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Nonlinear Processes in Geophysics Discussions
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Interactive comment on "Seasonal predictability of the winter precipitation over Iberian Peninsula and its relationship with finite-time Lyapunov exponents" *by* Daniel Garaboa-Paz et al.

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We would like to thank the Referee for his/her valuable comments and critics that we tried to take into account in the revised version of the manuscript. Hopefully, all the major and minor corrections pointed out by the reviewer have been corrected now. A detailed answer follows below. We provide replies to the reviewer' comments in bold. As well, corrections included in the manuscript are marked in red.

Answer to Referee 2

First, the title refers to "seasonal predictability" of winter precipitation, as opposed to "seasonal prediction". This might be a subtle difference, but the readership of Non-

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linear Processes in Geophysics might wish to distinguish between both aspects. The problem is that I did not really find the "seasonal predictability" (as a nonlinear dynamic characteristic) of the winter precipitation records being quantified (rather, one could argue that the FTLE fields discussed provide a means to quantify the spatio-temporally local predictability of atmospheric flow). I am not convinced that at the considered level of seasonal aggregates, it is even possible to quantify the predictability of seasonal precipitation sums, given the available time span of observations. I also did not find the aspect of "prediction" being specifically addressed at all (which would essentially mean building a regression(?) model for seasonal precipitation sums based on covariates identified by the performed correlation analysis.

We agree with the reviewer, may be the title of the paper is not clear. In this paper, we do not intend to construct a prediction model of winter precipitation based on FTLEs. Our goal is to analyze the potential of FTLEs to see the possibility of considering them as a seasonal prediction tool. So, in order to avoid misunderstandings, we prefer to change the title of the manuscript,

Influence of Finite-time Lyapunov exponents on winter precipitation over Iberian Peninsula

Second, it is appreciated that the authors use dynamical characteristics of the atmospheric circulation to establish a kind of "climatology" in terms of statistical relationships with teleconnection indices. This is most valuable for obtaining a process-based understanding of the observations made. However, it is not clear to me at all why the authors define their four seasons as "JFM", "AMJ", "JAS" and "OND" instead of using the classical - and climatologically well motivated - definitions "DJF", "MAM", "JJA" and "SON". The problem is that when using the terms "summer" and "winter" in the paper, the corresponding definitions do not match what is usually understood by climatologists when using these terms. This makes it hard to establish clear relationships between the findings of the present paper and those of previous works. I strongly recommend revising the results by sticking to the established definitions of seasons.

To our viewpoint there is not a standard definition of seasons. It depends on the scope of the study. Moreover, there exists a large amount of literature where the seasonal periods are defined as we did. Some examples where winter is assimilated to (JFM) are,

- Gastineau G. D'Andrea F. Frankignoul C. (2013) Atmospheric response to the North Atlantic Ocean variability on seasonal to decadal time scales. Clim Dyn (2013) 40:2311–2330 DOI 10.1007/s00382-012-1333-0 - Picado A, Alvarez I, Vaz N, Varela R, Gómez-Gesteira M, Dias JM. 2014. Assessment of chlorophyll variability along the northwestern coast of Iberian Peninsula. J. Sea Res. 93: 2–11, doi: 10.1016/j.seares.2014.01.008. - Bamzai A. S. (2003) Relationship between snow cover variability and Arctic oscillation index on a hierarchy of time scales Int. J. Climatol. 23: 131–142 (2003) doi: 10.1002/joc.854

Third, I recommend giving precise definitions/explanations of how the different types of anomalies used in the paper are calculated. In some cases, this is not obvious from the text and makes evaluating the obtained results quite hard.

We agree with the reviewer, so we add some explanations at the end of the Methods section 2.1. Thanks to point us this.

Seasonal composites (averages) of the anomalies (mean - total mean) of SST, geopotential height and wind speed were obtained from the page (https://www.esrl.noaa.gov/psd/cgi-bin/data/composites) for the period 1979-2008. Total mean makes reference to the climatological mean in this case 1981-2010.

Then, two time series (positive and negative phases) of these seasonal composites were calculated for years with positive/negative summer FTLE anomalies. Finally, Figs.(3-5) show the time-averaged mean of both phases.

Fourth, atmospheric circulation is highly dynamic and involves a multiplicity (actually, a continuum) of spatial and temporal scales. I think that it can be justified to restrict the attention within the present work to a single atmospheric layer (850 hPa pressure level) and a constant integration time (5 days; this information should be given in the main text instead of a figure caption), but the motivation of both specific choices should be made transparent. I wonder how much the obtained FTLE fields and established statistical relations may depend on the pressure level at which the tracers are initiated.

We agree with the referee with this insight. We move the information given in the caption to the main text and add some details to clarify this description.

We want to focus on the troposphere, but at the same time we wanted to avoid the atmospheric events close to the surface within the PBL. We are interested in the large-scale tropospheric mixing. To that end, we start the advection at the intermediate level of 850hPa so the observed coherent structures are not perturbed by turbulence effects coming from the PBL.

With respect to the integration time, five days is about the mean length of the typical synoptic time scale in mid-latitudes. For larger time scales, observed coherent structures are smeared out, while for smaller tau values those structures are not well shaped, and multiple patterns arise.

Moreover, how much can we actually learn from time-averaged FTLEs given that Lagrangian coherent structures (LCS), hyperbolic trajectories and related objects embedded in the atmospheric flow are not stationary over the seasonal time scales considered in this work?

Lagrangian coherent structures correspond to flow regions where mixing is larger than the average for a period of tau days. The activity, intensity and presence of these coherent structures in the atmosphere are highly influenced by the atmospheric flow. Their position and shape evolves with time as the flow does. The evolution rate depends on how fast the flow changes as it happens with the rest of atmospheric structures. The FTLE have been widely used in oceanography and meteorology to describe transport phenomena. In our opinion, trying to understand the atmospheric dynamics over the seasonal time scales with the FTLE is equivalent to do it with the SST, SLP, etc. The FTLE describe the amount of large-scale tropospheric mixing available to perturb the SST.

I am willing to accept that the seasonally averaged FTLE fields still provide useful and interpretable information, but what is beyond the mean? For example, does the variance of FTLEs show similar and possibly relevant spatio-temporal patterns? I think that what the authors present is an interesting starting point, but much more could (and should) be done in this regard.

This is an interesting question and we acknowledge the reviewer to point us this idea.

As a first approach, and in a different context, we have performed some simulations to study the variability of the FTLE in terms of the intra-annual (standard deviation of the monthly means for the whole period) and inter-annual (standard deviation of the annual means) variabilities (see pictures below).

These results highlight El Niño Southern Oscillation, the storm track or the Intertropical Convergence Zone among other large-scale structures.

A time-series consisting of the variance of the FTLEs within the region studied in this manuscript, or the intra or inter-season variabilities of the FTLE could also be used to correlate them with the winter precipitation. However, in our opinion we believe that this study deserves further work and it is beyond the scope of this manuscript.

Finally, the authors just report a relationship between summer mixing and winter precipitation, but I do not find information describing a corresponding physical linkage connecting both seasons. At least some speculations about corresponding mechanisms should be given.

In the Introduction of our manuscript several references were given to previous works that established a possible link between the Iberian precipitation and other variables like summer Sea Surface Temperature (SST) anomalies over the north Atlantic basin

(Rodríguez-Fonseca and deCastro, 2002; Lorenzo et al., 2010; Hatzaki et al., 2015), other teleconnection patterns (deCastro et al., 2006; Casanueva et al., 2014) or the Euroasian snow cover in autumn (Brands et al., 2014).

Concerning the mechanisms linking the atmospheric variability with precipitation, we believe that it happens via changes in the SST. The interaction between the ocean and atmosphere is complex. Heat and momentum flux at the interface modify currents and winds near the surface. Cayan showed that vast regions of the middle-latitude ocean surface temperature variability are forced by the atmospheric variations. He showed a strong dependence between heat flux, SST anomalies and the SLP modes on spatial scales that often span major portions of the North Atlantic. The heat flux anomalies, derived from bulk formulations, exhibit large-scale patterns of variability which are related to patterns of sea level pressure (SLP) variability and also to patterns of SST anomalies. In our case, we showed that FTLE anomalies also correspond to patterns of SST and SLP variability. In our opinion, large-scale tropospheric mixing drives summer SST anomalies that lead to changes in the next seasons storm tracks, and consequently changes in the location of action centers (low and high pressures centers).

- Cayan, D.R. Latent and sensible heat flux anomalies over the northern oceans: Driving the sea surface temperature. J. of Phys. Ocean. 22, 859-881, 1992.

Specific comments:

p.1, l.3: Teleconnection patterns and severe weather (events) have not just evolved during the last years, but are constantly changing.

We have modified the Abstract.

When working with wind data, please specific if you consider just the wind speed or the full vector field.

Yes, you are right. We have modified the text. We used the scalar Wind Speed.

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p.3, l.10: "the significance of this coefficient was assessed to be greater than 95%" is a quite awkward formulation

We agree with the reviewer. We have modified the text at the end of Section 2.1 as, The Pearson correlation coefficient and the Student's t test were used to identify the statistical significance of the correlations between the anomalies of the FTLE and precipitation.

p.4, l.19: What do you mean by "lead-lag correlation"?

Lead-lag correlation, describes the situation where one (leading) variable cross-correlated with the values of another (lagging) variable. But, probably you are right and we do not use the correct term, so we changed it to "lag correlation".

p.4, l.20: What is the "North Atlantic East Ocean"?

We have modified the manuscript in page 4 at the end of the Methods Section as follow, FTLE anomalies were calculated from the FTLE median for the area between 30°W and 0°W and between 25°N and 65°N for the period 1979-2008.

Later on, within the Results section,

Figure 2 shows the lag correlation between winter (JFM) precipitation in Iberian Peninsula and the anomalies of the FTLE for three different seasons through the period 1979-2008.

And,

The summer FTLE time series that show the higher correlation values with the winter precipitation cover approximately the area between 30°W and 0°W and between 25°N and 65°N. The size of the area chosen to correlate with the precipitation was varied within the North Atlantic Ocean without modifying significantly the results shown here.

p.5, l.1: What is the "IPNA region"?

We agree with the reviewer, IPNA was not defined in the text. IPNA (Iberian Peninsula North Atlantic).

p.5, l.33 and below: Please be specific in whether correlations are positive or negative.

We agree with the reviewer, and the text has been modified including the signs (+) or (-) to account for positive or negative anomalies.

Tab. 1: use capital letters for indicating calendar months

Modified.

p.6, l.9: SCA is not the third leading mode of WINTER SLP variability, but can be computed for all seasons (as every teleconnection index).

You are right, we have modified the text. The Scandinavia pattern (SCAND) consists of a primary circulation center over Scandinavia, with weaker centers of opposite sign over western Europe and eastern Russia/ western Mongolia. The Scandinavia pattern has been previously referred to as the Eurasia-1 pattern by Barnston and Livezey (1987). and other studies also show its influence on the Iberian Peninsula precipitation (deCastro et al., 2006; Casanueva et al., 2014).

In addition, the English could be further polished here and there, especially regarding the proper use of articles and (in just a few cases) the consistency of tenses.

We thank the Referee to point us this problem. We have revised the paper and hopefully the English style has been improved.

Please also note the supplement to this comment:
http://www.nonlin-processes-geophys-discuss.net/npg-2016-79/npg-2016-79-AC2-supplement.pdf

Interactive comment on Nonlin. Processes Geophys. Discuss., doi:10.5194/npg-2016-79, 2016.

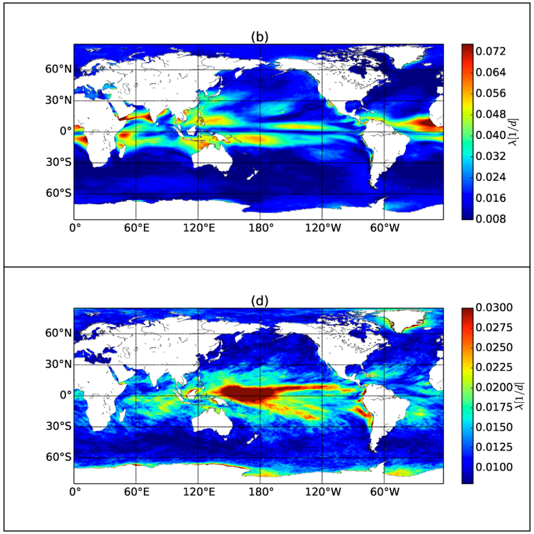

Fig. 1. Examples of FTLE intra and inter-annual variabilities

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