Atmospheric circulation errors in the CMCC-SPSv3 model: climate drift dynamics and impact on seasonal forecasts

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Abstract

Any general circulation model suffer from climate drift, a problem which is ultimately due to errors in the models themselves. Climate drift consists on the fact that, starting from realistic initial conditions, the model integration asymptotically drifts to a mean state (the model's own climate) that is different from the observed one. That is, the model has a tendency to produce biased forecasts, which limits their usefulness. Characterize climate drift dynamics and the resulting biases is very important in order to identify the model errors determining the drift. The aim of this work is to study the climate drift and biases of the CMCC-SPSv3 prediction system, a fully-coupled climate model developed at Centro EuroMediterraneo sui Cambiamenti Climatici (CMCC), currently used in operational mode to produce global seasonal forecasts [Sanna et al., 2017]. Here we present some preliminary results focused on Northern Hemisphere mid-latitude atmospheric dynamics during winter. Compared to Era Interim data, the simulated Northern Hemisphere westerly jet is too strong over Eurasia and Pacific Ocean; the latitudinal distribution of the daily maximum wind speed is too narrow, missing the trimodality found in reanalysis over North Atlantic. Many features of the lead-1 season zonal wind bias are evident after 5 days, suggesting that these errors could be due to the misrepresentation of some "fast physics" process. Moreover, the model underestimate the frequency of occurrence of Euro-Atlantic blocking. It is shown that, in this sector, a large portion of the total error on the 850 hPa zonal wind is due to an erroneous representation of blocking events.

Methods and Results

The result we present here are obtained comparing 24 years of model's hindcasts, initialized on the 1st of November in a 40-members ensemble mode from 1993 to 2016, with Era Interim reanalysis [Dee et al. 2011] for the same period.
The the lead-1 season (DJF) ensemble mean zonal wind at 850 mb (u850) shows the larger biases over Eurasia and North Pacific Ocean (**Fig. 1**). On the Atlantic sector, this bias is results from a too strong simulated westerly jet. The jet extends too much over the European Continent and the velocity maximum is located too far east. On the Pacific sector, the simulated westerly jet is too strong and is located equatorward with respect to reanalysis. This interpretation is confirmed by the Jet Latitude Index [Woollings et al. 2010], defined as the latitude where the maximum of the sector-mean zonal wind occurs on each day. In the Atlantic sector (**Fig. 2**) the model clearly fails in reproducing the trimodal distribution found in observations, and also in the Pacific sector (not shown) the simulated distribution is too narrow and shifted equatorward.

The vertical cross-section of zonal-mean zonal wind in DJF (**Fig. 3, upper panel**) corroborate the previous findings, showing too strong zonal westerly jets in both hemispheres. Interestingly, the global structure of the zonal mean zonal wind errors in the first five days of forecast (that is, from 1st to 5th November) (**Fig. 3, lower panel**) is remarkably similar to the DJF bias, suggesting that some systematic errors can arise from "fast physics" processes, and thus that they can be diagnosed looking at the error evolution in the first forecast steps [Klinker and Sardeshmukh, 1992; Rodwell and Palmer, 2007].

Thereafter, the ability of CMCC-SPSv3 in reproducing atmospheric blocking is assessed. Due to its quasi-stationary nature, this phenomenon is often associated with anomalous meteorological conditions in mid-latitudes; therefore, a correct representation of blocking dynamics and statistics in numerical models is crucial, from short-range weather forecasts to climate predictions. Blocking events are detected using the two-dimensional index proposed by [Davini et al. 2012], based on the gradient reversal of the daily 500mb geopotential field originally proposed by [Tibaldi and Molteni, 1990]. Every event detected at a given point is defined as Istantaneous Blocking (IB); if a given point is blocked for 5 consecutive days, a Persistent Blocking (PB) is occurring. The two-dimensional Era Interim PB frequency for the Northern Hemisphere is shown in **Fig. 4 , left panel**, while the model frequency bias is shown in **Fig. 4, right panel**. In the Euro-Atlantic Sector, the most problematic region extends from southern Greenland to Scandinavia and British Isles.

In order study the mutual interaction between total systematic error and Euro-Atlantic PB bias, and the impact of the wrong representation of Euro-Atlantic PB on the quality of seasonal forecasts, we followed the strategy suggested by [Davini and D'Andrea, 2016], adapted to our case. First of all, we constructed composites of hemispheric daily fields on the occurrence of PB within the area 40W-40E;40N-75N, for both hindcasts and reanalysis. The sector is defined as blocked if PB is detected in at least one grid point inside it, non-blocked otherwise. The total systematic error on u850 can be mathematically decomposed into three terms: one indicating the part of the systematic error due to a bias in the frequency of blocking, one representing the error due to the wrong simulation of the difference between blocked and non-blocked states, and one due to the systematic error when blocking is not occurring:

$$u - \hat{u} = (f - \hat{f})(u_b - u_z) + \hat{f}[u_b - \hat{u}_b - (u_z - \hat{u}_z)] + (u_z - \hat{u}_z)$$

where u_b and u_z denotes the average model u850 field when blocking is occurring or not occurring, and f is the simulated blocking frequency. The hat denotes Era Interim. The three components of the total u850 error are show in **Fig. 5**: over North Atlantic ocean and Western Europe, a considerable portion of the zonal wind error is associated to blocking.

Fig. 1

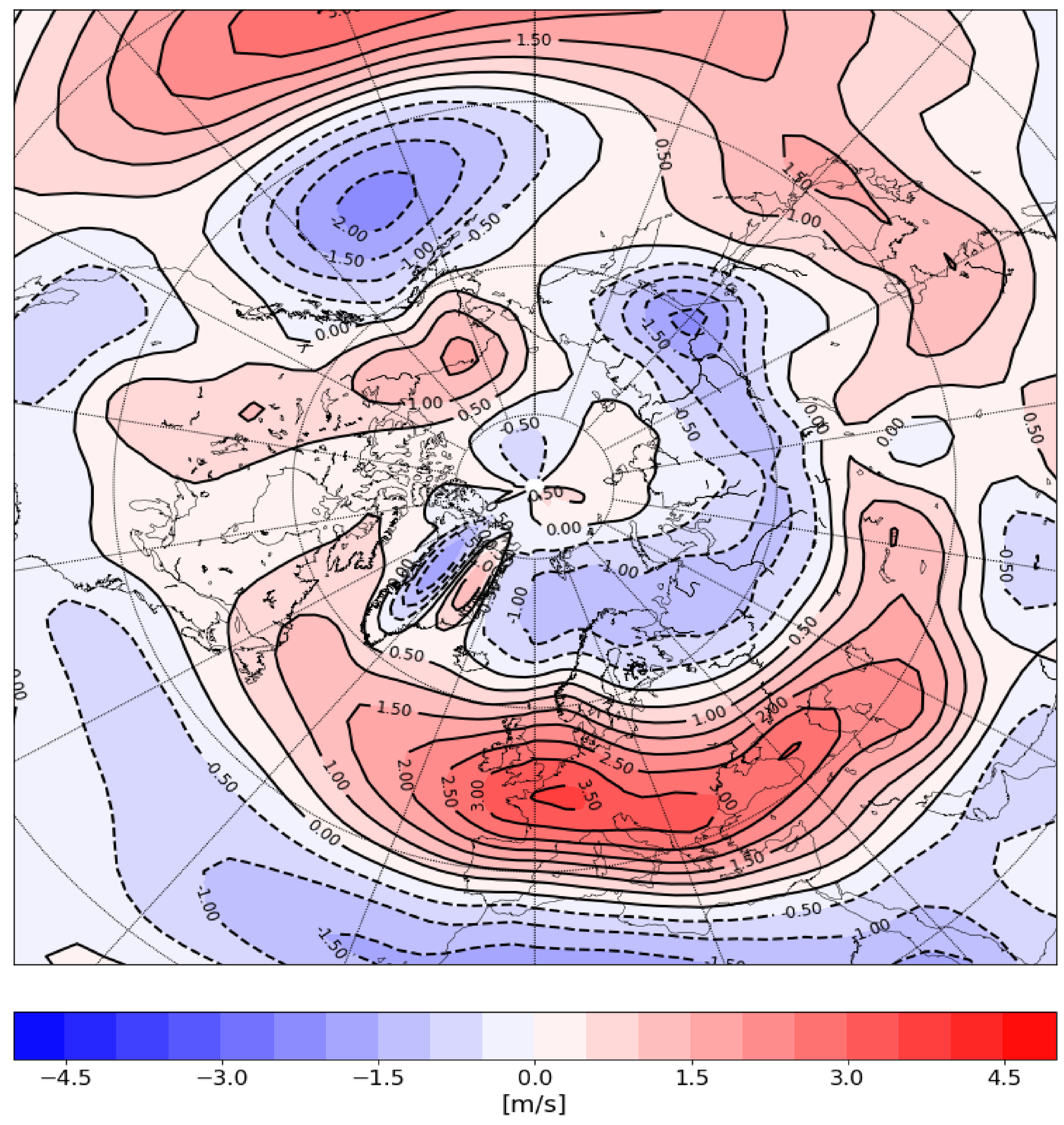


Fig. 2

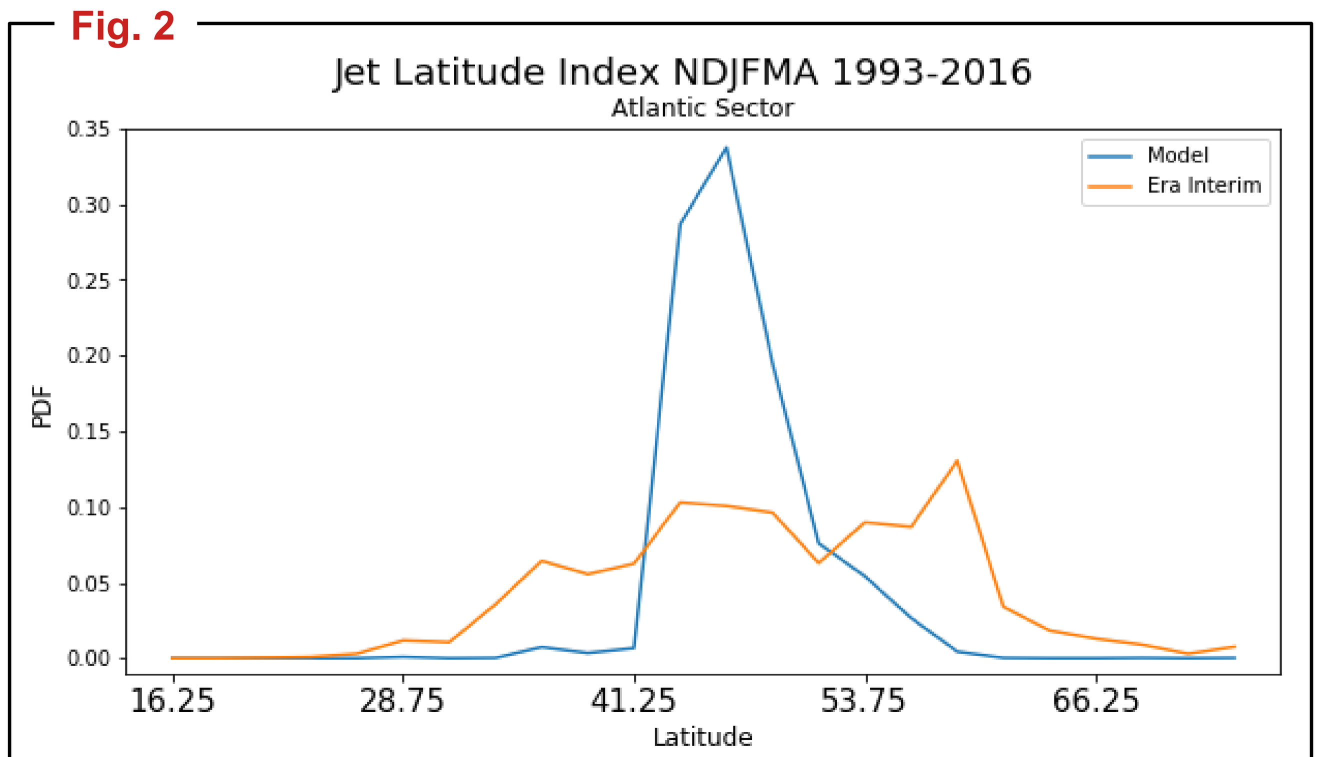


Fig. 4

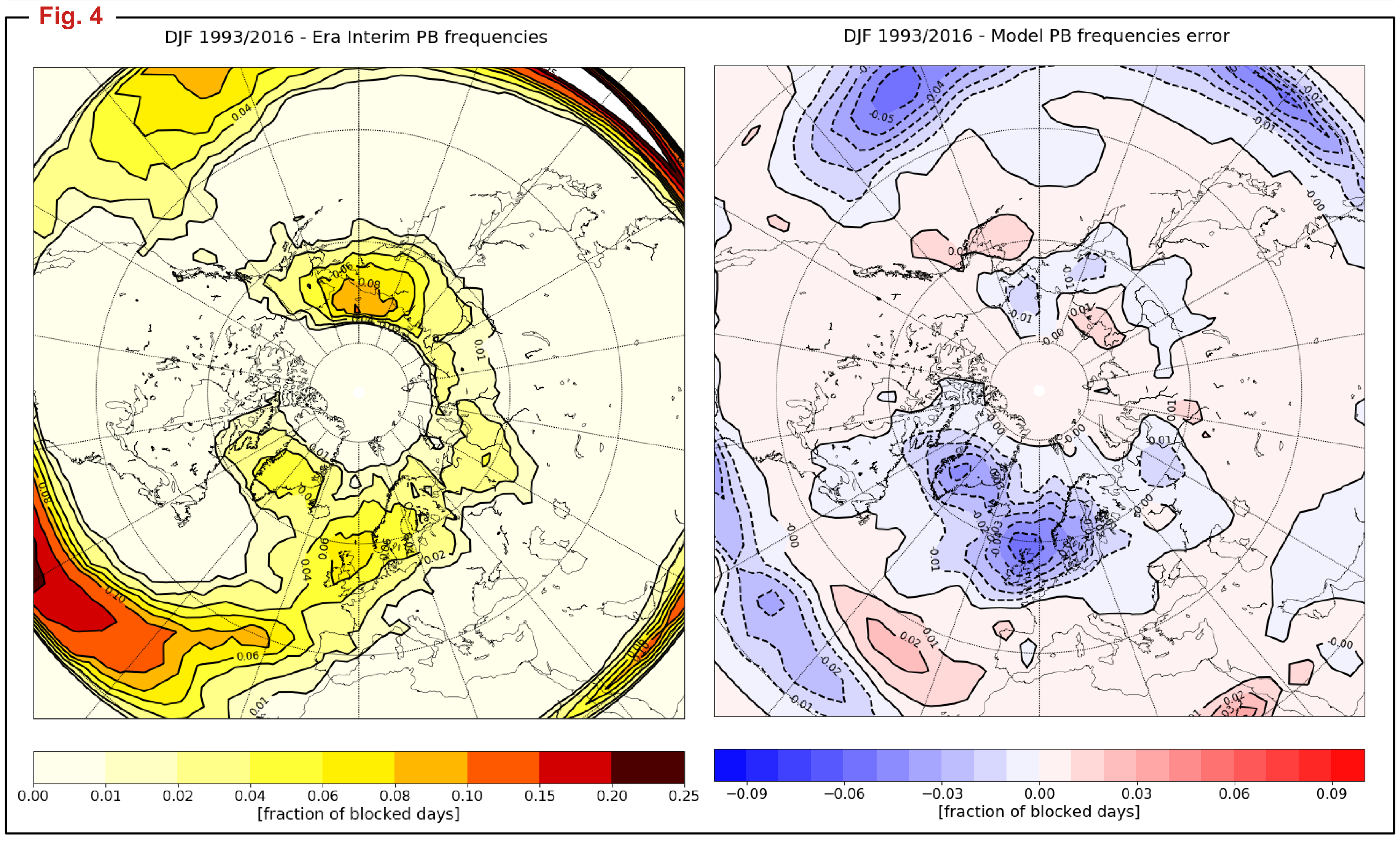


Fig. 3

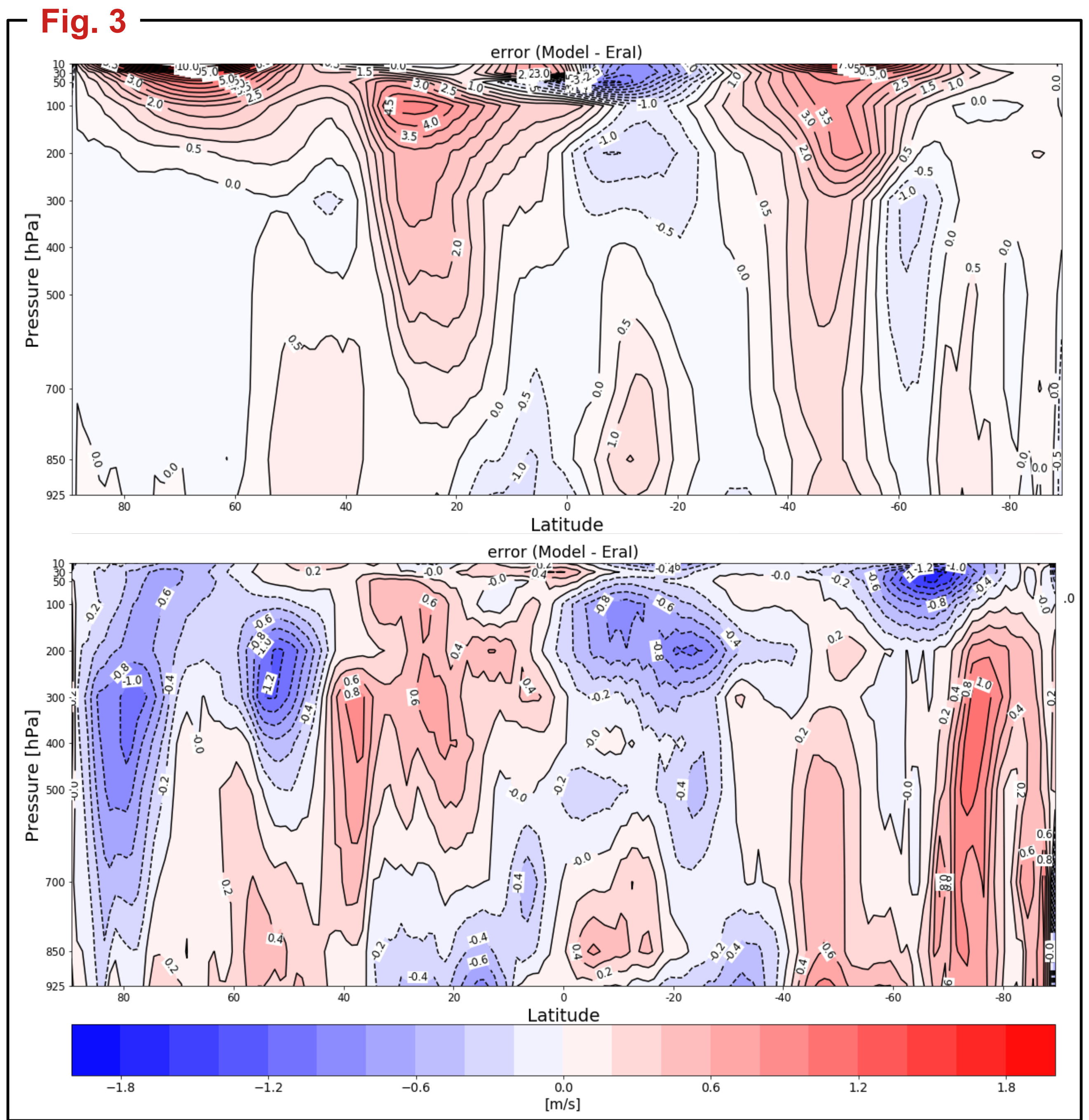
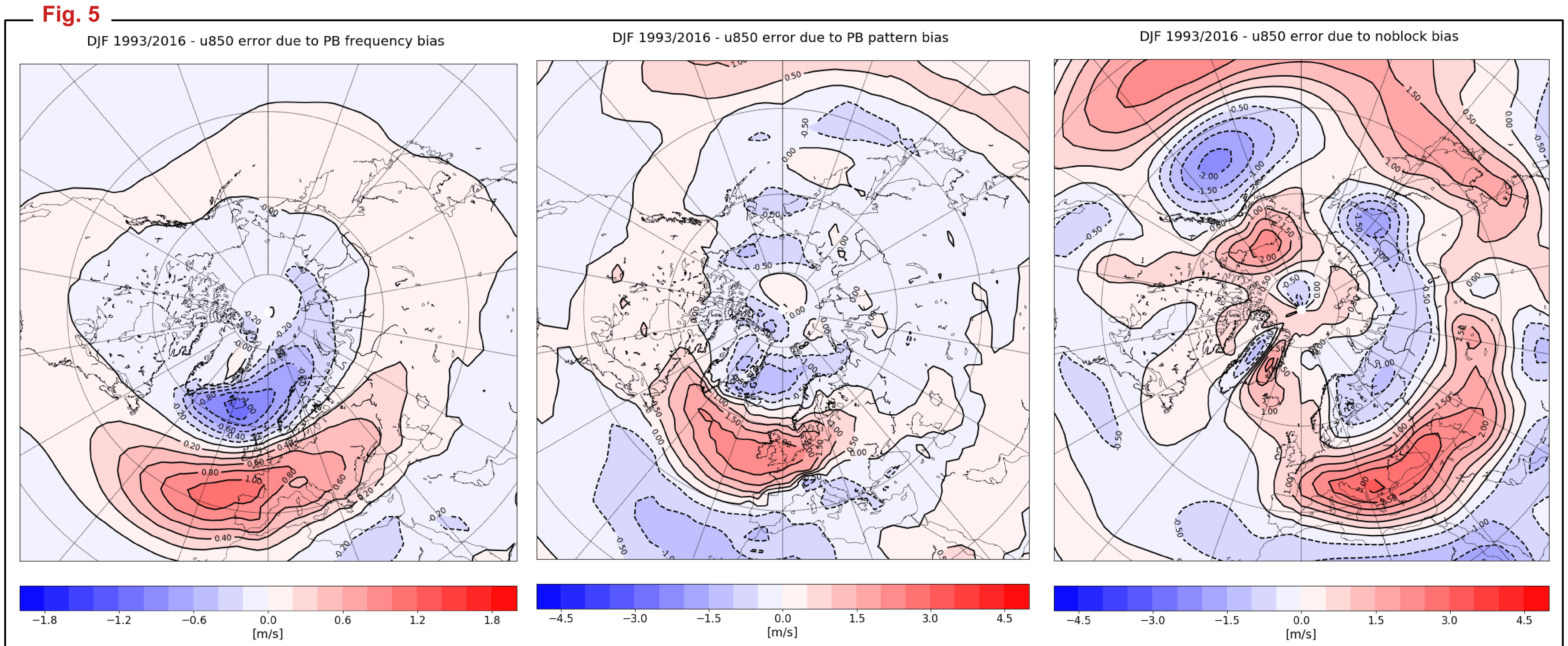


Fig. 5



Conclusions ad future work

In this work we presented some of the features of the atmospheric circulation errors affecting the CMCSC-SPSv3 seasonal prediction system. The model simulate a too strong Northern Hemisphere westerly jet. The jet is located equatorward with respect to reanalysis data in the North Pacific ocean, and its maximum is too fare east in the Atlantic Sector. Moreover, the latitudinal distribution is much narrower than what observations reveal. The frequency of Euro-Atlantic blocking events is underestimated; a consistent portion of the total 850 hPa zonal wind bias in this sector is due to the spatio-temporal misrepresentation of blocking events. The fact that the general feature of the lead-1 season zonal mean zonal wind error over the whole troposphere are present in the first-5-days mean bias suggests that some systematic errors can arise from "fast physics" processes.
We believe that a possible source of the circulation errors discussed above is the absence of the representation of the unresolved low-level drag in the atmospheric component of the CMCC-SPSv3 model. In fact, many recents works [Pithan et al, 2016; Sandu et al, 2016; van Nieker et al 2017] suggest that some of the common and long-standing deficiencies of state-of the-art climate models (too-zonal North Atlantic jet and storm track, equatorward North Pacific jet, less blocking events) may be alleviated improving low level drag parameterizations.

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