Role of Surface Temperature in the Life Cycle of Mediterranean Cyclones

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Abstract

The evolution and intensity of marine-developed storms are strongly linked to air-sea interface activities. In particular, during the various stages of Mediterranean cyclonic episodes, air-ocean temperature differences play a significant effect. As a result, there is a greater demand for improved information and depiction of Sea Surface Temperature (SST). This paper attempts to analyse the impact and uncertainty of SST from various well-known datasets on the life-cycle of Mediterranean cyclones. The RAMS/ICLAMS-WAM coupled modelling system incorporates daily SST fields from the Real Time Global SST (RTG SST) and hourly SST fields from the Operational SST and Sea Ice Ocean Analysis (OSTIA) and the NEMO ocean circulation model.

Keywords: • Mediterranean cyclones • Sea Surface Temperature (SST) • RAMS model• WAM model

Introduction

The development, progression, and intensity of extreme weather occurrences are strongly linked to air-ocean interface processes. The interchange of heat, moisture, and momentum caused by ocean drag and thermodynamic disequilibrium between the ocean surface and the higher air causes strong atmospheric perturbations. In the Mediterranean Sea, the aforementioned air-sea dynamics frequently contribute to significant cyclonic activity. Cyclogenesis occurs when cold cut-off lows in the middle and upper troposphere combine with warmer ocean surfaces. Despite the large number of storms that pass through the Mediterranean basin each year, only a handful of them exhibit features comparable to Tropical Cyclones (TCs), known as Mediterranean Tropical-Like Cyclones (TLCs) or medicanes. Air-ocean temperature differences, which arise in a marine context, are one of the key triggering mechanisms of Mediterranean TLCs, which are analogous to tropical storms .Cold air intrusions from the European mainland over the warmer sea surface increase the importance of heat and moisture fluxes in the establishment and evolution of such systems. Improved understanding and depiction of Sea Surface Temperatures (SSTs) and the intensity of marine-developed storms have garnered substantial attention in several related studies. The upper-ocean layer is affected by TCs, resulting in changes in water surface temperature. Some of the fundamental mechanisms occurring under TCs include wind mixing and upwelling of colder water masses from deeper regions. This storm-induced SST cooling is likely to have an impact on air-sea enthalpy differences and the intensity of TCs.

The lack of large regionally distributed observational datasets is a significant drawback in numerical research focused on the sensitivity of the SST. Under extreme weather circumstances, the scarcity of in-situ and satellite observations may lead to uncertainties in both the appropriate depiction of air-sea heat exchanges and the evaluation techniques. for example, a 3°C decrease in the SST fields during a Mediterranean cyclone resulted in a reduction in sea surface fluxes of up to 150 W/m^2 and the disappearance of the tropical characteristics. Furthermore, found that using climatological SST in a simulation analysis of a Mediterranean cyclone reduced its lifespan. Large data networks have been created in the last decade to improve the description of current SST conditions. This resulted in the development of high-resolution SST gridded fields, as well as the use of quality-controlled satellites, buoys, and other ocean observations. Concurrently, a lack of information on the rapidly changing conditions at the air-water interface may obscure various aspects of these catastrophic events. Coupling approaches have been devised to efficiently reflect the ongoing interplay between the atmospheric and oceanic environments. Including ocean impacts in the operational European Centre for Medium-Range Weather Forecasting (ECMWF) high-resolution forecast improved hurricane foresting intensity. Similarly, the incorporation of air-ocean interaction approaches into the Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS-TC) improved foresting capability in the track, intensity, and fine-scale structure of a number of hurricanes.

Model description

To enable continuous feedback of information between the atmospheric-wave and ocean systems, a coupled modelling system was deployed. An atmosphere and a wave model were online connected in the modelling system. Furthermore, a 2-D ocean component incorporating SST values from many sources was used to continually update the boundary conditions in the atmospheric model.

Atmospheric component: The atmospheric component was an improved version of the Regional Atmospheric Modeling System (RAMS), the RAMS/ICLAMS Integrated Community Limited Area Modeling System . The online treatment of mineral dust and sea salt from wave breaking is one of its most noticeable features. These natural aerosols contribute to model calculations via feedback mechanisms such as direct, semi-direct, and indirect impacts in the radiation scheme as well as estimates of ice nuclei (IN) and Cloud Condensation Nuclei (CCN).

Wave component: The Wave Analysis Model (WAM) version CY33R1 was utilised. The model simulates wave variance distribution at various frequencies and propagation directions. The basic transport equation describes the evolution of the model's two-dimensional wave spectrum. The solution of this equation yields many parameters such as significant and swell wave height, peak frequency, and directional spread. For the explanation of white-capping dissipation and bottom friction, the employed version employs explicit source functions. Additional features, such as depth-induced wave breaking and shallow water effects, were also included.

Ocean component: A 2-D model was built to account for the dynamic variation of the current SST conditions. This is an algorithm that takes SST from numerous sources and interpolates it in a gridded domain that corresponds to the spatial coverage of the atmospheric model. Due to the interpolation method, a minor distortion of the initial SST fields is unavoidable, particularly in nearshore and complicated locations.

Coupled modeling system: The OASIS-MCT coupling module was utilized to allow the model components to work synchronously and in a coupled manner. The latter permitted parameter interchange between atmospheric-wave components in a two-way mode and atmospheric-ocean components in a one-way mode. The communication between the various components was carried out at predetermined time intervals based on the model time step.The wave model was fed surface wind speed components and air density, with wind speed acting as a forcing factor and density utilised to compute ocean surface stress. The wave model conveyed the roughness of the ocean surface to the atmospheric model at the same time. This enables for a more realistic depiction of sea state conditions in the atmospheric model, which influences both the wind speed profile and the calculation of surface heat fluxes.

Data used: Three Mediterranean cyclones were simulated for the purposes of the study using the coupled system and sensitivity testing with varying SST fields. The initial focus of the investigation was on the spatiotemporal evolution of the various ocean surface temperatures in terms of anomalies and comparison with data. In terms of numerical experiments, an analysis and comparison of storm paths, maximum surface wind speed, and air-sea fluxes was carried out, which was backed by available observations.

Model configuration

In terms of the atmospheric component, two nests were used, the fine one covering the whole Mediterranean as well as much of Europe and North Africa. This configuration was used to capture the impacts of differential heating between Africa and Europe , as well as the possible direct, indirect, and semi-direct effects of dust particles, and to incorporate the entire Mediterranean Basin. The SST for the atmospheric model stem from three different sources briefly described below.

RTG-SST: Since 2001, the Real Time Global SST (RTG SST) has been a global operational analytic product . An analysis algorithm runs once each day, incorporating in-situ and satellite data from the previous 24 hours. Fixed buoys, floating buoys, and ships provide in-situ data. NOAA and METOP-A AVHRR data are averaged in day and night fields using a physical technique to provide satellite retrievals.

OSTIA-SST : The Operational SST and Sea Ice Ocean Analysis (OSTIA) dataset is a worldwide coverage SST dataset generated by the Met Office in the United Kingdom with a resolution of 1/4 degrees. The system combines in-situ data with satellite observations, as well as a warm layer diurnal algorithm that incorporates satellite data and a cool skin model. Remote sensing data with varying coverage is derived from eleven separate Infrared and Microwave sensors. SEVIRI, GOES-W, MTSAT 2, and METOP-A AVHRR data are used to retrieve satellites . For operational forecasts, the UK Met Office and European Centre Weather for Medium Range Weather Forecasting (ECMWF) models utilise OSTIA SST analysis fields.

NEMO–SST : Forecast sea surface temperature data are available from the Operational Mercator global ocean analysis and forecast system. The system is based on the NEMO ocean model, version 3.1 , with a horizontal resolution of 1/12 degrees. From the sea surface to 5000 m deep, fifty vertical levels are used, with the first 28 distributed within the first 450 m of water depth. Bathymetry information is derived from the GEBCO8 database for depths less than 300 m and the ETOPO1 database for deeper waters. contains model physics as well as recent revisions and enhancements to the advection, assimilation, and sea/ice schemes, as well as evaluation studies.

Case Studies

Three recent Mediterranean cyclones with tropical-like features were investigated. The storm cases were chosen from the EUMESTAT database, which was discovered via a satellite network in operation. The events developed and matured over the Central and Eastern Mediterranean waterways. These places are located in a zone where such systems are more likely to form in late autumn and early winter due to relatively high SST. The choice was made based on the availability of the OSTIA SST and the data for analysis. The first Mediterranean storm occurred between October 27 and November 1, 2016. It formed in the early hours of October 27 in the offshore area of Italy's western shoreline. Moving southward, the system was over reasonably warm waters east of Malta, and an eye-like structure appeared and began moving eastward towards Greece in the early hours of 30 October. On September 27, 2018, a storm formed over warm waters in the eastern Mediterranean Sea, prompting the third scenario to be chosen. The following day, as it moved northeast, the cyclone gradually developed and took on tropical-like features. On September 29, the cyclone reached its zenith when it approached the southwest section of Greece. The storm moved northeastward, passing over the Aegean Sea before dissipating over Turkey the next day.

Discussion

The study investigated the uncertainty in model results in the simulation of Mediterranean cyclones using different SSTs. As a preliminary step, a comparison of the SST time series from the three datasets and an independent source, data from a buoy with reference 61277 at a specific position, was done. The coordinates (35.72 N, 25.13 E) corresponded to the site, which was inside the affected zone of the selected occurrences. Unfortunately, no other buoy was available to cover all of the identified circumstances. Following the changes of the observational data, SSTs from RTG and NEMO compared pretty well in the instance of storm Trixi. At this stage, the SST from OSTIA tended to underestimate, yielding values about 21.0°C-21.5°C, roughly one degree lower than the other sources. The second incidence involving storm Numa occurred in November, with lower temperatures than projected. The NEMO and OSTIA products had a modest underestimation of the values, whereas RTG had a tiny overestimation. In any event, the first two datasets followed the measurement trend, whereas RTG did not. Because it was October in the case of cyclone Zorbas, the sea was warmer than in the prior case.

When compared to observations with gradually decreasing values, the NEMO and OSTIA datasets behaved similarly. The RTG performance can be divided into two sections. RTG overestimated the water temperature for the first two days, but it able to better capture the SST for the rest of the event. RTG is a daily product, it should be acknowledged. The spatial variability of the SST is also explored, as are the various phases of the events under consideration. Specifically, the discrepancies between the SST at various stages of the simulations and the beginning one were investigated. The SST anomalies for the case of cyclone Zorbas are presented for clarity. This event was also shown to have the greatest heterogeneity in the evolution of ocean surface temperatures among datasets.

The sea surface tended to get colder as the system progressed in all situations. As the cyclone gets energy from the warm water, this is to be expected. Other factors that contribute to SST lowering include evaporative cooling and mixing of the top water layers caused by wind and precipitation. Tropical cyclones are well recognised for cooling the upper ocean by up to 6 degrees Celsius. In general, SST cooling reduces air-sea heat exchange and, as a result, cyclone intensity. The cooling impacts were obviously smaller here due to the event's scaling and the basin's local peculiarities. The largest variations were detected in the NEMO product beginning with the first 24 hours of simulations, with SST decreasing more than one degree in the area north of the cyclonic core. At the same period, the satellite-oriented OSTIA dataset showed a minor maximum dip of roughly 0.5°C. In comparison, the RTG daily differences appeared to be insignificant. It should also be noted that the early fields of RTG and NEMO had a similar pattern and magnitude, however the OSTIA had slightly lower initial fields values. Continuing with the next 48 hours, NEMO-sst simulation showed a maximum temperature drop of 2°C, while RTG and OSTIA had maximum drops of around 1°C. This reduction was traced on the east side of the storm in RTG, while it was around the cyclone in the other two datasets.

Finally, the third day, 72 hours after the simulations began, was marked by considerably lower temperatures. The cyclone's passage deepened the thermocline base, forcing the ocean surface temperature to drop even lower. The greatest variations were likewise discovered in the NEMO-sst output, which was followed by RTG and OSTIA and all regions of Africa. By the end of the century under RCP8.5, all African regions will very likely experience a warming larger than 3°C except Central Africa, where warming is very likely expected above 2.5°C, while under RCP2.6, the warming remains very likely limited to below 2oC. A very likely warming with ranges between 0.5°C and 2.5°C is projected by the mid-century for all scenarios depending on the region. On other hand precipitation decreases in North Africa and West Southern Africa and medium confidence in East Southern Africa by the end of the 21st century. The Western Africa region features a gradient in which precipitation decreases in the west and increases in the east and increase is also projected over Eastern Africa. East Africa has experienced strong precipitation variability and intense wet spells leading to widespread pluvial flooding events hitting most countries including Ethiopia, Somalia, Kenya and Tanzania.

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