Volcanic plume modelling and assimilation with the global MACC system (with emphasis on SO_2)

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Introduction

- How can we use timely observations in combination with data assimilation for initial values to improve the MACC forecasts of volcanic eruptions ?

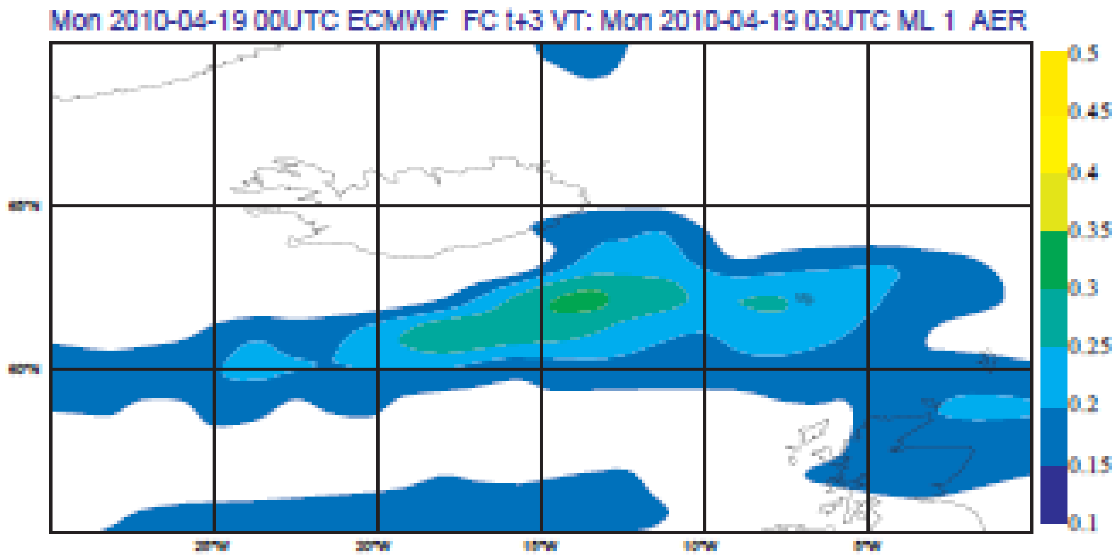
- Eyjafjallajökull eruption in 2010 set the agenda

  ➔ The MACC data assimilation system needs to be improved to be able to assimilate plume observations (retrievals)

  ➔ Estimates of injection profile and emission rate are essential for reasonable forecasts

- MACC makes forecast and analyses volcanic aerosol and volcanic SO_2 using the Integrated forecasting system (IFS) of ECMWF (4DVAR, NWP forecasting model with a semi-lagrangian advection scheme)

First Attempts …in April 2010



from Benedetti et al. 2012

Figure 1: Sea salt plume off the coast of Iceland on April 19, 2010 at 030UTC.

- MODIS AOD north of 60N blacklisted
- No volcanic aerosol tracer
- No assimilation of volcanic SO_2 retrievals
- Forecast runs with arbitrary emissions

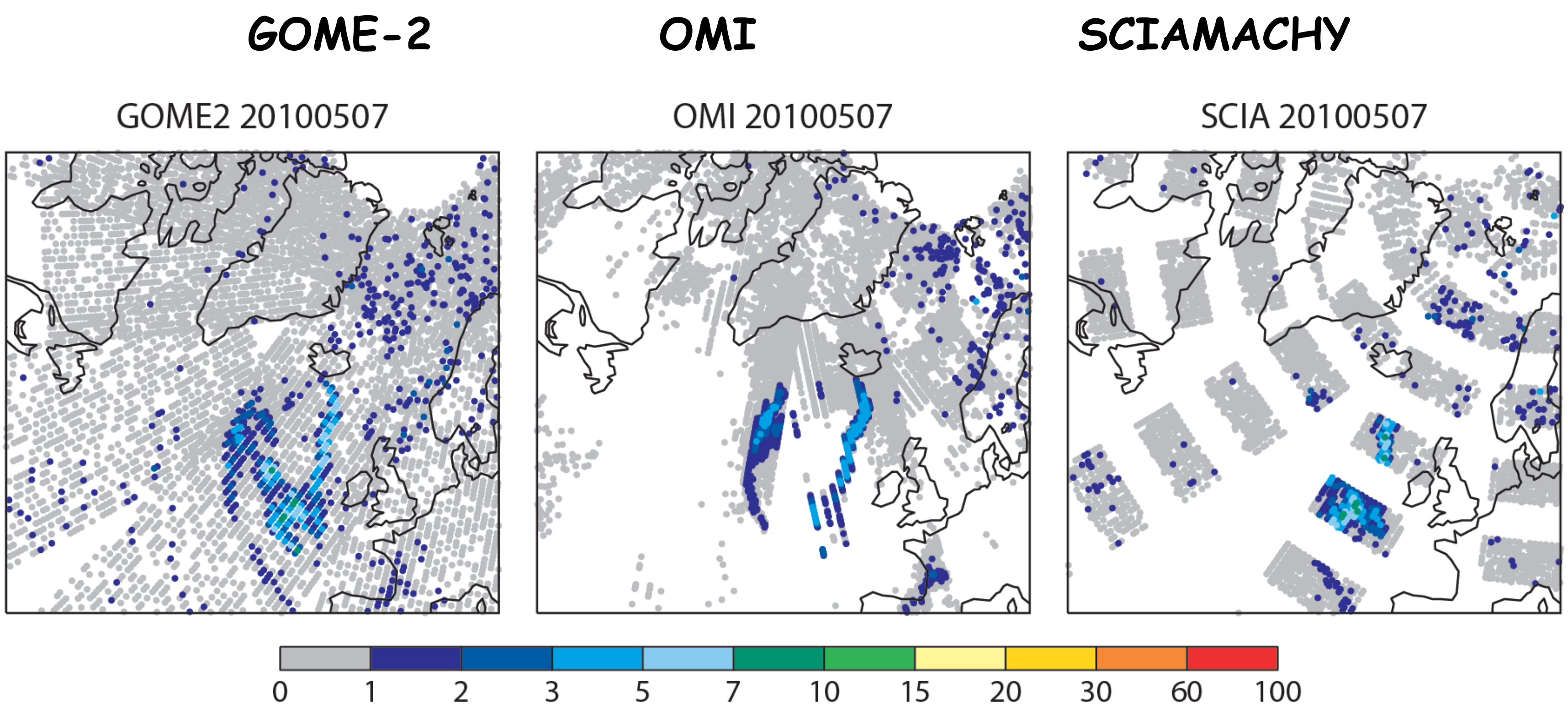
Recent Developments: Forecast and Assimilation of volcanic Ash and SO_2 Plumes

- Assimilation of MODIS AOD to change proportionally modelled aerosol species
  - ➔Introduce volcanic aerosol model (new)
  - ➔Relax quality criteria to not filter out volcanic signal
- Assimilation of middle-trop to strat UV SO_2 retrievals
  - ➔Volcanic SO_2 model field and loss terms
  - ➔Optimise DA for plume assimilation (specific background error statistics, variable transformation)
- Method to estimate injection height and emission flux from UV SO_2 retrievals

Parameter Estimation and Data Assimilation for SO_2 Plume Forecasts

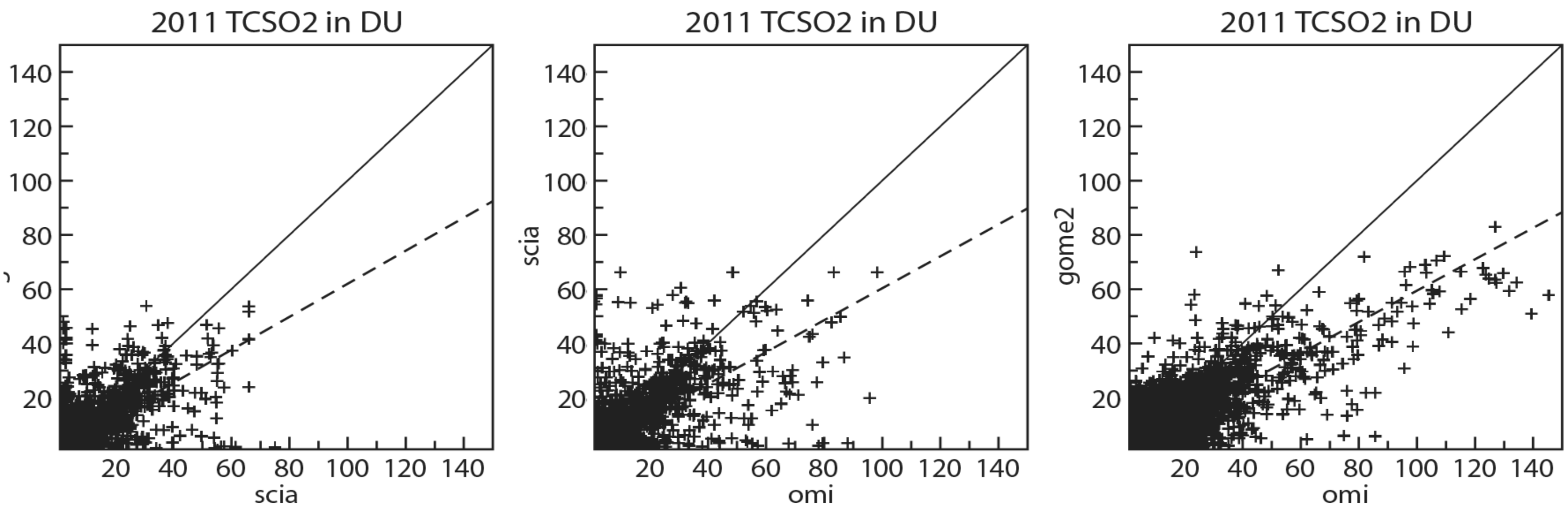
- What are can be inferred from satellite SO_2 retrievals to make (good) SO_2 plume forecast?
  - ➔ Initial conditions (DA)
  - ➔ Emissions flux (PE)
  - ➔ Injection profile (PE)
  - ➔ SO_2 life time (PE)
- Are the SO_2 retrievals providing the required information ?
- How important is meteorological forecast error and realism of model transport by the IFS ?
- How to represent uncertainty ?
- Test cases: 2011 Grímsvötn and 2010 Eyjafjallajökull erruption

Spatial and temporal Coverage – Total Column SO_2 retrieval



- Good coverage essential (GOME-2 is best)
- No night time retrievals for UV instruments
- No vertical information

High TCSO2: OMI vs GOME-2 vs SCIA

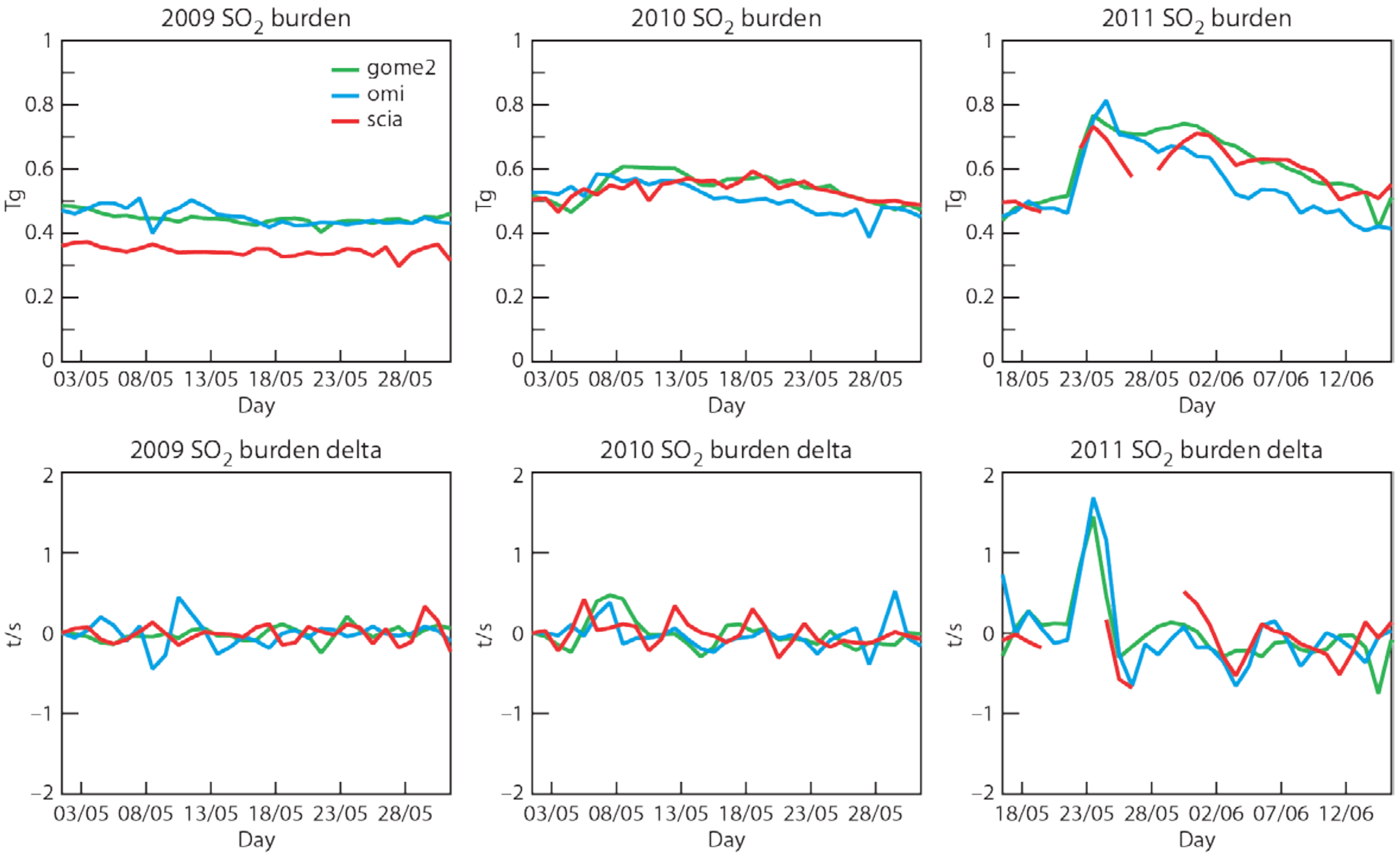


Gridded observations
OMI tends to have highest maxima

Grimsvoetn 2011

Variability of observed SO_2 Burden used to estimate Emissions

SO_2 Burden 4000 km around Iceland



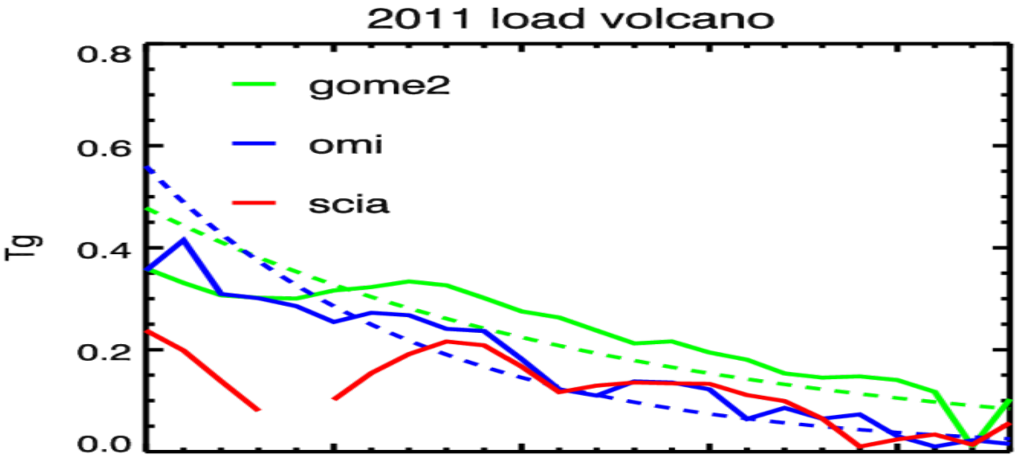
Total SO_2

Delta SO_2

No eruption | Eyjafjallajökull | Grimsvötn

SO_2 Lifetime Estimate from SO_2 Retrievals

- Use reduction of observed SO_2 burden to estimate lifetime after end of eruption



$SO_2 \rightarrow SO_4$

$dSO_2/dt = - k\ SO_2$

$SO_2(t) = SO_2(0) \exp(- t/T)$

- “GOME-2 Lifetime” : 15 days
- “OMI-Lifetime” : 9 days
- No really exponential loss
- According to exponential loss obs have too low SO_2 in the concentrated plume at the start

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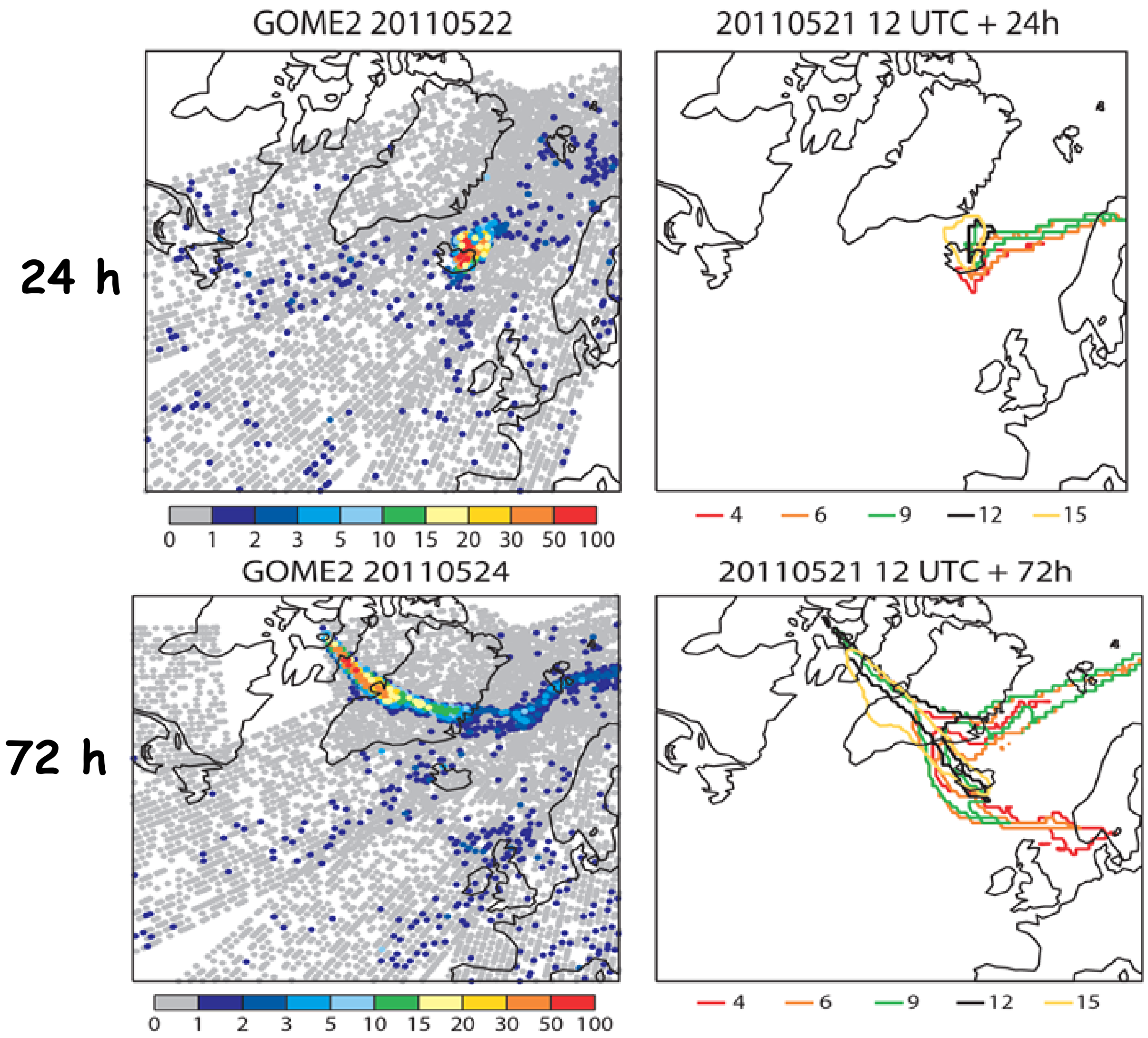
Emission and Injection Height Estimate using Ensembles of Tracers

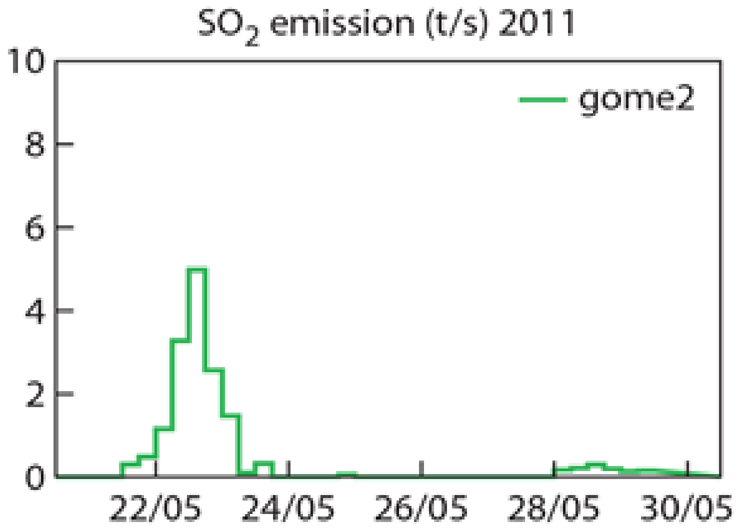
- Simulate test tracers with fixed emission rate (1t/s) injected at different levels up to 24 h before observation
- Find best overlap of test plume with plume observations (1DU)
  - ➔ Identify plume height by plume locations (wind shear)
- “scale” fixed emissions to fit observations in “best” test plume
  - ➔ minimise area to calculate burdens (only area covered by test plumes)
- Refine temporal resolution of estimate with test forecast 18/12/6 h before observation time, if possible

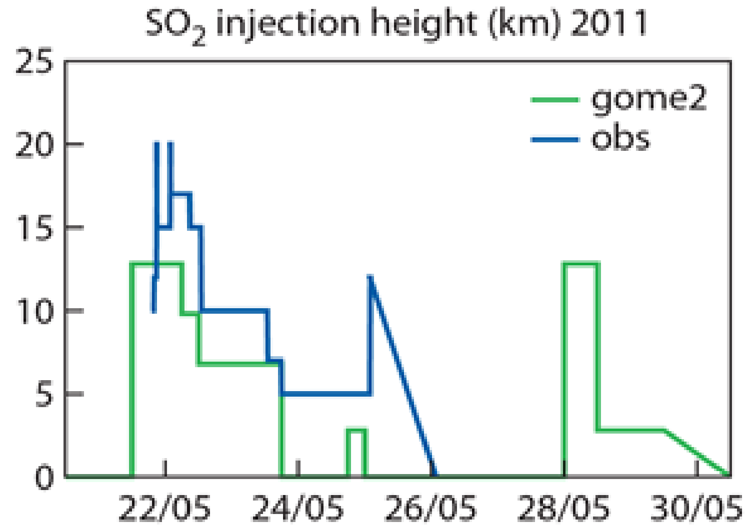
Test Tracer Grimsvötn



Eruption start
19 UTC 21.5.11

Emissions Flux and Injection height - Grimsvötn



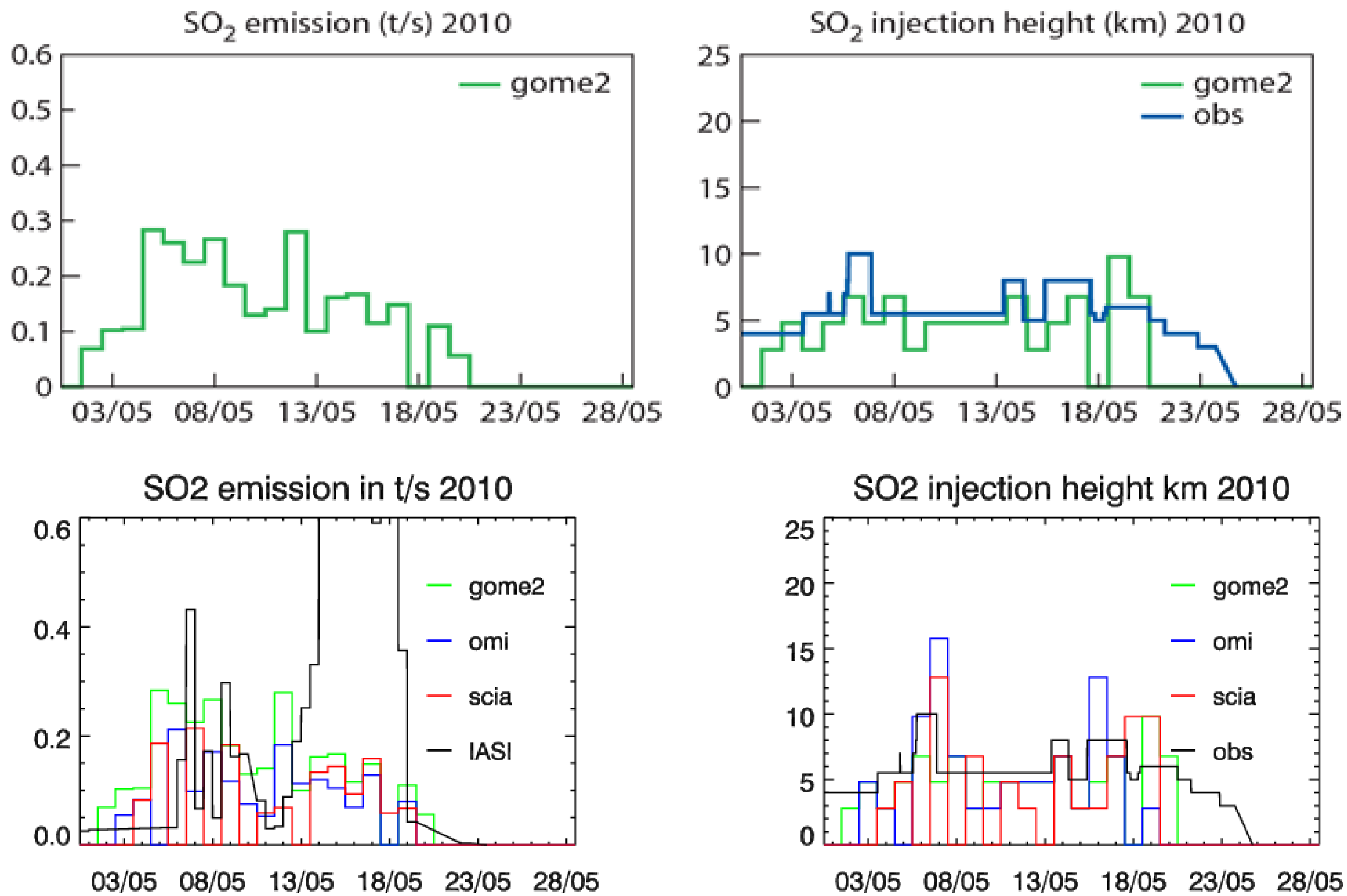


Using GOME-2

Reasonable agreement with plume top height observations from radar

Estimate after 28.5 is artefact caused by plume returning to Iceland

Emissions Flux and Injection height - Eyjafjallajökull



OMI and SCIA estimates more "jumpy" than GOME-2
Larger differences with IASI based estimate by Heard et al. 2012

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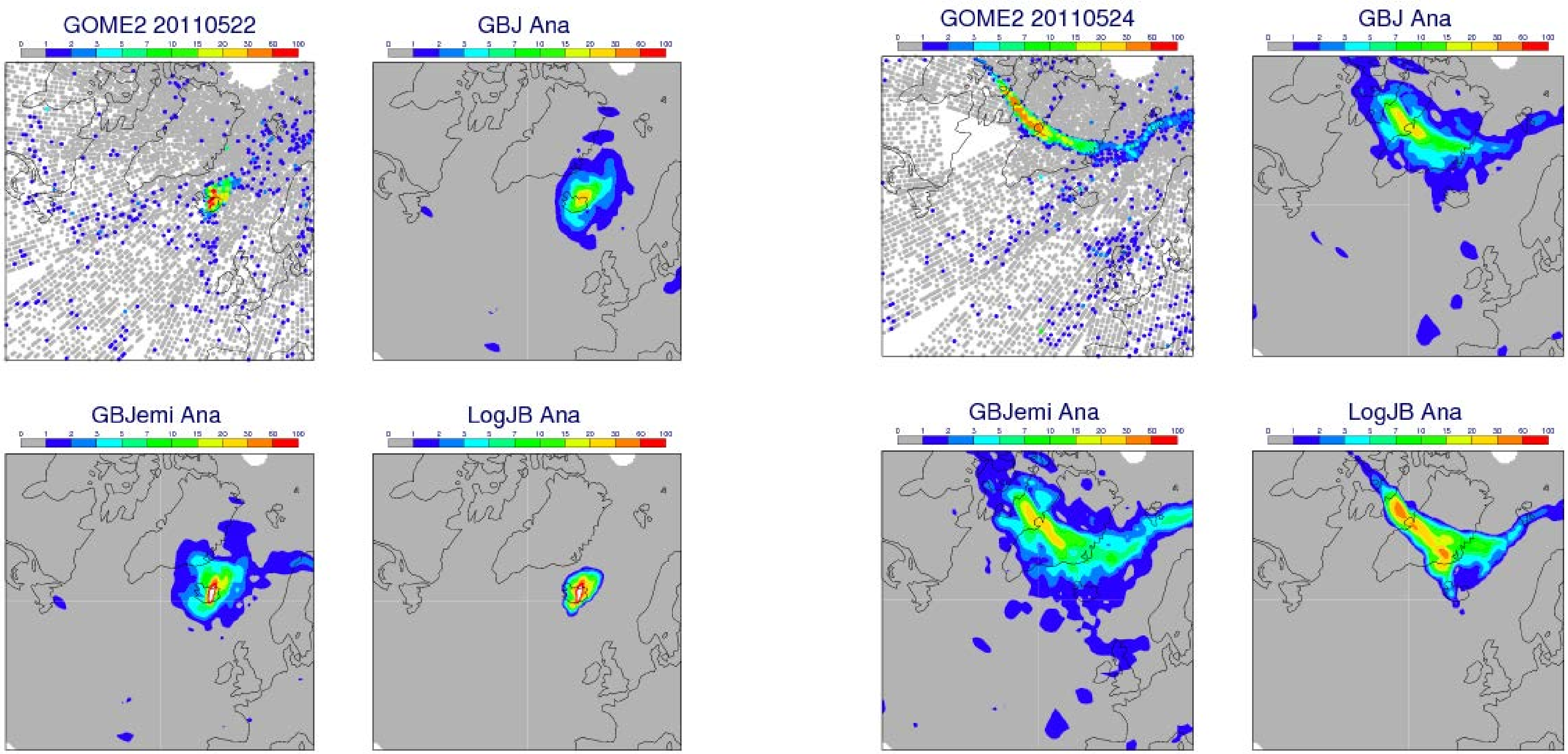
Data Assimilation of volcanic SO_2 (GOME-2)

- Emissions flux in assimilating model yes – no
  - ➔ DA was good in producing plumes but not correcting wrong plumes
- With log-Jb and Normal Jb
  - ➔ Log-Jb required existing plume to be amplified
- “External” plume height information needed to locate plume vertically
- Final setup for SO_2 plume assimilation
  - ➔ Normal JB
  - ➔ minimum > 0.1 DU, no thinning
  - ➔ increased back ground error variance at height of plume – obtained form plume height estimate
  - ➔ 100 km horizontal length scale

SO_2 Analysis Examples

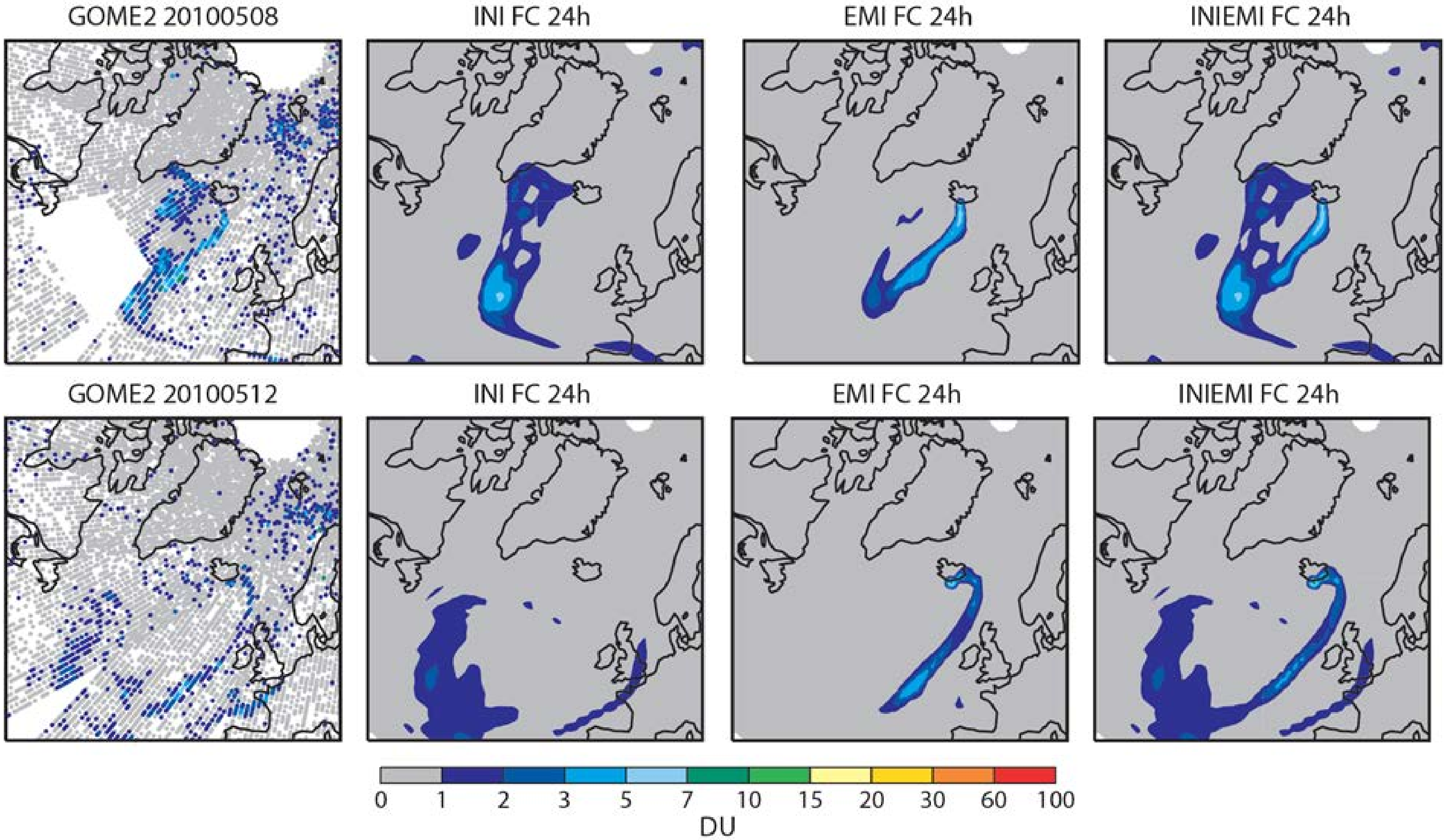


Log-Analysis not "over dispersive" but too high and dependent on a plume in background
Analysis exaggerate plume extent

Initial Conditions vs. / and Emission Parameters

- SO_2 forecasts for 2011 Grímsvötn and 2010 Eyjafjallajökull
- Forecasts configurations:
  - ➔**EMI** : Forecast with SO_2 source parameter (also for duration of forecast)
  - ➔**INI:** Forecast with SO_2 analysis (GOME-2) as initial conditions only and no SO_2 source term (INI)
  - ➔**INIEMI** Forecast with SO_2 analysis as initial conditions and estimated SO_2 source terms
- Daily 12 UTC Forecast over 120 h, T511L60, Mass fixer applied
- Evaluated with GOME-2 - How good can we forecast tomorrow TCSO2 plume using todays TCSO2 retrievals?
- (*NOTE EMI is not a NRT scenario because we don't know future emissions* !)

Eye-ball Plume Forecast Evaluation 2010



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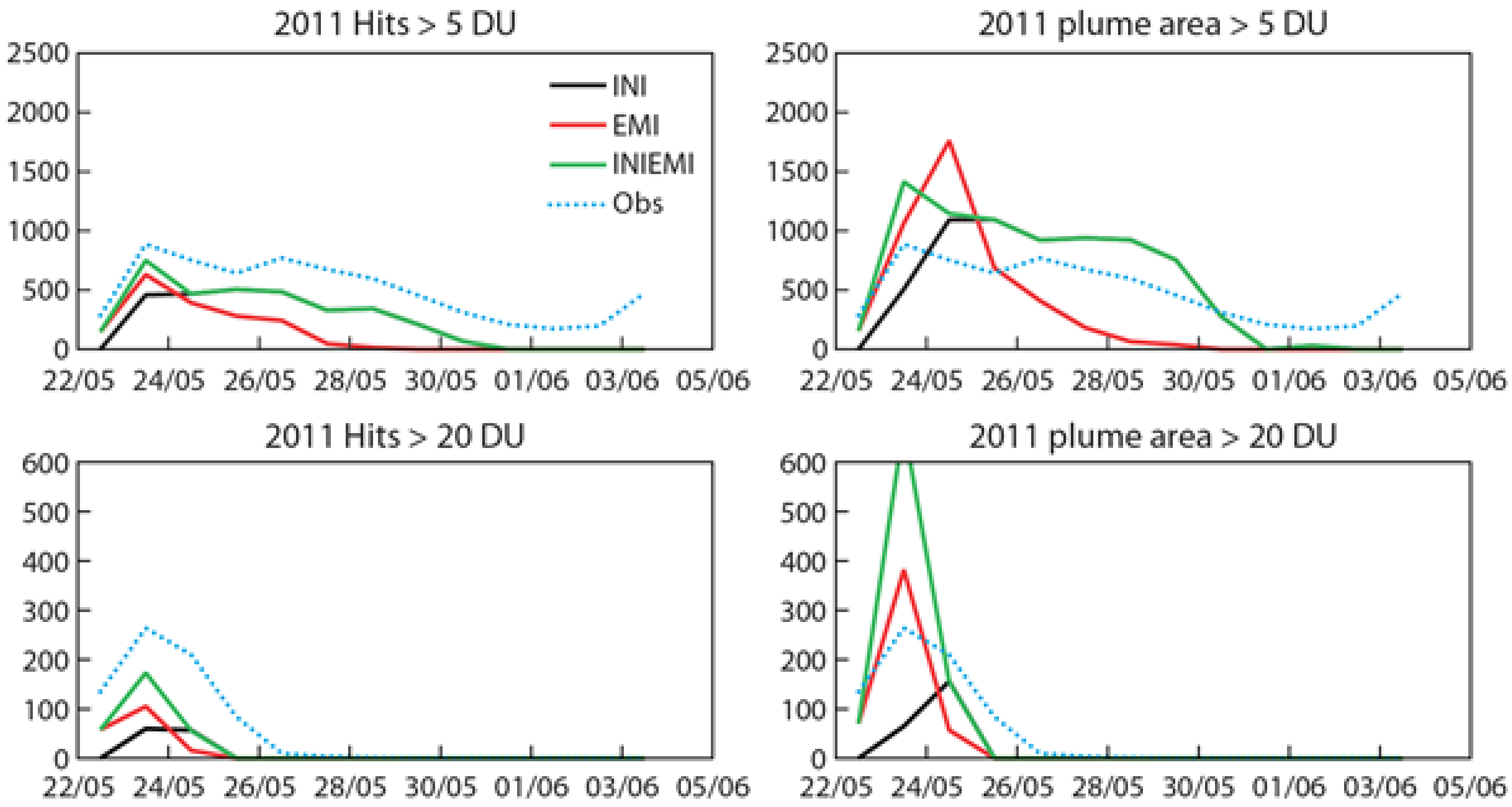
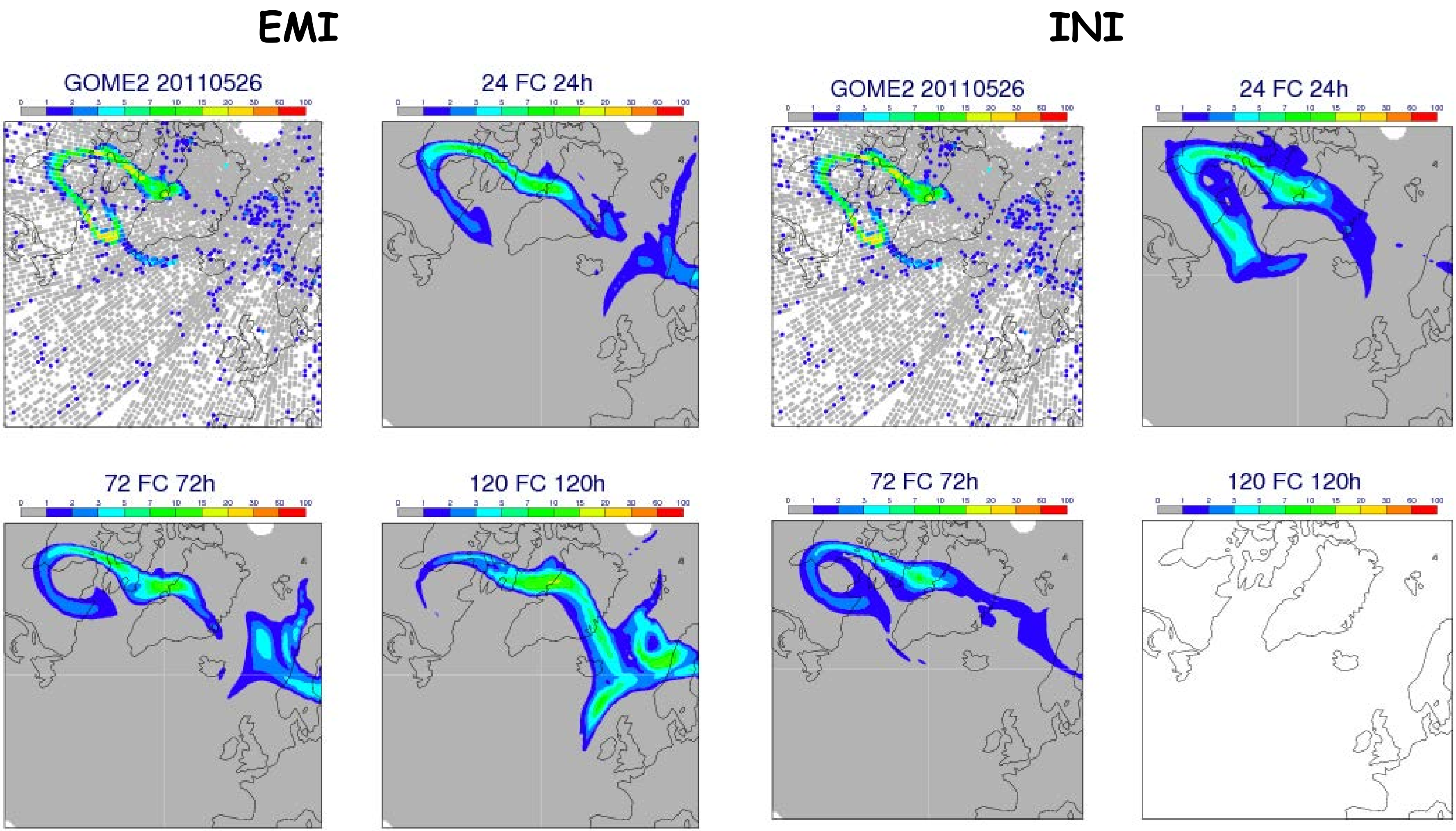
24 FC SO_2 Plume Forecast Evaluation – 2011



Evaluation w.r.t to gridded observations (0.5x 0.25)

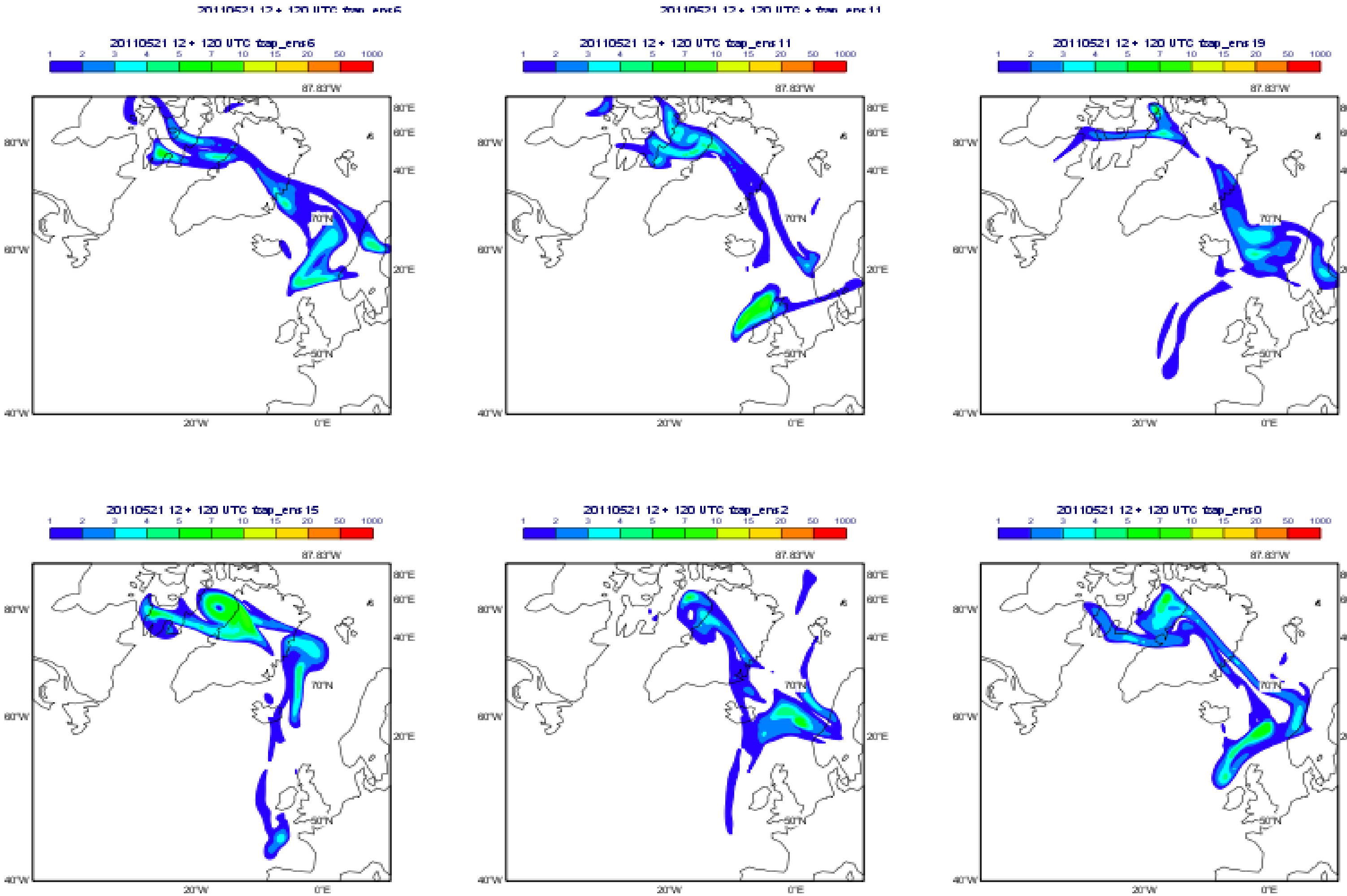
- Threshold based exceedance hits/miss/false alarm
- Plume size (w.r.t to threshold) independent of overlap

Forecast Lead Time 24, 72 & 120 hours



Quality of meteo forecast was very important for plume forecast

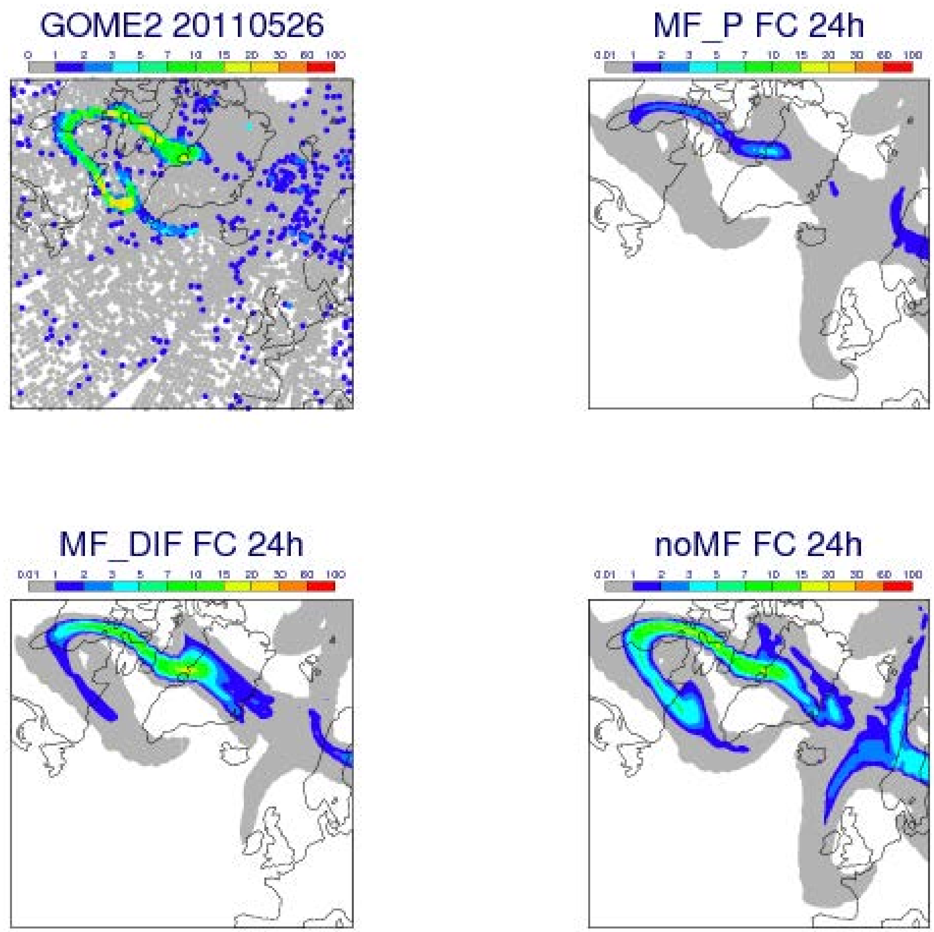
Meteorological Ensemble Forecast (T639L91 20 Members)



120 h
Forecast
6 of 20
Members
Same
emissions

This diversity
is specific of
2011 Grimsvoetn

Model Numerics and Transport



Different mass fixers

Model transport has difficulties to maintain the high observed values after the end of eruption.

Current Status of Response to Volcanic Eruptions with MACC system

Automated, no intervention	NRT intervention (working hours)	1-2 day delay intervention
• **Assimilation of OMI SO_2 retrievals** prescribed heights • **Assimilation of MODIS AOD** in existing aerosols	• **Emit SO_2 and ash** in model at volcano location using **ad-hoc emission** estimate • **Relax QC** and reduce thinning for assimilated MODIS observations • Active assimilation of TRM SO_2 retrieval (**GOME-2, OMI**)	• **Estimate SO_2 emission rate and injection** height based on UV-VIS satellite retrievals • **Rerun MACC system for eruption period** with improved settings and emission estimates

MACC has no mandate to volcano forecast but the MACC products might be useful for VAAC etc.

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Summary

- MACC Data assimilation system picks up automatically volcanic ash and SO_2 plumes if they are observed
- The DA assimilation requires emission rate and injection height estimates (ash) or only injection height (SO_2) estimate
- A method to estimate injection height and emission rate from SO_2 retrievals using an ensemble of test plumes has been developed
- Combing emission estimate and initial value data assimilation provided best results for SO_2 plume forecasts.
- Uncertainty of meteorological forecast and SO_2 lifetime is less important than emission parameters but still influential
- Ensembles of forecasts might be useful to express uncertainty of emission estimates , in particular after forecast start time

References:

SO_2:

Flemming, J., and A. Inness (2013), Volcanic sulfur dioxide plume forecasts based on UV satellite retrievals for the 2011 Grímsvötn and the 2010 Eyjafjallajökull eruption, J. Geophys. Res. Atmos., 118, doi:10.1002/jgrd.50753.

AOD:

Benedetti, A., J. W. Kaiser, J-J. Morcrette, R. Eresmaa and S. Lu (2011), Simulations of volcanic plumes with the ECMWF/MACC aerosol system, December 2011, ECMWF Technical Memorandum, 653,

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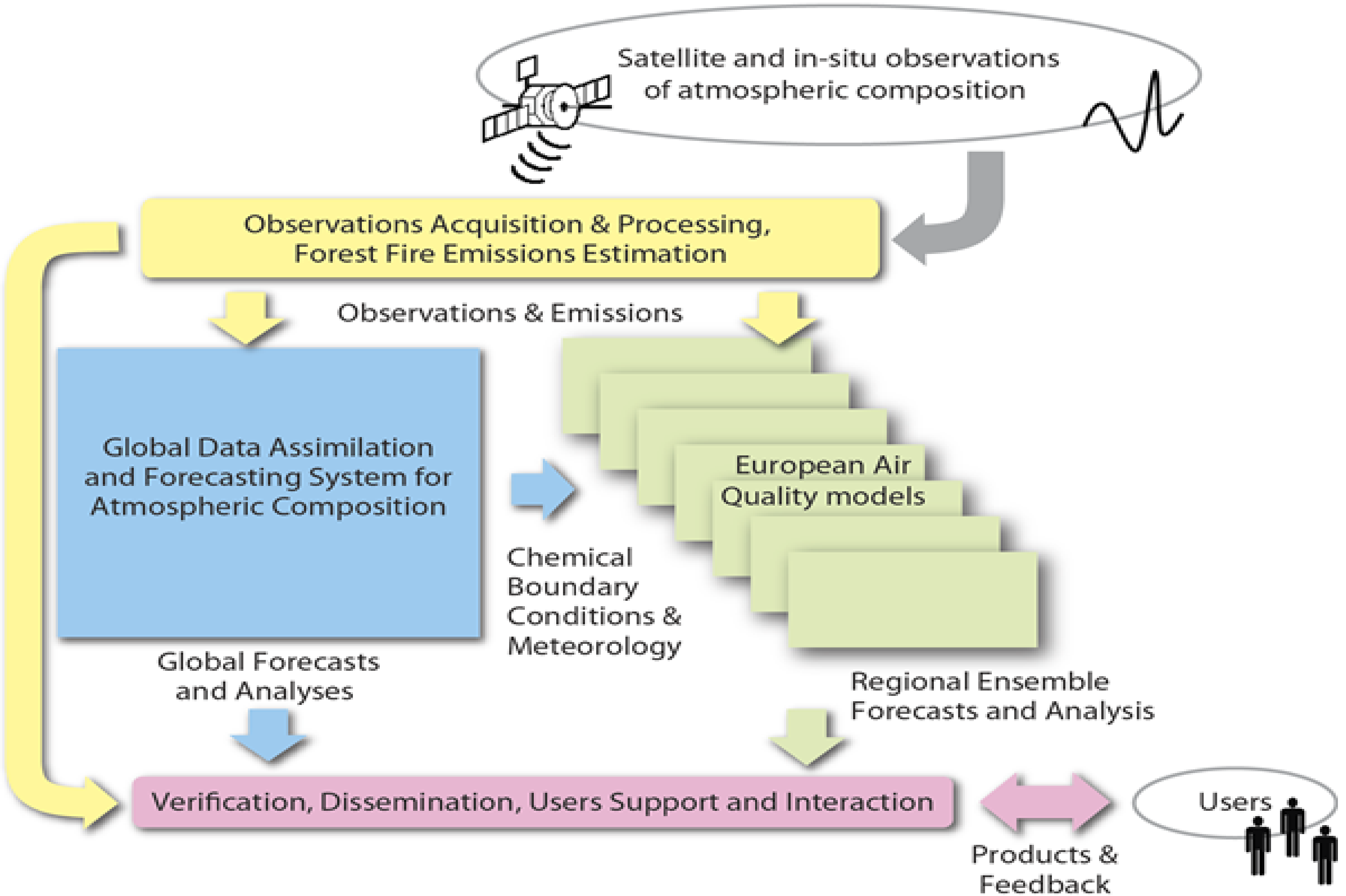
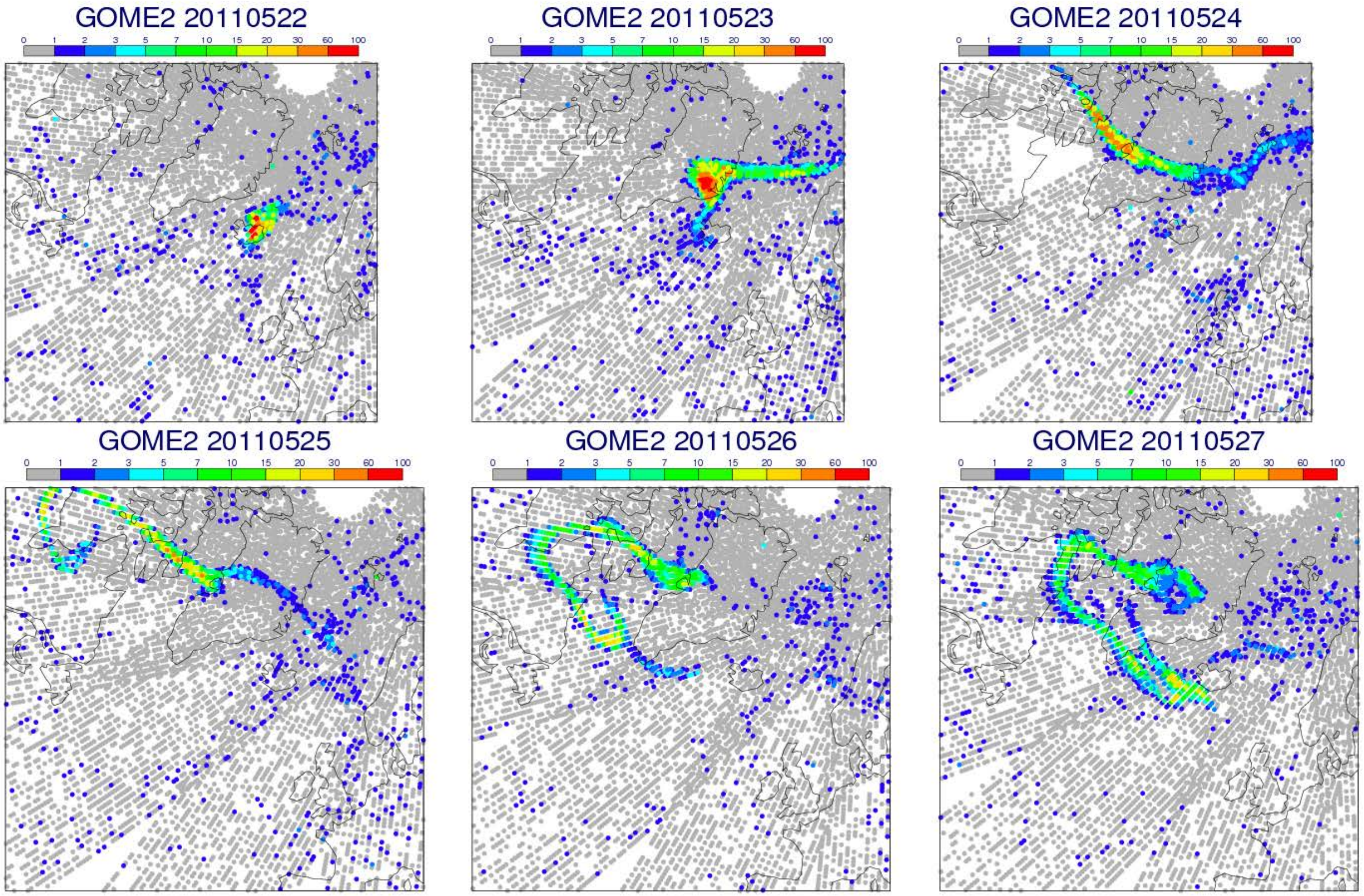
MACC system – A global-to-regional forecasting system for atmospheric composition



Grimsvötn (21-24.5.2011 eruption) – well sustained plume for over two weeks



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