An integrated approach of in-situ data, remote sensing measurements and numerical simulations to study storm events in the Ligurian Sea

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UNIVERSITÀ DEGLI STUDI DI NAPOLI
PARTHENOPE

Outline

- General overview of VAIA storm event
- In-situ observations: the National Tidegauge Network and the Wave Buoy Network CFR Toscana
- Remotely sensed observations: ASCAT sea wind field
- Recostruction of meteo-waves pattern during VAIA by means numerical simulations
- Comparison statistics
- Conclusions and future directions

VAIA storm event: general overview

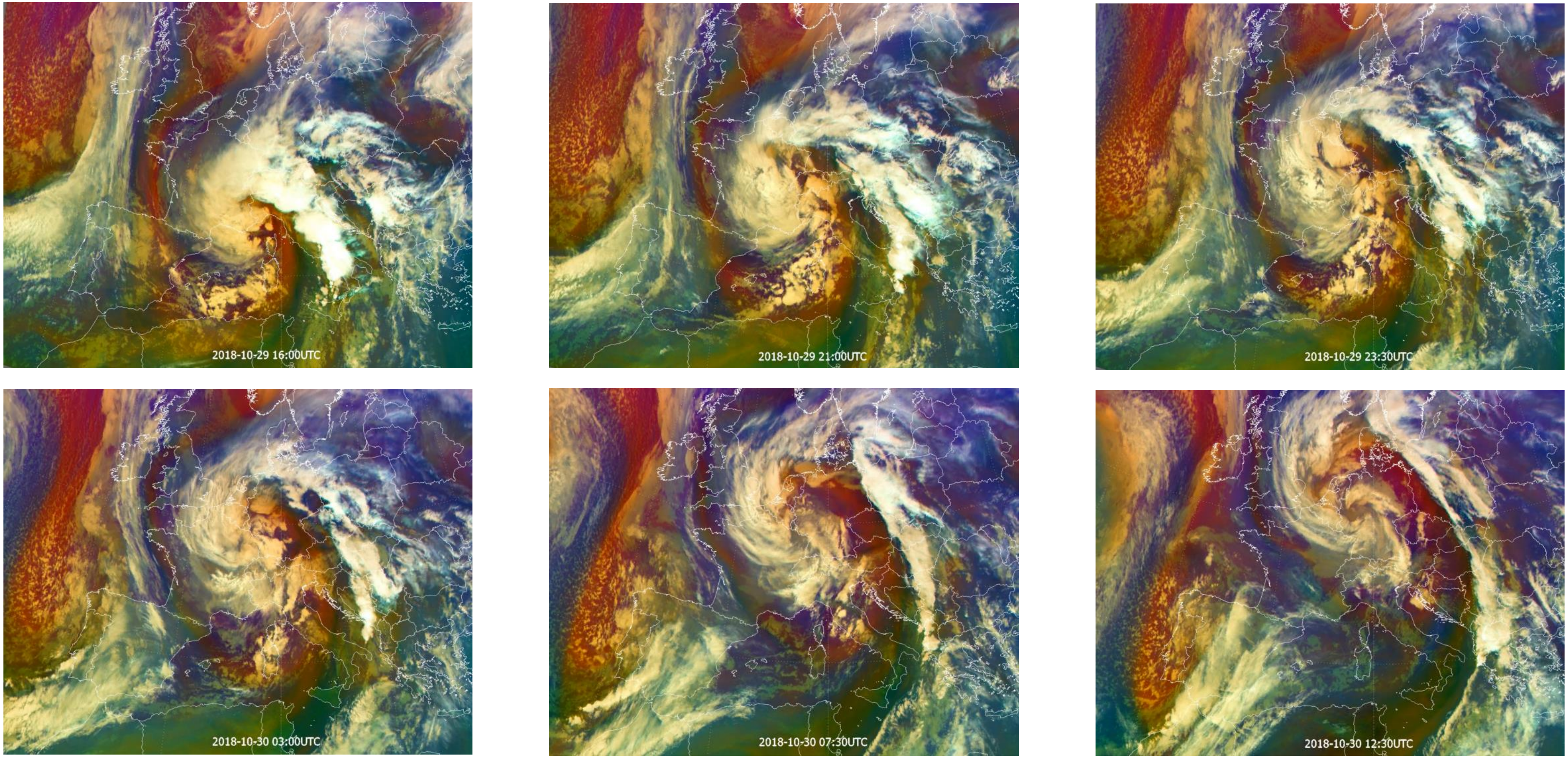
We characterized the storm event of 29-30 October 2018 that occurred in the Ligurian Sea through the analysis of high resolution meteo-sea numerical simulations, highlighting the importance of an integrated approach, involving also in-situ and remotely sensed observations in a coastal management framework.

This storm was characterized by wind generated waves and storm surge, which is a rise of sea level associated with a moving low pressure system for an amount of one centimetre for each mbar decrease in pressure. High sea levels and strong forces exerted by accompanying waves impacted on sea defences, property and inhabitats, causing loss of life, damage (through inundation and waves) with loss of property and infrastructure.

Leisure boats damaged in the Rapallo harbour. Source: Il secolo XIX, digital photograph (accessed 17 September 2020).

VAIA from space

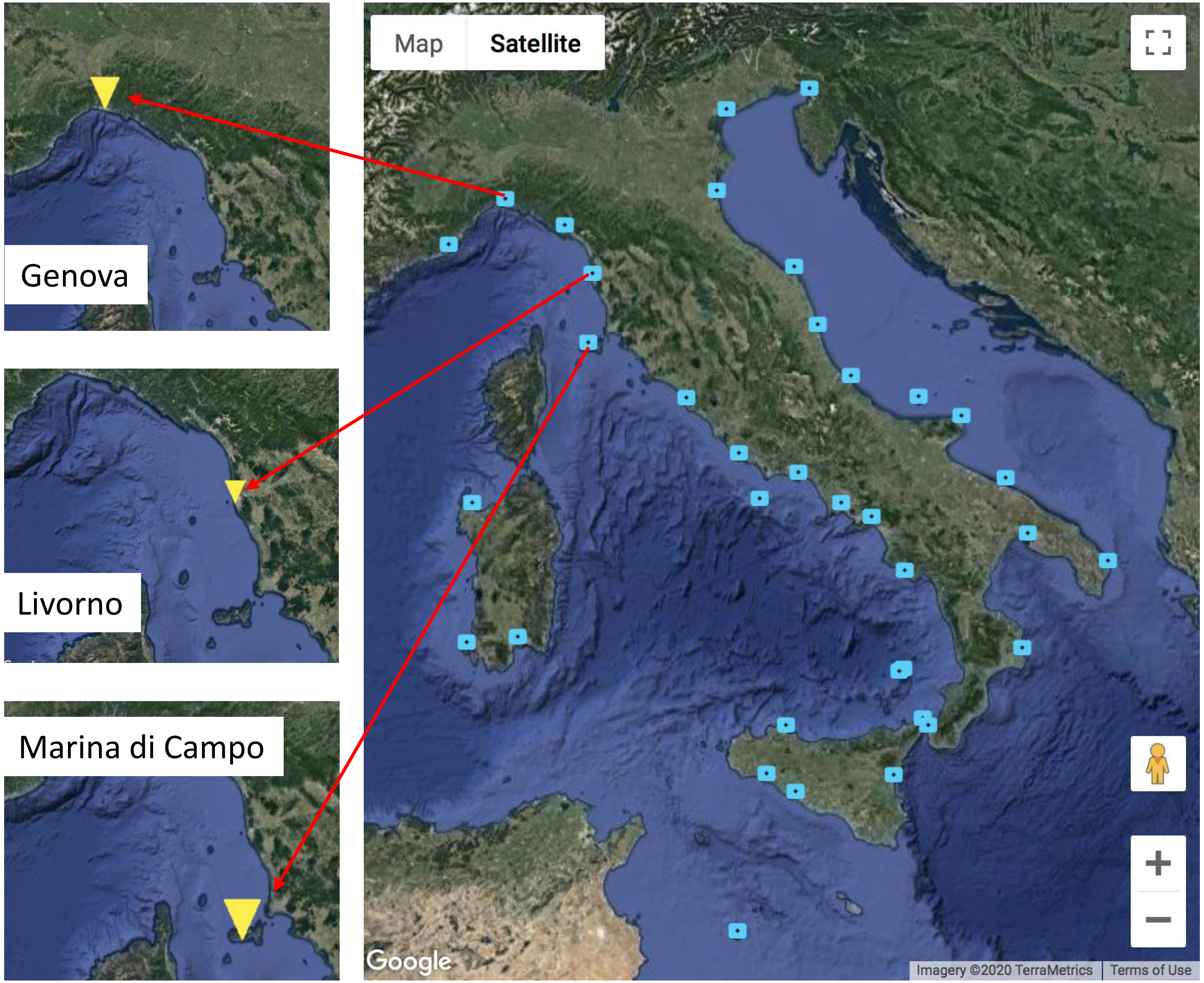
Meteosat-11 Airmass RGB



The maximum intensity was reached on 29 October, when severe storms formed on the cold front. The media-storm centre is visible west of Corsica. These crossed over almost all of Italy, then moved on to Croatia and Slovenia during the evening.

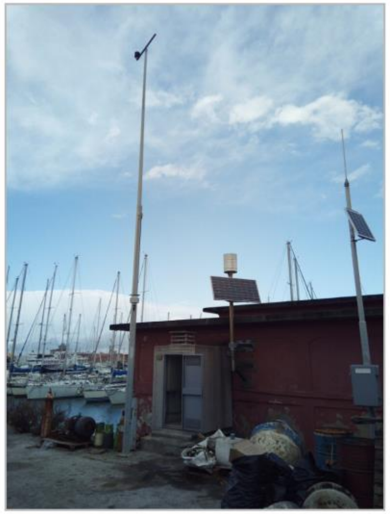
Observations: The National Tidegauge Network

ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale



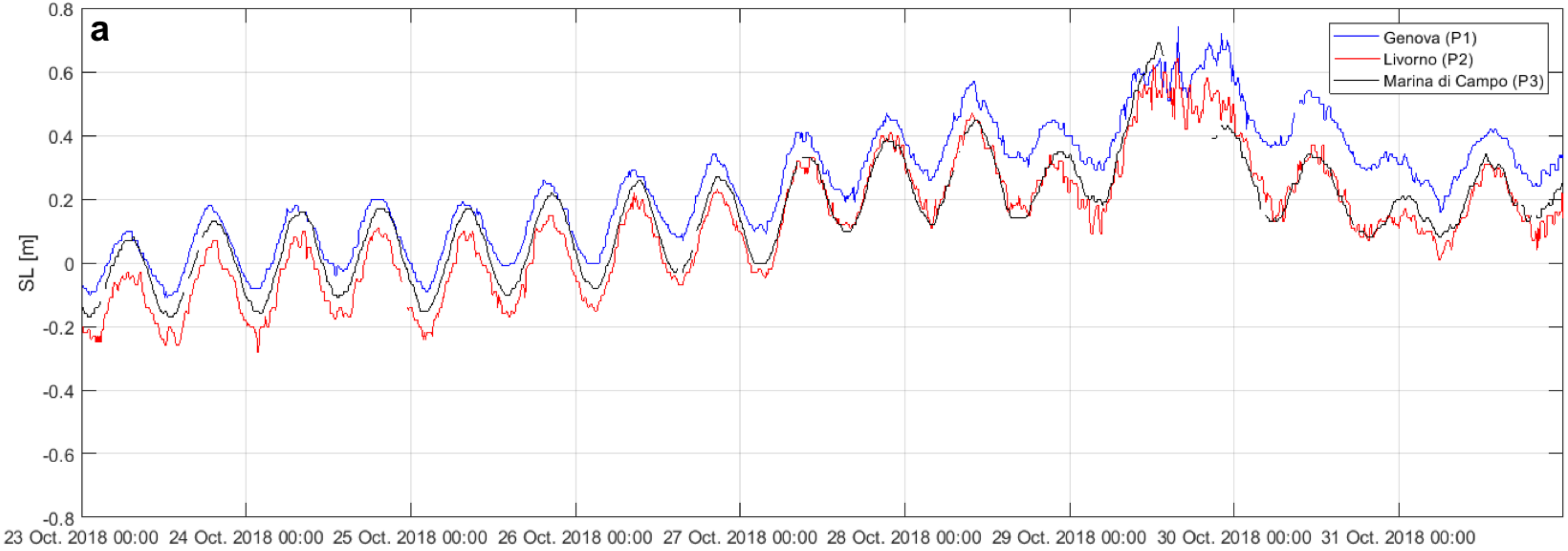
Available parameters:

- Hydrometric level
- Water temperature
- Air temperature
- Relative humidity
- Atmospheric pressure
- 10 m wind speed and direction



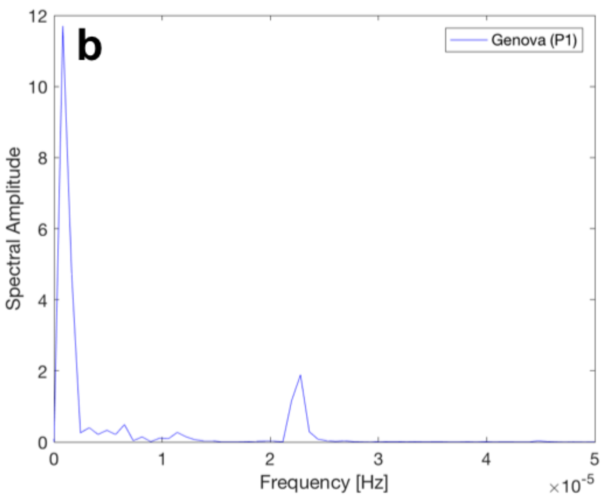
Livorno station (Mediceo seaport, near the Police lance shelter).

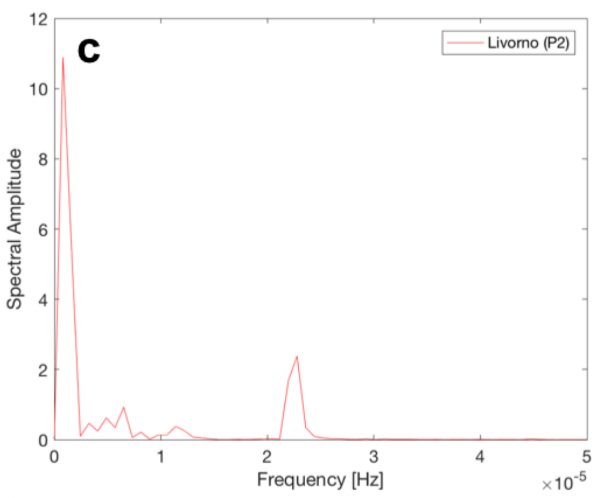
Sea level observations

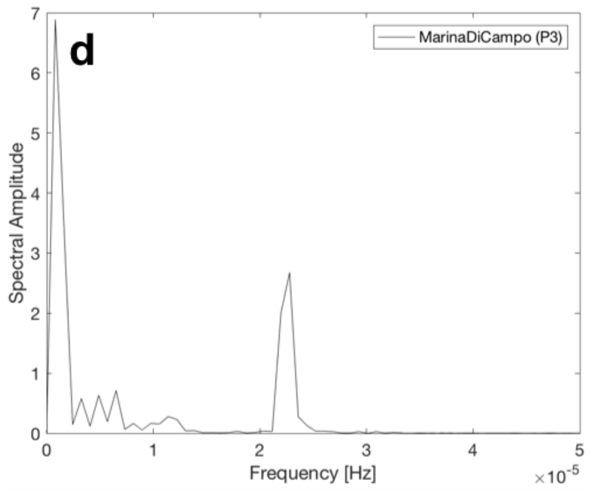


Sea level observed during the period 23-31 October 2018 in:

- P1 (Genova)
- P2 (Livorno)
- P3 (Marina di Campo)







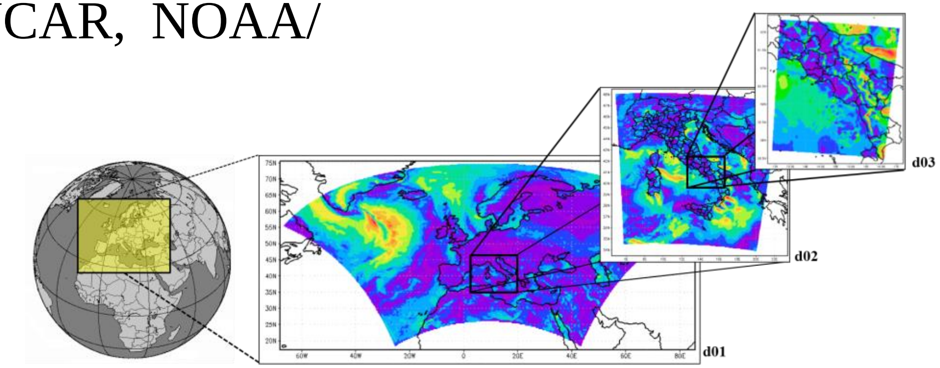
Corresponding sea amplitude spectrum evaluated during the same period in:

- Genova – b
- Livorno – c
- Marina di Campo – d

Scientific workflow: *meteo@uniparthenope*

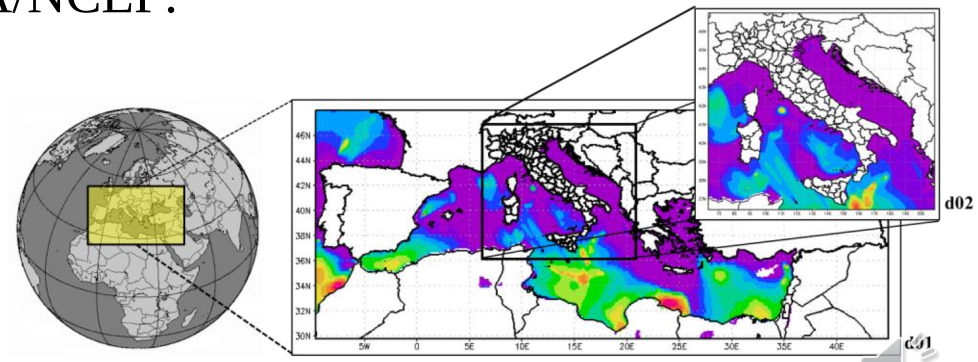
A met-ocean high resolution model is used to simulate the media-storm event:

WRF is an open source Limited Area Model (LAM) developed by NCAR, NOAA/ESRL, NOAA/NCEP/EMC and others:



- **Nesting scheme:** Two-way with two nesting levels
- **Computational domains:** d01 (about 25 km) and d02 (about 5 km)
- **Output timestep:** 3600 seconds
- **Initial and boundary condition:** NCEP *Global Forecast Syst*em (GFS)
- **DTM and land use:** USGS (United States Geological Survey).

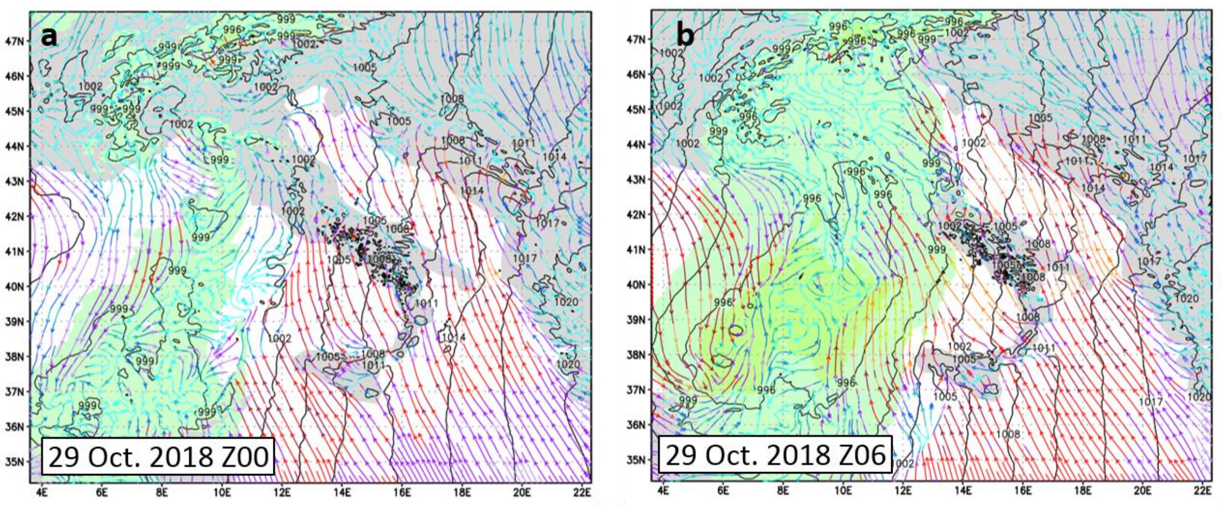
WAVEWATCH III is a third generation wave model developed at NOAA/NCEP:



- **Nesting scheme:** Two-way with two nesting levels
- **Computational domains:** d01 (9 km) and d02 (3 km)
- **Initial condition:** fetch-limited based on local wind and grid spacing
- **Forcing:** WRF hourly output

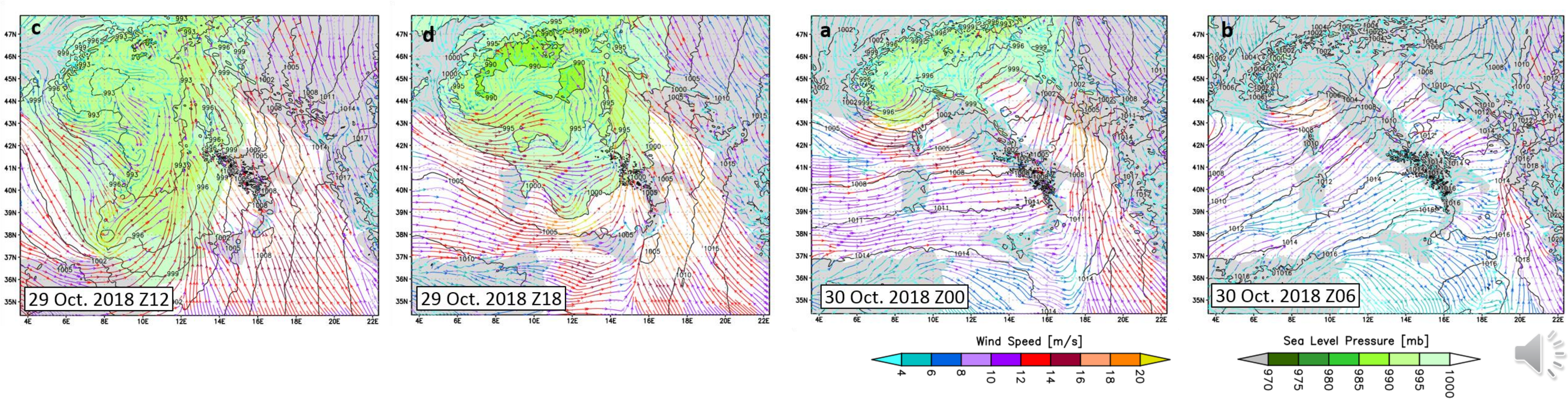
Athmosferic simulation

WRF model simulation of VAIA storm event



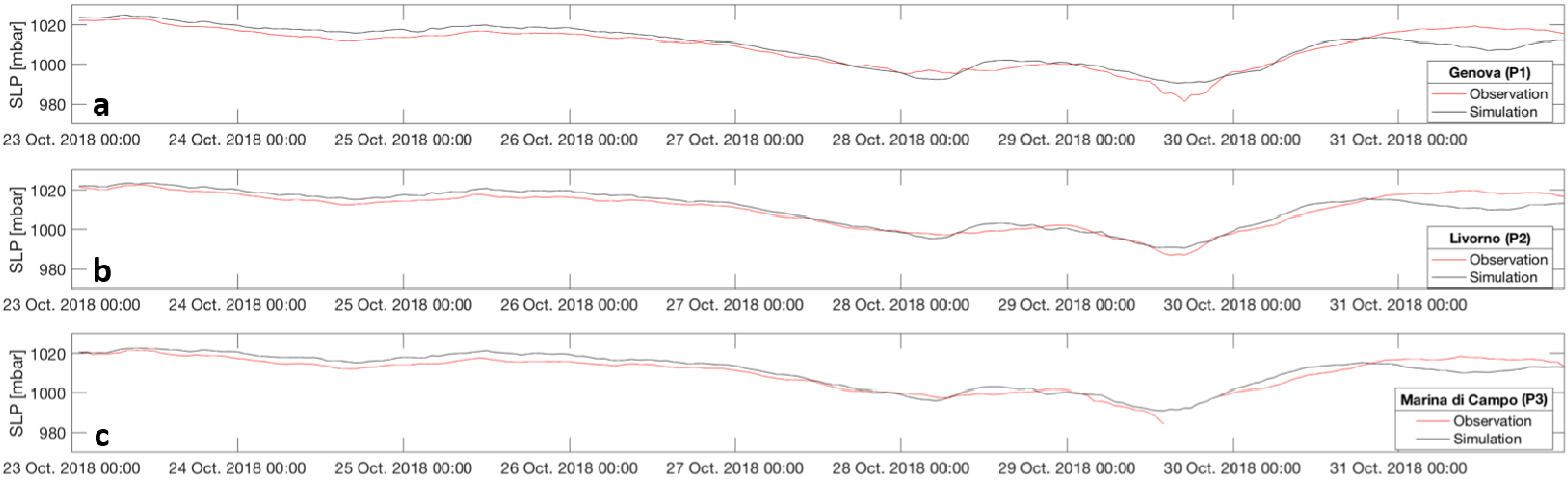
Intense and persistent wind forcing associated with the cyclone was responsible for the build up of the waves and sea levels.

During the first phase of the storm, the south-easternly ‘*Scirocco*’ wind was responsible of ‘pumping up’ the sea levels in the northwest Adriatic sea, bringing a level rise of more than 150 cm in Venice.



Sea Level Pressure: Simulation vs Observation

Pressure data from WRF simulations and in-situ observations both reported a significant pressure drop (down to 990 mb):

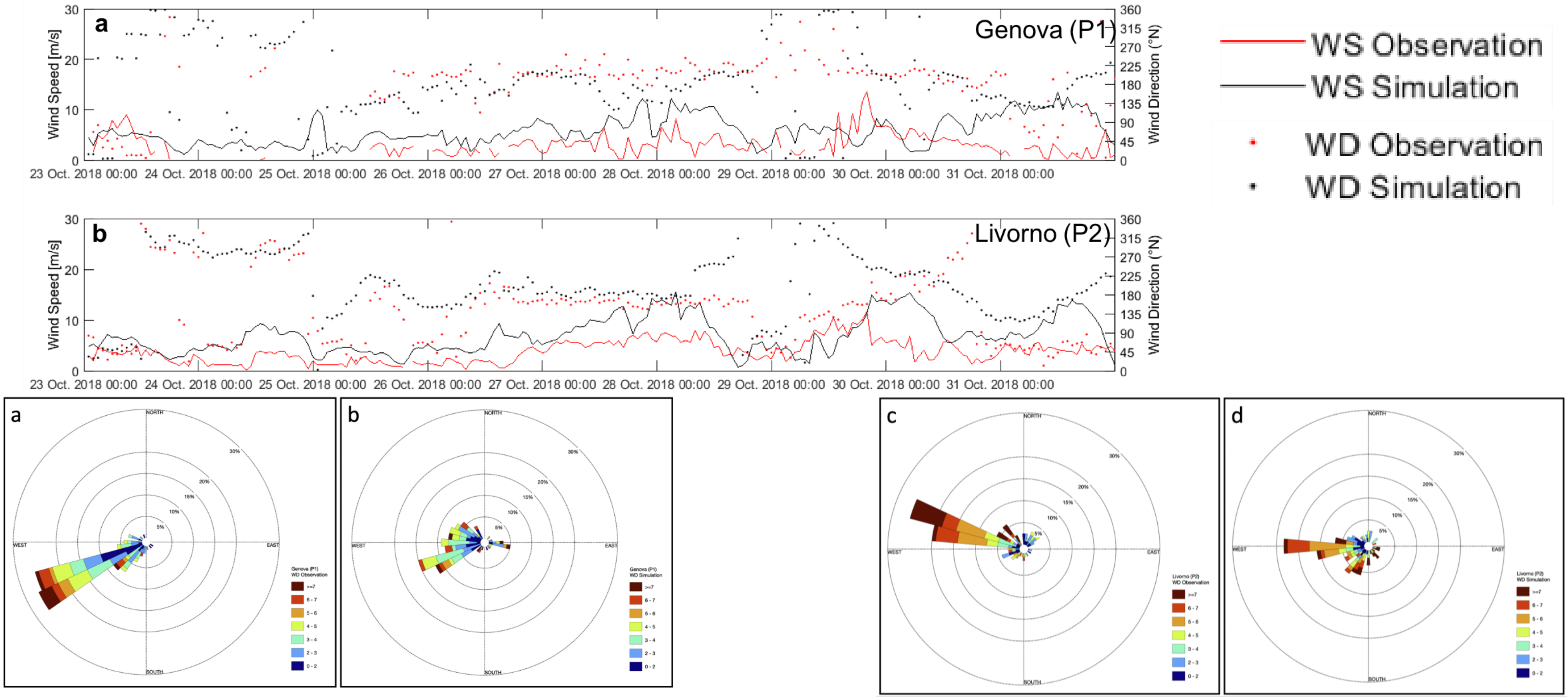


	RMSE	BI	SI	R	SPS
P1 Genova	3.7898	7.7408e-04	0.0037	0.9275	0.9973
P2 Livorno	3.1602	7.4446e-04	0.0030	0.9425	0.9977
P3 Marina di Campo	3.0812	0.0013	0.0029	0.9396	0.9976

Mentaschi et al. (2013); Melby et al. (2012)

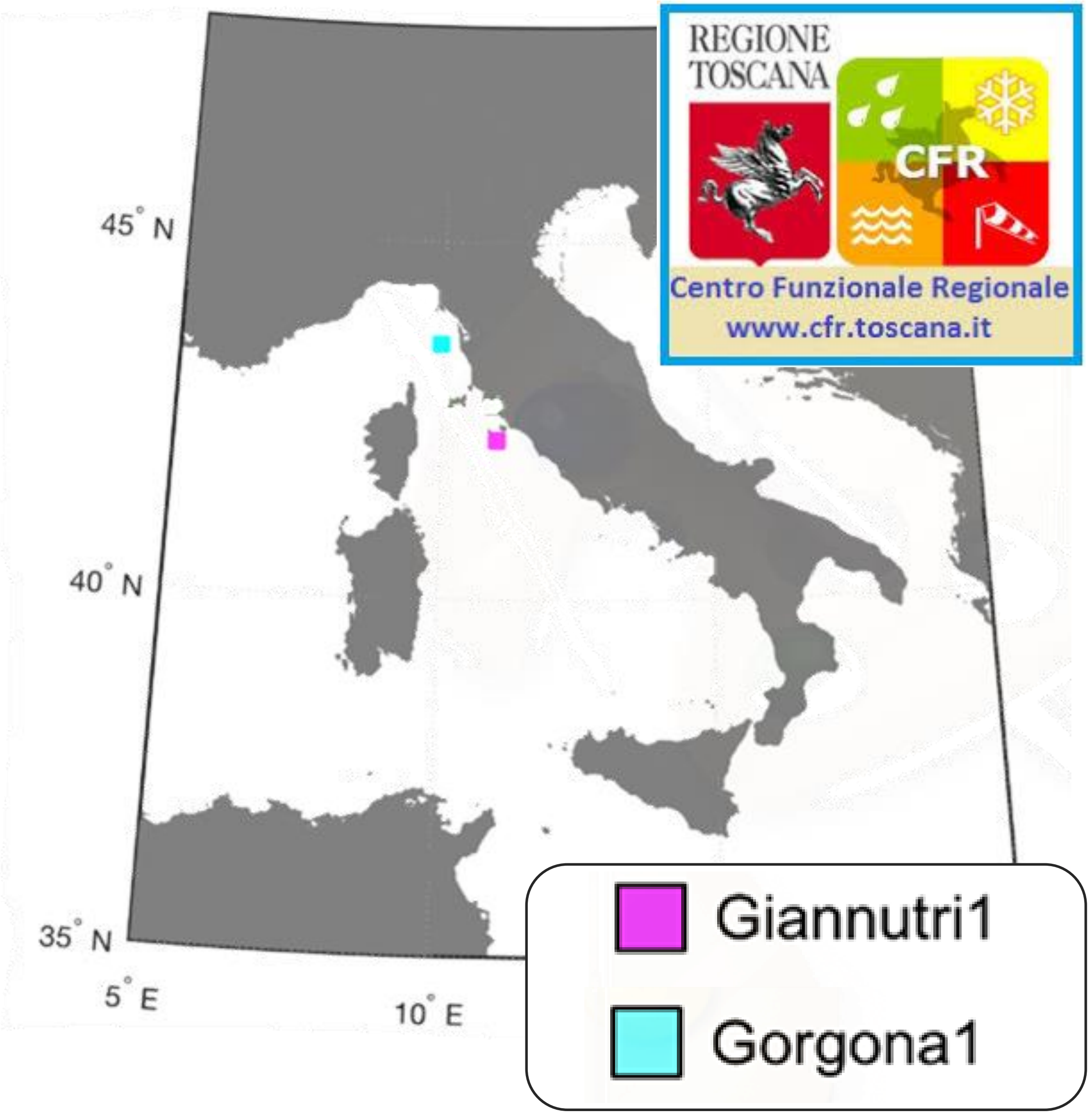
Comparison between observed and simulated sea level pressure data during the period 23-31 October 2018 in P1 (Genova), P2 (Livorno) and P3 (Marina di Campo).

Wind Speed: Simulation vs Observation



Comparison between observed and simulated wind speed in P1 (Genova) and P2 (Livorno).

Observations: Wave Buoy Network CFR Toscana



Buoy CFR Toscana:

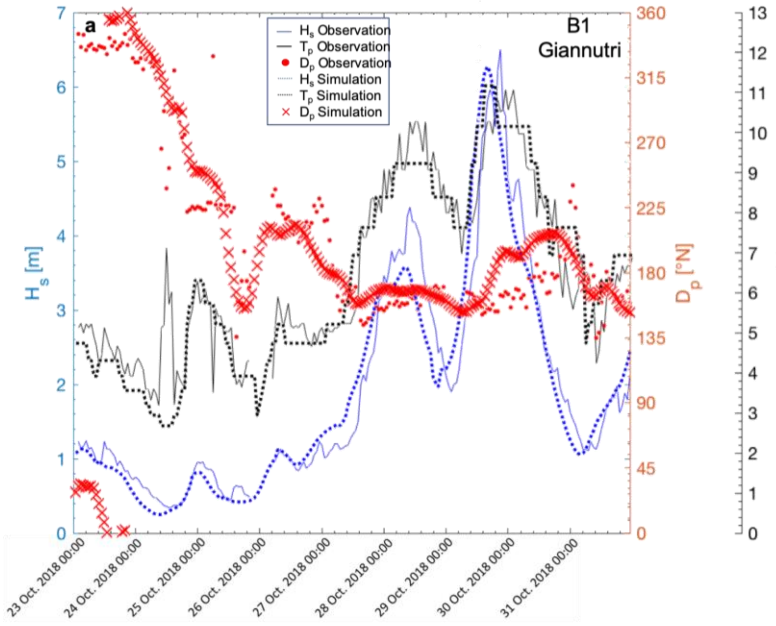
- B1: Giannutri1 (42.23°N, 11.04°E)
- B2: Gorgona1 (43.57°N, 09.95°E)

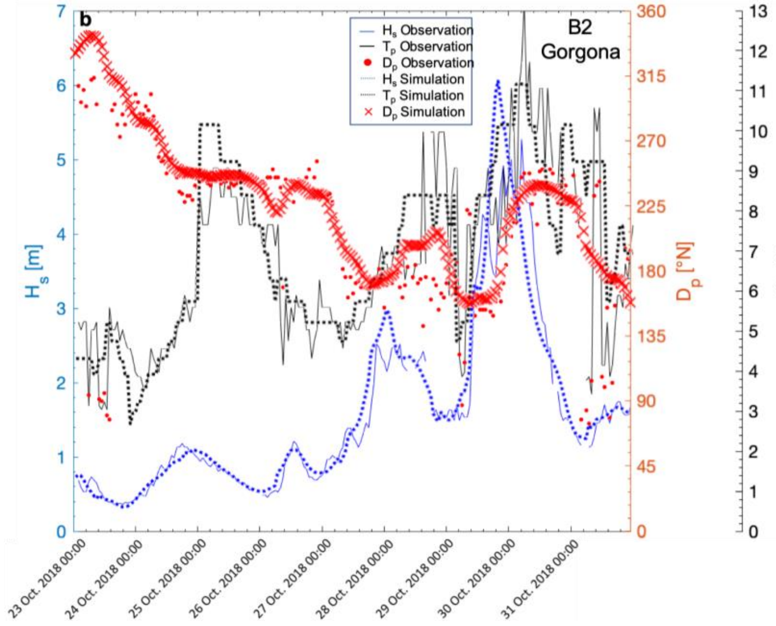
Timestep: 3600 seconds

The buoys, placed at 140 m depth, are operating since 1 October 2008 and 6 December 2013, respectively, recording:

✓ Sea wave height (H_s)
✓ Peak period (T_p)
✓ Peak direction (Dp)

Wave conditions: Simulation vs Observation





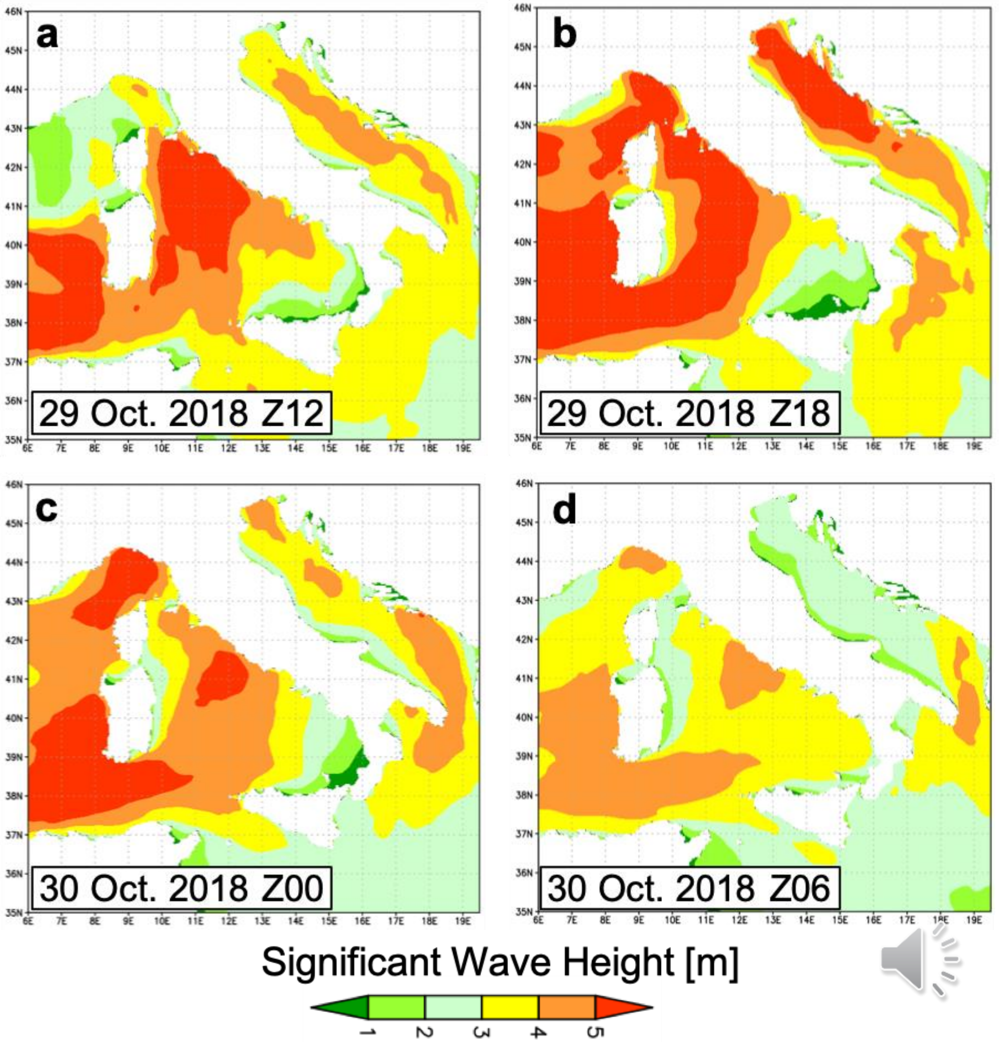
		RMSE	BI	SI	R	SPS
B1 Giannutri	H_s	0.4064	-0.0180	0.1715	0.9593	0.8800
	T_p	0.8361	-0.0120	0.1245	0.9281	0.9132
B2 Gorgona	H_s	0.3822	0.0326	0.2005	0.9480	0.8549
	T_p	1.4109	0.0356	0.2011	0.7766	0.8532

Mentaschi et al. (2013); Melby et al. (2012)

Statistical comparison between observed and simulated wave fields (H_s and T_p) in B_1 and B_2.

- The northwestern coast of Italy suffered the most from the high waves impacting coastal infrastructures and communities.

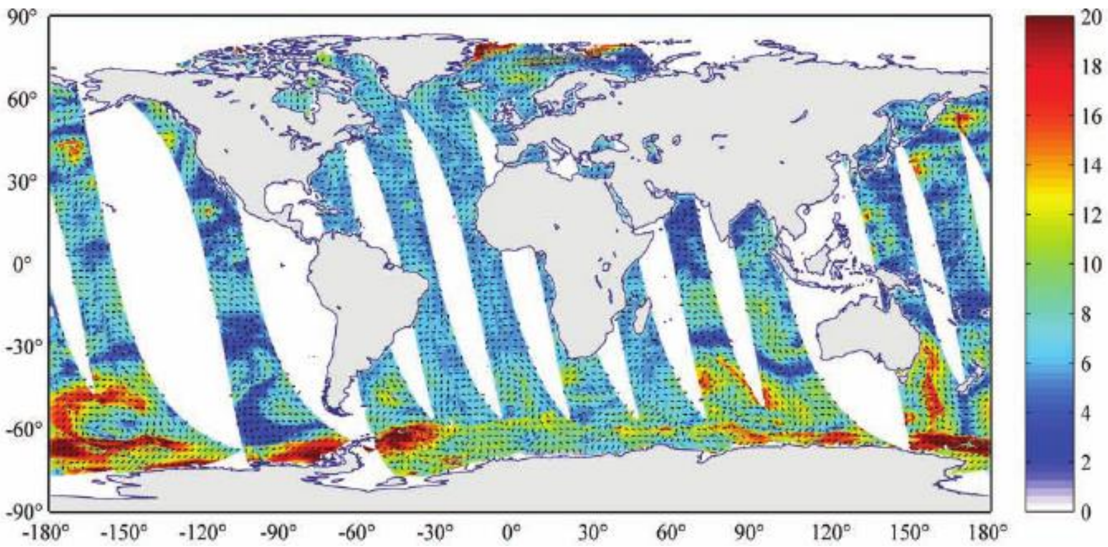
- The WW3 wave model clearly indicates that significant wave heights exceeded 5 m.



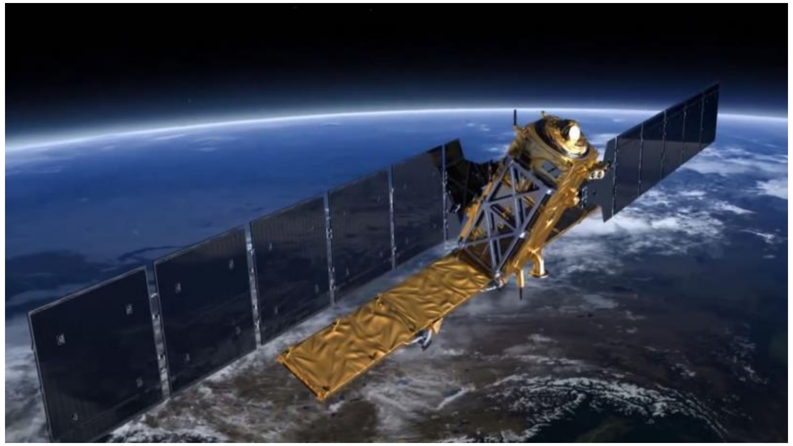
Sea wind from space: Microwaves

REAL APERTURE RADAR

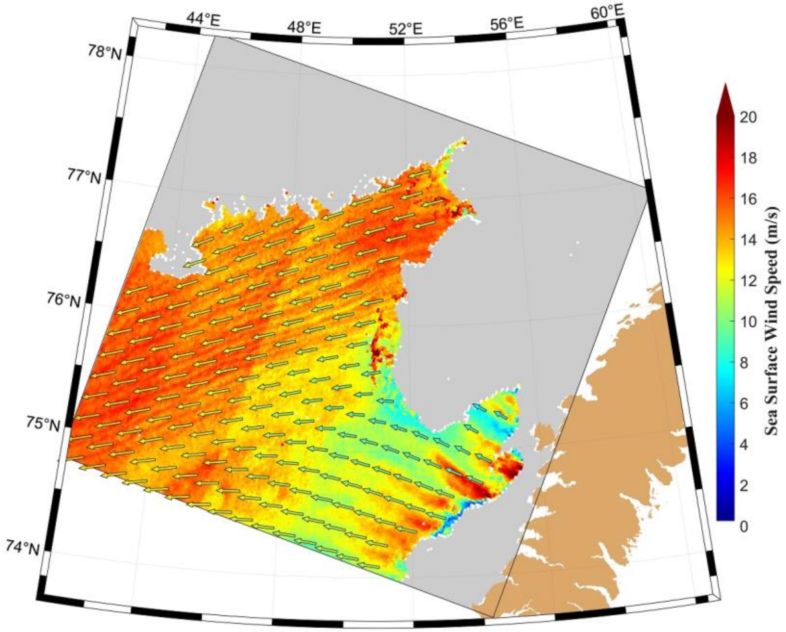
- Operational
- Global scale
- Daily coverage
- Mesoscale resolution (≅ 10 km)



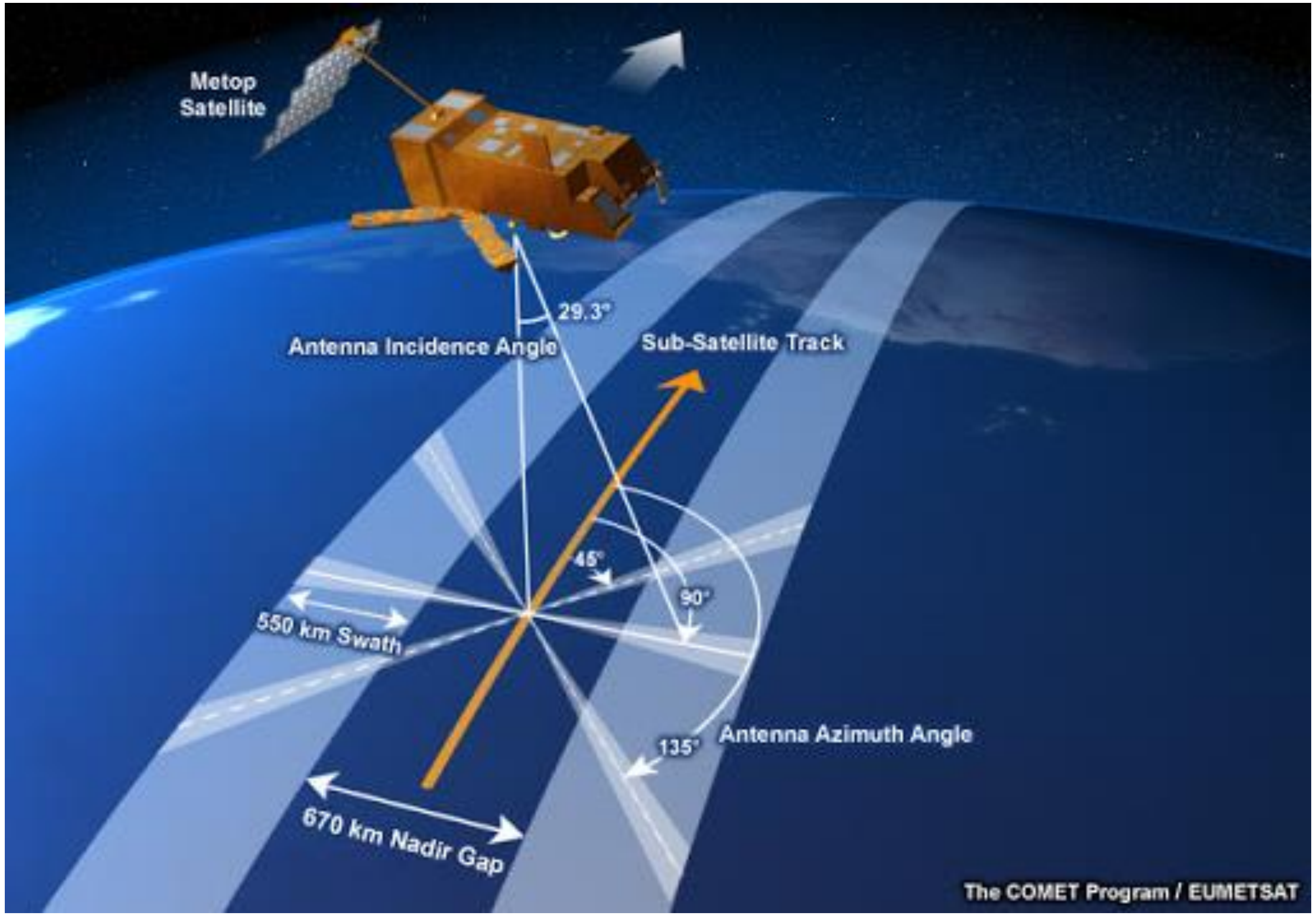
SYNTHETIC APERTURE RADAR



- Local scale
- Weekly coverage
- Fine resolution (≅ 10 m)



Sea wind from space: Scatterometers



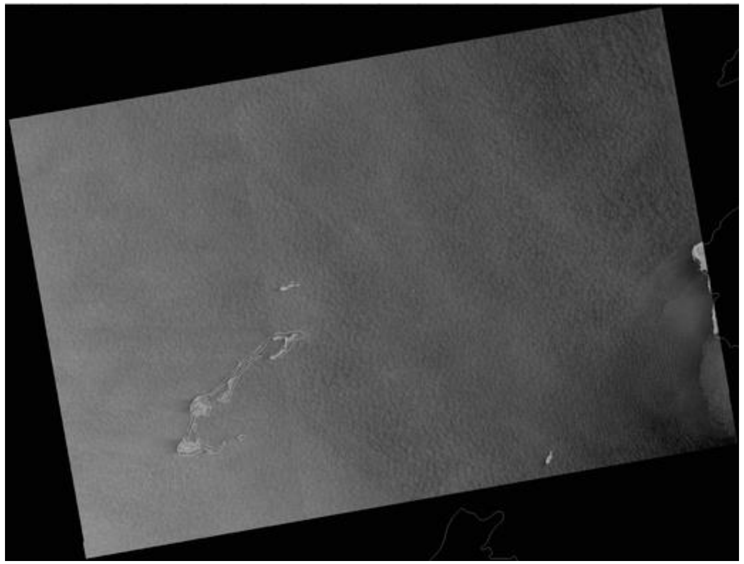
- EUMETSAT MetOp satellites
- ASCAT (Advanced Scatterometer)
- C-band (5.255 GHz)
- Incidence angle range: 25° - 65°
- Multiple NRCS measurements
- VV polarization
- Swath: 550 km
- Twice daily coverage (at mid-latitudes)

In this study, we considered:

- Global wind level-3 products
- Output: Wind speed at 10 m a.s.l. under neutral conditions (U_{10})
- Spatial resolution 12.5 km

Wind field retrieval from scatterometers: GMF

Measurement: NRCS

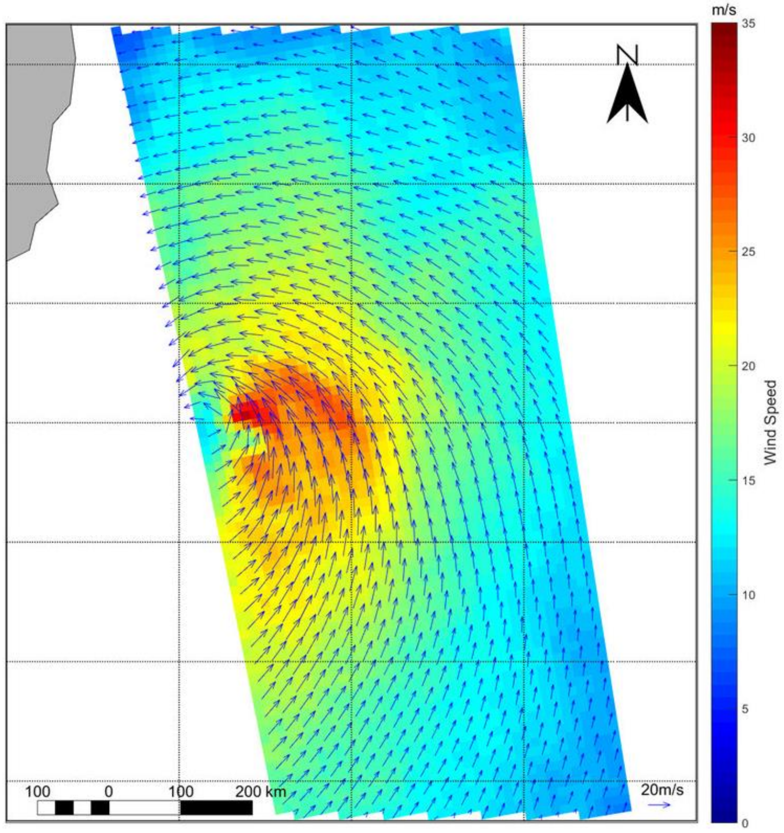


GEOPHYSICAL MODEL FUNCTION
CMOD FAMILY

$$\sigma^0_{pq} = B_0(U_{10},\theta)[1 + B_1(U_{10},\theta)cos\varphi + B_2(U_{10},\theta)cos2\varphi)]$$

In this study, the CMOD7 GMF is considered

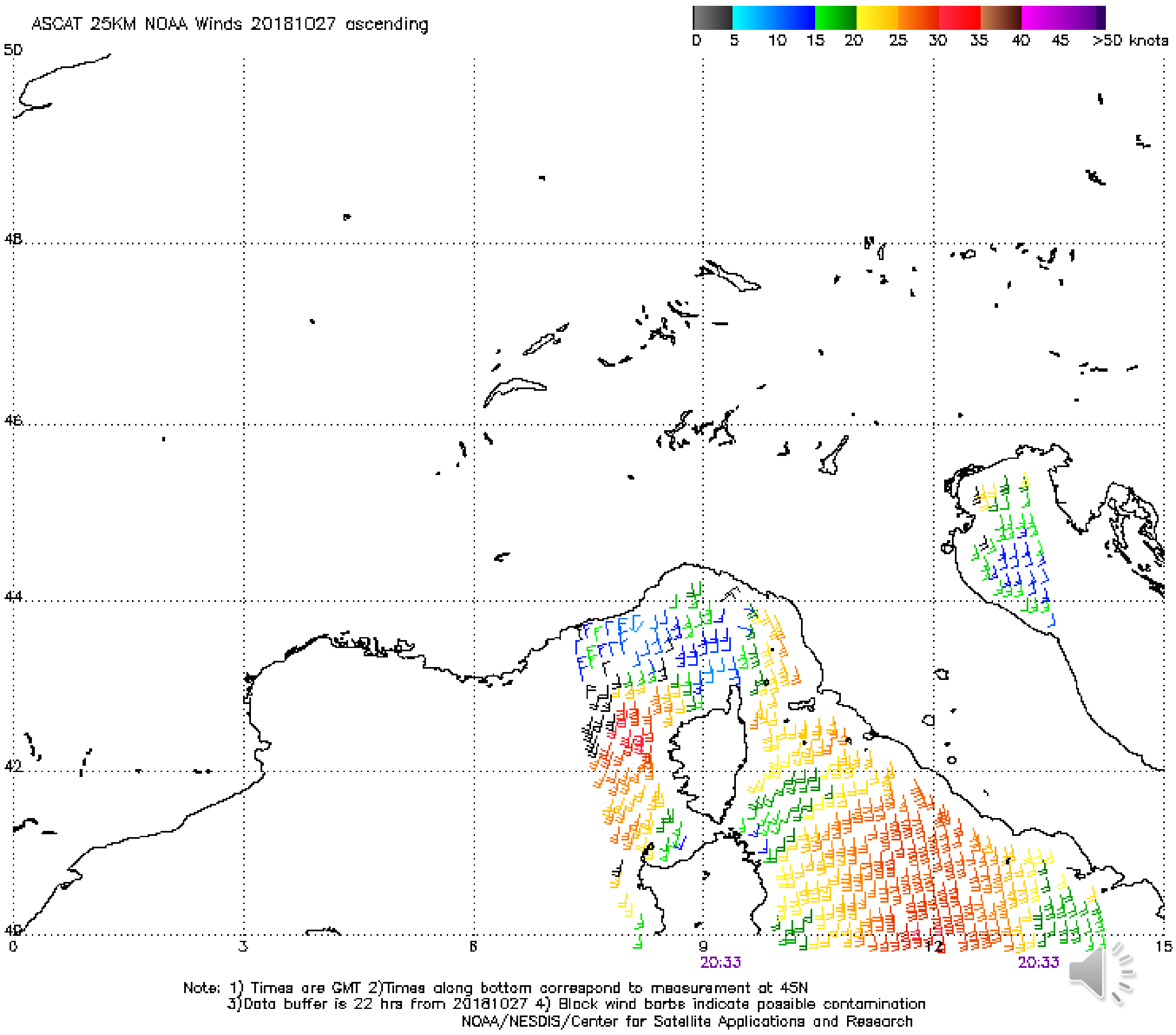
Product: Wind field map



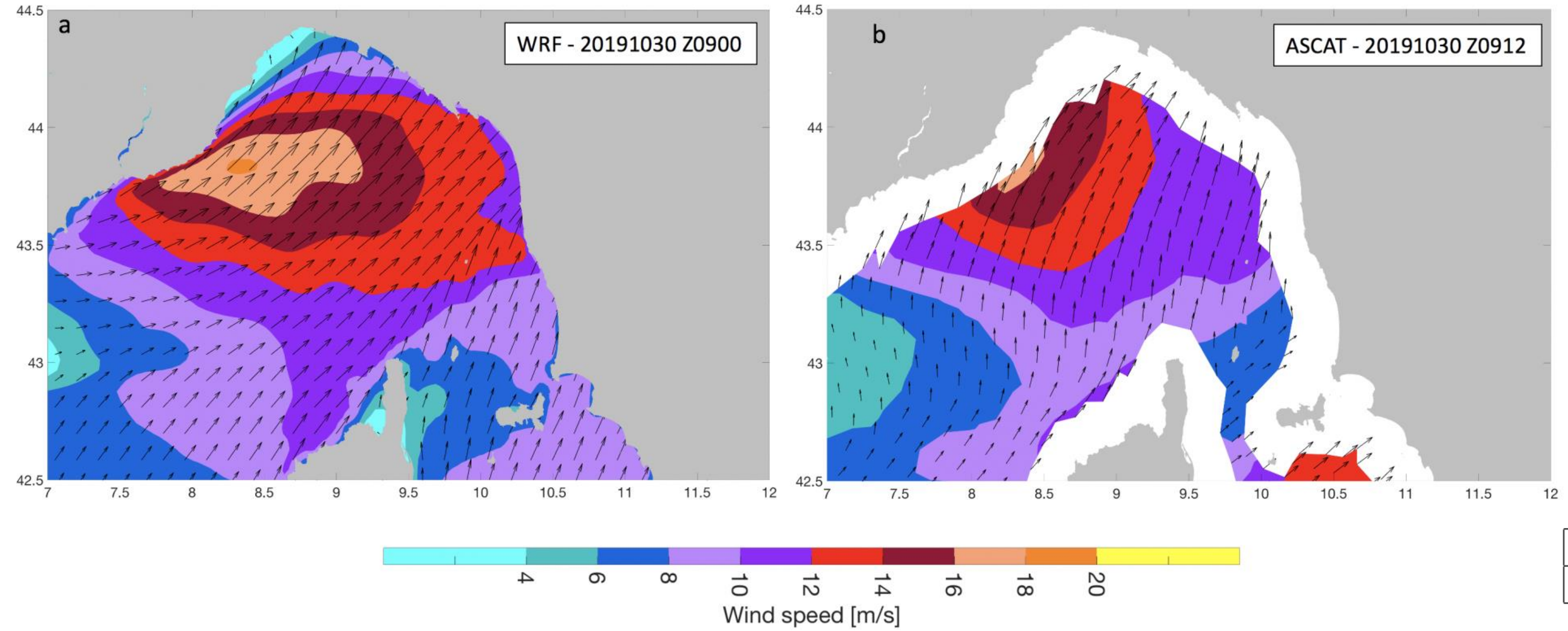
- GMF: given the imaging parameters (polarizations *pq*, incidence angle θ, frequency band, antenna beam), there is a non-linear relationship between the NRCS σ^0 and the wind vector, i.e., speed U_{10} and relative direction φ). The semi-empirical coefficients are the bias term $B_{0,}$ the up/down wind modulation term B_1 and B_2, which describe the signal modulation induced by the main wind direction.

ASCAT sea wind field

- The retrieval accuracy is ≤ 2m/s under standard wind conditions (4 m/s – 25 m/s) off the coast (≥ 10 km).
- The accuracy and reliability of the retrieval are significantly affected by NRCS signal contamination induced by rain and land.
- At C-band, the land effect on NRCS can be effective close to the coast.
- Due to non-linear modulation processes, extreme wind speeds, i. e., > 25 m/s tend to be underestimated.



Wind Speed: WRF simulation vs ASCAT



Comparison between ASCAT-based and simulated wind speed

RMSE	BI	SI	R	SPS
2.8400	0.1307	0.2427	0.5988	0.7844

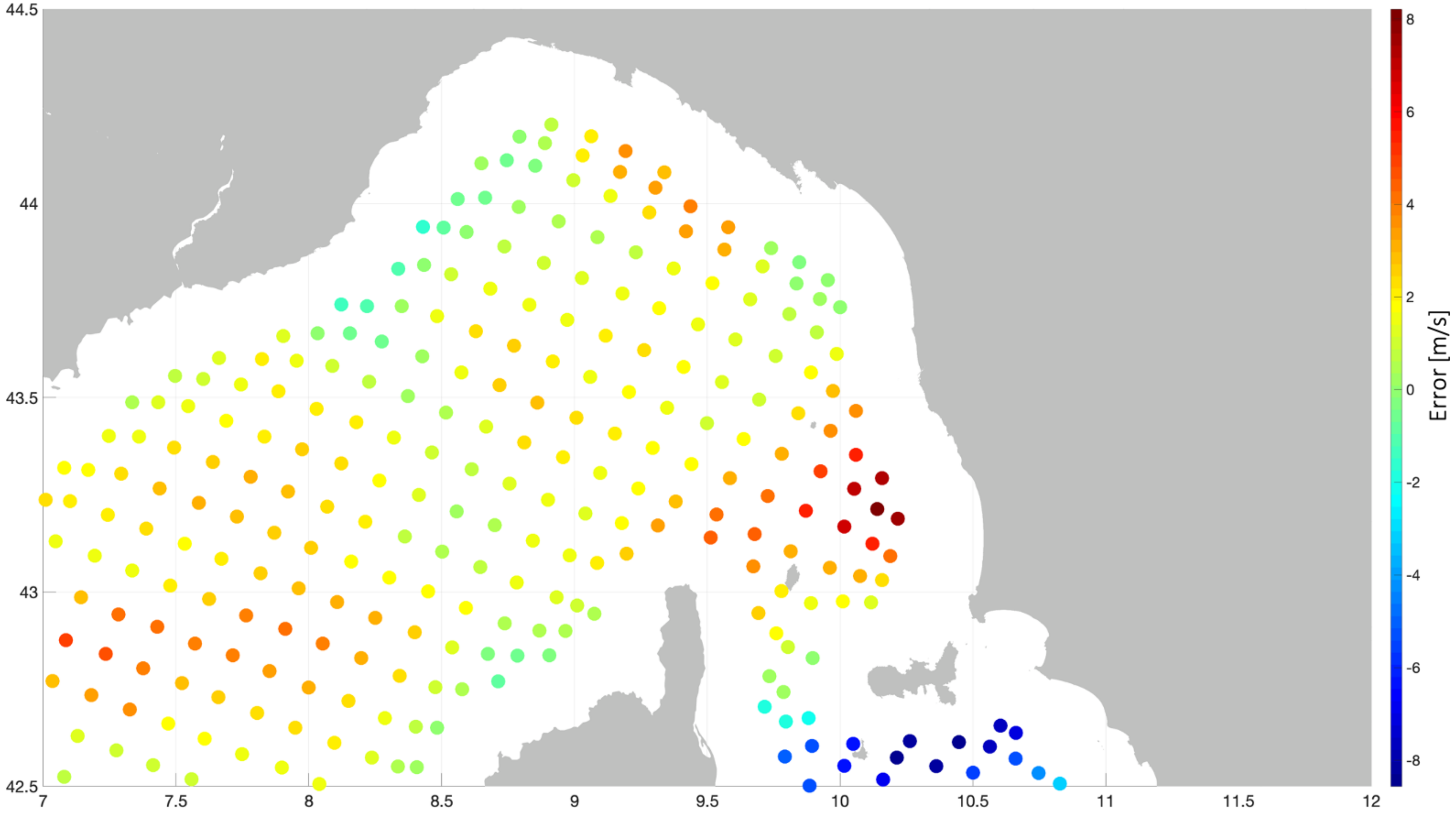
Mentaschi et al. (2013); Melby et al. (2012)

The stastical comparative analysis, performed on 275 independent samples, show that:

- R and SI values confirms the satisfactory performance of the numerical simulations.
- The positive BI (the difference between simulated WRF and ASCAT wind speed) shows that the WRF simulations slightly overestimate the wind speed over the whole study area.
- Overall, the statistical comparison indicates a fairly good agreement, with RMSE lower than 3 m/s standing for a remarkable results during a storm event.

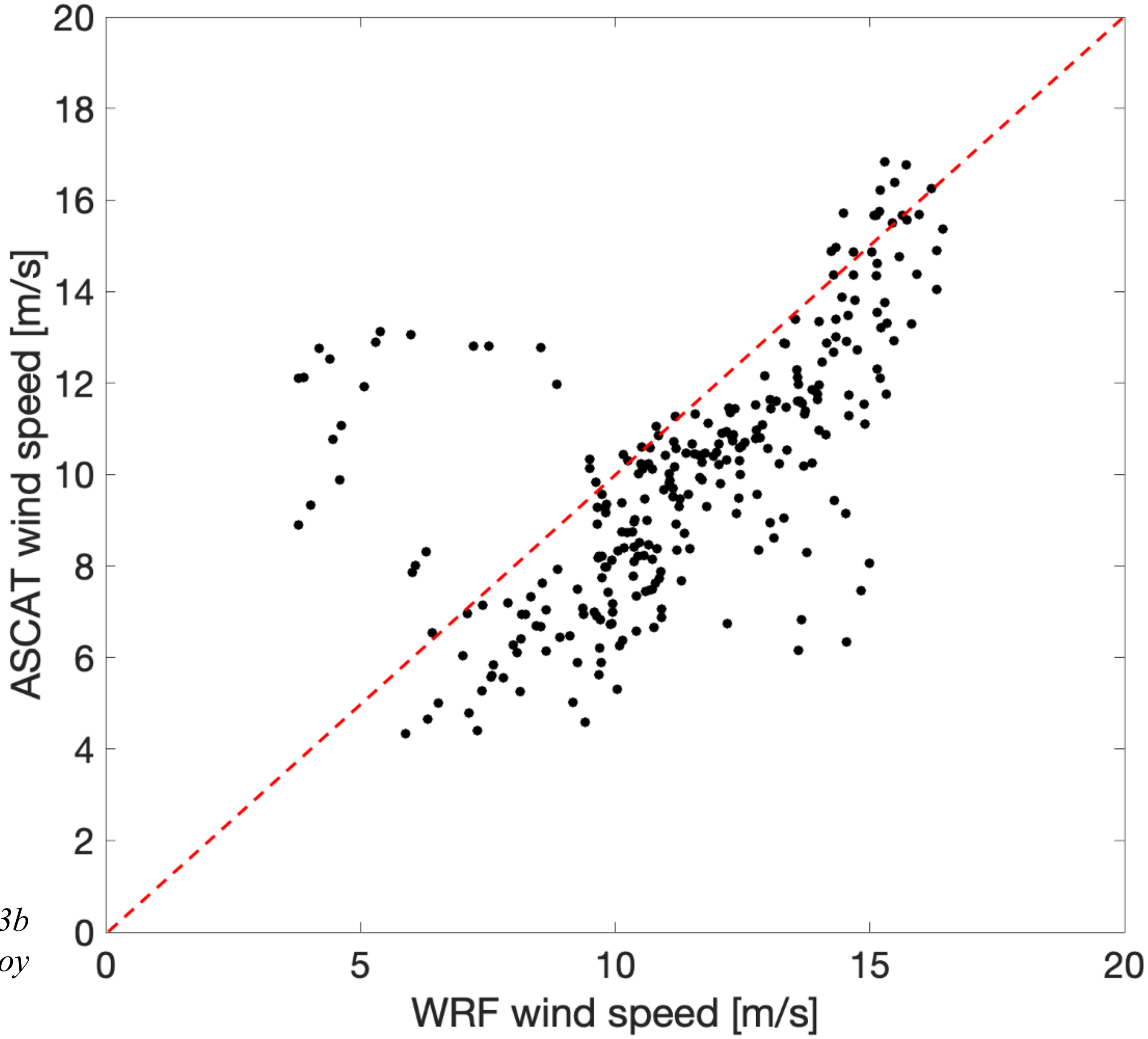
Wind Speed: WRF simulation vs ASCAT

The geographical distribution of the mismatches shows a fairly good agreement (within 3 m/s) over the study area, especially along the Ligurian coast mostly affected by the storm surge, but in the southern part of the study area (blue dots), an underestimation of the ASCAT wind speed can be noted, which can be ascribed likely to land contamination (presence of isles).



Wind Speed: WRF simulation vs ASCAT

The accuracy of the ASCAT-derived wind speed is better in the open sea with error always lower than 3 m/s. Moreover, the region of wind speed higher than 12 m/s is wider for WRF. This is consistent with the results of Yang et al. (2020), who noticed a systematic ASCAT underestimation for wind speed larger than 15 m/s.



Yang, J. Zhang, Y. Jia, C. Fan, and W. Cui, "Validation of sentinel-3a/3b and jason-3 altimeter wind speeds and significant wave heights using buoy and ascat data," Remote Sensing, vol. 12, no. 13, p. 2079,2020.

Conclusions

1. Our ability to forecast weather and global climate changes strongly depends on our capability to observe the changes in atmosphere and ocean in real-time at spatial and temporal scales with the required resolution and accuracy.

2. Starting from the real test case of VAIA storm event, we discuss about the necessity to apply an integrated approach, involving in-situ data, remote sensing measurements and numerical simulations, to study the environmental meteo-marine phenomena in a coastal management framework.

3. The choice of the remote sensing measurements was satellite radar data from ASCAT (Advanced Scatterometer), which have been exploited for sea wind speed retrieval to support in-situ measurements and numerical modelling.

4. The experimental results demonstrate the effectiveness of the proposed integrated approach, because the satellite-based wind speeds better agree with numerical simulations if compared to the in situ wind observations, which are affected by sheltered position of the weather stations.

5. However, a number of improvements of the proposed approach have to be considered, among which the correction of the ASCAT underestimation in case of land contamination and WS higher than 15 m/s.

An integrated approach of in-situ data, remote sensing measurements and numerical simulations to study storm events in the Ligurian Sea

THANKS FOR YOUR ATTENTION!