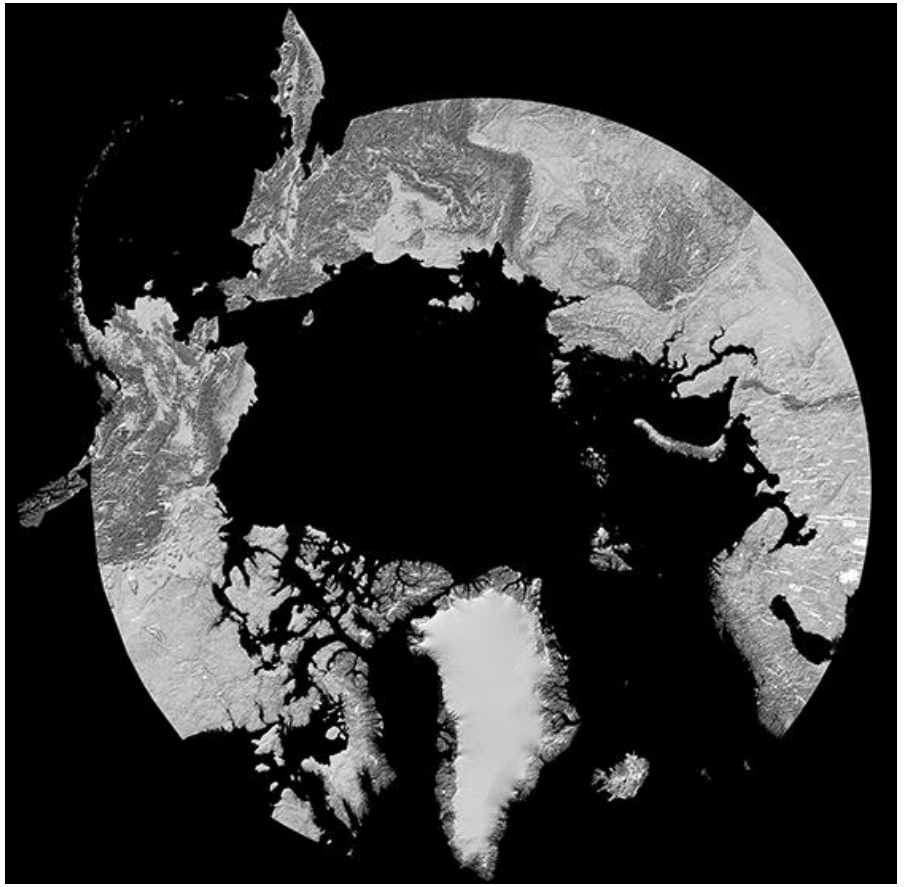
ArcticDEM

Next generation elevation model for wind farms in cold climate?



A hillshade rendering of ArcticDEM. Source: Polar Geospatial Center

Morten Lybech Thøgersen (mlt@emd.dk), Marie Cecilie Pedersen, Lasse Svenningsen, Tobias Ahsbahs
EMD International A/S, Denmark

Winterwind, Skellefteå, Sweden, April 19th -21th - 2022

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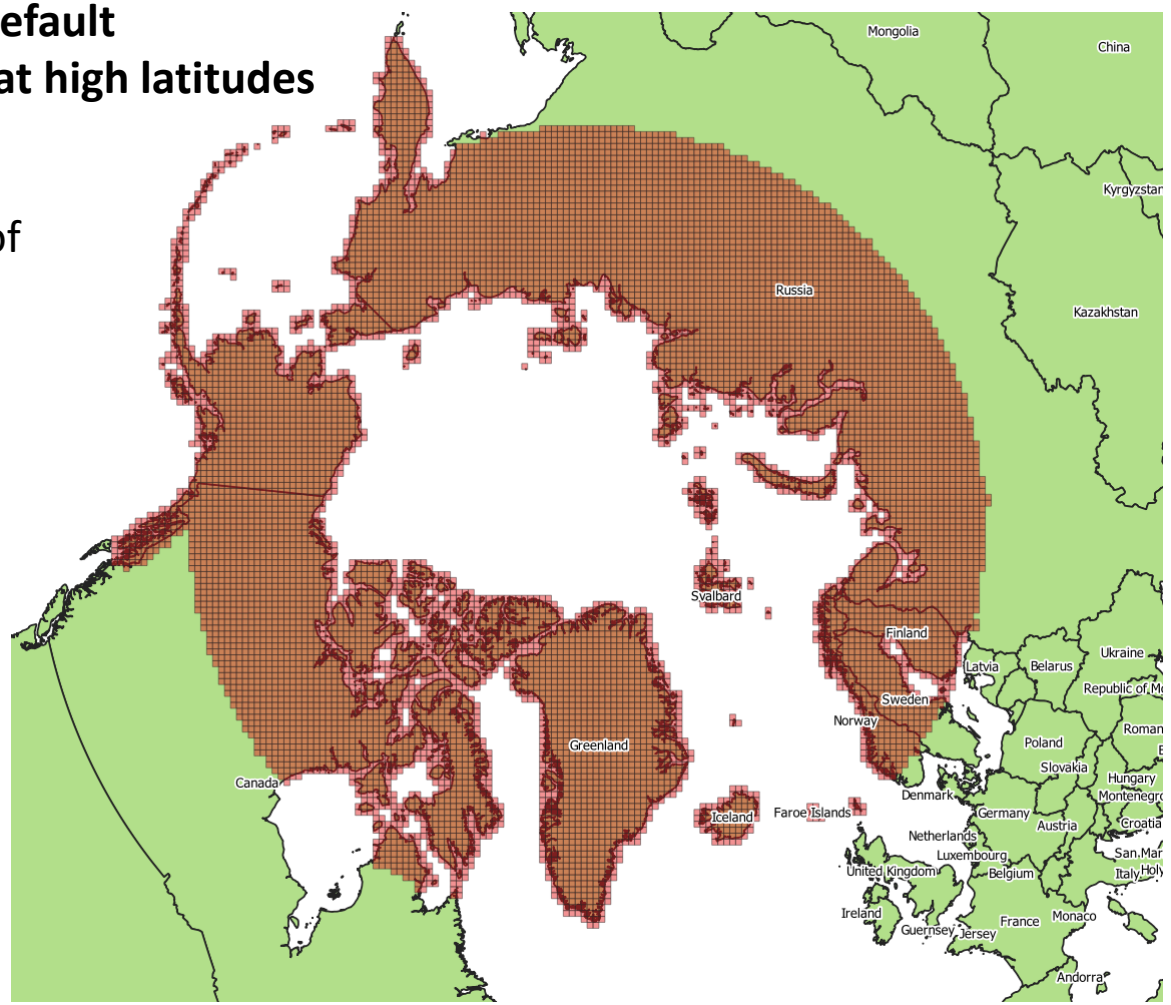
What is ArcticDEM?

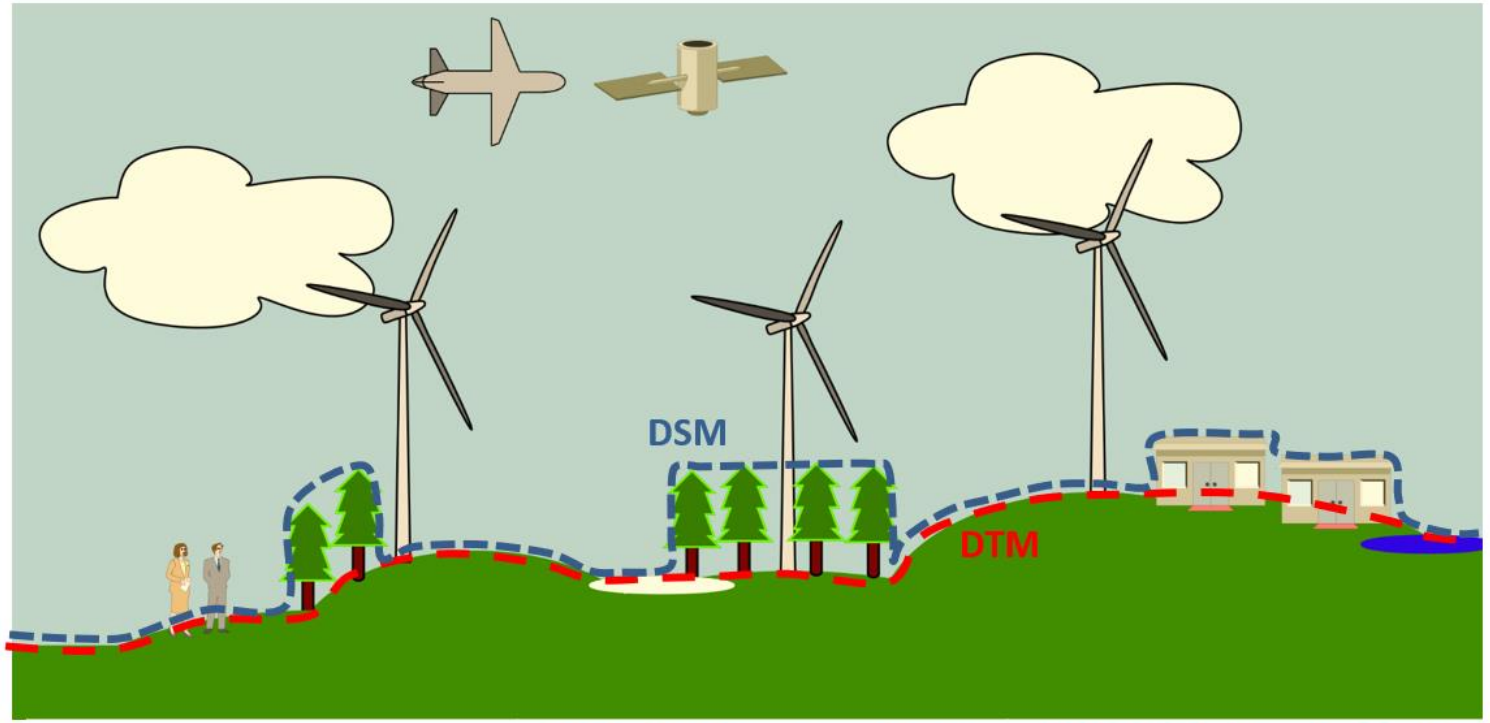
The ArcticDEM model has the potential to become the default choice of elevation model when developing wind farms at high latitudes

- High-resolution, high-quality digital surface model (DSM)
- Freely available from the Polar Geospatial Center of the University of Minnesota, USA
- Coverage of current release 7
  - All territory north of 60°N
  - Full territory of Greenland, Alaska and Kamchatka peninsula
- Created by optical stereo imagery & high-performance computing
- Open-Source software used: Surface Extraction from TIN-based Searchspace Minimization (SETSM) software by Noh & Howat
- Source is 0.5m imagery of the Maxar satellites: WorldView-1, WorldView-2, WorldView-3 & GeoEye-1
- Provided in resolutions 2m, 10m, 32m, 100m, 500m and 1km
- Output available as strip data and multi-year mosaics
- 260,741 scenes covering an area of 159,902,690 km^2
- A total of 2488 sub-tiles in mosaic dataset (each 100x100 km^2)
- IceSAT altimetry data use for improving vertical accuracy of mosaics



What elevation model? DEM, DSM, DTM?

The ArcticDEM model has the potential to become the default choice of elevation model when developing wind farms at high latitudes. But how good is it and which are the DEM/DSM/DTM alternatives?



DEM: Digital Elevation Model
Is often used as a generic term for both DSM's & DTM's

DSM: Digital Surface Model
Surface representation with objects

DTM: Digital Terrain Model
Bare earth representation without objects

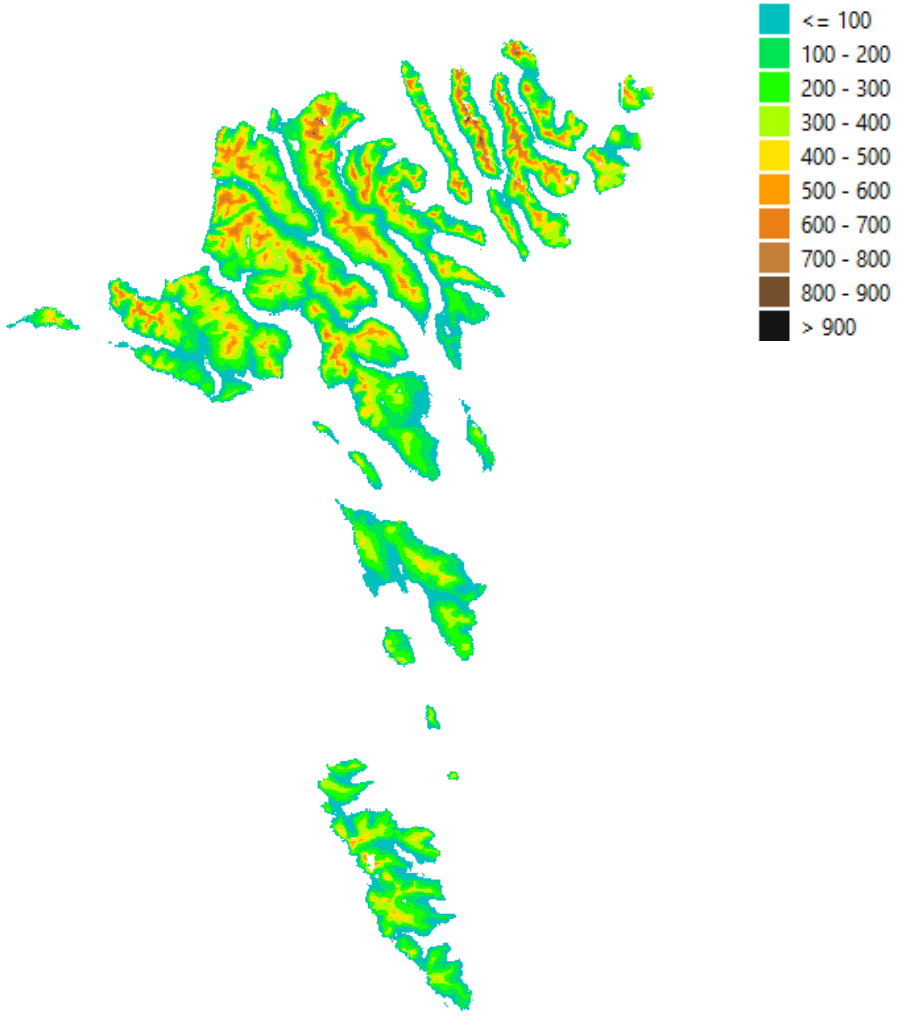
Global & Regional Digital Elevation Models (DEM)

- ALOS World 3D 30m mesh (AW3D30)
- Copernicus DEM
- European Elevation Model (EU-DEM)
- NASADEM (successor of SRTM)
- Shuttle Radar Topography Mission (SRTM)
- Viewfinder Panoramas DEM

National Digital Elevation Models (DEM)

- Austrian Elevation Model (DGM)
- Australian Elevation Models
- Belgium Flemish Elevation Model (DTM)
- Belgium Walloon Elevation Models (MNT)
- Danish Elevation Model (Danmarks Højdemodel)
- Estonian Elevation Models
- Finnish Elevation Model
- French Elevation Models
- German Elevation Models (DGM)
- Italian Nationwide Model (TINITALY)
- Italian-Sardinia Elevation Model
- Italian-Tuscany Elevation Model
- Latvian Elevation Model
- Luxembourg Elevation Model (BD-L-MNT5)
- Netherlands Elevation Models (AHN2/AHN3)
- Norwegian Digital Elevation Models (DTM/DOM)
- Slovenia Elevation Model
- Spanish Elevation Models (MTD)
- Swedish Elevation Model (GSD)
- Switzerland Elevation Model (DGM)
- United Kingdom Elevation Datasets
- US National Elevation Dataset (NED)

Potential Drawbacks

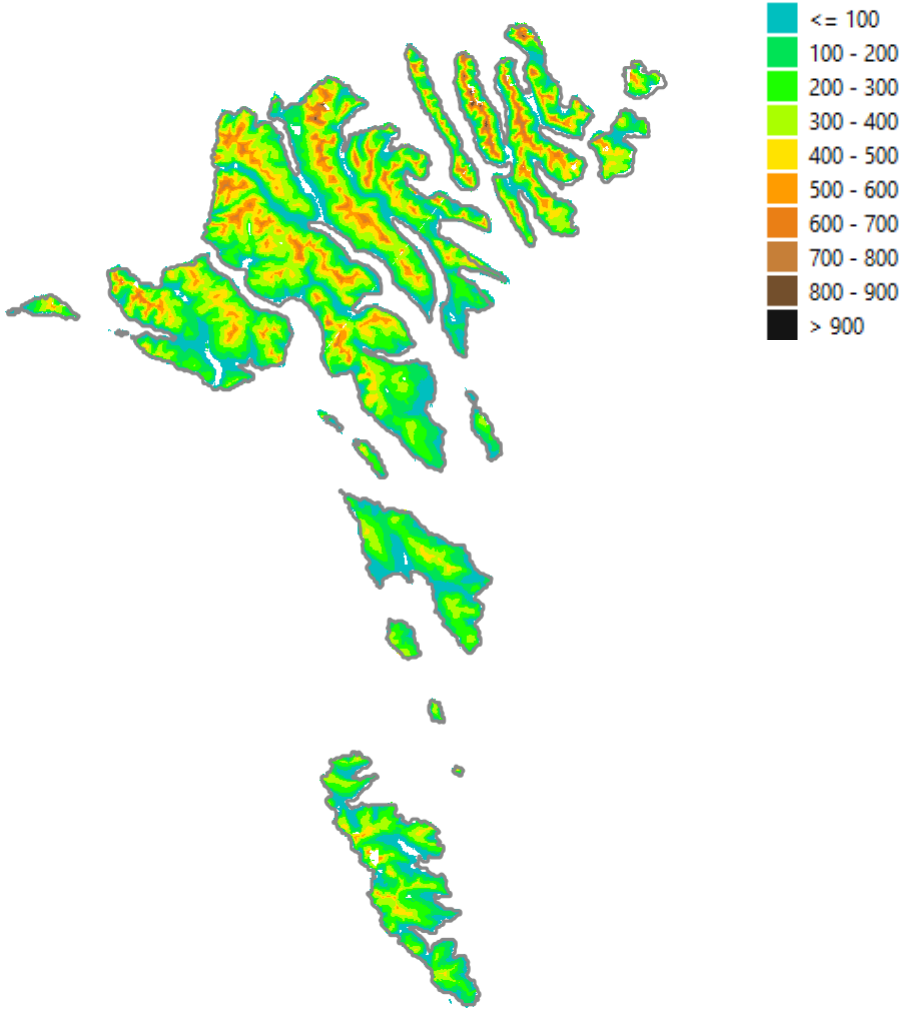


ArcticDEM – 2m resolution @ Work at Faroe Islands (mosaic with 7 tiles)

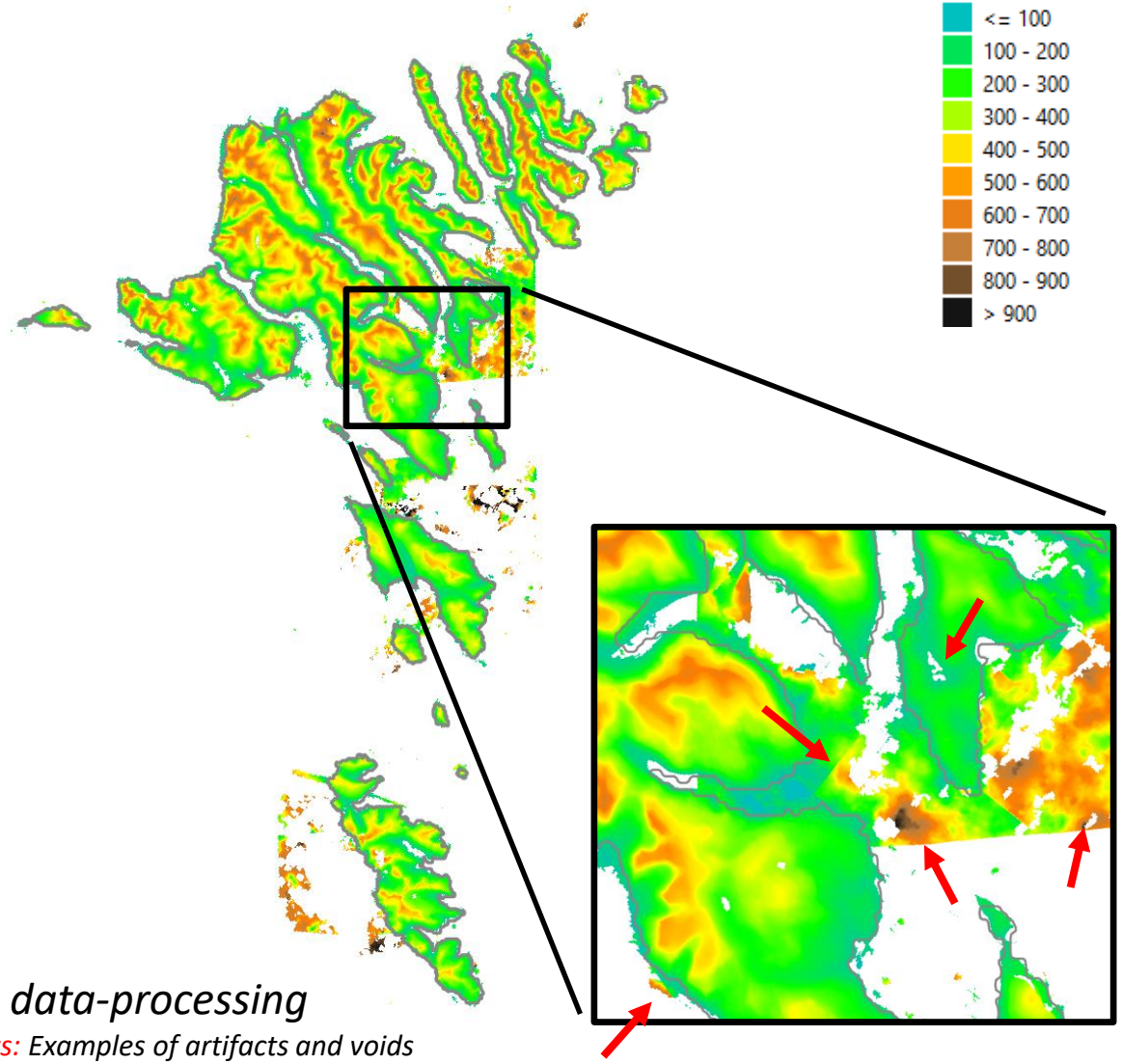
- Absolute horizontal and vertical accuracy specifications of ArcticDEM data have not been verified, however:
  - Is about 4m without GCP correction applied
  - For mosaic data – estimates from IceSAT GCP's in metadata
- Hydrographic features has not been flattened
- Data has not been hydro-enforced
- Optical product: Void areas and artifacts due to cloud cover, fog, shadows and unfrozen water bodies
- Product has not been edge-matched
- Multiple seasons in mosaic model
- A huge dataset: 10m resolution data at approx. 800Gb
- Original data with WGS84 ellipsoid as vertical reference

ArcticDEM – 2m resolution @ Work at Faroe Islands
(mosaic with 7 tiles)

Potential Drawbacks



***After** a little data-processing*

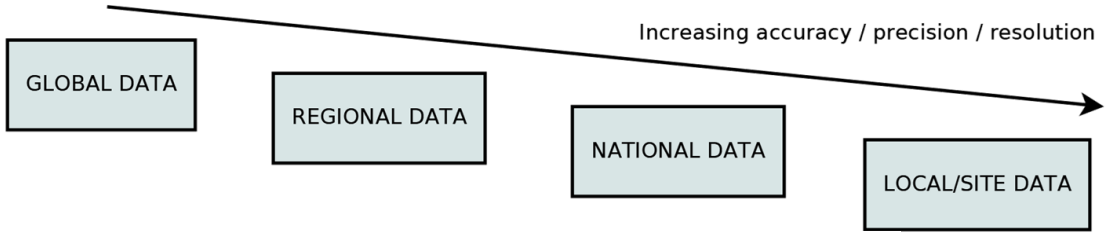


***Before** data-processing*

Red arrows: Examples of artifacts and voids

Evaluating Accuracy and Vertical Error

Typically, national or regional DEM's have better accuracy than global ones – but is is also very technology dependent – with LiDAR campaigns in cm-range



Global Datasources	Grid [m]	Vertical Accuracy		Vertical Datum	Technology
ALOS-AW3D30	30.0	7.0	LE90	-	Satellite - optical - stereo imagery
ASTER GDEM v2	30.0	15.0 - 20.0	LE90	-	Optical - stereo imagery
Copernicus DEM - 10m	30.0	2.2	LE90	EGM2008	Radar
SRTM1	30.0	6.0 - 9.0	LE90	EGM96	C-Band radar (~ 5cm)
SRTM3	90.0	< 16.0	-	EGM96	C-Band radar (~ 5cm)
Regional Datasources	**Grid [m]**	**Vertical Accuracy**		**Vertical Datum**	**Technology**
ArcticDEM	2.0			-	
EU-DEM	30.0	2.9	RMS	-	Multi-source: SRTM and contour lines
ViewFinder	90.0	-	-	-	Multi-source: SRTM and contour lines
National Datasources	**Grid [m]**	**Vertical Accuracy**		**Vertical Datum**	**Technology**
Belgium-Flandern	5.0	0.05	-	TAW	LiDAR
Danish Elevation Model	0.4	0.05	-	DVR90	LiDAR
Finish Elevation Model	10.0	1.4	P95	N2000	Mix: Contours, stereo-imagery and LiDAR
German NRW Model	1.0	0.20	-	-	LiDAR
Netherlands - AHN2	0.5	0.20	P99.7	-	LiDAR
Slovenia Elevation Model	1.0	< 0.11	RMS	-	LiDAR
Swedish GSD50+ NH	50.0	1.00	P50	-	LiDAR
UK-Northern Ireland	10.0	1.00	RMSE	Belfast Lough	Stereo Imagery
US NED	10.0	3.04	P95	-	-
Commercial Datasources	**Grid [m]**	**Vertical Accuracy**		**Vertical Datum**	**Technology**
ALOS-AW3D30	5.0	4.1	RMSE	-	Satellite - optical - stereo imagery
Euro Maps 3D	5.0	5.0 - 10.0	LE90	EGM96	Optical - stereo imagery - Cartosat-1
WorldDEM	12.0	< 4.0	LE90	-	X-Band radar (~ 3 cm)
Vricon DSM-0.5	0.5	3.0	LE90	-	Satellite - optical - Digital Globe
Vricon DSM-10	10.0	3.0	LE90	-	Satellite - optical - Digital Globe
NEXTMap-10	10.0	10.0	LE95	-	?
NEXTMap One	1.0	3.6	LE95	-	2016 or newer satellite data

Vertical error for datasets is determined from ground control points (GCP's)

Vertical error:

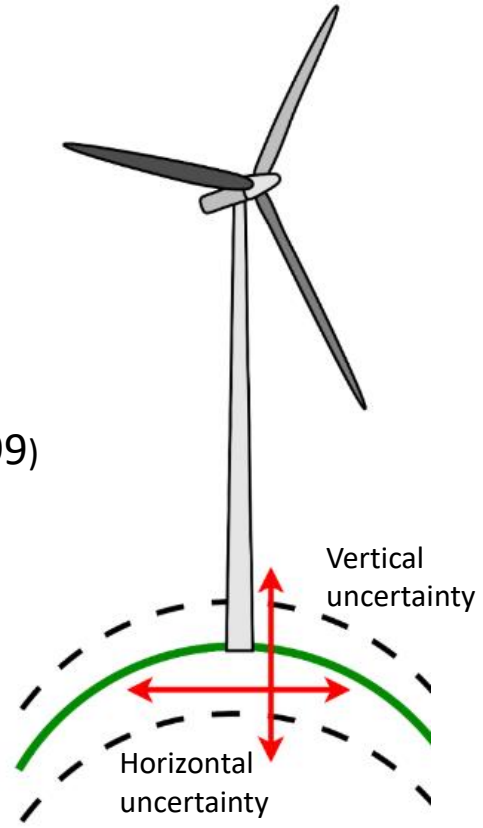
$$\Delta z = z_{DEM} - z_{REF}$$

Metrics / statistics:

- Mean error (bias)
- Standard deviation
- Root mean square error (RMSE)
- Quantiles (P25, P50; P75, P90, P95 & P99)

GCP's may come from

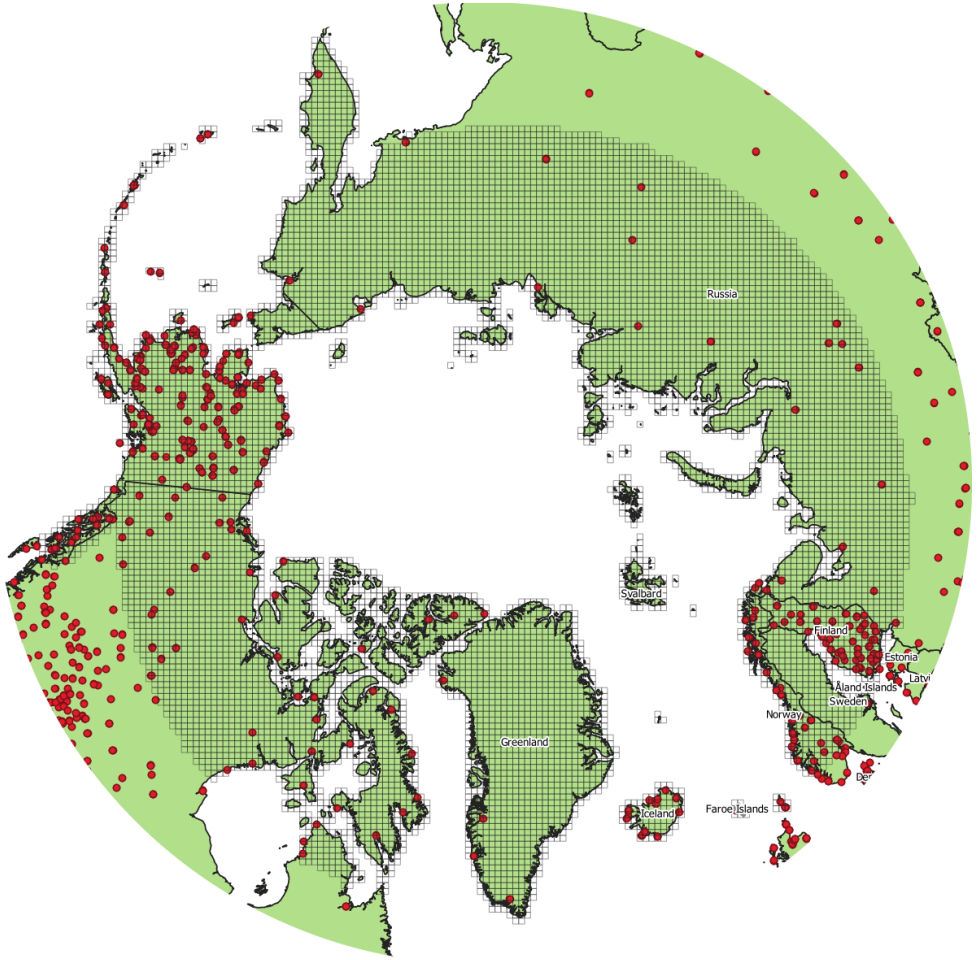
- LiDAR campaigns
- Airport runways
- IceSAT data
- High-quality national datasets

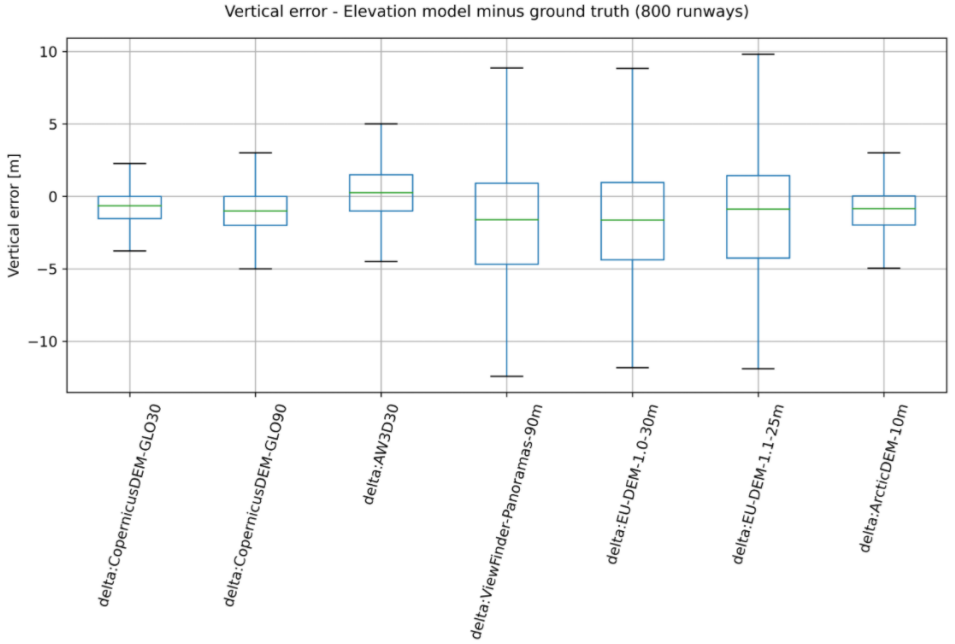


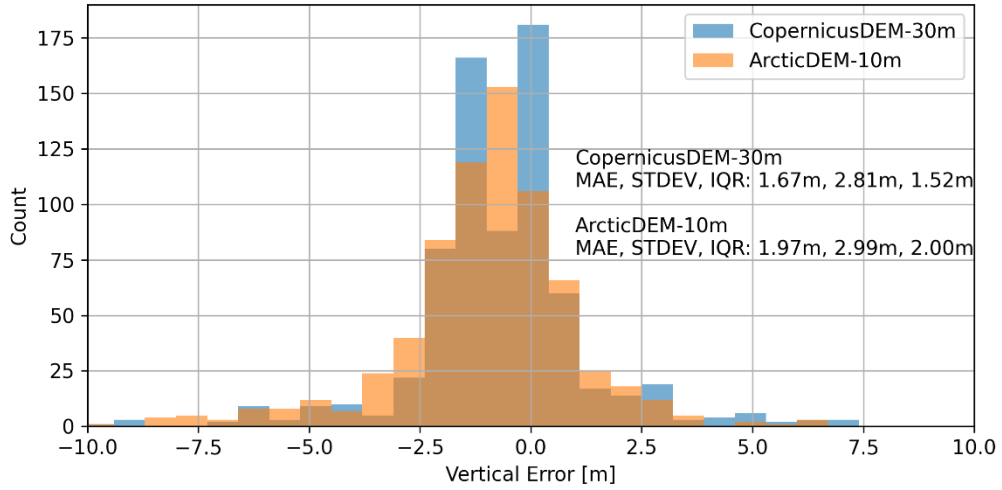
Accuracy also depends on:

- Location, slope, land-cover, vegetation height…

ArcticDEM and the Runways Dataset







Acknowledgement: The Runways dataset is from the Global Elevation Data Testing Facility (GEDTF) by Kazimierz Bęcek, Monika Stepnowska & Jakub Łuczak.

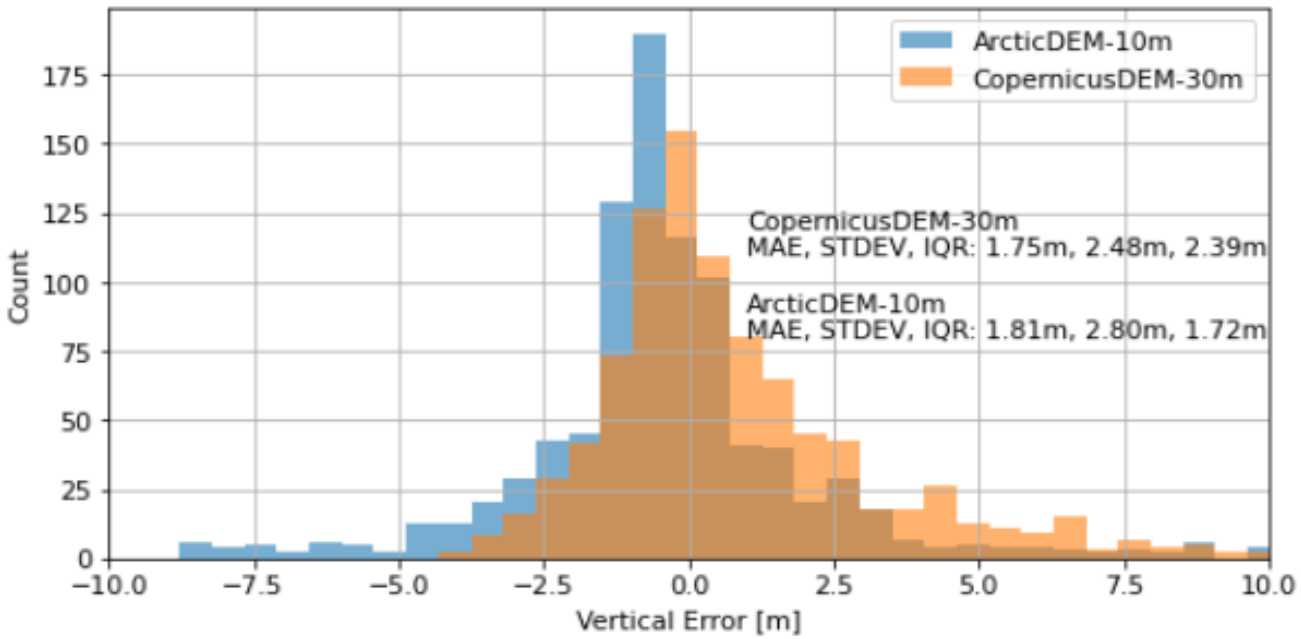
ArcticDEM: Next generation elevation model for wind farms in cold climate?

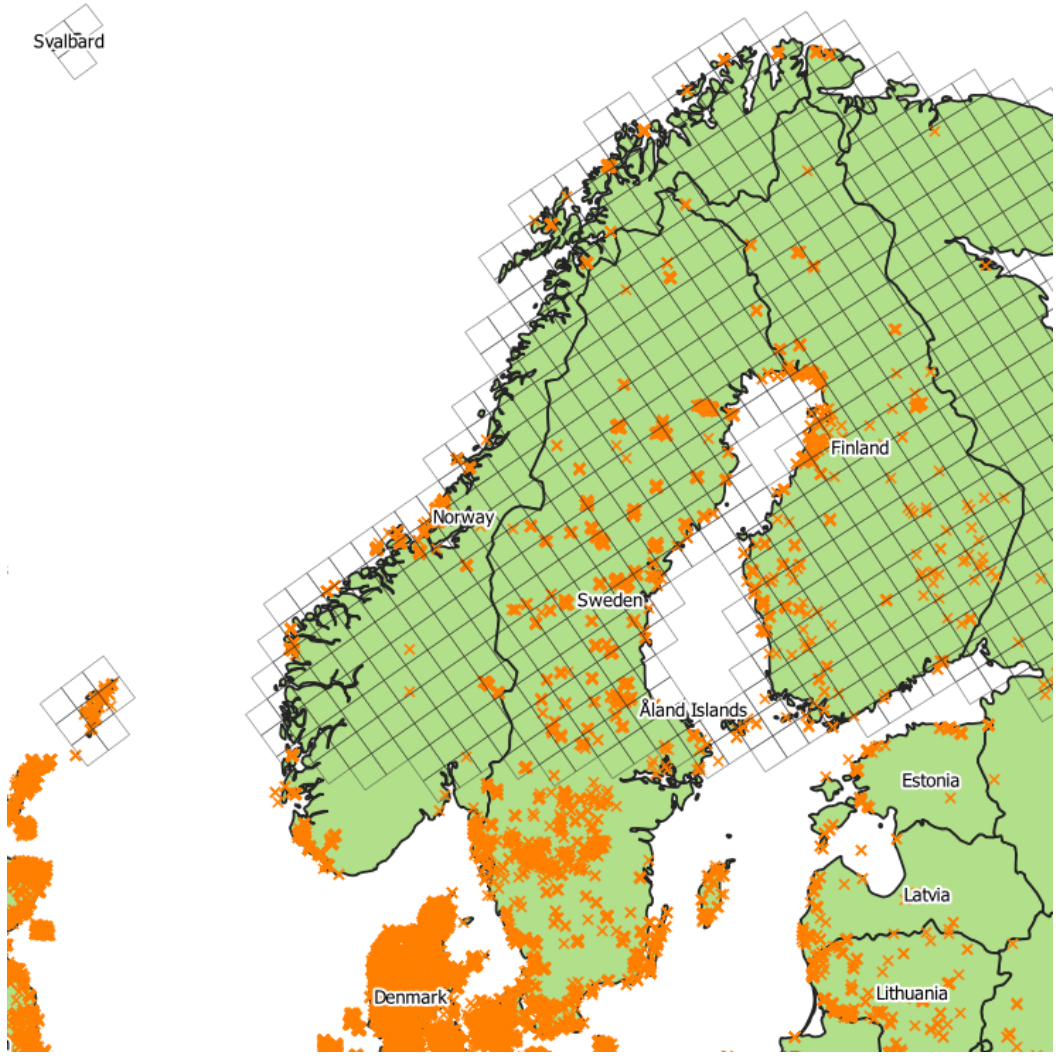
M.L. Thøgersen, M.C. Pedersen, L. Svenningsen, T. Ahsbahs, EMD International A/S, WinterWind 2022 - Skellefteå

EMD International A/S
www.emd.dk

ArcticDEM at Turbine Locations, NO & FI

- ArcticDEM and CopernicusDEM-GLO30 have almost the same vertical errors – here evaluated on more than 1000 turbine locations.
- However, ArcticDEM has more outliers, probably due to its optical origin.

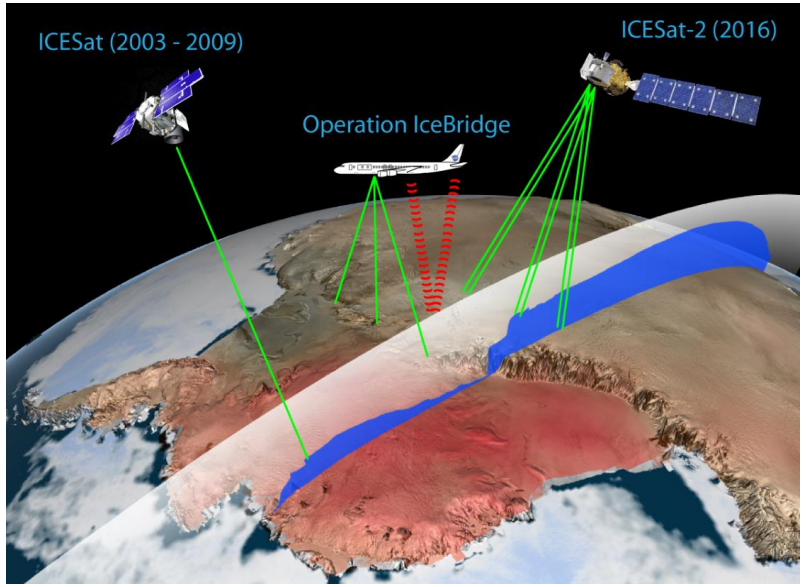


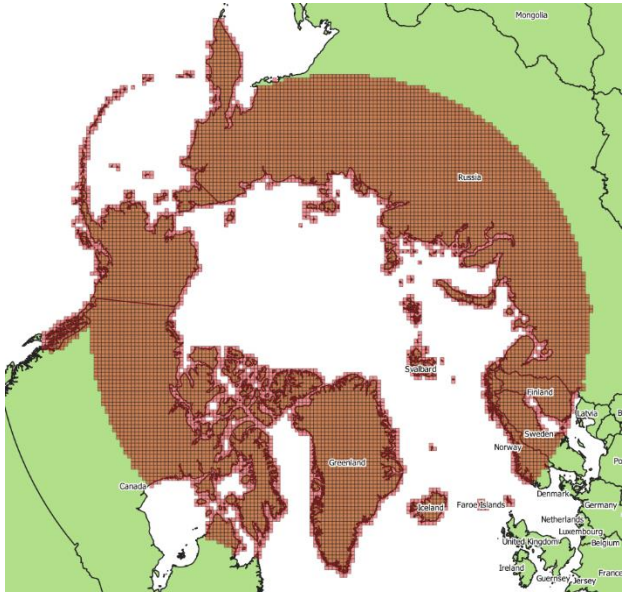


ArcticDEM and ICESat

- ICESat altimetry data has been used to align/translate the ArcticDEM Mosaics.
- It is used to evaluate the vertical accuracy:
  - Ground control points (GCP's) at the 2488 individual tiles
  - More that 2 million GCP's from ICESat is used
  - Metadata error statistics stored at the individual tiles
- Summary statistics for the 2488 tiles in the table to the right (all values in meters)
  - average residual
  - error-percentiles P50, P90 & P100
- Largest maximum error is 788m !

	average_residual	P50	P90	P100
mean	0.0613271	1.04782	4.04438	30.8457
std	1.14149	1.05098	9.5838	45.999
min	-3.921	0.051	0.499	0.943
25%	-0.003	0.49	1.559	13.866
50%	0	0.665	2.251	20.326
75%	0.002	1.031	4.532	31.919
max	37.894	8.502	283.94	788.712





Findings / Conclusions

Vertical Accuracy and Data Quality

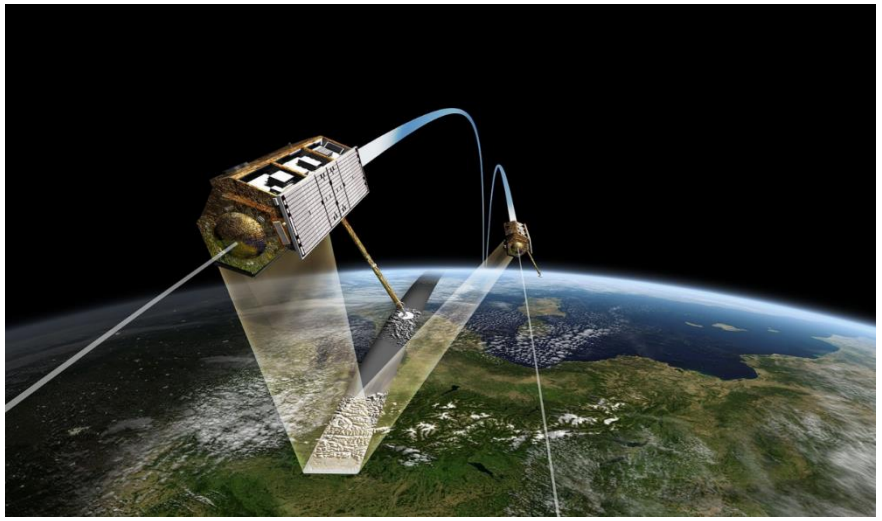
- Vertical accuracy probably as good as CopernicusDEM 90m
- However, more outliers and artifacts (that needs to be removed)
- A small negative average bias is seen
  (similar to most other 'competing' datasets)

ICESat Data and Translated ArcticDEM tiles

- ICESat does a good job in removing bias's (average vertical residual is about 0)
- Still some artifacts and problems to be expected
  (largest registered error in 2 million GCP's is 788 meters

ArcticDEM as the next-generation DEM for wind farms in cold climate?

Yes, I will be useful at many locations –
especially if we know how to handle and remove artifacts within the model.



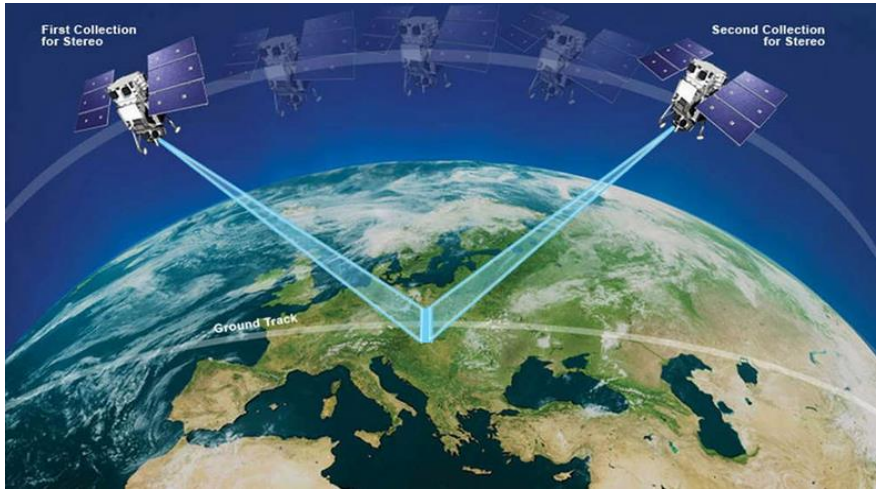


Image-Top: The two radar satellites TanDEM-X and TerraSAR-X in close formation flight at a distance of 350m apart. Credit DLR (CC-BY-3.0)
Image-Bottom: WorldView Satellite in Stereoscopic Mode.
Credit: PGC & Digital Globe.

Data Acknowledgements and References

ArcticDEM - PGC Services and Data-Access:
Geospatial support for this work provided by the Polar Geospatial Center under NSF-OPP awards 1043681 and 1559691.

ArcticDEM - DEM's:
DEMs provided by the Polar Geospatial Center under NSF-OPP awards 1043681, 1559691, and 1542736.

ArcticDEM:
Porter, Claire; Morin, Paul; Howat, Ian; Noh, Myoung-Jon; Bates, Brian; Peterman, Kenneth; Keesey, Scott; Schlenk, Matthew; Gardiner, Judith; Tomko, Karen; Willis, Michael; Kelleher, Cole; Cloutier, Michael; Husby, Eric; Foga, Steven; Nakamura, Hitomi; Platson, Melisa; Wethington, Michael, Jr.; Williamson, Cathleen; Bauer, Gregory; Enos, Jeremy; Arnold, Galen; Kramer, William; Becker, Peter; Doshi, Abhijit; D'Souza, Cristelle; Cummens, Pat; Laurier, Fabien; Bojesen, Mikkel, 2018, "ArcticDEM", https://doi.org/10.7910/DVN/OHHUKH, Harvard Dataverse, V1, [2022-04-14].

Copernicus DEM:
The European Commission and the Copernicus team are acknowledged for the development and release of the free and open Copernicus data.

PALSAR_Forest Non Forest:
Global PALSAR-2/PALSAR/JERS-1 Mosaic and Forest/Non-Forest map by JAXA.

Global Forest Heights:
Caltech/JPL (2014) Global vegetation height (Simard).

Copernicus Land Cover 100:
Acknowledgement: European Commission and Copernicus team for release of free and open Copernicus data.

InnoWind:
InnoWind was a joint R&D effort for improving land-surface models for wind energy modelling. The project focused on land-surface modelling with the aid of modern satellite sensors and remote sensing equipment. The project was executed during years 2017-2020 as a co-operation between EMD, DTU DHI-GRAS, Vestas and Vattenfall and co-funding from the Innovation Fund Denmark.

Global Elevation Data Testing Facility (GEDTF):
Kazimierz Bęcek, Monika Stepnowska, Jakub Łuczak, Wrocław University of Science and Technology
Available at: https://zasobynauki.pl/zasoby/global-elevation-data-testing-facility-gedtf,49859/

Finnish Elevation Model:
The National Land Survey of Finland (Maanmittauslaitos, MML) are thanked for producing this digital elevation dataset – and disseminating it in the public domain and thus for aiding the development of renewable energy. Contains elevation data from the National Land Survey of Finland - Topographic Database 01/2019.

Norwegian Elevation Models:
Kartverket is acknowledged for the development and release of this free and open dataset. Data source: "DTM10/DOM10" by Kartverket is licensed under CC BY 4.0.

Swedish Elevation Model:
Lantmäteriet, Sweden for the dissemination of the GSD-Höjddata (GSD-Elevation Data) are thanked for making this great digital elevation dataset available in the public domain and thus for aiding the development of renewable energy. Source: Contains GSD elevation data from Lantmäteriet, Sweden.

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Data and tools used in this project were developed as a part of the RECAST project. RECAST is a joint R&D project with participants from the wind energy industry and academia: EMD, Vestas, RES and DTU. The RECAST project is co-funded by the Innovation Fund Denmark.

GASP:
GASP 1.0, by EMD and DTU, is a free dataset accessible via windprospecting.com, windPRO and EMD-API.

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

AW3D30:
The AlosWorld 3D 30m data is provided by JAXA which also holds copyright of the data. JAXA is acknowledged for the development and release of this free dataset

ViewFinder Panoramas:
The dataset is available in WindPRO by courtesy of Jonathan de Ferranti and his website www.viewfinderpanoramas.org.

Sentinel Imagery and EU-DEM:
The European Commission and the European Space Agency are acknowledged for the development and release of the free and open Sentinel-2 data. The analysis' were made using Copernicus data and information funded by the European Union – such as the EU-DEM layers.

ArcticDEM

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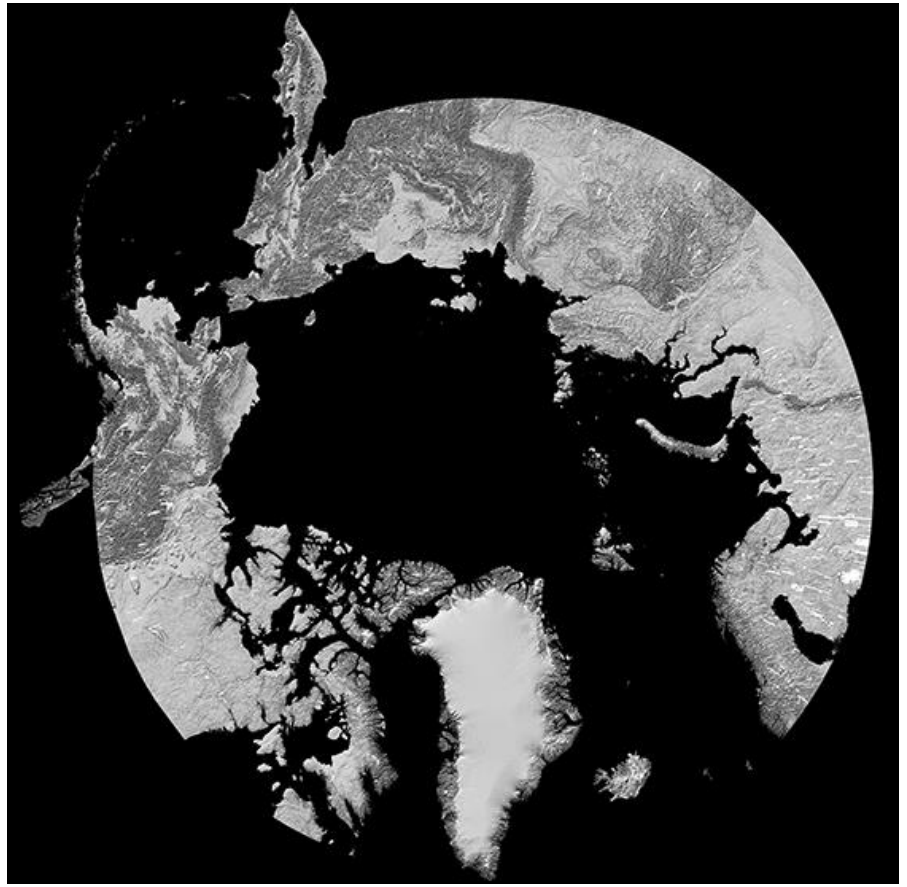

Hillshade rendering of ArcticDEM. Acknowledgement: Polar Geospatial Center

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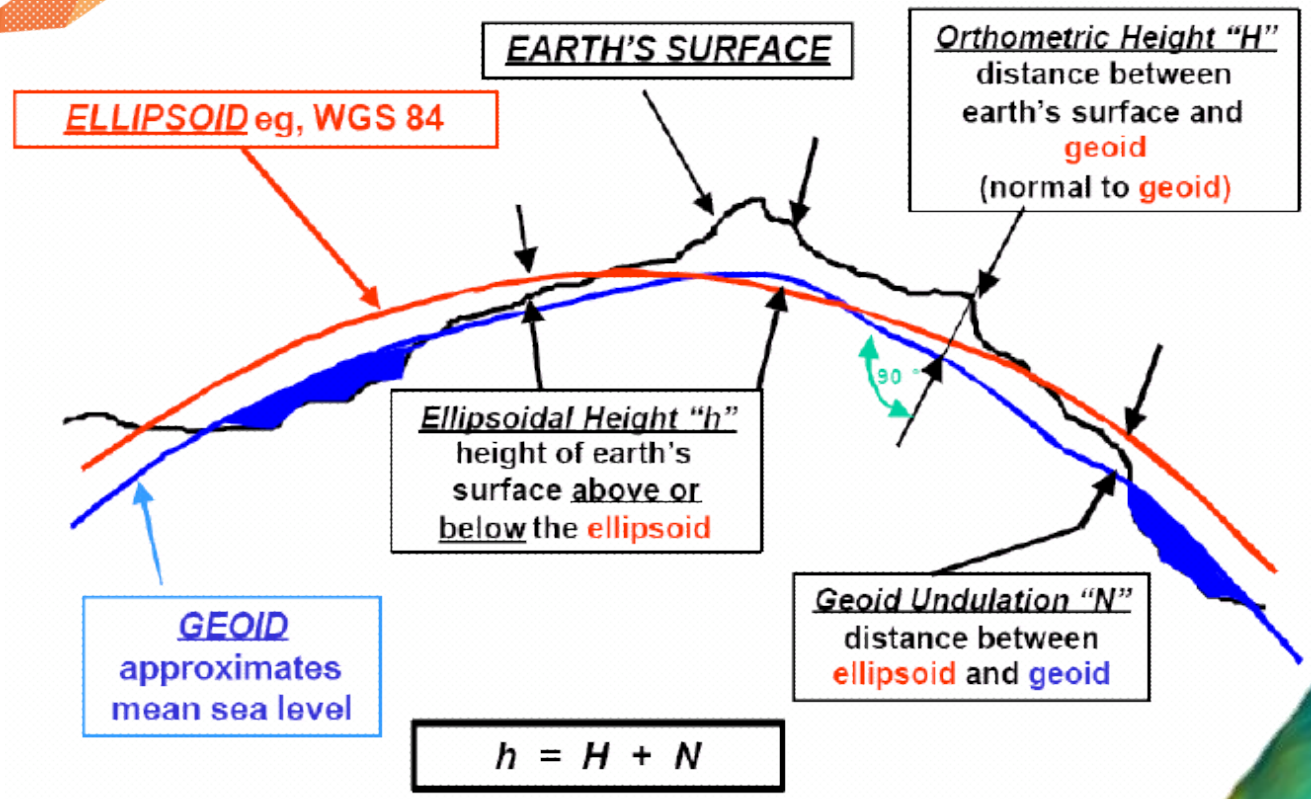
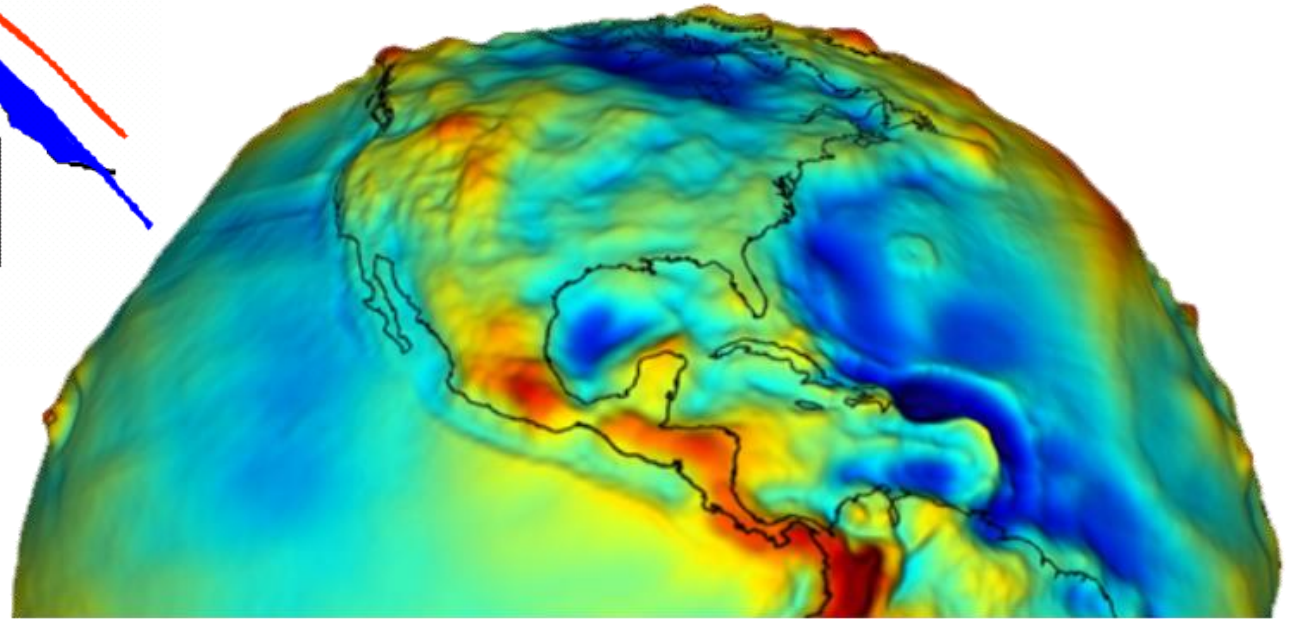
Extra Slide: Vertical Reference Systems



Vertical reference systems.
Image credit: https://nptel.ac.in/courses/105104100/lectureB_8/B_8_8coordinate.htm



Geoid: From NASA's Grace Mission - Image Courtesy of NASA/JPL