Validation of ADMS in modelling short time scales

Christine McHugh

Cambridge Environmental Research Consultants

DMUG, 20 May 2004

CERC

Validation of ADMS in modelling short time scales

- Atmospheric turbulence
- ADMS fluctuations module
- Validation: Cement Works
- Validation: Fired heater stack
- Summary

CERC

Atmospheric Turbulence

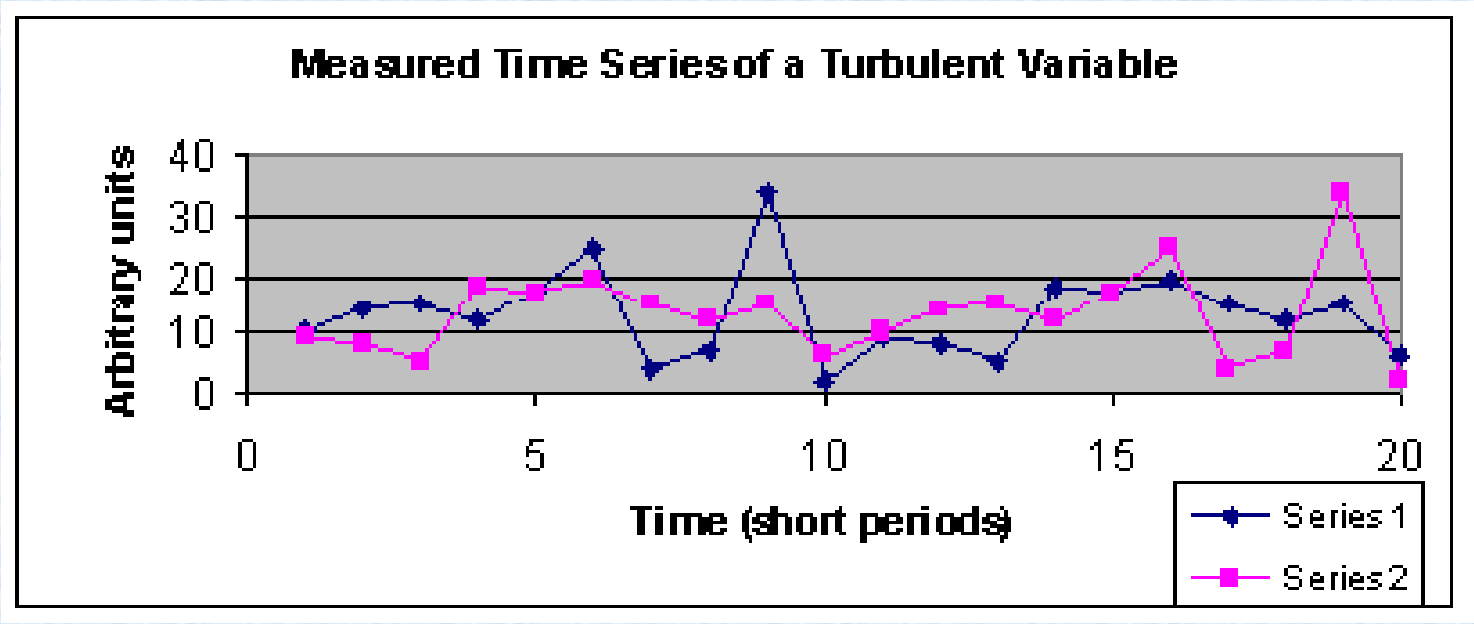
CERC

Atmospheric Turbulence

- The atmospheric boundary layer is a **turbulent** boundary layer
- If you measure at a fixed point and all the external conditions are constant (meteorology, source, topography), the measurements of wind speed, wind direction and concentration over a succession of short periods would not be constant
- e.g unsteadiness of a weather vane, high resolution measurements

CERC

Turbulence

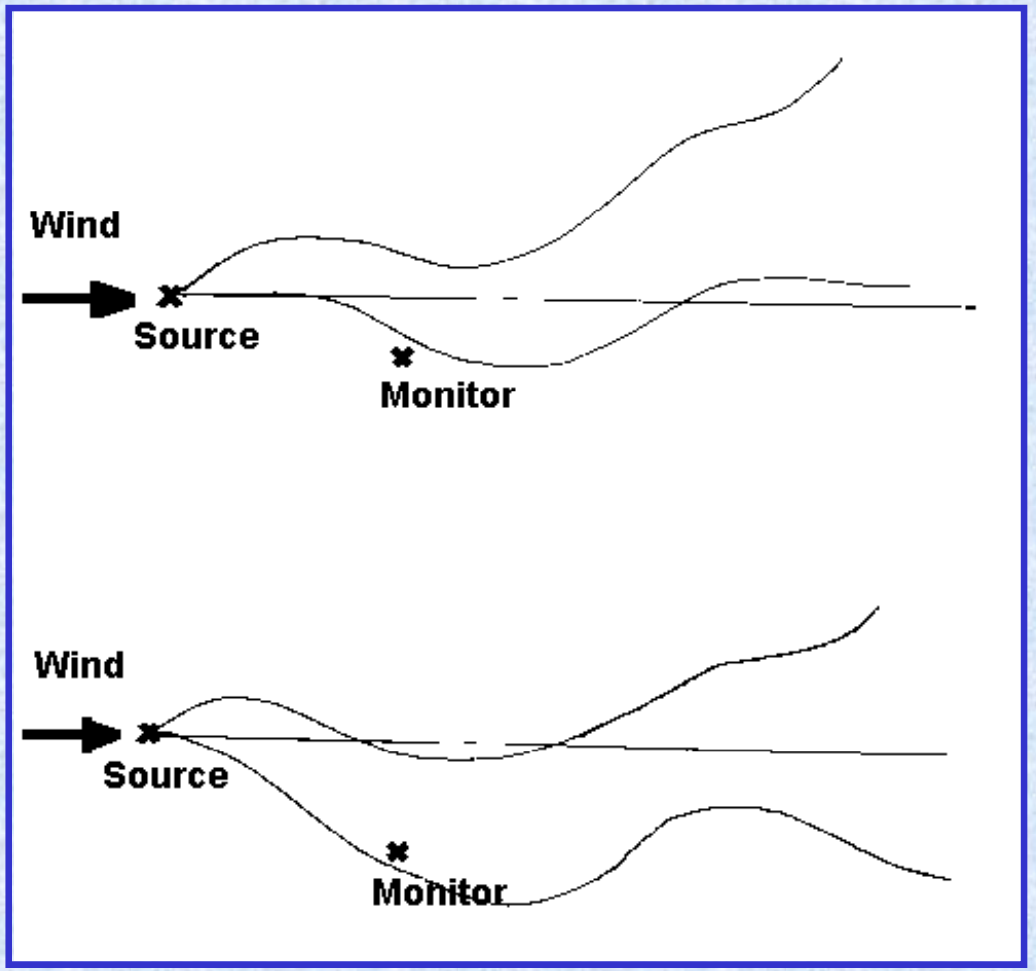


- Turbulent flows are usually described by statistical measures e.g. mean, standard deviation, percentiles
- Statistical measures can be constant whilst the details of turbulent flows vary
- These two time series contain the same 20 values and so have the same overall statistics, but the time series vary

CERC

Turbulence

- Boundary layer turbulence leads to **fluctuations in concentration** due to:
  - movement of the plume
  - inhomogeneities i.e. imperfect mixing within the plume

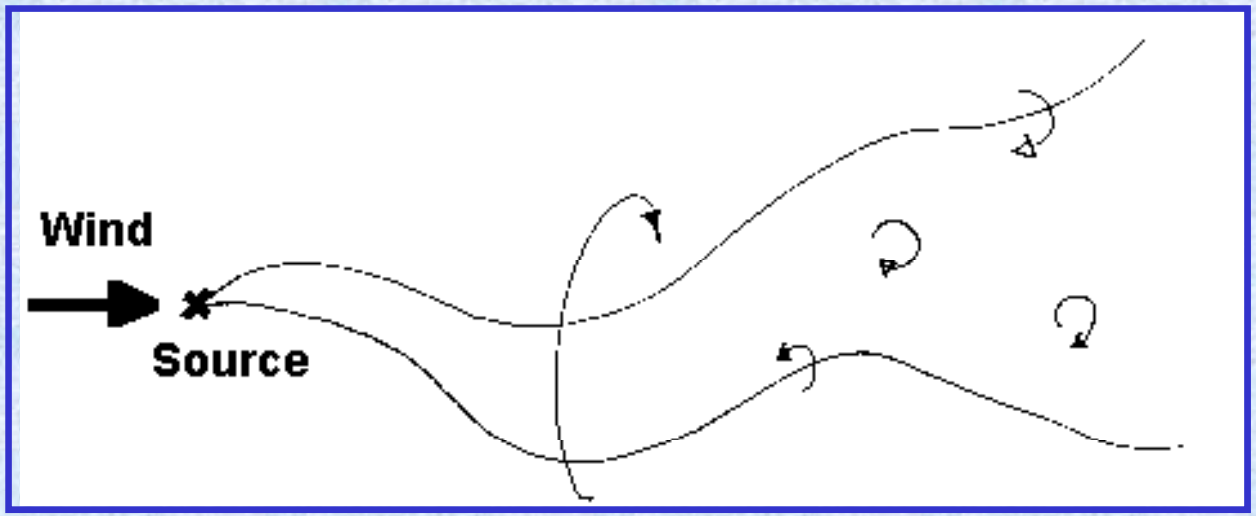


- Fluctuations are most evident over short time scales

CERC

Scales of Turbulence

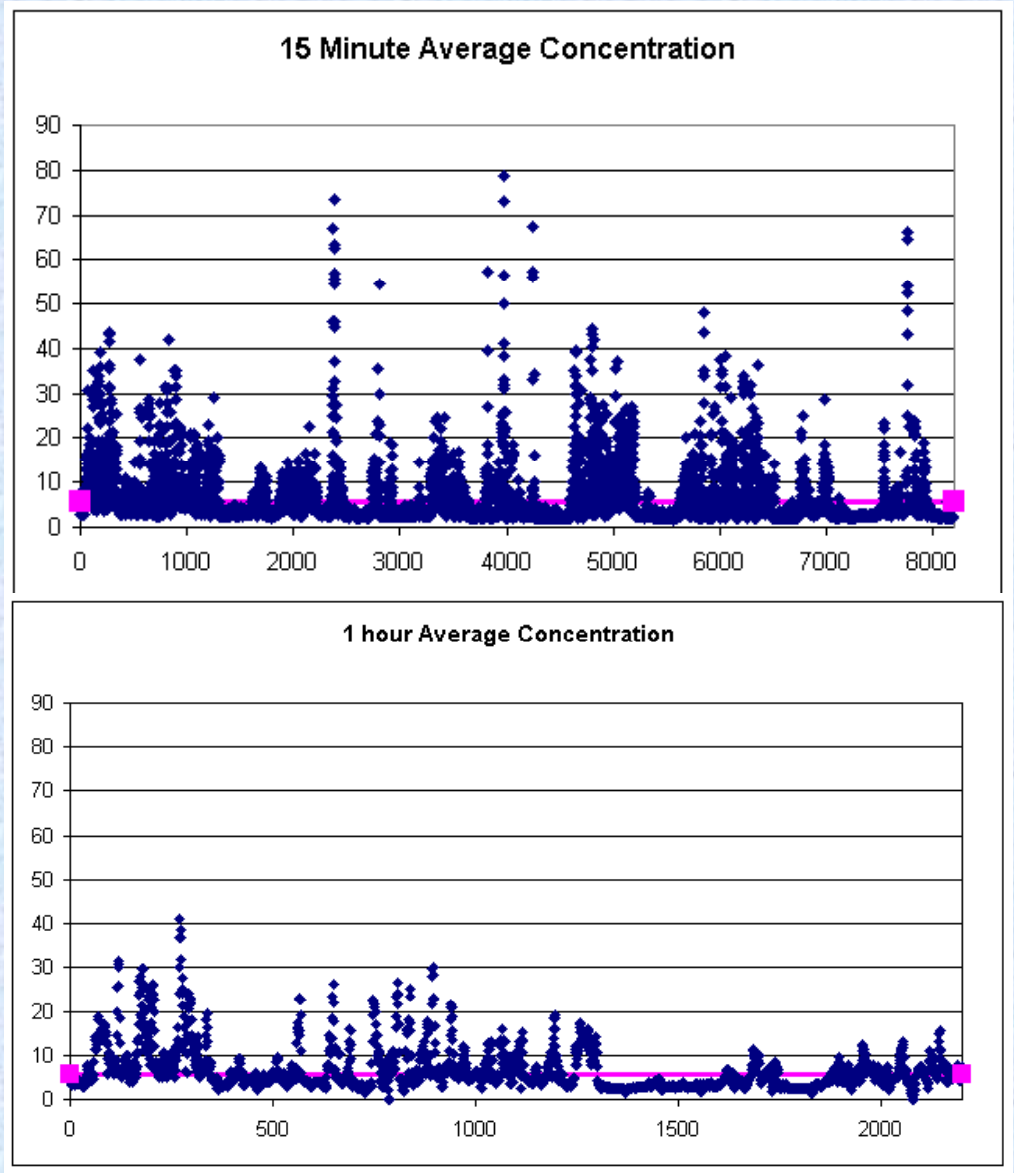
- there are different scales of turbulence - different sizes of turbulent eddies
- the larger eddies cause the plume to move
- smaller eddies cause mixing and widening of the plume
- the familiar “Bar-B-Q effect”



CERC

Compare 15 minute and hourly averages

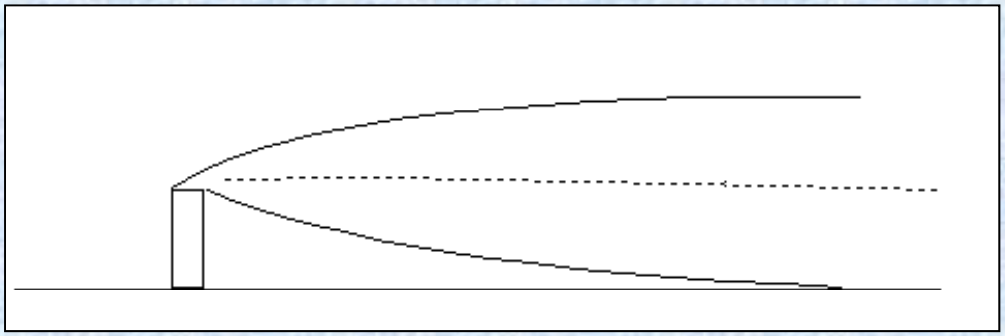
- Two plots show the same data, 15 minute averages (top) and hourly averages (bottom)
- The average of all readings is the same in both cases - of course (pink line)
- But, as the averaging time increases the peak values decrease
- Short time scale extreme events are “averaged out”



CERC

Ensemble Means

- Hourly average air quality standards have been taken as referring to **ensemble means,** although fluctuations are relevant for hourly averages

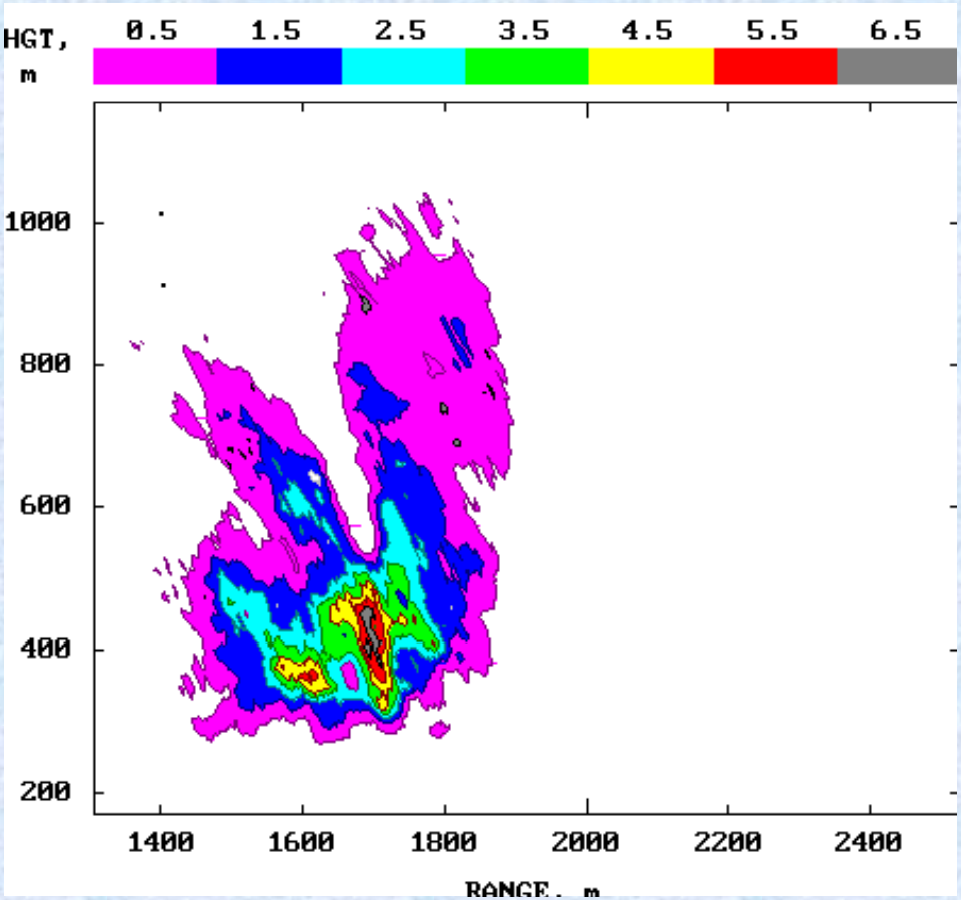


- An ensemble mean is the average over a very large number of measurements with identical external conditions
- Our classic view of a plume represents the ensemble mean. Experience shows that plumes vary, the time of variation depending on a number of factors
- Fuzzy line between what is meteorology and what is turbulence
- Regard changes on time scales greater than 1/2 hour as meteorology
- Regard changes on time scales less than 1/2 hour as turbulence

CERC

LIDAR Image

- Cross-section of a plume from an oil-fired power station taken with a rapid-scanning LIDAR in July 1991.
- Mean of 200 scans over 30 minutes
- Colours indicate concentration levels

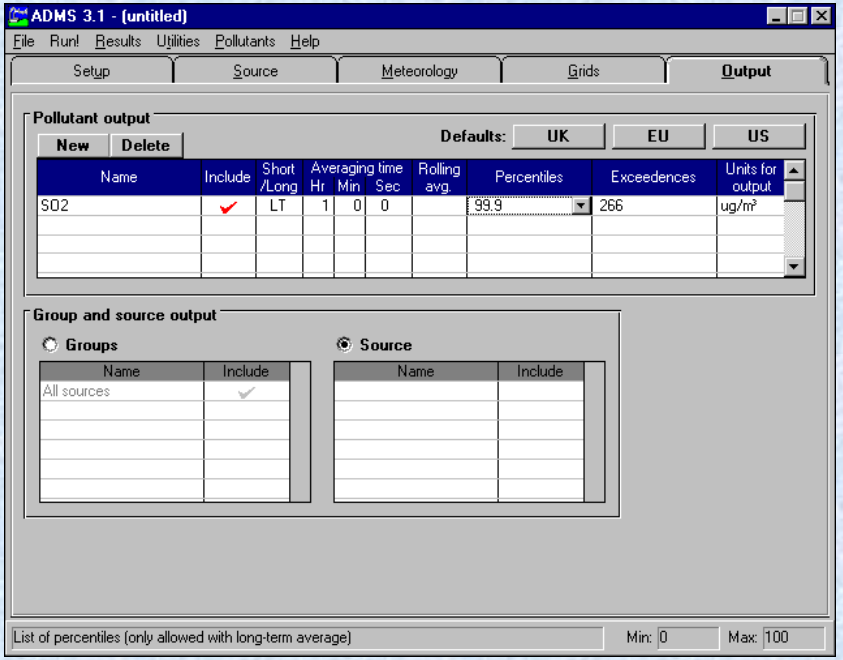


Vaidation of the ADMS Dispersion Model and Assessment of its Performance Relative to R-91 and ISC using Archived LIDAR data.(DoE/HMIP)/RR/95/022)

CERC

How can we model this uncertainty?

- Approaches such as changing the ensemble mean averaging time or using ratios are an attempt to predict the higher peak values that are expected for shorter averaging times
- But, fluctuations depend on: **meteorology, height in the boundary layer, downstream distance from the source, crosswind distance from the source**



- ADMS fluctuations module takes these factors into account and models not just the effect on peak values.
- Modelling fluctuations can predict fewer exceedences of a given value than an ensemble mean approach

CERC

ADMS Fluctuations Module

CERC

ADMS Fluctuations Module

- Based on a “two particle dispersion” concept but has much in common with Gifford’s meandering plume model
- Calculates fluctuations in concentration due to boundary layer turbulence and plume “meandering” – all other met variables are assumed constant
- Uses a clipped normal distribution for the probability of exceeding given concentrations
- Reference: Dyster SJ, Thompson DJ, McHugh CA and Carruthers DJ. (1999) Turbulent Fluctuations And Their Use in Estimating Compliance Standards And In Model Evaluation. International Journal of Environment and Pollution (Volume 16, Nos. 1-6, 2001)

CERC

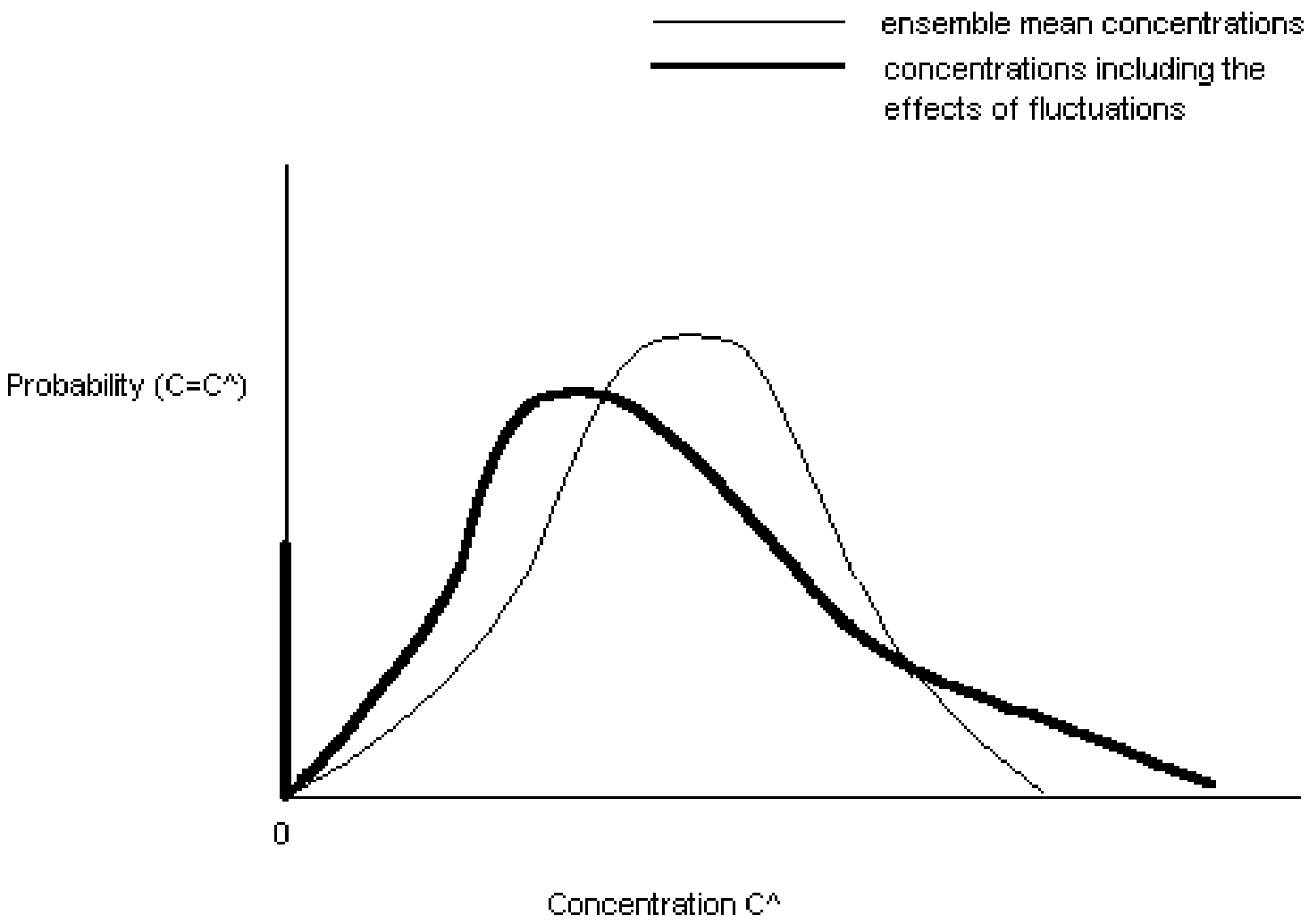
ADMS Fluctuations Module

- The fluctuations averaging time may range from 0 seconds to 1 hour
- Models anisotropic sources, multiple sources
- Model output:
  - Standard deviation of concentration
  - Short term percentile concentrations
  - Probability of exceeding thresholds - single met condition or multiple met conditions e.g. 1 year
  - Ensemble mean of concentration to the power p_{dose} (for exposure to toxic substances)

CERC

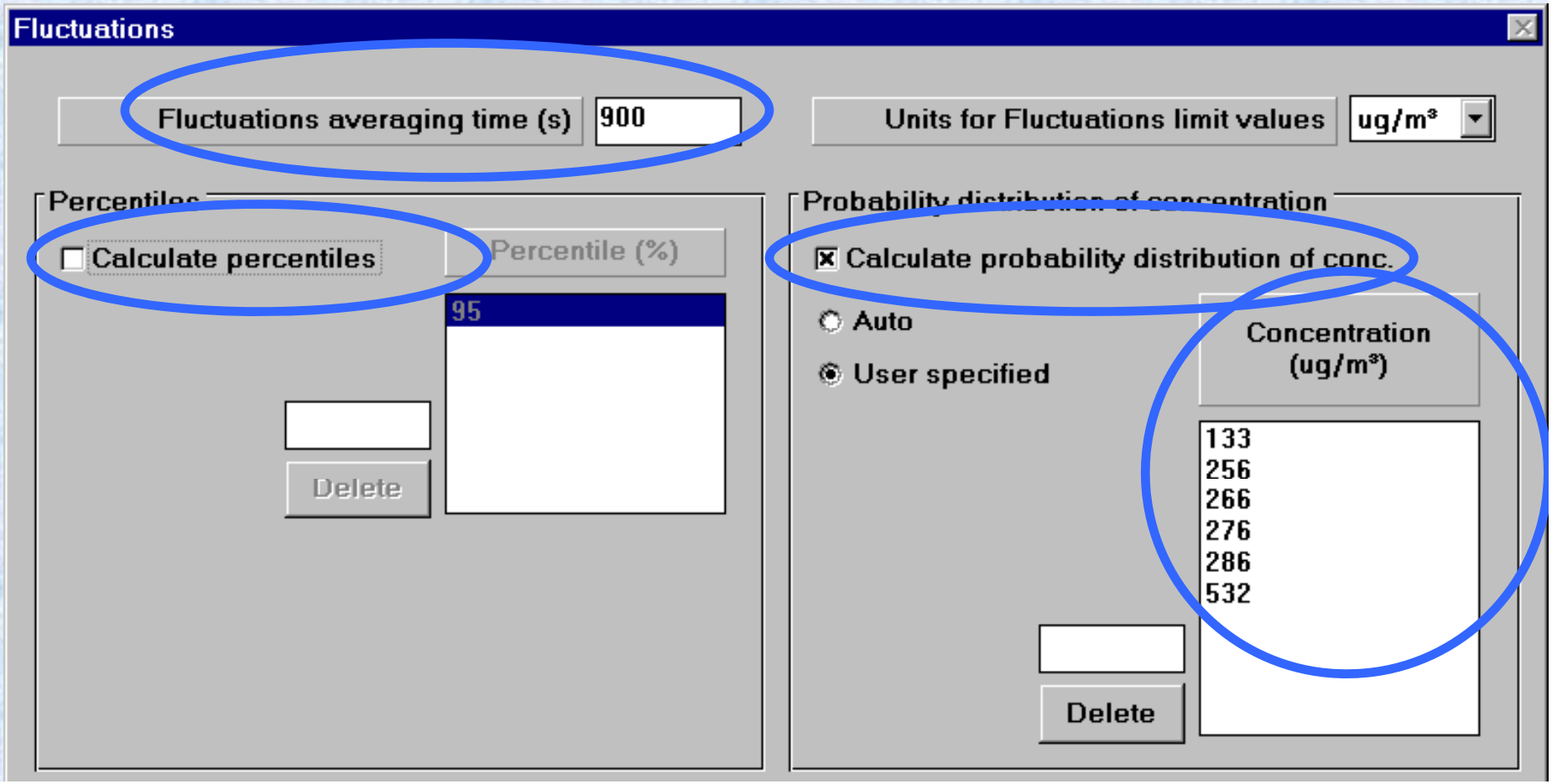
ADMS Fluctuations Module

- Clipped normal distribution for probability of exceeding given concentrations



ADMS Fluctuations Module

- Set the ensemble averaging time equal to 1 hour - the time over which the met data were measured
- Select the fluctuations option and set the fluctuations averaging time



Validation: Cement Works

CERC

Validation: Cement Works

- Two kiln stacks
- Undertaken for Environment Agency
- Modelled concentrations compared with monitored data obtained by the National Physical Laboratory (NPL)
- Measured 1 minute averages were supplied as 1 minute and 10 minute average values
- Short monitoring campaign

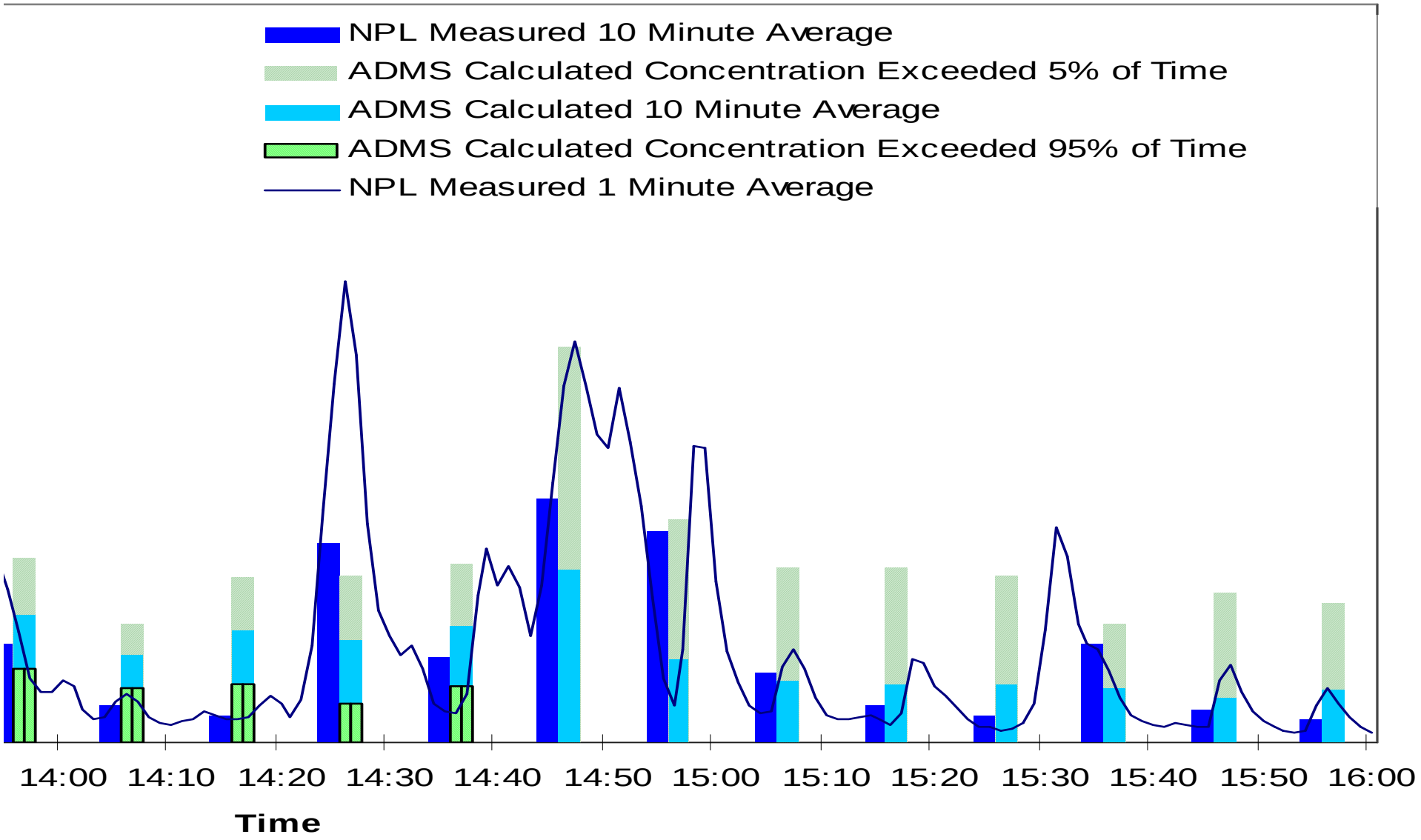
CERC

Validation: Cement Works

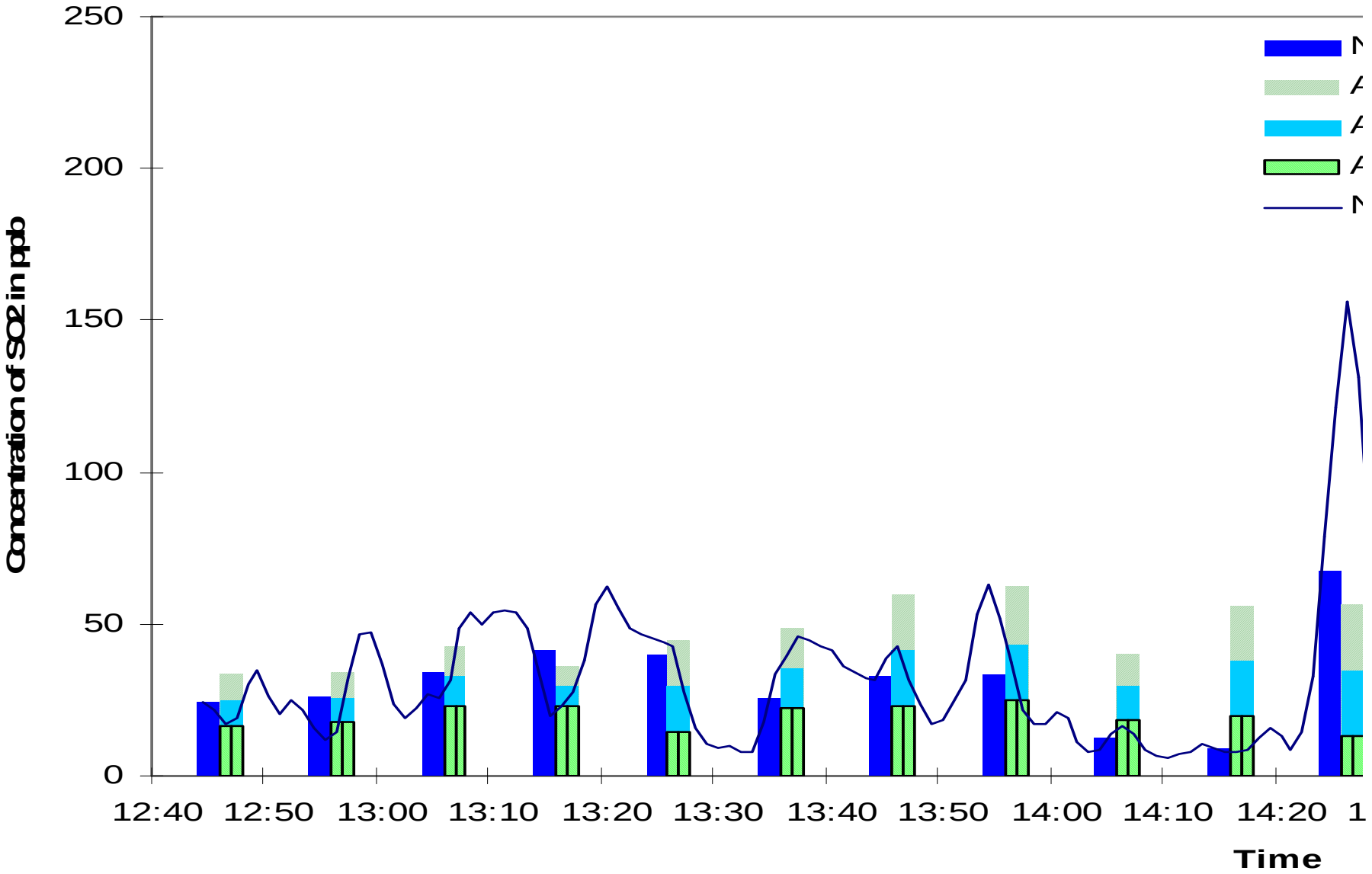
- Monitored 1 and 10 minute averages compared with modelled values of:
  - 10 minute ensemble mean
  - 1 minute concentration exceeded 5% of the time (peak 1 minute concentrations)
  - 1 minute concentration exceeded 95% of the time (low 1 minute concentration)
- The 5th and 95th percentile 1 minute concentrations give a good indication of the range of measured 1 minute concentrations.
- Measured and predicted 10 minute average concentrations agree fairly well – but the peak values are under-estimated

CERC

Validation: Cement Works



Validation: Cement Works



Validation: Fired Heater Stack

CERC

Description of study

- Consultees/expert witness to Environment Agency for public inquiry
- Examining odour impact from a fired heater stack at Petrus Oils Ltd near Stoke-on-Trent
- Site details:
  - surface roughness = 0.5m corresponding to parkland/open suburbia
  - Hill south east of site, ground rises 35m but terrain effects were investigated and found to be minor

CERC

Description of study

- Stack height = 13 m
- Emission conditions assume 95% combustion of effluent gases
- Emission rate = 24240 OU/s
- Grid resolution of 10m to capture maximum concentrations
- Odour nuisance occurs between 2 and 10 ou/m^3, greater nuisance above 10 ou/m^3

CERC

Site photo

CERC

Background to the study

- Modelling showed no exceedence of the SO_2 annual average objective (15-23ppb) nor the 99.9th percentile of 15 minute averages objective (100ppb).
- Maximum concentrations were predicted within 100m of the site
- Monitored annual average concentrations were around 8ppb of SO_2
- Yet – odour complaints were received from residents almost 300m away
- Complaints came from a variety of locations and a variety of residents – not just those most sensitive

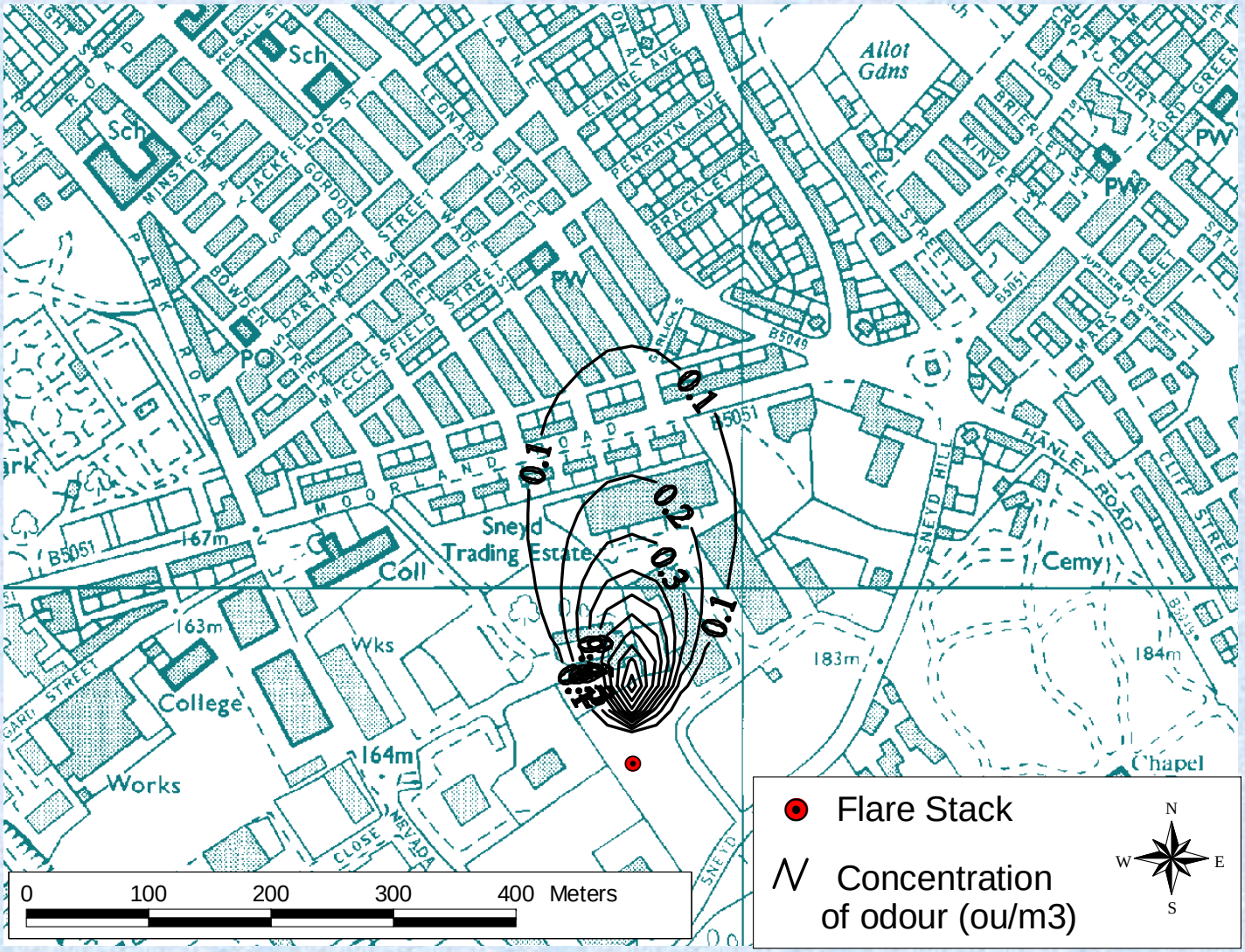
CERC

Methods of assessing odours with ADMS

- **Approach 1:**
  - Calculate highest hourly average concentration
- **Approach 2:**
  - Use fluctuations module to calculate peak concentrations for short time average e.g. 1 minute or 1 second
- **Approach 3:**
  - Calculate 95th percentile of 4 second average (using fluctuations option) - gives indication of exceedences of high levels

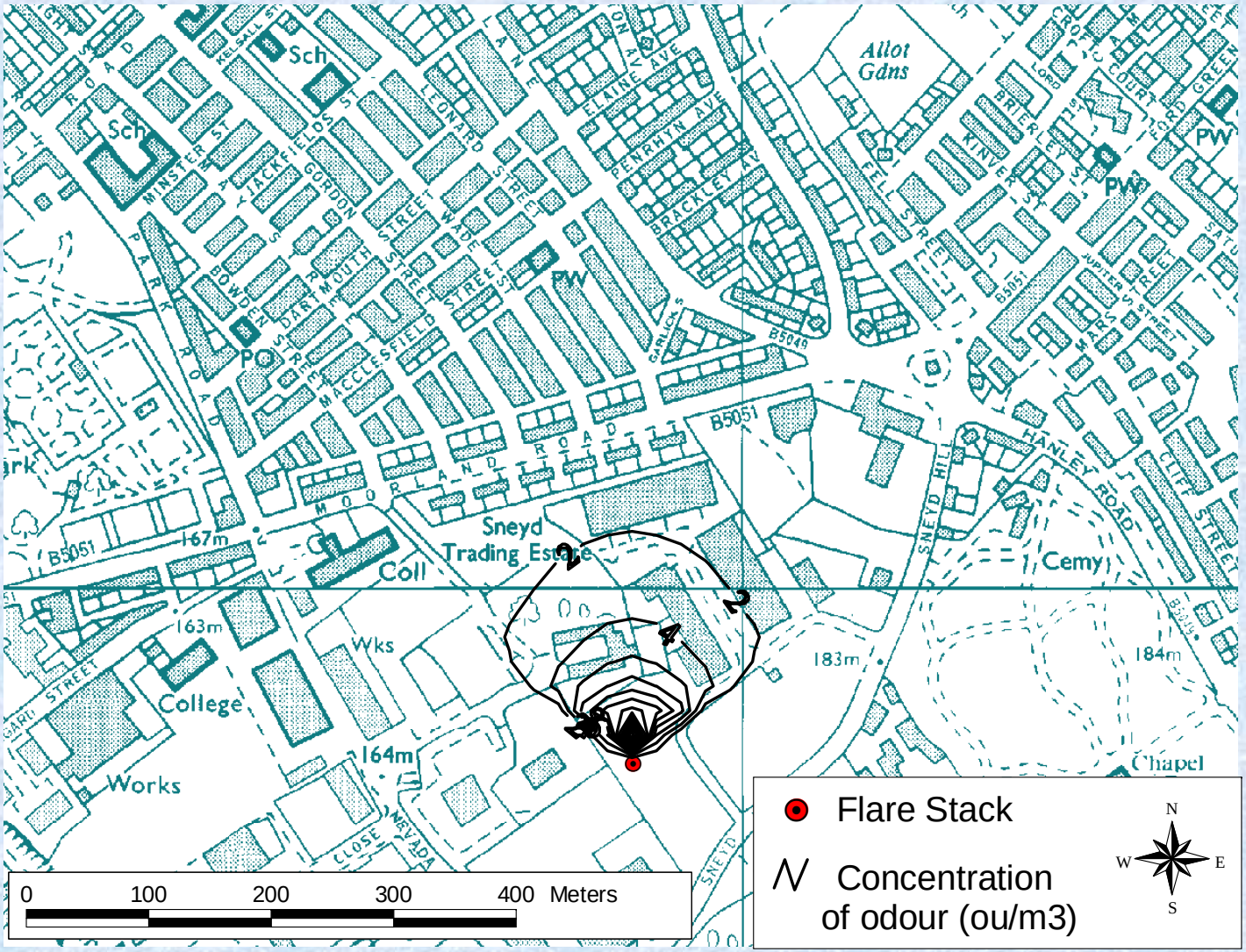
CERC

1 hour average (Slightly convective)



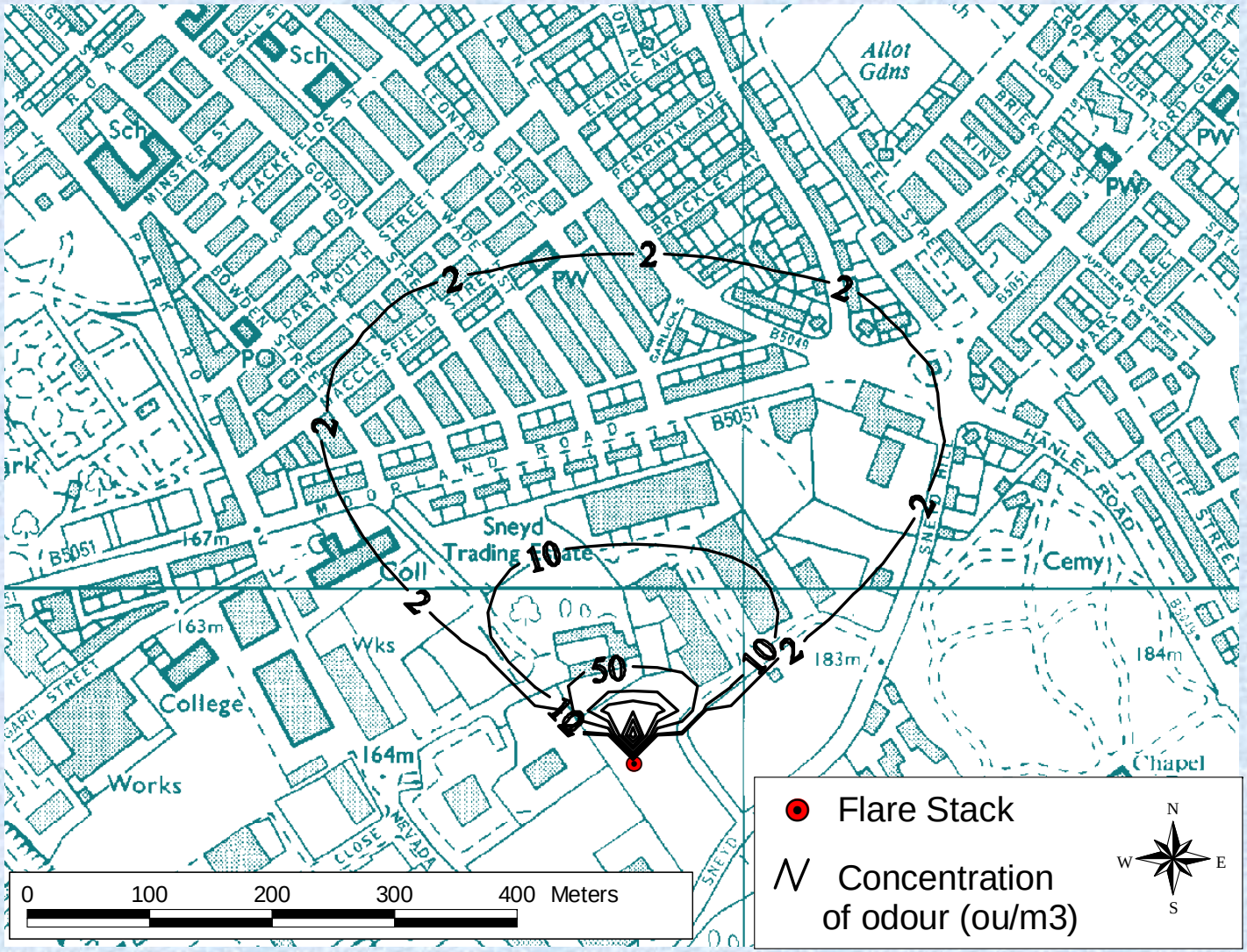
CERC

1 minute peak (Slightly convective)



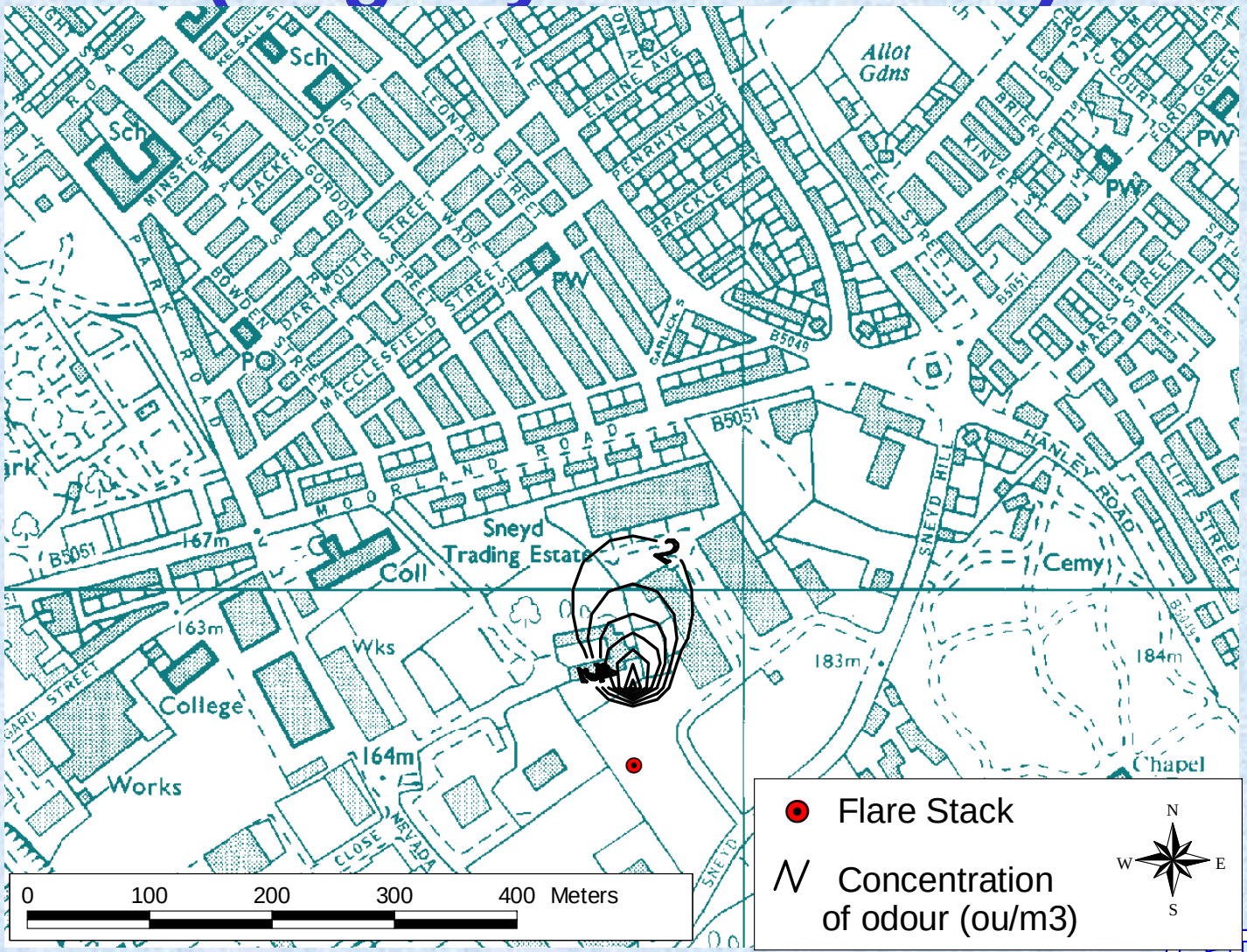
CERC

1 second peak (Slightly convective)



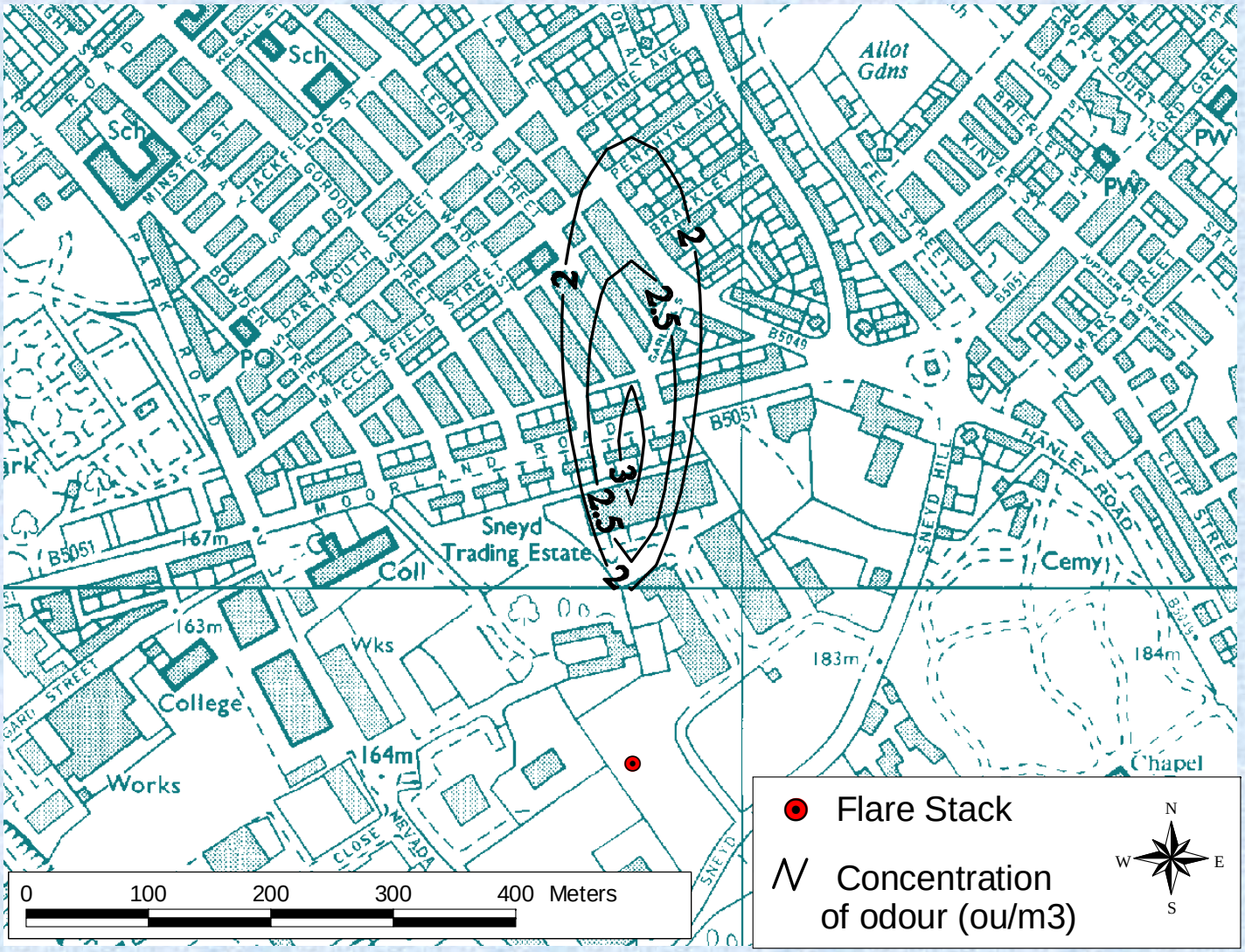
CERC

95% percentile of 4 sec average (Slightly convective)



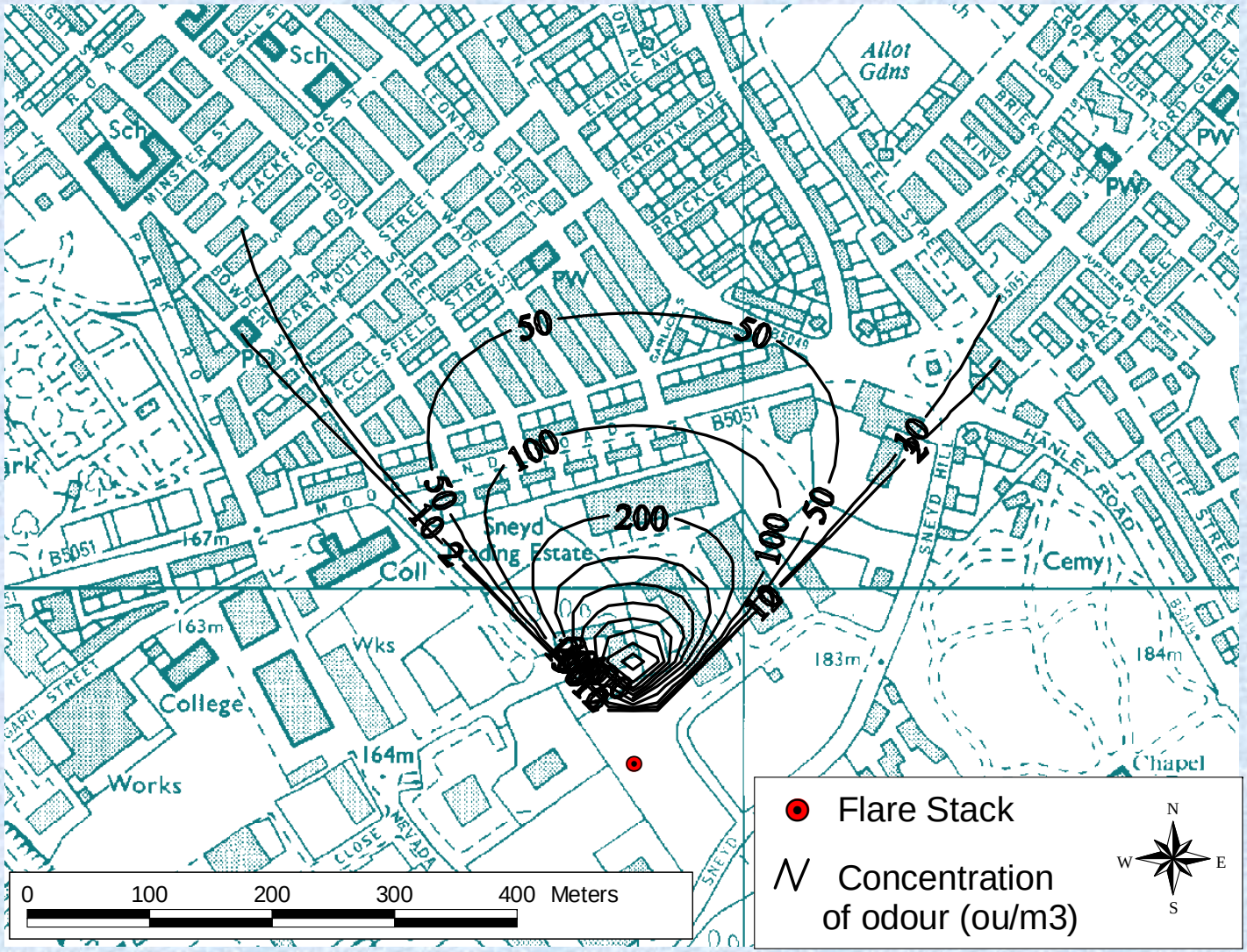
CERC

1 hour average (Stable)



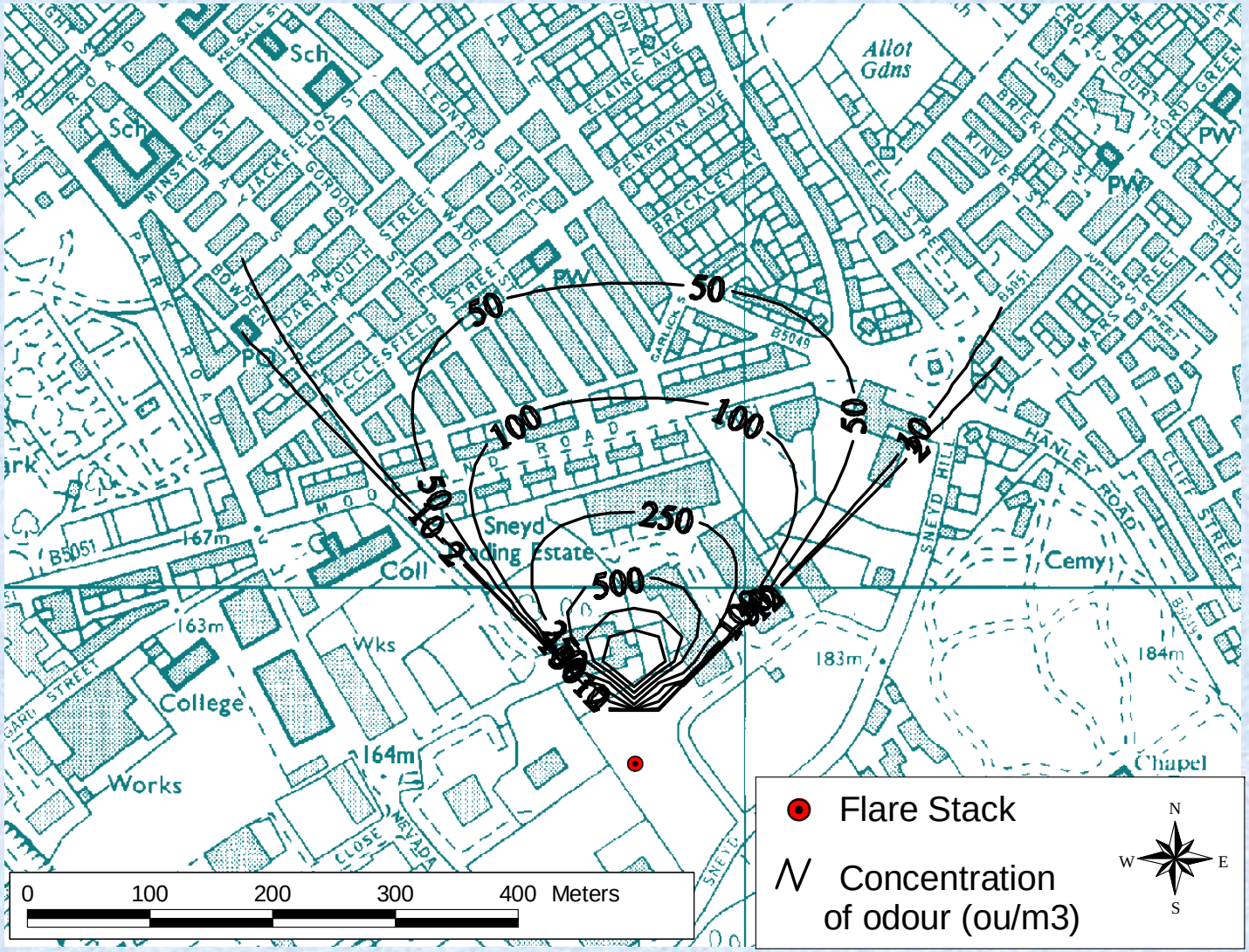
CERC

1 minute peak (Stable)



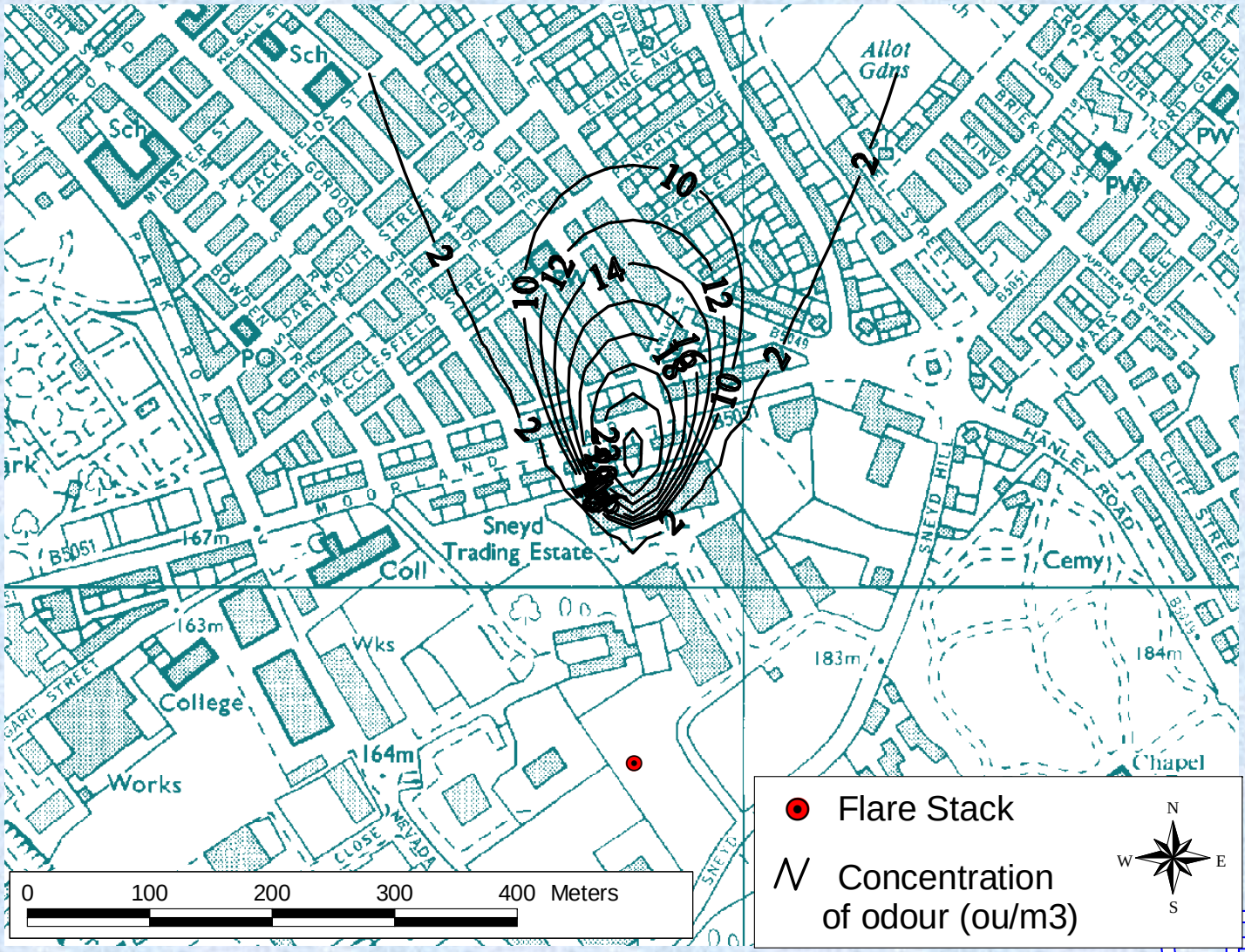
CERC

1 second peak (Stable)



CERC

95 percentile of 4 second average (Stable)



CERC

Validation: Heater Stack

- Hourly averages under-estimate odour nuisance as the short time scales are not resolved
- 1 second peak values are useful where short time scale peaks cause acute nuisance
- 1 minute peak values or 95th percentiles of 4 second averages are more representative for odour nuisance

CERC

Summary

CERC

Summary 1

- Flow field turbulence leads to fluctuations in concentration
- The fluctuations depend on several factors: meteorology, height in the boundary layer, downstream distance from the source, crosswind distance from the source
- It is important to model the effect of these different factors
- **Neglect of fluctuations will underestimate peak values**

CERC

Summary 2

- In addition to air quality objectives and limits with short averaging times (15 minute AQS, 10 minute WHO) it is often important to be able to assess accurately short duration high concentrations:
  - Flammability
  - Chemical reactions
  - Toxicity
- Modelling of fluctuations due to atmospheric turbulence is possible and should be used when modelling short time scales.

CERC