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PRELIMINARY METEOROLOGICAL ANALYSIS OF SELECTED COASTAL EROSIONAL EVENTS IN SOUTHERN ITALY

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Abstract: Two meteorological models, Regional Atmospheric Modeling System (RAMS) and Weather Research and Forecasting (WRF), were tested for Southern Italy extreme events related to coastal erosion phenomena. Simulations are compared with observational data for some meteorological surface parameters: temperature, relative humidity, wind speed and direction, atmospheric pressure. In addition, WRF model performance were tested also at different vertical levels, by a comparison with rawinsonde data.

Keywords: Coastal erosion, extreme events, meteorological models.

1. INTRODUCTION

In this work we analyzed selected extreme events, related to coastal erosion episodes, for some of the monitoring sites considered in the "Integrated Management System for Coastal Erosion" (SIGIEC) project. In particular, the study is focused on Southern Italy, in Calabria and Puglia regions, where different monitoring sites were investigated.

Some erosional cases were identified in these sites in a monitoring period between 2009 and 2012. For each selected event two meteorological models, Weather Research and Forecasting Model (WRF) and Regional Atmospheric Modeling System (RAMS), were run in order to simulate the main atmospheric parameters, such as temperature, relative humidity, wind speed and direction, atmospheric pressure. RAMS model outputs have an horizontal resolution of 5 km for the finest grid, while for WRF the horizontal resolution is 3 km.

For the verification observed data from different datasets were employed.

For Calabrian site, surface data from Agenzia Regionale Protezione Ambientale (ARPA) were used, while surface data from Servizio Mareografico Nazionale (SMN) were employed for sites in the Puglia region.

Furthermore, WRF performances were tested also at different vertical levels by a comparison, for the selected study cases, with rawinsonde data at Brindisi site, in Puglia region.

2. DATA AND METHODS

2.1 OBSERVATIONAL DATASETS AND STUDY CASES

The study area covers two regions in southern Italy: Calabria and Puglia. In particular, we considered Bagnara Calabra site for the Calabria region and Alimini and Porto Cesareo sites for Puglia region. For these three monitoring sites, some dates, in which coastal erosion phenomena were recorded, are found. These events took place in different dates and sites in the study area.

The selected erosional episodes, organized for the different monitoring site, are listed in Table 1. For all these cases WRF and RAMS models performances were evaluated for extreme events.

PORTO CESAREO	ALIMINI	BAGNARA
14-Jan-2009	18-Oct-2010	06-Jan-2012
12-Feb-2010	19-Oct-2010	
13-Feb-2010	06-Jan-2012	
20-Feb-2010		
15-May-2010		
19-Oct-2010		
10-Nov-2010		
11-Nov-2010		
02-Dec-2010		
17-Dec-2011		
03-Feb-2012		
16-Feb-2012		

Table 1: Considered study cases.

Unfortunately, surface meteorological measurements were not available in correspondence of the monitoring sites. Therefore, for these sites, the nearest measurement stations were considered for analysis. As mentioned, the observation network for the verification includes, for the Calabrian site, data from Agenzia Regionale Protezione Ambientale (ARPA), while for the Puglia sites, data from the Servizio Mareografico Nazionale (SMN).

In particular, the observation stations considered for Calabria are Capo Vaticano, Reggio Calabria and Scilla for the verification on Bagnara Calabra site; regarding Puglia region, the measured parameters come from Otranto, for the verification near the Alimini site, and from Taranto, for the verification near Porto Cesareo site.

The observed data considered for comparison with models were available for several meteorological parameters: temperature, wind speed and direction, relative

humidity, atmospheric pressure, except for the Capo Vaticano site, where only temperature and wind data were available, and the Scilla site, where only temperature data were available.

Available data are reported in Table 2.

	Temperature	Relative Humidity	Wind Speed	Wind Direction	Atmospheric Pressure
Reggio Calabria	X	X	X	X	X
Scilla	X				
Capo Vaticano	X		X	X	
Taranto	X	X	X	X	X
Otranto	X	X	X	X	X

Table 2: Available data for each measurement site.

In Figure 1 all stations and all monitoring sites locations are shown. It can be noted that measurement stations are sufficiently near to monitoring sites, but it is reasonable to think that not considering the exact position for all monitoring sites can be a cause of further uncertainties besides model errors.
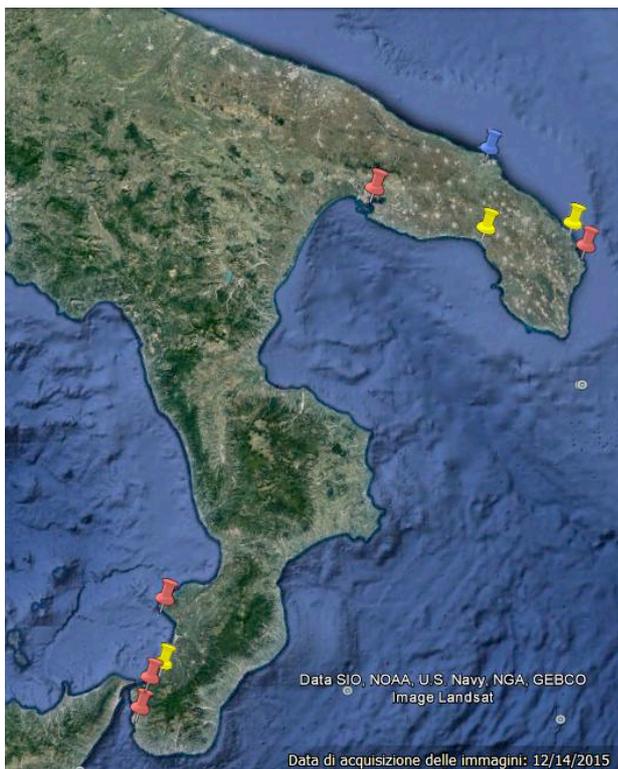

Figure 1: Monitoring sites and measurement stations locations. Yellow marks represent monitoring sites of Alimini, Porto Cesareo and Bagnara Calabra; red marks represent surface meteorological measurement stations near monitoring sites (Reggio Calabria, Scilla, Capo Vaticano, Otranto, Taranto); blue mark represents Brindisi site (rawinsonde).

In addition to the surface datasets over mentioned, another important observed dataset is considered in order to deepen the knowledge about the costal erosional effects. For all the study cases, WRF model performances were evaluated also for the vertical profile parameters, considering wind, temperature and moisture at different vertical levels; for this test, rawinsonde data available for Brindisi site were considered. Two daily measures are available: at 00:00 and at 12:00 UTC. The verification is conducted comparing rawinsonde data and WRF model outputs on Brindisi site (which is the only available site with rawinsonde measures in the study area) for the selected days and for both the daily measures. Measured parameters obtained by rawinsonde are the following: Atmospheric Pressure [hPa], Geopotential height [m], Temperature [°C], Relative Humidity [%], Wind direction [°], Wind speed [knot], where wind speed has been converted from [knot] to [m/s] for the comparison with model outputs.

The heights at which the different meteorological parameters are recorded vary for every day and time.

2.2 METEOROLOGICAL MODELS FOR EXTREME EVENTS SIMULATIONS

Coastal erosion extreme events were analysed by the comparison between observed and simulated data in the study cases dates. Two models were employed for this analysis: the WRF [1] and the RAMS [2] model. These models can be used with many configurations and parameterizations schemes, depending on the research scopes. Several studies are performed by ISAC-CNR about the performance evaluation of these models in forecasting the principal atmospheric parameters [3,4]. WRF model configuration counts three nested grids. The first grid has an horizontal resolution of 27km and covers the whole Italian peninsula and part of the Mediterranean Basin, the second grid covers an area including the Central and Southern Italy and has an horizontal resolution of 9km, while the third and finest grid has an horizontal resolution of 3km and covers Southern regions of Italy, focusing in particular on Calabria and Puglia, which form the study area.

The RAMS model counts two nested grids: the first (25 km resolution) covering The Central Mediterranean, while the second (5 km resolution) covering Southern Italy.

Model outputs, for both models, where extracted taking into account the finest grid. The extracted surface parameters are the following: temperature [K], relative humidity [%], wind speed [m/s], wind direction [degrees], atmospheric pressure [hPa].

Models and observation are compared for all the parameters where measures were available. Therefore, the number of data used for statistics calculation is different for each parameter and for each measurement site considered. In each case, comparisons are made considering data every three hour.

2.3 VERIFICATION METHODS

In order to test models performance, some statistical parameters are calculated. In the following the calculated parameters are listed:

- **Root mean square error:** measures the mean square gap between observed and modelled data:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Forecast_i - Observation_i)^2}$$

- **Correlation coefficient:** Measures the strength of the linear relation between forecasted and observed data.

$$r = \frac{N\sum_{i=1}^{N}Fore_i \cdot Obs_i - \sum_{i=1}^{N}Fore_i \cdot \sum_{i=1}^{N}Obs_i}{\sqrt{[N\sum_{i=1}^{N}Fore_i^2 - (\sum_{i=1}^{N}Fore_i)^2][N\sum_{i=1}^{N}Obs_i^2 - (\sum_{i=1}^{N}Obs_i)^2]}}$$

where N is the number of couples forecast-observation employed for statistics calculation.

3 RESULTS AND DISCUSSION

3.1 VERIFICATION OF SURFACE PARAMETERS

In the following section, statistical results are presented. Results of comparisons between observed data and models are shown in Table 3. In this table, results are divided according to the monitoring site and the study cases for each site. Not all parameters are available for all measurement station.
In Table 3 RMSE statistics are reported. For each site errors are calculated for all days in which coastal erosion phenomena occurred in the specific site. For each event three days are considered, taking into account the two days before the event for each case, with model outputs and observed data every three hours.
Parameters considered for comparison are: temperature, relative humidity, wind speed and direction and atmospheric pressure. For each site, a mean value of events errors is calculated for each parameter and for each model (green character on table).
Table 3 is useful to analyze case studies to find properties that characterize a specific site. Results show a good agreement between models and observed data as regards the simulation of the main atmospheric parameters in correspondence of the extreme events.
In most cases RAMS has a higher prediction capability as regards wind speed and direction, while WRF has better performance in predicting temperature in some circumstances. For most cases errors are lower than 2°C (in some cases lower than 1.5°C) for temperature, and often lower than 4 m/s for wind speed.
In Figure 2 wind roses for each monitoring site are shown, of course considering the different extreme events occurred in each specific site. Wind roses are produced for three datasets: observed wind data, WRF and RAMS wind forecasts. In general, a good agreement between measured and simulated values can be noted, as regards both the direction and the intensities. Therefore, a good capability of

both models in simulating wind behaviour in correspondence of coastal erosion phenomena is found.
Similar analysis (not shown here) are performed in correspondence of maxima wind speed and direction. Max wind direction values are those directions measured at the hour in which wind speed maximum occurs, for each day. Differences between simulated data, both from WRF and RAMS, and observed ones, are calculated. In this case WRF outputs are mainly nearest to measures than RAMS values. These results suggest that for wind extreme event, maybe related to coastal erosion phenomena, WRF has better performance, and this occurs probably because of its higher spatial resolution.

3.2 VERIFICATION ON SURFACE PARAMETERS

In the previous sections, surface parameters analysis and comparisons were discussed.
However, a meteorological extreme event is often related to particular perturbation conditions that happen at high altitude. These effects are often used as precursors of intense phenomena recorded at the surface level. For this reason, also an analysis for data at high altitude is carried out. In this analysis, WRF model capability to predict wind behaviour at different altitudes is tested.
For this comparison, 42 different vertical levels were chosen for model data extraction, while rawinsonde levels, as said, are different for each launch.
Hence, as a first step, a spatial bilinear interpolation of fields at rawinsonde levels on WRF selected levels is produced.
Results are shown in Table 4, where in the first column are listed the levels, while the other columns represent RMSE and correlation coefficient (R) for all considered parameters.
In Figure 3, RMSE values at different altitudes are shown. The RMSE behaviour is shown for different parameters: temperature, relative humidity, wind speed, wind direction, atmospheric pressure.
From Table 4, it can be noted that correlation coefficients are sufficiently high for each parameter. RMSE statistics show good results in particular for temperature, also at highest levels. Good performances are also obtained for wind speed and in particular for atmospheric pressure.
As can be seen from Table 4, for temperature, errors lower than 2°C are obtained for the lowest levels, until a height of 10km. A good result is obtained also for higher altitudes. In fact, for heights until 20km, the RMSE is lower than 3°C.
As regards relative humidity, higher errors are found for lower levels, while errors decrease with height, starting from the altitude of 10km.
Errors in wind speed forecast vary from 3.5 m/s to 6.5 m/s, depending on level considered. Wind direction is well simulated for levels upper than 1500-2000 meters, where the mountains effect is lower.

TARANTO	temp		rh		wsp		wdir		press	
	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF
14-Jan-2009	1,46	0,56	-	-	3,95	4,55	20,69	21,83	2,00	2,09
12-Feb-2010	1,59	2,00	-	-	3,17	2,26	62,12	67,26	3,33	1,74
13-Feb-2010	2,33	1,64	-	-	3,57	3,13	44,66	91,44	2,41	0,84
20-Feb-2010	2,39	1,89	-	-	5,19	3,44	46,46	64,57	1,75	1,77
15-May-2010	3,22	0,97	-	-	6,70	4,28	19,53	23,67	3,40	1,36
19-Oct-2010	1,39	1,96	9,78	11,35	3,39	3,81	100,36	71,17	1,10	1,60
10-Nov-2010	3,19	1,43	21,03	10,94	4,52	3,33	46,31	25,91	5,10	0,55
11-Nov-2010	2,00	2,86	17,40	14,02	1,80	2,38	89,99	77,32	3,90	0,97
02-Dec-2010	2,41	1,17	19,90	11,41	2,21	1,86	61,17	60,60	5,63	0,94
17-Dec-2011	2,49	2,76	16,99	13,45	4,96	3,36	37,66	33,24	3,04	3,64
03-Feb-2012	1,92	2,90	5,80	5,00	4,65	6,01	83,53	87,50	0,87	0,70
16-Feb-2012	1,43	2,56	15,77	14,86	1,93	1,97	51,12	70,94	2,54	2,90
Mean	**2,15**	**1,89**	**15,24**	**11,58**	**3,82**	**3,37**	**-**	**-**	**2,92**	**1,59**
OTRANTO	temp		rh		wsp		wdir		press	
	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF
18-Oct-2010	1,36	1,83	6,91	3,56	1,76	3,72	75,89	113,21	1,09	1,34
19-Oct-2010	1,57	0,29	8,46	8,36	3,73	5,72	49,56	61,71	0,58	2,08
06-Jan-2012	0,82	2,44	9,41	22,55	3,23	5,35	24,74	46,69	3,38	8,56
Mean	1,25	1,52	8,26	11,49	2,91	4,93	-	-	1,68	3,99
REGGIO CALABRIA	temp		rh		wsp		wdir		press	
	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF
06-Jan-2012	1,37	1,22	13,06	20,14	4,56	8,72	34,07	57,68	14,95	19,20
Mean	1,37	1,22	13,06	20,14	4,56	8,72	-	-	14,95	19,20
SCILLA	temp		rh		wsp		wdir		press	
	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF
06-Jan-2012	1,20	1,91	-	-	-	-	-	-	-	-
Mean	1,20	1,91	-	-	-	-	-	-	-	-
CAPO VATICANO	temp		rh		wsp		wdir		press	
	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF	RAMS	WRF
06-Jan-2012	1,21	1,51	-	-	5,56	6,45	26,63	37,06	-	-
Mean	1,21	1,51	-	-	5,56	6,45	-	-	-	-

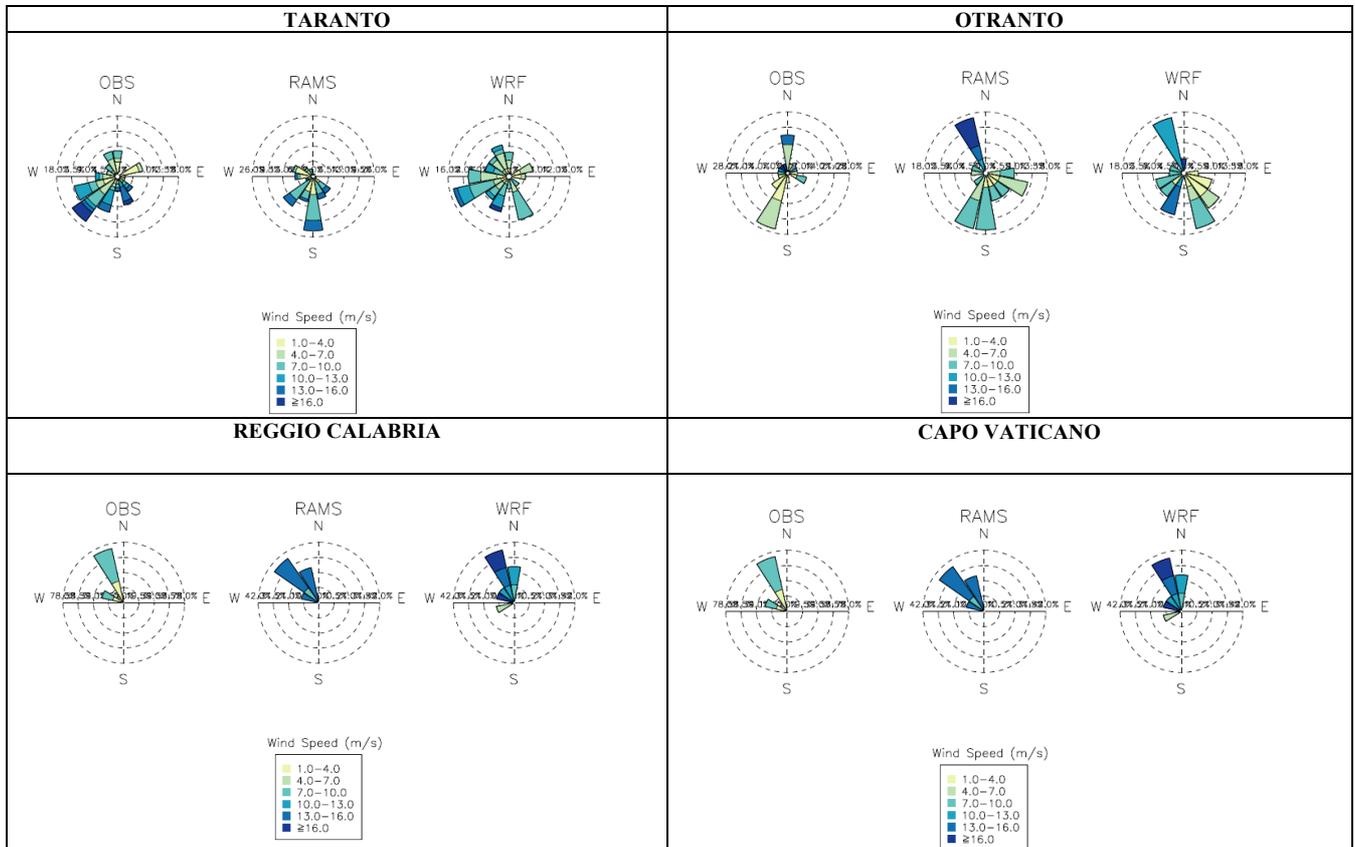Table 3: RMSE for monitoring sites.

Figure 2: wind roses for monitoring sites

Level (m)	RMSE Temperature (°C)		RMSE Relative Humidity (%)		RMSE Wind speed (m/s)		RMSE Wind direction (°)		RMSE Atmospheric Pressure (hPa)	
	RMSE	r	RMSE	r	RMSE	r	RMSE	r	RMSE	r
20	1,83	0,93	16,86	0,53	3,91	0,59	53,39	0,77	4,09	0,88
50	1,80	0,93	16,61	0,51	3,77	0,60	50,66	0,80	3,09	0,88
100	1,58	0,95	16,02	0,51	3,96	0,60	51,30	0,81	3,06	0,88
200	1,52	0,95	16,20	0,52	4,35	0,56	50,21	0,76	3,07	0,88
400	1,50	0,95	17,55	0,52	4,72	0,61	34,04	0,89	3,03	0,88
600	1,44	0,95	16,96	0,52	4,48	0,73	41,87	0,90	2,92	0,88
800	1,52	0,95	17,40	0,46	4,59	0,77	41,18	0,91	2,79	0,89
1000	1,59	0,95	17,64	0,44	4,90	0,76	40,42	0,90	2,75	0,89
1500	1,42	0,97	30,29	-0,22	5,10	0,72	32,84	0,95	2,29	0,92
2000	1,73	0,96	32,03	-0,32	4,87	0,67	44,16	0,86	2,14	0,94
2500	1,89	0,95	32,37	-0,19	4,34	0,71	24,74	0,94	2,02	0,95
3000	1,38	0,97	30,70	-0,03	3,93	0,75	22,26	0,91	1,08	0,99
3500	1,89	0,95	24,95	0,31	3,85	0,81	23,43	0,88	1,32	0,99
4000	1,74	0,96	27,18	0,31	5,06	0,76	19,72	0,91	1,34	0,98
4500	1,73	0,96	31,13	0,29	4,86	0,81	18,40	0,93	1,40	0,98
5000	1,82	0,96	26,36	0,43	5,26	0,84	23,00	0,88	1,30	0,98
5500	1,92	0,96	26,23	0,30	5,04	0,88	18,04	0,92	1,60	0,98
6000	1,50	0,97	27,12	0,50	5,21	0,90	18,84	0,91	1,31	0,98
6500	1,76	0,96	28,46	0,40	5,74	0,90	19,90	0,90	1,49	0,98
7000	1,86	0,96	25,47	0,54	6,08	0,91	19,37	0,92	1,35	0,99
7500	1,90	0,96	24,18	0,67	4,95	0,95	20,23	0,92	1,43	0,99
8000	1,81	0,96	22,54	0,70	4,43	0,97	23,47	0,92	1,45	0,98
8500	1,84	0,96	25,67	0,55	4,75	0,97	26,99	0,92	1,48	0,98
9000	1,77	0,97	26,29	0,44	5,49	0,96	46,24	0,47	1,47	0,99
9500	1,63	0,97	20,75	0,62	5,80	0,95	13,07	0,97	1,21	0,99
10000	2,30	0,92	19,45	0,64	6,70	0,92	15,14	0,93	1,24	0,99
10500	2,41	0,85	14,88	0,75	6,08	0,93	18,15	0,86	1,11	0,99
11000	2,38	0,76	11,64	0,85	4,81	0,96	19,37	0,76	1,07	0,99
11500	2,30	0,76	13,01	0,75	3,71	0,98	39,88	0,36	0,89	1,00
12000	2,23	0,76	12,00	0,61	3,88	0,97	11,74	0,87	0,88	1,00
12500	1,67	0,89	11,67	0,30	5,02	0,95	8,60	0,91	0,68	1,00
13000	1,96	0,84	10,85	0,13	5,18	0,94	11,85	0,86	0,77	1,00
13500	2,36	0,80	9,60	0,13	6,03	0,91	8,47	0,93	0,65	1,00
14000	1,99	0,82	7,47	0,21	6,40	0,87	9,58	0,88	0,63	1,00
14500	2,02	0,78	5,73	0,05	5,69	0,89	9,38	0,86	0,53	1,00
15000	2,65	0,67	4,08	-0,12	4,95	0,88	11,46	0,81	0,58	0,99
16000	2,16	0,91	2,25	-0,18	5,48	0,81	15,10	0,70	0,51	1,00
17000	2,90	0,72	1,84	0,03	6,69	0,78	24,98	0,62	0,55	1,00
18000	2,56	0,66	2,06	-0,18	5,74	0,85	19,98	0,76	0,60	1,00
19000	2,62	0,64	2,00	-0,24	5,86	0,88	25,77	0,86	0,51	1,00
20000	3,41	0,75	1,86	-0,03	4,95	0,91	17,62	0,96	2,78	0,52

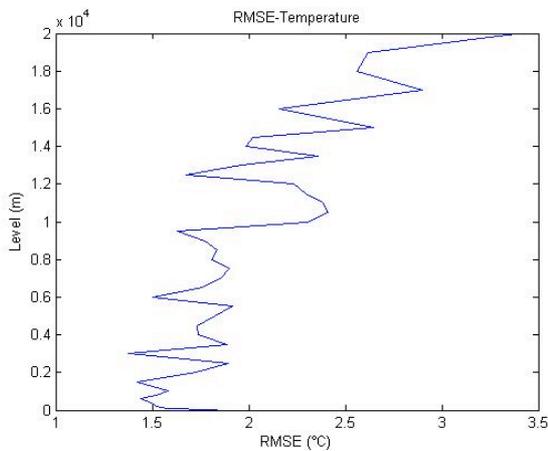Table 4: Statistics for rawinsonde parameters

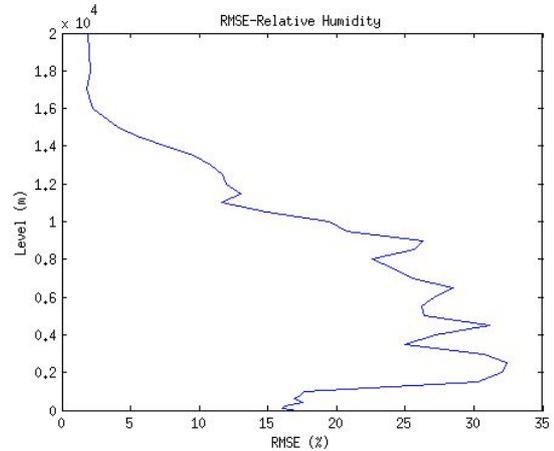Figure 3a: RMSE values for temperature

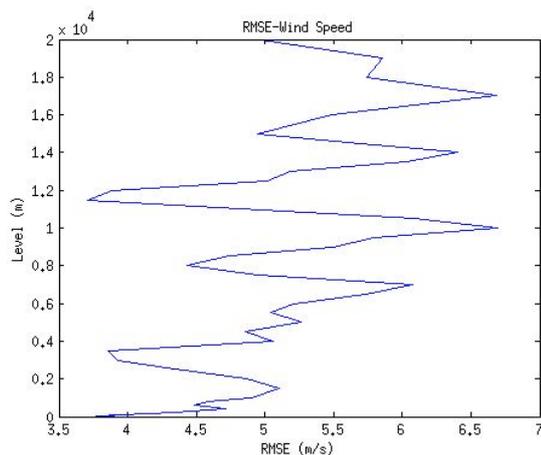
Figure 3b: RMSE values for relative humidity

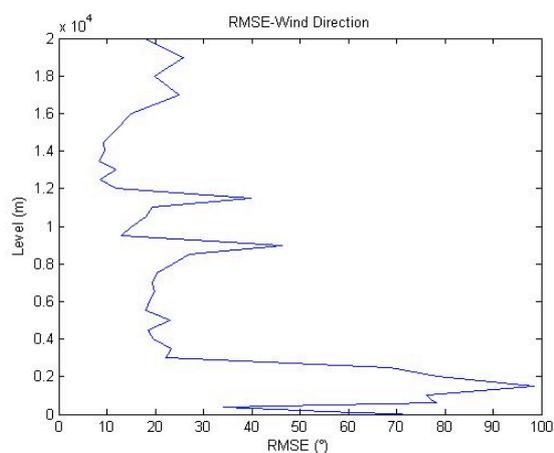Figure 3c: RMSE values for wind speed

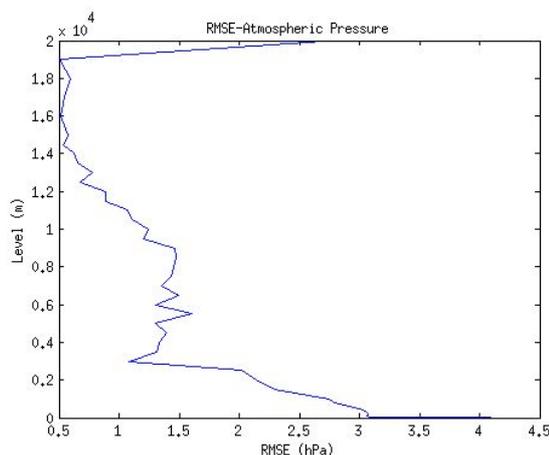Figure 3d: RMSE values for wind direction

Figure 3e: RMSE values for atmospheric pressure

4. CONCLUSION

Selected extreme events, related to coastal erosion episodes, were analysed on southern Italy during the period 2009-2012. Three sites of interest in Puglia and Calabria regions are considered for the study.

For each event two meteorological models, WRF and RAMS, were run in order to simulate the main atmospheric

parameters directly related to erosional phenomenology. For the model performance evaluation both surface data and vertical profile measurements (rawinsonde) were taken into account.

From surface verification follows that, on average, the errors are lower than 2°C (in some cases lower than 1.5°C) for temperature and lower than 4 m/s (in some cases lower than 3 m/s) for wind speed. Also by wind-roses evaluation, follows a good agreement between observed and simulated wind directions.

From vertical profiles analysis follows a good agreement, in particular for temperature, also at highest levels. Good performances are also obtained for wind speed and in particular for atmospheric pressure.

Obviously these results must be interpreted considering that they are related to extreme events, whereas it's much more difficult to make reliable forecasts.

Further analysis is needed, especially considering a larger statistical sample, to better assess the link between the erosive events and the behaviour of the meteorological parameters.

5. REFERENCES

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