Uncertainty and Potential of Wind Power in Switzerland

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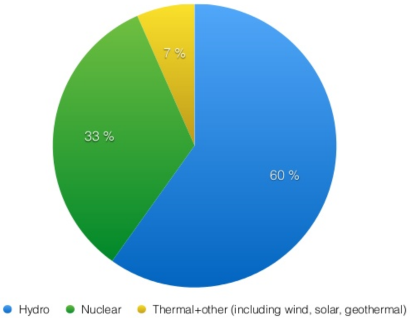
OUTLINE

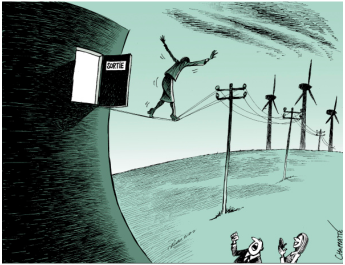
- Intro: ES 2050 & Swiss demand
- What does the Swiss wind resource look like?
- Potential assessment with COSMO-1
- high-resolution modeling of wind in complex terrain

Introduction - ES2050

Switzerland electricity mix - 2015



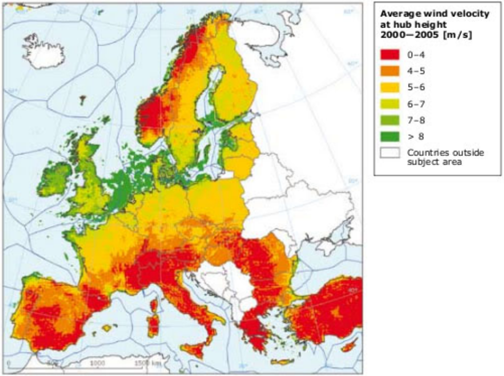
Source: Swiss Energy Authority



70 NRP

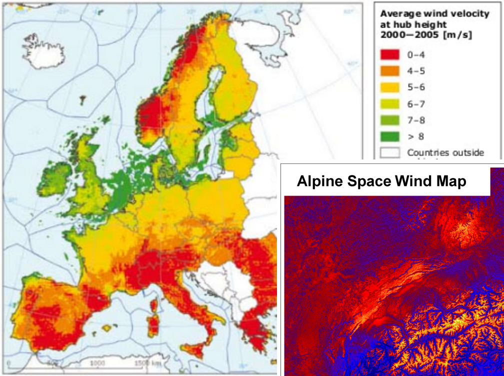
Energy Turnaround
National Research Programme

Alpine Wind Potential



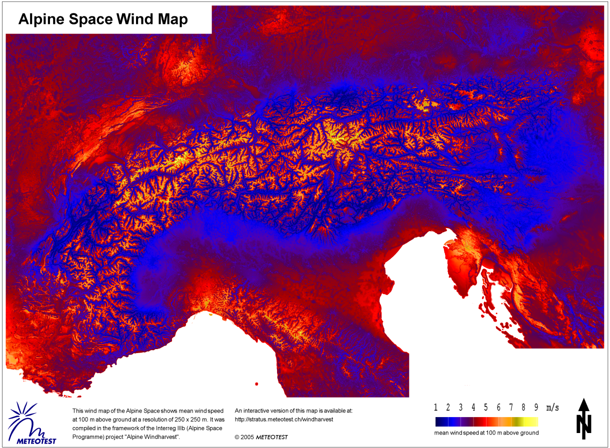
EEA 2009

ALPINE WIND POTENTIAL



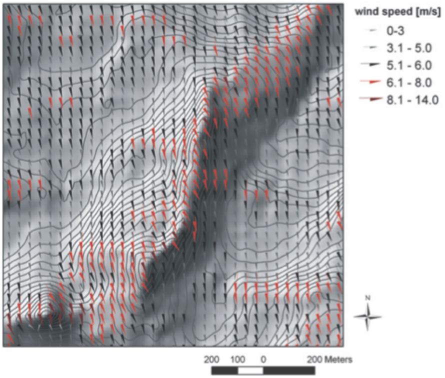
EEA 2009

Schaffner and Kunz, 2005



POTENTIAL IN COMPLEX TERRAIN

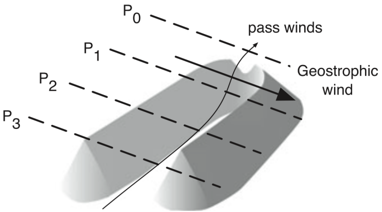
Gaudergrat, Davos



(Mott & Lehning 2010)

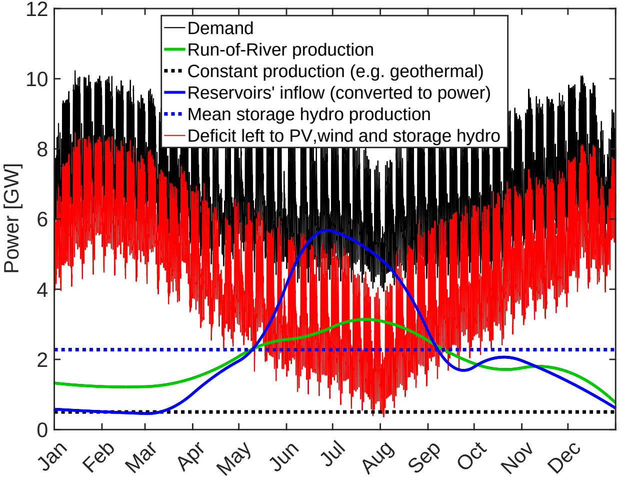
’Gap winds and orographic channels could outperform offshore wind’

(Draxl & Mayr 2011)



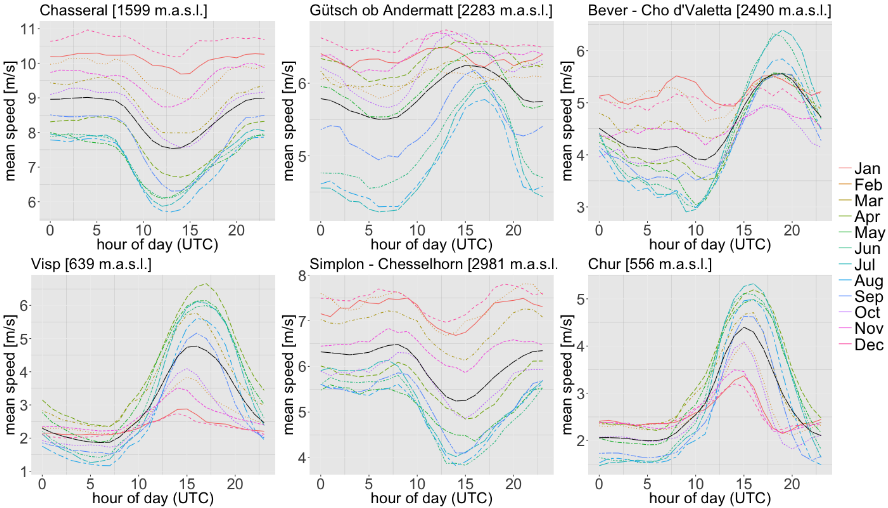
Clifton et al. 2014

SEASONAL PATTERNS

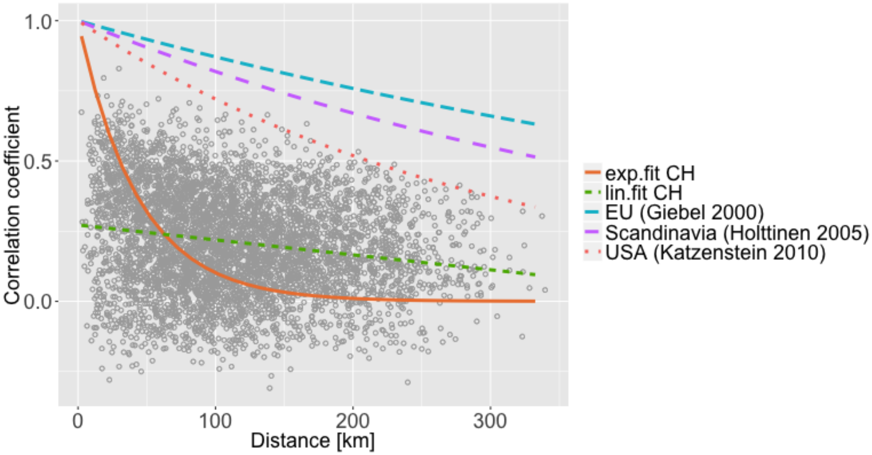


Dujardin et al 2017

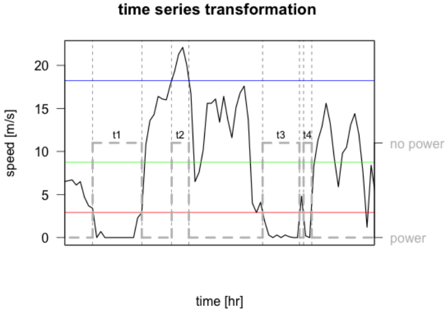
Diurnal and seasonal patterns differ greatly



The Benefits of Complex Terrain

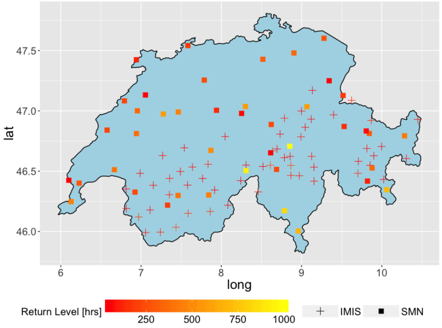


Risk of Sustained Low-wind Conditions

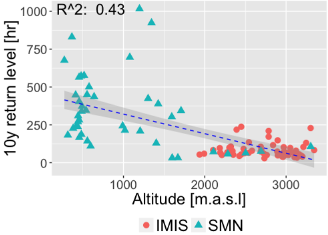


1. Create a metric for the lenght of no-power intervals

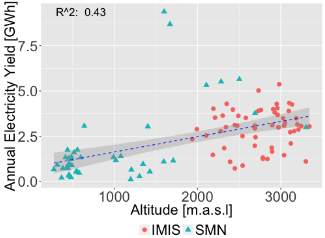
2. Extreme value theory to calculate 10 year return levels:



With increasing elevation...



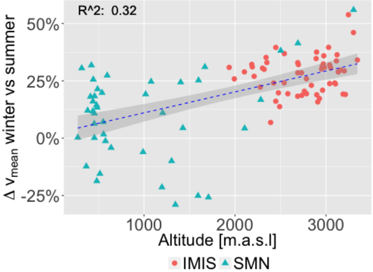
...shorter no-power periods



...more power, despite lower air density

...higher winter mean speeds

(=more power in winter)

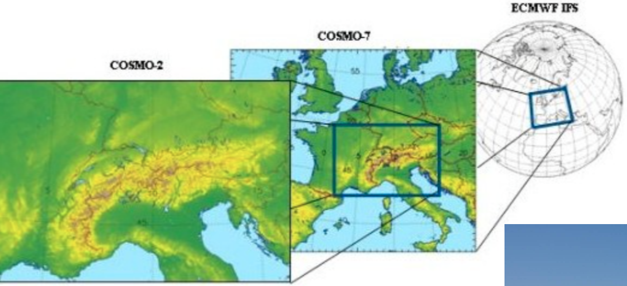


- wind power at elevation can bring stabilising benefits

Wind characteristics in CH

- ...differ greatly from those in flat areas
  - Low correlation
  - Distinct influence of topography on diurnal and seasonal wind pattern
    $\rightarrow$ can help to mitigate winter gap
- With increased elevation:
  - Lower risk of sustained periods without power production
  - increased power production
  - increased winter production
- Wind power could prove important for the Swiss energy transition

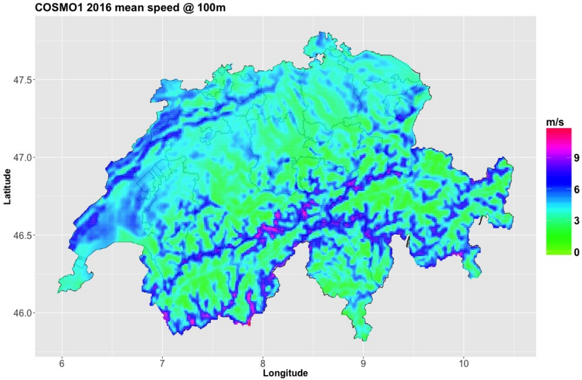
Motivation



- Fully physical
- able to simulate terrain induced flows

Can we use a mesoscale NWP model to assess wind power potential in Switzerland?

COSMO1



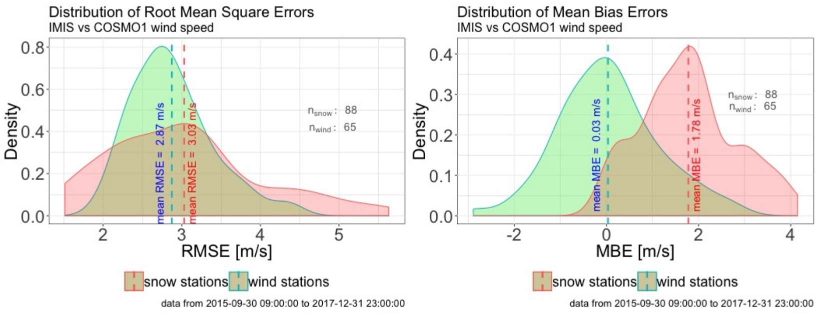
- horizontal resolution of 0.01° (1.11 km N-S & 0.74 to 0.78 km E-S)
- Running from 10/2015 = ca 2 yrs data @ 1h resolution

METHODS

- **Verification**: 10 m COSMO-1 speeds against IMIS stations
- vertical interpolation between model levels to attain **100 m wind speeds**
- simple power model: E82 power curve
  $\rightarrow$ **capacity factors** and **power time series**
- Model of the *renewable* Swiss power system[1]:
  - 53% Hydropower
  - 47% Wind, PV, geothermal (2.2 TWh/a)
  - 2 years of simulation, but presented as annual
- Different wind **siting scenarios**: calculate import etc

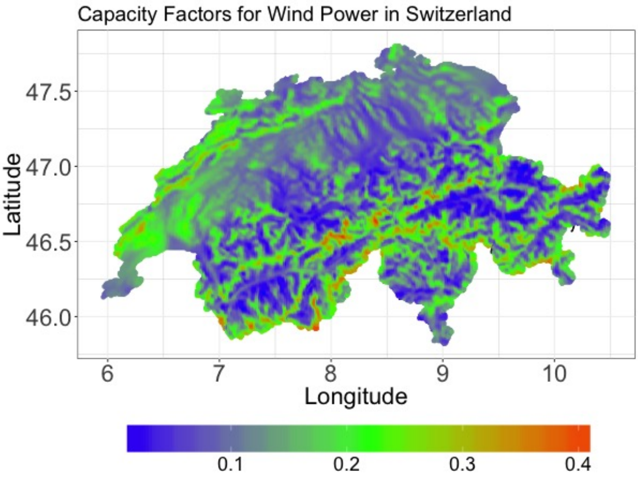
[1] Dujardin 2017, Bartlett 2018

VERIFICATION AGAINST IMIS STATIONS



MAE of annual mean speeds: 0.83 m/s
(vs 1.5 m/s for the Wind Atlas)

CAPACITY FACTORS



Range: 0.01 to 0.42

Includes availability factor of 96% [Williams, 2014].

Based on the powercurve of Enercon E82 Turbine @ 100 m

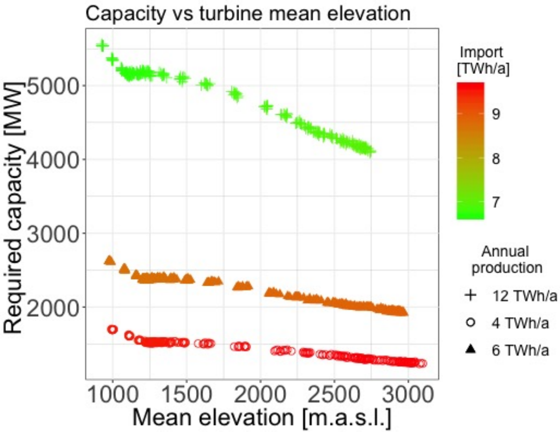
REQUIRED CAPACITY

Rather than calculating wind power potential, what would it take to realize a certain wind power production target?

Method:

- production target (4, 6, or 12 TWh/a)
- populate locations with highest capacity factors until target is reached.
- 6 MW /pixel (3 2MW turbines)
- repeat & vary the maximum allowed altitude for locating turbines

CAPACITY


Capacity vs turbine mean elevation
Required capacity [MW]
5000
4000
3000
2000
1000
1500
2000
2500
3000
Mean elevation [m.a.s.l.]
Import
[TWh/a]
9
8
7
Annual
production
12 TWh/a
4 TWh/a
6 TWh/a

Conclusions

- **Improvement over wind atlas**: average MAE of bi-annual mean speeds: 0.83 m/s vs 1.5 m/s for the Wind Atlas (45%)
- The **required capacity** strongly depends on the **elevation** at which turbines are allowed to be built
- **Konzept** Windenergie Schweiz: 2508 MW for 6 TWh/a
- Theoretical best (unconstrained scenario): 1824 MW for 6 TWh/a

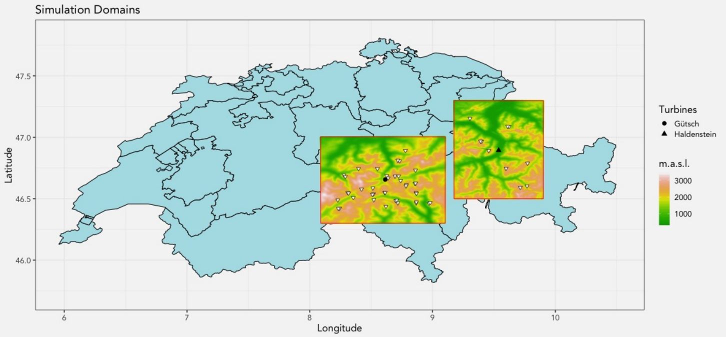
Can we improve on the wind speed assessments of the COSMO model with higher resolution simulations?

Does increased resolution lead to higher wind resource assessment due to better terrain representation?

Weather Research & Forecasting

CSCS
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

WRF 4.0



1. Gütsch (Andermatt)
   - 77 by 78 km
   - 900 kW Enercon E44 @ 55m hub-height
   - 2340 m.a.s.l.
   - very complex terrain

2. Haldenstein (Chur)
   - 55 km (e-w) by 89 km (n-s)
   - 3 MW Vestas V112 @ 119 m hub-height
   - 540 m.a.s.l.
   - complex terrain

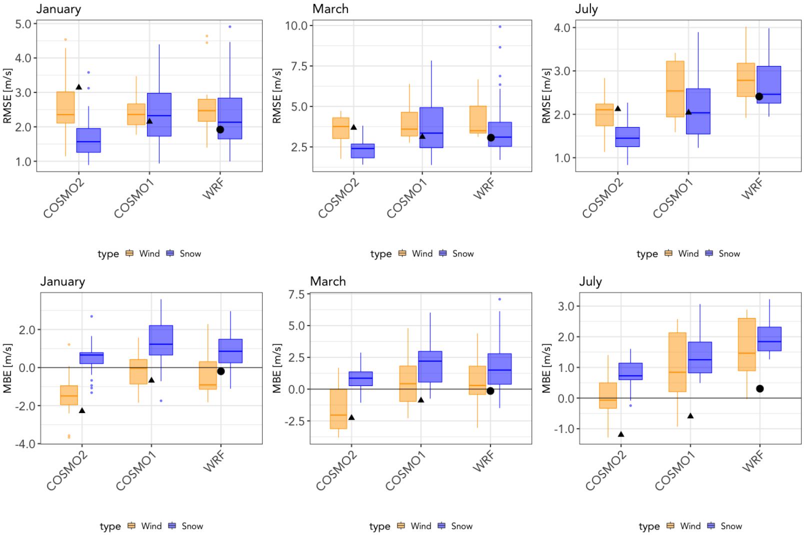
PARAMETERIZATION

Wealth of parameterization options:
Balance performance with computational time

- PBL: YSU with topowind
- 450 m horizontal resolution
- vertical resolution: 10 m to 1200 m, 80 levels (50mb top)
- terrain smoothed to max 35°
- no micro-physics or cumulus parameterization
- small time step (0.2 - 0.3 sec)

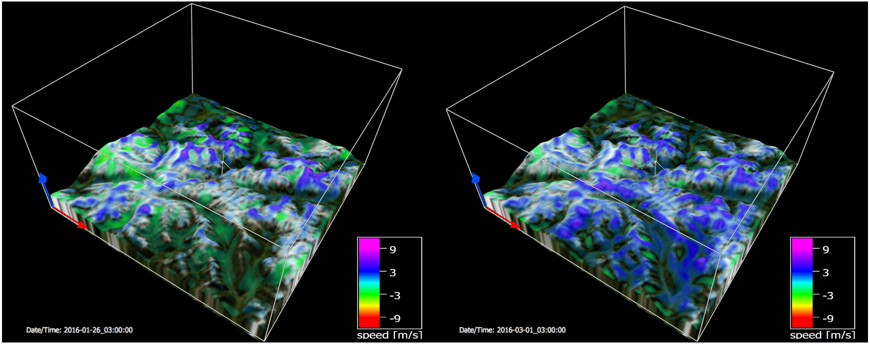
- Boundary conditions: COSMO-2 (2.2 km)

GÜTSCH: VALIDATION



WRF vs COSMO-2

Gütsch January Gütsch March



Difference in mean speeds WRF - COSMO-2

HIGH-RES MODELING

- increased model resolution shows higher wind speeds
  - highly terrain dependent → Allow for identification of 'hot spots'
  - not similar under all weather patterns
- **Potential** in very complex terrain will be **underrepresented** if terrain is not accurately simulated.
- Need for a well-informed discussion: Incorporate high-resolution modeling into resource assessment for the ES2050

Summary & Conclusions

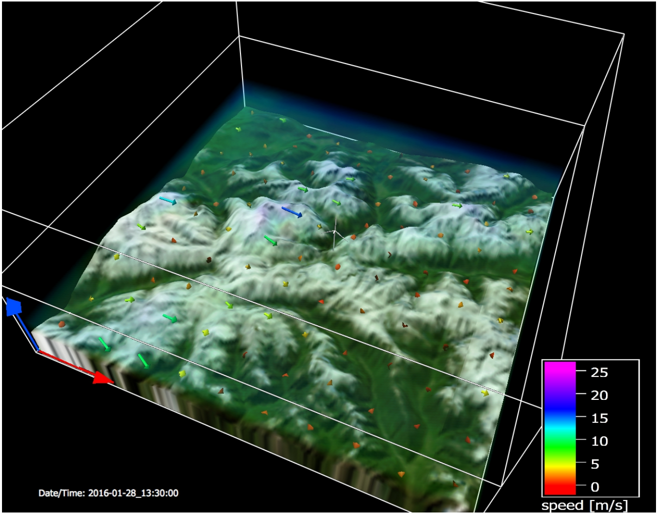
- **Complex terrain** of the Alps provides promising wind conditions: With increasing **elevation**:
  - higher power production (/ fewer turbines)
  - shorter no-power periods
  - many locations with favourable seasonal profiles
- COSMO-1 is able to produce **better** wind resource estimates for complex terrain than wind atlas
- capacity factors up to 0.42
- Using wind power at high altitudes requires **fewer turbines**
- higher model resolutions $\rightarrow$ terrain better resolved $\rightarrow$ higher wind resource

High altitude wind power could provide a very important contribution to ES 2050

Outlook

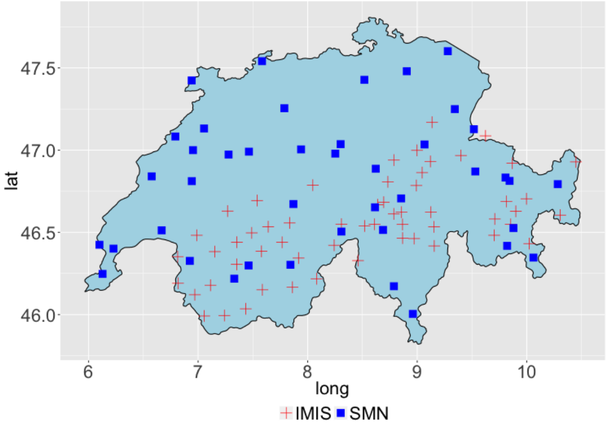
Wind Resource Assessment (@CRYOS)

- Towards resolutions that capture terrain features (˜100 m):
- Combine multi-year (COSMO) with shorter high-res (WRF) simulations
  - clustering weather types based on COSMO-2 / stations
  - simulate weather types at high resolutions w. WRF
- more mast data for hub-height validation (and vertical wind profile)


25
20
15
10
5
0
speed [m/s]
Date/Time: 2016-01-28_13:30:00

ANNEXES

Measurement Data



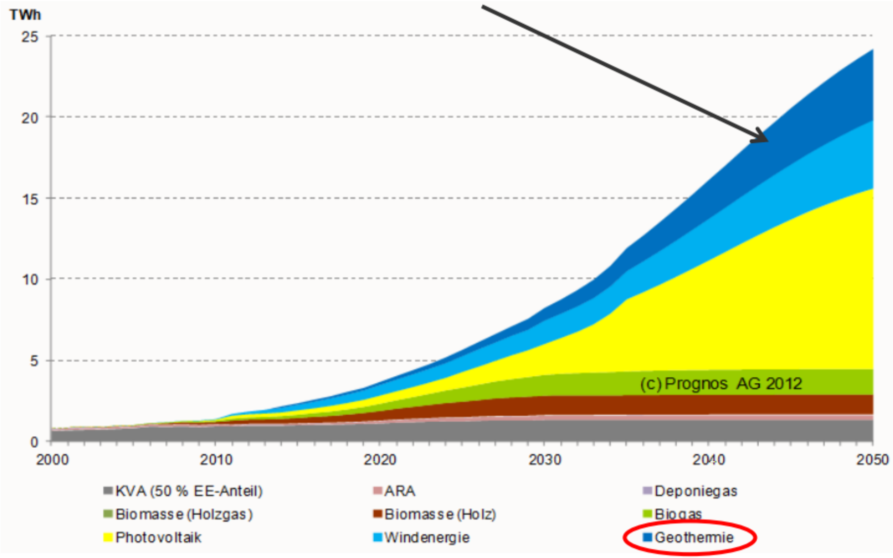
110 stations, 2 networks, hourly resolution

Public Opposition

LIMITATIONS

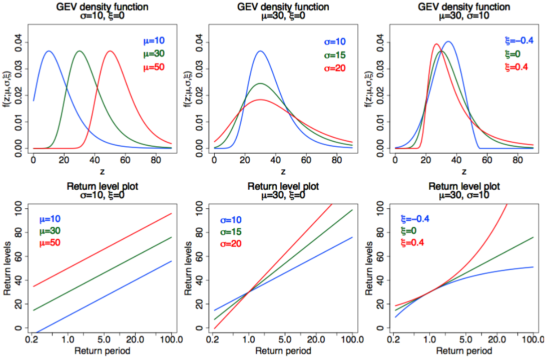
- one turbine /power curve
- logistical constraints (cost, installation)
- technical constraints
  - shear
  - turbulence
  - icing
- regulatory problems (State, Canton, Municipality)
- land-use conflicts (tourism, agriculture)

ENERGY STRATEGY 2050



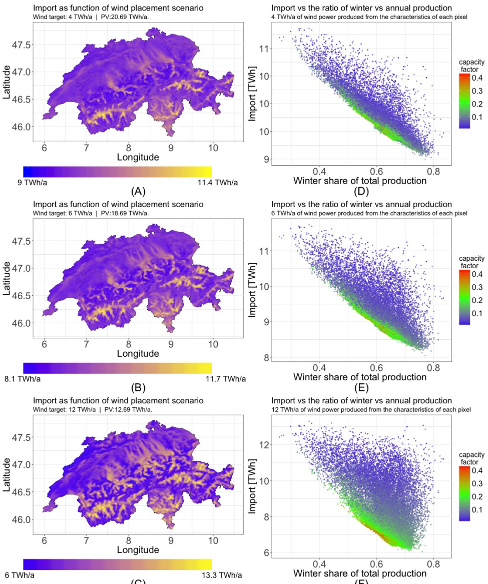
Generalised Extreme Value Distribution

$$G(z;\mu;\sigma;\xi) = exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\}$$

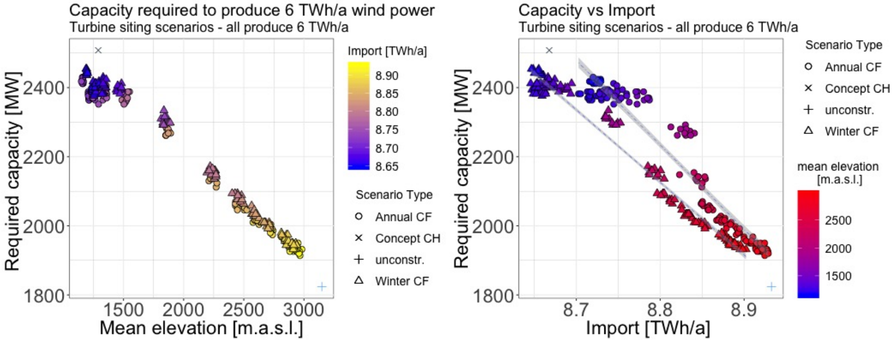


(Blanchet & Lehning 2010)

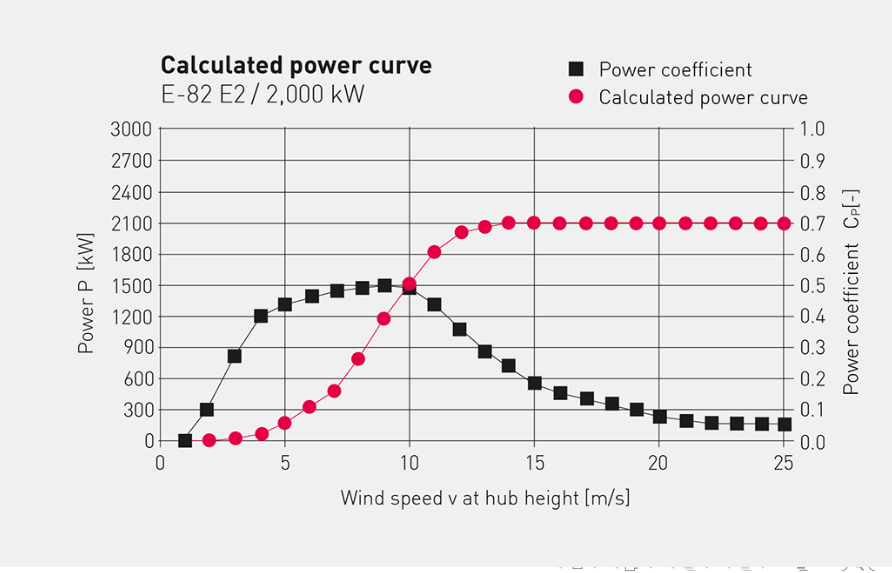
Capacity


Import as function of wind placement scenario
Wind target: 4 TWh/a | PV:20.69 TWh/a.
Latitude
Longitude
9 TWh/a
11.4 TWh/a
(A)
Import vs the ratio of winter vs annual production
4 TWh/a of wind power produced from the characteristics of each pixel
Import [TWh]
Winter share of total production
capacity factor
(D)
Import as function of wind placement scenario
Wind target: 6 TWh/a | PV:18.69 TWh/a.
Latitude
Longitude
8.1 TWh/a
11.7 TWh/a
(B)
Import vs the ratio of winter vs annual production
6 TWh/a of wind power produced from the characteristics of each pixel
Import [TWh]
Winter share of total production
capacity factor
(E)
Import as function of wind placement scenario
Wind target: 12 TWh/a | PV:12.69 TWh/a.
Latitude
Longitude
6 TWh/a
13.3 TWh/a
(C)
Import vs the ratio of winter vs annual production
12 TWh/a of wind power produced from the characteristics of each pixel
Import [TWh]
Winter share of total production
capacity factor
(F)

Capacity to produce 6 TWh/a

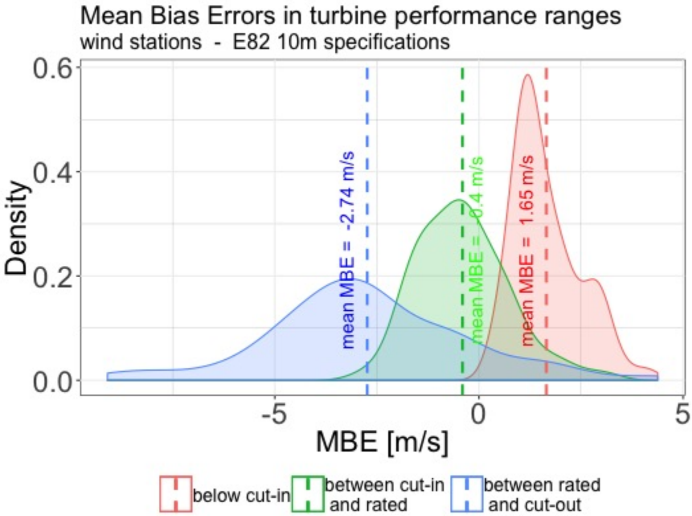


Enercon E-82 power curve

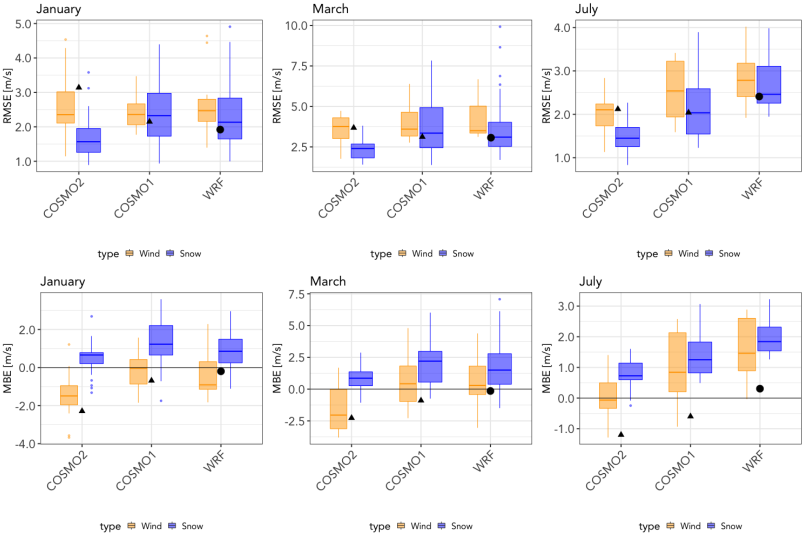


SENSITIVY TO WIND SPEED ERRORS

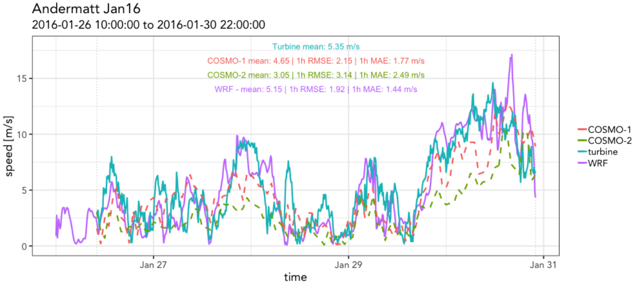
How do errors in wind speed inpact the simulated power?

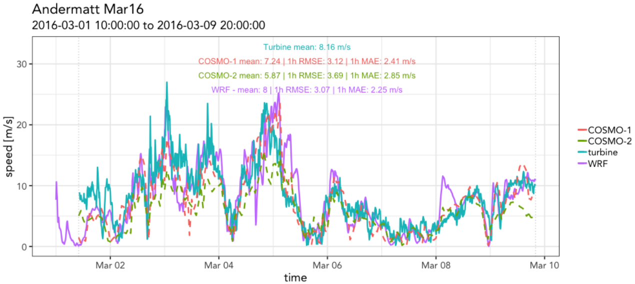


Gütsch: Validation

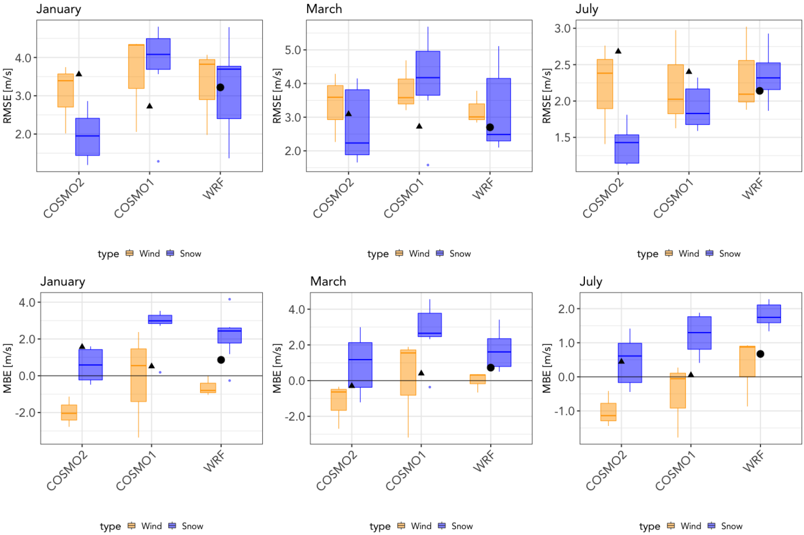


Gütsch Validation (Turbine)

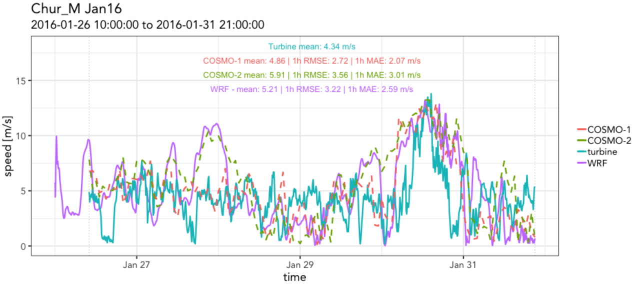


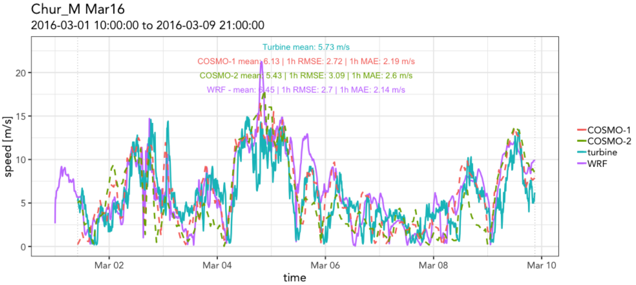


Chur Validation

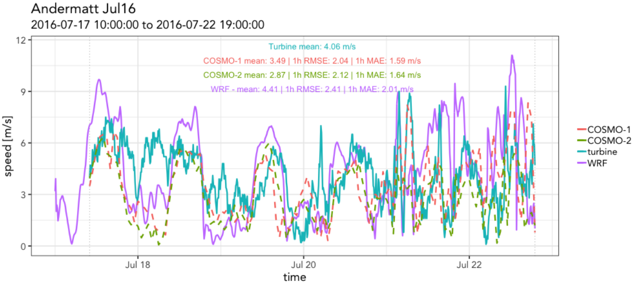


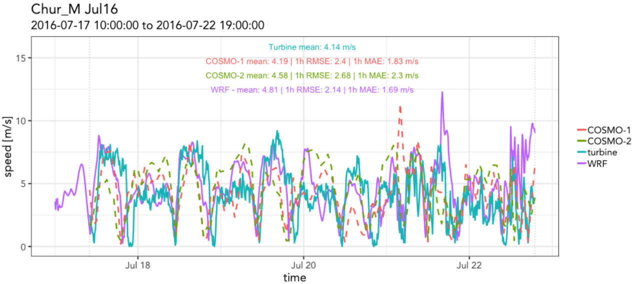
CHUR VALIDATION (TURBINE)





THERMAL FLOWS





WRF 4.0 Settings

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ra_sw_physics               = 1, 1, 0, 0,
slope_rad                   = 1, 1, 0, 0,
topo_shading                = 1, 1, 0, 0,
radt                        = 5, 5, 5, 5,
sf_sfclay_physics           = 1, 1, 1, 2,
sf_surface_physics          = 0, 0, 0, 0,
bl_pbl_physics              = 1, 0, 0, 0,
bldt                        = 0, 0, 0, 0,
cu_physics                  = 0, 0, 0, 0,
cudt                        = 0, 0, 0, 0,
isfflx                      = 0,
ifsnow                      = 1,
icloud                      = 1,
surface_input_source        = 1,
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num_land_cat                = 24,
sf_urban_physics            = 0, 0, 0, 0,
topo_wind                   = 1,
/
```

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&dynamics
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diff_opt                    = 2,
km_opt                      = 2,
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zdamp                       = 5000., 5000.,
dampcoef                    = 0.2, 0.2, 0.2
w_damping                   = 1,
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kvdif                       = 0, 0, 0, 0,
non_hydrostatic             = .true., .true
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scalar_adv_opt              = 1, 1, 1, 1,
epssm                       = 1, 1, 5., 5.,
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/
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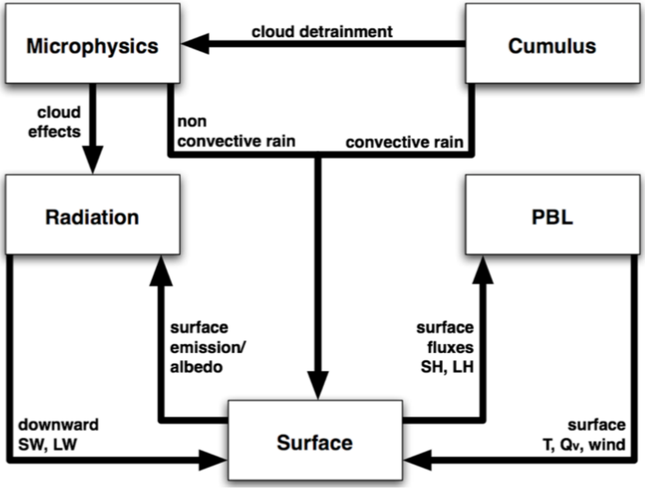
Direct Interactions of Parameterizations



Source: Dudhia - NCAR

WIND PROFILE