Thermal Remote Sensing Data Enhancement over Alpine Vegetated Areas for Evapotranspiration Modelling

Paulina Bartkowiak [1,2], Mariapina Castelli [1], Roberto Colombo [2], Claudia Notarnicola [1]

[1] Institute for Earth Observation, Eurac Research, Bolzano/Bozen, Italy

[2] Department of Chemical, Geological and Environmental Sciences, University of Milano Bicocca, Milano, Italy

Motivation and main application domain

- Recent increase in frequency of droughts periods in the Alps
- Thermal remote sensing provides relevant spatial information about vegetation conditions and dynamics
- Land surface temperature (LST) is a fundamental input for remotely sensed evapotranspiration (ET) models
- In the Alpine region characterized by complex orography and heterogenous land-cover, the performance of TSEB [1] is limited by cloud contaminated pixels and low spatial resolution of LST data [2]

Objectives

- Enhancement of satellite-based LST maps over vegetated areas of the Alps
  - Improving data quality in spatio-temporal domain
    - Thermal downscaling
  - Predicting commonly missing pixels beneath the clouds
    - Meteorological-based modelling of LST

Outline

- Thermal downscaling procedure
- Gap-filing procedure
- Conclusions
- Outlook

Thermal downscaling procedure

- Implementation of a LST sharpening to low spatial resolution of 1-km MODIS LST (MOD11A1) images (Fig. 1) [3]
- Random forest (RF) algorithm
- Predictors: DEM and NDVI with 250-m pixel size
- Three different models applied
  - All vegetated pixels (VM1)
  - Pixels with more than 90% of vegetation content (VM2)
  - Pixels covered by vegetation with 75% threshold homogeneity for land-cover classes (VM3)
- Outputs: daily 250-m downscaled LST maps (LST_{mod})

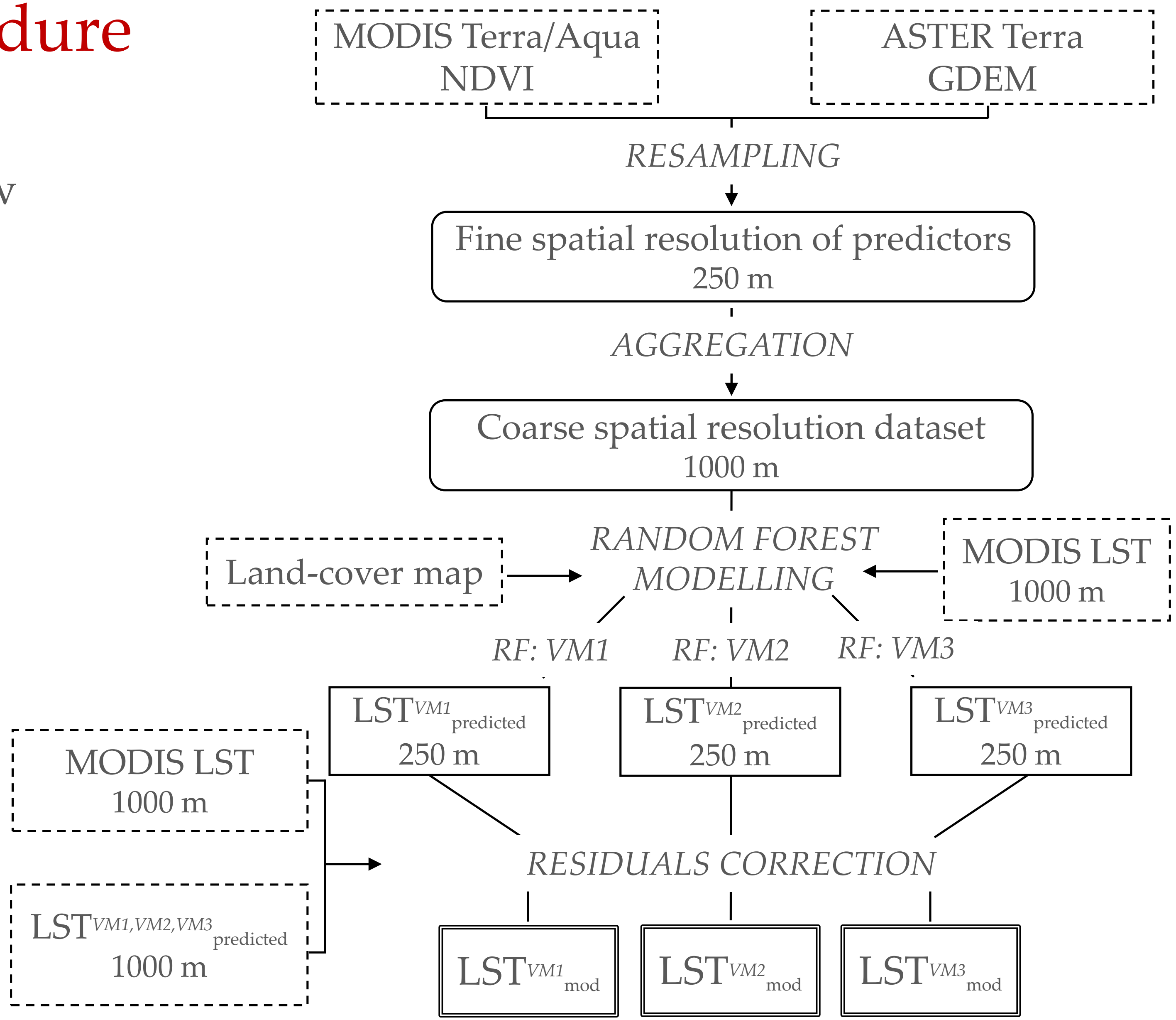

Fig.1. Scheme of the RF downscaling approach [3]

● Downscaling results for Alpine areas

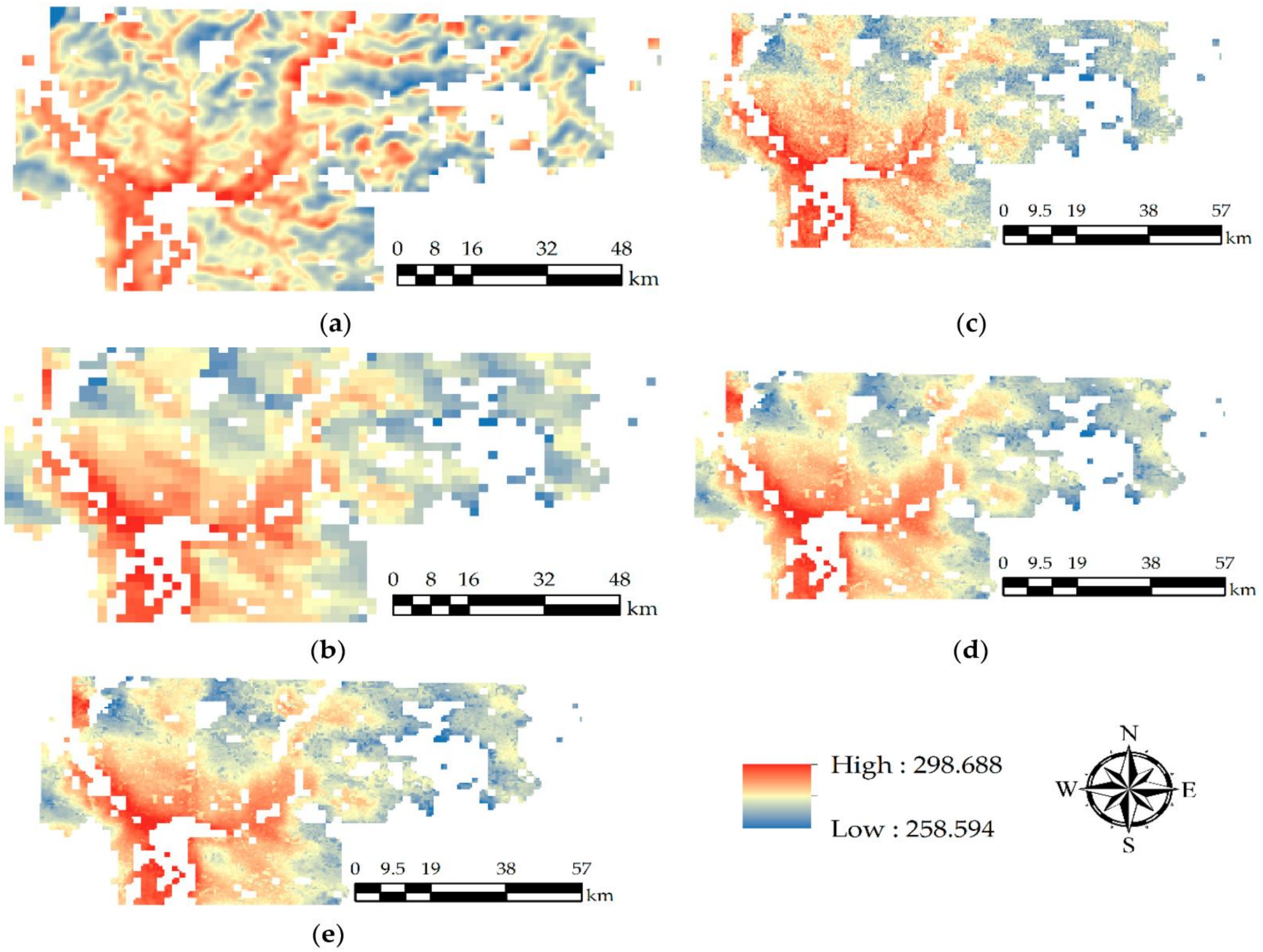

Fig. 2. Visual comparison between MODIS and Landsat LST degraded to 250-m pixel size on 27 September 2004:

(a) degraded Landsat reference image (250 m)
(b) original MODIS LST (1000 m)
(c) VM1
(d) VM2
(e) VM3 [3]

Downscaling results for Alpine areas

- To evaluate the effectiveness of the VM1, VM2 and VM3 random forest regression, we conducted spatial degradation of TIR bands from Landsat 5 and Landsat 8 to downscaled 250-m MODIS maps in different seasons, i.e. spring, summer and autumn (Fig. 3).
- Additionally, to assess Random Forest performance, Landsat LST reference data were compared with the original MOD11A1 and the downscaled images (Fig. 4)

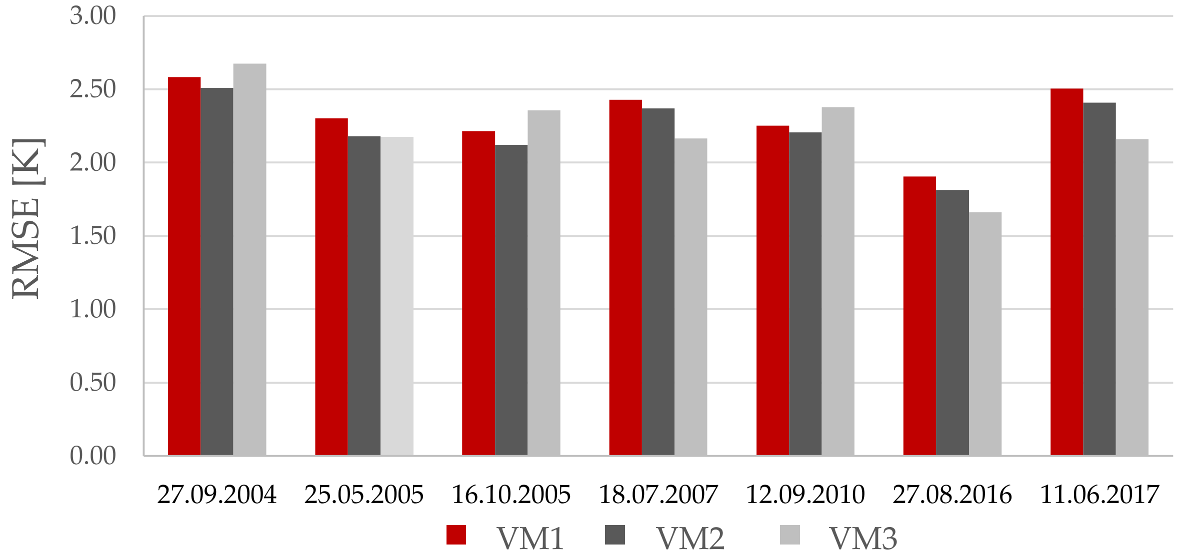

Fig. 3. Average Root Mean Square Error (RMSE) between enhanced images and reference images for VM1, VM2 and VM3 approaches

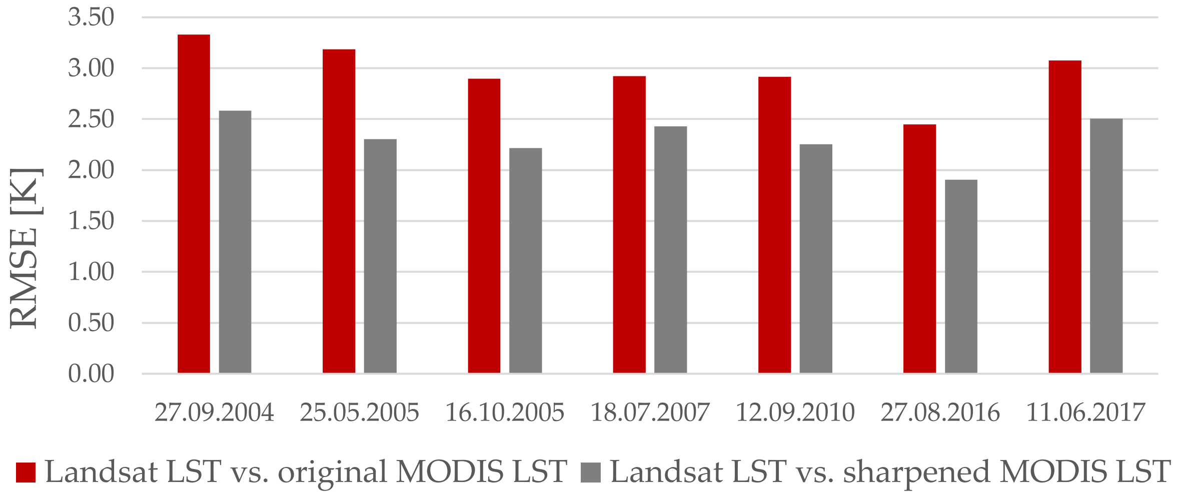

Fig. 4. RMSE between reference Landsat LST images and original and downscaled MODIS LST maps

Gap-filling procedure

- Investigation of relationships between LST and meteorological data at 16 stations over the Alps located in different ecosystems to predict cloud contaminated pixels for MODIS LST
- Firstly, dependency between LST and daily mean air temperature (TA_{mean}) has been explored considering clear- and cloudy-sky conditions [4,5] (Fig. 5)

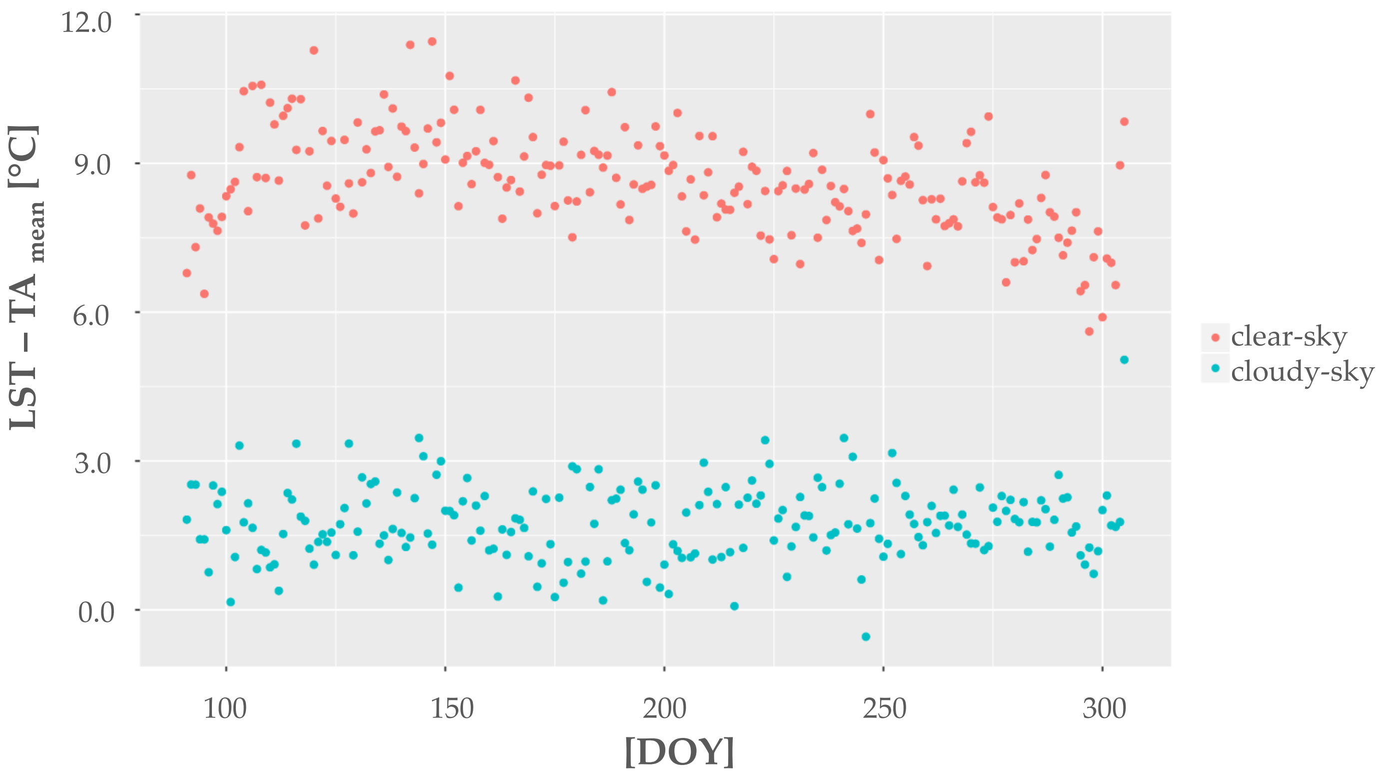

Fig. 5. Mean difference between LST and daily TA mean by day of year (DOY) for all stations

Univariate linear modelling of LST

- Regressions between LST and daily TA_{mean} as a main predictor show a high site dependency driven by different land-cover types and/or altitude of the stations (Fig. 6-7)

LULC: Grassland
Elevation: 1450 m a.s.l.

LULC: Grassland
Elevation: 1553 m a.s.l.

LULC: Grassland
Elevation: 1550 m a.s.l.

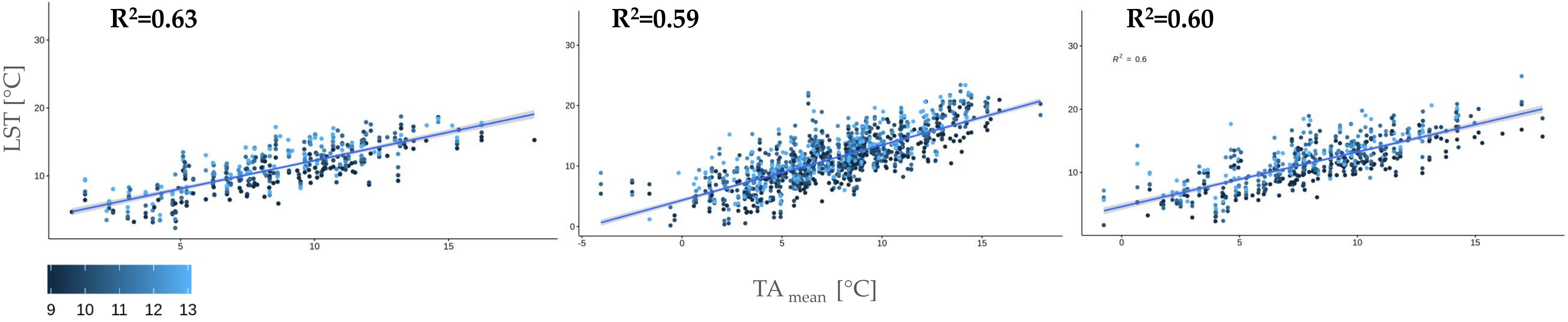

Fig. 6. Scatterplots between LST and TA_{mean} for stations covered by grassland under cloudy-sky conditions

Univariate linear modelling of LST

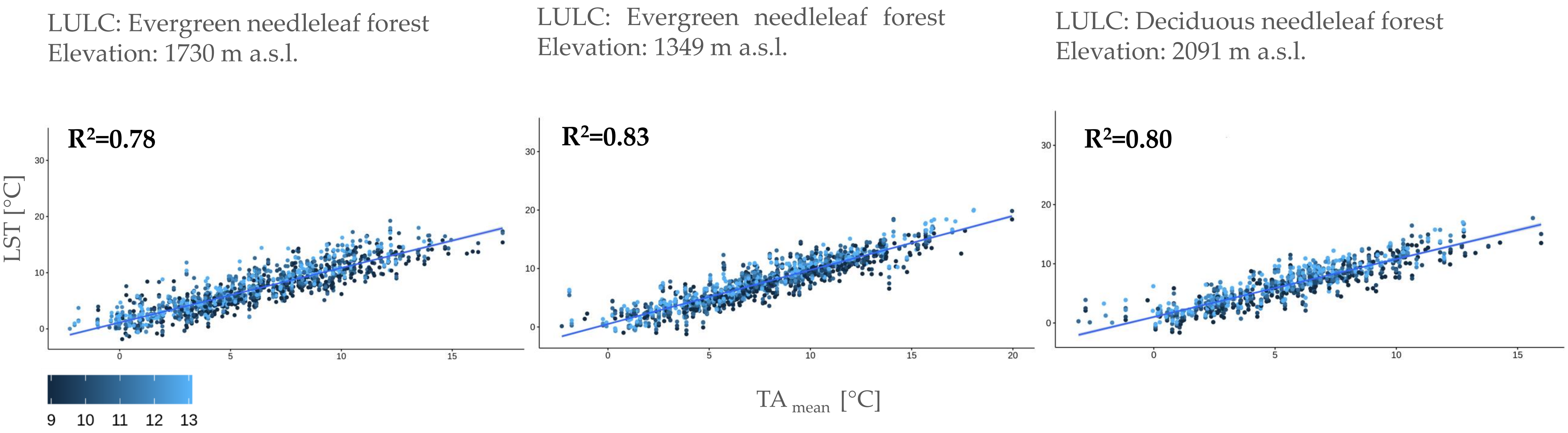

Fig. 7. Scatterplots between LST and TA_{mean} for stations located in the forest under cloudy-sky conditions

Univariate linear modelling of LST

- Linear regression between LST and TA_{mean} under cloudy-sky conditions have been conducted for aggregated stations that represent similar environmental conditions (Tab. 1)
- The linear modeling has allowed predicting LST values from TA_{mean} with a leave-one-out cross validated (LOOCV) $RMSE_{LOOCV}$ ranging from 1.86 to 3.42°C and R^2_{LOOCV} between 0.48 and 0.88 (Fig. 8)

Aggregation group	Stations	Elevation range [m a.s.l.]
Upland grassland	Rotholz, Chamau, Fruebuel, Oensingen	300-1000
Average mountainous grassland	Mazia Valley, Monte Bondone	1000-1600
Mountainous grassland at the high altitude	Mazia Valley, Torgnon	>1600
Agriculture areas (vineyards, orchards)	Valle dell'Adige, Caldaro	<500
Forest	Lavrone, Davos, Renon, Torgnon	-

Tab. 1. Overview of the stations used in the study

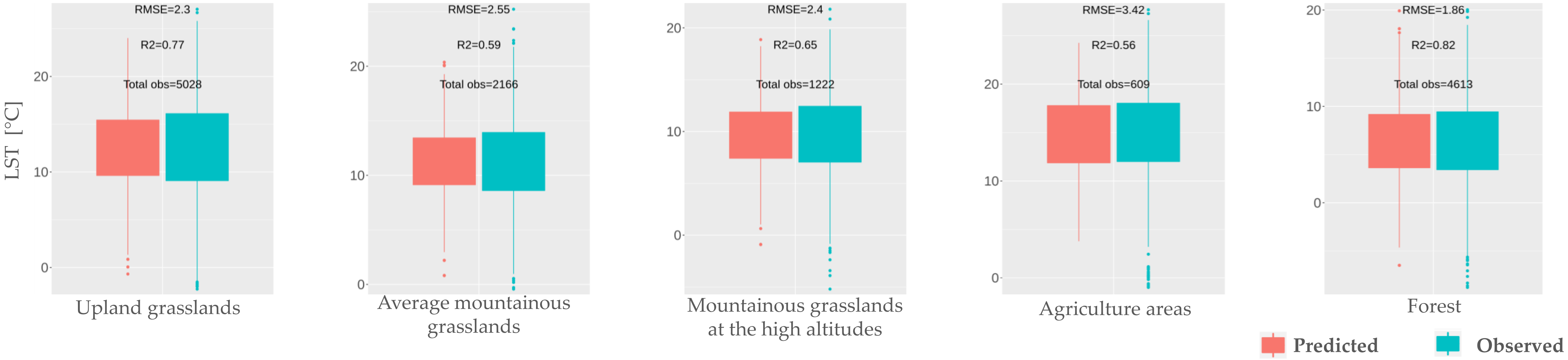

Fig. 8. Performance of the simple linear modelling (LM) based on LOOCV under cloudy-sky conditions at the aggregated stations

Multiple linear modelling of LST

- Auxiliary data incorporated into modelling LST= $f(X_i)$
  - Elevation
  - Ground measurements for daily maximum air temperature (TA_{max})
  - Measured incoming shortwave radiation (SW)
- Selection of predictors based on All Subsets Regression approach
- Validation results:
  - $RMSE_{LOOCV}$: 1.56 - 2.89°C
  - R^2_{LOOCV} : 0.69 - 0.87

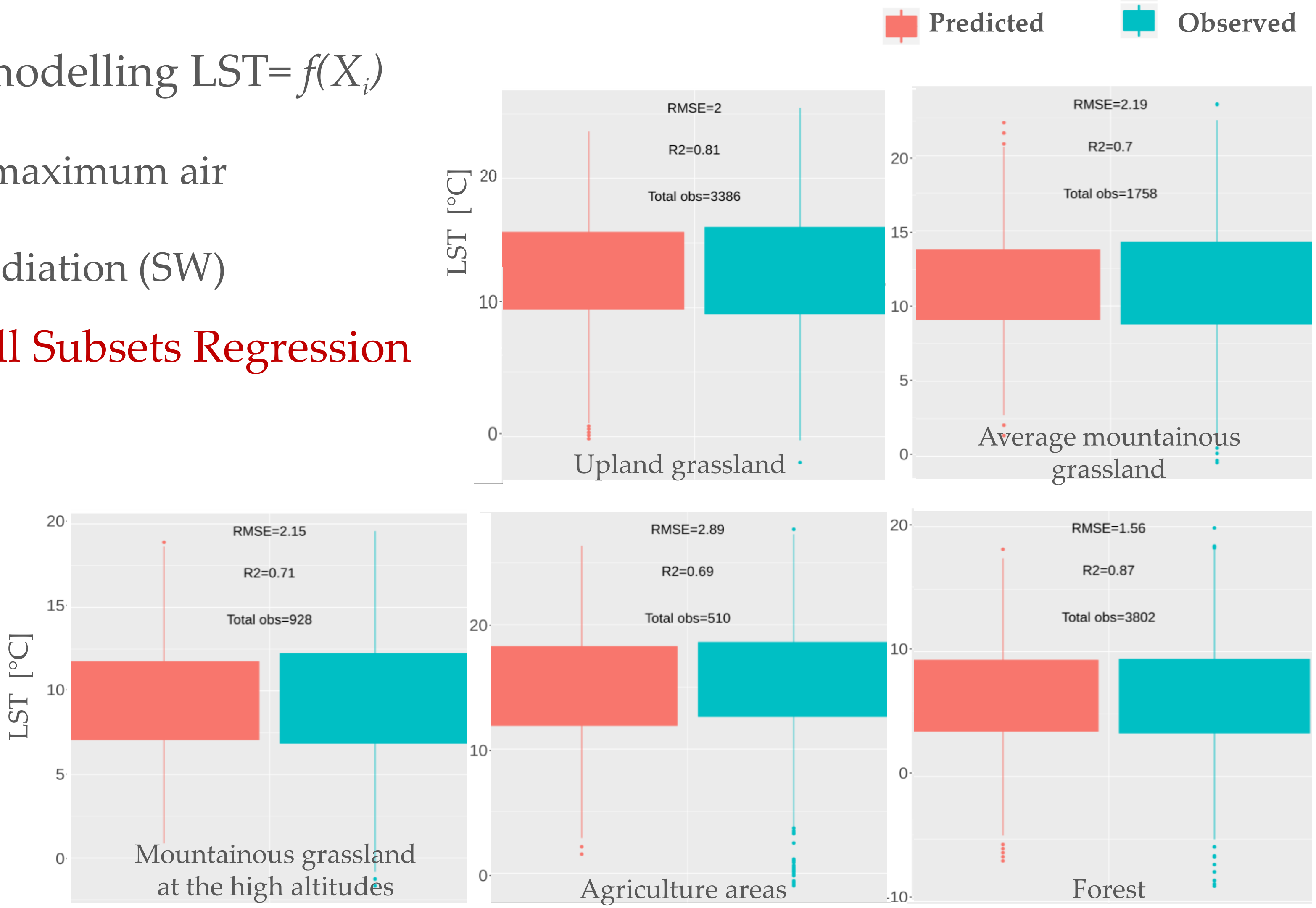

Fig. 9. Performance of the multiple linear modelling (MLM) at field scale based on LOOCV

Conclusions

- Random Forest algorithm was capable of modelling non-linear relationships between variables in a very robust way. The performance of the proposed regressions (VM1, VM2, VM3) images gave similar results.
- The RF modelling indicates an improvement of about 20% in the agreement between Landsat and the sharpened MODIS LST compared to statistics obtained for the original MOD11A1.
- The statistical-based modeling of LST under cloudy-sky conditions yielded quite satisfactory results that depend on land-cover type and elevation of the stations.
- Multiple regression seems to be more robust than $f(TA_{mean})$ modelling due to complex conditions of the Alpine ecosystems. The MLM models showed an average reduction of 15% of the RMSE with regard to the simple linear approach.

Outlook

- Further exploration of pixel-based gap-filling approach to extend modelling to overcast MODIS LST maps over the Alpine region
- Application of the improved datasets (by downscaling and recovering missing pixels beneath the clouds) for energy balance modelling of ET

Acknowledgements

This work has been carried out within the project CYCLAMEN funded by Provincia Autonoma di Bolzano, Alto Adige/Südtirol, Ripartizione Diritto allo studio, Università e ricerca scientifica, within the scope of Provincial Law 14 from 13. December 2006 (Project Nr. 5/34). The authors would like to thank the Department of Innovation, Research and University of the Autonomous Province of Bozen/Bolzano for their financial support.

References

[1] Kustas, W. P., Norman, J. M., Hain, C. R., Mecikalski, J. R., Schultz, L., Gonzalez-Dugo, M. P., & Gao, F. (2011). Mapping daily evapotranspiration at field to continental scales using geostationary and polar orbiting satellite imagery. *Hydrology and Earth System Sciences*, 15(1), 223.

[2] Castelli, M., Anderson, M. C., Yang, Y., Wohlfahrt, G., Bertoldi, G., Niedrist, G., Notarnicola, C. (2018). Two-source energy balance modeling of evapotranspiration in Alpine grasslands. *Remote Sensing of Environment*, 209, 327-342.

[3] Bartkowiak, P., Castelli, M., & Notarnicola, C. (2019). Downscaling Land Surface Temperature from MODIS Dataset with Random Forest Approach over Alpine Vegetated Areas. *Remote Sensing*, *11*(11), 1319.

[4] Rigollier, C., Bauer, O., & Wald, L. (2000). On the clear sky model of the ESRA—European Solar Radiation Atlas—with respect to the Heliosat method. Solar energy, 68(1), 33-48.

[5] Gallo, K., Hale, R., Tarpley, D., & Yu, Y. (2011). Evaluation of the relationship between air and land surface temperature under clear-and cloudy-sky conditions. Journal of applied meteorology and climatology, 50(3), 767-775.