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Biological Air quality modelling

Additional general aspects, specifics of birch and grass

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Summary of part 1: challenges for models

- Biological aerosols: a new type of pollutant (?)
- Production of the bioaerosols: a complicated and weakly quantified set of biological processes
  - long memory of biosystems: models have to keep up with it
  - quick response to short-term environmental stress
  - observational datasets with unusual features
- Physical and chemical transformations in the atmosphere during transport
- Direct health impact – to be included in the models?

Pollen: a new type of pollutant?

- The coarsest aerosol so far suggested for atmospheric dispersion modelling
  - >20 μm in diameter but comparatively light
  - sometimes strongly non-spherical, may have wings and other features helping to stay in air
- Often tricky process ensuring the release at right moment
  - sometimes active injection
  - protecting mechanisms against humidity and rain and promoting injection when conditions are most-favourable
- A small fraction of near-source concentration is harmful
  - 50-100 grains m^{-3} is a high level while near source up to 10000 can be observed: have to chaise tails of the plumes
- A question: can current dispersion models cope with this pollutant?
  - will these particles follow the eddies?
  - will the signal be noticeable at the receptor point when ~1% of mass is still in air?
  - …

Pollen in turbulent air: quick screening

- Ability to follow the atmospheric flows
  - the relaxation time against the surrounding flow
  - sedimentation velocity
  - assumptions behind both

Navier-Stokes: $$\frac{\partial \vec{v}}{\partial t} + (\vec{v}\nabla)\vec{v} = -\frac{1}{\rho} grad\ p + \frac{\eta}{\rho}\Delta\vec{v}$$

… and for slow laminar motion: $\eta\Delta\vec{v} - grad\ p = 0$

Laminar? : $Re = {|\vec{v}|d}/{\nu} << 1$, $\nu = \eta / \rho$ is kinematic viscosity

Stokes' force (motion through air): $$F_{Stokes} = 6\pi r \eta u \left(1 + \frac{3ru}{8\nu}\right)$$

Small if Re<<1

Sofiev *et al*, 2006

Pollen in turbulent air: quick screening (2)

Relaxation due to Stokes force: $m\frac{dv}{dt} = -F_{Stokes} = -3\pi\, d\, \eta u$

relaxation time and distance for birch: $\tau = \frac{d^2\rho_{part}}{18\eta} \sim 10^{-3}\,\mathrm{sec}, \quad l \sim 10^{-3} m$

Sedimentation: gravity vs Stokes force: $u = \frac{g\rho_{part} d^2}{18\eta}$

birch: $u \sim 1.2\ cm/s\ ; \quad \frac{3du}{16\nu} \sim 3.2 \cdot 10^{-3}; \quad Re \sim 1.7 \cdot 10^{-2}$

Processes during transport: drying/wetting (change of transport features!!), releasing the allergen, interaction with other atmospheric components

Dry deposition ~ sedimentation, wet deposition ~ impact scavenging (sub-cloud), resuspension is highly uncertain

Conclusion 1

- Pollen (at least some of) can be modelled by the current CTMs as the main assumptions behind their applicability are fulfilled
  - significantly non-spherical grains have to be taken with care: their actual aerodynamic size had to be evaluated (possibly, more than one if dimensions are strongly different)
- Uncertainties in absolute levels will be high, both near the sources (emission mechanisms, total amount available) and in remote regions (uncertainties in the atmospheric models)
- A helping hand of Nature: grains are made to fly and mechanisms available for selecting the right conditions, which reduces the list of questions

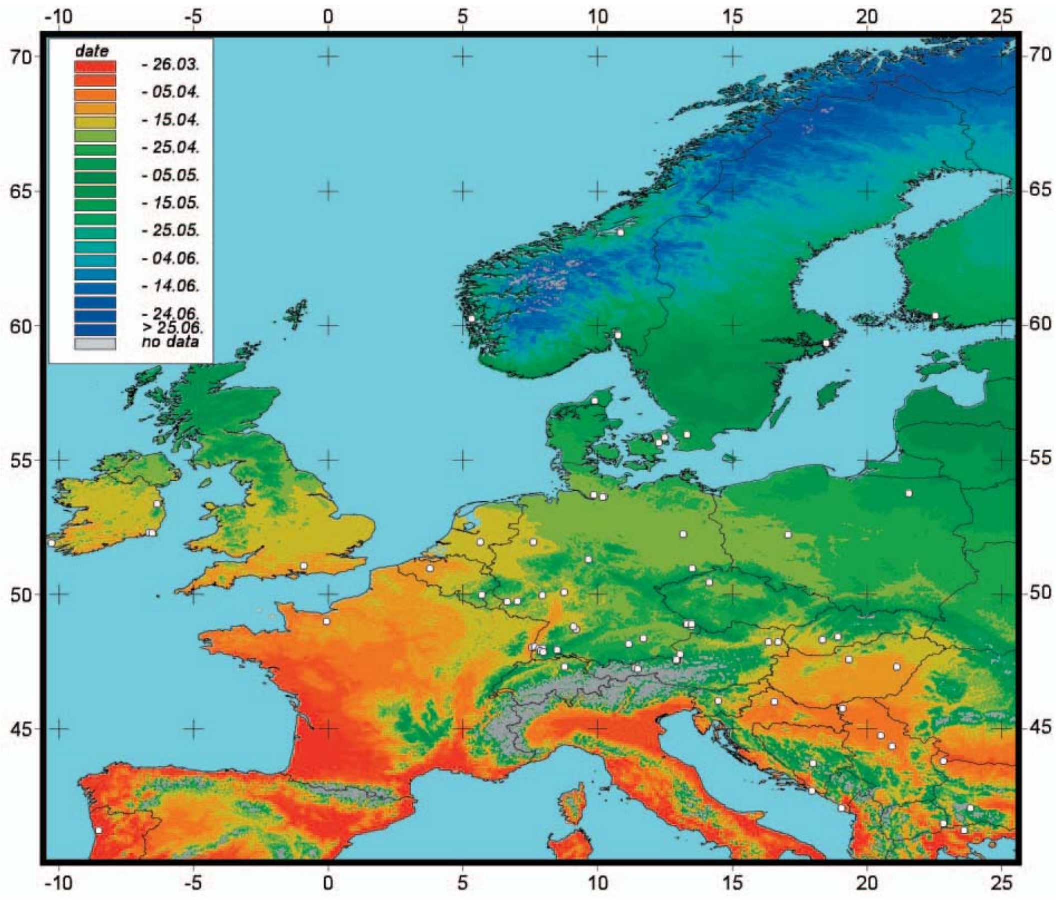
Emission: phenological uncertainty

- Phenology studies the stages of the vegetation development and related processes
- Tricky data: one value per station per year (e.g. the date of start of flowering of species *xx*)
  - Manual and, to some extent, subjective observations (criterion for leaves unfolding stage: ‘In at least 3 places on the object under observation first leaves have pushed themselves completely out of the bud and have unfolded completely, so that the leaf stalk or leaf base is visible. The individual leaf has taken on its ultimate form, but has not yet reached its ultimate size’)
- Data are collected by countries individually and sometimes with limited coordination, by professionals and/or amateurs. European phenological network: a meta-network of national networks. No central database
  - COST-725 is about to build such a database

Phenological products: mean, trends, …

- A standard way to utilise the phenological data is to average them over decades, parameterise against some variables, perform trend analysis
- An example: International Phenological Garden (Rotzer & Chmielewsky, 2001): 30-years mean over 54 sites parameterised as:

$$D_{start\_grow} =$$
$$a * lon + b * lat + c * height + d$$

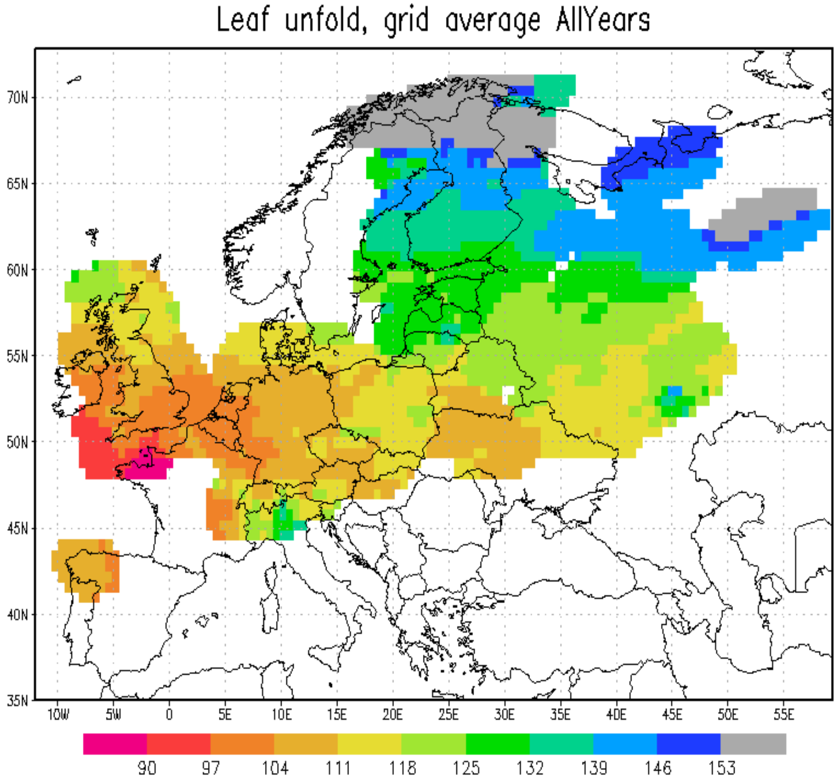


Emission: phenological uncertainty (2)

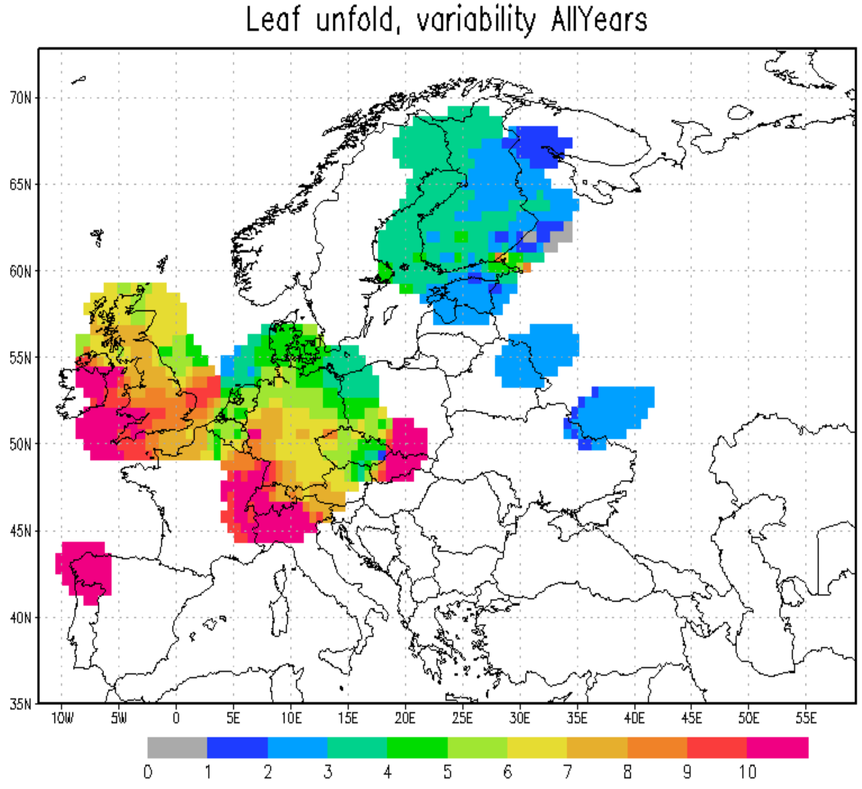
- Effort for birch: a standalone database collected country-by-country with ~60000 dates from 15 countries (Siljamo *et al*, 2008)

Birch leaf unfolding: mean 1970-2004

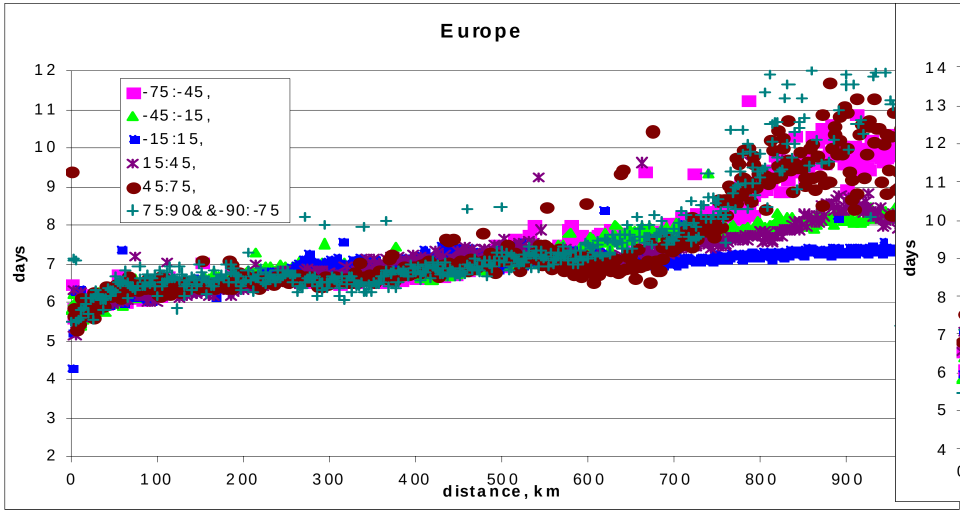
Median

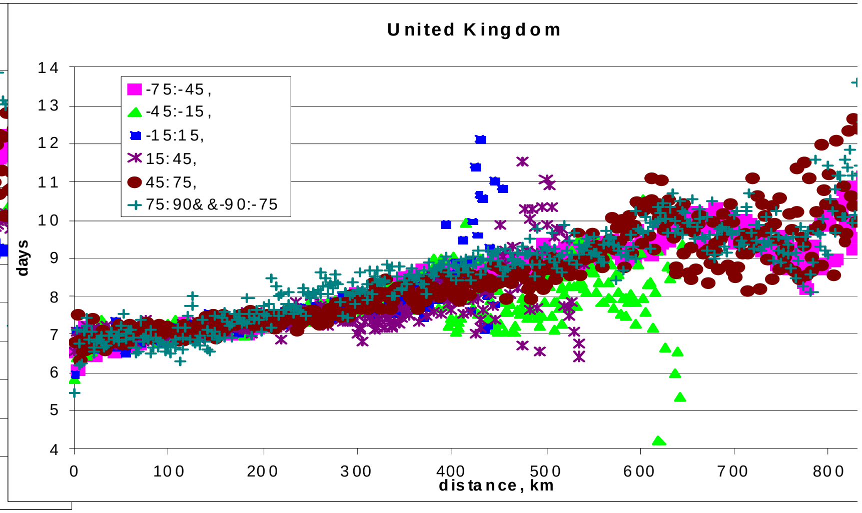


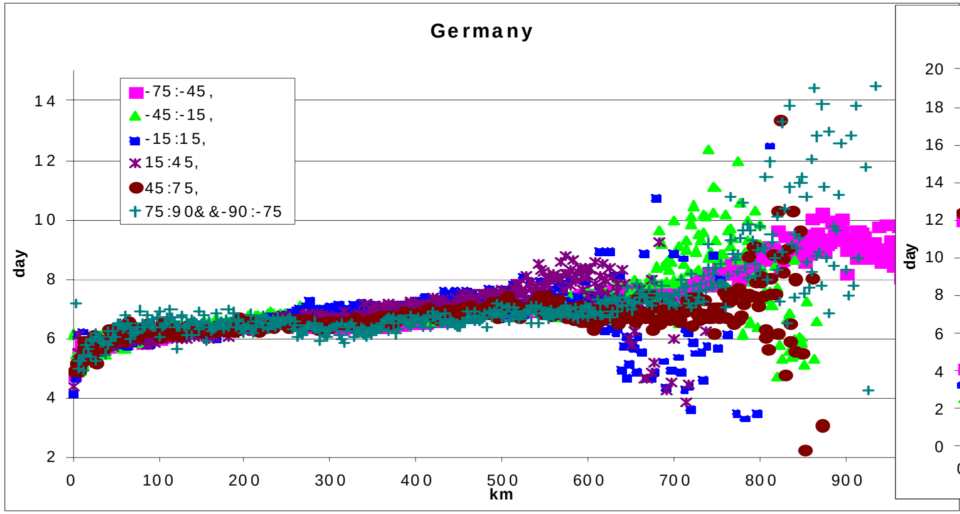
Spatial variability (point-to-point)

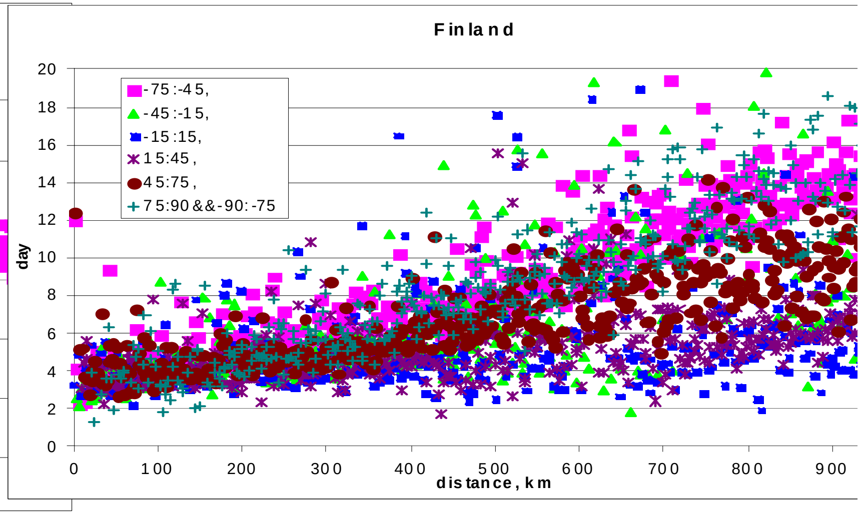


Phenological uncertainty: structure functions



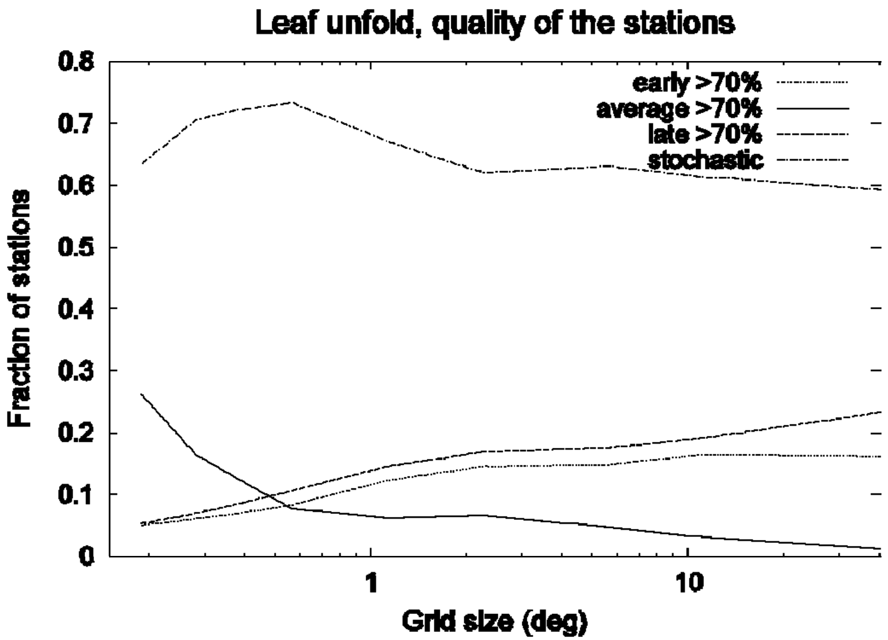


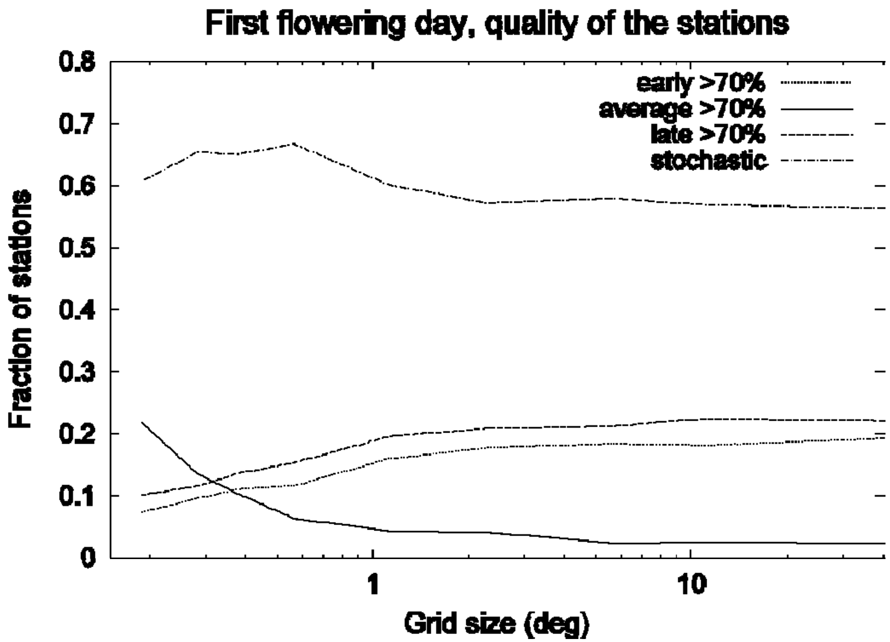




Phenological uncertainty: year-to-year variability

- Station following the median of a grid-cell for more than 70% of observed years ±2days is "average"
- Station earlier/later than median for >2 days for >70% of years is "early/late"
- Station not falling into above classes is "stochastic"





Phenological uncertainty: who's the guilty one?

Birches in Helsinki, Finland, October 29, 2006

Green yellow no leaves

Source: P.Siljamo

Conclusion 2: phenological uncertainty

- Phenological data showed at least 1 week of uncertainty of the flowering period, largest in warm and marine, smallest in continental and cold climatic zones
- >60% of current sites classified as “stochastic” with regard to regional median – even for regions 20×20km
  - no major problem with sites – uncertainty is objective
- Hopes for deterministic source term are dashed
- Hopes for stable in time climatology-type parameterization are dashed
  - climate-induced trend seems to be well-pronounced but actual estimates vary widely from region to region and from species to species

Observations in air: EAN

- EAN = European Aeroallergen Network
- One of the most extensive and well-organised European networks (totally 300 stations, tens of species but coverage and list of available species strongly vary from site to site)
- Several decades of operational work
- Manual reading of the observations, no NRT data
- Perfect for model validation, problematic for flowering parameterization due to long-range transport
  - Partly commercial network, data are not openly available

Flowering model parameterization

- Once flowering started
  - sun promotes it
  - heat promotes it
  - wind helps it

  - humidity inhibits it
  - cold inhibits it
  - rain stops it

  - most of species do not have explicit mechanism to day-night recognition (unlike sunflower): a problem of diurnal variation becomes complicated
- Flowering is over once all pollen is released
  - Several alternative formulations exist but this seems to work the best

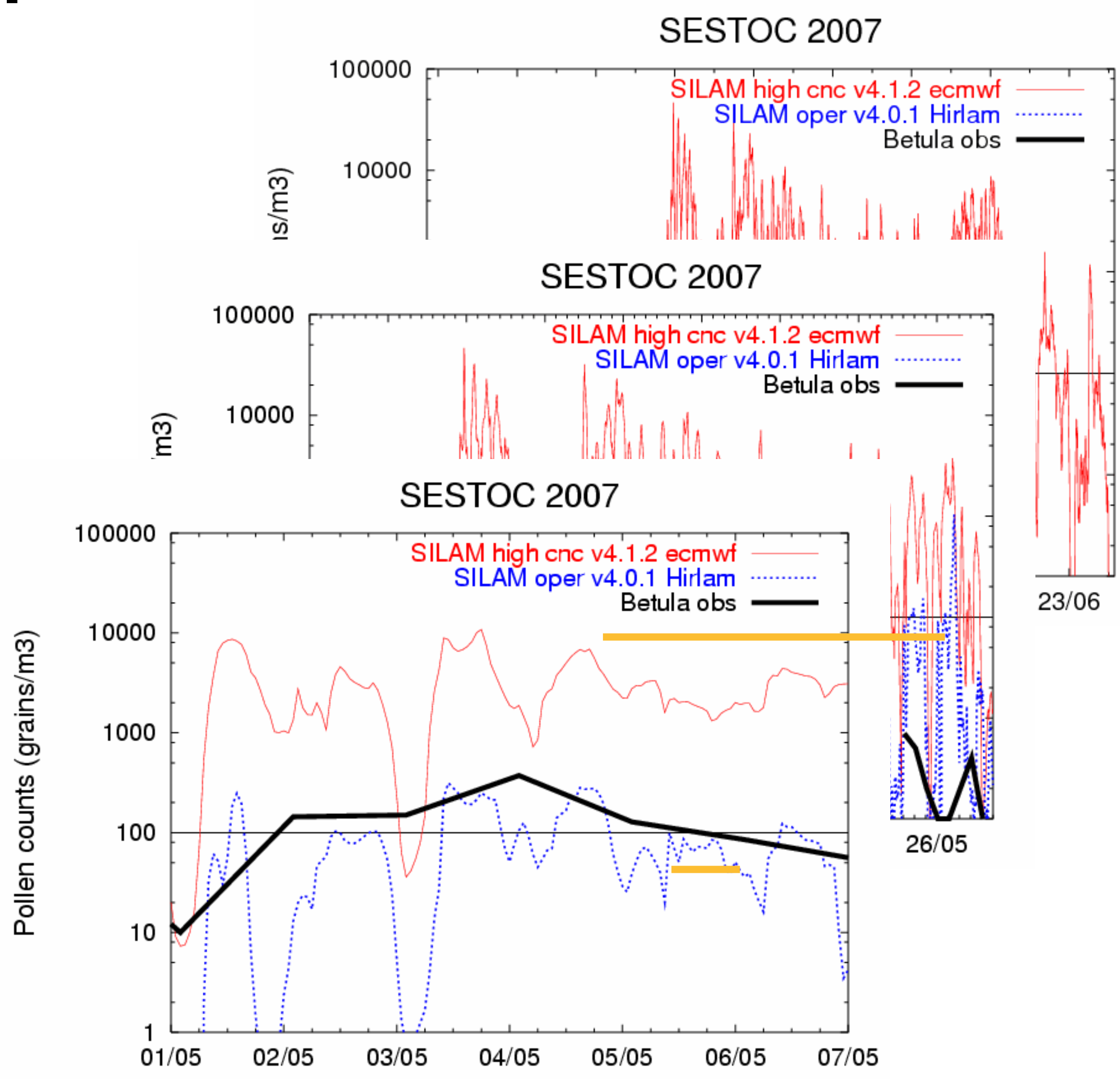
Birch: model performance, 2006

Results in spring 2007

- Warm winter and March, cold and rainy April/May
- No extreme birch pollen counts in Finland
- LRT-episode before local flowering season
- Difficult case to models
  - 1.5ºC negative bias in HIRLAM in north (lat >60º)
  - Complicated pollen release because of rain and humidity

Birch: model performance, Stockholm 2007

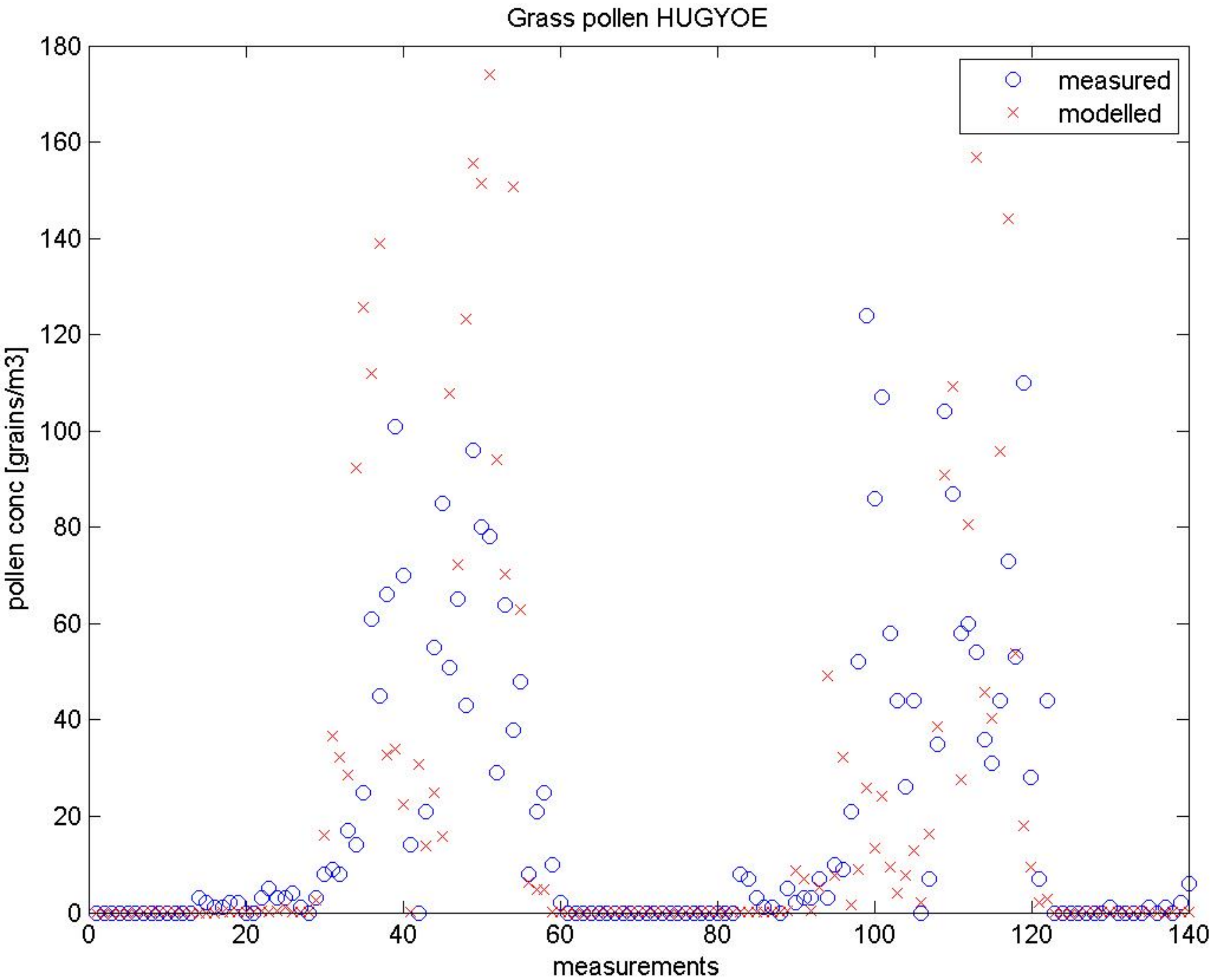
- SILAM-HIRLAM fc (blue) almost perfect in April and May
- Diurnal variability well seen both in HIRLAM and ECMWF cases



Grass: elements of the model setup

- Main difference: “grass” includes many species flowering at more or less same time (not all, though)
  - Quite stable timing from year to year
- Heavy pollen (~1.5 times larger in diameter than birch)
- No phenological data readily available
- For 2008 climatologic dates mapped from observations of EAN were used
- Other parameters were kept same as for birch

Grass: model performance in 2008



Observations:EAN, comparison: J.Soares

Conclusions 3

- Processes governing the bioaerosol (pollen) production and release are numerous and highly irregular, with large fraction of information available at a descriptive level only
- Pure deterministic models probably have little chance to cope with the uncertainty
- Current level of agreement for absolute values is between factors of 5 and 10 (for ~90% confidence interval)
  - sensitivity to the model setup is high, with several key parameters being also the worst-known ones
- Already simple accounting for stochastic features significantly improves the results allowing to capture the main features of the flowering season and even reach some quantitative agreement