



The Abdus Salam
International Centre for Theoretical Physics



310/1749-48

ICTP-COST-USNSWP-CAWSES-INAF-INFN
International Advanced School
on
Space Weather
2-19 May 2006

*Effects of the Ionosphere
on Radiopropagation*

*Sandro M. RADICELLA
Aeronomy and Radiopropagation Laboratory (ARPL)
ICTP
Via Beirut, 7
34100 Trieste
ITALY*

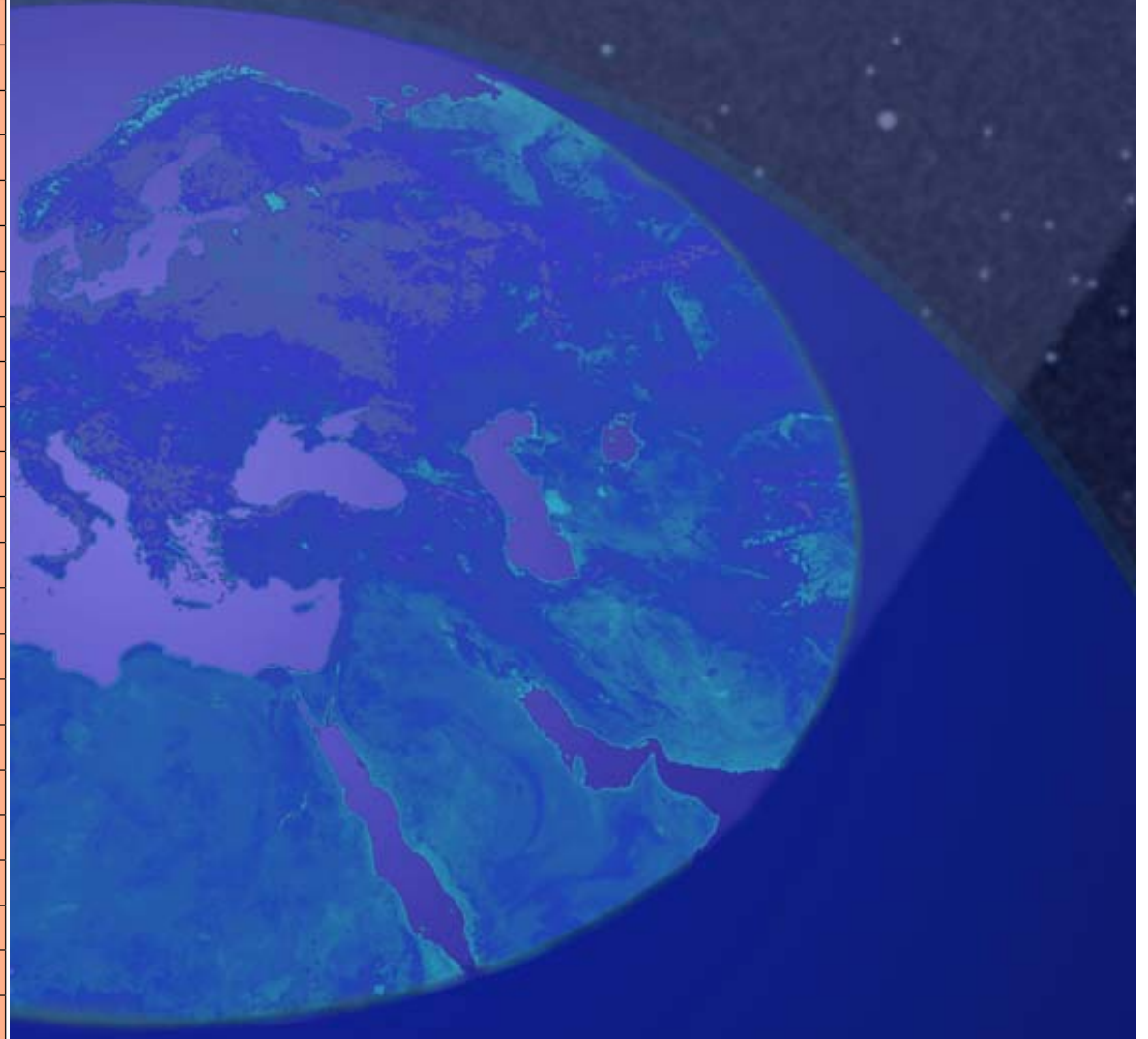
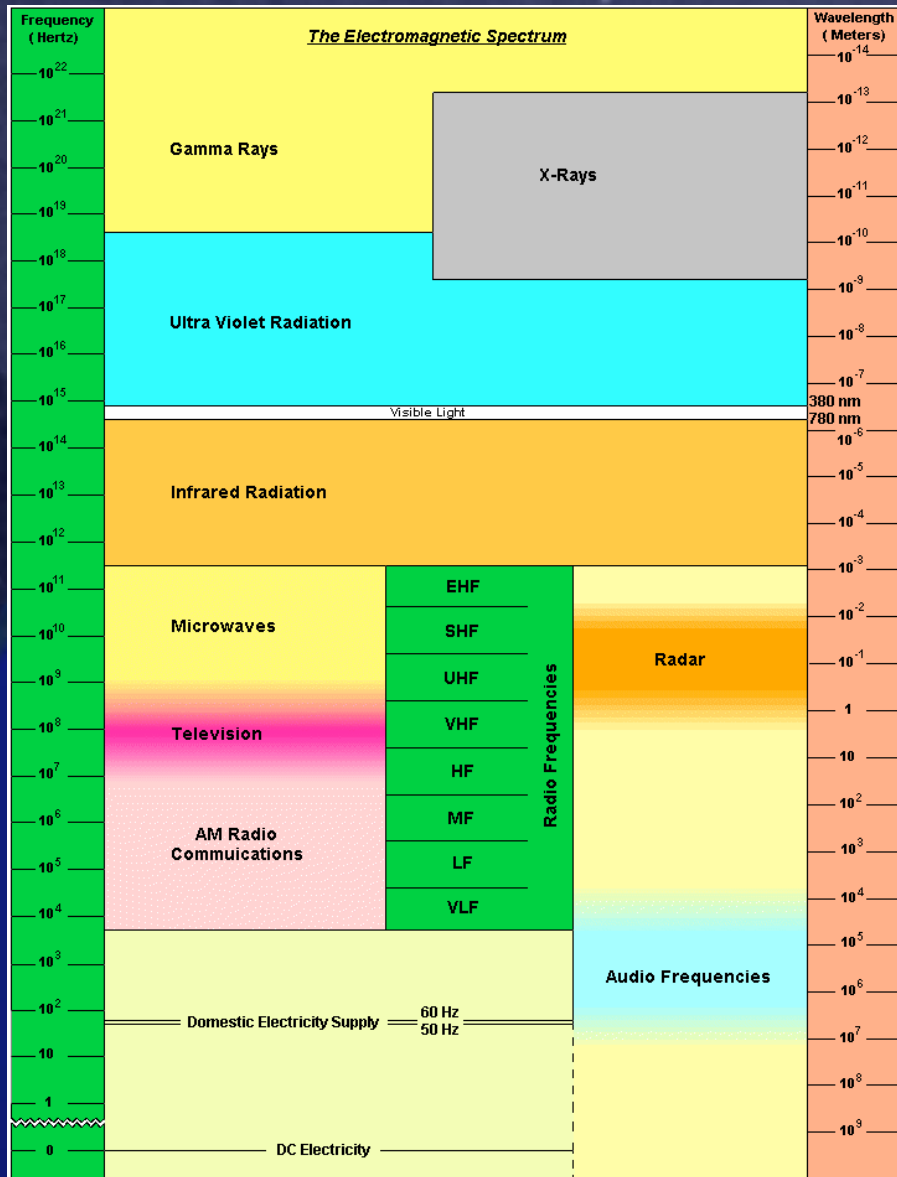
These lecture notes are intended only for distribution to participants



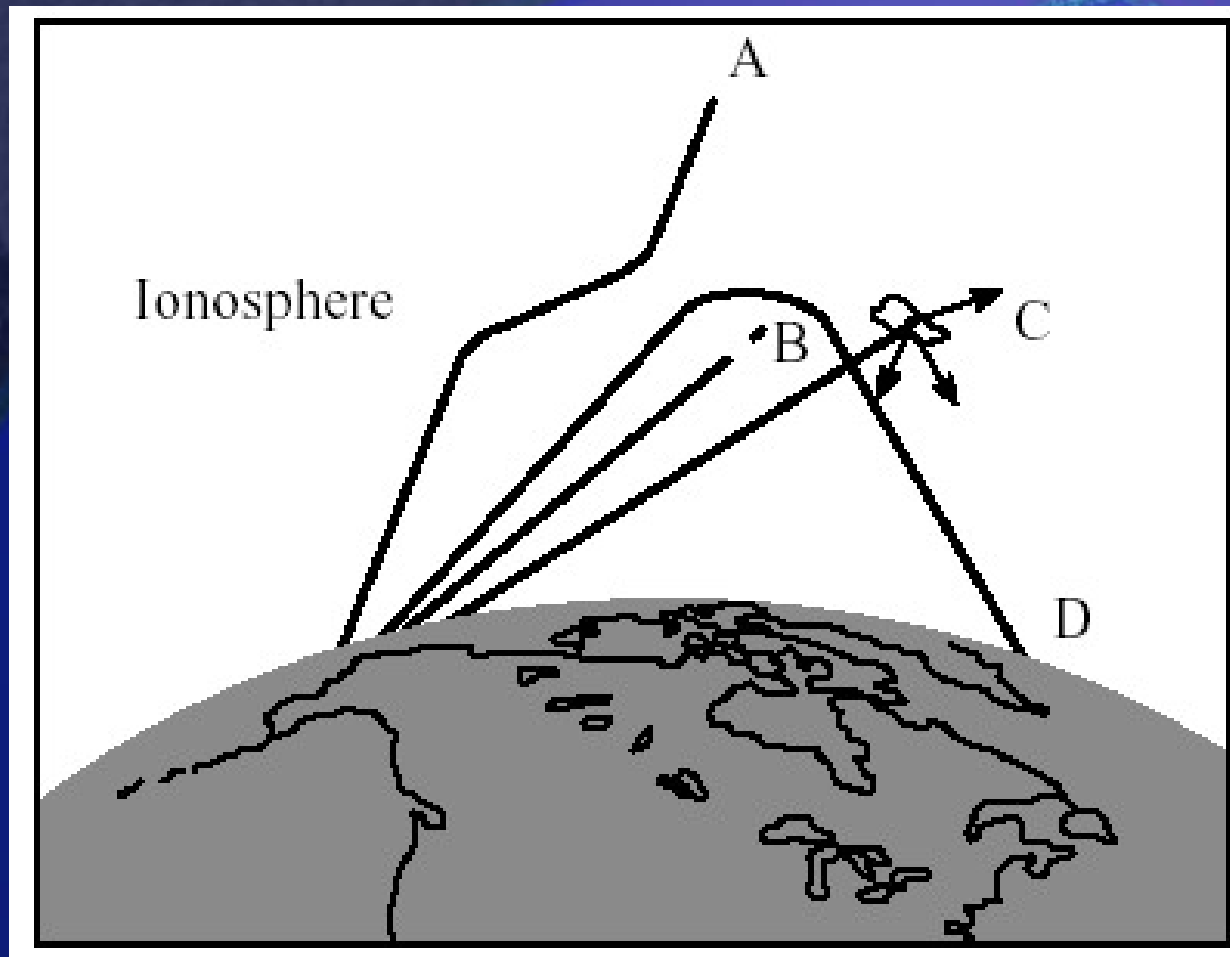
Effects of the Ionosphere on radiopropagation

S. M. Radicella
***Aeronomy and Radiopropagation
Laboratory***
***The Abdus Salam International
Centre for Theoretical Physics***





Electromagnetic Spectrum



Effects of the Ionosphere on radiopropagation



Rays:

-  A - Penetrate totally
-  B - Are totally absorbed
-  C - Are scattered in different directions by ionospheric irregularities
-  D - Are reflected by the ionosphere

VLF and LF propagation

VLF and LF propagation (10 Hz to 30 kHz and 30 to 300 kHz)

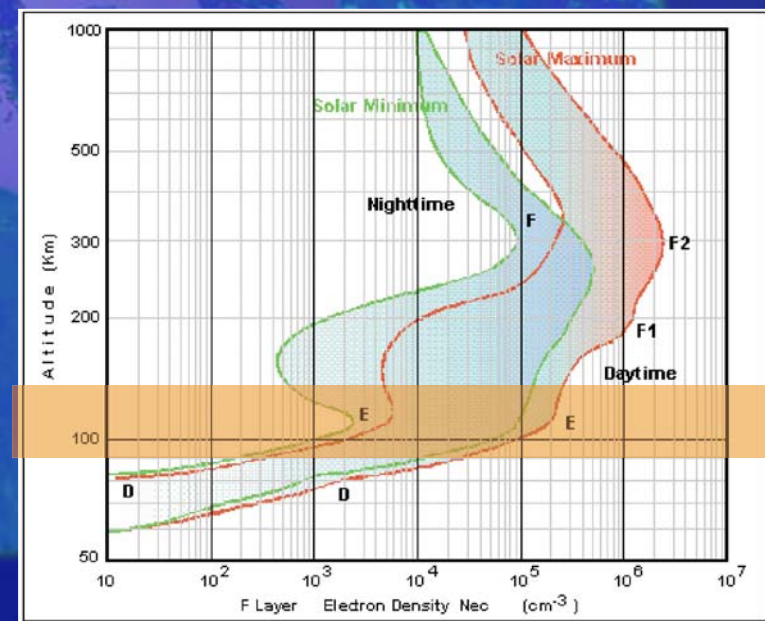
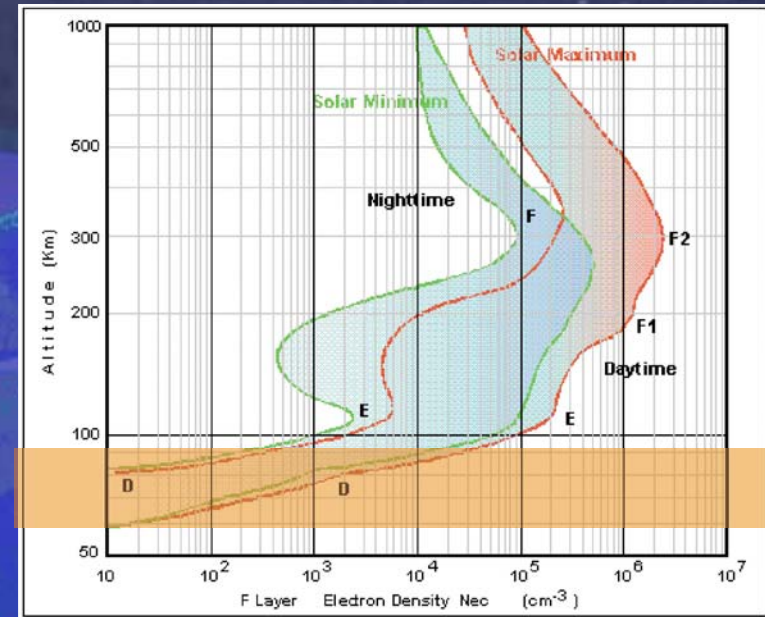
Radio waves are reflected by the D and E regions of the ionosphere.

🔧 Wave-guide propagation:

- 🔧 very stable in phase and amplitude
- 🔧 reach long distances in rock soil and in water
- 🔧 VLF covers practically all the globe
- 🔧 LF reach several thousand kilometres

🔧 Main communication systems:

- 🔧 LF - Broadcasting in Europe, North Africa and Asia
- 🔧 VLF - Navy communications



MF propagation

MF propagation (300 to 3000 kHz)

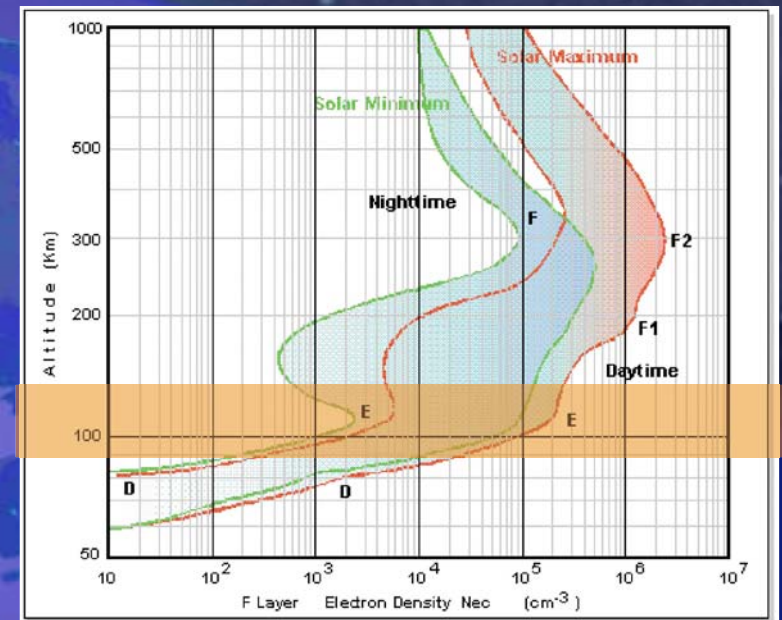
Ground wave is absorbed rapidly with a maximum reach of approximately 1500 km

• Sky wave:

- strongly absorbed in the D region during daytime
- reflected in the E region particularly at frequencies greater than 1500 kHz during nighttime.
- dominant wave at night after roughly 150 km at 500 kHz and 50 km at 1500 kHz.

• Communication systems that use these frequencies::

- Broadcasting
- Radiolocation
- Emergency services
- Radio beacon



HF propagation

HF propagation (3 to 30 MHz)

Radio waves at these frequencies are reflected by the ionosphere (E and F regions) reaching up to global ranges as a function of:

frequency

ionospheric conditions given by :

hour of the day, season, solar activity

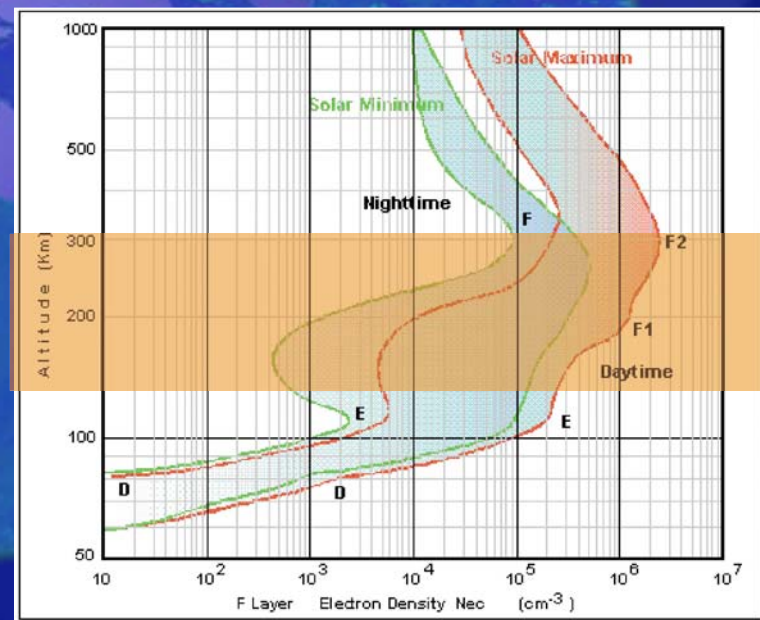
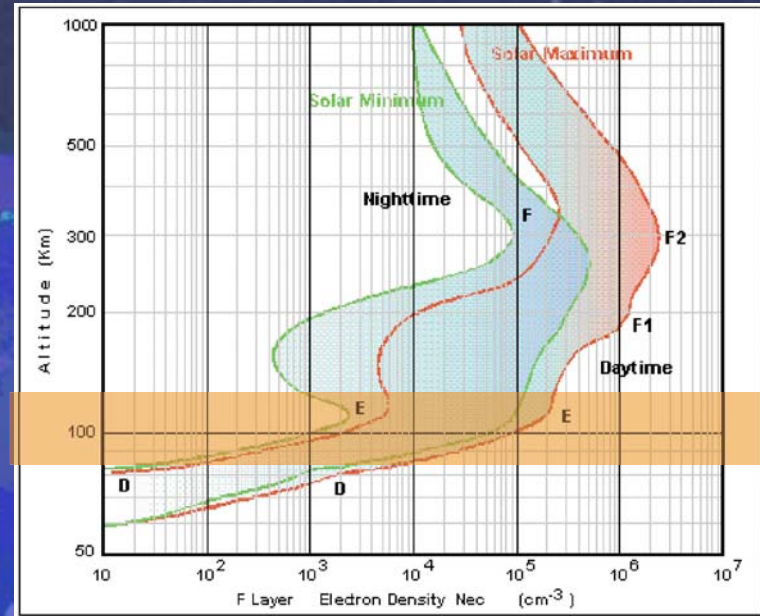
geographic location of transmitter and receiver

ray angle

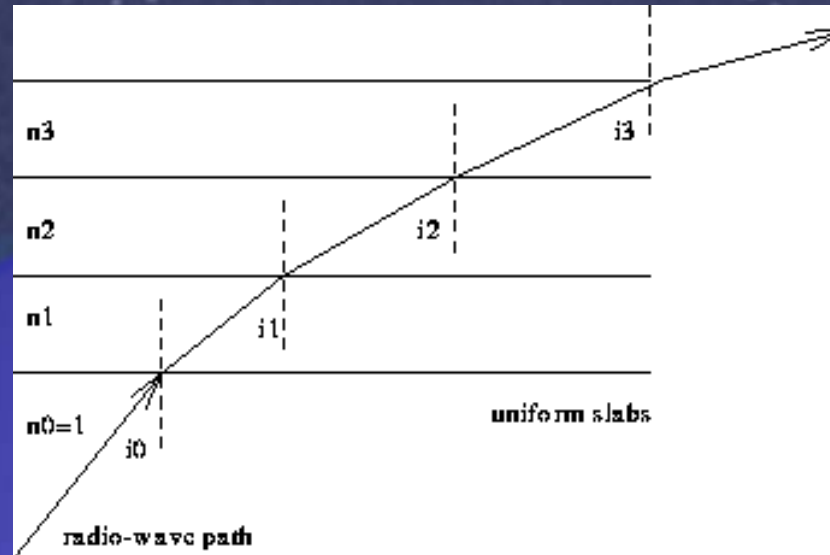
These frequencies are used for:

Point-to-point fixed and mobile services

Broadcasting



HF ray propagation theory



The ionosphere is considered as a pile of thin slabs with constant refractive indices n_1, n_2, n_3 , etc. A plane wave incides from free space (with refractive index $n_0=1$) at an angle i_0 . Snell's law can then be applied to each slab boundary, giving:

$$n_{(r-1)} \sin i_{(r-1)} = n_r \sin i_r ; r=1,2,\dots$$

Since the plasma frequency increases with height, n becomes smaller and the ray gradually bends toward the horizontal.

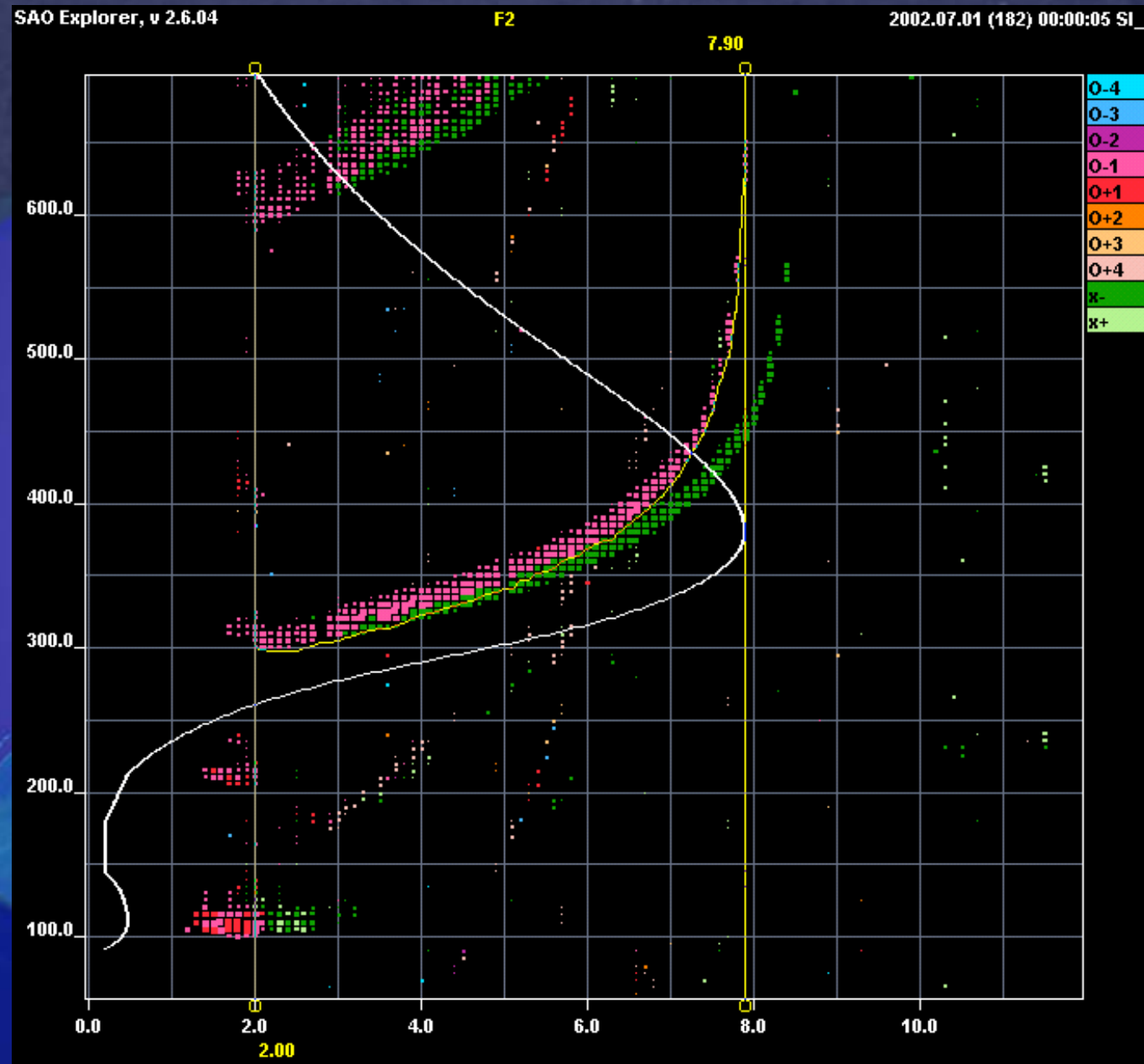
Raytracing

The method of treating radio propagation in a slowly varying ionosphere is the basis of raytracing programs that treats the propagation in a given electron density profile, and can include the effect of geomagnetic field and collisions.

Raytracing can be used to investigate HF propagation conditions under different ionospheric conditions.

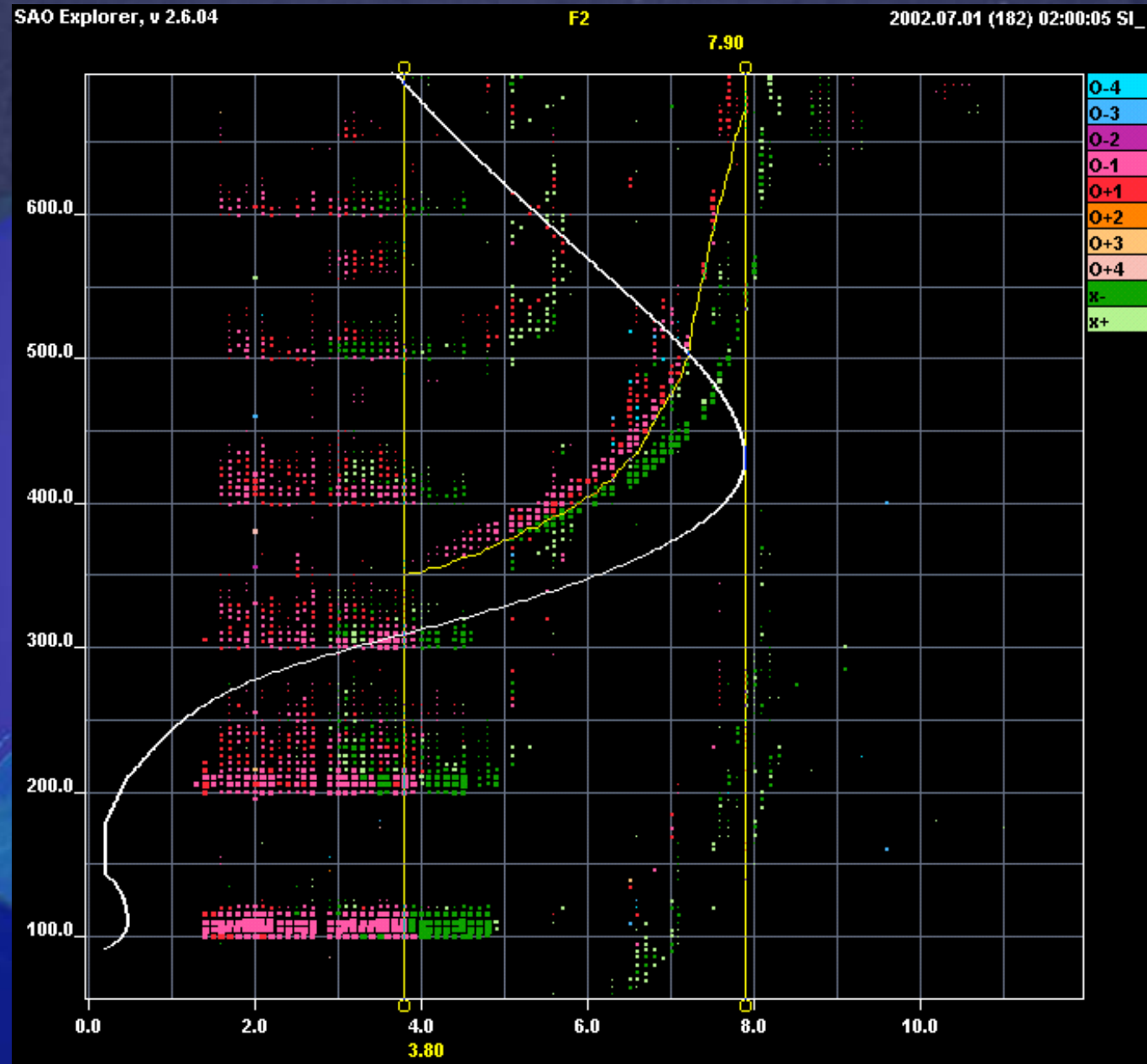
Ionogramma (ora: 00)

00
02
04
06
08
10
12
14
16
18
20



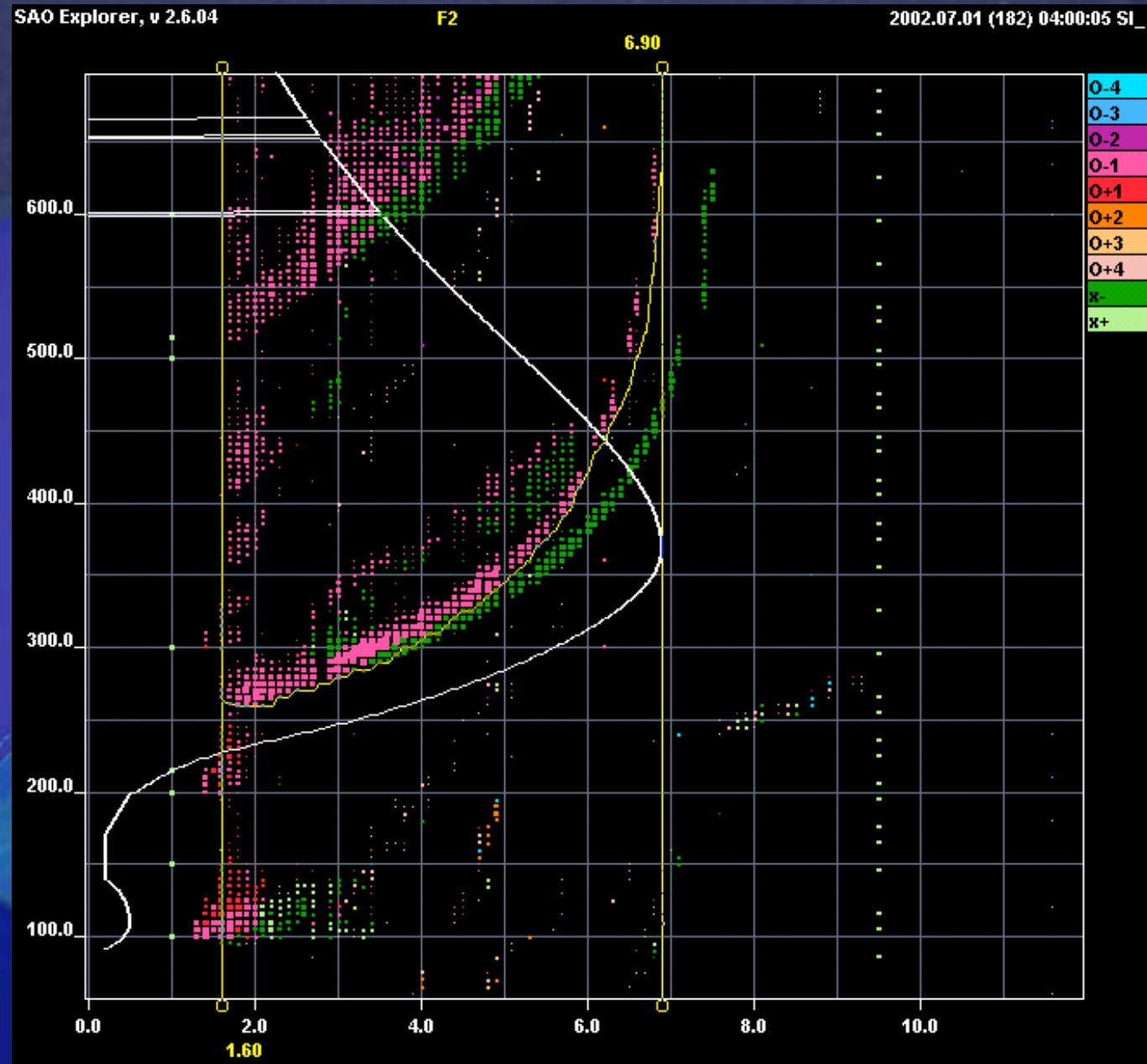
Ionogramma (ora: 02)

00
02
04
06
08
10
12
14
16
18
20



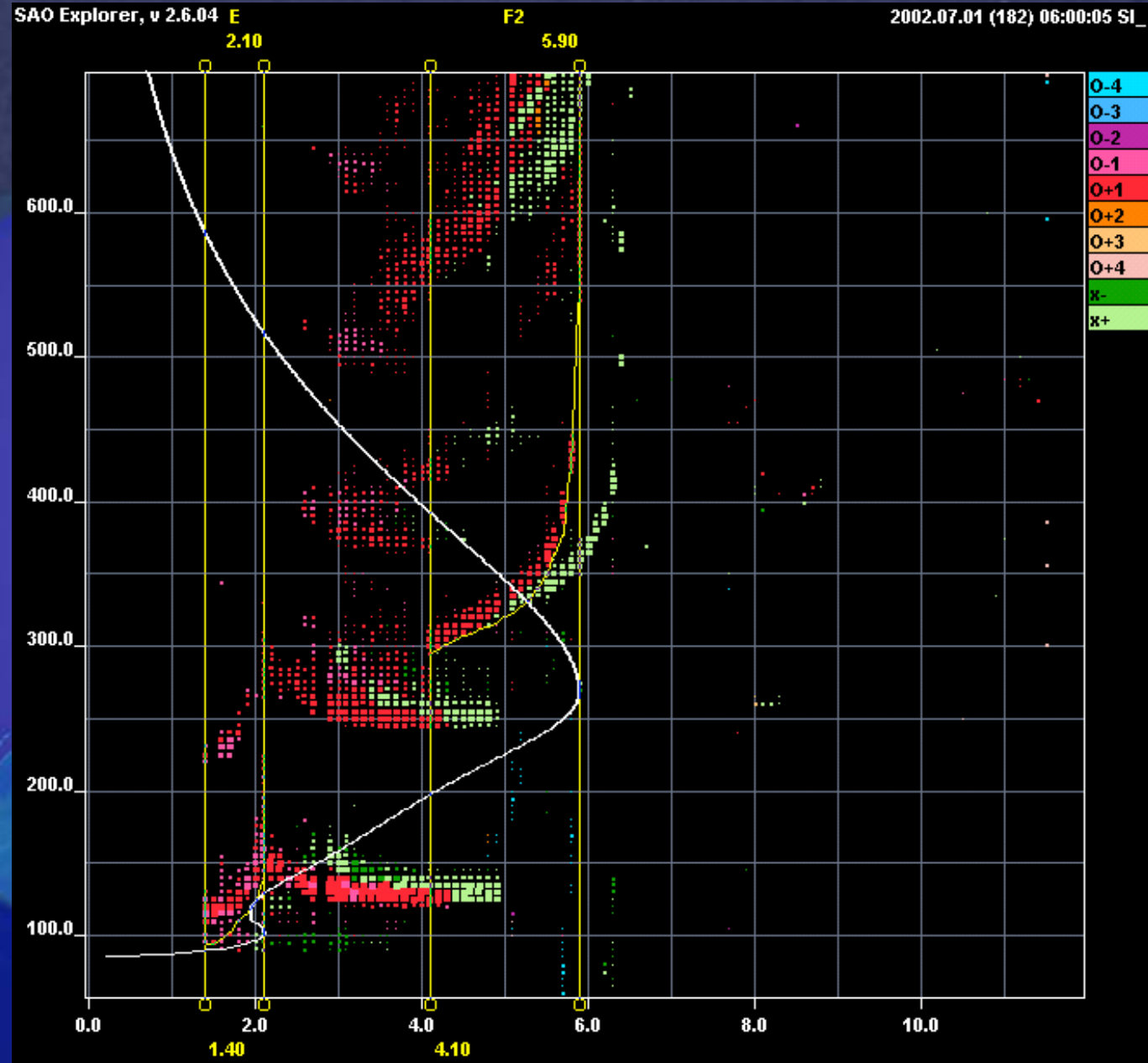
Ionogramma (ora: 04)

00
02
04
06
08
10
12
14
16
18
20



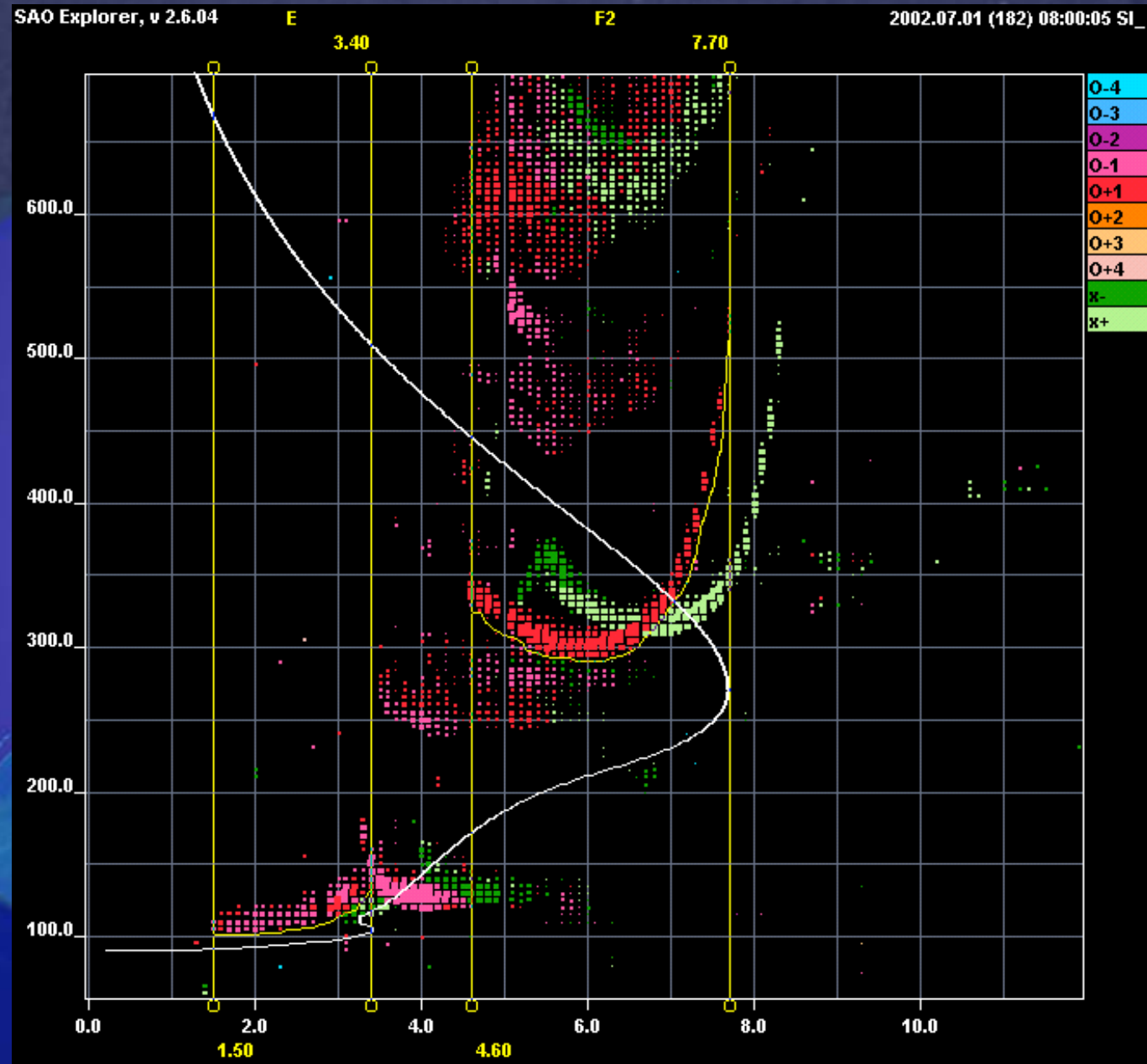
Ionogramma (ora: 06)

00
02
04
06
08
10
12
14
16
18
20



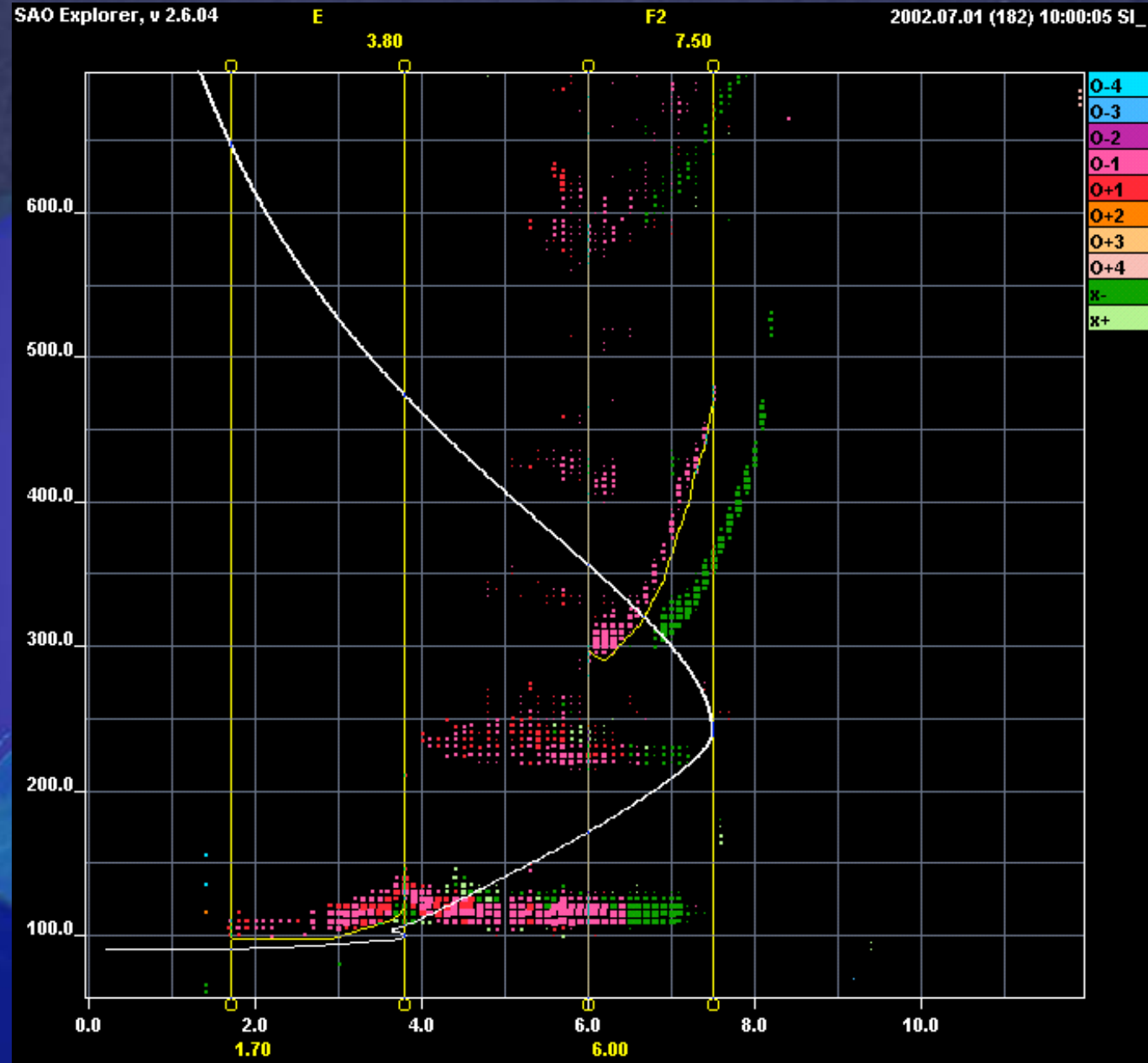
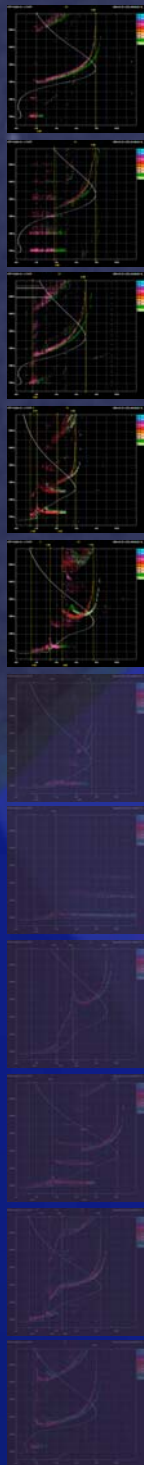
Ionogramma (ora: 08)

00
02
04
06
08
10
12
14
16
18
20



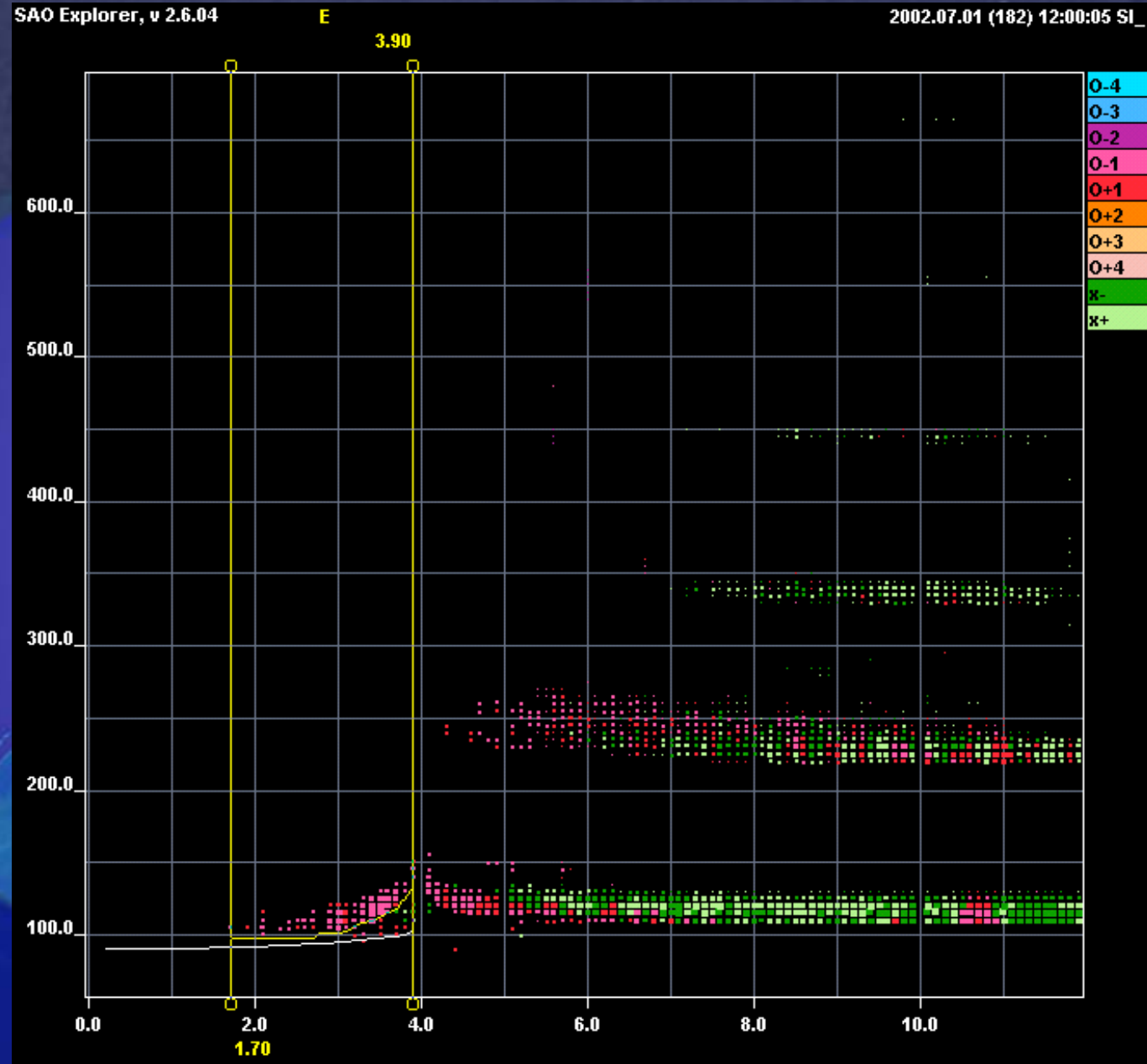
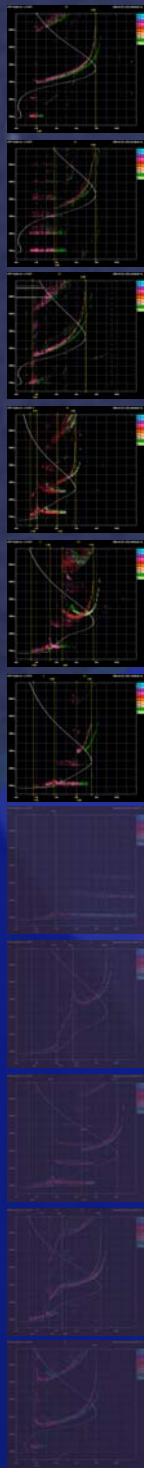
Ionogramma (ora: 10)

00
02
04
06
08
10
12
14
16
18
20



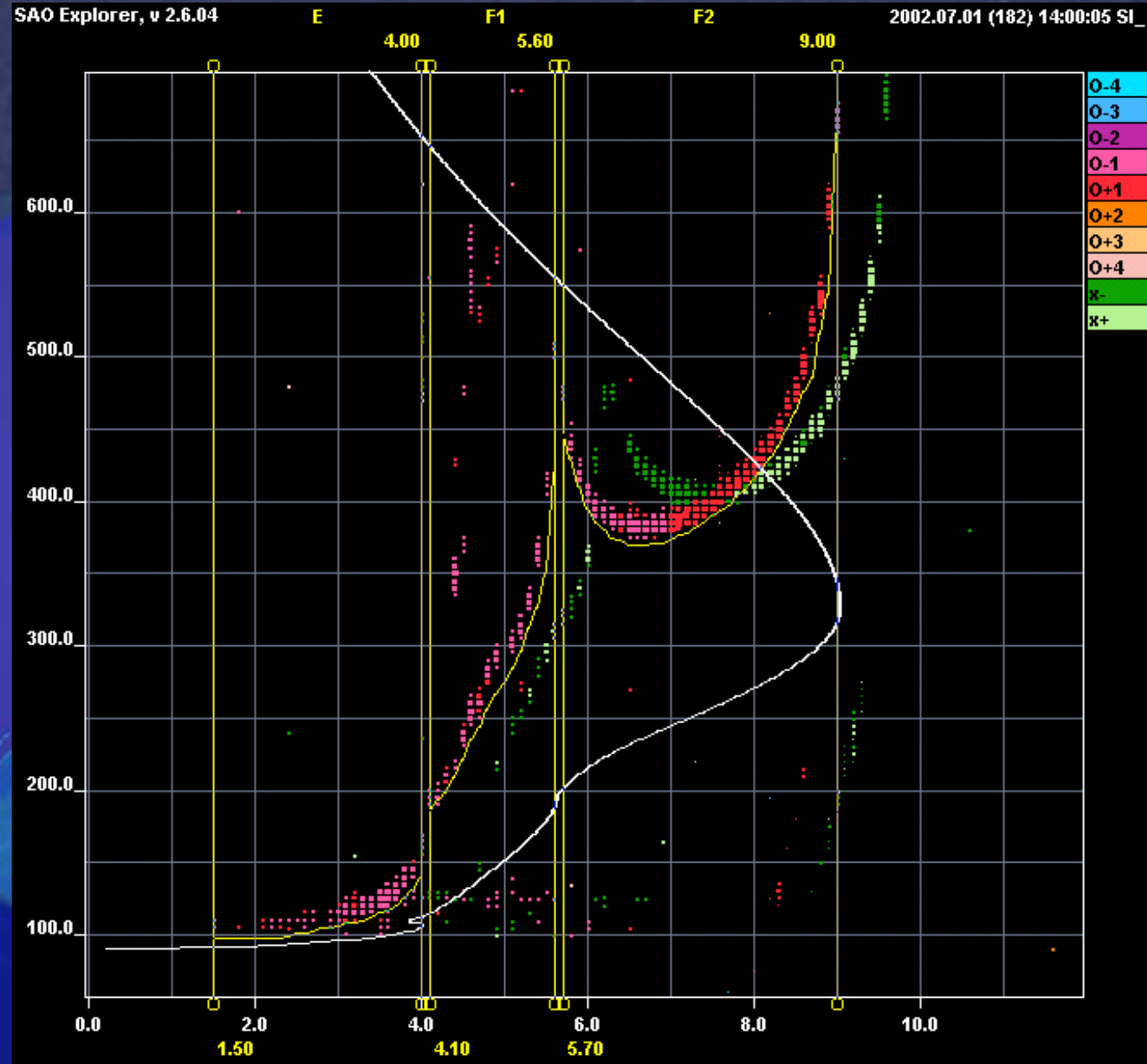
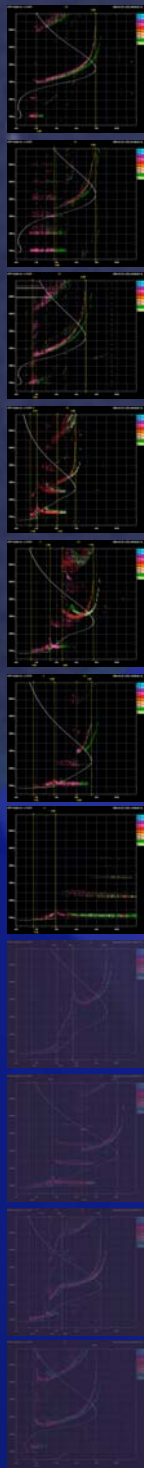
Ionogramma (ora: 12)

00
02
04
06
08
10
12
14
16
18
20



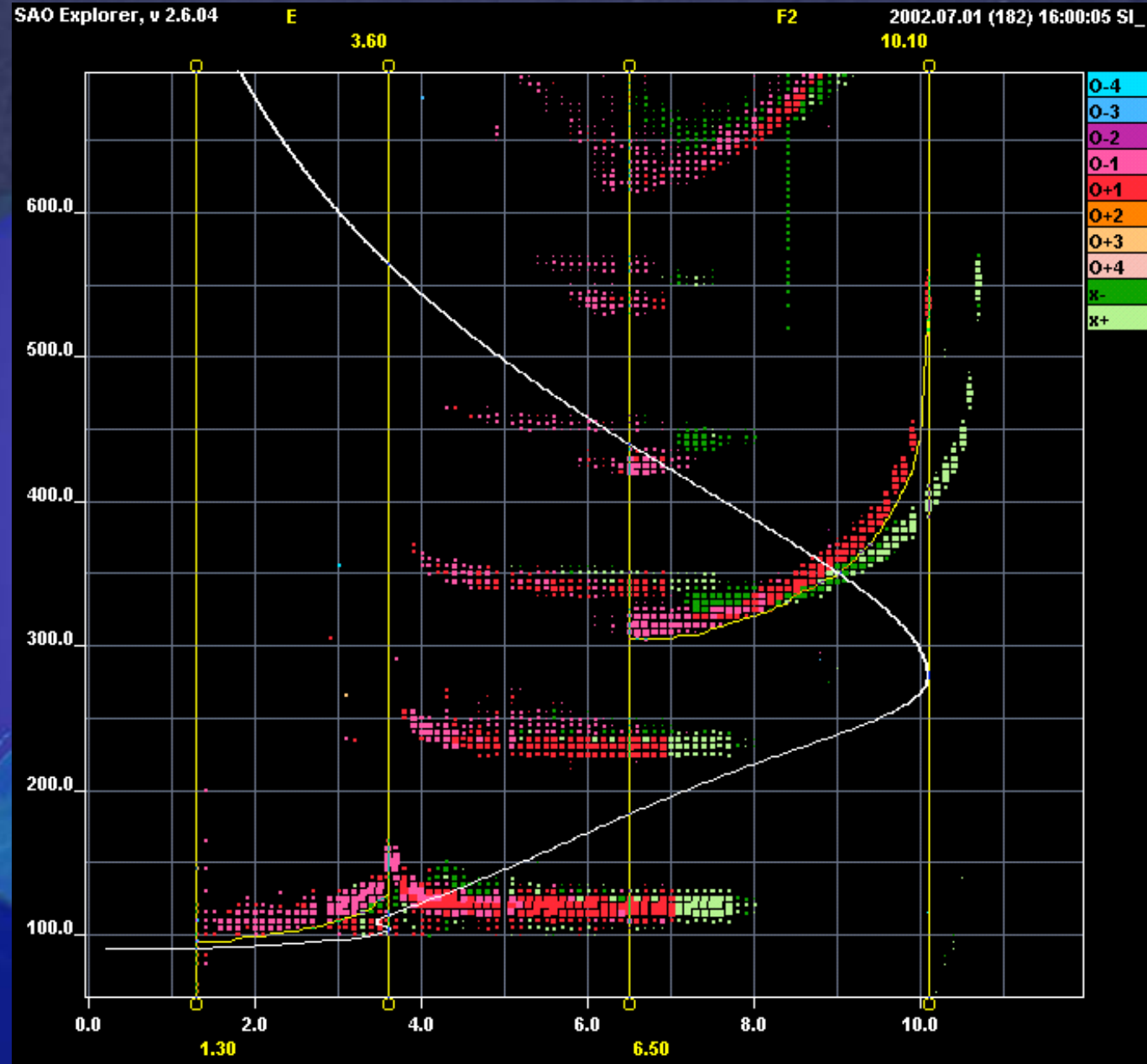
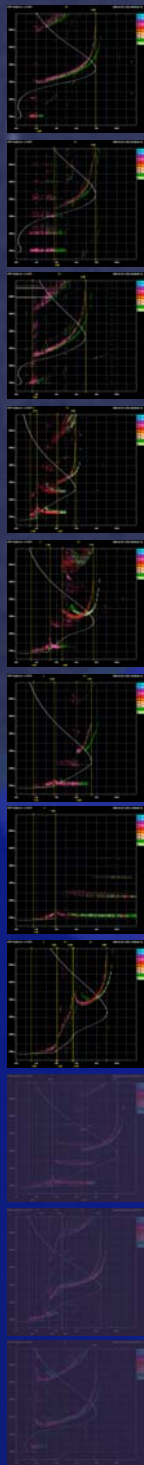
Ionogramma (ora: 14)

00
02
04
06
08
10
12
14
16
18
20



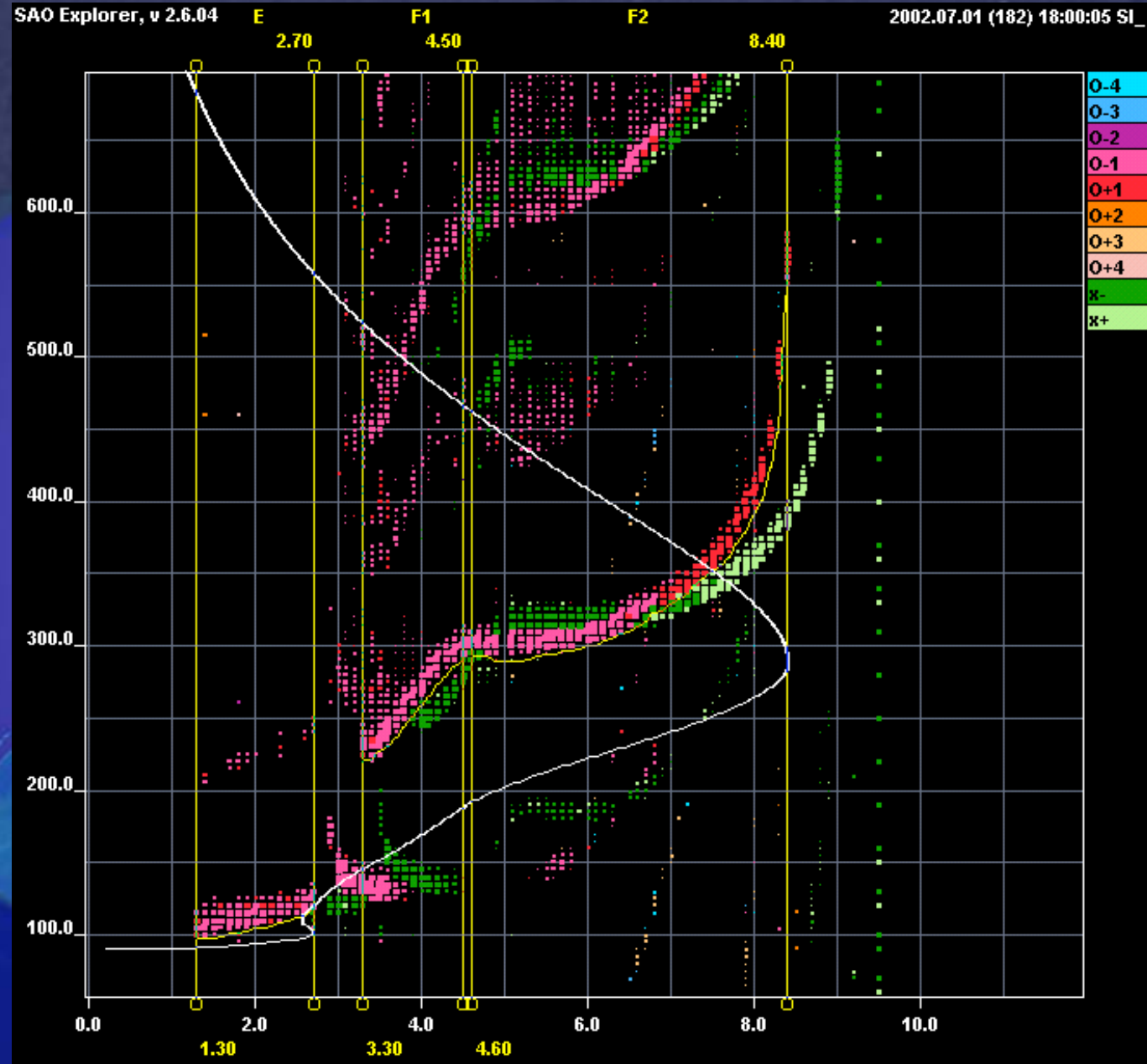
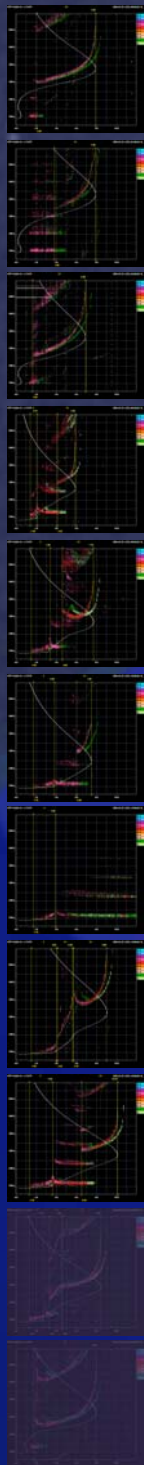
Ionogramma (ora: 16)

00
02
04
06
08
10
12
14
16
18
20



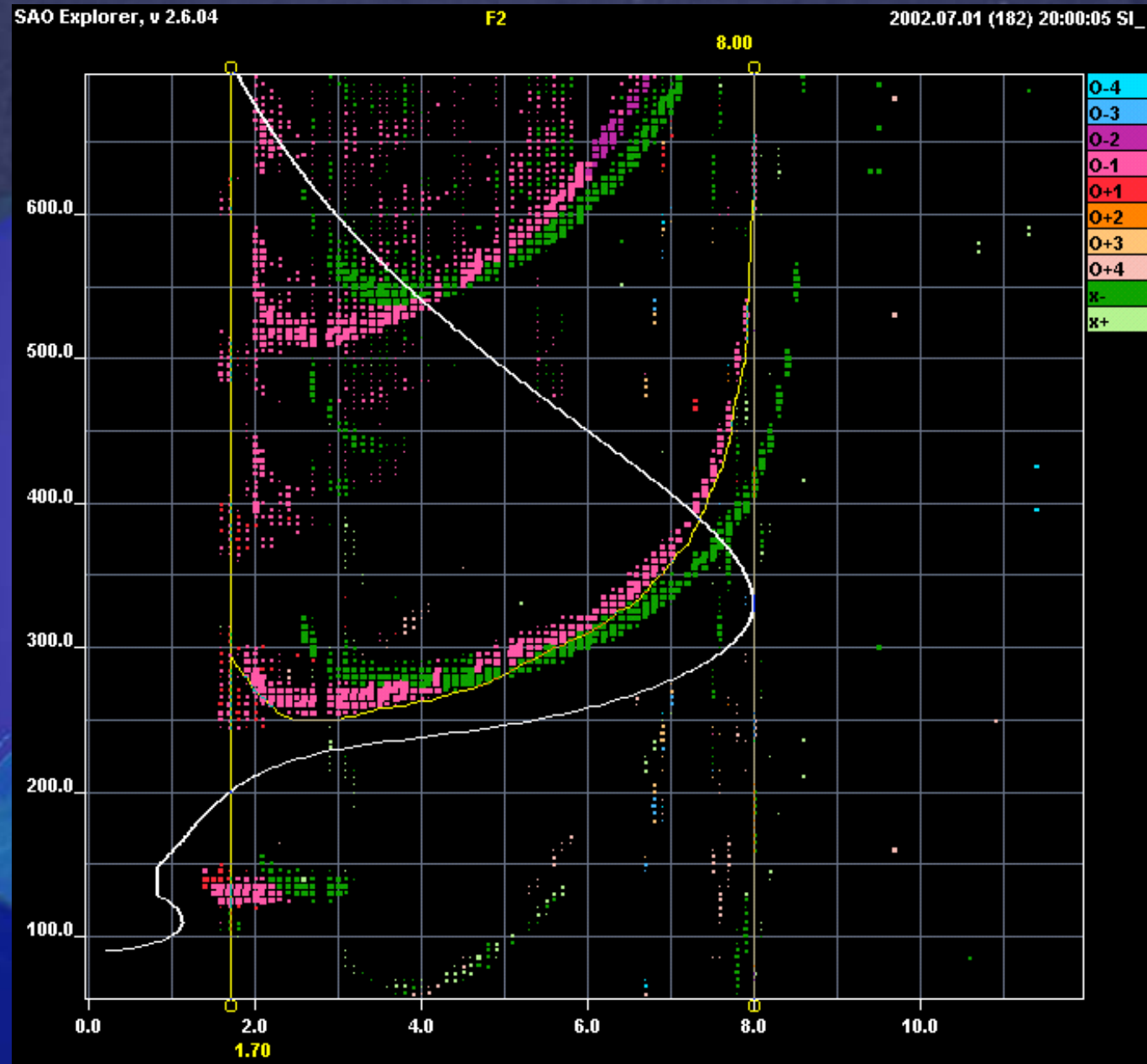
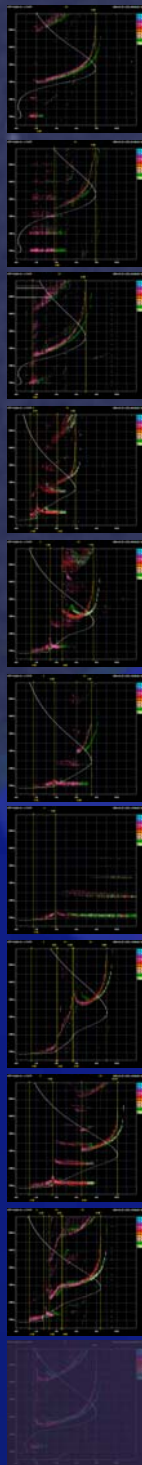
Ionogramma (ora: 18)

00
02
04
06
08
10
12
14
16
18
20



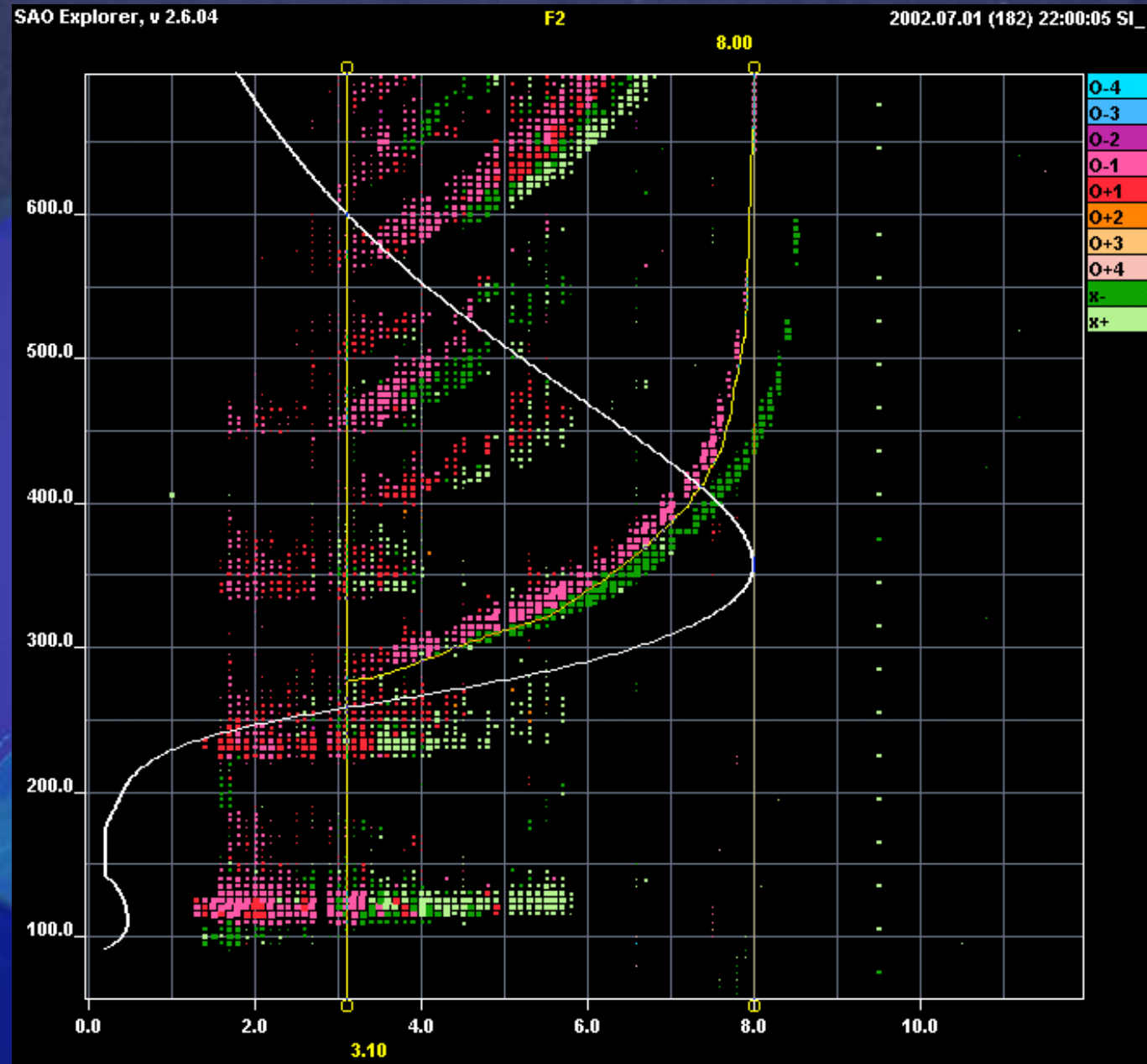
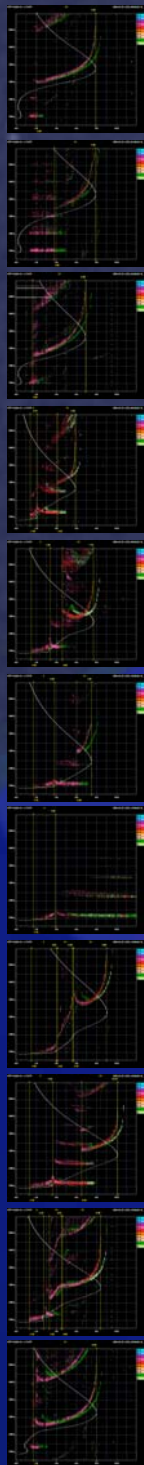
Ionogramma (ora: 20)

00
02
04
06
08
10
12
14
16
18
20

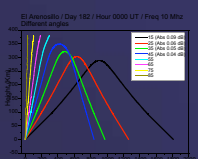
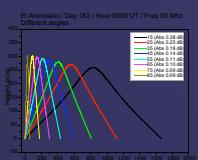
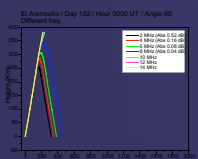
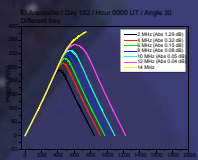
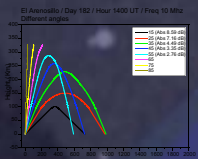
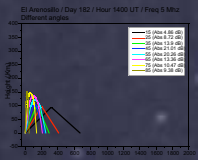
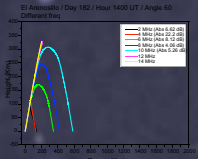
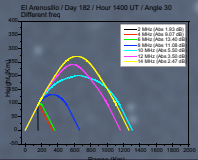


Ionogramma (ora: 22)

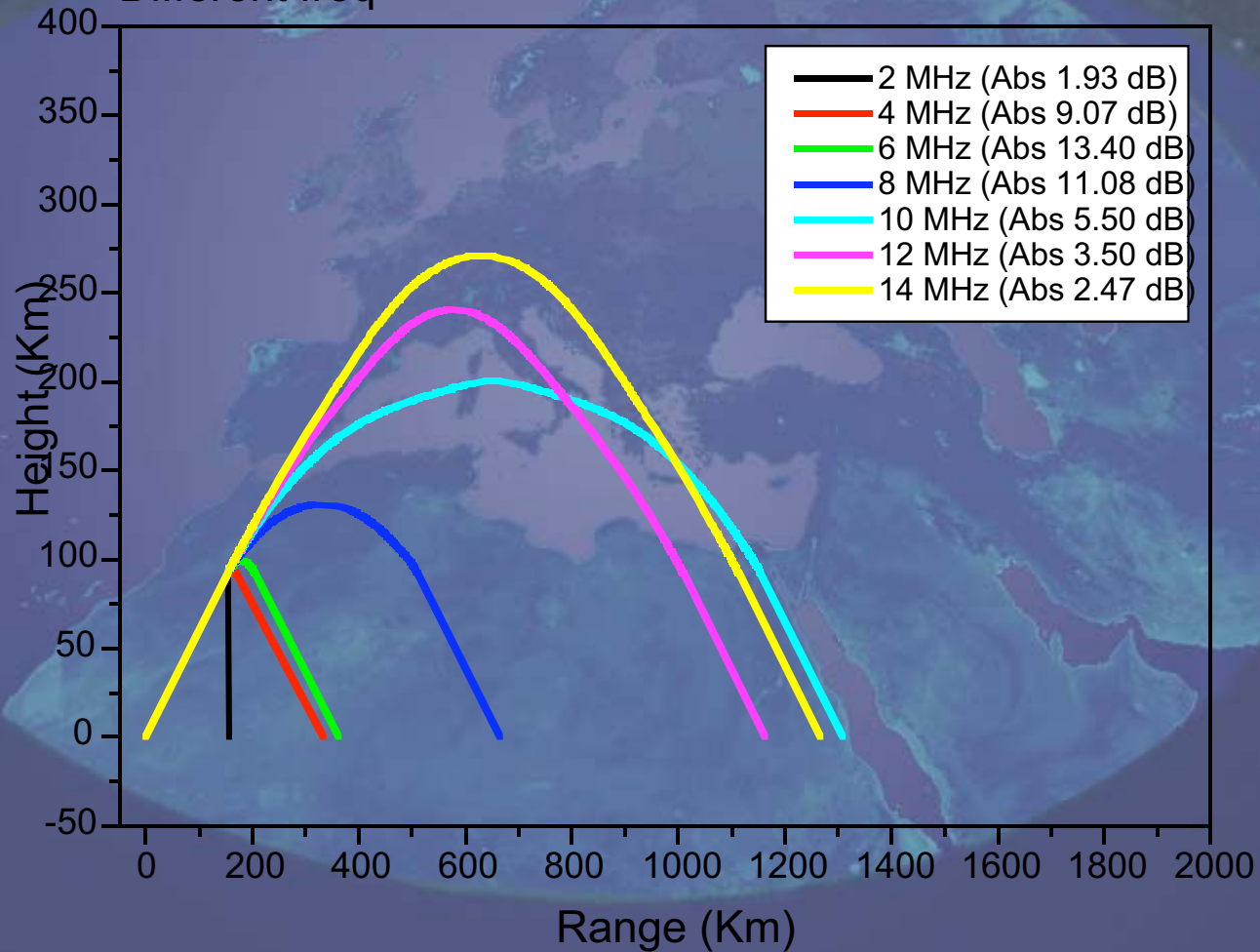
00
02
04
06
08
10
12
14
16
18
20

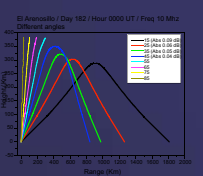
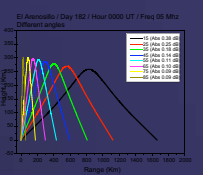
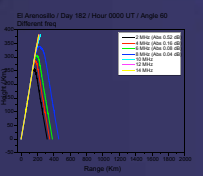
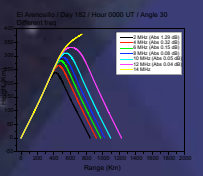
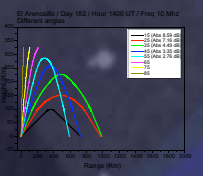
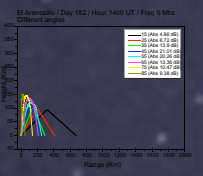
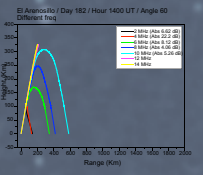
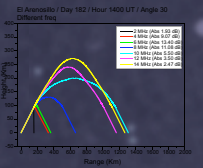


HF propagation conditions

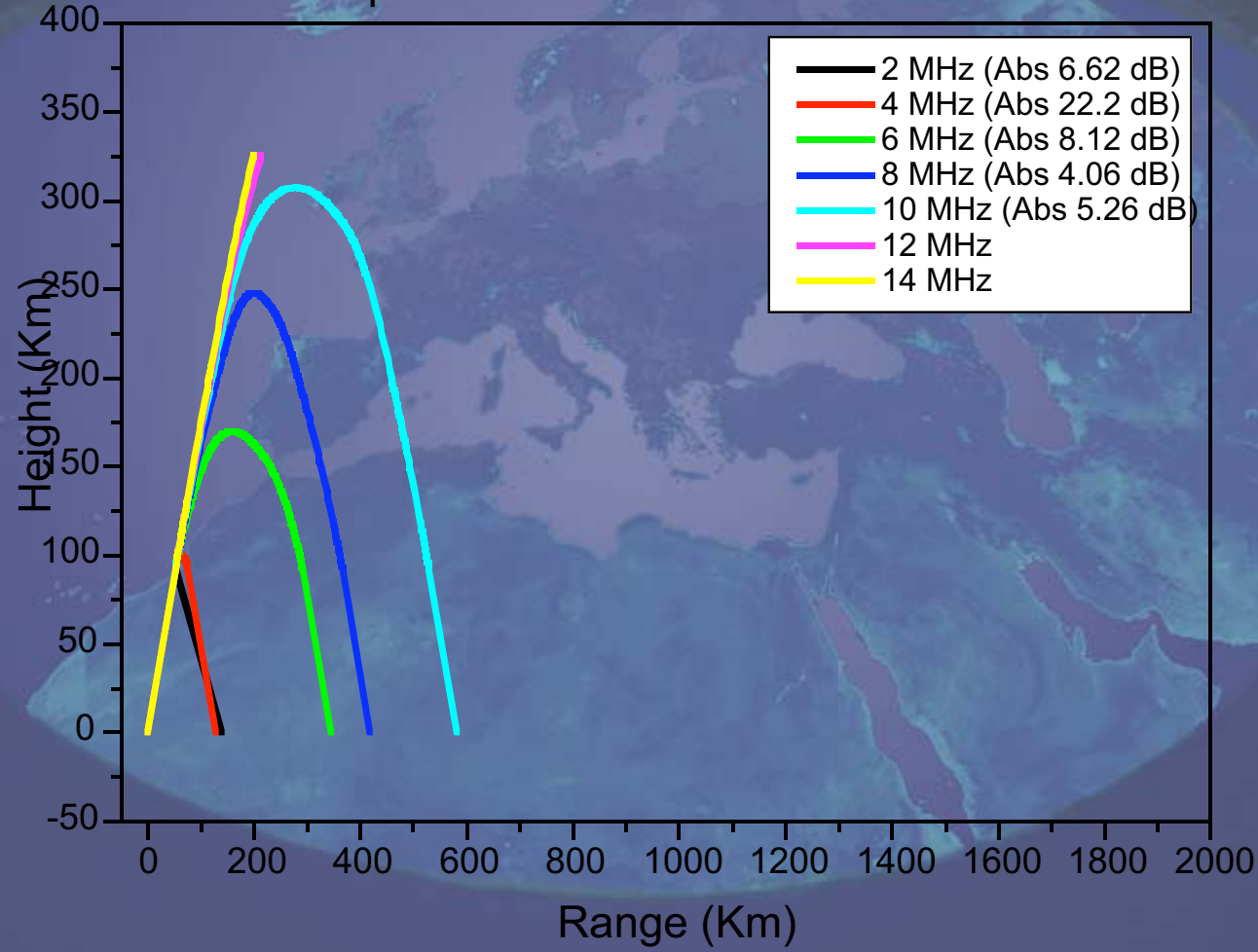


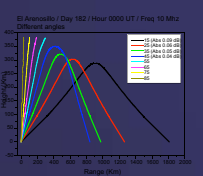
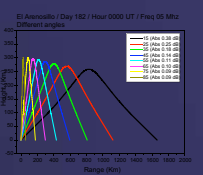
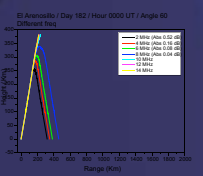
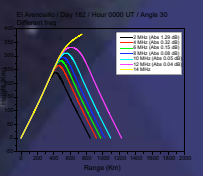
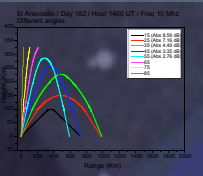
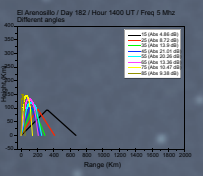
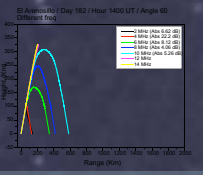
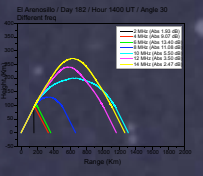
El Arenosillo / Day 182 / Hour 1400 UT / Angle 30
Different freq



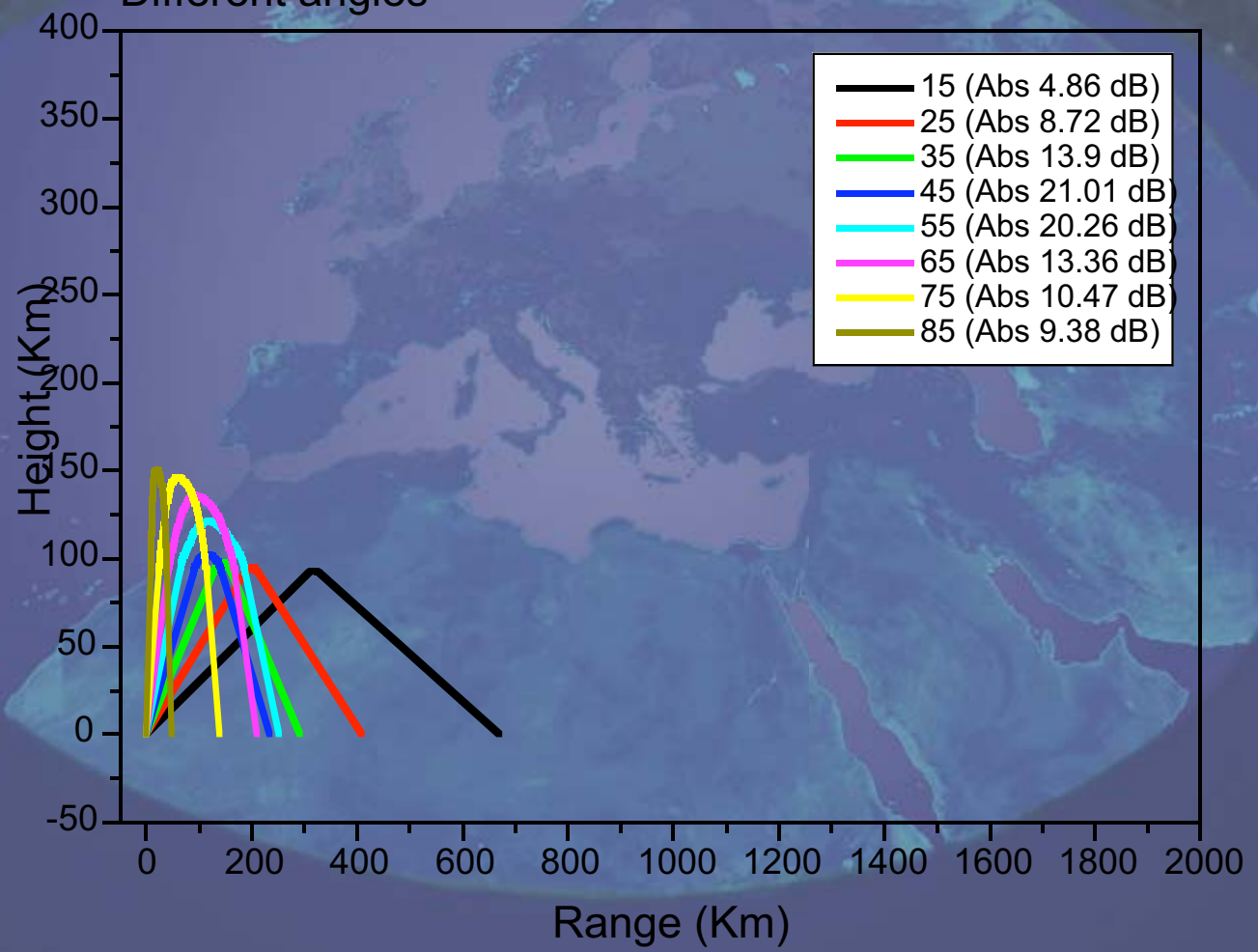


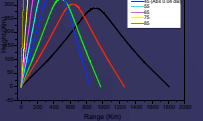
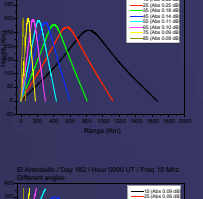
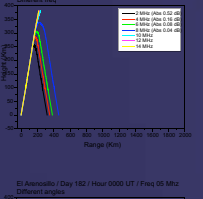
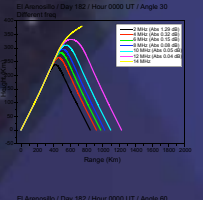
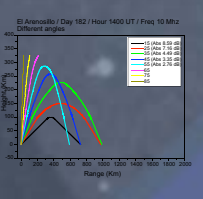
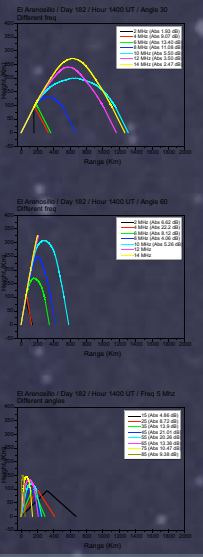
El Arenosillo / Day 182 / Hour 1400 UT / Angle 60 Different freq



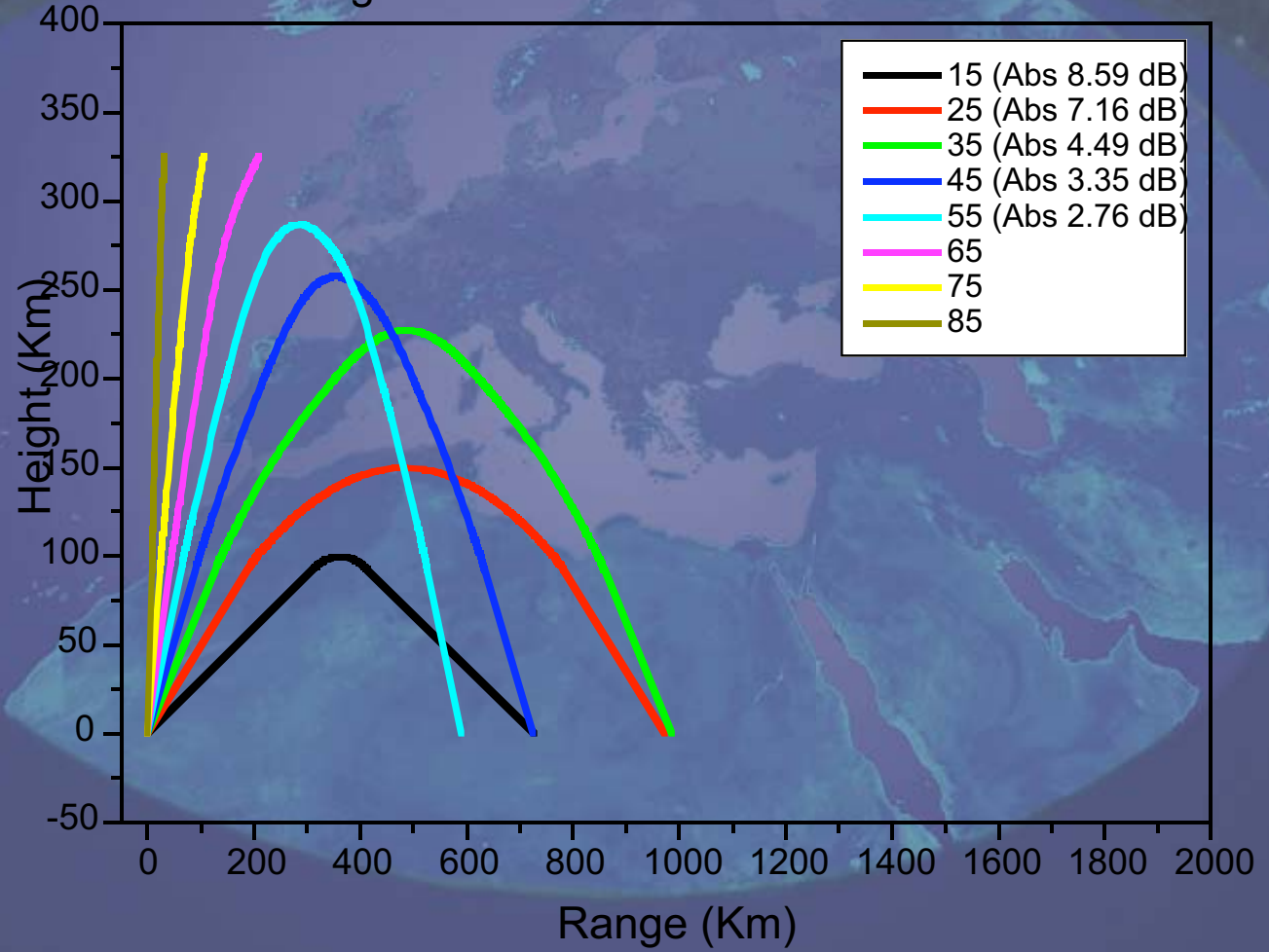


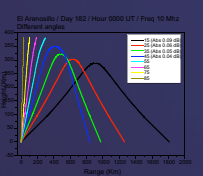
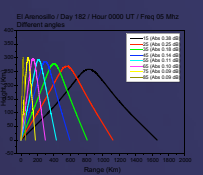
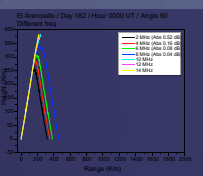
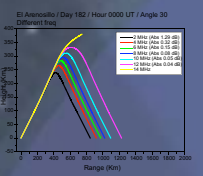
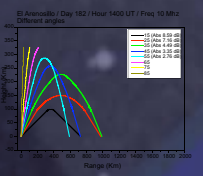
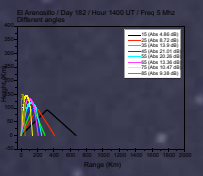
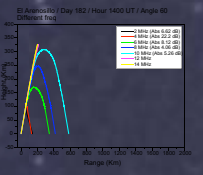
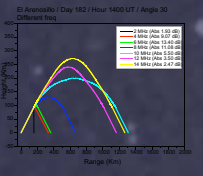
El Arenosillo / Day 182 / Hour 1400 UT / Freq 5 Mhz Different angles



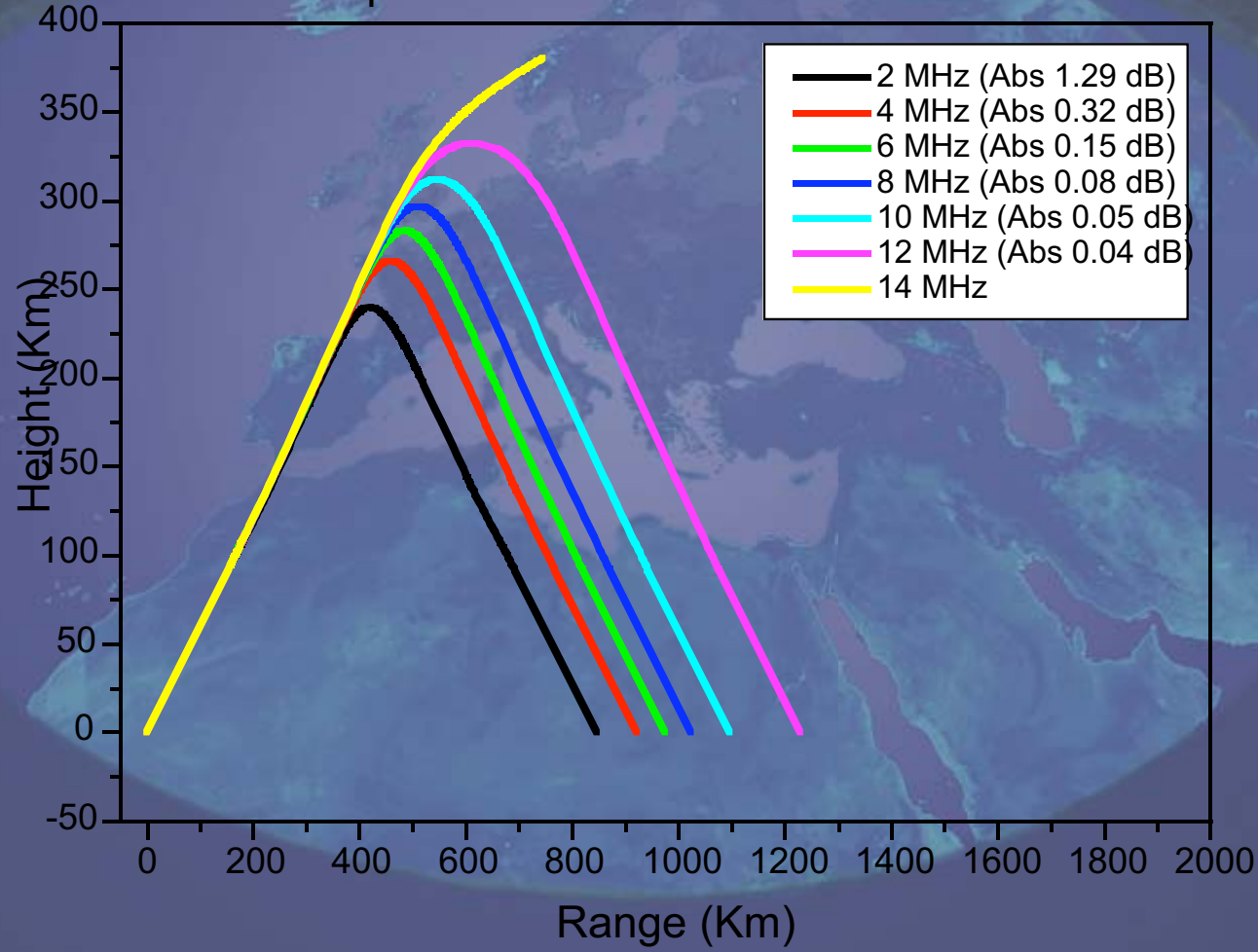


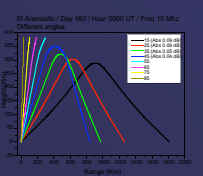
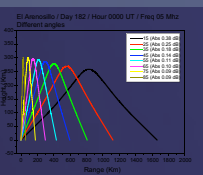
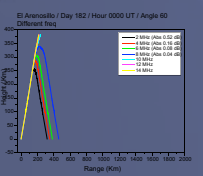
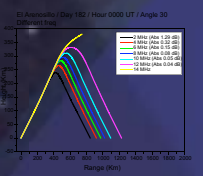
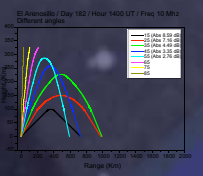
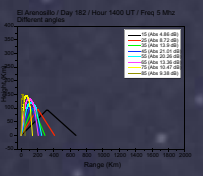
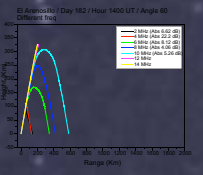
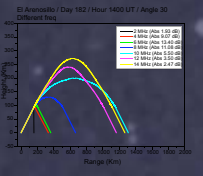
El Arenosillo / Day 182 / Hour 1400 UT / Freq 10 Mhz Different angles



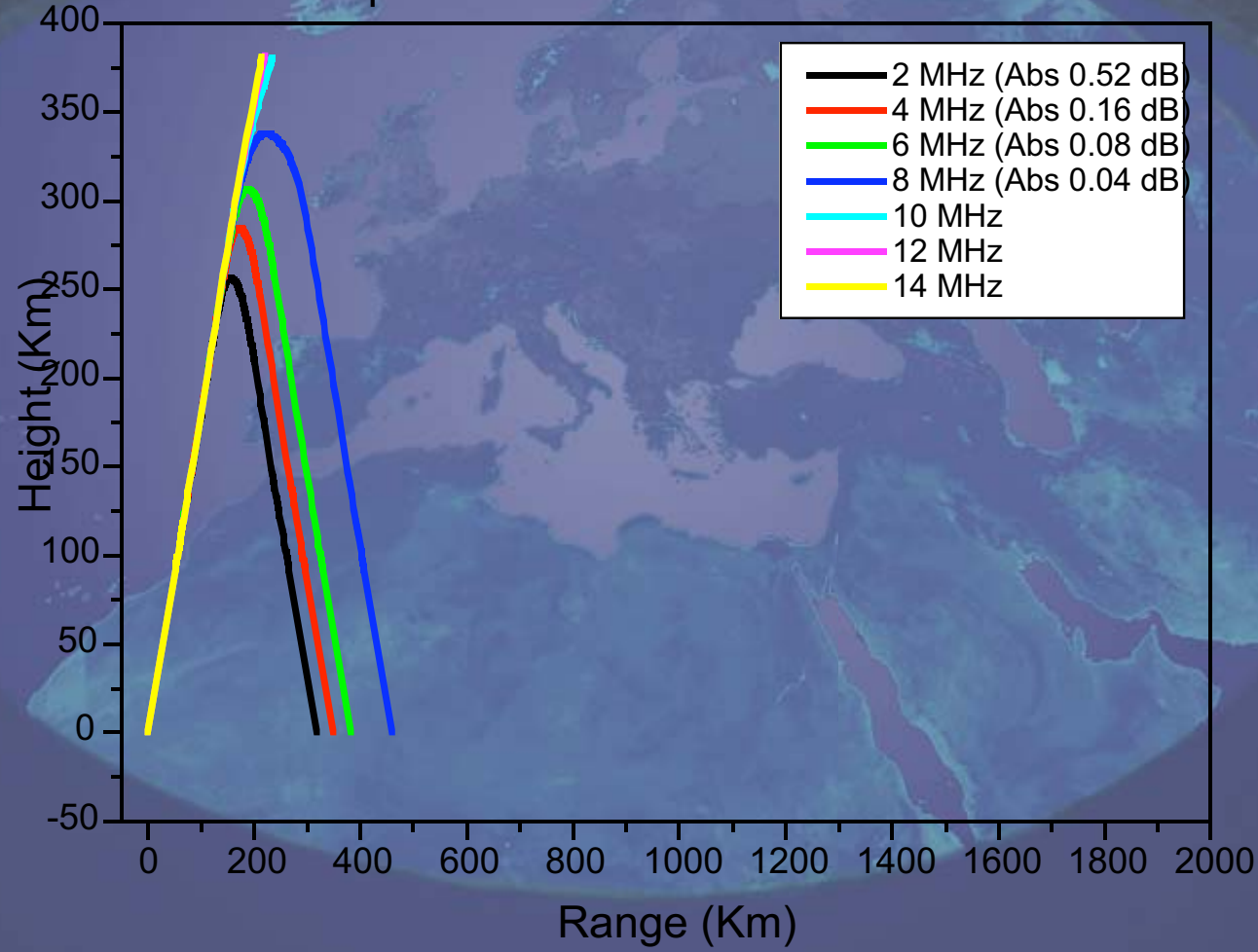


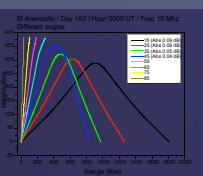
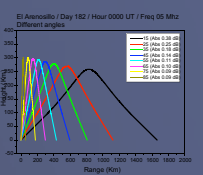
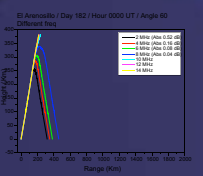
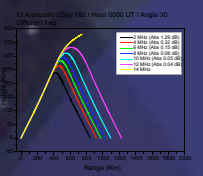
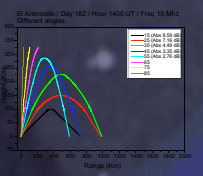
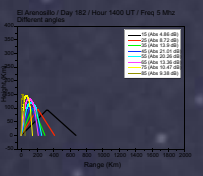
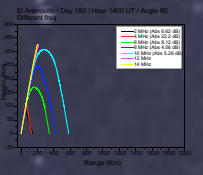
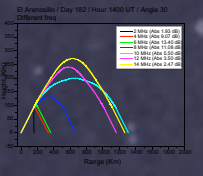
El Arenosillo / Day 182 / Hour 0000 UT / Angle 30 Different freq



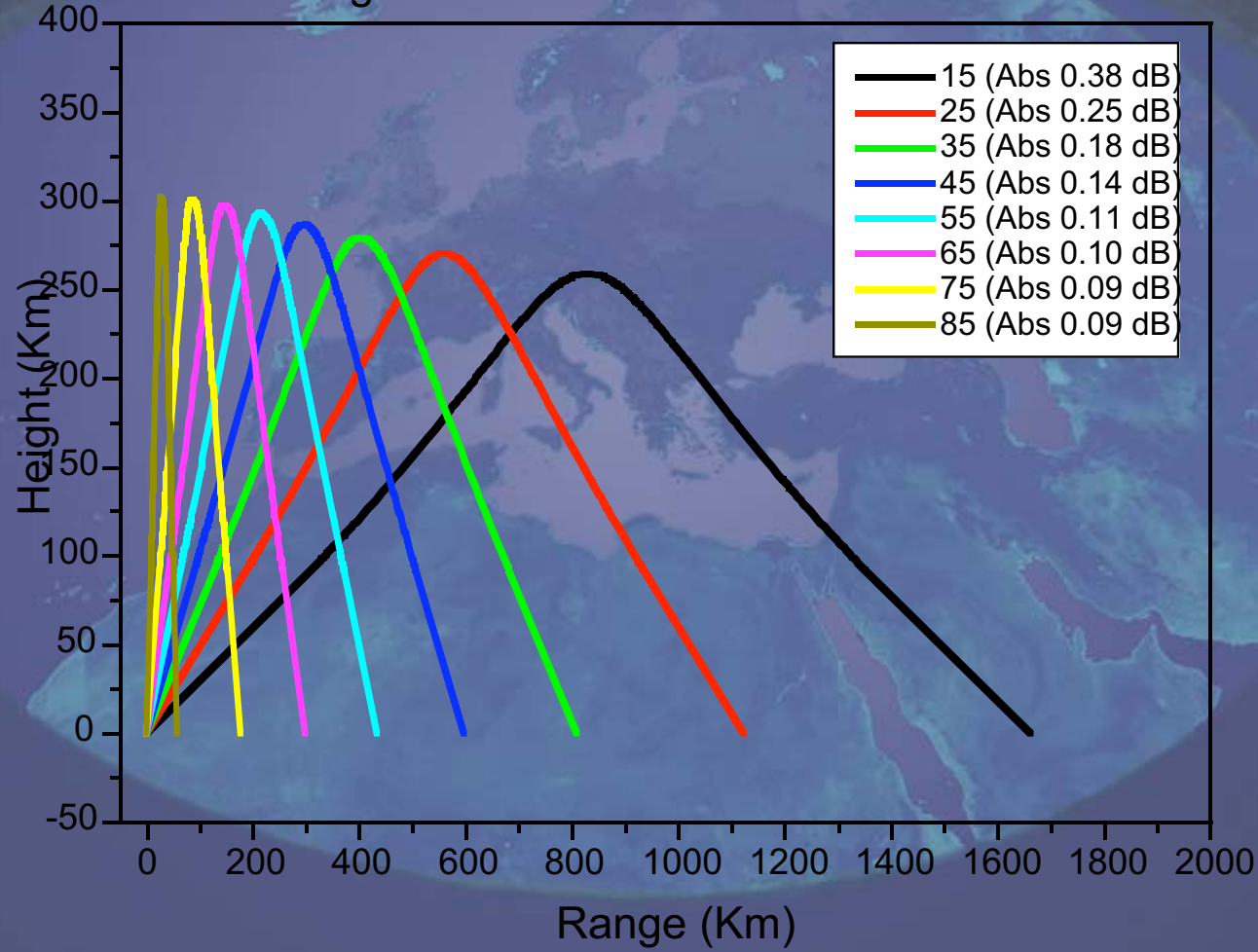


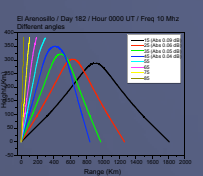
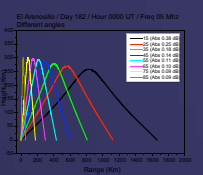
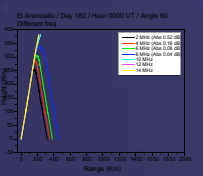
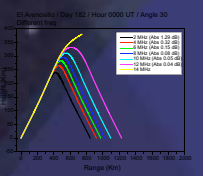
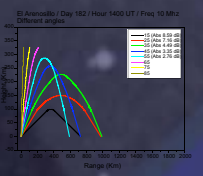
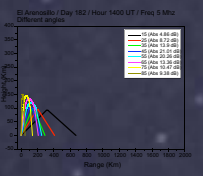
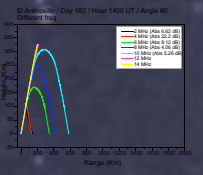
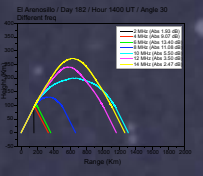
El Arenosillo / Day 182 / Hour 0000 UT / Angle 60 Different freq



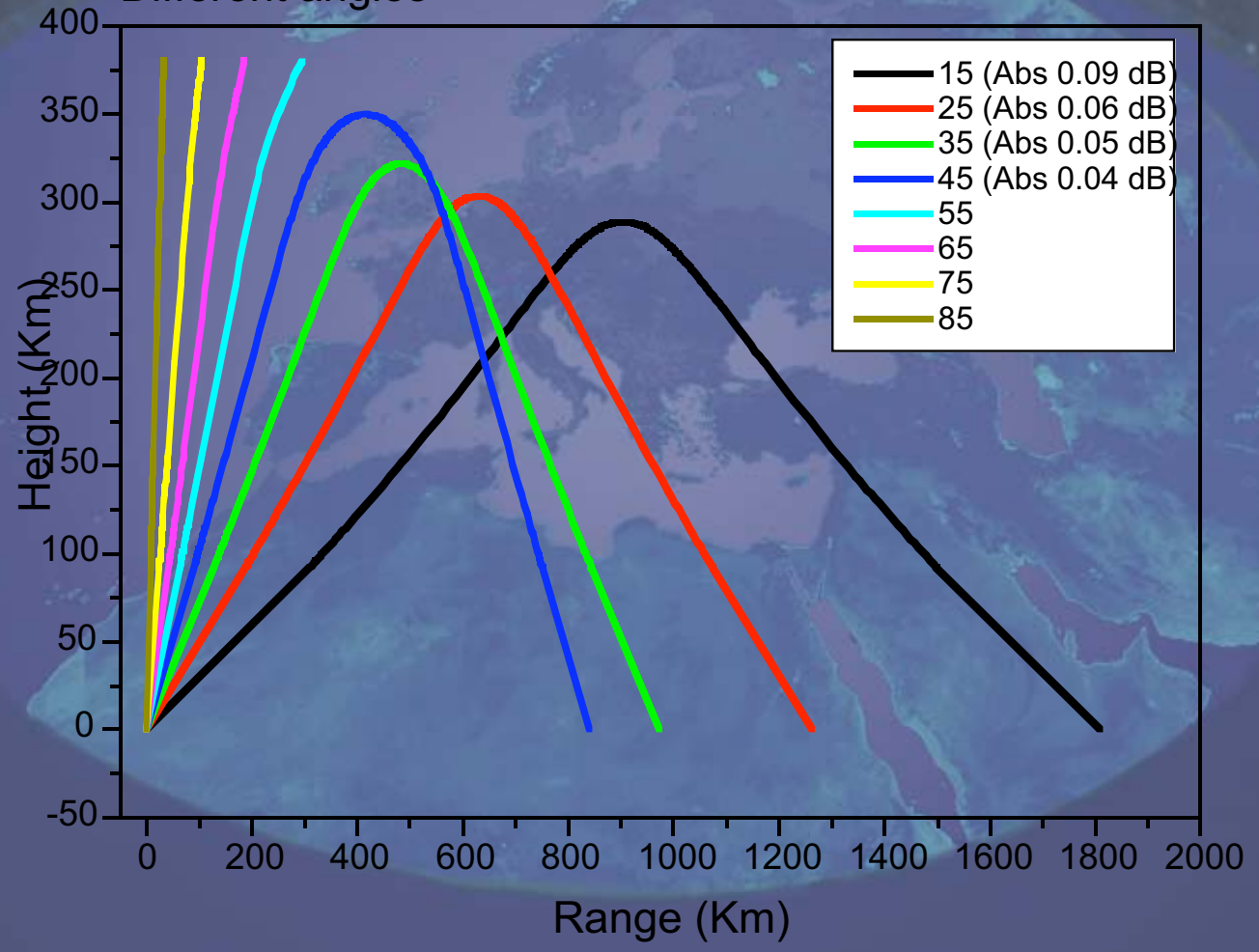


El Arenosillo / Day 182 / Hour 0000 UT / Freq 05 Mhz Different angles

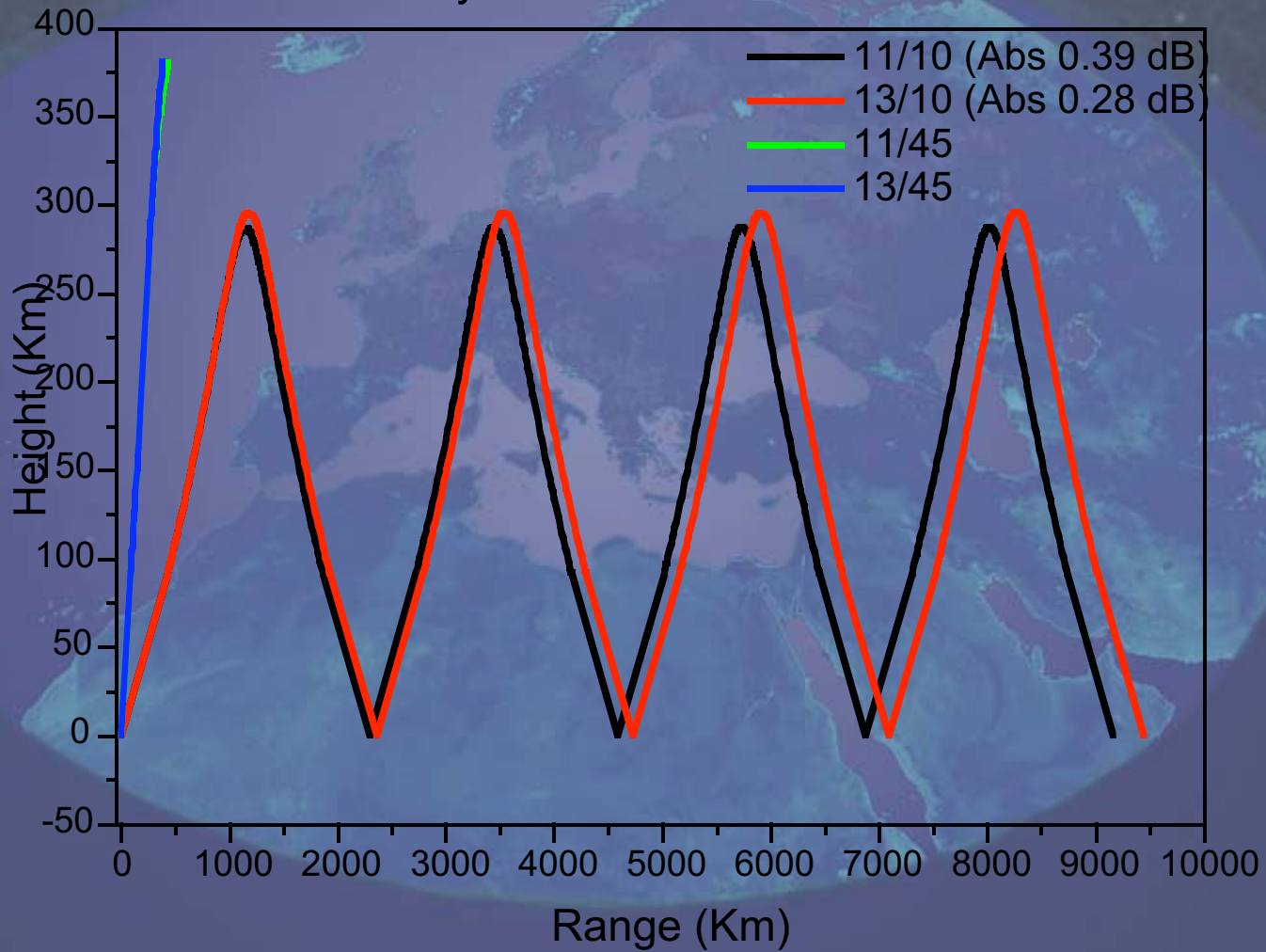




El Arenosillo / Day 182 / Hour 0000 UT / Freq 10 Mhz Different angles



El Arenosillo / Day 182 / Hour 0000 UT



VHF propagation

VHF propagation (30 to 300 Mhz)

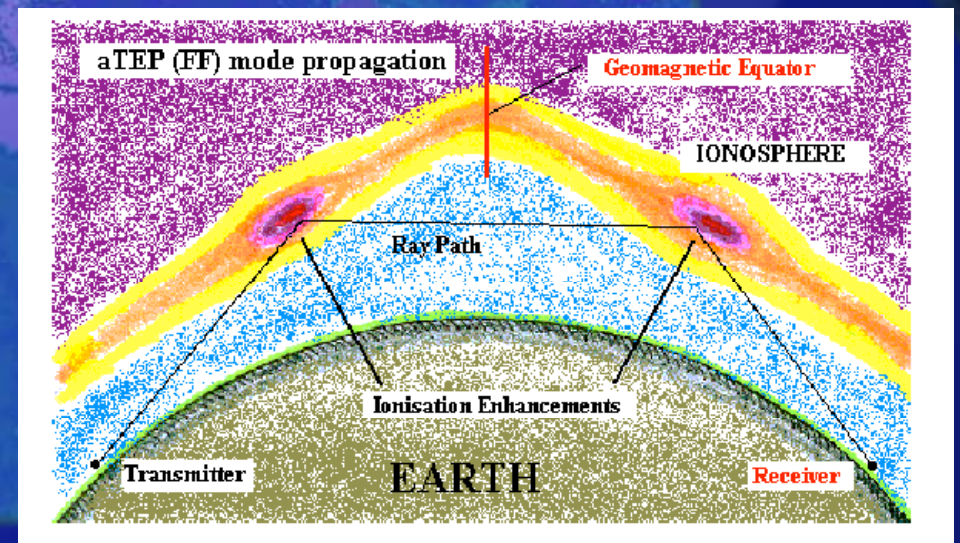
Waves propagate essentially along line of sight

📍 Ionospheric effects:

📍 ionospheric reflection with multiple hops at great distances up to 70 MHz

📍 Sporadic E reflections up to 225 Mhz

📍 Transequatorial propagation up to 144 Mhz



UHF propagation

UHF propagation (300 to 3000 Mhz)

Mainly line of sight propagation

📍 trans-ionospheric effects:

📍 Time delay due to the total electron content (TEC)

📍 Signal scintillations due to ionospheric irregularities.

📍 Frequencies used for:

📍 Terrestrial and satellite point-to-point communications

📍 Satellite navigation and positioning



HF communications frontiers

Old HF system disadvantages

- 📍 Operator dependent
- 📍 Highly variable propagation
- 📍 Interference vulnerability
- 📍 low data transmission rate
- 📍 difficult short distance communications


New technologies overcome limitations

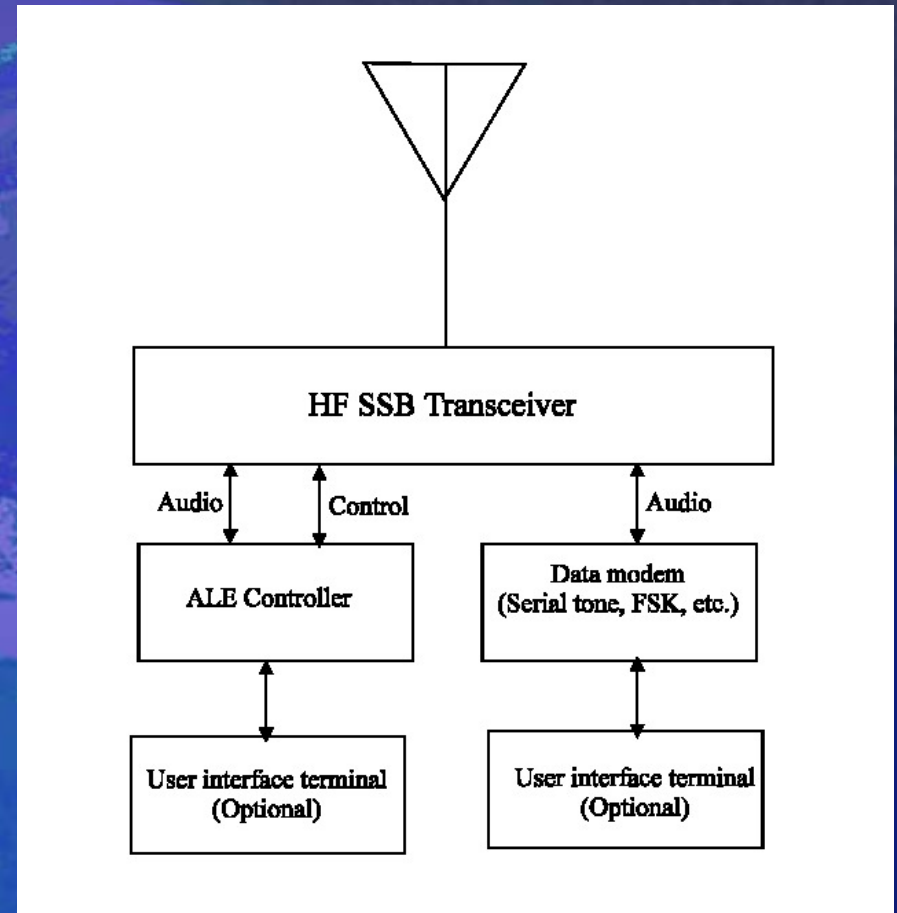
- 📍 Microprocessor operated transmitters and receivers
- 📍 Frequency automatic search and selection
- 📍 Automatic operation management
- 📍 Use of network protocols
- 📍 Use of advanced technology antennas

New HF systems

- 📍 Automatic Link Establishment (ALE) technology
- 📍 Spread Spectrum technologies
- 📍 HF communications as part of the Global Information Infrastructure

ALE technologies

 Based on adaptive automatic link establishment as a function of propagation condition variations and environmental noise conditions.



A basic condition

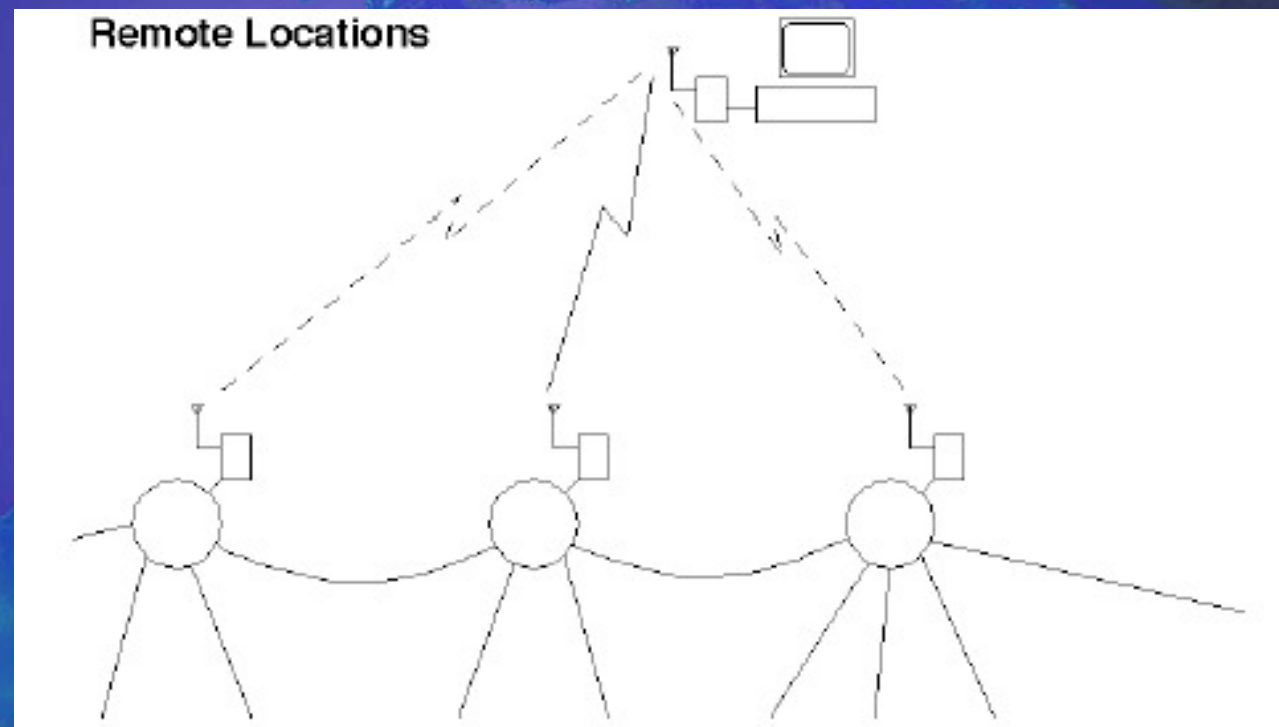
- 📍 ALE technologies needs a careful choice of a limited number of propagation parameters in order to select automatically the optimal operation conditions.
- 📍 This choice depends on the knowledge of the ionosphere and of the ionospheric channel characteristics.

Spread Spectrum technology

- 📌 Used since more than 25 years in military systems in the last 10 years is used for civilian purposes
- 📌 In these systems information and power is spread in a wide range of frequencies like noise and reconstructed afterwards in the receiver.
- 📌 Spread spectrum signals are:
 - 📌 not easily intercepted
 - 📌 not easily interfered and in turn do not interfere.

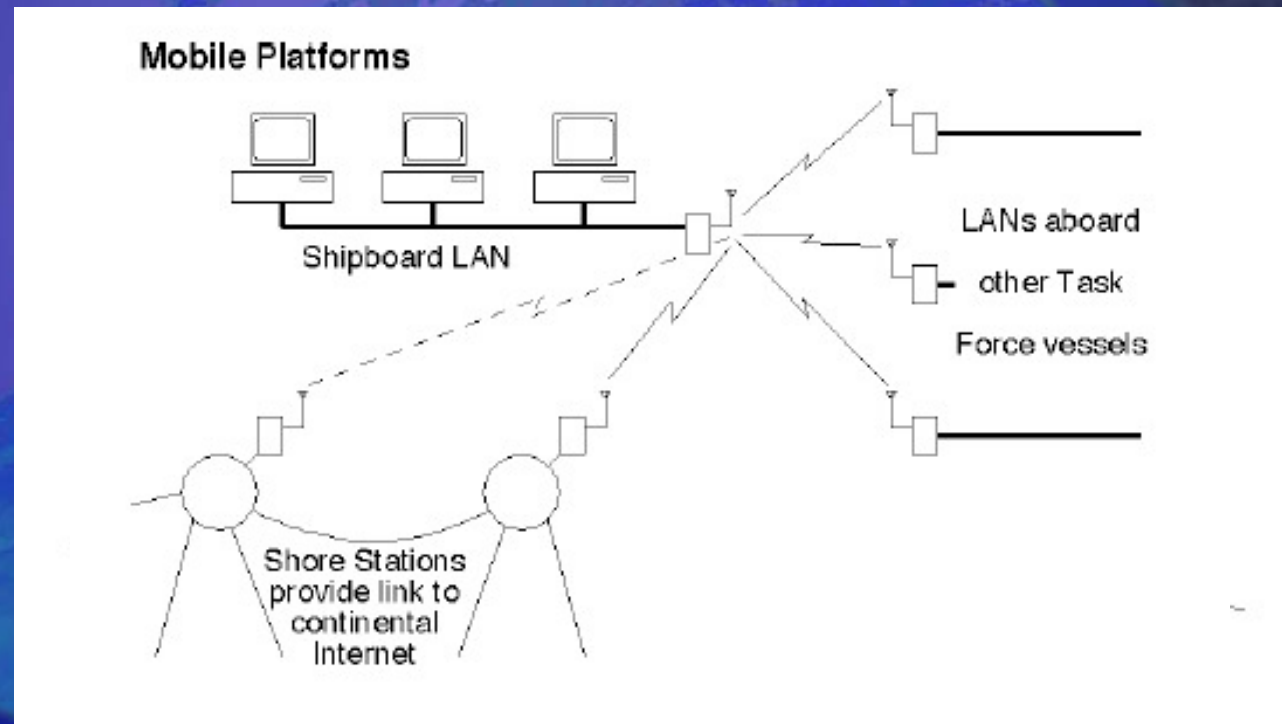
HF communications and the Global Communication Infrastructure

 Remote areas Voice and Data access



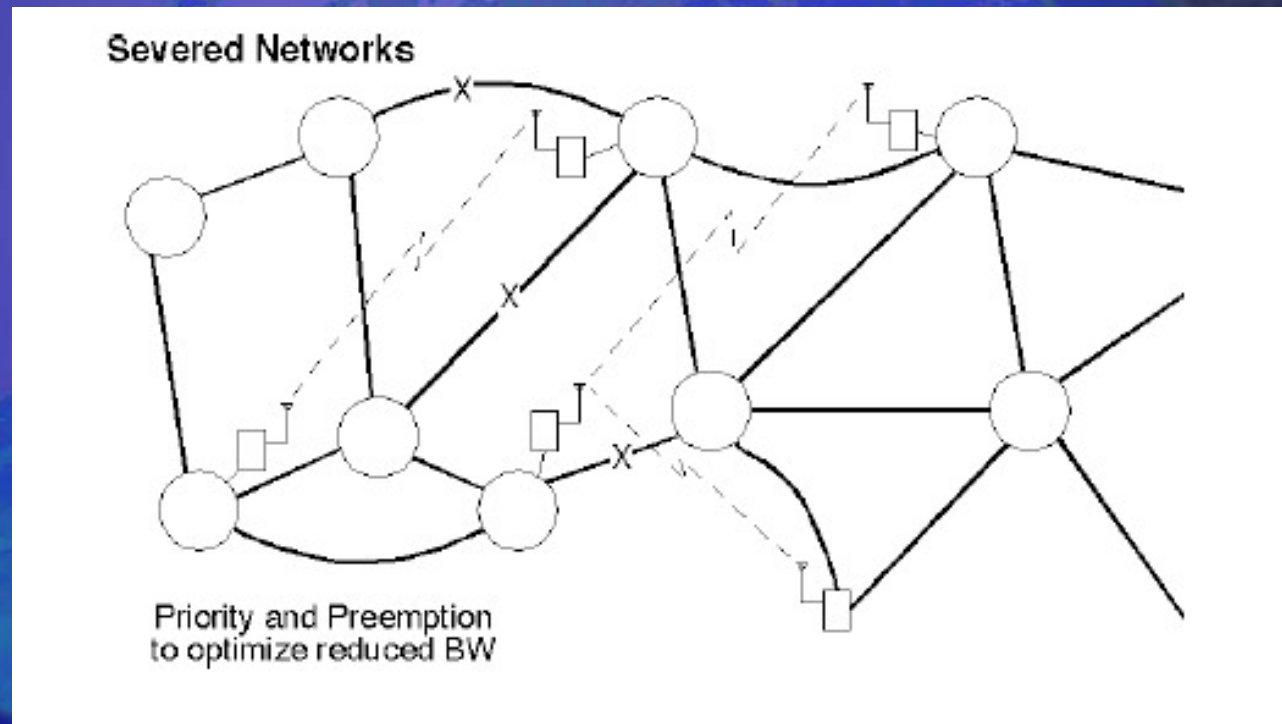
HF communications and the Global Communication Infrastructure

Mobile platform for Voice and Data



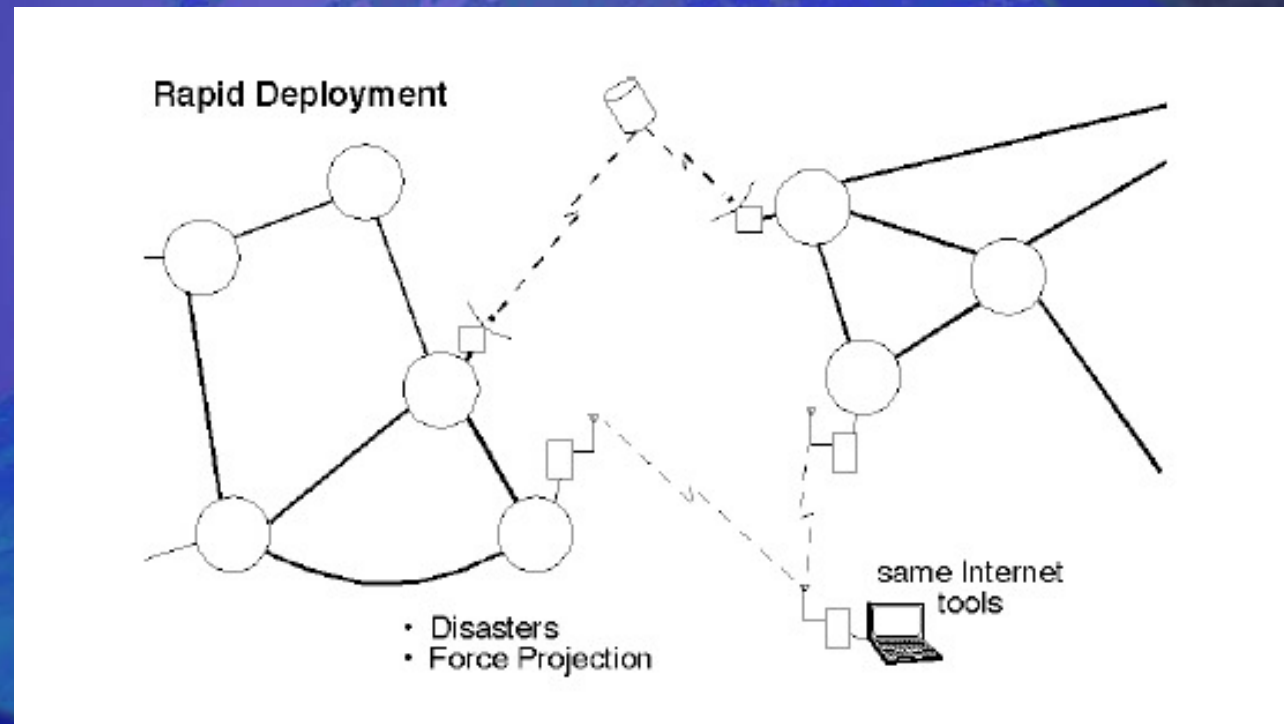
HF communications and the Global Communication Infrastructure

 Emergency links in severed networks



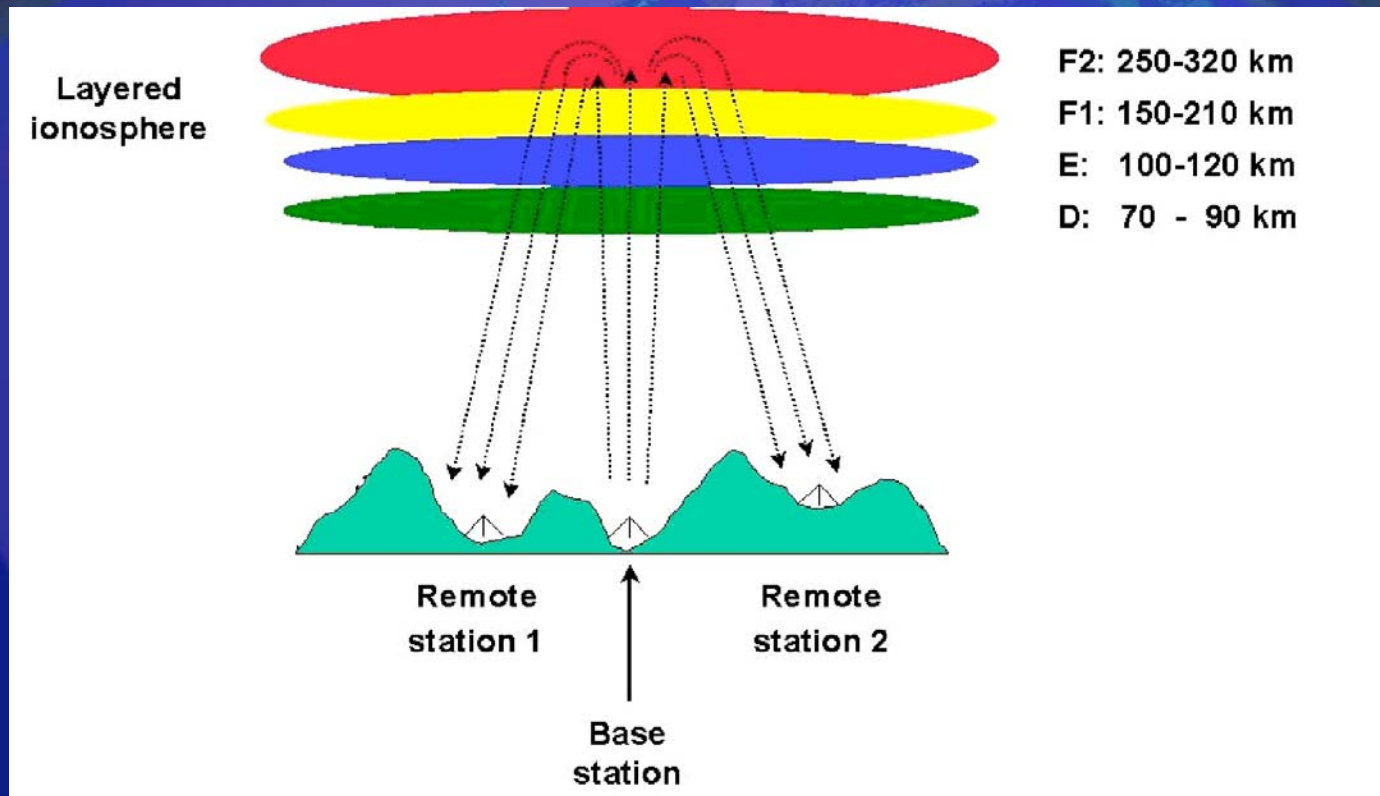
HF communications and the Global Communication Infrastructure

- 📡 Rapid deployment networks for disaster conditions



Near Vertical Incidence Skywave (NVIS)

- 🔦 NVIS are used for mountain remote locations



New HF communication techniques and the future

- The increase of ALE systems management speed will reduce the time needed for the automatic choice of optimal communication conditions.
- New modems development will allow standard transmission at 9600 bps and up to 64 kbps in special cases.
- New modems will be able to manage signals from multiband (HF-VHF-UHF) transrecivers.
- New Digital Signal Processing technologies will improve the interference removal process.

New HF communication techniques and the future

- Spread Spectrum technology development will reduce the presence of multipath problems related to the ionosphere
- New Networking designs will allow the optimal integration of HF systems with more complex networks and the Global Information Infrastructure.
- New hardware technologies will allow to standardize the multiband (HF-VHF-UHF) communication systems. standard.



**Thank you
for your attention**