Mapping Environmental Factors for Spatial Epidemiology: Experiences and Examples

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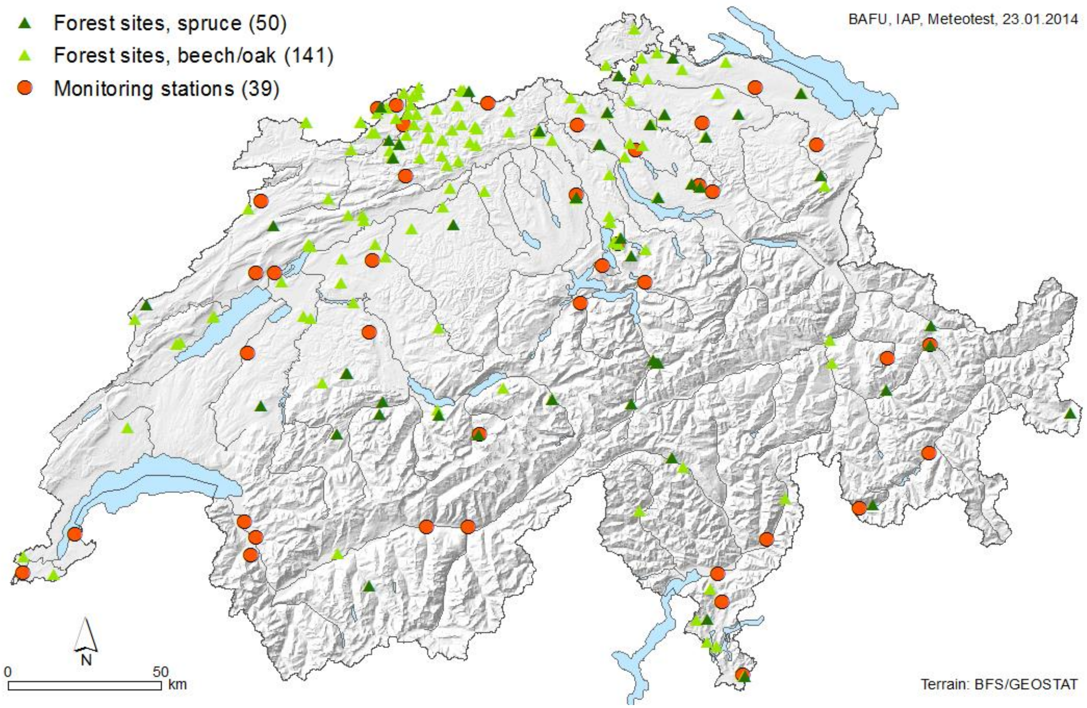
Overview

Spatial epidemiology: we include environmental factors to study geographic correlations.

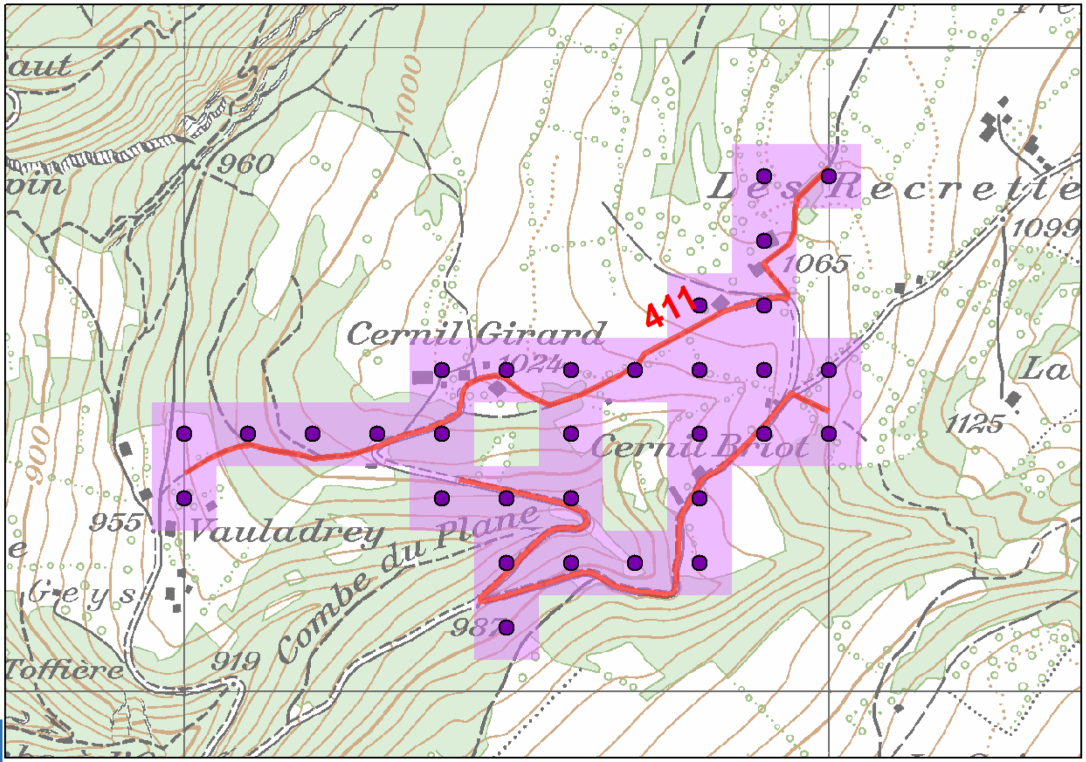
If the explaining/predicting factors (pollutants, climate…) are not measured at the same site as the dependent ecological factors (growth, health…) we need "mapping". I.e. we calculate the environmental factors at the ecological receptor points. Questions arise such as:

- Type of model/interpolation
- Raster vs. sites (points)
- Time vs. space
- Basic parameters
  vs. integrated parameters
- Examples:
  ammonia,
  nitrogen deposition,
  ozone flux



What Is a Site?

- **Point** on the earth: xzy, land-use, surface roughness
- Height above ground of measurements.
  Reference height of modelled concentrations.
- Forest: above/below canopy, throughfall/open field deposition.
- A **line** or **area**: e.g. transects of Swiss Biodiversity-Monitoring (BDM Z7) in 1x1 km cells:
  Plant species observed along the paths (red).
  Deposition was modelled for points nearby the line on a hectar-grid (purple).

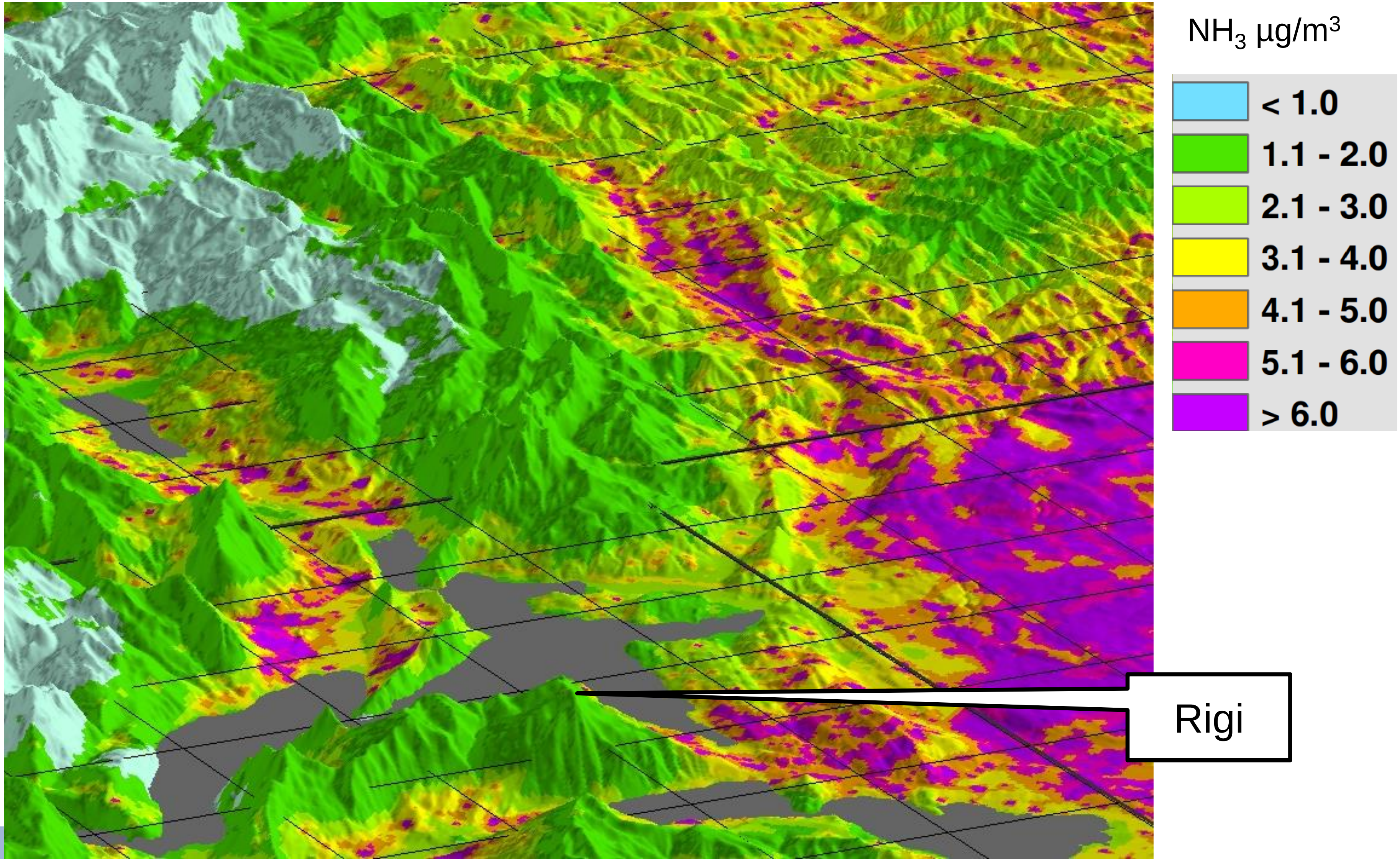


Analytical Atmospheric Models e.g. EMEP Unified

- The differential equations describing atmospheric transport are calculated numerically.
- Advantages: integrated meteorology and pollutants; long-range transport; chemical reactions; soil-interaction; prognostic; high temporal resolution.
- Disadvantages: complex; parametrisation may be difficult; "low" spatial resolution (mountains, local sources).
- In Switzerland:
  - research and case studies at PSI with CAMx (Sebnem Aksoyoglu et al.).
  - model Cosmo 2.2 km at MeteoSwiss, only for meteo (?).

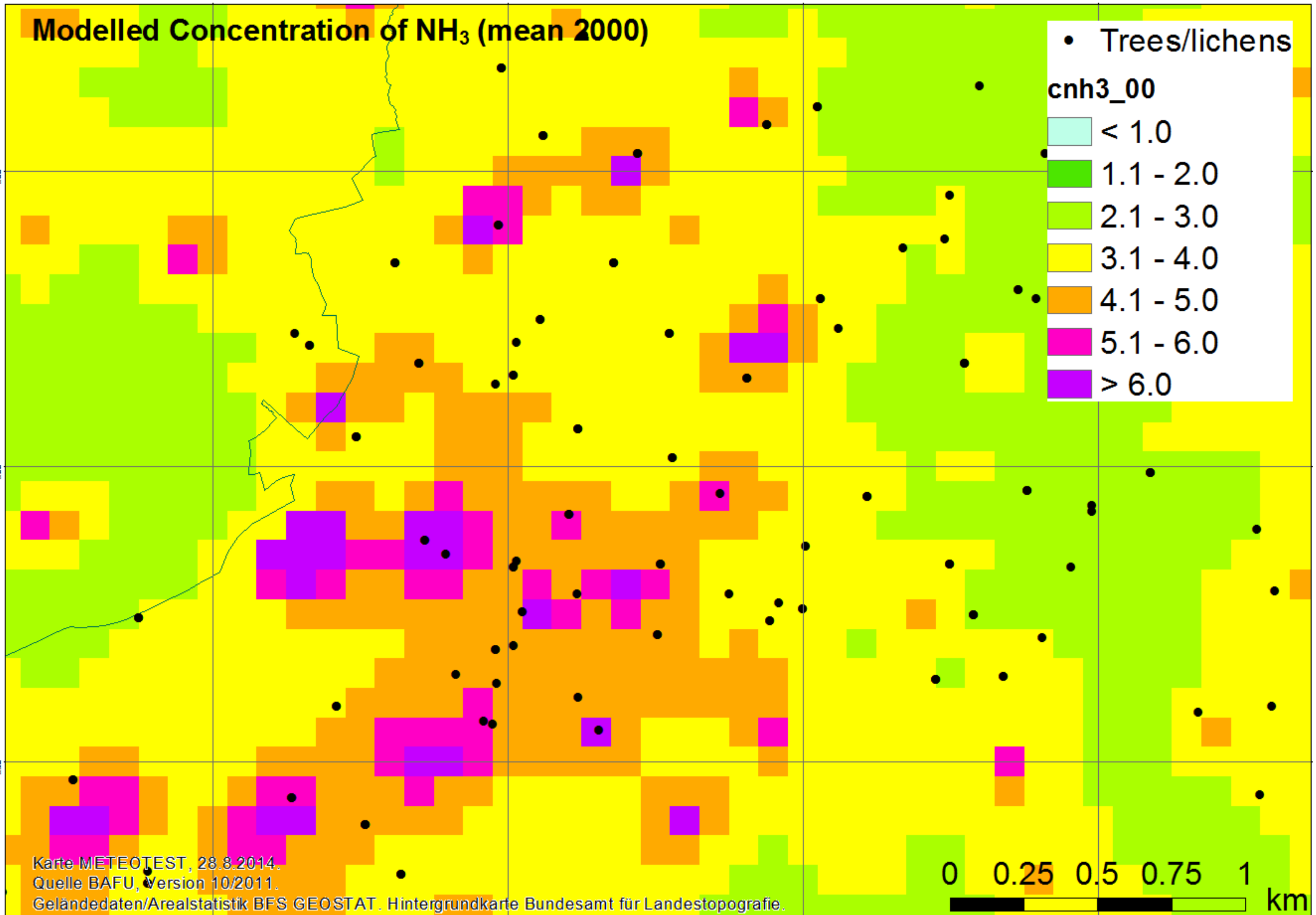
Spatial Resolution of Models (1)

Example: NH_3-concentration calculated at 100x100 m vs. EMEP 5x5 km grid (drawn at constant alt. 1000 m). → local sources!



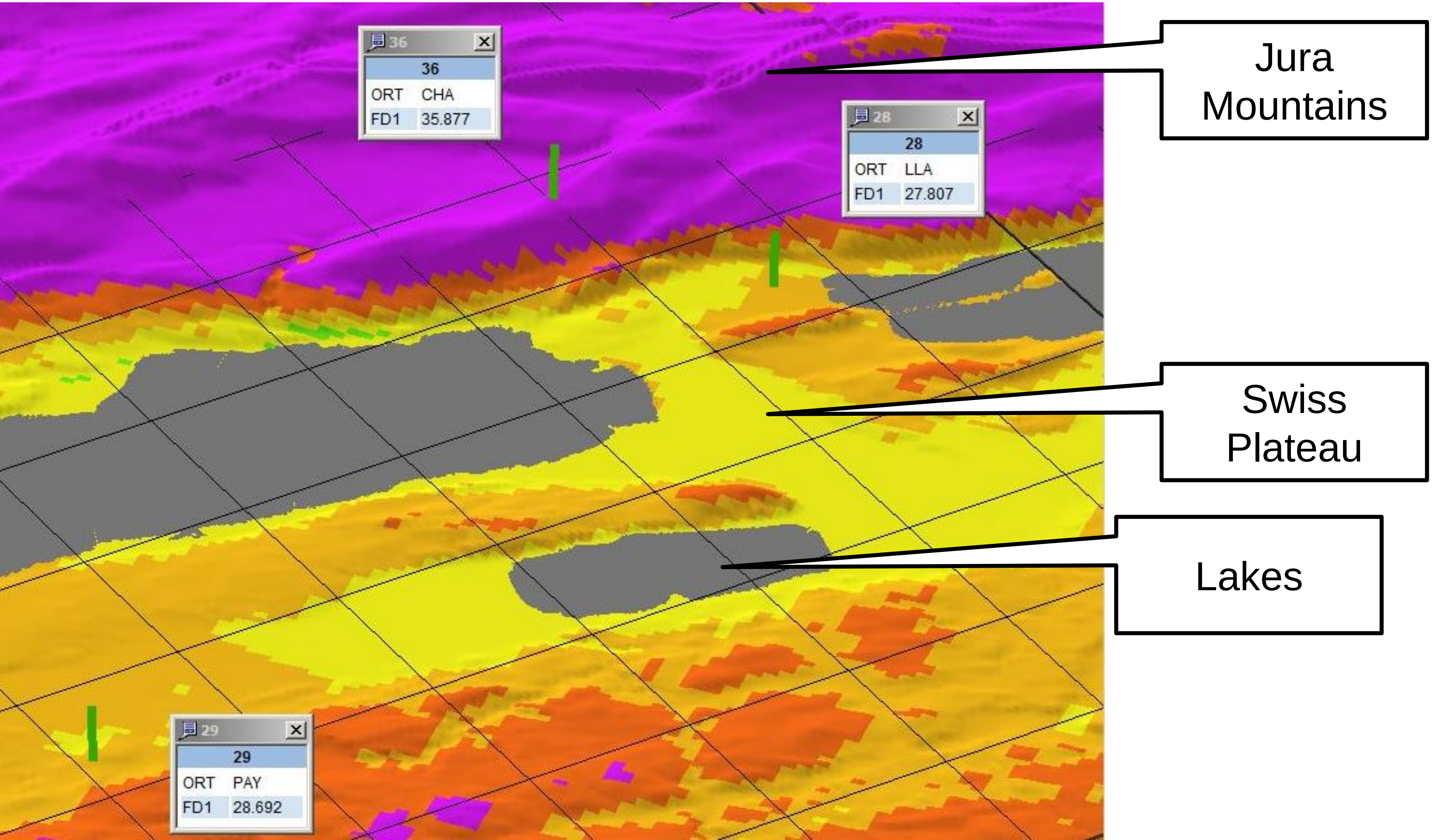
Spatial Resolution of Models (2)

Example: NH_3 concentration (µg/m³) calculated at 100x100 m and locations of trees with recorded epiphytic lichens → local sources/farms!



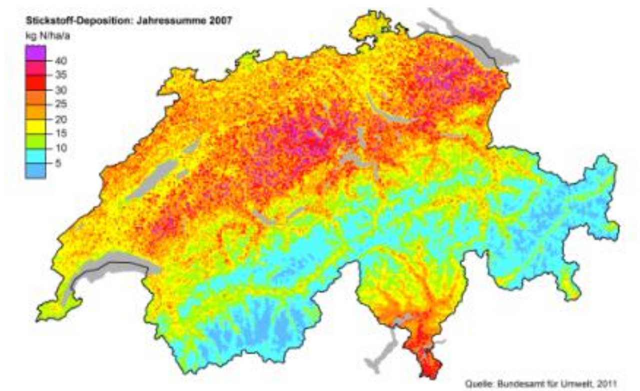
Spatial Resolution of Models (3)

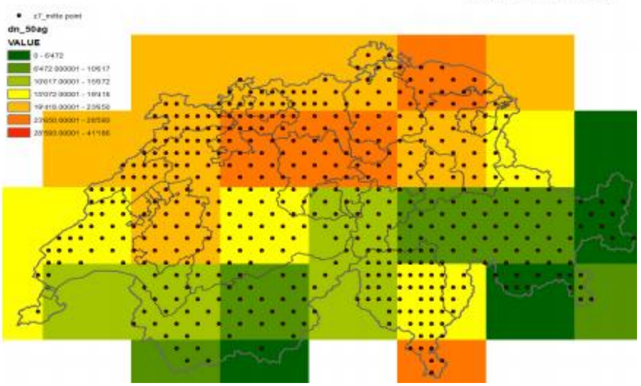
- Example: O3-flux spruce, mapped at 250x250 m, EMEP 5 km grid (drawn at constant alt. 1000 m). → Topography/climate!

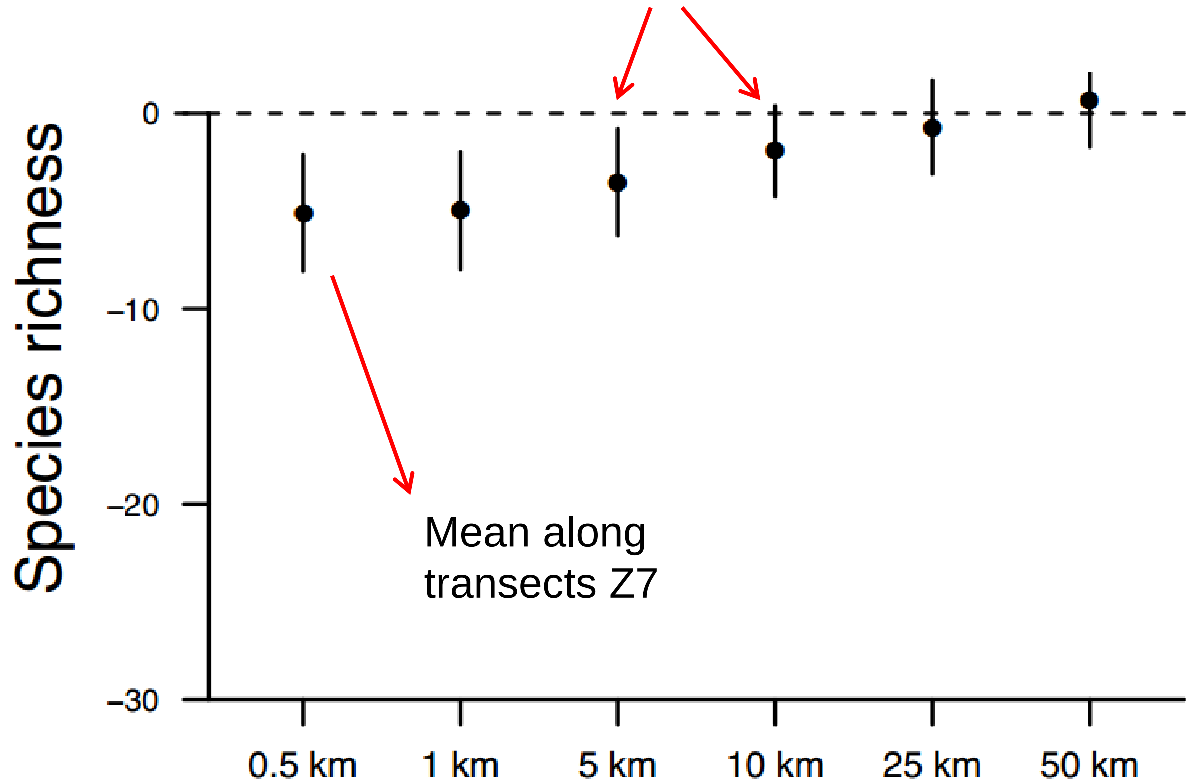


How Much Spatial Resolution?

L. Kohli, T. Roth, B. Rihm, B. Achermann, 2013 (unpubl.): *Scale-dependent effects of nitrogen deposition on plant diversity (at the 1x1 km BDM Z7-sites).* The modelled deposition on the ha-grid was aggregated to grids of 1, 5, 10, 25 and 50 km resolution. Above 5 km, the effect of 20 kg N /ha/yr deposition is no longer significant (example):







Mapping Approaches Aiming at High Spatial Resolution

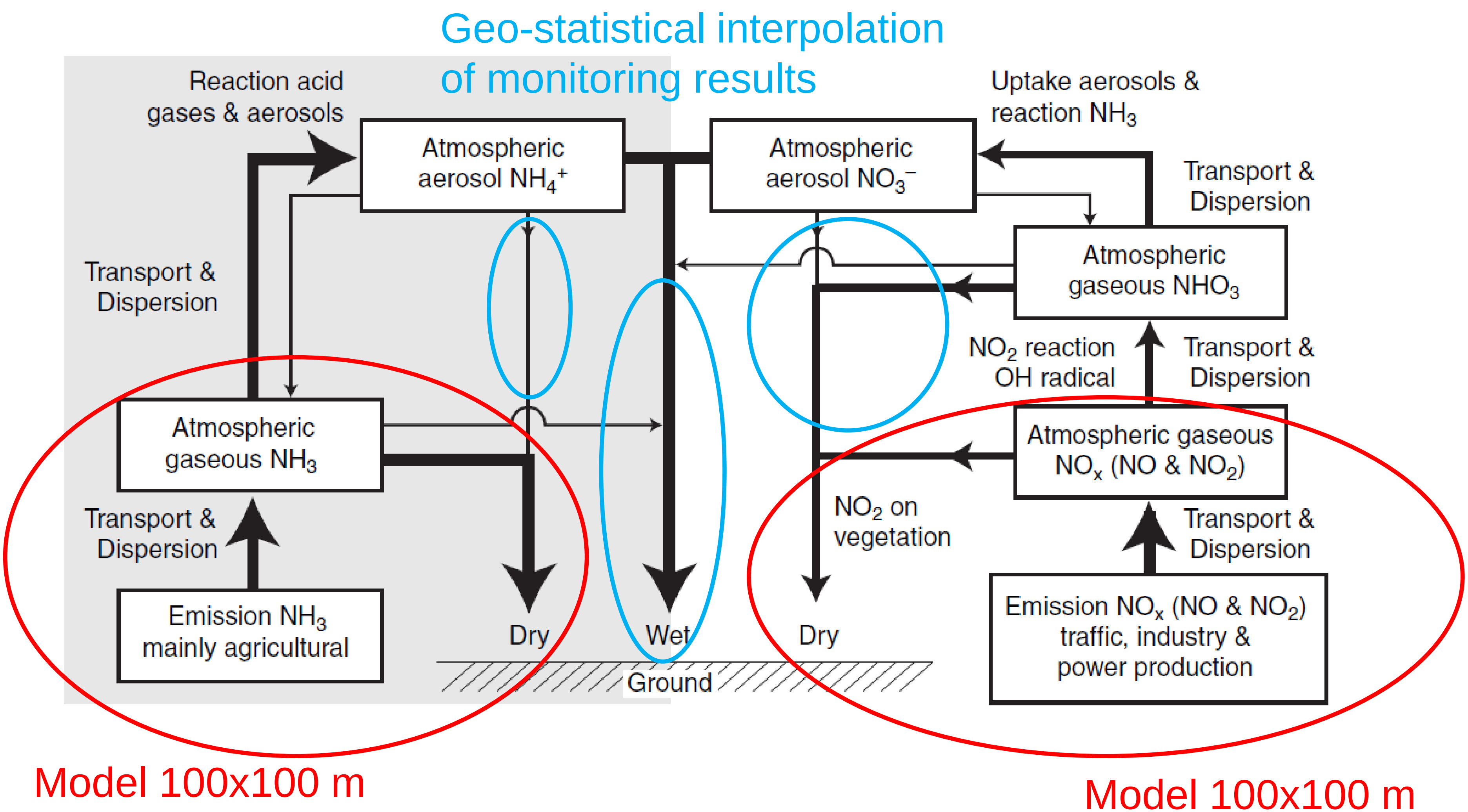
1. Climatic parameters such as temp., prec., radiation:
   3-D inverse distance model (Shepard's gravity interpolation), with vertical scale factors/vertical gradients and local corrections for northern/southern slopes, cities, lakes, depressions...
   http://meteonorm.com/de/downloads/documents (Jan Remund)

2. Primary pollutants closely related to the emission sources:
   emission maps and **statistical dispersion models**:
   NH_3, NO_2, (also SO_2, CH_4, Benzol, PM10 available).
   → quality of the emission map is crucial for modeling local peaks.

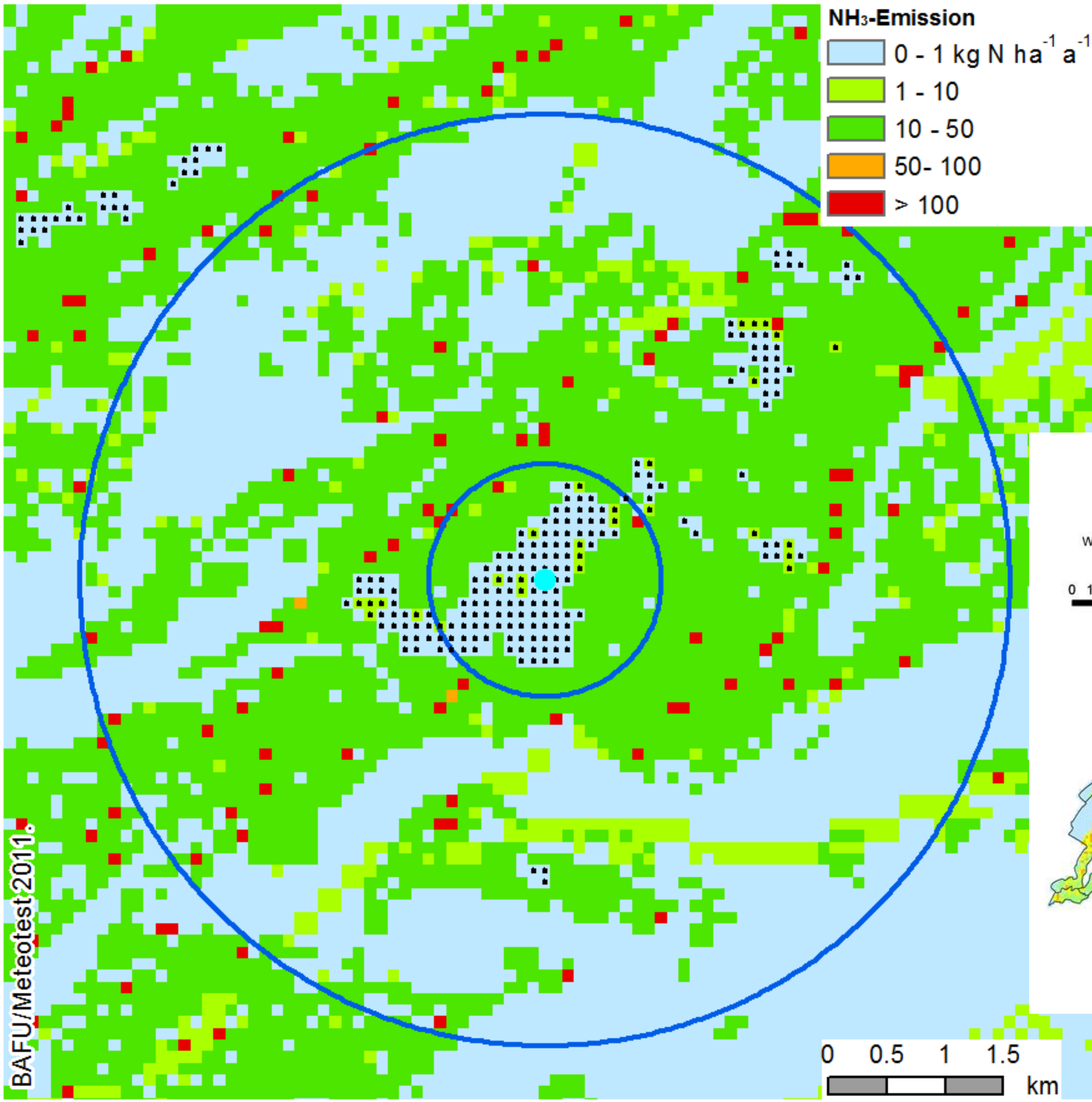
3. O_3 concentration and other integrated parameters (e.g. O_3 flux):
   geo-statistical interpolation, i.e. regression with available maps of explaining parameters.
   → not always feasible, depends on spatial variabilty of the dependent parameter and the quality of the predictor maps. Spatial **stratification** may help.

Modeling Nitrogen Deposition with High Spatial Resolution

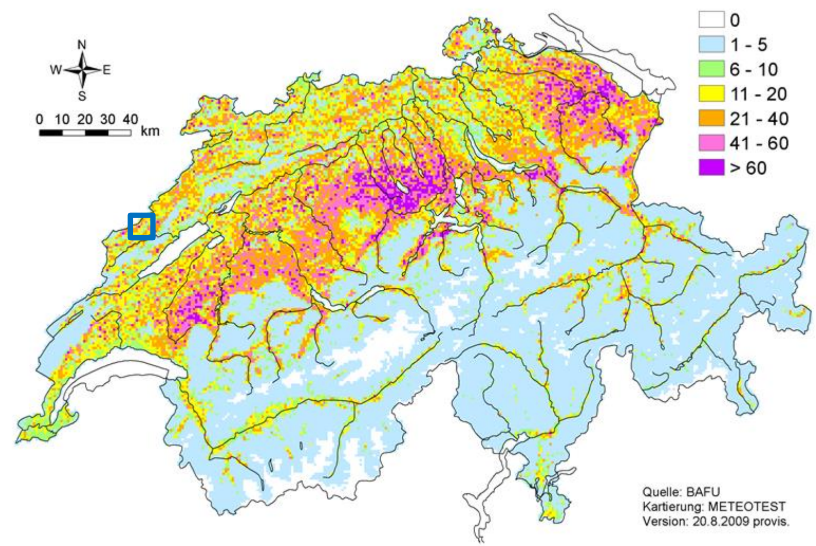
Path ways of reactive N in the atmosphere (Hertel et al. 2011, http://www.nine-esf.org/ENA)



Ammonia Emission Map, Point Sources (Farms) with ha-Resolution



Example in Jura Mountains:
Raised bog (black dots) with farms (red class) and crop/ grassland (green class). Forests are in light blue class.
Circles: 1 and 4 km distance

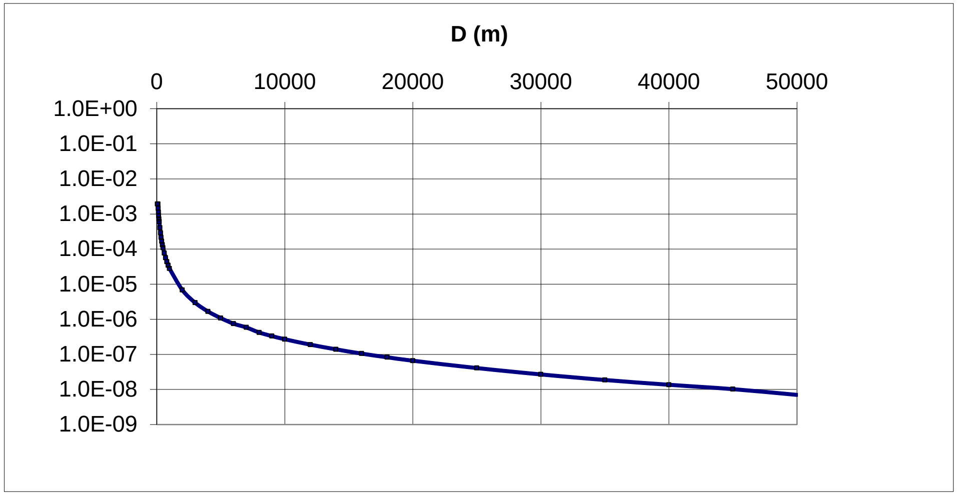


Modeling Ammonia Concentration and Deposition

Methods:

- Dispersion function f(distance), Asman & Jaarsveld (modified)
- Concentration = f(distance) * source_strength
- Deposition = concentration * deposition_velocity
- Ammonia monitoring network with passive samplers (model validation)

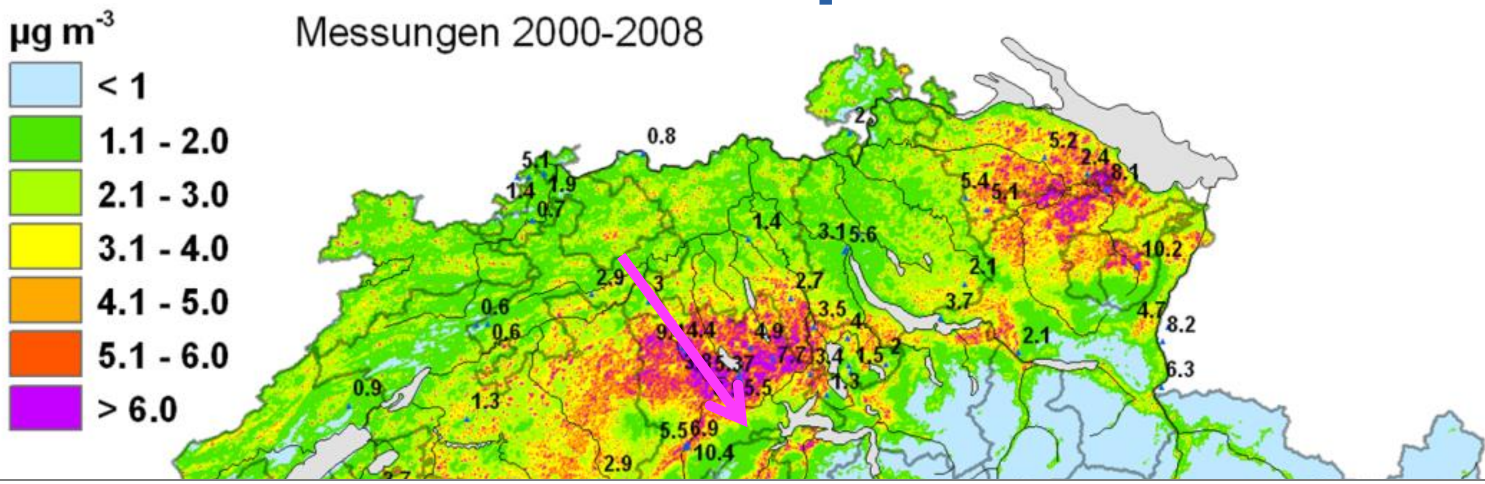
f(distance), distance to source 50m - 50km:

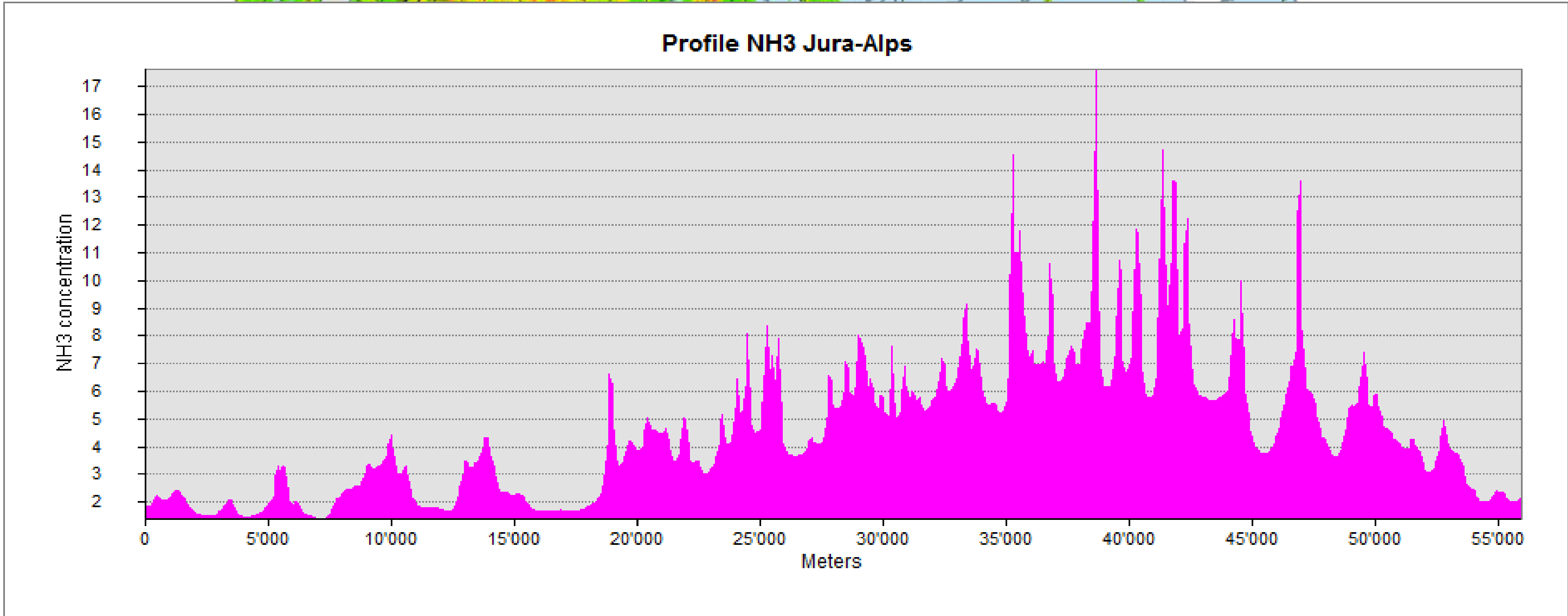


Deposition velocities:

land-use type	mm s^{-1}
coniferous forest	30
deciduous forest	22
agricultural land	12
surface water	20
unproductive vegetation	20
settlement	8
no vegetation	5

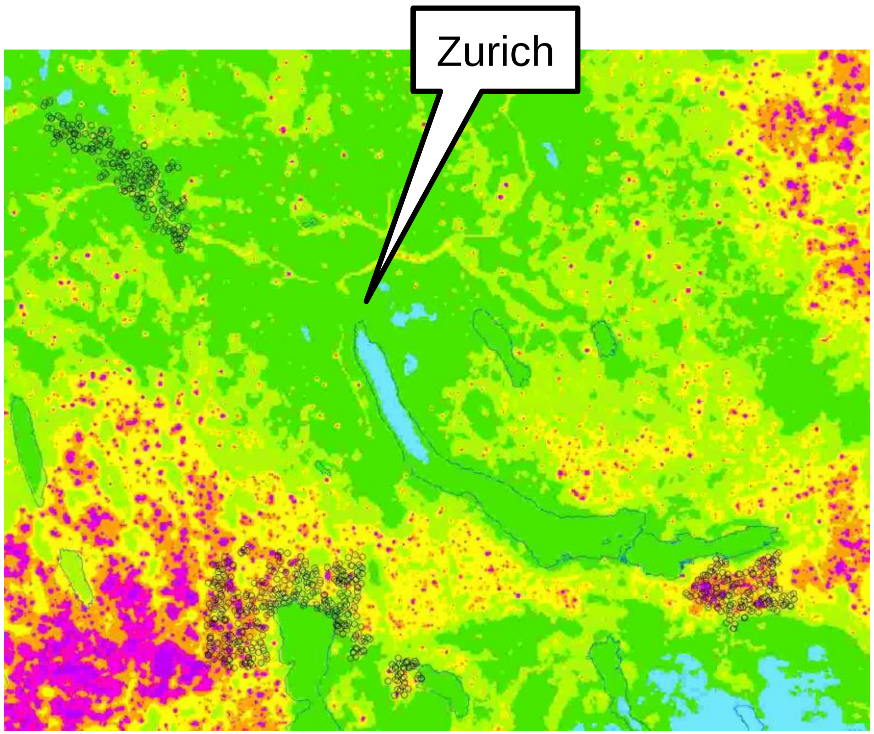
Ammonia Landscape: a Sea Urchin

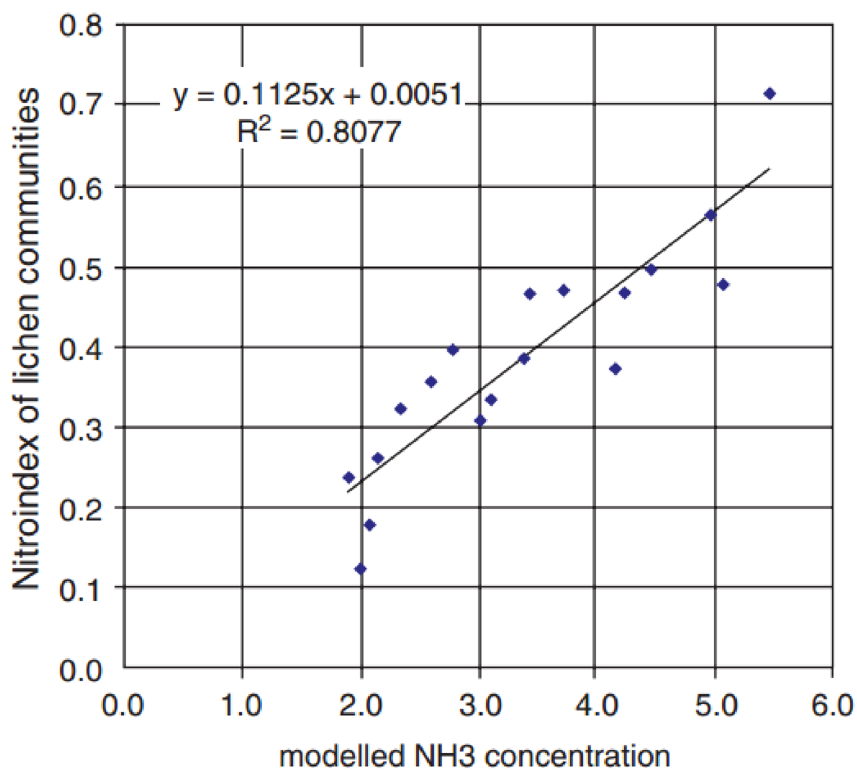




Example: Lichens and Ammonia

Rihm B., Urech M., Peter K., 2009.
Relationship between modelled NH_3 concentration and population of lichens observed on 786 trees (black circles); Nitroindex is calculated from the occurence of seven nitrophilous/anitrophilous species.
The sites (trees) are grouped; mean values per group:

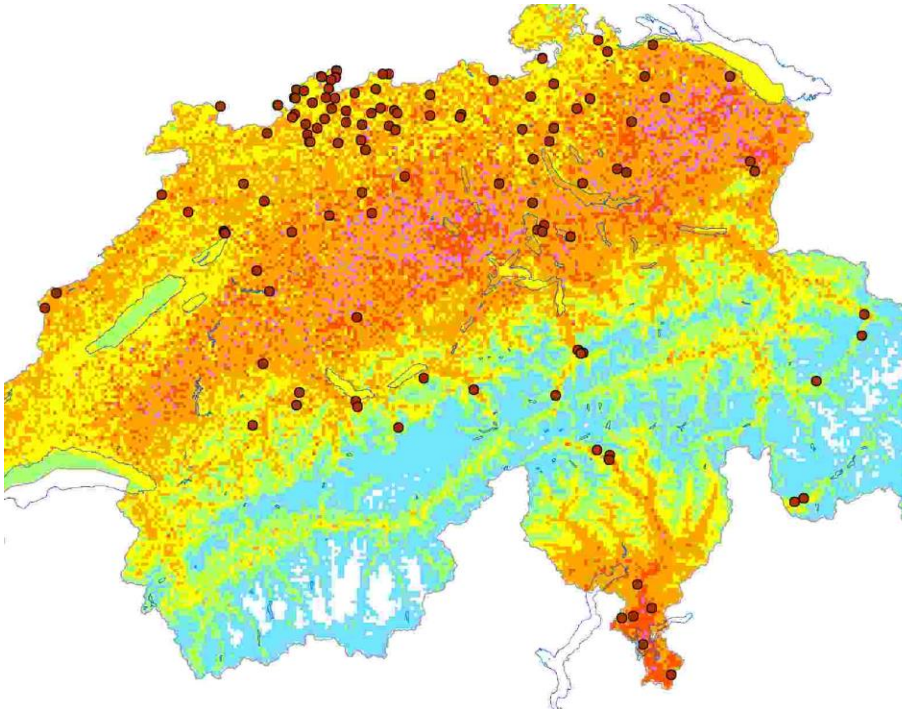


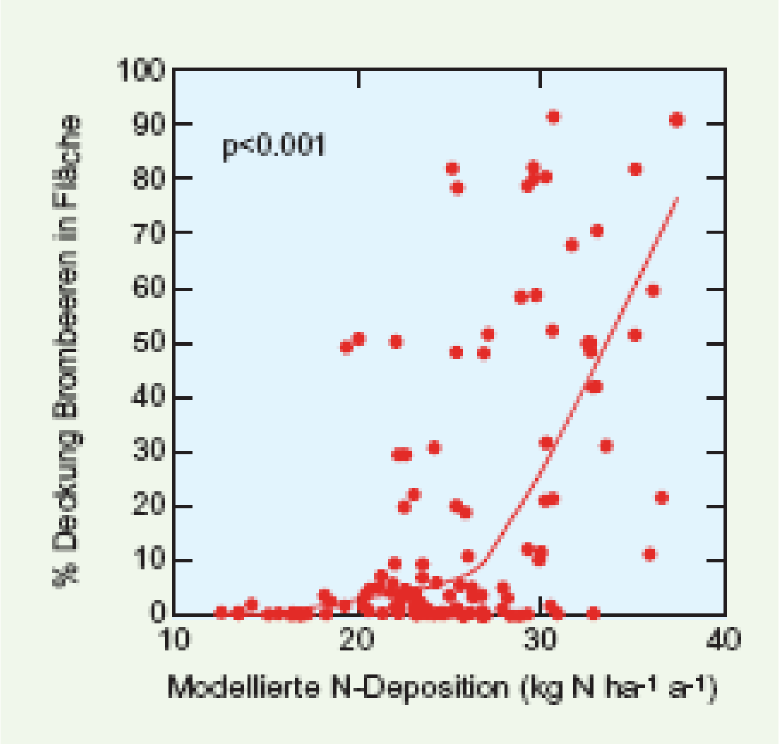


Vegetation of lichens (Nitroindex) vs. modelled ammonia concentrations ($\mu g\ m^{-3}$)

Example: N and Blackberries

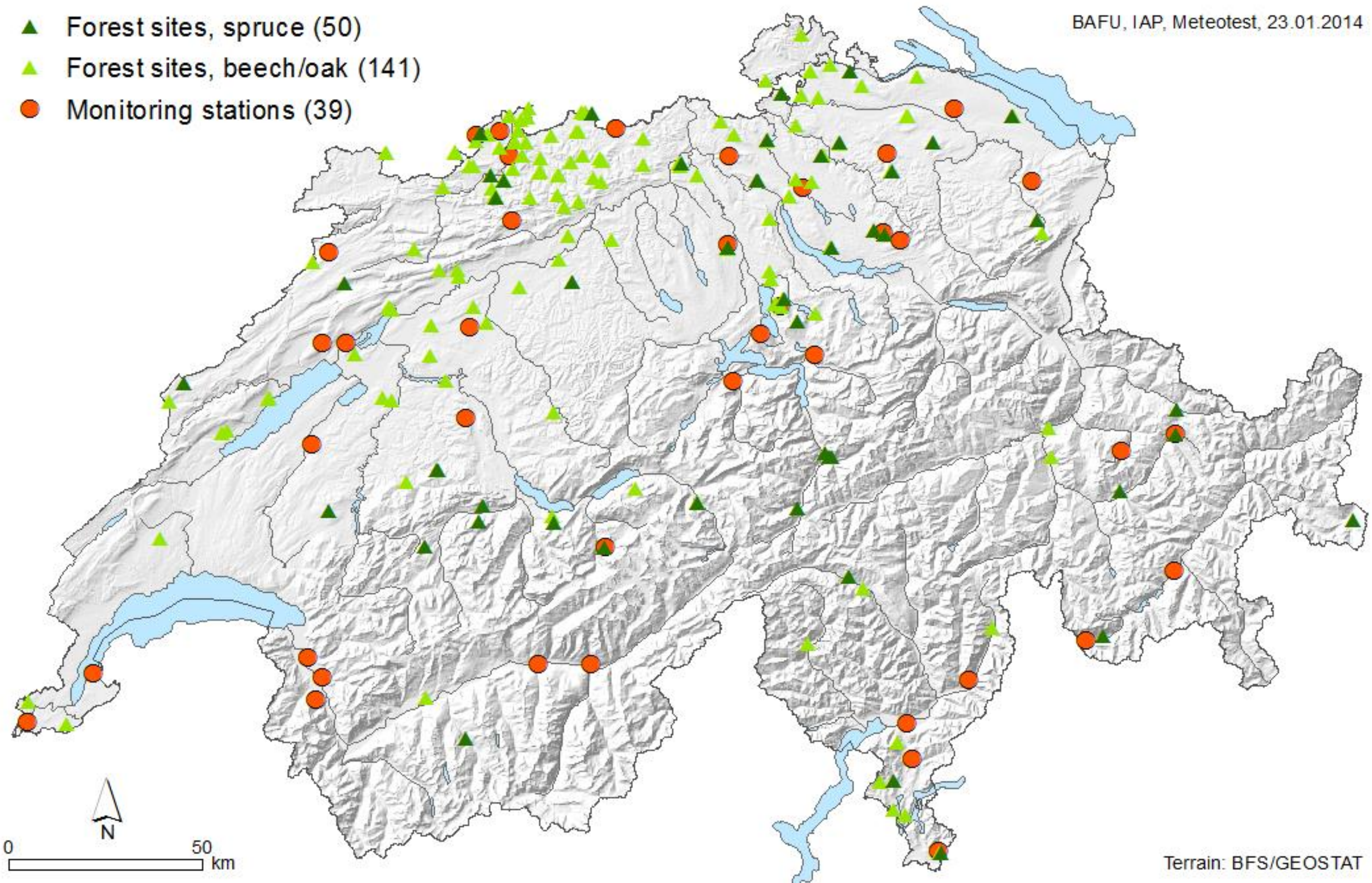
Braun S./IAP 2004: Relationship between N-deposition and the occurence of blackberries in forest observation plots.





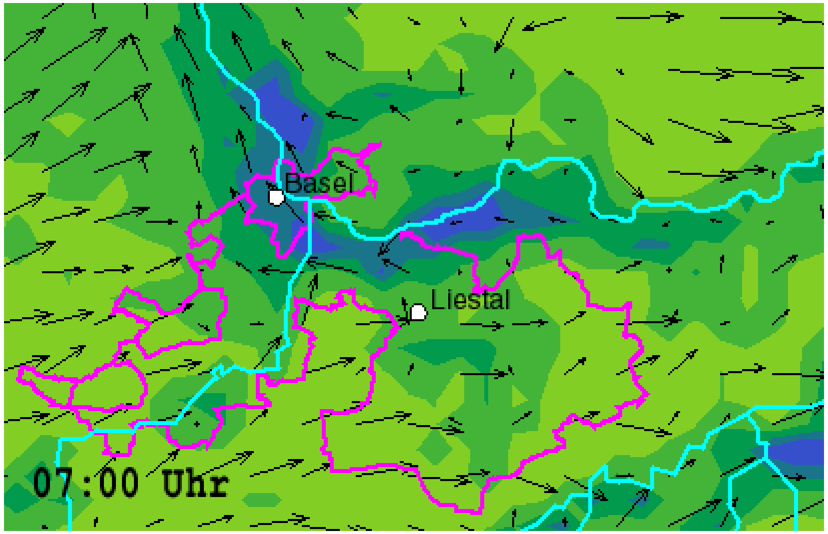
Mapping Ozone Flux (POD1) with High Spatial Resolution, 1991-2011

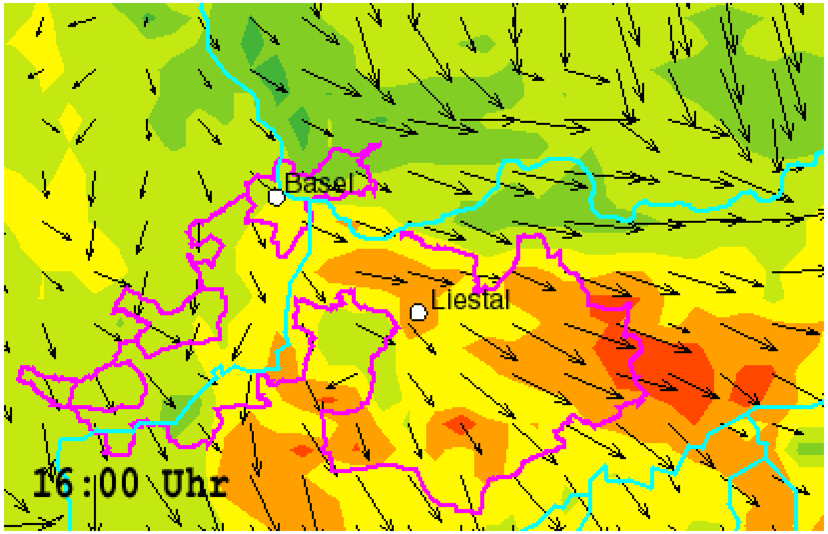
- Selection of 38 monitoring stations for ozone and meteorology.



Problem: Hourly O_3 Concentration for POD1 Calculation (1)

- The O_3 concentration is highly variable in time and space as shown during this 1-day-episode in the region of Basel (output of the analytical model Berphomod, 1998; animated gif).





Problem: Hourly O_3 Concentration for POD1 Calculation (2)

- Hourly O_3 concentration maps derived from monitoring stations are produced for public information, but they are too coarse for site-specific POD1 calculations ☹ http://www.bafu.admin.ch/luft/luftbelastung/blick_zurueck/04751/index.html?lang=en

- Idea: Calculate POD1 at the 39 monitoring stations (where hourly O_3 and meteo values are available) and then try to map that integrated parameter, instead of the "basic" O_3 concentration.

POD1 1991-2011, DO$_3$SE, 38 Stations

(Beech)

Station	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	MEAN
AIG																		12	6	11	5	8
ANI																	14	14	9	14	11	12
ARO	6	6	5	8	5	4	4	6	5	7	6	4	14	6	7	10	11	12	13	11	12	8
BAC		21	23	23	20	20	21	20	20	21	20	20		21	19	19	19	20				20
BAS	14	14	13	13	15	15	15	17	17	17	6	17	10	14	17	16	16	15	15	15	13	14
BRU																	20	21	22	20	18	20
CAS																	17	17	17	18	15	17
CHA	24	25	22	24	23	24	27	26	28	26	26	26	25	26	25	24	22	23	24	22	23	25
chablais			14	14	14	18	17	11	19	17	19	16	8	13	11	13						14
DAV	13	15	13	15	13	14	15	14	15	14	14	15	16	15	14	14	13	13	14	12	12	14
DOR	23	26	32	24	17	39	10	21	18	17	5	17	11	17	17	16	11	12	10	10	10	17
DUE	11	13	13	13	15	16	15	16	15	13	14	15	11	16	15	14	15	15	15	14	14	14
EGG																	15	12	8	13	4	10
ETZ										17	18	19	12	17	14	14	19	18	18	19	16	17
GIE																	12	16	16	18	14	15
LAE	14	16	15	15	15	16	16	16	18	18	17	18	10	19	17	16	16	16	17	15	15	16
LLA																		20	17	15	12	16
MAG	12	13	16	12	16	18	15	17	17	16	14	16	13	14	15	14	13	15	13	14	14	15
muri							12	17	13	16	15	13	11	18	16	15	14	13	14	11	9	14
PAS																	16	15	11	15	11	14
PAY	23	22	21	21	21	22	23	16	25	13	24	25	16	23	23	22	19	18	12	16	13	20
RIG	24	25	22	25	23	23	25	25	26	26	25	24	27	25	24	25	21	22	22	20	23	24
sagno							29	34	37	22	29	35	25	22	24	24	21	23	21	17	24	26
SAI																	21	22	20	21	19	21
schoebu		22	25	21	24	23	18	22	16	12	11	16	7	10	12	12	13	12	14	16	12	16
sciss								30	24	23	24	27	16	24	18	19		11		17		21
SGS	22	19	15	16	16	12	20	22	21	25	22	23	24	25	24	22	20	19	20	20	23	20
SIS	10	11	13	12	15	15	17	13	15	16	15	17	9	14	15	14	15	14	16	15	11	14
SOG																	17	17	18	17	16	17
STA									26	41	38	35	23	22	32	25						30
STM		13	14	13	14	14	14	15	15	15	13	13	14	14	12	12	11	11	13	11	11	13
SYZ																	11	12	11	11	13	11
TAE	18	18	18	18	19	20	21	22	20	21	20	20	18	21	19	18	19	19	19	17	19	19
TUR																	11	7	5	9	4	7
WEE																	20	19	20	16	12	17
wengen								15	18	12	11	11	15	13	12	14	7	10	10	7	8	12
WLD																			21	19	20	20
ZIM																	21	23	25	23	21	23
zugerb							22	25	26	22	26	29	18	23	23	25	21	17	19	13	21	22
n	13	16	17	17	17	17	20	22	23	24	24	24	23	24	24	24	33	36	35	36	35	24

Scheme POD1 Mapping

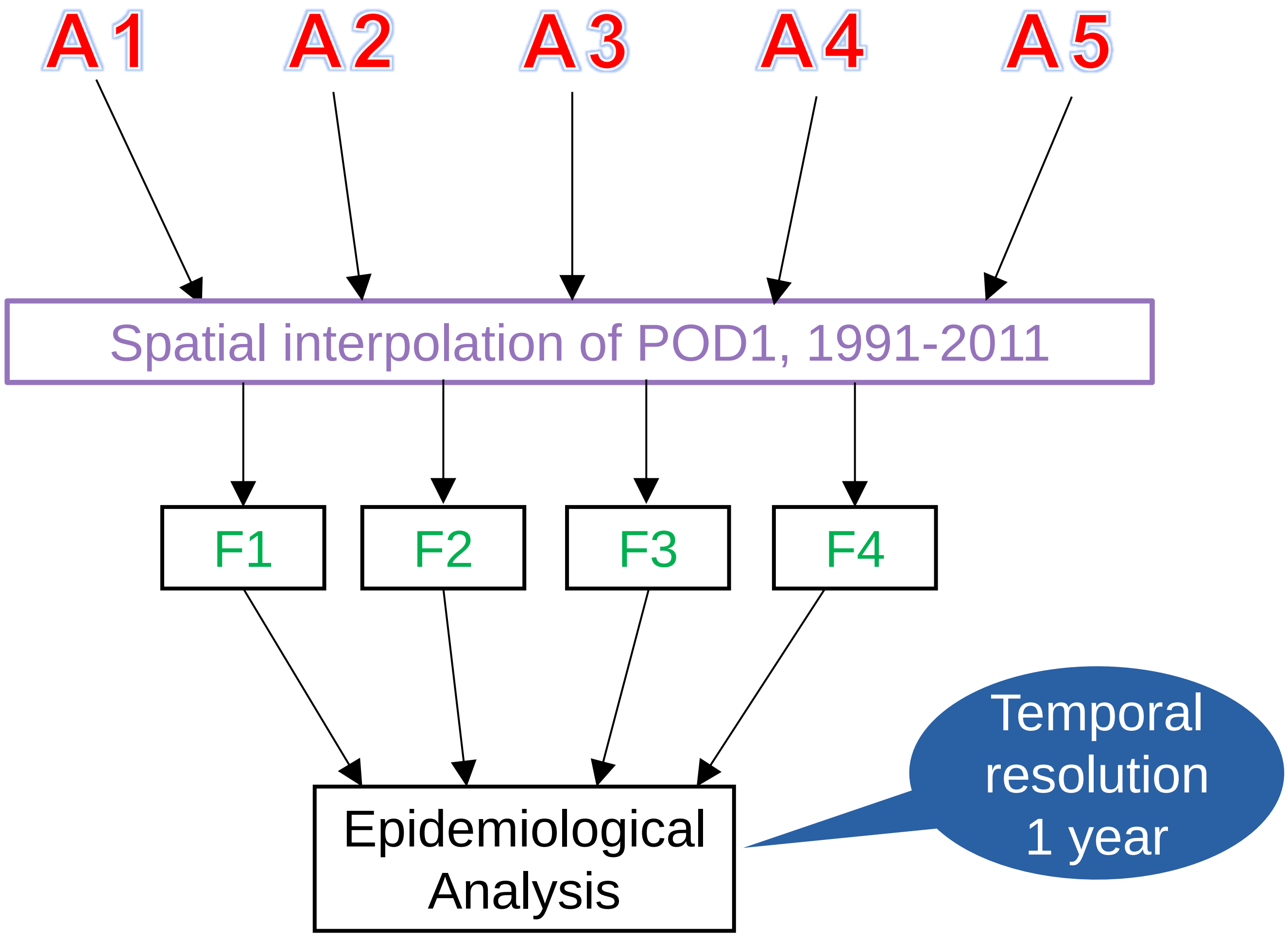
Air Monitoring Sites A1..A5:

Ozone, Meteo: hourly data for DO3SE model (POD1)

Forest Sites F1..F4:

Tree Growth, 4-yr-means

Soil water

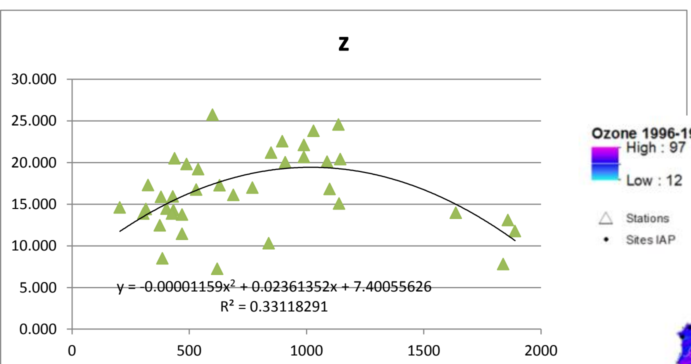


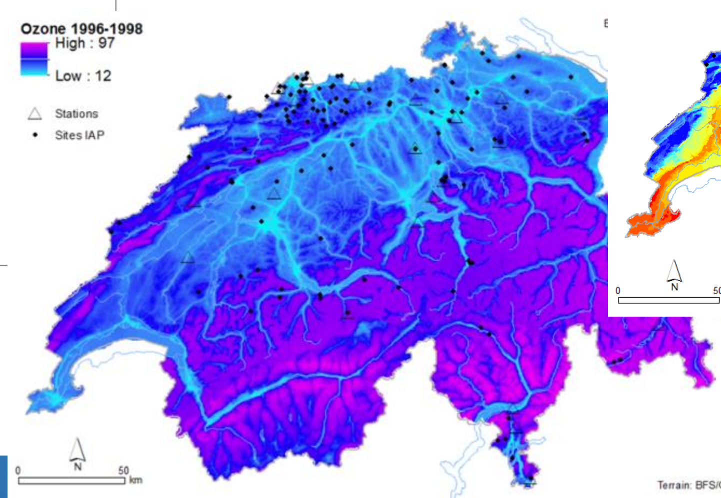
Geo-statistical Interpolation Using Predictor Maps & Regression Analysis

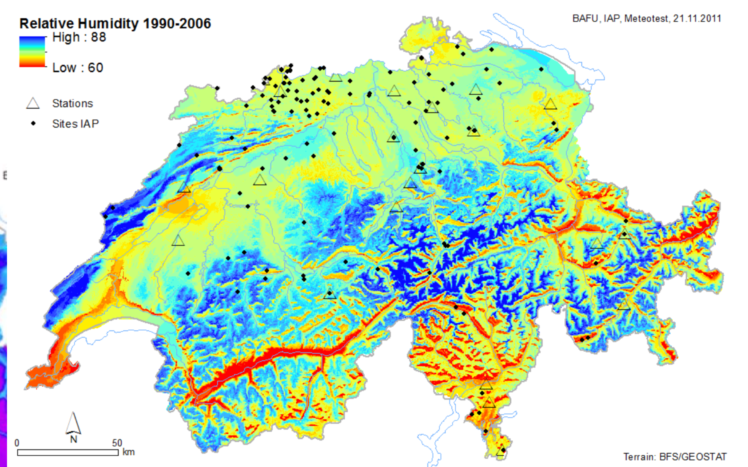
Beech, POD1 mean 1991-2011 (mmol/m²/yr): (spruce not shown)

$POD1 = -33.01 + 0.4984 * relh + 0.2093 * (o3mean^{0.333} * zq)$
adj.$R^2 = 0.51$, $n = 38$, units: mmol m^{-2} yr^{-1}

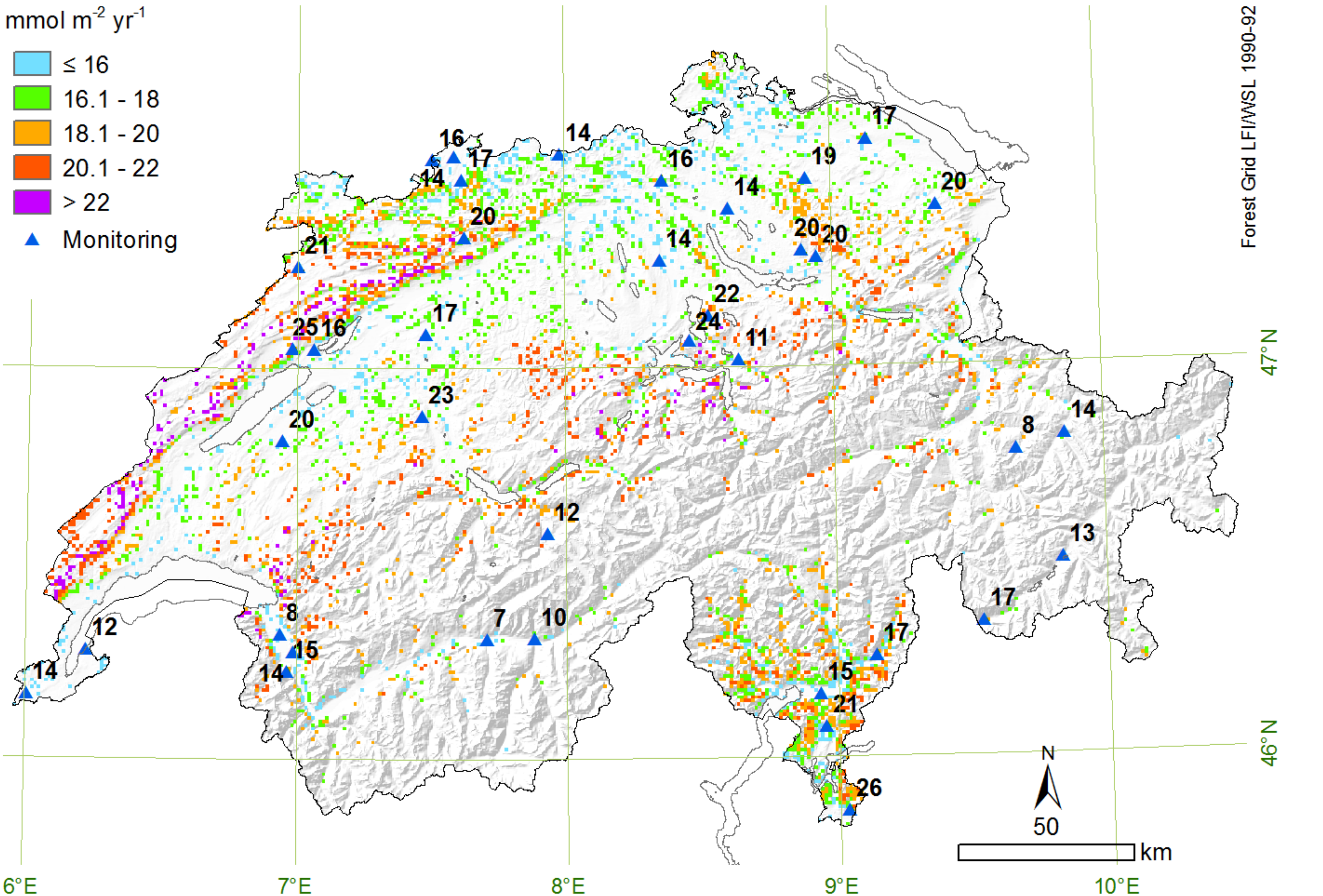
Predictor maps, 250 m raster:
1) $zq = -11.59 * z^2 + 23.61 * z + 7.40$, z = altitude (km)
2) o3mean: mean ozone concentration (µg m^{-3}), 1996-1998
3) relh: relative air humidity (%)







POD1 Beech, Mean 1991-2011

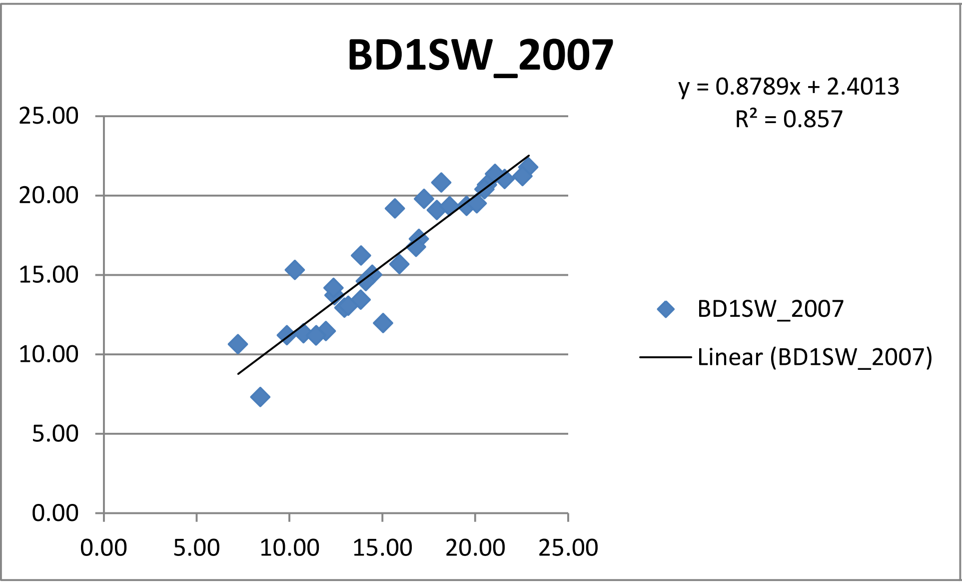


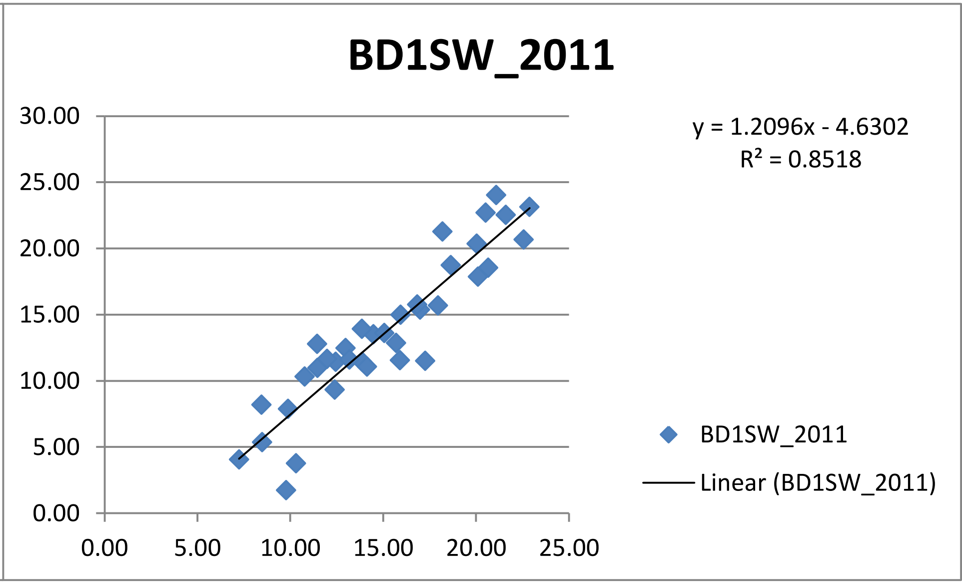
POD1, Yearly Maps 1991-2011 (1)

The spatial pattern of the POD1 average 1991-2011 is quite stable; the chosen input-maps explained 51% of the variation.

For the epidemiological analysis the **temporal resolution** is crucial as the stem growth relative to the average stem growth is analysed.

→ We need yearly maps. Is there an easy way for calculating them?
Look at relative flux: $relPOD1_{year} = POD1_{year} / POD_{1991-2011}$
relPOD1 of all stations is ~linear! Mean R^2 1991-2011 = 0.78

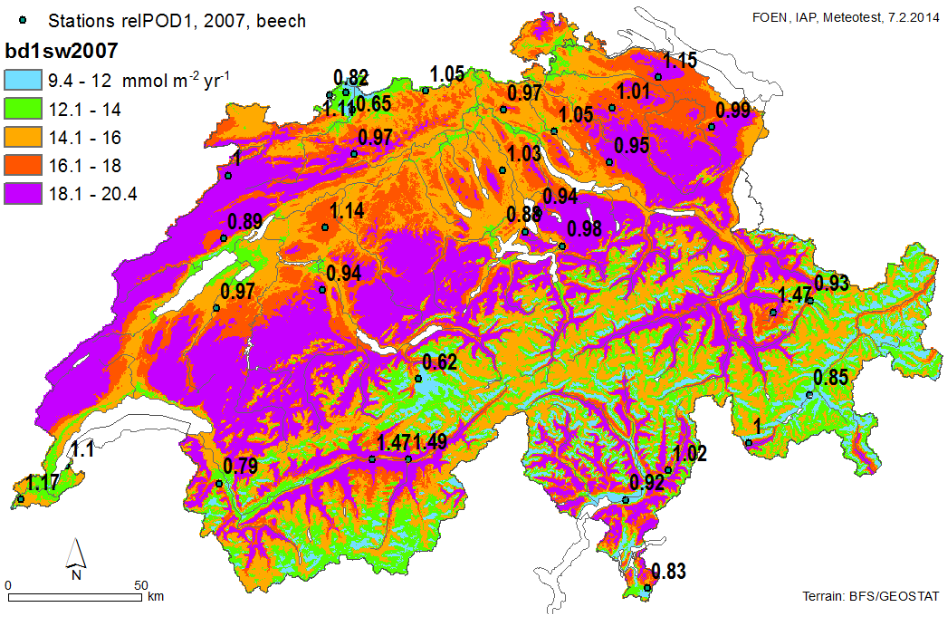


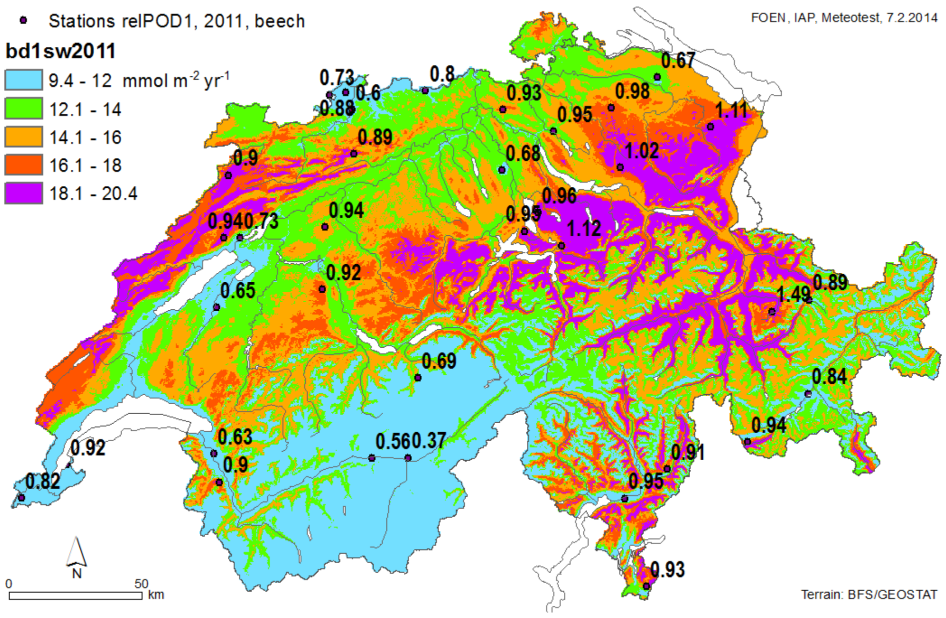


POD1, Yearly Maps 1991-2011 (2)

As relPOD1 behaves quite linearly, we can map it with a inverse-distance weight (IDW) interpolation: no further data are needed.

The yearly POD1 maps are calculated by multiplying the relPOD1-map with the POD1 average map on a cell-by-cell basis;
examples 2007 and 2011:





Comments and Conclusions - Spatial Resolution

1) If the sites are influenced by **local sources** of pollutants (e.g. NH_3), the spatial resolution of the model should depict the horizontal gradients around those sources (cellsize ~ 0.1 – 0.5 km).
   For secondary pollutants (e.g. O_3) larger cellsizes may be OK.

2) If **topography** around sites is complex, meteo parameters show strong gradients.
   For depicting alpine valleys: cellsize < 0.5 – 2 km

3) For spatial epidemiology we need **gradients** in the environmental factors. The mapping of these factors must have enough spatial resolution to depict the gradients within the investigation area.

4) Sub-grid variation of factors leads to scatter or also to bias (if the sites are not randomly situated).

Comments and Conclusions - Mapping Methods

5) If analytical atmospheric models cannot be applied (costs, complexity, spatial resolution) geo-statistical **interpolation** and **statistical** dispersion models might be useful.

6) For defined investigation areas, the spatial pattern of environmental factors is often easier to be mapped if the factors are **time-averaged** or **integrated**.

7) For mapping environmental factors, clarify what is essential in the epidemiological analyis: variation in **time** or in **space**. Mapping is generally easier if not both, time and space, must be in high resolution.

8) Avoid using unnecessary **"bad" data** in the mapping process, i.e. input maps with small predicting power in comparison with their quality.

Thank you for your attention!

Beat Rihm, Meteotest

Churfirsten in clouds (CH)