SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2022
Project Title:	ASIM-CPL - Air-Sea Interactions on the Mediterranean basin, using "atmosphere-ocean-waves" CouPLed numerical models
Computer Project Account:	…………………………………………………………….……
Principal Investigator(s):	Dr. Antonio Ricchi
Affiliation:	CETEMPS – Department of Physical and Chemical sciences, University of L'Aquila
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Prof. Rossella Ferretti; Dr. Lorenzo Sangelantoni
Start date of the project:	2 January 2022
Expected end date:	30 June 2022

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	10000000.00	578921.63	10.000.000	11.538.131
Data storage capacity	(Gbytes)	10000	100	1000	100

Summary of project objectives (10 lines max)

Air-sea interactions play a fundamental role in the earth system dynamics. They drive circulation at different spatial-temporal scales, from the short-term, to the seasonal and climatological scales, and from synoptic scale to local scale. In this complex context, waves play the triple crucial role, modulating the surface roughness, transfers kinetic energy and heat into the ocean, modifying the dynamics of ocean mixing and circulation. These effects have repercussions on short-term atmospheric and marine phenomena, such as marine and atmospheric Heat Waves and Cold Air Outbrek, High Precipitation Event and Hail storm, Tropical-Like Ciclones and marine storms, but also on mid- and long term environmental dynamics. In this work apply various numerical approaches on various time scales, with uncoupled, semi-coupled, Pseudo Global Warming, and fully-coupled models, with the help of the numerical system COAWST, which allows varoius degree ofcoupling between the various models.

Summary of problems encountered (10 lines max)

Unfortunately this year (characterized by many case studies to simulate) we have used all the SBUs available, in a few months (5) . This is because we ran very intensive simulations, at resolutions of 5-1 km for extreme atmospheric and marine events and for seasonal forecast simulations. This work involved an extensive sensitivity study to SST, Soil Moisture, Soul Temperature, Mixed Layer Depth and SST anomaly under Pseudo Global Warming approach. For this we would like to ask for an additional 5,000,000 SBUs, not used last year.

Summary of plans for the continuation of the project (10 lines max)

In early 2022 we investigated case studies with the uncoupled model (atmosphere only) and semi-coupled model (using a simplified 1D ocean). The results, on many events, of short, mid-long term a convection permitting scales, have produced interesting results, which we are advertising in the main international congresses (EGU22, EMS22, Plinius22, COST Action etc). In the coming months we would like to complete the simulations about 4 heat waves events, thermal anomalies of 2021/2022 and reproduce the cases studied, with the fully coupled model, using the main wave roughness parameterizations and adding 2, experimental ones, which implement the effect of aerosols and marine sprays produced by waves and wind. Furthermore, we would like to simulate with fully-coupled model, the impact of air-sea interactions on thermal extremes both at sea and atmospheric, during summer 2003 and 2022, isolating the impact sea, its anomaly and influence synoptic and local scale

List of publications/reports from the project with complete references

Ferretti, R., Mazzarella, V., Marzano, F., Miglietta, M. M., Picciotti, E., Montopoli, M., Baldini, L., Vulpiani, G., Tiesi, A., Mazzà, S., and Ricchi, A.: Analysis of the development mechanisms of a large-hail storm event, on the Adriatic Sea using an atmosphere-ocean coupled model (COAWST), EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-12876, https://doi.org/10.5194/egusphere-egu22-12876, 2022.

Carniel, C. E., Ferretti, R., Ricchi, A., and Zardi, D.: On the statistical analysis of explosive-cyclogenesis over the Mediterranean Sea using ERA5 dataset , EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-11763, https://doi.org/10.5194/egusphere-egu22-11763, 2022.

Ricchi, A., Liguori, G., Cavicchia, L., Miglietta, M. M., Bonaldo, D., Carniel, S., and Ferretti, R.: On the influence of Ocean Mixed Layer and Sea Surface Temperature Anomaly in the genesis and evolution of the Mediterranean Tropical-Like cyclones "IANOS"., EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-11515, https://doi.org/10.5194/egusphere-egu22-11515, 2022.

Sangelantoni, L. and Sobolowski, S.: Exploring the effect of kilometer-scale climate modeling on the representation of historical and future heat waves. A multi-model ensemble perspective, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-4318, https://doi.org/10.5194/egusphere-egu22-4318, 2022.

Carniel, C. E., Ferretti, R., Ricchi, A., Curci, G., Serafini, P., Wellmeyer, E. D., and Zardi, D.: Statistical analysis and classification of cyclogenesis events in the Mediterranean, EMS Annual Meeting 2022, Bonn, Germany, 5–9 Sep 2022, EMS2022-485, https://doi.org/10.5194/ems2022-485, 2022.

Neduncheran, A., Ricchi, A., and Ferretti, R.: Case study of Medicane Ianos: Investigation into its triggering mechanism, EMS Annual Meeting 2022, Bonn, Germany, 5–9 Sep 2022, EMS2022-127, https://doi.org/10.5194/ems2022-127, 2022.

Ricchi, A., Liguori, G., Cavicchia, L., Miglietta, M. M., Bonaldo, D., Carniel, S., and Ferretti, R.: On the role of Ocean Mixed Layer and Sea Surface Temperature Anomaly in the genesis, intensification and evolution of the Mediterranean Tropical-Like cyclones "IANOS"., EMS Annual Meeting 2022, Bonn, Germany, 5–9 Sep 2022, EMS2022-312, https://doi.org/10.5194/ems2022-312, 2022.

Ricchi, A., Sangelantoni, L., Redaelli, G., and Ferretti, R.: Multi-Physics Ensemble approach to investigate two summer 2021extreme Heat Waves over central Mediterranean basin, EMS Annual Meeting 2022, Bonn, Germany, 5–9 Sep 2022, EMS2022-315, https://doi.org/10.5194/ems2022-315, 2022.

Sangelantoni, L., Ferretti, R., Redaelli, G., and Sobolowski, S.: Summer season convection inhibition and soil moisture memory in km-scale climate simulations, EMS Annual Meeting 2022, Bonn, Germany, 5–9 Sep 2022, EMS2022-155, https://doi.org/10.5194/ems2022-155, 2022.

Ricchi, A., Mazzarella, V., Marzano, F., Miglietta, M. M., Picciotti, E., Montopoli, M., Baldini, L., Vulpiani, G., Tiesi, A., Mazzà, S., and Ferretti, R.: Analysis of the development mechanisms of a large-hail storm event, on the Adriatic Sea using an atmosphere-ocean coupled model (COAWST), 17th Plinius Conference on Mediterranean Risks, Frascati, Rome, Italy, 12–15 Oct 2021, Plinius17-19, https://doi.org/10.5194/egusphere-plinius17-19, 2021.

Ricchi, A., Liguori, G., Cavicchia, L., Miglietta, M. M., Bonaldo, D., Carniel, S., and Ferretti, R.: On the influence of Ocean Mixed Layer depth and Sea Surface Temperature Anomaly in the genesis and evolution of the Mediterranean Tropical-Like cyclones “IANOS”, 17th Plinius Conference on Mediterranean Risks, Frascati, Rome, Italy, 12–15 Oct 2021, Plinius17-18, https://doi.org/10.5194/egusphere-plinius17-18, 2021.

Partecipation at “1st MedCyclones Workshop, in Athens, 27-29 June 2022 with Talk “Case study of Medicane Ianos : Investigation into its triggering mechanism and different Sea Surface Temperature datasets impact.

Partecipation at VIII Summer School: Atmospheric Composition and Meteorology
Castro Marina, Hotel Orsa Maggiore, 20-24 June 2022. Talk on : On the influence of Ocean Mixed Layer and Sea Surface Temperature in the genesis and evolution of the Mediterranean Tropical-Like cyclones "IANOS".

Starting from 2021 work:

Sangelantoni, Lorenzo, Antonio Ricchi, Rossella Ferretti, and Gianluca Redaelli. 2021. "Dynamical Downscaling in Seasonal Climate Forecasts: Comparison between RegCM- and WRF-Based Approaches" *Atmosphere* 12, no. 6: 757. https://doi.org/10.3390/atmos12060757

Summary of results

The research developed in this period of the project focused on the numerical study of extreme atmospheric and marine events, selected in the previous phases of the work. In particular, this year has given us the opportunity to study, by collaborating in international activities of great scientific importance, some extreme events of particular importance, even if very different from each other (following the project scope). We can divide the activities carried out into two groups:

Short Term: In this group we have selected atmospheric and marine events that play a crucial role, both physically and socio-economically. The events chosen concern high Precipitation events (HPE), Hail Storm (HS), Tropical-Like Cyclones (TLC) and atmospheric and marine heat waves (HW). The intensive use of the computing resources available to the project proved to be fundamental in being able to carry out the work at extremely high time scales and resolutions and with innovative study techniques. This has allowed us to deepen extremely relevant and pioneering scientific issues that open the possibility to continue our works and open new future activities. In particular, they will be investigated with coupled models in order to determine the impact of the sea and waves in the formation and intensification of these phenomena.

Pescara Hail Storm case study: On 10/07/2019 an intense hailstorm hit the Adriatic coast (Italy), in particular the city of Pescara, with very intense rainfall, exceeding 130 mm/h and "giant" hail size (> 10 cm) (Tiesi et al 2022). During this event, extensive damage to agricultural crops and urban structures was recorded (Figure 1.). The purpose of the work was divided into three phases. In the first phase, we carried out an extensive sensitivity numerical study to identify the physical configurations that best reproduce the event. In a second phase we investigated the causes that generated this event, analyzing the impact of the topography, the SST, and the combination of the two components. In the third phase we studied the physics of the event. The simulations were carried out by the COAWST model using only the atmospheric component (WRF-ARW model ver. 4.02), on a numerical grid at 3 km over the whole Italian basin and a nested grid at 1 km resolution over the whole Adriatic basin (Figure 2.), and 110 vertical levels (first level at 15 mt above ground). We approach the work testing different types of SST, available on the Copernicus Marine Portal, in particular the SST CMEMS, the result of the Copernicus operational ocean model at 4.5 km resolution (Escudiar et al 2020). The second SST dataset is produced by the CNR-GOS (Merchant et al 2019; Pisano et al 2016; Saha 2018) center and can be found on the Copernicus Marine portal. It is the result of satellite observations at a resolution of 1 km. The control run uses the SST of the ECMWF-ISF operating model at 9 km of resolution. In the experiments (Figure 3) we removed part of the Apennine topography, such as the Picentine mountains and the Gran Sasso mountain. In a third experiment, we significantly improved the topography, in particular by optimizing the highest peaks. The results show that the impact of the topography is very relevant for the location of the event (better represented topographic downlift) The SST plays a fundamental role in the genesis of the event In particular, the heat fluxes at the air-sea interface are better represented , with values higher than 1500 W/m^2 in the vicinity of the storm. In the second article we physically analyzed the event, trying to classify it as a supercell, and studying the ability to reproduce the size and quantity of hail. The results showed that the storm structure is a supercell, with a rotating updraft, with vertical speeds of 60 m/s at about 9000 meters above sea level, such as to it is necessary produce and mantain in suspension in atmosphere hail (smooth, low roughness) of a size greater than 10-12 cm. The event will be studied with the fully-coupled COAWST model to analyze in more detail the mass and momentum exchange and the oceanic factors that can prove to be precursors of extreme storm events (Ricchi et al 2021), in a context of higher SST anomalies at 5 ° C, as in this event. **(Paper under submission)**

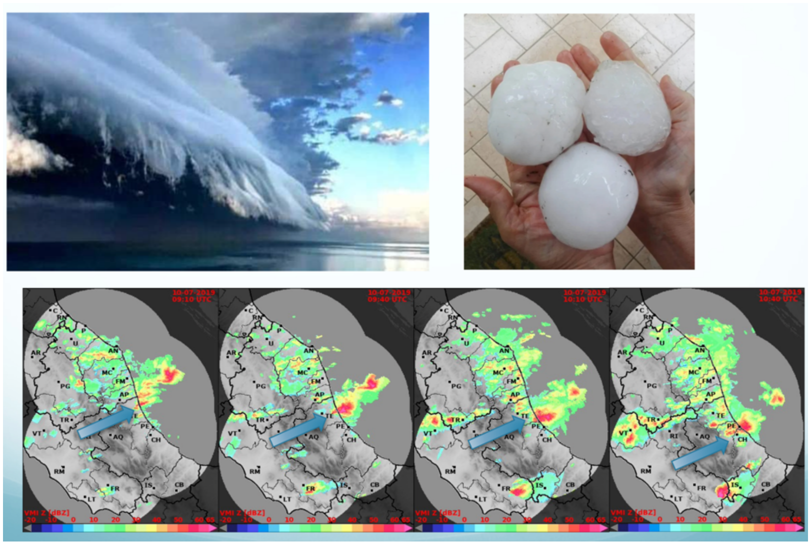

Figura 1. In figura è mostrata la dimensione della grandine caduta durante l’evento e le immagini radar dell’evoluzione della supercella.

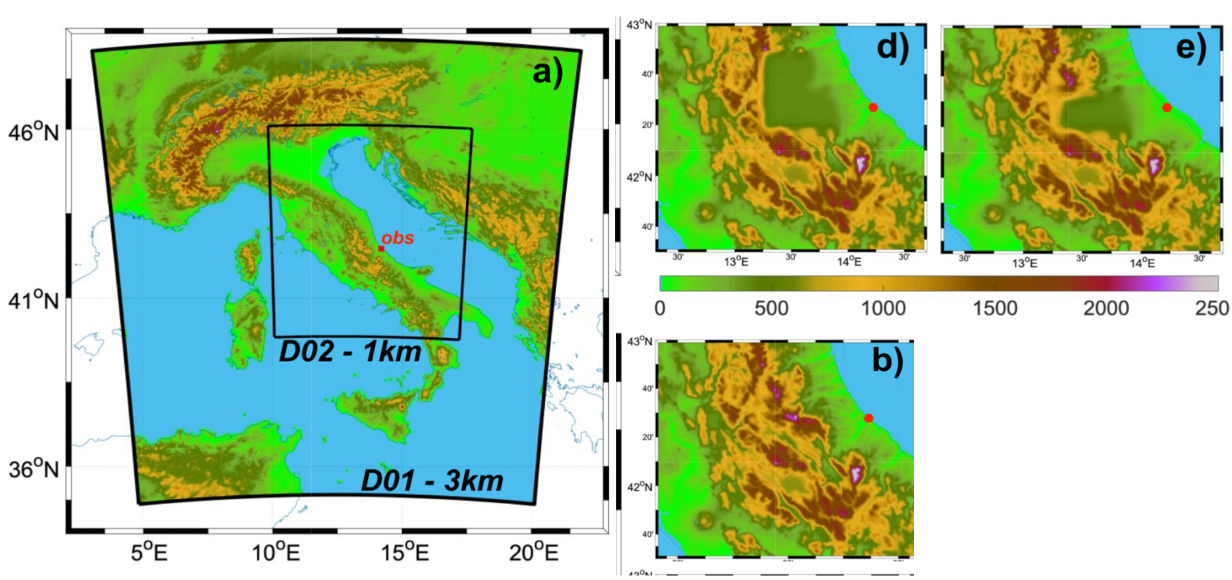

Figure 2. Characterization of the numerical domain and topography sensitivity approaches used.

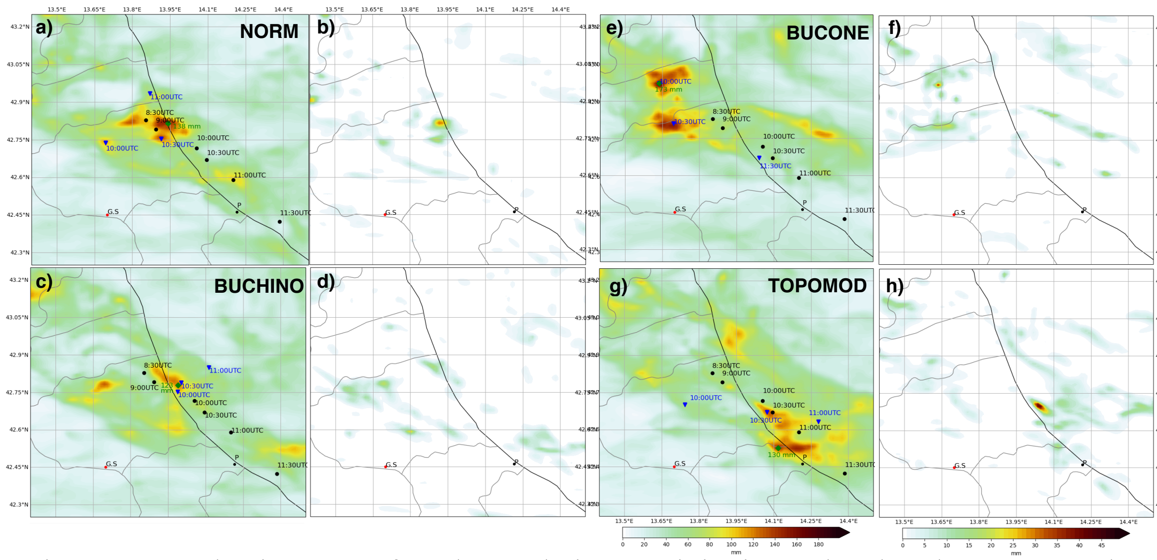

Figure 3. Results, in terms of total cumulative precipitation, related to the 4 proposed approaches.

Summer Hail Storm. The second extreme event studied is part of a master degree thesis and investigates the development of a supercell, on the Po Valley, which on 26 July 2021 generated intense hailstorms between Ferrara and Venice, causing extensive damage. The results show that the model, at a resolution of 1 km, is particularly efficient in representing the storm cell, but despite the resolution of 1 km, the most realistic results are obtained by parameterizing the cumulus scheme. This, probably, because in the initial phase of development, the sub-grid phenomena play a fundamental role and develop on scales of the order of hundreds of meters, not represented by a 1 km grid. **(Paper under submission)**

Alluvione catania. Using a 1 km resolution numerical grid, and a simplified 1D model of the ocean, we studied a storm front that generated a flood between Messina and Catania, in particular in the Catanese plain. The peculiarity of this event is that it was not foreseen by almost any met forecast center. The study shows that in this case, the fundamental trigger is characterized by the SST and the type of microphysics used in the model (Figure 1). **(paper in writing)**

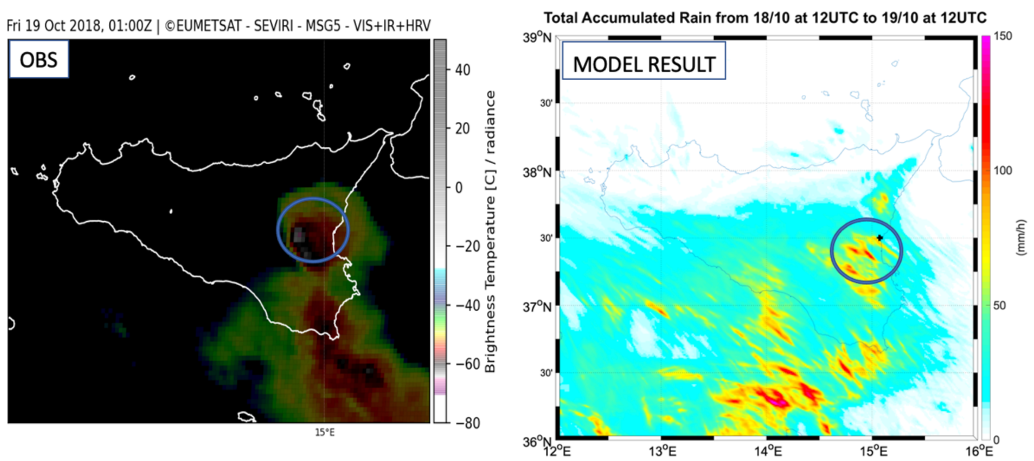

Figure 1 Image of brightness temperature and precipitation simulated by the WRF model, with the best configuration identified in the paper.

Impact of Ocean Mixed Layer Depth (MDL) on the genesis and intensification of IANOS Tropical-Like Cyclones (2020).

Tropical-like cyclones are quite frequent in the Western Mediterranean (about 1.53/yr). They play a role of particular scientific interest because they acquire, during a tropicalization phase, characteristics similar to tropical cyclones. Warm core, well defined eye, and intensity that can reach category 1 of hurricane. This occurs on a very small basin, if compared to the large oceans, and strongly anthropized. Unlike Tropical Ciclones, TLCs are influenced by the temperature difference between the SST and the atmosphere (in fact they can also form in winter), and not by the absolute value of energy contained in the sea. To understand how true this is, and what impact the heat content has in the ocean, we studied the IONAS TLC with the simplified ocean (Polland et al 1973) COAWST model. We used the SST CNR-GOS (Marullo et al 2014; Buongiorno Nardelli et al 2013) and we changed the depth of the mixed layer, starting from 10 meters (climatological value of September on the Ionian), up to 30, 50, 100 meters of depth and leaving the SST unchanged. This variation in the depth of the MDL induces a variation in the Ocean Heat Content (OHC). The results show that this variation does not significantly impact the trajectory of the cyclone, and only partially the intensity. What is greatly affected by the MLD is the transfer of heat to the atmosphere, which changes the structure of the cyclone which is larger, with intense winds over a larger area (Figure 1). Even the precipitations, especially in the convective component, show an increase of about 20% between the case with MDL 10 m and the case MDL 100. This work will continue using other investigation techniques and finally the more realistic application of the fully-coupled COAWST (WRF + ROMS + SWAN), in order to also implement the effects of the atmosphere and waves on the MDL, which changes rapidly during these phenomena. Furthermore, the Pseudo Global Warming technique will be applied to this coupled case study, in order to estimate how this TLC would behave in a context of climate change under the two scenarios RCP4.5, RCP8.5. These settlements were preceded by a predictability and multi-pysics ensemble study, in order to use the physical configuration that best represented the trajectory and intensity of the cyclone. The simulations were performed on two 5-1 km grids with offline nesting, and ECMWF-IFS 9km initialization (analysis data only, every 6 hours). ***(Paper under submission)***

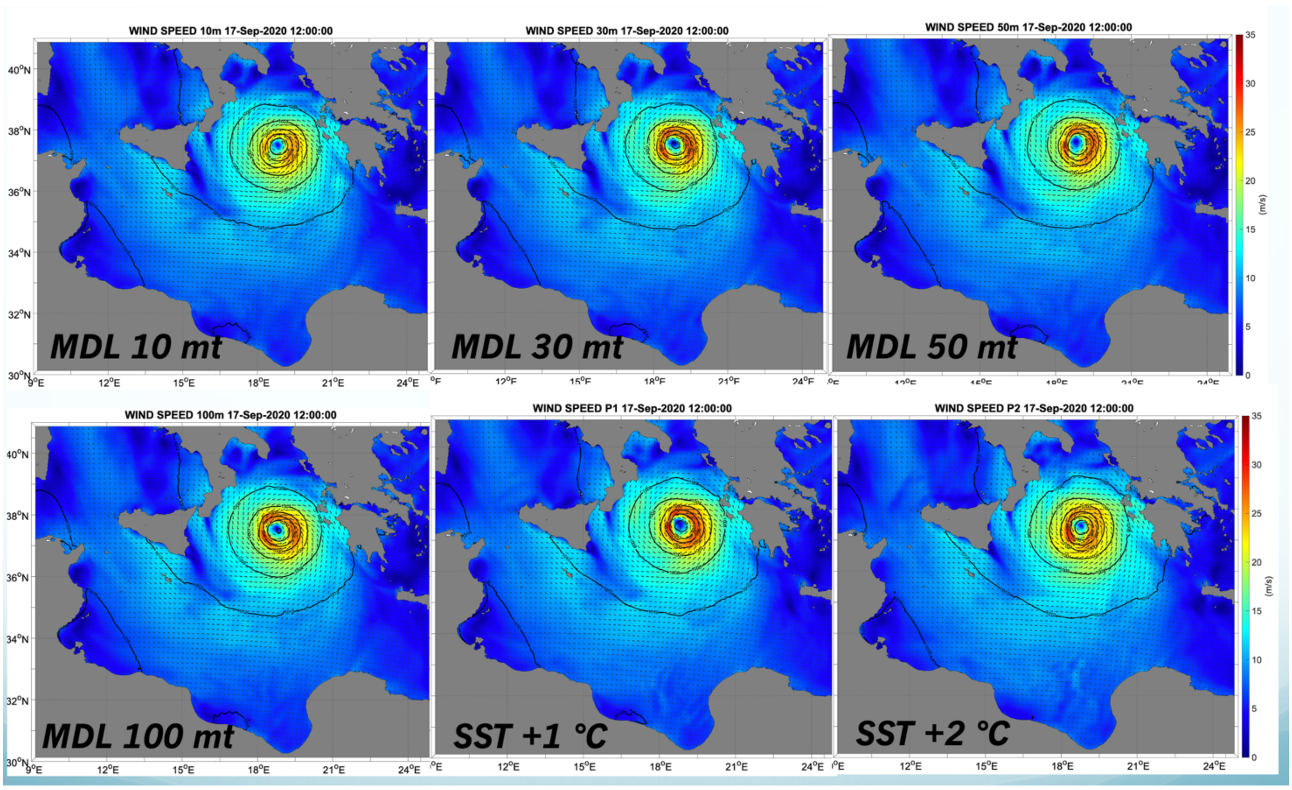

Figure 1. Wind fields generated by different depths of MDL simulations

August 2022

Medicane e SST: Further experiments are, with the previous approach, were carried out using all the main SST datasets present on the Copernicus portal. The results (Figure 1) show large differences between satellite and modeling data in the SST datasets, which affect the trajectory and intensity of the cyclone (work in progress) (Figure 2). This approach will be very useful, as a comparison, and to estimate which triggers at the air-sea interface drive the TLCs, also in anticipation of applying the coupled atmosphere-ocean-waves model in the next phases of the project. **(Paper in progress)**

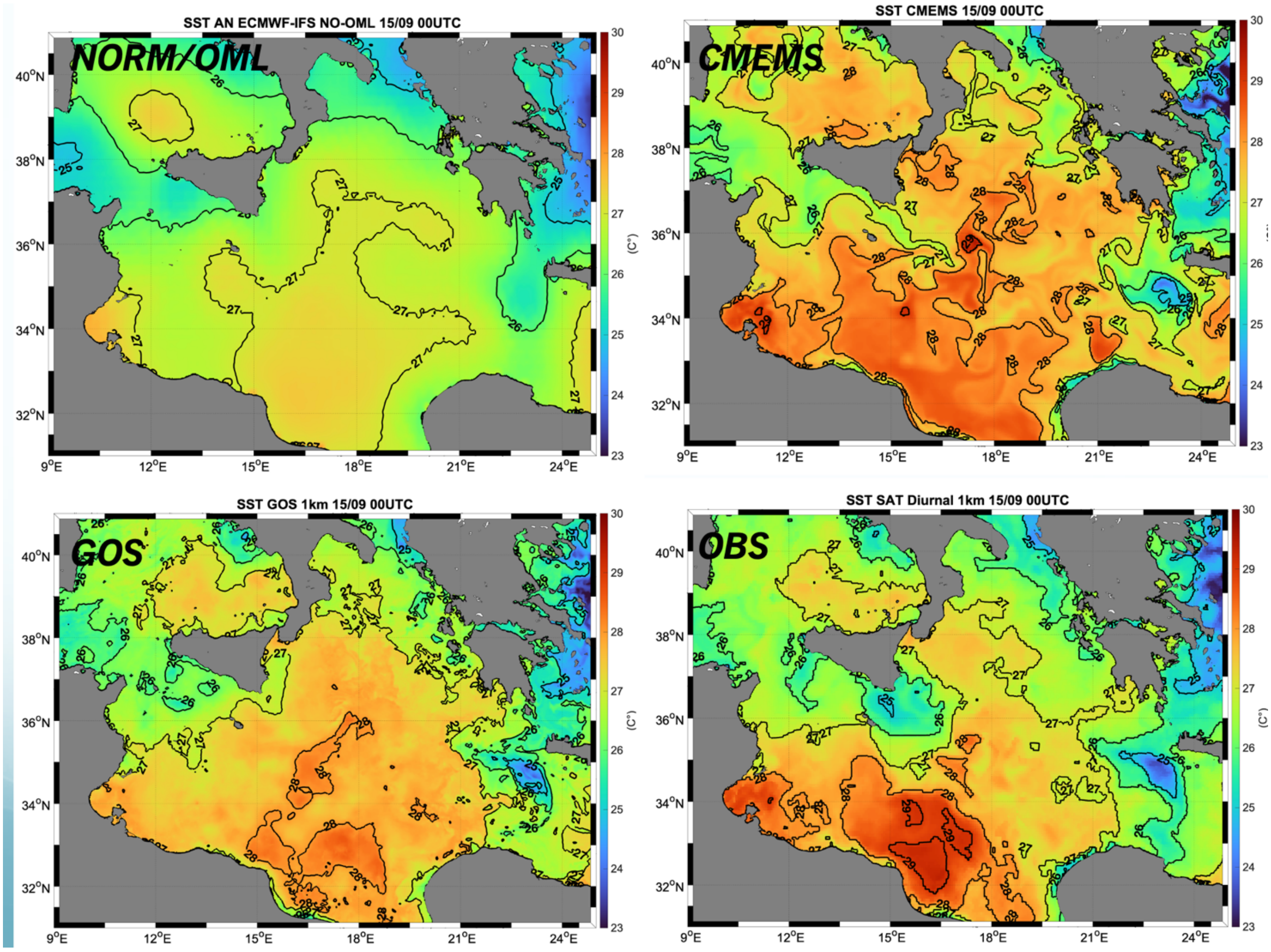

Figure 1. The figure shows the differences between the 4 SST datasets used: IFS 9km, CMEMS 4.5 km, GOS 1 km, Subdayly observed SST (OBS)

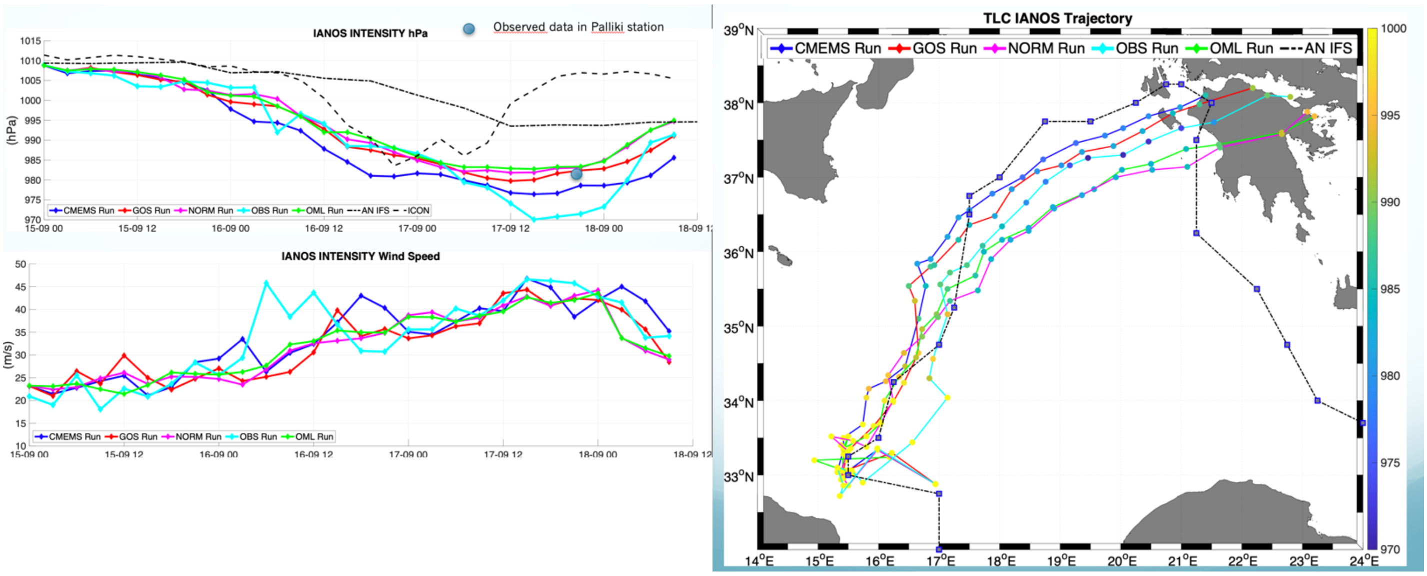

Figure 2. Results in terms of intensity and trajectory of the IANOS TLC, as a function of the SST used.

Atmospheric Summer African-Type Heat Waves: In Italy, the summer of 2021 was characterized by two intense African-type heat waves, between late July and mid-August. The characteristics of these Heat Waves are very different from each other, although both fall within the range of extreme values (99th) of temperature at 2 meters. The first heat wave mainly affected the south-central Adriatic basin. Although not very intense, on a synoptic scale, it recorded temperature values at extreme 2 meters in some coastal cities of the Adriatic, such as Pescara, where locally over 45 °C was recorded. This heat wave was triggered by the advections of a fairly warm North African air mass (about 20 °C at 850 hpa), which crossed the Apennines. In the "spill-over" effects on a downstream phase (Fhoen) the air heated up rapidly, producing very high day and night temperatures. The second heat wave hit the western coasts of Italy around 11 August, causing extreme temperatures in many cities such as Naples and Rome. In this work we used the "simple ocean model" (Polland et al 1973) approach with SST CMEMS (Escudiar et al 2020), 1 km resolution grid on central-southern Italy, inserted into a 3 km grid, 85 vertical levels, with the first vertical level at 15 meters above the ground. ECMWF-IFS initialization. Starting from a control configuration, and to identify the best configuration, (Figure 1), more representative of the event, in order to be able to study it physically. The results show the importance of using complex PBL schemes with parameterizations of complex urban physics and dynamics, as well as further highlight the importance of using very modern and complex soil schemes. This work also gives us a further suggestion, namely which numerical approach to use in seasonal simulations with the fully-coupled model that we will use in the next months of the project. (**Paper under submission**)

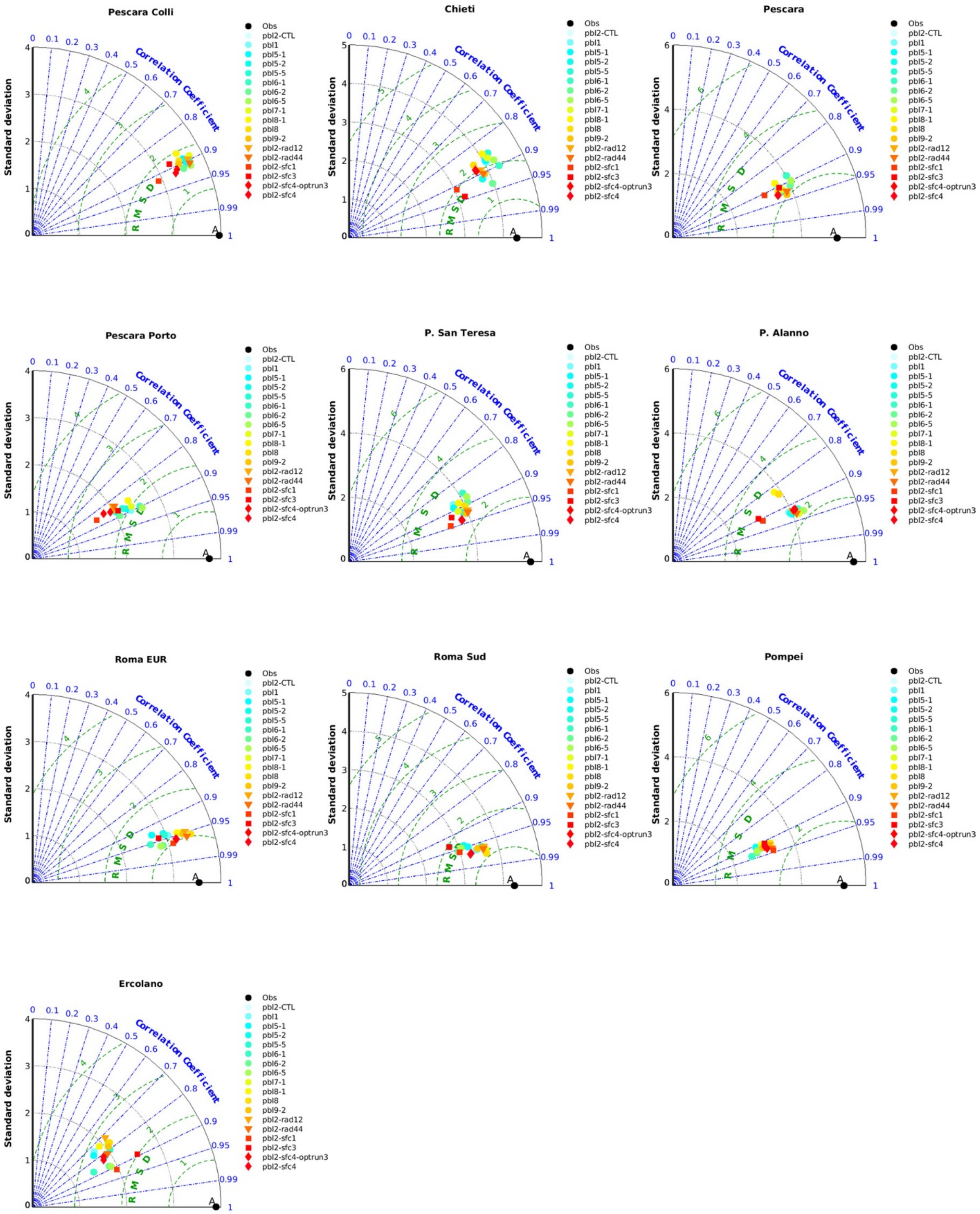

Figure 1. Taylor Diagramm in various urban locations, in the 1 km domain, with different

calculation schemes (Heat Waves July 2021)

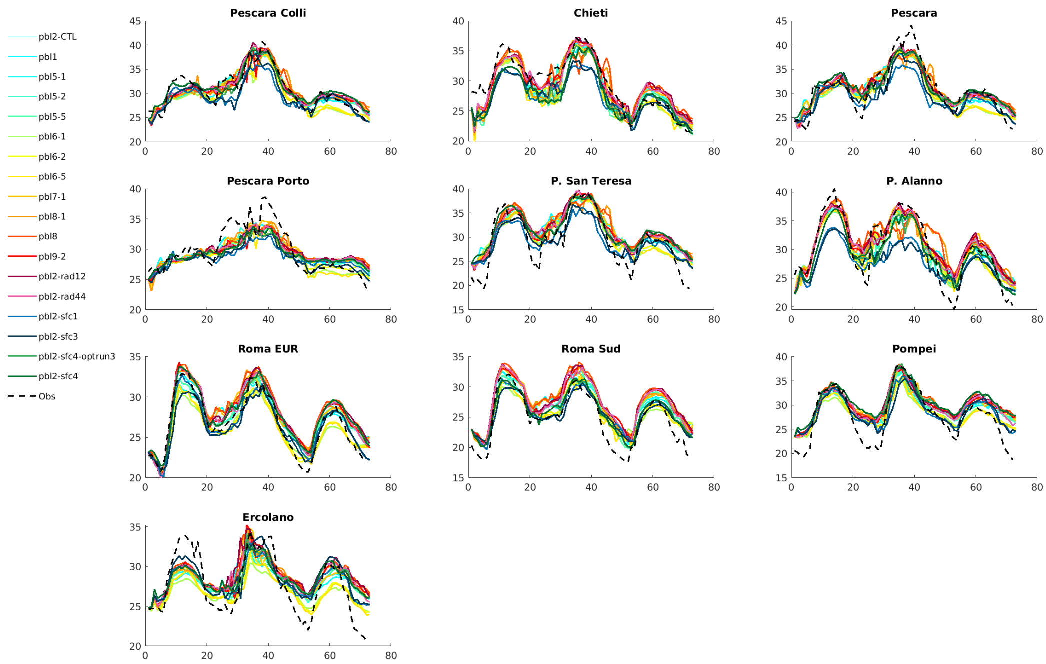

Figure 2. Timeseries in various urban locations, in the 1 km domain, with different calculation schemes (Heat Waves July 2021)

Mid term:

Soil moisture-atmosphere feedback plays an important role in shaping summer temperature variability and eventually in modulating duration, intensity, and predictability of heat waves.

Recent studies point out a modulation of summer temperatures introduced by the new generation of km-scale (or convection-permitting, CP) regional climate models (RCMs), compared to convection-parameterized RCMs. Modifications are likely originated from changes in soil moisture-precipitation feedback. This generally turns into an extension of dry spell length (DSL) determining warmer conditions in response to an altered partitioning of surface heat fluxes.

In this study, two potentially relevant factors behind modifications in land-atmosphere interactions at the two resolutions are investigated on a seasonal temporal scale. The first, is the underestimation of summer season convective phenomena, as an outcome of a poor sensitivity to triggering factors and driving longer DSL in km-scale simulations. The second is represented by differences in soil moisture memory between RCM and CPRCM.

We perform simulations with the ECMWF-ERA5 driven WRF-4.2.1 model consisting of a two-step dynamical downscaling at ~15 km (non-CP scale) and ~ 3km (CP scale) respectively. The greater alpine region and extended summer seasons (May to September) represent spatial and temporal domains.

The underestimation of the summer season convection will be explored considering simulations at (i) 15 km with parameterized convection, (ii) 3 km with explicit convection (CPRCM_exp) and (iii) 3 km with parameterized convection (CPRCM_par) according to different numerical schemes. This is to explore whether parameterizing deep convection at CP scale mitigates poor convection-triggering processes sensitivity caused by weak large scale forcing.

The soil moisture memory is assessed through autocorrelation analysis applied to three simulations: one standard and two idealized soil-moisture-perturbed-initialization defining anomalously dry- and wet-initialization experiments. Here, ground-water-aware configuration of Noah-MP land surface model (LSM) will be compared to a more simplified LSM configuration.

Preliminary results for the 2003 summer season show differences in precipitation statistics between the two different resolutions and between CPRCM_exp/CPRCM_par. We observe an increase in wet-hour frequency, an increase and different spatial pattern of precipitation 99th percentile in CPRCM_par.
Concerning soil moisture memory, initial differences are preserved in the two resolutions for the first month run. After that, differences decay in the CPRCM, where all the three simulations converge to similar soil moisture at the end of the run. Differently, RCM preserves a larger difference of soil moisture until the end of the run indicating a longer memory of the initial state, particularly in the wet-initialization experiment.
Several reference products will be considered to evaluate resulting modulations, namely if a km-scale deep convection parameterization can be beneficial and if the shorter soil moisture memory resulting in the km-scale simulations represents an improvement.
Outcomes might offer insights on the km-scale influence on seasonal time-scale prediction of soil-atmosphere-interaction-driven extreme events.

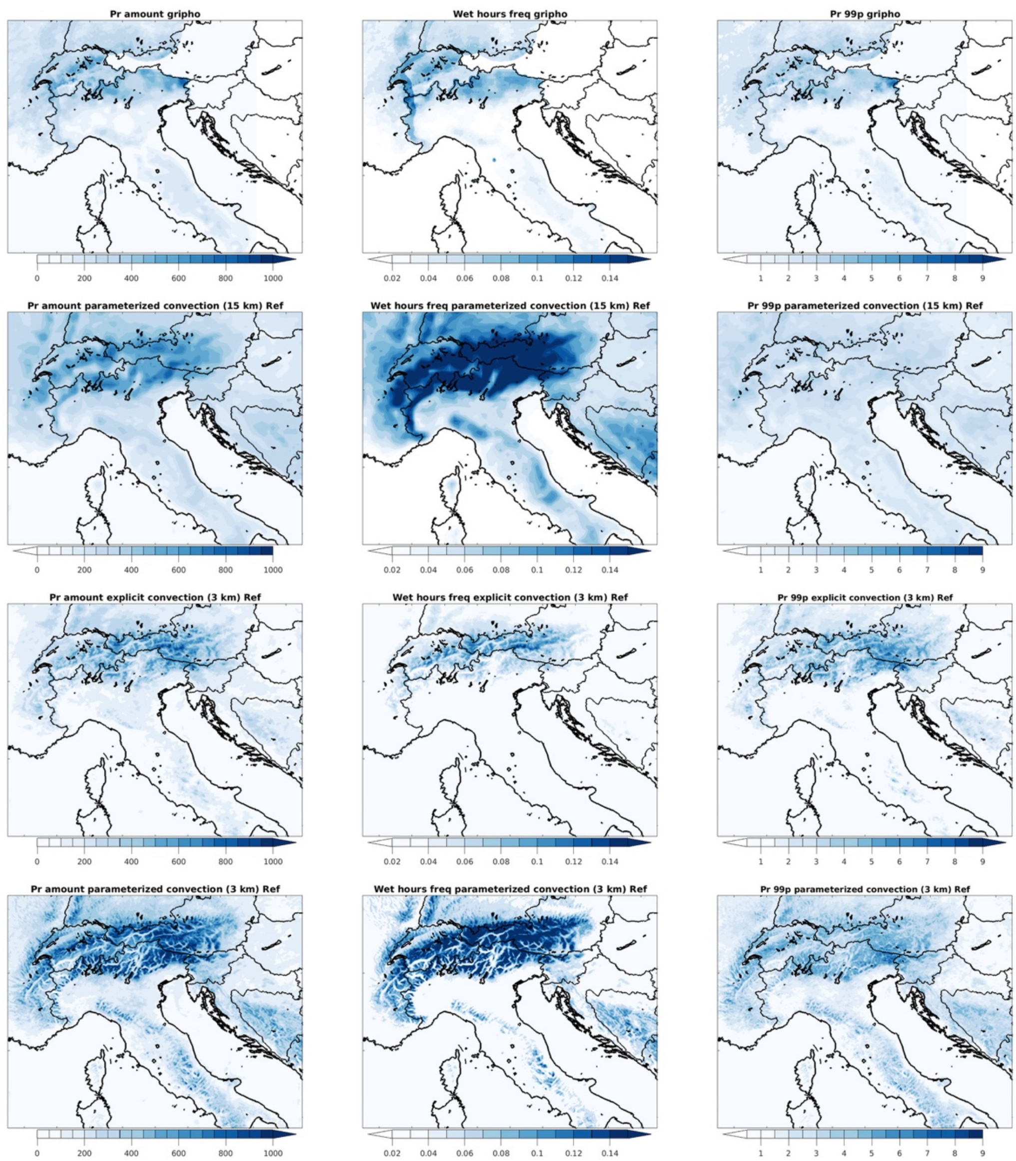

Figure 1. Comparison between observed (upper panels) and simulated hourly precipitation statistics (amount, wet hours frequency, and 99th percentile). Period corresponds to May-Aug. 2003

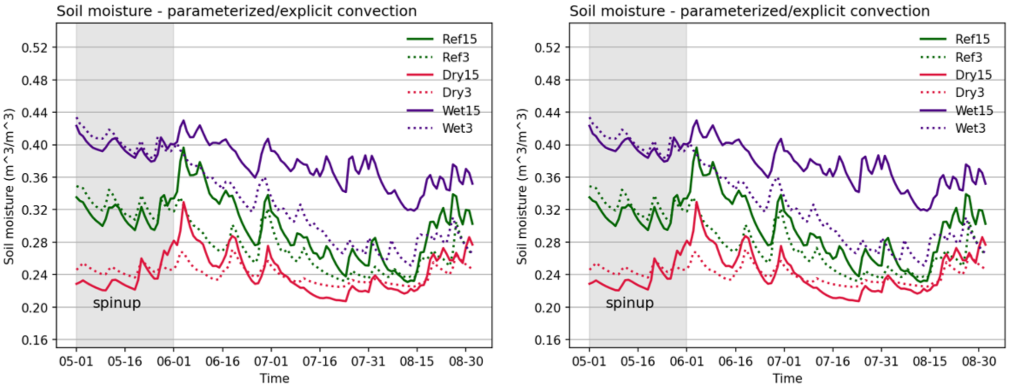

Figure 2. time series (1 Jun – 31 Aug 2003) of daily top soil layer (0.10m) soil moisture content for the three different soil moisture initialization experiments (reference, dry, and wet). Time series refer to spatial means over Po valley (a) and the entire greater alpine region (b). Solid lines represent 15 km resolution simulations whereas dotted lines represent 3 km (explicit convection) simulations.

Future plans

Planning for the next 12 months of the project.

- All the case studies analyzed will be simulated with the COAWST coupled model
- The results obtained will be applied to coupled seasonal simulations of atmosphere-ocean waves, for summer and winter seasons.
- The whole year (with coupled and uncoupled seasonal simulations) of 2003 and 2022 will be analyzed, to identify the impact of SST, Ocean Heat Content and SST anomaly, on the evolution and intensity of heat waves and droughts that have characterized these two years (simulating the whole year and not just the single season in order to take in account the past effect in ocean, land and soil levels.
- Further simulations of two Tropical Like Ciclones (ZORBAS and APOLLO), 2 Heat Waves and 2 HPE, which took place during the years in which we will carry out the coupled seasonal simulations, in order to evaluate not only the physics of the processes, but also the capacity of the fully-coupled, convection model permitting, to identify the statistical signs of these extreme events with large amount of time before.

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