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Seasonal predictions of Fire Weather Index: Paving the way for their operational applicability in Mediterranean Europe

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Managers of wildfire-prone landscapes in the Euro-Mediterranean region would greatly benefit from fire weather predictions a few months in advance, and particularly from the reliable prediction of extreme fire seasons. However, in some cases model biases prevent from a direct application of these predictions in an operational context. Fire risk management requires precise knowledge of the likely consequences of climate on fire risk, and the interest for decision-makers is focused on multi-variable fire danger indices, calculated through the combination of different model output variables. In this paper we consider whether the skill in dynamical seasonal predictions of one of the most widely applied of such indices (the Canadian Fire Weather Index, FWI) is sufficient to inform management decisions, and we examine various methodological aspects regarding the calibration of model outputs prior to its verification and operational applicability. We find that there is significant skill in predicting above average summer FWI in parts of SE Europe at 1 month lead time, but poor skill elsewhere. These results are largely linked to the predictability of relative humidity. Moreover, practical recommendations are given for the use of empirical quantile mapping in probabilistic seasonal FWI forecasts. Furthermore, we show how researchers, fire managers and other stakeholders can take advantage of a new open-source climate service in order to undertake all the necessary steps for data download, post-processing, analysis and verification in a straightforward and fully reproducible manner.

Practical Implications

Wildfires represent a critical natural hazard in the Euro-Mediterranean (EU-MED) region (San-Miguel-Ayanz et al., 2013), causing considerable economic and environmental damages and loss of life. Estimating fire risk a few months in advance is therefore an urgent requirement, allowing fire protection agencies a timely reaction and an adequate provision of human and material resources.

Until the recent development of dynamical climate models, seasonal forecasts of fire activity relied on empirical-statistical techniques exploiting the lagged relationships between slowly-varying components of the climate system used as predictors, such as sea-surface temperatures (based on atmospheric teleconnections; Chu et al., 2002; Chen et al., 2011; Chen et al., 2016; Harris et al., 2014) or meteorological droughts (related to water content in the soils; Preisler and Westerling, 2007; Gudmundsson et al., 2014). There are also some local empirical prediction examples within the EU-MED region (see e.g. Turco et al., 2013; Marcos et al., 2015). Nevertheless, to date none of these studies, at least for the EU-MED region, has led to conclusive results on the operational applicability of seasonal forecasts, although all of them suggest a potential for their application. With this regard, recent advances in the modelling of the atmosphere–ocean coupled circulation have lead to the development of a new generation of

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numerical models (Global Climate Models, GCMs) producing predictions on a seasonal time horizon (Doblas-Reyes et al., 2013). In order to account for the various sources of uncertainty, a probabilistic approach based on the use of several predictions with slightly perturbed initial conditions is nowadays routinely applied, a technique known as *ensemble* prediction (Richardson, 2000; Palmer et al., 2004). The potential of such prediction systems to inform decision-makers in different economic sectors is huge, due to the provision of a large number of physically consistent variables at a sub-daily temporal scale from one to several months in advance, although their applicability is still hampered by the limited skill of such predictions in the extra-tropics (Palmer and Anderson, 1994; Manzanas et al., 2014) and the limits to accessibility and understanding by end-users (Hartmann et al., 2002; Lemos et al., 2012; Mason, 2008).

In order to ease the applicability of these products, here we present a climate service that greatly facilitates the different tasks involved in seasonal forecast application within an operational context. This climate service can be applied to a broad range of impact applications in the framework of seasonal forecast studies, although its capabilities are illustrated in this paper through a particular application in the framework of wildfire danger assessment. Its components are next briefly described:

- The User Data Gateway (UDG) is the one-stop shop for climate data access maintained by the Santander Meteorology Group, providing metadata and data access to a set of georeferenced atmospheric variables using OPeNDAP and other remote data access protocols. Its main features and its user-tailored extension for the European Climate Observations, Modelling and Services initiative (ECOMS), that coordinates the activities of three ongoing European projects (EUPORIAS, SPECS and NACLIM), are detailed in a paper in this issue (Cofi·o et al., submitted). Data access and harmonization is achieved through the `loadeR.ECOMS` interface to the ECOMS-UDG (see Cofi·o et al., submitted, for further details, and specific examples in the companion vignette to this paper: http://meteo.unican.es/work/fireDanger/Climate_Services_2017.html).
- `downscaleR` (Bedia et al., 2016) is an R package for empirical-statistical downscaling, with a special focus on daily data. It is fully integrated with the `loadeR` bundle and therefore it works seamlessly with the datasets loaded from the UDG. The package is available in this URL: https://github.com/SantanderMetGroup/downscaleR.
- `transformeR` (Santander Meteorology Group, 2017b) performs data post-processing tasks such as re-gridding/interpolation, principal component/EOF analysis, detrending, aggregation, sub-setting, plotting ..., being fully integrated with the above-mentioned packages. An introduction to the package and examples of application are available in the transformeR's wiki (https://github.com/SantanderMetGroup/transformeR/wiki).
- `fireDanger` (Santander Meteorology Group, 2017a) is an R package for the Implementation of the Canadian Fire Weather Index System, specially tailored to receive as input climate data structures as provided by the `loadeR` bundle, including the calculation of FWI from seasonal forecast datasets. The package is available in this URL: https://github.com/SantanderMetGroup/fireDangeR.
- `visualizeR` (Frias, submitted) is an R package implementing a set of advanced visualization tools for forecast verification. It is fully integrated (yet independent) from the R climate data structures generated by the loading functions of the `loadeR`, thus providing seamless integration with all steps of forecast data analysis, from data loading to post-processing, downscaling and bias correction and visualization. The package is available in this URL: https://github.com/SantanderMetGroup/visualizeR
- Integration with forecast verification software. As part of the ECOMS initiative, two different verification R packages have been developed: `SpecsVerification`, (Siegert, 2015) in SPECS and `easyVerification` (MeteoSwiss, 2016) in EUPORIAS, implementing verification metrics used in this application. Several bridging functions have been developed in `transformeR` for a complete integration of the above packages with the verification software.

The application of this climate service has allowed the production of the results presented in this study. A worked example covering the different components of the climate service is provided in the `fireDanger` documentation as a package vignette (also available online at http://meteo.unican.es/work/fireDanger/Climate_Services_2017.html). We show the potential for a successful application of seasonal forecast predictions for operational fire risk management in Mediterranean Europe, and in particular in the eastern area, where significantly skilful predictions have been found. Our results indicate that a moderate improvement in the skill can be achieved through the application of empirical quantile mapping (QM). Given the multi-variable nature of FWI, we advocate the application of QM on FWI directly, as computed from the raw model outputs, rather than performing a correction of its input components separately. This promising results, together with the development of new climate services facilitating the access and post-processing of seasonal forecast data to end users, pave the way for the applicability of this climate products within an operational framework in the near future.

1. Introduction

Wildfires represent the most important natural hazard in the Euro-Mediterranean (EU-MED) region, where an average of 4500 km^2 of forested and shrubland areas burn every year (San-Miguel-Ayanz et al., 2013), causing considerable economic and environmental damages and loss of life. In the context of climate analysis, the term *fire danger* refers to the assessment of the climatic factors which determine the ease of ignition, rate of spread, difficulty of control and impact of a fire. Thus, estimating fire danger a few months in advance is an urgent requirement, allowing fire protection agencies a timely reaction and an adequate provision of human and material resources.

Historically, seasonal forecasting of fire danger has relied on statistical techniques exploiting the lagged relationships between different fire statistics (number of fires, total burned area ...) and slowly-varying components of the climate system used as predictors, such as sea-surface temperatures (Chu et al., 2002; Chen et al., 2011; Chen et al., 2016; Harris et al., 2014) or meteorological droughts (Preisler and Westerling, 2007; Gudmundsson et al., 2014), at global to regional scales. There are also some local empirical prediction examples within the EU-MED region (see e.g. Turco et al., 2013; Marcos et al., 2015). However, the empirical approach poses some limitations due to the sensitivity of the statistical methods to the often short history of the observational databases and to non-stationarities in the training data.

Recent advances in the modelling of the atmosphere–ocean coupled circulation have lead to the development of a new generation of numerical models (Global Climate Models, GCMs) producing dynamical predictions on a seasonal time horizon (Doblas-Reyes et al., 2013), offering an alternative to the empirical approach. In order to account for the various sources of uncer-