A collection of data from dense gas experiments

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Abstract As part of the CEC DG XII ENVIRONMENT project REDIPHEM, a database on dense gas dispersion experiments was created. This includes measurements from a) wind tunnel experiments carried out at the University of Hamburg, TNO, and Warren Spring Laboratory, and b) field experiments from the MTH BA and STEP Fladis projects, and four US Lawrence Livermore National Laboratory projects. The purpose and design of each experiment are described. A set of characteristic scales originally developed for isothermal dense gas releases is adopted, and extended also to characterize the non-isothermal releases of the field experiments. The database includes general descriptions of the gas releases, information on the instruments applied, sensor positions, and measured time series. The quality of the measurements and simple methods for data screening are discussed. It is described 1) how to inspect the collected information with a MS-DOS program distributed with the data, 2) how to access the data with user written programs, and 3) how to install more data sets.

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1 Introduction

This report is a description of the dense gas data collection created during the Rediphem project. It may be read alone or in parallel to Bakkum & Duijm (1995), who describe the other part of the material for the Rediphem project, i.e. numerical models on dense gas dispersion and source terms.

The purpose of this document is the same as that of the data collection itself – to present the information in a way which provides an overview of dense gas experiments and at the same time assist future analyses.

The objective and the design of each experimental project are described. We adopt a system of characteristic length and time scales which originally was developed for isothermal releases in wind tunnels (König 1987). Cold gas clouds are characterized by an 'effective' molar weight, which we define as the molar weight of the isothermal model gas producing the same density effect as that of the cold gas cloud in the case of adiabatic mixing. The different gas sources and the origin of the background meteorological information are documented. Some meteorological parameters are estimated by us.

The value of experimental information is a combination of the general usefulness of the data and the measurement quality. The usefulness is an aspect which may be judged only in relation to a theory or the predictions of a model, and we leave it to the data user to decide whether the experiments contain the information needed for a given analysis. The measurement quality has been considered, and we have rejected most time series with obvious severe problems. Time series with less severe faults have been included without corrections, but we describe the general measurement quality and typical errors of the concentration sensors applied. In order to check the integrity of the data sets received and to search for data problems, we inspected the visual appearance and simple statistics of time series.

The Rediphem database is organized in files containing different kinds of information. The instrumentation is described by lists of sensor positions and text files describing the signal types. Likewise, the description of the experiments is divided into quantitative release specifications and comments in text files. The measurements are represented by time series. The appendices to this reports give a practical description on how to work with the database. It is described:

- How to access the database. Most files are written as plain ascii text files, and we provide tools which make it easy to access the binary time series with user written programs in Borland Pascal.
- How to add more data sets to the Rediphem data structure, and to check the consistency of the added information.
- How to inspect the data through a user-friendly MS-DOS program distributed together with the database. This program enables the user to overview the entire database, to select an experiment, to read the text files, to inspect the setup with interactive graphical displays, and to plot measured time series.

In the dense gas model evaluation project of Hanna, Strimaitis & Chang (1991) the concentration measurements were fitted to Gaussian profiles across the plume at a typical height and at a number of distances. This condensed information, called the Modellers Data Archive (MDA), was then compared to the model output by statistical tests. The data reduction of the MDA files gave a clear protocol for the model evaluation, i.e. it was transparent what the models was supposed to predict and they could be ranked after their abilities of doing so. In the Rediphem

collection we have not made a data reduction in advance, but since we store the full information in a standardized format, it will not be difficult to extract the information for different types of analysis. The advantage of storing the full data set is that we don't make initial decisions on aspects like the appropriate average time or the shape of the concentration profiles.

2 Wind tunnel experiments

The wind tunnel experiments in the Rediphem database have been collected from

- the Meteorological Institute at the University of Hamburg (UH)
- TNO Division for Technology for Society (TNO)
- Warren Spring Laboratory (WSL).

Most of the experiments were made in the MTH BA and STEP Fladis projects. The database also includes earlier work from UH (König 1987).

Figure 1. Sketch of a typical open-circuit wind tunnel.

2.1 Laboratory equipment

Wind tunnels

Figure 1 shows a sketch of the open-circuit wind tunnel type. In order to avoid disturbances, the flow is driven by a ventilation system downstream of the test section. Initial vorticity and turbulence are moderated by the filter at the inlet and the contraction just after the air intake. New, more well defined, turbulence is then generated by Counihan or 'shark-fin' vortex generators. The long boundary layer conditioning section is used to establish the desired turbulence and flow profile in the test section. In order to produce a deep boundary layer within a short distance from the inlet the roughness elements are larger than in the test section. The walls and the ceiling are smooth. Pressure gradients associated with possible blocking effects of obstacles placed in the test section may be avoided by adjusting the height of the ceiling.

The open-circuit wind tunnel type was used at all three laboratories – with some differences, as described by Schatzmann, Marotzke & Donat (1991), Hall, Waters, Marsland, Upton & Emmott (1991), and Oort & Builtjes (1990). The WSL tunnel used honeycombs instead of an initial contraction and only the UH tunnel had an adjustable ceiling. In the conditioning sections, the UH tunnel was equipped with 2 cm high roughness elements, the TNO used carpets of of variable texture, and WSL used coarse roughness elements close to the inlet which gradually were

graded down towards the test section. Wind profiles measured in the test regions, fitted to a logarithmic flow profiles of the type

$$u = \frac{u_*}{\kappa} \ln \frac{z}{z_0} \tag{1}$$

with the roughness length z_0=0.05-0.1 mm at WSL and ≈0.1 mm at UH. The different roughness elements applied at TNO, described as smooth floor, smooth carpet, and rough carpet, produced flow profiles with the roughness lengths 0.005, 0.05, and 0.5 mm, respectively. The dimensions of the test sections (width × height × length) were 1.5 × 1.0 × 4.0 m in the UH tunnel, 2.65 × 1.2 × 6.8 m in the TNO tunnel, and 4.3 × 1.5 × 8 m at the WSL tunnel.

Gas sources

instantaneous releases

The gas source for the instantaneous releases in the WSL tunnel was a 1:100 scale model of the cylindrical tent used in the Thorney Island (TI) field experiments, i.e. with a diameter of 140 mm and a height of 130 mm. The cylinder was filled with a dense gas, and removed leaving an initially still column of dense gas. In the field experiments the tent simply fell to the ground, but in the laboratory this motion was driven by an apparatus under the floor. The top of the cylinder was a disc, which ensured that the gas did not dilute before the intended release, and at WSL this disc remained after the release. The work programme of WSL required many repetitions, and for the second part of the project (with an obstacle), the filling and firing of the source was automated with pneumatic control. The instantaneous release sources at TNO and UH were similar to the WSL source (in model scale 1:107 and 1:164, respectively), but Oort & Builtjes (1990) explain that the lid of the source at TNO was carefully removed just before release.

continuous release

The continuous release source at TNO was a 107 mm orifice covered by a gauze of 50% porosity and mounted in the floor. The vertical momentum of this source was small.

model gas

The released gas at TNO and UH was sulphur hexafluoride (SF_6), only pre-mixed with air in a few cases. The released gas at WSL was either 50% or 100% Argon, 50% or 100% Bromo-Chloro-di-flouro-methane (BCF), or air with an 1–2% methane tracer for neutral buoyancy. UH presents the concentration measurements from experiments with pre-mixed gases as concentrations of the pure gas, in contrast to WSL who presents concentrations relative to the released mixture. In the Rediphem database, the initial concentration in the WSL experiments is formally set to 100% and associated with the average molar weight of the released mixture.

Gas sensors

aspirated hot-wires

The gas sensor used at TNO was an aspirated hot-wire probe. The principle of this instrument is that the heat transfer from a thin heated wire depends on the heat conductivity of the surrounding gas mixture. The wire was connected to a standard hot-wire amplifier running in temperature compensation mode. The sample flow past the heated wire was controlled by a nozzle, where the velocity reached the speed of sound. The speed of sound also depends on the mixture composition, but this was included in the calibration.

UH applied a similar instrument (called an aspirated hot-film probe), but without sonic flow in the nozzle. Instead a 6 m long tube was mounted between sensor and pump, making it possible to ventilate the sensor for 6 minutes, before the aspiration velocity was distorted by the changing density at the pump. The UH measurements were more sensitive to pressure fluctuations, but the advantage was a smaller sample volume.

WSL used a similar instrument (called a catharometer) and in addition a Cambustion flame ionization detector (FID). The FID was also applied in the later TNO experiments (Duijm 1992). *Cambustion FID*

It must be stated that the time series from one release configuration in the laboratories (a 'run' in our database) are *not* necessarily measured simultaneously. TNO repeated the experiment with a single probe at different positions, and WLS applied two adjacent probes placed at two measurering positions. Experiments with identical release conditions were repeated, and these are normally assembled into one or a few 'runs' of the Rediphem database. *timing*

Table 1. Characteristic length, time and velocity scales for instantaneous and continuous dense gas releases.

	Instantaneous	Continuous
Length	$L_{ci} = V^{\frac{1}{3}}$	$L_{cc} = (\dot{V}^2/g')^{\frac{1}{5}}$
Time	$T_{ci} = (L_{ci}/g')^{\frac{1}{2}}$	$T_{cc} = (\dot{V}/g'^3)^{\frac{1}{5}}$
Velocity	$U_{ci} = (L_{ci}g')^{\frac{1}{2}}$	$U_{cc} = (\dot{V}g^2)^{\frac{1}{5}}$

2.2 Scaling laws

TNO and UH present their experiments in the scaling system shown in table 1. This is based on dimensional analysis, using the release volume V or volumetric release rate $\dot{V}$, and the reduced gravity g' defined from *UH/TNO system*

$$g' = \frac{\rho_{\text{gas}} - \rho_{\text{air}}}{\rho_{\text{air}}} g$$

where

- ρ_{gas} is the density of the released gas
- ρ_{air} is the density of the ambient air
- g is the acceleration of gravity

It is noted that the time scale for both instantaneous and continuous releases is given by $T_c = \sqrt{L_c/g'}$ and the velocity scale is $U_c = L_c/T_c$. The description of sensor positions et cetera were given in non-dimensional units. For the Rediphem database we revert to SI units, but include the characteristic length and time scales in the *specs.dat* files, see chapter 4.

WSL characterize their instantaneous releases by means of the bulk cloud Richardson number *WSL system*

$$R_i = \frac{g'L}{U^2} \tag{2}$$

where

- L is the initial height of the gas cloud
- U is the average velocity at the height L

All of the WSL releases have the same initial shape, which means that $L \propto L_{ci}$ and $R_i \propto \left(\frac{U_{ci}}{U}\right)^2$.

2.3 Summary of laboratory experiments

Table 2. Overview of experiments from TNO

INST	Model of TI 17
CONT01	U=0.389 U_{cc}
CONT02	U=0.778 U_{cc}
CONT03	U=1.556 U_{cc}
TUV01	Unobstructed reference case
TUV02	EEC57 with fence
TUV03	EEC57 with fence removed after 30 sec
TUV11	Unobstructed reference case
TUV12	EEC57 with +15°fence
TUV13	EEC57 with -15°fence
TUV14	EEC57 with +15°fence removed after 30 sec
TUV15	EEC57 with -15°fence removed after 30 sec
FLS	Continuous release, with many measurement points

TNO experiments

intercomparison tests

Table 2 is an overview of the experiments carried out in the TNO tunnel. The INST experiment was a model of the TI17 field experiment. This experiment and the CONT01–CONT03 ones were made as an intercomparison test with HU and WSL (Oort & Builtjes 1990).

re-modelling

The the TUV01–TUV03 experiments were a 1:78 model of the EEC57 field experiment (see chapter 3) with continuous release over a linear fence perpendicular to the wind direction. In the full size experiment the wind direction was 15° off the ideal direction, and the TUV11–TUV15 series is a study of the effect of the fence orientation (Oort & Builtjes 1991).

DIP reference

The FLS 'run' contains time series from many positions at 7 downwind distances, 15 crosswind distances, and at 4 heights, i.e. a three-dimensional concentration field (Duijm 1992). The purpose of these measurements was to provide a reference for digital image processing (DIP) of video recordings of the light scatter from a laser sheet through the plume. The Rediphem database is designed for time series and therefore we have not inclueded the DIP results.

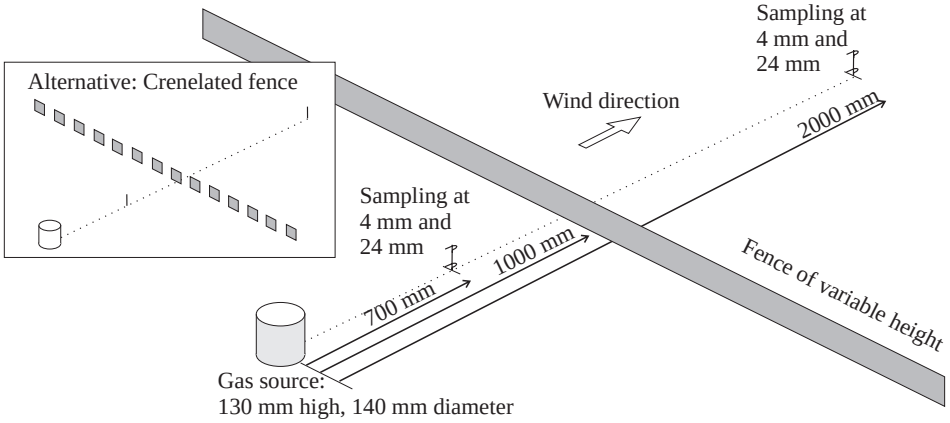


Figure 2. Experimental setup in the instantaneous releases at WSL.

Table 3. Overview of experiments conducted at WSL

Solid fence

	Fence Height						
	0mm	16mm	38mm	51mm	76mm	102mm	153mm
R_i							
10	√	√	√	√	√	√	√
5	√		√		√		√
2	√		√		√		√
1	√		√		√		√
$\frac{1}{2}$	√						
0	√			√	√	√	√

Crenelated fence

	Fence Height						
	0mm	16mm	38mm	51mm	76mm	102mm	153mm
R_i							
10	√		√		√		√
5	√						
2	√		√		√		√
1	√						
$\frac{1}{2}$	√						
0	√		√		√		√

Repeated experiments from WSL

The repeated experiments from WSL consist of two experimental series with instantaneous gas releases: a study of the effect of variable cloud stability (Hall, Waters, Marsland, Upton & Emmott 1991), and an extension in which a fence of variable height and porosity was introduced (Hall, Kukadia, Upton, Marsland & Emmott 1991). In practice, repeated releases will disperse with random differences, even though the nominal release conditions are the same. The objective of the experiment was to quantify this variability, by up to 100 repeats for each configuration. In Rediphem we treat the two experimental series as one data set.

layout

The fence was placed perpendicular to the flow 1 m downstream of the source, as shown in figure 2. In some of the trials the fence was exchanged with a line of screens with 1:1 width to height ratio giving a 50% overall porosity. This obstacle configuration is called a crenelated fence. The experiments were repeated with sensors placed at two heights on measurering stations in front of and behind the fence. The R_i number was set to either 0, 0.5, 1, 2, 5 or 10, using appropriate combinations of density ratio $\rho_{\mathrm{gas}}/\rho_{\mathrm{air}}$ and reference wind speed U. The work included the experimental configurations shown in table 3.

release scenarios

Figure 3 is a graphical presentation of statistics calculated by WSL. It shows how a statistical measure (the peak of the average signal) depends on the fence height and cloud stablity. We include this figure in order to illustrate that the WSL experiments were a systematic study of the effect of several release parameters, but that a physical interpretation of the cloud spreading may be difficult. Presumably, the dispersion is both influenced by the size of the obstacle wake and an upstream gravity wave reflection when the cloud hits a tall fence.

file names

In the Rediphem data structure, the experiments are named by a code where the first letter indicates the fence type (N=no fence, F=solid fence, C=crenelated fence), the next three digits are the fence height in mm, and the final two digits are

the bulk Richardson number, e.g. *F153RI02* for solid fence, of height 153 mm and Ri=02. Experiments with Richardson numbers $R_1 = 0.5$ are indicated by *P5*, e.g. *N000RIP5*. The WSL data set is voluminous, and therefore we made a reduced data set consisting of the average signal at each sensor position, the standard deviation, and a 'typical' signal. We define 'typical' as the pair of signals from a measurering station, which has the least root mean square deviation from the average signals.

data reduction

Obstacle experiments at UH

release scenarios

Figure 4 is a sketch of the wide range of obstacle geometries studied at UH. With most of these obstacle configurations, parameters were varied, i.e. parameters such as the distance from source to obstacle, obstacle height, and distance between obstacles. Furthermore, the source could be either instantaneous or continuous, and releases were done both in calm air and with ambient wind. Appendix B contains tables of these release scenarios. Measurements were made at variable downstream distances, except in the case with two walls and skew wind direction, where the measurering positions were aligned according to the obstacles instead of the wind. Figure 5 is an example of the results, showing the effect of a box array with two different orientations. The experiments were designed to detect the distance to the safe concentration at ground level.

data organization

All instantaneous releases were repeated in the order of 10 times, while the continuous releases were of sufficient duration to obtain stable statistics. The file names of the database are abbreviations of the original file names, as explained in the *data\hamburg\camp01.not* file of the Rediphem database.

Table 4. Dense gas field experiments included in the Rediphem database

Experiment	Gas	Release type	Trials	Special topics
Burro [a]	LNG	Pool on water	8	
Coyote [b]	LNG	Pool on water	3	Ignition and RPT
Desert Tortoise[c]	NH_3	Liquified jet	4	
Eagle [d]	N_2O_4	Pool on soil	4	Evaporation
Lathen [e]	C_3H_8	Variable	51	Obstacles and source types
Fladis [f]	NH_3	Liquified jet	7	Dense→passive

[a] (Koopman, Baker, Cederwall, H. C. Goldwire, Hogan, Kamppinen, Kiefer, McClure, McRae, Morgan, Morris, Spann & Lind 1982)
[b] (Goldwire, Rodean, Cederwall, Kansa, Koopman, McClure, Morris, McRae, Kamppinen, Kiefer, Urtiew & Lind 1983)
[c] (Goldwire, McRae, Johnson, Hipple, Koopman, McClure, Morris & Cederwall 1985)
[d] (McRae, Cederwall, Ermak, H. C. Goldwire, Hipple, Johnson, Koopman, McClure & Morris 1987)
[e] (Heinrich & Scherwinski 1990) and (Nielsen & Jensen 1991)
[f] (Nielsen, Bengtsson, Jones, Nyrén, Ott & Ride 1994)

3 Field experiments

projects

The collection of field data includes the projects listed in table 4. The four experiments Burro, Coyote, Dessert Tortoise and Eagle were all conducted by the US Lawrence Livermore National Laboratory (LLNL). We obtained the data from Sigma Research Inc. (Hanna et al. 1991). Descriptions of instruments and sensor positions were found in the data reports listed in the footnotes of table 4. The

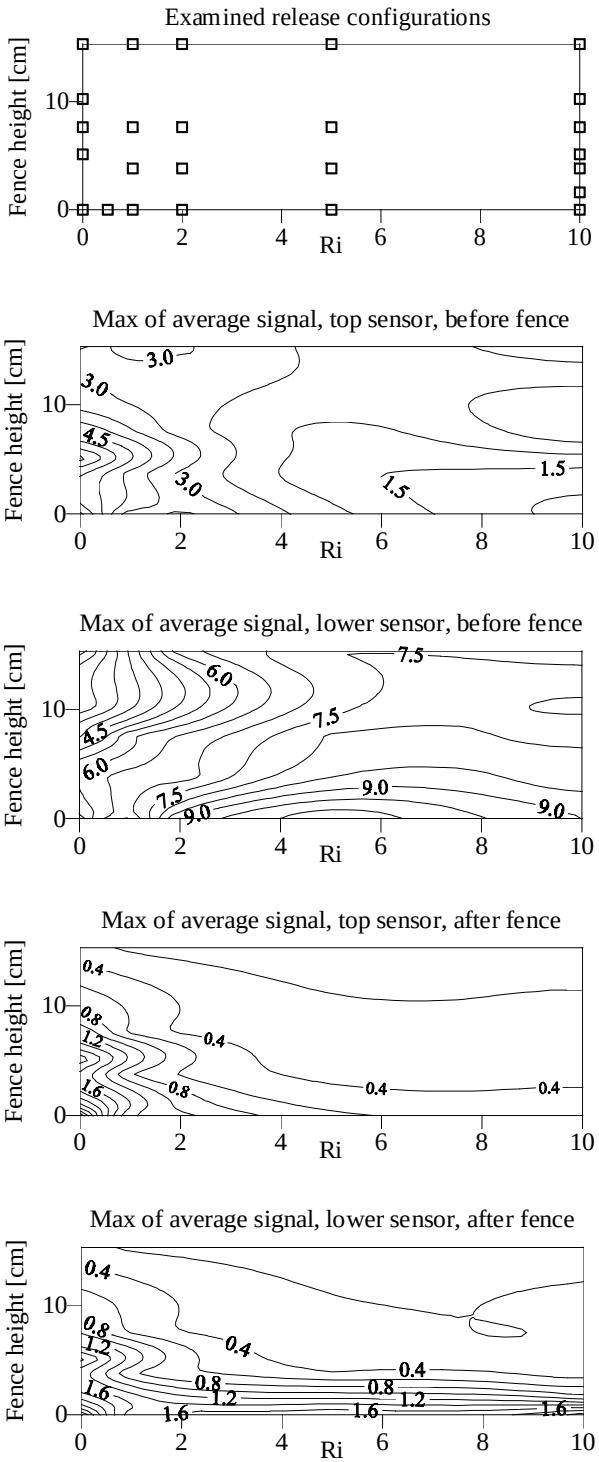


Figure 3. The peak of the average of repeated instantaneous releases as a function of cloud stability and fence height. The map at the top shows the release configurations observed, and the four contour plots below are interpolated between statistics from the four measurering positions. These statistics were calculated by Hall, Waters, Marsland, Upton & Emmott (1991, table 3) and Hall, Kukadia, Upton, Marsland & Emmott (1991, table 4–8).

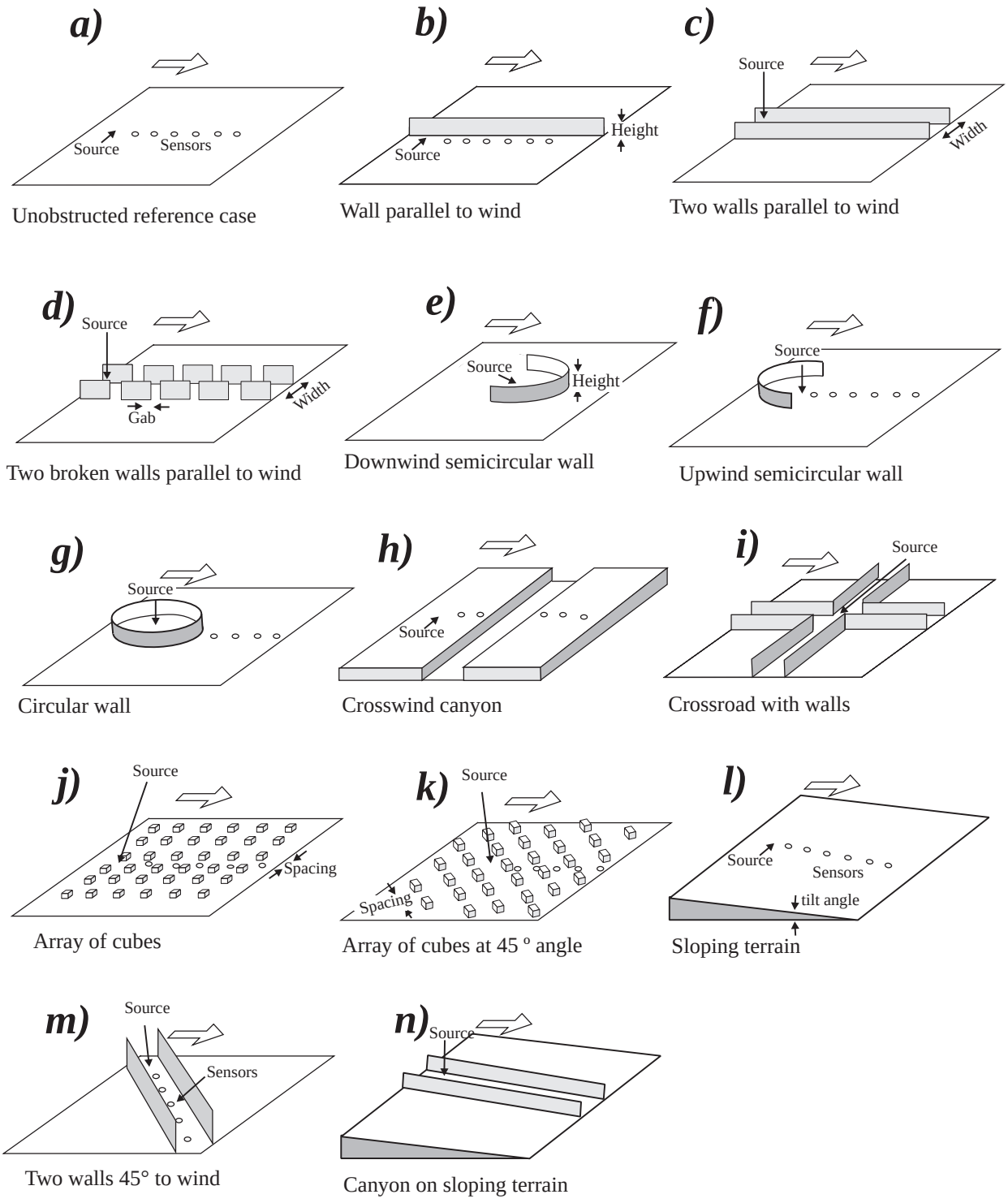


Figure 4. Obstacle configurations applied at Hamburg University.

LLNL data reports contain plots of virtually all measured time series, and these were useful as a check of the data integrity. We excluded a few measurements in the files received, since LLNL discredit them. Apparently, we miss some of the time series shown in the data reports, e.g. measurements inside the release system.

The experiments from the MTH BA project at Lathen were conducted by TüV Norddeutschland in collaboration with Risø, except the last experiments which

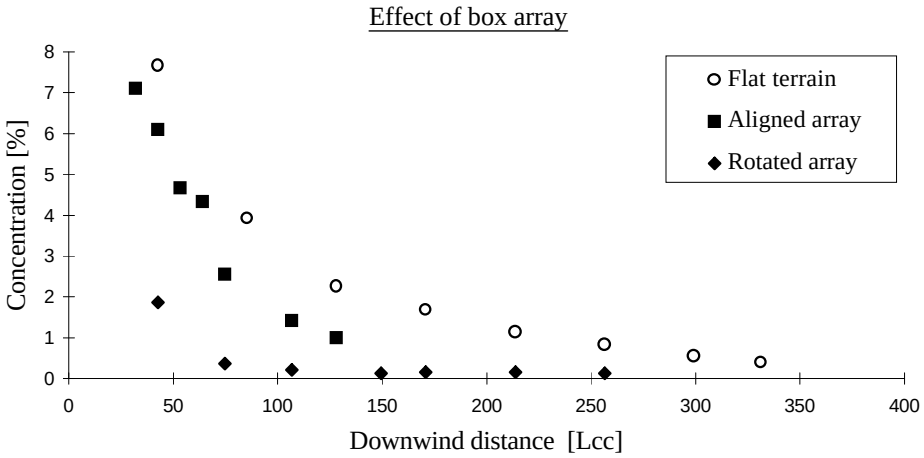


Figure 5. Example of results from UH: Average concentration as a function of downwind distance, measured with continuous release and arrays of cubic boxes with side length 11 L_{cc}, box spacing 32 L_{cc}, and ambient wind 1 U_{cc} (see figure 4a,j,k) – statistics calculated by Marotzke (1994).

TüV conducted all by themselves. The Fladis field experiments were conducted by a team from Risø, Hydro-Care, FOA and CBDE. Data from the Lathen and Fladis experiments are available at Risø.

special topics

The last column in table 4 lists special topics in the experiments. In some of the Coyote releases, the gas cloud was set on fire at the end of the release. From the dispersion research point of view, these trials are only useful until ignition, or rather the time when the flame reaches the individual sensors. Following Hanna et al. (1991) we exclude the Coyote experiments which were dedicated to studies of rapid phase transitions (RPT) near the water basin. Also some of the Eagle trials are are excluded, since the pool was covered by a foam which reduced the evaporation rate. Almost all of the experiments from Lathen had obstacles across or parallel to the plume. The FLADIS experiments covered both dense gas and ordinary passive dispersion, i.e. the gas plume was only dense in the upstream part of the measurering array. An overview of all field experiments is given in appendix C.

3.1 Source description

Generally, the source terms of the field experiment were more complex than in the wind-tunnel experiments, since the gas was stored as a liquid which evaporated after release. This section will describe the sources applied and estimate the initial temperature, aerosol fraction, and aerosol rain-out. Section 3.2 will make use of these source parameters to estimate the density of the gas. The gas storages were pressurized with inert gas and the release rates were almost steady.

Burro and Coyote

evaporation from water

These two LNG experiments were made at the US Naval Weapon Center (NWC) test site at China Lake, California, where liquified natural gas was poured into a water basin, as sketched in figure 6a. A steel plate was placed below the exit of the pipeline and the LNG was directed radially outwards on the water surface. The diameter of the basin was 58 m, the average depth of the water basin was 1 m, and the water level was 1.5 m below the terrain. We estimate that

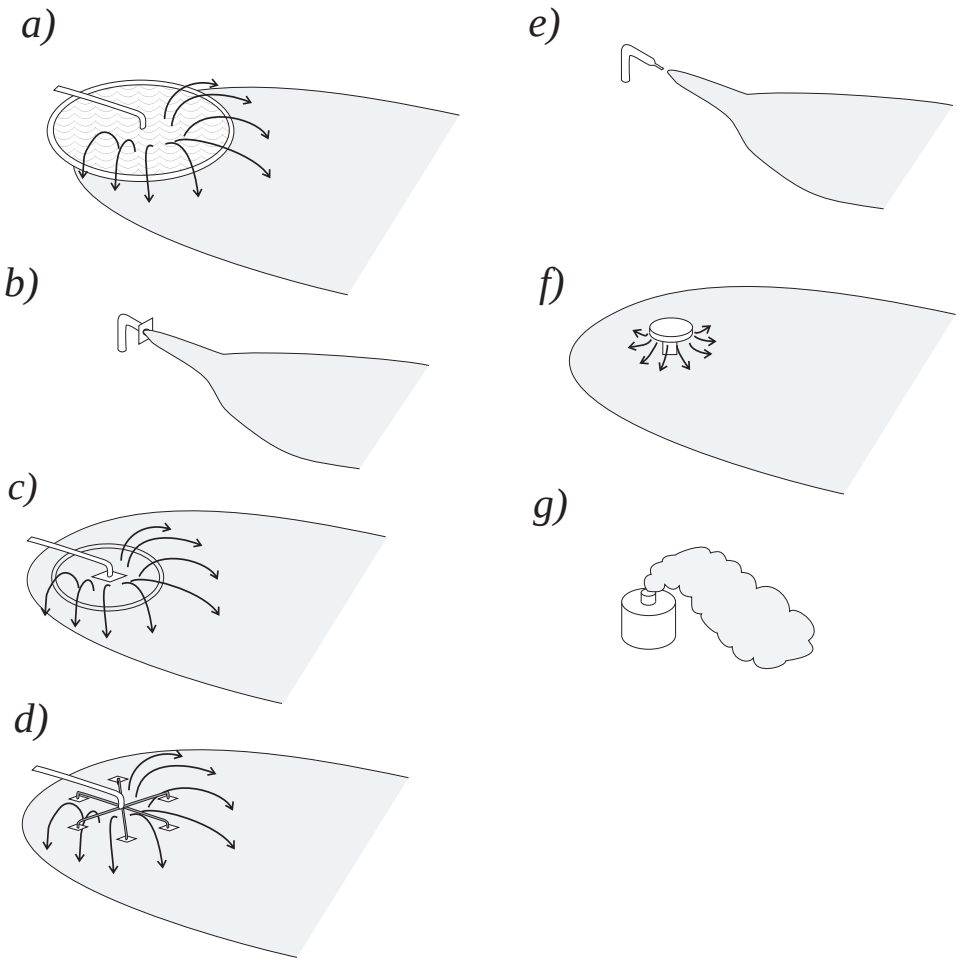


Figure 6. Sketches of different source types: a) Evaporation from a pool of liquified gas poured on a water basin (Burro & Coyote), b) a jet of liquified gas spilled through an orifice (Dessert Tortoise), c) evaporation from a pool spilled directly on the ground within a confinement (Eagle), d) evaporation from a pool spilled on the ground through several exits (Eagle), e) jet of liquified gas emitted through a nozzle (Lathen & Fladis), f) two-phase emission from a cyclone source (Lathen), and g) gas phase emission from a container with boiling liquid (Lathen).

- the water was an efficient heat supply, which made the gas evaporate at the same rate as it was supplied from the pipeline
- the LNG was boiling, i.e. the exit temperature was at the atmospheric boiling point.

Dessert Tortoise

orifice plate

Dessert Tortoise was conducted at the Frenchmans Flat site in Nevada, and here the liquified gas was emitted through an orifice plate as sketched in figure 6b. The pressure drop from the exit to the atmosphere caused part of the material to evaporate instantaneously, and the heat for this phase transition was supplied by a temperature drop of the released material. This heat was not sufficient enough to evaporate all of the released material, but the sudden evaporation fragmented the liquid into tiny droplets, of which most remained in the the two-phase jet. According to Koopman et al. (1982) some of the liquid deposited in a pool covering

liquid rain-out

up to 2000 m^3, but Koopman, McRae, Goldwire, Ermak & Kansa (1986) state that: 'this pool represented, however, a small percentage of the total liquid spilled'. We interpret this as a rain-out mass fraction of 5%.

Eagle

evaporation from soil

The nitrogen tetroxide N_2O_4 in the Eagle trials was poured directly on the ground, either through a single exit within a confinement as in figure 6c, or through many exits as in figure 6d. With the single exit, the gas did not evaporate as fast as supplied to the pool, and therefore the source type used in the E1 trial is not ideal for dispersion tests[1]. The boiling point of N_2O_4 is 21°C, which is not much below the ambient temperature. Therefore, it is not critical to know whether this was the exact pool temperature, since it has little effect on the gas cloud density.

confined pool

chemical reactions

A major complication with the Eagle experiments is that during the dispersion process, the released N_2O_4 dissociated into NO_2, which partly reacted with water vapor to form HNO_3.

Lathen

jet release

At least four different gas sources were used in the Lathen experiments. The source shown in figure 6e was a nozzle producing a two-phase jet as in Dessert Tortoise. Sometimes this nozzle was pointed in the vertical direction. The exit pressure was quite high and no pool formed on the ground. Nozzles with different dimensions could be mounted on the source. Unfortunately, test measurement at the source indicated that the actual release rate for the largest of these nozzles was much higher than the nominal value (Nyrén & Winter 1990). The actual release rate in trials with nominal release rates higher than 3 kg/s, must be considered as unknown.

spurious spill rate

cyclone release

The second source type was the cyclone source sketched in figure 6f. This source had no net momentum, since the material was emitted in all directions, but the initial plume width was larger than the source dimensions, as sketched in the figure. About 33% of the liquid material separated inside the cyclone and formed a pool on the ground. We estimate the temperature of the rain-out material to be at the boiling point.

rain-out

mobile jet source

In order to make use of less favourable wind directions, TüV improvised a mobile jet source, which may be considered as a miniature version of the main jet source. This jet was usually directed towards the ground, but little rain-out was observed. The pressure and temperature of the mobile source were not measured. In the Rediphem database we estimate these to be the ambient air temperature and the corresponding saturation pressure. The release rate of the mobile jet source was found from the total weight of each emission.

gaseous release

The principle of the pure gas source, sketched in figure 6g, is that liquified gas is led into a large kettle and the evaporated gas is emitted through an exit at the top. The release pressure and temperature of this source are also unknown, so we shall treat it as a boiling pool.

Fladis

The source used in Fladis was a nozzle similar to that used in Lathen. The release system shown in figure 7 was monitored by pressure transducers and by temperature sensors in the nozzle and the ammonia storage. Pressure measurements upstream and downstream a concentration in the nozzle made it possible to calculate the release rate. The weight of the tank was messured by a load cell,

[1] Actually, the main objective of Eagle was the evaporation rate and to test methods of mitigation

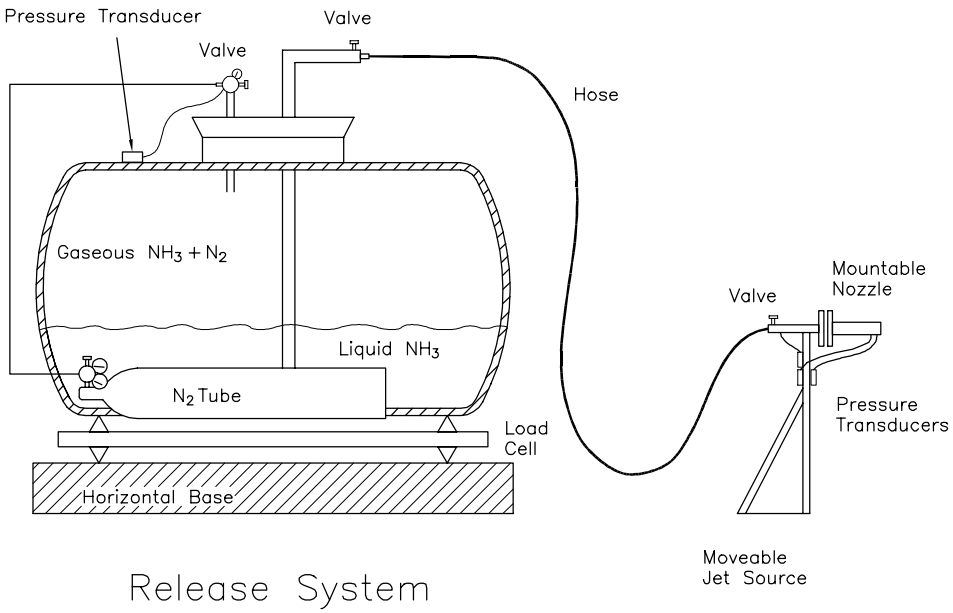


Figure 7. The release system in the Fladis field experiments.

and the weight loss during release was used as an independent check of the release rate. Also the jet momentum was calculated from the measurements in the nozzle.

3.2 Estimates of characteristic scales in field experiments

This section describes how to estimate the density effect of the different gas sources described above. We shall adopt the characteristic scales in table 1 which were based on the reduced gravity $g_0' = \Delta\rho/\rho_{\rm air} \cdot g$. This scaling system was developed for isothermal dense gas releases in wind tunnels, where the density ratio between gas mixture and ambient air is given by

isothermal release

$$\frac{\Delta\rho}{\rho_{\rm air}} = \frac{\Delta M}{M_{\rm air}} \cdot c \qquad \text{(for isothermal release)} \tag{3}$$

where c is the molar gas concentration, and $\Delta M = M - M_{\rm air}$ is the difference between the molar weights of the released gas and the ambient air. None of the field experiments in the Rediphem database used isothermal gas sources, so the relationship between density and concentration is more complex than for the laboratory experiments.

We consider the density of an ideal mixture of gas and air after evaporation of liquid droplets

$$\rho = \frac{p \cdot [(1-c)M_{\rm air} + cM]}{RT} \tag{4}$$

where

- p is the ambient pressure
- c is the molar gas concentration
- R is the universal gas constant $= 8.314\ \frac{\rm J}{\rm K \cdot mole}$
- T is the absolute temperature of the mixture

The difference between the pressure inside and outside the cloud is very small, and therefore the relative density difference becomes

$$\frac{\Delta\rho}{\rho_{\rm air}} = \frac{T_{\rm air} \cdot (M_{\rm air} + c \cdot \Delta M)}{T \cdot M_{\rm air}} - 1. \tag{5}$$

where $T_{\rm air}$ is the absolute temperature of the surrounding air. We assume that the mixing between gas and air is *adiabatic* and that the mixture temperature T is determined from the following enthalpy budget: *adiabatic mixing*

$$(T - T_{\rm air}) \cdot \left((1-c) \cdot M_{\rm air} c_p^{\rm air} + c \cdot M c_p\right) = c \cdot \Delta H \qquad \text{(for adiabatic mixing)} \quad (6)$$

where c_p is the heat capacity of the released gas, and $c_p^{\rm air}$ is the heat capacity of air. The left-hand side of this equation is the mixture enthalpy deficit between the actual temperature and that of the surroundings. The entrained air does not contribute to this, but the released material contributes with ΔH, defined as the enthalpy change between the exit conditions and the conditions at the ambient temperature and pressure. If the material evaporates from the liquid phase, this enthalpy change will be negative.

For the sake of convenience we assume that the enthalpy is conserved in a flash boiling jet release, although for this release type it would be more accurate to state that the *energy* is conserved. However, Duijm (1994, chapter 5.1 and annex B) calculates the velocity of the ammonia jet in Fladis trial 16 to 96 m/s (after flash, before entrainment). This corresponds to a kinetic energy of 4.6 kJ/kg which is a small amount compared to the 1270 kJ/kg heat of evaporation. Therefore, equation 6 is sufficiently accurate for a temperature prediction, also when we neglect the change of kinetic energy in a flash boiling jet.

From equation 6 we derive the ratio of the absolute temperature

$$\frac{T}{T_{\rm air}} = 1 + \frac{c \cdot \Delta H}{\left((1-c) \cdot M_{\rm air} c_p^{\rm air} + c \cdot M c_p\right) \cdot T_{\rm air}} \qquad \text{(for adiabatic mixing)} \quad (7)$$

and the relative density deficit given in equation 5 becomes

$$\frac{\Delta\rho}{\rho_{\rm air}} = \frac{1 + c \cdot \frac{\Delta M}{M_{\rm air}}}{1 + \frac{c \cdot \Delta H}{\left((1-c) \cdot M_{\rm air} c_p^{\rm air} + c \cdot M c_p\right) \cdot T_{\rm air}}} - 1 \qquad \text{(for adiabatic mixing)} \quad (8)$$

In most cases the gas will be dilute already within a short distance from the source and using $c \ll 1$, we linearize the expression to

$$\frac{\Delta\rho}{\rho_{\rm air}} \approx c \cdot \left\{ \frac{\Delta M}{M_{\rm air}} - \frac{\Delta H}{M_{\rm air} c_p^{\rm air} T_{\rm air}} \right\} \qquad \text{(for adiabatic mixing)} \quad (9)$$

In this linearized formula, the effect of an enthalpy deficit is equivalent to an excess molar weight, and we define an 'effective' molar weight $M_{\rm eff} = M - \Delta H / c_p^{\rm air} T_{\rm air}$. In the case of adiabatic mixing, $M_{\rm eff}$ would be the relevant molar weight of a model gas in isothermal wind-tunnel simulations of non-isothermal releases[2]. *'effective' molar weight*

In calculating the length scales we use the volume of such an model gas, i.e.

$$\dot{V} \approx \dot{m} / \rho_{\rm eff} = \dot{m} \frac{R T_{\rm air}}{p M_{\rm eff}} \quad (10)$$

where $\dot{m}$ is the known release rate by mass. Of course, this estimate is different from the real volume flow for high concentrations when the cloud contains a substantial liquid fraction. The purpose of the 'effective' molar weight concept is to model the appropriate density at lower concentrations. In case of heat transfer from the ground, the mixing process will not be adiabatic and the 'effective' molar weight approach will *overestimate* the cloud density.

Ideally, the enthalpy deficit between the released material at exit conditions and at ambient temperature should be looked up in a chemical handbook, but it may also be estimated by *approximate enthalpy deficit*

$$\Delta H = -\overbrace{\alpha \cdot M L}^{\text{evaporation}} - \overbrace{M c_p'' \cdot (T_{\rm air} - T_{\rm exit})}^{\text{heating}} - \overbrace{\frac{f}{1-f} M c_p' \cdot (T_{\rm rain} - T_{\rm exit})}^{\text{rain-out}} \quad (11)$$

[2] 'effective' molar weight may not be a very precise term, but it sounds better than the 'isothermal pseudo gas' molar weight

where

α = liquid mass fraction of airborne material
f = mass fraction of rain-out aerosols (relative to total mass)
T_{air} = temperature of the ambient air
T_{exit} = temperature of the gas source
T_{rain} = temperature of rain-out aerosols
L = heat of evaporation
c'_p = heat capacity of the released material in liquid phase
c''_p = heat capacity of the released material in gas phase.

Note that in this formula the rain-out fraction f is taken relative to the total mass including the rain-out material, whereas the liquid mass fraction α is taken relative to the airborne mass only. The formula consists of three contributions. The first term is the heat of evaporation for the airborne liquid. The second term is the heat, used to heat the released material after evaporation. The third term is a correction applied in cases with liquid rain-out, e.g. the trials with the cyclone source at Lathen. The argument for this correction is that if the rain-out mass fraction f is cooled down before being separated from the flow, this heat will be absorbed in the remaining $1 - f$ mass fraction of the release. The temperature of the rain-out material will typically be the boiling point. Equation 11 assumes that the rain-out material is removed completely from the flow. The exit conditions for pool sources are evaluated just after evaporation, i.e. the liquid mass fraction is set to *zero*, but the exit temperature is that of the pool surface, which we set to the boiling point. The thermodynamical properties L, c''_p, and c'_p are functions of temperature, and for accuracy we apply $L(T_{\text{exit}})$ in the evaporation term, $c''_p\left(\frac{T_{\text{air}}+T_{\text{exit}}}{2}\right)$ in the heating term, and $c'_p\left(\frac{T_{\text{rain}}+T_{\text{exit}}}{2}\right)$ in the aerosol rain-out term.

M_{eff} of LNG mixtures

The composition of the LNG mixtures applied in the Burro and Coyote releases was variable, giving a different average molar weight for each release. Preliminary estimates of the 'effective' molar weight in the Burro experiments were calculated with the simplifying assumption that each component of the methan–ethane–propane mixture evaporated at their individual boiling point. The individual boiling points of the three components increase with the real molar weight, and this implies that the second term in equation 11 is less significant for propane. The net result is that the standard deviation of the 'effective' molar weight in the Burro releases was just 1%, much lower than the 4.8% standard deviation of the real molar weight. Therefore, we decided to apply the average 'effective' molar weight for all LNG releases.

Table 5. Instrumentation in Burro

			Distance from source [m]			
Measurement	**Instrument**	**Number**	57	140	400	800
Concentration	LLNL IR	29	√	√	√	√
	IST	45	√	√	√	√
Temperature	Thermocouple	96	√	√	√	√
Humidity	LLNL	8	√	√	√	√
Heat flux	Hy-Cal	7	√	√	√	√

3.3 Experimental setup

Burro and Coyote

Figure 8 shows the experimental layout of the two experiments at China Lake. In Burro, four arcs of 10 m masts were erected and equipped with thermocouples and

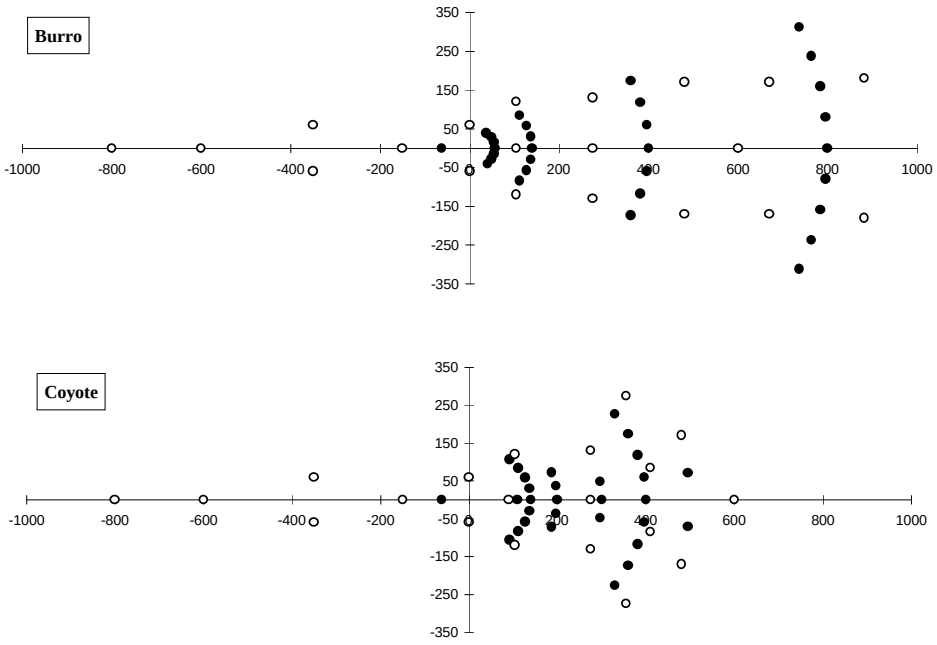


Figure 8. Measurement array in Burro and Coyote. The closed circles are 10 m masts with concentration sensors at three or more levels, plus other instruments. The open circles indicate stations which measured wind speed and direction at 2 m height.

Table 6. Instrumentation used in Coyote

			Distance from source [m]				
Measurement	**Instrument**	**Number**	140	200	300	400	500
Concentration	LLNL IR	28	√	√	√	√	
	IST	36	√	√		√	√
	MSA	12				√	
	JPL IR	7	√		√		
Temperature	Thermocouple	96	√	√	√	√	√
Humidity	LLNL	8	√	√	√	√	
Flame sensor	Hy-Cal	2	√				
Heat flux	Hy-Cal	7	√	√	√	√	

concentration sensors at three levels. Instruments of each type were distributed at all distances as shown in table 5. The LLNL infrared absorption sensor is faster and more accurate than the solid state IST sensor. The air humidity and the heat flux from the ground were measured along the array centerline. The data were sampled by a unit near each mast and transferred to a main computer by telemetry. Unfortunately, this system did not work well in the Burro experiment, and therefore 72 s blocks of all data from individual masts are frequently missing in the time series. The wind speed and direction were measured at a separate array of measurement stations.

bad data transmission

The Coyote setup was a modification of the previous Burro arrangement. It had been found that the sensors at the 800 m arc had been exposed only to very low concentrations, and in many cases the measurements at the 60 m arc had been disturbed by mud and water thrown up by RPT explosions. In Coyote, the

measurement array was therefore concentrated between 140 m and 500 m. Two new types of concentration sensors were added: the JPL infrared absorption sensor (with a faster response time than the LLNL IR sensor) and the MSA catalytic combustion sensor (which was less sensitive to gas composition, air humidity and wind speed than the solid state IST sensors). Table 6 indicates the distribution of these sensors.

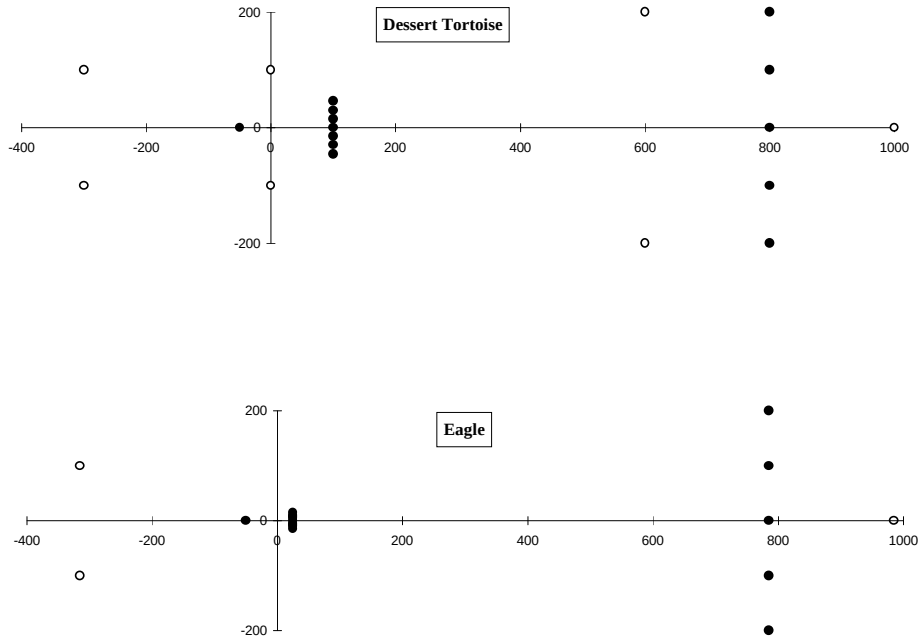


Figure 9. Measurement array in Dessert Tortoise and Eagle. The closed circles are 10 m masts with concentration sensors at three or more levels, plus other instruments. The first row of seven 10 m masts was moved very close to the source in the Eagle experiment. The open circles indicate stations measuring wind speed and direction at 2 m height.

Table 7. Diagnostic instrumentation used in Dessert Tortoise – after Koopman et al. (1986)

			Distance from source [m]				
Measurement	**Instrument**	**Number**	0	100	800	2800	5500
Concentration	MSA NDIR	20		√			
	LLNL IR	31		√	√		
	IST	24	√		√	√	√
	Dosimeter	8				√	√
Temperature	Thermocouple	36	√	√	√		
Aerosols	Beta gauge	5		√			
	Nephelometer	2		√			
	Particle counter	1		√			
	LLNL IR	31		√	√		
Humidity	LLNL	1	√				
Heat flux	Hy-Cal	3		√			

Dessert Tortoise

Figure 9 shows the central part of the mast array in the two experiments from the Frenchmans Flat site. As in Burro and Coyote the wind measurements were spread over a wider area. Concentration sensors were also placed far downwind, but these were not logged by the main data acquisition system, and they are not directly available. This time the masts were organized in straight lines across the plume. The MSA NDIR sensor was applied for ammonia measurements at the 100 m row. In order to measure the ammonia content from both the gas and liquid phase, the sampled cloud mixute were passed through heating devices before the measurering the concentraion. The LLNL IR sensors were the same as those in the previous LNG experiments, since these instruments were also able to detect NH_3. Goldwire et al. (1985) explain that it would be possible also to derive a signal for water vapor, but this analysis is not in our possession. Nor were the other aerosol signals listed in table 7 included in the files received, but judged from the data report, the aerosol data would be difficult to interprete, anyhow.

aerosol data

Table 8. Diagnostic instrumentation used in Eagle – after Koopman et al. (1986)

			Distance from source [m]			
Measurement	**Instrument**	**Number**	0	25	800	2800
Concentration	LLNL IR	21		√		
	ESI electrochem.	13			√	
	Interscan	2				√
	Dosimeter	8				√
Temperature	Thermocouple	36	√	√	√	
Aerosols	LLNL IR	31		√	√	
Humidity	LLNL	1	√			
Heat flux	Hy-Cal	3		√		

Eagle

The setup in the Eagle experiments was similar to that of Dessert Tortoise, except that the front row was moved closer to the source. The LLNL IR sensors in the front row detected gaseous N_2O_4, where as the new ESI electrochemical sensors at the 800 m row measured NO_2. McRae et al. (1987) explain that the released gas must have been completely dissociated at the rear row, where as both components are likely to be present at the front row. Assuming homogeneous equilibrium, the concentrations of the two components should relate to each other through the ideal law of mass action

chemical reactions

$$\frac{[NO_2]^2}{[N_2O_4]} = K(T) \tag{12}$$

where the equilibrium constant is

$$K(T) = \exp\left\{\frac{33.815769 + 0.027048675\,T - 0.000029114204\,T^2 - \frac{12875}{T}}{1.9871}\right\}$$

in which the temperature T is measured in °K (McRae et al. 1987). Thus, knowing the N_2O_4 concentration and the temperature from the adjacent thermocouple, it is possible to estimate the total gas flux. Characteristic scales based on the 'effective molar weight' from section 3.2, do not make much sense in this case.

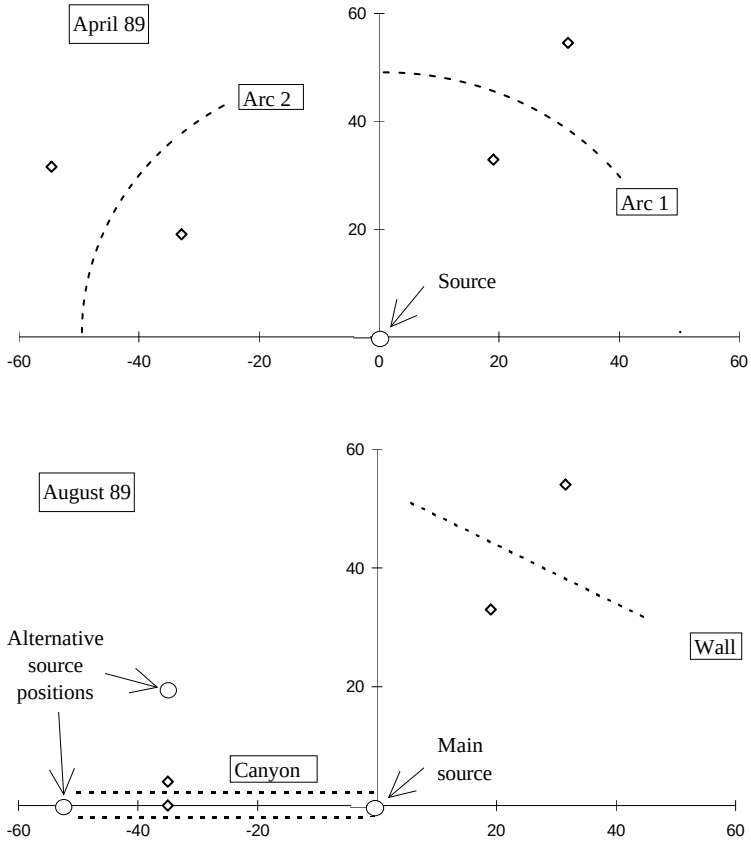


Figure 10. Measurering arrays at two field campaigns in Lathen. The dotted lines represent 2 m high fences which could be removed during each trial. Each setup was able to make use of two alternative wind directions. In August 1989 also an improvised mobile source was used north and west of the two parallel fences. Four 6 m masts (marked by ⋄) were placed in front of and behind each obstacle, and concentration sensors were distributed in different configurations around the obstacles.

Table 9. Instrumentation used in Lathen

Measurement	**Instrument**	**Number**
Concentration	TüV catalytic	40
	TüV IR	9
	TüV IR (modified)	1
	Sonic+thermocouple	6
Temperature	Thermocouple	29
Wind direction	wind vanes	4
Wind speed	wind direction	12
Turbulence	Kaijo-Denki	6

Lathen

The setup at Lathen was more flexible than in the rest of the collected field experiments. Figure 10 shows the obstacle configuration in each of two experimental campaigns. The obstacles were 2 m high and consisted of curtains, which could be removed by a pull in a wire. In order to compare with the unobstructed flow situation, the obstacles were generally removed in the middle of each trial. Each

obstacles

campaign used two obstacle configurations which were aligned after two alternative wind directions. The experiment was designed to study the gas flow over a linear or curved wall or between the two parallel walls shown on the left-hand side of the August 89 setup in figure 10. During release the curtains were mounted only on the part of the obstacle configuration which was exposed to gas. In order to make use of more wind directions, a small mobile source was improvised in the August 89 campain, and releases were made from the alternative source positions shown in figure 10. Sometimes, only every other curtain in the obstacle lines was mounted, giving a 50% overall porosity similar to the WSL crenelated fence. Concentration, temperature, wind speed, wind direction and turbulence *measurements* were measured on the 6 m masts which were placed in front of and after the walls perpendicular to the preferred wind direction. With the two walls parallel to the wind direction, masts were placed at the centerline and just outside of the street canyon. Concentration sensors were also placed at ground level and at 1 m height in a flexible (irregular) array of poles. The TüV catalytic instruments were the primary concentration sensors. Faster infrared absorption devices were applied, but these had problems with the fog of condensed water vapor and the measurement path had to be covered by a fleece which slowed down the response time. The combination of sonic anemometers and thermocouples was used to deduce an alternative fast concentration signal.

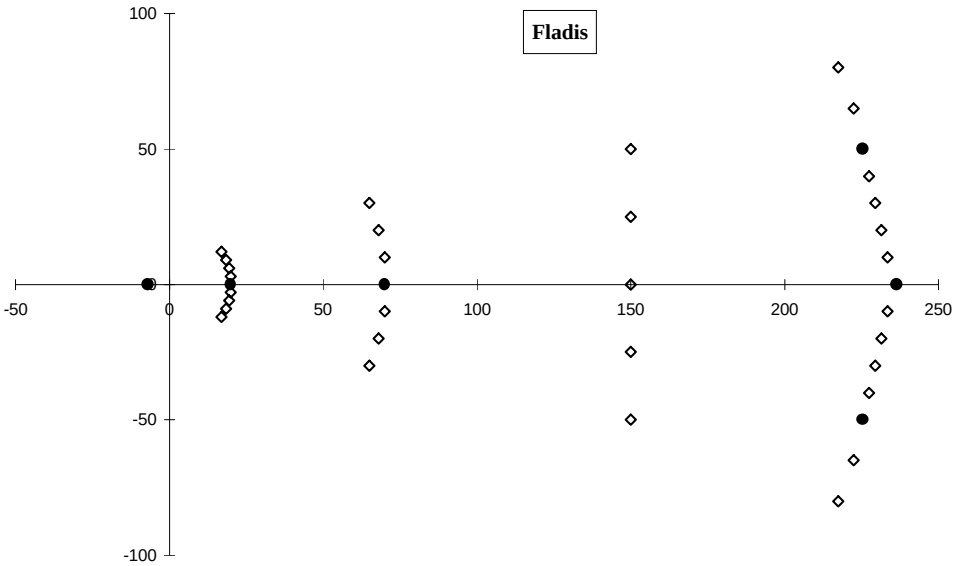


Figure 11. Measurering array in Fladis. The closed circles • represent 10 m masts, and the ◇ marks represent 2 m poles with concentration sensors.

Fladis

The Fladis setup in figure 11 consisted of three main arcs of sensors at 20, 70 and 238 m from the source. Each array had one 10 m mast on the centerline, and the third arc of sensors had two additional masts on the sides. Catalytic and electrochemical sensors were mounted on both the 10 m masts and on poles at ground level or at 1.5 m. The gas plume in Fladis became dilute at the downstream part of the array with little temperature difference from the ambinet air. Therefore, temperature was measured only close to the source. Very fast Uvic® sensors were either arranged in a flexible array at 150 m distance or mounted on the center mast

Table 10. Instrumentation used in Fladis with downwind distance.

Measurement	Instrument type	Number of instruments					
		-7m	0m	10m	20m	70m	240m
Pressure	Transducer		4				
Tank weight	Load cell		1				
Concentration	Catalytic				22	12	
	Electrochemical						22
	Uvic®						10[a]
	Sonic anemometer[b]				3		
Temperature	Thermocouple		2	64[a]	29		
Speed	Cup anemometer	3				3	5
Direction	Wind vane	1				1	2
Turbulence	Sonic anemometer	1				1	1
Humidity	Psycrometer	1					
Hum. & temp.	Solid state w. Pt100	1			1	2	
Short wave rad.	Pyranometer	1					
	Albedometer[c]				1		
Long wave rad.	Pyrgeometer				1		
Surface temp.	Infrared[d]				1		
Air pressure	Barometer[e]	1					

[a] sometimes re-arranged
[b] equipped with thermocouple
[c] upward and downward pyranometer
[d] remote sensing
[e] solid state sensor

at 238 m distance. As in Lathen, the sonic/thermocouple concentration method was applied at 20 m distance. Table 10 gives an overview of the instrumentation.

3.4 Meteorological parameters

In this section the different observation methods for the meteorological background information are described. Some meteorological parameters were measured directly, and some are a result of the analysis of the experimentalists. In other cases we used existing information to estimate parameters specified in the Rediphem database.

Burro, Coyote, Dessert Tortoise and Eagle

wind field

The site averaged wind speed and direction in the LLNL experiments were measured by arrays of O(20) stations, each carrying a cup anemometer and a wind vane at 2 m height. These measurements are only available in 10 s block averages, and this is why the speed and direction time series appear to have discreet jumps in the Rediphem database.

flux estimates

The flux estimates were derived by LLNL using profile measured upstream of the source. According to the diabatic surface layer theory, the flow and temperature are described by the Monin-Obukhov profiles

$$u(z) = \frac{u_*}{\kappa}\left\{\ln\frac{z}{z_0} - \psi_m\left(\frac{z}{L}\right)\right\}$$

$$T(z) - T_0 = \frac{T_*}{\kappa}\left\{\ln\frac{z}{z_0} - \psi_h\left(\frac{z}{L}\right)\right\} \qquad (13)$$

where u_* is the friction velocity, κ is the von Karman constant, z_0 is the surface

roughness, L is the Monin-Obukhov length scale, and T_* is the temperature fluctuation scale. The applied stability corrections ψ_m and ψ_h were modified versions of the parametrizations by Paulson (1970). These profiles were fitted to measurements at an upstream reference mast, and the sensible heat flux was derived from $\varphi = \rho c_p u_* T_*$. The atmospheric pressure and cloud cover were registered, whereas the humidity measurements are part of the data set.

Lathen

The Rediphem database contains data from the main campaigns with Risø participation and the later campaign where TüV operated on their own with little meteorological equipment.

the main releases

For the releases made in collaboration with Risø, the ambient wind speed and direction are generally obtained from mesurements at the side of the array where the obstacle was not erected. In some cases these wind measurements were missing, and the speed and direction were obtained from a separate station which logged 10-min average values of speed and direction. Prior to each release, the ambient humidity and temperature were measured with a hand held psycrometer, and (with some neglects) a note was made on the cloud cover. Generally, the atmospheric pressure is not available, but for consistency we write P=1 atm in the database (the altitude was about sea level). The surface roughness was estimated from wind profiles measured in a period without obstacles or gas release.

stability classification

Direct measures of atmospheric stability are not available, but for the Rediphem project, the Pasquill-Turner class has been estimated from the wind speed and cloud cover. The Monin-Obukhov length L was estimated from this stability class and the surface roughness, using the diagram of Golder (1972). This is probably an inaccurate procedure.

the last releases

In the later releases, TüV had to continue without meteorological equipment, and the meteorological description was obtained from 10-min average values measured at a met-tower 800 m away. Some of the meteorological parameters in these releases are mere visual observations, e.g. 'easterly wind direction'. The stability is described by the special bulk Richardson number

$$Ri = \frac{g}{T} \frac{\frac{T_3 - T_1}{z_3 - z_1} - \gamma_{\mathrm{dry}}}{\frac{u_3 - u_2}{z_3 - z_2}} \tag{14}$$

where γ_{dry} is the adiabatic lapse rate for dry air, i.e. a bulk Richardson number obtained from temperature and velocity gradients over different intervals. By insertion of the Monin-Obukhov profiles in equation 13 with the known surface roughness z_0, the temperature T_1, and the velocity u_2, a relationship between Ri and L was obtained. This was solved by iteration, producing an estimate of the Monin-Obukhov length for trial EEC60–EEC98 in the Rediphem database.

Fladis

The meteorological conditions in Fladis are taken from the upstream reference mast, which measured wind profile, wind direction, humidity, and turbulence.

flux measurements

Direct measurements of the friction velocity u_*, the temperature scale T_*, and the Monin-Obukhov length L, were calculated by eddy correlation of turbulence measurements with sonic anemometers. Also the atmospheric pressure, the shortwave radiation and the infrared radiation from the sky were measured.

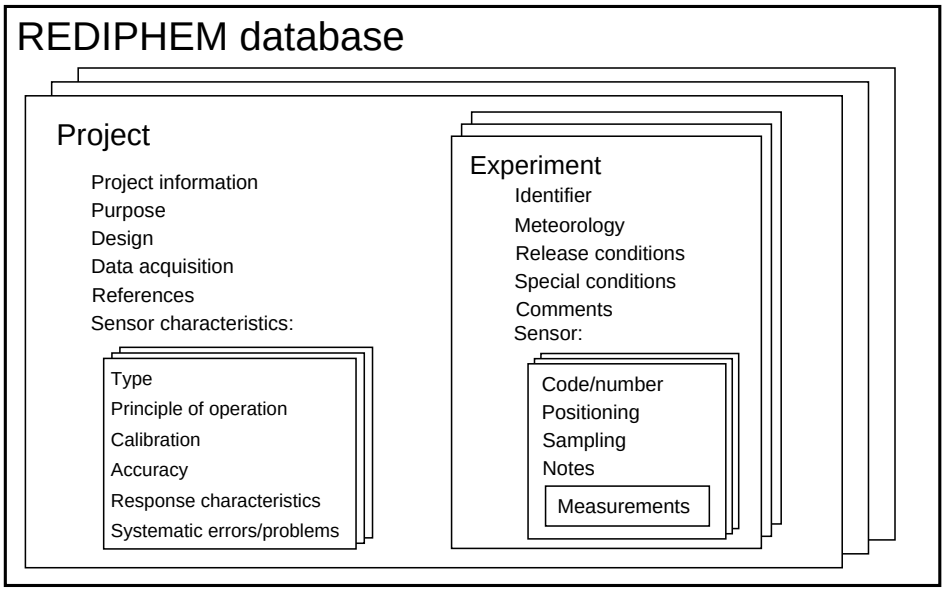


Figure 12. Structure of the REDIPHEM database.

4 The database

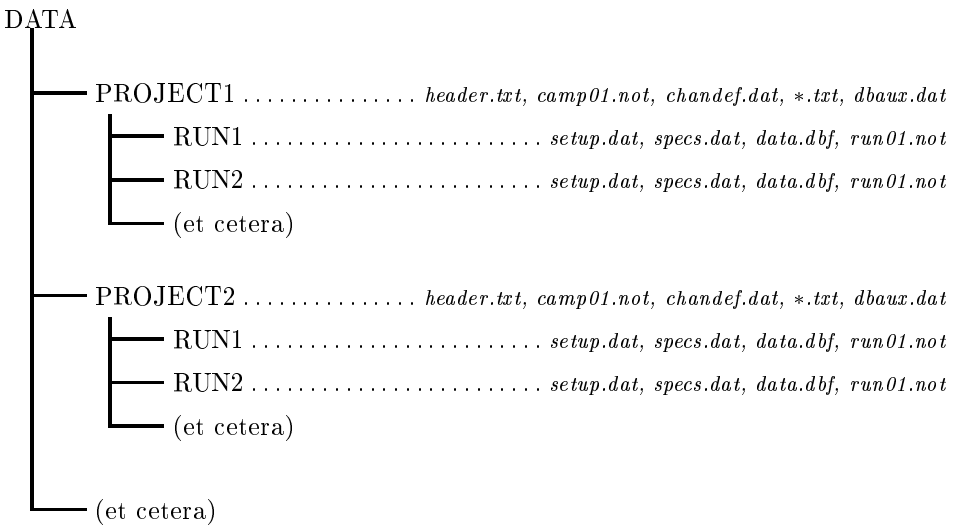
The experimental data came in various magnetic formats and written documents, and it was soon realized that the information would be more accessible in an integrated database. We set out the following aims: *aims*

- To survey a large number of experiments.
- To use the system for model evaluation.
- To collect relevant background information on experimental procedures, experimental set-up, sensor characteristics, calibrations, and to ensure that this information remain with data.
- To enable data selection and export to external programs, e.g. spreadsheets and commercial databases.
- To assist model developers in finding data for model comparison.
- To make empirical knowledge more accessible, also for non-specialists.

Thus, our objective was both to organize data for the Rediphem model evaluation, and to communicate the information to a wider audience. At present, the consequence assessment in risk analysis usually relies on a complex system of simplified models, and raw data are seldom used directly, even if this may be relevant. An accessible database could be used to find experiments matching a given scenario, either directly or through the use of scaling laws. *data dissemination*

4.1 Data organization

The collected information was organized in the structure sketched in figure 12, i.e. basically in the hierarchy: experimental series - experiment - sensor - data. This is a way to link background information to the actual measurements and it reflects a natural search process. *information hierarchy*



header.txt	Short presentation of each project
camp01.not	Comprehensive description of each project
chandef.dat	A sub-database which defines signal types in each project
**.txt*	Text files describing the instruments of a project
dbaux.dat	File used by the *db.exe* program (need not be present)
setup.dat	Registration of measurering positions and signal types
data.dbf	A file containing the binary time series
specs.dat	Formal specification of the release conditions
run01.not	Comments to an experiment.

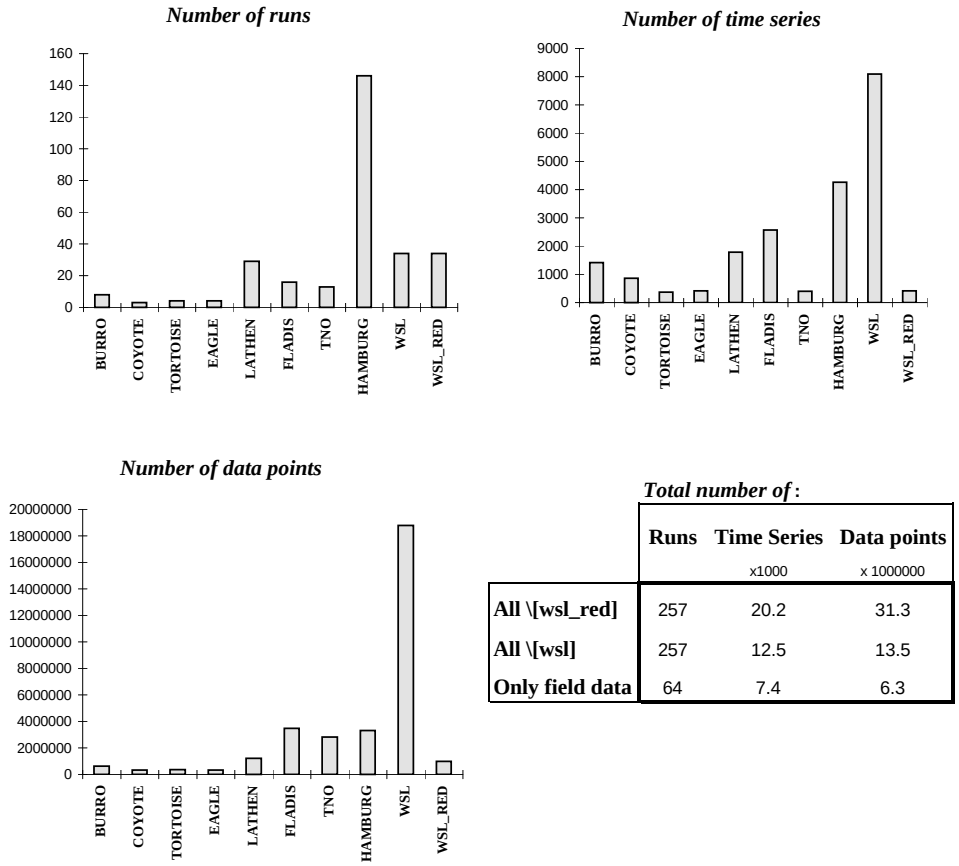
Figure 13. The files in the REDIPHEM database

- At the top level we put the purpose and general design of the experimental project together with a reference to written material, the names of responsible persons and organizations. Other information relevant to the project as a whole is also found here. *projects*
- For each project a small sub-database holds information about general characteristics for all instrument types used. *instruments*
- At the second level we put information on individual experiments such as release parameters. For each experiment, relevant comments are available in the form of an ascii text file. This information could regard the success of the experiment in general (e.g. whether the wind direction was favorable), or information on how the data were processed or how signals were sampled. *releases*
- At the third level we put information on the measuring instruments, e.g. the position. *experimental setup*
- The actual measurements are found at the innermost level. Data are in the form of time series. *measurements*

The database was implemented as a set of MS-DOS files organized in a directory for each project and sub-directories for each release scenario or 'run' in the projects, see figure 13. The system is described by appendices to this report. In these appendices it is explained *file structure*

- how to inspect the data with the *db.exe* MS-DOS program distributed with the data (appendix G),

- how to access the information directly through user written programs (appendix E), and
- how to install more data (appendix F).



	Runs	Time Series x1000	Data points x 1000000
All \[wsl_red]	257	20.2	31.3
All \[wsl]	257	12.5	13.5
Only field data	64	7.4	6.3

Figure 14. Volume of the Rediphem database (November 1995).

data volume

Figure 14 gives an overview of the data volume. The laboratory work were done with just a few sensors, but the many repetitions mean that this part of the data is quite voluminous. However, the total volume of the time series may be reduced to 40% of the full size, if we use the reduced WSL data set instead of the original one.

text files

Table 11 is an overview of the associated text files *camp01.not, run01.not & ∗.txt.* The total volume of the descriptions is longer than the present report, although some instrument types (e.g. the LLNL-IR sensor) were used in several campaigns and therefore described more than once. The release descriptions are generally longer for the field experiments than for the laboratory work, perhaps reflecting more unforeseen problems which needed description. Most of these descriptions are taken from the project data reports, listed in the footnote to table 4.

4.2 Data quality

The data included in the database are basically the original data delivered to us by the experimentalists. Most of the data sets have been checked in some way before delivery and bad data have been filtered out. However, this is not always the case and the database contains time series of a highly varying quality. The question of how to screen data and make quality checks is discussed in appendix

Table 11. Volume of text files in the database (November 1995).

Project descriptions (*camp01.not* files):	11 files	89 kB
Release descriptions (*run01.not* files):	245 files	103 kB
Sensor descriptions (**.txt* files):	102 files	150 kB

A. That text was written at an early stage of the project, and most but not all of the suggestions made have been followed. In a wide sense data quality must be understood as fitness-for-purpose, the purpose being model evaluation, and this will involve many more aspects than just sensor accuracy. Ultimately, the value of data depends on whether they represent crusial information, so data quality will always be an issue open for discussion. A qualitative measurement, such as a visual observation written down in a notebook, may turn out to be of a great value, and, conversely, an experiment performed with the best of instruments is not necessarily very interesting. In this project it has not been the intention to canonize such judgements of the value of experiments. Instead we take data quality in the narrow sense meaning technical quality of the measurements. The main purpose of the data screening performed by us has been to identify and reject obviously strange data and to report general sensor problems that should be taken into consideration in a data analysis.

Data screening

It soon became clear that a screening of all of the data in the database would be prohibitively time consuming, and only subsets of the experiments have been screened. These constitute all field experiments and all unobstructed instantanious releases made in wind tunnels. The following procedures were used

Release conditions were taken from reports and other available material. The experimentalists were consulted to provide missing information.

Consistency checks were made whenever possible, e.g. to ensure that file headers match other information.

Sensor characteristics as specified in data reports have been included in the database text files.

Statistics of time series were used as a crude check of the data quality. The following statistics calculated :

1) Average value. Checking of range and comparison with readings from nabouring instruments.
2) Standard deviation. (Too low $\sim$ dead sensor, too high $\sim$ noisy signal).
3) Maximum and minimum values. (Spikes, negative concentrations).

The visual appearance of time series. All time series were inspected paying special attension to baseline stability, spikes, noise, oscillations and saturation.

Time series with obvious and severe problems were excluded from the database. Many of these are signals from datalogger channels apparently not connected with any instrument, others show severe malfunctioning of the sensor or an inacceptable signal to noise ratio. Only the worst data, which must be considered of no value, were rejected. In less severe cases notes were written to the file *run01.not* of the experiment. Among the most common imperfections are: baseline drift, spurious oscillations (sinosoidal or other regular patterns), clipped signals and datalogger blackouts. Appendix D gives a summary of recognized concentration sensor problems.

In a few cases singular spikes overriding a steady signal (e.g. thermocouple signals from the LLNL experiments) were corrected, since this was judged to be completely safe. Correction for baseline drift or other 'improvements' of signals were not made. The processing of data done by us was essentially restricted to a simple conversion of gas concentrations to mole% and to changing of error codes (indicating datalogger blackout) to the value -1234.00.

The 3D animation in the data browsing program *db* (see appendix G), showing concentrations by inflating 'balloons', was used to check the consistancy of levels of adjacent concentration sensors. It is our experience that such a visual inspection of data is a powerful tool, and we have detected many spurious signals in this way.

Computer aided screening

Computer programs were made to aid the data inspection and store the results. Particularly helpful was an interface consisting of a plot of a time series, some statistics and mouse buttons. The pc mouse was used to zoom in on the graph and to click 'data ok' or 'data rejected' plus one or more of a set of preset complaints ('spikes', 'wobbling baseline', 'oscillations', 'no signal' et cetera). The use of this interface provided a considerably speed up of the screening process.

As mentioned above all of the field data have been checked in this way. Not many time series were rejected. Concentration measurements can be regarded with some confidence when bearing in mind, that the sensors have different response characteristics. Also wind-tunnel data from puff experiments were looked through. Here the main problem was signals from disconnected sensors of which there are many in the Hamburg data. It seems that the aspirated hot-wire technique has been improved over the years, and most of the problems seen in the earlier experiments have been overcome.

Dose and data quality

Different kinds of data analyses set different demands on data quality, and the true value of measurements may first become apparent when they are used to answer specific questions. The following sketch of a simple data analysis is meant as an example to illustrate this point. Suppose that we want to study instantaneous releases by means of the accumulated dose $D(t) = \int_0^t C(t)dt$, where $C(t)$ is the ground-level concentration at a point on the plume centerline. We expect $D(t)$ to increase with t and to level off at a constant value D_∞ with increasing t. From the $D(t)$ curve it is possible to find a characteristic passage time $t_{\rm pass}$ (e.g. the time for $D(t)$ to rise from $0.1D_\infty$ to $0.9D_\infty$) and a characteristic concentration (e.g. $D_\infty/t_{\rm pass}$). Figure 15 shows $C(t)$ measured in a puff made in a wind tunnel. The sensor works well, and the time series is about as perfect as it can be, but $D(t)$ does not seem to level off as $t \to \infty$. In order for it to do so the sensor offset has to be mathematically zero, and it never is. In the present example it is clear that the sensor returns to a small and fairly constant level after the passage of the cloud, causing a linear increase of $D(t)$ for large t. This is the general behaviour of ground level concentrations measured in wind tunnels, and it is not related to one particular kind of sensor. Therefore, the cause is not likely to be a sensor defect[3]. Examples of very long time series also show that the 'constant' level in fact decreases slowly to (almost) zero over a very long period. Therefore the most likely explanation of the slow disappearance of $C(t)$ is that gas is being trapped in the viscous sub-layer on the wind-tunnel floor. Most time series are much shorter, and, if the definition of passage time defined above is uncritically adopted, $t_{\rm pass}$ effectively becomes a measure of the length of the time series instead of a measure of the time for the bulk of the cloud to pass the sensor. Viscous effects, on the other hand, do not scale with the dimensions of an experiment, so the tail has to be removed from the data in some way. In the example given in figure 15 this can be done by e.g. subtracting a linear trend from $D(t)$ replacing it by $D(t) - C_\infty(t - t_1)$

[3]Teoretically the long lasting tail of the signal may be caused by the detector system having a large volume, but the construction of the sensors rules this out.

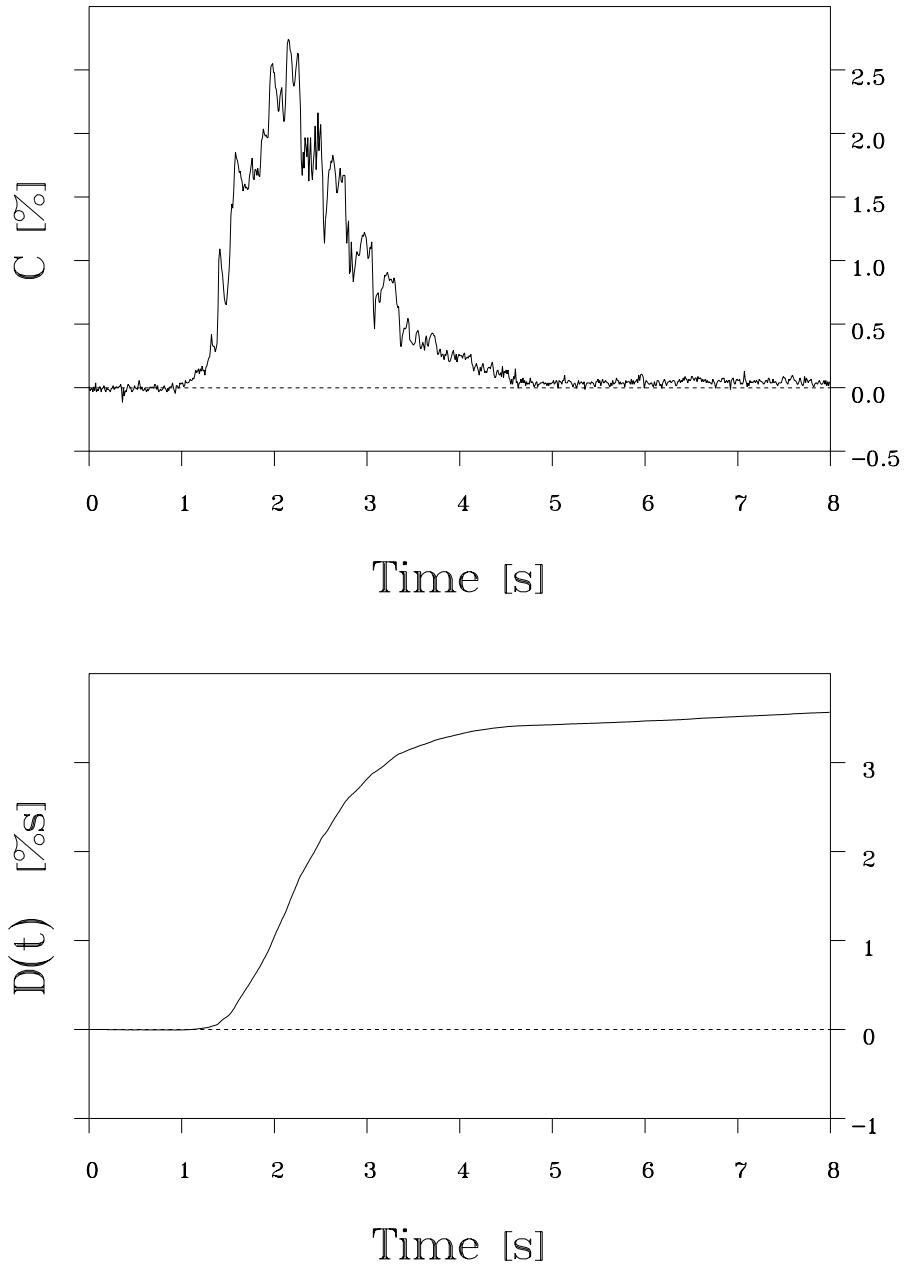


Figure 15. An example of excellent data. The dose integral, however, does not reach a constant level.

for $t > t_1$, where t_1 is the time-of-arrival of the cloud and C_∞ is the 'constant' level. To make this work, time series have to be sufficiently long and the baseline sufficiently steady (whereas an offset is not so severe). So for this kind of analysis, these characteristics should be checked in the data screening. Another question is whether viscous effects are still important, in other words: is it safe to remove the long tails of the concentration signals or does viscosity influence the mixing directly? One way of checking this is to make sure that the Reynolds number $Re = hu_*/\nu$ is large ($Re \gg 10$, say). Here, h is the local cloud height and u_* is

$Re \sim \infty$?

the local friction velocity. Unfortunately, few examples of wind tunnel experiments allow a determination of h, and u_* is either not measured or given for the approach flow. Due to the smooth floor in the test section and the stratification of the dense gas the turbulence in the cloud could be attenuated compared to the turbulence of the approach flow.

General remarks

Although it has not been our intention to evaluate data quality in the 'wider' sense mentioned above, some general remarks should be made on thier possible use. The field experiments are few in number compared to wind tunnel experiments, but generally they are much more sensely instrumented. In most field tests concentration sensors are placed in arrays allowing estimates to be made of both vertical and cross-plume profiles. Irregular arrangements of sensors are seen in some of the experiments, making them less attractive to analyse. In comparison much fewer instruments are used in the wind tunnel experiments and the majority of these measurements are made at ground level at the line of symmetry. Therefore, most of the wind-tunnel data are primarily useable for determination of ground level centerline concentrations, whereas the cloud geometry (height, width etc.) is out of reach.[4] The average ground level centerline concentration is an important parameter, but more test parameters should be used in order to be sure that models are not judged 'right for the wrong reason'. In the database there are about 2500 time series from instantaneous releases in wind tunnels made at 20 different sets of release conditions. As these figures indicate, these experiments have been aimed at investigating repeat statistics, and in this respect the data set is unique. In other respects, such as the determination of the cloud height mentioned above, the experiments are less informative. Figure 16 shows a plot of mean ground level centerline concentrations (based on the dose and passage time) for a fixed non-dimensional distance x/L_{ci} ($L_{ci} = {V_0}^{1/3}$) as a function of the Richardson number $Ri = \frac{g' L_{ci}}{U_a^2}$. Surprisingly, perhaps, the concentration does not depend on the stability parameter Ri - even if the geometry of the cloud must have been highly affected by changes of the initial gas density. A passive dispersion model could probably very easily be tuned to fit the data, thus being 'right for the wrong reason'.[5]

For the non-isothermal releases temperature measurements can provide hints as to the correctness of the modeling of thermodynamics. Most models are made up from a number of submodels, describing e.g. cloud motion, entrainment, aerosols and thermodynamics. Individual testing of the submodels would certainly be of interest, since this could point to possible improvements of specific model assumptions. Such tests are, however, difficult to make from the present data, since it would require more idealized, less 'realistic', experiments to highlight particular effects. It would, for example, be interesting to test model correlations used to determine the entrainment rate by direct measurements of the quatities involved. However, this is better done with plumes confined to a channel, and there are no such experiments in the database. The experiments in the database are designed to simulate accidental releases, with all the complicated effects acting together. From the point of view of practical application of dense gas models in risk analyses, the ultimate tests of a model is that it can reproduce such data. On the other hand, if a model does not fit the data, it will be difficult to find the reason, because so many effects are involved at the same time. What distinguishes the physics of dense gas clouds from passive clouds is the reduction of turbulent mixing caused by a stable density stratification, and an understanding of this effect is essential to dense gas modeling. Unfortunately, turbulence measurements inside the cloud are scarce, a fact that can be explained partly by the price of sonic anemometers. The

[4] The experiment *FLS* in the TNO data set is a noteworthy exception.

[5] It should be noted, that a Ri dependence *is* seen in the corresponding plot for an elevated sensor position.

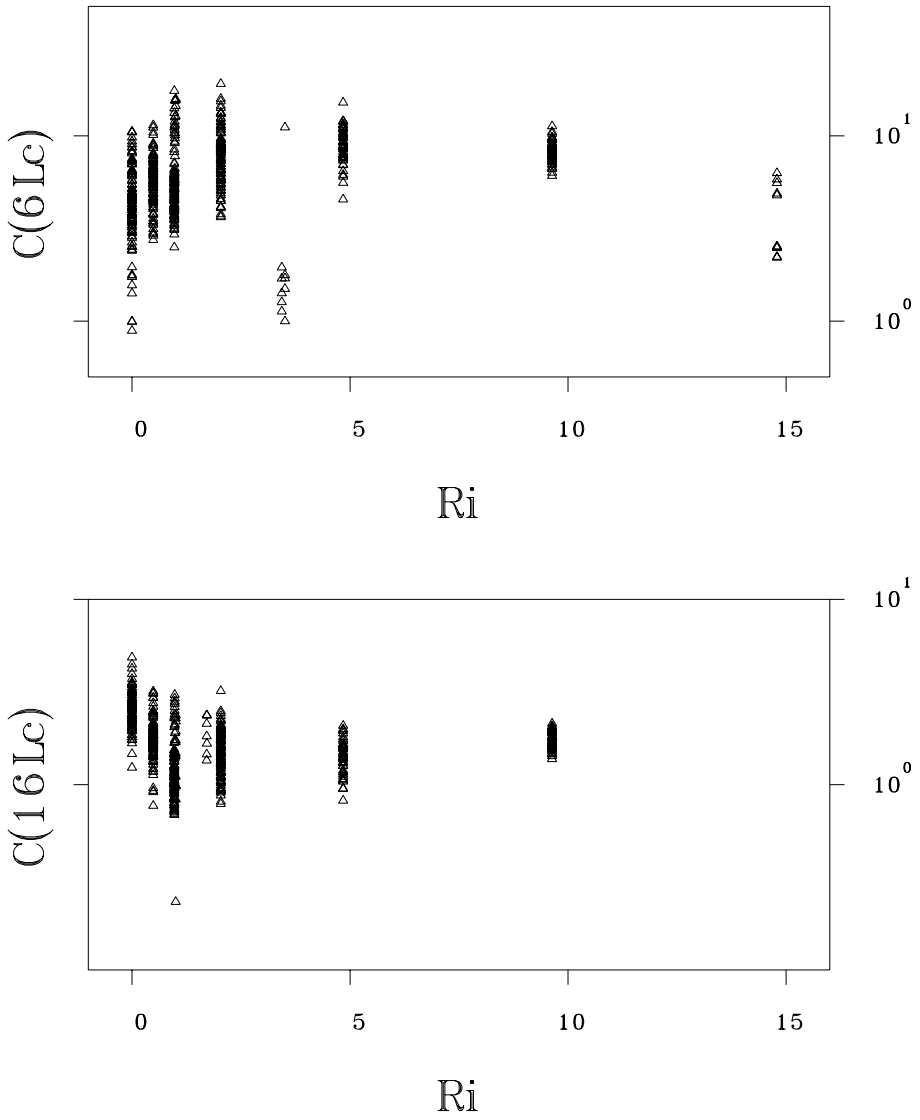


Figure 16. Centerline ground level concentration versus Ri for $x/L_c = 6$ (upper) and $x/L_c = 16$ (lower).

Lathen data set contains some turbulence and flux measurements that indicate rather complex profiles, but the number of measuring points are too few to see what is happening. More details on topics such as liquid aerosol composition and density, deposition, heat transfer from the ground, or the flow behind obstacles will also have to await future experiments. To sum up, the field experiments give a rather detailed picture of the concentration and temperature fields, and some indirect information on the physics of the mixing process.

5 Conclusion

This report gives a summary description of the Rediphem data collection. The data collection covers instantaneous and continuous dense gas releases, with or without obstacles, either done in wind tunnels or in the field. The purpose and the experimental setup of each experiment have been described with special attention to the various gas sources of the field experiments. An overview of the database system has been given and detailed documentation is provided in the appendices. The usefulness and the quality of the measurements has been discussed. The data collection will be used mainly for model evaluation purposes, and it will be available also to the public from January 96. There will be no guarantee for future maintenance of the system, but everyone is welcome to inquire by e-mail to *ott@risoe.dk* or *metmn@risoe.dk*.

Acknowledgement

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A Data checklist

Scope

The checklist given below summarizes considerations that have been made during the Rediphem project regarding evaluation of the data quality. The aim is to find means of selecting the best data to be used in tests of dense gas models and to define criteria for discarding data not suitable for a specific purpose. The intention is to enable as much information as possible to be extracted from an experimental database without making overinterpretations. This involves questions of sensor quality as well as questions of experimental design and uncontrolled factors such as weather. Ultimately, the quality of an experiment must be a question of what we can learn from it, and that may not simply be a matter of the accuracy of the measurements. A particular set of data may for instance be well suited for deriving average concentrations, but not adequate for making concentration probability density functions because of the response characteristics of the sensors. The primary aim here is to consider how to extract the relevant information from experiments and it is not the intention to establish an abstract measure of 'quality'.

For practical reasons we shall limit ourselves to technical aspects of data quality, which can be assessed on the basis of available information. The checklist is meant to be an aid to determine what kind of data analysis an experiment is suited for.

The experimentalist's filter

Experimentalists spend much time checking up on equipment and correcting errors. A list of what possibly may go wrong in e.g. a field experiment would be virtually endless. Problems that are resolved on appearance are usually not reported, since this would involve too much peculiar information on for instance rabbits eating the cables etc. For our purpose it is not interesting to know exactly how a lot of practical problems were solved, the main concern is whether the instruments worked or not. For instance, to see if a wind vane is working the vane must be fixed in one or a few known directions. Spider's web can alter the response characteristics of thermocouples, and should be removed every now and then. There is no point in making formal checklists to verify that the proper procedures have been followed in such matters. This should be placed in the hands of the experimentalists, and one should only be concerned with spider's web if it can be seen in the results. The only way to check things out completely is by repeating the experiment.

It is the privilege of the experimentalist to reject data that he, for whatever reason, does not believe in. It is common practice to respect the experimentalists decisions on what data to pass on to colleagues.

In some cases the experimentalist chooses to deliver imperfect data together with proper warnings (signal out of range, data missing, noise problems, et cetera). It is important that such information remain with the data to avoid future misinterpretations. Other kinds of background information, which can supplement the data, can be relevant, e.g. visual observations, and special weather conditions (it was raining). It is an aim of the Rediphem project to collect all available information from the experiments and store it together with data in a database. The relevance of special background information will depend on the data analysis in question.

Screening for strange data

In large experiments involving many instruments (100, say) it is exceptional if all instruments work. Therefore, data have to be screened for strange data. The best way to discover malfunctioning instruments is probably to look at plots of data series. The human ability to discover strange data from plots should not be underestimated. In most cases signals from defective instruments look peculiar when they are plotted. They may be fluctuating, but in an unusual way, which is often very easy to detect.

A computer animated plot showing the signals from many sensors together in a 'replay' of the experiment can give a useful overview. The plot could visualise e.g. concentration signals as circles with time varying radii. This is a convenient and fast way of comparing instruments.

In most cases the mean value of a bad signal will be clearly wrong, and the standard deviation will be either too high (bad electrical connection) or too low (sensor dead).

It would be nice to have automatic screening procedures that do not rely on the human eye. The method developed by Højstrup (1993) may be of interest.

We propose the following screening procedure:

- Data are rejected whenever the experimentalists express serious doubts about them.
- Mean and standard deviations are calculated and comparison is made between neighbouring instruments.
- Individual time series are plotted and inspected. In case of obvious strange behaviour data are rejected. This can be quite time consuming.
- Computer generated visualizations of fluctuating signals from several sensors are studied in order to look for strange data.
- Whenever different kinds of sensors are measuring the same property, the results should be compared.
- For very large data sets automatic tests could be used to select data for further examination.

It should be noted that access to raw data (time series) is essential.

Data massage

Raw data are sometimes corrected in various ways before delivery. This could involve

- Averaging (noise suppression, data reduction)
- Removal of bad data points (e.g. electronic spikes)
- Deconvolution of the instrumental response function (speed-up)
- Other corrections (e.g. baseline drift).

Information regarding such special treatments should be collected.

The data to be included in the Rediphem database will, for practical reasons, be limited in size to of the order of 1 Megabyte per experiment. This has required a certain amount of data reduction (1-second block averaging of signals).

Data reduction

Generally, a *data reduction* can be defined as an extraction of what is believed to be the essential information in a data set. This could also work as the definition of *data analysis*, so there is no reason to make a clear destinction. A reduced data set will be easier to manipulate, but in reducing the data there will always be the risk of degrading the information, especially when it comes to questions of data quality. The proper way to define e.g. average concentrations can also be debated. This is the main reason for storing full time series in the database, rather than statistics. It is left to the user to make reductions.

A fine example of a reduced data set of gas dispersion experiments is the modellers data archive (MDA) which was developed in the model evaluation work by Hanna et al. (1991). The information in the MDA files are much simplified and therefore convenient to handle. They consist of tables of the highest average concentrations observed at various distances and plume widths based on average concentrations. For field experiment data these quantities are affected by the sweeping of the plume from side to side in the particular experiment. The instantaneous plume width would be more narrow with higher concentrations - i.e. if the observation period is more than a minute or so. Surface releases in a wind tunnel are usually steady, but elevated releases may have fluctuating plume centerlines. The predictions of a dispersion model are either the long-time averages (of concentration and dimensions) or they provide values of a non-meandering plume. If a non-meandering plume model predicts the long-time average concentrations of an unsteady plume, it means that the mixing with air is overpredicted, i.e. the model is right for the wrong reasons. Thus, before using a reduced data set in the validation, it must be checked that the filter implied by the data reduction is compatible with the model predictions.

If it is found that the reduced data are distorted in some way, the data reduction procedure has to be reconsidered.

The relation to data analysis

Data analysis is necessary in order to learn something from an experiment. It can be regarded as a decoding of the information embedded in the experimental data. The data quality is a matter of the precision of this information, so the data quality can not be fully appreciated until a data analysis has been made.

In practical data analysis one formulates a list of questions (guided by theory and common sense) and looks for the answers in the data. The extraction of an answer involves data processing and data quality considerations. In case the data do not contain the answer to a question, the question is restated in a weaker form. Reasons for not getting an answer could be e.g. too much scatter in results due to turbulence, lack of sensor accuracy, poor spatial resolution, or it turns out that the question is not formulated in terms of the quantities being measured. If the data do contain an answer, the question is sharpened. Eventually, the data quality limits the precision with which the questions can be formulated, and will reveal itself in the course of the iteration. Therefore, the assessment of data quality cannot be formalized in a protocol separated from data analysis. The iterative data analysis sketched above is probably the best way to check that all relevant aspects of data quality have been covered.

Sensor characteristics

For each sensor type a brief description should be made and included in the database as background information. It should contain the following information

based on reports and consultation with the experimentalists:

- Sensor type and model
- Nominal specifications (if a data sheet is available)
- Principle of operation
- Known systematic errors
- Calibration method and results (condensed)
- Estimates of
  - Error bounds
  - Baseline stability
  - Long term drift
  - Noise levels
- Response characteristics
  - Linearity
  - Response time(s)
  - Sampling volume
  - Electronic or digital filters
- Any special problems?

The demands on sensor quality depends on the data analysis.

Data acquisition

A full description of the data logging system is not needed, but the following information would be nice

- Resolution of digitalization
- Electronic signal conditioning
- Sampling rates
- Accuracy of timing
- Noise

Experimental design

An experiment can have the character of a survey, in which case data are collected systematically, but where the expectations regarding the results are not very specific. Another type is the 'crucial' experiment, which is aimed at answering one particular key question, which tests the validity of a theory. Usually, dispersion experiments are a mixture of the two. A clear statement of the purpose of the experiment should be given. If the experiment is meant for model validation it must be clear what 'valid' means and how experimental evidence could possibly 'invalidate' the model.

As a rule the data from an experiment should be so detailed as to give adequate documentation of the release. This means that the population of sensors should be sufficiently dense to allow estimates to be made of what happened in the space between them. The meteorological boundary conditions should also be well described. In practice a full documentation is not possible due to the exceedingly complex geometry of a cloud, and a reasonable compromise has to be made. The

experimentalist must make a choice between buying relatively many inexpensive sensors to get a good spatial resolution or buying fewer more accurate and more expensive sensors in order to get a good temporal resolution.

As stated above the value of experimental data depends on what use we make of them. In order to compare data with model predictions it is important that

- All input parameters to the model should be available from the experiment. The release conditions of the experiment should match the model input.
- It seems at present that all dense gas models are based on the assumption of a steady wind (constant speed and direction) and this condition is extremely rare in the atmosphere. Releases done under stable conditions with less meandering of the plume are therefore best suited for comparison with present day models.
- Usually, model predictions are given in terms of mean values. Mean values extracted from the experimental results should be defined in the same way as in the models. If the model predicts e.g. a ten-minute average, the duration of the release should be at least ten minutes. In case of predictions of peak concentrations or concentration probability density functions, a full documentation of the sensor response characteristics is important.
- If the model is not precise with respect to the definition of parameters in terms of measurable quantities we have a severe problem, which is, however, not a data quality problem.
- The release condition parameters should be varied to allow for a statistical analysis. The results should complement the results from other experimental projects.
- The results should be consistent with existing experimental data.

In case of a previous analysis of the data, the conclusions should be taken into account.

A comment on the problem of meandering

A comment should be made here regarding the meandering problem. The problem is that present day models do not take the meandering into account, even if the meandering plays a dominant role in most field experiments. The restriction of considering only releases made under very steady wind conditions is very severe. In the Lathen experiments this would mean that only two or three runs out of 58 would be used. The best thing to do would be to develop models capable of treating the measured time dependent meteorological boundary conditions as model input (not just the average wind speed). The next best thing to do is to remove the meandering from the data in some way. This would allow a larger amount of experimental data to be used. One way of doing this is to define a coordinate system that moves together with the cloud centerline and assume that model predictions refer to the moving coordinates. In order to do this, the number of sensors should be sufficiently large to document the changing cloud geometry (instantaneous centerline). The more successful experiments will still be those with a steady wind direction, where the plume remained within the sensor array during major parts of the release, and where unexposed sensors mark the cloud edges.

B Summary of UH wind tunnel experiments

Marotzke (1994) gives a lists of release configurations in the Hamburg experiments, and in table 12–24 we have sorted this information for each of the obstacles configurations shown in figure 4. Also listed are various reference cases and sensitivity studies in table 25–27, and models of large-scale field experiments in table 28.

Table 12. Hamburg experiments with release near a wall parallel to the wind direction, see figure 4b.

Instantaneous release				Continuous release			
File	source distance $[L_{ci}]$	fence height $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$	File	source distance $[L_{cc}]$	fence height $[L_{cc}]$	velocity @ L_{cc} $[U_{cc}]$
DA0111	1	?	1	DA0123	5.6	?	1
DAT211	1	1	0	DAT222	8.5	8.5	0
DAT216	1	1	1	DAT224	8.5	8.5	1
DAT225	1	0.1	0	DAT230	9	1.1	0
DAT231	1	0.1	1	DAT236	9	1.1	1

Table 13. Hamburg experiments with release in the middle of a street canyon consisting of two walls parallel to the wind direction, see figure 4c.

Instantaneous release				Continuous release			
File	width of canyon $[L_{ci}]$	fence heights $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$	File	width of canyon $[L_{cc}]$	fence heights $[L_{cc}]$	velocity @ L_{cc} $[U_{cc}]$
DA0311	2	1	1	DA0422	28	7	1
DAT301	2	0.1	1	DAT311	11	1.1	0
DAT306	2	0.1	0	DAT312	11	1.1	1

Table 14. Hamburg experiments with release in the middle of a street canyon consisting of two broken walls parallel to the wind direction, see figure 4d. In all cases the gap length is equal to the width of the canyon and the velocity is 1 U_c at the reference height L_c.

Instantaneous release				Continuous release			
File	width of canyon $[L_{ci}]$	fence heights $[L_{ci}]$	fence lengths $[L_{ci}]$	File	width of canyon $[L_{cc}]$	fence heights $[L_{cc}]$	fence lengths $[L_{cc}]$
089021	2	1.5	15	129030	14	11	105
099021	3	1.5	15	129026	14	11	105
089071	3	1.5	15	129034	14	11	105
099071	3	1.5	15	129018	21	11	105
109071	4	1.5	15	129022	21	11	105
119021	4	1.5	15	129014	21	11	105
109021	4	1.5	15	129006	28	11	105
				129002	28	11	105
				129010	28	11	105

Table 15. Hamburg experiments with a semi-circular fence downwind of the release, see figure 4e.

Instantaneous release				Continuous release			
File	fence height $[L_{ci}]$	fence diameter $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$	File	fence height $[L_{cc}]$	fence diameter $[L_{cc}]$	velocity @ L_{ci} $[U_{cc}]$
DA0502	0.4	4	1	DA0501	2.24	22.4	1
DA0517	0.4	4	1	DA0532	2.24	22.4	1

Table 16. Hamburg experiments with a semi-circular fence upwind of the release, see figure 4f.

Instantaneous release				Continuous release			
File	fence height $[L_{ci}]$	fence diameter $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$	File	fence height $[L_{cc}]$	fence diameter $[L_{cc}]$	velocity @ L_{ci} $[U_{cc}]$
029039	0.4	2.5	1	039051	2.24	14	1
039052	0.4	2.5	1	039072	2.24	22.4	1
039062	0.4	4	1				
039074	0.4	4	1				

Table 17. Hamburg experiments with a semi-circular fence surrounding the release, see figure 4g.

Instantaneous release				Continuous release			
File	fence height $[L_{ci}]$	fence diameter $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$	File	fence height $[L_{cc}]$	fence diameter $[L_{cc}]$	velocity @ L_{ci} $[U_{cc}]$
049011	0.4	2.5	1	039097	2.24	14	1
049021	0.4	2.5	1	039094	2.24	22.4	1
039084	0.4	4	1	039095	2.24	22.4	1
049001	0.4	4	1				

Table 18. Hamburg experiments with release upstream of a trench perpendicular parallel to the wind direction, see figure 4h.

Instantaneous release				
File	distance canyon $[L_{ci}]$	trench depth $[L_{ci}]$	trench width $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$
DAT453	5	0.29	2	0
DAT463	5	0.29	2	0.5
DAT458	5	0.29	2	1

Continuous release				
File	distance canyon $[L_{cc}]$	trench depth $[L_{cc}]$	trench width $[L_{cc}]$	velocity @ L_{ci} $[U_{cc}]$
DAT469	28	1.6	11	0.5
DAT468	28	1.6	11	1
DAT452	45	2.6	18	0
DAT471	45	2.6	18	0.5
DAT470	45	2.6	18	1

Table 19. Hamburg experiments with release in a crossroad with surrounding walls parallel and perpendicular to the wind direction, see figure 4i.

Instantaneous release			
File	fence heights $[L_{ci}]$	width of canyon $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$
DAT333	?	2	0.5
DAT328	?	2	1

Table 20. Hamburg experiments with release in a regular array of boxes aligned with the wind direction, see figure 4j.

Instantaneous release				
File	box height $[L_{ci}]$	box sides $[L_{ci}]$	box spacing $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$
029101	1	1	2	1
039108	1	1	2.5	1
049101	1	1	3	1
039222	2	1	3	1
039234	2	1	4	1
Continuous release				
File	box height $[L_{cc}]$	box sides $[L_{cc}]$	box spacing $[L_{cc}]$	velocity @ L_{ci} $[U_{cc}]$
029128	11	11	21	1
039104	11	11	27	1
049124	11	11	32	1
039232	21	11	32	1
039233	21	11	43	1

Table 21. Hamburg experiments with release in a regular array of boxes which is rotated 45°relative to the wind direction, see figure 4k.

Instantaneous release				
File	box height $[L_{ci}]$	box sides $[L_{ci}]$	box spacing $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$
049219	1	1	3	1
049233	1	1	5	1
Continuous release				
File	box height $[L_{cc}]$	box sides $[L_{cc}]$	box spacing $[L_{cc}]$	velocity @ L_{ci} $[U_{cc}]$
049217	11	11	32	1
049243	11	11	53	1

Table 22. Hamburg experiments with release on a sloping surface, see figure 4l.

Instantaneous release		Continuous release	
File	Slope	File	Slope
DAT648	4.0%	DAT647	4.0%
DAT601	8.6%	DAT631	8.6%
DAT638	11.6%	DAT632	8.6%
		DAT637	11.6%

Table 23. Hamburg experiments with release in the middle of a street canyon consisting of two walls which are aligned with 45° relative to the wind direction, see figure 4m.

Instantaneous release				Continuous release			
File	width of canyon $[L_{ci}]$	fence heights $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$	File	width of canyon $[L_{cc}]$	fence heights $[L_{cc}]$	velocity @ L_{cc} $[U_{cc}]$
DAT475	2	1	1	DAT472	12	6	1
				DAT473	18	9	1
				DAT474	18	9	0.5

Table 24. Hamburg experiments with release in calm air in a street canyon on a sloping surface, see figure 4n. The canyon is aligned according to the down-slope direction.

Instantaneous release				Continuous release			
File	slope [%]	width of canyon $[L_{ci}]$	fence heights $[L_{ci}]$	File	slope [%]	width of canyon $[L_{cc}]$	fence heights $[L_{cc}]$
DAT753	8.6	1.5	2	DAT768	8.6	11	21
DAT758	8.6	1.5	4				

Table 25. Hamburg reference experiments without obstacle see figure 4a.

Instantaneous release		Continuous release	
File	velocity @ L_{ci}	File	velocity @ L_{cc}
DA0101	1	DA0120	1
DAT201	0	DAT221	0
DAT206	1	DAT223	1
DAT511	0		
DAT516	1		

Table 26. Hamburg experiments on the influence of initial concentration – without obstacle.

Instantaneous release			Continuous release		
File	initial conc. [%]	velocity @ L_{ci} [U_{ci}]	File	initial conc. [%]	velocity @ L_{ci} [U_{cc}]
DAT101	100	0	DAT151	100	0
DAT141	50	0	DAT152	50	0
DAT106	33	0	DAT153	33	0
DAT111	10	0	DAT154	10	0
DAT116	100	1	DAT155	100	1
DAT146	50	1	DAT156	50	1
DAT121	33	1	DAT157	33	1
DAT126	10	1	DAT158	10	1

Table 27. Hamburg experiments on the influence of release time – without obstacle and with continuous release.

Continuous release			
File	velocity [U_{cc}]	reference height [L_{cc}]	release duration [T_{cc}]
DAT501	0	1	1000
DAT502	0	1	∞
DAT503	0	1	500
DAT504	0	1	∞
DAT505	0	1	200
DAT506	0	1	∞
DAT507	0	1	100
DAT508	0	1	∞
DAT509	0	1	50
DAT510	0	1	∞
DAT521	2.2	4.8	50
DAT522	2.2	4.8	50
DAT523	1	1	50
DAT524	1	1	50
DAT525	2.6	6.3	100
DAT526	2.2	4.8	∞
DAT527	2.6	1.0	100
DAT528	2.2	0.78	∞
DAT529	2.9	8.3	200
DAT530	2.9	8.3	∞
DAT531	1	1	200
DAT532	1	1	∞

Table 28. Hamburg simulations of field experiments.

File	Experiment	Model gas	Velocity
69024	EEC57 (with fence)	100% SF_6	0.77 U_{cc} @ L_{cc}
69025	EEC57 (with fence)	100% SF_6	0.77 U_{cc} @ L_{cc}
69026	EEC57 (with fence)	100% SF_6	0.77 U_{cc} @ L_{cc}
69027	EEC57 (with fence)	100% SF_6	0.77 U_{cc} @ L_{cc}
69028	EEC57 (with fence)	100% SF_6	0.77 U_{cc} @ L_{cc}
69029	EEC57 (with fence)	100% SF_6	0.77 U_{cc} @ L_{cc}
69030	EEC57 (without fence)	100% SF_6	0.77 U_{cc} @ L_{cc}
DAT131	TI15 (distorted density)	100% SF_6	0.32 U_{ci} @ 0.8 L_{ci}
DAT136	TI15	10% SF_6	1.32 U_{ci} @ 0.8 L_{ci}
DAT169	TI17	78% SF_6	0.26 U_{ci} @ 0.8 L_{ci}
DAT313	TI20	22% SF_6	0.5 U_{ci} @ L_{ci}
DAT318	TI20	22% SF_6	0.5 U_{ci} @ L_{ci}
DAT323	TI20 (distorted density)	100% SF_6	0.5 U_{ci} @ L_{ci}

C Summary of field experiments

This appendix summarizes the trials of the field experiments included in the database.

Table 29. Summary of experiments collected from Burro, Coyote, Dessert Tortoise, Eagle and Fladis

Trial	Date	Time	Flow	Dur	Type	M_{eff}	Speed	ΔDir	Comments
	d/m/y	h:m	[kg/s]	[sec]		[g/mole]	[m/s]	[Deg]	
Burro 2	18/6/80	16:00	81.8	187	Pool	38.5	5.4	-4	
Burro 3	2/7/80	15:08	88.0	167	Pool	37.9	5.4	-1	
Burro 4	9/7/80	14:07	87.0	175	Pool	37.5	9.0	-8	
Burro 5	16/7/80	16:20	81.8	190	Pool	37.8	7.4	-7	
Burro 6	5/8/80	16:05	92.2	129	Pool	38.1	9.1	-5	large RPT near end
Burro 7	27/8/80	18:21	99.5	174	Pool	40.4	8.4	-18	
Burro 8	3/9/80	19:09	117	107	Pool	39.8	1.8	10	
Burro 9	17/9/80	18:37	136	79	Pool	41.5	5.7	7	
Coyote 3	3/9/81	15:38	101	65	Pool	44.5	6.0	-22	
Coyote 5	7/10/81	12:08	129	98	Pool	42.6	9.7	2	
Coyote 6	27/10/81	16:43	129	82	Pool	41.5	4.6	-7	
DT 1	24/8/83	16:37	81	255	Jet→	82.3	7.4	-1	
DT 2	1/9/83	11:20	117	255	Jet→	82.5	5.8	1	
DT 3	1/9/83	15:37	133	166	Jet→	81.9	7.4	-6	
DT 4	6/9/83	18:15	108	381	Jet→	81.3	5.5	4	
Eagle 1	17/9/83	14:07	42.3	45	Pool	95.6	6.2	8	evap. rate < spill rate
Eagle 2	23/9/83	17:02	34.0	65	Pool	94.5	5.8	-2	
Eagle 3	13/10/83	16:48	34.0	188	Pool	92.7	3.1	4	
Eagle 6	30/10/83	14:37	16.9	296	Pool	92.8	5.0	-2	
Fladis 6	7/4/93	13:25	0.48	600	Jet→	85.7	2.7	2	
Fladis 7	7/4/93	14:00	0.47	300	Jet→	85.7	2.9	4	
Fladis 9	7/8/93	14:39	0.46	1140	Jet→	85.7	6.3	6	
Fladis 12	10/8/93	15:31	0.21	335	Jet↑	85.0	2.1	-8	
Fladis 13	11/8/93	14:25	0.56	900	Jet→	85.0	5.5	-28	
Fladis 14	11/8/93	15:51	0.54	600	Jet→	85.0	4.8	-31	
Fladis 15	13/8/93	19:18	0.58	185	Jet→	84.5	4.2	-9	
Fladis 16	13/8/93	19:51	0.27	1140	Jet→	84.7	3.2	-12	
Fladis 17	13/8/93	21:09	0.25	1500	Jet→	85.4	3.2	-26	
Fladis 20	23/8/94	12:29	0.23	2422	Jet→	87.6	3.8	-8	
Fladis 21	23/8/94	16:50	0.57	1212	Jet→	88.9	4.1	+25	
Fladis 23	30/8/94	11:56	0.43	1200	Jet→	87.9	6.7	-9	
Fladis 24	30/8/94	16:06	0.46	600	Jet→	90.0	5.0	-9	
Fladis 25	30/8/94	16:38	0.46	1380	Jet→	90.3	4.7	-7	
Fladis 26	31/8/94	14:50	0.21	1200	Jet→	85.8	3.1	-34	
Fladis 27	31/8/94	16:41	0.22	1235	Jet→	85.7	2.5	-9	

where the abbreviations in the headings means

Dur	Release duration
Type	Source type (Jet→ is horizontal jet in downwind direction)
M_{eff}	'Effective' molar weight
Speed	Average wind speed
ΔDir	Difference between the average wind direction and ideal wind direction

Table 30. Overview of experiments from Lathen, part 1. These experiments were performed TüV in collaboration with Risø.

Trial	Date d/m/y	Time h:m	Flow [kg/s]	Dur [sec]	Type	M_{eff} [g/mole]	Speed [m/s]	ΔDir [Deg]	Obstacle	Comments
Lathen 7	9/5/89	9:08	2.9	200	jet→	99.8	4.3	22		
Lathen 8	9/5/89	9:49	2.9	250	jet→	99.9	4.4	10		
Lathen 17	18/5/89	8:56	2.9	160	jet→	100.0	3.9	-1		
Lathen 18	18/5/89	9:19	2.9	180	jet→	99.8	4.4	11		
Lathen 23	18/5/89	13:00	15.0	240	cyclone	92.4	2.9	-21		unreliable release rate
Lathen 24	18/5/89	13:44	15.0	433	cyclone	93.0	3.3	-11		unreliable release rate
Lathen 33	31/8/89	11:16	0.13	660	jet→	98.8	2.9	96		
Lathen 34	31/8/89	12:05	0.30	585	jet→	98.6	2.5	92		
Lathen 35	31/8/89	12:45	0.30	570	jet→	98.6	3.0	80		
Lathen 36	1/9/89	18:59	0.11	198	jet→	99.0	3.4	-3		
Lathen 37	1/9/89	19:54	0.11	199	jet→	99.3	2.0	-18		
Lathen 38	1/9/89	20:30	0.10	240	jet→	99.7	1.0	-40		
Lathen 41	2/9/89	15:54	0.11	240	jet→	98.6	3.3	9		
Lathen 42	2/9/89	16:49	0.11	240	jet→	98.6	1.6	6		
Lathen 43	2/9/89	17:30	0.11	300	cyclone	95.9	4.5	3		fence not removed
Lathen 44	2/9/89	18:09	0.11	360	jet→	98.1	3.2	12		
Lathen 47	4/9/89	14:32	0.11	300	jet→	97.6	2.3	26		
Lathen 48	4/9/89	15:55	0.18	240	jet→	97.6	2.1	30		
Lathen 49	4/9/89	17:36	7.00	1	puff	58.5	2.9	14		
Lathen 50	5/9/89	10:04	0.11	360	jet↓	98.2	3.5	-11		
Lathen 51	5/9/89	10:56	0.11	360	jet↓	97.6	3.0	-13		
Lathen 52	5/9/89	13:35	0.16	360	jet↓	96.8	3.7	-27		
Lathen 53	5/9/89	14:26	0.17	300	jet↓	96.8	3.1	-15		
Lathen 54	6/9/89	7:33	3.0	300	jet→	98.5	2.3	-16		fence not removed
Lathen 55	6/9/89	8:30	3.0	360	jet→	98.5	3.2	-12		
Lathen 56	6/9/89	8:55	3.0	360	jet→	98.5	2.4	-7		
Lathen 57	6/9/89	9:42	3.0	480	cyclone	89.3	2.4	16		
Lathen 58	6/9/89	10:24	3.0	490	cyclone	89.4	2.8	29		

where the abbreviations in the headings and the obstacle symbols means

Dur	Release duration
Type	Source type (Jet→ is horizontal jet in downwind direction)
M_{eff}	'Effective' molar weight
Speed	Average wind speed
ΔDir	Difference between the average wind direction and ideal wind direction
	Release towards NE over a curved fence
	Release towards NW over a curved fence
	Release towards NW over a curved fence with 50% porosity
	Release towards W inside two parallel fences
	Release towards S over two parallel fences (mobile source)
	Release towards S over two parallel fences with 50% porosity (mobile source)
	Release towards E inside two parallel fences (mobile source)
	Release towards E along a fence (mobile source)
	Release towards NE over a straight fence
	Release towards NE over a straight fence with 50% porosity

Table 31. Overview of experiments from Lathen, part 2. These experiments were performed by TüV alone.

Trial	Date d/m/y	Time h:m	Flow [kg/s]	Dur [sec]	Type	M_{eff} [g/mole]	Speed [m/s]	ΔDir [Deg]	Obstacle	Comments
Lathen 60	15/9/89	9:01	3.0	420	jet→	98.4	1.5	0		
Lathen 61	15/9/89	39:46	3.0	475	jet→	98.4	2.0	45		
Lathen 62	15/9/89	10:32	3.0	180	jet→	98.3	?	45		fence not removed
Lathen 63	15/9/89	13:21	3.0	360	jet→	98.6	1.5	0		
Lathen 64	15/9/89	13:49	3.0	390	jet→	98.6	2.0	15		
Lathen 65	19/9/89	16:30	3.0	420	cyclone	89.0	2.7	15		
Lathen 66	19/9/89	16:58	2.9	420	cyclone	88.9	2.8	15		
Lathen 67	19/9/89	17:32	2.9	420	cyclone	89.1	2.8	15		
Lathen 68	19/9/89	17:56	2.9	397	cyclone	89.1	2.8	15		
Lathen 69	21/9/89	8:15	3.0	420	jet↑	98.8	0.5	180		
Lathen 70	21/9/89	18:42	2.9	280	jet↑	98.3	0.2	90		
Lathen 71	27/9/89	6:42	3.0	360	jet→	98.3	0.1	15		1/3 of fence remained
Lathen 72	27/9/89	7:22	3.0	447	jet→	98.4	0.2	-5		
Lathen 73	27/9/89	7:50	3.0	450	jet→	98.3	0.2	40		
Lathen 74	27/9/89	8:10	20.0	2	jet/puff	100.1	0.9	40		puff with momentum
Lathen 75	27/9/89	8:17	20.0	2	jet/puff	100.1	0.9	40		puff with momentum
Lathen 76	3/10/90	17:06	0.14	300	cyclone	100.3	?	-65		
Lathen 77	5/10/90	8:14	2.90	250	jet↑	99.4	2.5	0		
Lathen 86	28/3/90	6:43	0.37	330	jet↑	55.3	0.8	0		pure gas phase
Lathen 88	28/3/90	8:21	0.32	295	jet↑	55.5	2.0	0		pure gas phase
Lathen 91	29/3/90	6:45	0.17	265	jet↑	55.6	1.1	0		pure gas phase
Lathen 95	6/4/90	6:53	0.20	275	jet↑	54.9	2.2	0		pure gas phase
Lathen 98	6/4/90	8:28	0.77	105	jet↑	54.8	1.6	0		pure gas phase

where the abbreviations in the headings and the obstacle symbols means

Dur	Release duration
Type	Source type (Jet→ is horizontal jet in downwind direction)
M_{eff}	'Effective' molar weight
Speed	Average wind speed
ΔDir	Difference between the average wind direction and ideal wind direction
	Release towards NE over a curved fence
	Release towards NW over a curved fence
	Release towards NW over a curved fence with 50% porosity
	Release towards W inside two parallel fences
	Release towards S over two parallel fences (mobile source)
	Release towards S over two parallel fences with 50% porosity (mobile source)
	Release towards E inside two parallel fences (mobile source)
	Release towards E along a fence (mobile source)
	Release towards NE over a straight fence
	Release towards NE over a straight fence with 50% porosity
	Release towards W inside two parallel fences
	Release towards W inside two parallel fences with 50% porosity
	Release towards NE over a straight fence
	Release towards NE over a straight fence with 50% porosity
	Release towards S over two parallel fences (mobile source)

D Concentration sensor performance

As stated in chapter 4 and appendix A, we find the visual appearance of time series to be a good indicator of the measurement quality. The examples or data errors in figure 17 illustrate this point. Measurements by instruments exposed to a starting gas release are not statitionary stochastic processes, and therefore some of the phenomena in figure 17 would be hard to detect with automatic screening procedures.

During the creation of the Rediphem database time series with severe problems were rejected. However, we kept data with minor problems (e.g. individual spikes, as in figure 17F) and we can not guarantee that all bad data were recognized. The remaining part of this appendix will comment on the general measurement quality for each type of concentration sensor. These observations are not meant to discredit the data set as such, but merely as a registration of occasional problems. A broader description of the sensors is given in the $*.txt$ files of the database and in the data reports referenced in chapter 2 and 3.

Cambustion Flame Ionization Detector

This instrument was used at WSL and the later experiments at TNO. Hall, Waters, Marsland, Upton & Emmott (1991, page 9) mention that the measured time series had spikes up to 2% gas concentration, but without analysing all the WSL data, it is our impression that these events are very rare. The FID is judged to be a good instrument.

Aspirated hot-wire probes

This instrument type was used at all the wind tunnel laboratories. A characteristic oscillation with variable amplitude is sometimes observed in the TNO and UH signals, and sometimes the signal baseline is drifting. The UH signals often have a strange noise just before the actual measurements, but in most cases it is relatively easy to discriminate this from the true measurements. The received UH data set contained time series from data acquisition channels with no sensor attached. These false time series appear as noisy negative concentrations.

International Sensor Technology solid state sensor (IST)

This sensor was used in the Burro, Coyote and Dessert Tortoise experiments. Goldwire et al. (1983) explain that the sensor had different sensitivity to the methane, ethane and propane components of the variable LNG mixtures used in Burro and Coyote. The IST sensor was sensitive to atmospheric humidity, particularly in the presence of heavy hydro-carbons. Some baseline drift was observed, especially for sensors which previously had been exposed to high gas concentrations. The results were estimated to be accurate within 20% of the readings. The signals from some sensors close to the source in the Burro experiments were clipped, probably because the gas concentration exceeded the measurement range.

Lawrence Livermore National Laboratory infrared absorption sensor (LLNL-IR)

This sensor measures absorption in open paths at four distinct infrared wave lengths, and therefore it was possible to apply the instrument both in the Burro, Coyote, Dessert Tortoise and Eagle experiments. The visual appearance of time

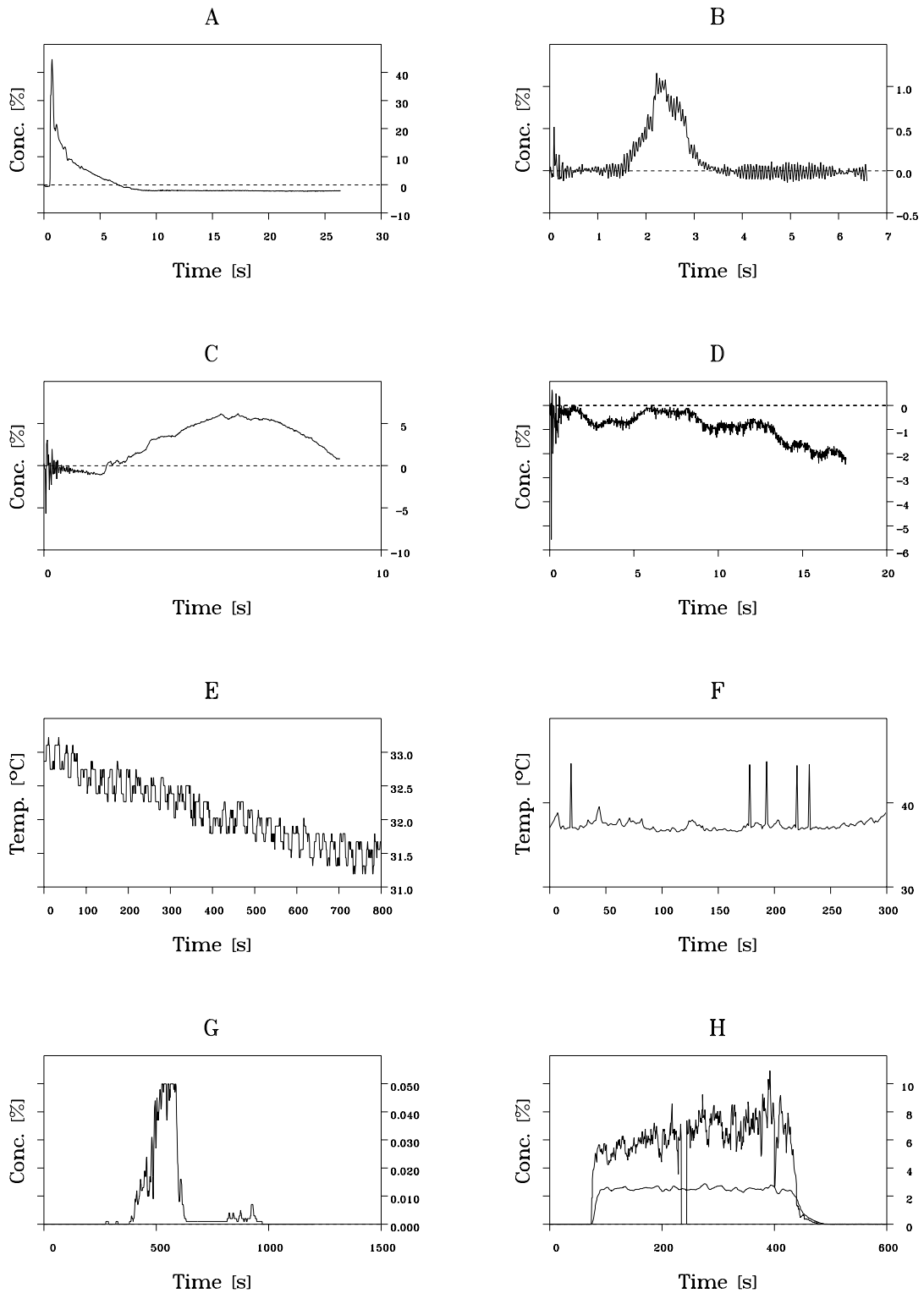

Figure 17. Examples of data problems: A) Baseline shift during exposure; B) Spurious humming; C) Bursts of noise at the start and a seriously drifting baseline. Since the time series ends prematurely, it is impossible to determine if the signal returned to zero; D) An utterly strange signal; E) Periodic noise in a thermocouple signal; F) Singular spikes; G) Clipped signal; and H) Incompatible signals from two adjacent sensors.

series from this instrument type indicates that the instrument worked in a fine way. Goldwire et al. (1983) mention that the LLNL-IR sensors detected ambient infrared light and therefore overpredicted the gas concentrations during the flame passage in the Coyote experiments.

Mine Safety Appliances catalytic sensor (MSA)

This sensor was used in the Coyote experiments. The response time was O(10) s and Goldwire et al. (1983) estimate that the accuracy is within 10% of the readings. The visual appearance of MSA time series does not reveal additional problems.

Jet Propulsion Laboratory infrared sensors (JPL)

This sensors was deployed in the Coyote experiments. It worked on a principle similar to that of the LLNL-IR sensors and showed a good performance.

Mine Safety Appliances non-dispersive infrared absorption sensor (MSA-NDIR)

This instrument was deployed in the Dessert Tortoise experiments. It detected infrared absorption of both the sampled gas and a reference cell and showed a good performance.

Energetic Science, Inc. electrochemical sensors (ESI)

This instrument was applied in the Eagle experiments. Though McRae et al. (1987) note that the cloud did pass these sensors in the E1 and E2 experiments, not much gas is indicated by the signals. In the E3 and E6 experiments the low level sensors at the centerline mast were clipped due to too high concentrations.

TüV catalytic sensor

This instrument was applied in the tests at Lathen and worked on the principle of catalytic burning similar to that of the MSA sensor. Heinrich & Scherwinski (1990) mention that the signal was ambiguous, when the inflammable propane concentration exceeded the stoichiometric mixture at 8% propane. However, this is not the case in the distributed signals. In some time series the signal baseline is unsteady and a few spikes were observed.

TüV infrared sensor

This instrument was applied in the tests at Lathen. The principle of the instrument is to detect absorption by the gas mixture passing a beam of infrared light. However, the water/ice aerosols present under field conditions disturbed this measurement and the measurement path had to be shielded with fleece. The distributed signals were measured by instruments covered with the measurement path covered by fleece and they appear to be accurate, however, with a much slower response time than originally planned. Each instrument automatically made in-situ reference measurements, and this is why the signals disappear with regular intervals.

TüV modified infrared sensor

This instrument was an modified version of the instrument described above and it was applied without covering the measurement path by fleece. It was always

applied next to a TüV catalytic sensor, and this reveals that the signal gain is unreliable. Probably the measurements were still disturbed by aerosols. Before using data from this instrument, we recommend a comparison with the nearby catalytic sensor.

Sonic–Thermocouple estimates

This signal was obtained from adjacent sonic and thermocouple signals in the Lathen and Fladis experiments. Typical measurement problems are liquid condensation on the thermocouple leading to 1) a change of the thermocouple response time, which affects the synchronization of the two measurements, leading to noise in the concentration estimate, and 2) too low thermocouple temperatures just after release, which lead to slightly negative concentration estimates.

Ultra Violet Ion Collector (UVIC)

This sensor was used in the Fladis experiment, and it was capable of measuring very fast peaks in the concentration field (faster than the data frequency of the Rediphem database). In a few situations the range of the data acquisition was not optimized, leading to a slight clipping of the signal, but this did not affect the average concentration much.

Dräger Polytron Ex catalytic sensor

This sensor was used in the Fladis field experiment and the principle of operation is similar to that of the MSA and TüV catalytic sensors. The baseline was not steady and a negative concentration is often observed just after gas exposure.

Dräger Polytron NH_3 electrochemical sensor

This sensor was also used in the Fladis field experiments. It had baseline problems similar to that of the Dräger catalytic sensor. After each gas exposure a very long tail is observed in the concentration signal.

E How to access the database

The first thing to do with the database is probably to run the *db.exe* program (described in appendix G). The *db.exe* program is a data browser that allows you to overview the content of the data base, but it is not an environment in which data are manipulated, and you may soon find yourself wanting to get data on the kitchen table. The purpose of this appendix is to describe how data in the database can be accessed and analysed.

Data files

The data is organized in a directory tree as described in section 4. Most files are plain ascii text files that can be viewed by means of a viewer or an editor or read by a program. The only exceptions are the files named *data.dbf*[6] that contain the time series. These are binary files that can be read from a Borland Pascal program like this:

Reading data.dbf

```
program readdbf;
uses crt;
var
  buf:array[0..999] of single;
  x:single;
  rowln:integer;
  dbf:file;

begin
  assign(dbf,'data.dbf');
  {We assume that you are in the right experiment directory}

  reset(dbf,4);
  {Preparing to read 4 bytes (1 single) at a time}

  blockread(dbf,x);
  rowln:=round(x);
  {The first number in the file is the rowlength}

  reset(dbf,4*rowln);
  {Preparing to read one row at the time}

  blockread(dbf,buf,1);
  {The first row contains the row length followed by rowln-1 channel
   numbers. These numbers are represented as singles even if they
   actually are integers. At present buf[0] is the rowlength and
   buf[i] is the channel number of the i'th column. Channel numbers
   are found in the file setup.dat}

  {You may wish to store channel numbers at this point}

  repeat
    blockread(dbf,buf,1);
    {buf[0] is the time in seconds and buf[i] is the reading from
```

[6] The extension dbf stands for 'database file'. Unfortunately, the same extension is used also by dBaseIV.

```
    the i'th channel}

   {Store data..}

  until eof(dbf);

  close(dbf);

  {Data analysis..}

end.
```

The type `single` in Borland Pascal is a four byte real. It is the same as a `real*8` in Fortran, but if you try to read *data.dbf* from a Fortran program you will get into trouble. This is because most Fortran compilers assume that binary data is written in the IEEE standard format. The program *dbftoie3.exe* creates a file called *data.ie3* with the right record structure by adding some extra bytes to *data.dbf*. Each row becomes a Fortran style record of 8 byte reals. The program *ie3todbf.exe* does the inverse conversion. These conversions do not change the data.

Reading from Fortran

If everything else fails you can convert *data.dbf* to ascii by means of *dbftoasc.exe* and return to binary using *asctodbf.exe*. The conversion to ascii may lead to some rounding errors. *Dbftoasc* will create a file called *data.asc* which can be viewed directly or read into a spreadsheet.

Converting to ascii

Another possibility is to run the *db.exe* program. Find the appropriate experiment and go to the time series menu. This is the one that shows a list of all of the channels. Select one or more of the channels by pressing the **INS** key, hit **RETURN** and select the EXPORT option in the window that pops up. This will create an ascii file containing the data from the selected channels (and the time in the first column). This is same format as *data.asc* except that there will be fewer columns. The *db.exe* program puts the file in the *rediphem\export* directory.

Exporting from db.exe

Instrumentation

Each experiment directory contains an acsii file called *setup.dat* containing sensor positions and channel numbers. The first entry in a line is the channel number, then follows x, y and z coordinates, a number indicating the signal type, and possibly two more numbers indicating e.g. sensor orientation.

Experimental setup

Signal types are common to all experiments in a project. A signal type defines a certain measurement. A signal is typically a reading from a particular type of sensor, but it can also be derived from several measurements. Signal types are defined in the file *chandef.dat* in the project directory. The attributes are: color, icon, text describing the measured quantity, units (text) and a file name (**.txt*). The colour and the icon are numbers that are used by the program *db.exe*, and they can be regarded as dummy. The file **.txt* is an ascii file containing a description of the measurement/sensor.

Signal types

Additional information may be found in the files *camp01.not* and *run01.not*.

Release conditions

Release conditions are defined in the ascii file *specs.dat*. One problem with release conditions is that a parameter may be relevant in relation to some experiment and not to others. The cloudiness, for example, is not relevant for a wind-tunnel experiment. Different systems are also used to characterize e.g. background meteorology and some conversions have to be made in order to align definitions. Furthermore,

there are problems of unreliable or missing data. In light of this it was decided to make the specification of release conditions in *specs.dat* that reflect the status of the input. The rules for making the file are as follows.

Input processing

- Each line specifies a parameter. The first part of the line, ending with a colon, is a text containing a unique combination of keywords. Thus a line containing 'release' and 'rate' specifies the release rate. The allowed keyword combinations are found in the procedure `getasciispecs` in *dbadm.pas*. After the colon follows the value of the parameter[7]. After this number one or more (or none) of the following status keywords can be added to indicate the status of the input.

Status flags

Status keyword	Status
?	uncertain value
spur	spurious value, probably not ok
appr	approximate value, but probably ok
na	not applicable
esti	estimated, not directly measured
note	there is a note about the data

  Combinations of keywords are allowed.

- It is allowed to omit an input, in which case the status is 'missing'.
- Input lines may come in any order.
- Lines that do not contain a recognizable combination of keywords in the leading part (to the left of the colon) are allowed. This is to ensure that data can be put in for future use without affecting existing programs. Below it is described how new parameters and keywords can be added.

Easy input files

Thus it takes an interpreteor to read *specs.dat*, and Pascal programmers will find one in the unit *dbadm.pas* (see next section). In order to make life easier for e.g. Fortran programmers more straightforward, but also less flexible, input files can be generated. This is done by running the program *mkspex.exe*. This program interprets all *specs.dat* files and makes more streamlined ascii file called *spex.dat*. The format of the file *spex.dat* is straightforward. Most lines are written in the format: Status Value Units Text. 'Status' is an integer obtained as a sum of one or more of the following constants

data missing	1
input error	2
data unknown	4
not applicable	8
spurious	16
approximate	32
estimated	64
uncertain	128
ok	256

'Value' is a real number, 'Units' is the appropriate units and at the end of each line in *spex.dat* 32 characters of text (column 40 to 72) describe the input. In *spex.dat* the lines always appear in the same order. Note that if new release conditions are defined, these are appended to the *spex.dat* files, but only after the call of *mkspex.exe*.

[7] Or you may write some nonsense, that does not make a number. If the nonsense contains a question mark the status will be 'unknown', meaning that you have reported the parameter as not known. Otherwise, the status will be 'inputerror'.

Borland Pascal data structure and procedures

Software for free!

A number of programs were written in the course of constructing the database. Some of these are included in the *rediphem* directory. The software can be used and modified free of charge as long as this is done on a non-commercial basis. Since the software is written in Borland Pascal 7.0 this and the following sections are written mainly for Borland Pascal users.

No OOP

Borland Pascal 7.0 features object-oriented programming (OOP), but whe this project was initiated this was regarded by us as rather advanced and it was felt that programs using OOP might be difficult to use by others without massive documentation.

Predefined data structure

The program unit *globals.pas* defines a data structure by means of linked lists of Pascal records, and the program unit *dbadm.pas* contains useful procedures that enable relatively uncomplicated access to the data base. The software makes intensive use of Pascal `record`s and `pointer`s. We assume that the reader is familiar with these data types. The whole data structure 'hangs' in a single pointer called `firstproject` of type `projectpointer`. It points to the first project, which is a record of type `projectrec`, which looks like this :

```
type

  projectpointer=^projectrec;

  runpointer=^runrec;

  signalpointer=^signalrec;

  projectrec =
  record
    logo:str16;
    dir:dirstr;
    projflag:word;
    projinfo:screen;
    firstrun:runpointer;
    firstsgn:signalpointer;
    nextproj,prevcamp:projectpointer;
  end;
```

Records and pointers

Here `logo` is the project logo (e.g. 'LATHEN'), `dir` is the path to the project directory, `projflag` is a general purpose flag and `projinfo` is the content of *header.txt*. The remaining variables are pointers. `Firstrun` points to a `runrec` containing information relating to the first experiment in the project, and `firstsgn` points to the first signal/instrument type. These record types contain pointers to yet other types of records as illustrated in figure 18. The names of the variables contained in these records can be found by inspection of *globals.pas*. You can *add more* items to the record types without corrupting other programs, whereas *deleting* items might be problematic.

Making a list of projects

The following program makes a list of all projects in the database

```
program projectlist;
uses crt,dbadm,globals;
var
  project:projectpointer;
```

```
begin

  initdb('','data');
  {This initializes the database.
   ' ' is the path to the rediphem directory (we assume we are in it).
   'data' is the subdirectory containing the data base.}

  addallprojects;
  {This makes the system find all projects and allocate memory
  to the records of type projectrec}

  clrscr;
  writeln('Projects in the rediphem data base');

  project:=firstproject;
  repeat
    with project^ do
    begin
      writeln(logo);
      {or do more complicated stuff..}
      project:=nextproj;
    end;
  until project=firstproject;

  repeat until keypressed;

  cleanup;
  {This closes the data base and clears extended menory.}

end.
```

Loading data

This program uses three procedures from the unit *dbadm*: `dbinit`, `cleanup` and `addallprojects`. In every application using *dbadm*, `dbinit` is called at the beginning and `cleanup` is called at the end. The procedure `addallprojects` reserves extended memory to the project records, i.e. the first vertical list of linked records in figure 18. The records below are still non-existing and the pointers to them are equal to `nil`. In order to create in the rest of the structure and fill in the appropriate data you make a call to `loadallruns`. Furthermore, we will make things slightly more complicated by demanding a listing of release rate, wind speed and relative atmospheric humidity for all jet releases. The following program does that.

Opus 2

```
program dblist2;
uses crt,dbadm,globals;

var
  project:projectpointer;
  run:runpointer;
  outfile:text; {the list is too long for the screen}

begin
  clrscr;

  writeln('Available extended memory:',memavail,' bytes');

  initdb('','data');
```

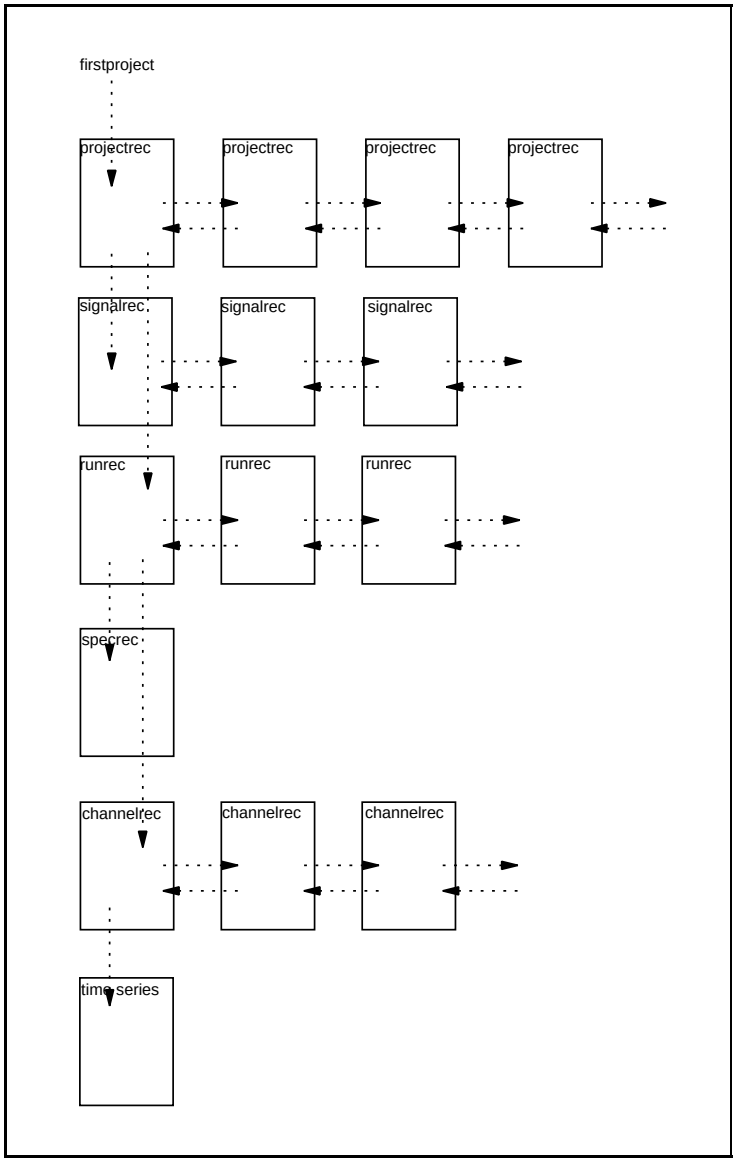

Figure 18. The data structure defined in globals.pas.

```
{Compulsory}

addallprojects;
{Add the projects that are to be loaded}

loadallruns(ascii);
{Create the data structure and fill in data. This is damned slow.
 The ascii option is recommended. It means that the interpretator
 is used to read the release conditions from the specs.dat files.}

writeln('Available extended memory:',memavail,' bytes');
{Hopefully we have not run out ot memory}

writeln('go!');
```

```
assign(outfile,'export\dblist.txt');
rewrite(outfile);

writeln(outfile);
writeln(outfile,'A list of experiments involving jet releases');
writeln(outfile);
writeln(outfile);
writeln(outfile,'Project   Experiment  Release rate  Windspeed  Rel. Humidity');
writeln(outfile,'                          kg/s         m/s         %        ');
writeln(outfile);

project:=firstproject;
repeat
  {Outer loop running through the project list}
  with project^ do
  begin
    run:=firstrun;
    {Every project has a first experiment}
    repeat
      {Inner loop running through all experiments in the project}
      with run^ do
      begin
        with spec^ do
        begin
          if releasetype=jet then   {jet is a constant, cfr. globals}
          begin
            write(outfile,copy(logo+'          ',1,10)
                  ,copy(id+'            ',1,10));
            {We want straight columns!}

            if (releaserate.stat and absent)>0 then
            begin
              write(outfile,'    missing');
            end
            else
            begin
              write(outfile,releaserate.value:12:5);
            end;
            {absent is a constant (see globals)}

            if (windspeed.stat and absent)>0 then
            begin
              write(outfile,'    missing');
            end
            else
            begin
              write(outfile,windspeed.value:11:2);
            end;
            if (atmrelhum.stat and absent)>0 then
            begin
              writeln(outfile,'    missing');
            end
            else
            begin
```

```
                writeln(outfile,100*atmrelhum.value:11:2);
              end;
            end;
          end;
        run:=nextrun;
        end;
      until (run=firstrun);
      project:=nextproj;
    end;
  until (project =firstproject);

  close(outfile);

  cleanup;
  {garbage collection}

  writeln('finito');

end.
```

Pointing to data

From this example you can see how it works: `run^.spec^.releaserate.value` is the release rate in the experiment named `run^.id`, which, by the way, is found in the project `run^.fromproject^.logo`. Note that `releaserate` is not a `single`, it is a `zingle`, which is a record containing `value` (which *is* a `single`) and `stat` (which is a `word`).

Removing projects

When you run the program you will note that it takes quite some time to assemble the database (1 or two minutes). While this is done, things are written on the screen so that you can see that your computer is working. Making the list, on the other hand, takes no time. In case you do not want to consider all projects you can remove projects before the call to `loadallruns`, viz.

```
  ....
  addallprojects;

  project:=firstproject;
  repeat
    while (pos('HAMBURG',project^.logo)+
           pos('WSL',project^.logo)>0 do
      removeproject(project);
    project:=project^.prevproj;
  until project=firstproject;

  loadallruns;
  ....
```

The `repeat` ... `until` loop scrools the project list backwards and removes unwanted projects. The reason for going backwards is technical: if `removeproject` removes the first project in the project list `firstproject` will shift to the next project in the list, and that could make the loop end prematurely if we scrolled forwards. We admit that linked lists are not always intuitive to work with, especially when you want to go through a list and alter it at the same time. Note that removing `project` within a `with project^ do` loop will result in a runtime error (#216: General Protection fault).

Hopefully, this will give you an idea of how to manœuvre in the pointer-tree structure and how release conditions are obtained. The next thing to think of is how to access the time series. Each channel is linked to a time series by means of the pointer `data` of the type `datapointer`. It would be natural if `loadallruns` allocated memory to all the time series, but that would soon fill up your the extended memory of your computer. Therefore, time series are loaded for one run at a time and removed again after use in order to save memory. This is done by a call to `opendata` in the following way

Loading time series

```
...
opendata(run,errorcode);
...
my_data_analysis;
...
closedata(run);
...
```

More than one run can be opened at a time, but take care not to run out of memory. If you are short of heap `opendata` will truncate the time series. `Opendata` returns the `integer errorcode` with the following meaning:

- `errorcode`=0. No errors
- `errorcode`=1. The data are already open.
- `errorcode`=2. You are short of heap. Time series truncated.
- `errorcode`=4. Empty run (`=nil`). Experiment not loaded.

The procedure `my_data_analysis` is supposed to be user defined. In principle a `datapointer` is a pointer to an array of `single`s corresponding to a column in data.dbf. Time series differ in length and unfortunately the largest possible array size in Borland Pascal is 64k. This size could be too small to hold a long time series and too long in case there are many short time series. Therefore, we have invented at data type that simulates an array of varying length. The following version of `my_data_analysis` simply finds the maximum value in a time series and the time it occurred. The program *dbcomb.pas* is a skeleton program for making data analysis. You may take a copy of this program and make the necessary alterations.

Dynamic arrays

Making a data analysis.

```
procedure my_data_analysis(
  run:runpointer;
  chn:channelpointer;
  var maximum,tmaximum:single);
var
  i:longint;
  i1,i2:integer;
  x:single;
begin
  with run^, chn^ do
  begin
    maximum:=data^[0]^[0];
    tmaximum:=time^[0]^[0];
    for i:=1 to dataend do
    begin
      i1:=i div 256;
```

```
      i2:=i mod 256;
      x:=data^[i1]^[i2];
      if x>maximum then
      begin
        maximum:=x;
        tmaximum:=time^[i1]^[i2];
      end;
    end;
  end;
end;
```

Here you can think of `data` as being of the type `array[0..dataend] of single`, and when you think `data[i]` you write `data^[i div 256]^[i mod 256]` instead. The variables `time:datapointer` and `dataend:longint` are items in the record `runrec`, which are loaded by `opendata`. After performing `opendata(run,err)` a third item, `run^.getchannel`, holds an array of pointers into the channel list. When the data are open `run^.getchannel^[27]` is the pointer to the channel with channel number 27. Using `getchannel` is faster than scrolling the channel list to look for number 27.

`getchannel`

You may also find the procedure `findrun` useful. It returns the pointer to a run when given the project logo and the run identifier (in ascii).

Finally, this is how a new release condition is added to the system:

Adding release conditions

- Change to the *rediphem* directory and start Borland Pascal.
- Open *globals.pas* and search for the word `shoe`. There are three `shoe`s in the file indicating where and how to add a shoe number to the list of recognized release conditions.
- Increase the global constant `nparam` by one.
- Open *dbadm.pas*. In the file one line is a comment containing two `shoe`s. This is where keywords for the input interpretor are defined.
- Recompile *db.pas* in protected mode.

F How to add more data

The Rediphem database is a collection of project directories (with subdirectories). Each project directory is self contained and the information is not linked to other project directories. This means that you can delete a project by removing the project directory from *rediphem\data*. Likewise new projects are installed simply by making the project directory (plus subdirectories, `xcopy .... /s`) as a subdirectory of *rediphem\data*. The file formats in the Rediphem database are relatively simple, and installing experimental results in the database is one way of making sure that most relevant information are reported. We hope that more dense gas data will be added. The following installation instruction is a listing in the file *install.hlp*.

```
How to install new experiments in the database.

1. Choose a project name consisting of max. 8 characters, and make
   a directory for it:

       mkdir rediphem\data\zilk

   Here we have assumed that the name is 'zilk'. It must be a
   subdirectory of the data directory (= e.g. rediphem\data).

2. Choose 8 character names for each experiment and make directories:

       mkdir rediphem\data\zilk\exp1
       mkdir rediphem\data\zilk\exp2
       etc.

   Note that extensions are NOT allowed in the experiment directory
   names. The system will ignore a directory called EXP.001.

3. Construction of input files:

   a.  Make an ascii file called \zilk\camp01.not, and write in it a
       general description of the project. Important information
       that is general for all experiments in the project should be
       included here.

   b.  Make an ascii file called zilk\header.txt containing a 'front
       page' (max. 16 lines of max. 40 characters). It should look
       something like this

         FLADIS experiments
         Landskrona 1993-1994

         Risø, HydroCare, FOA, Porton Down

         Ammonia
         Atmospheric releases
         Flashing jet
         Dense to neutral clouds
         Flat terrain
         Non-obstructed
```

```
  Scales: 0.5 kg/s
          200 m
```

c. Make an ascii file called zilk\chandef.dat using the format

```
  SIGNALTYPE  COLOR ICON<end of line>
  MEASUREMENT  <end of line>
  UNITS  <end of line>
  DEVICENAME <end of line>
  FILENAME <end of line>
  SIGNALTYPE  <end of line>
  MEASUREMENT  <end of line>
  UNITS  <end of line>
  DEVICENAME <end of line>
  FILENAME <end of line>
  etc.
```

Five lines are used here to define a signal type. A signal type describes a particular kind of measurement. The signal may simply correspond to an output from a specific type of instrument, or it could be derived from the measurements in some other way. Please note the distinction being made here between signal types and channels. There is one channel for each measured time series, whereas one signal type can be shared by many channels.

SIGNALTYPE is an integer in the range 0<SIGNALTYPE<256, which identifies the signal type. A signal type will typically represent output from a commercial instrument (e.g. Gill sonic, Draeger polytron EX NH3). It is recommended that you define many signal types, since you can teach the system later on which data are to be grouped together (concentration sensors, thermometers, chains of instruments etc.).

COLOR and ICON are two integers defining the colour and the icon used in 3D grafics to represent the device. Since these can be changed later you can use COLOR=1 and ICON=1.

MEASUREMENT is an ascii string (max. 32 characters) describing the physical quantity being measured (e.g. NH3 concentration, wind speed (w) etc). Different signal types may have identical descriptions.

UNITS is an ascii string (max. 16 characters) indicating the physical units of the measured quantity.

DEVICENAME is an ascii string (max 32 characters) containing the name of the measuring device (e.g. Gill sonic, UVIC). The combination of MEASUREMENT, UNITS and DEVICENAME should be unique for each signal type.

FILENAME is the name of an ascii file containing a description of the characteristics of the device (see below). The name should not include the directory path: gill.txt is enough.

d. Next step is to write the ascii files containing device characteristics. You may add any comment regarding the instrument, which you judge to be essential for the interpretation of the measurements. The files are placed in the project directory (e.g zilk\cup.txt for a cup anemometer). Please check the consistency of file name.

e. Make an ascii file called setup.dat in each of the experiment directories (zilk\exp1\setup.dat etc.) using the following format

```
CHANNEL X Y Z SIGNALTYPE  [A  B] <end of line>
CHANNEL X Y Z SIGNALTYPE  <end of line>
etc
```

Each line specifies a channel. For each channel a time series of measured data will exist.

CHANNEL is an integer in the range 0<CHANNEL<1000. A different channel number is assigned to each time series. This will identify a time series.

X,Y and Z are the coordinates (in meters) of the point where the measurement is taken (real numbers).

SIGNALTYPE is an integer in the range 0<=SIGNALTYPE<256. It should correspond to the SIGNALTYPE entry in the file chandef.dat. The value SIGNALTYPE=0 is also allowed, and it indicates that the channel is not used and will be ignored by the system (no time series).

A and B are two reals describing e.g. the orientation of the device. They are optional and can be omitted.

f. For each experiment make an ascii file called specs.dat placed in the corresponding experiment directory (e.g. zilk\exp1\specs.dat). This file is to contain the release conditions of the experiment as illustrated by the following example

```
identificator                       :Trial016
month                               :8
day                                 :13
substance                           :ammonia
release type (puff/jet/cyclone)     :jet
nozzle diameter                     :0.004
pool mass fraction                  :0.0
release point x                     :-2.0
              y                     :0.0
              z                     :1.5
release direction a                 :283
                  b                 :0
phase (liquid to gas mass ratio)    :1.0
exit temperature                    :17
exit pressure                       :7.913
```

```
release rate                          :0.27
release starttime h                   :19
                  m                   :50
                  s                   :0
release duration                      :1140
number of fences                      :0
site average wind direction           :282
wind direction standard deviation     :9.6
ideal wind direction                  :283
site average windspeed at 10m         :4.4
windspeed standard deviation          :0.87
friction velocity                     :0.286
surface roughness                     :0.04
Monin-Obukov length                   :45
stability class                       :?
cloud cover                           :?
ambient temperature                   :16
ambient pressure (bar)                :1.020
relative humidity                     :0.60
```

You can take a copy of rediphem\specs.dat and make the relevant changes. Please do not alter the keywords to the left of the colon and be sure not to omit the colon. The value after the colon can be followed by one or more remarks with the following meanings

```
?         uncertain value
spur      spurious value, probably not ok
appr      approximate value, but probably ok
na        not applicable
esti      estimated, not measured
note      there is a note about the data
```

Delete the line if there is no input (the value will be regarded as missing by the system)

g. For each run make an ascii file containing information specific for that particular run. The file name should be run01.not and it should be placed in the experiment directory (zilk\exp2\run01.not). Notes on the performance of particular instruments and of the overall success of the experiment can be put here. Special information regarding conditions for the particular run (it rained!) are put here.

   You may omit the file.

4. For each experiment make a binary file called data.dbf (in each of the experiment directories). The file should have the following format (dbf format)

```
n+1   CHANNEL1    CHANNEL2  ....  CHANNELn
TIME  VALUE1      VALUE2    ....  VALUEn
TIME  VALUE1      VALUE2    ....  VALUEn
```

etc.

All entries are single precision (4 bytes) Borland Pascal floating point reals. In Borland/Turbo Pascal the file type is 'file of single'. There are no end-of-line marks in binary data files written by Pascal.

In the first line n+1 is the row length or number of time series in the file. It is equal to the number of channels PLUS ONE. CHANNELx is a channel number (as specified by CHANNEL in setup.dat). Even if these numbers are integers they should be entered as single precision Borland Pascal reals.

The following lines each contain simultaneous readings of the n signals. TIME is the time in seconds, and VALUEx is the reading of CHANNELx.

Alternatively you can write an ascii file with the same entries (Carriage return (end-of-line mark) after each line). The program asctodbf will convert the ascii file to a dbf file:

```
asctodbf data\zilk\exp1\ascfile data\zilk\exp1\data.dbf
```

You can also write the file in Fortran as an unformatted binary file. All numbers should be of the fortran type REAL. Pc Fortran writes the record structure into data files using the IEEE standard, while Pascal does not. The program ie3todbf will convert the fortran file to the dbf format:

```
ie3todbf data\zilk\exp1\ie3file data\zilk\exp1\data.dbf
```

The record size in ie3file is immaterial and may even be variable.

4. Run the program setup2 to see if you have remembered everything. This program writes an output file to the export directory containing diagnostics. The number of errors detected are found at the end of the file.

5. Run db and see if it works.

6. If you have serious problems try ott@risoe.dk

7. Send a copy to Risø!

G How to inspect the database

This note is a brief manual to the November 1995 version of the MS-DOS program *db.exe*, which will allow an inspection of the contents of the Rediphem database. Some of the menus may appear slightly different from the present description, since new options may appear in future program versions. The hardware requirements depend on the number and the data volume of the projects installed in the database. We recommend to use the system on a PC with DX 80486 processor, 8 MB EMS memory, and a VGA monitor.

Table 32. General function keys

F1	Brief system information
Crtl F1	Short explanation of the purpose of the current screen
F2	Information related to the experimental data
↑, ↓	Arrow keys which move the bouncing bar in the menus
Enter	Selects an item in the menus
ESC	The general exit key

Table 32 is a list of general function keys which have the same meaning throughout the program. Please note the online help system associated with the **F1** and **Crtl F1** keys. It is not possible to destroy the database from inside the program, so press any button, if you like.

help system

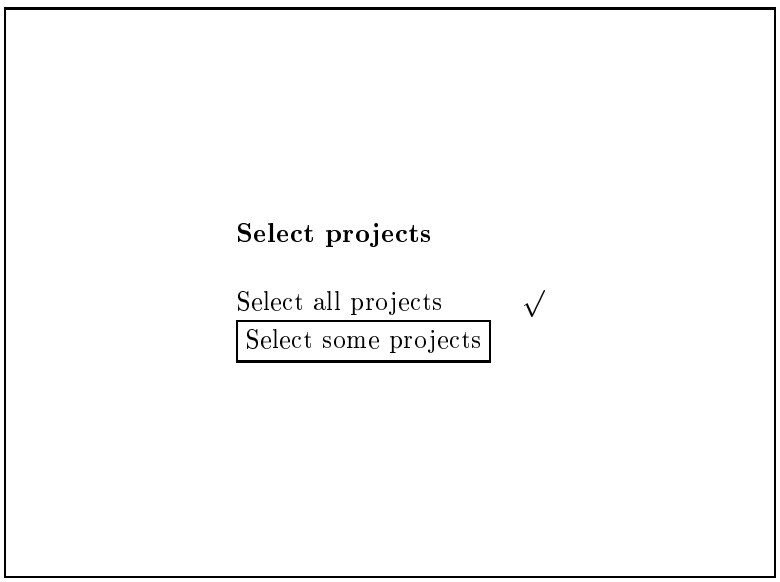

Figure 19. The project selection menu

Figure 19 shows the screen which will appear after the start of the program. The box around the text illustrates the bouncing bar which is operated with the ↑ and ↓ keys. On the PC screen this bar is indicated by a light color. The program will take some time to read the database, but the entrance menu allows the user to select one or a few projects only.

entry screen

Choosing to load only a limited set of projects (by focusing on the second menu option and pressing the **Enter** key), the submenu shown in figure 20 will appear.

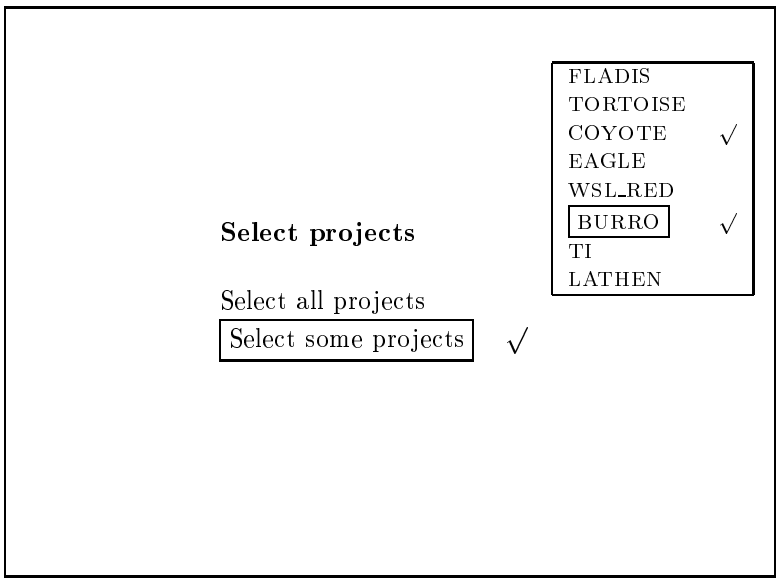

Figure 20. The project selection menu with a submenu for selection of some projects only.

The selected projects are indicated by the √ marks, and to modify this selection you scroll the list and include/exclude the projects with the **Enter** key. Having defined a selection of projects you exit the menu with the **ESC** key, and the program will start to read the selected experiments from the database.

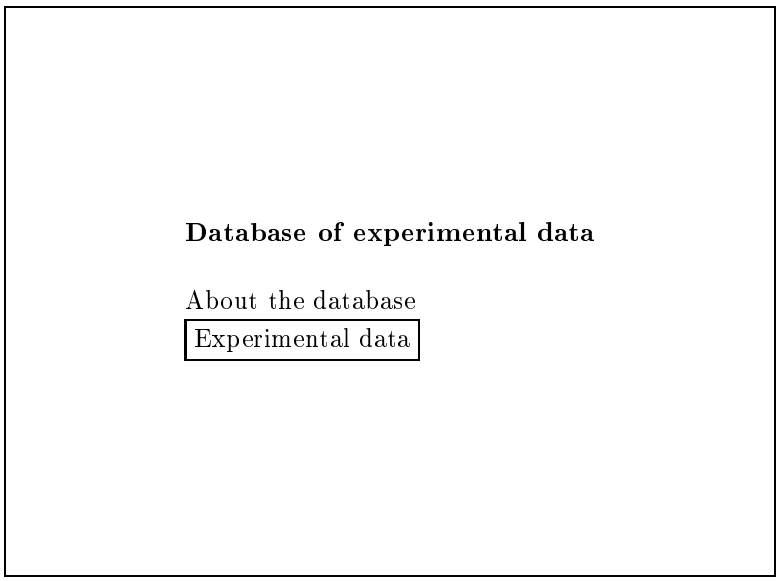

Figure 21. The screen which appear when the database has been read.

entry screen

Figure 21 shows the screen which appears when the program has scanned the database. Select 'About the database' for an introduction to the system or 'Experimental data' for access to the database.

data selection menu

If you choose 'Experimental data', the experiment selection menu will appear. This menu has two modes for project and run selection, shown in figure 22 and 23. Start by scrolling the project list in the leftmost frame, and select a project by

pressing the **Enter** key. You then enter the run selection list, which is scrolled in a similar manner. The condensed project/run information in the rightmost frame will guide you. Detailed information on the focused project or run (the *camp01.not* and *run01.not* files) is accessed by pressing **F2**. You may toggle between the two lists with the ← and → keys.

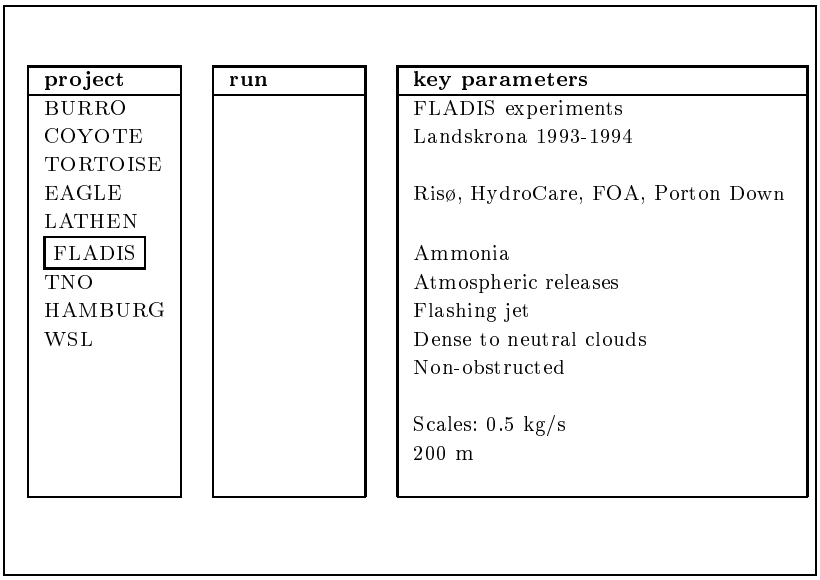

Figure 22. The experiment selection menu in the project information mode.

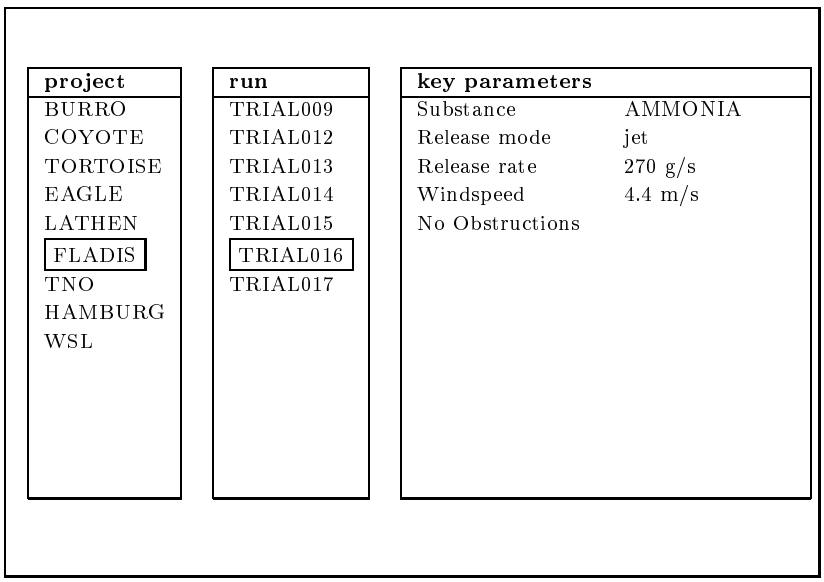

Figure 23. The experiment selection menu in the run information mode.

Having found an experiment, you enter the menu shown in figure 24. The four *information type menu* options will allow you to

- read about the run specifications (from the *specs.dat* file)

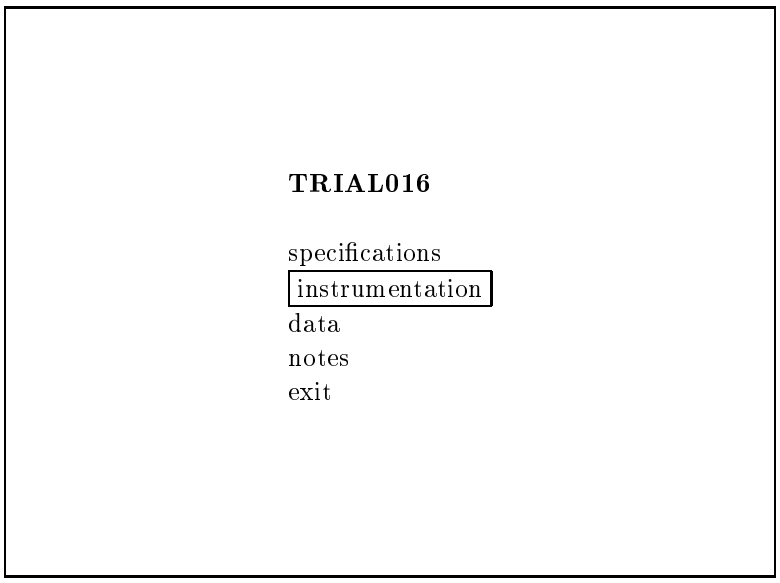

Figure 24. The information menu for the selected run.

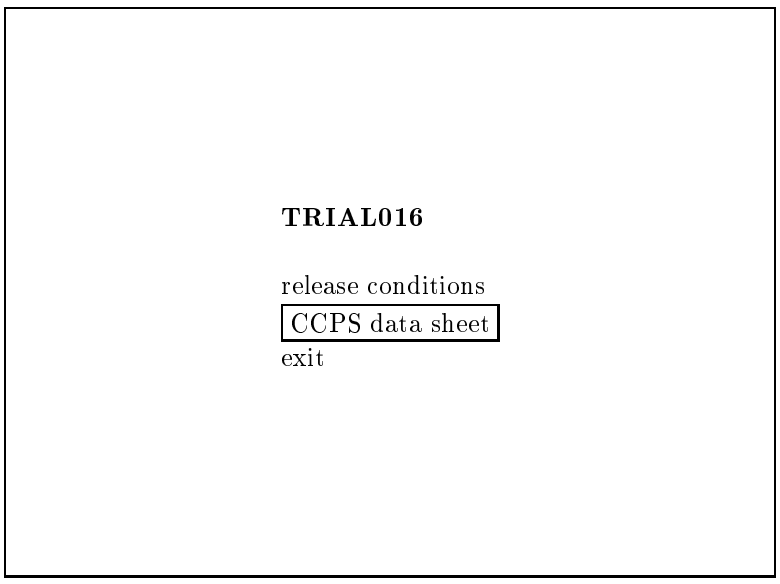

Figure 25. The run specification menu.

- inspect the instrumentation
- inspect the measurements
- read the run information (from the *run01.not* file)

run specification

Figure 25 will appear after selecting 'specifications' in the run information menu. Here, the 'release conditions' option will display the information shown in figure 26 (information read from the *specs.dat* file). The 'CCPS data sheet' option does not work for all experiments.

instrumentation

Figure 27 will appear if you choose 'instrumentation' from the run information menu. The 'instrument info' options will give a 2D view sketched in figure 28, and 'setup graphics' option gives the 3D view sketched in figure 29. These graphic

TRIAL016
AMMONIA
jet
Pasquill-Gifford class : DE

Release start	71511.00	s	
Release duration	1140.00	s	
Release rate	0.2700	kg/s	
Initial concentration	1.00	mol/mol	
Nozzle diameter	0.00400	m	
Pool fraction	0		
X (source)	-2.00	m	
Y (source)	0	m	
Z (source)	1.50	m	
A (source)	110.00	deg	
B (source)	0	deg	
Ideal wind direction	290.00	deg	
Exit temperature	17.10	°C	
Exit pressure	7.98	Bar	
Atmospheric temperature	16.50	°C	
Atmospheric pressure	1.02	Bar	
Relative atmospheric humidity	0.62		
Windspeed	4.40	m/s	
Reference height	10.00	m	
Wind direction	278.00	deg	
Cloudiness	?		Unknown.
Monin-Obukhov length scale	138.00	m	
Liquid phase fraction	1.00		
Effective molecular weight	84.71	g/mole	
Ground slope	0		
Friction velocity	0.41	m/s	
Surface roughness	0.0400	m	
Length scale	0.2428	m	
Time scale	0.1134	s	

Figure 26. Example of the run specification view.

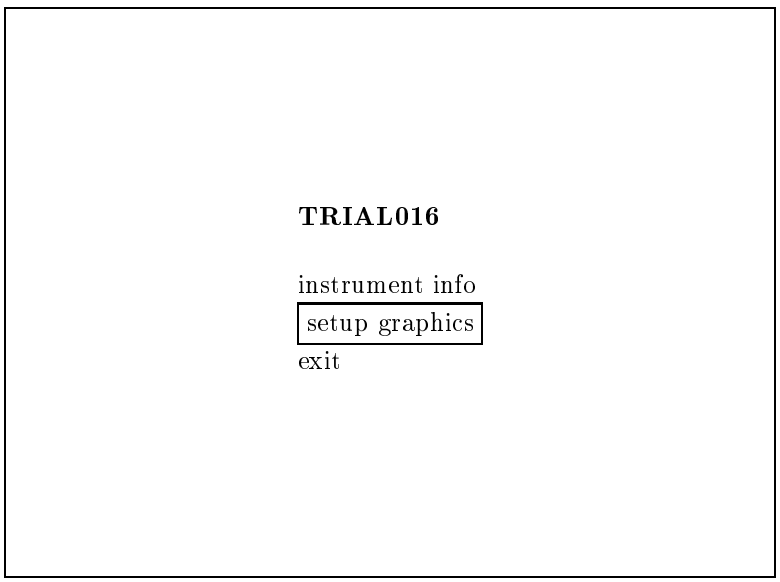

Figure 27. The inspect instrumentation menu.

displays are generated from the *setup.dat* and *chandef.data* files. The 2D view is a map of the measurement positions, and the arrow points on the sensor associated with the focused channel, which is selected by the ↑ and ↓ keys. If you press **F1** the time series of the focused signal will appear on the screen, and pressing **F5** will initiate an animation with concentration signals illustrated by circles and wind directions presented by small lines. Table 33 lists the active function keys in the 2D setup view.

2D view

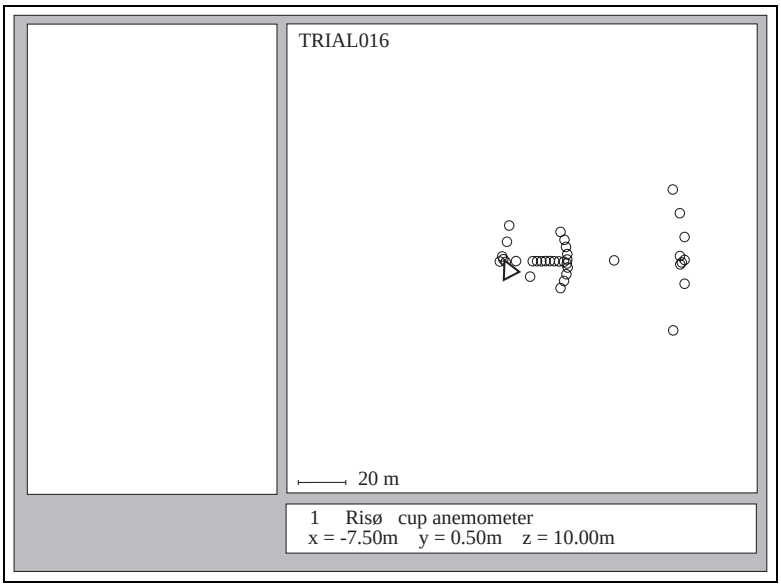

Figure 28. The interactive 2D view of the setup.

Table 33. Function keys in the interactive 2D graphics view of the setup.

↑,↓	Select next or previous signal
Home, End	Move the window in the x-direction
Page Up, Page Down	Move the window in the y-direction
F1	Display time series of selected sensor
F5	Animation of concentration and wind direction
+,-	Zoom in or out
ESC	Quit

The 3D view works like a primitive flight simulator, and the idea is that you should take a walk and look at the instrumentation. The picture on the screen shows the ground and the instruments as seen through a camera. The view point and camera direction are controlled by the function keys listed in table 34 (you will soon get better manœuvering this camera - just press the bottoms). If you step close to the instruments, you will see that they are represented by 3D icons, which identify the instrument types. Pressing **F2** or **Alt F2** will display the instrument types or identification codes. **F3** starts an animation of the concentration signals, as in the 2D view.

3D view

Initially, the camera is hanging in the air looking down. Use the arrow keys to move horizontally, decent with the **Page Down** or **Home** keys, and turn upright with **Crtl Page Up**. Your view will be horizontal when the horizon appears in

Hints for 3D view

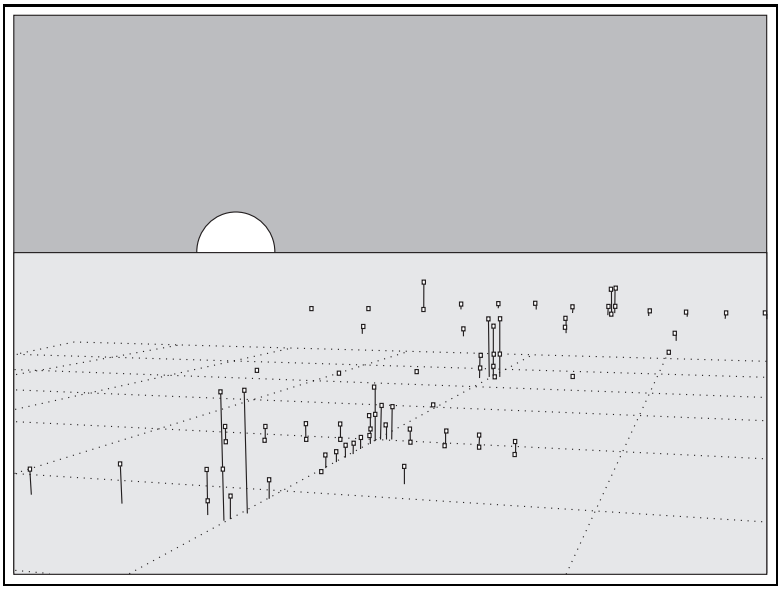

Figure 29. The interactive 3D view of the setup.

the middle of the picture. Now, you are on the ground and may walk using the → or ← keys, and turn around with the **Ctrl** → or **Ctrl** ← keys.

Table 34. Function keys in the interactive 3D graphics view of the setup.

ESC	Quit
→, ←	You move right or left. These movements are parallel to the ground.
↑, ↓	You move forward or backward. These movements are parallel to the ground even if you are looking down.
Home/End	You move into/out of the picture. These movements are not always parallel to the ground, but follow the line of sight.
Ctrl →, Ctrl ←	You turn left or right.
PgUp, PgDown	You are lifted vertically up or down.
Ctrl PgUp	You look (turn the head) up.
Ctrl PgDown	You look (turn the head) down.
+, -	Zoom in or out. You do not move.
Ins	You walk faster (larger steps).
Del	You slower down (smaller steps).
=	Return to default settings.
F1	This help.
F2	Instrument types are displayed. It may look a bit messy but each type has its own colour.
Alt F2	Instrument numbers are displayed.
F3	Animation of the release. The measured concentrations are displayed as balloons.
ESC	Quit

The menu in figure 30 will appear after pressing 'data' in the select run informa- *select channel*

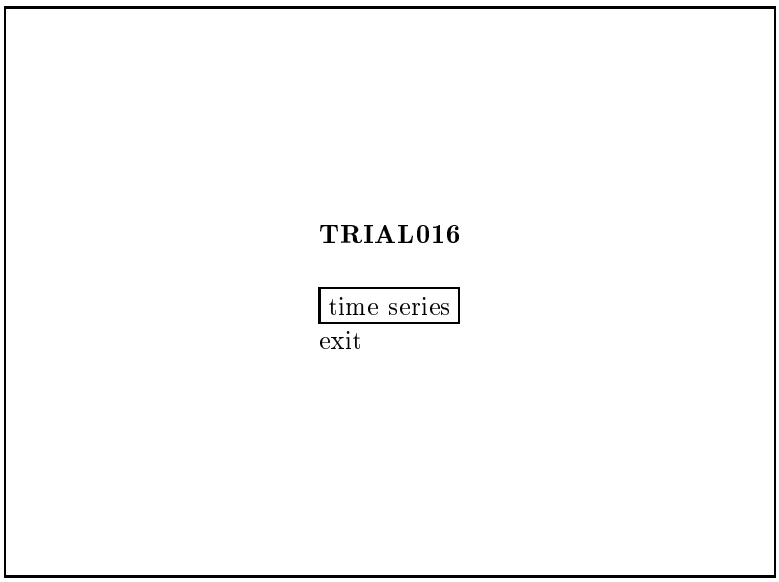

Figure 30. The select measurement display menu

TRIAL016
no channels selected

chn	x	y	z	description
1	-7.50	0.500	10.00	Wind speed
2	-8.00	1.30	4.00	Wind speed
3	-8.00	1.30	1.50	Wind speed
4	-8.30	0.000	4.00	Streamwise wind component
5	-8.30	0.000	4.00	Lateral wind component
6	-8.30	0.000	4.00	Vertical wind component
7	-8.30	0.000	4.00	Sound virtual temperature
10	-5.00	15.00	2.00	Atmospheric pressure
11	-7.70	0.000	1.50	Relative humidity
12	-7.70	0.000	1.50	Air Temperature
13	-8.30	0.000	1.50	Downward short wave radiation
16	-6.50	-0.500	1.50	Absolute humidity
19	-6.50	-0.500	10.00	Wind direction
20	8.00	0.000	0.350	Air temperature
21	8.00	0.000	0.450	Air temperature
22	8.00	0.000	0.550	Air temperature

Select one none type near go
Ins **Del** **End** **Home** **Enter**

Figure 31. The time series selection menu

tion menu. At present this has only one option, which leads you to the time series selection menu in figure 31. The table on this screen displays channel numbers, measurement positions, and signal descriptions. The descriptions are either signal types, instrument names, or measurement units, and you may toggle between the description modes with the **Ctrl** ← and **Ctrl** → keys. The **F2** key will give a longer description of the instrument type of the focused signal. The purpose of this screen is to select signals for plots of time series using the function keys below the table. You may select the signal focused by the bouncing bar, nearby signals, or signals of the same type as the focused one.

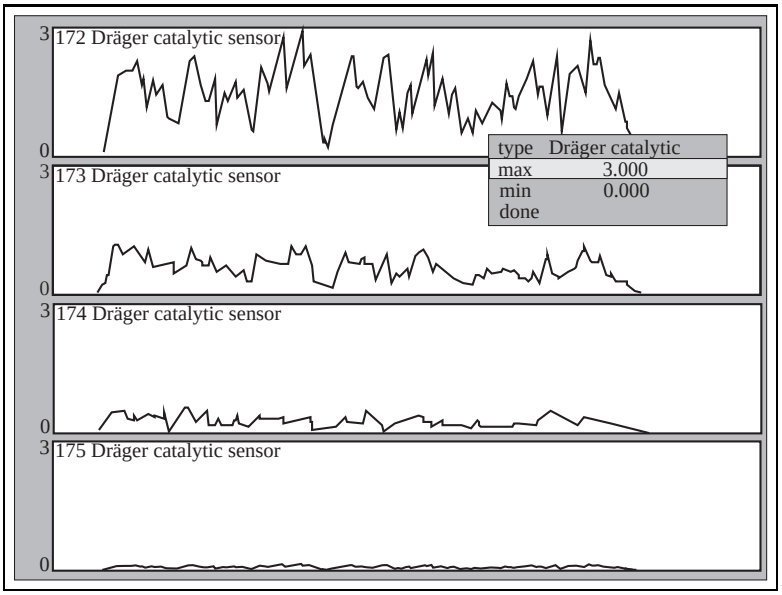

Figure 32. The time series view after pressing F2 for signal range adjustment. The signals are simplified in this sketch.

plots of time series

Having selected the signals, you enter the time series plots shown in figure 32. The channel number and the instrument names are displayed in the top-left corner of each frame. The range for the y-axes may be adjusted after pressing **F2**, which will produce the menu shown on top of the graphics in figure 32. In this menu you may enter the range for each of the selected signal types. The number of displayed time series are limited to 16.

exit

You return to the previous screens and finally exit the program by pressing the **Esc** key.

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A collection of data from dense gas experiments

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Abstract (Max. 2000 char.)

As part of the CEC DG XII ENVIRONMENT project REDIPHEM, a database on dense gas dispersion experiments was created. This includes measurements from a) wind tunnel experiments carried out at the University of Hamburg, TNO, and Warren Spring Laboratory, and b) field experiments from the MTH BA and STEP Fladis projects, and four US Lawrence Livermore National Laboratory projects. The purpose and design of each experiment are described. A set of characteristic scales originally developed for isothermal dense gas releases is adopted, and extended also to characterize the non-isothermal releases of the field experiments. The database includes general descriptions of the gas releases, information on the instruments applied, sensor positions, and measured time series. The quality of the measurements and simple methods for data screening are discussed. It is described 1) how to inspect the collected information with a MS-DOS program distributed with the data, 2) how to access the data with user written programs, and 3) how to install more data sets.

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