Global Ionospheric propagation Model

GISM

USER MANUAL

release n° 6.53
(January 2011)

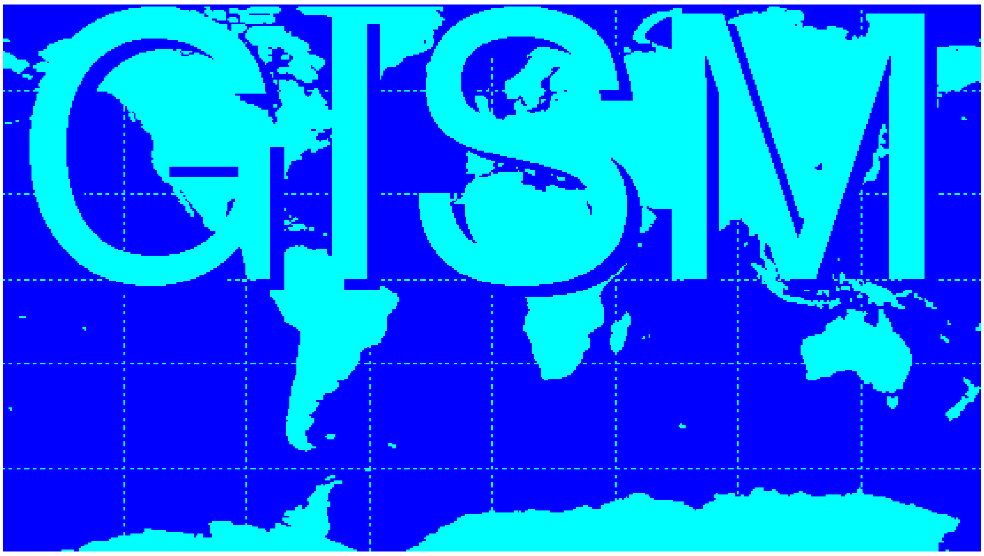


TABLE OF CONTENTS

1. Introduction

As a result of propagation through ionosphere electron density irregularities, transionospheric radio signals may experience amplitude and phase fluctuations. In equatorial regions, these signal fluctuations specially occur during equinoxes, after sunset, and last a few hours. They are more intense in periods of high solar activity. These fluctuations result in signal degradation from VHF up to C band. They are a major issue for many systems including Global Navigation Satellite Systems (GNSS), telecommunications, remote sensing and earth observation systems.

The signal fluctuations, referred as scintillations, are created by random fluctuations of the medium’s refractive index, which are caused by inhomogeneities inside the ionosphere. These inhomogeneities (or bubbles), or more generally the turbulences, develop under several deionization instability processes. These processes start after sunset when the sun ionization drops to zero, consequently at nighttime. To produce signal scintillation, the bubbles sizes should be below a typical dimension (typically one km) such that the diffracting pattern is inside the first Fresnel zone. The Fresnel zone dimension also depends on the distance from the Ionospheric Pierce Point (usually defined at about 350 km height) to the receiver and on the frequency.

The Global Ionospheric Propagation Model (GISM), presented in this document aims to calculate these effects, in particular:

- The Line of sight errors
- The Faraday rotation effect on polarization: being an anisotropic medium, ionosphere layers will impact a linear polarized wave by rotating its polarization plane.
- The propagation Delay: the ranging error is proportional to the TEC and to the inverse square of the frequency.
- The scintillation effects: phase and amplitude scintillations, shorter correlation distances with respect to space, time and frequency, cycle slips, loss of lock.

GISM model uses the Multiple Phase Screen technique (MPS). With this technique, the medium is divided into successive layers, each of them acting as a phase screen. The locations and altitudes of both the transmitter and the receiver are arbitrary. The link can consequently go through the entire ionosphere or through a small part of it.

The whole calculation for one particular link is composed of two steps

- The calculation of the Line Of Sight (LOS)
- The calculation of scintillations

The calculation of the Line of sight is done using a ray technique. GISM uses the NeQuick model to provide the value of the electron density inside ionosphere required at any time and location. At the end of this calculation the LOS errors, the Faraday rotation and the delays are calculated.

The LOS being determined, the scintillations are then calculated. To do this, at each screen location along the line of sight, the parabolic equation (PE) is solved. This calculation requires the knowledge of the medium statistical characteristics. They are defined with respect to the ionosphere electron density mean value at all points along the LOS.

GISM model estimates the scintillation parameters from the knowledge of the time series at receiver level using the signal intensity and phase and its correlation and structure functions. In case of strong scintillations (typically S4 > 0.7), the phase may exhibit cycle slips with consequences on the receiver phase loop. It may also in that case lead to losses of lock for one or several satellites.

GISM model allows considering either a trajectory described by a list of successive points or a constellation (GPS, Galileo or Glonass). An orbit generator has been introduced for this capability. The input in that case is the Yuma file. GISM allows considering either links, from a receiver to a satellite or a constellation, or maps.

Details on the theoretical formulation and corresponding algorithm may be found in the GISM technical report [1], [2].

This document is organized as follows:

Section 2 presents the code organisation
Section 3 presents the input data
Section 4 presents the output files
Section 5 defines the input parameters default values
Section 6 is related to the algorithm convergence
Section 7 presents the mapping capability
Section 8 is related to the output options
Section 9 presents some input data files for typical scenarios
Section 10 indicates the changes in the input data file with respect to the previous version.

2. GISM implementation

The 4 tasks required for execution are detailed below:

- Task 1: Create a directory inside which will be located all files (input and output) related to the problem case.
- Task 2: Fill the input data file.
- Task 3: Define the satellite location and trajectory.
- Task 4: Run a test case.

2.1 Task 1: Create a project directory

Each problem will correspond to a specific directory. This is the first task to be completed by the user. This directory shall be located inside directory Scenarios. Before GISM execution, this directory must contain two files. The first one named data.txt contains the link or map data. The second one is the satellite trajectory.

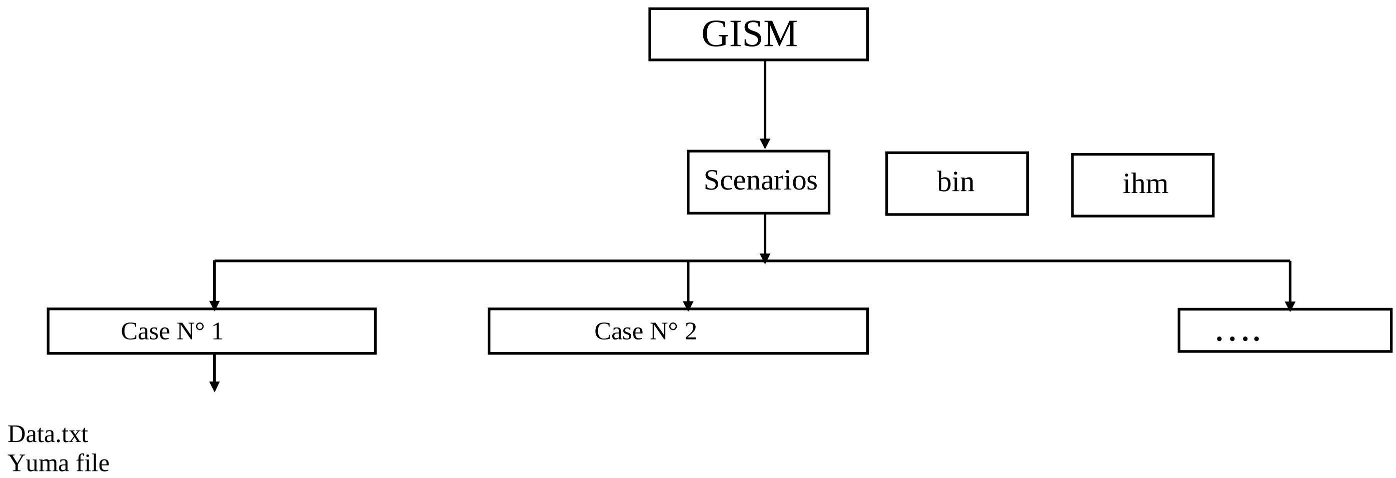


Figure 1: GISM implementation

The executable file must be at the same level than Scenarios and bin.

2.2 Task 2: inputs

- create the data.txt file inside the corresponding folder
- Include a trajectory file in the project folder

For GPS: a Yuma file. GPS Yuma files can be downloaded from
http://www.navcen.uscg.gov/ftp/GPS/almanacs/yuma/

For Glonass : a Yuma file. The Glonass Yuma file contains one additional datum for the frequency dependency of the satellite.

The corresponding files are stored for Galileo.

For a trajectory: a .txt file containing the trajectory.

2.3 Task 3: Execute

Once, the data file and the trajectory file are properly created and stored in a directory, the execution can be launched from a DOS window.

- gism *project_name* on a DOS window;

3. Input data

The input data file must be saved inside the directory corresponding to the problem of interest. The following sections may be addressed:

Satellite position
One of the following options: gps ; glonass ; galileo ; point_2_point ; orbit_trajectory

Medium description
slope ; BubblesRMS ; OuterScale
All these parameters are optional. Default values are assigned to each one.

Geophysical parameters
flux_number ; vdrift

Scintillation analysis parameters
frequency
same_seed (optional)
LOSSpaceStep (the space step along the line of sight: optional)

Receiver Location
receiver

Map Analysis
GlobalMap

Analysis Period of time
time_window ; time_start, date
tgps ; UT ; SLT

Outputs options
sampling_frequency; average_duration_of_fades ; spectrum
All these keywords are optional

Keyword List

Project_name
gps, glonass, Galileo, point_2_point, orbit_trajectory
slope, BubblesRMS, Outerscale
flux_number, vdrift
frequency,
same_seed, LOSSpaceStep,
receiver
GlobalMap
time_window, time_start, date
tgps, UT, SLT
sampling_frequency, average_duration_of_fades, spectrum

3.1 Trajectory

The satellite location may be defined by one of the following options : gps ; glonass ; galileo ; Point2Point ; OrbitTrajectory.

3.1.1 GPS constellation

Yuma files are used. GPS Yuma files can be downloaded from
http://www.navcen.uscg.gov/ftp/GPS/almanacs/yuma/
GPS Yuma file example :

******** Week 109 almanac for PRN-01 ********

ID:	01
Health:	000
Eccentricity:	0.5046367645E-002
Time of Applicability(s):	319488.0000
Orbital Inclination(rad):	0.9655654054
Rate of Right Ascen(r/s):	-0.7943188009E-008
SQRT(A) (m 1/2):	5153.693359
Right Ascen at Week(rad):	0.1580654101E+001
Argument of Perigee(rad):	-1.732023850
Mean Anom(rad):	0.1213174697E+001
Af0(s):	0.1964569092E-003
Af1(s/s):	0.0000000000E+000
week:	109

constellation parameters : printed in the history file

PRN	Semi-major axis	Eccentricity	Inclination	Argument of perigee	RAAN	Mean anomaly
1	26560.555	0.505E-02	55.323	-99.238	90.565	69.510
2	26559.529	0.213E-01	53.464	-115.284	-155.177	-103.414
3	26559.855	0.238E-02	53.588	29.984	-93.358	-178.421
4	26558.496	0.556E-02	55.743	-24.585	-29.194	25.230
5	26558.809	0.312E-02	53.640	25.810	-153.976	13.929
6	26559.604	0.685E-02	54.021	-128.902	-90.729	74.593
7	26560.711	0.121E-01	54.122	-114.051	-92.447	-170.945
8	26560.350	0.815E-02	54.966	117.344	151.123	91.425
9	26560.127	0.123E-01	54.171	43.545	148.044	59.600
10	26559.680	0.449E-02	56.097	4.843	29.482	-100.709
11	26560.102	0.995E-03	52.749	-133.675	-33.650	-124.151
13	26560.012	0.184E-02	55.563	6.589	89.356	-68.616
14	26559.840	0.224E-02	55.258	-28.220	89.114	102.658
15	26559.725	0.806E-02	56.114	100.564	-26.577	112.876
17	26560.027	0.135E-01	56.222	-178.768	-24.278	48.302
18	26559.559	0.236E-02	55.108	159.857	32.216	9.208
20	26560.625	0.221E-02	55.150	121.231	29.231	-88.161
21	26559.398	0.177E-01	56.077	-138.349	29.821	-84.738
22	26558.910	0.145E-01	53.436	40.565	-154.405	-122.015
23	26556.625	0.156E-01	56.263	-104.139	32.249	-61.685
24	26559.125	0.938E-02	56.323	-93.038	-28.230	63.017
25	26561.018	0.906E-02	53.757	-111.155	145.591	107.498
26	26560.430	0.131E-01	55.487	16.709	89.632	165.750
27	26559.740	0.153E-01	54.017	-145.610	146.944	21.611
28	26572.707	0.531E-02	54.992	-137.061	-150.616	-68.702
29	26562.156	0.843E-02	55.308	-106.837	87.942	162.146
30	26559.459	0.585E-02	54.047	77.274	-151.998	-69.371
31	26559.826	0.103E-01	54.090	49.513	-92.451	130.243

3.1.2 Glonass

Glonass Yuma file example :

******** Week 109 almanac for PRN-01 ********

ID:	01
Health:	000
Eccentricity:	0.5046367645E-002
Time of Applicability(s):	319488.0000
Orbital Inclination(rad):	0.9655654054
Rate of Right Ascen(r/s):	-0.7943188009E-008
SQRT(A) (m 1/2):	5153.693359
Right Ascen at Week(rad):	0.1580654101E+001
Argument of Perigee(rad):	-1.732023850
Mean Anom(rad):	0.1213174697E+001
Af0(s):	0.1964569092E-003
Af1(s/s):	0.0000000000E+000
week:	109
frequency channel:	8

The Glonass Yuma file includes one additional line with respect to GPS Yuma file. This additional line specifies the frequency channel of the corresponding PRN required for the frequency calculation which depends on the PRN for the Glonass constellation.

3.1.3 Galileo

In case of Galileo, no Yuma file is required. The data is already stored. The corresponding values are reproduced below.

constellation parameters : printed in history file

PRN	Semi-major axis	Eccentricity	Inclination	Argument of perigee	RAAN	Mean anomaly
1	29993.711	0.000E+00	56.000	0.000	0.000	0.000
2	29993.711	0.000E+00	56.000	0.000	0.000	40.000
3	29993.711	0.000E+00	56.000	0.000	0.000	80.000
4	29993.711	0.000E+00	56.000	0.000	0.000	120.000
5	29993.711	0.000E+00	56.000	0.000	0.000	160.000
6	29993.711	0.000E+00	56.000	0.000	0.000	200.000
7	29993.711	0.000E+00	56.000	0.000	0.000	240.000
8	29993.711	0.000E+00	56.000	0.000	0.000	280.000
9	29993.711	0.000E+00	56.000	0.000	0.000	320.000
10	29993.711	0.000E+00	56.000	0.000	120.000	13.330
11	29993.711	0.000E+00	56.000	0.000	120.000	53.330
12	29993.711	0.000E+00	56.000	0.000	120.000	93.330
13	29993.711	0.000E+00	56.000	0.000	120.000	133.330
14	29993.711	0.000E+00	56.000	0.000	120.000	173.330
15	29993.711	0.000E+00	56.000	0.000	120.000	213.330
16	29993.711	0.000E+00	56.000	0.000	120.000	253.330
17	29993.711	0.000E+00	56.000	0.000	120.000	293.330
18	29993.711	0.000E+00	56.000	0.000	120.000	333.330
19	29993.711	0.000E+00	56.000	0.000	240.000	26.660
20	29993.711	0.000E+00	56.000	0.000	240.000	66.660
21	29993.711	0.000E+00	56.000	0.000	240.000	106.660
22	29993.711	0.000E+00	56.000	0.000	240.000	146.660
23	29993.711	0.000E+00	56.000	0.000	240.000	186.660
24	29993.711	0.000E+00	56.000	0.000	240.000	226.660
25	29993.711	0.000E+00	56.000	0.000	240.000	266.660
26	29993.711	0.000E+00	56.000	0.000	240.000	306.660
27	29993.711	0.000E+00	56.000	0.000	240.000	346.660
28	29993.711	0.000E+00	56.000	0.000	0.000	20.000
29	29993.711	0.000E+00	56.000	0.000	120.000	20.000
30	29993.711	0.000E+00	56.000	0.000	240.000	20.000

3.1.4 Orbit trajectory

#orbit_trajectory
File name
Coordinate system

Two possibilities:

- ECEF : relative time along the trajectory (s.) & x, y z coordinates (m) in the earth referential.
- latitude, longitude, altitude (km with respect to ground) plus relative time (hrs) along the trajectory.

A calculation is performed for each line of the trajectory file.

In both cases, the time considered is a relative time along the trajectory. The initial time is defined by the time_start keyword

#time_start
monday 14 03 1999 20 00 0

3.2 Medium Description

slope ; BubblesRMS ; OuterScale
All these parameters are optional. Default values are assigned to each one.

Examples

#slope
4

#BubblesMS
0.1

#OuterScale
500. ! (in meters)

3.3 Geophysical Parameters

Flux_number ; vdrift

The Flux number is the solar spot number. The ITU recommendation is to limit this value to 193. However this limitation has been removed in the NeQuick2 version used in GISM.

Example:

#flux_number
150.0

#vdrift
100. ! (in meters / second)

3.4 Scintillation Analysis Parameters

frequency
same_seed (optional)
LOSSpaceStep (the space step along the line of sight: optional)

#frequency
range
first frequency, step, number of frequencies ! (the first two values in MHz)

or

#frequency
L1 or L2 or L5 or E1 or E2 or E5 or E6

or

#frequency
other
value ! (in MHz)

#same_seed

This keyword allows running several cases in the same conditions, to obtain in particular the frequency correlation. GISM uses a random number generator. The seed is the PC clock. If the “same seed” keyword is used, the seed will be identical for successive runs.

#LOSSpaceStep
15.e3 ! (in meters)

This keyword is optional. It allows defining a space step along the Line Of Sight. The default value is 15 km (as above). The algorithm convergence with the space step value is commented at section 6.

3.5 Receiver Location

#receiver
Name of receiver
Latitude (degrees, minutes, seconds), longitude (degrees, minutes, seconds), altitude (meters)

Example:

#receiver
MarakParak
6 0 0 116 0 0 0.0   ! latitude (degrees, minutes, seconds), longitude (degrees, minutes, seconds), altitude
                      ! the first 6 data integer, the last one real

3.6 Map Analysis

GlobalMap

Example:
#GlobalMap
-50 0 0 2 0 0 51   !latitude minimum(degrees, minutes seconds) step latitude (id.), number of steps
-100 0 0 2 0 0 76 !longitude minimum(degrees, minutes seconds) step longitude (id.), number of steps
                         ! all values integer

3.7 Analysis Period of time

time_window ; time_start ; date
UT ; SLT ; tgps

If the calculation applies to a GPS constellation, the time window shall be specified.
If the calculation applies to a satellite defined by its trajectory, the initial time and date shall be initialised.
If the calculation applies to a Global or regional map, the date shall be specified.

GPS, UT or Solar Local Time (UT - longitudinal delay) can be considered.

Examples:
#time_window
Tuesday 11 05 2001 20 0 0   ! start of analysis : day name, date (day, month, year), hour, minute, second
Tuesday 11 05 2001 21 0 0   ! end of analysis : day name, date (day, month, year), hour, minute, second
0 5 0   ! time step : hour, minute, second
                            ! all values integer

#time_start
Tuesday 11 05 2001 20 0 0   ! start of analysis : day name, date (day, month, year), hour, minute, second
                            ! all values integer

#date
Tuesday 11 05 2001 20 0 0   ! date of analysis : day name, date (day, month, year), hour, minute, second
                            ! all values integer

#UT   or   #SLT or #tgps

3.8 Outputs options

sampling_frequency, average_duration_of_fades, spectrum
All these keywords are optional

Additional files will be created for each one of the above optional calculations. Each new link will add data to the files. In order to limit this size, it may be convenient to limit the creation of such files to one particular link.

sampling_frequency
This will create time series files of intensity and phase.

average_duration_of_fades
Performs the calculation of the average duration of fades

#spectrum
Calculates the spectrum of the intensity and phase of received signal.

Examples:
sampling_frequency
100. ! in Hz
500. ! in seconds

The first number (100 in the above example) is the sampling frequency
The second number (500) is the sample time duration.

average_duration_of_fades

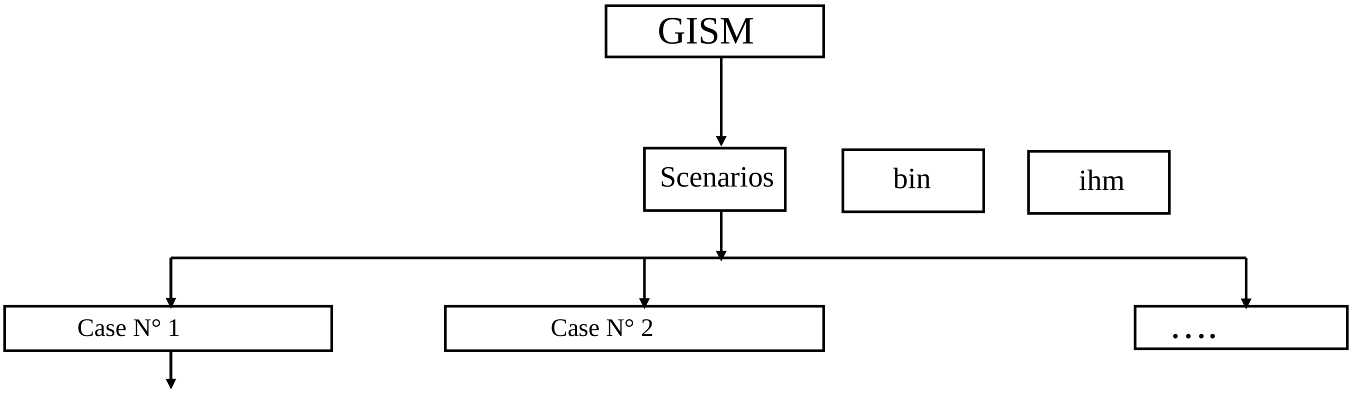
#spectrum

4. Output files

Inside the folder corresponding to the problem under analysis, the following files are created during execution :

- one « history file »,
- one file for the mean errors synthesis,
- one file for the scintillation errors synthesis,
- one summary file.

- n files for the mean errors,
- n files for the scintillation errors,
- on option : n Rinex files : signal + scintillation noise (amplitude and phase).



Data.txt
Yuma file

history.txt
mean_effects_synthesis.txt
scintillations_synthesis.txt
Summary.txt

Ground_station_name _date_prn_n°xx_mean_effects
Ground_station_name _date_prn_n°xx_scintillations
…..

Figure 2: Output files

4.1 History File

File name : history.txt

```
                         GISM v6.50

                         input data


GPS constellation


frequency =  1575.42 MHz

ground station name :                             Kourou

time of analysis : start =  20.000 hours  LT  end =  21.000 hours LT  time step =   5.000 mn.

Geophysical parameters

          F10.7 =  150.00
          year 2004 month =    5 day of month =   11


                         yuma file for week number  246
```

PRN	Semi-major axis	Eccentricity	Inclination	Argument of perigee	RAAN	Mean anomaly
3	26559.936	0.556E-02	53.214	31.199	1.384	84.027
5	26560.893	0.522E-02	53.612	47.594	-58.508	-99.658
6	26561.340	0.655E-02	53.645	-115.540	4.417	-29.022
10	26560.289	0.611E-02	56.157	17.473	126.425	153.285
14	26559.207	0.141E-02	56.041	-83.299	-174.372	64.992
15	26559.936	0.886E-02	55.392	127.520	69.978	-35.291
16	26561.385	0.246E-02	55.057	-81.499	-54.398	-98.448
18	26559.766	0.473E-02	55.222	-169.252	128.304	-112.793
21	26559.951	0.869E-02	54.624	171.048	68.398	-35.646
22	26559.016	0.489E-02	55.071	-81.535	128.870	129.187
25	26559.896	0.114E-01	54.118	-90.580	-119.146	-3.335
26	26559.779	0.154E-01	56.265	33.316	-173.691	58.514
29	26560.299	0.823E-02	56.090	-78.577	-175.553	-176.106
30	26559.699	0.733E-02	54.008	72.705	-56.145	-159.797

```
Statistics...
  CPU time :
     Lecture des fichiers d'entree :           6 mn,  8.05 s        ( 47.43%)
     Calcul scintillations :                          0.00 s        (  0.00%)
     Post-traitement :                         6 mn, 47.94 s        ( 52.57%)
     Total :                                  12 mn, 55.98 s        (100.00%)
end of job
```

4.2 Mean effects synthesis

file name : mean_effects_buget_link_synthesis.txt

Mean effects synthesis
GISM v6.50

PRN	UT	LT	azimut (deg)	elevation (deg)	sat._lat (deg)	sat._long (deg)	TEC	Faraday rotation (deg)	Doppler shift (Hz)	Iono Range delay (m.)
operating frequency = 1575.420 MHz										
5	23.06	20.00	28.16	6.33	38.64	348.64	127.95	-1.30	0.0	20.62
6	23.06	20.00	113.68	49.74	-31.90	348.21	21.25	-0.05	0.0	3.42
10	23.06	20.00	145.26	0.47	-56.04	52.95	6.67	0.01	0.0	1.08
15	23.06	20.00	275.63	36.28	-13.26	270.39	52.36	0.14	0.0	8.44
16	23.06	20.00	220.71	19.78	-53.04	248.46	40.56	0.43	0.0	6.54
18	23.06	20.00	14.83	59.90	-0.74	319.87	34.37	-0.20	0.0	5.54
21	23.06	20.00	199.14	60.16	-44.54	303.77	23.45	0.10	0.0	3.78
22	23.06	20.00	345.04	29.34	23.94	301.87	71.11	-0.55	0.0	11.46
25	23.06	20.00	293.20	13.26	8.40	258.04	112.85	-0.06	0.0	18.19
26	23.06	20.00	95.19	7.81	-12.77	26.08	19.22	-0.10	0.0	3.10
29	23.06	20.00	106.78	5.64	-22.43	31.63	12.72	-0.05	0.0	2.05
30	23.06	20.00	16.31	43.07	12.28	324.01	45.41	-0.37	0.0	7.32
12 satellites in view										
operating frequency = 1575.420 MHz										
5	23.14	20.08	28.05	4.39	40.26	349.91	133.48	-1.34	-3.9	21.51
6	23.14	20.08	110.10	49.15	-30.08	348.98	21.38	-0.06	-1.1	3.45
15	23.14	20.08	272.87	37.36	-15.31	270.67	50.11	0.15	0.9	8.08
16	23.14	20.08	221.52	21.63	-52.21	251.12	39.61	0.41	2.8	6.38
18	23.14	20.08	16.69	62.39	-2.81	320.07	32.90	-0.18	1.5	5.30
21	23.14	20.08	194.98	59.07	-45.97	305.46	22.89	0.10	-1.3	3.69
22	23.14	20.08	344.88	31.61	21.98	302.30	66.24	-0.50	3.1	10.67
25	23.14	20.08	295.25	12.37	10.40	258.29	115.26	-0.13	-2.1	18.58
26	23.14	20.08	97.28	8.34	-14.77	26.26	18.28	-0.09	0.6	2.95
29	23.14	20.08	108.93	5.88	-24.44	32.04	12.09	-0.04	0.3	1.95
30	23.14	20.08	15.93	40.65	14.30	324.33	47.67	-0.40	-3.2	7.68

4.3 Scintillations effects synthesis

File name : scintillations_synthesis.txt

Scintillations synthesis

ground station name : naha
ground station coordinates : latitude = 26.00 longitude = 128.00 altitude = 0.00

PRN	UT	LT	azimut (deg)	elevation (deg)	sat.lat (deg)	sat.long (deg)	S4	sigma_phi (rad)
1	12.500	21.033	224.788	23.640	-14.690	92.101	0.730	0.658
3	12.500	21.033	27.133	49.421	52.404	151.044	0.048	0.027
11	12.500	21.033	191.439	27.762	-23.118	118.496	0.757	0.975
13	12.500	21.033	265.269	23.124	11.346	72.534	0.284	0.125
15	12.500	21.033	37.594	6.569	55.137	219.097	0.020	0.013
22	12.500	21.033	80.219	35.307	25.043	176.409	0.087	0.048
25	12.500	21.033	146.836	5.651	-34.181	166.533	0.822	1.352
27	12.500	21.033	317.379	26.532	52.189	68.689	0.046	0.022
31	12.500	21.033	312.017	66.814	36.910	111.587	0.045	0.026

9 satellites in view

ground station name : naha
ground station coordinates : latitude = 26.00 longitude = 128.00 altitude = 0.00

PRN	UT	LT	Angular error (mr)	Coh. length (km)	PLL (deg)	DLL (m.)	C / N	Proba of LoL
1	12.500	21.033	0.11	0.27	17.52	23.97	30.13	0.061
3	12.500	21.033	0.00	0.62	6.99	0.00	35.78	0.000
11	12.500	21.033	0.18	0.23	21.17	30.72	31.31	0.045
13	12.500	21.033	0.01	0.60	9.37	7.33	29.82	0.000
15	12.500	21.033	0.00	0.62	6.99	0.00	24.99	0.000
22	12.500	21.033	0.00	0.62	6.99	0.00	32.87	0.000
25	12.500	21.033	0.52	0.11	318.88	515.13	24.55	0.428
27	12.500	21.033	0.00	0.62	6.99	0.00	30.60	0.000
31	12.500	21.033	0.00	0.62	6.99	0.00	37.75	0.000

9 satellites in view

4.4 Time series

File name : time_series_date_prn_N°_freq_xxxx.txt

The sampling frequency was set to 100 Hz in this example.

time_(s.)	space_(m.)	intensity_(dB)	phase
0.000000E+00	0.000000E+00	-0.762298E+01	0.298807E+03
0.100000E-01	0.761126E-04	-0.821385E+01	0.298771E+03
0.200000E-01	0.152225E-03	-0.849797E+01	0.299469E+03
0.300000E-01	0.228338E-03	-0.908886E+01	0.298860E+03
0.400000E-01	0.304451E-03	-0.101918E+02	0.296034E+03
0.500000E-01	0.380563E-03	-0.120797E+02	0.292014E+03
0.600000E-01	0.456676E-03	-0.131336E+02	0.288960E+03
0.700000E-01	0.532788E-03	-0.141804E+02	0.287346E+03
0.800000E-01	0.608901E-03	-0.156958E+02	0.282881E+03
0.900000E-01	0.685014E-03	-0.169978E+02	0.274451E+03
0.100000E+00	0.761126E-03	-0.182382E+02	0.264135E+03
0.110000E+00	0.837239E-03	-0.192509E+02	0.250123E+03
0.120000E+00	0.913352E-03	-0.183583E+02	0.237005E+03
0.130000E+00	0.989464E-03	-0.174382E+02	0.233726E+03
0.140000E+00	0.106558E-02	-0.172032E+02	0.228183E+03
0.150000E+00	0.114169E-02	-0.178852E+02	0.225673E+03
0.160000E+00	0.121780E-02	-0.189303E+02	0.223187E+03
0.170000E+00	0.129391E-02	-0.217322E+02	0.213924E+03
0.180000E+00	0.137003E-02	-0.231782E+02	0.187752E+03
0.190000E+00	0.144614E-02	-0.237992E+02	0.172429E+03
0.200000E+00	0.152225E-02	-0.236272E+02	0.143847E+03
0.210000E+00	0.159837E-02	-0.206789E+02	0.140867E+03
0.220000E+00	0.167448E-02	-0.201939E+02	0.141575E+03
0.230000E+00	0.175059E-02	-0.189822E+02	0.135646E+03
0.240000E+00	0.182670E-02	-0.173508E+02	0.129857E+03
0.250000E+00	0.190282E-02	-0.163160E+02	0.123090E+03
0.260000E+00	0.197893E-02	-0.160415E+02	0.114207E+03
0.270000E+00	0.205504E-02	-0.151073E+02	0.108590E+03
0.280000E+00	0.213115E-02	-0.143561E+02	0.108939E+03
0.290000E+00	0.220727E-02	-0.135358E+02	0.109511E+03
0.300000E+00	0.228338E-02	-0.130335E+02	0.107429E+03
0.310000E+00	0.235949E-02	-0.123911E+02	0.102146E+03
0.320000E+00	0.243560E-02	-0.122338E+02	0.103194E+03
0.330000E+00	0.251172E-02	-0.121449E+02	0.102073E+03
0.340000E+00	0.258783E-02	-0.118687E+02	0.103323E+03
0.350000E+00	0.266394E-02	-0.111315E+02	0.105020E+03
0.360000E+00	0.274005E-02	-0.104477E+02	0.103367E+03
0.370000E+00	0.281617E-02	-0.100490E+02	0.102367E+03
0.380000E+00	0.289228E-02	-0.960621E+01	0.982320E+02
0.390000E+00	0.296839E-02	-0.896533E+01	0.975469E+02
0.400000E+00	0.304451E-02	-0.842352E+01	0.956622E+02
0.410000E+00	0.312062E-02	-0.771452E+01	0.961412E+02
0.420000E+00	0.319673E-02	-0.712984E+01	0.958126E+02
0.430000E+00	0.327284E-02	-0.681901E+01	0.972888E+02
0.440000E+00	0.334896E-02	-0.654294E+01	0.967332E+02
0.450000E+00	0.342507E-02	-0.636994E+01	0.952092E+02
0.460000E+00	0.350118E-02	-0.611882E+01	0.933004E+02
0.470000E+00	0.357729E-02	-0.603951E+01	0.905376E+02
0.480000E+00	0.365341E-02	-0.605220E+01	0.873096E+02
0.490000E+00	0.372952E-02	-0.618746E+01	0.854393E+02
0.500000E+00	0.380563E-02	-0.659656E+01	0.845988E+02
0.510000E+00	0.388174E-02	-0.697071E+01	0.835733E+02
0.520000E+00	0.395786E-02	-0.708083E+01	0.819983E+02
0.530000E+00	0.403397E-02	-0.686434E+01	0.814429E+02
0.540000E+00	0.411008E-02	-0.680798E+01	0.814522E+02
0.550000E+00	0.418619E-02	-0.660537E+01	0.817039E+02
0.560000E+00	0.426231E-02	-0.652016E+01	0.817347E+02
0.570000E+00	0.433842E-02	-0.641566E+01	0.813418E+02
0.580000E+00	0.441453E-02	-0.608524E+01	0.815059E+02
0.590000E+00	0.449065E-02	-0.599178E+01	0.797182E+02
0.600000E+00	0.456676E-02	-0.562115E+01	0.778461E+02
0.610000E+00	0.464287E-02	-0.529458E+01	0.770854E+02
0.620000E+00	0.471898E-02	-0.506193E+01	0.772410E+02

5. Input Parameters Default Values

5.1 Medium's definition

The medium is defined by three parameters: the fluctuations spectrum slope, the average size of inhomogeneities and the strength of fluctuations.

The fluctuations spectrum slope

The slope coefficient of the power law spectrum and the turbulence strength can be deduced from measurements. Figure 3 shows the slope value deduced from measurements in Cayenne recorded during the PRIS measurement campaign [3]. One week of 50 Hz raw data files was used to obtain these plots. A slope value equal to 3 is the most probable value. This is in agreement with what is usually considered in the literature [7]. The slope value decreases with time after sunset corresponding to the fact that the inhomogeneities sizes decreases with time after sunset. It should be noticed however that the PRIS measurement campaign was done in a year close to solar minimum. High solar activity values might be different, in particular for the strength.

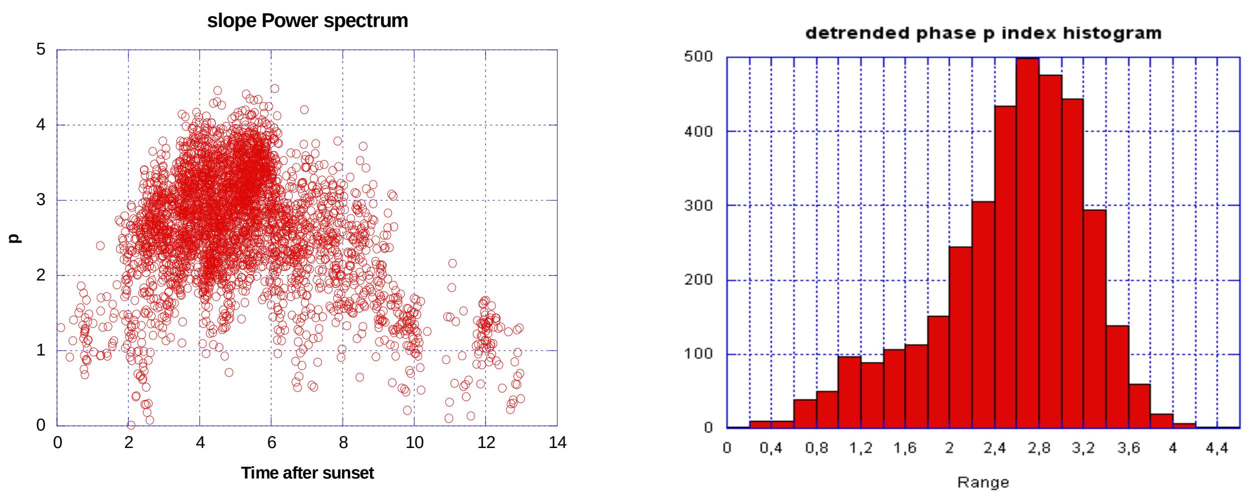


Figure 3: Slope distribution

GISM uses 1D phase screen. It has been shown [1] that using 1D phase screens to define the medium is equivalent to a 2D isotropic medium provided that the slope is increased by one. The GISM spectrum slope default value is set to 4.

Average value of inhomogeneities dimension

The inhomogeneities dimensions which contribute to scintillations are linked to the first Fresnel zone dimension given by expression $\sqrt{\lambda d}$ with d the distance from the fluctuating medium to the receiver. In the L band the dimension is a few hundreds of meters.

The default value is set to 500 meters.

Fluctuation strength

This parameter defines the RMS electron density value with respect to the mean value.
0.05 is an average value. 0.15 is considered as a maximum value.
The default value is 0.1.

5.2 Geophysical parameters

Flux number

The flux number may be set to any value. The past and future values of this index are shown on the following plot taken from NOAA web site.

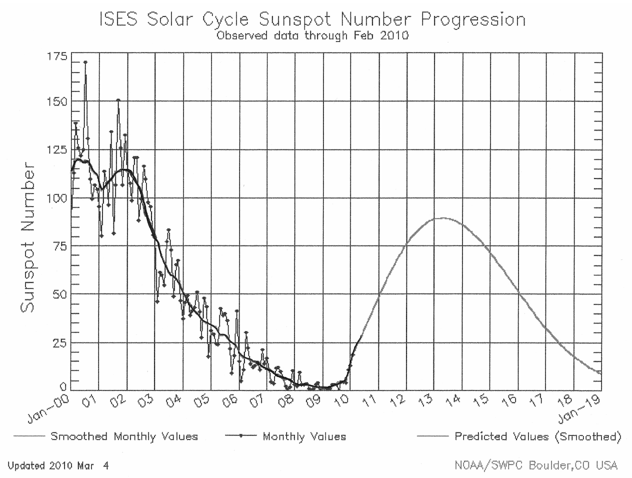


Figure 4: Solar Spot Number

Drift velocity

The apparent drift velocity at receiver level, is a combination of ionosphere drift velocity and motion of the link ionosphere pierce point (IPP). The IPP motion modifies the fades duration. It can be an increase or a decrease depending on the geometry. It also depends on the magnetic field as a result of elongated bubbles in that direction [4], [5].

The IPP drift velocity default value is set to 100 m / s at low latitudes and to 1000 m / s at high latitudes

5.3 Nequick model

NeQuick 2 used in GISM is the latest version of the NeQuick ionosphere electron density model developed at the Aeronomy and Radiopropagation Laboratory of the Abdus Salam International Centre for Theoretical Physics (ICTP) - Trieste, Italy with the collaboration of the Institute for Geophysics, Astrophysics and Meteorology of the University of Graz, Austria [6].

The NeQuick is a quick-run ionospheric electron density model particularly designed for transionospheric propagation applications. To describe the electron density of the ionosphere above 100 km and up to the peak of the F2 layer, the NeQuick uses a profile formulation which includes five semi-Epstein layers with modelled thickness parameters. Three profile anchor points are used: the E layer peak, the F1 peak and the F2 peak, that are modelled in terms of the ionosonde parameters foE, foF1, foF2 and M(3000)F2. These values can be modelled (e.g. ITU- R coefficients for foF2, M3000) or experimentally derived. A semi-Epstein layer represents the model topside with a height-dependent thickness parameter empirically determined.
The NeQuick package includes routines to evaluate the electron density along any ray-path and the corresponding Total Electron Content (TEC) by numerical integration.

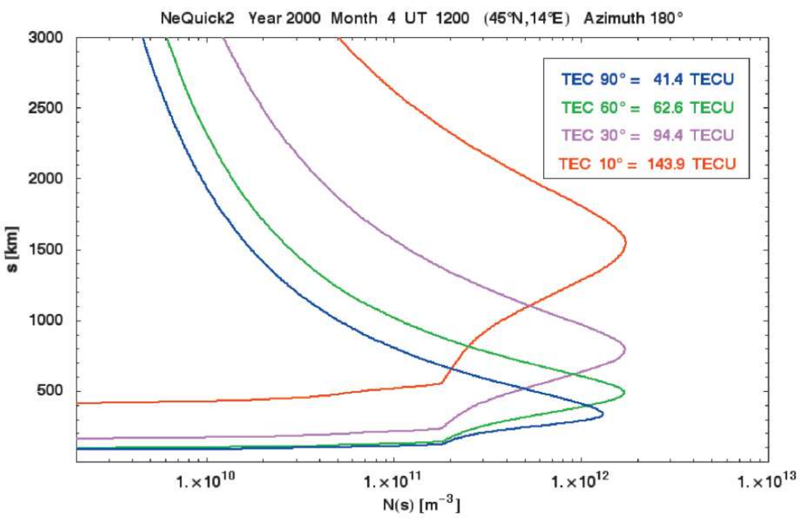
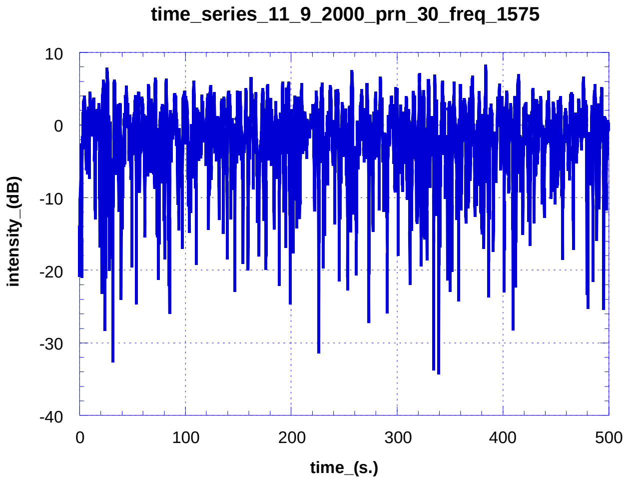


Figure 5: Example of NeQuick 2 profiles and TEC along ray-paths. Different colours correspond to different path elevation angles. 90º means vertical profile and TEC (from Radicella, 2009 [6])

6. Outputs

6.1 Time series



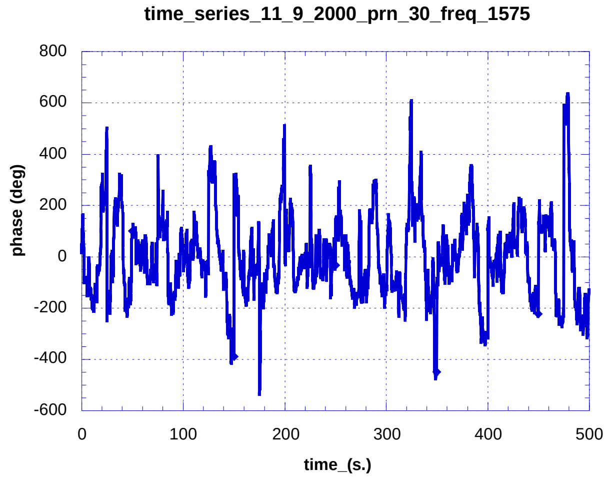


Figure 6: Intensity and phase time series for S4 = 0.89

6.2 Average duration of fades

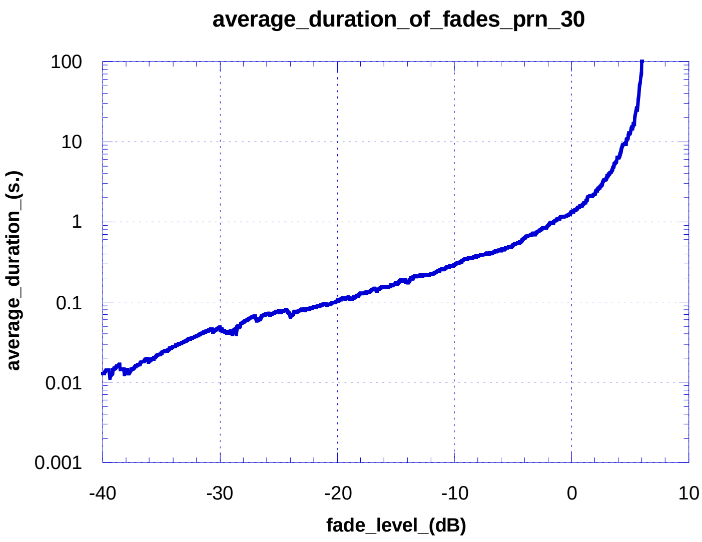


Figure 7: Average duration of fades for S4 = 0.89

6.3 Spectrum

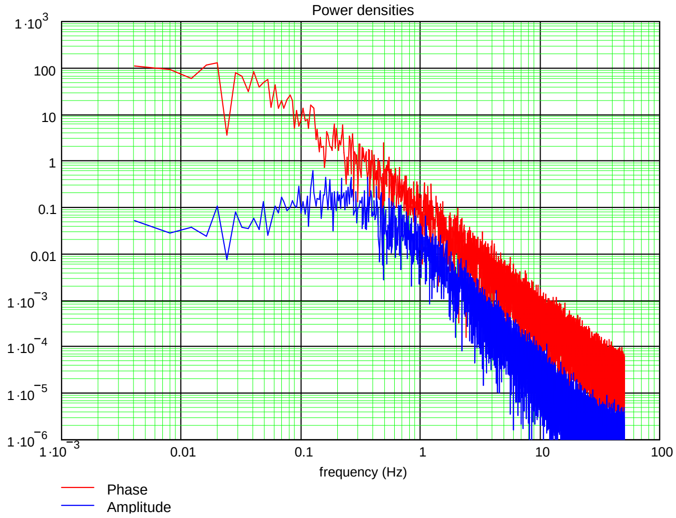


Figure 8: Intensity and phase spectrum

6.4 Maps

Figure 9 shows the correspondence between a Total Electron Content (TEC) map and a scintillation map. Those two maps were obtained by modeling using NeQuick (Radicella, 2009) model for the TEC and GISM for scintillations. They correspond to vertical links. The electron density is consequently integrated along a vertical at each grid point on the map to get the TEC. Slant observations may however exhibit higher values. The propagation length inside the ionosphere would increase in that case and by consequence the levels obtained.

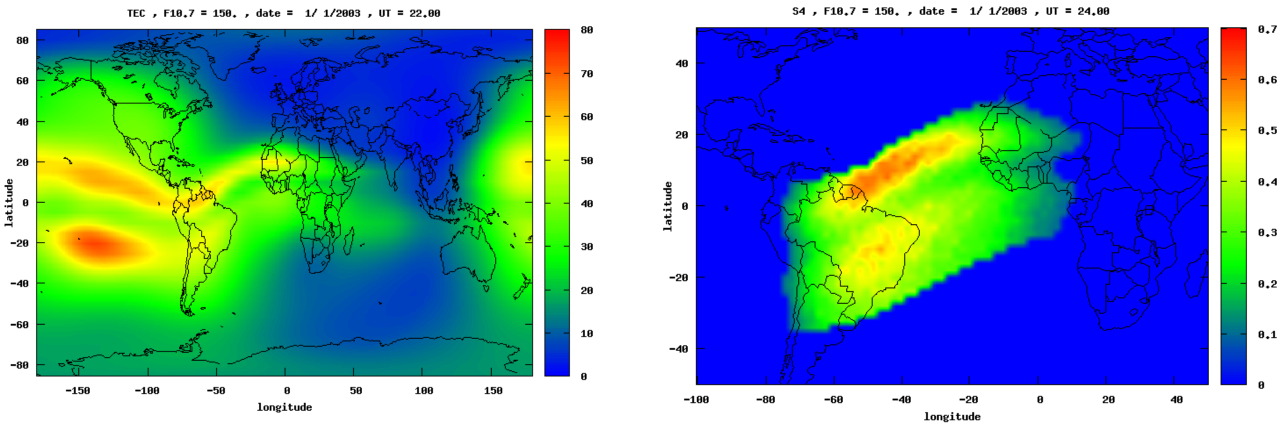


Figure 9: TEC (left panel) and scintillation map (right panel) obtained by modeling

Figure 9 was obtained with a solar radio flux at 10.7 cm set to 150. It corresponds to a high value. Universal time is 10 p.m. for the TEC map and 12 p.m. for the scintillation map. At this time the peak values for the TEC occur in the Pacific Ocean area. For the scintillations the time duration of the events is a few hours after sunset. This is what gives the model. Both plots reproduce the same features regarding the peak values on both sides of the magnetic equator. The values decrease increasing the latitude. For scintillations the model calculates the effects at the equatorial regions. The high latitudes regions are also concerned by this problem but this is not taken into account by the model. The TEC maximum is 80 TEC units which is a significant value. It is directly linked to the solar flux value. The peak value for the intensity RMS (S4 parameter) is 0.7. Such a value corresponds to strong fluctuations. It is also linked to the electron density levels. Depending on the signal to noise ratio, one receiver may lose lock at this level.

7. Comparison with measurements

The results reported hereafter are taken from the PRIS measurement campaign [3] carried out under one ESA / ESTEC contract. For this study, a number of receivers were deployed both at low and high latitudes, in particular in Vietnam, Indonesia, Guiana, Cameroon, Chad and Sweden. These receivers were dedicated receivers, operating at 50 Hz. A data bank has been constituted and the scintillation characteristics have been derived from an extensive analysis of this data bank.

For assessment of the model performance, we have selected one week of measurements at Cayenne, French Guiana taken from the PRIS data bank. The results are presented on Figures below.

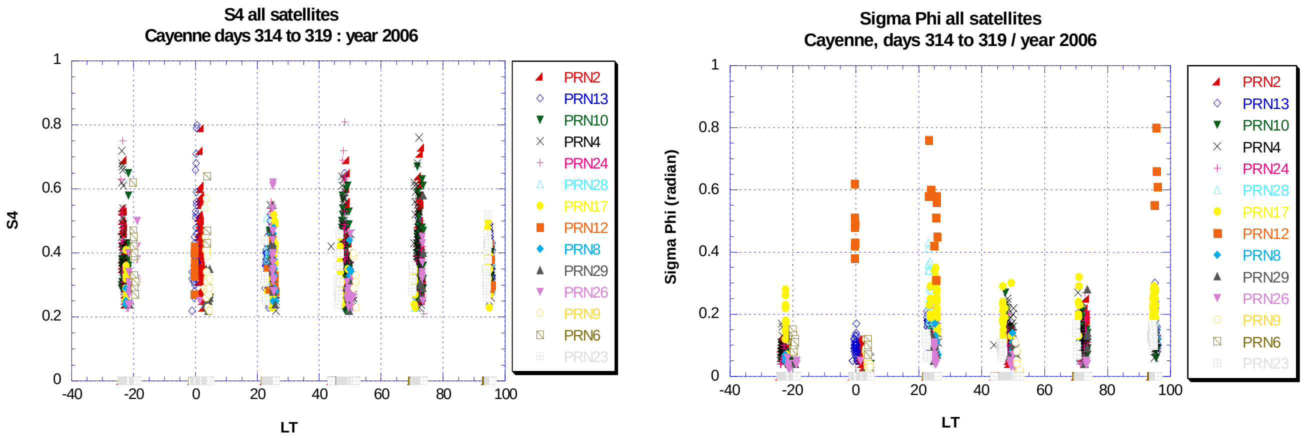


Figure 10: Intensity and phase scintillation indices measurements on GPS week N° 377

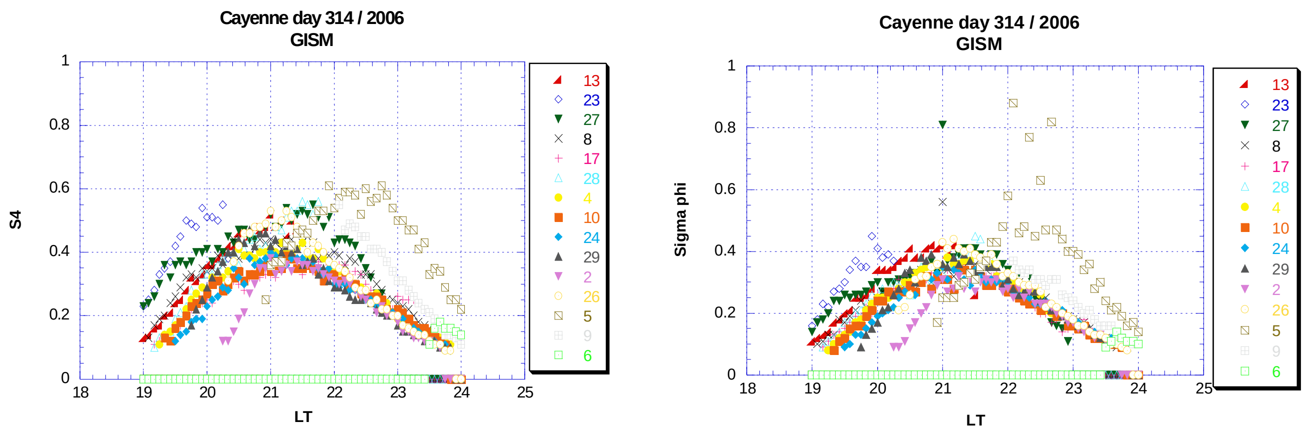


Figure 11: Intensity and phase scintillation indices on day 314, GPS week N° 377, obtained by modeling

<u>Measurements</u>

The local time corresponds to hours in GPS time. Each point corresponds to a 1 mn sample. Only points with a S4 value greater than 0.2 were retained in the analysis. The points are clustered every evening at post sunset hours. The scintillation activity occurred quite regularly that week with comparable levels. The S4 average value is about 0.4. The flux number that week (GPS week N° 377) was equal to 90.

The phase fluctuations are plotted concurrently. The mean value is about 0.2, consequently lower than the S4 value. This observation is quite general. In addition, it has to be noticed that some points exhibit high values. This is due to phase jumps.

Modelling

The case was replayed one day using the Yuma files. Another week day will not bring significant differences considering that the geophysical parameters would have been quite identical. As mentioned previously, the model provides a mean value. It overestimates the number of affected links due to the fact that the probability of occurrence is not considered. Only the mean values can be compared. For the intensity, they compare quite well. It is about 0.4 in both cases. For the phase, the mean measurements value is around .2. The value obtained by modelling is slightly greater. In both cases the phase RMS is lower than the intensity RMS and in both cases some points exhibit high values due to the phase jumps.

8. Examples

8.1 Scenarios

The scenarios considered are:

- Simulation assuming static user and satellite constellation
- Simulation assuming static user and static satellite i.e. a point to point link,
- Simulation assuming static user and moving satellite (trajectory, specific locations and times)
- Global and regional maps of vertical S4 and σ_ϕ.

The input data files for each one of these different cases are presented in the next sections.

8.2 Simulation assuming static user and satellite constellation

Input data file
#gps Yuma246.txt #frequency L1 #SLT #time_window tuesday 11 05 2004 20 0 0 wednesday 11 05 2004 20 0 0 0 5 0 #flux_number 150.0 # receiver Cayenne 4 49 27 307 38 12 0.

8.3 Simulation assuming static user and static satellite: point to point link

Input data file
#point_2_point 0. -35. 3.65E4 #frequency L1 #UT #time tuesday 11 10 2004 0 0 0 tuesday 11 10 2004 7 0 0 0 12 0 #flux_number 193.   #receiver Kourou 5 4 48 -53 22 12 0.

8.4 Static user + trajectory

Input data file	orbit_trajectory.txt
#orbit_trajectory satellite_trajectory.txt geodetic #frequency L1 #SLT #time_start monday 14 09 2000 21 00 0 #flux_number 150.0 #receiver MarakParak 6 0 0 116 0 0 0.0	time(s.) latitude longitude altitude(km.) 600.0000 2.000000 5.000000 28000. 1200.000 4.000000 10.00000 28000. 1800.000 6.000000 15.00000 28000. 2400.000 8.000000 20.00000 28000. 3000.000 10.00000 25.00000 28000. 3600.000 12.00000 30.00000 28000. 4200.000 14.00000 35.00000 28000. 4800.000 16.00000 40.00000 28000. 5400.000 18.00000 45.00000 28000. 6000.000 20.00000 50.00000 28000. 6600.000 22.00000 55.00000 28000. 7200.000 24.00000 60.00000 28000. 7800.000 26.00000 65.00000 28000. 8400.000 28.00000 70.00000 28000. 9000.000 30.00000 75.00000 28000. 9600.000 32.00000 80.00000 28000. 10200.00 34.00000 85.00000 28000. 10800.00 36.00000 90.00000 28000. 11400.00 38.00000 95.00000 28000. 12000.00 40.00000 100.0000 28000.

8.5 Maps

Input data file
#GlobalMap -85. 0 0 5 0 0 35 -180 0 0 5 0 0 73 #date monday 1 1 2003 22 0 0 #flux_number 150.0 #frequency L1

9. Migrating from previous version to GISM version 6.53

Satellite trajectory

The keyword time was renamed in time_window
For a satellite trajectory, the keyword time_start shall be used

Maps

GlobalMap instead of map_coordinates
keyword date as before
maps_flux_number replace by flux_number
maps_frequency replaced by frequency

10. References

[1] Béniguel Y., “A Global Ionosphere Scintillation Propagation Model for Equatorial Regions”, submitted to Space Weather Space Science (SWSC).

[2] Béniguel Y., “Global Ionospheric Propagation Model (GIM): a propagation model for scintillations of transmitted signals”, Radio Sci., Vol 37, N° 3, May 2002.

[3] Béniguel Y., J-P Adam, N. Jakowski, T. Noack, V. Wilken, J-J Valette, M. Cueto, A. Bourdillon, P. Lassudrie-Duchesne, B. Arbesser-Rastburg, 2009, Analysis of scintillation recorded during the PRIS measurement campaign, Radio Sci., 44, doi 1029/2008RS004090.

[4] Kintner P, H. Kil, T. Beach, E. de Paula, « Fading timescales associated with GPS signals and potential consequences », Radio Science, Vol. 36, N°4, 731-743.

[5] DasGupta A., A. Paul, S. Ray, A. Das, S. Ananthakrisnan, “ Equatorial bubbles as observed with GPS measurements over Pune, India”, Radio Science, 2006, Vol 41, RS5S28

[6] Radicella S.M.: "The NeQuick model genesis, uses and evolution", Annales of Geophysicae, Vol. 52, N. 3/4, June/August 2009

[7] Wernik A., L. Alfonsi, M. Materassi, Scintillation modeling using in situ data, Radio Sci., Vol. 42, (2007), doi:0.1029/2006RS003512