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Interactive Comment

Interactive comment on "Dynamical analysis of sea-breeze hodograph rotation in Sardinia" *by* N. Moisseeva and D. G. Steyn

N. Moisseeva and D. G. Steyn

nmoisseeva@eos.ubc.ca

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This paper is well-written, concise, and presents novel research with respect to sea breeze dynamics in the presence of complex topography and coastline. I think the paper is worth of publication as is, but would benefit from expanded discussion and analysis regarding the modeled hodograph rotation. These changes could be either a major or minor revision depending on how rigorous the response.

Response: We would like to thank the reviewer for the constructive feedback and helpful suggestions. Please see our additions and comments below.

1). The discussion of why the modeled and observed hodographs change as a function of location around the island would benefit from more discussion and background in general. For example, do inland penetration speeds and intensity of the breeze vary as a function of topography or land use types and subsequent sensible heat fluxes (which might modulate the rotation rates/types), do the breezes on either side of the island ever converge in the middle of the island, and what is the prevailing large-scale flow (if any) and how might that play into the picture? If weak large-scale flow were to be changed, would that change the rotation or have little effect?

Response: Thank you for highlighting the lack of background on synoptic conditions in the paper. The issue has been raised by a number of reviewers, and we agree strongly that the article does not provide sufficient clarity about possible large-scale flow. We have considered including a sample synoptic map as supplementary material for reference, but felt it was rather trivial. Rather, we would like to include the following clarification in the revised version of the manuscript:

The analysis is based on seven sea breeze episodes, studied previously by Furberg (2000). These pre-selected days were identified using a fairly conservative filter, ensuring the exclusion of cases with strong overriding synoptic scale winds. The model, similarly, produces very weak synoptic flow, and as evident from Fig 5. and Fig. 7, very weak synoptic rotational forcing. Hence, it does not appear to be an important factor in determining the rotation of the sea breeze.

Regarding the remaining suggestions about the characteristics of sea-breezes in Sardinia, and their dependence on various geophysical variables:
The authors agree that all these are valid and interesting topics, but they have largely been covered in an earlier modeling study by Melas (2000). We, hence, wanted to avoid the unnecessary overlap, and focus solely on hodograph rotation, rather than general behavior of sea breezes in Sardinia.

2) Do slope flows combine with the sea breezes, and are they distinguishable from the sea breeze (I don't think they are, but these flows should be mentioned). In addition to the blocking or whatever other effects the mountains have, the mountains generate their own flows as a function of slope, vegetation type, height, etc.

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Response: Sardinia's complex topography certainly favors the formation of slope flows and they are generally impossible to distinguish from the SB. The two mechanisms tend to operate in combination over all of the island, particularly on the East side. However, as suggested by Melas (2000), slope winds tend to prevail near the mountains. To isolate the rotational effects of SB we, hence, performed our analysis on areas away from the coast, to avoid the local effects of slope flows, variable friction effects of land cover/use and other influences of local geophysical variables.

3). Is the synoptic forcing really 'synoptic' when it is apparently highly influenced by the breeze return circulation itself? I think this should be mentioned even if the forcing is still discussed as synoptic.

Response: We agree that a more detailed description of the physical meaning of each term is needed. The revised version of the manuscript will contain a brief overview of each individual forcing term and its possible influence on sea-breeze rotation, as shown below. More specifically, the 'synoptic' term is really an upper level pressure gradient term. Unfortunately, the formulation of WRF does not allow for a separation between pressure gradient and synoptic forcing. Hence, it had to be inferred indirectly by establishing a reasonable synoptic level (850mb) to be representative of the overlaying conditions.

Surface Pressure Gradient
The surface pressure gradient is predominantly driven by the temperature contrast between land and water, and its influence on the sense of rotation depends largely on the location and shape of the landmass. More subtle, local effects of the sea surface temperature inhomogeneity may further alter the turning direction of the surface wind. Moreover, non-uniform surface heating due to topography and irregular coastline of Sardinia are likely to introduce further complexity into surface pressure distribution, as previously suggested by Kusuda and Alpert (1983).
Synoptic Pressure Gradient
As the synoptic pressure gradient term is derived from total pressure gradient it in-

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evitably represents a total of upper level forcings and true synoptic flow. While the synoptic component of the pressure gradient force generally acts in opposition to the surface gradient under SB conditions due to the formation of the SB return flow (Miller et al.,2003), it also responds to the local topography. Cyclonic and anti-cyclonic rotation may be induced depending on the direction of the local wind and shape of the topography. As SBs are known to develop on all coasts of Sardinia and have variable inland penetration the direction of dominant wind flowing over the primary mountain range on the island is likely to vary throughout the day.

Advection

Advection of the horizontal momentum may similarly result in the formation of both CR and ACR. The importance of the term depends largely on the presence of velocity gradients at a given location. Since the regions selected for our analysis are located away from the coast, we can expect the rotational effects of the advection to be of secondary importance.

Horizontal and Vertical Diffusion

The horizontal and vertical diffusion are friction driven effects, and hence always act to oppose the local wind. Varying surface roughness due to the spatial distribution of land use, cover and topography may introduce shear and rotation into wind flow. As our analysis is performed for locations away from the coast, these remain largely negligible.

4). What does the advection term physically represent and why does it change between locations?

Response: See response to Comment (3).

5). In Fig. 4 and 5, would presenting the analysis at a couple more locations around the island provide additional insight?

Response: We understand that it may appear unclear why the specific locations were selected for further analysis. Whereas we are unsure that the following information is easily presentable in the revised manuscript, we would like to include it here as sup-

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plementary material (please view SupplementaryAnimation.pdf using Adobe Acrobat Reader). Fig. 4 and Fig. 6 present daytime temporal averages of rotational forcings, however, as seen in the attached animation the spatial distribution of these patterns is not stationary through the day. The animation shows the temporal evolution of total rotational forcing and its diurnal movement, as likely explained by the location of the sun relative to Sardinia. As seen in the animation, many regions around the island undergo a switch between being CR and ACR. Performing dynamical analysis on such regions would introduce large uncertainties, and not allow us to draw any firm conclusions. We, therefore, selected those particular locations, which maintained their sense of rotation throughout the day, and hence corresponded to largest positive and negative values of average diurnal rotational forcing. This was not explicitly stated in our paper and, hence, we'll add the following clarification in the revised manuscript on line 352:
These locations correspond to largest positive and negative values of average diurnal rotational forcing, as they maintain their sense of rotation throughout the length of the day.

6). A brief mention of latitude dependence if any was found (I doubt given how small the island is) and reference to this paper's findings (and comparison to these findings) would be valuable P. Alpert, M. Kusuda, and N. Abe, 1984: Anticlockwise Rotation, Eccentricity and Tilt Angle of the Wind Hodograph. Part II: An Observational Study. J. Atmos. Sci., 41, 3568–3583. doi: http://dx.doi.org/10.1175/1520-0469(1984)041<3568:AREATA>2.0.CO;2

Response: As suggested, the island is too small and no latitude dependence was found.

7). No discussion of the SB hodographs as a function of distance inland from the coast were given. That would possibly be a topic of interest. The observations might not be there, but choosing a station from WRF model inland say 10 km from coast and seeing if there was any change from the coastal location could be of interest.

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Response: As noted in response for Comment (5), the locations for dynamical analysis were not selected arbitrarily. By focusing on off-coast locations we aimed to reduce the uncertainty due to temporal averaging of tendency values. Moreover, this allowed us to avoid the local influences of particular land features and study SB as a true mesoscale phenomenon. We have examined the evolution of rotational tendencies for a number of inland locations and while they generally resembled those presented in the manuscript large error bars did not allow us to firm conclusions.

References:

Kusuda, M., and P. Alpert (1983), Anti-clockwise rotation of the wind hodograph. Part I: Theoretica study, Journal of the Atmospheric Sciences , 40 (2), 487–499.

Melas, D., A. Lavagnini, and A. Sempreviva (2000), An investigation of the boundary layer dynamics of Sardinia island under sea-breeze conditions, Journal of Applied Meteorology , 39 (4), 516–524.

Miller, S., B. Keim, R. Talbot, and H. Mao (2003), Sea breeze: Structure, forecasting, and impacts, Reviews of Geophysics , 41 (3).

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/14/C8772/2014/acpd-14-C8772-2014-supplement.pdf

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 22881, 2014.

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