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A high-resolution solar radiation atlas for the Trentino region in the Alps

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1 Introduction

Accurate estimates of the solar radiation available at the Earth's surface are essential for a wide range of renewable energy applications, as well as for the investigation of climatological and hydrological processes. In particular, the characterization of the temporal and spatial distribution of solar radiation is very challenging in mountainous areas. Here the variability of the radiation field is greatly increased, due to orographic shadows, sky-view factor variability, variations of atmosphere thickness and turbidity with altitude, and local weather phenomena.

At present, many different approaches are adopted for solar radiation mapping, including the interpolation of ground-based measurements (e.g. Alsamamra et al., 2009) and the downscaling of satellite data (e.g. Blanc et al., 2011). Over complex terrain areas both methods reveal well-known weaknesses, such as:

- insufficient density of radiometric stations, especially at high elevations
- difficulties in discriminating clouds from snow in satellite images
- insufficient spatial representativeness and/or resolution (pointwise vs. pixel-averaged observed values).

These lead to inaccuracies in the final estimates of surface solar radiation. Accordingly, in mountainous areas the different datasets may show considerable discrepancies.

2 Study area

The Trentino region, in the eastern Italian Alps, is almost entirely mountainous and displays a heterogeneous morphology, characterized by the presence of many mountain chains and valleys (see Fig. 1). As a consequence, the local climate is also very heterogeneous. The region has a dense radiometric station network (104 stations; see Fig. 1) managed by three institutions: Meteotrentino (the regional meteorological service), the E. Mach Foundation and the University of Trento. However, the spatial distribution of the stations is not homogeneous, as they are preferentially found in the valleys and in most densely populated areas.

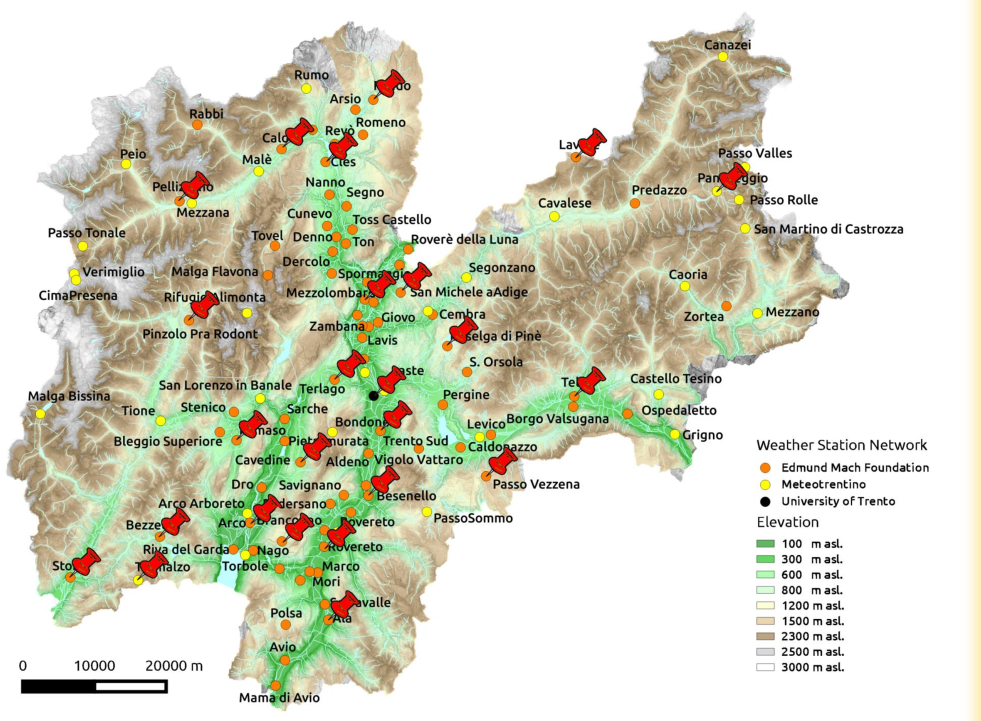

Fig. 1. Map of Trentino and radiometric network. Red place-marks indicate the stations selected for the Solar Atlas.

3 Datasets

	PVGIS-3	PVGIS-CMSAF	Heliomont	Solar Atlas
resolution	1.0-1.8 km	1.9-2.7 km	1.5-2.2 km	0.2 km
climatology	1981-1990	1998-2011	2004-2012	2004-2012
data type	ground	satellite	satellite	ground

Tab. 1. Resolution, period of reference and type of data source for the compared datasets.

PVGIS

Two datasets are available: the old PVGIS-3 (produced by interpolation of ground observations) and the new PVGIS-CMSAF (based on satellite data). In general PVGIS-CMSAF is more accurate than PVGIS-3. However, for the Alpine area it has large errors (e.g. MBE=-15%) and considerable differences between the two databases are found. Therefore, it is not clear if the new database is more accurate than the old one over the Alps (Huld et al., 2012).

HelioMont

The HelioMont dataset (from MSG-SEVIRI images) has been specifically developed for mountainous regions and bright surfaces, accounting for terrain shadowing, sky view and terrain slope and aspect. Accordingly, it overcomes most terrain and snow-related issues affecting most satellite datasets (Stöckli, 2013). HelioMont accuracy over Trentino was evaluated by comparison with the ground-based data. On average, monthly mean values show a small positive bias (MBE=3%), while MAE=6%, with better accuracies in warm months than in cold months.

Solar Atlas of Trentino

The Solar Atlas of Trentino is based on hourly global radiation data from 25 selected stations (Fig. 1) for the 2004-2012 period and has a spatial resolution of 200 m (Laiti et al., 2014). A locally-calibrated decomposition model was applied to estimate diffuse and direct radiation components (Laiti et al., 2015).

The R.SUN module of GRASS GIS (Hofierka and Šúri, 2002) was used to model the clear-sky radiation, using as input data:

- 200-m res. digital terrain model
- 200-m res. maps of monthly-average Linke turbidity factor, estimated from ground observations (Polo et al., 2009)
- 2-km res. maps of monthly-average albedo, obtained from numerical simulations (P1.26)

Then, monthly clear-sky index values (i.e. ratios between observed and modeled values of global, diffuse and direct irradiation) were interpolated by means of a residual kriging method (cf. Laiti et al., 2013) under the hypothesis of linear drift with terrain height. A leave-one-out cross-validation provided an interpolation MBE≈0% and a MAE=5%, with smaller errors in warm months than in cold months.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
GHI - MBE (%)	-5.0	-5.0	-1.5	-0.8	-2.5	-2.2	0.2	0.4	-0.9	-0.6	8.4	6.2	-0.9
GHI - MAE (%)	7.2	6.8	4.8	4.8	5.0	5.9	5.1	4.5	4.0	4.5	9.2	8.3	3.9
DHI - MBE (%)	1.1	-3.0	-8.7	-6.6	-10.6	-6.6	-3.6	-7.9	-6.5	-1.7	19.6	21.5	-1.9
DHI - MAE (%)	9.9	9.2	9.4	7.4	10.9	7.7	7.7	8.7	7.8	6.5	19.6	21.6	10.5

Tab. 2. Relative differences between HelioMont and ground data for global and diffuse monthly mean irradiation.

4 Results

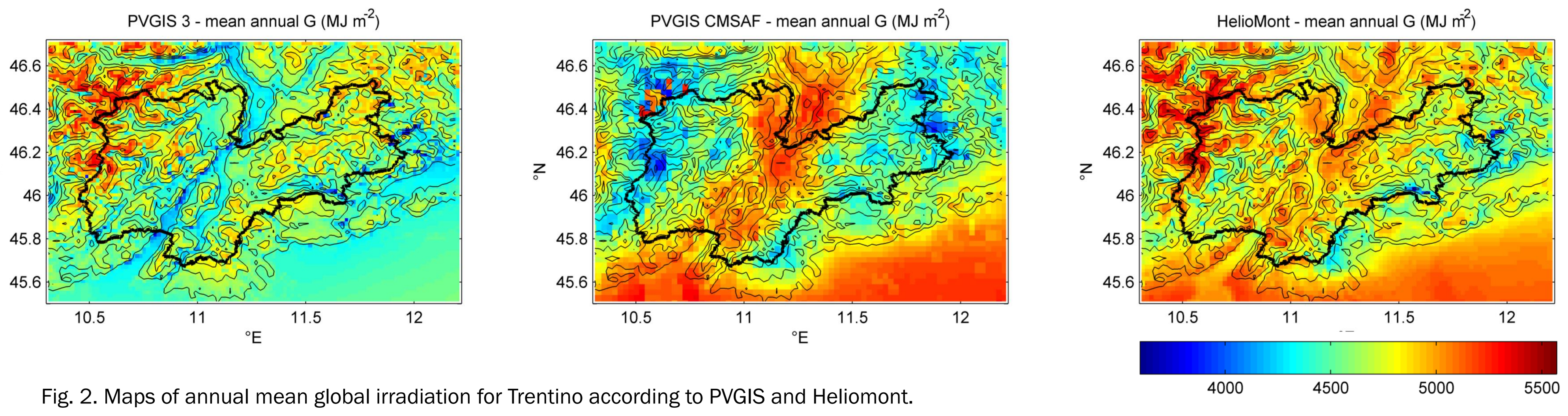

Fig. 2. Maps of annual mean global irradiation for Trentino according to PVGIS and Heliomont.

- PVGIS-3 (Fig. 2): minimum irradiation values are found in the valleys, while maximum values are found in the most elevated areas; there is a clear correlation between irradiation and terrain height.
- PVGIS-CMSAF (Fig. 2): the central part of Trentino (major valleys) displays the maximum values, while over the most elevated areas minimum values are found.
- HelioMont (Fig. 2): high irradiation values are found in the central part, while maximum values are over the highest reliefs along the western border; the minimum irradiation is found on the eastern extremity.
- Differences between PVGIS-3 and PVGIS-CMSAF: from -30% to +40%, with largest discrepancies over the highest reliefs and in the major valleys. PVGIS-3 provides lower values than HelioMont (-4%), especially at the major valleys floor (up to -27%). PVGIS-CMSAF gives lower values than HelioMont (-3%), especially over the most elevated areas (up to -28%).

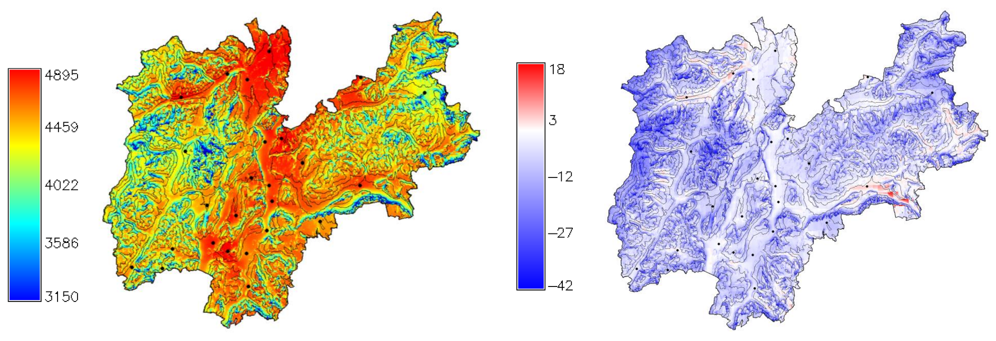

Fig. 3. Left: map of annual mean global irradiation for Trentino (MJ m^{-2}) according to the Solar Atlas produced by mapping the clear-sky index calculated from global radiation. Right: relative differeces (%) between the Solar Atlas and HelioMont.

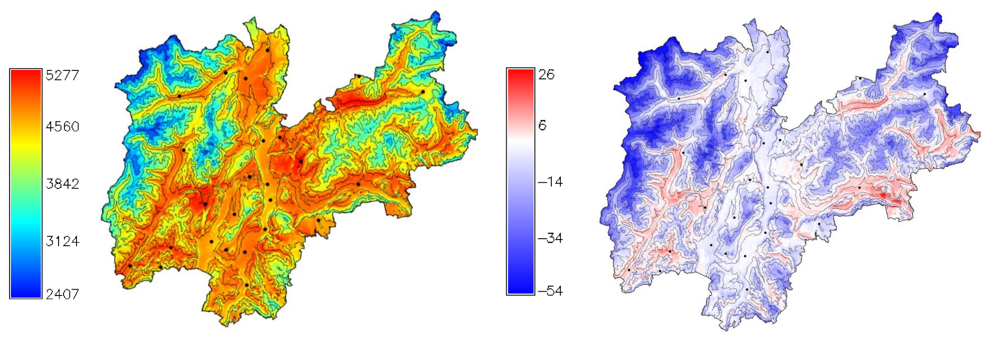

Fig. 4. Left: map of annual mean global irradiation for Trentino (MJ m^{-2}) according to the Solar Atlas produced by mapping separately the clear-sky index for direct and the diffuse components. Right: relative differeces (%) between the Solar Atlas and HelioMont.

- Solar Atlas of Trentino (Fig. 3 and 4): the central part of Trentino displays the maximum values, especially the floor and the south-facing slopes of the major valleys. The minimum values are found over the most elevated regions and the north-facing slopes. The database displays the fine-scale features induced by the local orography (thanks to R.SUN modeling). This is less evident when direct and diffuse radiation are mapped separately. In this case the terrain elevation seems to play a more relevant role.
- The Solar Atlas of Trentino and HelioMont are in good accord over the flat areas (valleys and plateaus), while mountain tops and north-facing slopes show the largest (typically negative) discrepancies.
- On average the Solar Atlas of Trentino provides lower irradiation values than HelioMont (MBE=-9% when just global radiation is mapped, MBE=-6% when direct and diffuse radiation are mapped separately) and than PVGIS-CMSAF dataset.
- Fine-scale vs. large-scale discrepancies between the Solar Atlas and HelioMont: modeling of orographic effects under clear-sky conditions and different spatial resolutions vs. sparseness of ground stations (especially at high altitude).
- Great underestimation by the Solar Atlas at high altitude when the two components are mapped separately: the decomposition model is not adequate at high altitude and/or wrong modeling of drift in the residual kriging.

5 Conclusions and outlook

- Four datasets of solar radiation, with different data sources and resolutions, are compared for the small Alpine region of Trentino.
- PVGIS-3 and PVGIS-CMSAF provide considerably different, partially conflicting solar radiation maps. Their resolution is not adequate over the Alps and the Trentino region.
- HelioMont dataset shows a good accuracy (MBE=3%, MAE=6%) but provides irradiation fields consistently different from both PVGIS versions.
- The high-resolution Solar Atlas of Trentino is in reasonably good accord with HelioMont. Fine-scale differences are ascribable to the accurate GIS-modeling of orographic effects and different spatial resolutions, while large-scale discrepancies are probably due to stations' sparseness (especially in the most elevated areas) and/or inaccuracies of the satellite database.
- The separate mapping of diffuse and direct for the Solar Atlas of Trentino: reduces the negative bias between the Atlas and HelioMont in the valleys, but still produces higher errors in the most elevated areas.
- Future complete integration of HelioMont data in the Solar Atlas of Trentino, by means of co-kriging or kriging with external drift: benefits for areas characterized by low stations density and high terrain elevation.

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