Spectral Analysis of Six Years Long Time Series of Radio Wave Surface Refraction Index

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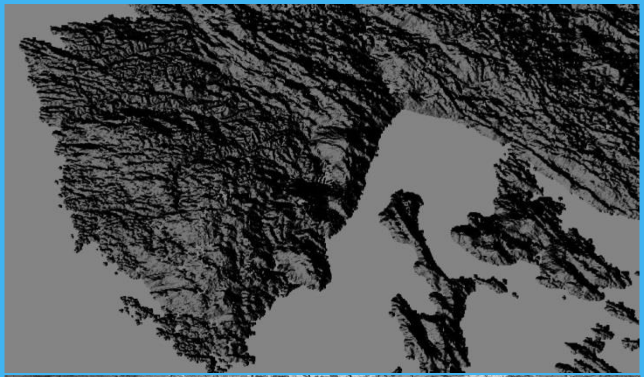
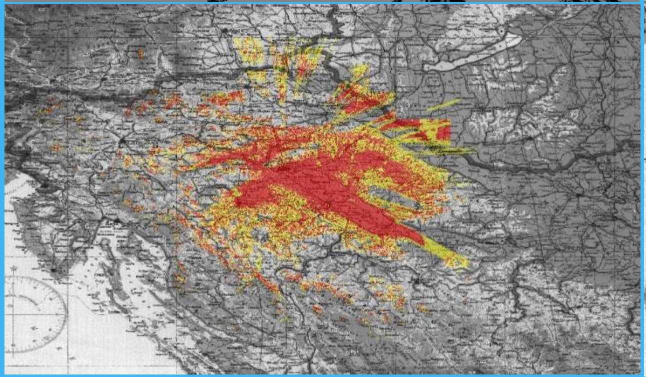
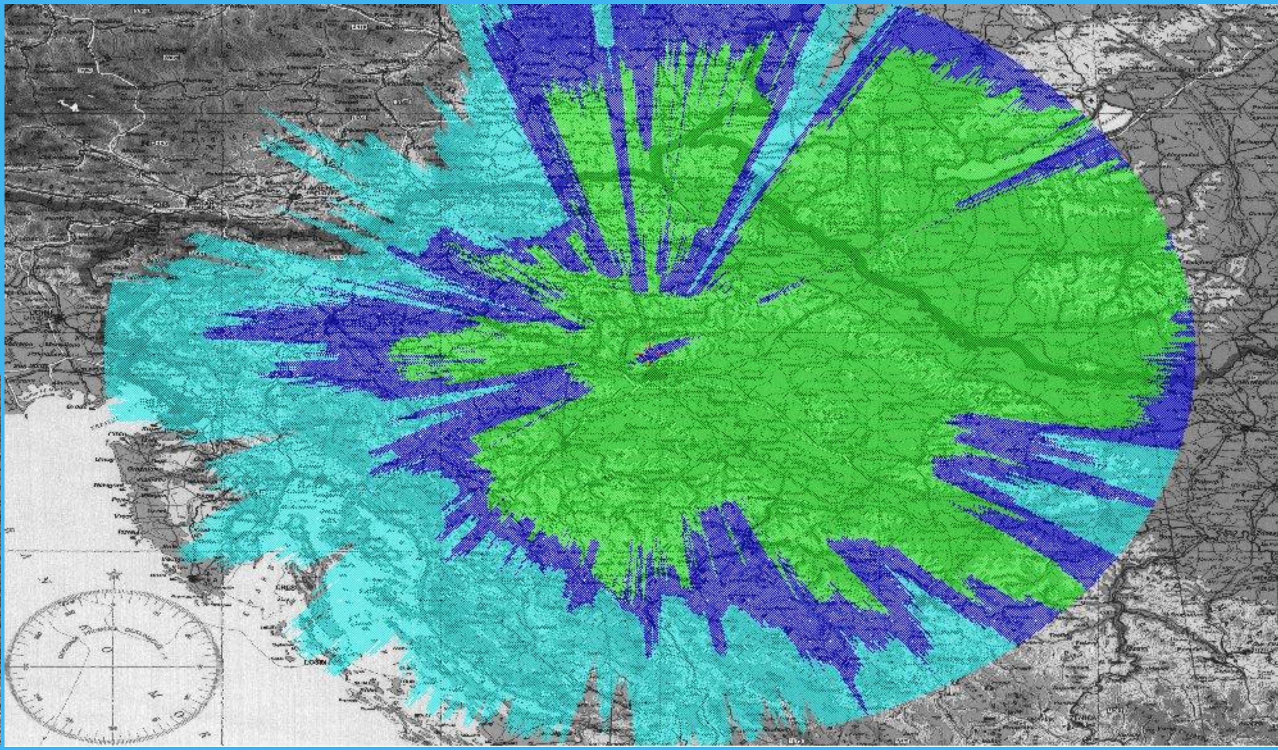
RAY TRACING MODEL AND STANDARD REFRACTIVITY



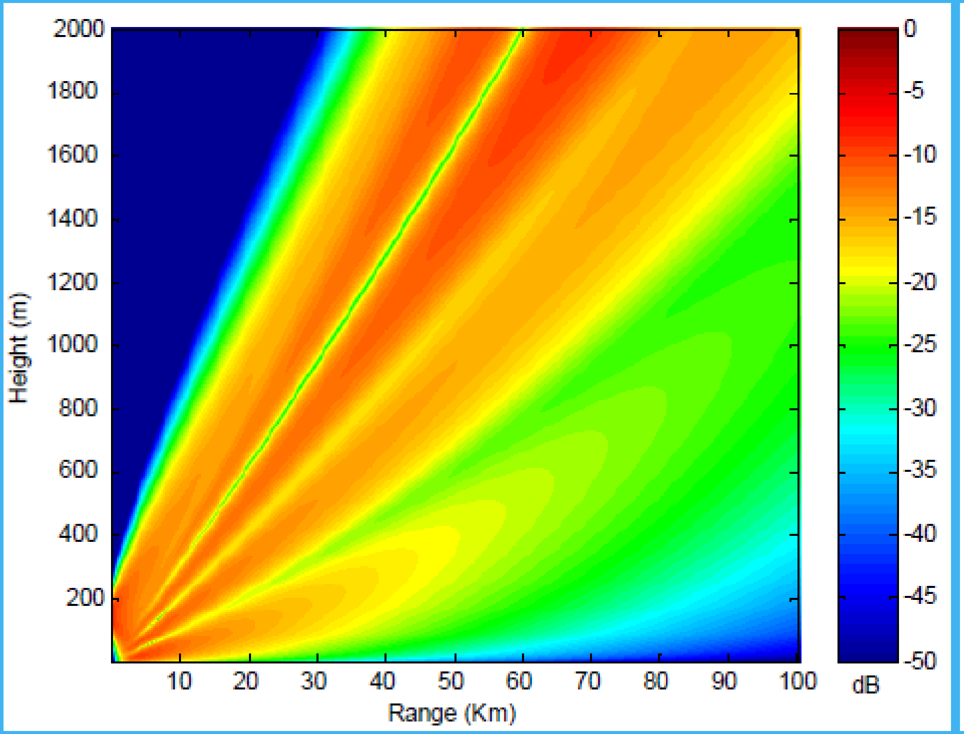




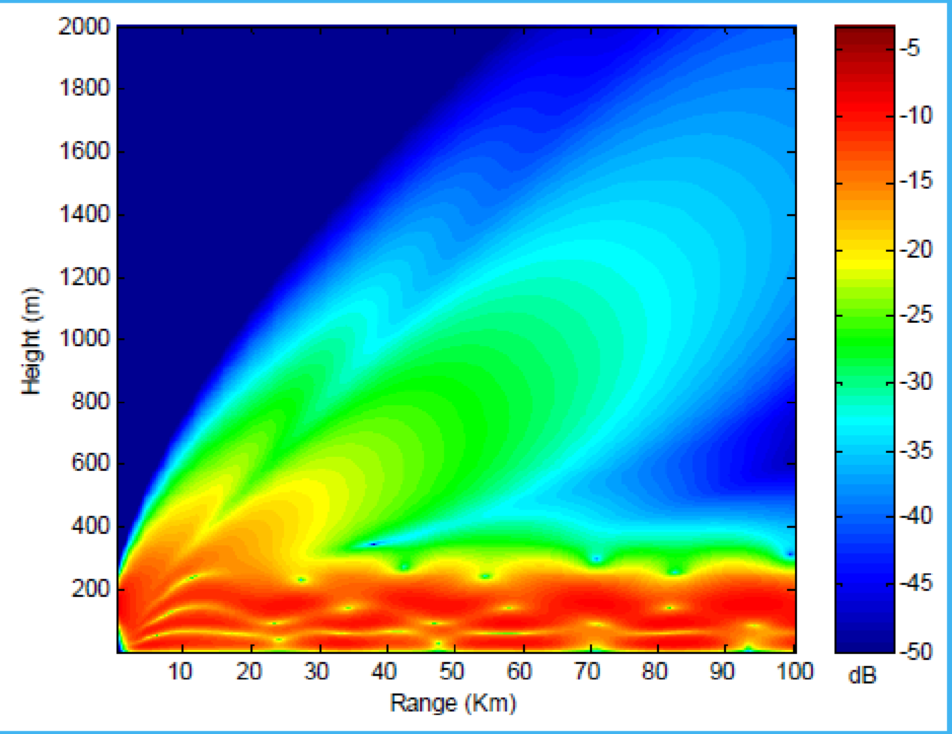
PARABOLIC PROPAGATION MODEL

$$\frac{\partial^2 E(x,z)}{\partial z^2} + 2jk\frac{\partial E(x,z)}{\partial x} + k^2\left(\left[n(x,z)\right]^2 - 1 + \frac{2z}{R}\right)E(x,z) = 0$$

Isaakidis i Xenos, 2004

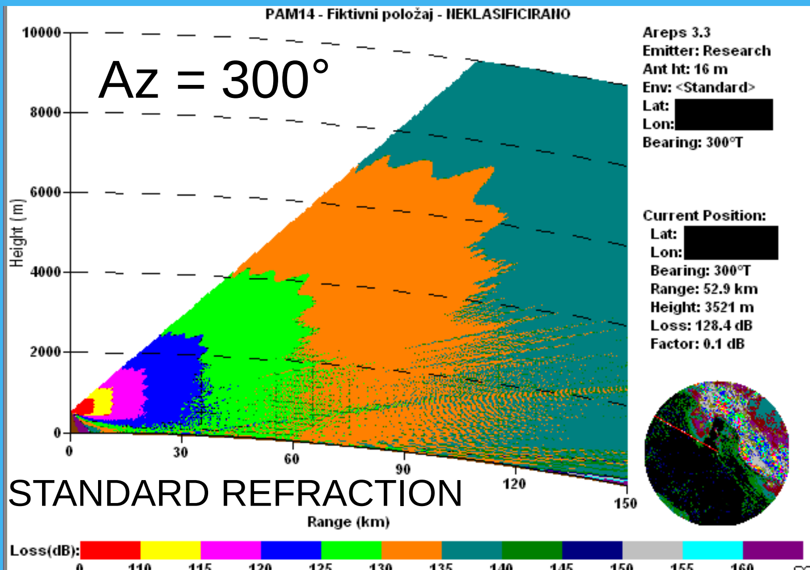


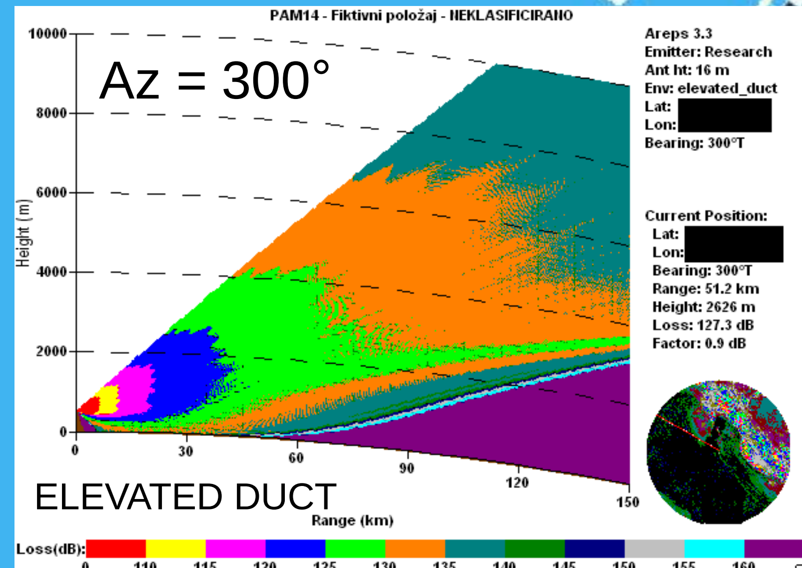
STANDARD REFRACTION

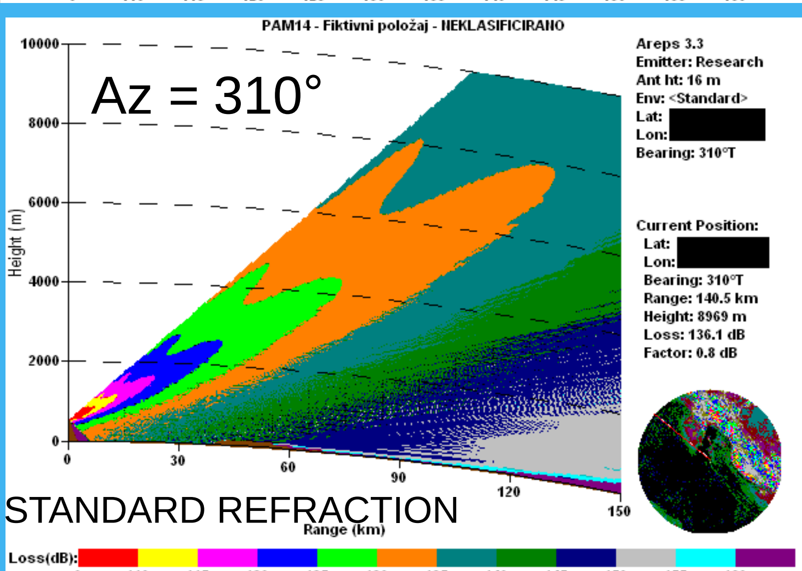


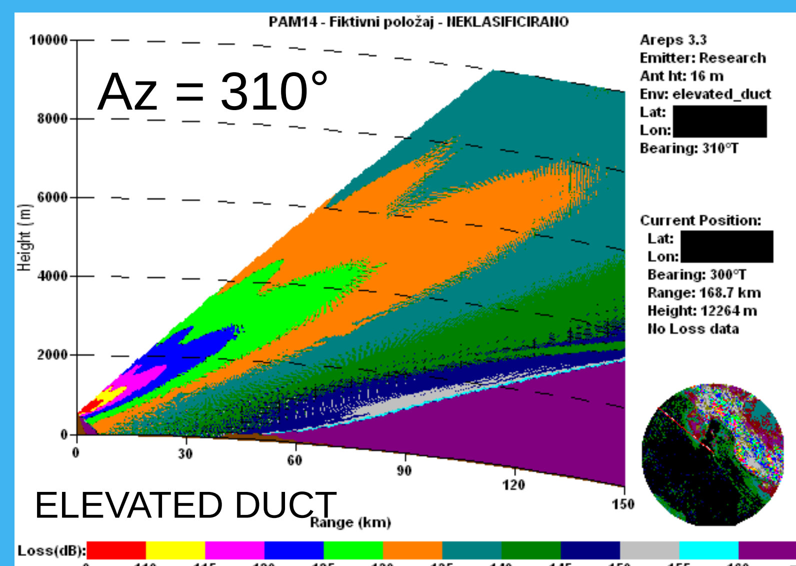
SURFACE DUCT

AREPS APPLICATION









EMPIRICAL FORMULAS FOR THE REFRACTION INDEX

IUGG, 1963.

$$N = (n - 1) \cdot 10^6$$

$$N = 77.624\frac{p_d}{T} + 64.700\frac{p_w}{T} + 371897\frac{p_w}{T^2}$$

International Radio Consultative Committee, 1986.

$$N = \frac{77.6\,p}{T} - \frac{5.6\,e}{T} + \frac{3.75 \cdot 10^5\,e}{T^2}$$

Patterson i dr., 1994; Battan, 1973

$$N = (n-1) \cdot 10^6 = \frac{77.6\left[\mathrm{K} \cdot \mathrm{Pa}^{-1}\right] \cdot p}{T} + \frac{e_s' \cdot 3.73 \cdot 10^5 \left[\mathrm{K}^2\right]}{T^2}$$

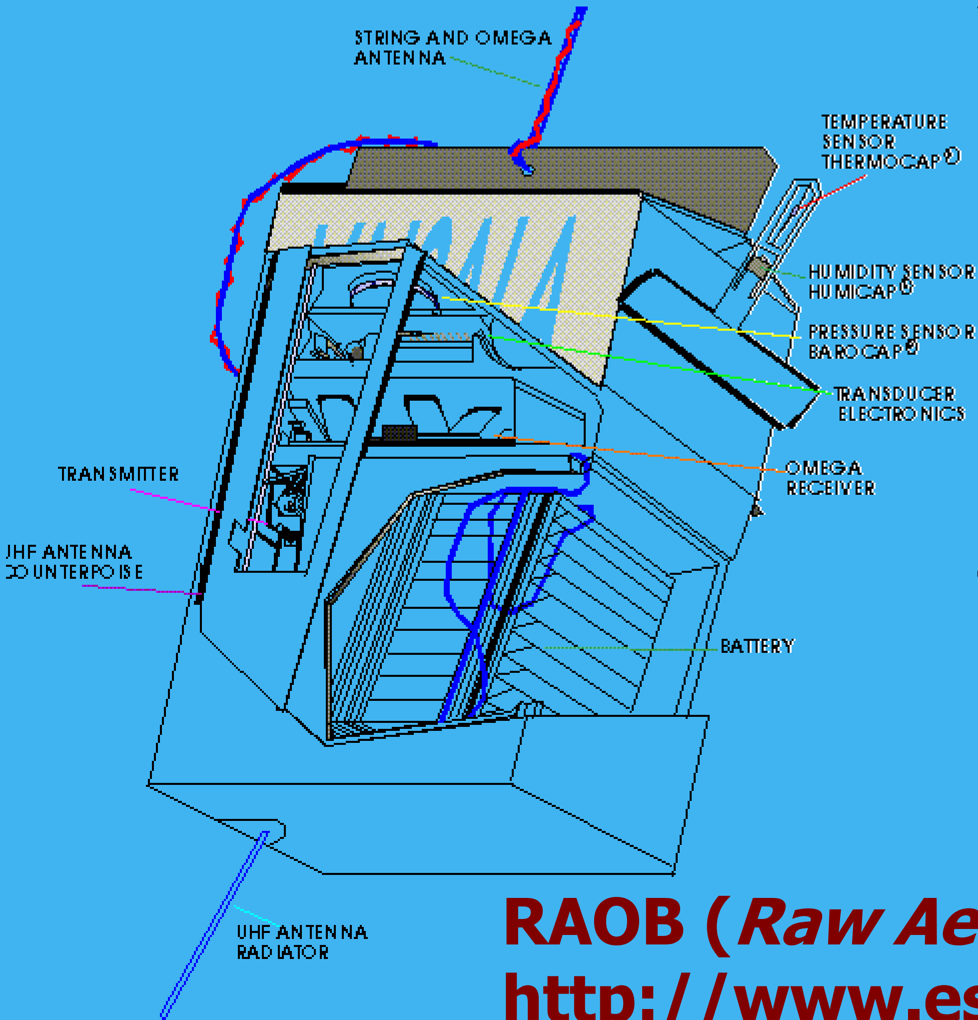
$$e_s' = \frac{rh \cdot 6.105 \cdot \exp(x)}{100}$$

$$x = 25.22\frac{T - 273.15[K]}{T} - 5.31 \cdot \ln\left(\frac{T}{T_0}\right)$$

ITU-R P.453-9 iz 2003

$$N = \frac{77.6}{T}\left(p + 4810\frac{e}{T}\right)$$

METHODOLOGY



Station	Period of soundings	Type of the probe
14430 Zadar	12 hours	RS-80
16044 Udine	6 hours	RS-90
16144 San Pietro	12 hours	RS-80
16320 Brindisi	6 hours	RS-90

RAOB (*Raw Aero sonde OBservation*)
http://www.esrl.noaa.gov/raobs/

		RS-80	RS-90
PRESSURE	Sensor type	BAROCAP	Silicone
	Range	1060 hPa – 3 hPa	1080 hPa – 3 hPa
	Resolution	0.1 hPa	0.1 hPa
	Absolute error	0.5 hPa	1 hPa (1080 hPa > p > 100 hPa) 0.6 hPa (100 hPa > p > 3 hPa)
TEMPERATURE	Sensor type	THERMOCAP	Capacitive conductor
	Range	+60° C do -90° C	+60° C do -90° C
	Resolution	0.1° C	0.1° C
	Absolute error	0.2° C (p > 50 hPa) 0.3° C (50 hPa > p > 15 hPa) 0.4° C (p < 15 hPa)	0.2° C (1080 hPa > p > 100 hPa) 0.3° C (100 hPa > p > 20 hPa) 0.5° C (20 hPa > p > 3 hPa)
	Time resolution	2.5 s	< 0.4 s na 1000 hPa < 1 s na 100 hPa
HUMIDITY	Sensor type	HUMICAP	Thin film capacitor
	Range	0 – 100 %	0 – 100 %
	Resolution	1 %	1 %
	Absolute error	3 %	5 %
	Time resolution	1 s	< 0.5 s na +20° C < 20 s na -40° C

VERTICAL PROFILES OF THE REFRACTION INDEX

Effective Earth Model for Refraction

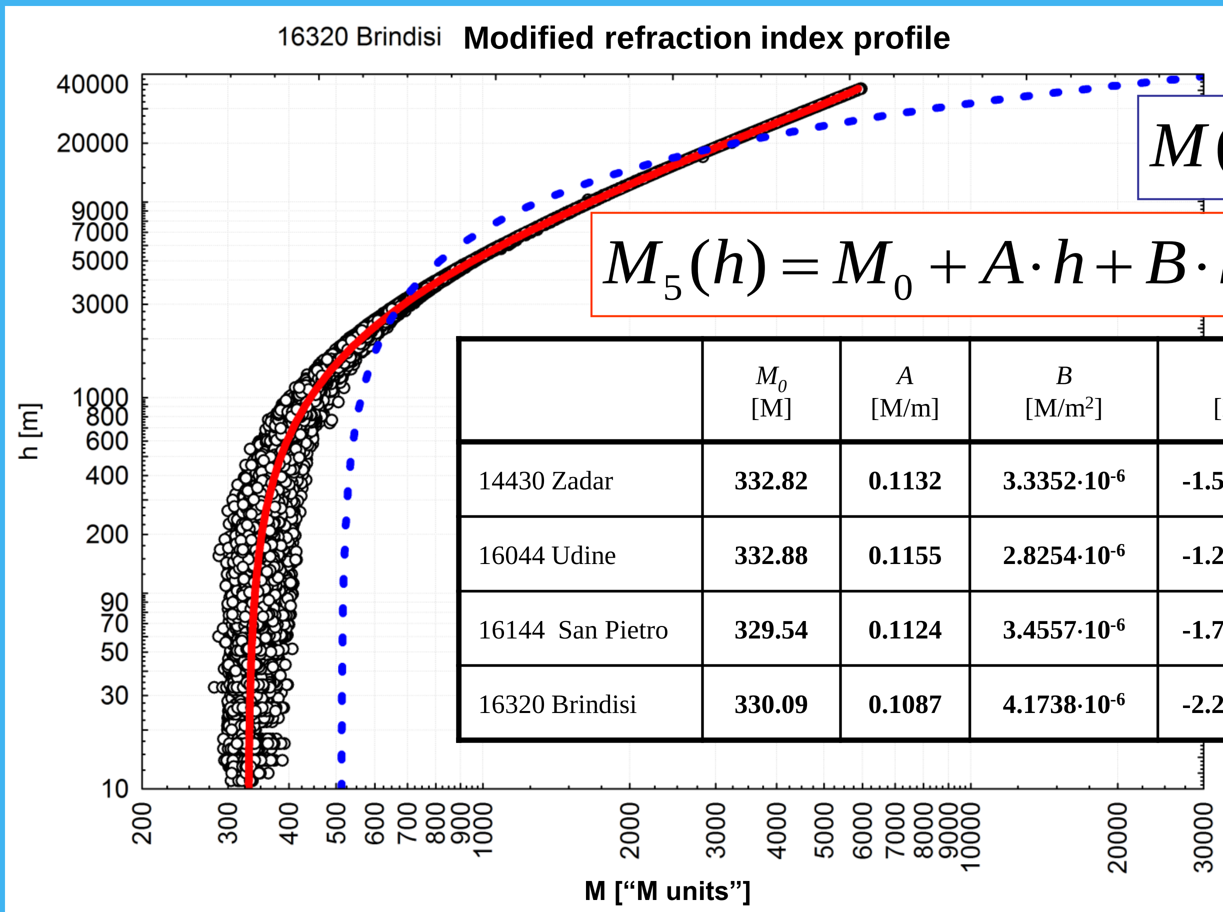
To further develop the subject of refraction through use of (2.3-1) requires that some model be chosen for the behavior of n with height. Several models exist. Two of the more important ones are the *exponential model* (Skolnik, 1980, p. 450), which assumes $n - 1$ decreases exponentially with altitude, and the *standard model*, where n is assumed to vary linearly with altitude as

$$n = n_0 + \frac{dn}{dh} h \tag{2.3-3}$$

with dn/dh taken as constant. The standard model is in agreement with measured results mainly in the lower atmosphere where $h \leq 1$ km. In this region it allows a simple interpretation of refraction, as discussed below. The exponential model more closely represents measured results when $h > 1$ km, but it is more difficult to obtain simple results for refraction.

Peebles; Radar Principles, 1998

VERTICAL PROFILES OF THE REFRACTION INDEX



$$M(h) = M_s \, e^{h/h_0}$$

$$M_5(h) = M_0 + A \cdot h + B \cdot h^2 + C \cdot h^3 + D \cdot h^4 + E \cdot h^5$$

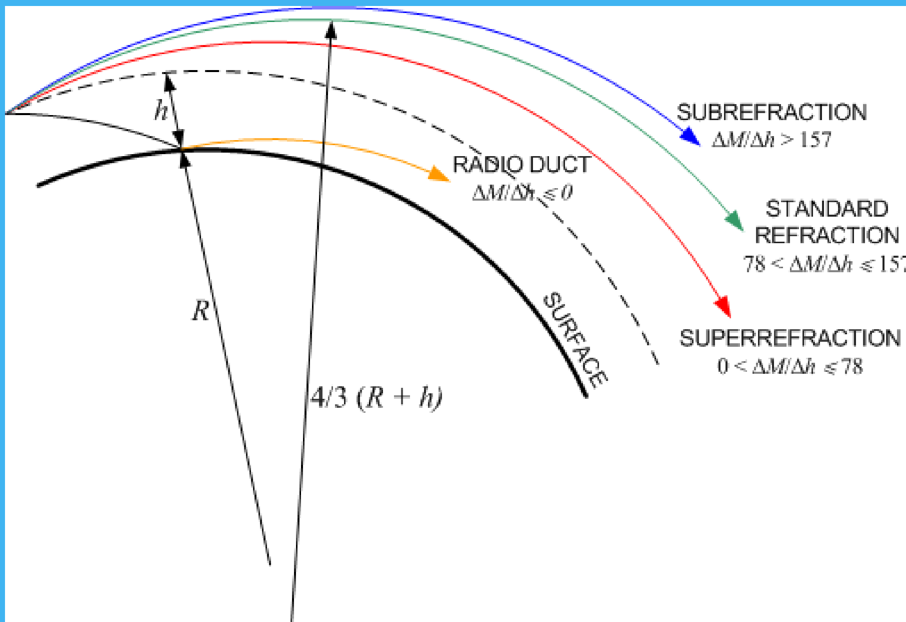
	M_0 [M]	A [M/m]	B [M/m^2]	C [M/m^3]	D [M/m^4]	E [M/m^5]	r
14430 Zadar	**332.82**	**0.1132**	**$3.3352\cdot10^{-6}$**	**$-1.5576\cdot10^{-10}$**	**$3.7792\cdot10^{-15}$**	**$-3.5445\cdot10^{-20}$**	**0.99807**
16044 Udine	**332.88**	**0.1155**	**$2.8254\cdot10^{-6}$**	**$-1.2279\cdot10^{-10}$**	**$2.9590\cdot10^{-15}$**	**$-2.8856\cdot10^{-20}$**	**0.99931**
16144 San Pietro	**329.54**	**0.1124**	**$3.4557\cdot10^{-6}$**	**$-1.7419\cdot10^{-10}$**	**$4.7508\cdot10^{-15}$**	**$-5.0760\cdot10^{-20}$**	**0.99927**
16320 Brindisi	**330.09**	**0.1087**	**$4.1738\cdot10^{-6}$**	**$-2.2888\cdot10^{-10}$**	**$6.5242\cdot10^{-15}$**	**$-7.1355\cdot10^{-20}$**	**0.99919**

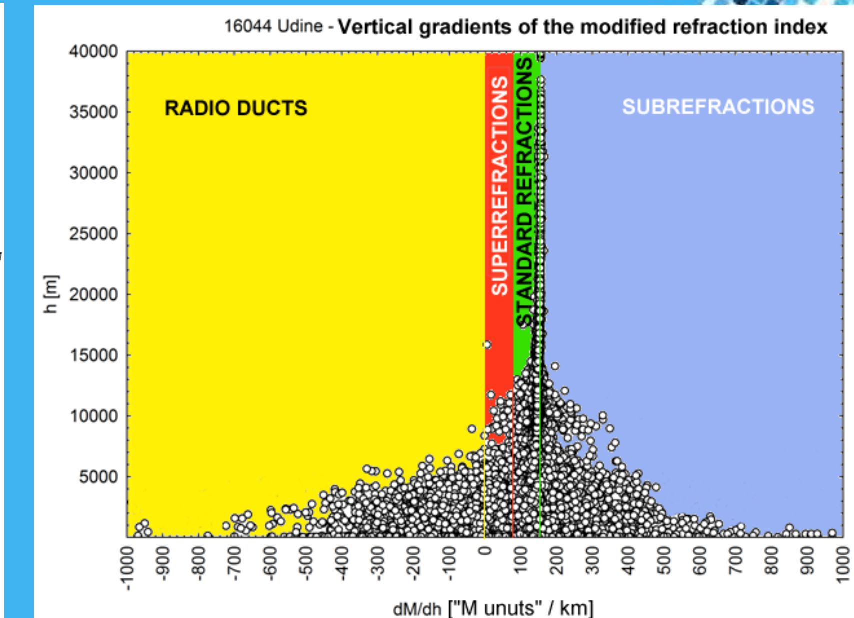
Viher, Telišman Prtenjak (2012)

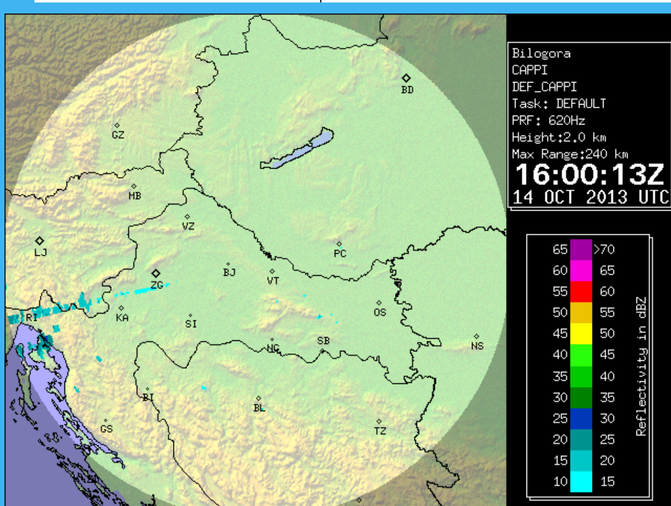
ANAPROPs

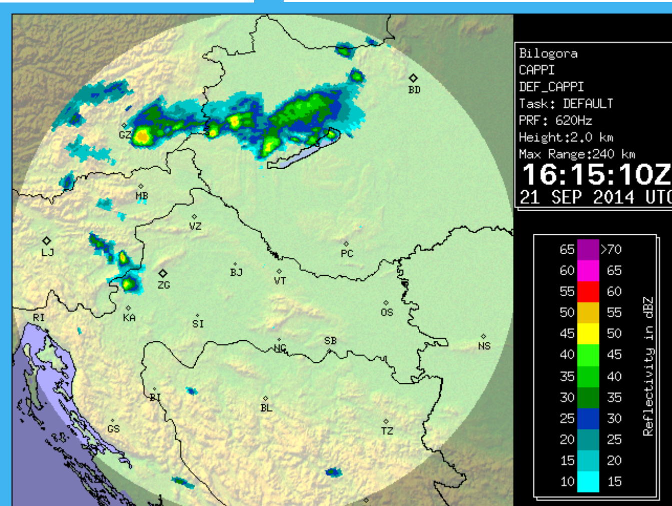
Viher, Telišman Prtenjak, Grisogono (2013)

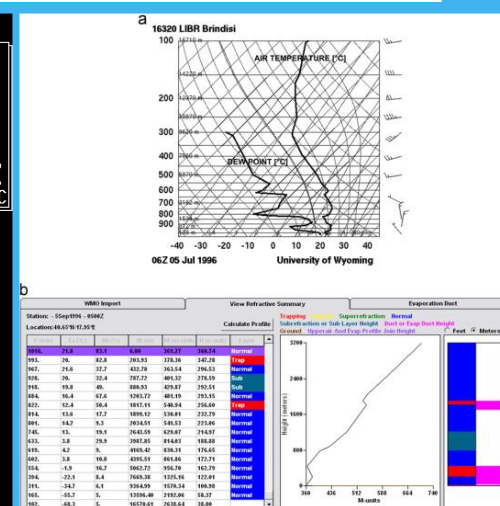
$$M = \frac{h}{R_Z} \cdot 10^6 + (n-1) \cdot 10^6 = \frac{h}{R_Z} \cdot 10^6 + N = 0.157 \left[\mathrm{m}^{-1} \right] \cdot h + N$$



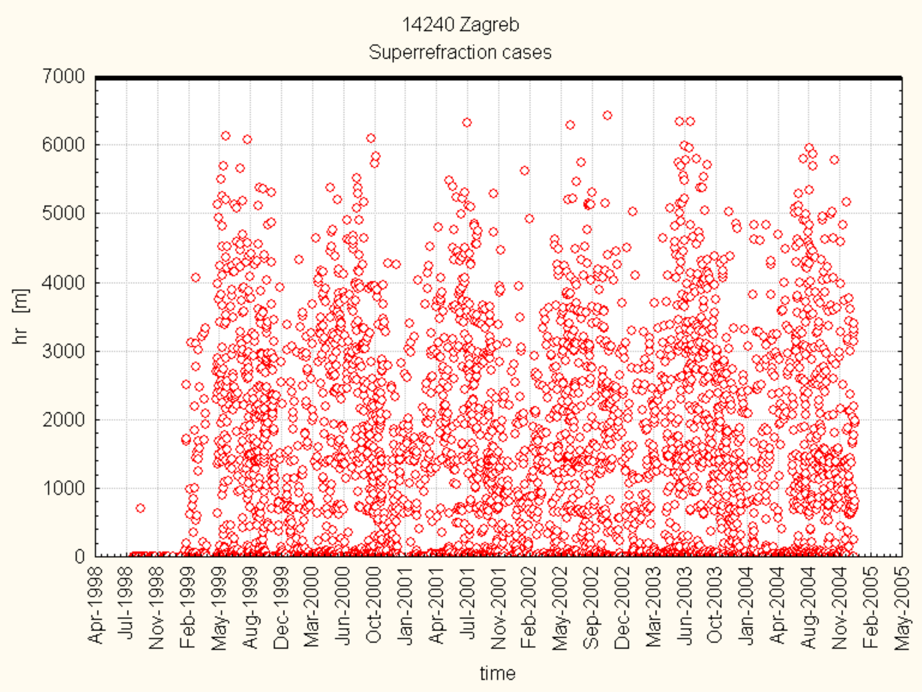


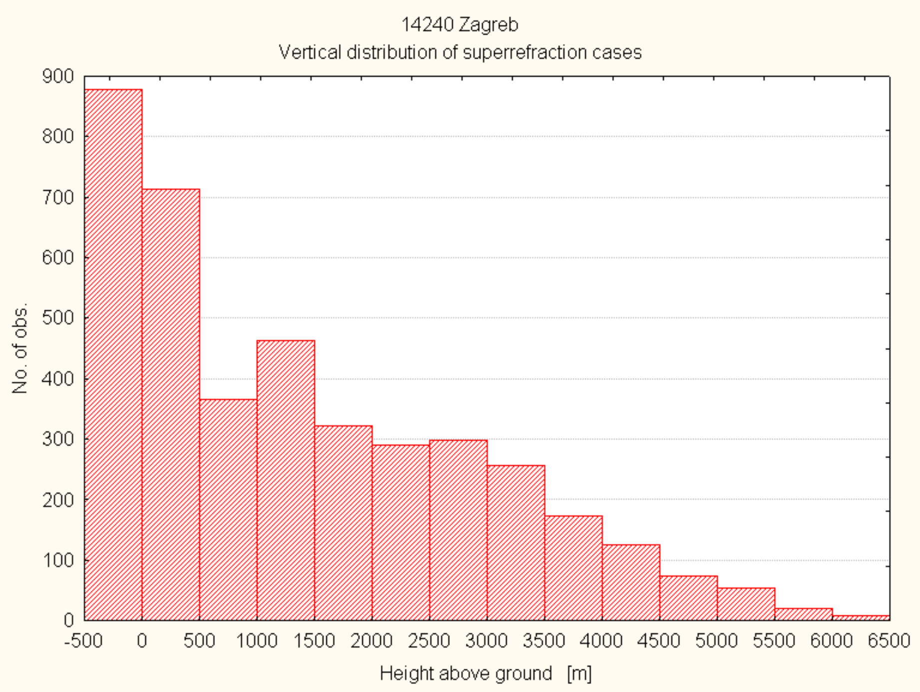




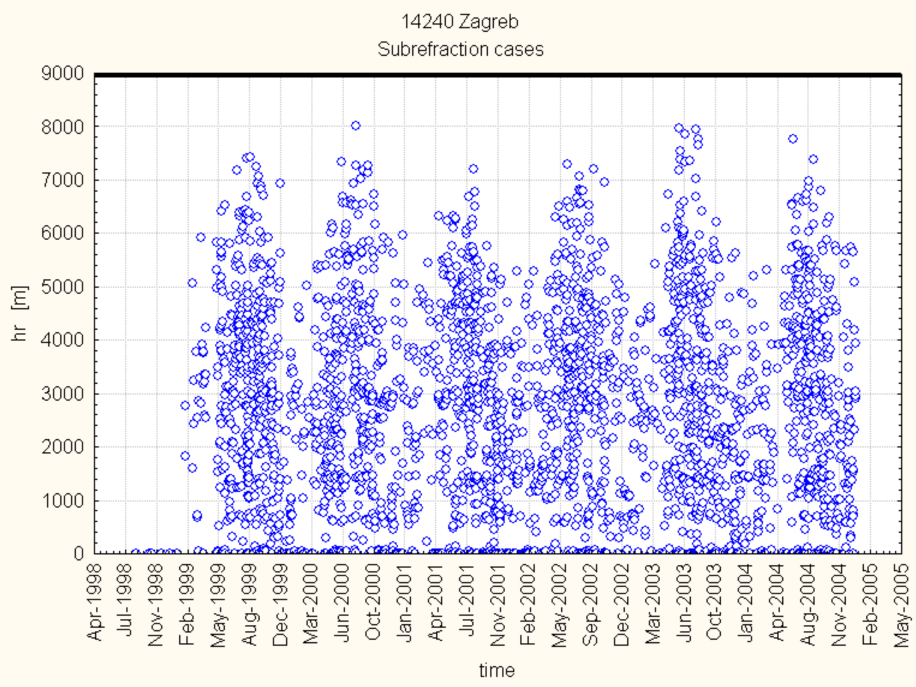


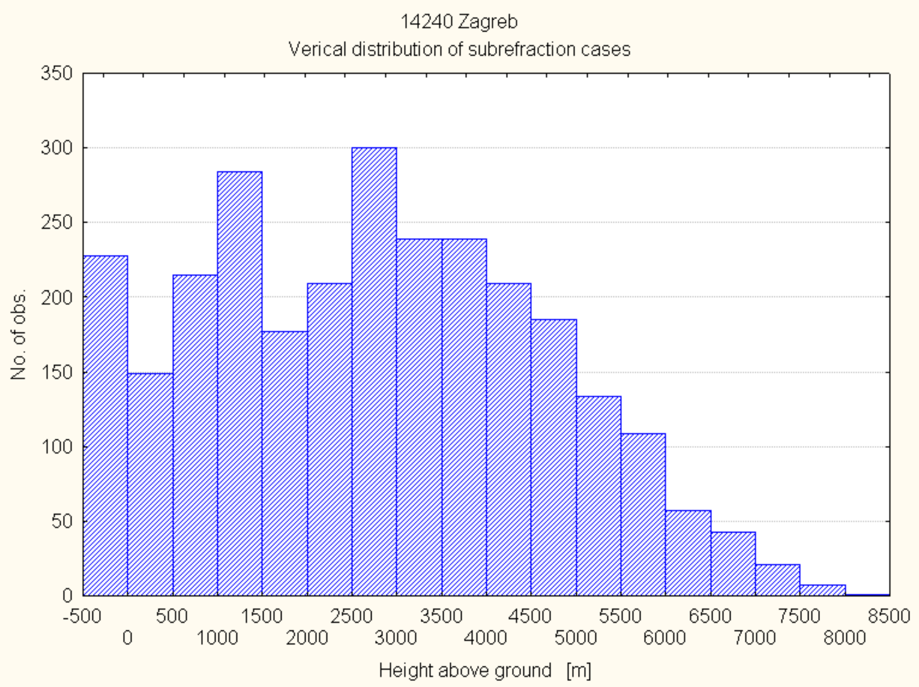
SUPERREFRACTIONS



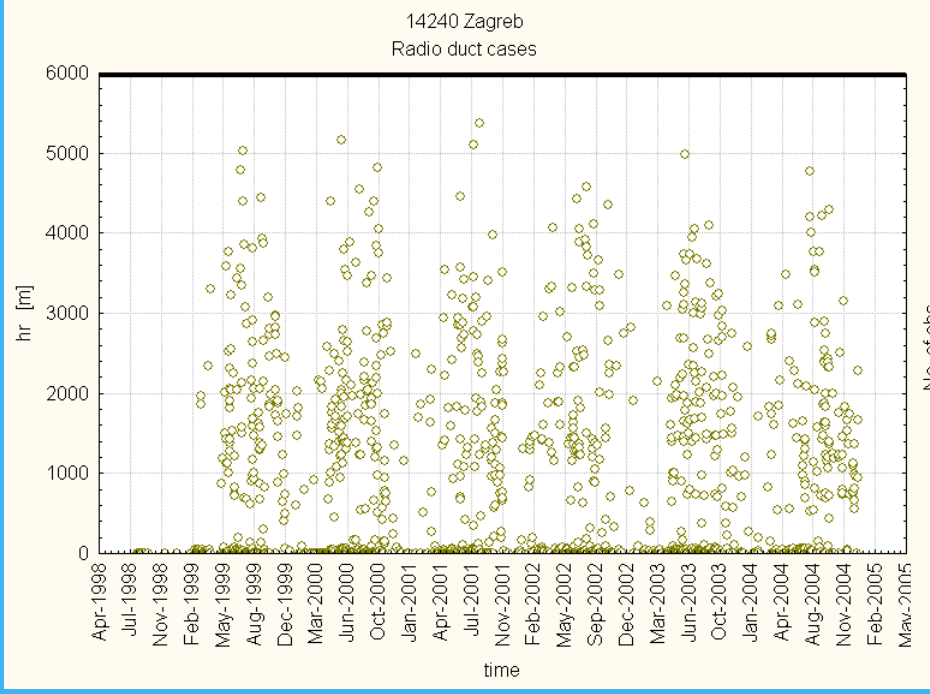


SUBREFRACTIONS





RADIO DUCTS


14240 Zagreb
Radio duct cases
hr [m]
6000
5000
4000
3000
2000
1000
0
Apr-1998
Jul-1998
Nov-1998
Feb-1999
May-1999
Aug-1999
Dec-1999
Mar-2000
Jun-2000
Oct-2000
Jan-2001
Apr-2001
Jul-2001
Nov-2001
Feb-2002
May-2002
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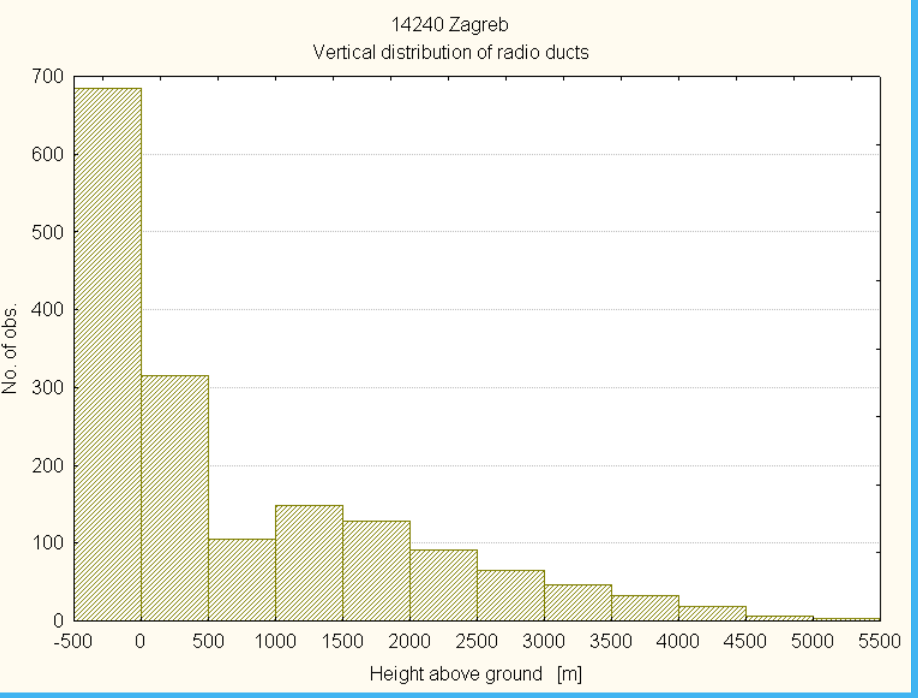
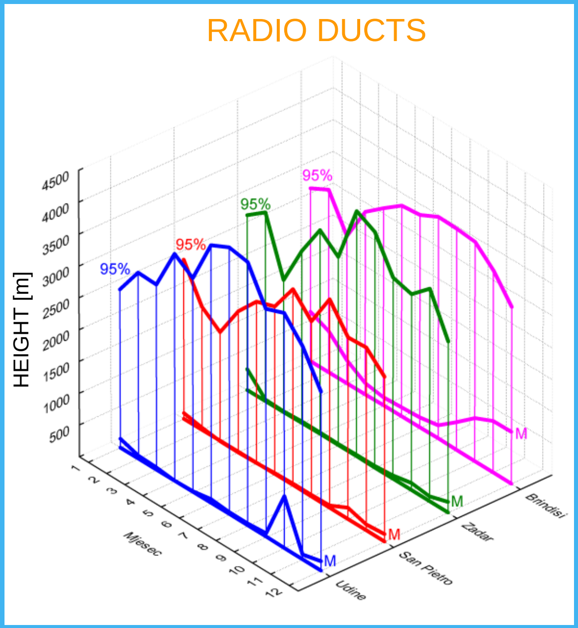
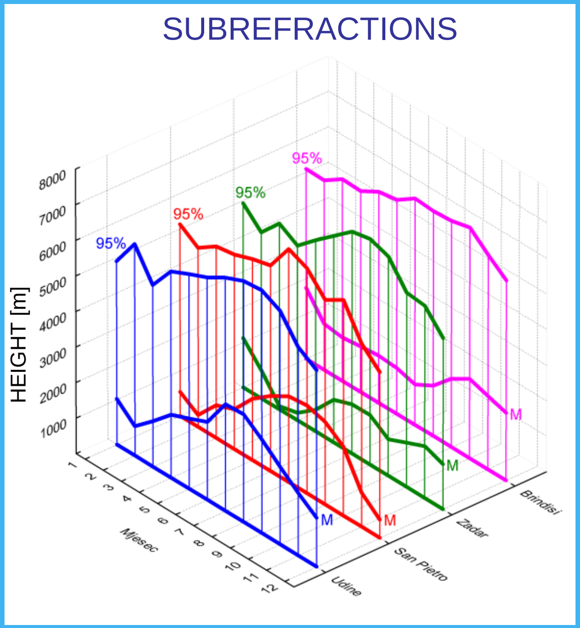
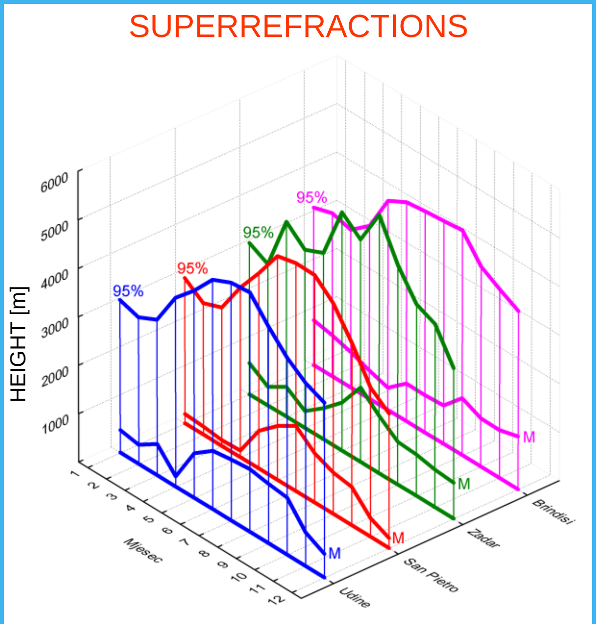
Feb-2005
May-2005
time


14240 Zagreb
Vertical distribution of radio ducts
No. of obs.
700
600
500
400
300
200
100
0
-500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Height above ground [m]

ANNUAL VARIATIONS OF ANAPROPs OVER ADRIATIC

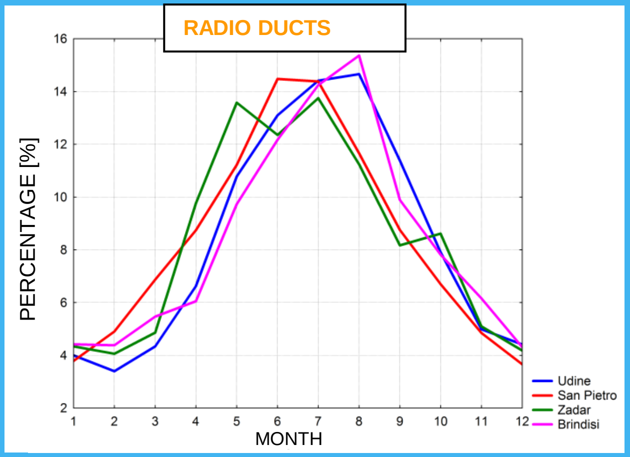


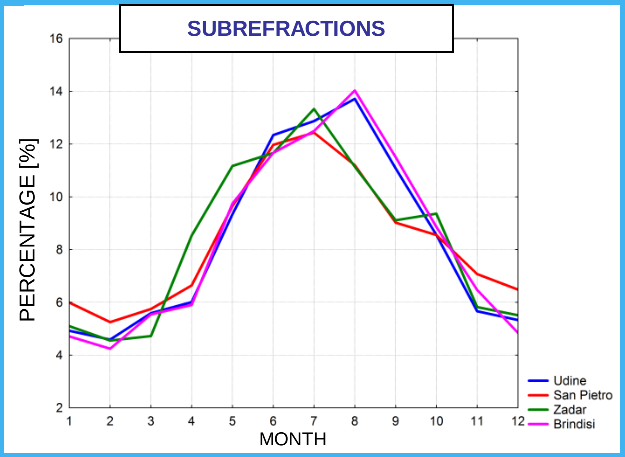


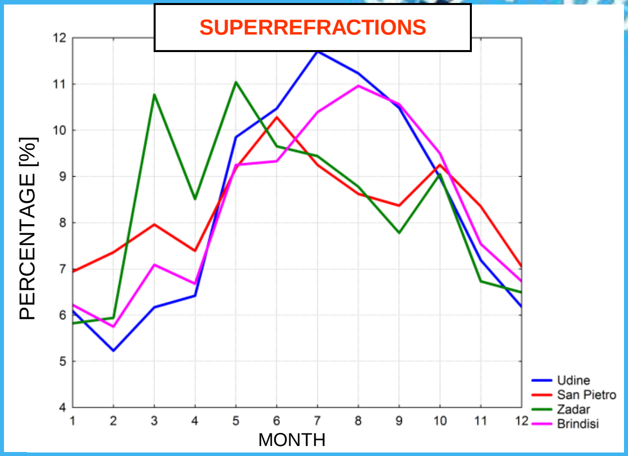


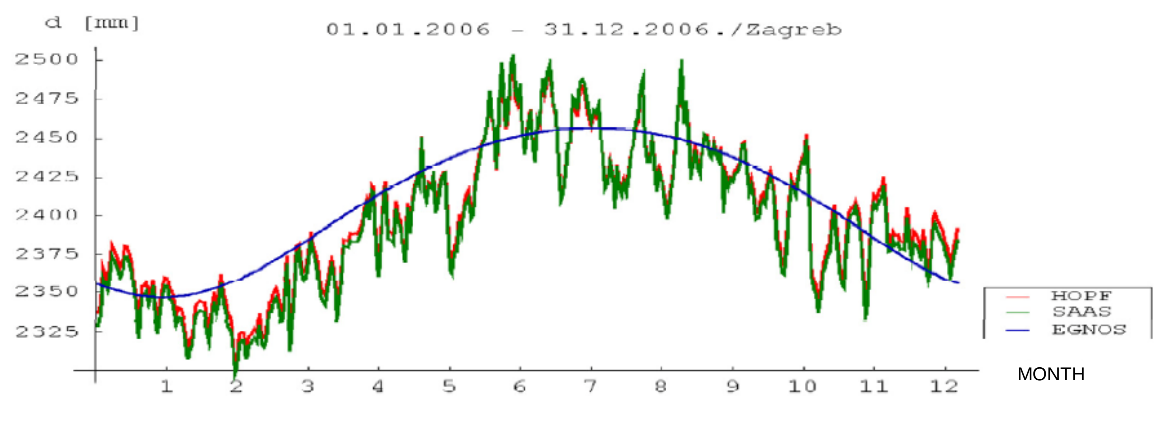
Viher, Telišman Prtenjak, Grisogono (2011)

Annual variation in percentage of the ANAPROPs





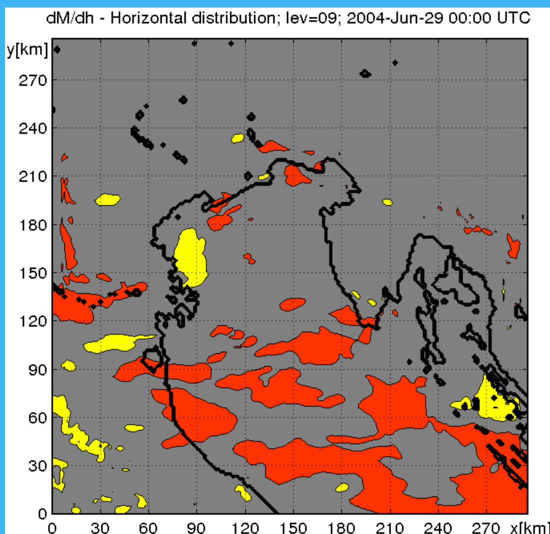


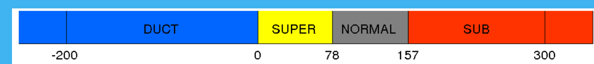


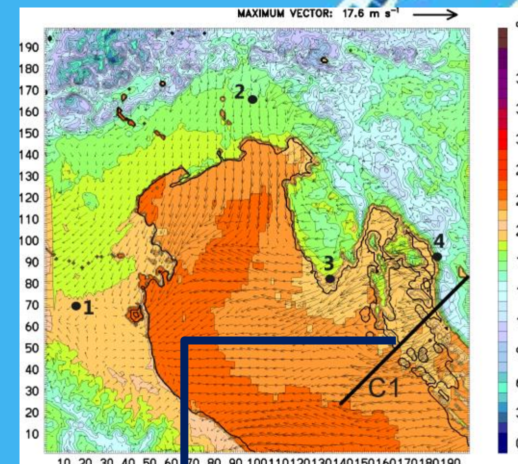
ANNUAL TROPOSPHERIC DELAY, ZAGREB

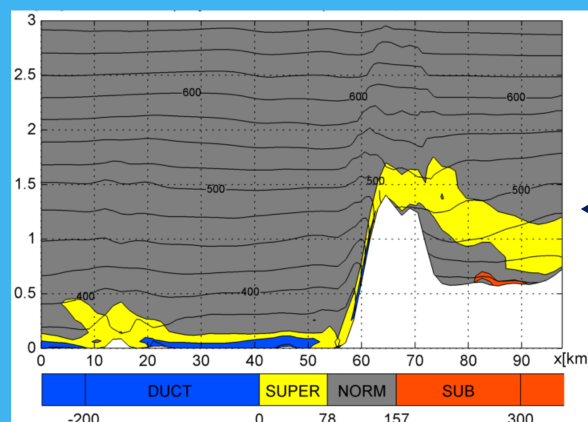
Kos, Botinčan, Markezić, 2009

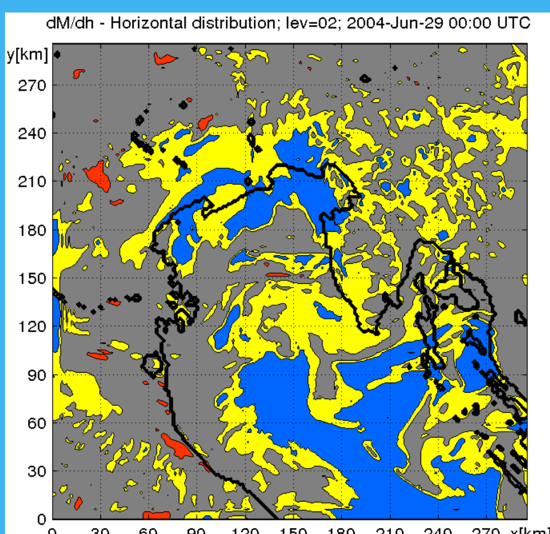
WRF MODEL USED AS DATA SOURCE

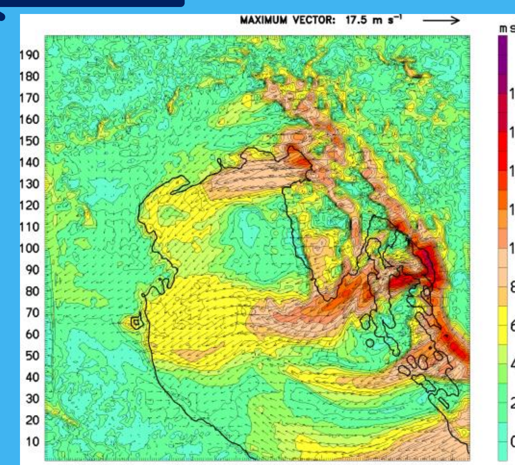








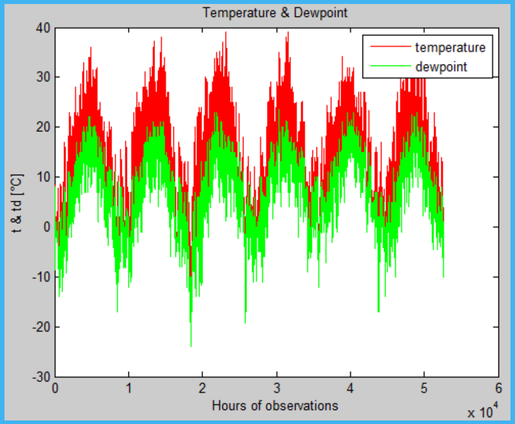


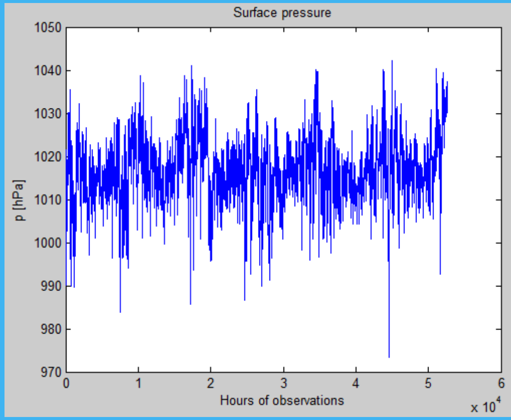


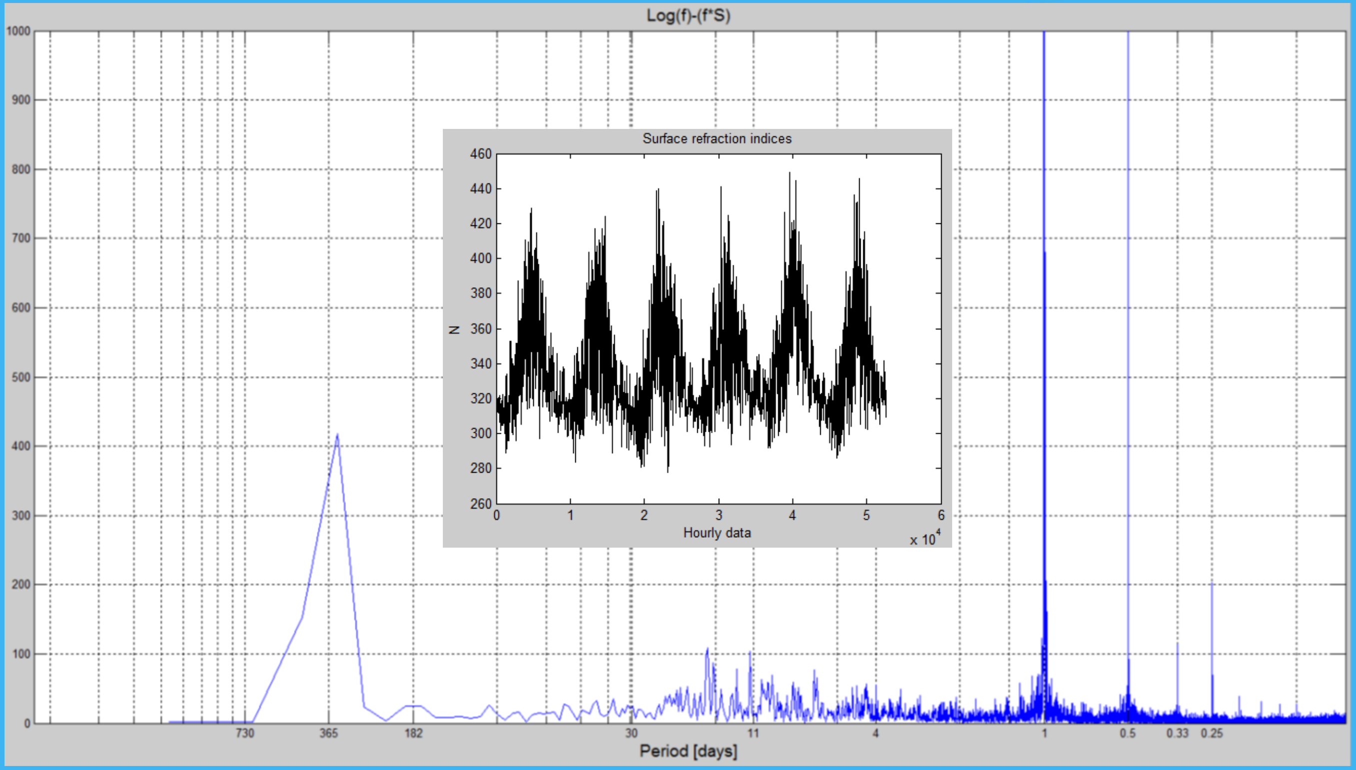
Telišman Prtenjak M., Horvat I., Tomažić I., Kvakić M., Grisogono B., Viher M. (2013, 2015)

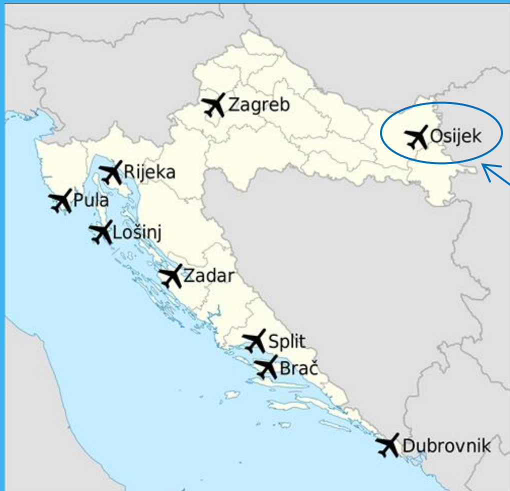
Pleso (Zagreb)

WMO# 14241



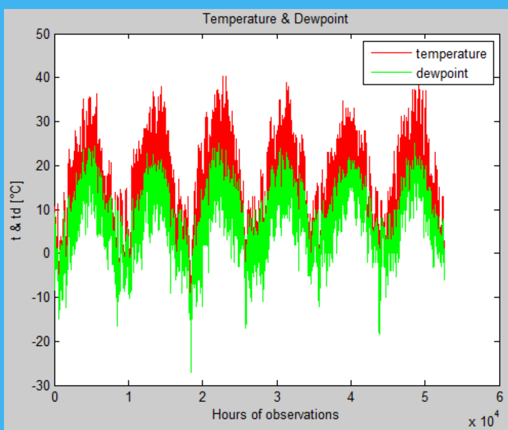


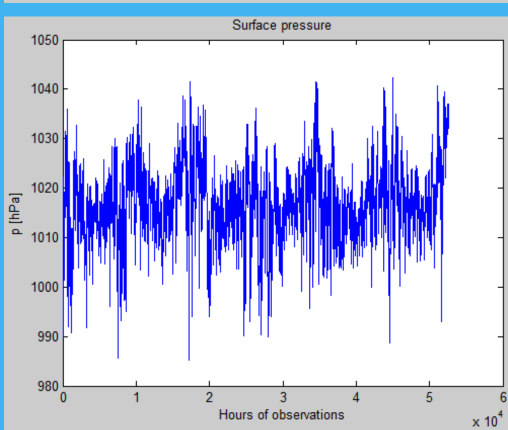


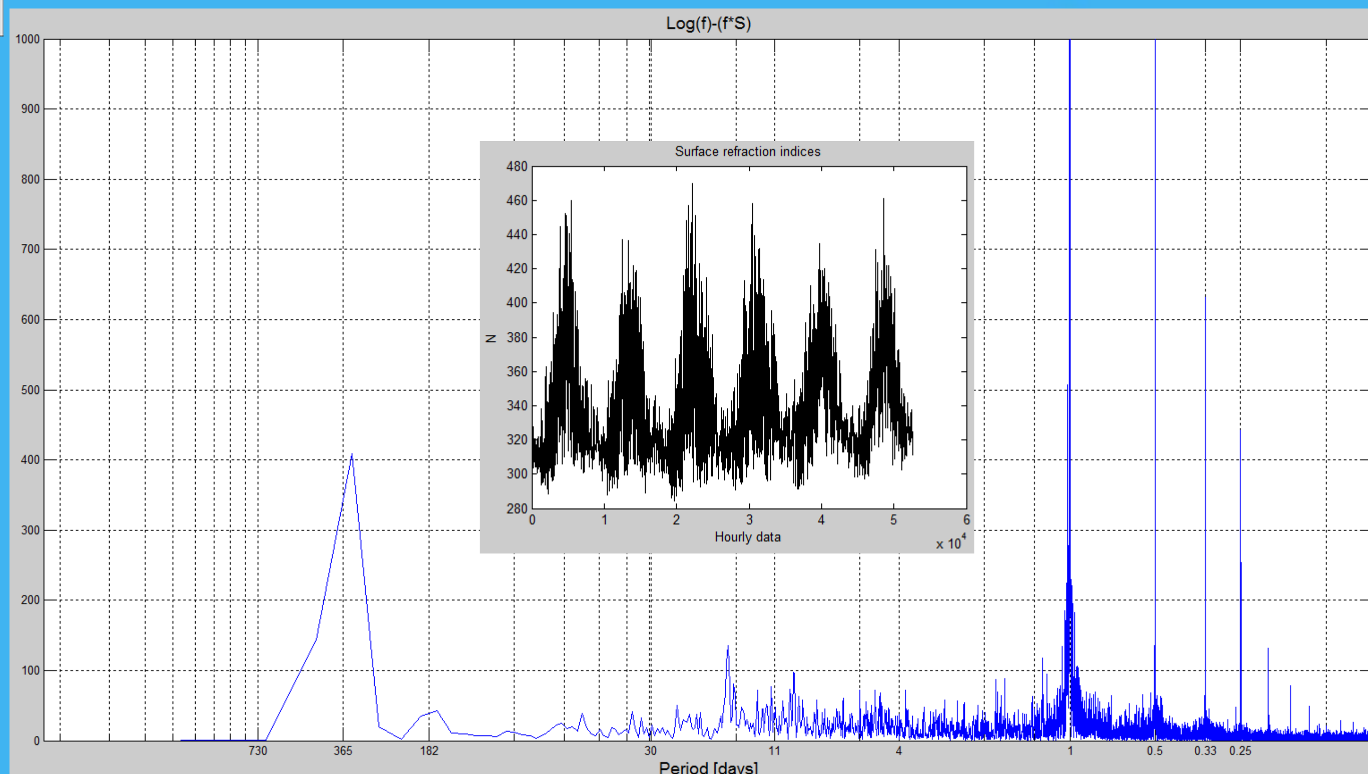


Klisa (Osijek)

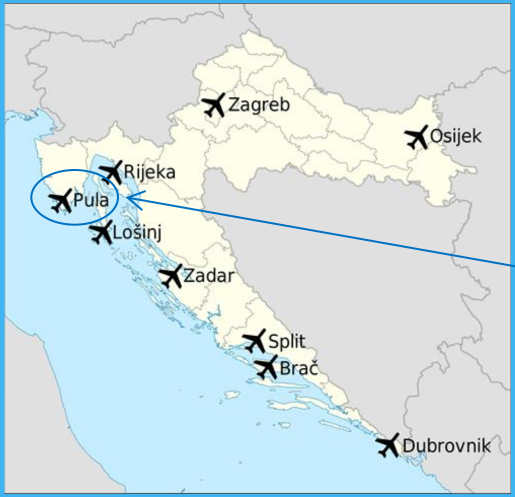
WMO# 14284



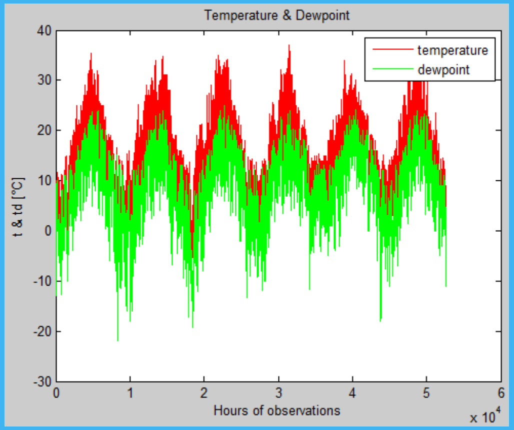


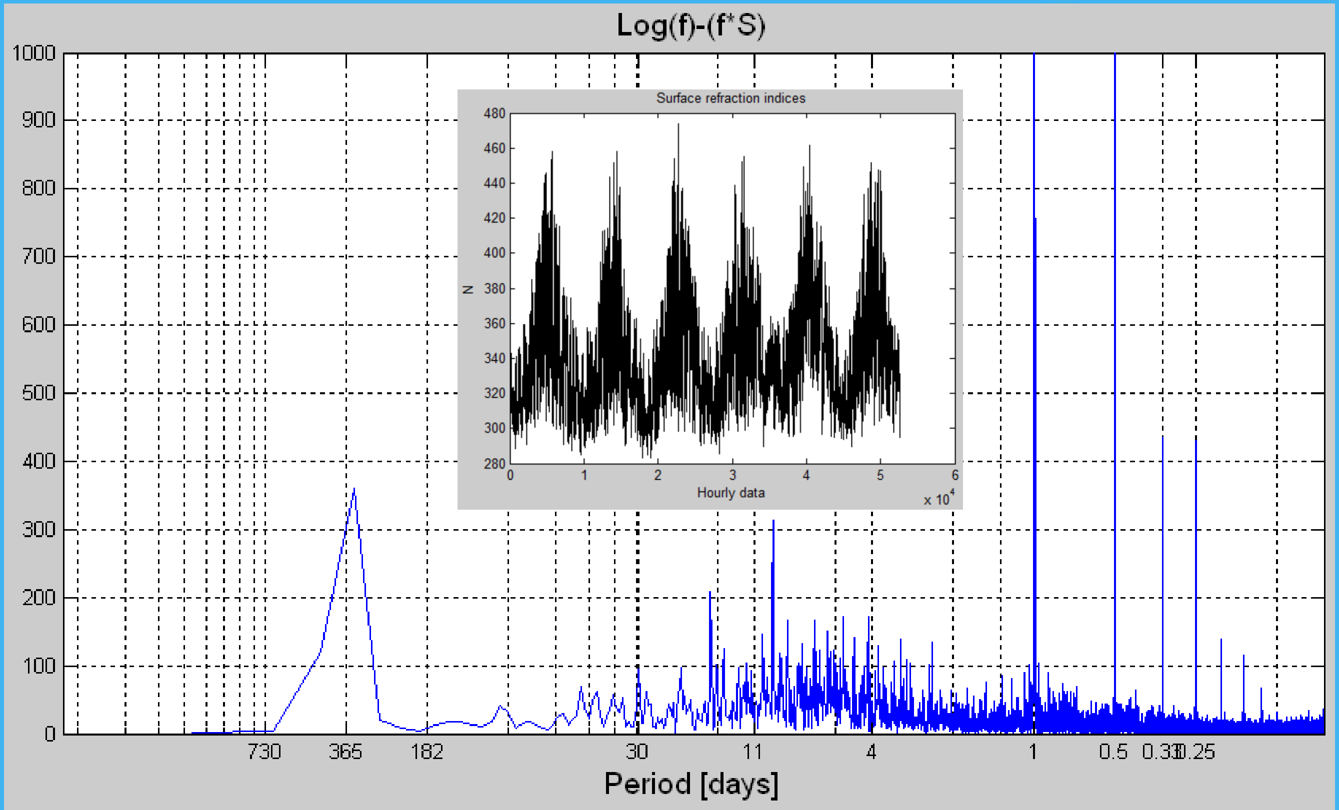


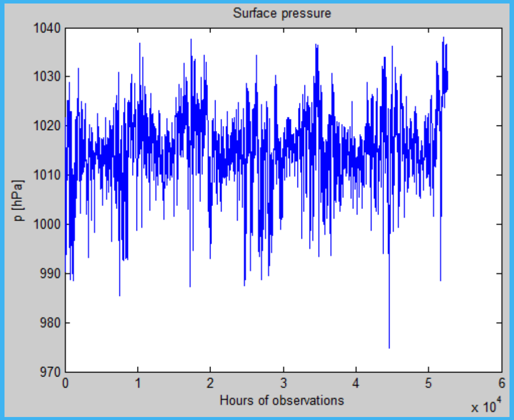
Pula



WMO# 14307

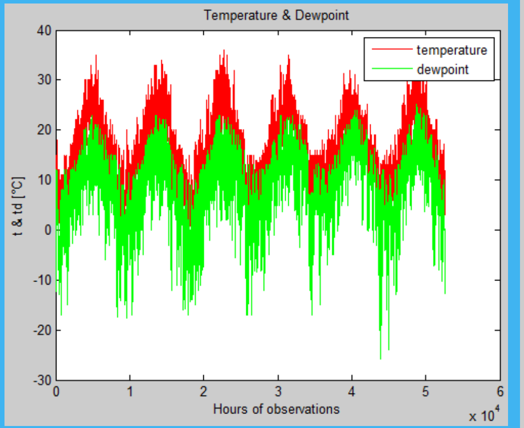


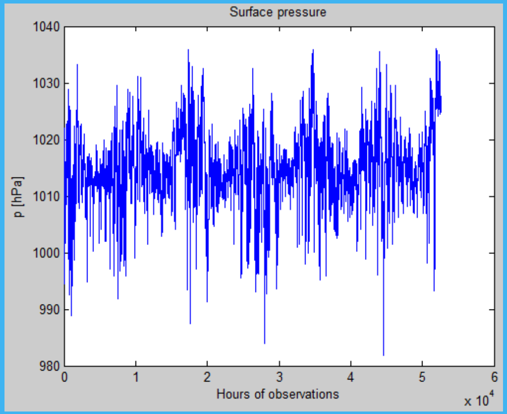


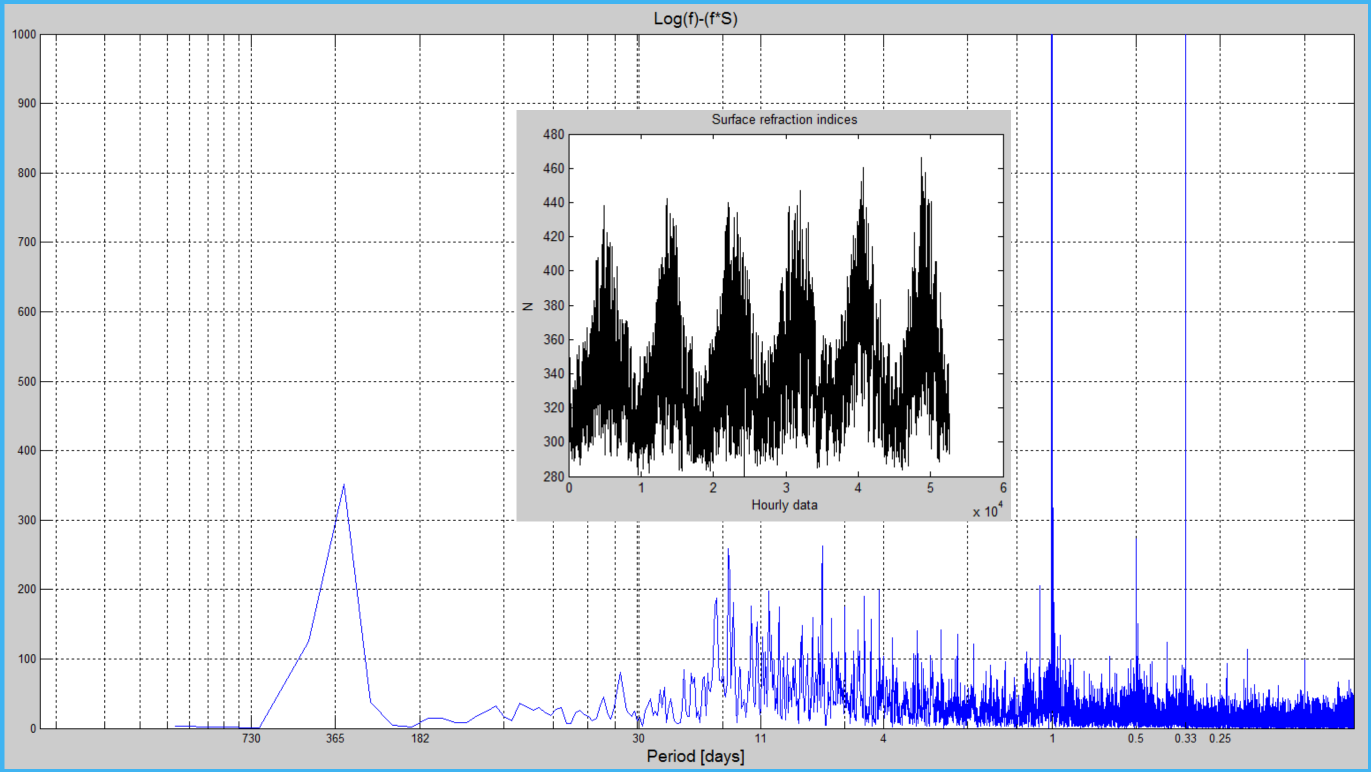


Ćilipi - Dubrovnik

WMO# 14474







CONCLUSIONS

- INFLUENCE OF “THE LAST NANOSECOND” ON PRECISION NAVIGATION SYSTEMS
- REGULAR METEOROLOGICAL MEASUREMENTS ARE APPLIABLE FOR REFRACTION INDEX DETERMINATION
- ATMOSPHERIC MODELS COULD PROVIDE PREDICTION OF THE ANAPROPS