Tropospheric ducting

Electromagnetics
and
Remote Sensing Lab
(ERSLab)

Università degli Studi di Napoli Parthenope
Dipartimento di Ingegneria
Centro Direzionale, isola C4 - 80143 - Napoli, Italy

ferdinando.nunziata@uniparthenope.it

Outline

Ducting

ERSLab

F. Nunziata

Mirages

Fata Morgana

Earth's atmosphere

Refractivity gradients

Bending

Anomalous propagation

Ducting

Temperature inversion

b-LoS propagation

Appendix

For Further Reading

Outline

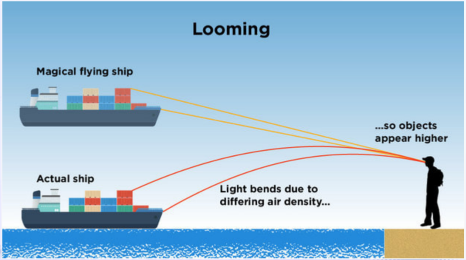
Strait of Messina

Pollino - Ionian sea

Fata Morgana

FATA MORGANA IN THE STRAIT OF MESSINA (1773), MESSINA REGIONAL LIBRARY

How it works



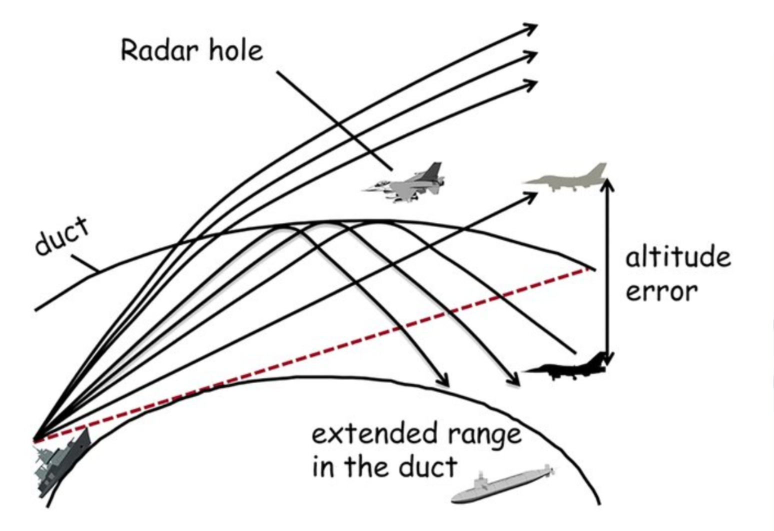
Fata Morgana mirage

- Light bends downward when entering colder (denser) air due to the larger refractive index.
- We naturally assume light rays taking a straight path from the true object to our eyes.

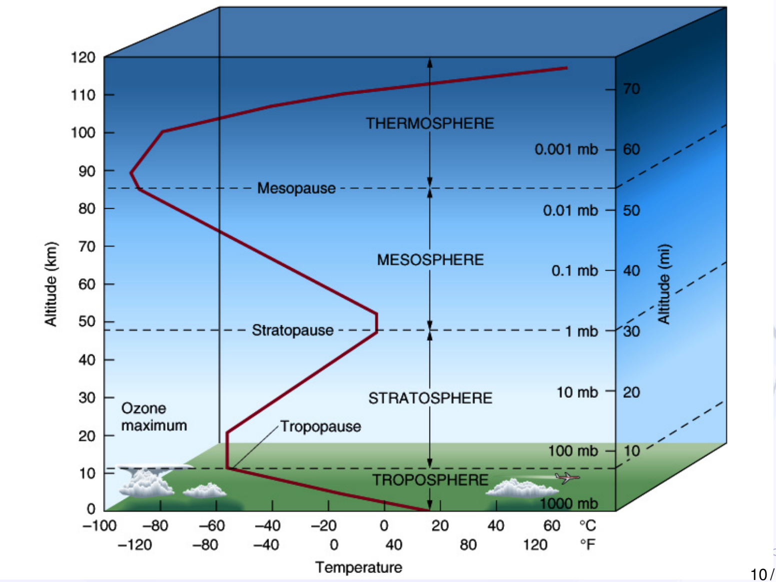
UFO?...

No...Fata Morgana

A key issue in maritime radar



Earth's atmosphere



Outline

Index of refraction

$$\varepsilon = \left(\varepsilon - j\frac{\sigma}{\omega}\right) = \varepsilon' - j\varepsilon''$$

ε'

- **Refraction**
- **Diffraction**
- **Depolarization**
- **Reflection**
- **DUCTING**

ε''

Absorption by:

- **Atmospheric gases**
- **Hydrometeors**

The real part of the index of refraction, *n*, is here accounted for.

Stratified atmosphere

Variations of the index of refraction

- We focus on the lowest part of the atm, namely the troposphere, which extends up to 14km asl.
- Variations of the refraction index involve both variations of the mean refractive index (causing bending) and fluctuations due to turbulence (scintillation, lensing).
- Here we focus on variations in the mean refraction index that are largest in the vertical direction.
- The troposphere is assumed to be horizontally stratified.

Index of refraction

Debye's formula

- The index of refraction can be expressed as a function of the atmospheric pressure P, water vapor pressure e and temperature T:

$$n = 1 + 77.6 \times 10^{6} \frac{P}{T} + 0.373 \frac{e}{T^{2}} \tag{1}$$

Characteristics of n

- The index of refraction rarely exceeds 1.0004 at the surface.
- Radiowave propagation, as pointed out by GO theory, depends mainly on the gradient of the refractivity index.

Radio refractivity index N

- The behavior of n in the atm is such that it is more convenient to define the radio refractivity index N:

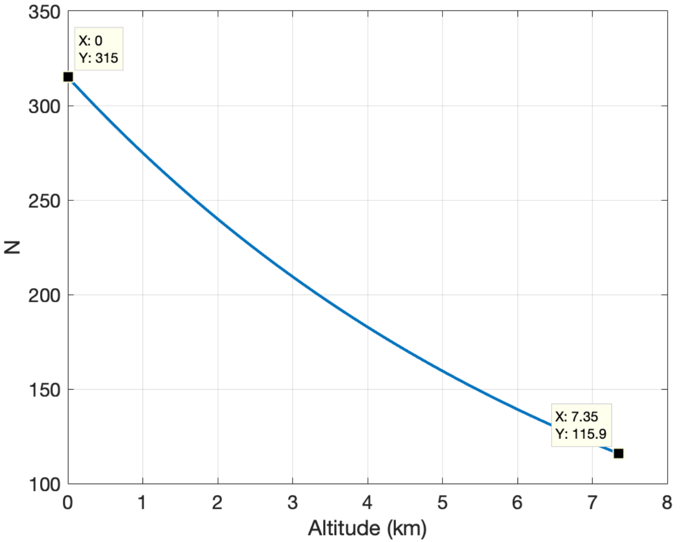
$$N = (n - 1) \times 10^6 \qquad (2)$$

- The International telecommunication Union (ITU), defined a standard atm in terms of N, proposing an exponential decay of N with the height above the ground z

$$N = N_s e^{-\frac{z}{H}} \qquad (3)$$

- An alternative index - termed as modified refractivity M - is also very common in radio propagation. It includes the Earth's curvature.

Standard atmosphere



Geometric optic

The Geometric optic approximation

GO suggests that a wave propagating in a medium calling for a gentle n variability bends according to the portion of the gradient of n transverse to the direction of the ray travel.

- According to GO, the ray curvature ρ is given by:

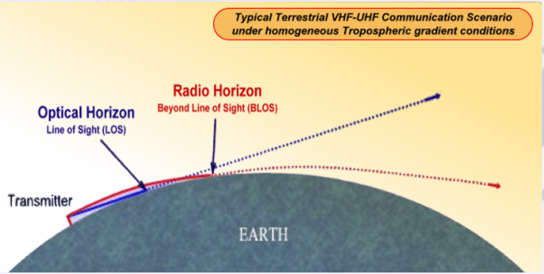
$$\frac{1}{\rho} = -\frac{1}{n}\frac{dN}{dz} cos\alpha \tag{4}$$

- which, assuming $n \approx 1$ and for small α angle, can be equivalently rewritten in terms of refractivity:

$$\frac{1}{\rho} = -\frac{dn}{dh} = -\frac{dN}{dz}10^{-6} \tag{5}$$

Bending in the standard atm

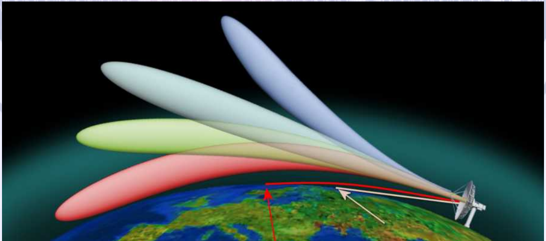
- In the first kilometer of the standard atm eq.(3) can be linearized and N calls for a constant decreasing trend of -43 [N/km]
- This results in a ray that bends towards the Earth extending the optical horizon:



Anomalous propagation

Non-standard or anomalous propagation occurs when the refractive index is modified in a way that is different by the standard atmosphere.

- This may be due to changes in temperature gradient, pressure or water vapor content.
- A wide range of non-standard propagation conditions may apply.



Anomalous propagation

$$\frac{dN}{dh}$$

Digitare l'equazione qui.

> 0
SUB-REFRACTION
$\rho < 0$
The ray path is curved upward

= 0
ZERO-REFRACTION
$\rho = \infty$
The ray path is a straight line

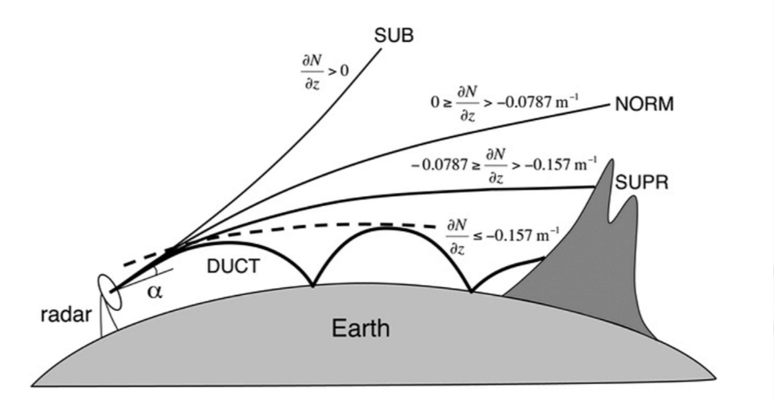
< 0
POSITIVE-REFRACTION

STANDARD ATMOSPHERE
$\frac{dN}{dh} = -40 \left[\frac{\mathrm{N}}{\mathrm{km}}\right]$

SUPER REFRACTION
$\frac{dN}{dh} < -40 \left[\frac{\mathrm{N}}{\mathrm{km}}\right]$
The ray bends towards the E[illegible]th

DUCTING
$\frac{dN}{dh} < -157 \left[\frac{\mathrm{N}}{\mathrm{km}}\right]$

Anomalous propagation



Formation conditions

Ducting

- It is an anomalous propagation mechanism that occurs in case of sharp *N* variations.
- This may happen in two cases (or a combination of both):
  - a sharp decrease in vapor pressure with height;
  - a temperature inversion, i.e.; the temperature increases with height.
- Temperature inversion is the dominant factor.

Outline

Temperature inversion

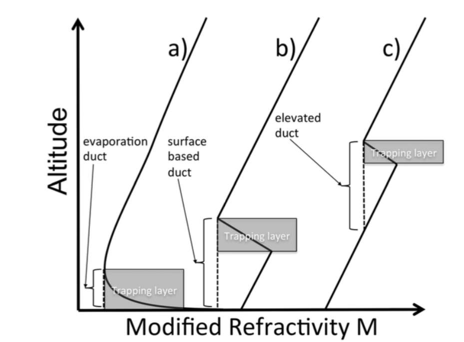
- Under normal atmospheric conditions, the warmest air is found near the surface of the Earth.
- The air gradually becomes cooler as altitude increases.
- An unusual situation can develop in which layers of warm air are formed above layers of cool air.

This condition is known as temperature inversion

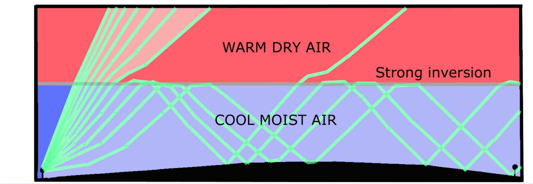
These temperature inversions cause channels, or ducts, of cool air to be sandwiched between the surface of the Earth and a layer of warm air, or between two layers of warm air.

Ducting

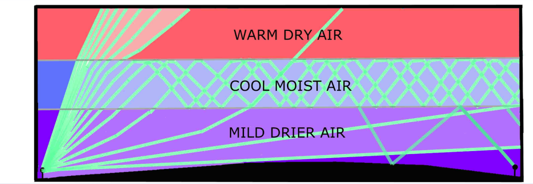
According to the mechanisms that determine the duct's formation, different types of ducts can be observed



Ducting



surface duct



elevated duct

Outline

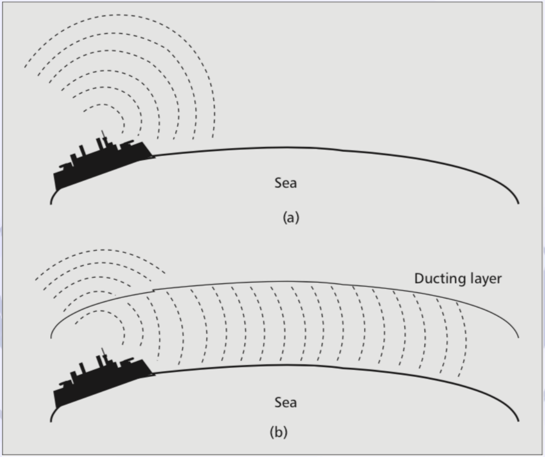
Beyond-LoS propagation

Under ducting conditions:

- The signals do not spread isotropically through the atmosphere but they mostly spread in the ducting layer.
- This implies a spreading loss that decreases considerably compared to the standard atmosphere.

In this way, the trapped signals can travel over the horizon, making the ducting layer convenient for beyond-line-of-sight (b-LoS) communications.

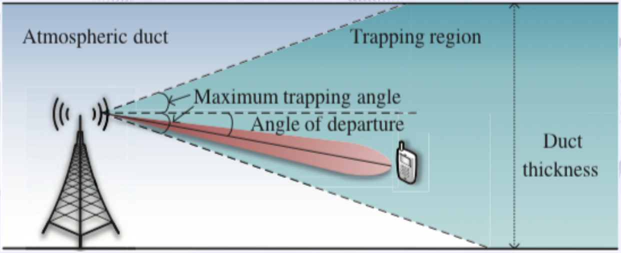
b-LoS



Trapping conditions

For a wave to be trapped:

- The maximum trapping angle should be small (≈ 0.4 degree).
- The minimum trapping frequency is around 300MHz.



For Further Reading I

- ITU. *Effects of tropospheric refraction on radiowave propagation*
  P Series, 2016.
- Fangfang Liu et al.. *Atmospheric Ducting Effect in Wireless Communications: Challenges and Opportunities*
  Journal of Communications and Information Networks, vol6., no.2, 2021.
- Alex Mahalov and Austin McDaniel *Long-range propagation through inhomogeneous turbulent atmosphere: analysis beyond phase screens*
  Phys. Scr. 94 034003