Fusion of airborne LiDAR and satellite multispectral data for the estimation of timber volume in the Southern Alps

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INTRODUCTION

- Estimation of timber volume at regional scale is a challenging and important issue
- Remote sensing data can be very useful, but high point density LiDAR data, and high spectral and spatial resolution images can be too expensive
- Satellite multispectral data and low point density LiDAR data can be an efficient tool

Satellite Multispectral data

- Spectral information on tree species
- Coverage of large areas at very low cost

Low point density airborne LiDAR

- Sometimes available by public administrations as acquired for DTM generation
- Useful for structural parameters estimation of trees

- These two data provide complementary information and their combination can be useful for improving the volume estimation results

OBJECTIVES

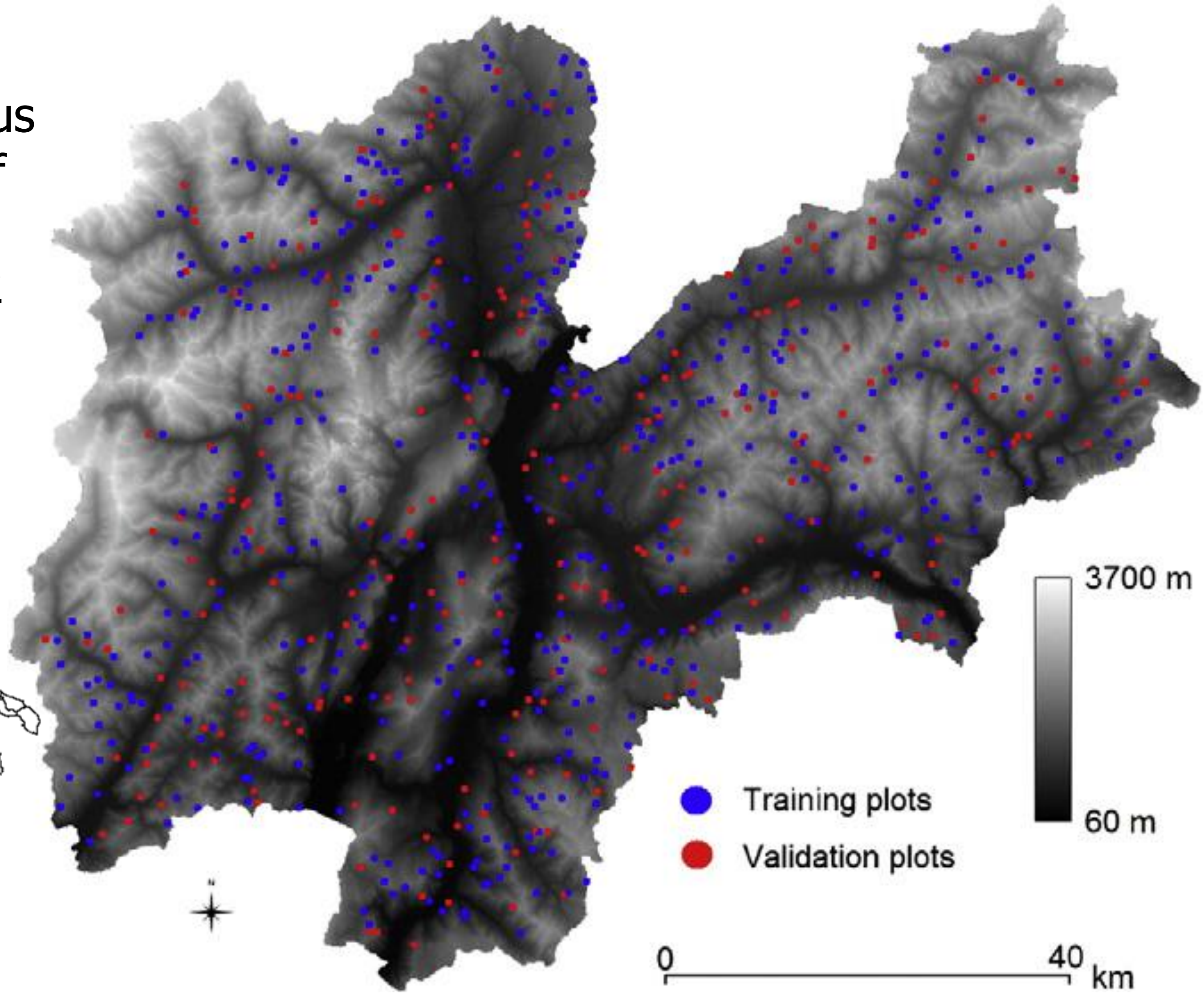
- The goal of this work was to present an analysis on the combined use of satellite multispectral data and low point density LiDAR data in an area that comprises three characteristics:
  - large extension
  - high altitudinal range
  - large species variability

- These data were analyzed both separately and combined, considering different levels of species aggregations (all the sample areas together, divided by macro classes and divided by single species) and different altitude and slope ranges

DATA SET DESCRIPTION

Study area

- Autonomous Province of Trento
- Area: 6212 km²



DATA SET DESCRIPTION

Multispectral data

- Sensor: IRS 1C LISS III
- Number of bands: 4
- Spectral bands: green (520 - 590 nm), red (620 - 680 nm), near-infrared (NIR; 770 - 860 nm), and shortwave infrared (SWIR; 1550 - 1700 nm)
- Spatial resolution: 23.5m

LiDAR data

- Sensor: Optech ALTM 3100C
- Point density: 0.5 points per m^2

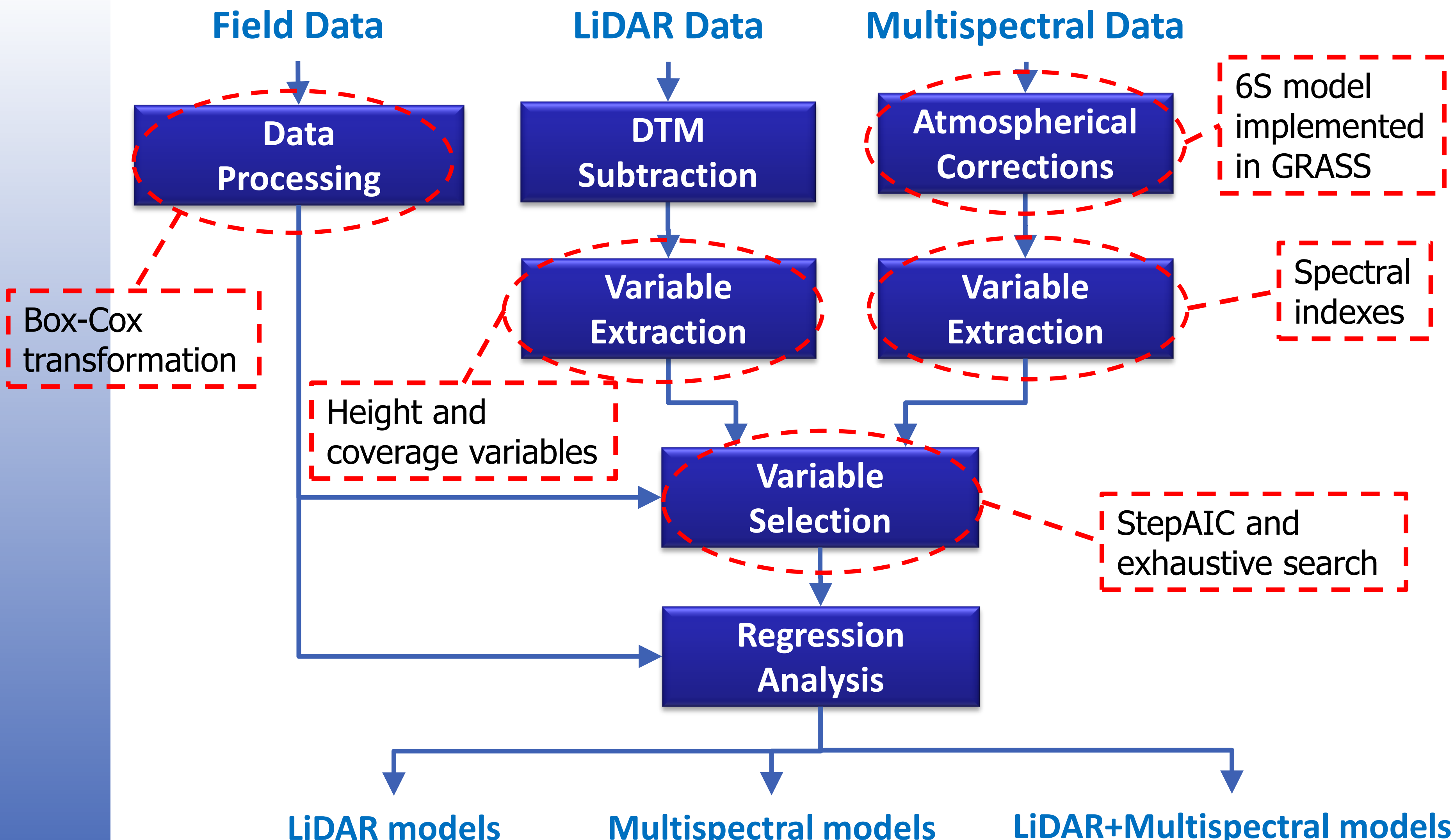
Field data

- Field plots number: 799
- Main Species:
  - 67% conifers (i.e. Silver fir, Norway spruce, European larch, Austrian pine and Scots pine)
  - 33% broadleaves (i.e. European beech, Hop hornbeam, Oaks and Maples)

DATA SET DESCRIPTION

	N	Mean (m^3 ha^{-1})	SD	Range (m^3 ha^{-1})
Training Set				
All	534	241.9	148.8	6.9 - 874.9
Deciduous	169	157.3	118.8	6.9 - 630.9
Evergreen	199	317.3	157.6	20.2 - 874.9
Mixed	166	237.6	114.7	19.7 - 698.3
Silver fir and Norway spruce	247	320.6	149.0	19.7 - 874.9
Pine	54	183.5	81.6	49.9 - 372.2
Larch	71	166.1	117.9	11.8 - 491.7
European beech	68	208.8	107.0	6.9 - 630.9
Other Broadleaves	94	149.6	116.3	9.3 - 560.9
Validation Set				
All	265	240.6	150.0	9.3 - 749.6
Deciduous	83	137.7	77.8	18.4 - 383.5
Evergreen	99	326.7	158.3	9.3 - 749.6
Mixed	83	240.9	129.6	10.2 - 508.9
Silver fir and Norway spruce	117	321.5	154.5	9.3 - 749.6
Pine	31	201.8	113.6	10.2 - 421.3
Larch	39	201.4	141.9	15.2 - 508.8
European beech	35	183.4	87.2	38.8 - 414.1
Other Broadleaves	43	130.8	77.7	18.4 - 323.2

METHODS: Processing Chain Adopted



METHODS

Variables extracted from LiDAR data

Variable ID	Variable description
Height	
Hmean	mean height value
Hmax	max height value
HCV	coefficient of variation
Hq20	20th height quintile
Hq50	50th height quintile
Hq90	90th height quintile
Hq902.5	90th height quintile at the power of 2.5
Hq95	95th height quintile
Coverage	
C1.3m	ratio of the number of pulses with height higher than 1.3m and the total number of pulses
Cmean	ratio of the number of pulses with height higher than Hmean and the total number of pulses
Cq20	ratio of the number of pulses with height higher than Hq20 and the total number of pulses
Cq50	ratio of the number of pulses with height higher than Hq50 and the total number of pulses
Cq90	ratio of the number of pulses with height higher than Hq90 and the total number of pulses
Other variables	
N_LiDAR	number of tree tops extracted from LiDAR data

METHODS

Variable extracted from multispectral data

Variable ID	Variable description
Normalized bands	
B1N	Green band normalized between 0 and 1
B2N	Red band normalized between 0 and 1
B3N	NIR band normalized between 0 and 1
B4N	SWIR band normalized between 0 and 1
Simple band ratios	
RR	SWIR / Red reflectance ratio
SR	Simple ratio: NIR / Red reflectance ratio (Jordan, 1969)
SRc	Corrected Simple Ratio (Brown et al. 2000)
MSR	Modified Simple Ratio (Chen, 1996)
CI	Canopy Index (Vescovo & Gianelle, 2008)
Normalized band ratios	
NDVI	Normalized Difference Vegetation Index (Rouse et al., 1974)
NDVIc	Corrected NDVI (Nemani et al. 1993)
GNDVIgreen	Green Normalised Difference Vegetation Index (Gitelson et al. 1996)
NDWI	Normalized Difference Water Index (Lymburner et al. 2000)
NCI	Normalized Canopy Index (Vescovo & Gianelle, 2008)

METHODS

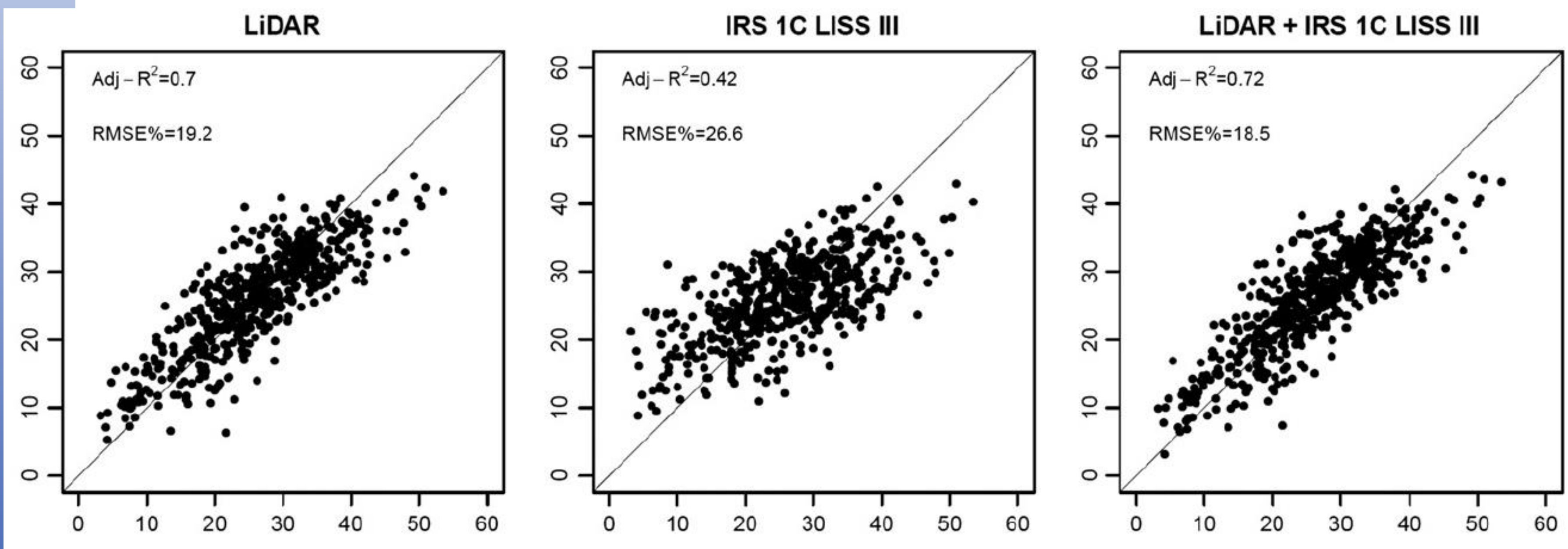
Variable selection

- *lm* function in R was used to create the full model with all the available variables.
- Variable selection was applied to the full model using the function *stepAIC*.
- Exhaustive search starting from one variable to the number variables identified by stepAIC (function *regsubsets* of package *leaps* in R).
- Among these models, we selected the one with the lowest number of variables that had no significant differences (tested with an ANOVA test) with the model with the lowest AIC.

RESULTS: all the plots

	Selected variables	Hmax	Hcv	Hq20	Hq90	Hq902.5	Cq50	B3norm	SR	NDVI	RR	NDVIc	NDWI
L	6	■	■	■	■	■	■						
M	5							■	■	■	■		■
L+M	9	■	■		■	■	■	■			■	■	■

- Mainly height variables among LiDAR ones
- RED, NIR and SWIR based variables among the multispectral ones



RESULTS: stratified by macro classes of species

		Selected variables	Hmax	Hmed	Hcv	Hq20	Hq50	Hq90	Hq902.5	Hq95	C1.3m	Cq20	Cq50	Cq90	N_LiDAR	B1norm	B2norm	B3norm	B4norm	NDVI	RR	SRc	NDVIc	NDWI	NCI
Deciduous	L	5					■	■		■			■	■											
	M	4																■			■		■	■	
	L+M	6					■		■			■		■					■		■				
Evergreen	L	6	■	■		■	■							■	■										
	M	5																■	■	■	■			■	
	L+M	14	■	■			■	■	■		■		■		■		■			■	■	■		■	■
Mixed	L	4			■					■				■	■										
	M	4														■	■				■				■
	L+M	4			■					■				■	■										

	LiDAR			**IRS 1C LISS III**			**LiDAR + IRS 1C LISS III**		
	Adj-R^2	**RMSE% TR**	**RMSE% VD**	**Adj-R^2**	**RMSE% TR**	**RMSE% VD**	**Adj-R^2**	**RMSE% TR**	**RMSE% VD**
Deciduous	0.69	23.2	26.0	0.37	34.5	35.6	0.72	22	26.5
Evergreen	0.64	16.1	18.5	0.32	22.1	23.0	0.67	15.1	17.2
Mixed	0.60	16.9	18.9	0.23	23.4	28.9	0.60	16.9	18.9

RESULTS: stratified by species

		Selected variables	Hmax	Hmed	Hcv	Hq20	Hq50	Hq90	Hq902.5	Hq95	C1.3m	Cmed	Cq20	Cq50	Cq90	N_LiDAR	B2norm	B3norm	B4norm	SR	NDVI	MSR	RR	SRc	NDVIc	NDWI	CI	NCI
Silver Fir Norway Spruce	L	6	■	■			■	■				■				■												
	M	4																■					■		■	■		
	L+M	10	■	■			■	■				■				■		■			■				■	■		
Pine	L	5	■		■				■		■		■															
	M	2																							■			■
	L+M	10	■			■		■	■		■						■	■				■	■			■		
Larch	L	5			■					■	■				■	■												
	M	4															■	■					■		■			
	L+M	9		■			■							■	■	■			■	■					■	■		
European Beech	L	3			■					■					■													
	M	2																			■						■	
	L+M	5					■								■					■		■						■
Other Broadleaves	L	7						■	■		■	■	■	■		■												
	M	3															■	■						■				
	L+M	11						■	■	■	■	■	■	■		■							■		■		■	

RESULTS: stratified by species

	LiDAR			IRS 1C LISS III			LiDAR + IRS 1C LISS III		
	Adj-R^2	RMSE% TR	RMSE% VD	Adj-R^2	RMSE% TR	RMSE% VD	Adj-R^2	RMSE% TR	RMSE% VD
Silver Fir Norway Spruce	0.59	16	17.9	0.25	21.7	24.5	0.6	15.6	17.5
Pine	0.48	16.9	28.0	0.2	21.5	31.1	0.58	14.4	27.9
Larch	0.78	18.8	21.4	0.29	34.1	37.9	0.81	17	26.5
European Beech	0.61	17.8	21.6	0.2	25.6	26.9	0.64	16.8	23.0
Other Broadleaves	0.71	21.9	28.6	0.49	29.8	40.7	0.79	18.3	29.0

- A stratification by species improve the results, especially for evergreen species
- LiDAR models provide the majority of the information
- There is a big difference among the results with deciduous species and evergreen ones

RESULTS: stratified by altitude

	LiDAR			IRS 1C LISS III			LiDAR + IRS 1C LISS III		
	Adj-R^2	RMSE% TR	RMSE% VD	Adj-R^2	RMSE% TR	RMSE% VD	Adj-R^2	RMSE% TR	RMSE% VD
≤750 m	0.68	20.4	21.9	0.43	27.4	29.5	0.69	19.8	21.3
750 – ≤1250 m	0.61	19.6	18.8	0.27	27.0	25.9	0.63	18.9	18.2
1250 – ≤ 1750 m	0.68	16.4	16.3	0.34	23.6	23.4	0.71	15.7	15.5
> 1750 m	0.76	21.3	21.6	0.63	25.5	25.8	0.81	18.6	18.8

- A stratification by altitude improves the results only when the altitude as an influence on the species distribution:
  - over 1750 m almost only Larches with very similar characteristics

RESULTS: stratified by slope

	LiDAR			IRS 1C LISS III			LiDAR + IRS 1C LISS III		
	Adj-R^2	RMSE% TR	RMSE% VD	Adj-R^2	RMSE% TR	RMSE% VD	Adj-R^2	RMSE% TR	RMSE% VD
≤ 15 degrees	0.71	17.4	17.5	0.41	25.4	25.5	0.72	16.7	16.8
>15 – ≤ 25 degrees	0.69	18.3	19.4	0.42	25.1	26.6	0.71	17.6	18.7
>25 – ≤ 35 degrees	0.75	17.2	17.2	0.46	25.1	25.1	0.77	16.3	16.3
35 degrees	0.68	20.0	19.4	0.37	28.3	27.3	0.70	19.6	19.0

- A stratification by slope have little effect on the results
  - Example: with a slope higher than 35° and altitude below 750 m, mainly broadleaves species are present (e.g., Hop Hornbeam), while with the same slope but altitude over 1250 mainly Norway Spruce is present

CONCLUSIONS

- The combination of LiDAR and multispectral data can be useful as it provides a slight increase in estimation accuracy (an increase of Adjusted-R^2 between 1 to 4%), especially for some species groups.
- Models derived using only multispectral data do not provide high level results for the estimation of stem volumes in an area like the Province of Trento.
- LiDAR variables alone provide the majority of the explanative contribution.
- Stratification according to species, altitude and slope allow in some cases to improve the estimation results
- The models presented can be effectively used for the estimation of stem volume over the entire Province of Trento, even if the LiDAR data considered were acquired at low point density.

QUESTIONS?

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RESULTS: stratified by altitude

		Selected variables	Hmax	Hmed	Hcv	Hq20	Hq90	Hq902.5	Hq95	C1.3m	Cq20	Cq50	Cq90	N_LiDAR	B1norm	B2norm	B3norm	B4norm	SR	NDVI	MSR	RR	GNDVIgreen	NDVIc	NDWI	CI	NCI
≤ 750 m	L	4			■		■	■			■																
	M	3													■		■										■
	L+M	5			■		■	■			■				■												
750- ≤ 1250 m	L	4	■		■				■				■														
	M	2														■											■
	L+M	7	■		■		■						■			■						■				■	
1250- ≤ 1750 m	L	4		■				■					■	■													
	M	4															■					■		■	■		
	L+M	8			■		■			■		■	■	■				■					■				
>1750 m	L	4	■	■								■		■													
	M	8													■	■	■		■	■	■	■					■
	L+M	8				■				■									■	■	■			■		■	■

RESULTS: stratified by slope

		Selected variables	Hmax	Hmed	Hcv	Hq20	Hq50	Hq90	Hq902.5	Hq95	Cmed	Cq20	Cq50	Cq90	N_LiDAR	B1norm	B2norm	B3norm	B4norm	SR	NDVI	RR	SRc	NDVIc	NDWI	CI	NCI
≤ 15 degrees	L	6	■					■		■	■	■			■												
	M	2																		■			■				
	L+M	8	■					■	■	■	■	■			■				■								
15- ≤25 degrees	L	5	■			■		■	■					■													
	M	4														■	■					■					■
	L+M	8	■			■	■	■	■		■					■	■										
25- ≤35 degrees	L	5	■		■				■	■	■																
	M	6														■				■	■	■		■	■		
	L+M	9	■		■				■	■		■	■	■								■				■	
35 degrees	L	3		■		■							■														
	M	4																■				■		■	■		
	L+M	4				■								■								■				■	