Inverse modelling of the 2010 Eyjafjallajökull eruption and comparison with infrasound signals

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Poster
T1-P31

Introduction and methods

In March and April 2010, the Eyjafjallajøkull volcano, located in the south of Iceland, had prolongued eruption associated with emission of large amounts of fine ash. Together with the northwesterly winds prevailing at the time, this lead to massive impact on aviation over Europe. On this poster, two methods of work with different aims are put together:

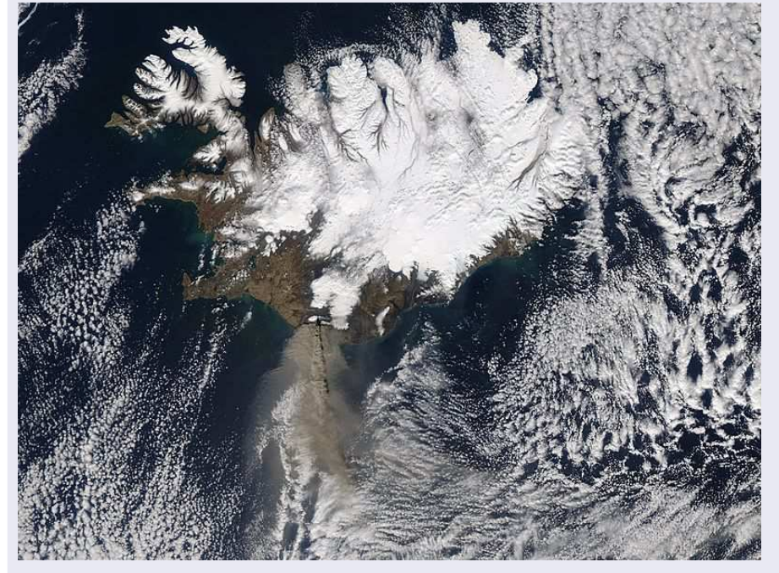
Dispersion meteorologists have tried to use inverse modelling methodology to derive a detailed ash source term using ash column values retrieved from satellite data, mainly the SEVIRI instrument on MSG (Stohl et al. 2011). The inversion searches the two-dimensional source term (vertical profile as function of time) which, plugged into forward dispersion calculations with the Lagrangian particle dispersion model FLEXPART, yields results closest to the satellite observations. This is done in an efficient analytical way. The method uses an a priori obtained from observed plume tops and a very simple 1D eruption model. Finding source terms from observations using atmospheric transport modelling is also one of the topics of relevance for the CTBTO.

Infrasound (IS) researchers find that volcanos provide significant sources of infrasound and, because many other methods provide data as well (at least for well-monitored volcanoes such as in Iceland) are suitable for testing and refining infrasound processing methods. A long-lasting eruption such as the one studied here (Matoza et al., 2011) furthermore offers the possibility to study temporal changes in the atmospheric transmission. Infrasound as a means for detection of volcanic eruptions has been suggested as a civil application of the CTBT IMS system, however, due to the long travel times of the signal to many of the stations it is not the ideal alerting system as needed especially for aviation applications.

Ash in images

Picture from one of the Vodafone web cams, 14 April 2010 (first day of eruption). We see the massive brown ash cloud interspersed with white parts made up of water droplets like a regular cloud.

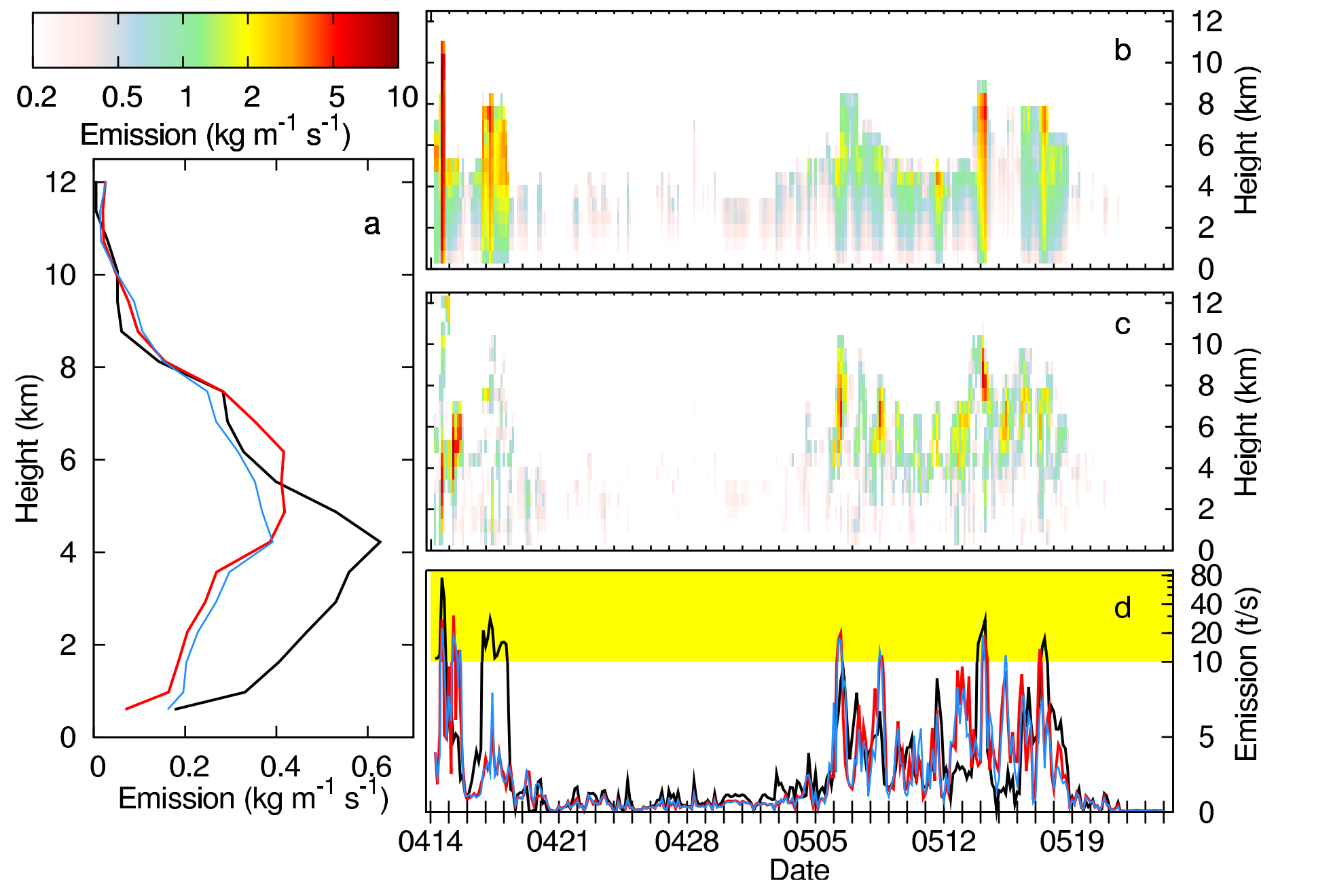
Another Vodafone web cam image, 04 May 2010, the beginning of the second major period of ash eruption. Fallout of heavy ash particles is visible below the plume.



Aqua MODIS image of the Eyjafjallajøkull ash plume 17 April 2010 at 13:20 UTC, during the first peak of ash emission. Credit: MODIS Rapid Response System. Close inspection reveals a tightly bundled upper part (probably transport in the jet stream) and a wide fanned part below (probably under the influence of wind shear). Such features – ash emission at different heights encounter different wind conditions, leading to different transport patterns identifiable by satellite remote sensing – are the base of the method for inverse modelling of the eruption profile.

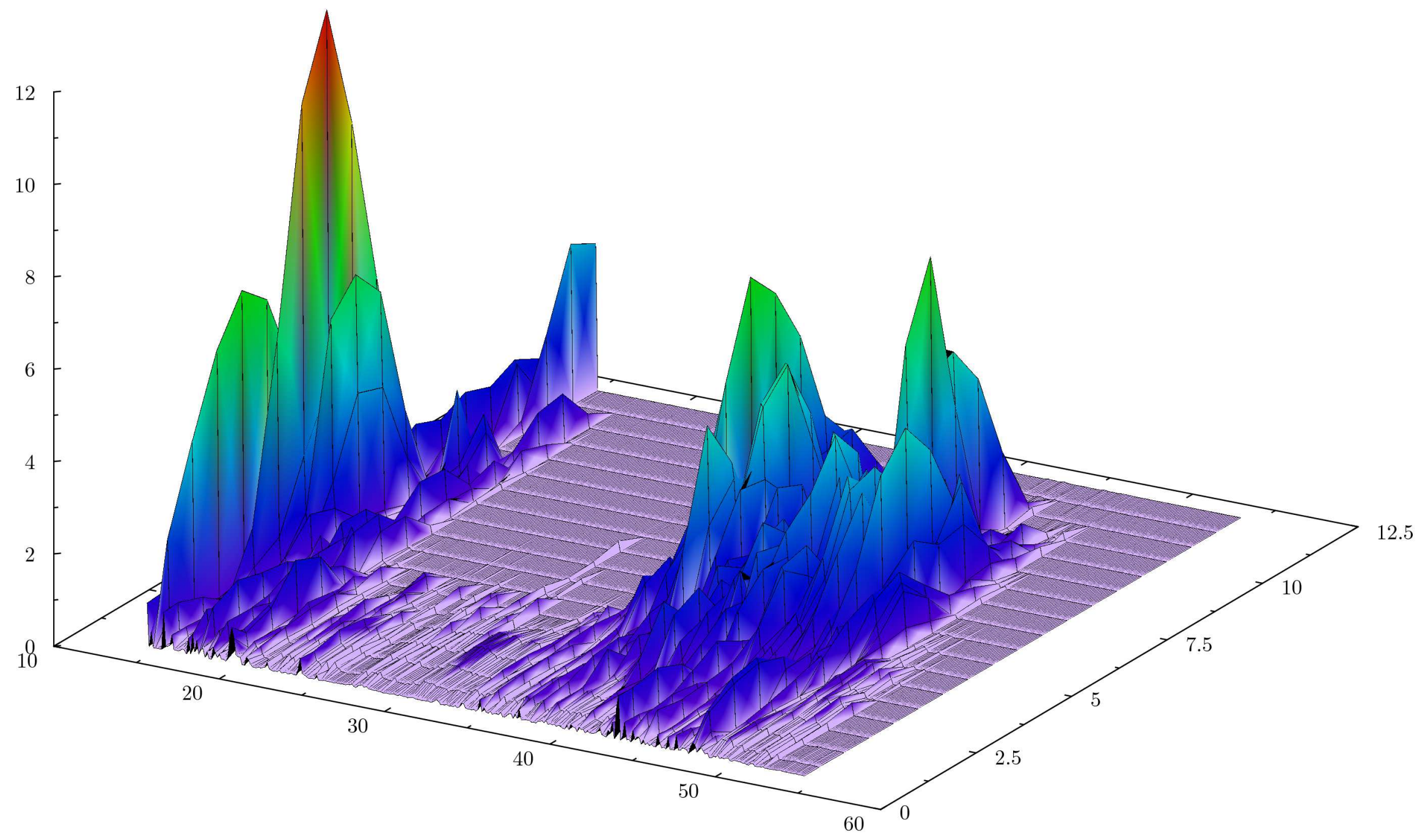
Terra MODIS image of the Eyjafjallajøkull ash plume 11 May 2010 at 13:20 UTC, during the peak of the second ash emission period. Only one plume visible, emission probably more concentrated vertically. Credit: MODIS Rapid Response System.

Results of inverse modelling of the ash eruption



(from Stohl et al., 2011)

Part a: Vertical distribution of ash emission, integrated over the whole duration of the eruption.
Black: a priori profile.
Red: ECMWF-based a posteriori profile.
Blue: NFS-based a posteriori profile.
Part b: Ash emission strength as function of time and height – a priori.
Part c: Ash emission strength as function of time and height – a posteriori.
Part d: Time series of vertically integrated ash emission, same colours as in Part a.



Two-dimensional view of the a posteriori ash emission strength (mean of ECMWF- and NFS-based results). *x-axis:* time in days after 2010-04-01. *y-axis:* height in km. *z-axis and colour:* emission in kg/m/s.

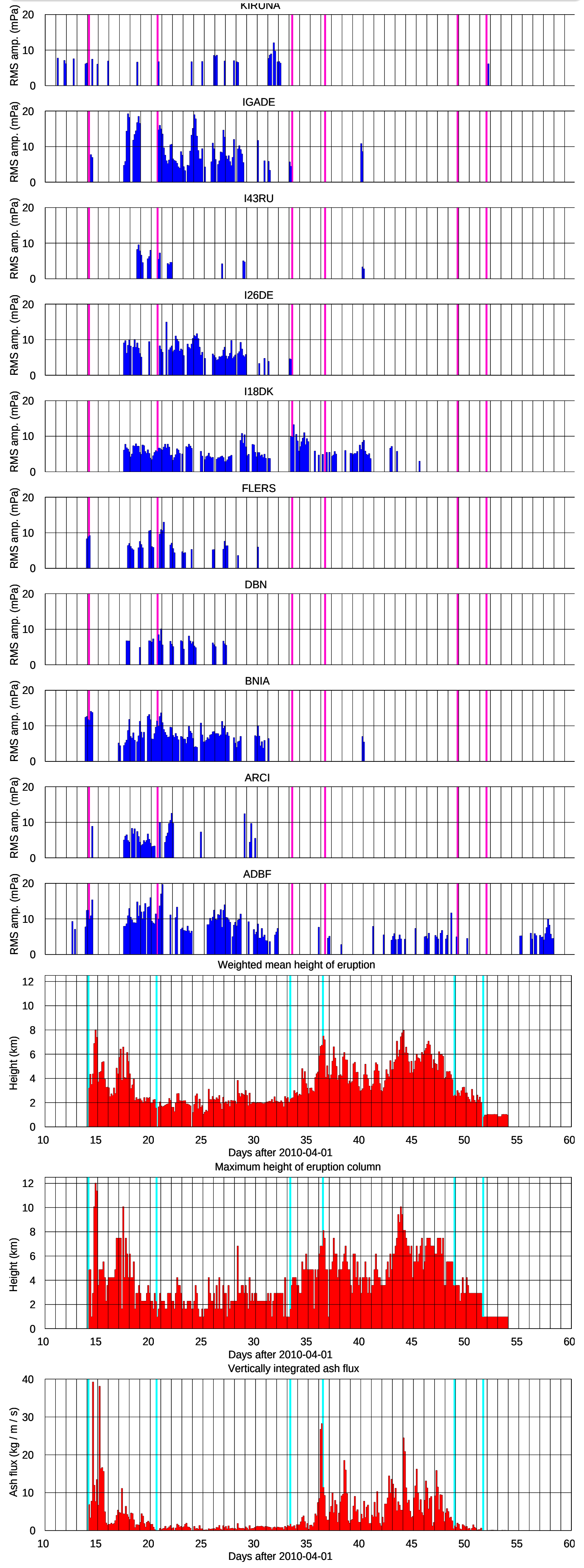
Interpretation

- Two major eruption phases can be distinguished, the first week of the eruption and then a second one in May. During the period inbetween little ash was emitted.
- There is more temporal variation in the a posteriori results than was assumed in the a priori.
- The intensity and vertical distribution of the peak phases during the first days of the eruption is considerably changed by the inversion.
- The first large eruption pulse reaches to 12 km, while the bulk of ash emission is around 5 km.

URL for MODIS imagery:
`http://rapidfire.sci.gsfc.nasa.gov/gallery/`

Results of infrasound (IS) processing and comparison with inverse ash modelling

Time series comparison

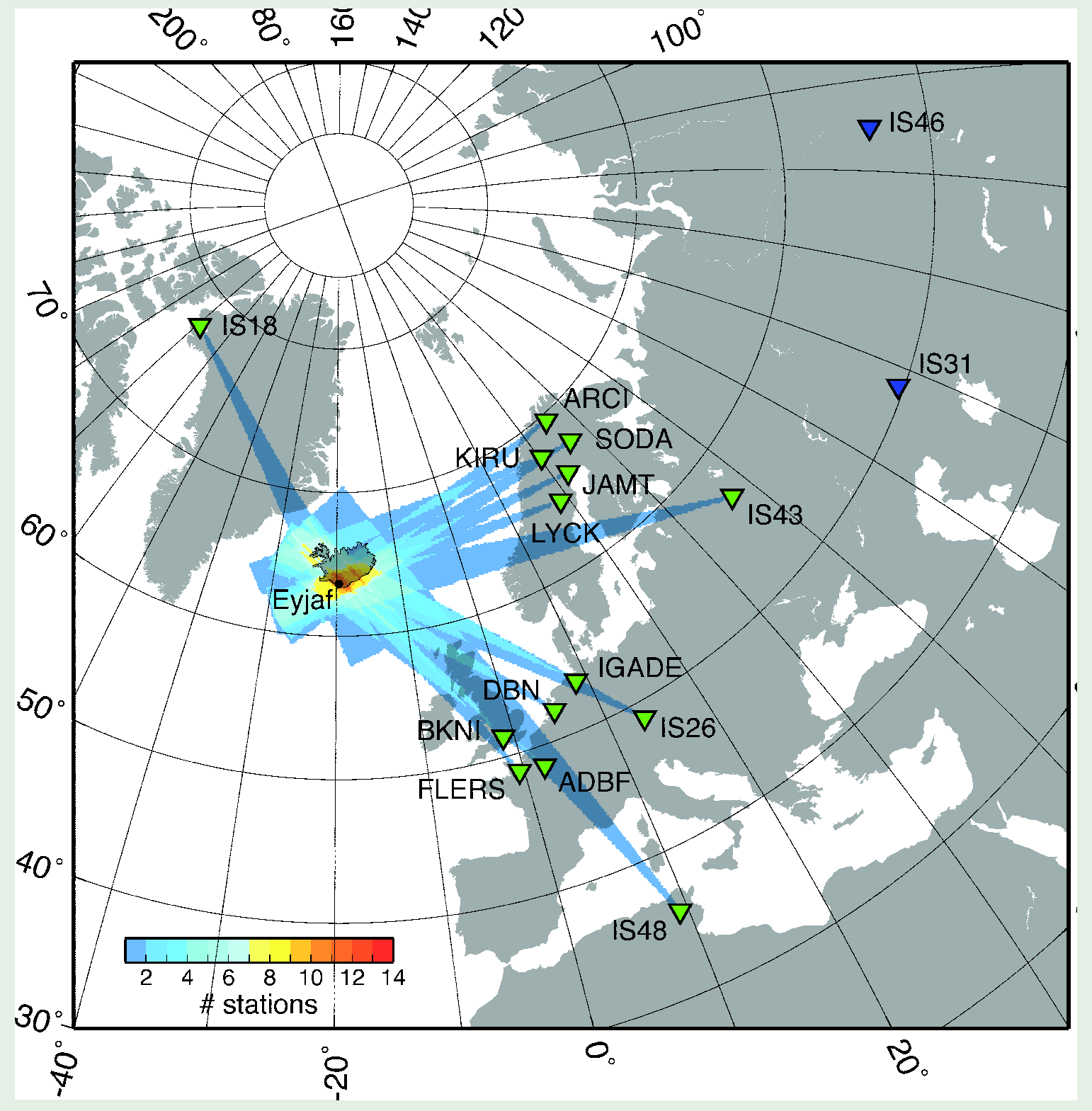


Time series of the amplitudes of the processed infrasound signals which came from the back azimuth of the volcano at the various stations (in blue) and ash source parameters (in red):

- bottom: vertically integrated ash emission flux
- middle: height of top of the ash emission;
- top: weighted mean height of the ash emission.

The vertical lines (light blue in the source parameters, red in the IS data) serve to trace interesting points in time (onset of ash eruption etc.) through all the frames.

Infrasound stations



(from Matoza et al., 2011)

Infrasound (IS) stations with detections of the eruption. Coloured beams show the backazimuths and the colour hue indicates the number of stations that detect a signal from the region. The backazimuth beams meet in the region of Eyjafjallajokull. Blue triangles (no back-beams) had no identifyable detections.

Discussion

- Probably some of the detections categorised as volcanic signals are associated to microbaroms (ocean swells), not the eruption. This is not easily discerned.
- For long-range transmission of infrasound signals, the degree of attenuation in the atmosphere (presence or not of sound ducts) has an important influence on the presence of detectable signals.
- Start of signals (where present) and onset of the eruption agree well, though there seems to be a small time difference. (Maybe sound speed variability?) . KIRUNA and ADBF show some signals before – could be microbaroms, not associated with the volcano.
- The high mass flux on 14 April corresponds broadly to the IS signals.
- The restart of IS signals on 17 April (after a break, probably caused by variability in atmospheric transmission) corresponds to an increased ash flux episode.
- In the period of day 20–35, ash flux is low but IS signals persist.
- There is increased ash activity from day 36 on. Eruption top heights already increase on day 33. This is recorded in the IS, but only at the I18DK station (Greenland) where good atmospheric transmission conditions (waveguides) prevailed.
- The end of the ash flux between day 49 and 53 corresponds to last signals at ADBF and KIRUNA.
- ADBF detections after day 55 should be attributed to microbaroms. This holds probably also for all the I43RU detections.
- Diurnal variations in the parameters of the infrasound signals were analysed for BNIA/BKNI and I18DK (see GRL paper). They were attributed to stratospheric solar tides and the diurnal variation of the atmospheric boundary layer. However, the inverse modelling reveals clearly a diurnal variation in the ash source parameters (height and source strength), mainly during the second eruption period in May, but withy respect to to the eruption top also in the weak-ash emission period before. Their reason is not yet clear, could be due to interaction of the eruption column with the atmospheric boundary layer and/or solar radiation. This effect will come on top of the atmospheric conditions for sound propagation.

Conclusions

- The interpretation of infrasound signals is note easy as measured waveforms account for the effects of both local noise and fine structures of winds in high-altitude which are highly variable in space and time; good models and modelling tools to address such effects are just available now.
- The association between ash eruption and IS signal at long distances is **not close enough** for direct application in application quantitative ash estimation.
- Still, for the two strongest ash eruptions (14 and 17 April) a correlation between IS and mass flux seems is visible.
- There is place for future work, especially with respect to refinement of the consideration of atmospheric transmission variability or the detailed source information available through the inverse modelling.
- The good success of the inverse modelling of the ash source points towards a potential of such methods also in the CTBT source location context.

References

Stohl, A., Prata, A. J., Eckhardt, S., Clarisse, L., Durant, A., Henne, S., Kristiansen, N. I., Minikin, A., Schumann, U., Seibert, P., Stebel, K., Thomas, H. E., Thorsteinsson, T., Tørseth, K., Weinzierl, B. (2011): **Determination of time- and height-resolved volcanic ash emissions and their use for quantitative ash dispersion modeling: the 2010 Eyjafjallajøkull eruption.** *Atmos. Chem. Phys.*, 11, 4333-4351, `www.atmos-chem-phys.net/11/4333/2011/`

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See also references inside these main publications!

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