VARION extension to GEO satellites: application to recent tsunami induced TIDs events

Michela Ravanelli, Giorgio Savastano, **Augusto Mazzoni** and Mattia Crespi

Geodesy and Geomatics Division, DICEA, Sapienza University of Rome

20th International Beacon Satellite Symposium - 23 August 2019
Session 10. Monitoring Natural Hazards: Signatures of Earth-Ocean Coupling to the Ionosphere

Outline

Outline

Our work

Aim of the work

To show the **benefit of combined application** of **MEO** and **GEO** satellites for detecting and analysing **Travelling Ionospheric Disturbances (TIDs)** through the **VARION** algorithm

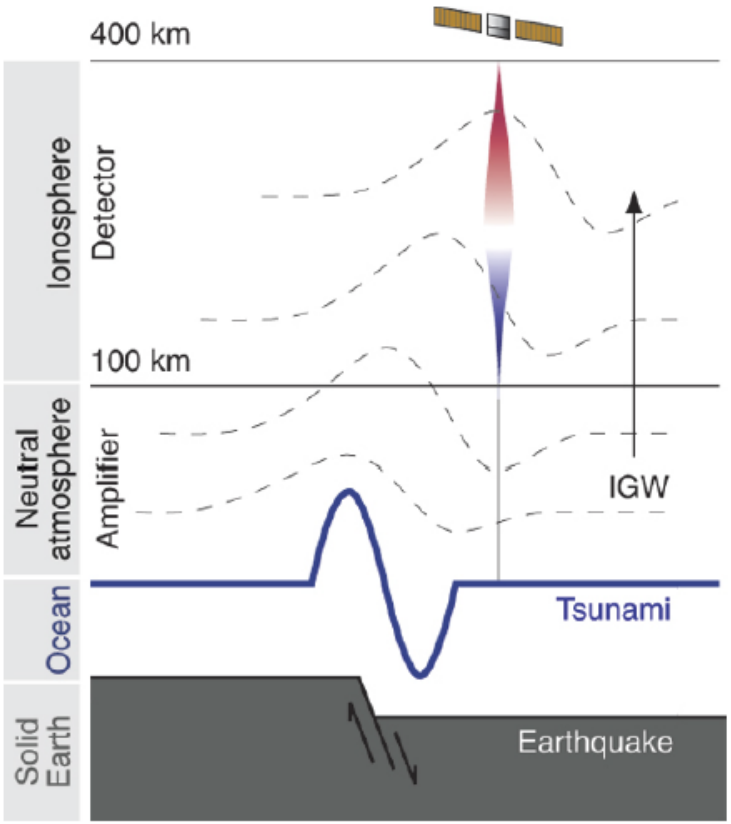
MEO satellites

- Medium Earth Orbit satellites (GNSS)
- height of $\approx$ **20200 km**
- orbital period of $\approx$ **12 hours**

GEO satellites

- Geostationary Earth Orbit satellites
- height of $\approx$ **35800 km**
- orbital period equal to the **Earth rotation period**

Travelling Ionospheric Disturbances (TIDs)



(*Figure from Giovanni Occhipinti*)

TIDs related to gravity waves

- atmosphere as **low-pass filter**: only waves with **frequency lower than buoyancy frequency** (about 3.3 mHz at sea level) reach the ionosphere
- **strong amplification** during the upward propagation (density decreasing, momentum conservation)
- ionosphere **perturbations detectable with GNSS**

Outline

VARION fundamentals

Variometric **A**pproach for **R**eal-time **IO**nosphere Observatio**N**

Features

- derived from **VADASE (real-time ground velocity and displacement)**
- **sTEC variation** estimation from the observations of a **stand-alone GNSS receiver** (single station approach) in **real time**
- advantages: no infrastructure, no post-processing, no initialization needed

Realization

- designed in 2015 at **Sapienza University of Rome**
- developed and validated in 2016 in collaboration with the **Jet Propulsion Laboratory, Ionospheric and Atmospheric Remote Sensing Group**

Reference

Savastano, G.; et al. Real-Time Detection of Tsunami Ionospheric Disturbances with a Stand-Alone GNSS Receiver: A Preliminary Feasibility Demonstration. Sci. Rep. 2017, 7, 46607. DOI: 10.1038/srep46607.

VARION fundamentals

Methodology

$$\underbrace{L_{4R}^{S}(t+1) - L_{4R}^{S}(t) =}_{\text{time single difference geometry free observation}}$$

$$\underbrace{\frac{f_1^2 - f_2^2}{f_2^2}\left[I_{1R}^{S}(t+1) - I_{1R}^{S}(t)\right]}_{\text{unknown term, sTEC variation}} + \underbrace{\Delta m_R^S + \Delta\epsilon_R^S}_{noise}$$

- **epoch-to-epoch sTEC variations**

$$\delta sTEC(t+1,t) = \frac{{f_1}^2 {f_2}^2}{A({f_1}^2 - {f_2}^2)}\left[L_{4R}^{S}(t+1) - L_{4R}^{S}(t)\right] \quad (1)$$

note: (this is a **total space-time variation)**

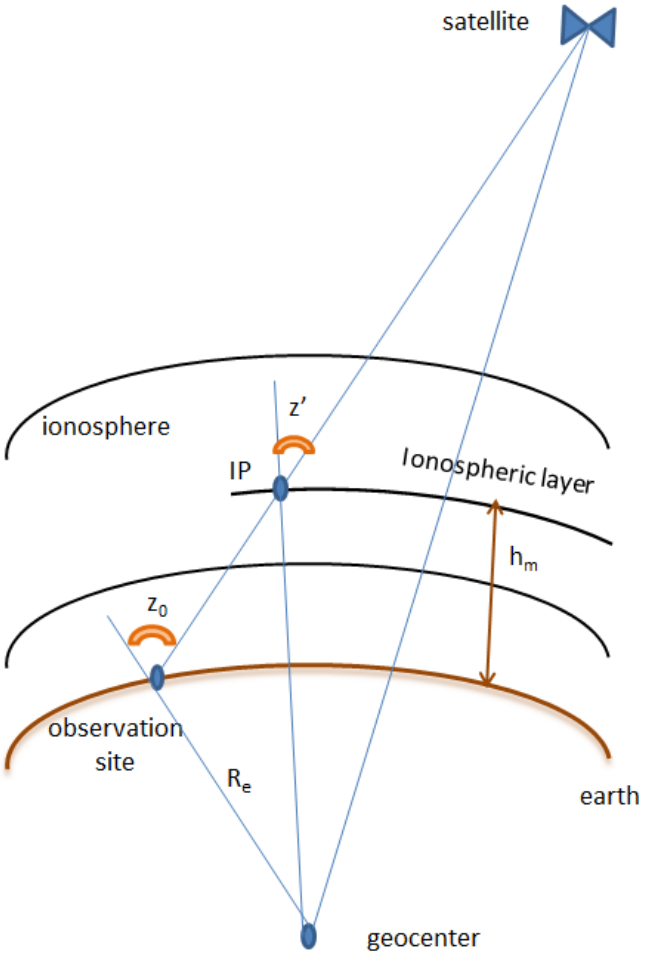
VARION Algorithm for MEO vs. GEO satellites

MEO satellites

$$\frac{dsTEC}{dt} = \frac{\partial sTEC(t,s)}{\partial t} + \frac{\partial sTEC(t,s)}{\partial s}\frac{\partial s}{\partial t} \quad (2)$$

GEO satellites

$$\frac{dsTEC}{dt} = \frac{\partial sTEC(t,s)}{\partial t} + \cancel{\frac{\partial sTEC(t,s)}{\partial s}\frac{\partial s}{\partial t}} \quad (3)$$



(*Figure from Hoffman et al., 2008*)

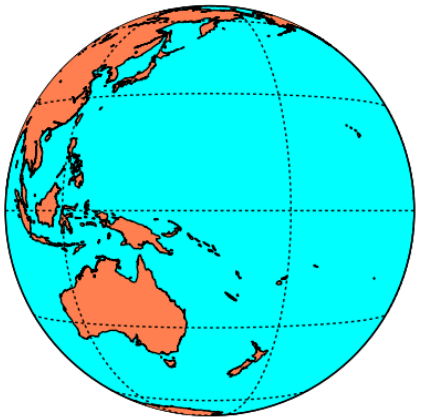
GEO satellites: pros and cons

Pros

- **determination of the sTEC time variation**
- **elimination of all the effects** due to **satellite motion** in sTEC time series
  (i.e. increasing observational noise, IPP velocity and trends for elevation decrease)
- **continuous sTEC time series**

Cons

- still **low spatial coverage**:
  - few dual frequency GEO satellites
  - few stations observing GEO satellites

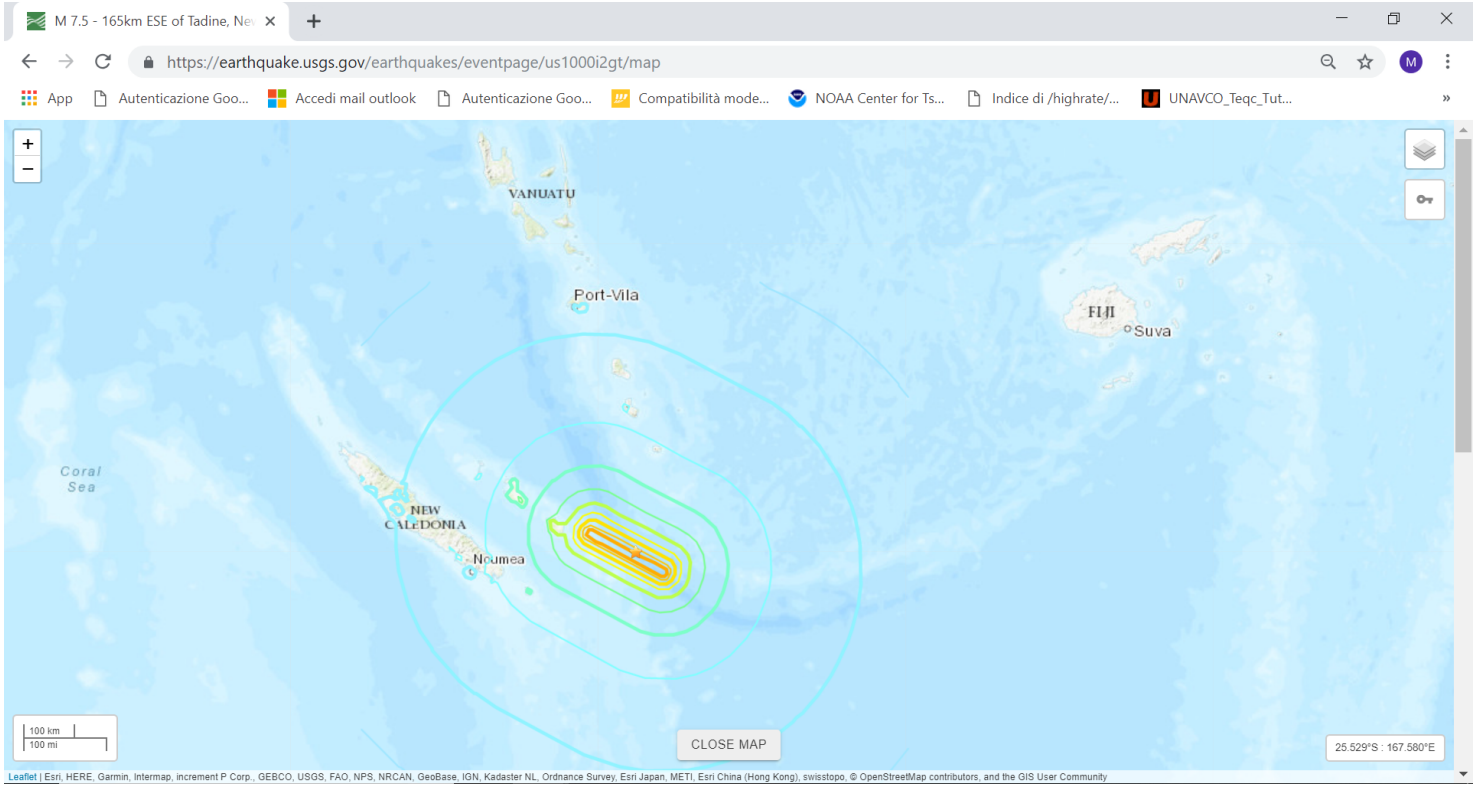


The Earth from GEO satellite C04

Outline

Mw 7.5 New Caledonia earthquake and tsunami

On September 5, 2018, at 04:08:18 UTC, a Mw 7.5 earthquake occurred **165km ESE of Tadine**, New Caledonia, (21.950°S, 169.427°E, depth = 10.0 km)



Mw 7.5 New Caledonia earthquake and tsunami

On September 5, 2018, at 04:08:18 UTC, a Mw 7.5 earthquake occurred **165km ESE of Tadine**, New Caledonia, (21.950°S, 169.427°E, depth = 10.0 km)

Tsunami

- waves **2 meters** high damaged a school and several homes at **Anelghowhat** and **Oumetch**, Vanuatu
- waves **72 cm** high were observed at **Tanna**, Vanuatu and at **Loyality Islands**

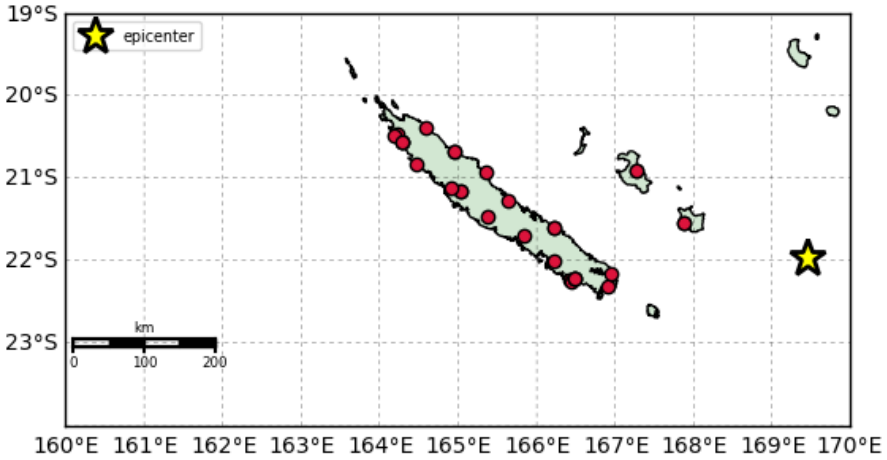
GAUGE LOCATION	GAUGE COORDINATES LAT	LON	TIME OF MEASURE (UTC)	MAXIMUM TSUNAMI HEIGHT	WAVE PERIOD (MIN)
SUVA VITI LEVU FJ	18.1S	178.4E	0652	0.03M/ 0.1FT	38
NUMBO NEW CALEDONIA	22.2S	166.4E	0613	0.04M/ 0.1FT	06
THIO NEW CALEDONIA	21.6S	166.2E	0631	0.23M/ 0.8FT	12
VANUATU	17.8S	168.3E	0601	0.30M/ 1.0FT	18
HIENGHENE NEW CALED	20.7S	164.9E	0557	0.09M/ 0.3FT	22
OUINNE NEW CALEDONI	22.0S	166.7E	0554	0.45M/ 1.5FT	06
LIFOU NEW CALEDONIA	20.9S	167.3E	0522	0.29M/ 1.0FT	06
MARE NEW CALEDONIA	21.5S	167.9E	0519	0.43M/ 1.4FT	10
LENAKEL VU	19.5S	169.3E	0505	0.72M/ 2.4FT	06

Mw 7.5 New Caledonia earthquake and tsunami

On September 5, 2018, at 04:08:18 UTC, a Mw 7.5 earthquake occurred **165km ESE of Tadine**, New Caledonia, (21.950°S, 169.427°E, depth = 10.0 km)

Dataset

- stations from BANIAN GNSS network
- **20 GNSS stations**, located over the territory of New Caledonia

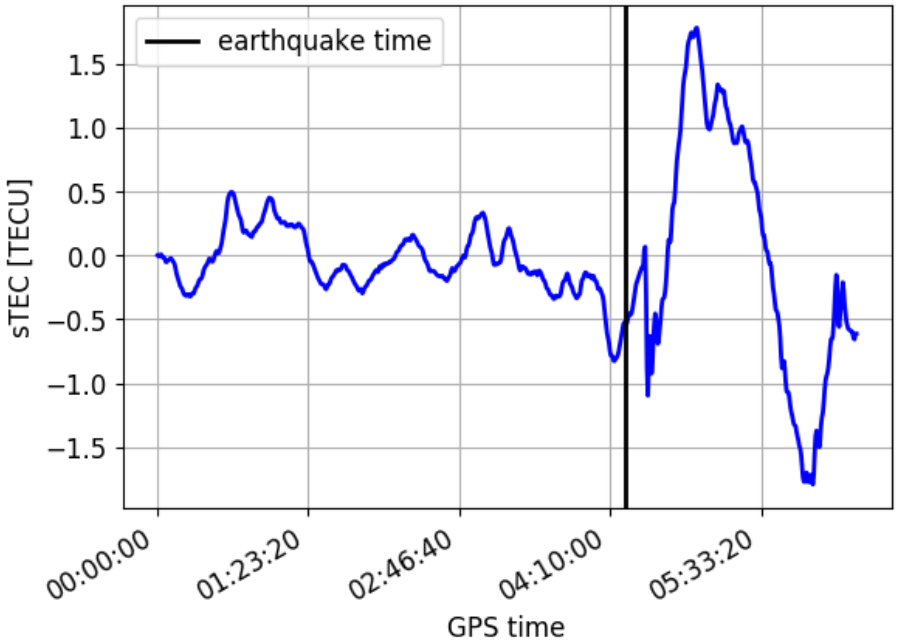


VARION processing

Analysis

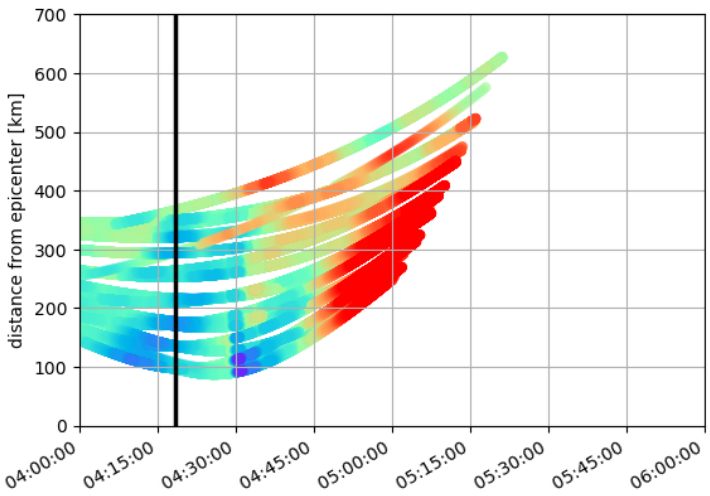
- VARION was applied to both MEO and GEO GNSS data
- sTEC variations filtered with **bandpass filter** (0.1-1 mHz)

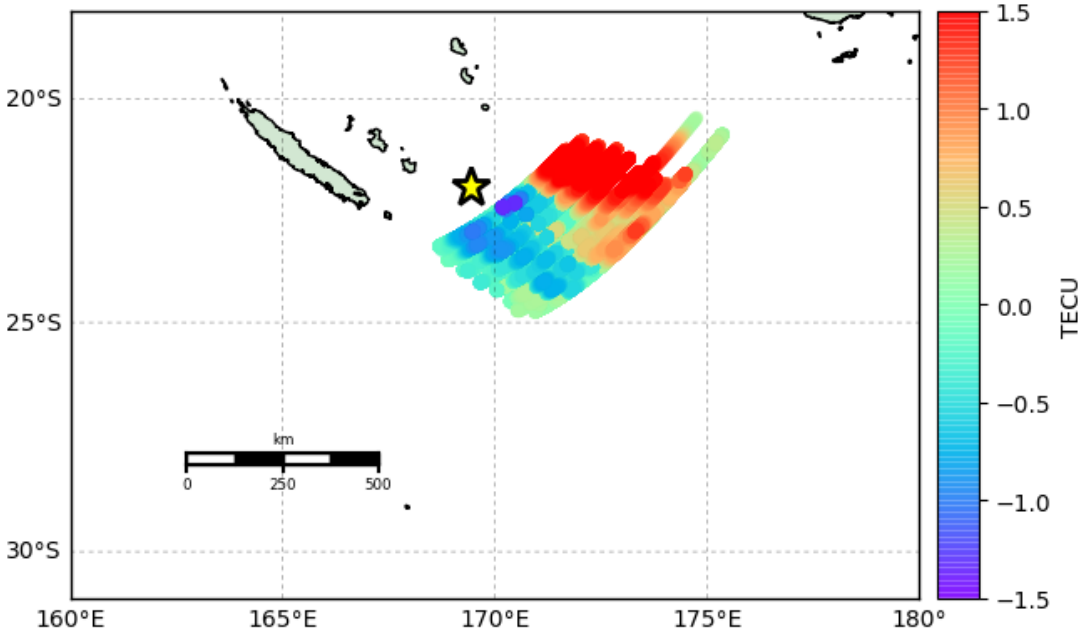
GPS satellite G19 observed from KOUC



VARION processing

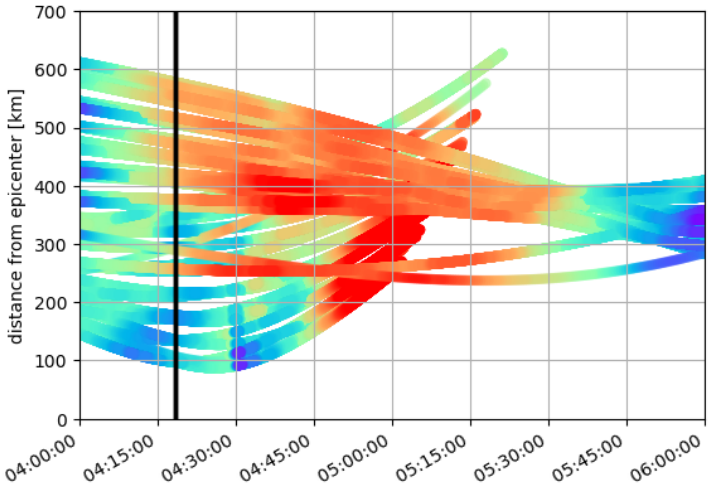
GPS satellite G19

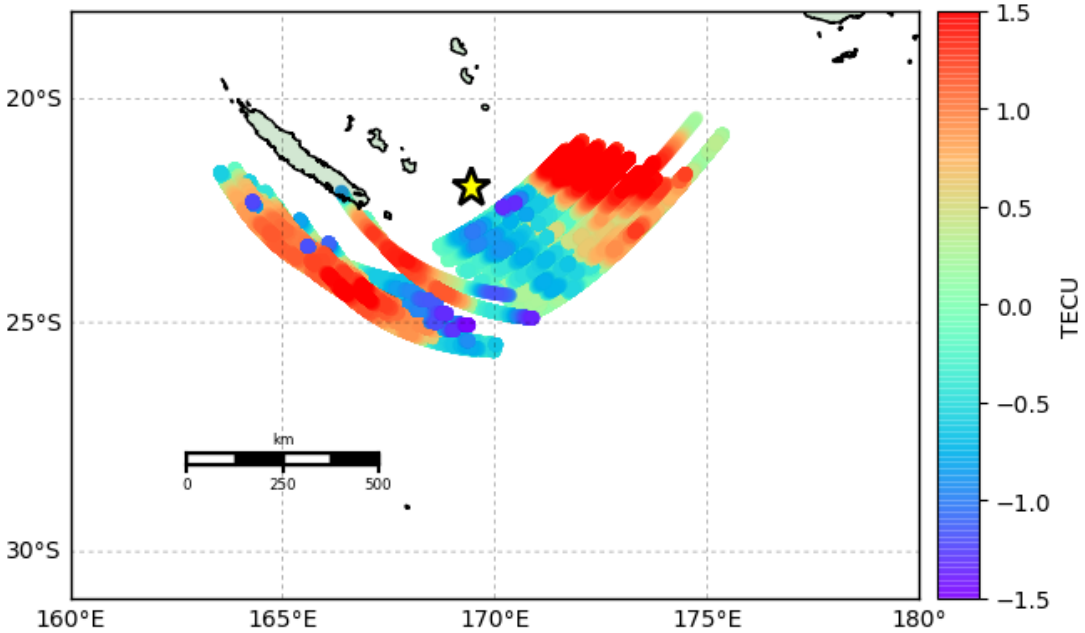




VARION processing

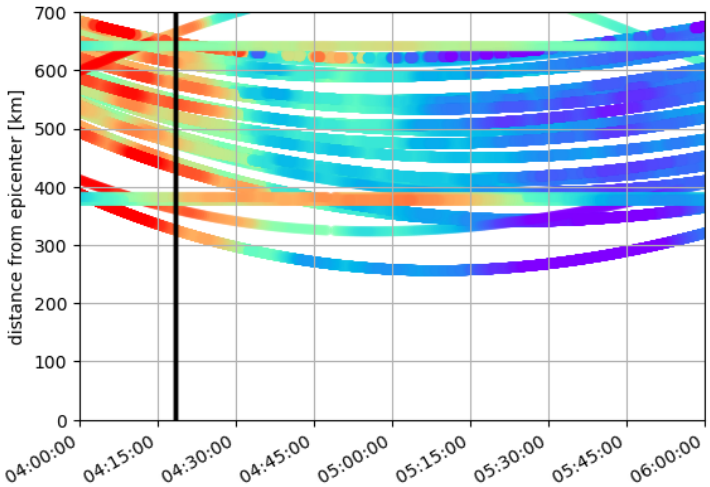
GPS satellites G19 and G02

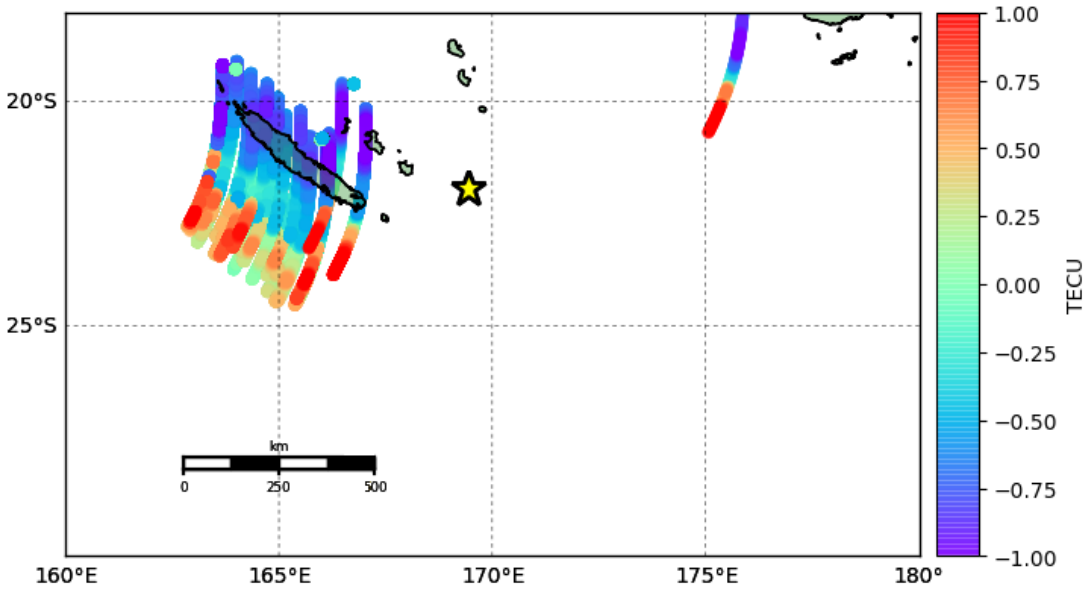




VARION processing

Beidou GEO satellite C04 and GPS satellite G12

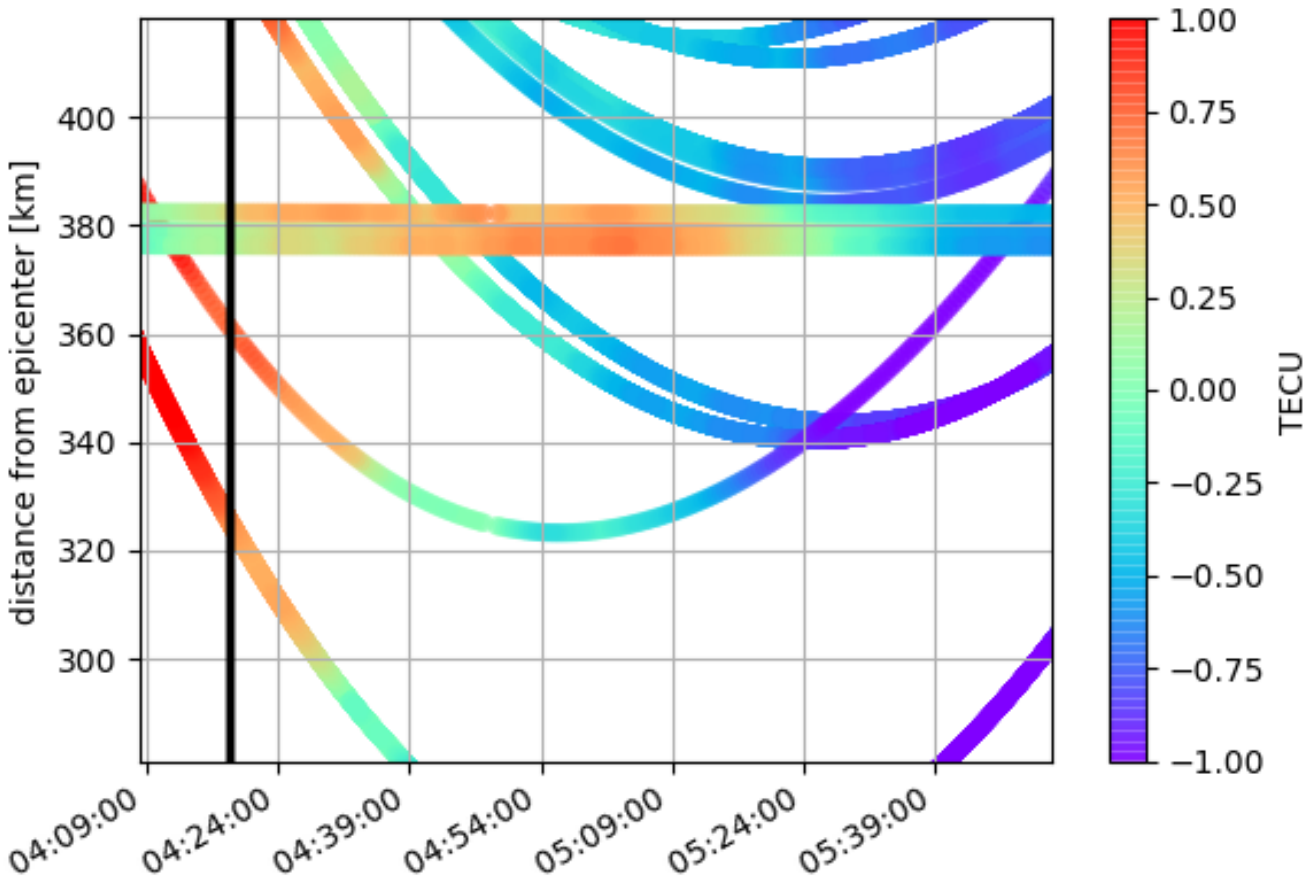




C04 observed from KOUC, LPIL, NRMG and NMEA

VARION processing

Beidou GEO satellite C04 and GPS satellite G12



VARION processing

Summary of results

- GPS satellite **G19** and **G02** well highlight the TIDs connected to the tsunami
- Beidou **GEO** satellite **C04** show a good sTEC signature

unfortunately

- **still few GNSS stations** can observe GEO satellites nowadays

Outline

Conclusions and prospects

VARION combined application of MEO and GEO satellites

GEO satellites

- **no geometric effects** ⇒ potentially better TIDs detection
- **continous sTEC solutions** ⇒ ionosphere activity monitoring

Mutual benefits of GEO and MEO satellites for **ionosphere monitoring** and **enhancement of tsunami early warning system**

Outlook I

- application to more intense tsunami events such as **January 23, 2018, Mw 7.9 Gulf of Alaska earthquake and tsunami**
- application to other kinds of ionospheric disturbances

A challenge for societal benefits

Outlook II

- **hoped increase** of the number of **stations** observing **GEO satellites**
- VARION-GEO as a contributing tool to reliably confirm tsunamy alert and **to prevent casualties as in case of Palu (Indonesia)**
- in this background, Indonesia/Philippines area can already benefit of dual frequency GEO satellites from Beidou constellation

This research and its outlook have been/will be developed under the umbrella of **GETWS initiative, within GGOS Geohazards Focus Area**

Thank you very much for your kind attention