8.8 TOWARDS IMPROVED FORECASTS OF ATMOSPHERIC AND OCEANIC CIRCULATIONS OVER THE COMPLEX TERRAIN OF THE EASTERN MEDITERRANEAN

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1. INTRODUCTION

Forecasting atmospheric and oceanic circulations accurately over the Eastern Mediterranean has proved to be an exceptional challenge. The existence of fine-scale topographic variability (land/sea coverage) and seasonal dynamics variations can create strong spatial gradients in temperature, wind and other state variables, which numerical models may have difficulty capturing.

The Hellenic Center for Marine Research (HCMR) is one of the main operational centers for wave forecasting in the eastern Mediterranean. Currently, HCMR's operational numerical weather/ocean prediction model is based on the coupled Eta/Princeton Ocean Model (POM). Since 1999, HCMR has also operated the POSEIDON floating buoys as a means of state-of-the-art, real-time observations of several oceanic and surface atmospheric variables. This study attempts a first assessment at improving both atmospheric and oceanic prediction by initializing a regional Numerical Weather Prediction (NWP) model with high-resolution sea surface temperatures (SST) from remotely sensed platforms in order to capture the small-scale characteristics.

2. DESCRIPTION OF POSEIDON SYSTEM

Quality weather forecasting of the Mediterranean Sea is a distinct challenge as well as of utmost importance. More than 145 million people inhabit the Mediterranean coast line and billions of tons of cargo are transferred along ship trade routes, with their number rising every year. The complex coastlines and corresponding shadowing effects, coupled with strong topographic and seasonal variations, make the Mediterranean basin an excellent candidate for the study of rigorous air-sea-land interactions.

To address the observing and forecasting challenges of the Mediterranean region, the HCMR established the POSEIDON system, dedicated to the operational monitoring and integrated forecasting of the marine environmental conditions of the eastern Mediterranean basin and the Greek seas (Nittis *et al.* 2001). The primary objective of the POSEIDON system is to provide real-time analysis and short–medium range forecasting for several meteorological and oceanic variables over coastal areas and open seas. The POSEIDON system currently consists of two main components: observations and numerical modeling. POSEIDON's observational part consists of 10 oceanographic buoys (Figure 1). The main physical parameters monitored consist of mean sea level pressure, temperature, wind speed and direction, wave height and direction (Figure 2), as well as water chemistry proxies such as salinity, dissolved oxygen, chlorophyll-A, etc.

3. POSEIDON'S ATMOSPHERIC AND OCEANIC FORECASTING

To satisfy the forecasting requirements, a fully operational coupled modeling system has been developed consisting of meteorological, deep and shallow wave hydrodynamics and surface pollutant dispersion. The POSEIDON weather forecasting sub-system is based on the SKIRON/Eta model and is fully operational since September 1999, providing daily 72-hour weather forecasts (Figure 3). The SKIRON/Eta is an evolution of the 1997 version of the NCEP/Eta (National Centers for Environmental Predictions) model, developed at the University of Athens (Papadopoulos *et al.* 2002). POM is an evolution from the initial numerical model designed by Blumberg and Mellor (1987). POSEIDON's POM products include among others, predicted wave height, direction and period (Figure 4). The aforementioned in situ buoy meteorological observations are currently used to assess the validity of the weather forecasting model, while wave-height measurements are used to evaluate systematic errors in order to provide adjustments to the wave model.

The POSEIDON operational NWP (SKIRON/Eta) requires SST as bottom boundary conditions, which in certain cases have an important impact on the quality of the forecasts (e.g. fog formation, cyclogenesis, precipitation and air-sea flux calculations). POM provides a full 4-dimensional description of the ocean at a variety of vertical and horizontal spatial resolutions. SST data are used as a boundary condition and in data assimilation schemes within these modeling systems. For real-time applications, SST data must be accurate and available in a timely manner from operationally robust systems. An important issue arises directly related to the SST resolution used to initialize both forecasting

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models: the extensive island landmasses of the Eastern part of the Mediterranean Sea lead to substantial heat capacity differentials and resulting SST gradients from near-shore to few kilometers into the open Archipelago. Moreover, air/sea interaction phenomena such as Ekman upwelling due to the complex coastal orientation, or thermohaline circulation induced by the predominant wind direction, can give rise to limited-area strong SST differentials. All the aforementioned regional characteristics can cause unresolveable features in the analyses of surface wind, temperature, and humidity, which can subsequently lead to erroneous forecasts.

At present, the highest-resolution, continuous and global SST products available consist of the 1/12° Real-Time Global (RTG) product generated by NCEP (Thiébaux *et al.* 2003). However, subjective examination of these data by the authors suggest that the product does not capture data at resolutions as high as 1/12°. The Met Office has recently developed a new Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) system that provides global products at 1/20º (~6 km) resolution each day (Stark *et al.* 2007). OSTIA has been designed to provide an estimate based on a multi-scale optimal interpolation (OI) scheme which combines infrared and microwave satellite and in situ SST measurements from ships, buoys, etc. (Martin *et al.* 2006). Meanwhile, Haines *et al.* (2007) have demonstrated the capability of generating very high-resolution (1 km) SST composites from the Earth Observing System Aqua and Terra satellites for regional weather and modeling applications.

This study seeks to take advantage of these available datasets by assimilating these fields into a high-resolution configuration of an NWP model, with the ultimate goal of improving predictions of sensible weather elements over the Eastern Mediterranean.

4. PRELIMINARY EXPERIMENT

A first comparison is attempted between a control run (CR) (i.e. SST originating from the RTG product) and the experimental run (AR) (i.e. SST originating from the OSTIA product). The NWP model used for these runs is the Weather Research and Forecasting (WRF) model, using version 2.1.2 of the Advanced Research WRF dynamical core (Skamarock *et al.* 2005). A one-way nested simulation was initialized at 0000 UTC 7 January 2008, with 12-km horizontal grid spacing on the outer domain, and 4-km horizontal grid spacing on the inner domain centered on Greece and the Aegean Sea. The nested run was integrated for 36 hours to 1200 UTC 8 January.

The ARW dynamical core is used with physics options consisting of the rapid radiative transfer model (Mlawer *et al.* 1997) and the Dudhia scheme (Dudhia 1989) for longwave and shortwave radiation, respectively. The WRF Single Moment 6-class microphysics scheme (WSM6, Hong *et al.* 2004; Skamarock *et al.* 2005) is used in conjunction with the modified Kain-Fritsch convective parameterization scheme (Kain 2004) on the 12-km domain only, and without any convective parameterization on the 4-km inner nested grid. The planetary boundary layer and turbulence processes are parameterized by the Mellor-Yamada-Janjić scheme (Janjić 1990, 1996, 2002). The Noah land surface model (LSM, Ek *et al.* 2003) provides interactions between the land and atmosphere. Surface-layer calculations of friction velocities and exchange coefficients needed for sensible and latent fluxes in the LSM are provided by the NCEP Eta similarity theory scheme (Janjić 1996, 2002). Horizontal diffusion is handled by the two-dimensional Smagorinsky first-order closure scheme (Smagorinsky *et al.* 1965).

Figure 5 illustrates the SST of the CR (^{o}C, upper left), SST of the AR (^{o}C, upper right) and their respective difference (^{o}C, AR–CR, bottom), all valid at 00Z (no forecasting is performed). AR-CR reveals some key observations:

- the 1–4 ^{o}C colder waters over the Bosporous Straits (1),
- the colder waters originating from the Ekman upwelling layers across the eastern Aegean Sea (2) and Thermaikos Gulf coasts (3),
- the colder waters from the Peloponnesian gyre (4) and the associated thermohaline (deep oceanic convection)
- the typically warmer waters of the Levantine basin (5), overall one of the Mediterranean areas with the highest SST recordings,
- the positive SST differences surrounding the Greek islands (6), depicting the heat capacity gradients originating from the land/ocean transition.

Most of the aforementioned features are translated into the sensible weather elements after several hours of forecast (note the 30-h forecast 2-m temperatures in Figure 6, valid at 0600 UTC 8 January). Both variables have a direct effect of the forecast quality of other state variables such as humidity, heat fluxes, and precipitation forecasting. Figure 7 and Figure 8 show the 30-hour forecast sensible heat flux and simulated 1000-mb frontogenesis (also valid at 0600 UTC 8 January) from the CR (upper left), the AR (upper right) and the AR-CR (lower panel). The sensible heat flux differences approach ±25–50 W m^{-2}, an amount that is well beyond the measurement uncertainties (Krahmann *et al.* 2000). Also, note the differences in 1000-mb frontogenesis axes over the Aegean Sea and Mediterranean Sea northeast of Crete, corresponding to displacements in the predicted convergence zones and shower activity (not shown). This sample simulation with the higher-resolution OSTIA data clearly shows the sensitivity of the NWP solution and the importance of resolving fine-scale SST structure in the Aegean Sea region.

5. SUMMARY

This paper described ways of improving the HCMR's POSEIDON forecasting capabilities. Forecasting over the eastern Mediterranean basin, due to its particular physiography, is particularly sensitive to small-scale variations in SST. WRF forecasts based on SST products of different resolution were presented and shown to be sensitive to the static SST fields used in the simulations. Further test-cases combined with regional ground and satellite validation is required to underline the overall forecast improvement. Ongoing efforts in assimilating surface and satellite-retrieved winds, soil moisture, humidity, and atmospheric temperature profiles, focused over the eastern Mediterranean basin will further enhance the POSEIDON's meteorological and oceanic forecasting skills.

6. ACKNOWLEDGEMENTS/DISCLAIMER

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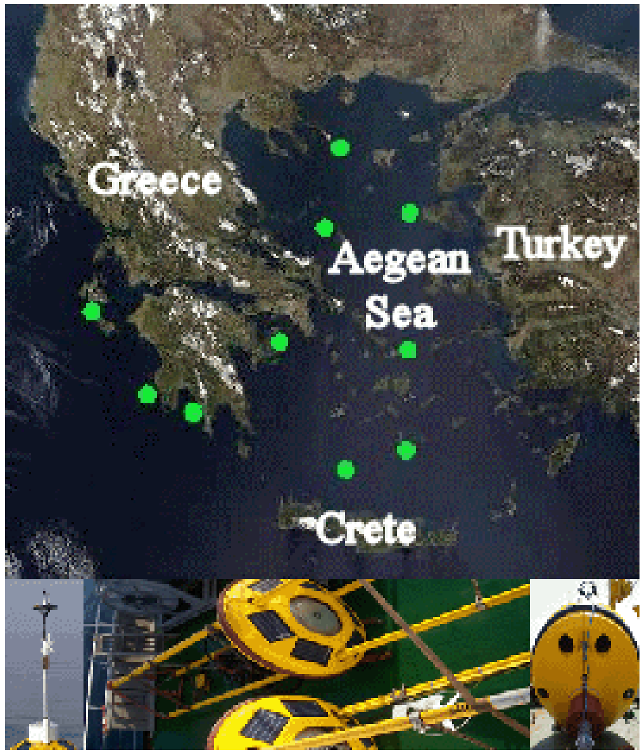

Figure 1. Locations of the 10 POSEIDON oceanic buoys.

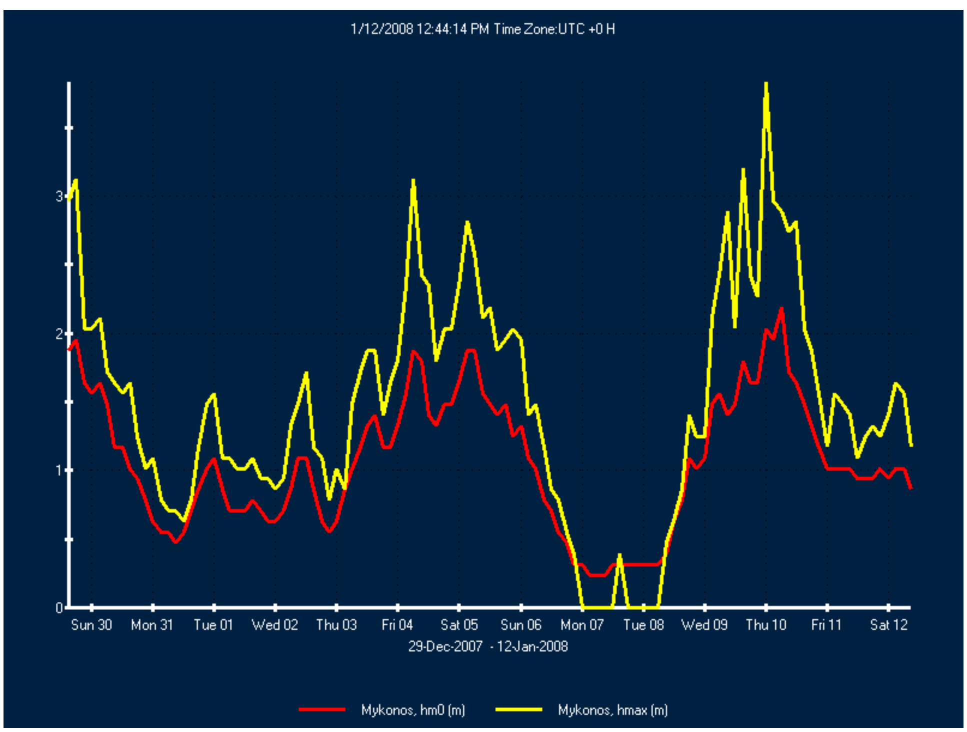

Figure 2. Sample plot of significant and maximum wave height (m) at the POSEIDON Mykonos buoy.

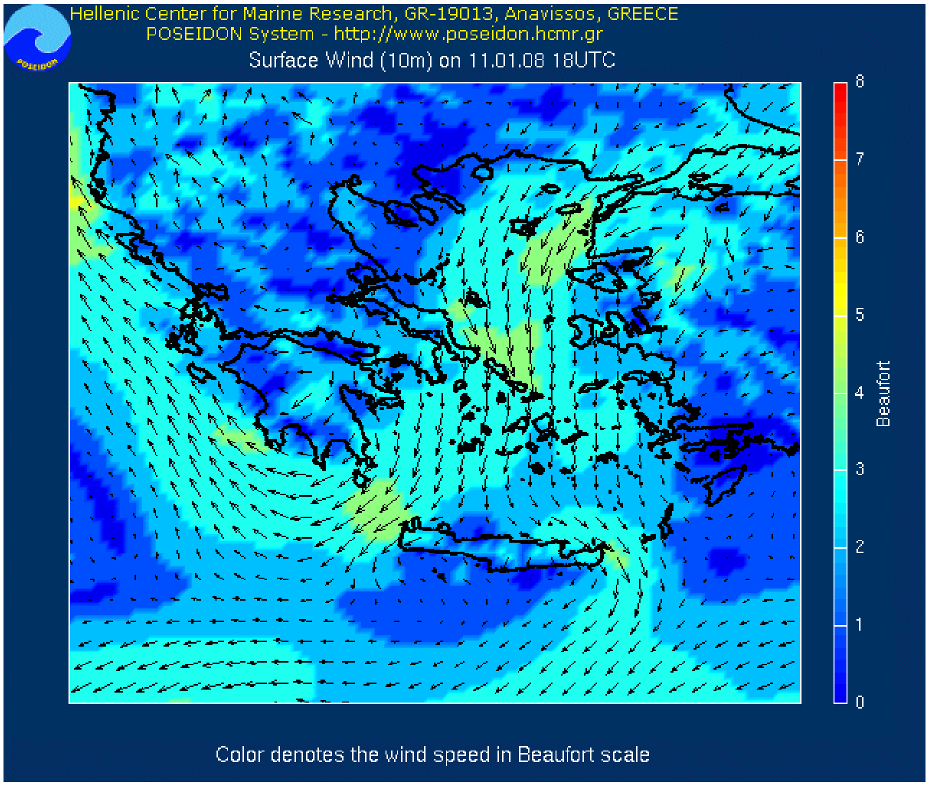

Figure 3. Sample numerical forecast of 10-m winds from the coupled atmospheric/oceanic SKIRON/Eta model.

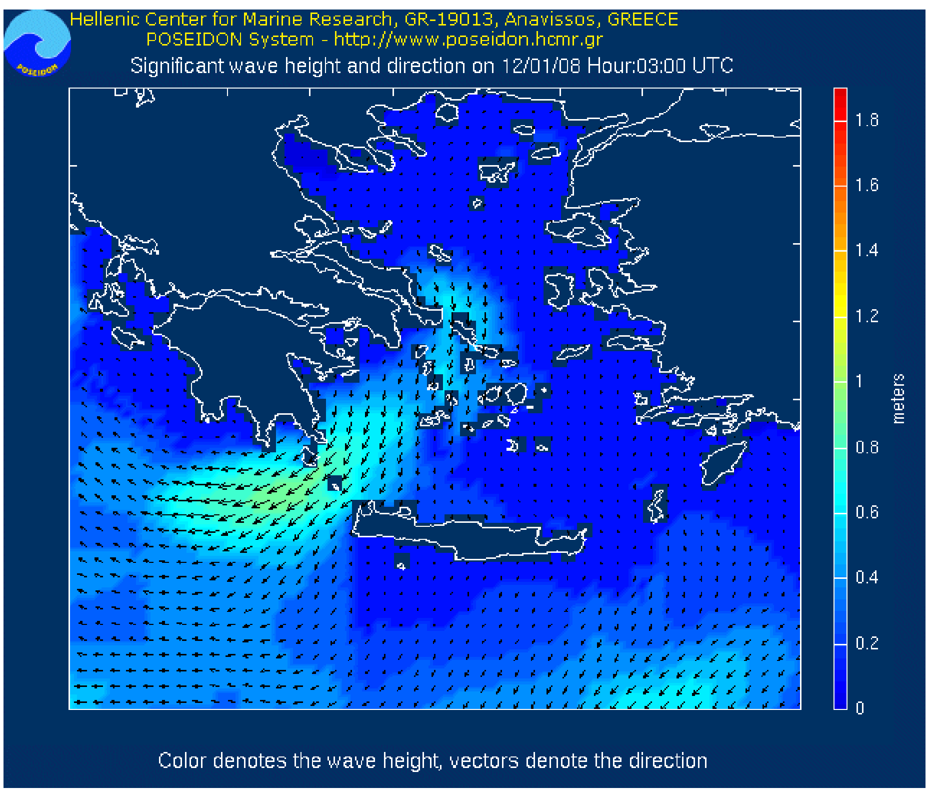

Figure 4. Sample prediction of significant wave height and direction from the Princeton Ocean Model as run at HCMR.

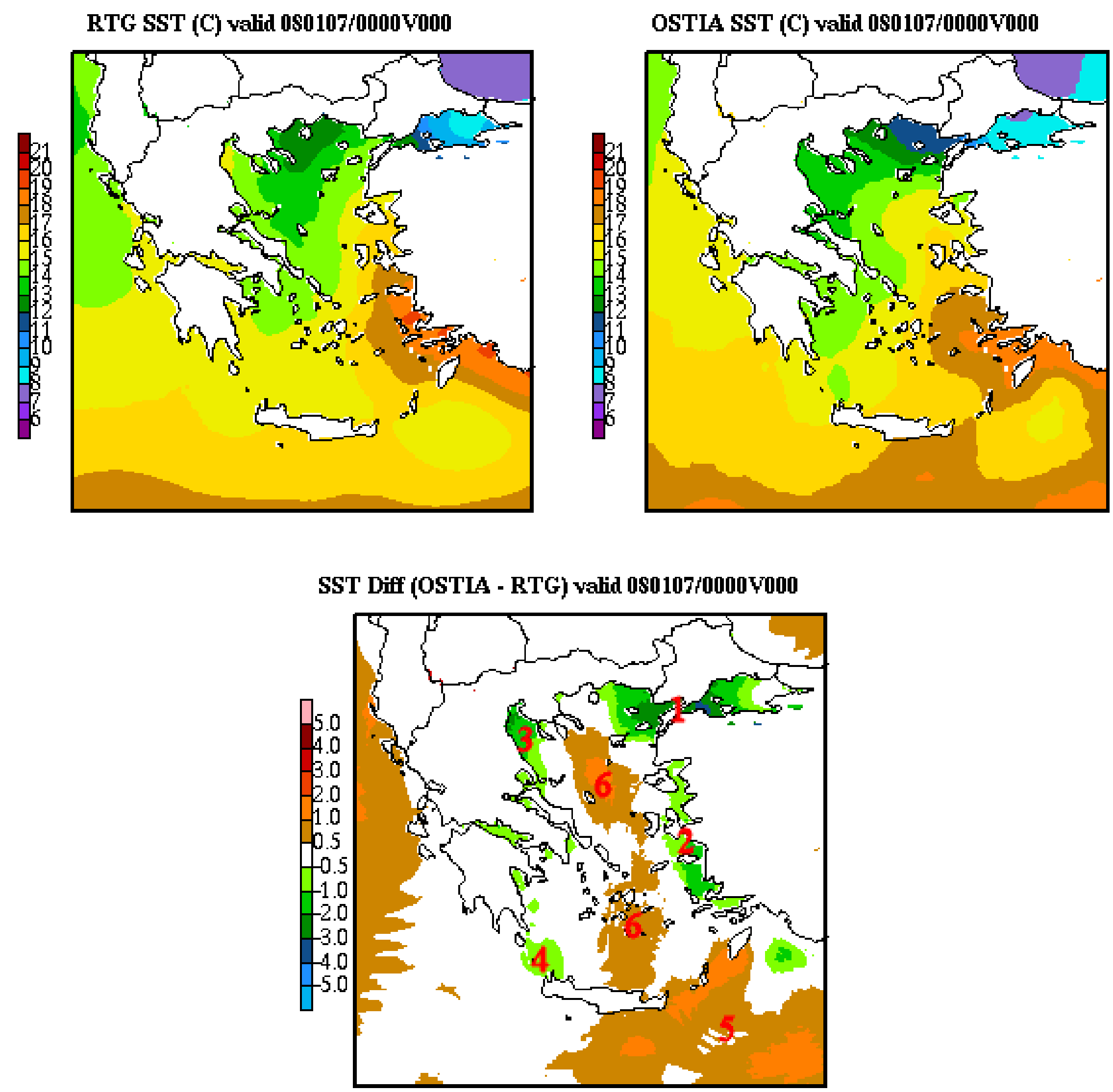

Figure 5. Initial SST fields at 0000 UTC 7 January 2008 for the Control Run (i.e. RTG, upper-left), Experimental Run (OSTIA, upper-right), and difference field (OSTIA-RTG, bottom panel). Major geographical features referred to in the text include (1) Bosporous Straits, (2) eastern Aegean Sea, (3) Thermaikos Gulf Coast, (4) Peloponnesian gyre, (5) Levantine basin, and (6) Greek islands.

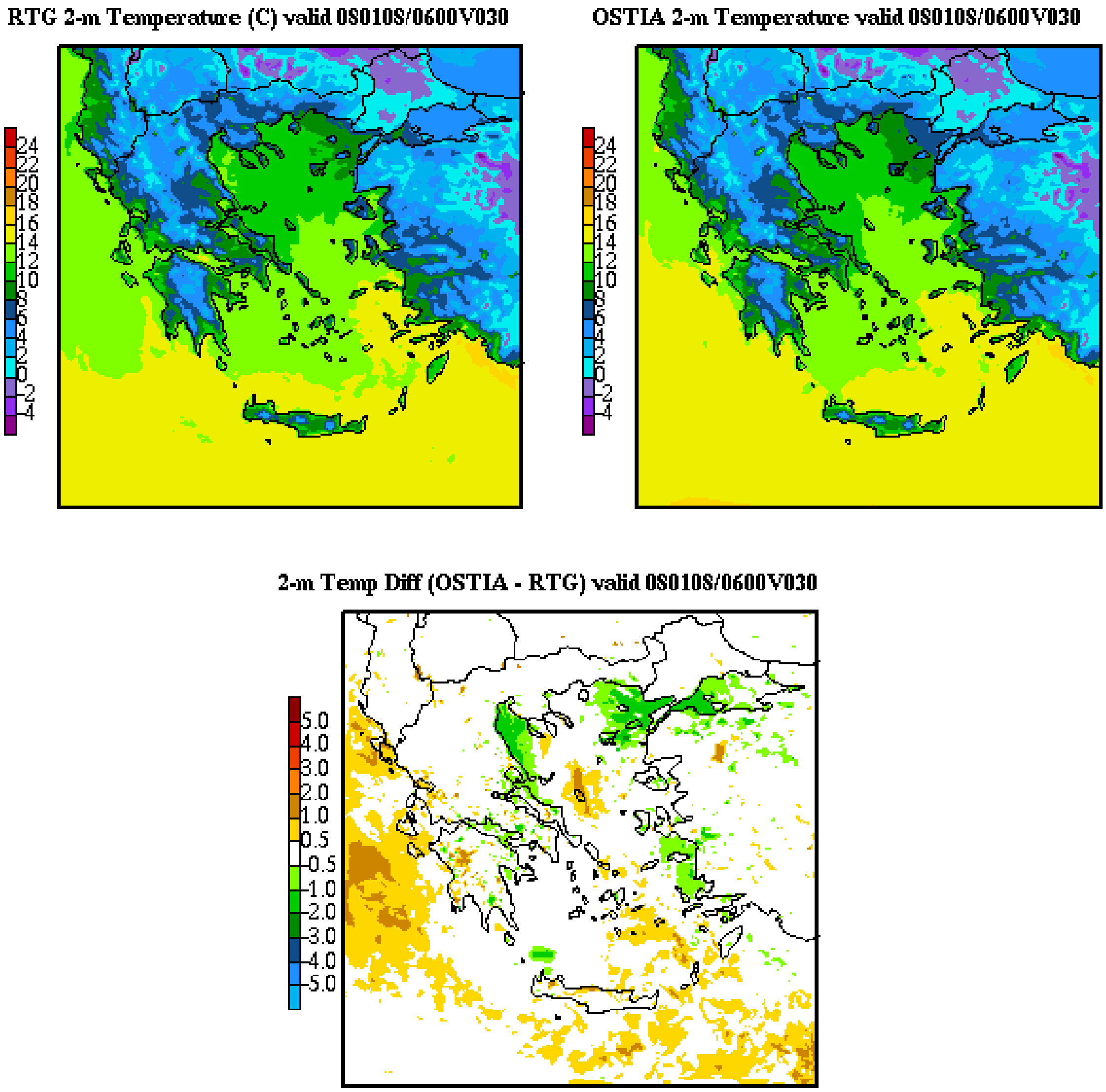

Figure 6. WRF simulated 2-m temperatures at the 30-hour forecast valid 0600 UTC 8 January for the Control Run (upper-left), OSTIA run (upper-right), and difference fields (OSTIA–RTG, bottom).

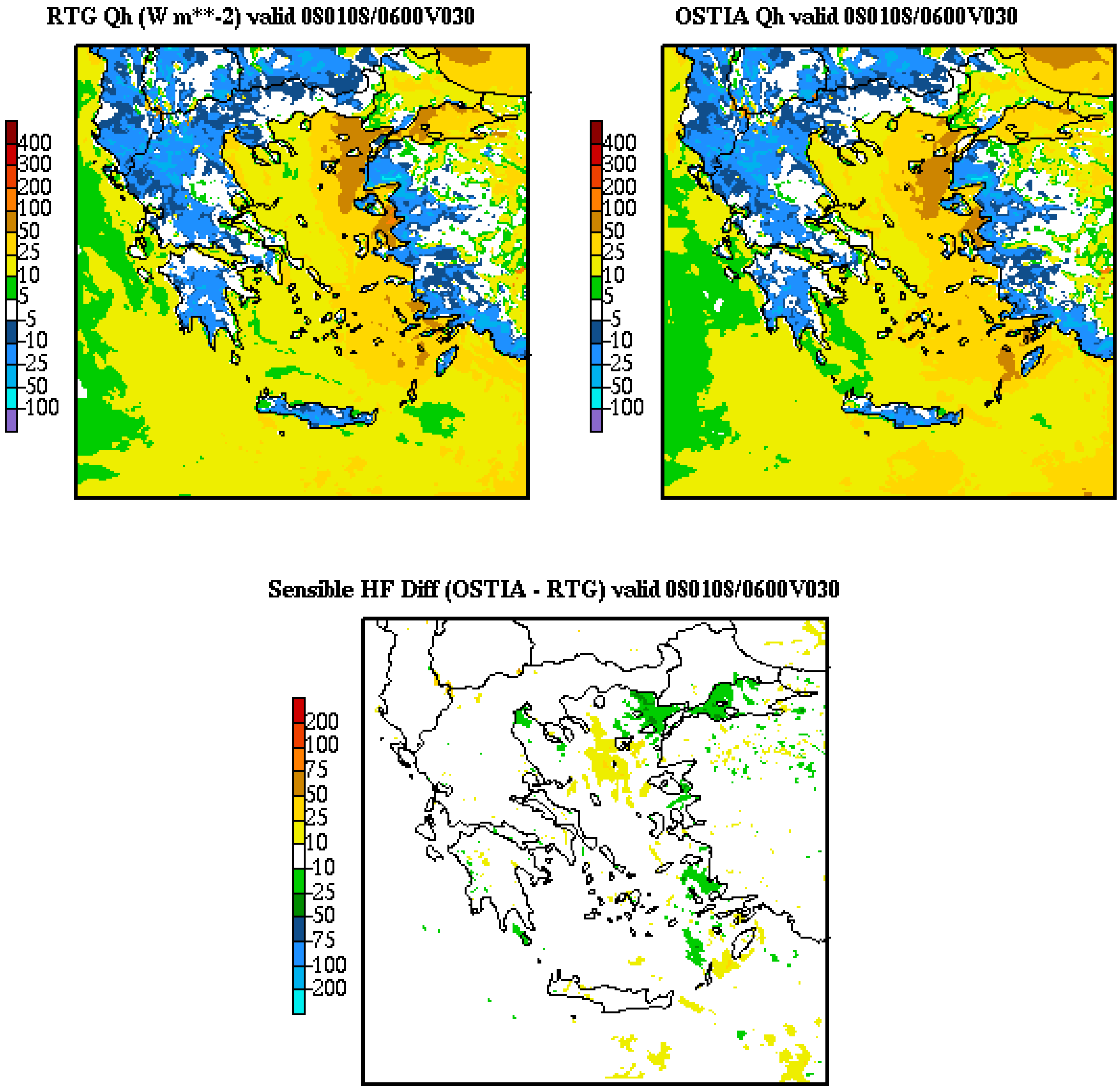

Figure 7. WRF simulated sensible heat flux at the 30-hour forecast valid 0600 UTC 8 January for the Control Run (upper-left), OSTIA run (upper-right), and difference fields (OSTIA–RTG, bottom).

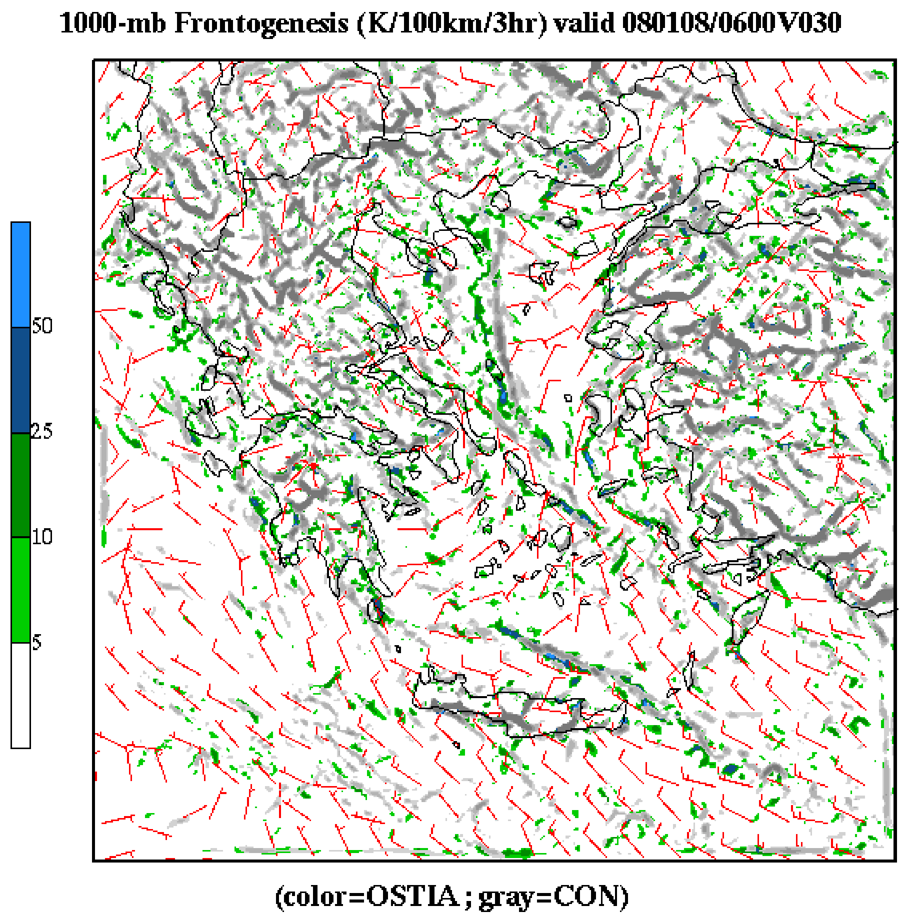

Figure 8. WRF simulated 1000-mb frontogenesis and 10-m wind vectors at the 30-hour forecast valid 0600 UTC 8 January for the Control Run (gray shading), and OSTIA run (color shading, according to scale provided).