Operational Earthquake Forecasting in Italy: perspectives and the role of CSEP activities

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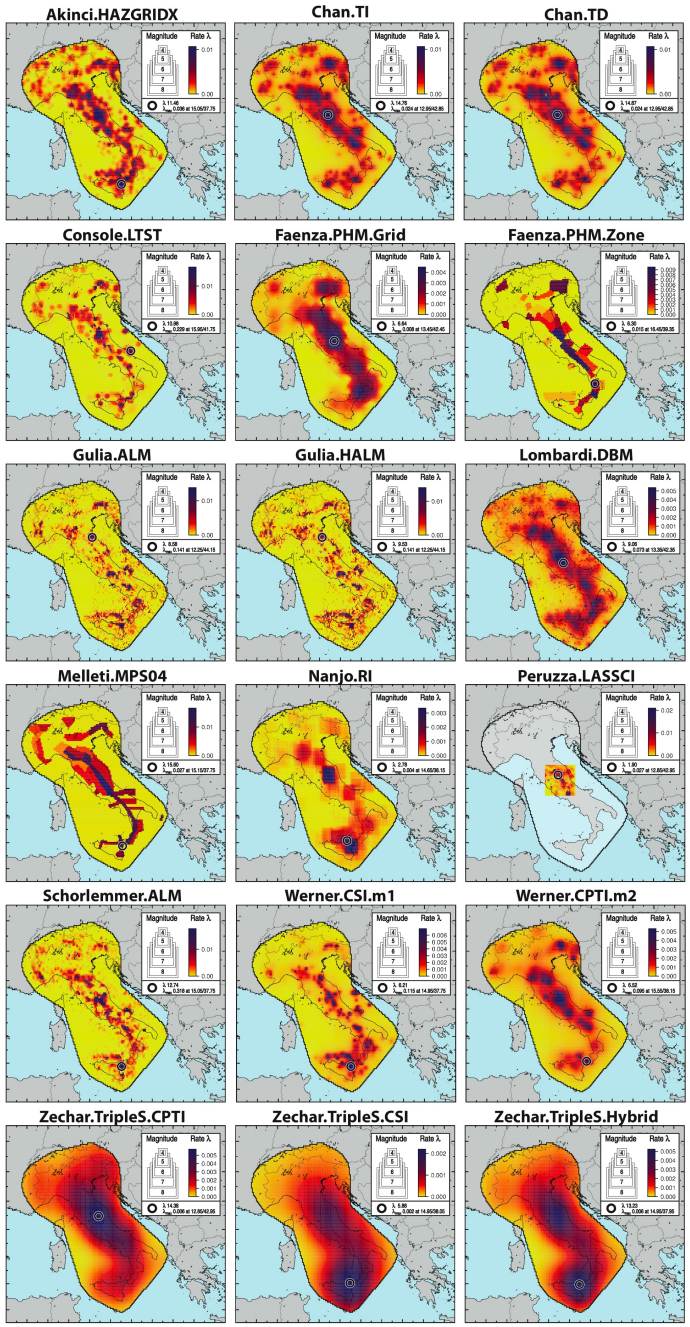


The CSEP experiment in Italy

- August 1, 2009, a CSEP experiment in Italy started
- EU testing center is at ETH Zurich
- First testing region in EU is Italy
- 18 *five-ten years* forecasting models have been submitted (M 5+)
- 5 *three-months* models (M 4+)
- 5 *one-day* models (M 4+)

The CSEP experiment in Italy

- Each model submitted for earthquake forecasting in the Italian testing region run in the CSEP EU Testing Center at ETH Zurich for the predefined time of the experiment. Models cannot be withdrawn from the test without the agreement of the board of directors of the CSEP EU Testing Center.

- The forecasts must be based on a predefined spatial grid with 0.1 deg spacing. Each forecast consists of a seismicity rate for each magnitude bin in each cell and the defined time window; it is assumed a Poisson distribution for the number of events. Only earthquakes with depth less than 30 km are considered.

- Masking of areas and magnitudes is allowed; a model has to provide forecast for the whole area and all magnitude bins; however, it can mask a subset of bins to limit the area and magnitudes for which the model is considered valid. This subset will be tested separately.

The CSEP experiment in Italy

- The following testing classes are defined for the Italian testing region:
  - 5- and 10-year models: These models define a forecast rate for each magnitude bin in the range M5-9 (0.1 magnitude unit steps) for the period 1 April 2009 to 1 April 2014 and 1 April 2019. The forecasted rates at each bin must be received by the testing center before 1 April 2009.
  - 3-months model. These models define a forecast rate for each magnitude bin in the range M5-9 (0.1 magnitude unit steps) for consecutive 3-month periods (starting at midnight UTC of 1 January 1 April, 1 July, and 1 October). Models must be implemented at the CSEP EU Testing Center as code that can independently and automatically compute forecast rates, based on predefined authoritative input data.
  - 1-day forecasts. These models define a forecast rate for each magnitude bin in the range M4-9 (0.1 magnitude units steps) for consecutive 1-day periods starting at midnight UTC. Models must be implemented at the CSEP EU Testing Center as code that can independently and automatically compute the forecast rates, based on predefined authoritative input data.

The CSEP experiment in Italy

- The testing center will not distribute the codes supplied; however, in the interest of advancing the science of earthquake forecasting, open-source codes are highly preferable. In the event that the codes cannot be made open source, the testing center and modeler will work on a case-by-case basis on finding a solution that fits the needs of both sides. In any case, the board of directors will decide which models to include on the basis of scientific publications or reports. For the long-term testing class (5/10 years forecast and M5-9), numerical tables in ForecastML format (template can be downloaded at eu.cseptesting.org) containing the forecasts will be accepted.

- The official bulletin for future earthquakes that will be used for evaluation of the forecasts is the INGV bulletin; the reliability of the bulletin in terms of homogeneity and spatio-temporal completeness has been checked since 16 April 2005 (see www.completenessweb.org). The INGV ML magnitude scale will be considered the reference scale for model development and testing. No declustering will be applied to the observations.

Operational Earthquake Forecasting is the process of providing communities with authoritative information about the time dependence of seismic hazard that can be used for decision-making

(International Commission on Earthquake Forecasting for Civil Protection, 2009; Jordan et al., 2011)

ICEF Findings & Recommendations

- Development of Operational Earthquake Forecasting capability
  - Scientists need to assess hazard at different time scales

    Recommendation: "DPC should support development of earthquake forecasting methods based on seismicity changes to quantify short-term probability variations."

  - **Authoritative** models require testing

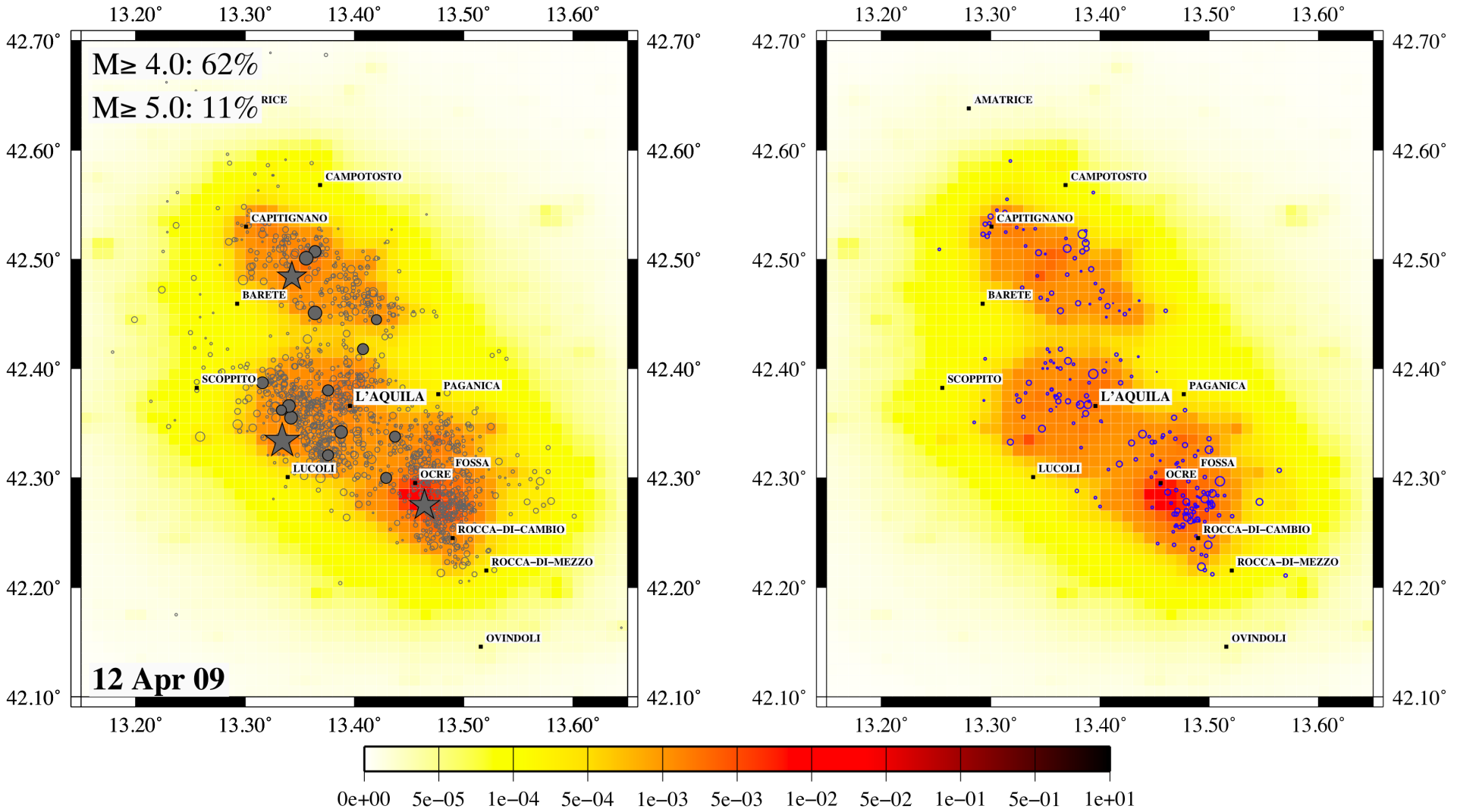
    Recommendation: Forecasting methods intended for operational use should be scientifically tested against the available data for reliability and skill, both retrospectively and prospectively. All operational models should be under continuous prospective testing.

    Recommendation: The international infrastructure being developed to test earthquake forecasting methods prospectively should be used as a tool for validating the forecasting models for Italy.

OEF in Italy: L'Aquila aftershocks

The 1-day forecasts *(the palette represents the rate of M 4+)*

Daily forecasts released at 8:00 AM (no overlaps)

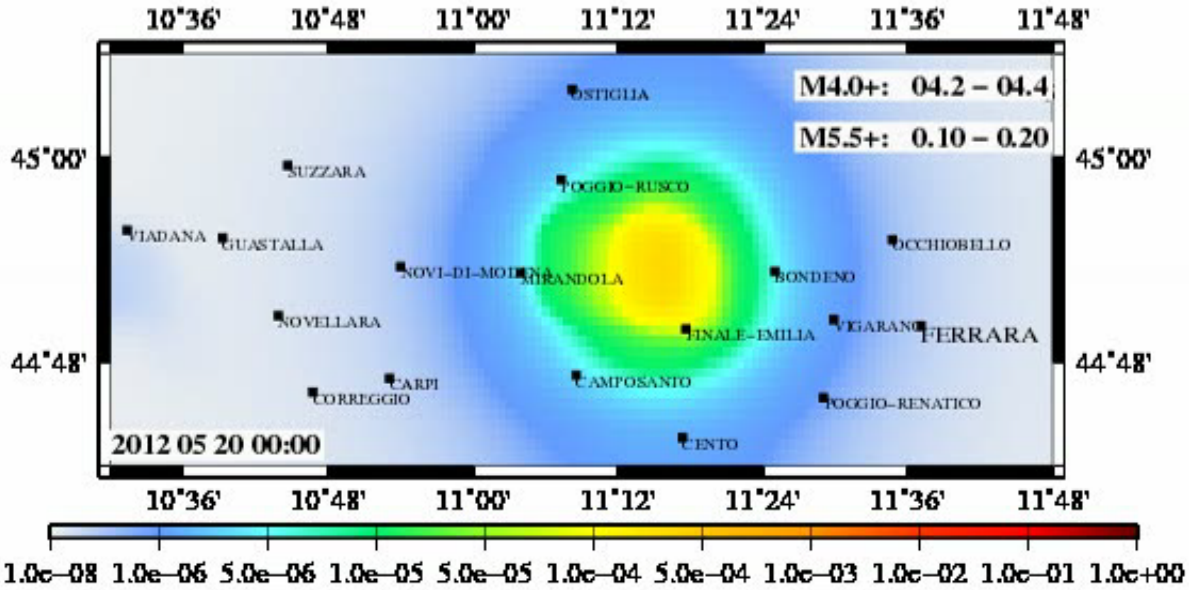


OEF in Italy: Emilia 2012 aftershocks

The 1-day forecast since May 19
(2 independent models: **Lombardi-Marzocchi** & **Murru-Console-Falcone**)

Background probability for M4+= 0.007%
Probability gain on May 19= about 500
Probability gain on May 28= about 5000

The plot shows the expected density of events with M 4+ per km^2



In January 2013, INGV established a Center for Seismic Hazard (Centro di Pericolosità Sismica, CPS)
Coordinators: W. Marzocchi, C. Meletti

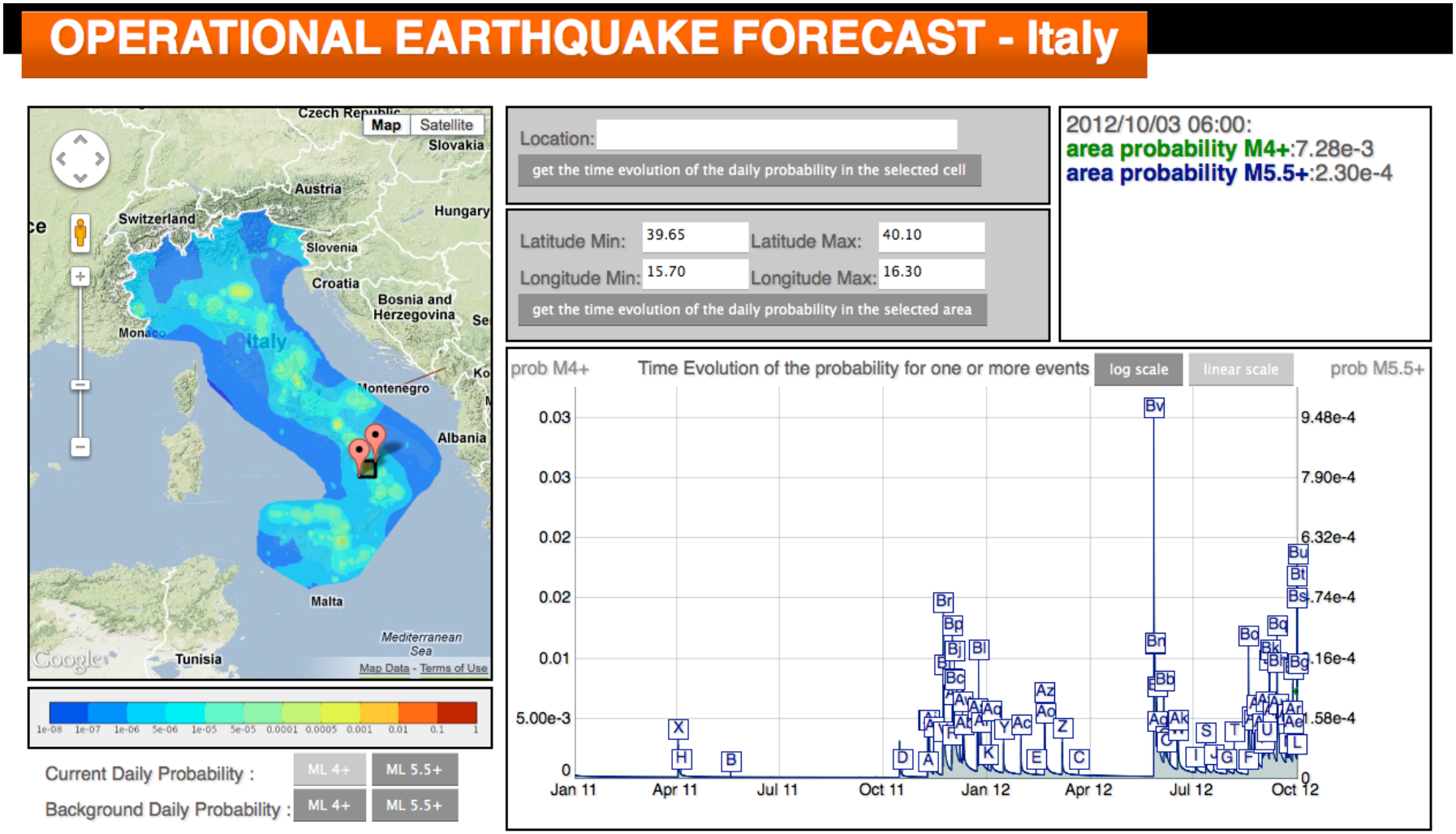
CPS goals:

1. to promote innovative reasearches for seismic hazard

2. to provide authoritative seismic hazard assessment at different time scales: long-term (50 years), mid-term (5-10 years), short-term (1-7 days).

OEF in Italy: Cassandra

CASSANDRA v01: the example of the recent seismic sequence @ Pollino



Evolution of the daily probability with time for the selected area

OEF in Italy: Cassandra

ANNALS OF GEOPHYSICS, 53, 3, 2010; doi: 10.4401/ag-4848

The ETAS model for daily forecasting of Italian seismicity in the CSEP experiment

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Subject classification:
Earthquake probability, Forecasting, Italian seismicity, Hypothesis test, Aftershocks.

ABSTRACT

This study investigates the basic properties of the recent shallow seismicity in Italy, through stochastic modeling and statistical methods. Assuming that earthquakes are the realization of a stochastic point process, we have modeled the occurrence rate density in space, time and magnitude using an epidemic-type aftershock sequence model. By applying the maximum likelihood procedure, we estimated the parameters of the model that best fit the Italian instrumental catalog, as recorded by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) from April 16, 2005, to June 1, 2009. Then we applied the estimated model to a second independent dataset (June 1, 2009, to September 1, 2009). We show that the model performed well on this second database, through the relevant statistical tests. The model proposed

ANNALS OF GEOPHYSICS, 53, 3, 2010; doi: 10.4401/ag-4812

Building self-consistent, short-term earthquake probability (STEP) models: improved strategies and calibration procedures

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Subject classification:
Earthquake statistics, Earthquake forecasting, Likelihood testing, Aftershock model, Seismicity analysis.

ABSTRACT

We present two self-consistent implementations of a short-term earthquake probability (STEP) model that produces daily seismicity forecasts for the area of the Italian national seismic network. Both implementations combine a time-varying and a time-invariant contribution, for which we

frameworks such as epidemic type aftershock sequence (ETAS) models and short-term earthquake probability (STEP) models are used for automated, near-real-time applications [e.g., Console et al. 2003, Gerstenberger et al. 2005, Helmstetter et al. 2006, Marzocchi and Lombardi 2008]. Both of these frameworks can adapt to ongoing earthquake sequences by re-estimating model parameter values and automatically generating forecasts that account for the most recent seismicity. Physics-based models that combine calculations of stress changes with a rate-and-state friction

ANNALS OF GEOPHYSICS, 53, 3, 2010; doi: 10.4401/ag-4760

Short-term and long-term earthquake occurrence models for Italy: ETES, ERS and LTST

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Subject classification:
Earthquake interactions and probability, Statistical analysis, Stress, Historical seismology, Earthquake faults.

ABSTRACT

This study describes three earthquake occurrence models as applied to the whole Italian territory, to assess the occurrence probabilities of future ($M \geq 5.0$) earthquakes: two as short-term (24 hour) models, and one as long-term (5 and 10 years). The first model for short-term forecasts is a purely stochastic epidemic type earthquake sequence (ETES) model. The second short-term model is an epidemic rate-state (ERS) forecast based on a model that is physically constrained by the application to the earthquake clustering of the Dieterich rate-state constitutive law. The third forecast is based on a long-term stress transfer (LTST) model that considers the perturbations of earthquake probability for interacting faults by static Coulomb stress changes. These models have been submitted to the Collaboratory for the Study of Earthquake Predictability (CSEP) for forecast testing for Italy (ETH Zurich), and they were locked down to test their validity on real data in a future setting starting from August 1, 2009.

Helmstetter et al. 2006]. These models were proposed to answer the most common questions of the general public and the media that arise in particular after sizable events, such as, «What will happen next?» and, «What is the chance that another large earthquake will occur?».

Stochastic short-term models describe seismicity as a random point-process, for which a continuous space-time density distribution of the earthquake occurrence can be defined. A best-fit procedure based on the maximum likelihood criterion has been used for statistical analysis of random processes. In particular, Kagan and Knopoff [1976, 1987], Kagan [1991], Ogata [1999], Kagan and Jackson [2000], Console and Murru [2001], Imoto [2004], Rhoades and Evison [2006], and Helmstetter et al. [2006] have applied the

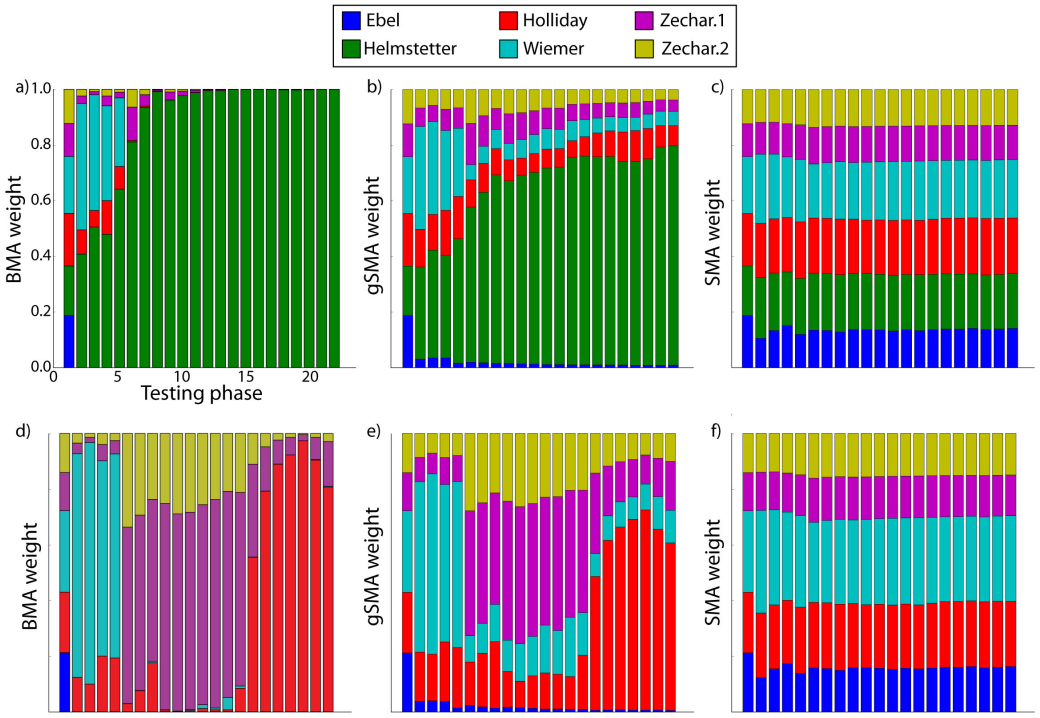
ENSEMBLE forecasting model. Each model is weighted according to its forecasting performances

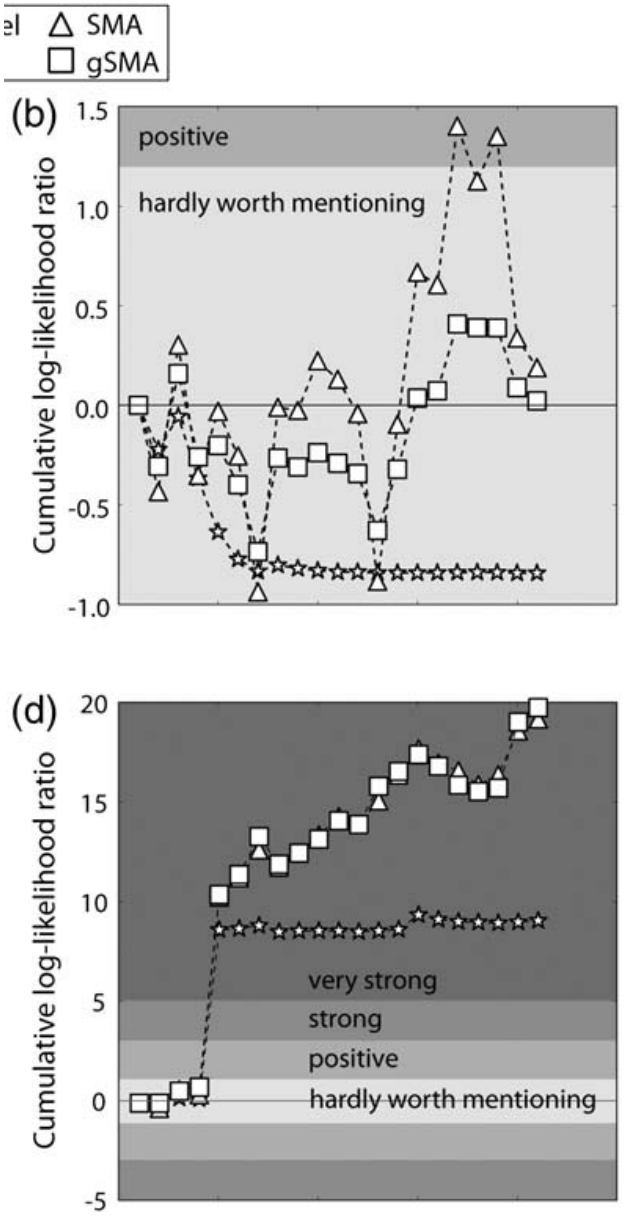
Selected models (constraints)

- They must be submitted to at least one CSEP experiment earthquake

OEF in Italy: Cassandra

Marzocchi, Zechar, Jordan, BSSA, 2012
RELM/CSEP experiment.
Forecasting time window: 5 years
Target earthquakes: M5+



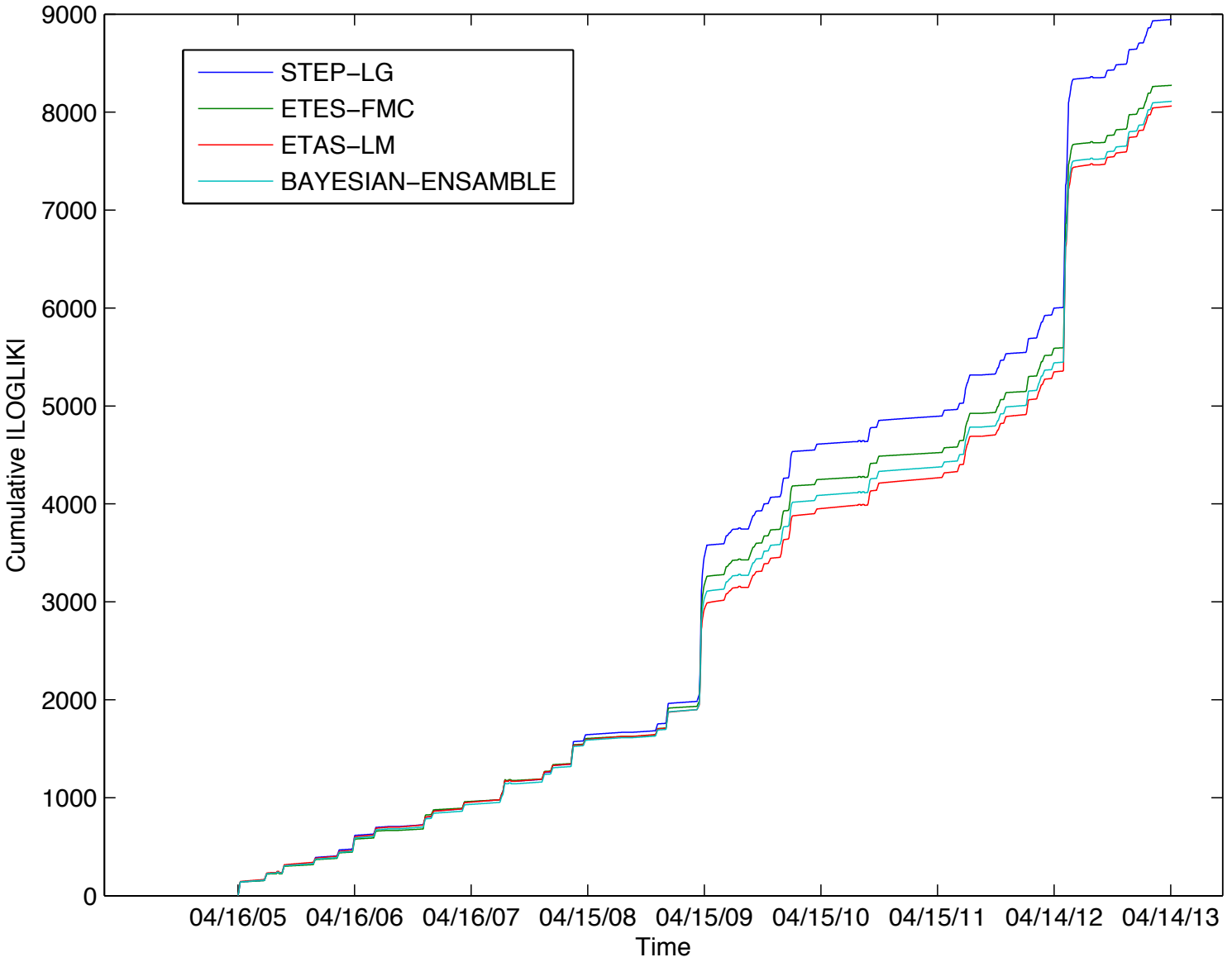


CSEP global test (Taroni, Zechar, Marzocchi, 2013, in preparation)

2009	2010	2011	2012
EM: -451.5	**P2PGMA: -513.6**	**P2PGMA: -469.2**	**P2PGMA: -419.5**
DBM: -507.9	**SMA: -536.5**	**SMA: -478.0**	**SMA: -438.3**
TripleS: -1160	KJSS: -539.5	**BFMA: -482.0**	**BFMA: -449.6**
	BFMA: -584.8	TripleS: -483.1	**gSMA: -455.4**
	gSMA: -612.6	**gSMA: -484.8**	KJSS: -456.1
	DBM: -615.1	KJSS: -485.5	DBM: -502.7
	TripleS: -2649	DBM: -535.5	TripleS: -1119

Table 5. CSEP and Ensemble models ordered as a function of their cumulative log-likelihood for 2009, 2010, 2011 and 2012. For 2009 we have only one ensemble model (EM), because we do not have evaluations of the past models' performance, then TripleS and DBM have the same weight (50%) for each one of the four ensemble models. Bold character is for ensemble models.

Cumulative loglikelihood of three 1-day forecasting models (used to assign weights)



Ongoing... (to be finished before the end of 2013)

- Moving from earthquake occurrence to seismic hazard (in terms of shaking intensity)
  - Weekly probabilities (suggested by Civil Protection)
  - Which GMPE should be used? CSEP testing?
  - A communication/decision making protocol shared with Civil Protection (who has to say/do what)

- We are running tests on preliminary catalog
  - Any difference with CSEP tests?
  - We update the forecasts using overlapping time windows. How to perform tests? (and how to calculate weights?)

- Providing forecasts including epistemic uncertainties

Next challenges

- The consistency problem (evaluating the 'degree of consistency')

- How possibly incorporate 'predictions'