Multi-constellation GNSS observation of ionospheric scintillation at SANAE-IV in Antarctica

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2019-08-19 BSS 2019, Olsztyn, Poland

AGENDA

DemoGRAPE project

Why study scintillation in Antarctica?

SANAE-IV, SANSA, INPE, INGV

First multiconstellation S4 observations

September 2017 storm

Background (1)

http://www.demograpе.net/

- SANSA (South Africa), INPE (Brazil), ISMB (Istituto Superiore Mario Boella, Italy) and POLITO (Politecnico di Turino, Italy) are key collaborators on an international project DemoGRAPE coordinated by INGV (Italy) which is designed *to improve satellite navigation* in Antarctica.
- DemoGRAPE is a demonstrator using cutting edge technology for the empirical assessment of the ionospheric delay and ionospheric scintillations in the polar regions *from multiple GNSS constellations*.
- DemoGRAPE equipment has been installed at the South African base (SANAE-IV) in *2015* and has been maintained and operated by SANSA with support from INGV since 2015.

Background (2)

- The DemoGRAPE project at SANAE comprises
  - Septentrio PolaRxS receiver and
  - A GNSS software defined radio (SDR) receiver,
- These instruments provide access to ionospheric delay and related measurements from the following navigation satellite systems
  - GPS (US),
  - GLONASS (Russian)
  - Galileo (European Space Agency) satellites.
- Software and data exchange continues to take place via the Cloud computing infrastructure.
- Quicklook plots of the signal to noise ratio (C/No) and of scintillation indices and summary files from the SDR receiver are sent to the data-node at SANSA, to INGV and to POLITO every 24 hours.

Why study scintillation in Antarctica ?

- At high latitude GNSS navigation degradation is *more severe* than elsewhere because the polar ionosphere is often hit by solar energetic particles driven by the cusps of the geomagnetic field into the high latitude atmosphere.
- Precise positioning based on GNSS can be heavily corrupted, resulting in *positioning errors of tens of meters* or, even worst, in the positioning blackout due to the loss of satellite lock.
- Satellite navigation is often used for overland travel in Antarctica. Navigation errors may be hazardous to life and limb.

demGRAPE

Crevasses near SANAE from the air

Photo: Martin Louw

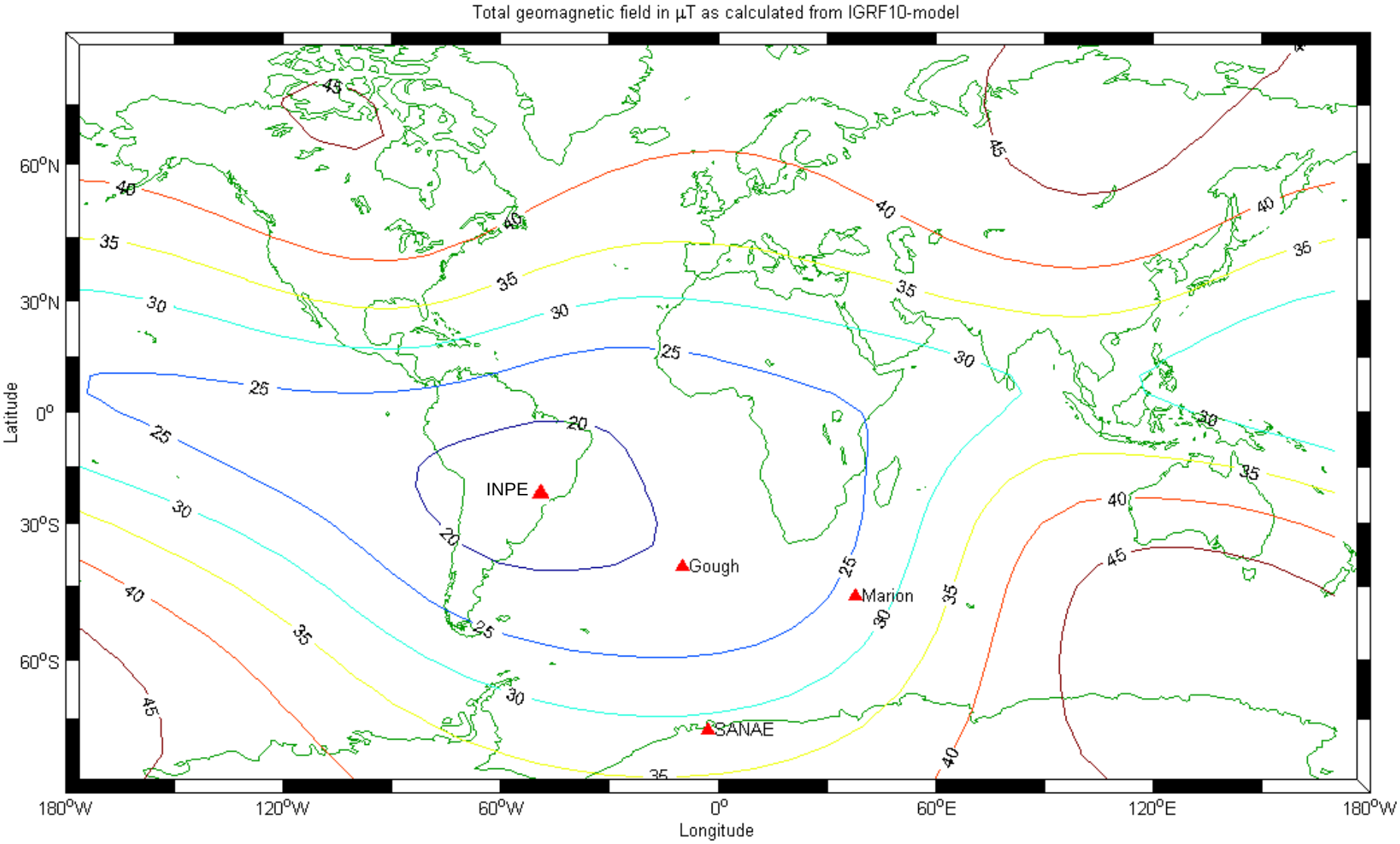
White-out in Antarctica

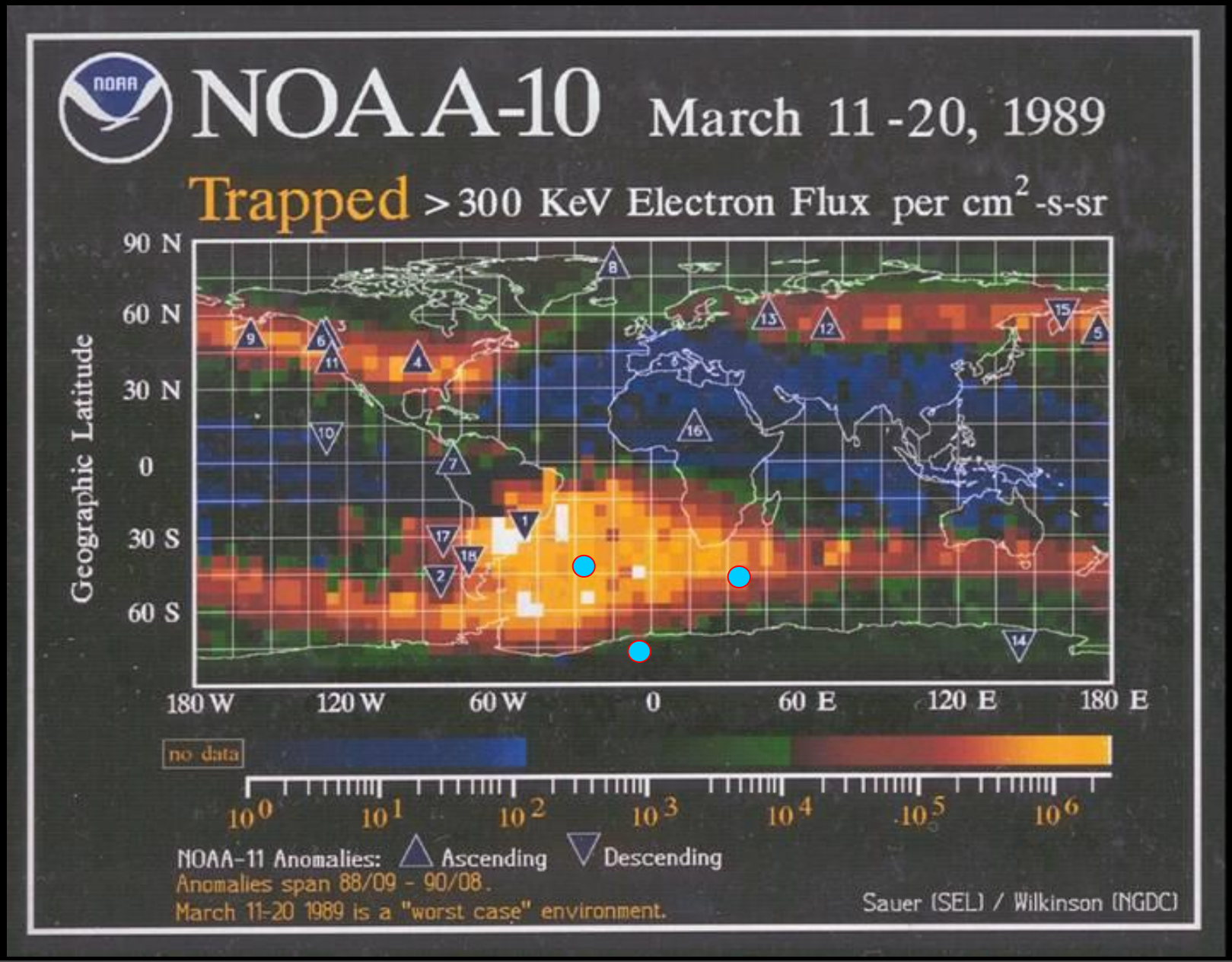
Crevasse from closer by

Photo: Helena Kruger

SOUTH ATLANTIC MAGNETIC ANOMALY

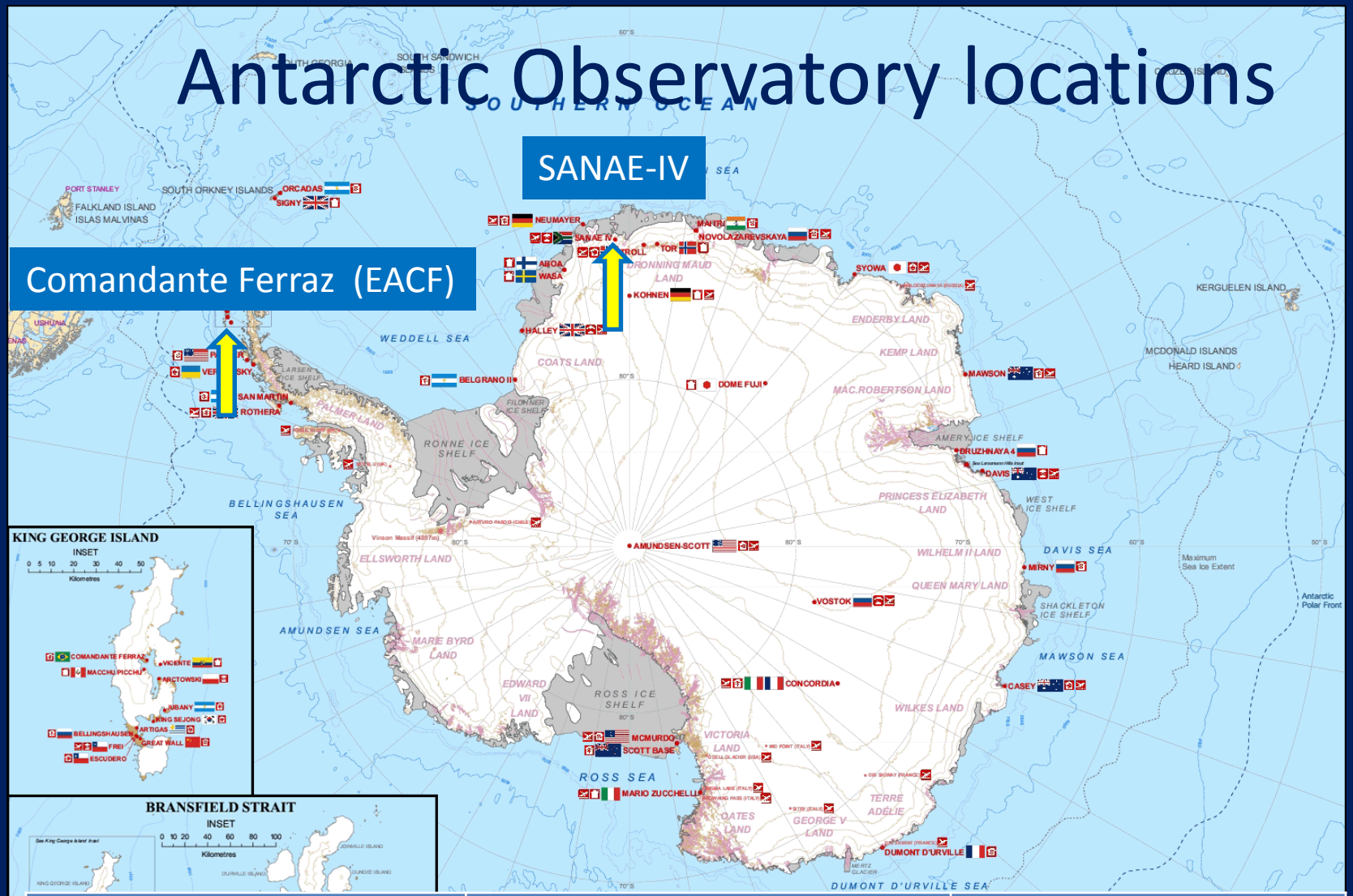
Main Field Total Intensity F at ground level from IGRF10





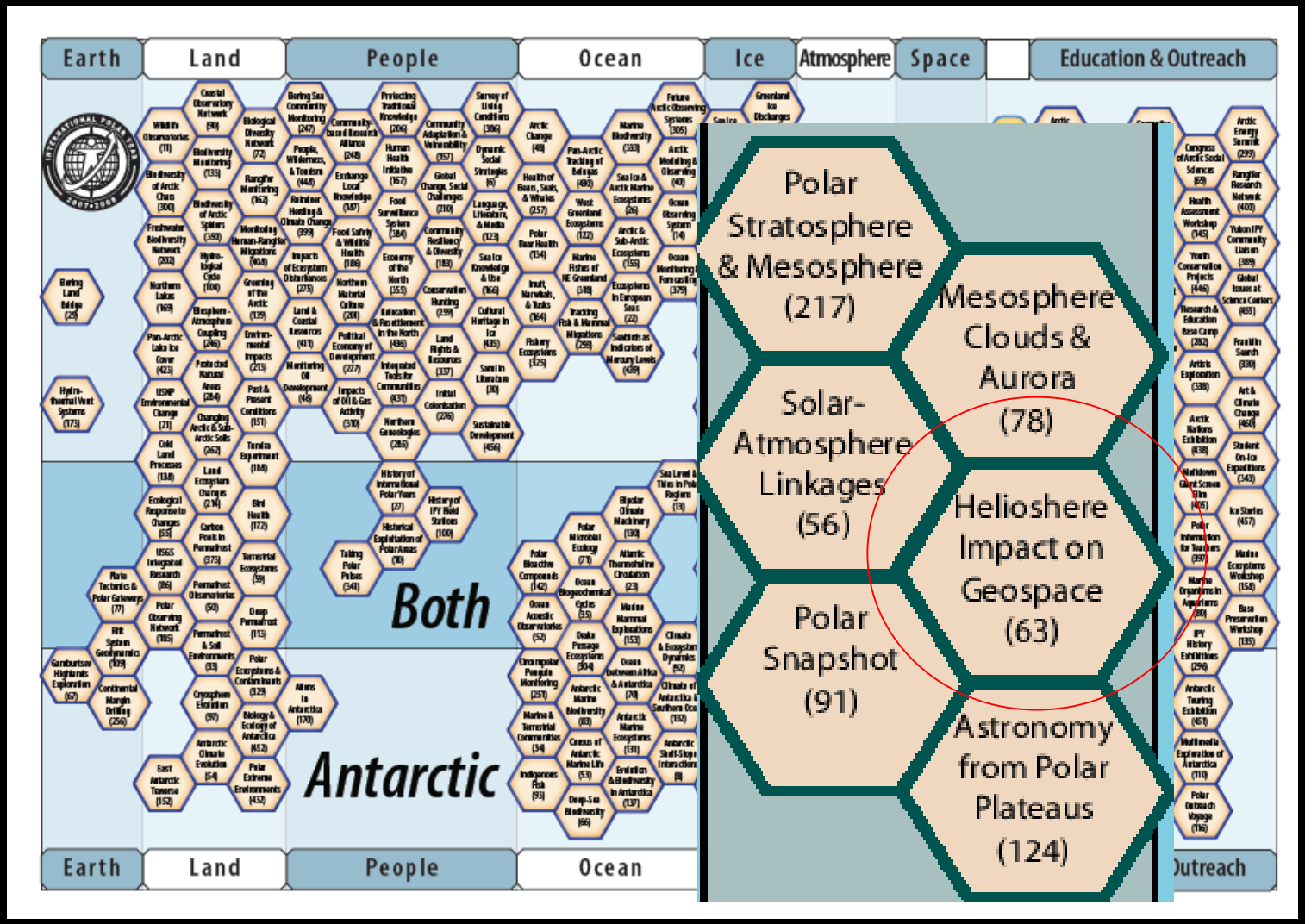
Flux of energetic electrons observed by a polar orbiting satellite 800 km above the Earth's surface during a large magnetic storm.

Antarctic Observatory locations



Coordinates	Comandante Ferraz(EACF)	SANAE IV
Geographic	62°34’S, 58°23.5’W	71°40’S,2°50’W
Geomagnetic dipole coordinate IGRF	52°95’S ,10°90’ E	66°45’, 48°00’E

IPY4 (Participants in ICESTAR project 63)



SANSA is part of the South African National Antarctic Programme (SANAP)

South African National Antarctic Expedition (SANAE), since 1960

DemoGRAPE First expedition: EACF

Estação Antártica Comandante Ferraz, King George Island, South Shetland Islands

DemoGRAPE Second expedition: SANAE IV

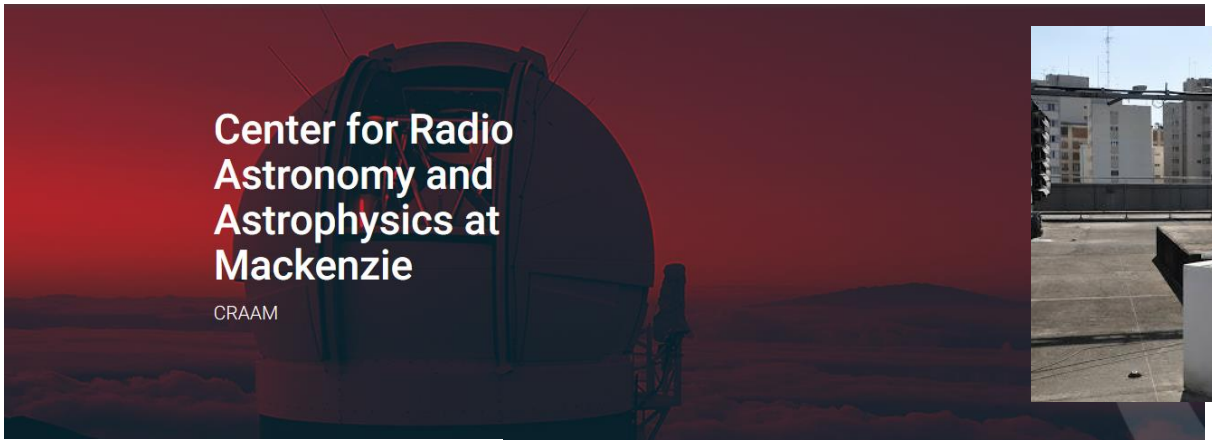
Queen Maud Land Region of Eastern Antarctica

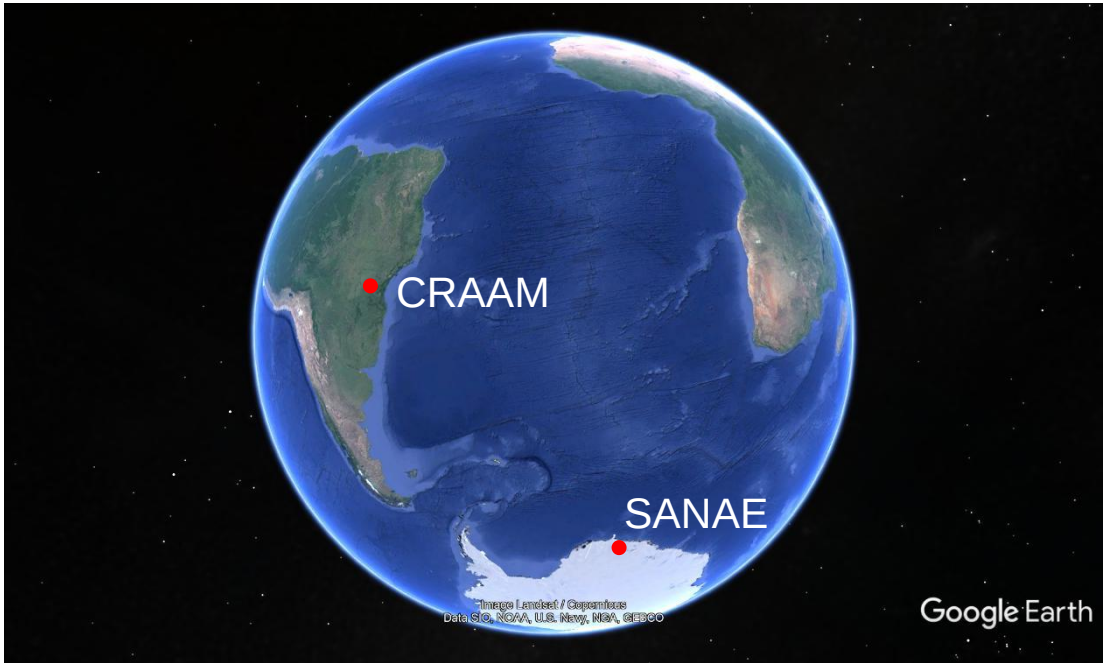
December 2, 2015 – March, 2017

Proposed relation of DemoGRAPE Antenna at SANAE-IV

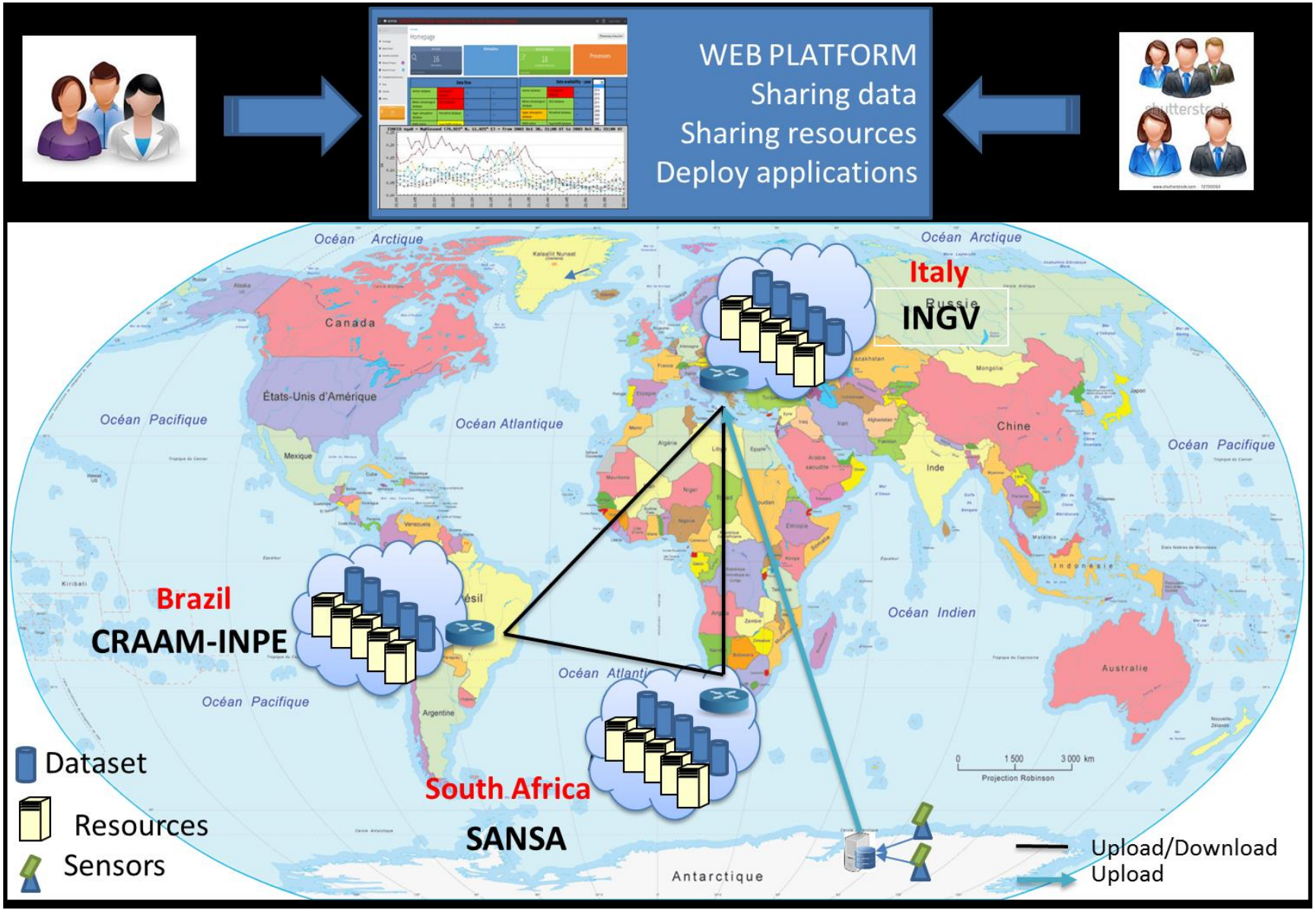
Brazilian Station in 2017 relocated to CRAAM-INPE

Brazilian Centro de Radioastronomia e Astrofísica Mackenzie (CRAAM)



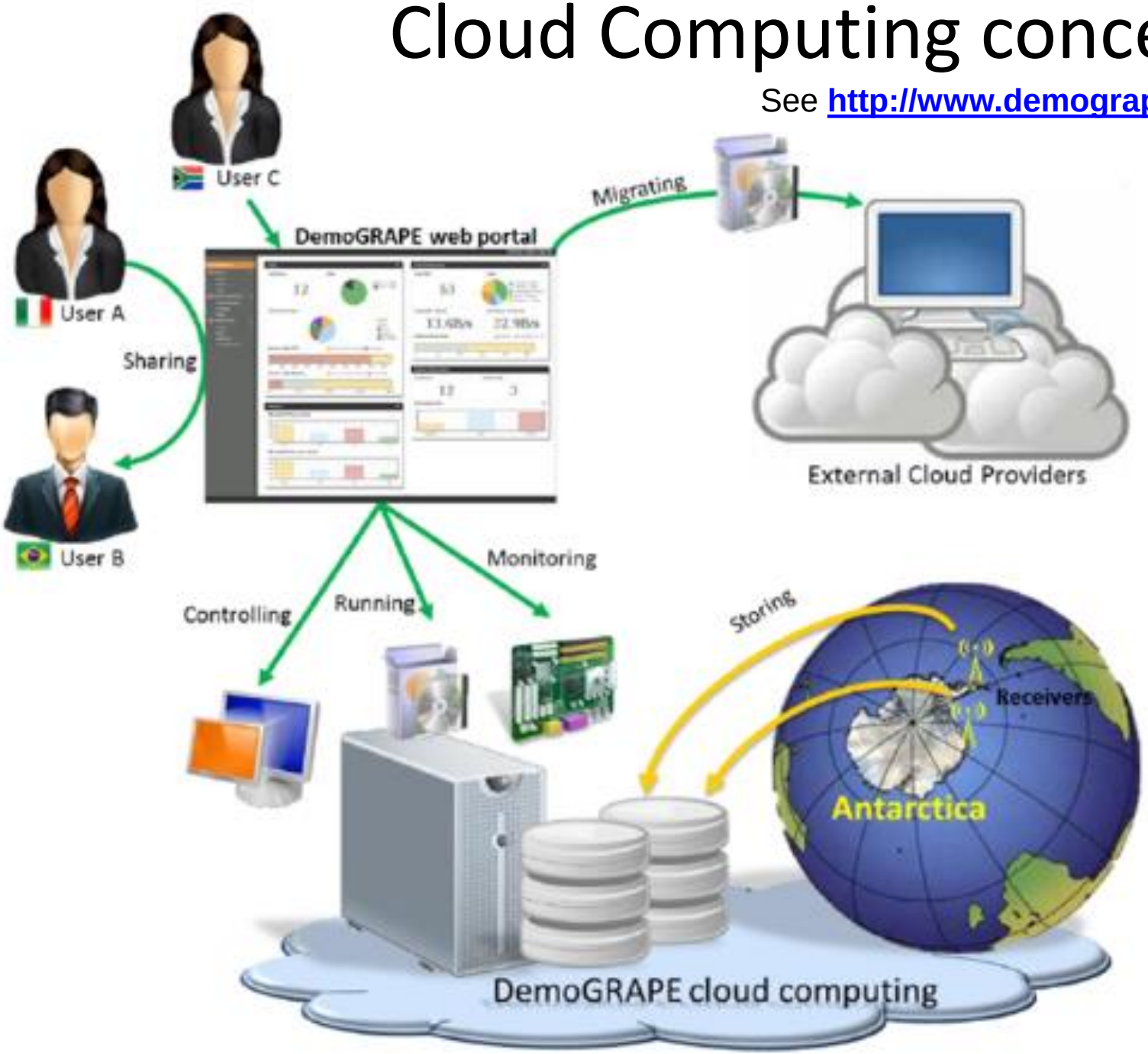


DemoGRAPE activities in Italy, Brazil, South Africa



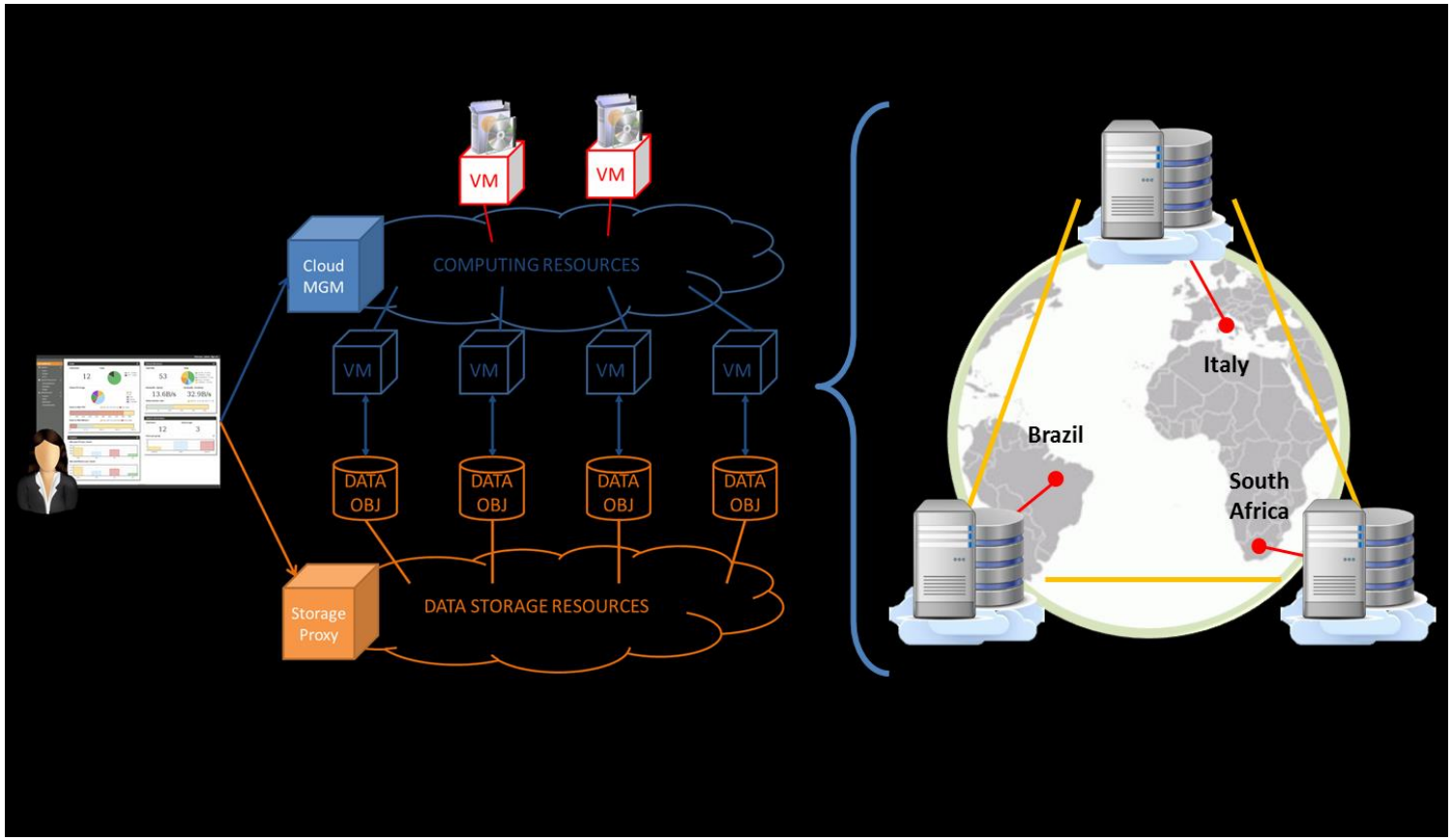
Cloud Computing concept

See http://www.demogrape.net/

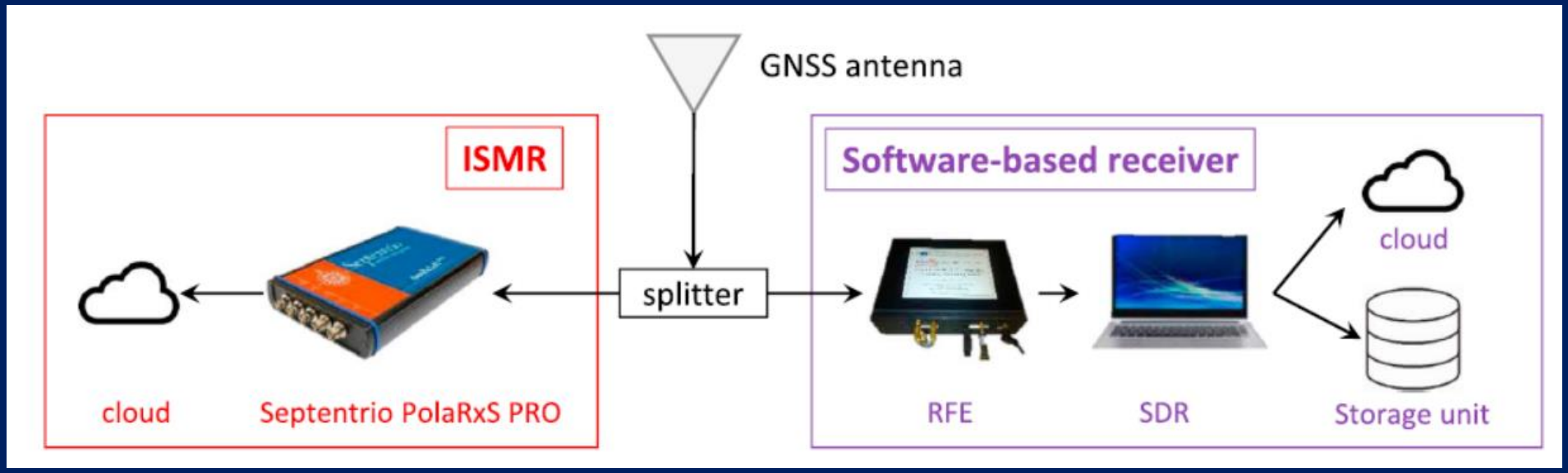


The Cloud computing advantages for Antarctic sciences

- Keep the intellectual property of the owners' data and software
- Reduce time machines consuming
- Optimize data transmission and storage requirements
- Allow to run the software where data are stored without moving the data

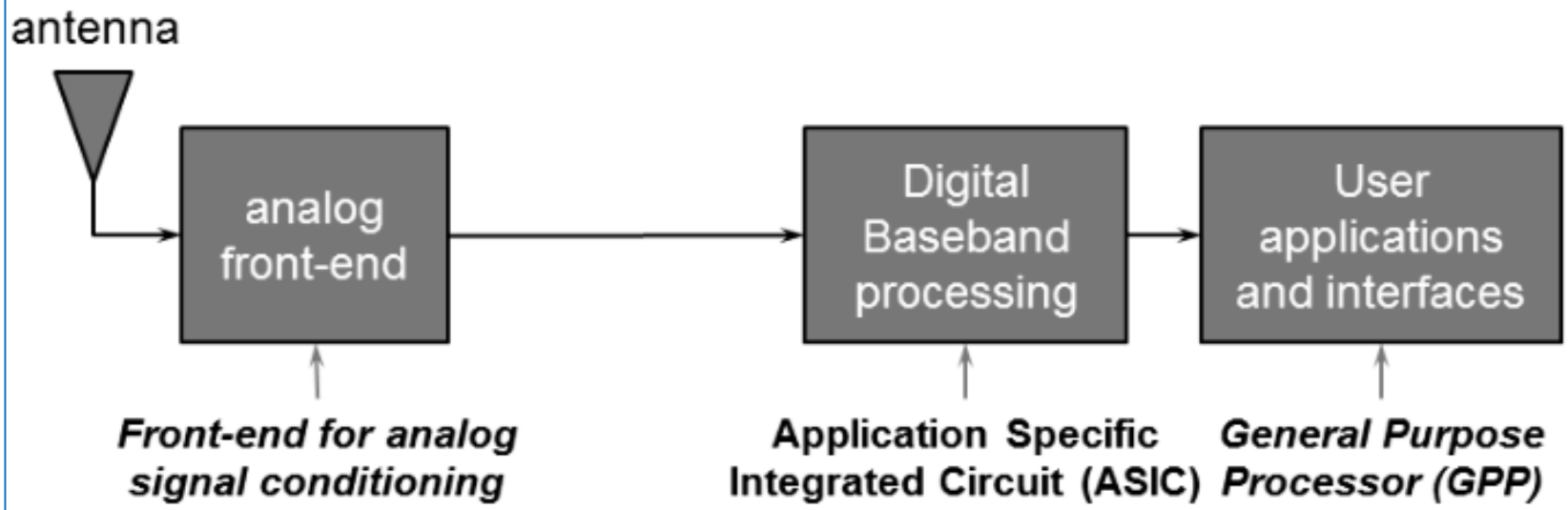


DemoGRAPE Hardware

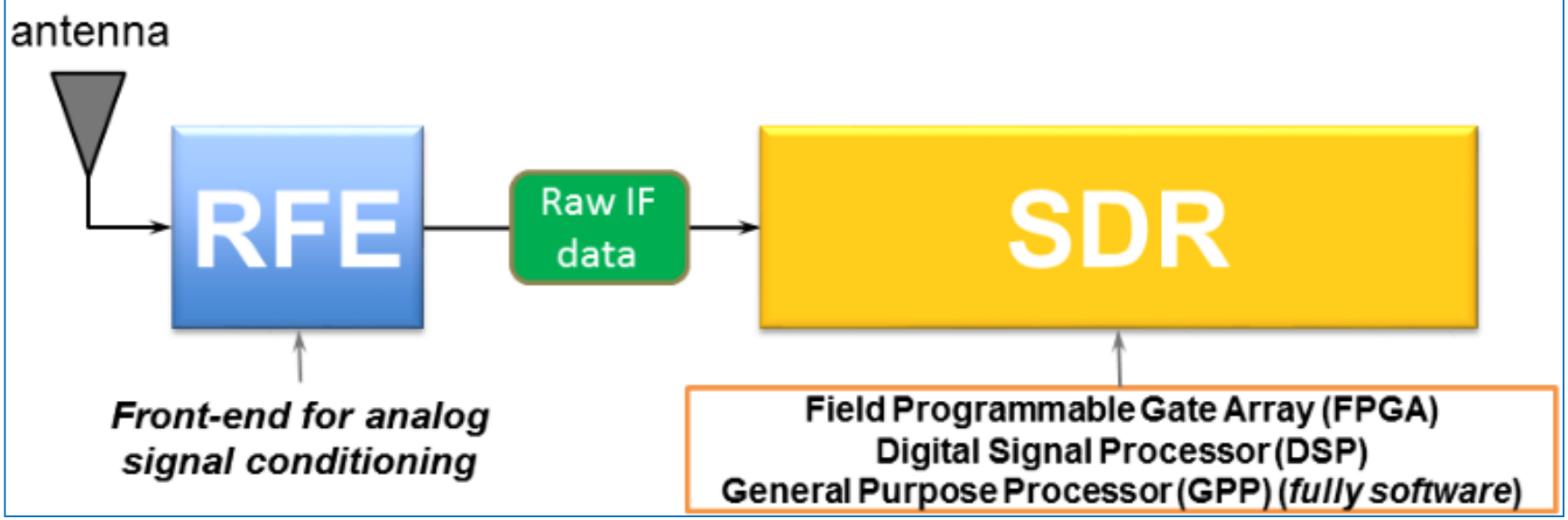


The GNSS multiband antenna is shared by the Septentrio PolaRxS PRO high sampling rate GNSS receiver and the SDR GNSS receiver.

HW receiver architecture



SDR receiver architecture



Other related instruments at SANAE

SuperDARN HF radar: Ionospheric dynamics,

VLF receivers (part of World-Wide Lightning Location Network): Particle precipitation studies and recording of whistlers in the magnetosphere,

Magnetometers: characterization of long-term magnetic field variation and geomagnetic storms,

GNSS receivers : for Total Electron content and ionospheric scintillation monitoring ,

Riometers : for studying high energy particle precipitation,

Ozone radiometers: for detecting the impact of particle precipitation on mesospheric ozone

Other Physical Science Instrumentation at SANAE-IV

- Aurora cameras
- Neutron Monitors
- Seismometer
- Meteorology

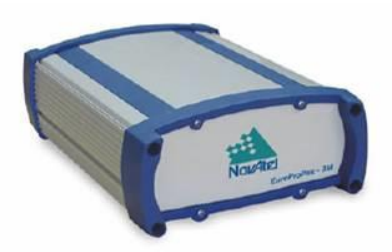
GPS Scintillation receivers:

Novatel

PolaRxS

SDR

Space Weather Instruments deployed during IPY4 (2006-2009)



GPS Ionospheric scintillation monitor (2006)

FGE 3-axis magnetometer (2007)

DI flux magnetometer on non-magnetic theodolite(2006)

GPS receiver (< 2006)

Overhauser Total Field magnetometer (2006)


CATERPILLAR


CATERPILLAR


11/01/2008

COSMIC Ray sensor in Astrid Satellite Radome

SuperDARN Radar

Co-located instruments at SANAE-IV

https://sandims.sansa.org.za/

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Instruments

Type	Model	Version	Commissioning Date
Geomagnetic Instruments			
Legacy Magnetometer	DI-Fluxgate Magnetometer	None	1961-01-01
DTU 3-axis Fluxgate Magnetometer Model FGE	DTU Fluxgate	K2	2015-01-01
Fluxgate Magnetometer FGE	DMI-FGE Fluxgate Magnetometer	None	2008-01-15
Overhauser Scalar Magnetometer	Overhauser GSM-19	7.0	2007-05-25
Rock Magnetometer	Rock Magnetometer	None	2011-01-01
SANAE Pulsation Magnetometer	Pulsation Magnetometer	None	2012-04-30

Co-located instruments at SANAE-IV

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Ionospheric Instruments			
Dual Frequency GPS Reference Station Receiver	Ashtech uZ12	None	2011-08-16
GPS Ionospheric TEC and Scintillation Monitor	GSV4004B	1.77	2006-12-25
Beam Forming Riometer	SSR	None	1997-04-01
Wide Angle Riometer	SSR	None	1998-02-21
SuperDARN	T3	1.0	2013-10-02
SuperDARN	T3	None	2012-01-01
Magnetospheric Instruments			
Automatic Whistler Detector	Automatic Whistler Detector	None	2012-01-30
AWESOME Narrowband Receiver	AWESOME Narrowband	None	2009-02-17
AWESOME Synoptic Receiver	AWESOME Synoptic	None	2013-10-13
MSK Narrowband VLF Receiver	UltraMSK	1.0 beta 14	2011-01-01
VLF Receiver	DVRAS	None	2012-02-10

SANSA's high latitude Geophysical Instruments

Location	Instruments
SANAE-IV, Antarctica **2.84^{o}W** **71.67^{o}S** **Mag 61.85^{o}S**	SuperDARN HF Radar, Magnetometers(Overhauser, Pulsation, Rock, Fluxgate, DTU), Riometers(wide-angle(30, 51.4 MHz), beamforming(38.2 MHz), GNSS Receivers(Geodetic(Trimble), Scintillation and TEC monitors(Novatel GSV4004B, Septentrio PolaRsX PRO, 4tuNe SDR), VLF(AWESOME, UltraMSK, DVRAS, Whistler Detector), Ozone monitor, Neutron Monitor
Gough Island **9.88^{o}W** **40.34^{o}S** **Mag 43.01^{o}S**	Scintillation and Total Electron Content (TEC) monitors (Novatel), Dual Frequency GPS Receiver (Trimble)
Marion Island **37.86^{o}E** **46.87^{o}S** **Mag 52.04^{o}S**	Magnetometers (LEMI), Scintillation and TEC monitor (Novatel), VLF(DVRAS, UltraMSK, Whistler Detector), Tidal Gauge, WWLLN, Dual Frequency GPS Receiver, Seismometer

SANDIMS Data Portal

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SOUTH AFRICAN NATIONAL GEOPHYSICAL DATA AND INSTRUMENTATION MANAGEMENT SYSTEM

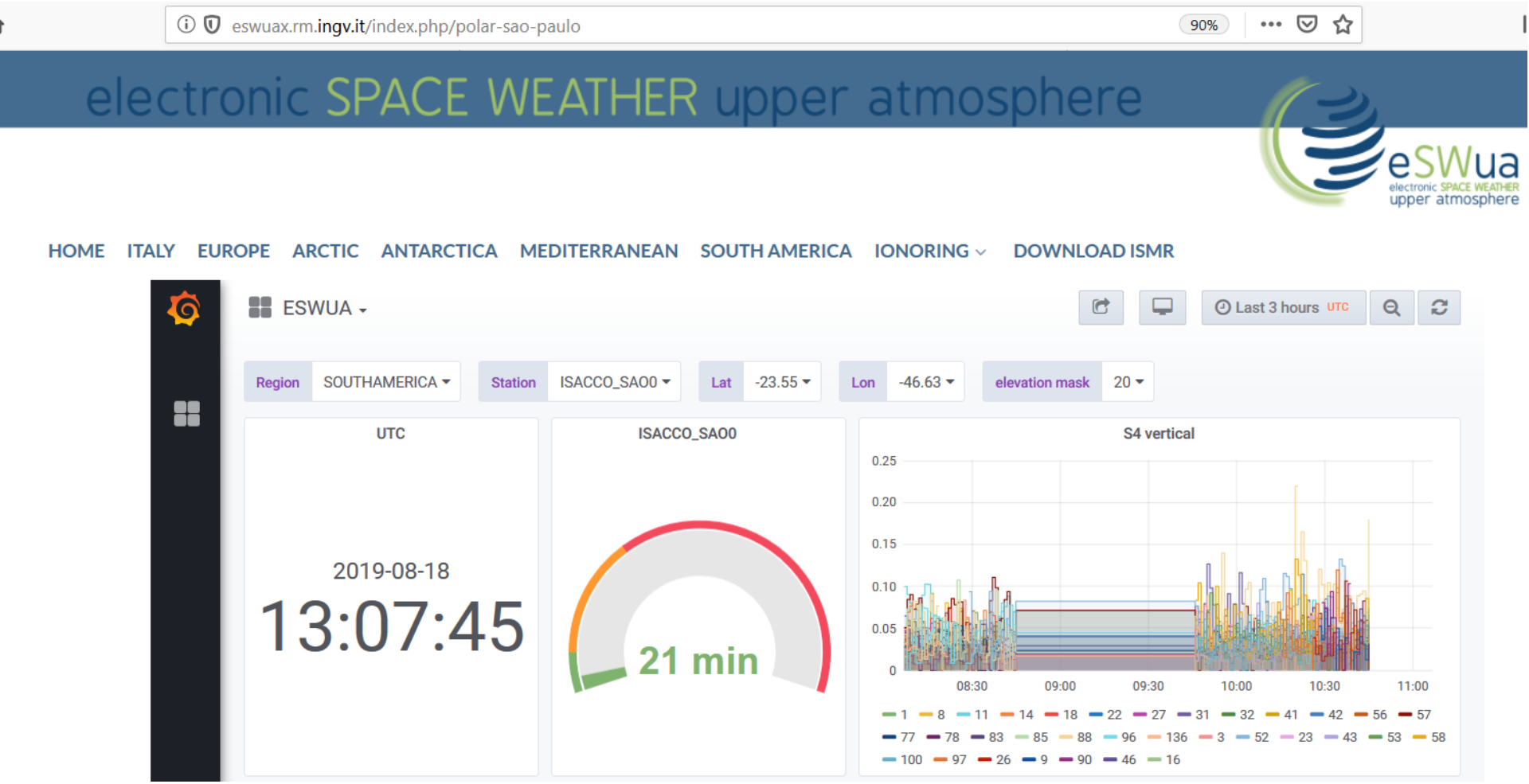
***SANDIMS* is the repository of all Geomagnetic, Ionospheric and Magnetospheric data gathered from SANSA Space Science's instrumentation network.**

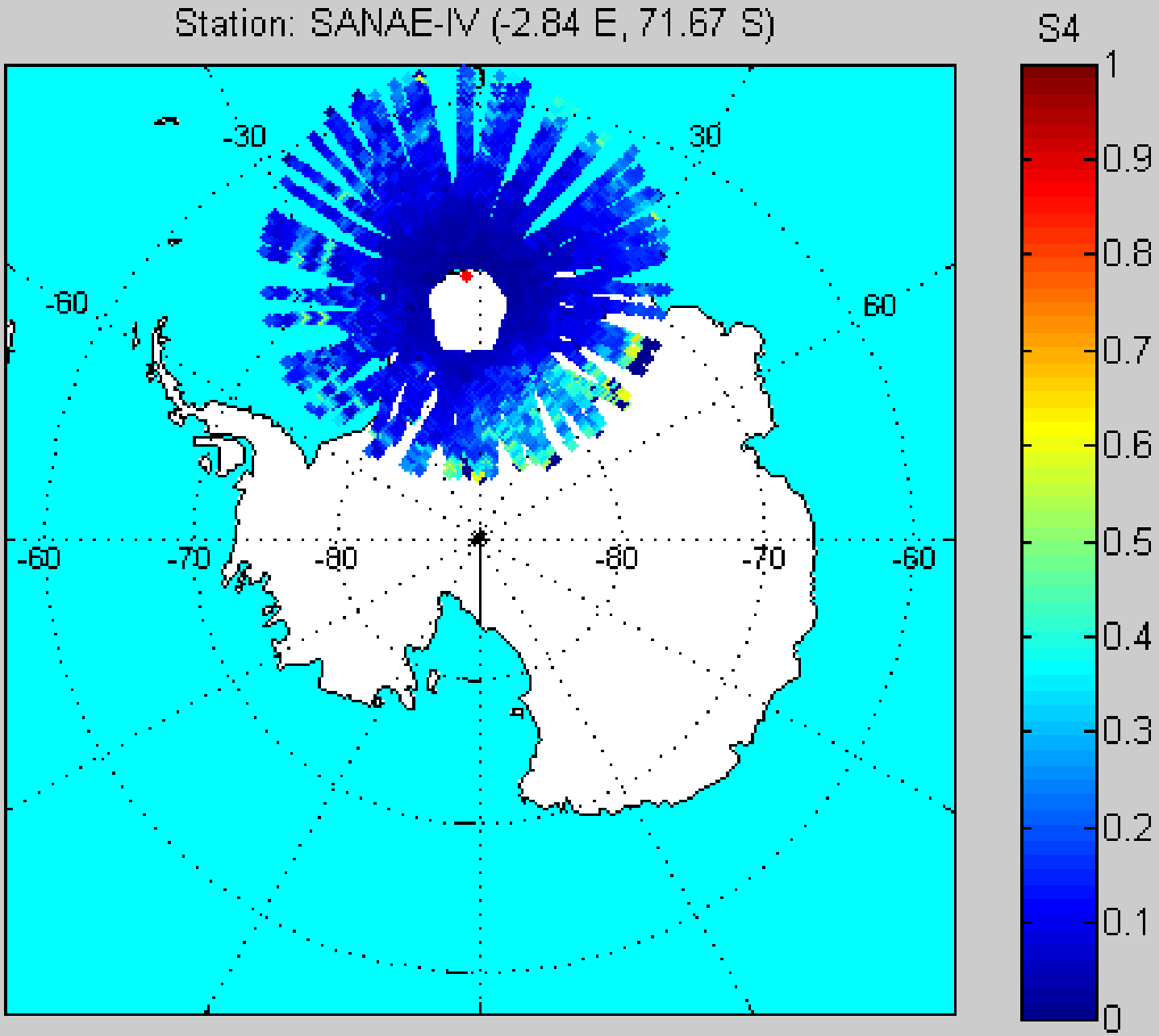
Instrumentation Network

Instruments in the network are grouped into the above three classes, and further sub-classed by **Instrument Type**, each of which is represented by one or more **Instrument Models**. Specific instruments so classified are the **Field Instruments** of the network, which extends throughout **South Africa** and **Namibia**, as well as **Gough** and **Marion** islands in the southern oceans and the **SANAE IV** research base in Antarctica. The SANDIMS Metadata Model includes GPS location, manufacturer and Principal Investigator information, as well as technical parameters of the instruments (most importantly sampling interval) and their antennae. Metadata associated with a data bundle may be exported and shared using NASA's DIF v10.0 interchange format.

ESWUA Data Portal

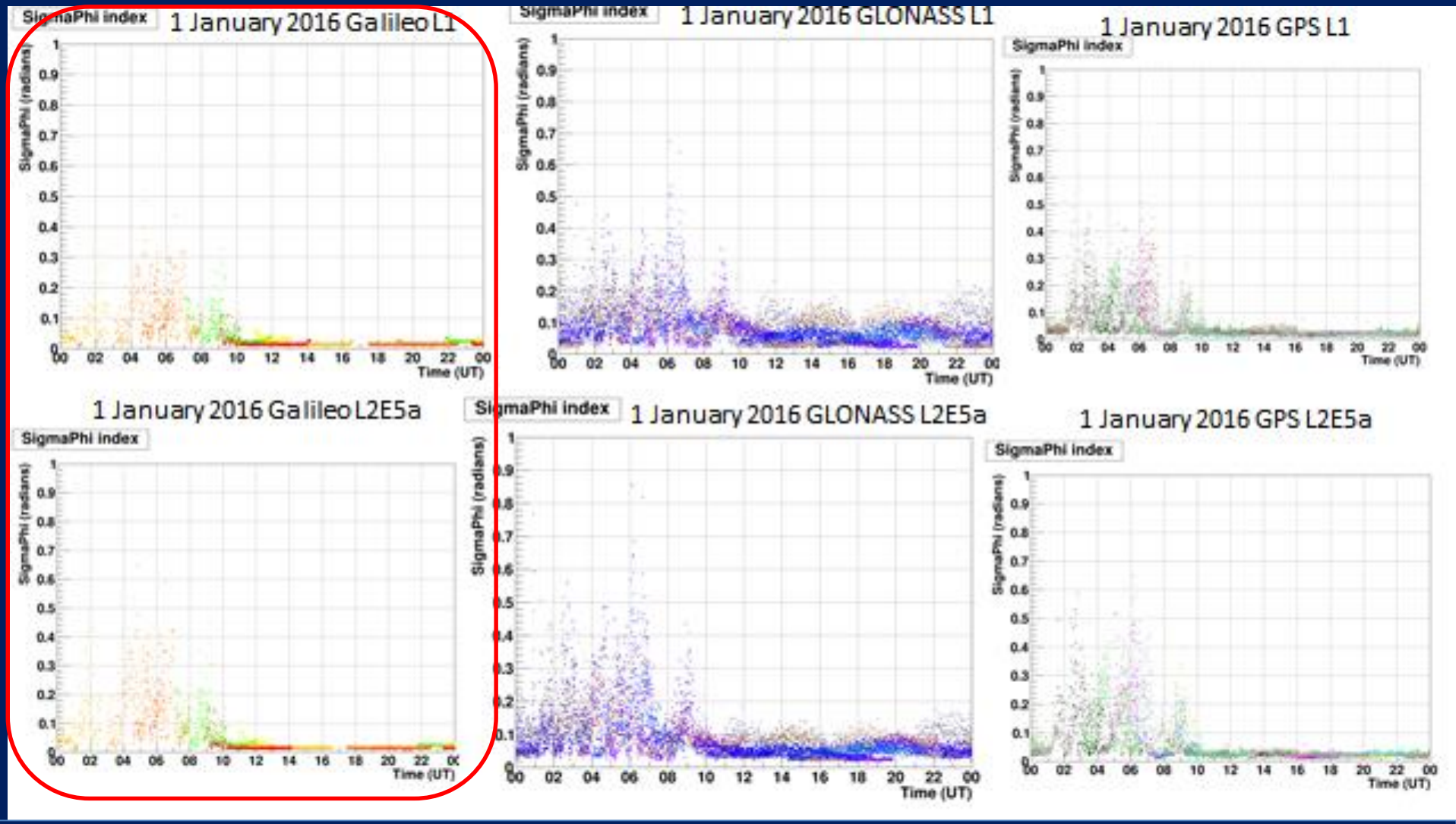
http://eswuax.rm.ingv.it/index.php/polar-sao-paulo





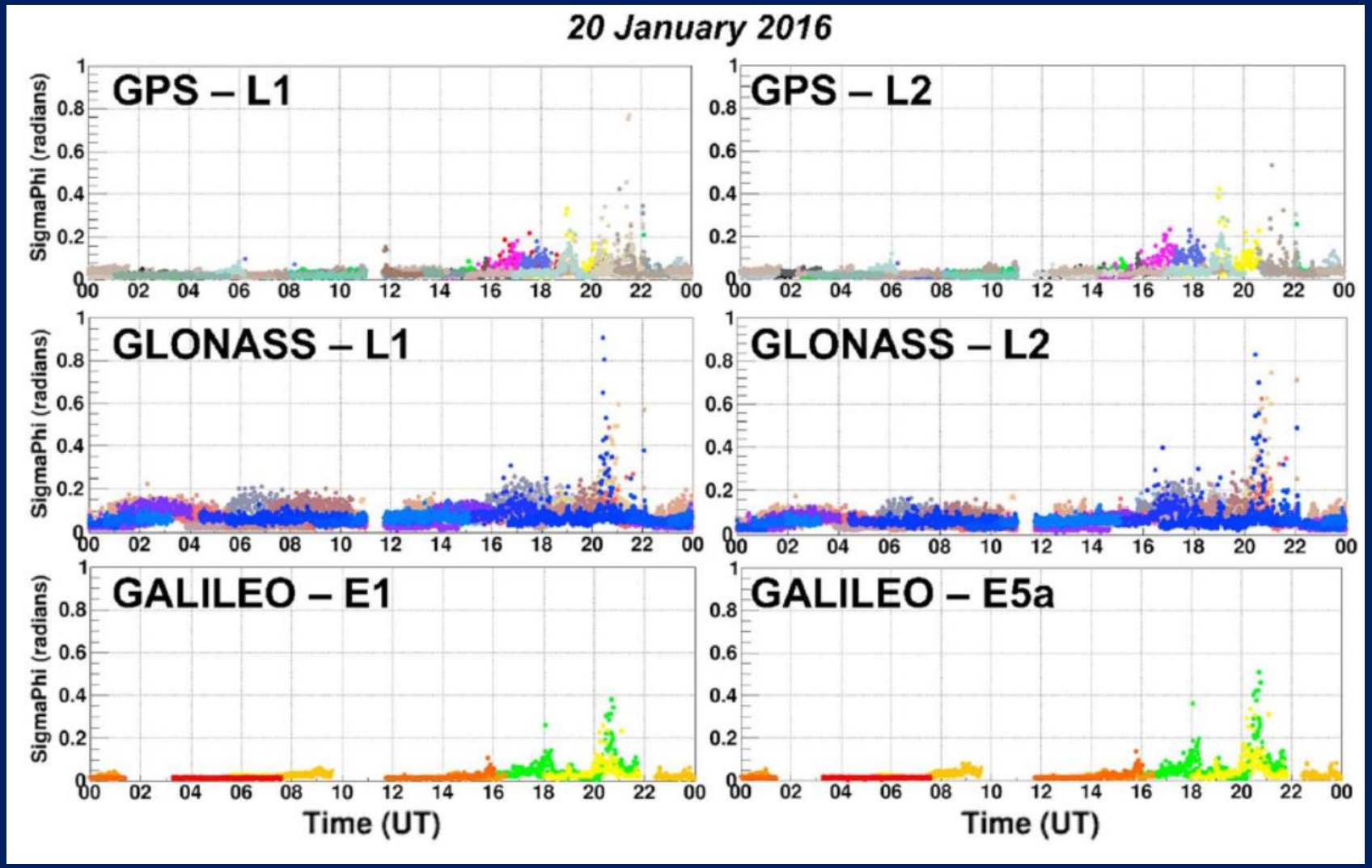
Geographical coverage of SANAE ISM 15 August 2007 00:00 to 23:59 UT

First recording of scintillations using data from the Galileo GNSS system.



First observations of an ionospheric storm using the suite of scintillation receivers deployed by the DemoGRAPE project at SANAE-IV. There is a clear enhancement of phase scintillation (σ_ϕ) on both the L1 and L2E5 frequencies visible on all three GNSS constellations received at SANAE on 1 January 2016, a day with a moderate geomagnetic storm (Dst = -100 nT).

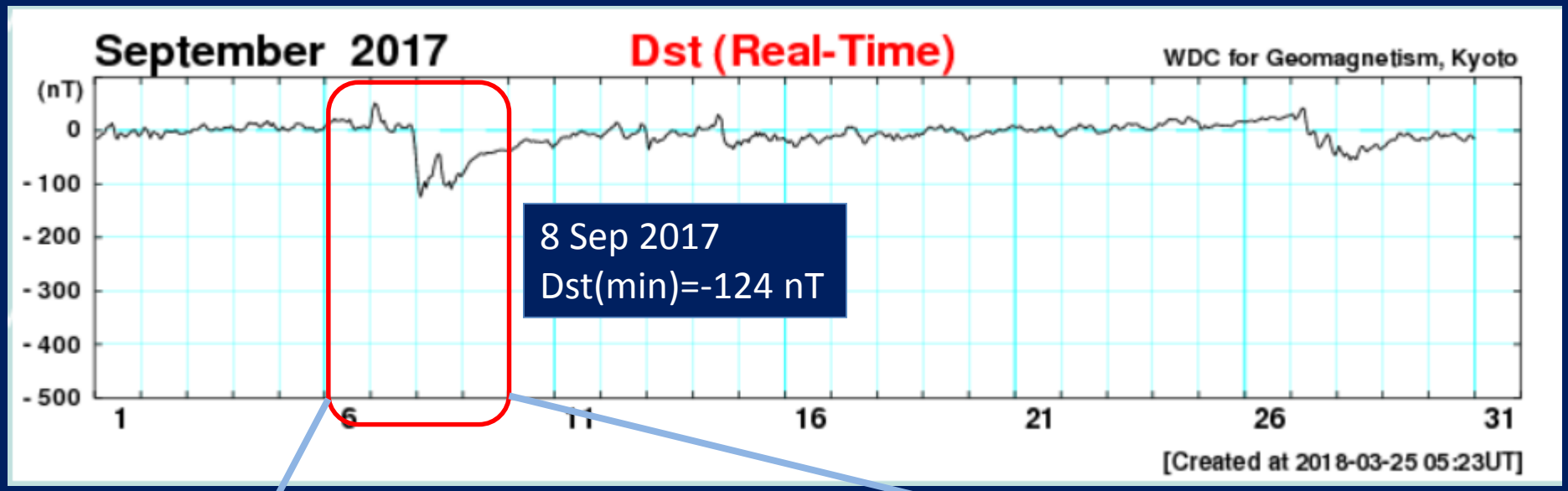
20 January 2016 multi-constellation scintillation recordings at SANAE-IV.

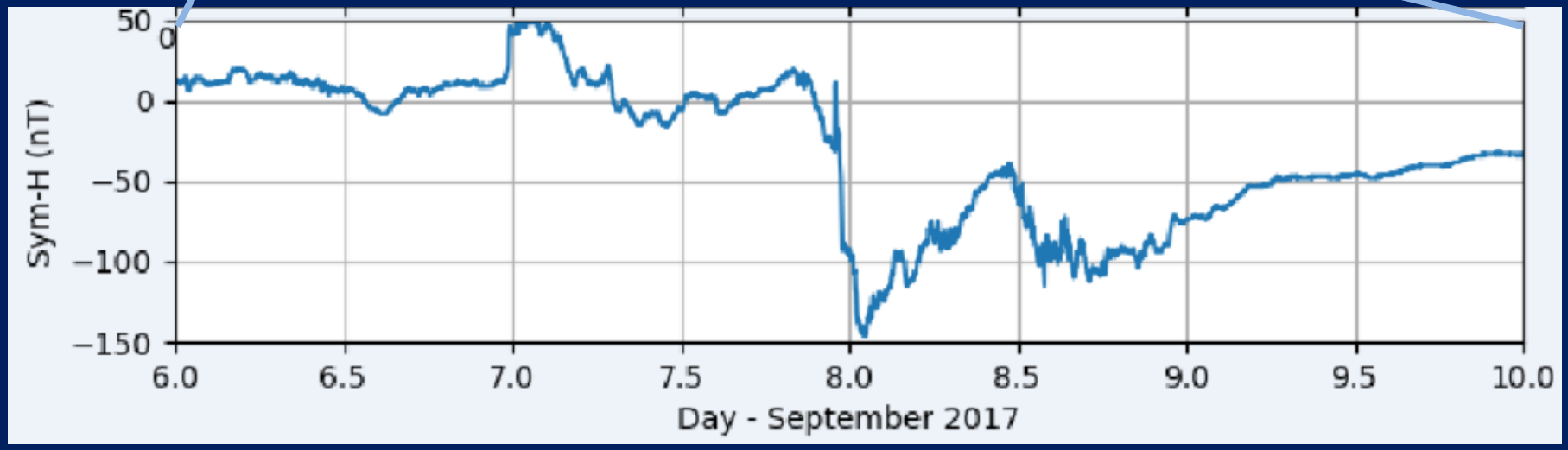


Alfonsi et al. *Space Weather*, 14(10), pp.704-709.

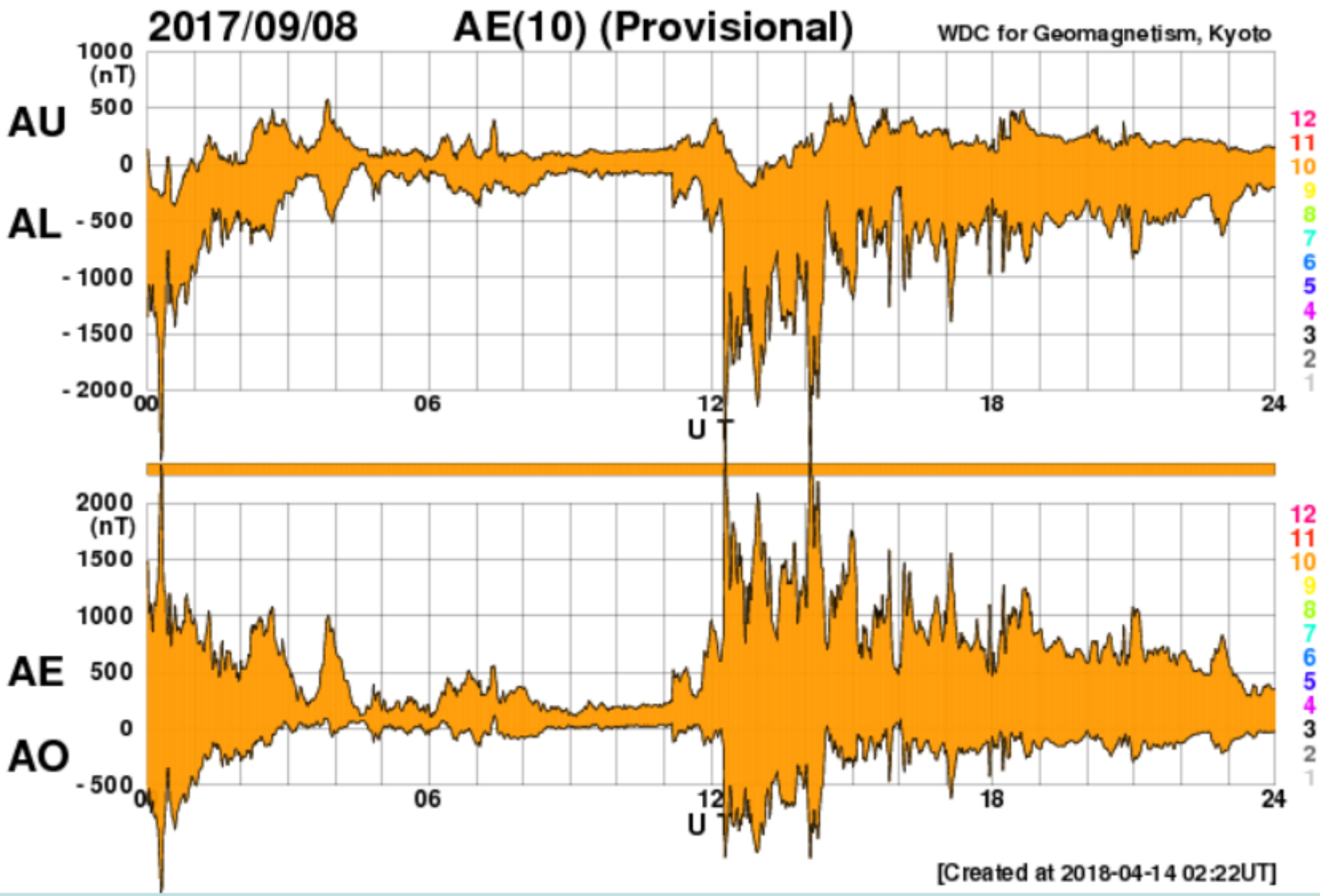
There is a clear enhancement of phase scintillation (σ_ϕ) on both the L1 and L2E5 frequencies visible on all three GNSS constellations received at SANAE on 20 January 2016, a day with a moderate geomagnetic storm (Dst = -100 nT).

Storm indicators on 6-10 September 2017

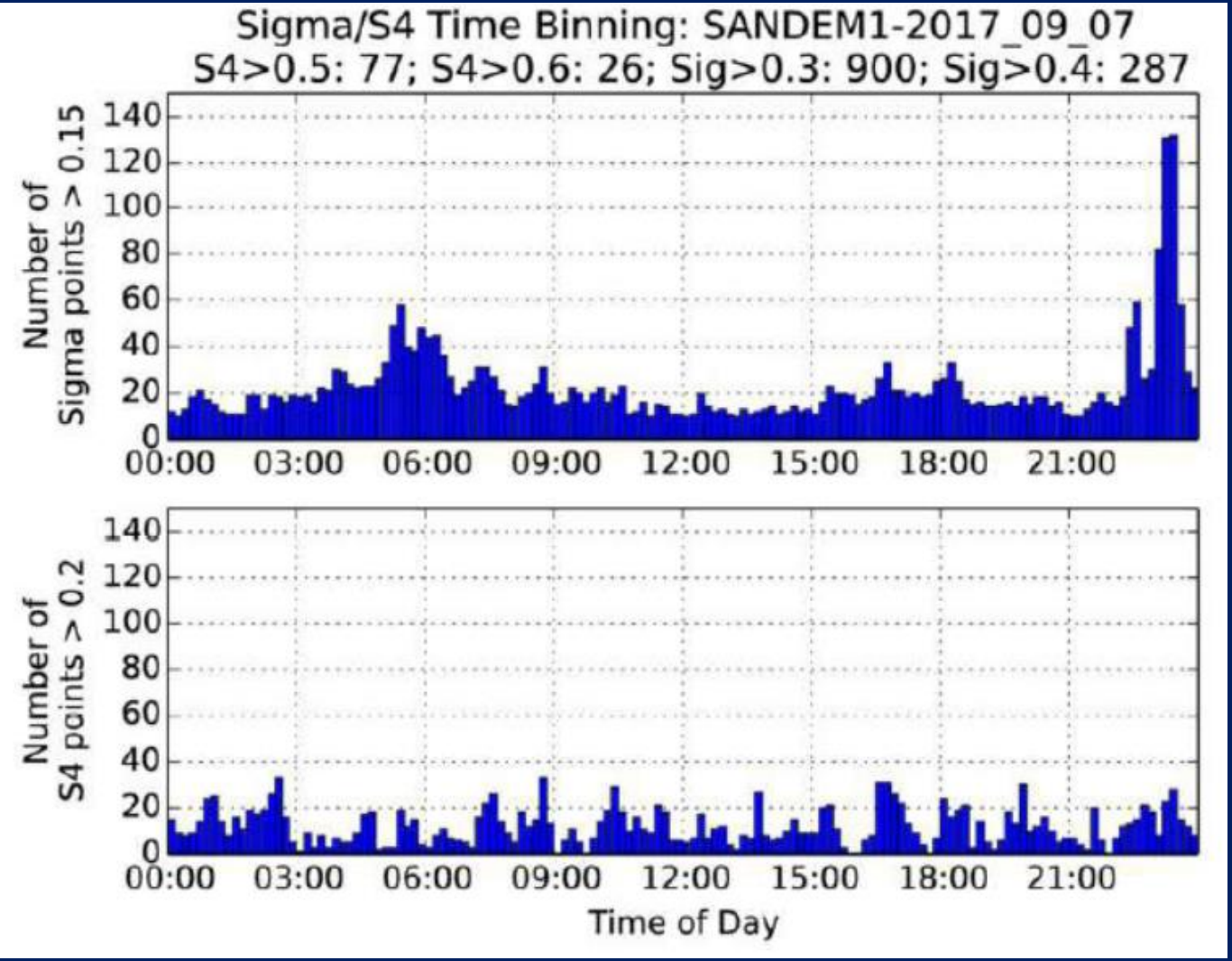




Storm indicators on 8 September 2017

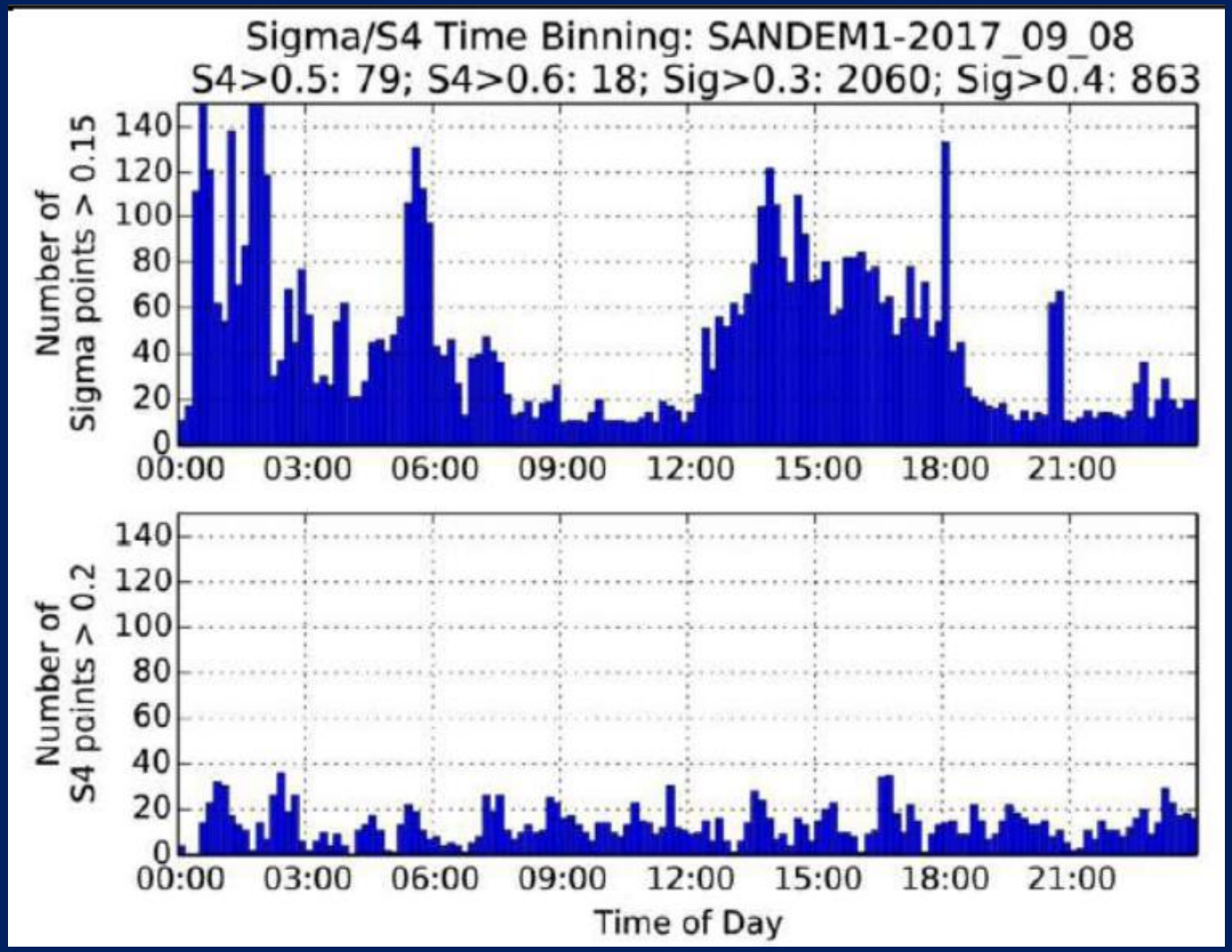


Scintillations recorded at SANAE on 7 September 2017



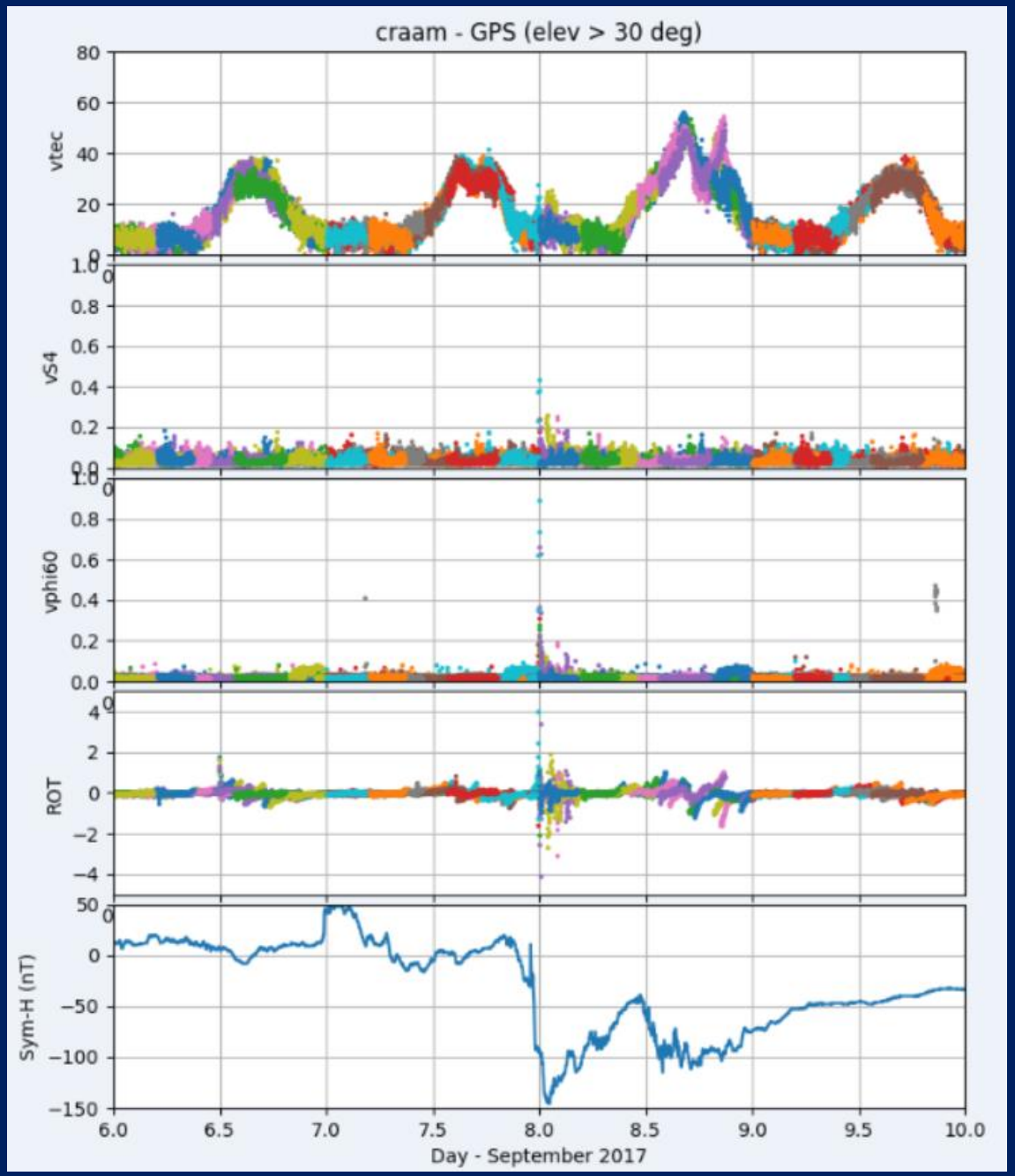
Frequency of occurrence of ionospheric scintillation observed at SANAE by means of the Septentrio receiver of the DemoGRAPE project at SANAE-IV. There is strong enhancement of amplitude scintillation without any concurrent enhancement in the phase scintillation (σ_ϕ) on L1 on a day with a moderate geomagnetic storm (Dst = -124 nT, AE > 2000 nT).

Scintillations recorded at SANAE on 8 September 2017

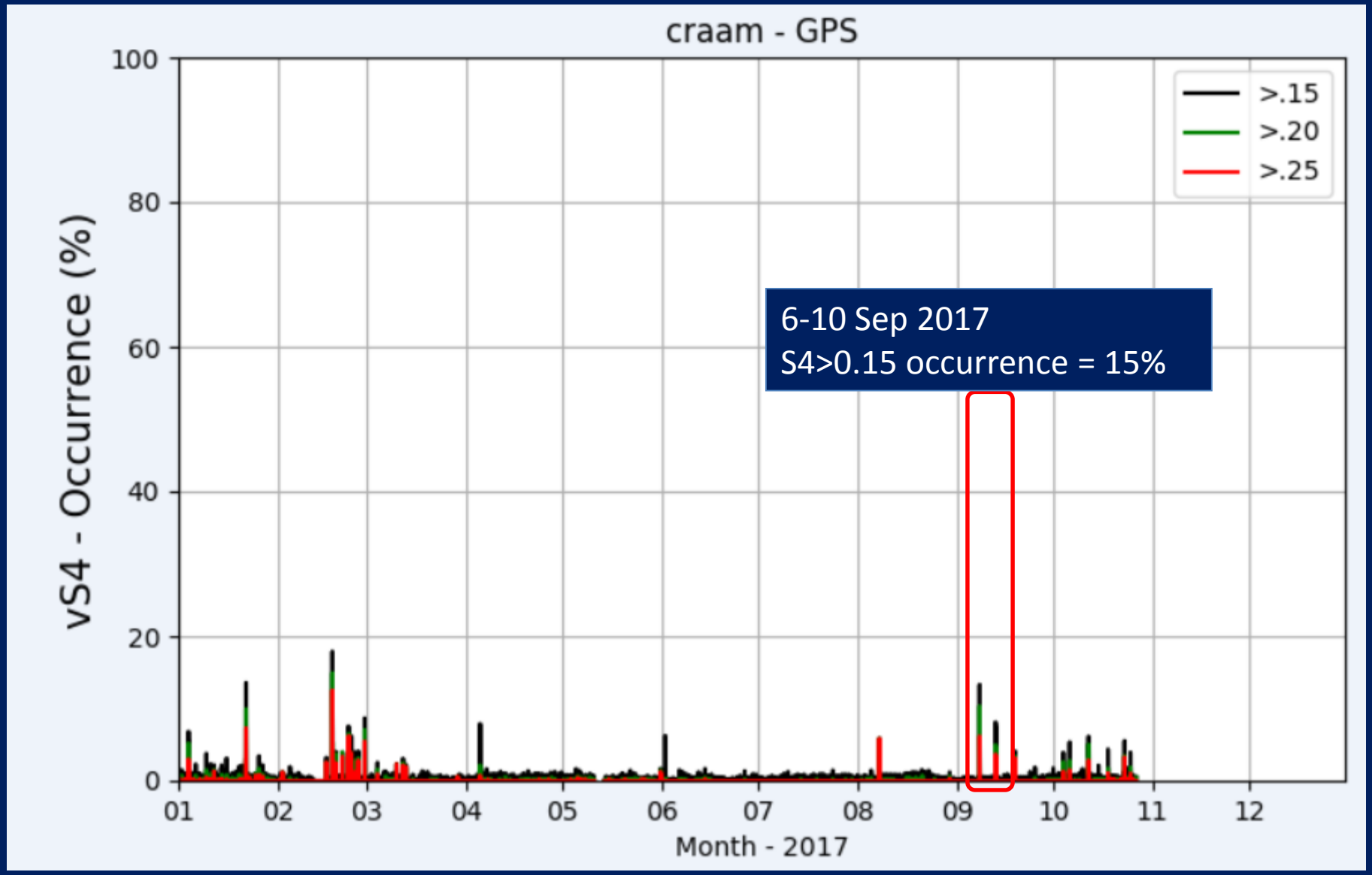


Frequency of occurrence of ionospheric scintillation observed at SANAE by means of the Septentrio receiver of the DemoGRAPE project at SANAE-IV. There is strong enhancement of amplitude scintillation without any concurrent enhancement in the phase scintillation (σ_ϕ) on L1 on a day with a moderate geomagnetic storm (Dst = -124 nT, AE > 2000 nT).

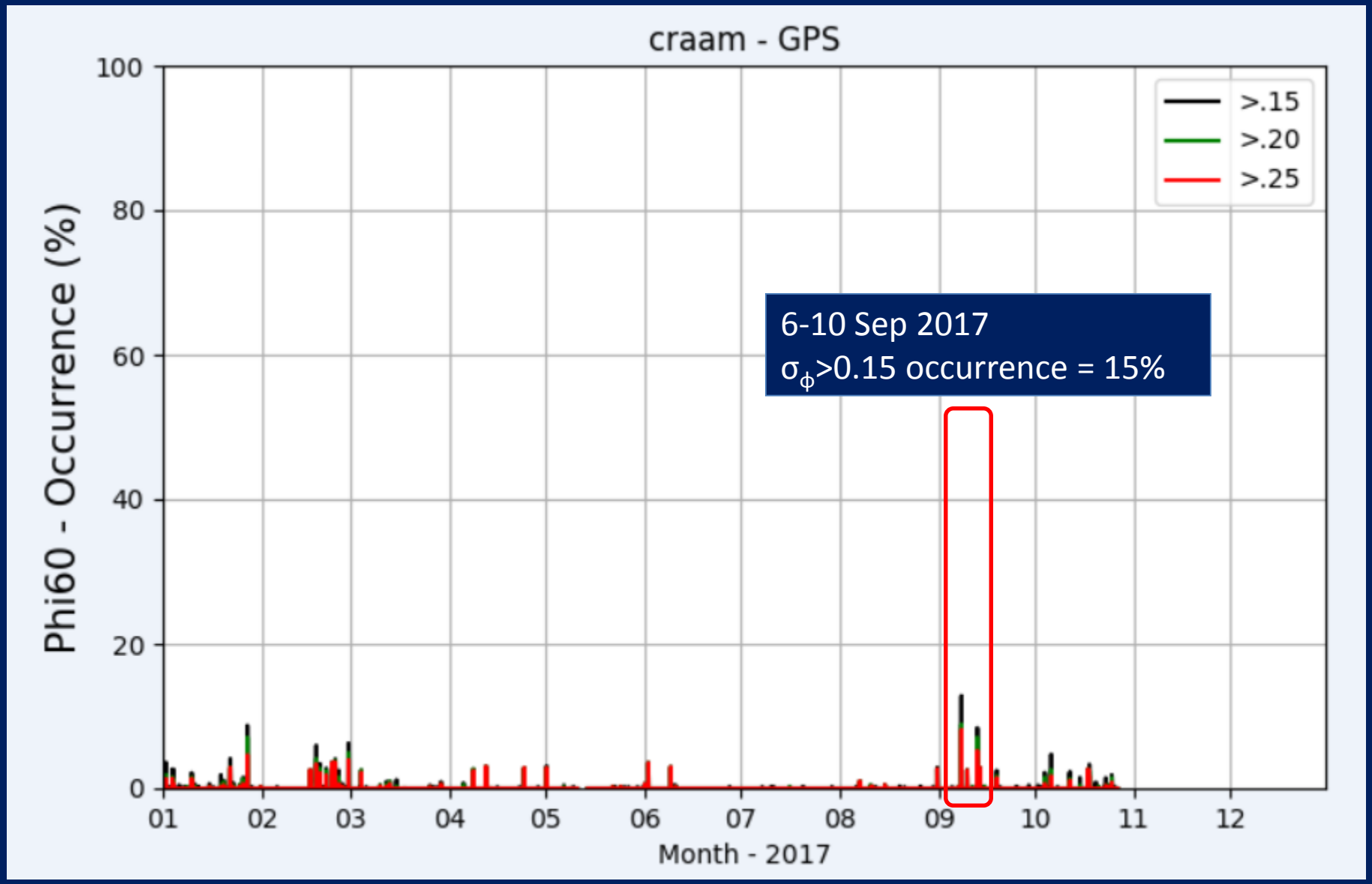
Scintillations recorded at CRAAM-INPE 6-8 September 2017



CRAAM-INPE S4 Scintillation occurrence 6-8 September 2017



CRAAM-INPE σ_ϕ Scintillation occurrence 6-8 September 2017



DemoGRAPE Research projects (1)

1. Correlate Scintillation with geomagnetic activity
2. Compare L1 and L2 scintillation levels
3. Compare Galileo, GLONASS, and GPS scintillation
4. Map scintillation IPPs to TEC gradient locations (derived from dTEC & spatial derivatives)
5. Estimate size of structures from spatial distribution of IPPs with σ_ϕ>threshold
6. Estimate scintillation proxies (ROTI, sDPR) from TEC & TEC-rate and correlate with S4 and σ_ϕ

DemoGRAPE Research projects (2)

7. Compare error estimates (GDOP, horizontal position error, loss of lock, lock-time) with S4 and σ_ϕ
8. Compare different integration times of σ_ϕ (1,3,10,30,60 sec)
9. Compare Signal-to-Noise ratio (C/No) with S4 and σ_ϕ
10. Compare SI index with S4 and σ_ϕ
11. Compare spectral indices (p, T) with scintillation intensity and size of scintillation structures
12. Estimate drift velocity and ionospheric height from comparison of S4 and ROTI.
13. Estimate the influence of base vibration (due to wind gusts) on S4 and σ_ϕ
14. Develop azimuth-dependent elevation threshold map to reduce multipath.

Student Projects using data from DemoGRAPE

- **Politecnico di Torino (Feb 2019):**
- *1 Internship, 1 MS thesis, 1 BS thesis, 1 student project*, *2 PhD*
- MS theses:
- *Ariel Belga Fedeli*, "An open-loop receiver architecture for monitoring of ionospheric scintillations by means of GNSS signals"
- *Chunhui Li*, "GNSS Data processing and characterization of ionospheric scintillations"
- PhD theses: "Innovative machine learning techniques for scintillation detection and mitigation."
- *Rayan Imam*
- *Caner Savas*

Student Projects related to DemoGRAPE

- **INGV**:
- 2 PhD (TREASURE) students:
- *Juliana Damaceno: "Forecasting model of TEC and scintillation parameters"*
- *Hossien Gobadi :* "Disentangling refractive from diffractive contribution in GNSS scintillation". "

Conclusions

- The DemoGRAPE multi-instrument GNSS data recorded since 2015 provides a valuable resource that has been used in several research projects and publications.
- New developments have improved the real-time access to the data.
- The new instruments continue to provide new research opportunities at international level in Antarctica, and will further global partnerships in Space Research.

Publications(1)

1. Alfonsi, L., Cilliers, P.J., Romano, V., Hunstad, I., Correia, E., Linty, N., Dovis, F., Terzo, O., Ruiu, P., Ward, J. and Riley, P., 2016. First observations of GNSS ionospheric scintillations from DemoGRAPE project. Space Weather, 14(10), pp.704-709.
2. Linty, N., Romero, R., Cristodaro, C., Dovis, F., Bavaro, M., Curran, J.T., Fortuny-Guasch, J., Ward, J., Lamprecht, G., Riley, P. and Cilliers, P., 2016, May. Ionospheric scintillation threats to GNSS in polar regions: the DemoGRAPE case study in Antarctica. In 2016 European Navigation Conference (ENC) (pp. 1-7). IEEE
3. Scionti, A., Ruiu, P., Terzo, O., Spogli, L., Alfonsi, L. and Romano, V., 2016, July. Demograpе: managing scientific applications in a cloud-federated environment. In 2016 10th International Conference on Complex, Intelligent, and Software Intensive Systems (CISIS) (pp. 426-431). IEEE.
4. Cilliers, P.J., Alfonsi, L., Spogli, L., De Franceschi, G., Romano, V., Hunstad, I., Linty, N., Teizo, O., Dovis, F., Ward, J. and Cesaroni, C., 2017, August. Analysis of the ionospheric scintillations during 20–21 January 2016 from SANAE by means of the DemoGRAPE scintillation receivers. In 2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS) (pp. 1-4). IEEE.

Publications(2)

5. Linty, N., Dovis, F. and Alfonsi, L., 2018. Software-defined radio technology for GNSS scintillation analysis: bring Antarctica to the lab. GPS Solutions, 22(4), p.96.
6. Terzo, O., Ruiu, P., Alfonsi, L., Romano, V. and Spogli, L., 2015, May. International cloud infrastructure for space weather data management: The DemoGRAPE challenge. In 2015 1st URSI Atlantic Radio Science Conference (URSI AT-RASC) (pp. 1-1). IEEE.
7. Linty, N., Romero, R., Dovis, F. and Alfonsi, L., 2015, May. Benefits of GNSS software receivers for ionospheric monitoring at high latitudes. In 2015 1st URSI Atlantic Radio Science Conference (URSI AT-RASC) (pp. 1-6). IEEE.
8. Linty, N. and Hunstad, I., 2016. Installation and configuration of an ionospheric scintillation monitoring station based on GNSS receivers in Antarctica. Rapporti Tecnici-INGV
9. Dabove, P., Linty, N. and Dovis, F., 2019. Analysis of multi-constellation GNSS PPP solutions under phase scintillations at high latitudes. Applied Geomatics, pp.1-8.

Publications(3)

10. N. Linty, A. Farasin, A. Favenza and F. Dovis, "Detection of GNSS Ionospheric Scintillations Based on Machine Learning Decision Tree," IEEE Transactions on Aerospace and Electronic Systems, vol. 55, no. 1, pp. 303-317, Feb. 2019. doi: 10.1109/TAES.2018.2850385
11. C. Savas and F. Dovis, “Comparative performance study of linear and gaussian kernel SVM implementations for phase scintillation detection,” in 2019 International Conference on Localization and GNSS (ICL-GNSS), June 2019. doi: 10.1109/ICL-GNSS.2019.8752635. ISSN 2325-0771 pp. 1-6
12. C. Savas, G. Falco, and F. Dovis, “A comparative analysis of polar and equatorial scintillation effects on GPS L1 and L5 tracking loops,” in ION 2019 International Technical Meeting Proceedings, 2019. doi: 10.33012/2019.16677 pp. 632-646
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Thank you for your attention

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