Estimating regional greenhouse gas emissions from surface observations through inversion modelling

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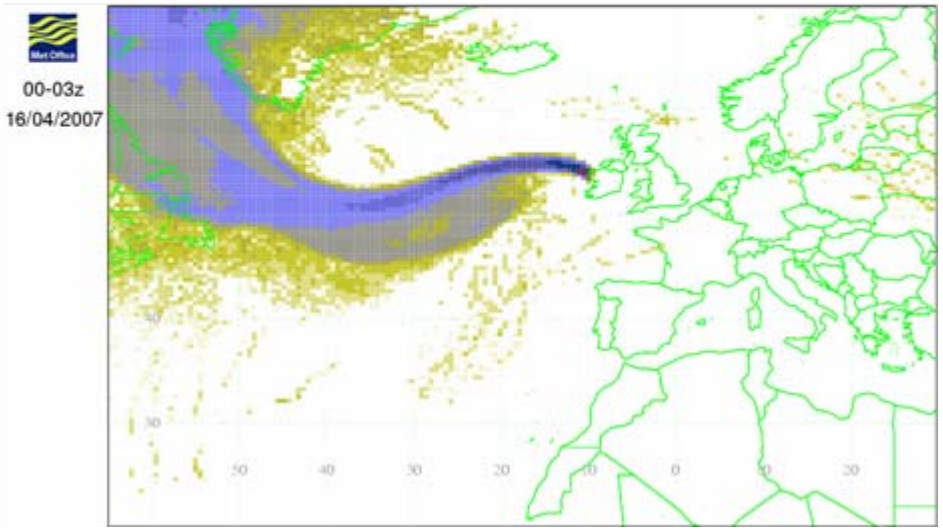
NAME-Inversion method (1)

- NAME model (Lagrangian particle dispersion model).
- Uses 3-D met. data
  - UK Met Office NWP model (~40-60 km)
  - ECMWF ERA Interim (re-analysis) (~80 km).
- Run backwards in time
  - Assume dispersion is reversible
  - Significant improvement in efficiency.
- Scale NAME output to a unit release per second from each grid box



Example Air History Map using NAME

- Run back in time for 2-3 weeks from the observation location
- Describes surface sources that would impact on the observation point during a specific time period (e.g. 3 hours)
- Output = Time integrated air concentration [gs/m^3]
- Dispersion based on thousands of particles

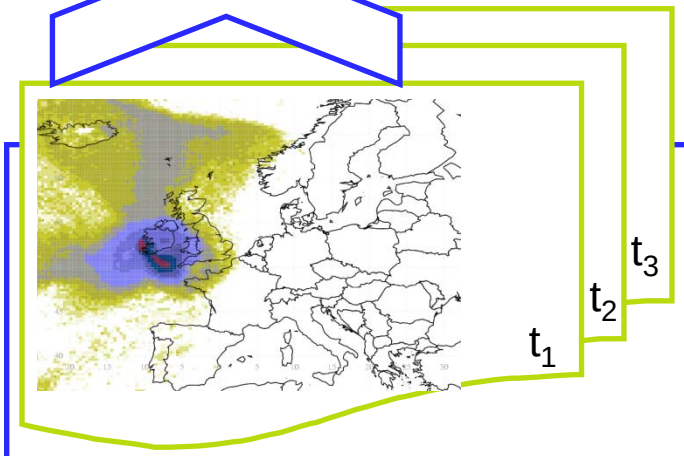
The NAME-Inversion Method (2)

$$\underline{M}\ [T \times N]\ [s/m^3] \quad ¤ \quad \underline{e}\ [Nx1]\ [g/s] \quad = \quad \underline{o}\ [Tx1]\ [g/m^3]$$

Transport matrix

Emission map:
The solution.
Assumed constant in time.

Time series of observations, related to recent emissions



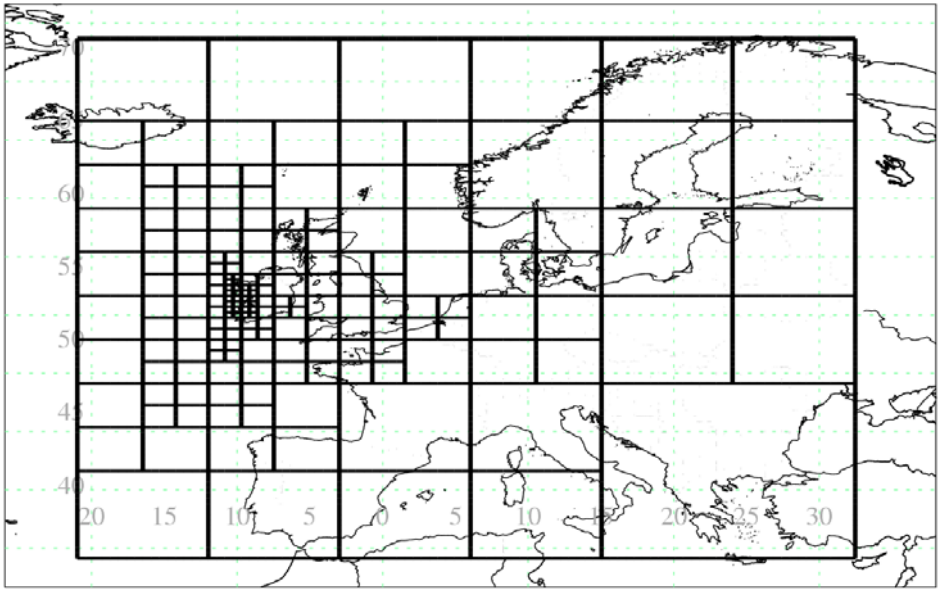
- Air history maps from observation point generated using NAME.
- Contribution of surface sources to concentration at observation pt.

T = Number of time-intervals

N = Number of emission grid boxes

The NAME-Inversion Method (3) : Grid used to Estimate Emissions

- Balance equation so that each grid contributes equally (approximately).
- More distant grids grouped together so have same impact at the observation station.



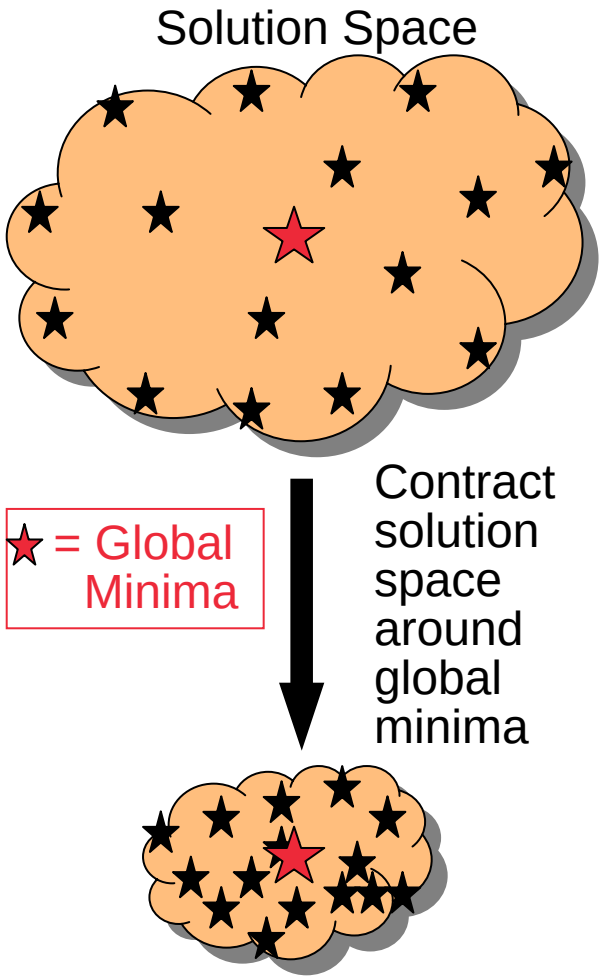
Example: Grouping of grids based on observations at Mace Head (on west coast of Ireland).

The NAME-Inversion Method (4) : COST (skill score) function

- Inversion method requires an ability to measure the 'goodness-of-fit' of an estimated emission map to the time-series of observation.
- Through experimentation NAME-inversion method uses a combined combination of statistics:
  - Correlation
  - Normalised Mean Square Error
  - Fraction within estimated noise (of observation)
- Inversion will iterate towards the minimum of the cost function.

The NAME-Inversion Method (5) : Simulated Annealing

- Randomly (or based on *a priori*) generate many emission maps – calculate score for each.
- Generate new emission map based on (but different to) current ‘best’ emission map.
- Keep new emission map if better score than current ‘worst’ emission map.
- How near new emission map is to the current ‘best’ emission map controlled by ‘temperature’.
- Reduce ‘temperature’ slowly (annealing) to try and capture ‘true’ global minima.
- Iterate until ‘best’ - ‘worst’ difference is small.



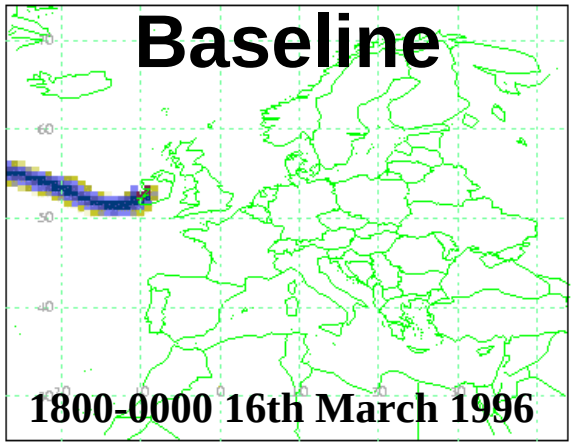
Application of NAME-inversion method

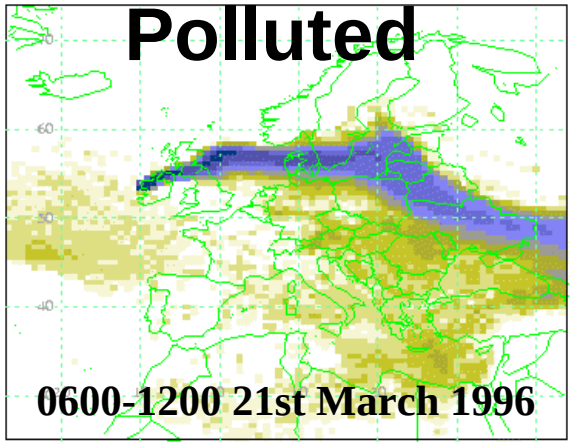
Estimating UK emissions of greenhouse and ozone-depleting gases

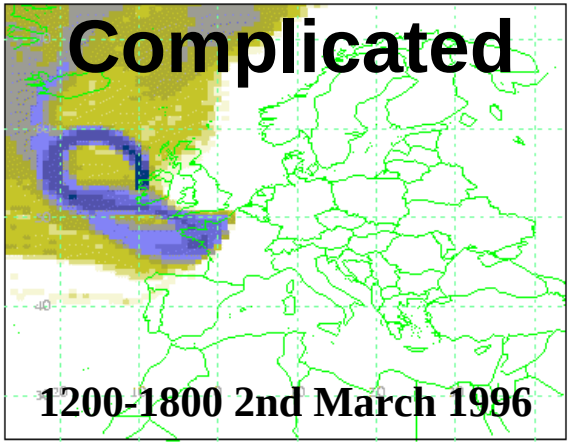
Overview

- Estimate UK emissions of greenhouse and ozone-depleting gases totally independent of UNFCCC (United Nations Framework Convention on Climate Change) inventory process.
- Use in-situ high-frequency atmospheric observations from the remote station on the west coast of Ireland (Mace Head).
- Two stage process:
  - Estimate long-term Northern Hemisphere baseline concentration.
  - Estimate regional emissions through inversion modelling.
- Compare NAME-inversion estimates to UNFCCC inventory estimates.

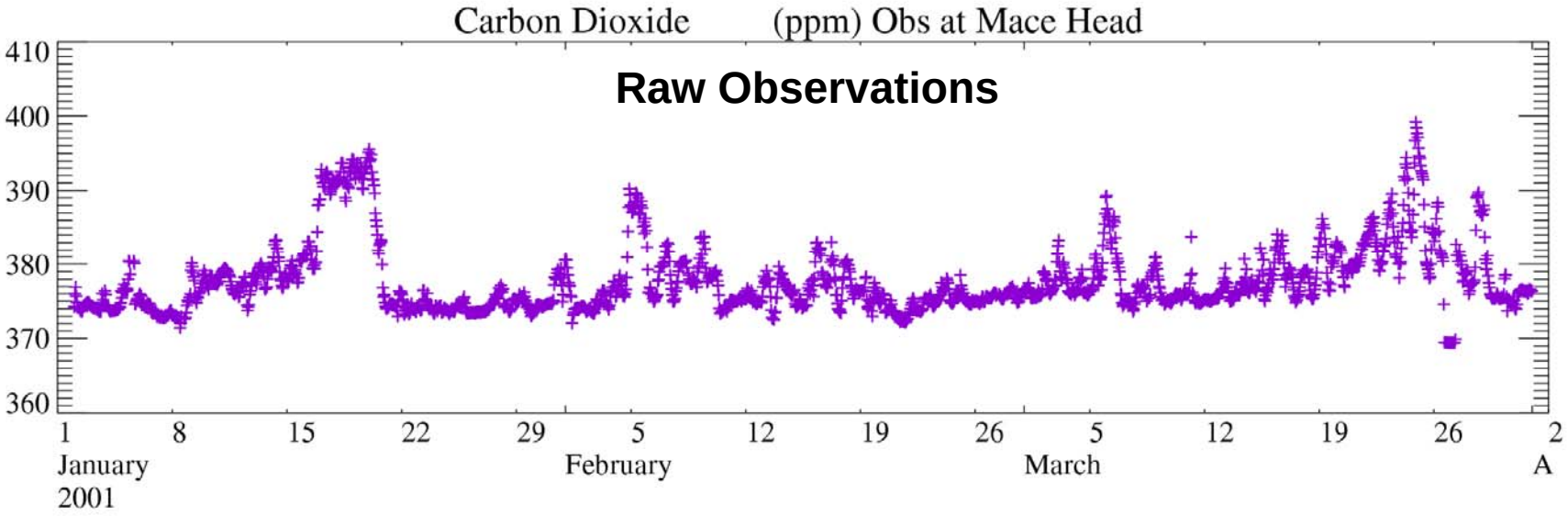
Where has the air come from? Examples:

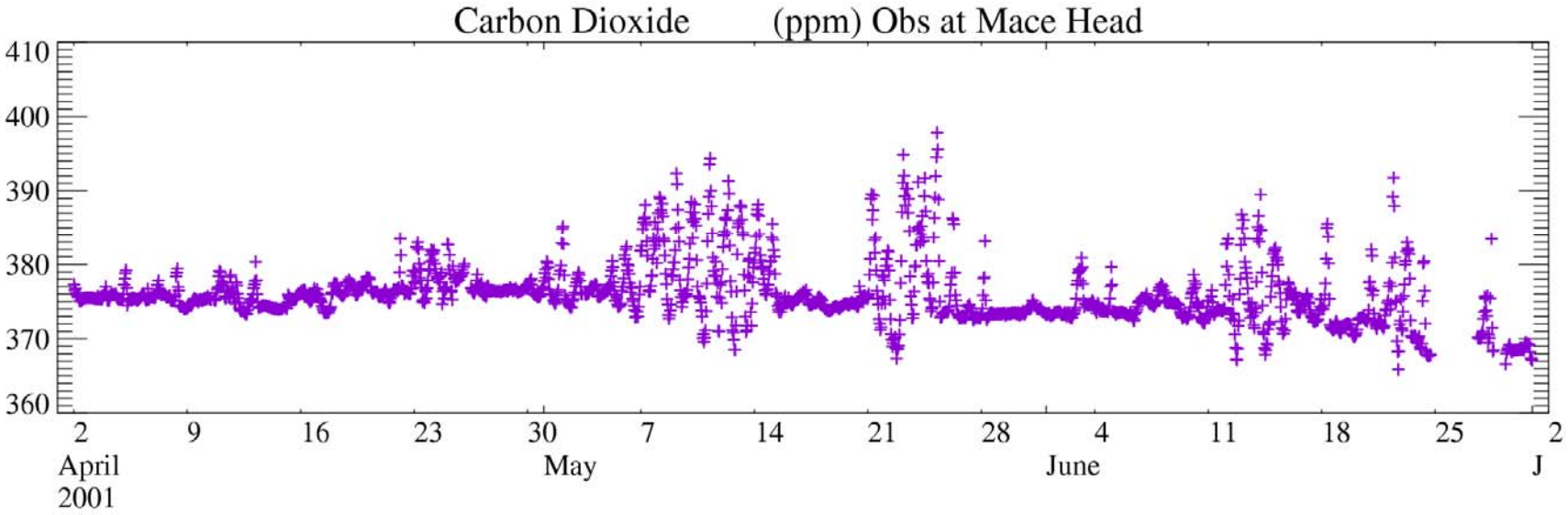






Baseline Concentration Methodology: Classifying Mace Head Observations





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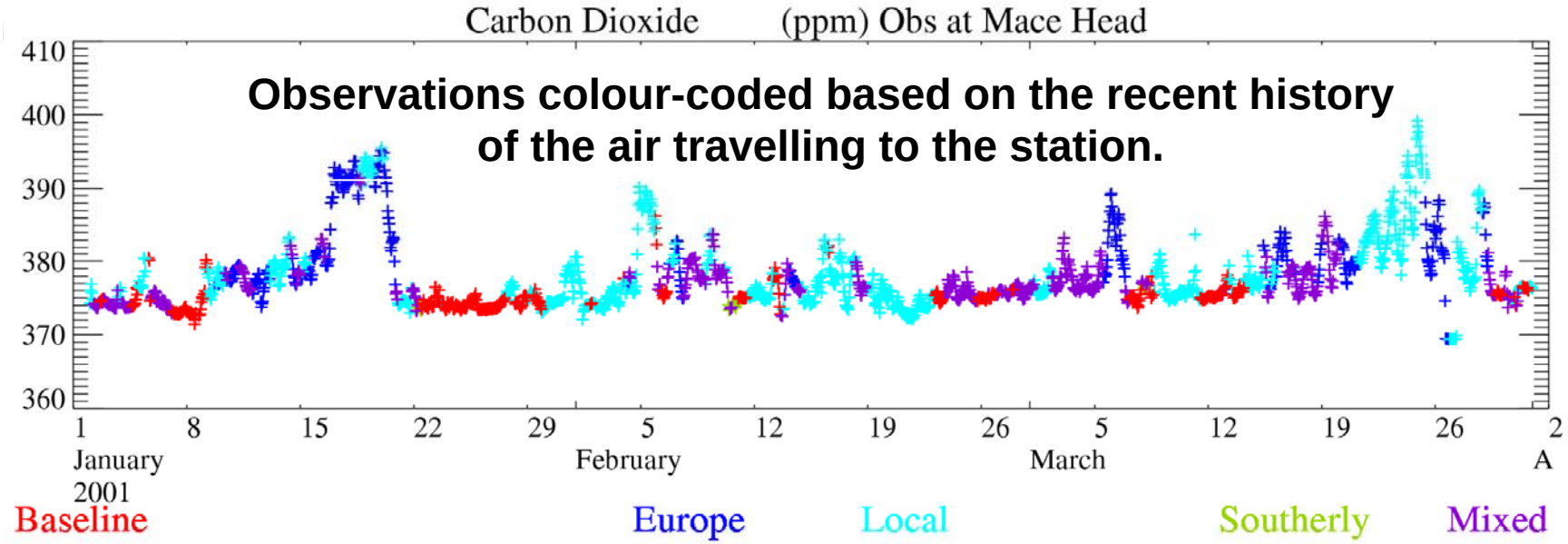

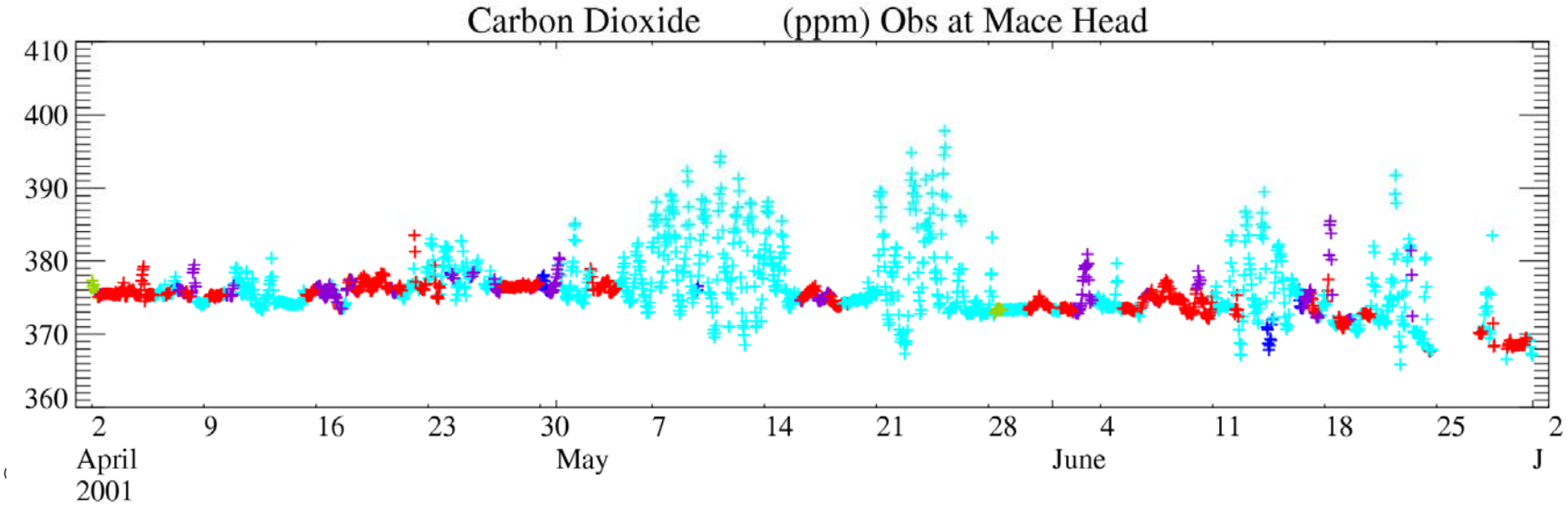

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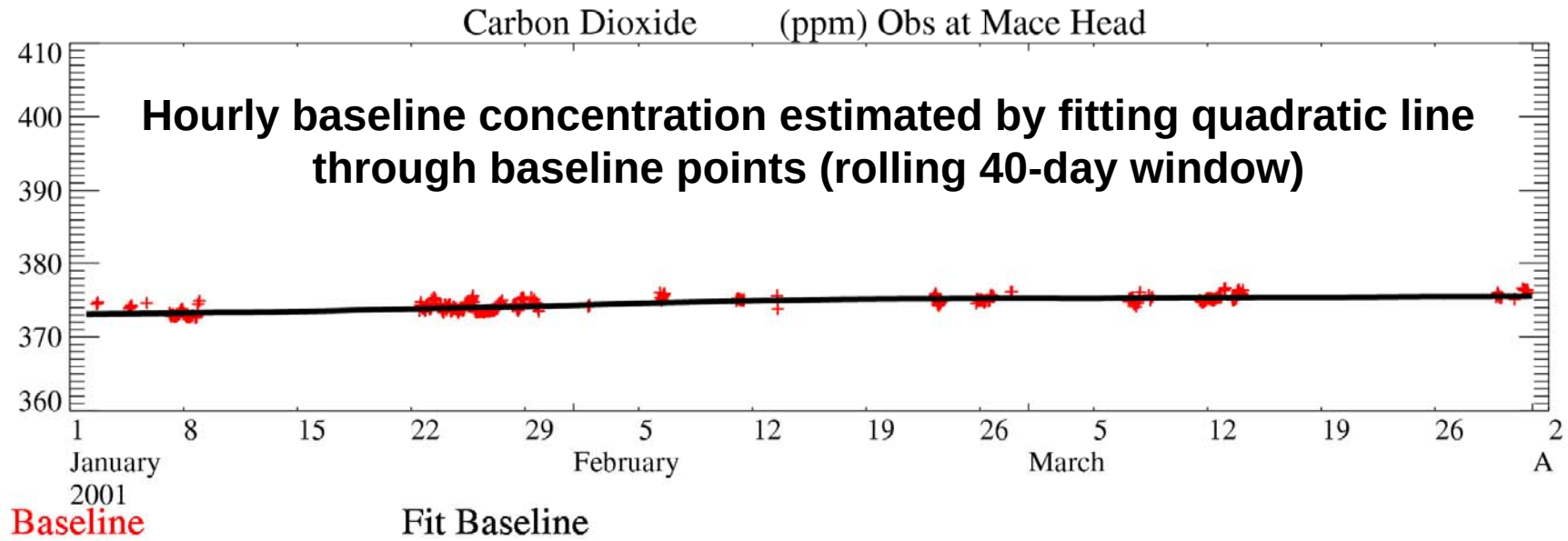

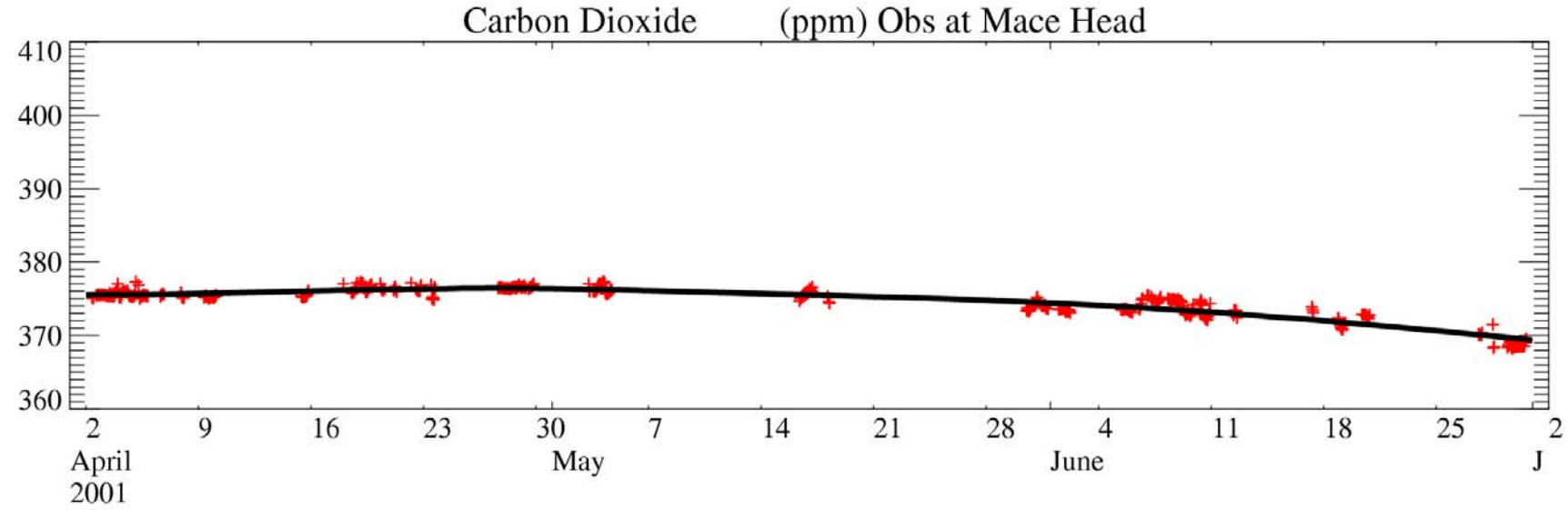

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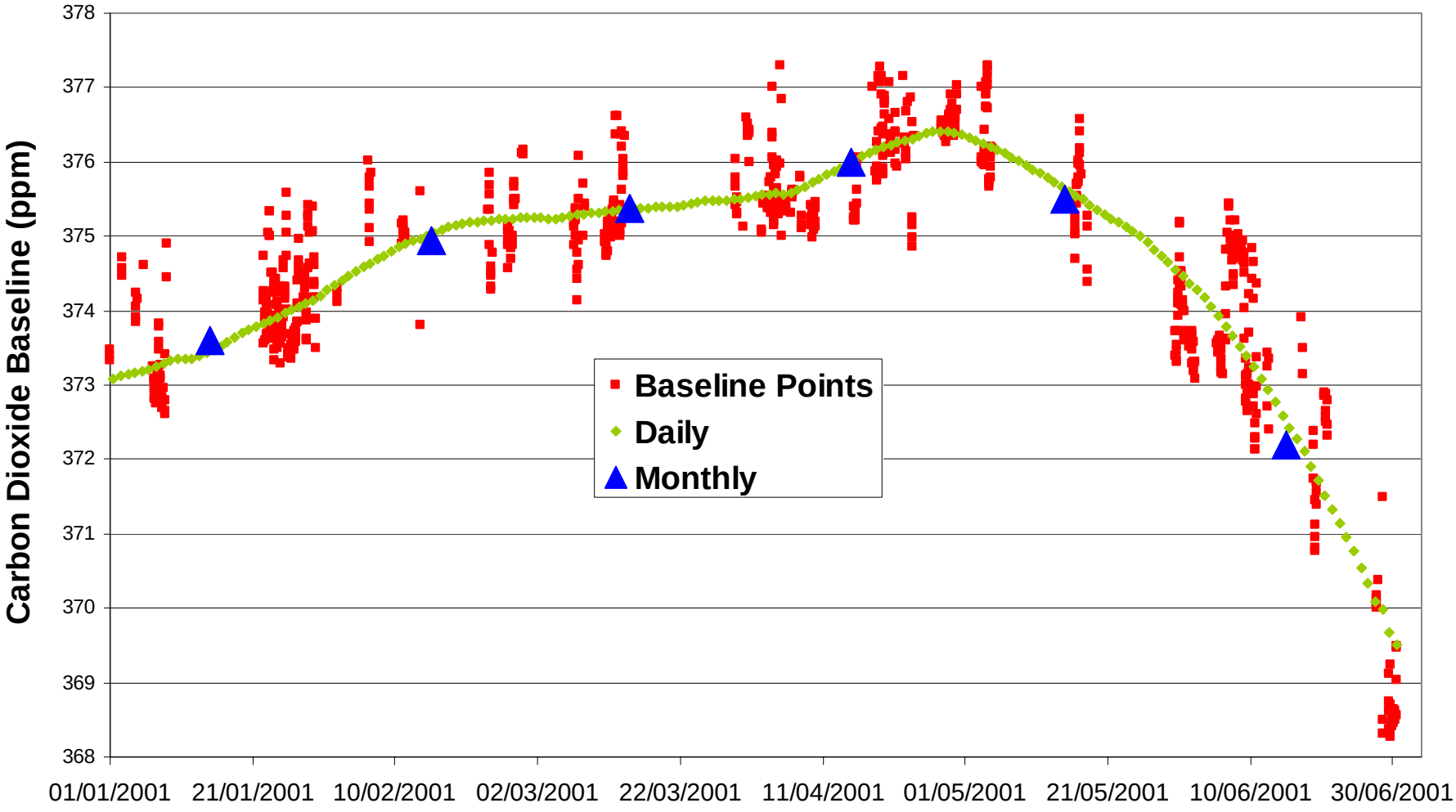
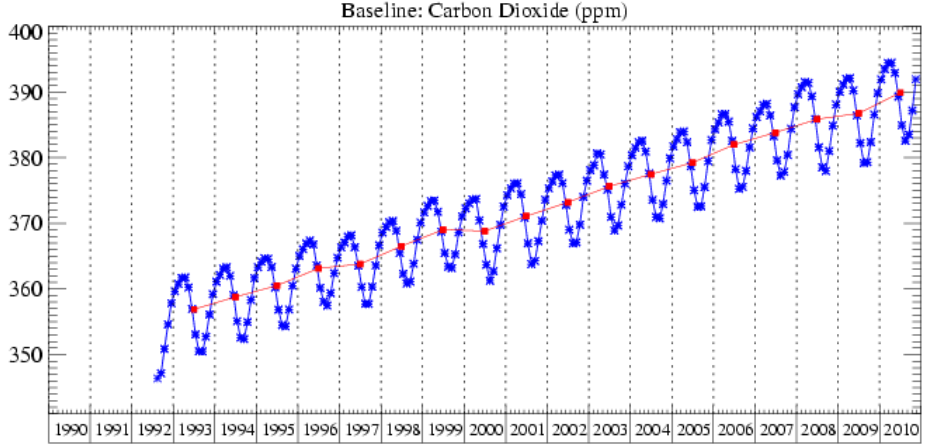


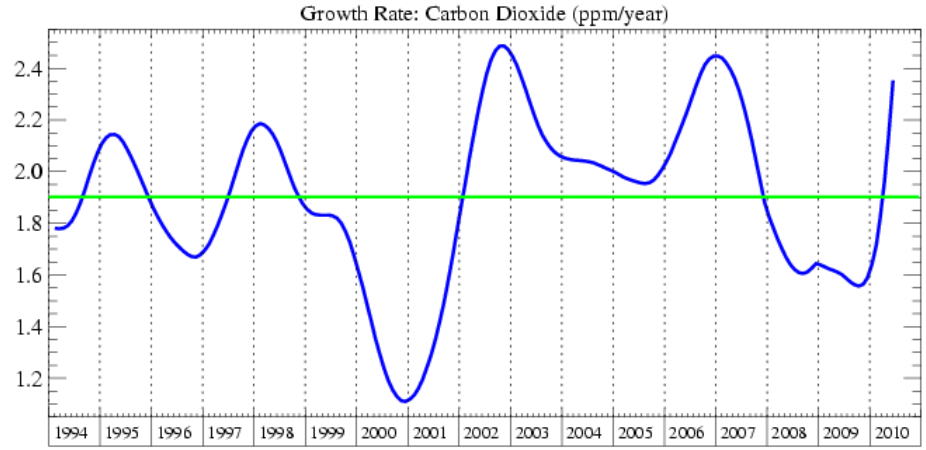
Met Office

Mid-latitude baseline concentration of: **Carbon Dioxide** (ppm)

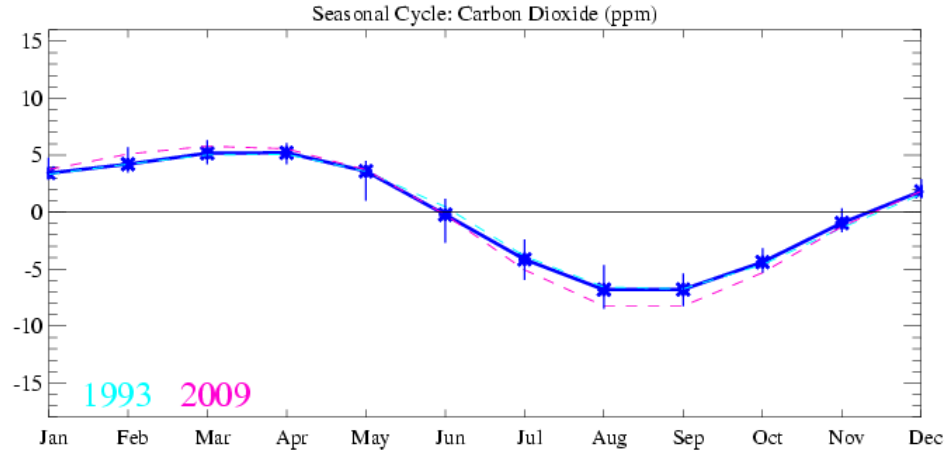
Baseline



Growth Rate



Seasonal Cycle

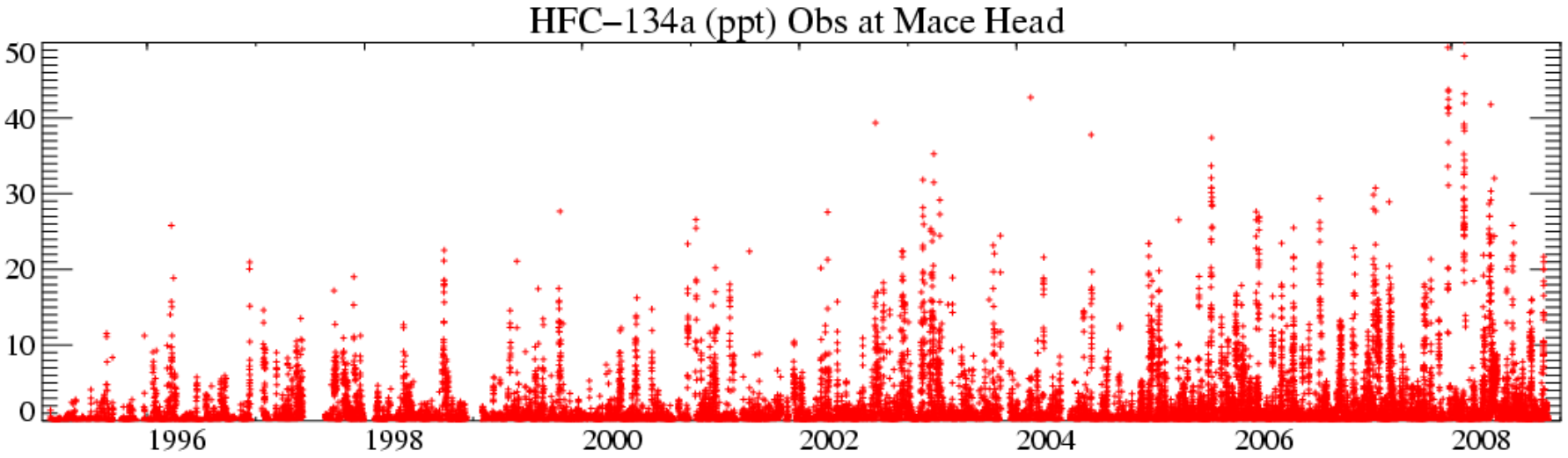


Estimating regional emissions from above baseline concentrations

Estimating Regional Emissions: Inverse Modelling

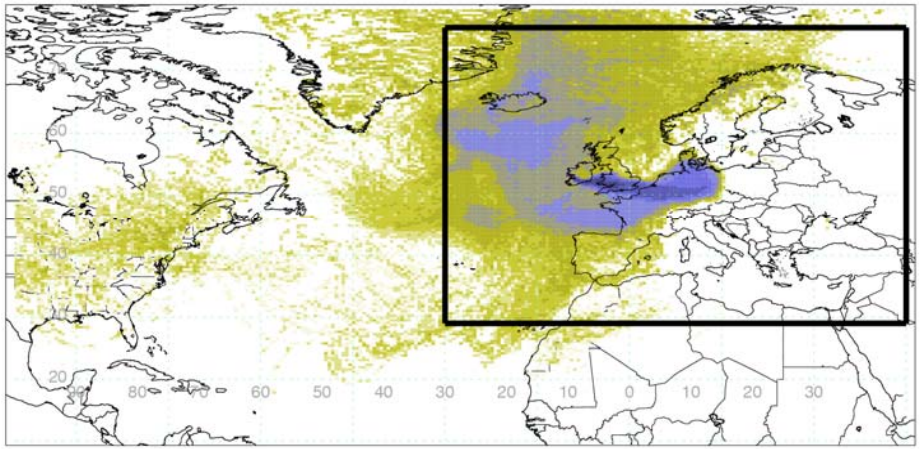
Aim: **Generate emission estimates from 'polluted' (above baseline) observations.**

Subtract the baseline concentration from each observation.



Inversion Technique

Air Origin Map = Matrix **M**
(N^{o} times x N^{o} grids)



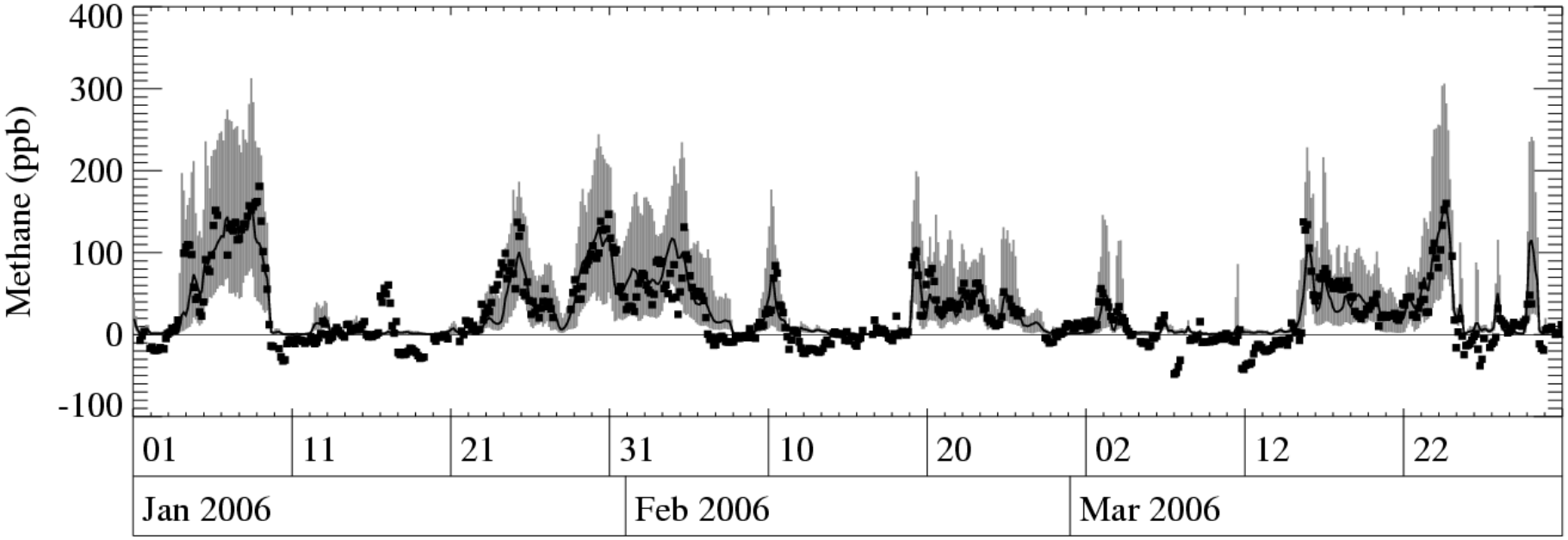
Dilution matrix = **M**
Measurement - Baseline = ***o***
Emission Map = ***e*** (the solution)
Relationship: **M** ***e*** = ***o***
Problem: Minimise ***o*** - **M** ***e***

- Remove observations that have a strong **local** influence.
- No prior information – **Random** initial guess – Not steered by *a priori*.
- Solve for each **3-yr** period stepping monthly e.g. Feb'89 – Jan'92, Mar'89 – Feb'92, …
- Solve **multiple** times, each time start from different random initial guess.
- Apply random **'noise'** to observations (log-normal distribution).

Model Solution Vs Observation

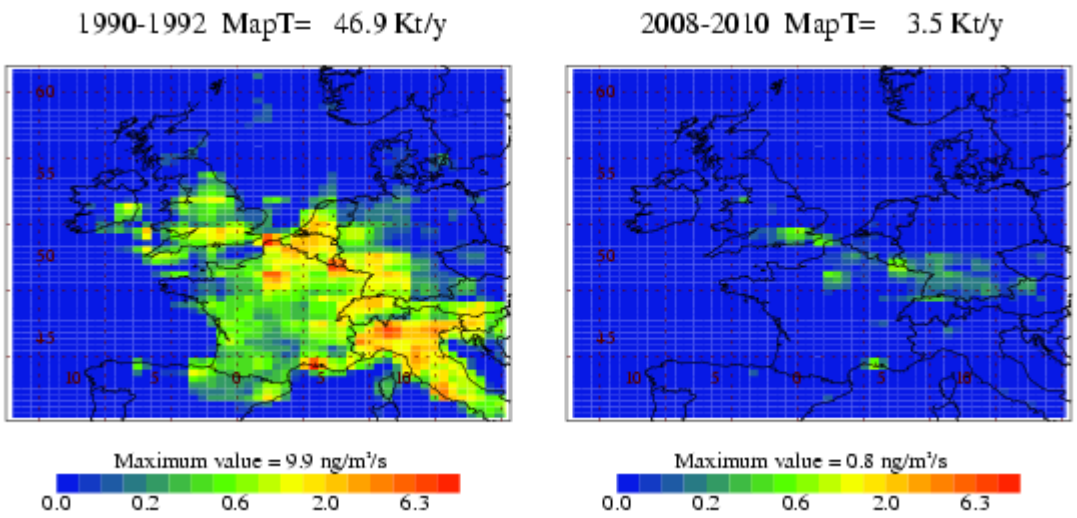
‘Best-Fit’ Model (Black Line + Grey Uncertainty)
Observation (Black Dots)

Time-series for methane (ppb) Jan-Mar 2006

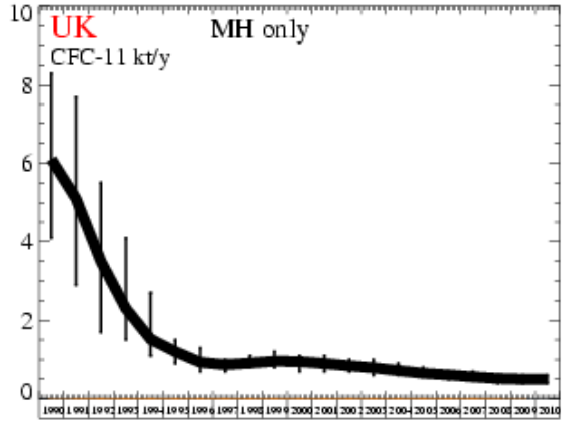


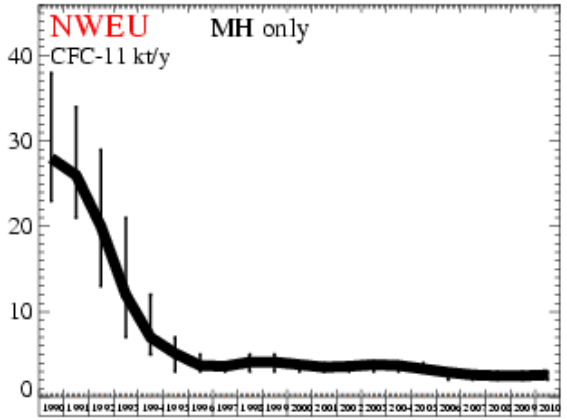
CFC-11

Uncertainty = 5th and 95th percentile of solutions from all solutions covering complete calendar year



1990-1992 2008-2010



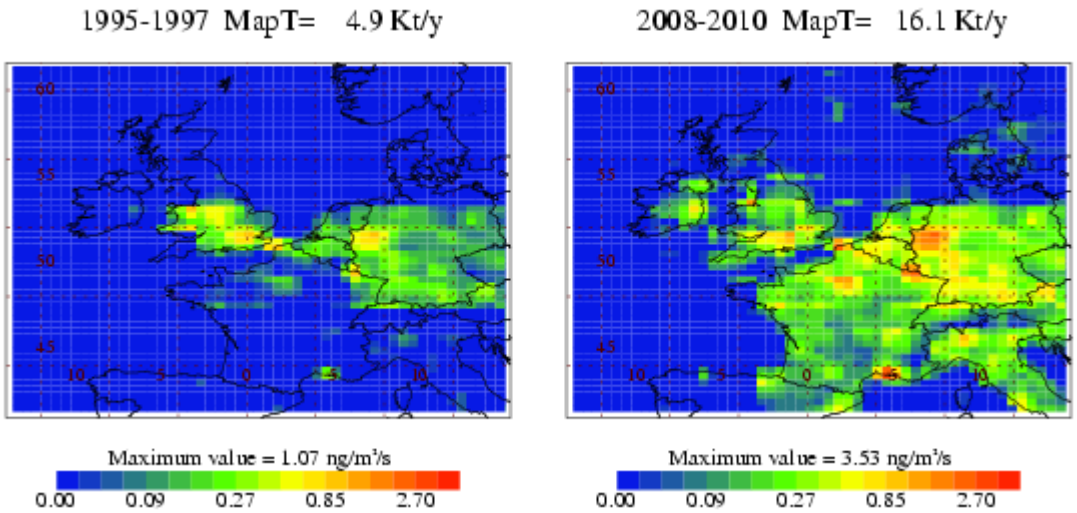


Post-adjustment: Emission distribution within inversion grid boxes based on inventory CO (population) distribution.

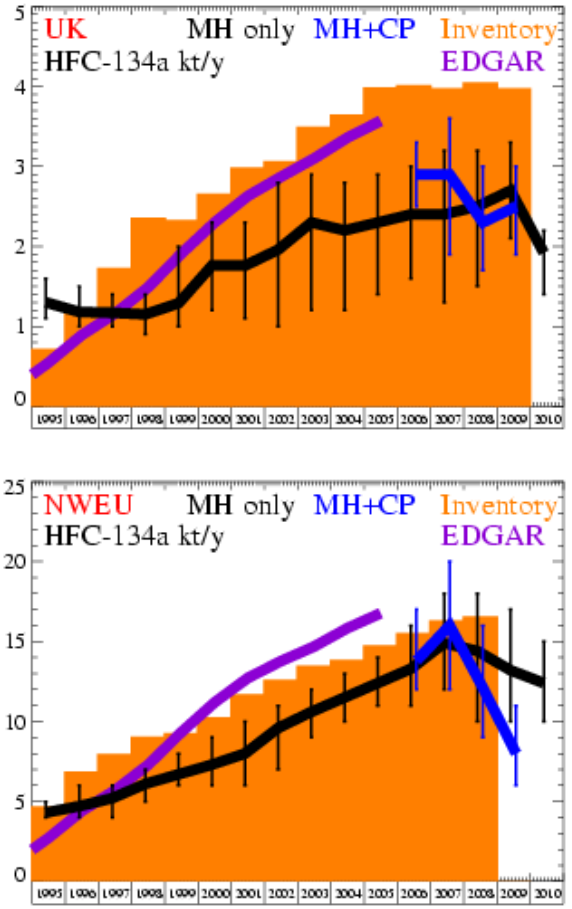
NWEU = North West Europe

[Ire, UK, Fra, Ger, Bel, Neth, Lux, Den]

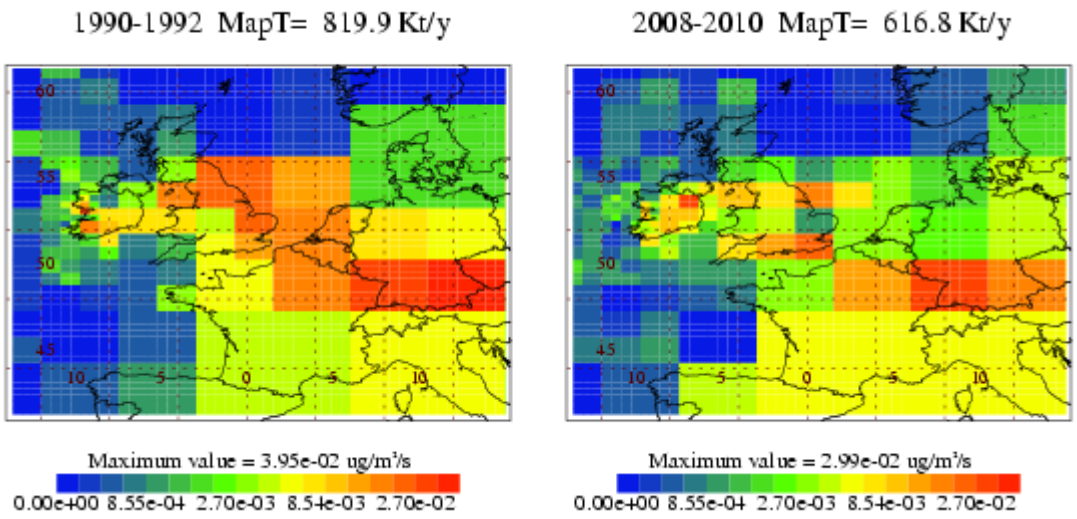
HFC-134a



1995-1997 2008-2010



Nitrous Oxide



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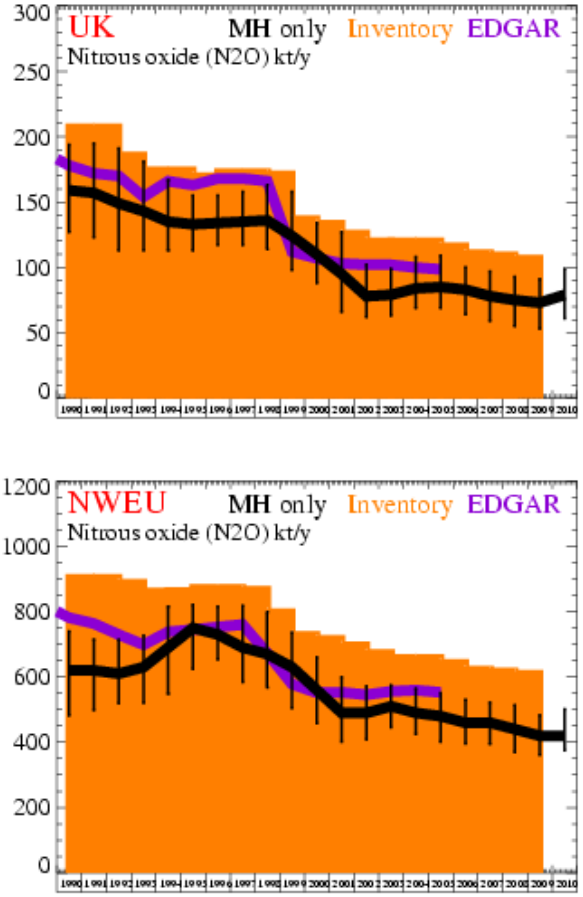
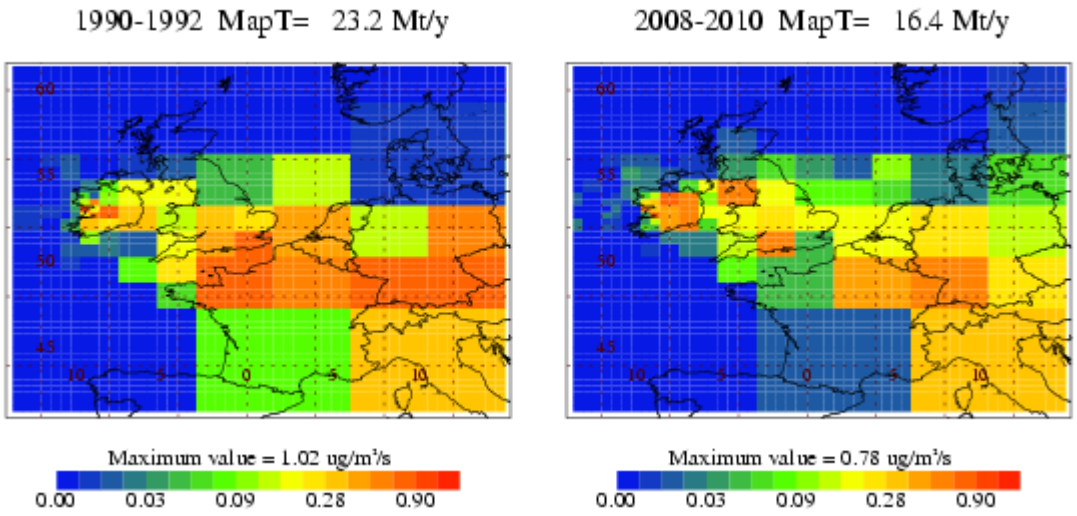


Methane and nitrous oxide discussed in detail in recent JGR paper (Manning *et al* 2011)

Methane



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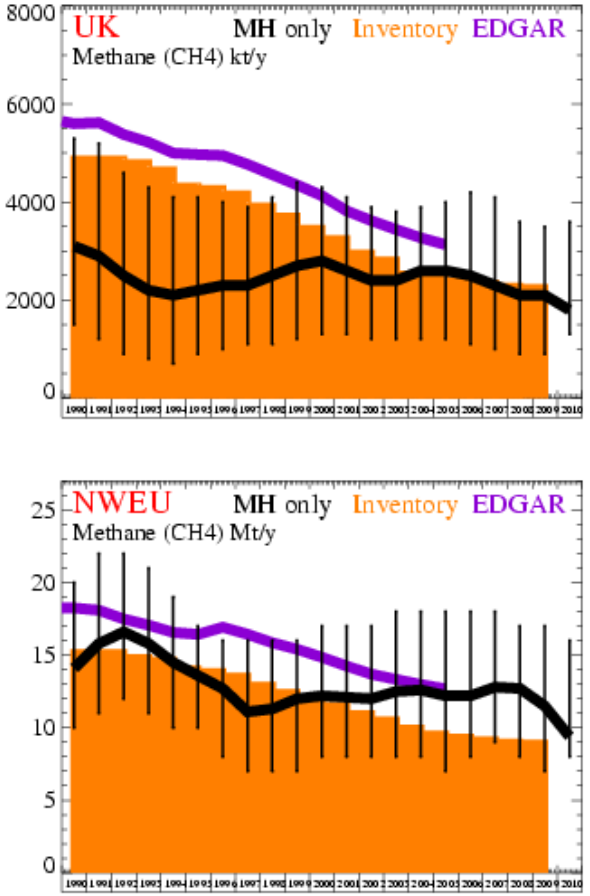

Methane and nitrous oxide discussed in detail in recent JGR paper (Manning *et al* 2011)

Conclusion

- NAME-Inversion system described
  - Uses NAME in backwards mode
  - Solves **M** $\underline{\boldsymbol{e}}$ = $\underline{\boldsymbol{o}}$ equation
  - Grid of emissions grouped together
  - Cost function
  - Simulated annealing
- Applied to estimate UK greenhouse and ozone-depleting gas emissions
- Observations from multiple stations can be used
- Method can be altered for other inversion studies
  - Emergency response (variables: strength and height)

Challenges

- Using observations where local meteorology not well resolved (mountain sites, urban areas)
- Isolating contributions from different source categories (e.g. industry Vs. agriculture)
- Uncertainty analysis of inversion results

Further information:

Manning, A.J., S. O'Doherty, A. R. Jones, P. G. Simmonds and R. G. Derwent
Estimating UK methane and nitrous oxide emissions from 1990 to 2007 using an inversion modeling approach.
Journal Geophysical Research, doi:10.1029/2010JD014763, Jan 2011