Vortex FARM

3D Remodeling Validation

Vortex Technical background

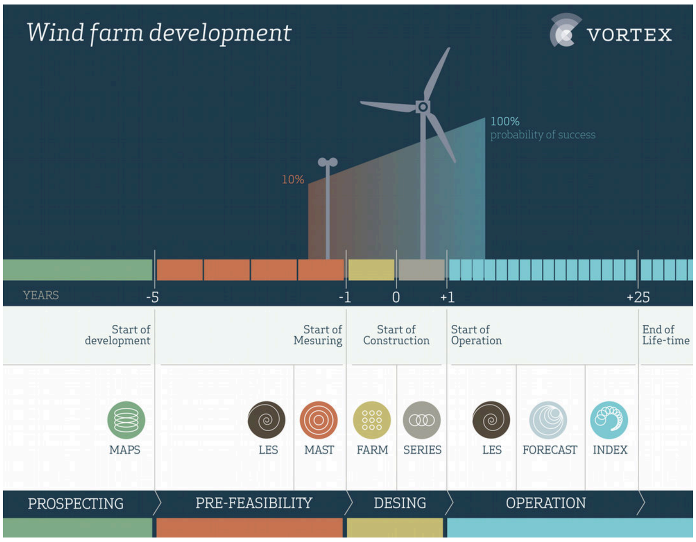


Figure 1: Vortex products at each wind-farm development phase

Mesoscale modeling technology is employed by Vortex to obtain global wind climate at different resolution and with customized specification to provide high quality wind resources information to support project development at each stage.

The mesoscale model Weather & Research Forecast Model, WRF, developed at NCAR/NCEP, is employed as Vortex mesoscale modeling core. WRF model has a long record on usage and it is employed operational in many weather services, cutting-the-edge research activities and different industry applications.

Vortex FdC has based their modeling expertise in the optimized and automated use of WRF for wind industry applications. The experience gained guarantees a stable and robust model configuration which has been tested and verified by Vortex.

The high-resolution numerical modeling of weather conditions provides today sensitive information of unprecedented quality crucial for the development of any wind project, from the early stages of prospection to the wind farm design and long-term adjustments.

In particular, usage of mesoscale modeled downscaled products driven by global Reanalysis databases gained a considerable acceptance among the wind industry community as reliable reference long-term data and resource screening assessment. Mesoscale downscaled products provide realistic localization of the wind regimes and the topography controlled variables which allows more accurate site impact assessment and climate representation.

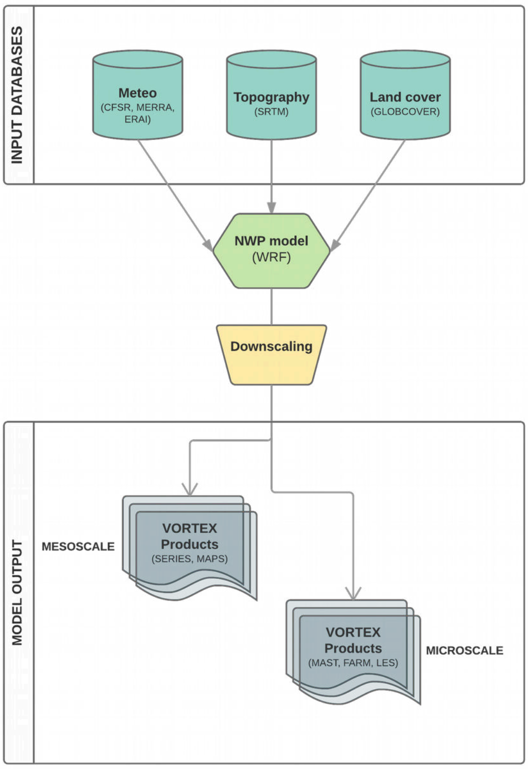


Figure 2: Vortex system flowchart

Vortex FARM Features

FARM

Vortex FARM product has been developed to support AEP analysis, windfarm layout design and site suitability impact studies facilitating the decision making process at the windfarm pre-construction stage. FARM product provides the following features:

- Fully selectable areas in size, location and orientation.
- Up to 100 m resolution.
- Any height between 50 and 150 m.
- Unlimited points within the selected area.
- Wind speed histograms with their Weibull fits.
- 16 sectors wind direction rose.
- 50 years extreme wind (Vref) via 30 years Gumbel fit.
- Characteristic turbulence intensity spectra.
- Sector-wise inflow angle and vertical shear.
- Exportable to Google Earth KML, ESRI grid and WAsP WRG files for WindPro, WindFARMer, OpenWind...

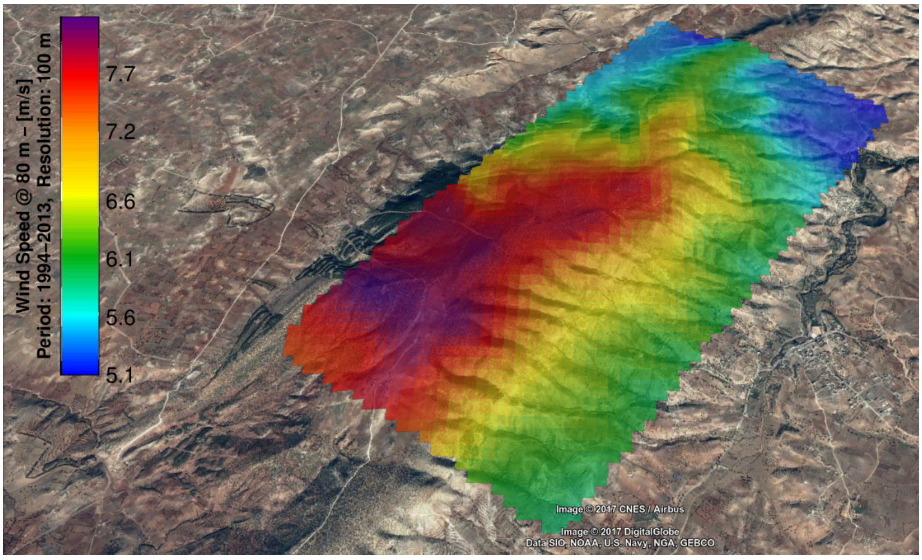


Figure 3: Vortex Farm sample. Google Earth output

Technical specifications

A. Physics:

The mesoscale model include a full physics package to describe mechanical and thermal drivers of wind regime turbulence and speed-up effects affecting the flow. Physics and dynamics specification are based on operation Vortex WRF setup, which benefits of gained experience and cumulated validation exercises and feedback from different Vortex products users;

B. Input data:

Topography data comes from the Shuttle Radar Topography Mission (SRTM)

High resolution topography database.

11 days radar mission (February 2000).

International project carried out by NGA & NASA.

Land cover data comes from ESA GlobCover Land Cover1 product.

Land cover information worldwide.

22 classes defined with LCCS system.

ESA Globcover Land Cover 1.

Macroscale meteorological inputs come from the newest NCEP version of reanalysis:

1979 – present

50 x 50 km horizontal resolution

37 presure levels

6h temporal resolution

C. Wind-farm effective resolution:

Vortex FARM is designed to downscale climate wind conditions up to 100m horizontal resolution with 8 levels in the first 150 m . Downscaling is made in a nesting down procedure where atmospheric flows are refined with enhanced physics options adequate to each scale;

D. Climate representativity:

Mesoscale model is integrated to span over representative climate period, 20 years backwards from current year.

E. Turbulence:

Mesoscale model is configured to output standard deviation at 10’ sampling to effectively derive turbulence intensity. Mesoscale model at final 100m nest is configured to use boundary layer parametrization that takes into account computation of turbulence kinetic energy, allowing a more realistic estimation of turbulence for site assessment.

F. Extremes:

As the FARM focus on site suitability, Vref is required. Vref is computed within Vortex modeling chain by selecting the 30 last years highest wind candidate events at a mesoscale level to launch the downscaling 100m resolution. Standard extreme theory analysis applied based on Gumbel distribution.

FARM 3D Remodeling

The main purpose of 3D Farm *Remodeling* is to provide with a better estimation of the wind resource characteristics for a given area, if wind observations are available at some coordinates within the referred area.

There are various methods for correcting maps based on a discrete reference sample observations. The basic concept behind all of them is to spread the information provided by the measures to surrounding points. To do this you can apply different strategies, classified as non-geostatistical, geostatistical (univariate or multivariate) and combined.

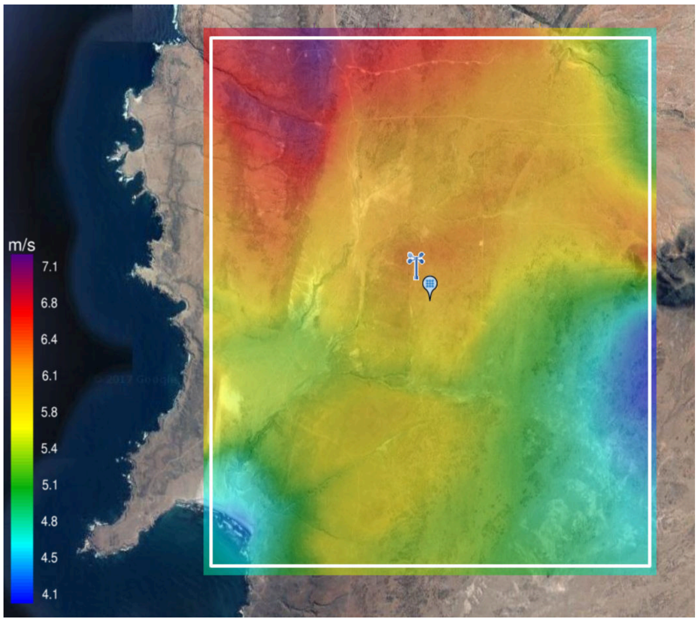


Figure 5: Sample Vortex FARM remodeled

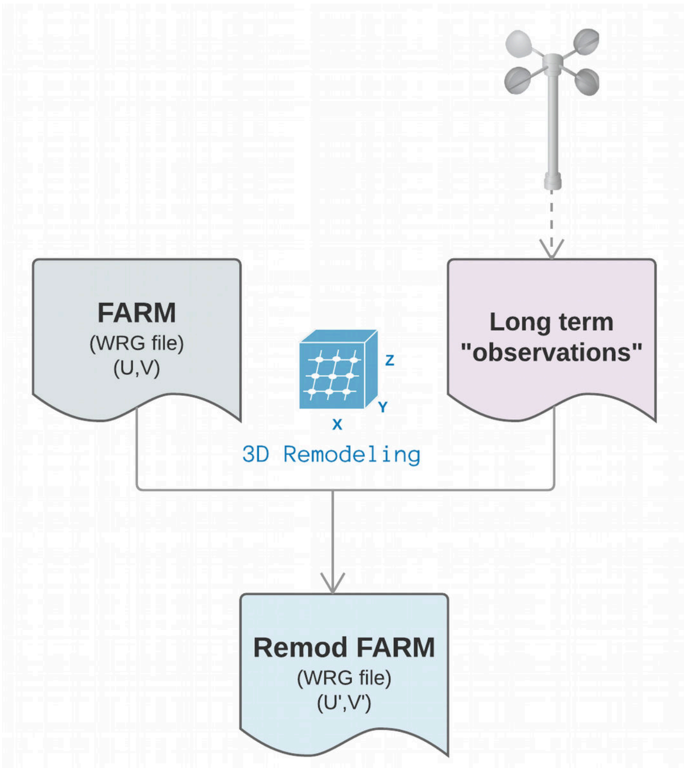


Figure 4: 3D Farm remodeling flowchart.

Vortex 3D remodeling ensures :

- Consistent correction factor s in time and domain space are applied.
- Avoiding to use Weibull fittings.
- No need to rely on sector s & bin simplification.
- Obtained correction factors are time dependent and synchronized with observations.
- Multiple observation points with different heights can be employed.
- Results are long term representative.
- Localized spot influence of the point of measurements is mitigated.

FARM 3D Remodeling

Vortex 3D Farm Remodeling is divided in three steps to prepare all the required input observations, modeled data and to obtain the final corrected wind resources output.:

STEP 1:

Extension of observations on time using Vortex Remodeling.

Aim: Obtain a long-term representation of observations consistent with modeled data.

STEP 2:

Time series of modeled data at very high resolution (500m or 100m *) are computed.

* depending on the domain complexity and extension.

STEP 3:

Calculate correction factors for vector components (U-zonal, V-meridional) of wind speed in space (x,y,z) and time using adaptative statistical methods.

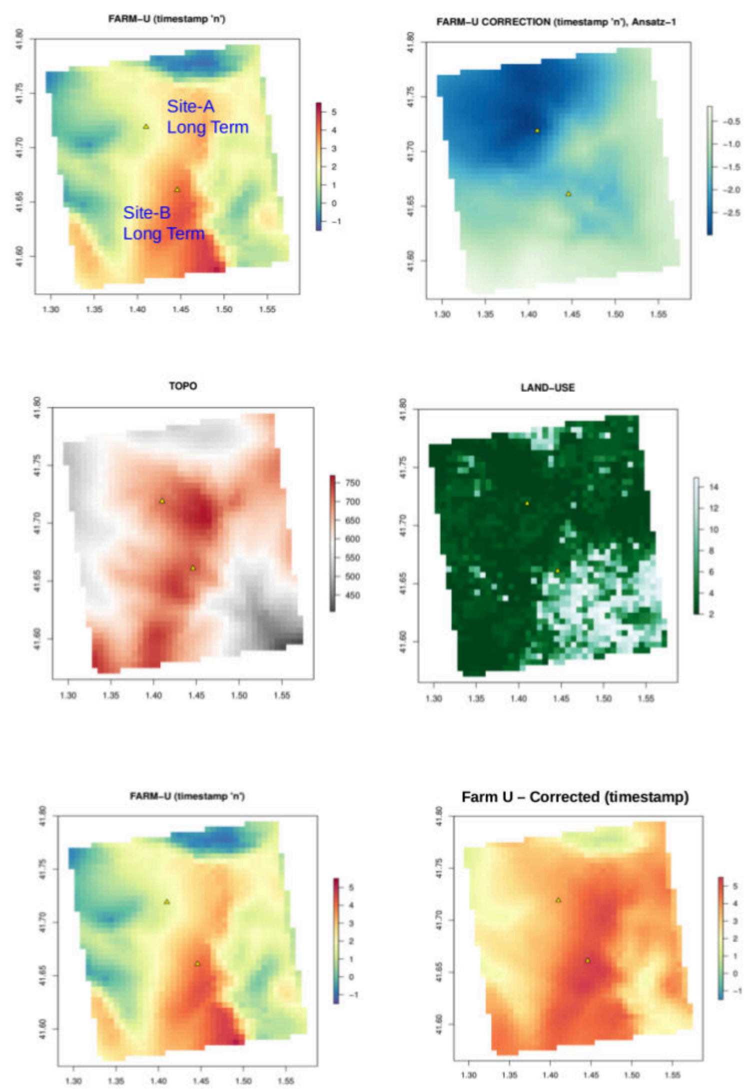
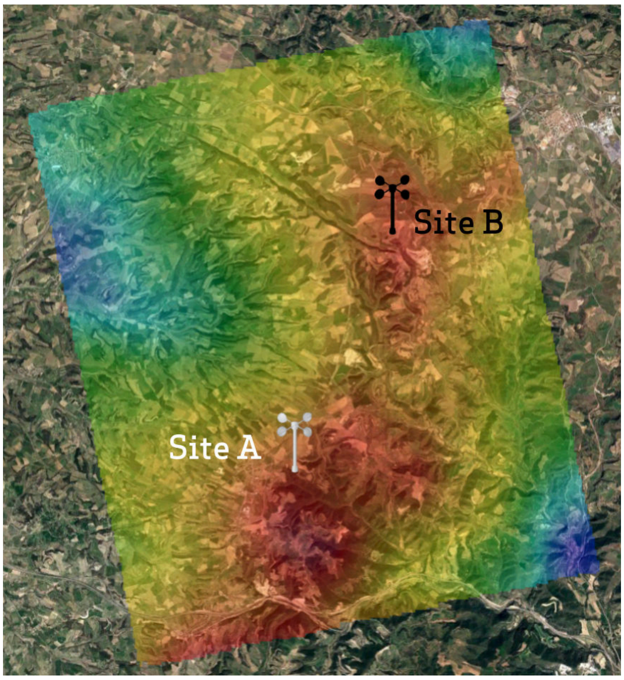


Figure 6: Step 3: calculate correction factors for each time step.

Example Vortex FARM Remodeled

Following pictures show a FARM before and after remodeling. Calibration made with observations from site A results in reducing error at site B more than 5 points: a bias in site B of -9% turns out -3.8% with a FARM remodeled.



Mean wind speed measured at site B: 7,7m/s

Mean wind speed obtained at site B from Vortex FARM no remodeling: 7 m/s

Mean wind speed obtained at site B from Vortex FARM 3D remodeling calibrated with observations at site A: 7,4 m/s

Figure. 7: Sample Vortex FARM before calibration with observations from site A.

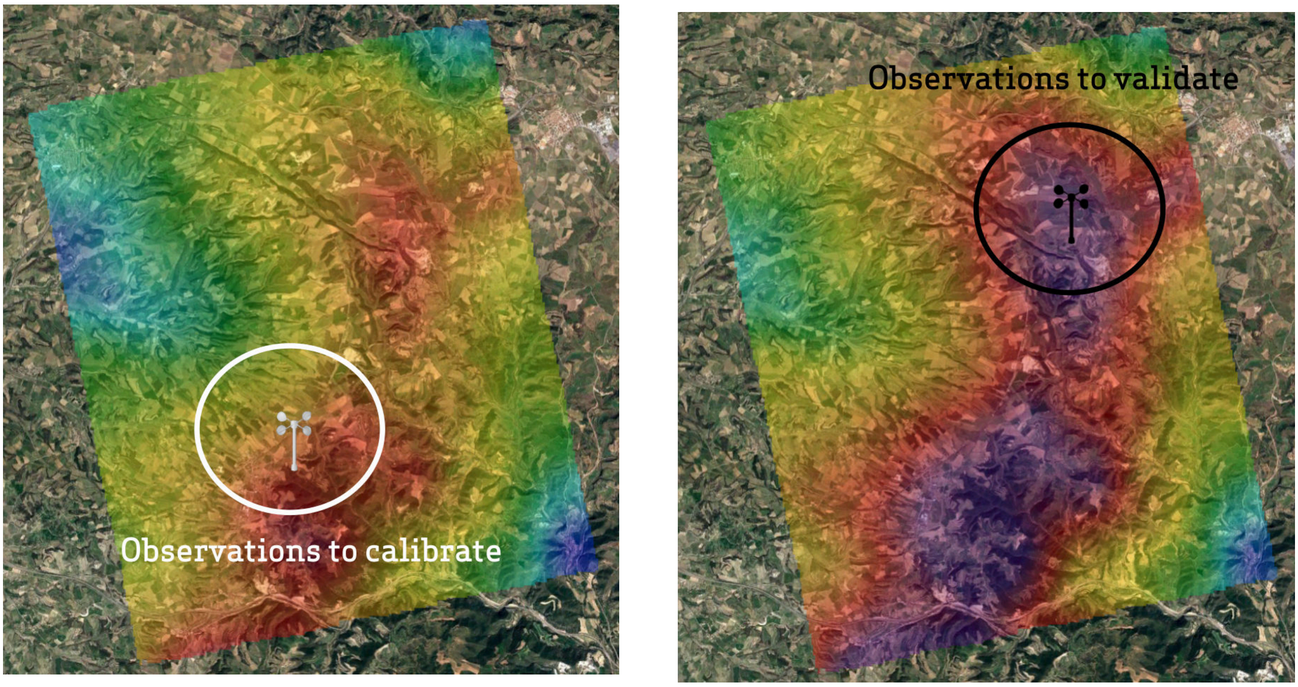


Figure 8: Sample Vortex FARM before (left) and after (right) remodeling.

Example Vortex FARM Remodeled

A set of FARMs remodeled has been externally validated by different Vortex users.

In this validation exercise a FARM was calibrated with data from a met mast located within the area of the FARM and validated against data from another met mast also located within the FARM extension.

Most of the Farms validated here have been calibrated with the mast A and validated with the mast B, and vice versa. In some cases it has been validated and/or calibrated even with more than one station.

The real data comprise at least one year of measurements from which a long-term series has been obtained, in order to be able to do the comparative.

Table 2 presents the results of the cross-validation exercise for mean wind speed. The table shows geographic location, distance between meteorological masts, site complexity and company contact, who made the study.

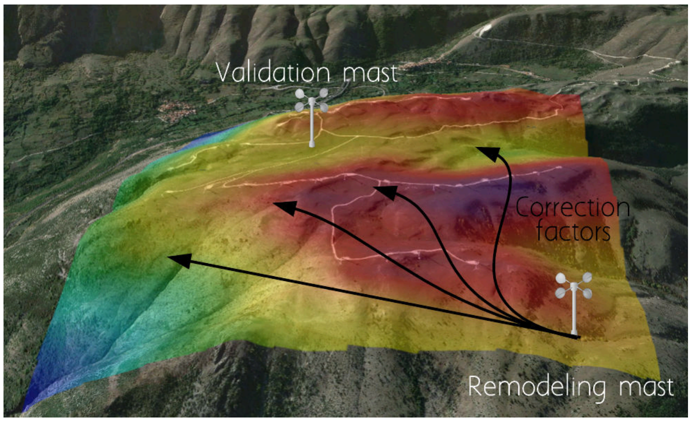


Figure 9: Illustration Farm remodeled validation exercise.

The average bias of mean wind speed for the sites validated is -0,22% with an standard deviation of 5,81%. Mean absolute er r or (MAE) results in 4,58%. The sites where errors were not as good as expected it might be due to:

- very complex terrains,
- observations used to calibrate were not horizontally representative,
- wind regime very conditioned by local effects.

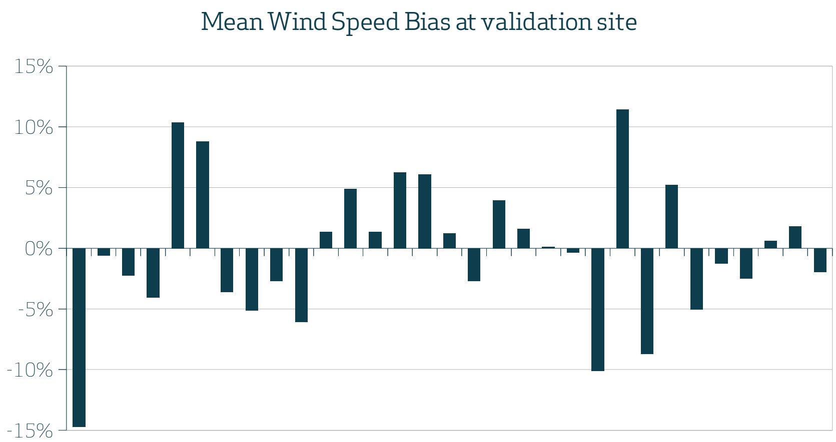


Fig. 10: Mean wind speed bias at each site validated..

Bias (%)	Bias St. Dev. (%)	MAE (%)
-0,22	5,81	4,58

Table 1: Vortex FARM 3D remodeling validation results for mean wind speed.

Company	Region	Terrain	Distance between calibration and validation mast	Long-term mean wind speed bias (%)
WSP	East Africa	Edge of the plateau	3,5 km	-14,7
	East Africa	Mountain plateau	3,6 km	-0,6
Acciona	Canada	Cropland, flat	5 km	-2,25
	Canada	Cropland, flat	5 km	-4,06
The Blue Circle	Thailand	Cropland, flat	4 km	+10,38
	Thailand	Cropland, flat	4 km	+8,79
RES	Sweden	Forest	1,7 & 6 km	-3,6
	Sweden	Forest	7,3 & 3 km	-5,13
Inores	Turkey	Complex	3 km	-2,69
	Turkey	Complex	8 km	-6,09
EDF	France	Forest	3,3 km	+1,32
	France	Forest	3 km	+4,88
	France	Forest	3,25 km	+1,33
	France	Forest	2,7 km	+6,25
	France	Cropland, flat	2,3 km	+6,10
	France	Cropland, flat	1,75 km	+1,23
	France	Cropland, flat	2,8 km	-2,7
	France	Forest	3,65 km	+3,95
	France	Cropland, flat	2,25 km	+1,6
(Anonymous)	-	Semi-complex	3,3 km	+0,10
	-	Semi-complex	4,3 km	-0,35
Barlovento	Morocco	Complex	4,5 km	-10,11
	Morocco	Complex	4,5 km	+11,42
	Spain	Semi-complex	6,6 km	-8,71
Enerfin	South Brazil	Cropland, flat	8,7 km	+5,19
	South Brazil	Cropland, flat	6,2 km	-5,06
	South Brazil	Cropland, flat	3,8 km	-1,27
PNEWIND	Turkey	Semi-complex	9,82 km	-2,50
VOLTALIA	North East Brazil	Cropland, flat	4,44 km	+0,58
Alcazar Energy	Turkey	Complex	2,32 km	+1,78
			2,32 km	-1,96

Table 2: Results of the cross validation exercise.