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The "Perfect Storm": From Across the Atlantic to the Hills of Genoa

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The city of Genoa, Italy, nestled between the Tyrrhenian Sea and the Apennine Mountains, was rocked by severe flash floods on 4 November 2011. About 500 millimeters of rain—a third of the average annual rainfall—fell in 6 hours, killing six people and devastating the city center. A storm of this intensity is considered to be a multicentennial-return-period event. The torrential rainfall inflicted the worst disaster Genoa has experienced since October 1970, when a similar event killed 25 people. The peculiar fine-scale properties of this event motivate a comprehensive research effort in the field of predictability of severe rainfall processes over areas of complex orography.

The Meteorological System Responsible for Flash Flooding

The synoptic-scale meteorological system responsible for the Genoa flash flood raged from West Virginia to Maine in the United States from 29 to 30 October and was blamed for at least 13 deaths. It moved across the Atlantic Ocean, generated floods that killed five people in southern France, and finally arrived over the Ligurian Sea and produced an extreme storm over the Genoa hills.

Several factors came together to produce the storm. An upper level cold low centered northwest of Ireland extended south to the Iberian Peninsula. A diffluent southwesterly flow over the Ligurian Apennines ridge at 500 hectopascals, accompanied by a southeasterly flow from below, supported a pronounced moist air advection from the subtropical Mediterranean areas near Africa. A strong pressure ridge centered on eastern Europe acted as a block to the motion of this system, which also encountered an anomalously warm western Mediterranean Sea (Figure 1), increasing the potential severity of the cyclone by strongly moistening the low-level troposphere. The sea surface temperature (SST) anomaly was determined to be 1°–1.25°C using the Global 1-km Sea Surface Temperature (G1SST) data set produced daily by the Jet Propulsion Laboratory Regional Ocean Modeling System (ROMS) and the SST National Research Council (CNR) MED data set distributed by the Global Monitoring for Environment and Security (GMES) MyOcean project.

Fine-Grained Structure

The large-scale features of the event were well predicted at the regional scale by the Liguria Office for Civil Protection, which issued a warning 48 hours in advance, on 2 November, with the maximum alert level. However, discrimination and focus on catchments that would receive the most rainfall were not possible because of the unusually intense small-scale structure of the storm.

The most intense period of the event occurred between 09:00 and 15:00 UTC on 4 November. The rainfall peak, observed by a private weather station, was about 500 millimeters in 6 hours (Figure 2), on top of a small urban catchment (5 square kilometers). The minor creek had a terrible flash flood, which peaked at 40–45 cubic meters per second per square kilometer. The small space-time

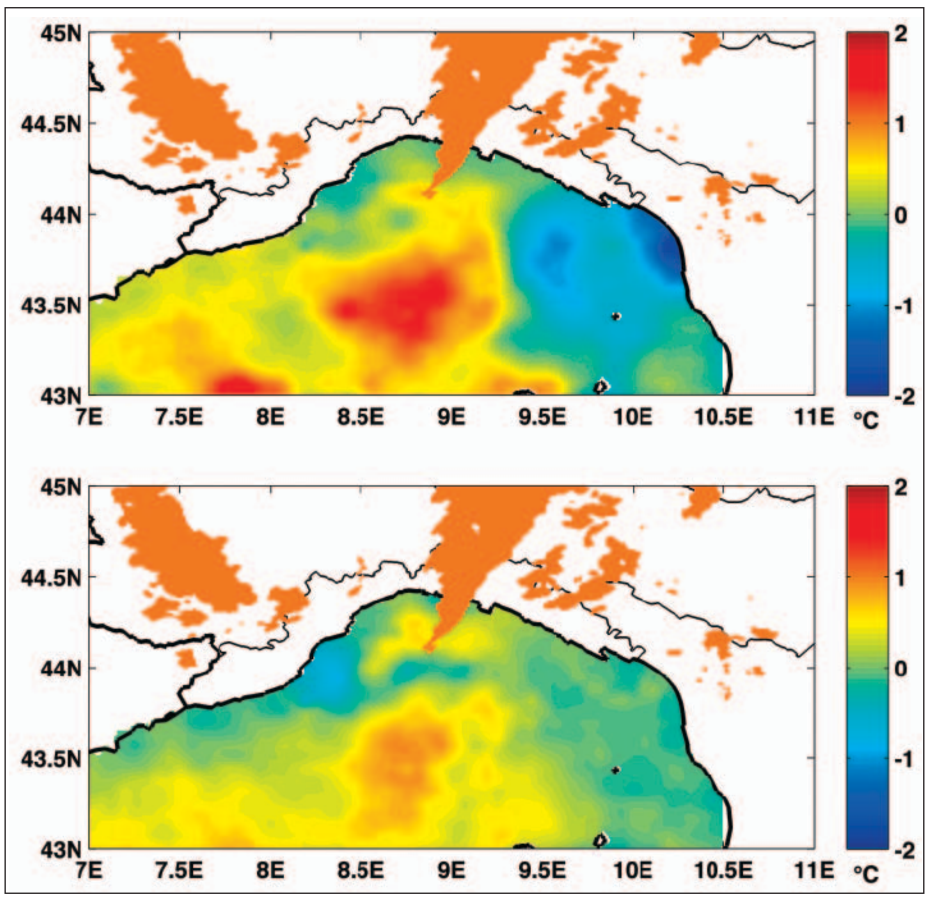

Fig. 1. Reflectivity footprint of the precipitation structures for the 4 November 2011 storm. The orange areas represent the pixels with reflectivity values larger than 25 dBZ (measured by the Italian radar mosaic, 4 November at 11:00 UTC). Sea surface temperature anomaly measured by (top) the Global 1-km Sea Surface Temperature data set (G1SST) and (bottom) the Global Monitoring for Environment and Security (GMES) MyOcean project.

variability of the event was amazing: A weather station belonging to the Liguria regional network, located 2 kilometers from the private one at the storm center, observed in the same period only 300 millimeters of rainfall (see Figure 2 inset), roughly half of the amount observed at the storm's center.

An initial understanding of such fine-grained structure can be obtained through the visual inspection of its region of intense radar reflectivity (greater than 25 decibels relative to *Z* (dBZ, a meteorological measure of reflectivity; higher reflectivity indicates increased precipitation intensity); Figure 1): A finger-like isolated and autoregenerating convective cell was triggered in the Gulf of Genoa on the night of 4 November (01:00–02:00 UTC). The convective cell started wandering along the eastern coast of Liguria and finally became stuck over the western hills of Genoa, producing the torrential rainfalls. Such finger-like convective structures were also observed in other recent disastrous flash flood events that occurred in Liguria on 4 October 2010 and 25 October 2011.

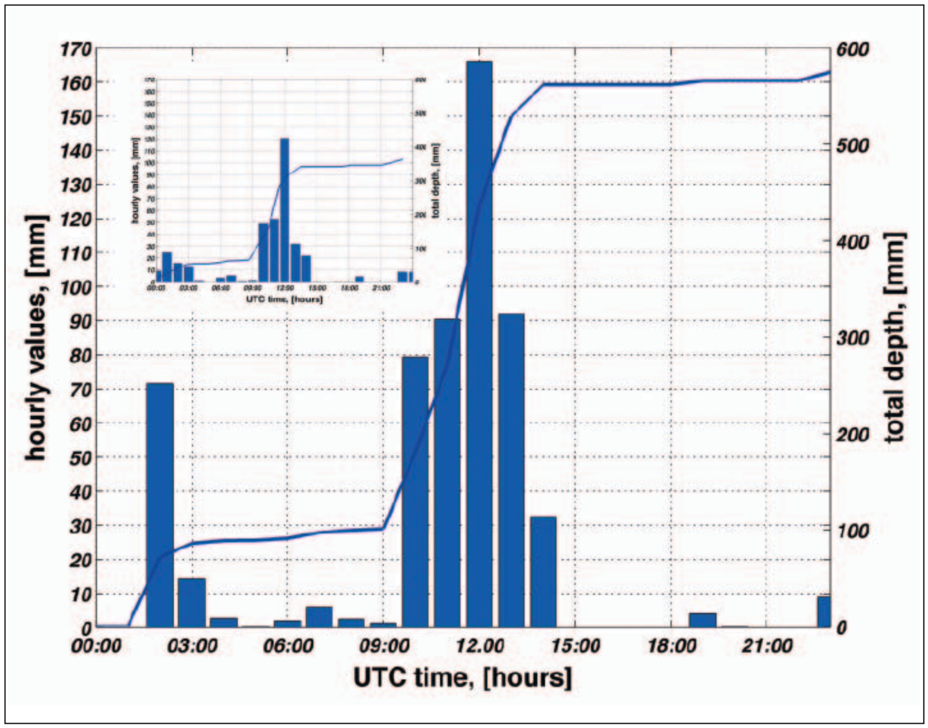

Fig. 2. Rainfall data for 4 November 2011 from a private weather station located at the Genoa city center, courtesy of the Liguria Meteorology Association (LIMET). Inset shows data from a regional weather station located 2 kilometers from the private weather station that measured peak rainfall, courtesy of ARPAL.

Future Research Needs

Together, these observations challenge current scientific understanding of severe hydrometeorological processes and demonstrate the need for focused hydrometeorological research to (1) understand, explain, and predict the physical processes producing such extreme storms; (2) understand the possible intensification of such events in the Mediterranean region and their physical origin; and (3) explore the potential of the increasing computational power and information and communication technology, such as grid computing and petascale computing systems, to provide deeper understanding of those events through fine-resolution modeling over large areal extents.

To tackle these scientific challenges, the International Centre on Environmental Monitoring (CIMA) Research Foundation, the Regional Agency for the Liguria Environment Protection (ARPAL), and the Italian Civil Protection Department will provide to the international community (solely for research purposes) access to the observational and modeling data on this case study, as well as data of the event that occurred on 25 October in eastern Liguria. Access will be granted in cooperation with the Hydrological Cycle in the Mediterranean Experiment (HyMeX; http://www.hymex.org) and the Distributed Research Infrastructure for Hydro-Meteorology (DRIHM; http://www.drihm.eu) research projects, which are funded by the European Commission.

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