19th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
3-6 June 2019, Bruges, Belgium

DISPERSION MODEL UNCERTAINTY SIMULATION USING A LIMITED AREA ENSEMBLE MODEL

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Abstract: In emergency response applications, the uncertainty of the atmospheric dispersion model results, based on which countermeasures are to be decided, would be an important information. Yet the uncertainty of the meteorological model simulation that is fed into the dispersion model is neglected in most cases, despite the fact that the results of dispersion models strongly depend on the meteorological input. The uncertainty of a meteorological prediction is commonly modelled with an ensemble model, running the same forecast with varying initial conditions and perturbations imposed on the model run. The European Centre for Medium-Range Weather Forecasts, for example, uses a 50-member ensemble (ENS) to simulate the uncertainty of the forecast. Embedded into this ensemble, MeteoSwiss routinely runs a 20-member limited area ensemble (COSMO-E) with 2.2 km grid spacing. The direct derivation of the uncertainty of a dispersion simulation using the spread of the meteorological ensemble is difficult, because the importance of some meteorological variables for the dispersion calculation strongly depends on the value of others, which makes the relation between the meteorological and dispersion uncertainties highly non-linear. Our approach to simulate the uncertainties of the resulting concentrations is the calculation of a dispersion ensemble based on the meteorological ensemble. At MeteoSwiss, the operational feasibility of a dispersion ensemble with the Lagrangian particle dispersion model FLEXPART is tested, taking advantage of the above-mentioned meteorological limited-area ensemble model COSMO-E.

Key words: *predictability, model uncertainties, emergency modelling, dispersion ensemble model.*

INTRODUCTION

An integrated system, comprised of a special measurement network and a kilometre-scale numerical weather prediction (NWP) model, delivers the meteorology for emergency response applications in Switzerland. Three upper-air measurement sites equipped with radar wind profilers, microwave radiometers, and soon also Doppler lidars, build the measurement network of the system called EMER-Met ("emergency-response meteorology"). The data gained from these strategically located sites are assimilated into the operational COSMO models of the Swiss national weather service MeteoSwiss. The output of the NWP models are then fed into atmospheric transport and dispersion (ATD) models, which in turn forecast concentrations and depositions for emergency response applications in Switzerland. While the Swiss Federal Nuclear Safety Inspectorate (ENSI) is in charge of making similar forecasts in the vicinity of Swiss nuclear power plants (NPPs), MeteoSwiss calculates longer-range dispersion also for foreign NPPs and for any source of dangerous airborne material.

To date, only single NWP model runs, the so-called 'deterministic runs', are used for emergency response in Switzerland and many other countries. The uncertainty of the meteorological forecast, however, cannot be quantified with this approach. In the meteorological community, the shift from single deterministic to ensemble models is in full swing, as the awareness of the importance of the uncertainty of a forecast is on the rise. A first attempt to derive the uncertainty of a dispersion forecast directly from the uncertainty of the meteorology failed and indicated that running a dispersion ensemble is the best way to simulate the uncertainty of dispersion calculation results due to uncertain meteorology (Weusthoff 2012).

The forecasts of ATD models play an important role in emergency response, as countermeasures and protective actions are decided based on them. To enable the decision maker to be on the safe side, the uncertainty of the respective forecasts is an important information. A large part of the total uncertainty of the dispersion forecast depends on the predictability of the current weather situation, which varies widely due to the chaotic properties of the atmosphere (Palmer 1993). Due to limitations in computing power, the ensemble approach until recently stopped short of the dispersion calculation. MeteoSwiss is now developing such a combined system of an ATD model ensemble based on a NWP ensemble. In this way, the uncertainty of the NWP forecast is translated into an uncertainty of the ATD forecast.

The European Centre for Medium-Range Weather Forecasts, for example, uses a 50-member ensemble (ENS) of its integrated forecasting system (IFS) to simulate the uncertainty of the forecast. Embedded into this ensemble, MeteoSwiss routinely runs a 20-member limited-area ensemble (COSMO-E) with 2.2 km grid spacing. The dispersion ensemble is then calculated with the Lagrangian Particle Dispersion Model FLEXPART based on COSMO-E. The details of this model chain and a case study are presented in the following sections.

DEDICATED MEASUREMENT NETWORK

A dedicated network of three measurement sites equipped with radar wind profilers and microwave radiometers is operated for assimilation into the NWP models. The measurement sites are located upstream, in the center, and downstream of the region containing the nuclear power plants and the main industrial sites. In an effort to update the measurements to the state of the art, Doppler wind lidars will soon be added, as they have proven to be reliable and precise instruments for wind profiling in the boundary layer (Päschke et al., 2015). They will complement the measurements of the radar wind profilers and enhance the data availability and vertical resolution in the boundary layer.

THE ENSEMBLE NWP MODEL COSMO-E

The ATD models for emergency response purposes take their meteorological input from the newest available NWP data. MeteoSwiss routinely runs the limited-area NWP model COSMO in two configurations. The very-high-resolution (1.1 km grid spacing) deterministic model COSMO-1 with a forecast length of 33 hours is operated every 3 hours in a rapid-update cycle. It will be extended within a year to become an 11-member ensemble (COSMO-1E). Twice daily, at 00 UTC and 12 UTC, an ensemble forecast (COSMO-E) is produced with 20 members and a reduced grid spacing of 2.2 km. The update frequency will be increased within a year to four per day (00, 06, 12 18 UTC) to become COSMO-2E. The forecast length of 120 hours (5 days) is aimed at short- and medium-range forecasting. The current models each have their own data assimilation cycle to produce initial conditions, while the future models will share a common assimilation cycle with 1.1 km grid spacing. The boundary conditions are taken from the IFS HRES model of the ECMWF for COSMO-1, and from IFS ENS for COSMO-E, COSMO-1E and COSMO-2E.

Table 1. Current and future (2020) operational NWP models at MeteoSwiss

Resolution (Grid spacing)	**Forecast Length**	**Current Type**	**Current Name**	**Future Ensemble Size**	**Future Name**
1.1 km	33 hours	Deterministic	COSMO-1	11 Members	COSMO-1E
2.2 km	120 hours	Ensemble	COSMO-E	21 Members	COSMO-2E

The main challenge for a short-range ensemble forecast is to achieve sufficient spread, i.e., sufficiently diverse members, covering the whole range of the forecast uncertainty. For COSMO-E, a two-fold strategy is applied. The initial conditions are taken from an analysis ensemble produced by the kilometric-scale ensemble Kalman filter data assimilation (KENDA), providing sensible spread for the initialization of the forecast ensemble right from the start. The initial disturbances are then further enhanced by a stochastic perturbation of the physics tendencies (SPPT) as well as perturbed lateral fields from the driving model.

The resulting spread of COSMO-E is considerably larger than the spread of the driving global ENS model, while the error is smaller due to the higher resolution of COSMO-E (C-E in Figure 1). Therefore, the gap between the ensemble spread and the skill is considerably smaller in the COSMO-E setup than in the driving ENS model, which is optimized for medium-range rather than short-range forecasting. Ideally, there should be no gap at all between the skill – represented here by the standard deviation of the model error – and the spread of the ensemble members – represented as standard deviations of the ensemble.

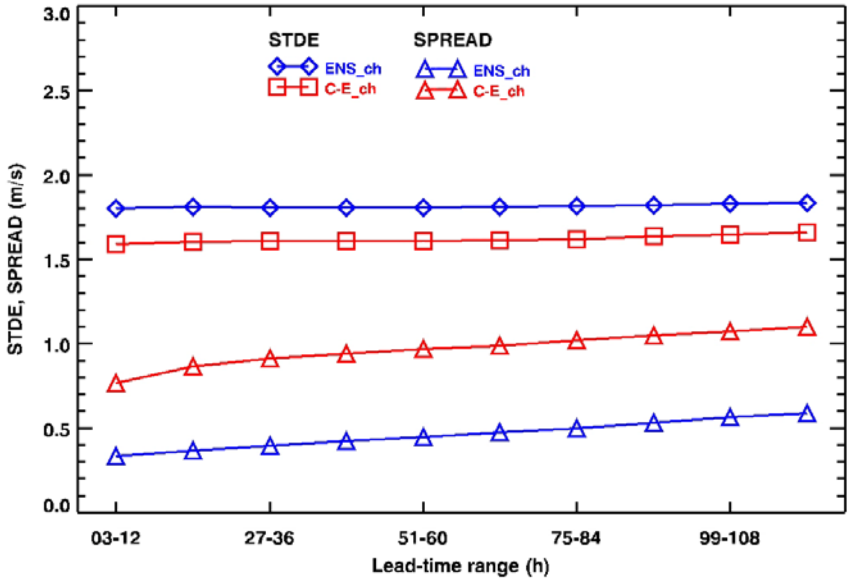

Figure 1. Spread-skill diagram for wind speed for several lead-time ranges (x-axis), for IFS-ENS (ENS_CH, blue) and COSMO-E (C-E_ch, red). Ideally, the SPREAD would be very close to the STDE, representing the full uncertainty.

The ENS members delivering boundary conditions for COSMO-E are currently selected arbitrarily. This will be replaced by a procedure selecting representative members of groups with similar ENS forecasts to better cover the whole range of the ENS ensemble spread. An additional increase in the spread at longer lead times is expected from this.

THE ATMOSPERIC TRANSPORT AND DISPERSION MODEL

The Lagrangian particle dispersion model FLEXPART (Stohl et al. 2005) is used at MeteoSwiss as the ATD model for emergency response purposes. FLEXPART has been adapted at EMPA for the COSMO model (Henne et al. 2016). Currently, only COSMO-1 is used as input for FLEXPART, as the full COSMO-E ensemble data is not stored. The challenge of running a dispersion ensemble is to fit it within the available computer resources. The full 3-d data from an ensemble needed for dispersion modelling requires a large storage capacity. The runtime of the FLEXPART ensemble needs to be sufficiently short to allow on-demand calculations.

CASE STUDY: 8 AUGUST 2017

This case study was selected for the large spread of the COSMO-E ensemble in wind direction. The intent was to achieve maximally diverse results among the members of the dispersion ensemble to showcase the potential of an ensemble simulation. As a consequence, this case represents a rather large amount of uncertainty, and is not representative for the average case.

The operational COSMO-E forecast of 2017-08-08 00:00 UTC was the basis for a dispersion simulation. The source of Cs-137 aerosols emitted from 06:00 until 09:00 UTC, and the dispersion was calculated for the first 6 hours after the begin of the release.

The concentration shows large variation among the ensemble members in the area covered. The affected regions are quite different, with each forecast of the ensemble having the same probability to be the correct one.

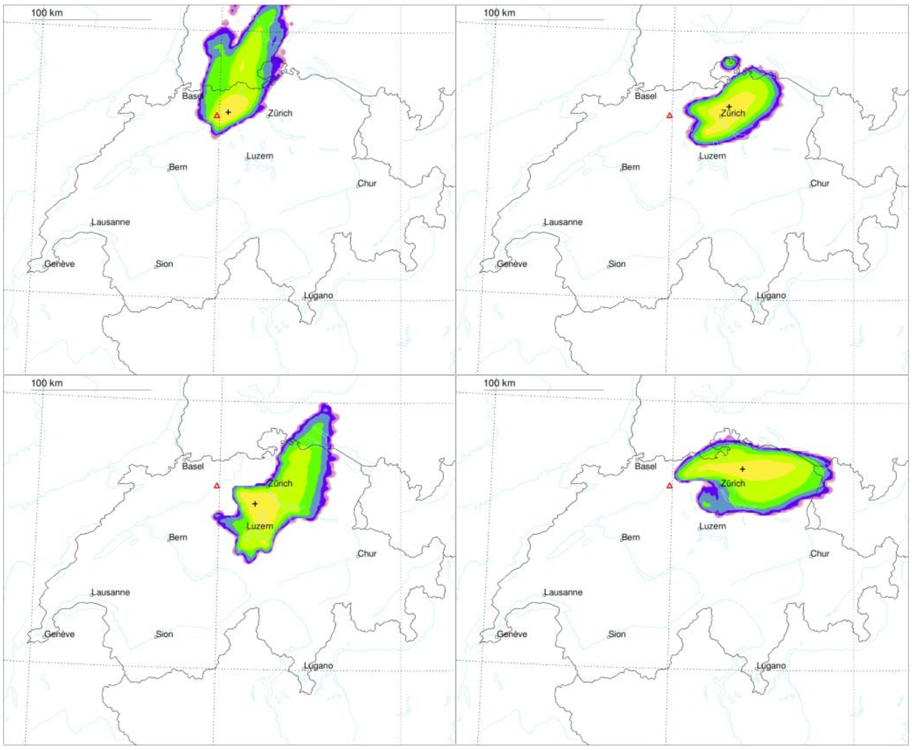

Figure 2. Four most disparate dispersion ensemble members after five hours of dispersion, two hours after the end of emissions from the source. Geographical area containing Switzerland, with the source indicated by a red triangle and the maximum concentration with a black plus sign.

Figure 1 shows the concentration two hours after the end of the release. As the absolute values of the source and the concentrations are not of interest here, no colour scale is provided. The filled contours however are separated by one order of magnitude, i.e., by a factor 10. After an initial dispersion towards the west, the wind direction has reversed, and all plumes now travel towards north-easterly directions. As the emission has stopped two hours earlier, the cloud is detached from the source in three cases. In one ensemble member (top left panel in Figure 1) with particularly low wind speed, however, the plume is still covering the source location. This is possible because it has first travelled into the opposite direction, and the part that first extended furthest to the southwest has not yet passed the source site after the wind reversal. In this ensemble member, the plume is heading north and half of the cloud has already passed the border into Germany. The other plumes are at quite different locations at this time. The member in the upper right panel is close to crossing the northeast border, still being fully within Switzerland 6 hours after the release started. In the lower left panel, the highest concentrations take a path towards south-east, but an important side-branch spreads all the way across Lake Constance and into Germany. Another side branch disperses towards the Alps, penetrating into valleys presumably due to thermally driven valley wind circulations. In the lower right panel, finally, the plume disperses fast towards the east, reaching the Austrian border within the 5 hours since the start of the release.

CONCLUSIONS

The example in the case study shows how different the results of a dispersion model can be when based on different members of a meteorological ensemble. The substantially different location of the plume in the four members is probably connected to the wind reversal that amplifies initially small differences to become large after only 6 hours. Such wind reversals are not uncommon in the region called Swiss Plateau or Swiss Midland, a hilly terrain enclosed by two mountain ranges extending from southwest to northeast, the Jura Mountains and the Alps. The consequences for emergency response are considerable. For example, big towns like Zurich or Lucerne are not at all affected in one simulation (upper left), but are located in the midst of the highest concentrations in another (upper right). Lucerne is not affected in three simulations (upper left, upper right, lower right), but in the fourth (lower left), the second highest concentration levels reach south all the way to the city of Lucerne. As all ensemble members are equally likely to show the correct dispersion, it is very important for the decision makers to know about the uncertainty of a dispersion forecast. With only one of the dispersion members as basis and no information about the uncertainty, as it is today, there is the imminent danger that the provisions arranged will be partially inadequate or, worse still, insufficient.

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