technological progress expected over the course of the Action; Section 1.2.1). Although implementing a real-time forecasting system is out of scope for this Action, WG1 will build a prototype of a cyclone-forecasting website to facilitate interaction between weather prediction centres and to set an example of the range of forecasting performances. This will be done for the case studies selected in WG1, as well as for exceptional cases that occur during the Action.

Dissemination and public engagement: WG1 will address mainly RC objectives 7 to 9 and CB objectives 3 and 4. The website, newsletters and social media will be the main tools for disseminating results, reports and general Action outcomes. The new scientific results and the proposed priorities for improving the forecasting of Mediterranean cyclones will be regularly communicated through newsletters to external stakeholders and weather prediction centres. Further activities within WG1 include the development of strategies for increasing international visibility and attracting stakeholders who will provide input on possible impacts that the network's research activity should consider. Concerning the general public, outreach activities will be performed through 3D visualisations of forecasts on dedicated social media channels. In this context, the case studies selected in WG1 will be also presented in popular science, while press releases to national and international media will be disseminated in case of imminent high-impact Mediterranean cyclones, assisted by the prototype forecasting website. This dissemination will be done through collaboration between WG1 members, the MC, the Communication Team, and the involved forecasting centres.

Tasks. T1.1: Define a set of case studies that are relevant from a forecasting and/or physical processes point of view; share validation tools and collect observations and model simulations. **T1.2**: Define and apply model assessment techniques to operational (including ensemble) forecasting for Mediterranean cyclones, including associated high-impact weather. **T1.3**: Define, propose and update priorities for improving cyclone prediction at weather forecasting scales. **T1.4**: Produce/publish scientific results on process understanding obtained through collaborative activities and submit joint proposals for scientific or services projects. **T1.5**: Identify, invite and interact with stakeholders about WG1 progress and perform outreach activities to increase public interest in, and awareness of, high-impact events related to Mediterranean cyclones.

WG2: Process-based understanding of Mediterranean cyclones at climate time scales

Coordination of research: WG2 will mainly address RC objectives 1 and 2. In contrast to WG1, activities will be performed in the framework of climate prediction (past, present and future). WG2 will take advantage of the new ERA5 reanalyses and CMIP6 and will share and apply a variety of diagnostic tools (e.g. cyclone tracking tools, cyclone phase diagrams and decomposition of surface pressure tendency) in order to identify the physical criteria that distinguish Mediterranean cyclones (e.g. from North Atlantic cyclones) and that quantify the relative contribution of diabatic and adiabatic processes to cyclogenesis, intensification and decay. This approach is expected to identify different categories of Mediterranean cyclones with regard to their dynamical processes. Furthermore, WG2 is expected to establish a widely accepted definition of the criteria that qualify some Mediterranean cyclones as tropical-like systems (known as medicanes). Results will be used to assess the ability of climatological datasets (e.g. MED-CORDEX simulations) to reproduce cyclone categories and their climatology, as well as to better understand the evolution of Mediterranean cyclone categories and their related processes in a changing climate. Finally, the SC will make particular effort to favour synergetic activities with WG1 to put the analysed cases as identified in Task 1.1 into a climatological context, e.g. by defining the representativeness of case studies with respect to the cyclone climatology. This, along with additional common studies, aims at facilitating transfer of benefits from improving cyclones representation in weather forecasting models to climate modelling and vice versa.

Operational implementation: WG2 will address RC objectives 3 to 5, as well as CB objectives 1 and 2. WG2 will establish protocols and assessment tools to be applied to cyclone climatologies for assessing climate models. Priorities will be proposed for improving regional climate modelling regarding cyclone processes (e.g. propose improvements to address systematic deficiencies). Comparisons of CMIP6 climate models with the ERA5 reanalysis will also provide the means for assessing uncertainties in future climate projections.

Dissemination and public engagement: The same means and methods as in WG1 will be used in WG2 in order to address RC objectives 7 to 9 and CB objectives 3 and 4. WG2 dissemination and involvement strategies will be aimed at stakeholders interested in climate aspects and long-term adaptation strategies, while communication with the general public will mainly address climate change and the future evolution of cyclone-related high-impact weather.

Tasks. T2.1: Define research protocol: catalogue of climatological datasets (past and future climate) including observations and model simulations. **T2.2**: Define protocol for assessing simulations: share diagnostic tools, making them easily applicable to all partners. **T2.3**: Define, propose and update priorities for improving cyclone prediction at climate scales. **T2.4**: Produce and publish scientific results on cyclone processes from a climatological perspective and on their future evolution. **T2.5**: Identify, invite and interact with stakeholders about WG2 progress and perform outreach activities to increase public interest and awareness of Mediterranean cyclone-related high-impact events.

WG3: Environmental and socio-economic impacts of Mediterranean cyclones

Coordination of research: WG3 will mainly address RC objective 6. WG3 participants will set a scientific agenda that addresses the still uncharted impacts of cyclones on regional climate and the environment, several of them outlined in Section 1.1.1. This demands close collaboration between researchers and forecasters. Therefore, brainstorming is a core issue for WG3. First WG3 will identify and catalogue different cyclone impacts and will propose research approaches. The less clearly defined structure of WG3 (in comparison to WG1 and WG2) reflects the fact it is highly innovative and therefore requires more flexibility. However, the impacts already mentioned in Section 1.1.1 will provide a starting point enabling a fast spin-up of WG3 activities, thereby minimizing risks. There may be a large variety of scientific and modelling issues to be dealt with by this WG, especially regarding poorly understood cyclone processes and their impacts on regional climate and the environment. For instance, dust uptake and transport by cyclones may be of interest for weather forecasts when addressing air quality issues, but it is also of interest for climate when considering the regional radiative budget. In collaboration with WG1 and WG2, WG3 participants will acquire simulations, climatologies and observations to address the identified cyclone impacts and advance the state-of-the-art in the field. Involvement of stakeholders and professionals from weather and climate prediction centres is crucial for harmonising the research with socio-economic needs.

Operational implementation: WG3 participants will work closely with stakeholders, weather and climate prediction services involved in the Action to propose new products for cyclone impacts on regional climate and the environment (mainly addressing CB objectives 1 and 2). Stakeholders are expected to provide input to enable tailoring of these products to their needs and thus to maximize the visibility and utility of the products.

Dissemination and public engagement: Website, newsletters and social media will be used to inform the general public and attract more stakeholders with regards to newly discovered cyclone-related impacts (RC objectives 8 and 9 and CB objectives 3 and 4). Special focus will be given to the general public through social media, while relevant case studies (connection with WG1) or climatological aspects of cyclones (connection with WG2) with new cyclone impacts will be further developed.

Tasks. T3.1: Define the state-of-the-art in understanding cyclone impacts, in part by identifying missing observations and deficiencies in model applications at different time scales. **T3.2**: Define and propose forecasting and climate prediction products, relevant to the newly identified cyclone impacts. **T3.3**: Produce and publish scientific results on cyclone impacts and submit joint proposals for scientific or service projects. **T3.4**: Identify, invite and interact with stakeholders about WG3 progress and perform outreach activities to increase public interest and awareness of newly discovered impacts of Mediterranean cyclones on the environment and climate system.

4.1.2 DESCRIPTION OF DELIVERABLES AND TIMEFRAME

All deliverables will be published to the website, open-accessed whenever possible. Especially scientific articles will be available under green or gold open access status. In particular, deliverables addressed to stakeholders will be co-written with stakeholders to optimise usefulness and appealingness.

WG1 - Deliverables. D1.1: Report addressed to Action members including case study descriptions and modelling systems and on agreed protocols for sensitivity simulations. This report will also serve as a detailed guide for partners who may join the Action at a later stage. **D1.2**: Documentation addressed to stakeholders on protocols and techniques for assessing forecast performance, tailored to the needs of

weather prediction centres. This document will be constantly updated with new methodologies. **D1.3**: Report addressed to Action members and stakeholders, devoted to priorities for improving cyclone prediction. This report will be constantly updated during the Action and tailored to the needs of forecasters and model developers. **D1.4**: Mid-term report of T1.4 addressed to Action members, describing scientific production so far and setting research orientations. **D1.5**: Scientific peer-reviewed overview article addressed to the scientific community on the challenges in forecasting high-impact weather in the Mediterranean. **D1.6**: Yearly internal report addressed to Action members, open public and stakeholders on dissemination strategies (including website, social media, newsletters, scientific papers etc.; see Section 2.2.2), stakeholder involvement and products tailored to their needs. **D1.7**: Setting up a prototype/experimental cyclone-devoted forecasting service with contributions from the Action partners.

WG1 - Milestones. M1.1: Deployment of the website section on forecasting and publication of the catalogue of the selected events to be analysed by WG1. **M1.2**: Repository with process-oriented validation tools (codes and user guides addressed to Action members). **M1.3**: First version of documentation on model development priorities published on the website. **M1.4**: Training school organized on cyclone processes and relevant forecasting issues.

WG2 - Deliverables. D2.1: Report addressed to Action members and stakeholders on the available datasets. D2.2: Documentation addressed to Action members and stakeholders describing the available diagnostic tools, the protocols and techniques for assessing climate simulations (tailored to the needs of climate prediction centres). This document will be constantly updated with new methodologies. **D2.3**: Report addressed to Action members and stakeholders, devoted to priorities for improving cyclone prediction on climate timescales. This report will be constantly updated during the Action and tailored to the needs of model developers and climate prediction services. **D2.4**: Mid-term report of T2.4 addressed to Action members, describing scientific production so far and setting research orientations. **D2.5**: Climatological overview article addressed to scientific community, on Mediterranean cyclone categories and on the future climatology of Mediterranean cyclones. **D2.6**: Yearly internal report addressed to Action members and stakeholders, on dissemination strategies (including social media, newsletters, scientific papers etc.; see Section 2.2.2), stakeholder involvement and products tailored to their needs.

WG2 - Milestones. M2.1: Deployment of the website section on climatological aspects of Mediterranean cyclones. **M2.2**: Repository of diagnostic tools for climatological analysis and user guides addressed to Action members and stakeholders. **M2.3**: First version of documentation on model development priorities published on the website. **M2.4**: Training school organized on cyclone processes and relevant climate prediction issues.

WG3 - Deliverables. D3.1: White paper addressed to Action members and stakeholders, about Mediterranean cyclone impacts on the regional climate and the environment, including future perspectives. **D3.2**: Documentation addressed to stakeholders, on proposed new products on cyclone impacts, tailored to the needs of stakeholders (to be constantly updated). **D3.3**: Mid-term report addressed to Action members and stakeholders of T3.4, describing scientific production so far and setting research orientations. **D3.4**: Overview article addressed to the scientific community, on the environmental and climate impacts of Mediterranean cyclones. **D3.5**: Yearly internal report addressed to Action members and stakeholders, on dissemination strategies (including social media, newsletters, scientific papers; see Section 2.2.2), stakeholder involvement and products tailored to their needs.

WG3 - Milestones. M3.1 Deployment of the website section on impacts. **M3.2**: Identification of new research orientations. **M3.3**: Training school organized on cyclone impacts.

4.1.3 RISK ANALYSIS AND CONTINGENCY PLANS

The SC (see section 2.2.1) will ensure the Action's scientific management, check the consistency of the deliverables, monitor the workflow and take necessary actions in case of deviations or problems. To this end, the SC will have monthly videoconferences. In addition to the SC meetings, the milestones will function as check points of the smooth and effective progress of the Action. The monthly SC meetings and the milestones are expected to address any administrative or implementation-related issues that may arise in a timely manner. The following potential risks have been identified and are presented along with contingency plans to overcome them or to minimise their impact:

Missing collaboration/coordination between WGs and/or slow progress: In case of slow or insufficient progress between the WGs, the SC will ask the WG leaders to set priorities (e.g. datasets, methods or expertise) for advancing with the WG tasks. The SC will communicate these needs and will propose

specific activities. Depending on the issue, these activities may include: (1) definition of dedicated temporary sub-groups, (2) collaboration with external projects/initiatives (see section 2.1.1), (3) invitation of new participants with relevant expertise to the Action, (4) creation of a discussion forum on the web to promote interaction, (5) setting of more regular MC meetings to identify problems and propose solutions, (6) fostering specific side-meetings between partners during the Action workshops, and (7) promotion of intra-WG STSMs to train qualified personnel who will address the Action needs.

Ineffective use of the Action outcomes by stakeholders and/or weather/climate prediction centres: The seemingly obvious feasibility of exchange of modelling expertise and tools between research and operations may present difficulties. In this case, more weight will be given to produce detailed documentation with examples and easy-to-use numerical applications for model evaluations, to include dedicated workshop presentations of tools, and hands-on tutorials training schools, as also, present Action results at national/international meetings that have high numbers of stakeholder participants.

Non-effective involvement of North African countries: There is the possibility of lack of interest from North African countries to participate in the Action and to contribute with datasets and observations. Although the participation of these countries is not a crucial issue for the core challenges of this Action, the SC will seek to integrate in the Action (and profit from) collaborations between North African countries and European institutions from already existing projects/initiatives. Such a contingency plan could be developed in collaboration with WMO which has relevant experience.

Non-effective involvement -or lack- of interest from stakeholders: As additional measures for the involvement of stakeholders, the SC will ask the MC members to identify specific entities from their countries with a high interest in this Action (e.g. institutions, companies, authorities) and to assist the Communication Team in contacting them – if possible also to acting as intermediates. An additional measure to increase the appeal of the Action to stakeholders is to further promote their involvement in dedicated meetings with developers of tools, and to promote their participation to STSMs in order to favour the utilization of the Action outcomes.

Conflicts on data policies and data availability: in this case the SC will directly communicate the relevant data providers, explicitly explaining that this Action does not aim at building its own database, but rather intends to construct a catalogue linking preexisting data. Concerning new data, in case of unavailability, the meteorological and climate prediction centres already participating in the Action will be asked to act as intermediates in order to facilitate availability of data at least for use within the network.

Limited interest from the general public: The SC will reinforce dissemination activities through the website and social media. Attractive material such as 3D animations and multimedia applications will be developed and communicated to increase visibility and appeal of the Action outcomes to general public.

4.1.4 GANTT DIAGRAM

European network for Mediterranean cyclones in weather and climate - Duration 4 years												
	Year 1			Year 2			Year 3			Year 4		
	I	II	III	I	II	III	I	II	III	I	II	III
WG1: Process-based understanding of Mediterranean cyclones at weather time scales												
T1.1			D1.1									
T1.2			M1.2	D1.2					D1.7			
T1.3					M1.4	D1.3 M1.3						
T1.4								D1.4				D1.5
T1.5		M1.1	D1.6			D1.6			D1.6			D1.6
WG2: Process-based understanding of Mediterranean cyclones at climate time scales												
T2.1			D2.1									
T2.2			M2.2	D2.2								
T2.3						D2.3 M2.3		M2.4				
T2.4								D2.4				D2.5
T2.5		M2.1	D2.6			D2.6			D2.6			D2.6
WG3: Environmental and socio-economic impacts of Mediterranean cyclones												
T3.1			M3.2			D3.1						
T3.2						D3.2					M3.3	
T3.3							D3.3					D3.4
T3.4		M3.1	D3.5			D3.5			D3.5			D3.5
Workshops	KO		WS1			WS2			WS3			WS4

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