The Effect of Variable Sea Surface Temperature on Forecasting Sea Fog and Sea Breezes: A Case Study

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ABSTRACT

A preliminary study of the effect of sea surface temperature (SST) temporal and spatial variability on regional coastal weather forecasts is described. A high-resolution numerical weather forecast model from the Met Office is run for the U.K. region with hourly updates of SST data obtained from a shelf sea model. When compared with a control run in which SST is maintained with Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) data, it is found that there are significant differences in the coastal-region forecasts for sea breezes and fog formation. The control run underestimates surface temperature and the strength of the sea breeze when compared with the run with hourly SST updates.

1. Introduction

It is widely known that—because of the ocean’s larger heat capacity, upper-ocean mixing, and basin-scale circulations—ocean processes are usually much slower than those in the atmosphere. As a consequence, ocean processes usually integrate atmospheric disturbances and then apply this forcing back to the atmosphere on much longer time scales and larger space scales. In particular, sea surface temperature (SST) is a key parameter in understanding processes of air–sea interaction, and its role in global climatology on seasonal and annual time scales is widely accepted. In contrast, much less is known on how the upper ocean can affect the weather on short time scales and in local regions. Kawai et al. (2006), Kawai and Wada (2007), Pullen et al. (2007), and Oda and Kanda (2009) have recently drawn attention to the effect of diurnal SST variations on coastal region forecasts, an effect that is especially significant under light wind conditions. In a review article, Kawai and Wada (2007) pointed out that diurnal SST variations can be large, even in excess of 5°C, and there are possible severe implications for coastal-region forecasts, especially for sea breezes. Kawai et al. (2006) investigated the effect of a diurnal SST increase on the weather in Mutsu Bay, Japan, and showed that the sea breeze becomes weaker and surface temperatures over land increase. Pullen et al. (2007), in a numerical study of the effect of coastal upwelling in the New York–New Jersey region, showed that using hourly SST data as compared with an analyzed SST product made a discernible difference and that, in particular, the near-surface air temperature was lower by 1°–2°C and the near-surface winds were weaker by 15%–20%. In an analogous numerical study of Tokyo Bay, Oda and Kanda (2009) also found that large diurnal SST variations, up to 5.5°C in summer, had a significant effect on air temperature at the coast, together with other consequent effects, although their results were sometimes also affected by strong winds.

Apart from these cited works, and a few related studies, there has been very little detailed study of how the ocean and atmosphere may interact on short time and space scales, especially through spatially and temporally varying SST, and to what extent such interactions may affect weather forecasts. Hence, in the Met Office we have begun a study of the interaction between the ocean and the atmosphere in limited-area domains, using a high-resolution NWP code combined with a coastal ocean numerical model. At this stage, it is run as a one-way coupled atmosphere–ocean model, with the ocean model providing SST data. In this preliminary study, we report on how SST variability affects U.K. weather forecasts, with a special focus on the southern coast.
2. Case study

a. Numerical models

The Met Office weather forecast now routinely uses the variable-resolution Unified Model (UM) for the U.K. region (UKV). The model setup used here is that described by Tang et al. (2012). The UKV is composed of three domains with different horizontal resolutions: an inner 1.5-km-resolution domain with 622 \times 810 grid points covering most of the model domain of interest, a transition zone with a grid-stretching ratio of about 4% in each direction, and an outer domain with a 4-km resolution. In total there are 744 \times 928 horizontal grid points in UKV. For the coastal ocean, we use the Nucleus for European Modelling of the Ocean (NEMO) shelf sea model (Madec 2008), which is also fully operational at the Met Office. The SST in the NEMO model is initialized from the Met Office North Atlantic and European weather forecasting model. Then the temporally and spatially varying SST data from the NEMO model are updated hourly, evaluated on a 7-km grid, and used to test the sensitivity of the UKV model. These SST data are interpolated onto the UKV grid using bilinear interpolation. In the control simulations, the SST is initialized with Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA; Donlon et al. 2011) data, which have a resolution of 6 km, and thereafter remains constant in time.

In this paper, we describe an illustrative case study. In early summer on a sunny day, the land starts to get warmer while the sea remains cool. Under light-wind conditions, the impact of wind waves is small and hence diurnal variation of SST becomes significant. In the United Kingdom, 9 June 2007 is such an early summer case with a high pressure system over the United Kingdom and very weak large-scale synoptic flows. We shall discuss this case here, with a special focus on how SST variability may influence the formation of fog and sea mist, and its effect on sea breezes.

b. Surface temperature

Figure 1 shows the sea surface temperature from the control run in comparison with the UKV run with hourly SST updates. Over the land, we have plotted the land surface temperature. Overall, there is a marked difference between the two runs. The SST from the control experiment has very little spatial variation and does not vary in time. The biggest difference between the two runs occurs along the coastal boundaries between the sea and the land and is as much as 2°C–3°C cooler in the control run (see the difference plot in Fig. 1). Along the center of the English Channel, the biggest diurnal variation occurs at the southwestern end adjacent to the open ocean as shown in Fig. 2. On average, the run with the SST updates is in the range of 0.5°C–1°C cooler than the control run along the middle of the English Channel.

c. Sea-breeze forecast and temperature

In Fig. 3 we compare the model temperature at 1.5-m height with observations at two coastal locations, Brighton and Eastbourne, on the south coast of England. These are coastal bay areas where sea breezes are common, and the issue is whether warmer and temporally varying SST would change these forecasts in a substantial way. Both the control experiment and the experiment with hourly SST updates from the NEMO shelf sea model forecast sea breezes at both locations, shown in each case by the sharp drop in temperature in the early afternoon. The former experiment tends to overestimate this temperature drop, however, whereas the results from the latter experiment agree better with the observations.
Figure 4 plots the 1.5-m air temperature and 10-m wind fields at 1400 UTC, showing the development of the sea breeze. First, we see that the sea-breeze front in the control run is stronger and farther inland than the sea-breeze front in the run with hourly SST updates. Next, the color contours of the 1.5-m air temperature show very clearly that the control run predicts up to 3°C lower temperature along the sea-breeze front than does the run with hourly SST updates (see especially the difference plot). This temperature difference is partly due to the different location of the sea breeze in the two runs. It is also interesting to note the “cold” patches in the difference plot behind the sea-breeze front, which are due to differences in the spatial structure of the temperature field behind the respective sea-breeze fronts.

Figure 2. Sea surface temperature at locations along the English Channel that are marked as blue dots on the map. The black lines are from the control run, and the blue lines are from the run with hourly SST updates from the NEMO shelf sea model. The biggest diurnal variation occurs at the southwestern end adjacent to the open ocean.

Figure 3. Air temperature at 1.5 m near (left) Brighton and (right) Eastbourne (marked as red dots on the map in Fig. 2). The black line is from the control run, the blue line is from the run with hourly SST updates from NEMO shelf sea model, and the plus signs are the observations.
d. Sea fog, mist, and low-level cloud

As mentioned above, in this case study for 9 June 2007, the winds were very light and sea fog and mist persisted in the English Channel. SST is expected to play a very important role in the spread and extent of fog and mist. In comparing the visibility from both runs, it is seen that throughout the forecasting period the control run produced much more widespread and dense fog. In Fig. 5 we show snapshot pictures of the model visibilities at 1230 UTC, in comparison with National Oceanic and Atmospheric Administration (NOAA) satellite imagery. To examine how much impact hourly SST updates from the NEMO shelf sea model have on the UKV model sea fog and mist forecasts, we calculated the percentage area with visibility forecasts that are below a given threshold. Here the domain used for this comparison is the same as shown in Fig. 1. Figure 6 shows the comparison with thresholds of 50 m, 200 m, 1 km, and 5 km. These plots show up to 50% more coverage of fog and mist in the control run than in the run with hourly SST updates.

3. Discussion

In this brief note we have described a preliminary case study to examine the impact of spatially and temporally varying SST on coastal weather forecasts. The sea surface temperature in the UKV model was updated hourly with SST data from the NEMO shelf sea model and compared with a control run using SST initialized from OSTIA data. Although this is only a one-way coupled model, we can see that diurnal variability of SST plays an important role in coastal-area weather forecasting. To be specific, when compared with the OSTIA SST used in the control experiment, the hourly SST data updates from the NEMO shelf sea model not only introduced an average (mean) SST difference of at least 1.5°C but also spatial variations of as much as 4.0°C in coastal bay areas. Because of the lower SST in the control run, there is

![Fig. 4. Vector plots of 10-m winds (kt; 1 kt = 0.5 m s⁻¹) and color contours of 1.5-m temperature (K) along the south coast (Brighton and Eastbourne) at 1400 UTC 9 Jun 2007, 14 h into the runs. Shown are (left) the results from the control experiment, (center) the results from the run with hourly SST updates, and (right) the differences (with SST updates − control). The black contour lines are the orographic height (m; 50-m intervals). The vector key arrow above each scale represents 5 kt. The numerals shown in the absolute scale range from 288 to 304 K, in increments of 2 K. The numerals shown in the difference scale range from −3 to +4.5 K, in increments of 1.5 K.](image)

![Fig. 5. Visibility (km) at 1.5 m at 1230 UTC. (left) The NOAA satellite image showing convection developing over the United Kingdom with marine fog and low cloud, (center) the control run, and (right) the run with hourly SST updates from the NEMO shelf sea model. The numerals in both keys are, from left to right, 50, 100, and 200 m and 1, 5, 10, 20, 30, 50, and 70 km.](image)
cooler air with more mist and fog in the boundary layer over the ocean. Although this is just one case study, the results are consistent with those obtained by Kawai et al. (2006) for Mutsu Bay, Japan, Pullen et al. (2007) for New York–New Jersey harbor, and Oda and Kanda (2009) for Tokyo Bay in analogous numerical experiments. We plan further case studies of this kind and a more detailed examination of the consequences, including the effects on humidity and heat distribution. This study, and those cited, have looked specifically at SST variability on coastal weather forecasts in one-way coupled models. It is likely that other effects with significant variability on short time and space scales, such as the wind wave conditions, will also affect weather forecasts. This, and using fully coupled models, will be examined in future work.

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REFERENCES


CORRIGENDUM

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There is an error in the final sentence of the abstract of Tang (2012). The word “overestimates” was omitted before “the strength of the sea breeze”; the full sentence should read as “The control run underestimates surface temperature and overestimates the strength of the sea breeze when compared with the run with hourly SST updates.”

REFERENCE


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