# Avian Sensitivity Mapping and Wind Energy

*GIS-based wind turbine micro-siting tool*

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# INnovative Tools to reduce Avian Collisions with wind Turbines

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Norwegian
Water Resources and
Energy Directorate
NVE

The Research Council
of Norway

# INTACT: R&D for green innovation

The primary objective is to develop measures and procedures to reduce the risk of bird – wind turbine collisions

The main focus of the research is to test promising deterrent measures at the Smøla wind-power plant and develop tools to facilitate this, and to test and refine micro-siting tools

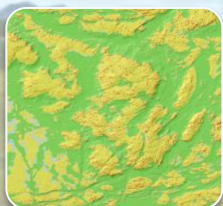
- *Develop a standalone GIS-based micro-siting tool for identification of high-risk turbine locations (in red) for birds in relation to thermals, local topography and wind conditions*

# Micro-siting of wind turbines

***Purpose:***

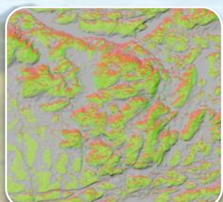
- Map and avoid sites of specific avian interest
- Minimize bird-turbine collision risk through pre-construction siting
- Bird-friendly turbine siting enhances socio-economic effectiveness
- Reduce uncertainty in decision-making regarding design of wind-power plants
- Predict, document and re-examine impacts

# INTACT Wind-turbine Micro-siting Toolbox



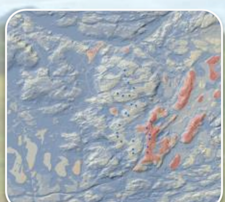
## 1. Landscape Orientation Toolbox

- Geomorfological classification (landscape metrics)
- Topografical and hydrological orientation



## 2. Updraft Estimation Toolbox

- Orographic updraft velocity based on DEM and proxy wind data
- Thermal updraft velocity based on LandSat 8 thermal band



## 3. Avian Site Risk Toolbox

- Weigthing of maps from the two first toolboxes
- Calculate relative risk distribution for raptors


Bohrer G, et al. 2012. Estimating updraft velocity components over large spatial scales: contrasting migration strategies of golden eagles and turkey vultures. *Ecology Letters* 15: 96-103.

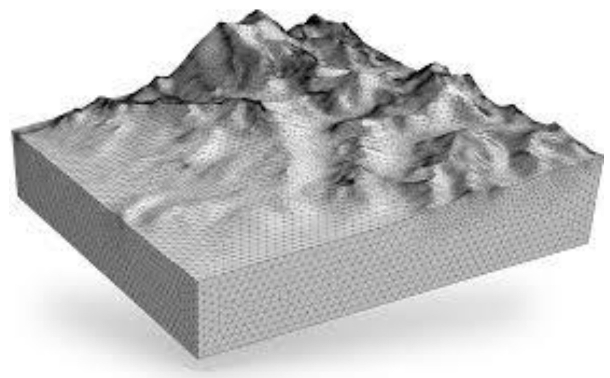
Pocewicz A, et al. 2013. *Mapping Migration: Important places for Wyoming's migratory birds*. Lander, Wyoming: The Nature Conservancy.

# 1. Landscape orientation

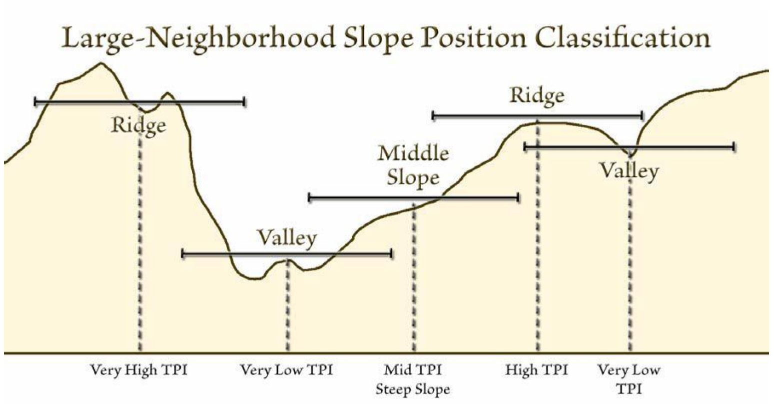
- During migration raptors prefer to follow topographical “leading lines” such as ridges, mountain ranges and main river systems
- Such orientation features depend on the geomorphometric complexity of the entire landscape at different scales in turn affecting how birds prefer to migrate across the landscape
- Classification of landscape features

# Landscape classification

- Topographical Position Index (TPI) compare pixel height with mean pixel height within a search window:
  - TPI < 0 (Valleys; concave)
  - TPI > 0 (Ridges; convex)
  - TPI = 0 (Plains and valley bottoms)



- Sensitive to geographical scale and DEM resolution (e.g. 3x3 or 60x60 pixels)




- Combining Slope and TPI (mean ± SD) within at least two search windows can assist in the landscape classification



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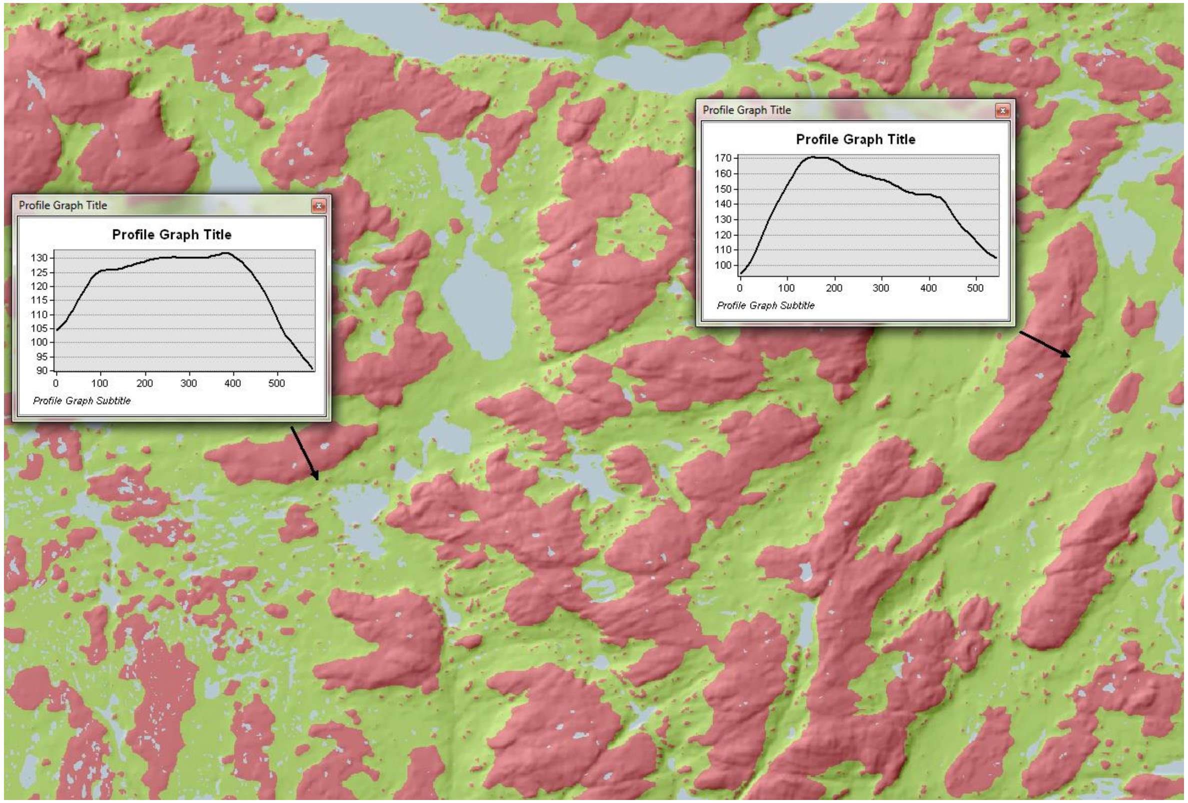
# Landscape classification

- Canyons
- Mid-valleys
- Upland
- U-valleys
- Plains
- Open
- Mesas
- Local ridges
- Mid-ridges
- Ridges
- Water (mask)



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# Landscape orientation

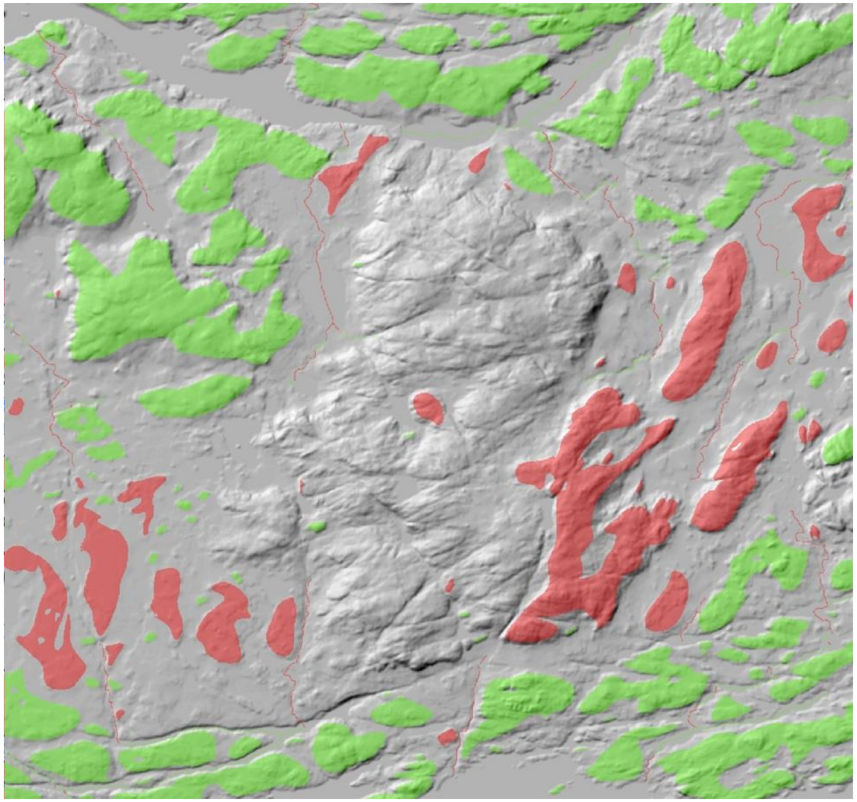
The tool estimates the azimuthal angles of ridges, mountain features and rivers

Measuring the azimuthal angles of some landscape features is complex because of their irregular shapes and non-linearity (e.g. valleys transitions and open plains)

Measuring angles of those geometrically complex features does not always give practical meaning with respect to bird migration preferences, and we have therefore used the features Long Axis to Short Axis ratio to select features that are mostly linear in nature

# Landscape orientation

- **Minimum Bounding Geometry (MBG) for each landscape feature:**
  - measures azimuth orientation, width and length
- **MBG Axis ratio = MBG length / MBG width:**
  - non-linear features (ratio < 1.5) are removed
- **A Northness index is calculated as a measure on how the features are oriented north-south or east-west:**
  - East-West oriented features
  - North-South oriented features





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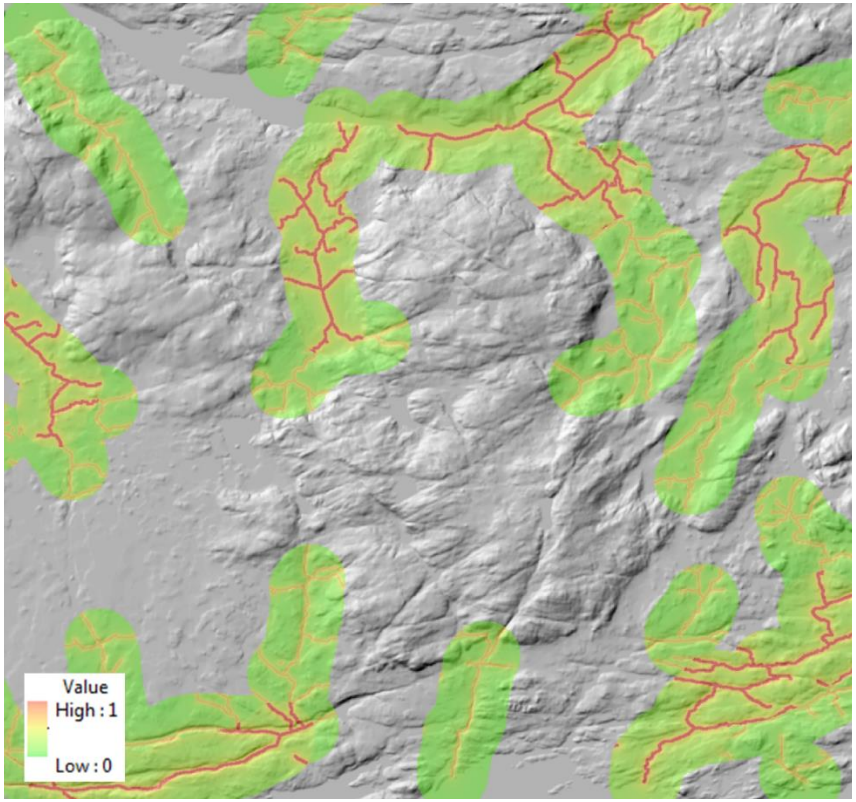
# Hydrological orientation

- **Norwegian river database (ELVIS)**
- **River order classification:**
    - Strahler stream order 3 (0.5)
    - Strahler stream order ≥4 (1.0)
- **Rivers ≥0.5 are buffered with 500m**
- **A Distance Decay model is used to measure how attractive rivers and the surrounding areas may be for migratory birds**



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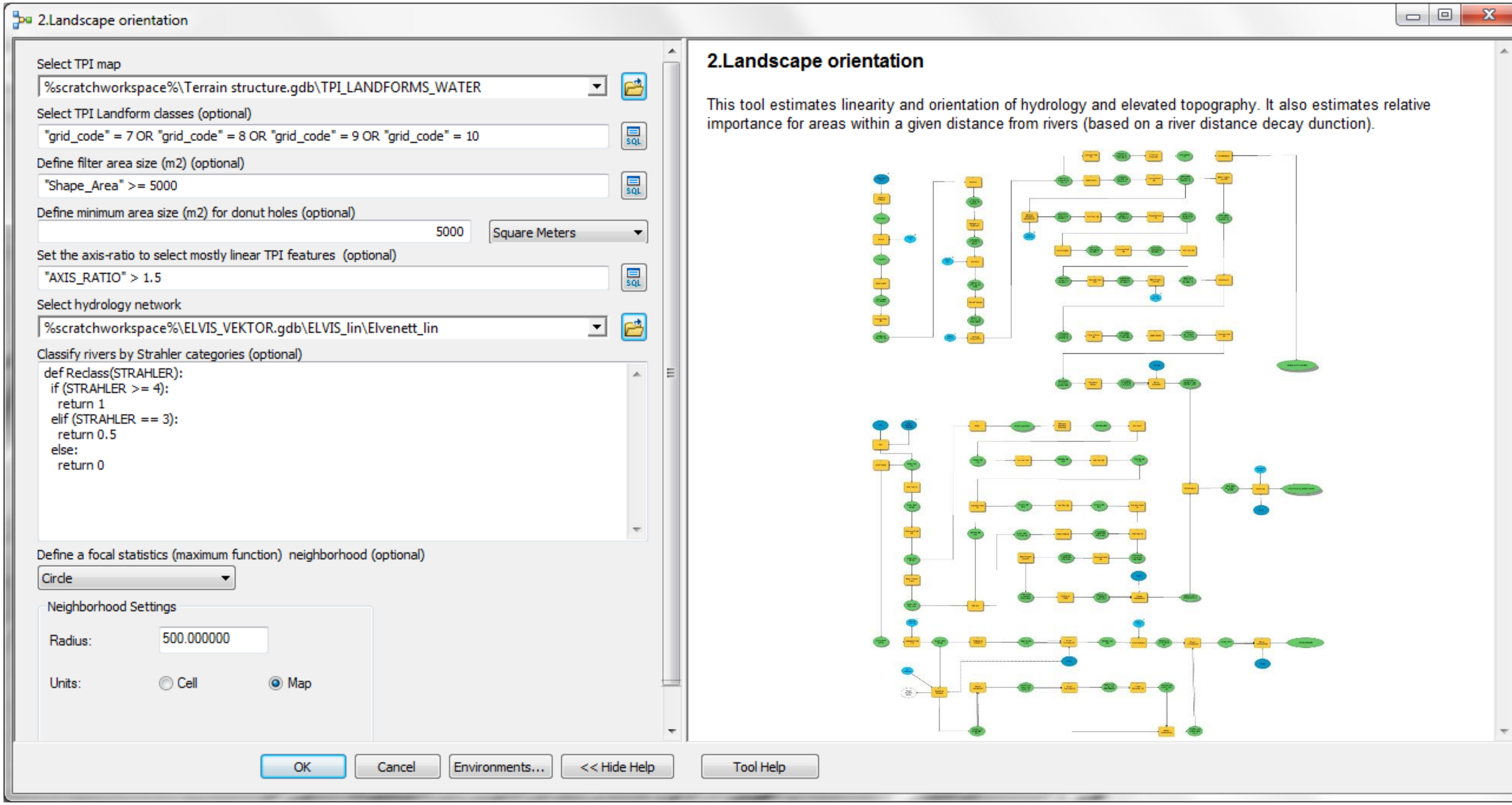
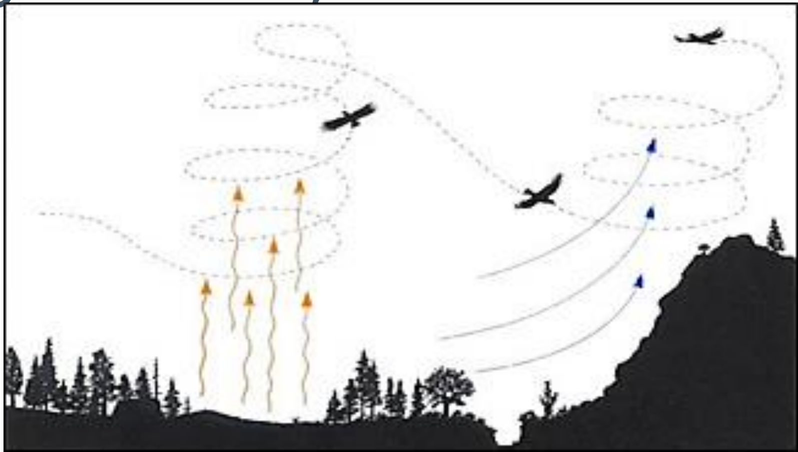
# Landscape orientation interface



# 2. Updraft estimation

- Soaring birds are attracted to topography providing local updrafting winds to subsidize soaring and gliding flight activity

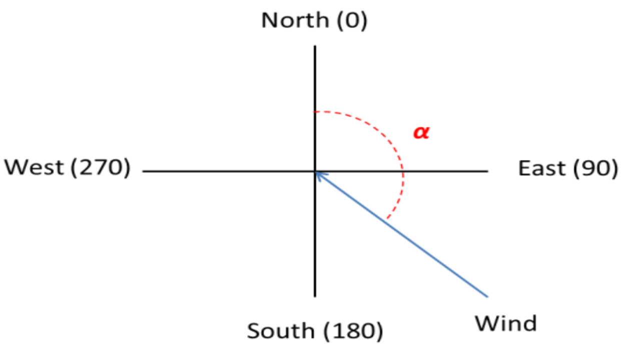
- Soaring birds do not maintain high altitudes during migration. Instead, they conserve energy by gaining lift from updrafts and gliding long distances, slowly losing altitude, to the next updraft



- Two types of lifting:
  - Orographic updrafts
  - Thermal updrafts

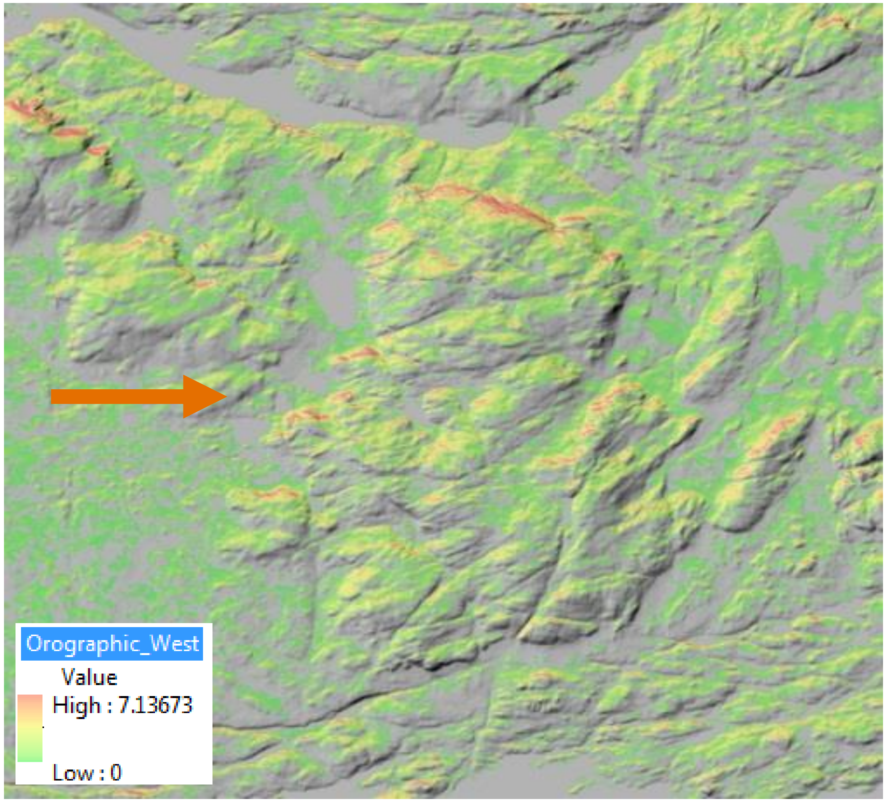
# Orographic updraft model

## *Orographic updraft ($w_0$)*




*Orographic* updraft coefficient *($C_\alpha$)*
$C_\alpha$ = *Sin* (slope) * *Cos (wind direction – aspect)*

*Orographic* updraft velocity *($w_0$)*
$w_0$ = *v (wind speed) * $C_\alpha$ (updraft coefficient)*



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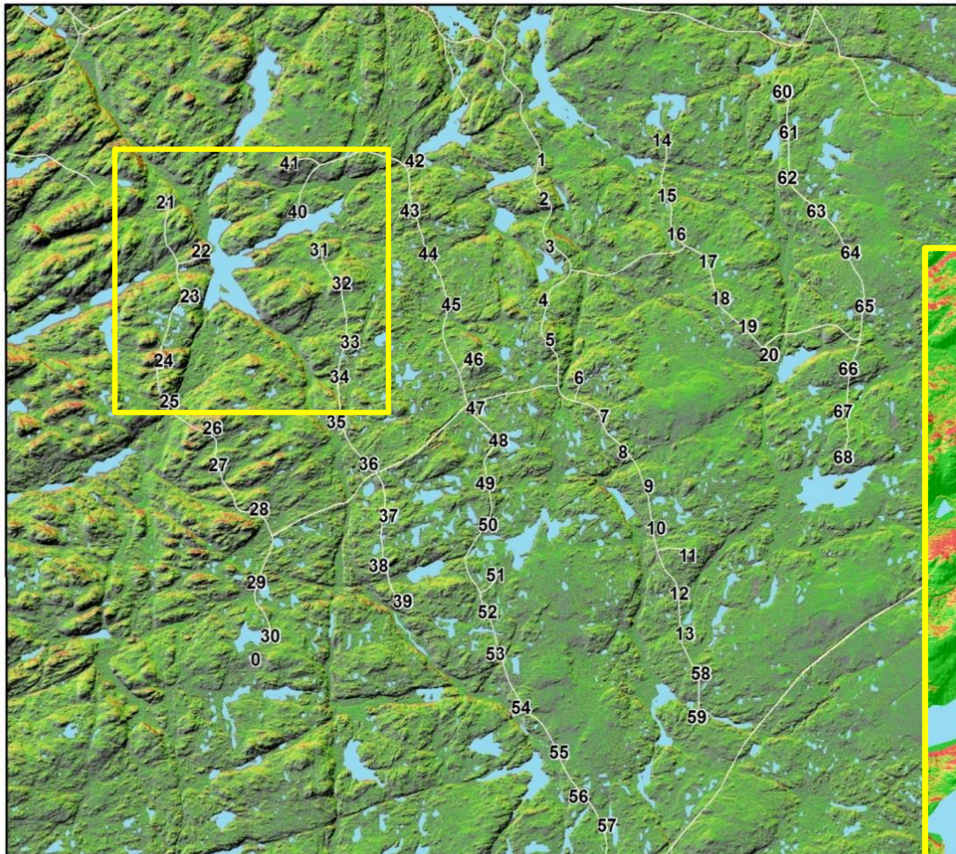
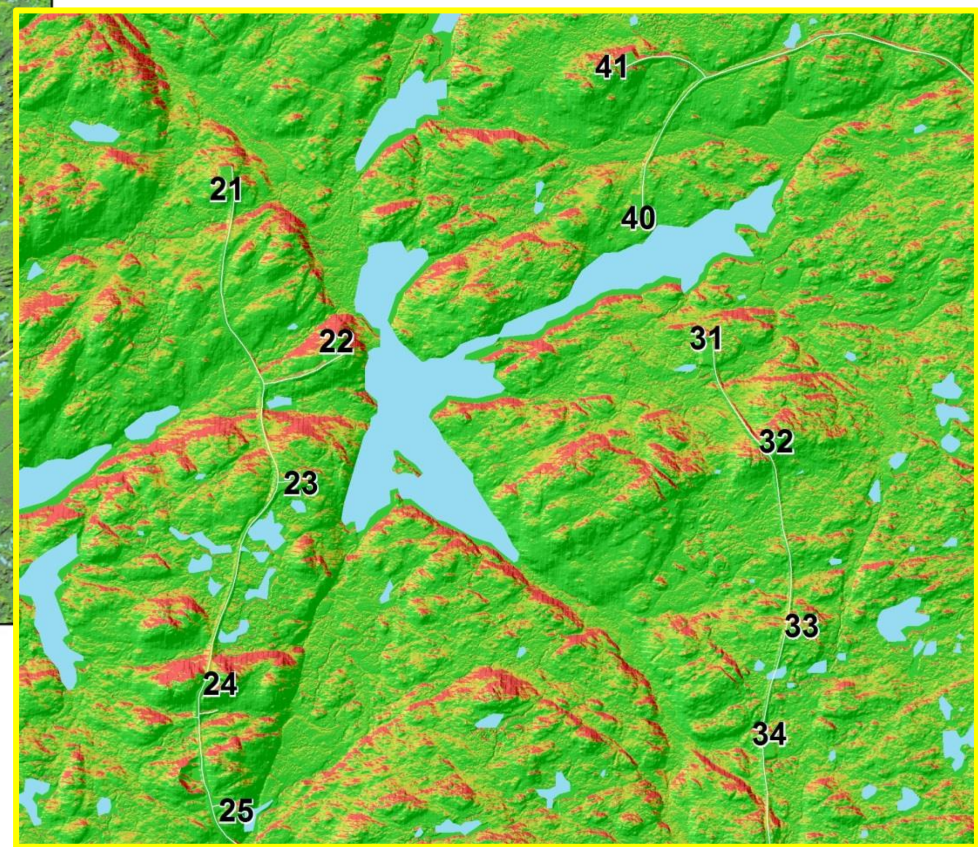
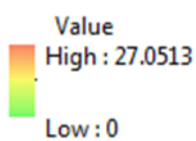
# Orographic updraft model

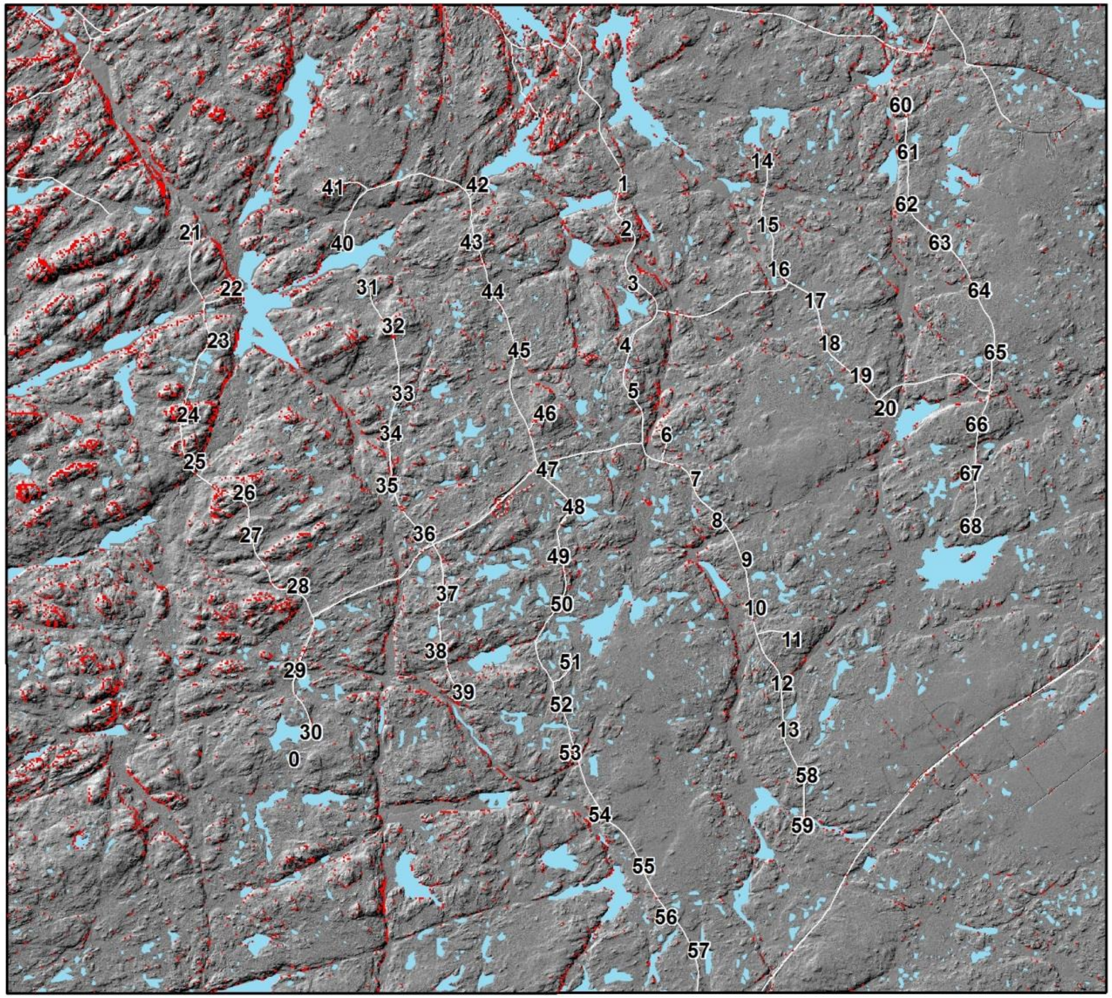



Approximated orographic updraft wind velocity at the Smøla wind-power plant derived from northern wind at 28.4 m/s (full storm)



# Orographic updraft model




To scope potential harmful turbine locations a proxy level of e.g. >10 m/s can be chosen, based on an aggregation of updrafts from all wind directions at 28.4 m/s

In reality, when based on species-specific updraft requirements and relevant flight strategy parameters (including topographic pathways and thermal updrafts), this could represent a realistic measure of potential harmful turbine locations in complex terrain



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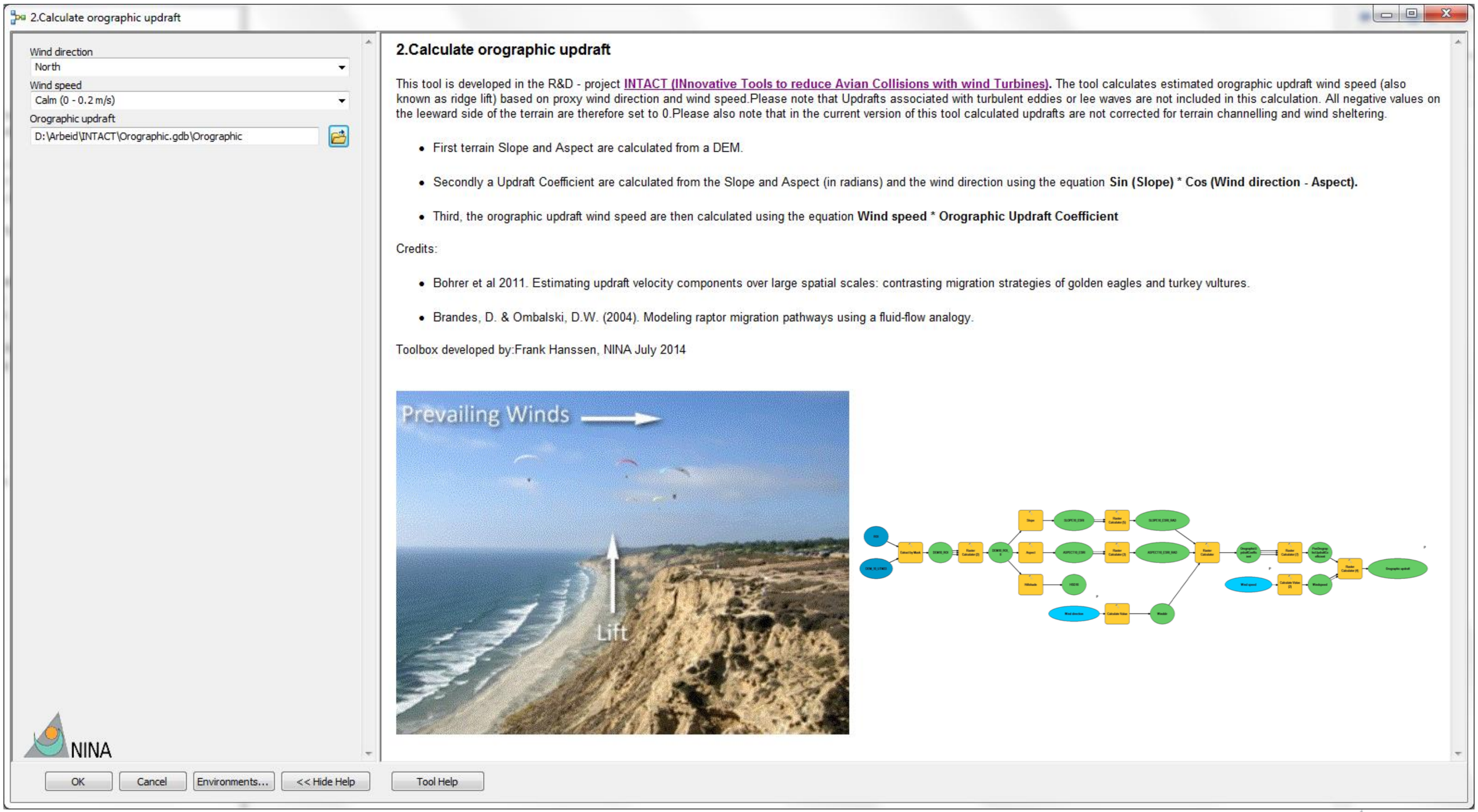
# Orographic updraft interface



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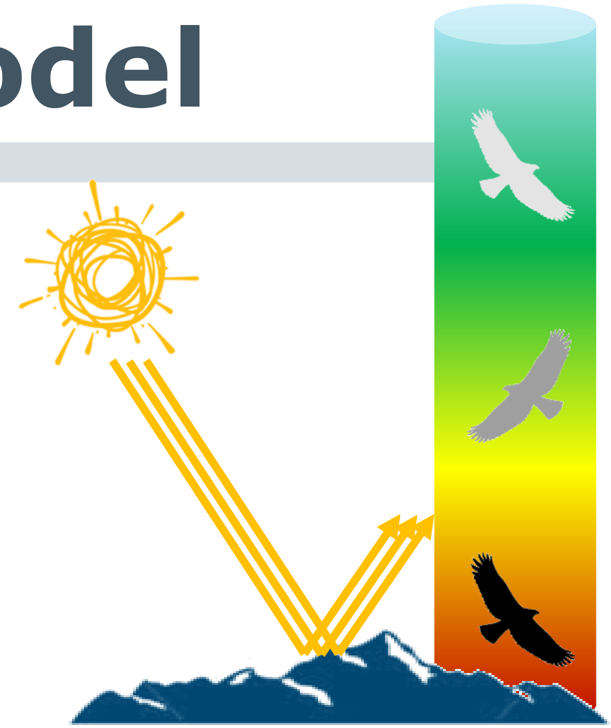
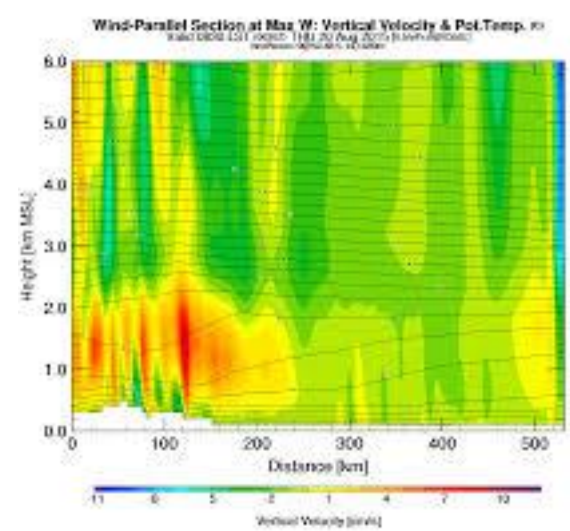
# Thermal updraft model

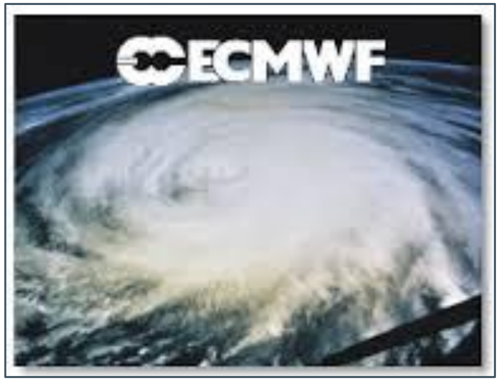
**Thermal updraft velocity**
**$W^* = [gzH / \theta]^{1/3}$**

- ***g*** is the gravitational acceleration
- ***θ*** is the potential temperature
- ***H*** is the surface sensible heat flux; determined by the *Land Surface Temperature*
- ***z*** is a bird's flight height within the atmospheric boundary layer

Thermal soaring flight is not possible when **W*** is negative (surface cooling during nights, after rainfalls or when the surface is covered by snow/ice)

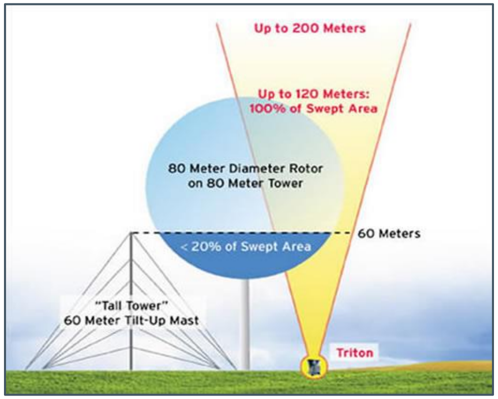






**Weather Forecast models:**

- Most usual to use for thermal updraft estimation
- Not applicable for micro-siting due to low resolution ~ 2.5 km (met.no) and 12.5 km (ECMWF)




**SOnic Detection And Ranging (SODAR)**

- Atmospheric turbulence
- Wind speeds in altitudinal layers
- Thermo-dynamics i lower parts of the atmosphere
- SODAR has limited coverage and is very costly

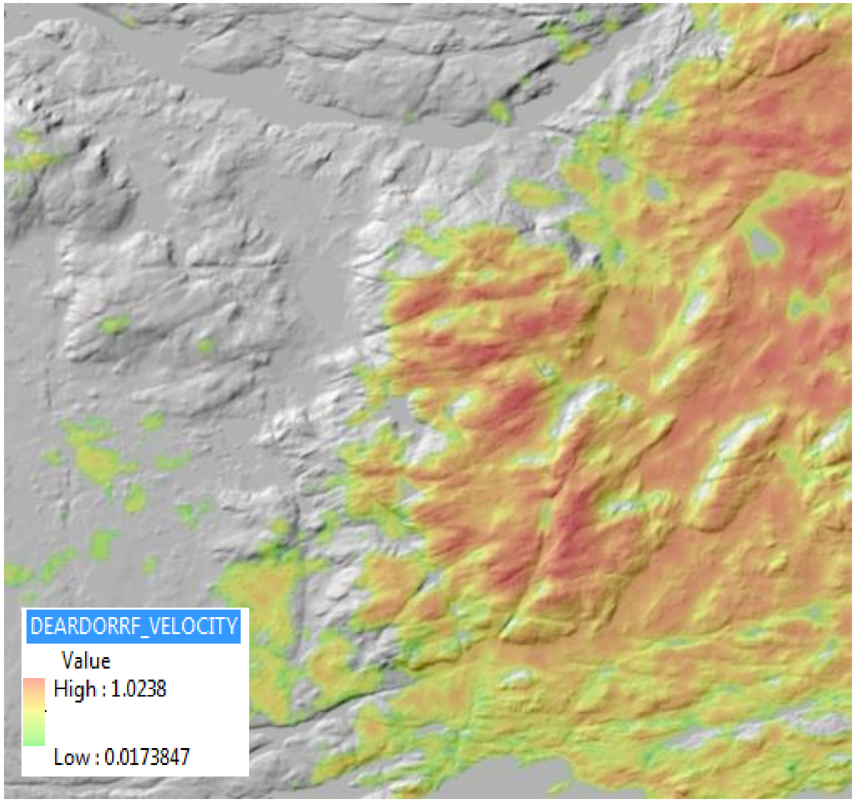
**LandSat8 thermal sensor:**

- Heat surface energy
- High reolution (30-100 meter)
- Cover the same are app. every 16 day
- 1 scene covers 170 km x 185 km
- Free access to data from NASA
- Sensor is sensitive to clouds

# Thermal updraft model

**Input parameters:**

- Region of interest
- Water mask
- LandSat Band 5 (NIR)
- LandSat Band 4 (Red)
- LandSat Band 10 (TIR)
- Flight heigth
- Horizontal wind direction
- Meteorological constants




**Calculations:**

- Solar radiation
- Surface-air heat exchange
- NDVI (absorbed radiation)
- Land surface temperature



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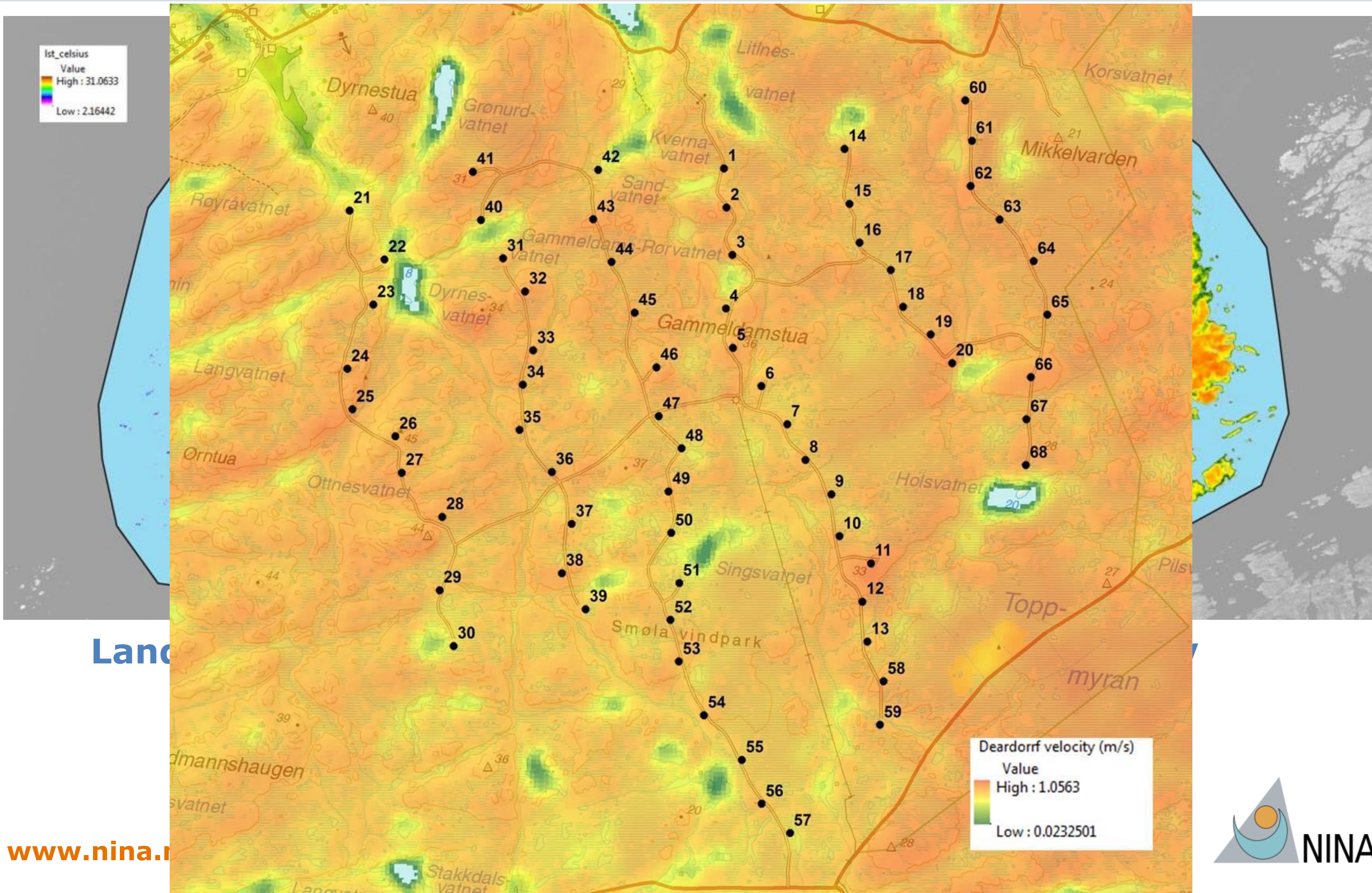
# Thermal updraft model

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# Thermal updraft model

Birds have different morphology and behavioural characteristics which influence species-specific flight strategies, and the species' capability to exploit orographic and thermal updrafts as they traverse the landscape

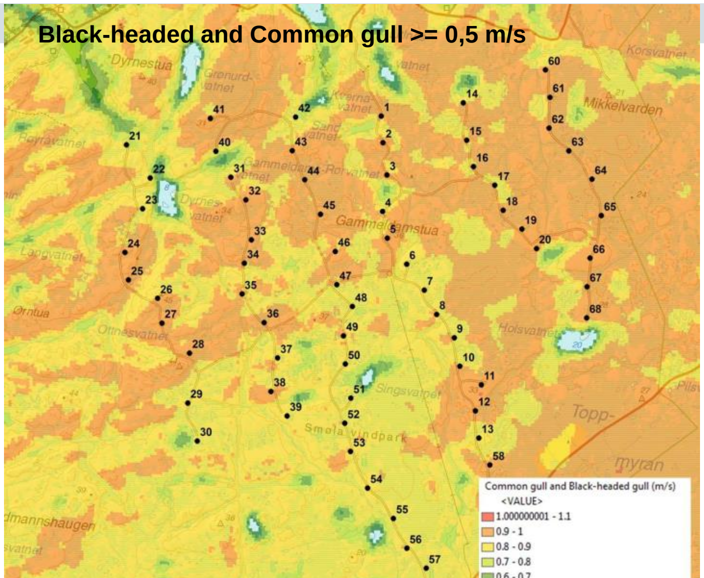
To determine bird-specific requirements for taking advantage of thermal updrafts in soaring flight activities we utilized the Flight program developed by Pennycuick (2008)

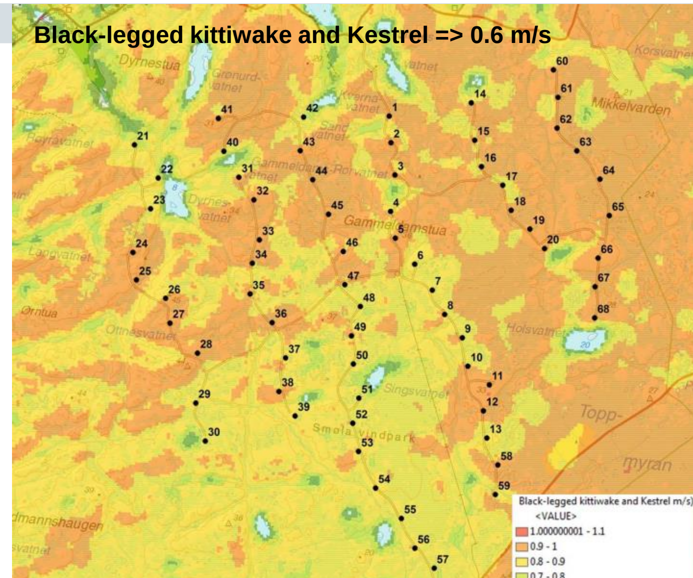
**Minimum sink ($V_{ms}$)** and **Best glide ($V_{bg}$)** defines the minimum and maximum requirement thermal updraft speeds needed to avoid sinking downwards in uplifting air currents. All speeds above $\mathbf{V_{ms}}$ makes it possible to climb upwards on an updraft

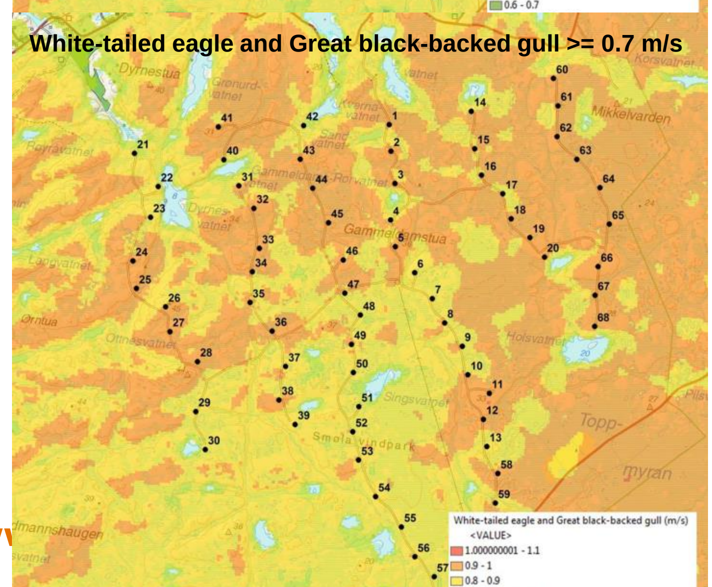
***Examples:***

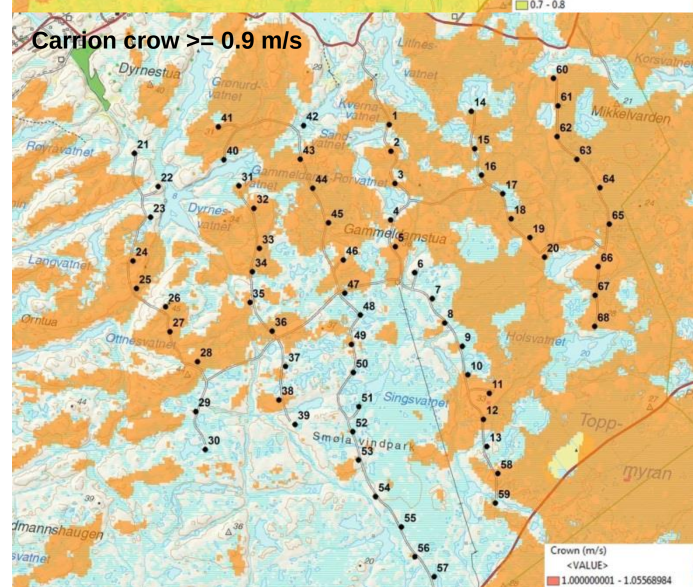
- Common gull and Black-headed gull: 0.4-0.5 m/s
- Black-legged kittiwake and Kestrel: 0.5-0.6 m/s
- White-tailed eagle and Great black-backed gull: 0.6-0.7 m/s
- Carrion crow: 0.7-0.9 m/s
- Willow ptarmigan: 14.2-16.5 m/s

# Thermal updraft model

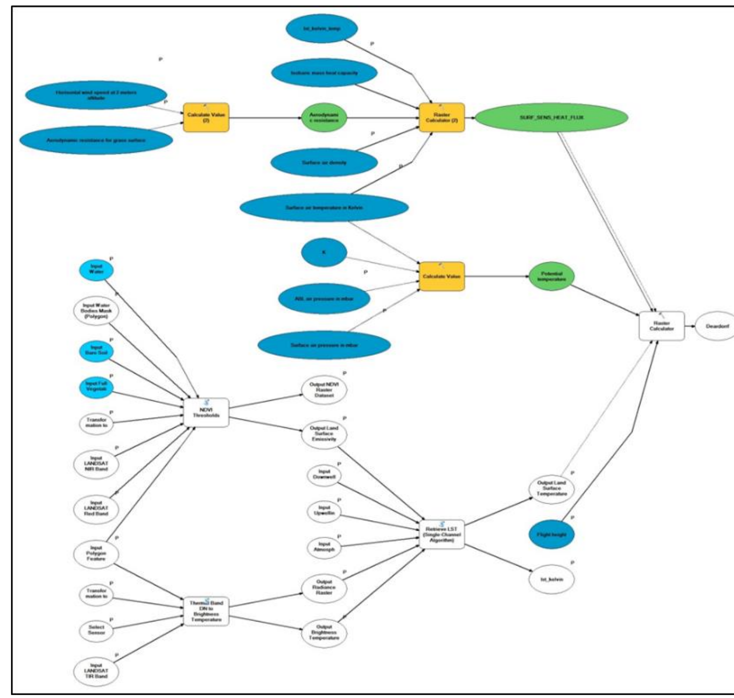


# Thermal updraft interface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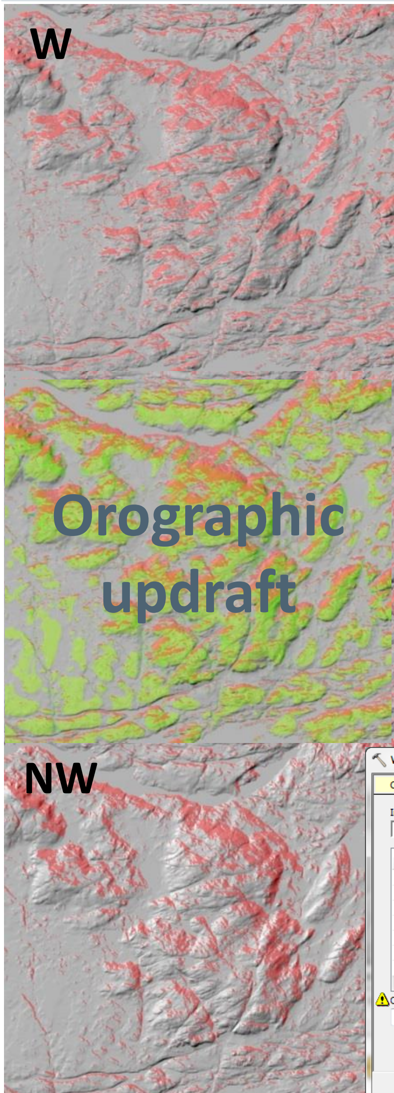
# 3. Integration: Avian site risk

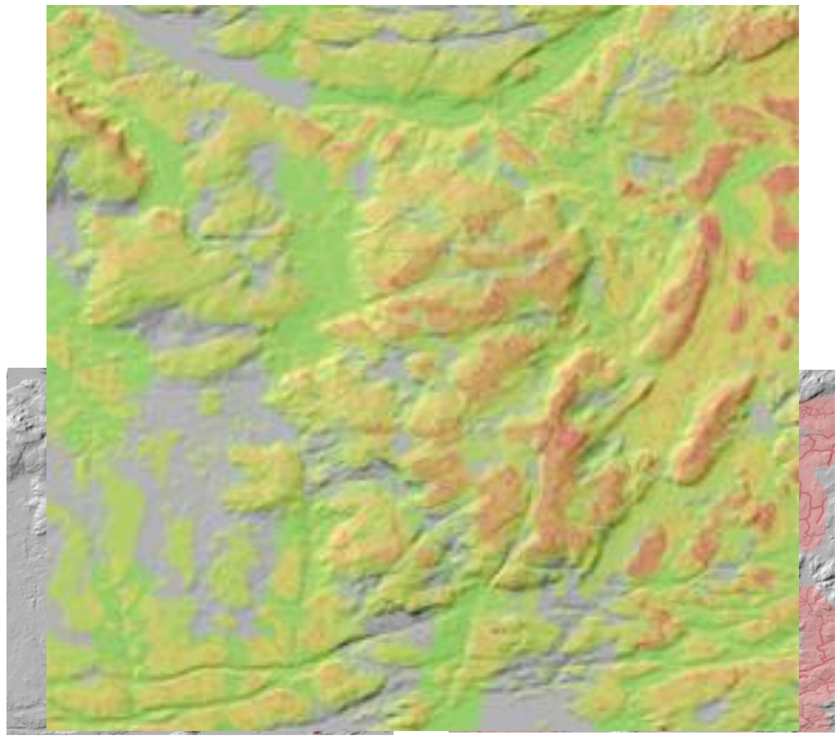
$$MIS_c = \sum_{i=1}^{n} w_i * (f_{ci} * m_i)$$

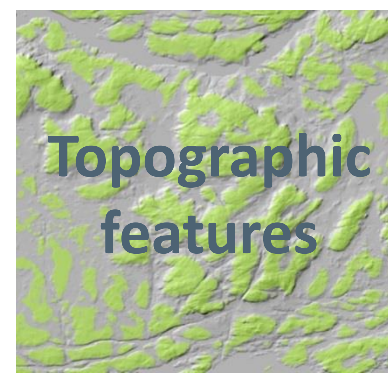
[Pocewicz et al. 2013]

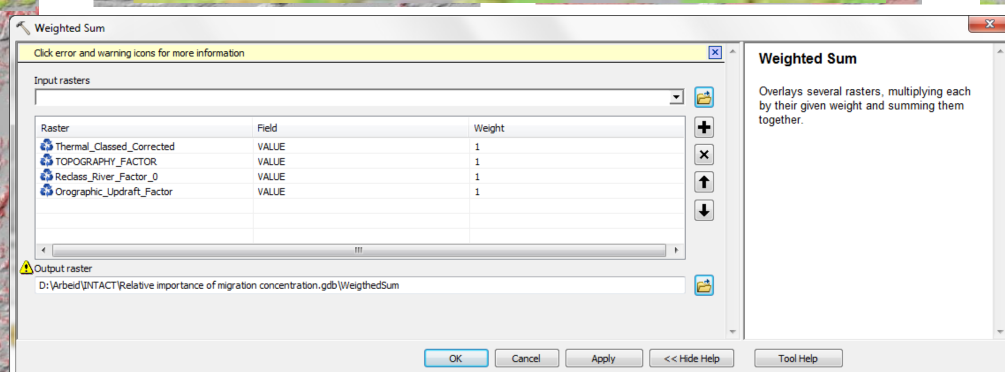
| Factor/Modificator | Value and description |
|---|---|
| Orographic updrafts (Factor)<br>- Areas in prevailing wind direction (e.g. West)<br>- Areas in prevailing wind direction +/- 45 degrees (e.g. NW and SW)<br>- All other areas | 1: High importance<br>0.5: Medium importance<br>0: No importance |
| Thermal updraft (Factor)<br>- Areas with thermal updraft velocity >= 0.7 m/s<br>- Areas with thermal updraft velocity < 0.7 m/s | 1: High importance<br>0: No importance |
| Stream distance decay function (Factor)<br>- Distance decay value >= 0.5<br>- Distance decay value > 0 & < 0.5<br>- Distance decay value = 0 | 1: High importance<br>0.5 Medium importance<br>0: No importance |
| Topography (Factor)<br>- Elevated topography (Ridges/Mesas)<br>- All other terrain (plains, valleys, fjords etc.) | 1: High importance<br>0: No importance |
| Topographical/Hydrological orientation (Modificator)<br>- Northness index = 2 (North-South)<br>- Northness index = 1 (East-West) | 2: Factor increased<br>1: Factor maintained |

# Integration: Avian site risk



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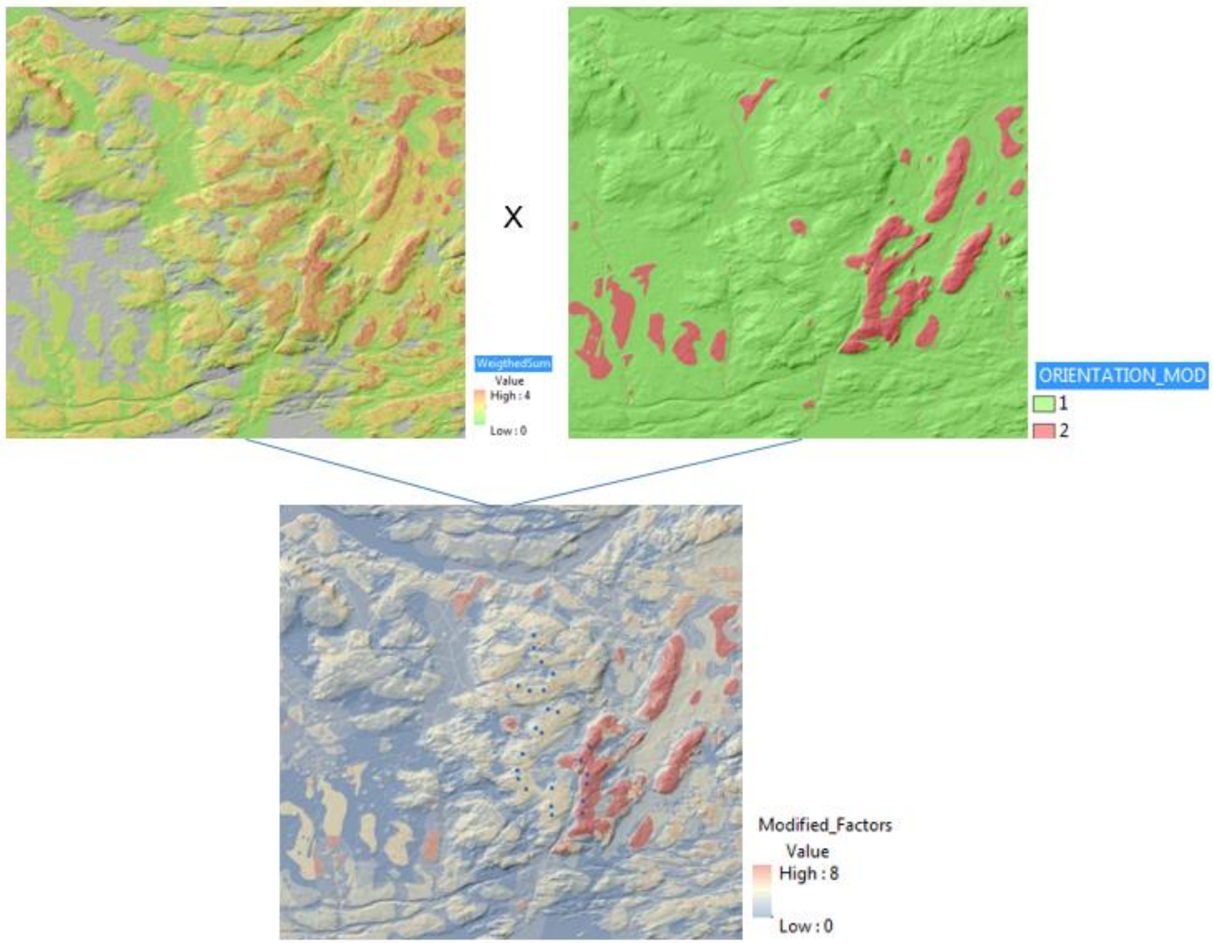
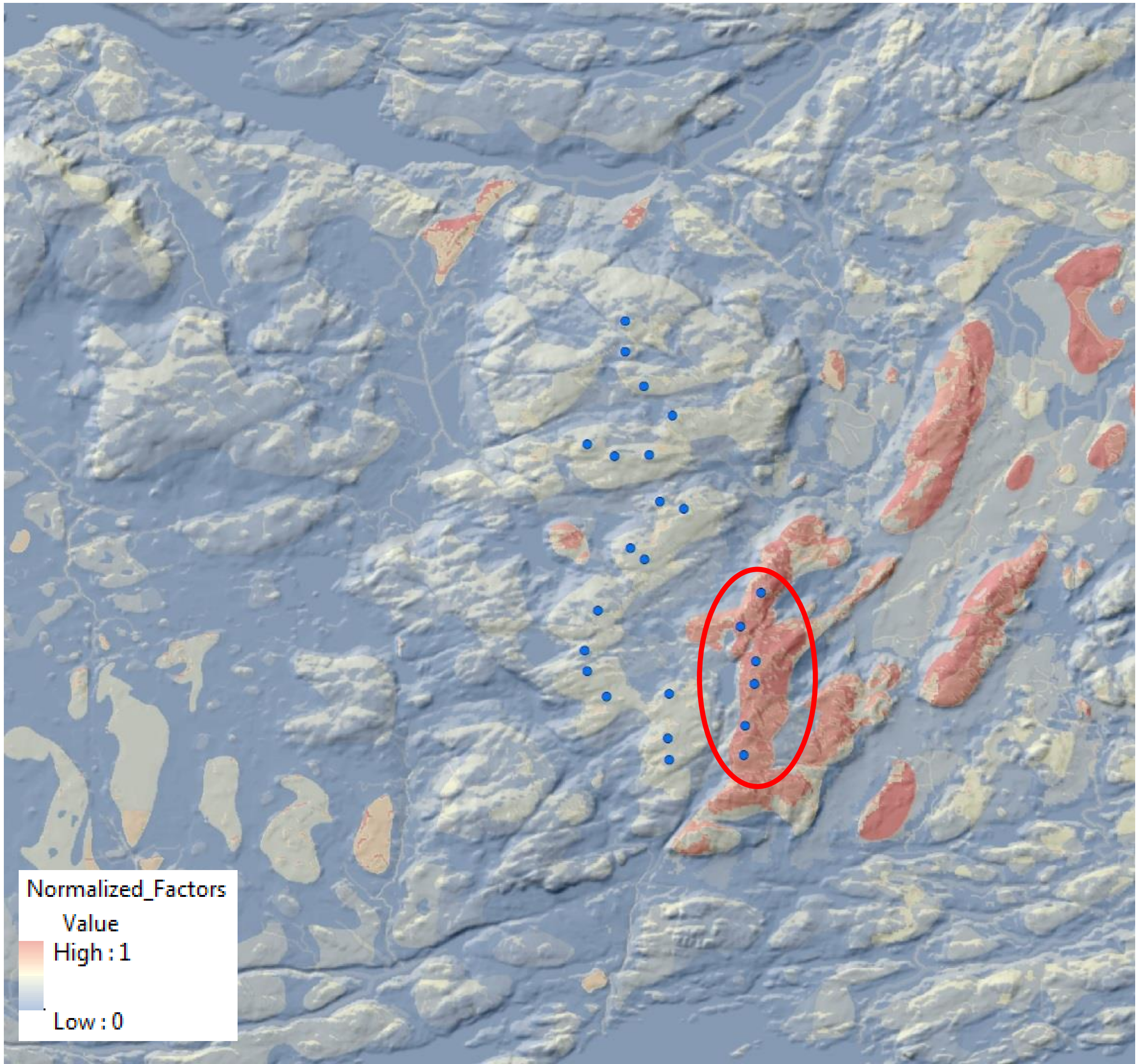
# Integration: Avian site risk

Risk assessment　　Orientation modificator




Modified risk assessment

# Integration: Avian site risk

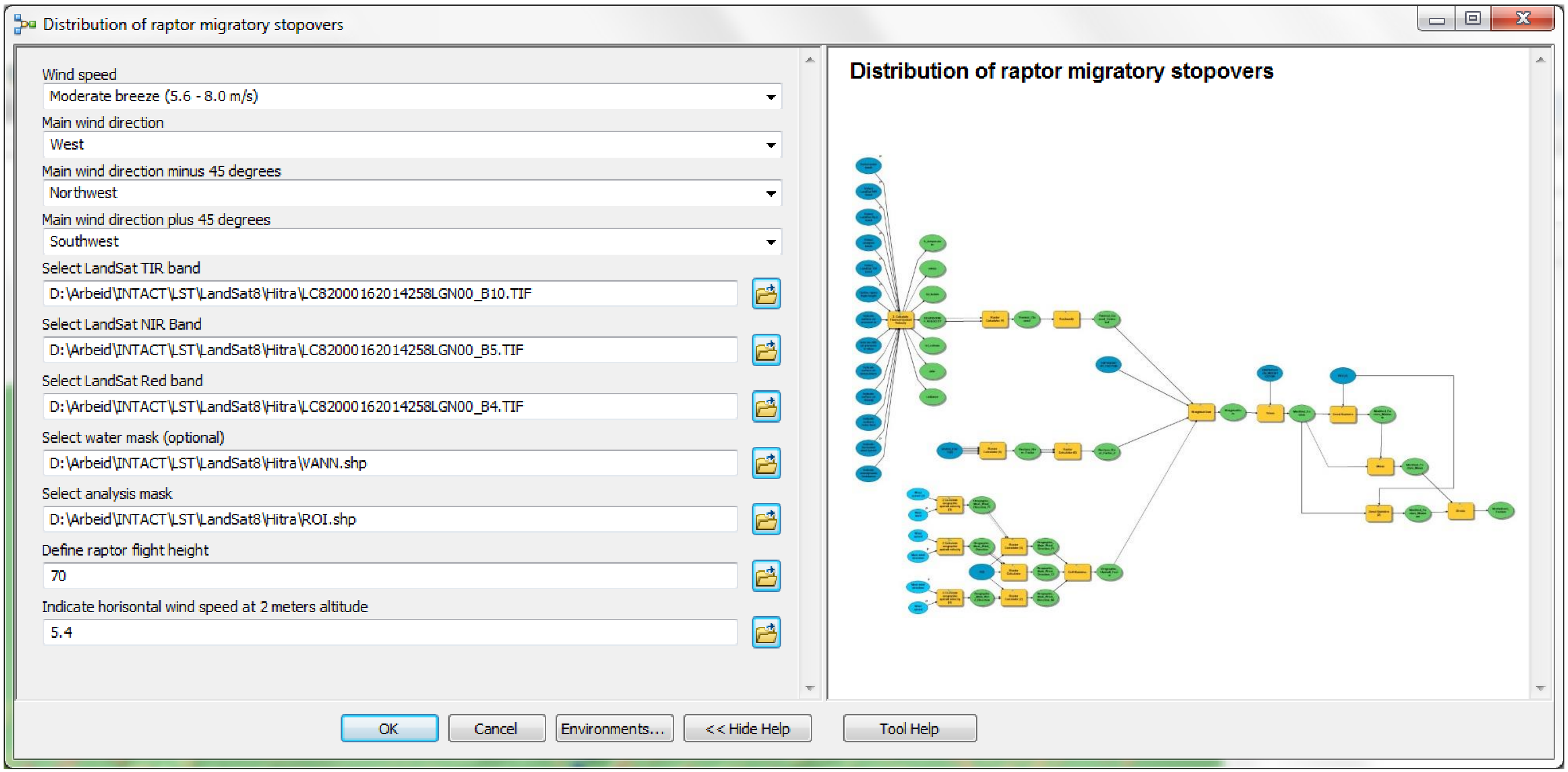



## Normalised risk map

$$\frac{Factor - Factor_{Min}}{Factor_{Max}}$$

Map shows relative risk distribution for raptors in the Hitra wind-power plant

# Avian site risk interface



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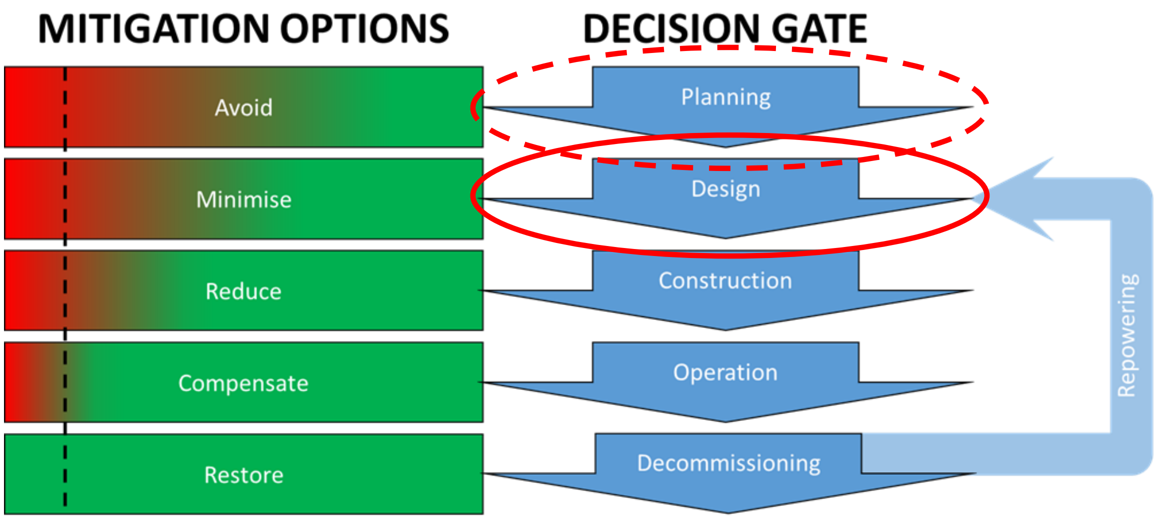
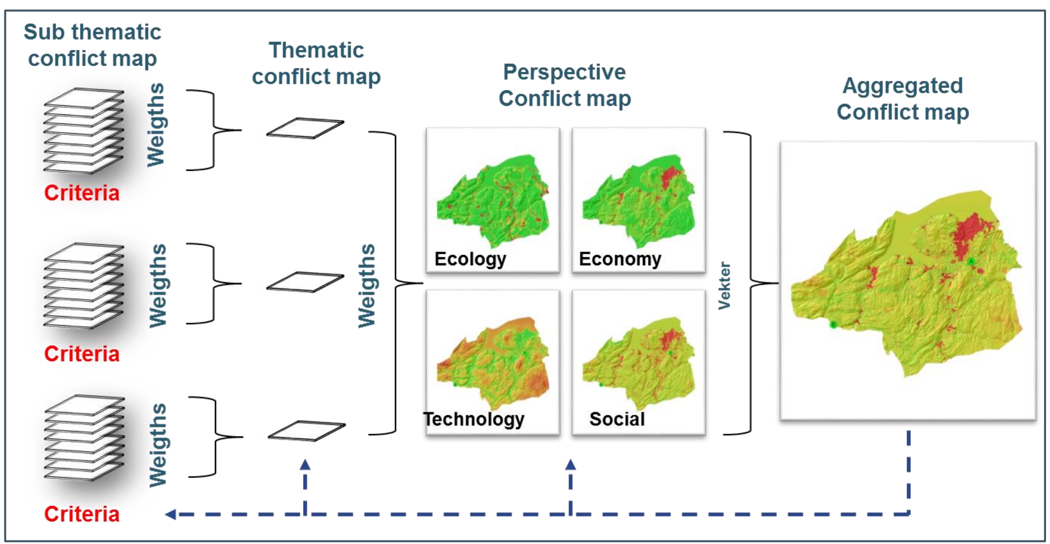
# Implementation




- Pre-construction wind farm design
- Repowering
- Scoping process
  - Consensus-based Siting (ConSite)




# Questions?

Cooperation and expertise for a sustainable future

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