WIND SPEED AND DIRECTION ESTIMATION USING RPG CLOUD RADAR

CCRES WORKSHOP

JOSÉ DIAS NETO 19.06.2026

AGENDA

- 1. Introduction
  - A bit of history
  - Basic principle
  - Validation
- 2. Examples of usage
  - Package installation
  - Wind retrieval 35 GHz
  - Wind retrieval 94 GHz

DOPPLER RADAR

- RADAR systems transmit an electromagnetic wave
- Calculate the Doppler velocity

DOPPLER VELOCITY

- The Doppler effect is an apparent change in frequency perceived by an observer moving relative to the source.

$$f_d = f_t[\frac{2v}{c-v}]$$

$$f_d \approx f_t[\frac{2v}{c}]$$

- For meteorological purpose: c >> v
  - c: speed of light
  - v: scatterer
  - fd: Doppler change in frequency
  - ft: Doppler transmitted frequency

Christophorus Buys Ballot proved the existence of the Doppler Effect.
He founded the Royal Dutch Meteorological Institute (KNMI) in 1854.

DOPPLER VELOCITY

- For radars, the Doppler velocity is estimated from the temporal change in phase (interferometry). As a consequence, the estimated velocity is limited to a maximum phase change of +- pi.

- We saw it during the lecture on Wednesday.

$$v_r = \frac{\Delta\Phi_r}{T_s} \cdot \frac{\lambda}{4\pi}$$

$$v_{\max} = \pm \frac{\lambda}{4T_0}$$

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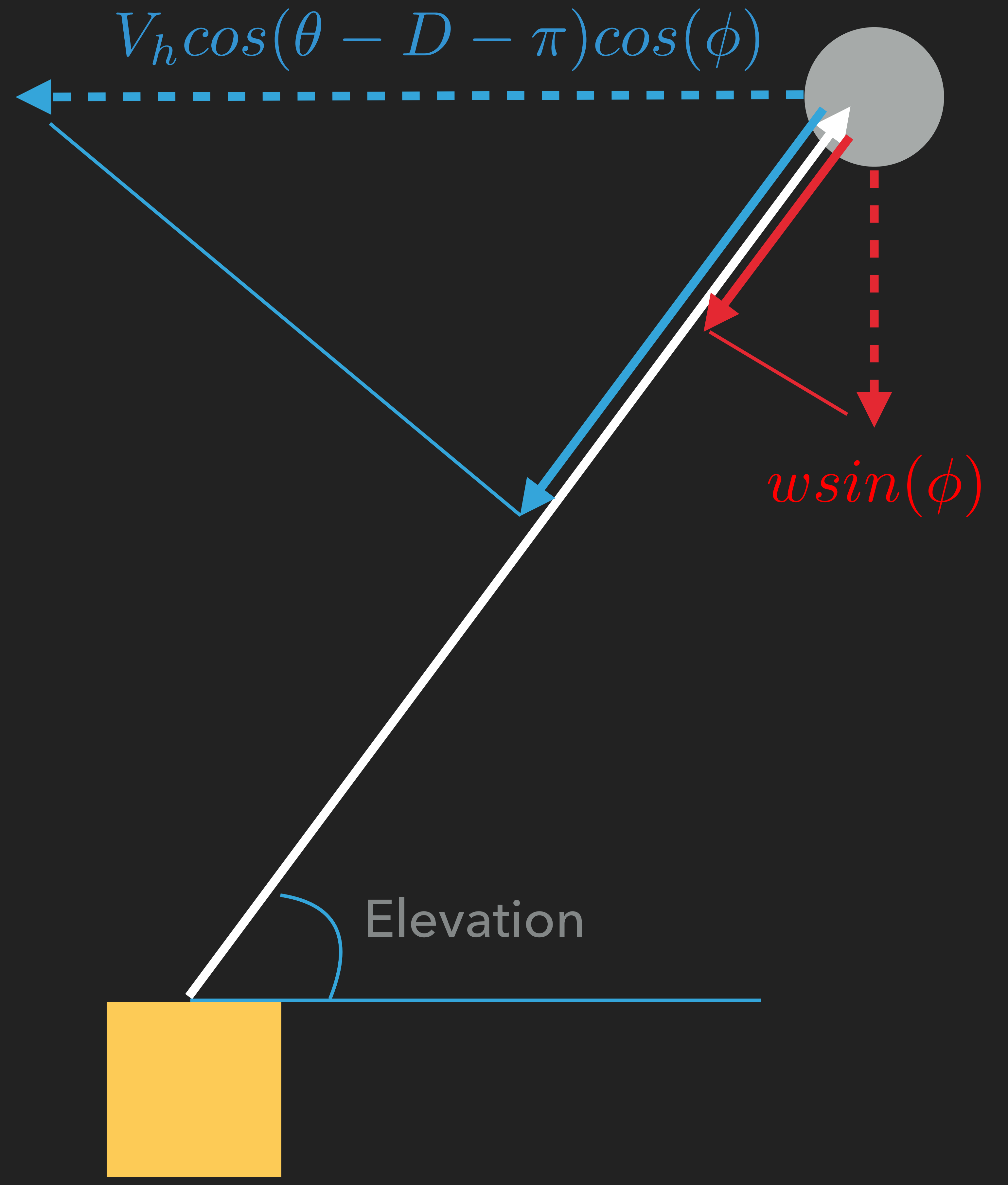
ENCODED WIND COMPONENTS

- The observed radial wind is a result of the contribution of the different components

$$v_r = V_h cos(\theta - D - \pi) cos(\phi) + w sin(\phi)$$

- Vh: horizontal wind speed
- theta: azimuth
- phi: elevation
- D: wind direction



$|v_r| \leq v_{\text{Nyquist}}$

Radial wind: projected wind along the line of sight

*** MIND THE NYQUIST VELOCITY**

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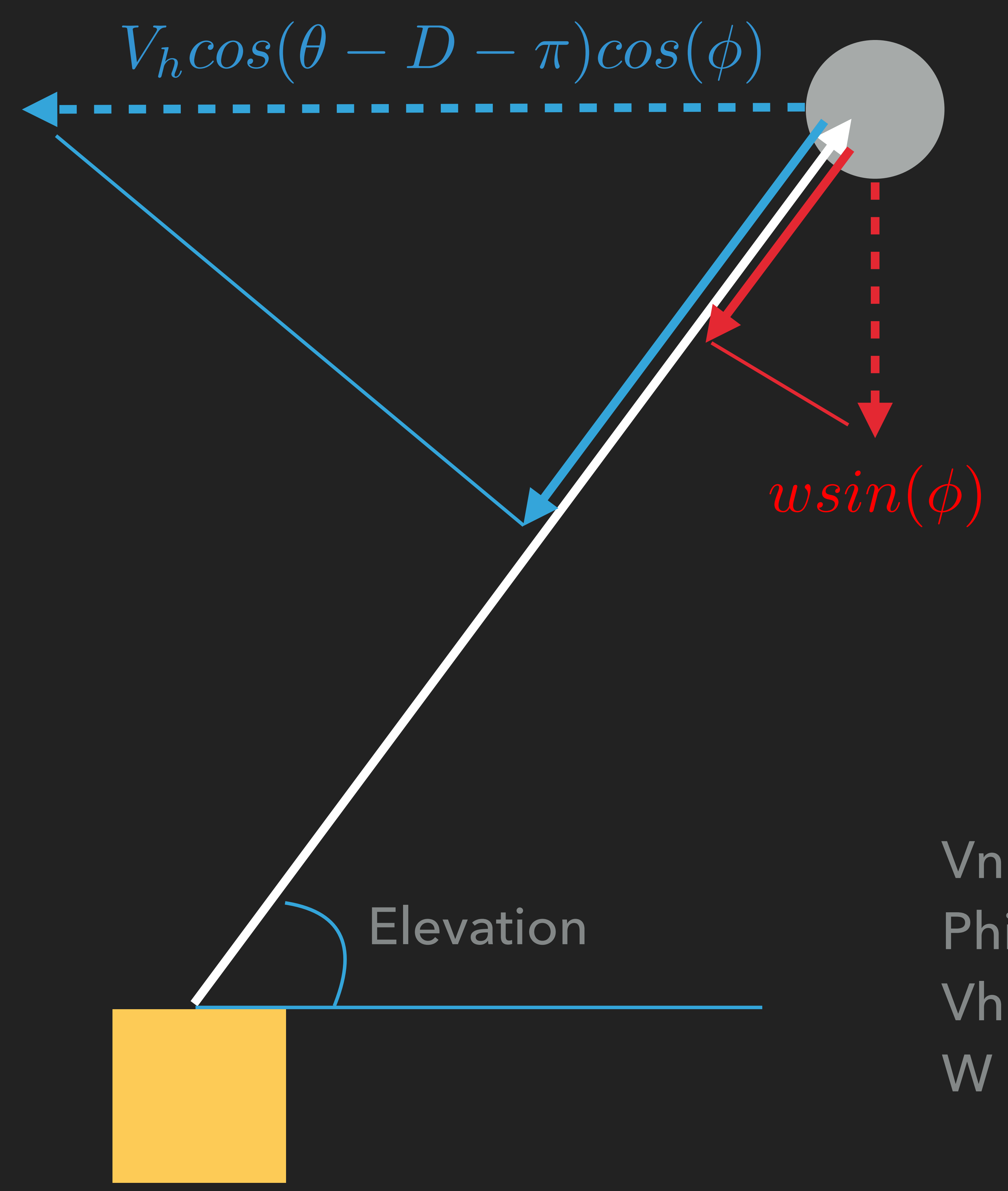

Vn = 5 m/s
Phi = 60 deg
Vh = 12 m/s
W = 1 m/s

Radial wind: projected wind along the line of sight

*** MIND THE NYQUIST VELOCITY**

VELOCITY AZIMUTH DISPLAY

- Lhermitte and Atlas (1961) the Velocity-Azimuth display (VAD) which utilizes an azimuthally scanning beam at an elevation angles.

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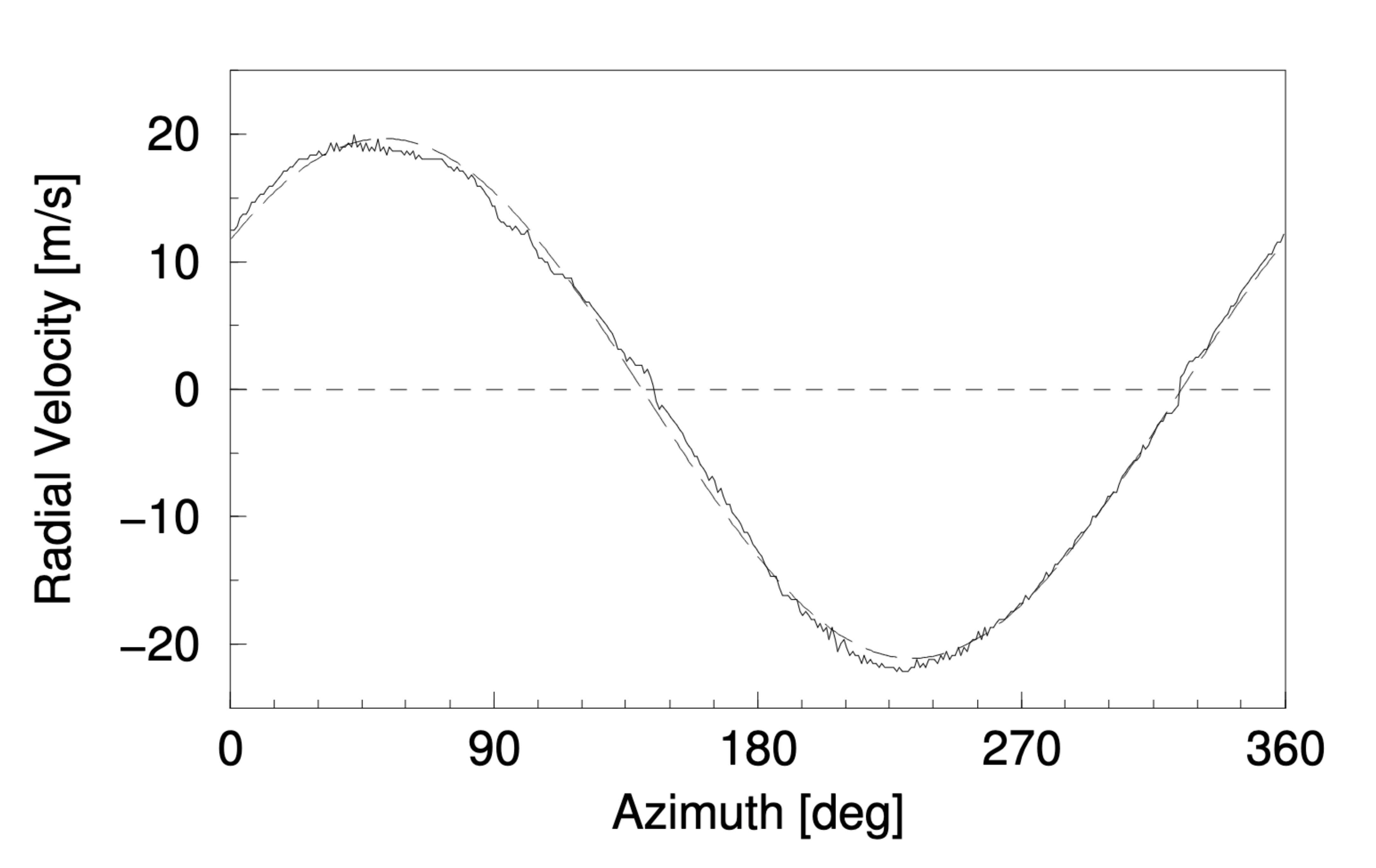

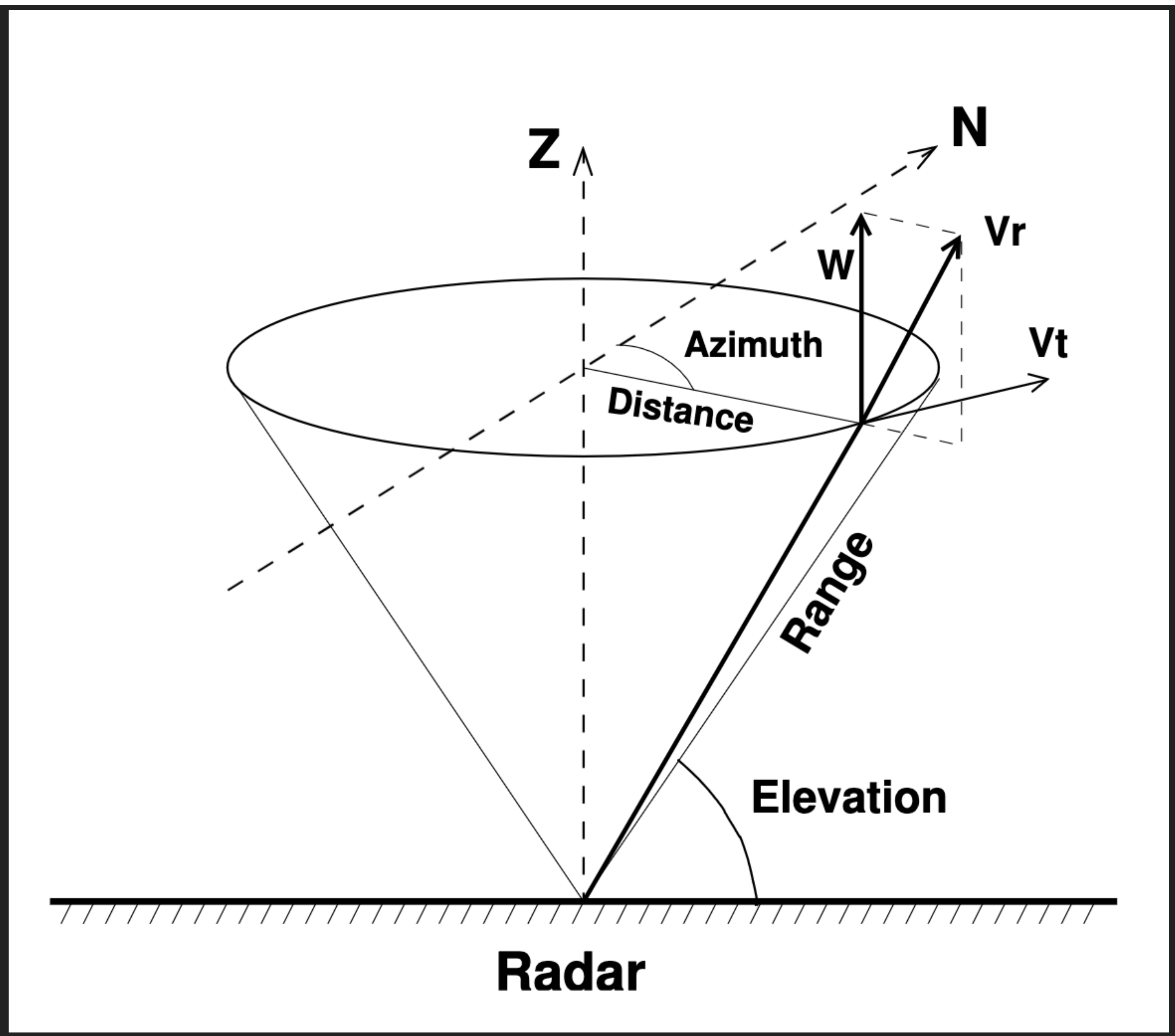

VELOCITY AZIMUTH DISPLAY

- In meteorology the wind direction is the direction the wind is coming from.
- Assuming that the velocity is negative towards the radar/lidar

$$v_r = V_h cos(\theta - D - \pi)cos(\phi) + wsin(\phi)$$

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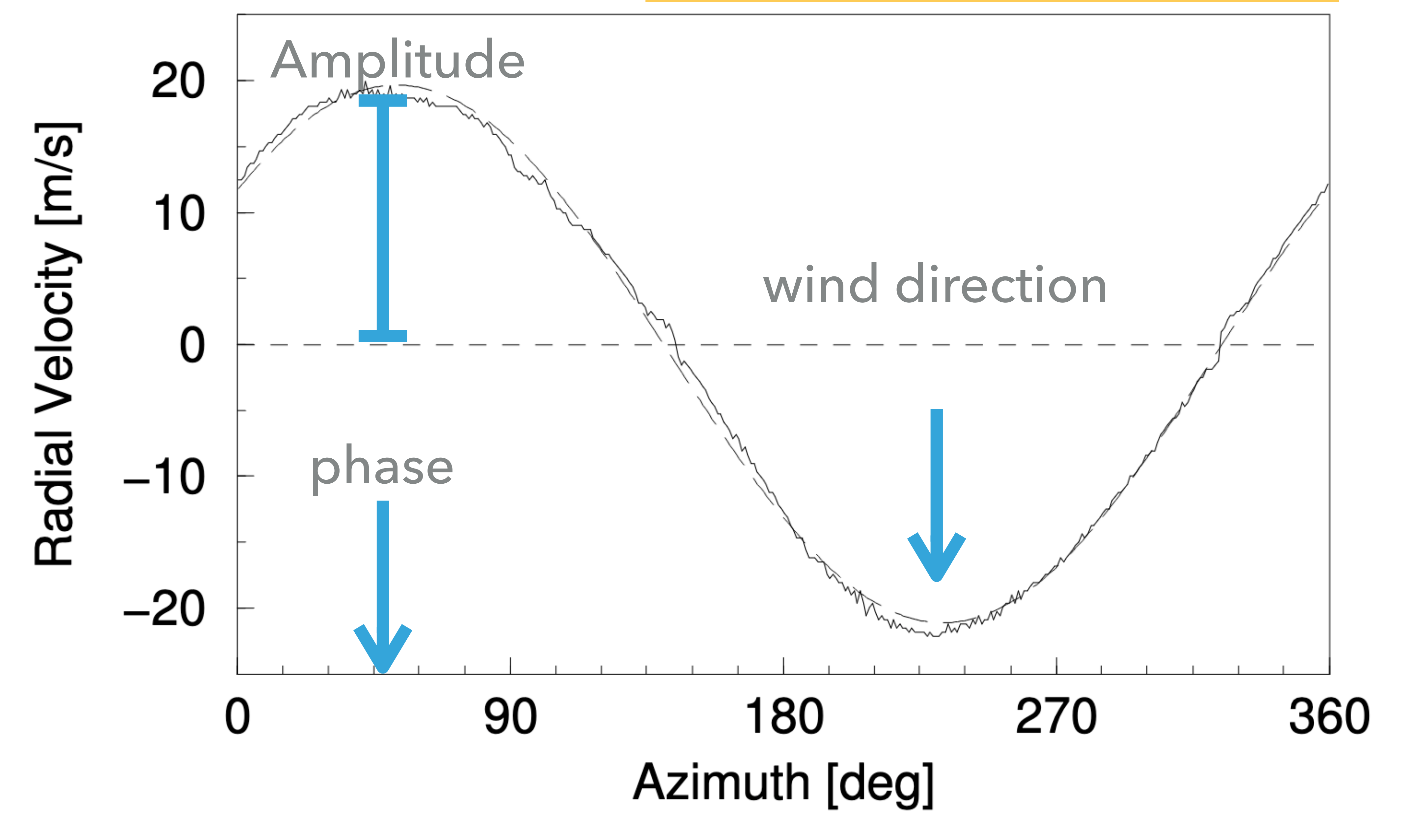
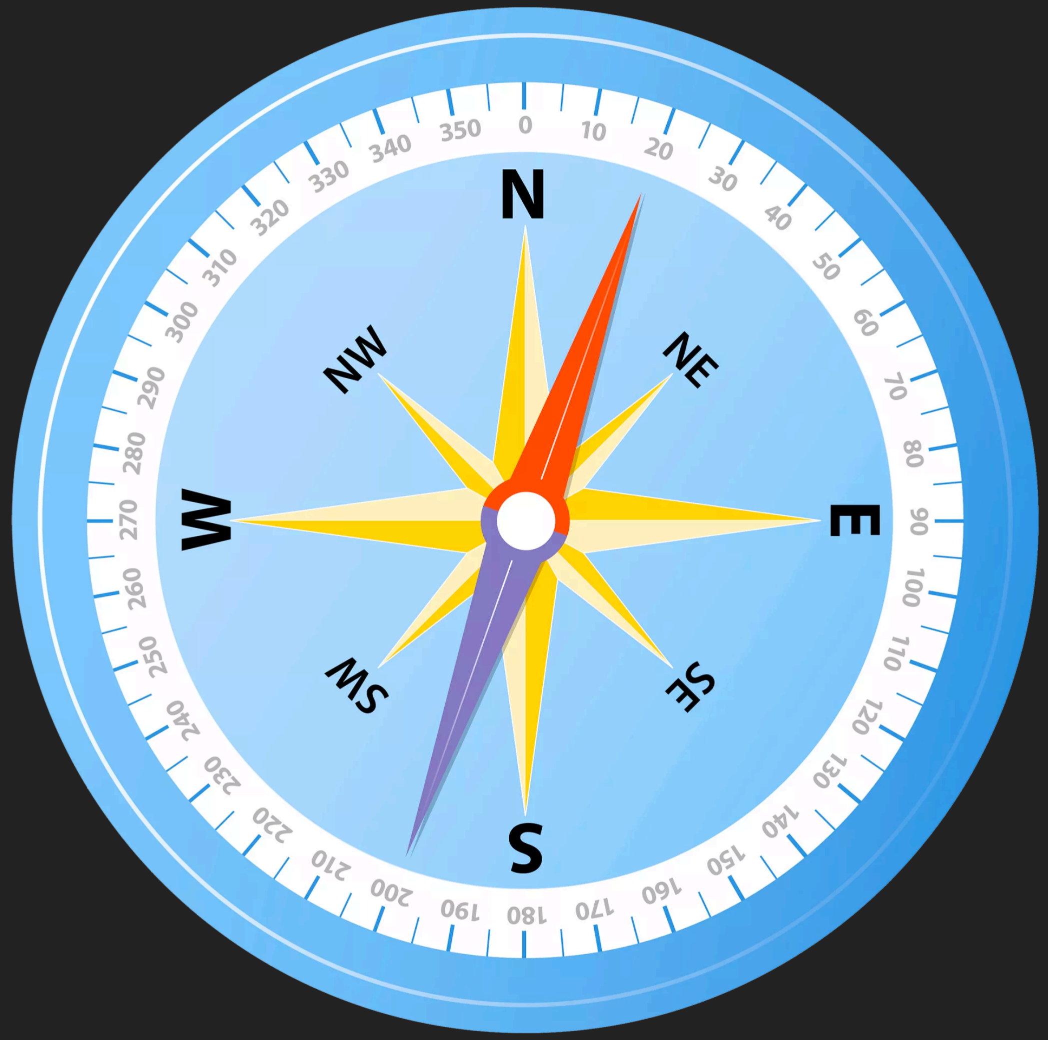
WHAT IS THE WIND DIRECTION ?





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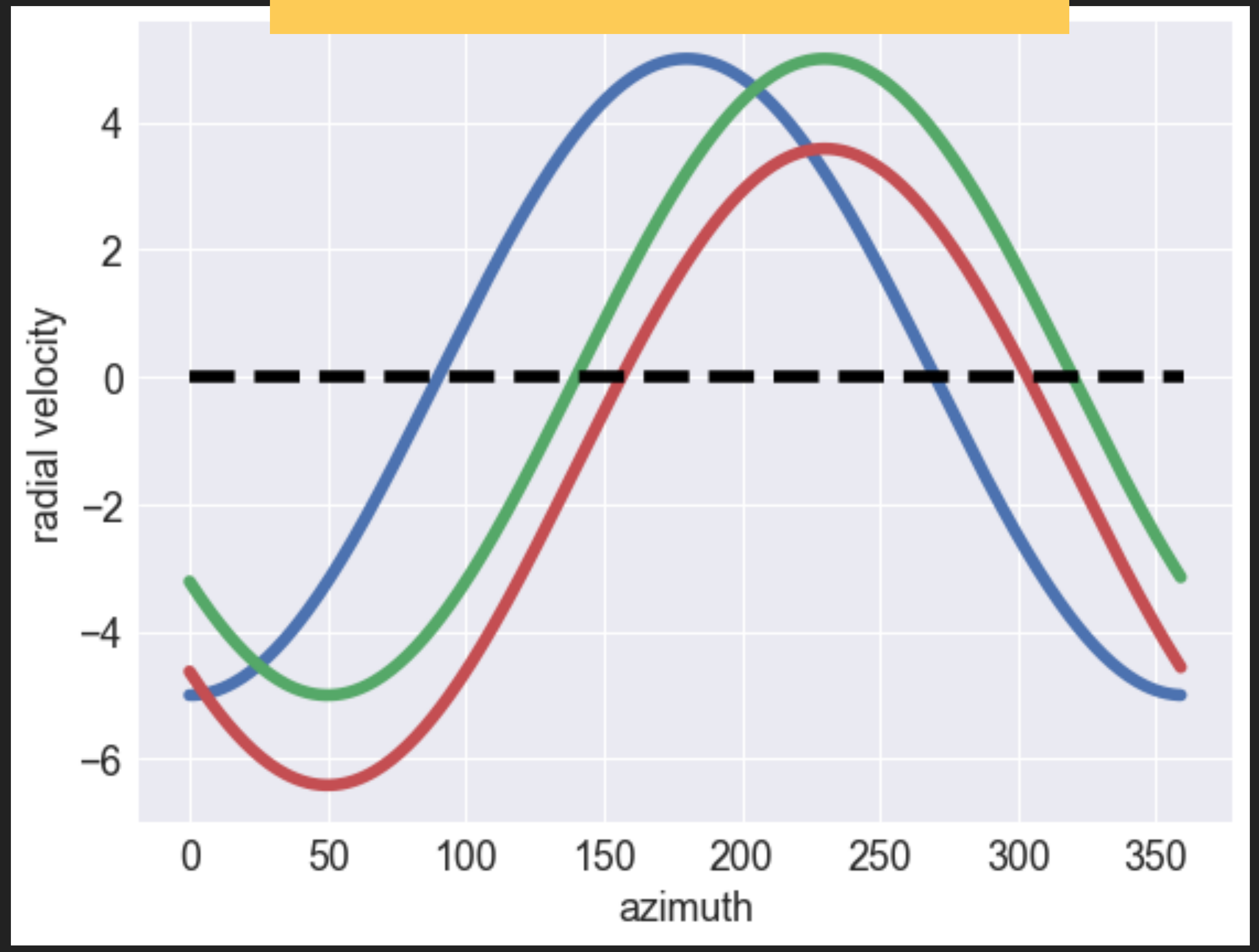
WHY ARE THEY DIFFERENT?



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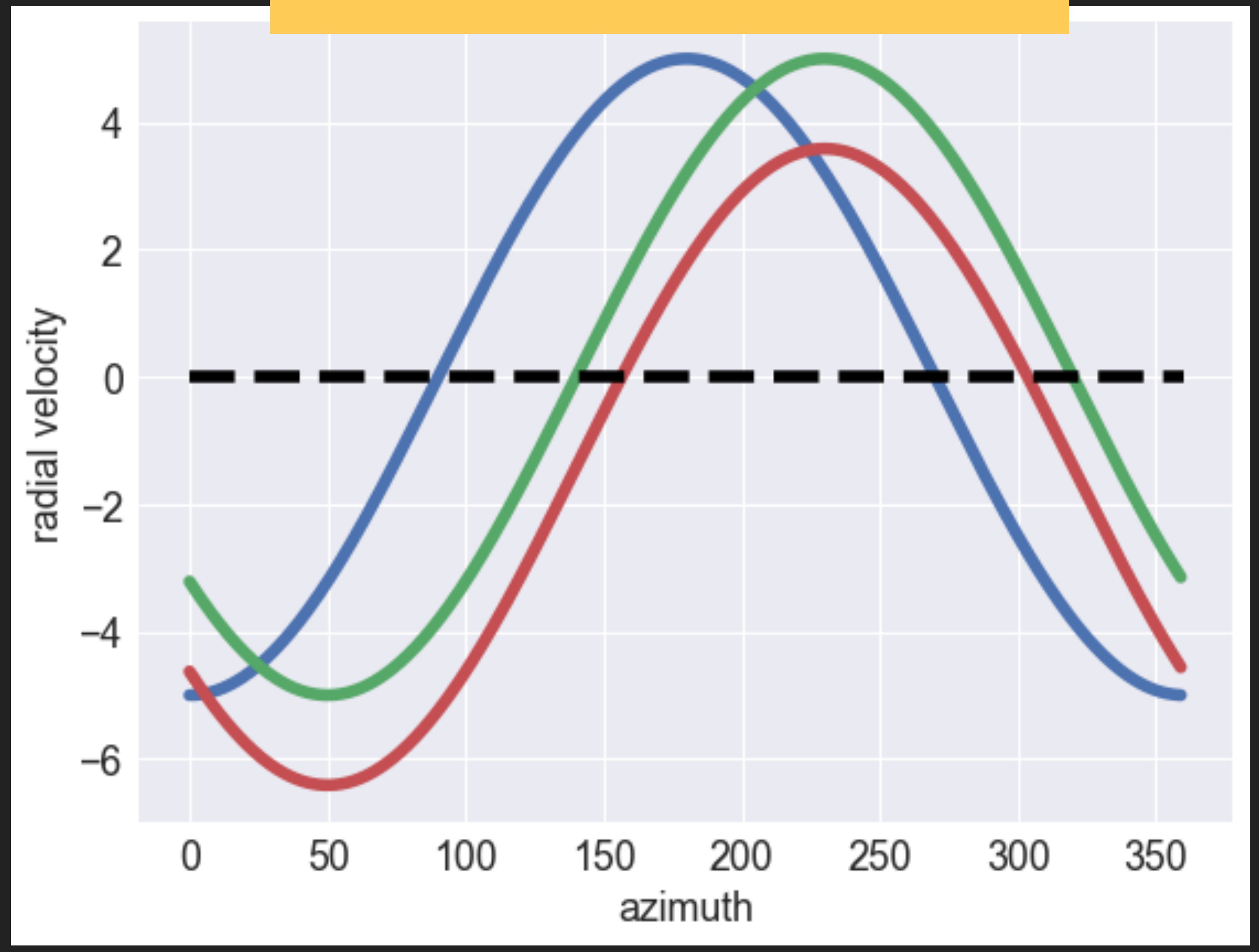

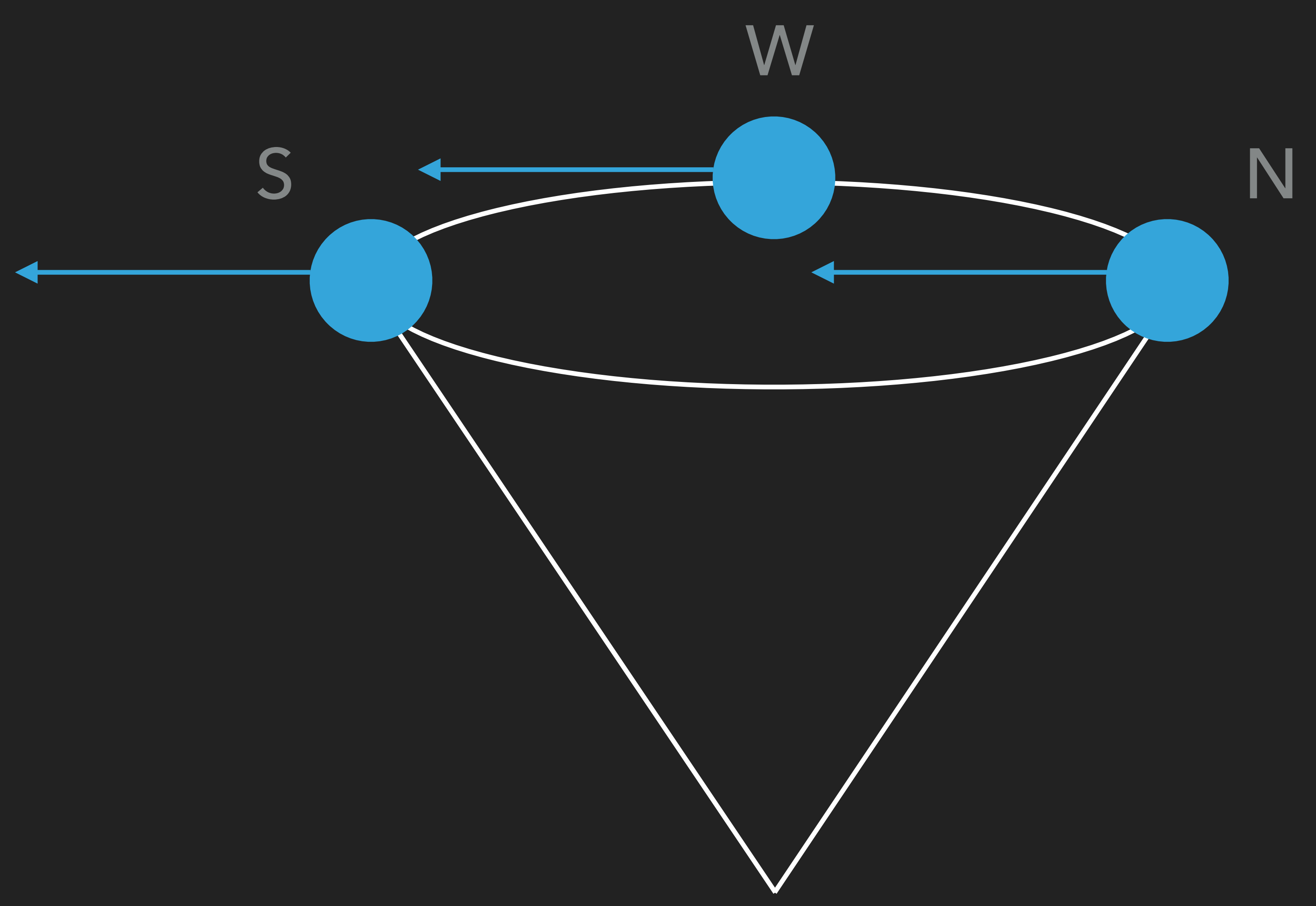

* VELOCITY IS NEGATIVE TOWARDS THE INSTRUMENT

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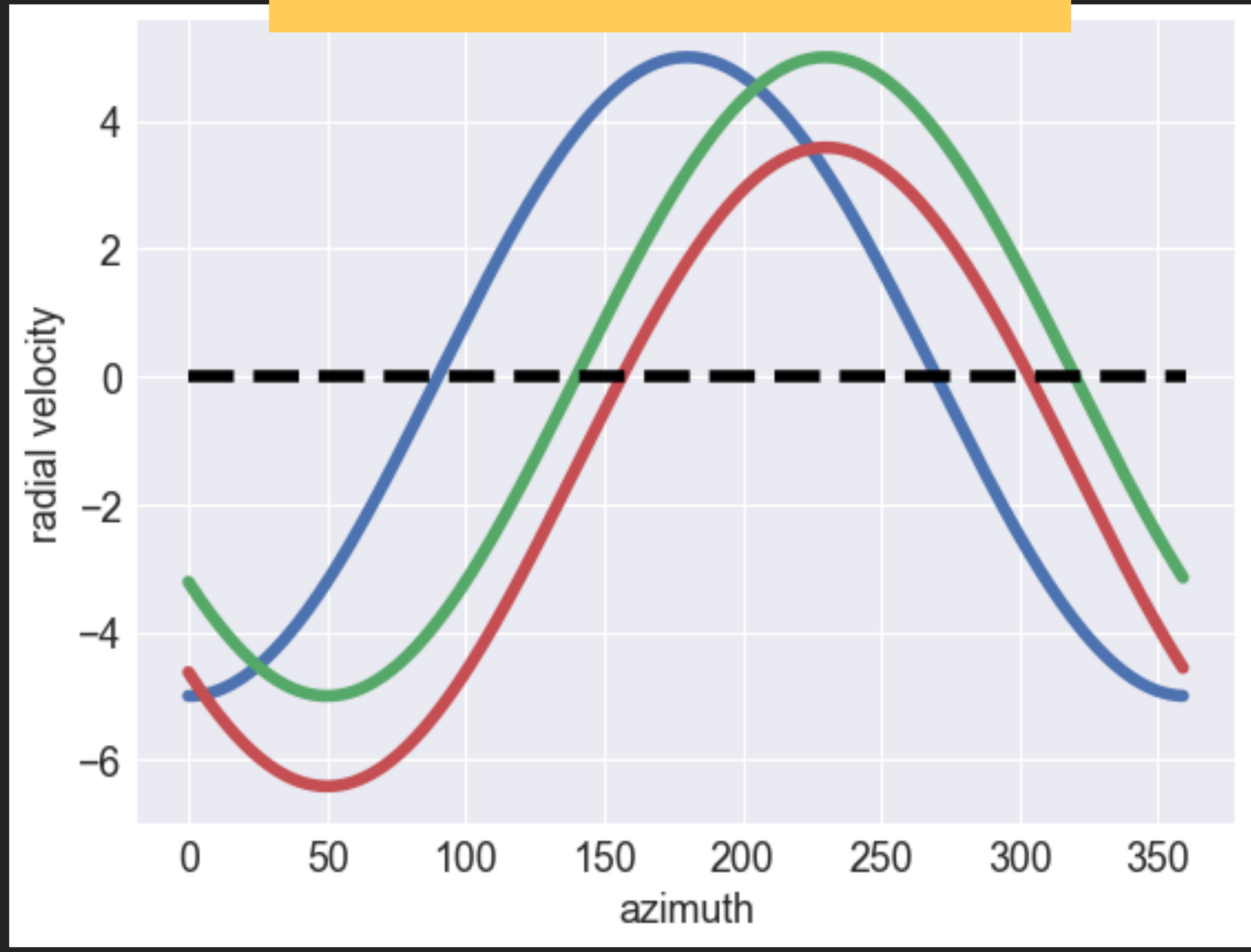

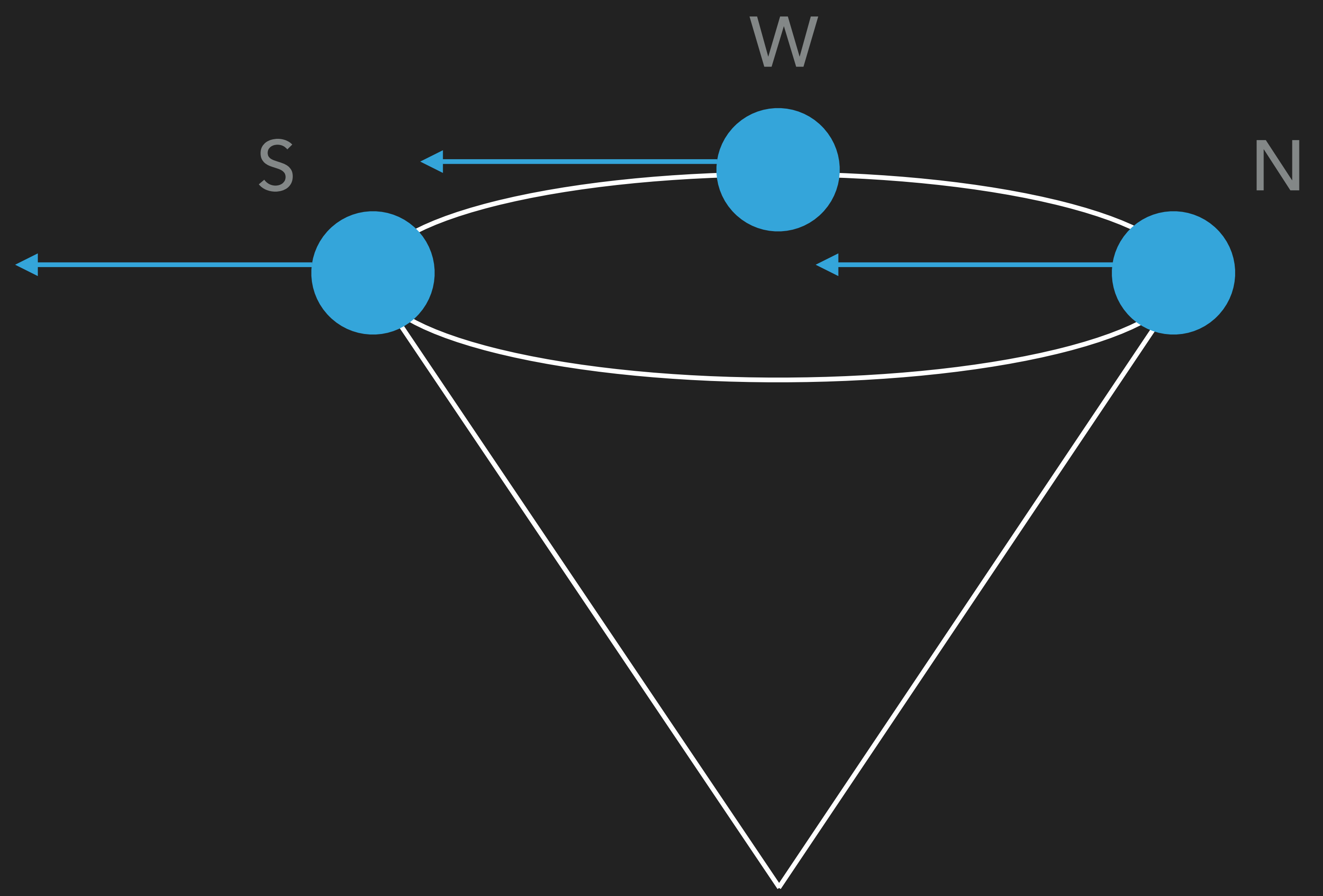

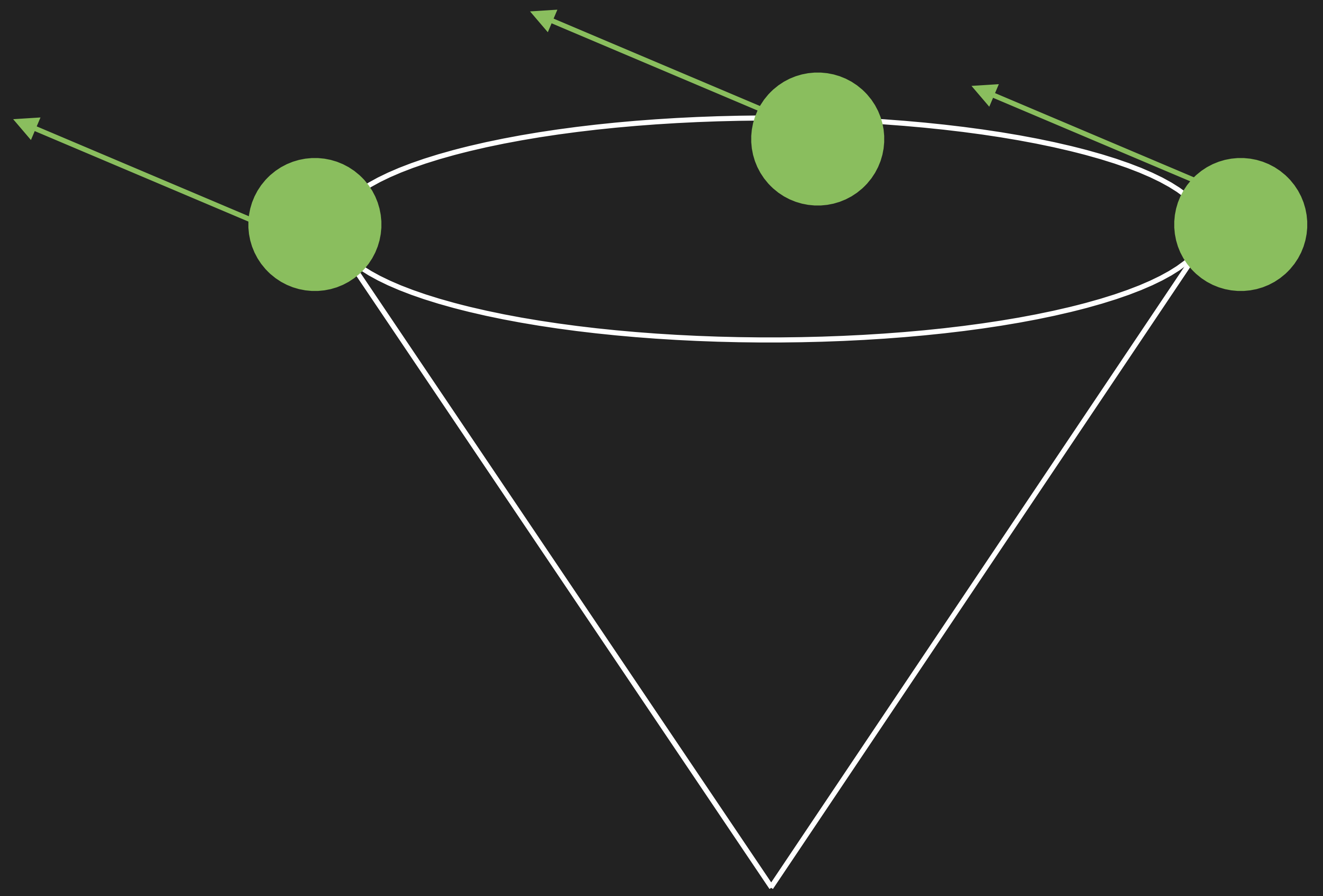

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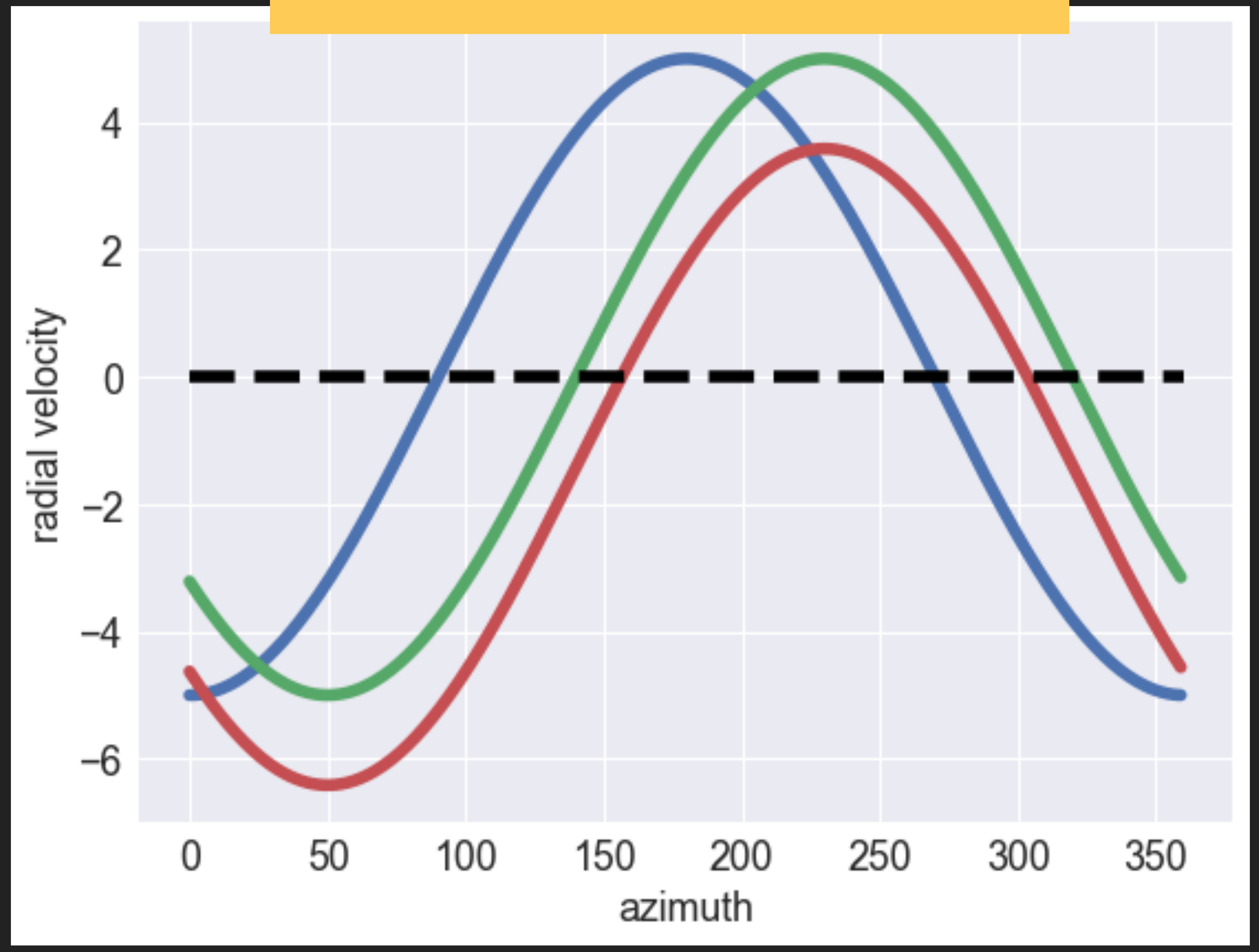

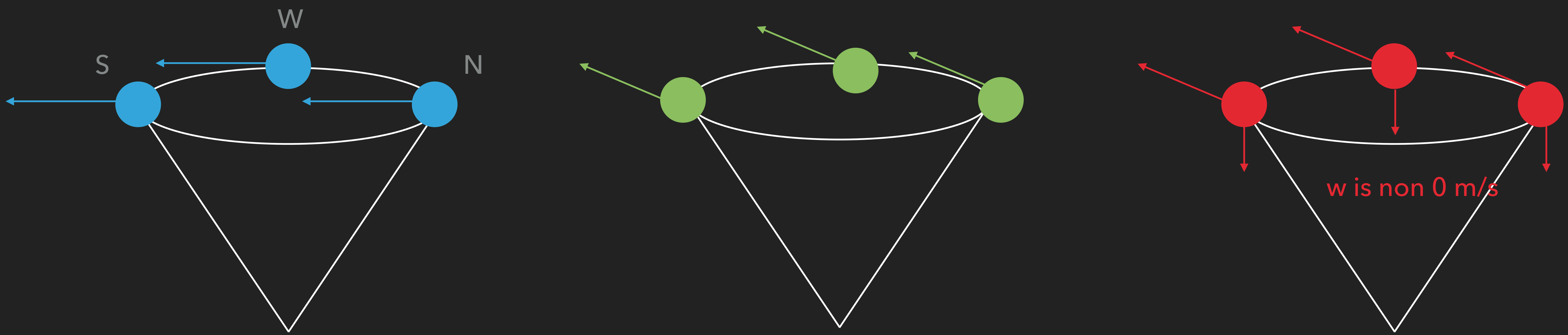

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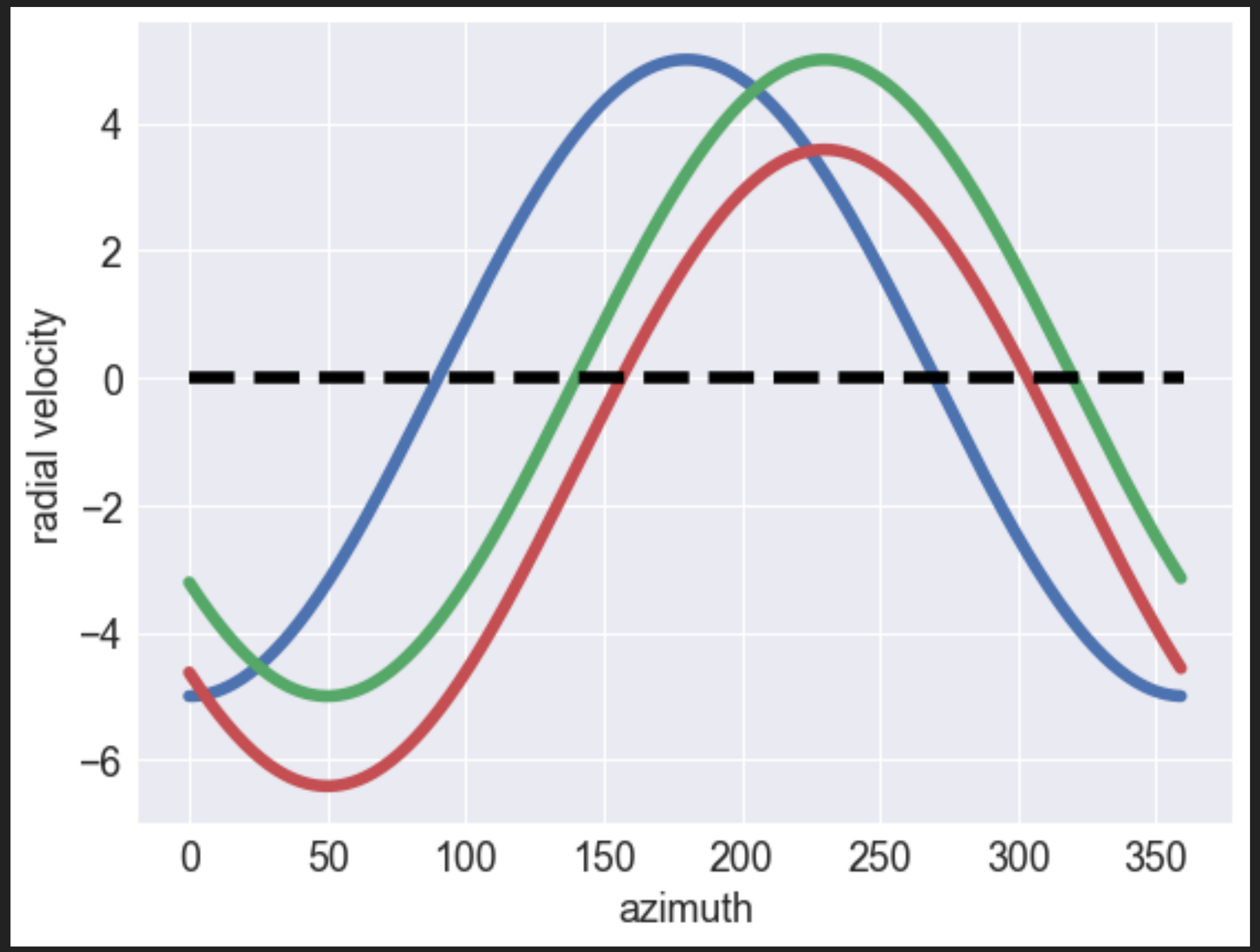
HOW TO RETRIEVE SPEED AND DIRECTION?

$$v_r = V_h cos(\theta - D - \pi) cos(\phi) + w sin(\phi)$$

- From observations numerical methods are used to calculate Vh and D (least square method, DFT)
- We will use the DFT based method
  - Speed and direction are derived from the first harmonic

- N is an amplitude correction parameter, and its value is equal to the number of data points used in the transformation.



$$a + bi = DFT(V(\theta))|_{1st}$$

$$D = -\arctan(\frac{b}{a}) + 180$$

$$V_h = \frac{2|a+bi|}{N\cos(\phi)}$$

IDEA: ISHWARDAT (2017)

PYTHON PACKAGE: DIAS NETO AND CASTELÃO (2023)

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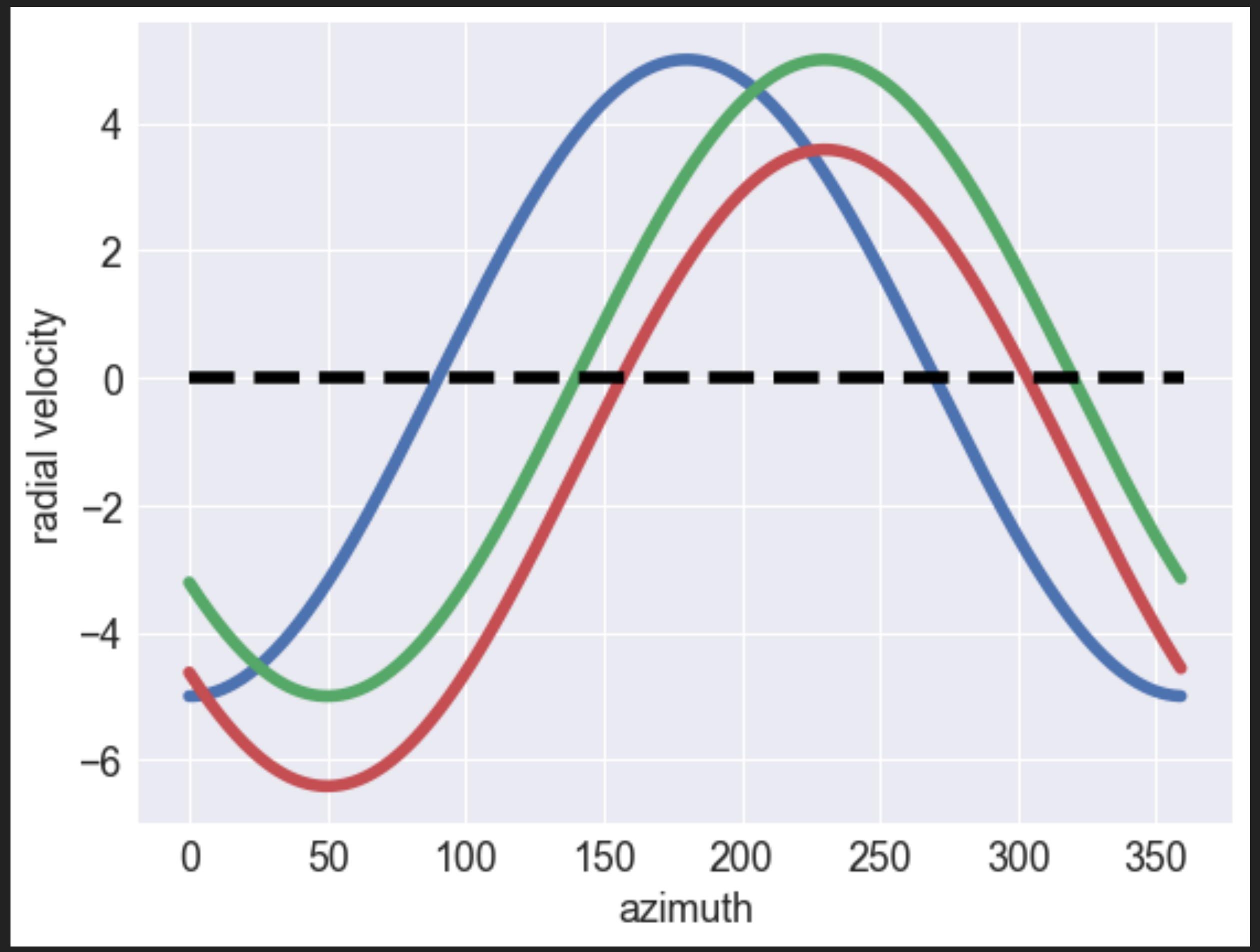
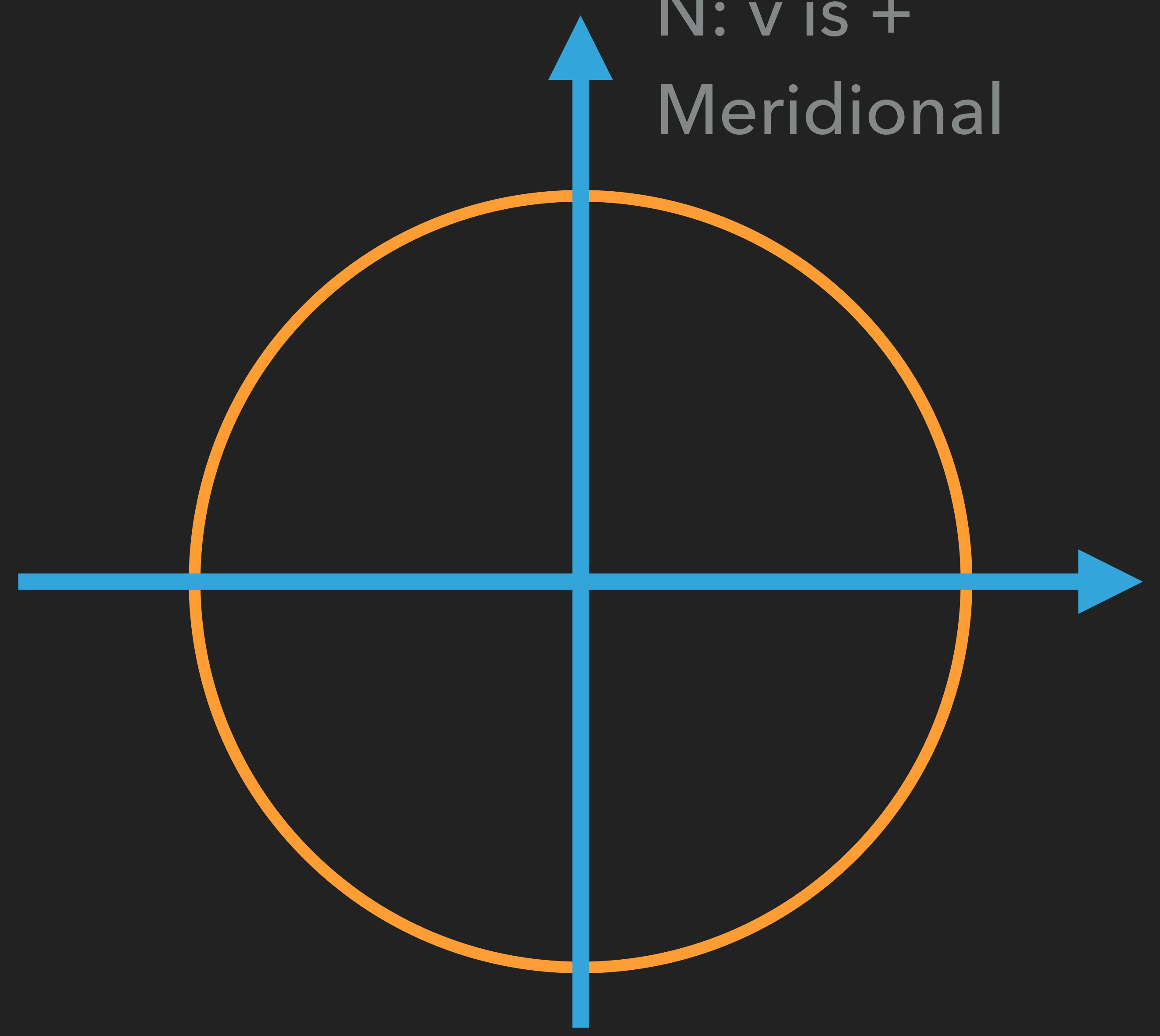


- u (zonal wind): is positive if it blows from the west

$$u = -V_h sin(D)$$

- v (meridional wind): is positive if from the south

$$v = -V_h cos(D)$$

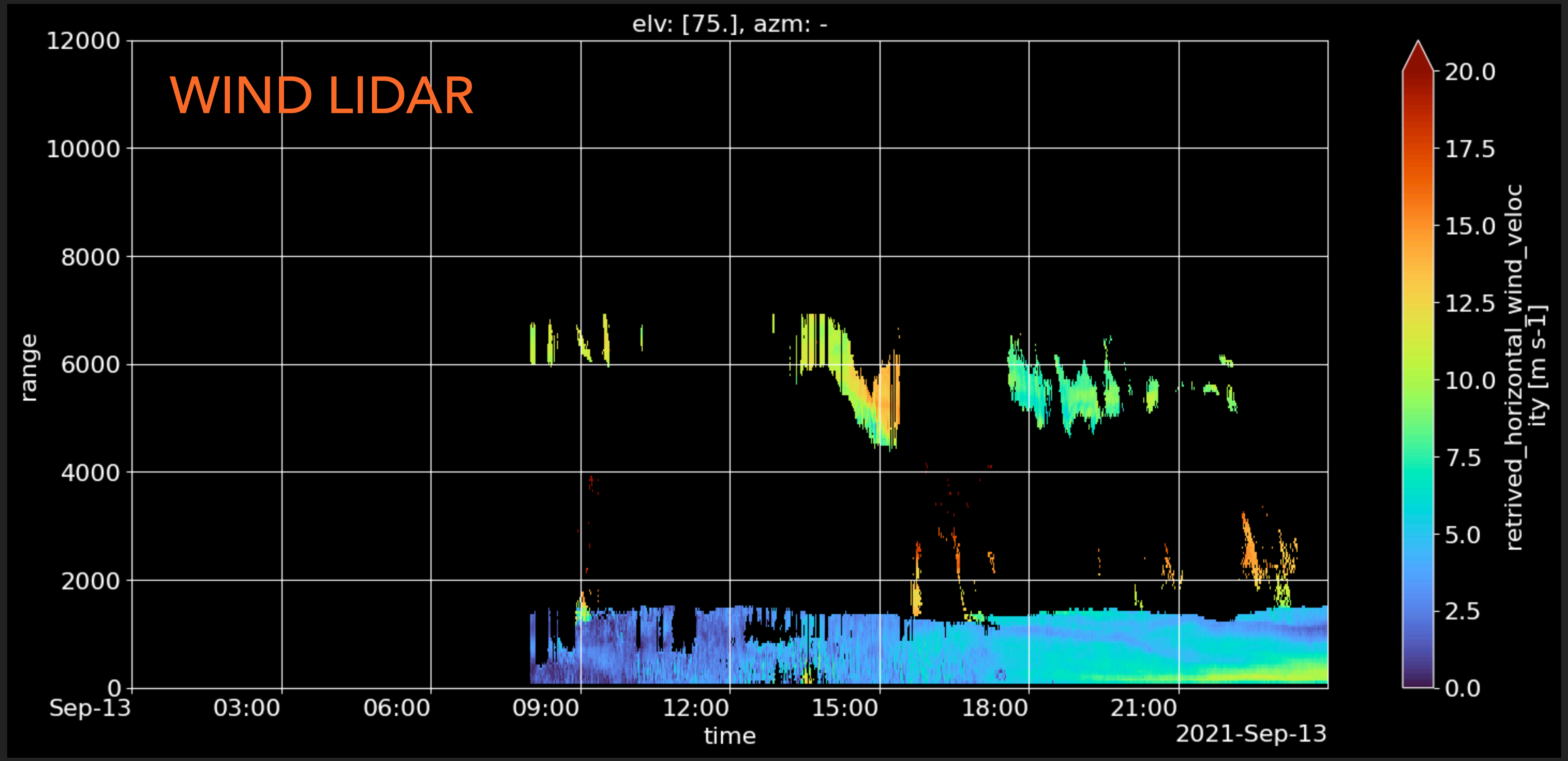


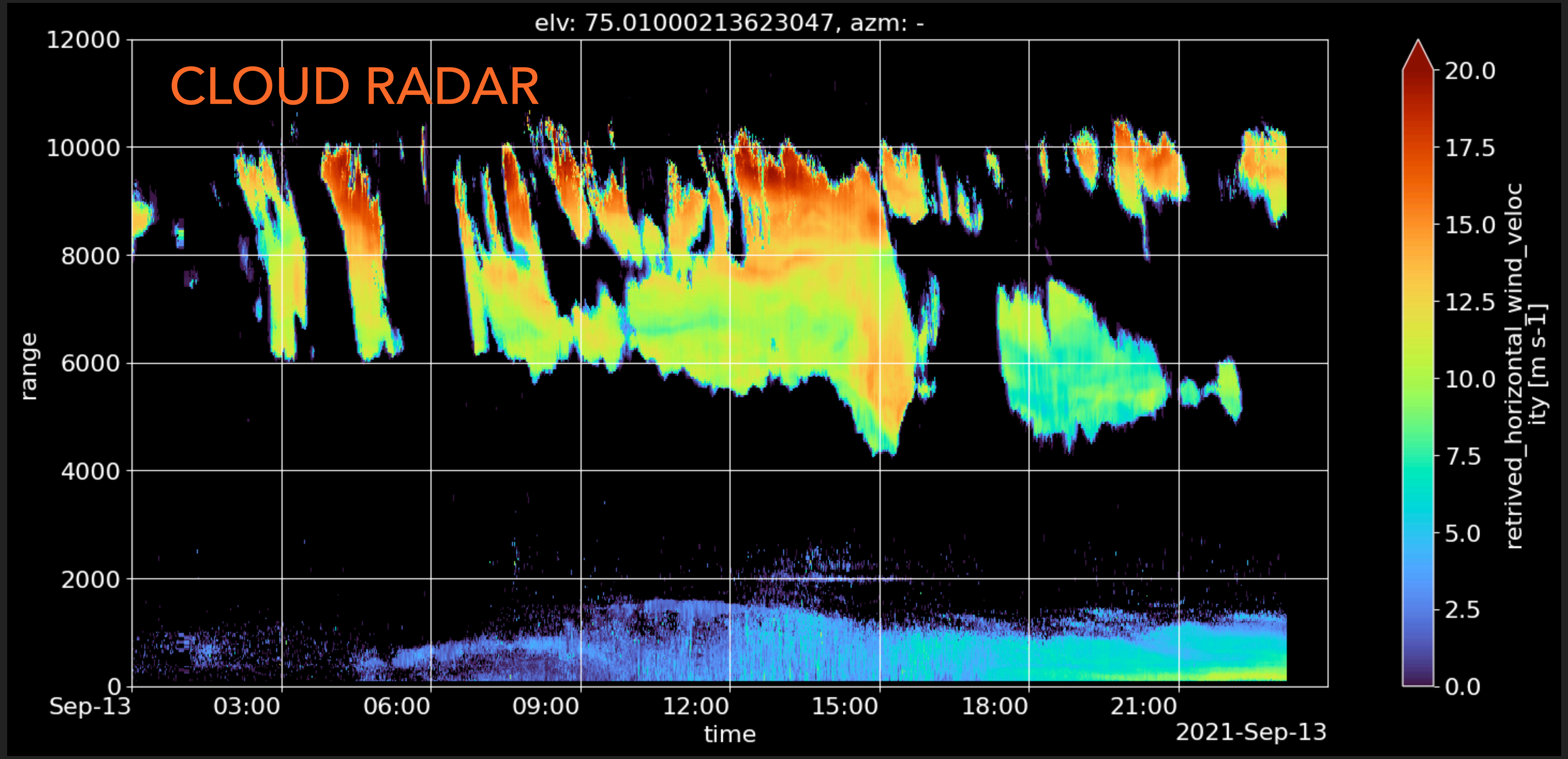
* the negative signs is used to account for our radar velocity convention (negative towards the instrument)

* It is possible that other places use the opposite convention (positive towards the instrument)

WIND SPEED

- LIDAR retrieved wind in the region where aerosols are present
- RADAR retrieved wind in the region where insects and clouds are present





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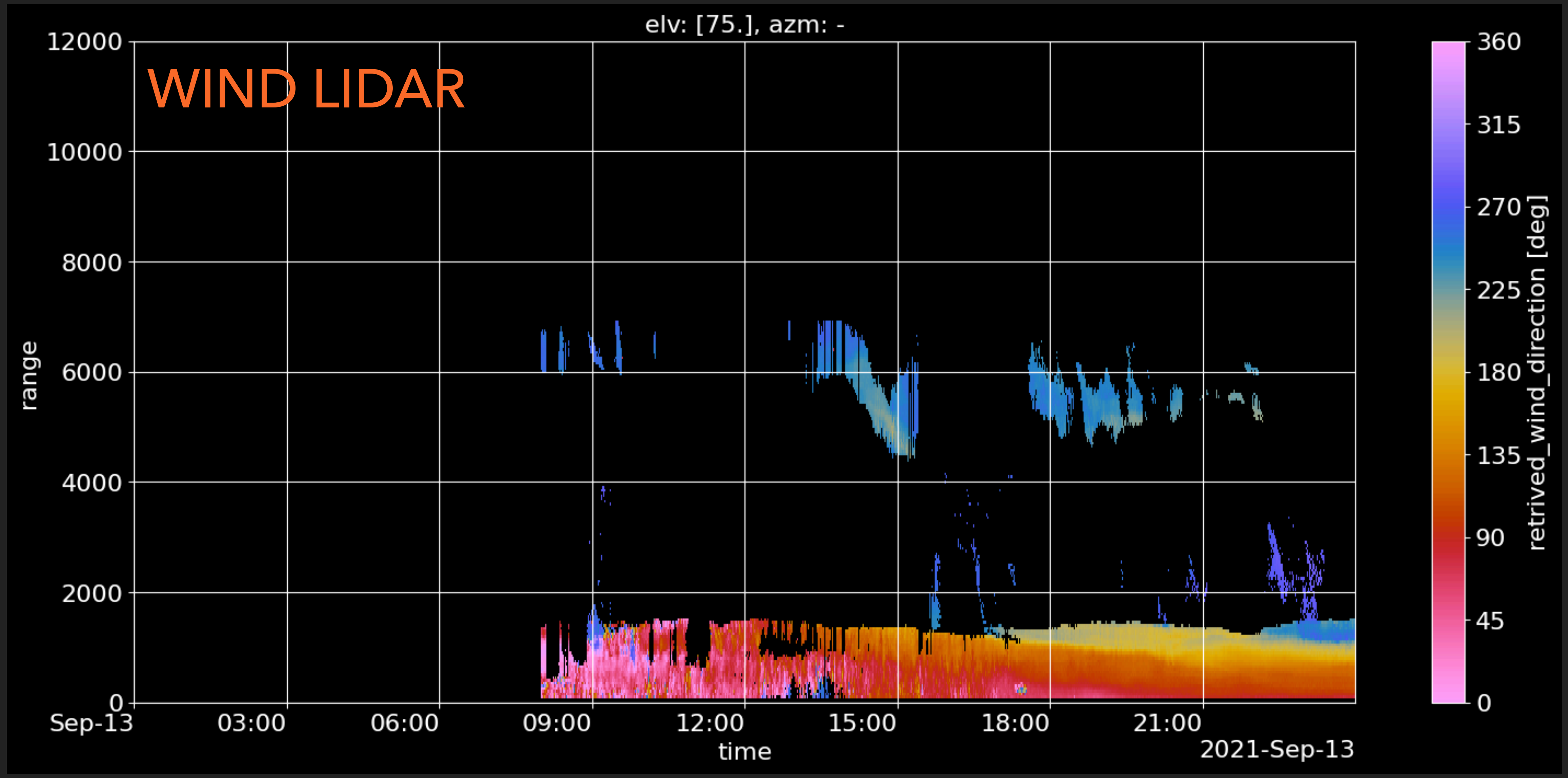
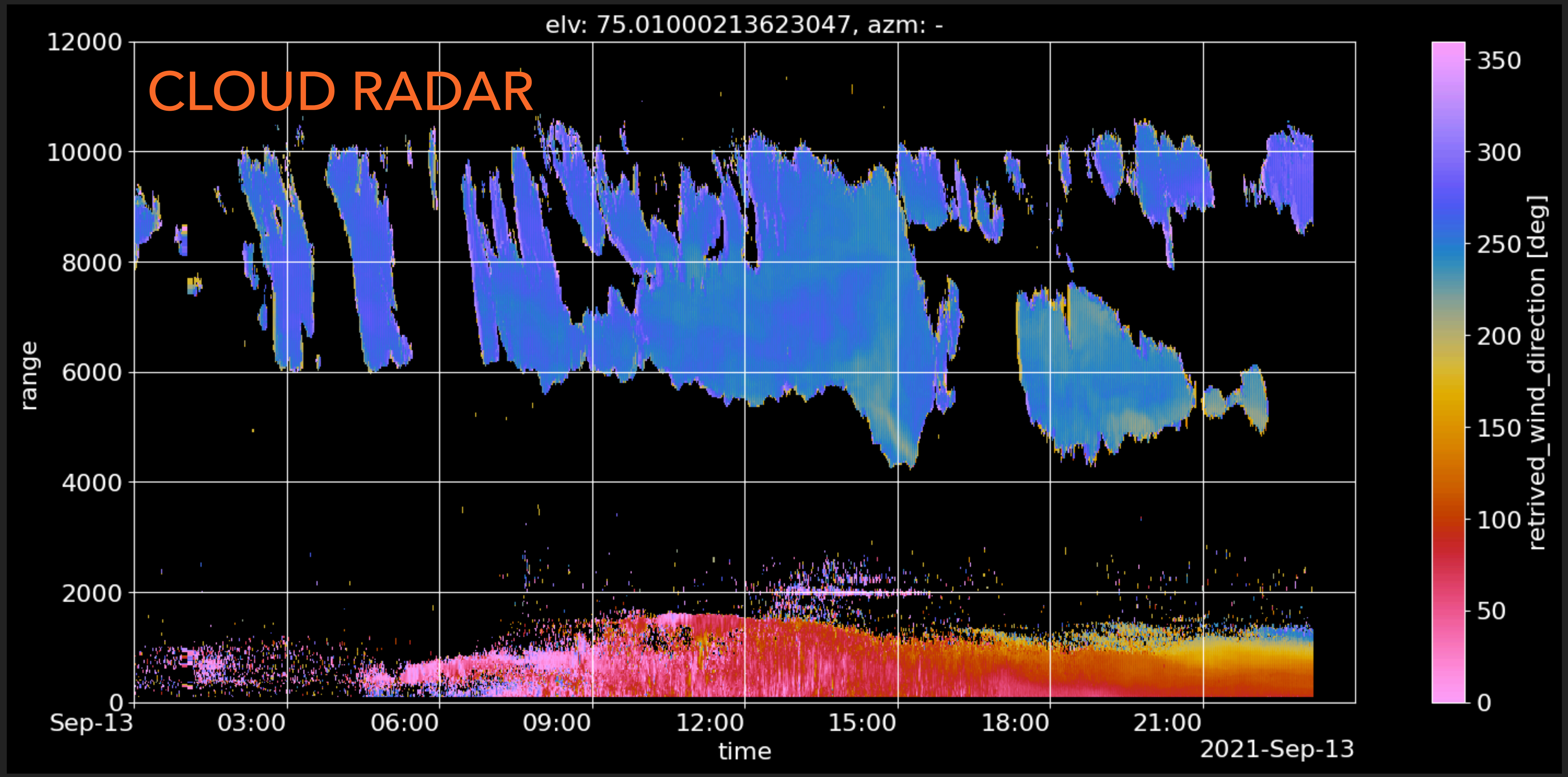
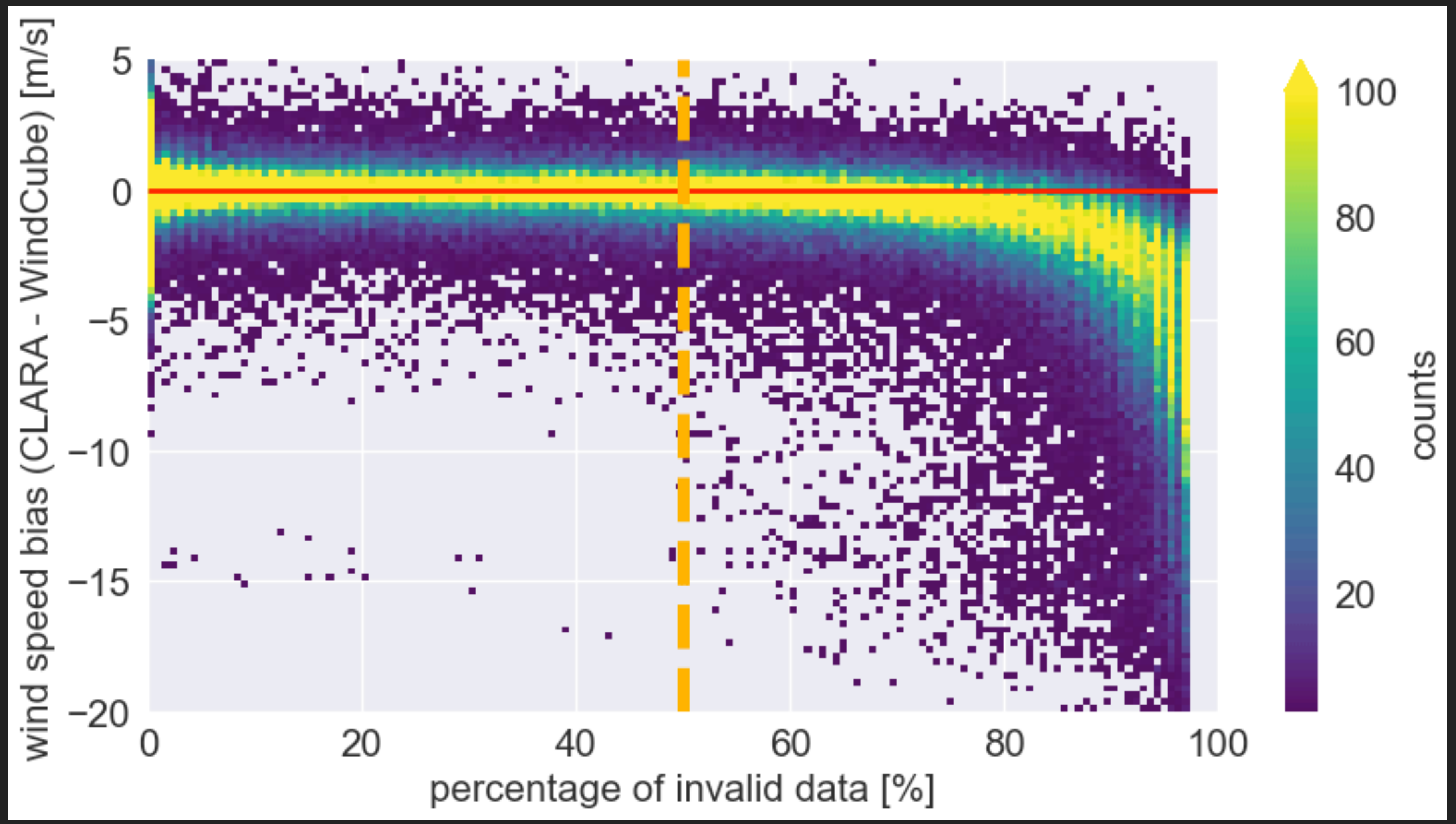


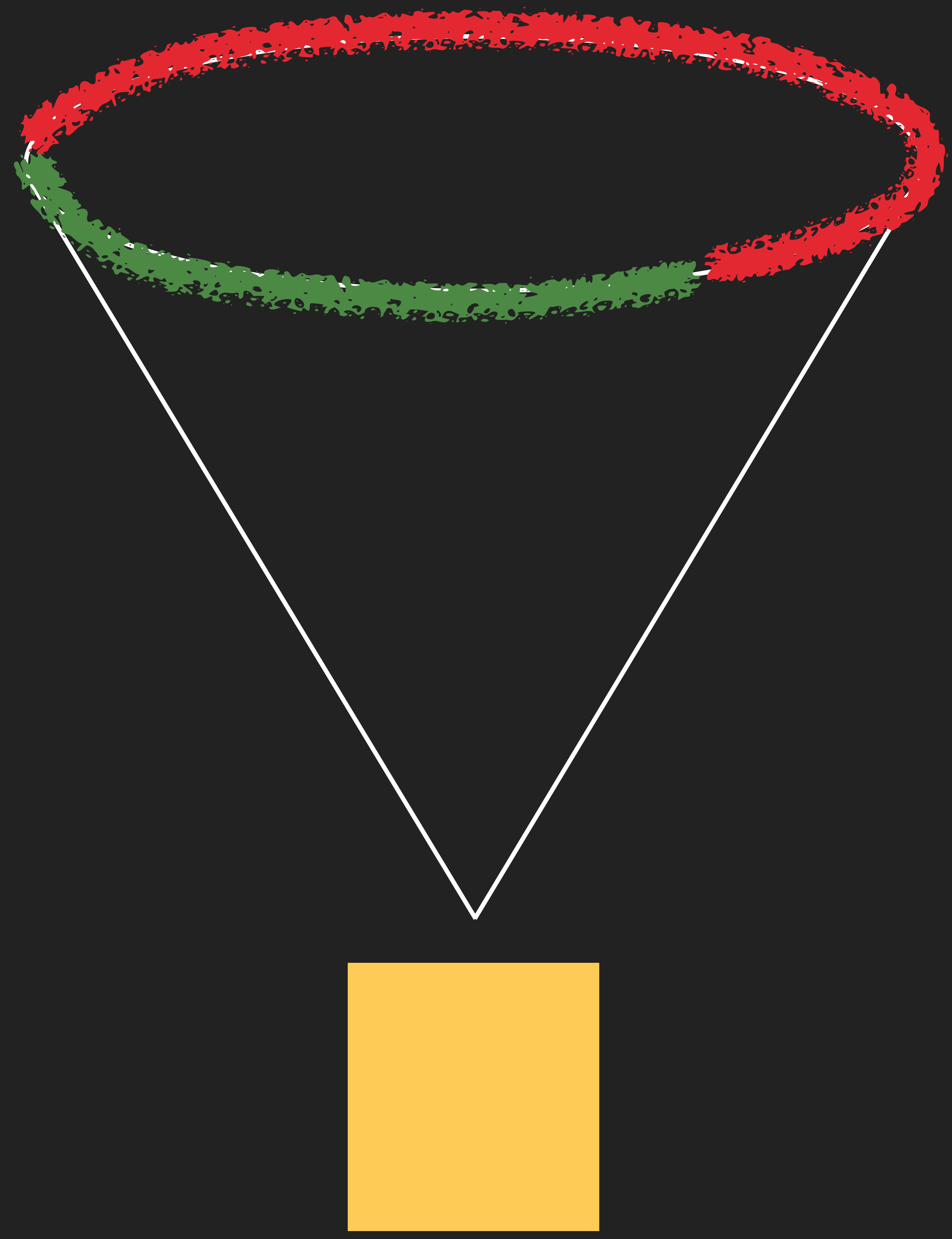


SPEED BIAS: LIDAR X RADAR

- The wind speed may be biased due to insufficient data in a scanned circle (current DFT method).

e.g: 70% is missing and only 30 % is available





- https://doi.org/10.5194/essd-15-769-2023 [DIAS NETO ET AL 2023]

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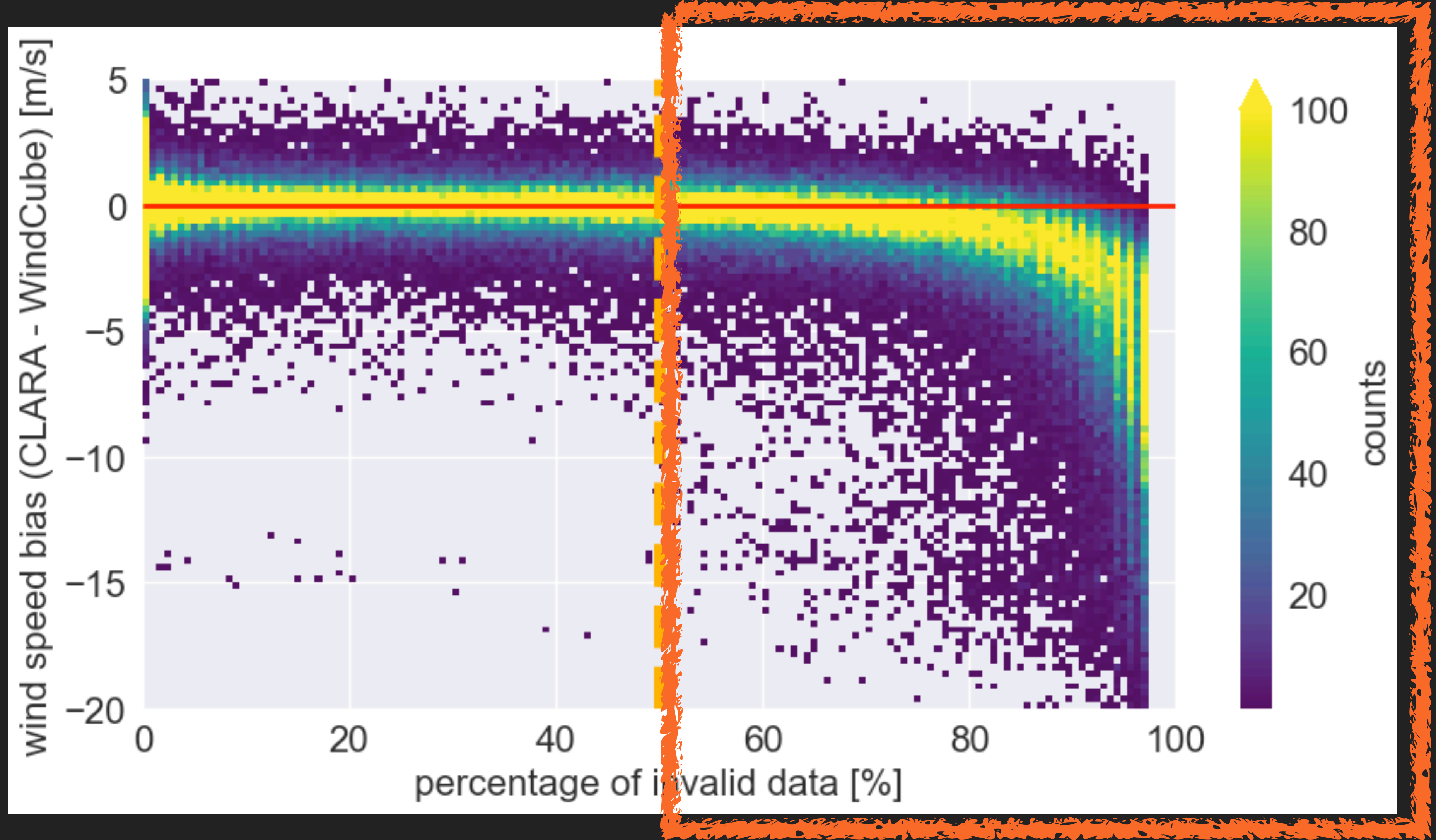
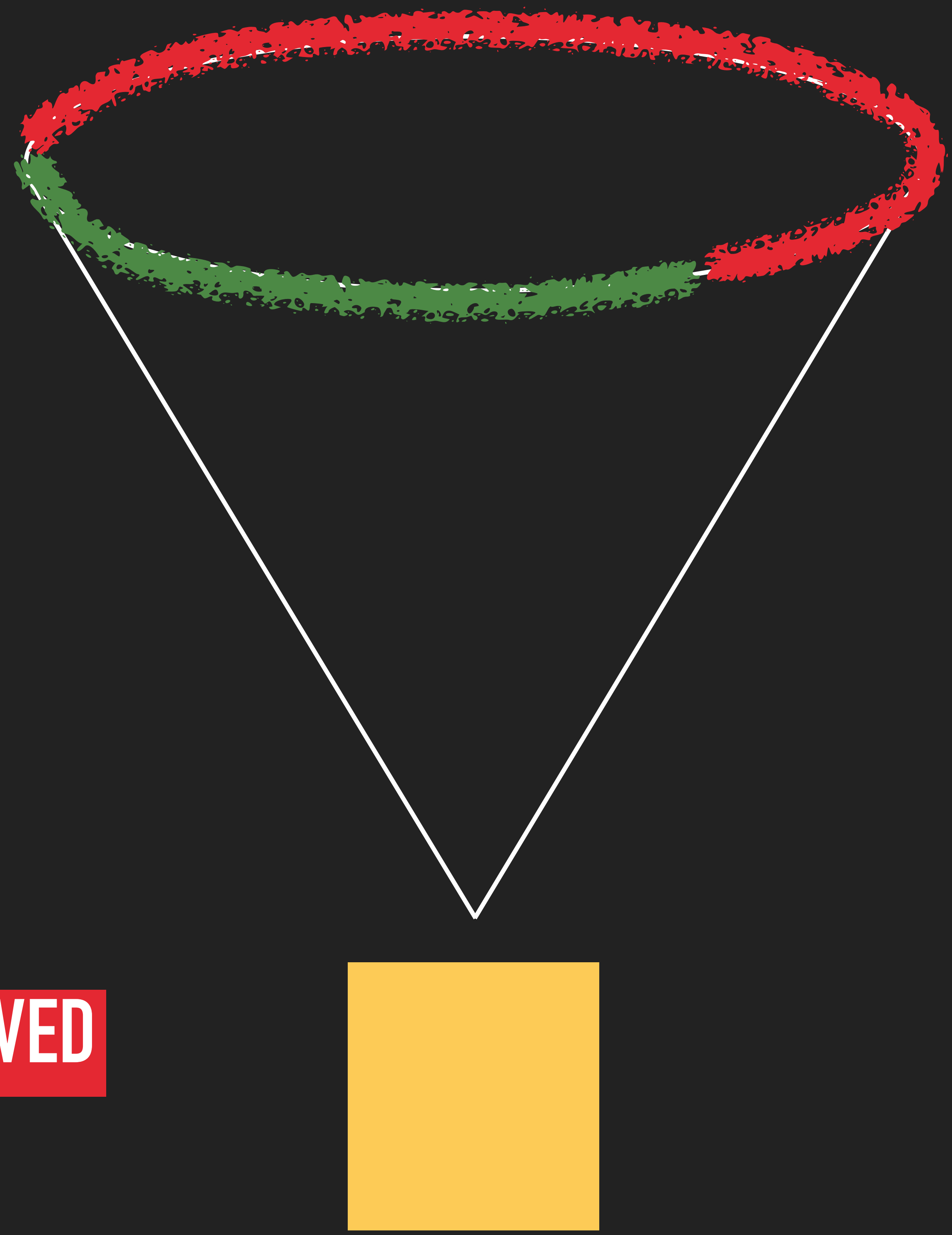


MAINLY CLOUD EDGES ARE REMOVED



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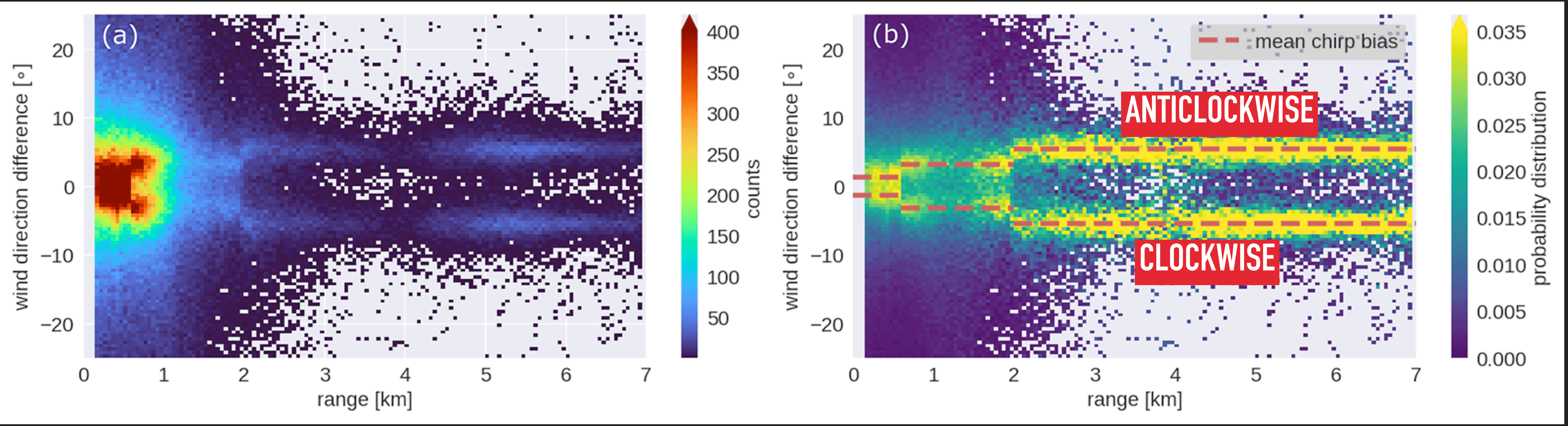
DIRECTION BIAS: LIDAR X RADAR

- The raw retrieved wind direction is biased and is chirp dependent.
- My interpretation: the radar does not record the azimuth of the actual measurement but from whre the measurement started.



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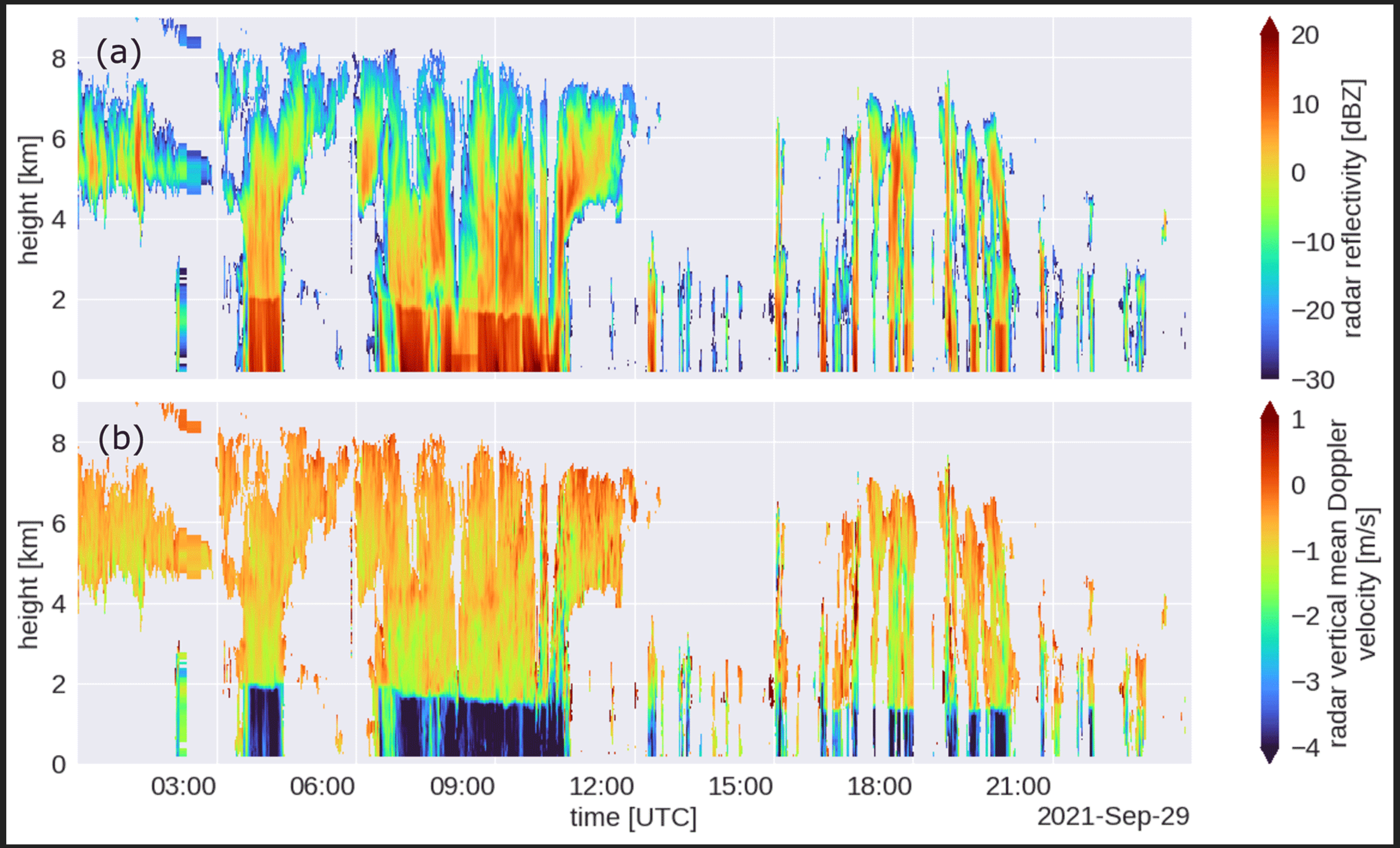
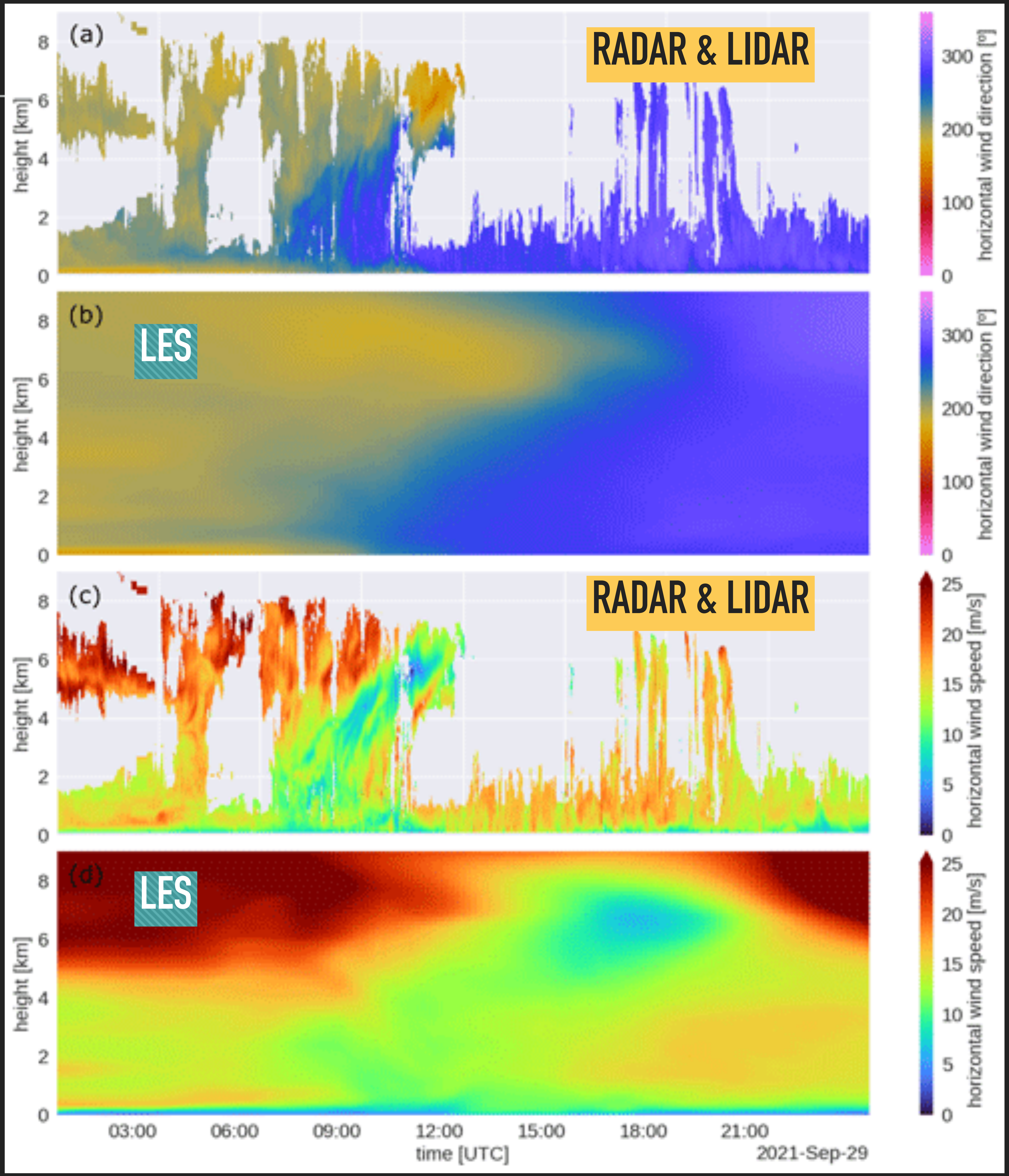
MERGERD WIND EXAMPLE (RADAR & LIDAR)





[DIAS NETO ET AL 2023]

DFT IMPLEMENTATION

- Overview over the DFT based method [Master thesis Ishwardat 2017]
  - https://resolver.tudelft.nl/uuid:a659654b-e76a-4513-a656-ecad761bdbc8
- Python implementation (lidarwind) [Dias Neto and Castelão 2023]
  - https://doi.org/10.21105/joss.04852
  - Documentation: https://lidarwind.readthedocs.io
- Radar X Lidar: validation [Dias Neto et al 2023]
  - https://doi.org/10.5194/essd-15-769-2023

WORKSHOP MATERIAL

- The notebooks and their rendered HTML version can be downloaded from:
  - https://ruisdael.citg.tudelft.nl
- CCRESS-workshop –> wind_retrieval

DOWNLOAD:

- 1st Package installation: lidarwind_4_rpg_radar_serial.ipynb
- 2 nd Wind retrieval 35 GHz: lidarwind_4_rpg_radar_parallel_35.ipynb
- 3 rd Wind retrieval 94 GHz: lidarwind_4_rpg_radar_parallel_94.ipynb

REQUIREMENTS

- For Windows users, the required Python version is 3.12.
- For macOS users, the Python version can be 3.12 or 3.13.
- For Linux users, the Python version can be any version from 3.12 to 3.14.