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HYDRO-METEOROLOGICAL AND REMOTE SENSING ANALYSES: THE CASE OF RECENT EXTREME FLOODS IN NORTHERN ITALY

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Abstract. Some recent events over Northern Italy, including the event of November 4-6th, 1994 are analyzed by means of the available satellite-borne monitoring devices. The use of remote sensing techniques provides that 'far-from-the-object' perspective that proves extremely useful in many hydrological applications including flood forecasting. The information content of geosynchronous satellite data is discussed in this paper with specific reference to image sequences as provided by the radiometer borne on the ESA-Meteosat platform in the thermal infrared band. Further useful information is derived from ERS-1/SAR images and from the passive microwave sensors presently flying on two spacecraft of the NASA DMSP (Defense Meteorological Satellite Program). The role of each source of information is discussed in the integrated use of multisensor produced data.

1. INTRODUCTION

The winter season sets in quite suddenly in the Mediterranean region as the summer eastward extension of the Azores high pressure cell collapses: in the western areas a sudden pressure drop occurs in the early fall. This is accompanied by a marked increase in the probability of intense precipitation. These changes in the synoptic pattern are associated with the early invasion of polar cold fronts. Extreme rainfall often results from the thermal effects induced by relatively high sea surface temperatures in that season. The prediction of such weather patterns is quite satisfactorily resolved, at present, over large space and time scales, by operational Global Circulation Models (GCMs) and "nested" Limited Area Models (LAMs). Unfortunately, however, they do not capture the sea surface temperature anomalies exceeding the climatological values over the long fetch from the northern African coastline up to the European borders. Together with a few additional shortcomings (low resolution description of the orography, hydrostatic approach, etc.), this results in frequent underestimation of the intensity and coverage of heavy precipitation patterns, whilst the occurrence of "average" events is fairly well predicted. In fact, the incursion of cold air masses into the Mediterranean region often leads to convective instabilities (Ramis *et al.*, 1994) along the cold fronts producing interactions between frontal and orographic enhancement. This may trigger the development of extreme events of convective origins whose duration do not exceed a few hours but whose rainfall depths exceed somewhere between 1/5-1/3 of the total annual average precipitation.

A diagnostic procedure based on LAM results was proposed by Ramis *et al*. (1994) in order to identify the areas where the large scale circulation induces favourable conditions for the development of thunderstorms. These areas are detected by cross-overlapping three causative components, i.e. the upward quasi-geostrophic forcing, the convergence of water vapor at low levels, and the convective instability in the lower troposphere. Within those areas, vertical radio-soundings may provide further elements for the local study of vertical instability. This local diagnosis is made through the determination of the Convective Available Potential Energy (CAPE) and the bulk Richardson number, and their temporal evolution during the event. The analysis produces interesting results when compared with the low level wind map obtained from high resolution Limited Area Models, where the convergence of the wind pattern toward the major orographic barriers may be easily detected as the major triggering factor for orographic enhancement mechanisms.

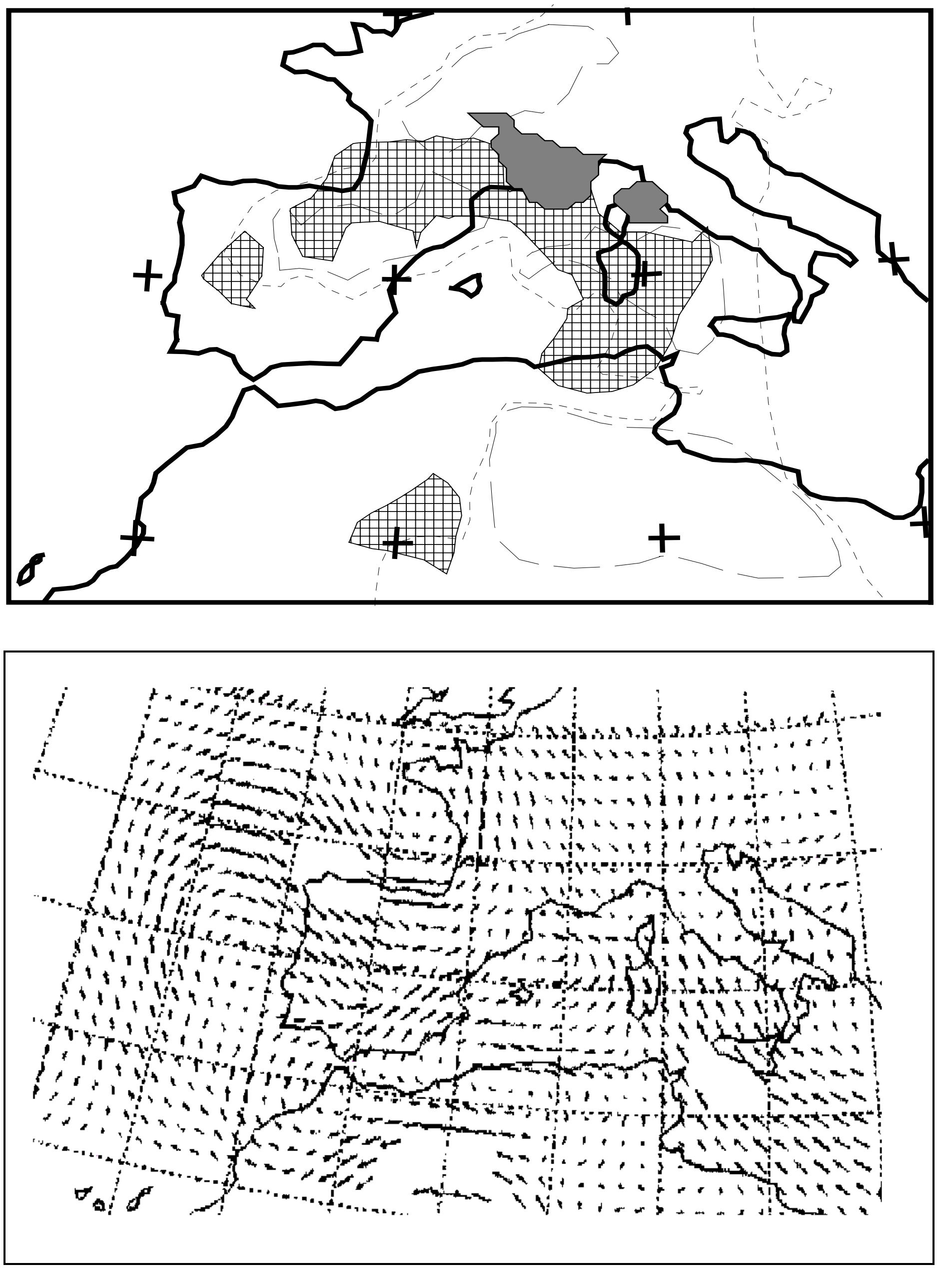
Figure 1 shows the result of the above mentioned diagnostic analysis (Llasat *et al*., 1994) for the event of September 27-28th, 1992, over the Liguria region of Italy, which is described later in the paper. Unfortunately the timing of the available map for the low level wind field is slightly different from that of the analysis and direct comparison is not possible in this case. However, the observed rotational pattern at 06.00 and 18.00 GMT indicates that at 12.00 GMT the wind pattern was most probably convergent toward the coastal orographic barrier, giving rise to the deep cumulonimbus formations that are easily detectable by inspection of the Meteosat infrared imagery.

These observations and results confirm that any efficient procedure for monitoring and forecasting of extreme flooding events in the Mediterranean region should deal simultaneously with the different scales of evolution that characterize the physics of the rainfall producing meteorological processes. Indeed, the meteorological conditions of interest in these cases develop within large mesoscale or synoptic areas with extension of thousands of km^2. The synoptic conditions are then reflected - at smaller scales - into bursts of frontal and/or convective structures yielding extreme effects at the basin scale. In this view, the analysis of extreme precipitation events should be addressed at various scales on the basis of the observational data collected by the different available monitoring systems.

Three case studies are presented in this paper, with reference to the heavy rainfall events observed over northern Italy during September 1992 and November 1994. Two of such events are characterised by the formation of a well defined and persistent Mesoscale Convective Complex (MCC) whose evolution in space and time was analysed by means of the available remote sensing and ground-based monitoring devices. The interpretation of the event dynamics is provided together with the relevant implications for quantitative rainfall forecasting and related early warning strategies. Cloud tracking and animation techniques are used to study the space-time evolution of the MCC and the role of possible enhancing factors at the local scale that may trigger convection mechanisms within the overall meteorological scenario.

2. REMOTE SENSING OBSERVATIONS

The images provided by the radiometers flying on geostationary satellites are traditionally used for cloud tracking (see Bolla *et al.,* 1996) and for quantitative rainfall estimation (see for example Barrett and Martin (1981) for a review of the various estimation methods). The algorithms employed essentially rely on empirical relationships based on the observation that, in the visible (VIS) band, clouds with the highest values of reflectivity have the highest rainfall probability and correspondingly, in the thermal infrared (IR) band, the coldest clouds denote more precipitation prone formations. The uncertainty of such estimates is quite large as no information about the microphysics of the inner cloud system is detectable from the images.



(a)

(b)

Figure 1: Synoptic diagnosis (a) at 12:00 GMT of 27 September 1992. Three forcing mechanisms for convection (upward quasi-geostrophic vertical forcing, negative values of the equivalent potential temperature between 500 and 1000 hPa, and moisture divergence) overlap in the gridded areas. Black areas denote the MCC structure as identified from the IR Meteosat image at 12:30 GMT (Llasat et al., 1994). Arrows in (b) represent the wind field at 18:00 GMT.

The estimates of "instantaneous" rainfall at the ground are thus reliable only at the scale of the cloud aggregates. As a result, quantitative estimation of rainfall rates at the ground from IR data is most appropriate when climatological analysis is performed (e.g., when the assessment of monthly to annual precipitation over large regions is concerned for agricultural, climatologic or water balance purposes). The use of IR data for "instantaneous" rainfall estimation in flood forecasting is limited to the analysis of the hydrological response of large size catchments. However, IR images can give information about potentially hazardous precipitating systems as highlighted by those regions of the cloud coverage presenting the lowest values of the radiance temperature.

Cloud tracking techniques have been proposed and implemented in order to automatically derive from IR satellite images the geometric characteristics of that portion of the cloud coverage showing the highest probability of heavy rainfall and to track them along image sequences. The identification of the areas of maximum rainfall probability (or the MCC) is performed by using suitable algorithms for cluster analysis as developed by Filice et al. (1991a,b). Animation may also be used to investigate the space-time evolution of the identified MCC and the role of possible enhancing factors at the locale scale as well as to derive cloud dynamics parameters during extreme events.

Because of its characteristics, the *Special Sensor Microwave/Imager* (SSM/I) on board spacecrafts of the *U.S. Defense Meteorological Satellite Program* (DMSP) is indicated as a major breakthrough (Spencer *et al.* 1989) for rainfall monitoring from space. The SSM/I can provide information on a variety of environmental parameters, including atmospheric water, wind speed, and sea ice (Hollinger *et al.* 1990). The SSM/I is a seven-channel, four-frequency (19.35, 22.235, 37.0, and 85.5 GHz) scanning passive-microwave radiometer system, operating in dual polarization (both vertical and horizontal) at each frequency except 22 GHz where only vertical polarization is measured (this channel corresponds to a water vapor absorption line and is primarily used to monitor atmospheric water vapor to correct for atmospheric attenuation). Each DMSP satellite flies in a circular sun-synchronous near-polar orbit at an altitude of about 850 km, with a period of 102 minutes - thus, for a total of 14.1 orbits per day. For the F8 spacecraft, the equatorial ascending node is at 6:13 local time, while for the F11 it is at 17:04 local time. Data are collected during 102° of this rotation (±51° about the aft direction for the F8, and ±51° about the fore direction for the F11) resulting in a swath of about 1400 km. The effective ground resolution (i.e., the size of the antenna footprint on the ground) is about 69 x 43, 60 x 40, 37 x 28, and 15 x 13 km at 19, 22, 37, and 85 GHz, respectively (for each frequency, the first value is in the along-track direction, whereas the second value is in the cross-track direction).

A precipitation retrieval algorithm based on space-borne multi-frequency microwave radiometers, has been developed in Italy within the “Flood hazard multisensor monitoring” CEE program. Since the algorithm was developed at the *Istituto di Fisica dell'Atmosfera* of the *National Research Council (CNR)* of Italy in Frascati and at the *Dipartimento di Ingegneria Elettronica* of *University "La Sapienza"* in Roma, it is referred to as the IFA-SAP algorithm. It is based on the theoretical studies by Mugnai *et al.* (1990, 1992, 1993, 1994), Smith *et al.* (1992), and Basili *et al.* (1992a, 1992b, 1994) and it has been described in detail by Marzano *et al.* (1994, 1995) (see also Smith *et al.*, 1994). An example of the application of the IFA-SAP retrieval algorithm in the case of the intense flash-flood event which occurred in Piemonte (Italy) on November 4-5, 1994, is described in Boni *et al.* (1996) and further referred in the following.

The ground effects of large flooding events can be also examined by using images provided by the SAR sensor flying on board the Earth Remote Sensor 1 (ERS-1) polar satellite.

The ERS-1 flies following a near-polar sun-synchronous orbit at an altitude of 777 Km. The repeat cycle ranges from 3 to 31 days, depending on the mission purposes. The ERS-1 SAR has a vertically-polarized channel at 5.3 GHz with a 4-look ground resolution of 30x30 m, a swath of 100 Km, a mean incidence angle of 23 deg and a radiometric accuracy of 2.5 dB. Though weather conditions were at their worst, the ESA (European Space Agency) ERS-1 satellite was able to provide images of the flooded areas in the case of the November 1994 event described below.

The investigation of the potential of integrated multisensor observation and the design of a preliminary operational system for flood hazard monitoring were the objectives of the EC-funded STORM'93 project (Storm Tracking and Observation for Rainfall Monitoring), developed under the DG XII Environment Programme in the framework of the Contract n° EV5V-CT92-0167, "Flood Hazard Control by Multisensor Storm Tracking in the Mediterranean Area" (Roth *et al.*, 1996). The STORM project was aimed at the development of methodologies for meteorological data interpretation, validation and integration based on multisensor data sources of varying spatial and temporal scales. The multisensor data sources employed included synoptic weather maps, polar and geostationary satellite observations, meterological radar maps and telemetered raingauge network information. The multisensor data resources and the hydrological analysis of the extreme event of September 27-28th, 1992 - which is reported below - were obtained in the framework of that project. Final reports for each of the project tasks are available from DG XII of the European Commission.

3. THE EVENTS OF SEPTEMBER 22-23RD AND 27-28TH, 1992

During September 1992, the Liguria region of Italy experienced two intense rainfall events induced by meteorological formations of convective origins and associated with a low pressure centre extending from northern France to Southern Italy. Though intense rainfall were observed all over the region, fortunately only a few catchments were subject to catastrophic floodings with relevant damages and several casualties in the urbanised areas. The rain depth exceeded 400 mm in less than 12 hours in a number of raingauges covering an area of about 200 km^2 on the southern slope of the Apennine range.

The city of Savona and its neighbouring hinterland were hit by the first wave of the described events during September 22nd and 23rd. In particular the small sized catchments named Letimbro (52 km^2), Sansobbia (70 km^2), Quiliano (51 km^2), Erro (130 km^2), and Bormida (50 km^2) flooded large urban areas along the river courses. Just a week later, on September 27th and 28th, a second storm wave was similarly experienced by the city of Genova. In this case, the urban areas were hit by the most intense precipitation, producing catastrophic flooding in the Bisagno (92 km^2), Nervi (9 km^2) and Sturla (14km^2) catchments.

Figure 2 shows in false colors the general circulation as observed by the METEOSAT geostationary satellite in the near infrared wavelength at 13.00 GMT on 22 September 1992, corresponding to the disastrous flooding event in the French Alpes Maritimes (Vaison la Roumaine) and in the Liguria region, where upstream flooded river basin areas ranged from a few hundreds to a few tens of km^2. Within the MCC, dark colors depict the "blob" of clouds with very high top elevations, where very intense rain showers are most probable. The size of these areas is in the order of 100 km^2. The "blob" is displaced eastward with an average advection speed of 10-15 ms^{-1}. In its "shadow," rain cells and macrocells of a few kilometers in size develop, grow, and die with a time scale of about one hour, overlapping each other and convecting ice particles and graupels to the top of the troposphere. During the lifetime of a cell, the “blob” moves east by a few tens of kilometers, according to its advection speed. Rain gauges at ground in such conditions observe showers whose duration do not exceed a few hours, but whose rainfall depths exceed between 1/5-1/3 of the total annual average precipitation. Rainfall depths measured by different rain gauges show high correlation only for the time window during which the “blob” covers the gauge sites. It follows that the probability to develop high flood peaks is maximum for catchments or subcatchments whose hydrological response times are of the same order of magnitude as the duration of the “blob” shadow. The space-time characteristics of such a kind of storm - with a high speed eastern displacement and deep convective instability - are conducive to possible flash flooding in randomly selected elements of the population of small sized river basins draining the Mediterranean slopes of the Catalan range, the southern Pirineos, the French Cevennes and Alpes Maritimes, the Liguria slopes and the Thirrenian side of the Central and South Apennine ranges. Due to the limited size of the involved catchments and the corresponding large number of elements in the sample, the chance that a few inundation events will occur somewhere in the region, given a synoptic pattern circulation like the one depicted in Fig. 2, is very near to unity.

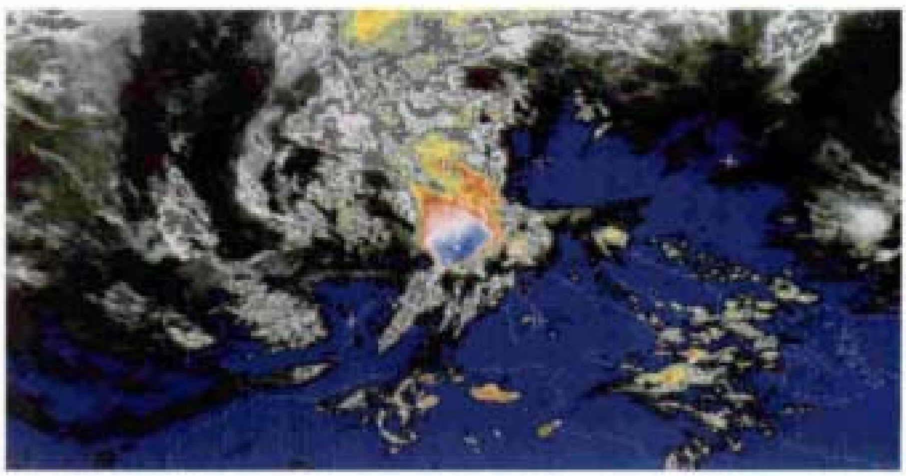


Figure 2. Image from the Meteosat geosyncronous satellite in the near infrared wavelength at 13.00 GMT on 22 September 1992. Coldest and highest clouds are depicted as dark "blobs" embedded into the general circulation: a larger "blob" is covering the Alpes Maritimes and a smaller one is developing over central Liguria.

From the analysis of the sequences of Meteosat images, in both cases, the MCC is observed to develop as a result of the dynamics of the frontal system at synoptic scale, and is generated by interaction of the advection velocity of the low pressure centre and the cyclonic rotational velocity with the local orography. Animated sequences of the Meteosat images show quite clearly the role played by the Alps Maritimes and the Apennine chains in determining the evolution in space of the MCC. This moves quite rapidly in the south-east direction, driven by the outline of the orography that runs almost parallel to the Thyrrenian coastline of Italy, while the entire cloud system is moving slowly towards east. This reflects the fact that the identified cluster of convective cloud is actually a different entity in each image (Boni et al., 1995).

In Fig. 3, the total area coverage of the main convective cloud cluster for the event of September 27-28th is shown as a cumulative parameter from 01.30 GMT of September 27th to 22.30 GMT of September 28th. The different colors are representative of the persistence in time of the cloud coverage over a given pixel of the satellite images. In Fig. 3a, a threshold at 253°K was used for detection of significant clouds while in Fig. 3b a threshold at 235°K allows the identification of the deeply convective portion of the cloud system only.

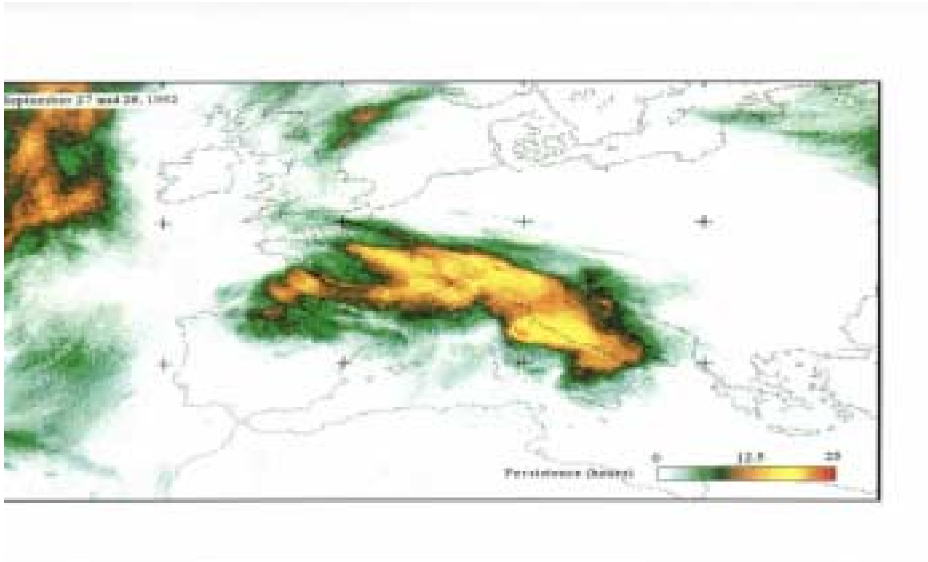
4. THE EVENT OF NOVEMBER 4-6TH, 1994

A second flood-threatening synoptic pattern is possible over the Mediterranean Europe during the fall season. This is very similar to that described above for the September 1992 events, but due to the presence of an intense high pressure system over the Carpatian area, its eastward advection speed is reduced. A typical example is observed by the METEOSAT geostationary satellite in the thermal infrared wavelength from 0400 UTC on 5 November to 1800 UTC on 6 November 1994, corresponding to
the disastrous flooding event in the upstream Po catchment.

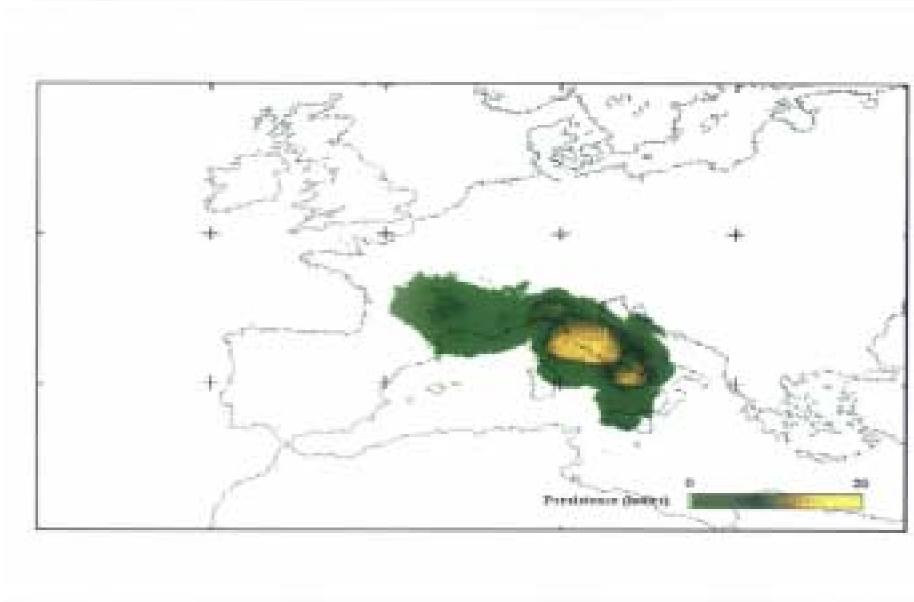
The Po river drains the largest morphological unit of the Italian territory, about 70,000 km^2 in size out of the 300,000 km^2 that form the continental area of the Italian peninsula. A description of the river training works and the risk mitigation policy in the Po River basin may be found in Marchi *et al.* (1995). The total annual precipitation over the Po river basin ranges from 700 to 2,000 mm, with frequent values of about 900-1000 mm. Major floods are due to long duration though not particularly intense rainfall. The river regime is dominated by rainfall, thus presenting two flood periods, in June and November. The statistical analysis of flood peak discharges at Pontelagoscuro (Ferrara) - the closure of the Po river basin - reveals that the expected flood is about 8,000 m^3/s with a return period of 10 years and about 12,000 m^3/s with a return period of 100 years.

During the flood of November 1994, upstream river basins flooded areas ranging from 500 to more than 10,000 km^2 (Boni *et al.*, 1996). In such a case, the cloud top formation corresponding to the maximum probability of precipitation in the Meteosat images remained quite steady over the same area. The space and time window in which rainfall depths had high correlation enlarged and large flood peaks were observed on medium and large size catchments. The randomness in the choice of the rivers that will reach a critical status in a region plays a minor role in this second synoptic pattern. However, centers of more intense convection and higher speed are frequently generated, embedded in the major circulation system, causing smaller basins also to go critical.

By comparison with other catastrophic rainfall event historically observed in the Po River basin, like the one in 1951, it is possible to recognize a few aspects of the dynamics of heavy rainfall pattern leading to disastrous flooding in the downstream branch of the Po River course. From the rainfall observations at the ground (unfortunately no satellite images were available for meteorological use in 1951), a two step hydro-meteorological process was the reason for the inundation of 1951. First, a rainfall pattern quite similar to the one observed in 1994 hit the upstream part of the Po basin causing a relevant flow discharge to be registered along the main river course. With a temporal delay of the order of the basin response time to the initial heavy rainfall, a second event hit the northern Apennine slopes and the downstream tributaries of the Po River causing the flood to inundate large flood-plain areas. Fortunately, the event of November 1994 showed only the first part of this particular pattern, allowing the flood to be limited at the level of the upstream tributaries, with contributing areas in the order of a few thousands of km² or less.



(a)



(b)

Figure 3. Total area coverage of the cloud system for the event of September 27-28th shown as a cumulative parameter from 01.30 GMT of September 27th to 22.30 GMT of September 28th with (a) a threshold at 253°K for identification of significant clouds and (b) at 235°K for identification of the deeply convective portion of the cloud system only.

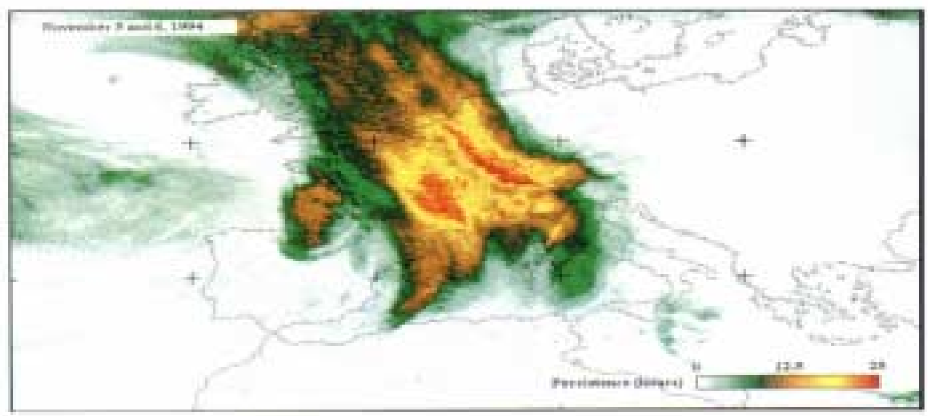
The detailed review and analysis of the multisensor observations made available during the event of Nov. 4-6th, 1994 is presented in Boni *et al.* (1996). Just an overview is therefore presented here so as to provide the reader with an overall description of the potential information content of multisensor observations in case of extreme floods. The Tanaro river overflowed from the late evening of November 5th to the early morning of November 6th, causing several casualties and considerable damage to property and breakdown of highway and railway bridges, isolating the whole area. The analysis of SAR images shows quite clearly the extent of the flooded areas reaching the order of several hundreds square kilometers (mainly included in a strip of land containing the meandering of the river). The 30x30 m spatial resolution of the SAR is well suited for flood hazard applications, but the large scale of the temporal sampling strongly reduces the suitability of ERS-1 SAR imagery in the framework of operational procedures for real-time flood management. However, the information content of the imagery can be exploited by comparing images surveyed before and after the flooding event for a careful distinction between the flooded areas and those normally covered by water (e.g. rice fields).

The description of the mesoscale meteorological situation producing large floods over northern Italy during November 1994 is provided here. At 00:30 of November 4^{th}, the situation is characterized by a large frontal system extending from the African coast to the British Isles moving slowly East South-East pushed by a cold airflow drawn from the north by a cyclone positioned westward the British Isles, over the Atlantic Ocean. The advection velocity of the front is strongly limited down by the presence of a deep high pressure centre over the Carpatian area. A warm airflow is advected at the same time from Northern Africa by the described circulation. The frontal system presents wide areas characterized by quite uniform and relatively higher radiance temperatures, characteristic of diffused stratiform precipitation. Cloudy areas indicative of high convective activity - associated with low values of the radiance temperature - were not observed until 10:30 GMT, when the coldest cloud area, fed by the southern warm airflow, developed in correspondence to the Catalonian coastline. The discrimination between cold convective clouds and cirri-form clouds was possible in this case by comparing the METEOSAT observations with the SSM/I data. However, the coldest cloud coverage rapidly exhausted its activity. Around 12:00 GMT the impact of the advected flow from Northern Africa with the orography of the Liguria region, in Northern Italy, caused some release of instability, generating a storm cell over the city of Genoa and the central part of Liguria that caused several failures of the sewer systems and problems to vehicle circulation.

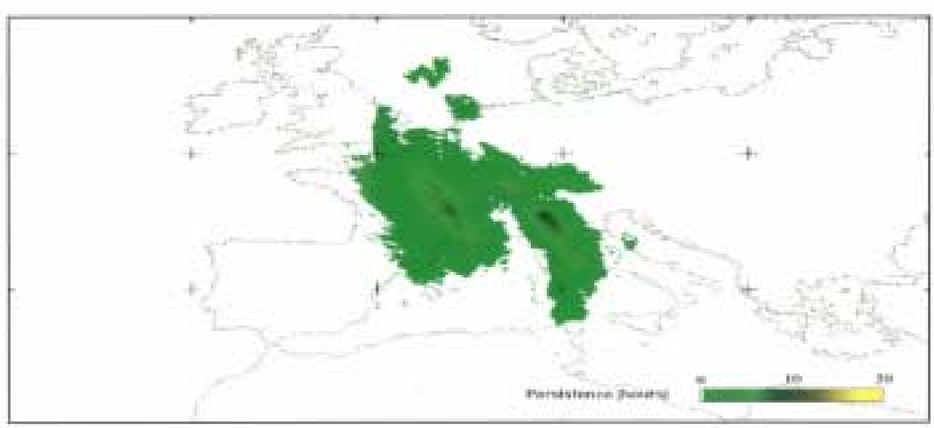
At about 15:30 GMT, convective clouds again developed over South-West France and extended progressively to the entire Western part of France. Even this second convective cloud area was characterized by quite a rapid evolution. The continuous contribution of warm air provided by the African airflow generated a third area of convective activity around 21:30 - 22:00 GMT of Nov. 4^{th}, over the Pyrenees. The area extended rapidly concerning progressively southern, central and northern France, until the early morning of Nov. 5th. During this period, the frontal system, embedding various smaller areas with deep convective activity displaced very slowly toward the East. Northern Italy was progressively concerned by the front since the late morning of the same day. In the afternoon the frontal system reached Northwest Italy and the Sardinia and Corsica islands, thus generating convective activity over these areas. During the night time, the Eastern deep high sank down and the front was advected by the Atlantic currents toward the Adriatic sea and central Europe in the morning of Nov. 6th.

Relatively warm precipitating clouds, as identified in the sequence of METEOSAT images persisted several hours above the upper Po river basin, starting on the late morning of Nov. 5^{th}, and for a large part of the next day while isolated convective cells developed embedded within the front. These observations are confirmed by ground based measurements and a fairly good correspondence was found between the persistence of the observed precipitating clouds over the area of interest and that of the rain during Nov. 5th and 6th (Boni et al., 1996).

The event of Nov. 1994 presents quite peculiar characteristics because of the presence of a stable high pressure centre over the Carpatian area, reducing the eastward advection of the frontal system. The sequence of METEOSAT images shows that the cloud coverage was quite persistent over the investigated area but the coldest cloud coverage corresponding to the maximum probability of intense precipitation presented quite a rapid evolution (low persistence). Figure 4 shows the persistence of the whole cloud system embedding convective clouds for the case of the Nov.1994 event: yellow to red areas are associated with the highest persistence values, i.e. the larger values of the rainfall depth. In Fig.4b, the area covered by clouds with top temperatures above 253 °K (namely the part of the cloud system where convection mainly develops) is depicted for the whole event duration. The zones corresponding to the Piemonte region, where major floods occurred, do not present a very high degree of persistence in time of convective clouds since the rainfall was mainly of stratiform origins. In Fig.4a, the same elaboration is shown with a threshold at 235 °K so as to show the persistence of significant clouds over the area.



(a)



(b)

Figure 4. Total area coverage of the cloud system for the event of Sept.27-28th shown as a cumulative parameter from 01.30 GMT of Sept.27th to 22.30 GMT of Sept. 28th with (a) a threshold at 253°K for identification of significant clouds and (b) at 235°K for identification of the deeply convective portion of the cloud system only.

Comparing the persistence in time of the convective clouds with the cumulative values of the persistence of the whole cloud system, the features of the events described above are easily distinguishable (Boni *et al.* 1995). In the November 1994 event, which produced floods over large size catchments in northern Italy, high persistence and high values of the radiance temperatures are indeed observed.

5. CONCLUDING REMARKS AND RESEARCH PERSECTIVES

The development of operational tools for reliable prediction of heavy rainfall patterns over the Mediterranean region at the time scales of interest for small to medium size catchments still deserve additional experimental evidence.

Most of the available applications of some interdisciplinary approach to the analysis of severe storm events over the Mediterranean area (e.g. Llasat et al., 1994; Castelli and Lanza, 1994) relate to individual cases, where the relative contributions of different triggering mechanisms at the synoptic scale are not easily detectable against the contribution of possible local enhancing factors. On the other hand, typical meteorological scenarios that are likely to produce heavy rainfall of convective origins do present some common features and quite similar behaviours (Llasat and Puigcerver, 1994) and call for a wider investigation over a set of suitable case studies.

A larger number of experimental records of space and time histories of rainfall intensities is also required, provided they are measured with coherent scales and methodologies. The investigation of further case studies is expected to provide a better understanding of the typical dynamic characteristics of different kinds of extreme meteorological events. The use of cloud tracking techniques using satellite derived cloud parameters has been shown to increase the understanding of the overall dynamics of the observed events in the diagnosis stage. The development of prediction techniques based on such improved understanding - as well as on coupled physically- based models of the atmosphere - will possibly lead to a wider use of satellite imagery resources in the operational context.

However, integrated multisensor systems hold the best compromise between the remote perception of the large scale cloud dynamics and the need for accurate forecasting of the small scale variability of the rainfall field and its unresolved internal structure. The latter is crucial for predicting critical flood conditions at some river section of interest when small and medium size catchments (10-100 km^2) are concerned. Monitoring tools and simulation techniques that are developed for operating - and thus provide some process interpretation at different space and time scales - need to be properly integrated when the support of remote sensing is invoked.

The present paper was written in the spirit of encouraging *a posteriori* multisensor analyses of observed heavy rainfall events so as to explore the potential of a real time operational integrated system for the Mediterranean area. The *a posteriori* analysis methodology provides a useful background for the identification of the pattern of future events using the information obtained from the whole set of available data sources, even in the framework of a real-time flood forecasting procedure.

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