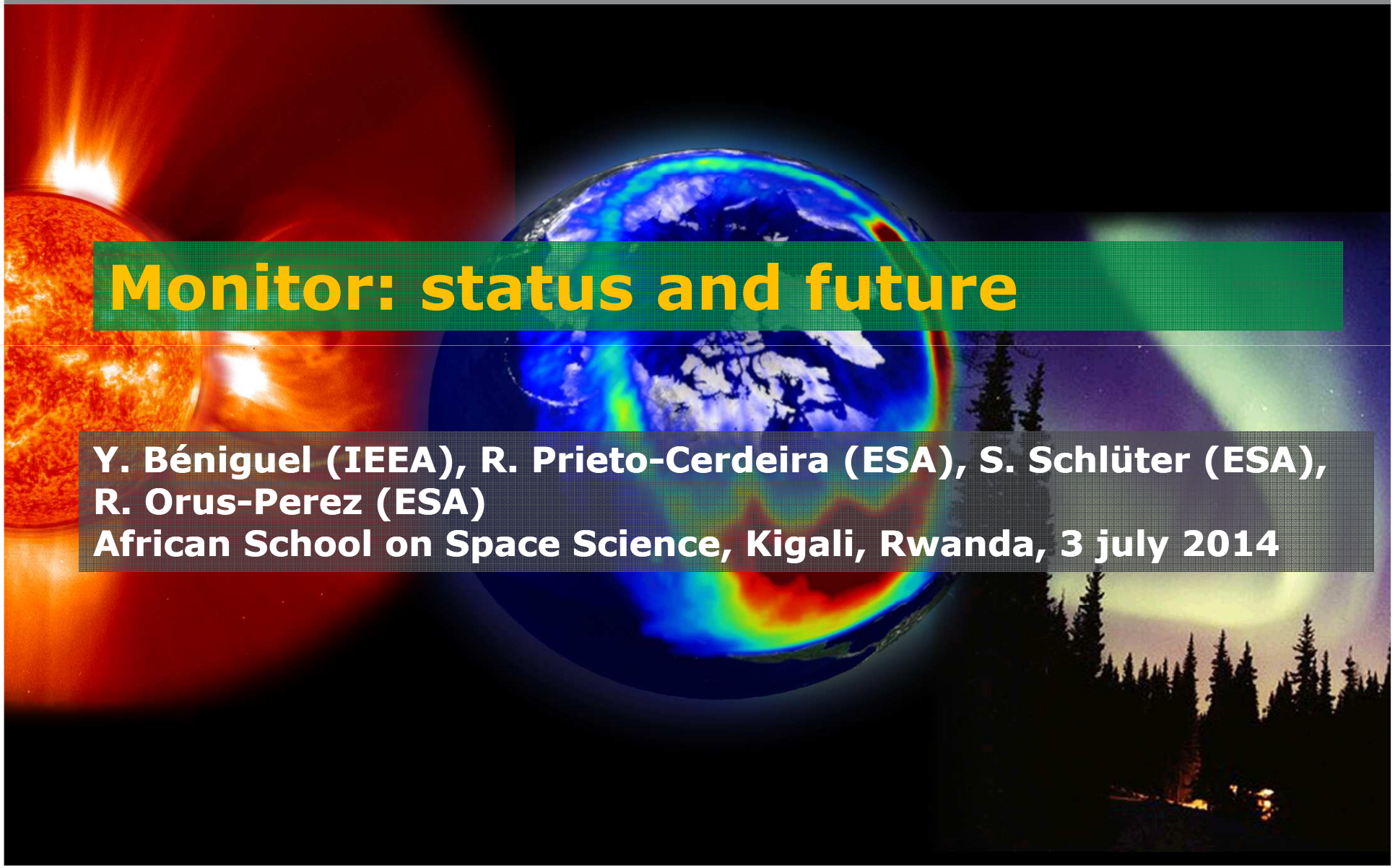


Monitor: status and future

Y. Béniguel (IEEA), R. Prieto-Cerdeira (ESA), S. Schlüter (ESA), R. Orus-Perez (ESA)

African School on Space Science, Kigali, Rwanda, 3 july 2014

Justification

- Collection, processing and archiving:
  - ionospheric experimental data
- Establish scintillation monitoring network
- Develop improved scintillation monitoring instrumentation

in order to build the infrastructure allowing to analyse:

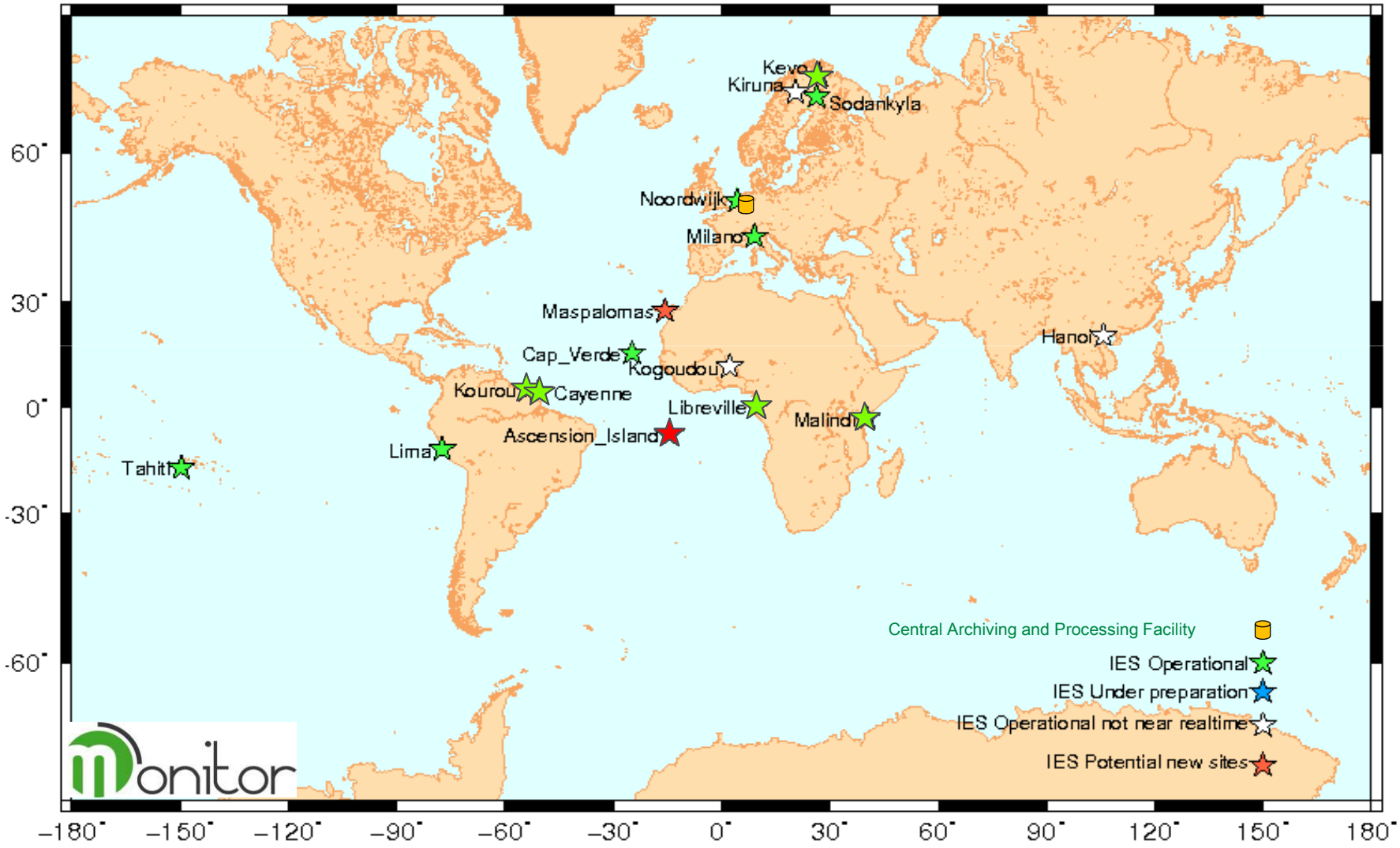
- impact on GNSS (EGNOS and Galileo)
- high solar activity periods
- extreme events

Phase 1 team & schedule

Collaborations:

Phase 1 duration ~ Spring Equinox 2010 – Winter Solstice 2013
Experimental data ~ Autumn Equinox 2011 – Winter Solstice 2013

Ionospheric Experimental Station Network



Monitor Architecture

GISMO+bitgrabber (new development)

Septentrio PolaRxS

IES station

IES station

IES station

Novatel GSV4004B

Located at ESA/ESTEC

Monitor: Ionospheric Experimental Stations

Former stations (from previous projects e.g. PRIS)

– Including Novatel GSV 4004B ISM or Javad receivers

– Most stations only provide 1-minute S4 and σ_Φ

New stations:

– One or two ISMs:

a. Novatel GSV4004B

b. Septentrio PolaRxS

c. TAS-I GISMO

– GISMO stations incorporate a bitgrabber

– Data:

a. 1-minute S4 and σ_Φ

b. Raw data at 50 or 100 Hz

c. RINEX at 1Hz

d. IF raw data (bitgrabber)

Tahiti

- Located at Faaa, Papeete
- Operational since 08/2012
- Managed by Meteo France
- Sharing antenna with HSO-GN GNSS receiver
- Direct transfer of data possible

Credits: Jens Martin (ESOC)

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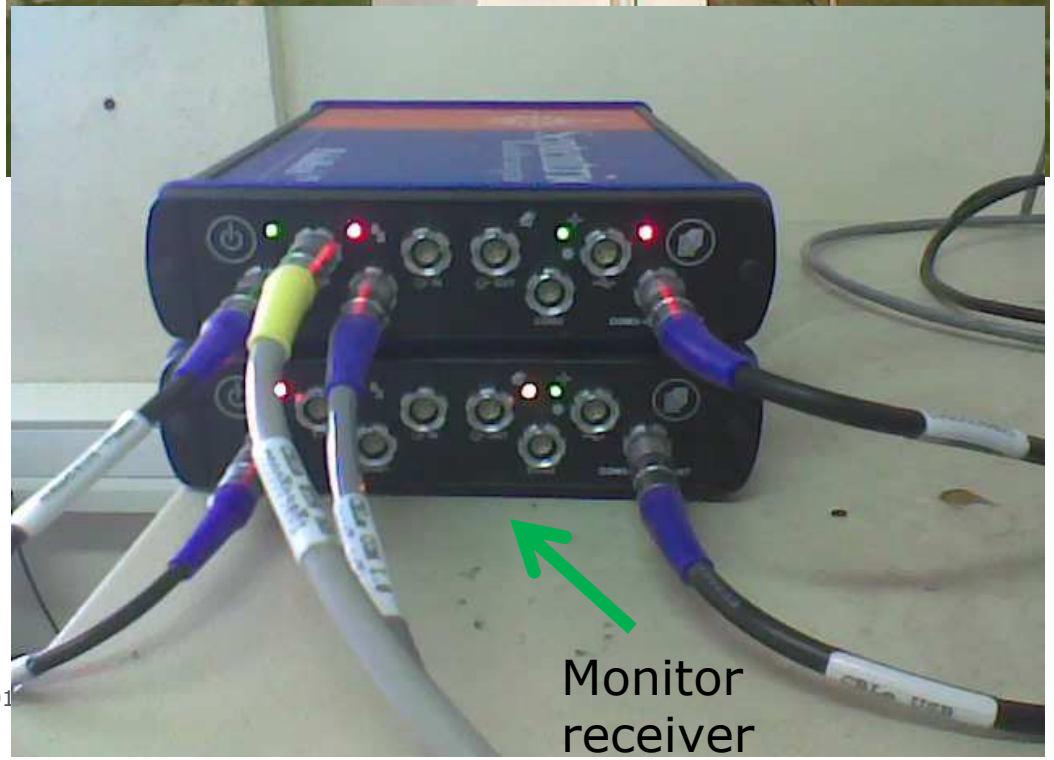

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- Sharing antenna with HSO-GN GNSS receiver
- Direct transfer of data possible

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Malindi

- Located at Malindi, Kenya
- Operational since 03/2013
- Managed by Agenzia Spaziale Italiana (ASI)
- Sharing antenna with HSO-GN GNSS receiver
- 50Hz are transferred by hard disk

Credits: Jens Martin (ESOC)

Malindi

- Located at Malindi, Kenya
- Operational since 03/2013
- Managed by Agenzia Spaziale Italiana (ASI)
- Sharing antenna with HSO-GN GNSS receiver
- 50Hz are transferred by hard disk

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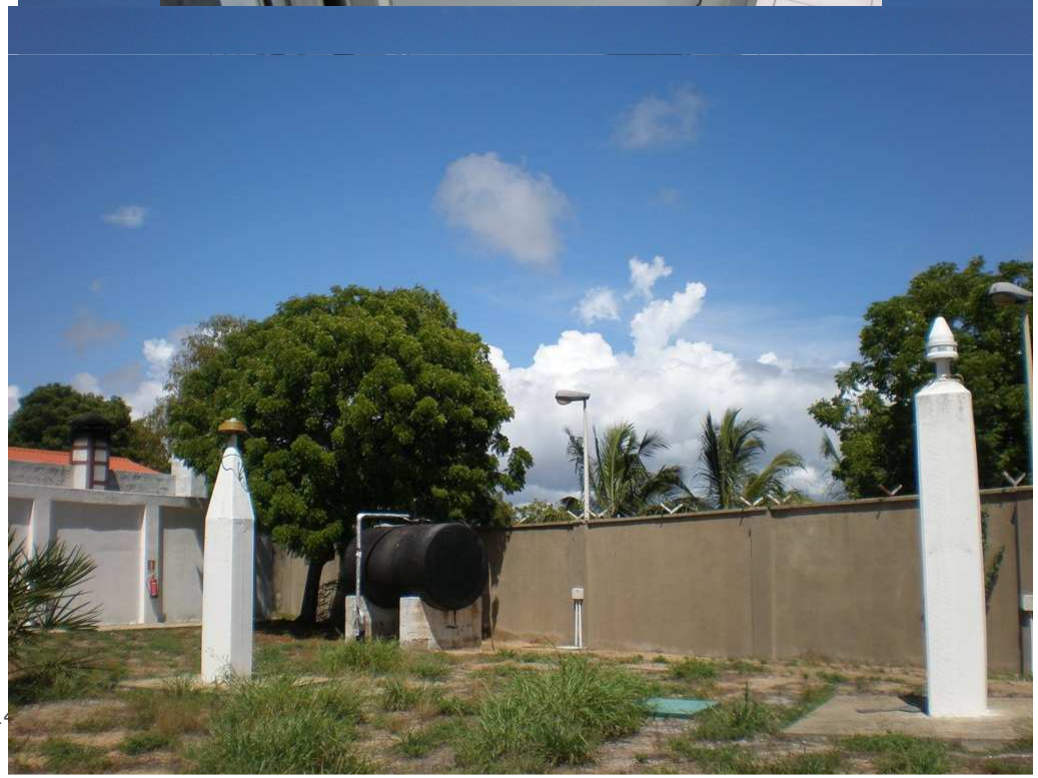


Credits: Jens Martin (ESOC)

Stations by CNES: Libreville & Kourou

Sites of Kourou CSG and Libreville CSG

KOUROU

- Equipment installed in March 2013
- At REGINA station, using REGINA Leica antenna
- ISM in REGINA Station rack at Galiot building

LIBREVILLE

- Equipment installed in March 2013
- At REGINA station, using REGINA Trimble antenna
- ISM placed in CNES SCG tracking station premises

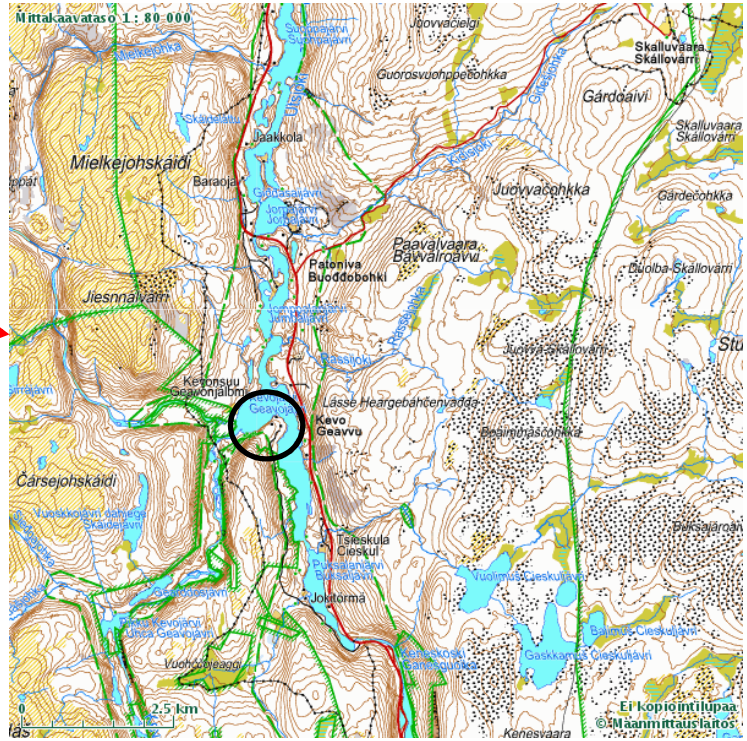
Credits: F. Carvalho, JL Issler (CNES)

Installation at Lima

Installation at Cape-Verde

High-latitude stations: Kevo

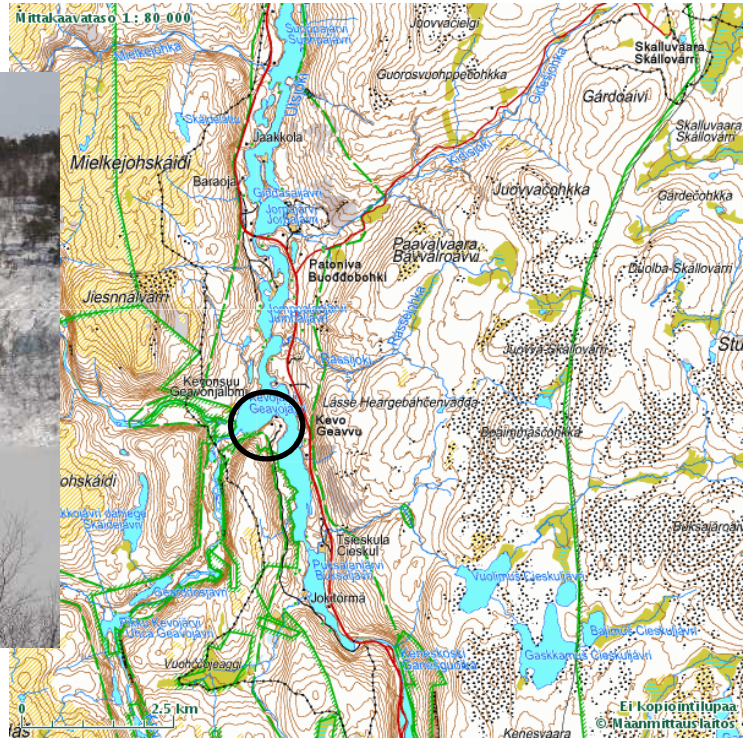
Site: Kevo Research Station (University of Turku)
(69°45‘ N, 27°01‘ E)



GSV Novatel installed in March 2013.

High-latitude stations: Kevo

Site: Kevo Research Station (University of Turku)
(69°45‘ N, 27°01‘ E)



GSV Novatel installed in March 2013.

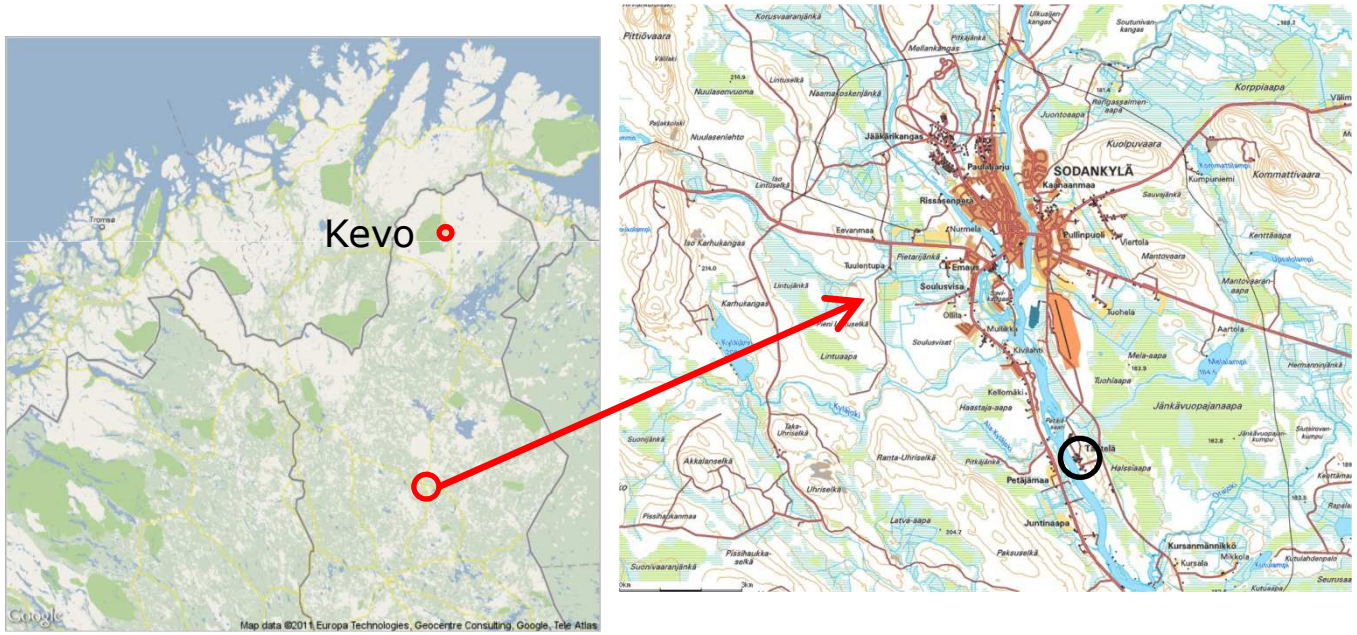
High-latitude stations: Kevo

Site: Kevo Research Station (University of Turku)
(69°45‘ N, 27°01‘ E)

GSV Novatel installed in March 2013.

High-latitude stations: Sodankylä

Site: Sodankylä Arctic Centre of FMI
(67.37° N, 26.63° E)



High-latitude stations: Sodankylä

Site: Sodankylä Arctic Centre of FMI
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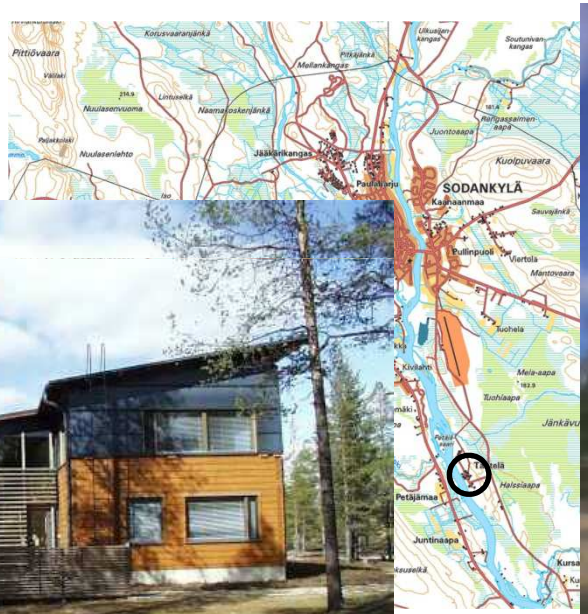


MONITOR: Data & Products

INTERNAL:

- Higher-order ionospheric maps
- Galileo ionospheric single frequency model (GALMOD)
- GALMOD correction performance evaluation (GALCOM)
- GALDIF (Galileo Ionospheric Disturbance Flag)
- Scintillation raw data analysis & mapping
  - Regional scintillation maps

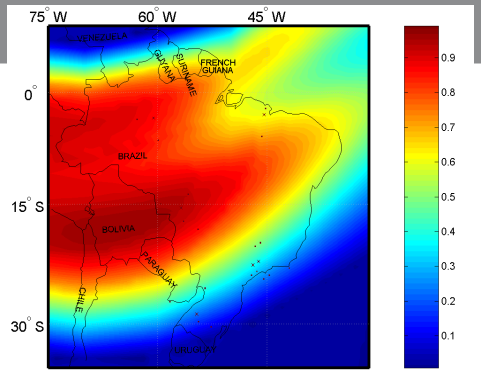
EXTERNAL:

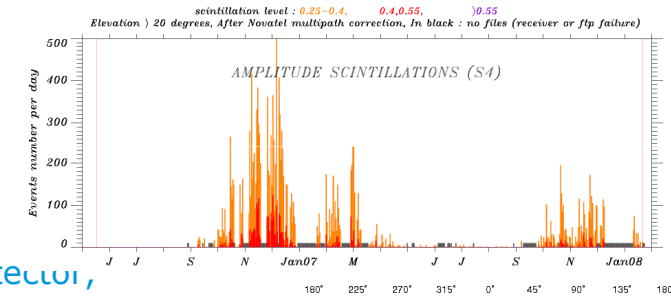
- TOMION: 15-minutes Global VTEC maps, GEC & IGS STEC
- Geodetic processor: stations STEC & DCBS
- Perturbation analysis:

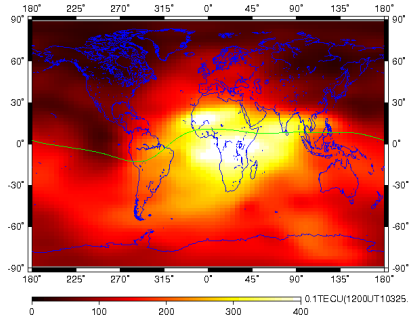
  sidereal day variability index, MS-TID index, Solar Flare detector, ROTI, AATR
- SWACI: 15 min nowcast and forecast VTEC European maps
- EDAM: Rapid (2 hours) and ultra-rapid (15 min) electron density datamaps

STATION DATA: 1-minute S4 and σ_Φ, Raw data at 50 or 100 Hz, RINEX at 1Hz

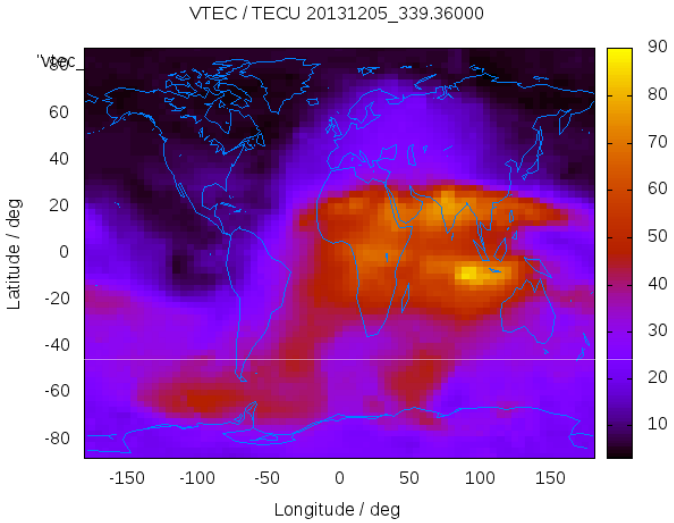
EXTERNAL DATA: Solar/geomagnetic indices, ionosonde data, EISCAT heating campaign

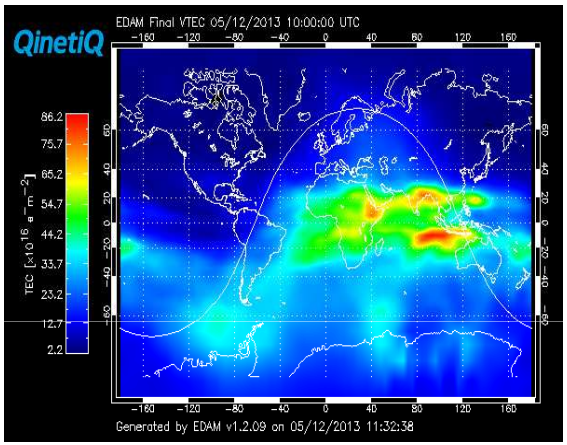


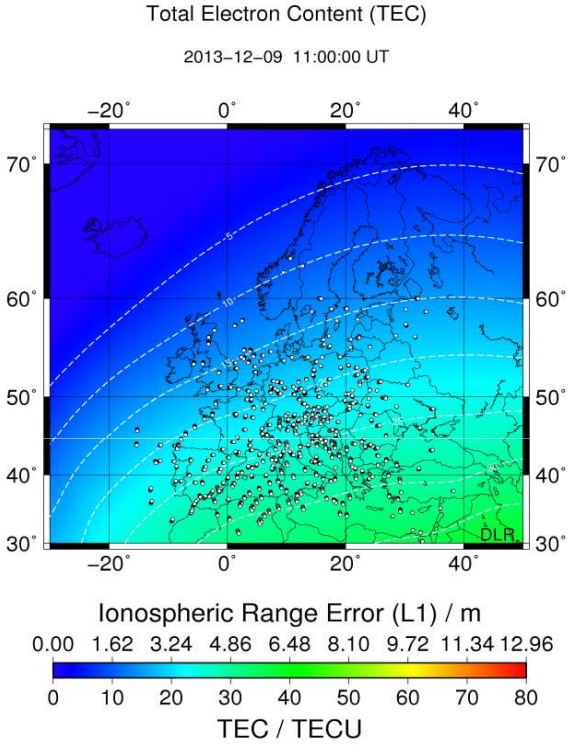




Monitor: example of products





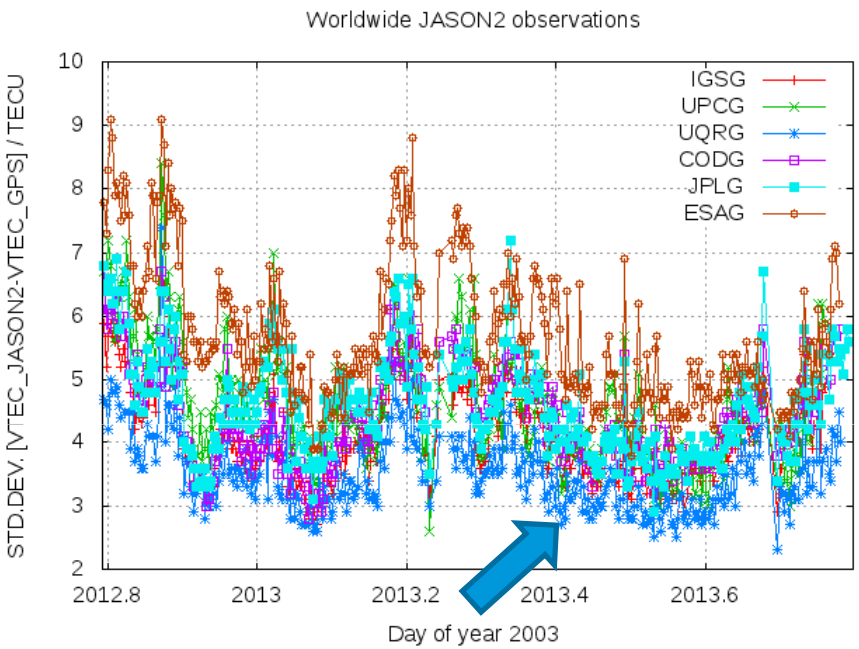


VTEC map plot associated to VTEC-TOMION UPC external products (240 IGS stations)
Latency : 1 < < 2 days

EDAM GUI showing the global vertical TEC (around 150 IGS stations + 20 ionosondes)
Latency : 1 < < 2 hours

SWACI output
Less than 100 EUREF stations
Latency : 5 mn

MONITOR rapid VTEC product: performing systematically better



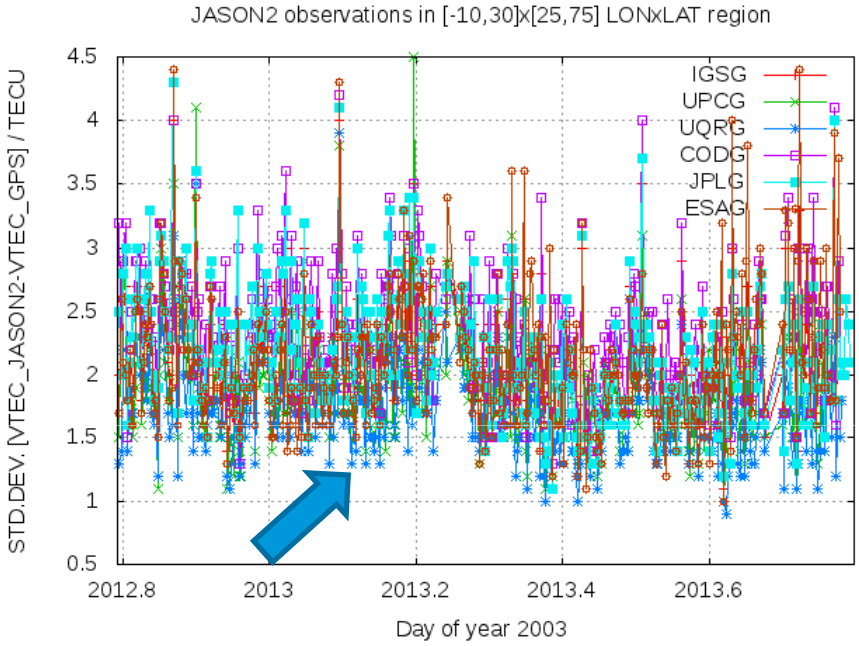


Figure: [Left-hand plot:] *Daily standard deviation of the* ***worldwide*** *differences* ***JASON2 VTEC – GNSS VTEC****, in TECU, for the global* ***MONITOR VTEC*** *(****new rapid, 1-2 days of latency, UPC product - UQRG-****, in dark blue)* ***vs. final (~11 days of latency) IGS VTEC*** *maps (combined and analysis center products) during the last year (second half of 2012 to second half of 2013).* ***[Right-hand plot:]*** *A similar study on the* ***European seas*** *only.*

Example of RT GNSS Solar Flare detection & agreement with external measurements

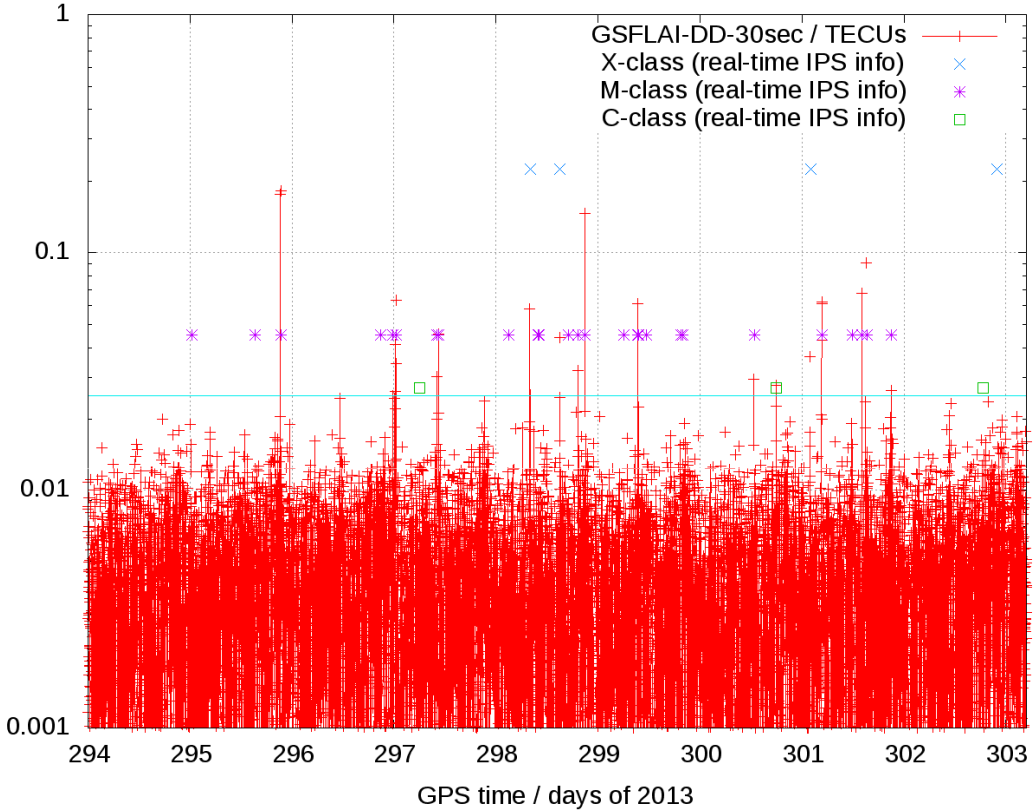
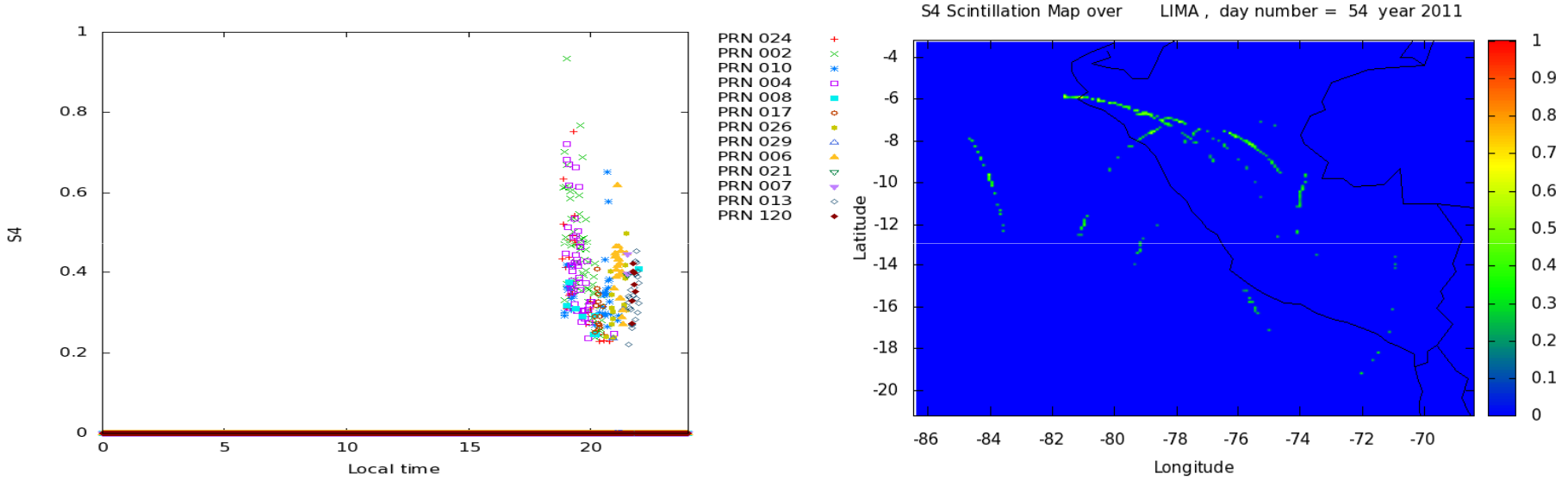


Figure: *Closer view to recent Solar Activity from MONITOR UPC products perspective :* ***GNSS Solar Flare Indicator*** *(red), versus the* ***IPS alerts*** *based on GOES direct X-rays flux measurements for* ***X****,* ***M*** *and* ***C*** *class flares (blue, magenta and green points, respectively ; days 294 to 302, 2013).*

Scintillations



Scintillations mapping over Peru








MONITOR 2

Phase 2 ~ Summer Solstice 2014 – Spring Equinox 2016
Experimental data ~ Winter Solstice 2013 – Winter Solstice 2015

Objectives

- **Maintenance** of existing MONITOR infrastructure.

- **Upgrade** the current Central Archiving and Processing Facility (CAPF) :
    a. Simplify data management and exchange.
    b. Interfaces, data access/policies, administration and usage.
    c. Simplify the integration of automatic processing tasks.
    d. Generation of new automatic data, products and reports tailored to EGNOS needs.

- **Expansion** of the Monitor ionospheric scintillation network.
    a. Integration of data from CNES-SAGAIE network and possibly some in Norway
    b. New stations at low-latitudes (Africa) and high-latitudes (Scandinavia).

Objectives (2)

- **Tools, datasets and scientific/engineering models** for example:
  a. Identification and analysis of disturbed events
  b. Relevant ionospheric scintillation data for consolidation of scintillation conditions for system performance.
  c. Provision of scintillation experimental reference datasets for analysis at receiver level (RIMS, final users).

- **Collaboration** with external entities:
  - CNES/ASECNA, SANSA, members of SBASIono group, Joint Research Center
  - LISN, SCINDA, CHAIN
  - …

Integration of data from SAGAIE

SAGAIE = **S**TATIONS **A**SECNA **G**NSS pour **A**NALYSE de la **I**ONOSPHERE **E**QUATORIALE (*assegai*)

CNES and ASECNA have decided in 2012 to deploy a GNSS data collection network in Sub-Saharian area for ionosphere characterization

Five sites were selected: Dakar, Lomé, Douala, Ouagadougou and N'Djamena

- Dakar and Ouagadougou are operational since in April 2013
- Douala, Lomé and N'djamena are operational since August 2013

Credits: Huges Secretan (CNES)

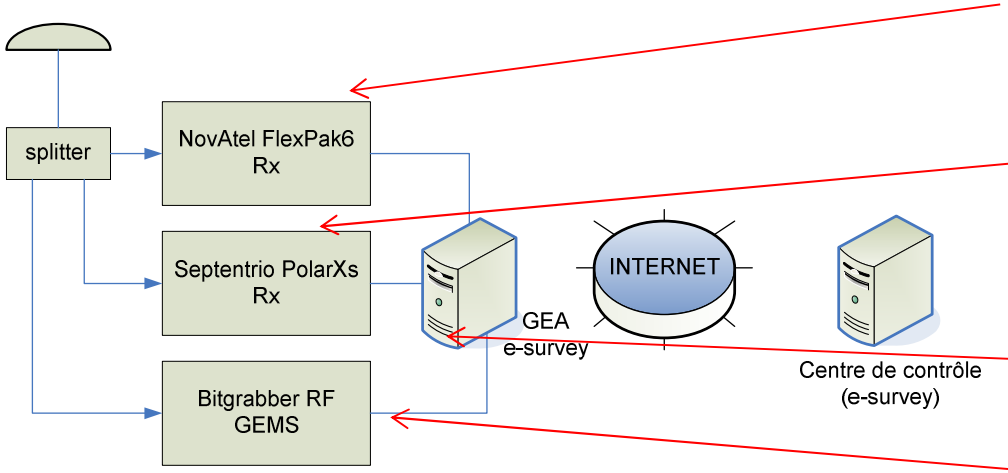
SAGAIE sites

All stations are deployed on airport sites to get benefice of high quality energy, telecom interfaces, security, skilled operators, ….

Credits: Huges Secretan (CNES)

Stations architectures

Architecture 1: Dakar, Lomé (PolarXS ISM))



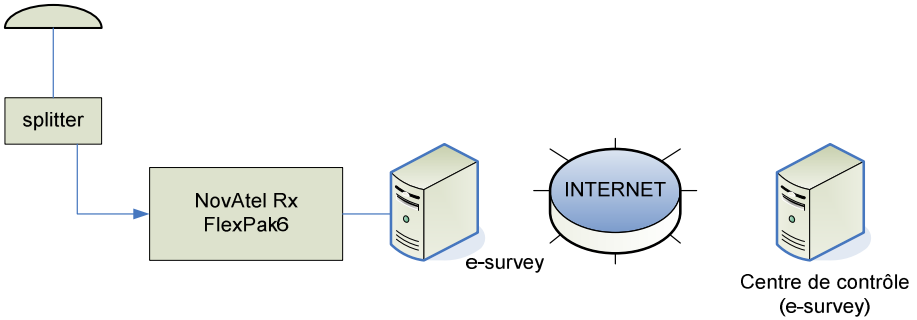
FLEXPAK6 Novatel Rx, GPS GLO GAL data Collection

PolarXS Septentrio Receiver, GPS, GLO, GAL raw data 50Hz and scintillations parameters (S4-σphi)

Archive all raw data measurements, Rinex compressed, and send to Toulouse

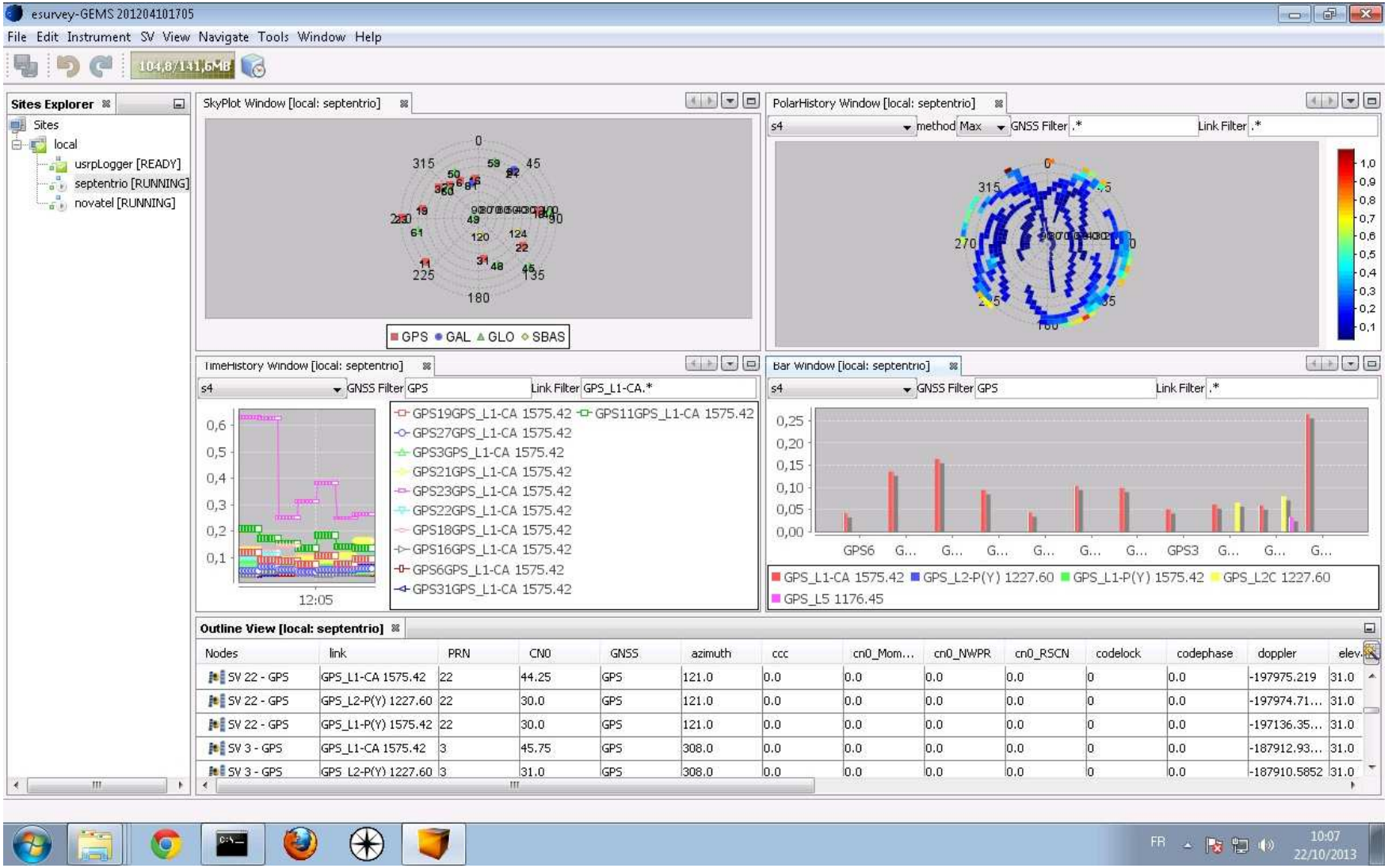
Bitgraber : 2XUSRPN200 for RF signal recording

Architecture 2: Douala, Ouagadougou, Ndjamena (Novatel OEM6)

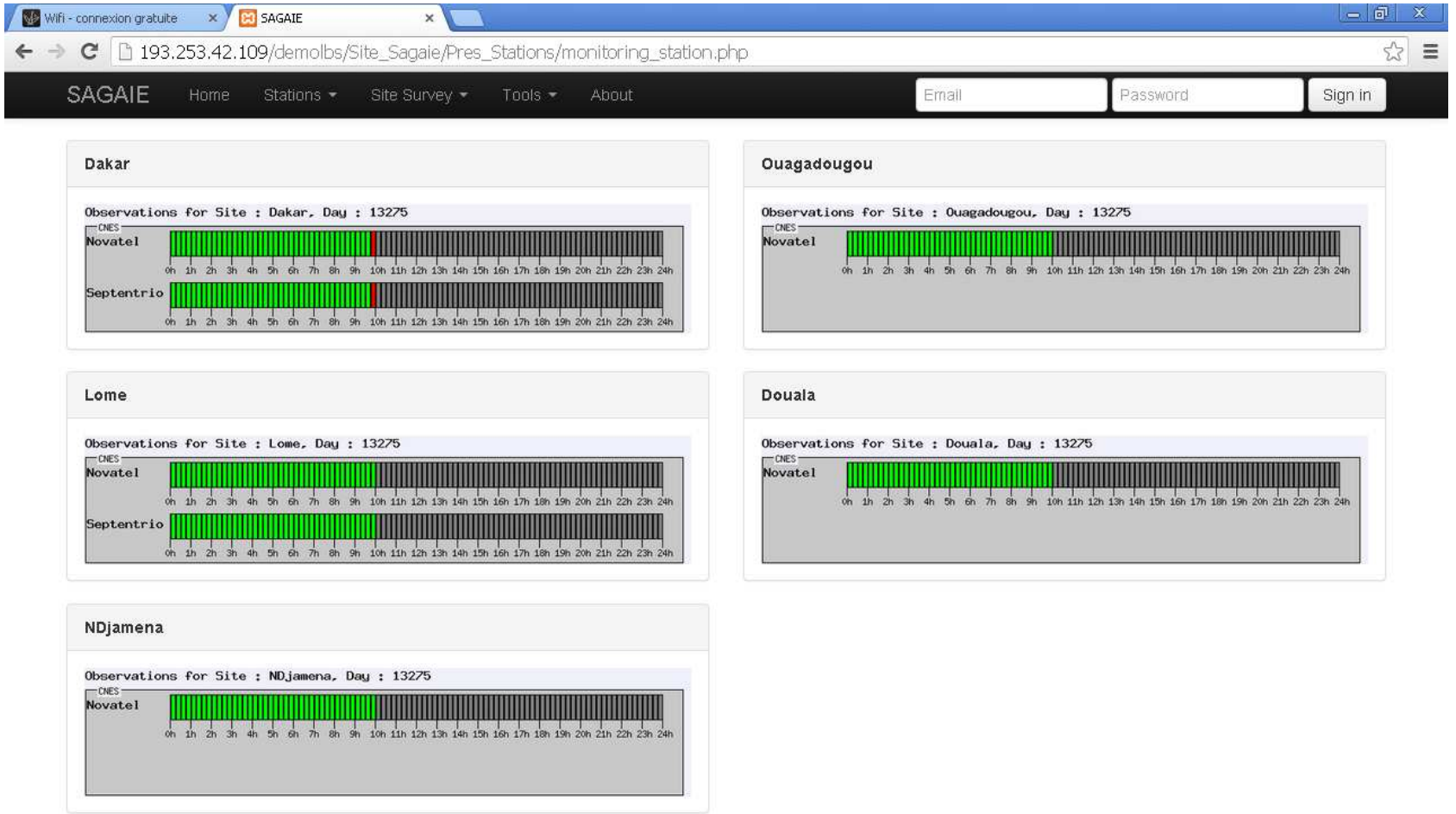


Credits: Huges Secretan (CNES)

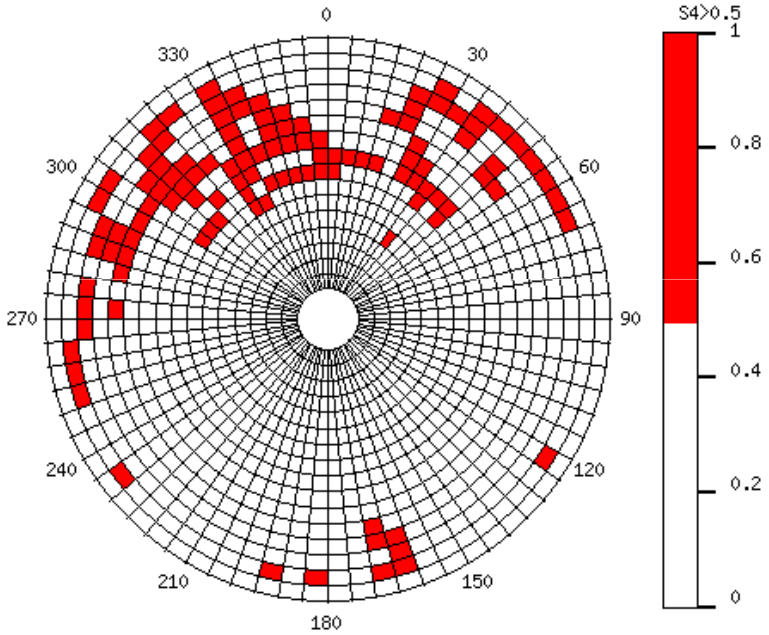
Remote Monitoring/Control with E_survey application

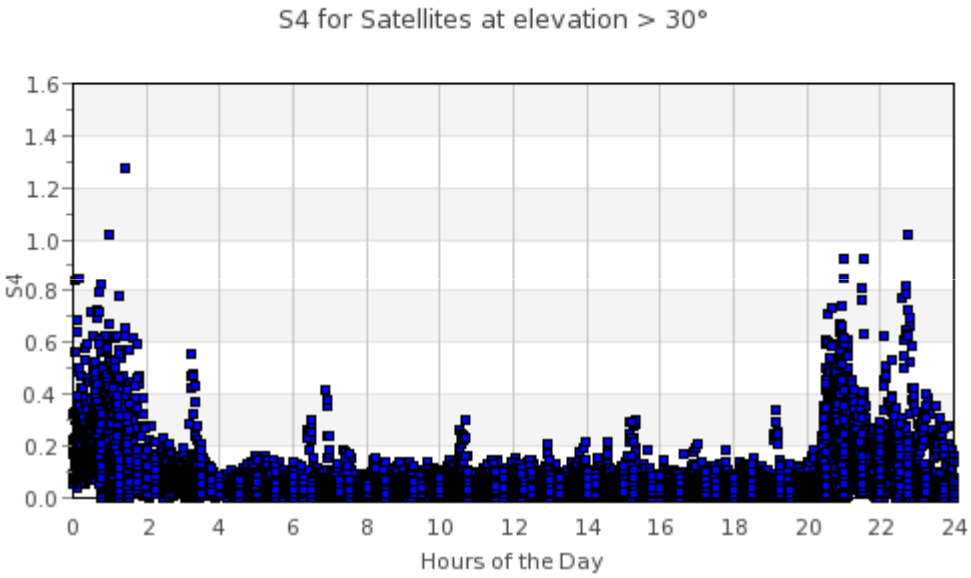


Monitoring of Rinex files transfer on server



S4 monitoring (day 11/11/2013)

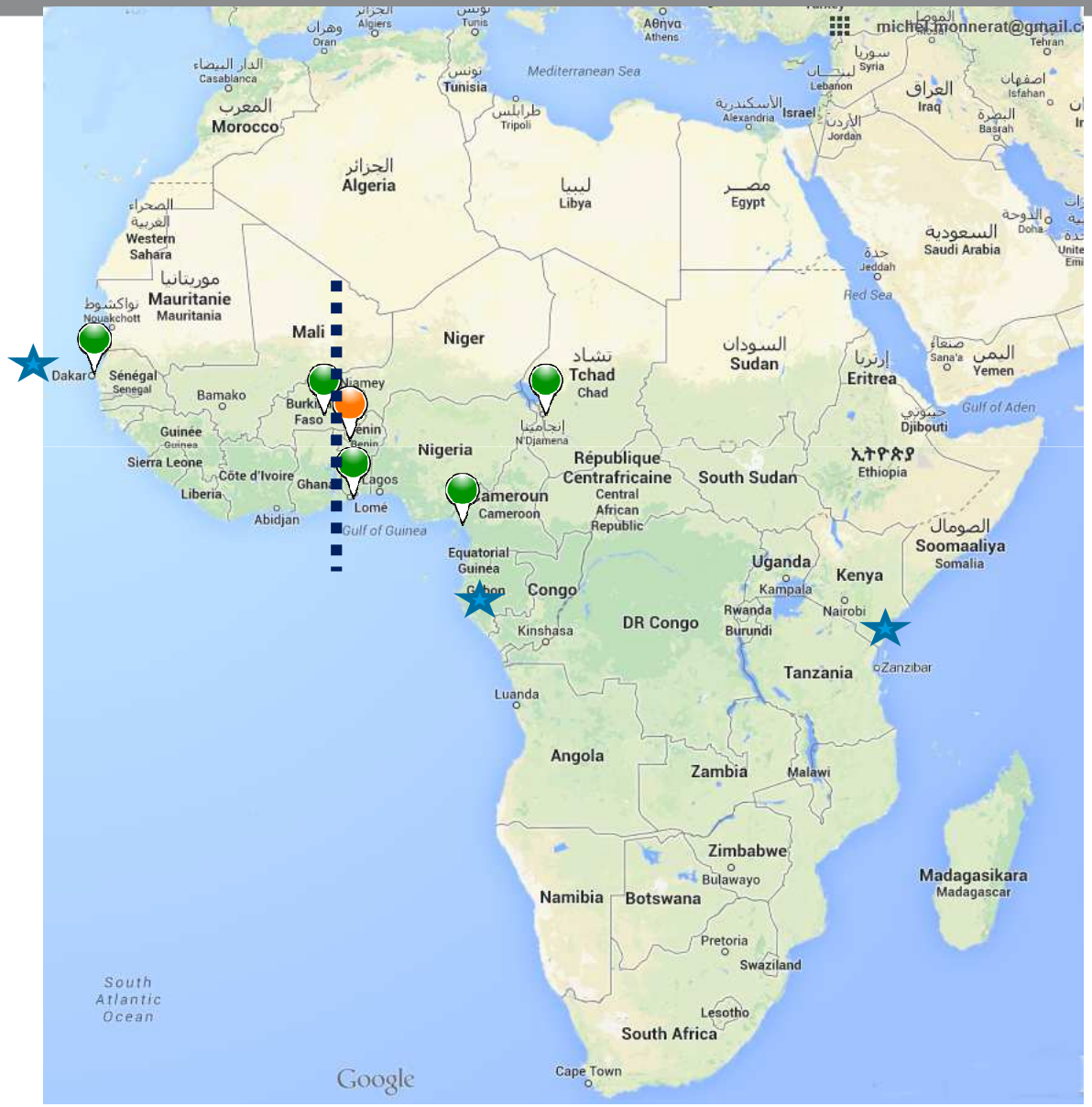




Potential new sites: low latitudes

1. Namibia (SANSA)
2. Fill gaps in ASECNA region
3. Small network in Togo

Sites Choice over Africa– First objective : Good sampling of an North-South Axis

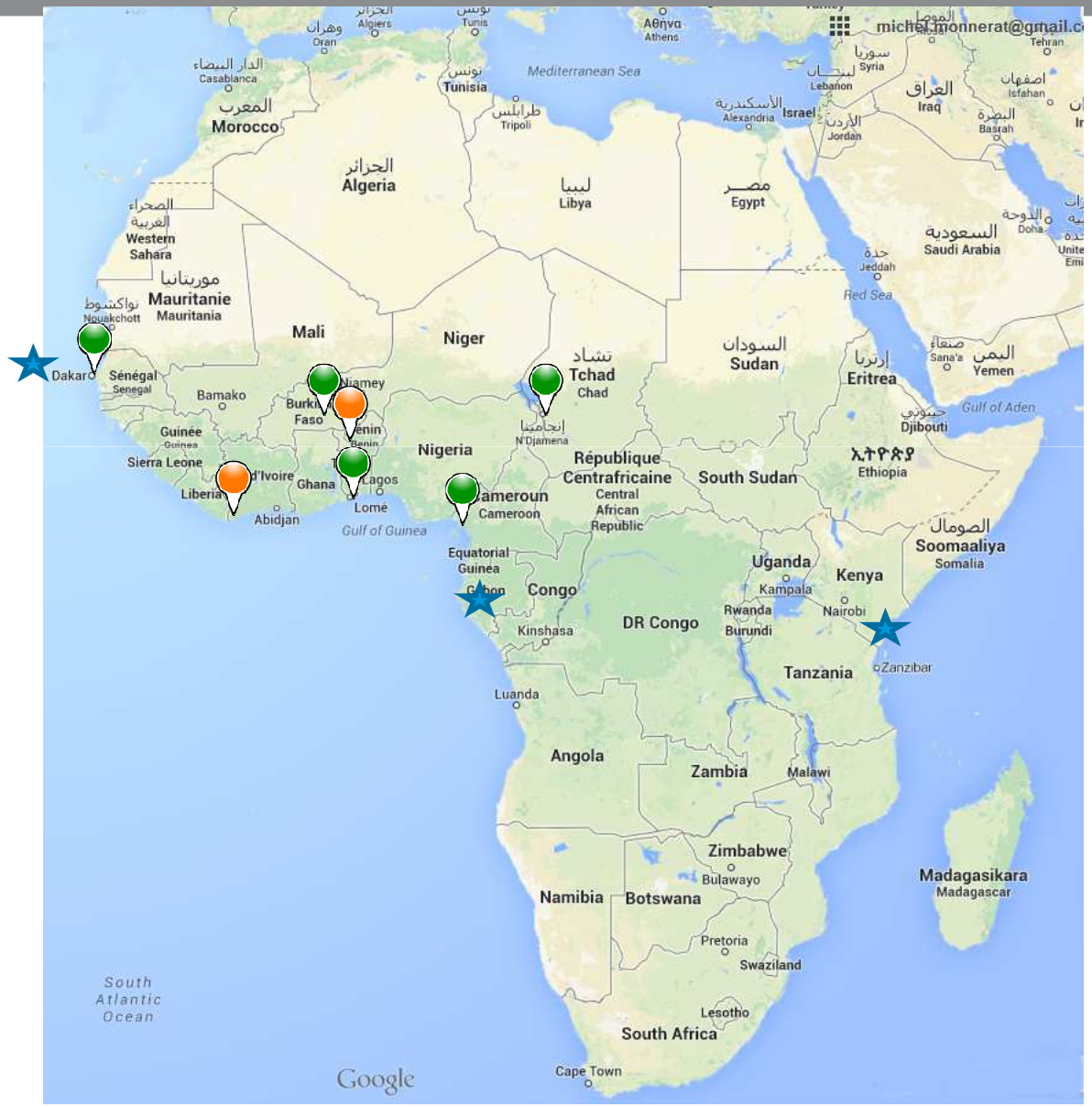


Niamtougou (Togo) Airport

- ASECNA Site
- Internet connection
- Power supply 24/7
- ASECNA staff on site

1. It also allows getting a bit grabber in this region. No bit grabber in SAGAIE/Ouagadougou site

Sites Choice over Africa– Second objective : Better coverage in south west

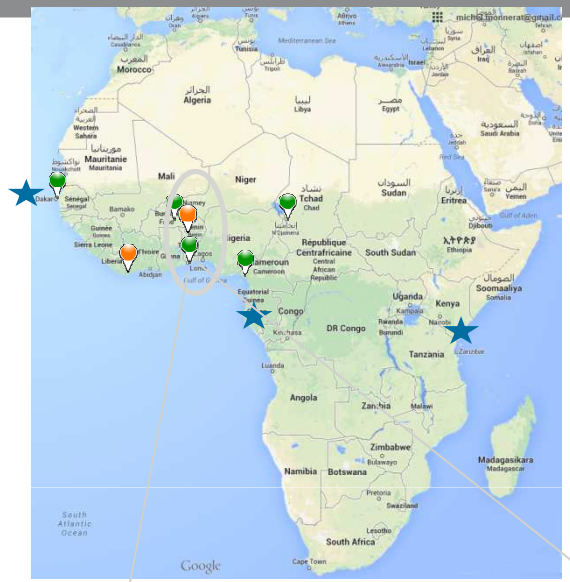


San Pedro Airport (Côte d'Ivoire)

- ASECNA Airport
- VSAT available
- Power supply 24/7
- ASECNA Staff on site

1. The ASECNA Site the most in the west,
2. Preferred to Conakry because of Ebola epidemic

Sites Choice over Africa– Third objective : Micro Network to observe bubble



Two possibilities :

- French School of Lomé
- Power 24/7
- Good Internet Connection

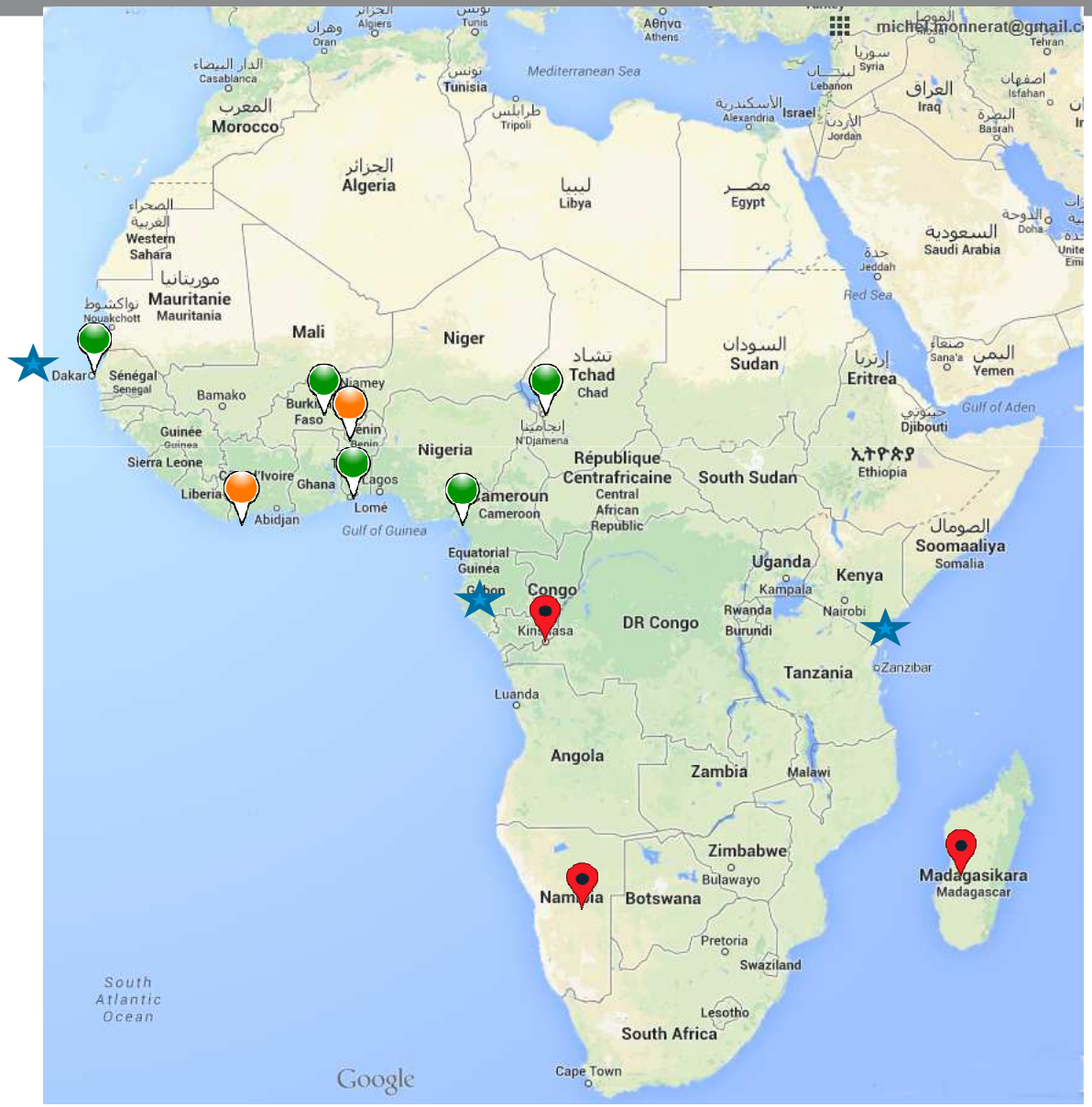
2. ILS Marker 8km from Lomé

1. ASECNA Site

2. Internet connection to be set up

3. Air cooling TBC

Sites Choice over Africa– Fourth objective : Increase observation in the south



Two possibilities :

- Namibia – SANSA site
- Brazzaville – ASECNA Site

Other Possibilities :

- Madagascar – ASECNA Site
- Bahir Dar - Ethiopia

Alternative (not for this objective):

1. Cotonou/Benin

Potential new sites: high latitudes

High-latitudes:

- Kiruna (new station at existing DLR site)
- Data exchange with NMA: Tromso, Ny Alesund, Vega,

Norway Mapping Authority
Scintillation network
Credits: Knut Stanley-Jacobsen (NMA)

SCINTILLATION RAW DATA FROM CAP VERDE AND VIETNAM

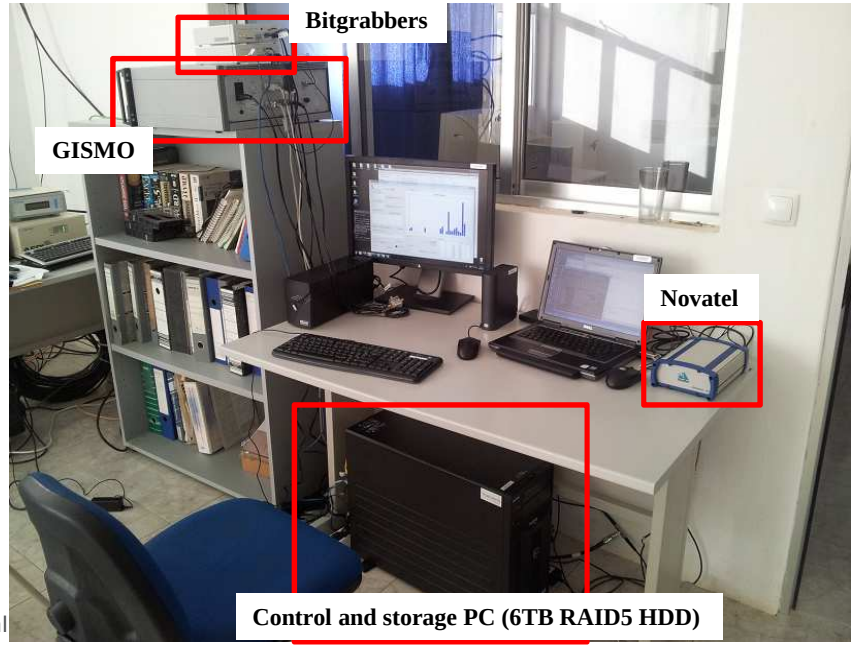
Acknowledgements:
D. Serant (Thales Alenia Space France)
Joaquim Fortuny (Joint Research Center)
Marco Pini & Gabriella Povero (Istituto Superiore Mario Boella)

Bitgrabber station in Cape Verde (1/2)

1. Location:
    a. Cape Verde, Sal island
    b. 16.73N, 22.9W

Bitgrabber station in Cape Verde (2/2)

1. Equipment:
    a. 1 GSV4004B Novatel receiver (L1, L2, SBAS)
    b. 1 GISMO receiver (TAS-I) (L1, L5, E1, E5a)
    c. 2 bitgrabbers, to record raw GNSS signal (baseband)
        - USRP2
        - L1 and L2, 5Mhz bandwidth, 8 bits quantization



MONITOR GISMO: Iono Monitoring Station Receiver

Based on MBOC Rx

- 1 NavCom Board
- 1 RF/IF Board
- 1 DSP Board configured as following:
  - GPSL1, GPS L2c, GPS L5
  - GALILEO E1, GALILEO E5b
  - GALILEO E1, GALILEO E5a
- 1 OCXO Board

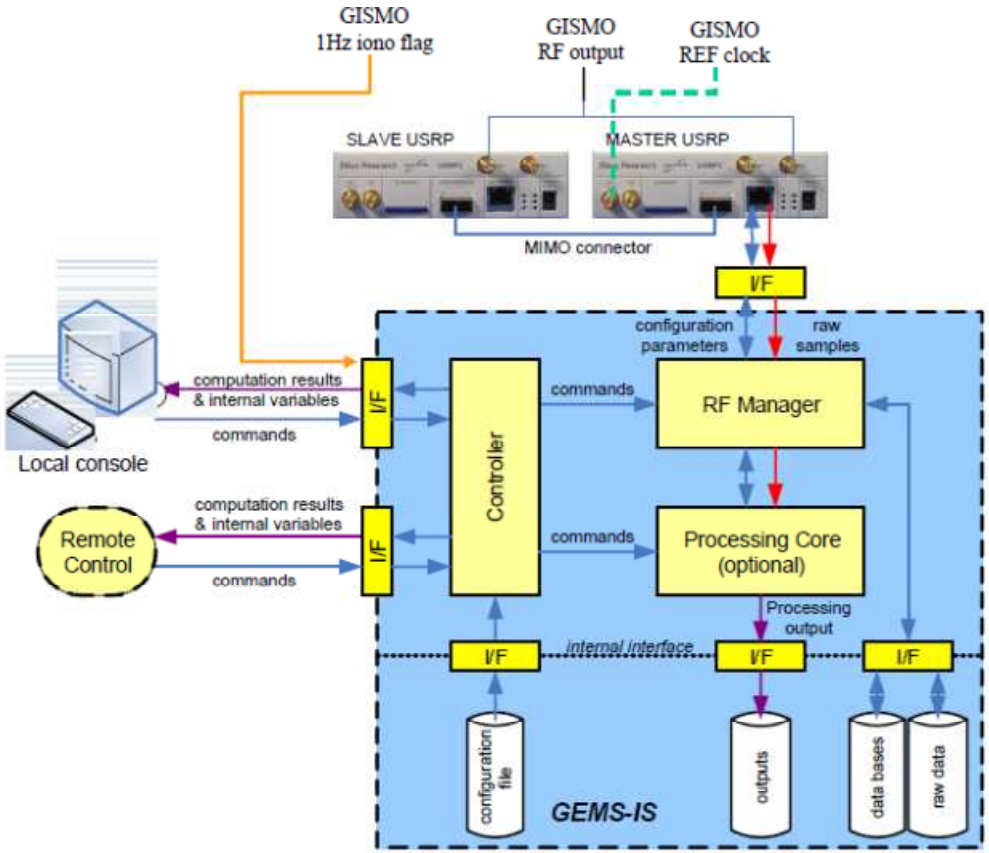
Includes Ionospheric parameters estimation

(S4, sigma-phi)

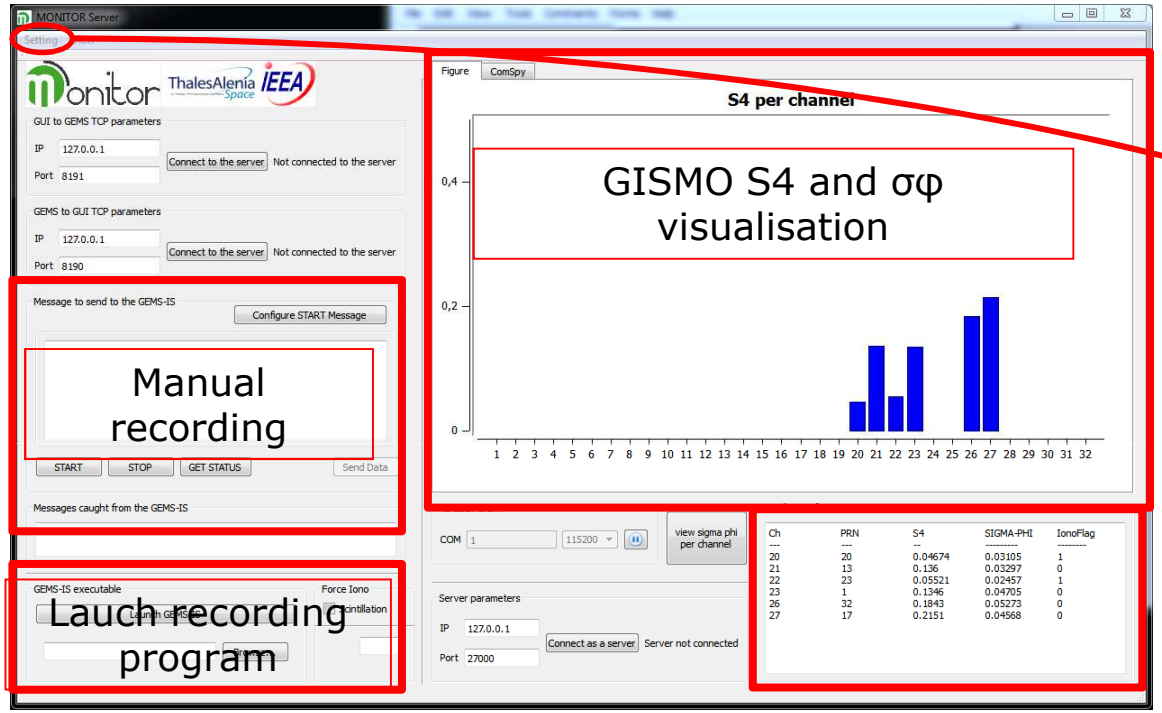
3 Rx Units delivered for the ESA MONITOR project

Scintillation Detection & BitGrabber Functionality

- **GISMO** implements a Scintillation Detection technique for each tracking channel
- The **Link Unit SW** is able to check in real-time the receiver outputs (ionosphere products) and start the grabber after the activation of a 'iono flag' (based on a S4 detector) coming from the receiver.
- User has the opportunity to record raw samples of the GNSS signals affected by strong scintillation that might have caused loss of tracking in the receiver channels thus preventing the ionosphere monitoring.
- **Post-processing** for scientific or receiver engineering purposes

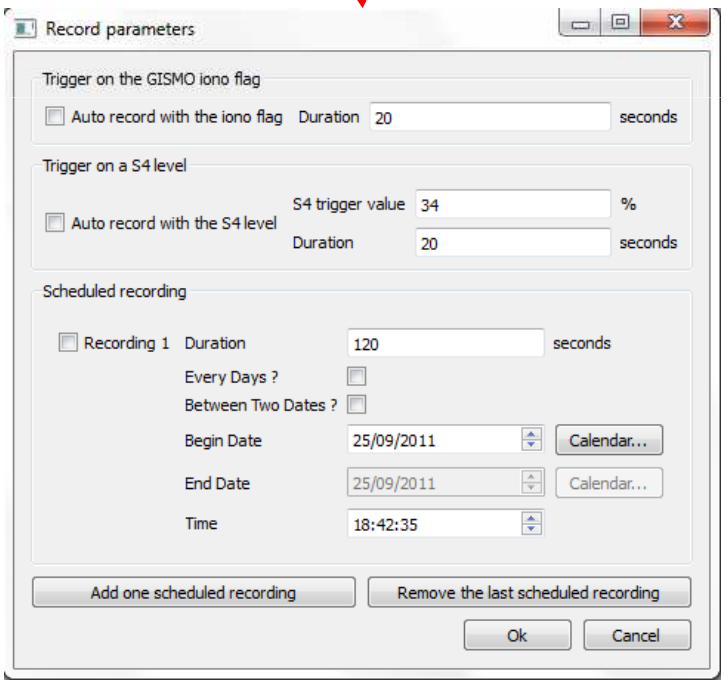


Bitgrabber Control Interface



Three automatic recording:

- on the GISMO ionospheric flag
- on a defined level of the S4 signal
- on scheduled dates

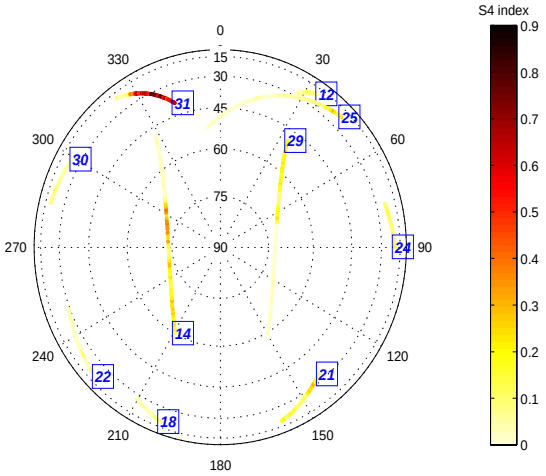


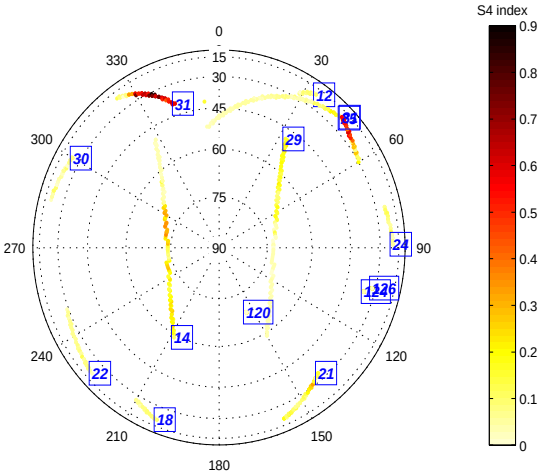
Data replay

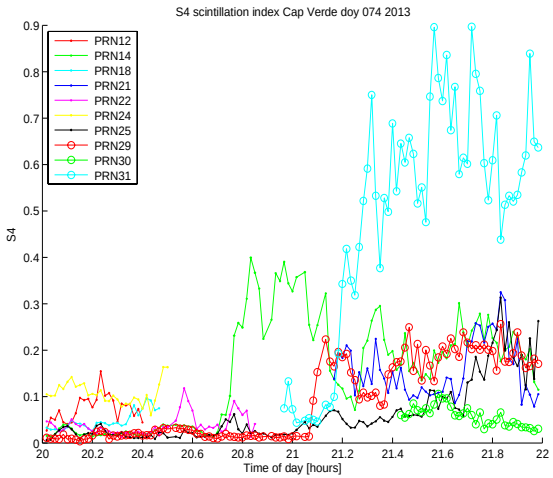
Data 15 of March 2013

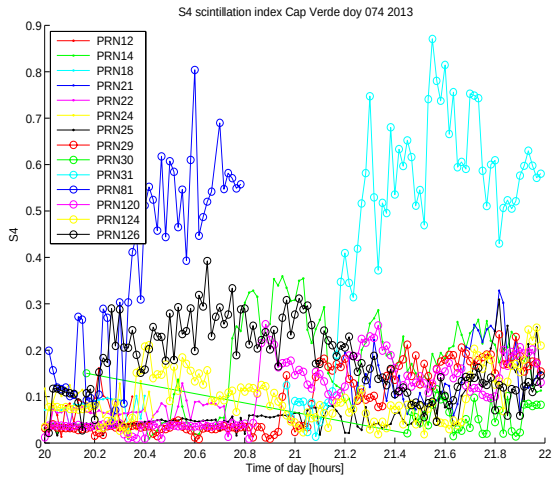
Comparison of

- Novatel GSV4004 data recorded in Cap Verde (left)
- USRP replay on Septentrio (right)



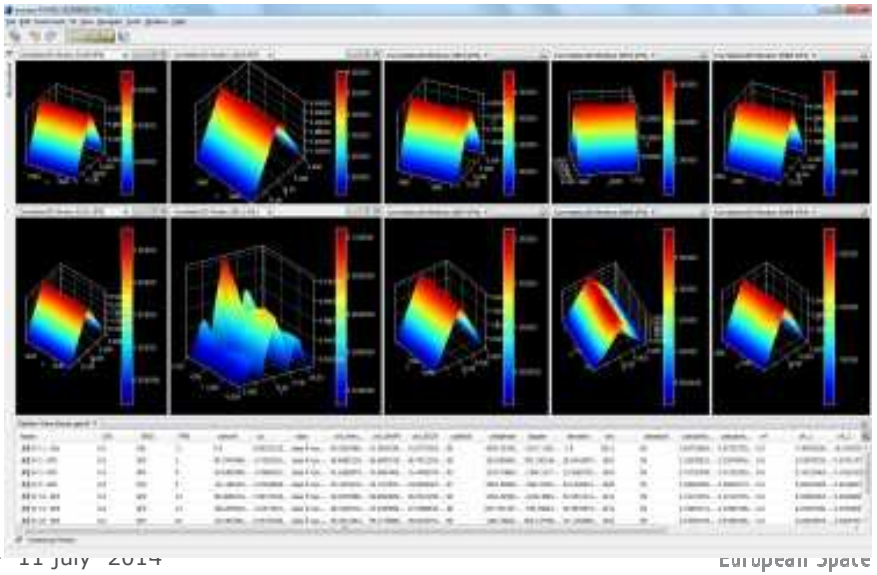






Post-processing tools

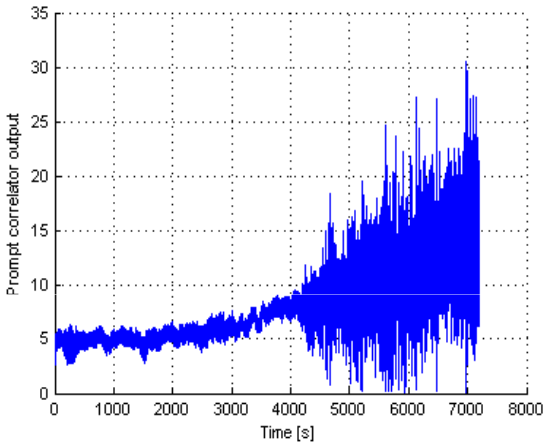
1. Replay of recorded signal
    a. Use of **TAS-F GPU GNSS Software receiver** (GEMS), allowing:
        - **fast** replay (5 to 10x faster than real time),
        - complete **tuning** and mastering of receiver parameters
        - **access to low level outputs** of the receiver (from correlators output s to pseudoranges)



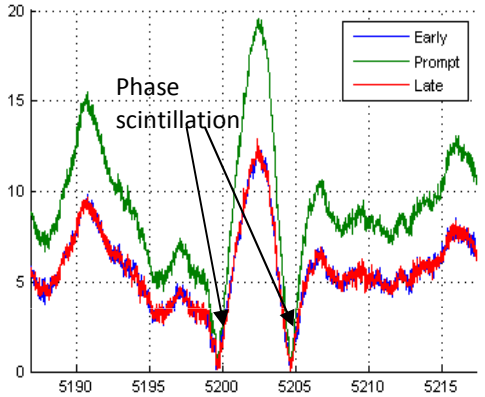
Analysis of impact of scintillation on GNSS receiver processing

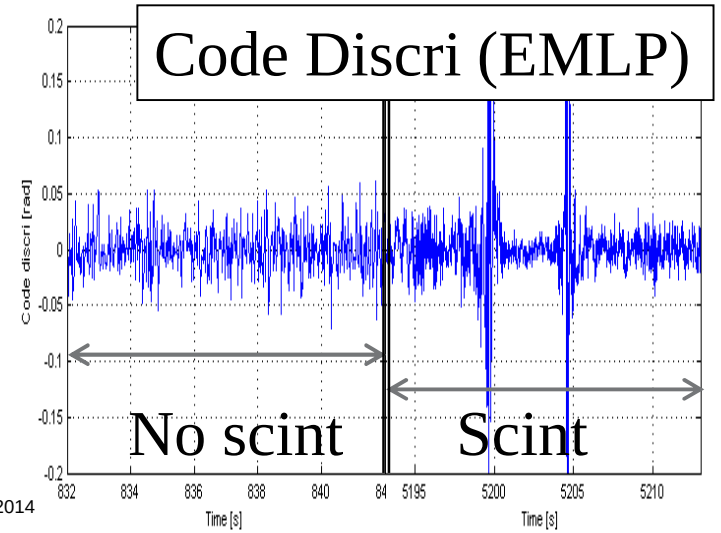
1. Impact on correlators outputs and discriminators

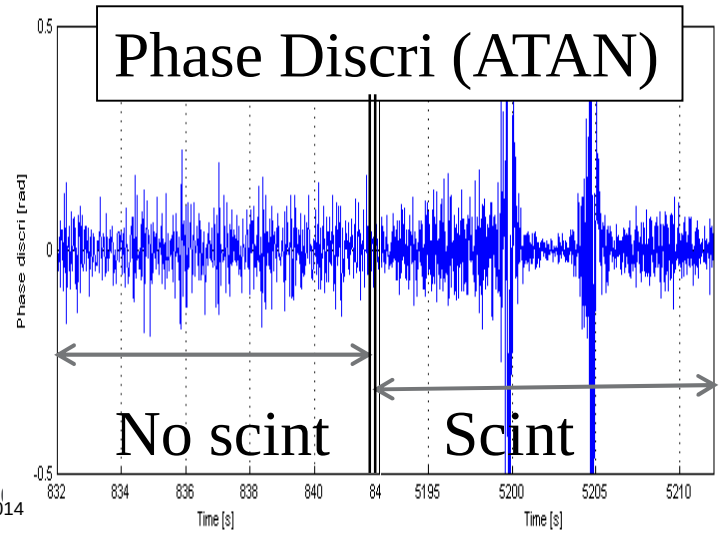
PROMT correlator



Zoom on EPL correlator

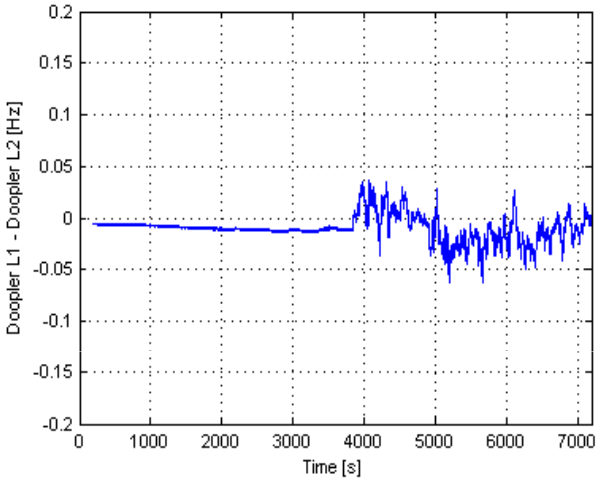






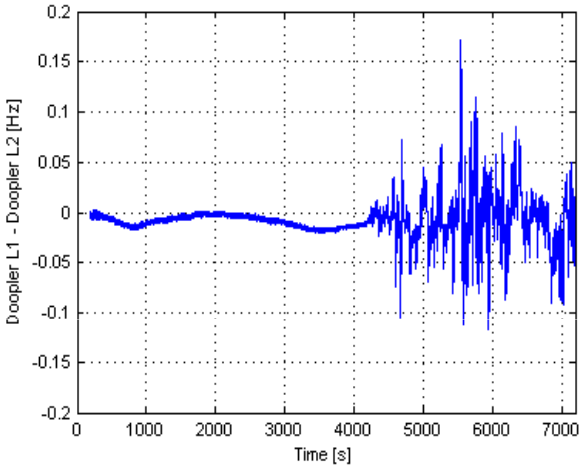
Analysis of impact of scintillation on GNSS receiver processing

1. Impact on Bi-frequency measurement

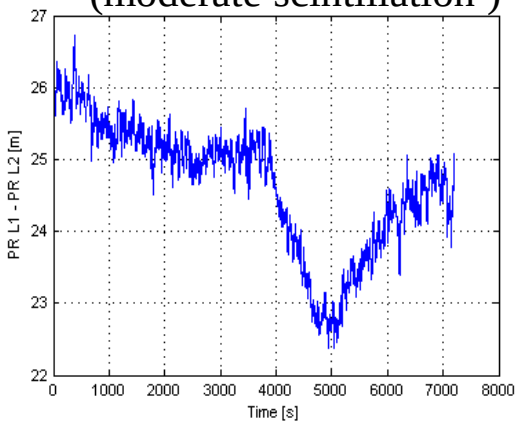


PRN14
(moderate scintillation)

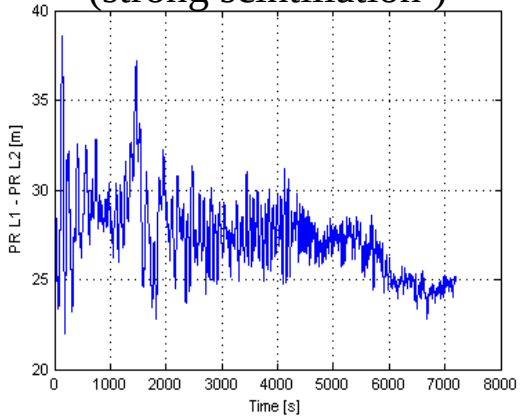
DoppL1 – L2/L1*DoppL2
10s averaging window



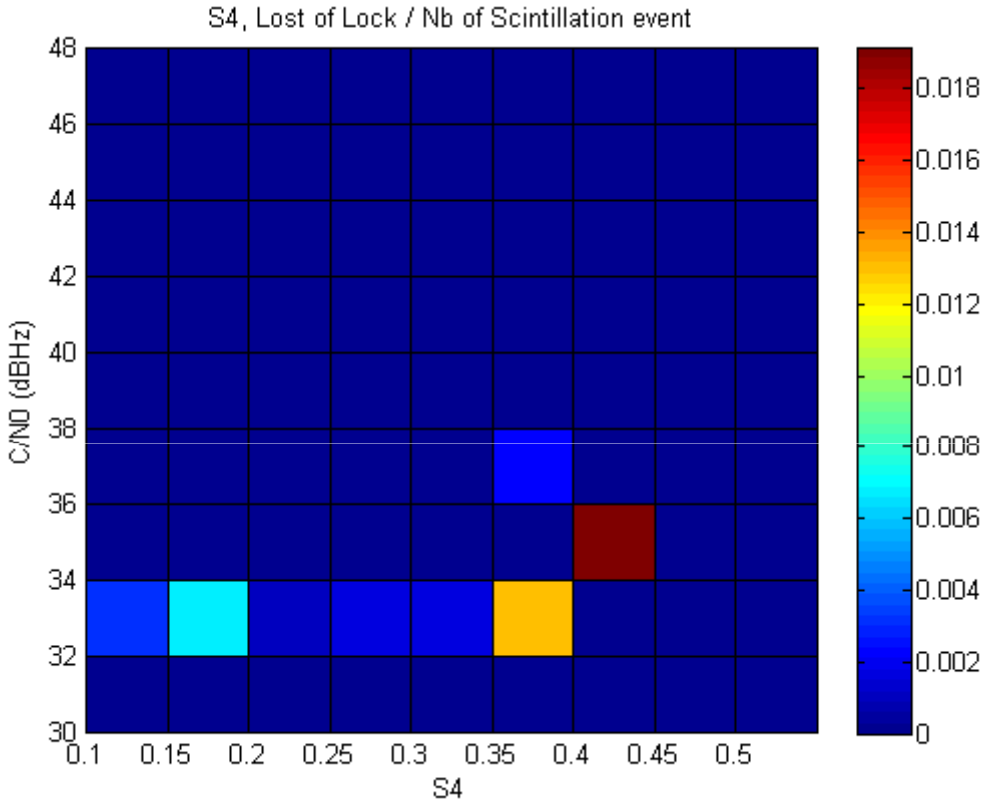
PRN31
(strong scintillation)



(PRL1-PRL2)* (L2²-L1²)/L2²
10s averaging window



Loss of Lock Analysis



38 dBHz > C / N > 34 dBHz LoL occurs when S4 is > 0.4

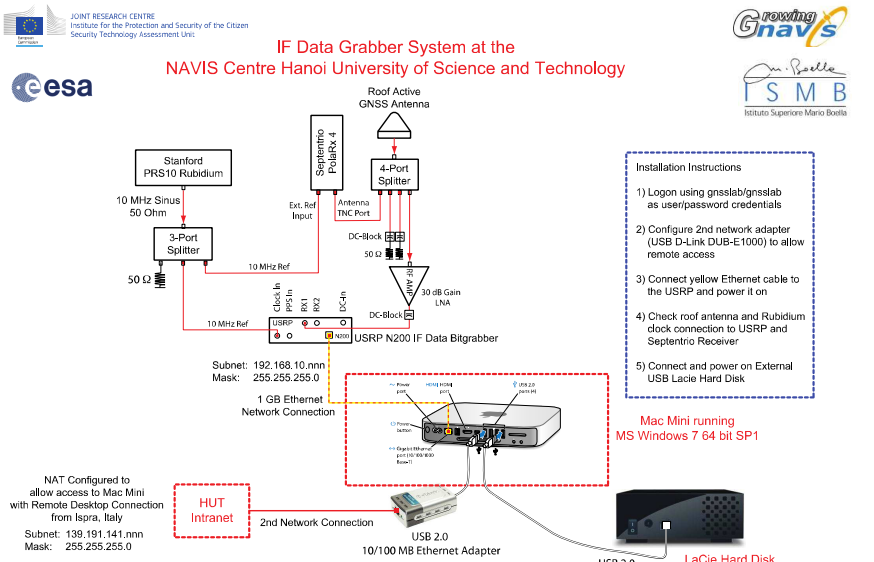
C / N > 40 dBHz no LoL even when S4 is high (> 0.6)

LoL is a combination of high S4 and low C / N

JRC Scintillation Monitoring Stations

1st Station hosted at Peru's IGP Jicamarca Radio Observatory with: 3 control PCs, 1 GPS/L1 Rx , 1 Multi-Freq Multi-Const PRO SMR (SSN), and a USRP IF Data Grabber

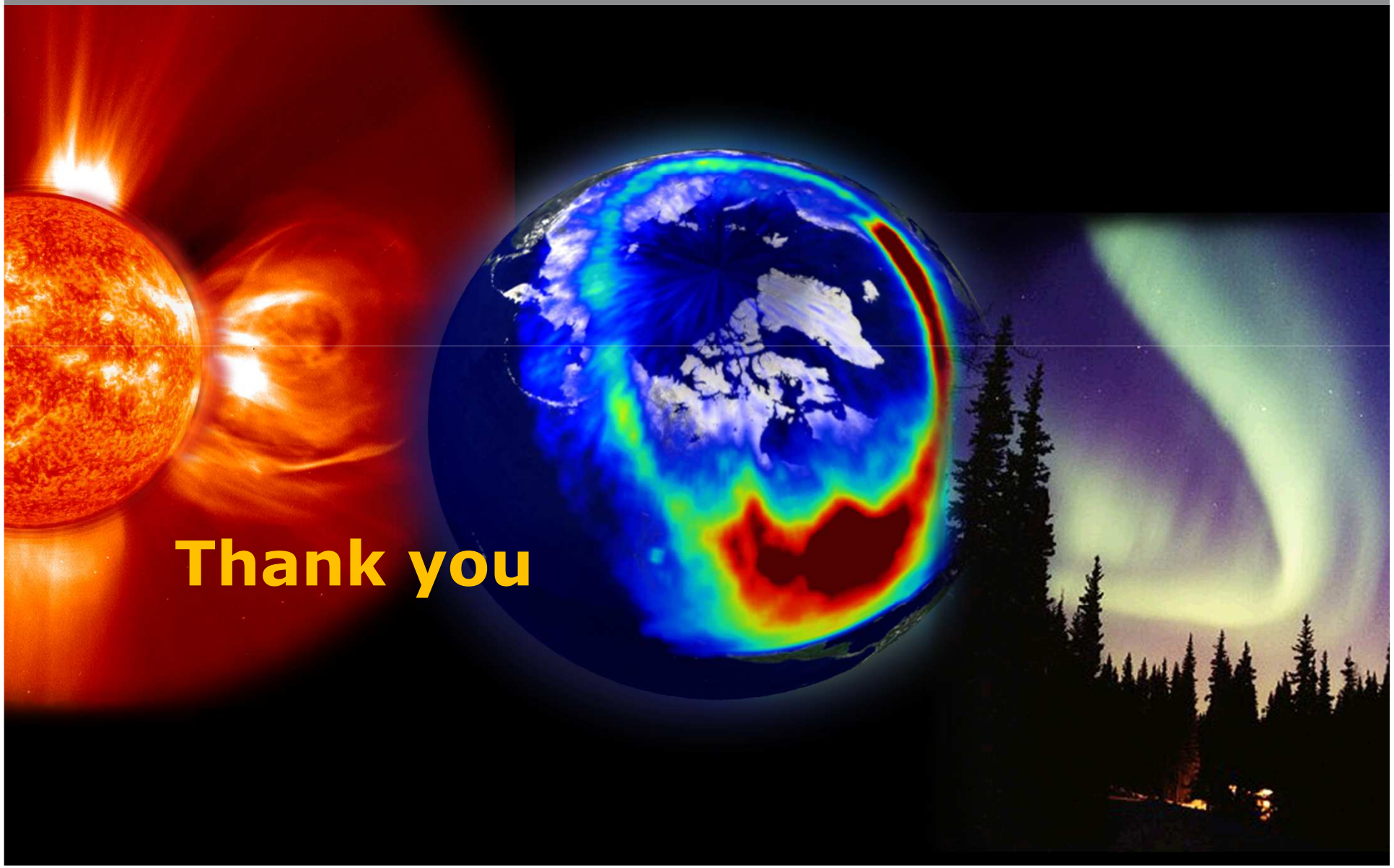
2nd Station operated in collaboration with ISMB Torino and NAVIS Center at HUST, Hanoi Vietnam with: 1 USRP IF Data Grabber and 1 control PC - Active since Feb' 13



Conclusion

The next steps

- To incorporate data from SAGAIE Network
- To agree on new sites (4 low lat, 1 high lat) (ASECNA)
- To develop new processors taylored to EGNOS needs
- To deploy the new stations (early 2015)
- On going measurement campaign


Thank you