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Study of the configurations and scanning strategies of Doppler Lidars for providing wind and aerosol/cloud profiles

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And our partners from DWD and SUNY

Motivation

- All networks worldwide equiped mostly with standard weather stations
- Few networks (MesoNet) / few sites (like super sites or GRUAN) equipped with upper air observations (radiosondes, ceilometers, Lidars)

➔ **Detailed tropospheric observations required to improve weather forecasts of NWP models**

- Target requirements for winds
  - Accuracy of 0.5-1m/s
  - Refresh rate of 5-10min
  - Monitoring of boundary layer from the ground to 2km of altitude
  - 50m of resolution

Source OSCAR-WMO, Pailleux-2002, Wulfmeyer-2015, Illingworth - 2015

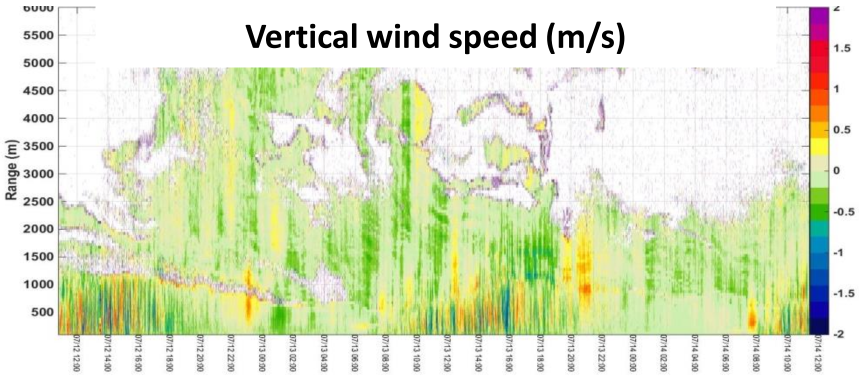
Measurement capabilities of Doppler Lidars

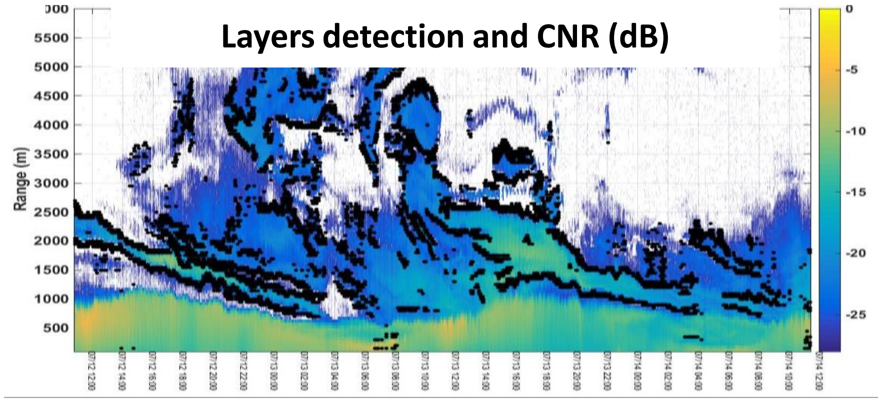
Measure **remotely** winds, aerosols / clouds and backscatter **inside PBL**

Flexible Scenarios PPI / RHI / DBS / LOS

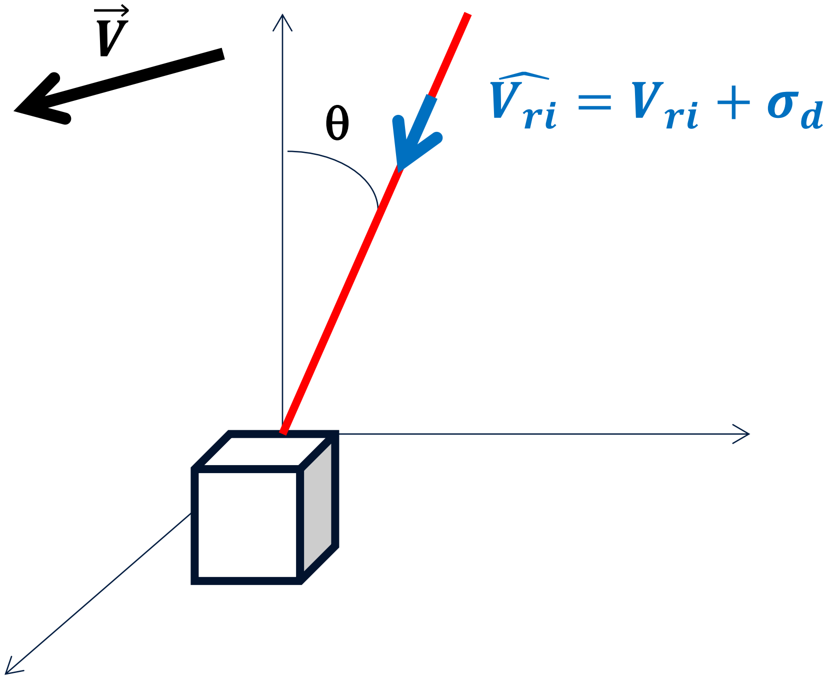
➔ **What is the optimal configuration ?**

➔ **How to integrate them into networks?**





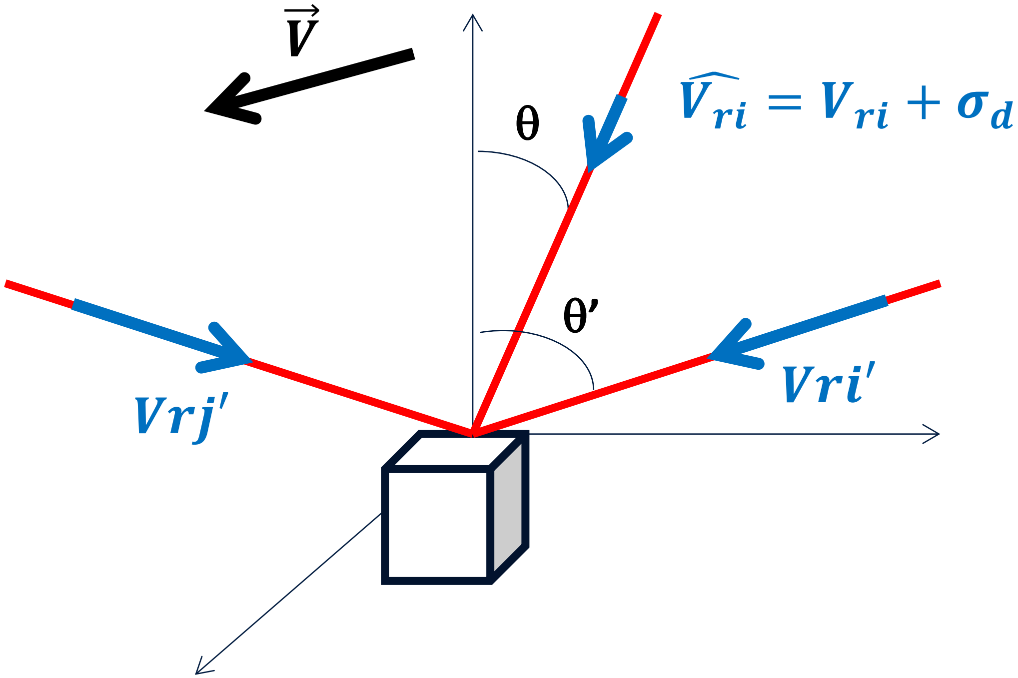
Scanning scenarios for wind reconstruction



$$v_r = P\vec{V} + \sigma_d$$

- **Combinaison of the Doppler velocities vr of n beams at the different altitudes with a random error σd**
- Which Lidar configuration?
- Which zenital angle ?
- How many beams ?
- Which algorithm for the combinaison ?

Scanning scenarios for wind reconstruction



- Which zenital angle ?
  - Higher angles reduce the impact of random error on relative error of radial wind speed
  - Smaller angles reduce the separation between the beams and thus the error linked to the heterogeneities of the wind at volumes I and j

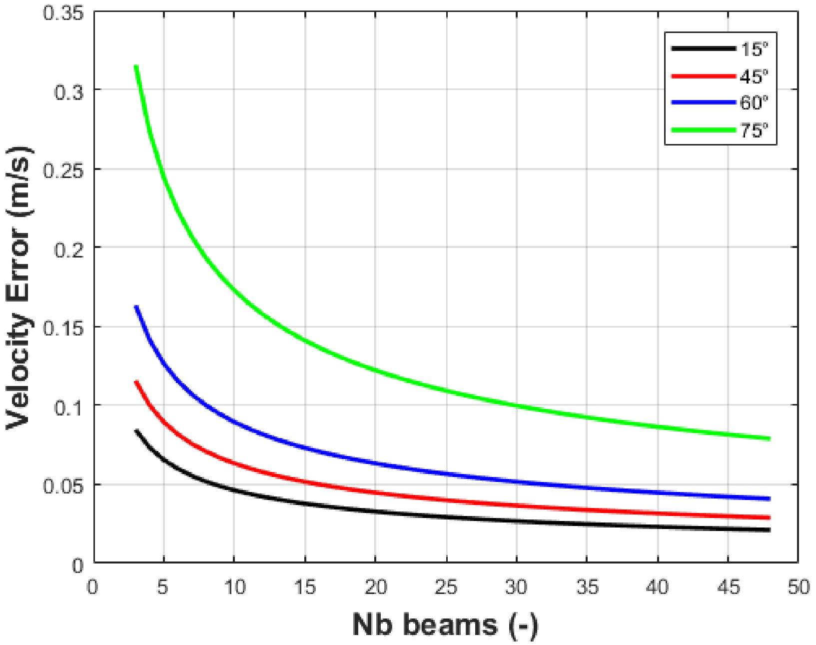
➔Trade-off

Theoretical study (Teschke 2017)

$$(\Delta u)^2 = \frac{2{\sigma_d}^2}{N \ \sin\theta^2}$$

Source G. Teschke and V. Lehmann: Sampling strategies for wind vector retrieval 2017

Scanning scenarios for wind reconstruction



- Which zenital angle ?

➔ **All zenital angles [10°,80°] are acceptable**

- How many beams ?
  - Taking σd=0.1m/s and different zenital angles

  ➔ **Even 3 beams are enough to comply with requirements**

BUT wind was considered as steady if not:

$$(\Delta u)^2 = \frac{2{\sigma_d}^2}{N \ \sin\theta^2} + f(u', Duration)$$

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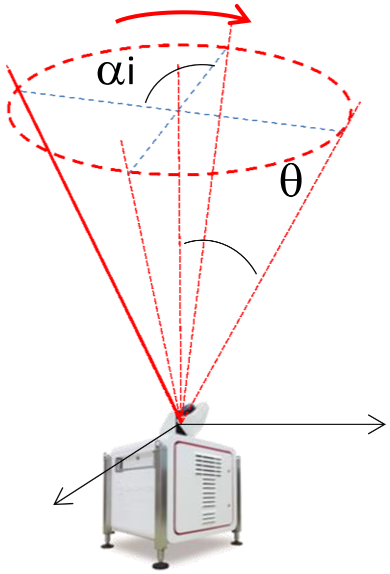
Scanning scenarios for wind reconstruction



Fixed elevation angle

- Which wind reconstruction algorithm ? **DBS (Doppler Beam Swinging)**

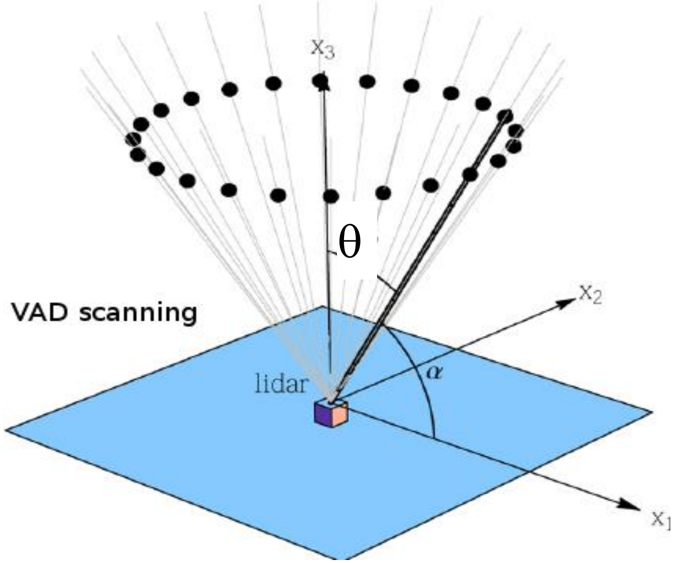
$$V = M \times v_r \quad \text{With} \quad v_r = \begin{pmatrix} v_{rN} \\ v_{rE} \\ v_{rS} \\ v_{rW} \end{pmatrix}$$

$$M = (P^t P)^{-1} P^t$$

In DBS, the wind vector can be retrieved explicitly with these formula.

$$P = \begin{pmatrix} sin(\alpha_N)sin(\theta) & cos(\alpha_N)sin(\theta) & cos(\theta) \\ sin(\alpha_E)sin(\theta) & cos(\alpha_E)sin(\theta) & cos(\theta) \\ sin(\alpha_S)sin(\theta) & cos(\alpha_S)sin(\theta) & cos(\theta) \\ sin(\alpha_W)sin(\theta) & cos(\alpha_W)sin(\theta) & cos(\theta) \end{pmatrix}$$

Scanning scenarios for wind reconstruction



- Which wind reconstruction algorithm ? **VAD (Velocity Azimut Display)**

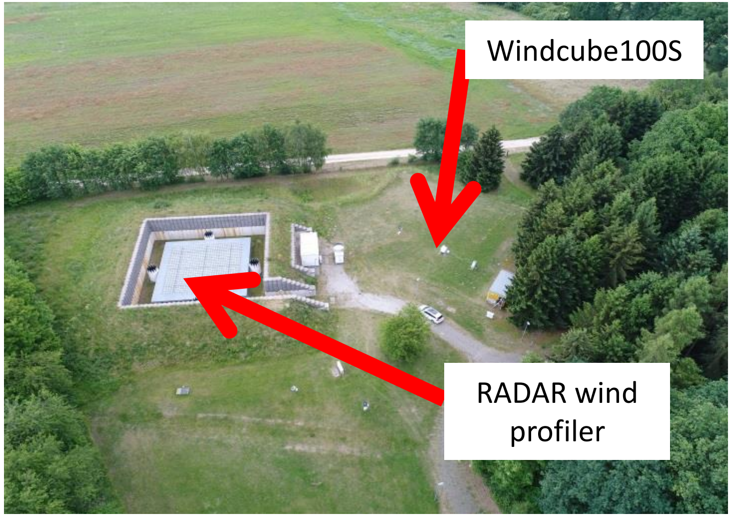
$v_r = PV$ With $v_r = (v_{r1} v_{r2} \dots v_{rN})^T$

In VAD, as no theoretical solution exists, the wind vector is estimated with an iterative loop through the fit of a cosinus function of the radial wind speeds.

$$V_r = u\ cos\alpha sin\theta + v\ sin\alpha sin\theta + wcos\theta$$

$$V_r = \underbrace{Vh\ sin\theta}_{Amplitude}.\cos(\alpha - \underbrace{\varphi_{dir}}_{Phase}) + \underbrace{wcos\theta}_{Offset}$$

Evaluation campaign



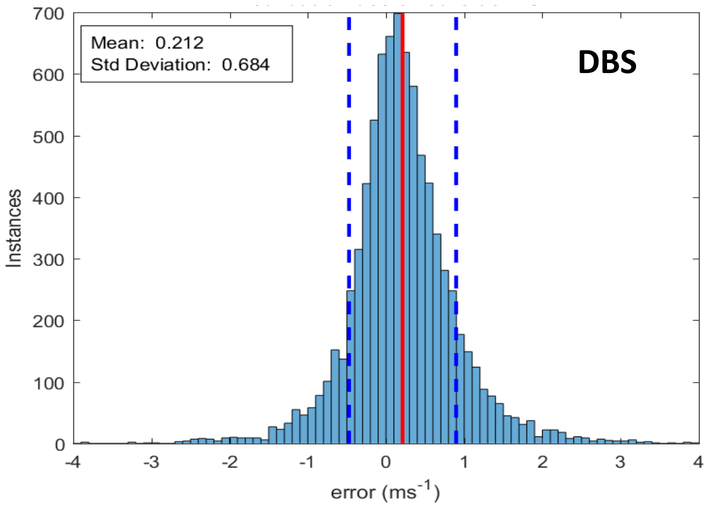
- DWD Lindenberg observatory
- 3 Months of measurements from June to August 2017
- Comparison against Radar Wind Profiler

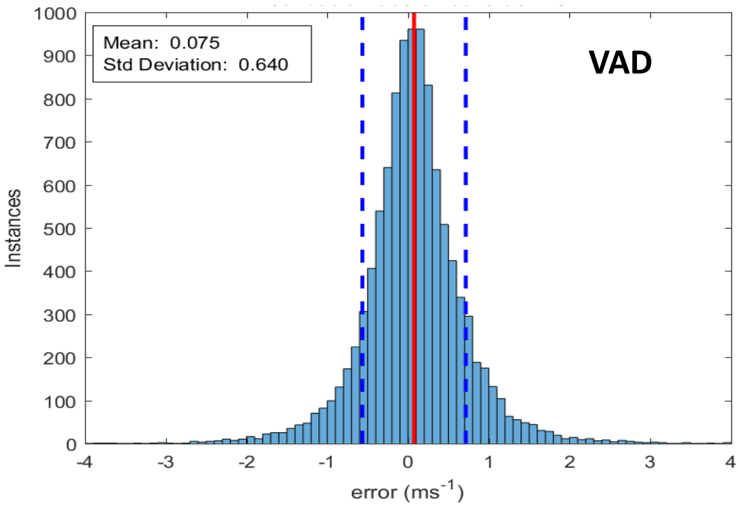
Many thanks again to DWD Lindenberg observatory for leaving us the possibility to install the Lidar and share the radar wind data !

	VAD	DBS
Nb LOS	24 titled	4 titled + 1 vertical
Zenital angle (°)	15°	15°
Averaging time	30min	30min
Duration	45s	18s

	Windcube 100S	RADAR
Wavelength	1.54 µm	62cm
Range resolution	50 m	94 m
First gate	100 m	450 m
Accumulation time	1s	41.65s

Evaluation campaign



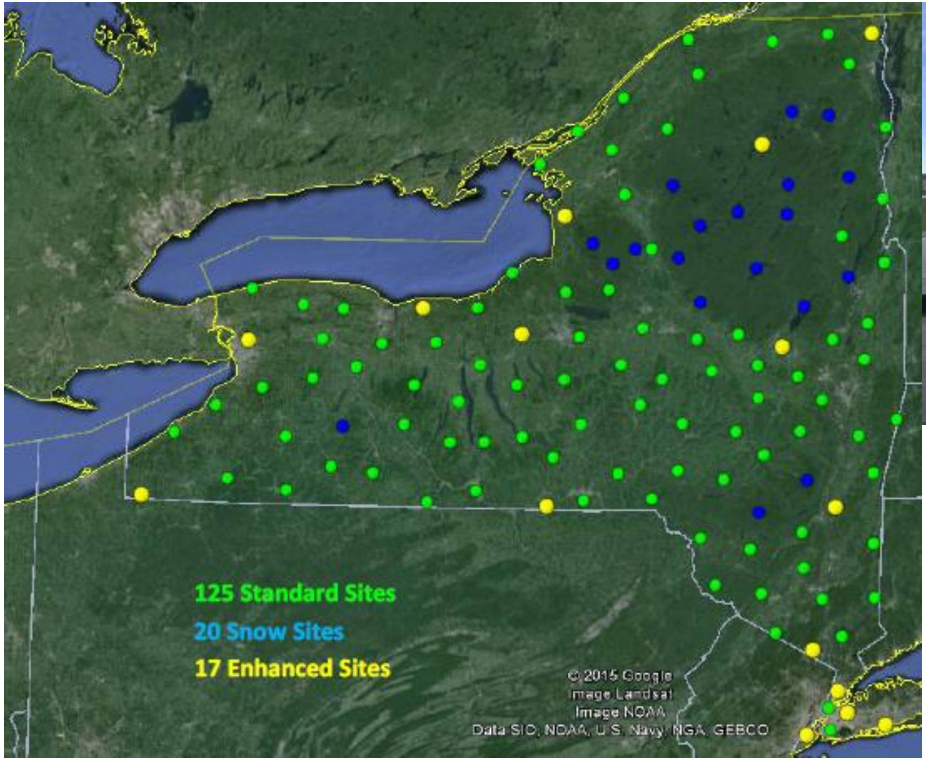


- Trueness of averaged horizontal wind speed significantly better with VAD compared to DBS
- Precision very similar for both Vh and W
- **Both VAD and DBS allows to get wind speeds better than requirements (0.5m/s – 1m/s)**

	DBS	VAD	DBS	VAD
KPI	Vh	Vh	W	W
ME (m/s)	0.21	0.08	0.10	0.07
RMSE (m/s)	0.68	0.64	0.61	0.52

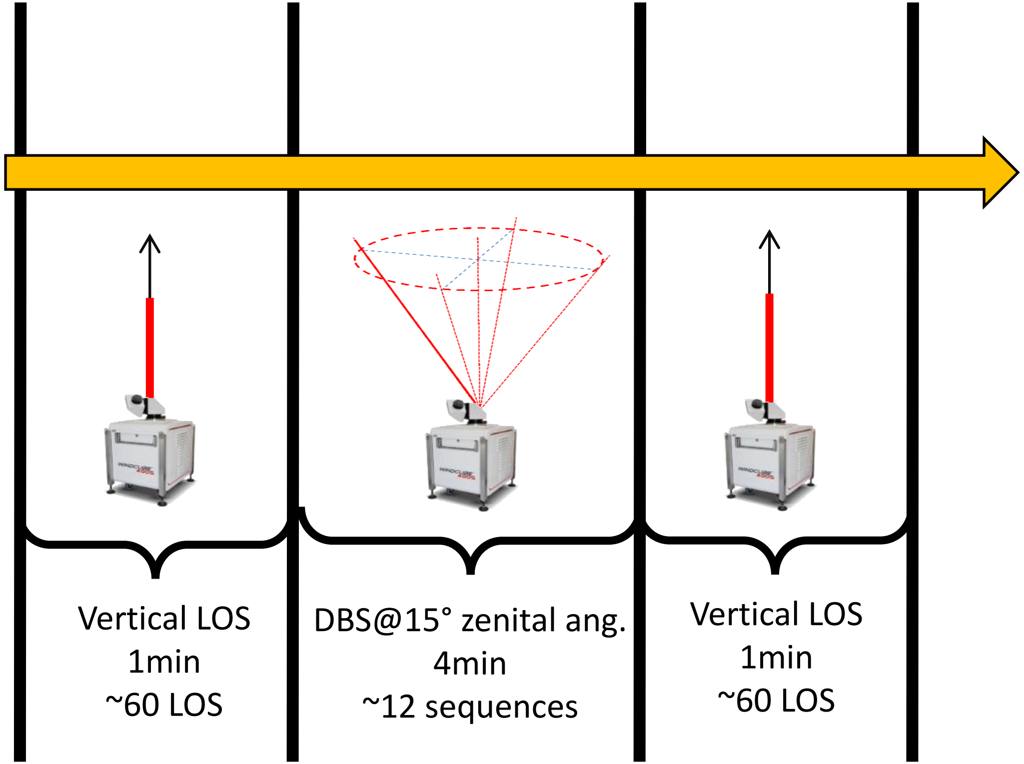
How to integrate Doppler Lidars into networks?

Integration of WINDCUBE Lidars in NY State Mesonet



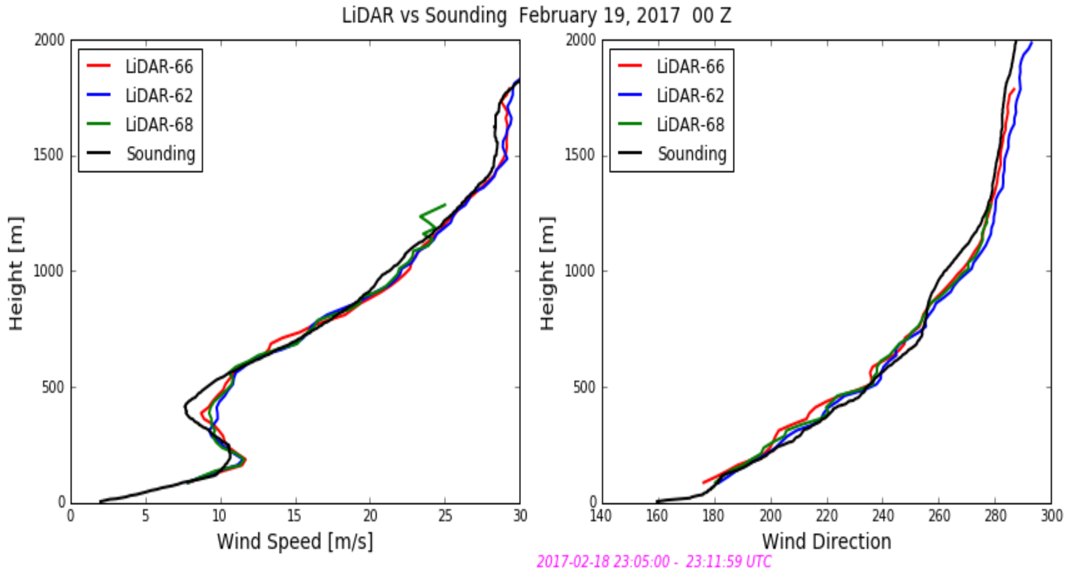
- 17 WINDCUBE100S deployed easily
- Autonomous 24h/7 operations as any std met sensor
- 2 years of continuous upper air observations

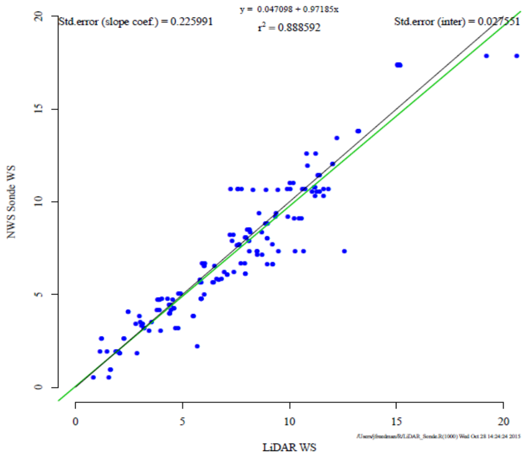
Configuration & Scenarios of Doppler LIDAR



- Adapted configuration: High resolution and long distance
  - Range Resolution of 75m
  - Display resolution of 30m
  - Altitudes from 38m to 10 km
  - 1s of Acc Time per LOS
- Sequence of 5min
  - 1min Vertical LOS
  - 4min DBS

Validation of wind measurements at Albany site





- Mean error on averaged wind speed with radiosounde = 0.23m/s
- High repeatability between Doppler Lidars (0.027m/s)

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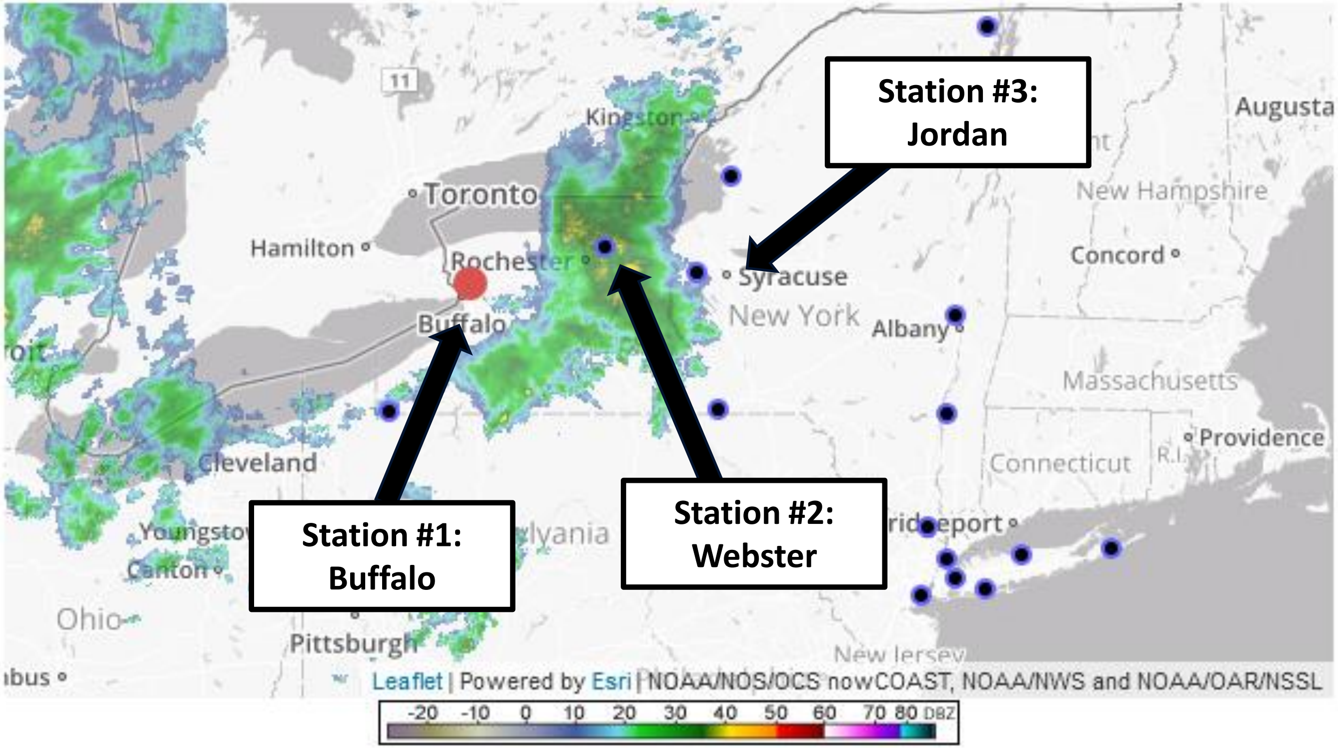
Convective storm the 5th of October



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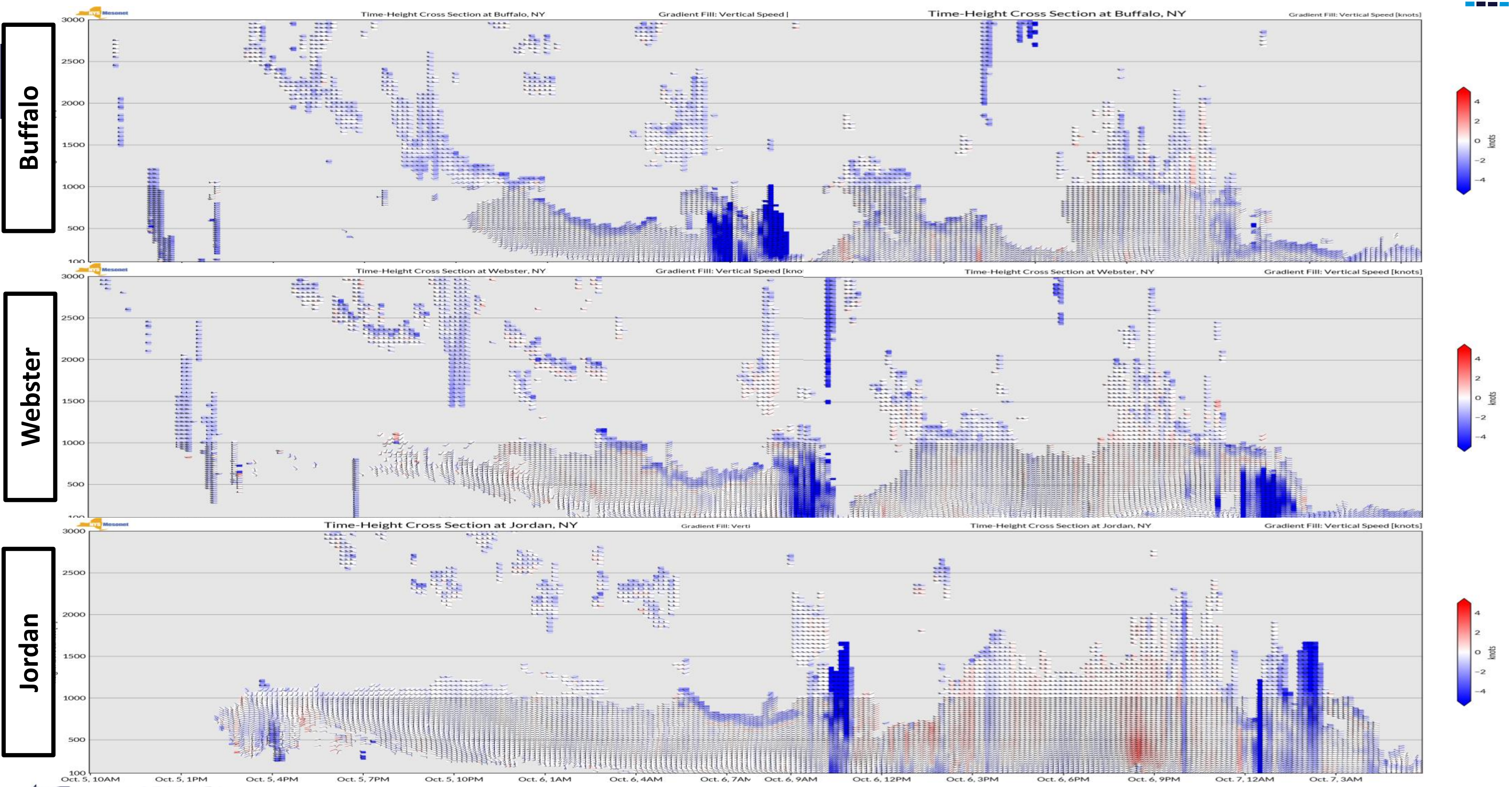
Buffalo
Webster
Jordan
NYS Mesonet
Time-Height Cross Section at Buffalo, NY
Gradient Fill: Vertical Speed [knots]
Time-Height Cross Section at Webster, NY
Gradient Fill: Vertical Speed [knots]
Time-Height Cross Section at Jordan, NY
Gradient Fill: Vertical Speed [knots]
3000
2500
2000
1500
1000
500
100
knots
4
2
0
−2
−4
Oct. 5, 10AM
Oct. 5, 1PM
Oct. 5, 4PM
Oct. 5, 7PM
Oct. 5, 10PM
Oct. 6, 1AM
Oct. 6, 4AM
Oct. 6, 7AM
Oct. 6, 9AM
Oct. 6, 12PM
Oct. 6, 3PM
Oct. 6, 6PM
Oct. 6, 9PM
Oct. 7, 12AM
Oct. 7, 3AM

Conclusions & Perspectives

- Many products can be retrieved with raw data of Doppler Lidars not only winds
- Scanning capabilities allow high versatility
- Common scenarios (DBS /VAD) ensure accuracy better than 0.2m/s
- Accuracy can be even improved to few cm/s with longer accumulation times >1s, lower resolutions >50m and with numerous beams in VAD scans
- Successful implementation of WINDCUBE Doppler Lidar in NYS Mesonet*
  - Data QCs show high repeatability between Doppler Lidars (0.027m/s) and high accuracy (0.23m/s) against RS
- Emerging Lidar network in Europe initiated through TOPROF cooperation

→ Next steps to determine the benefits of Doppler Lidars on weather forecasts

Questions ?

State University of New York