REGIONAL ASSESSMENT OF THE JENKINSON-COLLISON WEATHER TYPES CLASSIFICATION AND OBSERVATIONAL UNCERTAINTY BASED ON DIFFERENT REANALYSES OVER THE MEDITERRANEAN REGION

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RESUMEN
El algoritmo de clasificación en tipos de tiempo de Jenkinson y Collison (JC-WT, Jenkinson and Collison 1977) es una técnica de agrupamiento usada para clasificar la circulación atmosférica en un número reducido de patrones de presión a nivel del mar. Esta metodología se basa en el cálculo de 6 parámetros intermedios relacionados con las características del flujo del viento. Este método ha tenido numerosas aplicaciones, siendo una de ellas la caracterización objetiva de la circulación atmosférica tanto a nivel global como regional, esencial para la evaluación de modelos climáticos y para su aplicabilidad en regionalización dinámica y estadística. La primera definición del método JC-WT centraba el estudio sobre las Islas Británicas pero puede ser, en principio, aplicado en latitudes medias-altas (Jones et al., 2013). El presente estudio examina la aplicabilidad la metodología JC-WT sobre la región Mediterránea y explora las diferencias entre cinco reanálisis a la hora de representar las características de los 27 JC-WT (sus frecuencias relativas y las probabilidades de transición entre tipos). Los resultados muestran diferencias importantes entre los distintos catálogos, sobre todo en verano. Además, se analizan estas diferencias entre reanálisis a nivel de los 6 parámetros intermedios de JC-WT con el fin de arrojar luz sobre la naturaleza sinóptica de las mismas. Estas discrepancias pueden comprometer la robustez de los estudios relacionados con la evaluación de modelos basada en procesos para esta región y desaconsejan el uso de un único reanálisis como referencia.

Palabras clave: clasificación Jenkinson-Collison, tipos de tiempo, incertidumbre observacional, Mediterráneo.

ABSTRACT
The Jenkinson-Collison Weather Type (JC-WT; Jenkinson and Collison, 1977) classification is a clustering method used to classify the regional atmospheric circulation into a reduced number of typical recurrent sea-level pressure patterns. This methodology is a function of six parameters related to wind-flow characteristics. Originally developed for the British Isles, the method since then has seen many applications. One of its applications is serving for an objective characterization of either global or regional atmospheric circulation, a key feature for the assessment of climate models and their suitability for driving dynamical and statistical modeling experiments. Encouraged by the estimate that the JC-WT approach can in principle be applied to any mid-to-high latitude region (Jones et al, 2013), this study assesses the general application of JC-WT over the Mediterranean region, extending from the Iberian Peninsula in the west to the Levant in the east. We also explore to what extent the JC-WT features (such as frequencies of the 27 weather types and transition probabilities between pairs of types) obtained from five distinct reanalysis products agree with each other. Our results unveil important discrepancies among reanalyses, accentuated in summer. We furtherly explore these discrepancies deepening on the JC-WT base parameters in order to shed some light on the synoptic nature of these inconsistencies, that may compromise the robustness of circulation-based model assessments relying on a single reanalysis in these regions.

Key words: Jenkinson-Collison classification, weather types, observational uncertainty, Mediterranean.

1. INTRODUCTION

Regional climate is largely determined by the large-scale atmospheric circulation patterns which, particularly in the extra-tropics, exhibit recurrent spatial patterns operating at multiple scales (Soares et al, 2019). An adequate representation of the atmospheric circulation and high/low pressure variability becomes essential for a proper representation of the main regional climate features, although current Global Climate Models (GCMs) may show significant biases in this sense (Vial and Osborn, 2012; Dawson et al, 2012). GCMs are the primary tools producing future climate projections for impact and adaptation studies (Taylor et al, 2012; IPCC, 2021). However, uncertainties still remain for fundamental large-scale processes (see e.g., Fernandez-Granja et al, 2021) and sub-grid scale processes, which are often misrepresented due to the coarse resolution of some GCMs (see e.g., Maraun, 2016). The most recent generation of GCMs (CMIP6, Eyring et al, 2016) shows substantial improvements with respect to CMIP5 in the representation of the frequency and persistence of circulation types worldwide (Cannon, 2020; Fernandez-Granja et al, 2021; Brands, 2022), although more focused analyses are necessary to accurately evaluate the implications at a regional scale, remarkably for downscaling purposes (Addor et al, 2016; Otero et al, 2018). Observational uncertainty plays here an important role, since GCM evaluation involves the analytical comparison of model outputs against observations (or reanalysis, as pseudo-observations), adding a source of error that needs to be explicitly addressed (Gettelman and Rood, 2016). As a result, it is widely recognized the need to consider multiple observational products when evaluating climate models (Gibson et al, 2019). In the context of process-based model evaluation, automated weather typing or clustering approaches (see Huth et al, 2008, for a comprehensive review) are gaining increased popularity due to their ability to reduce complex atmospheric circulation patterns into a few construable types that can be consistently compared among models and against observations. One of such early methods was originally developed for the British Isles (Lamb, 1972), generally known as the Lamb Weather Types (LWT). The LWT classification was later automated by Jenkinson and Collison (1977) using a set of equations depending on SLP time series. The Jenkinson and Collison approach (JC-WT hereafter) not only reproduces the original LWT catalog over the British Isles, but can be applied to different geographical locations within a zonal belt from ca. 30 to 70º (Jones et al, 2013). Consequently, it has been used in different parts of the world and even to extensive global areas (Brands, 2022; Fernandez-Granja et al, 2022). The flexibility of the JC-WTs may be useful when analyzing atmospheric circulation over extensive global areas. However, some regions may exhibit particular circulation features not adequately represented by this method (Hochman et al, 2019), unearthing some limitations of this methodology.

According to the last IPCC Report, AR6 (IPCC, 2021) the Mediterranean Region is a climate change "hot spot", as it will experience one of the largest relative increases in temperature from the entire world. A proper model assessment is thus vital in this region where large climate change impacts are expected and informed adaptation and mitigation measures are required. The present study analyzes the observational uncertainty in the representation of the JC-WT classification focusing on the Mediterranean Sea and, particularly, the Iberian Peninsula, considering five widely used reanalyses in climate research. Furthermore, the advantages and limitations of the JC-WT approach are discussed in the context of Mediterranean circulation characteristics, as represented by the base parameters of the JC-WT formulation.

2. METHODOLOGY AND DATA

2.1. Jenkinson-Collinson Classification

We followed the JC-WT formulation developed by Jenkinson and Collison (1977) that yields 27 different weather types. As input, we used 6-hourly, instantaneous sea level pressure (SLP) data, which are sampled using a cross-shaped point pattern formed by 16 points with a separation of 5º in latitude and 10º in longitude (Jones et al, 2013). Due to its shape, in the following, we will refer to this scheme simply as "cross". The JC-WT classification derived at the central point of the cross is a function of 6 parameters related to wind-flow characteristics: southerly flow (S), westerly flow (W), total flow (F), southerly shear vorticity (ZS), westerly shear vorticity (ZW) and total shear vorticity (Z); computed upon the SLP records provided at a given time. The 27 weather types represent pure cyclonic (C) and anticyclonic (A) circulation over the center point, 8 pure directional types (N, NE, E,…, NW), 16 hybrid types (mixing A or C with any of the directional types) and a 27th type (U) accounting for unclassified records, that is, days with chaotic weak flow or days when incompatible hybrids are formed. The cross can, in principle, be centered on any extra-tropical location (Jones et al, 2013; Brands, 2022) and even beyond (Fernández-Granja et al., 2022). In order to produce the classification, the center of the cross is displaced from one grid-box to another through all points of a reference 2.5º regular SLP grid within the chosen domain.

2.2. Reanalysis data

Reanalysis	Nom. res. (º)	Modeling Center	Reference
ERA-20C	1.13	ECMWF	Poli *et al*. (2016)
ERA-Interim	0.75	ECMWF	Dee *et al*. (2011)
ERA-5	0.25	ECMWF	Hersbach *et al*. (2020)
JRA-55	1.25	JMA	Kobayashi *et al*. (2015)
NCEP Reanalysis 1	2.5	NCEP-NCAR	Kalnay *et al*. (1996)

Table 1: Set of reanalyses used in this study, their nominal resolution at the Equator (in º) and modeling centers producing them. ECMWF: European Center for Medium Range Weather Forecasts; JMA: Japanese Meteorological Agency; NCEP-NCAR: National Centers for Environmental Prediction / National Center for Atmospheric Research

Table 1 summarizes the reanalysis datasets used in this study and their main characteristics. Prior to JC-WT application, all reanalyses were conservatively interpolated to a common 2.5º regular longitude-latitude grid considering a spatial domain covering 30º-60º N and 30ºW-40ºE. In order to compare all reanalyses, we considered the 27-year common period 1979-2005 (AR5 CMIP5 historical baseline period; Taylor et al, 2012). The reanalysis uncertainty is here analyzed by validating all reanalysis against all.

2.3. Evaluation measures

One salient feature of a weather type is its probability of occurrence, which can be understood as the proportion of 6-h records classified in a particular category over the complete time series length. JC-WT persistence or, more generally, transition probabilities between two different types are also important. They determine key temporal features such as spell duration, serving as an effective tool for the assessment of the model ability to reproduce atmospheric circulation pattern sequences (Gibson et al, 2016; Hochman et al, 2019; Fernandez-granja et al, 2021). In order to measure the differences among reanalyses, we assessed the probability of transition of one type into another using a transition probability matrix (TPM), briefly described in Fernandez-Granja et al (2021). The TPM provides a visual ‘‘fingerprint’’ on how a given dataset reproduces the JC-WT classification when the cross is centered on a given grid cell. TPMs from different models or reanalyses can be compared through the TPM Score (TPMS), which provides a quantitative measure of dissimilarity between the two transition probability matrices (Fernandez-Granja et al., 2021):

$TPMS = \sum_{p \in A^*} |p - p_{ref}|$, where p and p_{ref} are the transition probabilities in the test and in the reference datasets, respectively. The (absolute) difference is calculated considering a subset of transition probabilities A^* from the full matrix (A), that are significantly different between the two reanalyses considered in each comparison, following a two-proportion Z-test. The null hypothesis for the two-proportions Z-test is that the relative frequencies of a given type for two different reanalyses are the same, using a 95% confidence level. In practice, the larger the TPMS departure from zero (perfect agreement), the larger the dissimilarity of the TPM fingerprints between the reanalyses for a given center grid cell.

3. RESULTS AND DISCUSSIONS

3.1. Applicability of the JC-WT classification in the Mediterranean region

The applicability of the method in the whole region is assessed by means of two quantities: (1) the number of different weather types as a measure of regional circulation's *diversity* and (2) the occurrence of the Unclassified type (U, Sec. 2.1) as a sign of a weak pressure gradient with no clear vorticity tendency, also known as *barometric* swamp. For the first criterion, we consider weather types attaining relative frequencies above 0.1%. Low diversity of weather types and frequent barometric swamp may be an indication of the method working at its theoretical limits.

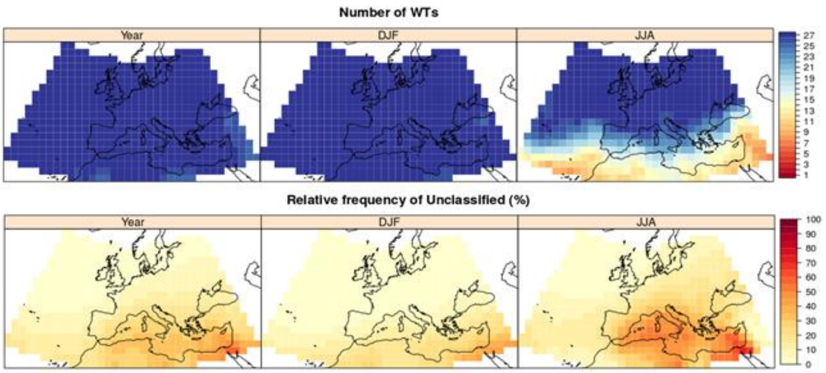

Fig. 1: Summary of the Jenkinson-Collison classification results centering the cross in all grid-boxes of the domain of study, calculated upon the SLP from ERA-Interim (6-hourly, 1979-2005), for the whole annual series (left panels) and DJF and JJA seasons (middle and right panels, respectively). Top row: Number of weather types per grid-box with a relative frequency above 0.1%. Bottom column: Relative frequency of the Unclassified type (U) per grid-box.

The distribution of the total number of distinct WTs (Fig. 1, upper panels) shows that all WTs are represented in winter (DJF), whereas a marked latitudinal gradient, with a decreasing diversity of types towards middle latitudes in the Iberian Peninsula and Mediterranean Sea, is found in summer (JJA). Concurrently, the frequency of the U type (Fig. 1, lower panels) is significantly higher over the Mediterranean Sea in summer. These results underpin the overall suitability of the JC-WT classification in the Mediterranean Basin, but provide a first warning on the sub-optimal performance of the approach in summer, due to the increased prevalence of the U type and the low type diversity found. In order to further investigate the JC-WT method consistency, next we intercompare the results obtained using different reanalysis products.

3.2. Observational uncertainty in the Mediterranean atmospheric circulation

The consistency among reanalyses is next analyzed by comparing their respective pairwise transition probability matrices (Sec. 2.3), using the TPMS as an evaluation measure of matrix dissimilarity (Fig. 2). In terms of annual TPMS (not shown), a good agreement among reanalysis is found in general. The same applies for winter (Fig. 2, lower right panels), spring (MAM) and autumn (SON). The best agreement between reanalyses is found in winter with the lowest TPMS values (<4). Brands (2022) found similar results for this region when comparing JRA-55 and ERA-Interim using the Mean Absolute Error between JC-WT type frequencies. Higher TPMS values are found all along the Mediterranean Sea and the Iberian Peninsula in summer for all pairs of reanalysis. The high TPMS is mainly located in the southern part of the region, showing a marked latitudinal gradient to lower TPMS values northward. This TPMS pattern aligns with the results found for type diversity and U-type frequency (Sec. 3.1).

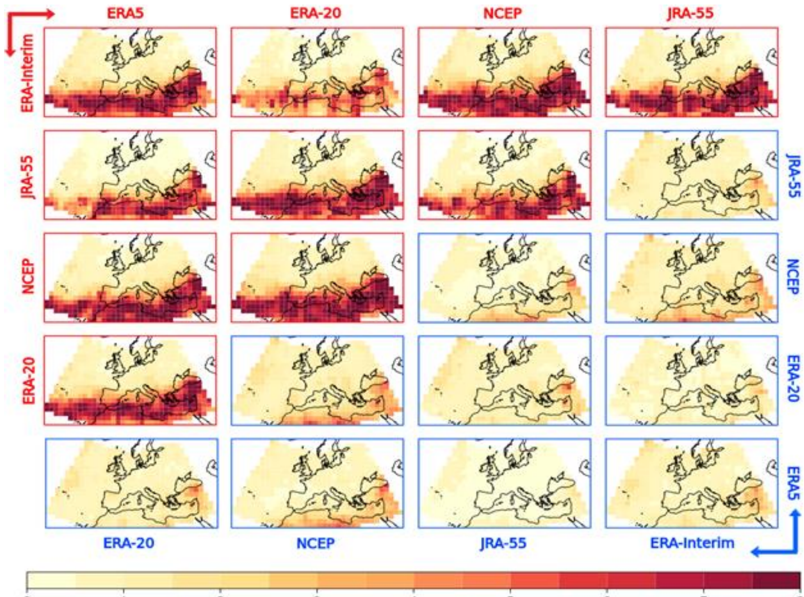

Fig. 2: Transition Probability Matrix Scores (TPMS, Sec. 2.3) for pairs of reanalyses in summer (red bordered and labeled panels) and winter (blue bordered and labeled panels) at the grid-box level, considering the all-against-all intercomparison scheme.

In order to shed light on the discrepancies found (Fig. 2), we analyze differences in specific weather type transitions through the transition probability matrices (TPM), choosing two arbitrary grid boxes with distinct behaviors. The TPM provides the reference fingerprint of the transitions among JC-WTs (non-diagonal cells) and the persistence probability of a given type (diagonal cells). For brevity, we show the results for two distinct reanalyses, i.e. ERA-Interim against NCEP summer (Fig. 3, upper panel) and winter (Fig. 3, lower panel). Generally, the most likely transition for the majority of the JC-WTs is to remain in the same state. This is not the case for the Balearic Islands in summer (top-left panel), where most of the transitions occur from or to U. Accordingly, U-type was found to be the most frequent type here in summer (approx. 50%, Fig.1). As a result, the TPMS from this TPM compared to the NCEP counterpart is 12, considerably larger than for the remaining TPM displayed in Fig. 3. The discrepancies between ERA-Interim and NCEP classifications in summer can be explained by the dissimilarities in the six intermediate JC-WT parameters. As illustrated in Fig. 4, in summer the six parameters show lower correlation in the Mediterranean Sea as compared to other locations of the domain. Correlation coefficients are particularly low for the southerly flow (s) and the total flow (f, norm of southerly and westerly flow). In this example (ERA-Interim/NCEP), the meridional component of the pressure gradient (s) emerges as the main responsible for the discrepancies between reanalyses in terms of the resulting classifications, more than the zonal component (w) and the shear vorticities (zw, zs, z), that exhibit a higher agreement. However, the degradation of parameter correlation may vary in magnitude and importance among reanalysis pairs. This finding suggests that small differences in the SLP fields can lead to significant differences in the JC-WTs features under situations of very weak pressure gradients, as reflected by the discrepancies of the intermediate parameters.

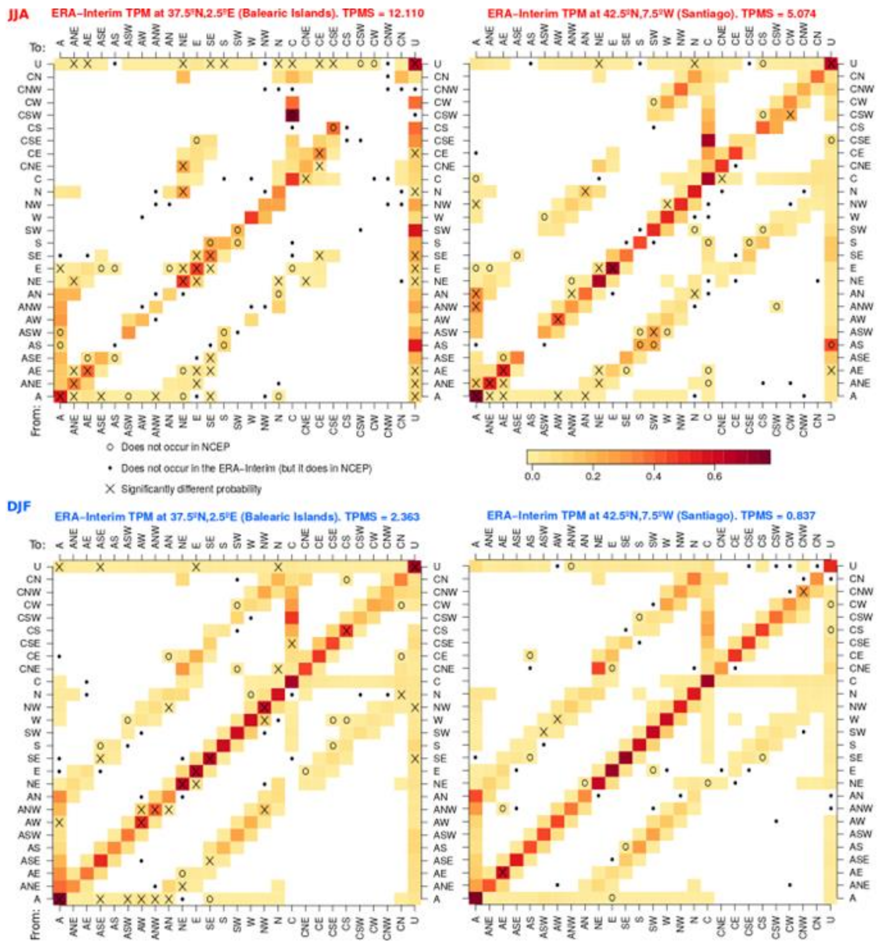

Fig. 3: Transition probability matrices (TPM) of JC-WTs from ERA-Interim. Two upper panels correspond to summer (JJA) and the two lower panels to winter (DJF). The two left TPMs refer to the grid box located over the Balearic Islands (high TPMS in Fig. 2) and the two right TPMs refer to a grid box over Santiago de Compostela (low TPMS against NCEP in Fig. 2). The persistence of a WT can be found by looking at the diagonal of the matrix (Sec. 2.3). Non-observed transitions have been blanked to differentiate them from low-probability ones.

Overall, we find a relationship between three factors, namely large values of TPMS, small number of WTs and high frequency of the U type. This relationship emerges more clearly with large TPMS and low number of WTs. The degradation of similarity among TPM, reflected by high TPMS values, is mostly associated with large U-type frequencies and the higher transition probabilities from/to type U, occurring mostly in summer.

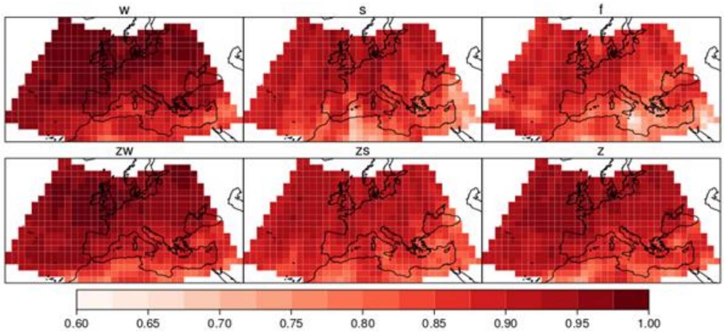

Fig. 4: Temporal correlation (Spearman correlation coefficient) of the six intermediate Jenkinson-Collison (JC) parameters from NCEP against ERA-Interim, in summer.

4. CONCLUSIONS

We assess the synoptic characteristics in terms of the JC-WT classification of the European domain, with a special focus on the Mediterranean Sea and Iberian Peninsula. We first check the applicability of JC-WT classification all along this domain, and then we explore to which extend the transitions probabilities of the 27 classes obtained from several reanalyses agree with each other. Lastly, we discuss the synoptic nature of these discrepancies in terms of correlation between the JC-WTs parameters of reanalyses. Five different reanalysis products are taken into account to assess reanalysis uncertainty by means of the TPMS. For a considerable fraction of the domain of study, a large diversity of JC-WT types occur, with marginal occurrence or complete absence of type U. This holds true for most of the domain but the Mediterranean Sea and South of the Iberian Peninsula, where type diversity decreases with the increase of type U frequency, particularly in summer, as an indicator of sub-optimal performance of the JC-WT method in this case. These limitations go hand in hand with increased observational uncertainty among reanalyses, observed in terms of TPMS. We find a severe empirical reduction of types occurring per season, associated with U-type frequencies around 50%, delimiting the applicability of the JC-WT methodology for a useful circulation type classification, that warns against a robust application of this method over the Mediterranean Sea and Southern Iberian Peninsula in summer. The reanalysis uncertainty found, resulting in differing JC-WT classifications for a given historical period, is due to the diverging results obtained for the internal JC-WT parameters related with air flow and vorticity, impaired by the increased frequency of situations of very weak pressure gradients within the cross point coordinates, which yield spurious transitions from and to type U, as unveiled by the transition probability matrix analysis. The JC-WT classification provides a valuable tool for synoptic classification and process-based GCM evaluation. However, our study reveals potential flaws in its applicability under specific regional conditions. Such is the case of the barometric swamps frequent in the Mediterranean Sea in summer, leading to inconsistent results. We advocate caution in these situations and a previous analysis of the method performance is recommended, looking at basic indicators of performance such as the JC-WT diversity and frequency of unclassified events (type U). Furthermore, transition probability matrices provide an effective means of comparison against alternative observational data sources, thus helping in the observational uncertainty quantification, as well as for GCM evaluation (Fernandez-Granja et al, 2021; Brands, 2022).

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