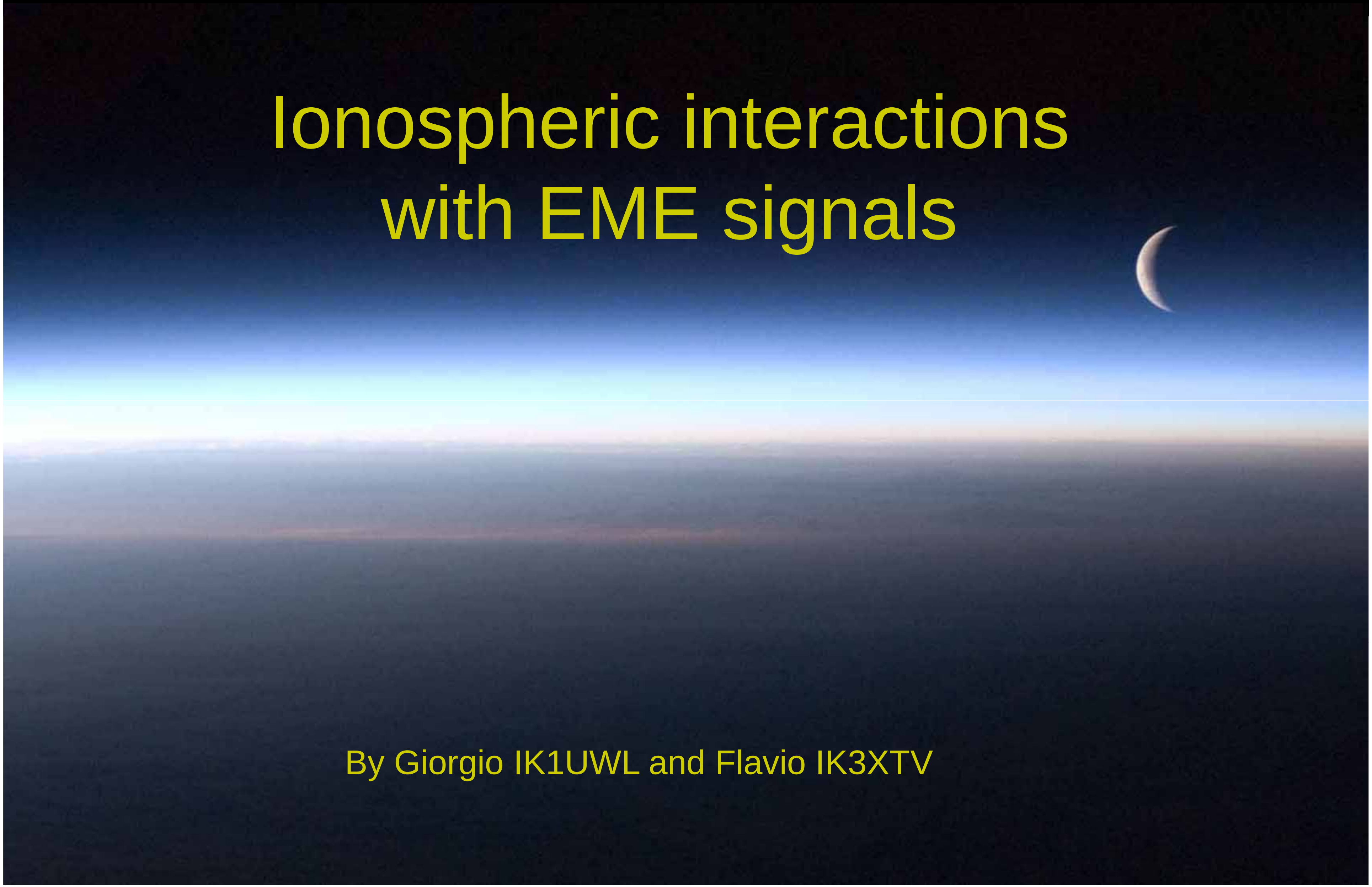
EME 2014 – Parc du Radome – Pleumeur Bodou - France

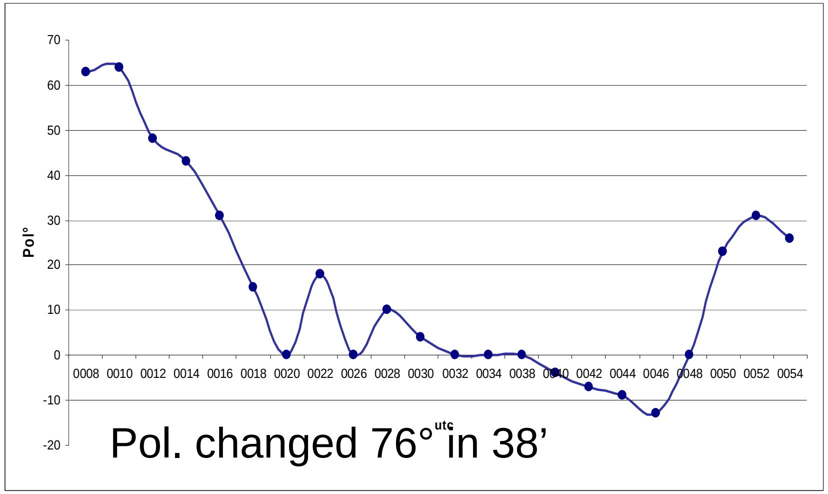


Ionospheric interactions with EME signals

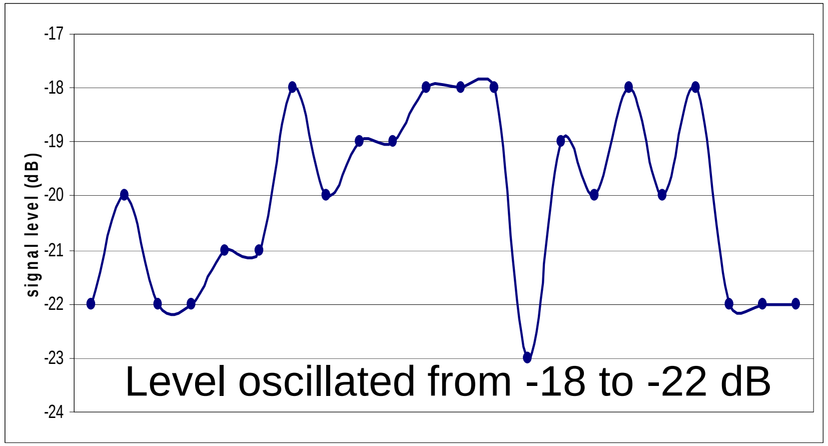
By Giorgio IK1UWL and Flavio IK3XTV

The beginning of this research: a pile-up on 2m band decoded with MAP65

```
Date: 2012-aug-03 – Station IK1UWL -  Band 144 MHz
-------------------------------------------------------------------------------
  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
```



Pol. changed 76° in 38’

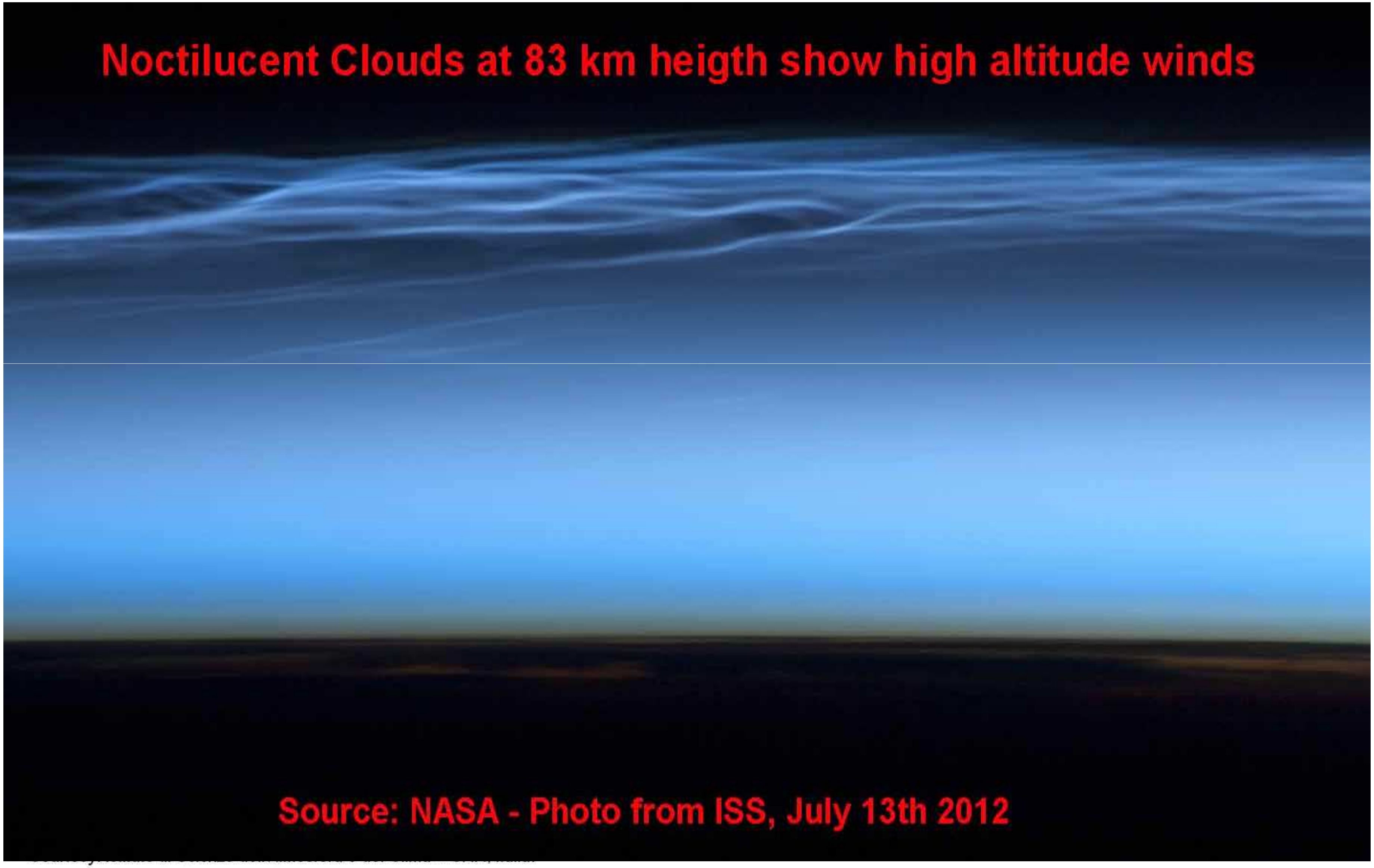


Level oscillated from -18 to -22 dB

MAP65 can be a research tool.
Besides decodes for ham activity,
it measures also levels and polarity.

With this tool we started to research what happens in the ionosphere.

The ionosphere, space weather



Noctilucent Clouds at 83 km heigth show high altitude winds

Source: NASA - Photo from ISS, July 13th 2012

Ionospheric Waves

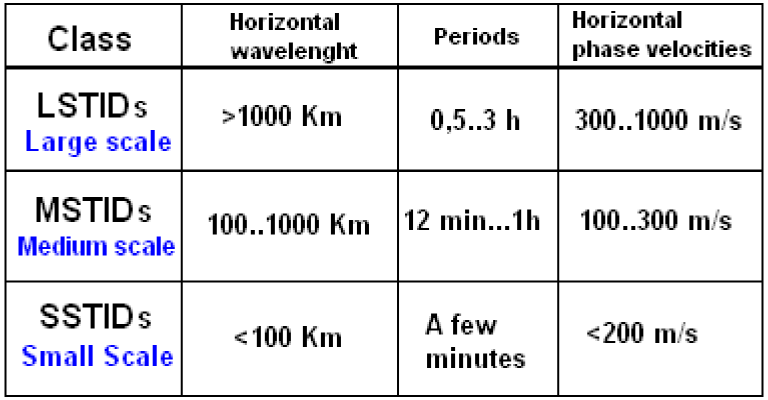
❑. Ionospheric effects: **Attenuation, Deviation, Rotation of the wave**

❑ Winds cause undulations and waves (TIDs), so free electron density varies in space and time.

❑ These fluctuations of electron density have a lens effect on our signals, **focusing or defocusing** them.

- Moon is wide 0.5 degrees
- our beam is wide many degrees
- change of width changes gain

The Travelling Ionospheric Disturbances (TIDs)



Class	Horizontal wavelenght	Periods	Horizontal phase velocities
LSTIDs Large scale	>1000 Km	0,5..3 h	300..1000 m/s
MSTIDs Medium scale	100..1000 Km	12 min...1h	100..300 m/s
SSTIDs Small Scale	<100 Km	A few minutes	<200 m/s

Source: INGV Istituto Nazionale di Geofisica e Vulcanologia - Italy

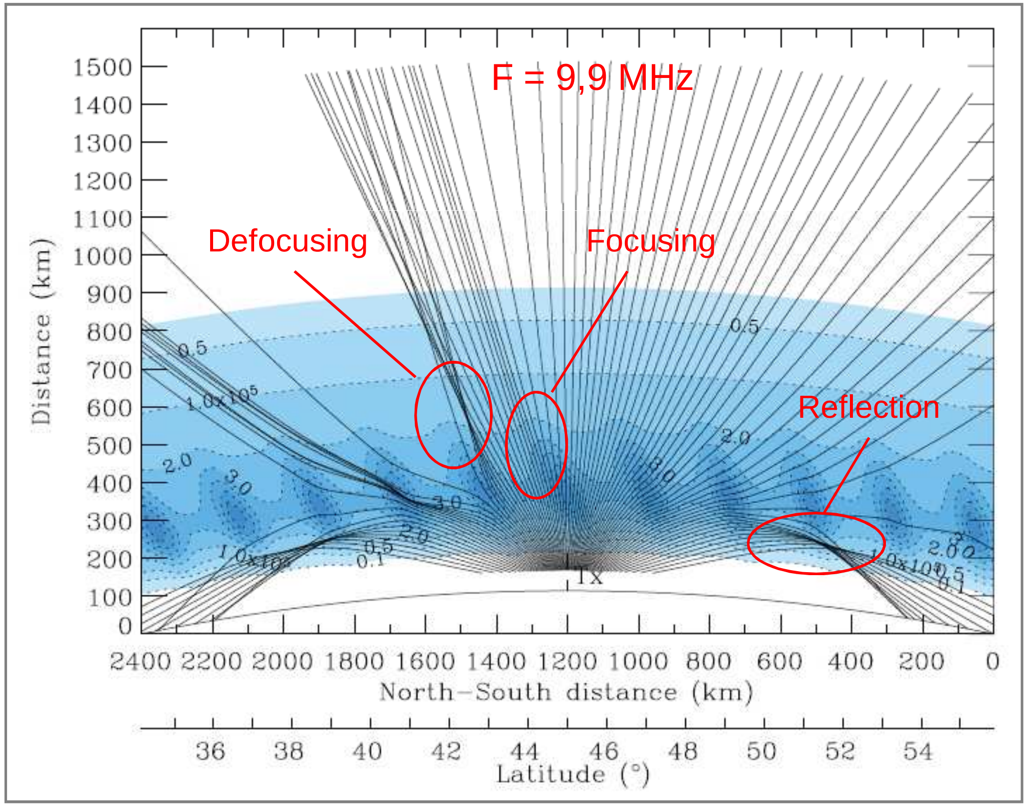
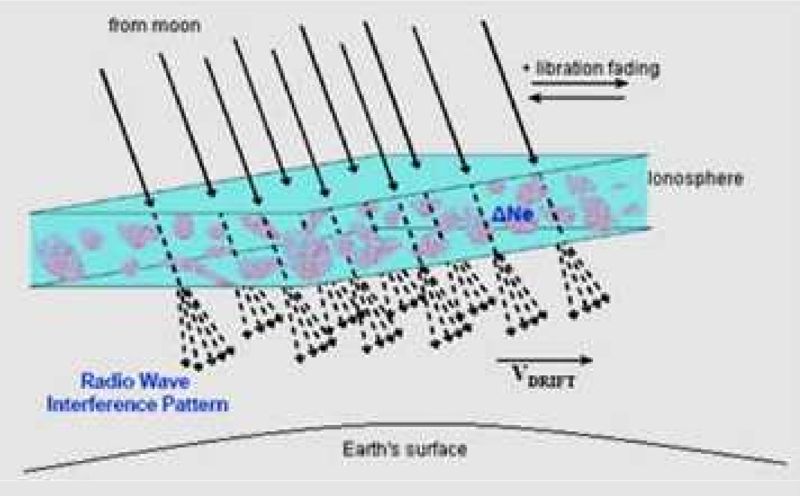


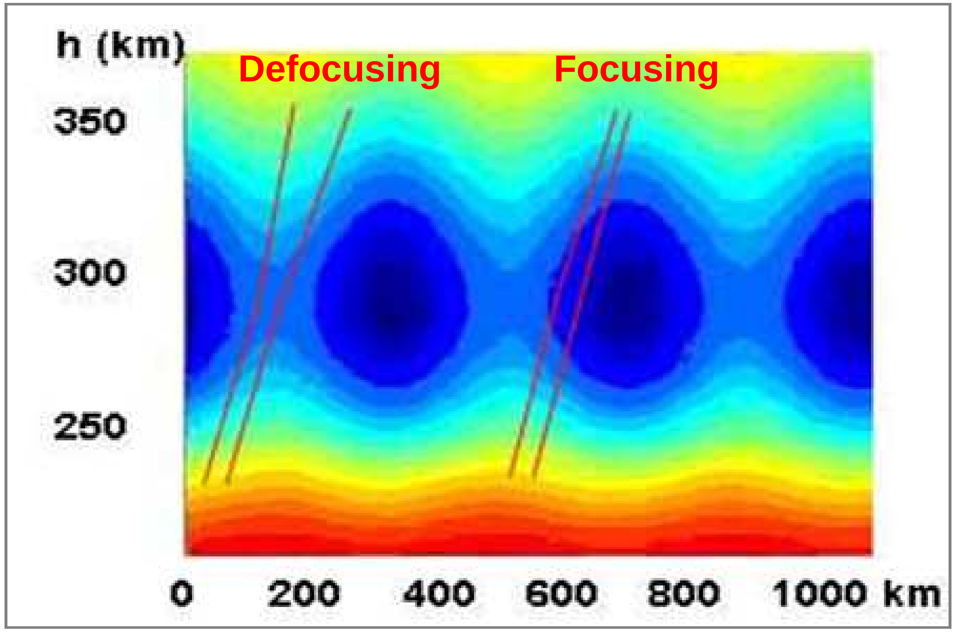
Image source:Research and Technology Organisation. North Atlantic Treaty Organisation. Characterising the Ionosphere. Author: G. Wyman (January 2009)

Focusing/Defocusing effects

- ❑ Fast scintillations caused by lunar libration and ionospheric turbulence (**ssTIDs**, periods of minutes)



- ❑ Slower fluctuations from **msTIDs** (observed at mid latitudes every day) (300 km wavelength, wind 100 m/s = 360 km/h, period 50 minutes)



QSB

- Band dependence (ionospheric refraction is proportional to **$1/f^2$**)

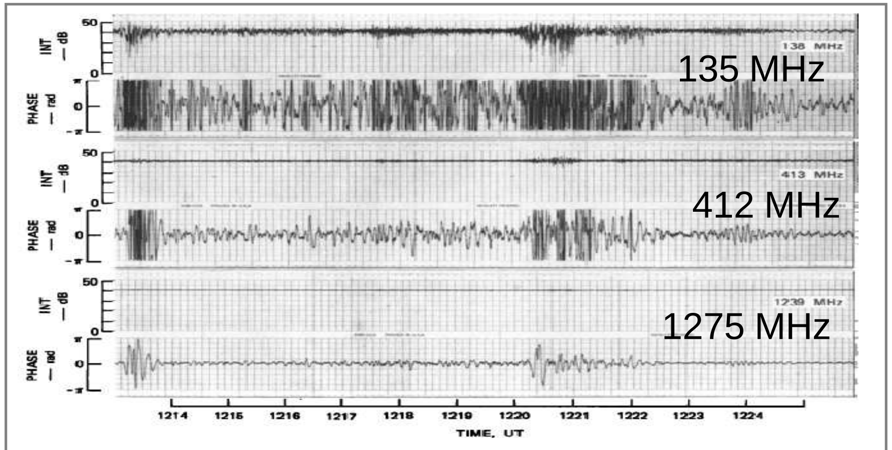
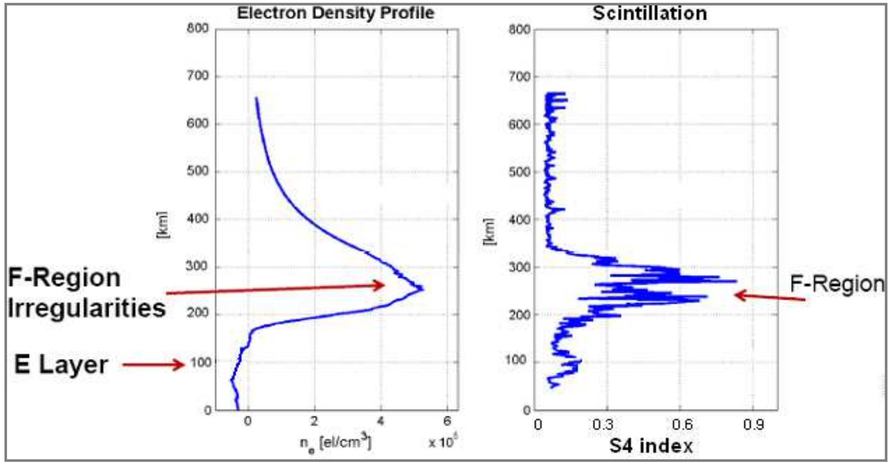


Fig. 8. Detrended VHF, UHF, and *L*-band strip charts from a pass recorded at Poker Flat on 29 May 1976.

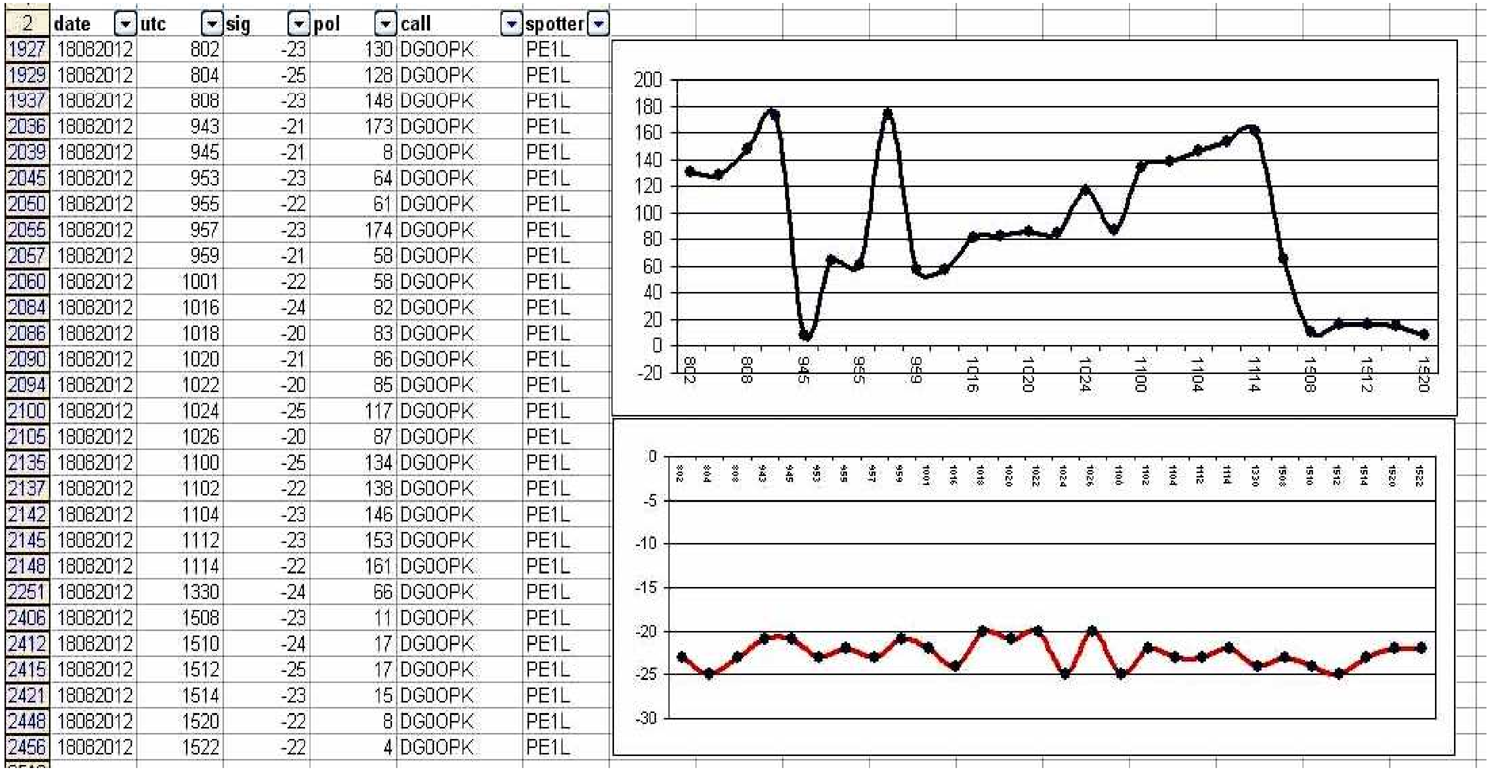
Courtesy: Radio Science, Volume 13, Number 1, pages 167-187, January-February 1978 AGU American Geophysical Union

- Regions dominating the effect



Collecting on-the-air data

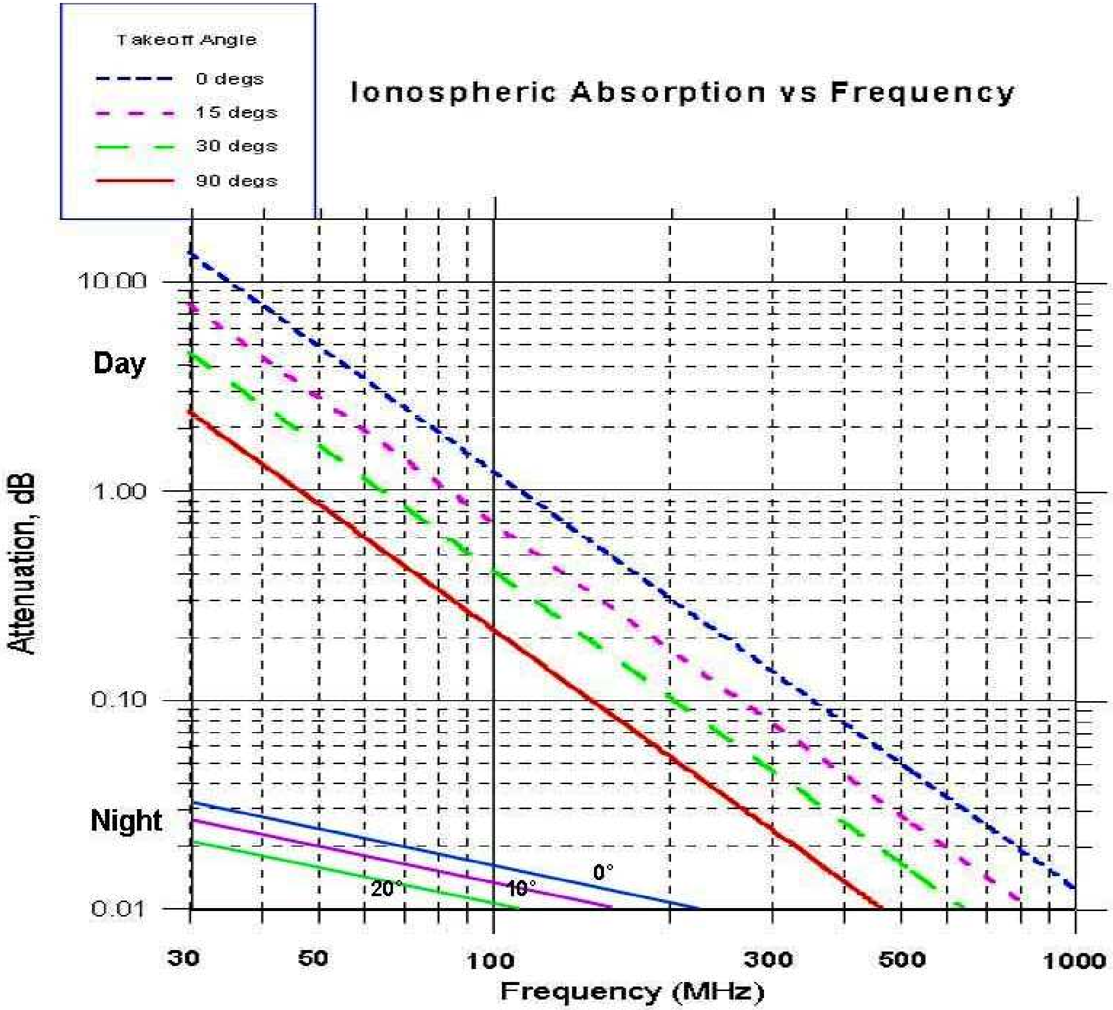
- Results must be checked with real situations, from different sources.
- We chose **LiveCQ** as a source.
- **René PE1L** accepted to store all decodes from MAP65 spotters (all 2m band) in a file.
- We made an Excel sheet, with data sorted by date, spotter and spotted.
- Example: 18/08/2012 – DG0OPK – PE1L, data, pol and level graphs
- *Note: MAP65 rotation is sum of spatial offset and up going and return Faraday rotation*



2	date	utc	sig	pol	call	spotter
1927	18082012	802	-23	130	DG0OPK	PE1L
1929	18082012	804	-25	128	DG0OPK	PE1L
1937	18082012	808	-23	148	DG0OPK	PE1L
2036	18082012	943	-21	173	DG0OPK	PE1L
2039	18082012	945	-21	8	DG0OPK	PE1L
2045	18082012	953	-23	64	DG0OPK	PE1L
2050	18082012	955	-22	61	DG0OPK	PE1L
2055	18082012	957	-23	174	DG0OPK	PE1L
2057	18082012	959	-21	58	DG0OPK	PE1L
2060	18082012	1001	-22	58	DG0OPK	PE1L
2084	18082012	1016	-24	82	DG0OPK	PE1L
2086	18082012	1018	-20	83	DG0OPK	PE1L
2090	18082012	1020	-21	86	DG0OPK	PE1L
2094	18082012	1022	-20	85	DG0OPK	PE1L
2100	18082012	1024	-25	117	DG0OPK	PE1L
2105	18082012	1026	-20	87	DG0OPK	PE1L
2135	18082012	1100	-25	134	DG0OPK	PE1L
2137	18082012	1102	-22	138	DG0OPK	PE1L
2142	18082012	1104	-23	146	DG0OPK	PE1L
2145	18082012	1112	-23	153	DG0OPK	PE1L
2148	18082012	1114	-22	161	DG0OPK	PE1L
2251	18082012	1330	-24	66	DG0OPK	PE1L
2406	18082012	1508	-23	11	DG0OPK	PE1L
2412	18082012	1510	-24	17	DG0OPK	PE1L
2415	18082012	1512	-25	17	DG0OPK	PE1L
2421	18082012	1514	-23	15	DG0OPK	PE1L
2448	18082012	1520	-22	8	DG0OPK	PE1L
2456	18082012	1522	-22	4	DG0OPK	PE1L

Static ionosphere absorption

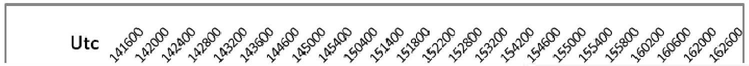
- At 50 MHz there are 5 dB at MR, then it decreases towards 1,5 dB.
- At 144 MHz the trend is 0,5 to 0,1 dB
- Negligible on the higher bands and in night conditions.

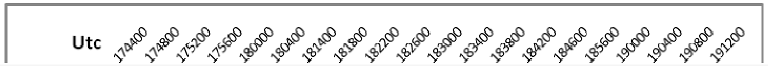


Source:Radio Wave Propagation by Lucien Boithias, published by North Oxford Academic

Dynamic ionosphere: signal level fluctuations

In 2 m JT65B decodes we see fluctuation of the levels, showing both medium term (4’-8’) ripple (2-3 dB) and long term (1-2 h) undulations (4-5 dB).





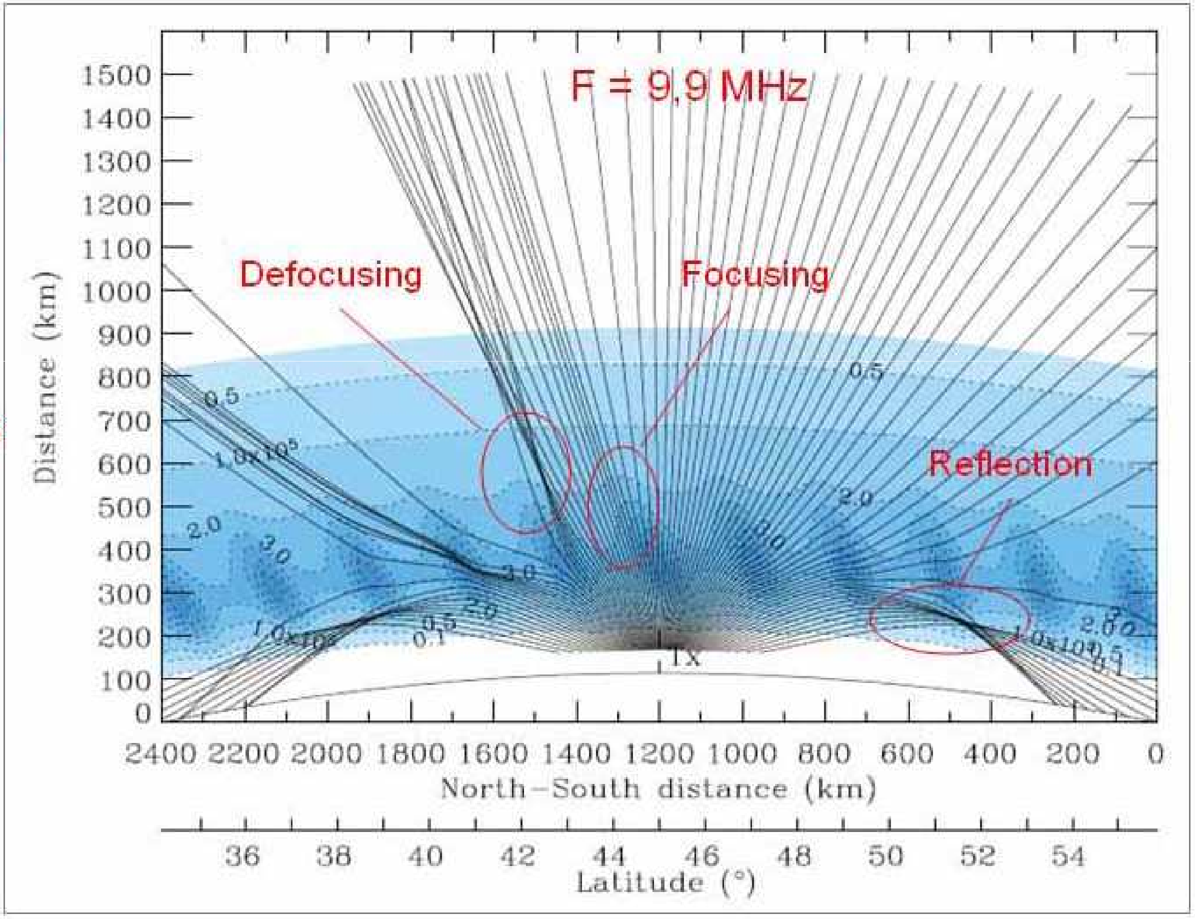
Moon is wide 0,5 deg

Our antenna beam

is wide many degrees

Change of width

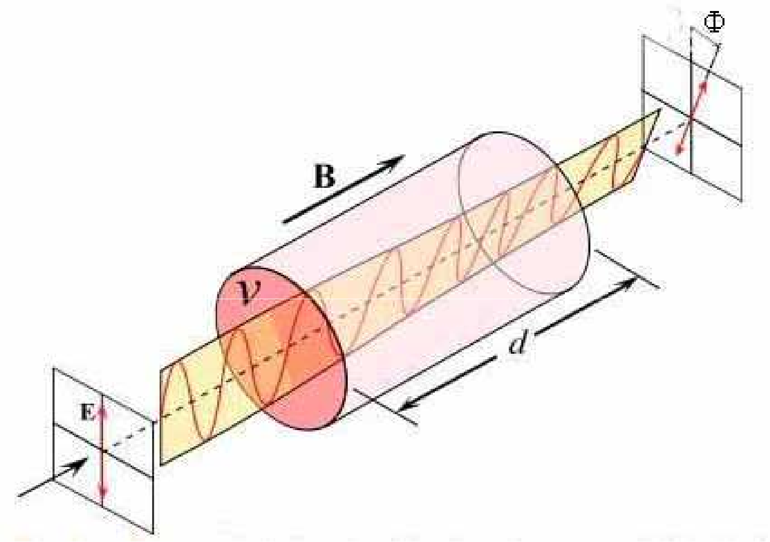
changes gain



Cannot be attributed to variation of attenuation. Most logical explanation is focusing or defocusing in curved layers of ionospheric waves.

Rotation: Faraday effect

- In 1845 Faraday discovered that the plane of polarization of linearly polarized light, traversing a medium, can be rotated by the application of an external magnetic field aligned in the direction in which the light is moving.



An electromagnetic wave, crossing the ionosphere, will rotate by:

Φ = k * B * TEC / f^2 (rad), with:

B = Geomagnetic field component in Moon’s direction

TEC = **T**otal **E**lectron **C**ontent of the path

f = wave frequency

$\Phi = k * B * TEC / f^2$

- **Band dependence**, with same B and TEC:

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

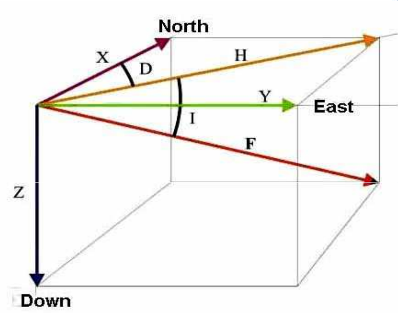
- Microwavers are concerned only by Spatial Offset
- Polar polarization is the angle between an antenna and earth's polar axis.
- **Spatial offset** between two stations is simply the difference between the polar polarizations of the two stations.

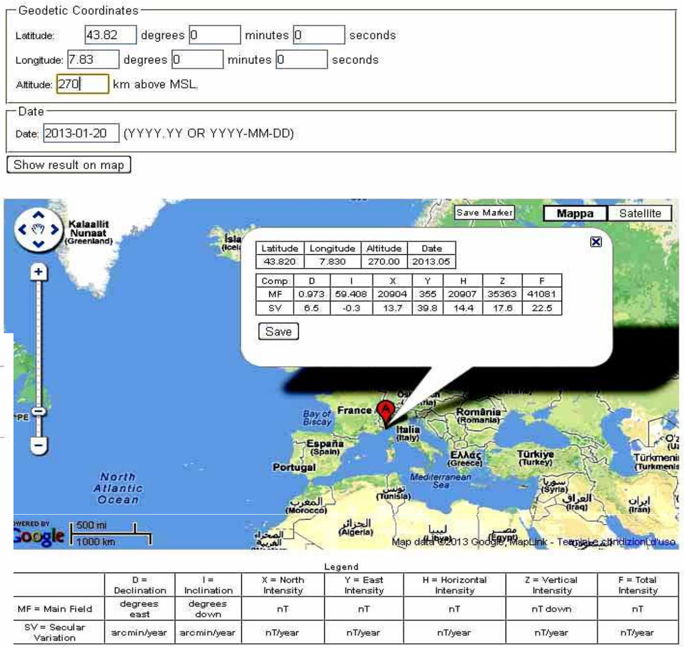
- **For solving the algorithm we need sources for B and TEC**

$\Phi = k * B * TEC / f^2$

- From the web site of the British Geological Survey, introducing Lat&Long of station,
  Median Height of the ionosphere, and Date, one obtains:

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





Geodetic Coordinates

Latitude: 43.82 degrees 0 minutes 0 seconds
Longitude: 7.83 degrees 0 minutes 0 seconds
Altitude: 270 km above MSL.

Date

Date: 2013-01-20 (YYYY.YY OR YYYY-MM-DD)

Latitude	Longitude	Altitude	Date
43.820	7.830	270.00	2013.05

Comp	D	I	X	Y	H	Z	F
MF	0.973	59.408	20904	355	20907	35363	41081
SV	6.5	-0.3	13.7	39.8	14.4	17.6	22.5

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

We need **B, Geomagnetic field component in Moon's direction.**

Vector F is defined by –**I***nclination* and **D***eclination*.
Vector Moon's direction is defined by **Az***imuth* and ***El****evation*.
For projecting Field F on the Moon's direction we need the angle FM between these two vectors. Formula:

cosFM=cosI*cosD*cosEL*cosAz+cosI*sinD*cosEl*sinAz-sinI*sinEl

B = F * cosFM

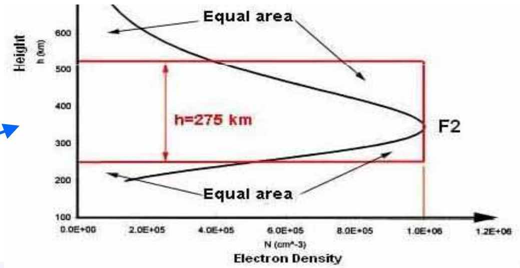
$\Phi = k * B * \mathbf{TEC} / f^2$

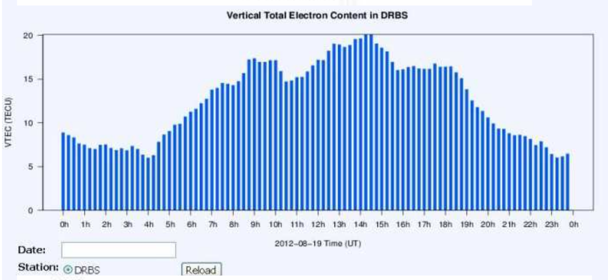
- TEC (Total Electron Content) is measured in TECU (TEC Units) = 10^{16} electrons/m^2
- The number of TECUs represent the total number of electrons present in a cylinder of 1 m^2 of section, crossing the ionosphere in the wave’s direction.
- We used data from the **Royal Observatory of Belgium (ROB),** in **Dourbes**, which publishes VTEC histograms with values every 15’, and archives each day of the year.

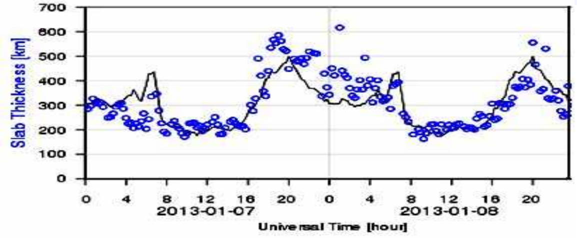
The ionosphere cannot be defined by a number, since its density varies with altitude.
A useful schematization is representing it by a slab of uniform density.
<u>This slab represent the transformation of the real ionosphere in an equivalent ionosphere</u>

With two numbers we can represent an equivalent ionosphere.

The ROB (Dourbes) site gives both VTEC and Slab Thickness







TEC: From Dourbes to other places

- **TEC Longitudinal variation:** Global trend quite regular and correlated to the local solar time

- **TEC Latitudinal variation**

The TEC value, varies non-linearly from the poles to the equator (geomagnetic)
With the algorithm representing this curve, introducing the Mag. Lat. of the station,
we find the correction of Dourbes VTEC.

- **Slant TEC**

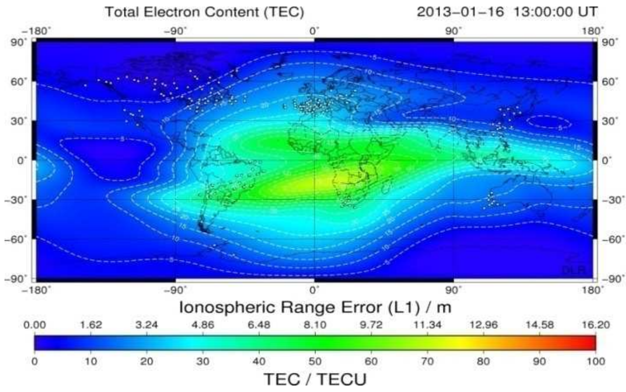
Crossing the slab obliquely there are more electrons.
Instead of Vertical TEC we must use Slant TEC.

TEC = STEC = Ka*VTEC

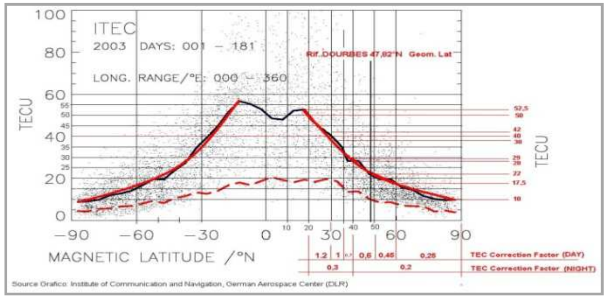
With Earth radius=6367 km, Ionosphere beginning at 100 km height, and h=Slab Thickness

Ka =(SQR((6467+h)^2-(6367*cosEl)^2)-SQR(6467^2-(6367*cosEl)^2))/h

Global VTEC Map

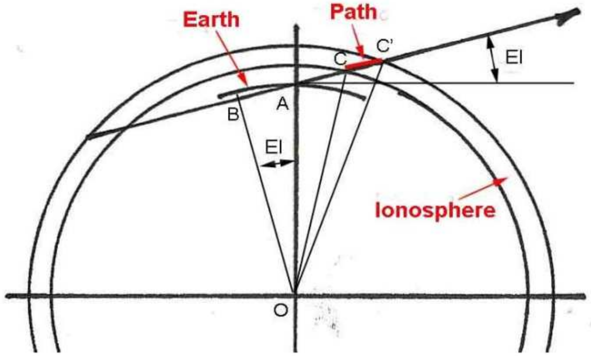


Institute of Communication and Navigation, German Aerospace Center (DLR)



Source Grafico: Institute of Communication and Navigation, German Aerospace Center (DLR)

TECU variation = 0,02*LAT^2-2,5*LAT+95



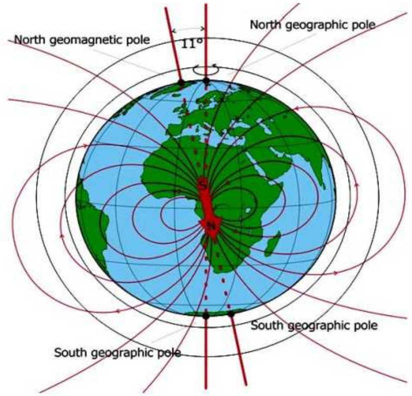
$\Phi=k*(F*cosFM)*(VTEC*corr*Ka)/f^2$

- We now have the data for the complete formula.
  For 144 MHz, $k/f^2=1,14$ with F in Gauss.

- Wave plane rotation is controlled by these variables:

☐ **Angle FM between Geomag. field and Moon direction**

N hemisphere:
cosFM ranges from 0 to -1
S hemisphere:
cosFM ranges from 0 to 1

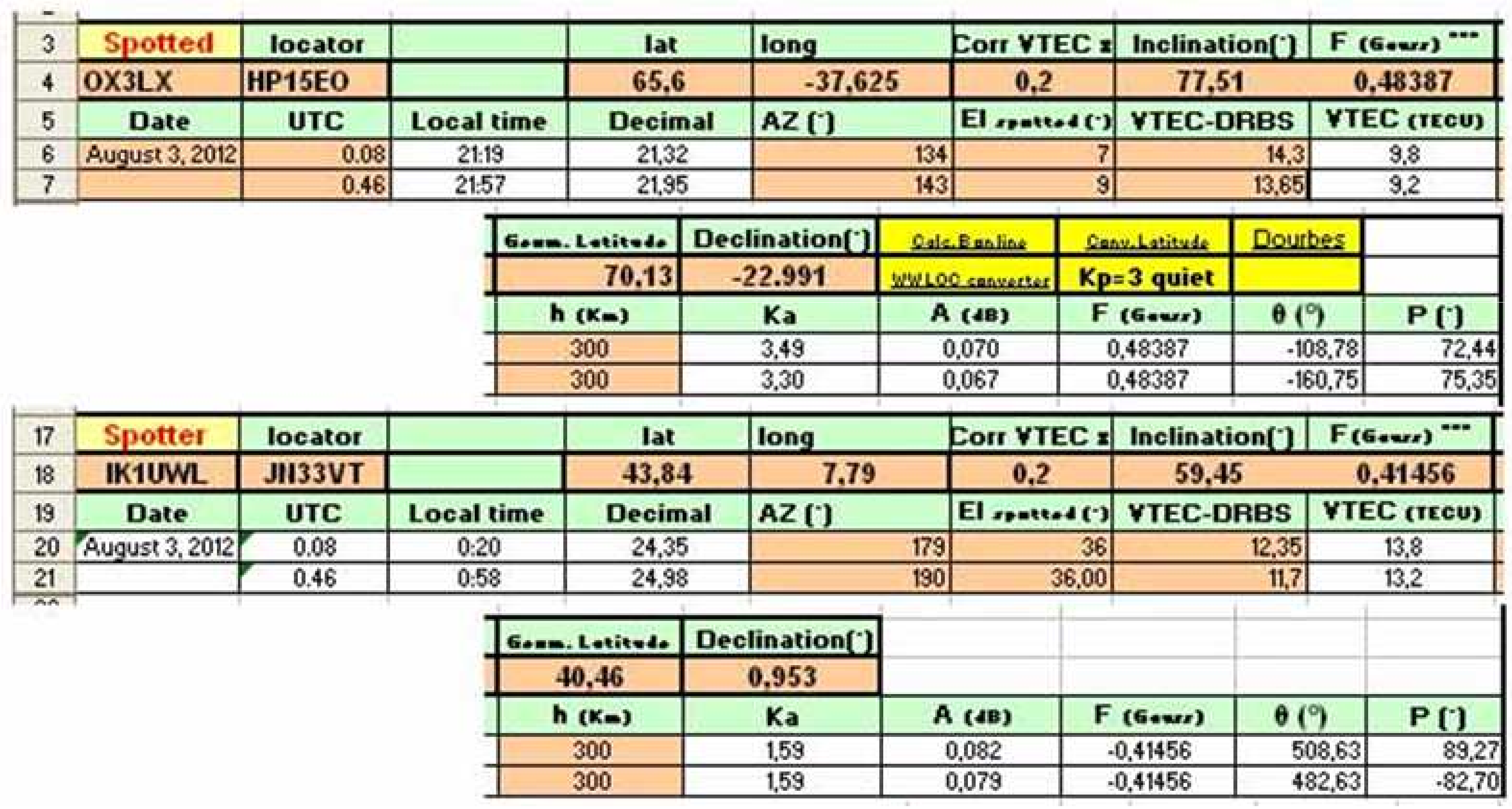


☐ **TEC (constant or changing slowly, 100% to 30%)**

☐ **Moon elevation (slant passage Ka from 3.7 towards 1)**

First check, amount of rotation

- We made an Excel sheet, and we got good congruence in the majority of cases analyzed. Example:



3	Spotted	locator		lat	long	Corr VTEC x	Inclination(°)	F (Gauss) ***
4	OX3LX	HP15EO		65,6	-37,625	0,2	77,51	0,48387
5	Date	UTC	Local time	Decimal	AZ (°)	El spotted (°)	VTEC-DRBS	VTEC (TECU)
6	August 3, 2012	0.08	21:19	21,32	134	7	14,3	9,8
7		0.46	21:57	21,95	143	9	13,65	9,2

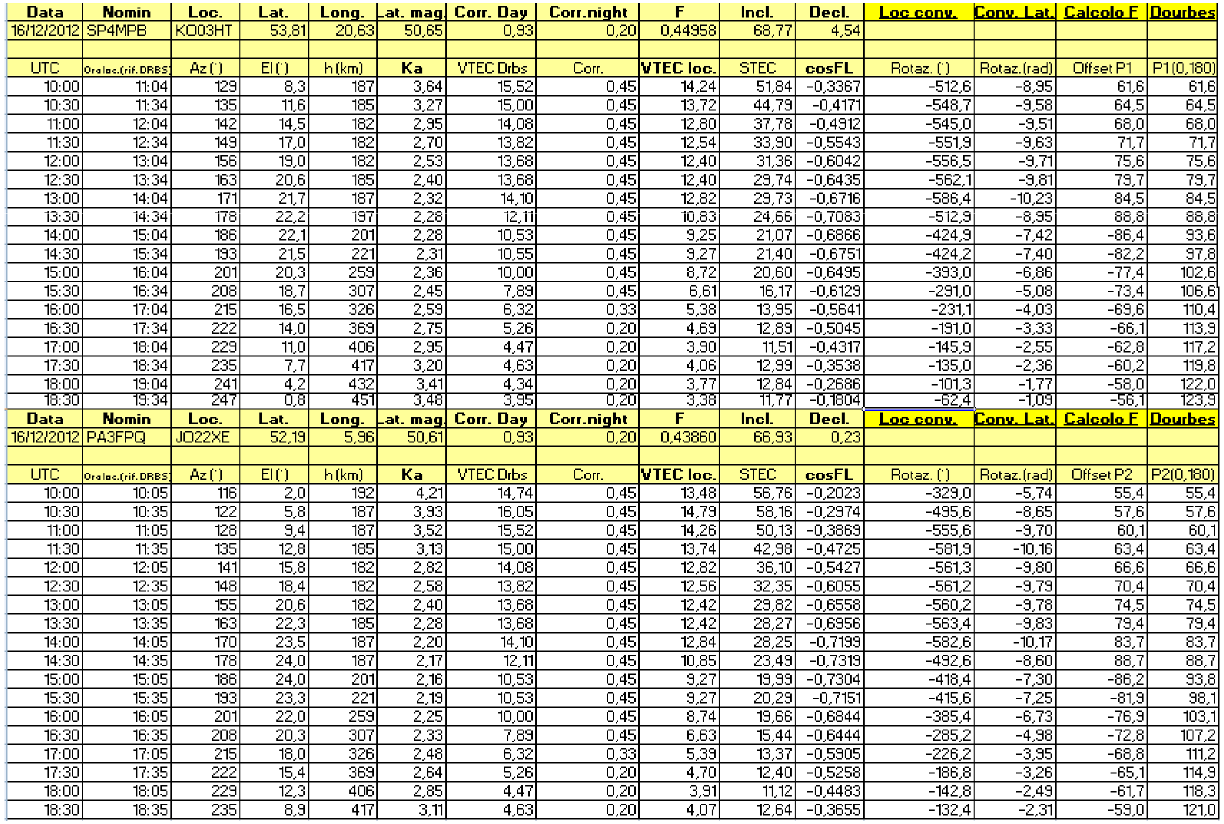
Geom. Latitude	Declination(°)	Calc.Bgnline	Conv.Latitude	Dourbes	
70,13	-22.991	WWLOC converter	Kp=3 quiet		
h (Km)	Ka	A (dB)	F (Gauss)	θ (°)	P (°)
300	3,49	0,070	0,48387	-108,78	72,44
300	3,30	0,067	0,48387	-160,75	75,35

17	Spotter	locator		lat	long	Corr VTEC x	Inclination(°)	F (Gauss) ***
18	IK1UWL	JN33VT		43,84	7,79	0,2	59,45	0,41456
19	Date	UTC	Local time	Decimal	AZ (°)	El spotted (°)	VTEC-DRBS	VTEC (TECU)
20	August 3, 2012	0.08	0:20	24,35	179	36	12,35	13,8
21		0.46	0:58	24,98	190	36,00	11,7	13,2

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

Common-moon pol. total trend

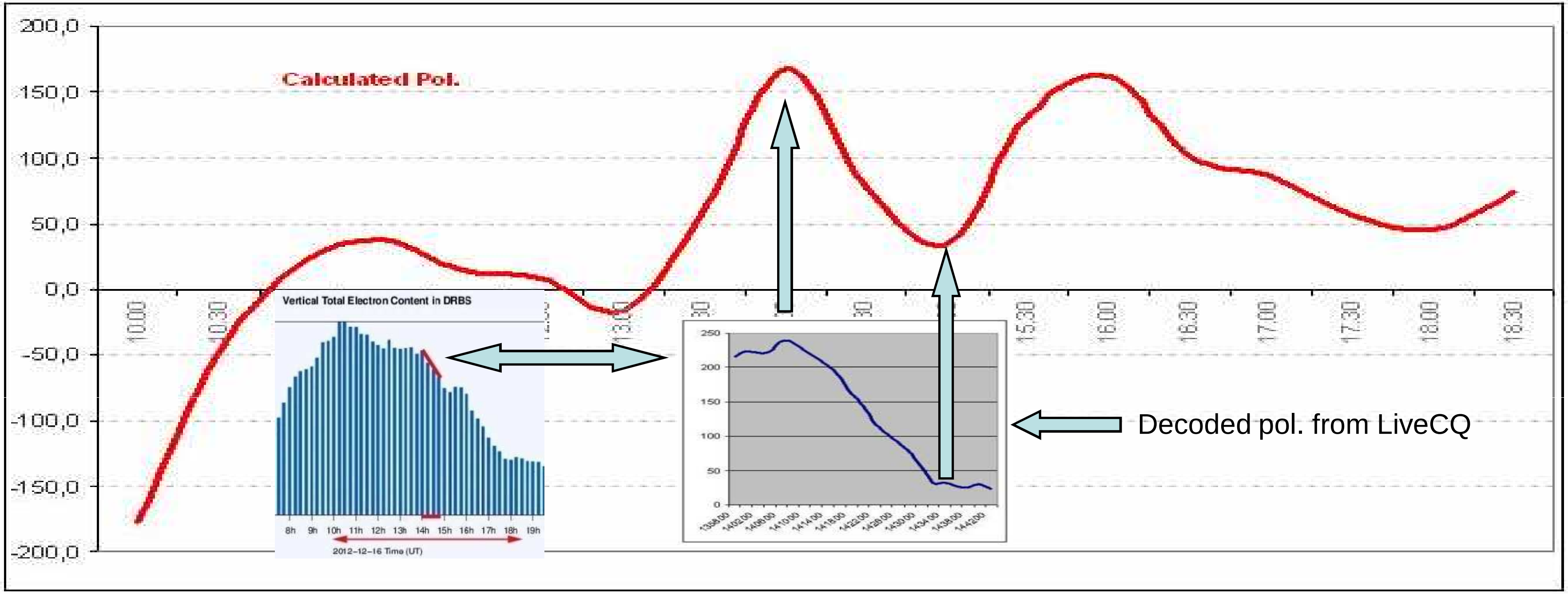
- Having now confidence in the basic correctness of formula and correction coefficients, we proceeded to build a new Excel sheet, covering the entire common-moon period.
- Partial checks were possible using the LiveCQ decoded periods.
- Example: SP4MPB spotted by PA3FPQ, total pass:



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	KO03HT	53,81	20,63	50,65	0,93	0,20	0,44958	68,77	4,54				
UTC	Ora loc.(rif. DRBS)	Az (°)	El (°)	h (km)	Ka	VTEC Drbs	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	JO22XE	52,19	5,96	50,61	0,93	0,20	0,43860	66,93	0,23				
UTC	Ora loc.(rif. DRBS)	Az (°)	El (°)	h (km)	Ka	VTEC Drbs	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	-0,2974	-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

POL trend: SP4MPB spotted by PA3FPQ

16-12-2012 – 1000 km ENE of spotter

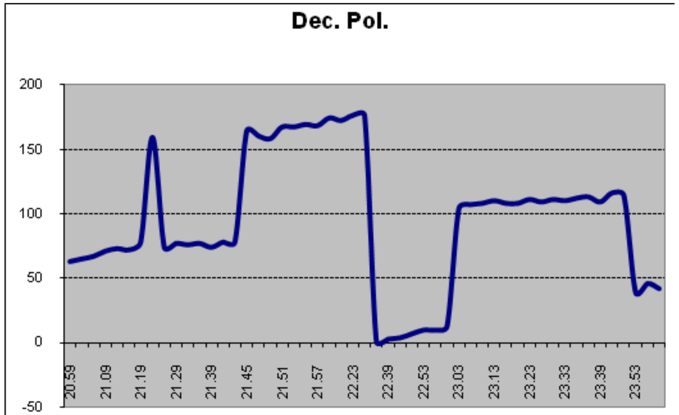


Decoded pol. from LiveCQ

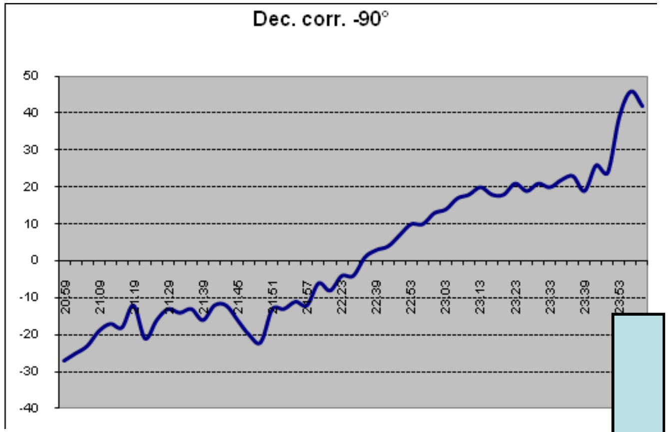
- SP4MPB was active from 13.58 to 14.42 utc (near sunset)
- In this phase, TEC had a quick decrease.
- Followed by a brief increase pre sunset, then decreasing from sunset to night.
- Calculated and real trend are coherent.

Pol trend: I2FAK spotted by PA3FPQ

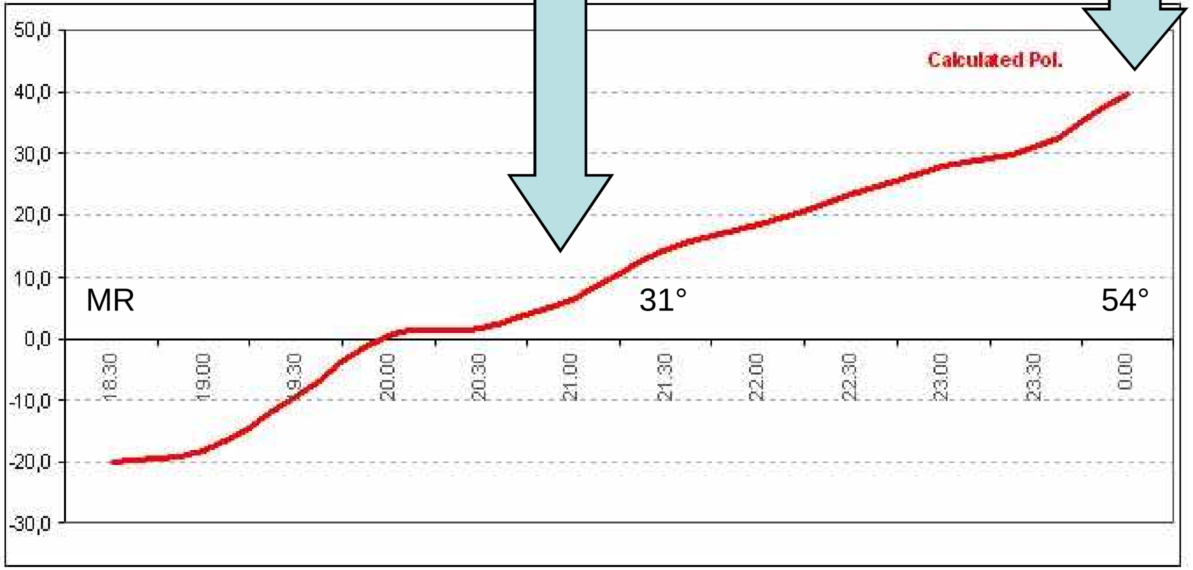
1/12/2012 – Contest ARRL – 828 km SSE of spotter



Xpol antenna; Tx H and V



Night conditions, with increasing Moon elevation

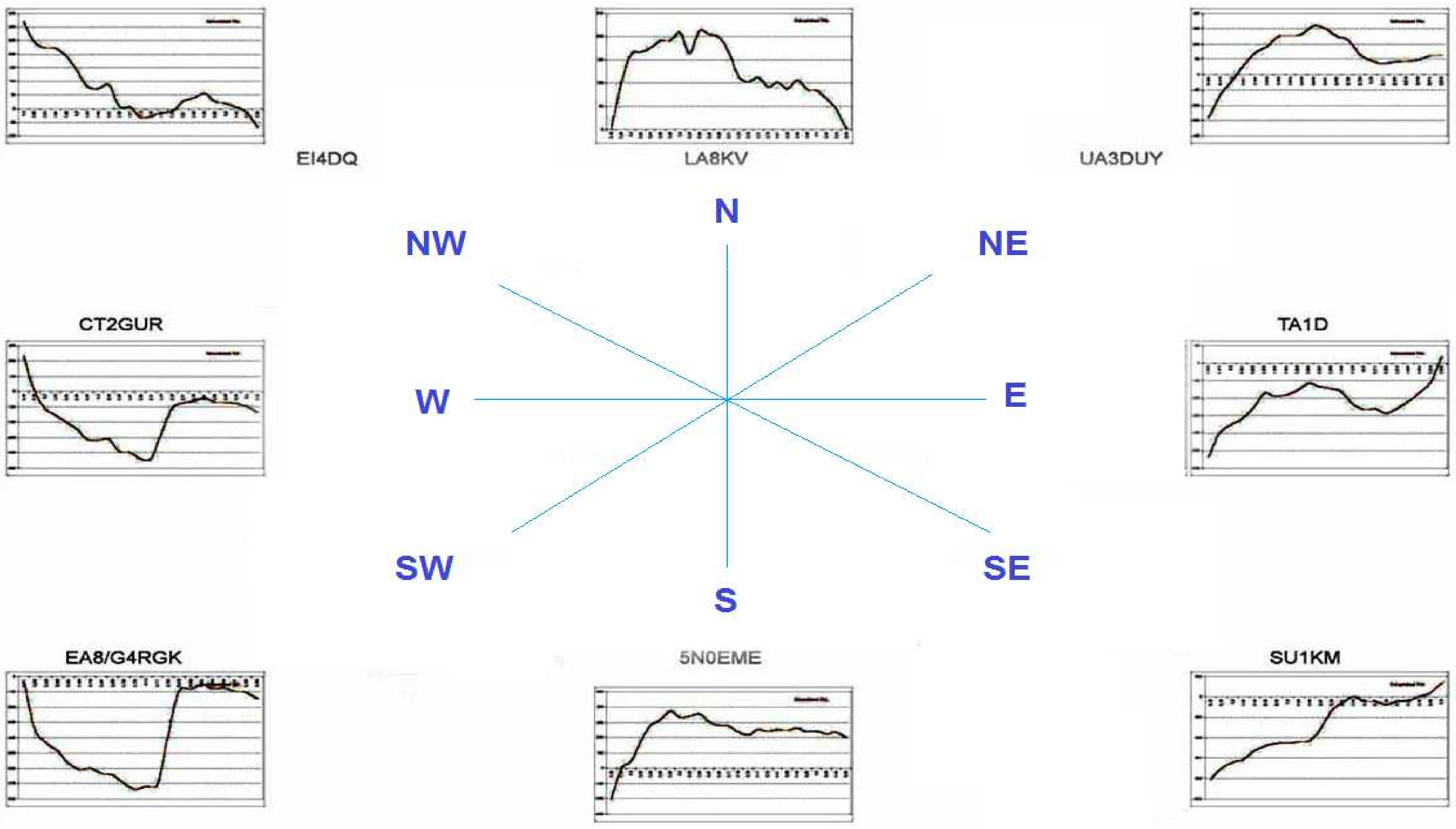


VTEC

Pol. trends as function of direction

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

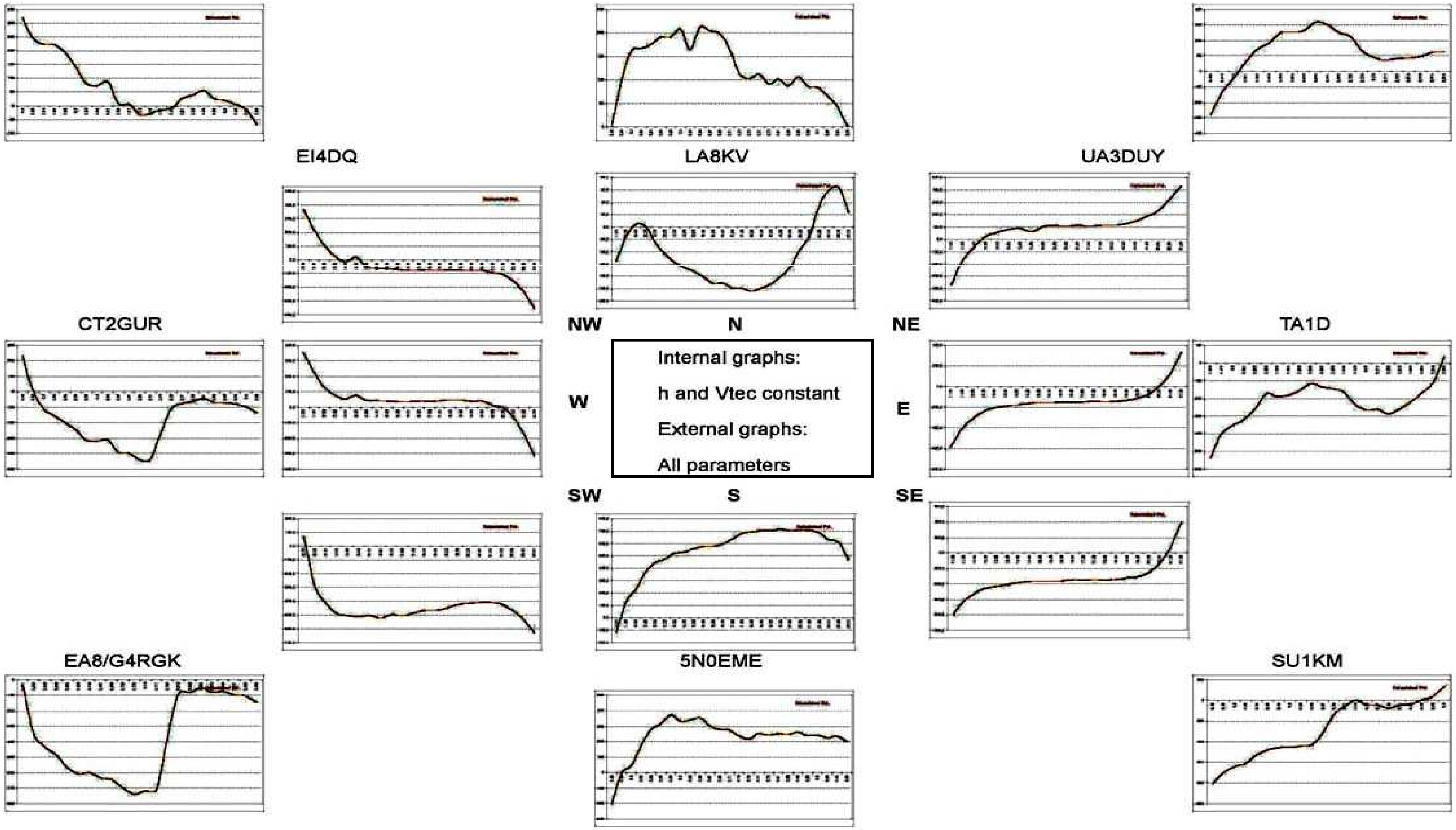
$$\Phi=k*(F*\cos FM)*(VTEC*corr*Ka)/f^2$$



Pol. trends as function of direction

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

$$\mathbf{\Phi=k*(F*cosFM)*(VTEC*corr*Ka)/f^2}$$



Internal graphs:

h and Vtec constant

External graphs:

All parameters

Pol. trends as function of direction

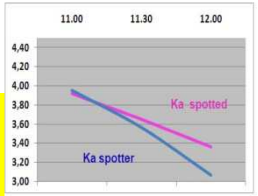
- Spotter IK1UWL, (Band 144 MHz - Dec 19, 2012 – Moon 11.00 – 23.00 UTC)
- All graphs computed for stations in a rose of directions

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

Westward stations

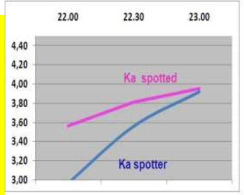
1st hour: They have MR,
My Moon higher.
Their cosFM dominates.
Pol decreases.

Last hour: I have MS,
Their Moon higher.
My cos FM dominates.
Pol. decreases.



Northern stations

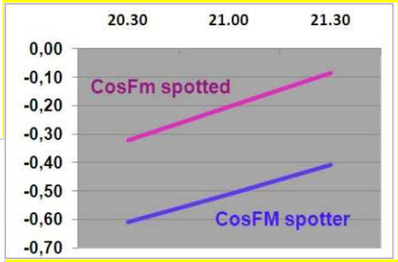
1st and last hour:
My Moon rises and sets more quickly.
My change of Ka dominates.

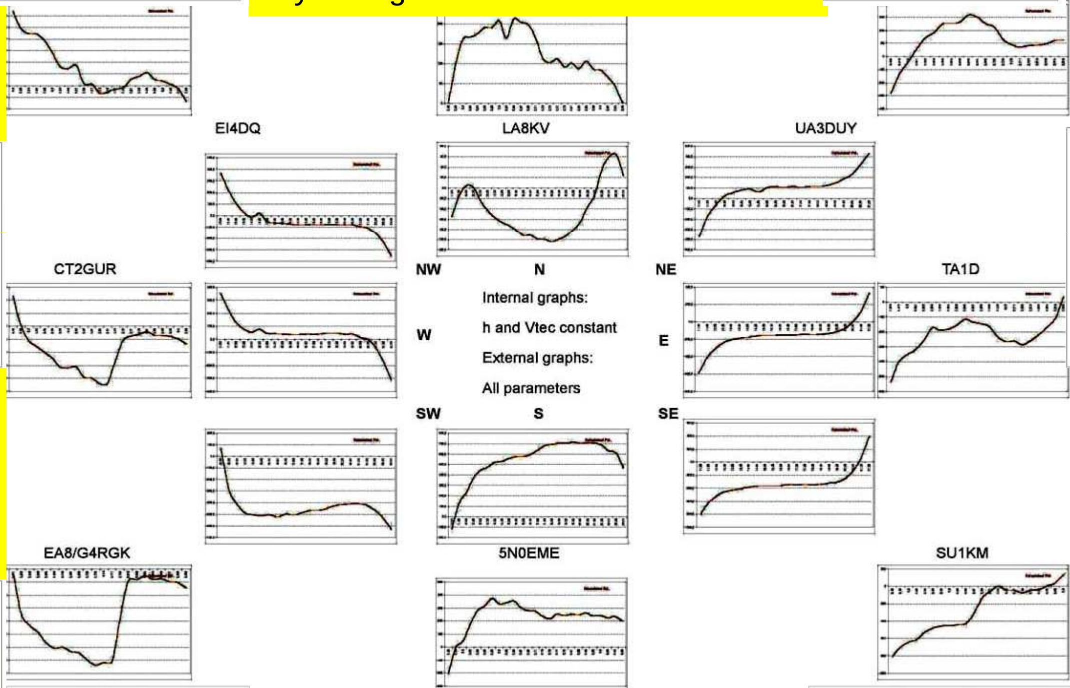


Eastward stations

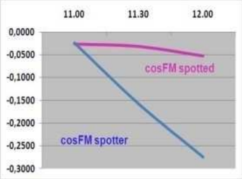
1st hour: I have MR,
their Moon is higher.
My cosFM dominates,
Pol. increases.

Last hour: they have MS,
My Moon is higher.
Their cosFM dominates.
Pol. increases.



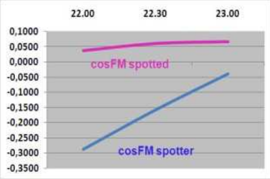


Internal graphs:
h and Vtec constant
External graphs:
All parameters



Southern stations

1° and last hour:
cosFM of spotter changes more quickly



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