Suggestions for Now casting of the optical environment

Ove Gustafsson, FOI

Ove.gustafsson@foi.se

Abstract

The use of optical och electro-optical system within society both the military part and the civil society are expanding continuously. The environmental influence on the optical signals are evinced as reduction of the signal and turbulence disturbance, with data loss, enlarged nominal optical hazard distances (NOHD) and disturbed images as consequences. The signal reduction due to absorption and scattering for active and passive system can be deduced out of weather parameters as humidity, temperature, wind, visual range etc. The important of the influence on atmospheric attenuation and optical turbulence on laser propagation and images as function of weather parameters as for instance the structure parameter of refractive index will be discussed. With the use of mesoscale numerical weather prediction methods there are also possibilities to deduce for instance the structure parameter for refractive index (C_n^2) as function of heights.

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Introduction

Lidar measurement

Nominal Ocular Hazard Distance, NOHD

Atmospheric influence on NOHD $\rightarrow$ OHD

Examples of effects due to turbulence

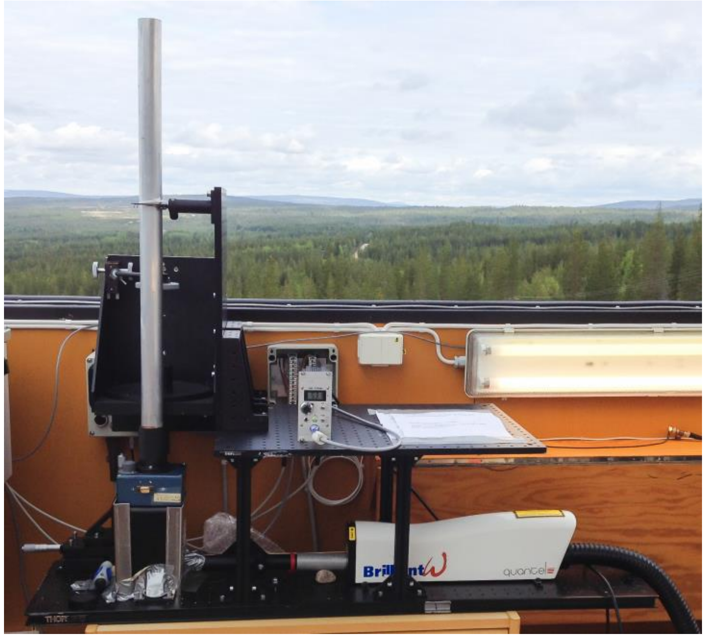
Turbulence influence on laser safety range

Structurfunction of refraction, C_n^2

Cloud characterization

Discussion and conclusions

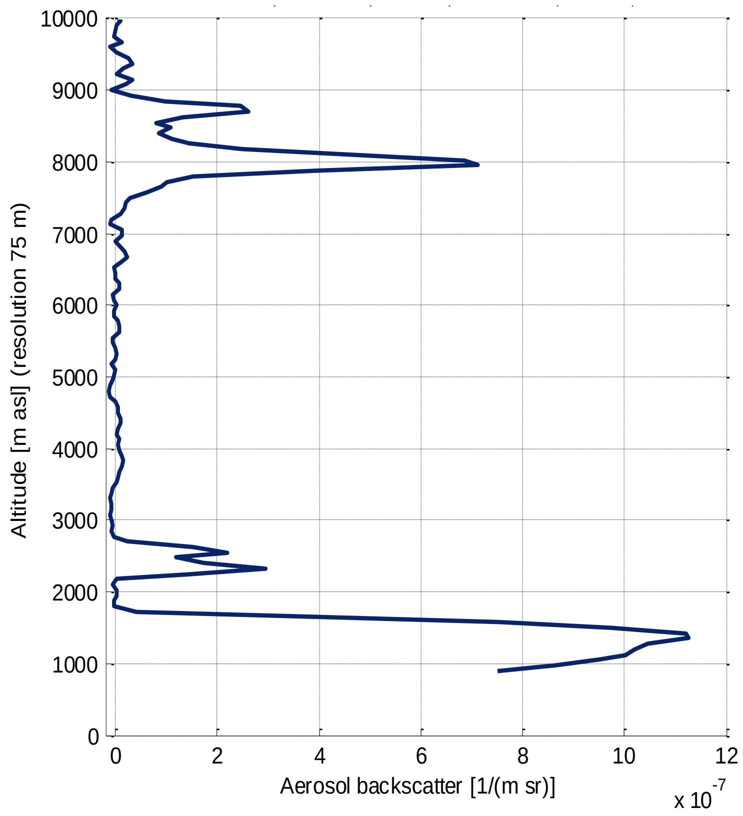
Lidar instrument

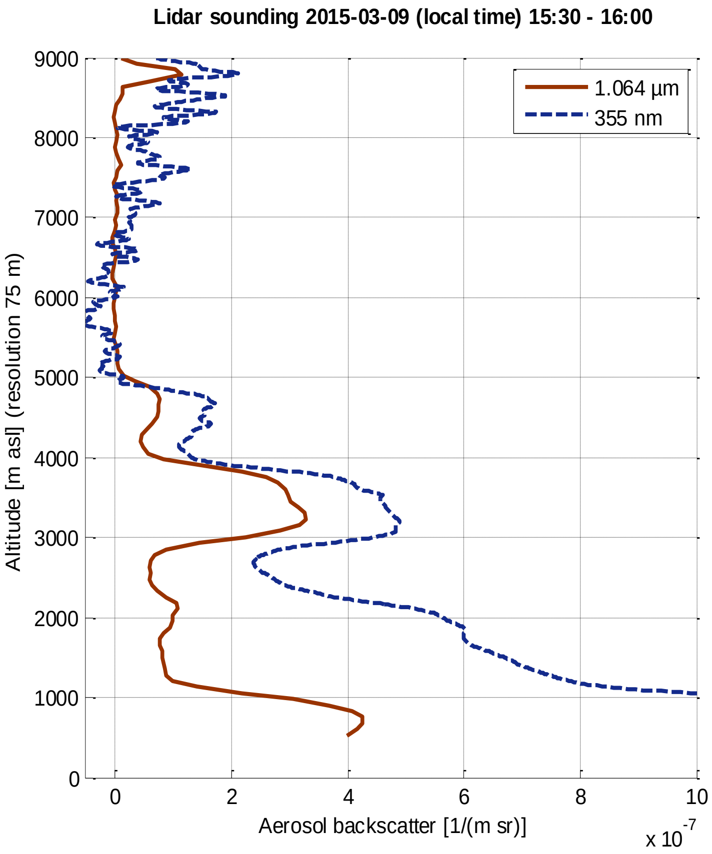


Receiver:
APD module diam. 1 mm
(Licel S11518-10)
focal length of 615 mm
FOV of 1.6 mrad
filter FWHM 12 nm
Licel TR40:
sample rate 40 MHz

Laser:
230 mJ,
1064 nm,
pulse length 5 ns,
PRF 10 Hz,
beam divergence 0.5 mrad
beam diameter 3 mm

IR-lidar measurement and comparison

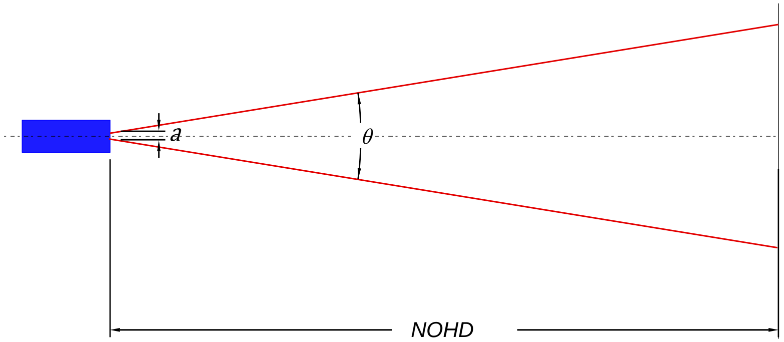




Nominal Ocular Hazard Distance, NOHD

$$E = \frac{4P_o}{\pi(a + \theta \cdot r)^2}$$

$$NOHD = \frac{1}{\theta}\left(\sqrt{\frac{4P_o}{\pi \cdot MPE}} - a\right)$$



Gustafsson etal. “Visual appearance of wind turbine tower at long range measured using imaging system” SPIE88921Y, 2013

	Laser Energy [J]	Divergence [mrad]	*MPE* [J/m²]	NOHD [km]
Designator Laser, single pulse	0,180	0,08	0,050	26,5
Designator Laser, pulse train	0,180	0,08	0,013	51,6

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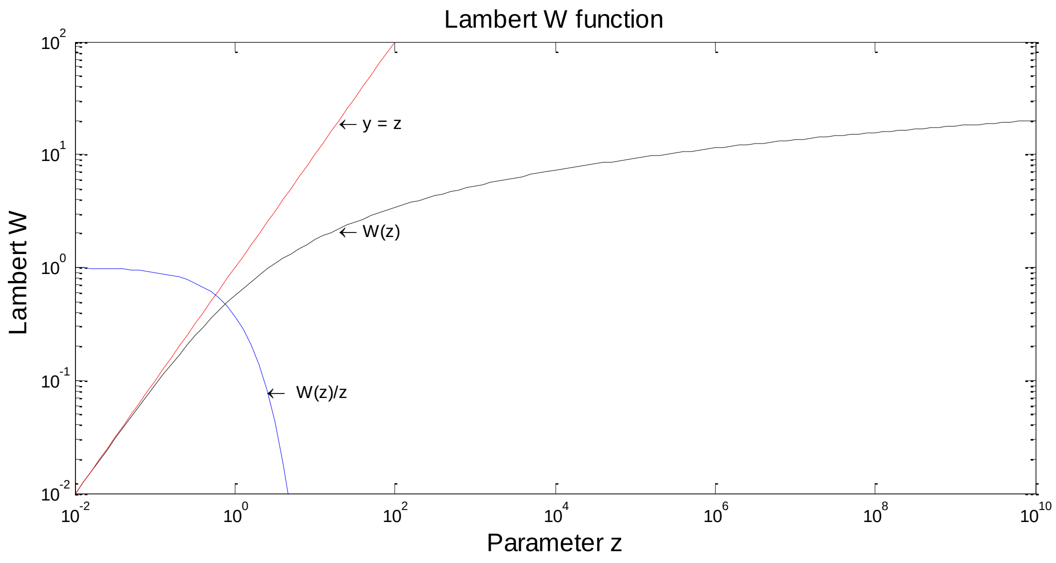
Influence of atmospheric attenuation on laser safety range

$$E = \frac{4P_o \cdot \boldsymbol{e}^{-\int \mu \cdot \boldsymbol{dx}}}{\pi(a+\theta\cdot r)^2} = \frac{4P_o \cdot \boldsymbol{e}^{-\mu\cdot r}}{\pi(a+\theta\cdot r)^2}$$

Lambert W function

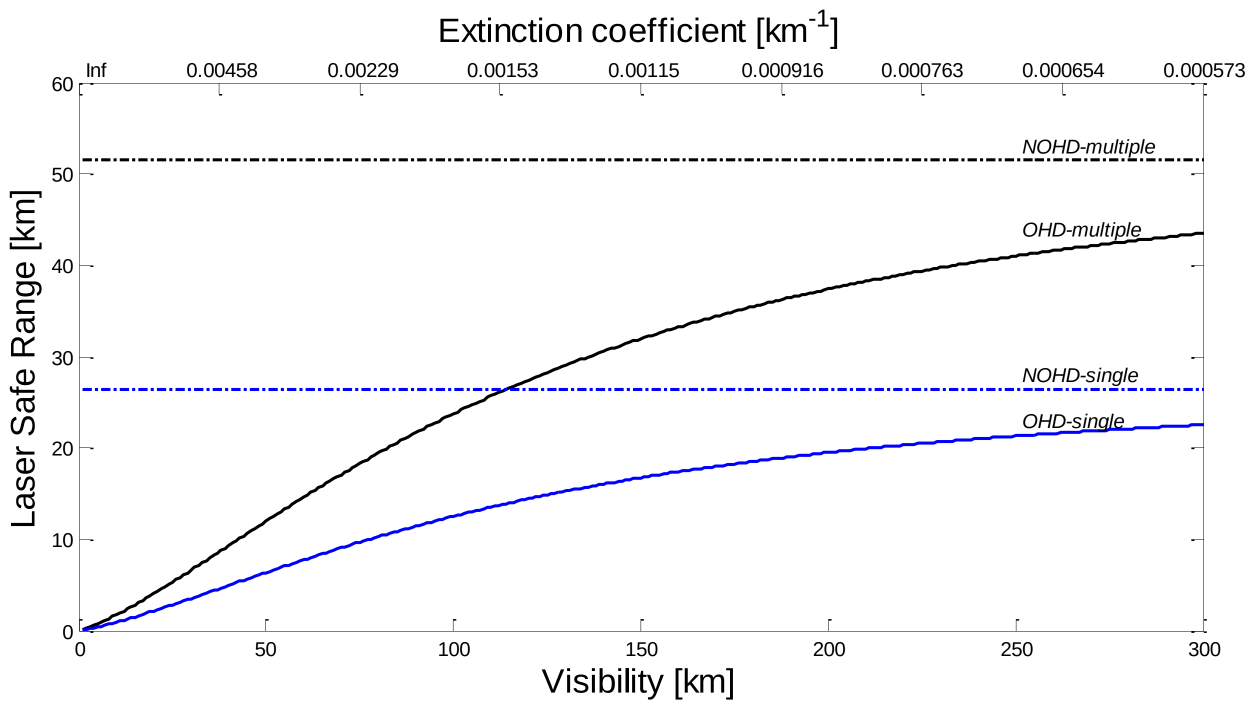
$$\omega e^{\omega} = z \qquad W(z)e^{W(z)} = z$$



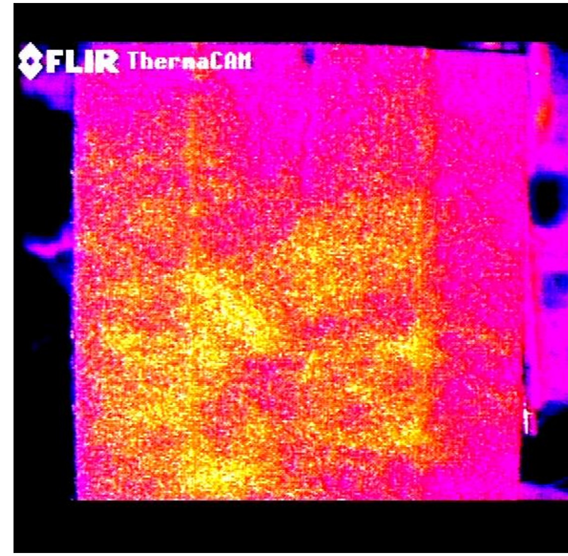
Steinvall, 2009
Coreless, et al 1996
Valluri et. al 2000
Chapeua-Blondeau et. al, 2002

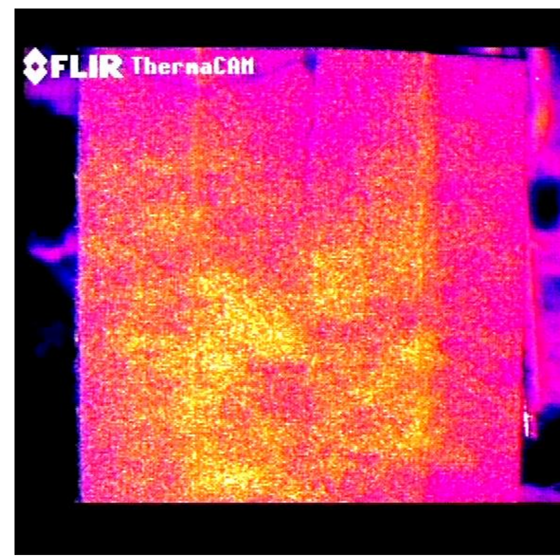
Atmospheric influence on laser safety range, NOHD →OHD

$$OHD_{\mu} = \frac{2W\left(\frac{\mu(a+\theta r)\cdot \exp\left(\frac{\mu(a+\theta r)}{2\theta}\right)}{2\theta}\right)}{\mu} - \frac{a}{\theta}$$



Exemple of laser spots





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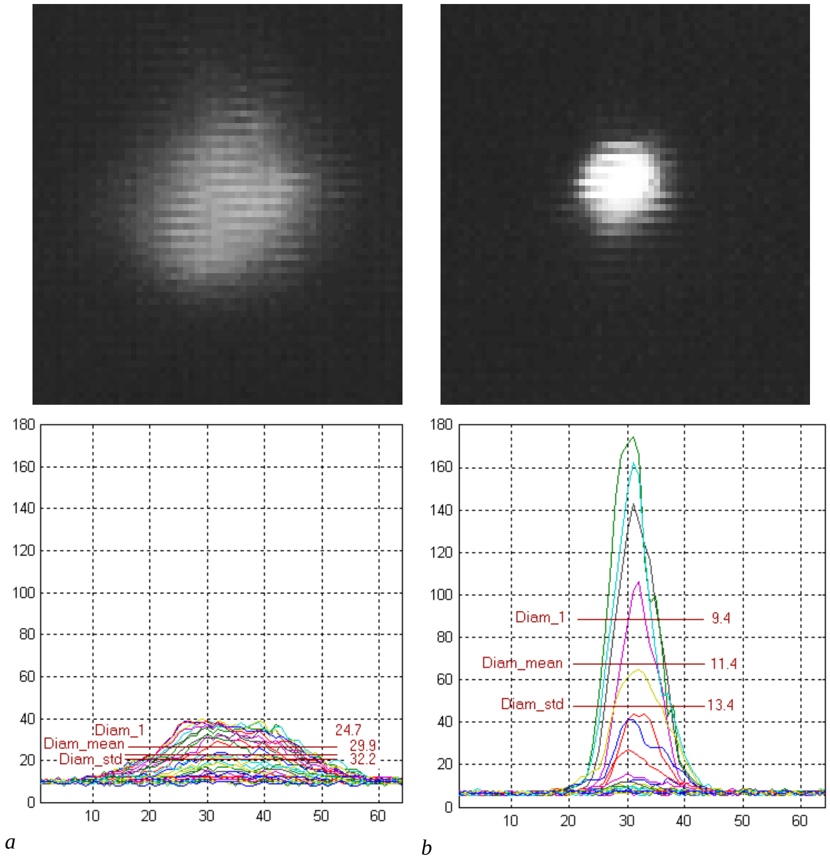
Turbulence, effects on image

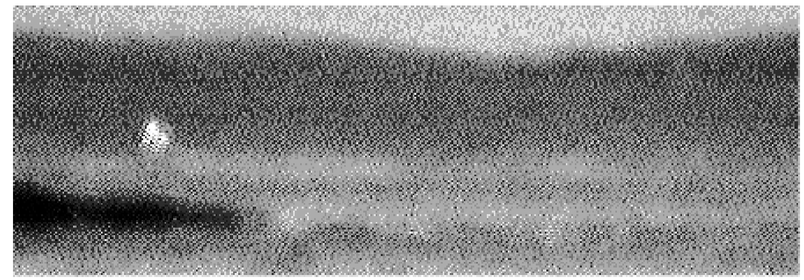
high

low



Intensity distributions in two
64 x 64 pixel image selections

high turbulence



low turbulence

Från Baltic ´99 mätningarna
FOA-R--00-0171-615--SE

Visual images,
range 18.6 km

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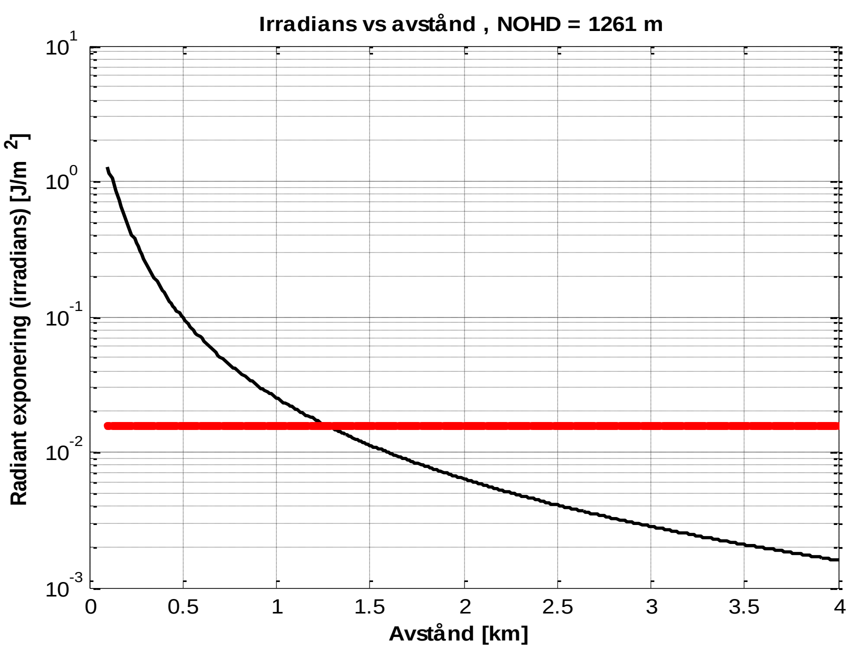
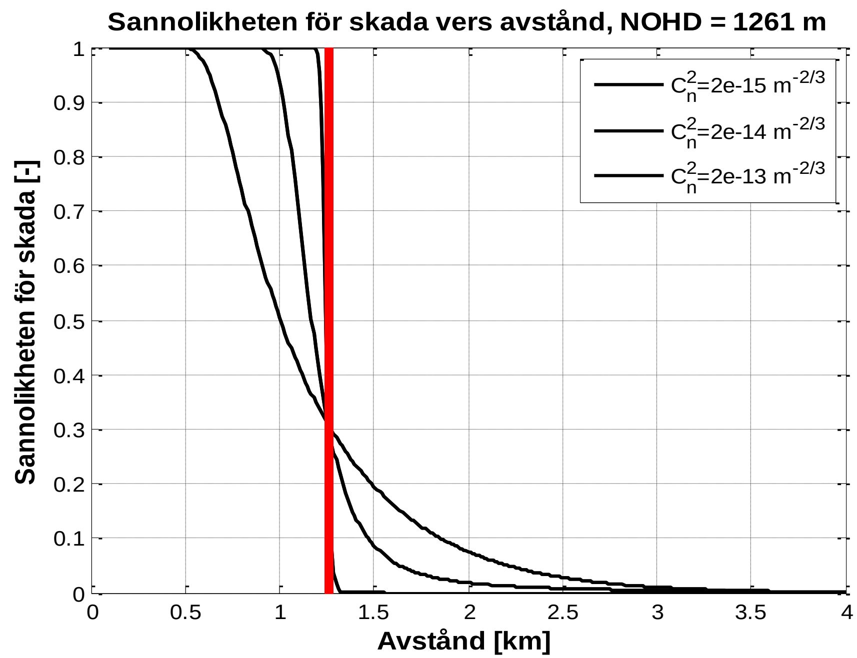
Turbulence influence on laser safety range, horizontal path





Nd:YAG laser
Laser Energy 5 mJ
Puls frequence 20 Hz,
Laser divergence 0,5 mrad

Gustafsson etal. “Lidar measurement as support to the ocular hazard distance calculation using atmospheric attenuation ” SPIE, Toulouse, 2015.

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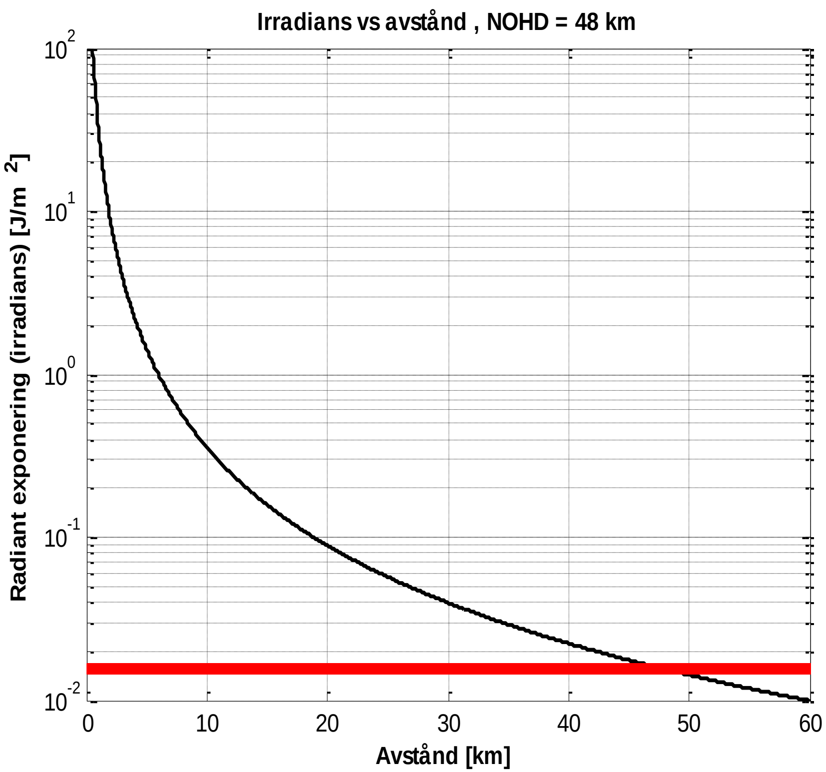
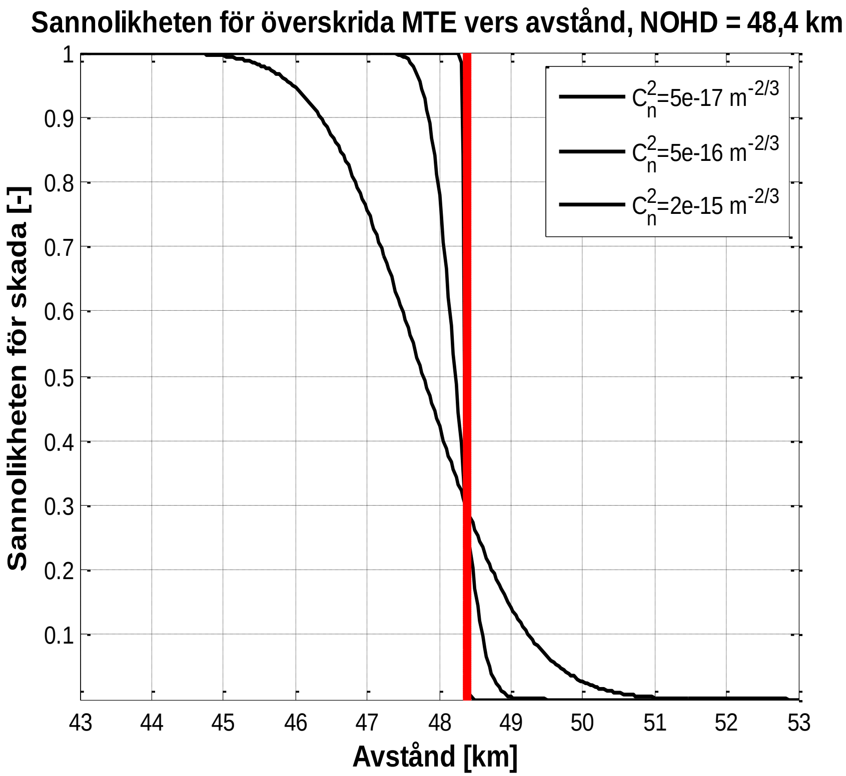
Turbulence influence on laser safety range, slant path





Nd:YAG laser
laser Energy 0.180 J
puls frequence 11.5 Hz,
laser divergence 0,08 mrad

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Structurfunction of refraction, C_n^2, is influenced by weather and environment

Sun
- time on the day
- season

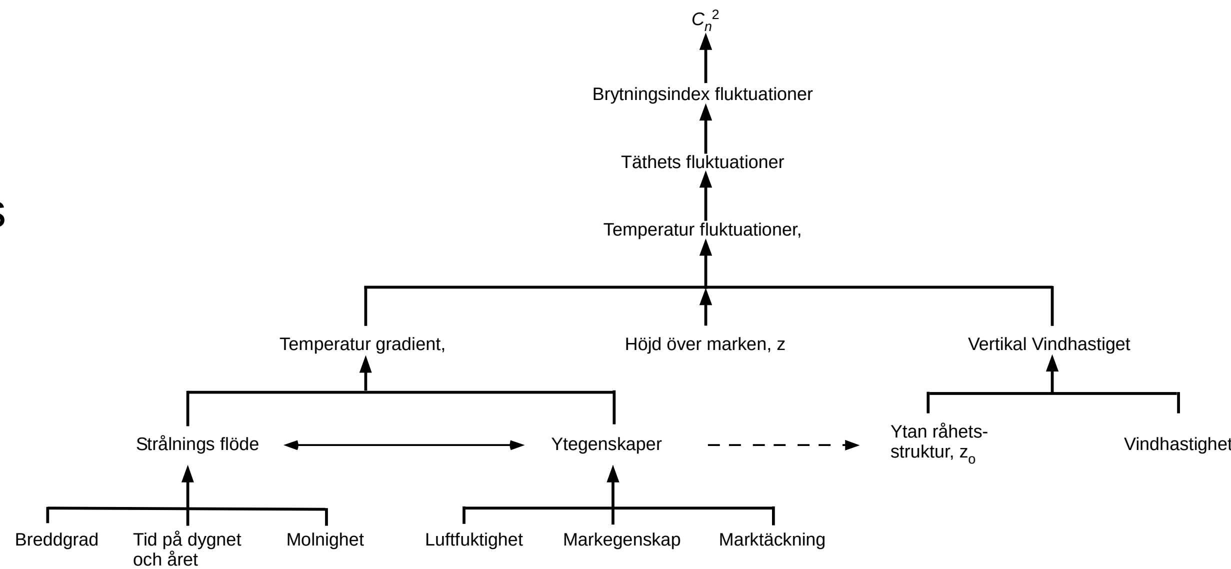
Cloud cover

Meteorological parameters
- temperature
- humidity
- wind
- pressure

Latitude

Altitude
- convection
- wind shear

Ground characteristics
- absorption och reflection
- vegetation
- buildings



Strukturfunktionen, C_n^2

Strukturfunktionen, C_n^2, mått på statistiska medelvärdet

$$C_n^2(r_{12}) = \langle (n_1 - n_2)^2 \rangle / r_{12}^{2/3}$$

Kolmogorov spektrum och gäller for skalära vågtalet, κ, inom området mellan inre och yttre skallängden.

$$\Phi_n(\kappa) = 0{,}00330 C_n^2 \kappa^{11/3}$$

Modeller av C_n^2

Tatarskiimodell

$$C_n^2(z) = C_{no}^2 z^{-x}$$

där

x = 4/3, dagtid
x = 2/3, natt

Fried's och Brookner's modeller

$$C_n^2(z) = C_{no}^2 z^{-b} e^{-z/z_o}$$

Fried's modell,
b = 1/3, z_o = 3200 m samt $C_{no}^2 = 4{,}22 \cdot 10^{-14}$ m$^{-1/3}$

Brookner's modell,
z_o = 320 m samt $C_{no}^2 = 3{,}6 \cdot 10^{-13}$ m$^{-1/3}$
b = 2/3, vid soluppgång och solnedgång
b = 5/6, vid sol och dag klart väder
b = 1, nattetid

forts. Modeller av C_n^2

Kaimal/Walters-Kunkels modell

$$\frac{C_n^2(z)}{C_{no}^2(z_0)} = \begin{cases} (z/z_0)^{-\frac{4}{3}} & z, z_0 \le 0{,}7z_i \\ (0{,}5z_i/z_0)^{-\frac{4}{3}} & 0{,}5z_i \le z \le 0{,}7z_i \\ 2{,}9(0{,}5z_i/z_0)^{-\frac{4}{3}}(z/z_i)^3 & 0{,}7z_i \le z \le z_i \end{cases}$$

Kukharets-Tsvangs modell (K-T)

$$\frac{C_n^2(z)}{C_{no}^2(z_0)} = \frac{0{,}046(z/z_i)^{-\frac{4}{3}} + 0{,}6 \cdot exp\{-12[(z/z_i) - 1{,}1]^2\}}{0{,}046(z_o/z_i)^{-\frac{4}{3}}}$$

forts. Modeller av $C_n{}^2$

<u>Similaritetsmodeller</u>

$$C_n^2 = \left|\frac{\partial n}{\partial T}\right|^2 C_T^2 \qquad \frac{\partial n}{\partial T} = 78 \cdot 10^{-6} \frac{P}{T^2}$$

$$Ri = \frac{(g/\bar{T})(\partial\bar{\Theta}/\partial z)}{(\partial\bar{U}/\partial z)^2}$$

$$C_T^2 = z^{4/3}(\partial\bar{\Theta}/\partial z)^2 f_3(Ri)$$

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forts. empiriska modeller av $C_n{}^2$

Hufnagel modellen

$$C_n^2(z) = 8{,}2 \cdot 10^{-56} U^2 z^{10} e^{-z/z_{o1}} + 2{,}7 \cdot 10^{-16} e^{-z/z_{o2}}$$

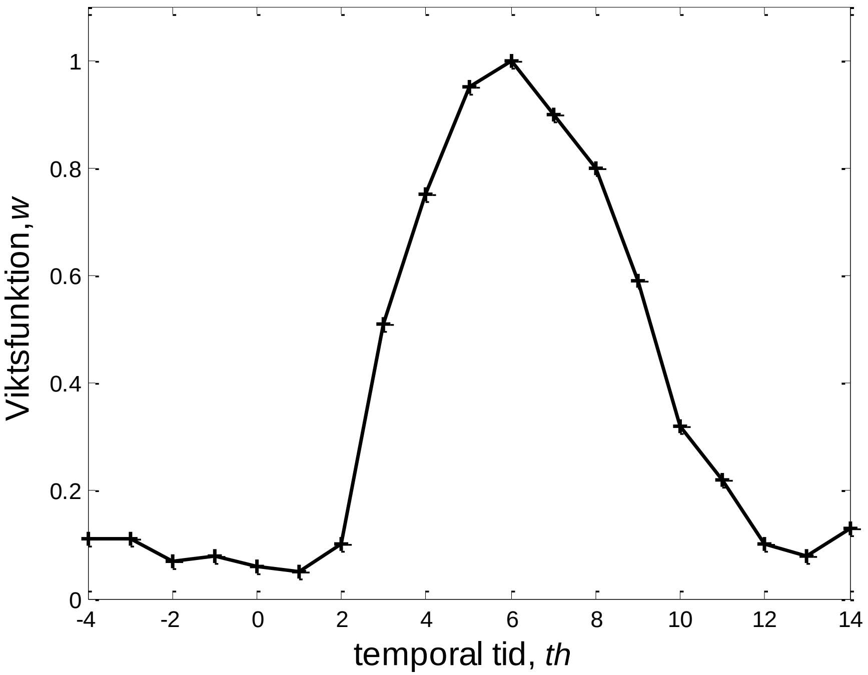
Hufnagel-Valley modellen

$$C_n^2(z) = 8{,}2 \cdot 10^{-56} U^2 z^{10} e^{-z/z_{o1}} + 2{,}7 \cdot 10^{-16} e^{-z/z_{o2}} + A e^{-z/z_{o3}}$$

forts. parametermodeller av C_n^2

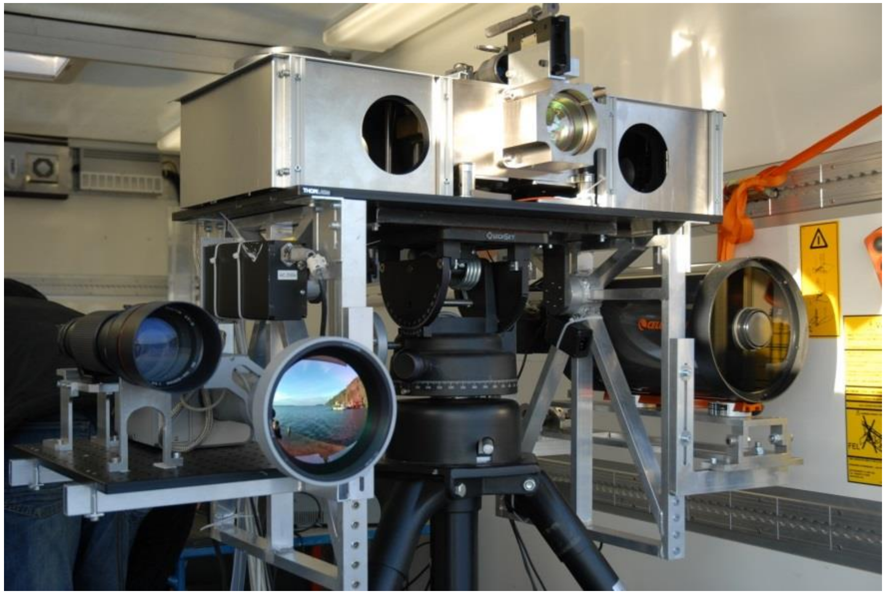
Sadot och Kopeika

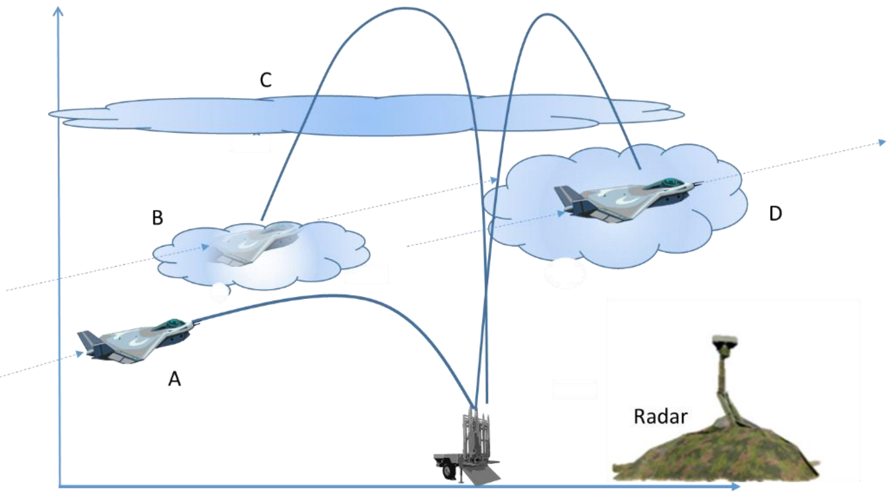
$$C_n^2 = 3{,}8 \cdot 10^{-14} w + 2 \cdot 10^{-15} T + 2{,}8 \cdot 10^{-15} (RH) + 2{,}9 \cdot 10^{-17} (RH)^2$$
$$-1{,}1 \cdot 10^{-19} (RH)^3 - 2{,}5 \cdot 10^{-15} (WS) - 1{,}2 \cdot 10^{-15} (WS)^2 - 8{,}5 \cdot 10^{-17} (WS)^3$$
$$-5{,}3 \cdot 10^{-13}$$



Moln karaktärisering

Karaktärisering
- moln fördelning
- molnbas
- molntjocklek
- molntäthet
- optisk täthet
- regn





Lidar med 1,5 µm laser kopplat till IR
ev. i kombination med avståndsmätare.
Studien “Lidaranvändning för EO system”

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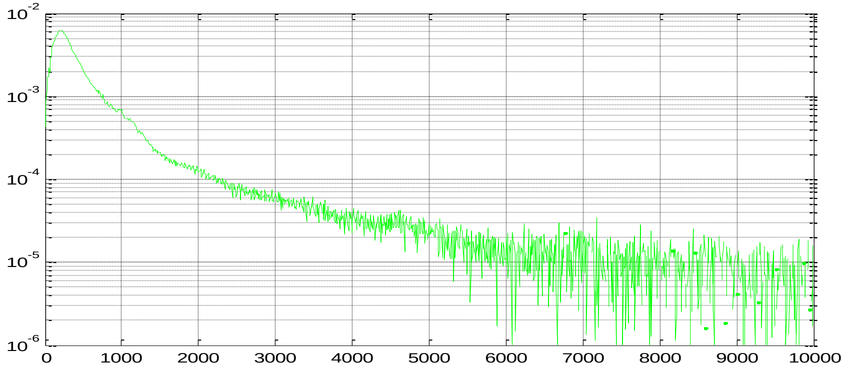
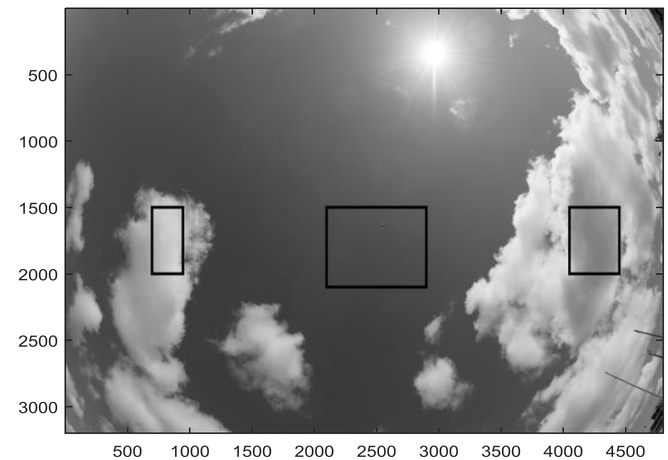
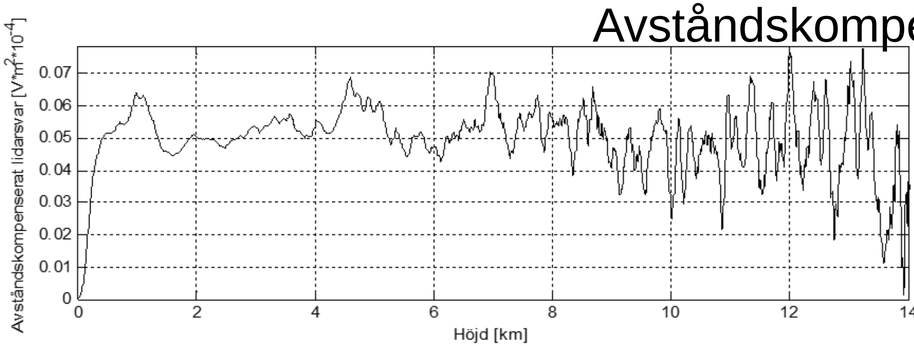
Exempel på lidarmätningar

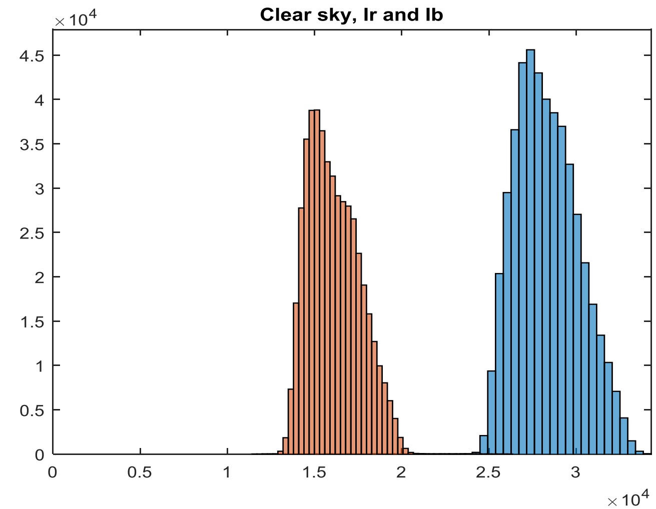


2000 vågformer
< 3 min
10 km

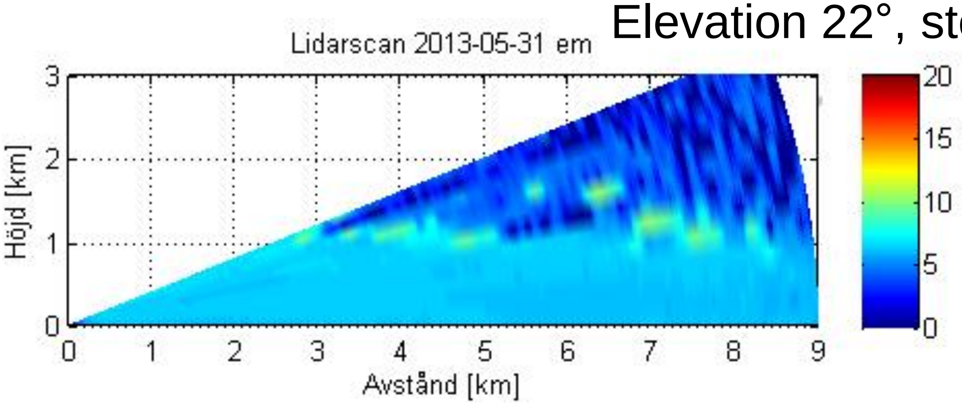


Avståndskompenserat





Elevation 22°, steg 2°



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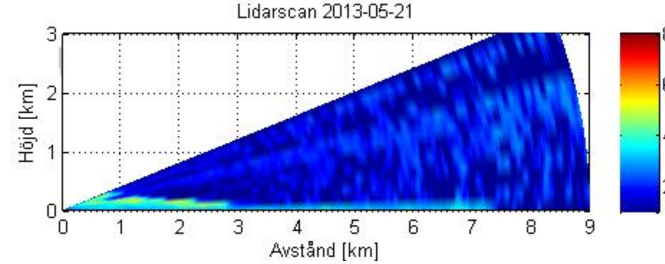
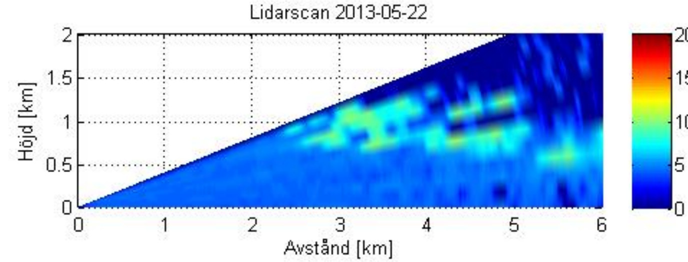
Other examples

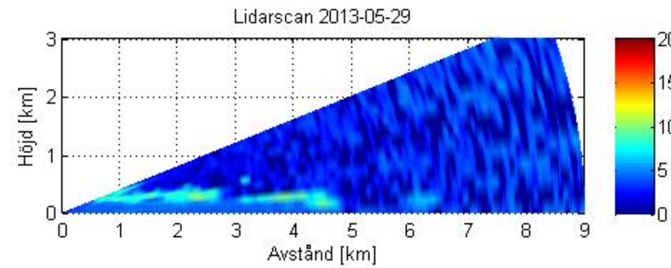
Cloudy day (stratus) with ligh drizzle,
T = +14° C, RH = 60 %, Vis. about 45 – 50 km
Haze close to ground



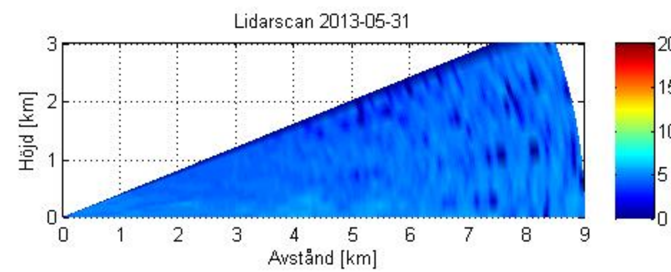
Cloudy day (Cumulus) T = +14° C,
RH = 60 %, Vis. 45 – 50 km.



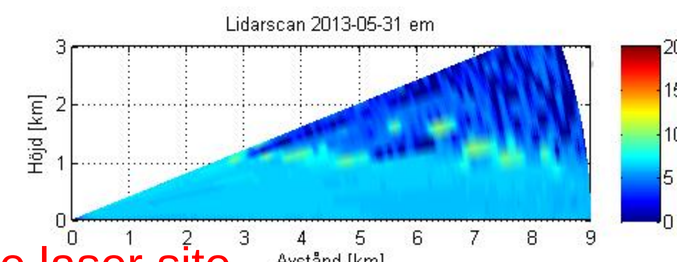
Cloudy day (stratus) with ligh drizzle,
T= 13° C, RH = 74 %, Vis. about 20 km



Clear, sun no clouds.
T= 17° C, RH = 55 %, Vis. 40 – 50 km



Clouds 2/8 cumulus.
T= 20° C, RH = 50 %,
Visibiility 25 – 40 km.



Visibility from pointmeter at the laser site

Diskussion

- 3D beskrivning av atmosfärsturbulens, C_n^2 sfa höjden, med numeriska modeller, ex SAF-WRF (Masciadri et al. 1999)
- Mängden aerosol sfa höjd med NWP + CTM (Kahnert 2008)
- Molntäckning, molnbas och tjocklek med NWP

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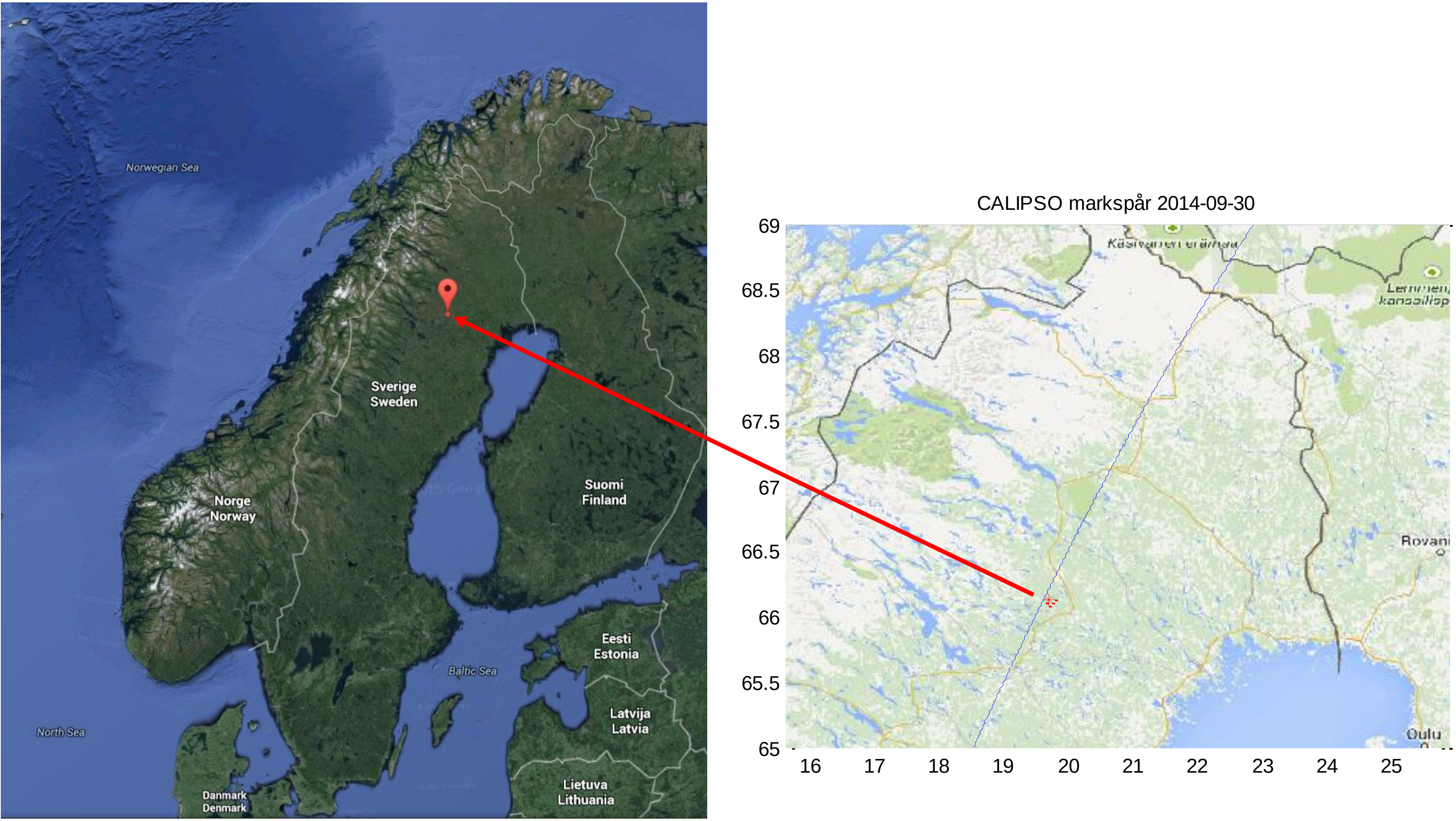
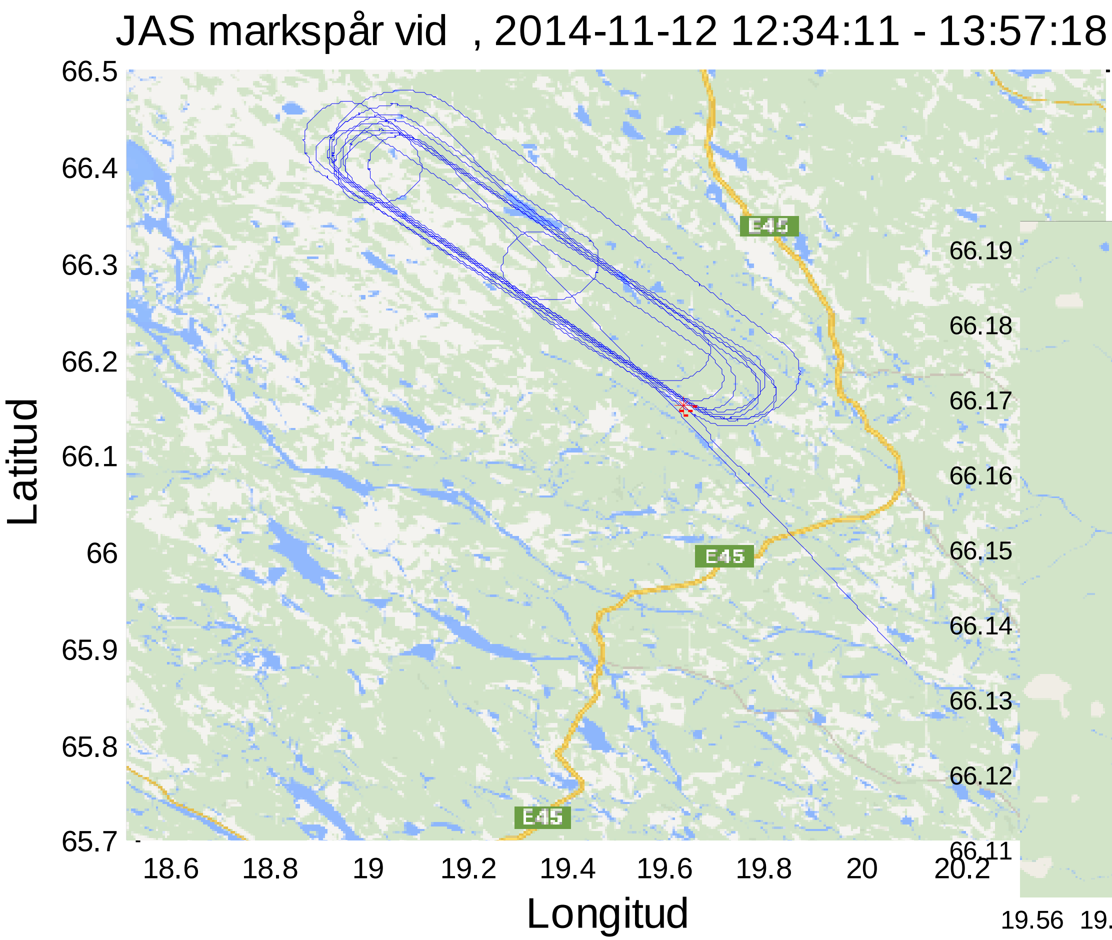
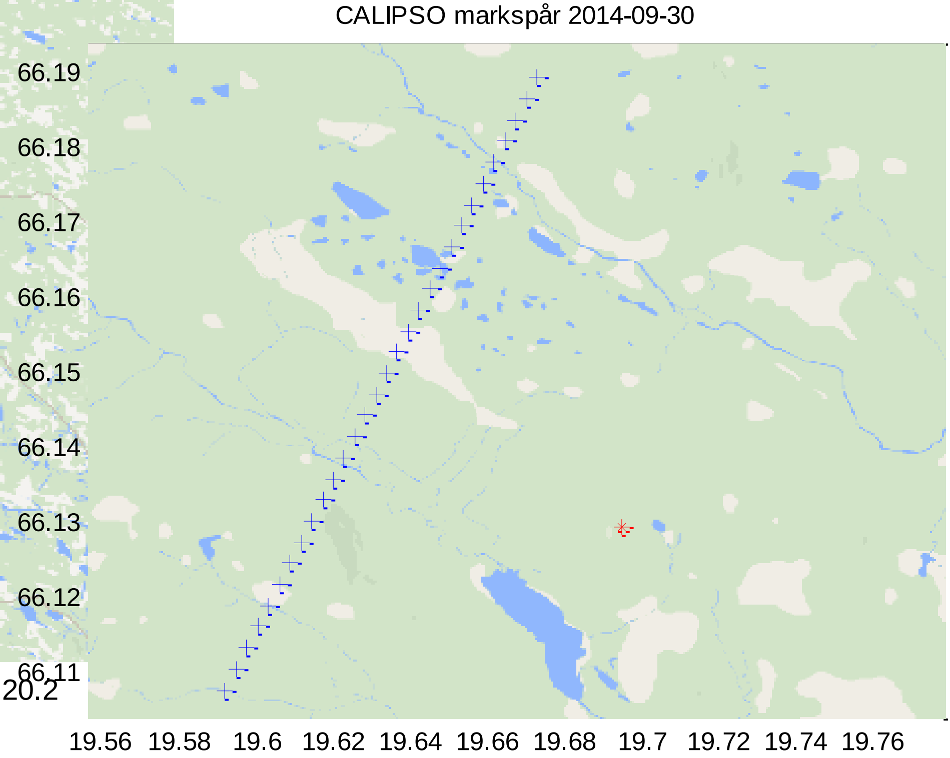
Tack för uppmärksamheten!

Lidar station Vidsel




JAS markspår vid , 2014-11-12 12:34:11 - 13:57:18
Latitud
Longitud
66.5
66.4
66.3
66.2
66.1
66
65.9
65.8
65.7
18.6
18.8
19
19.2
19.4
19.6
19.8
20
20.2
E45
E45
E45


CALIPSO markspår 2014-09-30
66.19
66.18
66.17
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66.14
66.13
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19.58
19.6
19.62
19.64
19.66
19.68
19.7
19.72
19.74
19.76