Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

InnoWind Project Team – www.innowind.dk

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Anders Sommer (VATTENFALL, DK)

Winterwind 2020, Åre, Sweden, February 4th @ 11:00-12:30

EMD International A/S
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DTU Wind Energy
Department of Wind Energy

DTU Space
National Space Institute

DHI GRAS

Vestas

VATTENFALL

Introduction

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

What would it mean for our current wind resource and flow models …
if they could rely on accurate, high-resolution, up-to-date land-surface descriptions which were instantly available and without excessive cost?

Contents

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

1.Introduction and Motivation

Innowind project objectives

Copernicus, the Sentinels and other big-data sources

2. Land-Surface Modelling

Roughness modelling and forest parameterization

Data – sources and models

3. Findings / Conclusions

Introduction & Motivation

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

InnoWind Theme

Land surfaces for wind energy modelling using new satellite (and airborne) sensors

InnoWind Goals

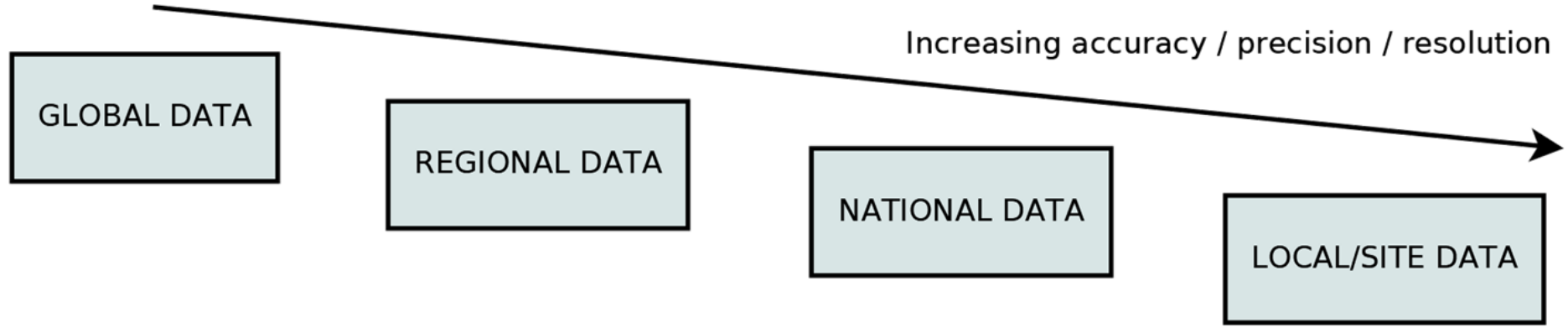
1. **Replace manual efforts** with automated procedures for wind farm siting
2. **Reduce uncertainties** of wind resource estimates
    a) Use of physical land surface parameters for wind energy modeling (e.g. tree heights, vegetation densities, LAI)
    b) Global coverage and frequent updating of map
3. **Reduce the Levelized Cost of Energy –** and thereby realize more wind energy projects

”By the end of InnoWind, we will ~~no longer~~ rely less on manual digitalization of maps”

- NN, EMD International A/S

Introduction & Motivation – Big Data

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

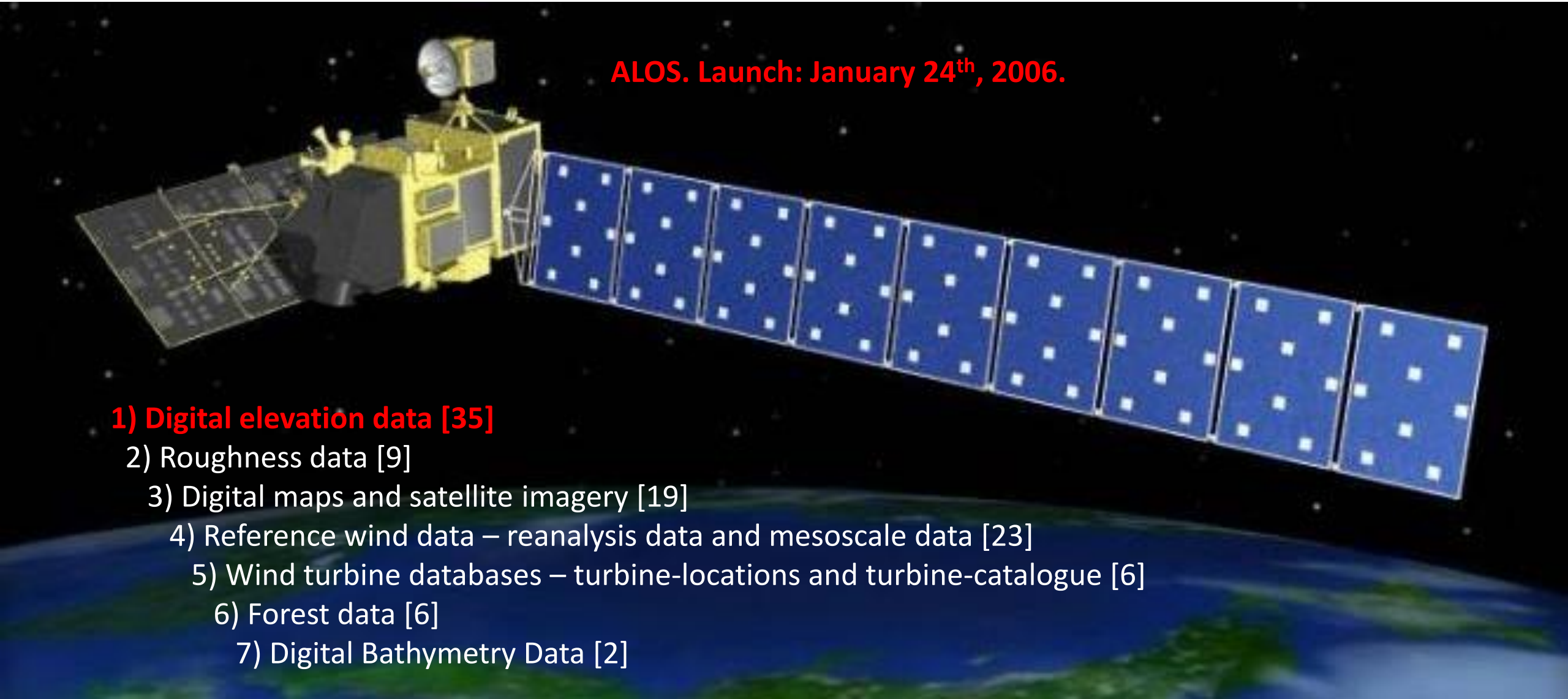


Big data is here - more than 1Pb of data in windPRO alone – or 150+ Pb in the Copernicus DB's.
With windPRO, currently 100+ Reanalysis and Remote Sensing Datasets available to improve modelling.

1) Digital elevation data [35]
2) Roughness data [9]
3) Digital maps and satellite imagery [19]
4) Reference wind data – reanalysis data and mesoscale data [23]
5) Wind turbine databases – turbine-locations and turbine-catalogue [6]
6) Forest data [6]
7) Digital Bathymetry Data [2]

Introduction & Motivation: ALOS

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources



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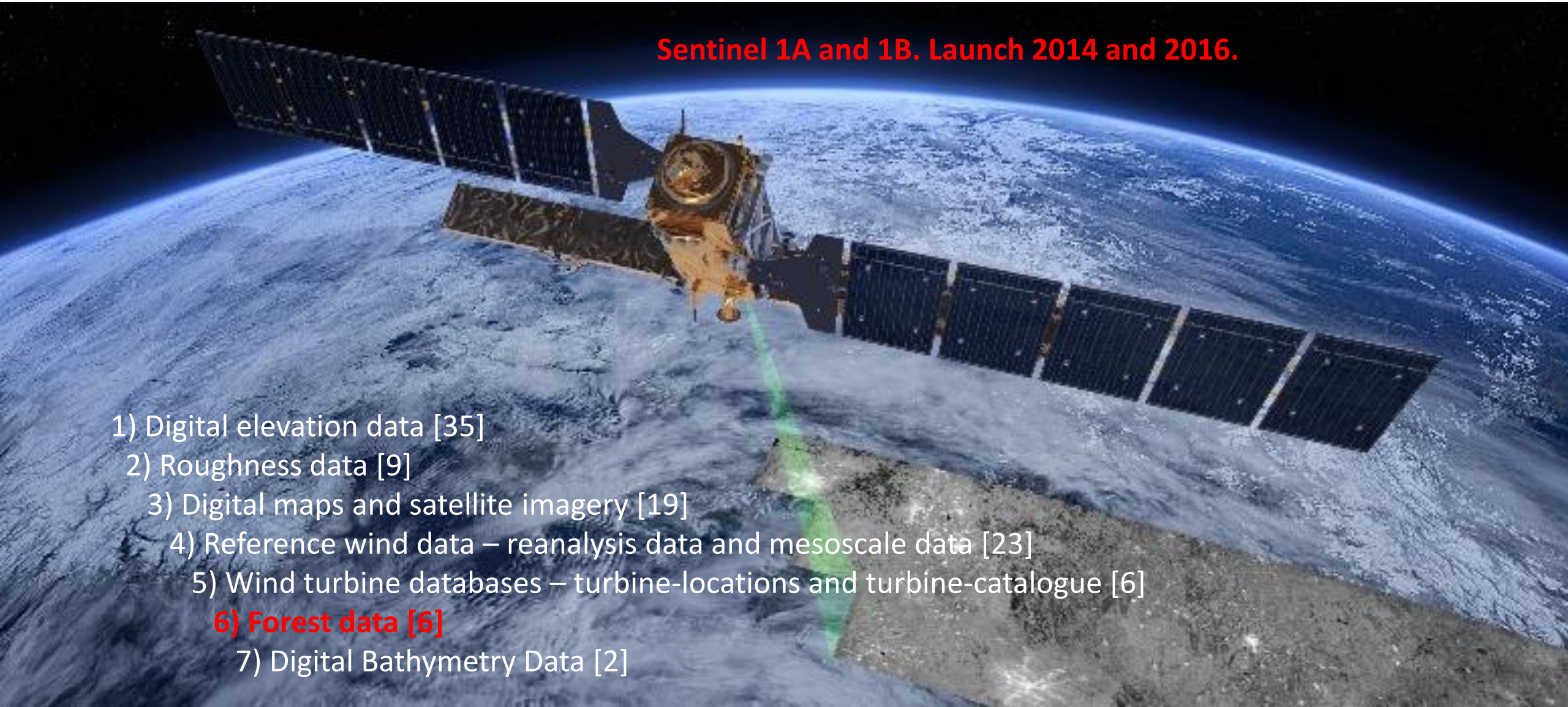
Introduction & Motivation: Sentinels 1A&1B

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources



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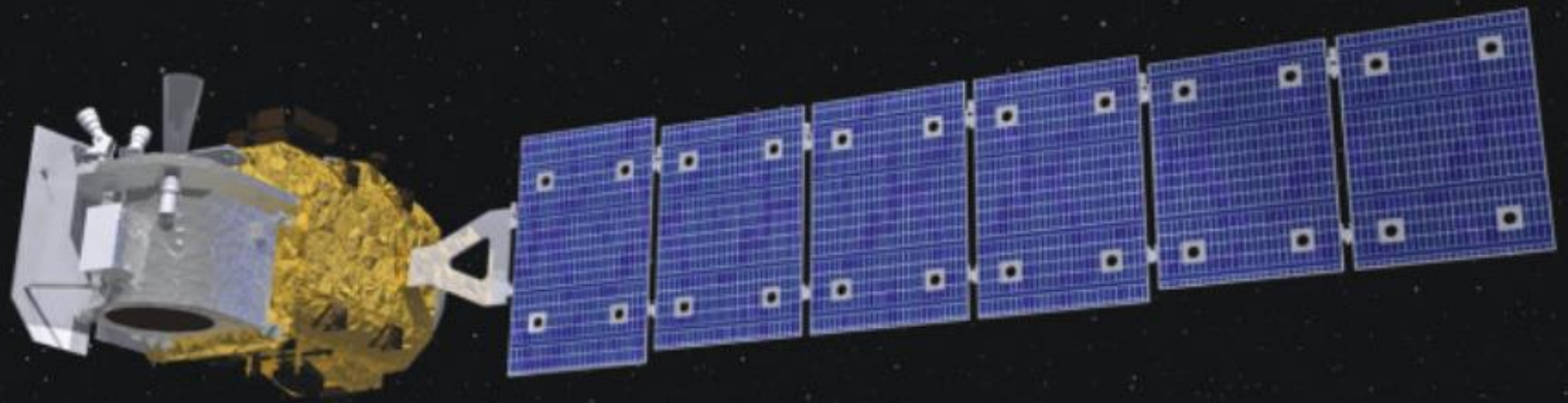
Introduction & Motivation: Icesat 2

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources



Icesat 2. Launch: September 15th 2018

1) Digital elevation data [35]
2) Roughness data [9]
3) Digital maps and satellite imagery [19]
4) Reference wind data – reanalysis data and mesoscale data [23]
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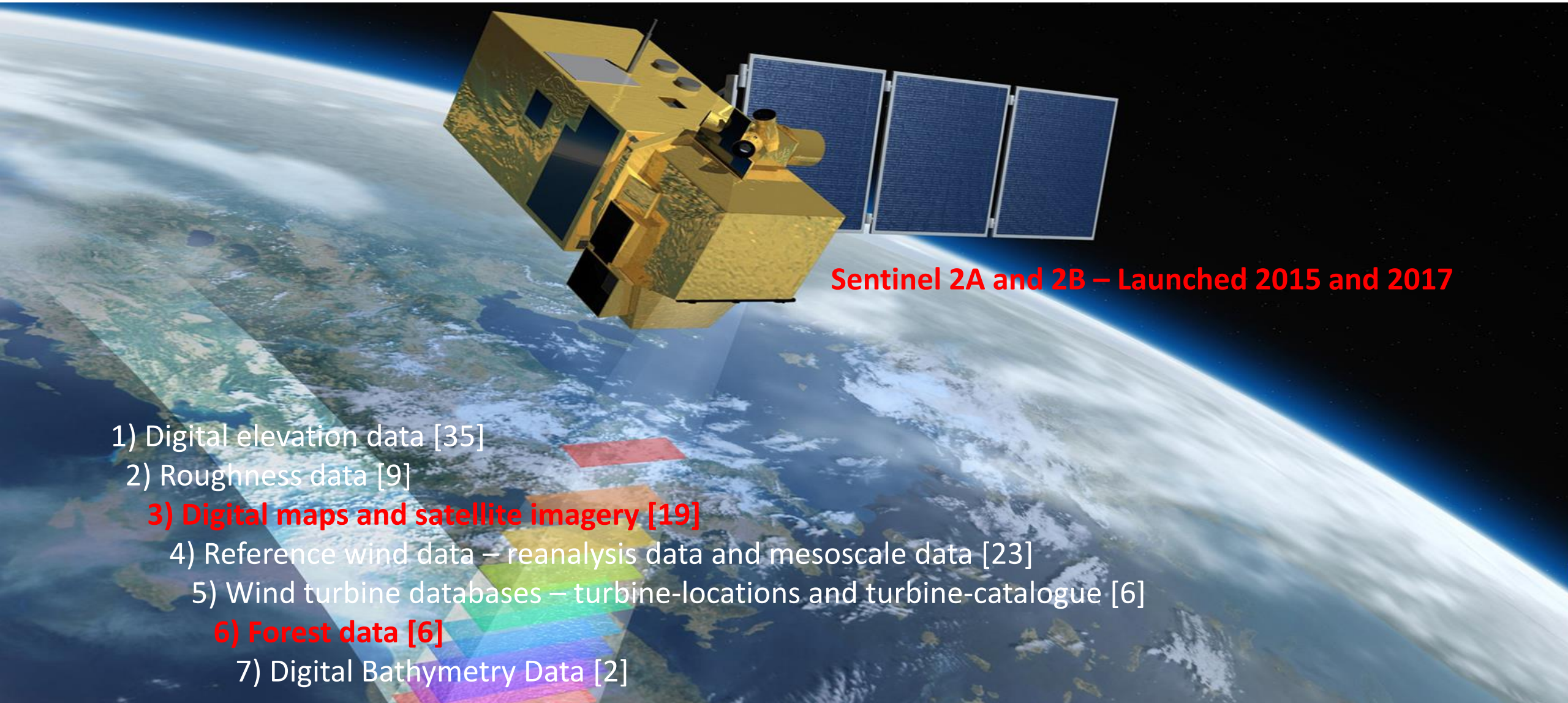
Introduction & Motivation: Sentinel 2A & 2B

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources



Sentinel 2A and 2B – Launched 2015 and 2017

1) Digital elevation data [35]
2) Roughness data [9]
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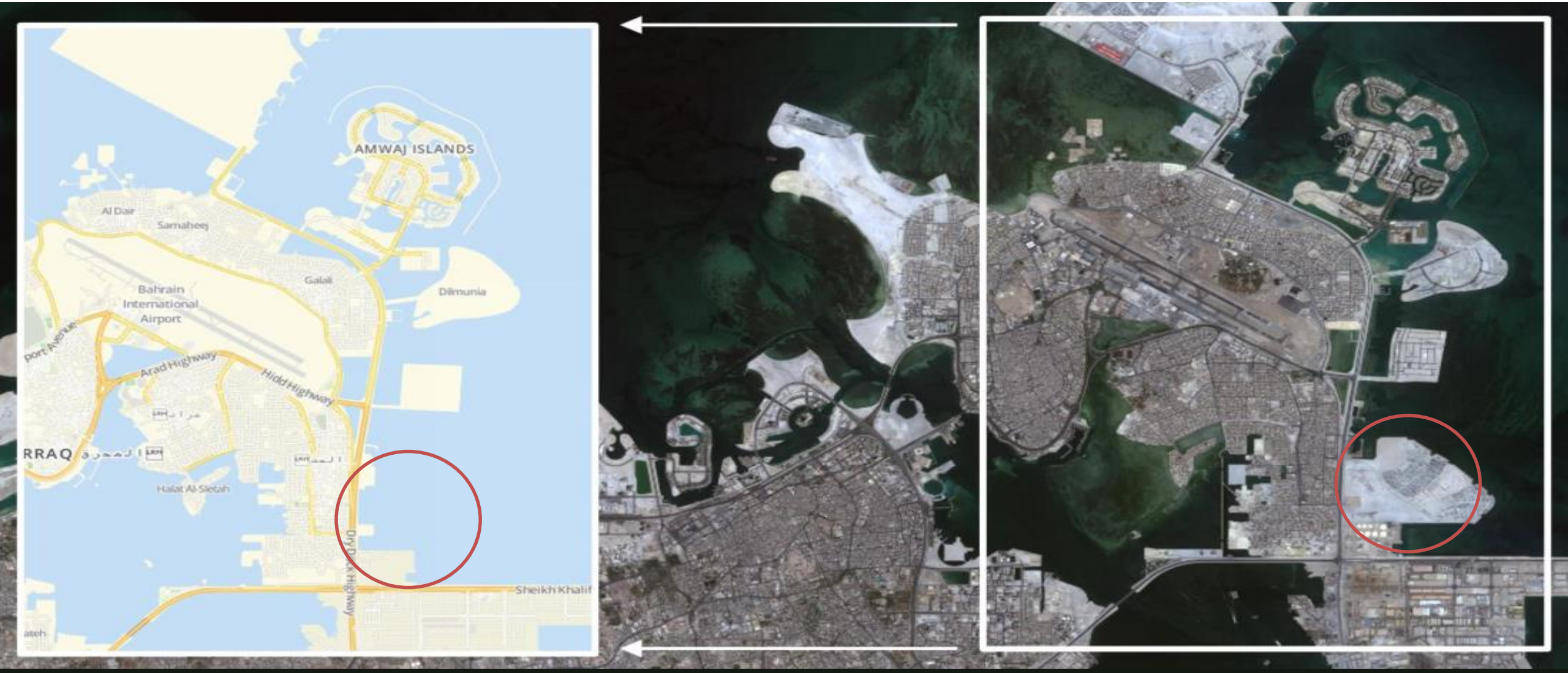
Land-Surface Modelling: Old Maps

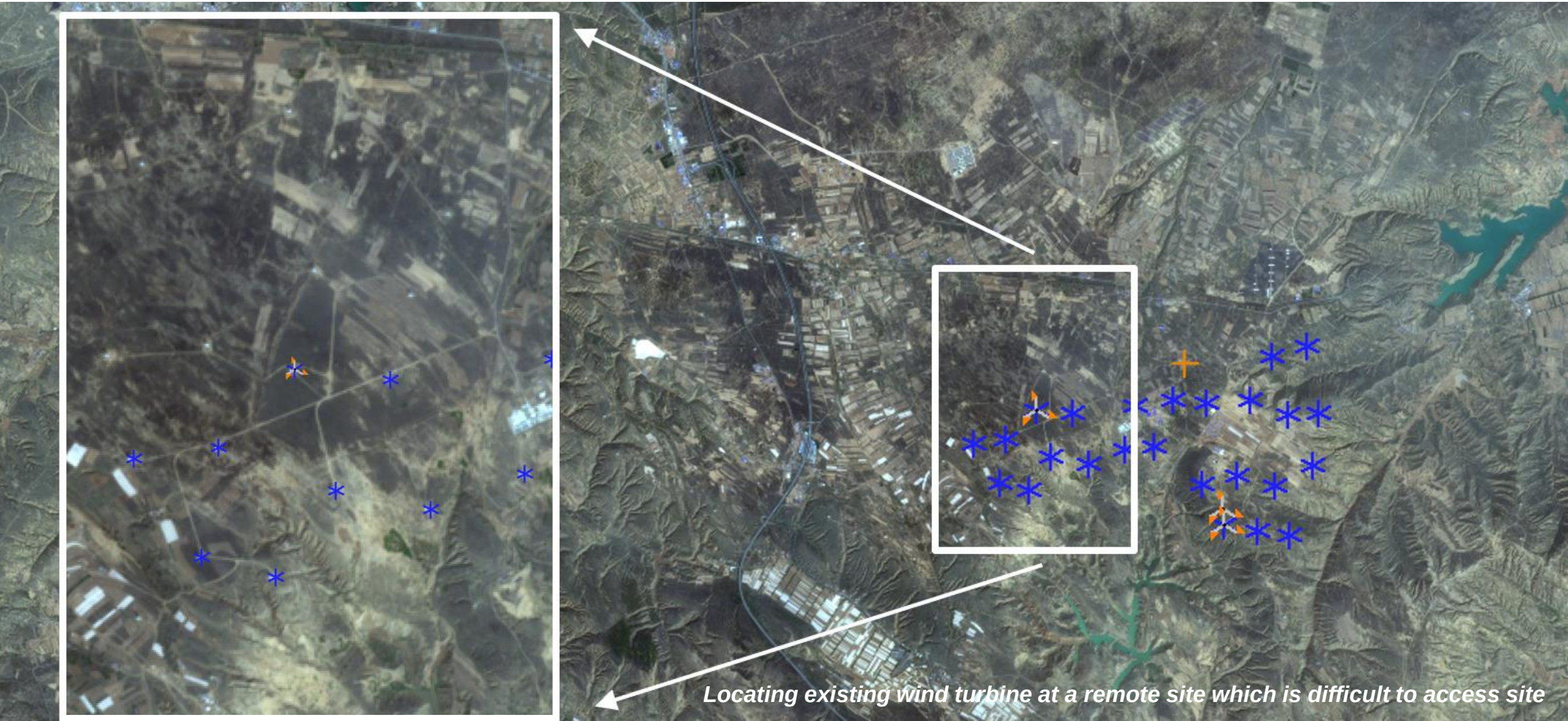
Improved flow modelling at cold climate sites through novel land-surface data from satellite sources



Old maps are not up to date: Sentinel 2 provides fully-up-to-date satellite images

Land-Surface Modelling: Updated Maps

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources



Locating existing wind turbine at a remote site which is difficult to access site

Land-Surface Modelling: In-situ conditions

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

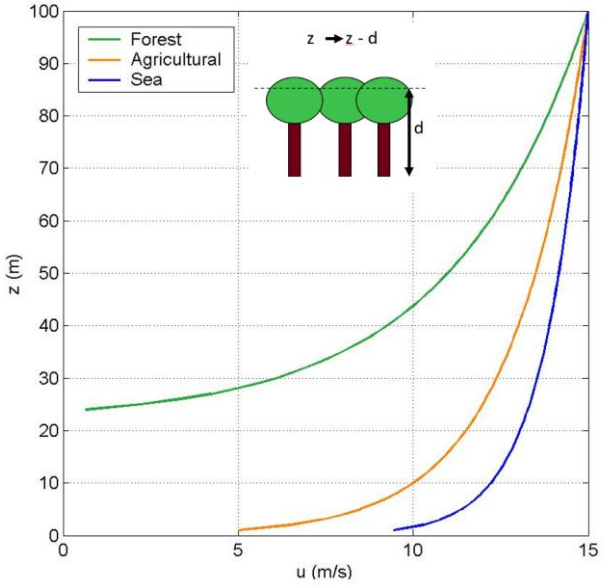
DTU Wind Energy
Department of Wind Energy

Land-Surface Modelling: Forests

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

The roughness of forested areas is challenging to estimate because…….

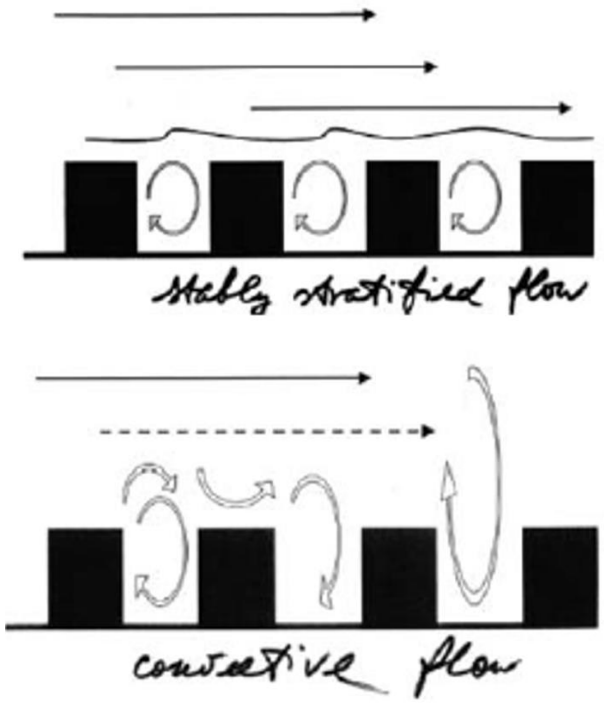
1 …… it is so high that it really matters

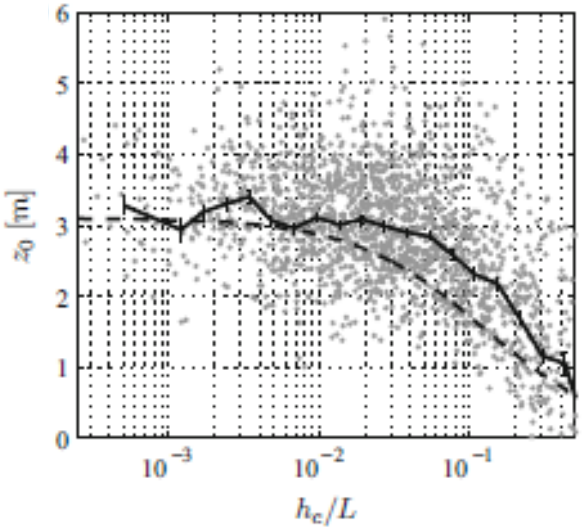


$$U = \frac{u_*}{\kappa} \ln \frac{z}{z_0}$$

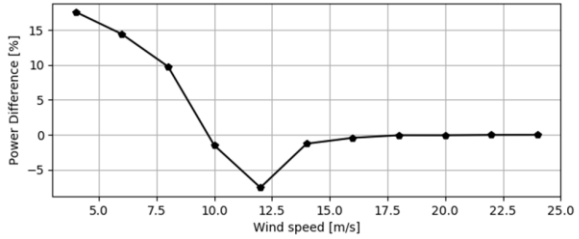
$$U = \frac{u_*}{\kappa} \ln \frac{z-d}{z_0}$$

2 …… our models are crude simplifications of reality, and different models





3 …. the roughness value that gives the right shear and the right mean wind speed might underestimate the power production.



4. …the roughness relates to the dimensions and density of the trees, which are challenging to measure.

References: 2: Zilitinkevich et al. (2008): The effect of stratification on the aerodynamic roughness length and displacement height, DOI 10.1007/s10546-008-9307-9
Arnqvist et al (2015): Wind Statistics from a Forested Landscape, DOI 10.1007/s10546-015-0016-x
3 + 4: Ebba Delwik (DTU): Unpublished work: Difference in simulated production from a forest and offshore wind turbine as a function of wind speed. Simulations from Mann box in HAWC2 using forest and offshore parameters.

Land-Surface Modelling: Forests

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

SOLUTION 1

Use manual roughness classification

SOLUTION 2:

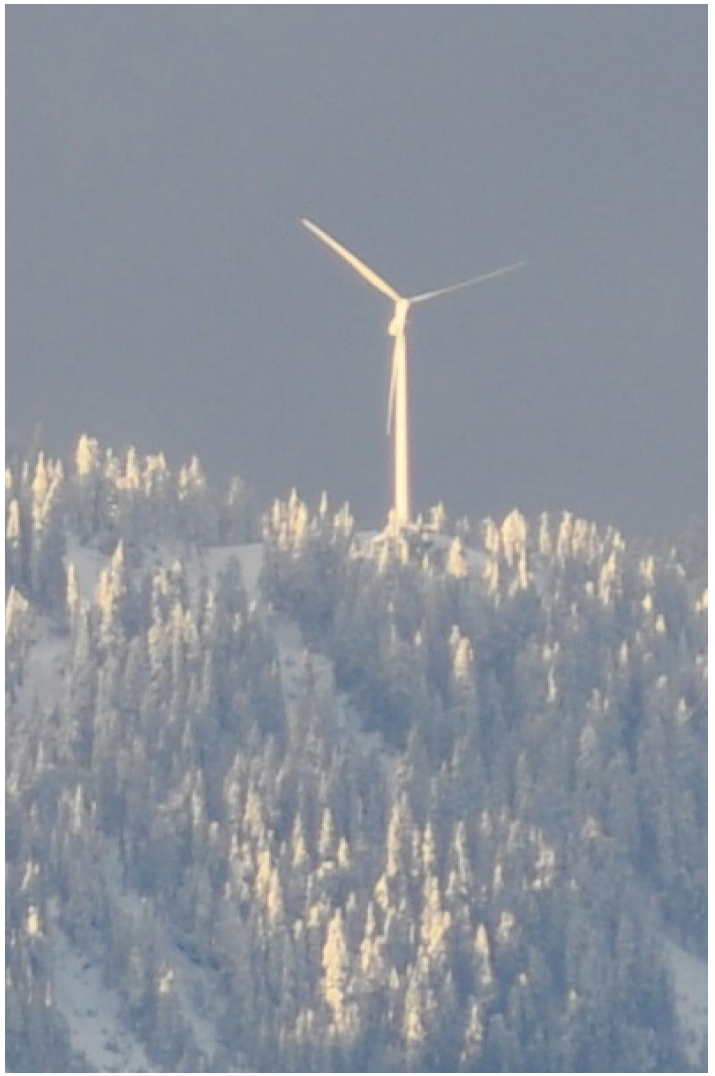
Use lookup tables with land-cover classifications

SOLUTION 3:

Aerial lidar scans (very detailed and expensive)

SOLUTION 4:

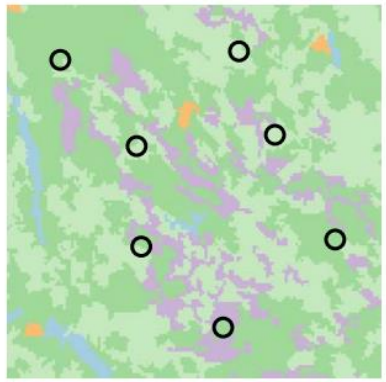
Use most recent satellite data (affordable)



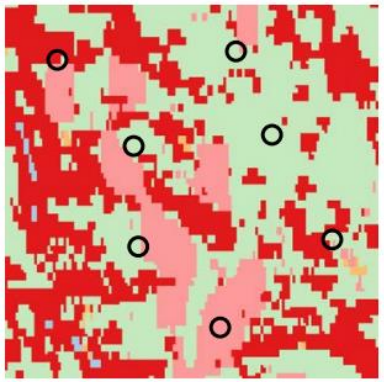
Land-Surface Modelling: Forests

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

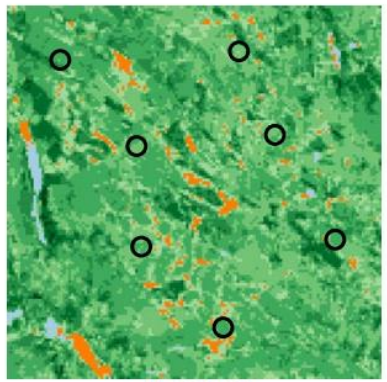
From forest heights to roughness maps using ORA (Objective Roughness Approach)



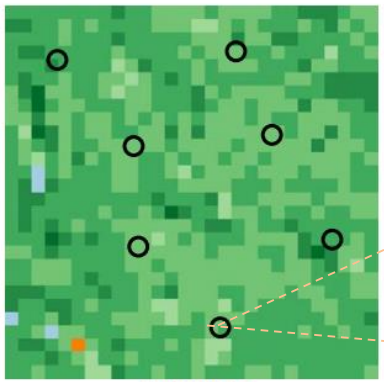
(a) CORINE100



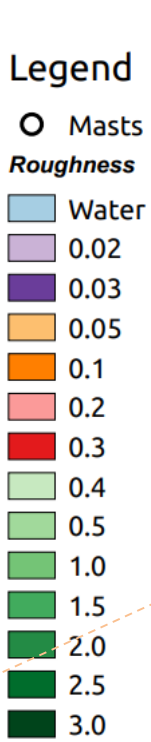
(b) GLOB300



(c) ORA100



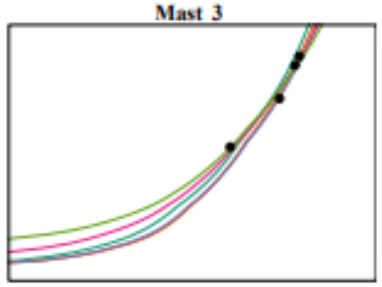
(d) ORA500



$$z_0 = \frac{h}{10}$$

$$d = \frac{2h}{3}$$

$$z \rightarrow z + d$$

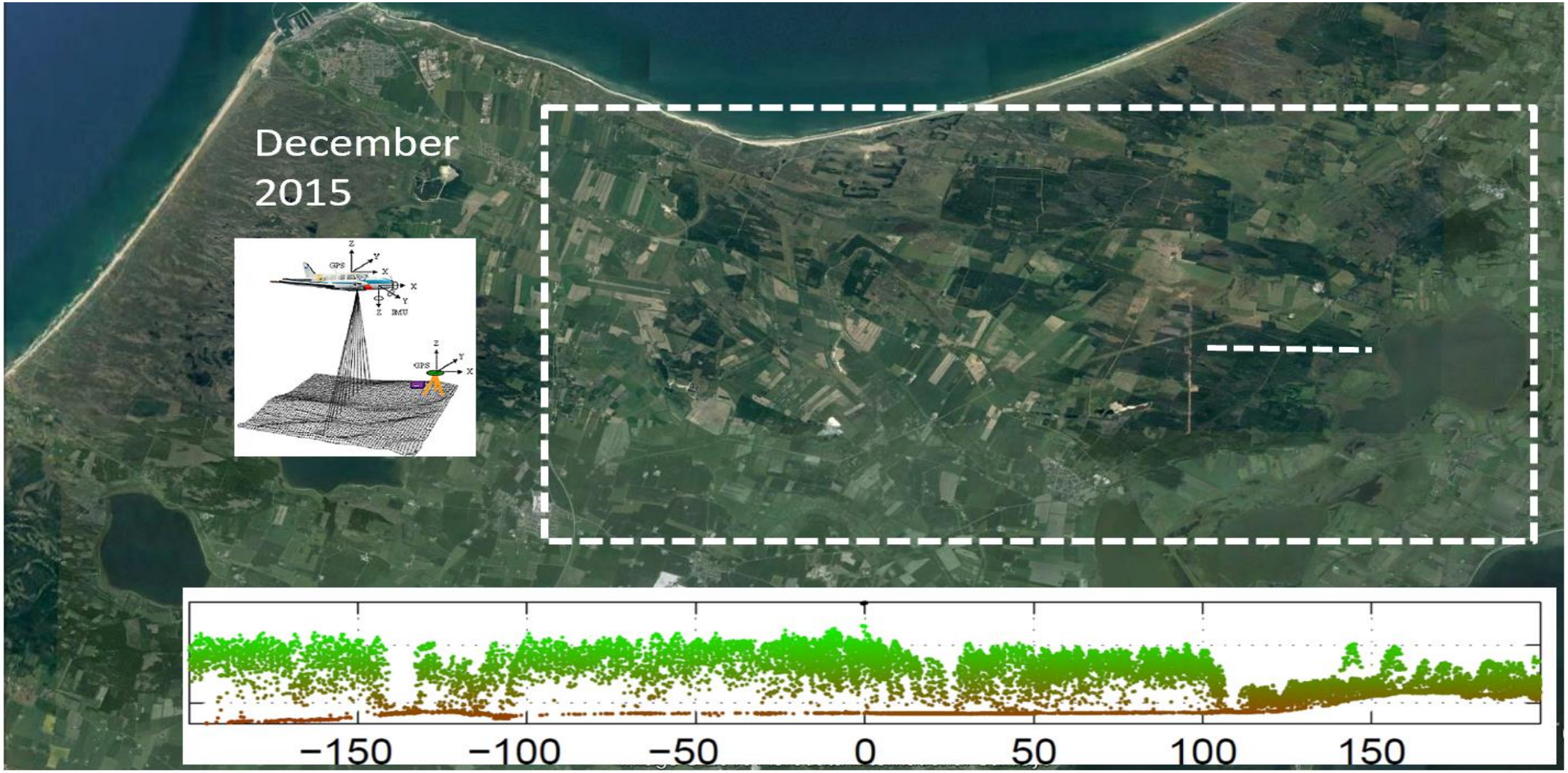


CORINE100
GLOB300
MODIS500
ORA20
ORA20D

Reference: R. Floors et al. (2018): From lidar scans to roughness maps for wind resource modelling in forested areas, https://doi.org/10.5194/wes-3-353-2018

Land-Surface Modelling: LiDARs

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

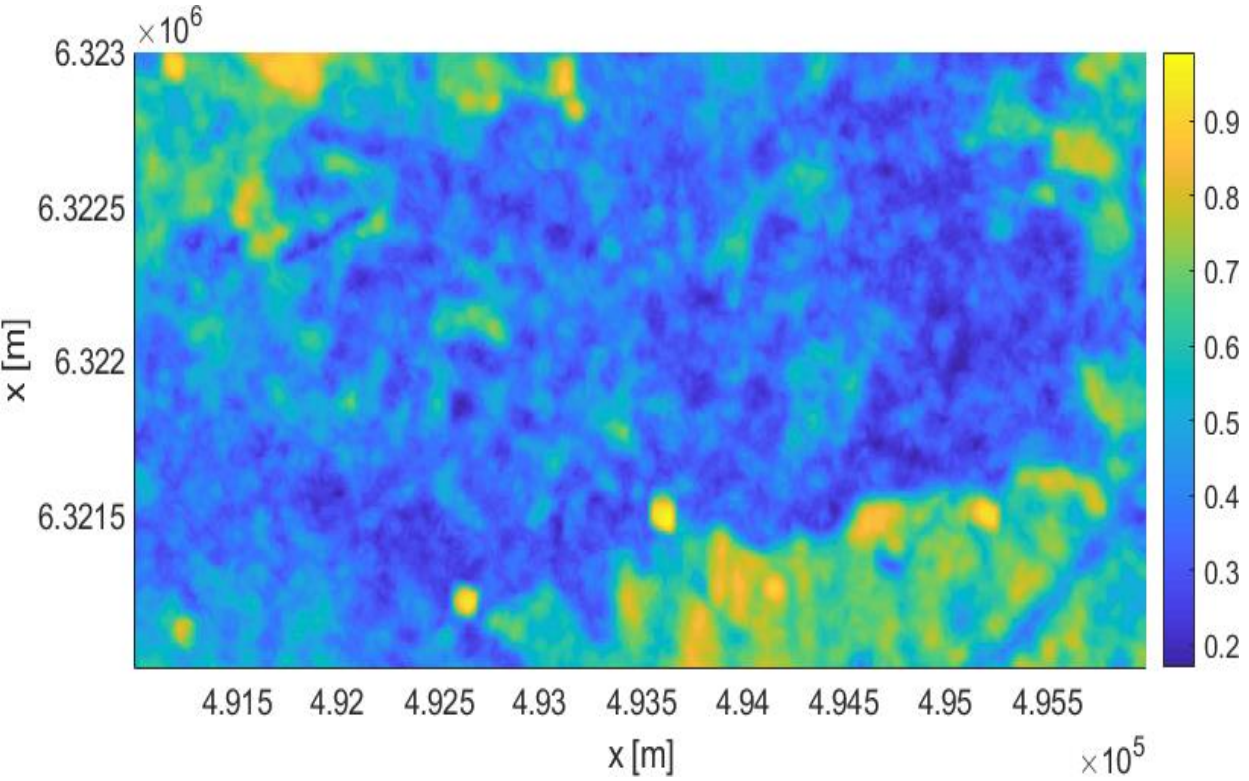


Reference: Boudreault et al 2015: A lidar method for canopy structure retrieval Agricultural and Forest Meteorology **201**, pages: 86-97

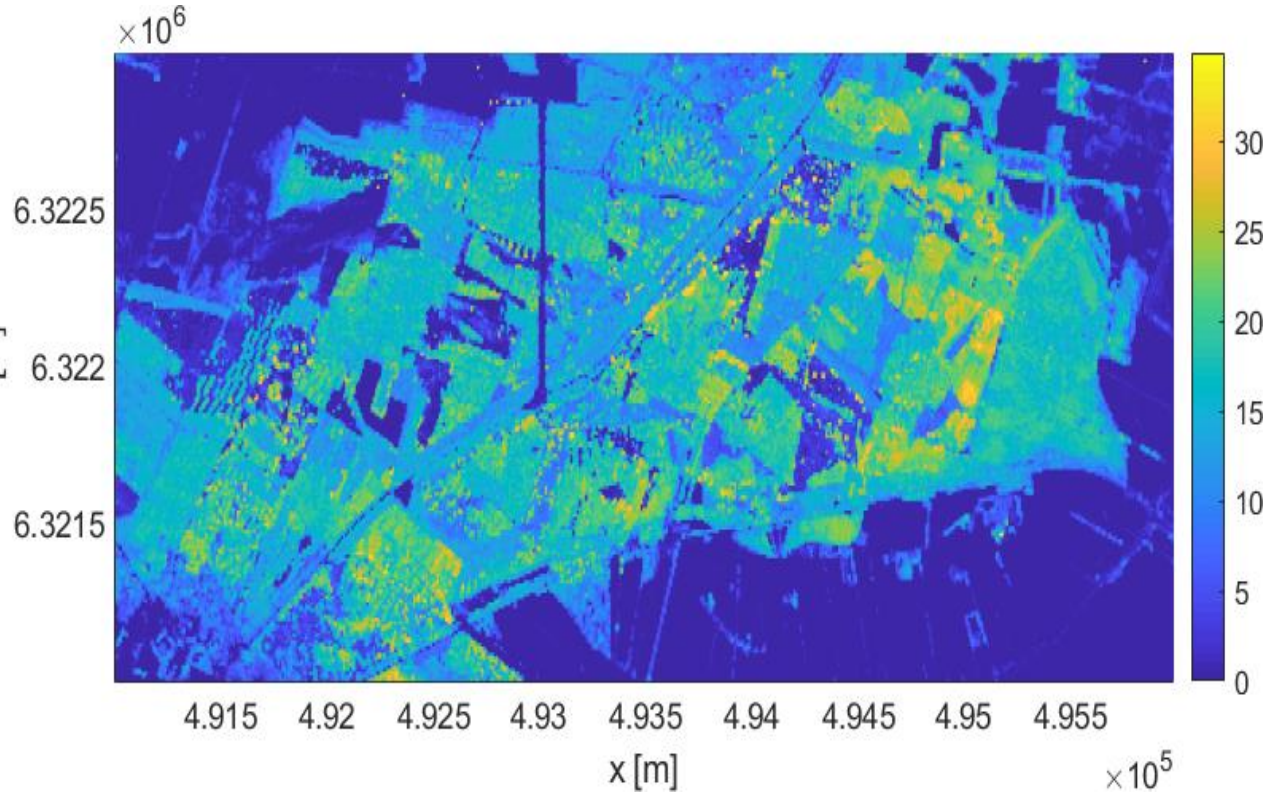
Land-Surface Modelling: SAR vs LIDAR

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

Satellite SAR, 2017



Airborne lidar scan, 2015



Reference: Ebba Delwik (DTU). Unpublished work.

Land-Surface Modelling: Forest Models

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

ORA: depends on treeheight h

- $z_0 = 0.1h$
- $d = \frac{2}{3}h$

Raupach: depends on treeheight h and LAI

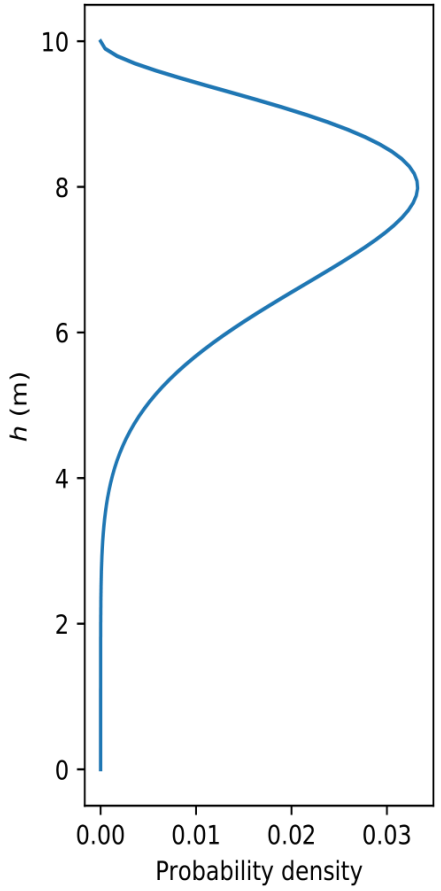
- Empirical model of relating z_0 and d to leaf-area index (LAI) and h

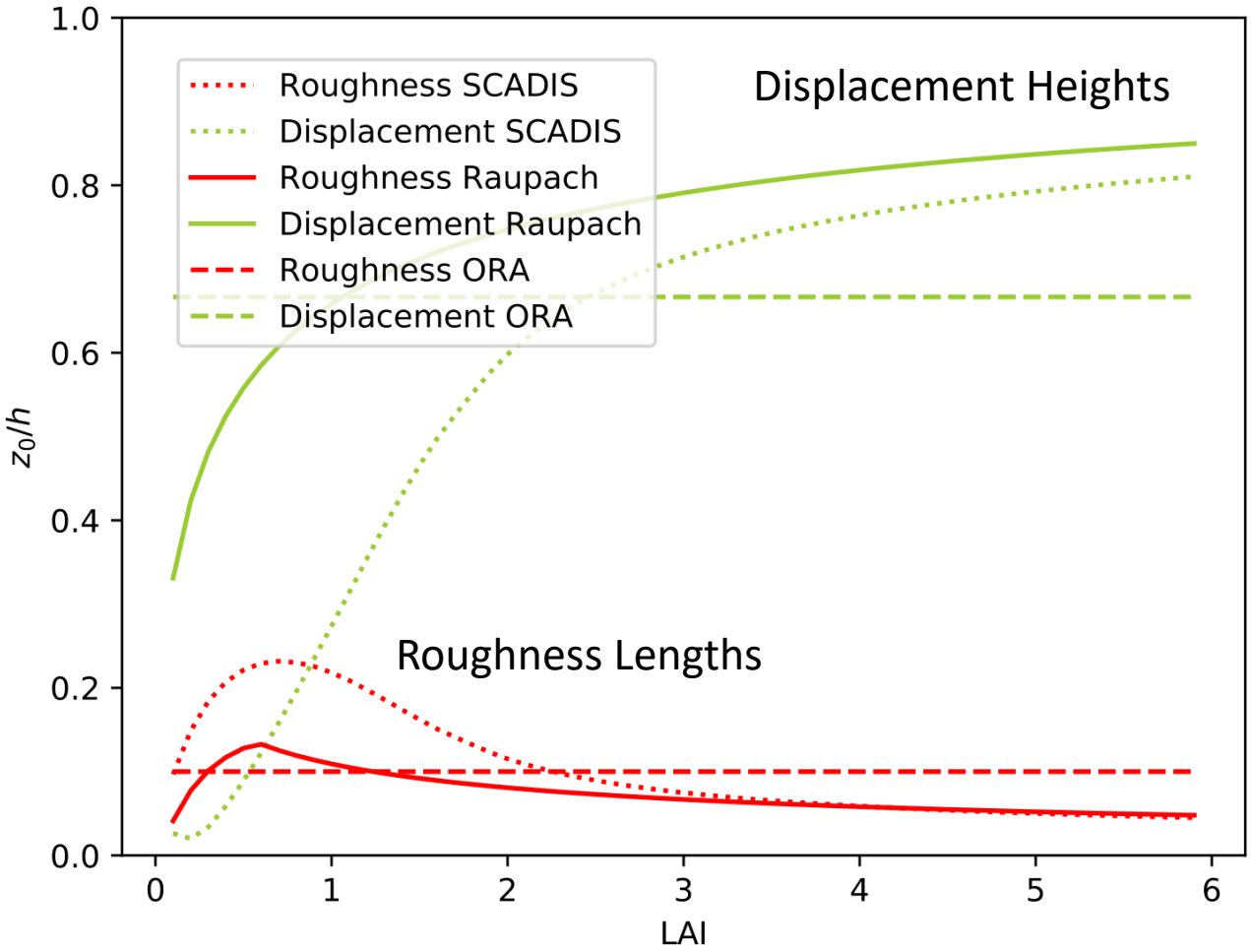
SCADIS 1D: depends on treeheight h, LAI and density profile of vegetation

- The model is run in “surface layer" mode (i.e no Coriolis force)
- Drag law implied by model similar A and B as WAsP

Land-Surface Modelling: Forest Models

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources





Reference: Rogier Floors (2019): Unpublished work.

Land-Surface Modelling: Machine Learning

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

Calibration Data

ICESat-2 ICE, CLOUD, AND LAND ELEVATION SATELLITE

GEDI ECOSYSTEM LIDAR

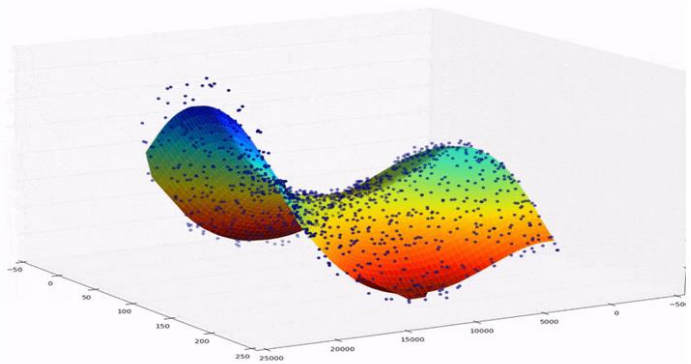
Predictor Data

sentinel-1

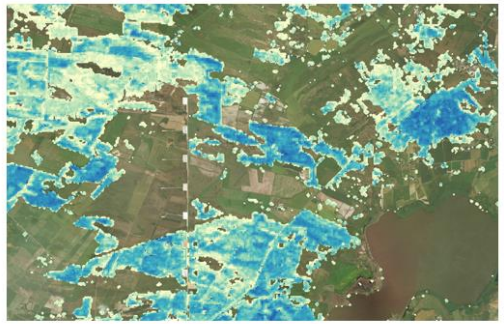
SENTINEL 2

LANDSAT LANDSAT-8 USGS NASA

Machine learning regression



3D Model of Forest Height



- Optical and RADAR satellite imagery
- Canopy height samples from ICESat-2 and GEDI
- Machine learning for modelling and predicting forest heights

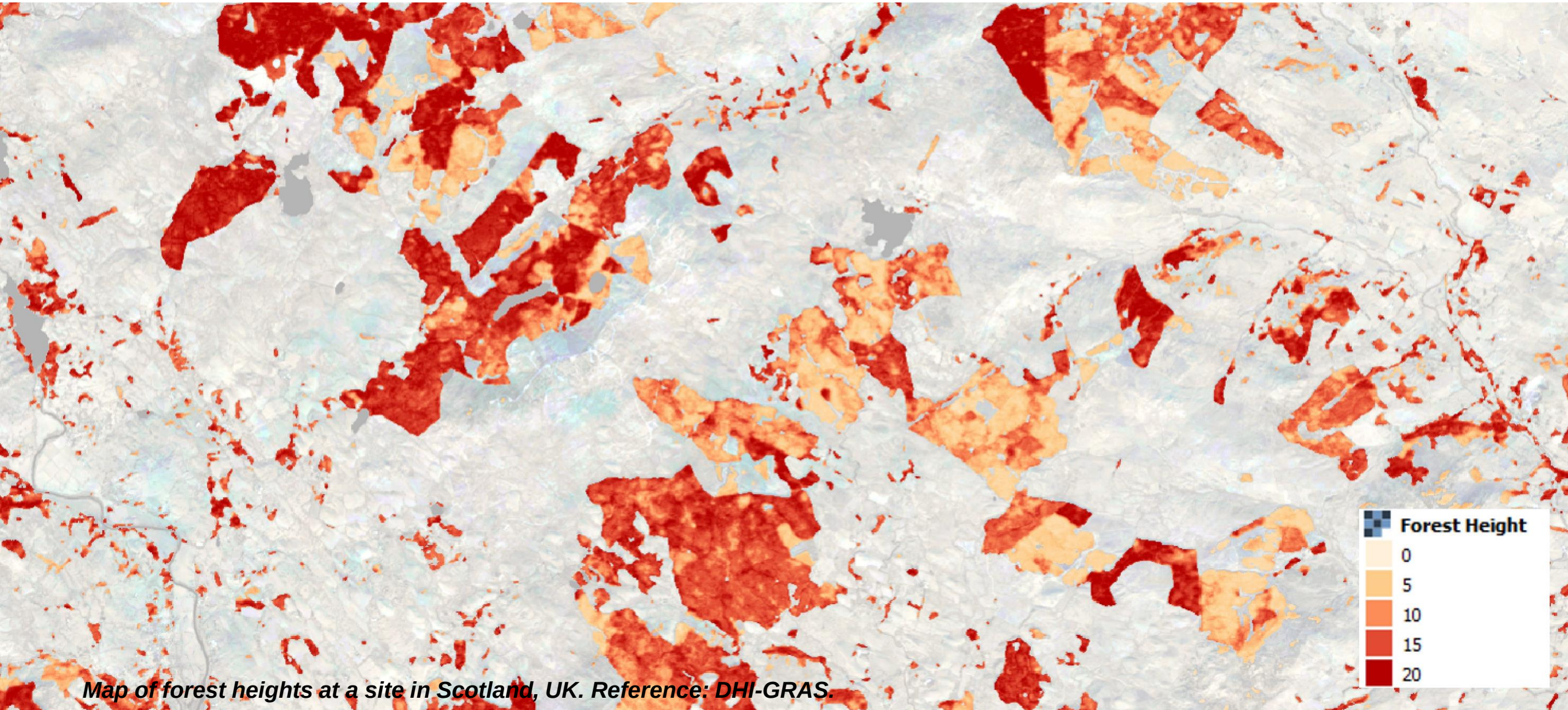
Microscale Modelling

Mesoscale Modelling

Reference: Kenneth Grogan (DHI-GRAS). Unpublished work.

Land-Surface Modelling: Machine Learning

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources



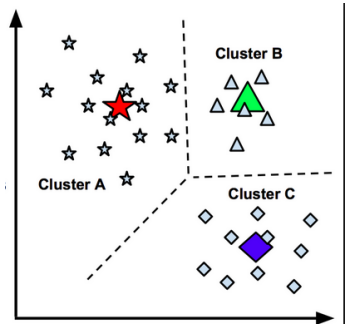
Map of forest heights at a site in Scotland, UK. Reference: DHI-GRAS.

Mesoscale Modelling

Created a workflow to use tree-height satellite data and new Z_0 for WRF simulations.

*.nc files with tree-height data (lat,lon)

```
On geog_em_<d0>3, 4
for x in xlon
  for y in xlat
    IF default LU_index[y,x] is forest
      - checks tree height from satellite data over that cell
      - checks which cluster they fit in
      - reassignes LU_INDEX to match VEGPARM.TBL new classes
```



Compute Z_0

VEGPARM.TBL

geogrid * ungrib metgrid

WPS

WRF

Reference: Mark Žagar & Yavor V. Hristov, Vestas. Unpublished work.

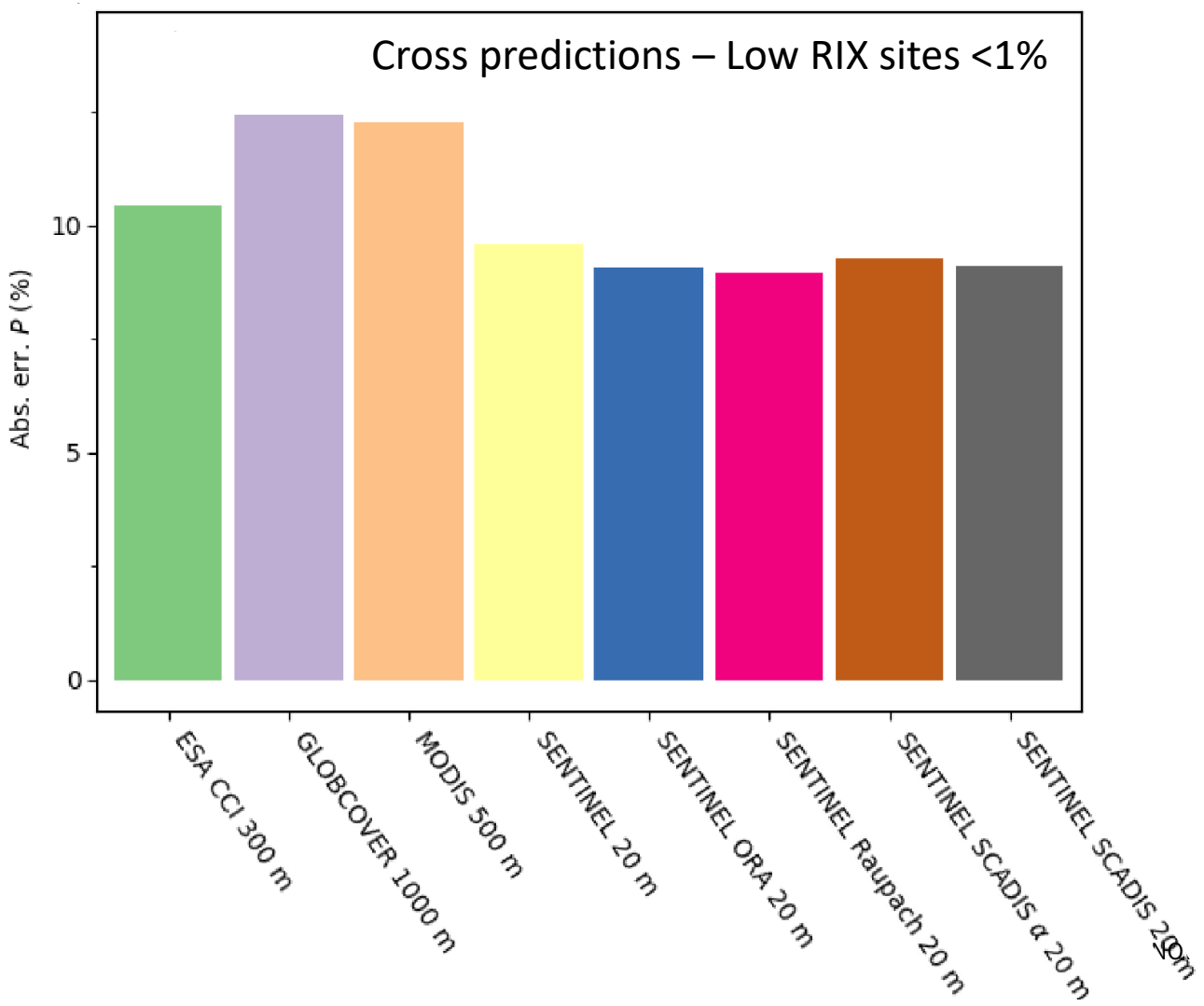
Findings

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

Results from Innowind 9 site study:

9 sites with total of 25 masts

- Varying complexities (RIX) and climates
- 8 different maps used at each site
- 20m grid resolution in sentinel based maps
- Cross-predictions done with WAsP



Reference: Rogier Floors – DTU Wind Energy (2019): Unpublished work.

Findings

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

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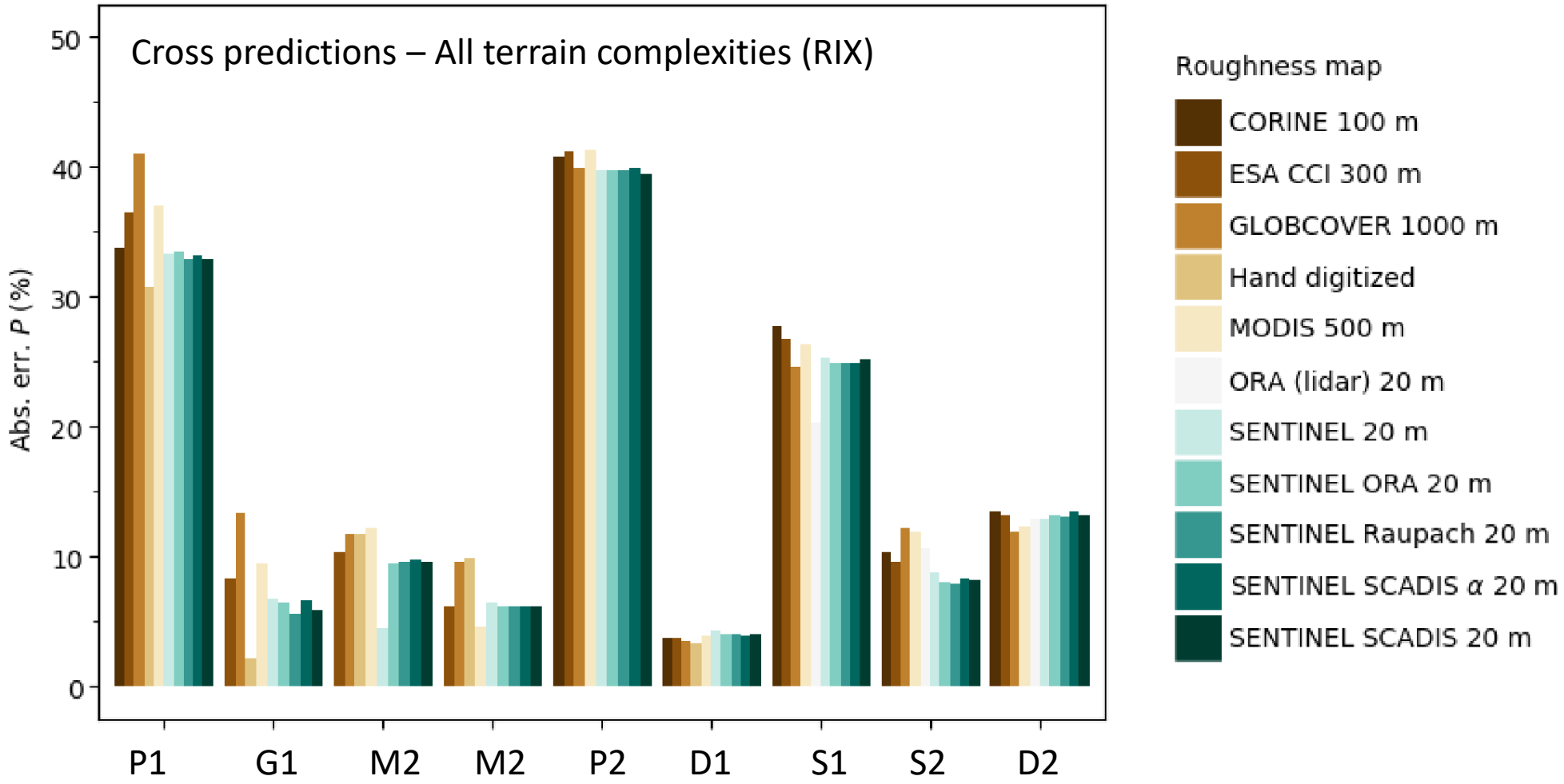

Reference: Rogier Floors – DTU Wind Energy (2019): Unpublished work.

Conclusion

Improved flow modelling at cold climate sites through novel land-surface data from satellite sources

What would it mean for our current wind resource and flow models …
if they could rely on accurate, high-resolution, up-to-date land-surface descriptions which were instantly available and without excessive cost?

Now

- Maps derived from Sentinel-data are better than standard roughness maps and lidar scans.
- Differences between ORA, Raupach and SCADIS are small (Raupach usually lowest errors)
- Biggest improvement is probably that all this can be done in a fully automated way.

Pending

- Feeding data into non-linear models (CFD) with additional validation results (RIX dependency?)
- Integrating with time-varying calculations – more land-cover datasets come with yearly updates
- More test on historical and future sites – benchmarking against skilled wind analysts and calibrated models

Not too distant future (or partly now)

High-resolution land-surface descriptions to fully reflect the physical in-situ conditions and its temporal variations.

… and followed by models at different fidelity levels that are able to consume these data

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VATTENFALL

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Sentinel Imagery and Data:
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ICESat-2 Data:
The ICESat-2 team, NASA and the US public are thanked for development of the mission and the release of the data into the public domain.

Corine Data:
European Environment Agency (EEA) is acknowledged for the development and release of this free and open dataset. European Environment Agency (EEA) standard re-use policy applies: unless otherwise indicated, re-use of content on the EEA website for commercial or non-commercial purposes is permitted free of charge, provided that the source is acknowledged (http://www.eea.europa.eu/legal/copyright). Copyright holder: European Environment Agency (EEA).

GlobCover Data:
Global land cover data: © ESA 2010 and UCLouvain http://due.esrin.esa.int/

InnoWind:
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