NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS
Department of Physics

The cold front identification scheme MedFTS_DT in the Mediterranean and the estimation of related frontal precipitation

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Background

- Cold fronts are often associated with extreme weather events.
- Frontal identification by automated methods is necessary.
- Automated identification methods employ:
  - Thermal criteria
  - Wind criteria (kinematic criteria)
- Particularity of the Mediterranean
  - Closed sea basin with complex topography
  - Mediterranean fronts present smaller spatial and time scales and more complicated evolution as compared to fronts over oceans.

Identification of cold fronts- thermal criteria

TFP (Thermal Frontal Parameter)

$$TFP(T) = -\vec{\nabla}\left|\vec{\nabla}T\right| \cdot \frac{\vec{\nabla}T}{\left|\vec{\nabla}T\right|} = -\vec{\nabla}\left|\vec{\nabla}T\right| \cdot \hat{n}_T$$

where T represents: temperature, potential temperature, wet bulb potential temperature, thickness

- Algorithms (e.g Hewson, 2009; Hewson and Titley, 2010; Jenkner et al., 2010; Berry et al., 2011; Schemm et al., 2018; Catto and Raveh-Rubin, 2019)

Advantages

- Satisfactory performance in baroclinic regions

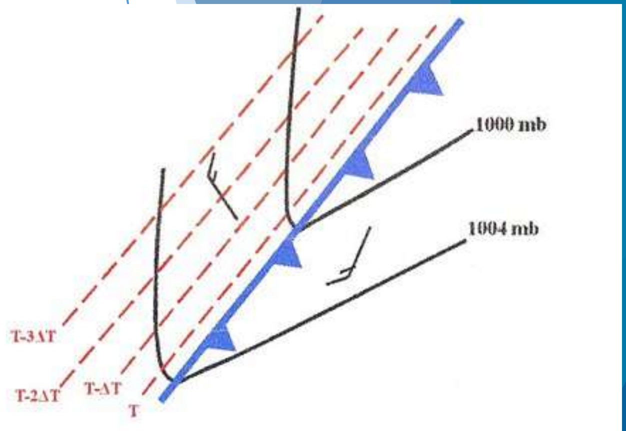
Disandantages

- Difficulty in discriminating cold from warm fronts
- Poor performance in regions with complex topography, such as coastal areas and regions with elevated topography

Identification of cold fronts- wind criteria

- Based on the wind direction shift: from southerly ahead of the cold front to northerly sector behind

Algorithm FTS (Simmonds et al., 2012)



Advantages

- Clear separation between cold and warm fronts
- Better performance for strongly elongated, meridionally oriented moving cold fronts

Disadvantages

- Poor performance for zonally elongated fronts

Objectives

- Description of the developed identification scheme of cold fronts in the Mediterranean, employing wind criteria additionally to thermal criteria.
- Application of the new scheme in the Mediterranean region on a climatological basis.
- Application of the new scheme in an Atlantic case (Storm Brendan-UK)

Development of MedFTS_DT

FTS

- FTS (University of Melbourne)
- wind criteria
- Application in Southern Hemisphere
- Simmonds et al (2012) J. Climate

MedFTS

- Modification and optimization of wind criteria to consider the characteristics of Mediterranean cold fronts
- Application in the Mediterranean

  Bitsa et al (2019) in Climate

MedFTS_DT

- Incorporation of thermal criteria to improve the performance of MedFTS
- Application in the Mediterranean-Climatology

  Bitsa et al (2021) in Int. J. Climatology

Data used

- ECMWF Re-analysis ERA 5 (2007-2020)
  - Surface(10-m)
  - 850 hPa level
- Variables:
  - Horizontal wind components (*u*,*v*)
  - Temperature (*T*)
  - Total precipitation
- Resolution:
  - Spatial resolution 0.5° x 0.5°
  - Temporal resolution 6 h

Validation:

- Surface analysis charts every 6 h derived from:
  - ✓ UK MetOffice
  - ✓ Deutsche Wetterdienst (DWD)
  - ✓ Hellenic National Meteorological Service (HNMS)
- Satellite images (Meteosat MSG IR 12μm)
- Temperature advection distribution (DWD)

The MedFTS Scheme

For each 6-h interval (from t to t+6h) the following criteria should be satisfied:

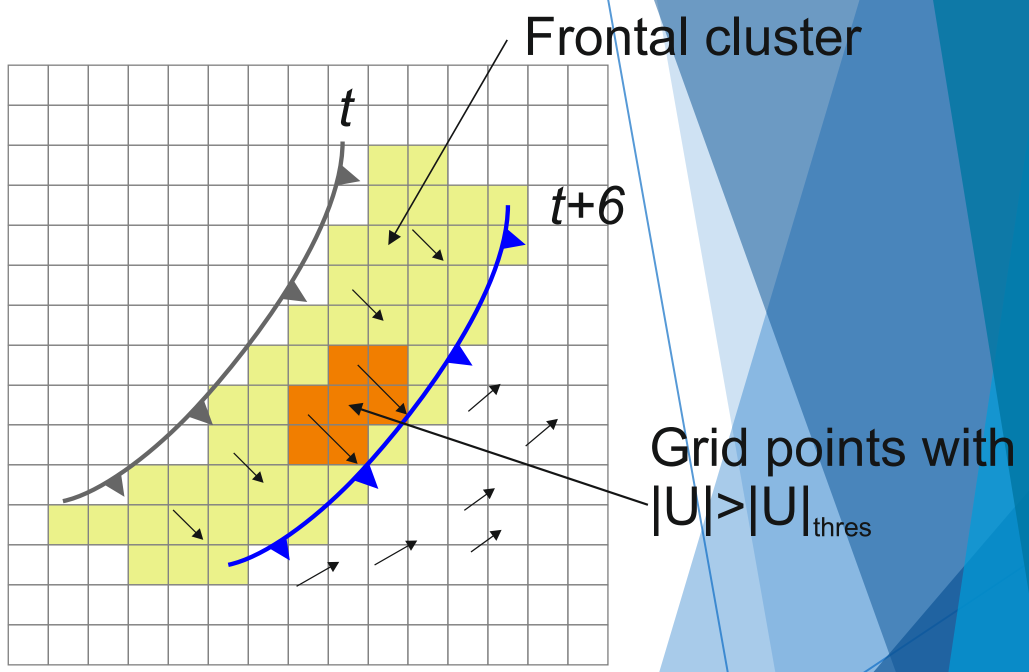
1. $u > 0$ for both t and $t + 6$ h (westerly direction)
2. $v(t) > 0$ and $v(t + 6\text{ h}) < 0$ (shift from southerly to northerly sector)
3. $\Delta\varphi > \Delta\varphi_{thres}$, where
   - $\Delta\varphi$ the wind shift in degrees
   - $\Delta\varphi_{thres} = 30^\circ$ the threshold value of the wind shift (after sensitivity tests)
4. $|U|(t + 6\text{h}) > |U|_{thres}$, where

   $|U|$ is the magnitude of the wind velocity (m/s) behind the cold front

   $|U|_{thres} = 5$ m/s the threshold value of the magnitude of the wind velocity after the passage of the front (after sensitivity tests)

The MedFTS Scheme

- The grid points which satisfy criteria 1-3 are flagged.
- The flagged points which are neighbors are grouped together to form a frontal cluster.
- The frontal line is positioned at the eastern edge of each cluster.
- For each cluster criterion 4 is checked. If the criterion is not satisfied in at least one point, the cluster is discarded.



Statistical indices and metrics

a=hits	Front exists in synoptic charts and identified
b=false alarms	Front identified but not appearing in charts
c=misses	Front appearing in charts not identified
d=correct rejection	No front identified and no front in charts

		Analysis YES	Analysis NO	
Algorithm	YES	a	b	$a + b$ (algorithm identifications)
Algorithm	NO	c	d	$c + d$ (algorithm rejections)
		$a + c$ (observed)	$b + d$ (not observed)	$n = a + b + c + d$ (sample)

Metric	Definition	Range	Perfect value
Frequency Bias Index (FBI)	$\frac{a+b}{a+c}$	0 ÷ ∞	1
Probability of Detection (POD)	$\frac{a}{a+c}$	0 ÷ 1	1
False Alarm Ratio (FAR)	$\frac{b}{a+b}$	0 ÷ 1	0
True Skill Statistics (TSS)	$\frac{ad-bc}{(a+c)(b+d)}$	-1 ÷ 1	1

Statistical validation of MedFTS

- Small number of erroneous identification or rejection of cold fronts

- Greater number of false alarms (FBI>1)

↓

- It was demonstrated that wind shift is a prerequisite for frontogenesis in the Mediterranean. ☺
- The transition of a simple baroclinic zone to an organised front in the Mediterranean indeed requires the wind shift ☺
- The wind criteria underestimated the length of the cold fronts ⚡
- The wind criteria overestimate the number of cold fronts ⚡

↓

Need for adoption of thermal criteria to filter erroneous cases

Additional Thermal criteria

1. Temperature advection criterion:

- $M_T < 0$, in at least one cluster point, where M_T the temperature advection at t+6h.

$$M_T = -\vec{U} \cdot \vec{\nabla} T = -\left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right)$$

2. TFP criterion:

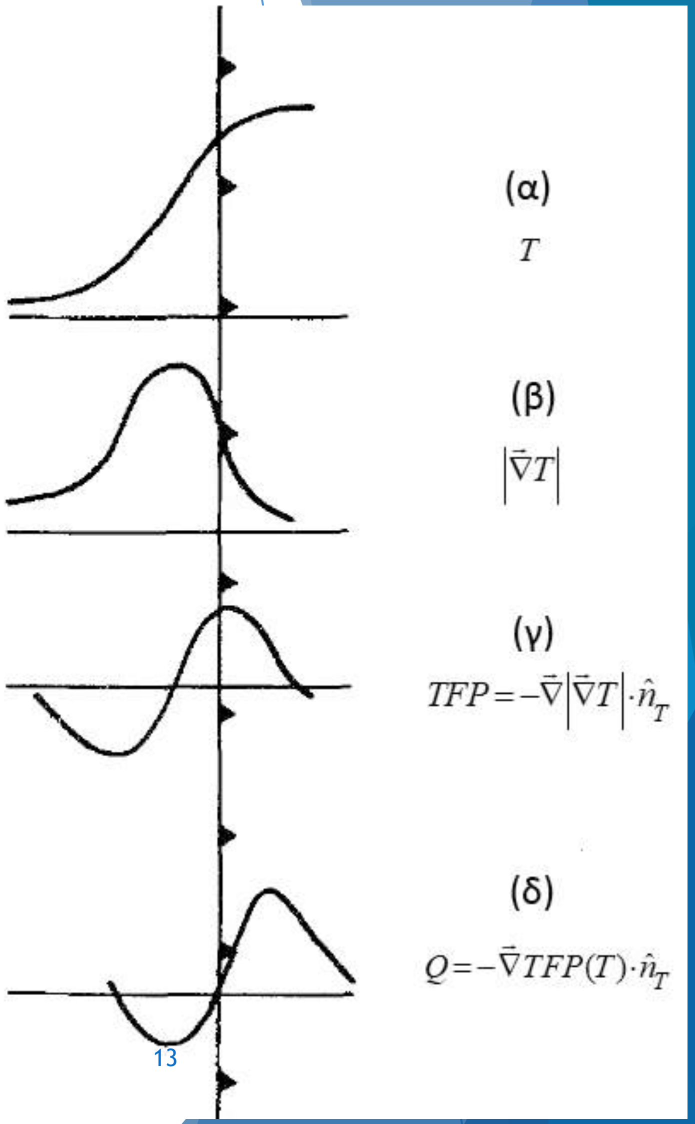
- The quantity $Q = -\vec{\nabla}\, TFP(T) \cdot \hat{n}_T < 0$ and $TFP > TFP_{thres} = 5 \times 10^{-12}$ K/m^2 in at least one cluster point, where

$$TFP(T) = -\vec{\nabla}|\vec{\nabla}T| \cdot \frac{\vec{\nabla}T}{|\vec{\nabla}T|} = -\vec{\nabla}|\vec{\nabla}T| \cdot \hat{n}_T$$

Both criteria should be satisfied in at least one cluster point, otherwise the cluster is discarded.

TFP Criterion

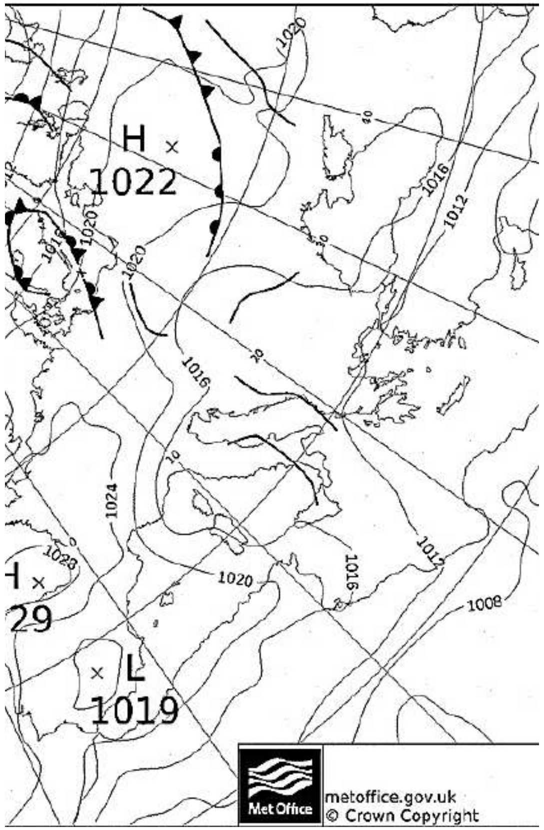
- *TFP* is the second derivative of *T* along the gradient of *T* (perpendicular to the frontal surface).
- *Q* is the derivative of -*TFP*.
- The front is located where the TFP is maximised or where Q becomes 0.
- Behind the cold front *Q* < 0.

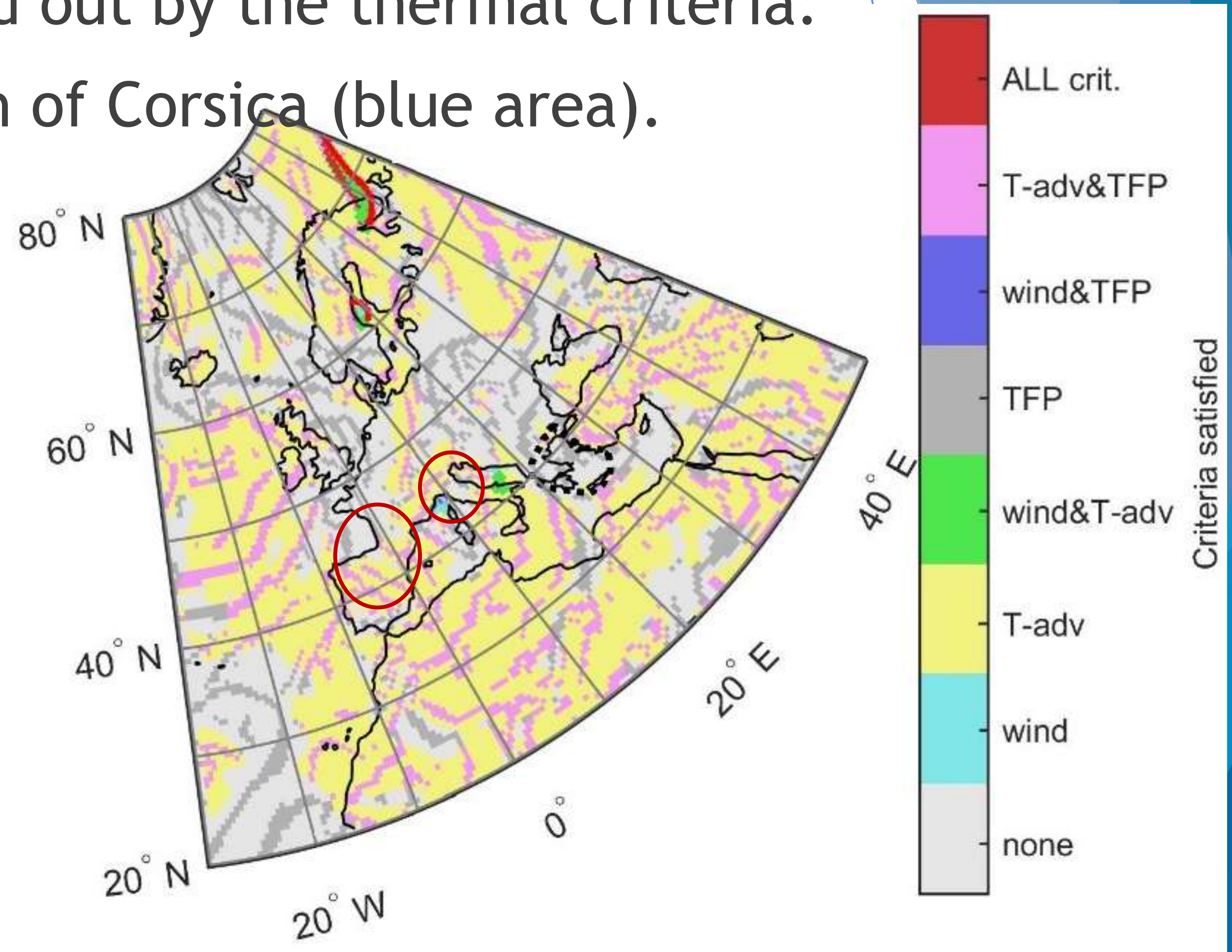


Typical results - 19/06/2016 18:00UTC

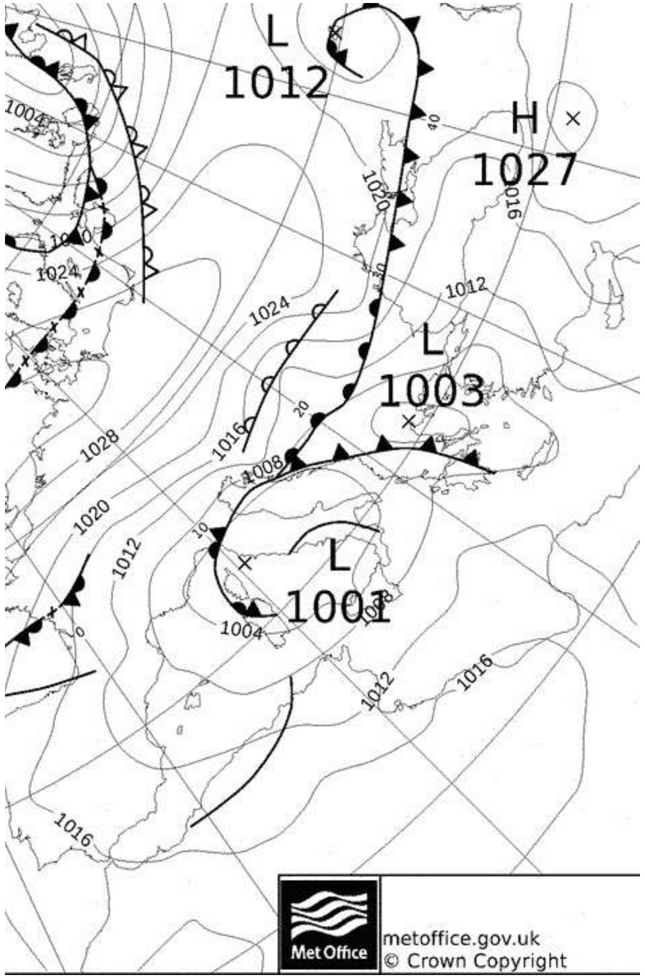
Erroneous identifications filtered out by the thermal criteria:

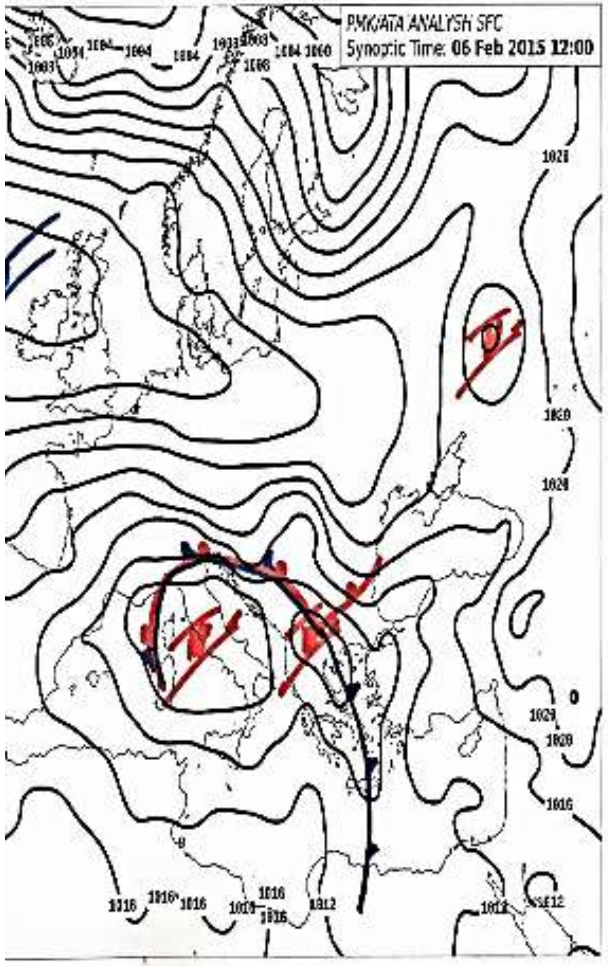
- In Italy (green area) and north of Corsica (blue area).

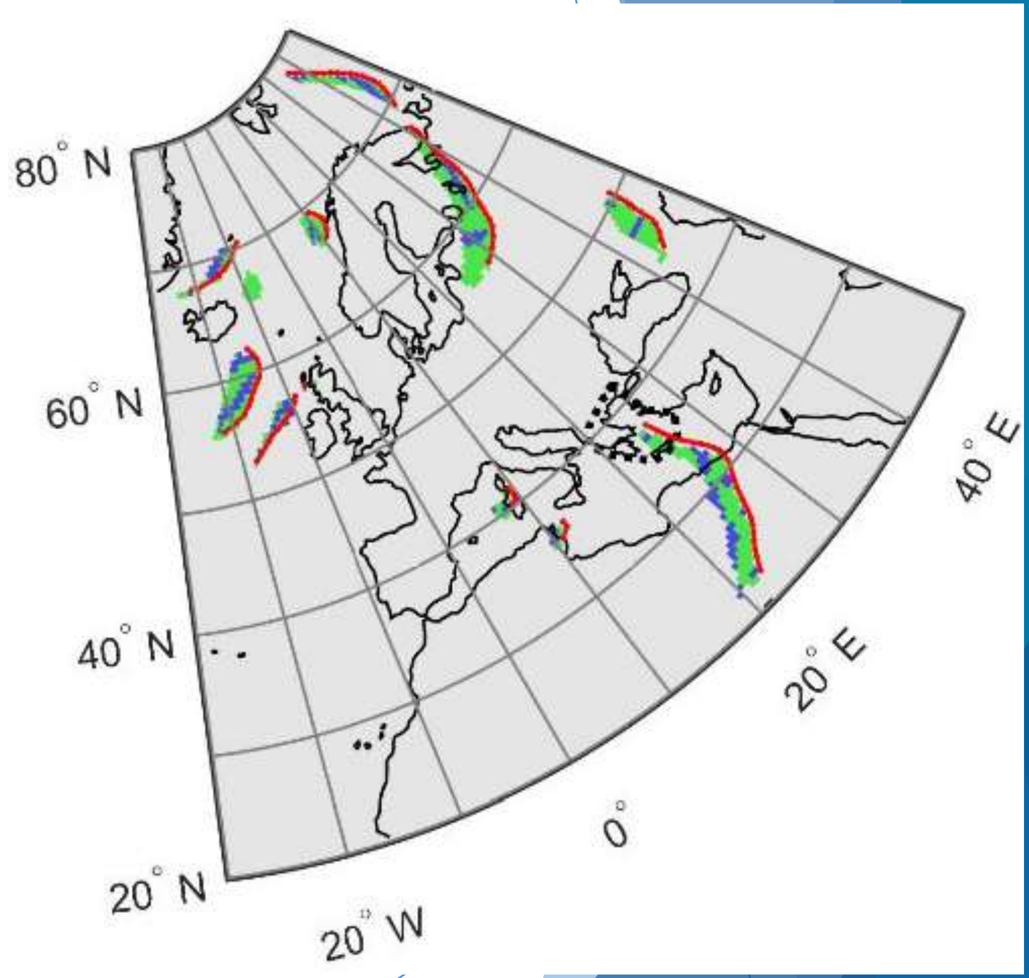




Typical results - 6/02/2015 12:00UTC







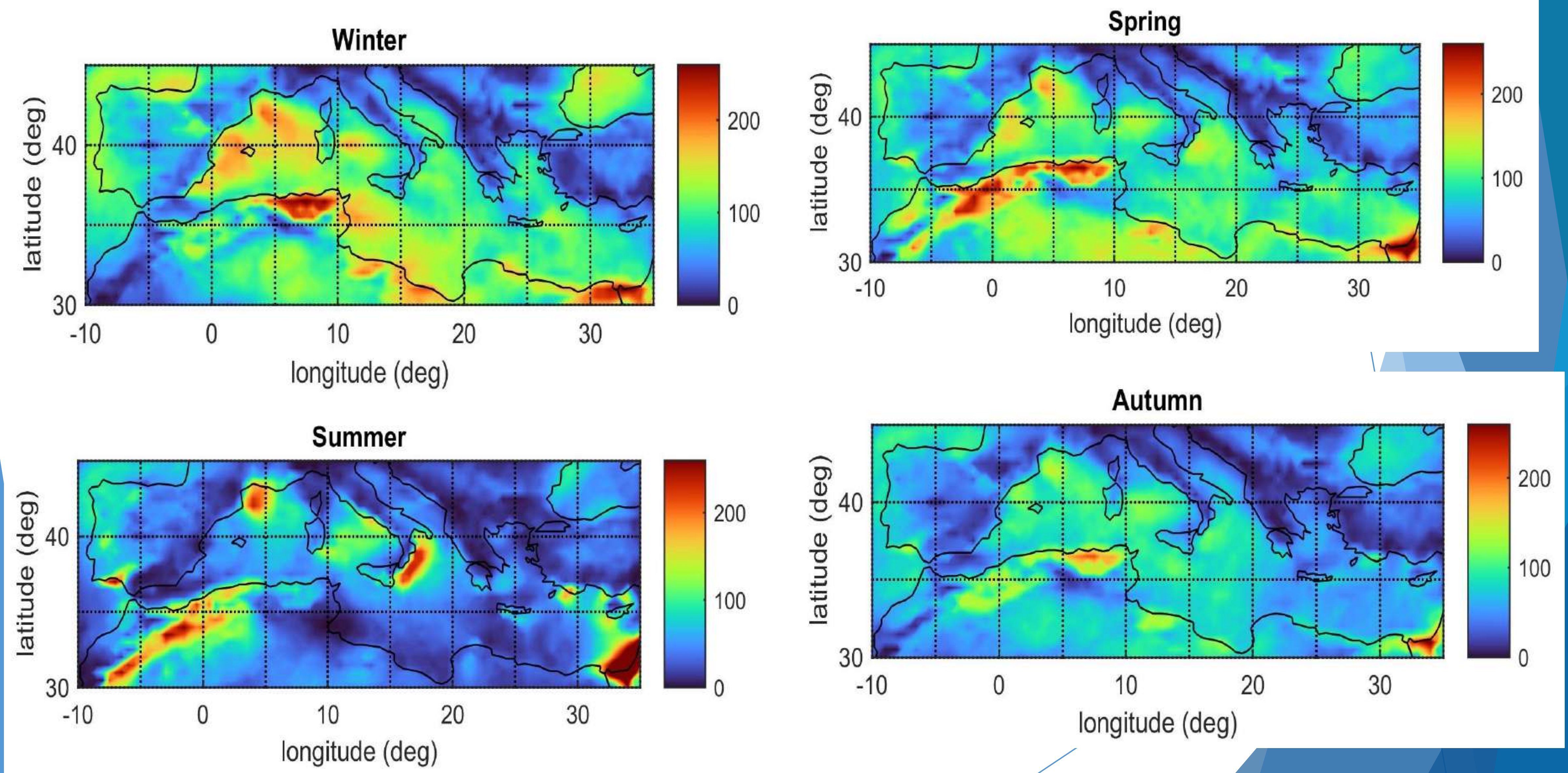
Statistical verification of MedFTS_DT

Significant reduction of false alarms (number of mis-identifications) was obtained. 🙂

The incorporation of the thermal criteria has significantly improved the scheme's performance by effectively filtering out erroneous identifications, such as secondary frontogenesis during the cold period of the year. 🙂

Climatology of frequency and precipitation during the period 2006-2020

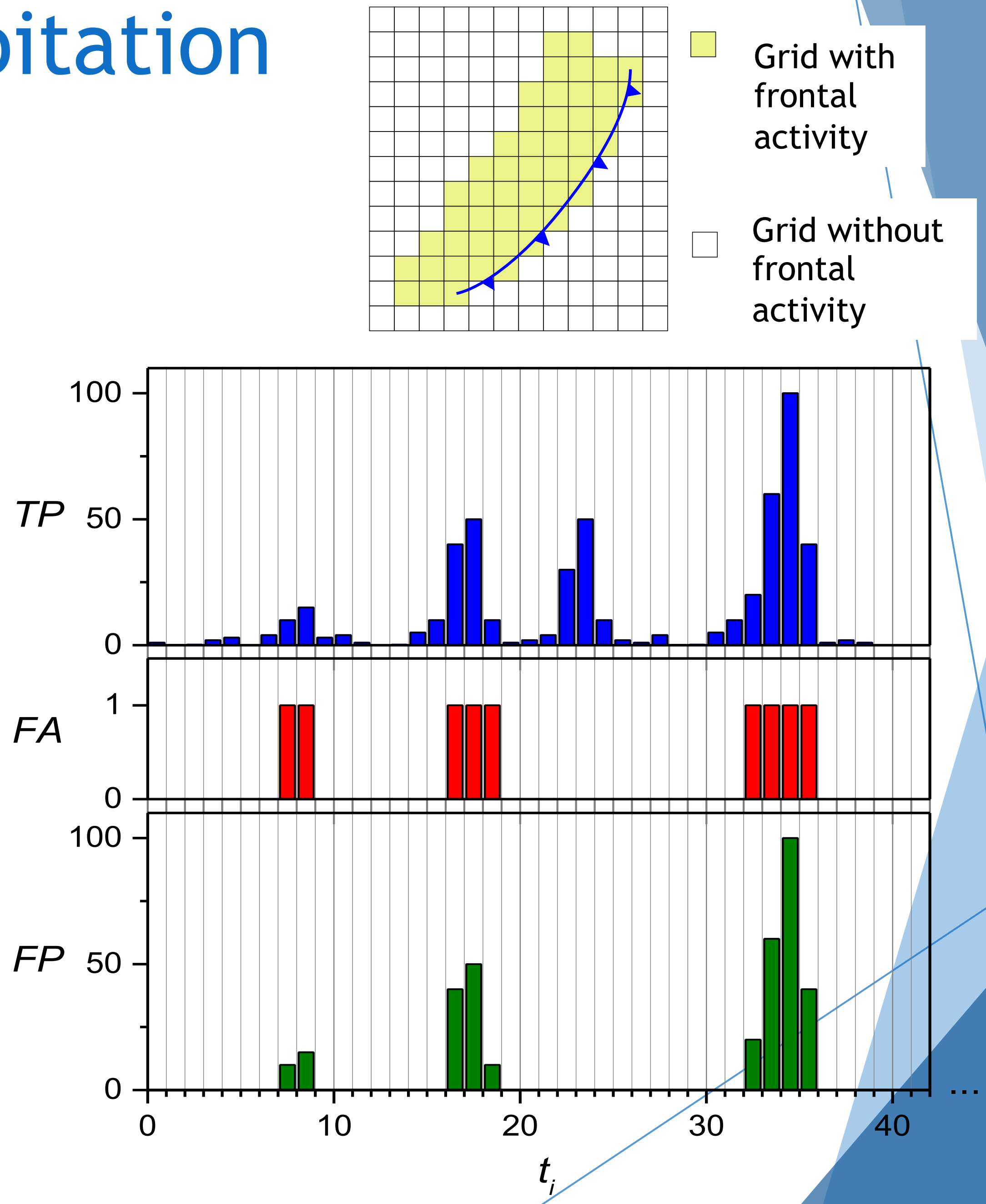
Seasonal spatial distribution of front frequency



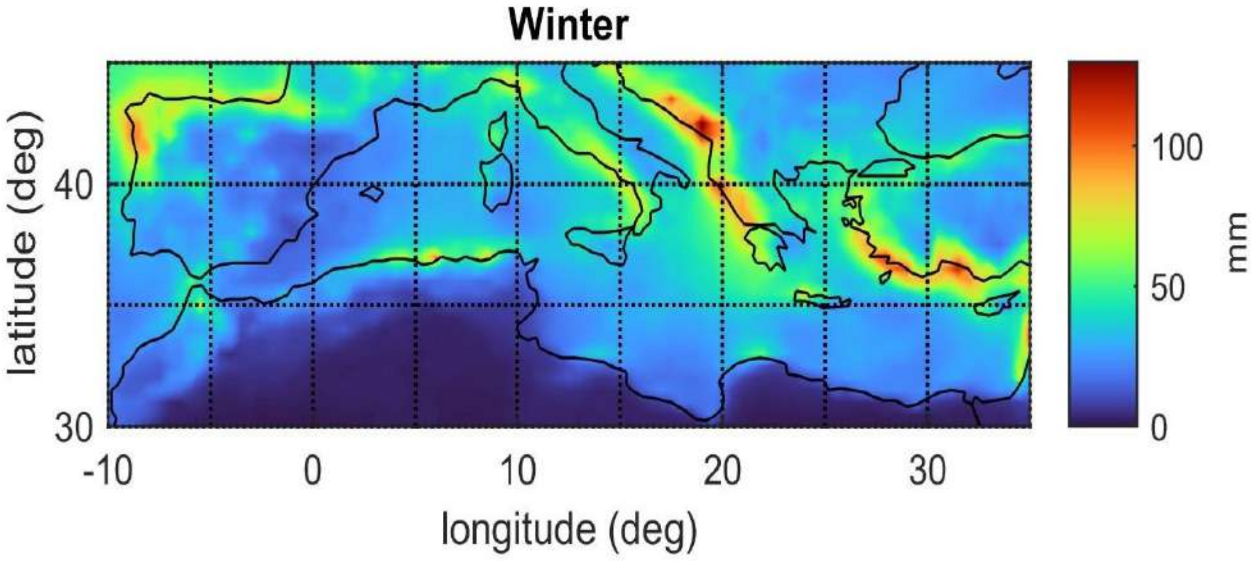
Cold fronts and precipitation

For each grid point:

- Total precipitation TP at each grid point for every t_i *for the period 2007-2020.*
- Frontal precipitation FP (accumulated precipitation at each grid only for t_i that the grid belongs to a frontal cluster:
- Contribution of frontal precipitation to total precipitation (ratio FP/TP)

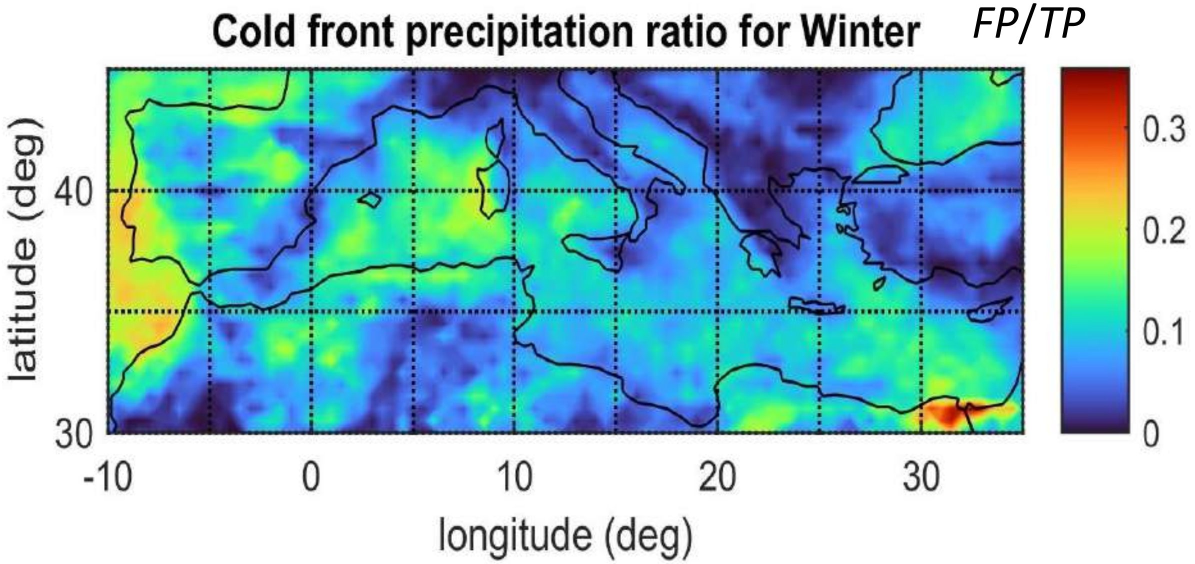


Cold fronts and precipitation - winter



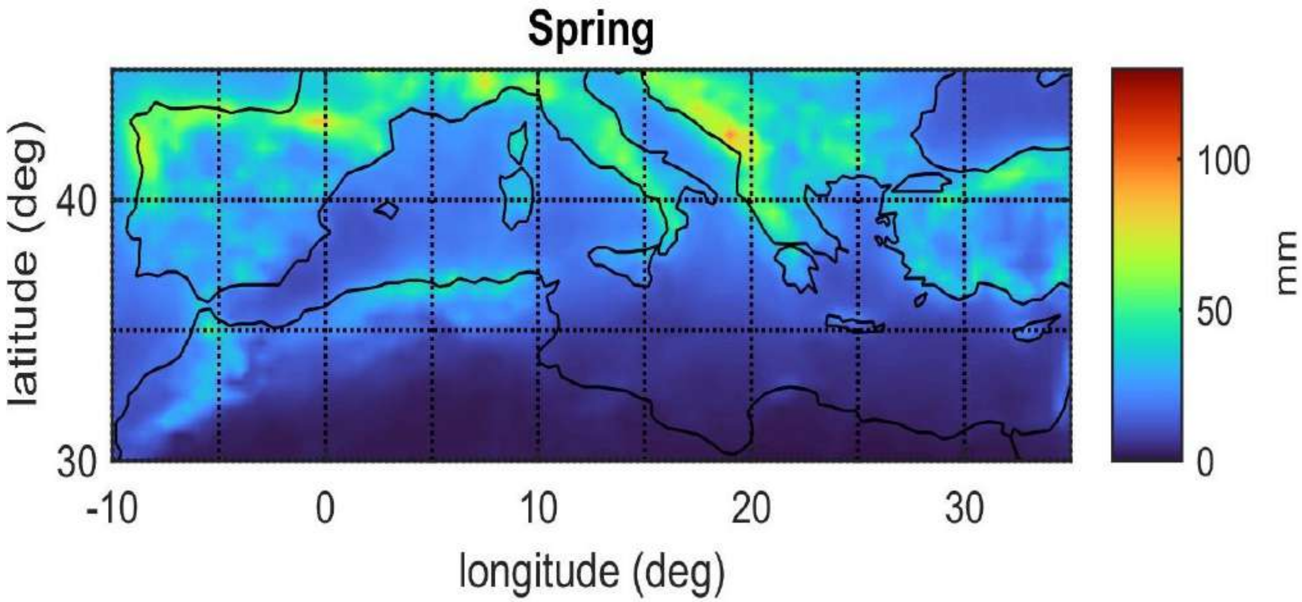
Mean annual precipitation (*TP*)

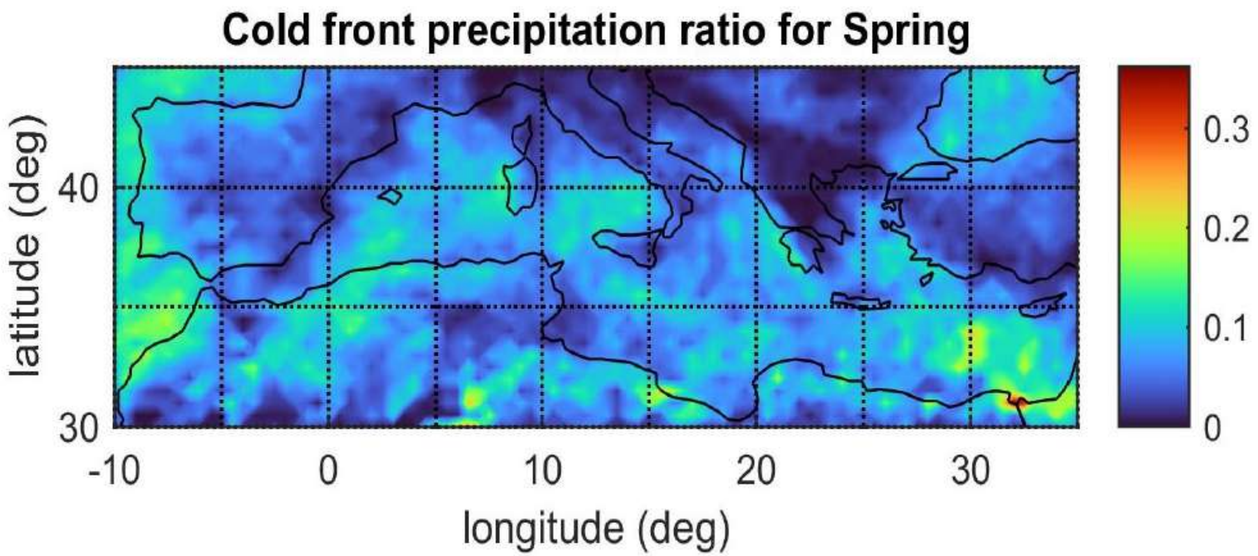
Contrary to the TP regime, the maxima of FP are not found over the main mountain ranges of the Mediterranean regions



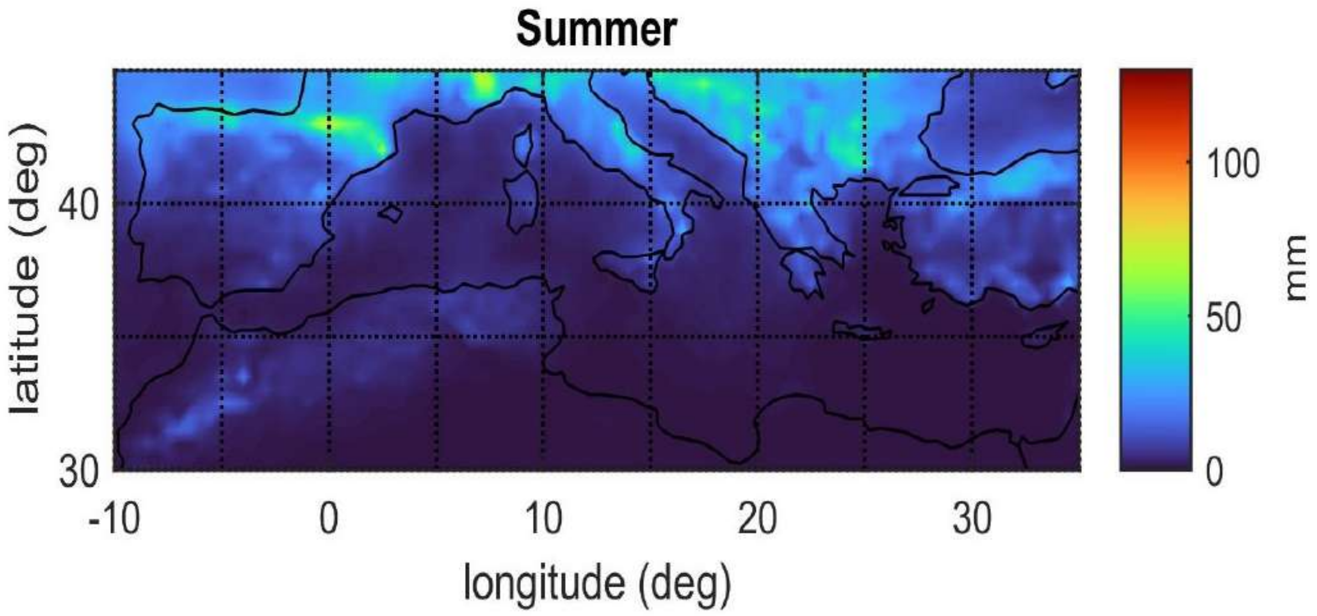
The local maxima of FP agree well with the corresponding maxima of frontal activity.

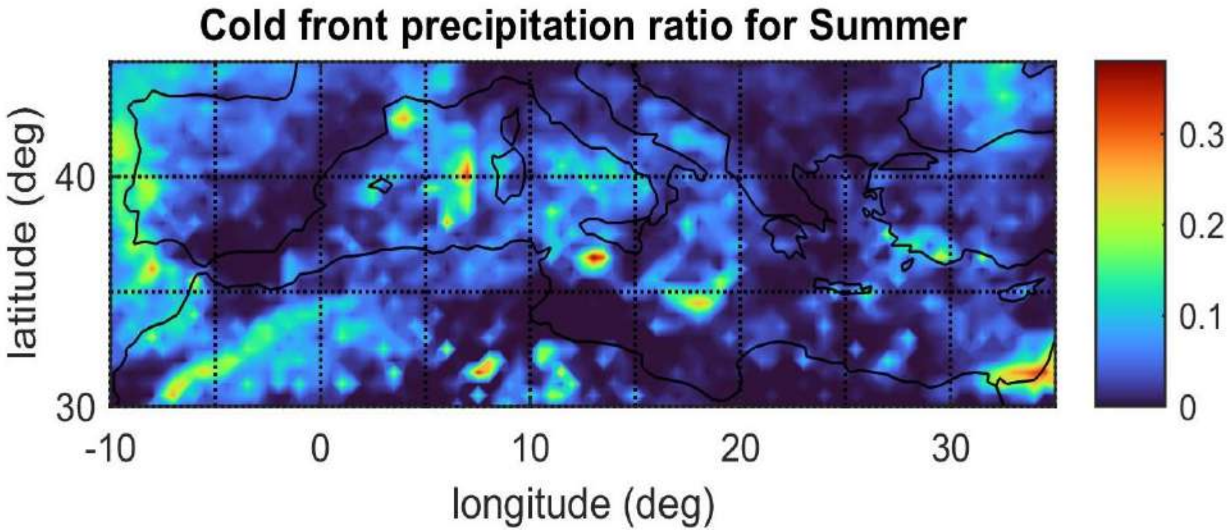
Cold fronts and precipitation - spring





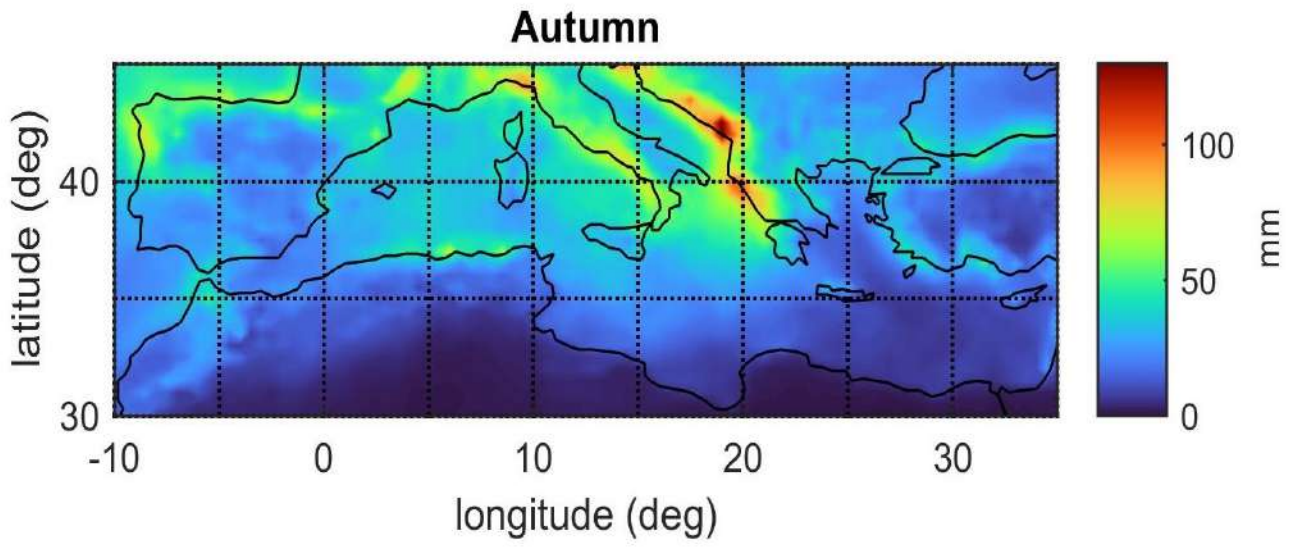
Cold fronts and precipitation - summer

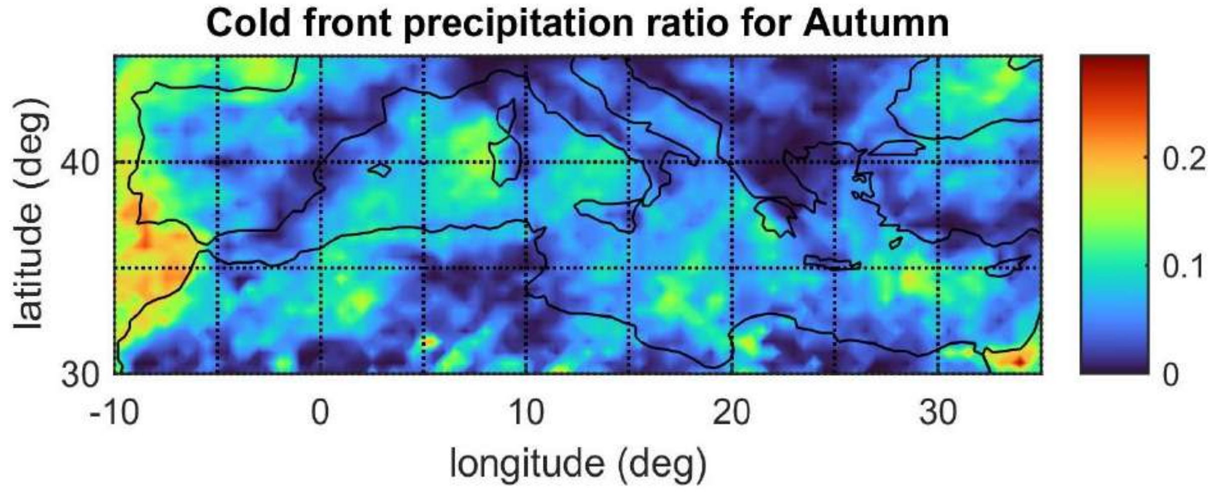




In the southern Mediterranean, even though the precipitation is relatively limited, the contribution of cold fronts is significant.

Cold fronts and precipitation – autumn



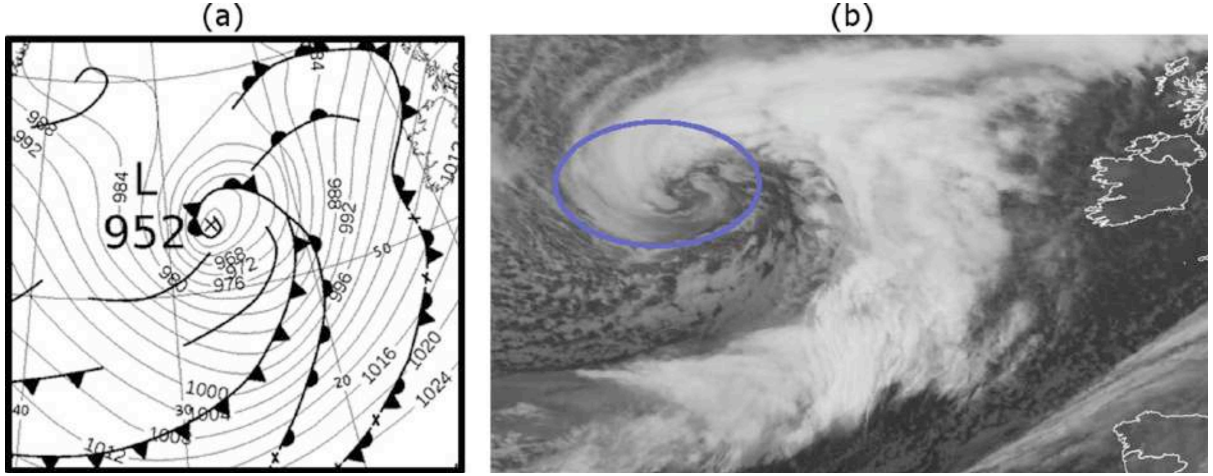


Conclusions

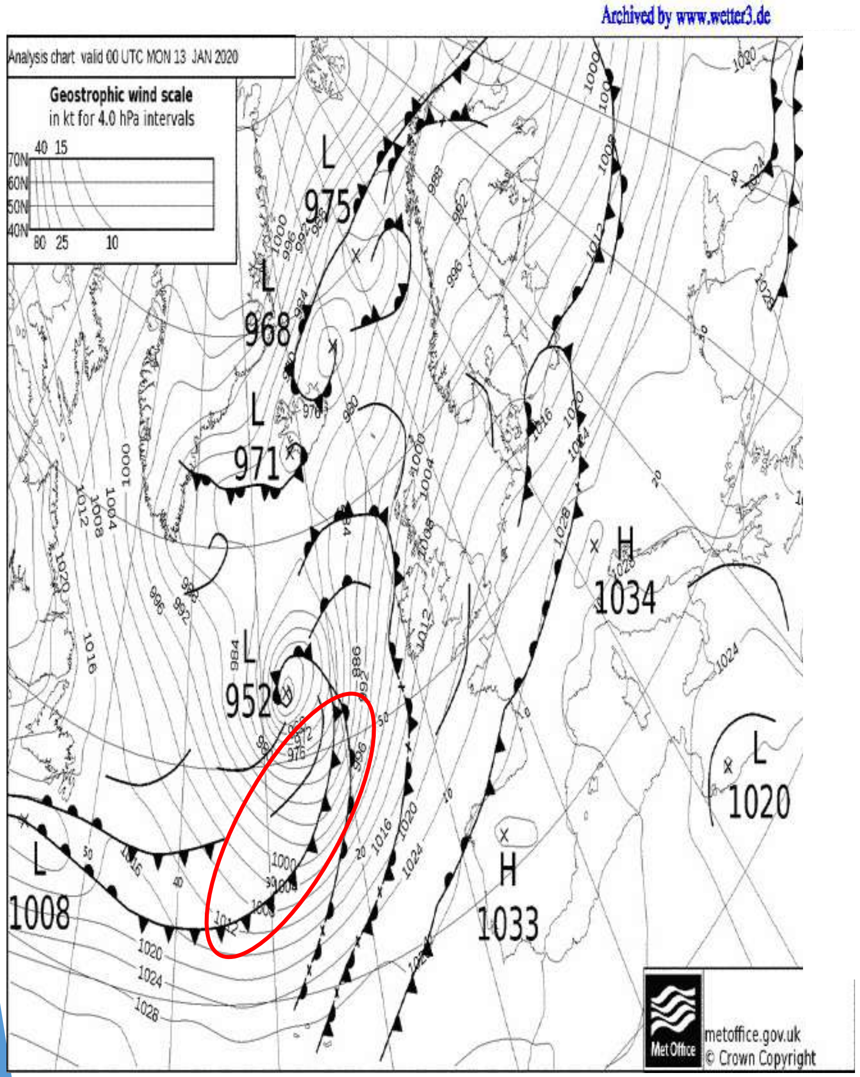
- The use of wind criteria as a prerequisite and the thermal criteria to filter the results appear to be the optimum choice, leading to a very good performance of MedFTS_DT.

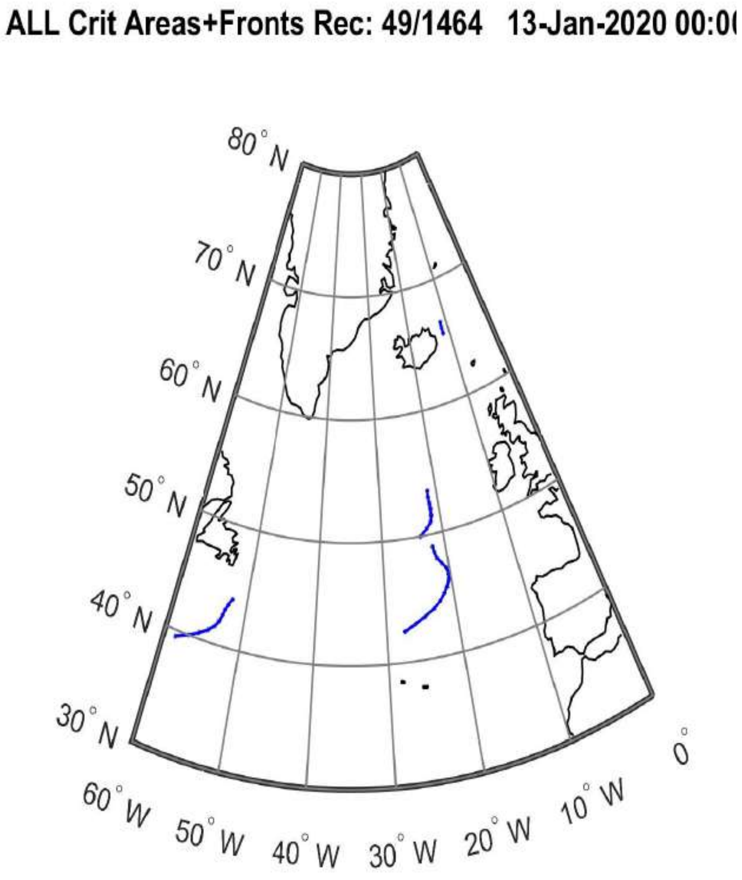
- The MedFTS_DT scheme appears to be a very effective tool for the identification of individual cold fronts in the Mediterranean and, furthermore, for the generation of an objective full climatology of cold fronts in the Mediterranean, which is missing in the climatological research

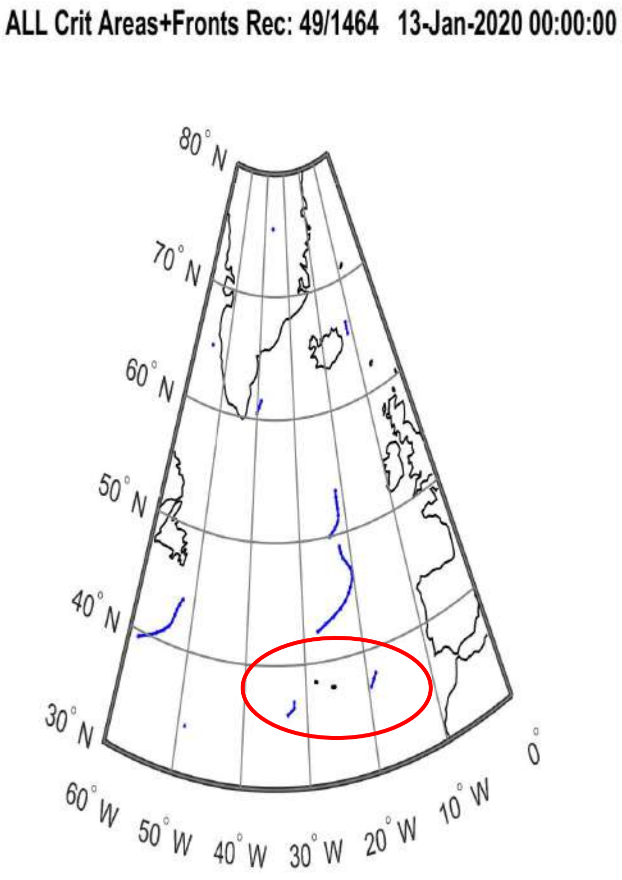
A case of cold front in the Atlantic (13.1.2020- Storm Brendan-UK)



(Gray et al, 2020)



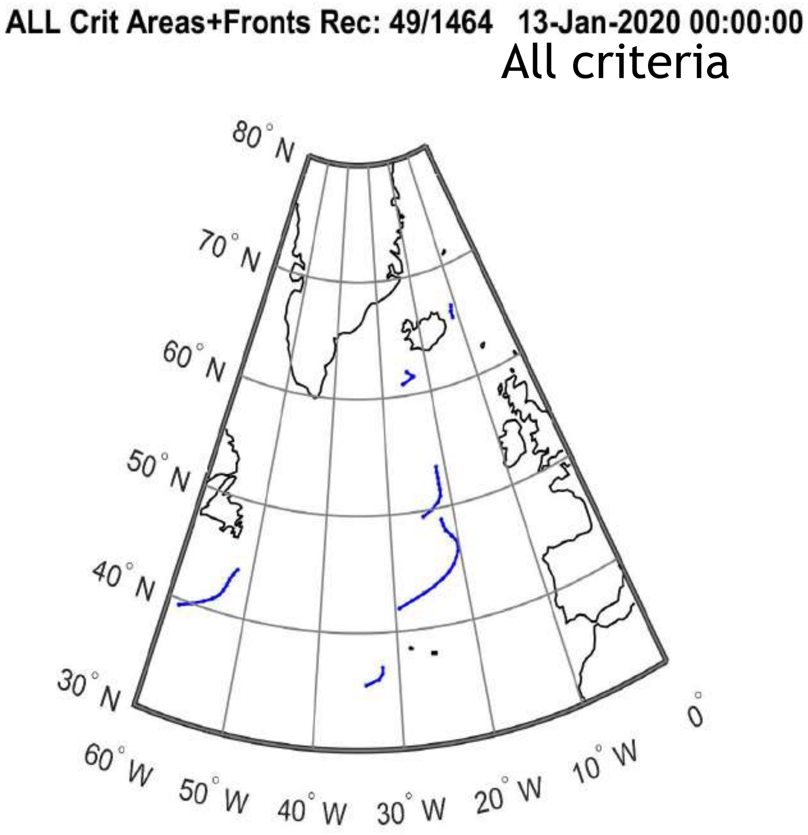


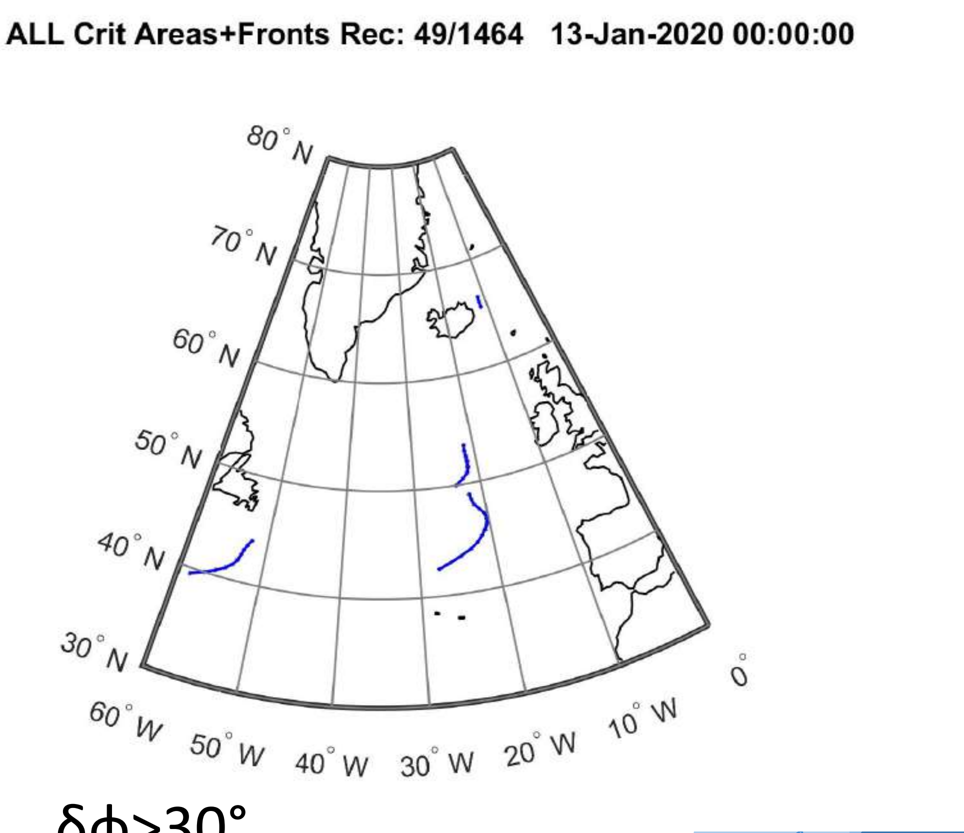


All criteria (wind and thermal)

Only wind criteria

All criteria





δϕ>30°

|U|>7m/s instead of 5m/s

The angle δφ affects the length of the front

δϕ>20° instead of 30° και

|U|>3m/s instead of 5m/s

New threshold values? New oprimization?

Specially related with the angle of wind shift δφ

Publications

Bitsa E., H. Flocas, J. Kouroutzoglou, M. Hatzaki, I. Rudeva, I. Simmonds, 2019. “Development of a Front Identification Scheme for Compiling a Cold Front Climatology of the Mediterranean”. Climate. 7. 130. DOI: 10.3390/cli7110130.

Bitsa E., H. Flocas, J. Kouroutzoglou, G. Galanis, G. Latsas, M. Hatzaki, I. Rudeva, I. Simmonds, 2021. “A Mediterranean cold front identification scheme combining wind and thermal criteria”. International Journal of Climatology, 1– 14. https://doi.org/10.1002/joc.7208.