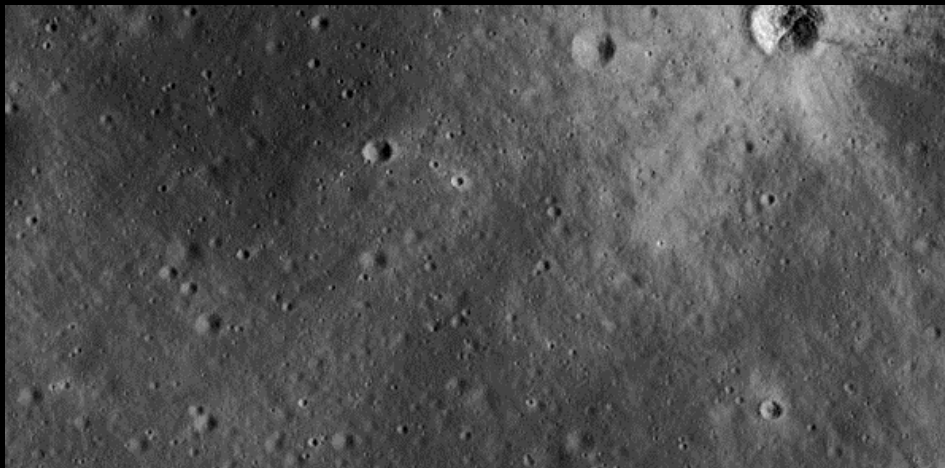


# INTERACTION EFFECTS OF THE IONOSPHERE IN EME



EME 2014  
World  
Conference

IONOSPHERIC  
INTERACTIONS  
WITH EME SIGNALS

IK1UWL-IK3XTV

## Abstract

Hundredths of kilometers above us there is a stormy sea: the ionosphere, through which our EME signals have to go through twice. The interactions are of various types: there are significant effects on signal amplitude (QSB), and wave polarization rotations (Faraday effect). Starting from data obtained from MAP65 decodes, we have made an analysis of QSB showing its dependence not on attenuation but on focusing or defocusing effects due to ionospheric waves. Then we have defined the algorithms for calculating Faraday rotation over the total moon pass, and compared them to actual MAP 65 decodes. We have found also how Faraday typically behaves as a function of correspondent station orientation. All this analysis is focused mainly on 144 MHz EME (our experience), but a good part is applicable to all bands.

**Note: this document contains the complete presentation, plus some additional detail information.**

# IONOSPHERIC INTERACTIONS WITH EME SIGNALS

Giorgio Marchi, IK1UWL – Flavio Egano, IK3XTV - EME 2014 Conference

Date: August 2014

## Study start

Ham EME communication through the ionosphere has evolved over the years, from CW to the first digital mode JT44, then the ubiquitous JT65, and today MAP65 (thanks Joe Taylor).

Latest software arrival for EME communication, for a station equipped with cross yagis and suitable hardware, MAP65 gives JT65 type message decodes over an 80 kHz wide band, adding info on level and polarization. But MAP65 is not only a communications method, it is also a scientific instrument which, besides message decodes, gives us two important data: signal level and polarization angle.

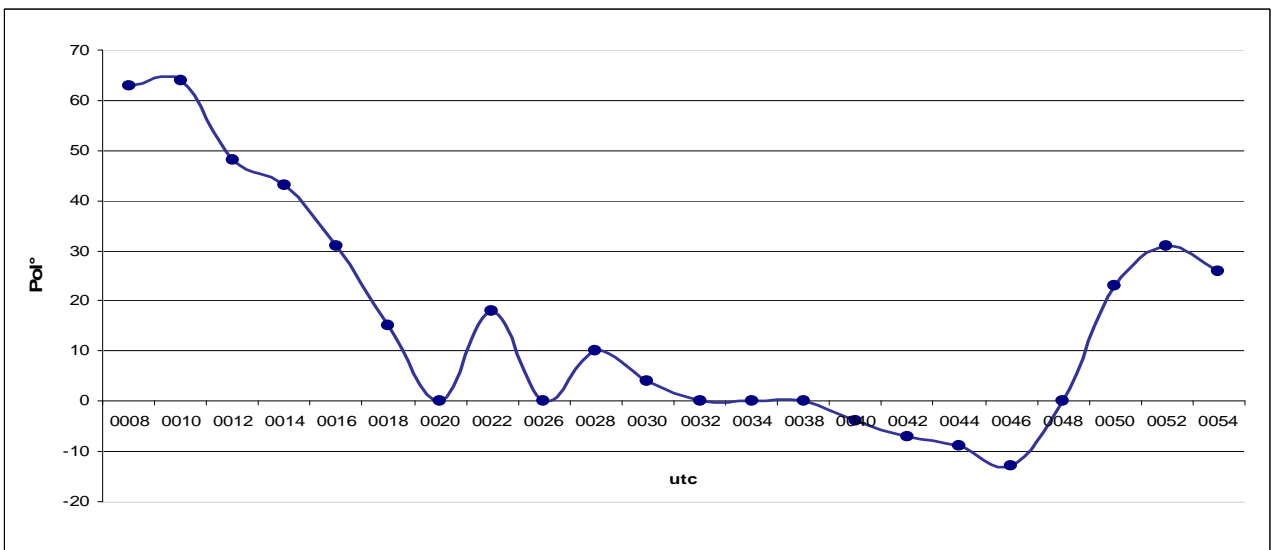
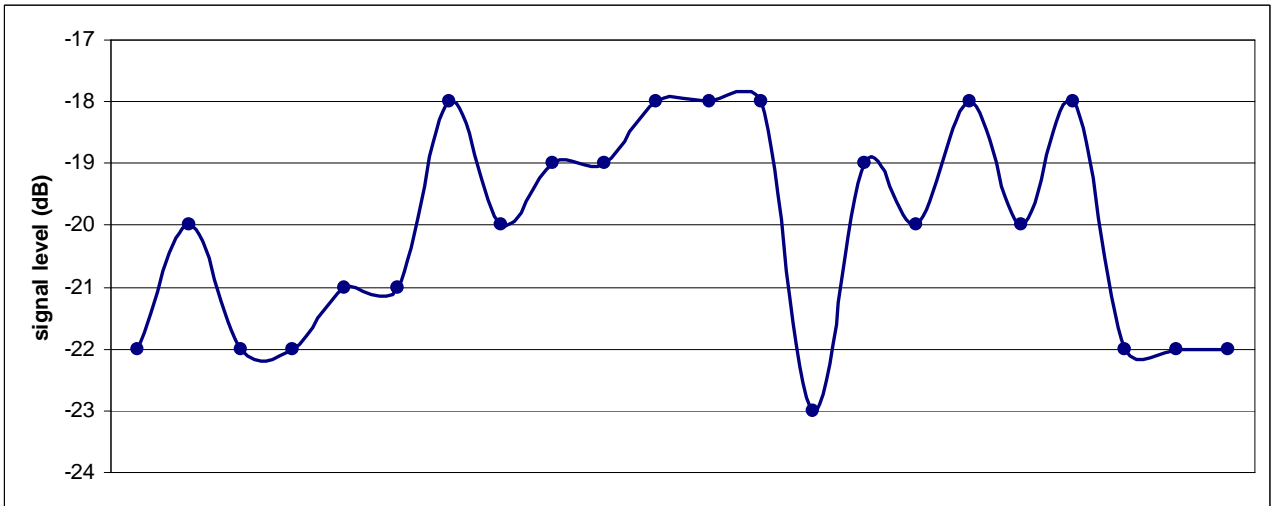
## An EME pile-up

Our interest for these two additional parameters arose from the beginning. Giorgio IK1UWL had just installed MAP65 and used it to monitor OX3LX (and qso him). He saved 46' of data

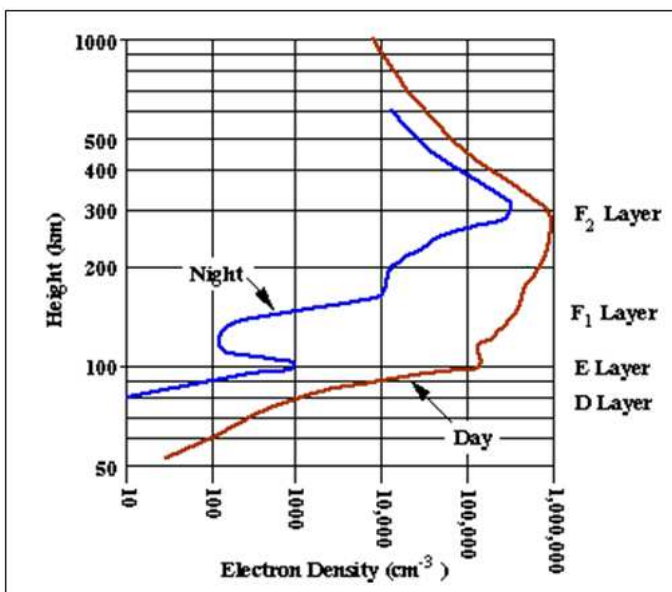
UTC Date: 2012-ago-03 00:00

```
-----  
  QRG  DF      DT Pol dB UTC  
144.143 -129 0 -2 0 1.7 63 4 -22 0008 CQ OX3LX HP15      1 10 8  
144.143 -138 3 -1 0 1.7 64 3 -20 0010 CQ OX3LX HP15      1 10 15  
144.143 -144 0 -2 -1 1.7 48 3 -22 0012 CQ OX3LX HP15      1 10 5  
144.143 -153 0 -2 -1 1.9 43 5 -22 0014 CQ OX3LX HP15      1 10 3  
144.143 -161 1 -1 0 1.5 31 1 -21 0016 CQ OX3LX HP15      1 10 4  
144.143 -170 0 -1 0 1.7 15 2 -21 0018 F6HVK OX3LX HP15 OOO  1 0 5  
144.143 -176 0 0 0 3.6 0 4 -18 0020 RRR                0 0 0  
144.143 -185 1 0 0 1.7 18 5 -20 0022 RK3FG OX3LX HP15 OOO  1 0 17  
144.143 -191 0 0 0 1.0 0 4 -19 0026 RRR                0 0 0  
144.143 -199 1 -1 0 1.7 10 4 -19 0028 CQ OX3LX HP15      1 10 3  
144.143 -205 0 -2 0 1.5 4 4 -18 0030 I3MEK OX3LX HP15 OOO  1 0 16  
144.143 -214 0 0 0 3.6 0 3 -18 0032 RRR                0 0 0  
144.143 -217 -1 0 -1 2.1 0 4 -18 0034 IZ3KGJ OX3LX HP15 OOO  1 0 18  
144.143 -226 0 0 0 1.0 0 4 -23 0038 RRR                0 0 0  
144.143 -229 -1 -1 -1 1.6 -4 4 -19 0040 CQ OX3LX HP15      1 10 15  
144.143 -232 -2 -1 -1 1.8 -7 5 -20 0042 CQ OX3LX HP15      1 10 12  
144.143 -238 0 -1 -1 1.8 -9 4 -18 0044 CQ OX3LX HP15      1 10 10  
144.143 -243 3 -1 1 1.8 -13 3 -20 0046 IK1UWL OX3LX HP15 OOO  1 0 7  
144.143 -246 0 0 0 1.0 0 4 -18 0048 RRR                0 0 0  
144.143 -252 1 -1 1 1.8 23 6 -22 0050 CQ OX3LX HP15      1 10 5  
144.143 -255 -1 -1 -1 1.8 31 5 -22 0052 CQ OX3LX HP15      1 10 4  
144.143 -261 2 0 -1 1.8 26 3 -22 0054 CQ OX3LX HP15      1 10 5
```

and put them in diagram



Besides being glad for the rare dx, the amount of variation of signal level and polarization angle in so short a time was surprising. Giorgio IK1UWL sent this data to Flavio IK3XTV, and we both decided to investigate on the causes of this.



### The ionosphere

- Partially ionized gas layer between ~50 and ~1000 km height and permeated by Earth's magnetic field is a **turbulent ocean, roughened by high speed winds**.
- Free electron density is variable in space and time.
- Their density (number per m<sup>3</sup>) determines various effects:  
**Slowdown, Attenuation, Deviation, Rotation**

## The ionosphere, space weather

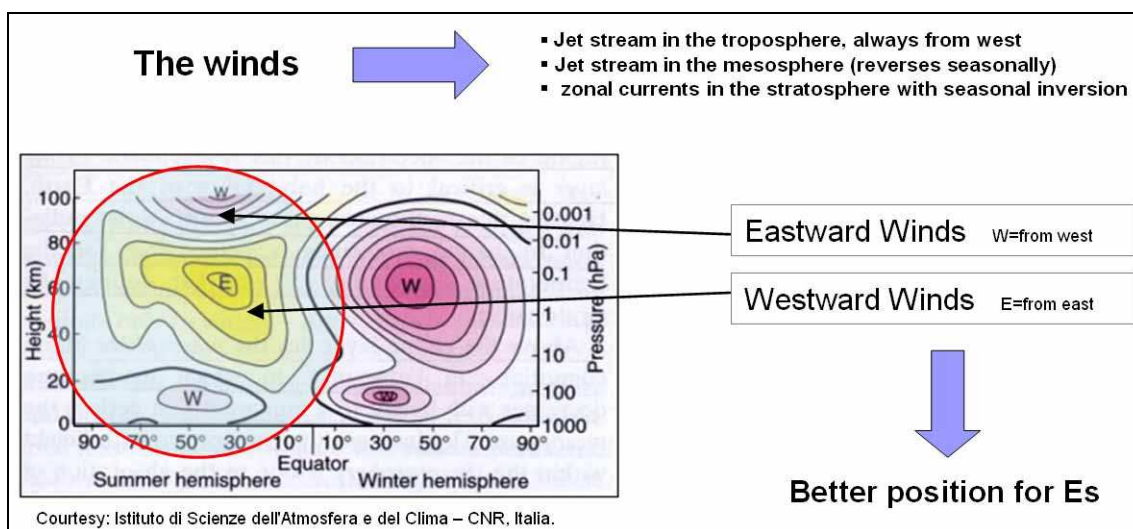
Weather near the surface involves winds that propagate like waves across the planet.

Weather in the upper atmosphere and in space is characterised by very strong winds, so has wavelike characteristics as well.

Space weather has two drivers: one is solar wind and radiation, the other is the dynamic atmosphere of Earth.

In the atmosphere travel waves very low in frequency (wavelength in the range of hundreds or thousands of kilometres) that carry energy and momentum also upwards (buoyancy waves).

Thermal effects cause tides with vertical movements and transfer of energy through shear winds. At the altitude at which sun radiation causes ionization there are winds with speed ranging in the hundreds of meters per second. Being shear winds the ionosphere is roughened by shorter waves and vortices.



These winds, which are active most days for part of the day, cause Travelling Ionospheric Disturbances (TIDs) which result in fluctuations of electron density and formation of amasses.

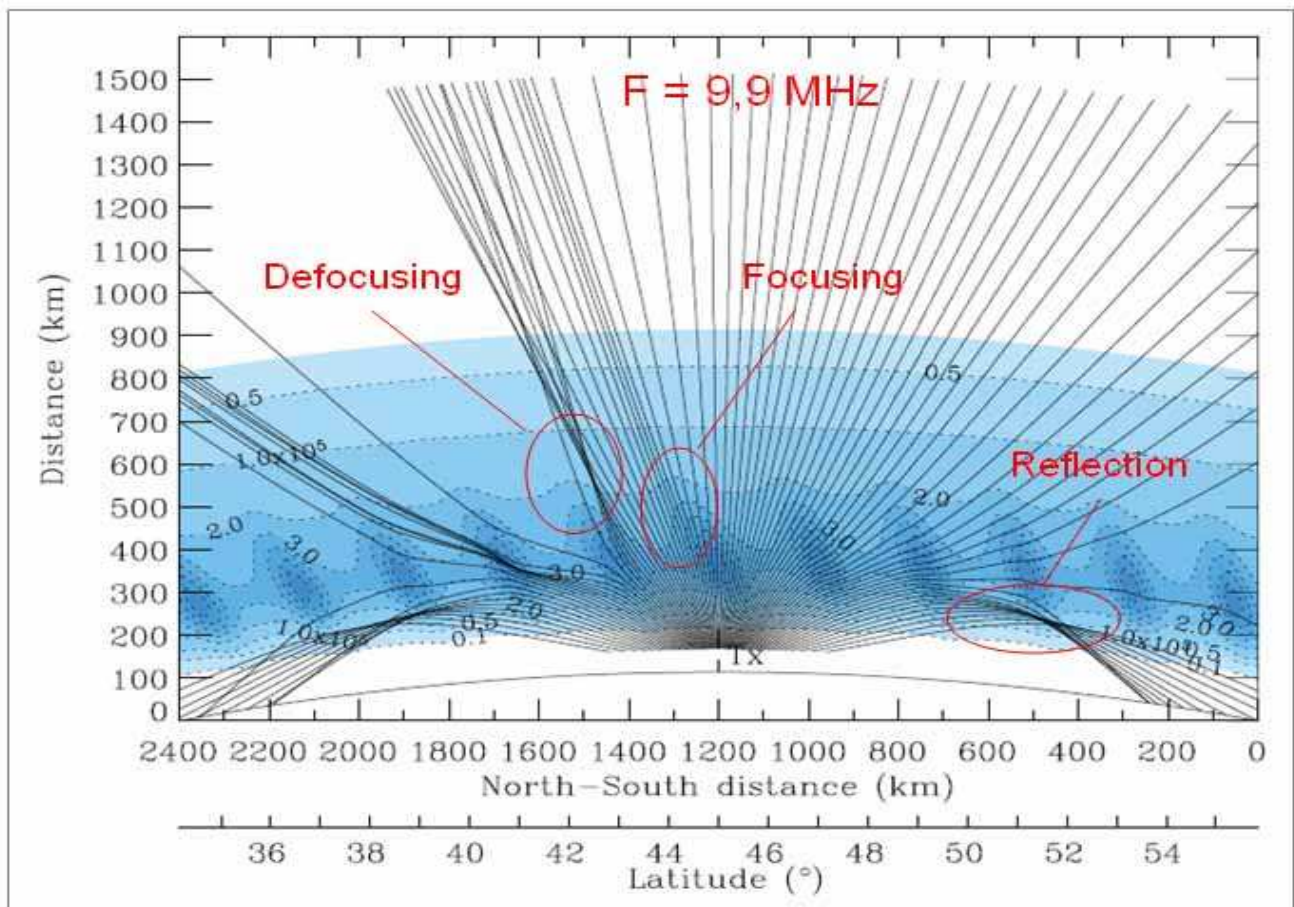
## Ionospheric waves

The ionospheric winds cause continuous undulations and waves (Traveling Ionospheric Disturbances, TIDs) resulting in fluctuations of electron density.

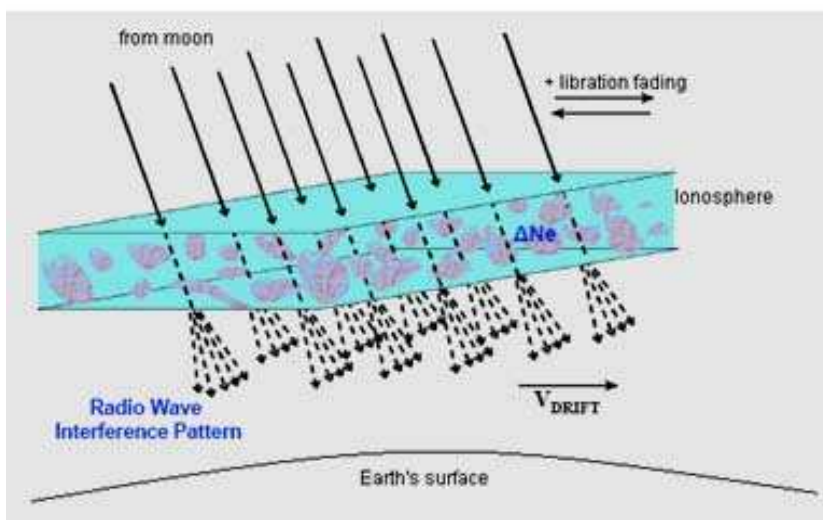
Class	Horizontal wavelength	Periods	Horizontal phase velocities
LSTID <sub>s</sub> Large scale	>1000 Km	0,5..3 h	300..1000 m/s
MSTID <sub>s</sub> Medium scale	100..1000 Km	12 min...1h	100..300 m/s
SSTID <sub>s</sub> Small Scale	<100 Km	A few minutes	<200 m/s

Source: INGV Istituto Nazionale di Geofisica e Vulcanologia - Italy

This turbulence and waves in the ionosphere have a lens effect on our signals, **focusing and defocusing** them.

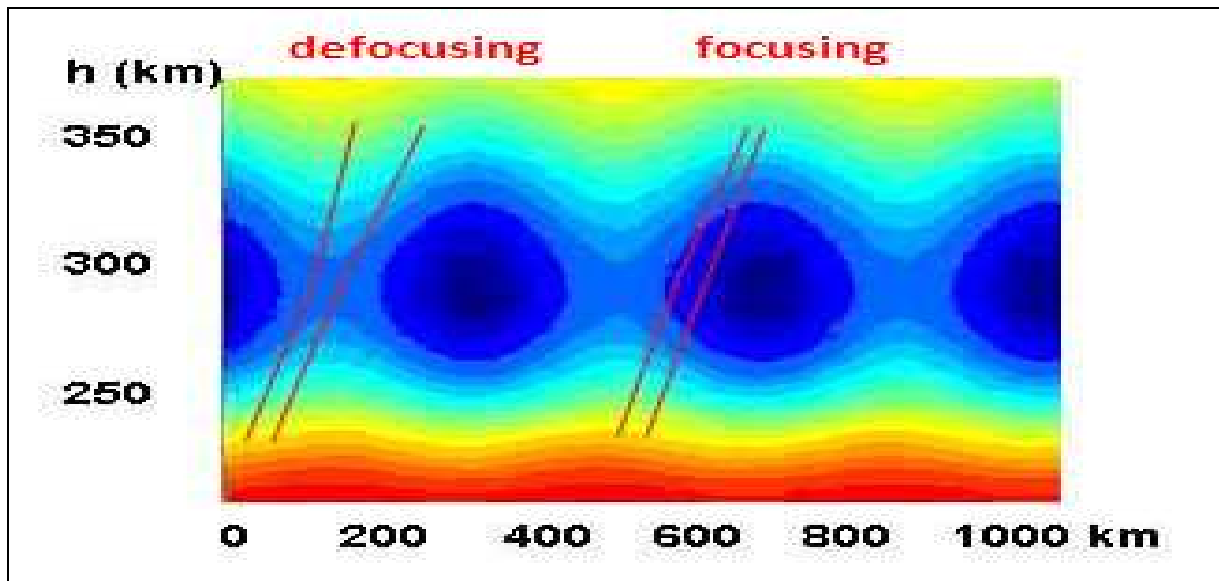


(Image source: Research and Technology Organisation. North Atlantic Treaty Organisation. Characterising the Ionosphere. Author: G. Wyman (January 2009))



Rapid scintillations caused by ionospheric irregularities (ssTIDs, periods of some minutes)



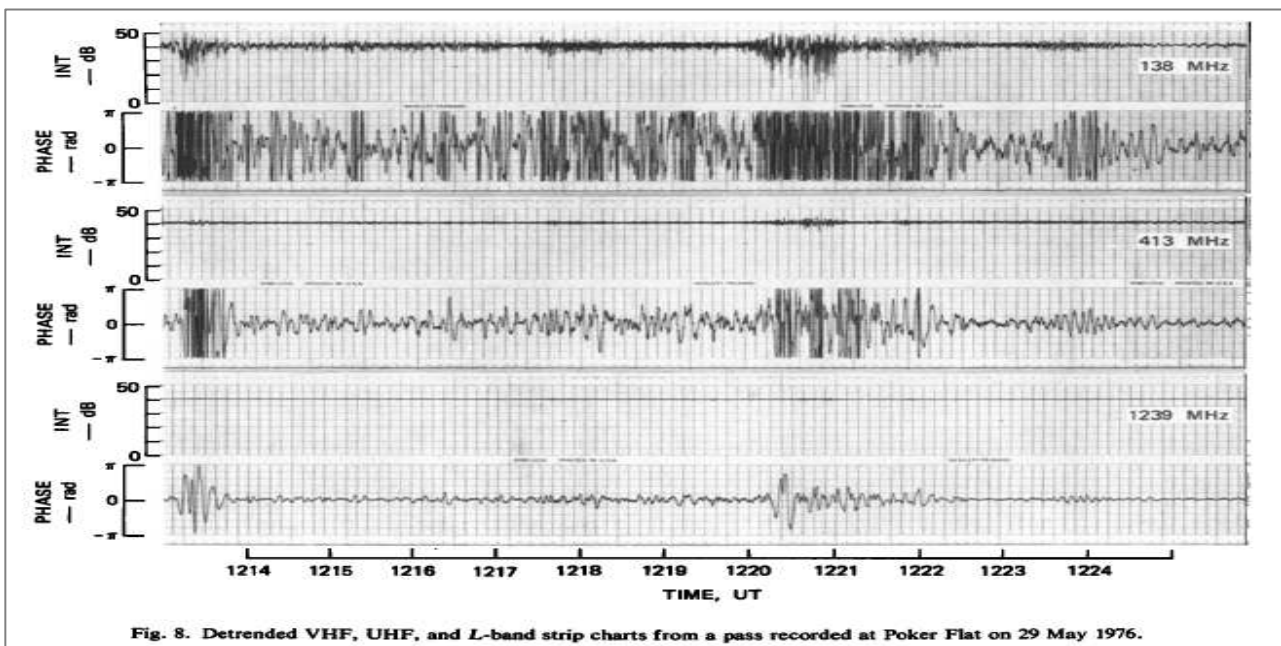


Slower scintillations due to mSTIDs

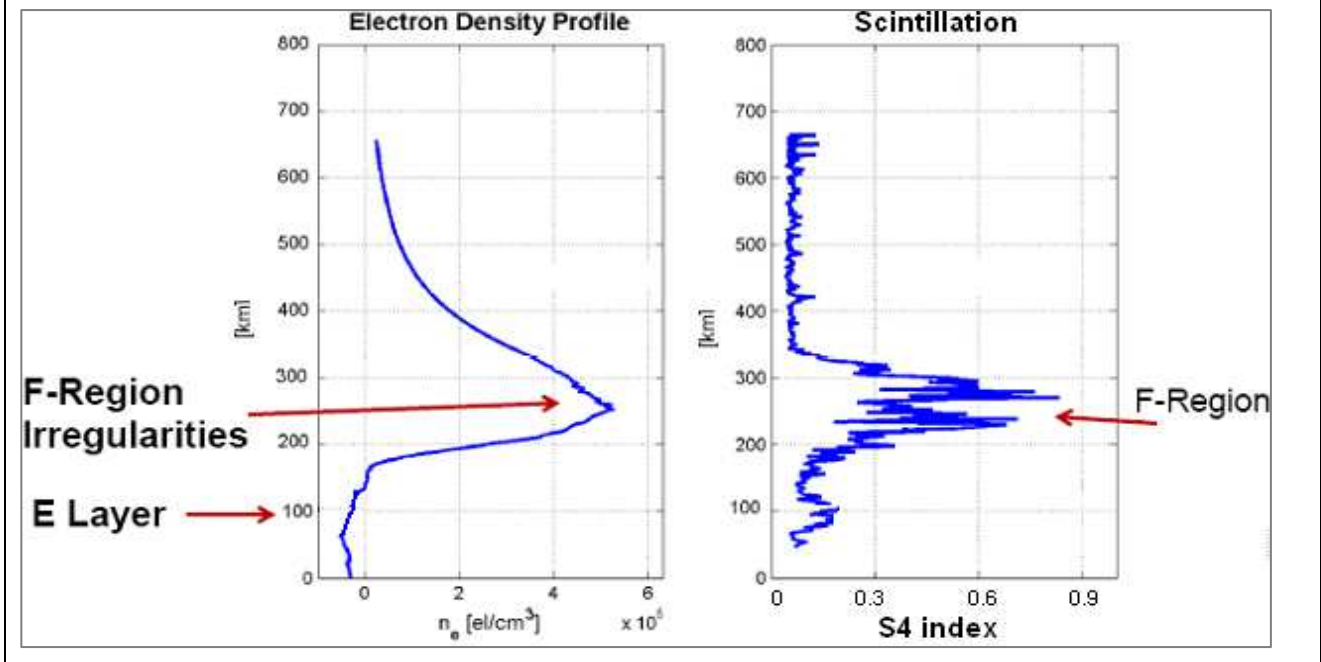
(observed at mid latitudes every day, wavelength 300 km, wind 100 m/s=360 km/h, period 50 minutes)

### QSB

QSB band dependence (ionospheric refraction is proportional to inverse square of frequency)



Regions dominating effect



Signal level fluctuations

A – Static ionosphere

Among the first notions of ionospheric behaviour we got, was that absorption of signal energy was in the range of 0,1 to 0,5 dB at 144 MHz.

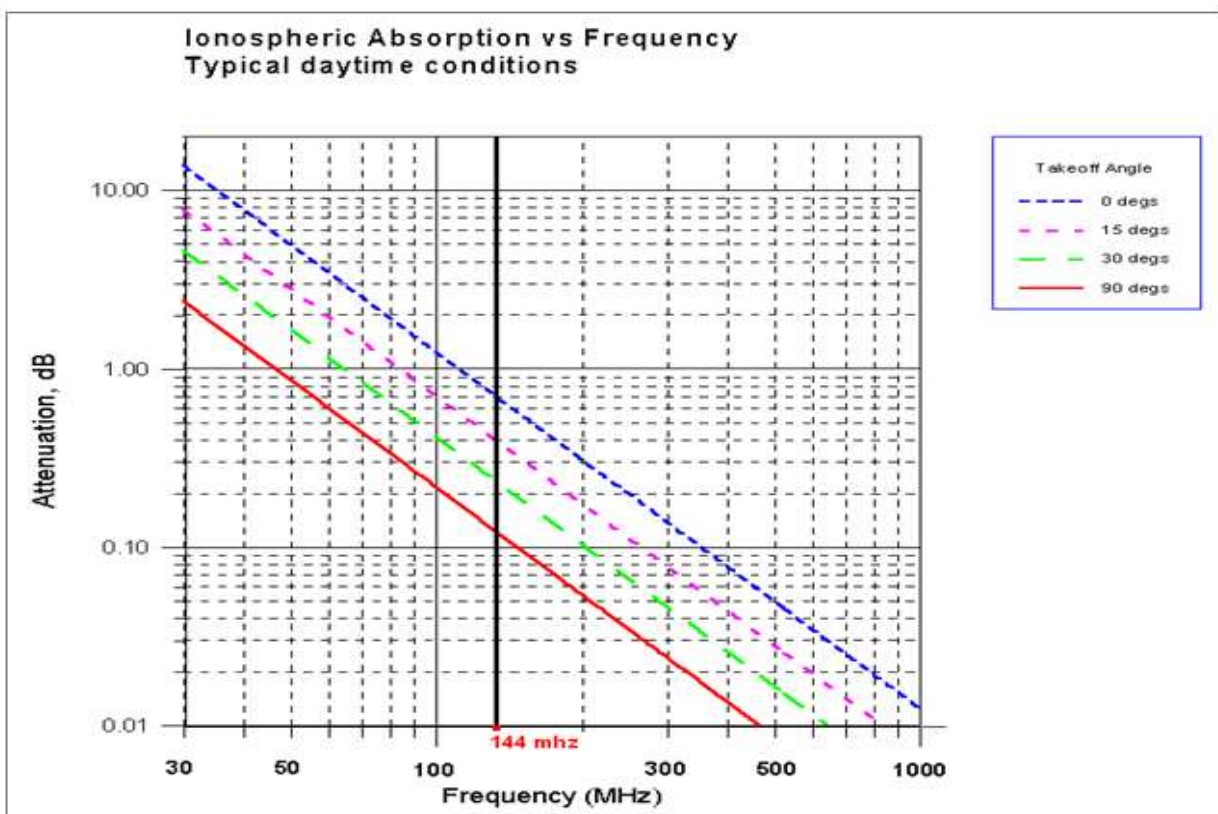
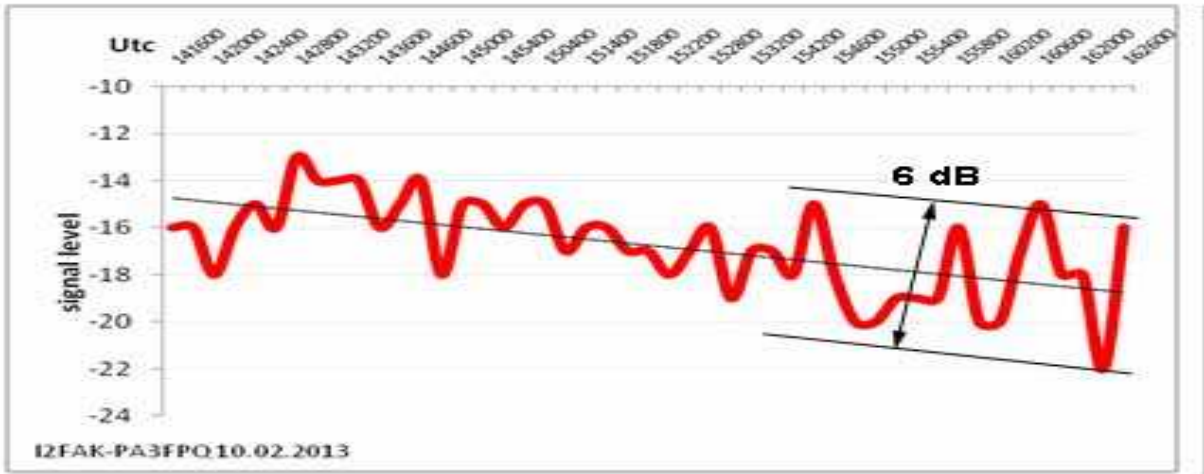


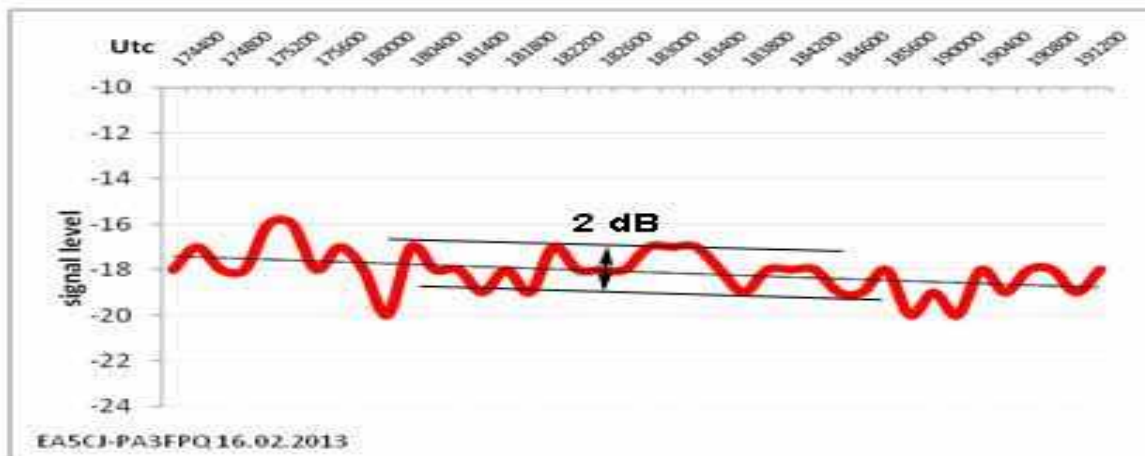
Image source: Darrel Emerson National Radio Astronomy Observatory - Tucson, AZ - USA

B – Dynamic ionosphere

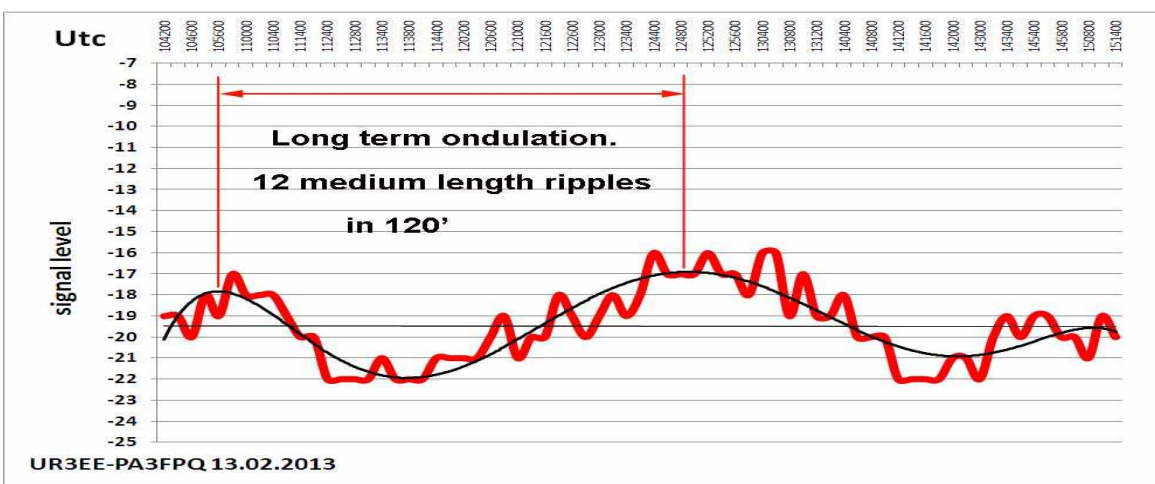
Whilst the observed medium period fluctuations of signal level are in the order of 3-6 dB in day conditions (attributable to ssTIDs)



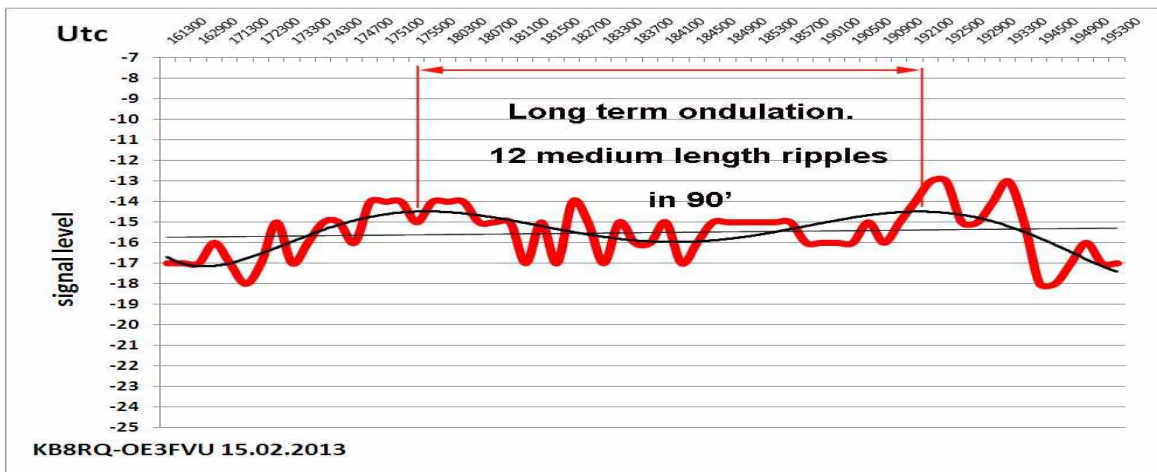
And of the order of 2 dB in night conditions



Additionally we noted long term fluctuations (attributable to mSTIDs):







These cannot be attributed to absorption because a thirty-fold density change would be needed. So we realized that turbulence and waves in the ionosphere have a **lens effect on our signals, focusing and defocusing them.**

**Faraday effect,**

Faraday rotation is what happens to the polarization plane of a wave going through a ionized medium intersected by a magnetic field. The formula is very simple:

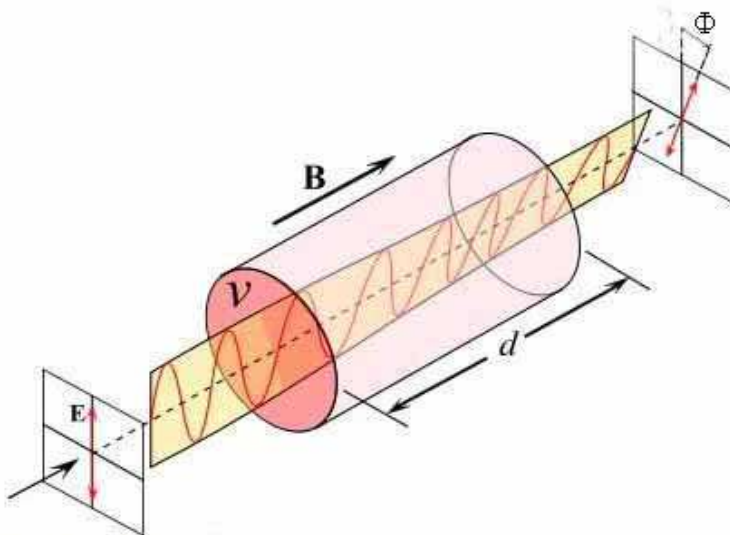
$$\Phi = k * B * TEC / f^2 \text{ (rad),}$$

with

B = Geomagnetic field component in wave's direction of travel (i.e. towards or from the Moon)

TEC = Total Electron Content of the path

f = wave frequency



**Effects tied to frequency**

Angle of rotation is inversely proportional to the square of frequency.

Since our bands have frequencies increasing by a factor of three, the rotation becomes one ninth from a band to the next.

With the same conditions for B and TEC:

Band	Rotation (°)		
50 MHz	90	360	2.25 turns
144 MHz	10	40	90
432 MHz	1,1	4,5	10
1296 MHz	0,1	0,5	1,1

Evidently, Faraday is a concern mainly in VHF

Microwavers are concerned only by Spatial Offset.

Clarification on spatial offset:

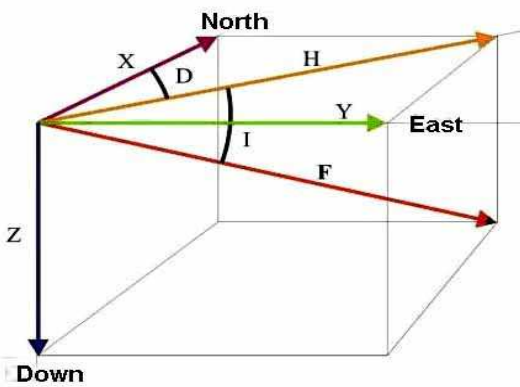
Polar polarization is the angle between an antenna and earth's polar axis.

**Spatial offset** between two stations is simply the difference between the polar polarizations of the two stations. This offset adds algebraically to Faraday rotation.

**Geomagnetic field**

We found a good source for F (total field) in the web site of the British Geological Survey.

Introducing Lat, Long, Median Height of the ionosphere, and Date, one obtains:



- Total field F (nTesla)
- Inclination I (°)
- Declination D (°)
- Magnetic latitude

Geodetic Coordinates

Latitude:  degrees  minutes  seconds

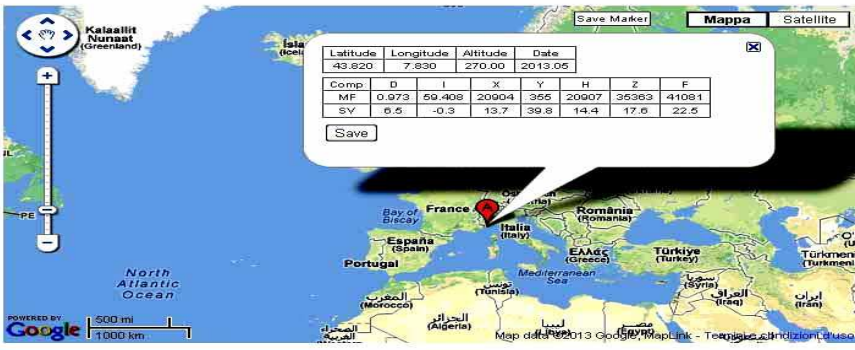
Longitude:  degrees  minutes  seconds

Altitude:  km above MSL

---

Date

Date:  (YYYY.YY OR YYYY-MM-DD)



Legend

	D = Declination	I = Inclination	X = North Intensity	Y = East Intensity	H = Horizontal Intensity	Z = Vertical Intensity	F = Total Intensity
MF = Main Field	degrees east	degrees down	nT	nT	nT	nT down	nT
SV = Secular Variation	arcmin/year	arcmin/year	nT/year	nT/year	nT/year	nT/year	nT/year

## Component B

In our formula we must introduce the Geomagnetic field component in Moon's direction.

Referred to a system of axis North, East, Up:

- The vector  $F$  is defined by *Inclination* and *Declination*.
- Moon's direction is defined by *Azimuth* and *Elevation*.

For projecting Field  $F$  on the Moon's direction we must calculate the angle  $FM$  between these two vectors.

The formula becomes:

$$\cos FM = \cos I \cdot \cos D \cdot \cos EL + \cos Az + \cos I \cdot \sin D \cdot \cos EL \cdot \sin Az - \sin I \cdot \sin EL$$

from which  $B = F \cdot \cos FM$

## TEC (Total Electron Content)

TEC is a key parameter for describing Earth's ionosphere.

It is measured in TECU (TEC Units) =  $10^{16}$  electrons/m<sup>2</sup>

The number of TECUs represent the total number of electrons present in a cylinder of 1 m<sup>2</sup> of section, crossing the ionosphere in the wave's direction.

## VTEC sources

Scientific Stations post VTEC (Vertical TEC) diagrams for each day. Among these we found the Royal Observatory of Belgium (ROB), that publishes VTEC histograms with values every 15', and keeps an archive for every day of the year. Measures are made by the observatory located in Dourbes (Belgium).

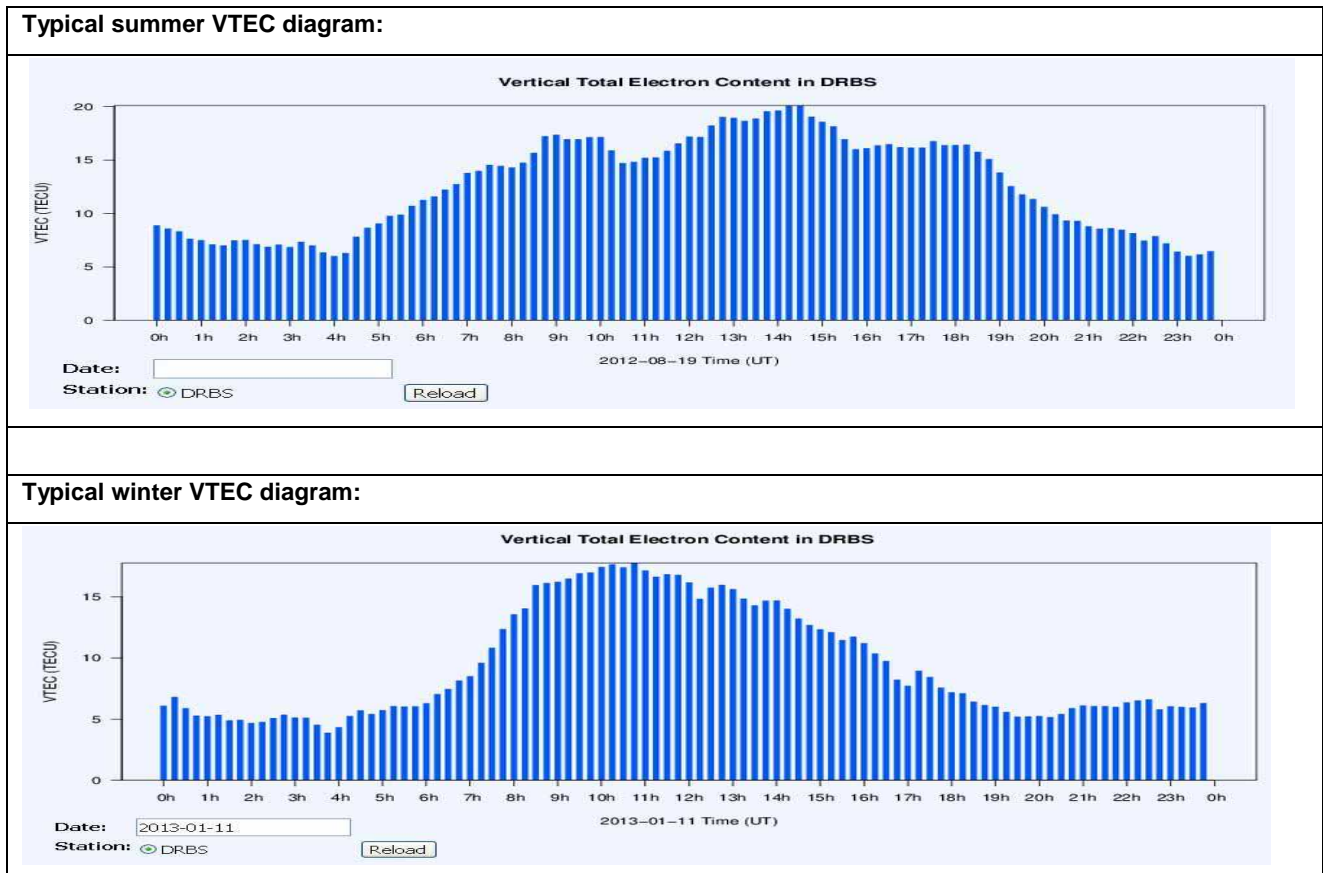
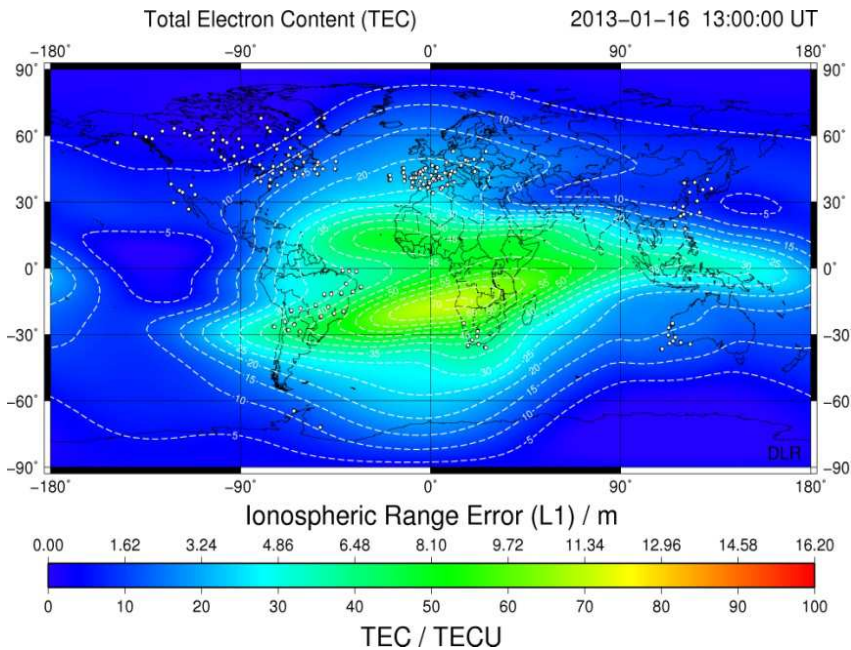


Image Source: ROB Royal Observatory Dourbes - Belgium

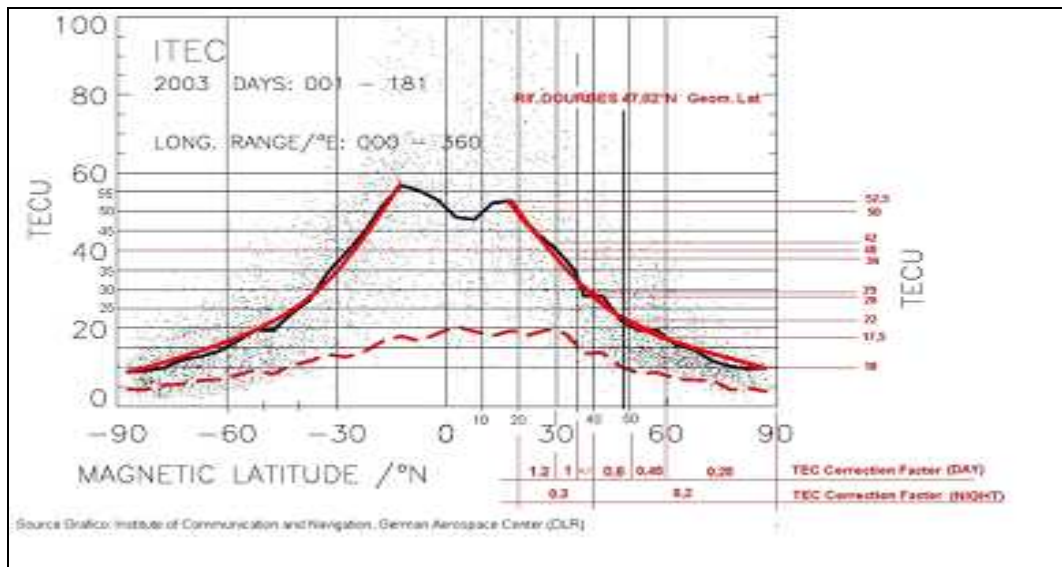
**From Dourbes to other places**

Spatial variation of TEC:

- Longitudinal variation: Global trend quite regular and correlated to the local solar time
- Latitudinal variation: The TEC value, varies non-linearly from the poles to the equator (geomagnetic)



This curve represents the latitudinal variation:



For our purposes we have simulated it with the algorithm:

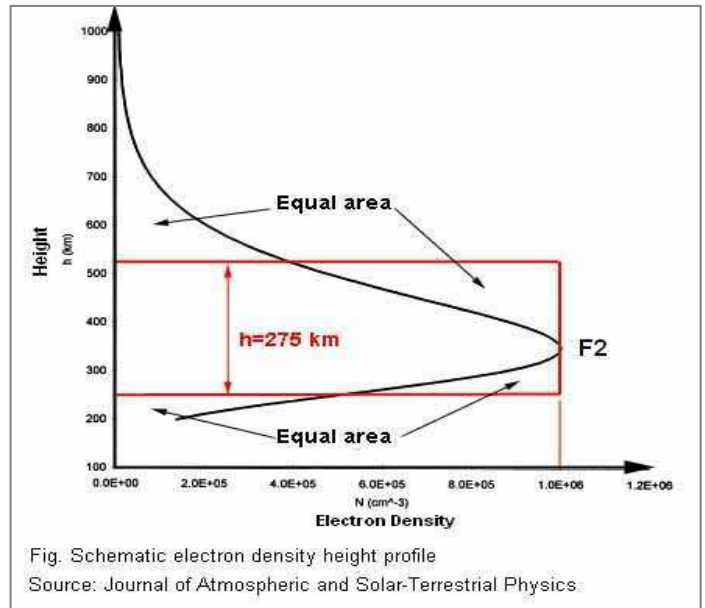
$$\text{TECU variation} = 0,02 \cdot \text{LAT}^2 - 2,5 \cdot \text{LAT} + 95$$

So for TEC value calculation:

- 1 – Dourbes VTEC at same time
- 2 – Magnetic latitude of station
- 3 – With algorithm representing the curve we find the correction to be applied to Dourbes VTEC

**Slab thickness**

Data on the Dourbes site give VTEC and slab thickness. These represent the transformation of the real ionosphere, with changing electron content with height and total thickness over 1000 km, in an equivalent ionosphere constituted by a uniform density layer with known TECU and thickness. Going through this slab gives the same effects as going through the real ionosphere. The advantage is that two numbers define this ionosphere, without the need for integration of a complex graph.



**Oblique passage (Slant TEC)**

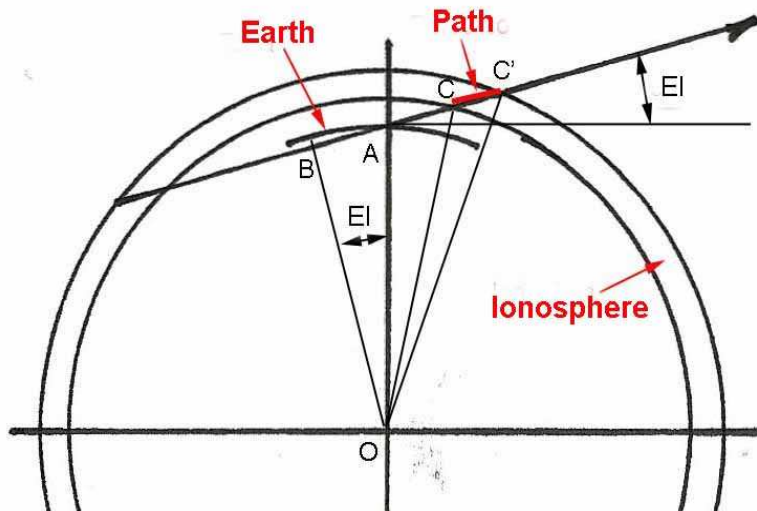
Ince the slab is crossed obliquely, the number of encountered electrons increases.

So TEC in our formula becomes  $TEC = STEC = Ka * VTEC$ , with  $Ka$  given by:

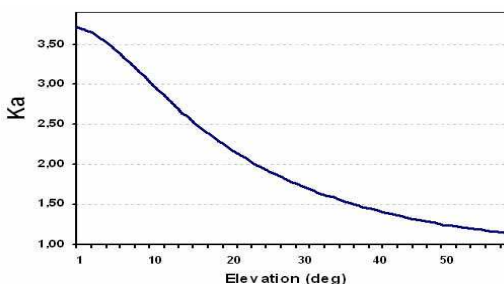
With Earth radius=6367 km, and Ionosphere beginning at 100 km height, with  $h$ =Slab Thickness

$$Ka = \frac{\sqrt{(64672+h)^2 - (6367 * \cos EI)^2} - \sqrt{64672 - (6367 * \cos EI)^2}}{h}$$

This is easily found with Pitagora's theorem from



For  $h=350$  km this is  $Ka$  as function of elevation





## Final formula

We have now the data for the complete formula:

$$\Phi = k \cdot (F \cdot \cos FM) \cdot (VTEC \cdot \text{corr} \cdot K_a) / f^2$$

For  $f = 144$  MHz,  $k/f^2 = 1,14$  with  $F$  in Gauss.

Wave plane rotation is controlled by these variables:

- Angle between Geomagnetic. field and Moon direction ( $\cos FM$  ranges from 1 to -1)
- TEC (constant or changing slowly, 100% to 30%)
- Moon elevation (oblique passage  $K_a$  from 1 to 3,7)

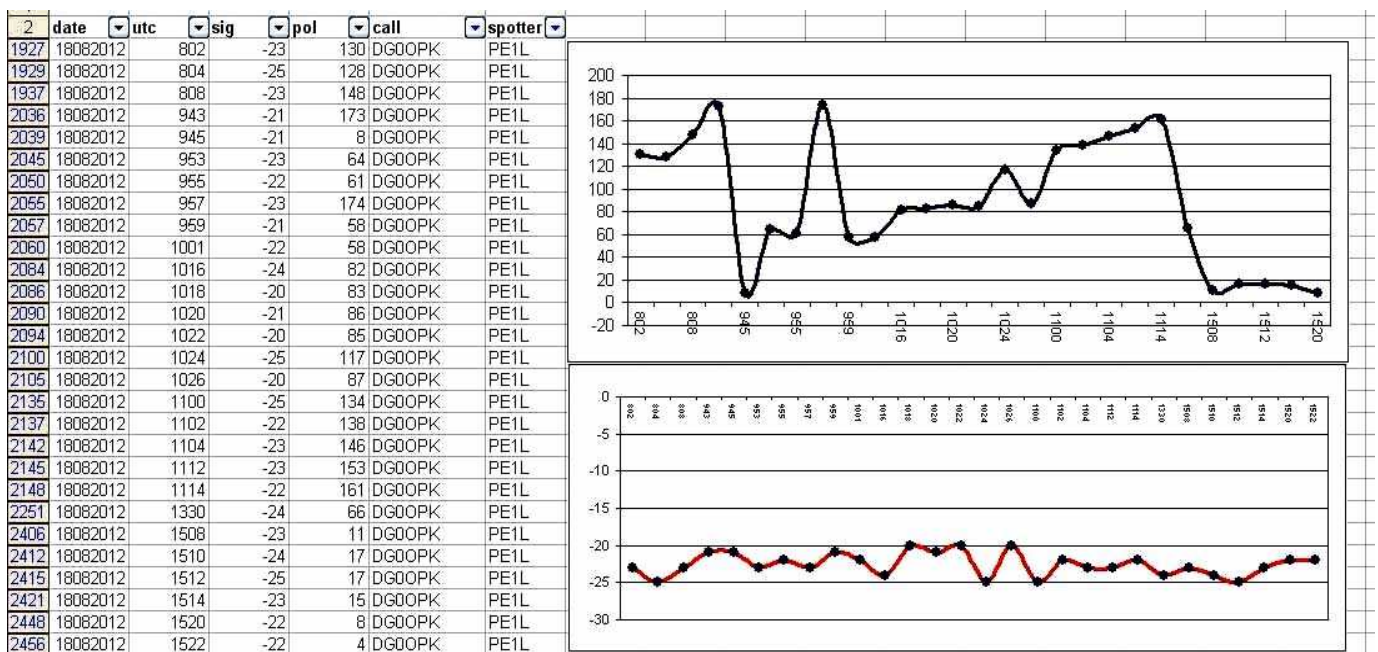
## Collecting on-the-air data

We needed many sources of data, geographically spread.

A big help came from René PE1L, who collected for us all the data published on line in LiveCQ in a file, accessible to us.

We sorted them in an Excel sheet by date, spotter and spotted.

Example: 18/08/2012 – DG0OPK – PE1L, data, pol and level graphs



So we could examine a great variety of cases, and start to identify tendencies.

Note: The polarization measured by MAP65 is the algebraic sum of spatial offset and of two ionospheric crossings: the Faraday rotation of the up going transmitted wave and that of the returning echo.

### Amount of rotation in an interval

As a first check on our formulas, we compiled an Excel sheet for calculating what happens in a time interval, generally not greater of an hour. An example:

3	Spotted	locator		lat	long	Corr VTEC z	Inclination(°)	F (6000z) ***
4	OX3LX	HP15EO		65,6	-37,625	0,2	77,51	0,48387
5	Date	UTC	Local time	Decimal	AZ (°)	EI spotted(°)	VTEC-DRBS	VTEC (TECU)
6	August 3, 2012	0.08	21:19	21,32		134	7	14,3
7		0.46	21:57	21,95		143	9	13,65

Geom. Latitude	Declination(°)	Calc. Baseline	Conv. Latitude	Dourbes	
70,13	-22,991	WWLQC converter	Kp=3 quiet		
h (Km)	Ka	A (dB)	F (6000z)	θ (°)	P (°)
300	3,49	0,070	0,48387	-108,78	72,44
300	3,30	0,067	0,48387	-160,75	75,35

17	Spotter	locator		lat	long	Corr VTEC z	Inclination(°)	F (6000z) ***
18	IK1UWL	JH33VT		43,84	7,79	0,2	59,45	0,41456
19	Date	UTC	Local time	Decimal	AZ (°)	EI spotted(°)	VTEC-DRBS	VTEC (TECU)
20	August 3, 2012	0.08	0:20	24,35		179	36	12,35
21		0.46	0:58	24,98		190	36,00	11,7

Geom. Latitude	Declination(°)				
40,46	0,953				
h (Km)	Ka	A (dB)	F (6000z)	θ (°)	P (°)
300	1,59	0,082	-0,41456	508,63	89,27
300	1,59	0,079	-0,41456	482,63	-82,70

We checked many cases with good congruence between computed and observed rotations.

### Global common moon trend

Having now confidence in the basic correctness of formula and correction coefficients, we proceeded to build a new Excel sheet, covering the entire common-moon period.

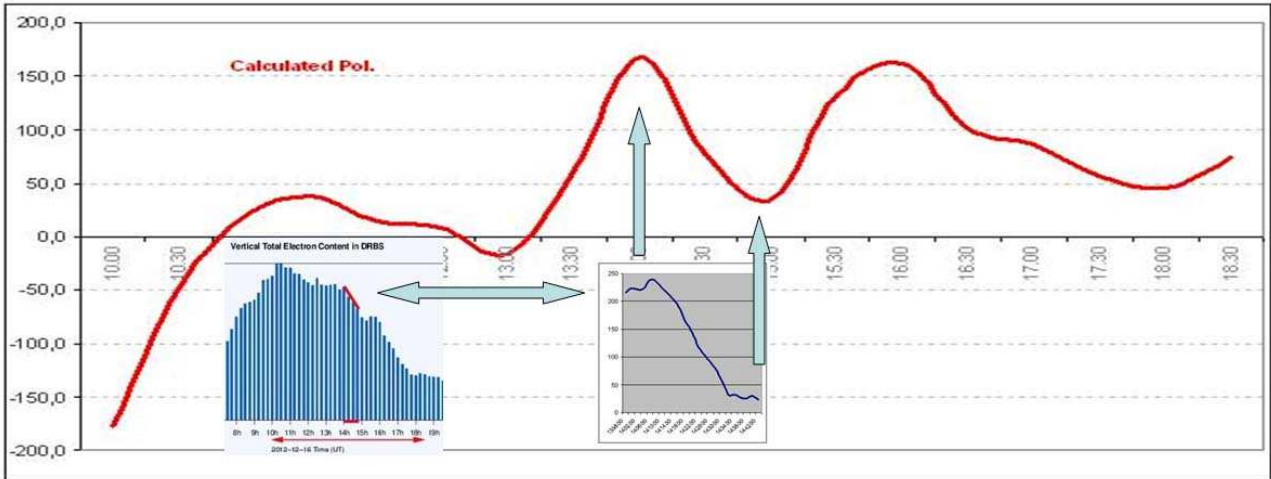
Our Excel sheet:

Data	Nomin	Loc.	Lat.	Long.	Lat. mag	Corr. Day	Corr. night	F	Incl.	Decl.	Loc. conv.	Conv. Lat.	Calcolo F	Dourbes
16/12/2012	SP4MPB	KD03HT	53,81	20,63	50,65	0,93	0,20	0,44958	68,77	4,54				
UTC	Oreloc.(rif. DRBS)	Az (°)	EI (°)	h (km)	Ka	VTEC Dbs	Corr.	VTEC loc.	STEC	cosFL	Rotaz. (°)	Rotaz. (rad)	Offset P1	P1(0,180)
10:00	11:04	129	8,3	187	3,64	15,52	0,45	14,24	51,84	-0,3367	-512,6	-8,95	61,6	61,6
10:30	11:34	135	11,6	185	3,27	15,00	0,45	13,72	44,79	-0,4171	-548,7	-9,58	64,5	64,5
11:00	12:04	142	14,5	182	2,95	14,08	0,45	12,80	37,78	-0,4912	-545,0	-9,51	68,0	68,0
11:30	12:34	149	17,0	182	2,70	13,82	0,45	12,54	33,90	-0,5543	-551,9	-9,63	71,7	71,7
12:00	13:04	156	19,0	182	2,53	13,68	0,45	12,40	31,36	-0,6042	-556,5	-9,71	75,6	75,6
12:30	13:34	163	20,6	185	2,40	13,68	0,45	12,40	29,74	-0,6435	-562,1	-9,81	79,7	79,7
13:00	14:04	171	21,7	187	2,32	14,10	0,45	12,82	29,73	-0,6716	-586,4	-10,23	84,5	84,5
13:30	14:34	178	22,2	197	2,28	12,11	0,45	10,83	24,66	-0,7083	-512,9	-8,95	88,8	88,8
14:00	15:04	186	22,1	201	2,28	10,53	0,45	9,25	21,07	-0,6866	-424,9	-7,42	86,4	93,6
14:30	15:34	193	21,5	221	2,31	10,55	0,45	9,27	21,40	-0,6751	-424,2	-7,40	82,2	97,8
15:00	16:04	201	20,3	259	2,36	10,00	0,45	8,72	20,60	-0,6495	-393,0	-6,86	77,4	102,6
15:30	16:34	208	18,7	307	2,45	7,89	0,45	6,61	16,17	-0,6129	-291,0	-5,08	73,4	106,6
16:00	17:04	215	16,5	326	2,59	6,32	0,33	5,38	13,95	-0,5641	-231,1	-4,03	69,6	110,4
16:30	17:34	222	14,0	369	2,75	5,26	0,20	4,69	12,89	-0,5045	-191,0	-3,33	66,1	113,9
17:00	18:04	229	11,0	406	2,95	4,47	0,20	3,90	11,51	-0,4317	-145,9	-2,55	62,8	117,2
17:30	18:34	235	7,7	417	3,20	4,63	0,20	4,06	12,99	-0,3538	-135,0	-2,36	60,2	119,8
18:00	19:04	241	4,2	432	3,41	4,34	0,20	3,77	12,84	-0,2686	-101,3	-1,77	58,0	122,0
18:30	19:34	247	0,8	451	3,48	3,95	0,20	3,38	11,77	-0,1804	-62,4	-1,09	56,1	123,9
Data	Nomin	Loc.	Lat.	Long.	Lat. mag	Corr. Day	Corr. night	F	Incl.	Decl.	Loc. conv.	Conv. Lat.	Calcolo F	Dourbes
16/12/2012	PA3FPQ	JQ22XE	52,19	5,96	50,61	0,93	0,20	0,43860	66,93	0,23				
UTC	Oreloc.(rif. DRBS)	Az (°)	EI (°)	h (km)	Ka	VTEC Dbs	Corr.	VTEC loc.	STEC	cosFL	Rotaz. (°)	Rotaz. (rad)	Offset P2	P2(0,180)
10:00	10:05	116	2,0	192	4,21	14,74	0,45	13,48	56,76	-0,2023	-329,0	-5,74	55,4	55,4
10:30	10:35	122	5,8	187	3,93	16,05	0,45	14,79	58,16	-0,2374	-495,6	-8,65	57,6	57,6
11:00	11:05	128	9,4	187	3,52	15,52	0,45	14,26	50,13	-0,3869	-555,6	-9,70	60,1	60,1
11:30	11:35	135	12,8	185	3,13	15,00	0,45	13,74	42,98	-0,4725	-581,9	-10,16	63,4	63,4
12:00	12:05	141	15,8	182	2,82	14,08	0,45	12,82	36,10	-0,5427	-561,3	-9,80	66,6	66,6
12:30	12:35	148	18,4	182	2,58	13,82	0,45	12,56	32,35	-0,6055	-561,2	-9,79	70,4	70,4
13:00	13:05	155	20,6	182	2,40	13,68	0,45	12,42	29,82	-0,6558	-560,2	-9,78	74,5	74,5
13:30	13:35	163	22,3	185	2,28	13,68	0,45	12,42	28,27	-0,6956	-563,4	-9,83	79,4	79,4
14:00	14:05	170	23,5	187	2,20	14,10	0,45	12,84	28,25	-0,7199	-582,6	-10,17	83,7	83,7
14:30	14:35	178	24,0	187	2,17	12,11	0,45	10,85	23,49	-0,7319	-492,6	-8,60	88,7	88,7
15:00	15:05	186	24,0	201	2,16	10,53	0,45	9,27	19,99	-0,7304	-418,4	-7,30	86,2	93,8
15:30	15:35	193	23,3	221	2,19	10,53	0,45	9,27	20,29	-0,7151	-415,6	-7,25	81,9	98,1
16:00	16:05	201	22,0	259	2,25	10,00	0,45	8,74	19,66	-0,6844	-385,4	-6,73	76,9	103,1
16:30	16:35	208	20,3	307	2,33	7,89	0,45	6,63	15,44	-0,6444	-285,2	-4,98	72,8	107,2
17:00	17:05	215	18,0	326	2,48	6,32	0,33	5,39	13,37	-0,5905	-226,2	-3,95	68,8	111,2
17:30	17:35	222	15,4	369	2,64	5,26	0,20	4,70	12,40	-0,5258	-186,8	-3,26	65,1	114,9
18:00	18:05	229	12,3	406	2,85	4,47	0,20	3,91	11,12	-0,4483	-142,8	-2,49	61,7	118,3
18:30	18:35	235	8,9	417	3,11	4,63	0,20	4,07	12,64	-0,3655	-132,4	-2,31	59,0	121,0

Partial checks were possible using the LiveCQ decoded periods.

An example for SP4MPB spotted by PA3FPQ on 16/12/2012. All data were computed for 30' intervals. The choice of these two stations depended on having a LiveCQ decode running continuously for 44'.

And the graphs we obtain from it (with superimposed the decoded graph):



SP4MPB was active from 13.58 to 14.42 utc.

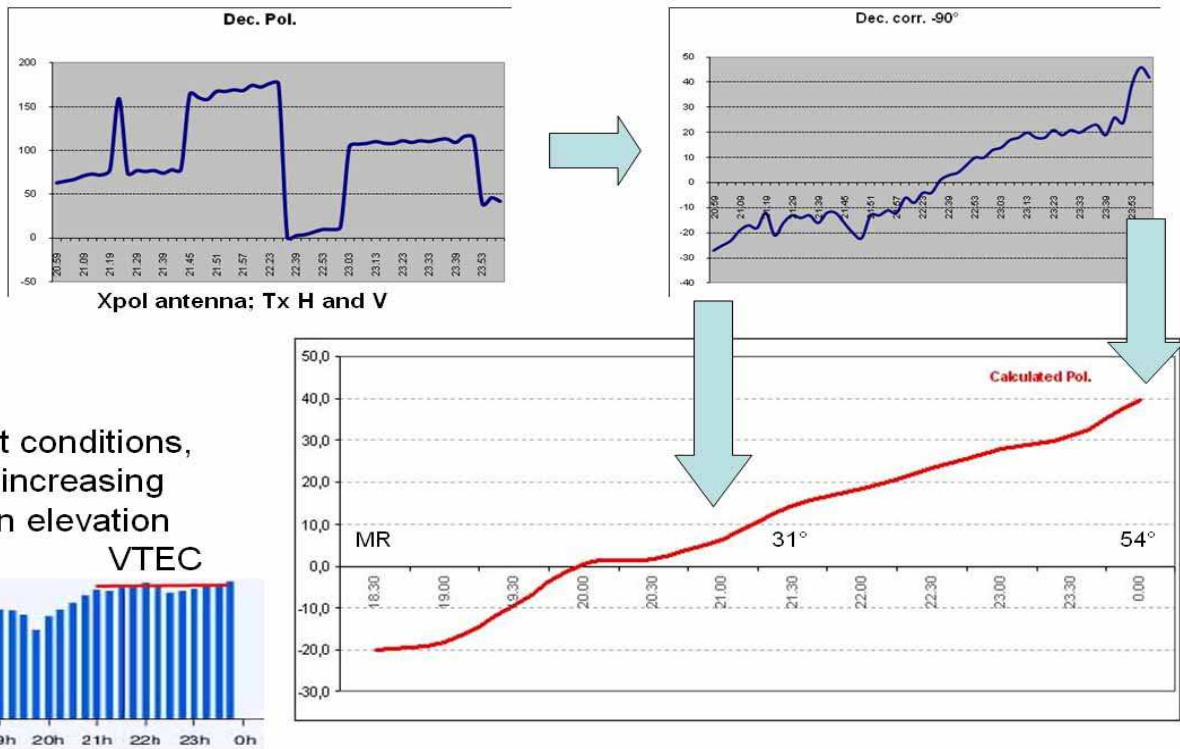
In this phase, TEC had a quick decrease, followed by a brief increase pre sunset, then decreasing from sunset to night. Calculated and real trend are coherent

A second example is I2FAK calling CQ in ARRL EME contest, on 1/12/2012.

Station is 828 SSE of spotter PA3FPQ.

Decoded pol showed 90° transitions when he changed tx form H to V.

Graph corrected for this is the right one.



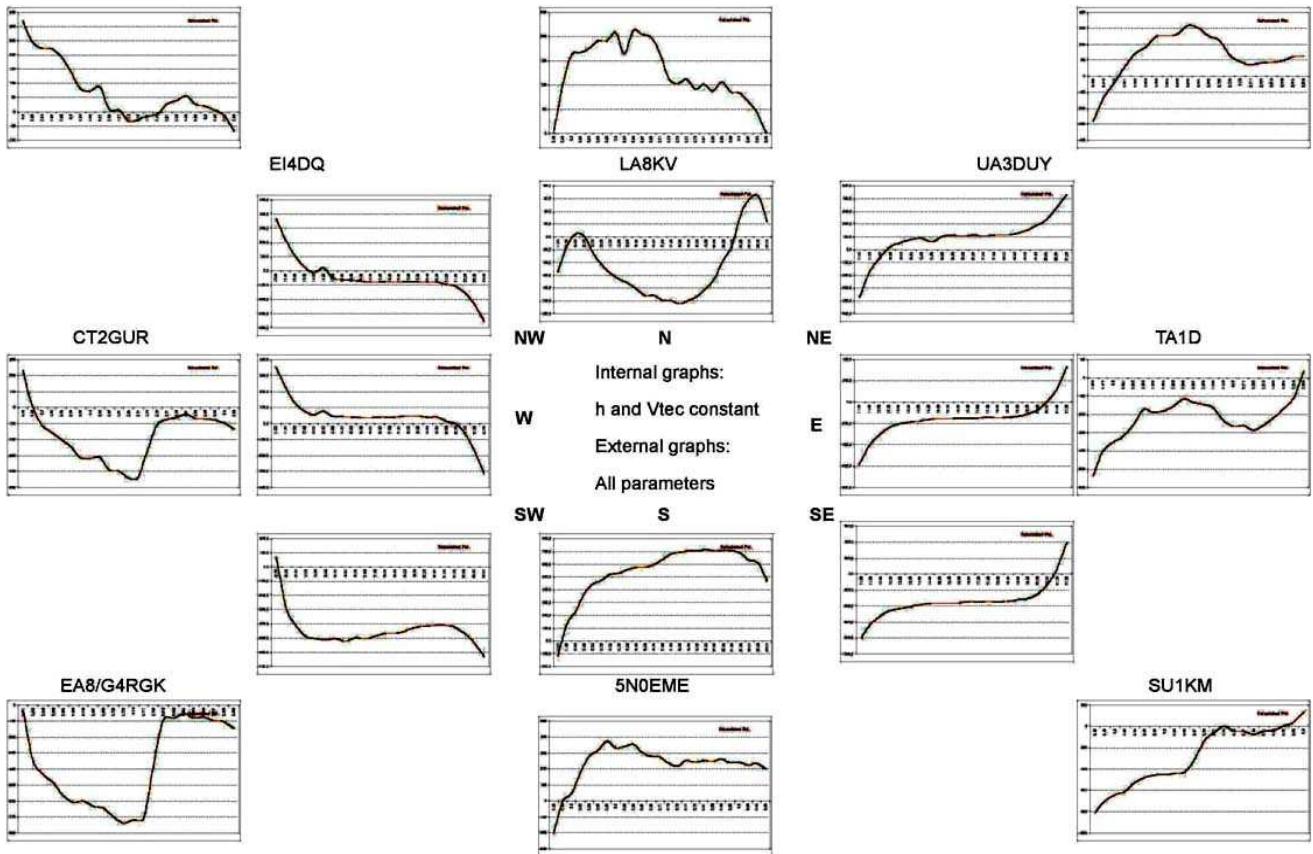
Night TEC was practically constant, so pol change derived mainly from increasing Moon elevation.

**Polarization trends**

When reception is difficult due to unfavorable Faraday rotation, one often wonders if this will change quickly. We decided to explore if tendencies could be found and used as a guide.

So we created a set of 8 computations for a full moon pass of IK1UWL station with stations in 8 different directions, N, NE, E, SE, S, SW, W, NW, all for the same moonpass, on Dec 19<sup>th</sup> 2012, in which the Moon was visible from 11.00 to 23.00 UTC. In this diagram the graphs are disposed in the outer ring.

**Azimuth rose**



In order to separate the eventual tendencies from changes in the ionosphere (which occur over a full moon pass, but are negligible in a short period), we computed also the rotations with constant VTEC and slab thickness, i.e. for an invariable ionosphere.

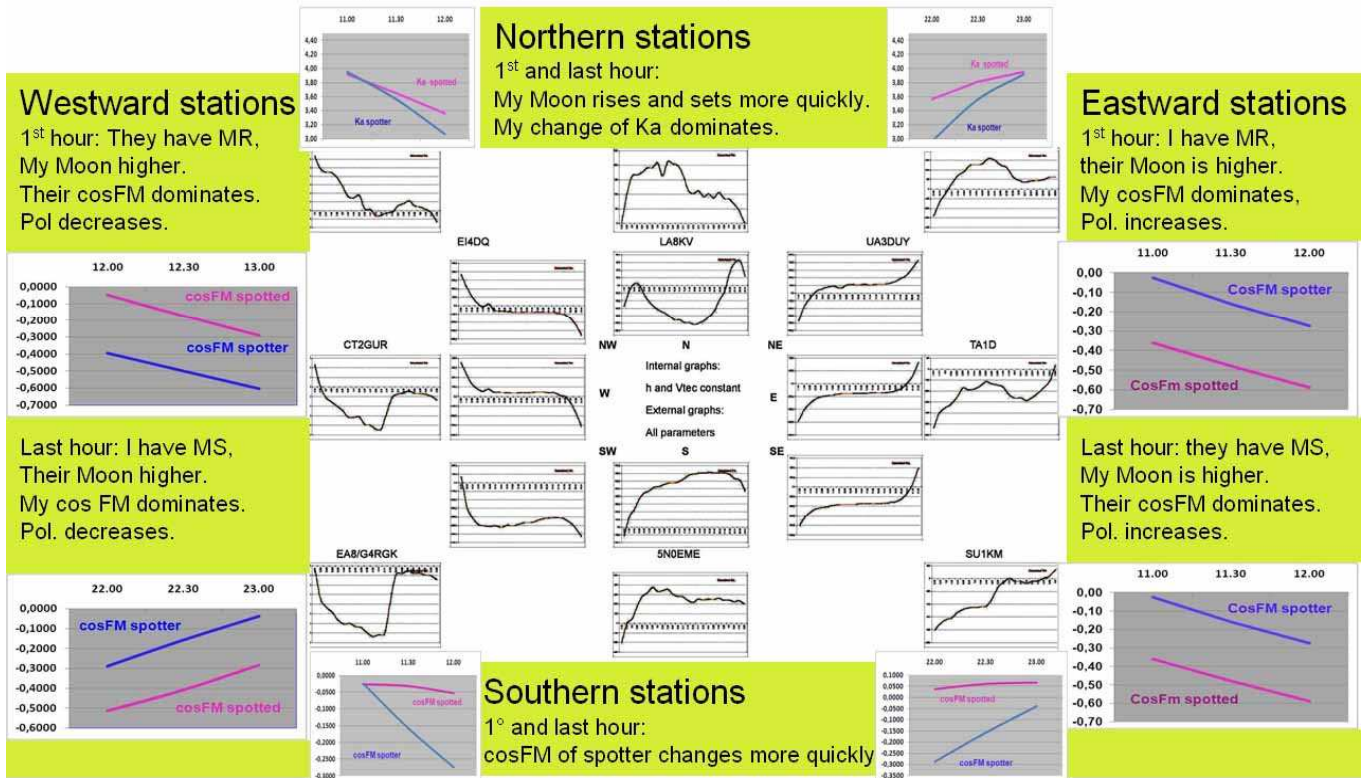
The relative graphs are disposed in the inner circle.



# Pol. trends

- Spotter IK1UWL, band 144 MHz, on Dec 19, 2012 – Moon 11.00 – 23.00 UTC
- All graphs computed for stations in a rose of directions

$$\Phi = k * (F * \cos FM) * (VTEC * \text{corr} * Ka) / f^2$$



The first noticeable fact is the similarity at the beginning and at the end of the moon pass, whilst ionospheric changes give different evolutions in the central part of the moon pass.

Evidently, at moonrise and moonset the rapid change of inclination (which influences both cosFM and Ka) causes quick variations of rotation.

The overall shape of Eastward and Westward graphs is similar to a sinusoid, with slower variations in the central part. Specifically, at MR, cosFM variation of the station having MR, has a dominant effect, and is the cause, in the first hour approximately, of the pol rotation. The same effect can be seen at MS.

For Northern stations the factor Ka (change of Slant TEC) is the dominant factor at MR and MS.

For Southern stations the dominant effect, with IK1UWL spotting, is more tied to cosFM (angle between earth's Geomagnetic field and Moon direction) due to the field's condition above IK1UWL station, but also Ka show a similar effect.

Generalizing, during hours in which TEC changes little (during the day and during the night), Faraday rotation is affected mainly by angle changes (Moon elevation and Moon direction respect Geomagnetic field). Changes tied to TEC occur mainly during sunrise and sunset.



## Conclusions

- **QSB of JT65 decodes:** Is caused by focusing or defocusing of our beam going through the waves of the windy ionosphere.
- **Faraday rotation:** There are **three phases** in a Moon pass:
  - 1 - In the **first hours** after Moon rise the rate of change of polarization is high. Causes:
    - a) – change of angle FM between Moon direction and magnetic field
    - b) – change in length of ionospheric crossing (slant coeff. Ka)
  - 2 – In the **central part** of Moon pass changes in angle FM and coeff. Ka balance each other, so polarization changes depend mainly from ionospheric evolution (of Total Electron Content)
  - 3 – In the **last hours** before Moon set the rate of change of polarization is high for the same causes of phase 1

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Date: August 2014

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