TOWARDS HIGH-PRECISION FLOOD MAPPING: MULTI-TEMPORAL SAR/INSAR DATA, BAYESIAN INFERENCE, AND HYDROLOGIC MODELING

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1. INTRODUCTION

High-resolution flood mapping is an essential step in the monitoring and prevention of inundation hazard, both to gain insight into the processes involved in the generation of flooding events, and from the practical point of view of the precise assessment of inundated areas, useful e.g. in the case of post-event recovery and insurance indemnity assessments. Synthetic Aperture Radar (SAR) data present several favourable characteristics for flood mapping, such as their relative insensitivity to the meteorological conditions during acquisitions, thanks to the use of microwaves as sensing radiation, as well as the possibility of acquiring imagery independently of solar illumination, thanks to the active nature of the radar sensors. The Italian COSMO-SkyMed (CSK) SAR constellation is particularly useful in this respect, because it allows image sequences of flooding events to be built up with short revisit times. The acquisition of several images before, during and after the event often allow a reconstruction of the flooding dynamics. Moreover, they help in interpreting the backscatter signatures of different land cover types, reducing uncertainties about the actual presence of water, which can be seriously misleading, especially over agricultural areas [1, 2]. Finally, when acquisitions are made from the same geometry, with short repeat intervals, SAR interferometry (InSAR) observables, such as the coherence or the differential InSAR phase can be exploited as additional information layers. The favorable characteristics of these next-generation sensors have been exploited by a number of researchers worldwide [3, 4, 5] to improve performances of flood mapping approaches. Recently, our group [6, 2] has used high-resolution CSK radar images for flood mapping exploiting both the intensity and the interferometric coherence, with promising results. Nevertheless, additional information can be used to improve flood detection. In case of flooding, distance from the river, terrain elevation, hydrologic information or some combination of these data can add useful information that leads to a better performance in flood detection.

2. DATA AND METHODS

We work on a test area including selected reaches in the Basilicata floodplain (southern Italy, see Fig. 1). We analyze COSMO-SkyMed data related to three consecutive flood events occurred respectively in November 2010, February 2011, and December 2013, for which several interferometric SAR pairs were available over the Bradano and Basento rivers, together with other SAR scenes acquired at times close to the events in the same acquisition geometry (see baseline plots at the top-right of Fig. 1). Plots of the Bradano river levels for the three events are also reported at the bottom right of Fig. 1. The river floodplains are generally characterized by mainly agricultural land cover, with cereal and vegetable crops or fruit shrubs, while an extended area near the river mouths and along the coast is occupied by pine forest stands [7]. Each flood event caused large areas of the floodplains to be inundated at different times, with different modes and temporal evolution.

The data were processed interferometrically using state of the art InSAR software tools [8], filtered through nonlocal complex filtering techniques [9], and precisely geocoded. We generate spatial inundation maps using SAR amplitude and InSAR coherence data. We interpret change backscatter signatures of different land cover types using a Bayesian network approach [10, 11], which helps in discriminating statistical (in)dependence between the variables involved, potentially connected to the presence of water. The Bayesian approach allows to elegantly formalize the contribution of the various information layers, including maps coming from external sources, such as flood models, which can be shown to help considerably in the effective delineation of inundated areas. Traditionally, in fact, the estimate of the probability that an area is inundated following an extreme meteorological event is made through use of more or less sophisticated hydraulic models (1-D, 2-D, 3-D). 2-D models show a good tradeoff between simplicity and computational efficiency [12]. Maps derived from simulation of events, based on the solution of flow equations starting from available gauge level data, and exploiting high-resolution elevation and land cover maps, can be used either as an independent reference for the posterior assessment of satellite-derived maps, or integrated within the flood mapping procedure, as a priori information layers restricting the occurrence of flooded fields to areas characterized by higher probability of getting flooded. Such areas are typically those at short flow distances from the river network. Simplified indicators based on morphological indices [13] can be also used in these cases.

Several BN processing schemes were applied to the data, focusing on each of the single events to track the spatial distribution of inundated fields, as well as the temporal evolution of the phenomena [10, 11]. They encode independence assumptions between different variables, allowing the joint distribution of all variables to be written down tractably. In particular, we want to infer the value of the conditional probability of the variable F, that is discrete and consists of only two states: flood and no flood, so that $P(F=\text{flood}) = 1 - P(F=\text{no flood})$. The BN architectures used in various experiments determine how we choose to write the final $p(F)$ as a function of the SAR data and the ancillary information. Two examples are shown in Fig. 2. The first scheme, depicted in Fig. 2-a, combines information extracted by a set of SAR intensity and coherence images (g), and some ancillary information about a

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