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UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI SCIENZE DELLA TERRA "ARDITO DESIO"

EGU General Assembly 2025 Vienna, Austria & Online | 27 April–2 May 2025

Atmospheric rivers in the Mediterranean basin and heavy precipitation over northern Italy

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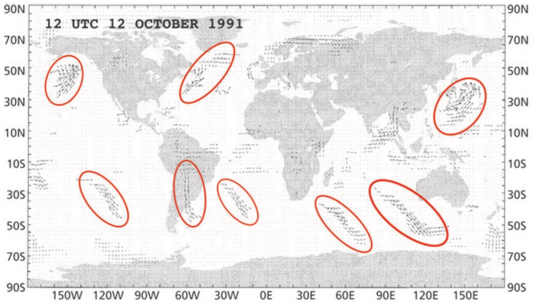
Acknowledgments: M. M. Miglietta[2], V. Levizzani[2], M. Vercellino

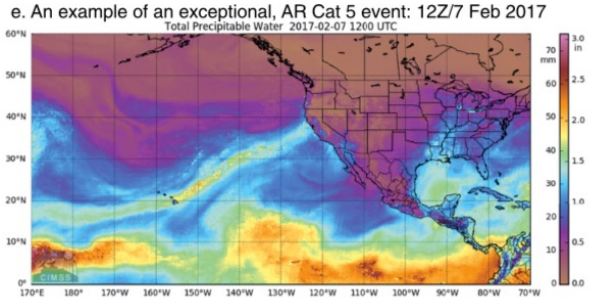
[1]Univ. Milan; [2]CNR - ISAC, Bologna; [3]CETEMPS/Univ. L'Aquila; [4]ARPAE; [5]Regional Civil Protection Agency - Abruzzo Region

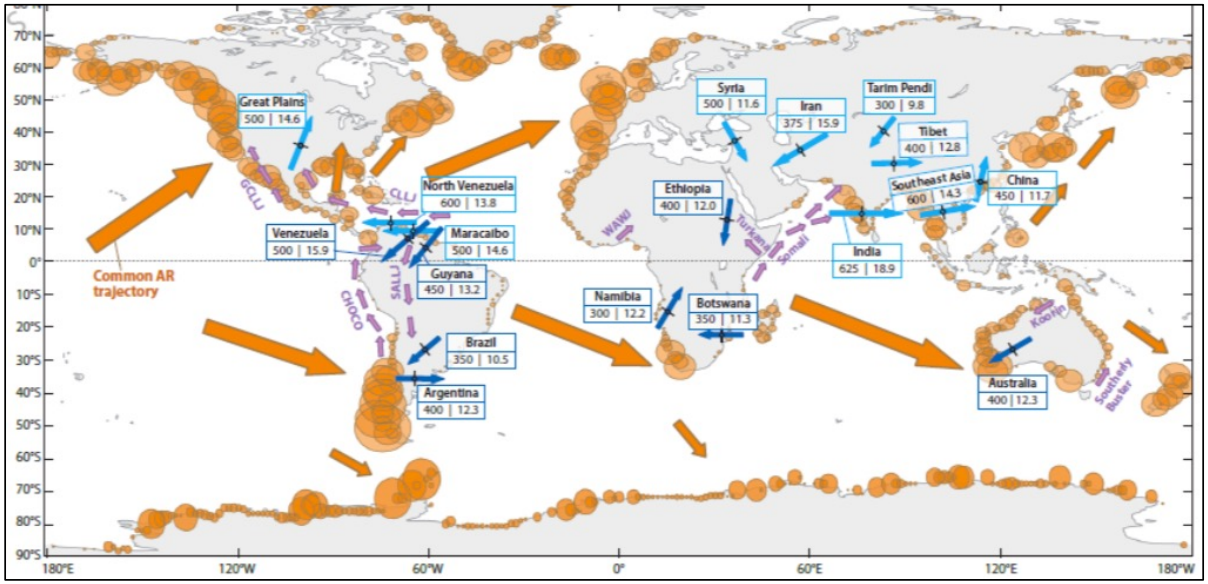
AR LANDFALL

Zhu & Newell, 1988, Mon Wea Rev



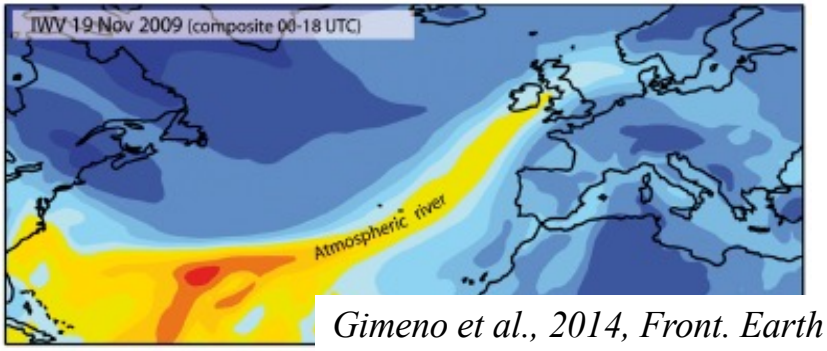
Ralph et al., 2019, BAMS



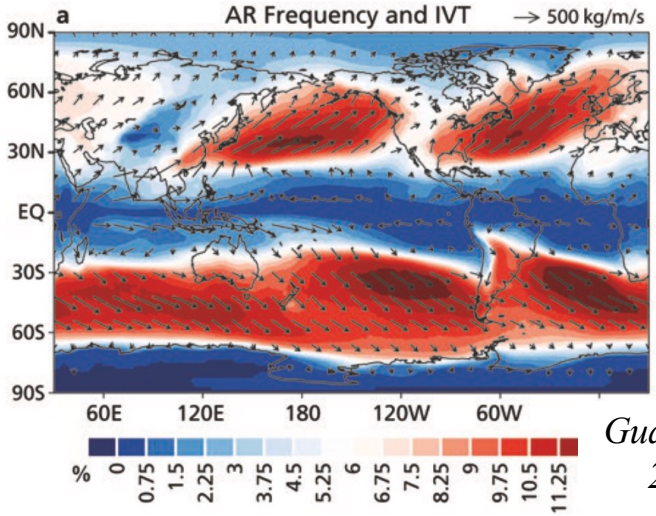


Gimeno et al., 2016, Annu. Rev. Env. Res.

ATMOSPHERIC RIVERS IN EUROPE



Gimeno et al., 2014, Front. Earth Sci.



Guan & Waliser, 2015, JGR

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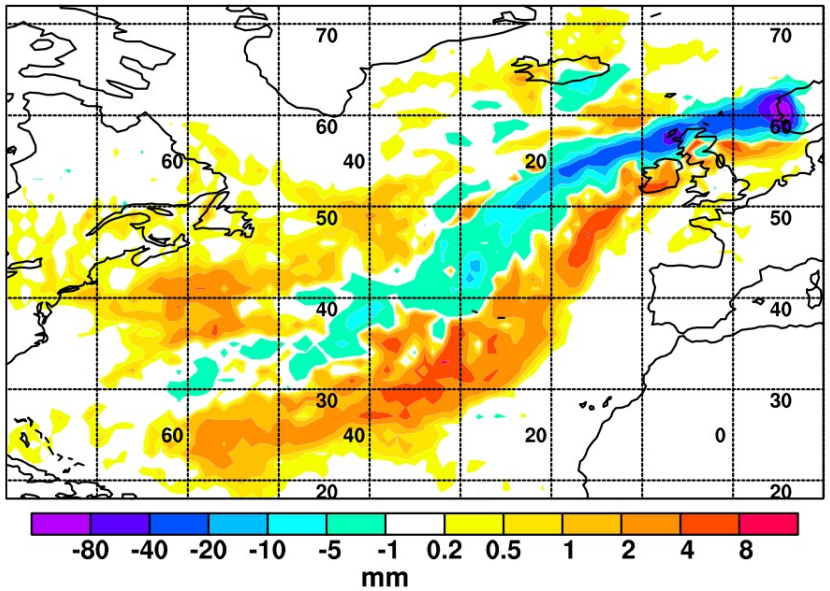


Scandinavian Peninsula

Sodemann and Stohl, 2013; Benedict et al., 2019

Iberian Peninsula

Liberato et al., 2012; Ramos et al., 2015; Eiras-Barca et al., 2016

Inland penetration in Central Europe

Rossler et al., 2014; Inoita et al., 2020

UK e France

Lavers et al., 2011; Lu et al., 2013; Lavers and Villarini, 2013, Browning , 2018; Doiteau et al., 2021

North Atlantic

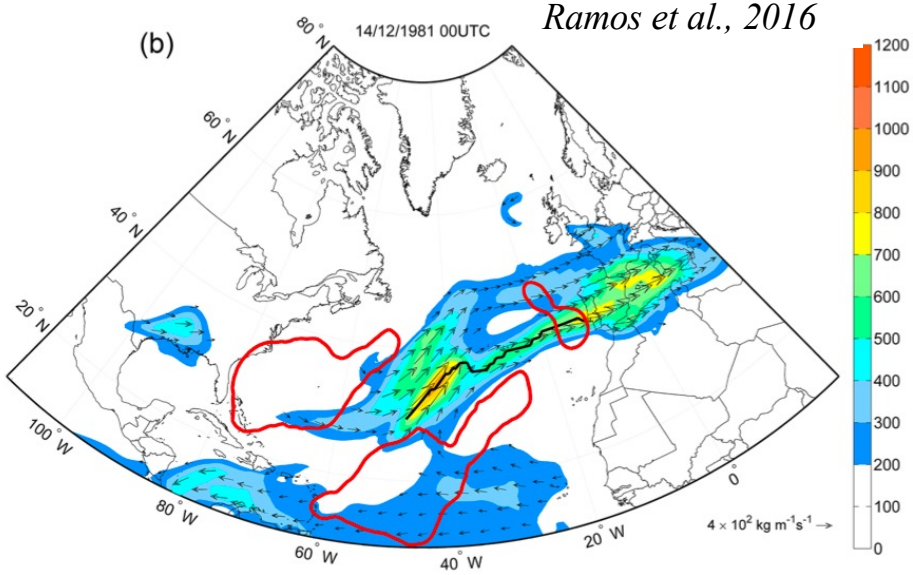
Stohl et al., 2008

Knippertz and Wernli, 2010; Ramos et al. 2016; Brands et al., 2017

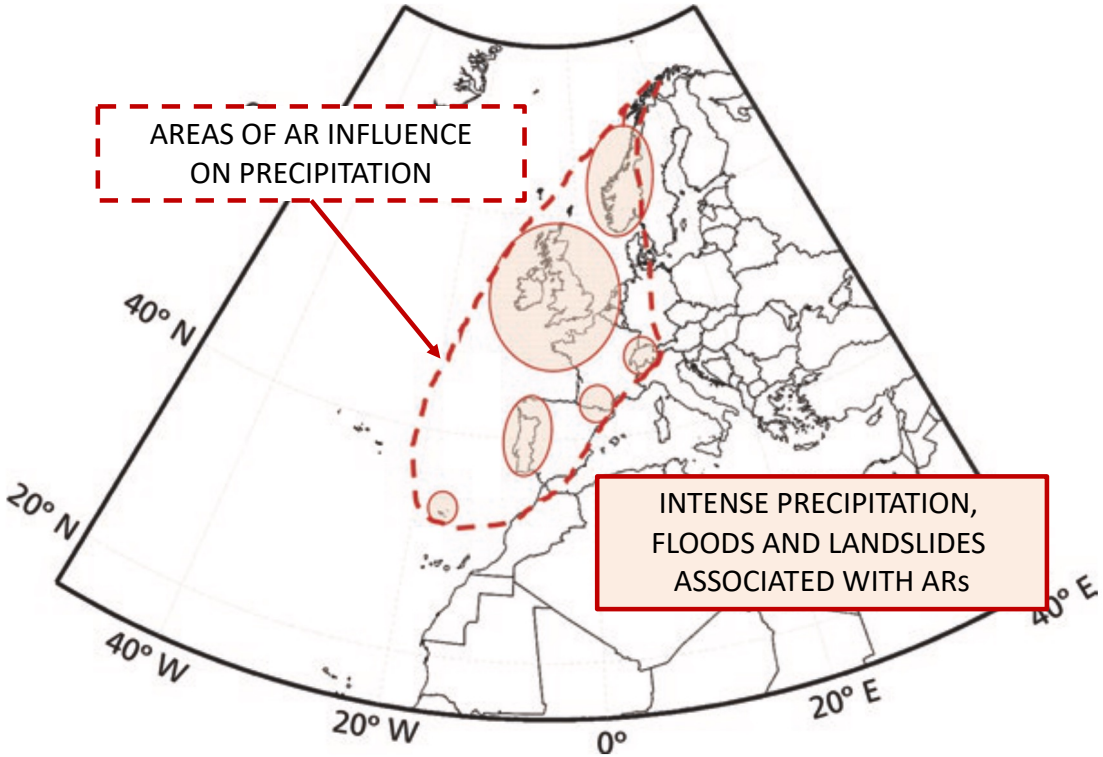
→ Moisture linked with the ARs comes mainly from subtropical areas but also from the tropical (TME) and mid-latitude regions closer to the landfall;

→ *Dacre et al., 2015* water vapor in the warm sector of the cyclone rather than long-distance transport

Ramos et al., 2016



AR & PRECIPITATION - Europe



Adapted and updated from Gimeno et al. 2016

- In Western Europe ARs are responsible for 20-30% of all precipitation
- Strong seasonality:
  - max in fall and winter (stronger storm track)
  - min in summer (mainly convective weather)
- More inland penetration compared to the US

However, increasing interest fostered by extreme events

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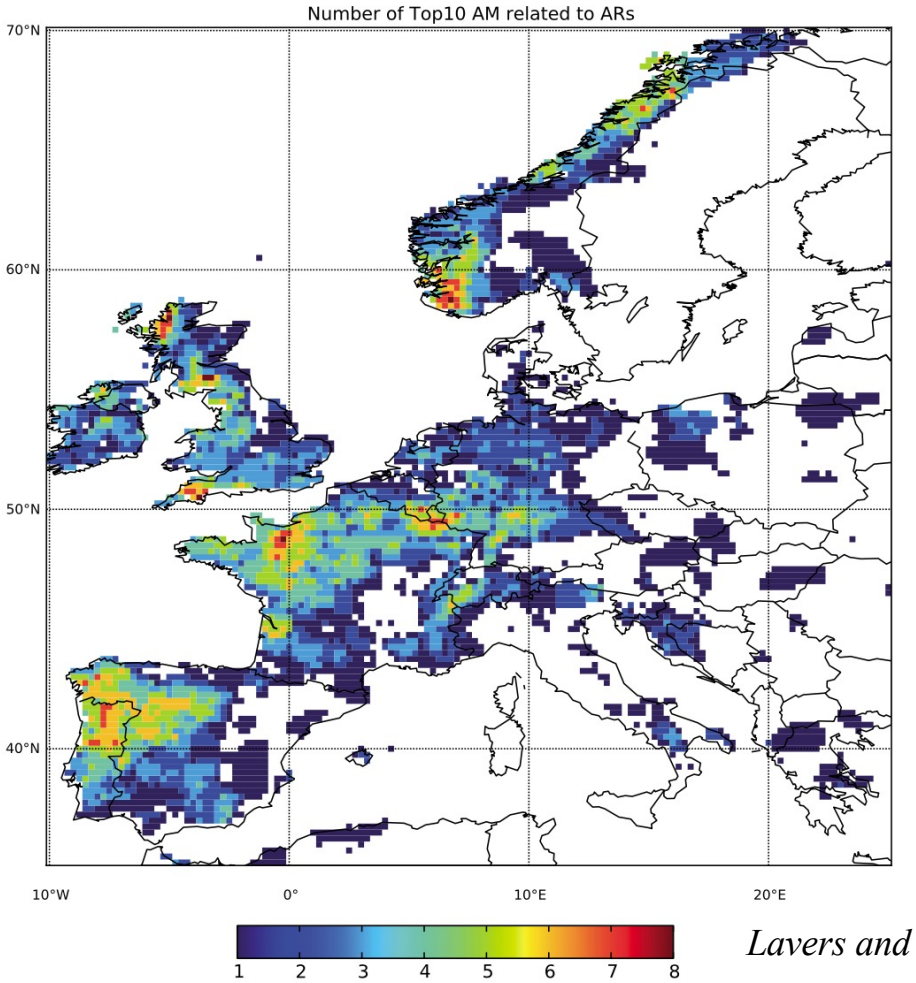
Number of the top 10 Annual Maxima daily precipitation that are associated with ARs



Lavers and Villarini, 2013

- Strong relationship between ARs and annual maximum precipitation days in W-Europe coasts
- The strongest AR-AM connection is found in mountainous areas, mainly in fall and winter
- Striking inland impacts

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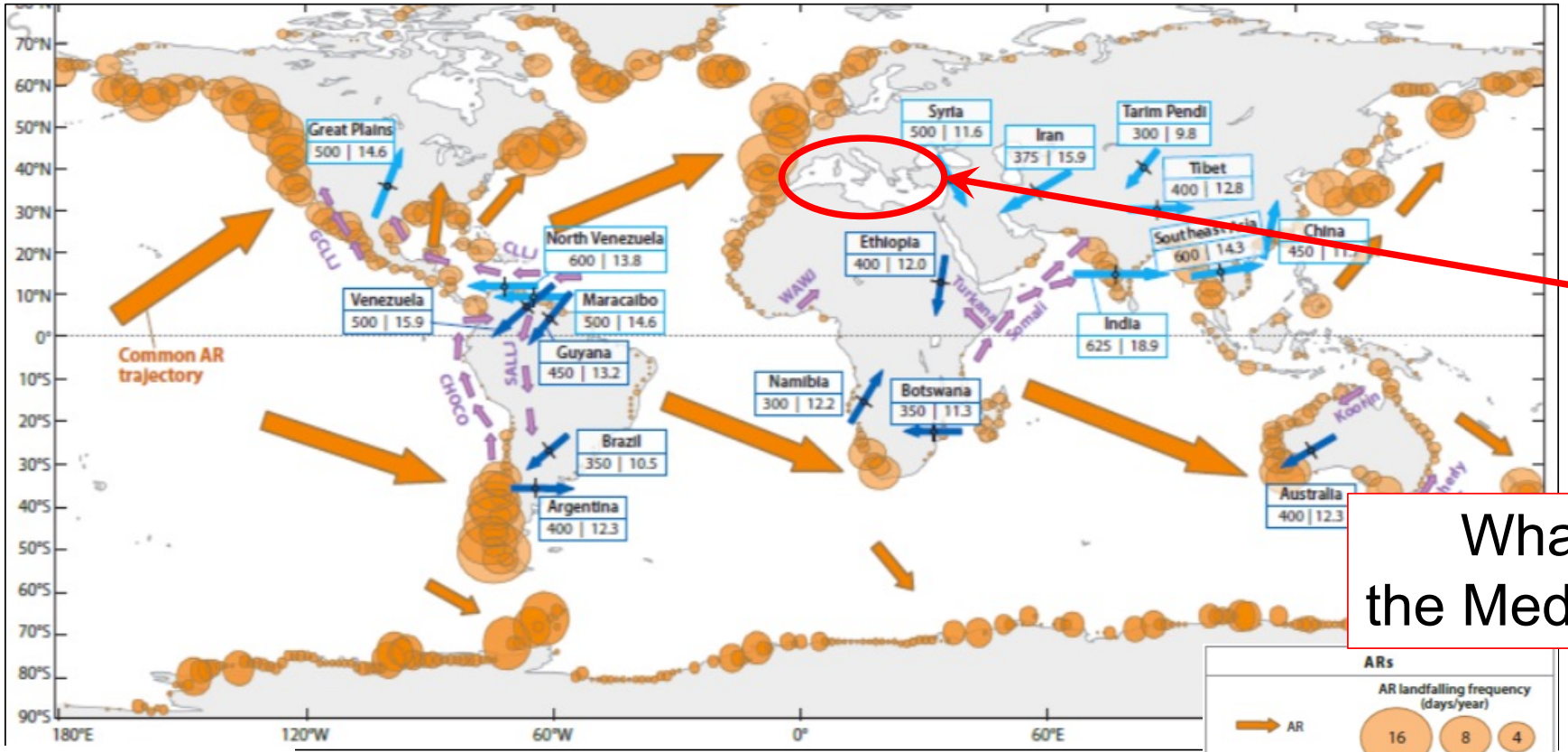
AR LANDFALL



What about the Mediterranean?

Gimeno et al., 2016

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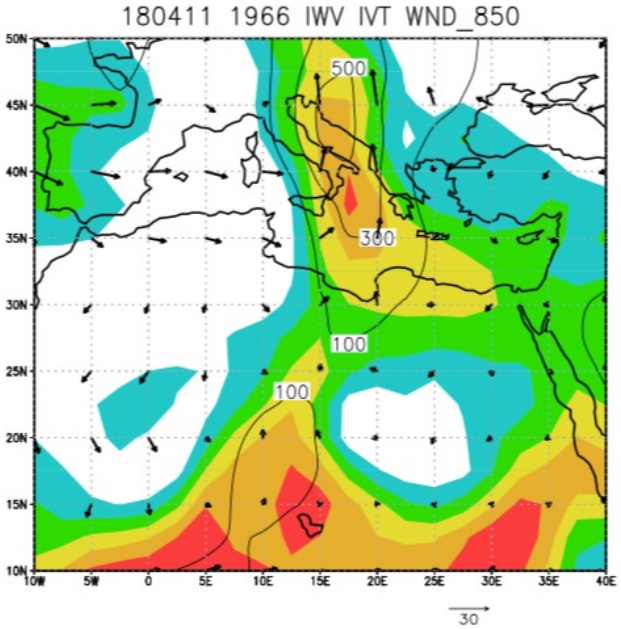
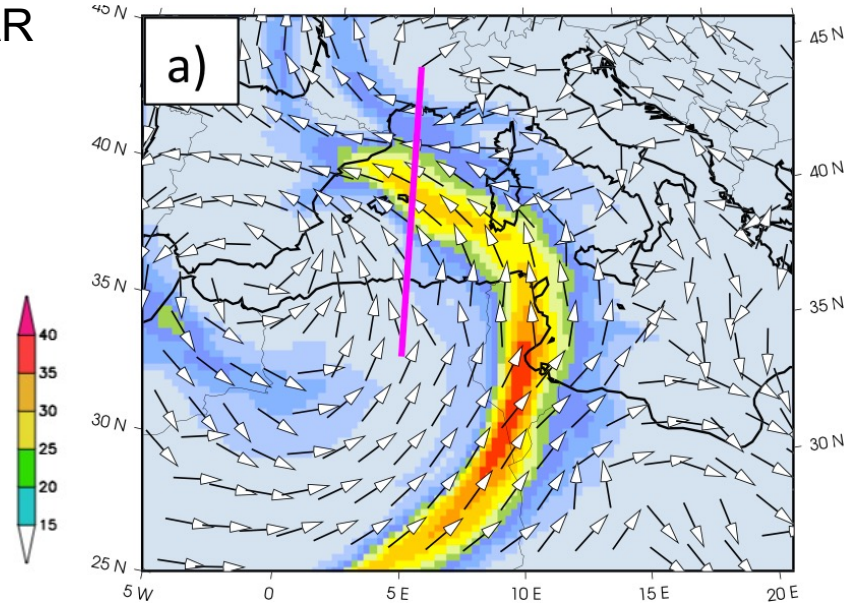
AR in the W-MEDITERRANEAN

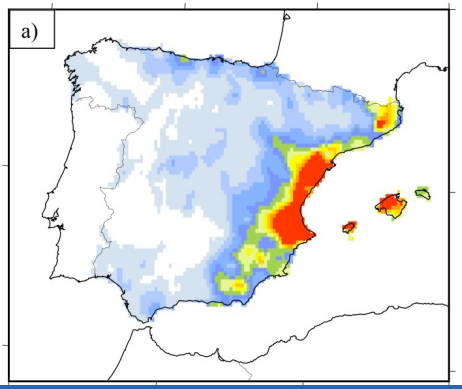
Suggesting the presence of an AR during the 1966 Florence flood



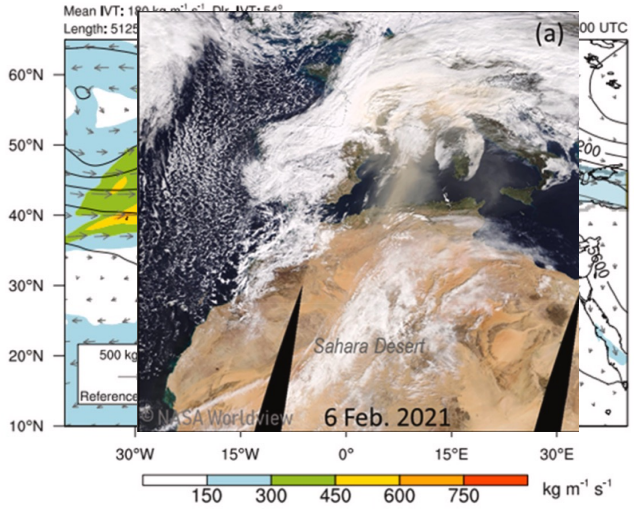
Krichak et al., 2016
Malguzzi et al., 2006
Buzzi et al., 2014

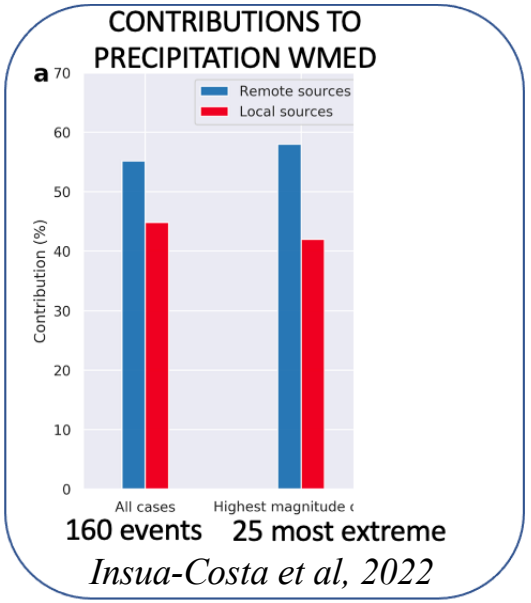


Lorente-Plazas et al, 2019



Francis et al, 2022





Insua-Costa et al, 2022

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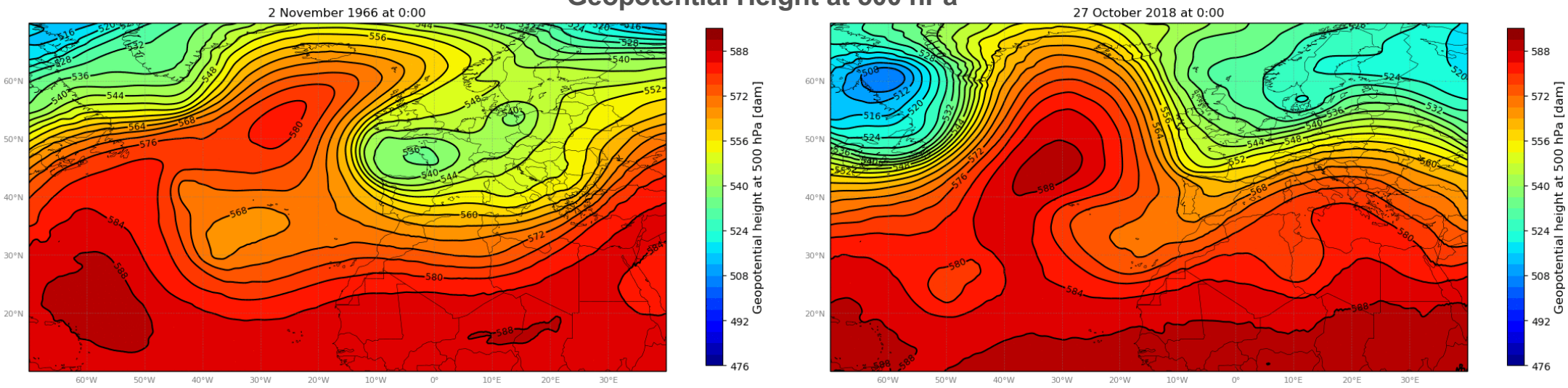
THE TWO “CENTURY FLOODS”

1966 FLOOD

2018 "VAIA" STORM



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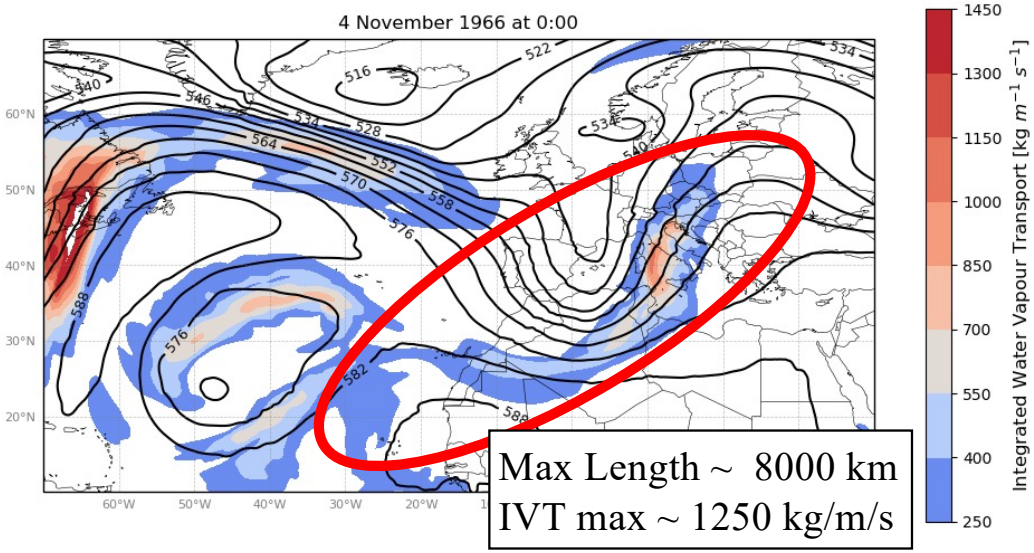
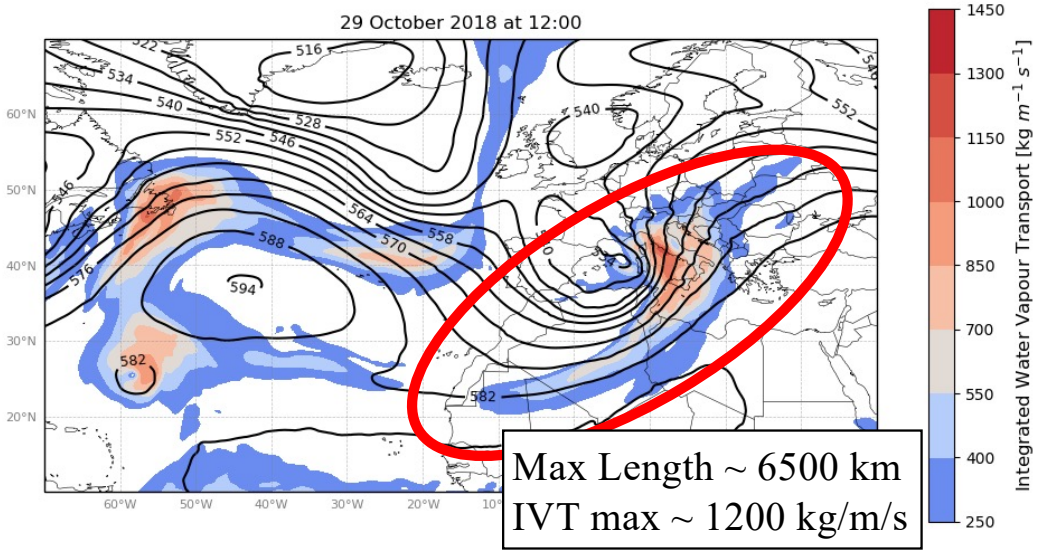
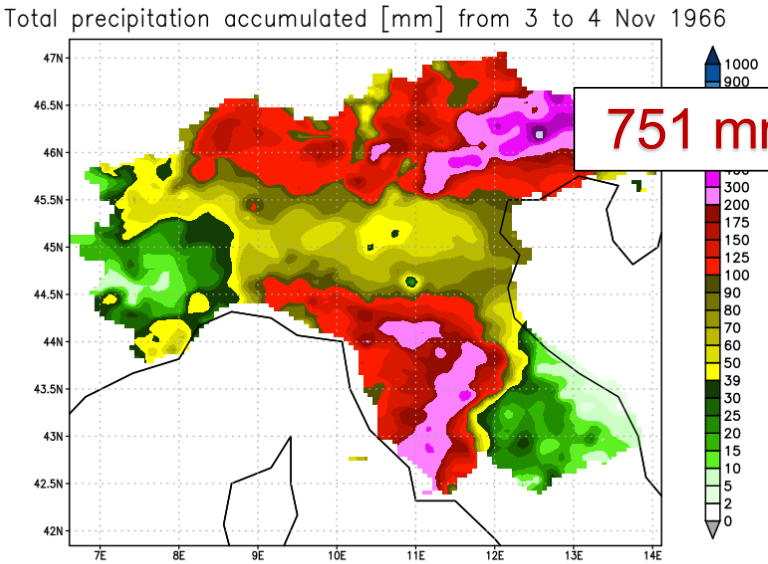


Max Length ~ 8000 km
IVT max ~ 1250 kg/m/s



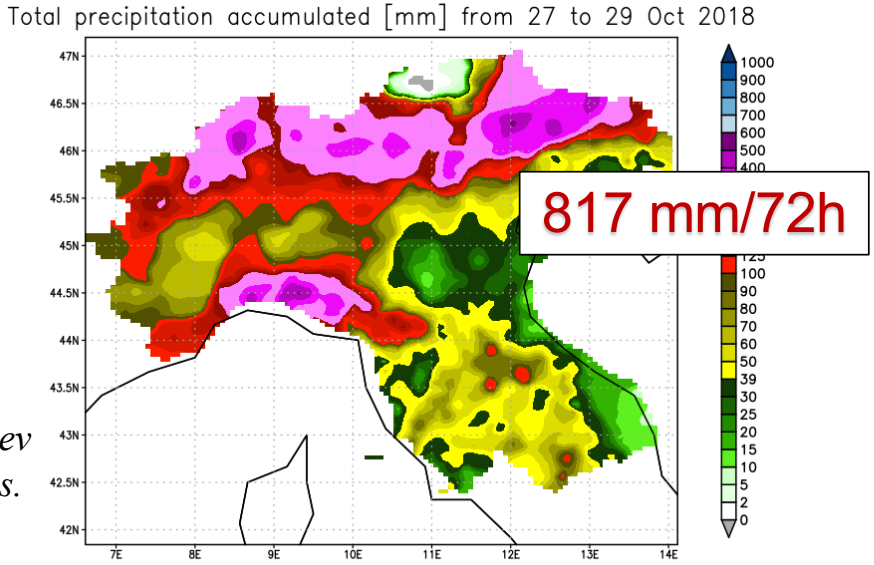
Max Length ~ 6500 km
IVT max ~ 1200 kg/m/s



751 mm/48h

ArCIS database
Rainfall
1960-2024

Davolio et al, 2020, Mon Wea Rev
Giovannini et al, 2021, Atm. Res.
Sioni et al, 2023, Atm. Res.



817 mm/72h

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ATMOSPHERIC RIVER & MEDITERRANEAN

Critical role of the AR in feeding the precipitation systems

The characteristics of the ARs (position, shape, intensity, steadiness) explain the observed heavy precipitation patterns

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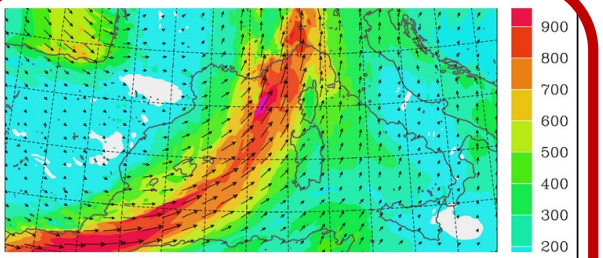
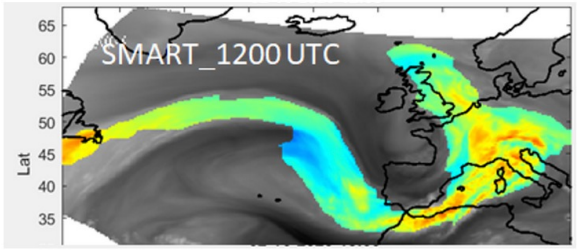
ARMEX

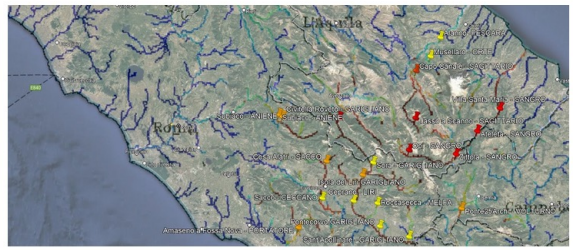
*Exploring **A**tmospheric **R**ivers in the **M**editerranean and their connection with **EX**treme hydrometeorological events over Italy: observation, modelling and impacts*



Meteorological modelling and analysis



Satellite monitoring and observations



Hydrological modelling and analysis

https://sites.google.com/view/armexproject

AIM:

- conduct a climatological analysis
- define AR characteristics and their impact in the mesoscale mechanisms of heavy precipitation
- reveal the hydrological impact of landfalling AR in several basins of different characteristics

TOWARDS A CLIMATOLOGY: ATMOSPHERIC RIVER DETECTION

Guan & Waliser (2015) algorithm with some adaptation for the Mediterranean

IVT Integrated Vapour Transport

i) IVT thresholds: IVT > 85-percentile
IVT > 250 $kgm^{-1}s^{-1}$

i) length > 2000 km

ii) aspect ratio > 2

AR Selection:

Target area: North/Central Italy

Origin area: outside the Mediterranean

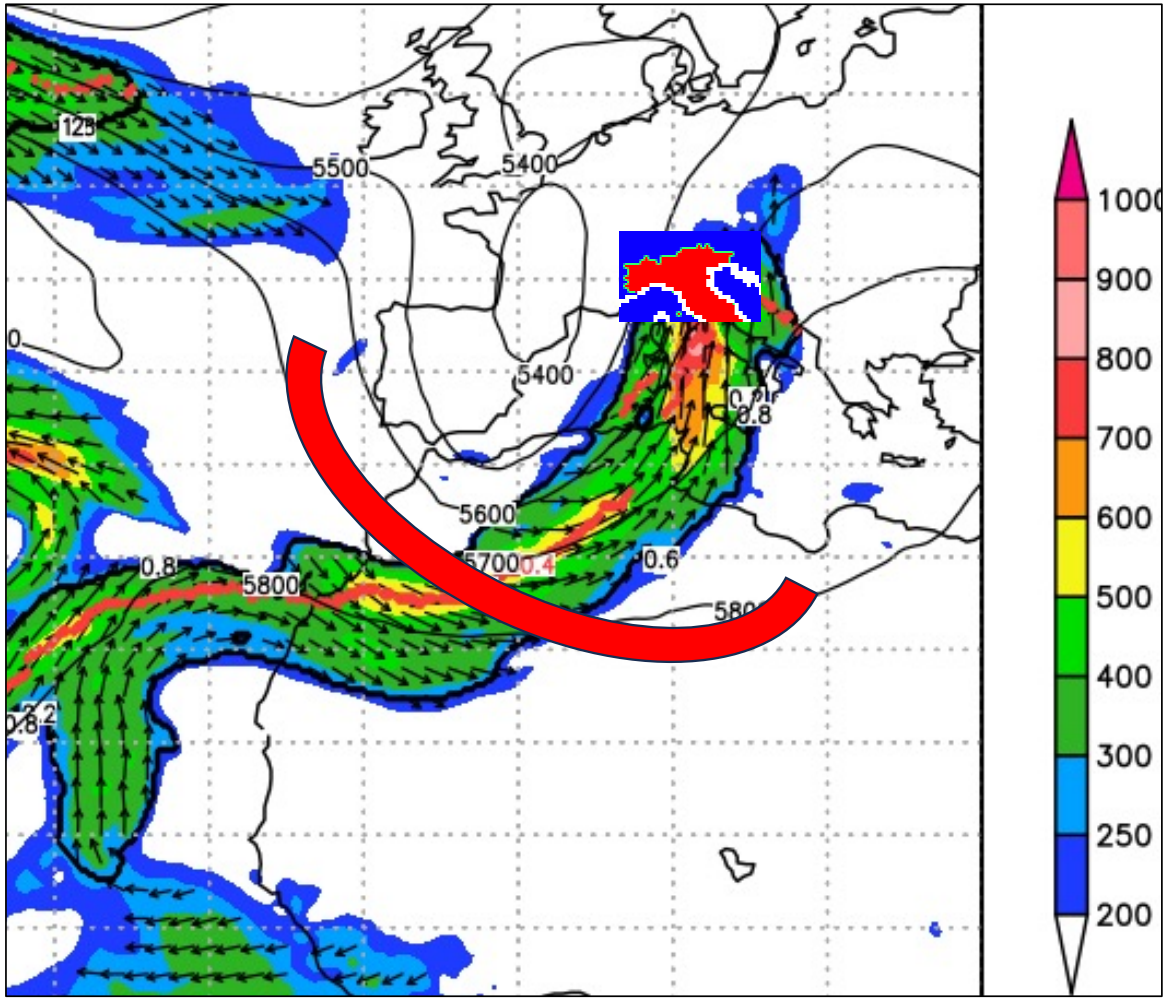
$IVT_y > 0$

Duration: at least 12 hours

MAX IVT over the sea, close to the target area

DATASETS:

ERA5 reanalysis (IVT) and ArCIS (1961-2024)



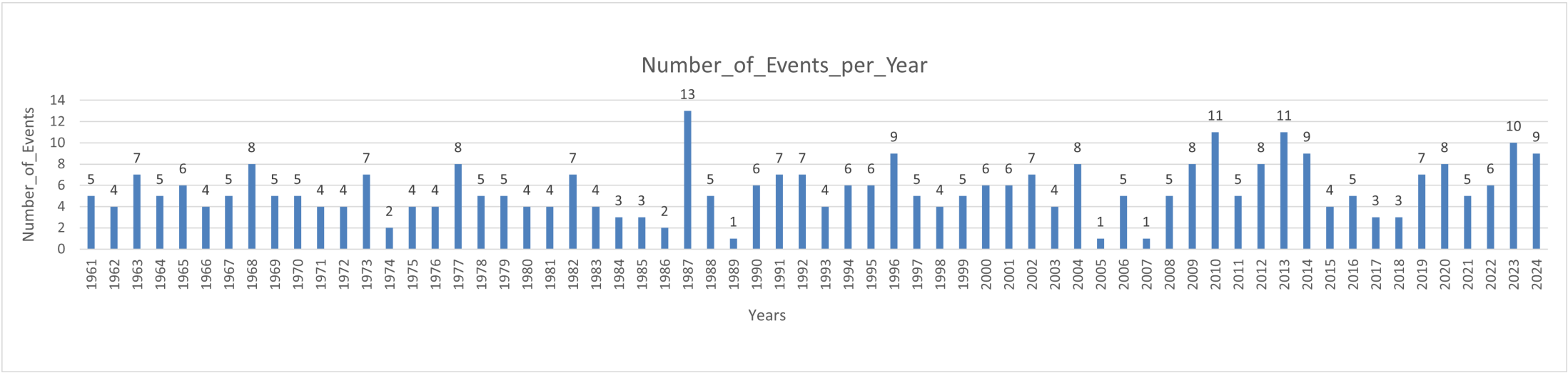
GUAN&WALISER ALGORITHM (adapted to the Med)

ERA5 1950-2024

IDENTIFICATION OF MOST INTENSE AR AFFECTING N-ITALY

MOST INTENSE EVENTS OVER N-ITALY

ARCIS RAINFALL 1961-2024



357 AR identified, on average 5.6 AR events per year

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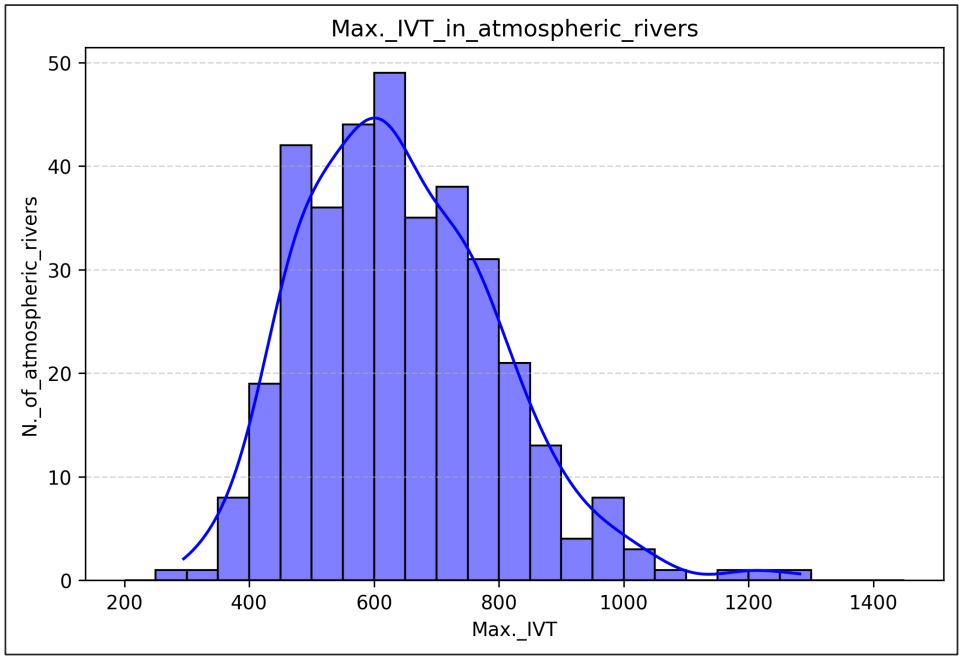
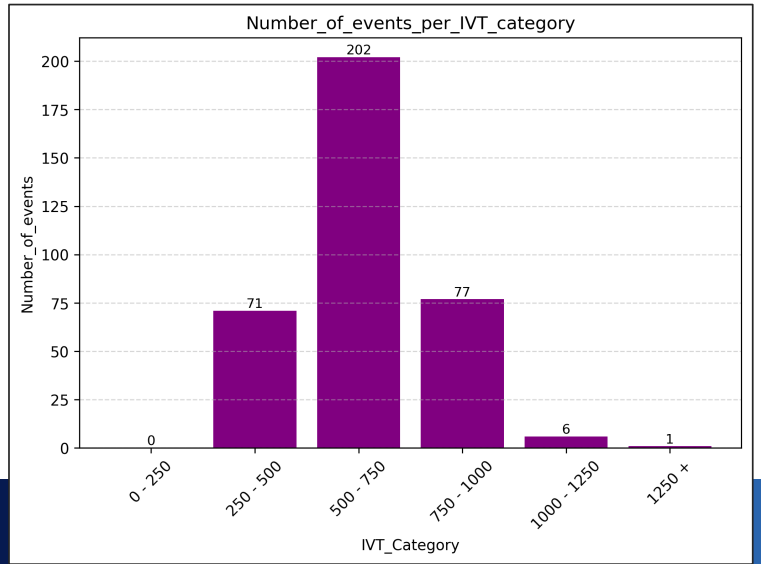
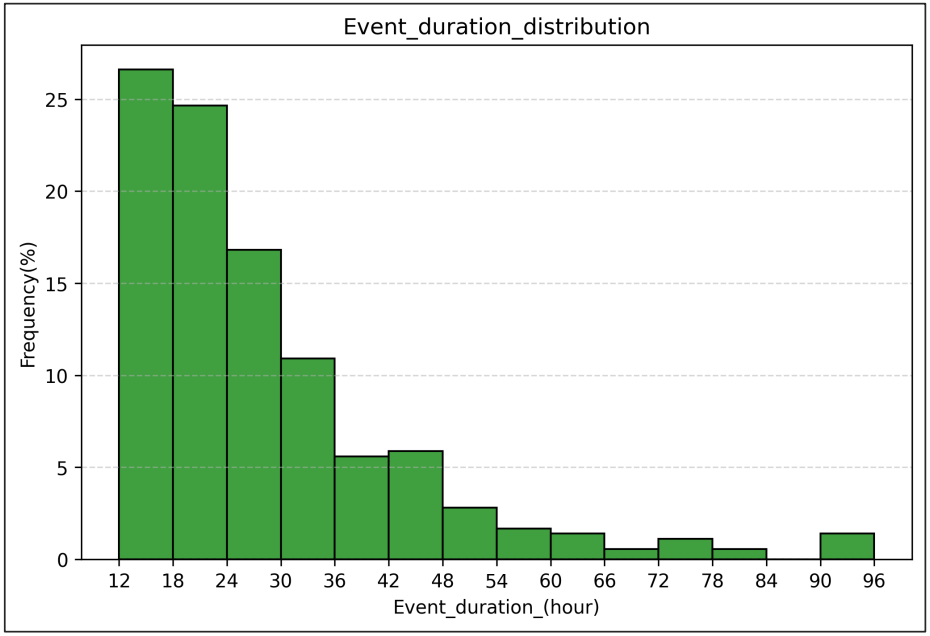
AR INTENSITY & DURATION







precipitation over northern Italy

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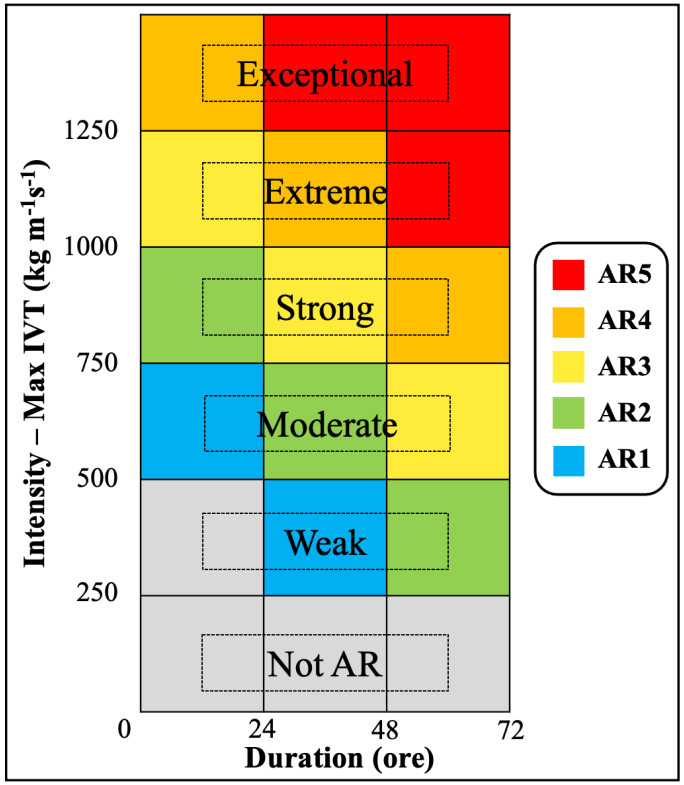
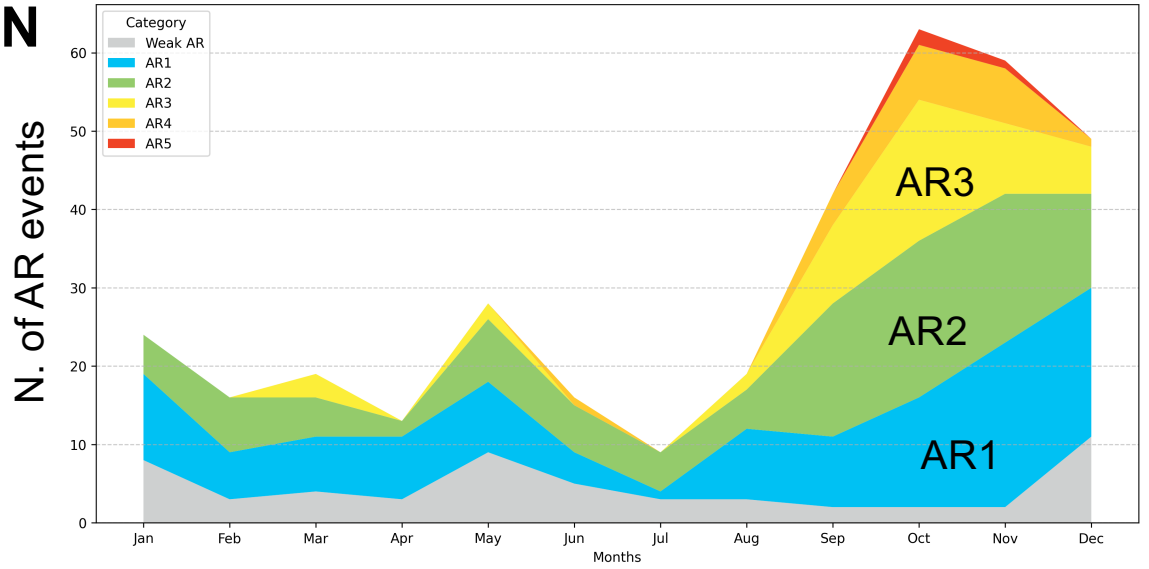
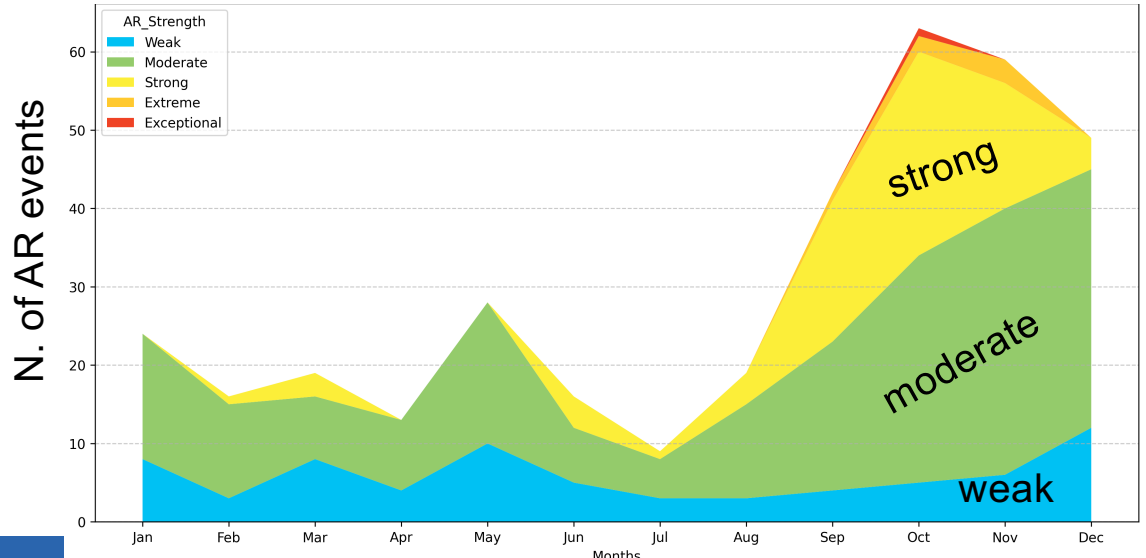
AR SEASONAL DISTRIBUTION



Ralph et al., 2019



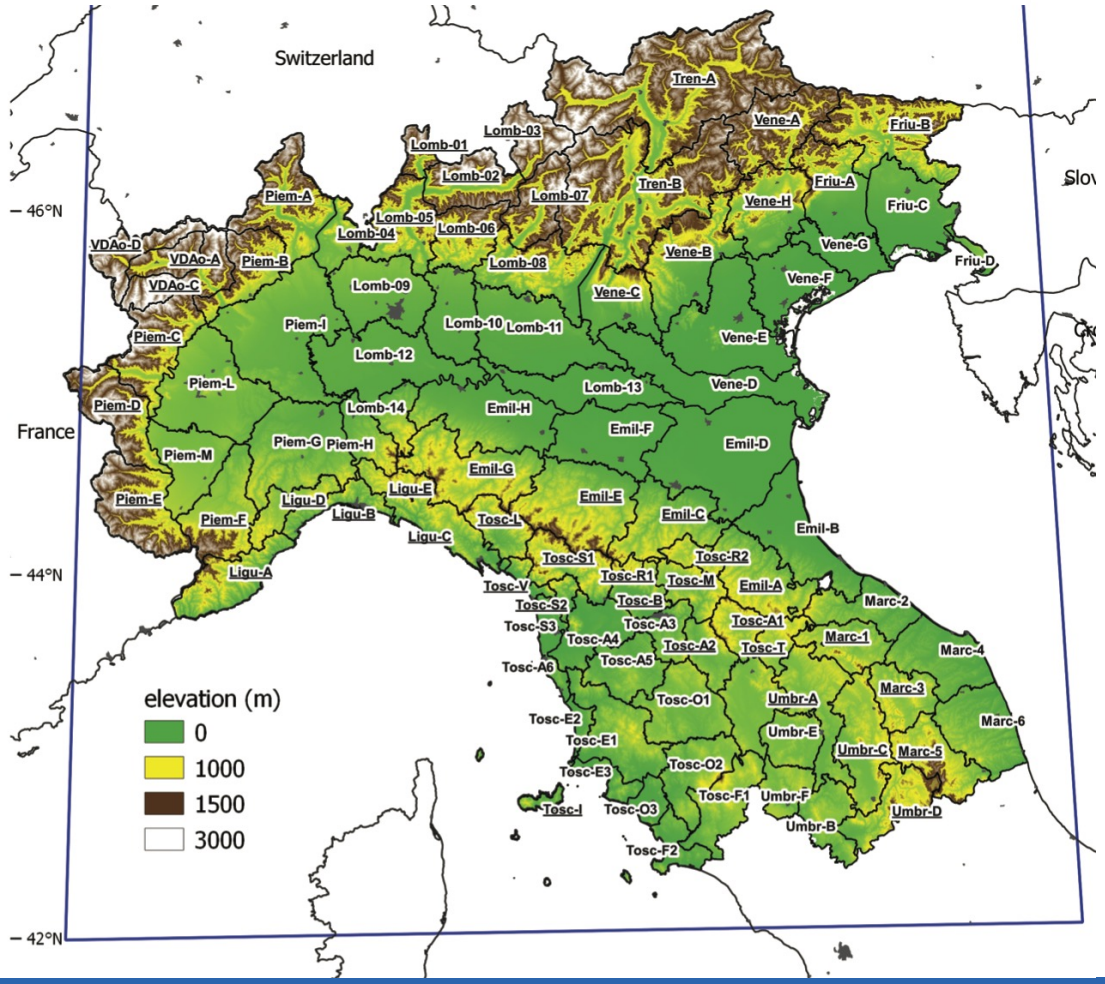


AR vs PRECIPITATION

- Daily precipitation aggregated over 94 warning-areas
- Mean area extension 1750 km^2
- **Extreme Precipitation Event (EPE)**: day with daily precipitation greater than 99th percentile (wet days only) across one or more warning areas

Grazzini et al., 2019, 2021

ITALIAN CIVIL PROTECTION WARNING AREAS



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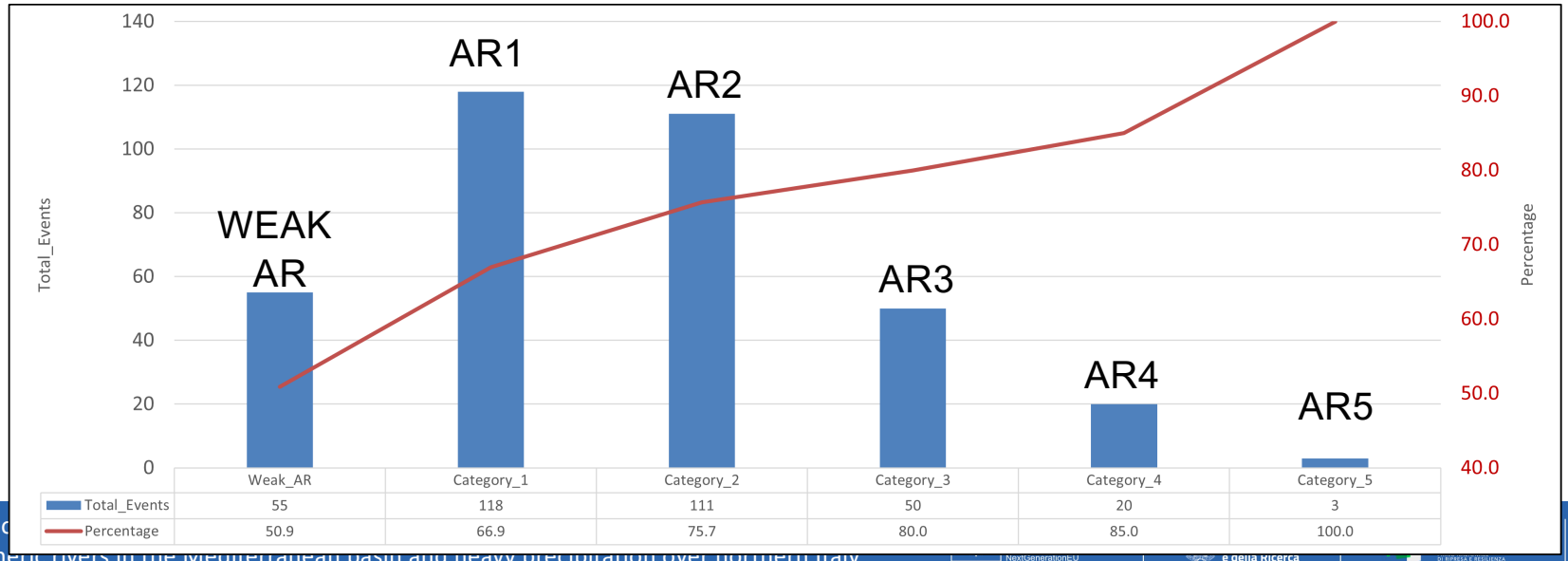
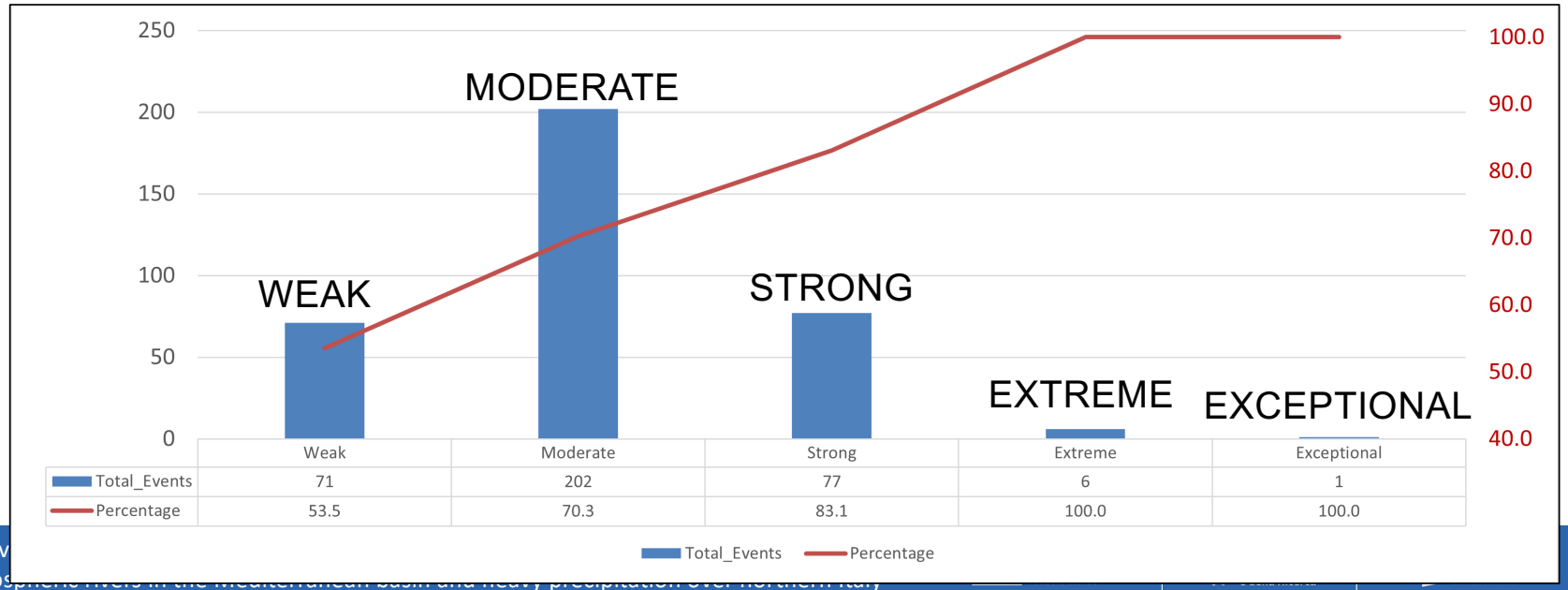
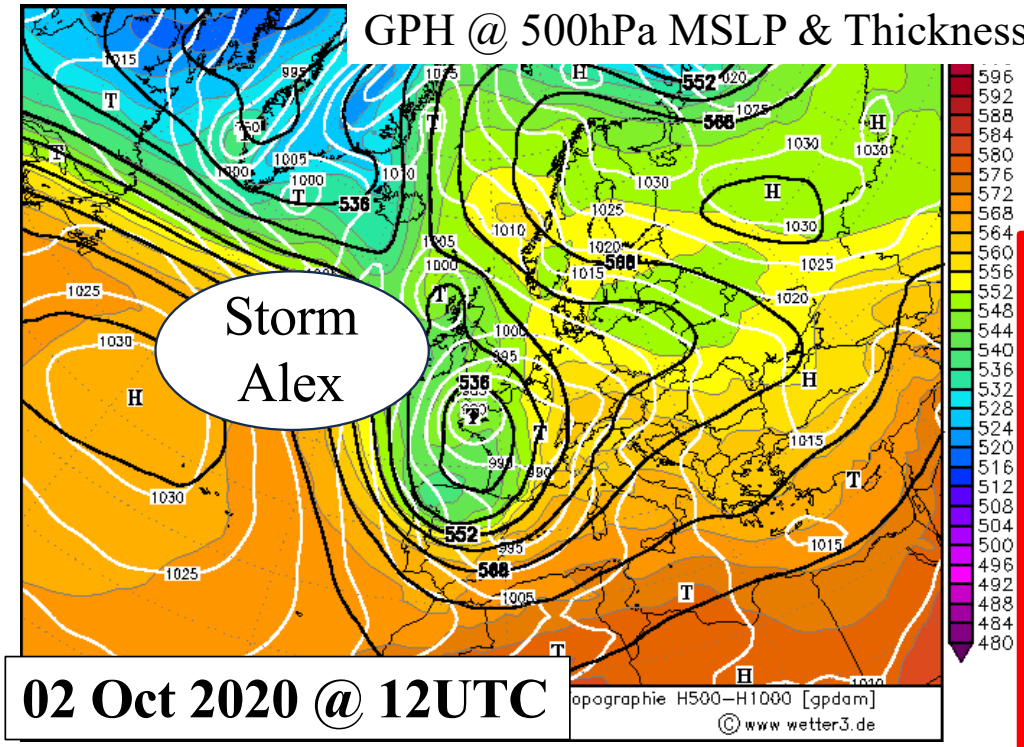
CATEGORY	N. of AR	N. of ARs associated with EPE	% of ARs associated with EPE
WEAK AR	55	28	51%
AR1	118	79	67%
AR2	111	84	76%
AR3	50	40	80%
AR4	20	17	85%
AR5	3	3	100%

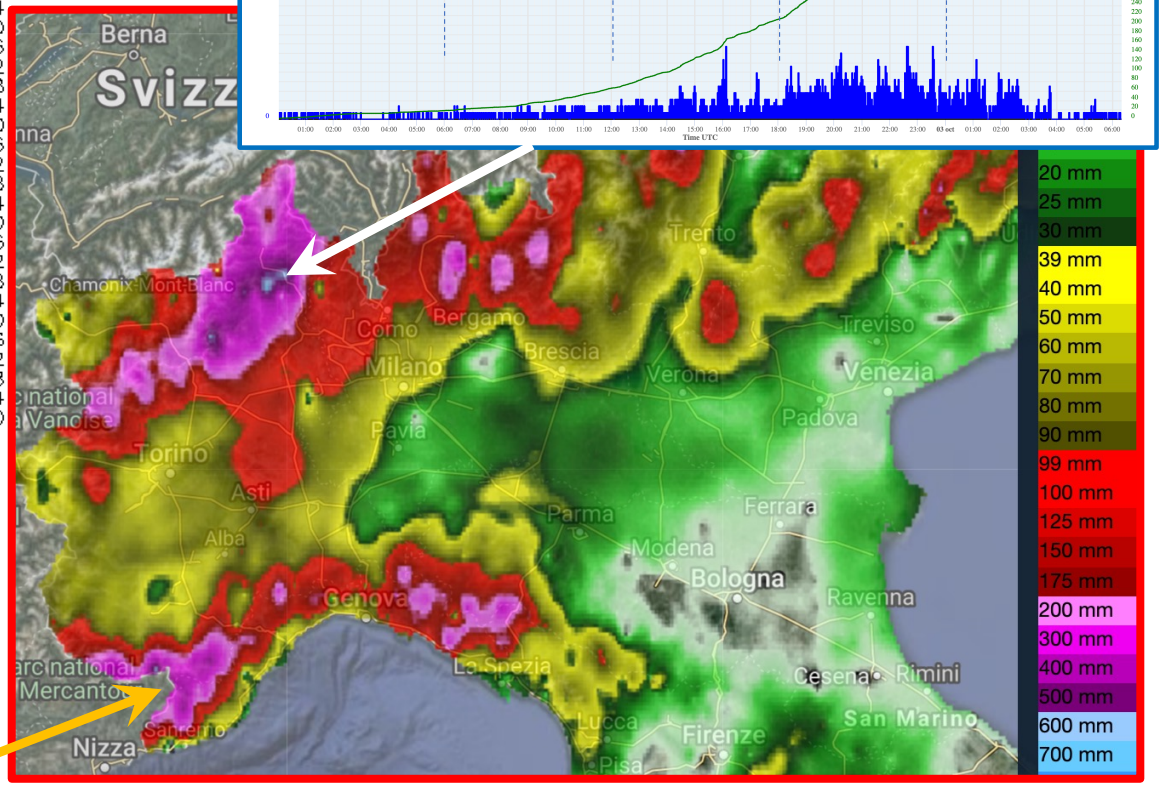


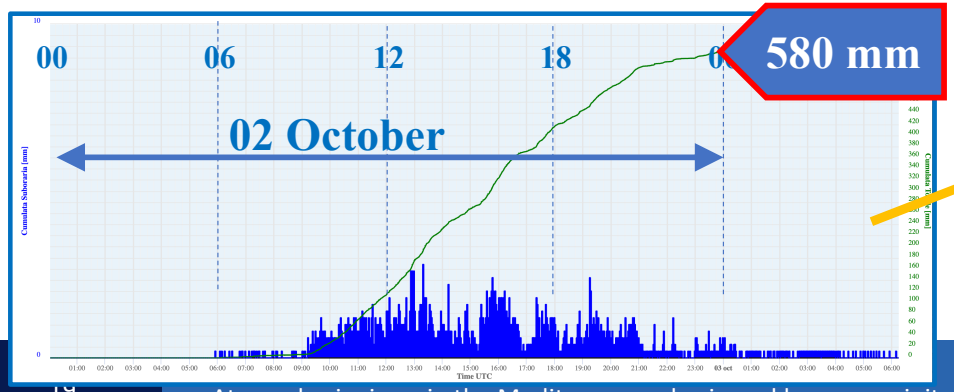
CATEGORY (IVTmax based)	N. of AR	N. of ARs associated with EPE	% of ARs associated with EPE
WEAK	71	38	**54%**
MODERATE	202	142	**70%**
STRONG	77	64	**83%**
EXTREME	6	6	**100%**
EXCEPTIONAL	1	1	**100%**



GPH @ 500hPa MSLP & Thickness







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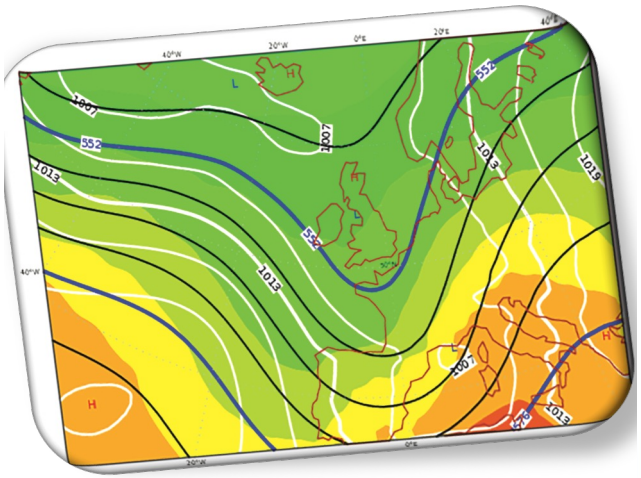
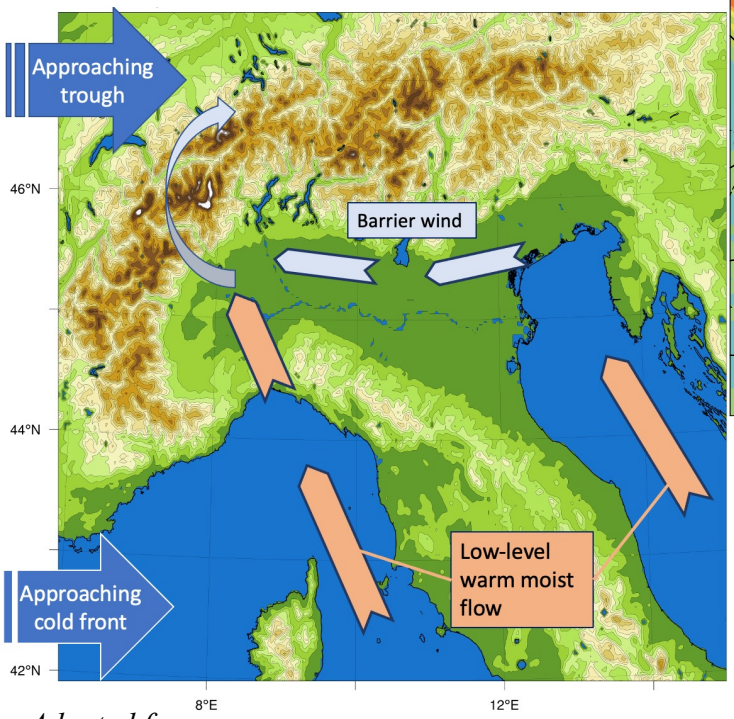
PAST ALPINE HEAVY RAINFALL

AT SYNOPTIC SCALE



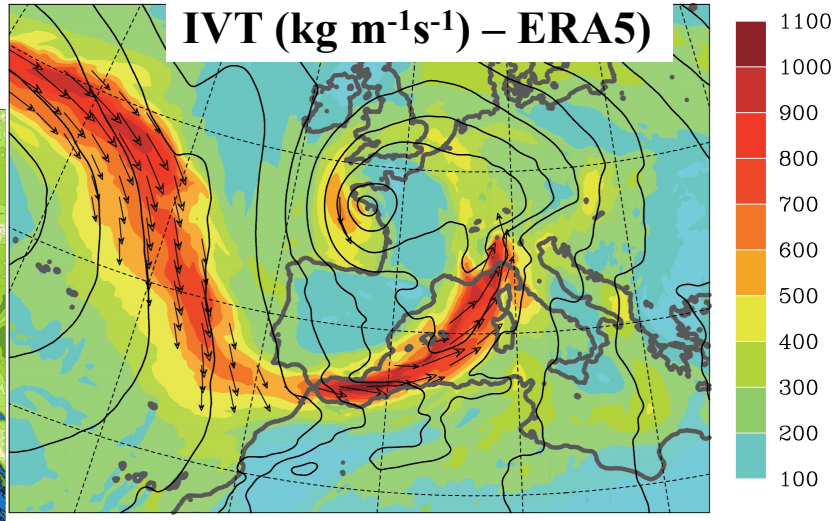
Grazzini et al, 2007, 2020

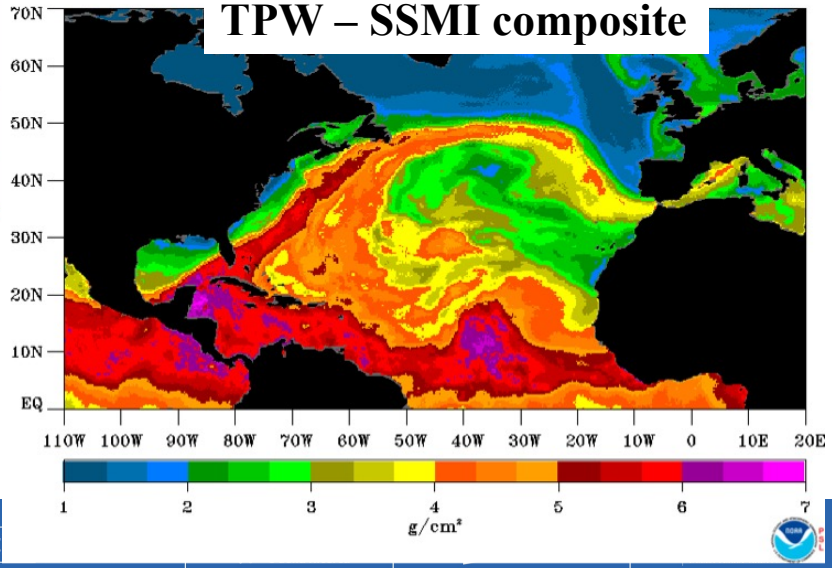
AT THE MESOSCALE



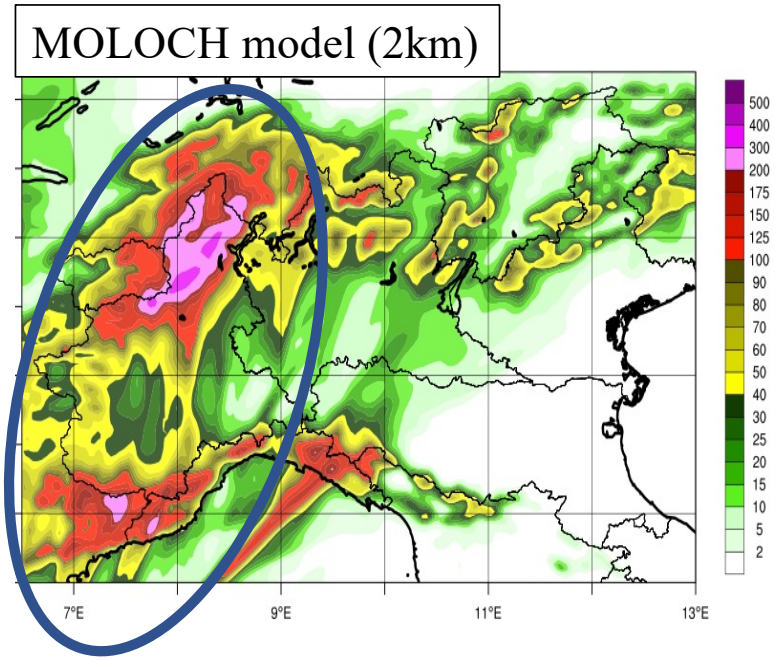
Adapted from Miglietta & Davolio, 2022

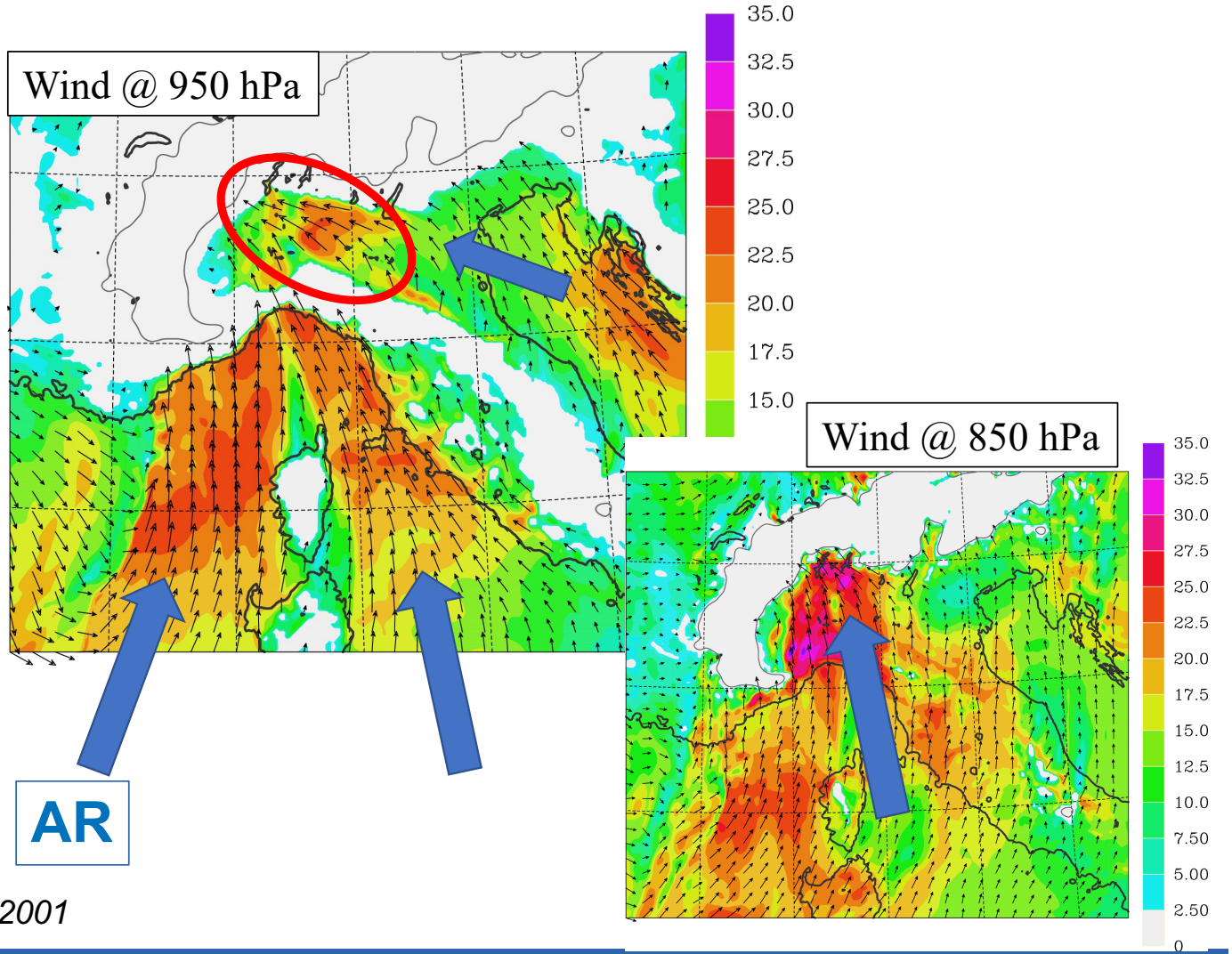
NOVELTY

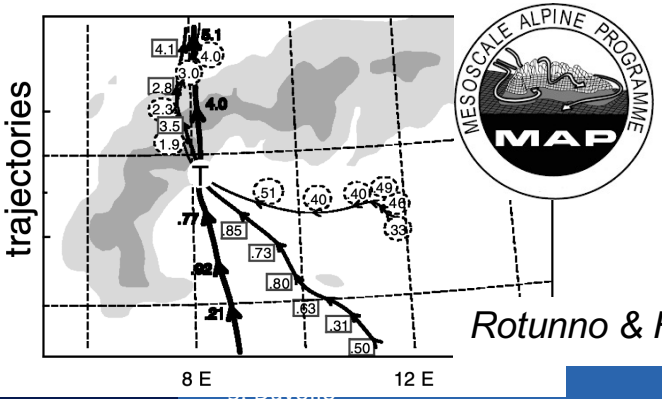




HIGH-RESOLUTION SIMULATIONS for MESOSCALE ANALYSIS





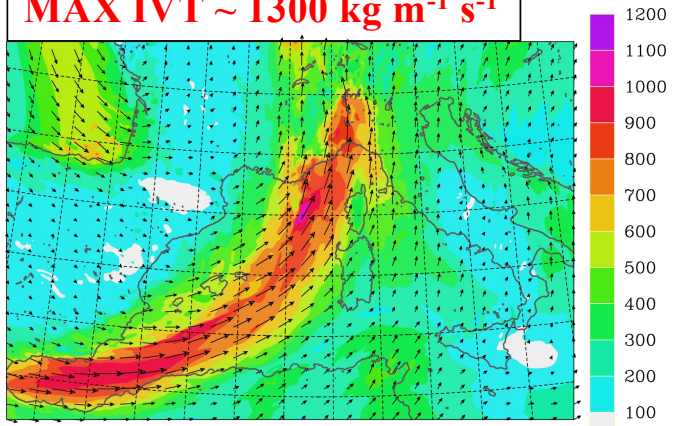


MESOSCALE ALPINE PROGRAMME MAP

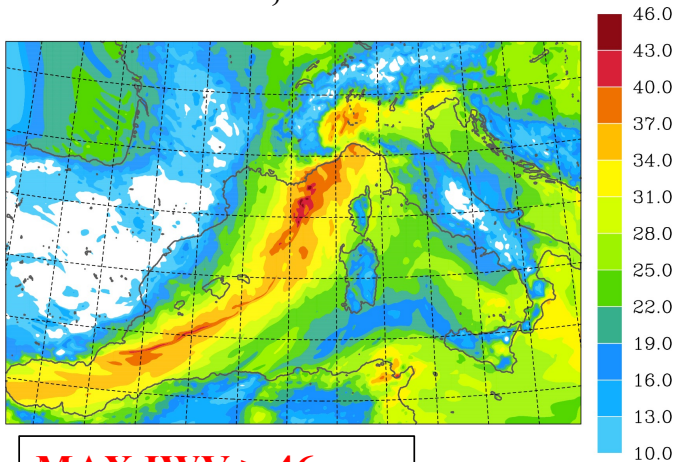
Rotunno & Ferretti, 2001

MOLOCH model (2km)

MAX IVT ~ 1300 kg m^{-1} s^{-1}



2 Oct, 18 UTC

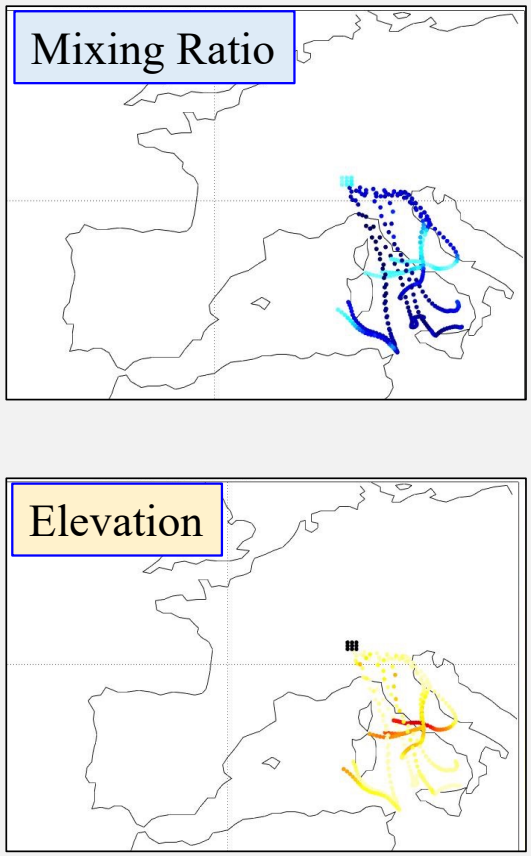


MAX IWV > 46 mm

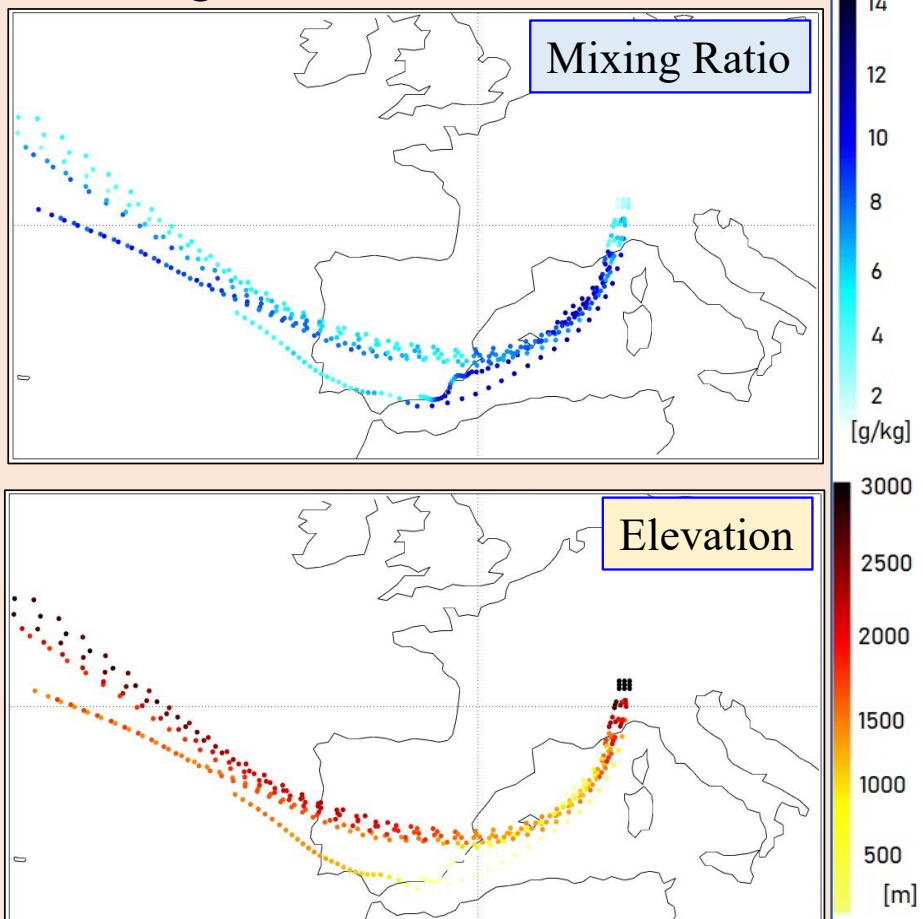
MOISTURE SOURCES → 48-h Backtrajectory

HYSPLIT AIR RESOURCES LAB

arriving at **2500 m**



arriving at **4000 m**



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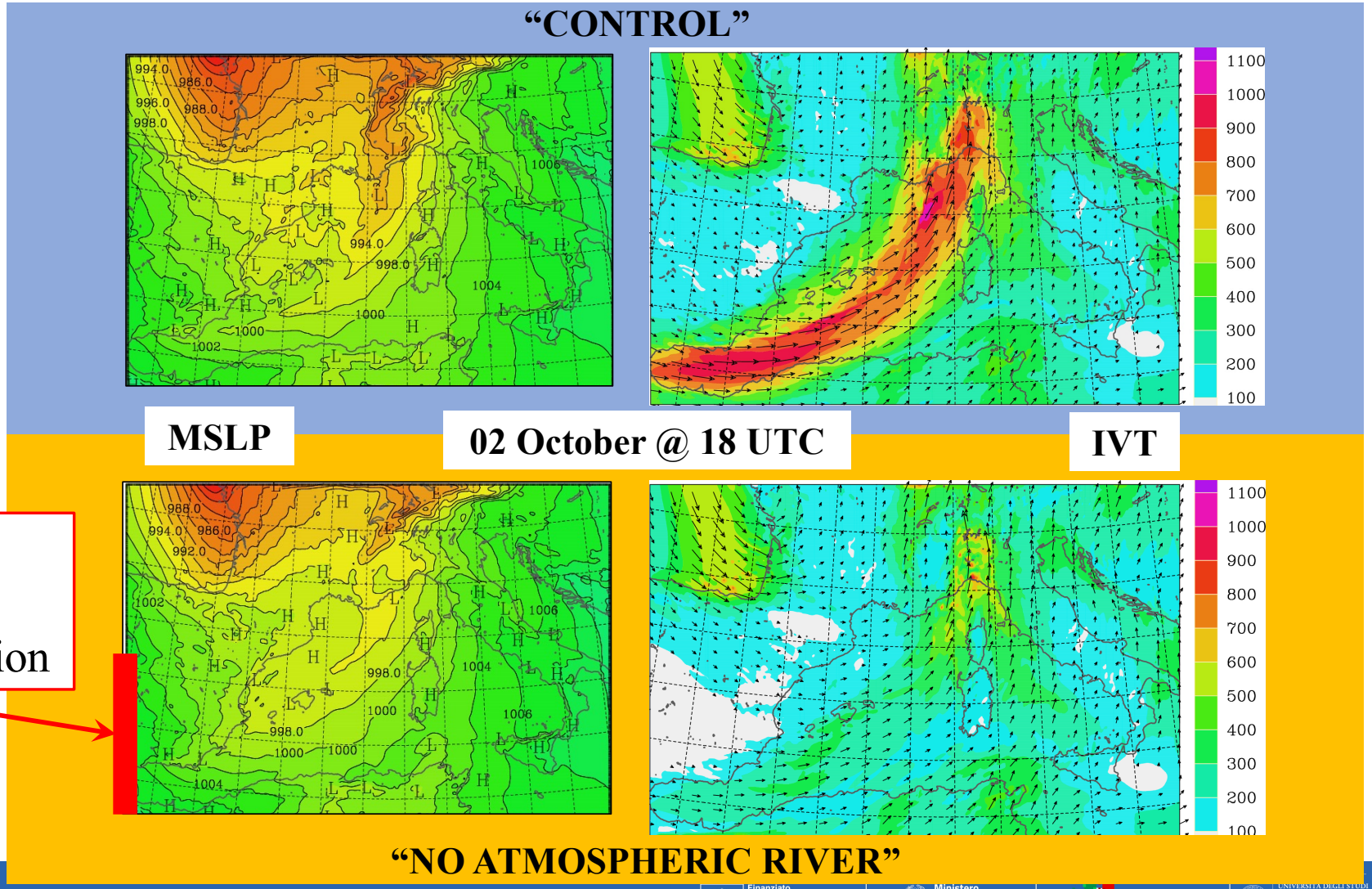
SENSITIVITY NUMERICAL EXPERIMENTS to ASSESS AR ROLE

Boundary condition modified:
75% moisture reduction



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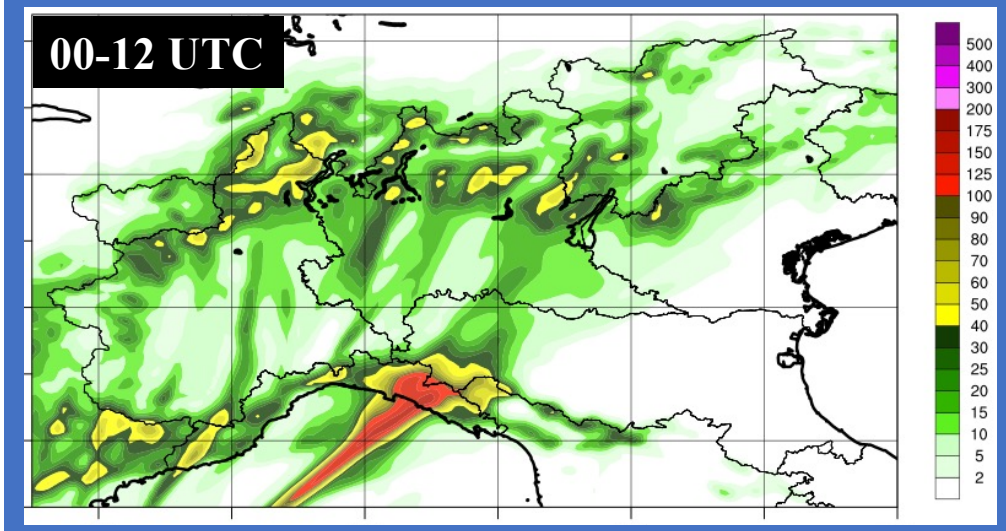
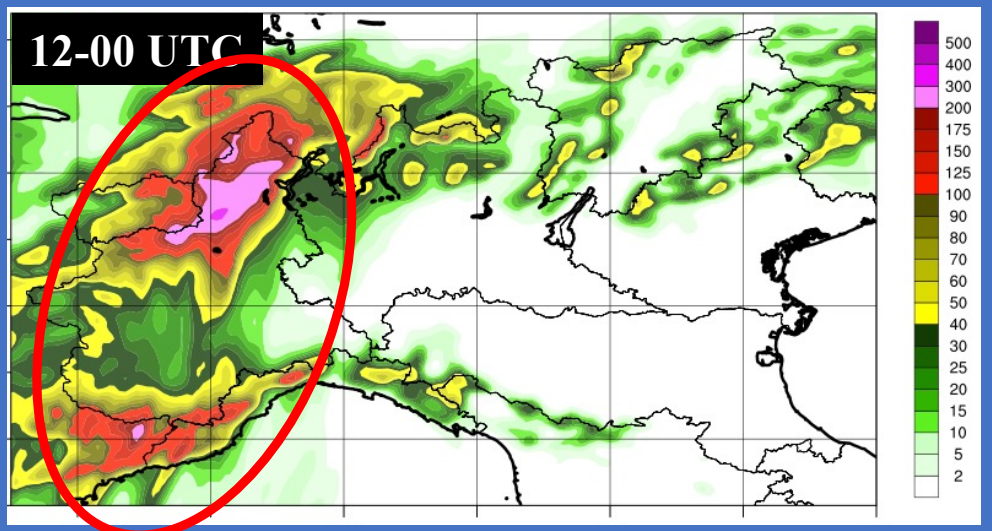
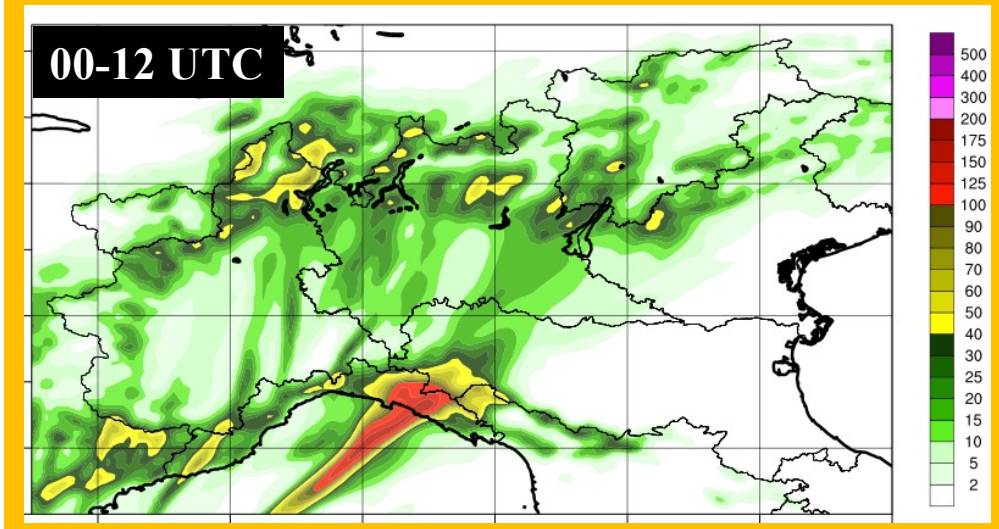
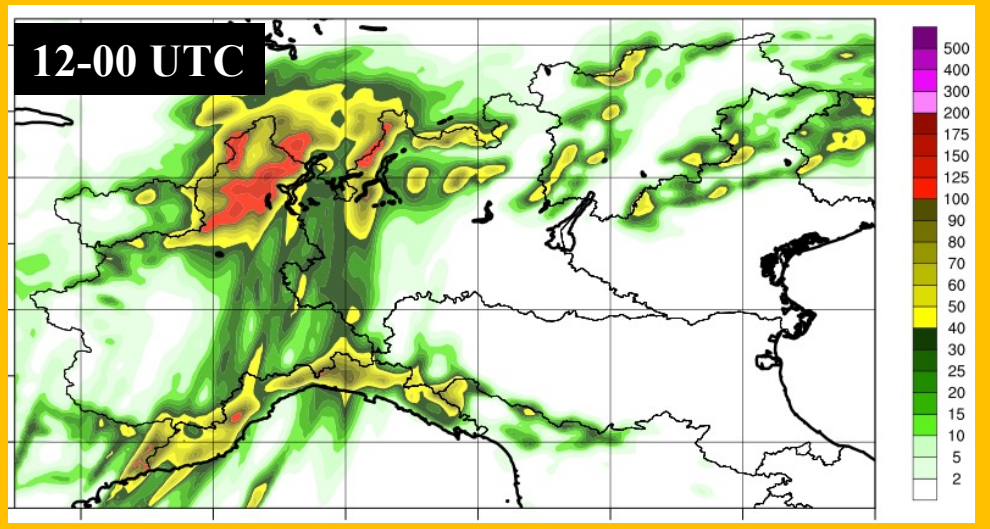
12 HOUR ACCUMULATED PRECIPITATION – 02 OCTOBER 2020





CONTROL





NO ATMOS RIV

EXPLORING PREDICTABILITY OF EPE and AR at MONTHLY TIME SCALE

Vaia storm event

25–31 Oct 2018, weekly anomalies

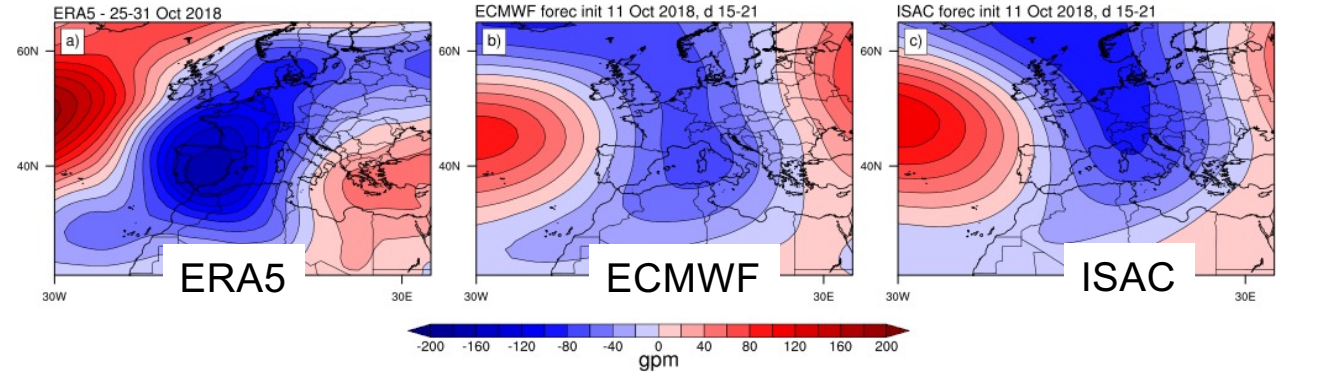
- **ERA5**: z500 (gpm)
- **CPC**: precipitation (mm/d)
- reference climate 1998–2017 (20 y)

ECMWF ensemble forecast

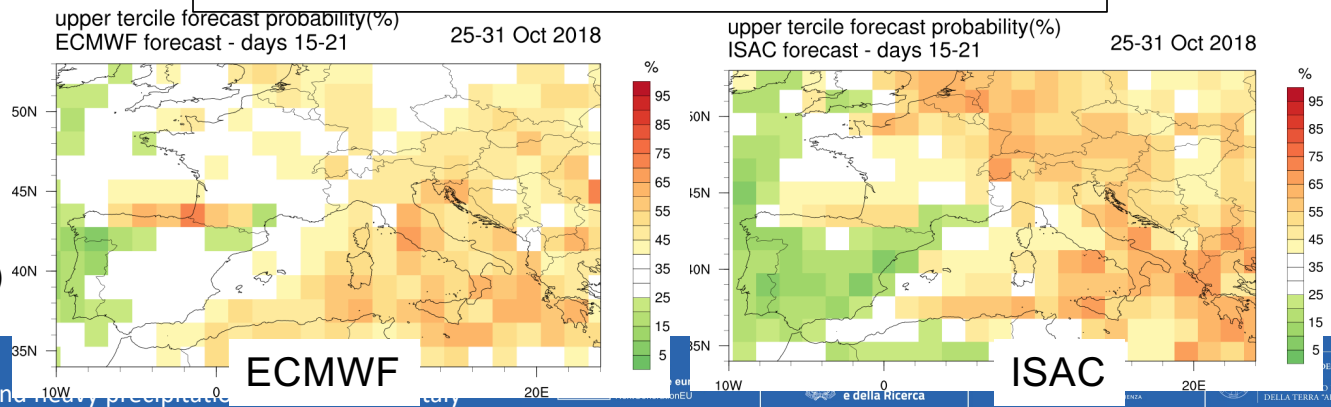
- initialized: 11 Oct 2018 (operational)
- 51 members, perturbed
- reference climate: 11-member ensemble reforecasts, 1998–2017 (20 y)

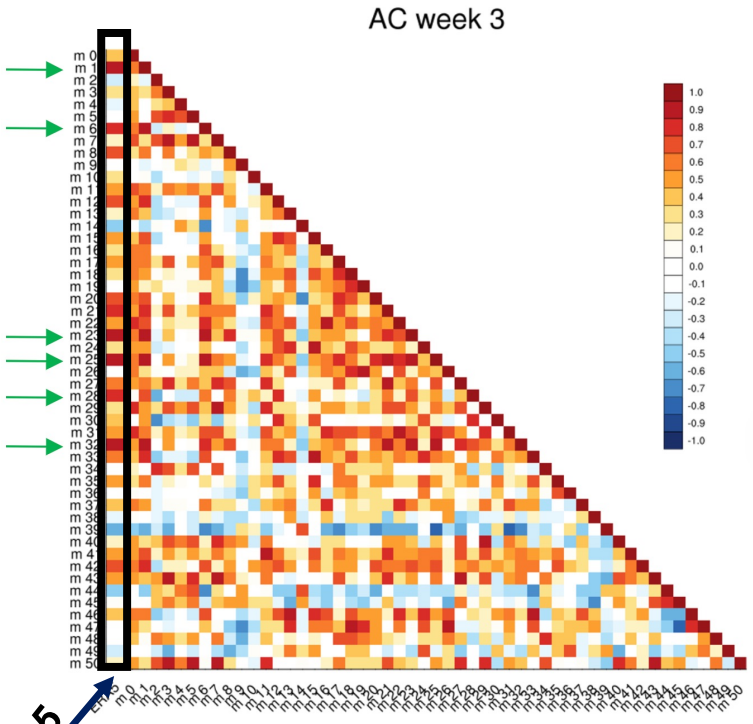
CNR-ISAC ensemble forecast

- initialized: 11 Oct 2018 (hindcast, ERA5)
- 41 members, lagged/perturbed
- reference climate: 8-member ensemble reforecasts, 2001–2020 (2018 removed, 19 y)

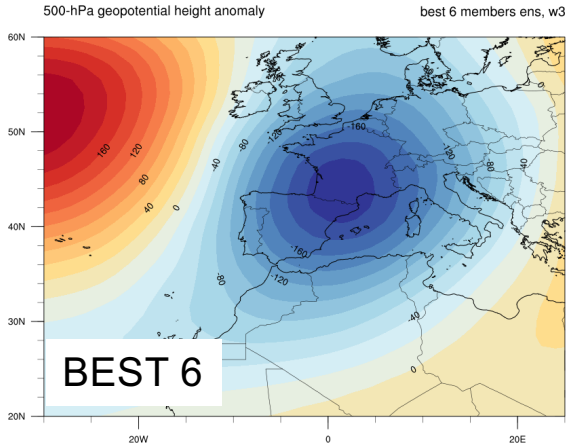


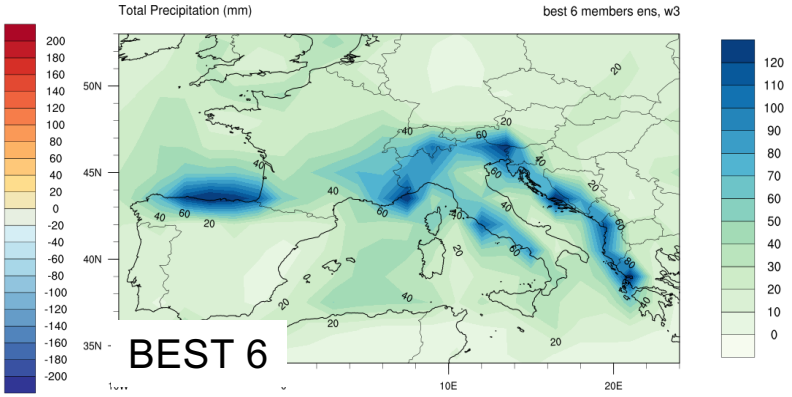
UPPER TERCILE PROBABILITY 3rd week



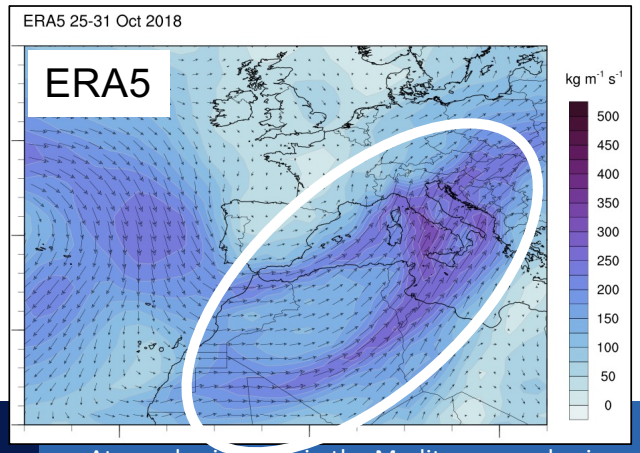


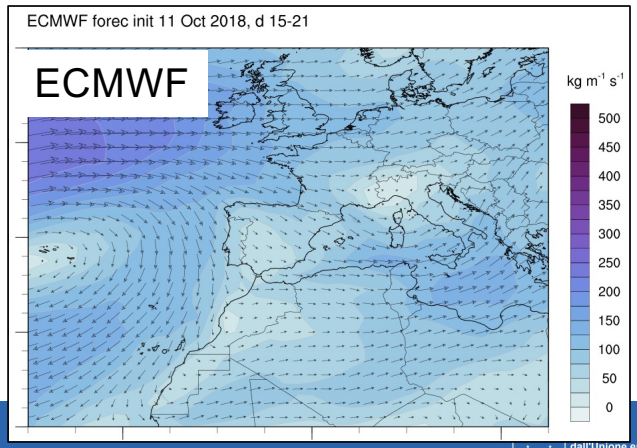
Extract the best (6) members higher anomaly correlation with ERA5 at week 3

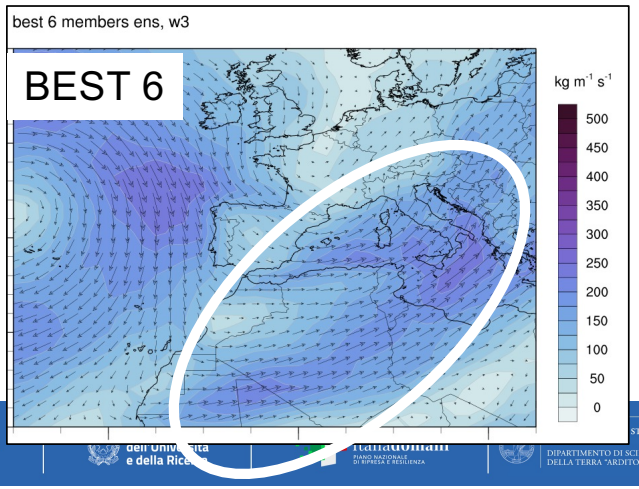




Why are they good? What happened upstream before?

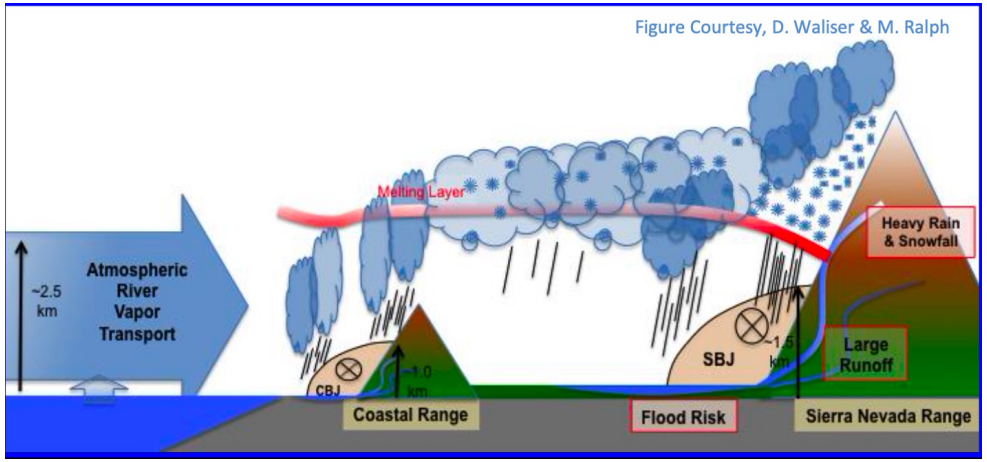






CONCLUSIONS

- Climatology: relevance of AR and connection with EPE
- Case study approach:
  - The AR may turn an ordinary intense rainfall event into a devastating flood
  - Mechanism of orographic precipitation
  - Local hydro-meteo impacts, forecasting at different time-scales



FUTURE PERSPECTIVES

- Connecting EPE to AR
- Exploring mechanisms associated with convection
- Extend the study to other Med areas

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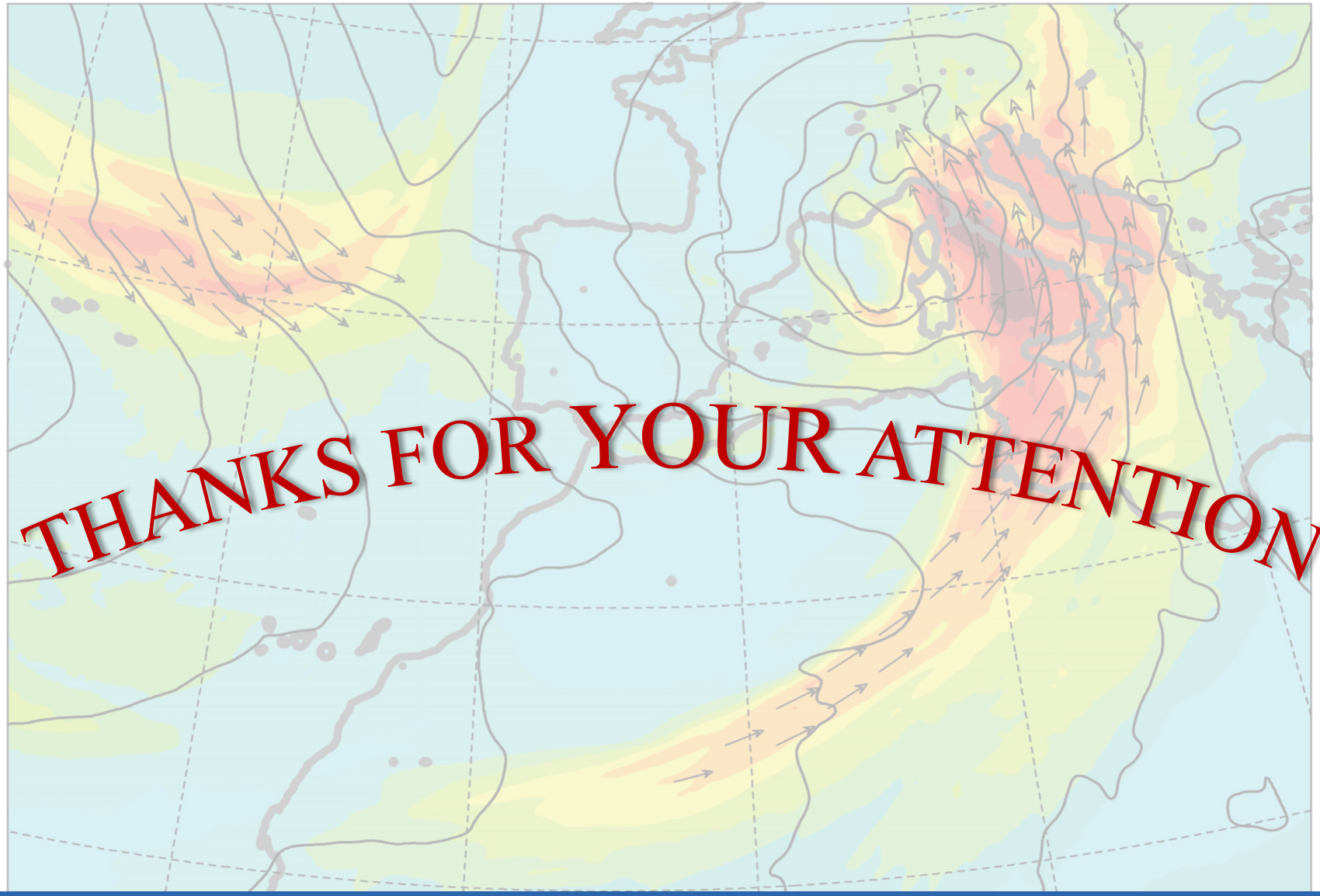

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