DTU

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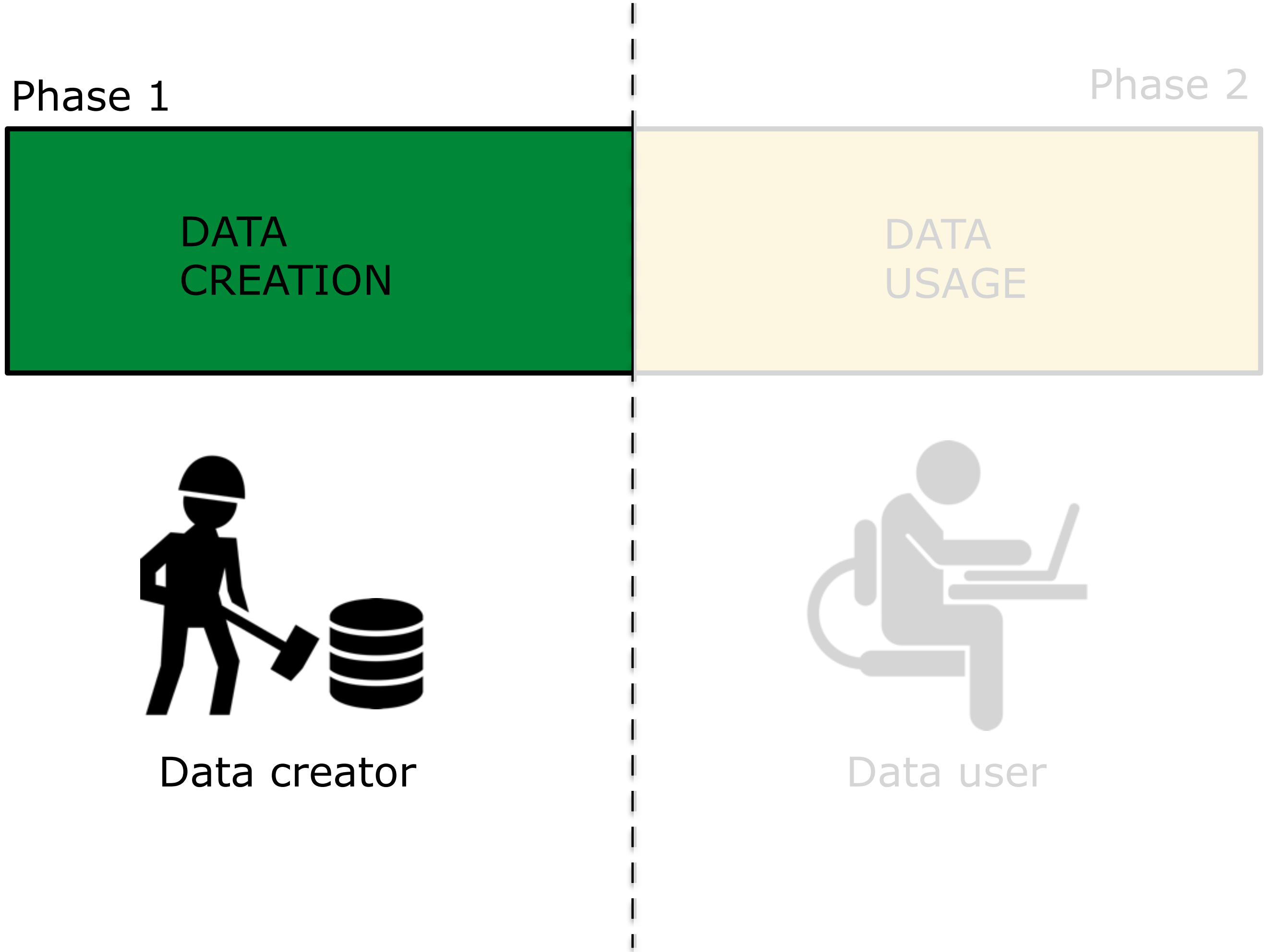
Wind Lidar Digitalization

NREL, 8th October 2019

Simplistic overview of (research) projects



Graphics designed using FlatIcon.com

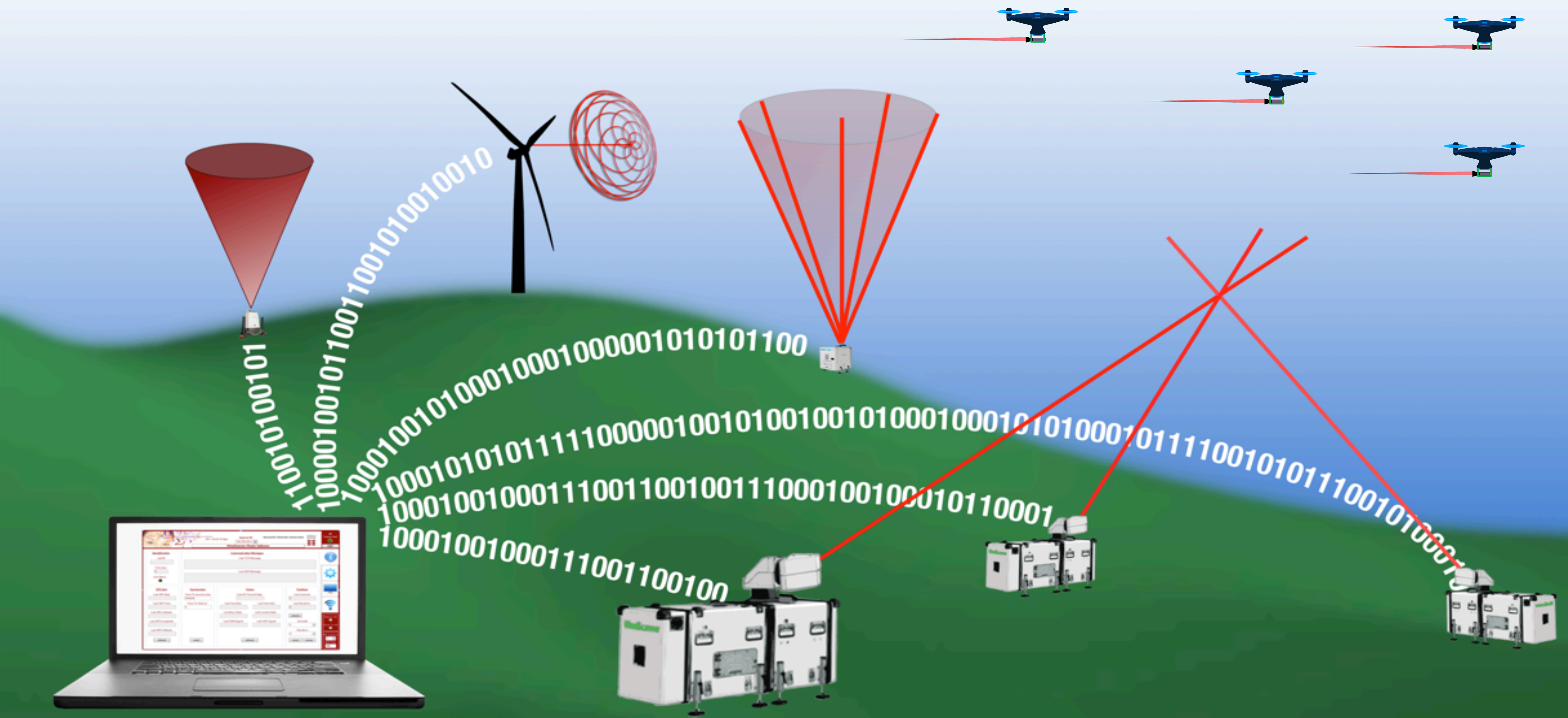
Digitalization

Digitalization most often refers to enabling, improving and/or transforming business operations and/or business functions and/or business models/processes and/or activities, by leveraging digital technologies and a broader use and context of **digitized data**, turned into **actionable knowledge** with a specific benefit in mind [1].

It requires digitization of information but it means more and at the very center of it is data.

[1] https://www.i-scoop.eu/digitization-digitalization-digital-transformation-disruption/

Unprecedented insight into the wind conditions
…but at what cost?



Challenge

There is a need to make the (lidar) technology "dummy-proof" for the larger audience, but also quite "open" for power users. [2]

[2] https://zenodo.org/record/1146326

Challenge continued

- How to create **TeraBytes** of affordable and high-quality data?
- How to make **TeraBytes** of data usable?

Challenge still continued

- How can we eliminate a need for lidar ‘experts’ ?

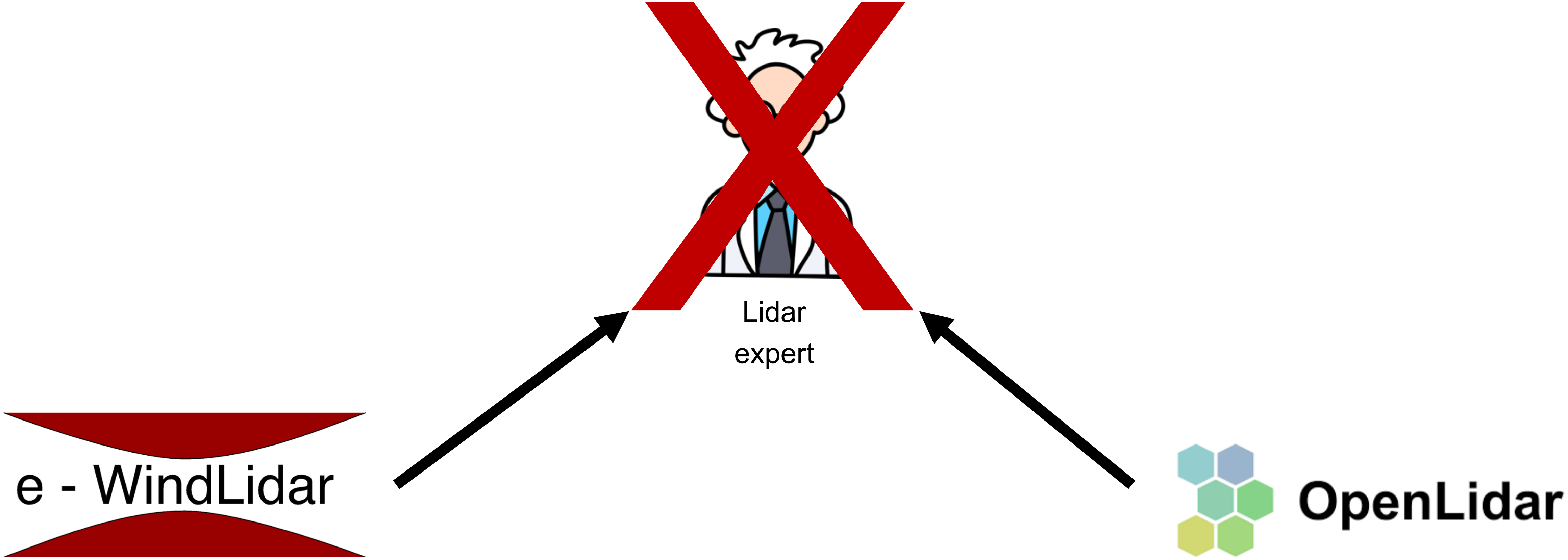


Image source: flaticon.com

e-WindLidar initiative

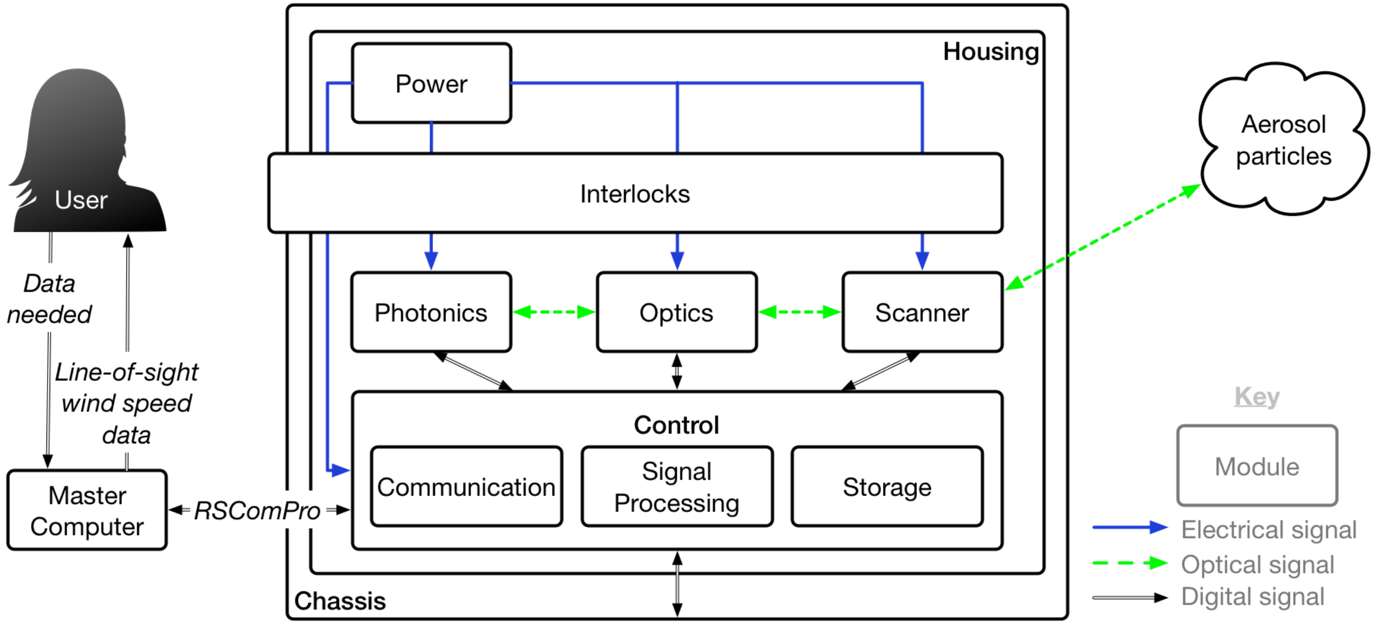
- Develop community-based tools that will simplify:
  - Planning and configuration of lidar-based field campaigns
  - Operation of lidars in field campaigns
  - Usage of lidar data

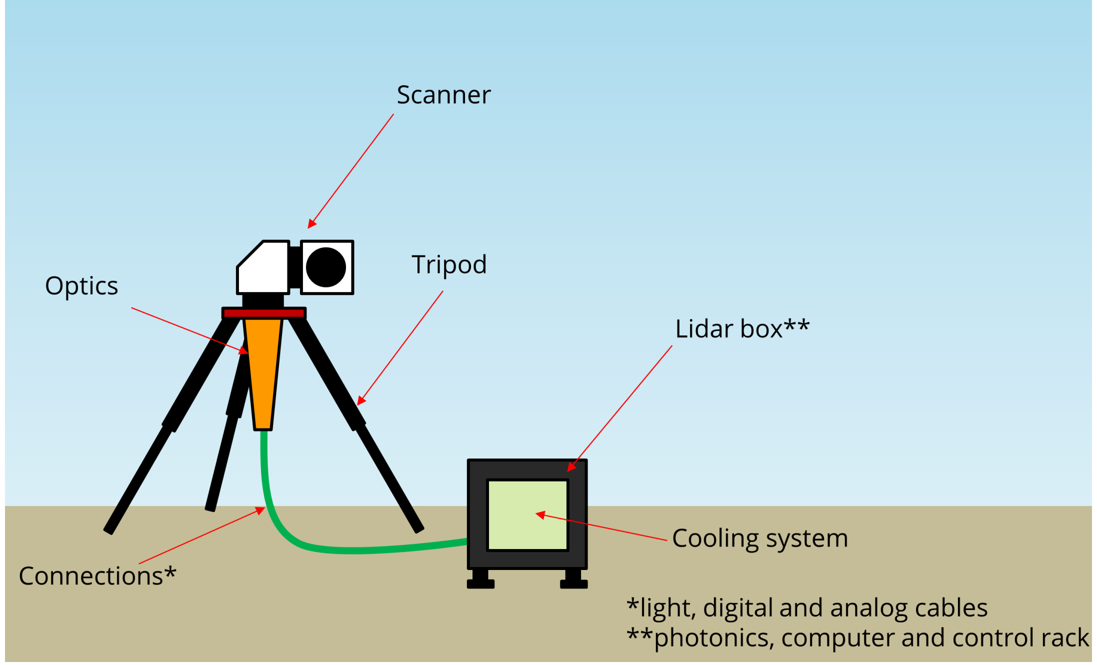
- e-WindLidar idea was conceived during the WindScanner.EU project under the name WindScanner Information System [3]

[3] https://zenodo.org/record/1175211

OpenLidar initiative

- Development of a modular wind lidar architecture [3, 4]
- Providing a framework for cooperation





[3] https://zenodo.org/record/3414197
[4] https://www.openlidar.net/

DTU contributions to e-WindLidar initiative

- Led application of FAIR data principles on wind lidar data [5, 6]
- Developed *campaign-planning-tool* – Python package for planning and configuring scanning lidar measurement campaigns [7, 8]
- Developed *YADDUM* (**Y**et **A**nother **D**ual-**D**oppler **U**ncertainty **M**odel) – Python package for calculating dual-Doppler uncertainty [9]
- Developed scanning lidar trajectory generator – Python package

[5] https://zenodo.org/record/2478051
[6] https://github.com/e-WindLidar/Lidaco
[7] https://www.wind-energ-sci-discuss.net/wes-2019-13/
[8] https://github.com/niva83/campaign-planning-tool
[9] https://zenodo.org/record/1441178

DTU

e - WindLidar

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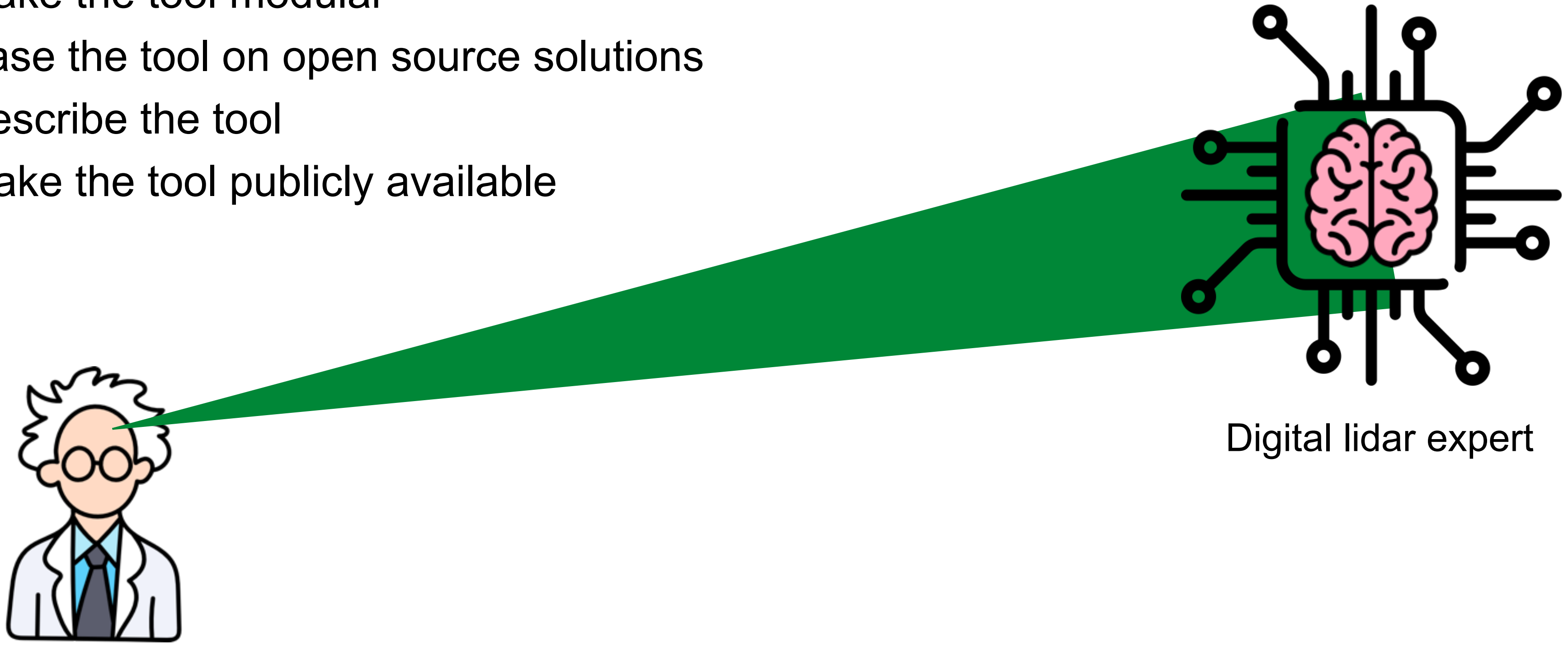
campaign-planning-tool background

- Establish the campaign planning workflow
- **Digitalize** the workflow, thus create a tool
- Make the tool modular
- Base the tool on open source solutions
- Describe the tool
- Make the tool publicly available



Digital lidar expert

Physical lidar expert

Workflow Phases

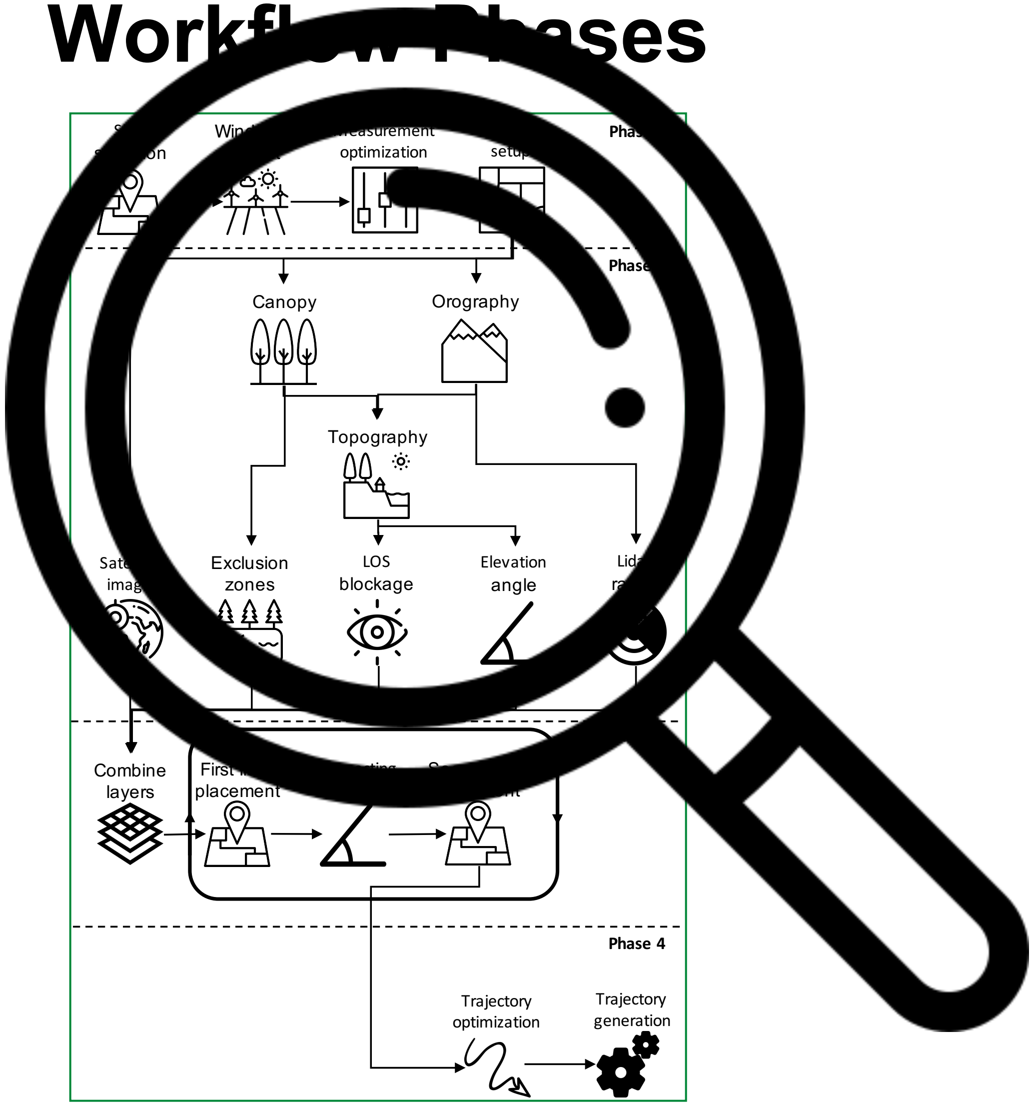
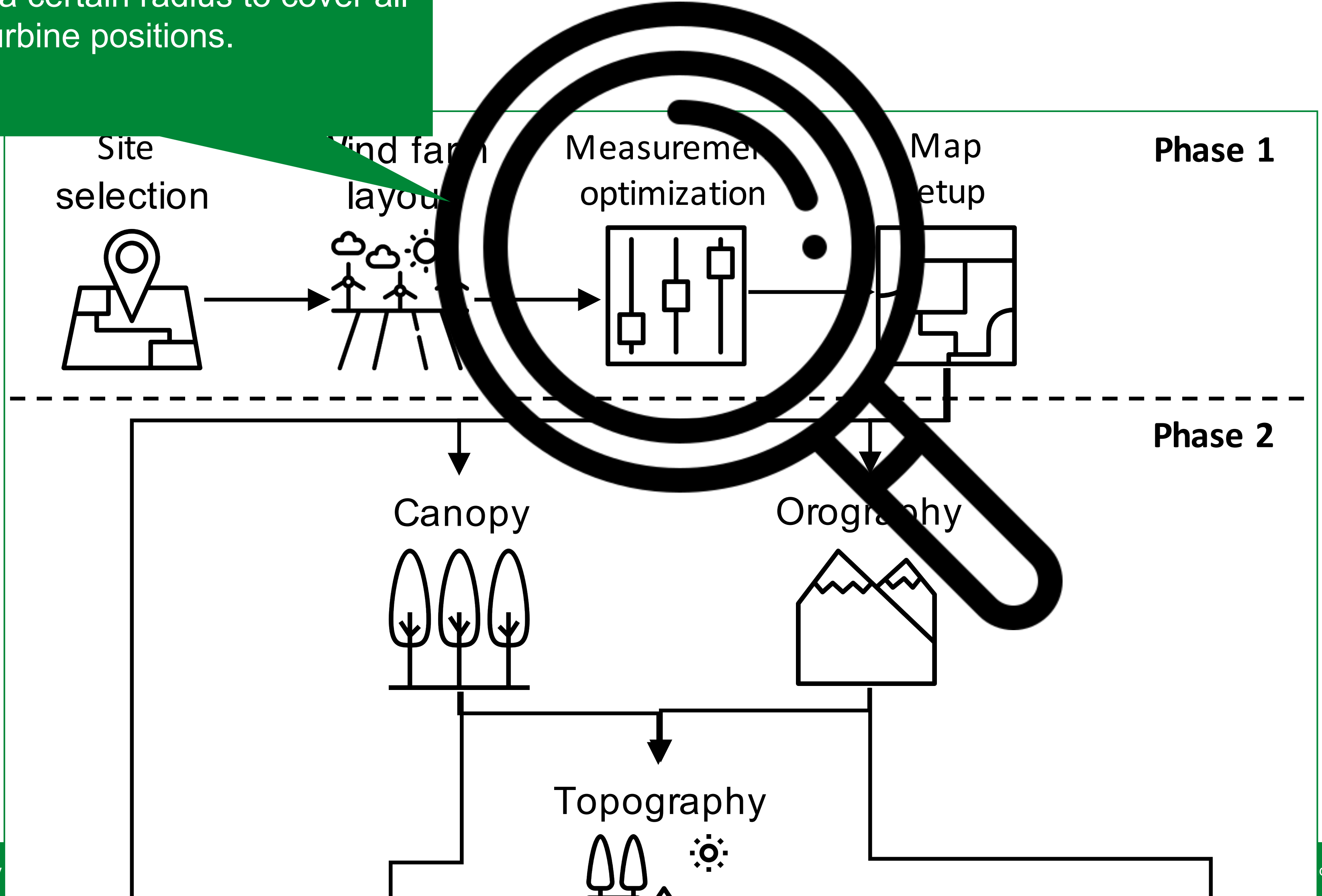
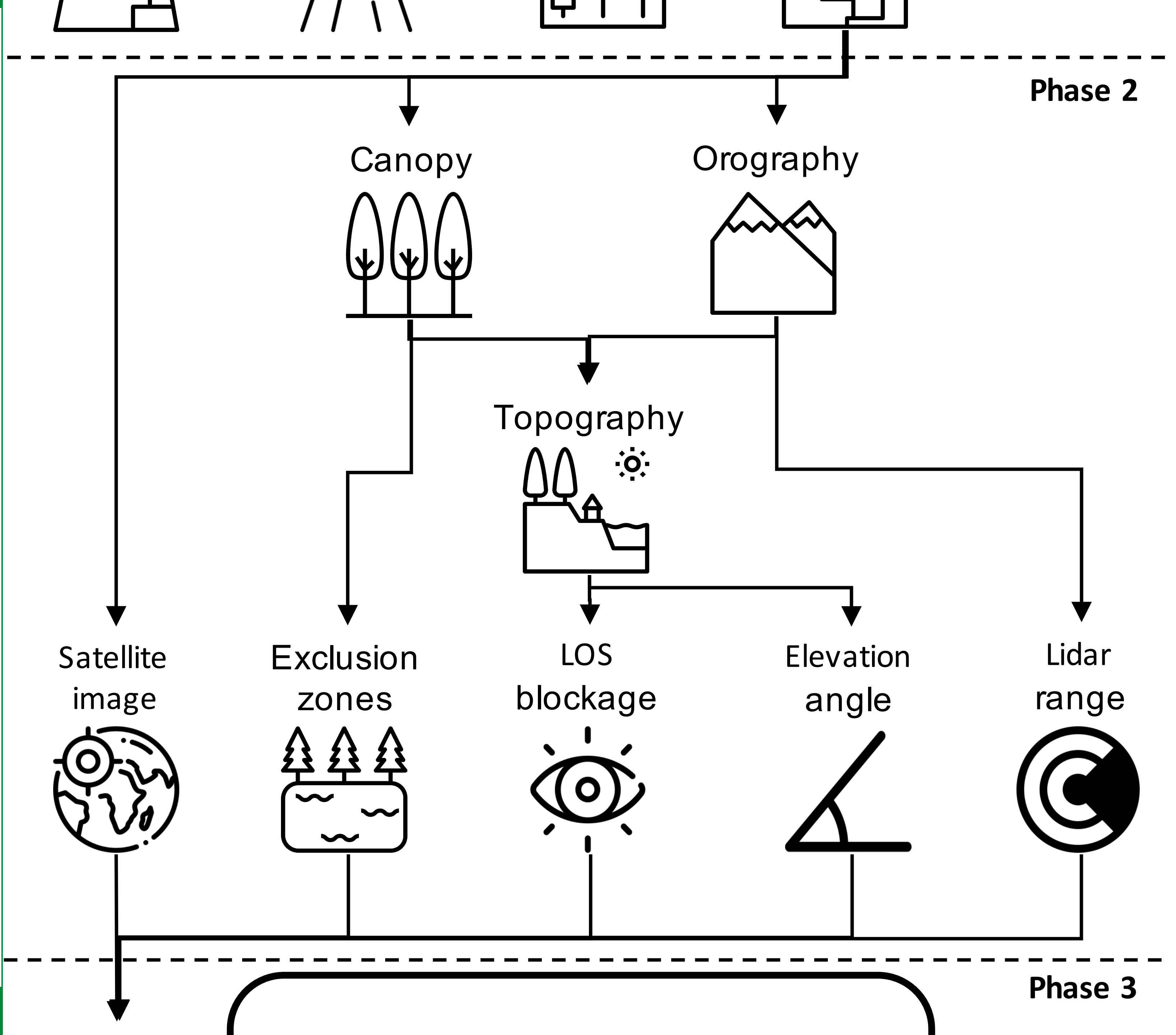


Image source: flaticon.com

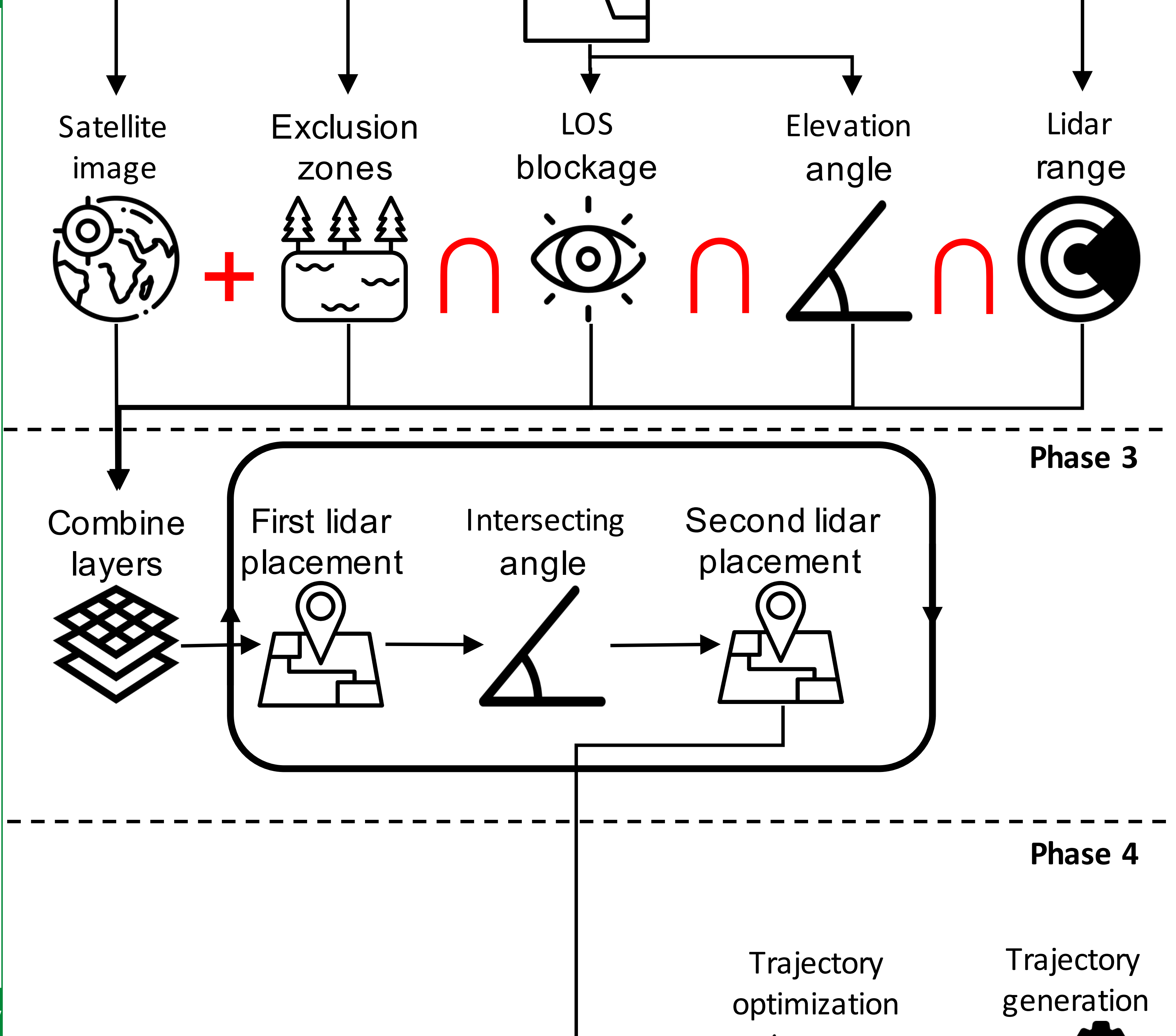
Solving **disc covering problem** in which we are searching for a minimum number of disks with a certain radius to cover all turbine positions.

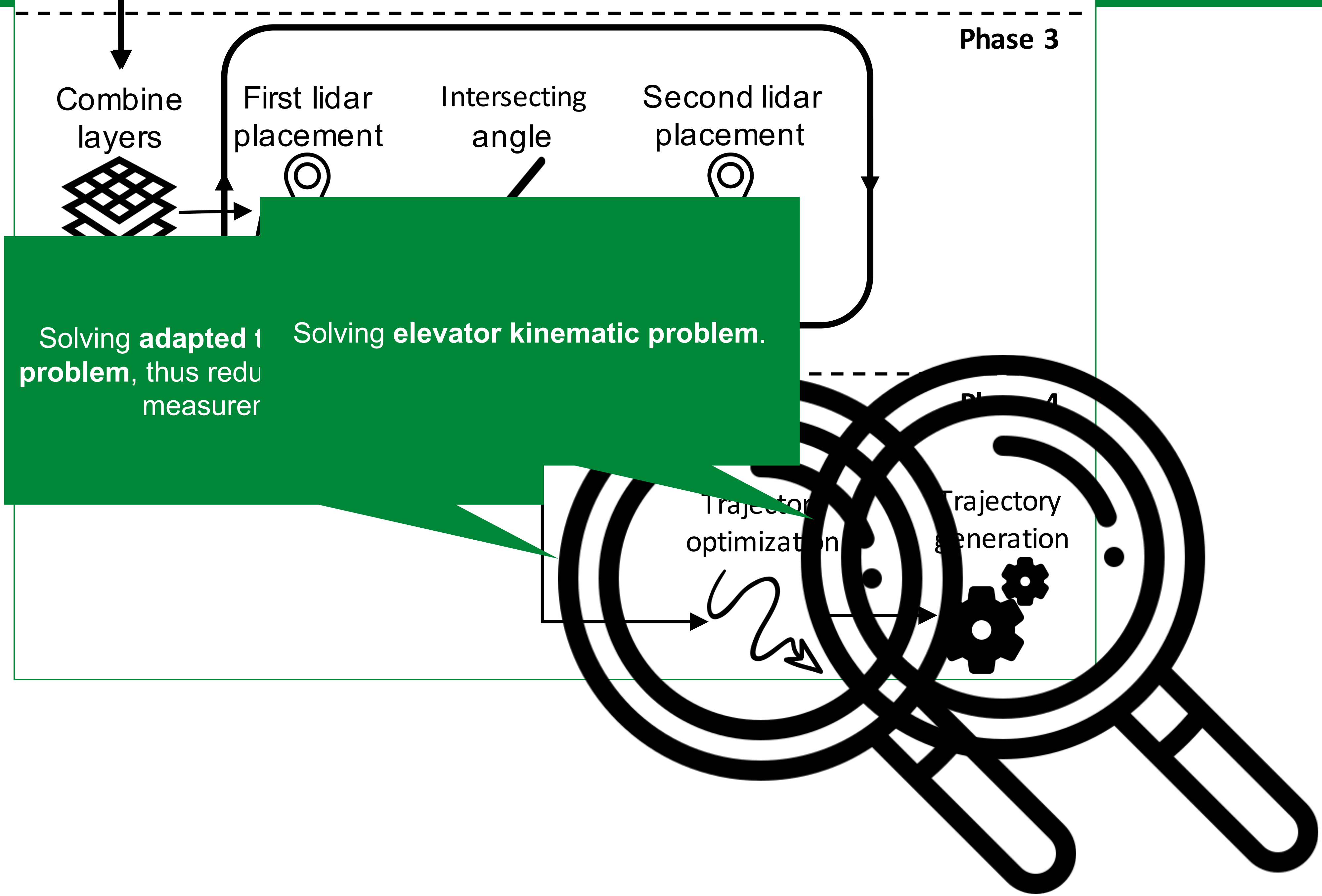
Workflow Phases



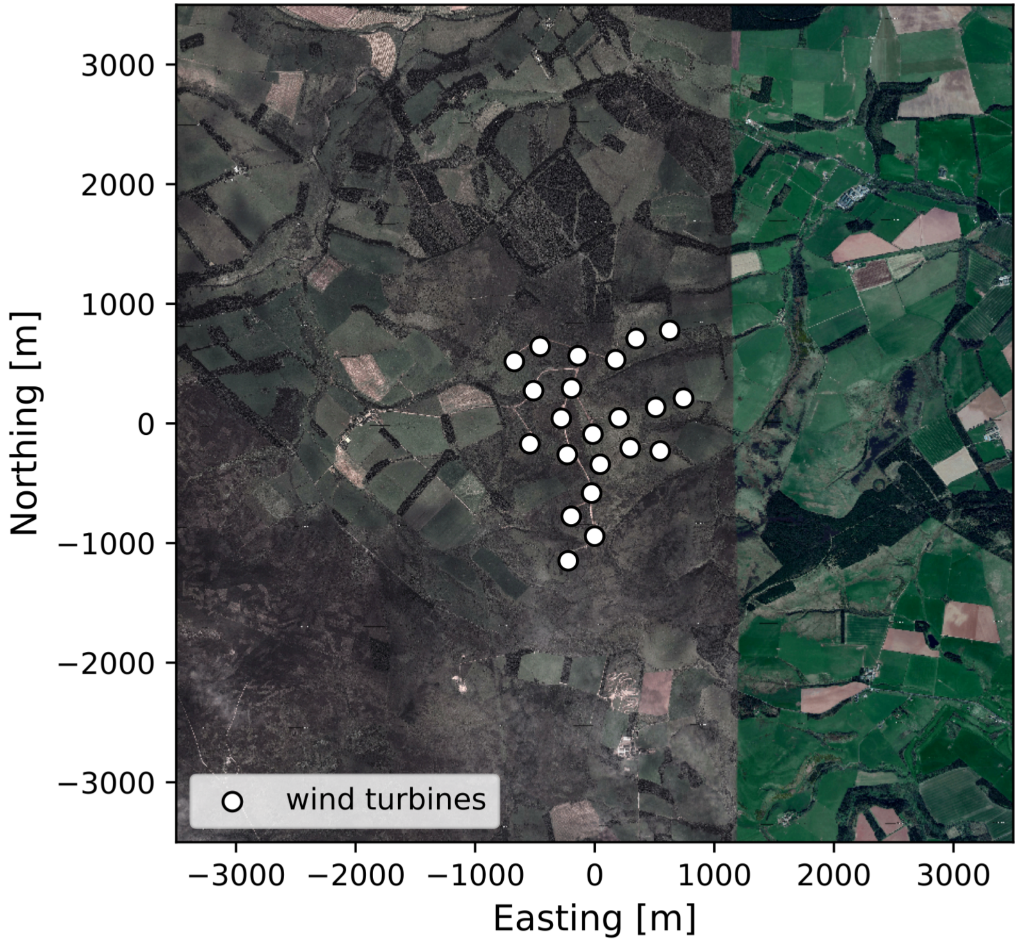


Phase 2
Canopy
Orography
Topography
Satellite image
Exclusion zones
LOS blockage
Elevation angle
Lidar range
Phase 3


Satellite image
Exclusion zones
LOS blockage
Elevation angle
Lidar range
Phase 3
Combine layers
First lidar placement
Intersecting angle
Second lidar placement
Phase 4
Trajectory optimization
Trajectory generation


Phase 3
Combine layers
First lidar placement
Intersecting angle
Second lidar placement
Solving adapted t
problem, thus redu
measurer
Solving elevator kinematic problem.
Trajectory generation

Example 1: Scottish site [10]

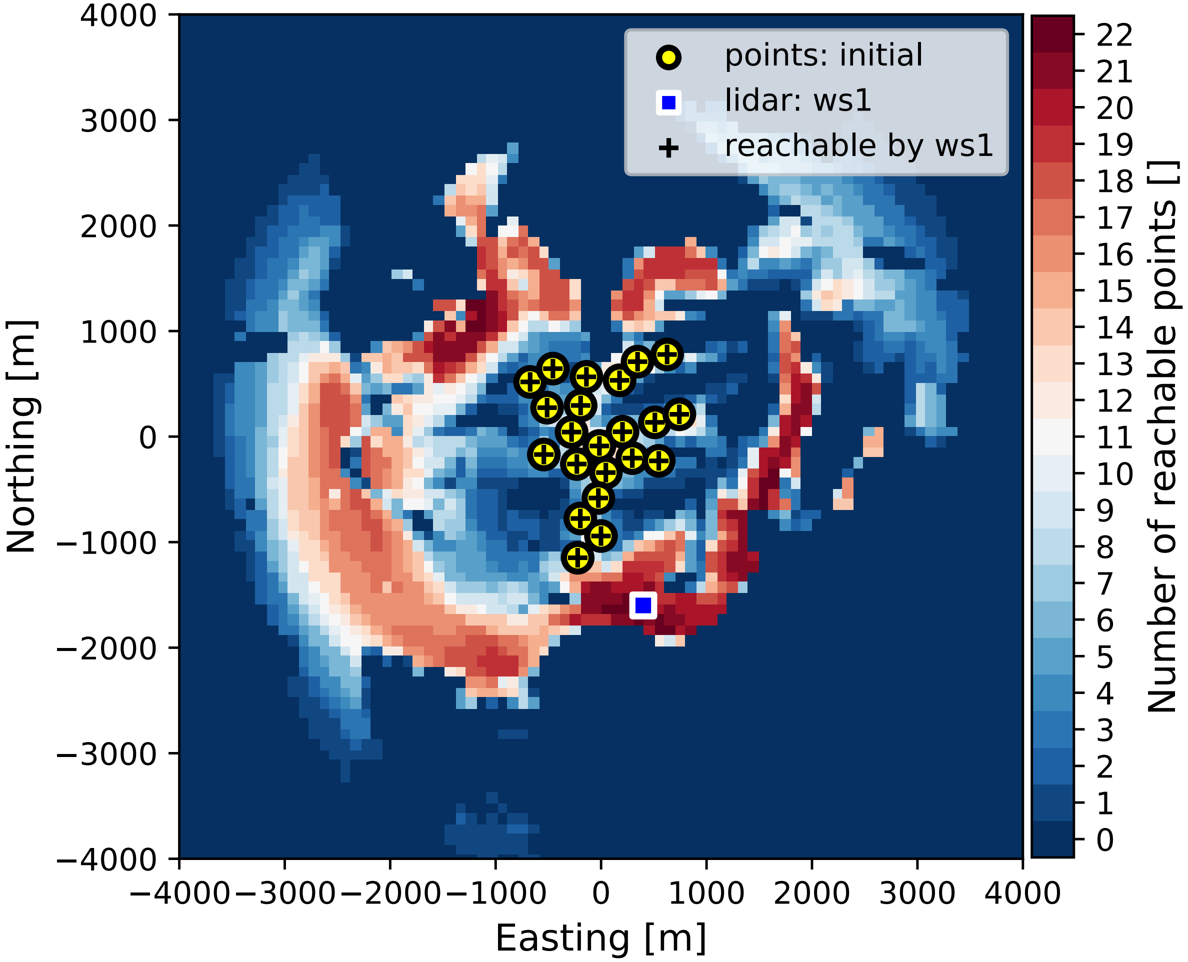


Info:

- 22 wind turbines with 47-m hub-heights
- Hilly terrain
- Aim to measure at each turbine position

[10] https://doi.org/10.11583/DTU.8343989.v3

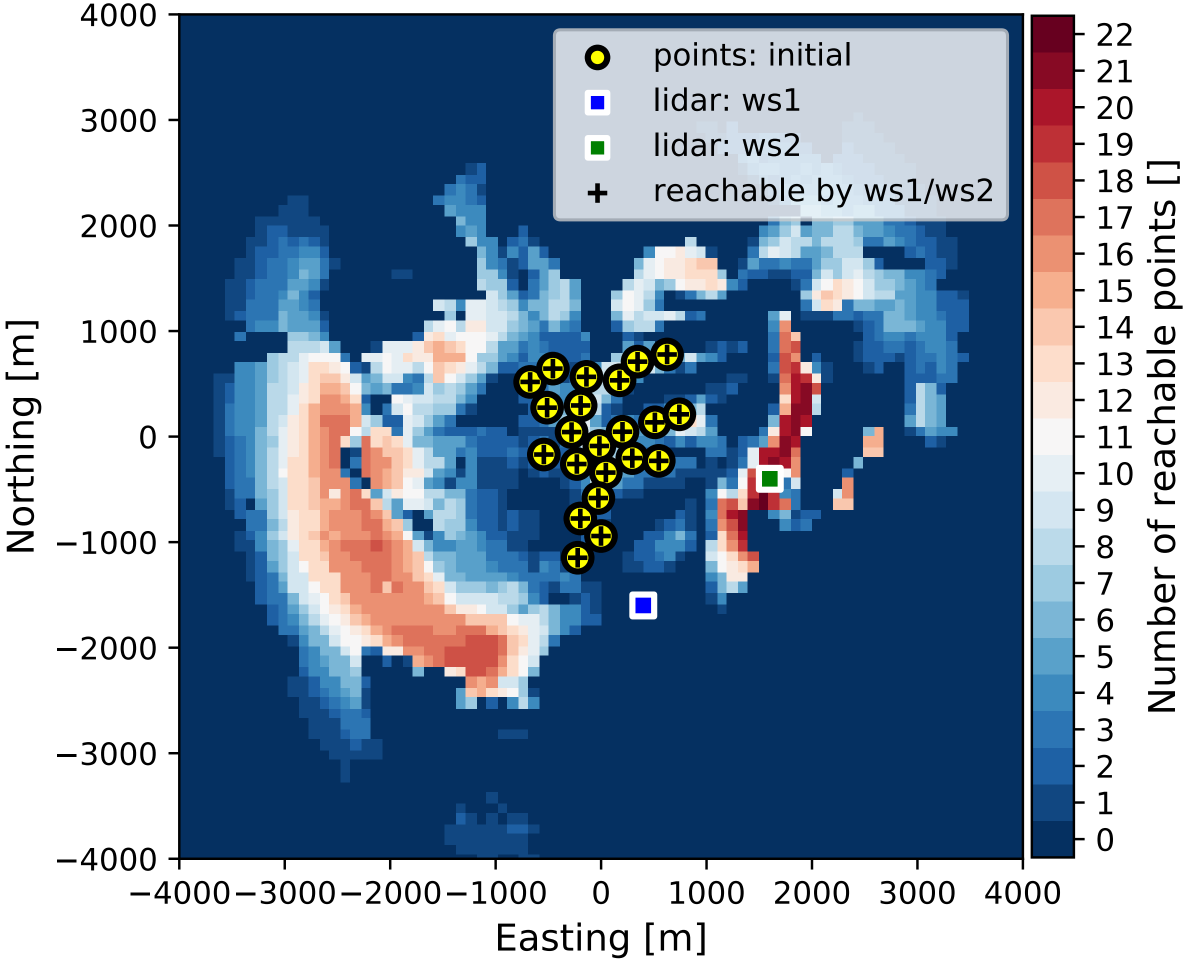
Example 1: Lidar placement GIS maps



Parameter	Value
Average range	3000 m
Max elevation angle	5°
Min intersecting angle	30°

Maps export to GeoTIFF / KML

Example 1: Lidar placement GIS maps



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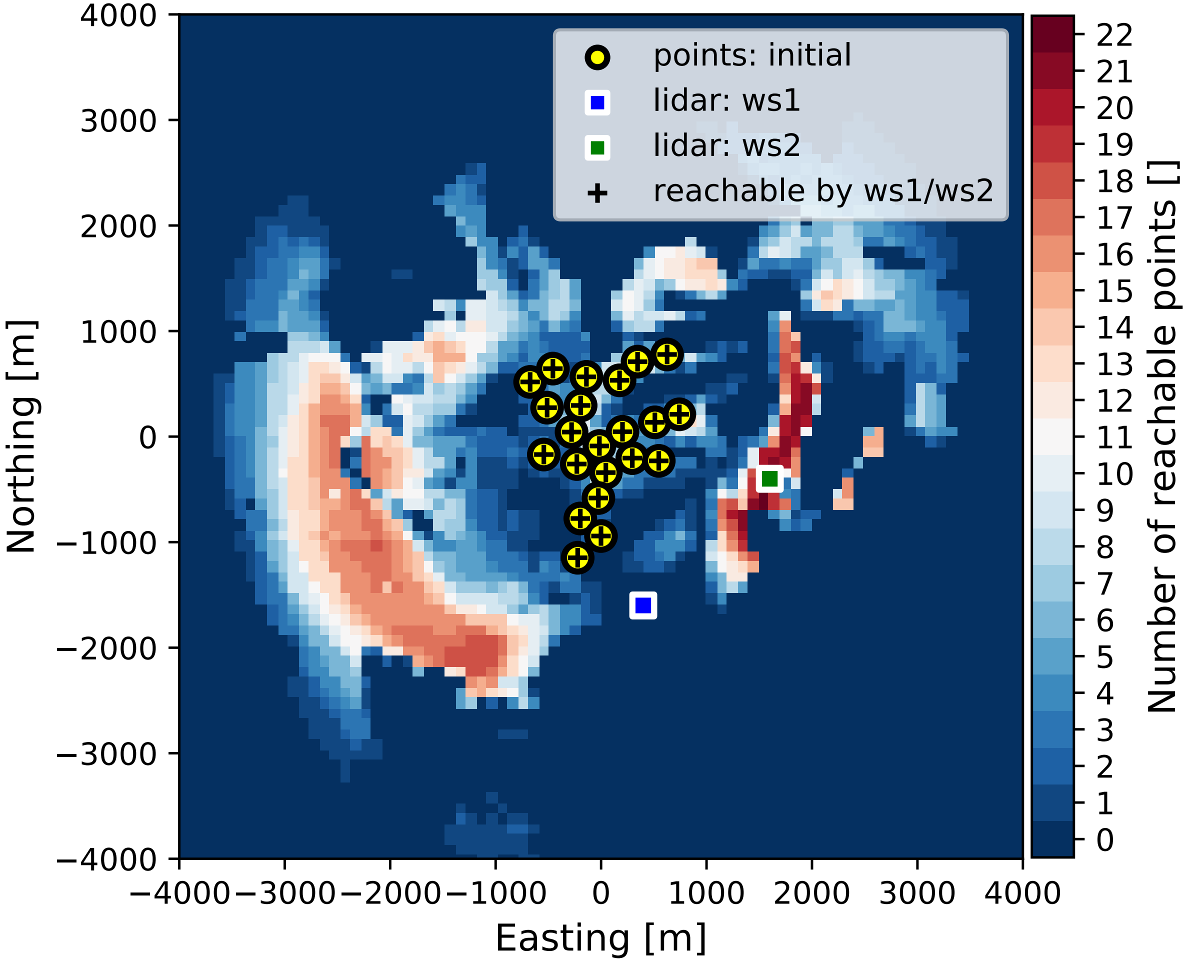
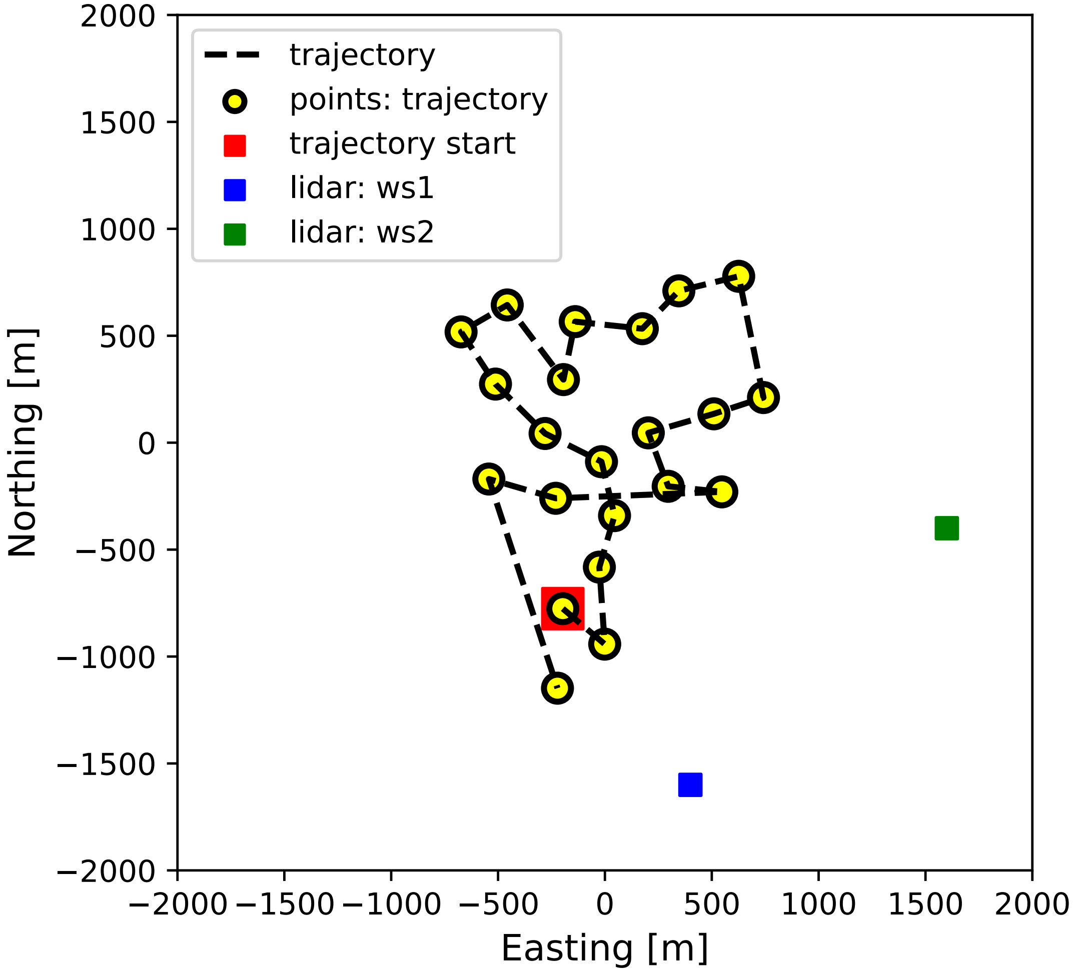


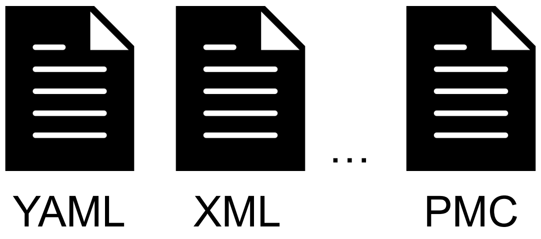
Parameter	Value
Average range	3000 m
Max elevation angle	5°
Min intersecting angle	30°

Maps export to GeoTIFF / KML

Example 1: Trajectory optimization and generation

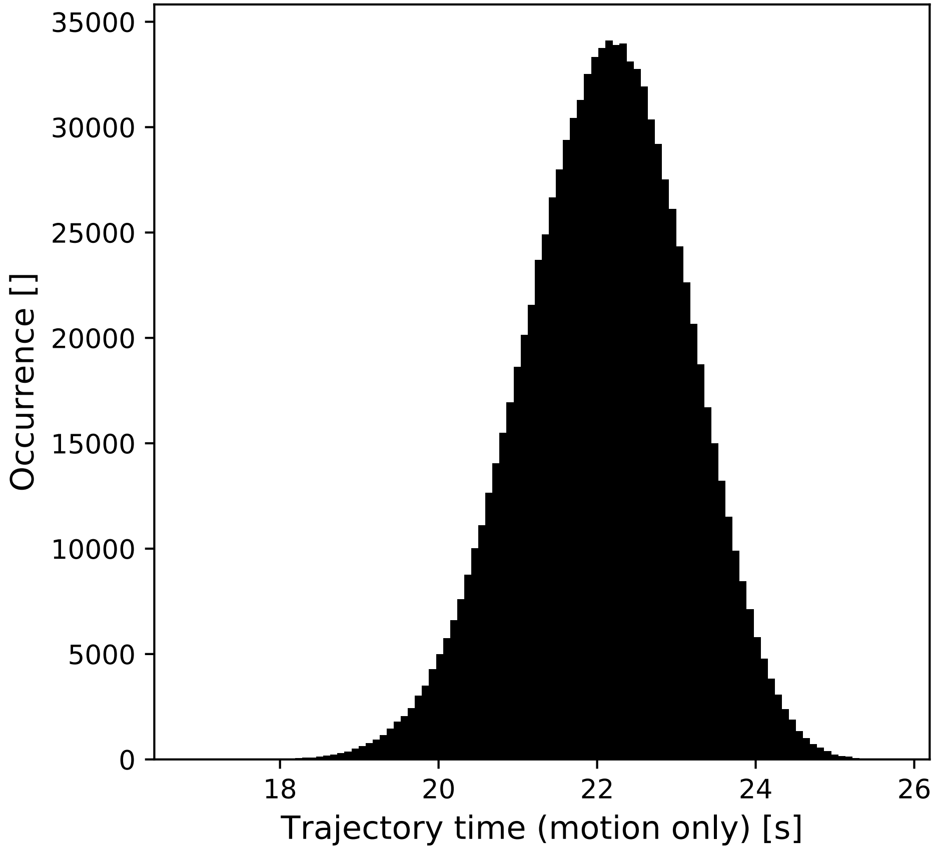


Parameter	Value
Max speed	50˚/s
Max acceleration	100˚/s^2
Measurement time	22 s
Motion time	14 s
Trajectory time	36 s



Results export in multiple files

Example 1: How well the trajectory is optimized?

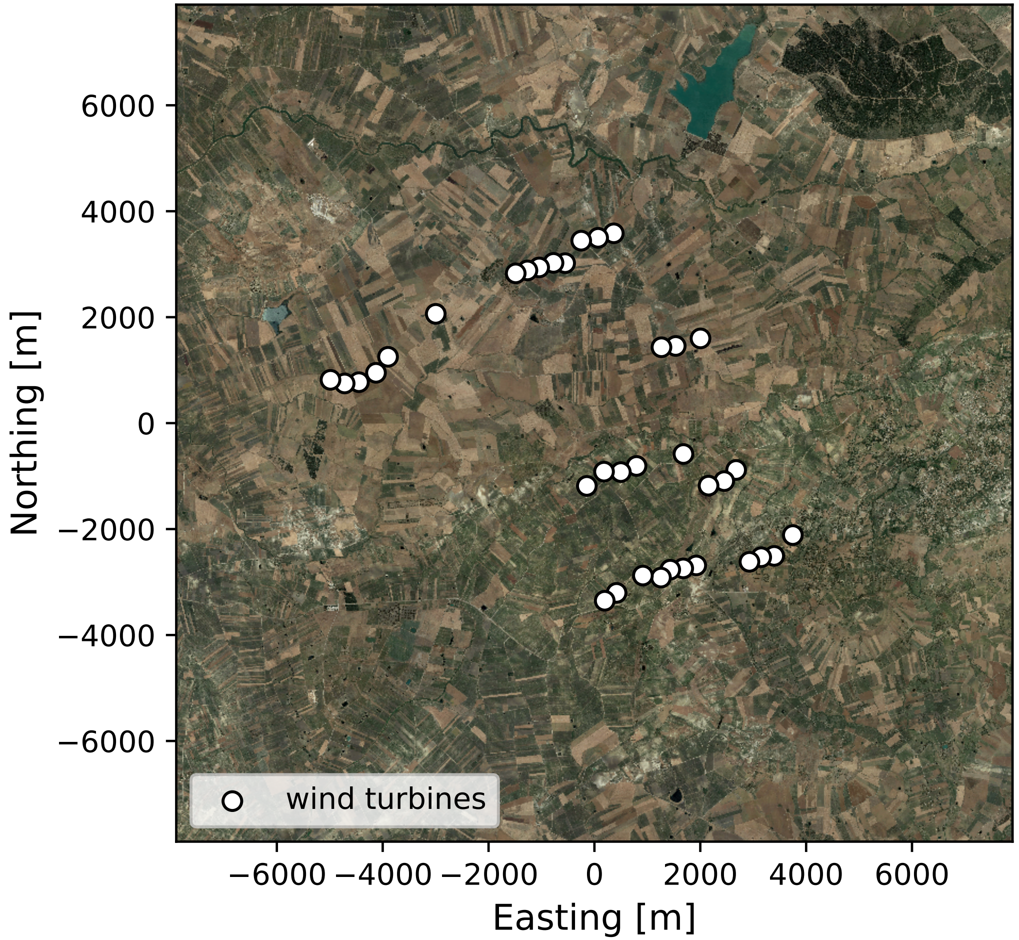


Parameter	Value
Mean motion time	22.09 s
Max motion time	25.76 s
Min motion time	17.15 s
Std motion time	1.03 s

A histogram of motion time for **10^6** randomly generated trajectory configurations for the Scottish site.

On average the optimized trajectory is 8 s shorter in duration!

Example 2: Italian site [11]

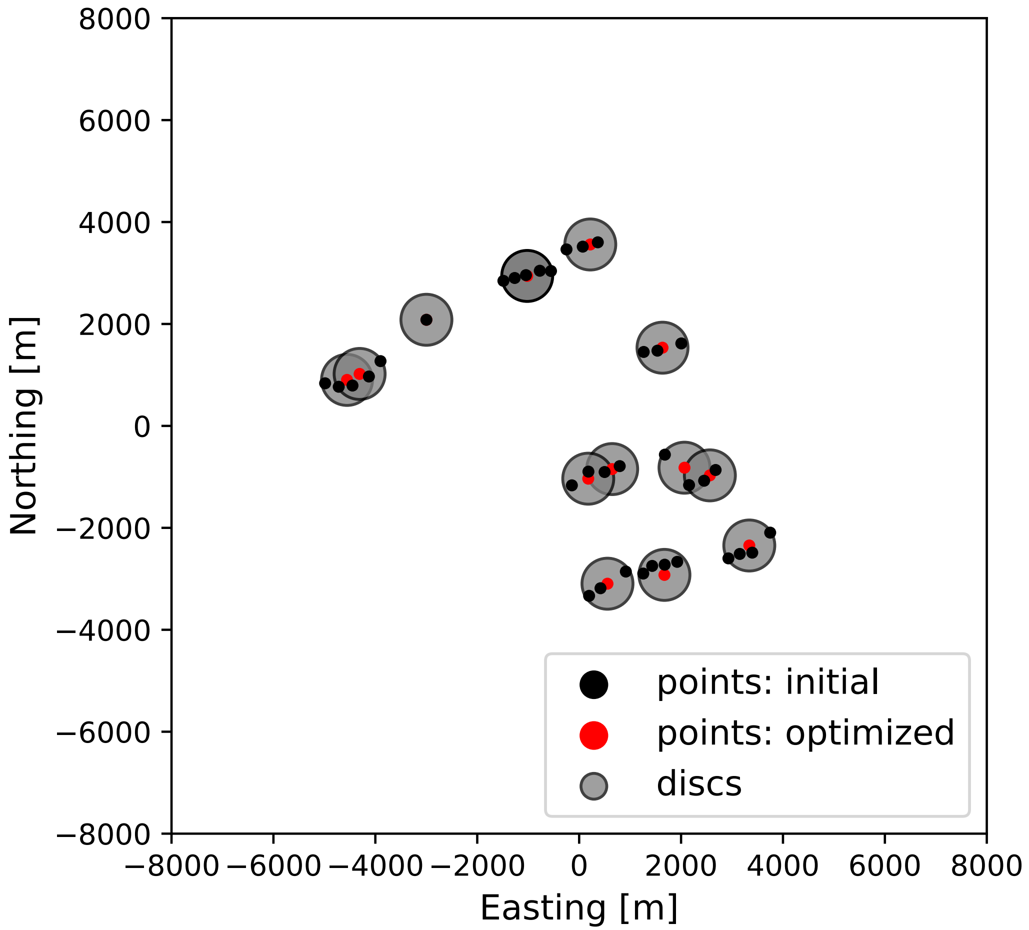


Info:

- 36 wind turbines with 78-m hub-heights
- Hilly terrain
- We will use measurement point optimization

[11] https://doi.org/10.11583/DTU.8343989.v3

Example 2: Measurement point optimization

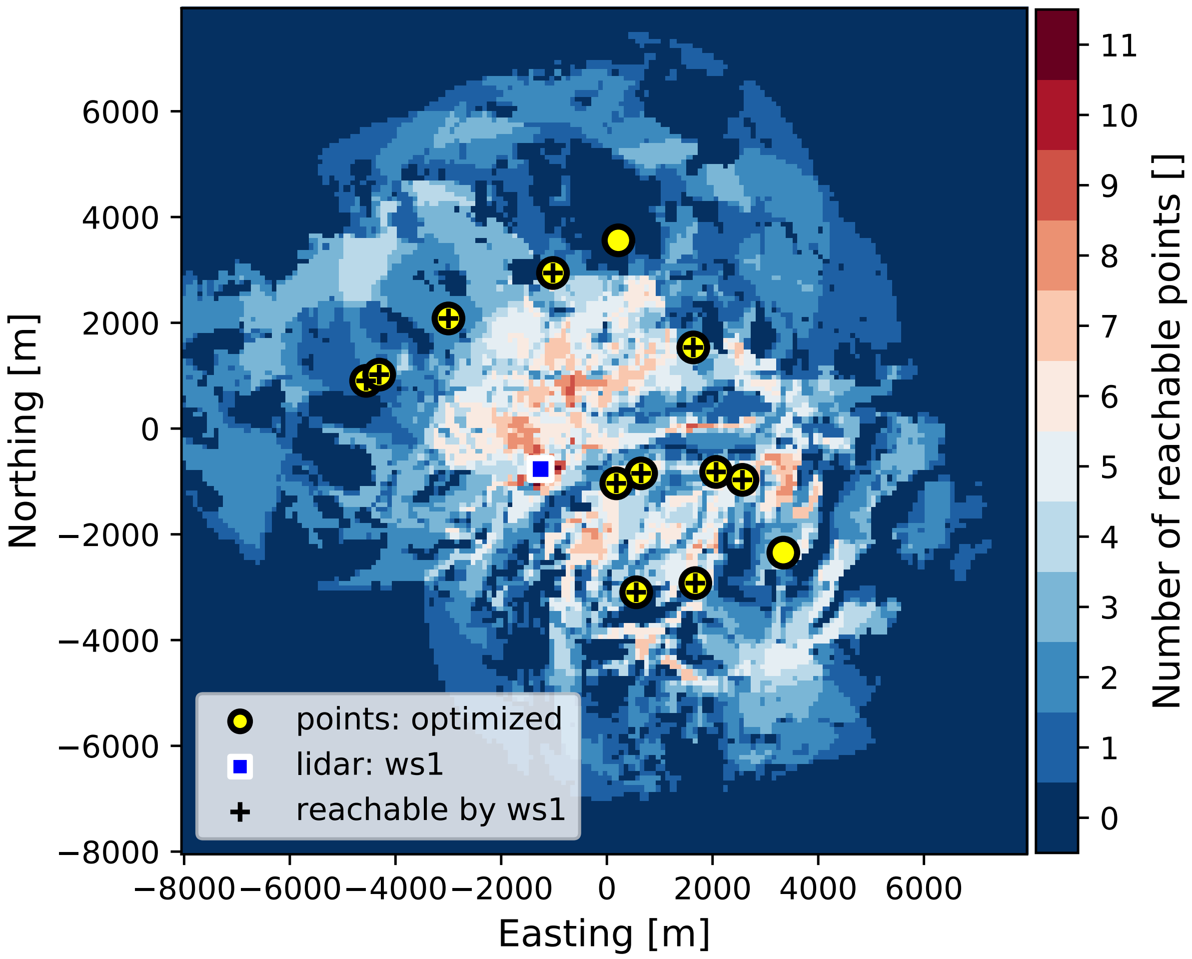


Parameter	Value
Representativeness radius [12]	500 m

[11] https://doi.org/10.11583/DTU.8343989.v3

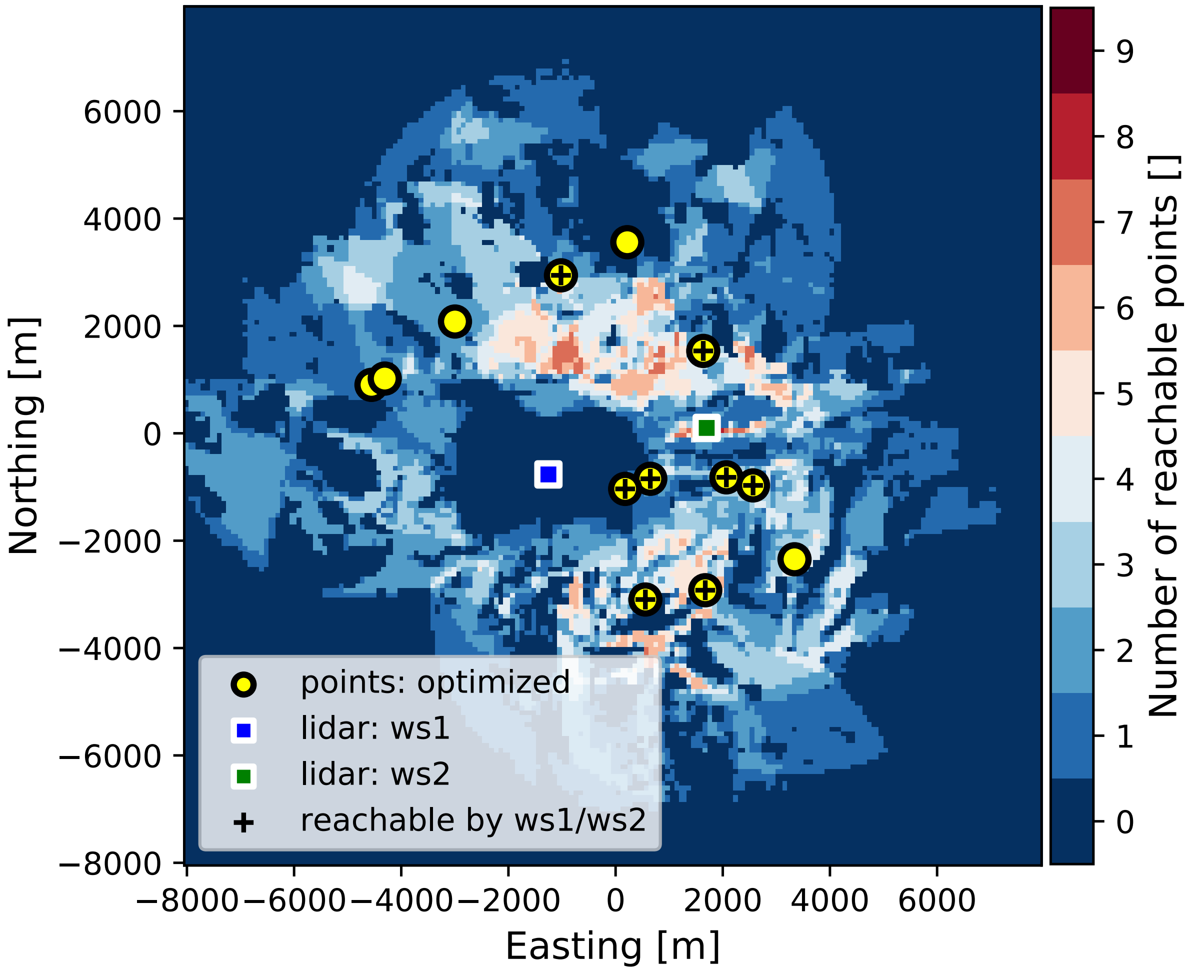
[12] MEASNET Procedure: Evaluation of Site-Specific Wind Conditions

Example 2: Lidar placement GIS maps



Parameter	Value
Average range	4000 m
Max elevation angle	5°
Min intersecting angle	30°

Example 2: Lidar placement GIS maps



Parameter	Value
Average range	4000 m
Max elevation angle	5°
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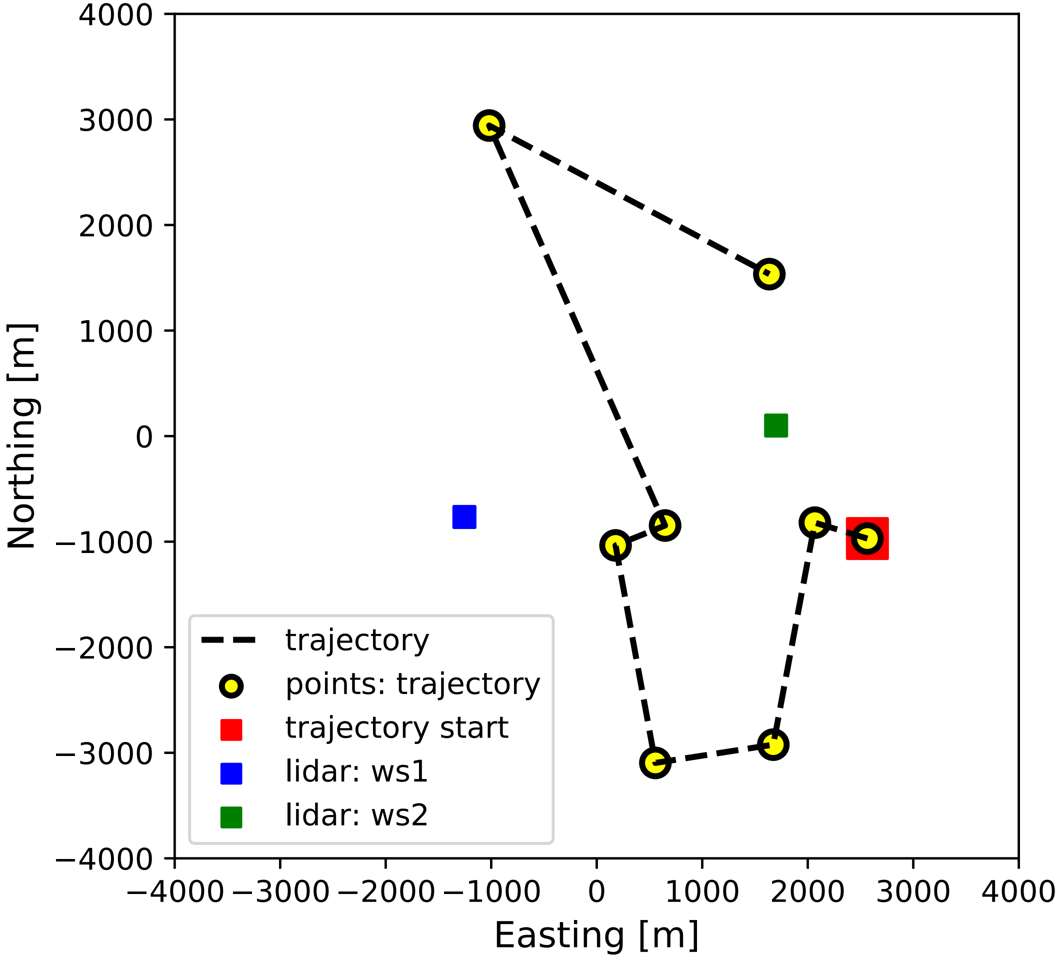
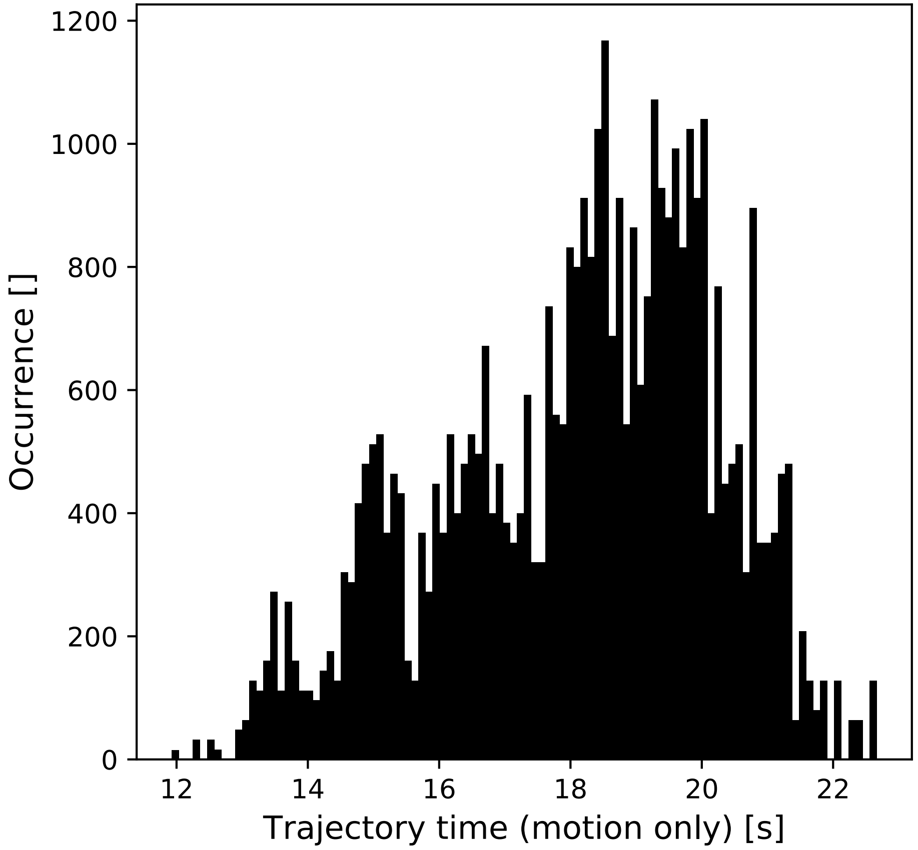
Example 2: Trajectory optimization and generation



Parameter	Value
Max speed	50˚/s
Max acceleration	100˚/s^2
Measurement time	8 s
Motion time	13 s
Trajectory time	21 s

Example 1: How well the trajectory is optimized?



Parameter	Value
Mean motion time	18.14 s
Max motion time	22.66 s
Min motion time	11.93 s
Std motion time	2.10 s

A histogram of motion time for 40320 unique trajectory configurations for the Italian site.

On average the optimized trajectory is 5 s shorter in duration!

Summary

- It takes **some minutes** even for non-lidar experts to design and configure scanning lidar campaigns, opposite to probably **days** if this is done manually by lidar experts

- The actual computational time to run the tool takes about **30 s**

- Trajectory optimization matters since it can shed some seconds per each scan
=> boost measurement rate

How to get *campaign-planning-tool*

- Current public version 0.1.3 is provided via DTU Wind Energy's conda channel
- Check out Github repo for the installation instructions: https://github.com/niva83/campaign-planning-tool

Future work

- Develop range prediction module
- Develop data availability prediction module
- Develop eye safety check module

OpenLidar

DTU contributions to OpenLidar initiative

- In collaboration with ForWind developed Remote Sensing Communication Protocol [13]
- Contributed to the OpenLidar architecture
- In collaboration with ZX Lidars developed proof-of-concept drone-based wind lidar [14]

[13] https://orbit.dtu.dk/ws/files/59175330/The_application_layer_protocol.pdf
[14] https://www.atmos-meas-tech-discuss.net/amt-2019-102/

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In quest for …

– Low cost accurate measurements

– High frequency small probe volume

– High availability of data

– Simple sophisticated measurements

Slide source: https://zenodo.org/record/3249999

Promising solution

- Use of drones as platforms for wind lidars

- Drones would be used to:
  - to position the lidar in the vicinity of the measurement points
  - to steer the outgoing laser beam

Impact of such solution

- Relax a requirement on maximum range (a few meters would be enough)
- No need to have a variable focus
- No need to have a scanning mechanism
- No need to have an acousto-optic modulator (AOM)
- A significant reduction in the lidar complexity (fewer and cheaper components), size, weight and power consumption, and thus potentially in the overall costs.
- The requirements for the drone-mounted lidar can be met by a low-power small-optics CW lidar with a manual focus adjustment.

Slide source: https://zenodo.org/record/3249999

Impact of such solution - continued

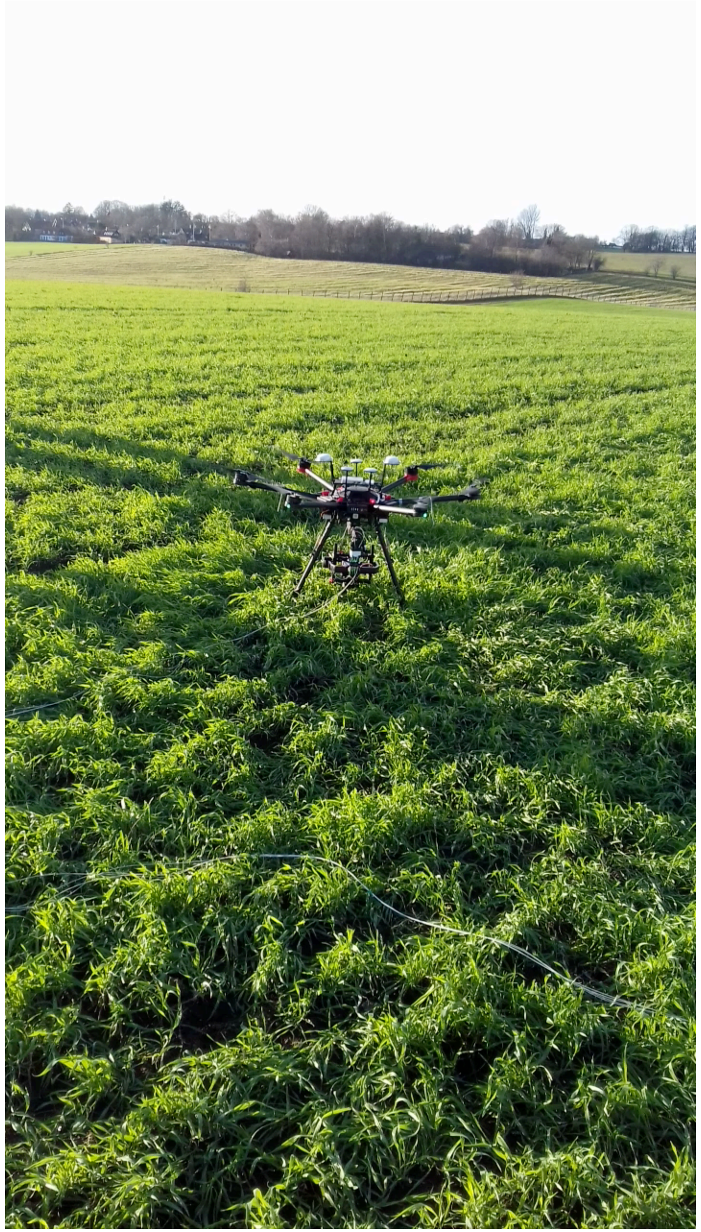
- High frequency measurements (50 Hz)
- Short focus distance = small probe length (~10 cm)
- Short-range measurements would not be hindered by fog or clouds
  => improved data availability
- Measurement can be made in difficult locations
- We don’t need to develop drones, drones are everywhere and developed by others

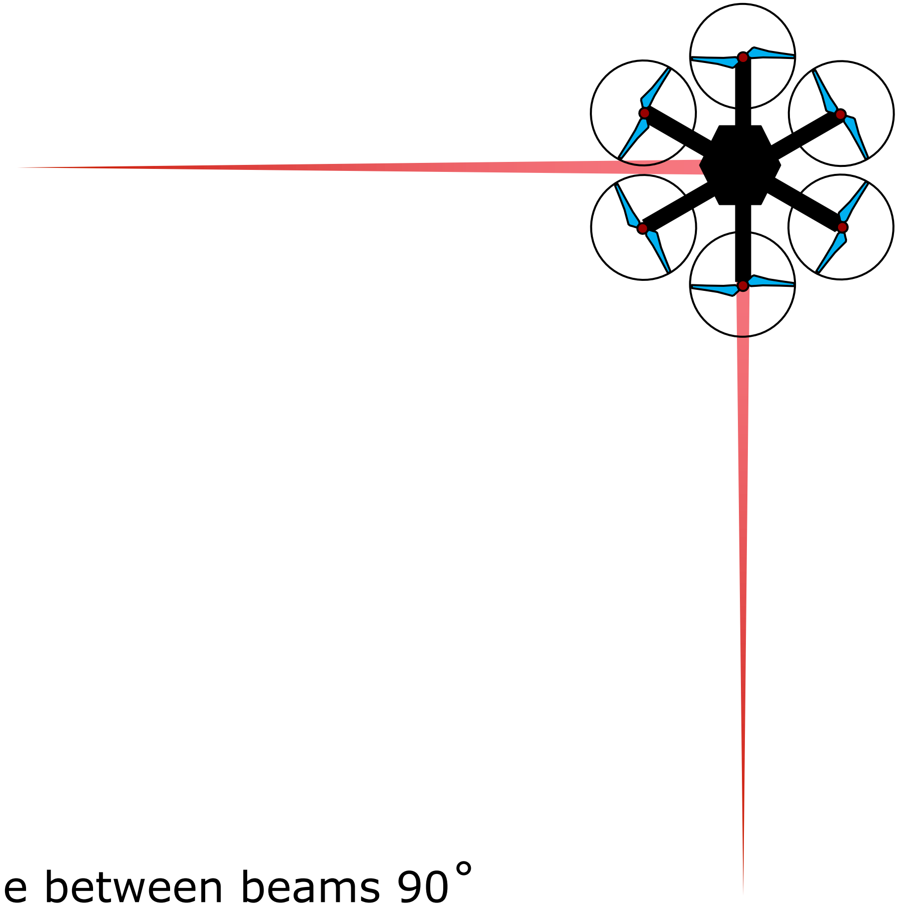
Dual-telescope proof-of-concept, Denmark

See picture gallery:
https://work.courtney.dk/#collection/364601

3 – 5 /12/2019 – proof-of-concept with a dual-single telescope system

Slide source: https://zenodo.org/record/3249999



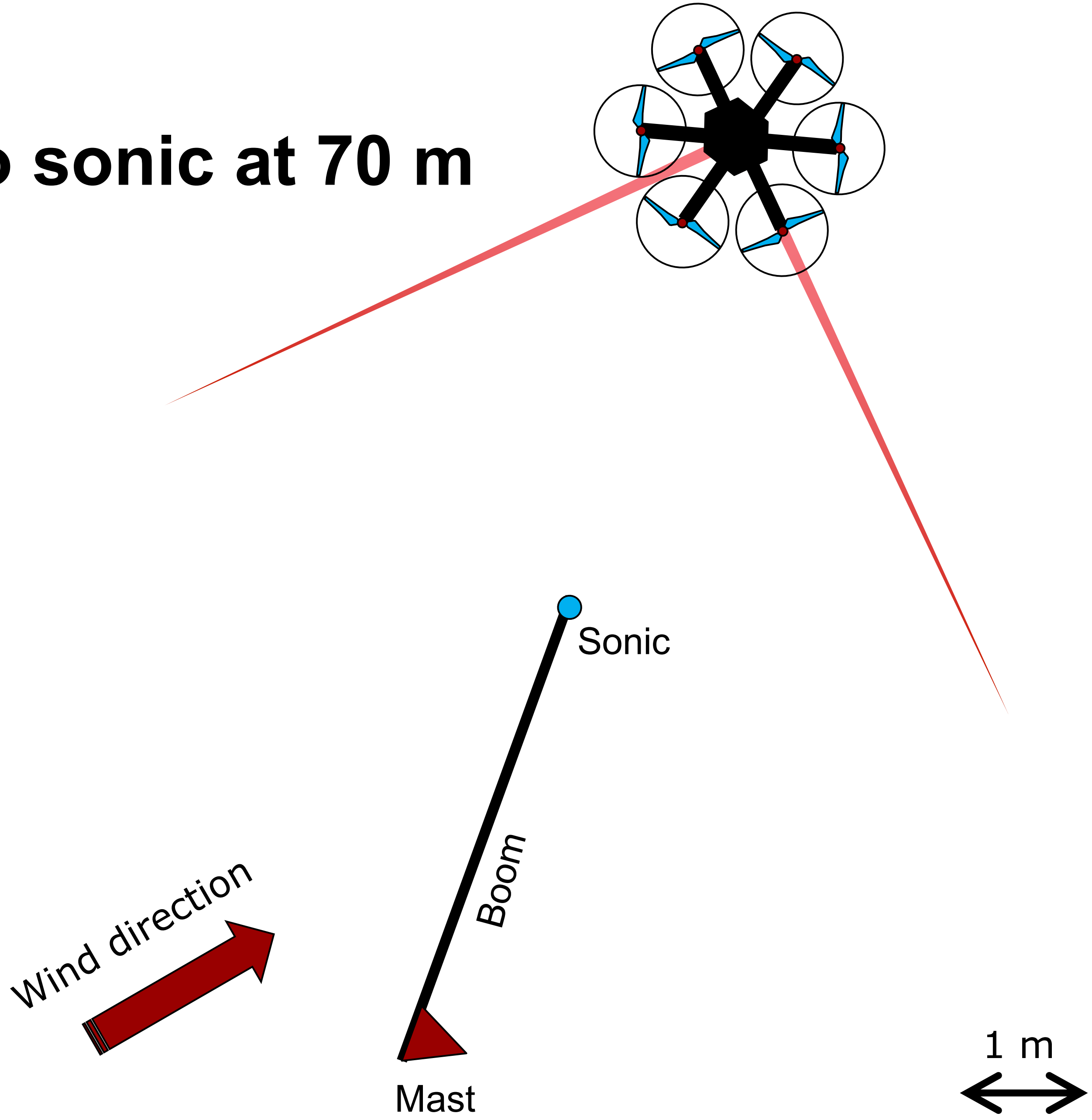


Angle between beams 90°
Effective probe length 25 cm
Beams focused @ 5 m
0.3 W per telescope
100% duty-cycle on both channels

Dual-telescope setup

Measurements next to sonic at 70 m

V52 met mast at Risø campus



Slide source: https://zenodo.org/record/3249999

Incoming 50 Hz data

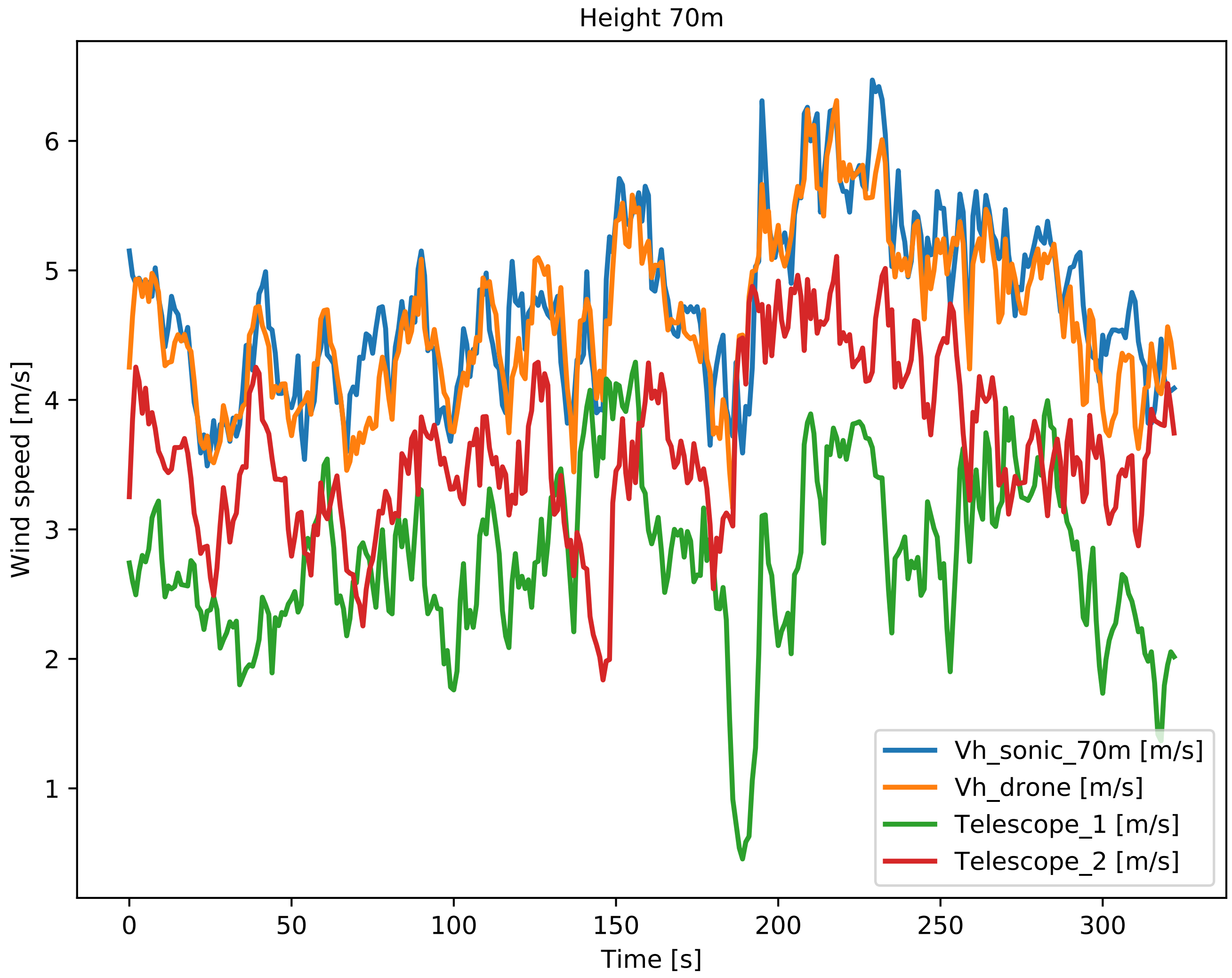
Slide source: https://zenodo.org/record/3249999

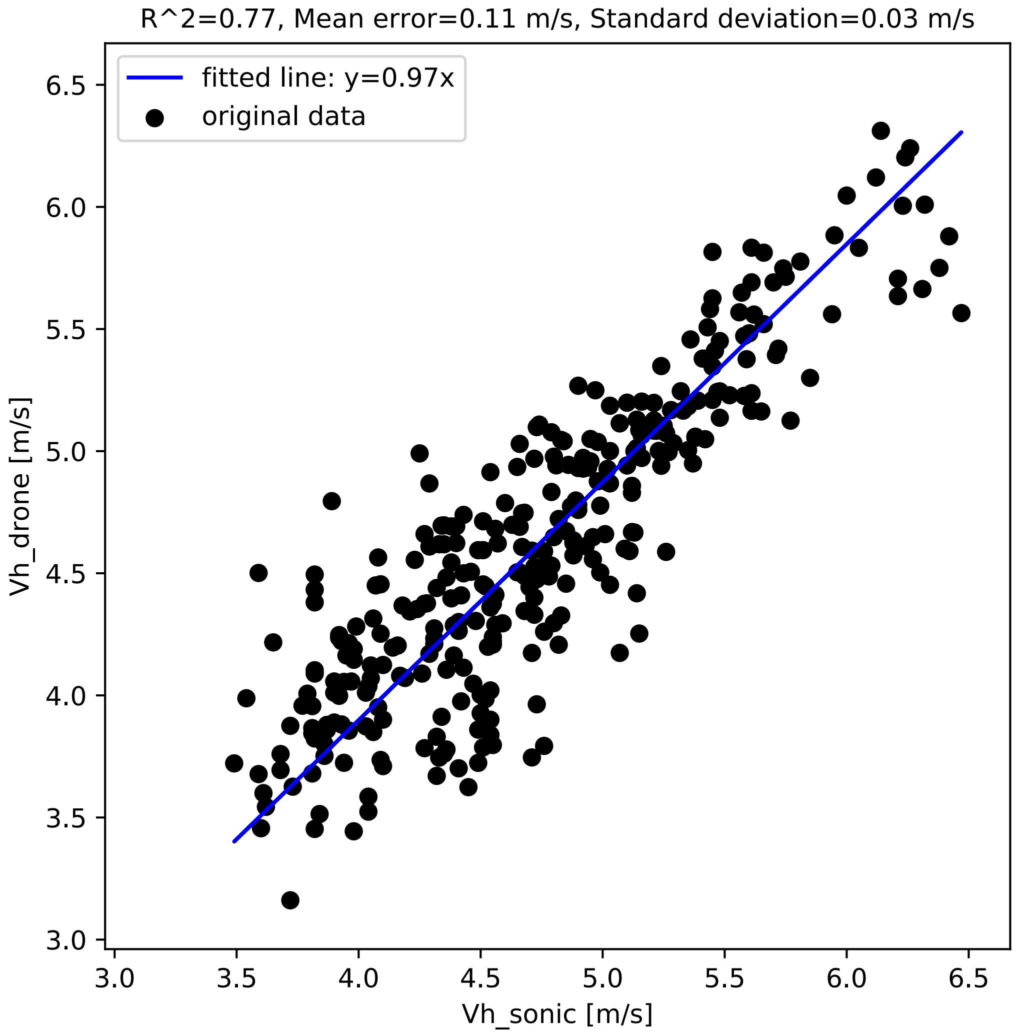
Beware

- This is a proof-of-concept stage in a product development
- Drone was manually positioned and maintained next to the sonic anemometer
  - RTK of Differential GPS did not work
  - We used basically our eyes and on-board + GoPro camera to work out drone position
- **Drone motion was not subtracted from the Doppler shift**
- These were not ‘co-located’ measurements
- You will see 1 Hz averaged data on next slide

Mean difference 0.11 m/s
y=0.97x
$R^2 = 0.77$

Results (1 Hz data comparison)





Slide source: https://zenodo.org/record/3249999

Summary

- Successfully demonstrated that:
  - Drone-lidar wind measurements are possible
  - Consistent with that measured by the nearby sonic anemometers

- Despite this being a first attempt we have already accomplished a close agreement to the nearby mast instrumentation

- **This has been achieved using only the basic drone position stabilization and without correcting in any way for the drone motion!**

- We done a bit more in December 2018 than what is showed in slides

- Currently a paper describing the results under review in AMT: https://www.atmos-meas-tech-discuss.net/amt-2019-102/

Slide source: https://zenodo.org/record/3249999

Future work

- Since the POC results are encouraging, we will proceed and enter in the phase of prototyping
- Explore both a fully tethered (optic and power link physically attached to the drone), non-tethered (battery powered drone and entire lidar(s) mounted on the drone), and hybrid (battery power drone and telescopes attached to the drone/gimbal) concepts
- Build a compact-form low-power data acquisition and control system (DACS) based on Raspberry Pi, where the DACS software will be based on Python
- Develop the uncertainty model for the drone-based wind lidar system based on the GUM methodology Joint Committee for Guides in Metrology (2008)
- In accordance to the uncertainty model we will propose testing and calibration procedures
- Demonstrate new measurement technique in various applications ranging from wind energy, wind engineering to sports and leisure

Slide source: https://zenodo.org/record/3249999

Acknowledgment

- NCAR and NSF for providing funding for my visit as a part of Robert Menke's ASP fellowship
- RECAST project for resources for *campaign-planning-tool* development
- DTU Wind Energy for internal funding for the drone-based wind lidar development

Thank you for your attention
Questions?

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