Evaluating pollution transport in weather prediction models?

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Talk Outline

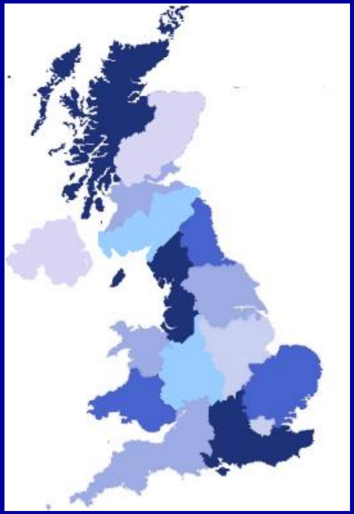
- Air pollution forecasting
  - Offline forecasting
  - Online forecasting
- Aim
- Overview of ETEX 2 case study
- Tracer experiments
  - NAME tracer analysis
  - UM tracer analysis
- Comparison with observations
- Conclusions and future work

Offline Air Pollution Forecasting

- Offline modelling is performed by Chemistry Transport Models (CTM's)
- CTM's require the input of data including:
  - Meteorology (NWP, site)
  - Emissions (NAEI, EMEP)
- Pollutants are transported by 3D winds
- CTM's can include parameterised processes including:
  - Turbulent diffusion
  - Chemical transformations
  - Wet and dry deposition
  - Depletion via radioactive decay
  - Downwash effects of buildings

Offline Air Pollution Forecasts

- 24 hour Air pollution forecast available from National Air Quality Archive (www.airquality.co.uk)
- Results from NAME model
- Forecasts NO_x, NO_2, CO, SO_2 and PM_{10} concentrations for 16 urban areas and 16 UK regions



- Forecast for East (last updated at 10:00 on 12/02/2009)
  - In towns & cities near busier roads: LOW 3
  - Elsewhere in towns and cities: LOW 3
  - In rural areas: LOW 3

Online Air Pollution Forecasts

- Online forecasting is performed using numerical weather prediction (NWP) models to transport chemical pollutants AND perform chemical transformations (MetCTM's)

- Advantages
  - No time interpolation – 3D fields available at each timestep
  - Physical parameterisations consistent
  - Met-Chemistry feedbacks
- Disadvantages
  - High computational cost - unsuitable for ensembles and operational activities or emission scenario forecasts

Online Air Pollution Forecasts

- Met Office UKCA (UK Chemistry Aerosol) model
- Climate resolution simulations
- Air quality forecasts – March 2010

- MetCTM's are more complex than existing tools and have not been subject to the degree of testing applied to short-range dispersion models

- Work needed to examine the ability and limitations of MetCTM's to adequately predict air pollution episodes during a range of met conditions

Aim

- Assess performance of UK Met Office's weather prediction model in forecasting the transport of pollutants across Europe

- Forecast errors
  - Input - emissions
  - Parameterised processes - deposition (dry/wet), chemical transformations, radioactive decay, ...
  - Transport – advection, convection, mixing

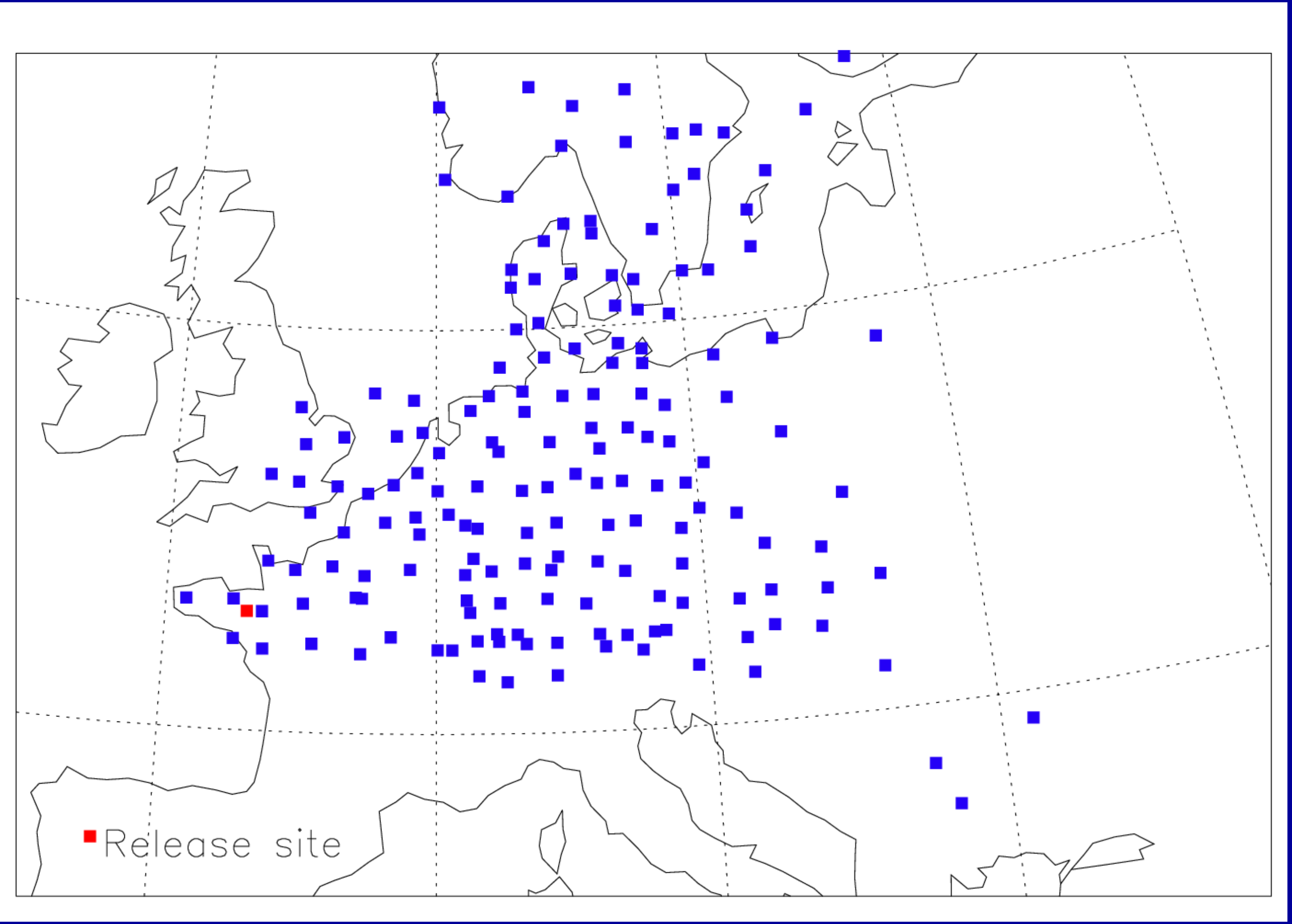
Overview of ETEX

- European Tracer Experiment (ETEX)
- Aim: To evaluate the ability of a variety of long-range dispersion models to predict pollution concentrations across Europe

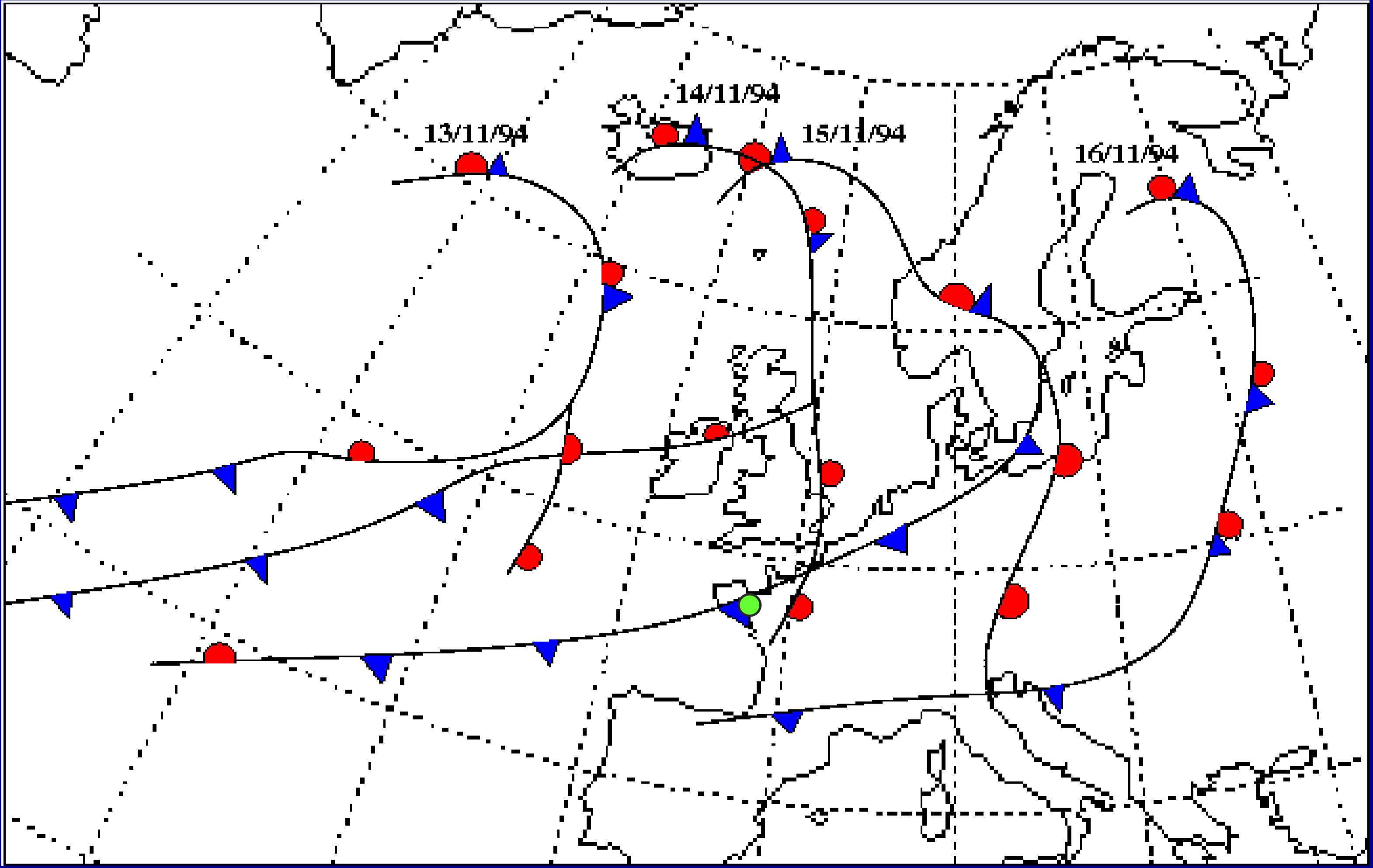
ETEX 2:

- Inert and non-depositing tracer released between 15UTC on 15/11/94 and 02:45UTC on 16/11/94 in NW France
- Tracer perfluoromethylcyclopentane (PMCP)
- 168 surface station measurements

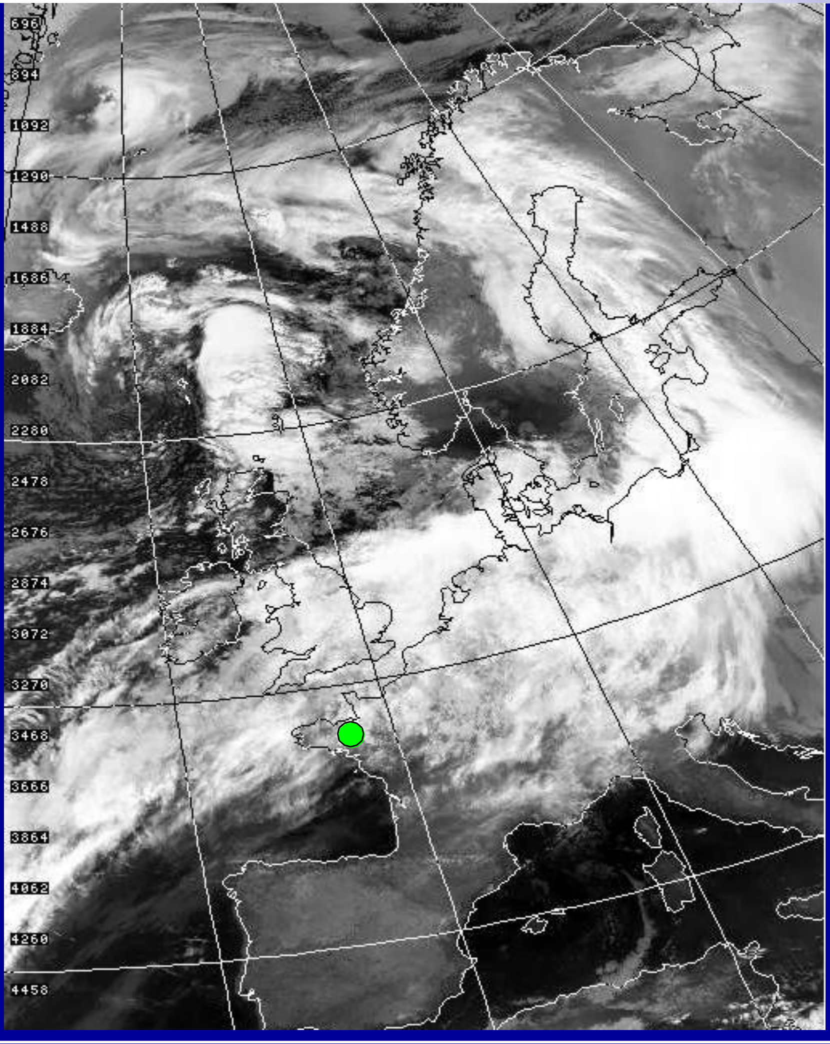
ETEX: Observational Network



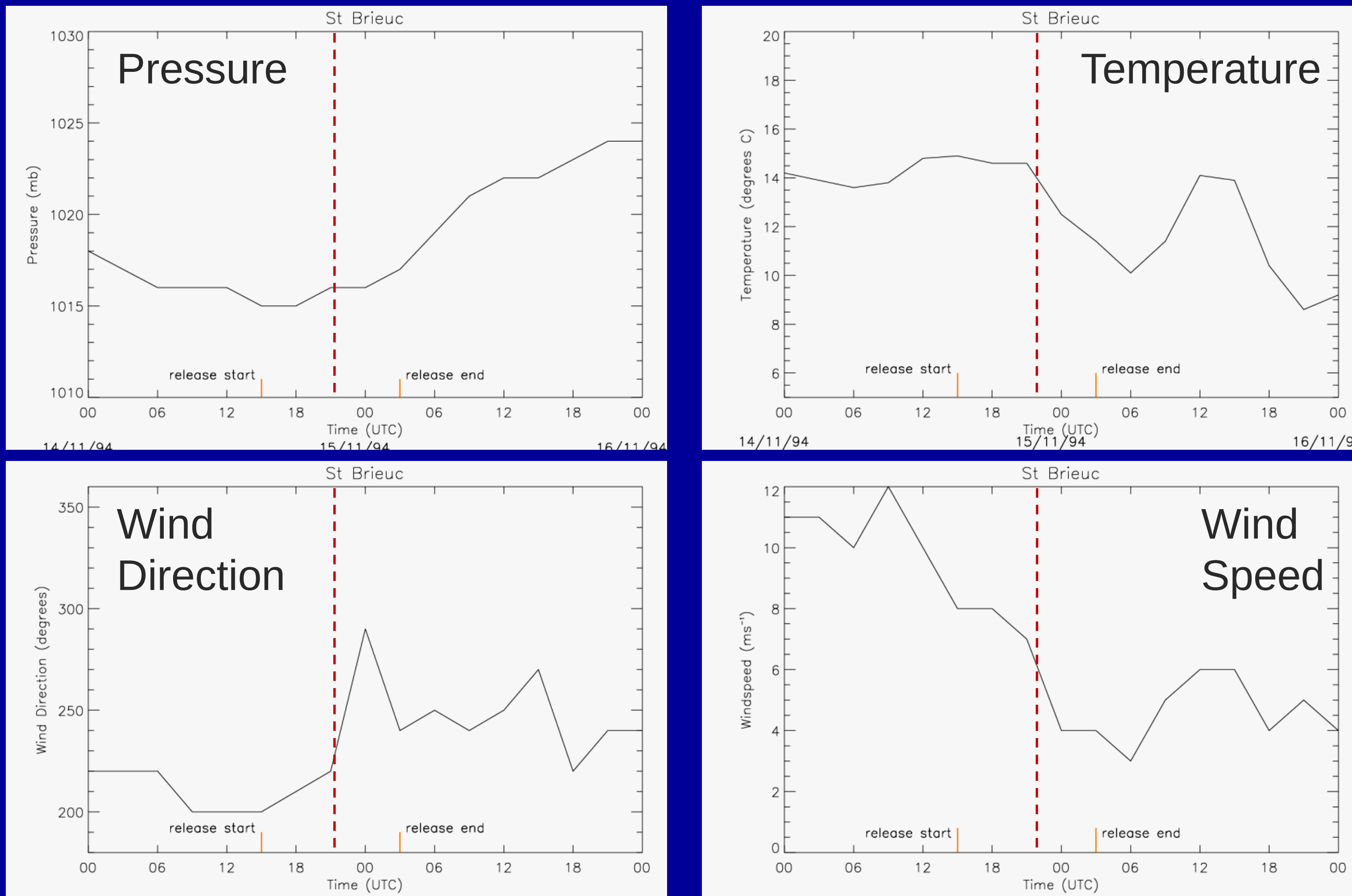
ETEX 2: Frontal Analysis 00Z



ETEX 2: Satellite IR 07:50 14/11/94



ETEX 2: Surface Observations

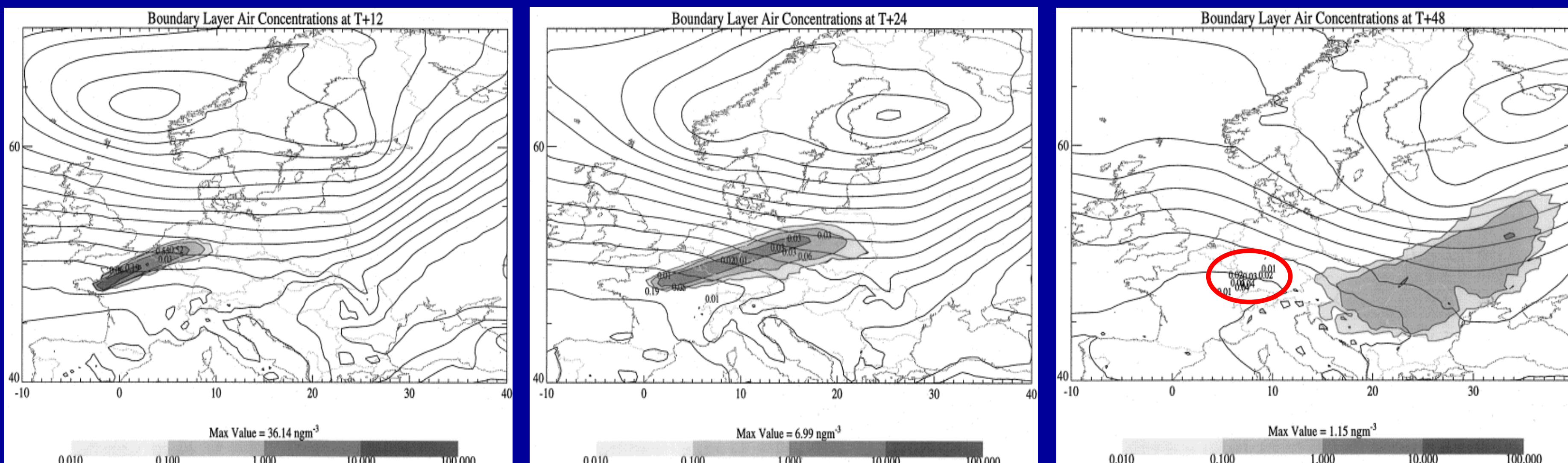


Tracer Experiments - NAME

- ‘Validation of the UK Met Office’s NAME model against the ETEX dataset’ (Ryall and Maryon, 1998)
- NAME (**N**umerical **A**tmospheric dispersion **M**odelling **E**nvironment)
  - Lagrangian particle dispersion model
  - Pollutants represented by particles each representing a mass of pollutant
  - Each particle carried by 3D wind, with random turbulent motions at each timestep
  - Each particle follows a different trajectory with whole representing plume
- UM meteorology with 50km, 3h resolution

Ryall and Maryon (1998)

T+12 T+24 T+48



- Plume matches obs in first 24h but fails to capture tracer behind cold front
- NAME over predicts obs tracer concentrations

ETEX 2: Hypothesis

- Surface over prediction due to failure to resolve pre-frontal ascent and convective updrafts

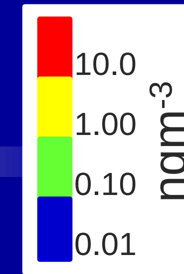
- Plume orientation error due to failure to capture rapid drop in wind speed and change in wind direction associated with passage of front

NAME Method

- Ryall and Maryon (1998) used 3 hourly met input at 50km resolution
- Vary temporal resolution of met input from UM (6h, 3h, 1h, 30min, 15min)
- Vary spatial resolution of met input from UM (50km, 12km)

- Can we capture the plume re-orientation behind the front?
- Can we reduce the over prediction of surface concentrations?

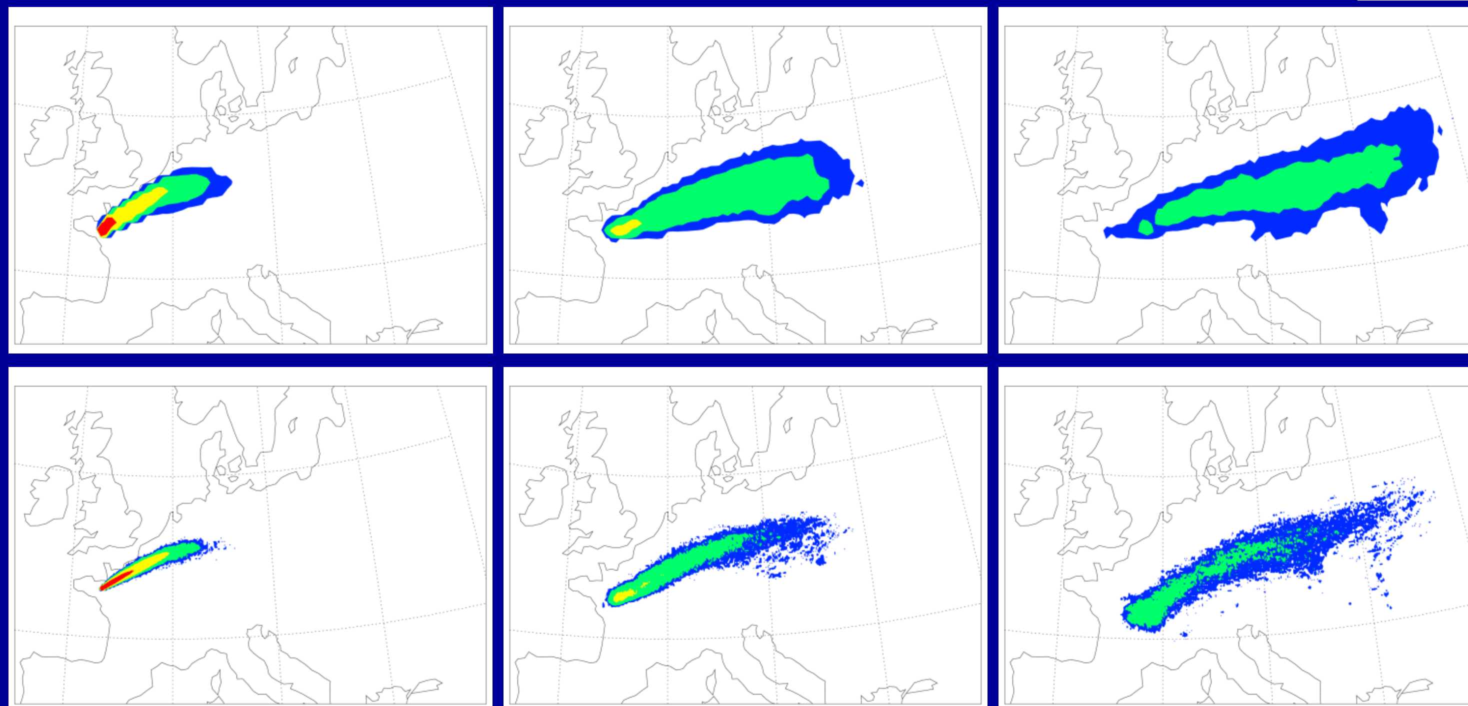
NAME – Tracer Concentrations



T+12 T+24 T+36

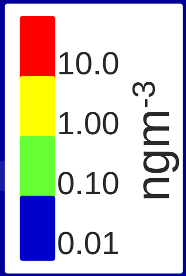
NAME
Δx=50km
Δt=3hr

NAME
Δx=12km
Δt=1hr



- High resolution tracer plume does not extend as far east
- High resolution maximum tracer behind cold front

NAME – OBS Comparison

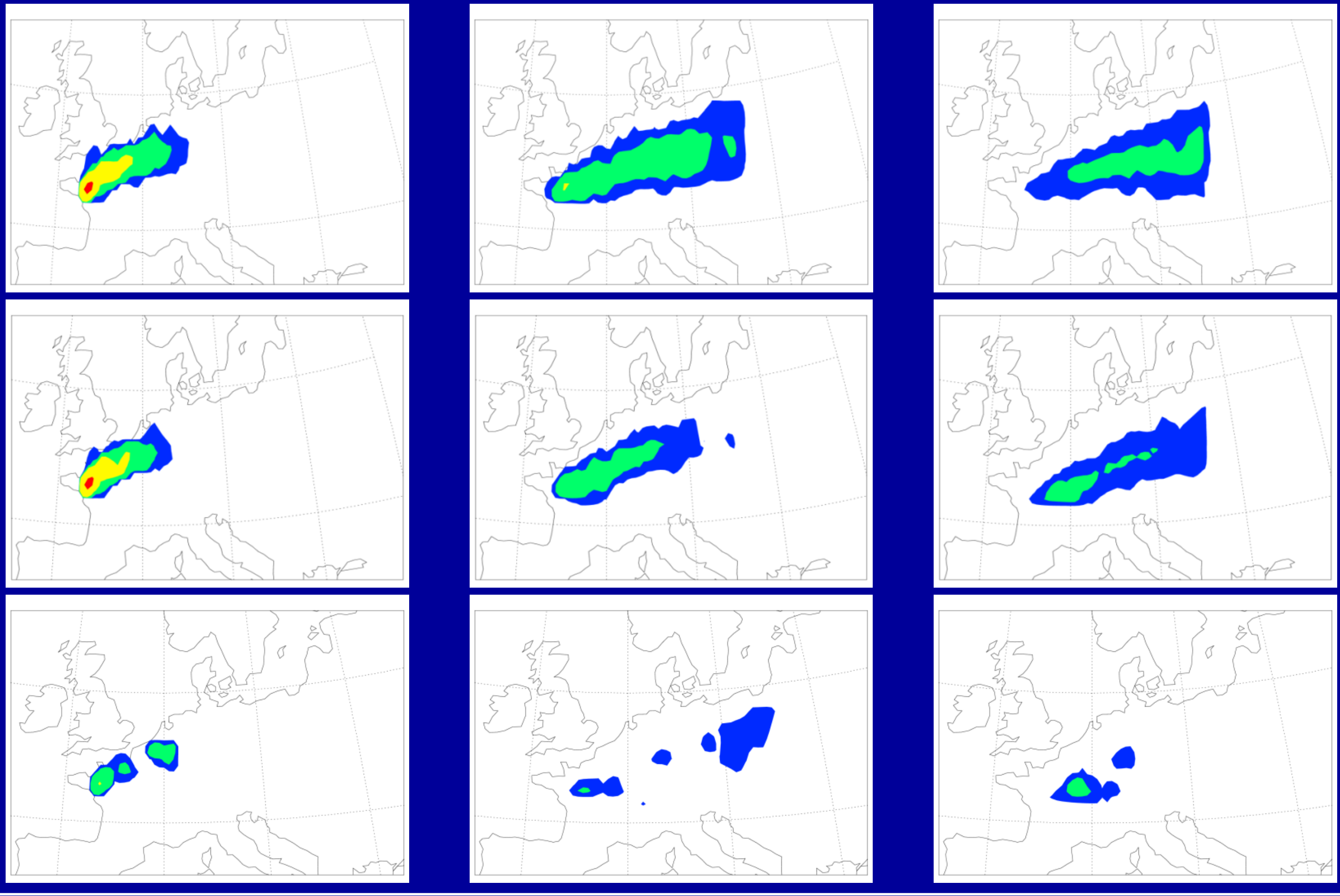


T+12 T+24 T+36

NAME
Δx=50km
Δt=3hr

NAME
Δx=12km
Δt=1hr

OBS



NAME Summary

- Agreement between the obs and NAME simulation increases when higher spatial resolution met data is used
  - Correlation coefficient increases T+24-T+48
  - Fractional bias decreases for high resolution simulation if higher temporal resolution met data is used

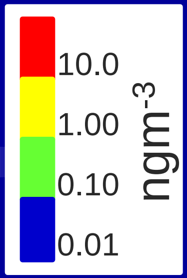
- Improvement due to better representation of
  - Rapid change in wind speed and direction associated with the cold front
  - Vertical ascent along the cold front

UM - Method

- UM is an Eulerian model
  - Emit tracer over 1 grid box
  - Emit tracer in lowest model level (20m)

- Tracer is passive, non-depositing and non-reactive
- Tracer transported by advection, convection and turbulent mixing
- Vary spatial resolution (50km, 12km)

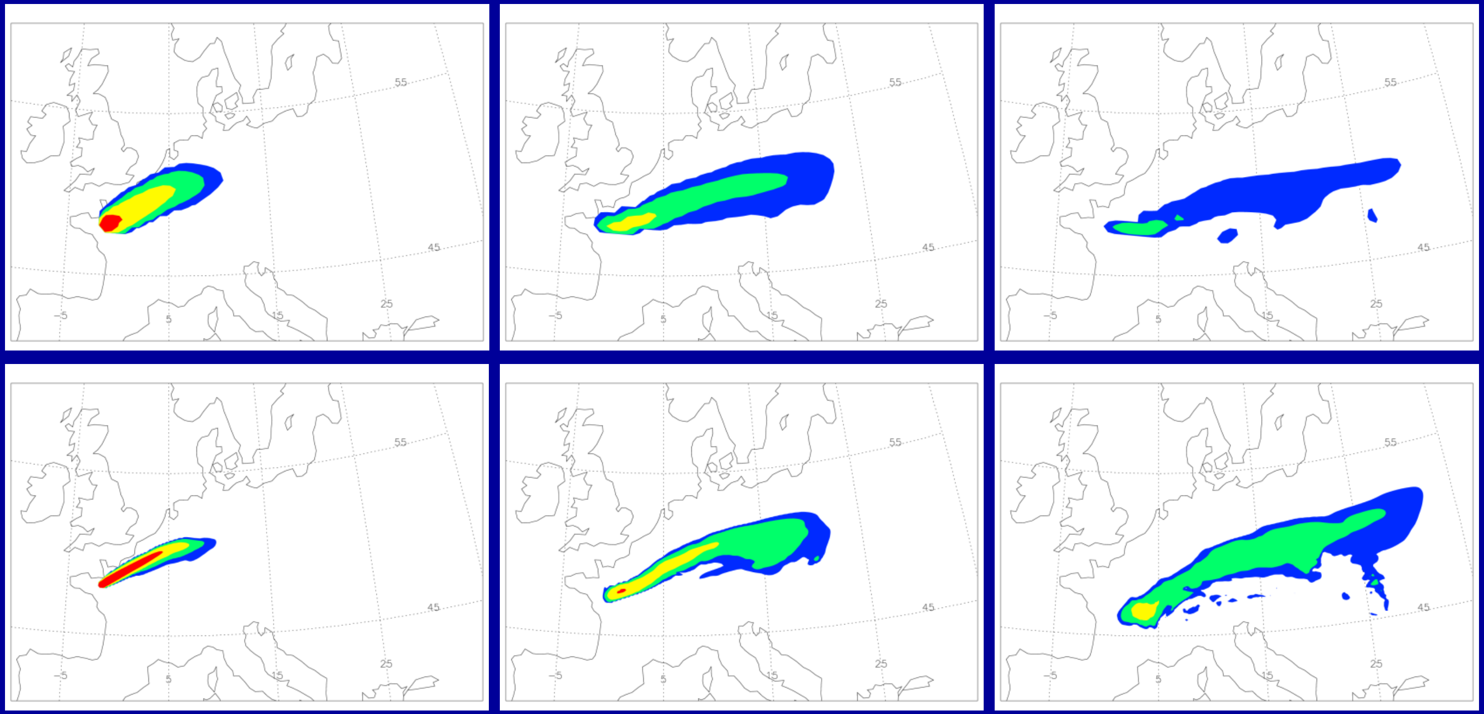
UM – Tracer Concentrations



T+12 T+24 T+36

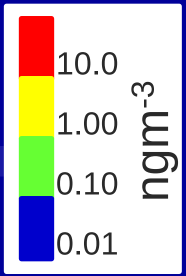
UM
Δx=50km
Δt=10min

UM
Δx=12km
Δt=5min



- High resolution maximum tracer concentrations larger
- Both resolutions capture tracer behind cold front

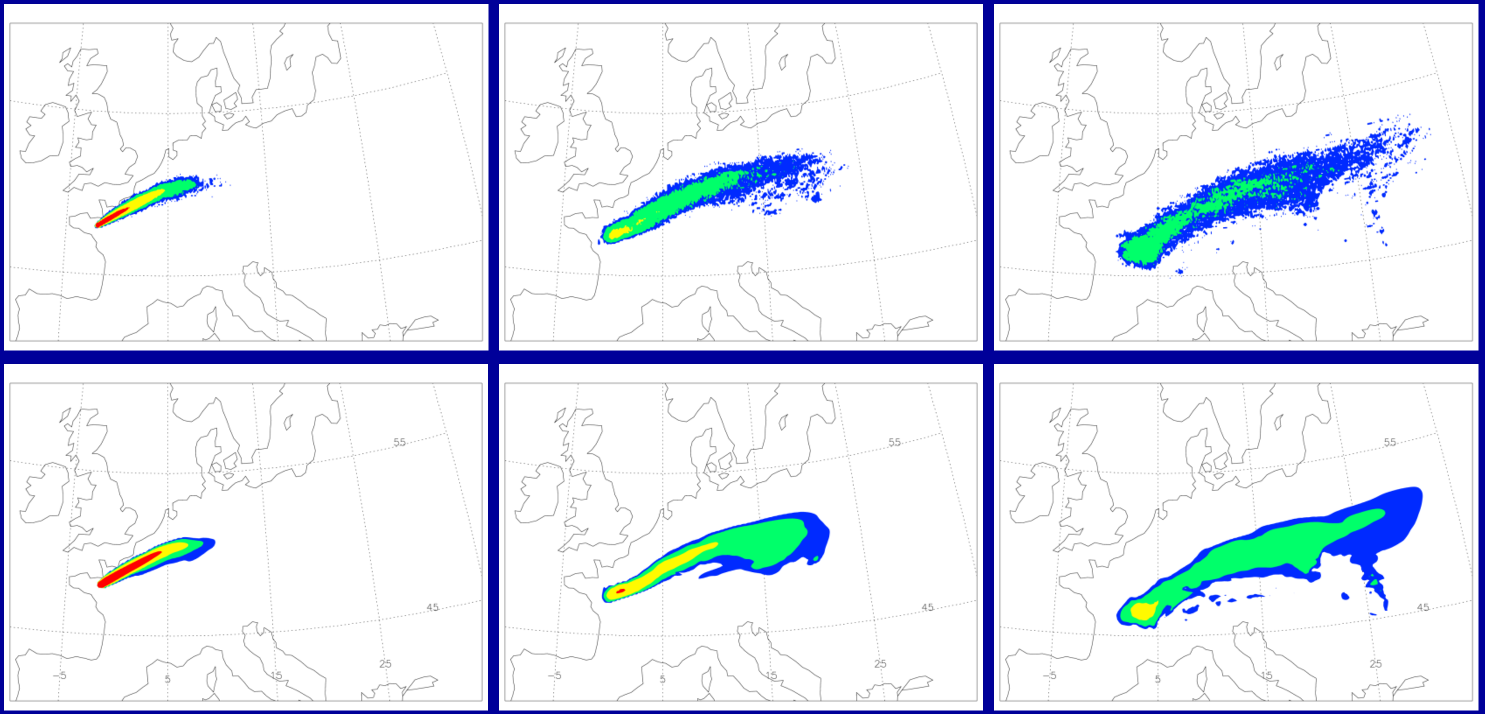
UM – NAME Comparison



T+12 T+24 T+36

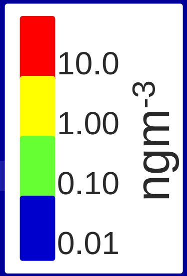
NAME
Δx=12km
Δt=1hour

UM
Δx=12km
Δt=5min



- UM shows similar plume shape to NAME simulation
- UM predicts larger tracer concentrations (bl mixing param?)

UM – OBS Comparison

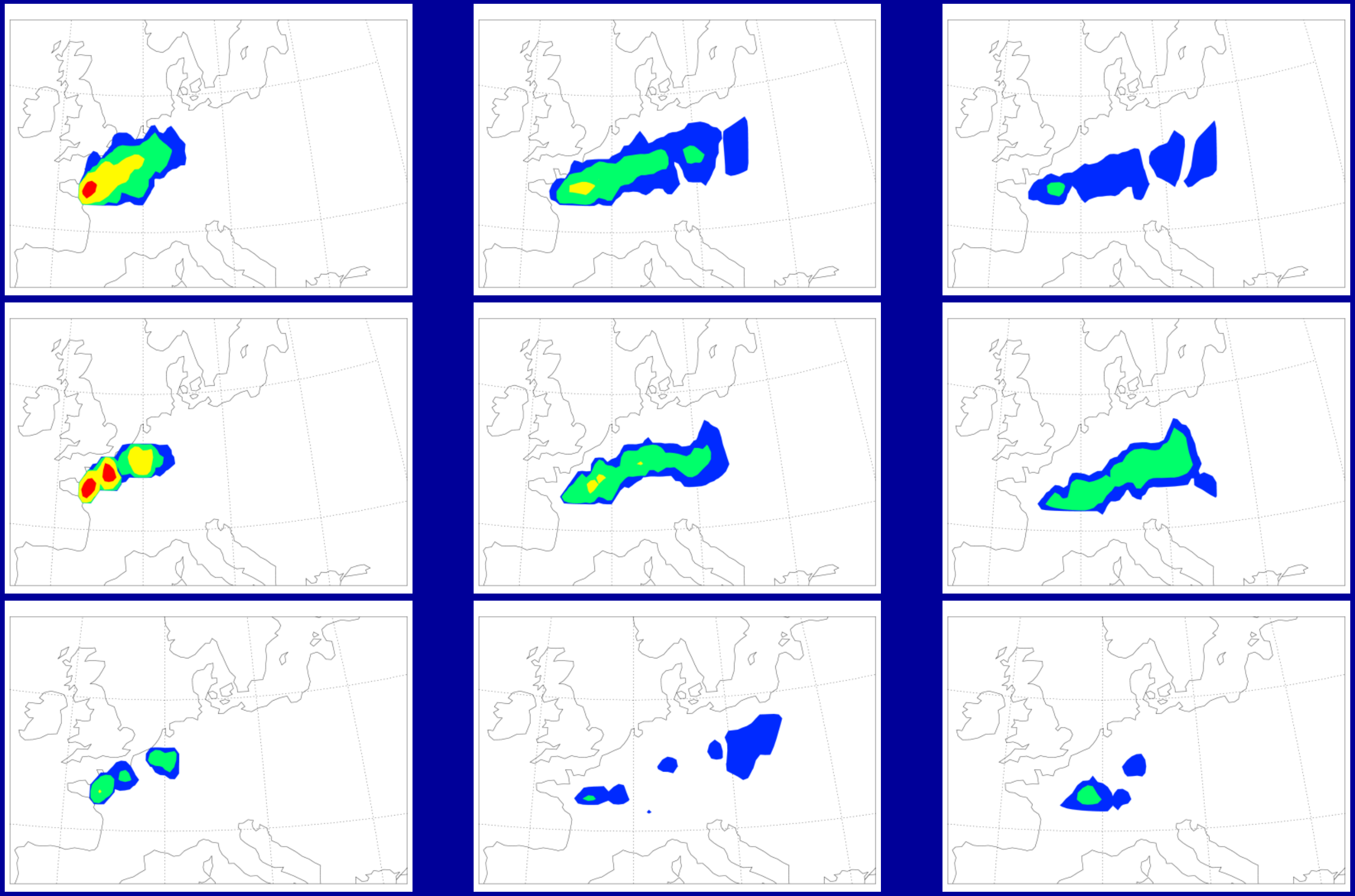


T+12 | T+24 | T+36

UM
Δx=50km
Δt=10min

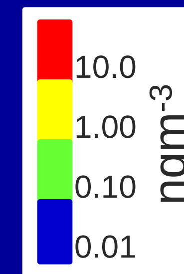
UM
Δx=12km
Δt=5min

OBS

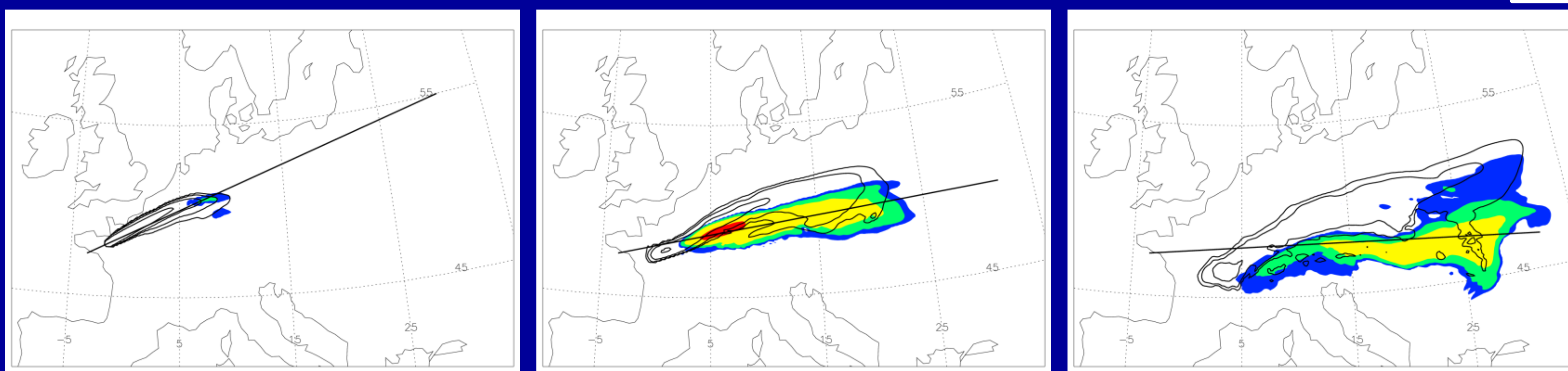


UM – Tracer Concentrations

- Tracer concentrations at 2880m



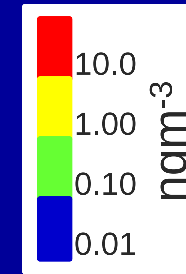
T+12 | T+24 | T+36



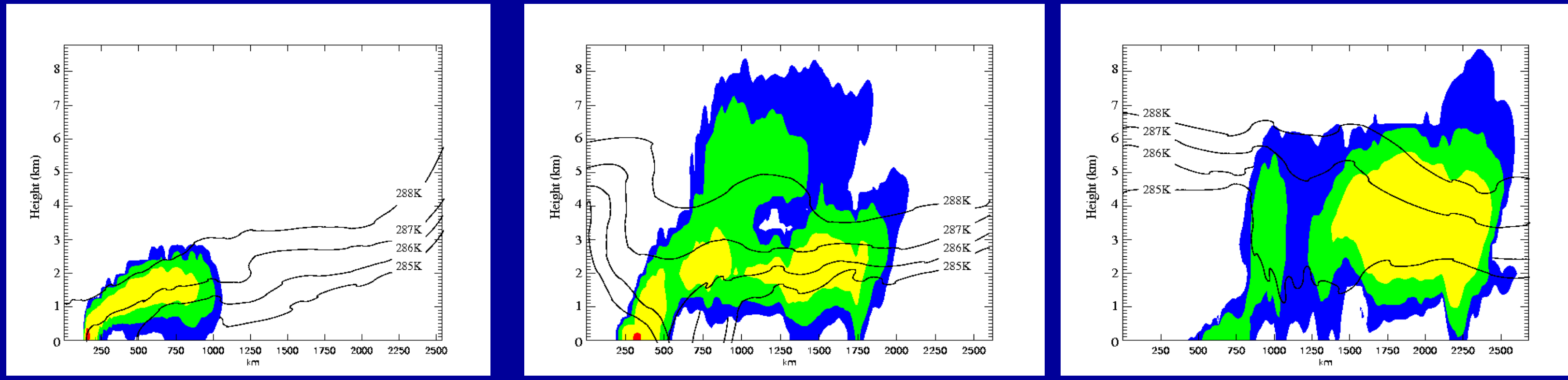
- Tracer transported vertically out of boundary layer
- Mid-level tracer plume is orientated east-west

UM – Tracer Concentrations

- Vertical Cross-section of tracer concentrations

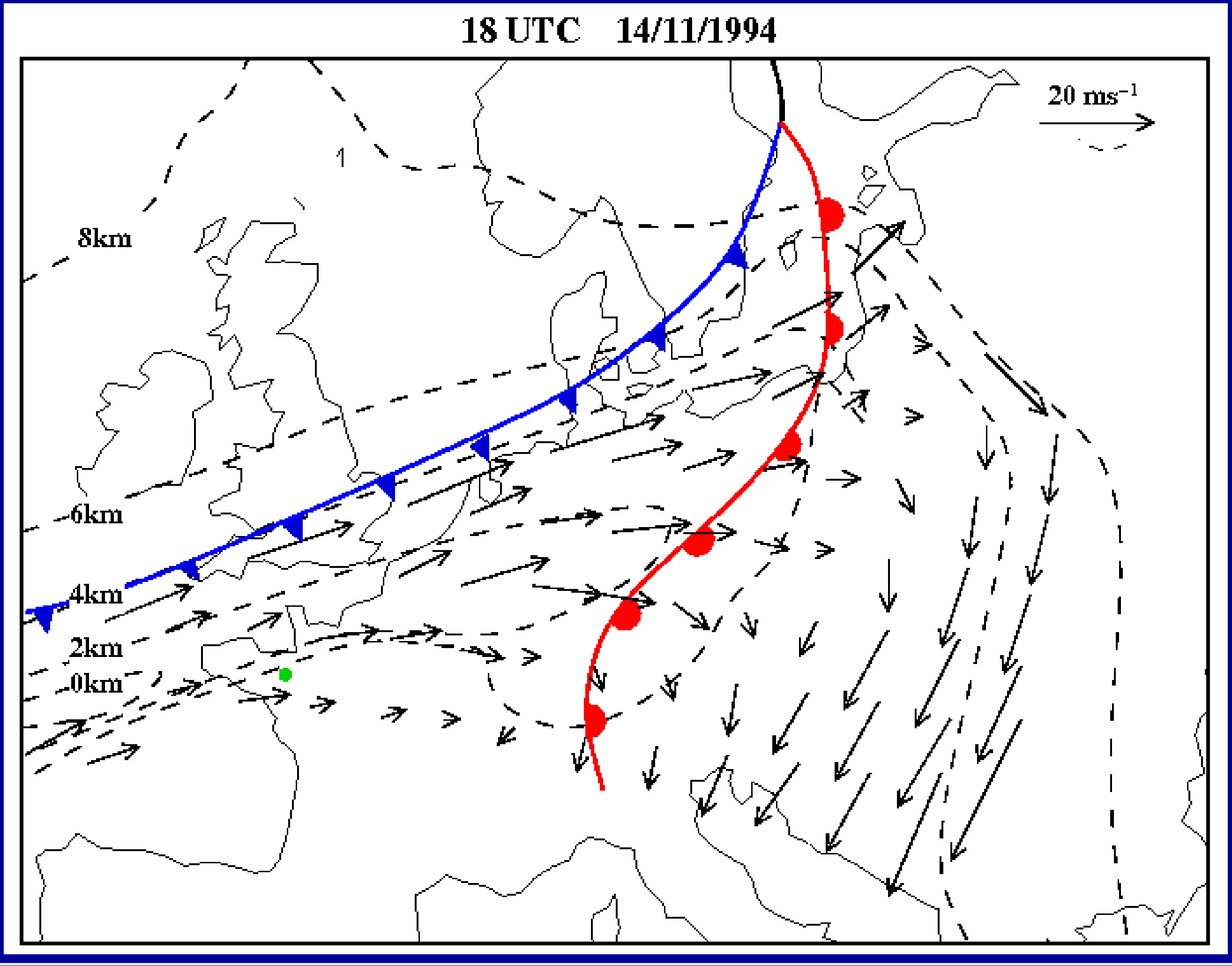


T+12 T+24 T+36

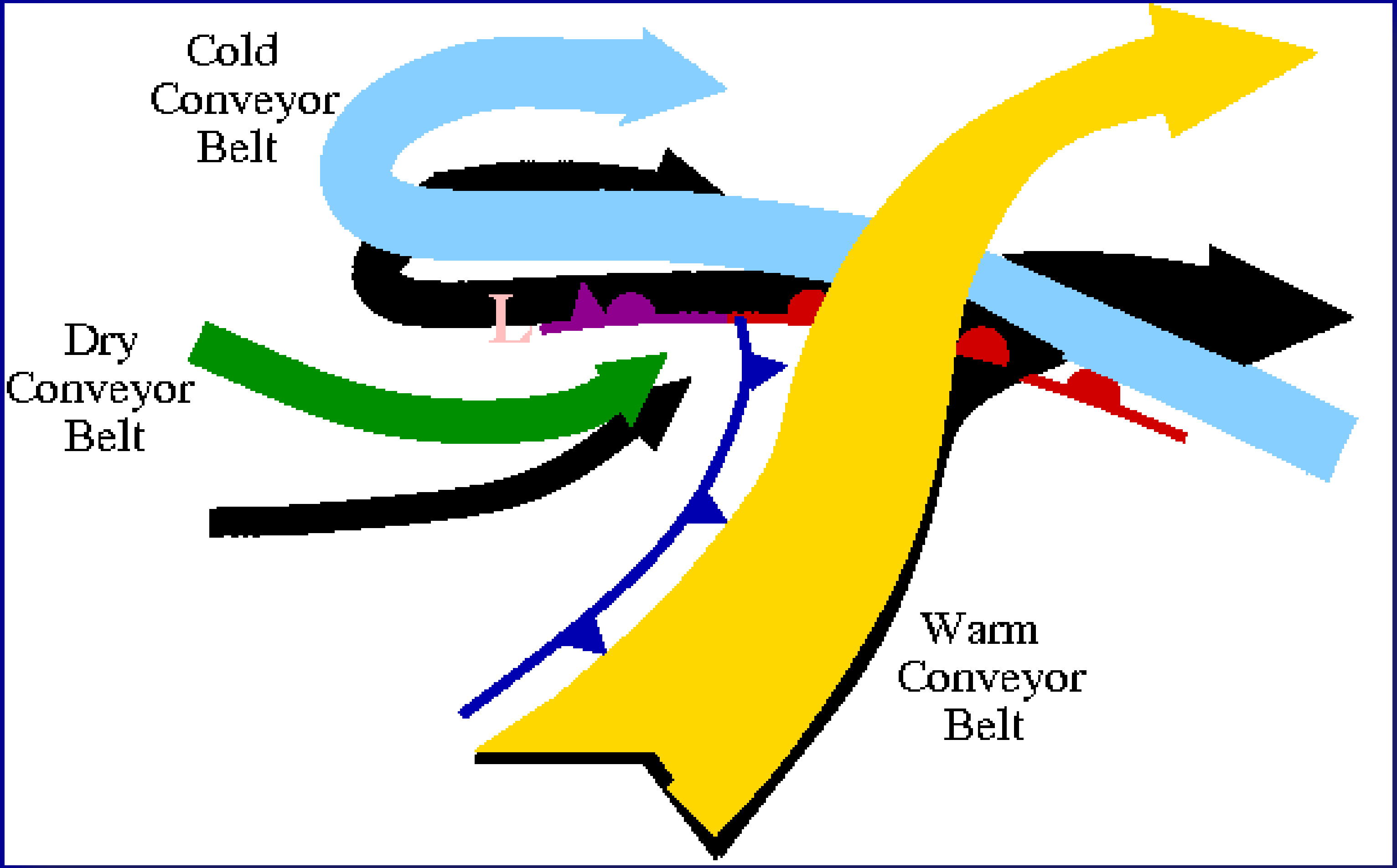


- Tracer transported vertically out of boundary layer along θ_w = 287K isotherm
- Convection transports tracer up to 8km

ETEX 2: Isentropic Surface Analysis



Frontal Cyclone Schematic



Conclusions

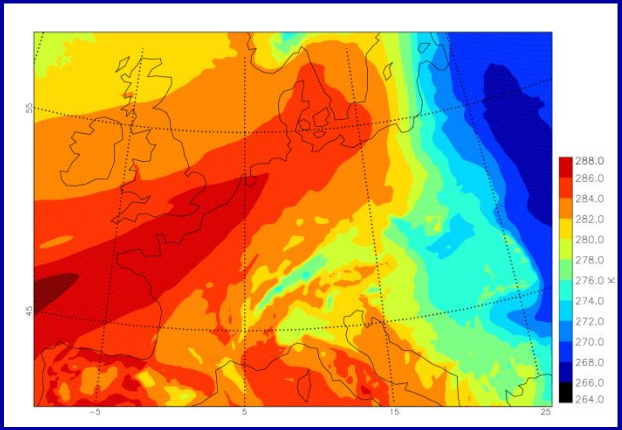
- Agreement between obs and NAME simulations increases when high res met data is used
- UM plume shape similar to NAME simulation but tracer magnitudes are larger
- UM is capable of simulating transport of point source emissions
- Analysis of tracer transport processes possible in online model
  - Vertical transport occurs in warm conveyor belt ascent and in frontal convection

Future Work

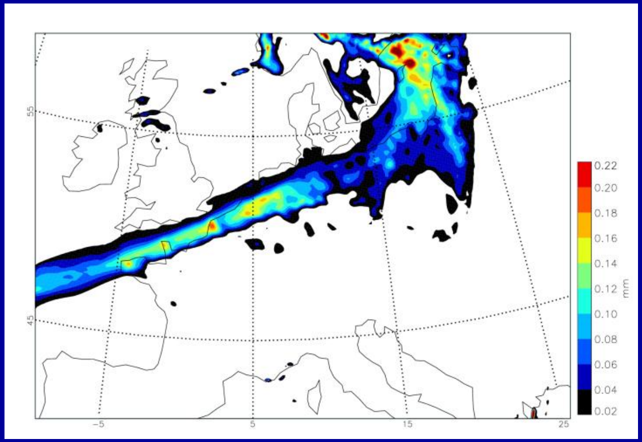
- Sensitivity studies to timing and location of emission relative to front show anomalies on the order of the tracer concentrations
- How do you quantitatively evaluate Eulerian pollution transport models?
- QPF techniques – too sparse observational network
- Model concentrations should be described in a probabilistic framework
- Concentration is a random variable and so should be described statistically using ensemble mean, variance and probability distribution

ETEX 2: UM fields at 18Z 14/11/94

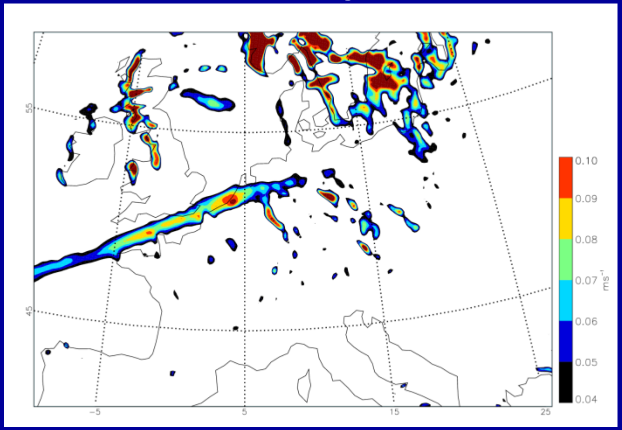
Wet-bulb potential temp at 500m



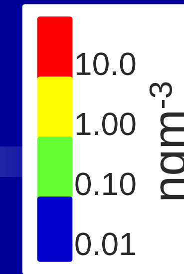
Large-scale rain amount



Vertical velocity at 750mb



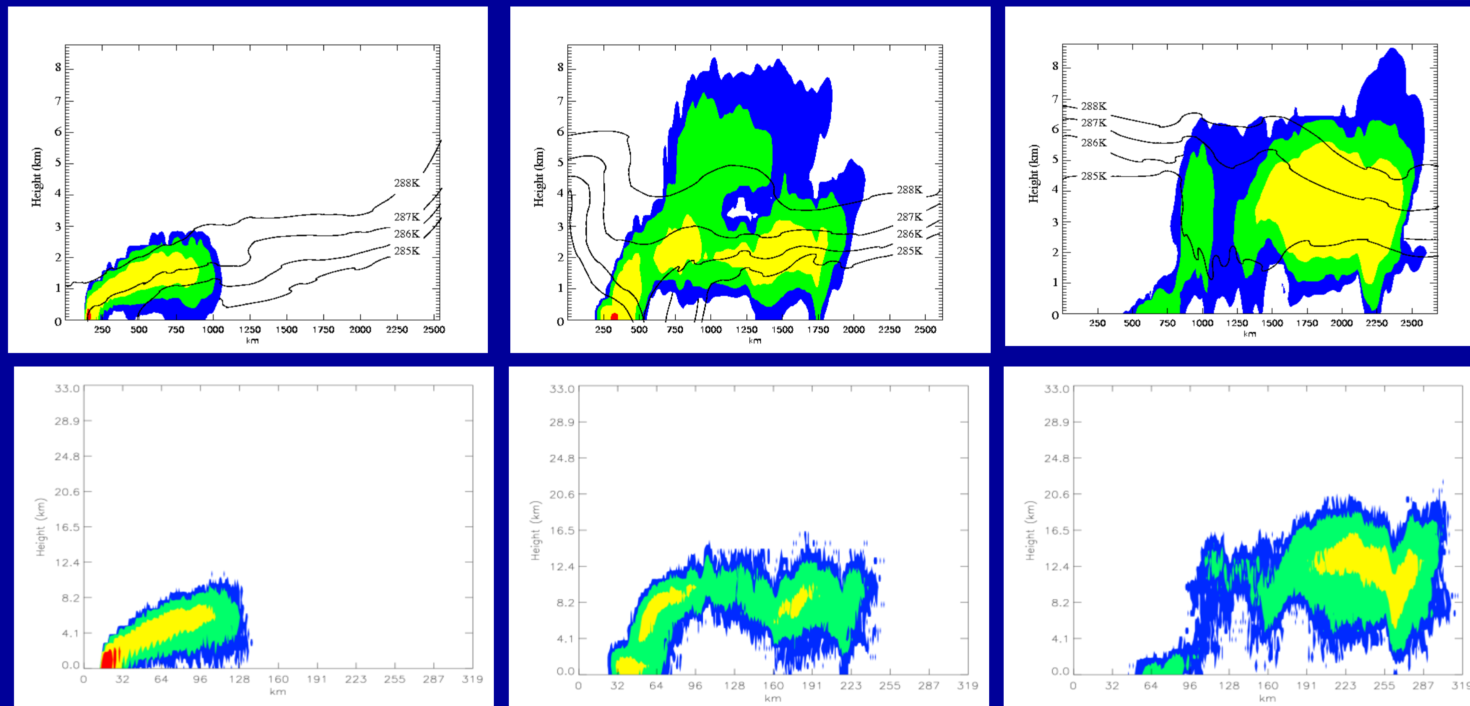
UM – NAME Comparison



T+12 | T+24 | T+36

UM
Δx=12km
Δt=5min

NAME
Δx=12km
Δt=1hour



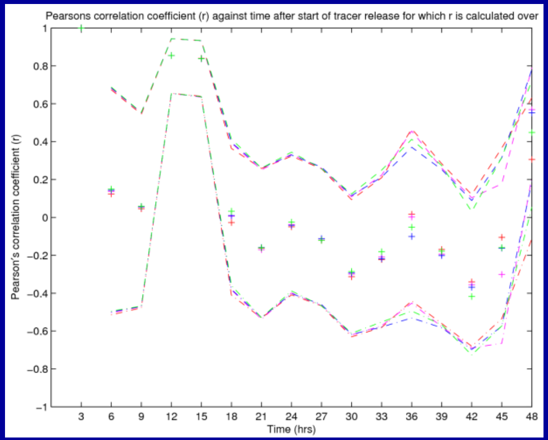
- UM shows similar plume shape and magnitude to NAME
- UM predicts deeper tracer plume

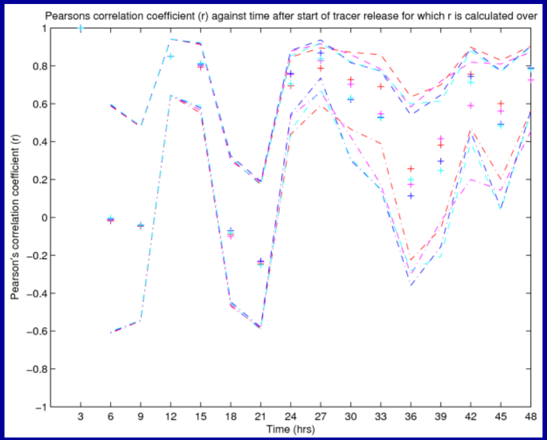
NAME - Statistics

NAME – 50km

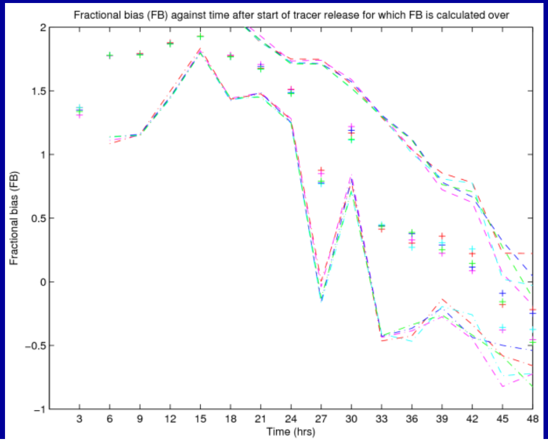
NAME – 12km

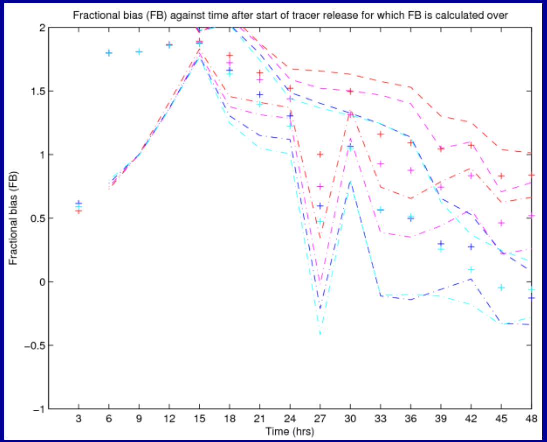
Correlation coefficient





Fractional Bias





+ 15 min + 3 hr + 6 hr + 9 hr + 12 hr

ETEX 2: Obs and UM