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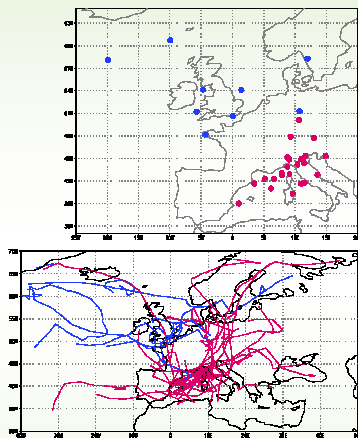
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Flooding of Venice is typically caused by a combination of high tides and a surge induced by regional strong winds. Intense surge events are associated with cyclones located over the north-western Mediterranean Basin or north-western Europe, inducing a strong atmospheric circulation over the Adriatic Sea that leads to an accumulation of water at its closed northern shore. In this study we identify and track the cyclones associated with extreme water levels in Venice using the ERA40 dataset. We analyze the cyclone characteristics and compare them to the characteristics of other non-hazardous regional cyclones.



## Hazardous cyclones

- The 25 events with water levels above 99<sup>th</sup> percentile (83 cm) during ERA40 period are associated with:
- 14 mature and independent Mediterranean cyclones.
- 10 are open depressions associated with stronger steering cyclones (blue) located over northern Europe or the North Atlantic.
- 1 double (twin) cyclone.
- Cyclones responsible for flooding in Venice (red) cross the north-western Mediterranean Sea.



Top: Location of responsible cyclone (red) and steering cyclone (blue) at time step with minimum time shift to maximum water levels in Venice. Bottom: Cyclone paths

## Teleconnection pattern

### Method:

- Analyzed is the phase of monthly mean large-scale teleconnection patterns during intense flooding in Venice
- Indices obtained using rotated principal component analysis on monthly mean standardized 500 hPa geopotential height
- <http://www.cpc.ncep.noaa.gov/data>

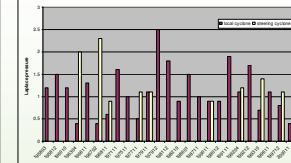
### Result:

- No preferred state can be deduced for either NAO, East Atlantic/West Russian or Scandinavian Pattern.

Date	NAO	EAWR	Scand
19580311	--	++	0
19581224	-	0	-
19601015	0	--	0
19630411	-	0	+
19661104	0	--	+
19670216	0	0	+
19681103	-	++	+
19711109	0	--	--
19751117	0	0	0
19771121	0	-	-
19791115	+	--	0
19791222	+	0	0
19811218	0	--	-
19821006	-	0	+
19860131	+	-	0
19871124	0	0	0
19901125	0	+	0
19901209	0	-	0
19911124	0	0	0
19920401	++	+	0
19921208	0	+	0
19931002	-	--	0
19961118	-	+	0
19971220	-	0	0
20001106	+	0	--

## Strength

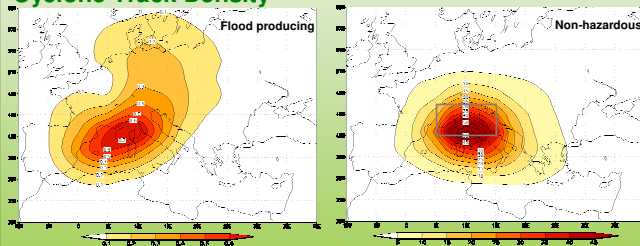
- Minimum intensity of flood producing Medit.cyclones is 0.9 hPa/(deg. lat)<sup>2</sup>.
- However, secondary depressions associated with stronger steering cyclones may be weaker.



Intensity (quantified as Laplacian of MSLP) for cyclones and steering cyclones at time step with smallest time shift to highest water levels.

## Comparison to non-hazardous local cyclones

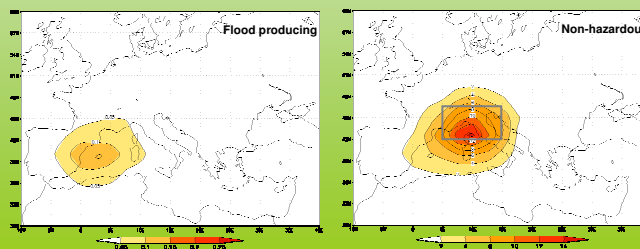
### Cyclone Track Density



- Maximum track density values located over Gulf of Genoa.
- Flood producing tracks typically enter region from south-west and propagate north-eastward.
- In contrast, non-hazardous cycl. crossing northern Italy (42N-47N/5E-15E) enter from west and leave in south-westerly direction.

### Cyclogenesis

- Preferred region for flood producing systems is western Mediterranean, particularly near Balears Isles.
- Preferred region for non-hazardous cyclones which cross northern Italy (42N-47N/5E-15E) is Gulf of Genoa.



## Summary

- Flooding in Venice can be caused both by Mediterranean cyclones and by local secondary depressions associated with Northern European cyclones.
- Preferred area of genesis for flood producing cyclones is the western Mediterranean particularly near the Balears Isles, while the majority of non-hazardous local cyclones originate over the Gulf of Genoa.
- Flood related cyclones typically pass west of Venice and often propagate north-eastward. Most non-hazardous local cyclones propagate south-westward.

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