A climatology of finite-time Lyapunov exponents

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The finite-time Lyapunov exponents (FTLE) time series at 850 hPa level has been computed over a climate period of 35 years using wind fields retrieved from ERA-Interim reanalysis data, Fig. 1. The FTLE provide information on areas where the dispersion (integration forward in time) or the convergence (backward) is large and allow classification of airstreams. The statistics over these Lagrangian quantities have shown the link between the climate system and the regional transport structures in terms of atmospheric mixing.

This study, one of the first to present a 35 year of large-scale atmospheric mixing, shows mean values, and intra-annual and inter-annual variability of the FTLE. To show the mixing effects more clearly, forward and backward in time FTLE fields were obtained. Mean Lyapunov exponents show a zonal localization; large values in the mid-latitudes for both hemispheres, while the lowest FTLE values were observed inter tropics. Especially in the tropics and Equator, mixing is strongly modulated by ENSO, while for mid-latitudes, large-scale mixing is associated to the interface between westerly extratropical circulation and Hadley cells. The meridional displacement of the ITCZ has also been well reproduced by the intra-annual backward FTLE field. Seasonal effects and ENSO are the largest effects that contribute to large-scale mixing variability over the globe.

The mean FTLE field was correlated to the Eady baroclinic growth rate. It was found that the best correlation is obtained for an integration time of $\tau = 5$ days, which is in agreement with the typical synoptic time scale in mid-latitudes. For larger time scales, structures observed in the intra-annual and inter-annual variability fields are smeared out, while for smaller τ values those structures are not well shaped, and multiple patterns arise. This suggests that baroclinicity, among other possible causes, drives large-scale atmospheric mixing on time scales longer than a few days.

As an example of air masses transport, we focused on the impact of atmospheric rivers (ARs) on mixing in the Atlantic Ocean. The advection of moisture by ARs is a key process for the Earth's sensible and latent heat redistribution and has a strong impact on the water cycle of the mid-latitudes. In a previous work we found that these structures can be well described in terms of the FTLE [1]. Here, we find that the impact of mixing in the Sahara-Morocco region is more important than for the British Isles. Although less ARs and low precipitation rates are observed in the Sahara-Morocco if compared to UK-Ireland, rain probability during ARs events and mixing are larger for the former than for the latter region. Our results suggest that atmospheric mixing, as shown in terms of large FTLE values, correlate well with baroclinic instability and could be used to forecast precipitation events in those regions where the persistence of coherent transport structures has a great impact [2].

The connection between winter precipitation over the Iberian Peninsula and the finite-time Lyapunov exponents (FTLE) calculated over the eastern Atlantic ocean has also been investigated. A significant negative correlation was observed between the summer FTLE anomalies and winter precipitation over the western Iberian Peninsula. The conclusions suggest the possibility of predicting the occurrence of rainy winters using these exponents several months in advance [3].

Summer anomalies of the FTLE have also been related to other circulation and temperature patterns as SST, SLP or the geopotential. In all cases, negative summer FTLE anomalies correspond to well known patterns of precipitation over western Iberian Peninsula. Low values of tropospheric mixing (negative FTLE anomalies) during summer correspond to positive SST anomalies and highs blocking the passage of fronts over the western Europe. However, wind, SLP and geopotential anomalies during next winter show the opposite relationship as lows may reach the Iberian Peninsula, in agreement with the negative correlation observed between summer FTLE and winter precipitation. Finally, the relationship with some teleconnection patterns of the Northern Hemisphere was shown. Once more, summer FTLE anomalies correlate with summer and next autumn EA indices which influence on winter rainfall patterns of the Iberian Peninsula.

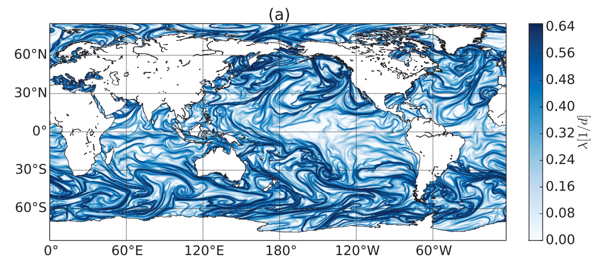

Figure 1: Backward finite-time Lyapunov exponents for the 1979-2014 period for one day.

[1] D. Garaboa-Paz, J. Eiras-Barca, F. Huhn, and V. Pérez-Muñuzuri, Chaos **25**, 063105 (2015).

[2] D. Garaboa-Paz, J. Eiras-Barca, and V. Pérez-Muñuzuri, Submmitted Earth Sys. Dyn. (2017).

[3] D. Garaboa-Paz, M.N. Lorenzo, and V. Pérez-Muñuzuri, Submmitted Nonlin. Proc. Geophys. (2017).