SOCIETÀ ITALIANA DI FISICA
106° CONGRESSO NAZIONALE

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

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NASA

Measurements of volcano surface changes by Remote Sensing: 10 years at Mt. Etna volcano

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SIF- on line 15-9-2020

Outline

- Active volcanoes topography: Mt. Etna case study
- Airborne Lidar Topography
- Stereo Satellite Topography
- ASP procedure
- Pleiades Topography Result and Validation
- Application: model to model comparison
- Result over 10 year of surface change
- Conclusions

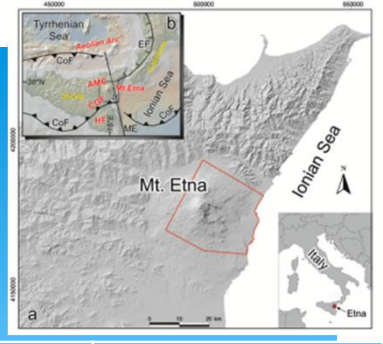
Areas characterized by dynamic and rapid morphological changes need accurate, up-to-date topographic data, especially if these areas are populated and urbanized

Active volcanic areas are frequently affected by surface changes due to effusive and explosive activities (lava flows, lava fountaining, fall out deposits).
In those areas the local population is exposed to volcanic hazard.

An updated and accurate topography of these areas is necessary for correct hazard simulations to mitigate the eruptive event.

This is particularly true for active volcanic areas such as Mount (Mt.) Etna located in the north-eastern portion of Sicily, Italy.

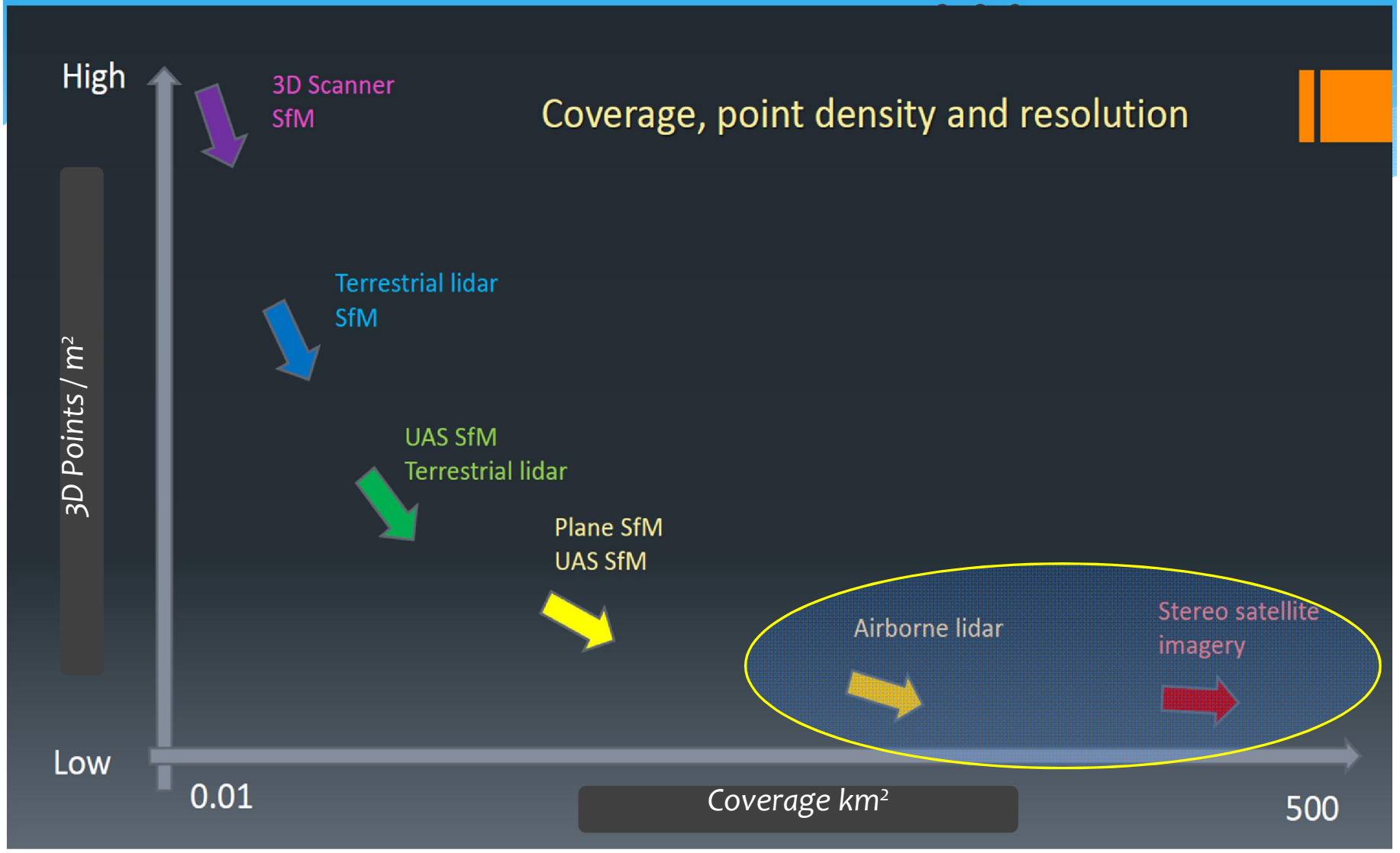
Digital Elevation Models of Mt. Etna available in literature



DEM	Geodetic Cartographic System	Acquisition Technique	Spatial Resolution (m)	Z Error (m)	Validation Accuracy (m)	Mt. Etna Coverage area	Availability	Bibliography
SRTM 2000	WGS 84 lat long	RADAR	90	+/- 6	+/- 1.7 in USA	**Full**	Yes	www.jpl.nasa.gov/srtm Brown et al., 2005
GDEM ASTER 2001	WGS 84 lat long	Satellite Stereo	30		+/- 8.6	**Partially**	No	Hirano et al., 2003
IGM 1980	ED 50 UTM 32 N	Raster Cartography 1:25,000	20	+/- (7-10)	---	**Full**	Yes	http://www.igmi.org
MATT 1980	WGS84 UTM 32 N	Raster Cartography 1:25,000	20	---	---	**Full**	Yes	http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais/
TINITALY 1980/90	WGS84 UTM 32 N	Raster Cartography 1:10,000	10	+/- (1.8-3.5)	---	**Full**	Yes	Tarquini et al., 2007
TanDEM-X 2012	-	RADAR	5		+/- 0.7	**Summit**	No	Wegmuller et al., 2014
ATLAS 1990	Roma40 GB East	Raster Cartography 1:10000	5	+/- 1	---	**Full**	Yes	Favalli et al., 1998
LiDAR 2004	WGS84 UTM 33 N	Airborne Lidar	2	+/- 0.35	---	**Partially**	No	Mazzarini et al., 2005
LiDAR 2005	WGS84 UTM 33 N	Airborne Lidar	2	+/- 0.35	+/- 0.24	**Full**	Yes	Bisson et al., 2016
LiDAR 2007	WGS84 UTM 33 N	Airborne Lidar	2	+/- 0.35	---	**Summit**	No	Neri et al., 2008
DSM 2012/2014	WGS84 UTM 33 N	Digital Photogrammetry	2	---	---	**Summit**	Yes	De Beni et al., 2015
Pleiades 2015	WGS84 UTM 33 N	Stereo Satellite Images	2	---	---	**Summit**	Yes	Ganci et al., 2018
DSM 2005	WGS84 UTM 33 N	Digital Photogrammetry	1	---	---	**Full**	No	Gwinner et al. 2006

***Full:** continuous coverage ≥ 600 km² - **Partially:** fragment coverage < 600 km² - **Summit:** coverage at elevations higher than 2000 m a.s.l.*

Techniques for 3D Data

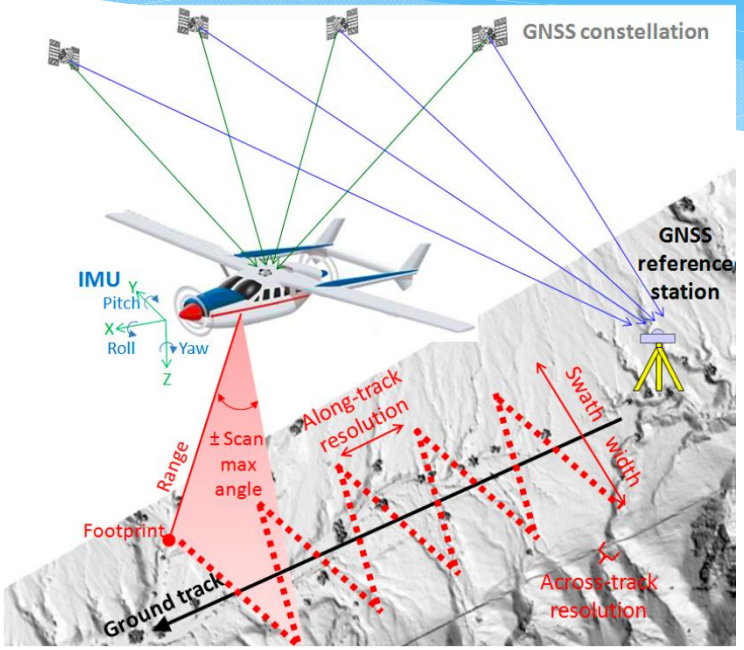


Airborne Lidar Topography

Airborne LIDAR

(*Light Detection and Ranging*)

ALS (*Airborne Laser Scanning*)



- **3D Point Acquisition (x, y, z)**
- **NIR Sensor single band**
- **Return of pulse in time**
- **Airtcraft Accurate position**
  (GPS, IMU)

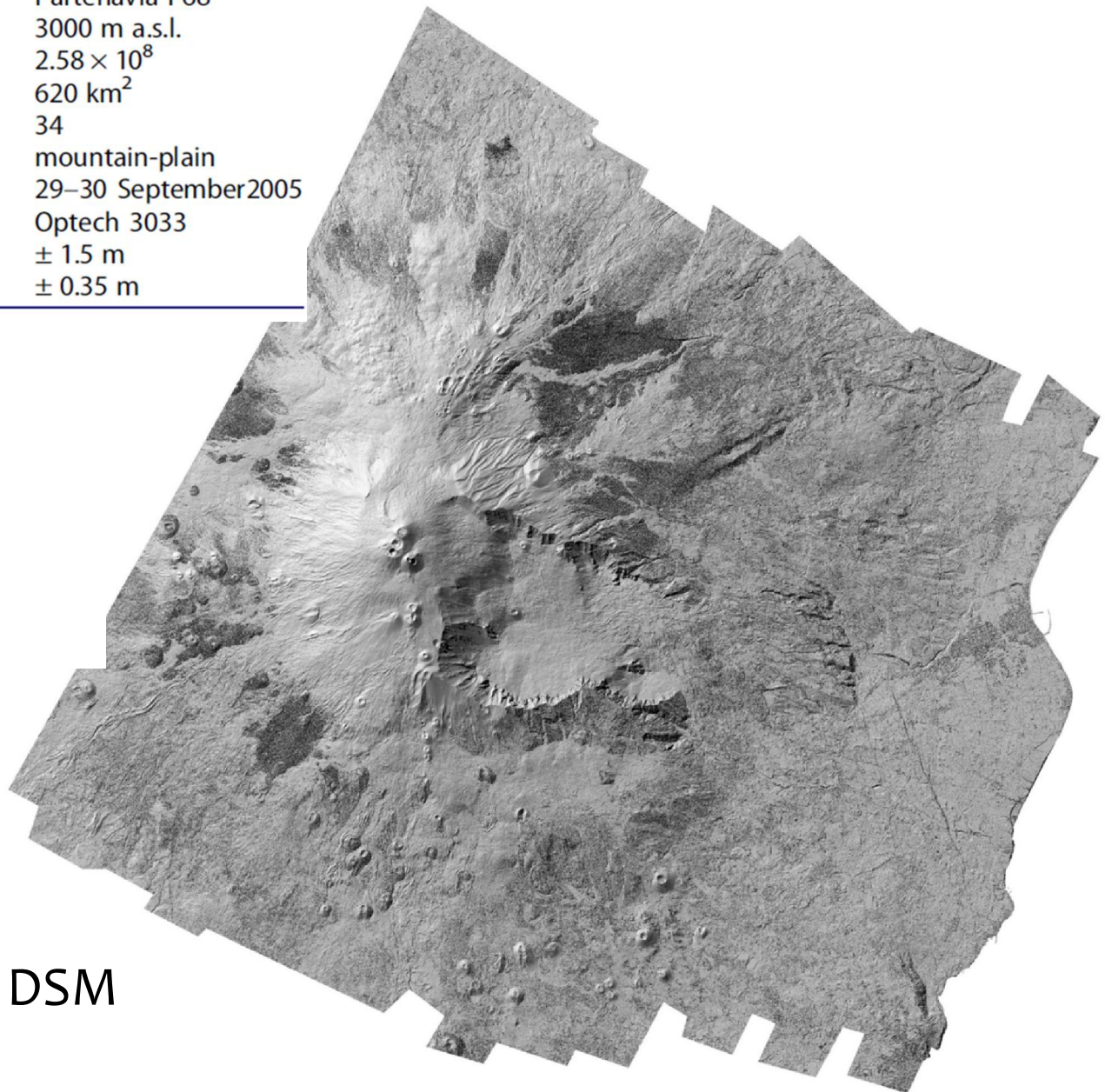
2005 LiDAR

LiDAR campaign general characteristics	
Aircraft	Partenavia P68
Average flight height	3000 m a.s.l.
Total points	2.58×10^8
Surface area	620 km^2
Strips number	34
Morphology	mountain-plain
Acquisition period	29–30 September 2005
Laser Altimeter	Optech 3033
Horizontal instrumental accuracy	± 1.5 m
Vertical instrumental accuracy	± 0.35 m

- **Spatial Resolution: 2m**
- **Accuracy in x ,y: strumental**
- **Accuracy in z: ± 24 cm**
- **Coverage: 620 km²**
- **Download: platform IJDE**

~2.5×10^8 LiDAR points
(on Terrasolid platform)

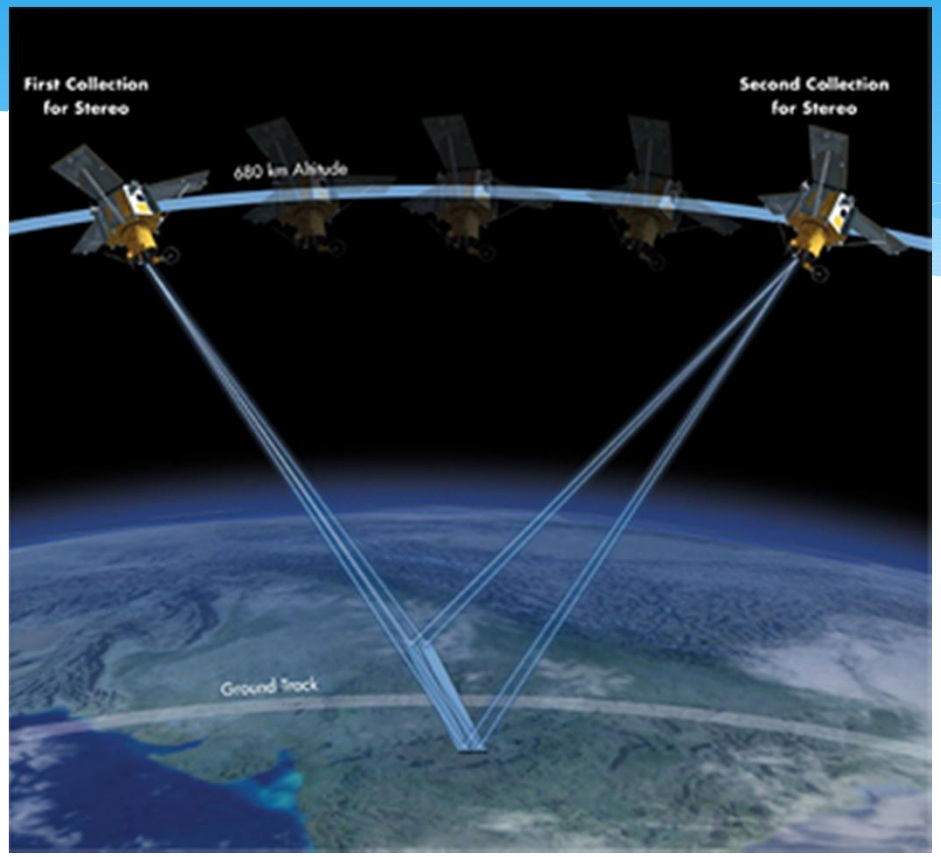
Bisson M, Spinetti C., Neri M., Bonforte A. (2016). "Mt. Etna volcano high resolution topography: Airborne Lidar modelling validated by GPS data", **International Journal of Digital Earth**, 9, 7, 710-732 doi:10.1080/17538947.2015.1119208



DSM

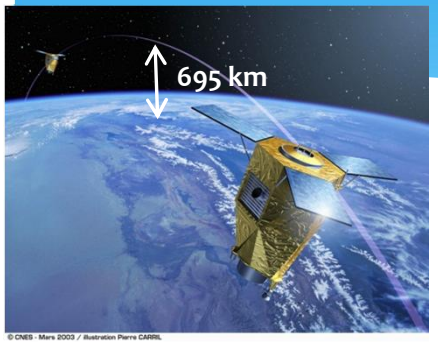
Stereo Satellite Topography

STEREO SATELLITE PHOTOGRAMMETRY



- Images Acquisition
- Multispectral Sensor
- Stereoscopy technique
- Satellite accurate position (Efemeridi/Attitude)

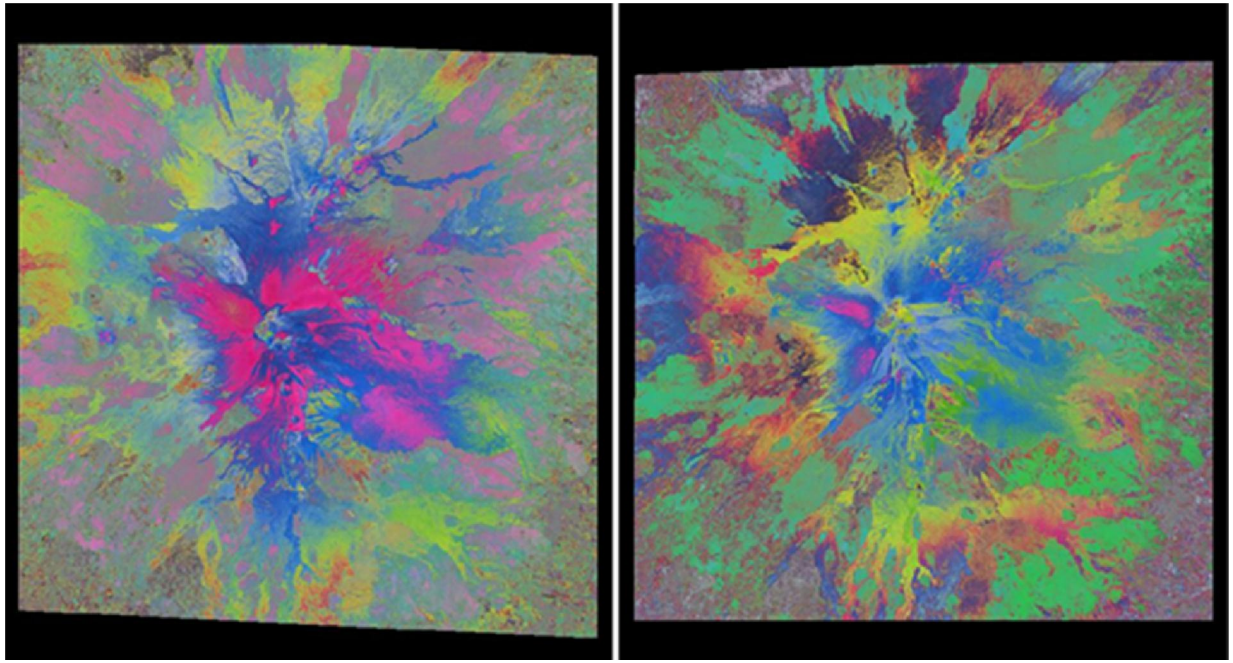
Plèiades DATA



Company: Airbus Defence and Space
Launch :Pléiades 1A (16 Dic 11), Pléiades 1B (2 Dic 12)
Site: Kourou (Guiana Francese)
Tipo di orbita: Sun-synchronous orbit
Life time: 5 year
Revisit Interval: 1 day
Intervallo di intensità 11 bits /pixel (2048 level)
Swath: 20 km a nadir
Strip mapping (mosaic): 100 x 100 km
Stereo Imaging: 20 x 280 km

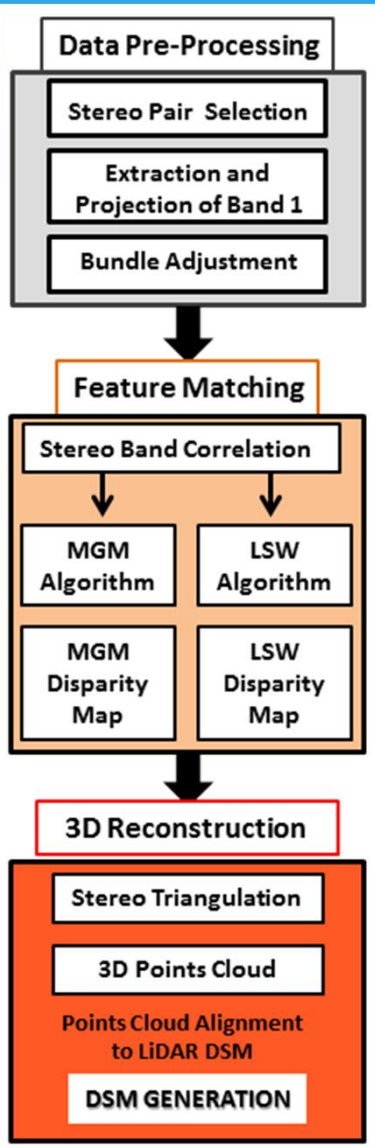
2 stereo images

- 28 July 2015
- 380 km²
- Band 1
- Spatial resolution: 2 m



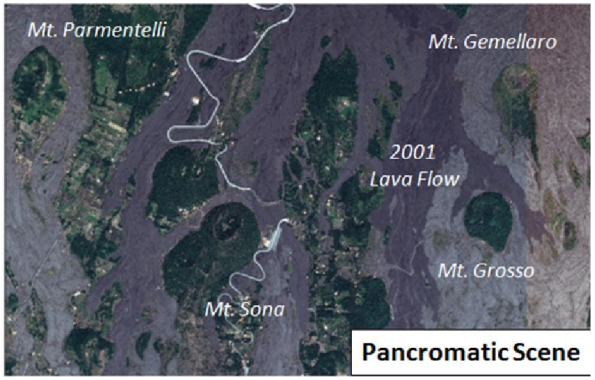
WORKFLOW

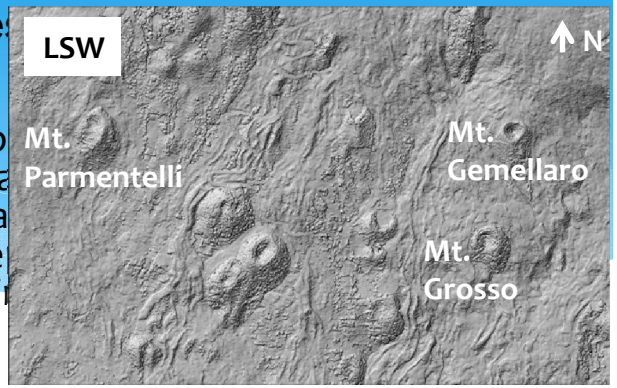
The Pleiades stereo pairs were processed using the **NASA Ames Stereo Pipeline** (**ASP**), a suite of open source automated geodesy and stereo-photogrammetry tools intended to proce
accurate camera pose information.

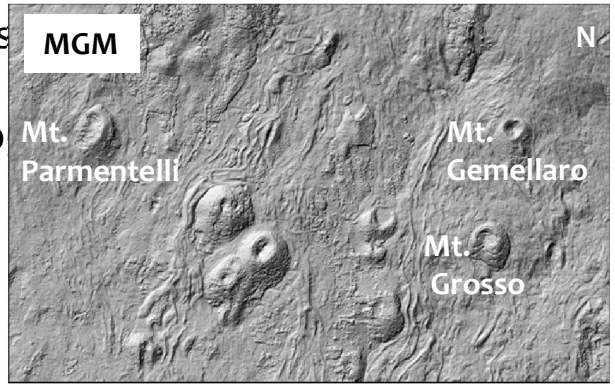


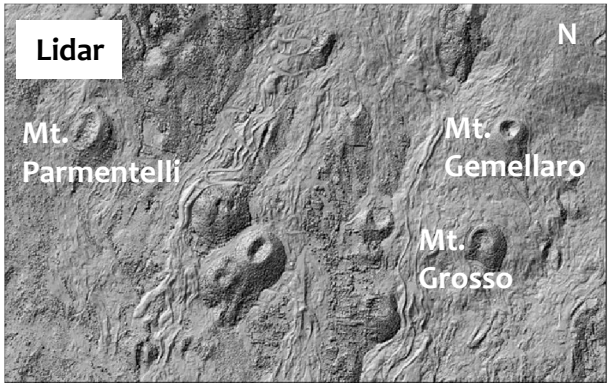
- The ASP procedure has been imp
algorithms of feature matching: Loca
Global Matching MGM (Facciollo et a
results shows a more detailed re
algorithm instead of LSW one reachi
the 2005 LiDAR DSM.

- The standard ASP procedure has
adding new step of alignment
previous topography of LiDAR 200



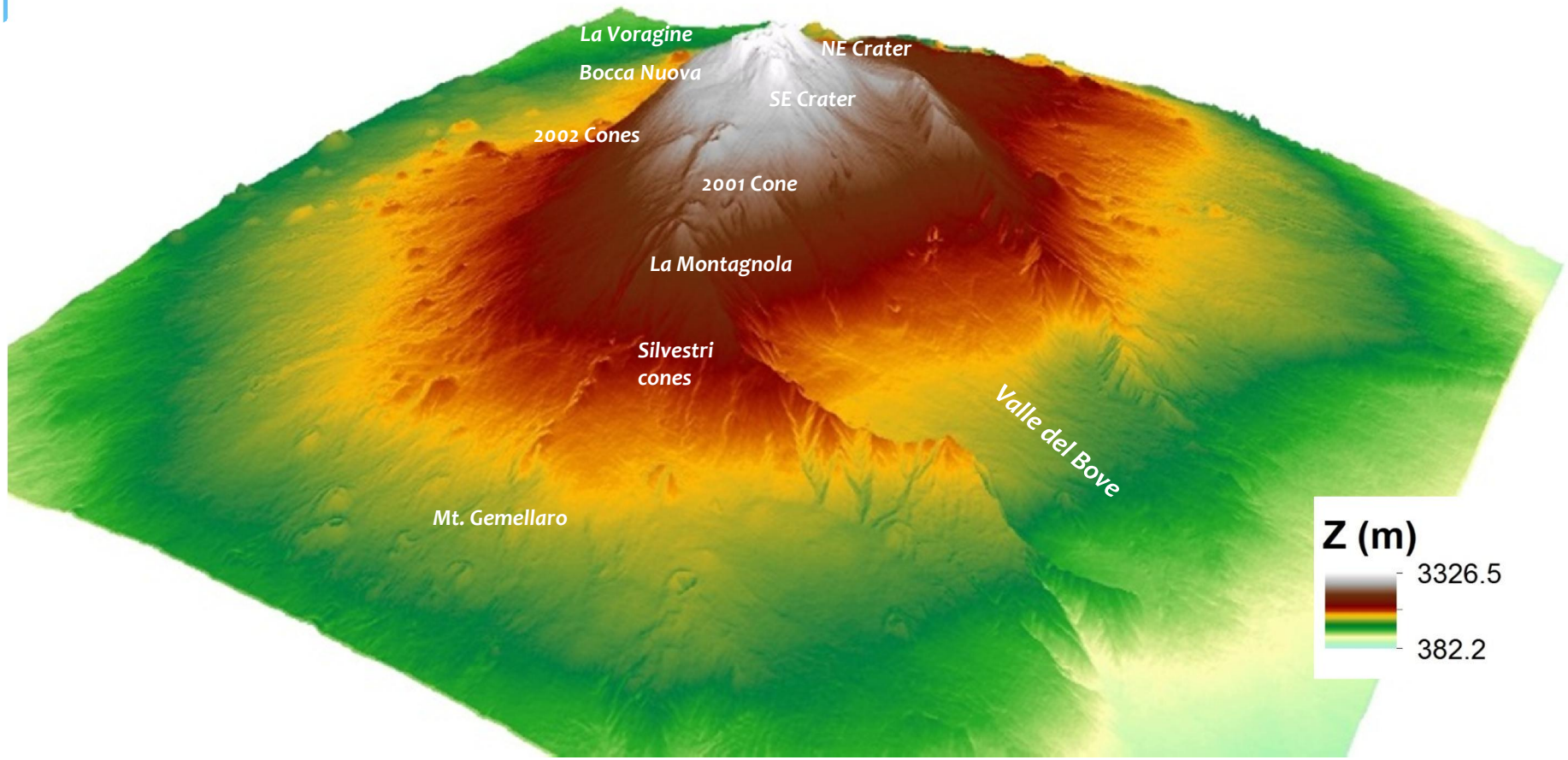






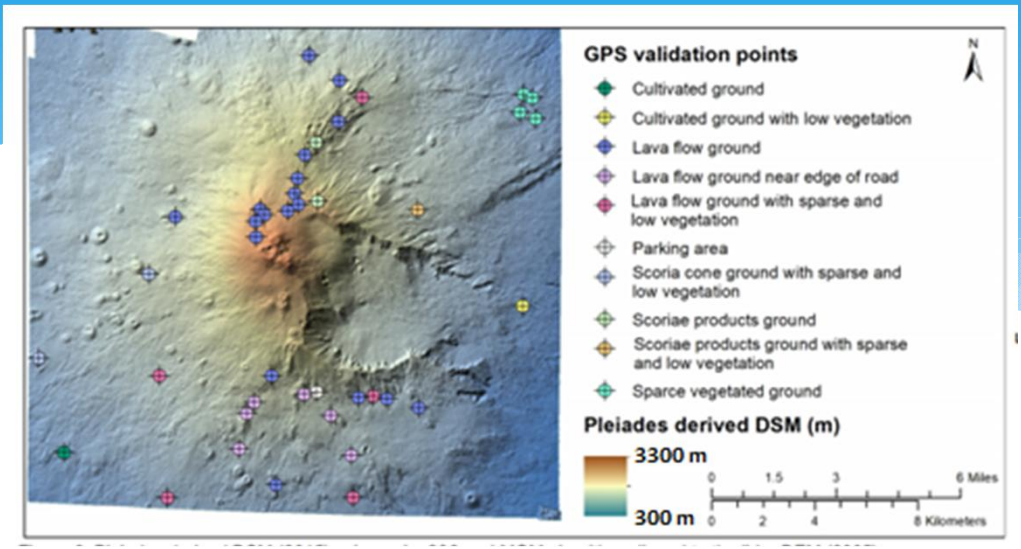
Resulting Mt. Etna volcano Digital Surface Model

- The Model covers an area of 400 km^2 with spatial resolution of 2 m



Palaseanu-Lovejoy M., M. Bisson, C. Spinetti, M.F. Buongiorno, O. Alexandrov, T. Cecere, 2019. *Mount Etna High-Resolution Topography from PLEIADES Satellite Data: a case Study for Active Volcanic Areas.* **Remote Sens. 2019, 11(24), 2983; https://doi.org/10.3390/rs11242983**

Validation



Often the 3D point cloud may be off by several meters or kilometers, depending on the errors in the position and orientation of the satellite cameras. The errors can be corrected in post-processing by aligning the 3D point cloud to a much more accurately positioned (if potentially sparser) dataset. We are using the Lidar 2005 derived 5m resolution DEM. The point cloud alignment uses the Iterative Closest Point algorithm (ICP). We aligned the results obtained from Pleiades imagery processed with the MGM algorithm. This area covers approximately 400 km2 and contains 41 of the GPS geodetic monitoring network of Mt. Etna points.

Planimetric Validation

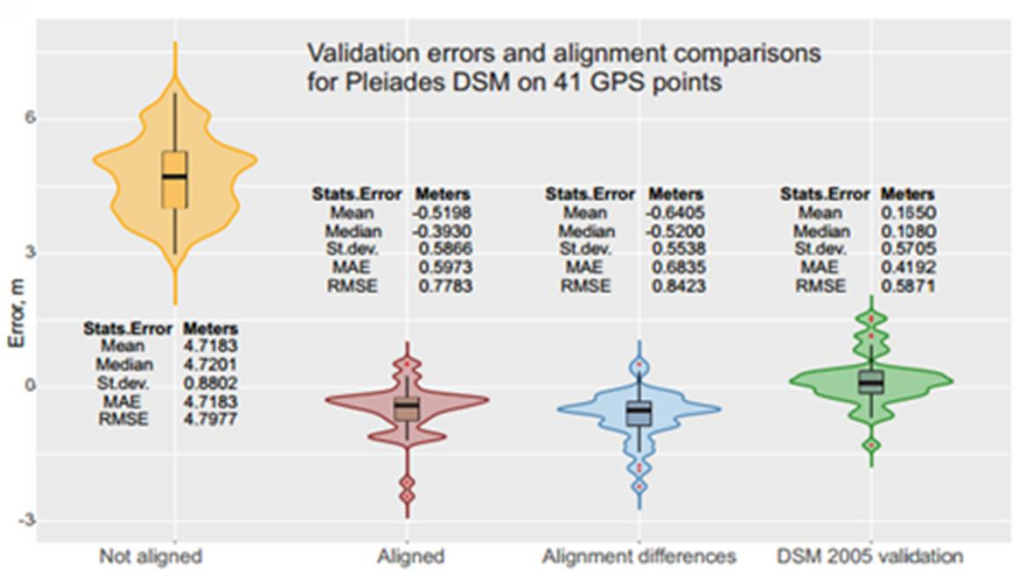
The Pleiades model results characterized by an error in x ed y equal to 1 pixel (2 m)

Altimetric Validation

Rigorous testing of NASA ASP using Pleiades stereo data over terrain with large elevation ranges and roughness. Findings:

- Two algorithms tested: local search window (LWS) and more global matching (MGM)
- Sub-meter vertical RMSE after alignment: 0.78 m
- Relative short time of processing when workflow is established: up to 48 hours
- Method adequate for updating topographies in a dynamic, changing and challenging environment.

Pleiades derived DSM

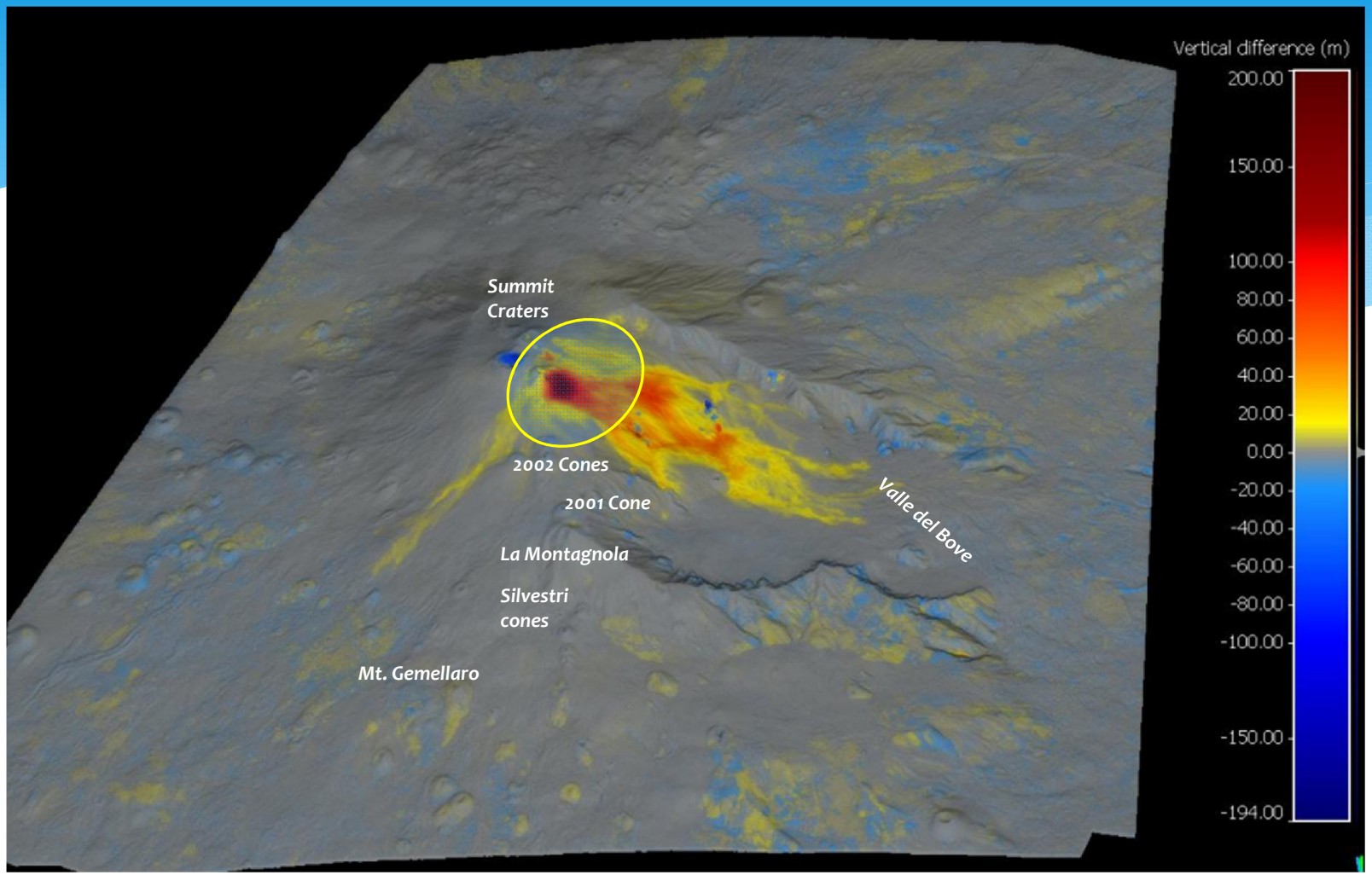


Validation error statistics for Pleiades DSM: MAE = Mean Absolute Error; RMSE = Root Mean Square Error, CCP = Check Control Points, DSM = Digital Surface Model, MGM = More Global Matching

Validation on 41 GCP points		
Statistics (meters)	Pleiades 2&3 DSM MGM correlation Not Aligned	Pleiades 2&3 DSM MGM correlation Aligned
Mean Error	4.72	-0.52
Median	4.72	-0.39
Standard deviation	0.88	0.59
MAE	4.72	0.60
RMSE	4.80	0.78

Application: MODEL TO MODEL DIFFERENCE

Results



Comparing the 2005 and 2015 DEMs it has been possible to produce the map of difference in height. The map highlights that all morphological changes occurred from 2005 to 2015 affect areas with elevations above 1300 m a.s.l. In detail, these changes are localized on Etna summit area, Valle del Bove and South-West Flank.

Accurate quantification of morphological changes at Mt Etna on 10 years of volcanic activity using high resolution mapping derived from Pleiades and Lidar data

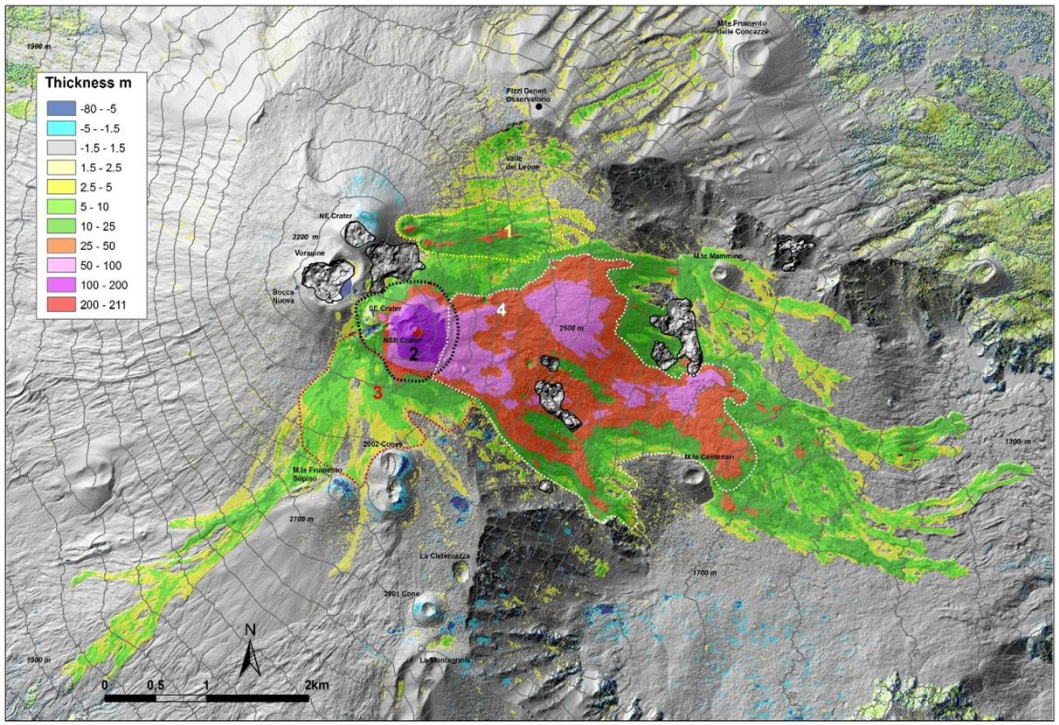
Erupted material volume results:

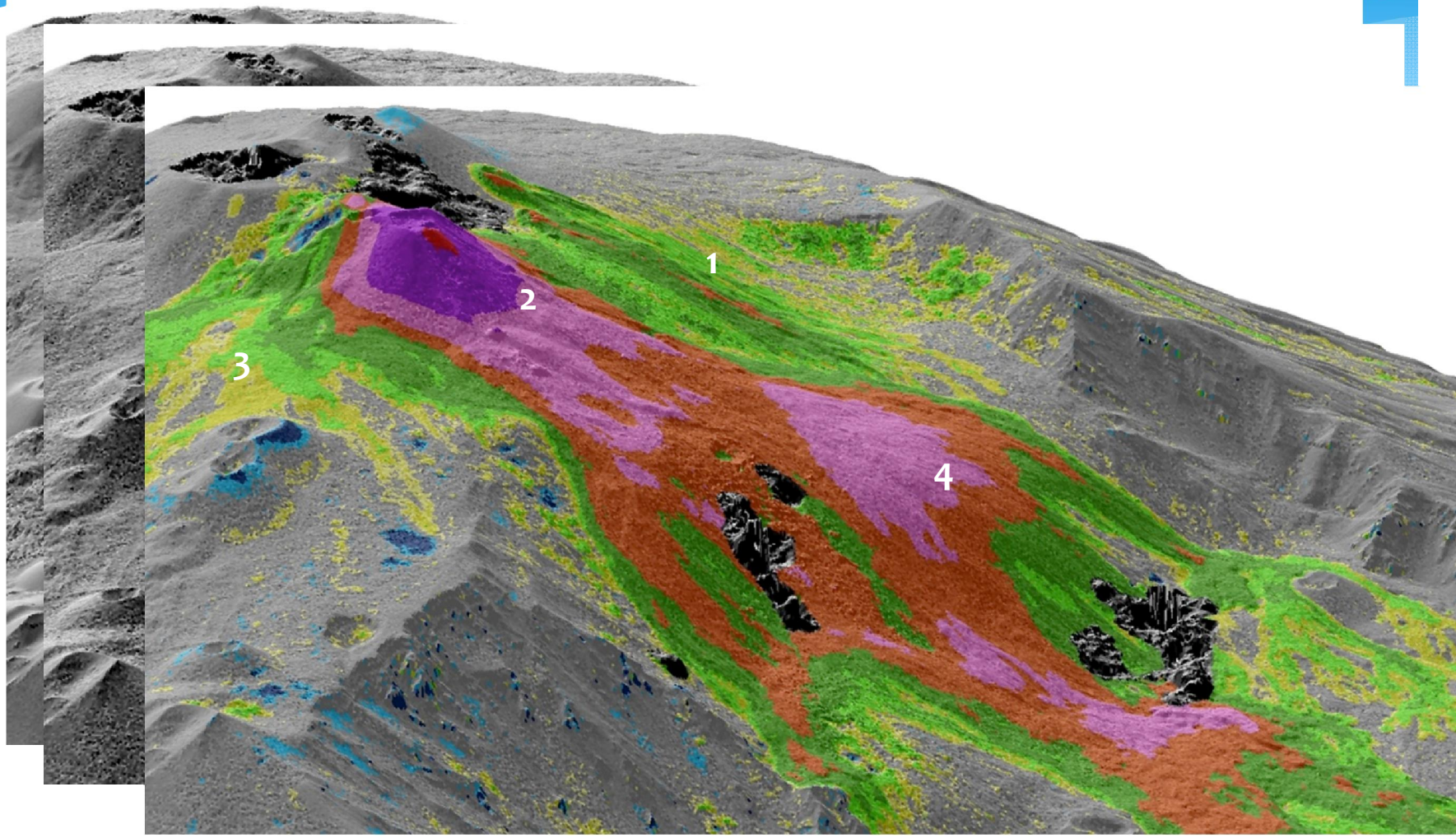
- Zone 1: sub-terminal eruption of 2014; area 0.76 km^2 , volume 8.6± 0.8 $*10^6$ m^3 at 95% C.I.

- Zone 2: SEC-NSEC apparatus volcanic activity from 2006 to 2015; area 0.72 km^2, volume 53.7 ± 0.7$*10^6$ m^3 at 95% C.I.

- Zone 3: stratified lithology of layers of lava and tephra fallout deposits; area 1.29 km^2, volume 10.1$*10^6$ m^3 ± 12.8% at 95% C. I.

- Zone 4: upper portion of Valle del Bove; area 4.22 km^2, volume 155.0 ± 4.2$*10^6$ m^3 at 95% C.I.





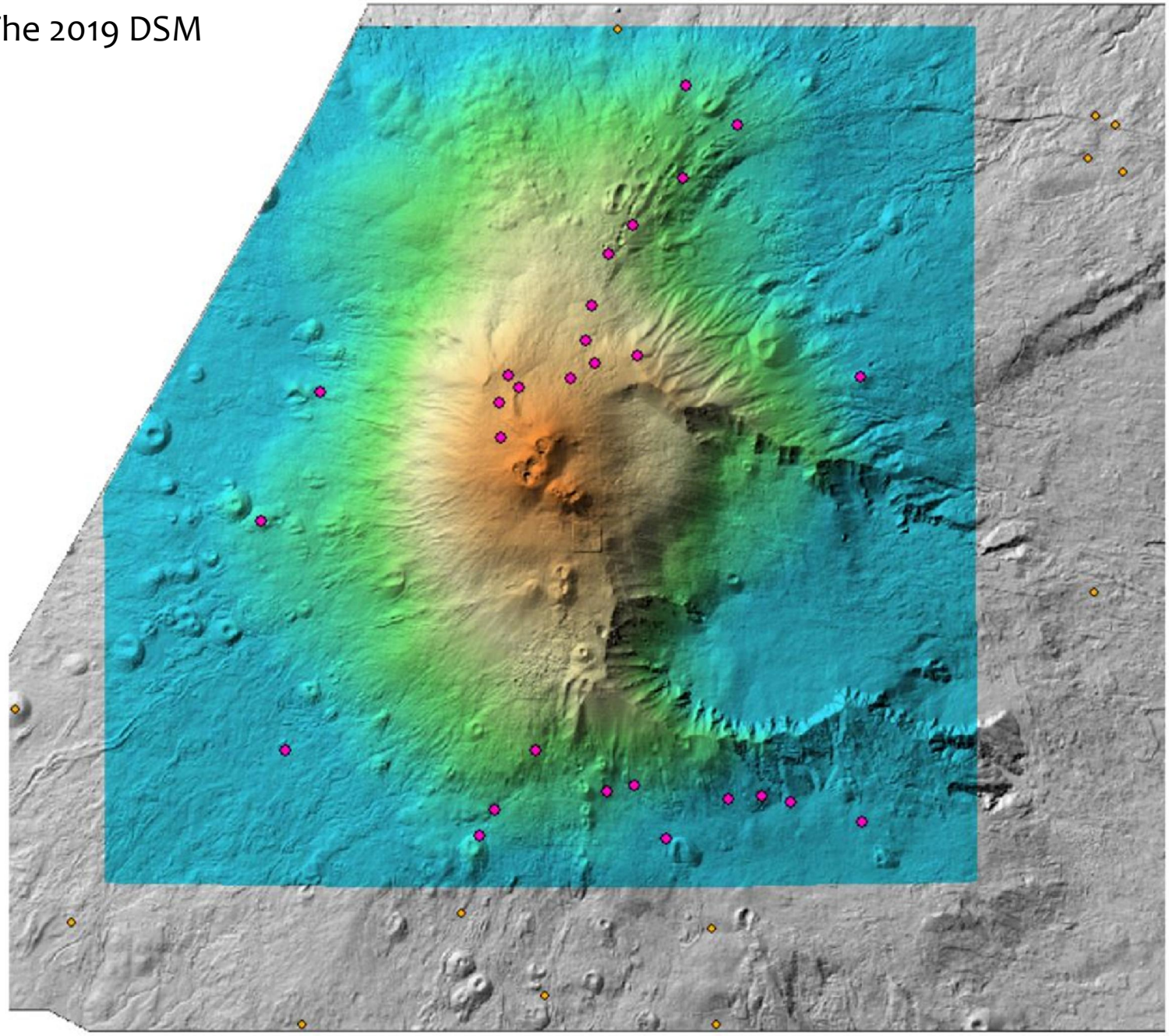
The results indicate that the volume of the 2005 to 2015 erupted products is equal to 284.3 ± 15.8*10^6 m^3

M. Bisson, C. Spinetti Palaseanu-Lovejoy M., M.F. Buongiorno, O. Alexandrov, T. Cecere, 2020. *Ten years of volcanic activity at Mt Etna: high resolution mapping and accurate quantification of the morphological changes by Pleiades and Lidar data. Submitted to* **IAG**

Comparison with previous works

year	date	type of activity	vent location	erupted volume estimation - $10^6 m^3$			References
				lava	proximal tephra	distal tephra	
2006	15-24 July		SEC	2	no estimate	no estimate	Harris et al., 2011
	13 September - 27 November	16 paroxysmal episodes	SEC	37	no estimate	1,41	Andronico et al., 2009a,b; Harris et al., 2011; Andronico et al., 2014b
2007	29 March - 23 November	6 paroxysmal episodes	SEC	5.4	9.48	2,35	Andronico et al., 2009a,b;
2008	10 May	paroxysmal episode	SEC	1.08	0.9	no estimate	Di Grazia et al., 2009
2008-2009	13 May 2008 - 6 July 2009	paroxysmal episode followed by flank eruption	NEC (?) W wall of the VdB	74	negligible	no estimate	Di Grazia et al., 2009 Behncke et al., 2016
2011-2012	12 January 2011 - 24 April 2012	25 paroxysmal episodes	NSEC	28	19	2,5	Behncke et al., 2014; Andronico et al., 2014b
2013	19 February - 28 December	21 paroxysmal episodes	NSEC	21.81	22.64	6,92	De Beni et al., 2015; Andronico et al., 2018a
2014	22 January - 7 April	subterminal eruption	NSEC	7.8	negligible	negligible	De Beni et al., 2015
	14-16 June	paroxysmal episode	NSEC	2.3	no estimate	no estimate	De Beni et al., 2015
	5 July - 10 August	subterminal eruption	base of the NEC	5.9	no estimate	no estimate	De Beni et al., 2015
	8-16 August	paroxysmal episode	NSEC	2.6	negligible	negligible	De Beni et al., 2015
	28 December	paroxysmal episode	NSEC	1.08	0.9	no estimate	INGV-OE, 2014
2015	31 January - 15 May	3 paroxysmal episodes	NSEC	3.24	no estimate	no estimate	INGV-OE, 2015a,b
total volume of lava, proximal tephra and air-distal tephra				192.21	52.92	13.18	
total volume	258.31 $10^6 m^3$						

The 2019 DSM



CONCLUSIONs

- A Digital Elevation Model of Mt Etna has been updated obtaining a topography of the summit and the entire volcano edifice covering an area of 400 km^2 with spatial resolution of 2 m;
- The Model has been validated as 2005 Lidar DEM by using the ground control points (GCP) of the Etna GPS permanent network;
- The obtained planimetric accuracy is 2 m and vertical accuracy is 0.8 m;
- The total volume of products emitted by Mt Etna from 2005 to 2015 was accurately quantified from high resolution remote sensing data resulting in 284×10^6 m^3 of products with 5% accuracy with an average rate of 28.5×10^6 m^3 per year;
- More than half of the magma volume erupted in ten years involves the only Valle del Bove;
- The highest thickness of erupted deposits is recorded in New SE Crater born in 2011 and in continuous evolution;
- For the first time, the 2014 lava field formed at the base of NE Crater was mapped and quantified in area, thickness and volume;
- Work in progress update the model with the 2020 data.

TGweb **GEOSCIENZE** News –
Ricostruzione 3D delle superfici vulcaniche da dati satellitari

https://www.youtube.com/watch?v=UwDgzp2l8IU

THANK YOU!

Courtesy of Behncke, 5-10-2019