AN OBJECTIVE DEFINITION OF SEASONS FOR THE MEDITERRANEAN REGION BASED ON SYNOPTIC WEATHER TYPES

KOTSIAS G.[1], LOLIS C.J.[1], HATZIANASTASSIOU N.[1], LIONELLO P.[2], BARTZOKAS A.[1]

[1]LABORATORY OF METEOROLOGY, DEPARTMENT OF PHYSICS, UNIVERSITY OF IOANNINA, IOANNINA, GREECE

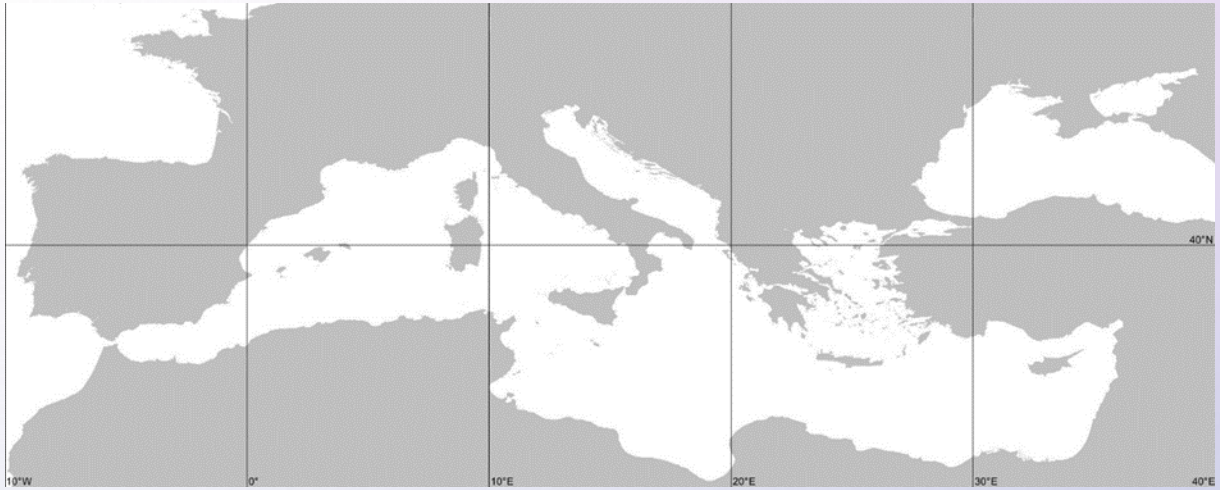
[2]DEPARTMENT OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES AND TECHNOLOGIES, UNIVERSITY OF SALENTO, LECCE, ITALY

AIM

- The aim of this work is to give an **objective** definition of the seasons for the Mediterranean region based on **synoptic weather types**.
- Comparison of the defined seasons with the conventional ones.
- Study of possible long-term changes of the seasons' characteristics.

DATA

- Daily grid point values of two sets of climatological parameters for the Mediterranean region (50°N-30°N και 10°W-40°E) obtained from the NCEP/NCAR database for the period 1/1/1949 - 31/12/2018
  - 2m air temperature, 2m zonal and meridional wind components and total cloud cover gridded at 1.875°×1.905°
  - 500hPa and 1000hPa geopotential heights, 500hPa and 850hPa temperature, 850hPa specific humidity and precipitable water gridded at 2.5°×2.5°



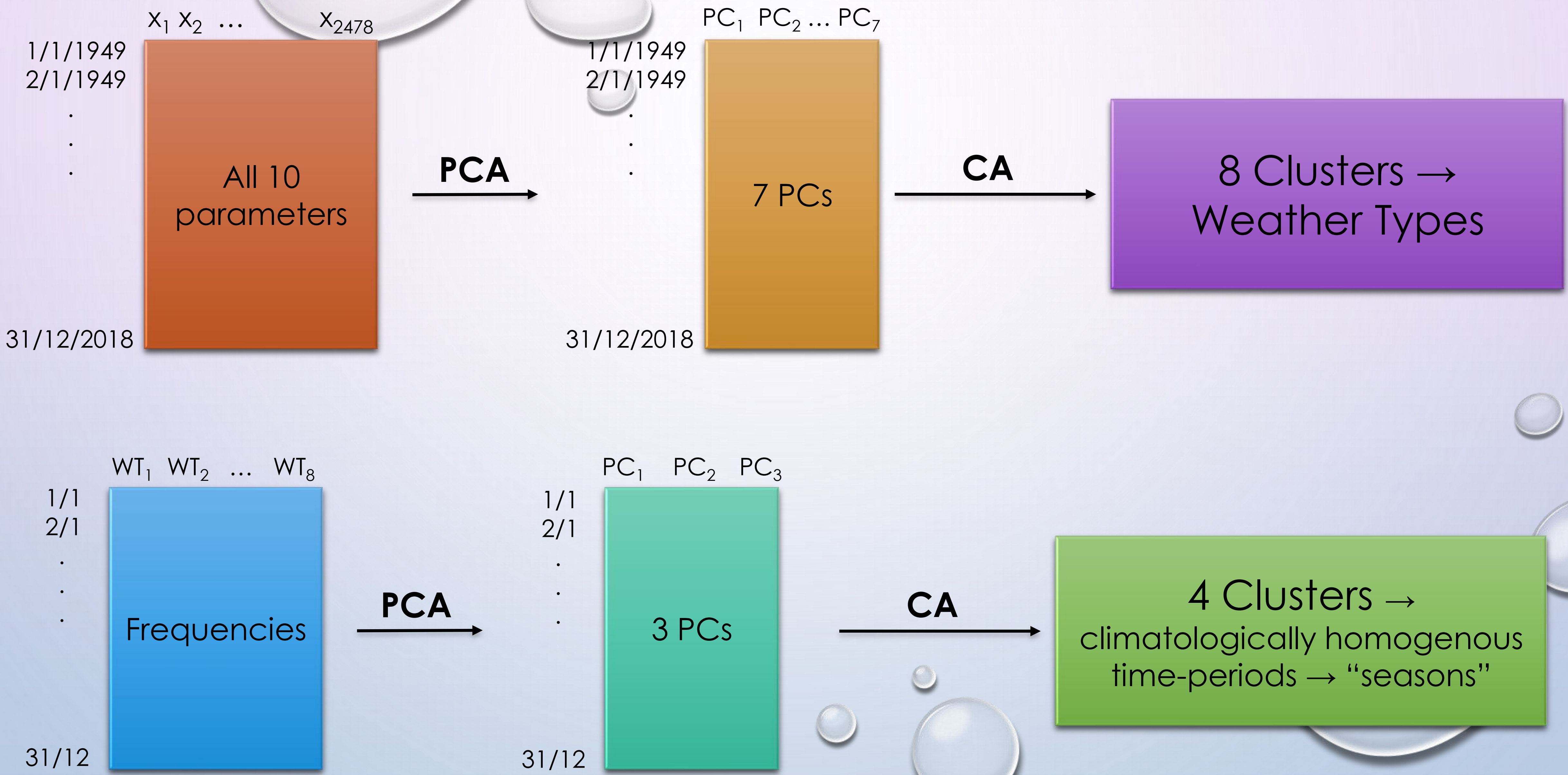
The Mediterranean region

METHODOLOGY

- Two multivariate statistical methods were applied: **Principal Component Analysis** (PCA) and **Cluster Analysis** (CA).
- **PCA** is a multivariate statistical method that expresses a set of p potentially correlated variables via a new smaller set of m (m<<p) uncorrelated variables, called Principal Components (PCs), and is commonly used as dimensionality reduction tool in climatological studies. The number of the statistically significant PCs is indicated by the SCREE plot.
- **CA** is a statistical method that classifies the cases of a set of variables into objectively defined distinct groups, which are called clusters, such that each cluster is as homogeneous as possible with respect to the clustering variables. The steps of CA include the selection of the measure of similarity (Euclidean distance), the type of clustering technique and clustering method (non-hierarchical k-mean) and a decision regarding the number of clusters (distortion test).

In the present work:

1. PCA is applied on the inter-annual variations of all 10 parameters → 7 PCs
2. CA is applied on the 7 PCs → 8 Weather Types (WTs)
3. PCA is applied on the 5-day moving averages of the intra-annual variations of the 8 WTs frequency → 3 PCs
4. CA is applied on the 3 PCs grouping dates of the year (forming time periods/seasons) with similar frequency distribution among the 8 WTs → 4 seasons
5. The same procedure is followed for the 5 overlapping 30-year sub-periods: 1949-1978, 1959-1988, 1969-1998, 1979-2008, 1989-2018 in order to study possible long-term changes of the seasons' characteristics.

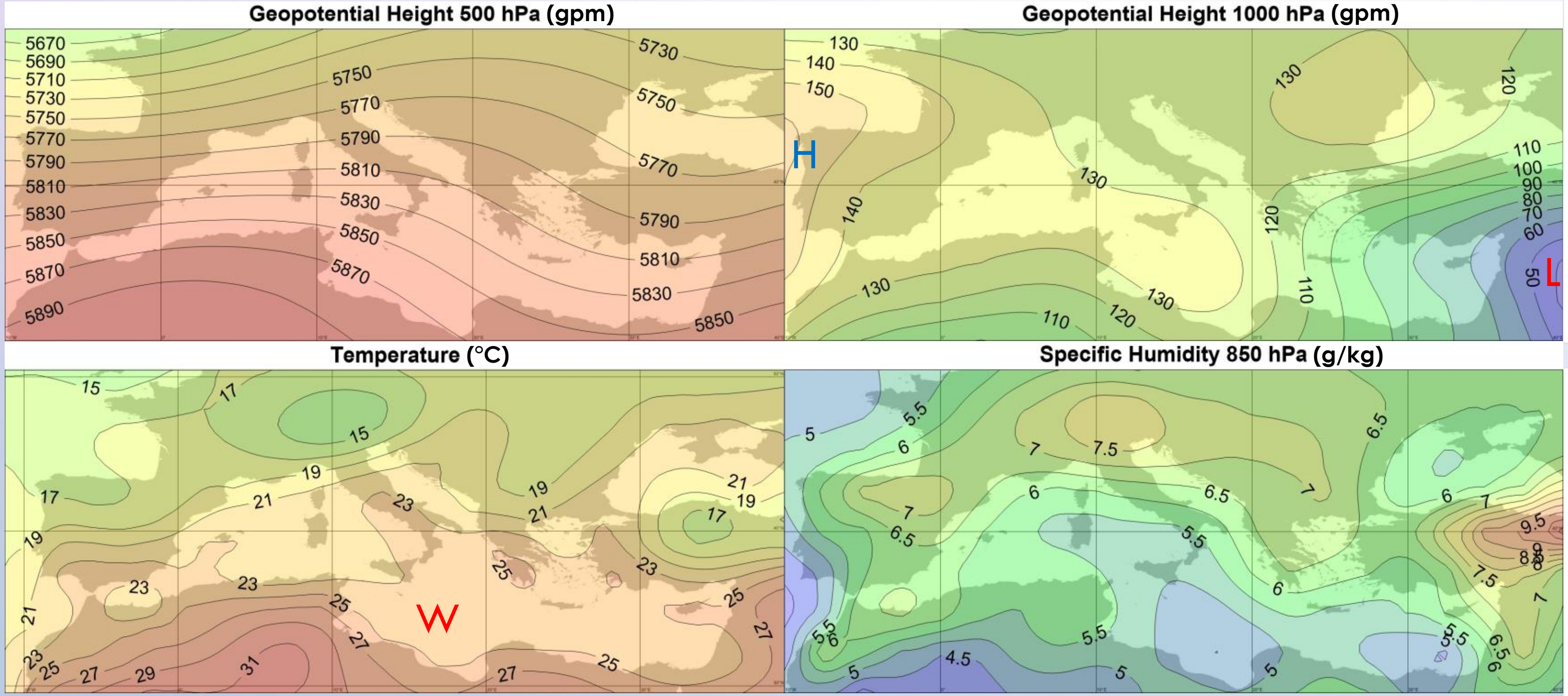


x_1 x_2 … x_{2478}
1/1/1949
2/1/1949
31/12/2018
All 10 parameters
PCA
PC_1 PC_2 … PC_7
1/1/1949
2/1/1949
31/12/2018
7 PCs
CA
8 Clusters → Weather Types
WT_1 WT_2 … WT_8
1/1
2/1
31/12
Frequencies
PCA
PC_1 PC_2 PC_3
1/1
2/1
31/12
3 PCs
CA
4 Clusters → climatologically homogenous time-periods → “seasons”

MEAN PATTERNS AND FREQUENCY HISTOGRAMS FOR THE 8 WEATHER TYPES

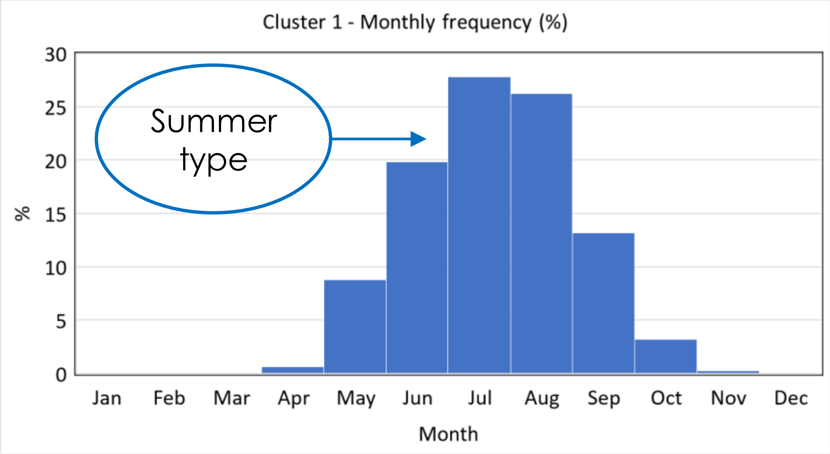
Weather Type 1

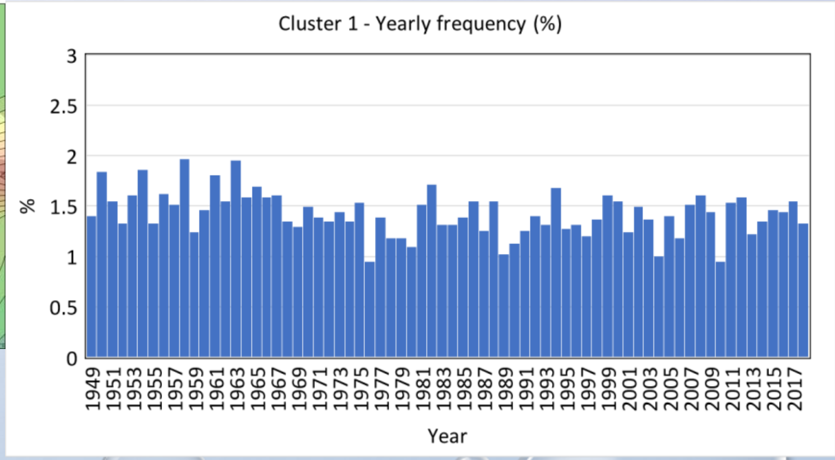
Extension of the Azores high
SW Asia thermal low



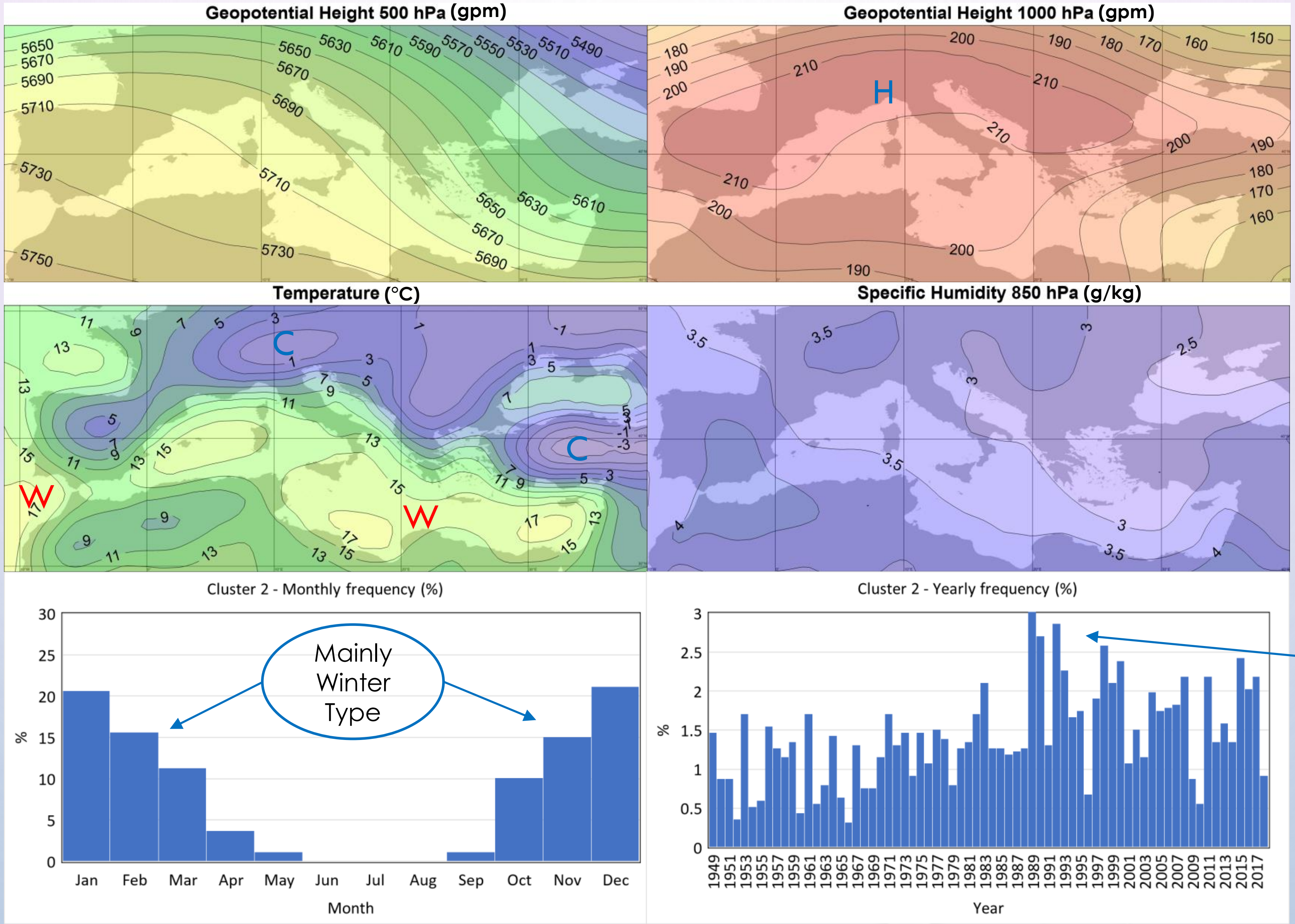
Warm Mediterranean Sea and N Africa

Increased humidity in eastern and northern Mediterranean





Weather Type 2



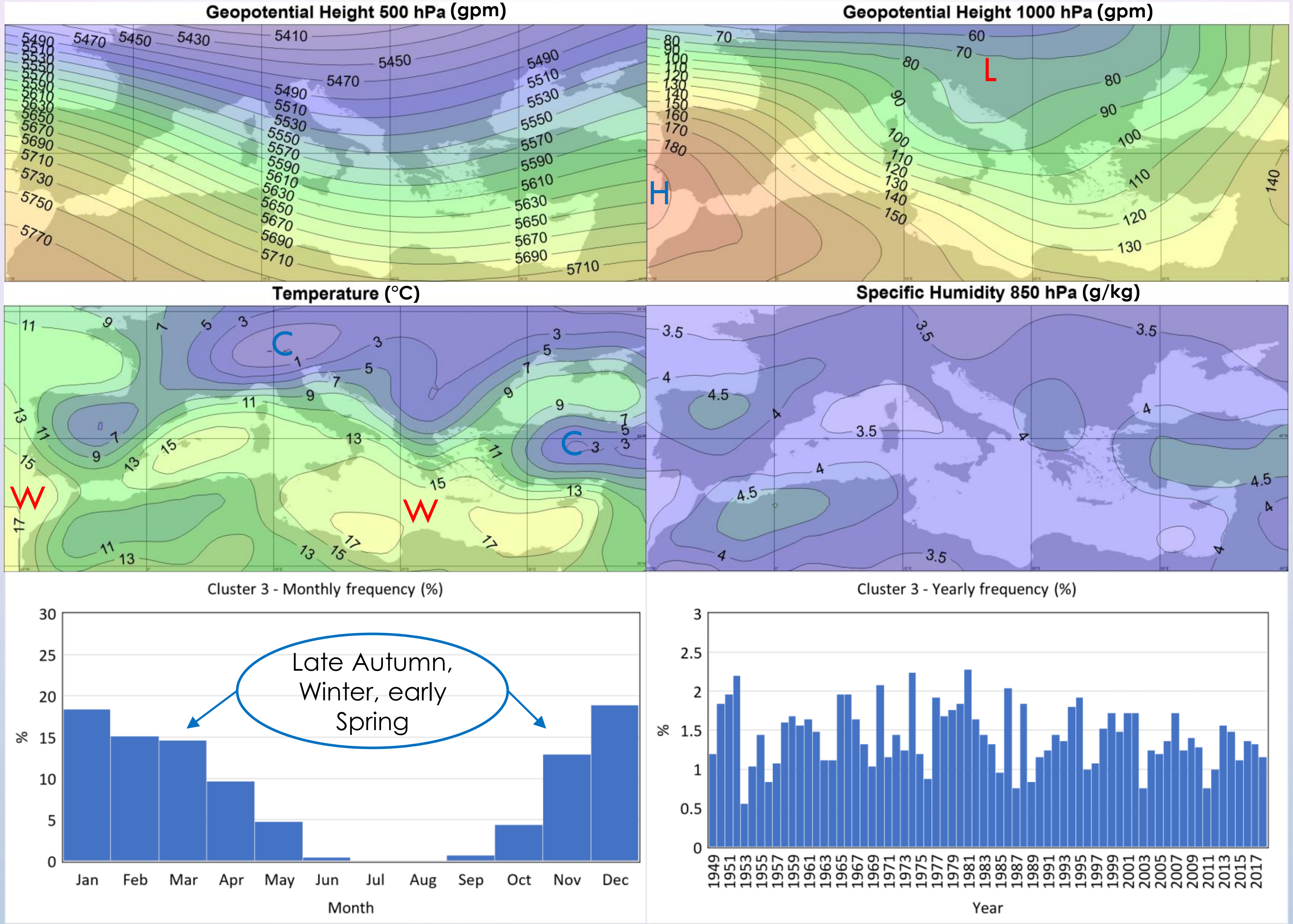
Strong anticyclone over the N Mediterranean

Warm seas and coastal areas
Cold inlands

Mostly during the 90s

Weather Type 3

Warm seas and coastal areas Cold inlands

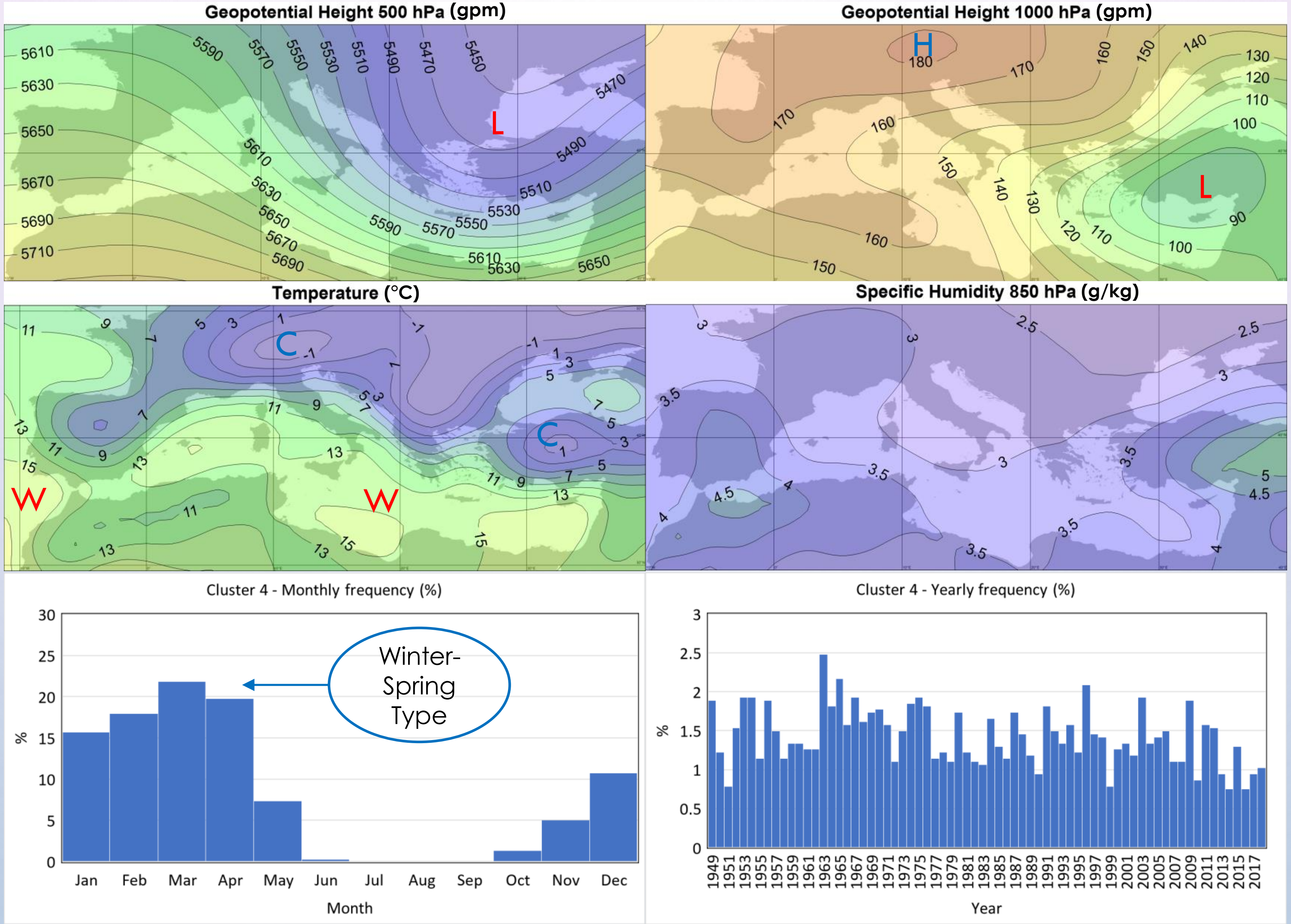


Low pressure system over northern Europe

Weather Type 4

Trough over E Mediterranean

Warm seas and coastal areas
Cold inlands

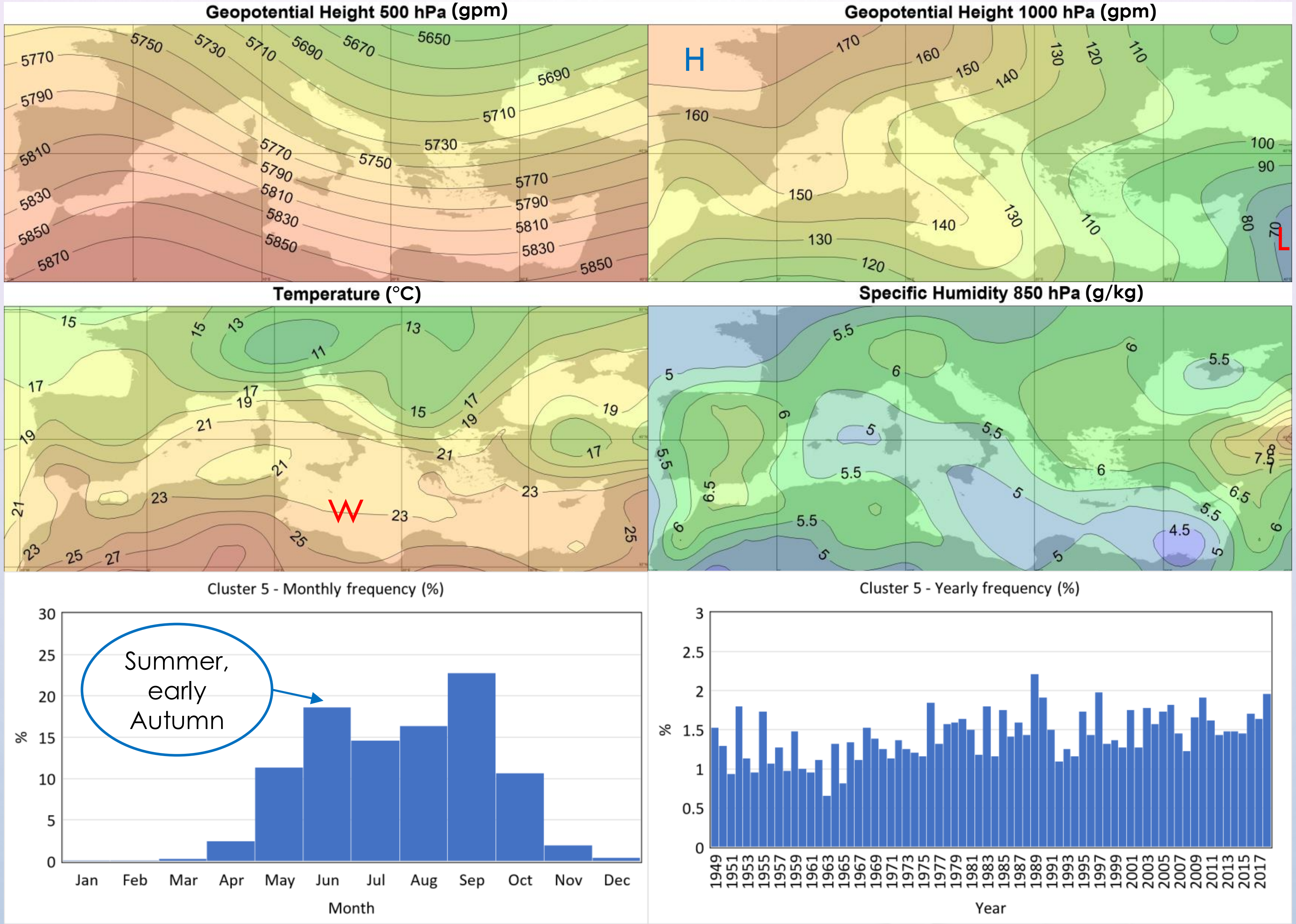


High-pressure system over central Europe
Low over E Mediterranean

Increased humidity in E Mediterranean and NW Africa

Weather Type 5

Warm Mediterranean Sea and southern areas



Anticyclone over NW Europe
SW Asia thermal low

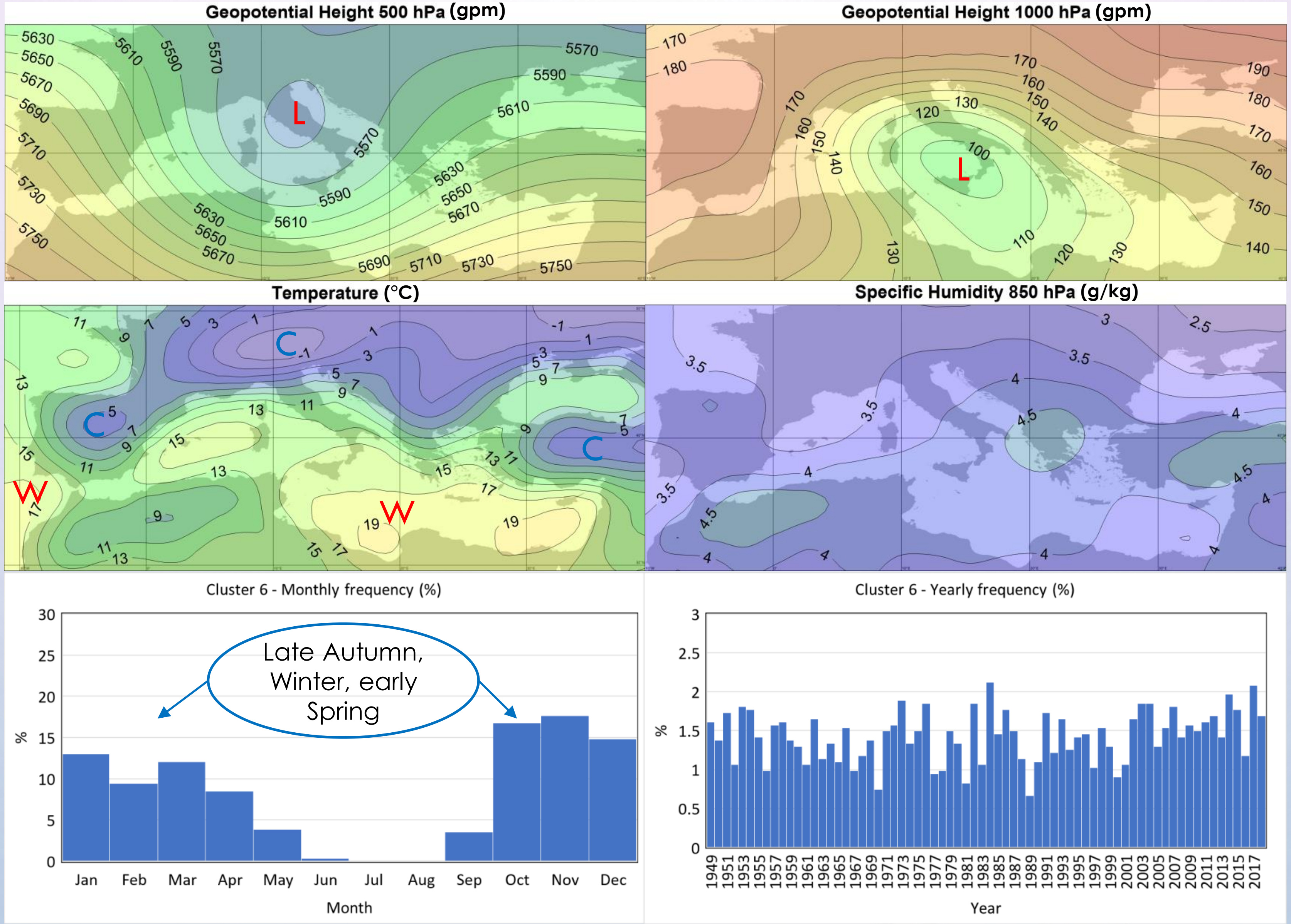
High humidity in E and N Mediterranean

Weather Type 6

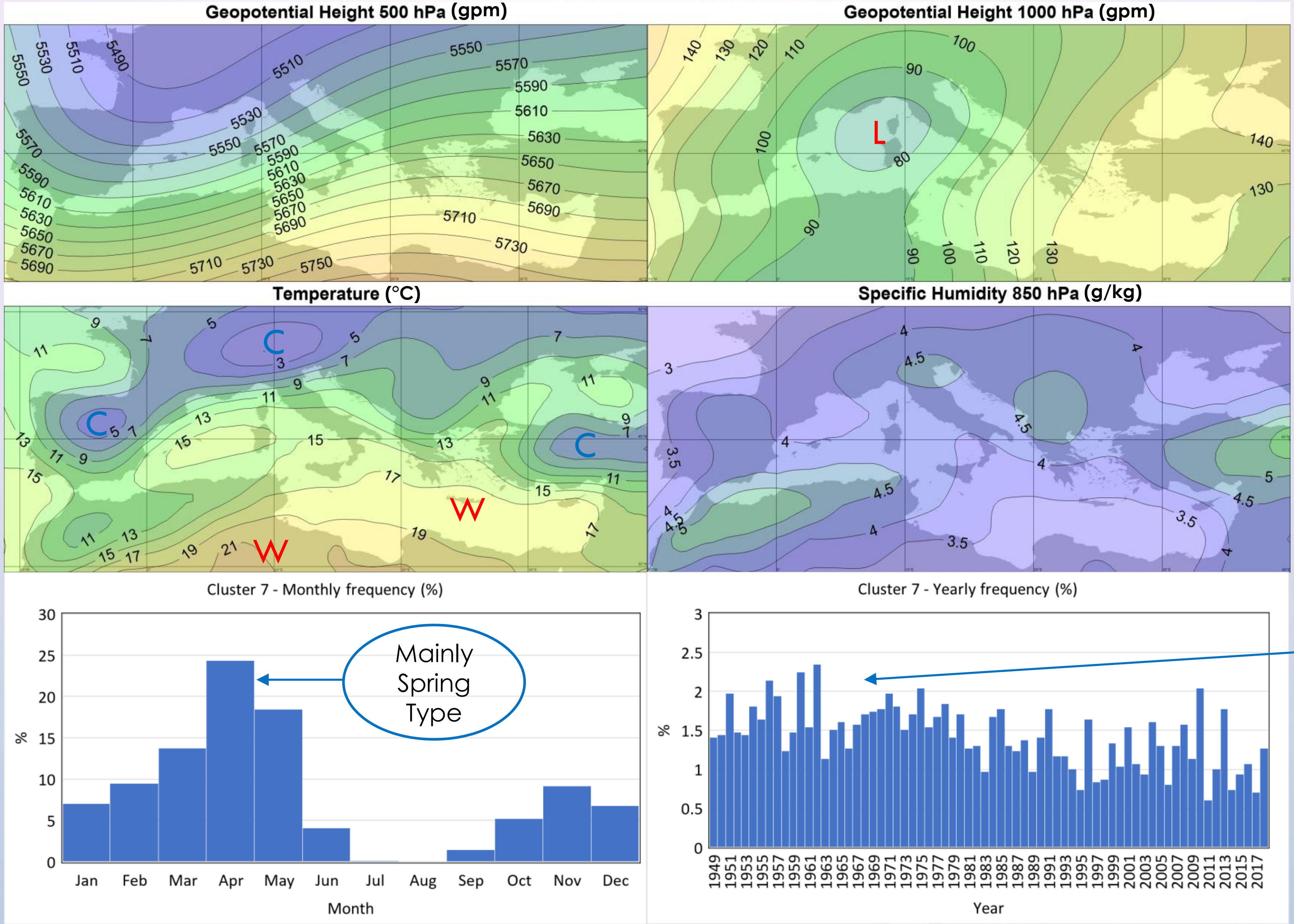
Trough over N Italy

Low-pressure system over Italy

Warm seas and coastal areas
Cold inlands



Weather Type 7



Low west of Italy

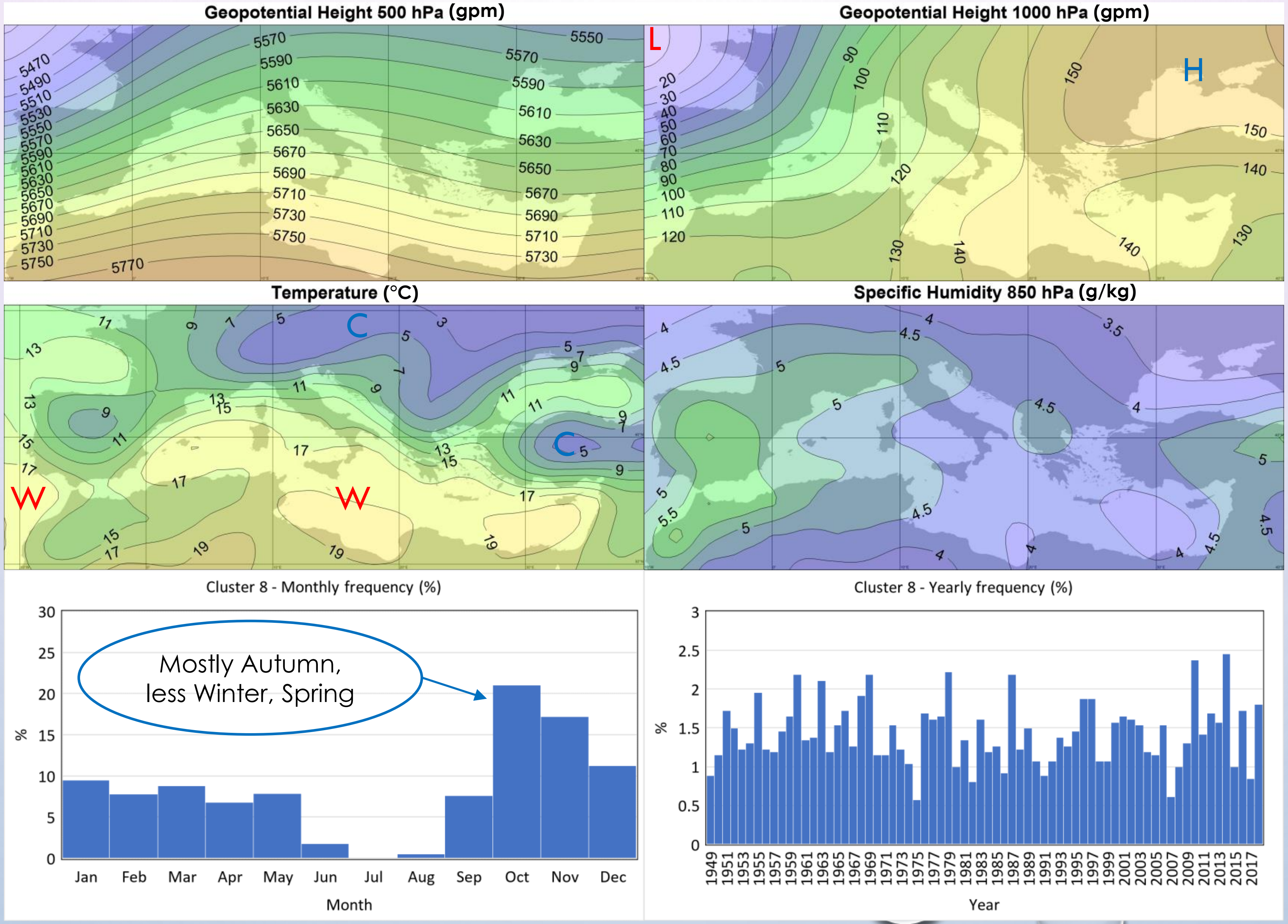
Higher temperatures over the seas, coasts and N Africa
Lower temperatures Europe and E Turkey

High humidity in E Turkey and NW Africa

Most in the first half

Weather Type 8

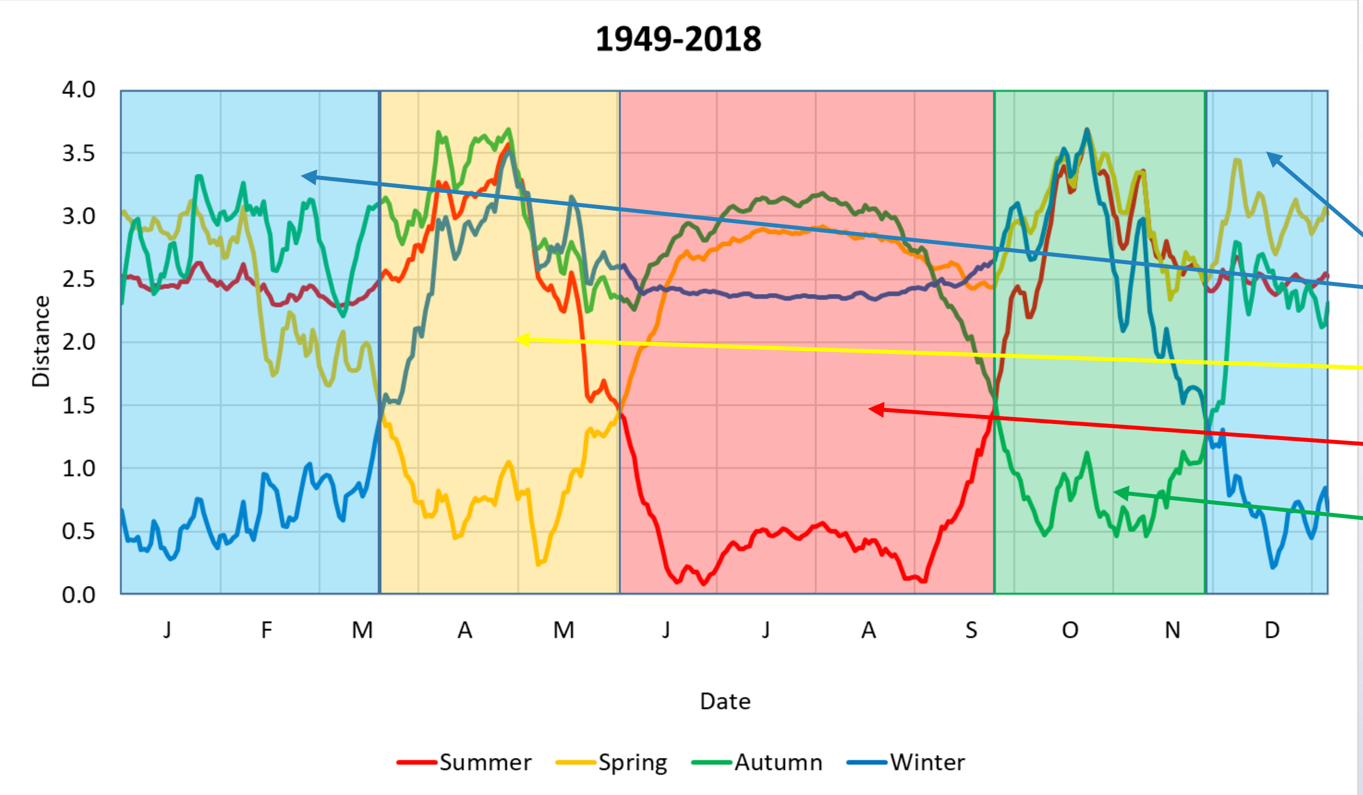
Warm seas and coastal areas
Cold conditions in Europe and E Turkey



High-pressure system over eastern Europe
Low in N Atlantic Ocean

Higher humidity in W Mediterranean

THE INTRA-ANNUAL VARIATION OF THE DISTANCES OF DATES FROM THE CLUSTER/SEASON CENTERS – DEFINITION OF SEASONS

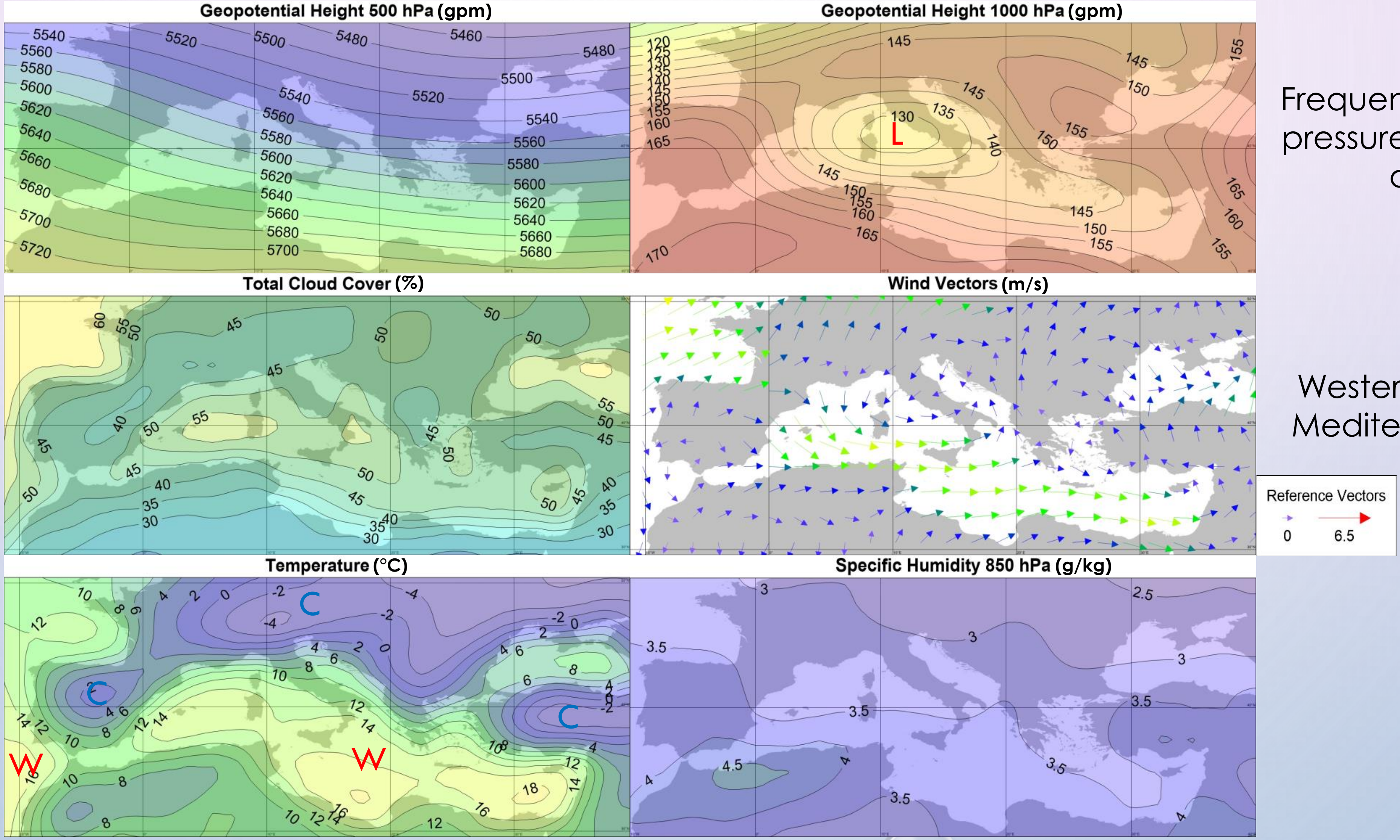


4 objectively defined and distinct seasons

Season	Onset/cessation dates	Duration (D)
Winter	26 November – 20 March	115
Spring	21 March – 31 May	72
Summer	1 June – 22 September	114
Autumn	23 September – 25 November	64

Season	Central Date
Winter	15 December
Spring	7 May
Summer	26 June
Autumn	7 November

Winter (15 December)



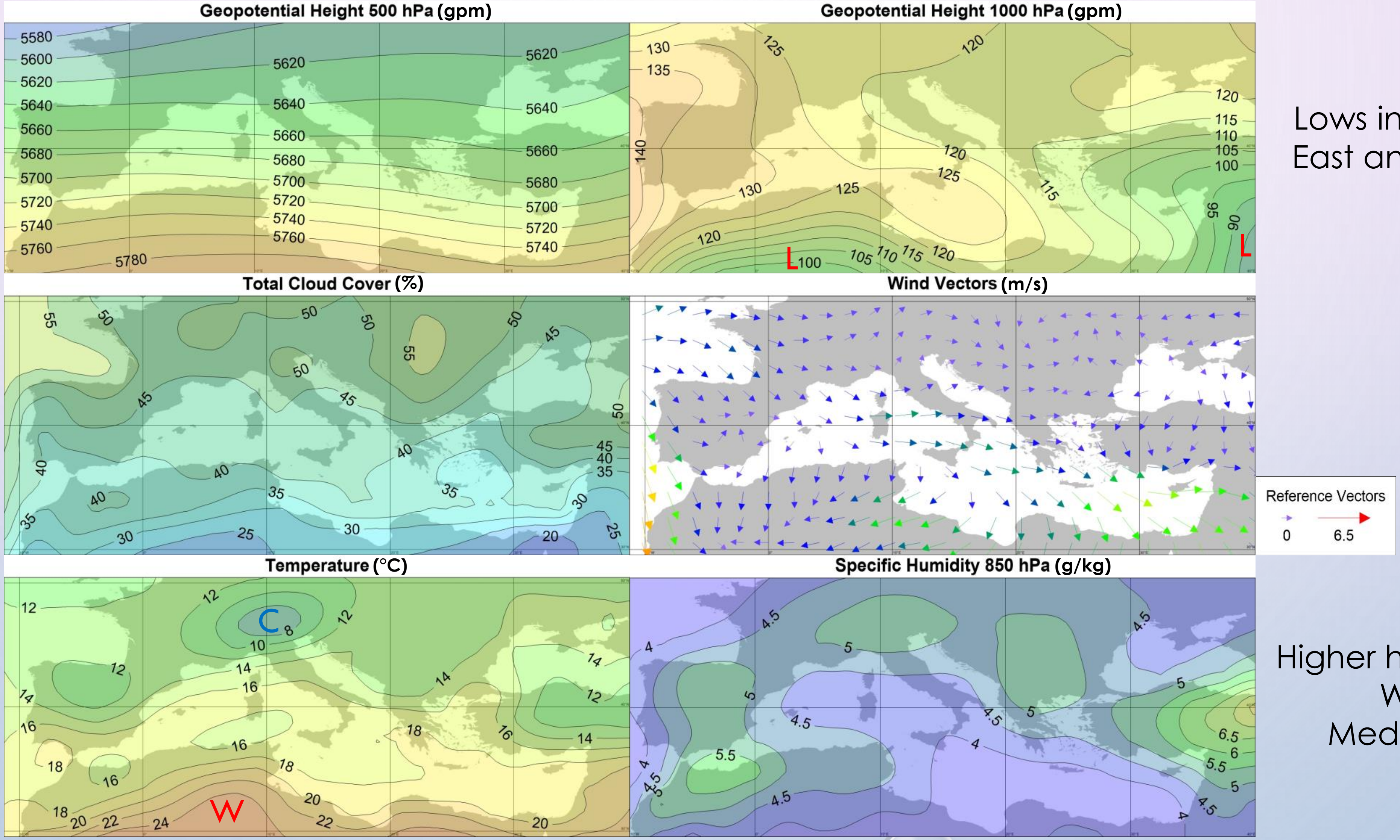
Frequent/strong low-pressure system west of Italy

Higher cloudiness over the seas

Westerlies over the Mediterranean Sea

Warm seas and coastal areas
Cold inlands

Spring (7 May)



Lows in the Middle-East and NW Africa

North-south cloudiness gradient

North-south temperature gradient

Higher humidity in the W and E Mediterranean

Summer (26 June)

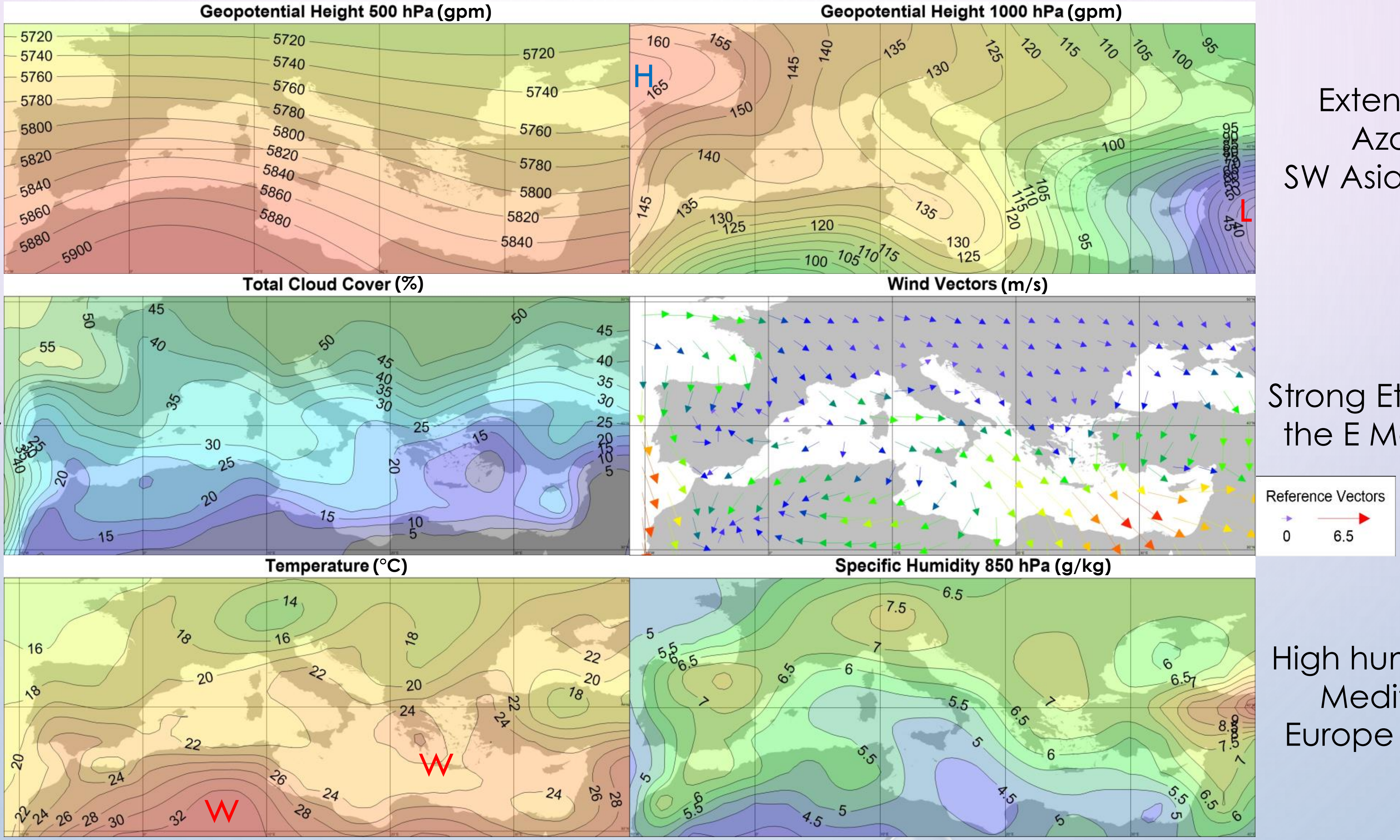
Extension of the Azores high
SW Asia thermal low

Low cloudiness in the Mediterranean, higher in Europe

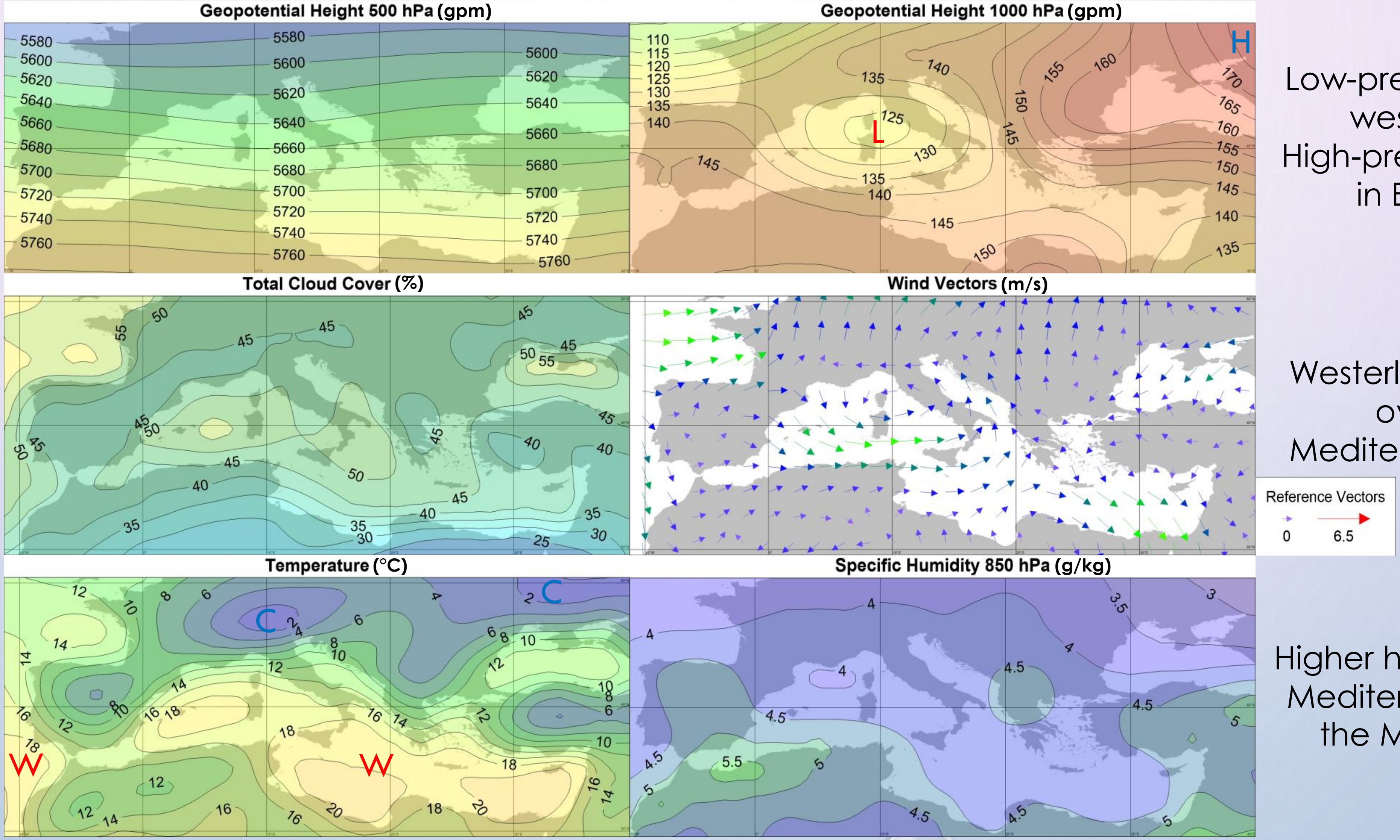
Strong Etesian winds in the E Mediterranean

High temperatures in the Mediterranean and N Africa

High humidity in the N Mediterranean, Europe and SW Asia



Autumn (7 November)



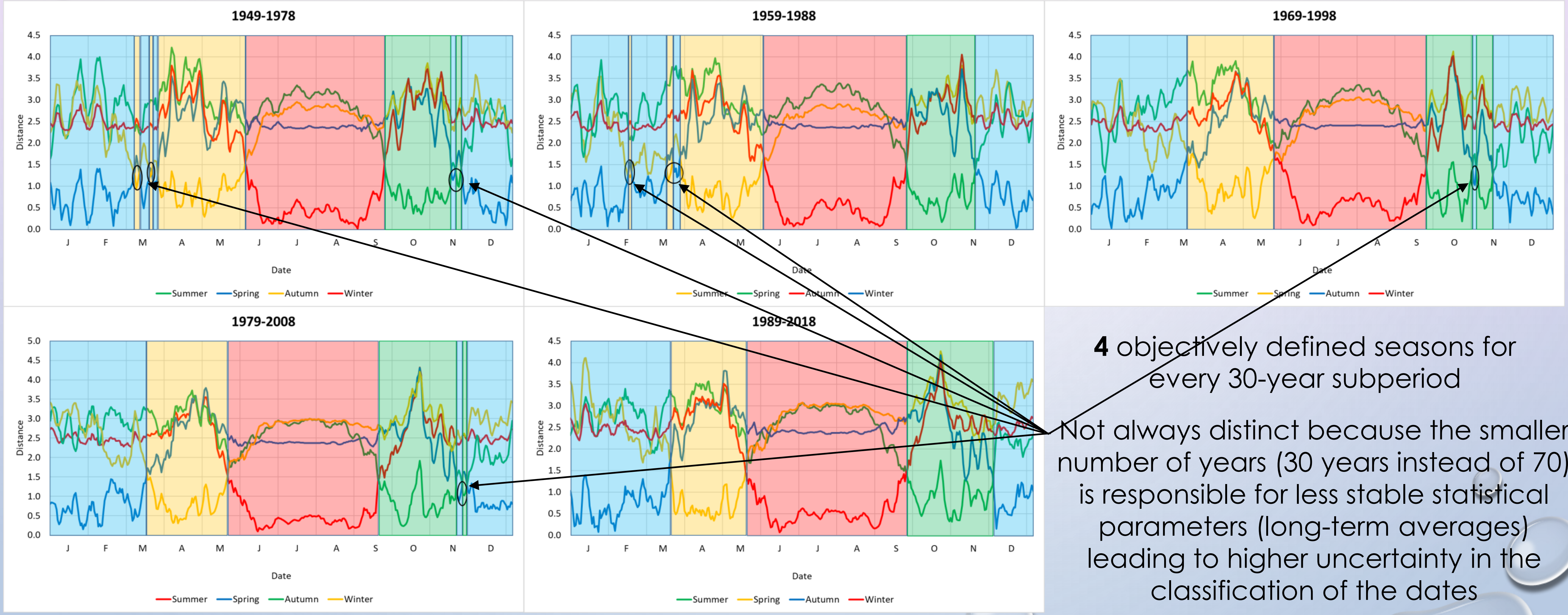
Low-pressure system west of Italy
High-pressure system in E Europe

Westerly circulation over the Mediterranean Sea

Warm seas and coastal areas
Cold inlands

Higher humidity in SW Mediterranean and the Middle-East

THE INTRA-ANNUAL VARIATION OF CLUSTER DISTANCES FOR EACH 30-YEAR SUB-PERIOD



4 objectively defined seasons for every 30-year subperiod

Not always distinct because the smaller number of years (30 years instead of 70) is responsible for less stable statistical parameters (long-term averages) leading to higher uncertainty in the classification of the dates

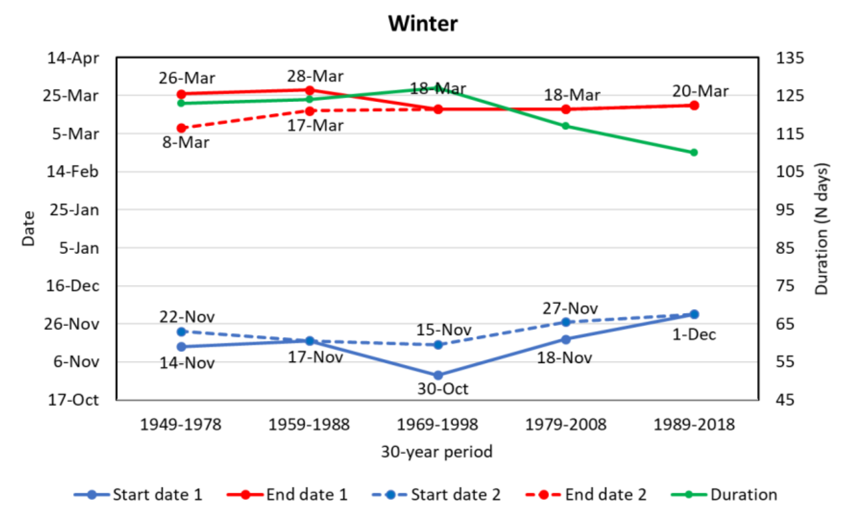
THE LONG-TERM VARIATIONS OF THE START/END DATES AND THE DURATION OF THE FOUR OBJECTIVELY DEFINED SEASONS

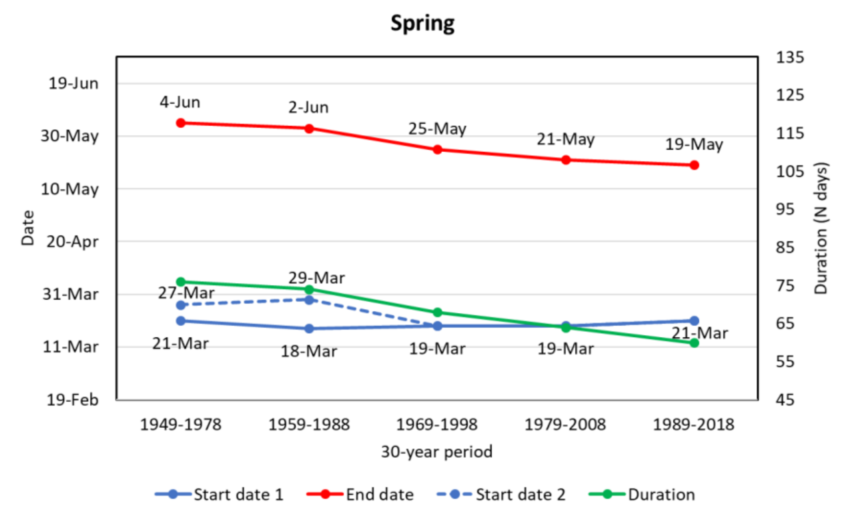
Start/End date 1 refer to the first/last appearance of the season while Start/End date 2 refer to the first/last appearance of the season after/before the intervention (if it exists) of the adjacent season

Duration is the actual number of dates in each season

Winter

- Duration decreases after the 3rd period
- Starts later in recent periods



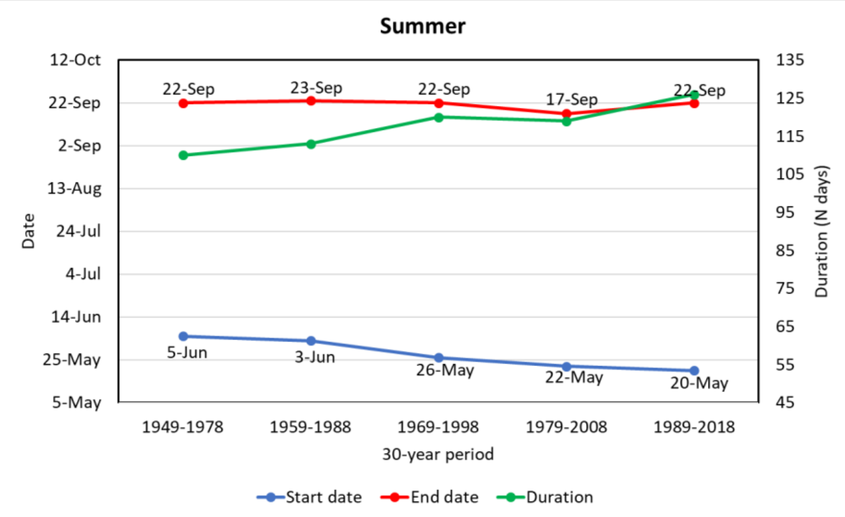


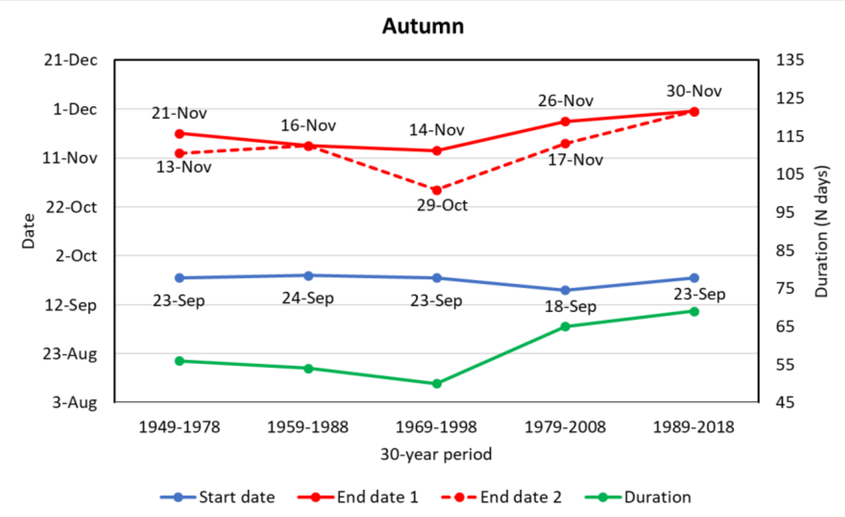
Spring

- End date continuously moves earlier
- Duration decreases

Summer

- Start date continuously moves earlier
- Duration increases





Autumn

- Ends later in last decades
- Duration increases in recent decades

CONCLUSIONS

- PCA and CA are applied to the daily time-series of 10 climatological parameters for the period 1/1/1949-31/12/2018 and result in 8 Weather Types for the Mediterranean region.
- PCA and CA are applied again now on the intra-annual variations of the frequencies of the 8 WTs and 4 seasons are objectively defined.
- Winter: 26 November – 20 March (115 days)
- Spring: 21 March – 31 May (74 days)
- Summer: 1 June – 22 September (114 days)
- Autumn: 23 September – 25 November (64 days)
- Same procedure followed for five overlapping 30-year sub-period : 1949-1978, 1959-1988, 1969-1998, 1979-2008, 1989-2018 → 4 objectively defined season in every case
- Long-term changes of the seasons' characteristics (start/end dates, duration)
  - Winter starts later in recent periods resulting in a decreased duration
  - Though spring starts about the same time, the continuously earlier end dates lead to a decreased duration
  - With nearly constant end date, summer experiences an increase in duration due to continuously earlier start dates
  - Autumn starts about the same time but ends later in recent periods resulting in increased duration