CREATION OF A MULTIRESOLUTION AND MULTIACCURACY DTM:
PROBLEMS AND SOLUTIONS FOR A CASE STUDY

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DTMs are fundamental in hydrogeological studies.

When events like landslides or floods happen at the border between countries, a unique and integrated DTM which covers the interest area is useful to analyze the scenario.
The HELI-DEM project

The work is part of HELI-DEM project

Goal

creation of a multiresolution and multiaccuracy DTM, unified for the Alpine area between Italy and Switzerland, through fusion of all the elevation data available
The HELI-DEM project

Regions involved:
Piedmont, Lombardy, Ticino and Grisons Cantons
Available Data

**DTM PIEDMONT REGION**

- **Resolution:** 50 meters / 5 meters
- **Extension:** Piedmont region
- **Year of creation:** '90s (re-organised in 2003)
- **Reference system:** WGS84 - IGM95 (ETRF89)
- **Coordinate system:** UTM fuse 32, orthometric heights
- **Accuracy:** 2.5 m (in height), 4 m (in planimetry)

**DTM LOMBARDIA REGION**

- **Resolution:** 20 meters
- **Extension:** Lombardy region
- **Year of creation:** 2002
- **Reference system:** Roma40
- **Coordinate system:** Gauss-Boaga fuse Ovest, orthometric heights
- **Accuracy:** 5-10 m (in height), 2 m (in planimetry)

**DTM SWISSTOPO**

- **Resolution:** 25 meters (1” sexagesimal)
- **Extension:** Switzerland
- **Year of creation:** 2001
- **Reference System:** ETRS89
- **Coordinate system:** geographic, orthometric heights LN02
- **Accuracy:** 1.5 - 3 m (in height)

**DTM LIDAR (RIVERS BASINS)**

- **Resolution:** 1 meter (0.00001 sexadecimal degrees)
- **Extension:** Piedmont and Lombardy – main idrographic basins
- **Year of creation:** in corso di realizzazioni
- **Reference system:** WGS84-IGM95 (ETRF89)
- **Coordinate system:** geographic, orthometric heights
- **Accuracy:** ~ 1 m (in height)
Cross-validation between the DTMss

Different reference frames:
All DTMss have been converted to ETRF-2000

Cross-validation between the available DTMss

Cross-border DTMss with similar planimetric resolution

LR and HR DTMss
Comparison between LR and HR DTM

1) DTM Piedmont 50 m VS. DTM LiDAR 1 m

2) DTM Lombardy 20 m VS. DTM LiDAR 1 m

- Covered area 12068 km²
- Covered area 2342 km²

1/6 of the area of interest is covered also by the HR DTM

Procedure:

- prediction of the LiDAR DTM on the Lombardy/Piedmont nodes
- comparison between the two elevations obtained
Comparison between LR and HR DTM:

No global bias is present and general statistics are consistent with nominal accuracies of dataset but...

Comparison of elevations:

<table>
<thead>
<tr>
<th>DIFFERENCES [m]</th>
<th>Percentage with respect to the total number of points</th>
</tr>
</thead>
<tbody>
<tr>
<td>diff &lt; -50</td>
<td>0.09 %</td>
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<td>0.4 %</td>
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<td>0.4 %</td>
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<td>diff &gt; 50</td>
<td>0.09 %</td>
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</table>
Comparison between LR and HR DTM:

**Statistics and Histogram of Height Differences in Valtellina**

- Points: 404,8660
- Max: 204 m
- Min: -138 m
- Mean: 0.5 m
- Std: 7 m

<table>
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<th>Percentage with respect to the total number of points</th>
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<td>0.6 %</td>
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<tr>
<td>diff &gt; 50</td>
<td>0.1 %</td>
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...analyzing smaller areas, some biases are present: positive differences on the East side, negative differences on the West side of the valley.
Comparison between LR and HR DTM

Is there any translation between the Lombardy and the LiDAR DTM?

LR DTM → to be checked

\[ q_1(P) = f(P) + \nu_1 \]

HR DTM → taken as reference

\[ q_2(P) = g(P) + \nu_2 \]

If no translation exists between the two DTM:

\[ g(P) = f(P) \quad \Rightarrow \quad q_1(P) = q_2(P) \]

If a translation and a bias exist:

\[ f(P) = g(P + t) + h \quad \Rightarrow \quad q_1(P) = q_2(P) + \nu^T t + h \]

\( t \) (planar translation) e \( h \) (elevation bias) are estimated by least squares, linearizing the observation equation:

\[ \Delta H = \nu^T t + h + \nu \]

\( \Delta H \) vector containing the elevation differences

\( \nu^T t \) vector of the slope gradient

\( h \) noise
Comparison between LR and HR DTM

Is there any translation between the Lombardy and the LiDAR DTM?

No translation or elevation bias exist between the two DTM.

Validation of the LiDAR DTM (HR) with IGM monographs and accurate GNSS-RTK measures.
LiDAR validation by IGM95 monographs

- Identification of IGM points which fall into the area covered by the two DTMs
- Comparison between the elevation of each point and the elevation assumed by the DTM in the same point

DTM Lombardia 20 m

mean = -1.39 m
std = 3.4 m

DTM LiDAR 1 m

mean = 0.19 m
std = 0.2 m
LiDAR validation by GNSS-RTK surveys

USE OF GNSS TRANSNATIONAL NETWORK

Geomatics Laboratory of Como Campus
After comparing LR and HR DTMs, 12 study areas have been chosen, where height differences are bigger than 10 meters and are significantly correlated in space.

VT1: L=420m H=213m
VT2: L=508m H=243m
VT3: L=1029m H=201m
VT4: L=697m H=204m
VT5: L=379m H=328m
VT6: L=1083m H=357m
VT7: L=908m H=520m
VT8: L=2488m H=542m
VT9: L=1161m H=7954m
VT10: L=1175m H=910m
VT11: L=1609m H=910m
VT12: L=472m H=1277m
4 Helidem permanent stations and 7 IGM95 points are present in the study area.
1. We moved along roads or paths easily accessible

2. In flat sections, static measurements of 5 seconds were repeated every about 20 meters

3. In slope sections, static measurements were more frequent (10 meters).

4. Each path has been surveyed twice, in order to have a cross check of the results.

Two campaigns, the former in June/July, the latter in October 2012

1300 RTK points have been collected
# GPS surveys: Statistics

## First campaign

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<th>Ps</th>
<th>O</th>
<th>%O</th>
<th>M</th>
<th>σ</th>
<th>Max</th>
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## Second campaign

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<td>7</td>
<td>19</td>
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</table>

(all metric results in cm)

Except for two areas the results are completely **satisfactory**. They are consistent with the nominal accuracy of the HR DTM.

Most **outliers** are clearly caused by RTK survey problems and do not represent DTM blunders. As expected, typically they are present under dense vegetation or in obstructed sites.
VT07
1° campaign: 7 outliers while all the other $\Delta h$ are between 0 and 30 cm. This problem does not repeat in the second campaign. It is clearly due to RTK survey problems.
VT10 RTK heights are systematically higher than HR DTM heights in the road side toward the valley and this survey contains most of the differences bigger than 1 m: this bias is clearly caused by a small error in the DTM horizontal georeferencing.
The paper has discussed the first operations needed for the final merging of HR and LR DTMs.

Several cross-checks have been performed.

External validation using GNSS-RTK surveys in area where the differences between the LR DTM and the HR DTM are bigger than 10 meters.

HR DTM has been compared with IGM95: the results are completely satisfactory.

Except for two areas, these gave completely satisfactory results, that are consistent with the nominal accuracy of the HR LiDAR DTM.
Future work

Step in progress

To achieve the goal of the project, i.e. a multiresolution DTM, two different DTMs will be produced:

**LR** (planimetric resolution of about 20 meters) DTM that cover the whole area of the project.

**HR** DTM that covers only the areas in which the LiDAR DTM exist.
To obtain the **LR DTM** some sequential steps are needed:

1) **merging and interpolation** of the three regional DTMs of Lombardy, Piedmont and Switzerland on the grid nodes of the global, final, LR DTM

2) **subsampling** of the HR LiDAR DTM on the grid nodes of the global LR DTM

3) **computation** of the elevation differences in all the LR grid nodes for which also HR values exist

4) Application of a **low pass filter** and to apply it to the elevation differences, in order to obtain a smoothed digital model differences

5) **sum** of the filtered differences to the LR global DTM
Thank’s