Projet d'antenne VLBI à Tahiti

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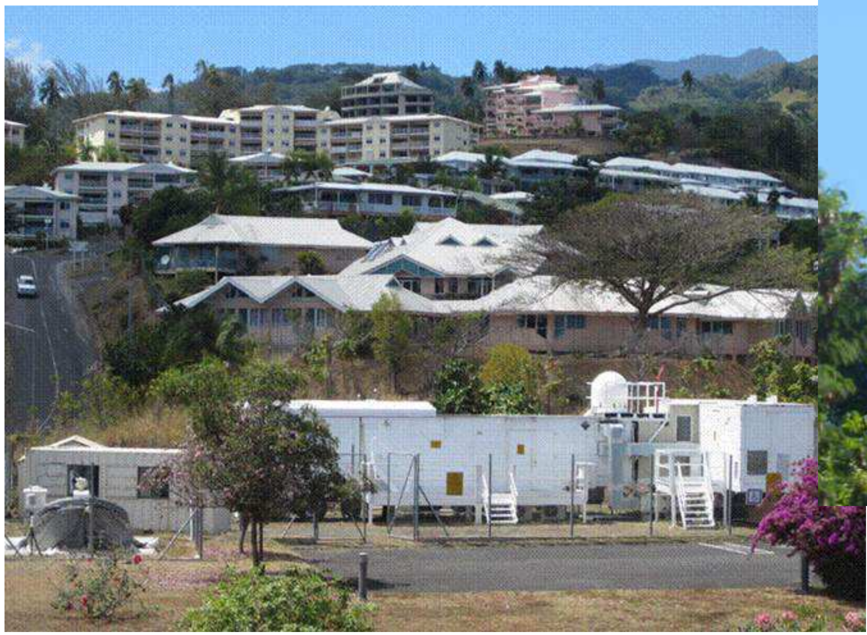
Université de Bordeaux
Observatoire Aquitain des Sciences de l'Univers

OGT

The present OGT site is integrated in the University of French Polynesia.
The NASA MOBLAS-8 SLR system (installed in 1997), now 37 years old (Quincy, 1981), is now in urban environment and needs to be replaced soon.
GPS and DORIS antennas on the roof of the research building do not satisfy GGOS setting up criteria.

The MOBLAS-8 station

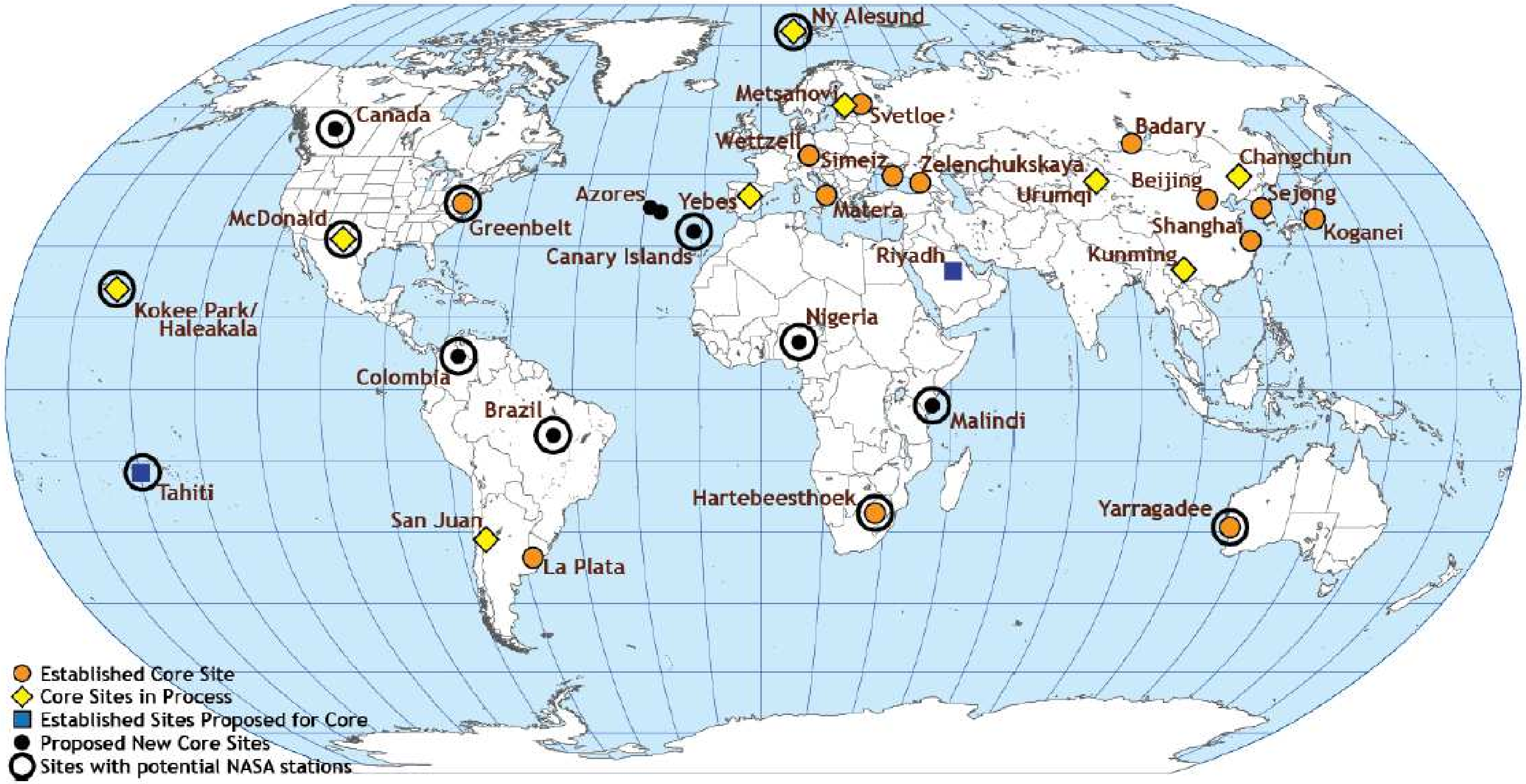


DORIS and GNSS antennas

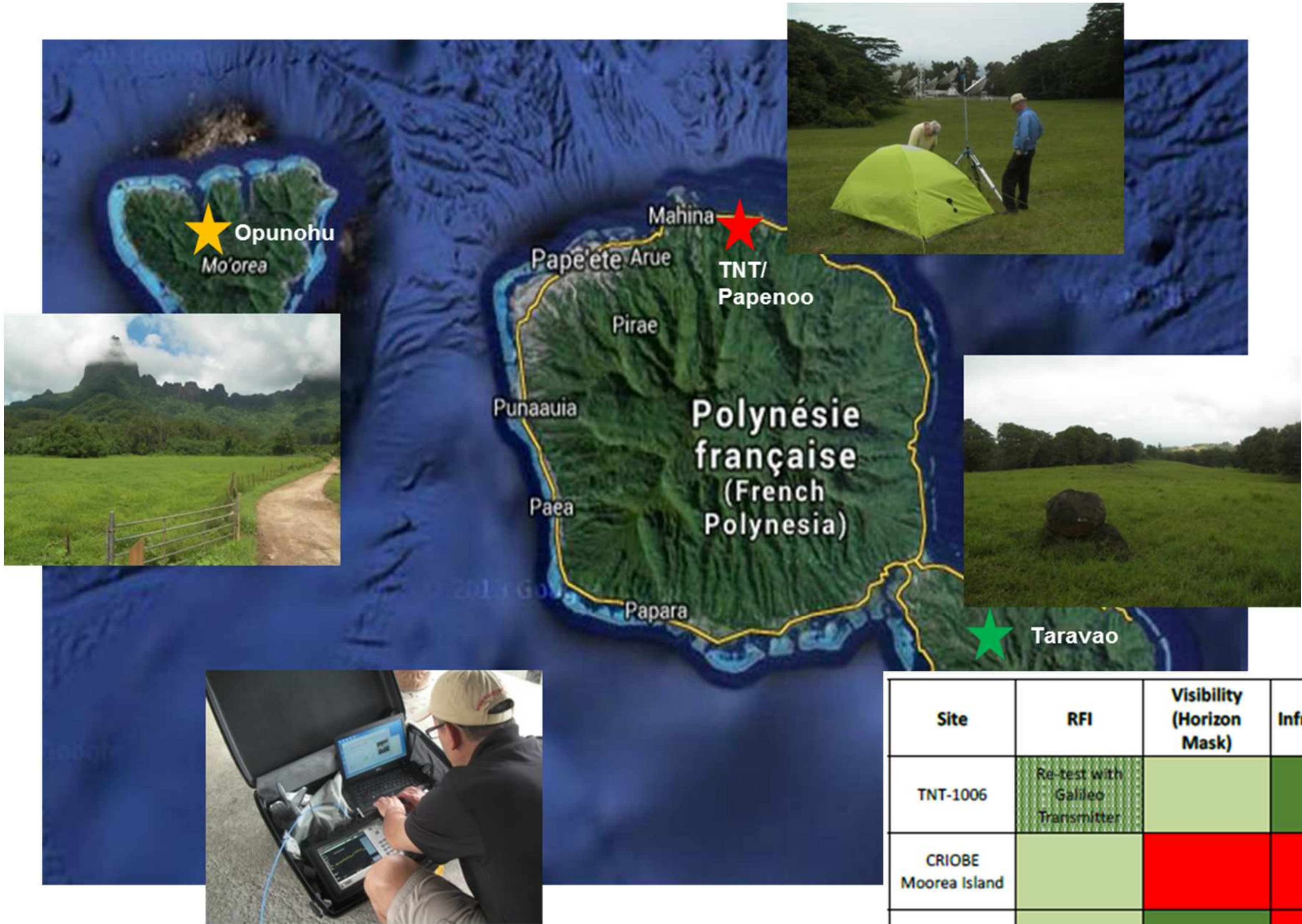
Moreover no place is available for setting up a VLBI antenna as proposed by NASA.

Core site network

The *Core site* network being realized consists of space geodetic sites gathering all **4 fundamental techniques collocated** (DORIS, GNSS, SLR, VLBI) and **continuously operated over the long term**. They should spread out as homogeneously as possible worldwide and on each tectonic plate. The coverage in the Pacific zone is supported mainly by the Hawaii and Tahiti islands.



Site exploration in French Polynesia



Site	RFI	Visibility (Horizon Mask)	Infrastructure	Technique Co-location
TNT-1006	Re-test with Galileo Transmitter			
CRIOBE Moorea Island				
Plateau de Taravao				

The Tahiti Nui Telecom site

Tahiti Nui Telecom (TNT) expressed its agreement in principle for hosting instruments of space geodesy at the south side of its ground in Papenoo for a 30 year period.

The site of Papenoo benefits from a recognized natural and physical protection. It already hosts the chief station of satellite reception in Tahiti, a ground station of the Galileo system as well as the Tahitian extremity of the international Honotua submarine fiber from the Hawaiian Islands.

The Telecom antennas

At the Papenoo Earth Station the following antennas are operating :

• 16 meter limited motion for international satellite traffic (C-band up and downlink at 4.2 and 6 GHz)

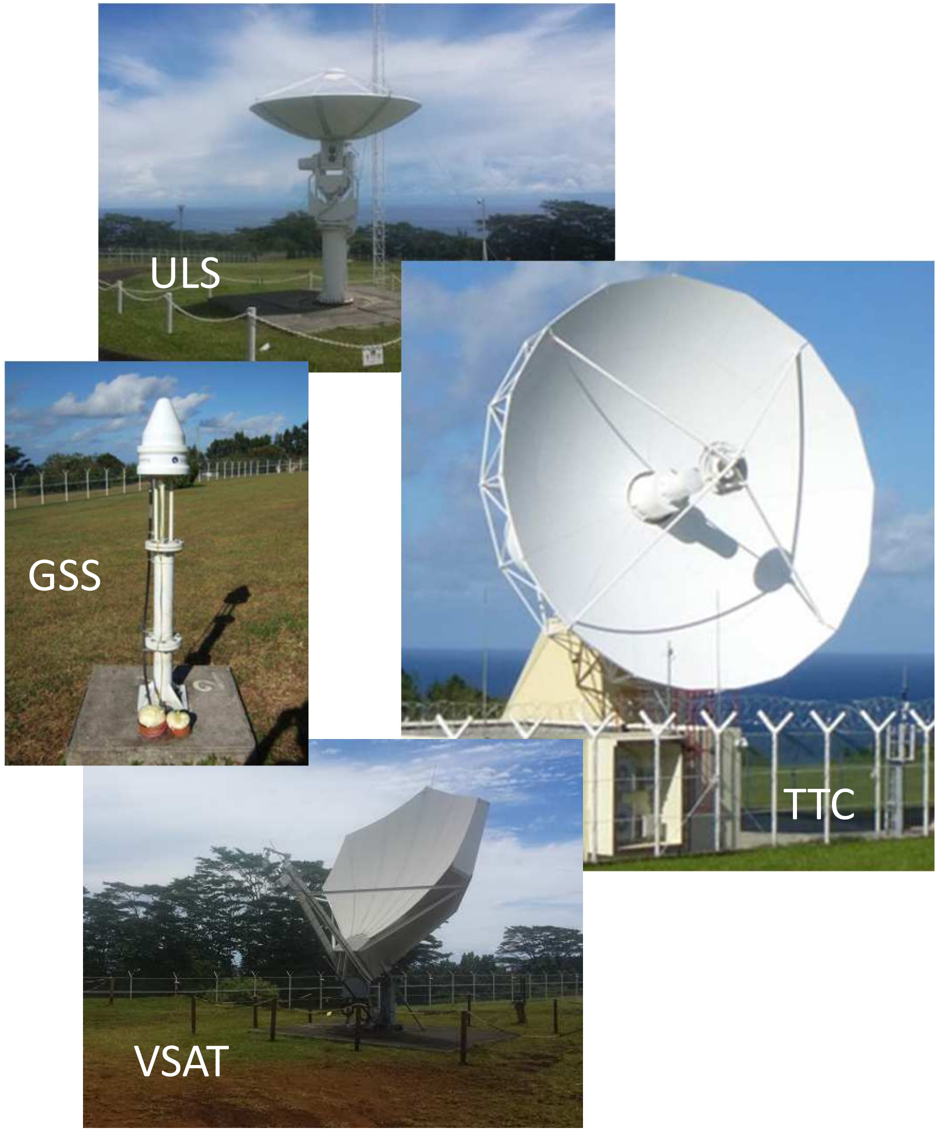
• 16,4 meter for intra-Polynesian satellite traffic (C-band up and downlink at 4.2 and 6 GHz)

• 11 meter for Internet traffic (C-band up and downlink at 4.2 and 6 GHz)

• 12 meter for TV-uplink (Ku-band)

The C-band antennas will become obsolete when fibers will connect most of the Polynesian islands in 2019. The remaining Austral islands should be connected in Ku-band.

The Galileo instruments



- **3 GSS (Galileo sensor station)**

L-Band

Specific Frequency constraints:

1176.450, 1207.140, 1278.750, 1575.421 MHz

- **4 ULS (up-link station)**

Transmission of navigation and integrity messages in C-Band

- Transmit frequency band: 5005MHz

.

- **VSAT (Very Small Aperture Terminal)**

Classic Geostationary VSAT C-Band Telecommunications Operations

- Transmit frequency band: 5850MHz - 6425MHz
- Receive frequency band: 3625 MHz - 4200MHz

- **TTC** (2016)

Telemetry Tracking and Command, 13.5m antenna, S-band: 2212 – 2237 MHz

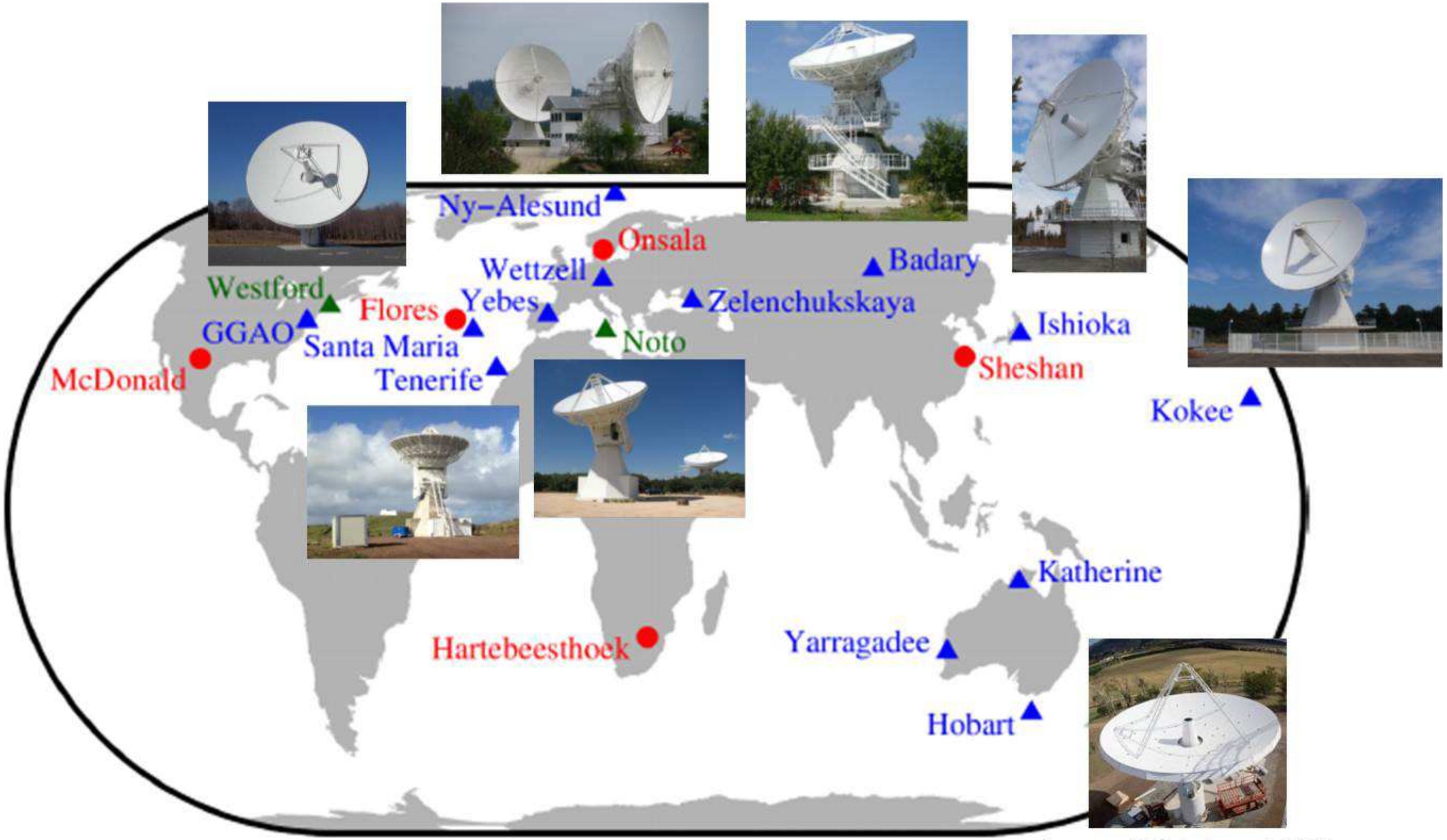
VGOS

To improve VLBI data to meet increasingly demanding requirements, an end-to-end redesign called the **VLBI Global Observing System** (VGOS) is in progress at NASA. The key concepts are a broadband signal acquisition chain (2-14 GHz) with digital electronics and fast, small antennas (12 m diameter).
VGOS is being developed to be minimally staffed, remotely controllable, broadband, RFI avoiding, fully digital, fast slewing, and capable of producing VLBI delays with precision of 4 picoseconds (⇔ 1 millimeter.) The system is designed to observe continuously.


Antenne VGOS à Koke'e Park (Hawaii)

<u>NASA plans:</u>
2015: prototype at GGAO/Greenbelt (Maryland)
2016: Koke'e Park (Hawaii)
2017: McDonald (Texas)
2020: TNT (Tahiti)

VGOS network



Source: Dirk Behrend, 2015

VGOS progress:
- ▲ hardware work in progress
- ● funding approved
- ▲ legacy upgrade in progress

GNSS

In the **REGINA** frame : **REseau GNSS pour l'IGS et la NAvigation**

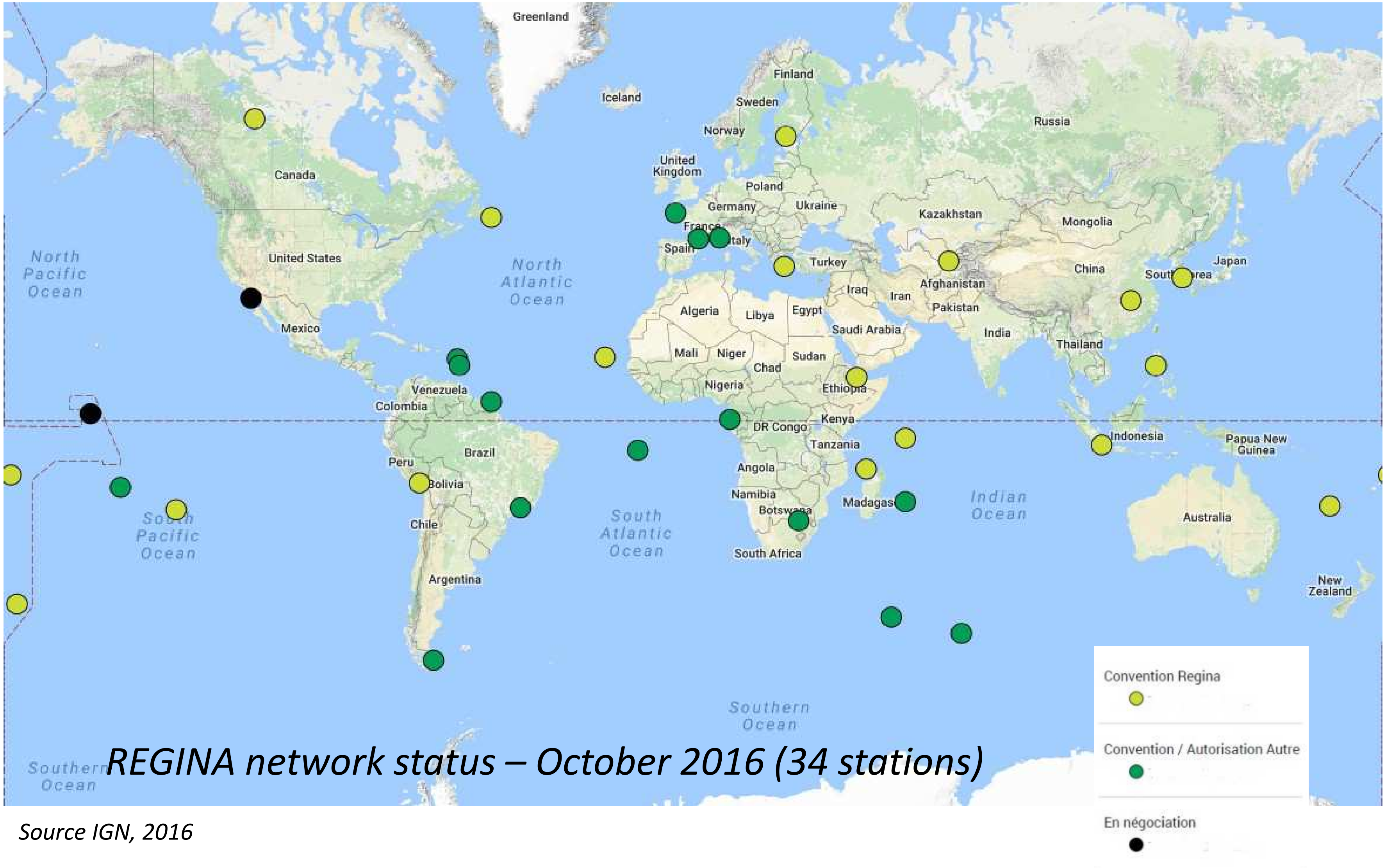
A worldwide network of GNSS stations (GPS L1/L2/L2C/L5, GLONASS L1/L2, GIOVE-GALILEO E5a/E5b/AltBocE5, E1BC, SBAS L1/L5) with global geographic coverage:

- Already 34 stations installed, most of them on DORIS sites
- Real-time NTRIP streams to IGS casters and CNES caster, 1 Hz data
- Consolidated data files (15 mn, 1 h and 1 day)

Hosting sites selection criteria for REGINA receivers:

- Location secure and viable over long term
- Preferentially, colocation with other geodetic infrastructures (DORIS, VLBI, SLR)
- Communication network availability, and logistical aspects
- External reference frequency, 5 or 10 Mhz
- …

REGINA network



REGINA network status – October 2016 (34 stations)

Source IGN, 2016

DORIS

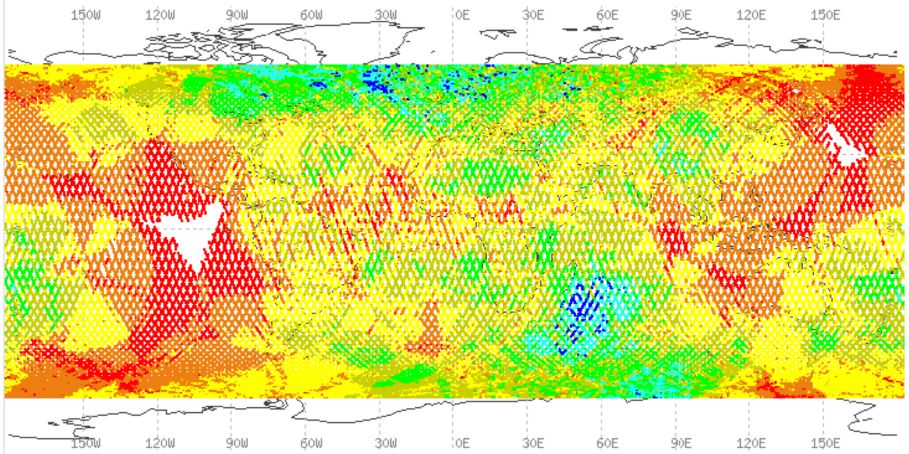
DORIS: Doppler Orbitography and Radio Positioning Integrated by Satellite

Fourth Generation Beacon (B4G) :

- New electronic (with up-to-date components)
- Better masks clearance expected thanks to longer distance between beacon and antenna (up to 50 m)
- First production units April 2019

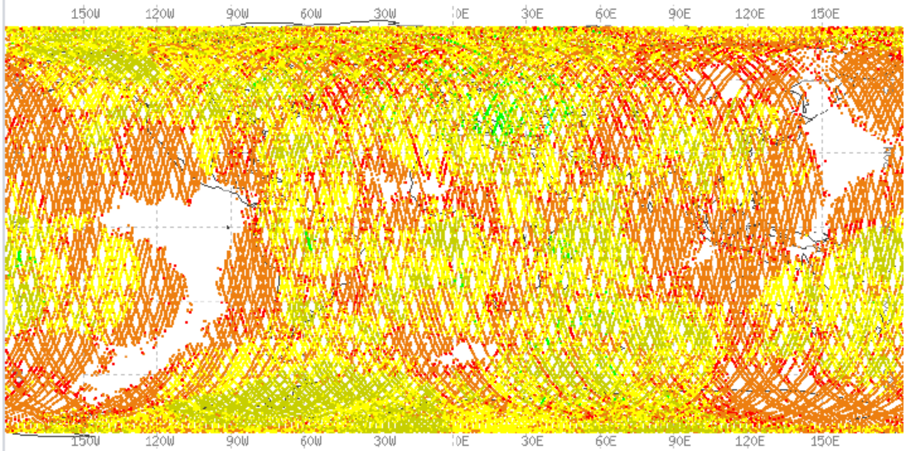
1 2 3 4 5 6 7

Jason2 (1336km, 66deg.) orbit coverage: 99% - 10 days, 2015

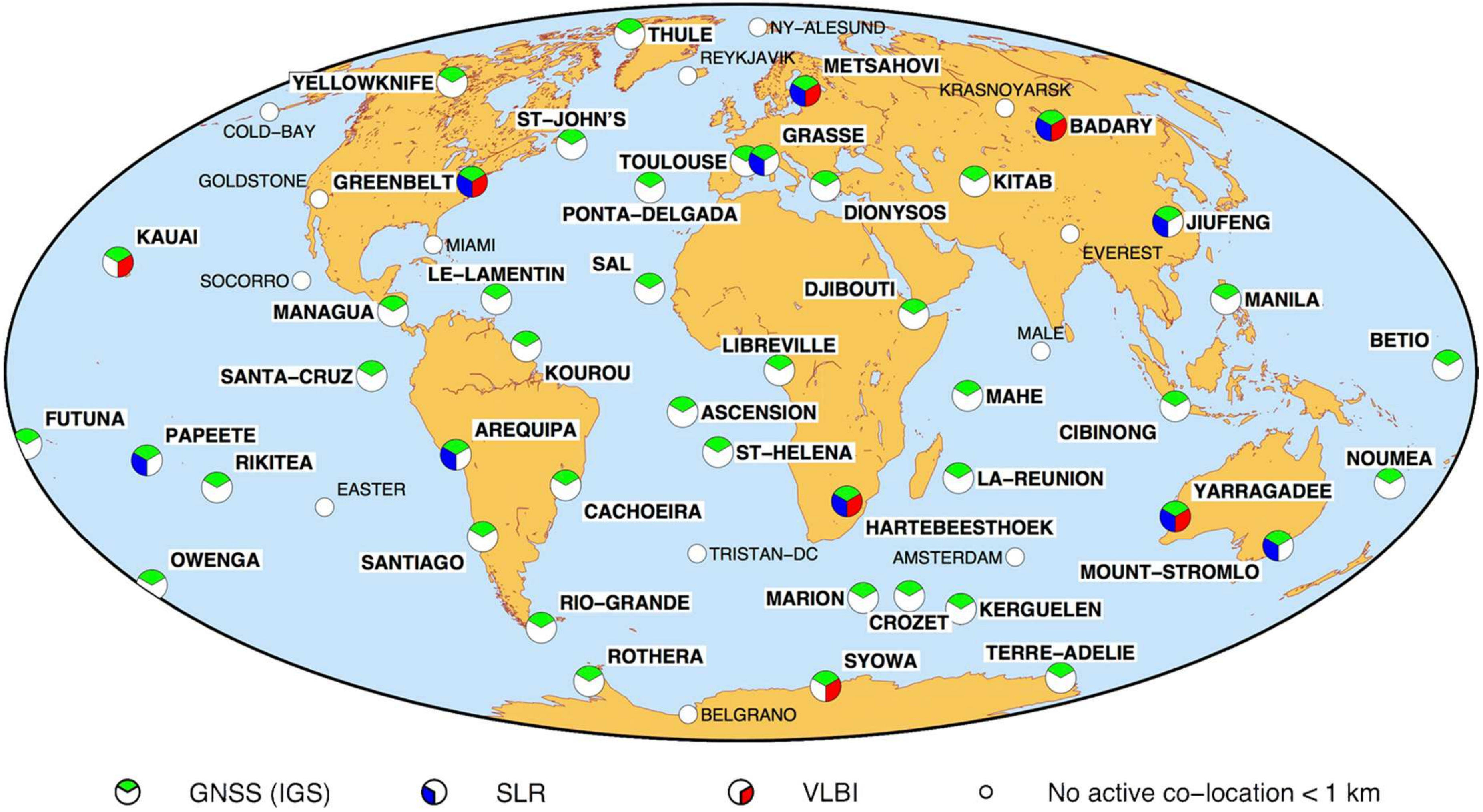


1 2 3 4 5 6 7

HY2A (960km, 99deg.) orbit coverage: 72% - 14 days, 2015



DORIS network



SLR

- Improvement of the metrological performances and automation
  - Lunar Laser Ranging in IR (1064 nm) (Courde et al., A&A, 2017)
  - Two color laser ranging at 100 kHz of repetition rate for mm accuracy
  - Sky safety / Sky characterization
- Demonstration of automated operation with MEO
- Funding: Phase 0 CNES (2017) and Project UniversCity-OCA (2017-2019)
- Possible cooperation with ESA for Galileo tracking

Picosecond pulsed laser @ 1064 nm

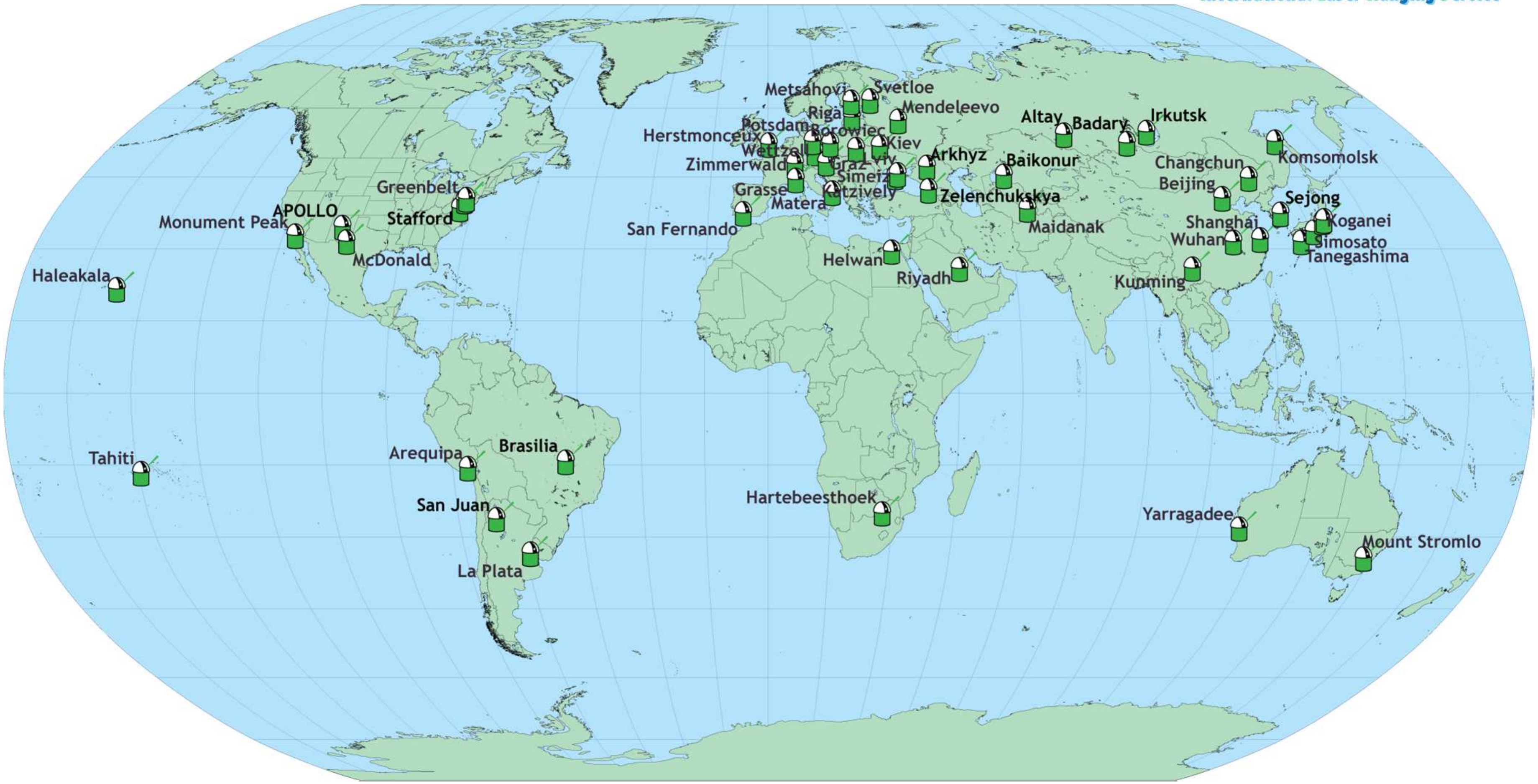
High-speed IR single-photon avalanche diode

Fork mount with direct drive motors @ 5°/s
500 mm telescope aperture
Optical coudé

Sub-picoseconde event-timer

SLR network

International Laser Ranging Service

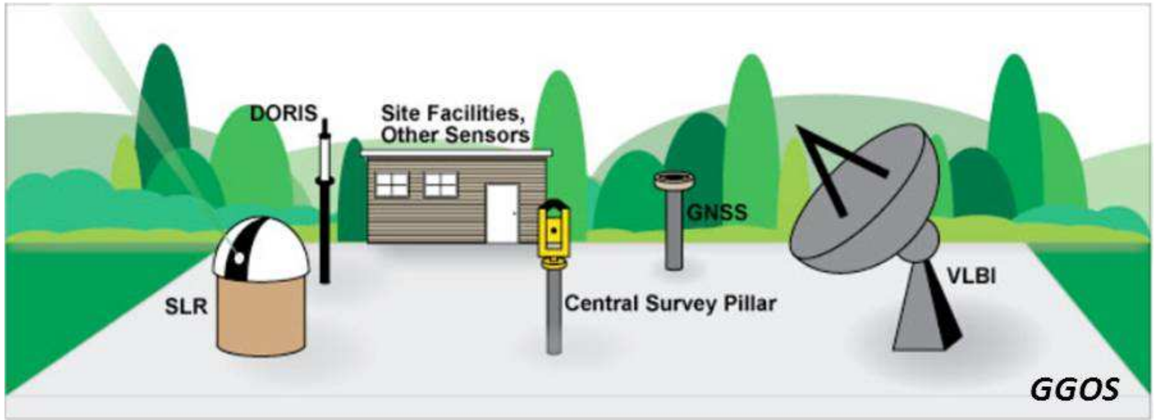


Local survey

Sub-mm accuracy of space geodesy system measurements may require a monitoring component in order to understand what is happening in real or near real-time. Small motions may corrupt measurements and subsequently the realization of the reference frame.

Automated measurement of inter-instrument vectors is an essential aspect of an integrated space geodesy station. Measurements provide closure between terrestrial reference frames derived from different space geodesy techniques.

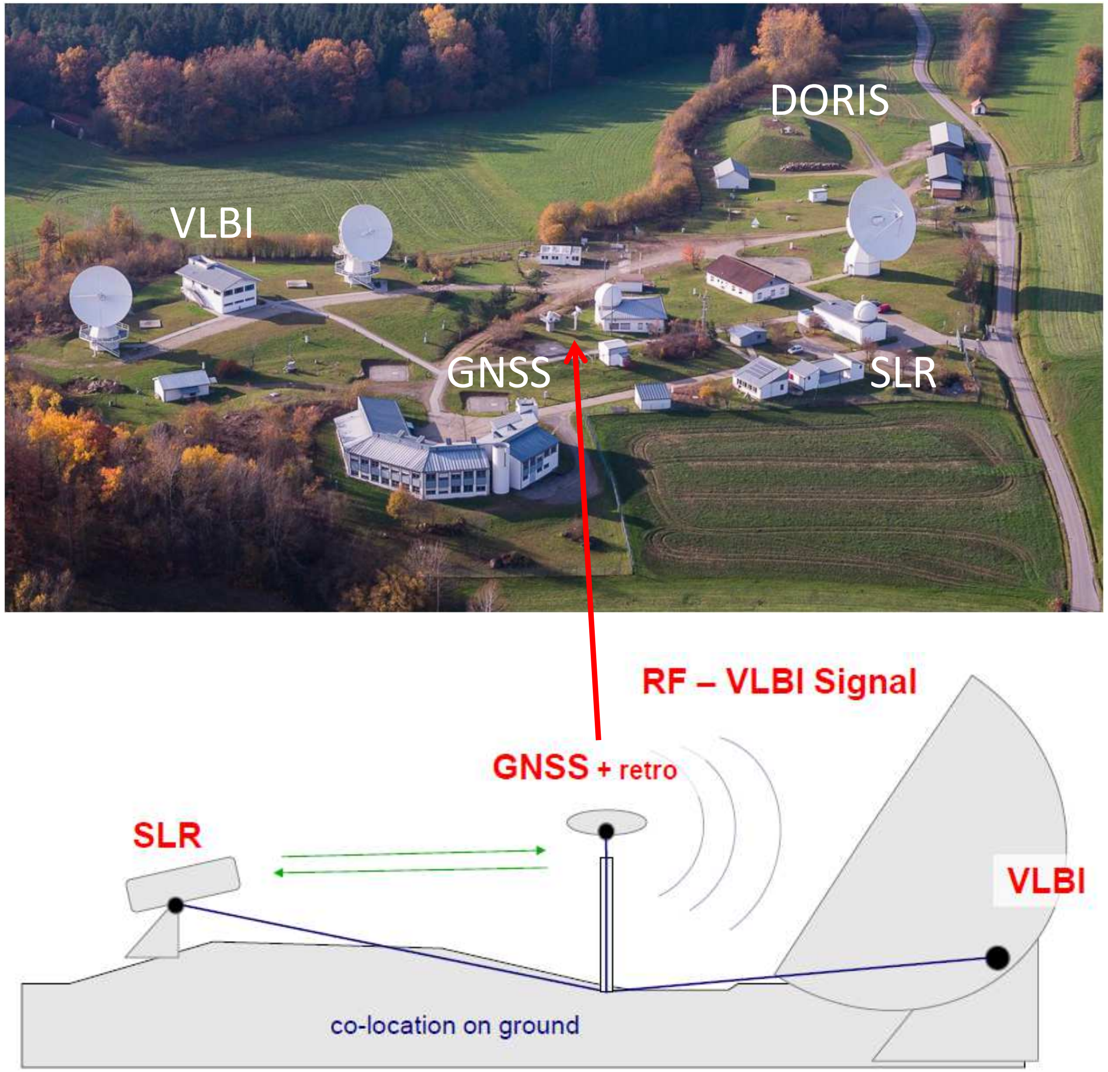
Various reference monuments need to be installed and utilized for visiting systems and general surveys as at GGAO.

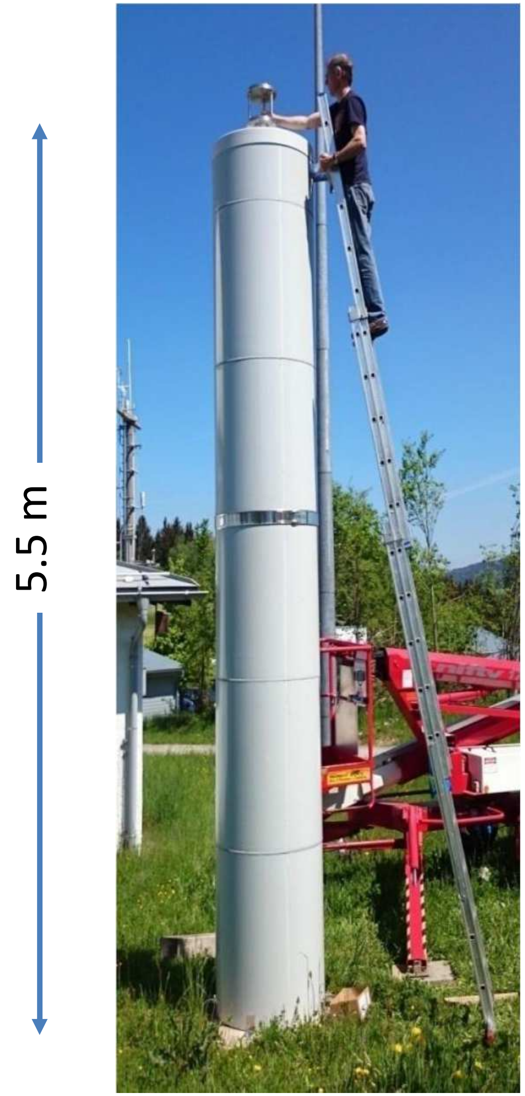


Terrestrial geodetic survey instruments to permanently and automatically monitor the local ties between the reference points of the space geodetic techniques

Leica Electronic Tacheometer at GGAO

Local survey in Wettzell





Multi-Technique Ground Target must be visible from WLRS, SOS-W, RTW, TWIN1 and TWIN2

Test equipment brought in TNT

Doris antenna and transmitter beacon

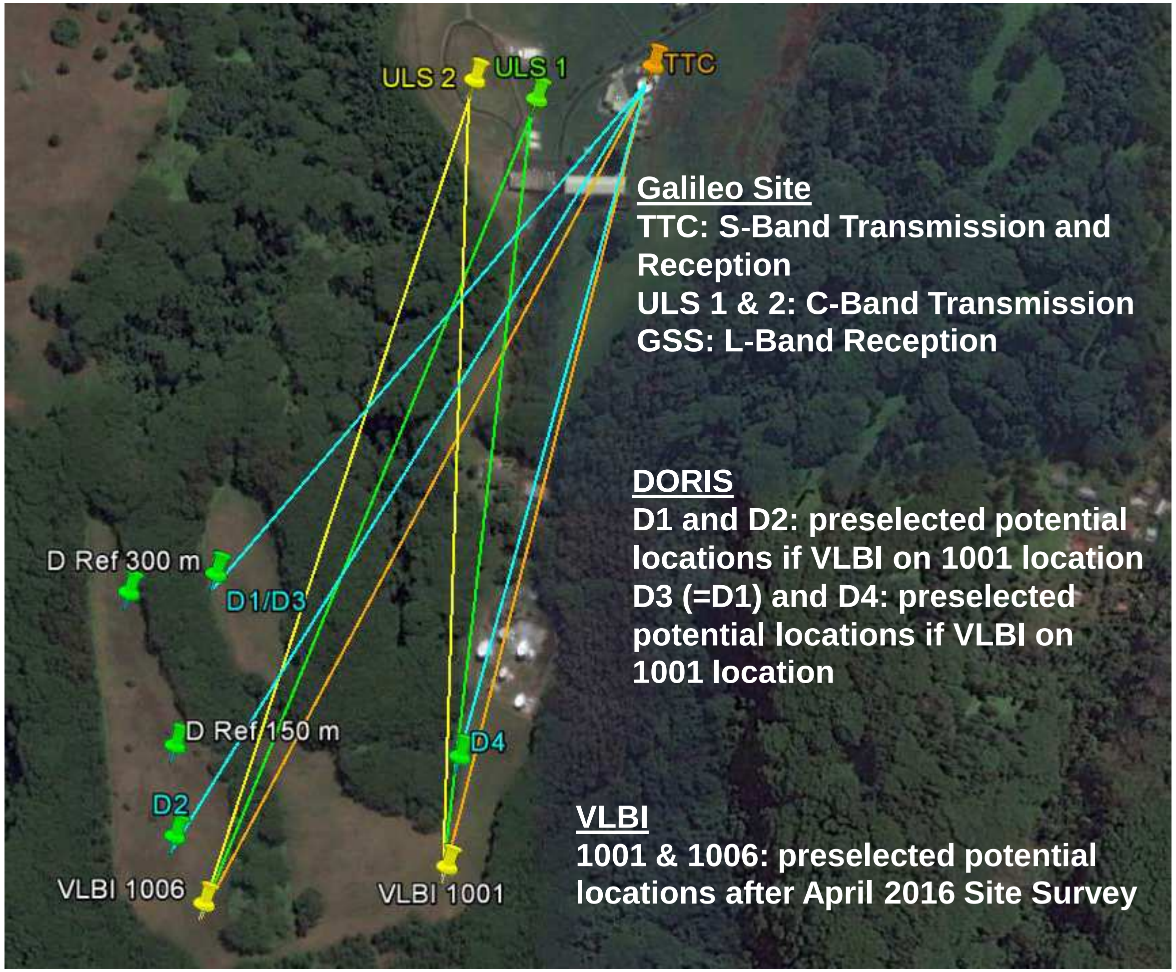
VLBI test equipment with spectrum analyser, 1 to 18 GHz
and biconical omnidirectional antenna

2017 RFI campaign (27 Feb.-3 March)

Follow-up campaign recommended after the Galileo antenna becomes operational.

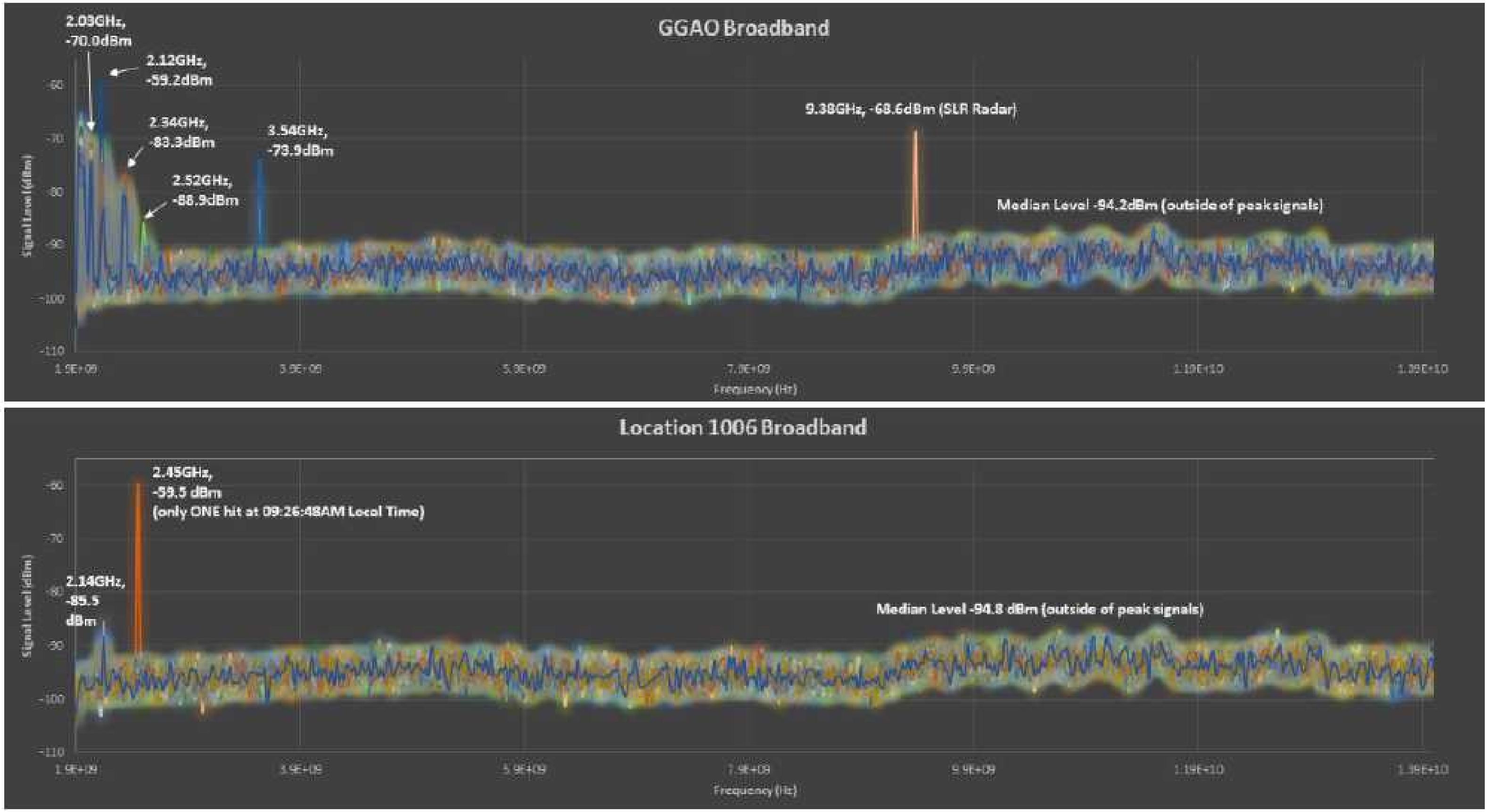
Organized between CNES, NASA, IGN, Indra/ESA, OGT, TNT.

CNES: R. Biancale (organisateur), M. Starozinski (coordinateur des tests), J.-M. Walter (DORIS)
IGN: J. Saunier et J.-C. Poyard (rattachements)
NASA: J. Esper (tests RFI), S. Merkowitz (Space Geodesy Project Manager)
ESA: B. Nejad (GALILEO Ground Control Segment Systems)
INDRA: P. L. Lopez, C. Barquinero
TNT: C. Moune (responsable site), P. Dugué (Directeur TNT)



2016 RFI campaign (9 - 16 April)

GGAO: Goddard Geophysical and Astronomical Observatory



Comparison of the broadband spectrum from TNT location 1006 (bottom) and NASA GGAO (top). The median levels are comparable but GGAO displays greater peak levels overall.

RFI Site Survey at Tahiti Nui Telecom

Test Set-Up

The tests involved the following equipment:

- Galileo 13.5 m S-band TTC antenna (not yet operational and not connected to the GCC)
- Galileo TTCF-6 Calibration Tower (Tx in S-Band Channel 5)
- Galileo 5 m C-band ULS-1 and ULS-2 operational antennas (tests performed during the approved Galileo ILS slots ILS#24400 for ULS1 and ILS#24401 for ULS2)
- DORIS UHF & S-band beacon
- NASA spectrum analyser (SA) connected to an antenna
- TNT C-band antennas

Some results

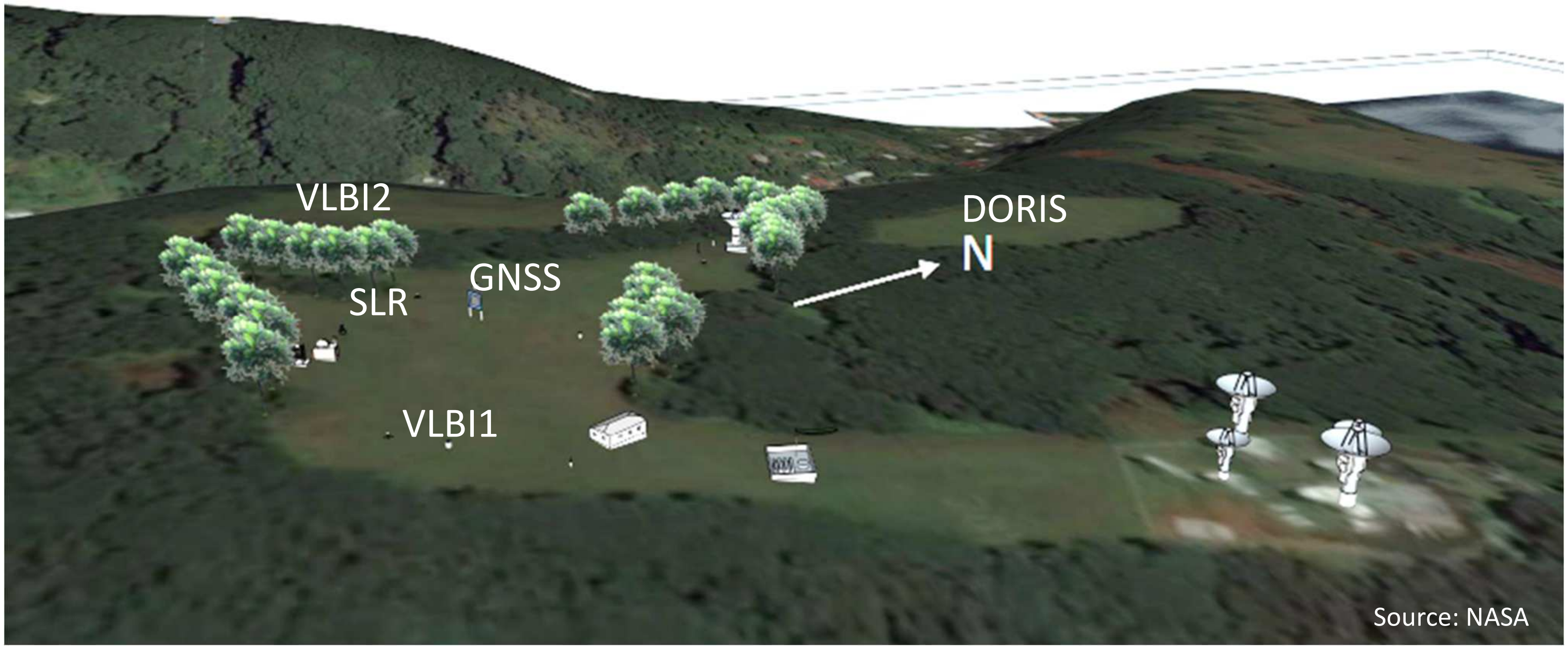
VLBI	DORIS	Relative Distance (m)	Power Level (dBm)	Comment
1001	D2	250	-52.3	direct line-of-sight with trees along the way
1006	D-Ref	172	-44.8	without any obstacles in the line-of-sight
1006	D3/D1	300	-69.9	tree line in between
1001	D3/D1	300	-67.2	tree line in between

$P=1mW*10^{dBm/10}$, *d*Bm=10*log10(P/1mW) , ratio of measured power to 1 mW

Objective	Achieved (Yes/No)	Comment
Objective 1: measure and quantify (if any) the impact of a potential future CNES DORIS beacon on the Galileo TTCF-6 S-band reception and transmission when transmitting from the specified candidate locations D1/3, D2, and D4.	Yes	No signal has been observed from any of the candidate Doris location D1/3, D2, and D4 in the TTCF-6 signal reception path and the Digital tracking receiver path during this survey. The DORIS beacon could be seen from the D5 location at the expected frequency. No adverse impact (i.e., loss of TM frame) has been seen when doing a TM loop back.
Objective 2: measure and quantify (if any) the impact of the Galileo TTCF-6 S-band transmission on the candidate VLBI antenna locations referred to as 1001 and 1006.	Yes	The Galileo TTCF-6 signal was observed at both VLBI candidate locations (1001 and 1006) with a signal strength ranging between –72.7 dBm (observed at the 1006 location with TTCF-6 Az/El 215/8) and -90.2 dBm (observed at the 1006 location with TTCF-6 Az/El 208/28).
Objective 3: measure and quantify (if any) the impact of the Galileo ULS-1 and ULS-2 C-band transmissions on the potential locations of a future VLBI antenna.	Yes	No signal has been detected from the Galileo ULS-1 and ULS-2 antennas on any of the VLBI candidate locations.
Objective 4: to collect sufficient measurements to determine the best relative geometry between the VLBI and DORIS instruments to minimise interference.	Yes	Sufficient data has been collected by VLBI to perform an analysis.
Objective 5: to collect geodetic data to fully specify the site.	Yes	A topographical survey was performed.

Layout proposal

- ~3 ha site in the South clearing of the Atohei plateau belonging to TNT (72 ha)
- 17.5178°S, 149.4370°W, 200m alt.
- NASA expertized the site first in April 2016 (RFI tests) then in Feb.-March 2017 together with CNES, IGN, ESA, TNT teams



VLBI simulations

A VLBI antenna in Tahiti would complete profitably the GGOS network . The plan is to rely on the development and installation of a new NASA VGOS antenna in 2018 in the framework of the CNES-NASA cooperation on space geodesy activities (NASA-CNES Implementing Arrangement, 2014).

Some simulation studies were already performed (eg from D. MacMillan, NASA/GSFC, 2010):

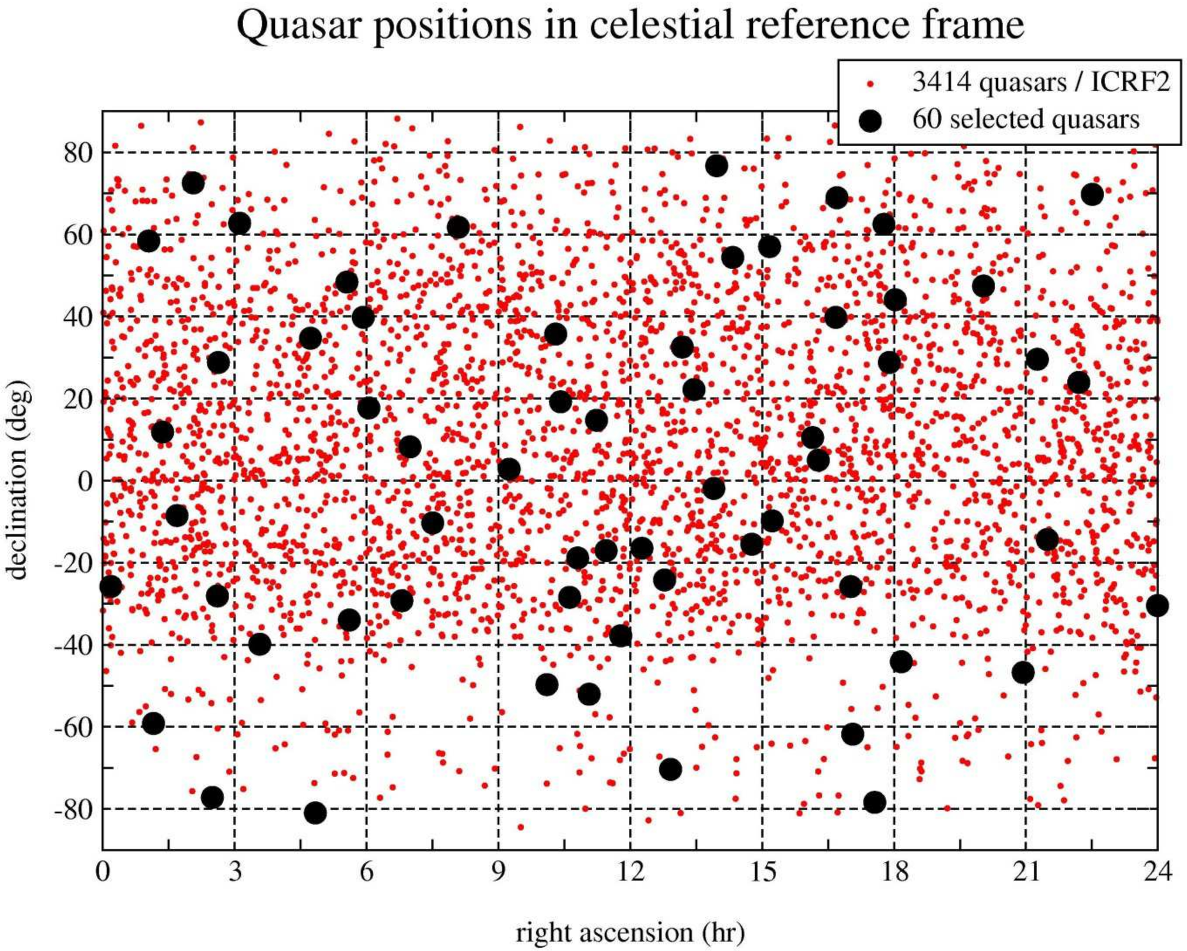
- adding Tahiti to a 8-station network (Hobart, Kokee, Canary Isl., NyAlesund, Tsukuba, GGAO, Wettzell, Badary) improves EOP precision by 25%,

- taking into account a set of 15-station globally distributed network, adding Tahiti improves EOP precision by 13%.

The CNES/GRGS GINS software is able to simulate all kinds of space geodesy measurements. This feature was used to estimate the impact of an additional VLBI antenna in Tahiti taking into account a limited set of 12 VLBI antennas well distributed all over the world with a set of 60 quasar sources.

Set of quasars for simulations

From 295 ICRF2 quasars used for the celestial reference frame orientation
we selected a set of 60 quasars equally distributed in right ascension and declination

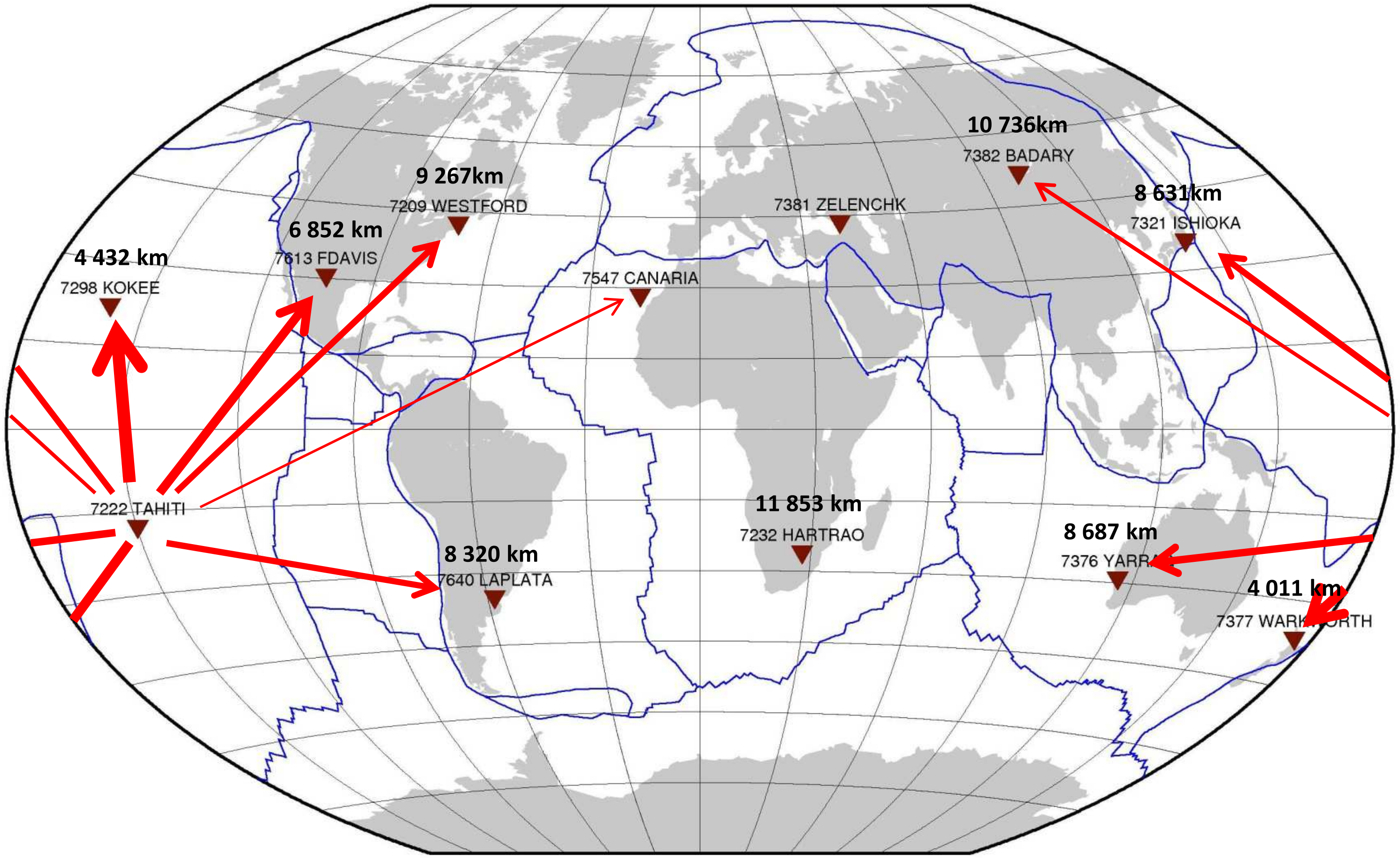


VLBI station network

Example of simulated data over one week from 12 stations and 60 quasars (~28 000 obs., ~4 800 obs. from Tahiti)

bases with Tahiti per week:

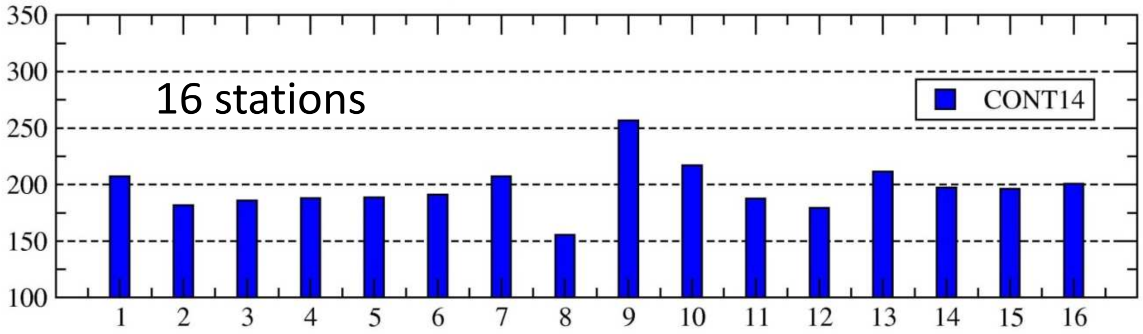
752 obs.	TAHITI - KOKEE	4431 km
715 obs.	TAHITI - WARKWORT	4011 km
667 obs.	TAHITI - FDAVIS	6851 km
472 obs.	TAHITI - YARRAG	8687 km
392 obs.	TAHITI - WESTFORD	9267 km
370 obs.	TAHITI - LAPLATA	8319 km
392 obs.	TAHITI - ISHIOKA	8630 km
84 obs.	TAHITI - BADARY	10736 km
15 obs.	TAHITI - CANARIA	11817 km

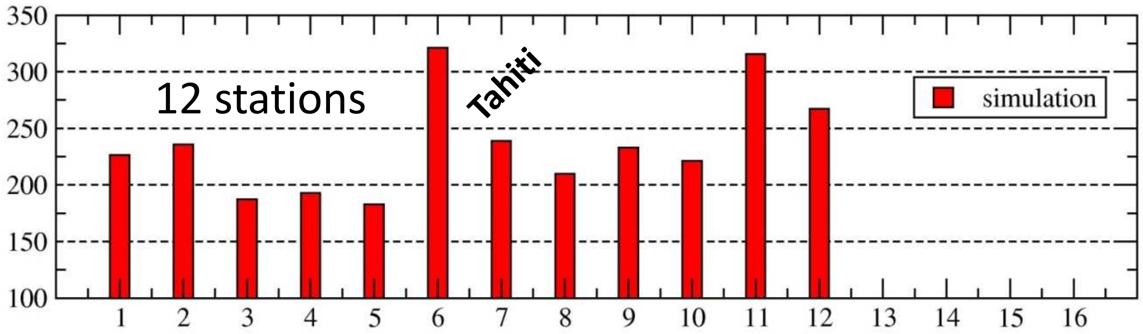


Simulation vs. CONT’14 data

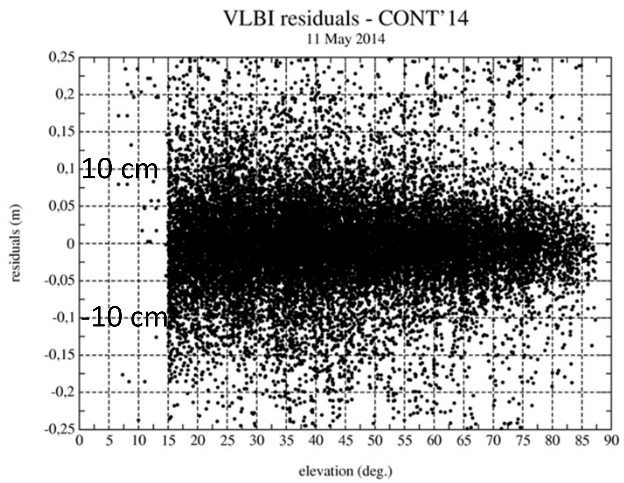
In order to be most realistic we considered equivalent observation density (one observation every ~200s in average per station) and simulated model errors giving similar results as for the CONT’14 campaign.

Mean scan interval (in sec.) per station over one week

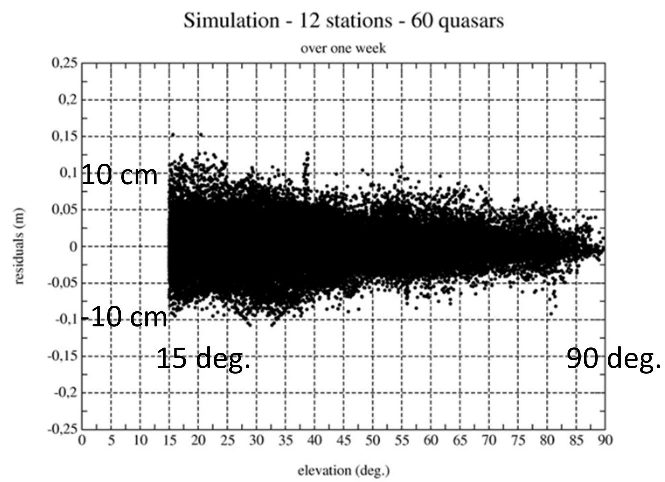




CONT’14 residuals / elevation angle



simulation residuals / elevation angle



Observations simulated every 90 s → 28 000 observations per week

Simulated errors

A white **measurement noise** of 1.4 mm (at 1σ) was introduced on VLBI-type measurements. Moreover standard errors were introduced on following models or parameters:

1. **Stations coordinates**: 3 cm random at 1σ per X, Y, Z coordinate

	X	Y	Z	Lat	Lon	H
12 stations - mean (m) :	0.023	0.012	-0.014	-0.017	0.002	-0.005
st. dev. (m) :	0.012	0.029	0.036	0.035	0.030	0.031

2. **Quasars coordinates**: randomly according to the standard errors of ICRF2

	Right Asc. (ms)	Decl. (mas)
60 quasars - mean :	0.002	-0.007
st. dev. :	0.010	0.081

3. **Pole coordinates**: randomly according to the standard errors of IERC04

	Xp (mas)	Yp (mas)	UT 1(ms)
over 8 weeks - mean :	0.002	0.000	-0.001
st. dev. :	0.042	0.044	0.015

4. **Troposphere models**: GPT/GMF vs. Hopfield with cut-off angle of 15 deg.

Simulation synopsis

Weekly processing over 8 consecutive weeks:

- 12 stations with 15 deg. elevation cutoff
- 60 quasars
- ~28 000 VLBI measures/week (every 200 s in average at each station)

VLBI residuals per noise type introduced:

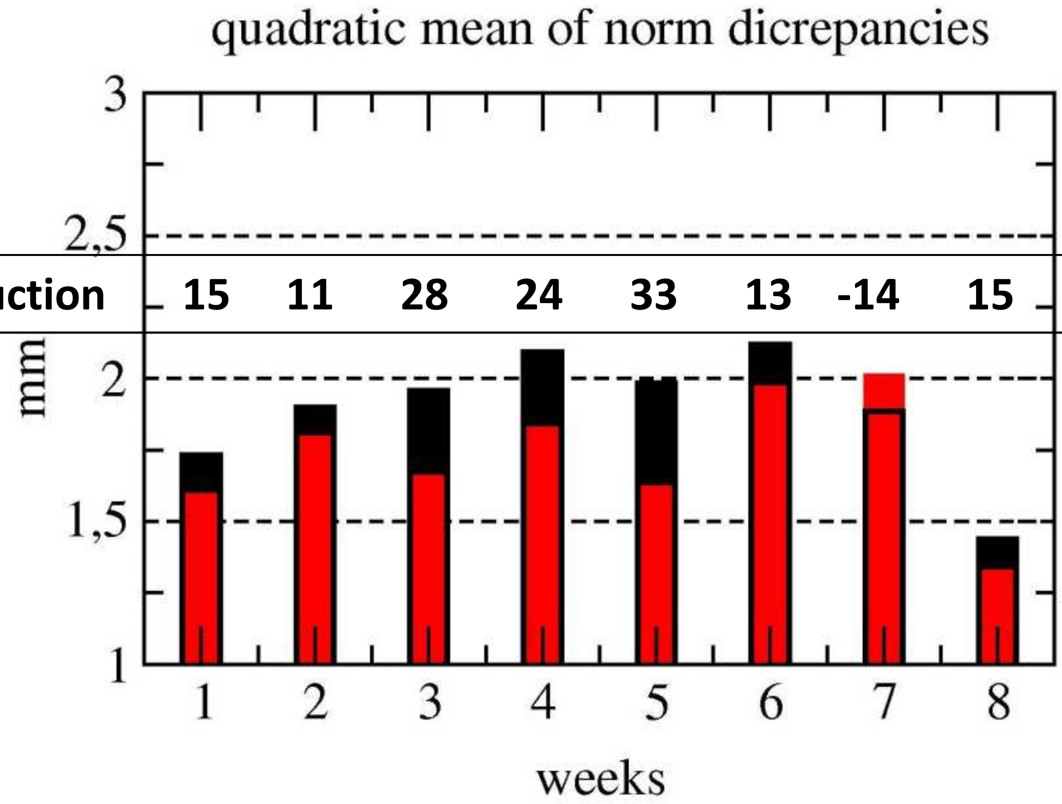
	before *(1st iteration)*	/	*after clock and troposphere adjustment* *(last iteration in processing)*
1. Stations coordinates:	37.3 mm	/	23.1 mm
2. Quasars coordinates:	2.9 mm	/	2.1 mm
3. Pole coordinates:	6.4 mm	/	4.8 mm
4. Troposphere models:	113.6 mm	/	2.0 mm
5. Measurements:	1.41 mm	/	1.37 mm
6. All effects together			**24.6 mm** (80 ps)

Adjusted parameters:

Troposphere zenithal bias per 2 hrs (in pwl mode) → 8064 parameters
Clock offset per 2hrs (in pwl mode) → 7392 parameters
Pole coordinates per day (Px, Py, UT in pwl mode) → 171 parameters
Quasar coordinates for 60 quasars over 8 weeks (r. asc./decl.) → 120 parameters
Station coordinates for 12 stations per week (X, Y, Z) → 288 parameters

TRF results

Stations coordinates are adjusted weekly considering or not a VLBI antenna in Tahiti.
One notes a general improvement of the TRF with variance reduction factors of ~15% in average after adjustment.



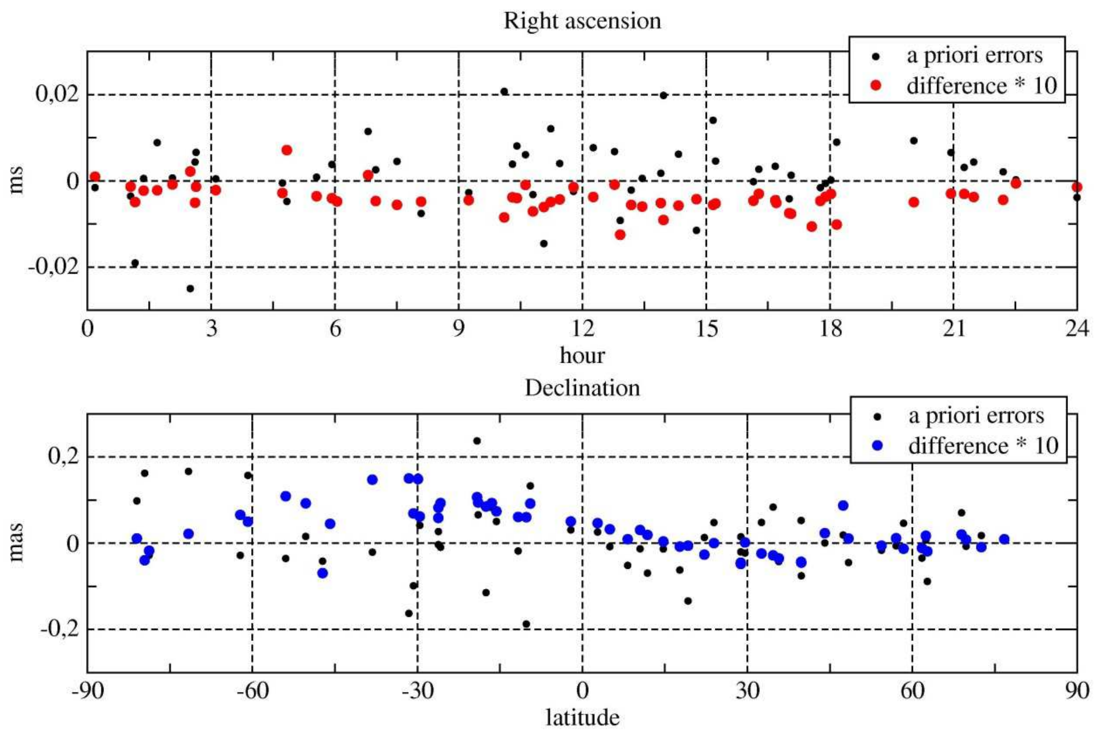
Variance reduction	**15**	**11**	**28**	**24**	**33**	**13**	**-14**	**15**	**(%)**

CRF results

Quasar coordinates are adjusted over the full 8-week test period with/without the Tahiti site.

rms / ref.	a priori noise	11 sta. wo T	12 sta.
R. asc. (ms)	.0105	.0022	.0025
Decl. (mas)	.0810	.0142	.0106

CRF declination is mainly improved in the southern hemisphere



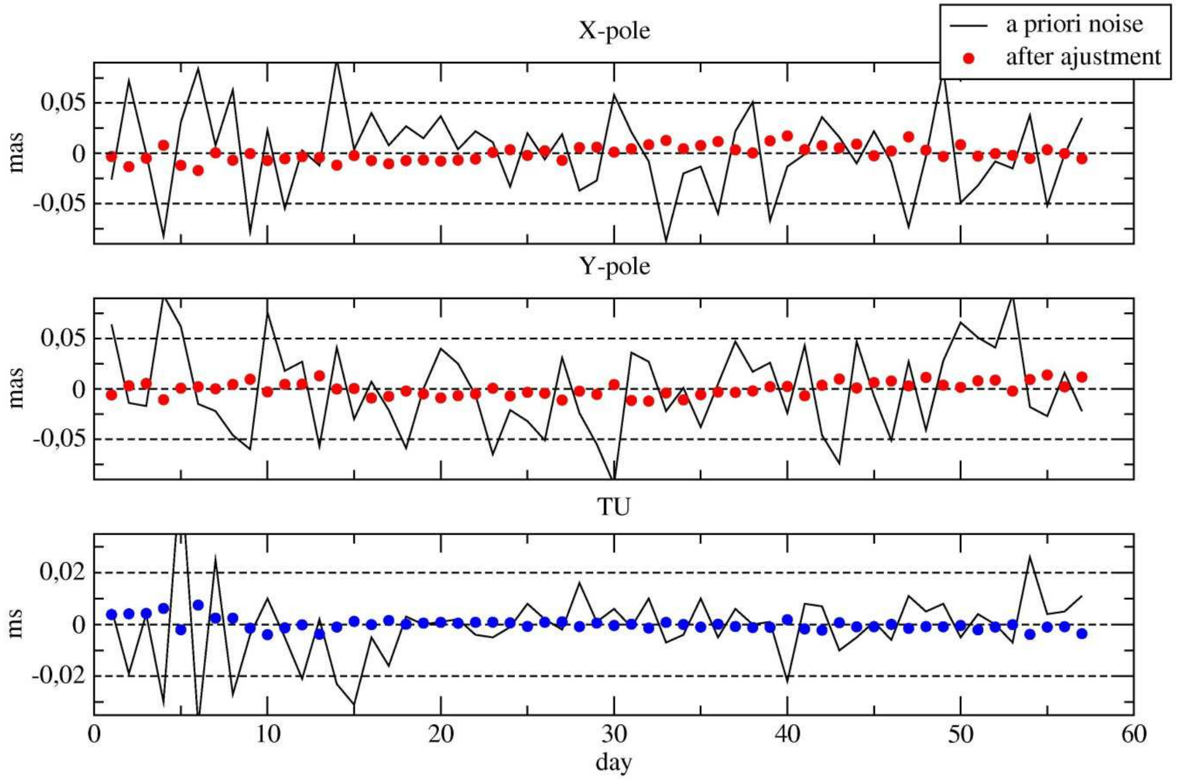
ERP results

Pole coordinates are adjusted per day with/without the Tahiti site.

rms / ref.	a priori noise	11 sta. wo T	12 sta.
Xp (mas)	.04203	.00887	.00745
Yp (mas)	.04407	.00541	.00676
UT1 (ms)	.01511	.00217	.00216

ERPs are not as much improved with Tahiti.
No improvement in UT1.

.03 mas ⇔ 1 mm
.002 ms ⇔ 1 mm



Summary

- No prejudicial radiofrequency interferences were detected for setting up the DORIS and VLBI equipment
- The TNT site is approved by CNES, IGN, NASA, ESA experts for hosting a geodetic observatory
- Its realization could occur in 2020
- Several previous simulations showed positive impacts of a VLBI station in Tahiti
- Concerning this simulation work, adding a VLBI antenna in Tahiti improves TRF with a ~15% variance reduction for a homogeneous 12- station network
- Observing down to 15 deg. (compared to 20 deg.) brings 17% improvement