22nd International Workshop on Laser Ranging 2022

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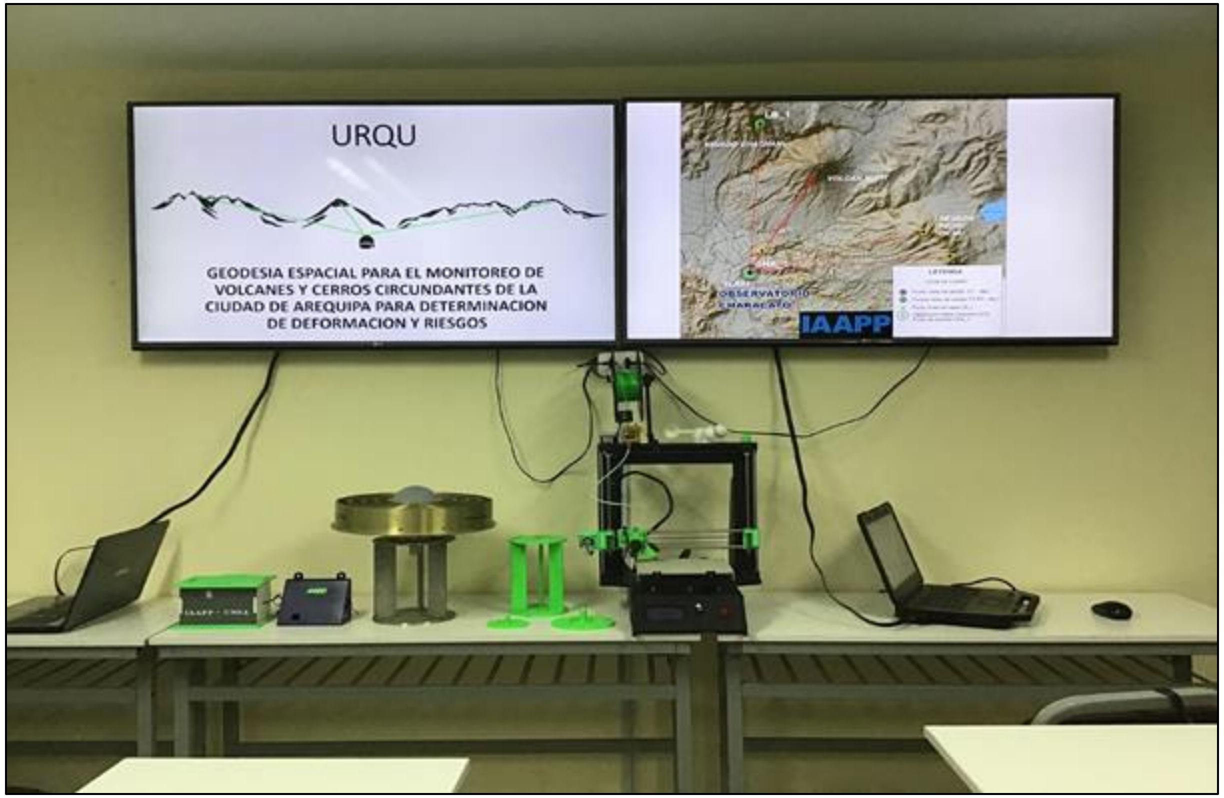
SPACE GEODESY FOR THE MONITORING OF VOLCANOES AND SURROUNDING HILLS OF AREQUIPA USING THE AREQUIPA STATION AS A REFERENCE



GUADALAJARA - SPAIN

07 November 2022

NASA – UNSA AGREEMENT

IAAPP – ASTRONOMICAL & AEROESPACE PEDRO PAULET INSTITUTE

UNSA – UNIVERSIDAD NACIONAL DE SAN AGUSTIN

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Project Location

Location: The Characato Observatory / Pedro Paulet Astronomical and Aerospace Research Institute (IAAPP).

Location: Aquisition and Processing of Satellite Data Center (CAPDS)

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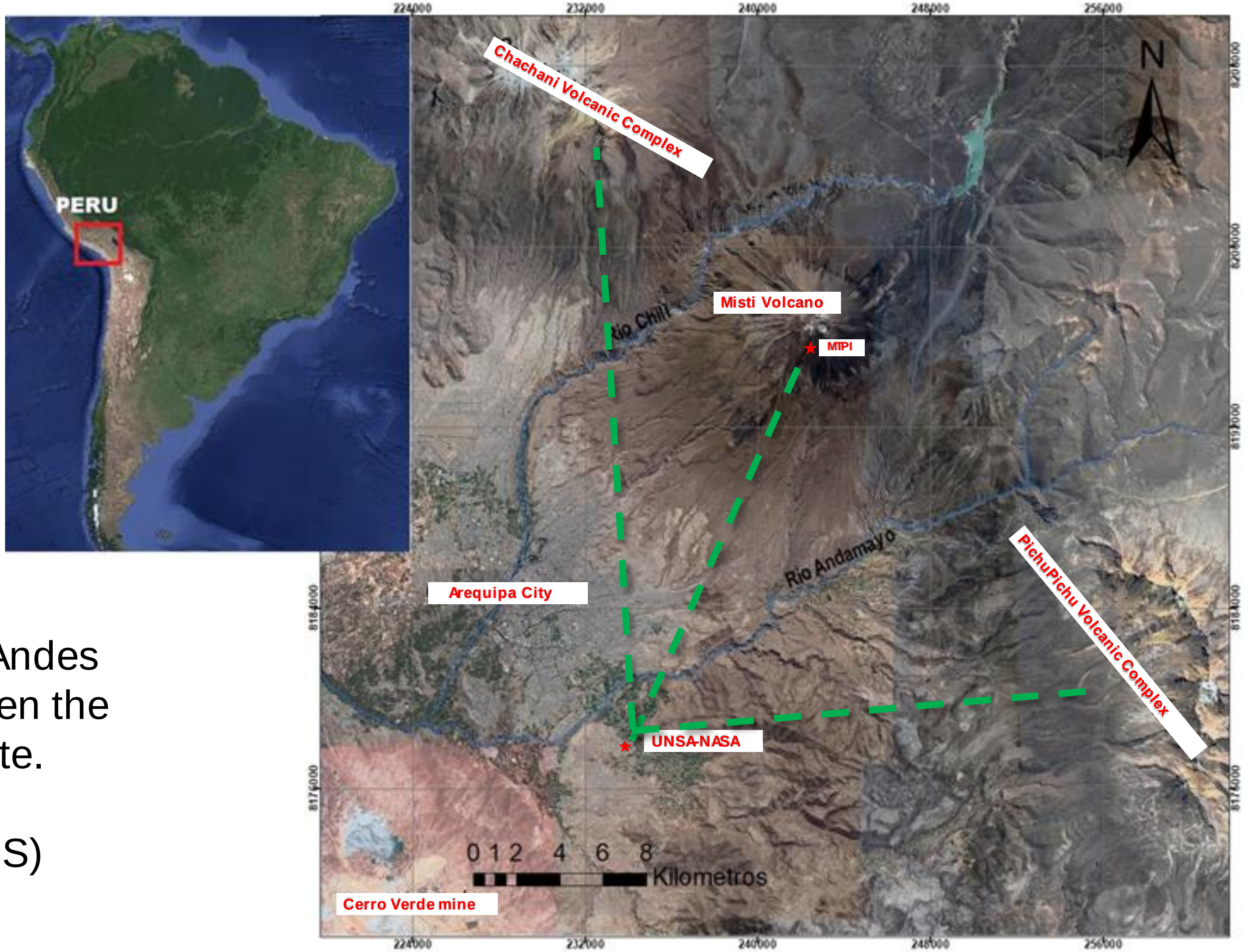
The study area: Arequipa, city in the South of Peru (1,382,730 pop) and includes the Misti Volcano, and the Chachani and the PichuPichu Volcanic Complex.

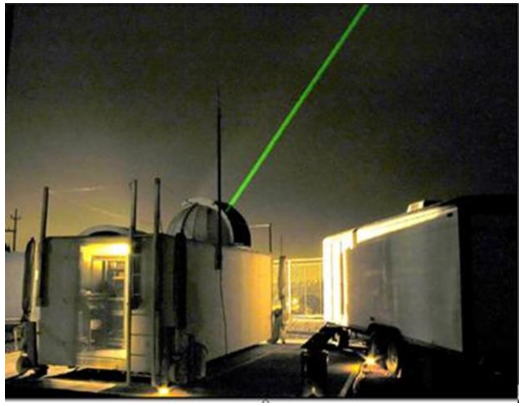
Volcano Activity:
Fumaroles in the cráter, growing dome concerns.



Arequipa: Located in the volcanic zone of the Andes Mountain range. In the subduction zone between the Nazca and the South American continental plate.

Last Earthquake: 23 June, 2001 - M 8.4 (USGS)

Main Objective: Analyze and Monitor with Space Geodetic Techniques the volcanoes around the city of Arequipa, to determine deformation and risk, using the Arequipa Station as a reference.



LRS SAO-2 1970 to 1990
TLRS-3 1990

DORIS 1990

GPS/GNSS UNAVCO 1994
GNSS CNES 2013

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The idea: Use Space Geodetic Techniques, with the Arequipa Station as reference.

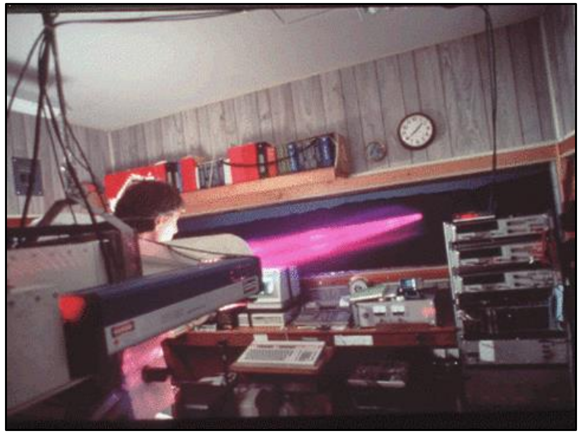
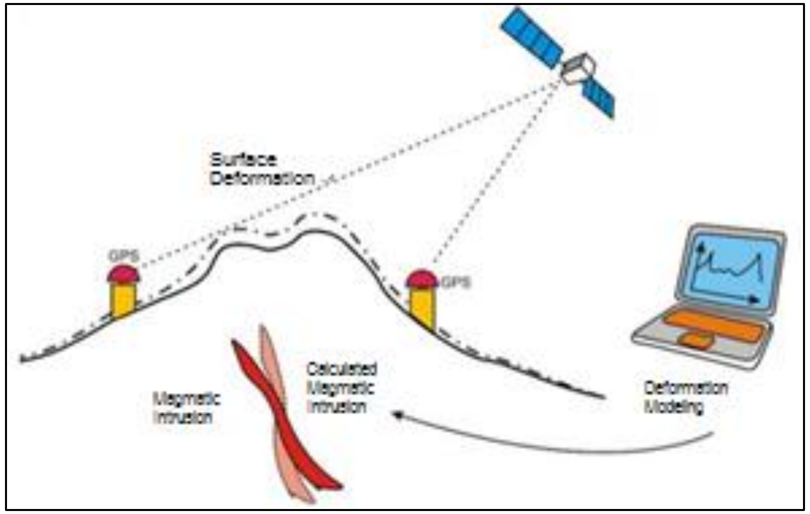


Photo by John Nakata, USGS.

- The two-color EDM in operation at Parkfield, California. Built in the mid-1970s.
- The magenta light is a combination of red and blue laser light expanded to 20 cm.
- Precision of 0.5–1.0 mm for ranges between 1 and 12 km.
- To measure distances to a 1 mm precision over a 10 km long baseline, or 0.1 part-per-million, the average temperature and pressure along the 10 km path need to be known to be better than 0.1 degrees C and 1 mb.
- However, the two-color EDM measures the travel time of light for two wavelengths, red and blue.
- Because the atmosphere is dispersive, there is a difference in travel time which is a direct function of temperature and pressure.



- The difference in travel time is used to measure the average temperature and pressure in the atmosphere for calculating the index of refraction. With the index of refraction, the distance is computed from the travel time of one of the colors.

  https://earthquake.usgs.gov/monitoring/deformation/edm/

Experimental Modeling of ground deformation associated with shallow magma intrusions.
Earth and Planetary Science Letters, 317, 145-156. 2012 O. Galland.
https://doi.org/10.1016/j.epsl.2011.10.017

The tries: Presented Posters in ILRS Workshop.

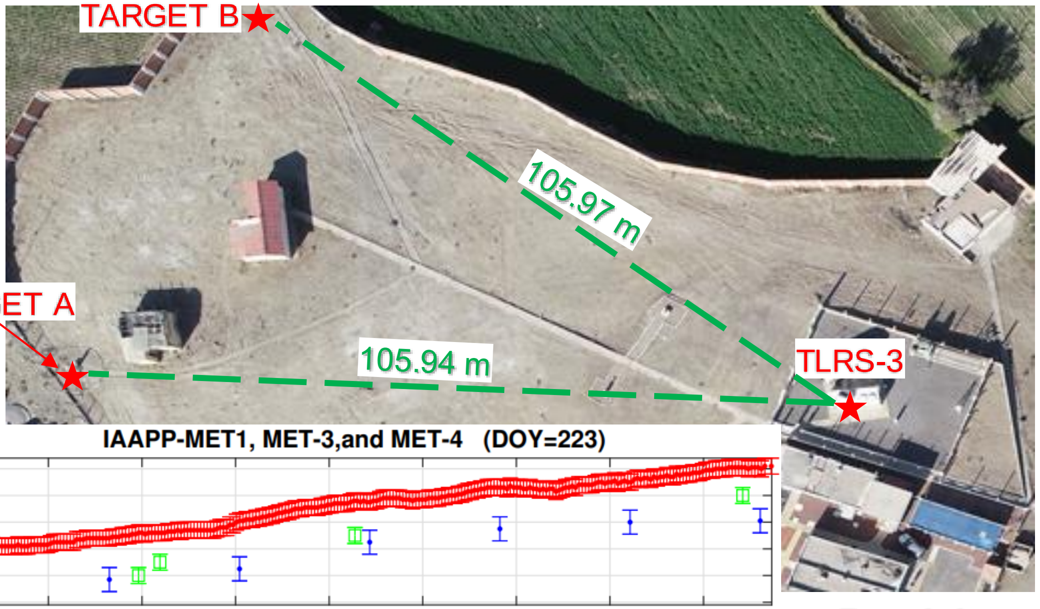
Laser Ranging and GPS Measurements to Misti, Chachani, Pichu Pichu Volcanoes and Surrounding Hills, and Applications of Precise Positioning to Monitoring of Volcanic Deformation and Seismic Risk.
19^{th} INTERNATIONAL WORKSHOP ON LASER RANGING ANNAPOLIS, MD October 27-31, 2014.

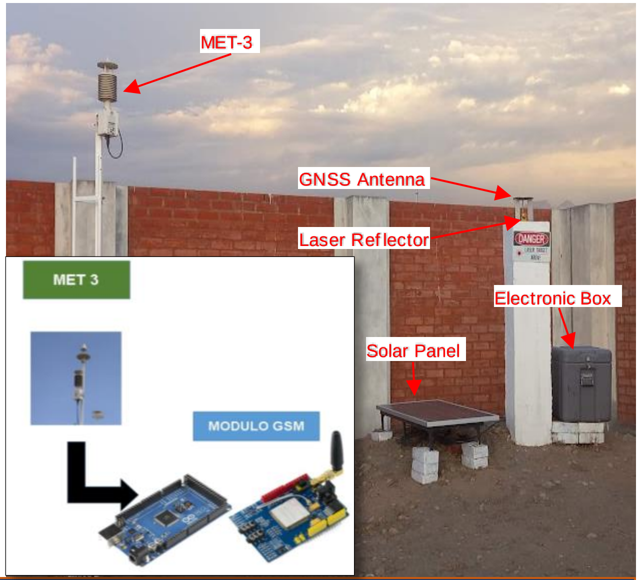
Installation of GNSS receivers and Laser Reflectors in Volcanoes and Hills surrounding the Arequipa Station
21^{ST} ILRS Workshop on Laser Ranging, Canberra, AUSTRALIA. 5-9 Nov. 2018.

Results: Monitoring Prototype Targets

Two prototype targets are implemented with GNSS, Laser reflectors and metereological stations.

Target	Equipment	Coordinates
A	**Receiver Type:** TRIMBLE NETR9 **Antenna:**TRM55971.00	**Lat:** -16.464781709 **Long:** 288.507237928 **Alt:**2487.8168 m
B	**Receiver Type:** SEPT POLARX5 **Antenna:** LEIAR20	**Lat:** -16.465080398 **Long:** 288.507778989 **Alt:** 2489.2329 m

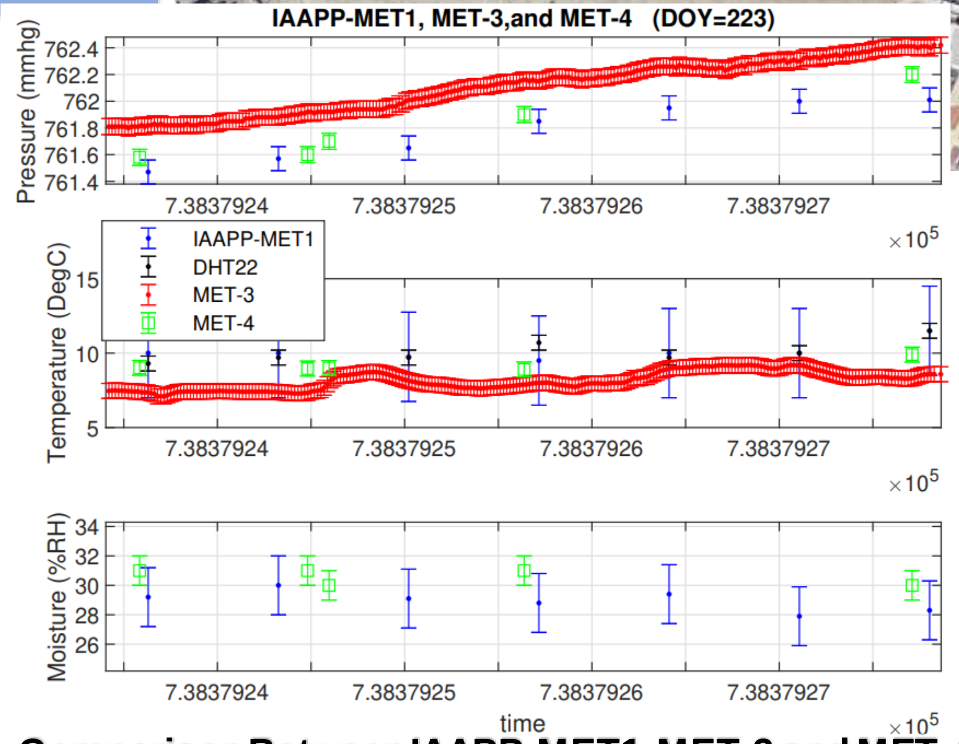




Target A has IAAPP-MET (Developed by IAAPP).
Target B has the MET-3

Target A

Target B



Comparison Between IAAPP-MET1, MET-3 and MET-4

Precision

IAAPP-MET1
±3 degC
±0.12 hPa
±2 %RH

MET-3
±0.5 degC
±0.08hPa
±2 %RH

MET-4
±0.5 degC
±0.08hPa
±1 %RH

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Results: Validation of Prototype Targets

$$d_{rec}^{sat}(t) = \frac{1}{2} * \frac{c}{\mu} * \Delta t_{rec}^{sat}$$

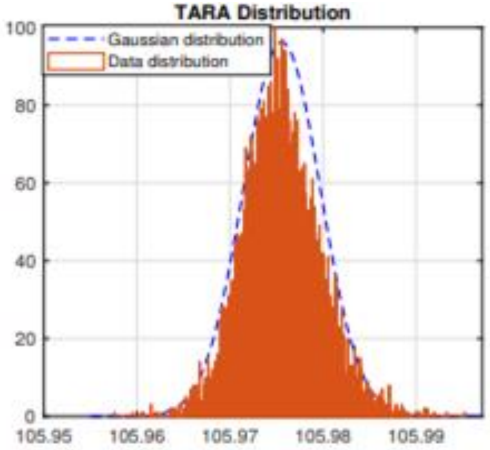
$d_{rec}^{sat}(t)$: Unidirectional range
c: Speed of light in a vacuum.
μ: Refractive index of the medium.
Δt_{rec}^{sat}: Bidirectional time of flight.

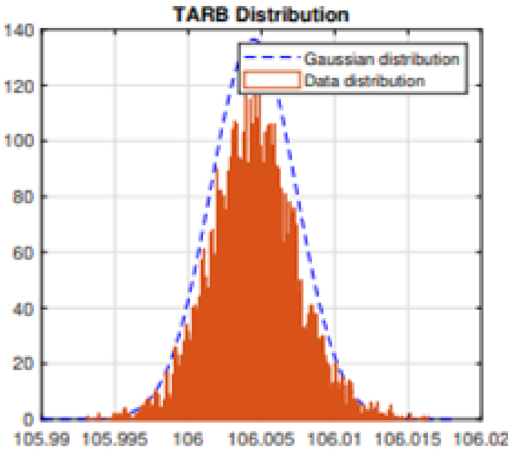
LRS Results: Standard Deviations (Considering Refraction Index = 1)

MIMICO data obtained

Target	Parameter	Attemp 1	Attemp 2	Attemp 3	Attemp 4	Attemp 5	Comb
Target A	Mean:	105.9756m	105.9756m	105.9757m	105.9755	105.9754	105.9756m
	S. Deviation:	4.6mm	4.6mm	4.4mm	3.0mm	3.8mm	4.1mm
	Min:	105.9576m	105.9637m	105.9619m	105.9646m	105.9604	105.9576
	Max:	105.9919m	105.9933m	105.9952m	105.9850m	105.9879	105.9952
Target B	Mean:	106.0045	106.0040	106.0043	106.0046	106.0044	106.0044m
	S. Deviation:	3.1mm	2.5mm	3.7mm	2.5mm	2.6mm	2.9mm
	Min:	105.9901m	105.9994m	105.9931m	105.9946m	105.9984	105.9931m
	Max:	106.0061m	106.0130m	106.0120m	106.0164m	106.0130	106.0164m

The measured data follows the Gausian Distribution (Considering Refraction Index = 1)

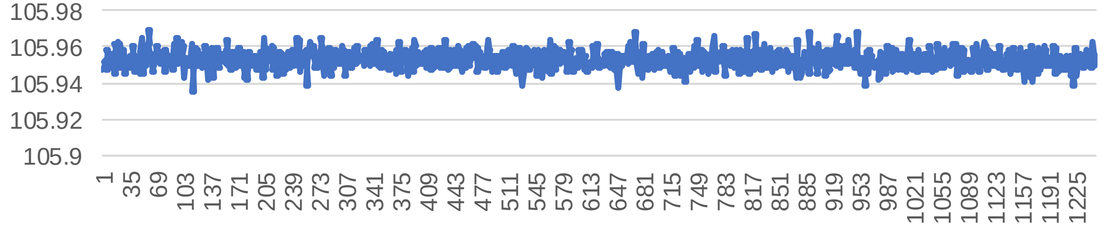




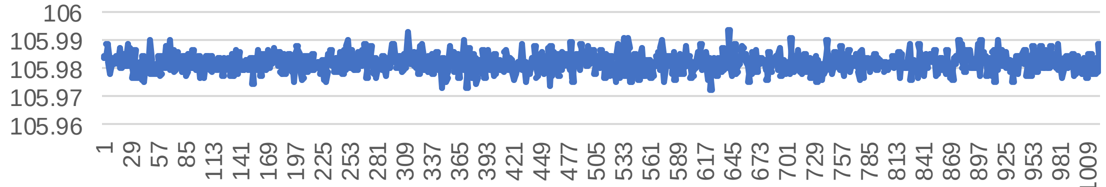
GNSS Results: Processed with GAMIT/GLOBK (AREG, AREQ reference)

Doy	215			216		
TARGET	Sn (mm)	Se (mm)	Su (mm)	Sn (mm)	Se (mm)	Su(mm)
A	1.33	1.77	6.49	1.33	1.76	6.37
B	1.22	1.67	6.02	1.23	1.67	5.95

TARGET A: Distance vs observation number (Index refraction 1.00021429)



TARGET B: Distance vs observations number (Index refraction 1.00021429)



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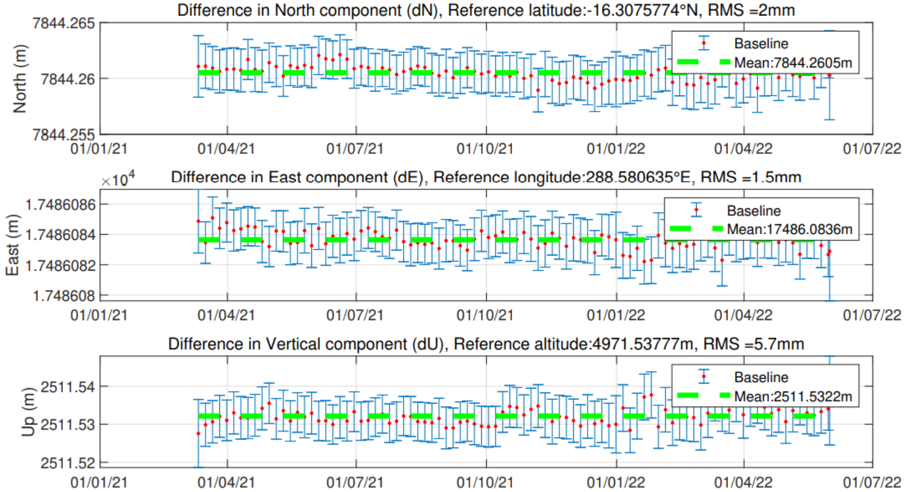
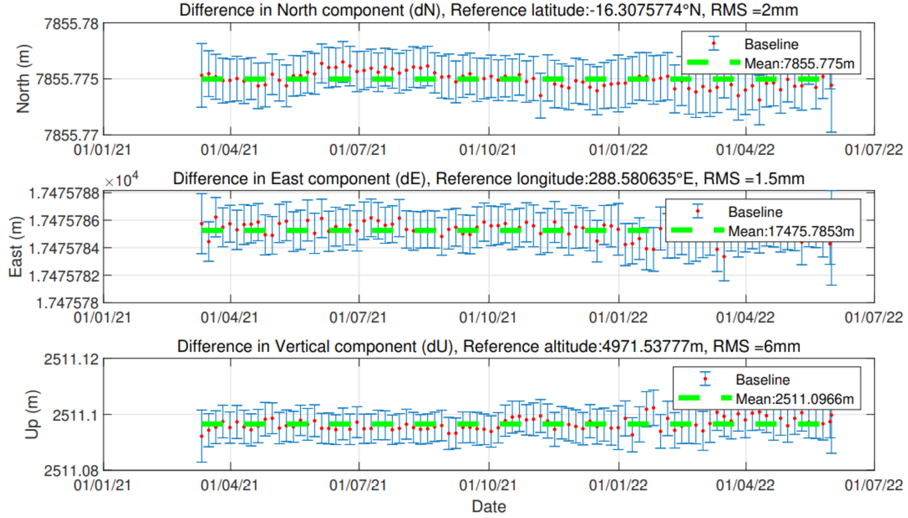
Results: Evaluation of Misti Data

Baseline MTPI-AREQ



Baseline MTPI-AREG



Data was measured by INGEMMET-OVI and shared with IAAPP.

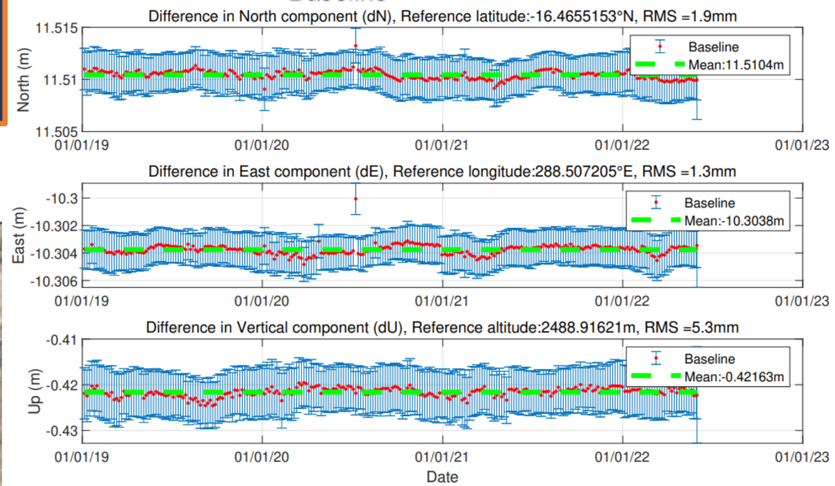
Data was processed with GAMIT/GLOBK and the IGS stations:
antc, areg, areq, bogt, brft, braz, chpg, cord, falk, kour, lpgs, mgue, mtv2, pove, rgdg, riop, salu, sant, savo, sptu, ufpr and unsa.

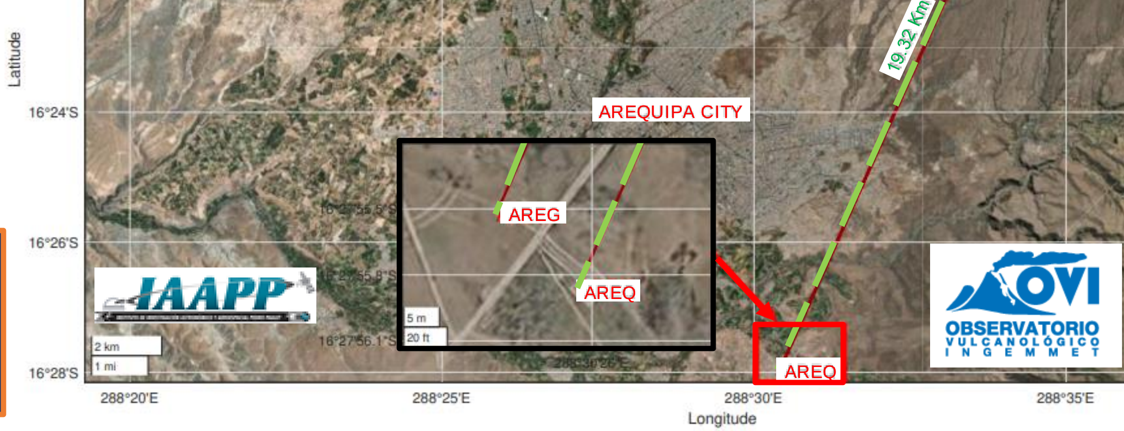
The "-ncomb" opción combines each 5 days h-files.

Baselines' Mean Standard Deviation

Baseline	East	North	Up
MTPI-AREQ	1.9	1.4	5.5
MTPI-AREG	1.9	1.4	5.7
AREG-AREQ	1.9	1.3	5.3

Baseline AREQ-AREG





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Conclusions:

- The GNSS Technique has been applied to determine deformations in the Misti Volcano. No deformation was observed between 2021 and 2022.
- The data of the GNSS system was processed with the Gamit Software, and analyzed with Matlab.
- Topographic and geomorphological studies has been carried out locating monitoring points in the Misti Volcano, Chachani Volcanic Complex, and Pichupichu Volcanic Complex. In total 5 monitoring points are pretended to be build.
- For the installation of the GNSS system and the coupling of the laser reflectors,the design of the pillar has a height of 1.80 m
- The low-cost meteorological station called IAAPP-MET was developed, and its accuracy was compared between the MET-3 and MET-4. We are looking to improve the design or purchase a meteorological station.
- Laser data processing has been carried out using a simplified equation, obtaining a standard deviation of 4 mm, which is typical of the TLRS-3 Systems and a Gaussian distribution.

Thank you to NASA-GSFC for letting us contemplate the use of the TLRS-3 station for this experiment.