Royal Netherlands
Meteorological Institute
Ministry of Infrastructure
and Water Management

Lidar Wind Measurements and Synergy with Radars

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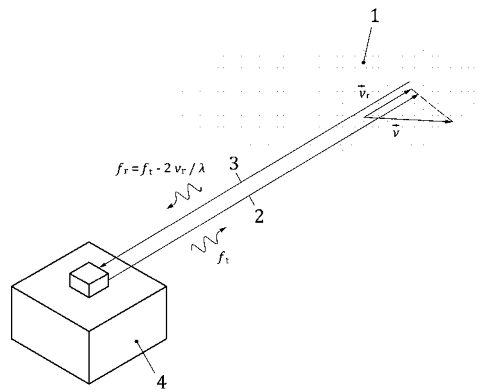
Outline

- Wind Lidar
- Lidar vs Radar
- Sensor Synergy
  - Clouds
  - Wind
- Summary

Wind Lidar

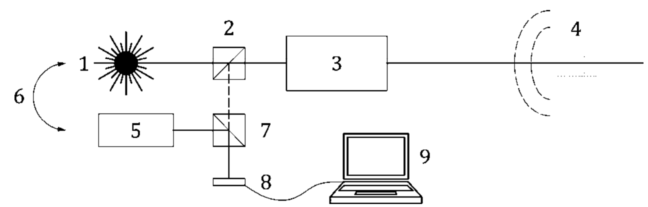
- Principle of operation
  - Based on motion of scatterers *in the line-of-sight* that produce a Doppler-shift of the emitted laser wavelength
  - Multiple line of sight measurements are needed to reproduce a 3-D wind vector
- Heterodyne lidar,
  - detection of the light captured by the receiving telescope (at frequency fr = ft + Δf)
  - The received light is mixed with the beam of a highly stable, continuous-wave laser called the local oscillator.
  - The sum of the two electromagnetic waves – backscattered and local oscillator – is converted into an electrical signal (producing an electrical current proportional to the power of the electromagnetic wave illuminating its sensitive surface).
  - An analogue, high-pass filter is then applied for eliminating the low-frequency components of the signal.



Key

1 scattering particles moving with the wind
2 Optical path of the emitted laser pulse (laser beam)
3 Optical axis of the receiver
4 Lidar instrument

Figure 1— Measurement principle of a heterodyne Doppler lidar: A laser pulse is emitted and propagates in the atmosphere. Aerosol particles and molecules scatter the laser light in all directions. At the wavelengths normally exploited by coherent Doppler wind lidar systems, the aerosol particles provide the back-scattered signal that can be exploited for Doppler wind measurements. The light scattered backwards is collected by a telescope, detected and analysed. The analysis aims at measuring the frequency Doppler shift between emission and reception. The Doppler shift is proportional to the line-of-sight wind component.



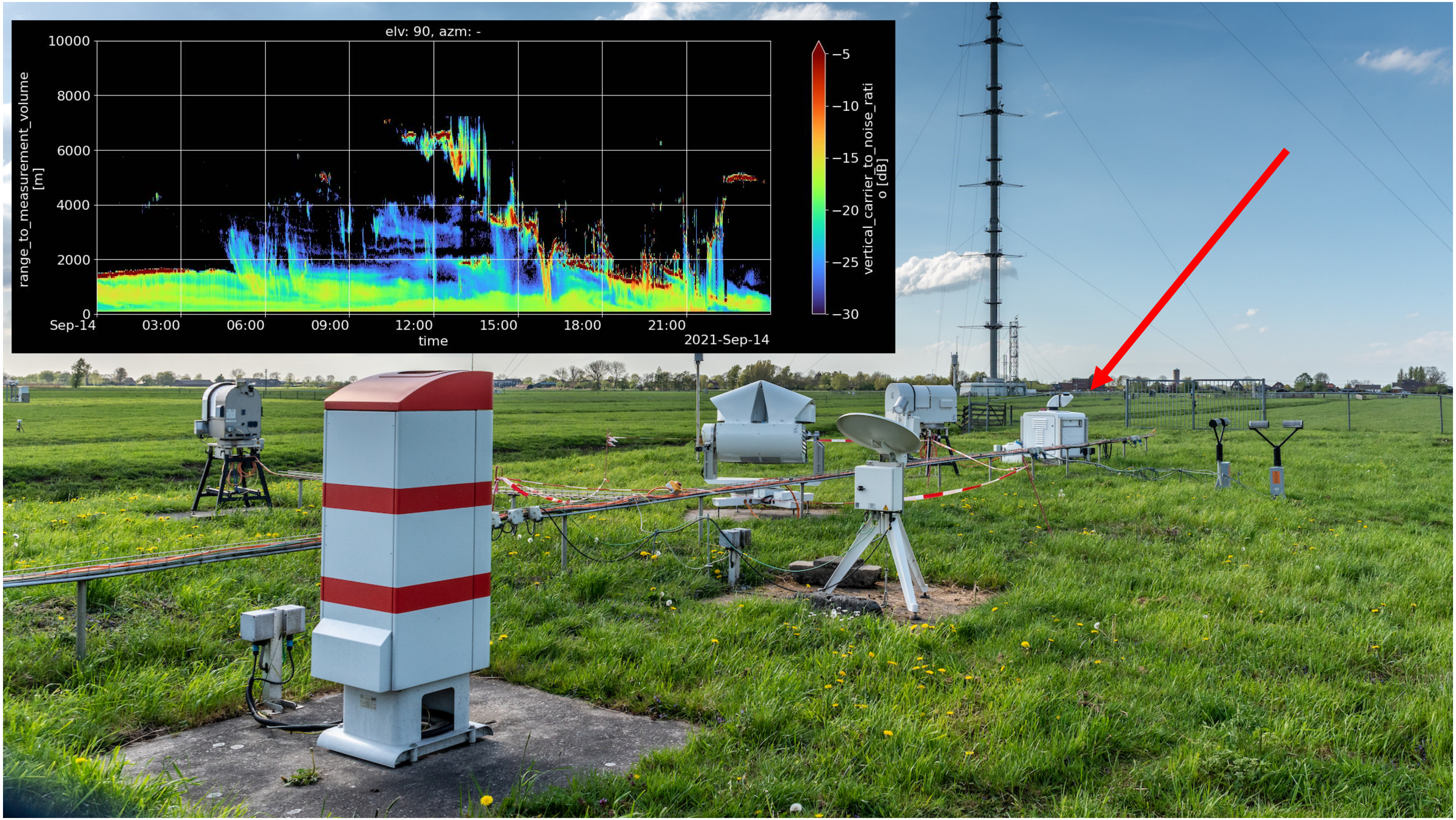
Key

——— Optical path of the emitted laser pulse (radiation at frequency f_t)

– – – – Optical path of the received light (radiation at frequency $f_t + \Delta f$)

——— Beam of the local oscillator laser (radiation at frequency f_{lo})

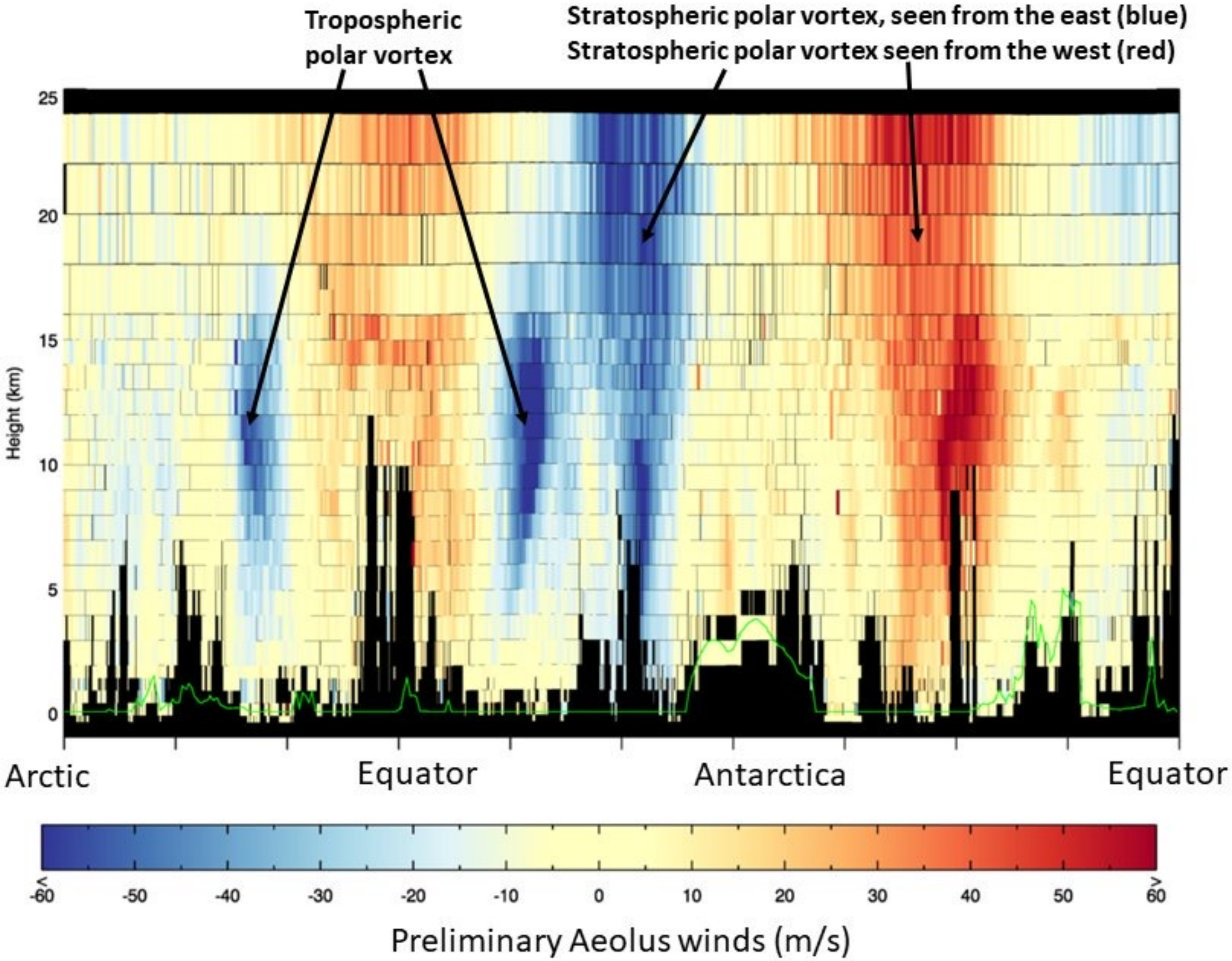
1 Pulsed Laser
2 Optical element separating the received and emitted lights
3 Telescope (used for transmitting and receiving)
4 Scatterers
5 Local oscillator laser (continuous wave laser)
6 Frequency control loop. This device sets the difference f_t-f_{lo}.
7 Optical element aligning the beam of the local oscillator along the optical axis of the received light beam and mixing them together
8 Quadratic detector
9 Analog to digital converter and digital signal processing unit


elv: 90, azm: -
range_to_measurement_volume [m]
10000
8000
6000
4000
2000
0
Sep-14
03:00
06:00
09:00
12:00
15:00
18:00
21:00
time
2021-Sep-14
vertical_carrier_to_noise_ratio [dB]
−5
−10
−15
−20
−25
−30

Wind Lidar – in space

- ESA Earth Explorer – Atmospheric Dynamics Mission (ADM) - Aeolus
- HSRL (High Spectral Resolution Lidar)
  - Rayleigh (molecular channel) and a Mie (particle) channel
  - Rayleigh channel is needed in upper (clear due to lack of particles) atmosphere


Sun
Flight direction
Flight altitude
320 km
Line-of-sight
35°
230 km
1 observation
87 km
Measurement track
esa
aeolus
because wind matters



First wind data from ESA's Aeolus satellite. These data are from three quarters of one orbit around Earth. The image shows large-scale easterly and westerly winds between Earth's surface and the lower stratosphere, including jet streams. As the satellite orbits from the Arctic towards the Antarctic, it senses, for example, strong westerly winds streams, called tropospheric vortices (shown in blue) each side of the equator at mid latitudes. Orbiting further towards the Antarctic, Aeolus senses the strong westerly winds (shown in blue left of Antarctica and in red right of Antarctica) circling the Antarctic continent in the troposphere and stratosphere (Stratospheric Polar Vortex). The overall direction of the wind is the same along the polar vortex, but because the Aeolus wind product is related to the viewing direction of the satellite, the colour changes from blue to red as the satellite passes the Antarctic continent. Credit: ESA/ECMWF

Read more at: https://phys.org/news/2018-09-aeolus-wows.html#jCp

esa

aeolus
because wind matters

Lidar vs Radar

- Lidar and Radar have in common:
  - Active remote sensing
  - Capable of determining the distance where scattering occurs unambiguously
- Main difference:
  - Lidar: sensitive to ‘smaller’ particles (molecules, aerosols)
  - Radar: sensitive to ‘larger’ particles (droplets, air parcels)

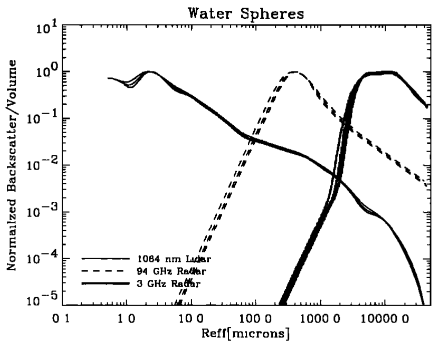


Figure 1. Normalized scattering per unit aerosol volume for water spheres. Results for three different values of γ (2.0, 5.0, 7.0) are shown.

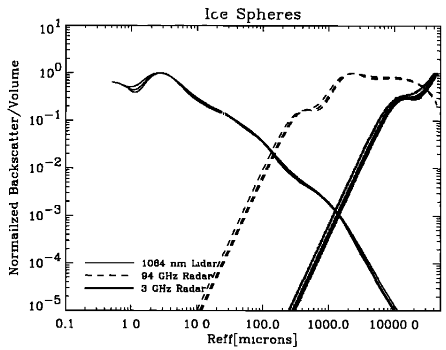


Figure 2. Normalized scattering per unit aerosol volume for ice spheres.

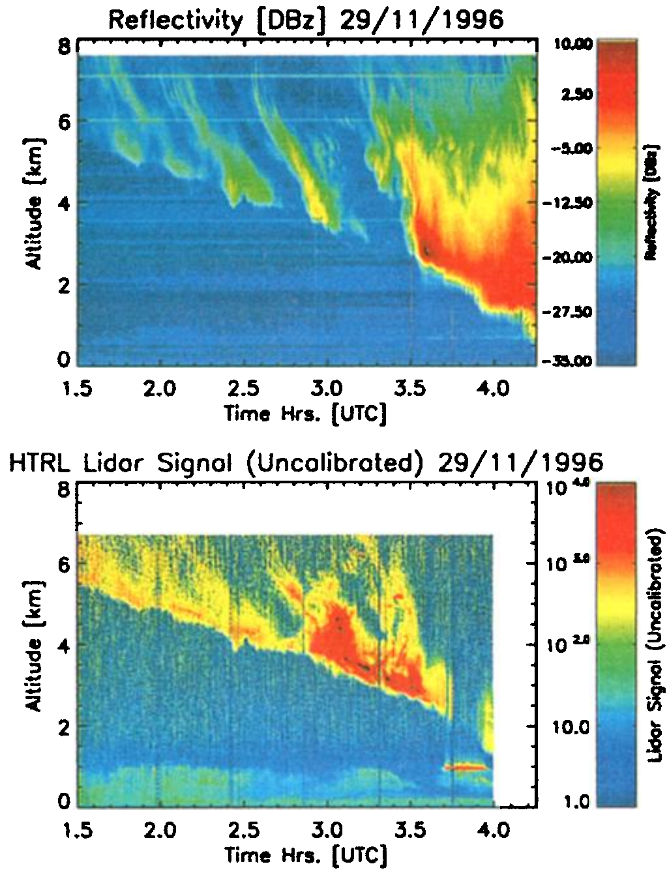


Plate 1. (top) Observed radar reflectivity and (bottom) lidar backscatter signal for November 29, 1996. The strong vertical lines in the radar image are due to pickup noise.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 106, NO. D21, PAGES 27,425–27,448, NOVEMBER 16, 2001

Cloud effective particle size and water content profile retrievals using combined lidar and radar observations
1. Theory and examples

D. P. Donovan and A. C. A. P. van Lammeren

Sensor Synergy

- Combination of both to infer effective particle sizes in clouds
- CLARA campaign (1996), Delft, The Netherlands

27,454 DONOVAN ET AL.: LIDAR/RADAR CLOUD OBSERVATIONS,2

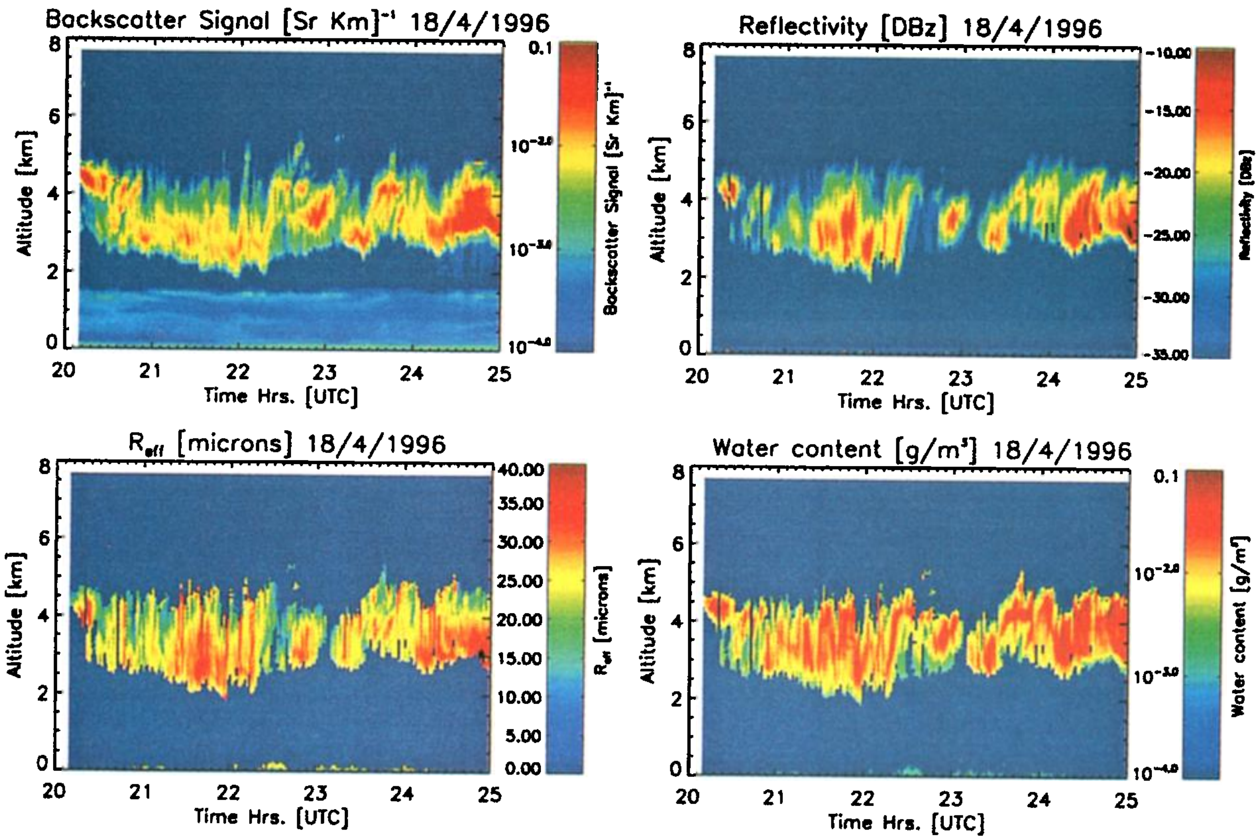
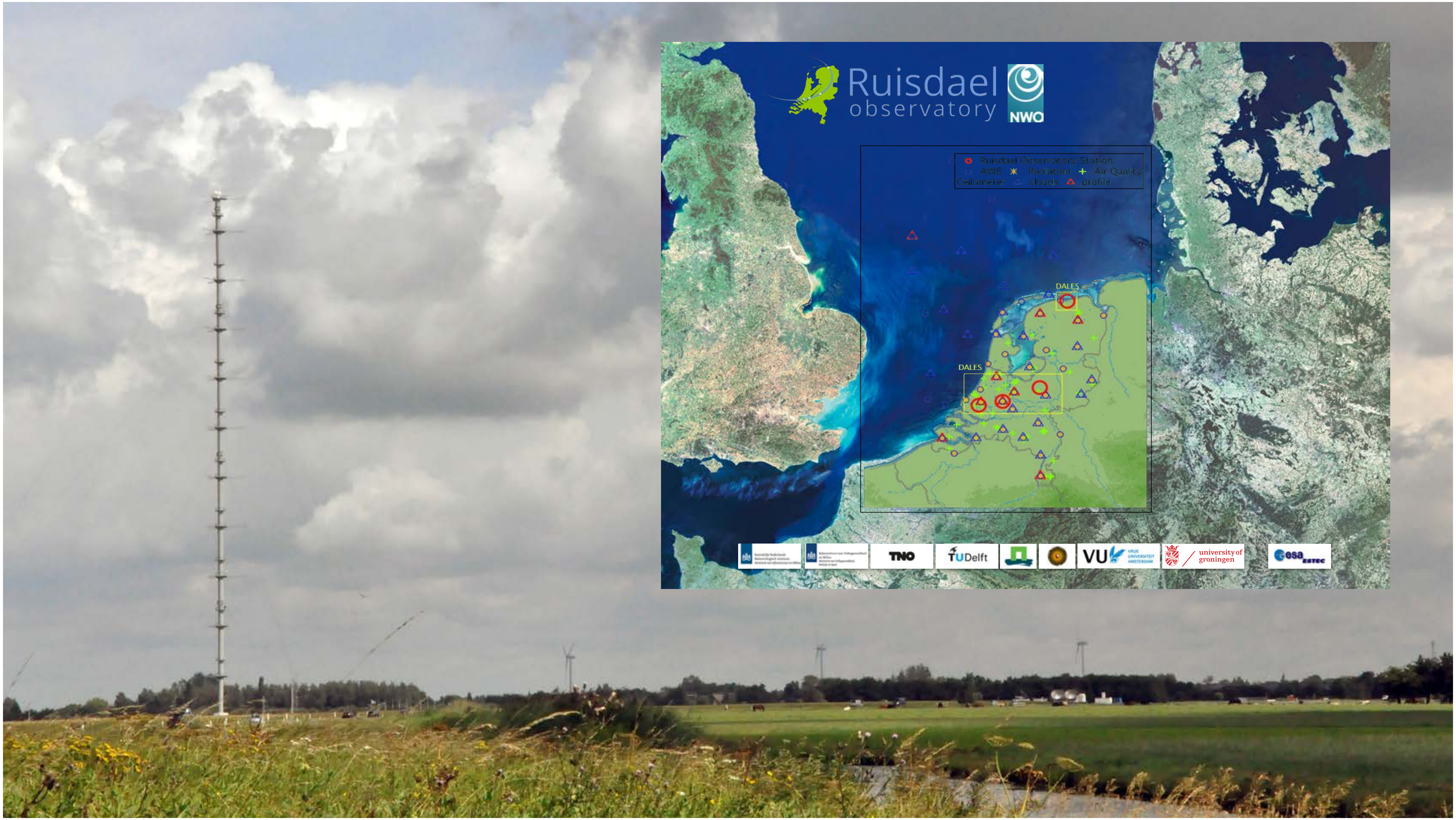


Plate 1. (top) Observed radar reflectivity and lidar backscatter signal together with (bottom) the results of the lidar/radar inversion for April 18, 1996.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 106, NO. D21, PAGES 27,449–27,464, NOVEMBER 16, 2001

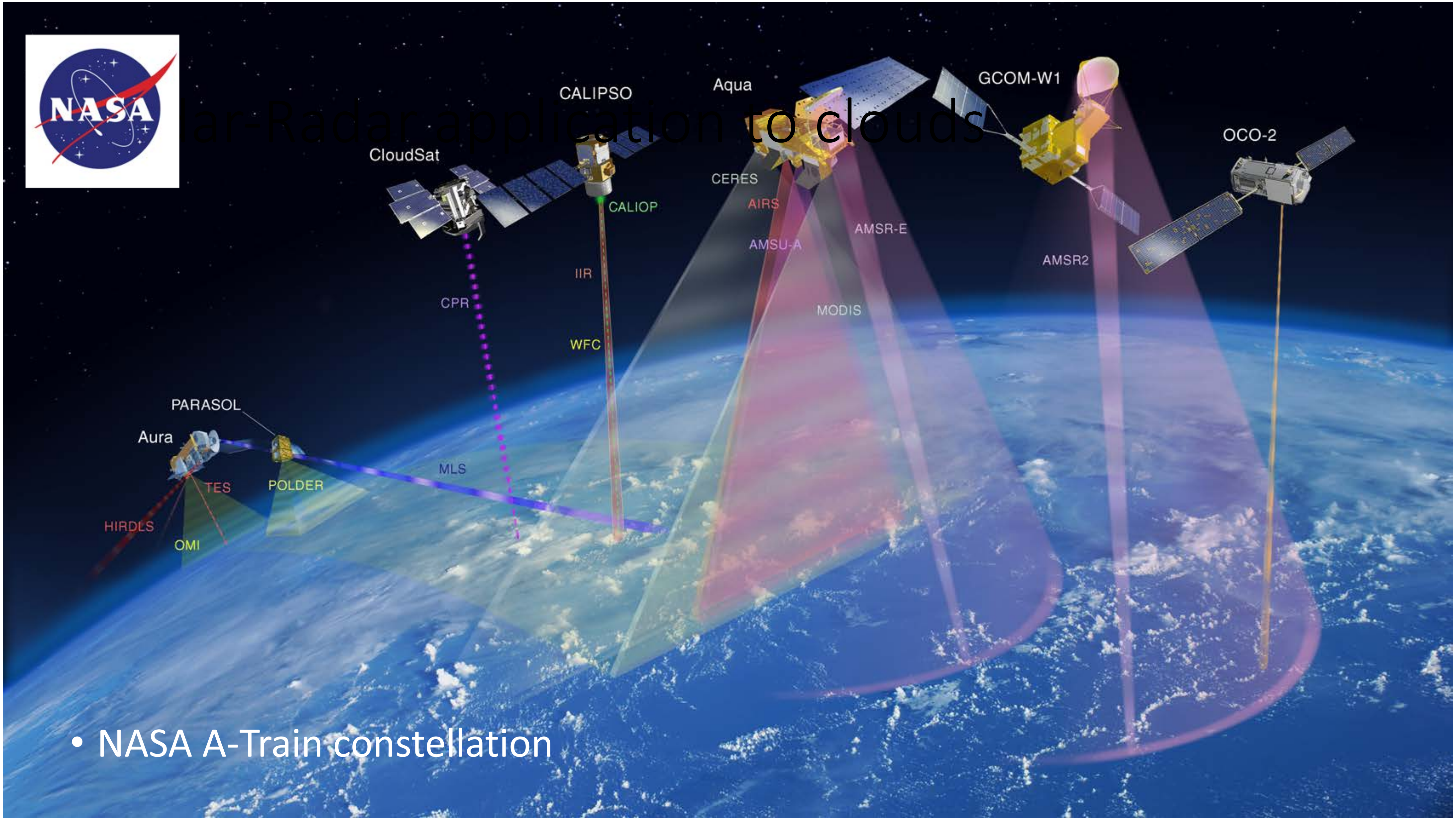
Cloud effective particle size and water content profile retrievals using combined lidar and radar observations
2. Comparison with IR radiometer and in situ measurements of ice clouds

D. P. Donovan, [1] A. C. A. P. van Lammeren, [1] R. J. Hogan, [2]
H. W. J. Russchenberg, [3] A. Apituley, [4] P. Francis, [5] J. Testud, [6] J. Pelon, [7]
M. Quante, [8] and J. Goddard [9]

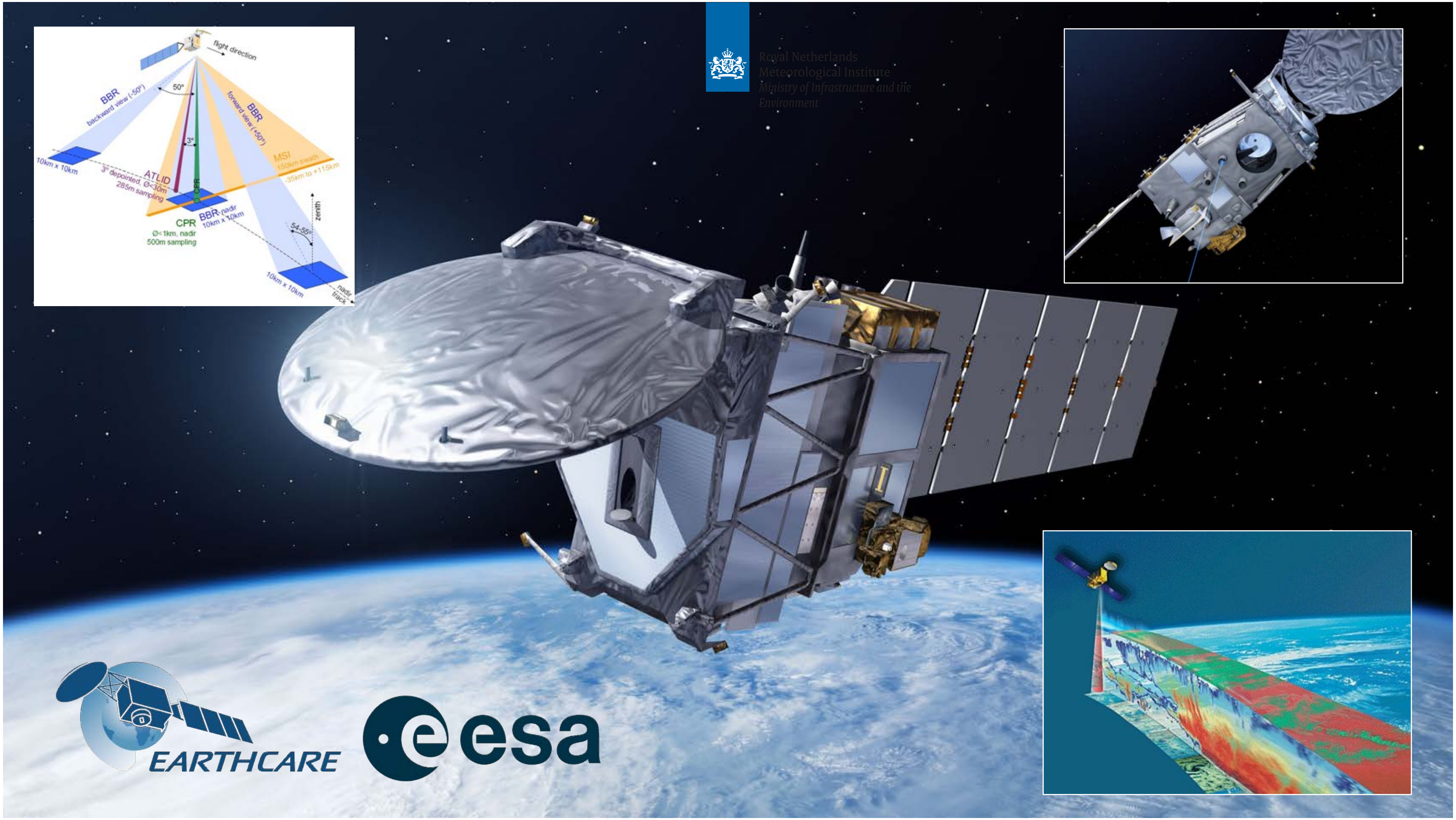

Ruisdael
observatory
NWO
Ruisdael Observatory Station
AWS
Radiation
Air Quality
Ceilometer
clouds
profile
DALES
DALES
TNO
TUDelft
VU
VRIJE UNIVERSITEIT AMSTERDAM
university of groningen
esa
ESTEC


Cabauw Observatory
Cabauw Experimental site for Atmospheric Research
A “Field Laboratory”
Ruisdael
observatory
Drizzle
suveillance
radar
In-situ
Wind profiler
Raman Lidar
Remote Sensing
Site
Aerosol inlet
Transport
line
Manifold
Ceilometer
UV-Lidar
In-situ Aerosol/
Trace Gases
Radiation site (BSRN, Aeronet)
MAXDOAS
Meteorological
Measurement
Tower
Calibration
and Support
Facility
Cloud Radar
Raman Lidar

lar-Radar application to clouds



• NASA A-Train constellation


flight direction
BBR
backward view (-50°)
50°
BBR
forward view (+50°)
3°
MSI
150km swath
-35km to +115km
10km x 10km
3° depointed, Ø<30m
285m sampling
ATLID
CPR
BBR nadir
10km x 10km
CPR
Ø< 1km, nadir
500m sampling
zenith
54-55°
10km x 10km
nadir
track
Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the
Environment
EARTHCARE
esa

Lidar-Radar application for Wind

- Lidar Wind
- Radar Wind
- Synergy

A. Sathe et al.: Six-beam method

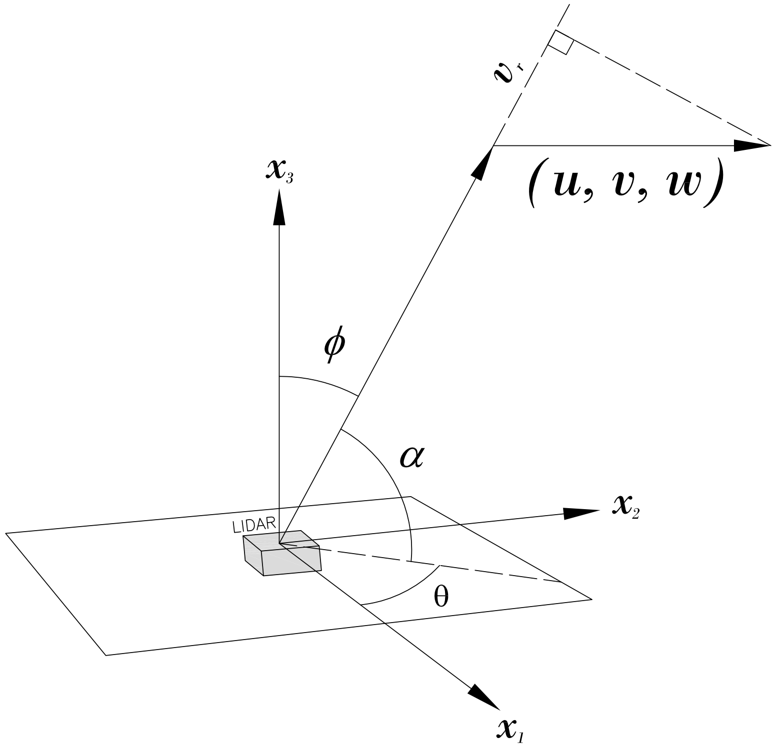


Figure 1. Coordinate system of a lidar.

Lidar wind

- Lidar data is processed using the so-called velocity azimuth display (VAD) method, where the measurements of the radial velocity (also called the line-of-sight velocity) at different azimuth angles are combined to deduce the wind field components.
- For the mean wind speed estimation, the VAD method produces negligible errors.
- For turbulence statistics the VAD method produces significant systematic errors (Sathe et al., 2011b; Sathe and Mann, 2012) mainly due to two reasons;
  - filtering of the smaller scales due to the large size of the probe volume within which the radial velocity is measured
  - second is the contamination by the two-point correlation between the components of the wind field.
- A six-beam method significantly improves the measurement of turbulence.
  - This method uses the variances of the radial velocities from six different lidar beams
  - Five of which are at equally spaced azimuth angles on the base of a scanning cone
  - One beam is vertical.
  - These variances are then combined in order to deduce the second-order moments of the wind field.

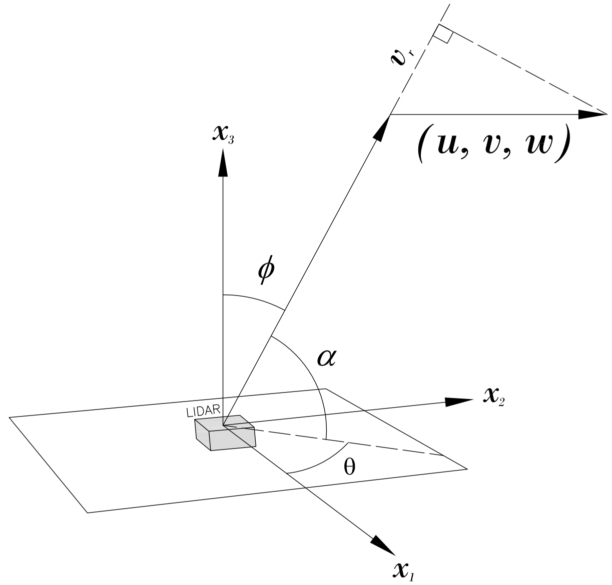


Figure 1. Coordinate system of a lidar.

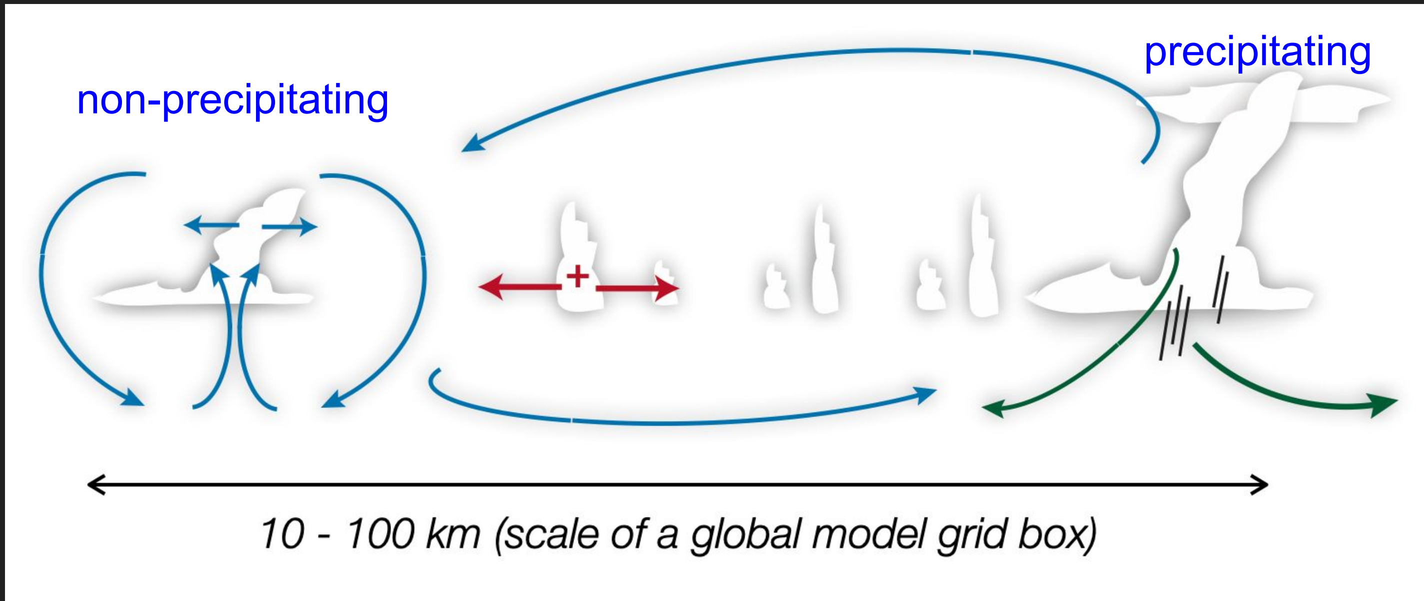
Atmos. Meas. Tech., 8, 729–740, 2015
www.atmos-meas-tech.net/8/729/2015/
doi:10.5194/amt-8-729-2015

Atmospheric Measurement Techniques
Open Access

A six-beam method to measure turbulence statistics using ground-based wind lidars

A. Sathe, J. Mann, N. Vasiljevic, and G. Lea

Motivation



Convective momentum transport (CMT) has mainly been studied with models. In contrast, there are only a few **experimental** studies focused on CMT and how it relates to different cloud types.

Courtesy J. Dias Neto

Goals

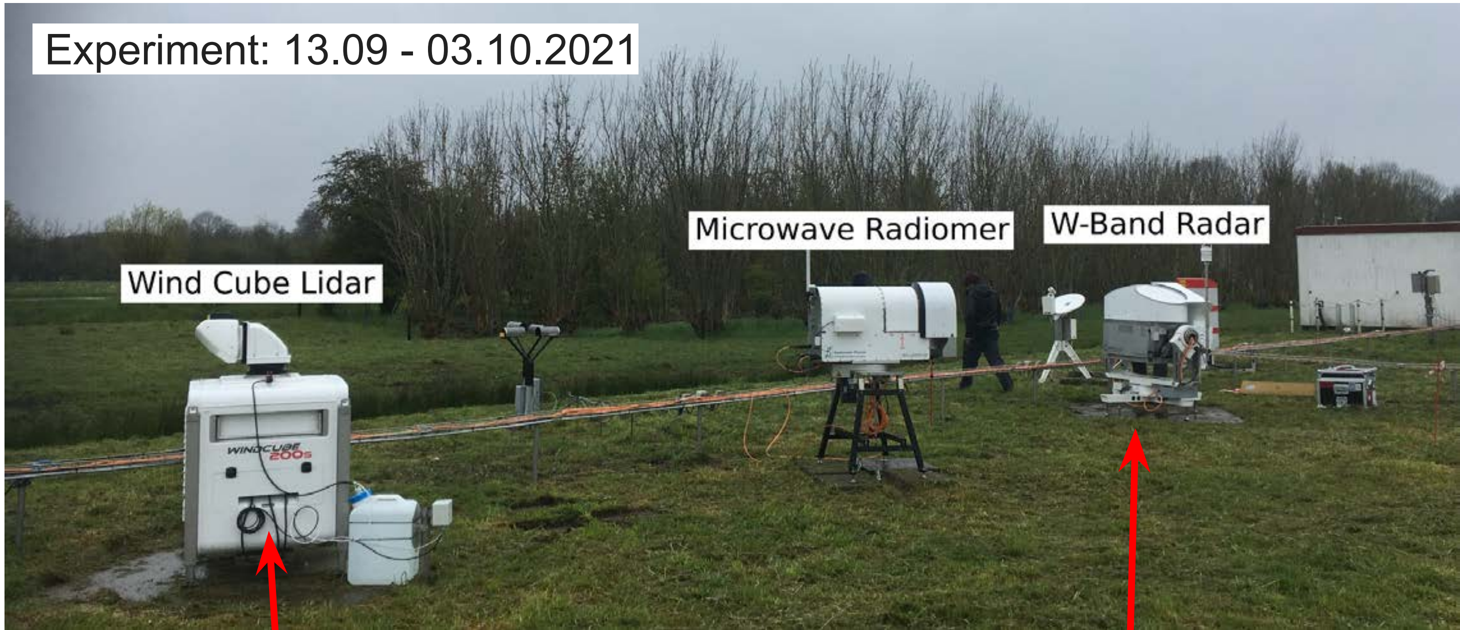
Visualize winds below and throughout cloud fields;

Derive momentum flux profiles extending through the boundary layer across different temporal/spatial scales;

Categorize wind and momentum flux profiles by large-scale wind and cloud regimes to understand the variability and impact of CMT;

Evaluate momentum fluxes in weather models and Large Eddy Simulations run in "weather mode"

Courtesy J. Dias Neto



Dual Ka-W-Band Radar:
Operated performing continuous PPI scans

PPI(a): Azm 0 - 360°
PPI(b): Azm 360 - 0°
Elv (1): 75°

Range resolution: 22 - 40 m
Scan period: 72 s

WindCube Lidar:
operated using the 6 beam strategy (Sathe et al. 2015)

Azm: 0°, 72°, 144°, 216°, 288°
Elv: 90°, 75°

Range resolution: 50 m
Scan period: 27 s

Mobile W-Band Radar:
Operated vertically pointing

Range resolution: 22 - 40 m
Temp. resolution: 1 s

Courtesy J. Dias Neto

Why those instruments?

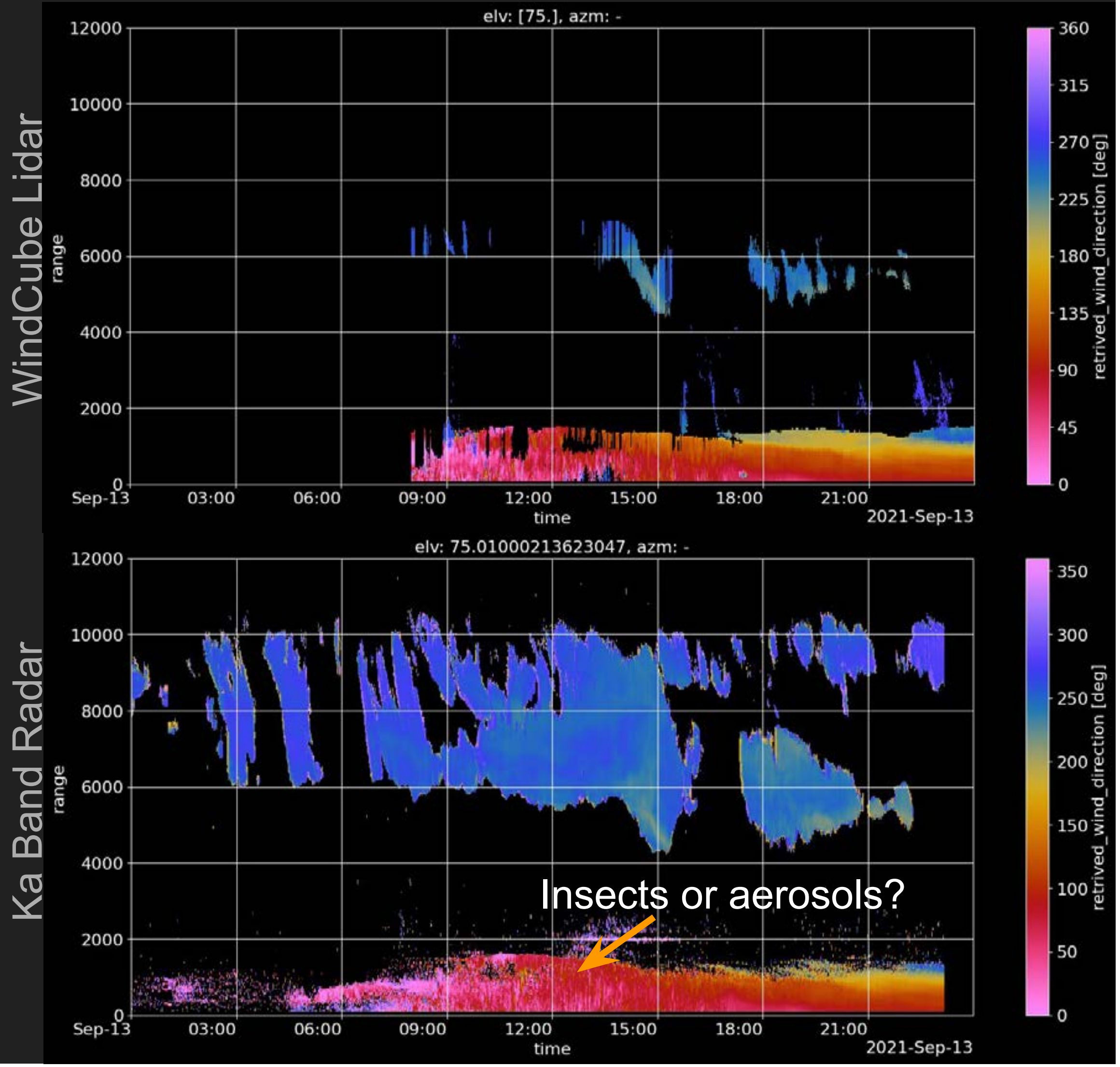
Wind lidar allows retrieving wind profiles in the sub cloud layer.

Radar allows retrieving wind profiles in the cloud layer

Radar bonus: profiles in the sub cloud layer

We see a good agreement between both systems (only one particular day?).

13.09.2021 - Wind direction



Courtesy J. Dias Neto

Why those instruments?

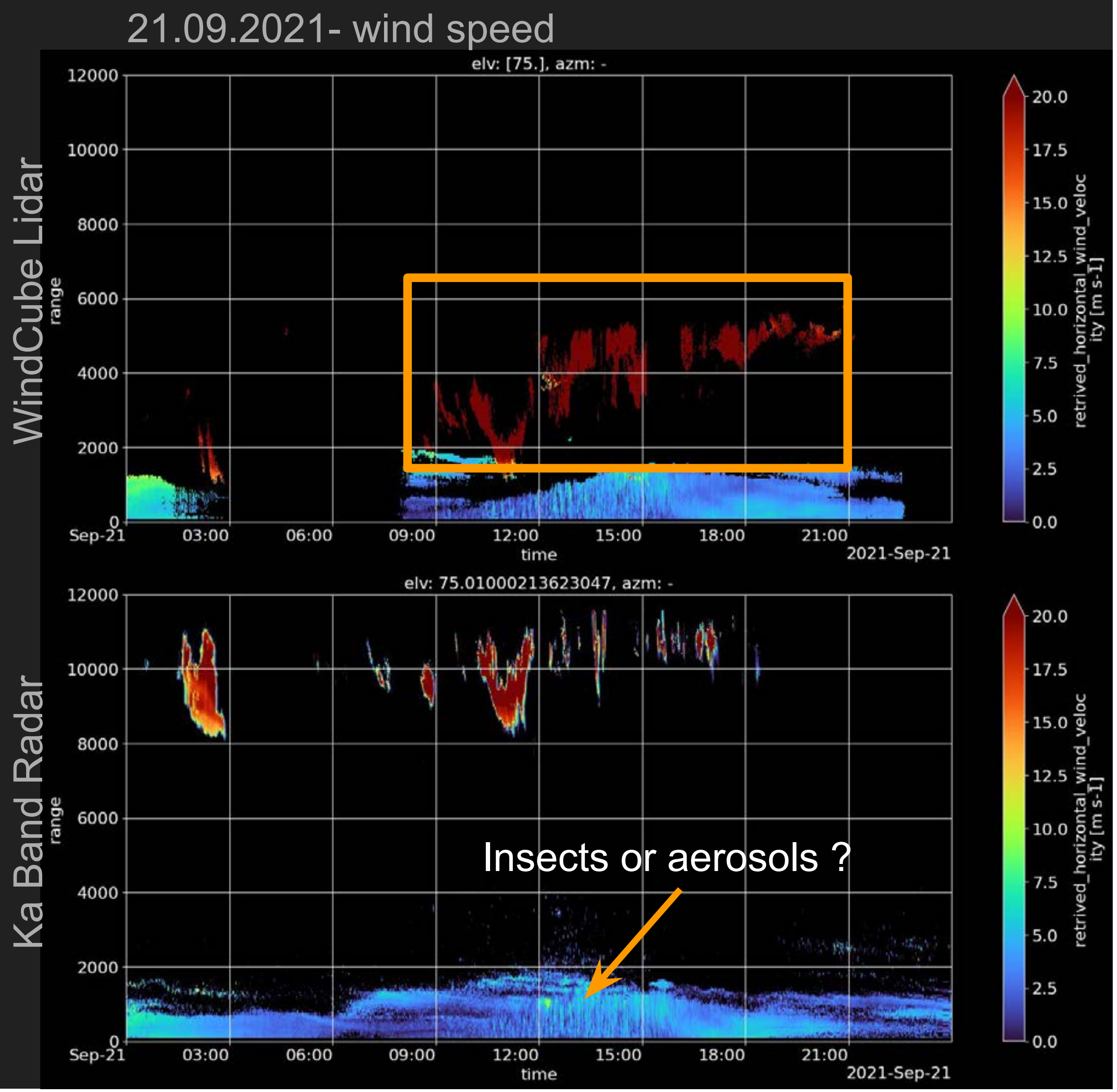
Again, We see a good agreement between both systems.

Limitations:

Strong second trip echos can lead to erroneous positioning of clouds.

Folded Doppler spectra in case of strong winds

Courtesy J. Dias Neto

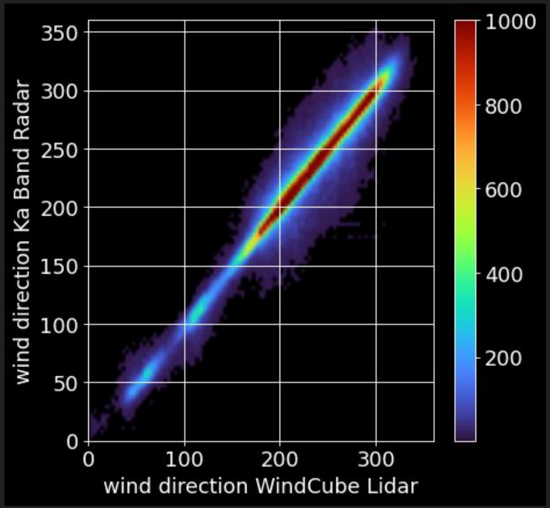


Radar x Lidar: Statistics

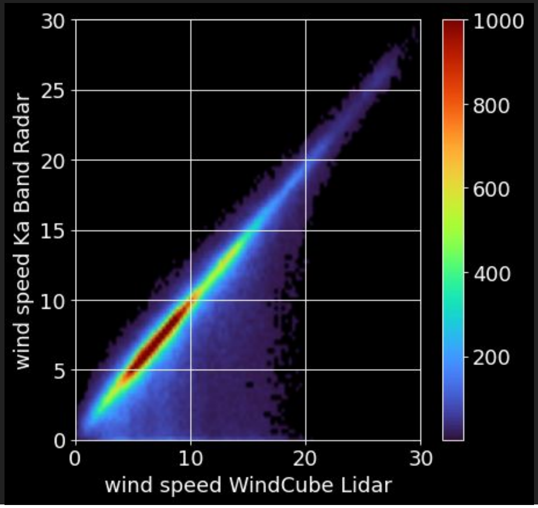
Statistics from the **entire campaign** suggest a good correlations between Lidar and Radar

The broadening of velocity histogram could be related to the second trip echos (Lidar problem) and cloud edges (Radar problem)

Correlation: 0.9



Correlation: 0.77



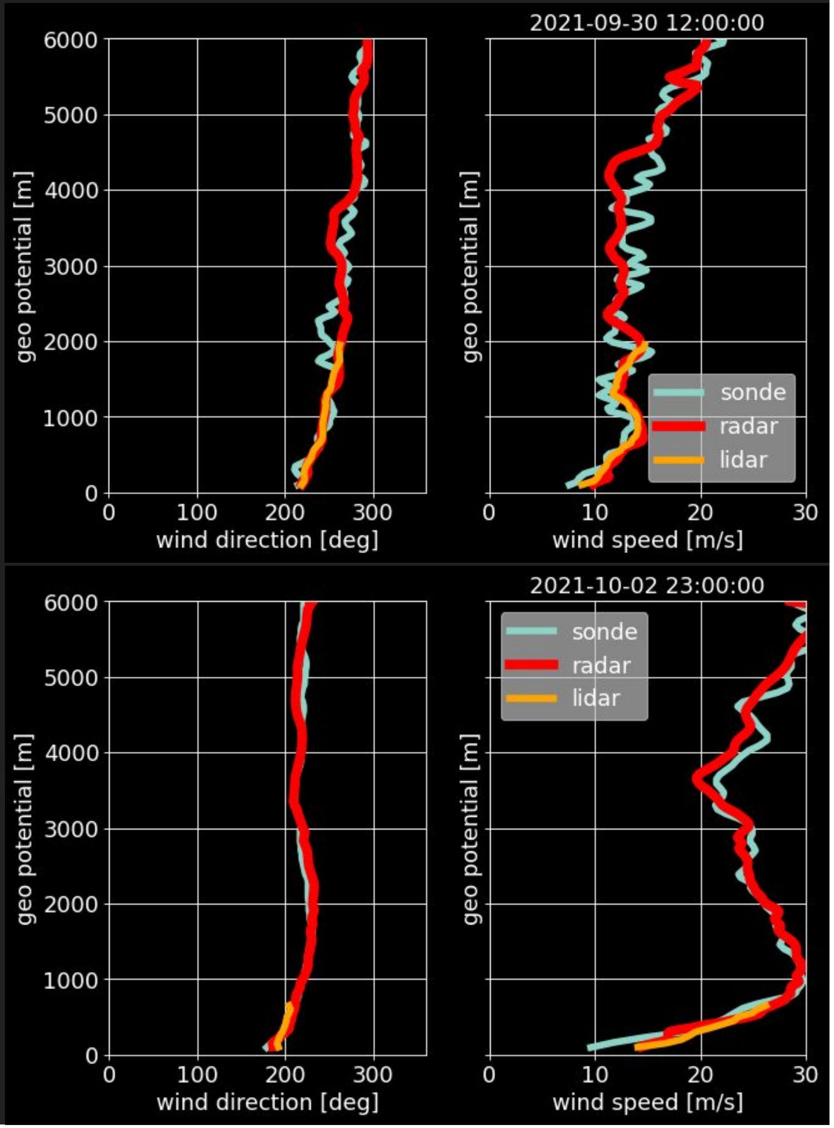
Courtesy J. Dias Neto

Can we get continuous profiles?

34 radiosondes (De Bilt)

Even though De Built is 23 km apart from the experimental site, wind speed and direction profiles from radar and lidar are comparable to the radiosonde.

Thank you KNMI for the radiosondes



Courtesy J. Dias Neto

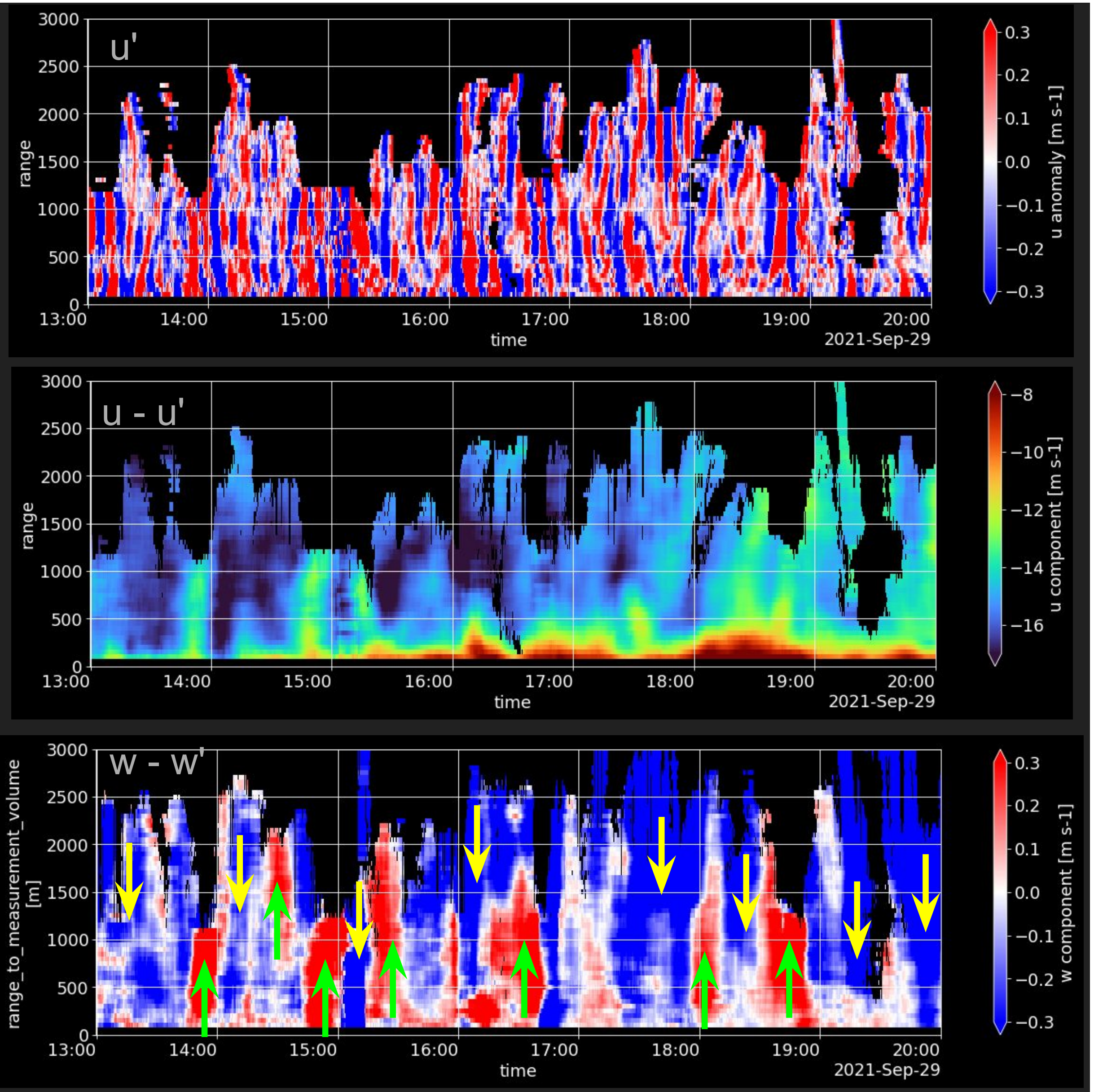
Can we see the circulation ?

u and w 10 min averages

horizontal scale ~ 10km

up and downward motion seems to be correlated with changes in the horizontal velocity

Could it also be related to the presence of clouds?



Courtesy J. Dias Neto

Summary

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and Water Management

- Active remote sensing with optical (lidar) and microwave (radar) based instrumentation can be used in a highly synergstic way when sufficiently closely located
- Proven applications include cloud physics (effective droplet size)
- Using Doppler techniques for detection of 3D atmospheric motion can be applied to study and monitor cloud dynamics
- Various sub-types of lidar and radar instruments can be applied
- Further synergies for other atmospheric parameters, using other profiling techniques and/or column integrated observations, are conceivable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https://ruisdael-observatory.nl