MSF Brussels – 7 March 2023

Introduction to Near Vertical Incidence Skywave

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[1] University of Twente, The Netherlands

[2] Radio Communications Agency Netherlands

1. **Who am I ?**

2. **Near Vertical Incidence Skywave**
   a. It all starts with the sun
   b. Elevation angles
   c. Optimum antenna height
   d. The “Dead Zone” problem
   e. Space weather

3. **PITHIA-NRF project**
   a. Who are we?
   b. How can we help you?

1. Who am I ?

I have an amateur radio background

The Netherlands

1974	NL4496 (SWL)
1981	PA3BXC
1996	PA5BW
2013	PE5B

I lived in several other countries

1961 - 1962	New Guinea (Irian Jaya)	
1982 - 1983	Monaco	PA3BXC / 3A2
1989 - 1991	Israel	4X / PA3BXC
1993 - 1995	Madagascar	5R8DS
2017 - 2019	England	MØIJQ

1. Who am I ?

I made my passion my work

Industry

1982

Trans World Radio
Monaco

Moshav Nes Amim
Israël

KPN Telecom
The Netherlands

Radio Netherlands
Madagascar

Netherlands Broadcast
Transmitter Company

1997

Government

1997

Radiocommunications Agency
Netherlands

today

Academia

2011

University of Twente
The Netherlands

University of Bath
England

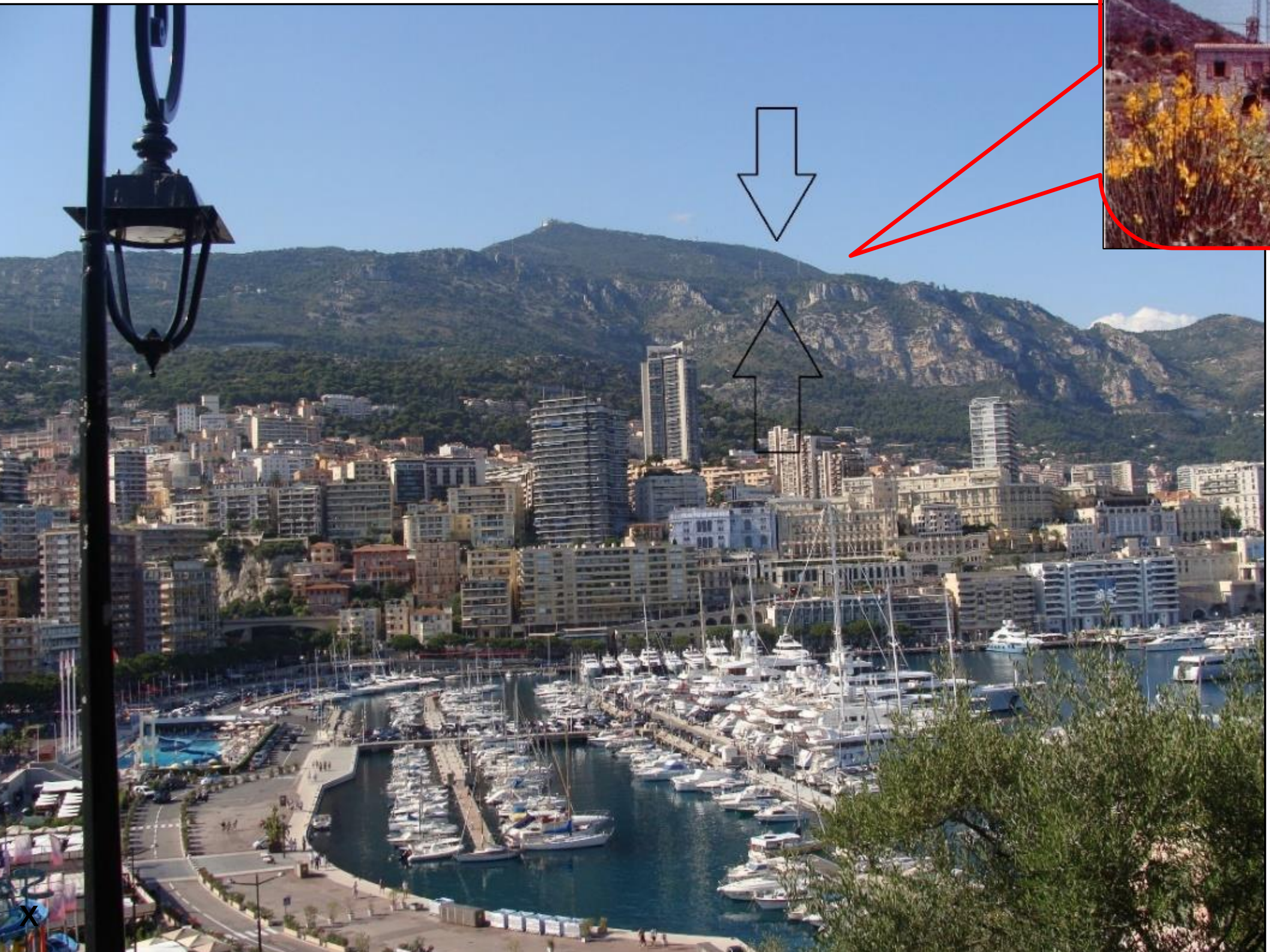
University of Twente
The Netherlands

today

1. Who am I ?

1982 - 1983

Trans World Radio
Monte-Carlo, Monaco



HF 600 kW + 18 dBi
MW 1.2 MW + 2 dBi

Trainee

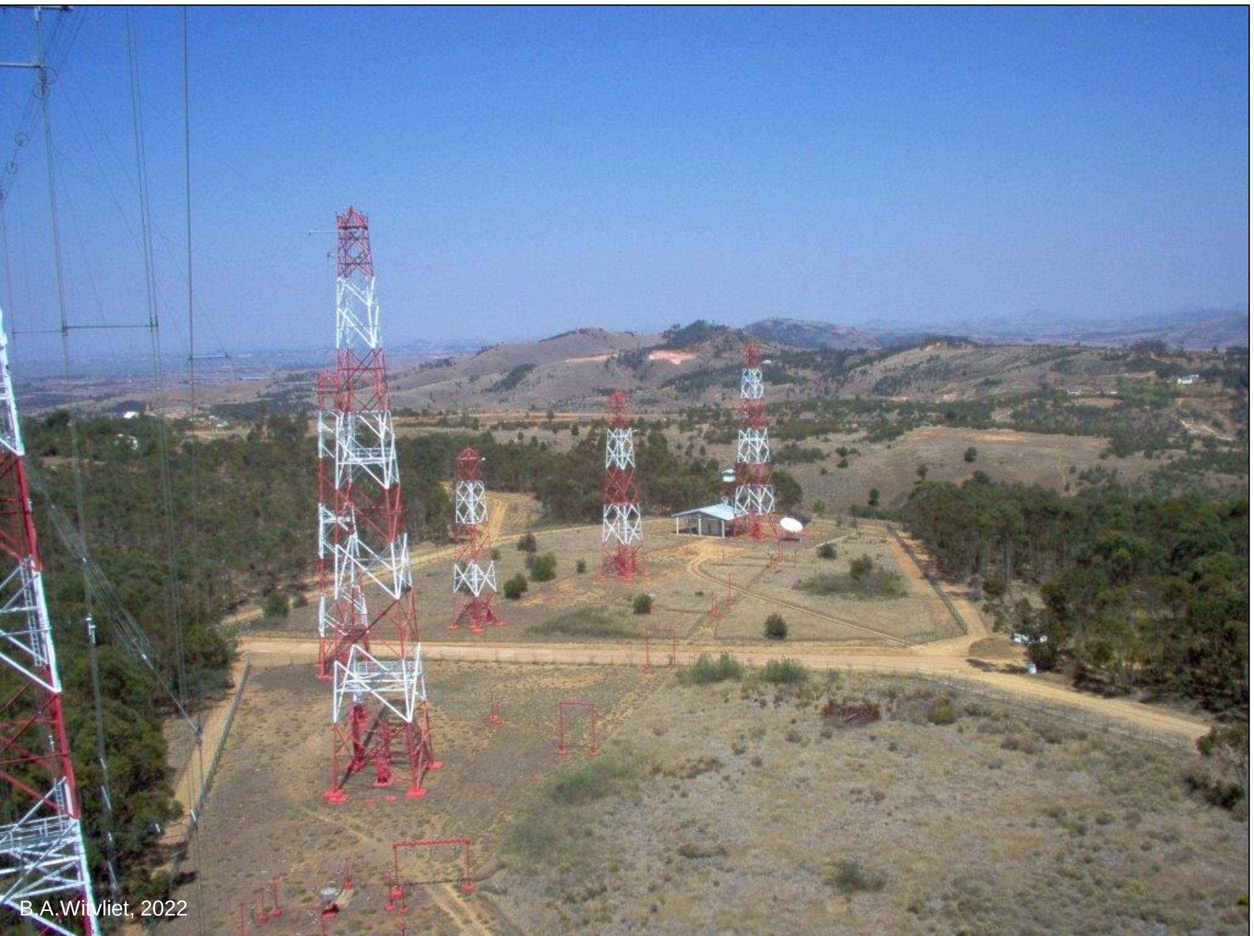
Studio maintenance
Antenna measurements

1. Who am I ?

1993 - 1995

Radio Netherlands Worldservice, Shortwave Relay Station

Antananarivo, Madagascar



Ingénieur en Chef

all Malagasy staff

HF 2x 300 kW AM

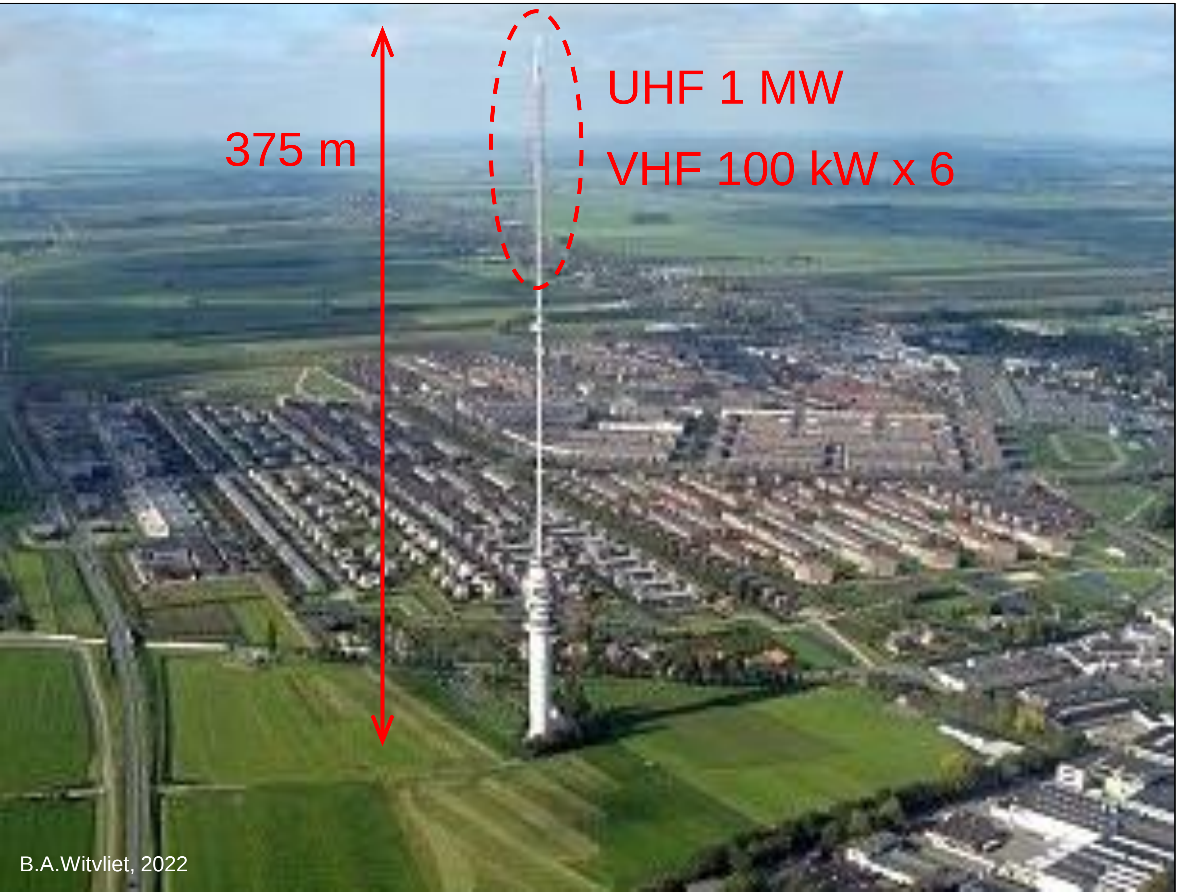
13 slewable
curtain reflector
antennas (18-24 dBi)

1. Who am I ?

1995 - 1997

Netherlands Broadcast Transmitter Company (NOZEMA)

Lopik, The Netherlands



Manager radio specialist team

1. Who am I ?

1997 - now

Ministry of Economic Affairs, Radiocommunications Agency

Groningen, The Netherlands

Technical expert

Spectrum management and radio equipment standardization (ITU and ETSI)

Technical projects

Design and realization of a helicopter measurement system for the **antenna radiation pattern** and **EIRP** of VHF FM broadcasting stations

1. Who am I ?

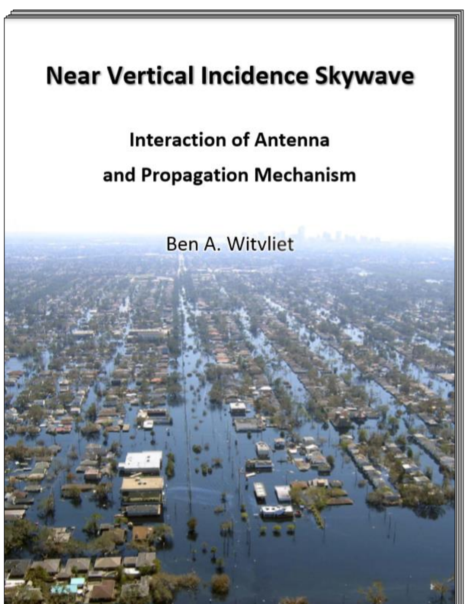
2011-2015

University of Twente, Telecommunication Engineering group

UNIVERSITY OF TWENTE.

Enschede, The Netherlands

After Hurricane Katrina, I wanted to help.
My PhD research is about NVIS for humanitarian applications.



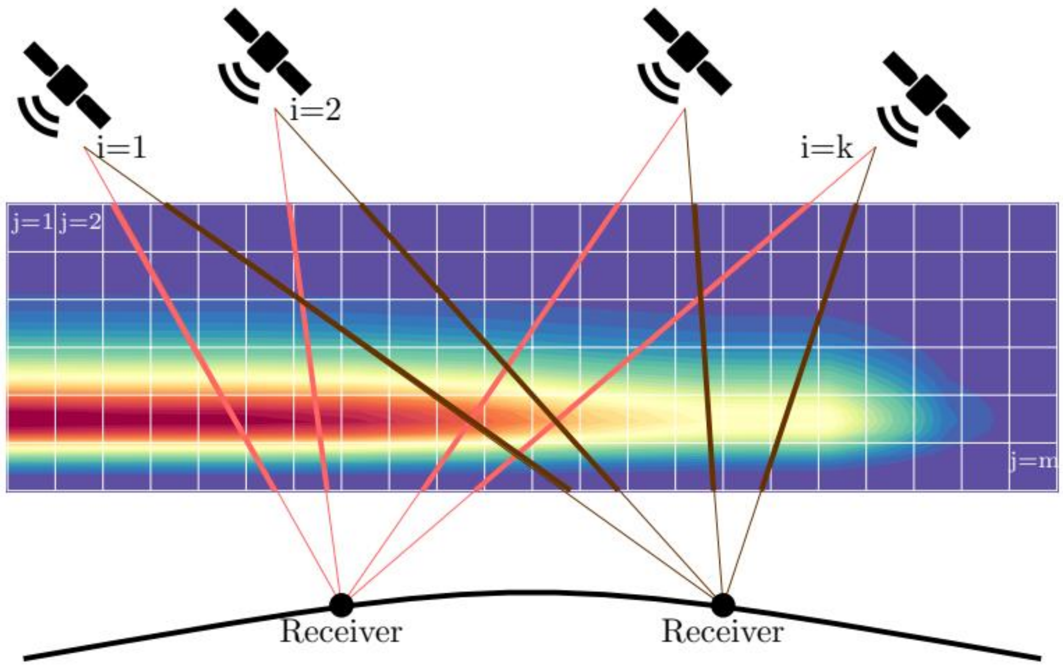
My NVIS research won the
Anton Veder Radio Research Prize

1. Who am I ?

2017-2019

University of Bath, Centre for Space, Atmospheric and Oceanic Science

Bath, United Kingdom



Research manager

Radio Science

PhD's

ionospheric tomography

HF greyline propagation

GNSS scintillation

1. Who am I ?

Now (2023)

Radiocommunications Agency Netherlands (24h / week)

University of Twente, 2 research projects (11h / week)

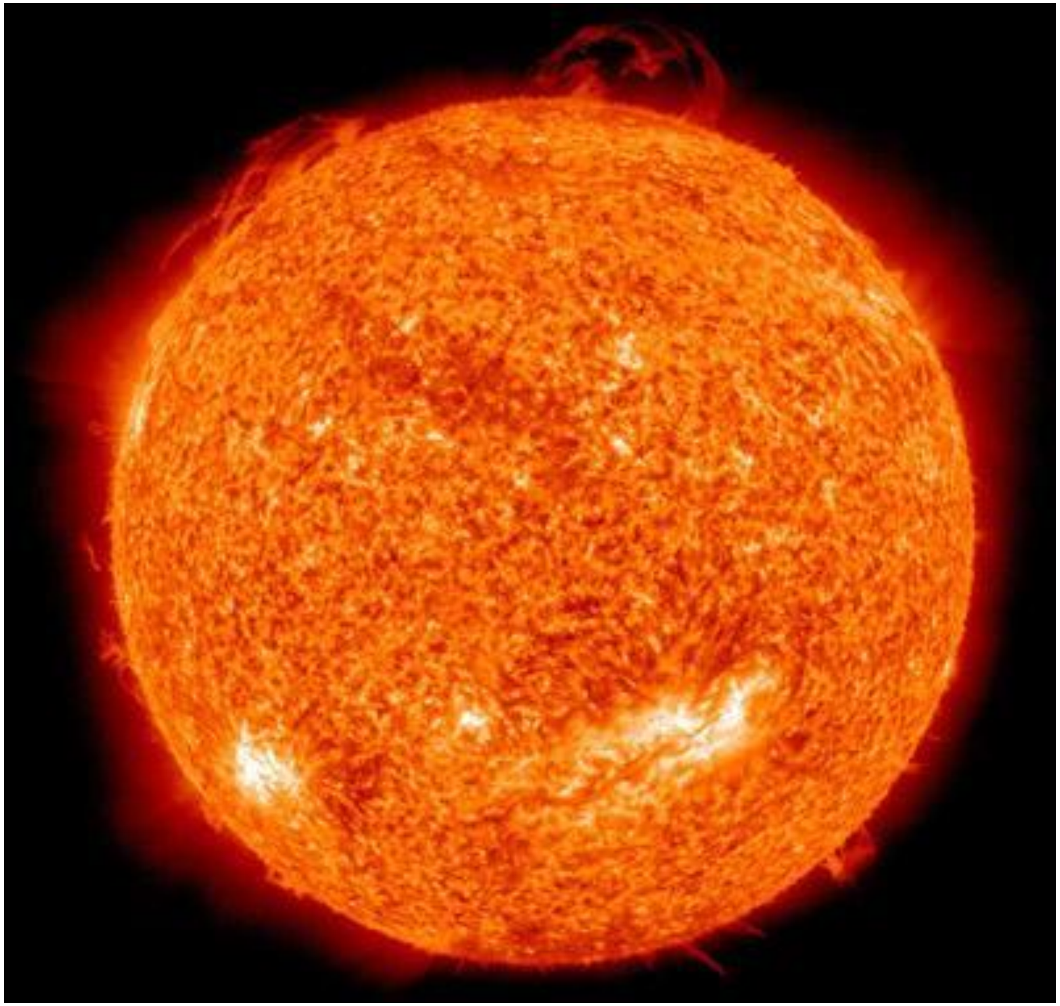
- **PITHIA-NRF**
  ionosphere, thermosphere, plasmasphere (2021, 4 years)
- **PARATUS**
  disaster risk management (2022, 4 years)

1. Who am I ?

Any questions about this part?

2. Near Vertical Incidence Skywave

a. It all starts with the sun



2. Near Vertical Incidence Skywave

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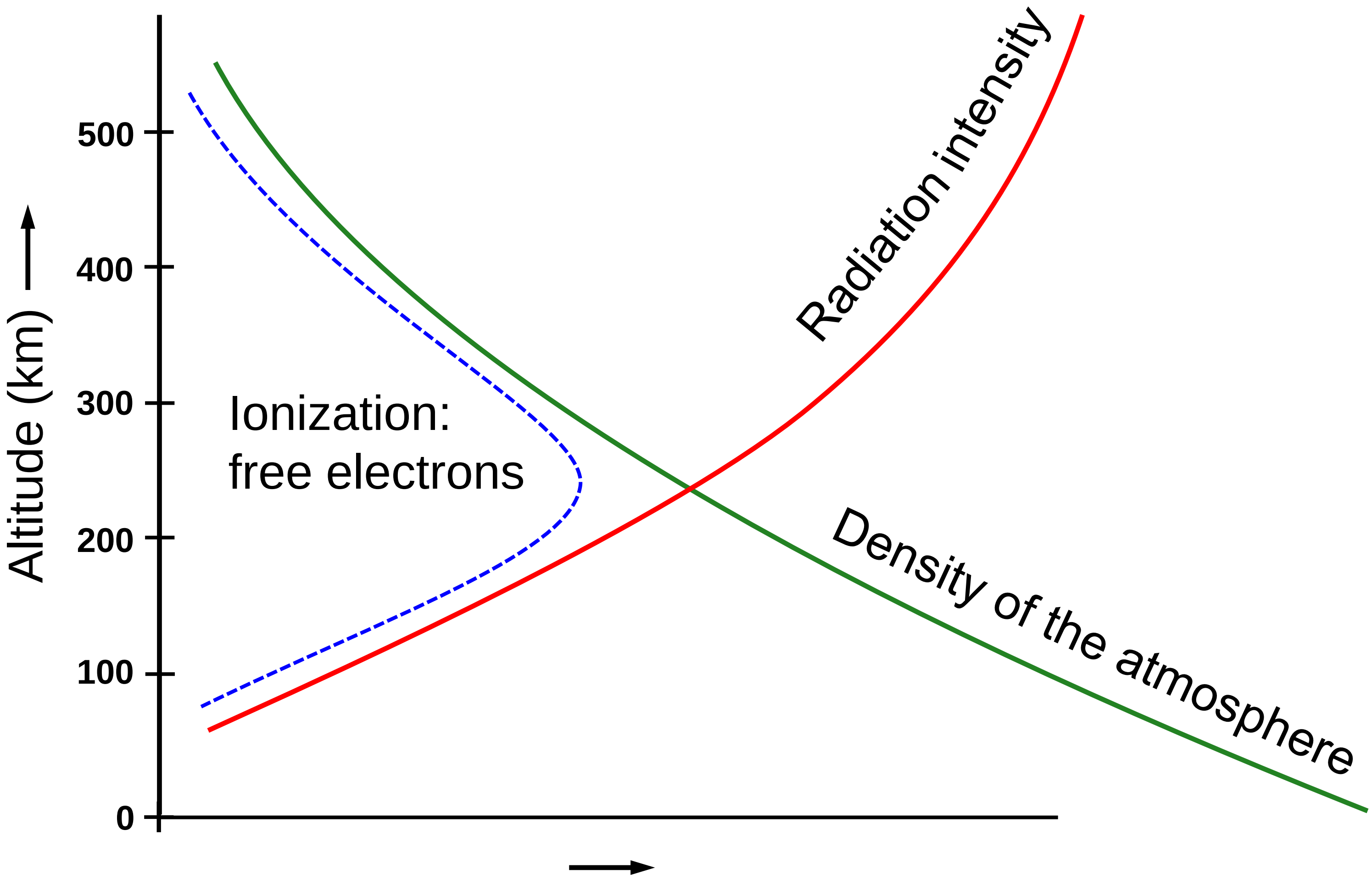

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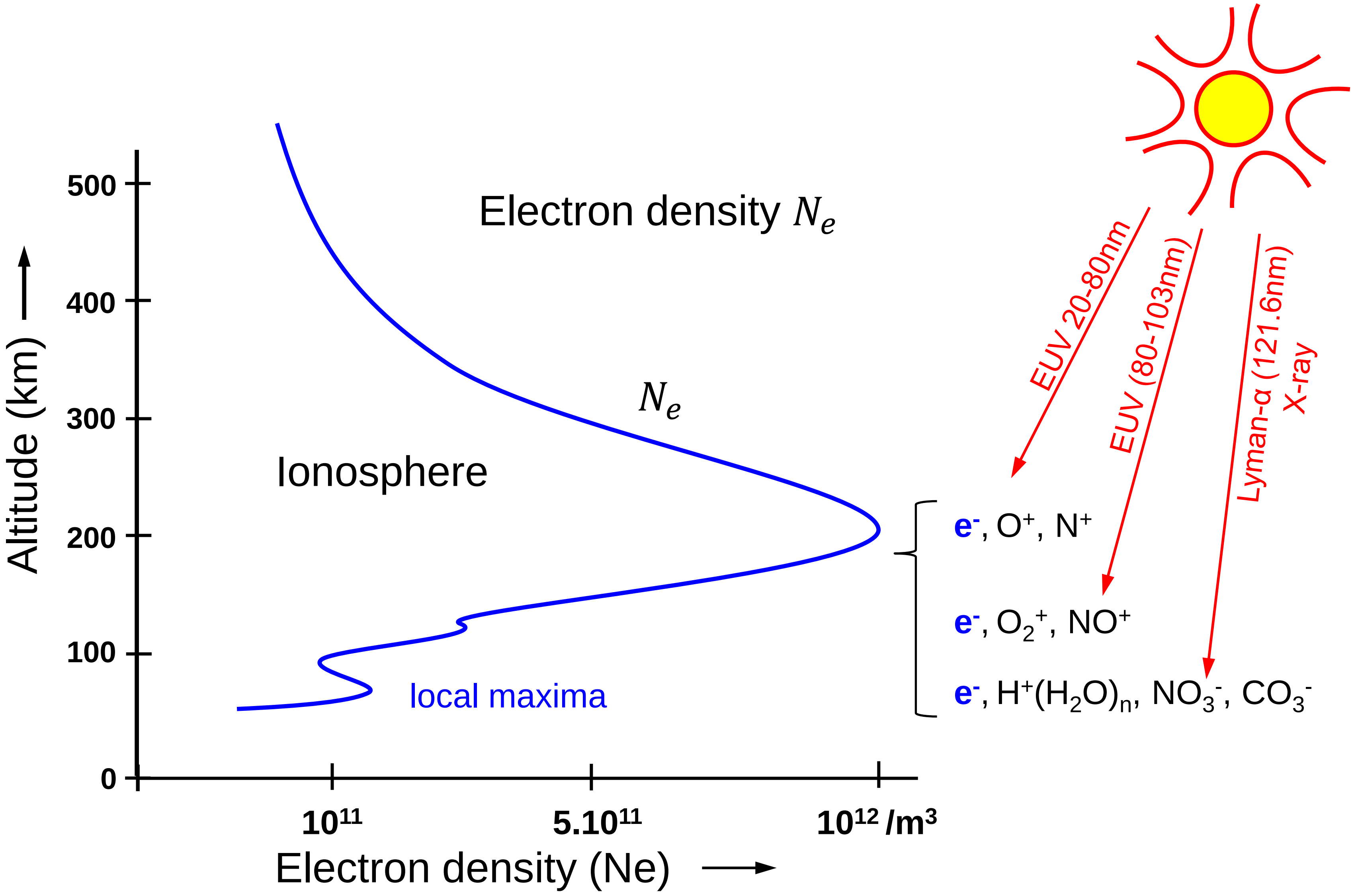

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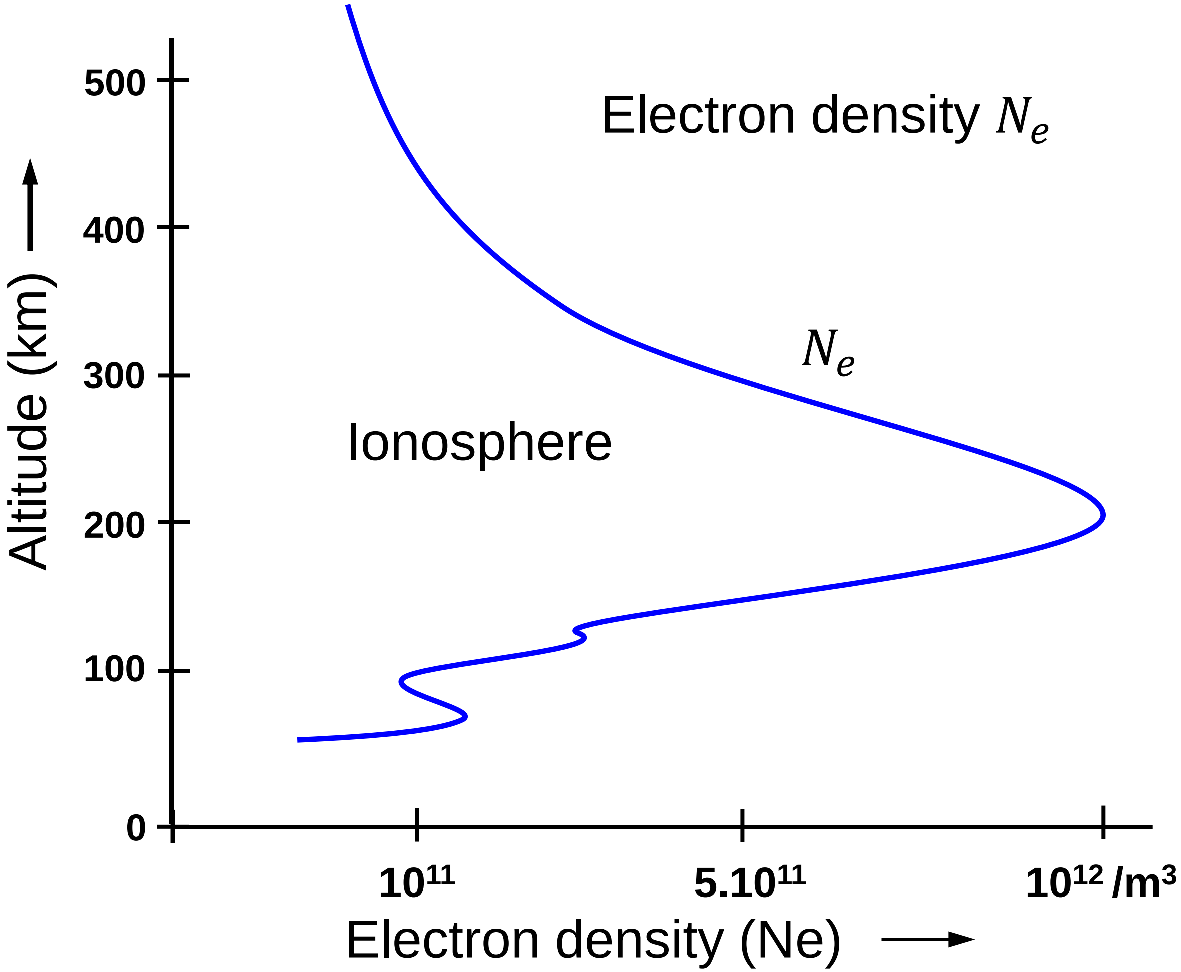
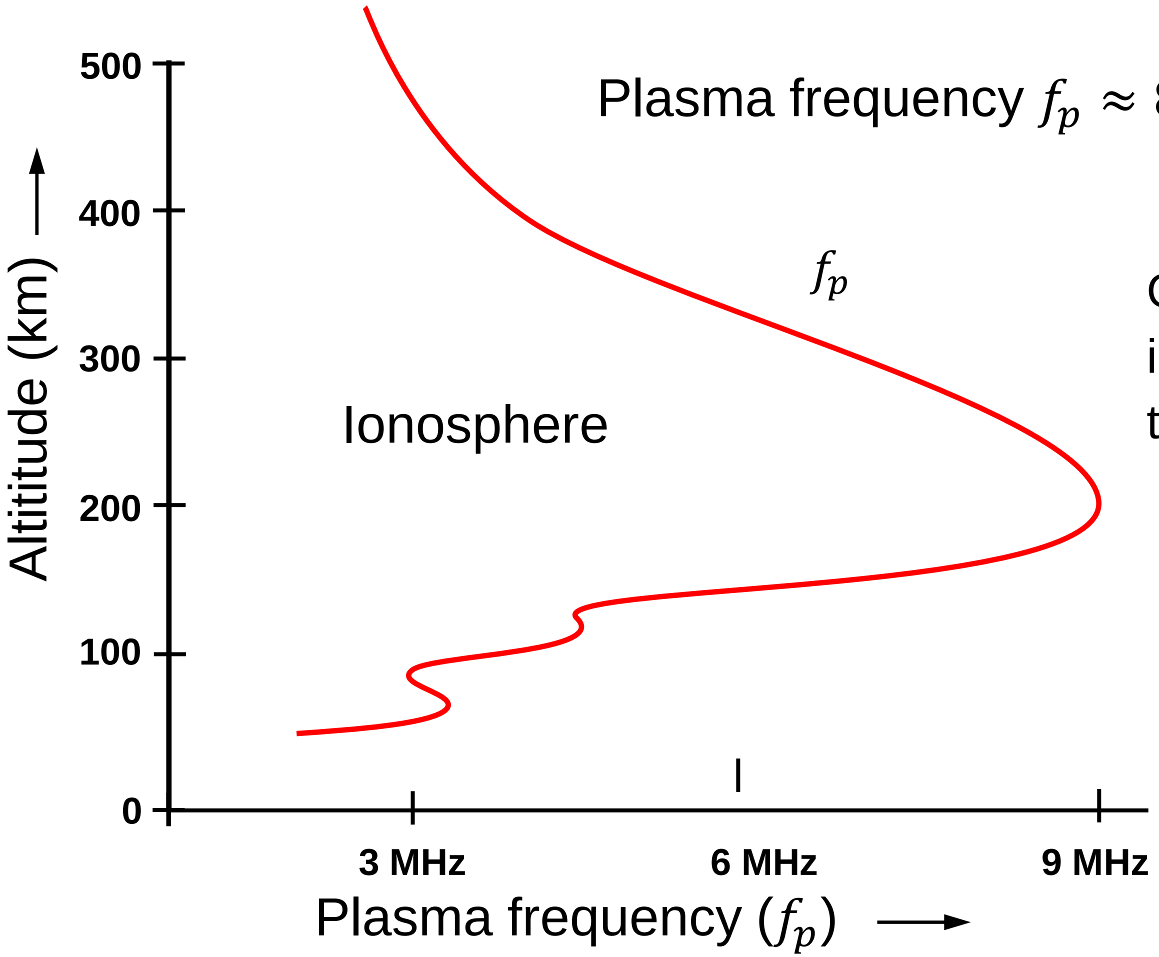


2. Near Vertical Incidence Skywave

a. It all starts with the sun

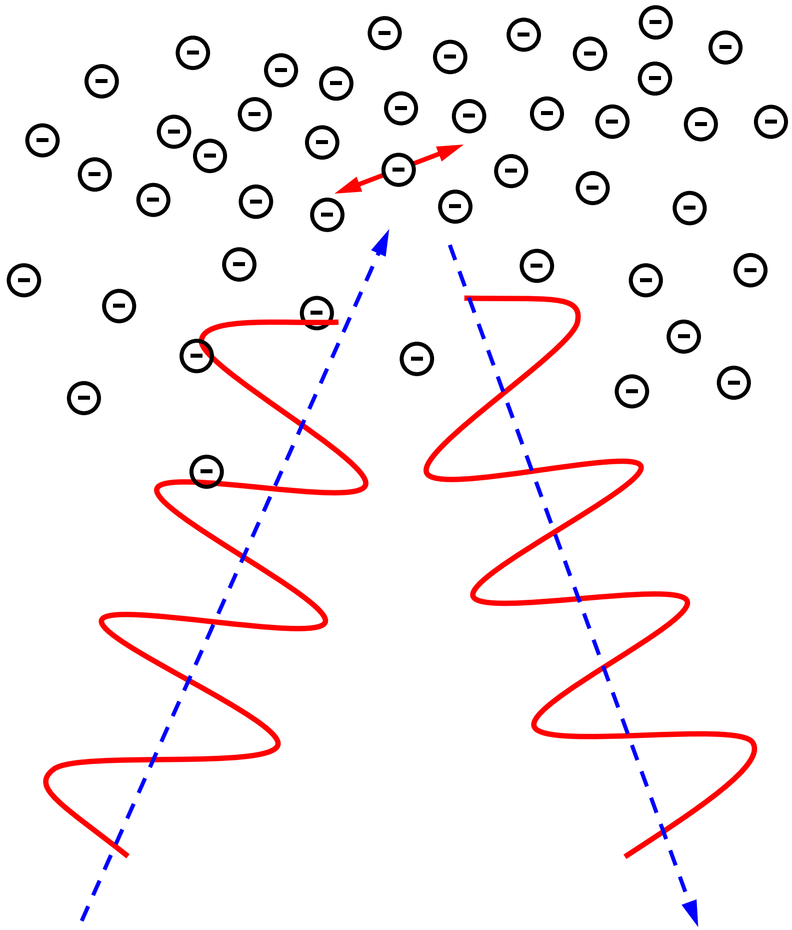
Plasma frequency $f_p \approx 8.9\sqrt{N_e}$

Oscillation of free electrons in the plasma depends on the electron density



2. Near Vertical Incidence Skywave

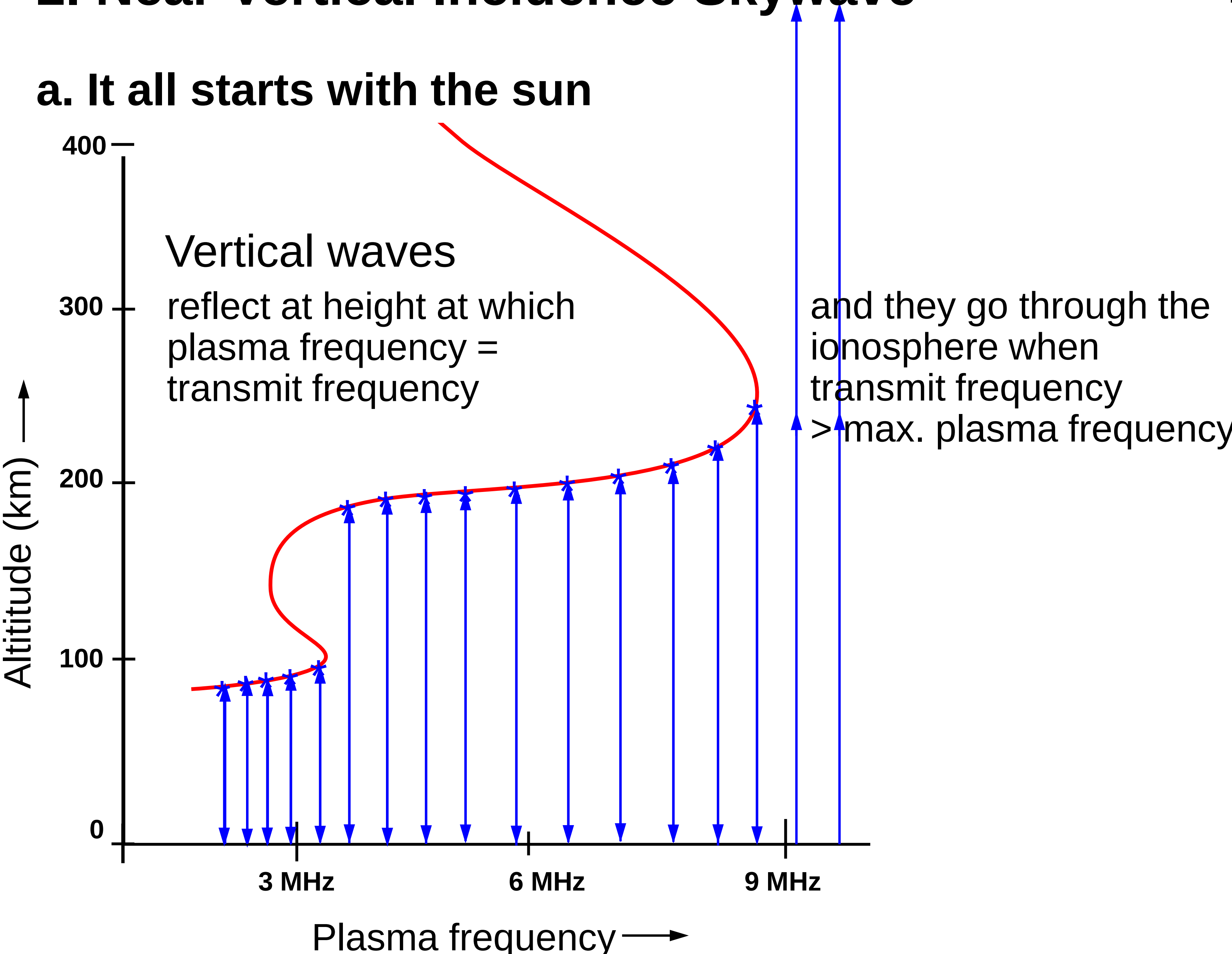
a. It all starts with the sun



Radio wave reflects at a height at which plasma frequency = transmit frequency

2. Near Vertical Incidence Skywave

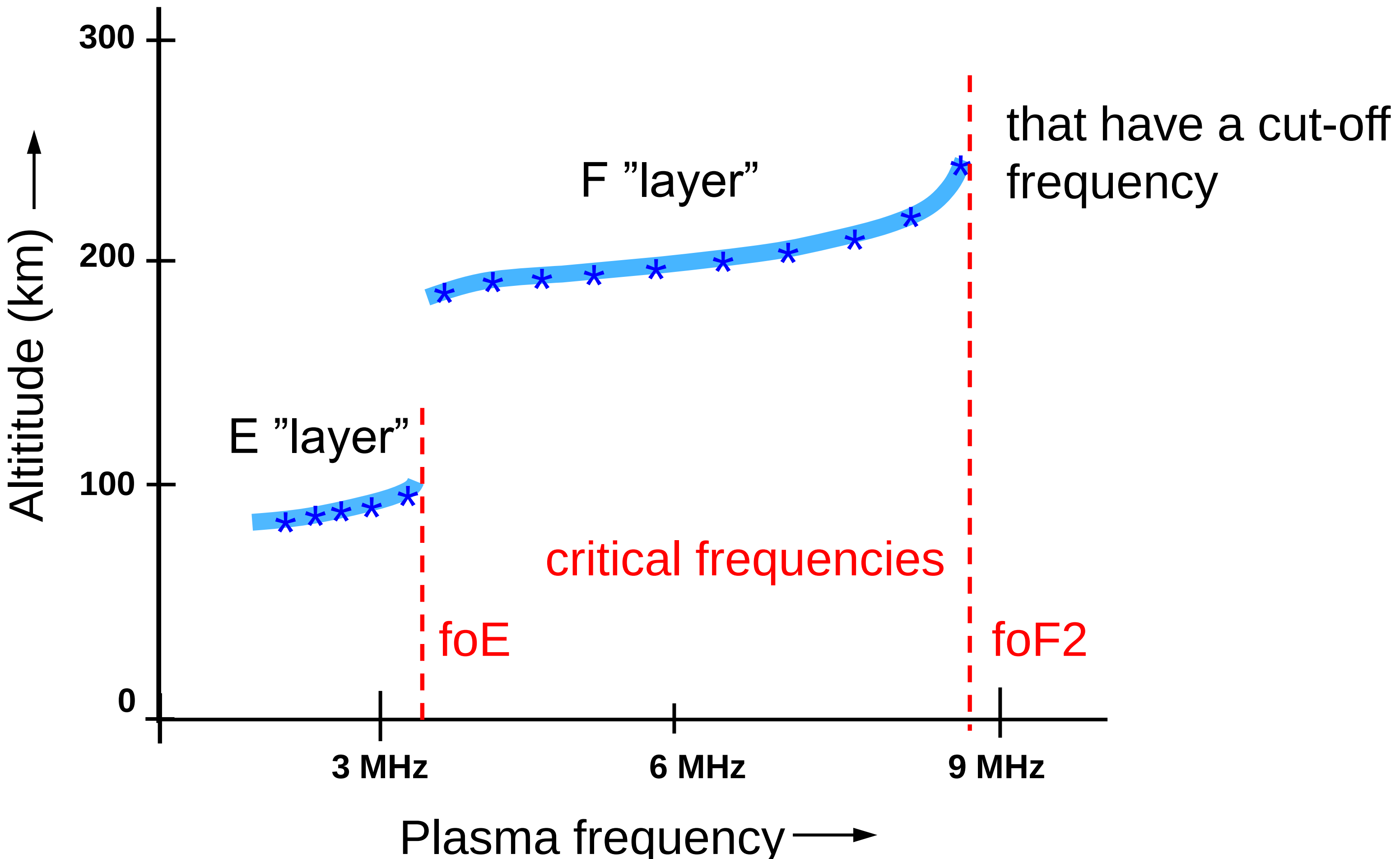
a. It all starts with the sun



2. Near Vertical Incidence Skywave

a. It all starts with the sun

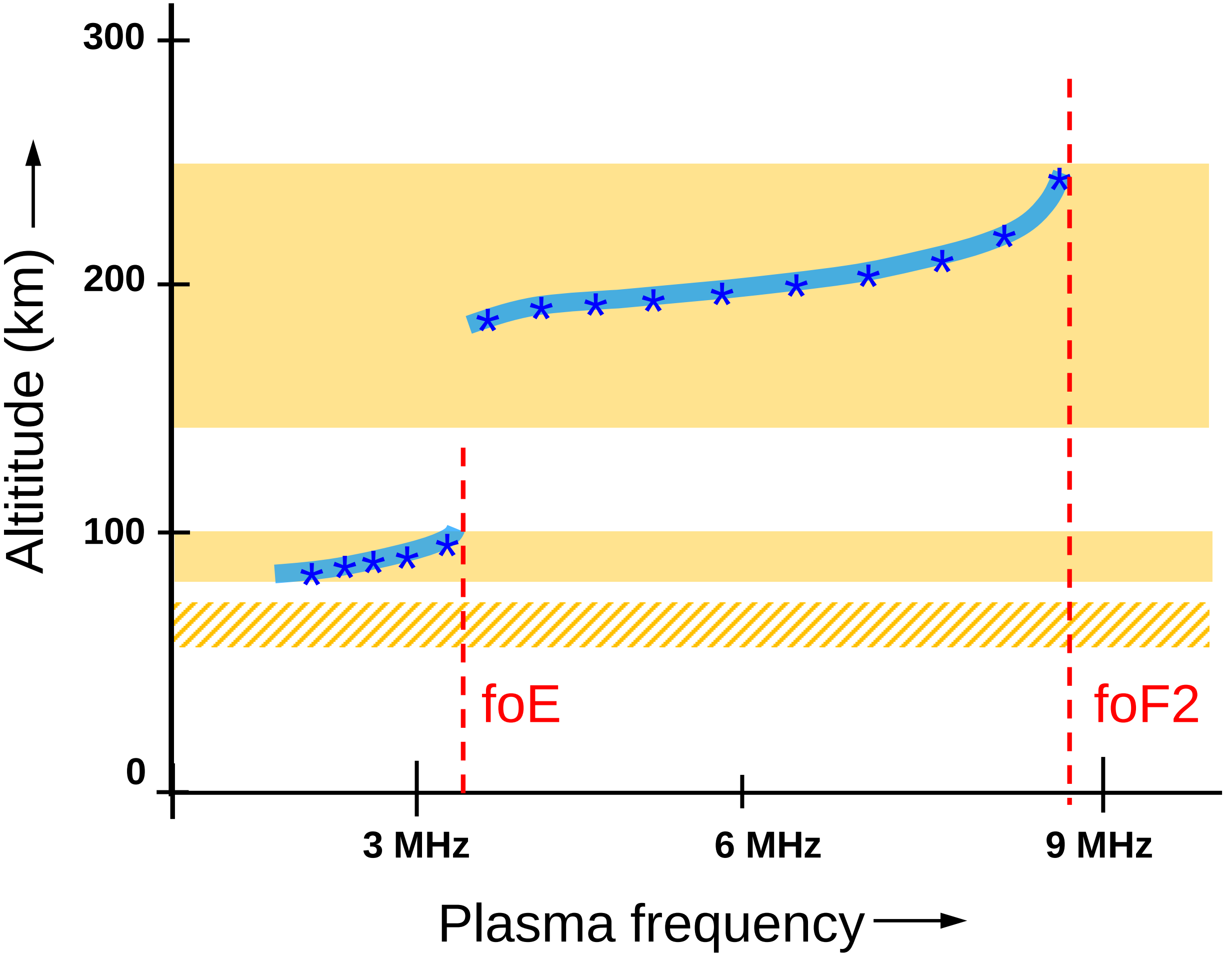
Seemingly as if there are reflecting layers



2. Near Vertical Incidence Skywave

a. It all starts with the sun

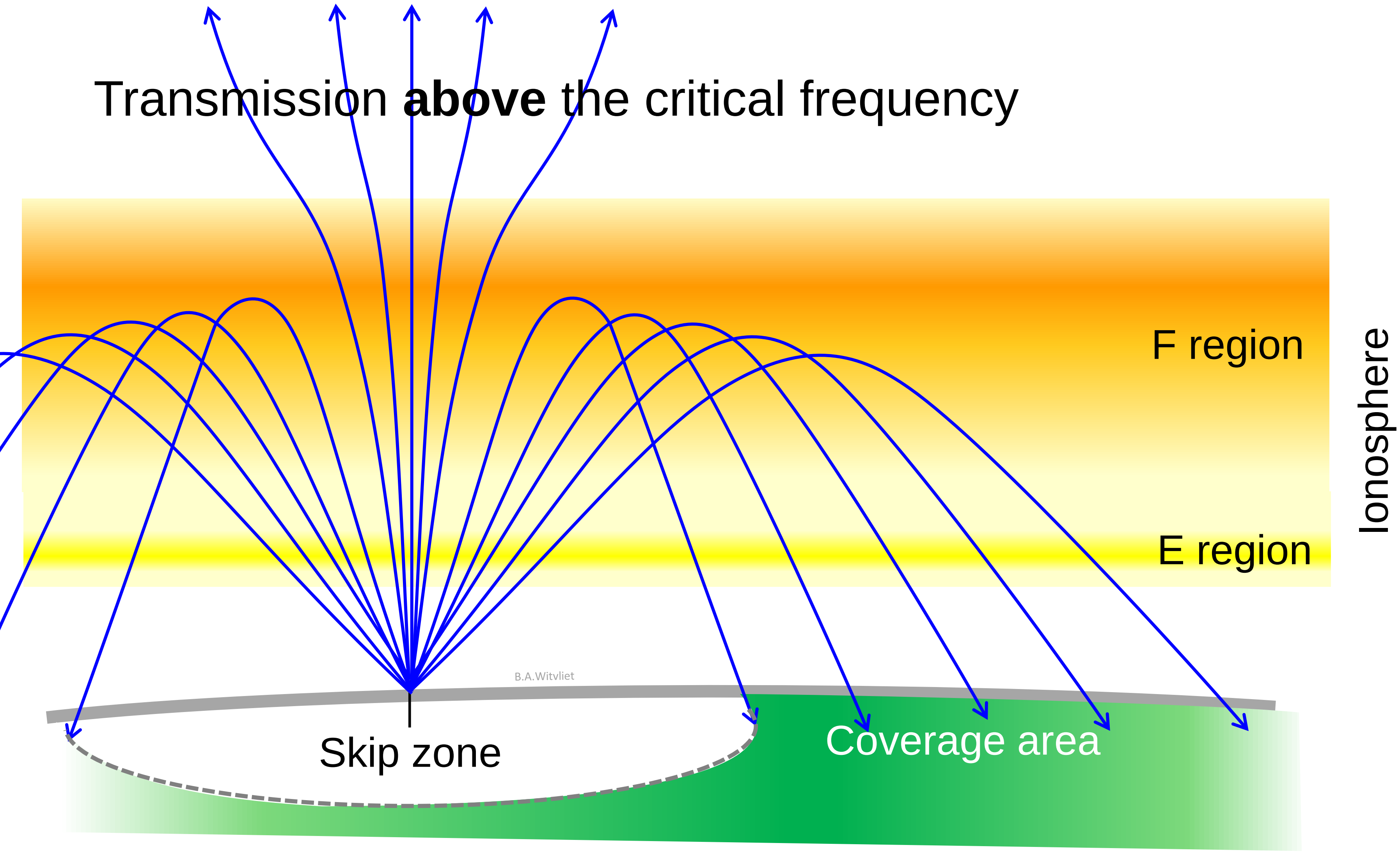
In reality there are no layers, but the expression has stuck



2. Near Vertical Incidence Skywave

a. It all starts with the sun

Transmission **above** the critical frequency

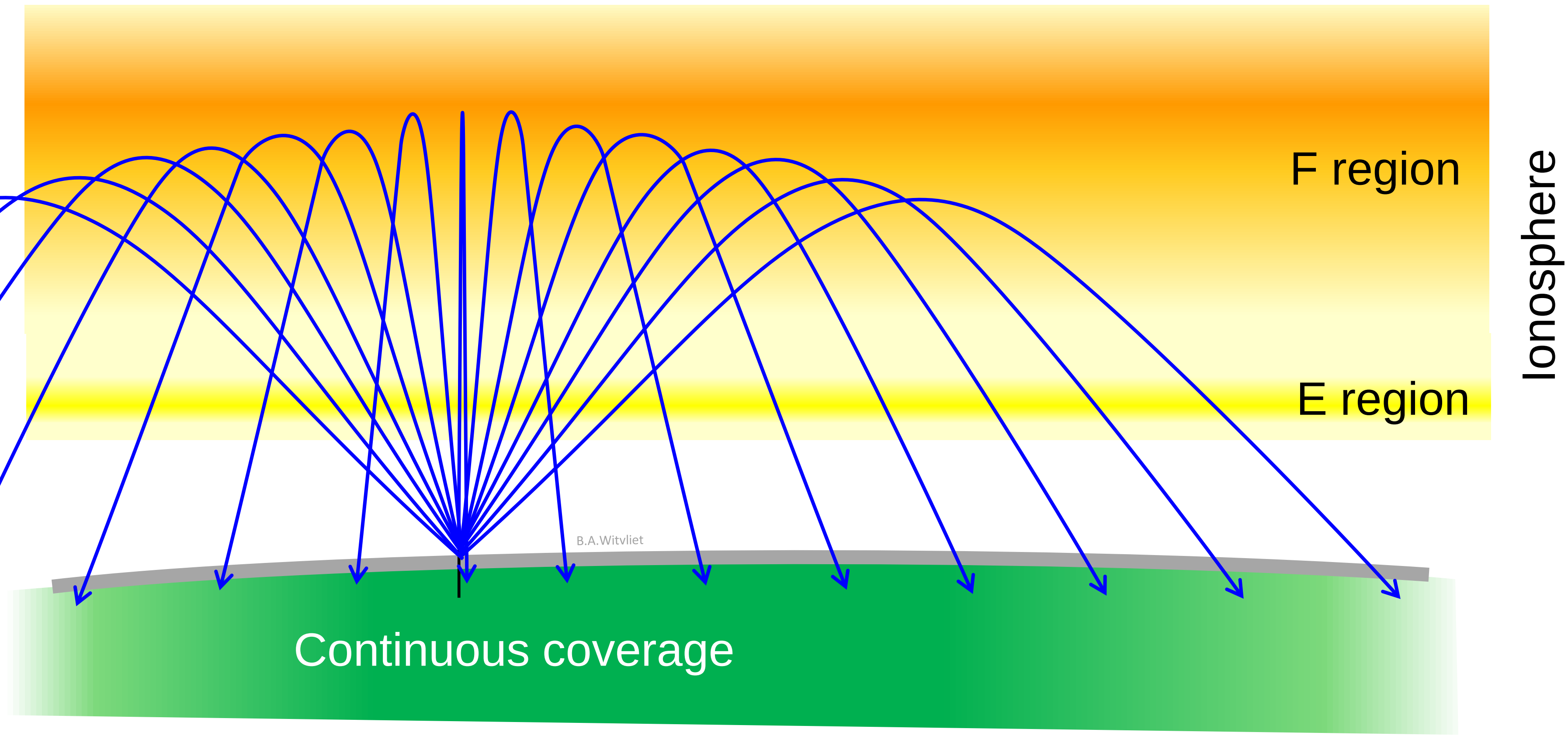


2. Near Vertical Incidence Skywave

a. It all starts with the sun

Transmission **below** the critical frequency:

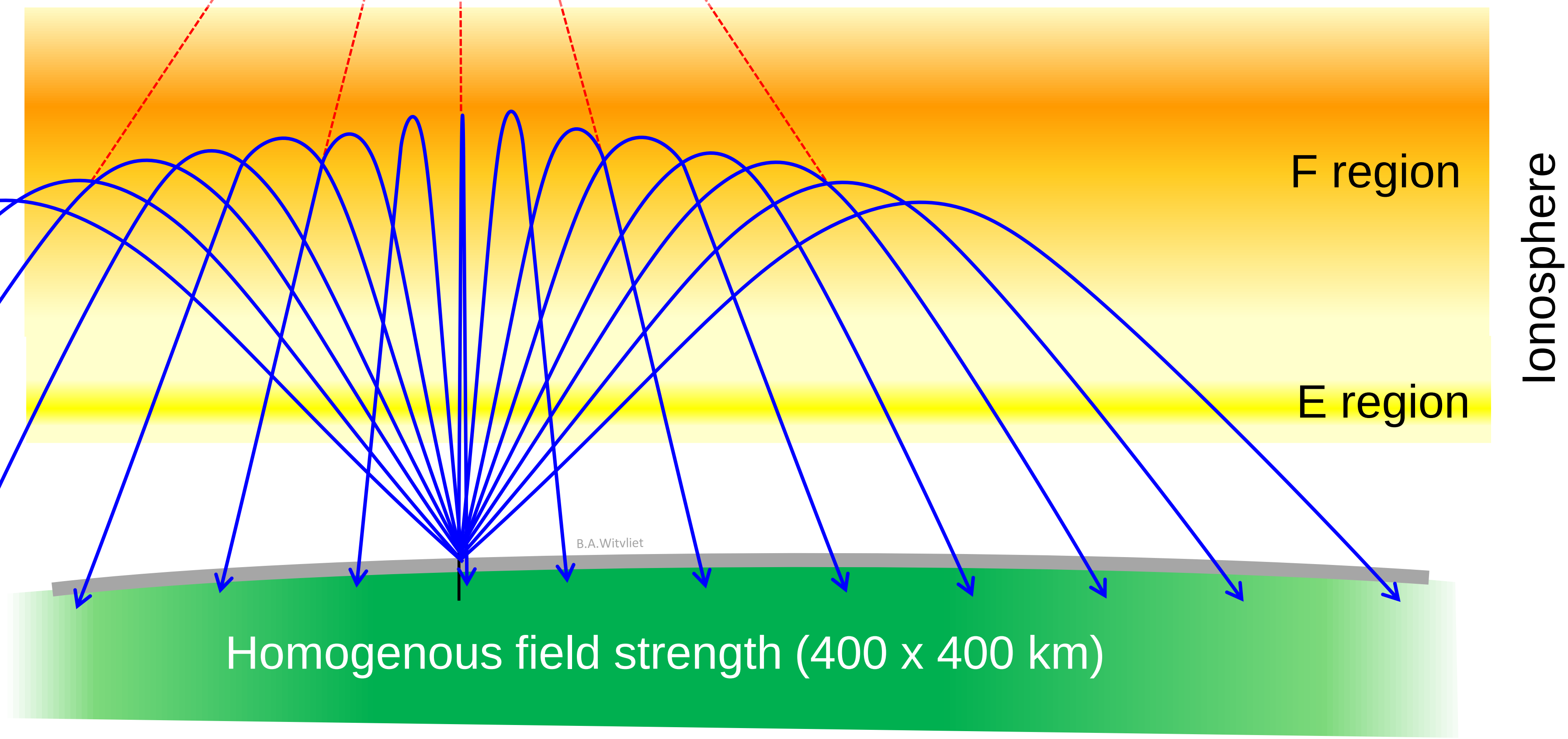
Even the vertical waves are reflected. This is NVIS.



2. Near Vertical Incidence Skywave

a. It all starts with the sun

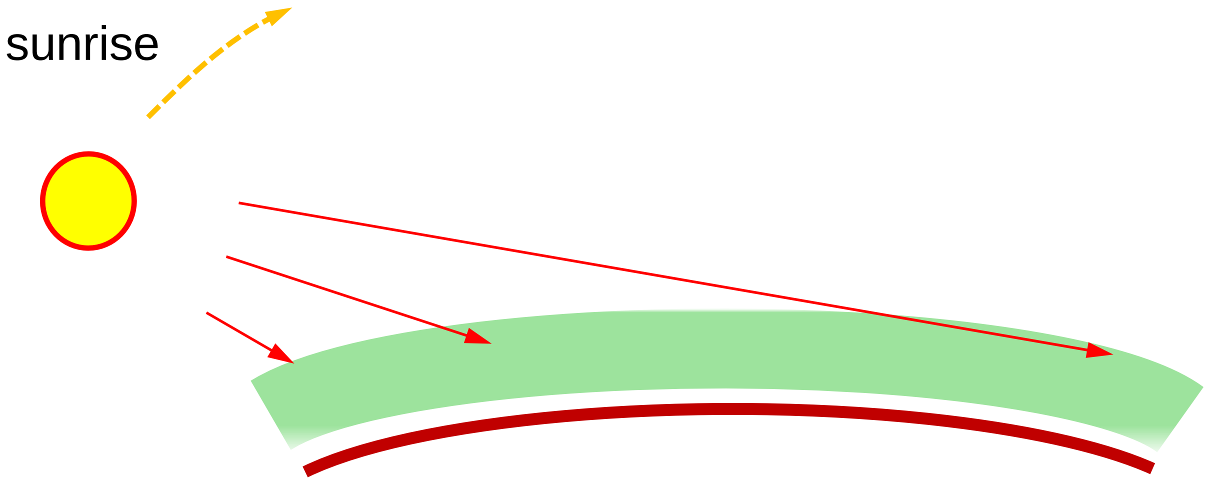
High angles of incidence: difficult to obstruct. Very efficient.
Homogenous field strength. Works in rain and in forests.



2. Near Vertical Incidence Skywave

a. It all starts with the sun

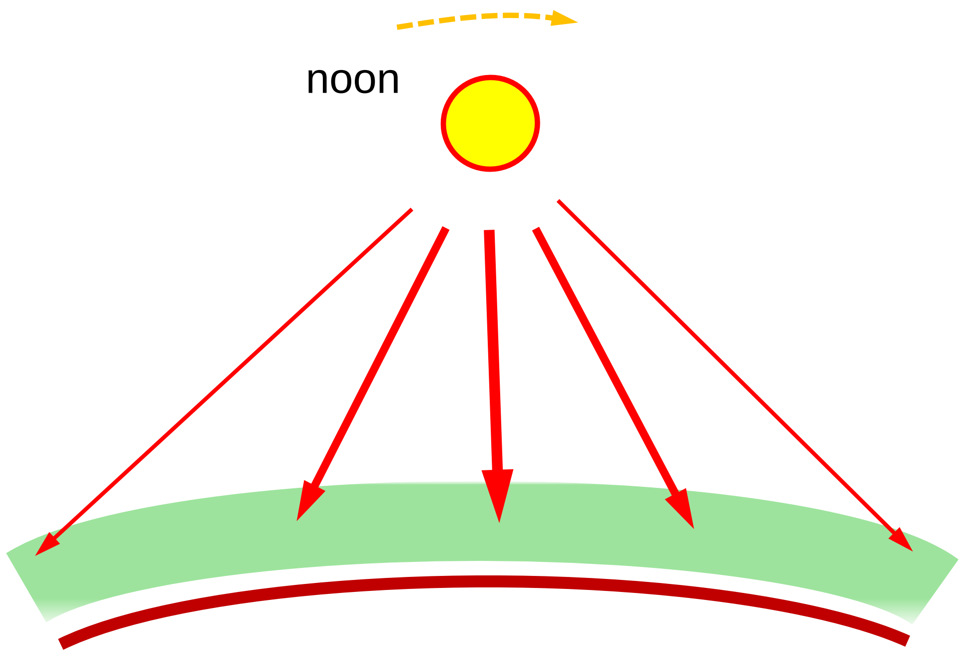
The electron density of the ionosphere follows the radiation of the sun. It increases in the morning…



2. Near Vertical Incidence Skywave

a. It all starts with the sun

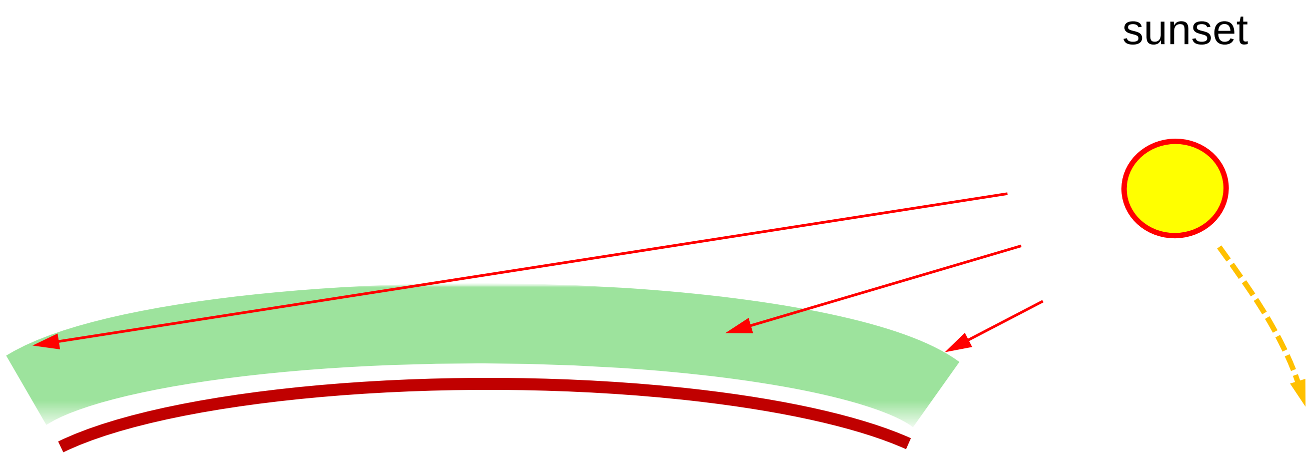
It is much stronger around noon…



2. Near Vertical Incidence Skywave

a. It all starts with the sun

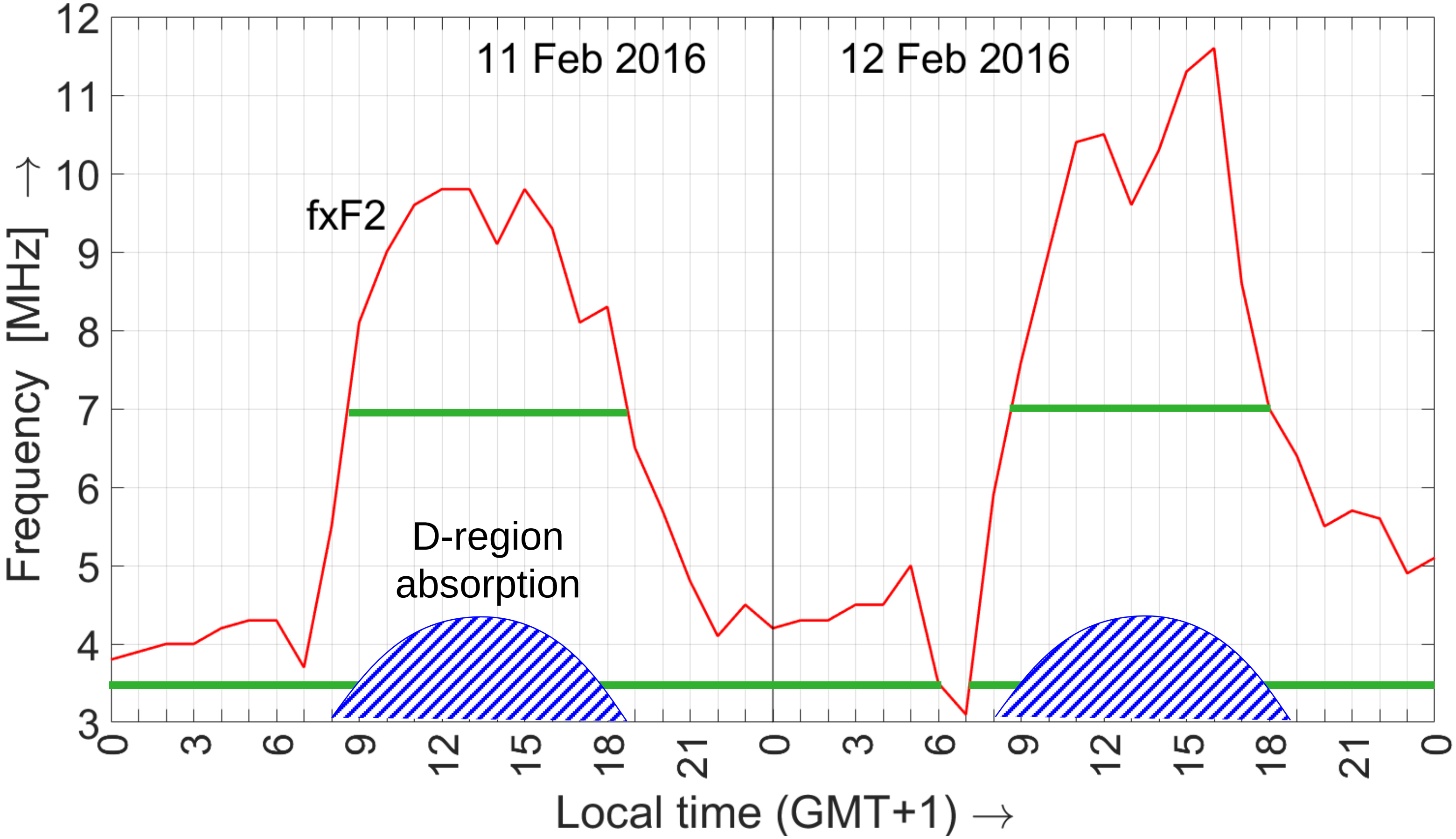
And decreases towards sunset. And is gone completely at night. So, the critical frequencies show a diurnal cycle.



2. Near Vertical Incidence Skywave

a. It all starts with the sun

This can be measured with an ionosonde.
A higher transmit frequency is needed during the day.



2. Near Vertical Incidence Skywave

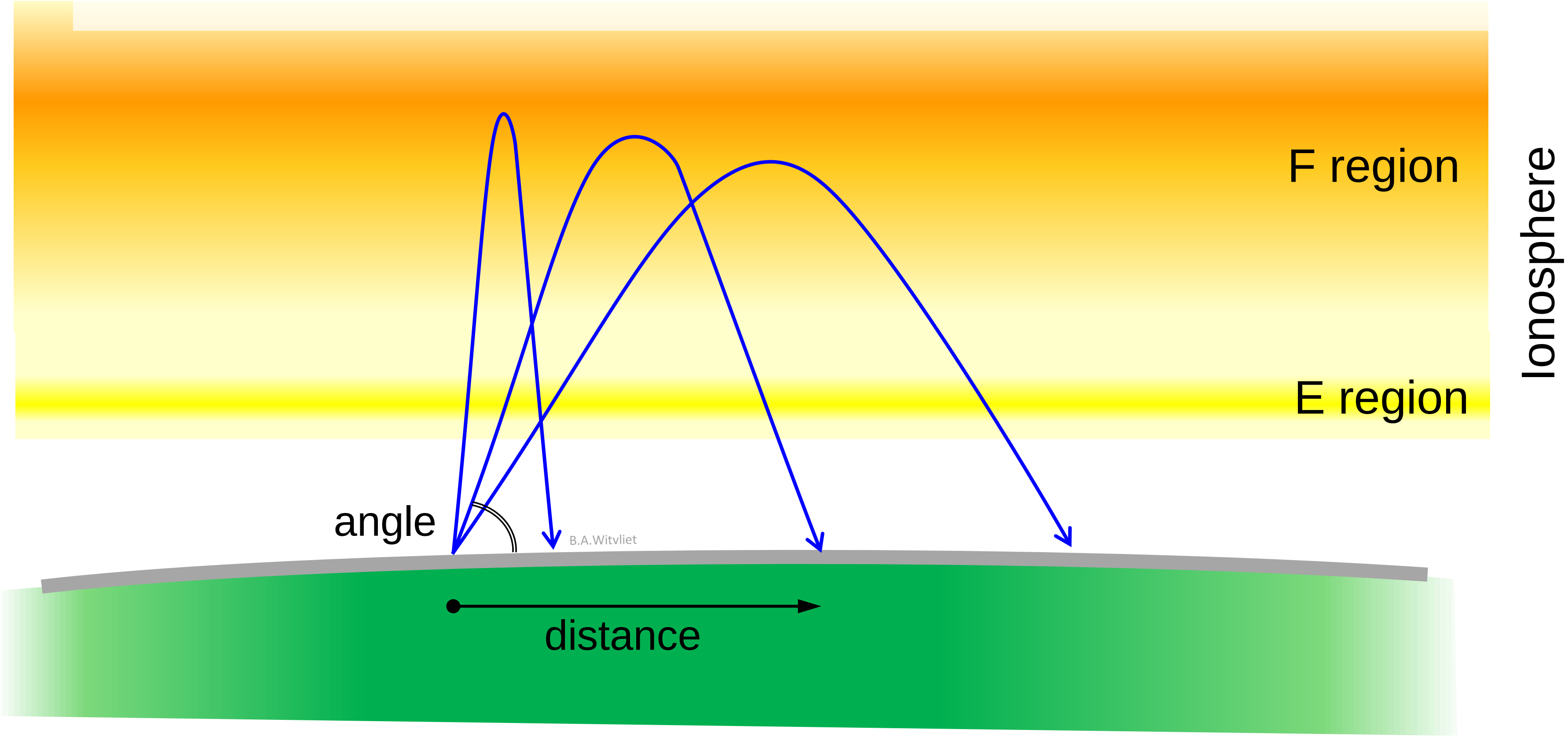
a. It all starts with the sun

Any questions about this part?

2. Near Vertical Incidence Skywave

b. Elevation angles

A short distance corresponds with a high elevation angle.

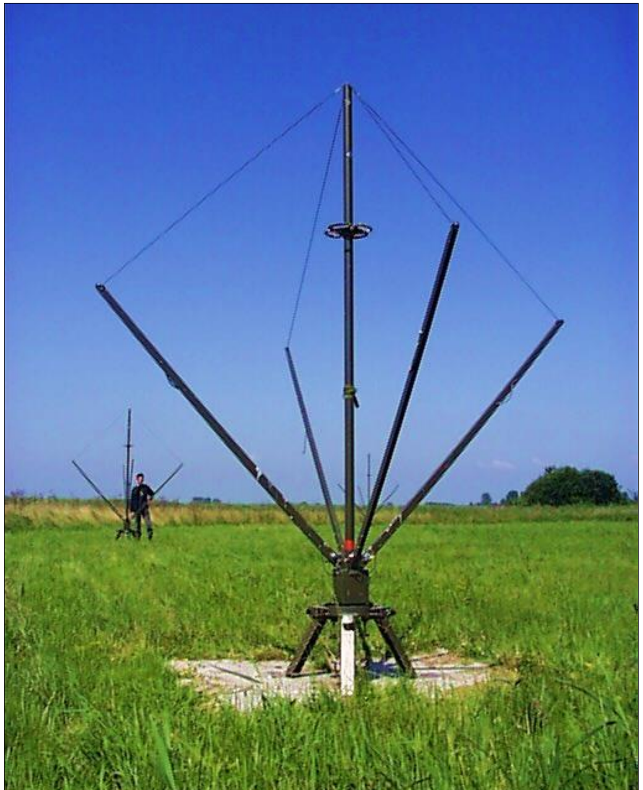


2. Near Vertical Incidence Skywave

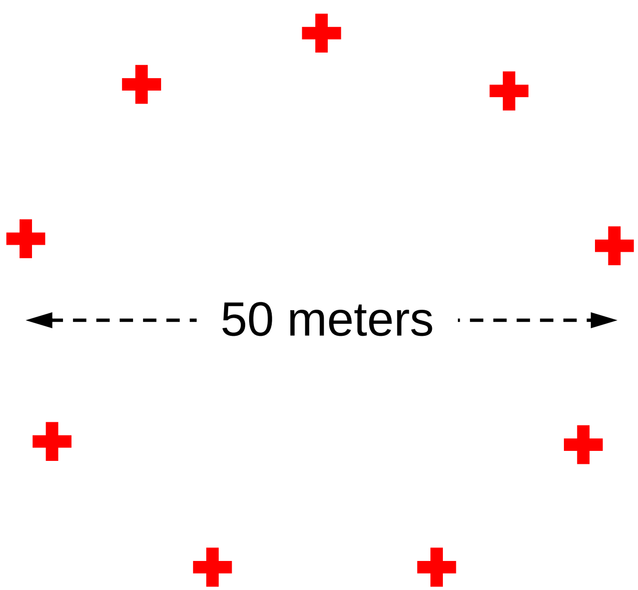
b. Elevation angles

We verified this with measurements, using a professional direction finder capable of measuring elevation angles.

one single antenna



9 antennas in a circle



R&S DDF0XM

2. Near Vertical Incidence Skywave

b. Elevation angles

Measurements during a Dutch amateur radio contest

Frequency 7 MHz
distance 10 -170 km

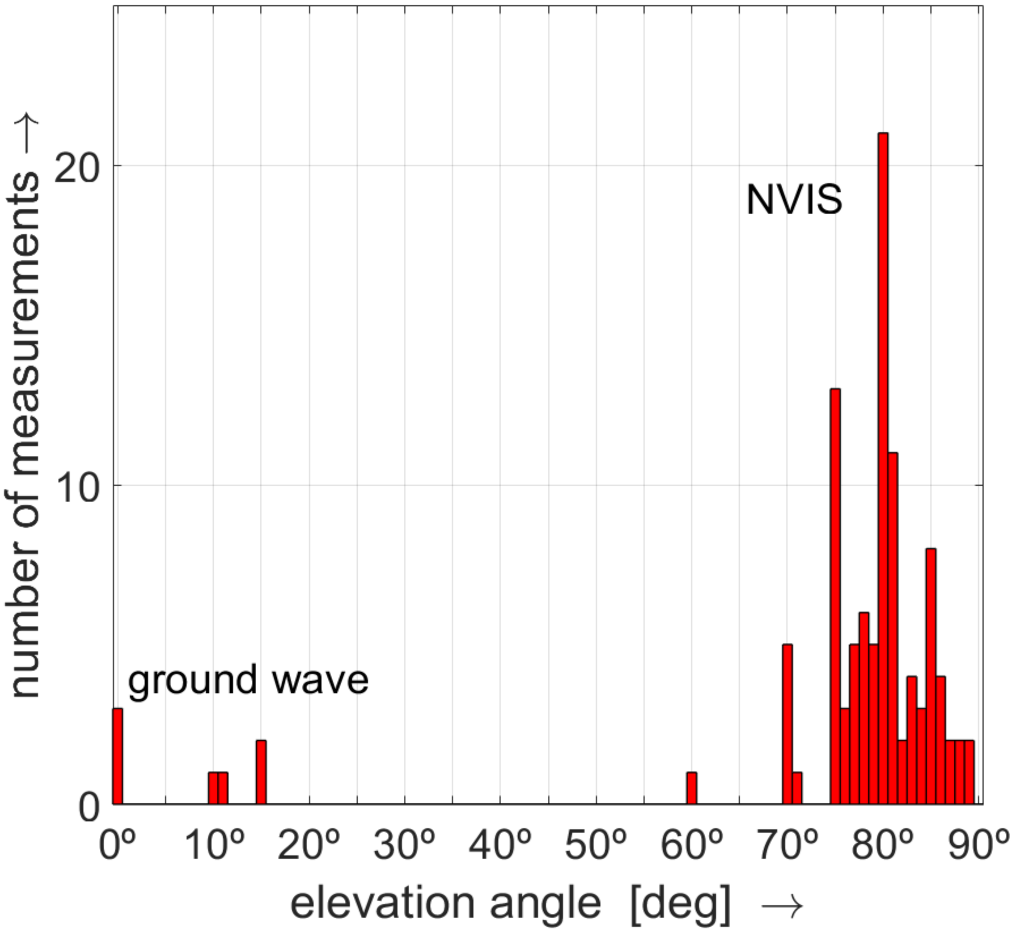
Manual logging (!)
2 hours, 85 stations
200 measurements

Azimuth angle verified against address of the stations

2. Near Vertical Incidence Skywave

b. Elevation angles

Measurements during a Dutch amateur radio contest



Frequency 7 MHz

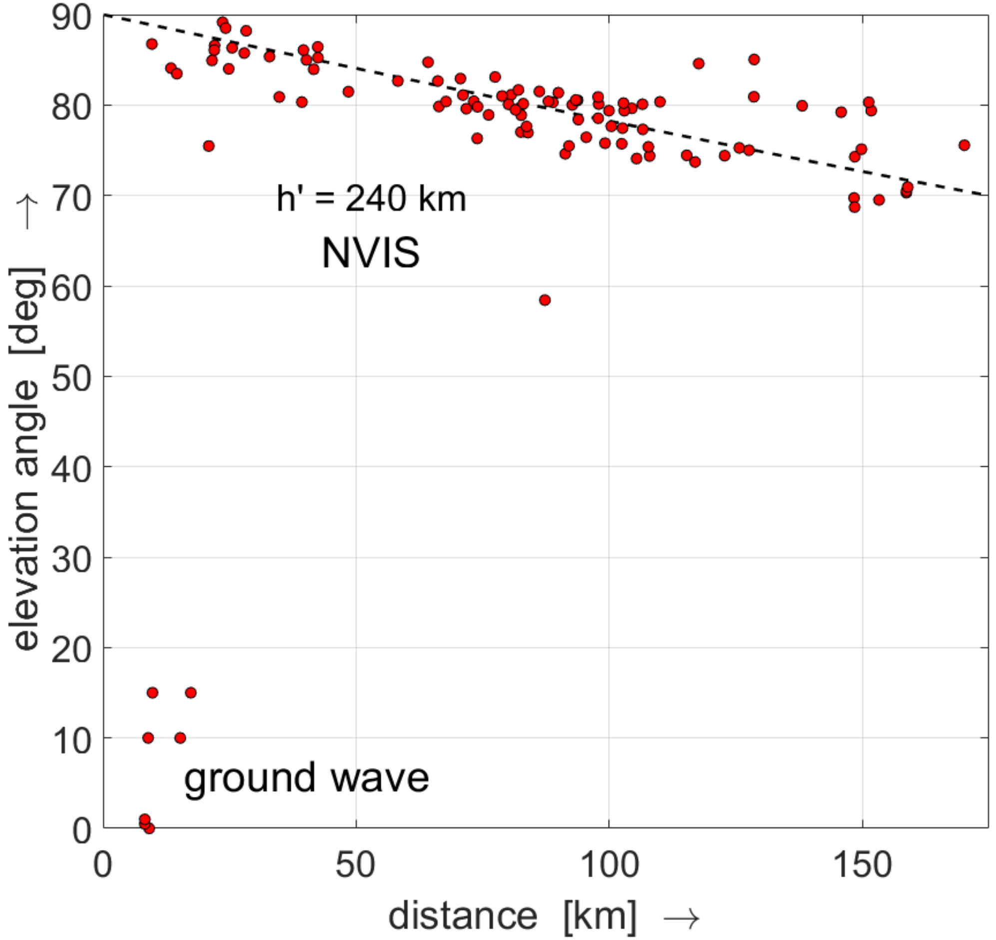
distance 10 -170 km

Most stations arrive at angles between 70 and 90 degrees

2. Near Vertical Incidence Skywave

b. Elevation angles

Measurements during a Dutch amateur radio contest



Frequency 7 MHz

distance 10 -170 km

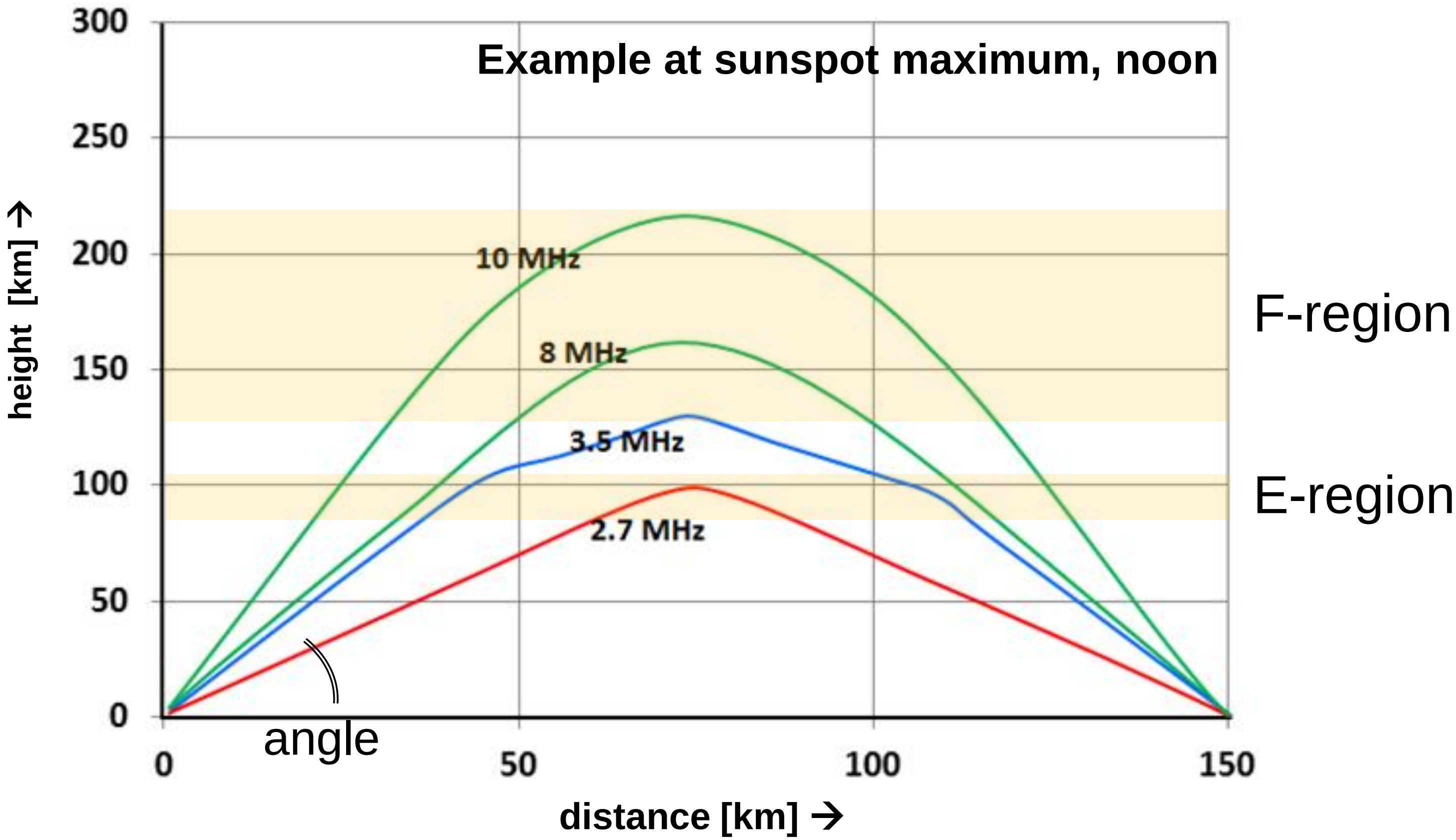
NVIS is dominant at distances above 15 km

The elevation angle depends on distance

2. Near Vertical Incidence Skywave

b. Elevation angles

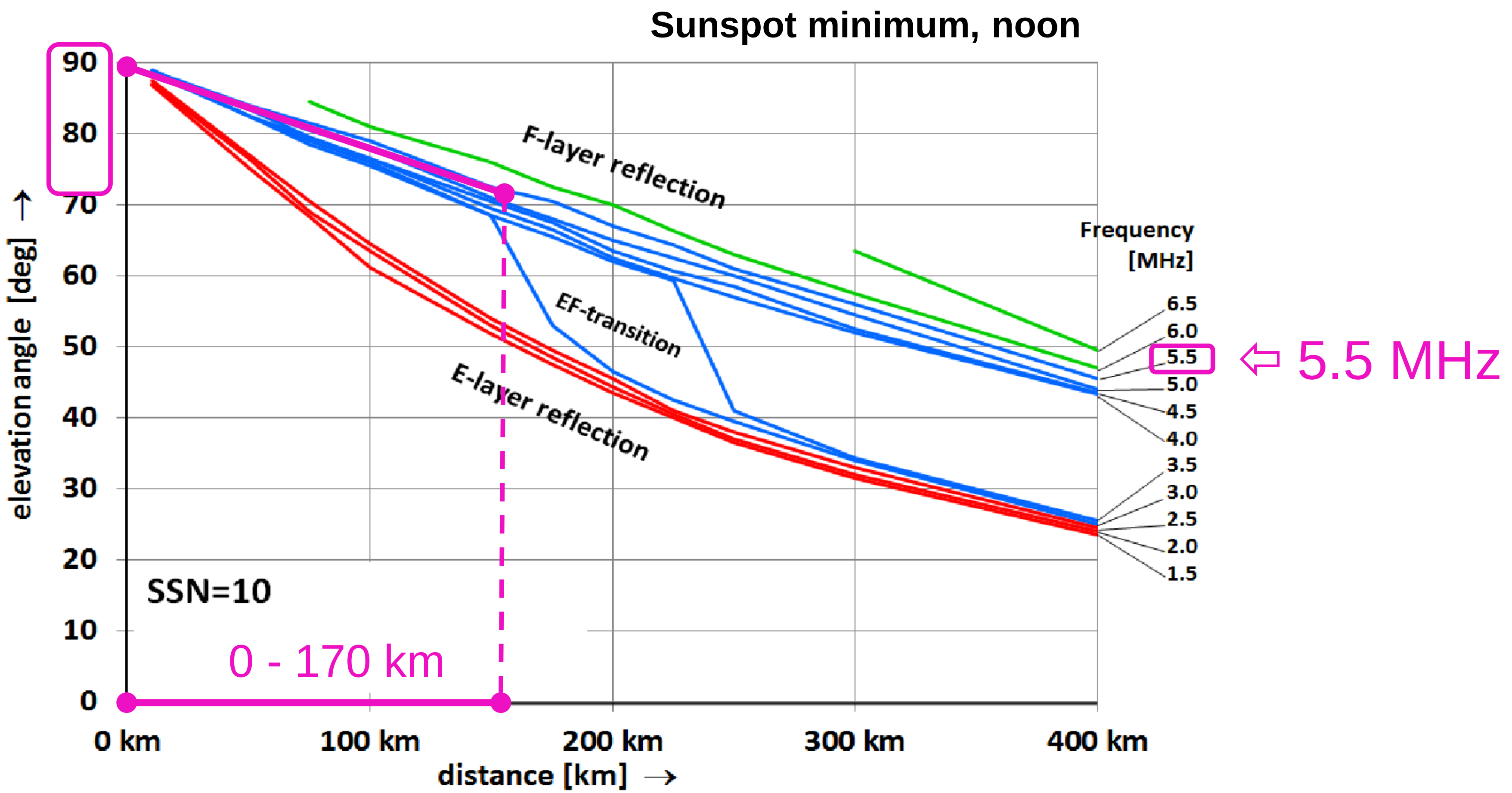
Using simulations, we can show that the elevation angle also depends on the transmit frequency



2. Near Vertical Incidence Skywave

b. Elevation angles

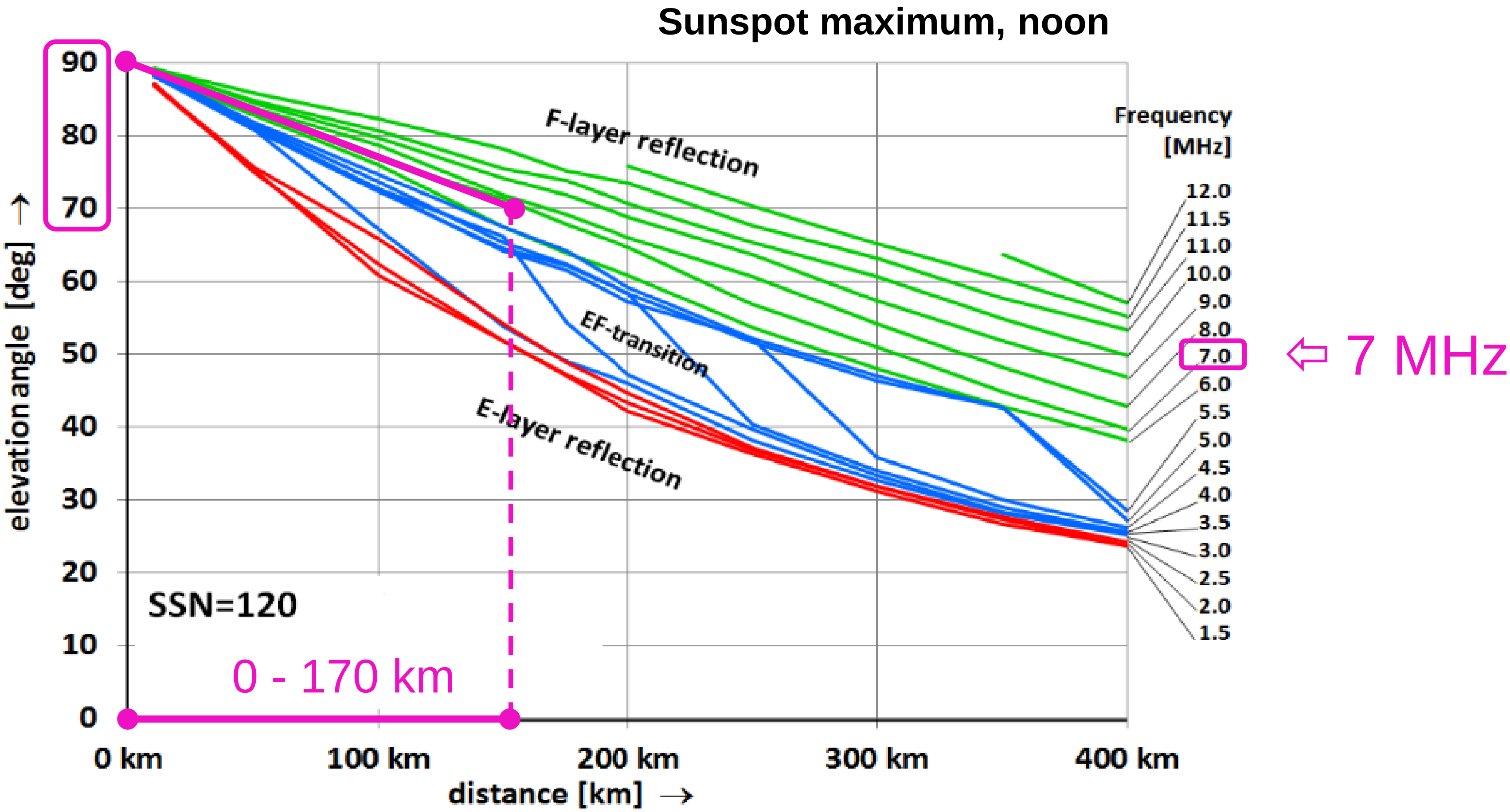
More simulations, also showing effect of sunspot cycle



2. Near Vertical Incidence Skywave

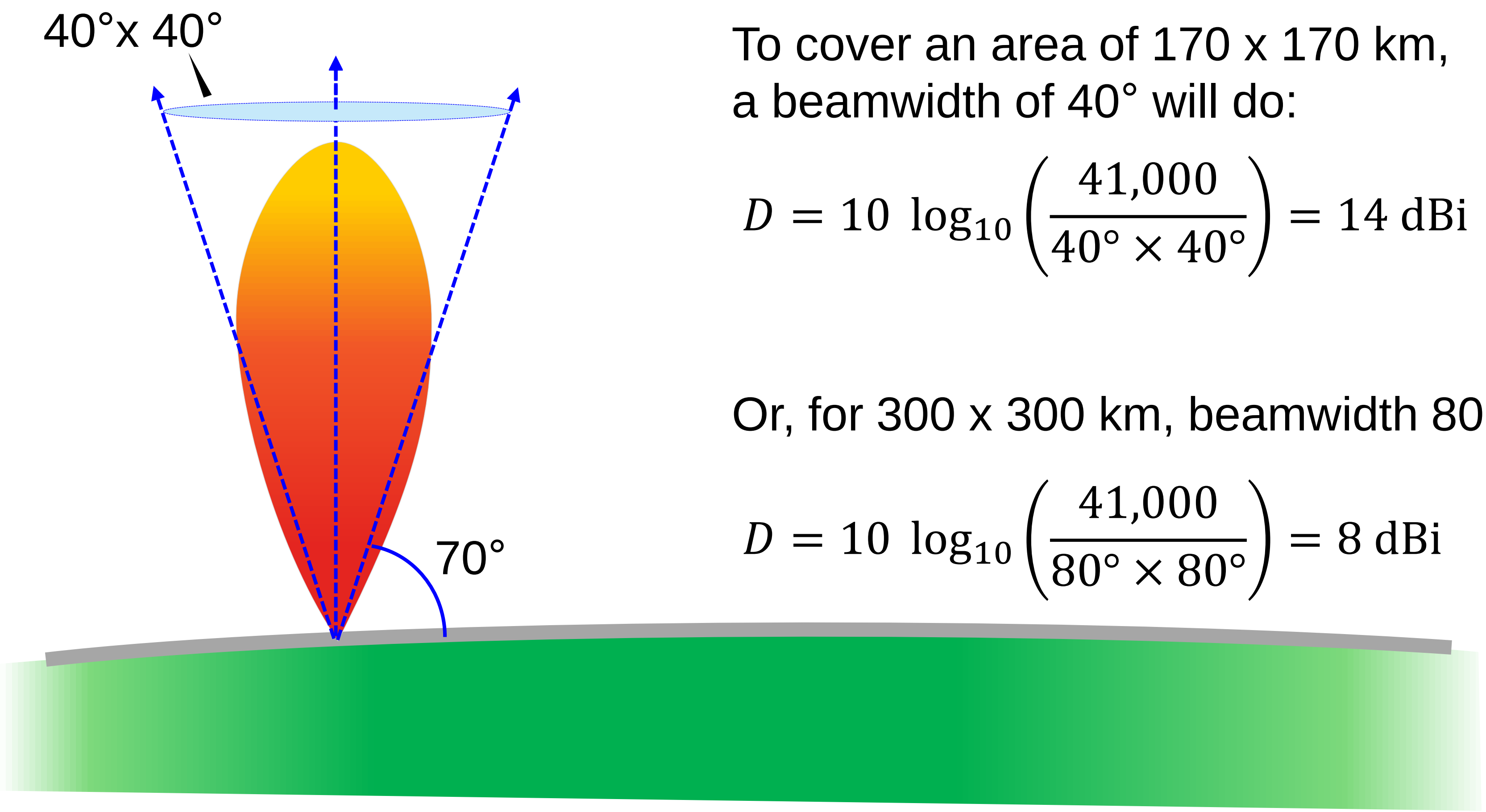
b. Elevation angles

More simulations, also showing effect of sunspot cycle



2. Near Vertical Incidence Skywave

b. Elevation angles



Antenna optimization

To cover an area of 170 x 170 km,
a beamwidth of 40° will do:

$$D = 10 \ \log_{10}\left(\frac{41{,}000}{40° \times 40°}\right) = 14 \text{ dBi}$$

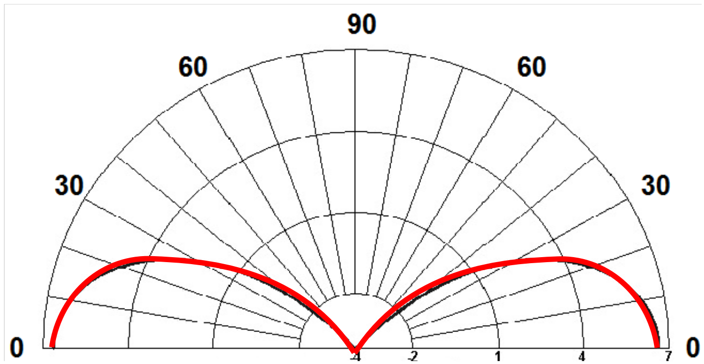
Or, for 300 x 300 km, beamwidth 80°:

$$D = 10 \ \log_{10}\left(\frac{41{,}000}{80° \times 80°}\right) = 8 \text{ dBi}$$

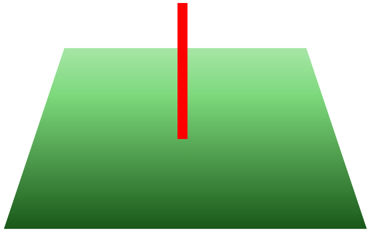
2. Near Vertical Incidence Skywave

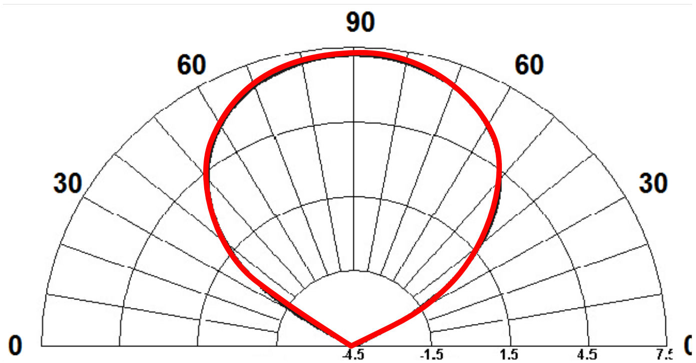
b. Elevation angles

Vertical antennas are very poor NVIS performers

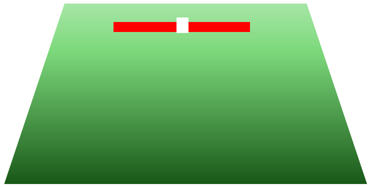


Vertically antenna
above ground





Horizontal antenna
above ground



2. Near Vertical Incidence Skywave

b. Elevation angles

Any questions about this part?

2. Near Vertical Incidence Skywave

c. Optimum antenna height

NVIS myths cause a lot of harm and are hard to root out.

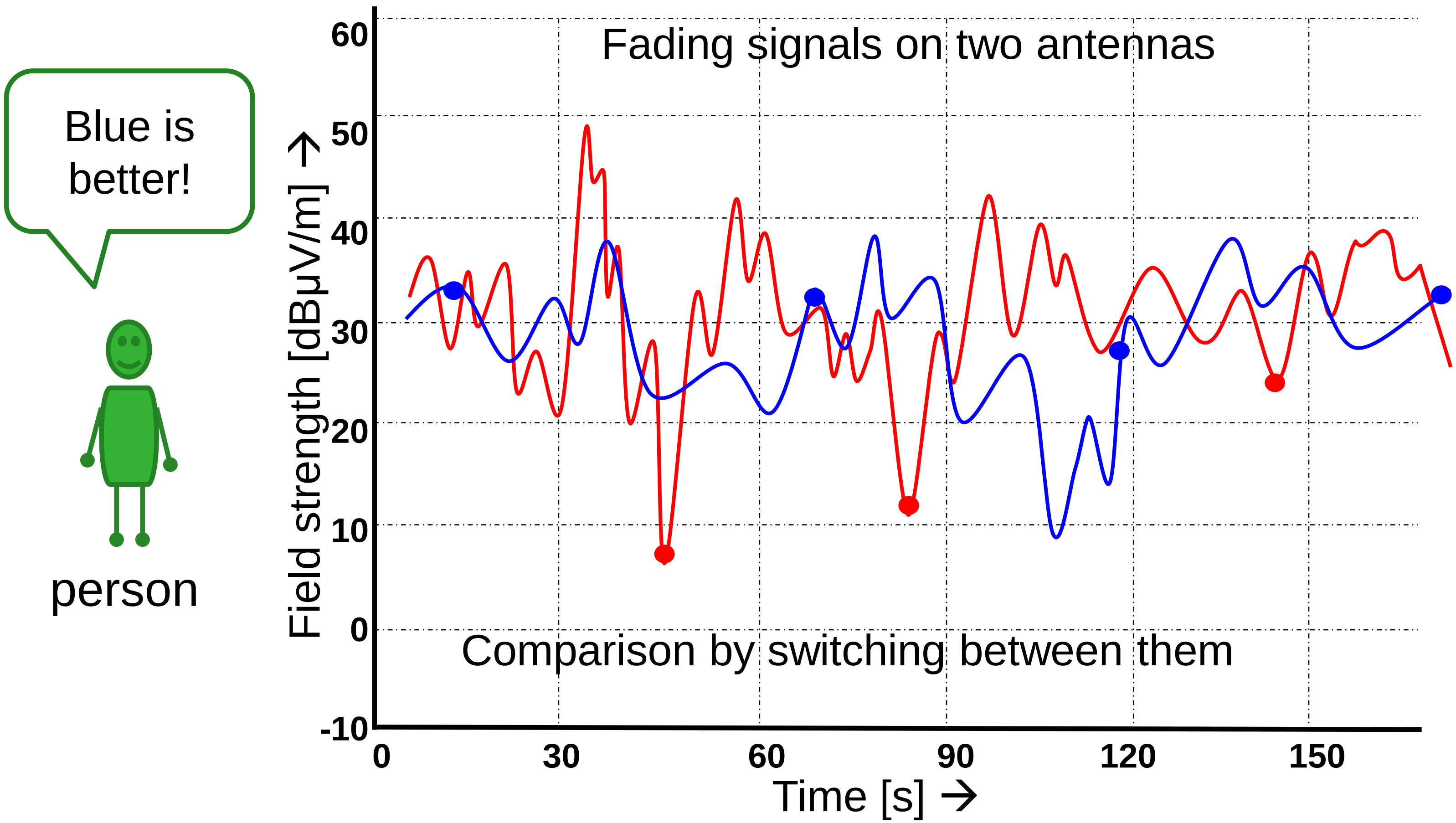
Myth 1: NVIS antenna must be as low as possible.

Myth 2: NVIS antenna must be 0.25 λ above ground.

2. Near Vertical Incidence Skywave

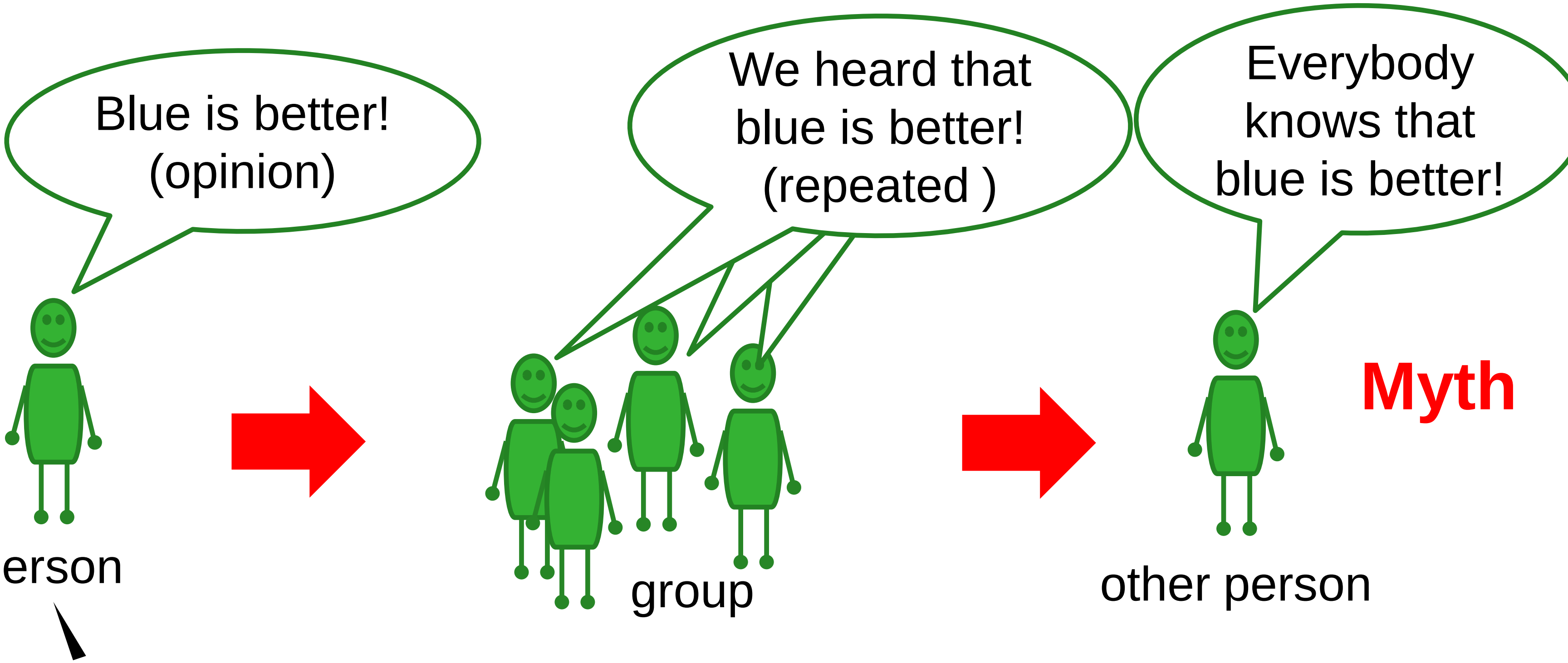
c. Optimum antenna height

Myths caused by poor experiments and wrong conclusions



c. Optimum antenna height

NVIS myths do a lot of damage (loss of lives and property)

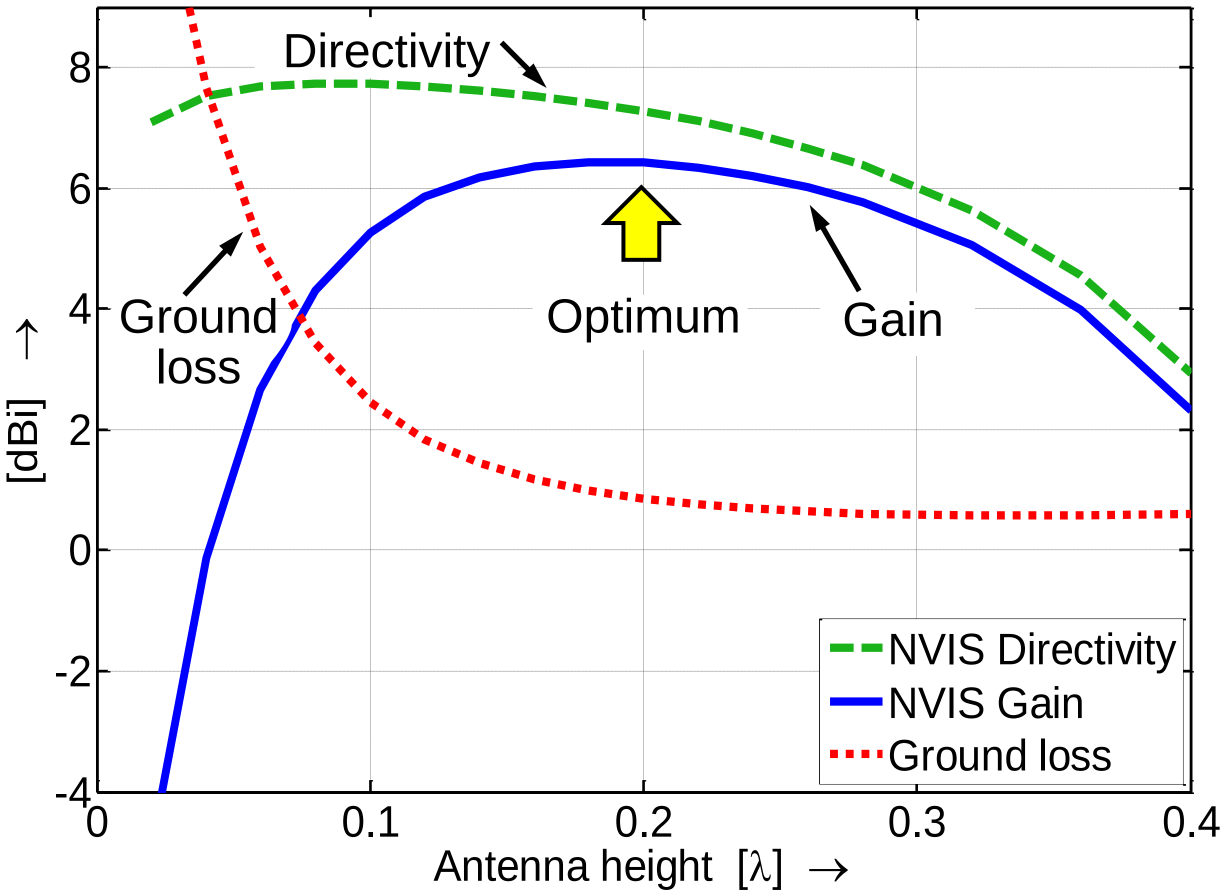


Performs an incomplete
and uncontrolled experiment

2. Near Vertical Incidence Skywave

c. Optimum antenna height

Simulation with NEC4 shows something different



NVIS Antenna Gain

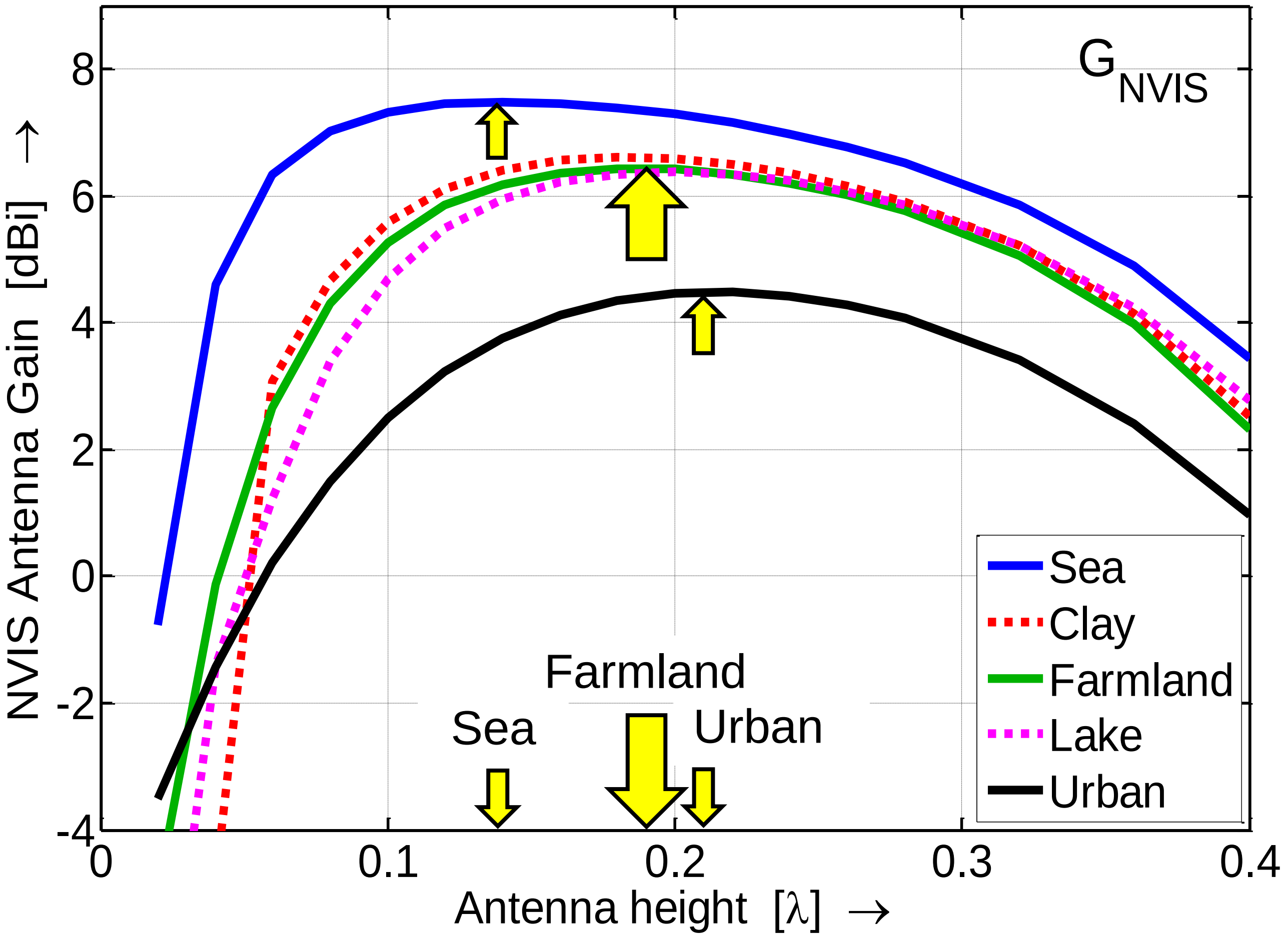
average gain
70°< α < 90°

Example for farmland

2. Near Vertical Incidence Skywave

c. Optimum antenna height

Simulation with NEC4 for 5 ground types



Optimum height

0.14 – 0.21 λ

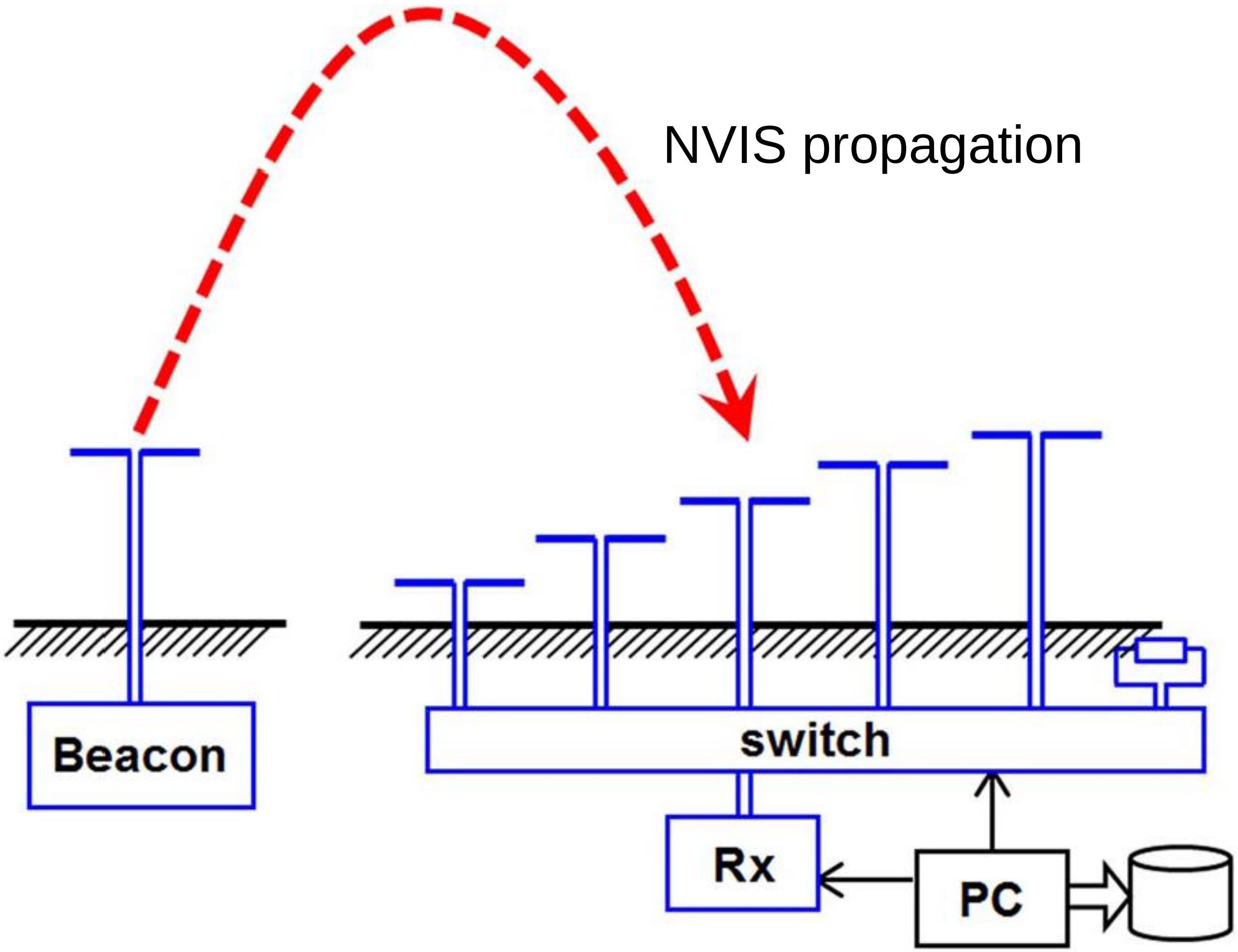
Definitely

NOT low !

2. Near Vertical Incidence Skywave

c. Optimum antenna height

Verification by controlled experiment



Unused antennas detuned with shorted λ/4 feedline

2. Near Vertical Incidence Skywave

c. Optimum antenna height

Verification by controlled experiment

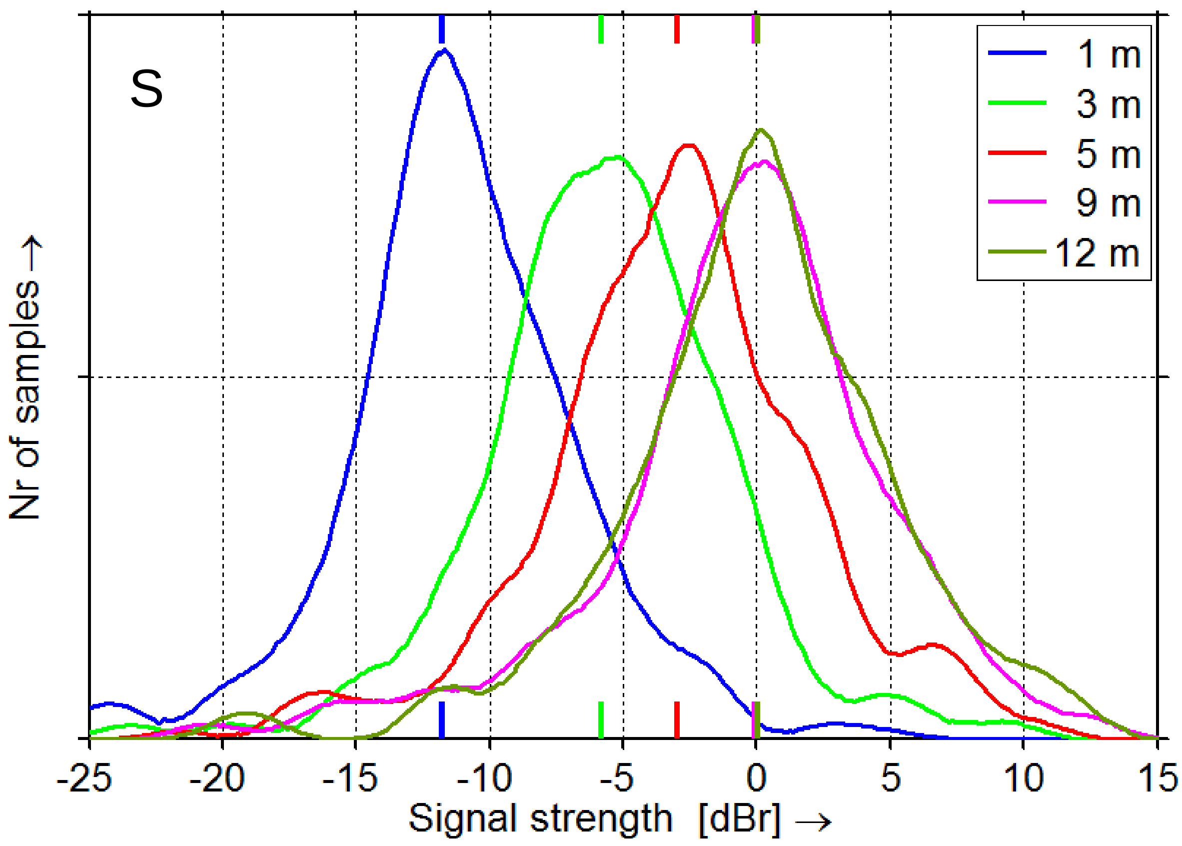
Measurements on 5.4 MHz using F2 NVIS propagation over 100 km

Antenna heights:	12.5 m	9 m	5 m	3 m	1 m
	0.22 λ	0.16 λ	0.09 λ	0.05 λ	0.02 λ

2. Near Vertical Incidence Skywave

c. Optimum antenna height

Verification by controlled experiment



0.02 λ -12 dB
0.05 λ
0.09 λ
0.16 λ optimum
0.22 λ

Low antennas are definitely not good !

c. Optimum antenna height

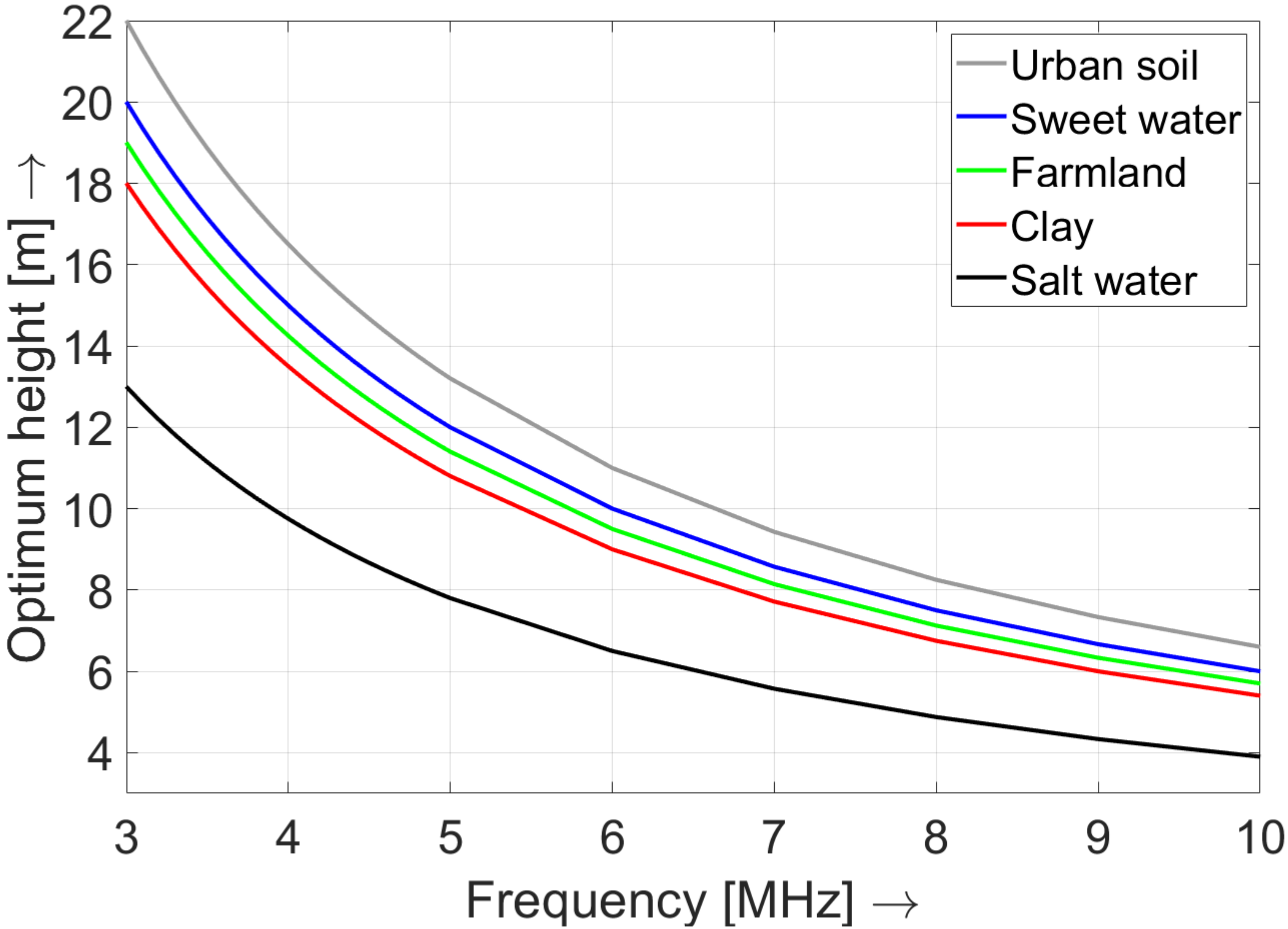
Verification by controlled experiment

Antenna height		NVIS Antenna Gain		
		Simulated	Meas.1	Meas.2
12.5 m	0.22 λ	-0.2 dBr	0.0 dBr	0.0 dBr
9 m	0.16 λ	-0.0 dBr	-0.8 dBr	0.0 dBr
5 m	0.09 λ	-1.5 dBr	-2.6 dBr	-3.0 dBr
3 m	0.05 λ	-5.0 dBr	-6.1 dBr	-5.8 dBr
1 m	0.02 λ	-12.0 dBr	-11.0 dBr	-11.8 dBr

You loose 11 to 12 dB by installing your NVIS antenna low

2. Near Vertical Incidence Skywave

c. Optimum antenna height



2. Near Vertical Incidence Skywave

c. Optimum antenna height

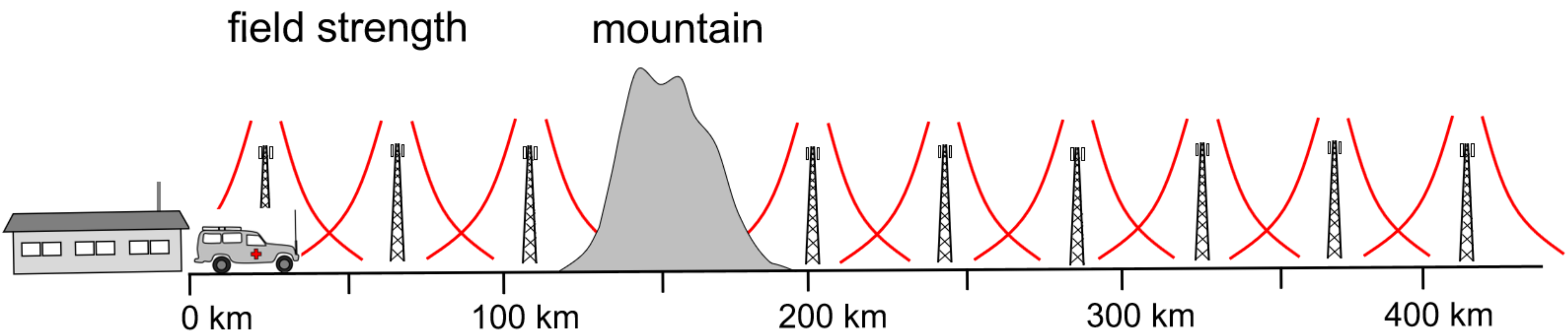
Any questions about this part?

2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Cell phone network

- Dense network of base stations with high towers
- Requires $$$ (and time) to install and maintain
- Natural obstacles reduce coverage

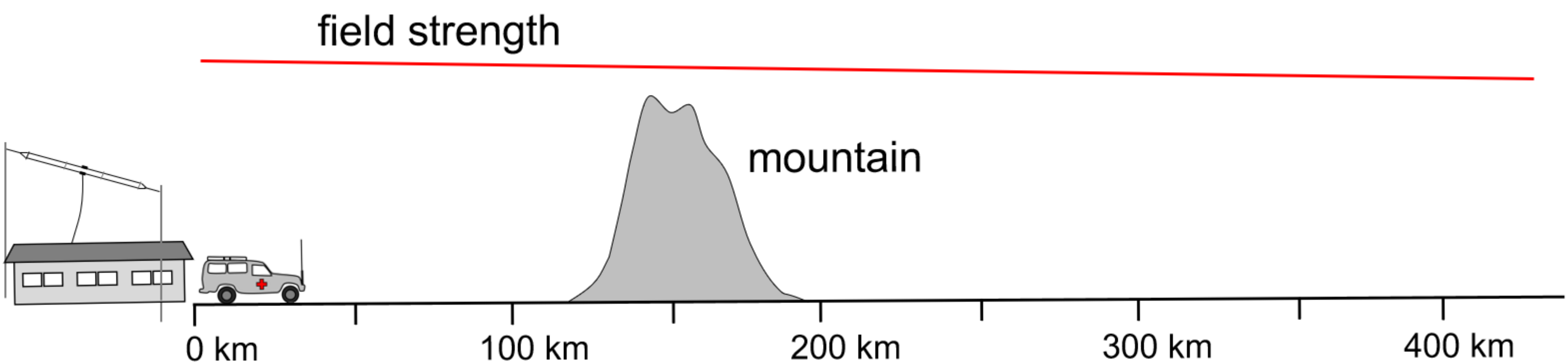


2. Near Vertical Incidence Skywave

d. The "Dead Zone" problem

HF radio

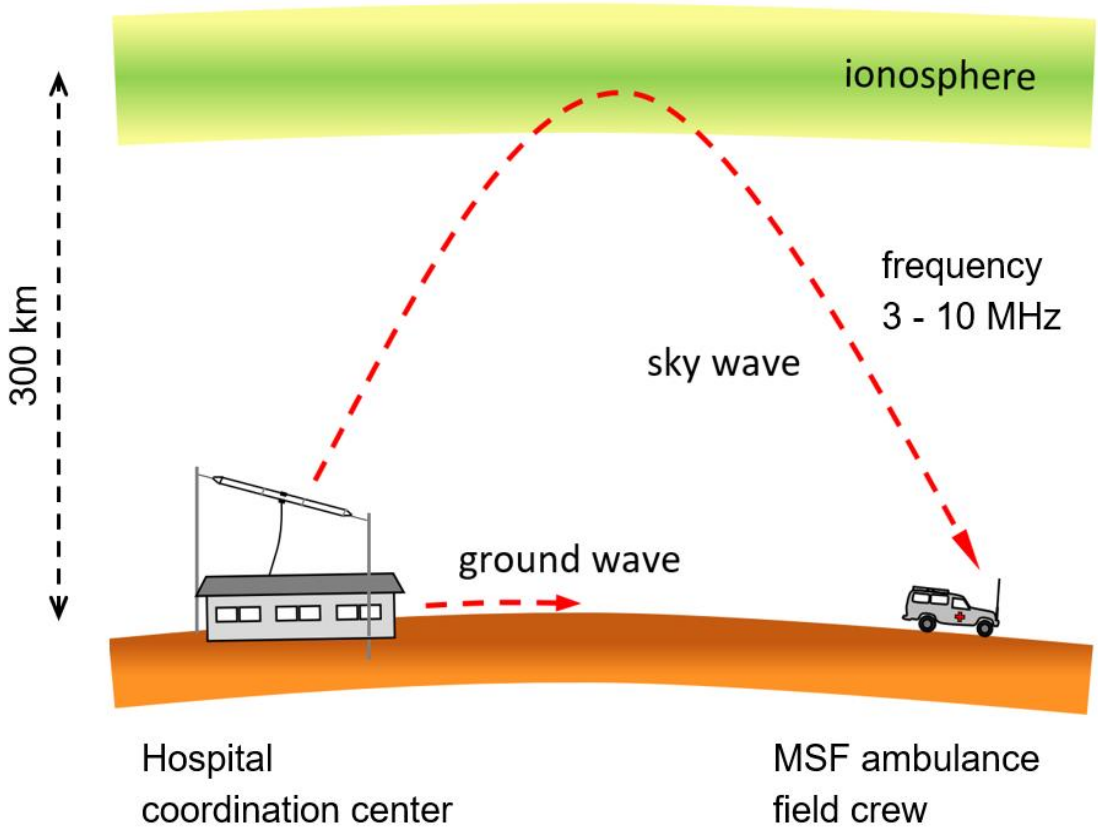
- Fast activation, cheap, no toll fees
- Independent of third parties
- Natural obstacles have no influence



2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

HF radio



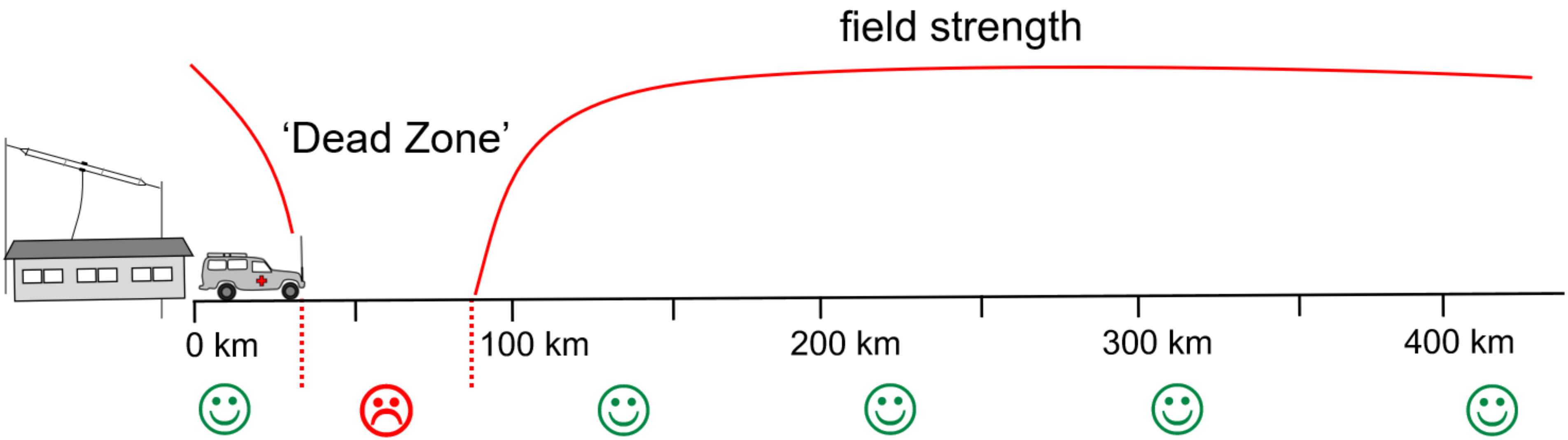
Coverage area (example)

2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Reports of gap in coverage that is not understood

A security threat for MSF staff and clients in
Central African Republic, Mali, Guinée Conakry,
Mozambique, Afghanistan



2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Possible causes

1. Ambient electromagnetic noise
2. Transmission above the critical frequency of the ionosphere
3. Antenna characteristics

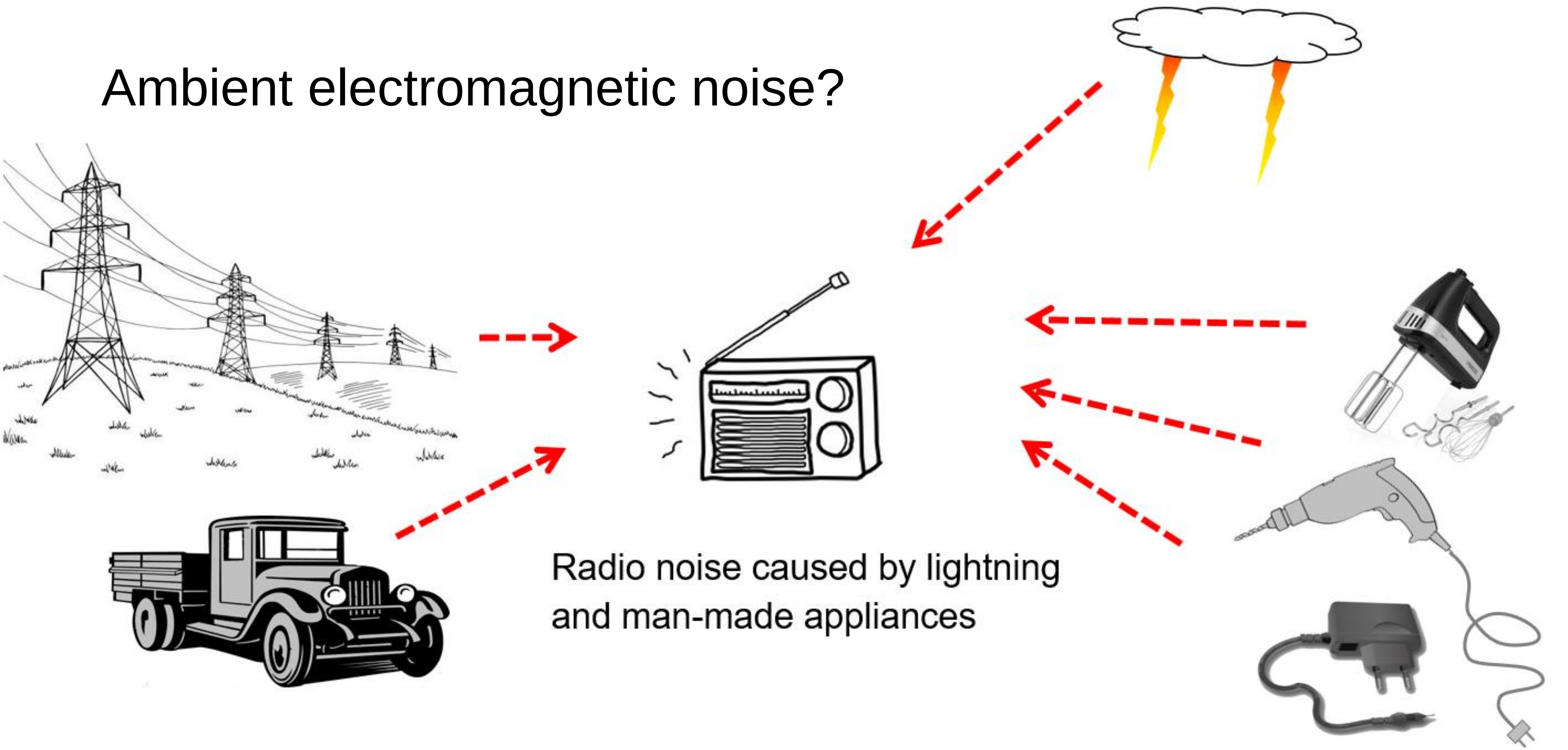
These issues have been investigated *theoretically.*

If desired, they can be verified by measurements.
If desired, mitigation can also be tested.
(Please let me know)

2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Ambient electromagnetic noise?



2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Ambient electromagnetic noise?

Simulated signal strength *assuming isotropic antennas*:

- Sky wave (PropLab Pro)
- Ground wave (NTIA LFMF)

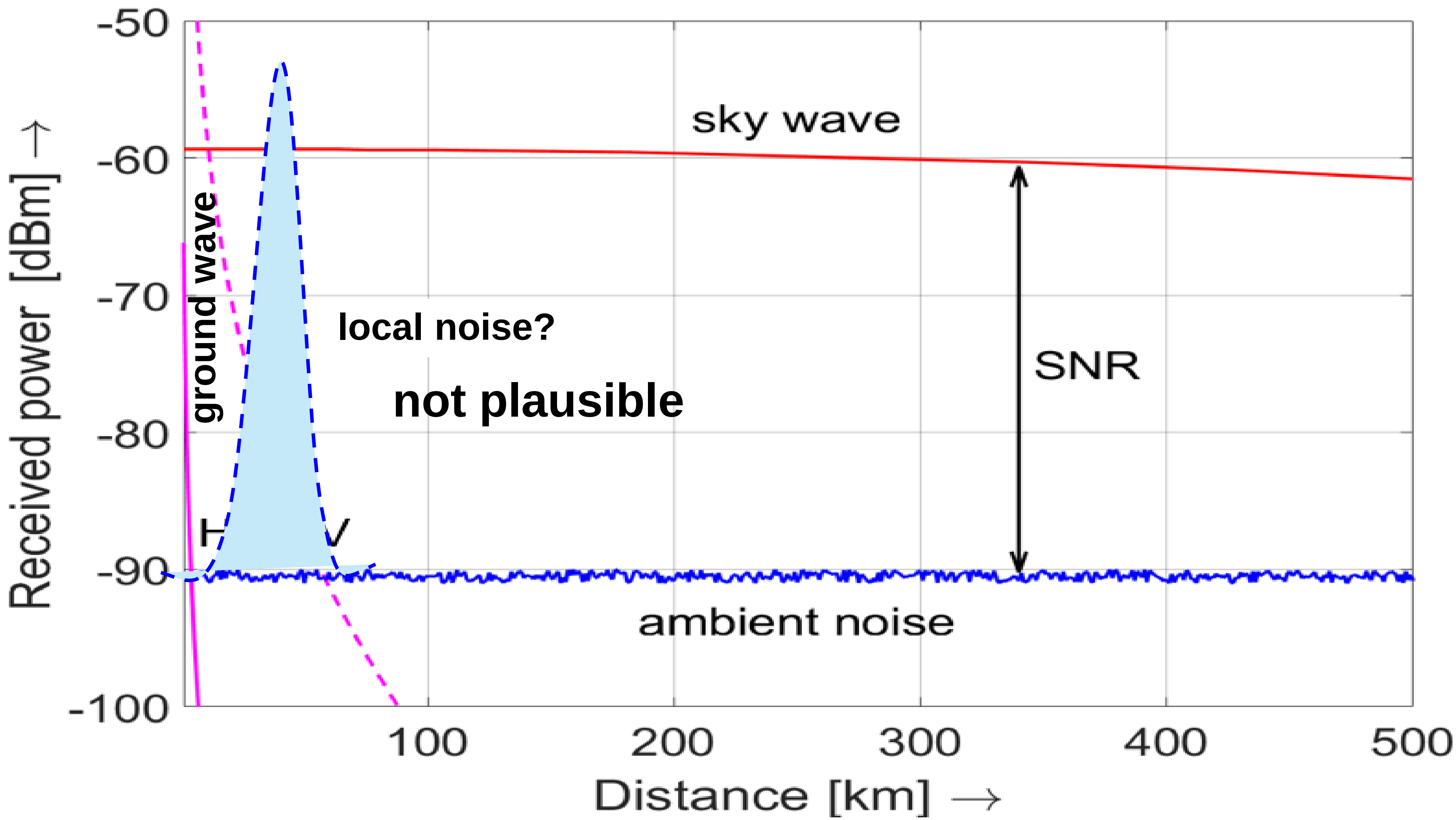
Empirical model for ambient noise:

- Rec. ITU-R P.372-14

2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

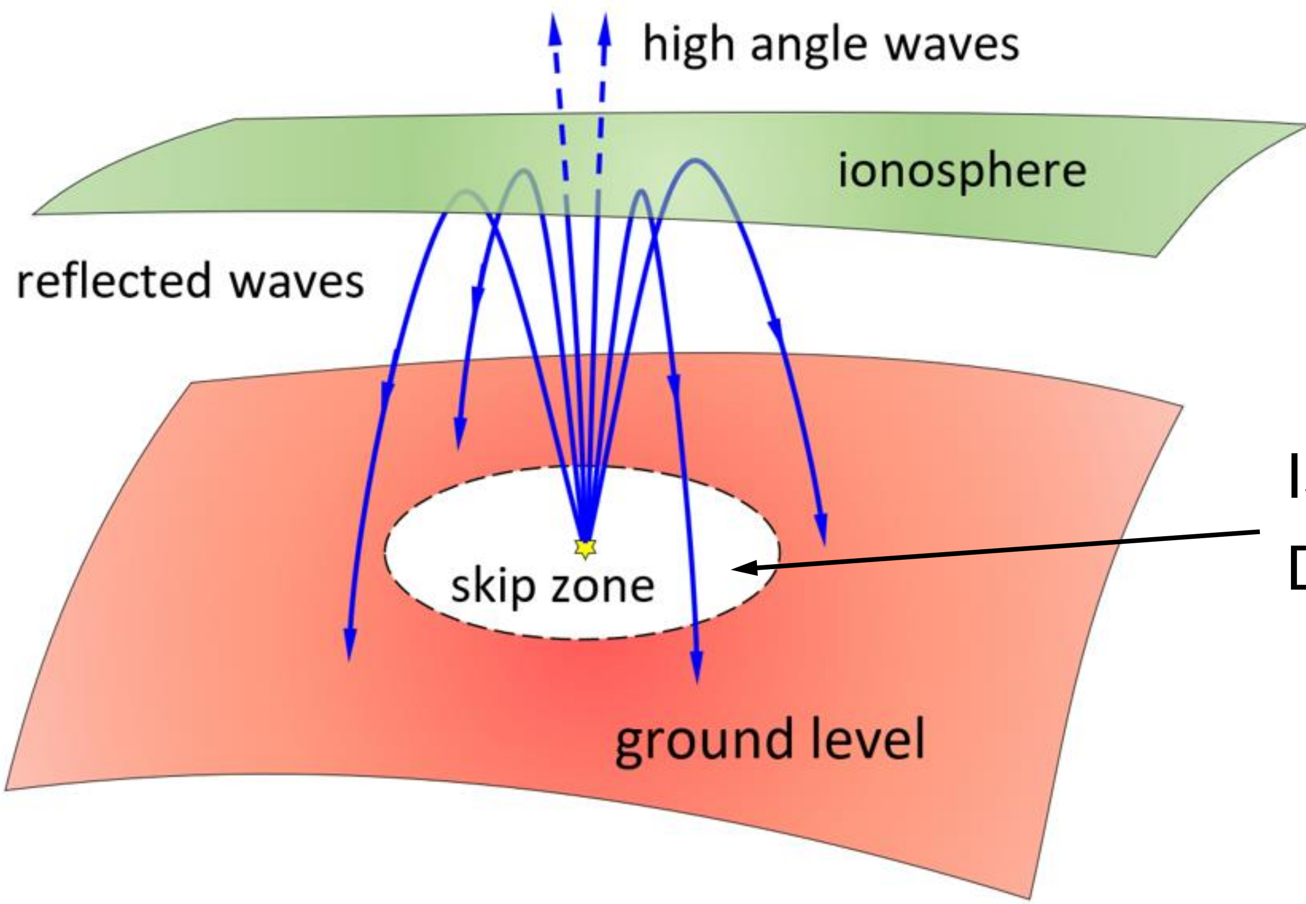
Ambient electromagnetic noise?



2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Above the critical frequency?

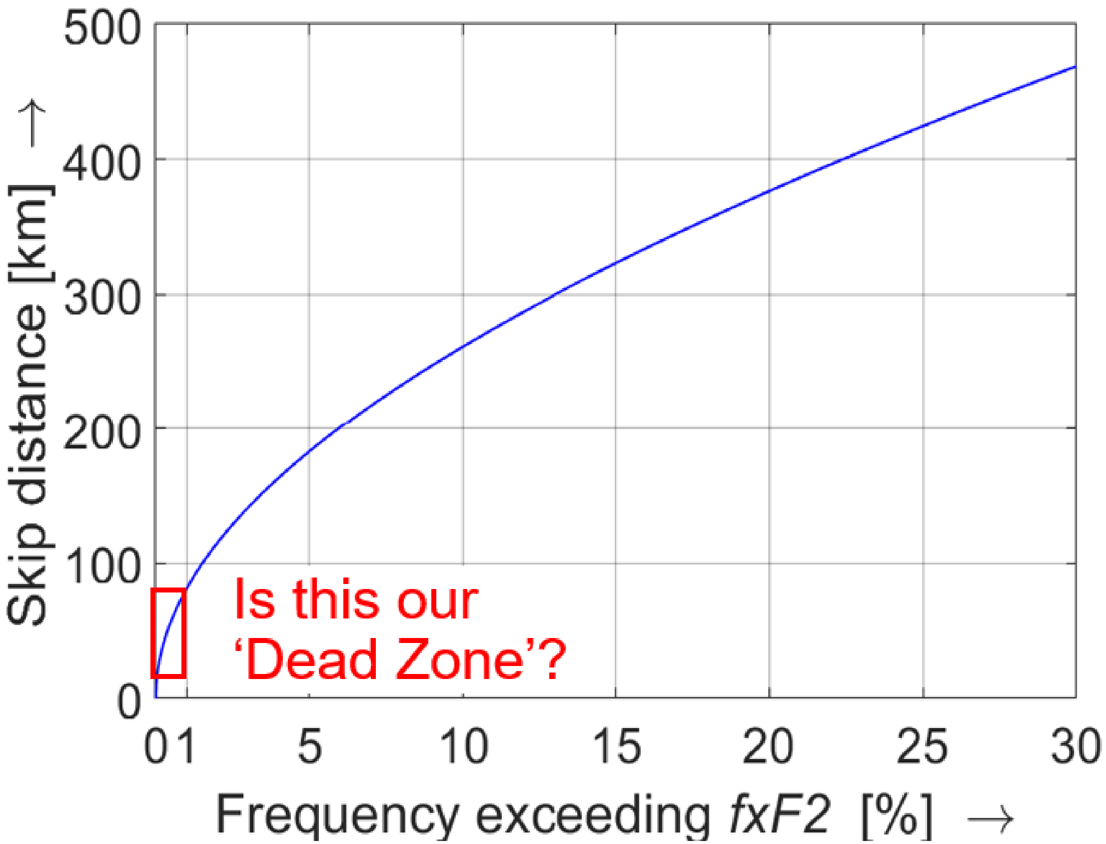


Is this the Dead Zone?

2. Near Vertical Incidence Skywave

d. The "Dead Zone" problem

Above the critical frequency?



Using Martyn's Secant Law, we can calculate the skip distance

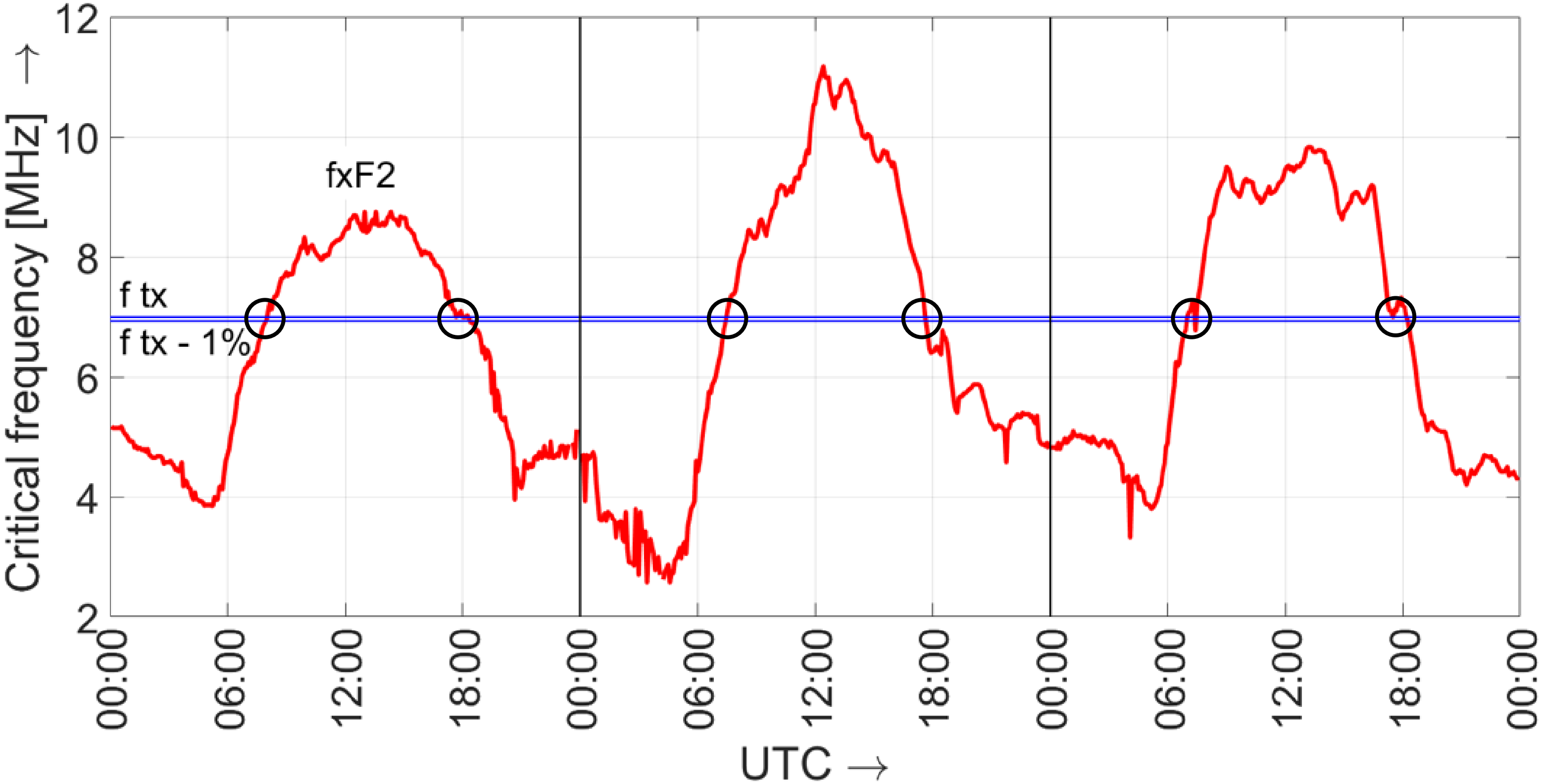
f_{tx} = fxF2 + 1% ?

2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Above the critical frequency?

1% above fxF2 will happen only a few minutes: **not plausible**

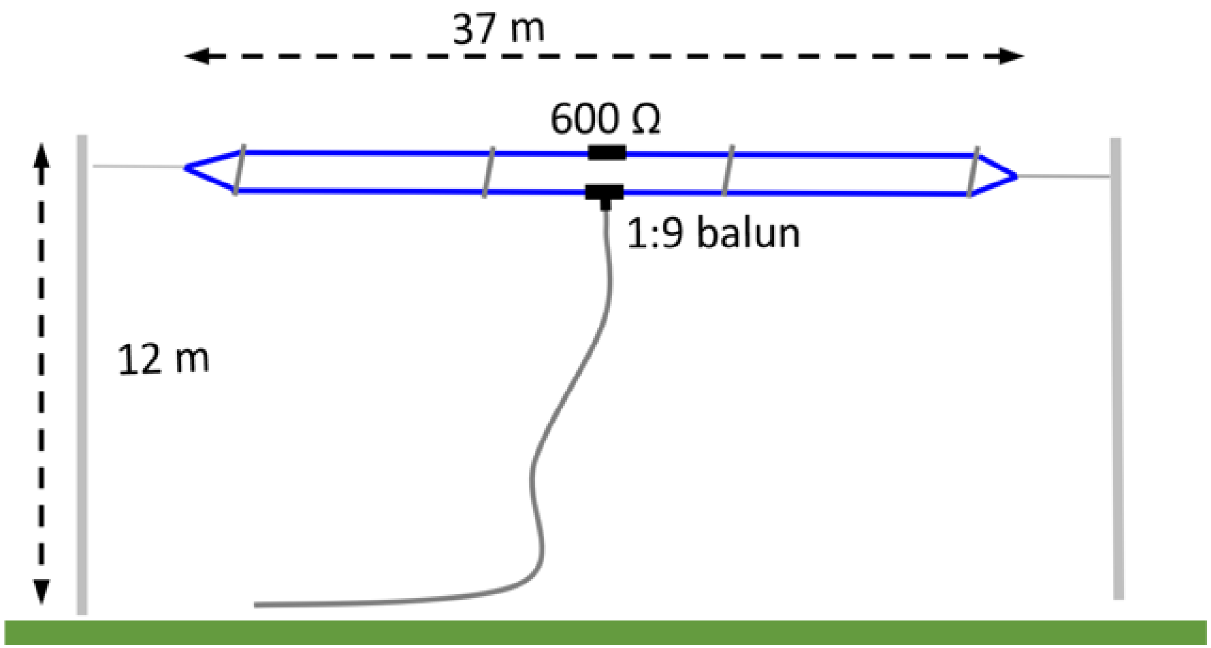


2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Antenna characteristics?

T2FD, horizontally polarized wideband antenna



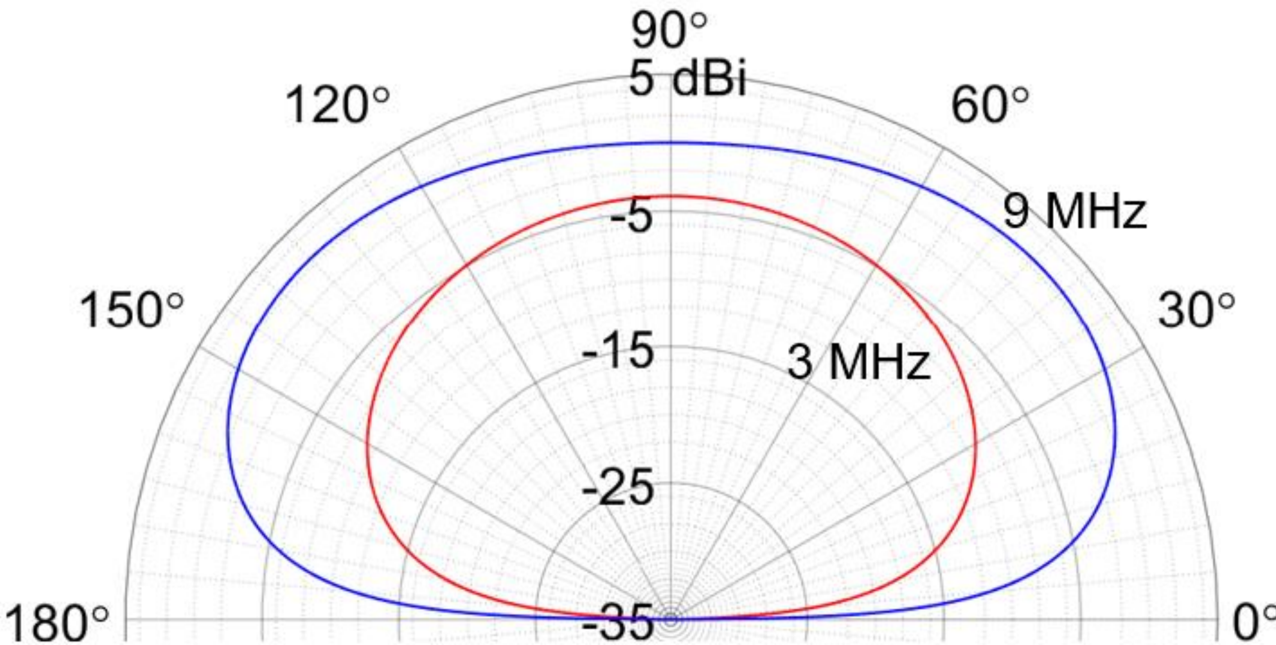
Hospital antenna

2. Near Vertical Incidence Skywave

d. The "Dead Zone" problem

Antenna characteristics?

Antenna gain versus elevation angle



Good coverage of high angles

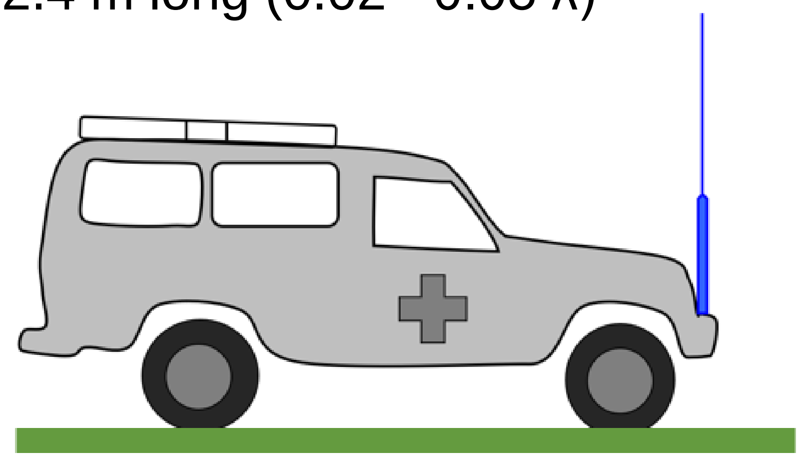
2. Near Vertical Incidence Skywave

d. The "Dead Zone" problem

Antenna characteristics?

Tuned short vertical whip antenna

2.4 m long (0.02 - 0.08 λ)



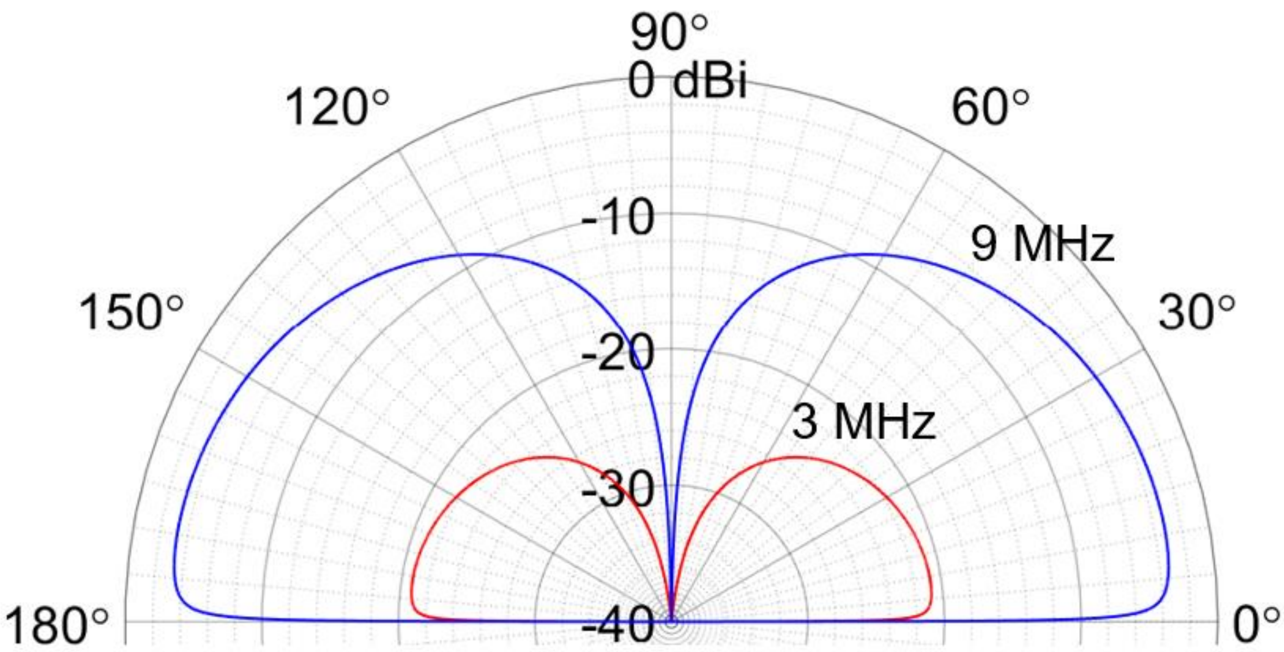
Ambulance antenna

2. Near Vertical Incidence Skywave

d. The “Dead Zone” problem

Antenna characteristics?

Antenna gain versus elevation angle



Poor coverage of high angles

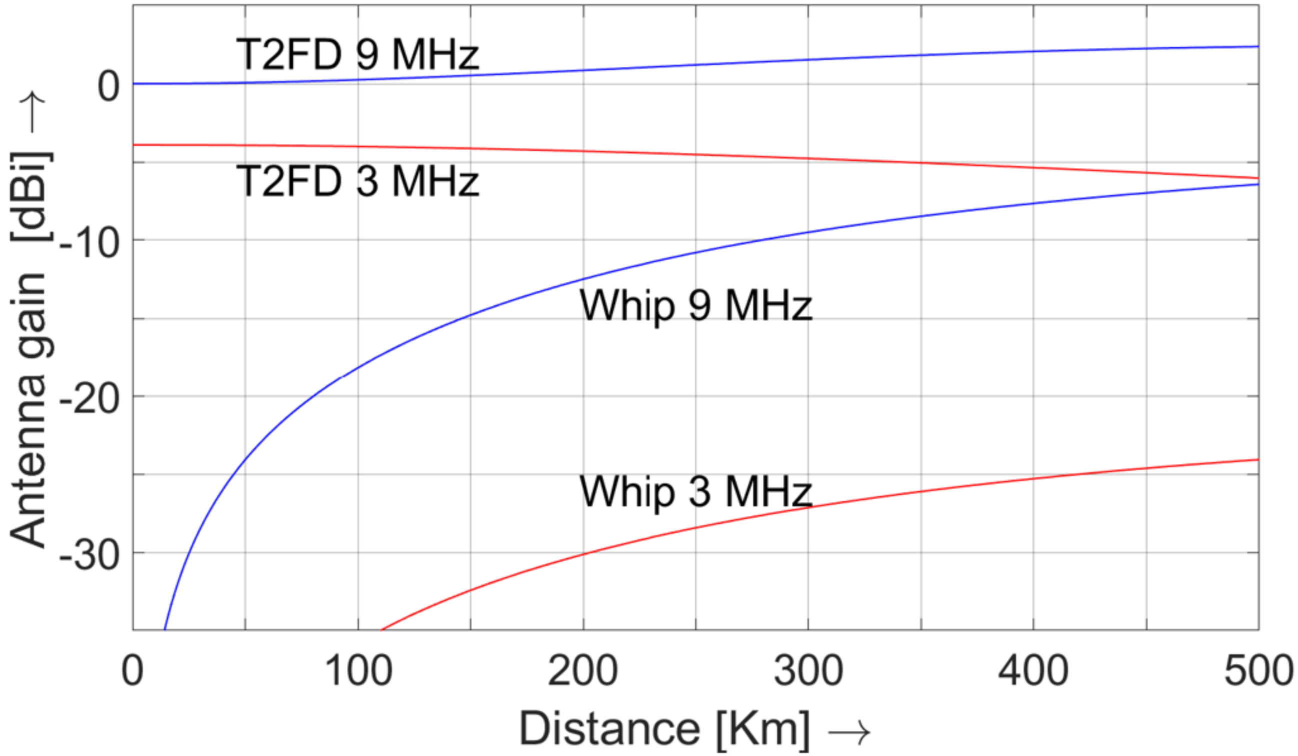
Low efficiency, especially at low frequencies

2. Near Vertical Incidence Skywave

d. The "Dead Zone" problem

Antenna characteristics?

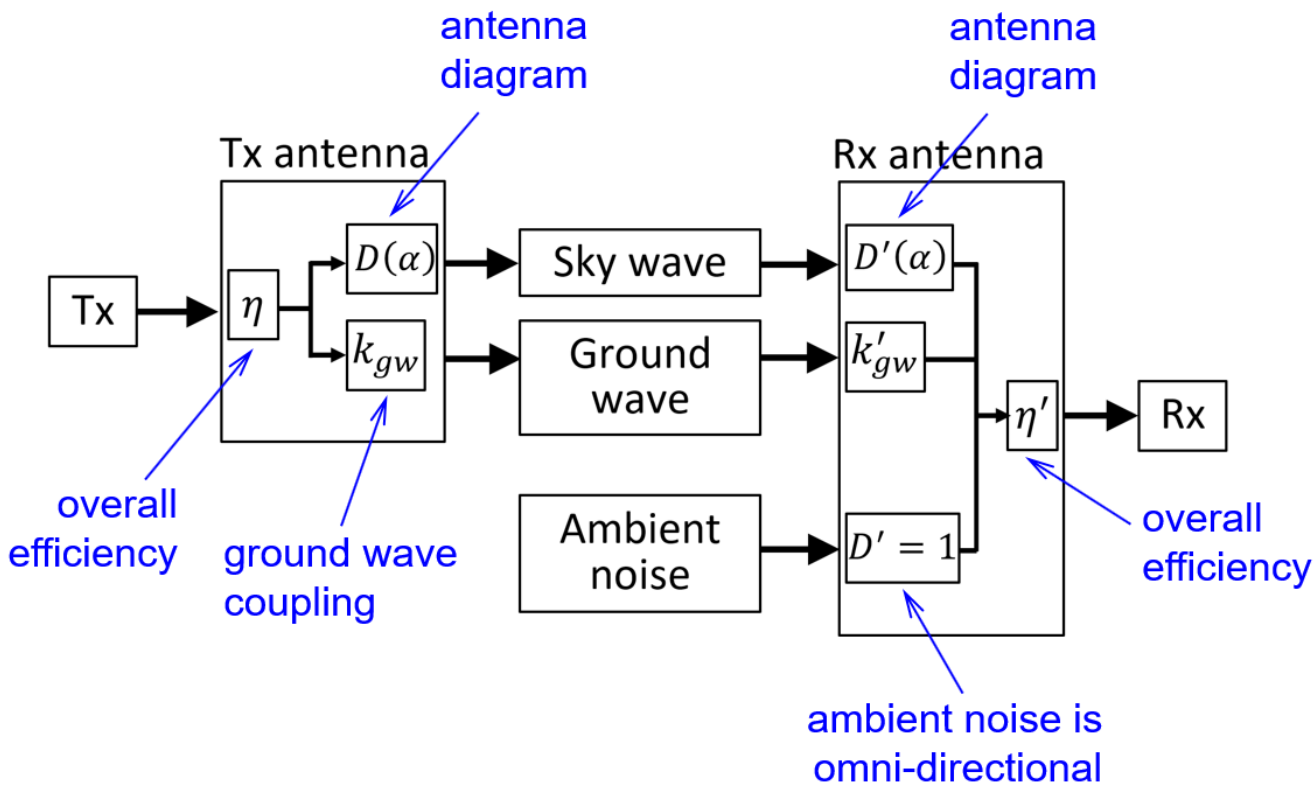
Antenna gain versus distance



d. The “Dead Zone” problem

Antenna characteristics?

Calculation model

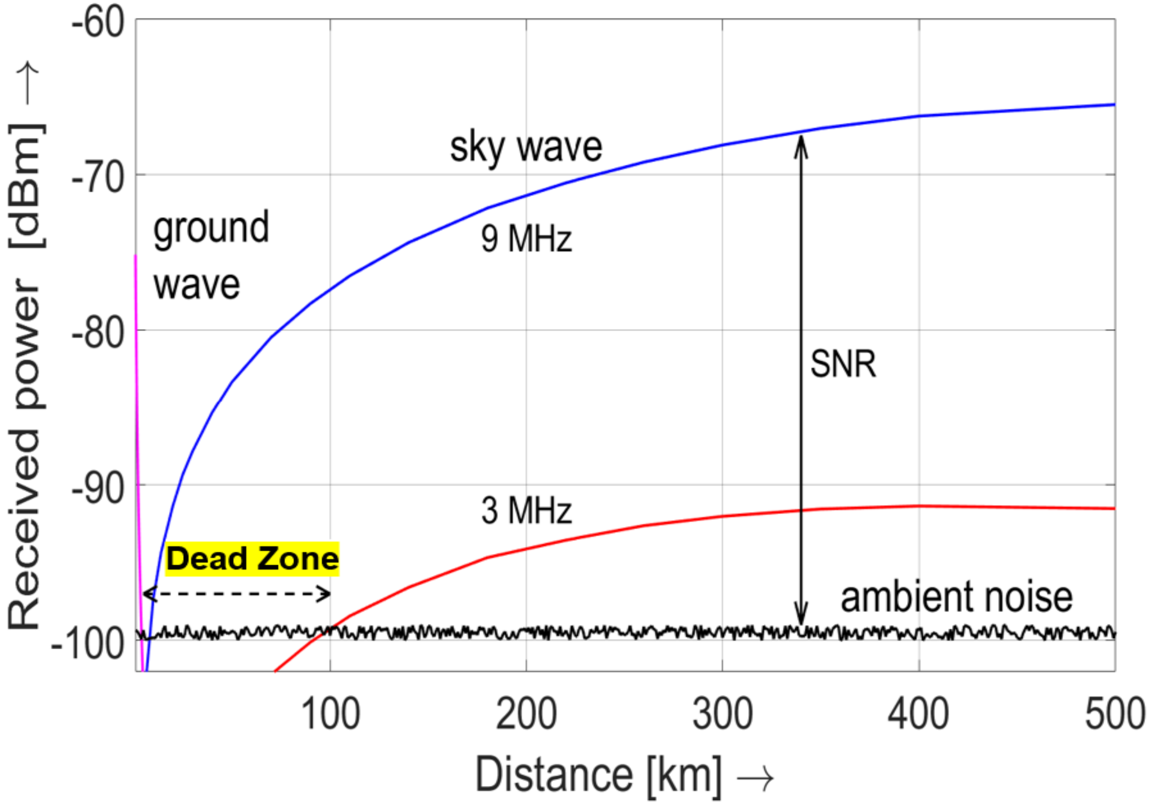


2. Near Vertical Incidence Skywave

d. The "Dead Zone" problem

Antenna characteristics?

Calculated results **highly plausible!**



2. Near Vertical Incidence Skywave

d. The "Dead Zone" problem

Antenna characteristics?

- The vertical antenna diagram of the vertical whip antenna is poor for short distance NVIS propagation, and this may cause the "Dead Zone".
- At high frequencies the antenna efficiency is better and there the "Dead Zone" is small.
- At low frequencies the antenna efficiency is very poor, which increases the size of the "Dead Zone".

The effect has been clearly demonstrated by simulation.

To further prove this is the cause, and to find solutions, measurements on the antennas are needed. Does MSF want these done?

2. Near Vertical Incidence Skywave

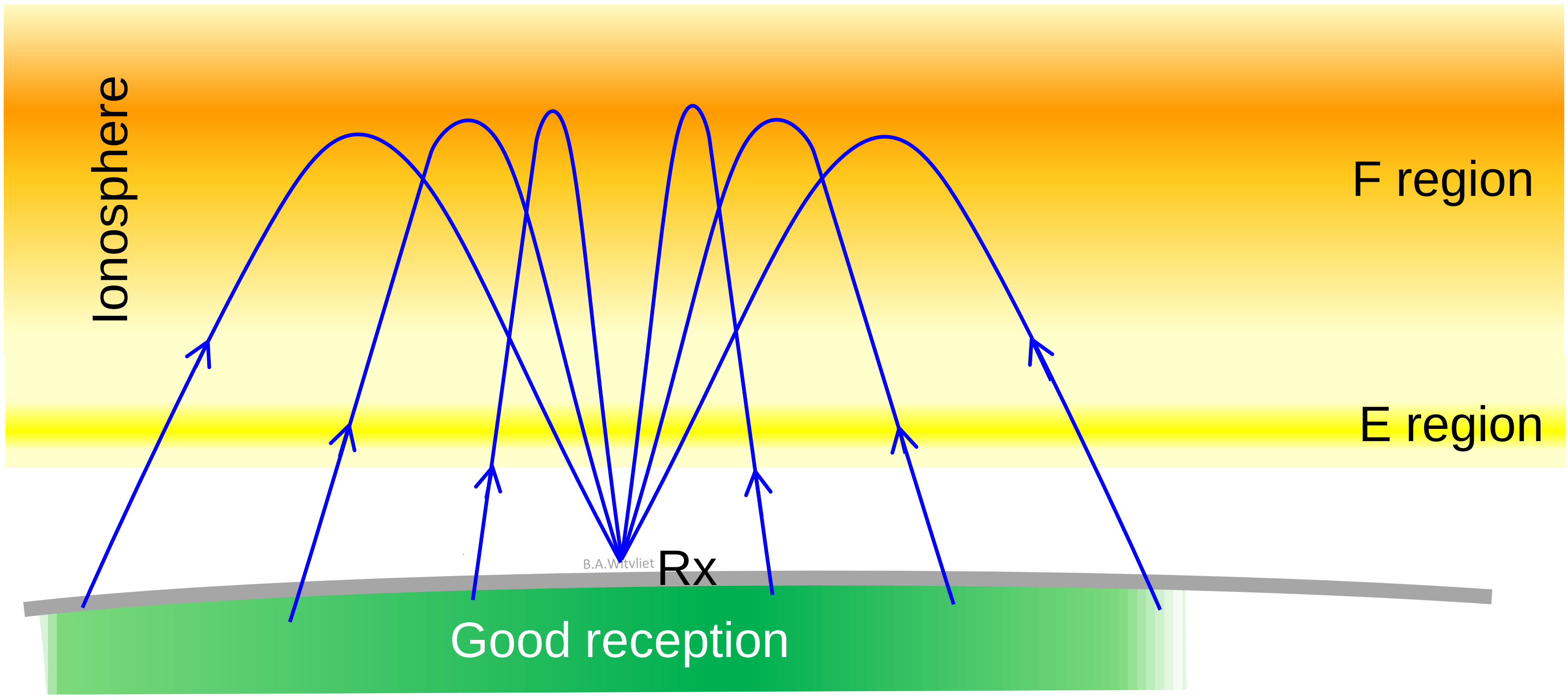
d. The “Dead Zone” problem

Any questions about this part?

2. Near Vertical Incidence Skywave

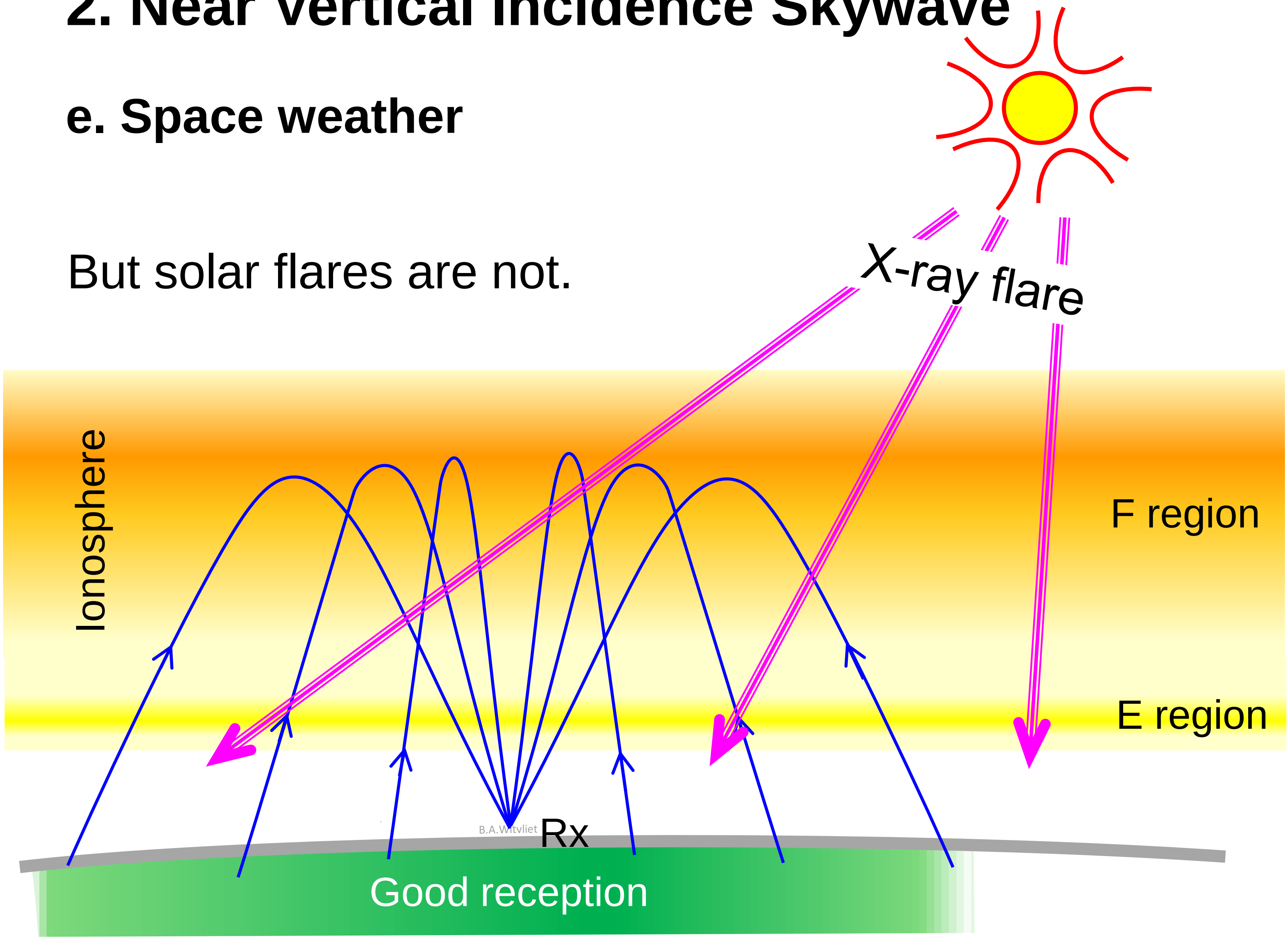
e. Space weather

With a quiet sun, the ionosphere is (more or less) predictable



e. Space weather

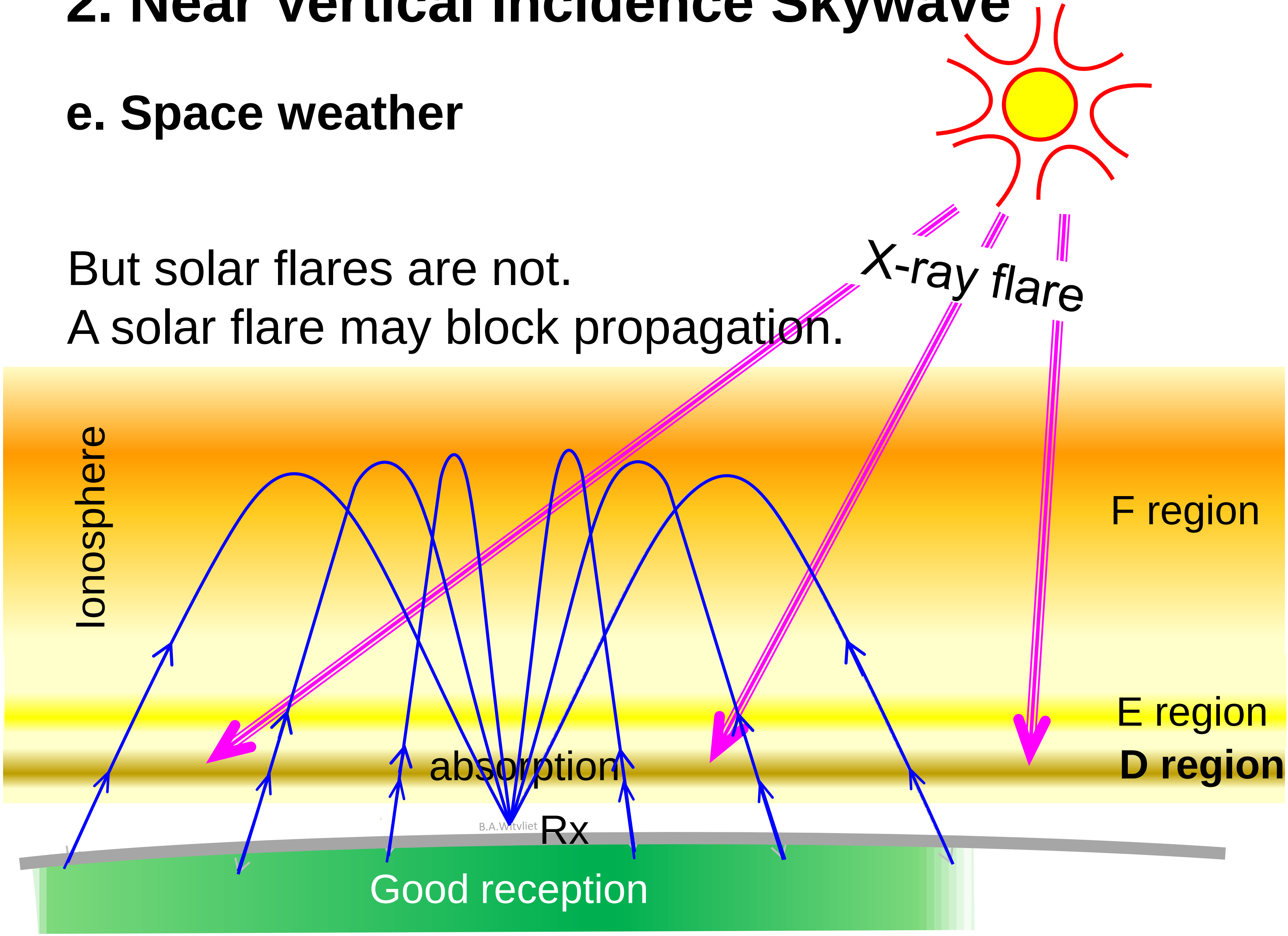
But solar flares are not.



2. Near Vertical Incidence Skywave

e. Space weather

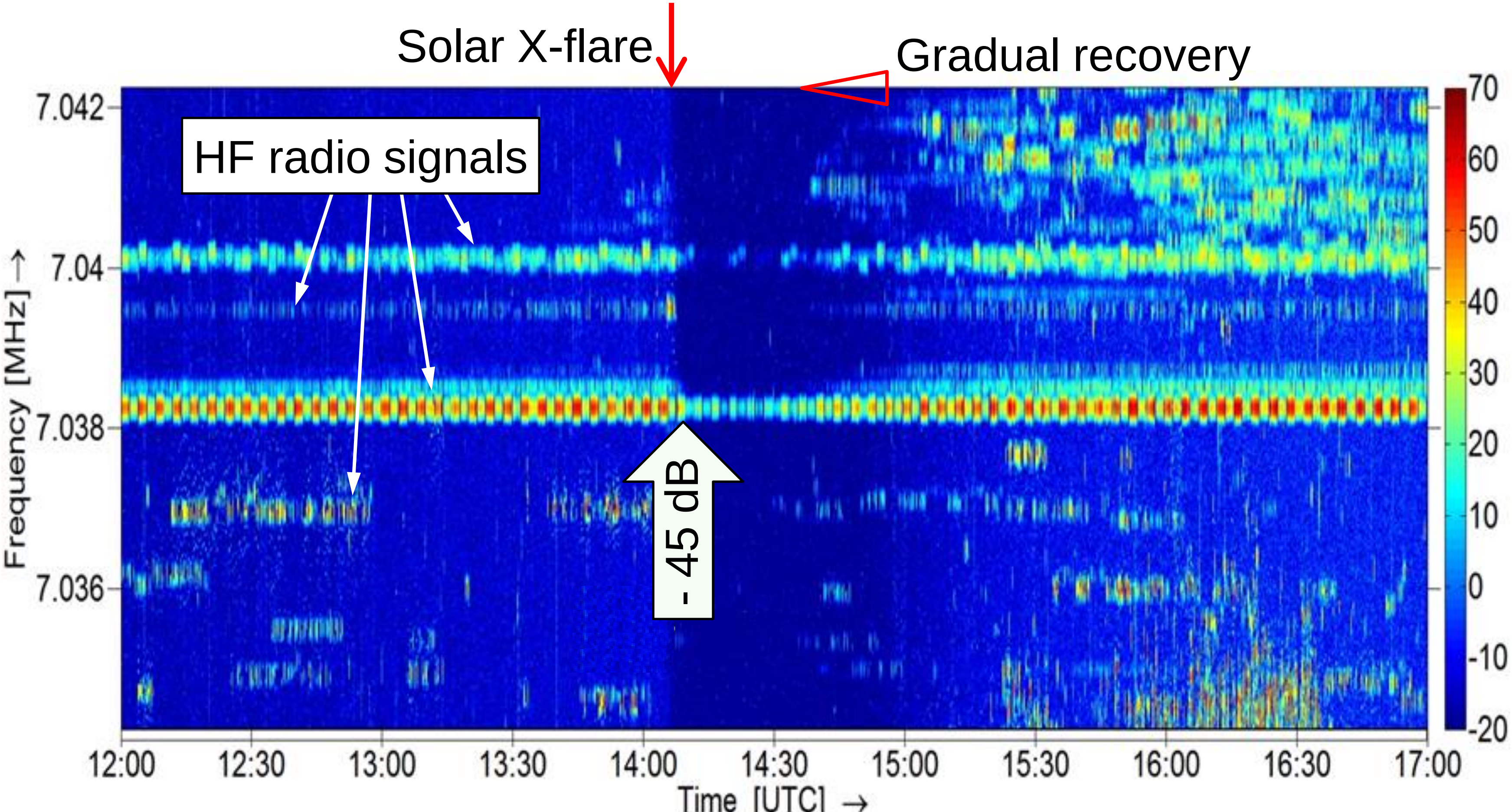
But solar flares are not.
A solar flare may block propagation.



2. Near Vertical Incidence Skywave

e. Space weather

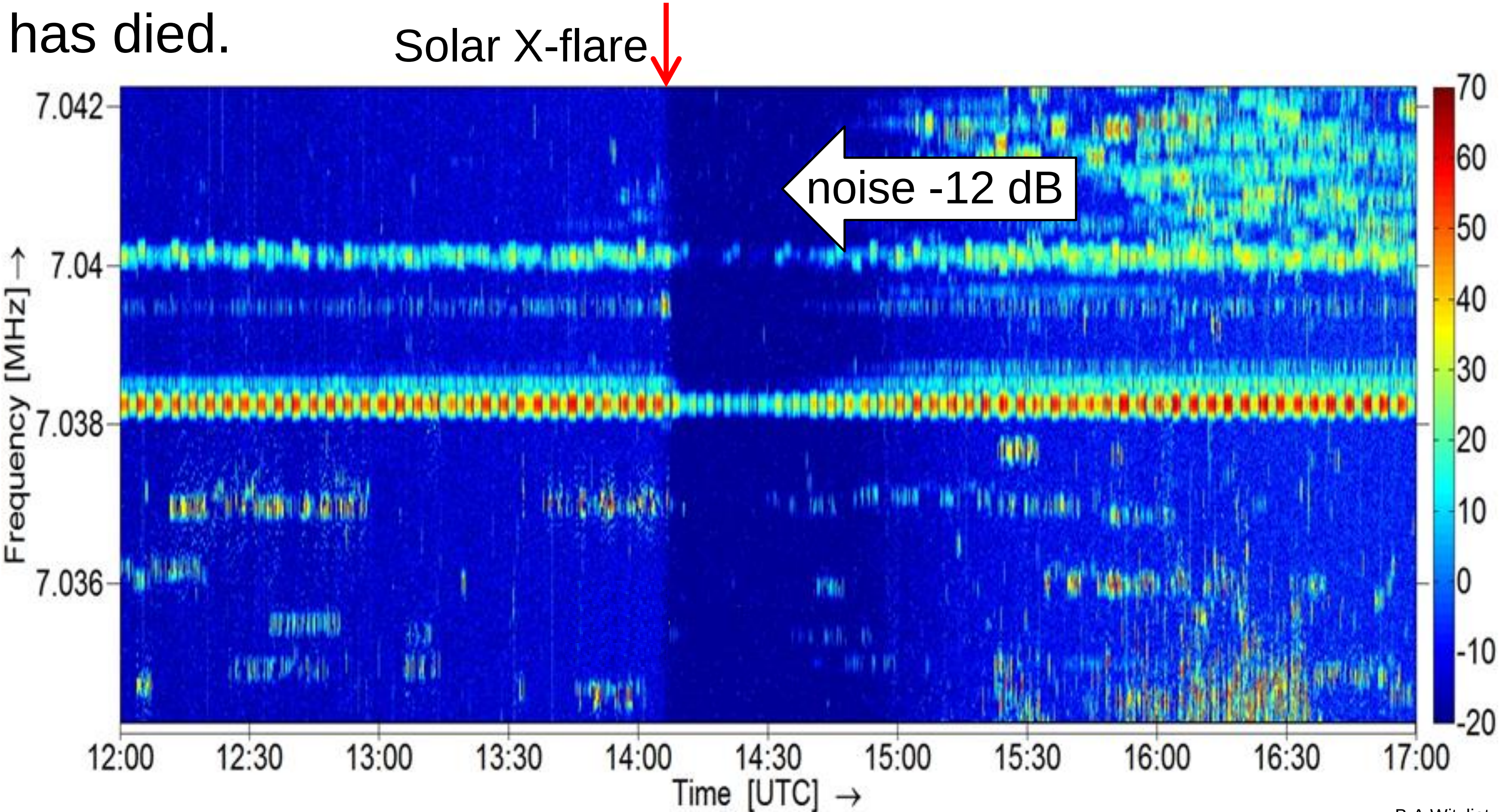
This is what it looks like for real (measurement)



2. Near Vertical Incidence Skywave

e. Space weather

As the noise drops out too, you may think your receiver has died.



e. Space weather

As the noise drops out too, you may think your receiver has died.

- ❑ Is the receiver dead?
- ❑ Is the antenna down?

???

- ❑ Is there a NOAA Space Weather warning? →

Space Weather Message Code: SUMX01
Serial Number: 105
Issue Time: 2014 Oct 22 1454 UTC

SUMMARY: X-ray Event exceeded X1

Begin Time: 2014 Oct 22 1402 UTC
Maximum Time: 2014 Oct 22 1428 UTC
End Time: 2014 Oct 22 1450 UTC

X-ray Class: X1.6
Optical Class: 2b
Location: S14E13
NOAA Scale: R3 - Strong

2. Near Vertical Incidence Skywave

e. Space weather

Any questions about this part?

3. PITHIA-NRF

a. Who are we?

Plasmasphere **I**onosphere **Th**ermosphere **I**ntegrated Research Environment and **A**ccess services:
a **N**etwork of **R**esearch **F**acilities

www.pithia-nrf.eu

This is a research project for upper atmosphere and space weather research that is funded by the European Union (5 Meuro)

Our goal is to make our (many) expensive research instruments accessible for coordinated / simultaneous measurements, and provide easy access to measurement data and models online.

3. PITHIA-NRF

a. Who are we?

ASTRON/NWO-I | Stichting Nederlandse Wetenschappelijke Onderzoek Instituten, The Netherlands | www.astron.nl

BGD | Borealis Global Designs Ltd., Bulgaria | www.borealis-designs.org

BIRA-IASB | Institut royal d'Aéronomie Spatiale de Belgique, Belgium | www.aeronomie.be

CBK/PAS | Centrum Badań Kosmicznych PAN, Poland | www.cbk.waw.pl

CNES | Centre National d’Etudes Spatiales, France | cnes.fr

DLR | German Aerospace Center - Institute for Solar-Terrestrial Physics, Germany | www.dlr.de

EGI | EGI Foundation, The Netherlands | www.egi.eu

EISCAT | EISCAT Scientific Association, Sweden | www.eiscat.se

GFZ | German Research Centre for Geosciences, Germany | www.gfz-potsdam.de

IAP | Institute of Atmospheric Physics of the Czech Academy of Science, Czech Republic | www.ufa.cas.cz

INGV | Istituto Nazionale di Geofisica e Vulcanologia, Italy | www.ingv.it

JFCONSULT | Watermann Juergen Friedrich Wilhelm, France | jfconsult.free.fr

KULEUVEN | Katholieke Universiteit Leuven, Belgium | kuleuven.be

NOA | National Observatory of Athens, Greece | www.astro.noa.gr

OE | Observatorio del Ebro Fundación, Spain | www.obsebre.es

RMI | Institut Royal Meteorolgique de Belgique, Belgium | ionosphere.meteo.be

ROB | Royal Observatory of Belgium, Belgium | www.astro.oma.be

UOULU-SGO | Oulu University, Sodankylä Geophysical Observatory, Finland | www.sgo.fi

UOW | University of Westminster, United Kingdom | www.westminster.ac.uk

UPC-IonSAT | Universitat Politècnica de Catalunya, Spain | futur.upc.edu/IonSAT

UT3-IRAP | The University Toulouse III-Paul Sabatier - Institut de Recherche en Astrophysique et Planétologie, France | www.irap.omp.eu

UTWENTE | University of Twente, The Netherlands | www.utwente.nl

3. PITHIA-NRF

a. Who are we?

- Ionosonde
- GNSS receiver network
- Incoherent scatter radar
- Low-frequency radio telescope
- VLF receivers
- Continuous Doppler Sounding System
- Field mill for the measurement of atmospheric electricity
- All-Sky Imager
- Infrasound network
- Meteor camera
- Meteor radar
- RIOmeter
- Magnetometer
- Cosmic ray detector
- Ionospheric heating

3. PITHIA-NRF

a. Who are we?

PITHIA research instruments	ASTRON	BGD	BIRA-IASB	CBK/PAS	CNES	DLR	EGI	EISCAT	GFZ	IAP	INGV	JFW	KULEUVEN	NOA	OE	RMI	ROB	UOULU-SGO	UoW	UPC-IonSAT	UT3-IRAP	UTWENTE
All-Sky Imager											X											
Continuous Doppler Sounding										X												
Cosmic ray detector																X		X				
Electric field mills										X												
GNSS receiver network				X		X					X						X			X		
Incoherent scatter radar								X														
Infrasound network																		X				
Ionosonde		X		X				X		X	X			X	X	X						
Ionospheric heating								X														
Low frequency radio telescope	X			X														X				
Magnetometer									X							X		X				
Meteor camera																		X				
Meteor radar																		X				
Research satellites																						
RIOmeter				X														X				
VLF receivers						X												X				

b. What can we do for you?

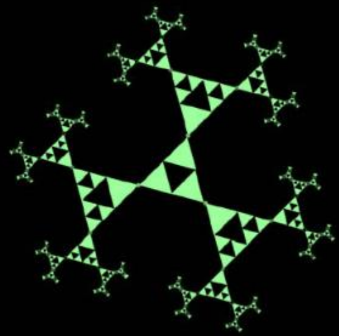
There are many very senior researchers in PITHIA-NRF.
Some are ionosonde, ionosphere and propagation experts.
Others know literally everything about space weather. Or antennas.

Please formulate your question, and we will help you to solve it.

The Innovation Day on 15 March, 09:00-17:00

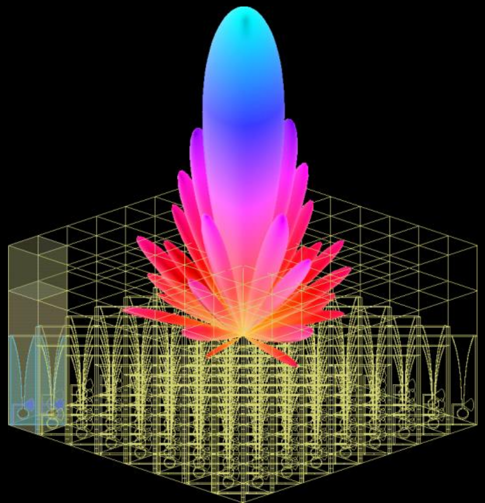
The Brussels Planetarium, Boechoutlaan 10, 1020 Brussels.

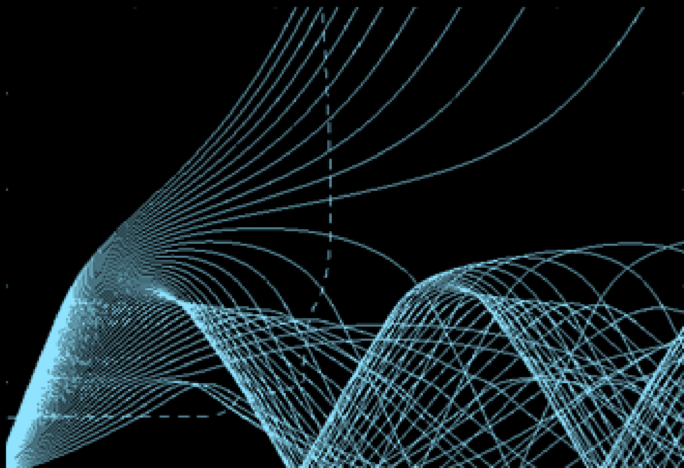
09:00	Opening
13:30 - 15:20	**Tell us your problem (20 min each)**. Users have the opportunity to tell us about concrete problems. Each brief presentation is followed by a discussion.
15:40 - 16:40	**B2B meetings**
17:00	Closing



This concludes my presentation

Any questions?





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Feel free to contact me any time

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