Analysis of equatorial ionospheric irregularities based on a two high rate GNSS station setup

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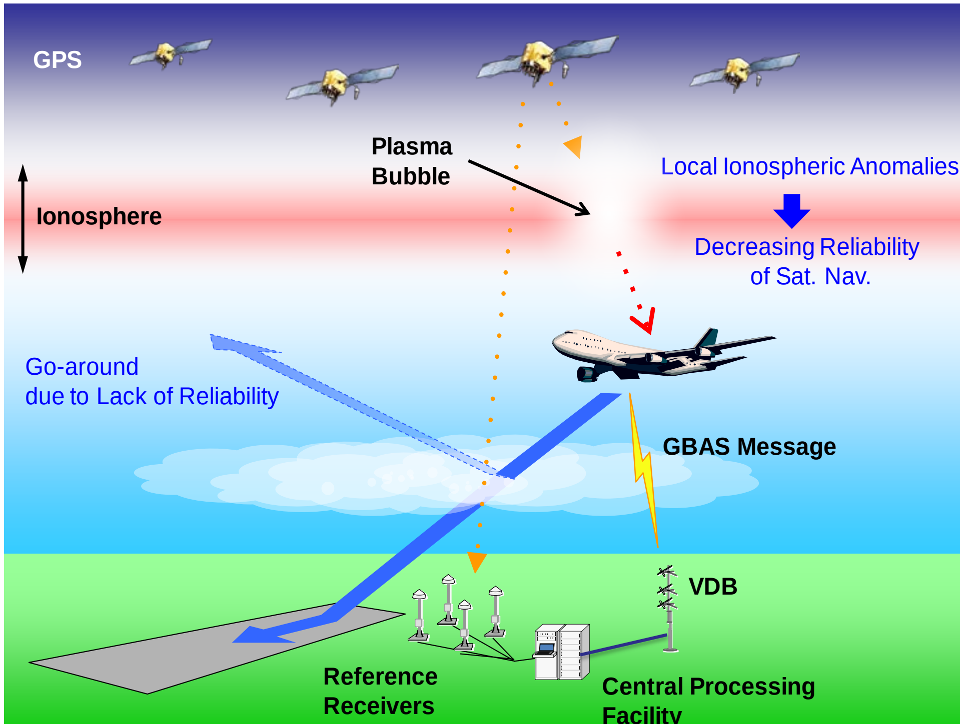
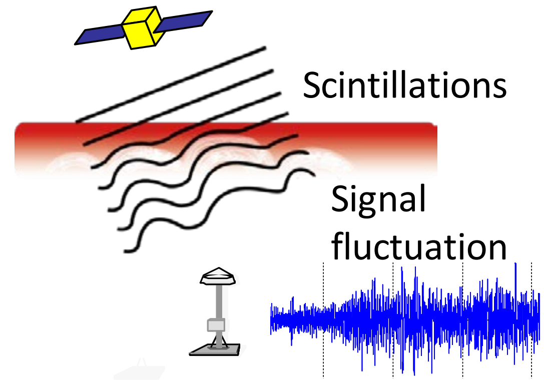
Motivation

Impact of Ionospheric Irregularities on GNSS Applications

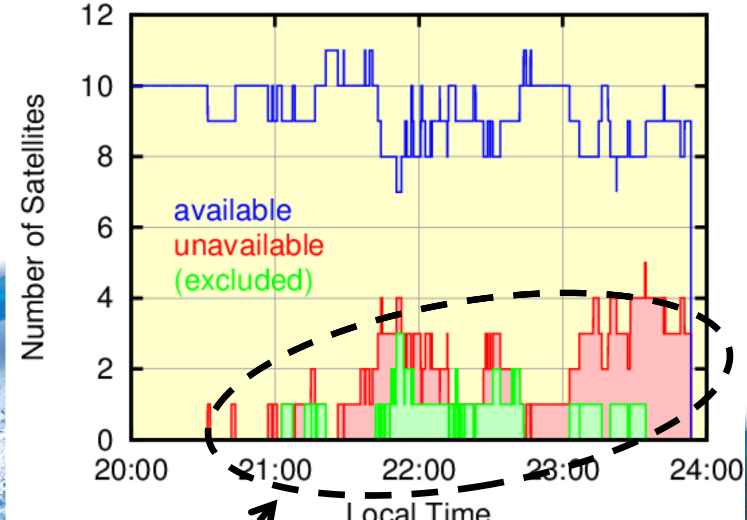
Airport Precision Approach



Plasma Bubble degrades availability of GNSS Precision Approach

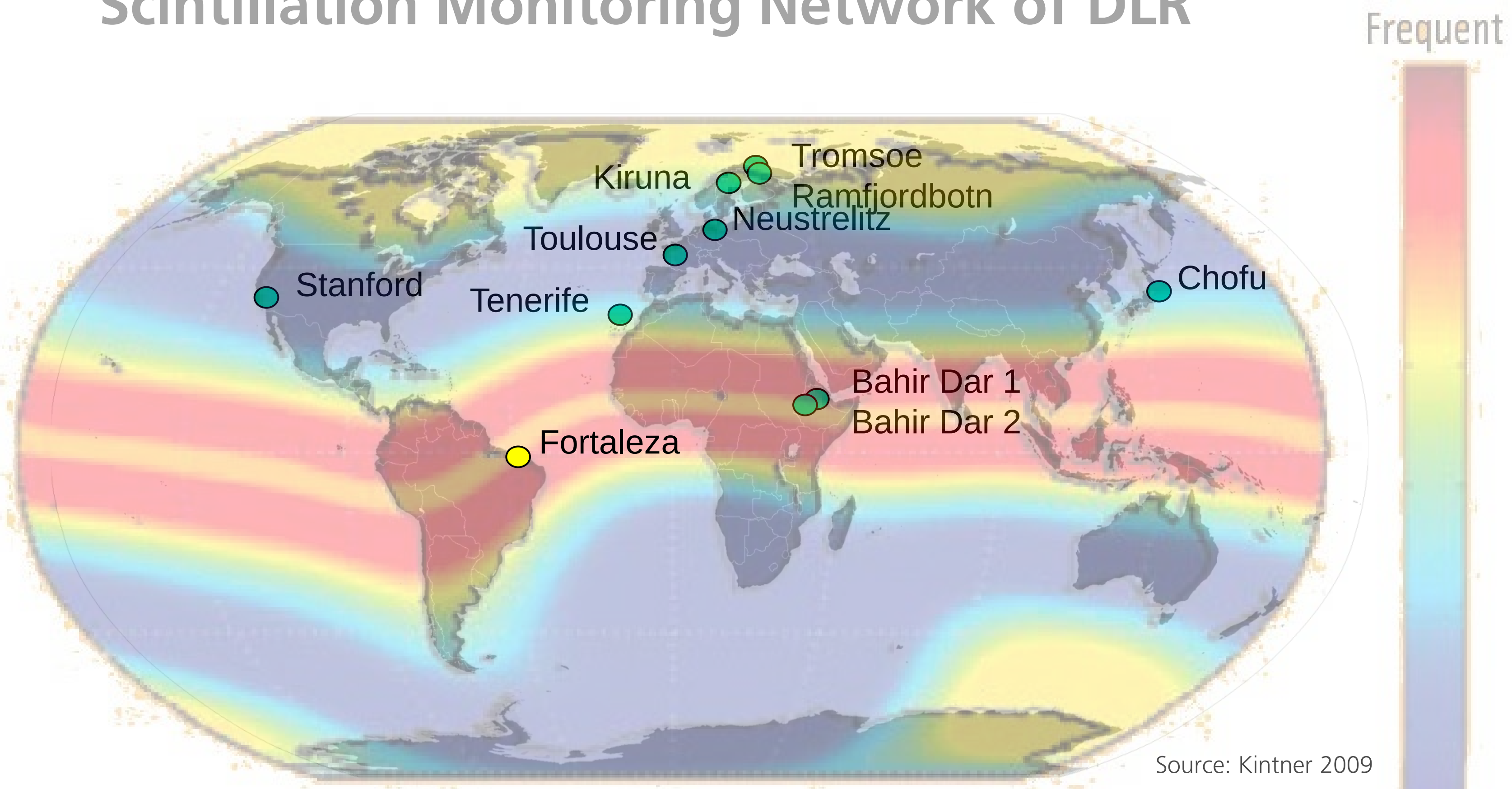


GNSS Signal is disturbed by ionospheric irregularities (plasma bubble) and may be lost in severe case.



Maximum 5 Sats. were Unavailable

Scintillation Monitoring Network of DLR



Source: Kintner 2009

DLR operates a own high rate GPS receiver network for scintillation measurement from high latitudes (Kiruna /Sweden) down to equatorial regions (Bahir Dar/Ethiopia). Scintillation data of several stations provided in real time via IMPC/SWACI http://swaciweb.dlr.de

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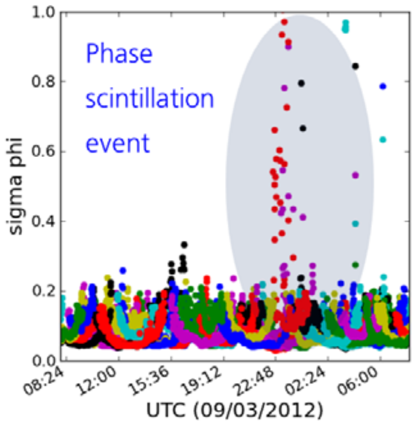
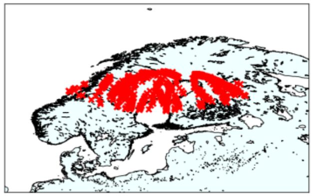
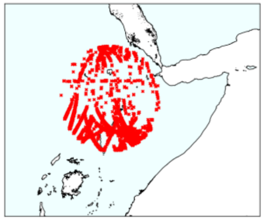
Regional differences of scintillation occurence



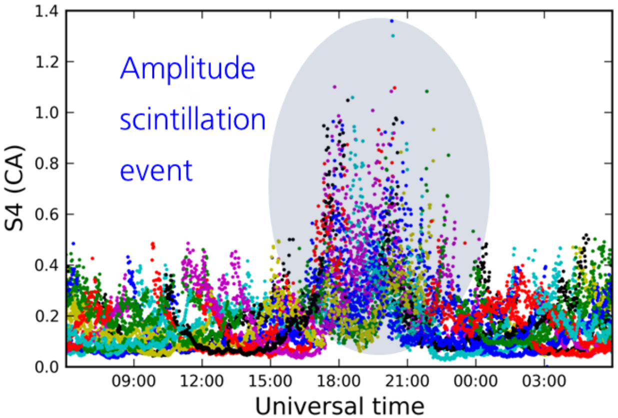
Kiruna / Schweden



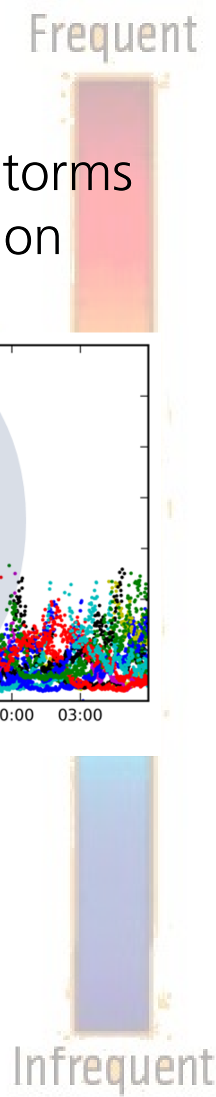
Source: Geomagnetic Storms
Causes: Phase scintillation



Bahir Dar/ Ethiopia



Source: Flow inversion of the equatorial plasma during evening hours (dusk) leads to Rayleigh-Taylor instabilities (RTI) and plasma bubbles.
Causes: Amplitude und Phase scintillations



Picture from Kintner 2009

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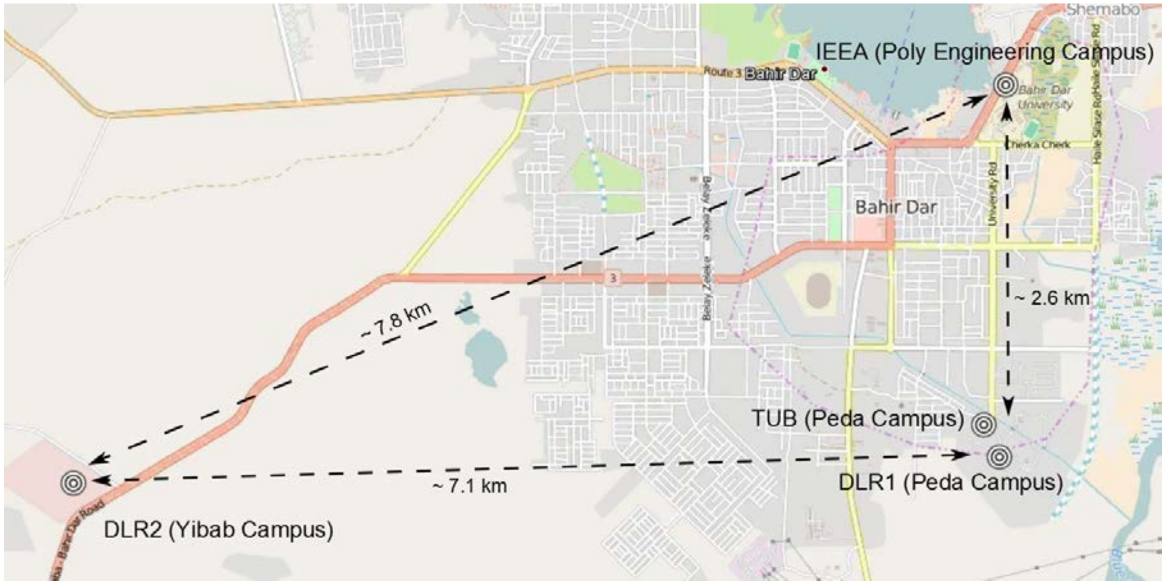
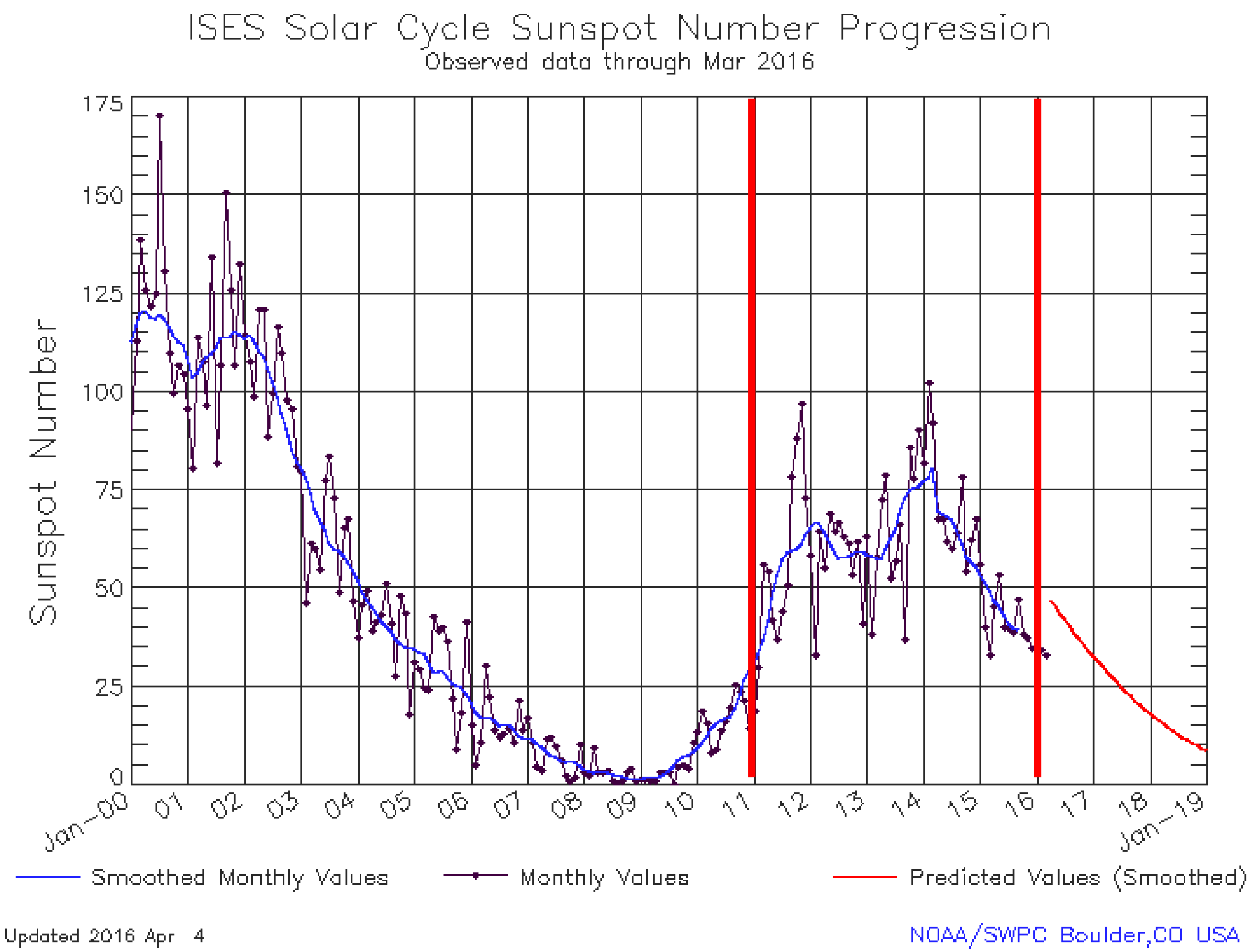
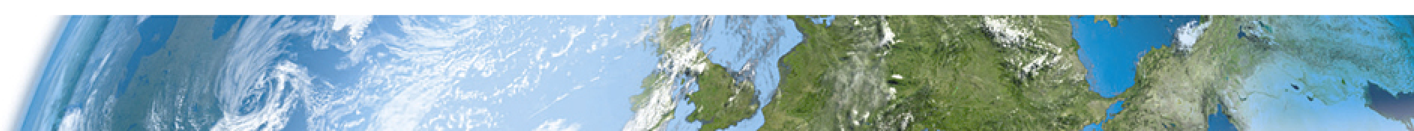
Equatorial latitudes: Current small scale receiver network in Bahir Dar



DLR 1 50 Hz Javad receiver (10/2011)
DLR 2 50 Hz Javad receiver (06/2014)
TUB 50 Hz Septentrio receiver (01/2015)
IEEA 50 Hz Novatel receiver (06/2014)

Solar cycle 24





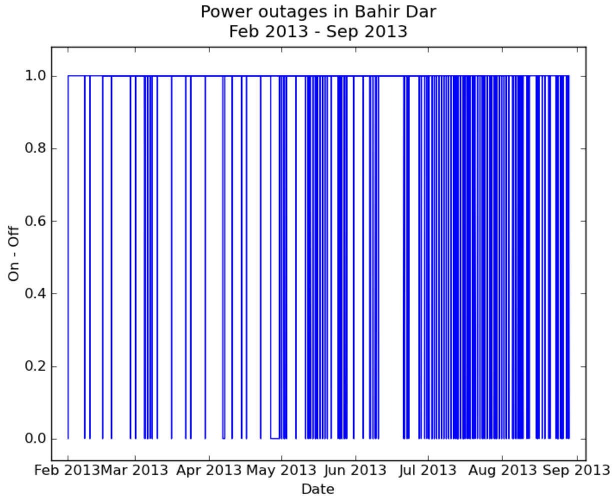
Small Scale Monitoring Network
Bahir Dar

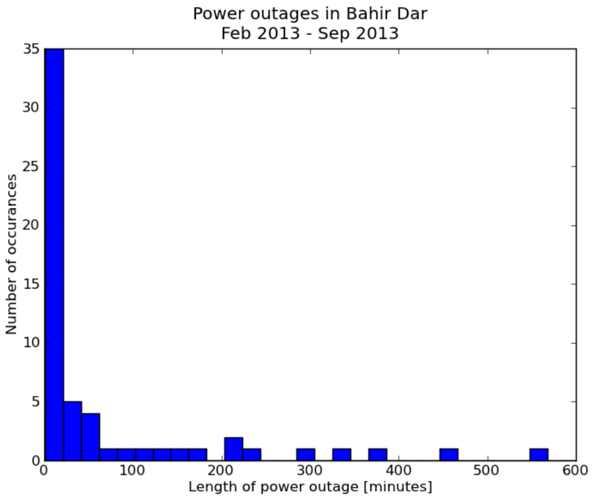
Benefit:

- Good location to observe phase and amplitude scintillations at low latitudes
- Current setup capable for receiving GPS, GLONASS and Galileo signals
- Cooperation with IEEA, TUB will produce valuable database for plasma bubble and plasma drift research

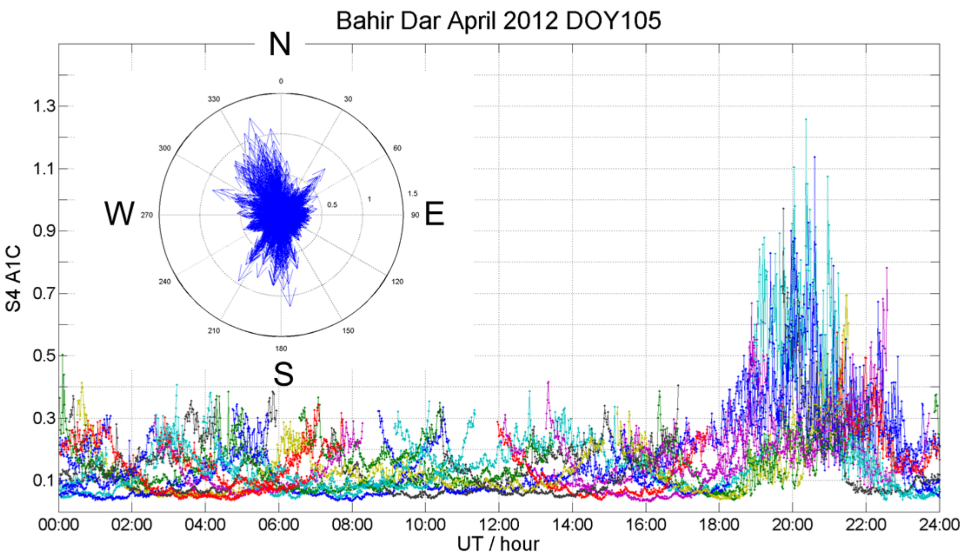
Problems:

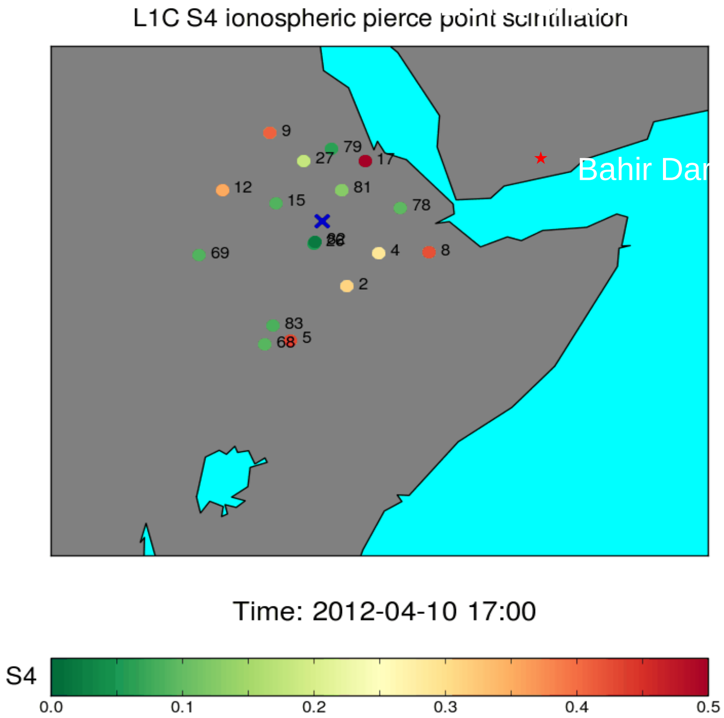
- Power outages in Bahir Dar





Diurnal variation of scintillation activity at Bahir Dar

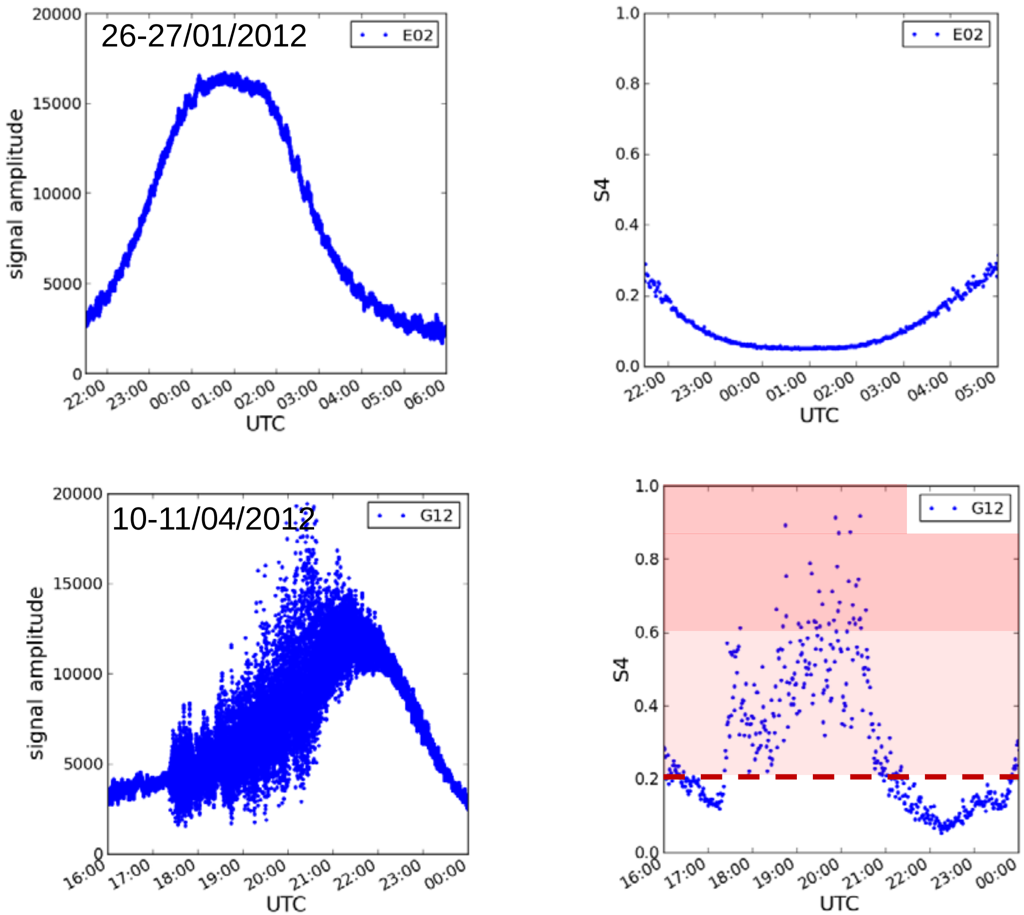




S_4 Scintillation activity enhances regularly in Bahir Dar / Ethiopia after sunset

Scintillations occur primarily in North-South direction

Amplitude scintillations



$$S_4 = \left(\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2} \right)^{1/2}$$

Enhancement of S_4 at low elevation due to multipath effects. Effect has to be mitigated in subsequent analysis.

S_4	Classification
> 0.2	moderate
> 0.6	strong
> 0.9	extreme

The monitoring of S4 derived from the DLR's worldwide distributed EVNET stations showed, that S4 values up to 0.1 are mostly caused by the natural noise of the signals intensity

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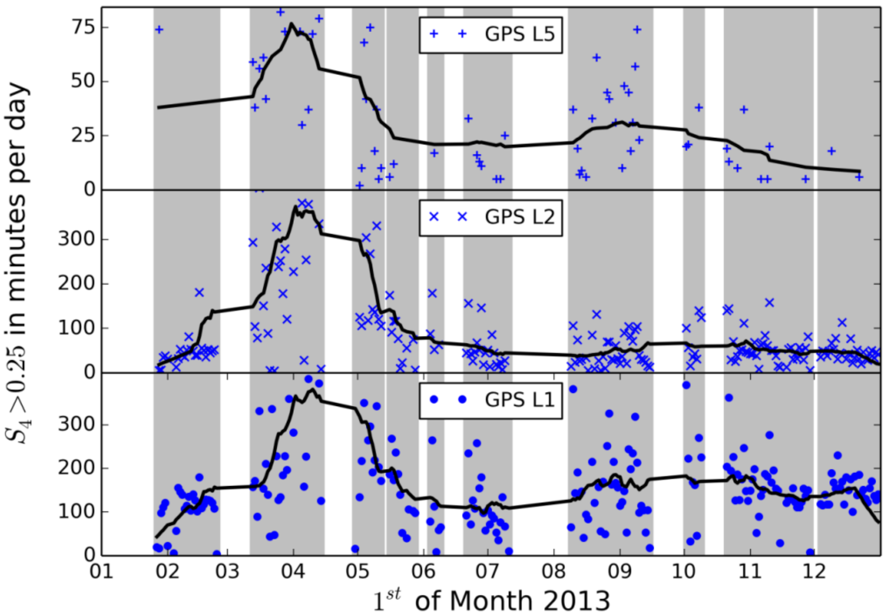
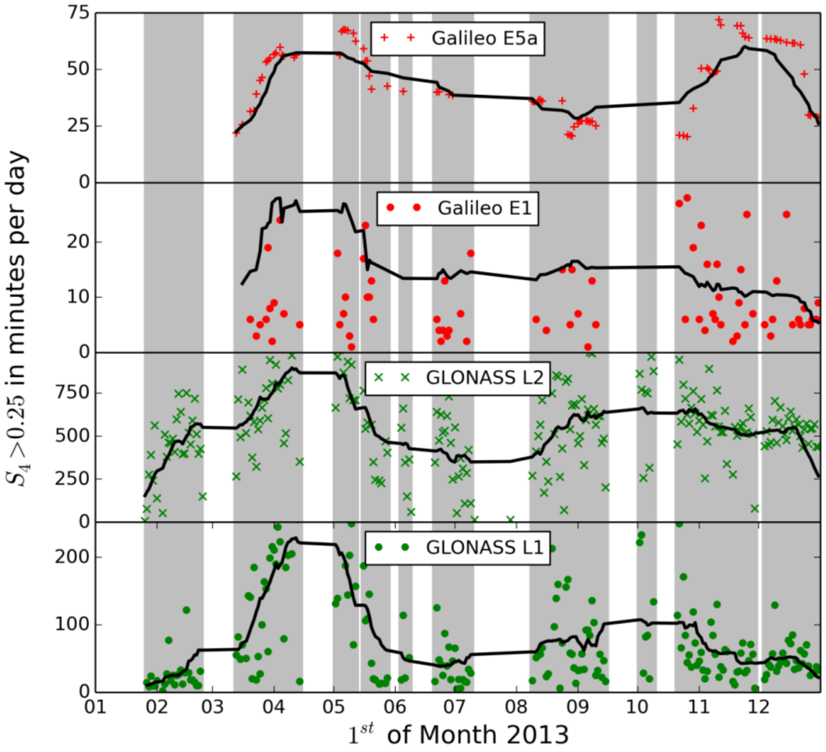
Yearly Scintillation Occurance over Bahir Dar – GPS (L1,L2,L5), Galileo (E1,E2,E5A)





Peaks at equinox periods

Scintillation largest: Solar terminator equals magnetic meridian

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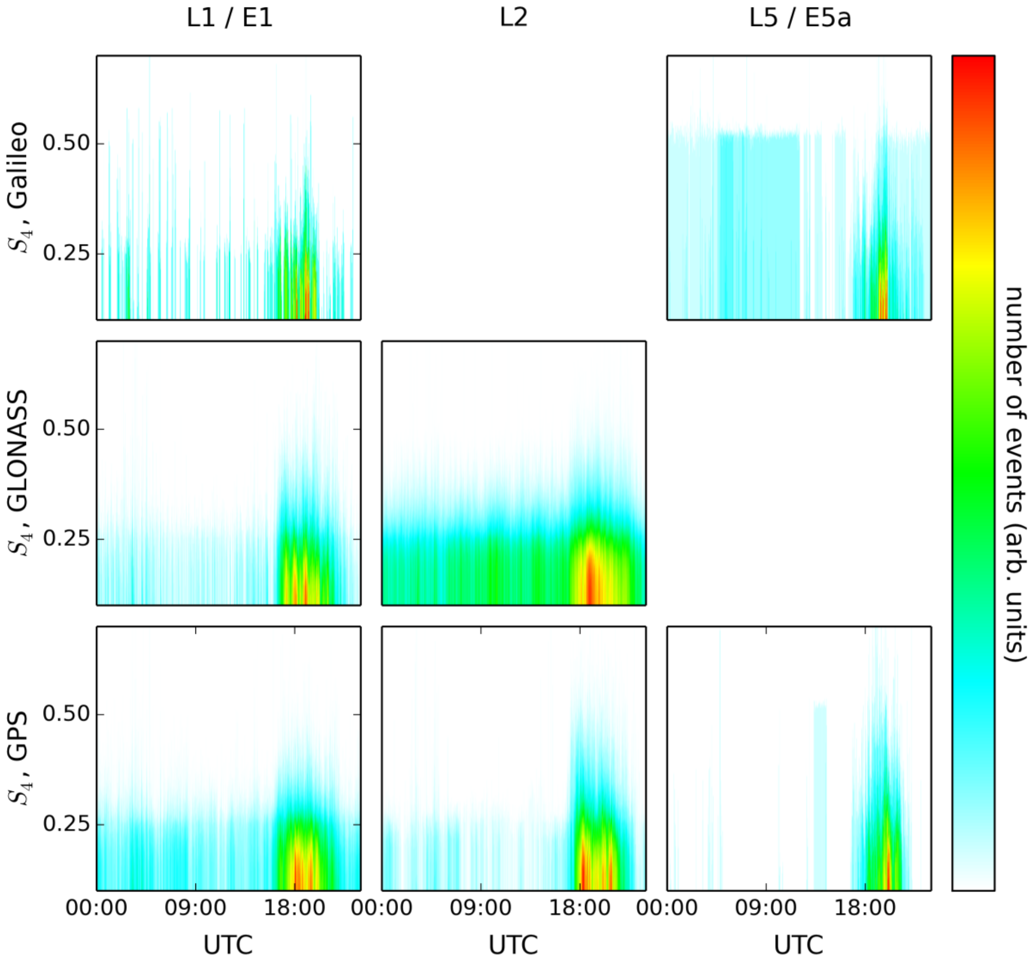
Daily Scintillation Occurance



Effect on L5 larger than on L1

GLONASS L2 strongly affected

GPS: 32 sats
GLONASS: 23 sats
Galileo: 4 sats

N. Hlubek, J. Berdermann, V. Wilken, S. Gewies, N. Jakowski, M. Wassaie, Baylie Damtie; Scintillations of the GPS, GLONASS, and Galileo signals at equatorial latitude, J. Space Weather Space Clim. 4 (2014) A22 DOI: 10.1051/swsc/2014020

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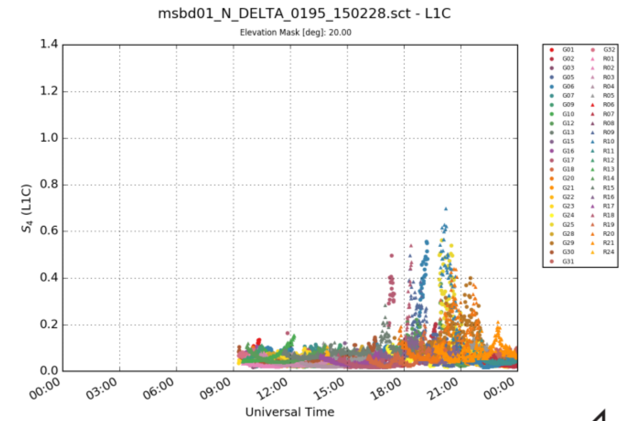
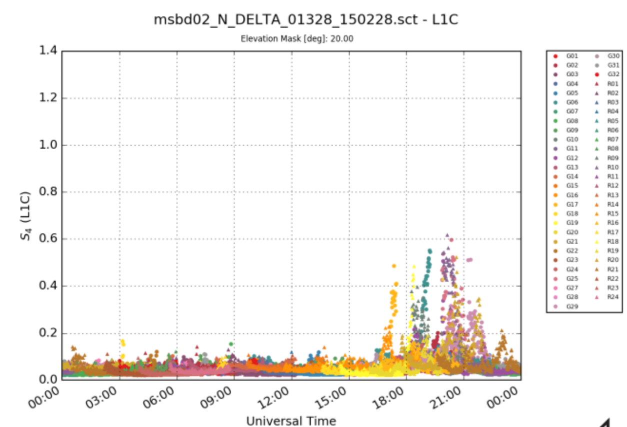
Scintillation events recorded by both DLR stations in 2015

Month	Affected days	Activity/Relevance
February	3	moderate
March	6	strong
April	9	strong
May	7	moderate
December	1	moderate

Gap between May to December due to outage of msbd01 before modernization in October 2015.

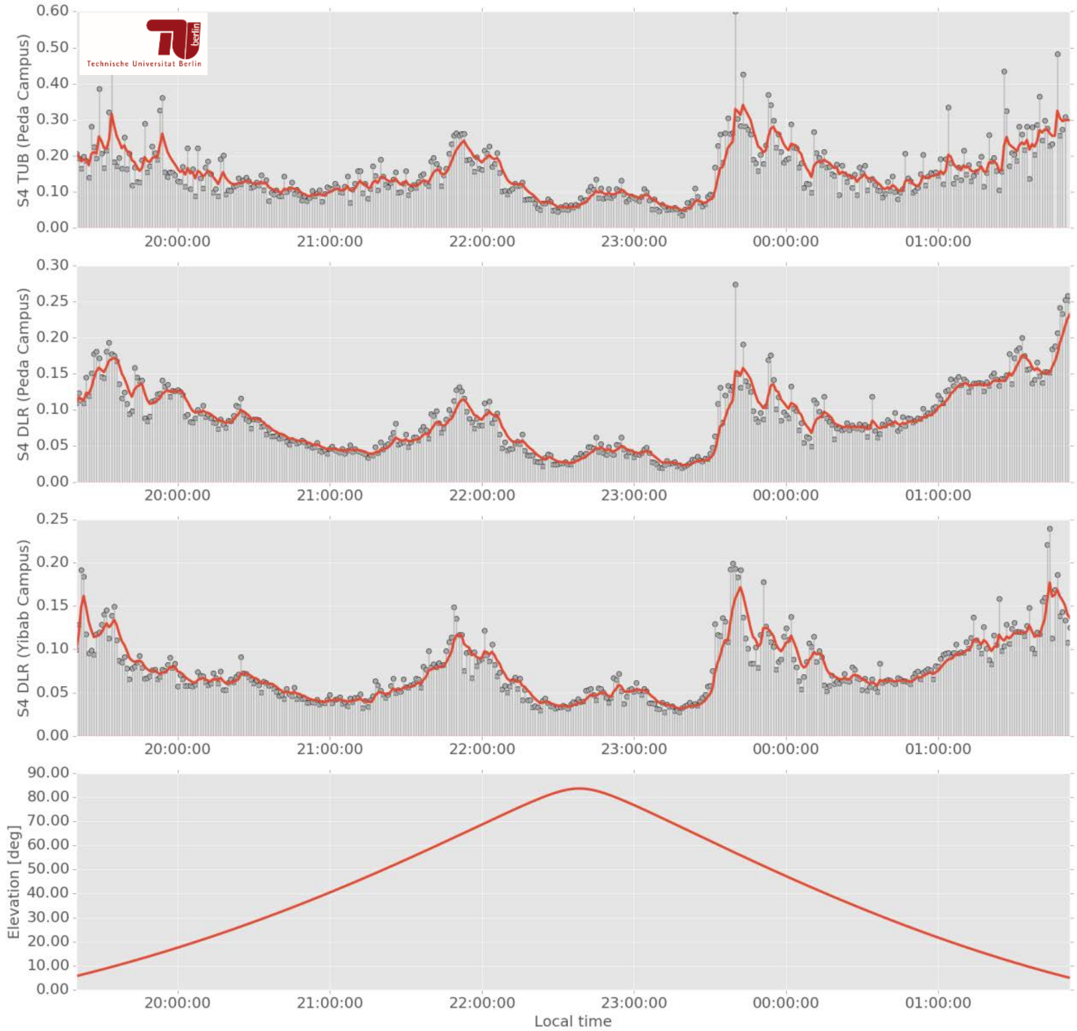




Scintillation and TEC depletion patterns can be observed by monitoring the signal power and the slant total electrontent sTEC over time.

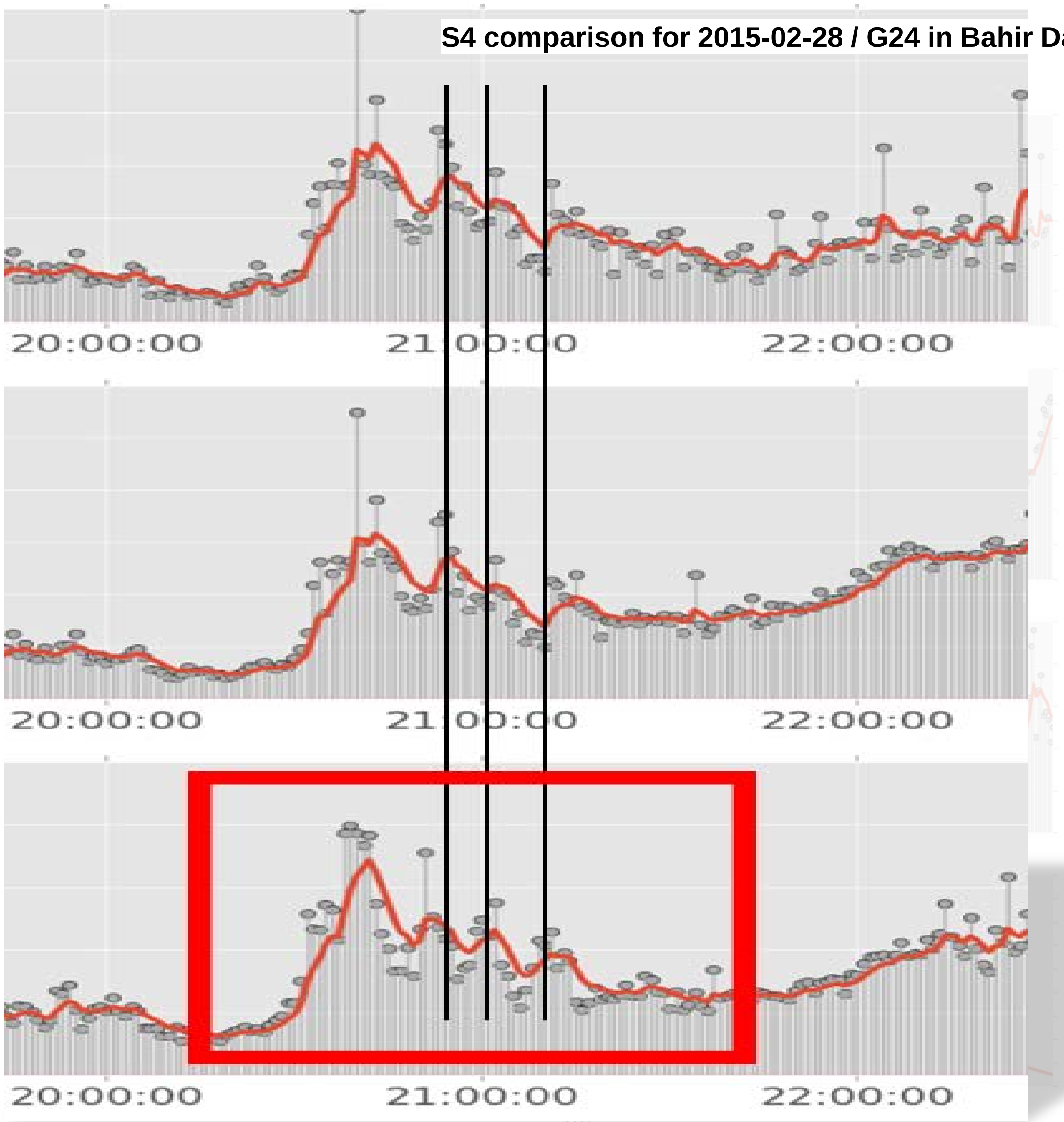
Stations are closely located in east west direction, which allows to estimate the zonal drift velocity and spatial dimension of plasma irregularities.

S4 comparision 28.02.2015 / G24



Signature (red line, exponentially-weighted moving average, window size: 3 min) of S4 indices (grey dots) calculated for satellite G24 from different scintillation processors in comparison
to the averaged elevation.

Link based comparison of amplitude scintillations



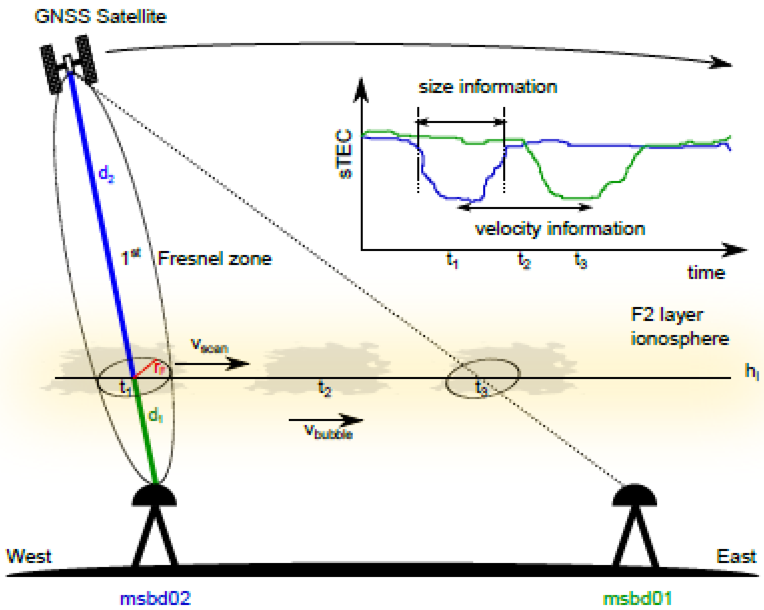
similar scintillation signatures with different hard-/software setup at same campus

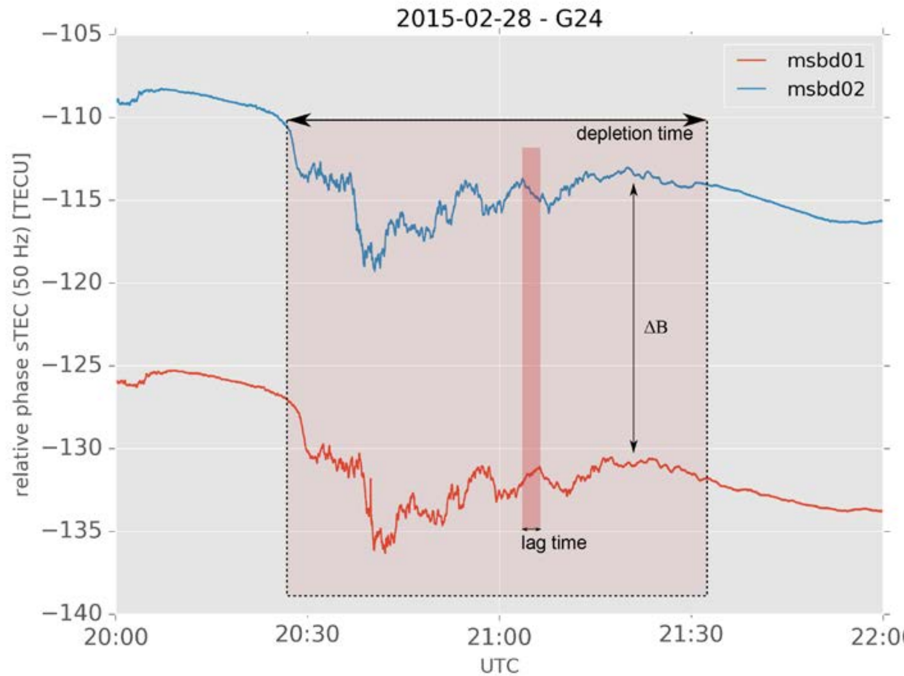
different S4 scaling between TUB and DLR has to be clarified

Estimation of drift of TEC depletions possible by using cross correlation of high rate phase TEC data

Lag of several minutes!

Estimation of plasma bubble characteristics





- Observed sTEC depletion moving eastward within a time span of 1 hour and a maximum depletion of 10 TECU for satellite G24 over Bahir Dar, Ethiopia
- The plasma drift velocity is known also the geographic dimension of the irregularity region in east-west direction and can be estimated by multiplying the estimated drift velocity by the width of the TEC depletion signature in the time domain

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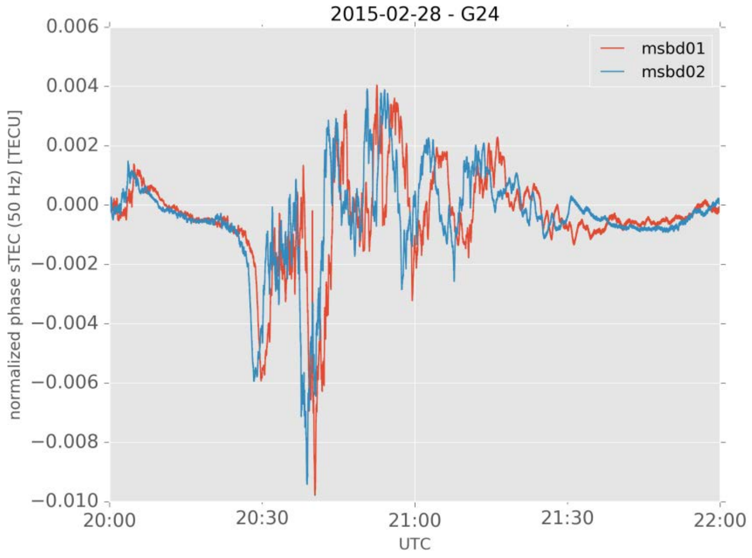
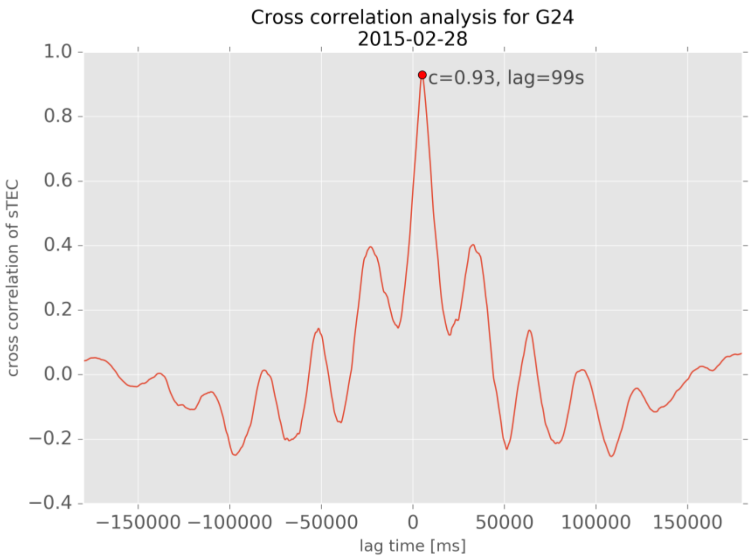
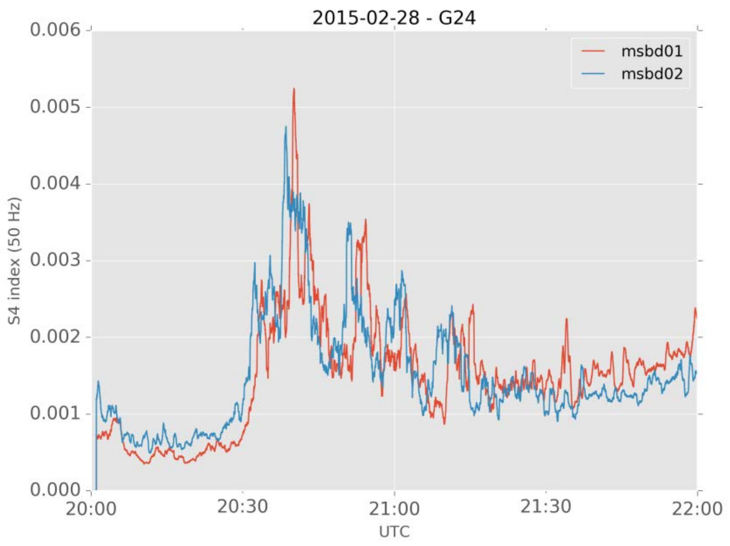
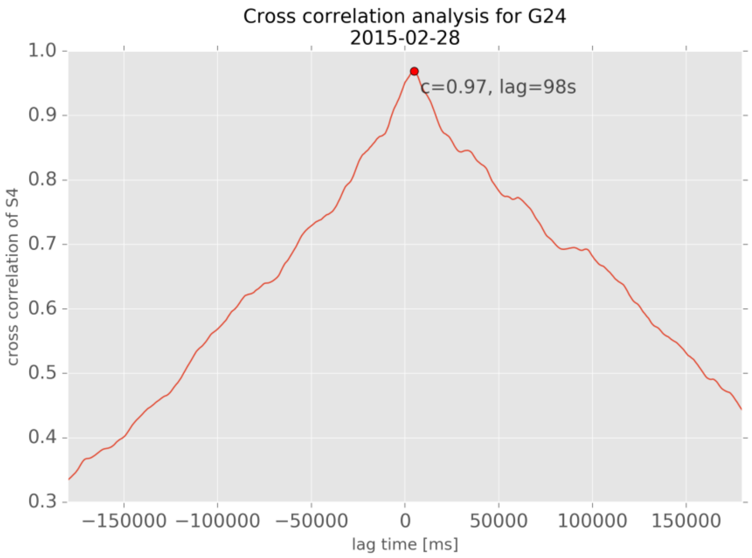
Cross correlation of both DLR stations on 28 February 2015









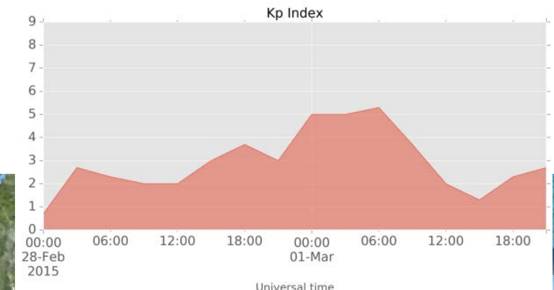
Results

The overall irregularity drift velocity has been estimated from irregularity pattern velocity and the scanning velocity.

Date	LT	PRN	Direction	Velocity	Size
28.02.2015	23:30	G24	eastward	81 m/s	292 km
28.02.2015	23:10	G29	eastward	80 m/s	144 km
28.02.2015	24:10	G29	westward	102 m/s	312 km
08.04.2015	23:00	G21	eastward	80 m/s	58 km
08.04.2015	23:00	G26	eastward	84 m/s	151 km
08.04.2015	23:30	G26	eatsward	78 m/s	187 km

M. Kriegel, N. Jakowski, J. Berdermann, H. Sato, and M. W. Mersha, Scintillation measurements at Bahir Dar during the high solar activity phase of solar cycle 24, (submitted to Annales Geophysicae)

- In agreement with earlier results from GPS L1 signal eastward velocities of ionospheric irregularities at midnight in the south american sector (50-100 m/s) [Kil et al. 2000]
- G29 eastward propagation decreased and changed into westward direction
- Might come from dominant role of a disturbance dynamo associated westward thermospheric wind during magnetospheric disturbances



[Bhattacharyya et al. 2002, Abdu et al. 2003]

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Summary & conclusion

- Seasonal statistics of S_4 with maxima around equinoxes confirms former studies, asymmetry between spring and autumn needs further investigation.
- GPS, GLONASS and Galileo systems show different sensitivity to ionospheric irregularities.
- Local network of scintillation receivers in Bahir Dar allows detecting plasma bubbles and their drift velocities.
- Drift velocities and size estimations are in agreement with earlier results from south american sector
- To explore the structure and dynamics of plasma bubbles more in detail, the current local GNSS network geometry should be optimized.
- Future studies will utilize the full network of high rate GNSS stations with its multi constellation links.
- Possible complementary spaceborn observations such as SWARM constellation or regional Beacon should be used.
- Detailed comparison with ionospheric irregularities at equatorial latitudes over South America

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Thank you!

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