

RESEARCH ARTICLE

A sub-regional approach to the influence analysis of teleconnection patterns on precipitation in Calabria (southern Italy)

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Abstract

In this study, the problem of determining, with an adequate statistical significance, the relationship between teleconnection pattern indices and precipitation at climatological time scales has been addressed through a novel technique based on a rainfall zonation, by means of creating a regional precipitation database for a whole-region correlation approach. Pearson correlation was performed to evaluate the mesoscale influence on precipitation in the Calabria region over the 1951–2010 time period, by means of a database of 79 rain gauges, divided in five Rainfall Zones (RZs) and seven teleconnection pattern indices relevant to the Mediterranean region, searching where results were significant (significance level < 0.05) and with an absolute correlation value higher than a prefixed threshold equal to 0.2. The Calabria region was chosen as it is located in the centre of the Mediterranean area, which constitutes a hot spot for climate change, and because it is equipped with a high-density, long-time series of precipitation gauge network, recently validated and homogenized. Correlation analysis between seasonal teleconnection indices and seasonal cumulated precipitation showed that the Western Mediterranean Oscillation and the East Atlantic/West Russian patterns were the most relevant teleconnections over all Calabria. Correlations of 3-month averaged teleconnection indices versus monthly precipitation showed that the Mediterranean and Western Mediterranean Oscillations produce most significant results with correlation values higher than 0.2, with East Atlantic pattern a third close. Comparison between monthly teleconnection indices and monthly cumulated precipitation indicate that all modes of variability taken into account share a similarly weak correlation. Comparing the rainfall zone-based study and the technique of averaging individual stations results post-correlation, it was shown that on average only 43% of the stations would produce useful correlations, while the novel technique used all the valid and available station data, resulting in statistically more robust findings.

KEYWORDS

Calabria, Pearson, rainfall, teleconnections

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1 | INTRODUCTION

Climate and weather do not depend exclusively on regional and local conditions and phenomena. The most important at-distance interactions between widely separated Earth's regions are called teleconnections (from the Greek “τηλε” and the English ‘connection’; Glantz, 1994). They are recurring patterns of the atmospheric circulation, or the coupled atmosphere–ocean system, which can be related to global climate variability from seasonal to interannual time scales. Teleconnection patterns are the preferred mode of long time scale variability and follow a quasi-periodic fluctuation, generally linked to air pressure differences between two definite zones. In fact, they can last from weeks to months at a time, or they can appear for several consecutive years, and, thus, they play a major role in interannual and interdecadal atmospheric variability. Since they can affect temperature, precipitation, storm tracks, and jet stream location and intensity, they are often responsible for abnormal weather patterns influencing simultaneously distant areas (Wallace and Gutzler, 1981; Mo and Livezey, 1986; Barnston and Livezey, 1987; Barnston *et al.*, 1991; Enfield *et al.*, 2001; Hurrell and Deser, 2009; Woollings *et al.*, 2010; Bader *et al.*, 2011). In particular, due to the importance of precipitation as a climatic and meteorological variable, it is paramount to detect the relationships between teleconnection patterns and precipitation at different time- and spatial-scales. As a matter of fact, large-scale systems can not only influence precipitation directly, but they can also establish a favourable environment to deep moist convection and, thus, to heavy-to-extreme precipitation (Doswell III, 1987; Dayan *et al.*, 2015), or, on the contrary, they can help triggering dry conditions and drought (e.g., Xoplaki *et al.*, 2004; Abiy *et al.*, 2019; Rust *et al.*, 2019). In order to determine these links, several analyses have been performed in many regions of the world (e.g., Lamb and Pepler, 1987; Trigo *et al.*, 2004; Caloiero *et al.*, 2011; Shaman and Tziperman, 2011; Lukovič *et al.*, 2014; Ríos-Cornejo *et al.*, 2015; Serrano-Notivoli *et al.*, 2018; Mathbout *et al.*, 2020). The majority of these studies were mainly based on the use of some point-to-point correlation technique, like Pearson product-moment correlation, Spearman rank correlation, and Kendall rank correlation (e.g., Kenyon and Hegerl, 2010; Coscarelli *et al.*, 2013; Ferrari *et al.*, 2013). In order to perform the correlation, some indices based on large-scale temperature and pressure anomalies have been developed and used to quantify and measure teleconnections. These indices are then usually compared with seasonal variables, for example,

seasonal cumulated precipitation at a grid point or at a weather station.

As regards the Mediterranean basin, extreme intensified mid-latitude cyclones are related to the large-scale atmospheric circulation in winter, while during summer local convection has a more relevant role in generating precipitation and extreme precipitation (Raible, 2007; Dayan *et al.*, 2015). The main moisture source of precipitation comes from winter Mediterranean cyclones (De Zolt *et al.*, 2006; Winschall *et al.*, 2014), but moisture sources from the North Atlantic and even the intertropical convergence zone (ITCZ) could play a role (Mariotti *et al.*, 2002a; Krichak and Alpert, 2005; Pinto *et al.*, 2013). Consequently, modes of variability like the Mediterranean Oscillation (MO; e.g., Conte *et al.*, 1989; Palutikof *et al.*, 1996), the Western Mediterranean Oscillation (WeMO; Martin-Vide and Lopez-Bustins, 2006), and the North Atlantic Oscillation (NAO; e.g., Barnston and Livezey, 1987; Lamb and Pepler, 1987), are all relevant to the Mediterranean precipitation regimes. Links between Mediterranean climate and the El Niño/La Niña Southern Oscillation or ENSO (Bjerknes, 1966; Bjerknes, 1969; Wolter and Timlin, 2011) have also been suggested (Price *et al.*, 1998; Lloyd-Hughes and Saunders, 2002; Mariotti *et al.*, 2002b; Shaman, 2014). For example, Alpert *et al.* (2002) found that severe precipitation ($>64 \text{ mm}\cdot\text{d}^{-1}$) over Italy tend to peak in El Niño years. However, not all climate anomalies are linked to ENSO occurrences and not even during strong El Niño years (Knippertz *et al.*, 2003; Donat *et al.*, 2014). Other major modes of variability able to influence weather patterns and anomalies in the Mediterranean region are the East Atlantic pattern (EA; Barnston and Livezey, 1987), the East Atlantic/West Russian pattern (EA/WR) and the SCANDinavian pattern (SCAND), introduced respectively as Eurasia-2 and Eurasia-1 in Barnston and Livezey (1987).

In this context, climatological large-scale influences over stations located in a small region characterized by the same climatic pattern should be, at first approximation, very similar. For instance, as regards precipitation, various studies have shown that in many cases, especially at mid-latitudes, orography and local wind patterns can influence the distribution of precipitation, and modify a general large scale moisture transport (e.g., Smith and Barstad, 2004; Roe, 2005; Caroletti and Barstad, 2010; Colle *et al.*, 2013). However, individual stations-based correlations with teleconnection indices allow only to use a few values over a certain time frame. Moreover, correlation is often performed at stations from reanalysis databases lacking both regularity and enough grid points to resolve precipitation processes in many areas. Otherwise, they are performed at GCM (General Circulation Model) data points on regular grids, but at a coarse scale. This can lead to a second problem, that is, to question the

reliability of those few points to represent the climatological patterns of a microclimatic zone.

In this study, an alternative approach based on a rainfall zonation for the analysis of localized response to large-scale moisture transport is presented. The aim of the study is to improve the statistical reliability of the teleconnection patterns analysis by correlating indices with data from gauge stations falling within a zone (RZ) characterized by a homogeneous precipitation regime. The method has been tested on the Calabria region, the southernmost region of Italian peninsula.

2 | DATA AND METHODOLOGY

This study was designed to test the response of a region, characterized by homogeneous rainfall conditions, to large-scale influences. The basic tenet of the method is that for each time step (i.e., a season or a month), the precipitation measure, taken at every station belonging to a region with a certain rainfall regime, can be considered as an independent measure to evaluate this influence.

2.1 | Study area and data

Calabria, the southernmost region of peninsular Italy, was chosen as a valuable test area, mainly because it is located in the centre of the Mediterranean region, which constitutes a hot spot for climate change (Sirangelo *et al.*, 2017). Moreover, Calabria has a high density, long-time network of precipitation gauges, recently validated and homogenized (Caloiero *et al.*, 2016). In particular, in this study 79 rain gauges have been selected. These rain gauges fall within distinct homogeneous areas, characterized by different precipitation conditions (Brunetti *et al.*, 2012), although Caroletti *et al.* (2019) found that precipitation in all regions roughly followed a normal distribution. These sub-regions were identified through the Principal Component Analysis, a multivariate approach which permits to represent a data set by means of new orthogonal variables called principal components and to display the similarity patterns of the observations and the variables as points on a map. The Varimax Rotation (also called Kaiser–Varimax rotation) of the Principal Components has been applied to the correlation matrix of daily records, thus maximizing the sum of the variance of the squared loadings. In this way, high factor loadings are present for few variables and low factor loadings for the remaining ones. In particular, by means of this methodology, each original variable could be associated with one of the (or a few) components and each component only

characterizes a few variables, simplifying the result interpretation. Specifically, the first five Empirical Orthogonal Functions led to the identification of the North-Eastern Zone (I1), the Central-Eastern Zone (I2) and the South-Eastern Zone (I3) on the Ionian side of Calabria, and of the North-Western Zone (T1) and the South-Western Zone (T2) on the Tyrrhenian part (Figure 1).

2.2 | Teleconnection data

The monthly and seasonal cumulated precipitation from 1951 to 2010 have been compared with seven teleconnection pattern indices, indicated as the most relevant for the Mediterranean climate (Barnston and Livezey, 1987; Dayan *et al.*, 2015): the Mediterranean Oscillation Index (MOI) and the Western Mediterranean Oscillation Index (WeMOI), both retrieved from the University of East Anglia's Climate Research Unit (CRU; <https://crudata.uea.ac.uk/cru/data/moi/>); the Oceanic Niño Index (ONI; Ropelewski and Halpert, 1996), as a measure of El Niño–Southern Oscillation (ENSO), retrieved from the United States National Weather Service's (NWS) Climate Prediction Center dedicated page (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php); the North Atlantic Oscillation Index (NAOI), the SCANDinavian Pattern index (SCAND), the East Atlantic Pattern index (EA), and the East Atlantic/Western Russia Pattern index (EAWR). These last four indices' data were also retrieved from the NWS's Climate Prediction Center (<https://www.cpc.ncep.noaa.gov>).

2.3 | Correlation methodology

In this study, the Pearson method has been used for the correlation analysis. Let x_i be a time series of rainfall data, with $i = 1, \dots, N$ time-steps, and let t_i be a time series of teleconnection index values taken at the same time-steps. Usually, the Pearson correlation performed for individual, point-by-point stations or grid cells/points, compares (x_i, \dots, x_N) with (t_i, \dots, t_N) .

In this paper, a new precipitation database, considering each precipitation measure of a rain gauge belonging to a RZ as an independent measure to be used in the relationship with the teleconnection index, has been built. Being $(x_{j1}, \dots, x_{jN_j})$ the precipitation time series of the j -th ($j = 1, \dots, M$) station located in a given RZ, the precipitation database P to be used for the correlation analysis for the given RZ is:

$$P = P_1, \dots, P_Q = x_{11}, \dots, x_{1N_1}, x_{21}, \dots, x_{2N_2}, \dots, x_{M1}, \dots, x_{MN_M} \quad (1)$$

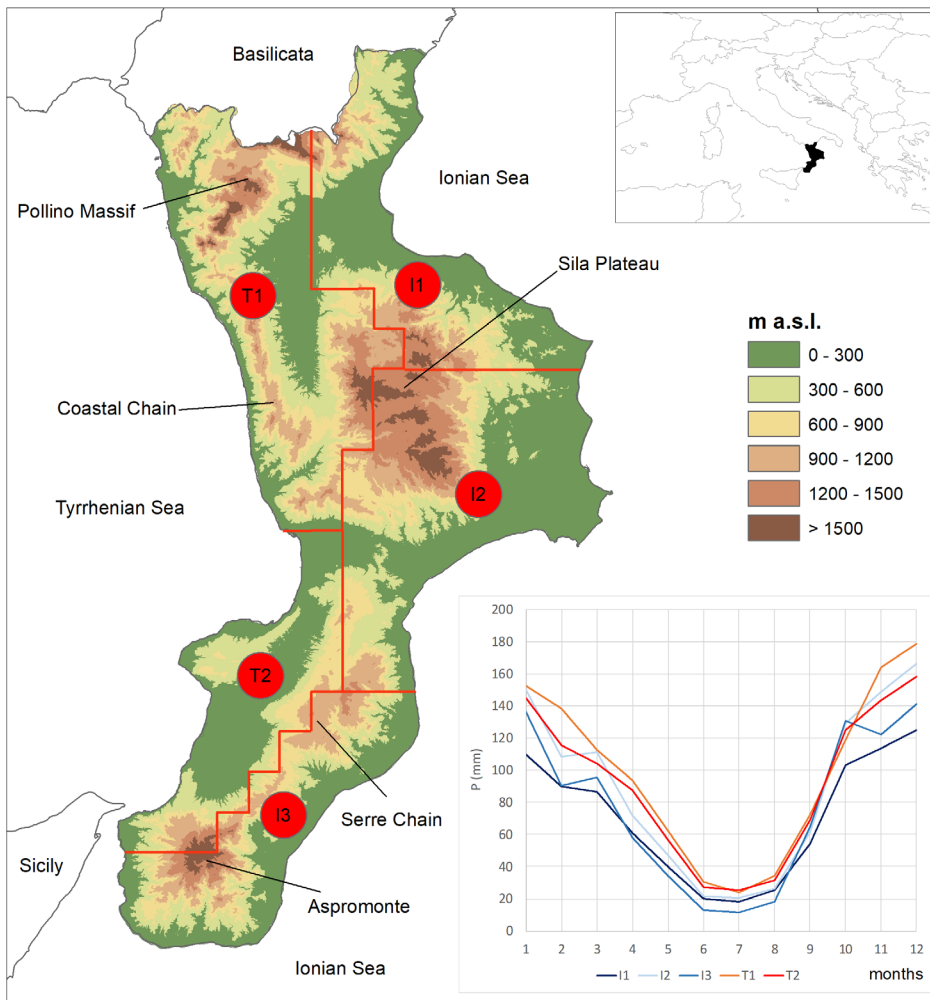


FIGURE 1 The five rainfall zones (RZs) over a DEM of Calabria and distributions of the average monthly rainfall in the five rainfall zones of the Calabria region (Caloiero *et al.*, 2020) [Colour figure can be viewed at wileyonlinelibrary.com]

where $Q = N_{tot} = \sum N_j$ is the length of the whole new database, and is equal to the sum of the number of valid time steps N_j of the M stations.

In order to correctly perform the correlation, each individual precipitation measure has been compared with the corresponding time-step teleconnection index value. Thus, the new teleconnection database is:

$$T = T_1, \dots, T_Q = t_1, \dots, t_{N_1}, t_1, \dots, t_{N_2}, \dots, t_1, \dots, t_{N_M} \quad (2)$$

The Pearson correlation coefficient between the regional precipitation data set (Equation (1)) and the teleconnection data set (Equation (2)) has been evaluated as:

$$\rho(P, T) = \frac{1}{Q-1} \sum_{i=1}^Q \left(\frac{P_i - \mu_P}{\sigma_P} \right) \left(\frac{T_i - \mu_T}{\sigma_T} \right) \quad (3)$$

where μ_P and σ_P are the mean and standard deviations of the precipitation P , while μ_T and σ_T are the mean and standard deviations of the teleconnection T .

It is important to note that N_j can differ from station to station due to some monthly missing data in the series,

and thus the stations of each region can have a different weight on the results computed through Equation (3).

In this study, monthly and seasonal precipitation have been compared with monthly and seasonal averaged teleconnections indices from the current and/or previous periods. For the next sections, a significance level of 0.05 for the correlation analysis has been fixed. In order to avoid taking into account too weak correlations, a threshold of 0.2 magnitude has been considered, based on previous studies on teleconnections in southern Europe (e.g., Mariotti *et al.*, 2002a; Ciarlo and Aquilina, 2015).

3 | RESULTS

Correlations were performed for: (a) seasonal teleconnection indices versus seasonal cumulated precipitation; (b) seasonal teleconnection indices versus monthly cumulated precipitation; and (c) monthly teleconnection indices versus monthly cumulated precipitation. Tables 1–3 show for each table box (i.e., for each season/month vs. season/month combination), only the significant teleconnection

TABLE 1 The highest values in magnitude of significant correlation coefficients higher, in absolute value, than 0.2 (OT CCs) between seasonal precipitation and seasonal teleconnections for each Rainfall Zone of Calabria [symbols/colours: * or Red: NAO; ** or Orange: MOI; + or Yellow: ONI/ENSO; ++ or Light Green: WeMOI; # or Green: EA; ## or Light blue: EA/WR; ^ or Blue: SCAND].

Rainfall zone	Teleconnection Period	RainSeason			
		DJF	MAM	JJA	SON
RZ I1	Season -1			-0.23++	
	Season -2				
	Season -3				
	Season -4		0.26++	0.29#	
RZ I2	Season -1				
	Season -2				
	Season -3	-0.28#			
	Season -4				
RZ I3	Season -1				
	Season -2				-0.21#
	Season -3				
	Season -4				0.22++
RZ T1	Season -1		-0.22++	-0.20++	
	Season -2			-0.22#	
	Season -3	0.22##			-0.26+
	Season -4	-0.21*			
RZ T2	Season -1				
	Season -2			-0.28#	-0.22++
	Season -3				
	Season -4				

TABLE 2 The highest values in magnitude of significant correlation coefficients higher, in absolute value, than 0.2 (OT CCs) between monthly precipitation and three-months averaged teleconnections for each Rainfall Zone of Calabria [symbols/colours: * or Red: NAO; ** or Orange: MOI; + or Yellow: ONI/ENSO; ++ or Light Green: WeMOI; # or Green: EA; ## or Light blue: EA/WR; ^ or Blue: SCAND].

Rainfall Zone	TeleconnectionPeriod	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RZI1	Current to month-2									-0.25##			
	Month -3 to -5					0.2##			0.3**			0.23++	
	Month -6 to -8	-0.23#						0.3#			-0.25#		
	Month -9 to -11		0.22^	-0.23**		0.24++			-0.27^	-0.21+		0.24++	0.22##
RZI2	Current to month-2									-0.24##			
	Month -3 to -5	0.21*				0.24##			0.29**				
	Month -6 to -8	-0.3#		-0.25++							-0.21#		
	Month -9 to -11		0.25^	-0.21**		0.23++				-0.22+		0.23++	
RZI3	Current to month-2									-0.22##	-0.26*		0.27##
	Month -3 to -5								0.21**			0.21++	
	Month -6 to -8	-0.24#							0.28++	-0.24**			
	Month -9 to -11					0.22++			0.22**	-0.24+	-0.21+	0.23++	
RZT1	Current to month-2	0.21^					-0.21#						-0.21^
	Month -3 to -5		0.2*	-0.2++		0.22##			0.32**		0.3##		
	Month -6 to -8							0.24#					
	Month -9 to -11												
RZT2	Current to month-2			0.21^			-0.22#				-0.2**		
	Month -3 to -5	0.2*				0.23^			0.34**				
	Month -6 to -8							0.22	0.21++				
	Month -9 to -11												

with the highest correlation coefficient (CC from now on) values greater than the prefixed threshold of 0.2. However, it is possible that other several significant CC values are

higher than 0.2 at the same time for the considered combination; in order to account for these results, Figures 2–4 show the full range of significant CCs higher than 0.2 (OT,

TABLE 3 The highest values in magnitude of significant correlation coefficients higher, in absolute value, than 0.2 (OT CCs) between monthly precipitation and monthly teleconnections for each Rainfall Zone (RZ) of Calabria [symbols/colours: * or Red: NAO; ** or Orange: MOI; + or Yellow: ONI/ENSO; ++ or Light Green: WeMOI; # or Green: EA; ## or Light blue: EA/WR; ^ or Blue: SCAND].

Rainfall zone	Teleconnection Period	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
RZ 11	Currentmonth	-0.37**	-0.27**	0.27^	0.23##	-0.27##				-0.32#	-0.23++	0.24*	-0.3#	
	Month -1				0.25^		0.24**					-0.2^		
	Month -2				0.2#	0.26##				-0.21++				
	Month -3				-0.24*		0.25##	0.2^	-0.21*	0.23**			-0.21#	
	Month -4	-0.24#								0.24##	0.2##	0.21++		
	Month -5										0.25++			
	Month -6											-0.22#		
	Month -7				0.2##	0.2##								0.24^
	Month -8	0.28^	0.22^						-0.21^			-0.3**		
	Month -9			-0.23**						-0.25##		0.23##		
	Month -10			0.2+						0.28**				
Month -11				-0.21##	0.24++		0.28#						0.24**	
RZ 12	Currentmonth	-0.39**	0.31^	0.38^	-0.29#	0.26+	0.2*	-0.23++	-0.29#	-0.24++	0.3*	-0.36#	-0.24**	
	Month -1			-0.22**		0.25+				0.27#				
	Month -2			-0.21**		0.25##			0.21##			0.27##		
	Month -3											-0.21#	-0.22#	
	Month -4	-0.25#				-0.21#						-0.21#	-0.25#	
	Month -5	-0.24#							-0.2++		0.23++	0.22++		
	Month -6											-0.21#		
	Month -7			-0.26++	0.26##	0.24##								
	Month -8	0.21^	0.25^	-0.2++								-0.24**	0.22*	
	Month -9		0.24^	-0.2**			0.22*			-0.25##				
	Month -10	-0.22#							0.27**		-0.2*			
Month -11					0.23++			-0.23*		0.26++				
RZ 13	Currentmonth	-0.33**	0.27^	0.36^		0.24+				0.24+	0.37*	-0.35#		
	Month -1			-0.21*	0.22#	0.26+				0.22+	0.24+			
	Month -2			-0.24**		0.22+			0.23##		-0.27##			
	Month -3										0.21+			
	Month -4						-0.2++				0.22##	-0.23*		
	Month -5										0.25++			
	Month -6										-0.25##			
	Month -7				0.21##						-0.21#			
	Month -8										-0.26**			
	Month -9				0.2++					-0.23##	-0.21#			
	Month -10										-0.28*	-0.22^		
Month -11					0.22++					-0.24##		0.21##		
RZ T1	Currentmonth	-0.35**	-0.46**	-0.37**	0.21++	-0.36#			-0.28#	-0.23**	0.31++	-0.26#	-0.43##	
	Month -1	0.22^	-0.23**						0.25*	0.25^		0.23^		
	Month -2						-0.21*							
	Month -3									-0.22++	0.23++			
	Month -4						-0.2++			-0.22+	0.26++			
	Month -5			-0.2++					0.22##					
	Month -6								-0.22##			-0.21#		
	Month -7					0.21##				-0.21##	-0.21++			
	Month -8	0.24^		0.26##			-0.2*						0.23*	
	Month -9				0.2^		-0.24##					-0.26**		
	Month -10								0.3**					
Month -11	-0.22*		0.23**				0.23#	0.25++		0.28++				
RZ T2	Currentmonth	-0.27**	-0.36**	-0.37**	-0.2#	0.23**			-0.24#		0.21*	-0.33#	-0.32##	
	Month -1					0.2+			0.25*					
	Month -2					0.21##		0.21*	0.24##					
	Month -3			0.21^						-0.23++				
	Month -4	-0.21#												
	Month -5													
	Month -6											-0.23**		
	Month -7		-0.22++		0.22##	0.22^	-0.21##			-0.2##				
	Month -8								-0.2#					
	Month -9				-0.2##		0.27*							
	Month -10								0.32**		-0.22**			
Month -11		-0.21^					0.22**	0.22++		-0.24##				

FIGURE 2 The number of significant correlation coefficients higher, in absolute value, than 0.2 (OT CCs) at each rain zone (RZ) in Calabria for the seven teleconnection indices. Correlations are computed between seasonally cumulated precipitation over each RZ and each of the teleconnection indices, seasonally averaged for the four previous seasons [Colour figure can be viewed at wileyonlinelibrary.com]

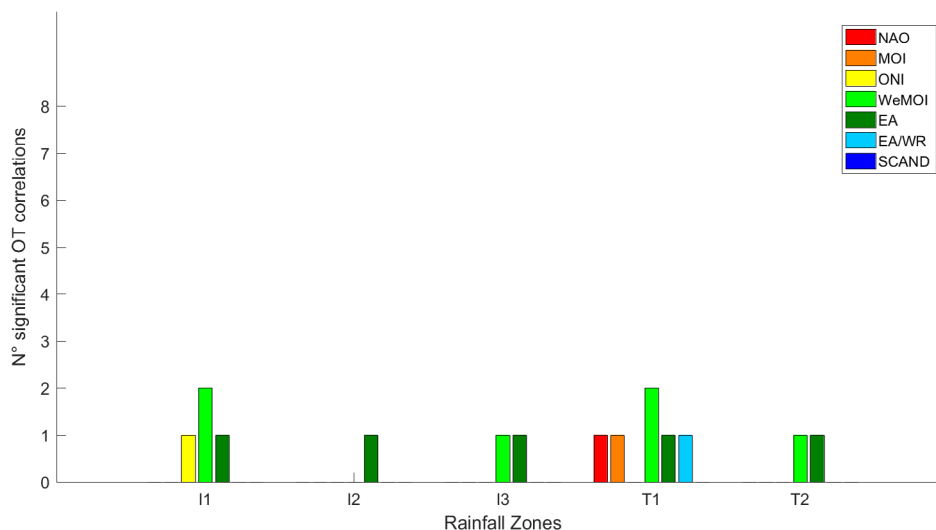


FIGURE 3 The number of significant correlation coefficients higher, in absolute value, than 0.2 (OT CCs) at each rain zone (RZ) in Calabria for the seven teleconnection indices. Correlations are computed between monthly precipitation over each RZ and each of the seasonal teleconnection indices, averaged over blocks of 3-months covering the current month and the previous 11 ones [Colour figure can be viewed at wileyonlinelibrary.com]

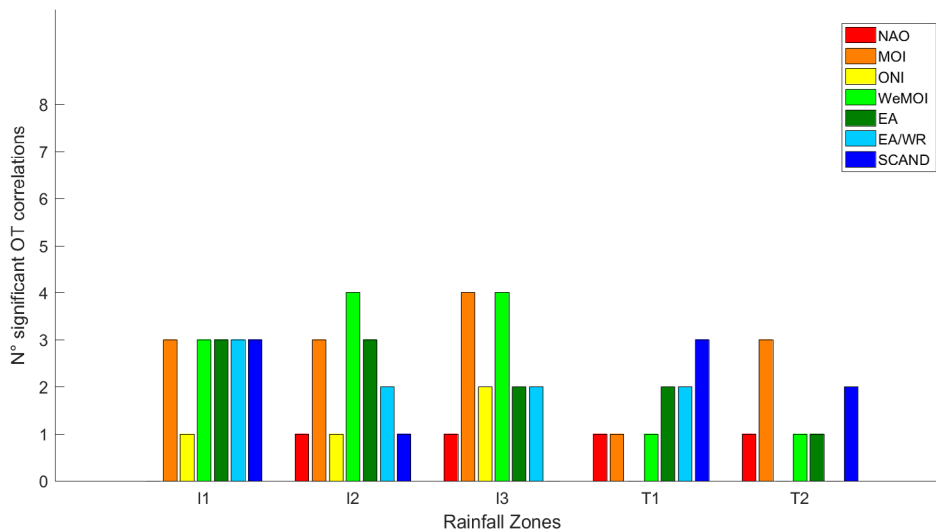
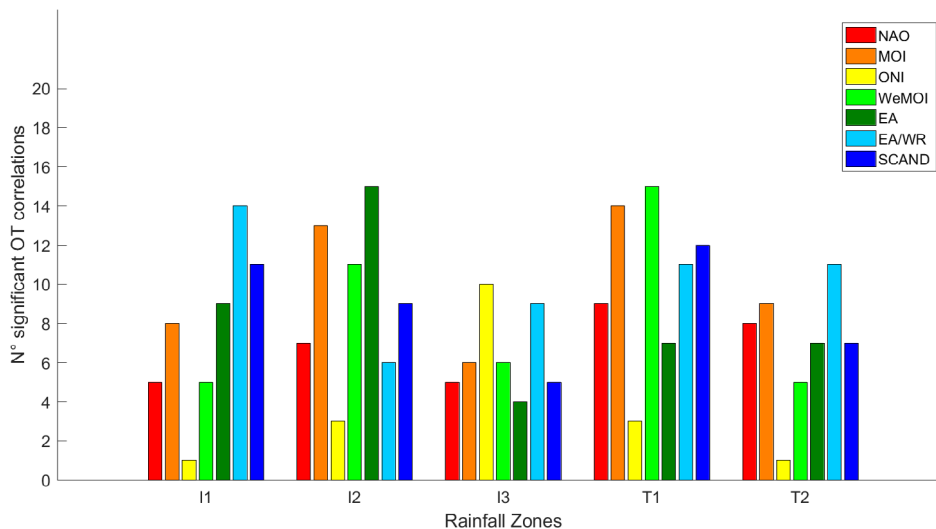


FIGURE 4 The number of significant correlation coefficients higher, in absolute value, than 0.2 (OT CCs) at each rain zone (RZ) in Calabria for the seven teleconnection indices. Correlations are computed between monthly precipitation over each RZ and each of the monthly teleconnection indices, for the current month and the previous 11 ones [Colour figure can be viewed at wileyonlinelibrary.com]



as Over-Threshold, from now on) for each teleconnection index and for each Rainfall Zone.

3.1 | Seasonal teleconnection indices versus seasonal cumulated precipitation

The first comparison between precipitation and teleconnection pattern indices was performed on a seasonal scale, following a usual climatological approach. Seasons were divided in the following way: December, January, and February (DJF) as winter; March, April, and May (MAM) as spring; June, July, and August (JJA) as summer; and September, October, and November (SON) as autumn. For each season, the Pearson correlation has been evaluated between seasonally cumulated precipitation and the seasonally averaged teleconnection pattern indices for the previous four seasons following Equation (3). For example, winter precipitation of 1952 was compared with autumn, summer, spring and winter average teleconnection pattern indices of 1951.

Table 1 shows, for each table box (i.e., for each season vs. season combination), the significant mode of variability with the highest CCs. Tags -1 to -4 refer to the previous one to four seasons' averaged teleconnection pattern indices, respectively, which precede the season of the examined precipitation. From Table 1, it is possible to see that the highest correlations are all comprised between magnitudes of 0.2 and 0.3 in absolute values. WeMOI and EA showed the greatest number of the highest correlations. In particular, the highest CCs (in absolute value) have been identified with EA in summer in the RZs I1 (0.29) and T2 (-0.28) and in winter in the RZ I2 (-0.28). The season which showed more significant OT correlations was autumn, while spring was the one with less. The RZ with the largest number of correlations was T1, where 6 of 16 season-season combinations experienced a significant OT CC. In the other RZs OT CCs have been detected as follows: 3 for I1, 2 for I3 and T2 and only 1 for I2.

Figure 2 shows the total number of OT correlation values identified for each teleconnection pattern index in each of the five RZs. As summarized in Table 1, the most relevant modes of variability in Calabria were WeMOI, with 6 OT correlation values, out of a total of 80 possible correlation values, and EA, with 5. NAOI, MOI, ONI, and EA/WR had only one OT correlation, while SCAND had none at all.

3.2 | Three-months averaged teleconnection indices versus monthly precipitation

For this analysis, monthly precipitation has been correlated with the 3-month averaged teleconnection indices

corresponding to the previous 3 months (including the current month) and then to the three previous blocks of 3-months (i.e., from 3 to 5 months back, 6 to 8 months back and 9 to 11 months back).

As regards the CC, only MOI, EA and EA/WR showed values equal or above 0.3 in absolute value (Table 2). In fact, August precipitation and MOI in the period March-to-May showed correlation coefficients equal to 0.3, 0.32, and 0.34 in the RZs I1, T1, and T2, respectively. Similarly, a CC equal to 0.3 in absolute value has been obtained in the RZ I2 between January precipitation and EA in the period May-to-July and in the RZ I1 between July precipitation and EA in the period December-to-February. Finally, a CC of 0.3 has been observed between October precipitation and EA/WR (May-to-July) in the RZ T1.

Globally, the 3-month averaged teleconnection pattern indices that most often correlate significantly and with OT CC with the monthly precipitation in Calabria have been identified as MOI, WeMOI and EA, with 14, 13, and 11 instances, respectively (Figure 3). On the other hand, NAO and ONI have been detected as the least frequently correlating, with four instances each; moreover, ONI does not correlate at all in the two western RZs T1 and T2.

Considering the RZs, the eastern Zones show more OT CC results (16 for I1, 15 for I2, and I3) than the western ones (10 for T1 and 8 for T2).

3.3 | Monthly teleconnection indices versus monthly cumulated precipitation

Monthly precipitation was finally compared with teleconnection pattern indices from the current month and back for the other 11 previous months (examining thus a full year, including the current month; see Table 3 and Figure 4).

An interesting result from Table 3 is that almost all the correlation values with the highest magnitude (equal or higher than 0.3 in absolute value, so greater than the prefixed value of 0.2) occur between monthly precipitation and the same month's index value. There are only few exceptions, all occurring for the Mediterranean Oscillation: in I1 for October precipitation versus February teleconnections (CC = -0.3) and in T1 and T2 for August precipitation versus October teleconnections (CCs equal to 0.3 and 0.32, respectively).

CC values with MOI are particularly high for the RZs T1 and T2 (for T1: 0.35, -0.46 , and -0.37 in January, February, and March, respectively; for T2: -0.36 and -0.37 in February and March, respectively). In four out of the five RZs, MOI is the teleconnection which has

the highest CCs; the only exception is I3, where NAO has the highest correlation (0.37, for October precipitation versus October teleconnections).

Looking at each individual rainfall zones, comparing Tables 1 and 3, we can see that by using month versus month analysis, I1 shows OT CC values in 43 month-month combinations out of 144 (30% of instances), compared to 18.75% of OT CC instances obtained through season-season analysis (see Section 3.1). A similar increase in relevance is seen at each RZ (I2 rises from 6.25 to 33%, I3 from 12.5 to 23%, and T2 from 12.5 to 22%), with the exception of the RZ T1, where season-season correlation gives OT values in 37.5% of instances but month-month correlation does so only in 28% of instances.

If we look at Figure 4 adding all OT CC values for each mode of variability from all RZs, it is clear that all teleconnection pattern indices taken into account have OT correlations with monthly precipitation. Correlations with EA/WR present OT values in 51 month-month calculations (out of globally 720, that is, 7% of instances), MOI in 50 (7%), SCAND in 45 (6%), WeMOI and EA in 42 out of 720 (6%), and NAO in 37 out of 720 (5%). For all six indices, the occurrences are divided more or less evenly between the five RZs. Correlations of monthly precipitation with ONI, on the other hand, have only 18 OT values (2.5%), and 14 of them are on the eastern RZs (I1, I2, I3): only four instances refer to the western zones (T1 and T2).

In regard to rainfall zone distribution (see Figure 4), the rainfall zone with more OT CCs is T1 with 71 values, followed by I2 with 64 and I1 with 53. RZs with the least values are T2 with 48 and I3 with 45.

4 | DISCUSSION

In order to produce significant correlation analyses, it is necessary to carefully select the data and their spatial and temporal resolution. This study clearly shows how the selection of data can impact the validity of the results. When using seasonal averages of teleconnections against seasonal precipitation, most correlation values were found to be not significant at the 5% confidence level, or did not show any correlation at all. On the other hand, when studying precipitation at the monthly scale, by comparing it either to seasonal or to monthly teleconnection averages, more correlation results showed up. In this way, it is possible to establish significant links between teleconnections and precipitation, which emphasize the benefit of increasing the statistical basis of the study from single stations or single points to include all the stations in a region with similar mesoscale precipitation characteristics.

Many studies have been published about the possible influence of teleconnections on European and especially Mediterranean precipitation (e.g., Fraedrich, 1994; Kutiel *et al.*, 1996; Maheras *et al.*, 1999; Mariotti *et al.*, 2002b; Dunkeloh and Jacobeit, 2003; Xoplaki *et al.*, 2004; Shaman and Tziperman, 2011; Shaman, 2014), and most of these studies were conducted seasonally by correlating punctual precipitation data at one station or grid point with teleconnection averages. However, this can lead to problems in obtaining meaningful results because the database for correlation analysis is too small. A different approach has been proposed by Ríos-Cornejo *et al.* (2015) in Spain, by building rainfall zones through Principal Component Analysis of kriging-interpolated teleconnection-precipitation Spearman correlation results, at monthly, seasonal and annual time scales. Often, studies analysed selected time periods (e.g., winter months and/or rainy seasons), while year-round analyses produced little significant results, and studies at increased temporal (i.e., monthly) scale were not performable because of statistical constraints. Comparing, for instance, seasonal accumulated precipitation with seasonal averaged teleconnection indices for a 30-years period (the usual time frame used in climate analysis), the test would be performed only over 30 values. This factor often leads to many correlation values calculated at the desired locations not passing significance tests, or giving very weak correlation results (e.g., Mariotti *et al.*, 2002b; Casanueva *et al.*, 2014; Ciarlo and Aquilina, 2015; Dayan *et al.*, 2015; Baek *et al.*, 2017; Verner *et al.*, 2018).

On the other hand, by using an ensemble of data from stations belonging to the same Rainfall Zone, it was possible to reproduce results from previous studies while expanding on them. For example, Mariotti *et al.* (2002b) found no correlation (i.e., no correlation coefficient with a magnitude higher than 0.05 in absolute values) between ENSO and fall precipitation in Calabria for the period 1948–1996, correlating precipitation with the SST anomalies in the Nino 3.4 region (which corresponds to the 5°N–5°S, 120°–170°W area of the Pacific Ocean). Conversely, in this study, correlations between ENSO and fall precipitation even higher than 0.2 in magnitude have been identified for the period 1951–2010, using the ONI index, which is a 3-months running mean of the above-mentioned SST Nino 3.4 values. More generally, results of this study suggested the Mediterranean Oscillation as the most important teleconnection driver of precipitation for Calabria, confirming with a higher degree of magnitude results from Ciarlo and Aquilina (2015) for Calabria during the 1969–1999 time period. In statistics, correlations between 0.4 and 0.6 are only considered moderate, and between 0.2 and 0.4 weak, so that a range in correlation between 0.2 and 0.37 does not really imply a qualitative differentiation. Thus, as the results still show weak correlation coefficients, the most

TABLE 4 Number of rain gauges, out of the total number of stations in a rainfall zone, for which individual Pearson correlation results had a level of significance of at least 0.05

Rainfall zone	Significant stations	Total stations	% stations
I1	6	11	54%
I2	4	13	31%
I3	7	19	37%
T1	10	20	50%
T2	7	16	44%
Calabria	34	79	43%

important feature of the method lies in the increased significance of the results themselves, as the statistics are based on a broader range of data.

Another possibility for expanding results to the regional scale has been to average individual correlation results from stations (e.g., Coscarelli *et al.*, 2013). To determine quantitatively similarities and differences between this rainfall zone-based study and the averaging of individual stations results, seasonal Pearson correlation and significance were also computed for the individual stations, and then averaged over the five RZs. A comparison between the two methods is presented in Table 4, which shows how many stations, out of the total number for each RZ, were able to produce statistically significant correlation results. Globally, only 43% of the stations would provide significant correlation results, so 57% of the data used for the regional averaging were completely discarded. On the other hand, the method proposed in this study uses all the valid and available station data. Thus, results from the averaging of stations (not shown) were much less robust than ones from creating a RZ database. Let us take, for example, the very large I2 RZ, with maritime, hilly and mountainous areas: only four valid stations would remain by considering them individually, making it very unlikely that they can be representative not only statistically but, above all, physically, of such a large and complex area. This is also a further argument for handling with care correlation results of teleconnection pattern indices against coarse GCM grid points or isolated representative stations in reanalysis.

In summary, the results show that it is possible to include seasonal teleconnection data into future seasonal outlook predictions. Even though not all teleconnections have significant correlations with seasonal and monthly precipitation, results can be tailored for each of the rainfall zones. As an example, in RZ T1 every season is significantly influenced by teleconnection averages from the previous year, while in RZ I1 monthly precipitation is influenced by teleconnection indices of the previous year

in 10 months out of 12. Positive or negative phases of NAO, WeMOI, and MOI might be especially relevant to include in projections over Calabria, to establish likelihood of seasonal precipitation excess or drought. For instance, a positive phase of MOI seems to increase the chance of August precipitation, which might be assessed as a risk factor for late summer thunderstorms and flash floods.

The main limitations of this novel procedure are two: first of all, in order to be used, a set of stations who are geographically close and show similar physical features (e.g., precipitation patterns) must have been detected as a prerequisite to the correlation study; secondarily, it is not possible to use this method to individuate stations or small areas in a region that show local features, microclimate zones, and anomalous stations.

5 | CONCLUSIONS

In this work, correlation analysis at different time frames has been approached with a novel technique that takes advantage of the large-scale components of precipitation. The results confirmed the work hypothesis, that by using this approach it would be possible to increase statistical significance of results without compromising their reliability for the rainfall zones taken into account. In fact, most previous results were confirmed with better statistical significance, while new results were also achieved.

As regards to this, results suggest an influence of several teleconnection patterns on the precipitation in Calabria for the 1951–2010 period. Not surprisingly, the mode of variability which is most present among meaningful results is the Mediterranean Oscillation, already understood to be a major driver of climate over the whole region. On the other hand, other modes came also out as relevant, especially the Western Mediterranean Oscillation and the Eastern Atlantic pattern.

The method has been used for a network of sparse rain gauges, however similar studies can easily be performed on regular gridded data networks. Moreover, although the method has been used for precipitation in Calabria, it can be easily applied to any meaningful climatic variable which is relevant at the local level, for example, temperature, and at any region in Europe, provided that the assumption of similar climate patterns (i. e., belonging to the same microclimate or local climate region) holds true, or at least in regard to the variable taken into account.

It is possible to compare results from this method with other tests: comparing correlation from individual stations and/or grid points with the results from regional correlation can test how well the assumption of similar

climate holds for a region; on the other hand, it can also allow to find outlier stations or grid points that can signal some special feature of the considered area.


Given the relevant number of significant correlations, it might also be attempted to devise a predictive function through multivariate regression to estimate average regional seasonal precipitation anomaly.

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