Long-term temperature changes in the large Italian lakes: assessment of trends and impacts using long-term in situ and satellite-based data

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The deep lakes south of the Alps (Maggiore, Lugano, Como, Iseo and Garda) represent more than the 80% of surface freshwater resources in Italy. These lakes have been the object of many long-term studies, while the Lakes Garda, Maggiore and Como have been included in the LTER (Long-Term Ecological Research) network (www.lteritalia.it). The analysis of long-term data series recorded since 1971 in the whole water column at the time of maximum spring overturn allowed the increase in water temperature to be estimated at around 0.011–0.021 °C yr^{-1}, which was very close to the warming rate found in other large lakes in Europe and North America. Nevertheless, besides the long-term trend, the data were clearly characterized by short-term structures with a periodicity greater than 10 years, highlighting that information relevant to climate change in these types of water bodies need to be based on sufficiently long time series. Detailed (0-350) monthly measurements of water temperatures in Lake Garda were recorded since 1991 using underwater multiparametric probes. In the mixolimnion (0-50 m), mean water temperatures during the maximum stratification period (Jun-Sep) increased significantly since 1991. In the same period, the increase in the winter months (Jan-Mar) was statistically not-significant, coinciding, as confirmed by the 1971-2012 series, with a period of relatively winter/spring stable temperatures. The deeper layers (200-300 m) showed a long-term pattern characterized by gradual constant warming, interrupted by sudden cooling episodes and complete overturn (such as in 1999-2000, and 2004-2006). As shown very recently, these patterns were controlled by large scale atmospheric modes of variability over the Mediterranean area, such as the East Atlantic pattern (EA) and the Eastern Mediterranean Pattern (EMP). In turn, EA and EMP were shown to control multiple cascading effects in freshwater ecosystems, including the spring replenishment of nutrients and the development of summer toxic cyanobacteria. We have developed unique, original algorithms to gap-fill MODIS (Aqua and Terra satellites) LST (Lake Surface Temperature) data in order to derive high resolution daily temperature time series all over Europe. To overcome the problem due to cloud-contaminated images, incomplete daily LST maps were reconstructed by filling in no-data areas resulting from map filtering using a model-based approach. Preliminary analyses allowed to estimate long-term temporal trends evaluated on a daily basis. Moreover, analyses all over N-Italy showed a concordant pattern in the temporal development of temperatures in the largest lakes. Using high resolution spatial and time series from MODIS sensors on board the Aqua and Terra satellites in a GIS framework it was possible to obtain detailed temperature maps at the basin scale. This research field is open to innovative ideas and fresh perspectives.