REVISITING THE ATMOSPHERIC DYNAMICS OF THE TWO CENTURY FLOODS OVER NORTH-EASTERN ITALY

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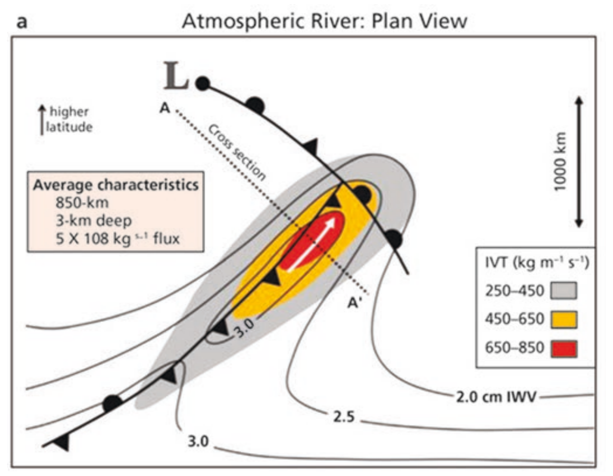
ABSTRACT

This work reconstructs the dynamics leading to the two most intense Extreme Precipitation Events (EPEs), both in terms of area affected and total accumulated precipitation volume over north-eastern Italy in the last 60 years: the 66 "century" flood (3-5 November 1966) and the Vaia storm (27-30 October 2018). The 66 flood led to the overflooding of Arno, Adige, Tagliamento and Ombrone rivers causing the death of 188 people. The Vaia storm is mainly known for the strong Sirocco wind gusts that reached 217 km/h at Passo Rolle (Trentino) and that damaged over 41,000 ha of forests. The approach is two-sided using both reanalysis data (ERA5 database, ArCIS precipitation archive) and numerical modelling (BOLAM). Heavy Precipitation and pluvial floods are expected to increase over the Mediterranean region due to climate change (IPCC, 6th report). Providing the forecasters with the necessary elements to identify in advance evidences of EPEs is of fundamental importance in terms of civil protection and damage confinement.

ATMOSPHERIC RIVERS

EPEs are generally characterized by intense and persistent precipitations. Consequently, water vapour (WV) has to be continuously supplied to the precipitation systems. WV can be supplied through long, narrow and transient filaments of horizontal WV transport known as **Atmospheric rivers (AR).** These structures develop ahead of the cold front of an extratropical cyclone. The name is related to the fact that they can be really thought as effective rivers made of WV.

Both 66 flood and Vaia storm are characterized by the presence of an AR.

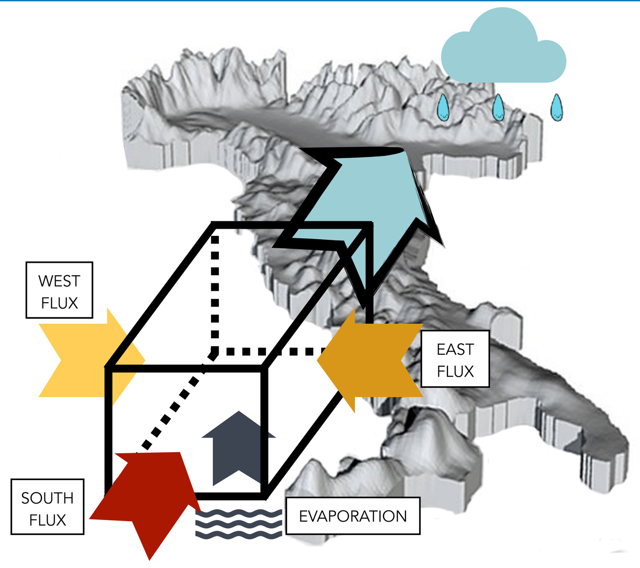


From Ralph et al. (2020). Schematic summary of the structure of an AR. Plan view including parent low pressure system, and associated cold and warm surface fronts. IVT is shown by color fill. IWV is contoured.

Water Vapor transport structures are labelled as ARs if they respect the following features:

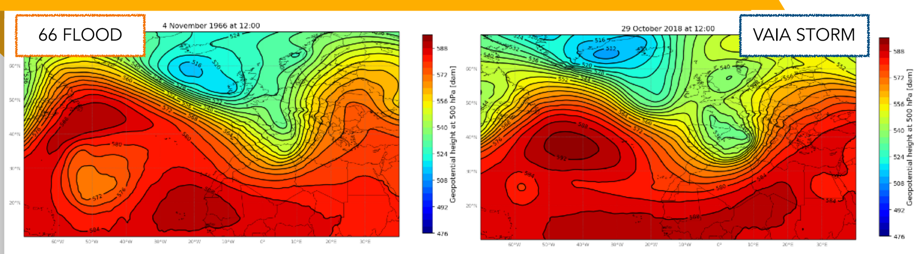
VARIABLE	THRESHOLD
Position	Poleward of 20°
Length	>2000 km
Integrated WV (IWV)	>20 kg m^{-2}
Integrated WV Transport	>250 kg m^{-1} s^{-1}

METHODS - WATER BUDGET

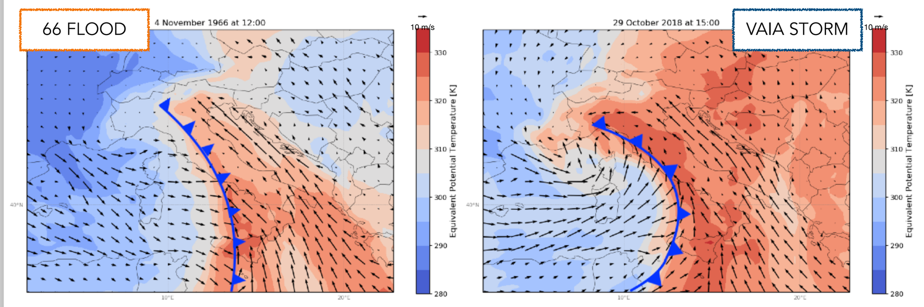


Numerical modelling allows to characterize the origin of the moisture that feeds the precipitation systems and to evaluate the local contribution of evaporation. This is assessed computing a water budget in the atmosphere. A parallelepiped box is placed upstream of the precipitation area (north-eastern Italy) such that WV fluxes that exit from the northern side are directed towards the investigated region of precipitation and thus coincide with the water fluxes that supply moisture to the EPEs. This technique allows to track the variation in time of the fluxes of WV through each lateral side (West, East, South) and through the bottom side due to evaporation processes. The fluxes are integrated in time and their percentage contribution is evaluated.

SYNOPTIC EVOLUTION



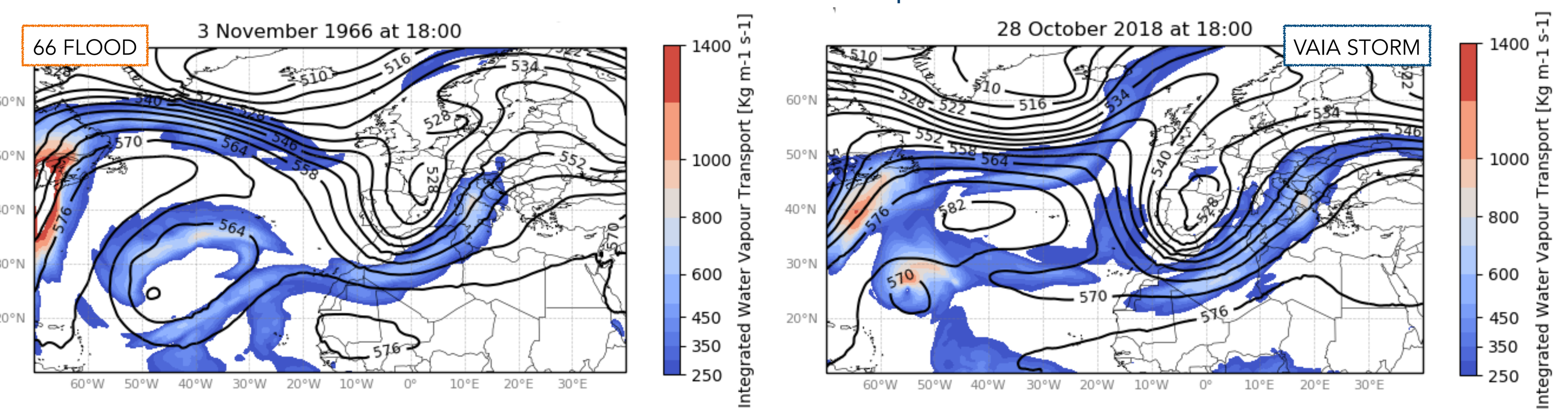
ERA5 reanalysis maps. Geopotential height at 500 hPa [dam] at Euroatlantic scale.



ERA5 reanalysis maps. Equivalent potential temperature [K] (filled), wind at 1000 hPa [m/s] over Italy.

The two EPEs share a similar synoptic evolution.

A trough deepened over western Europe leading to cyclogenesis at the surface, which was explosive in the case of Vaia with a pressure minimum of 977 hPa at sea level. The cold front driven by the cyclonic circulation was able to collect WV ahead of it. The precipitation over north-eastern Italy was mainly of orographic nature, associated with uplift of warm, moist and gusty Sirocco winds channelled between the Apennines and the Dinaric Alps impinging on the Alpine chain.



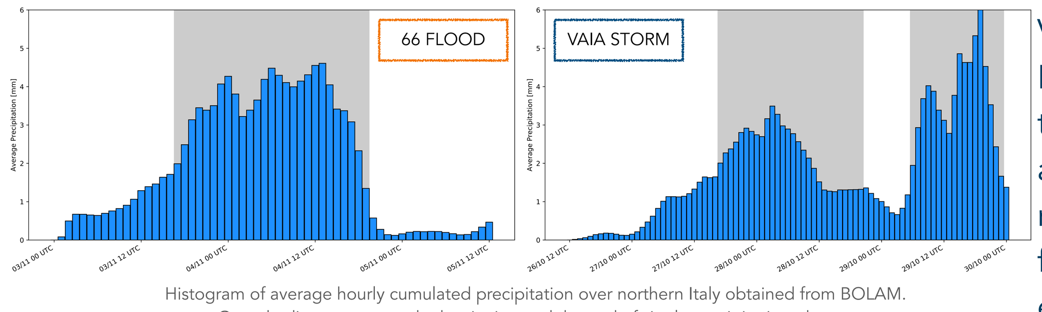
ARs at their maximum length. IVT [kg m-1 s-1] (filled), geopotential height at 500 hPa [dam] (contour) at Euroatlantic scale.

- Maximum Length: 8200 km
- Maximum IVT: 1244 kg m^{-1} s^{-1}
- Interaction with tropical depression "Lois"

- Maximum Length: 6500 km
- Maximum IVT: 1210 kg m^{-1} s^{-1}
- Interaction with subtropical storm "Oscar"

MODELLING - Precipitation histograms

66 flood is characterized by a single precipitation phase with almost constant intensity and persistent precipitation for almost 27 hours.

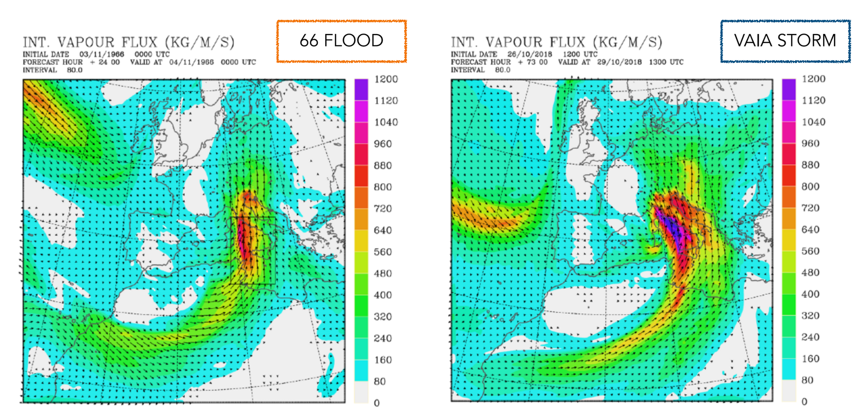


Histogram of average hourly cumulated precipitation over northern Italy obtained from BOLAM. Gray shadings represent the beginning and the end of single precipitation phases.

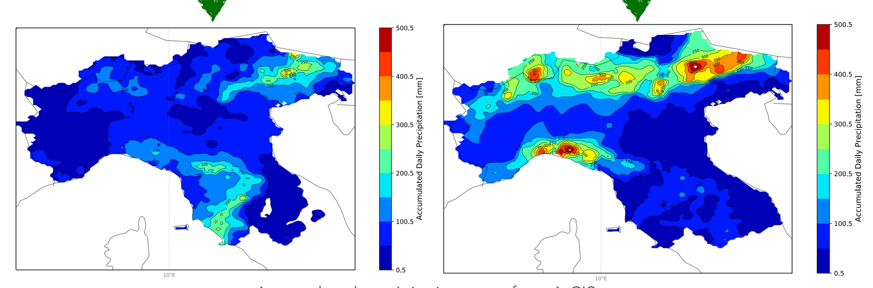
Vaia is a two-phased event. Between the two phases there is a net decrease of the average hourly precipitation rate which was probably fundamental for preventing extensive flooding.

MODELLING - Atmospheric Rivers impact

When the AR reached Italy it was narrow, very focused and its axis remained meridionally oriented towards Tuscany and north-eastern Italy, thus leading to an overall spatial pattern of precipitation that followed closely this direction. The persistence of the AR in the same position and direction for almost 18 hours produced steady and very intense precipitation.



ARs in the instant of maximum rainfall intensity over north-eastern Italy from BOLAM. IVT [kg m-1 s-1]



Accumulated precipitation maps from ArCIS.

from 3/11 at 8 UTC to 5/11 at 8 UTC (48 hrs) from 27/10 at 8 UTC to 30/10 at 8 UTC (72 hrs)

Total volume: 13.1 · 10^9 m^3

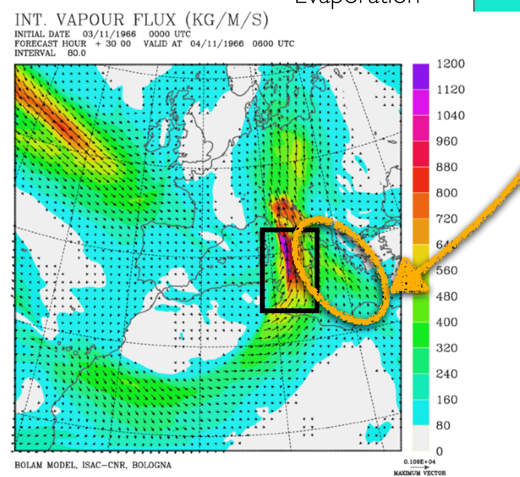
Total volume: 20.5 · 10^9 m^3

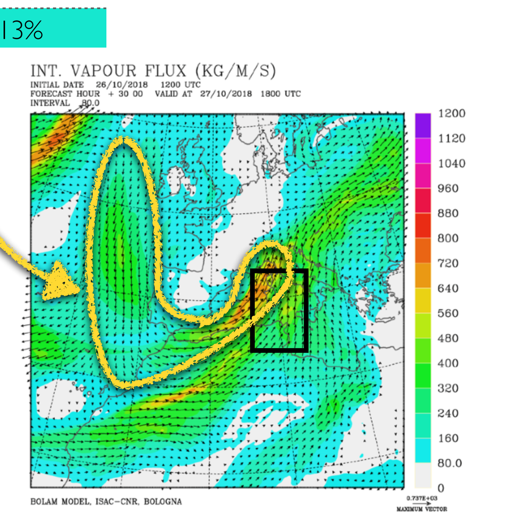
The AR was shorter but broader over the Italian territory with respect to the 66 flood. It was not stationary but it first moved eastward and then was bent back to affect again northern Italy. The AR had a diffluent behaviour over the Tyrrhenian Sea, leading to a spread transport of WV all over the Alps and causing more diffuse precipitation all over the Alpine chain and Liguria.

MODELLING - Water Budget contributions

Table reporting percentage contributions related to the water mass entering the box from each lateral flux or evaporation with respect to the overall entering mass (FW+FS+FE+E).

	66 Flood	Vaia 1st phase	Vaia 2nd phase
South Flux (FS)	42%	39%	59%
West Flux (FW)	21%	47%	22%
East Flux (FE)	21%	0%	4%
Evaporation	14%	13%	13%



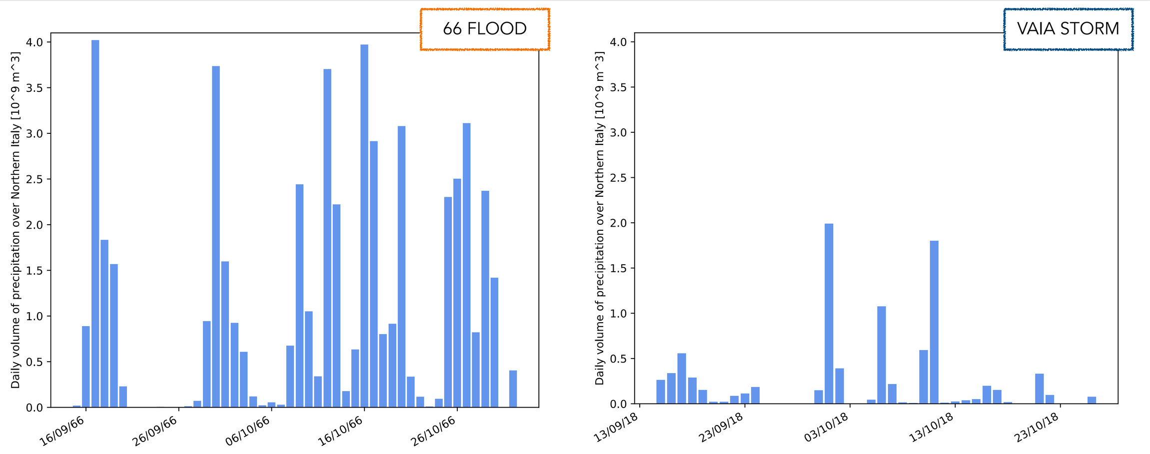


- **FS** is the main contribution in both events. This highlights the importance of the ARs that in fact enter in the boxes from the southern side. The percentage of FS in Vaia is the highest, especially in the second phase, underlying the strongest northward WV transport.
- **FW** in Vaia is linked to an eastward contribution coming from the northern Atlantic resulting critical as a main feeder for the first phase of precipitation, when the AR had not reached the Italian peninsula yet.
- **FE** in 66 flood is related to a local westward transport in the lower layers coming from the eastern Mediterranean. The origin of this WV was ascribed to the evaporation just outside the western side of the atmospheric box. Therefore, this can be considered as a local contribution.
- The WV input due to **evaporation** from the sea surface below the box resulted in percentage terms equal to 13% in both events, emerging as a less important contribution with respect to the transport from remote sources.
- The Vaia event is characterized by **remote transport** of WV, but coming from two different sources: a contribution crossing the western side of the box coming form the North Atlantic, and a transport across the southern side of the box that had a tropical origin.
- 66 flood is characterized both by remote and **local transport.**

IMPACTS

In conclusion, in VAIA, in agreement with a greater amount of WV transport, the impacts were more localized and less severe and this is due to several factors:

I. The current forecasting and warning procedures, certainly not available in 1966, limited the impact of the event.
II. The time interval with reduced precipitation in Vaia limited the damage and partially reduced the rivers' discharge.
III. State of the rivers and previous soil conditions: the VAIA storm was preceded by a very hot and dry October while, in the case of 1966, October was characterized by abundant precipitation, even snowy at high altitude, which had already saturated the soil and raised the level of rivers.



Total daily volume of precipitation [10^9 m^3] over the ArCIS data domain in the days preceding the EPEs

CONCLUSIONS

- The two events share the same synoptic evolution, that is the typical configuration leading to EPEs over northern Italy in autumn.
- In both events an AR is present. However, the tropical remote transport is not the only contribution supplying moisture to the precipitation systems as shown by the water budget analysis.
- The importance of the ARs to precipitation in the events was assessed performing a sensitivity experiment based on the reduction by 75% of the specific humidity at the boundary (not shown). The results show a strong reduction of the cumulated precipitation in the sensitivity simulations with respect to the control simulations highlighting the ARs as key ingredients for the EPEs development.