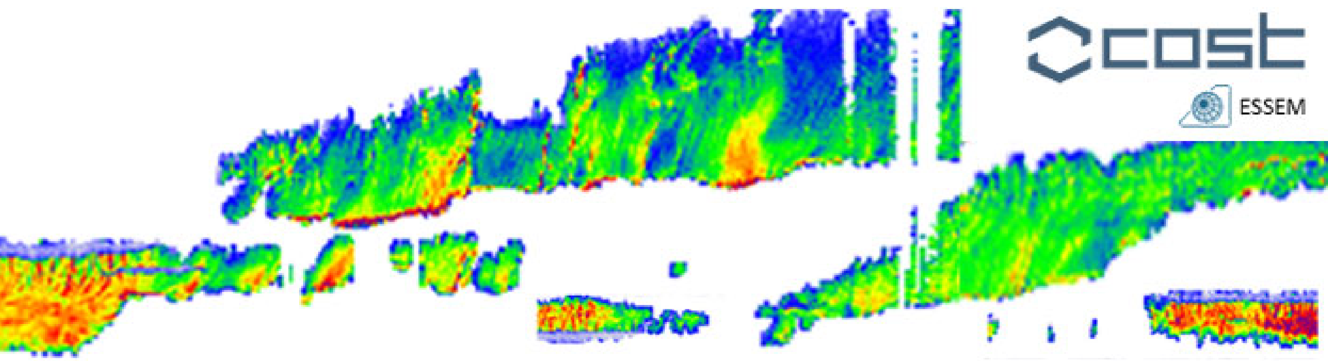


Combined wind & aerosol/cloud measurements with coherent Doppler LIDARs for operational networks

Ludovic Thobois,
Philippe ROYER,
Jean Pierre Cariou

LEOSPHERE
THE ATMOSPHERE IS YOURS

Key specifications of Doppler LIDARs

- Figure of Merit:
  - Allows to compare different lidars or different configurations. It allows to classify LIDAR sensitivities, independently of atmospheric parameters.
  - *WINDCUBE7v2 ~**5.6^E-12***
  - *WINDCUBE200S ~**3.39^E-10***

$$FOM = \eta \, E \; T_p \, A \sqrt{f_{PRF}}$$

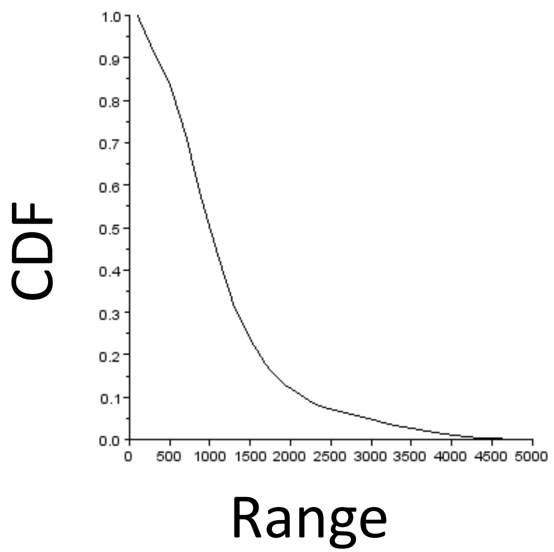
- Range resolution
- Maximum operational range

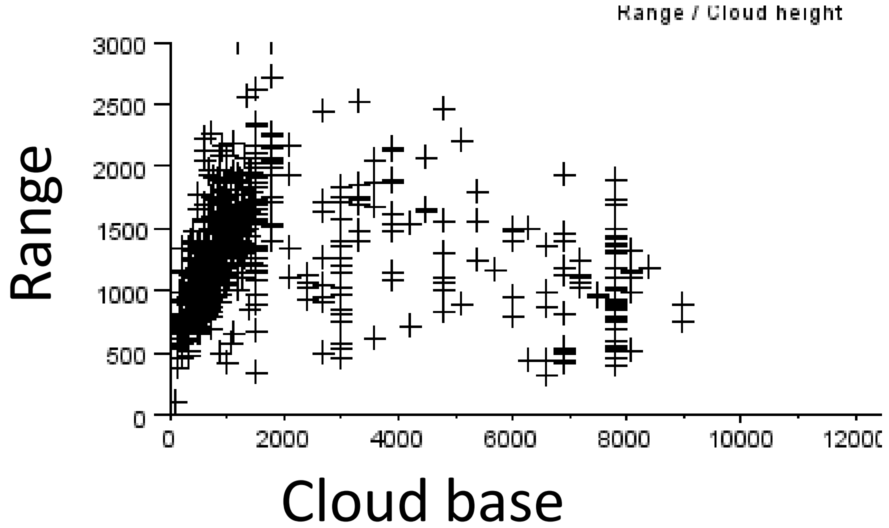
Key specifications of Doppler LIDARs

Range resolution:

- Is defined as the Full Width Half Maximum (FWHM) of the averaging kernel
- For pulses and weighted range gates
  - Squared

$$\Delta R = \frac{c}{2}\sqrt{\tau^2 + tm^2}$$





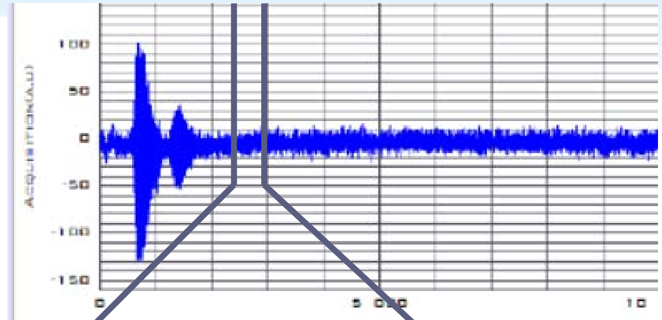
Data processing chain

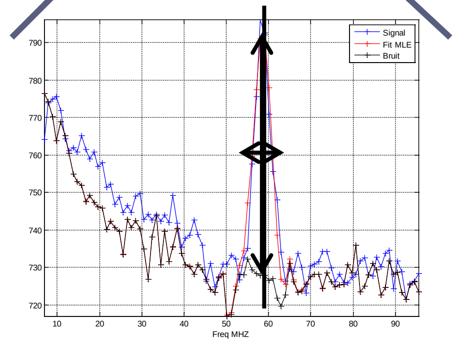
Level 0 — Temporal data

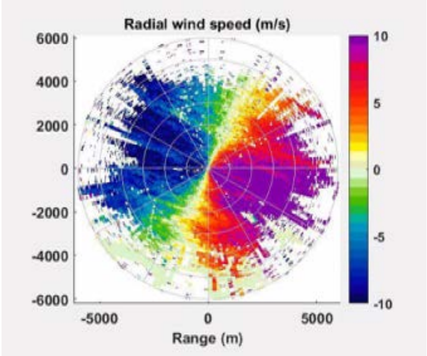
Spectra

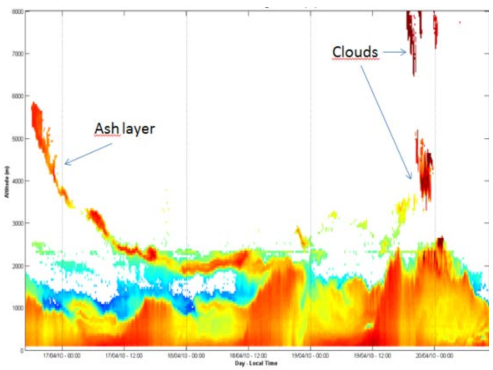
Level 1 — Signal to Noise Ratio
Radial windspeed
Dispersion

Level 2 — Horizontal wind speed
Wind direction
Turbulence
Windshear
Aerosol/cloud related data



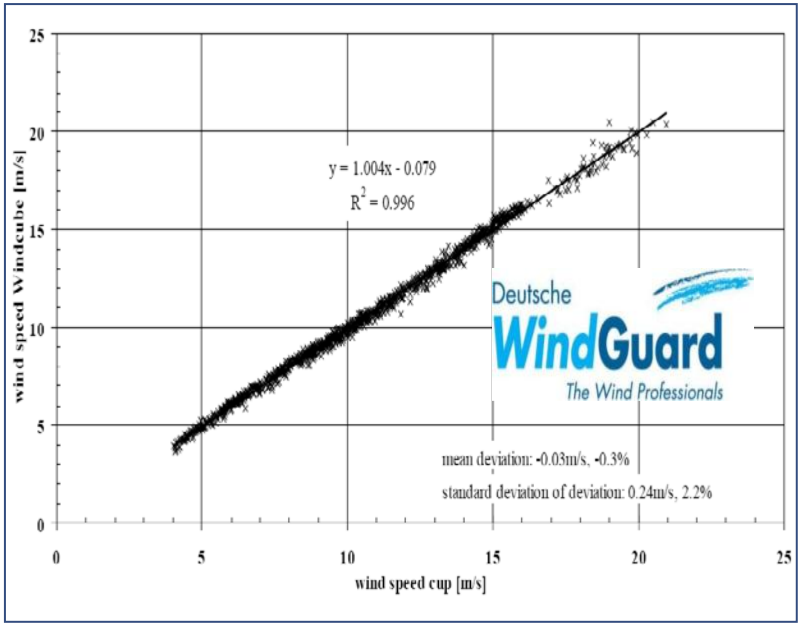


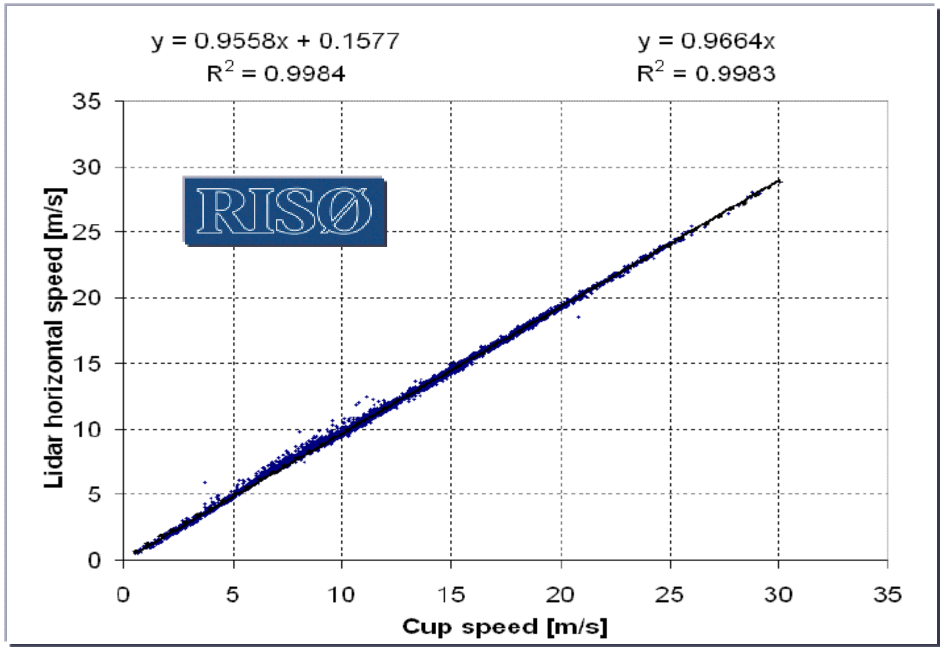




LIDAR profiler in DBS Mode: accuracy

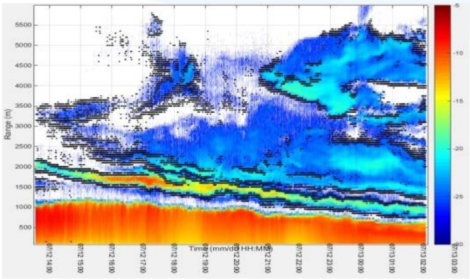
Numerous validations at reference independent sites (DTU, DEWI, Deutsche WindGuard…) against cup anemometers



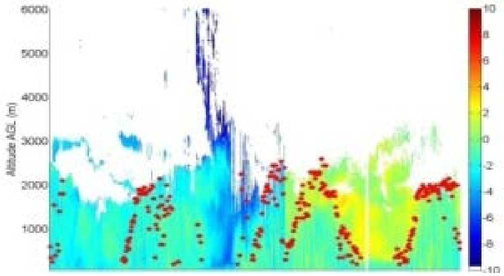


Accuracy is 0.1 m/s on windspeed and 2° on wind direction

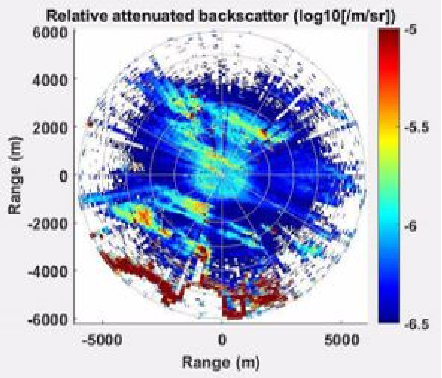
New aerosol/cloud features



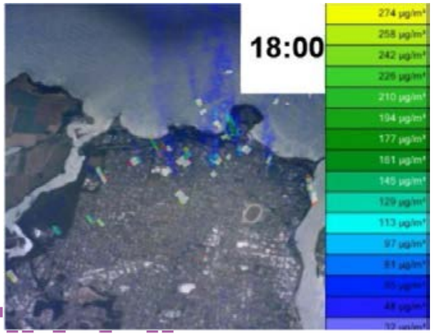
- Aerosol/cloud layer detection and discrimination



- Planetary Boundary Layer height detection



- Attenuated backscatter coefficient retrieval



- Mass concentration estimation (still in progress)

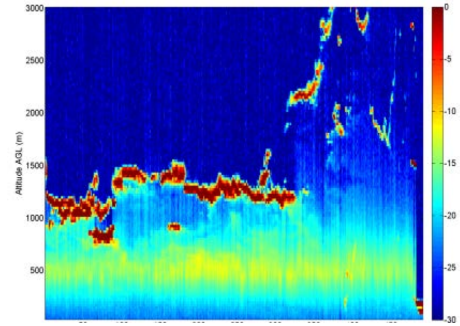
Aerosol/cloud layer detection

Aerosol/cloud layers detection

Principle

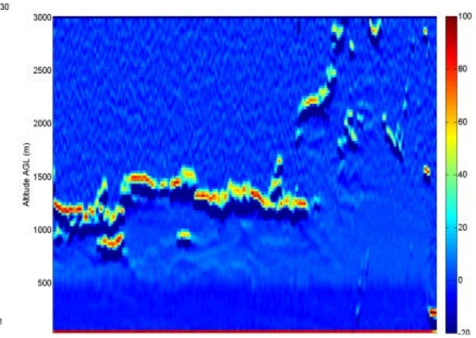
Detection of layers using CNR gradients

CNR

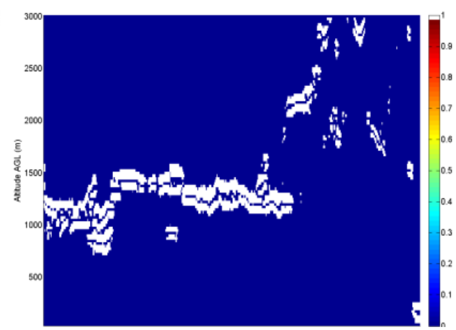


Step 1 : filtering and gradient calculation

Gradient



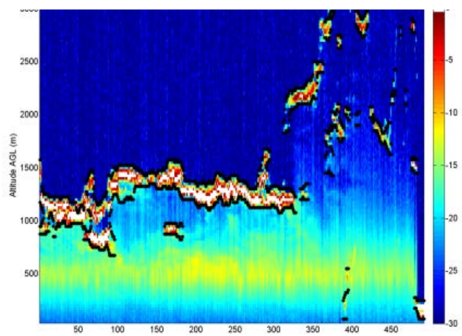
Step 2 : Automatic gradient segmentation (iterative OTSU method 1979)



Binary mask

Step 3 : Base and top detection

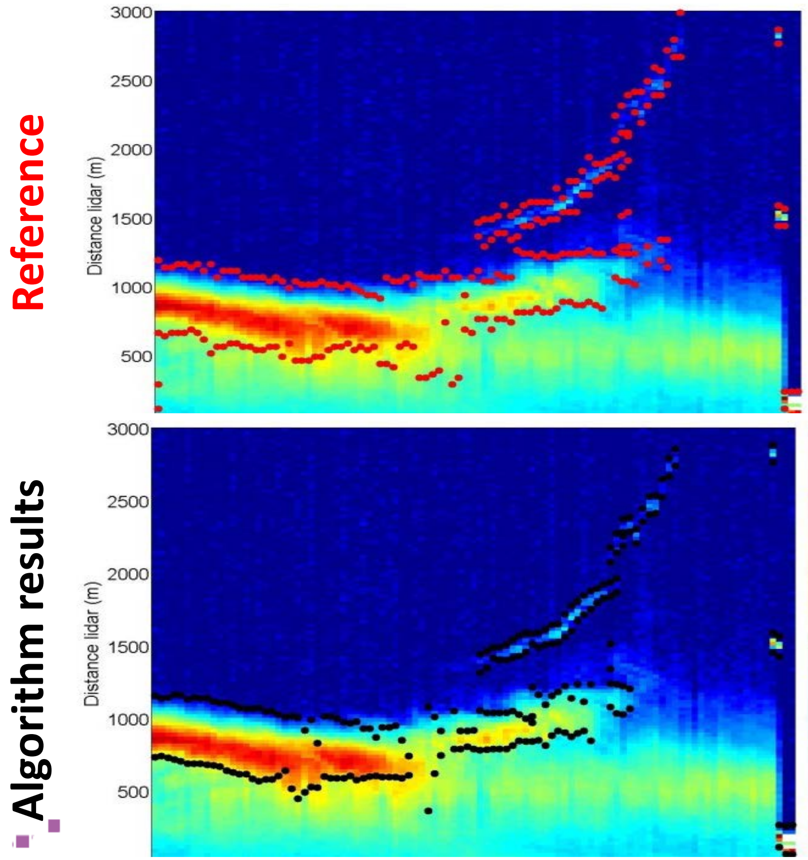
Base/top layers



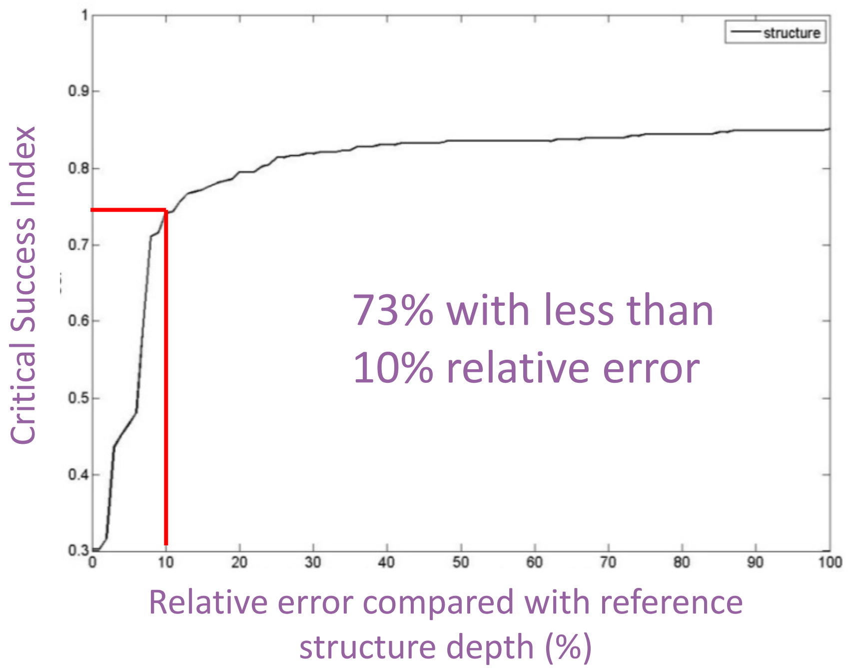
Aerosol/cloud layers detection

Validation

Comparison with a reference database



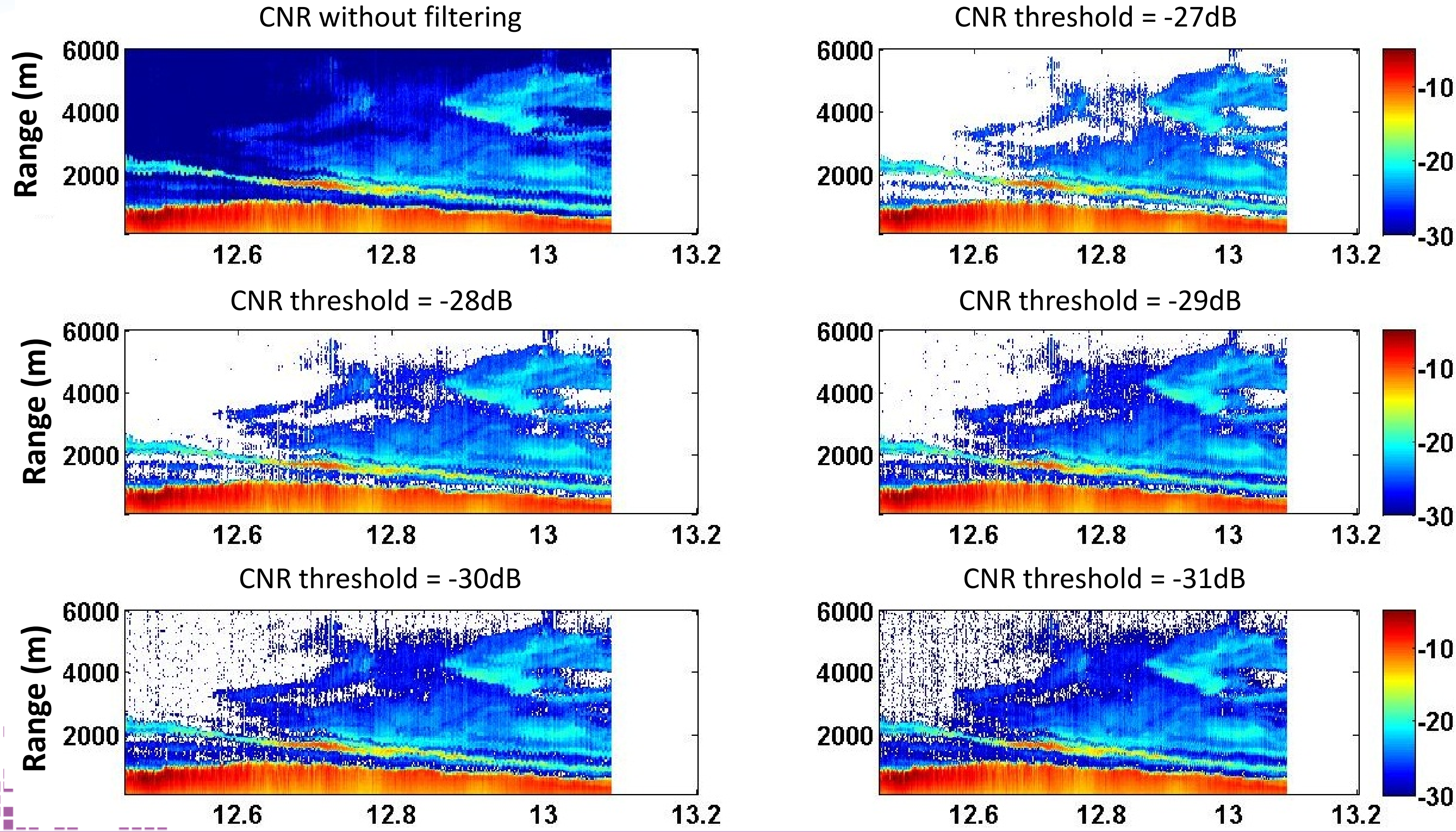
$$CSI = \frac{good\ detection}{good\ detection + misdetection + false\ alarm}$$



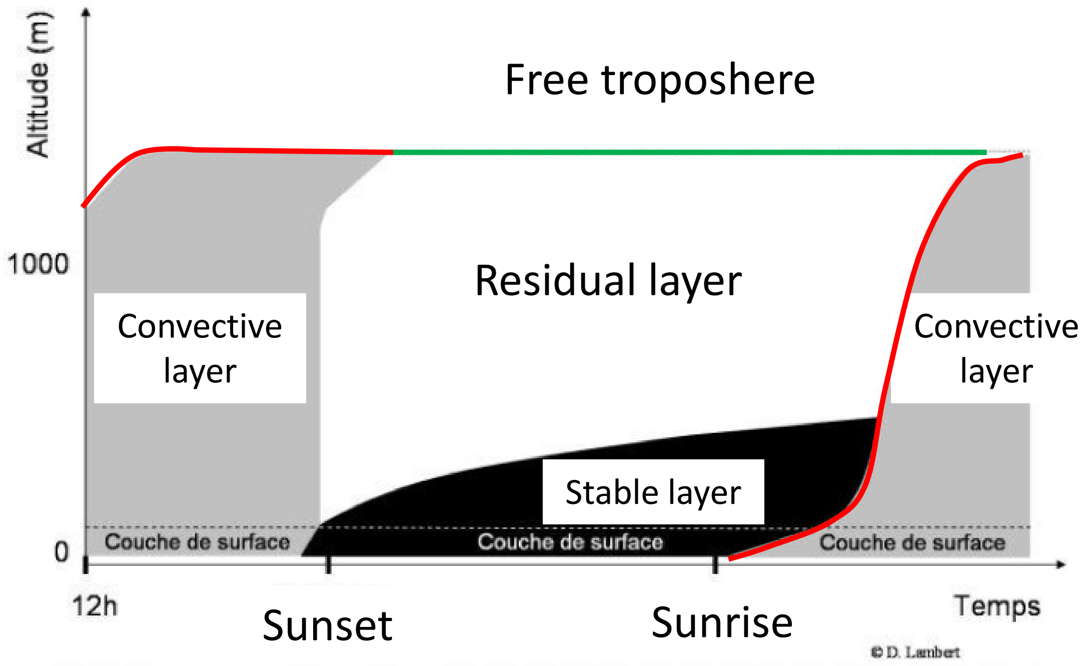
Detection capabilities

Scenario	ds	dt
LOS	50m	1s

Need to adjudt SNR thresholds defined for wind measurements for clouds/aerosols detection



PBL detection

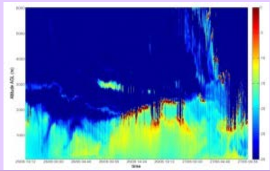


Planetary boundary layer height

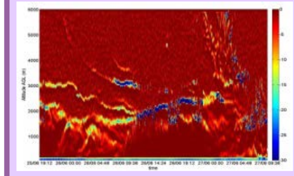
Principle of the detection

Residual layer

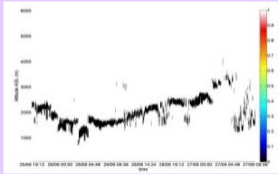
Signal reflectivity



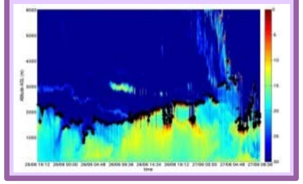
→ Gradient



→ Gradient mask



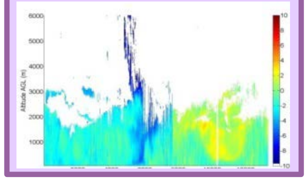
→ Residual layer detection



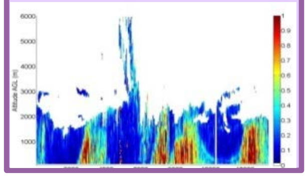
Threshold 0.2m/s
[Bianco et al, 2013]

Mixing layer

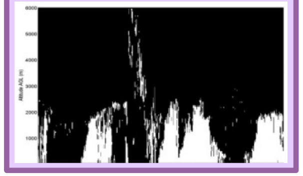
Vertical wind speed



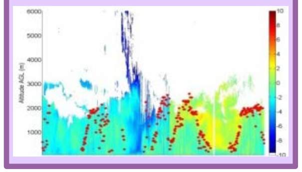
→ Variance of the vertical wind speed



→ Binarisation of the variance image

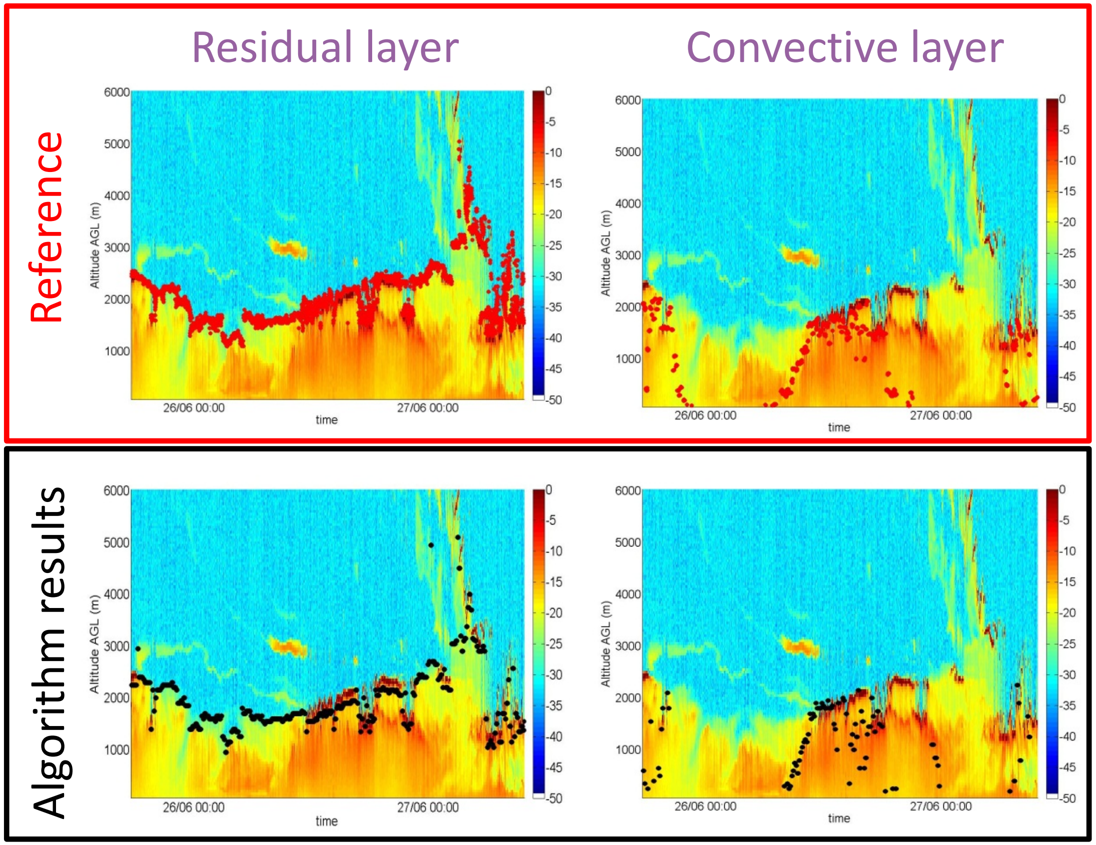


→ Mixing layer height



PBL height detection

Validation



Vertical pointing measurements (Δz = 25m, Δt=2min)

Comparison with database from various campaigns

PBL height detection with a relative error <20% :

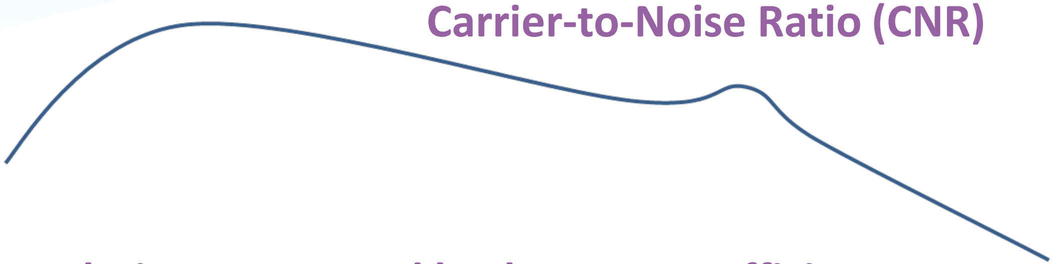
- 94% for the residual layer
- 78% for the mixing layer

Attenuated backscatter coefficent

Attenuated backscatter coefficient

Principle

Carrier-to-Noise Ratio (CNR)



$$CNR(z) = K.F(z).\beta(z)e^{-2\int_0^z \alpha(r)dr}$$

Instrumental function calibration

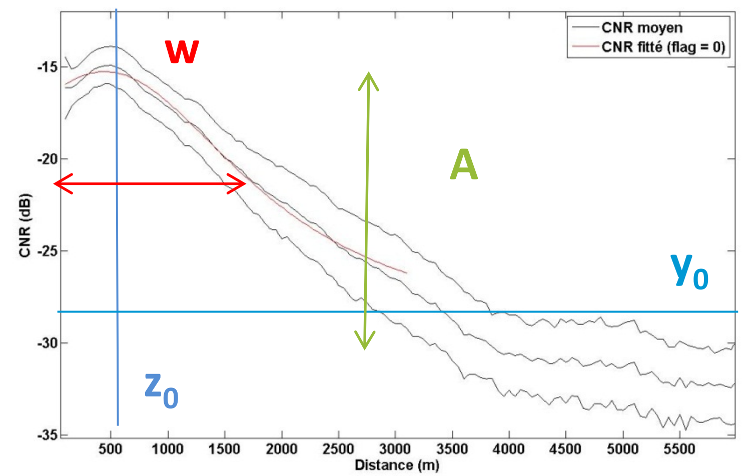
Relative attenuated backscatter coefficient

$$\beta_{rel.att.}(z) = K.\beta(z)e^{-2\int_0^z \alpha(r)dr}$$

Automatic calibration is performed with low elevation PPI

Lorentzian shape with 4 parameters :

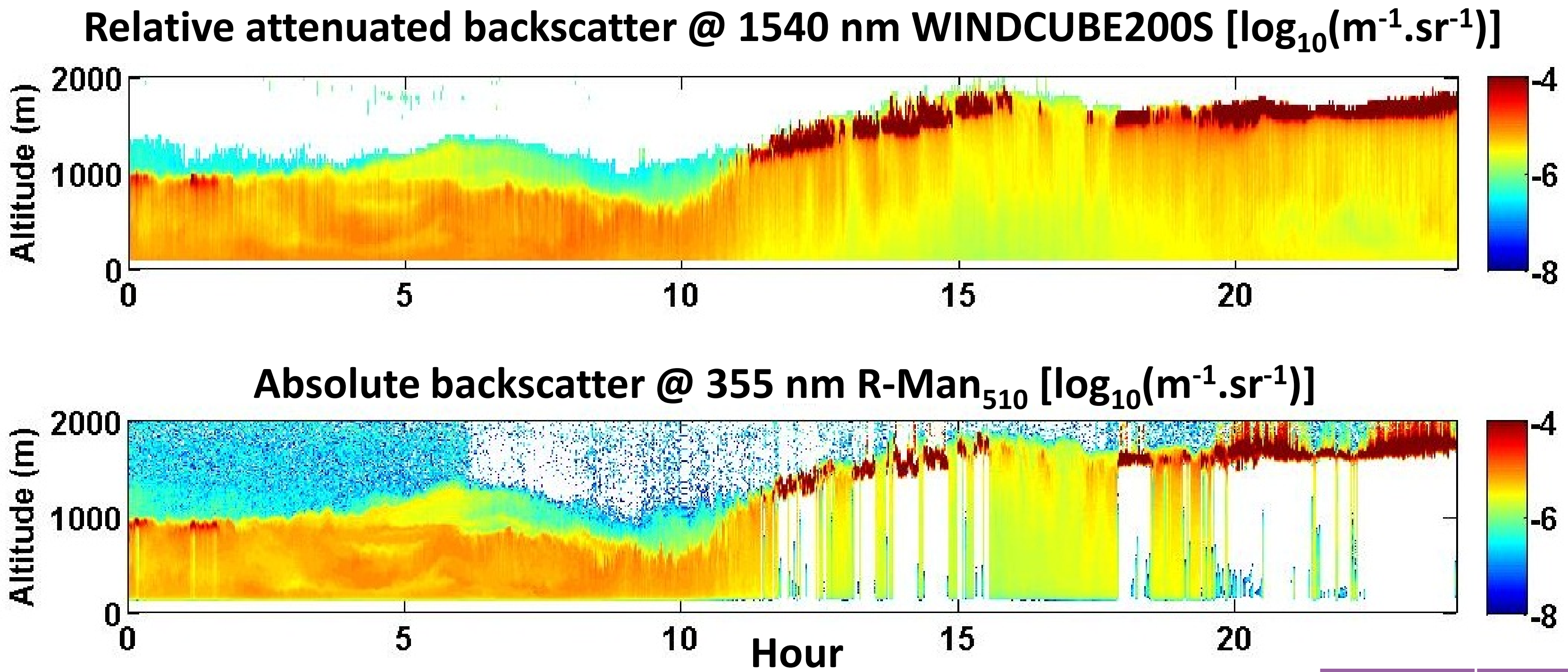
$$F(z) = y_0 + \frac{2A}{\pi} \cdot \frac{w}{4(z - z_0)^2 + w^2}$$



Attenuated backscatter coefficient

Validation

Comparison of WINDCUBE200S attenuated backscatter coefficient @1540nm with R-MAN510 absolute backscatter coefficient @ 355nm



Scenario	ds	dt
LOS	25m	1s

Building networks of Doppler LIDARs

Why building networks of LIDARs ?

- Enhance observation networks with Doppler LIDARs

1. To improve the « weather » monitoring

   Wind hazards: Severe weather, Wind Shears,

   Aerosol hazards (plumes dispersion): Air pollution, Mining, industrial risks

Why building networks of LIDARs ?

- Enhance observation networks with Doppler LIDARs

2. To improve weather nowcasts / forecasts
   - Area of interest?
     - Surface / Ekman Layers (up to 200m / 500m)
     - Boundary Layer (up to 1 – 2km)
     - Troposphere (up to XX km)?
   - Spatial and temporal Scales of the met phenomena
     - 10’, 2’?
   - Quantities to measure?
     - Averaged Wind Speed / Direction
     - Turbulence (tke?)
     - Detection of Cloud / Aerosol layers ?
     - Backscatter profiles?
   - Data of interest for the models?
     - Define accuracy, resolution of required observations

Technical constraints for the LIDARs in networks

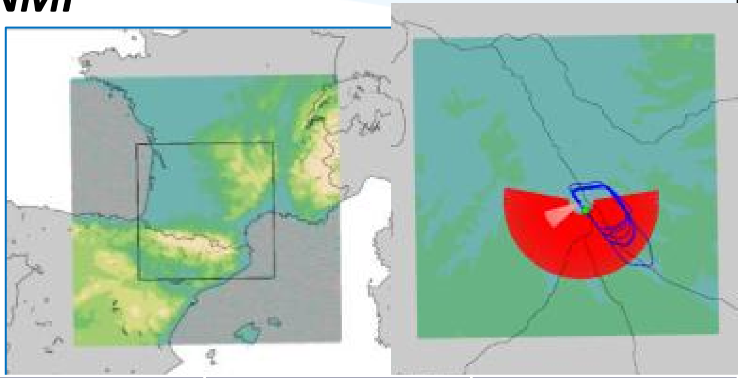
- Reliable (MTBF, MTTR)
- Design to maintenance / to cost
- Tracability of the system during its entire life

- Calibration / verification process → Consistency of the data for each system
  - Determine accurately noise level
  - Calibrate frequency offset
  - Calibrate the correspondance between temporal signal and range gates
  - Verify the accuracy of wind speed against a reference LIDAR

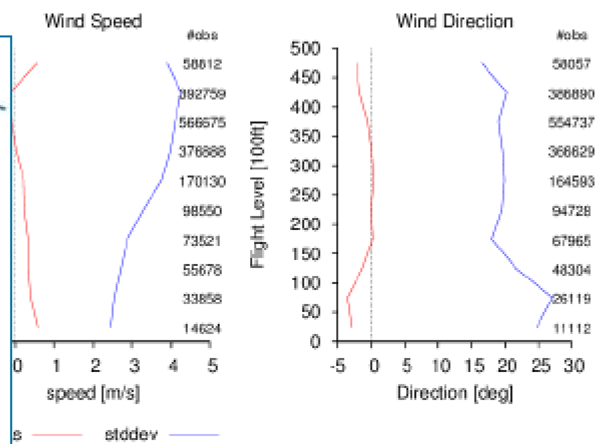
UFO Project: Assimilation of LIDAR data into HARMONIE Model

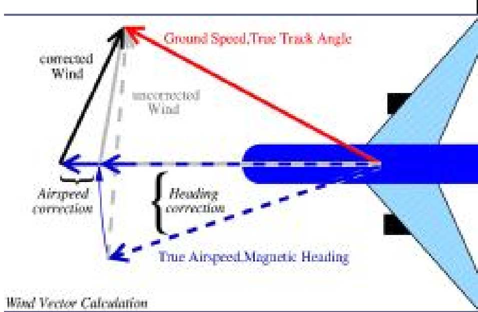
Courtesy of S. De Haan / KNMI

- Set-up of Harmonie model domain for Toulouse
  - 1km resolution: 500 x 500 grid points
  - Calculation of Model background error Characteristics
  - observations assimilation (area 400x400 grid points)
  - Preprocessing set up for UFO observations
    - Radar/Lidar Scanners and Profilers
    - TUBS aircraft data and Mode-S EHS data
- Mode S EHS & MRAR versus HIRLAM



	Nestor	Nested
Grid	200x200 5km	500x500 1km
Cycle	3 hours	1 hour
Lateral boundaries	ECMWF hourly	Nestor 15 min
Observations	Temp/aircraft/ synop	Temp/aircraft/ synop
Assimilation	3DVAR 3 hour window	3DVAR 1 hour window



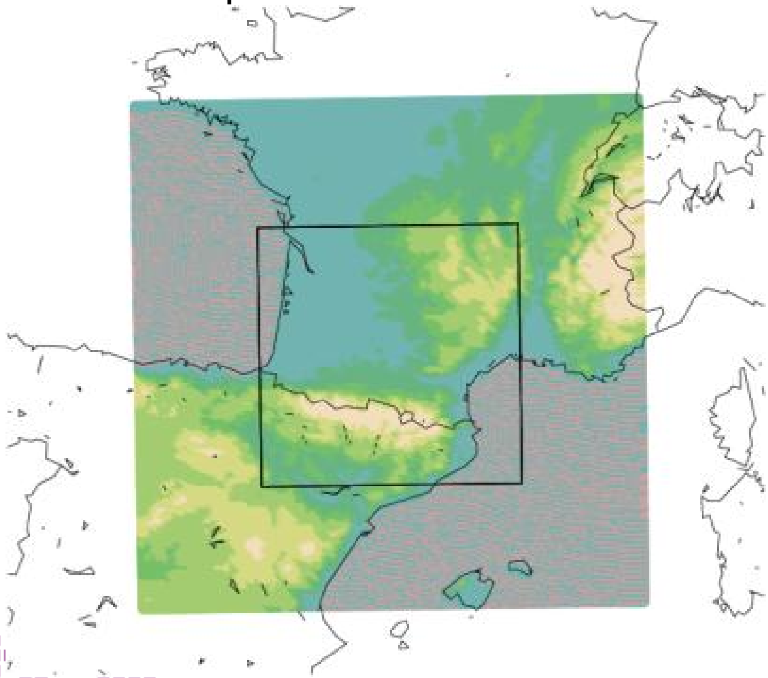


UFO Project: Assimilation of LIDAR data into HARMONIE Model

Courtesy of S. De Haan / KNMI

Experiments

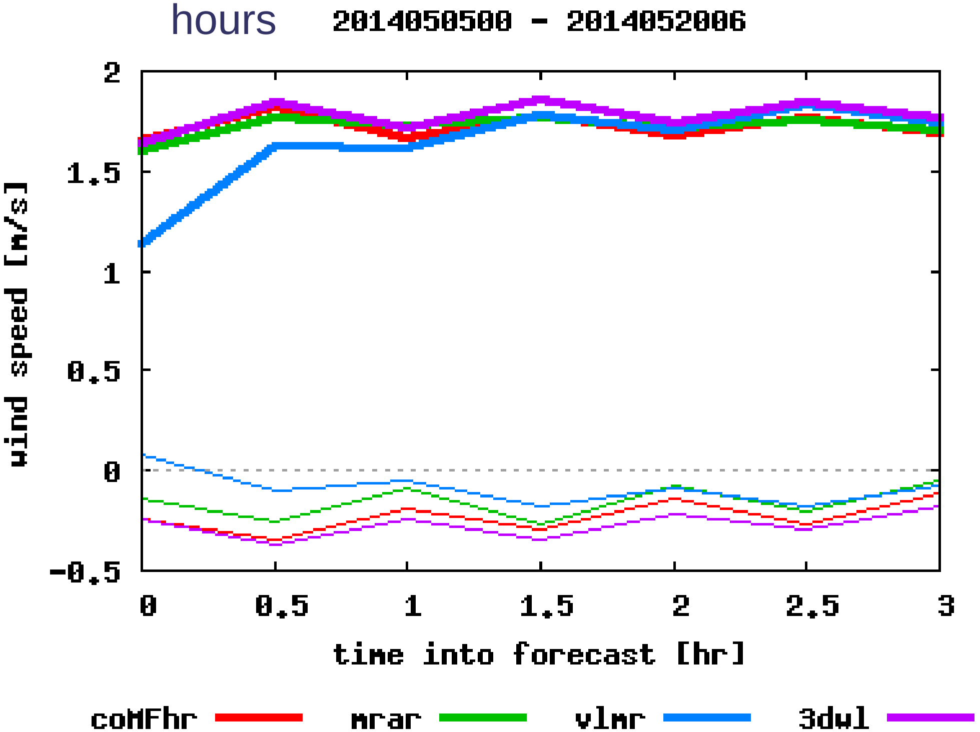
- Conventional obs MF: coMFhr
- + Mode-S MRAR : mrar
- + LeoSphere WindcubeV2: vlmr
- + LeoSphere 3D wind observations



Comparison with WindCubeV2

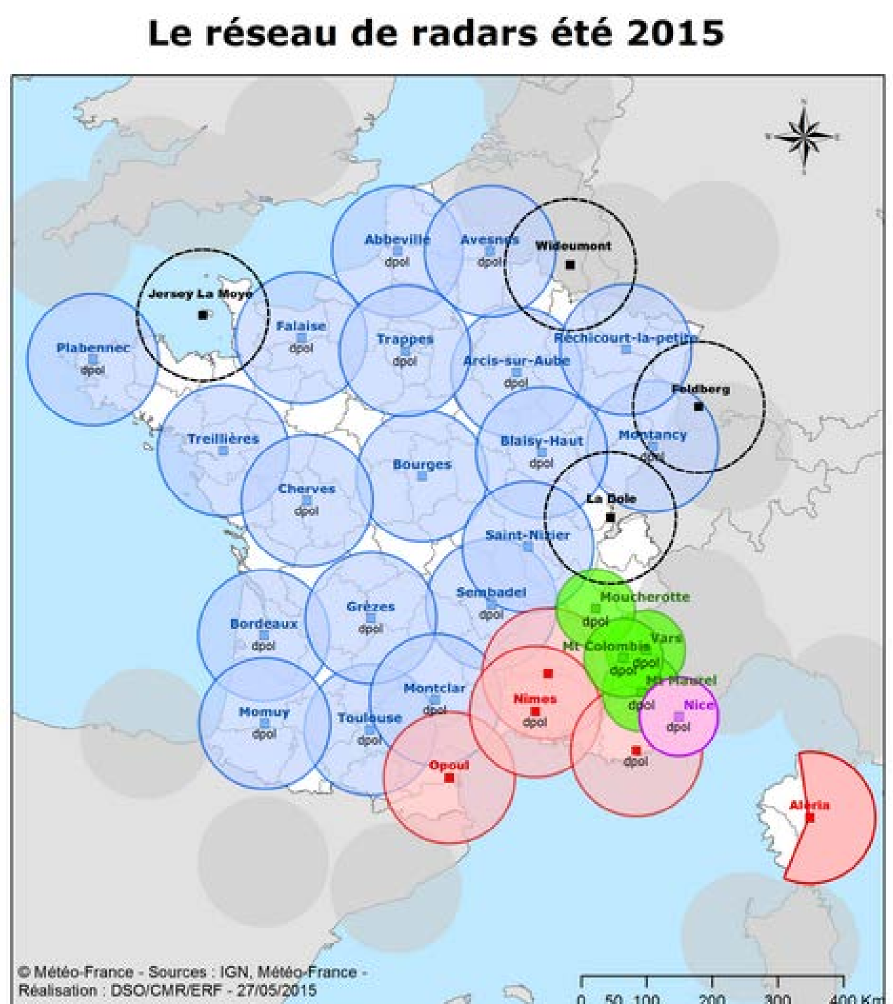
Experiment **vlmr**: best performance

- Positive impact on wind speed standard deviation in the first hour
- Wind speed bias is reduced in the first 2 hours



Weather monitoring and forecasting

LIDAR networks



http://www.nysmesonet.org/

Monitoring and nowcasting

Conclusion / Perspectives

- Coherent doppler lidars are used operationnally in many applications :

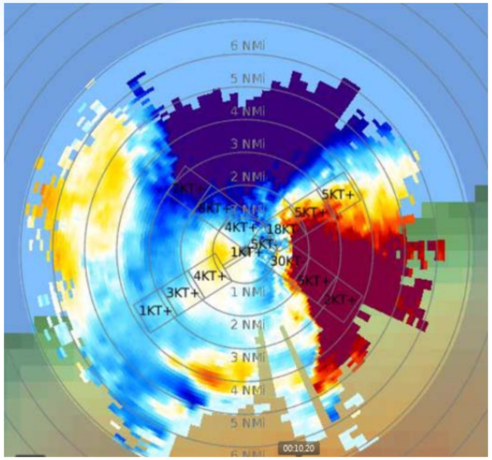
  Wind energy, aviation weather, air quality, weather & climate…

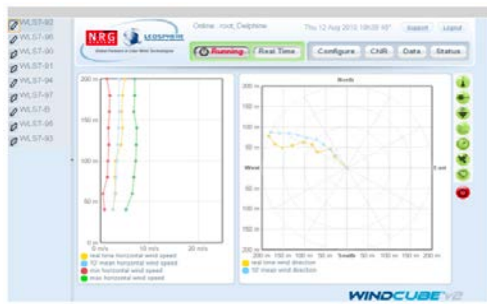
- Proven accuracy of the radial and reconstructed wind measurements (like in DBS mode)

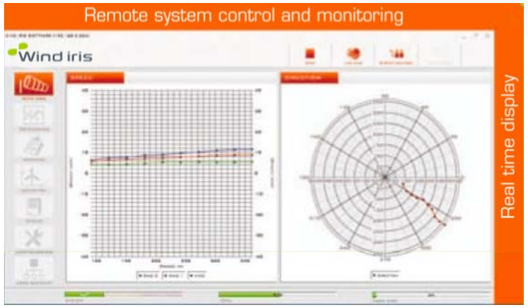
- Aerosol / cloud features can be retrieved from Dopler LIDARs
  - Should be evaluated within TOPROF research working group: cloud base, backscatter; PBL

- Long term assimilation of Doppler LIDAR data should be performed in TOPROF to evaluate the improvements of local weather forecasts

Current LIDAR products







avent
Lidar Technology

Questions ?

Backup slides

A suite of atmospheric parameters

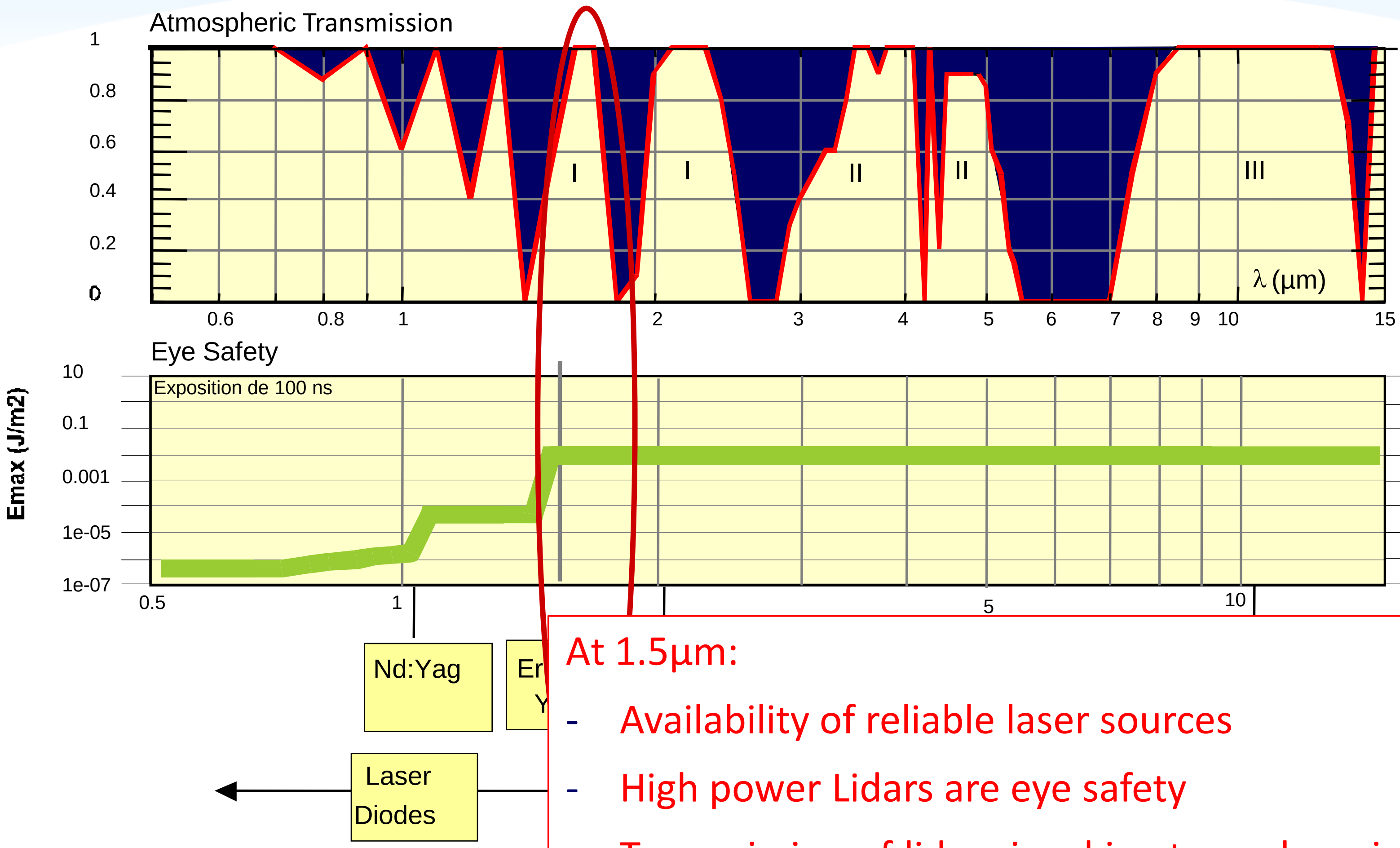
Wind
- Radial Wind Speed
- Vertical wind speed
- Horizontal wind speed
- Wind direction

Turbulence
- Turbulence intensity (TI)
- Turbulent Kinetic Energy (TKE)

Aerosol/ Clouds
- Structures
- Backscatter profile


LEOSPHERE
THE ATMOSPHERE IS YOURS

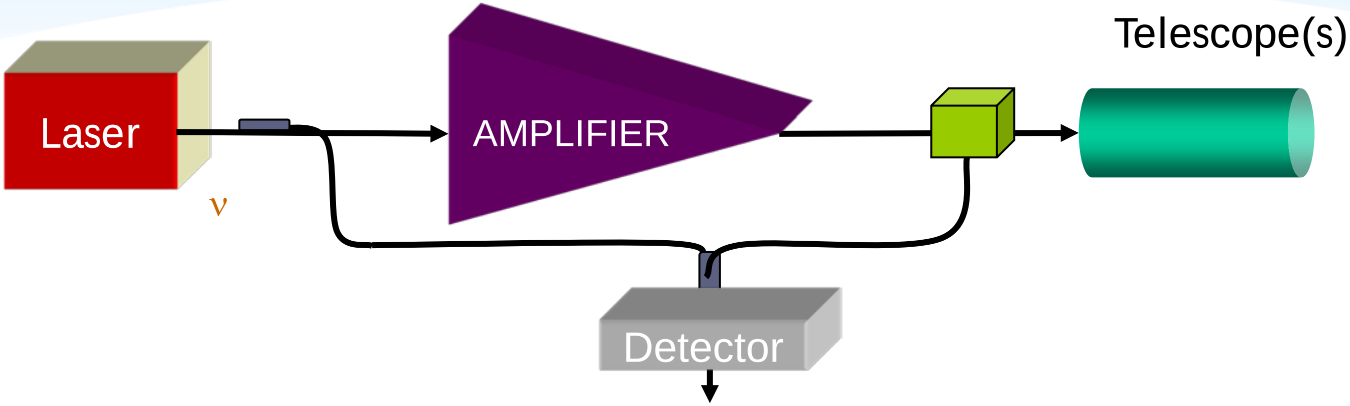
Choice of the wavelength of 1.5µm (NIR)



At 1.5µm:

- Availability of reliable laser sources
- High power Lidars are eye safety
- Transmission of lidar signal in atmosphere is very efficiency

Benefits of fiber technology

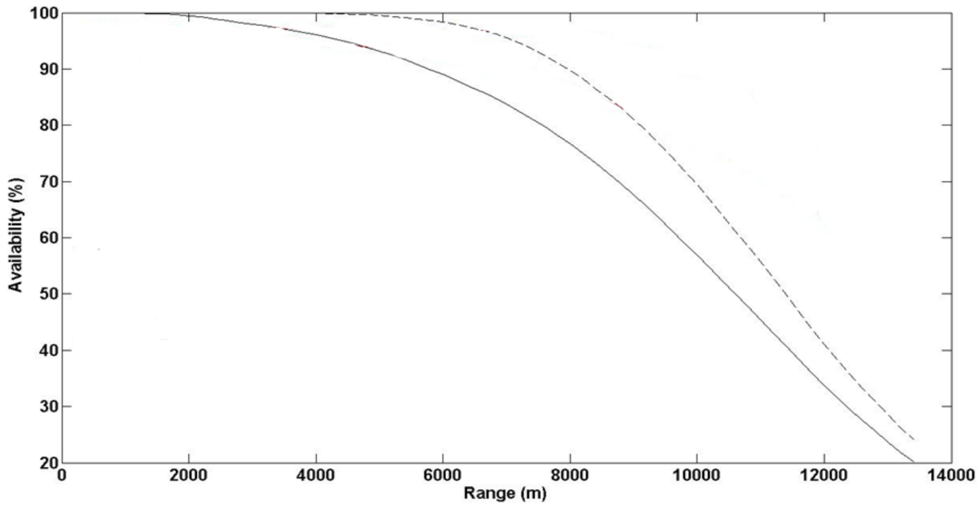


- **Why are we using fibers ?**
  - For guiding the light: avoid disalignment
  - For amplifying the light: low consumption and reliable laser diodes

- Used of reliable optronic components of mainstream telecommunication market ➔ **Low cost, reliable and compact architecture**
- Flexible architecture that allows to adjust
  - Pulse Repetition Frequency (ie. Power) ➔ **Measurement Range**
  - Pulse length ➔ **Spatial resolution**

Long Range Scanning LIDARs

- A 6 months trial has been performed in Palaiseau, France in 2014
  - Determine ranges for clear air conditions (visibility >10km, no rain) following the recommendations of ISO working groups on Doppler LIDARs
  - Assess the impact of weather conditions on range

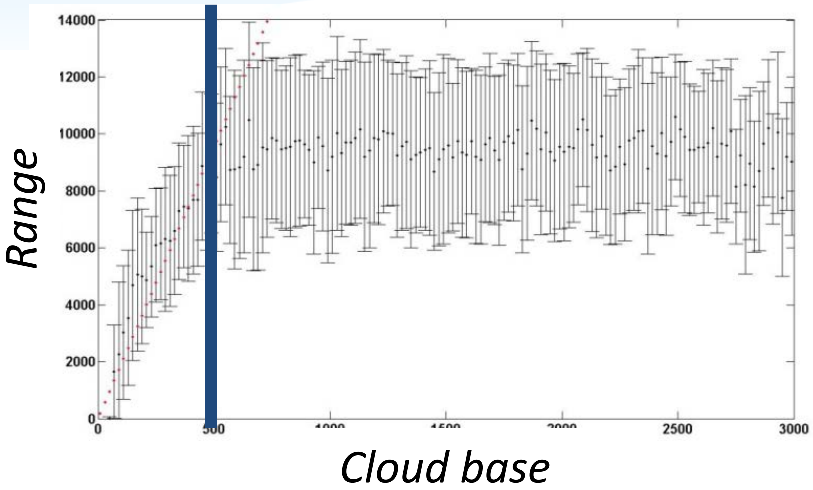


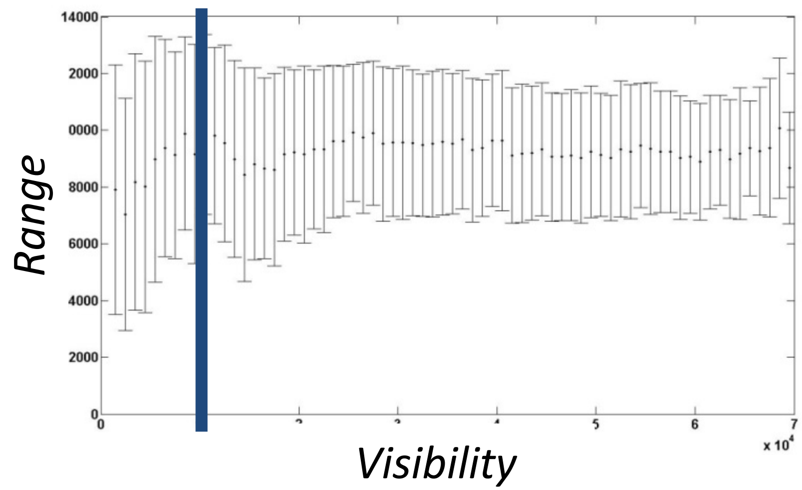
	Availability 80%	Availability 50%
Range	9km	11.5km

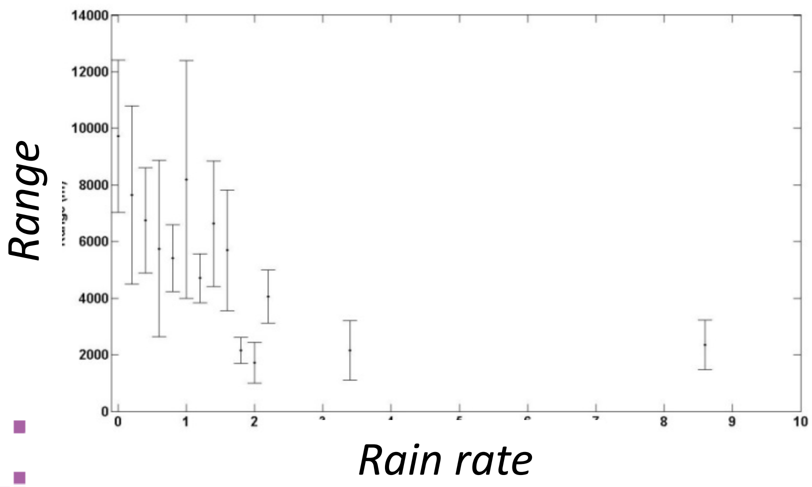
Measurements performed with a Scanning LIDAR

- *WINDCUBE400S*

Long Range Scanning LIDARs

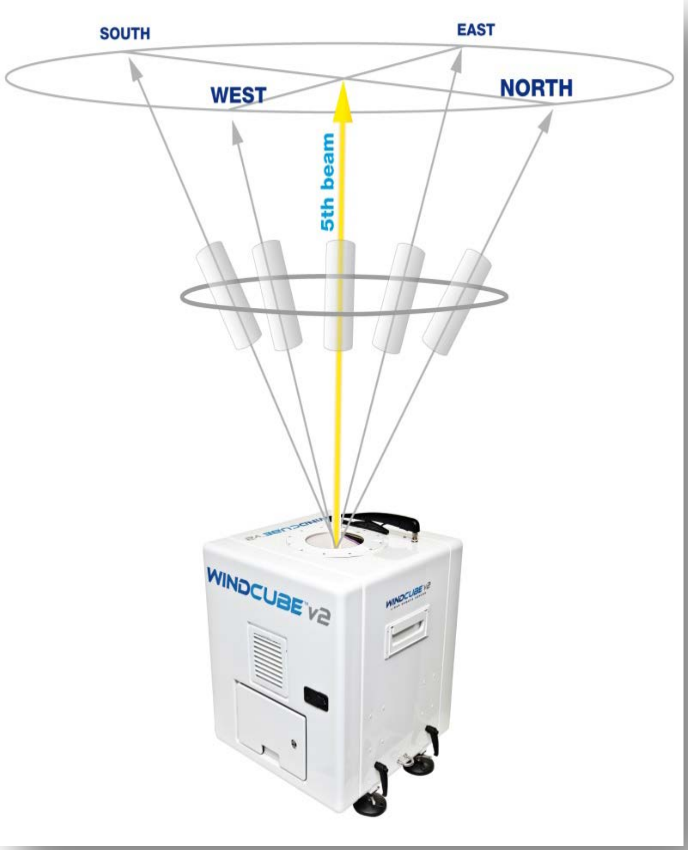






- **LIDARs measure at nominal performances in clear air conditions, ie.** above 10km of visibility and with no rain
- **For an all weather observations system, LIDAR must be coupled with RADAR**

Short range LIDAR profiler

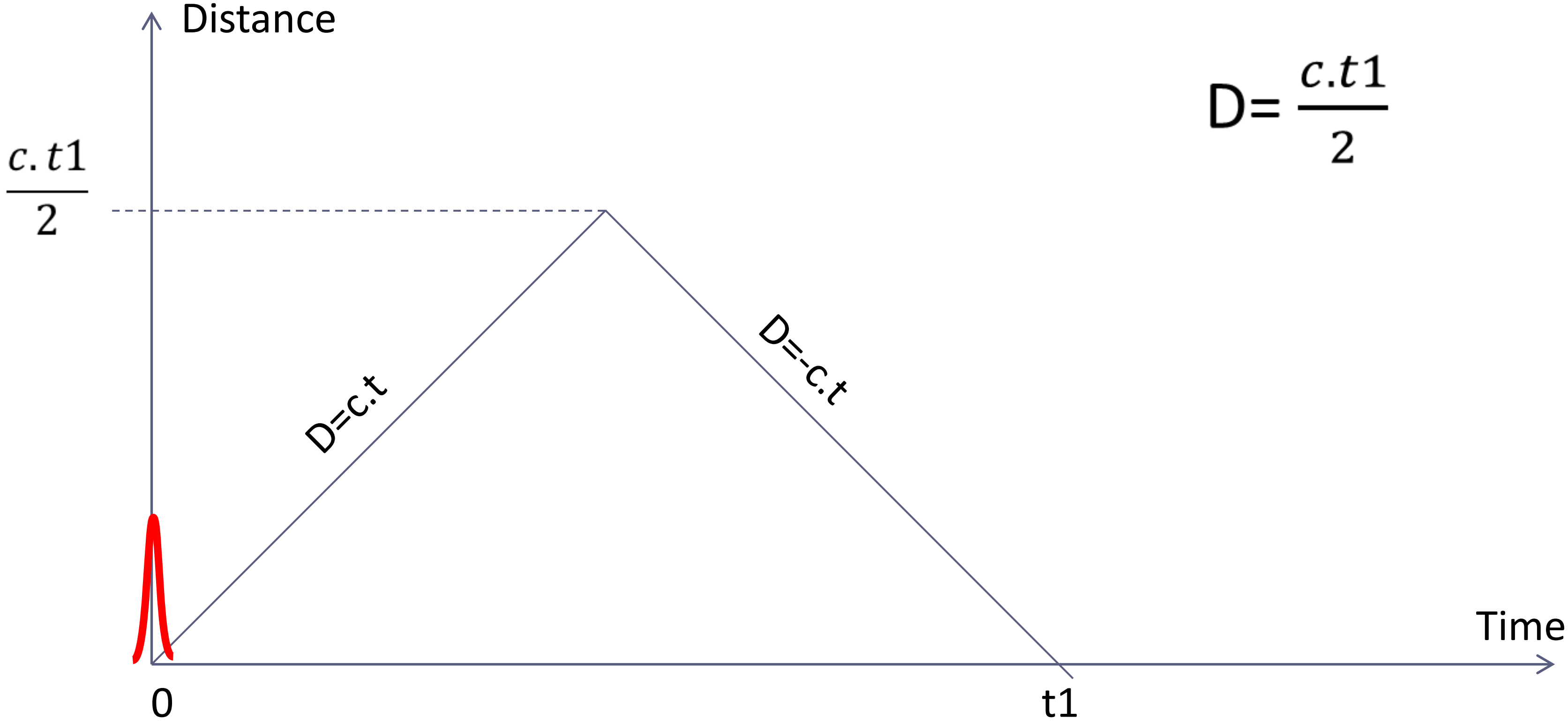


3 wind components (u,v,w)

- Operations in DBS Mode
- One sequence performed every 4s
- Worldwide 500 units are deployed

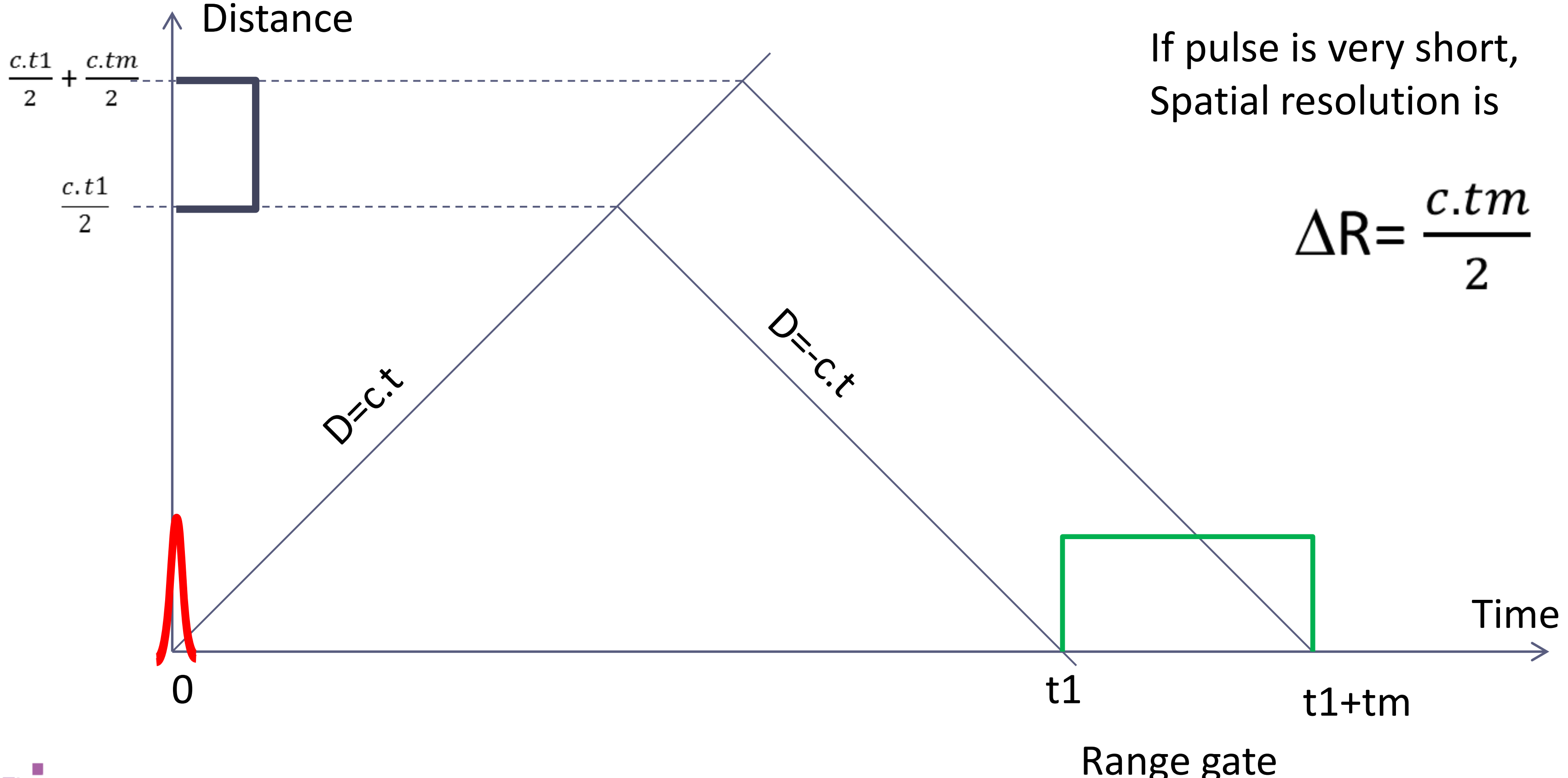
Measurements	Performances
Range	40 to 290m
Number of heights	12
Data sampling rate	1s
Speed range	0 to 60 m/s

Range resolution



$$D = \frac{c.t1}{2}$$

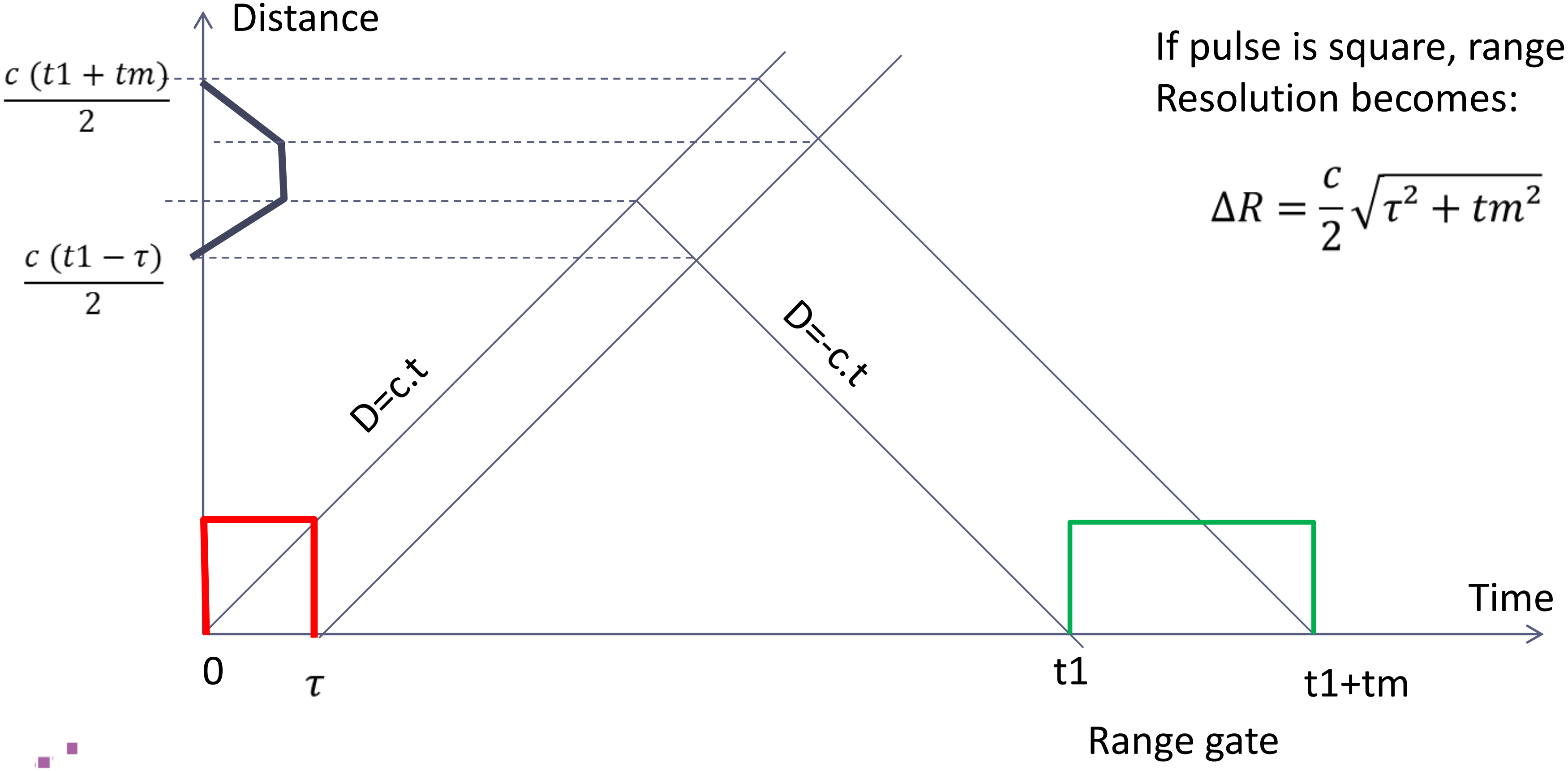
Range resolution



If pulse is very short,
Spatial resolution is

$$\Delta R = \frac{c.tm}{2}$$

Range resolution

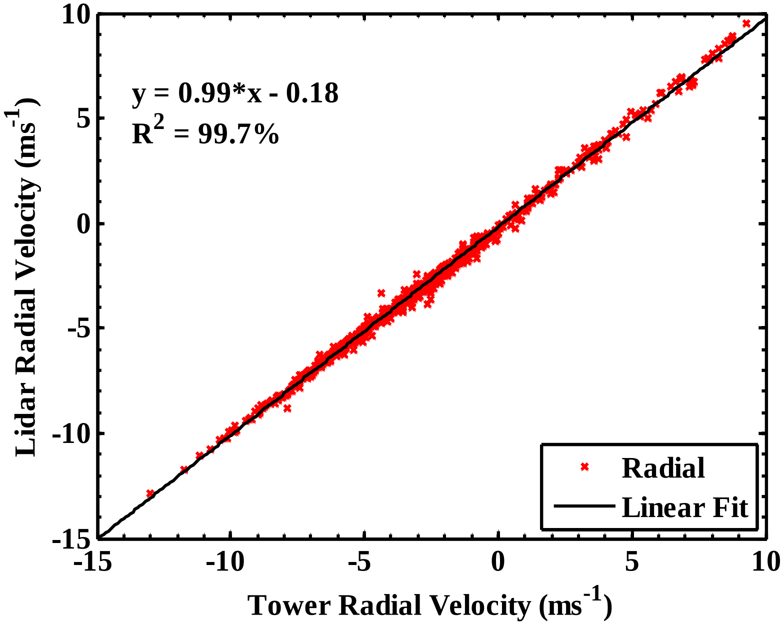


If pulse is square, range Resolution becomes:

$$\Delta R = \frac{c}{2}\sqrt{\tau^2 + tm^2}$$

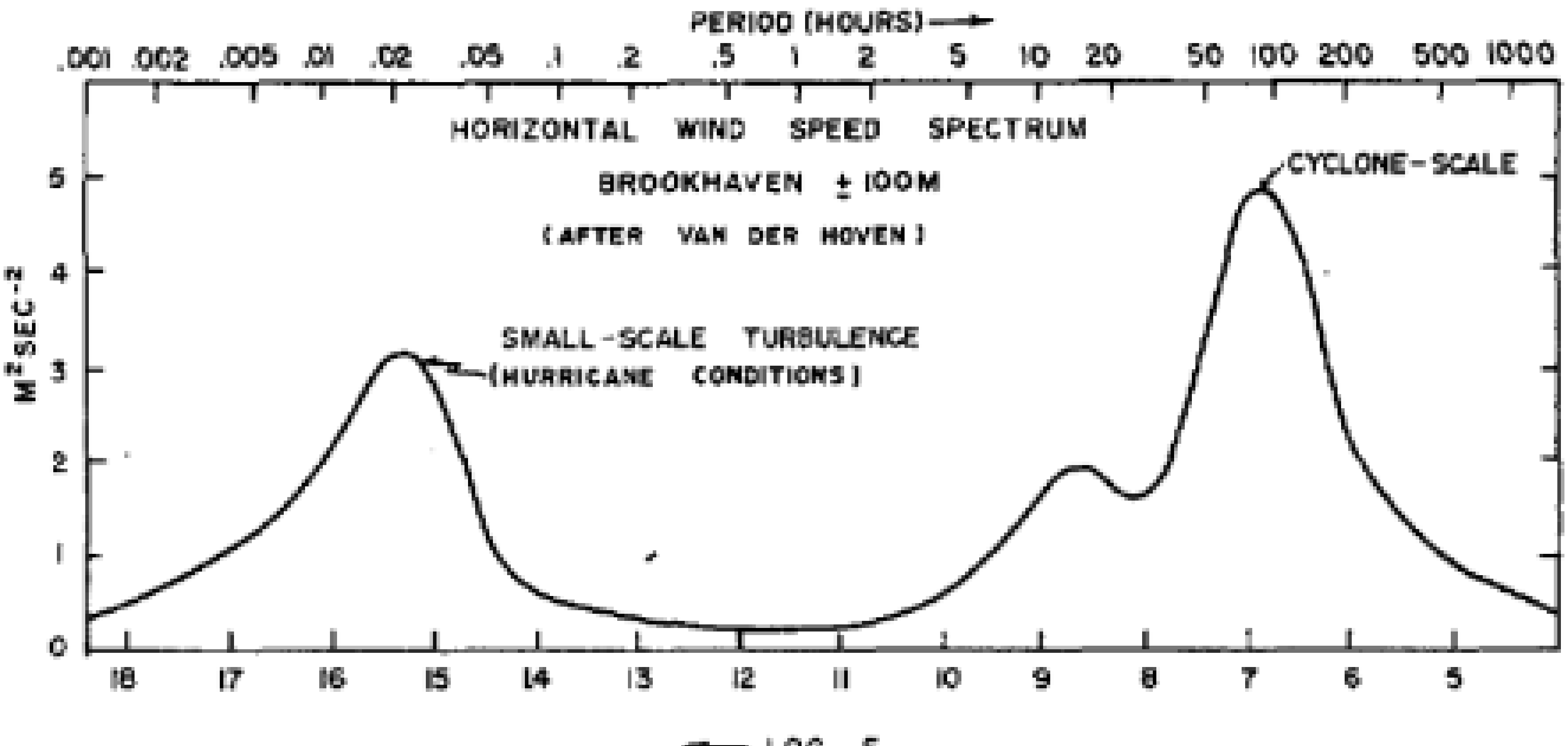
Long Range Scanning LIDARs

- Deployment during 3 months of a WINDCUBE200S at the certification test site in Denmark
- Objectives: To evaluate accuracy (mean difference) and precision (RMSE) of radial wind speeds and horizontal wind speeds



$\mu = 0.09\, m/s$ $RMSE = 0.27 m/s$

Why building networks of LIDARs ?



Source ON THE' KINETIC ENERGY SPECTRUM NEAR THE GROUND, A. OORT and A. TAYLOR, MONTHLY WEATHER REVIEW, VOLUME 97, NUMBER 9, SEPTEMBER 1969