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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "A case study of sea breeze blocking regulated by sea surface temperature along the English south coast" *by* J. K. Sweeney et al.

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General Comments to all Reviewers:

We thank all of the reviewers for their careful reading of our manuscript and their insightful comments. We are encouraged that each reviewer has recognized the key result of this paper, which is the identification of an offshore calm zone that is formed by orographic blocking and regulated by SST in a counterintuitive way via the static stability of the marine boundary layer. Each reviewer has provided recommendations for improving the article which have led us to make several changes. These changes

are detailed in the point-by-point responses included below. Two supplementary figures have been attached to the end of this response to support our reply to several of the reviewers' comments.

Reviewer 1

General comments:

1. The reviewer has enquired whether the southward-facing coastal hills in the runs with orography would warm more than the flat land in the runs without orography. While the coastal hills are not very tall (< 200m), the land surface is indeed warmer by approximately 0.2 K – 0.5 K in the runs with orography. The larger land-sea contrast would imply a stronger sea breeze, which would work against orographic blocking. The comparison of runs with and without orography demonstrates that a calm zone only forms in runs with orography. This primary result is unaffected by the minor difference in the land-sea contrast between runs. Note also that the 2 K range of SST used in the experiments is considerably larger than the warming due to sloping orography. A brief note has been added to the final paragraph of Section 2.

2. The surface wind velocities offshore do not exhibit a systematic increase or decrease in the warm versus cold SST experiments, which suggests that downward mixing of momentum is not significantly modified by a 2 K change in SST in this particular case. The onshore wind speed difference between the warm and cold runs exhibits a complicated pattern of increases and decreases. This pattern appears to be tied to the distribution of orography and to the shape of the coastline. The calm zone in Lyme Bay is distinctly evident in the difference field (i.e., weaker winds in the cold SST experiment). For the reviewer's interest, the difference fields are provided in Supplementary Figure 1.

3. The calm zone does extend approximately 3 km inland from Lyme Bay. The shallow depth of the blocked flow prevents deep inland extension, particularly where the slopes are steepest near the coastline. This is difficult to see in Figure 7d due to the scale on

the abscissa. A note has been added to the text (paragraph 4, Section 5). The role of downward mixing of momentum over the heated land mass has not been assessed, but is indeed an interesting consideration. As we have stated in the final sentence of the discussion section, a more detailed analysis of boundary-layer processes would constitute a very interesting avenue for further study.

4. The case was chosen as a typical sea-breeze event with light gradient winds and clear skies. A sentence has been added to the first paragraph of section 3 justifying the selection of this particular case. We have also noted in the Discussion section that the calm zone is commonly observed in Lyme Bay. The case study date is mentioned in the last paragraph of the Introduction section of the revised manuscript.

5. We have emphasized the novel aspects of this study in the abstract and introduction, as the reviewer has recommended.

Specific comments:

1. The sentence has been modified as suggested by the reviewer.

2. Typo corrected.

3. Phrase added.

4. By “climatological” we mean long-term monthly mean SST, as provided by the OSTIA dataset. This clarification has been made, as suggested.

5. The paragraph has been revised as suggested. The technical detail is provided in Section 2.

6. We have removed the introductory sentences as suggested.

7. We have added a few sentences to the first paragraph of Section 2 describing the observational data.

8. The satellite image indicates that the sea breeze penetrates approximately 15-20 km

inland from Lyme Bay, which is similar to the inland extent in the simulations, although it is difficult to make a direct quantitative comparison using only a coarse visible satellite image. As the reviewer suggested, we have provided this estimated value in the text.

9. Sentence removed.

10. We have added the reference to Miller et al. (2003) as suggested. The presence of orography and a variable coastline have a very strong influence on the local structure of the sea breeze.

11. The last two sentences have been removed.

12. We have highlighted that the differences are restricted to locations near the shore.

13. We have checked our estimates of the vertical gradient of theta and agree that the reviewer’s estimates are more accurate. The calculation of the Froude number has been revised accordingly. We also agree with the reviewer that the argument relies on the change in Froude number with SST, not the actual value. Partial flow stagnation is often observed at Froude number greater than 1.

14. We have edited the opening paragraph of the conclusion such that the novel aspects of our study are emphasized.

15. We have revised this sentence as recommended and thank the reviewer for their helpful suggestion.

16. The phrase has been modified as suggested.

17. The information in the caption has been moved to section 2.

18. We have revised the caption in Fig. 3 as recommended.

19. The figure has been edited.

20. The aspect ratio of the figure panels has been adjusted. The calm zone is wider, and the offshore wind differences are clearer.

Reviewer 2

Specific comments:

1. The reviewer suggests that our focus on the calm zone and not on the inland penetration seems counterintuitive. The article focuses on the offshore calm zone for several reasons.

a. First, this aspect of the analysis is novel. The calm zone is the main feature that is uniquely revealed by the combined analysis of SST and orography. The effect of orography on inland penetration can be analyzed without also testing sensitivity to SST. Several previous studies have demonstrated the effect of orography on inland penetration (see Porson et al. 2007 and references therein). We have added this reference to the final paragraph of Section 1.

b. Second, it is the combined effect of SST and orography that exhibits a counterintuitive control on the offshore calm zone structure. Specifically, a larger land-sea contrast (i.e., colder SST) would, by itself, lead to stronger onshore winds and thus less blocking. We demonstrate the opposite effect; colder SST results in more blocking because of the increased static stability. It is our opinion that this counterintuitive result is sufficiently interesting to merit the spotlight in this article. We have revised the abstract and introduction so that this novel aspect of the analysis is emphasized.

2. The reviewer suggests that the variable coastline and orography complicate the analysis. We agree that reality is complicated, but this is not an argument against conducting investigations of real cases. The sensitivity experiments were carefully designed to make two things clear: a) the presence of orography is a necessary condition for the formation of the offshore calm zone, and b) the calm zone is stronger for colder SST. Despite the variable coastline and orography, these two results are unambiguous. Furthermore, real cases afford comparison to observations, as has been done in this article. The reviewer also notes that there is evidence of reduced wind speed in Portland Harbour. This wind speed reduction is not as clear nor is obviously linked to

orography as is the calm zone in Lyme Bay.

3. The reviewer is not convinced that the calm zone forms due to partial orographic blocking. The experiments with and without orography clearly demonstrate that orography is a necessary condition for the formation of the calm zone. How else, if not by orographic blocking, could this result be explained? The reviewer has stated that "the Froude number argument is sketchy" because the Froude number is not strictly less than 1. In real cases, where the static stability and upstream wind are nonuniform and the mountain profile is not a simple analytic function, a critical Froude number is very difficult to determine. Furthermore, partial blocking is often observed for Froude number larger than 1 (e.g., see Reinnecke and Durran, 2008). What is important is that the Froude number is indeed smaller in the cold SST experiments than in the warm SST experiments (despite the stronger upstream wind in the cold SST). This reduction in Froude number corresponds to a wider calm zone in the cold SST experiments. The increased stagnation with decreasing Froude number is very strongly suggestive of orographic blocking. Reviewer 1 has also inquired about the method by which the Froude number is estimated, but this reviewer also notes that "For the argument to work, it is not critical that the Froude number is around 1, it is sufficient that it is larger in the warm SST case". We have added a few sentences to the final paragraph of Section 5 to make this clearer.

4. We thank the reviewer for pointing out these references concerning the offshore extent of the sea breeze. The excerpt from our paper to which the reviewer refers states specifically that "the sea-breeze spreads more rapidly offshore". Please note that we were referring to the propagation of the sea-breeze circulation offshore, not to its extent or structure. Arritt (1989) and Steele et al. (2013) (references suggested by the reviewer) do not explicitly describe how the signal is communicated. Finkele (1998) compares the offshore propagation speed in a numerical model to observations, but does not offer a theoretical explanation for the mechanism of signal propagation. Our claim that "the reasons for this (. . .) have not been investigated" is still, to our knowl-

edge, valid. We appreciate the reviewer's confusion, so we have deleted the discussion of offshore propagation from the text since it is not the focus of this investigation. The offshore propagation of the sea breeze is not a critical focus of this paper. The Steele et al. (2013) paper, which we were unaware of when this manuscript was prepared, is indeed relevant to our analysis, specifically because they describe a mechanism by which an offshore calm zone may be formed due to the interaction of the sea breeze with the gradient wind. We have added this reference to Section 6 and thank the reviewer for bringing this to our attention.

5. The reviewer makes a very good point. The diurnal variation of SST would typically render the OSTIA SST too cold, which would lead to a calm zone that is too strong in the model. We have added this commentary to Section 6 and have included a sentence in the last paragraph of Section 2. The colder SST experiment is still of relevance; the interannual range of SST is considerably larger than the 2 K range used in this investigation.

Technical comments:

1. We have clarified that the term "calm zone" has been used historically to refer to the region of reduced offshore winds caused by the interaction of the sea breeze with the gradient wind, and have added the appropriate references (Steele et al., 2013; Fett and Tag, 1984).

2. We have fixed all of the minor typos that we could find.

Reviewer 3

Specific comments:

1. The air temperature is affected by the sea breeze and is affected differently in the cold versus warm SST experiments. Supplementary Figure 2 (see below) shows that the inland temperature is cooler by 1-2 K in most inland locations behind the sea breeze front in the cold SST experiment. We have revised the manuscript such that this inland

cooling in stated in Section 5 following the discussion of Figure 8.

2. The calm zone amplifies in concert with the amplification of the sea breeze itself. The calm zone is apparent during the early stages of sea breeze onset. This is now stated in Section 4 (second paragraph), as the reviewer has suggested.

3. We have found evidence of the calm zone in wind speed observations (comparing Lyme Bay to Portland Harbour) on numerous other days. The calm zone appears to be a very regular feature at this location. While the presentation of this set of sensitivity tests focuses on only a single illustrative case, the reviewer correctly points out that this single case needs to be placed in context. We have therefore added a sentence to the Section 6 (final paragraph) stating the prevalence of the calm zone, and have also revised Section 3 justifying the selection of this particular case.

4. As pointed out by Reviewer 2 (specific comment 5), the diurnal variation of SST implies that the OSTIA SST values used in the control runs are likely to be colder than reality. Figure 2b suggests that this was indeed the case. The warm SST experiment is therefore likely to be a more accurate hindcast than the cold SST experiment. This probable bias is now stated in Section 6. 5. These references have been added

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/13/C10551/2013/acpd-13-C10551-2013-supplement.pdf

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 24785, 2013.

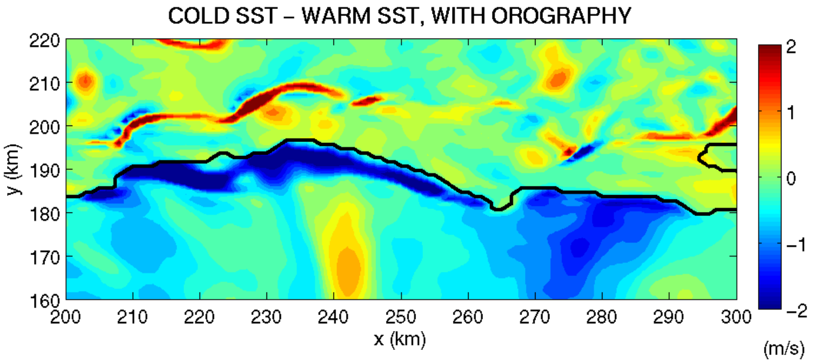

Fig. 1. Supplementary Figure 1. Difference in 10m wind speed between the OSTIA – 1K and OSTIA + 1K SST experiments (with orography).

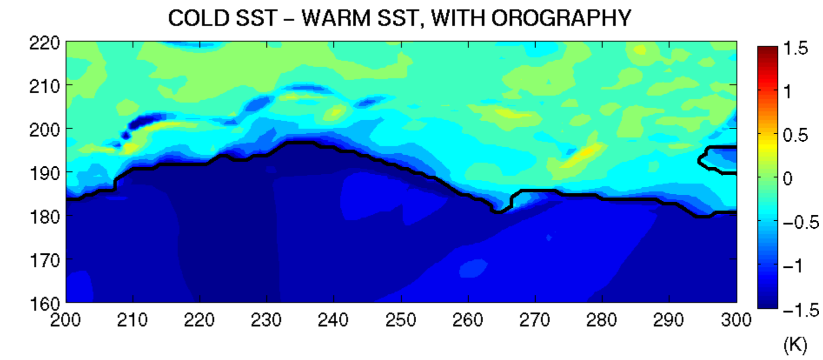

Fig. 2. Supplementary Figure 2. Difference in 10m potential temperature between the OSTIA – 1K and OSTIA + 1K SST experiments (with orography).