

# Air quality forecasting and assessment at FMI

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September 3, Helsinki, Finland



## Air pollution

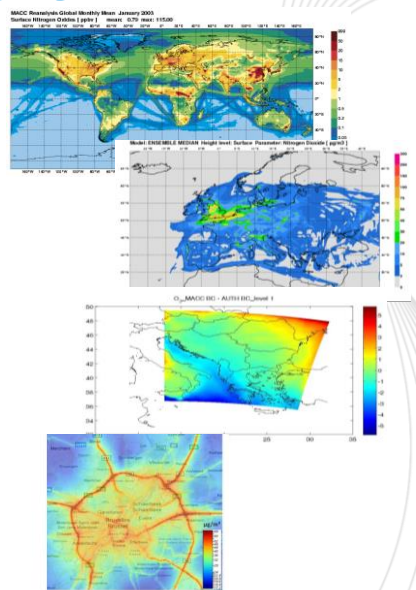
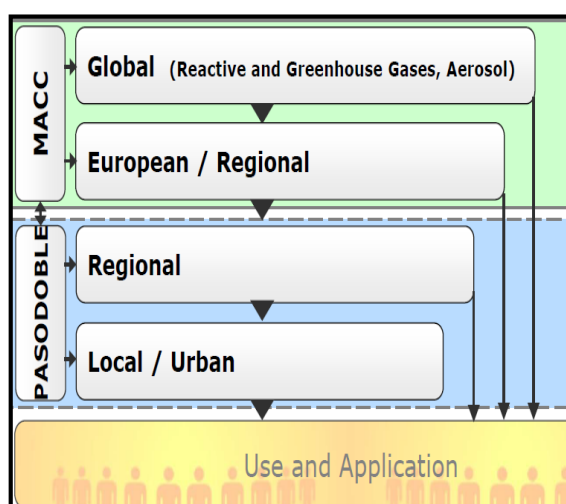
- Sources:
  - Anthropogenic
  - Biogenic from vegetation
  - Natural (e.g. sea salt and dust)
  - Wildland fires
- Important facts:
  - Marine traffic: 40% of NO<sub>x</sub> and 50% of SO<sub>x</sub> of total-European anthropogenic emission
  - Wild-land fires: on average contribute 10-50% of European anthropogenic emission of PM and some gases (e.g. CO)
  - AQ problems can have a regional/local or transboundary origin
  - Transport-related air pollution is increasingly contributing to environmental health risks in many countries.



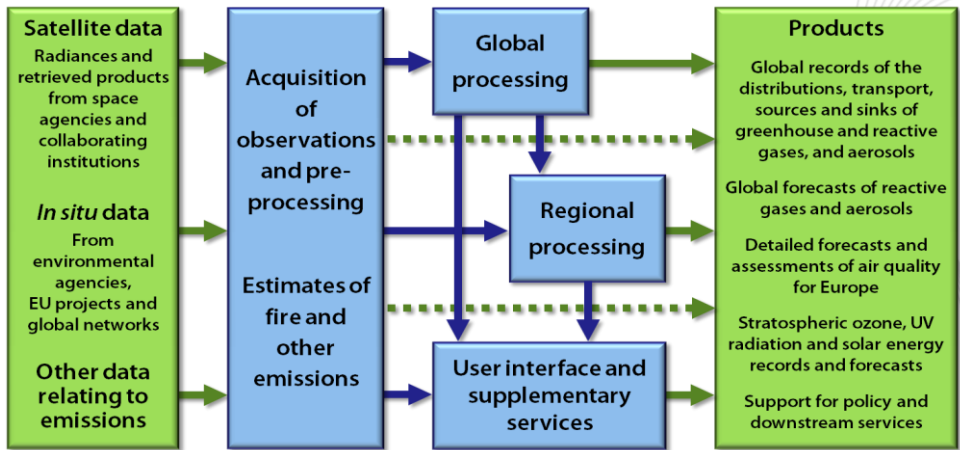
## Air quality forecast & assessment

- Goals:
  - information to public and authorities
  - AQ forecast: decision support for short-term abatement
  - AQ assessment: analysis for long-term decision-making
- Main regulated species in Europe:  $O_3$ ,  $NO_2$ ,  $SO_2$ ,  $PM_{2.5}$ ,  $PM_{10}$
- AQ forecasting/assessment: numerical models applied from global to national level
- Ensemble forecasting: MACC (Monitoring of Atmospheric Composition and Climate)

## European service chain



# Project Structure and Main Products

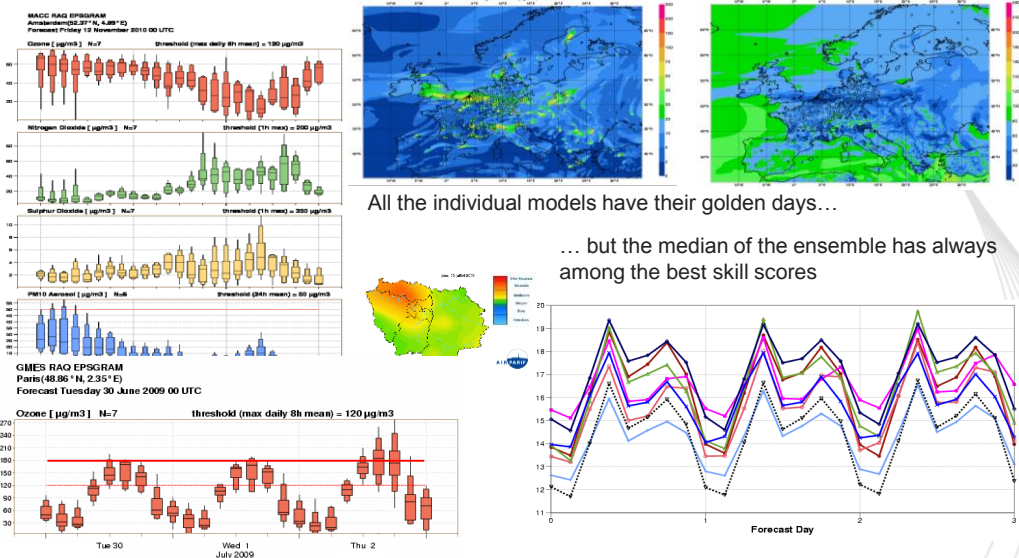


MACC is coordinated by ECMWF and the consortium comprises 36 partners from 13 countries.

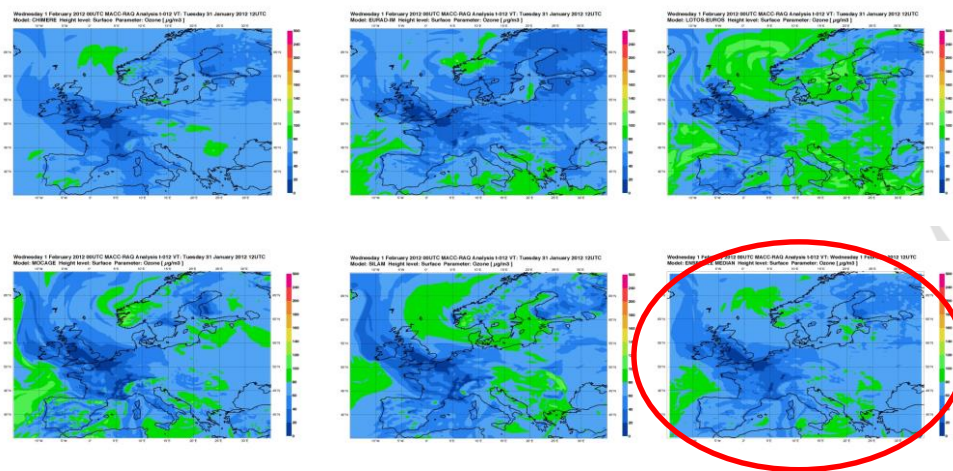


# Why an ensemble approach?

An ensemble of models provides additional useful products...

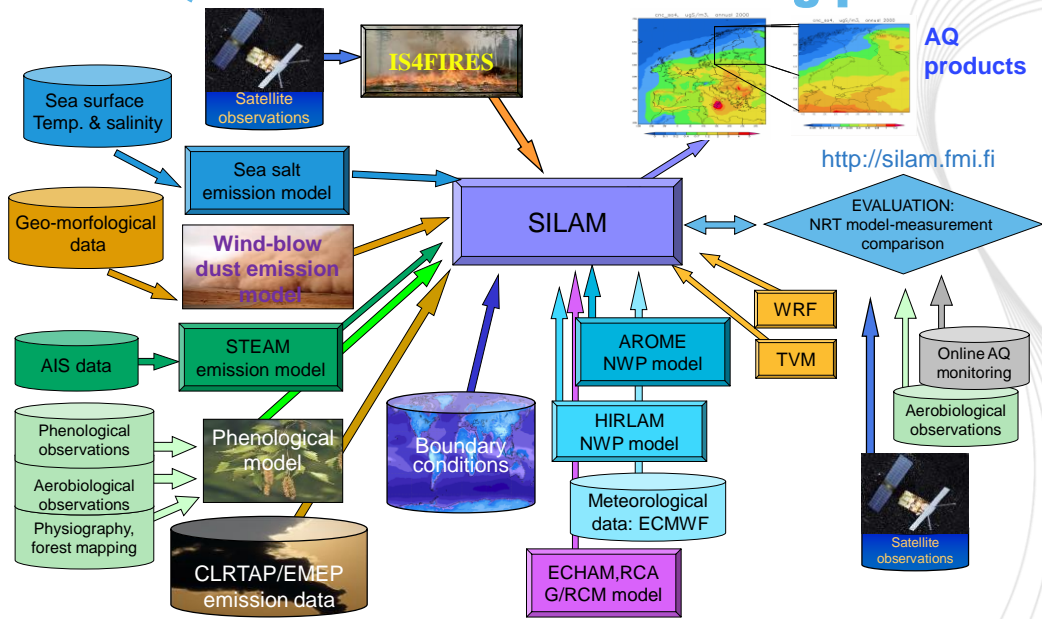


# Ensemble of European AQ Analyses



Improved timeliness of dataflow could permit to base forecasts and further improve skill

# FMI AQ assessment & forecasting platform

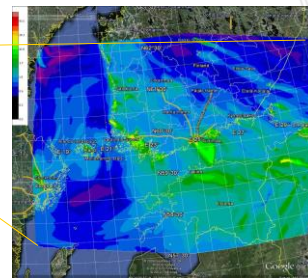
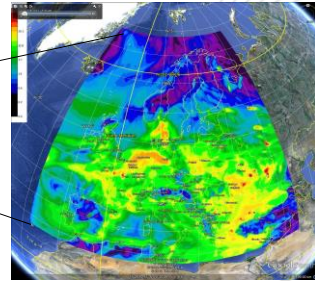
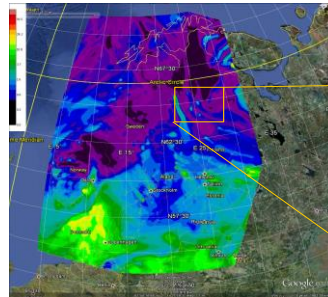
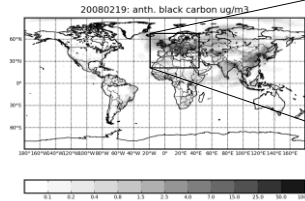




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## SILAM scales

SILAM is  
suitable from  
global to  
smaller scales  
(3 km)  
simulations



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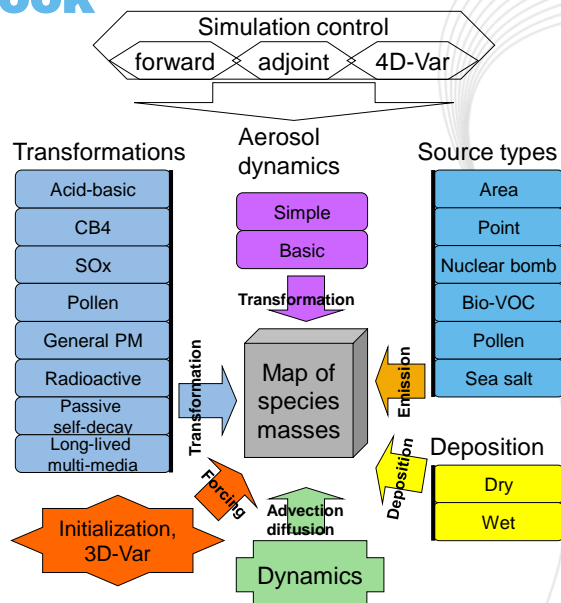
## SILAM v.5: outlook

### 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

### Meteo input:

- ECMWF
- HIRLAM, AROME, HIRHAM, ECHAM, and any other who can write GRIB-1 or GRIB-2
- WRF





## SILAM application types

- **Short-term forecasting and re-analysis**
  - atmospheric chemical composition
  - allergenic air pollution
  - plumes of wild-land fires
- **Emergency preparedness**
  - nuclear
  - volcanic
- **Observational campaign analysis**
- **Source apportionment studies**
  - anthropogenic sources
  - natural sources: allergenic pollen, volcanoes, fires
- **Risk assessment**
  - chemical
  - nuclear
- **Climate change forcing and impact**

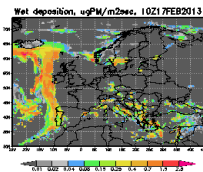
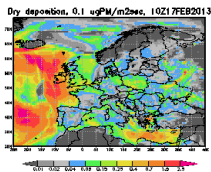
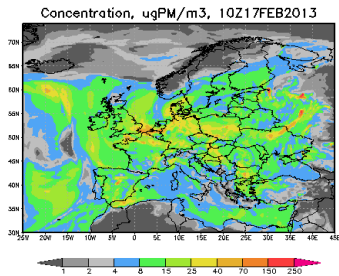
## SILAM network

- SILAM is a open-code system
  - Available from Web: ~40 downloads, over 15 countries
  - Known working installations: Estonia, Russia, Lithuania, Spain (2), FYR Macedonia
- SILAM system is a joint effort of
  - Finland: FMI, University of Helsinki, University of Turku, VTT Energy
  - Russia: Main Geophysical Observatory, Hydrometeorological University
  - Estonia: University of Tartu
  - Austria: Medical University of Vienna
  - Israel: Ben Gurion University
- SILAM algorithms in:
  - sea salt emission: EURAD (Germany), WRF-Chem (US)
  - pollen emission: GMES MACC-2 modelling ensemble (CHIMERE, EMEP, EURAD, LOTOS-EUROS, MATCH, MOCAGE)
- SILAM users
  - Finland: Helsinki Metropolitan Area Council, University of Turku (forecasts)
  - Estonia: University of Tartu (boundary conditions)
  - Lithuania: EPA (forecasts), Vilnius city (boundary conditions)
  - European Aeroallergen Network (forecasts)
  - FYR Macedonia: Macedonian Environmental Information Center (forecast/assessment)

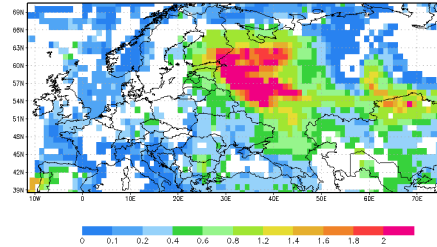
# SILAM application types

Short-term forecasting and re-analysis

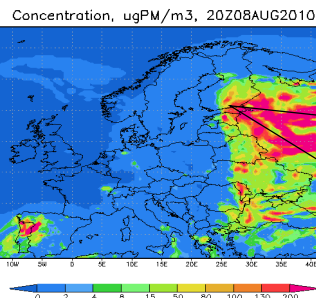
Forecast for PM10. Last analysis time: 20130217\_00



MODIS AOD, 08\_aug\_2010



Forecast  
Last a

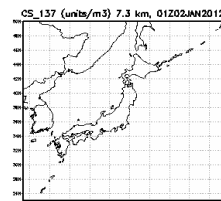
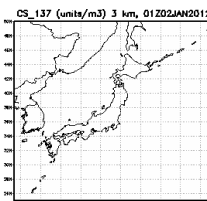
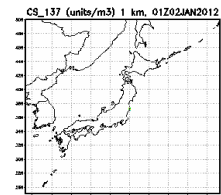
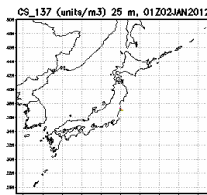
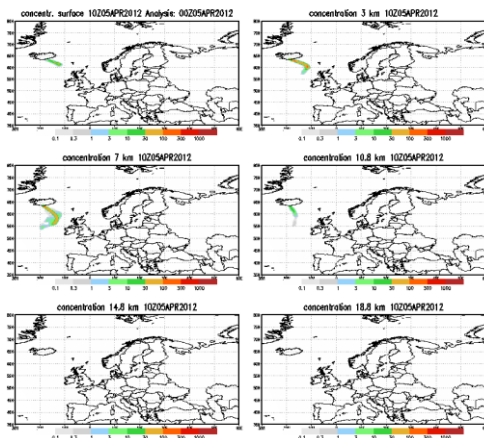


Virolahti,  
8.8.2010  
Predicted  
(+24hrs):  
120 ug  
PM2.5 / m<sup>3</sup>  
Observed:  
140 ug  
PM2.5 / m<sup>3</sup>

# SILAM application types

Emergency  
preparedness

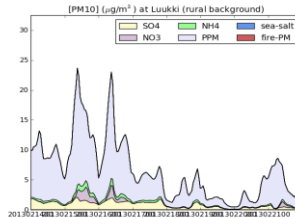
Nuclear



Volcanos

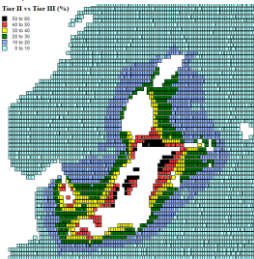
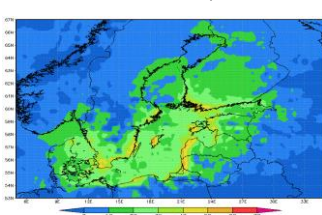
# SILAM application types

## Observational campaign analysis

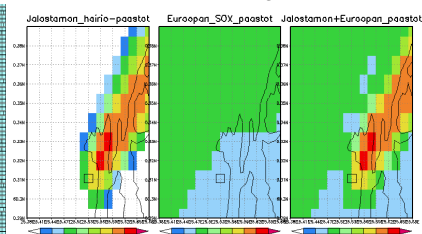


## Risk assessment

Impact on ecosystems (N deposition)  
and human health (N concentration)

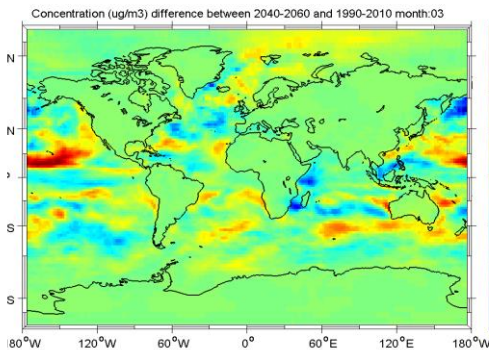


Impact of an uncontrolled release on  
the surroundings of the stack



# SILAM application types

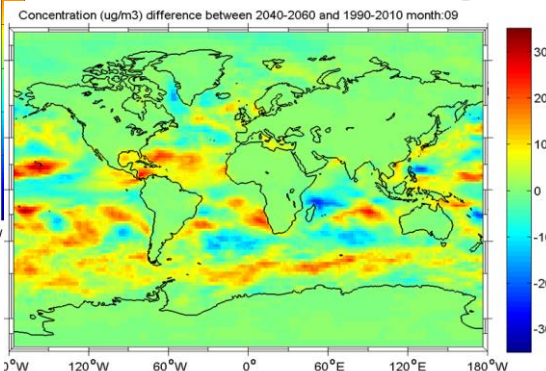
## Climate change forcing and impact



March

Closer to equator the concentration  
difference between current and future  
climate periods are substantial –  
increase of temperature

SSA concentration: Mean 2040-2060 vs  
Mean 1990-2010 (difference)



September

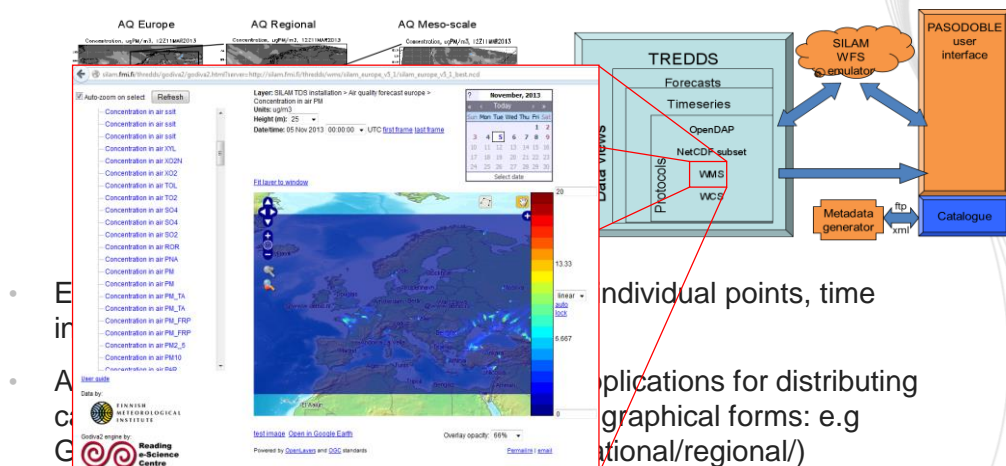


## Data users/providers

- Relies on the availability of MACC 2 and PASODOBLE products related to different pollutants for assessment and decision making
  - Boundary condition
  - Emissions
  - Ground and remote sensing data
- Forecast & reanalysis:
  - Boundary conditions
  - Concentrations, emissions
- AQ assessment:
  - long-range pollution transport impact on AQ in remote areas, for local level decision makers
  - Impact of AQ policies

## THREDDS

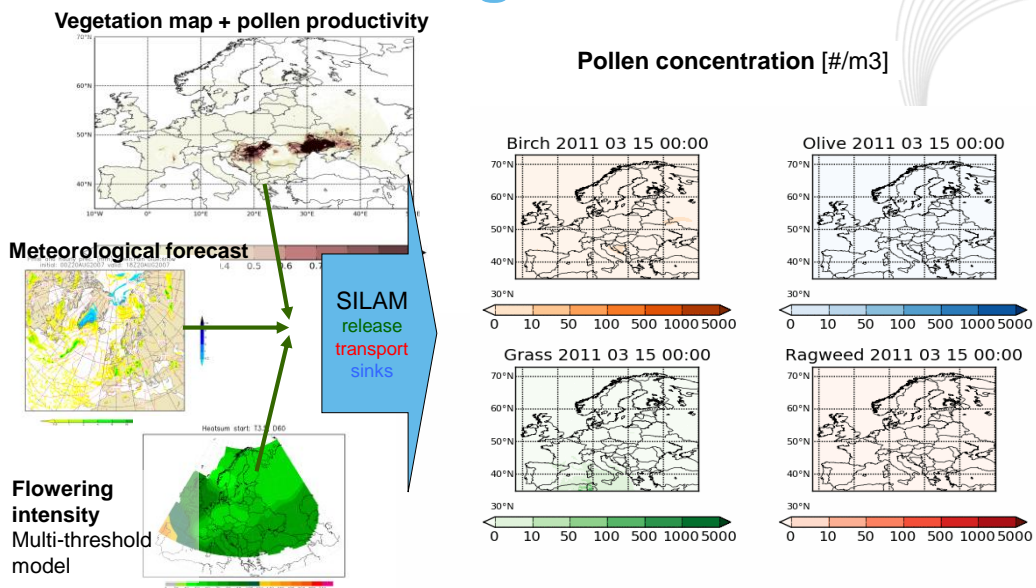
- SILAM operational forecast data availability via interfaces was setup within MACC and PASODOBLE projects



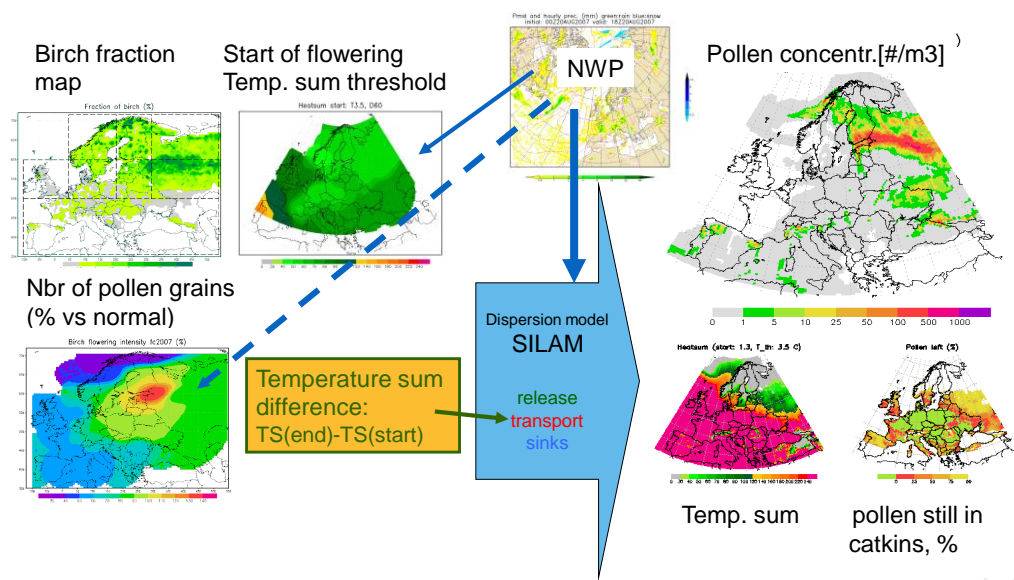
# Ground-breaking forecast: Pollen

- Goals
  - Support pollen allergy forecasting groups and organizations
  - Produce the best forecast: optimal combination of pollen monitoring and modelling
- Questions
  - Where does it grow?
  - When does it flower?
  - How much pollen does it produce?
- Tools
  - SILAM (Europe, zoom to N.Europe: birch, grass, olive, ragweed)
  - COSMO-Art (C. & W.Europe: birch, grass, **ragweed**)
  - EnviroHIRLAM (N.Europe: birch).
  - MACC 7-model ensemble (Europe: birch)

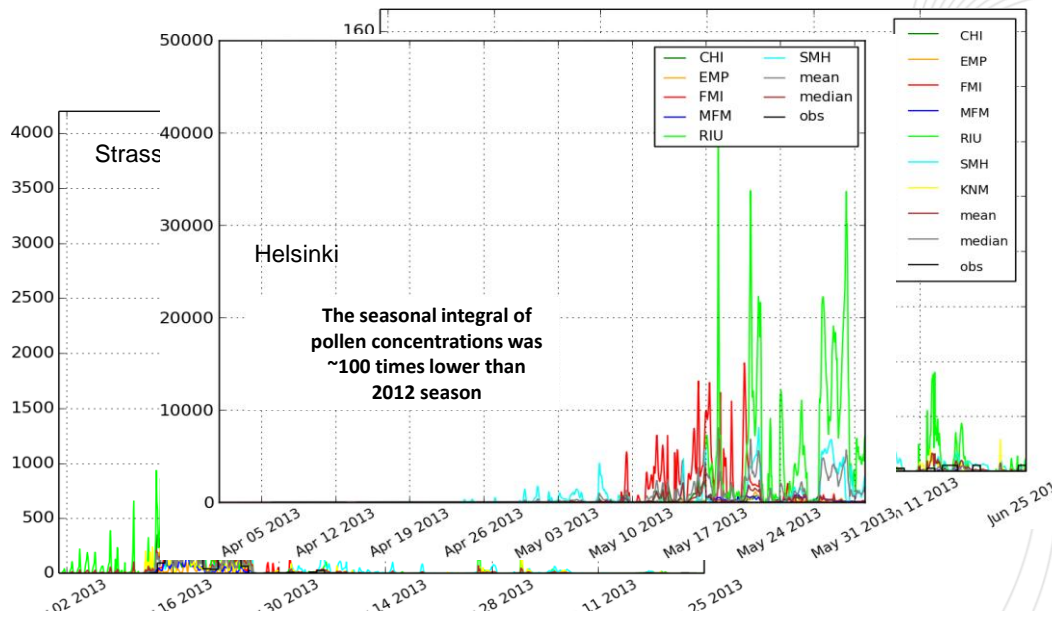
# Ground-breaking forecast: Pollen



# SILAM-Birch/Olive pollen forecasting system



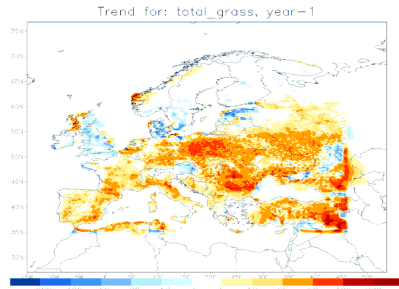
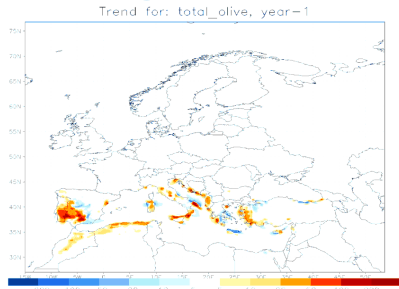
## Re-analysis: predicted vs measured



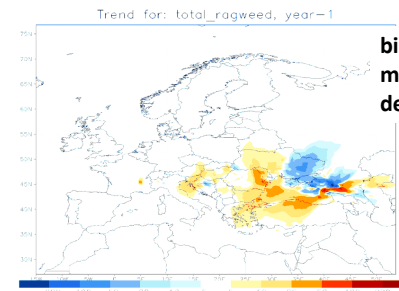
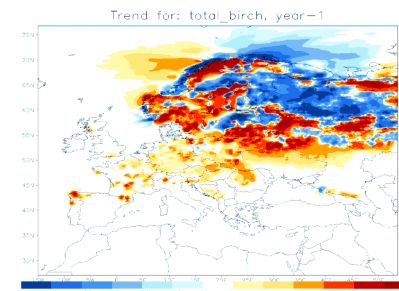


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# 30-years modelled trends



grass, olive:  
mainly increase



birch, ragweed:  
mixed, mainly  
decrease

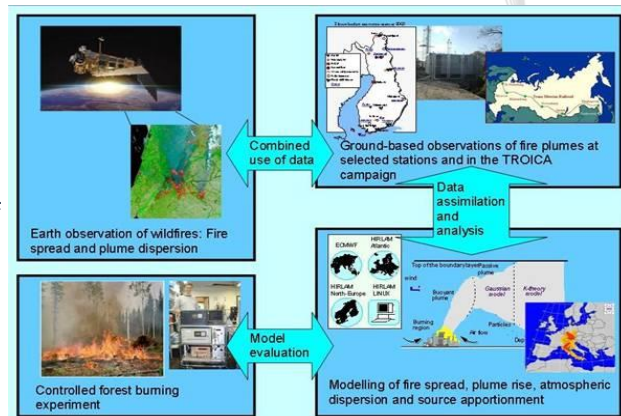


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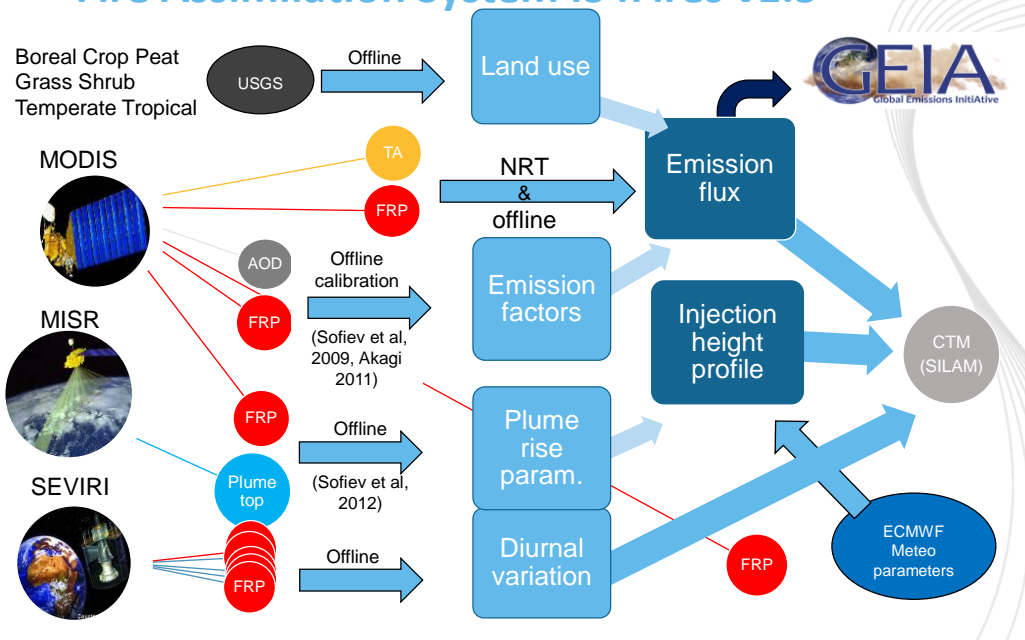
# Ground-breaking forecast: Fire

Goals of a fire system are to forecast the fire emissions and plume dispersion and support AQ assessments

- detecting major wildland fires: remote sensing and ground-based observations (location, intensity, spread, and height)
- modelling both the spread of the fires in the terrain and dispersion of the fire plumes in the atmosphere

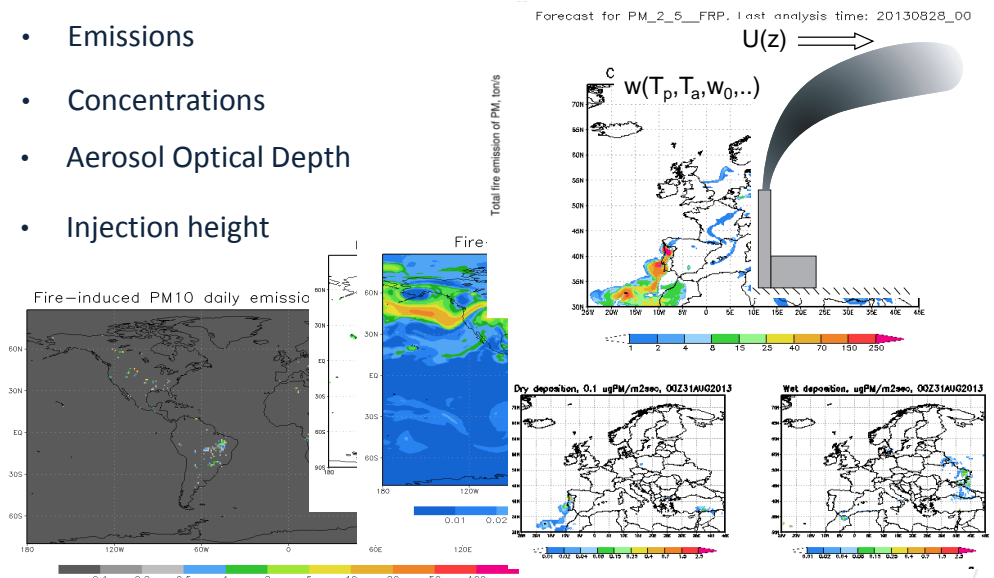


# Fire Assimilation System IS4Fires v1.5



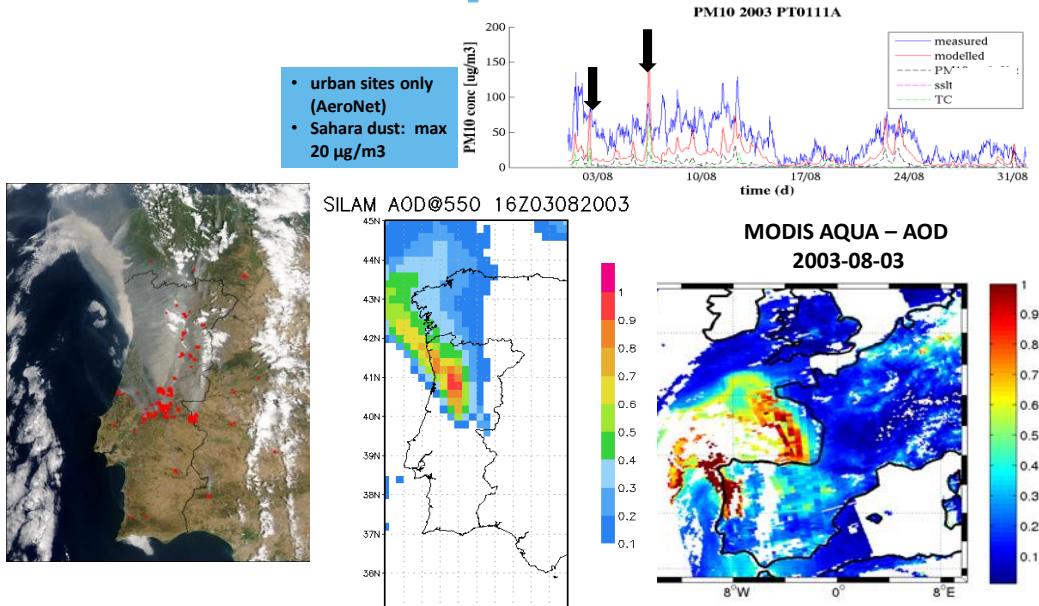
# Fire Assimilation System: products

- Emissions
- Concentrations
- Aerosol Optical Depth
- Injection height





## Fire season 2003: prediction vs observed



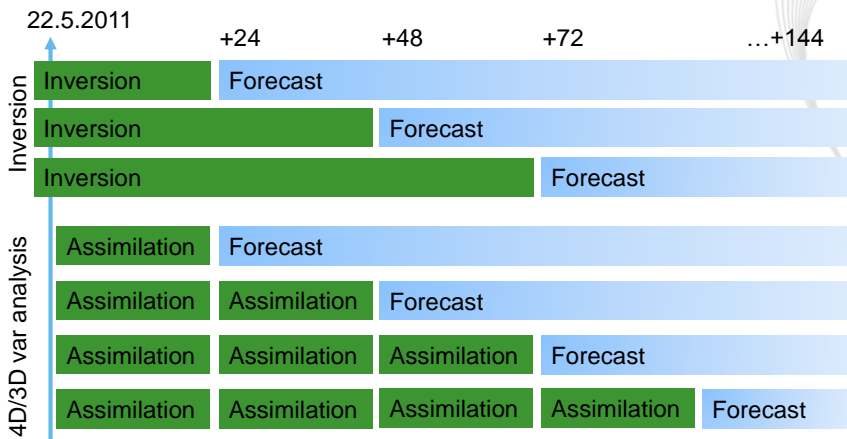
## Volcanic data assimilation

- So far performed only emission inversions in VAST:
  - use 4D-Var method to evaluate source term, then perform regular forecast
- What about traditional 4D/3D-Var
  - no source term adjustment, but concentration field updated at start of each assimilation window
- Pros/cons
  - + no information needed on eruption site or timing
  - + assimilation can correct for transport errors
  - + 3D-Var computationally cheap
  - - eruption location/time not used as a priori information
  - - no information gained about source term

# The assimilation experiment

- Grimsvötn 2011 eruption
- OMI (NASA) SO2 data
- Simulation period 22.5.2011 till 28.5.2011
- Increase assimilation period in steps of 24 h
  - emission inversion performed for 24, 48 and 72 hours of data followed by forecast
  - 4D-Var assimilation (“analysis” run) in cycled 24 h windows
  - 3D-Var assimilation hourly if data available

# Experiment setup





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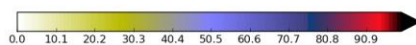
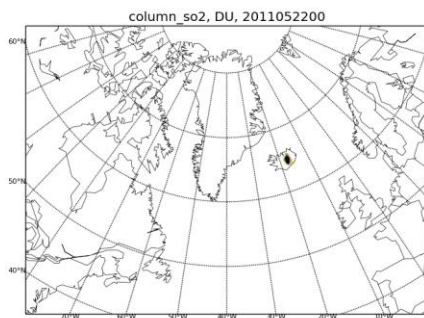
## Assimilation setup & evaluation

- Background covariance model needed for concentration assimilation
  - 50 km horizontal correlation radius
  - no vertical correlations
  - homogeneous background standard deviation equivalent to 1 km layer of 100 DU SO<sub>2</sub>
- Performance scores: correlation computed for OMI data for each forecast day
  - only total columns evaluated here
  - no independent data
- ERA interim meteo data: effect of meteorological forecast length on the dispersion forecast not considered

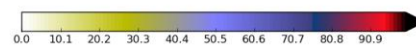
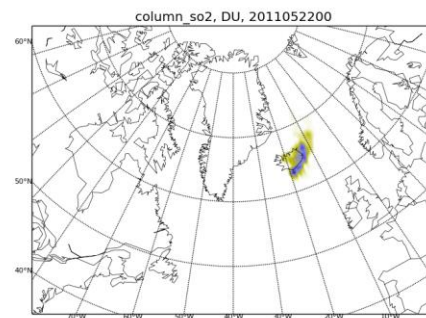


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## Total columns: analysis vs inversion

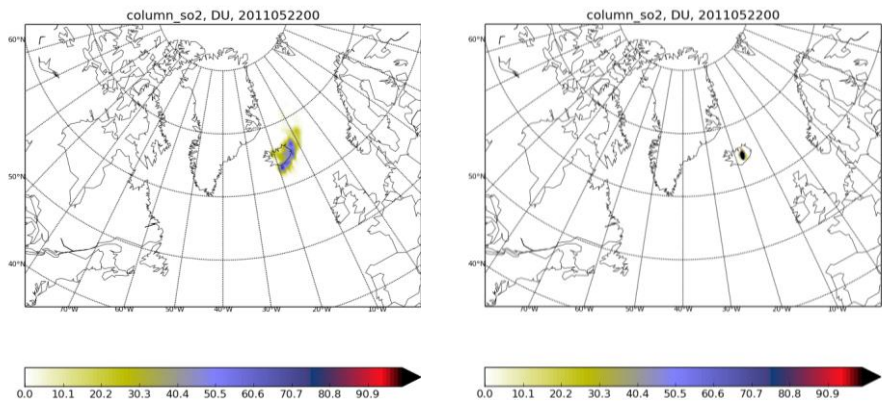


72 h inversion + forecast



72 (3\*24) h assimilation

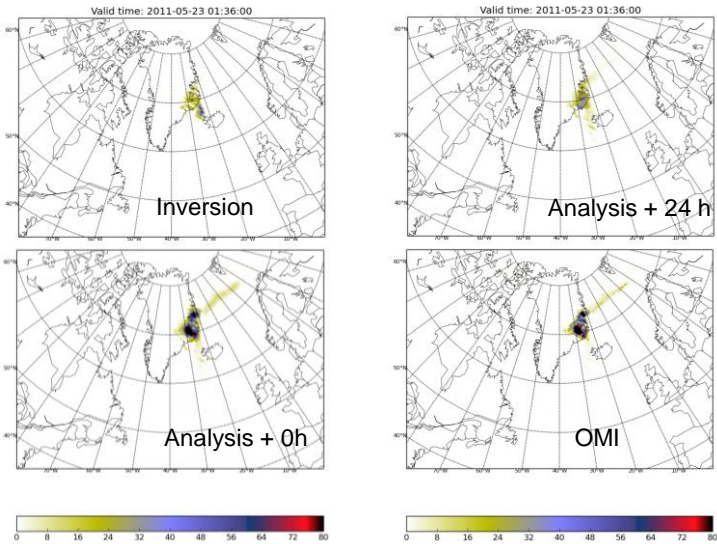
# Total columns: 22.5.2011 ...



Total column at first analysis time:  
this plume never existed

Corresponding map with inversion:  
SO2 attributed to the source term

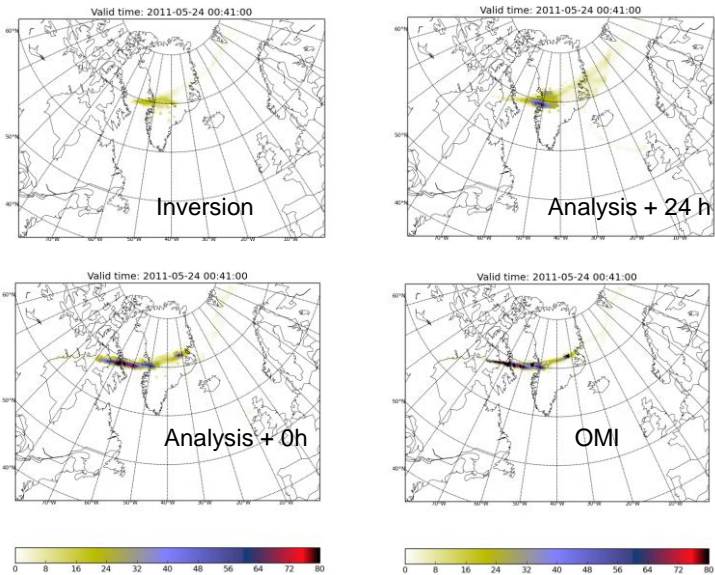
# Column densities, DU, 23.5.2011



Daily  
composites

Model data  
interpolated to  
OMI pixels

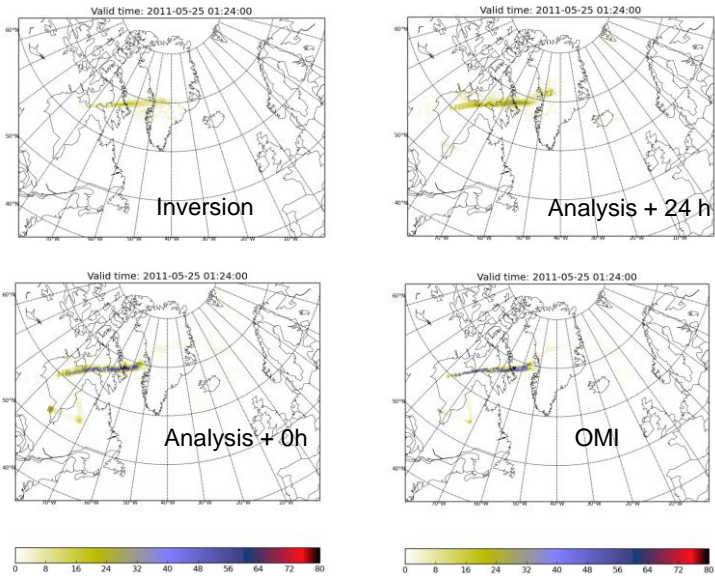
# Column densities, DU, 24.5.2011



Daily  
composites

Model data  
interpolated to  
OMI pixels

# Column densities, DU, 25.5.2011

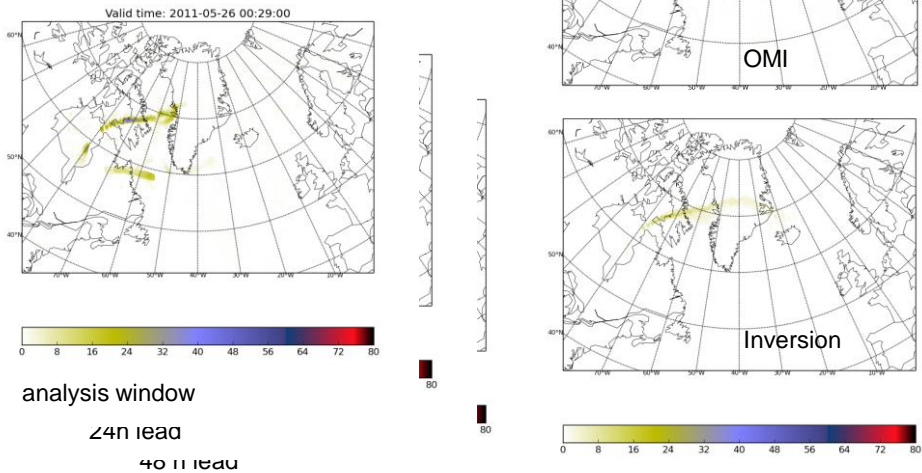


Daily  
composites

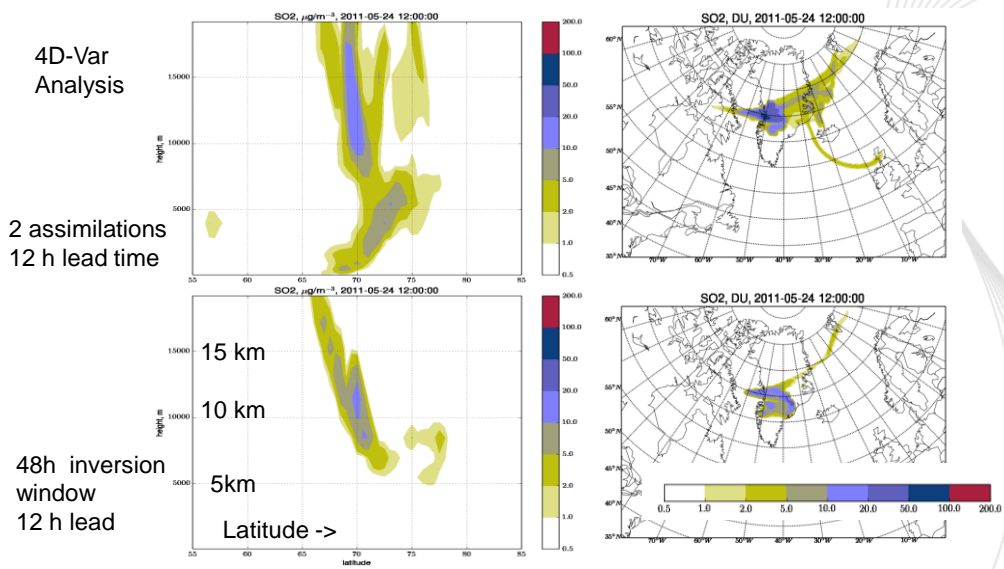
Model data  
interpolated to  
OMI pixels



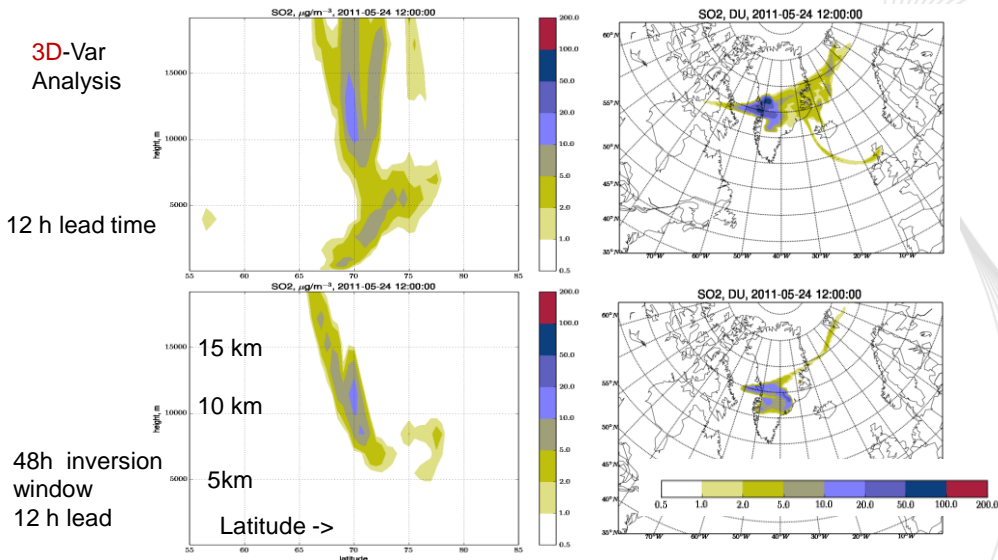
# Effect of forecast lead time



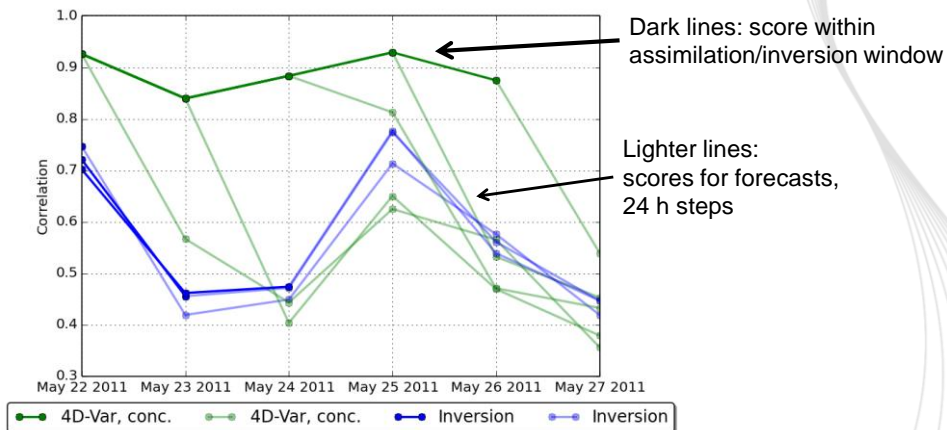
# Comparing zonal means



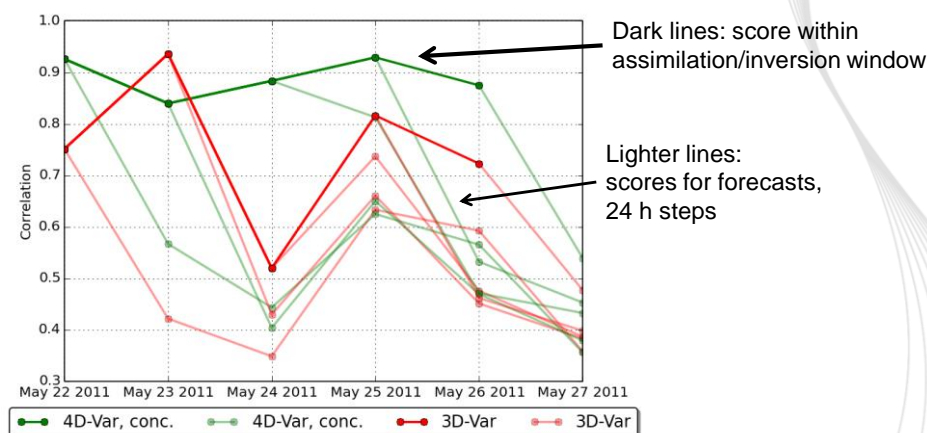
# Comparing cross sections, 3D-Var



# Comparing statistics: correlation 4D-Var analysis vs inversion



## Comparing statistics: correlation 4D vs 3D-Var



## Conclusions

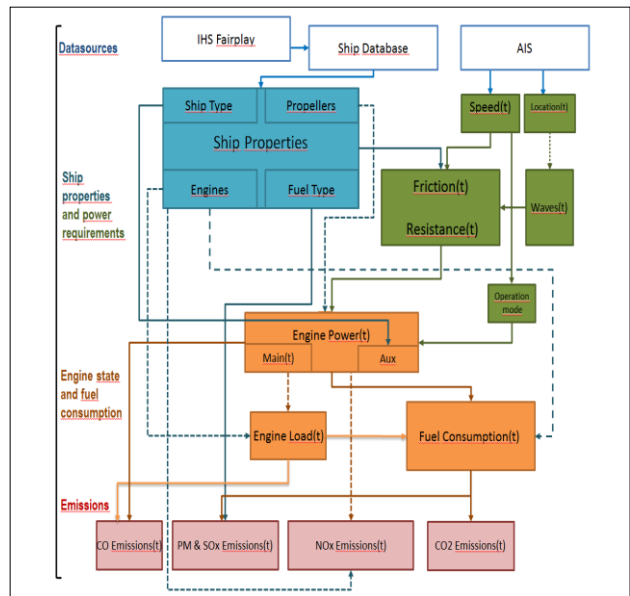
- For the Grimsvötn eruption, concentration-only 4D-Var feasible, but emission inversion has advantages
- For forecasting total columns:
  - analysis generally better for 24 h forecasts, inversion better for longer 48-72 h
  - 4D-Var somewhat better than 3D-Var
    - ~10-20x slower
    - but not expensive in absolute terms
- 4D/3D-Var analyses lack vertical structure: key advantage of including emission
- Flemming & Inness (2013, JGR) obtained similar conclusions with IFS and preferred doing both inversion and analysis
  - doable with separate 4D-Var for inversion and analysis
  - our goal: combine the approaches into a single inversion/analysis step

# Emission model

## Ship Traffic Emission Assessment Model (STEAM)

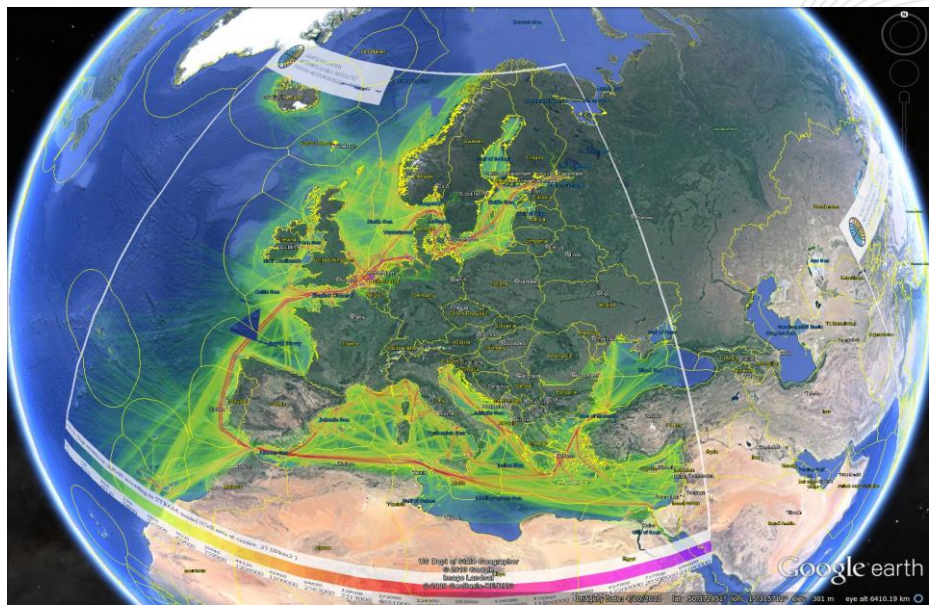
- Aim: General applicability
  - Local-Regional-Global
- Emission abatement included

28.10.2015



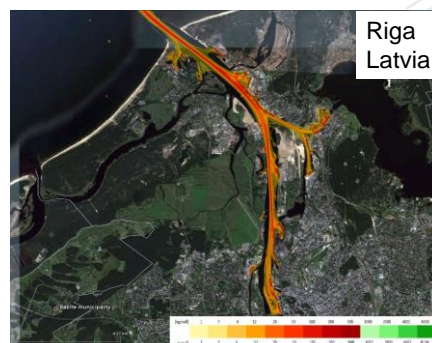
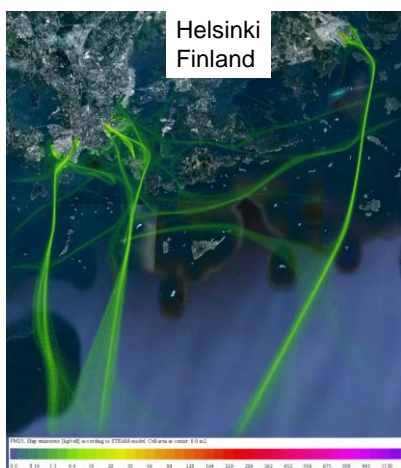
J.-P. Jalkanen, L. Johansson, J. Kukkonen, A. Brink, J. Kalli, and T. Stipa, Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide, *ACP*, 12 (2012) 2641-2659.

## Emissions CO<sub>2</sub> from ships in Europe, 2011





# Harbor emissions



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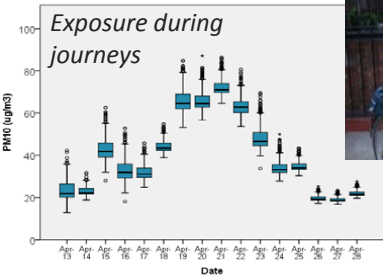
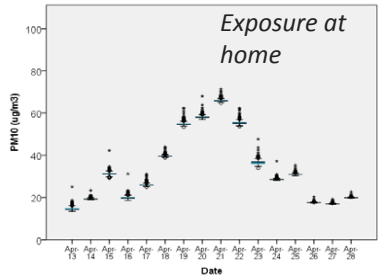
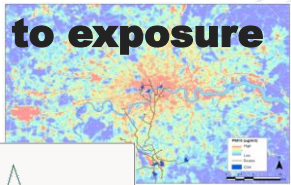
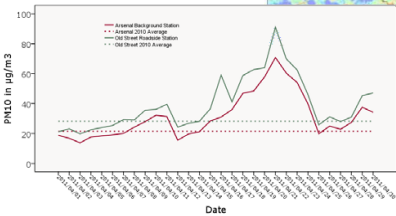
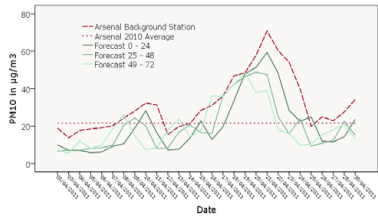
## Summary

- Observations and modelling of both natural aerosols and chemical pollutants exist and can be used for information services
- All SILAM numerical products are presently distributed via THREDDS Services. Animations are provided via original FMI interface, Google Earth, and WMS. Rolling archive ~2 TB
  - Pollen : birch, grass, olive, ragweed
  - Dust and sea salt
  - Chemical pollutants covered NO<sub>x</sub>, SO<sub>x</sub>, NH<sub>x</sub>, O<sub>3</sub>, VOC
  - PM: anthropogenic and fires
- Inter-annual variability and trends are available
  - Pollen & chemical pollutants
- Impact on AQ due to climate change is available



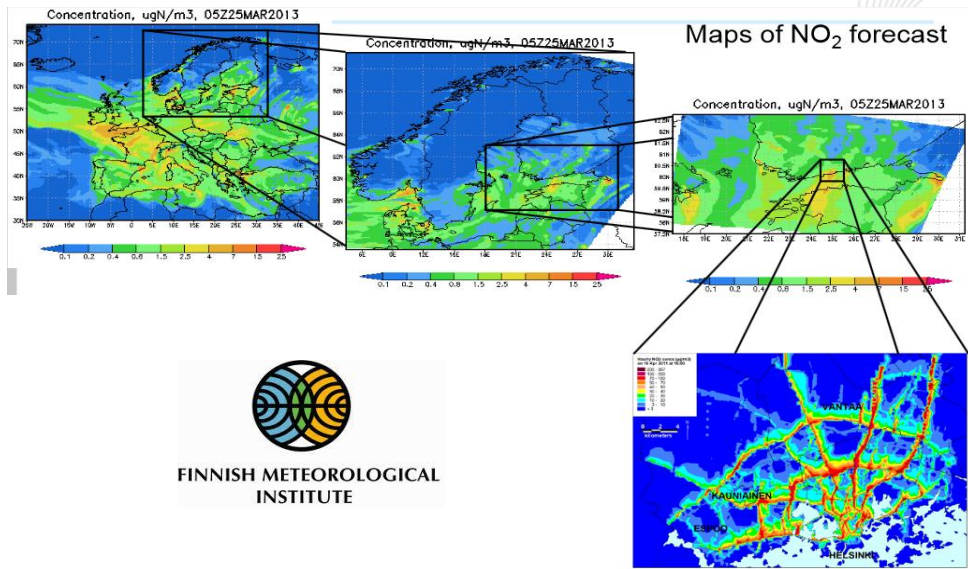
# From model forecasts to exposure

London April 2011 high PM event



Imperial College  
London

# Thank you!



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