Poster 451

Evaluation of the Global Atmospheric Multi-Layer Transport (GAMUT) Model using the European Tracer Experiment (ETEX)

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1. Introduction

The purpose of this work is to evaluate of the Global Atmospheric Multi-layer Transport Model (GAMUT) using an existing atmospheric tracer experiment. The objective is to validate the GAMUT model against real observations at medium- to long-range distances. We chose to evaluate GAMUT using the European Tracer Experiment (ETEX) which was conducted over Europe during the autumn of 1994.

We chose ETEX for several reasons. The ETEX experiment had a wide swath of samplers covering much of Europe. While the farthest samplers were well within the operational utility of GAMUT, ETEX is nonetheless one of the very few tracer experiments that are available for the ranges of over a thousand kilometers. While there was only two releases (and only one really useful one), the several thousand samples provide sufficient data to produce some meaningful statistics. The full set of experimental data is readily available. Finally, while early versions of GAMUT were evaluated against the Across North America Tracer Experiment (ANATEX, another long-range tracer study), no GAMUT evaluation over Europe using ETEX has been done.

2. Overview of the models and data

2.1 GAMUT Overview

The Global Atmospheric Multi-Layer Transport Model (GAMUT) can be described as a long-range, Lagrangian atmospheric transport-dispersion model (Masters, 1998; Masters and Atchison, 2000). Continuous or discrete releases from one or more sources are modeled by a series of puffs emitted at regular intervals. These puffs are tracked independently as they move horizontally with the estimated winds, mix vertically from the effects the diurnal PBL cycle, move vertically through synoptic-scale disturbances, and disperse horizontally. By combining the impacts from the many simultaneous puffs, hourly and daily concentrations can be calculated at ground-based or elevated receptor locations. GAMUT is designed to track effluent across trans-continental distances up to twenty days from initial release. It is frequently coupled with the Short Range Layered Atmospheric Model (SLAM) which provides transport estimates using higher resolution meteorological fields.

The GAMUT modeling system has two major components. The GAMUT preprocessor ingests data from world-wide rawinsonde and PIBAL soundings and creates a four-dimensional set of wind and thermodynamic fields covering the northern or southern hemisphere. The GAMUT transport-dispersion model reads these fields and calculates transport and dispersion from user selected sources. The basic data flows between these components are shown in Figure 1. The Atmospheric Modeling Interface (AMI-GAMUT), a graphical user interface, controls the model configuration and execution. Additionally, a suite of post-processing programs allows the user to display the output from GAMUT as maps, statistical plots, and tabular listing. .

2.2 European Tracer Experiment

The European Tracer experiment (ETEX) was conducted in the fall of 1994. (Nodop, et.al., 1998; Van dop, *et.al*., 1998; European Commission Joint Research Centre, 1996) It was originally conceived following the accident at the Chernobyl nuclear power station in 1986. The original purpose was two-fold. First, it was conducted as a test of various emergency response systems and models to determine how well future events could be handled as they unfolded. Second, evaluation of model predictions months after the experiment allowed for more detailed evaluation of the strengths and weaknesses of many transport-dispersion models.

Two releases of perflourocarbon tracers were conducted for this experiment. These tracers are inert and can be measured at parts-per-billion levels over a thousand miles from their release points. Table 1 gives the details of the releases.

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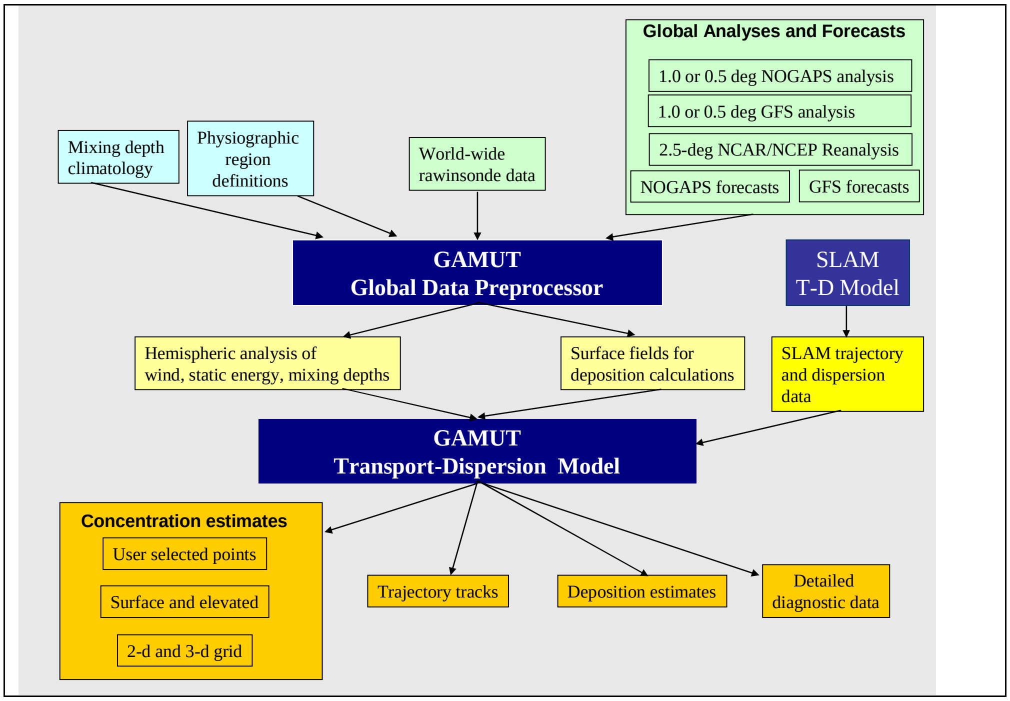

Figure 1. Basic data flow between components of the GAMUT system.

Sampling operations were conducted at 168 locations throughout much of Europe. Most of the samplers were placed at national weather observation sites where power and technical staff were available. Figure 2 depicts the locations of the source and samplers for the experiment. Following a release, each sampler collected three-hour samples for 72 hours. The sampler start-up times staggered from west to east in anticipation of the movement of the plume. Around 9000 samples were collected during the course of ETEX.

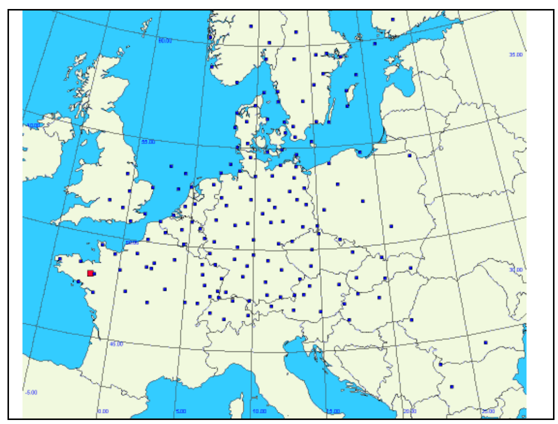

Figure 2. Source (red) and sampling (blue) locations for the ETEX experiment

Table 1. ETEX releases

Release	Start	Stop	Release amount	Location
1	1600 UTC 23 October 1994	0350 UTC 24 October 1994	340 kg PMCH (8.0 g/s)	Monterfil, France 48º03'30"N 2º 00'30"W
2	1500 UTC 14 November 1994	0245 UTC 15 November 1994	480 kg PMCP (11.6 g/s)	

The first ETEX release occurred well behind a cold front that was working its way through central Europe A deep, occluded low pressure center was located north of Scotland. This provided a well-defined westerly flow from the source in western France. The observed plume moved eastward across Germany into eastern

Europe. Over the following days, the tracer would be observed from southern Scandinavia to Romania. The horizontal distribution of the plume was reasonably well defined by the sampler network.

The second ETEX release occurred during a more complex synoptic situation. A warm front (and possibly multiple fronts) lay just to the northeast of the release point. A cold front was approaching rapidly from the northwest and passed the release point just after the end of the tracer release. While tracer was observed at different samplers on the network, no coherent plume could be easily identified. Only 13% of the second release's samples revealed elevated tracer concentrations compared to 32% for the first release (Nodop, 1998). The collected tracer levels, even in France were also much lower. It appeared that the plume was shredded into several parts and it also appears that much of the tracer was lofted above the ground. The transport models that took part in the real-time experiment generally performed poorly against this release.

For these reasons, only the first ETEX release was analyzed for this study. We did run several sets of GAMUT simulations using the second release, but detailed analyses were not performed.

2.3 GAMUT Configurations

The GAMUT preprocessor was run for the ETEX release using several combinations of input data processing. The meteorological data used to produce the input GAMUT data included:

- NCAR/NCEP Reanalysis data (Kalnay, et al. 1996) only. Winds were derived from Reanalysis; PBL depths were derived from a statistical procedure derived during GAMUT's original design work in the 1980s.
- Reanalysis and upper air. Winds were derived from the Reanalysis; PBL depths were derived from the upper air temperature and moisture profiles where available. The Potential Instability Mixing depth procedure (PIMIX) was used to calculate PBL depths from the sounding. Where upper air data were not available, the statistical procedure was used.
- Reanalysis and upper air with winds. Winds were derived from an optimum interpolation of Reanalysis data and upper air winds; PBL depths were derived from the upper air where available, from the statistical procedure where upper air data were not available.
- WRF. Winds and temperatures were derived from the special interpolation of the WRF output (Skamarock, 2008) to a 1-degree latitude-longitude grid.

Additionally, the GAMUT model was configured with several run-time processing options. Other than the two options below, the standard GAMUT configuration was used for this study. The two modified options were:

- Lofting procedure: Use static energy or use direct vertical velocity values for large-scale vertical motion (Masters and Atchison, 2000).
- Splitting procedure: Use a continuous or a discrete formulation when calculating the twice-daily vertical puff splitting driven by PBL depth variations.

The values for other important options:

- Model start interval: 1 hour
- Model step interval: 1 hour
- Trajectory duration: 144 hours
- Maximum segments per puff release: 75
- Concentration screening: Off
- Minimum mixing depth (for concentration calculations): 500 m
- One-sigma horizontal growth rate: 0.51 m/s

2.4 The DATEM Data Archive and Statistical Analysis Software

Objectively evaluating transport-dispersion model predictions is a very challenging enterprise. The traditional measures that use scatter plots of data paired in space and time often yield disappointing results. It can be difficult to evaluate various input data and model differences when the differences among them are small. Draxler, *et.al* (2001) has produced a software program DATEM that produces a set of statistical measures of the correspondence between the predicted and observed concentrations. Along with the software, data from many tracer experiments were gathered and placed in a common data format. This project was performed by the NOAA Air Resources Laboratory. We have chosen to use the ETEX data archive and DATEM software for this study as it provides an objective and efficient way to evaluate many different modeling configurations.

3. Discussion

3.1 Evolution of the predicted and observed plume

In this section, we compare the plumes predicted by several of the GAMUT model configurations with each other and with the observations. Figure 2 shows the detailed evolution of the GAMUT predicted plume for one model and data configuration. This configuration matches the GAMUT parameter setup for most operational uses. As we will see in Section 3.2, this configuration also produced the overall best evaluation statistics from this study. The dots on the map show the measured concentrations at the ETEX samplers at the same time as the model plume plot. The colors of the dots represent the level of the observed concentrations, with blue representing low concentrations and red higher values. Plots are shown at six hour intervals starting at 2300 UTC 23 October 1994.

The modeled plume spread eastward from the release point in Monterfil, France. By 0500 UTC 24 October, a split in the plume is notable. The most concentrated portion of the surface plume moved eastward into Germany, while the southern split pushed southeastwards towards Austria. By 1100 UTC 25 October, this GAMUT configuration showed material at the surface over Denmark. This compared quite well against the Denmark samples during this time. By 0500 UTC 26 October, the GAMUT plume stretched from Norway through southern Sweden and Poland to northern Romania. The GAMUT plume appeared to move eastward a little faster than indicated by the observations.

Figure 3. GAMUT predicted concentrations (shaded isopleths) and observed concentrations (colored dots) for ETEX release 1. The GAMUT concentrations are one hour averages starting at the time shown. The observed data is a three hour average approximately centered at the time shown.

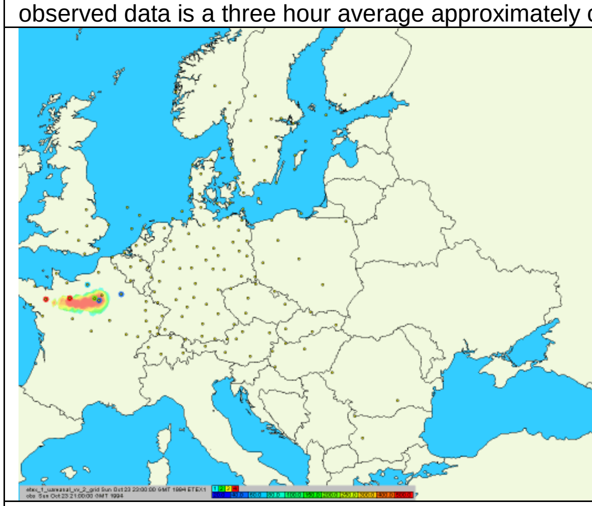

Figure 3a. 2300 UTC 23 Oct 1994

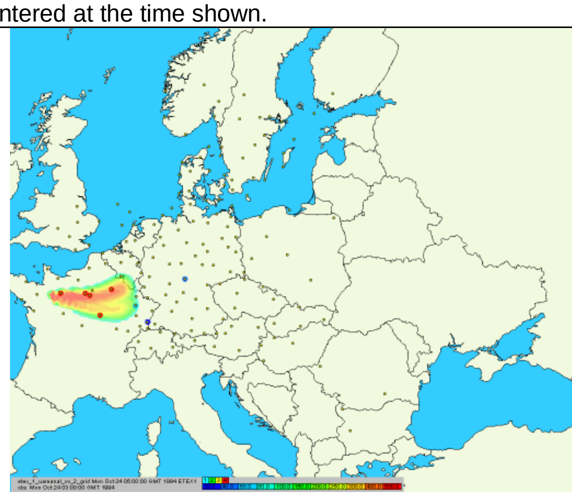

Figure 3b. 0500 UTC 24 Oct 1994

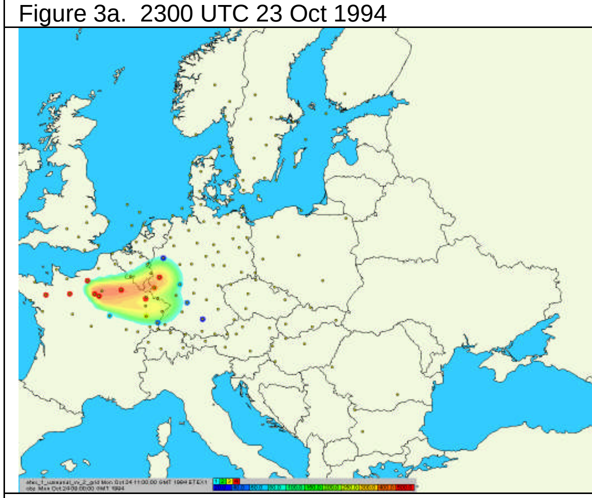

Figure 3c. 1100 UTC 24 Oct 1994

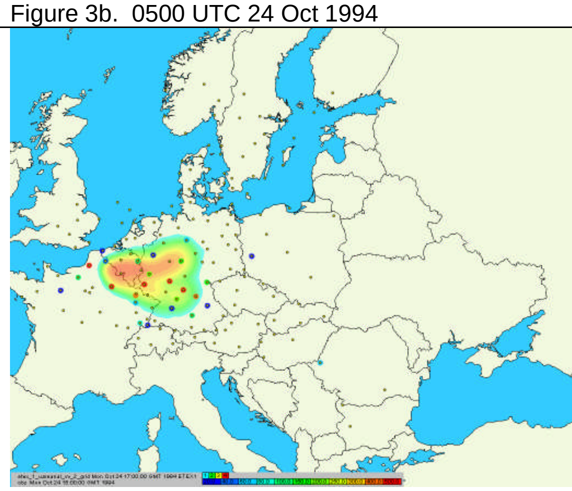

Figure 3d. 1700 UTC 24 Oct 1994

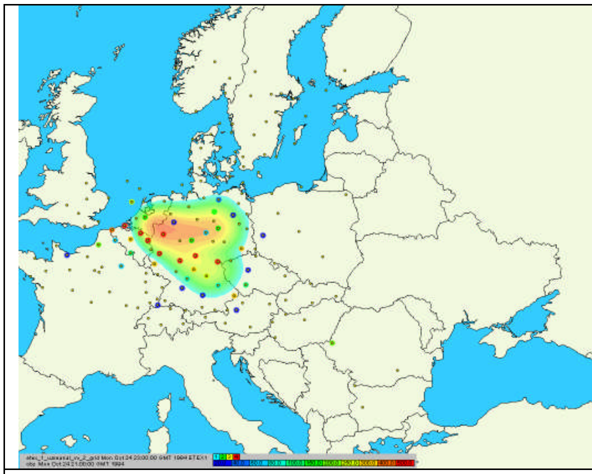
Figure 3e. 2300 UTC 24 Oct 1994

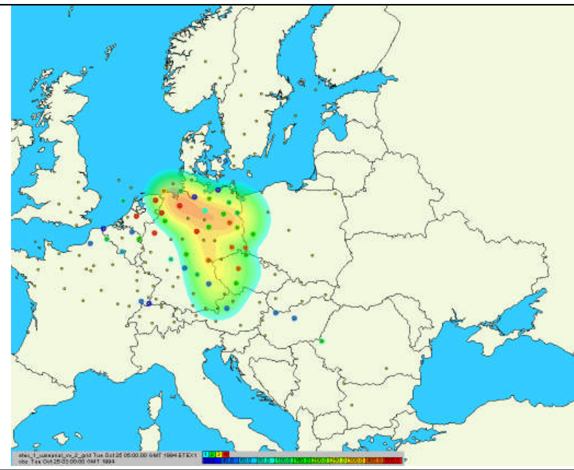
Figure 3f. 0500 UTC 25 Oct 1994

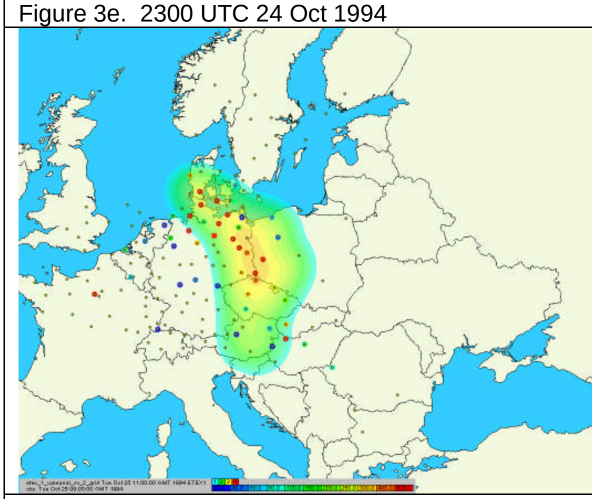
Figure 3g. 1100 UTC 25 Oct 1994

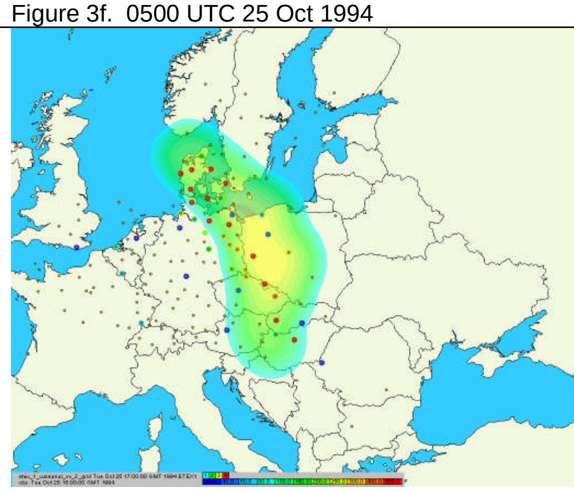
Figure 3h. 1700 UTC 25 Oct 1994

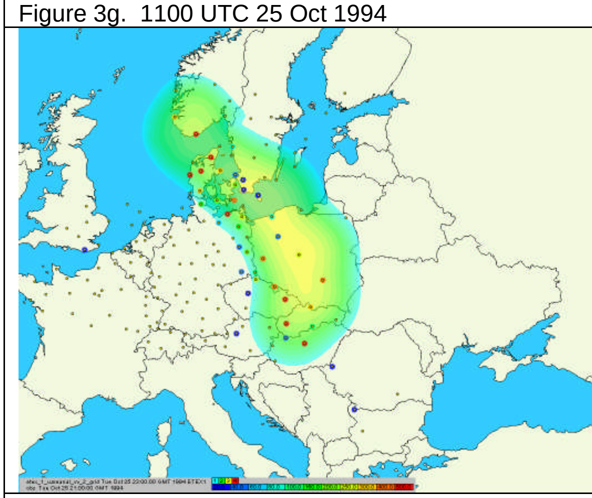
Figure 3i. 2300 UTC 25 Oct 1994.

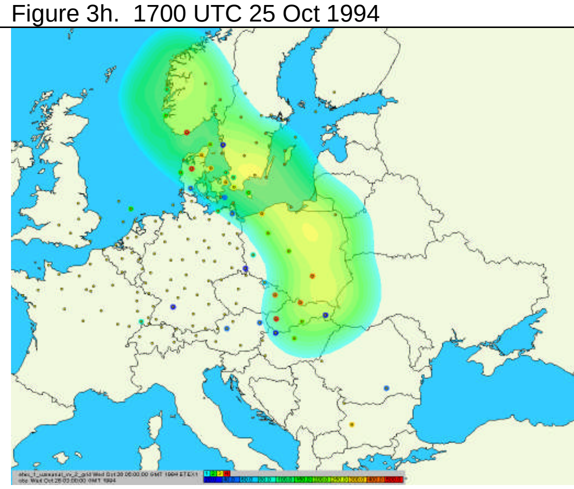
Figure 3j. 0500 UTC 26 Oct 1994

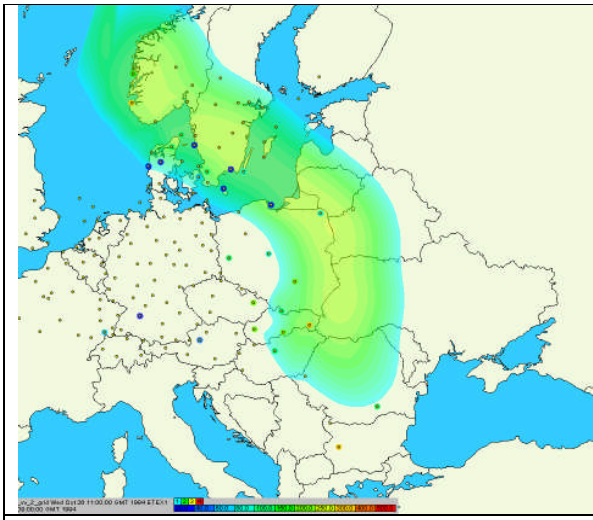

Figure 3k. 1100 UTC 26 Oct 1994

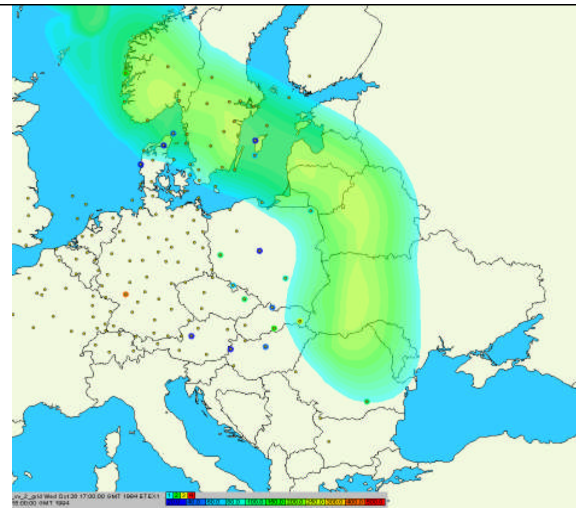

Figure 3l. 1700 UTC 26 Oct 1994.

3.2 Evaluation Statistics

In this section we present a summary of the results of the evaluation of ETEX release 1. We present a subset of the statistics that illustrate the differences between the model runs. Table 2 gives the results for some of the GAMUT tests. For reference and comparison, the statistics from two recent HYSPLIT versions are provided (Air Resources Laboratory, 2009).

From this sampling of the many tested configurations, one data configuration stands out as superior for this ETEX release. The NCAR/NCEP Reanalysis, when combined with the PBL heights derived from the regional rawinsonde reports, was the data configuration that produced the best verification statistics. The top five scores from various GAMUT configurations all used this data combination. Except for the bias, almost all the statistics for the Reanalysis + upper air PBL configurations were superior to those using other data. In particular, the Figure of Merit and correlation scores were clearly better. This indicates that the direction of the transport was close to that which was observed. This was further illustrated in the previous sections. While the bias was a little higher for the Reanal+upper air PBL cases than some others, the fractional bias was only around 10-15%.

The GAMUT runs that utilized other combinations of Reanalysis and upper air data did not perform as well. Somewhat surprisingly, the tests that utilized both the upper air rawinsonde winds and the PBL heights did not perform as well as those that did not include the rawinsonde wind data. In particular, the Figure of Merit was around 31 to 33 for the tests with the upper air winds and between 40 and 50 for the tests that only used the PBL estimates derived from the rawinsondes. This seems to indicate that the process of interpolating the upper air winds along with a gridded analysis that already includes these winds did not produce better results for this experiment. Not shown in this report, the configurations that used the upper air winds along with the PBL heights tended to take a more southerly track than those that only used the upper air data for PBL height. This was also true of the runs that utilized data from a WRF simulation.

Table 2. DATEM statistics for GAMUT and HYSPLIT, ETEX Release 1

#	Configuration		Rank	Fractional Bias	Figure of Merit	Correlation	
	Model	Data				r	t
3	Es, Cont	Reanal, UA for PBL	1.85	0.11	49.45	0.30	17.5
7	VV, Cont	Reanal, UA for PBL	1.84	0.14	50.04	0.30	17.6
4	VV, Discrete	Reanal, UA for PBL	1.75	0.17	43.34	0.29	16.7
3	Es, Discrete	Reanal, UA for PBL	1.75	0.10	39.91	0.28	16.2
67	SG, Es, Cont	Reanal, UA for PBL	1.62	0.87	32.64	0.63	45.5
14	Es, Cont	WRF run3	1.61	-0.04	30.88	0.08	4.3
6	VV, Discrete	Reanal, UA for PBL+wind	1.54	0.28	33.28	0.15	8.6
2	VV, Discrete	Reanal only	1.51	-0.65	48.69	0.18	16.2
5	Es, Discrete	Reanal, UA for PBL+wind	1.51	0.30	31.16	0.15	8.4
64	SG, Es, Cont	Reanal only	1.30	0.76	3.28	0.59	33.8
98	HYSPLIT 4.8	Reanalysis	1.55	0.44	36.31	0.30	17.5
99	HYSPLIT 4.9	Reanalysis	1.56	0.45	36.60	0.31	18.1

Model legend

SG: SLAM-GAMUT run. SLAM run for 24 hours.
VV: Vertical velocity lofting
Es: Static energy lofting
Cont: Continuous splitting algorithm
Discrete: Discrete splitting algorithm

Data legend

Reanal: NCAR/NCEP (2.5-degree) Reanalysis;
UA for PBL: Upper air soundings used only for mixing depths
UA for PBL+wind: Upper air soundings primary for PBL and used with Reanalysis for winds
WRF: WRF run.

The GAMUT runs that included only Reanalysis data (no upper air data) appear at first glance to perform much more poorly that those that included the rawinsonde PBL data. Inspection of the Figure of Merit statistic shows that the plume direction and coverage appeared to be very good. The Figure of Merit of configuration 2 was 48.7, which was the just under the best value of all the configurations tested. The GAMUT runs with only Reanalysis data had a strong low bias, however and somewhat worse correlation statistic than some of the other configurations. This led to a total rank score on the low end of the scale.

3.3 Comparison of the GAMUT and HYSPLIT Results

Comparing the statistics of the various GAMUT configurations with results from another transport-dispersion model can help put the results of this study in context. Configurations 98 and 99 in Table 2 are results from running HYSPLIT versions 4.8 and 4.9 against the first ETEX release. As already noted, we did not attempt to configure and execute HYSPLIT ourselves, but have used results produced by the NOAA Air Resources Laboratory (2009). The Reanalysis data were used to produce these results.

The HYSPLIT and the GAMUT results that used the Reanalysis data and rawinsonde PBL compare very favorably. The Figure of Merit statistic of the continuous-splitting configurations (3 and 7) of GAMUT was much better than those from HYSPLIT. The GAMUT bias was less than a third of HYSPLIT's. These (and other statistics) led to an overall Rank score from the best GAMUT configurations of around 1.84, compared to 1.56 for the published HYSPLIT results.

4. Acknowledgements

This study was funded by the United States Air Force under contract FA2521-05-C-8010.

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