ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Introduction to atmospheric dispersion modelling

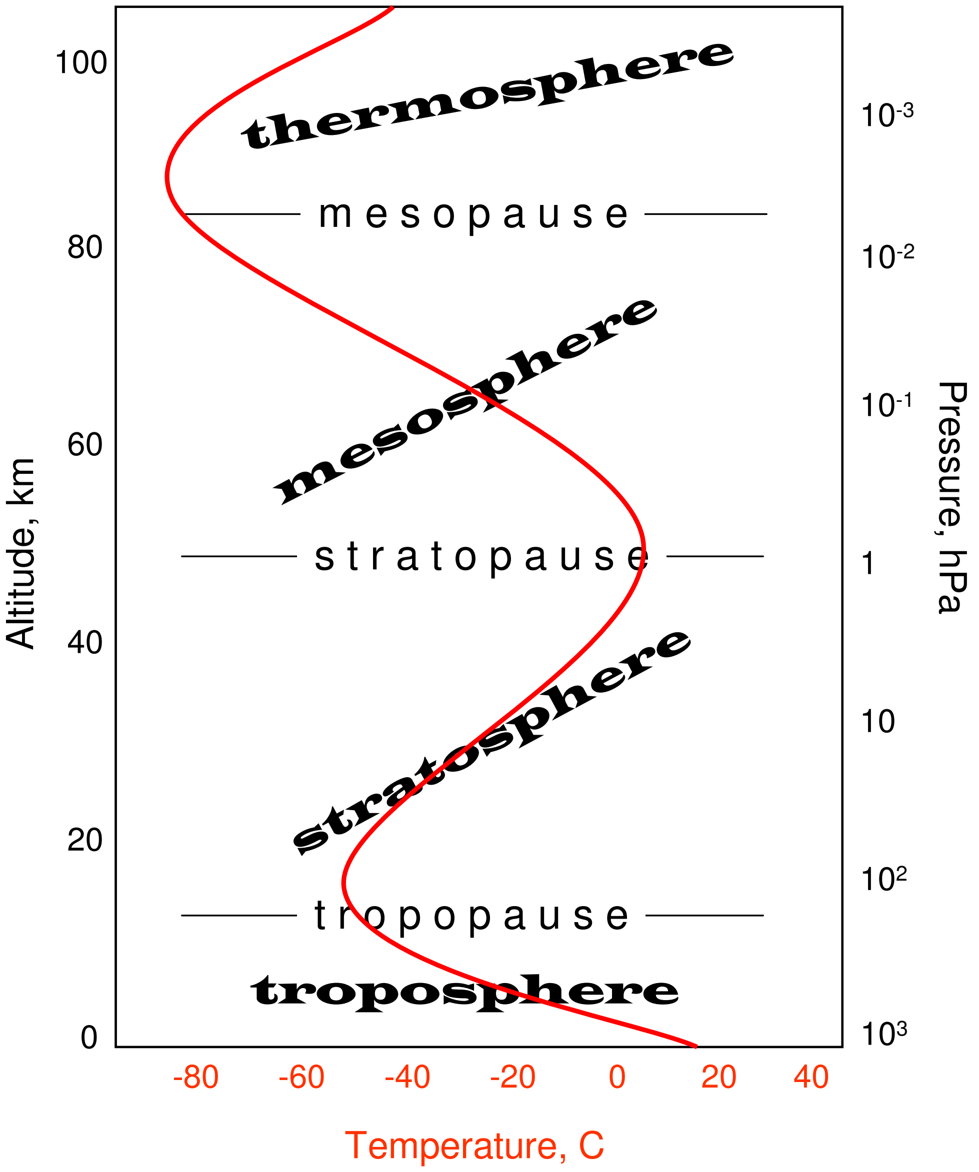
M.Sofiev

Content

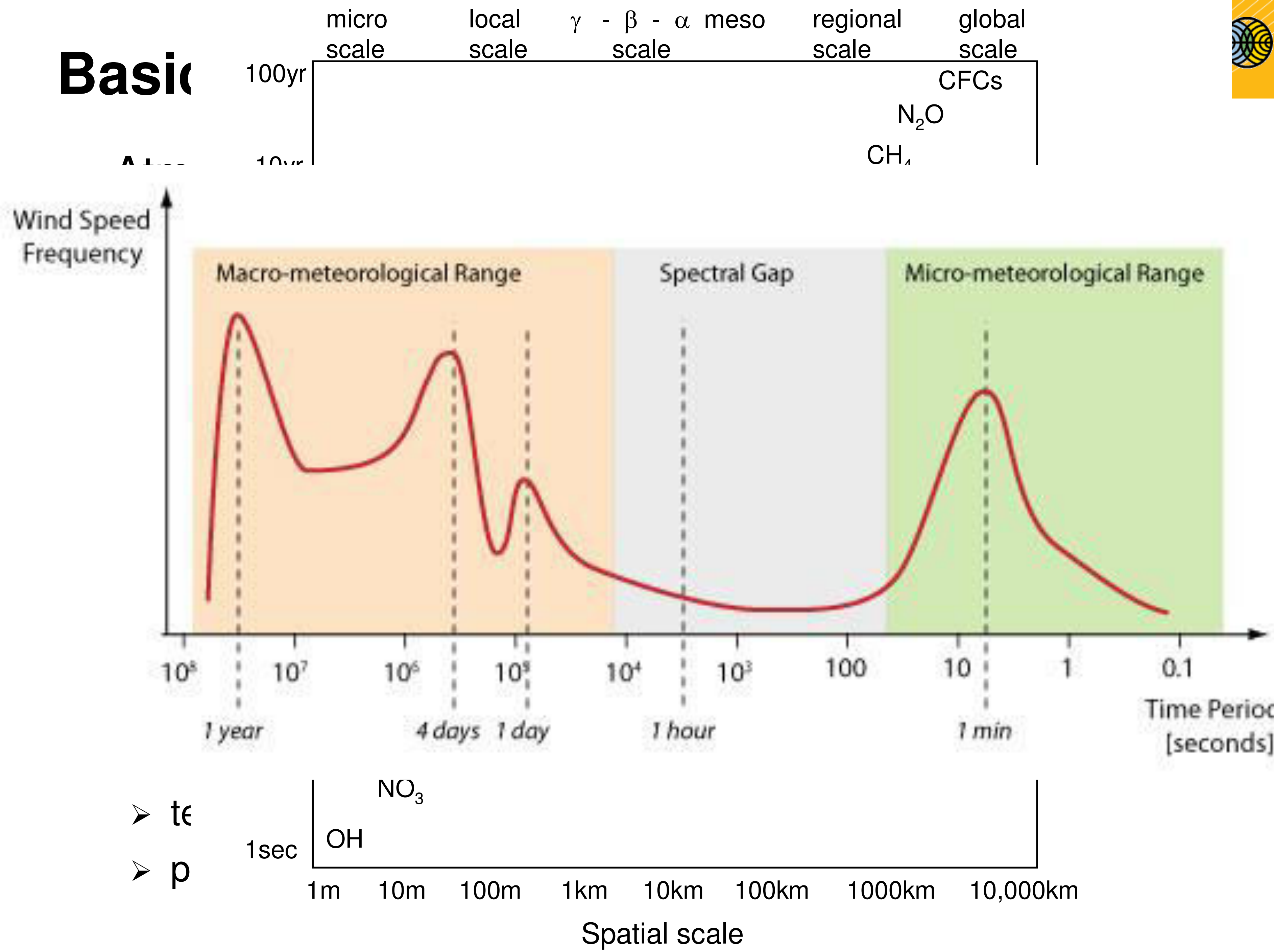
- Main parts of the atmosphere
- Basic terms
  - atmospheric tracer
  - temporal and spatial scales
  - life time in the atmosphere
  - life cycle of atmospheric tracers
- Dispersion equation
- Langrangian and Eulerian dispersion models
- Parts of a dispersion model
- Model Quality Assurance
- Summary

Major layers of the atmosphere

- Troposphere (tropos=mixing): interaction with surface
- Stratosphere: ozone-uv heating
- Mesosphere: mixing again
- Thermosphere: O_2, N_2 – solar radiation heating
- Ionosphere: ions
- Exosphere: fast molecules escape to the open space



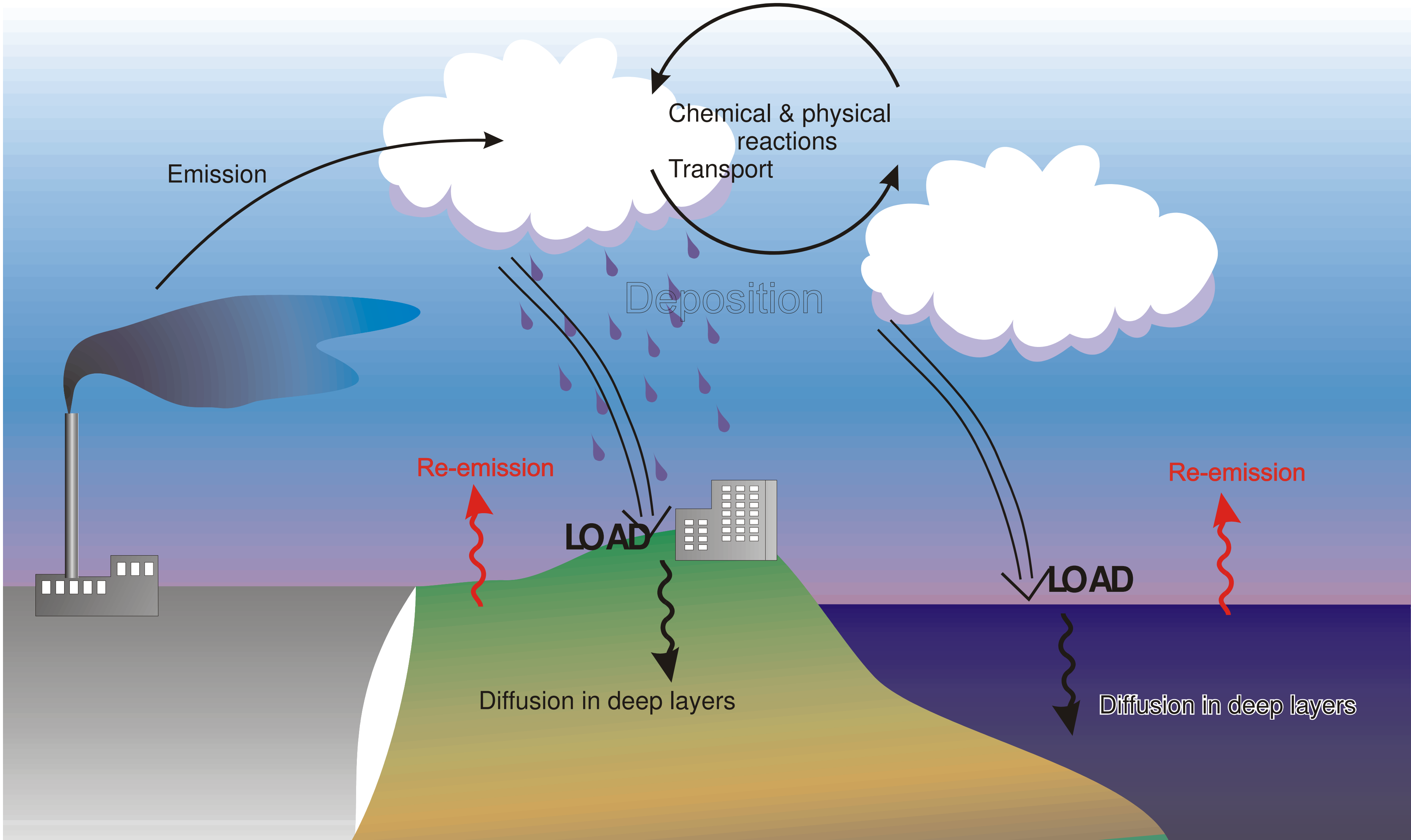
Basi



micro scale
local scale
γ - β - α meso scale
regional scale
global scale
100yr
CFCs
N_2O
CH_4
Wind Speed Frequency
Macro-meteorological Range
Spectral Gap
Micro-meteorological Range
10^8
10^7
10^6
10^5
10^4
10^3
100
10
1
0.1
Time Period [seconds]
1 year
4 days
1 day
1 hour
1 min
NO_3
OH
1sec
1m
10m
100m
1km
10km
100km
1000km
10,000km
Spatial scale

- te
- p

Pollution cycle in the troposphere



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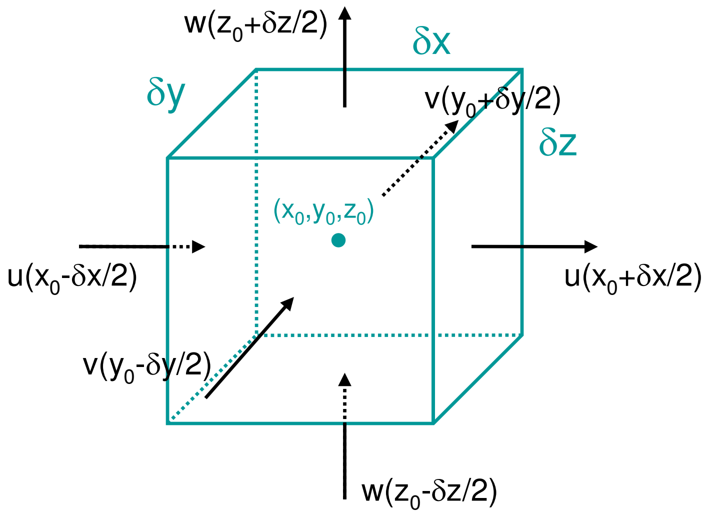
Dispersion equation

- Mass conservation
  - transport
  - sources
  - sinks
- Scale separation
  - mean flow
  - turbulence
- Closure problem
  - K-theory → turbulent diffusion coefficient



$$\frac{\partial c}{\partial t} = -\sum_{i=1}^{3} \frac{\partial}{\partial x_i}(u_i c) + E - R$$

$$LC \equiv \frac{\partial C}{\partial t} + \frac{\partial}{\partial x_i}(U_i C) - \frac{\partial}{\partial x_i} \rho K_{ii} \frac{\partial (C/\rho)}{\partial x_i} + R(C) = E$$

From concentration to load

$$M = \int_0^T dt \int_{-\infty}^{\infty}\int\int C\, p\, dx = (C, p) - \text{load functional}$$

p is a weight (sensitivity) function of the load:

- Population exposure $p(x,t) = \delta(x - x_{city})$
- Ecosystem damage $p(x,t) = p(t)\, 1(A_{ecosystem})$
- Observational site $p(x,t) = \delta(\mathbf{x} - \mathbf{x}_{site})\, 1(t, t_{beg}, t_{end})$

Alternative way to get the load function

Consider some function C^* satisfying

$L^* C^* = p$, where L^* is adjoint to L.

Then

$$M = (C^*, E) = (C^*, LC) = (L^* C^*, C) = (p, C)$$

$$L^* C^* = p \; - \; \text{adjoint dispersion equation}$$

$$L^* = -\frac{\partial}{\partial t} - \frac{\partial}{\partial x_i}(U_i) - \frac{\partial}{\partial x_i} K_{ii} \frac{\partial}{\partial x_i} + R(C)$$

$$C, C^* \xrightarrow{x \to \infty} 0$$

$$C^*(t = T) = 0$$

Dual features of dispersion problem

Forward problem:

$$L = \frac{\partial}{\partial t} + \frac{\partial}{\partial x_i}(U_i) - \frac{\partial}{\partial x_i}\rho K_{ii}\frac{\partial(1/\rho)}{\partial x_i} + R; \qquad LC = E; \;\; M = (p, C)$$

Inverse (adjoint) problem

$$L^* = -\frac{\partial}{\partial t} - \frac{\partial}{\partial x_i}(U_i) - \frac{\partial}{\partial x_i}K_{ii}\frac{\partial}{\partial x_i} + R; \qquad L^* C^* = p; \;\; M = (E, C^*)$$

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Classifications of models

- Model principles
  - Eulerian
  - Lagrangian
  - Gaussian
  - statistical Monte-Carlo
- Scales
  - global
  - continental
  - regional
  - local/urban

Classifications of models.2

- Chemicals
  - acid
  - ozone
  - greenhouse gas
  - inert aerosol/dust
  - radio-activity
  - toxic
  - persistent pollutants
- Model media
  - atmospheric
  - multi-media
  - integrated models

Classifications of models.3

- Input data
  - climatological
  - real-time data
- Time dimension: direction, horizon
  - re-analysis
  - now-casting
  - forecasting
- Problem to solve
  - forward
  - inverse

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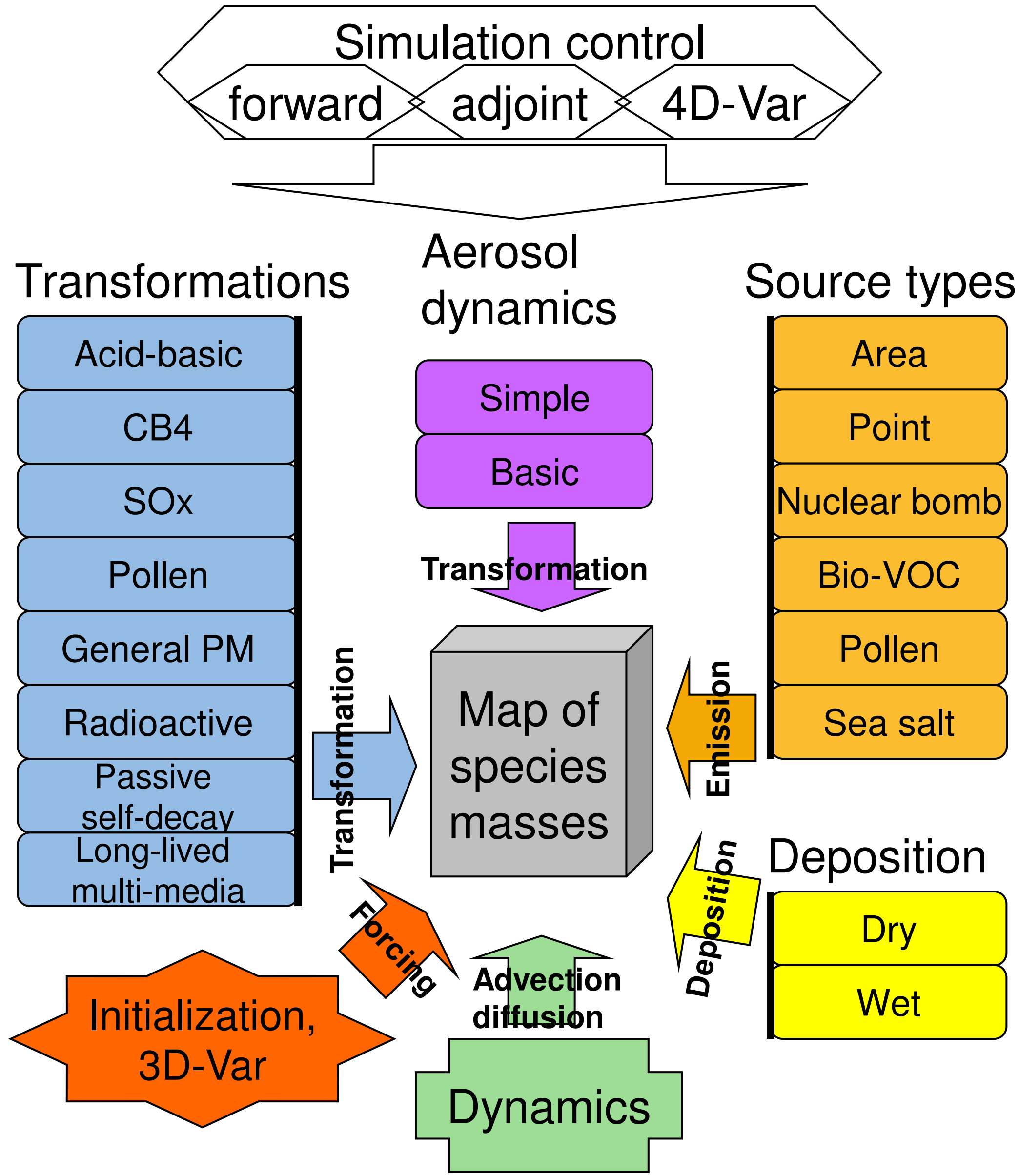
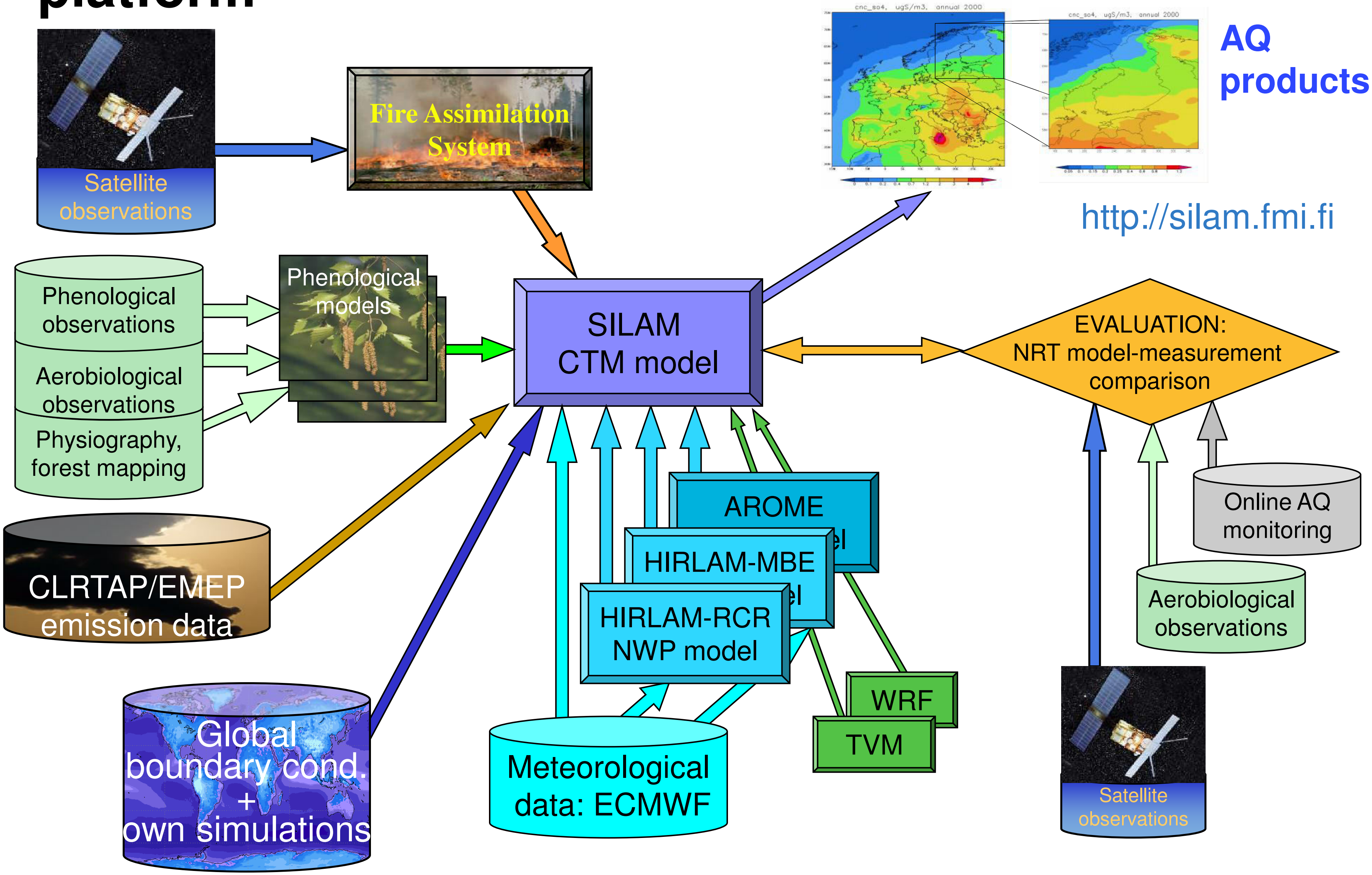
SILAM v.5: outlook

- Modules
  - 8 chemical and physical transformation modules (6 open for operational use),
  - 6 source terms (all open),
  - 2 aerosol dynamics (one open)
  - 3D- and 4D- Var
- Domains: from global to beta-meso scale (~1km resolution)
- Meteo input:
  - ECMWF
  - HIRLAM, AROME, HIRHAM, ECHAM, and any other who can write GRIB-1 or GRIB-2
  - WRF

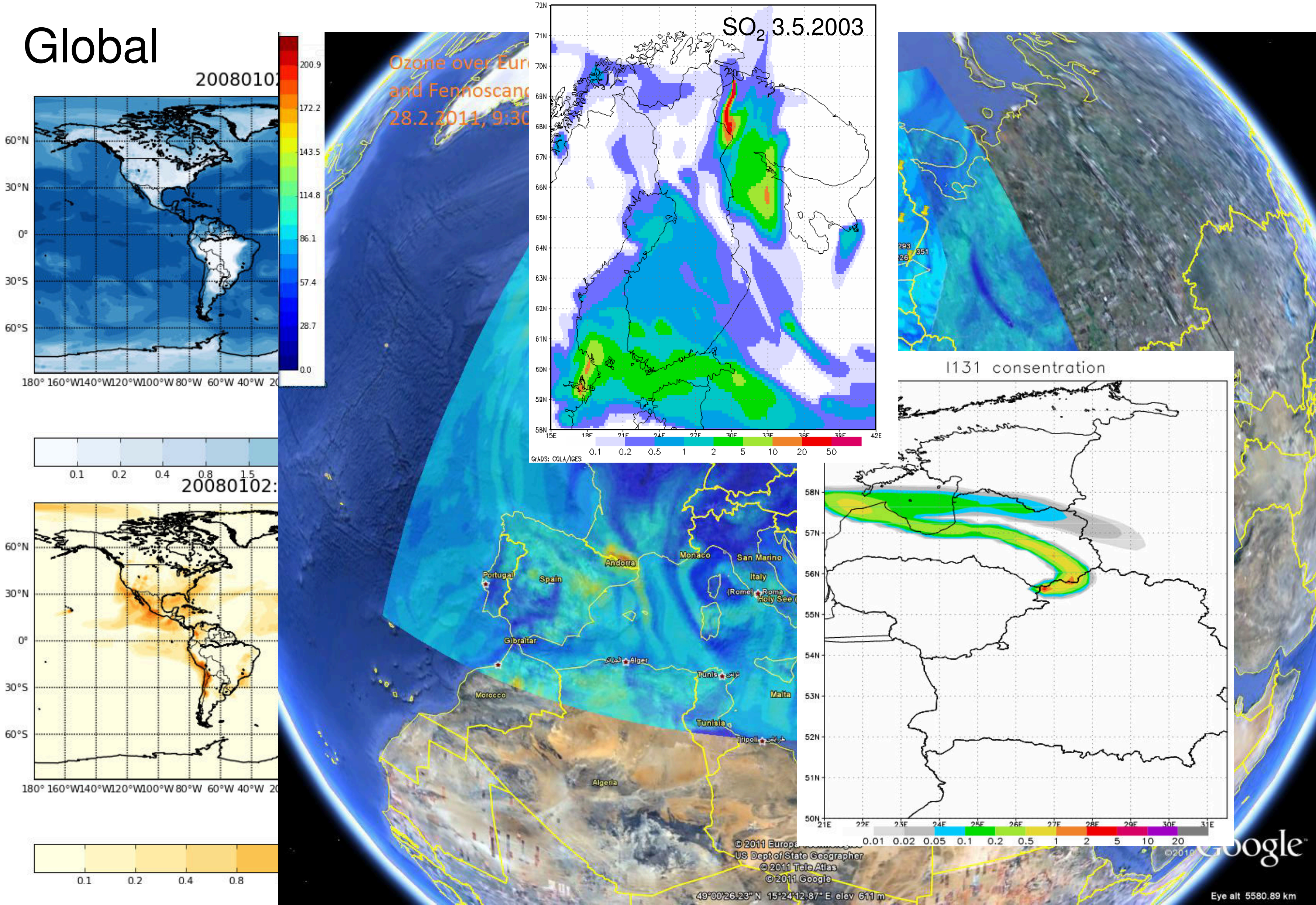


FMI regional AQ assessment and forecasting platform



SILAM scales

- Global



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Model vs reality

- Model is never a copy of reality
  - ➢ It represents only those features, which are deemed to be important for a specific application
- The extent of their similarity is to be established in each specific case

I.Repin. Zaporozhje Cossacks are writing a letter to Turkish sultan

W.Kandinski. Cossacks

Model Quality Assurance (QA)

- Tests of individual modules (development stage)
- Sensitivity runs
- Model-measurement comparison
- Model-model comparison

Model-measurement comparison

- The only connection between model and reality
- Data sets from different origin
  - point observations vs grid-mean model results
  - representativeness error
  - instrumental errors
- Observations are expensive => sparse
- Limited number of observed variables
- Specific statistical methods are required to obtain non-trivial conclusions

Model inter-comparison

- Useful if lacking measurements
- Similar features of data
- Large data sets => high accuracy
- Wide variety of analytical methods
- Ensemble model

- Possibly, no connection to reality

Summary

- Distribution of an atmospheric pollutant is described via dispersion equation, which is a representation of the mass conservation law
- Duality of dispersion problem allows for usage of forward and adjoint dispersion equations
  - identical final results – the load
  - choice depends on specific task
- Model quality assurance implies several actions and covers ALL stages of the model development