



# Assessing the meteorological uncertainties in dispersion forecasts using NWP Ensemble Prediction Systems

Andrew Jones, UK Met Office

*11th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Cambridge, 2-5 July 2007*

Uncertainty in dispersion forecasts

Ensemble dispersion prediction

- NAME III Lagrangian dispersion model
- ECMWF Ensemble Prediction System

Ensemble dispersion products

Case study: ETEX 1 tracer experiment

Future work

Summary

# Uncertainty in dispersion forecasts

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A **deterministic approach** is usually adopted in many dispersion applications:

- emergency-response modelling
- impact assessment studies

... but ...

**Uncertainty in dispersion predictions** caused by:

- errors and limitations of dispersion models
- uncertainty in the inputs to these models

**Meteorology** – synoptic-scale; meso-scale; local effects (e.g. topography, buildings)

**Source term** – source strength; release height; release nature (e.g. buoyant or dense gases); species mixture (chemistry, radiological properties)

**Dispersion model limitations** – model resolution (Eulerian model); particle numbers (Lagrangian model); advection-diffusion schemes; in-situ transformations (chemistry, etc.)

**Fluctuations at short-range** – response time (averaging time) of “receptor”; nature of release (explosive/flammable substances; impacts on toxicity, chemical reactions; biological agents)

Atmosphere is chaotic system

Sensitivity to initial state – the ‘butterfly effect’

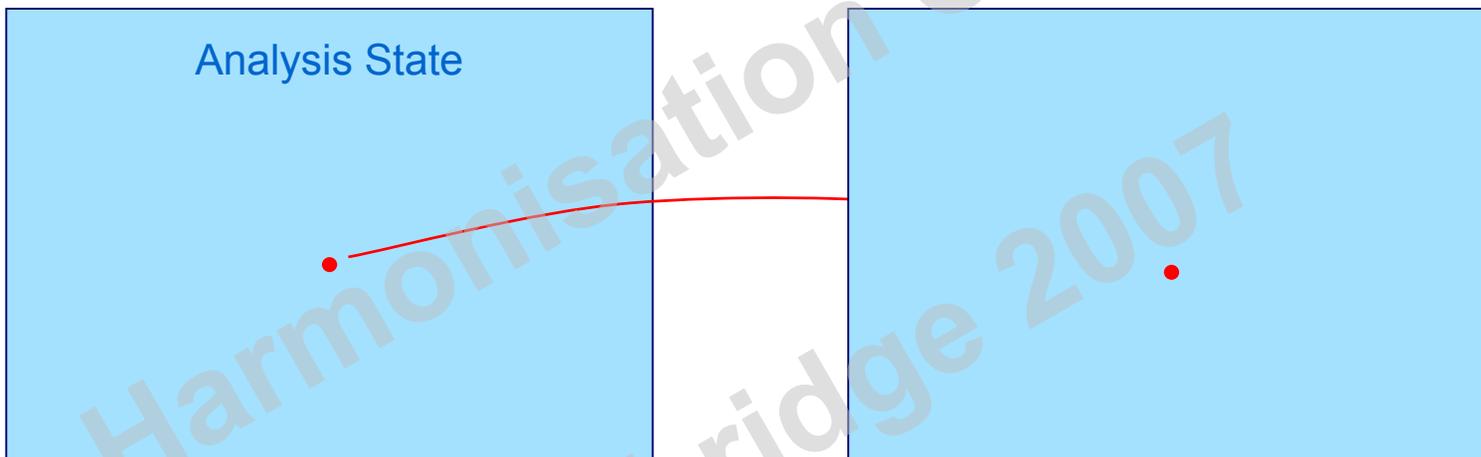
→ limit on predictability

Ensemble approach aims to estimate uncertainties in met forecast by sampling phase-space of possible evolutions

# NWP Ensembles – An Overview

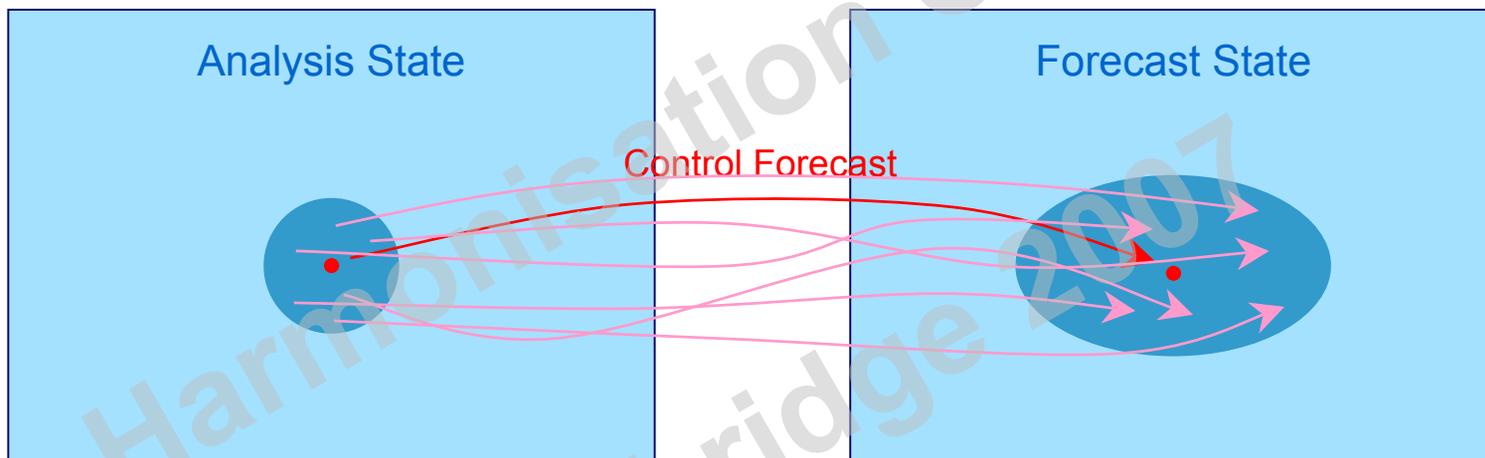


Deterministic prediction



# NWP Ensembles – An Overview

## Ensemble prediction



Gives quantitative measures of uncertainty in the model forecast

- degree of confidence in the forecast
- range of possible outcomes
- extreme forecast solutions

# Ensemble Dispersion Prediction

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NAME III is our operational atmospheric dispersion model

## Lagrangian particle model

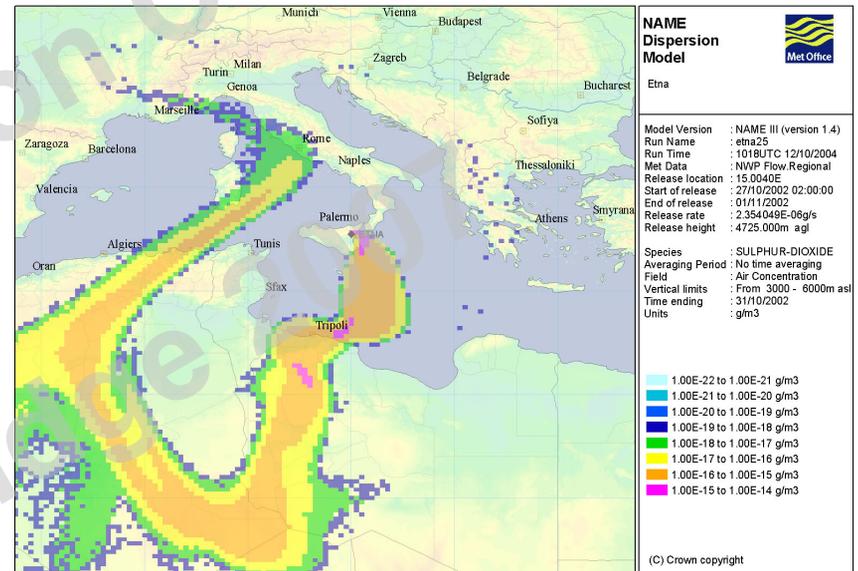
### Stochastic trajectories

- particles advected by mean flow
- + random-walk scheme for turbulent motions

### Many processes represented, including

- plume rise (buoyant/momentum-driven releases)
- radioactive decay (radionuclides)
- virus decay (biological species)
- chemical transformation (sulphur/nitrogen/hydrocarbons)
- dry and wet deposition

- puff scheme for use at short ranges (presentation by David Thomson)
- capability to run using 3-d NWP meteorological fields or single-site meteorology
- used operationally for emergency-response (nuclear accidents, volcanic eruptions, etc.)
- also research applications



## Operational global ensemble forecasting system run at the European Centre for Medium-Range Weather Forecasts (ECMWF)

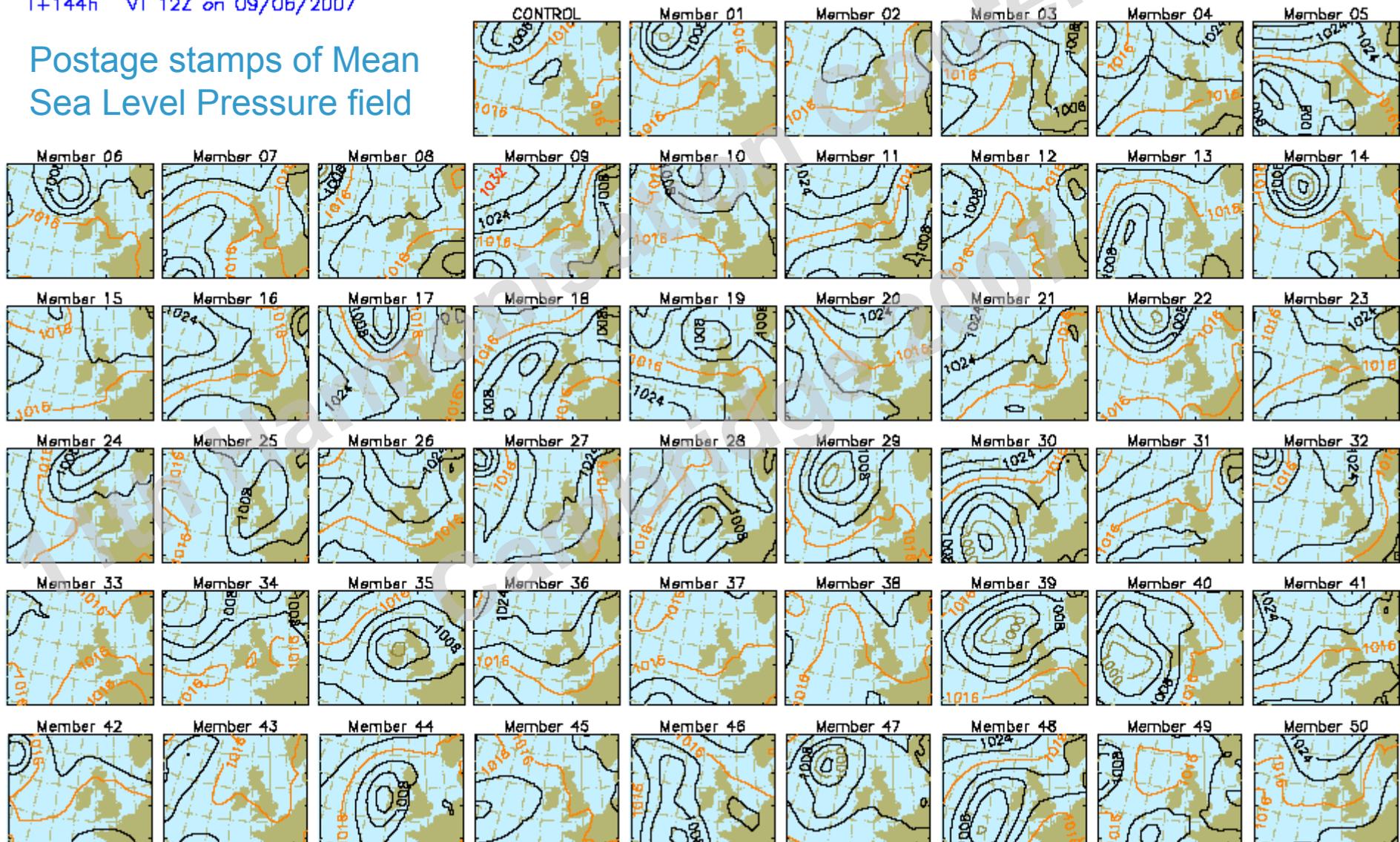
- ECMWF Ensemble Prediction System, VarEPS, produces a twice daily 51-member ensemble:
  - control forecast
  - 50 perturbed forecasts
- Initial condition perturbations based on singular vector method (fastest growing modes of growth in forecast error during early part of forecast)
- Stochastic parametrisation schemes perturb physical tendencies (to represent model errors and sub-grid scale uncertainties)

# ECMWF Ensemble Prediction System



T+144h VT 12Z on 09/06/2007

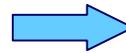
## Postage stamps of Mean Sea Level Pressure field



# Putting the systems together ...

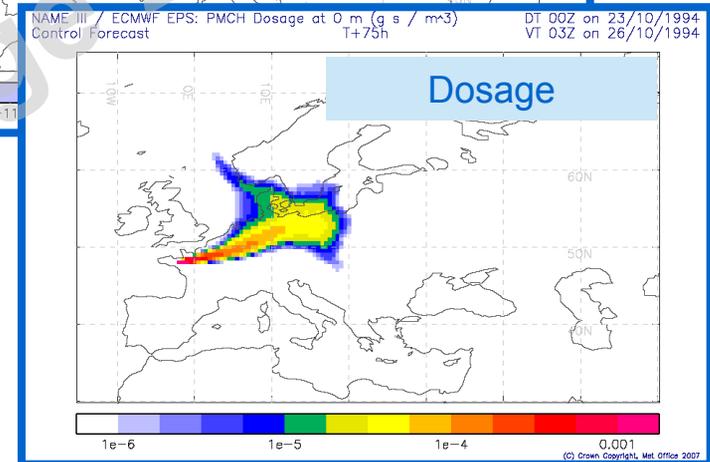
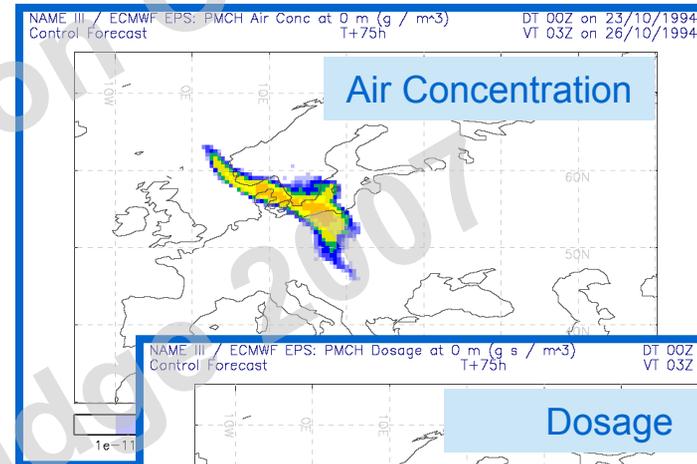
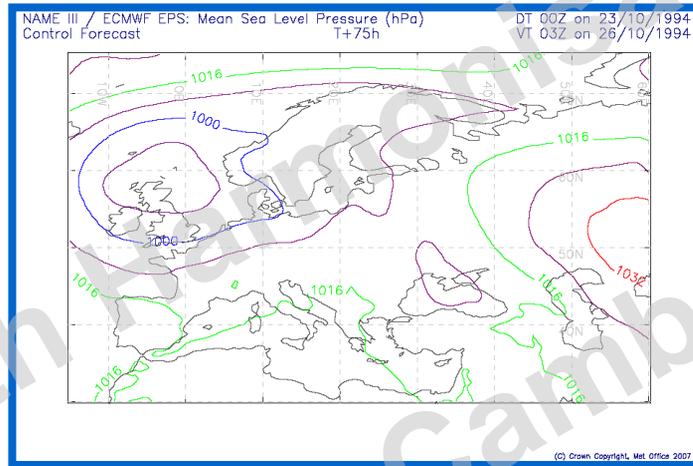
NAME III

Meteorology



Dispersion Prediction

Control  
Forecast



+ 50 ensemble members ...

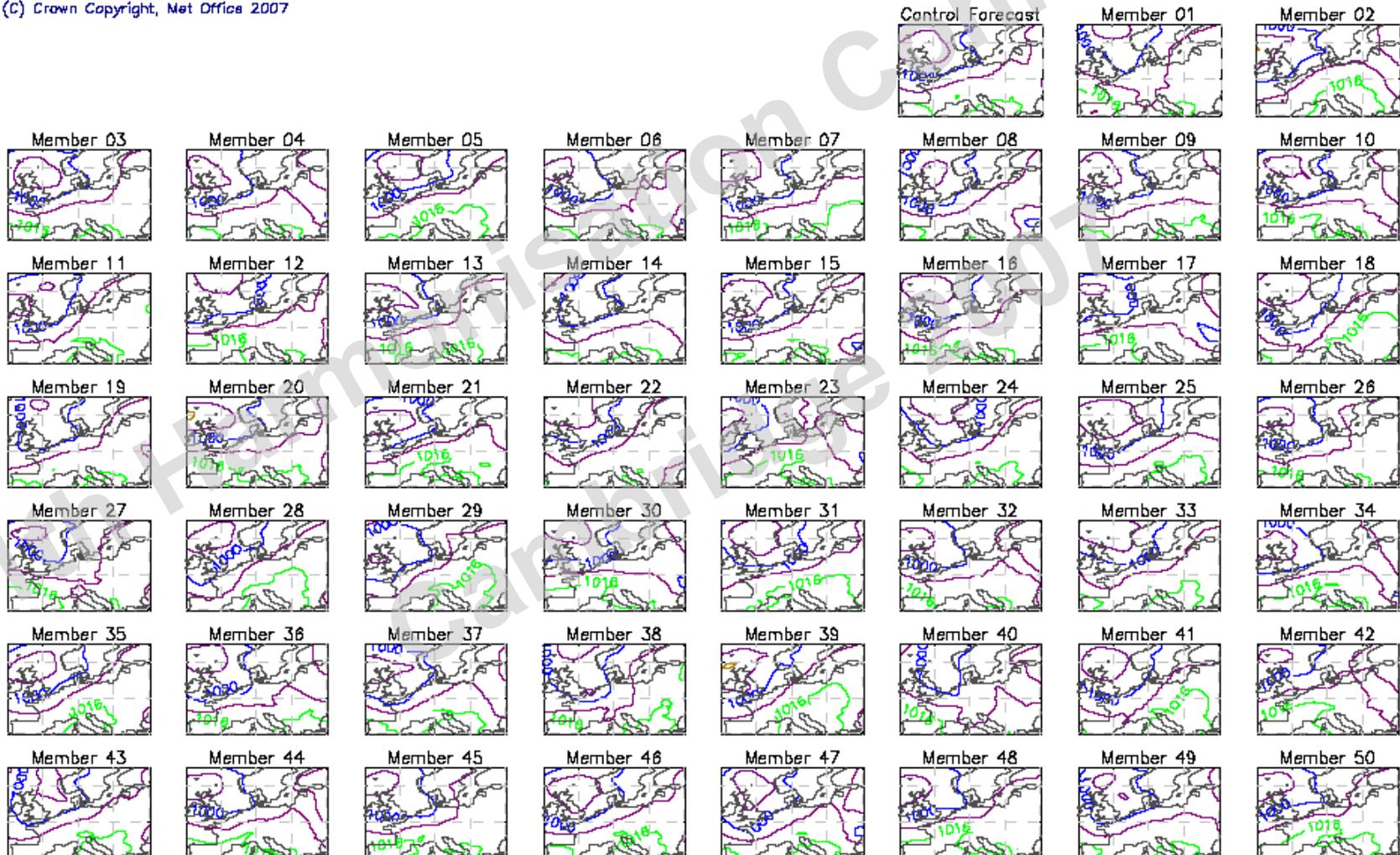
# 51 Meteorological Forecasts ...



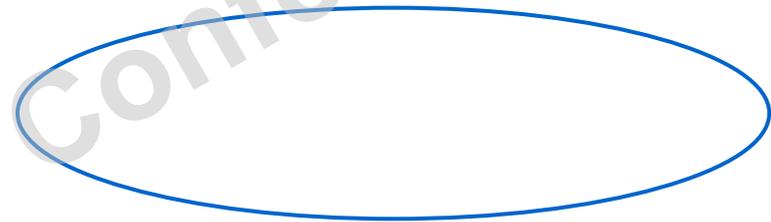
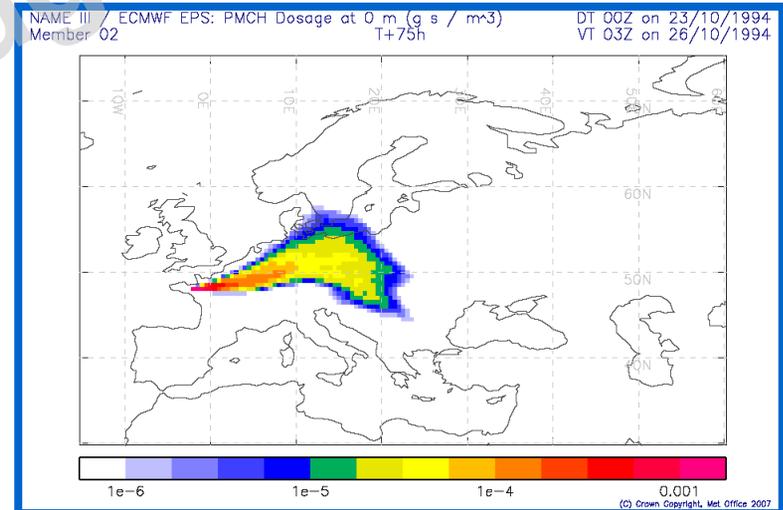
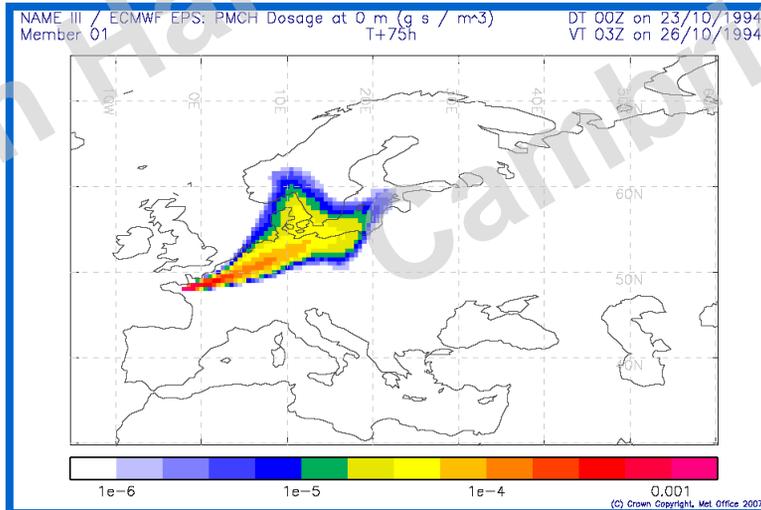
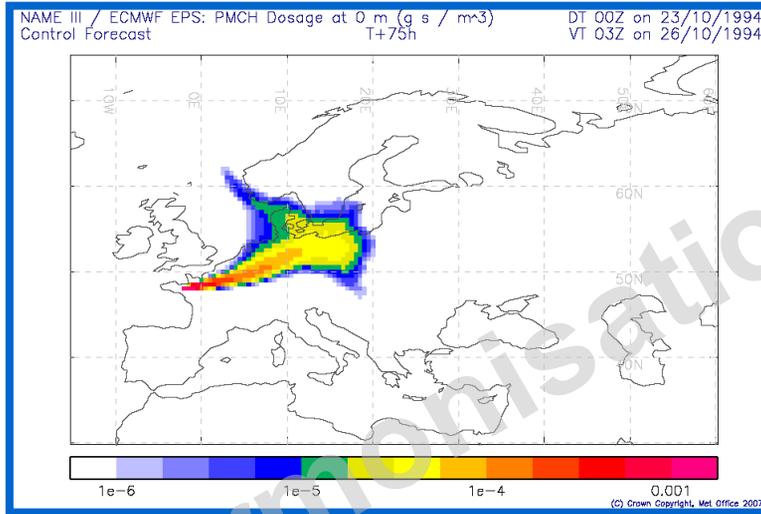
NAME III / ECMWF EPS: Mean Sea Level Pressure (hPa)  
All Members  
T+75h

DT 00Z on 23/10/1994  
VT 03Z on 26/10/1994

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# ... give 51 Dispersion Predictions!



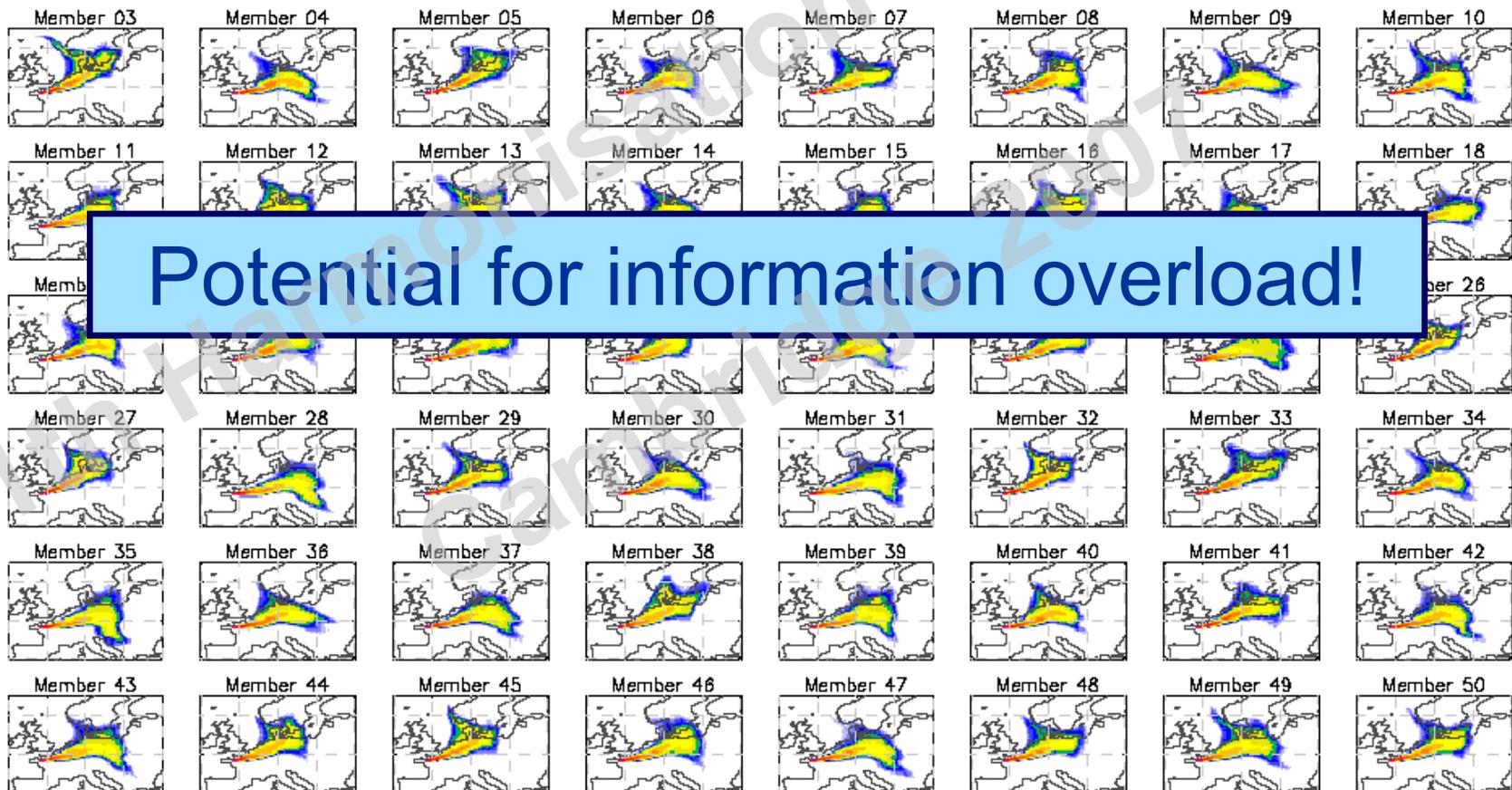
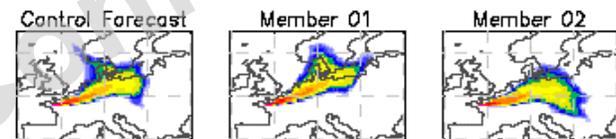
# ... give 51 Dispersion Predictions!



NAME III / ECMWF EPS: PMCH Dosage at 0 m ( $\text{g s} / \text{m}^3$ )  
All Members  
T+75h

DT 00Z on 23/10/1994  
VT 03Z on 26/10/1994

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# Ensemble Dispersion Products

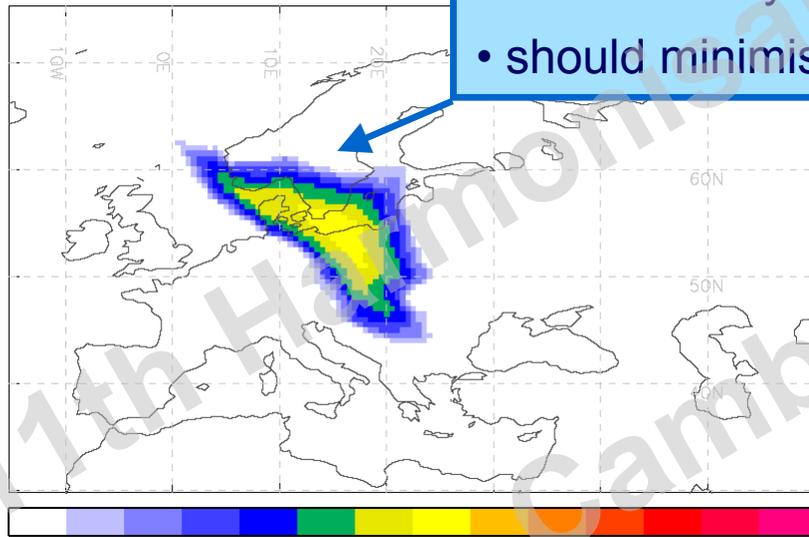
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# Ensemble Mean

Mean evaluated over all ensemble members

- highlights potential impact areas
- influenced by low-
- should minimise r

NAME III / ECMWF EPS: PMCH Air Conc at 0 m (g / m<sup>3</sup>)  
Ensemble Mean

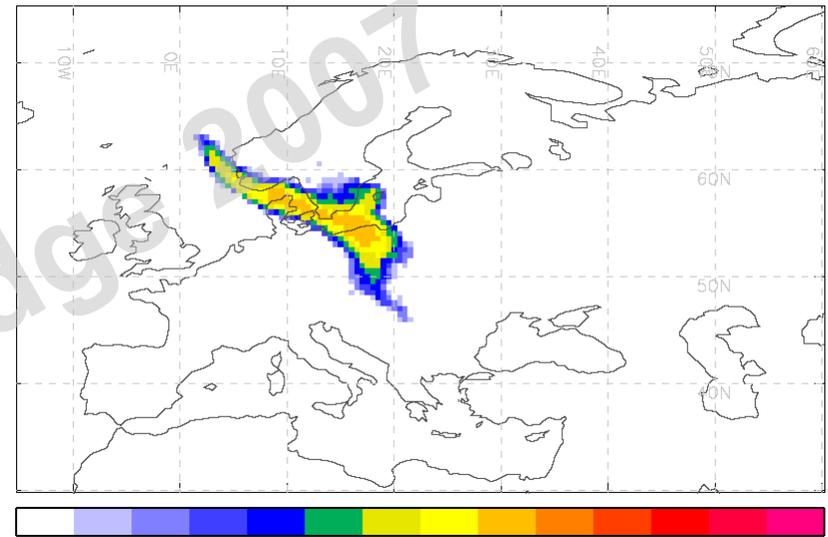


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Ensemble Mean

NAME III / ECMWF EPS: PMCH Air Conc at 0 m (g / m<sup>3</sup>)  
Control Forecast

DT 00Z on 23/10/1994  
VT 03Z on 26/10/1994



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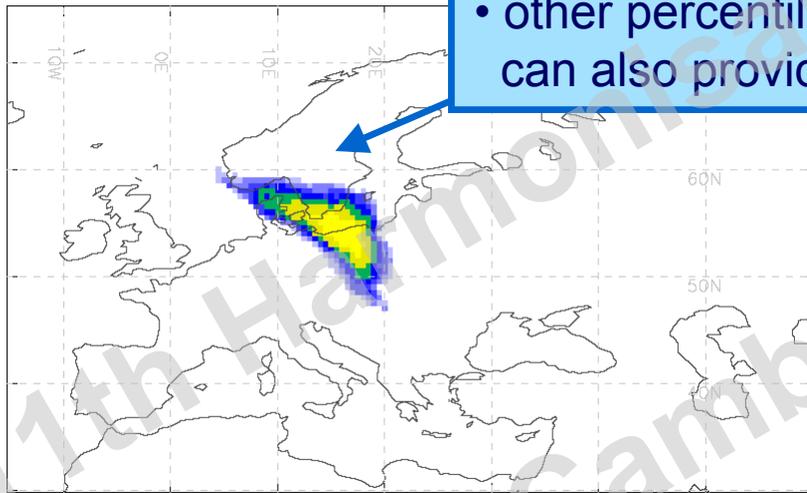
Control

# Ensemble Median

Median (i.e. 50<sup>th</sup> percentile) evaluated over all ensemble members

- identifies core impact areas
- filters out 'noise' of outliers
- other percentiles (min, max, etc.) can also provide useful information

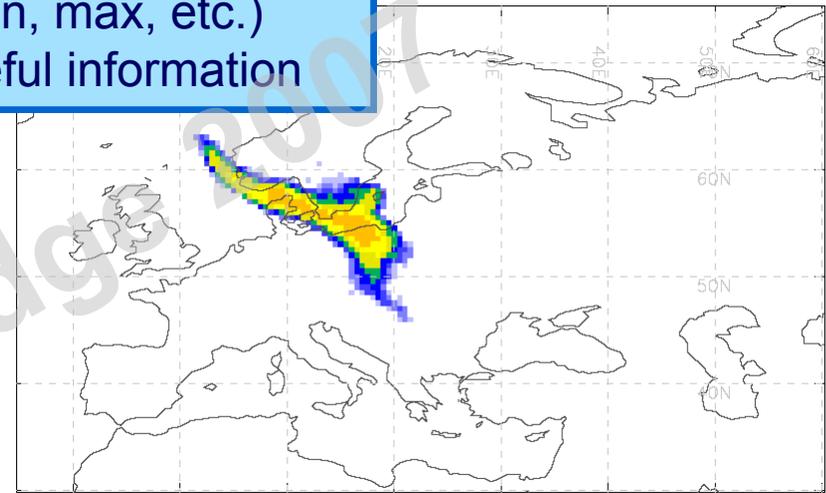
NAME III / ECMWF EPS: PMCH Air Conc at 0 m (g  
Percentile: 50  
T+75h



1e-11 1e-10 1e-9 1e-8  
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Ensemble Median

0 m (g / m<sup>3</sup>)  
T+75h  
DT 00Z on 23/10/1994  
VT 03Z on 26/10/1994



1e-11 1e-10 1e-9 1e-8  
(C) Crown Copyright, Met Office 2007

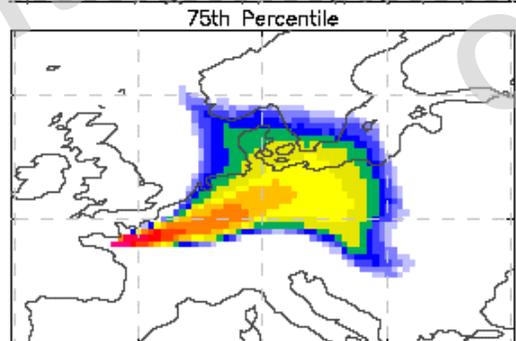
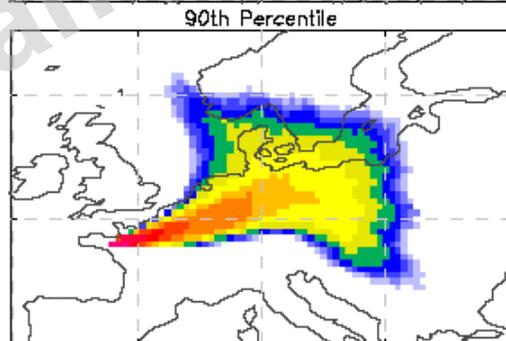
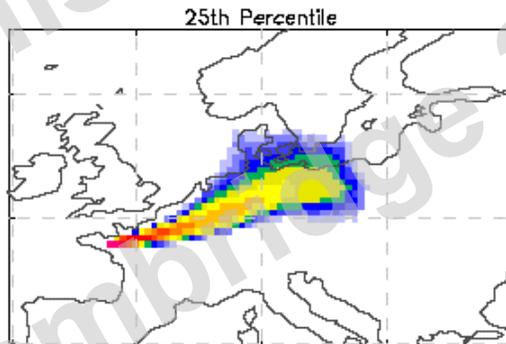
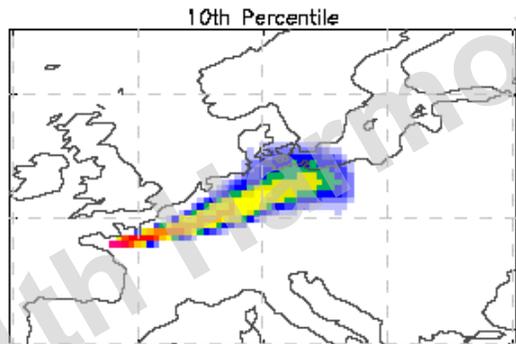
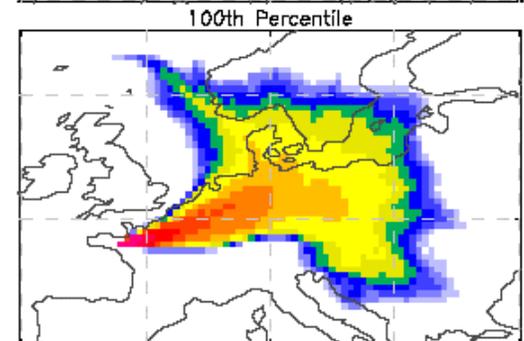
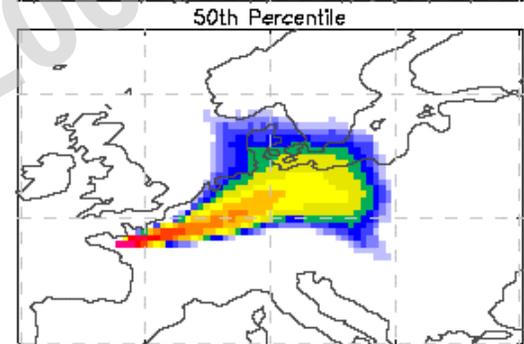
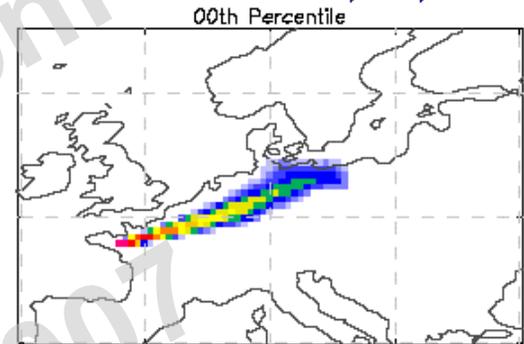
Control

# Percentiles

NAME III / ECMWF EPS: PMCH Dosage at 0 m ( $\text{g s} / \text{m}^3$ )  
Percentiles  
T+75h

DT 00Z on 23/10/1994  
VT 03Z on 26/10/1994

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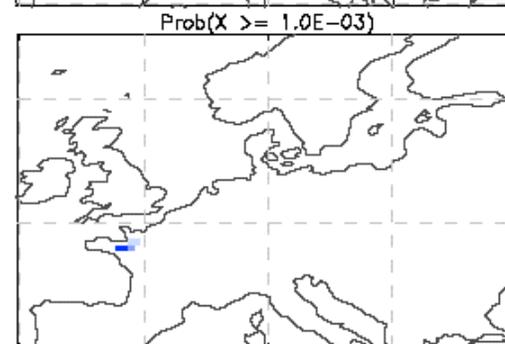
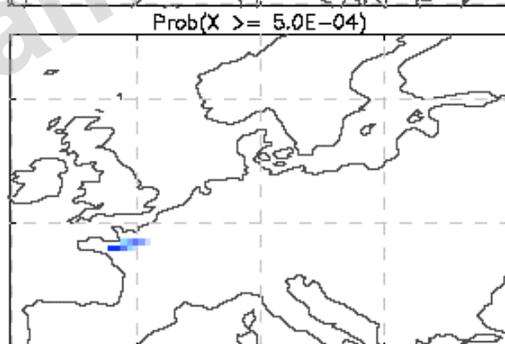
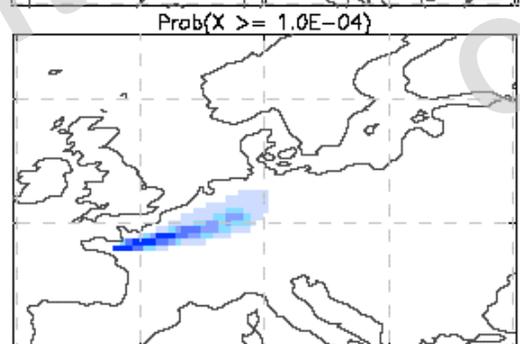
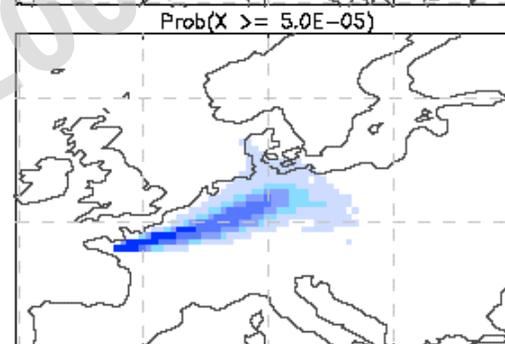
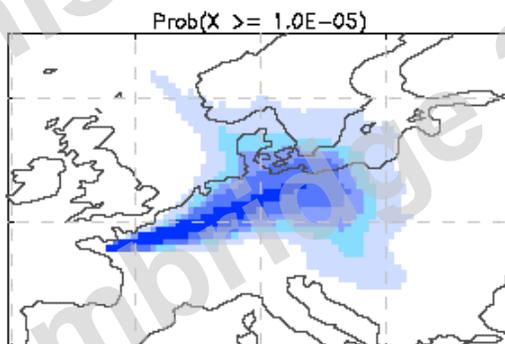
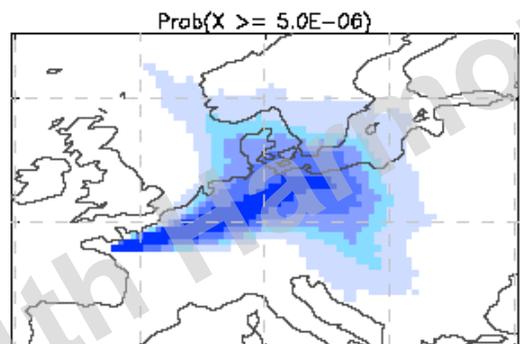
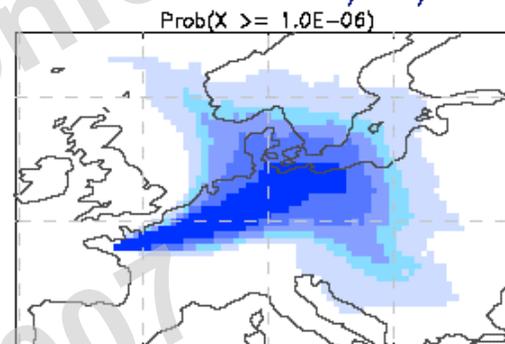
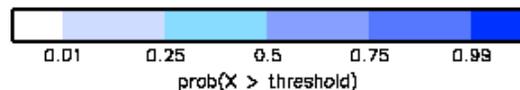


# Probabilities

NAME III / ECMWF EPS: PMCH Dosage at 0 m ( $\text{g s} / \text{m}^3$ )  
Probabilities  
T+75h

DT 00Z on 23/10/1994  
VT 03Z on 26/10/1994

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# ETEX 1 case study



## Experiment overview

- long-range tracer dispersion experiment in 1994
- two releases of tracers, ETEX1 and ETEX2
- release site in western France (2.0°W, 48.1°N)
- detection by sampling network of 168 ground-level stations distributed across Europe

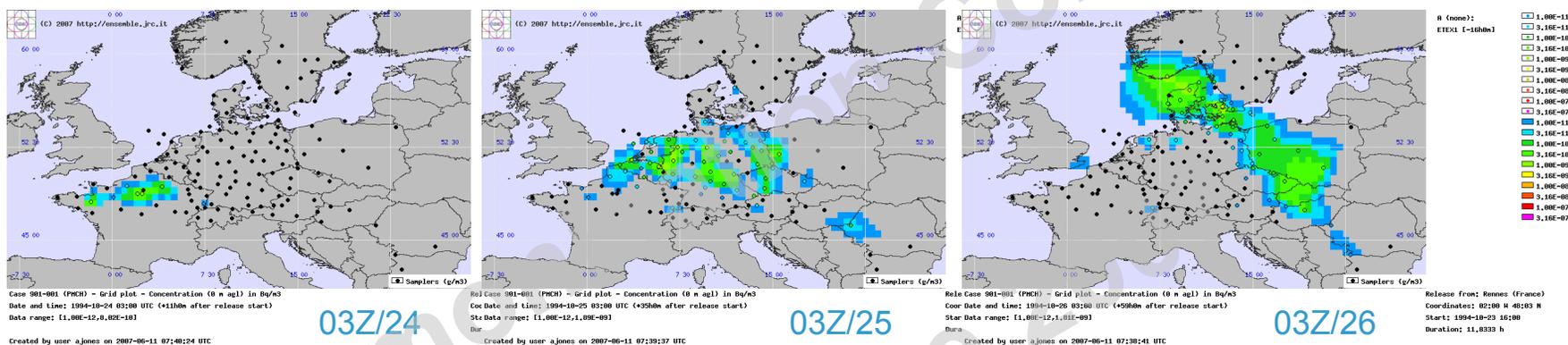
## ETEX1 case examined here:

- PMCH tracer released from 16:00UTC, 23/10/94 until 03:50UTC, 24/10/94
- 60-hr dispersion prediction produced over time window 15UTC, 23/10/94 → 03UTC, 26/10/94

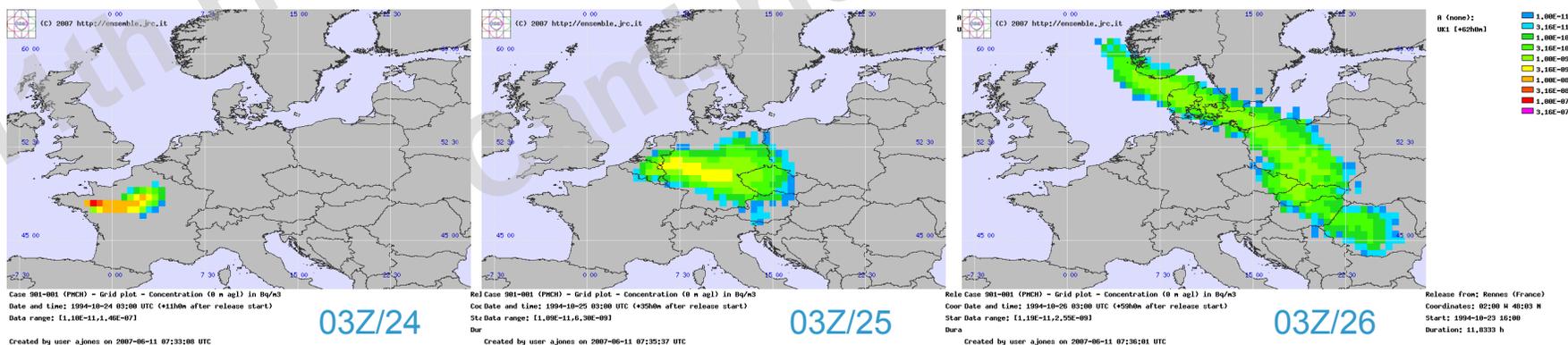
# Deterministic NAME prediction



## Observations (interpolated onto grid)

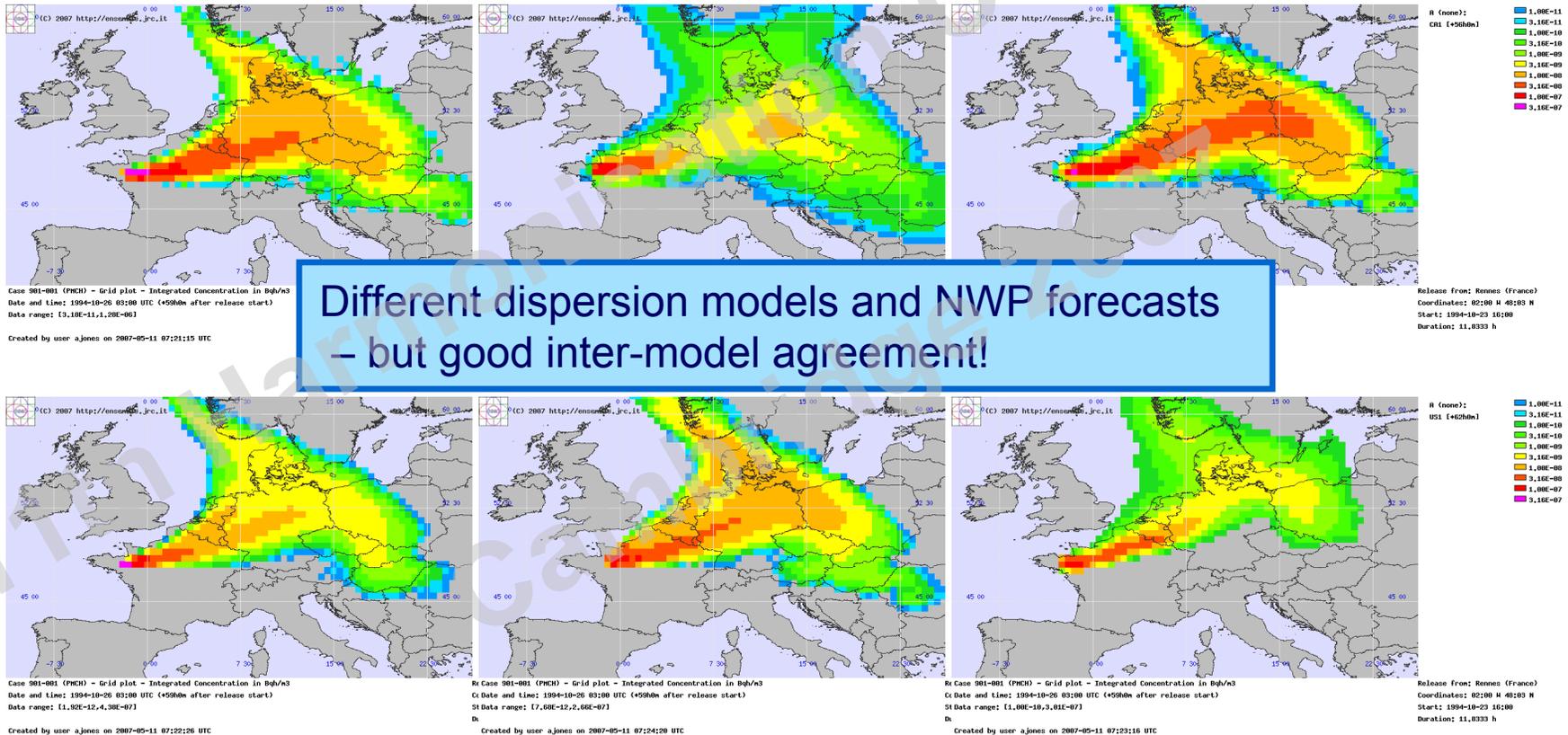


## NAME prediction (using Met Office Unified Model forecast)



# Results from other modelling centres

## Time-integrated ground-level concentration (ENSEMBLE modelling exercise)



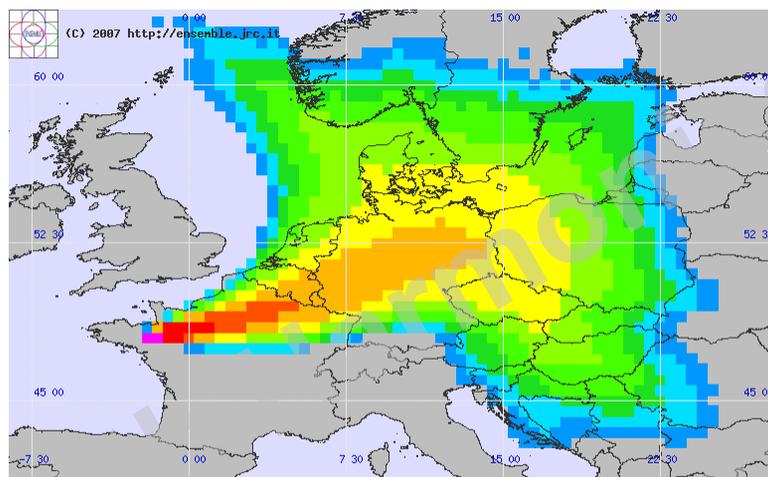
“poor-man’s ensemble”

# Ensemble NAME prediction



## Time-integrated ground-level concentration

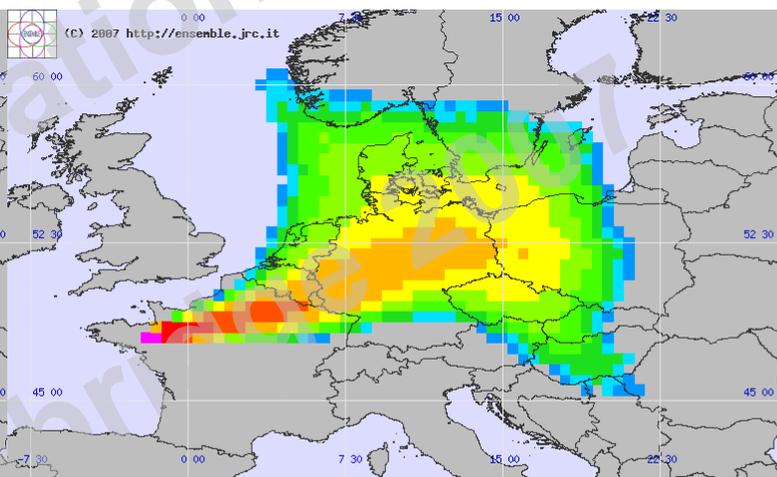
### Ensemble Mean



Case 901-001 (PHCH) - Grid plot - Integrated Concentration in Bq/m<sup>3</sup>  
Date and time: 1994-10-26 03:00 UTC (+59h0m after release start)  
Data range: [1.41E-13,6.19E-07]

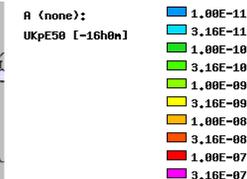
Created by user ajones on 2007-06-11 08:47:41 UTC

### Ensemble Median



Case 901-001 (PHCH) - Grid plot - Integrated Concentration in Bq/m<sup>3</sup>  
Date and time: 1994-10-26 03:00 UTC (+59h0m after release start)  
Data range: [5.15E-12,6.21E-07]

Created by user ajones on 2007-06-11 08:45:28 UTC

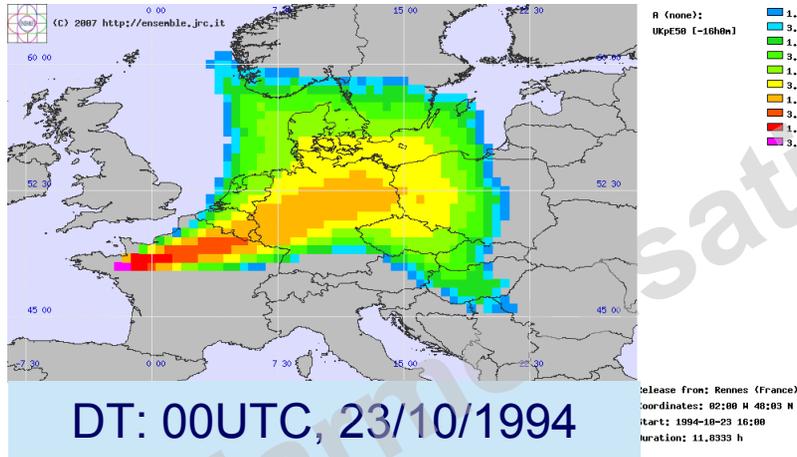


Release from: Rennes (France)  
Coordinates: 02:00 W 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h

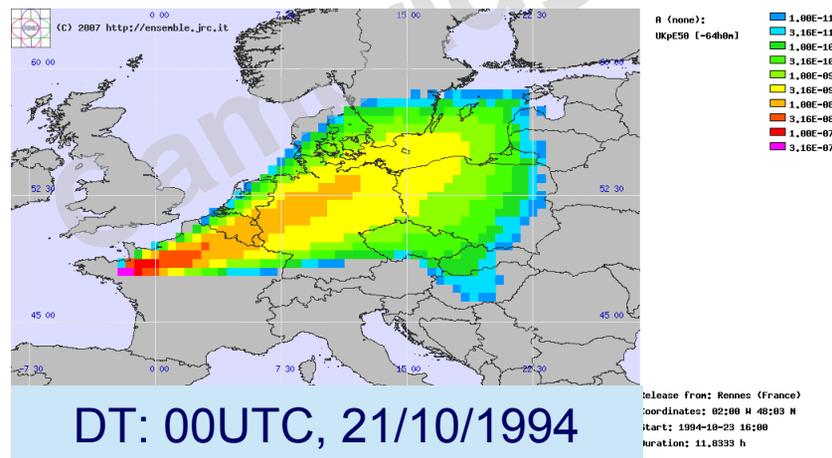
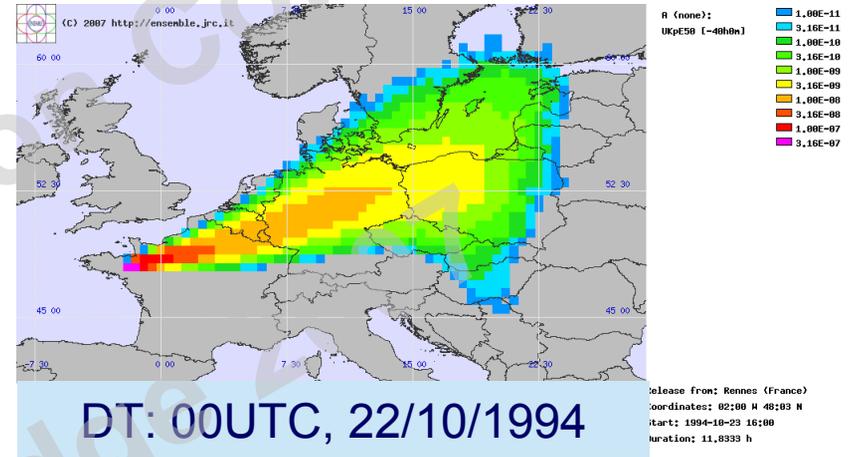
EPS experiments to generate ensemble forecasts for ETEX  
– thanks to Paul Dando and Carsten Maaß at ECMWF!

# Temporal consistency of EPS forecasts

## Latest median forecast



## 1-day old forecast



## 2-day old forecast

# So what does EPS approach tell us here?



- consistent message to the deterministic NAME III prediction and multi-model ENSEMBLE approach
- increased confidence in forecast due to relatively small spread over ensemble
- good temporal consistency between successive EPS forecasts

→ implies ETEX 1 had good predictability at synoptic scales



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# Future Work

Statistical analysis against ETEX-1 measurements

Extend to ETEX-2 release

Gain further experience of EPS dispersion approach

- 'typical levels' of uncertainty in predictions?
- impact of forecast lead-time (skill v spread)
- establish pre-operational modelling system

Clustering techniques

Use of Met Office short-range ensemble ...

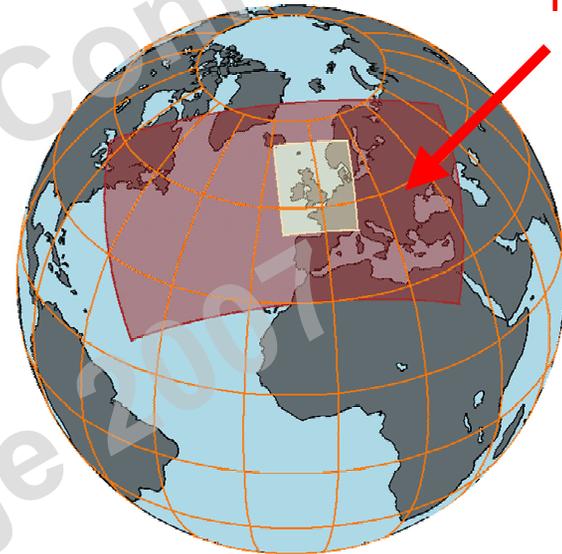
# Met Office Global and Regional Ensemble Prediction System



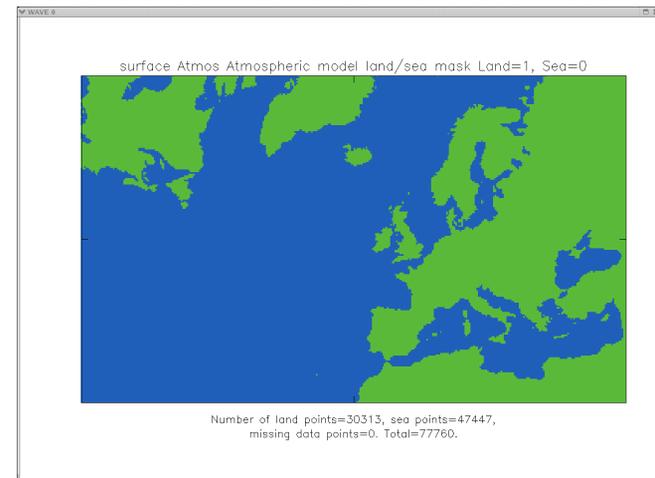
## MOGREPS

### Ensemble prediction for short-range forecasts

- Regional ensemble over North Atlantic and Europe
- Nested within global ensemble for lateral boundary conditions
- Ensemble Transform Kalman Filter (ETKF) perturbations
- Stochastic physics
- T+72 global, T+54 regional
- 24 km NAE resolution, 24 members



Regional model domain





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# Summary

- NAME III dispersion model has been successfully used with ECMWF EPS forecasts to produce an ensemble of dispersion predictions for ETEX-1
- Takes account of synoptic-scale met uncertainties
- Good spread, even at short forecast lead times!  
[ECMWF EPS designed to be fully representative of forecast spread only from T+48 onwards]
- Identification of low probability but high impact alternative solutions is possible
- Products such as ensemble mean and percentiles can be useful
- ETEX 1 – a predictable case?

# Acknowledgements



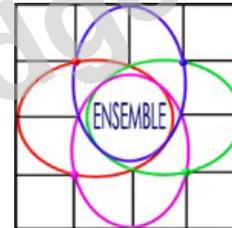
Colleagues at  
the Met Office



Scientific partners in  
PREVIEW project



Paul Dando and  
Carsten Maaß



ENSEMBLE dispersion  
modelling initiative

Thank you

**Questions**



# Additional Slides

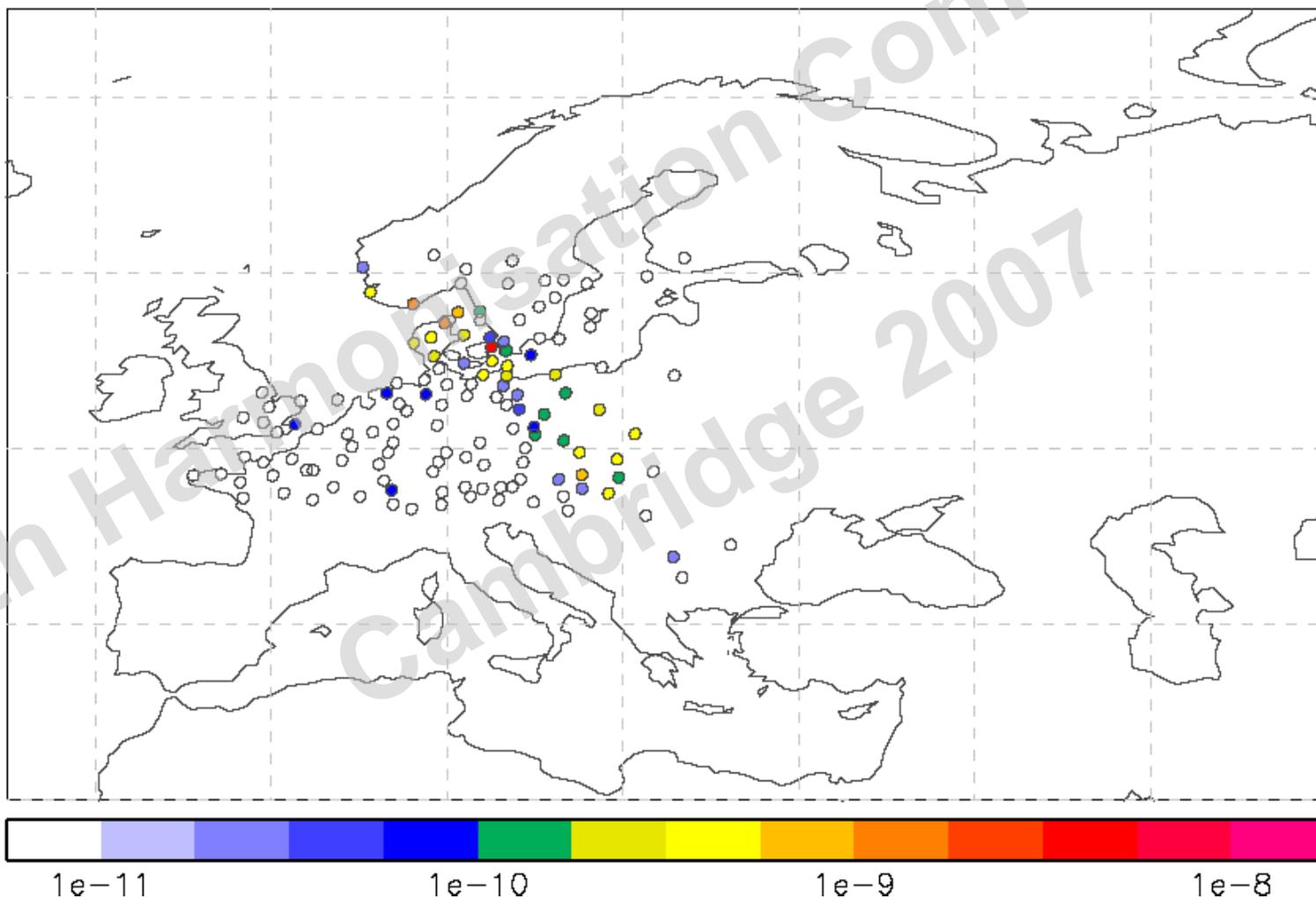


# ETEX 1 – European Tracer EXperiment



ETEX 1: PMCH Air Concentration (g / m<sup>3</sup>)  
Observations

DT 03Z on 26/10/1994





PREVIEW – PREVENTION, INFORMATION and  
EARLY WARNING

This research activity has been carried out partly under the Met Office contribution to PREVIEW. This is an EC FP6 project aimed at development of pre-operational services to support the management of risks.

PREVIEW objective: investigate the use of NWP ensembles (EPS) in dispersion modelling for industrial accidents

**A) EPS data sets at ECMWF  
for the ETEX experiments**

# EPS experiments at ECMWF



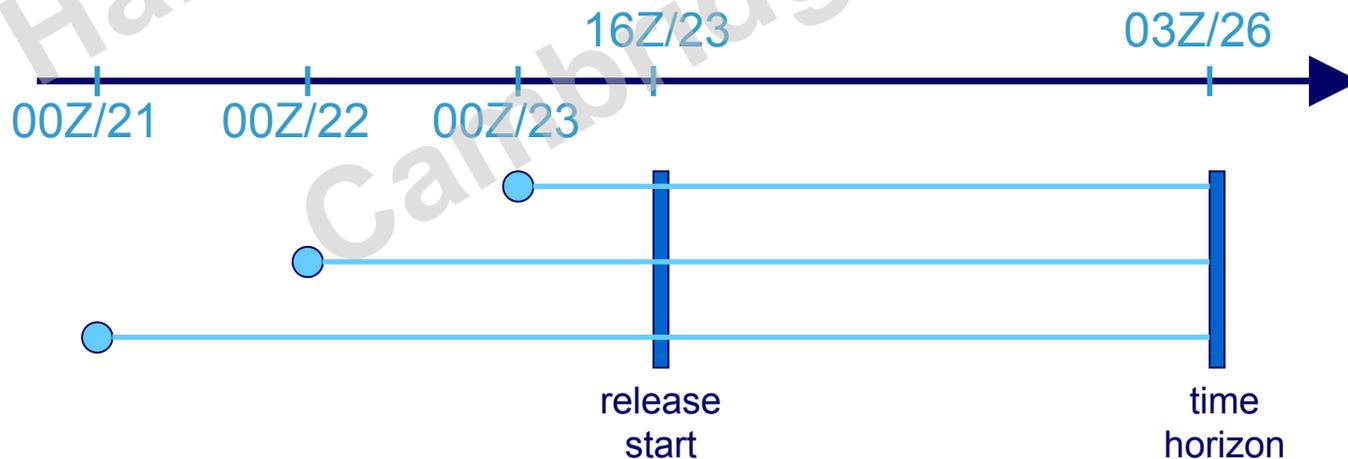
- used IFS cycle 31r1 (VarEPS)
- ETEX 1 and ETEX 2 cases studied

ETEX 1 (3 forecasts)	ETEX 2 (1 forecast)
DT: 00UTC, 23/10/94	DT: 00UTC, 14/11/94
DT: 00UTC, 22/10/94	
DT: 00UTC, 21/10/94	

- a big thank you to Paul Dando and Carsten Maaß at ECMWF!

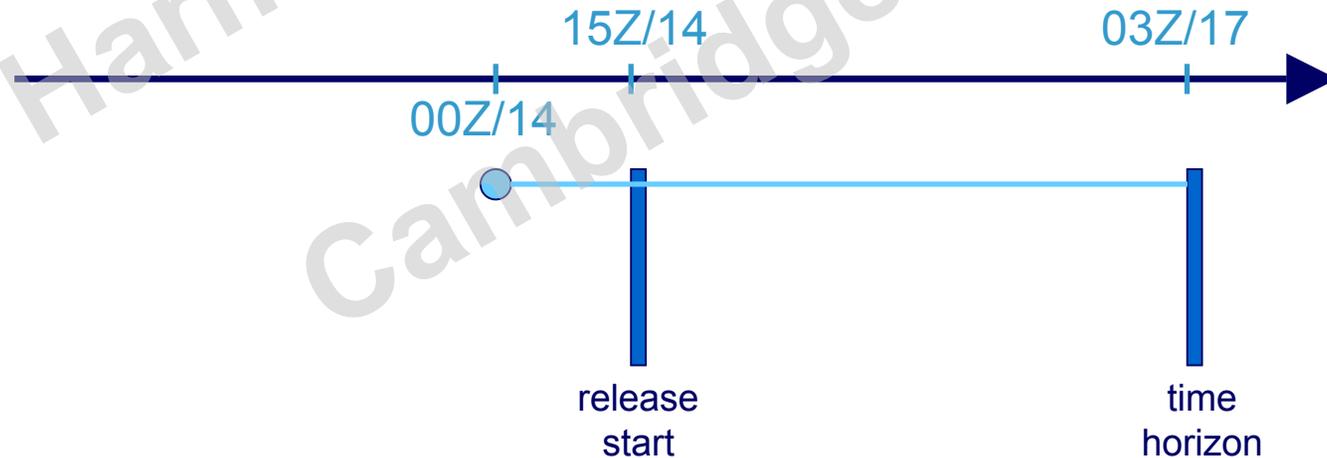
## ETEX-1

- three simulations with analysis times 00UTC on 21/22/23 October 1994
- 51 ensemble members in each case
- 3-hourly post-processed output fields



## ETEX-2

- single simulation only
- 51 member ensemble, 3-hourly output
- analysis time 00UTC, 14 November 1994

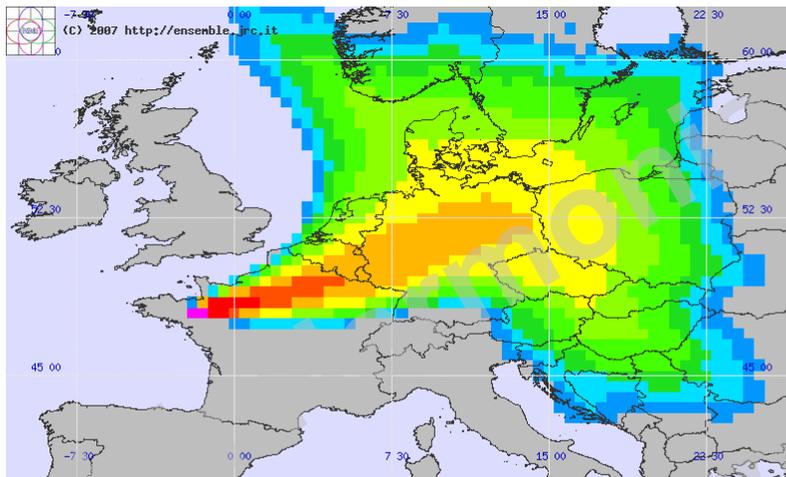


## B) Comparison with ENSEMBLE results

# Dosage: EPS Mean v ENSEMBLE Mean

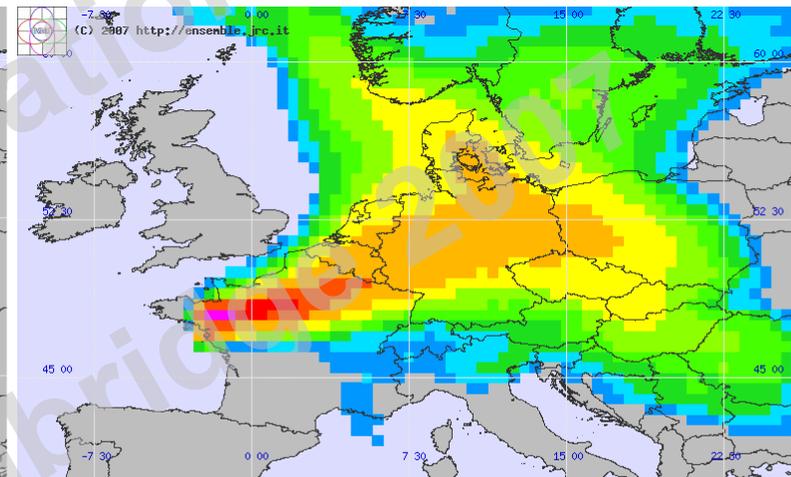


Integrated dosage at end of run (03UTC, 26/10/94)



Case 981-081 (PMCH) - Grid plot - Integrated Concentration in Bq/m<sup>3</sup>  
 Date and time: 1994-10-26 03:00 UTC (+59h0m after release start)  
 Data range: [1.41E-13,6.19E-07]

Created by user ajones on 2007-05-11 10:03:54 UTC



Case 981-081 (PMCH) - Grid plot - Integrated Concentration in Bq/m<sup>3</sup>  
 Date and time: 1994-10-26 03:00 UTC (+59h0m after release start)  
 Data range: [1.40E-45,4.52E-07]

Created by user ajones on 2007-05-11 09:53:13 UTC

- A (avg):
- UK2 [+68h0m]
  - UK1 [+62h0m]
  - DE1 [+62h0m]
  - DK2 [+62h0m]
  - US1 [+62h0m]
  - NL3 [+62h0m]
  - DE2 [+62h0m]
  - BG1 [+62h0m]
  - SE1 [+59h0m]
  - FR1 [+59h0m]
  - FR3 [+59h0m]
  - FR2 [+59h0m]
  - DK1 [+56h0m]
  - CR1 [+56h0m]
  - DK4 [+56h0m]
  - FI2 [+56h0m]
  - FI3 [+56h0m]
- 1.00E-11
  - 3.16E-11
  - 1.00E-10
  - 3.16E-10
  - 1.00E-09
  - 3.16E-09
  - 1.00E-08
  - 3.16E-08
  - 1.00E-07
  - 3.16E-07

Release from: Rennes (France)  
 Coordinates: 02:00 N 48:03 N  
 Start: 1994-10-23 16:00  
 Duration: 11.8333 h

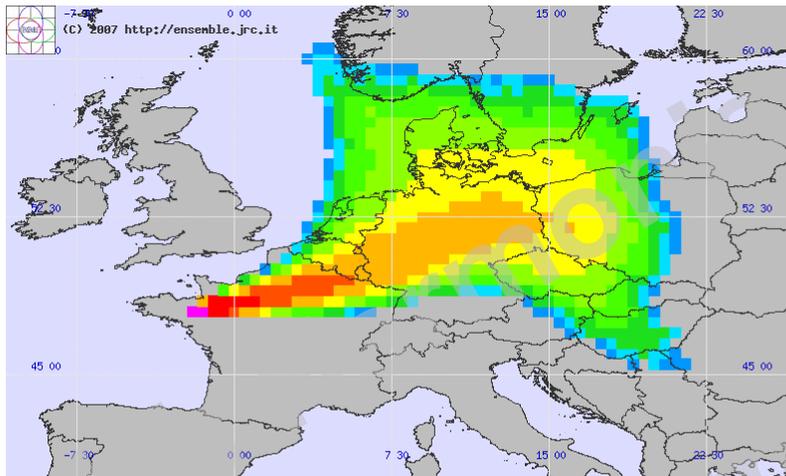
EPS Mean

ENSEMBLE Mean

# Dosage: EPS Median v ENSEMBLE Median

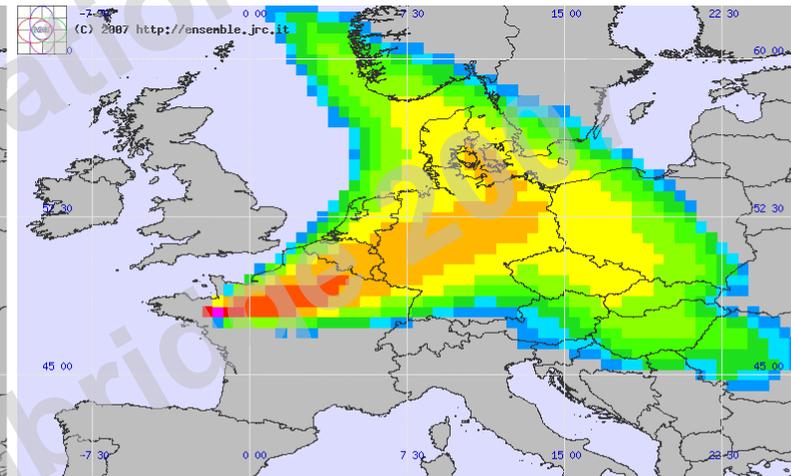


Integrated dosage at end of run (03UTC, 26/10/94)



Case 981-081 (PHCH) - Grid plot - Integrated Concentration in Bq/m<sup>3</sup>  
 Date and time: 1994-10-26 03:00 UTC (+59h0m after release start)  
 Data range: [5.15E-12,6.21E-07]

Created by user ajones on 2007-05-11 10:03:27 UTC



R: Case 981-081 (PHCH) - Agreement in percentile threshold - Integrated Concentration  
 C: Date and time: 1994-10-26 03:00 UTC (+59h0m after release start)  
 S: Percentile threshold = 50.0%  
 D:

Created by user ajones on 2007-05-11 07:43:34 UTC

- A (APT):
- UK2 [+68h0m]
  - UK1 [+62h0m]
  - DE1 [+62h0m]
  - NL1 [+62h0m]
  - DK2 [+62h0m]
  - US1 [+62h0m]
  - NL3 [+62h0m]
  - DE2 [+62h0m]
  - BG1 [+62h0m]
  - SE1 [+59h0m]
  - FR1 [+59h0m]
  - FR3 [+59h0m]
  - FR2 [+59h0m]
  - DK1 [+56h0m]
  - CR1 [+56h0m]
  - DK4 [+56h0m]
  - FI2 [+56h0m]
  - FI3 [+56h0m]
- 1.00E-11
  - 3.16E-11
  - 1.00E-10
  - 3.16E-10
  - 1.00E-09
  - 3.16E-09
  - 1.00E-08
  - 3.16E-08
  - 1.00E-07
  - 3.16E-07

Release from: Rennes (France)  
 Coordinates: 02:00 N 48:03 N  
 Start: 1994-10-23 16:00  
 Duration: 11.8333 h

EPS Median

ENSEMBLE Median

## C) Impact of forecast lead time

11th Harmonisation Conference  
Cambridge 2007

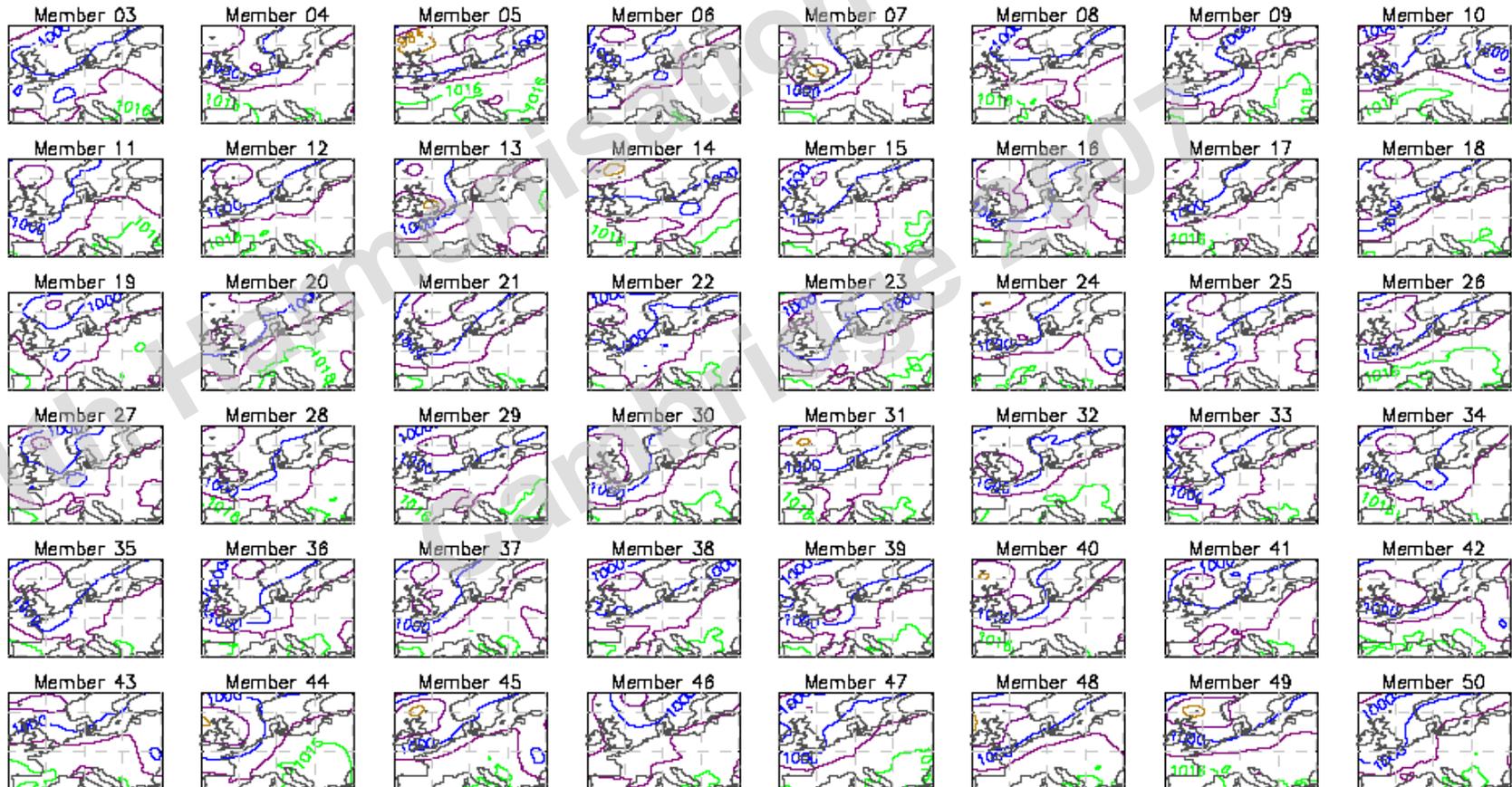
# MSLP at 03UTC, 26/10/94 (T-24 forecast)



NAME III / ECMWF EPS: Mean Sea Level Pressure (hPa)  
All Members  
T+99h

DT 00Z on 22/10/1994  
VT 03Z on 26/10/1994

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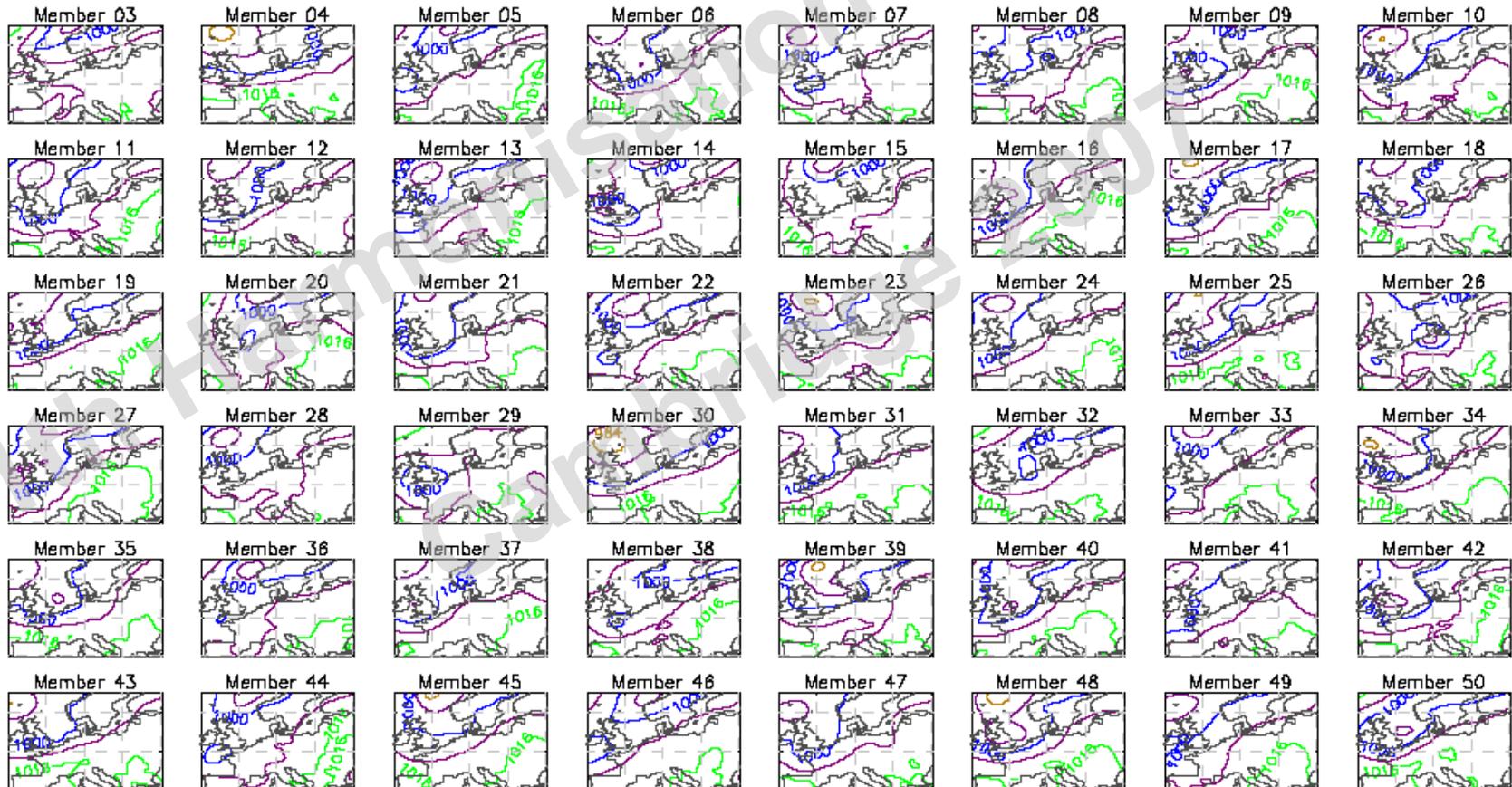
# MSLP at 03UTC, 26/10/94 (T-48 forecast)



NAME III / ECMWF EPS: Mean Sea Level Pressure (hPa)  
All Members  
T+123h

DT 00Z on 21/10/1994  
VT 03Z on 26/10/1994

(c) Crown Copyright, Met Office 2007



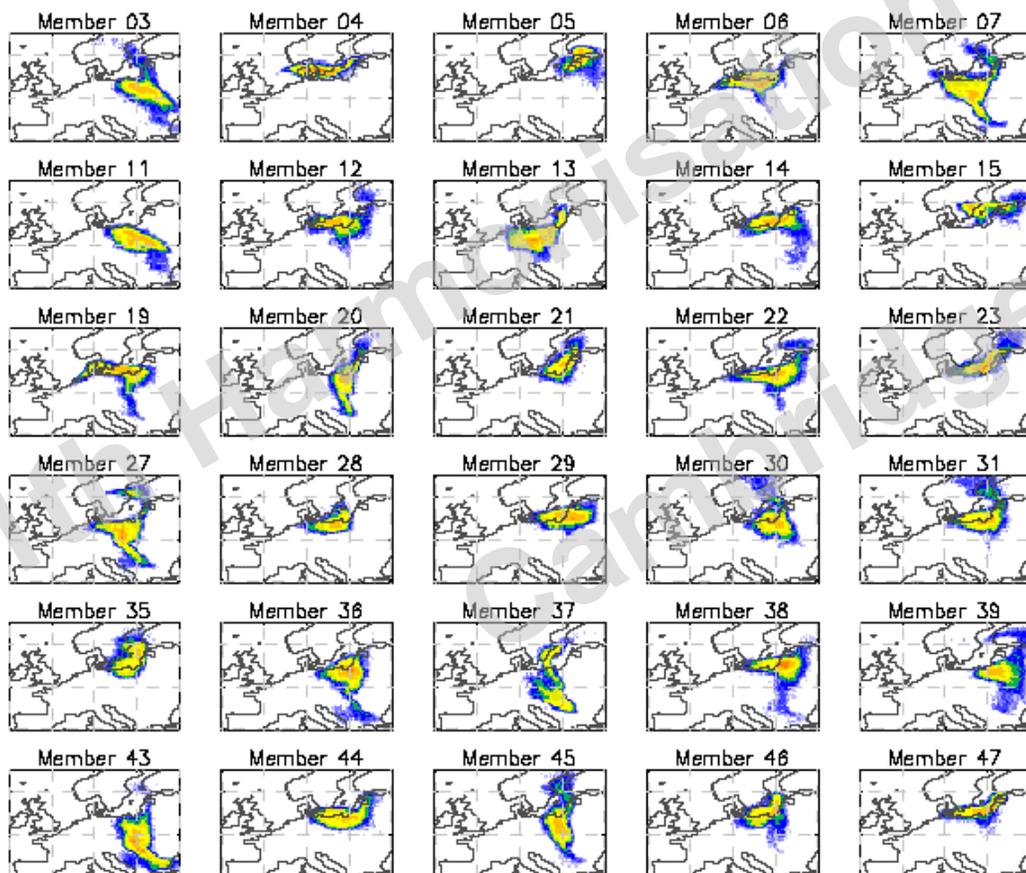
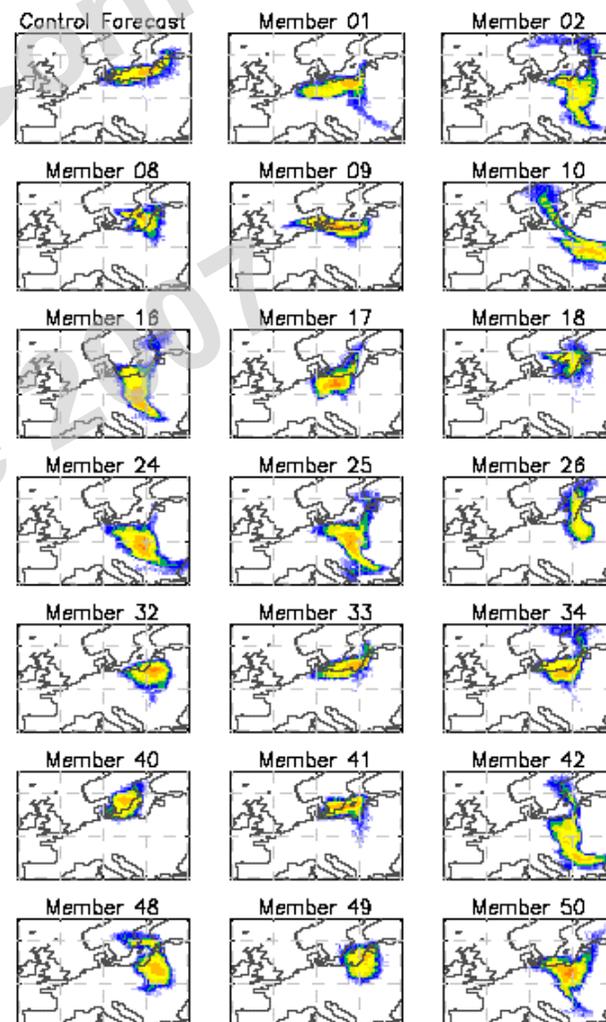
# Air Concentration at 03UTC, 26/10/94 (T-24)



NAME III / ECMWF EPS: PMCH Air Conc at 0 m ( $\text{g} / \text{m}^3$ )  
All Members  
T+99h

DT 00Z on 22/10/1994  
VT 03Z on 26/10/1994

(c) Crown Copyright, Met Office 2007



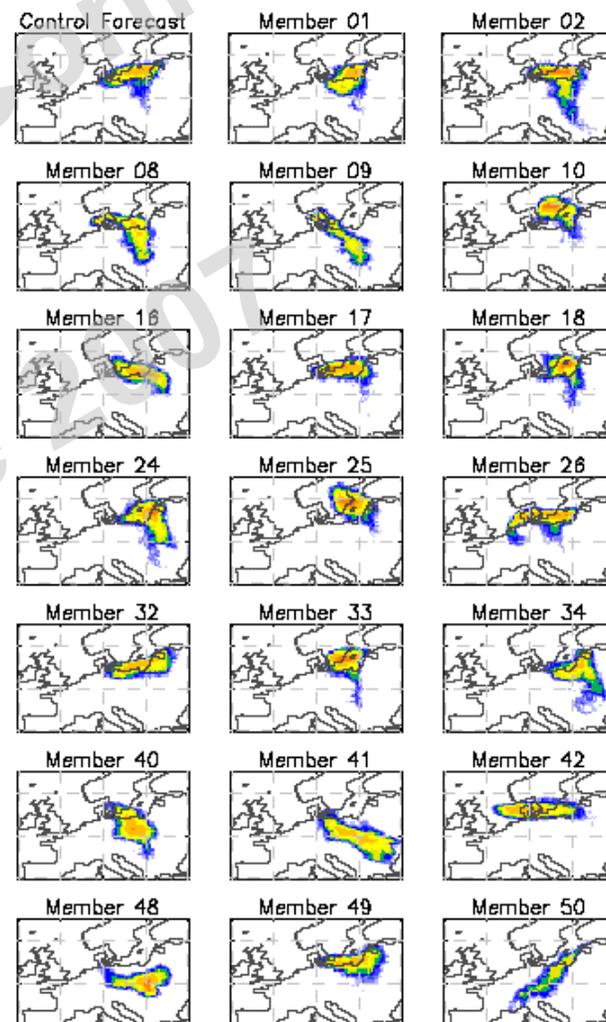
# Air Concentration at 03UTC, 26/10/94 (T-48)



NAME III / ECMWF EPS: PMCH Air Conc at 0 m ( $\text{g} / \text{m}^3$ )  
All Members  
T+123h

DT 00Z on 21/10/1994  
VT 03Z on 26/10/1994

(c) Crown Copyright, Met Office 2007



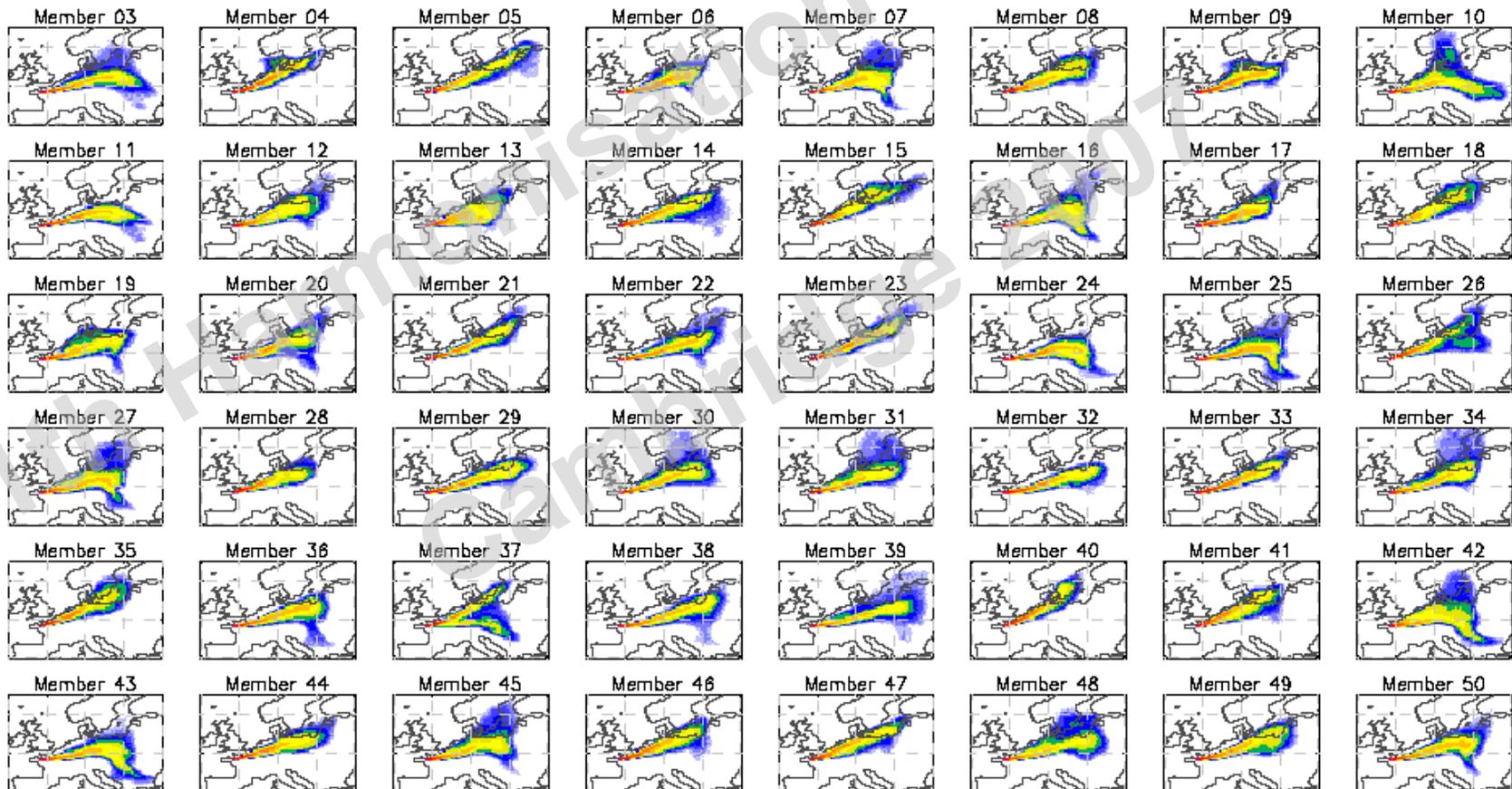
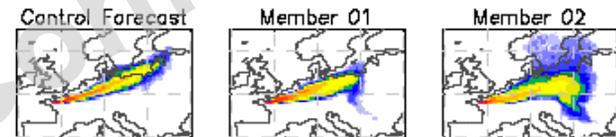
# Dosage at 03UTC, 26/10/94 (T-24)



NAME III / ECMWF EPS: PMCH Dosage at 0 m (g s / m<sup>3</sup>)  
All Members  
T+99h

DT 00Z on 22/10/1994  
VT 03Z on 26/10/1994

(c) Crown Copyright, Met Office 2007



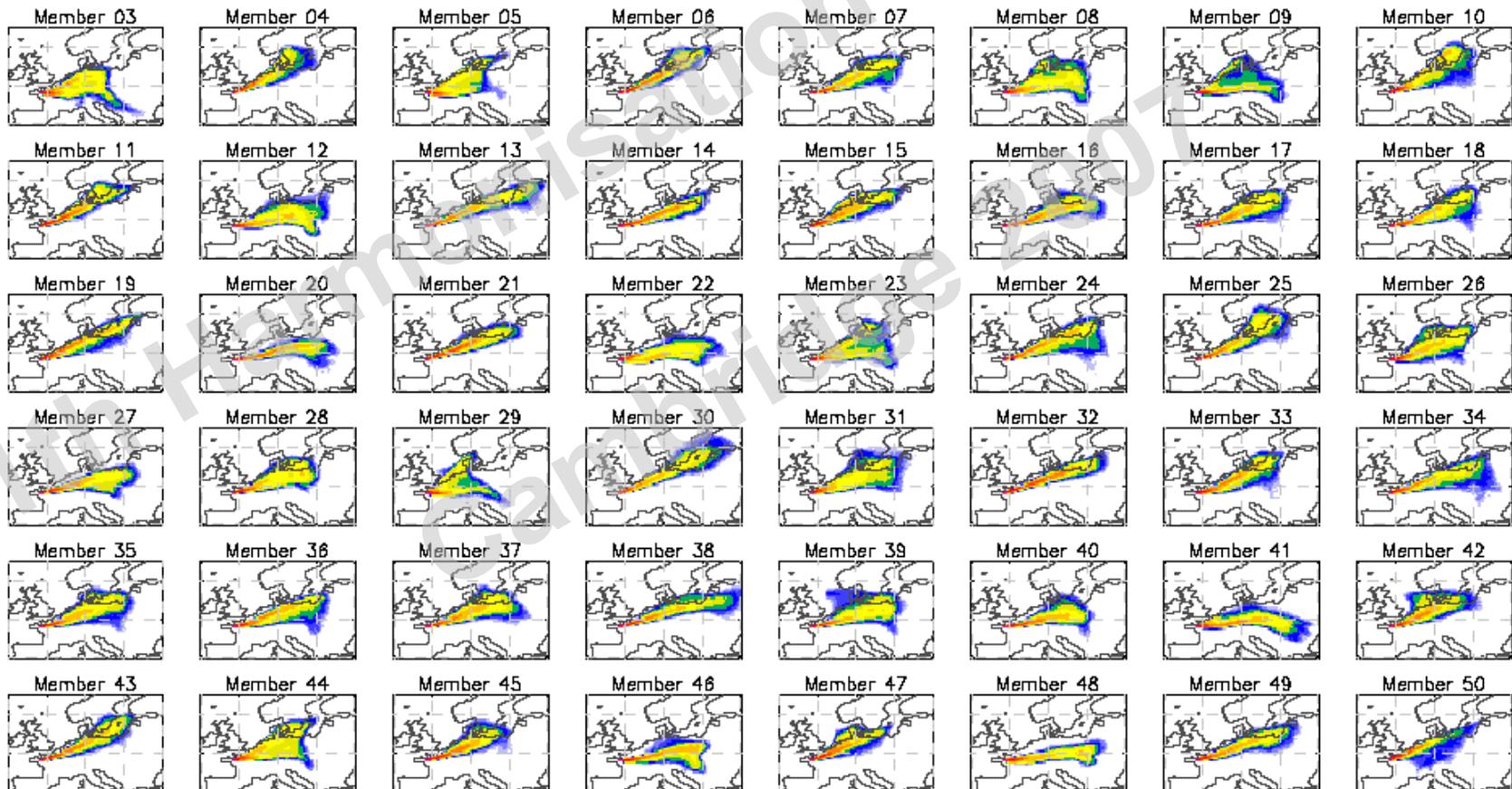
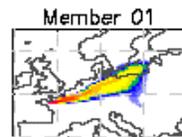
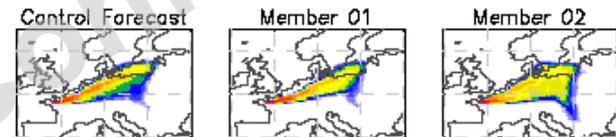
# Dosage at 03UTC, 26/10/94 (T-48)



NAME III / ECMWF EPS: PMCH Dosage at 0 m (g s / m<sup>3</sup>)  
All Members  
T+123h

DT 00Z on 21/10/1994  
VT 03Z on 26/10/1994

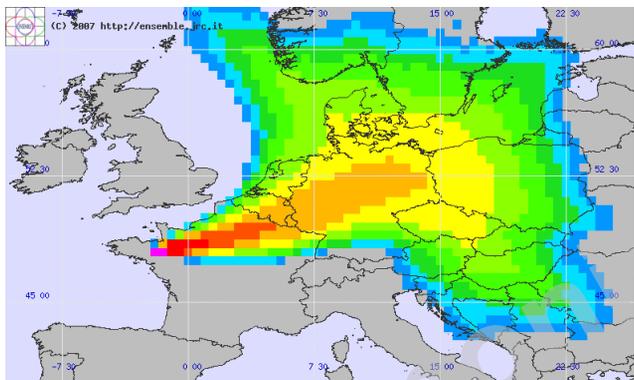
(c) Crown Copyright, Met Office 2007



# EPS Mean (23/22/21/ENSEMBLE)



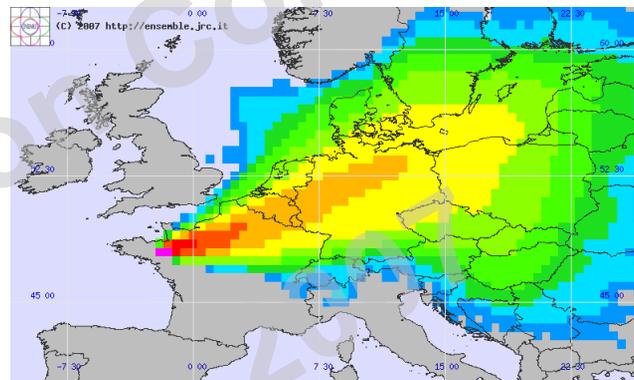
## Integrated dosage at end of run (03UTC, 26/10/94)



DT: 00UTC, 23/10/1994

A (none):  
UKPER [-16h0n]  
1.00E-11  
3.16E-11  
1.00E-10  
3.16E-10  
1.00E-09  
3.16E-09  
1.00E-08  
3.16E-08  
1.00E-07  
3.16E-07

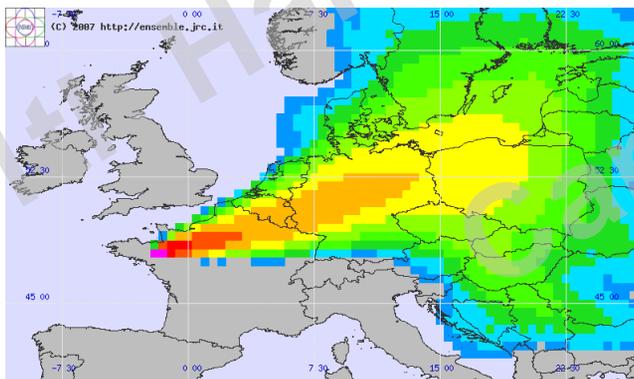
Release from: Rennes (France)  
Coordinates: 02:00 M 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h



DT: 00UTC, 21/10/1994

A (none):  
UKPER [-64h0n]  
1.00E-11  
3.16E-11  
1.00E-10  
3.16E-10  
1.00E-09  
3.16E-09  
1.00E-08  
3.16E-08  
1.00E-07  
3.16E-07

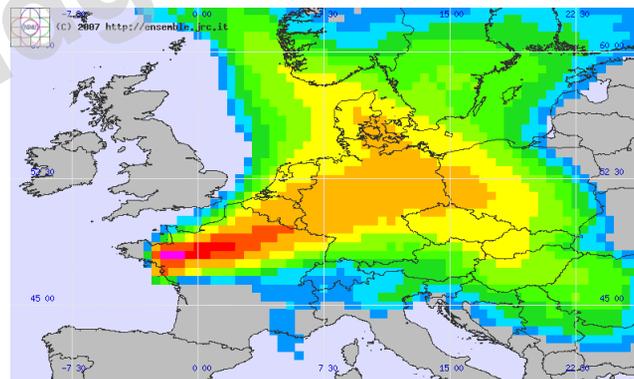
Release from: Rennes (France)  
Coordinates: 02:00 M 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h



DT: 00UTC, 22/10/1994

A (none):  
UKPER [-40h0n]  
1.00E-11  
3.16E-11  
1.00E-10  
3.16E-10  
1.00E-09  
3.16E-09  
1.00E-08  
3.16E-08  
1.00E-07  
3.16E-07

Release from: Rennes (France)  
Coordinates: 02:00 M 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h



ENSEMBLE Mean

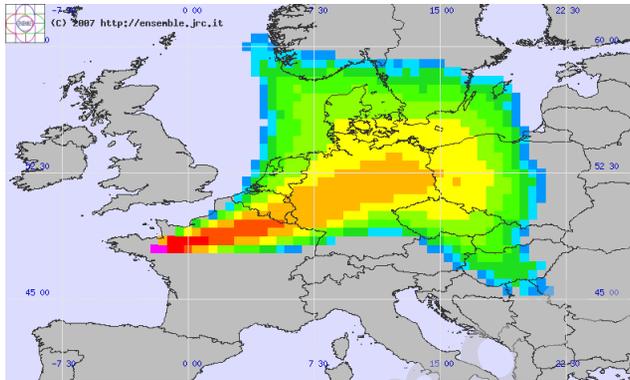
A (avg):  
UK2 [+62h0n]  
UK1 [+62h0n]  
DE1 [+62h0n]  
NL1 [+62h0n]  
DK2 [+62h0n]  
US1 [+62h0n]  
NL3 [+62h0n]  
DE2 [+62h0n]  
BG1 [+62h0n]  
SE1 [+59h0n]  
FR1 [+59h0n]  
FR3 [+59h0n]  
FR2 [+59h0n]  
DK1 [+56h0n]  
CR1 [+56h0n]  
DK4 [+56h0n]  
FI2 [+56h0n]  
FI3 [+56h0n]

Release from: Rennes (France)  
Coordinates: 02:00 M 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h

# EPS Median (23/22/21/ENSEMBLE)



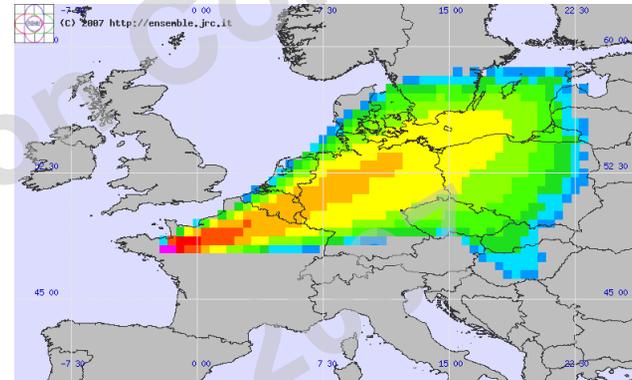
## Integrated dosage at end of run (03UTC, 26/10/94)



DT: 00UTC, 23/10/1994

A (none):  
UKpE50 [-16h0n]  
1.00E-11  
3.16E-11  
1.00E-10  
3.16E-10  
1.00E-09  
3.16E-09  
1.00E-08  
3.16E-08  
1.00E-07  
3.16E-07

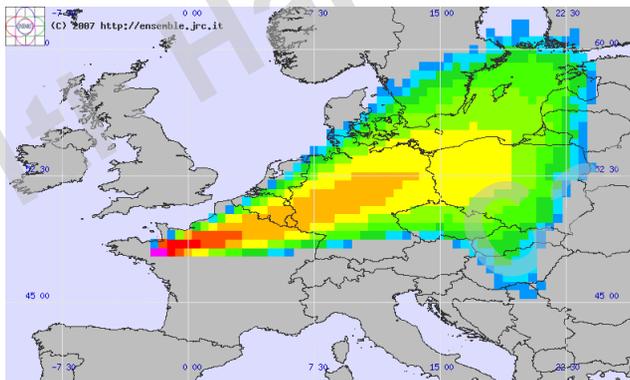
Release from: Rennes (France)  
Coordinates: 02:00 H 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h



DT: 00UTC, 21/10/1994

A (none):  
UKpE50 [-64h0n]  
1.00E-11  
3.16E-11  
1.00E-10  
3.16E-10  
1.00E-09  
3.16E-09  
1.00E-08  
3.16E-08  
1.00E-07  
3.16E-07

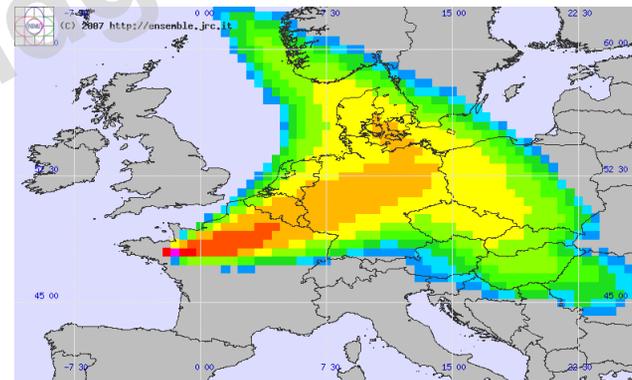
Release from: Rennes (France)  
Coordinates: 02:00 H 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h



DT: 00UTC, 22/10/1994

A (none):  
UKpE50 [-40h0n]  
1.00E-11  
3.16E-11  
1.00E-10  
3.16E-10  
1.00E-09  
3.16E-09  
1.00E-08  
3.16E-08  
1.00E-07  
3.16E-07

Release from: Rennes (France)  
Coordinates: 02:00 H 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h



ENSEMBLE Median

A (AP1):  
UK2 [+68h0n]  
UK1 [+62h0n]  
DE1 [+62h0n]  
NL1 [+62h0n]  
DK2 [+62h0n]  
US1 [+62h0n]  
NL3 [+62h0n]  
DE2 [+62h0n]  
BG1 [+59h0n]  
SE1 [+59h0n]  
FR1 [+59h0n]  
FR3 [+59h0n]  
FR2 [+59h0n]  
DK1 [+56h0n]  
CA1 [+56h0n]  
DK4 [+56h0n]  
FI2 [+56h0n]  
FI3 [+56h0n]

Release from: Rennes (France)  
Coordinates: 02:00 H 48:03 N  
Start: 1994-10-23 16:00  
Duration: 11.8333 h