We thank all the reviewers for the constructive comments.
All the major changes to the manuscript were marked in yellow.

Answers to Geoff Pegram

We thank Geoff Pegram for reviewing the manuscript and for the positive feedback.

Indeed, an exponential auto-correlation function (ACF) has an analytical integral which does not require the numerical integration using the Simpson's rule. It must be mentioned that we performed additional analyses with auto-regressive processes of order 2 (not presented in the paper) and also had in mind to use the Simpson's rule to integrate ACFs that are not necessarily exponential, for example derived by direct comparison of forecasts and observations at all lead times (without extrapolating the whole ACF using only the lag1 auto-correlation as it was done in our study). We included in the revised version of the paper that this particular ACF can be analytically integrated.

The idea of using a moving window approach for the online update of the mean and the variance is very interesting and will be included as a comment in the conclusion of the paper. It may not be so necessary for the temporal update of statistics pixel-by-pixel, for which it takes a long time before having enough samples. However, it is much more pertinent if the auto-regressive parameters are derived by integrating over the number of pixels within an image and need to be updated in real-time to adapt to the temporal transitions between stratiform and convective rain. These thoughts were also integrated in the manuscript.

Answers to Evan Ruzanski

We thank Evan Ruzanski for the constructive comments and for the extended discussion on the predictability of precipitation.

Answers to the review comments:

1. We specified in the title, abstract and introduction that we are talking about the predictability from composite radar images (by Lagrangian persistence).

2. There is no particular physical motivation for using rainfall rates in decibel scale (dBR) instead of the original reflectivity (dBZ). From a statistical viewpoint it is important that the field is lognormally distributed before applying the cascade decomposition. In our experience the decibel scale of rainfall rates is slightly closer to a lognormal distribution than the decibel scale of reflectivity measurements (as it was done in the original version of the Short Term Ensemble Prediction System). We do not expect the predictability estimates to be strongly affected by such choice since we do not use rain gauge measurements in the verification process. Decomposed fields of dBR are advected forward by 10 minutes and compared with decomposed fields of dBR. Similar results are expected if comparing decomposed fields of reflectivity (dBZ) if compared with decomposed fields of dBZ.
Unfortunately there are no operational radars in Australia that use the dual-polarization technology and we have to rely on the accuracy that can be obtained with single-polarization radars together with a well calibrated operational quantitative precipitation estimation system.

3. The analysis of the spatial distribution of the precipitation predictability also reveals the issue of edge effects, with lifetimes getting shorter when moving away from the center of the domain. The goal of the paper was exactly to analyze such spatial heterogeneities, which can be due to atmospheric processes, radar uncertainties and edge effects. The interesting exercise is to understand where these patterns carry a clean atmospheric signal. All studies based on radar observations have to deal with these issues when drawing interpretations and conclusions.

4. The sentence was rephrased to account for the study cited and only focus on the fact that the lifetimes and spatial scales cannot be directly compared. Please refer to the answer of question 1 in the Discussion comments below.

5. We are not questioning X-band radars in terms of Quantitative Precipitation Estimation or Very-Short Term Forecasting, but only the ability to measure the Lagrangian auto-correlation at such small scales. The paragraph was rewritten accordingly.

Answers to the discussion comments:

1. Indeed, the predictability is dependent upon a forecasting model and dataset used. In the paper we study the predictability by Lagrangian persistence (forecasting model) of composite radar images (dataset). All predictability studies will be relative to a given forecasting model and affected by the type of data assimilated within the model and/or used for verification.
The comparison of lifetimes with the study of Ruzanski and Chandrasekar (2012) was rephrased. The difference relies in the definition of scale. In our approach the rainfall features of a given scales are isolated in Fourier domain by a Gaussian filter centered on that scale (which removes the contribution of all scales above and below it). In our understanding, Ruzanski and Chandrasekar (2012) use a different definition of scale. In fact, the scale-dependence is studied by upscaling the rainfall fields to coarser resolutions. This is what we meant when we stated that the values are not directly comparable.

2. In section 2 of the manuscript we provided a summary of the quantitative precipitation estimation system that is operationally used at the Australian Bureau of Meteorology. This should give enough details and references to the techniques that are used to reduce the uncertainty in radar rainfall measurement. The accurate characterization of each source of uncertainty goes beyond the topic of this paper. As already mentioned, all predictability studies are relative to a forecasting method and dataset used, which includes the various model and observation uncertainties that may affect the interpretations.

3. Of course, the predictability study presented in our paper can be generalized further by using other data sources which optimally combine radar, satellite and rain gauges. However, different data sources will have different error structures, which will lead to a very complex error structure of the combined product. It could be very hard to understand the origin of the spatial heterogeneity of the predictability of precipitation of such combined product, in particular when trying to separate the contribution of the different data sources. In Section 4.1 we mentioned the possibility to use precipitation fields calculated by NWP models to eliminate the heterogeneities introduced by the inhomogeneous quality of radar measurements. This could be a good starting point for further research.

4. In Section 4.2 we compared the predictability estimates of the Fourier-based decomposition approach proposed in our paper with the wavelet-based decomposition of Germann et al. (2006) at similar spatial scales. Both methods gave comparable results although using different ways to decompose the rainfall field. When interpreting the spatial distribution of predictability we tried to carefully analyse the possible sources of uncertainty to avoid giving misleading statements. We are currently working on the quantification of radar measurement uncertainty, which may help in the comparison of predicted and observed fields.

5. The definition of predictability you give is interesting and it should also depend on the particular verification score used. Other predictability estimates than the lifetime can be employed

to account for phase or timing errors in precipitation forecasts, e. g. the fractions skill score and neighborhood verification approaches. This is particularly important for medium range NWP forecasts, which are known to suffer from timing and location errors. In the nowcasting range it is probably less of an issue since the model is only an extrapolation which is not designed to initiate, grow and dissipate rain in a dynamical way.

References:
- *Germann U, Zawadzki I, and Turner B (2006) Scale-dependence of the predictability of precipitation from continental radar images, Part IV: Limits to prediction, J. Atmos. Sci., 63, 2092–2108.*
- *Ruzanski E, and Chandrasekar V. (2012) An investigation of the short-term predictability of precipitation using high-resolution composite radar observations. J. Appl. Meteorol. Climatol., 51, 912-925.*

Answers to Hidde Leijnse

We thank Hidde Leijnse for the feedback. The detailed answers are provided below.

Answer 1. The lower accuracy of the radar measurements in the inner Victorian Alps is likely to affect the optical flow estimates. In particular, the blockage of radar beams, the rainfall attenuation and overshooting can affect the optical flow in a way that it reduces the Lagrangian correlation estimates (and consequently the lifetimes). In addition, it seems that there is a proportional effect between the precipitation lifetime and the climatological precipitation amount: lower is the amount lower is the lifetime (see e.g. Berenguer and Sempere-Torres, 2013). These additional interpretations were added to the manuscript.

Answer 2. Thanks for the remark. Both the C- and S- band radars of Yarrawonga and Melbourne have a 1 degree azimuth and 250 m range resolution (see for instance Rennie, 2012). Despite having the same nominal resolution, the rainfall field exhibits more power in the last cascade level in the sourroundings of the Melbourne radar, which can explain the lower spectral exponent beta2 (Figure 4b). However, the patterns observed in Figure 4b seem to be more connected to the type of radar rather than a different rainfall behaviour. We still cannot explain which component of the radar data processing chain provokes this effect. The text was modified to include these additional thoughts.

Answer 3. Of course, at these temporal scales the radar measurement uncertainty will be much more relevant than the very-short predictability obtained by a nowcasting system. The goal of the discussion was exactly to show that increasing the radar resolution does not necessarily lead to significant improvements in nowcasting, in particular if the lifetime is close to the temporal resolution of the radar. Very-high resolution nowcasts are computationally demanding and it is worth questioning whether the downstream hydrological applications are able to take advantage of such high resolution and very-short predictability. These observations motivate the further development of ensemble quantitative precipitation estimation systems and their combination with ensemble nowcasting systems, in particular because the measurement uncertainty is an important fraction of the nowcast errors up to one hour lead time. We added this last sentence to the manuscript with a reference.

Answer 4. From a previous paper (Foresti and Seed, 2014) we had the feeling that the forecast biases are easier to study if the topographic barrier is radially oriented with respect to the radar. This reduces the impact of range dependent radar biases when studying the spatial distribution of forecast biases. In fact, the windward and leeward sides of the topographic barrier would be located at the same range from the radar. However, it is much harder to draw these conclusions by observing the fields of precipitation lifetime and this interpretation was removed from the manuscript.

References:

- *Berenguer M, and Sempere-Torres D (2013) Radar-based rainfall nowcasting at European scale: long-term evaluation and performance assessment, in: Proc. of the 36th AMS Conf. on Radar Meteorology, Breckenridge, Colorado, USA.*
- *Foresti L, and Seed A (2014) On the spatial distribution of rainfall nowcasting errors due to orographic forcing, Meteorol. Appl., doi:10.1002/met.1440*
- *Rennie, SJ (2012) Doppler weather radar in Australia. CAWCR technical report, no. 055.*