Response to Referee Comment of A. Speranza on „Climatology of Vb-cyclones, physical mechanisms and their impact on extreme precipitation over Central Europe“ by M. Messmer et al.

We thank Prof. Dr. A Speranza for his constructive comments on this manuscript, with which we essentially agree. In this letter we will show some suggestions for modifications. Please note that due to time reasons the answers we provide are based on preliminary results and might differ in the next draft of the manuscript.

“Due to orographic and thermal effects closed isobars with gradients exceeding 4 mb over 100 km are found over the western Mediterranean almost one third of the time (1), but most of these depressions are shallow and have no meteorological impact; only a few are associated with deep cyclogenesis (2,3).“

We agree with this remark, and indeed it will be included in the discussion part:

Page 924, Line 7ff.:
“In the case of the WPEs, we conclude that the Alpine inflow takes place at the southern or south-eastern side of the Alps, which is supported by the mostly southernly located precipitation amounts. These features are similar to the “Canarian Trough” described by Stucki et al. (2012) in association with past extreme floods in Switzerland. These cyclones are strongly influenced by a low over Brittany and thus show a southwesterly flow (Stucki et al., 2012). The same is true for the WPEs, which are strongly influenced by a low in the northeast of their cyclone centres. **Additionally it must be kept in mind that cyclone development in the vicinity of the Alps is a very complex problem. Due to strong non-geostrophic secondary flows, the appearance of near-surface closed isobars is not sufficient to produce cyclonic vorticity (Speranza, 1975). Thus, we can conclude that although WPE can be detected as closed isobars, i.e. cyclones, they are shallow and show no real meteorological impact, in clear contrast to HPE.**”

“The proposed statistical procedure is not particularly stable: only 62% of selected Vb-cyclones coincide with those identified by Hofstätter and Chimani (2012).“

We do not fully agree with this statement for two reasons. First, *Hofstätter and Chimani* (2012) use slightly different methodology (for example geopotential height at different pressure levels). If eventual disagreements appear, it cannot be judged a priori which methodology is better, but it has to be elucidated according to more sophisticated criteria than just their agreement. In particular the sensitivity of the methodology to several parameters is a source of uncertainty we address in our study, since several methods are evaluated and the most convenient is used in the rest of the analysis. Second, certain level of disagreement is indeed expected as for example the comparison of Neu et al. (2013) and Raible et al. (2008) shows. Both studies differ in the detection and tracking methods, and just a 40% - 80% of agreement is found. , Clearly, the 62% of agreement we report with the Hofstätter and Chimani (2012) findings is included within this range.

“Some authors (4) show that a seasonal change exists in the moisture source for the Alpine regions: predominantly Mediterranean and/or Atlantic in the winter, continental in the summer.“

We will consider this comment to improve the introduction. However, the suggested paper analyses precipitation over the Alpine region, separating the Alps in a northern and southern part, but without a clear connection to Vb-events specifically. In our case we are concerned with Vb-cyclones, which have a northward trajectory, but lead to precipitation in the northern side of the Alps. Thus it is not apparent which moisture source (predominant for northern or southern Alps) is applicable in this case.

Page 910, Line 19ff.:
“Although there is only little literature specifically focused on climatological Vb-cyclone characteristics, there are several studies devoted to the cyclones in the Mediterranean region, a

more general category to which the Vb-cyclones belong to. Trigo et al. (1999) performed an objective climatology of cyclones in the Mediterranean region, concluding that the Genoa region, which is also the origin of Vb-cyclones, generates most of the cyclones in the Mediterranean region. The authors also stated that topography-controlled cyclogenesis regions account for the most intense events. Fricke and Kaminski (2002) showed that the period from 1881 to 2001, which includes the most extreme precipitation events, reveals a more frequent appearance of the weather pattern "trough over Middle Europe" (Fricke and Kaminski, 2002). This pattern encloses also the Vb-cyclones. **Sodemann and Zubler (2010) analysed a similar, although shorter period of time (1995-2002), focusing on precipitation over the Alps. They determined a seasonal change in the moisture source for both sides of the Alps, i.e. whereas the Mediterranean Sea and the Atlantic Ocean are the major sources in winter for the southern and northern slopes of the Alps, respectively, soil moisture content is predominant in summer.** Hence, Vb-cyclones show all the prerequisites needed to trigger high-impact weather events."

Furthermore, we will include a paragraph in the discussion part to point out that although our results are somewhat inconclusive, a set of sensitivity experiments on moisture sources carried out with a regional climate model is planned for future studies.

"But the problem should, in my opinion, be studied at more depth. For example, in a recent paper (5) the flooding event over central Europe of June 2013 is analysed in view of some dynamical processes like Rossby wave breaking (RWB) and warm conveyor belt (WCB)."

We agree and think this is an interesting point to analyse. At the moment we are elaborating a method to investigate such phenomenon and we plan to include the eventual results we obtain in the new version of the manuscript. Unfortunately we cannot develop more this answer due to the lack of time before the discussion is closed. Still, we would like to remark that this study focuses on the Vb-events climatology, rather than on the analysis of each case individually. It is very likely that this phenomenon is very case-dependent, and thus we are a bit sceptical about the scope of the conclusions we can draw with this analysis from a full set of independent storms.

"Also the speed of motion of cyclones can be relevant: for example, slow Mediterranean cyclones, having sufficient time to pump up water from the ocean can give rise to very intense precipitation (6,7)."

This is another interesting point that we will address in the new version of the manuscript. To figure out the relevance of the speed of Vb-cyclones on precipitation, we have regressed precipitation versus speed in all the Vb-events. Preliminary results indicate a slight but significant negative slope, hinting towards the result pointed out by the reviewer.

"However, in the present form, the paper is somewhat inconclusive"

By including the analyses proposed by the reviewer, we expect that we may overcome this drawback. Further, in the conclusion part we will point out more clearly how a deeper analysis is already planned for future studies using regional modelling. We would like to recall that the main focus in this paper is on a general characterisation of the climatology of Vb-cyclones. However, as there is a very high case-to-case variability, the somewhat inconclusive results are hardly avoidable.

Page 925, Line 9ff:
"Even though it is possible to find a reason for the high variability in Vb-cyclone triggered precipitation amounts, the exact triggering mechanism for precipitation cannot be found using the coarse resolution of ERA-Interim. This is especially true in the Alps where the coarse resolution is a strong limiting factor of ERA-Interim. As the Vb- cyclones are phenomena, which strongly depend on mountains, more insights could be gained using regional modelling. Dynamical downscaling will not only improve the spatial resolution, but also the temporal resolution. Such higher resolved

dataset will allow a closer look into thermodynamics, while an increased temporal resolution can provide additional information on dynamics (Muskulus and Jacob, 2005). **Planned sensitivity studies on SST over different locations and soil moisture in the regional model framework will allow to gain deeper insight on the moisture source and thus on thermodynamics in several single Vb-events. Furthermore, the fine resolution allows to distinguish the mechanisms that trigger a Vb-cyclone with and without meteorological impact. Additionally the regional model framework can simulate the diabatic heating processes and thus PV development or the presence of warm conveyor belts during the cyclones lifecycle.** Thus, future studies will consider the re-evaluation of the Vb-cyclone climatology based on high-regional downscaling products, as well as direct assessments of the evolution Vb-events through climate simulations.“

References

(1) Speranza A., 1975: “The formation of baric depressions near the Alps". Ann. Geoph., 28, 177-217.

(2) Speranza A, Buzzi A, Trevisan A, Malguzzi P (1985). A theory of deep cycloge- nesis in the lee of the Alps. Part I: modification of baroclinic instability by localized topography. J. Atmos. Sci. 42:1521–1535

(3) Buzzi A, Speranza A (1986). A theory of deep cyclogenesis in the lee of the Alps. Part II: Effects of finite topographic slope and height. J. Atmos. Sci., 43, 2826–2837.

(4) Sodemann H and Zubler E (2010). Seasonal and inter-annual variability of the moisture sources for Alpine precipitation during 1995– 2002, Int. J. Climatol., 30, 947– 961.

(5) Grams CM, Binder H, Pfahl S, Piaget N, Wernl H (2014). Atmospheric processes triggering the central European floods in June 2013, Nat. Hazards Earth Syst. Sci., 14, 1691–1702.

(6) Searching for resemblance between large-scale sea level pressure patterns leading to “intense” precipitation events over Italy (2009) N Tartaglione, M Maugeri, F Dalan, M Brunetti, T Nanni, A Speranza Theoretical and Applied Climatology 95 (1-2), 183-196

(7) The mobility of Atlantic baric depressions leading to intense precipitation over Italy: a preliminary statistical analysis (2006) N Tartaglione, A Speranza, F Dalan, T Nanni, M Brunetti, M Maugeri Natural Hazards and Earth System Science 6 (3), 451-458

Neu, U., M. G. Akperov, N. Bellenbaum, R. Benestad, R. Blender, R. Caballero, A. Cocozza, H. F. Dacre, Y. Feng, K. Fraedrich, J. Grieger, S. Gulev, J. Hanley, T. Hewson, M. Inatsu, K. Keay, S. F. Kew, I. Kindem, G. C. Leckebusch, M. L. R. Liberato, P. Lionello, I. I. Mokhov, J. G. Pinto, C. C. Raible, M. Reale, I. Rudeva, M. Schuster, I. Simmonds, M. Sinclair, M. Sprenger, N. D. Tilinina, I. F. Trigo, S. Ulbrich, U. Ulbrich, X. L. Wang, H. Wernli, (2013). IMILAST: A community effort to intercompare extratropical cyclone detection and tracking algorithms: assessing method-related uncertainties. *Bulletin of the American Meteorological Society, 94*, 529-547.

Raible, C. C., P. Della-Marta, C. Schwierz, H. Wernli, R. Blender, (2008). Northern Hemisphere extratropical cyclones: A comparison of detection and tracking methods and different reanalyses. *Monthly Weather Review, 136/3***, 880-897.**