T-FORS - 2nd Innovation Day

"Demonstration (forecasting models, effects in operations)“

Axel Garcia [1], Jean-Philippe Molinie [1], Philippe Brouard [1], Mariane Bourret [1], Stefan Unger [2], Jens Toelle [2]

1) ONERA – Département Electromagnetisme et Radar[1]
2) Bundespolizei (German Federal Police) [2]

Outline

1. Over The Horizon Radar (OTH-R) operations (ONERA)
   - ➢ OTH-R principle of operations
   - ➢ TID impact on OTH-R system performances
2. Direction Finding (DF) system operations (GFP)
   - ➢ DF principle of operations
   - ➢ TID impact on DF system performances

❑ expectations from a TID forecast capability

OTH-R principle 1/3

Over-the-horizon skywave radars use the refractive property of HF band electromagnetic waves to refract in the ionosphere to detect moving targets beyond the electromagnetic horizon.

Coherent integration separates moving targets from ground clutter.

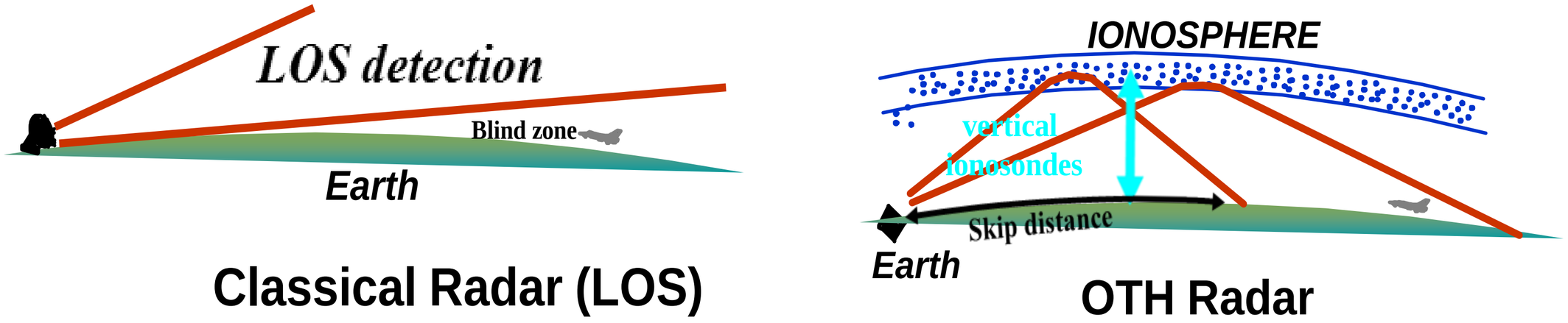


Figure 1: Difference between classical radar and OTH radar

EXAMPLE : NOSTRADAMUS HF OTH-R - ONERA

- Monostatic, surface array HF skywave system
- 288 bicone antenna elements distributed over the arms of a three-branch star
- Buried infrastructure to shelter the transmission and reception electronics
- Full digital radar system upgrade underway
- 360° coverage in azimuth
- Control of the beam in azimuth and elevation
- Located 80 km west from Paris

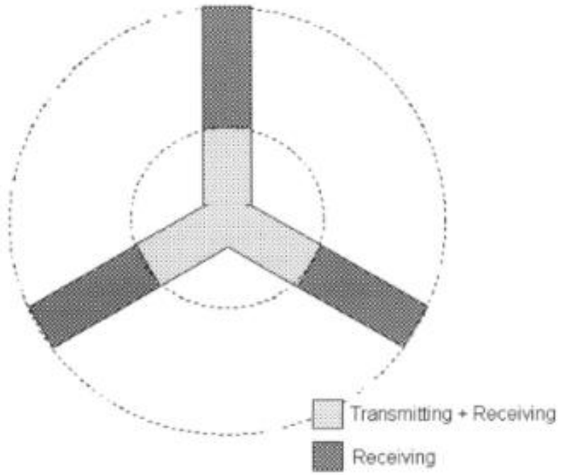


Figure 2: Repartition between transmiting and receiving antennas

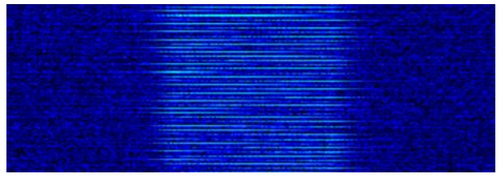
Figure 3: Nostradamus array

OTH-R principle 3/3

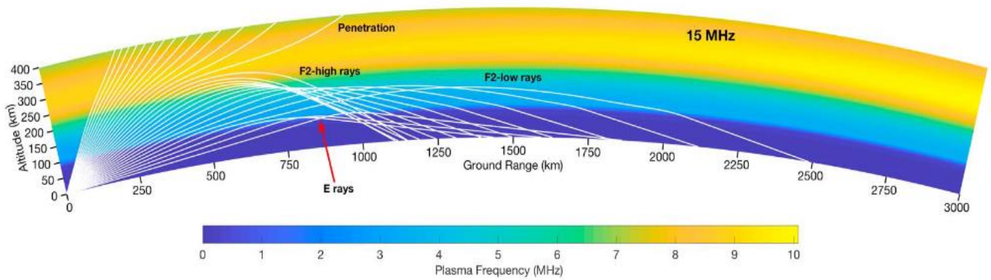
For each mission, transmitted frequency is selected according to

- [frequency allocation]
- noise and interferences, on the receiver side
- type of targets
- area to monitor (beam steering azimuth & elevation angles)
- propagation environment i.e. the ionosphere

Waterfall – OTH-R signal

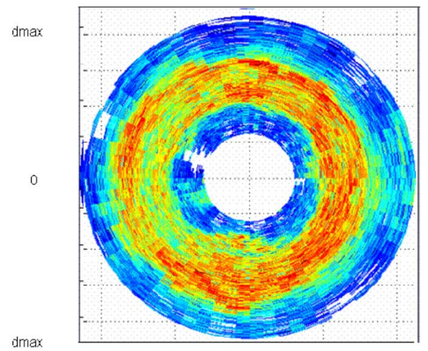


one-way ray-paths



M. A. Cervera, D. B. Francis, et G. J. Frazer, « Climatological Model of Over-the-Horizon Radar », *Radio Science*, vol. 53, n° 9, p. 988-1001, sept. 2018, doi: 10.1029/2018RS006607.

Oblique sounding



V. Bazin *et al.*, « A General Presentation About the OTH-Radar NOSTRADAMUS », in *2006 IEEE Conference on Radar*, Syracuse, NY, USA: IEEE, 2006, p. 634-642. doi: 10.1109/RADAR.2006.1631867.

TID impact on OTH-R

#1 - Radar availability, due to signal attenuation (1)

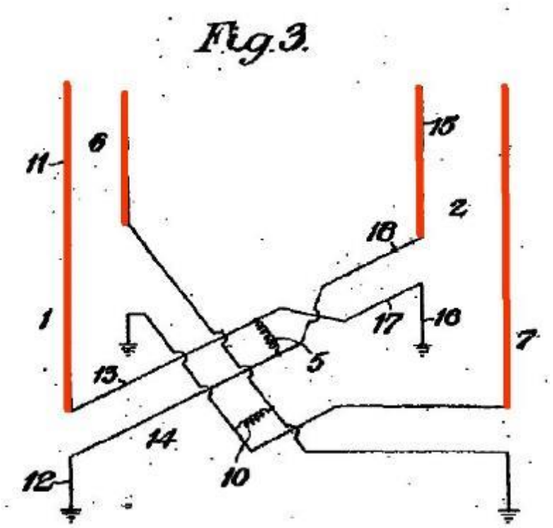
(1) S. Tomei, C. J. Coleman, M. Martorella, et F. Berizzi, « The effect of Travelling Ionospheric Disturbances upon the performance of an HF skywave MIMO radar », in 2013 IEEE Radar Conference (RadarCon13), avr. 2013, p. 1-6. doi: 10.1109/RADAR.2013.6586047.

#2 - Radar accuracy, as HF skywave signals are deflected by TID which results in coordinate registration error (2)

(2) L. J. Nickisch, M. A. Hausman, et S. Fridman, « Traveling Ionospheric Disturbance Mitigation for OTH Radar », in 2007 IEEE Radar Conference, avr. 2007, p. 362-366. doi: 10.1109/RADAR.2007.374243.

HF Direction Finding system - GFP

- Highly sensitive antenna system
- Rod antennas installed in two 16/8 elements concentric circles
- For skywave with high bearing accuracy
- Used as a directional antenna in order to analyze the azimuth of arriving HF signals
- Located 30 km south from Cologne



DF concept

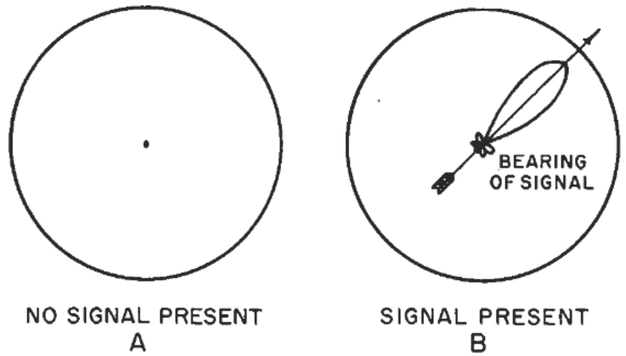
Picture of DF array

Google Earth View of DF array

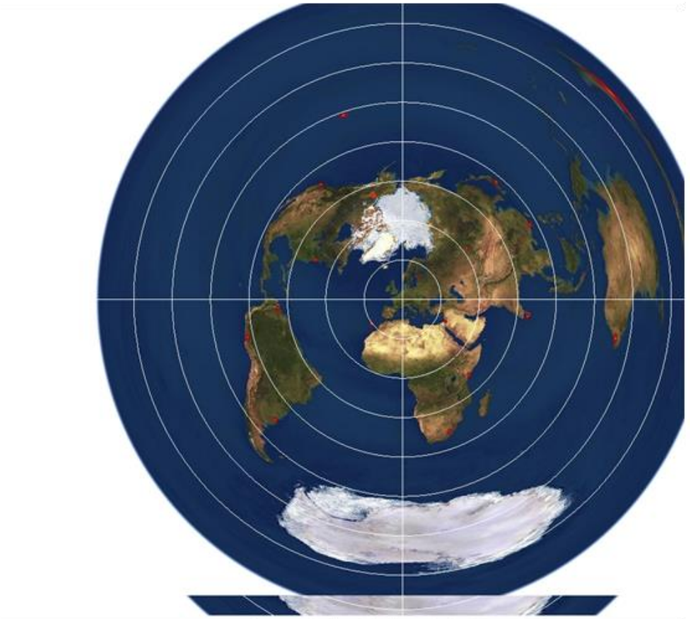
HF Direction Finding system - GFP

- For skywave with high bearing accuracy
- Used as a directional antenna in order to analyze the azimuth of arriving HF signals

https://seefunknetz.de



DF principle 2/3



Beacon	Beam Heading	Distance	Propagation
4U1UN	295°	6132 km	14 18 21 24 28
VE8AT	344°	6645 km	14 18 21 24 28
W6WX	321°	9237 km	14 18 21 24 LP
KH6RS	343°	12151 km	14 18 21 24 28
ZL6B	51°	18861 km	14 18 21 24 28
VK6RBP	100°	14005 km	14 18 21 24 28
JA2IGY	39°	9599 km	14 18 21 24 28
RR9O	51°	5078 km	14 18 21 24 28
VR2B	62°	9415 km	14 18 21 24 28
4S7B	98°	8220 km	14 18 21 24 LP
ZS6DN	160°	8592 km	14 18 21 24 28
5Z4B	142°	6218 km	14 18 21 24 28
4X6TU	116°	2980 km	14 18 21 24 28
OH2B	34°	1781 km	14 18 21 24 28
CS3B	238°	2600 km	14 18 21 24 28
LU4AA	229°	11213 km	14 18 21 24 28
OA4B	257°	10519 km	14 18 21 24 28
YV5B	264°	8080 km	14 18 21 24 28

Source picture and table:
https://www.ncdxf.org/beacon/AzMap/index.html

Distance and azimuth relative to Ollheim (GFP)

Propagation forecasts courtesy of OH6BG.

Signal strength color code: s0 s? s1 s2 s3 s4 s5 s6 s7 s8 s9

Results – (Example)

- As JR055 (digisonde), is located in the DF-OH2B path, TID azimuth detected over JR055 are used

TID-Event	$AvSQD_{NO\ TID}$	$AZIM_{HF-B}$	$AVSQD_{TID}$	$AZIM_{TID}$	ΔAZIM	Degraded
03/10/2021	8.13	39.5	14.7	267	227.5	YES
06/10/2021	8.13	39.5	0.56	255	215.5	NO
06/10/2021	8.13	39.5	1.67	186	146.5	NO
07/10/2021	8.13	39.5	3.12	220	180.5	NO
08/10/2021	8.13	39.5	9.38	258	218.5	YES
10/10/2021	8.13	39.5	1.63	274	234.5	NO

Figure 8: Path between DF and OH2B beacon

DF - On Ground Operation 1/2

Jun 2024 SSN = 91. Minimum Angle= 3.000 degrees

JN08mp	JO30kq	AZIMUTHS	N. MI.	KM
48.65 N 1.04 E	50.69 N 6.88 E	59.44 243.89	257.7	477.3

REQ.SNR = 19 dB, TX POWER = 1.20 kW, SHORT-PATH

The best operating frequencies (FREQ1, FREQ2, FREQ3) by hour

UTC	SDBW	ΔSIG	REL	SNR	ΔSNR	MUFday	FOT	MUF	HPF	FREQ1	FREQ2	FREQ3
01	-74 (S9+)	20.2	100%	70	24.2	99%	5.0	6.5	7.9	3.6	5.4	7.1
02	-75 (S9+)	19.9	100%	71	25.6	100%	4.8	6.2	7.5	3.6	5.4	7.1
03	-76 (S9+)	20.0	100%	72	26.2	100%	4.7	6.1	7.4	3.6	5.4	7.1
04	-78 (S9+)	25.0	100%	75	30.2	84%	4.8	6.3	7.6	5.4	3.6	7.1
05	-79 (S9+)	23.9	100%	76	30.7	91%	5.2	6.7	8.1	5.4	3.6	7.1
06	-81 (S9+)	26.0	100%	76	31.4	96%	5.5	7.2	8.7	5.4	7.1	3.6
07	-83 (S9+)	23.7	100%	75	28.0	60%	5.8	7.5	9.1	5.4	7.1	3.6
08	-85 (S9+)	20.2	100%	74	25.7	83%	6.0	7.8	9.4	5.4	7.1	10.1
09	-86 (S9+)	24.4	100%	76	28.5	69%	6.0	7.8	9.5	7.1	5.4	10.1
10	-87 (S9+)	21.8	100%	76	27.4	67%	6.2	7.8	9.4	7.1	5.4	10.1
11	-88 (S9+)	25.7	100%	75	29.4	66%	6.4	7.7	9.3	7.1	5.4	10.1
12	-88 (S9+)	26.7	100%	74	30.8	65%	6.4	7.6	9.2	7.1	5.4	10.1
13	-88 (S9+)	30.2	100%	74	34.5	63%	6.4	7.6	9.1	7.1	5.4	10.1
14	-88 (S9+)	31.7	100%	74	36.1	61%	6.2	7.5	9.1	7.1	5.4	10.1
15	-88 (S9+)	30.3	100%	73	34.5	63%	6.0	7.5	9.0	7.1	5.4	3.6
16	-87 (S9+)	25.8	100%	72	32.5	73%	5.8	7.5	9.1	5.4	7.1	3.6
17	-84 (S9+)	25.8	100%	73	32.5	98%	5.9	7.7	9.3	5.4	7.1	3.6
18	-81 (S9+)	18.4	100%	74	27.2	99%	6.2	8.0	9.7	5.4	7.1	3.6
19	-78 (S9+)	18.8	100%	72	28.1	100%	6.4	8.3	10.0	3.6	7.1	5.4
20	-77 (S9+)	16.7	100%	75	24.1	99%	6.4	8.3	10.1	5.4	3.6	7.1
21	-76 (S9+)	18.2	100%	74	22.4	99%	6.2	8.1	9.8	5.4	3.6	7.1
22	-75 (S9+)	19.9	100%	70	22.9	100%	5.9	7.7	9.3	3.6	5.4	7.1
23	-75 (S9+)	21.0	100%	70	24.1	100%	5.6	7.3	8.8	3.6	5.4	7.1
24	-75 (S9+)	21.0	100%	70	25.4	100%	5.3	6.9	8.4	3.6	5.4	7.1

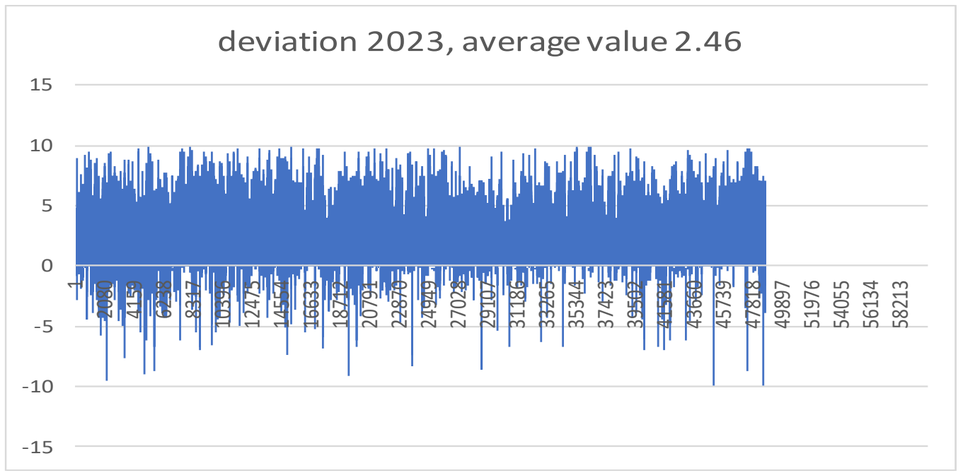
DF - On Ground Operation 2/2

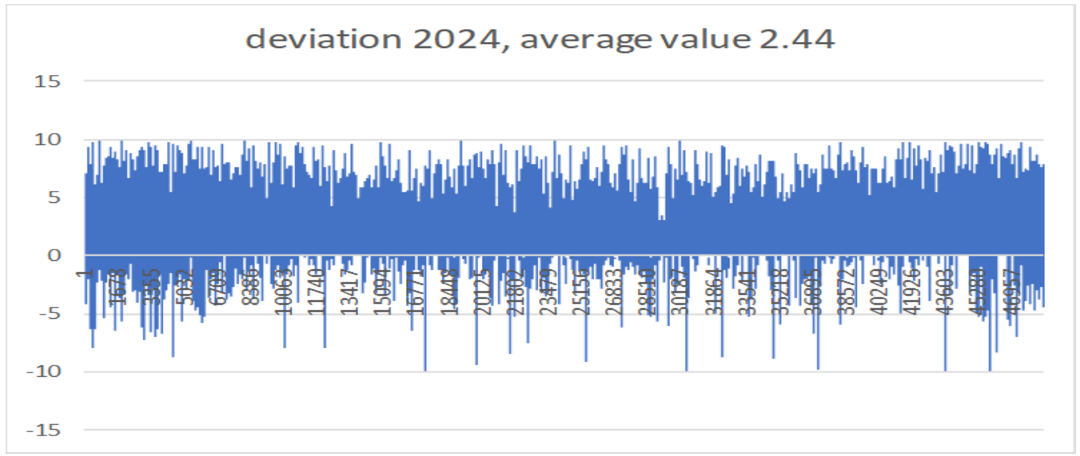
Datarows are transferred to the DF-jobs table and selected every day

06.700|000007 |000014 | |Nostradamus (OTH), (F) | | |OTH Onera, Frankreich, JN08mp | | | | |1234567 |2024-06-01|2026-12-31|
06.700|000015 |000029 | |Nostradamus (OTH), (F) | | |OTH Onera, Frankreich, JN08mp | | | | |1234567 |2024-06-01|2026-12-31| |06.700|000030 |000044 | |Nostradamus (OTH), (F) | | |OTH Onera, Frankreich, JN08mp | | | | |1234567 |2024-06-01|2026-12-31|
06.700	000045	000059		Nostradamus (OTH), (F)			OTH Onera, Frankreich, JN08mp					1234567	2024-06-01	2026-12-31
06.700	000207	000214		Nostradamus (OTH), (F)			OTH Onera, Frankreich, JN08mp					1234567	2024-06-01	2026-12-31
06.700	000215	000229		Nostradamus (OTH), (F)			OTH Onera, Frankreich, JN08mp					1234567	2024-06-01	2026-12-31
06.700	000230	000244		Nostradamus (OTH), (F)			OTH Onera, Frankreich, JN08mp					1234567	2024-06-01	2026-12-31

Example of results

- During the third campaign GFP monitored the beacon OH2B during two years on 14100 kHz
- The deviation in 2023 has an average value of 2.46 degree.
- The deviation in 2024 has an average value of 2.44 degree.
- The deviation was predominantly in the positive range

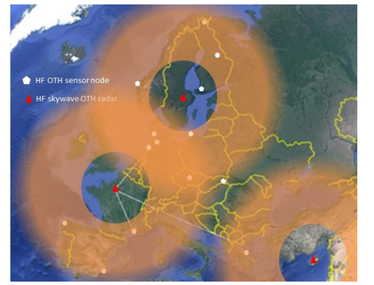




Expectations from a TID forecast capability

#1 – provide alert with e.g. timestamp, link to data sources for main information (Kp, storm parameters,…)

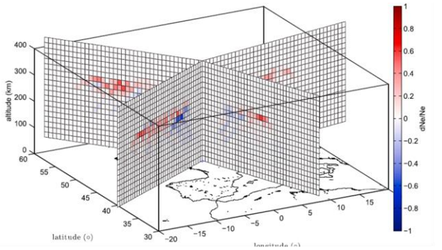
- to anticipate system availability – optimise resource management e.g. by reconfiguring a multistatic OTH-R systems (cf iFURTHER concept)



iFURTHER

#2 - alert + TID parameters

- anticipate TID features, to mitigate in real-time coordinate registration errors



Electron density perturbation obtained by real data inversion measured by the OTH radar Nostradamus

C. Roy, G. Occhipinti, L. Boschi, J. Molinié, et M. Wieczorek, « Effect of ray and speed perturbations on ionospheric tomography by over-the-horizon radar: A new method », *JGR Space Physics*, vol. 119, n° 9, p. 7841-7857, sept. 2014, doi: 10.1002/2014JA020137.

Expectations from a TID forecast capability

Discussion / ways forward