Quadtree grid for modelling and testing earthquake forecasts

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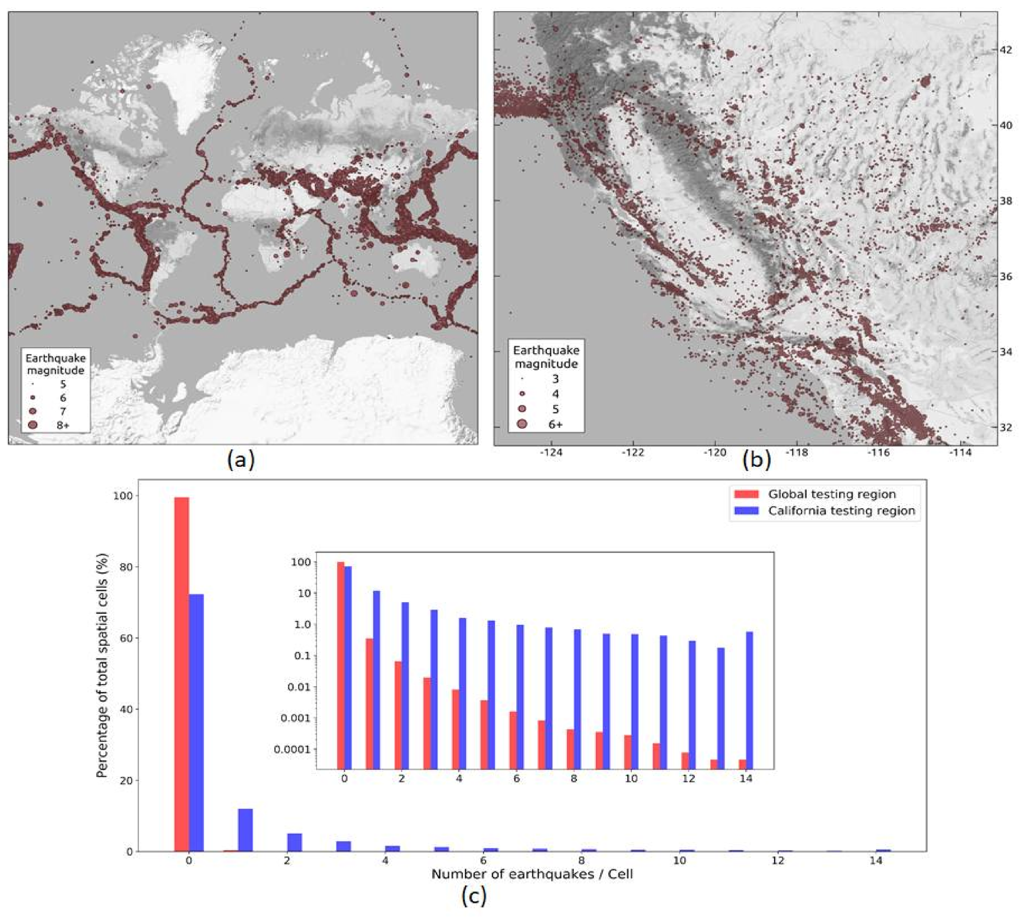
Abstract

The Collaboratory for the Study of Earthquake Predictability (CSEP) is an international effort to independently evaluate earthquake forecasting models. CSEP defines a grid-based format for expressing earthquake forecasts: the expected rate of earthquake occurrence within 0.1° x 0.1° spatial cells. This uniform gridding leads to 6.48 million spatial cells. The distribution of earthquakes around the globe is non-homogenous, resulting to approx. 99% of spatial cells containing no earthquake. This leads to an unjustifiably high-resolution grid in low-seismicity regions with an unnecessary computational burden. We propose a quadtree based multi-resolution grid, where resolution is determined by seismic density. Thus the number of cells in grid can be reduced from the order of millions to a few thousands. Most importantly, the quadtree offers ease of handling gridding process and compatibility with web mapping services for rendering the data.

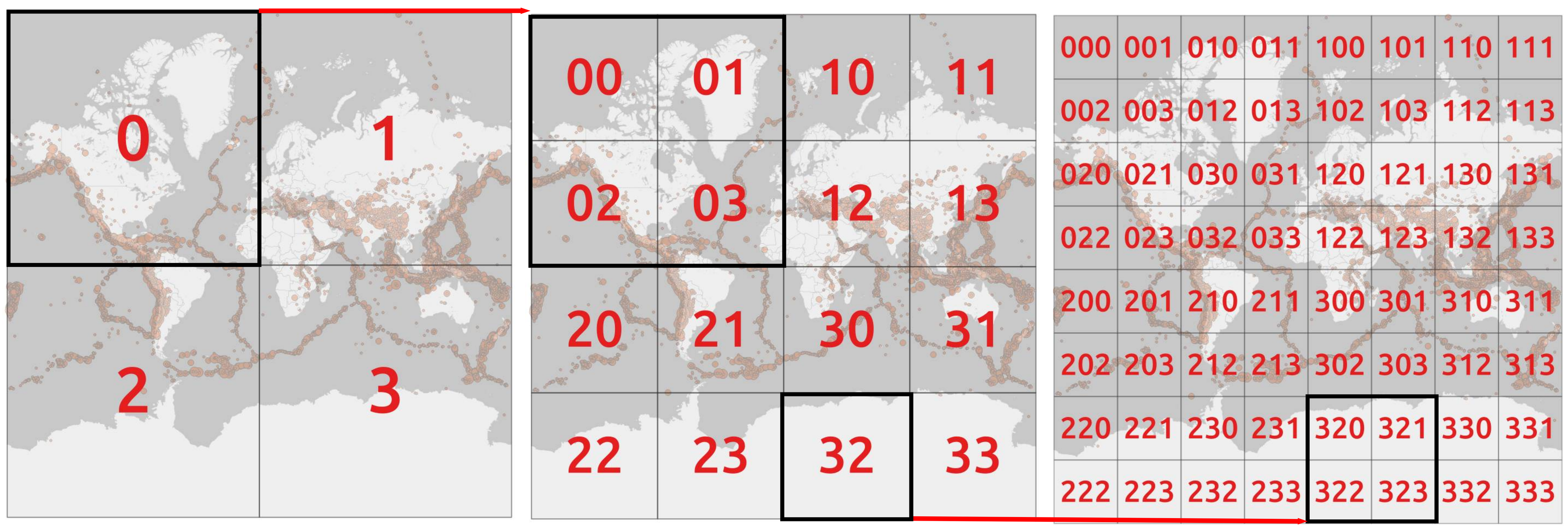


Non-homogenous distribution of earthquakes (a): M≥5.15, 1976-2013 (b): M≥2.5, 2000-2015 (c): Histogram of earthquakes/cell

Quadtree Grid

The quadtree is a hierarchical tiling strategy for storing and indexing geospatial data. It follows the Mercator projection in which the whole globe is divided into 4 squared tiles, represented by a unique identifier called quadkey: 0,1,2 and 3. Then each tile can be sub-divided into four children tiles, until a final desired grid is acquired. For example, the children of 3rd tile are identified as 20,21,22 and 23. The four children of any parent tile would divide the region into four non-overlapping sub-regions, thus making each tile unique in its representation of area on Earth. The total number of tiles in a single resolution quadtree grid are 4^L, where L is the number of times a tile has been divided (referred as zoom-level).

Quadtree approach is also being used by the mapping service providers such as OpenStreetMaps, Google maps and Bing maps. These mapping services use tile system to store and render global maps at different zoom-levels. Later on, these pre-rendered maps at different resolutions are used for efficient display and navigation. The quadtree grid does not include region beyond 85.05° North and South. All the maps shown here follow Mercator projection.

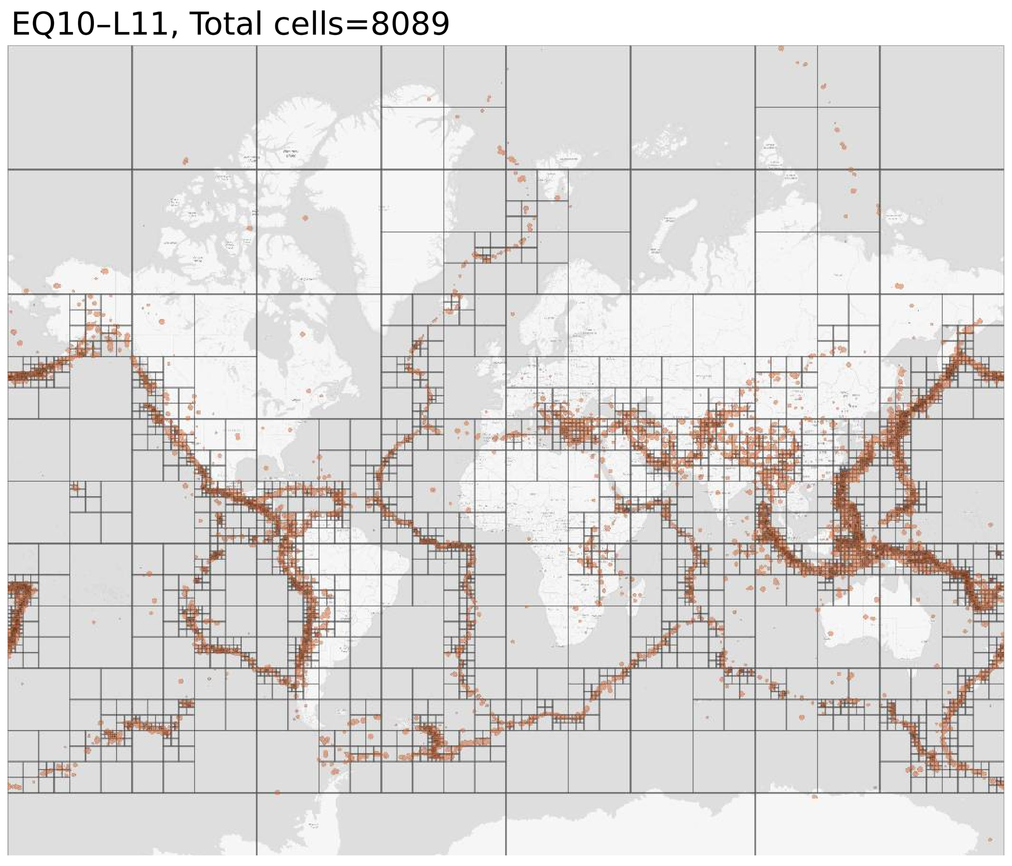


Recursive division of the globe into tiles from zoom-level 1 to 3

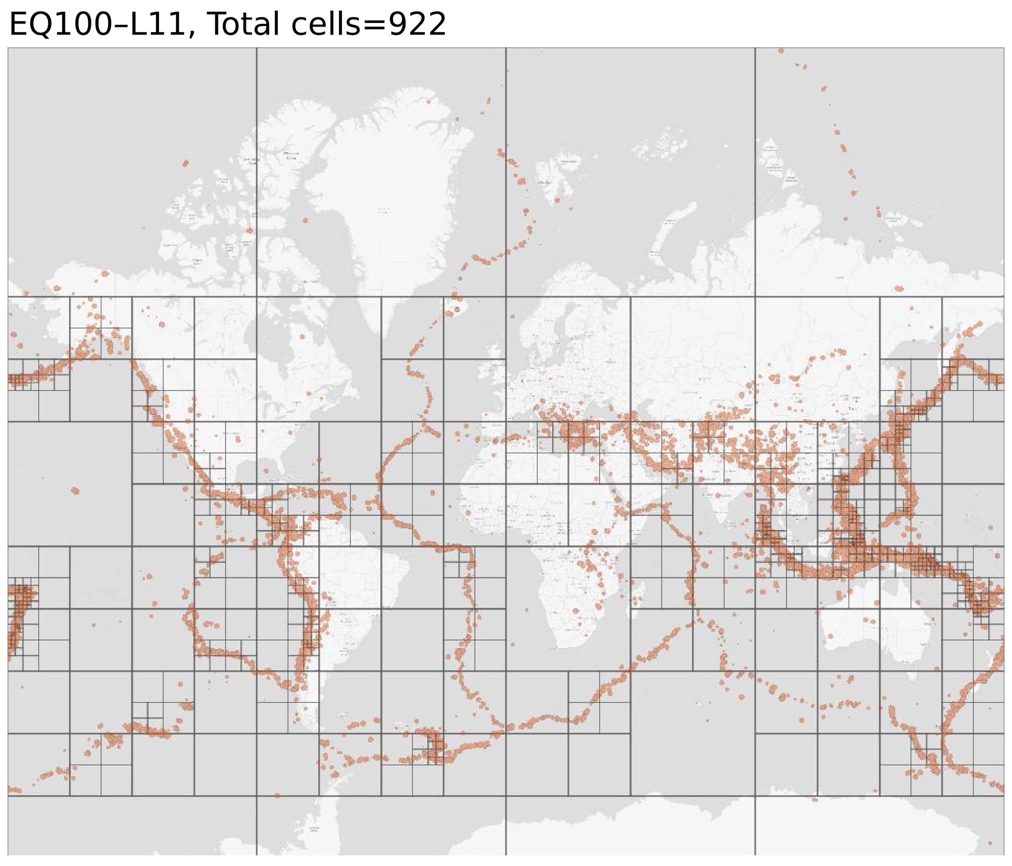
Multi-resolution Quadtree Grid

In multi-resolution grid, subdivision of a tile is driven by a criterion, e.g. maximum number of earthquakes allowed per cell (EQ). Thus, quadtree generates high-resolution (smaller) grid cells in seismically active regions and low-resolution (bigger) grid cells in seismically quiet regions. Multiple conditions can be employed to determine the grid resolution. For example, maximum allowed zoom-level (L) for a tile.

EQ10–L11, Total cells=8089



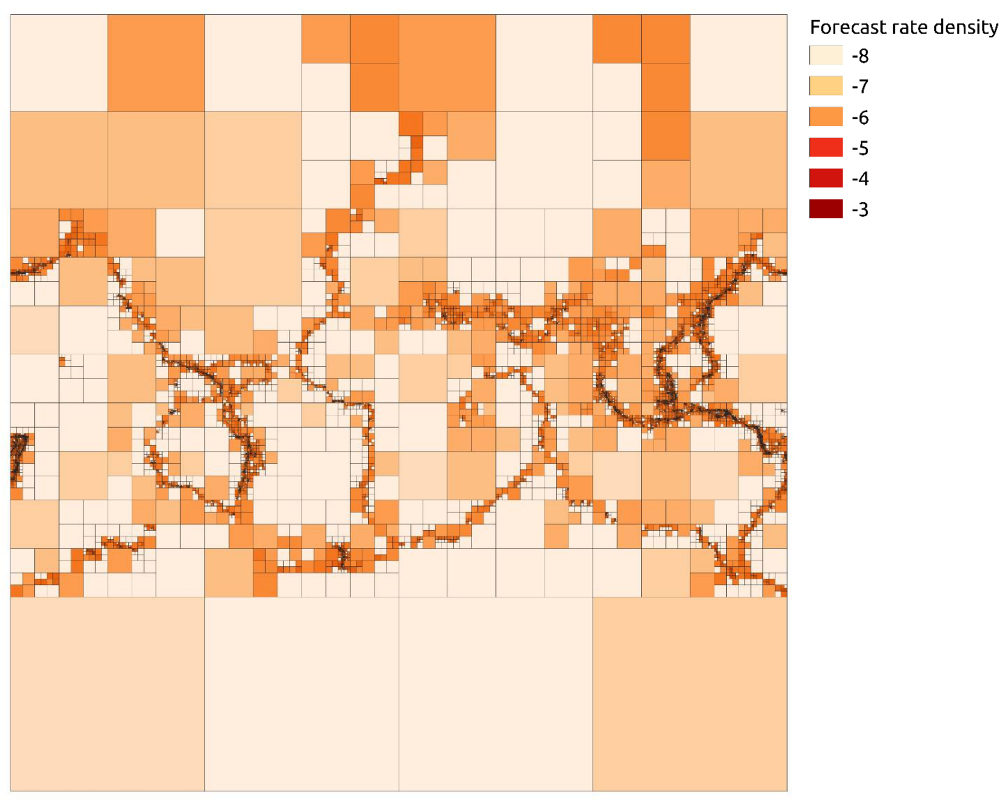
EQ100–L11, Total cells=922



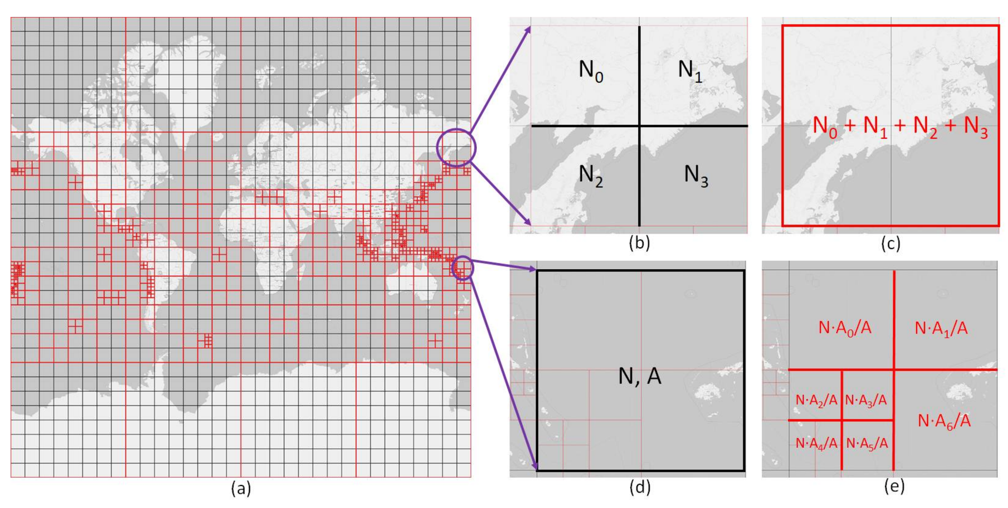
Multi-resolution grid acquired by using Global CMT Catalog (1976–2013, M ≥ 5.15, Total = 28456)

Forecast Testing and Comparison

Earthquake forecast should be acquired using a quadtree grid. A modeler has liberty to generate any quadtree grid based on the dataset available for training. But for comparing different forecasts with different quadtree grids, all the forecasts are first mapped to a single testing grid. If the forecast-rate of a cell is being mapped to bigger cell, then rates of all the corresponding smaller cells are summed up to get the forecast-rate for bigger cell of testing grid. Similarly, in the opposite case, the forecast is split into smaller target cells based on cell area.



Example forecast using quadtree grid EQ10L11



Forecast mapping from one grid to another for testing

References

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