The impact of ensemble meteorology on inverse volcano emission estimates and ash dispersion forecasts: Grimsvotn 2011

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1. Introduction

In the event of a volcanic eruption aviation authorities need to make **fast decisions** about which routes are safe to operate and to ensure airborne aircraft land safely. Currently these high-impact decisions are based on qualitative forecasts produced **without any quanitifcation of uncertainty**.

Two of the largest sources of uncertainty in forecasting ash cloud location and concentration are the **emissions of ash from the volcano** and the **meteorological situation**. This study extends the UK Met Office Inversion Technique for Emission Modelling (InTEM) system for volcanic ash to use an ensemble of meteorological conditions to determine the dependence of emission estimates on **wind field** and **wet deposition uncertainty**.

3. Case study: Grimsvotn 2011

The eruption started at 1913 UTC on **22 May 2011** and lasted 3 days.

Plume height varied substantially over the eruption and there is evidence that there was a partial column collapse (Prata et al. 2017) leading to **separation of the ash and SO2 clouds** (see Figure 1 – Moxnes et al. 2014) and errors in forecasting ash in northern Europe.

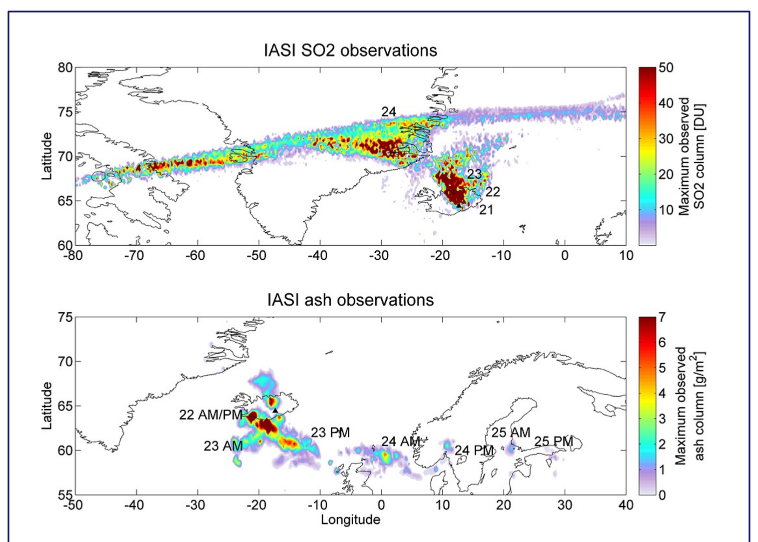

Figure 1: (top) SO2 and (bottom) ash column loading retrieved from IASI over the eruption period (taken from Moxnes et al. (2014).

During the eruption the synoptic situation was unsettled with an number of cyclones travelling across the North Atlantic (see Figure 2). Forecast errors in the **wind fields** and **precipitation** associated with these cyclones could lead to errors in forecast ash location and concentration due to **wet deposition modelling removing ash** that could have been dispersed further.

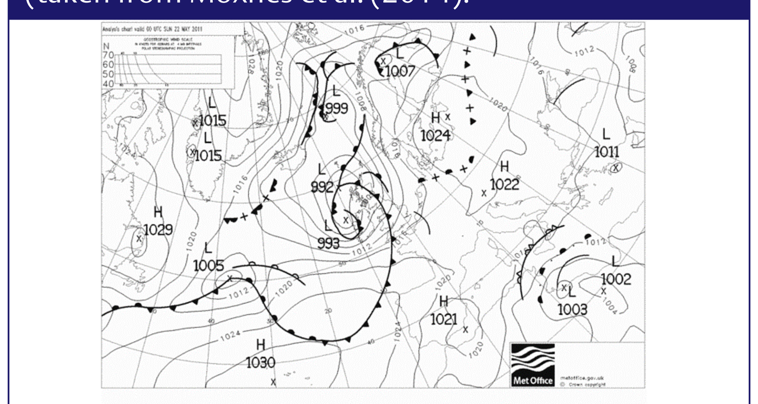

Figure 2: UK Met Office surface analysis chart at 0000Z on 22 May 2011. Mean sea level pressure isobars overlaid with surface fronts

To assess the relative importance of these processes, the InTEM inversion system was run using a **20 member meteorological ensemble** (from ECMWF EPS), **with** and **without** wet deposition processes being represented.

2. Inversion technique for ash emission modelling

The inversion system used in this study is the Inversion Technique for Emission Modelling for volcanic ash which uses a Bayesian approach to estimate **volcanic ash source parameters** using **satellite retrievals** combined with **dispersion modelling** (the NAME model is used in this study) and an ***a priori* estimate of the emission**. This system has been developed at the UK Met Office (see Pelley et al. 2015). It provides an optimal emissions profile for the fine ash that can undergo long range dispersion. This emission profile has a default vertical resolution of 4km and a time resolution of 3 hours.

4. Ensemble InTEM inversion estimates

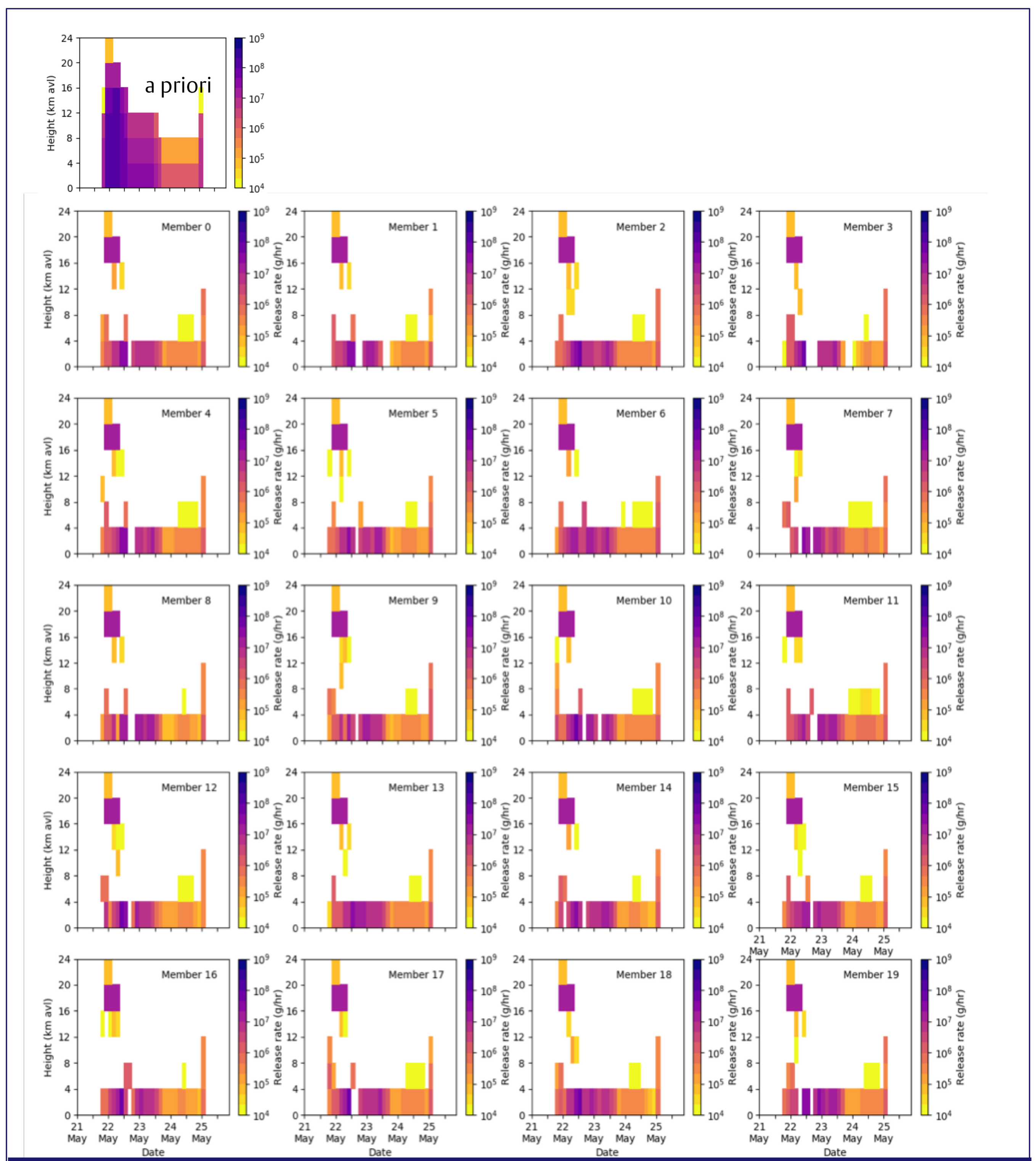

Figure 3: Emission profiles (g/hr) estimated by InTEM for the 2011 Grimsvotn eruption for each member of the ECMWF EPS ensemble using SEVIRI retrievals of ash and clear skies. The top panel shows the *a priori* emission profile. Note the logarithmic colour scale.

Figure 3 shows the **height-time InTEM inversion ash emission rates** throughout the eruption using each of the meteorological ensemble members and SEVIRI retrievals of **ash and clear skies.**

The vertical extent and emission rates are **substantially reduced compared to the *a priori* emission profile**, shown in the top panel in Figure 3.

All members have **high emission rates between 16 and 20km** above vent level (avl) shortly after the start of the eruption with ash emission **confined to between 0-8km avl** for the remaining eruption period.

These ensemble emission profiles are **comparable** to those found in Moxnes et al. (2014) and Webster et al. (2017).

Although the the vertical emission profiles are similar to each other, there are **differences in the magnitude of ash emitted at different heights**. These differences lead to values ranging from 1.72 - 2.66 x10^{12} g for the total ash emitted over the entire eruption (shown in Figure 4).

There is also a range, 350,000-400,000, in the number of satellite observations which influence the inversion between ensemble members.

5. Quantifying wet deposition uncertainty

The ensemble of emission rates obtained from InTEM without wet deposition parameterised (not shown) are **qualitatively similar** to those shown in Figure 3 but with **smaller emission rates.** This is expected, as to match to the SEVIRI observations, **less ash needs to be released if ash is not removed through wet deposition** in the NAME simulations.

The range of ash emissions for the ensemble without wet deposition is 0.81 - 0.97 x 10^{12} g which is **over a factor of 2 less than the total emissions for the ensemble with wet deposition** processes represented .This suggests that, in this case, **wet deposition has a significant impact on the inverted emission profiles**. In both sets of inversions, the uncertainty in the total emission is large and skewed due to the non-negative constraint on the inversion.

The ensemble mean total emission with wet deposition represented is 2.08 x 10^{12} g compared to 0.89 x 10^{12} g without wet deposition processes (last bar on Figure 4). The large separation of the ensemble means shows that the inclusion of wet deposition processes has a greater impact on the uncertainty than variability of the winds for this particular eruption.

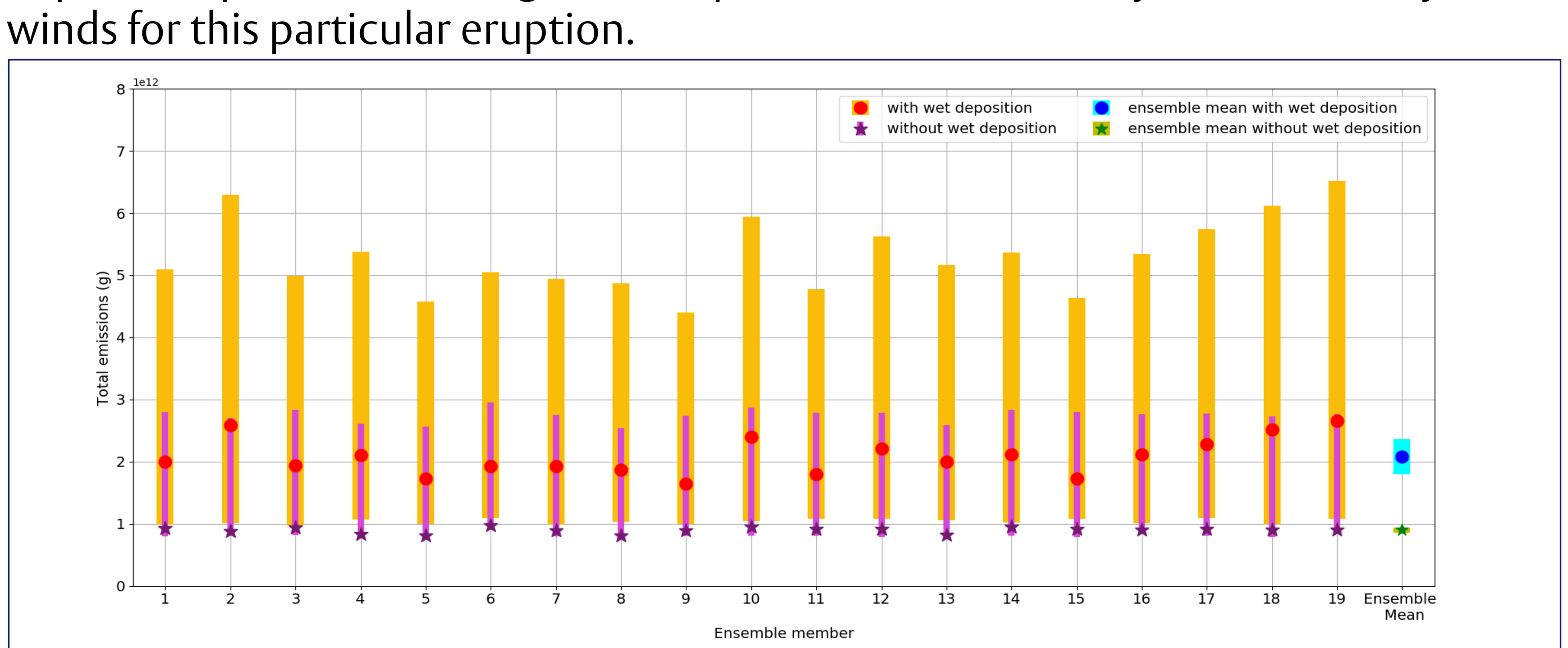

Figure 4: Total ash emitted over the Grimsvotn eruption for each ensemble member in the EPS ensemble determined using InTEM. Red circles and yellow bars indicate the best estimate and associated uncertainty (one standard deviation) of the total ash emitted for simulations that include wet deposition. Purple stars and lilac bars indicate the best estimate and associated uncertainty (one standard deviation) of the total ash emitted for simulations that do not include wet deposition. The ensemble mean bars indicate the ensemble mean total emission and standard deviation of the ensemble mean with wet deposition (blue circle and cyan bar) and without wet deposition (green star and light green bar).

6. Summary

For the 2011 Grimsvotn eruption:

- The InTEM inversion ash emission rates are substantially reduced compared to the *a priori* emission profile
- Ensemble emission profiles are similar but there are differences in the magnitude of the ash emitted at different heights. This leads to large range of values for the total amount of ash emitted over the eruption period.
- The inclusion of wet deposition processes has a greater impact on the uncertainty on the total amount of ash than the variability of the winds.

References

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