Estimating UK methane and nitrous oxide emissions from 1990 to 2007 using an inversion modelling approach

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Overview

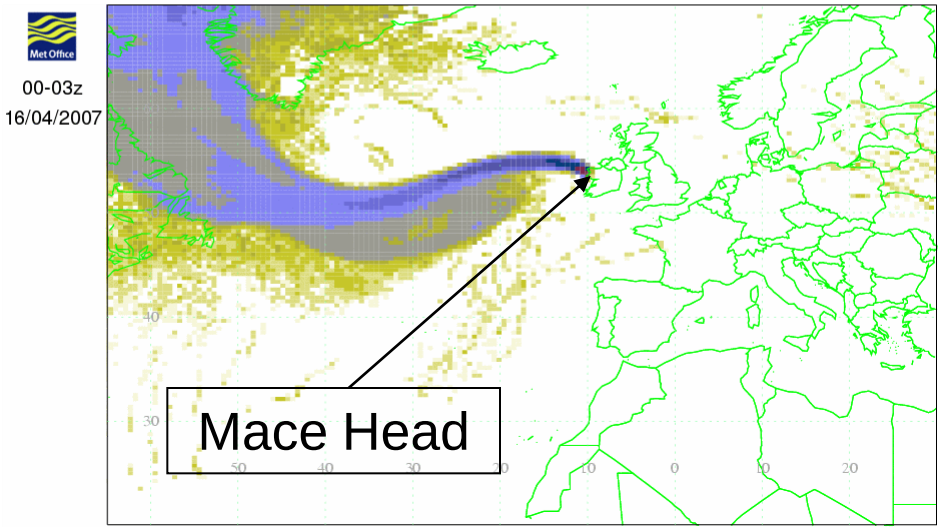
- Estimate UK emissions of CH_4 and N_2O totally independent of UNFCCC inventory process.
- Use in-situ high-frequency atmospheric observations from the remote station on the west coast of Ireland (Mace Head).
- Employ an atmospheric dispersion model (NAME) coupled with 3-D meteorology to understand the recent history of the air arriving at 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.
- Investigate uncertainties of modelling estimates.

Estimating Baseline Concentrations at each remote measurement site

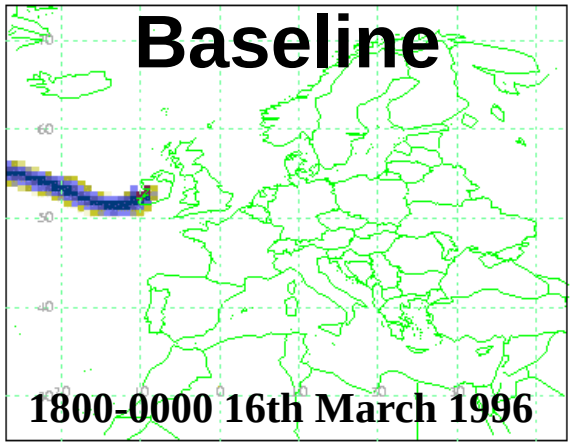
- NAME model (Lagrangian particle dispersion model).
- Uses 3-D meteorological data from UK Met Office NWP model (40-60 km resolution) and ECMWF ERA Interim (re-analysis) (~80 km).
- Derive air history map for each site for a 3-hour period:
  - Combination of tens of thousands of trajectories.
  - Darker shade means greater contribution from that area.
  - All surface sources within previous 12 days of travel that contribute to an observation during a 3-hour period are recorded.

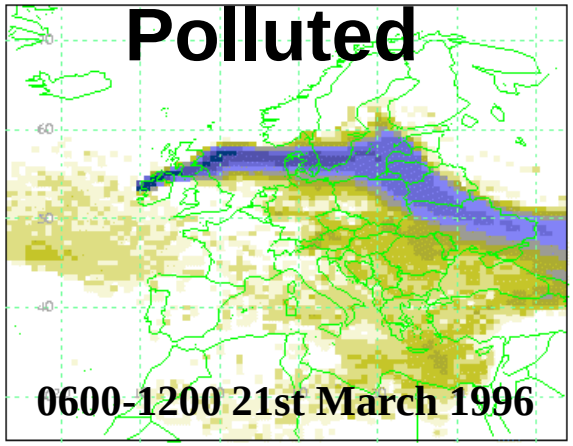
Mace Head maps generated each 3-hour period:

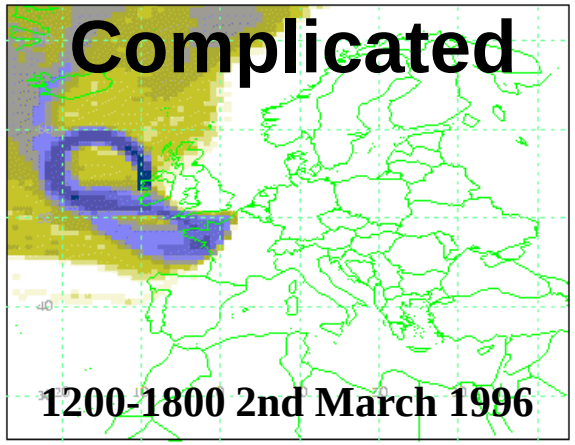
- 1995-2010 UK Met Office UM
- 1989-2008 ECMWF ERA Interim



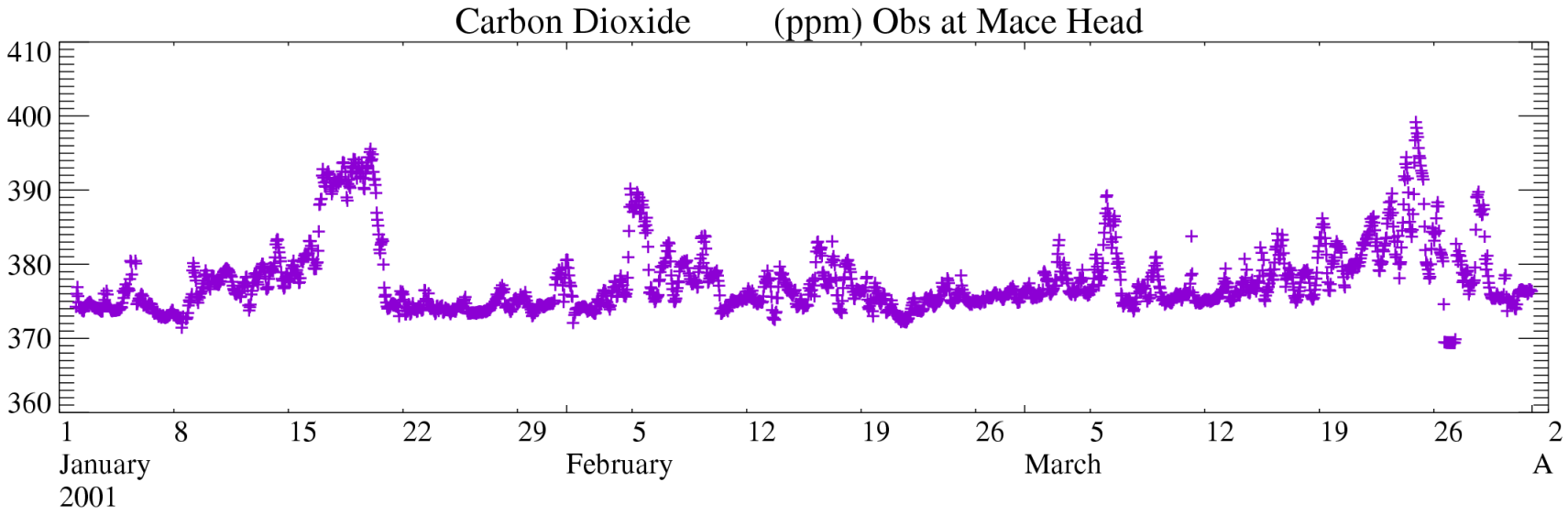
Where has the air come from? Examples:

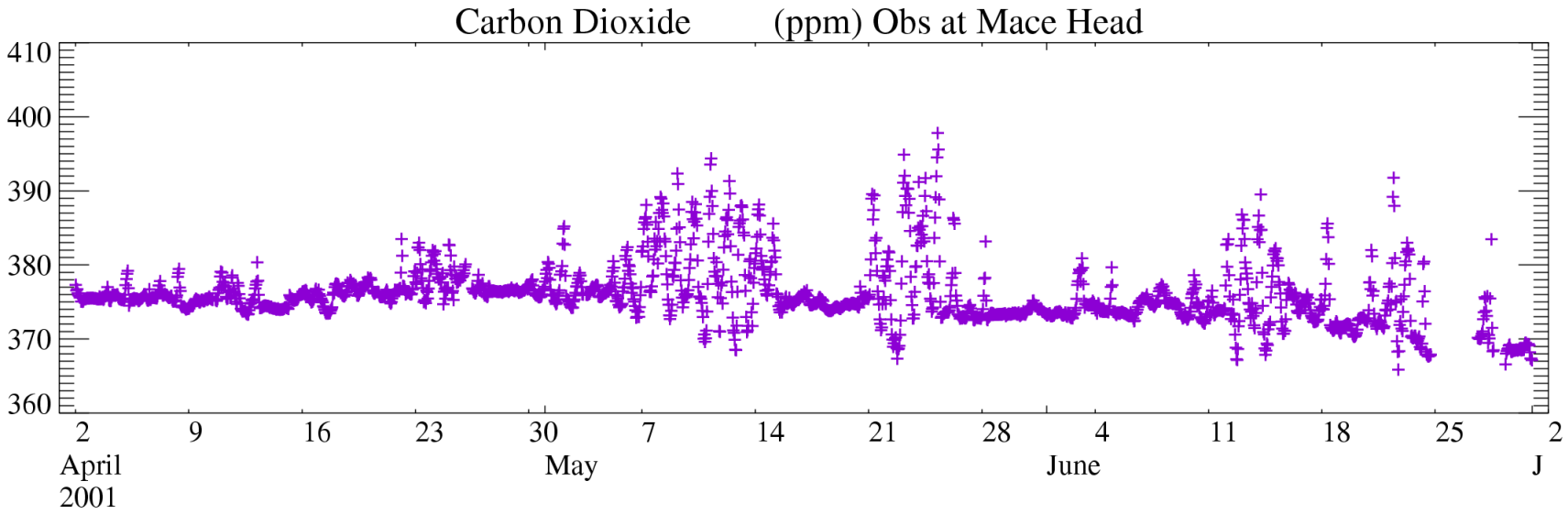




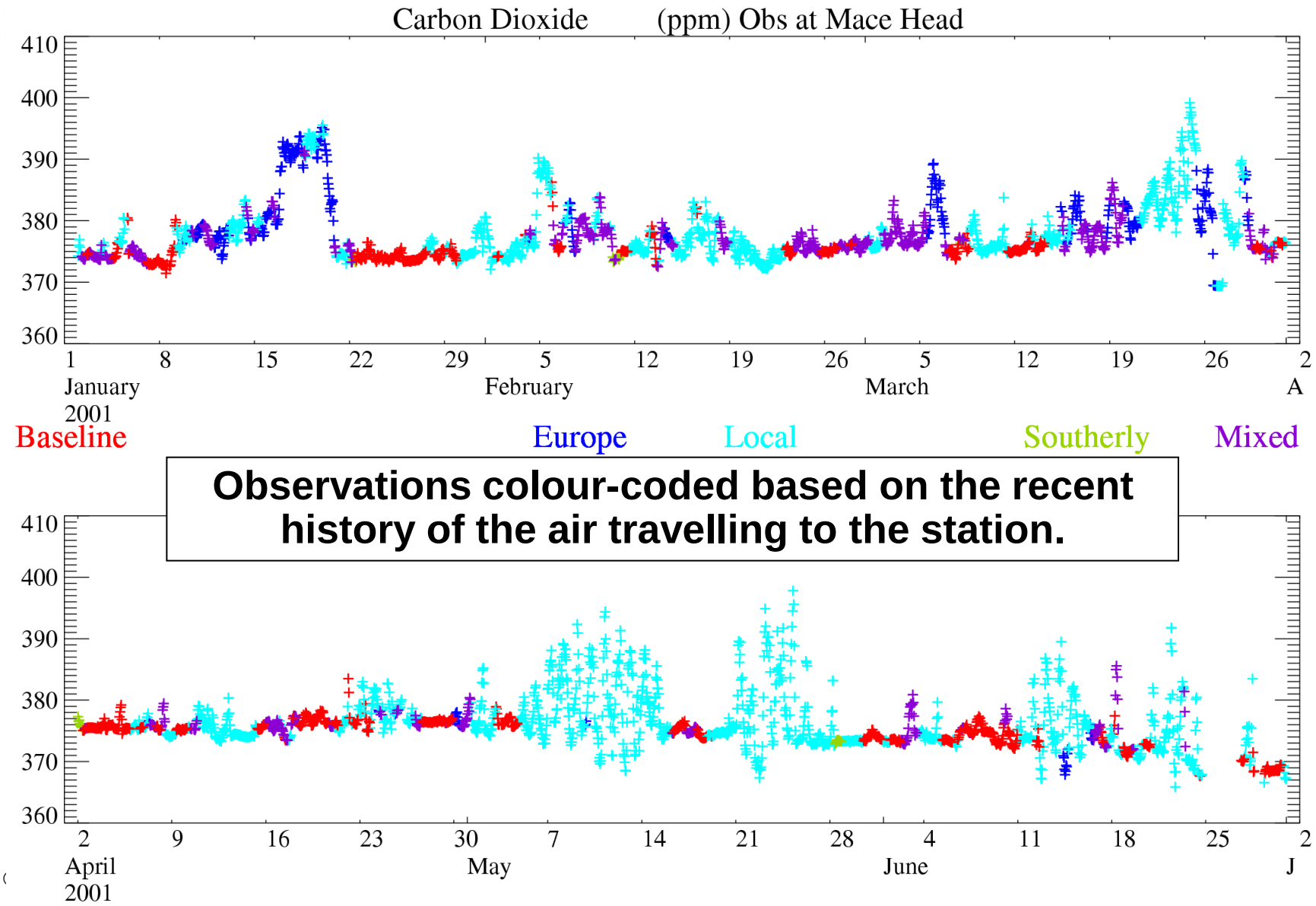


Baseline Concentration Methodology (1): Classifying Mace Head Observations

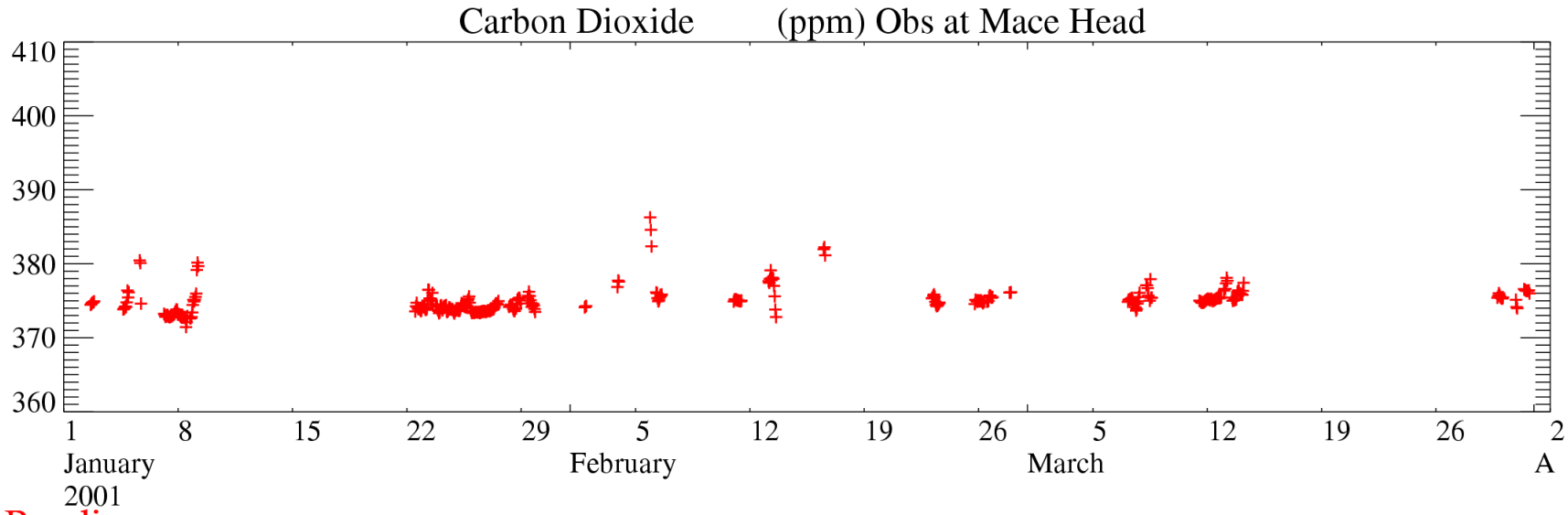




Baseline Concentration Methodology (2): Classifying Mace Head Observations

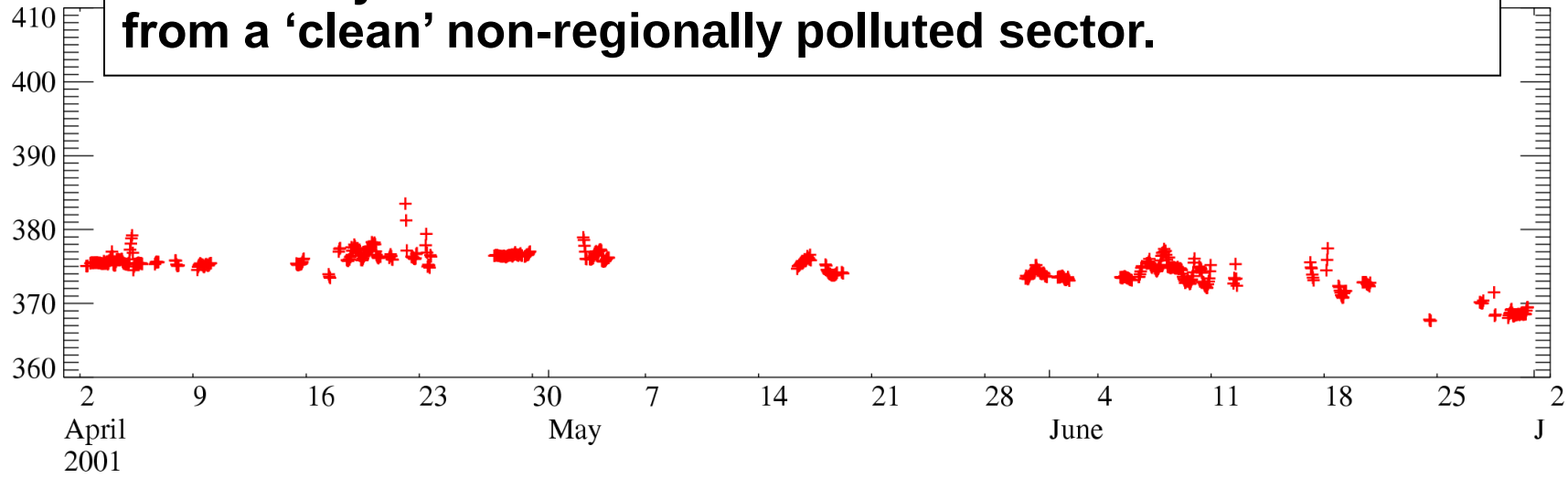


Baseline Concentration Methodology (3): Classifying Mace Head Observations

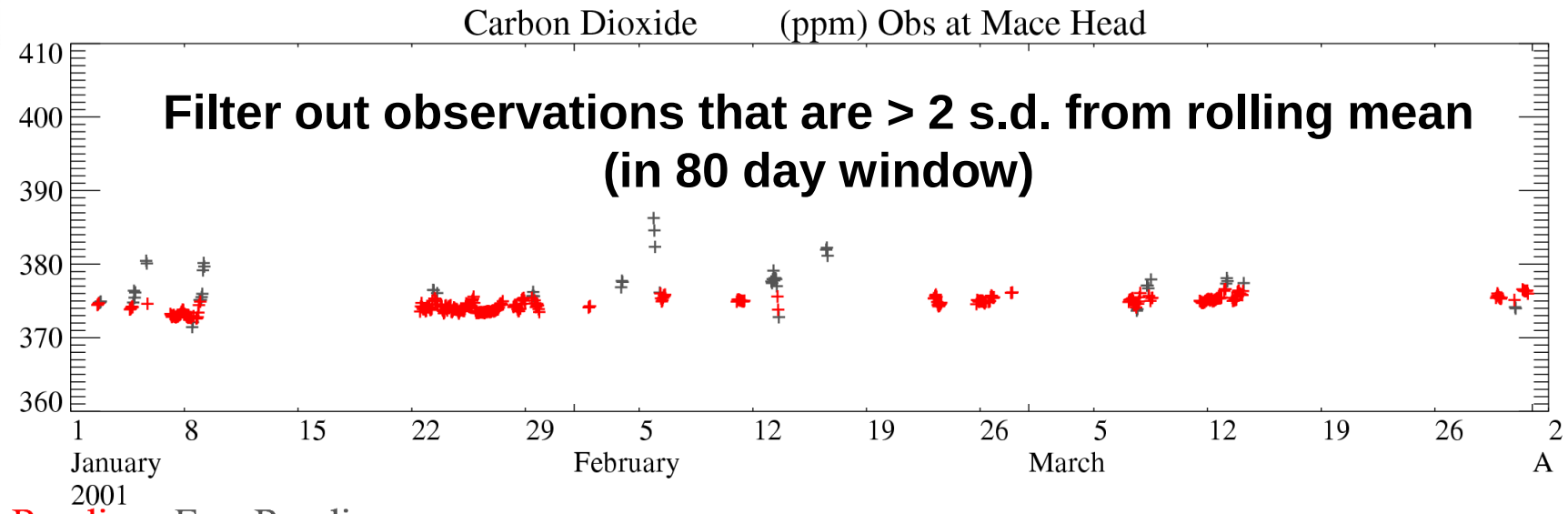


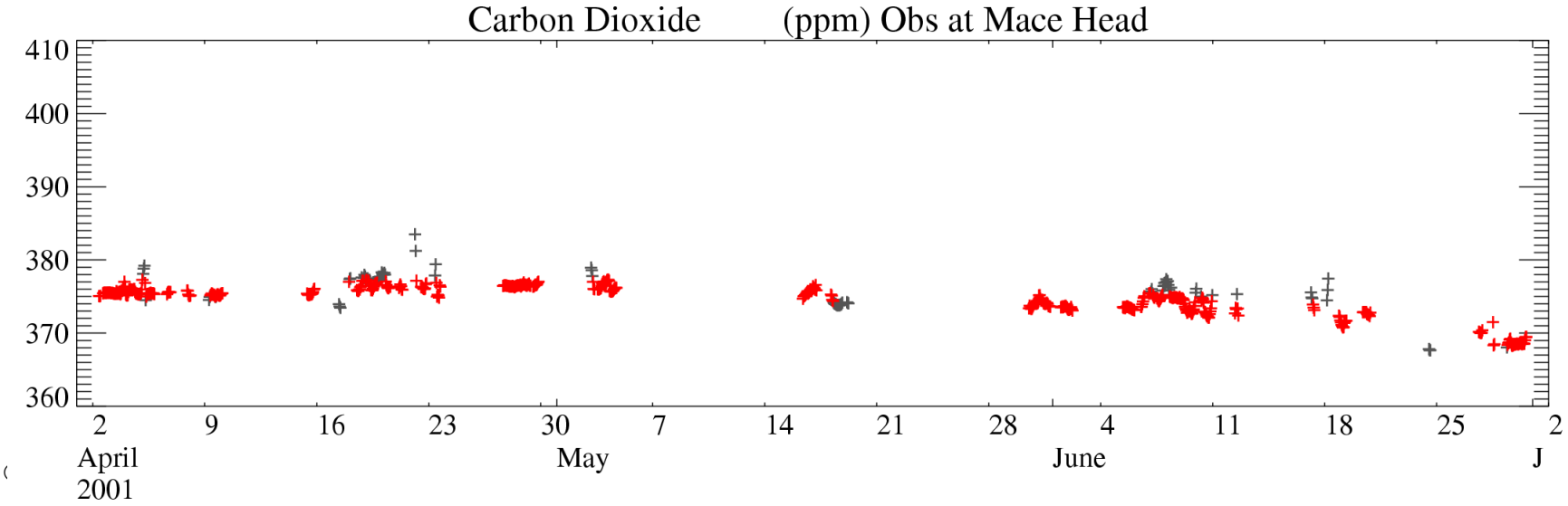
Baseline

Select only those observations that are considered to be from a 'clean' non-regionally polluted sector.

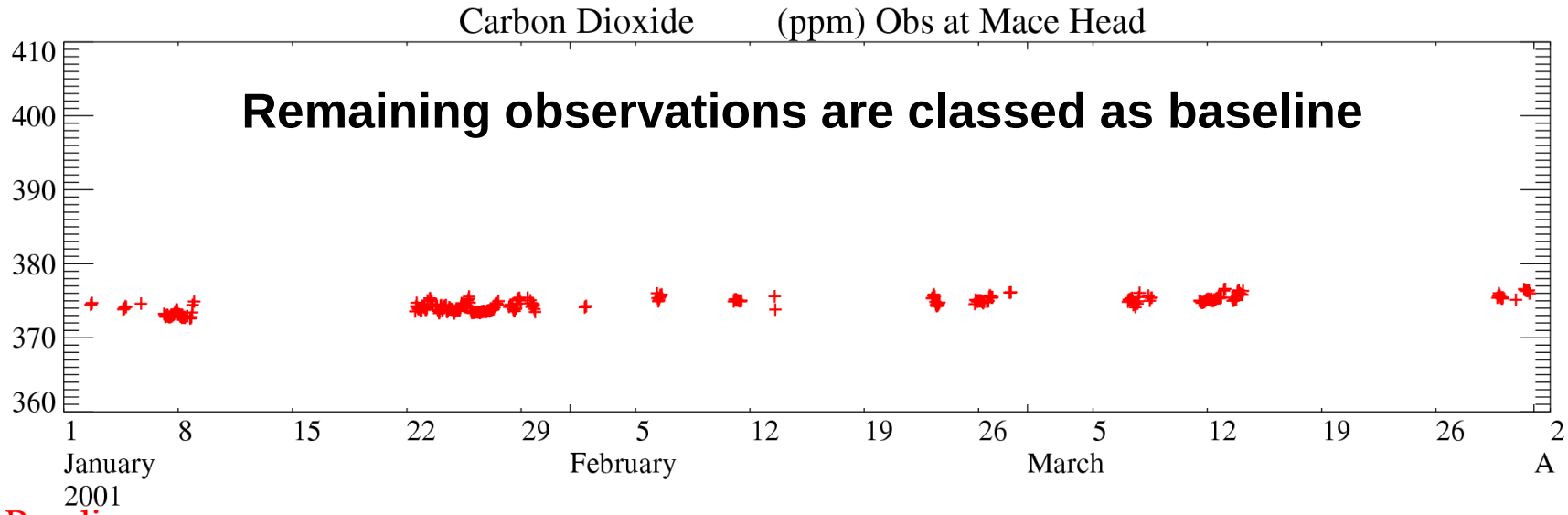


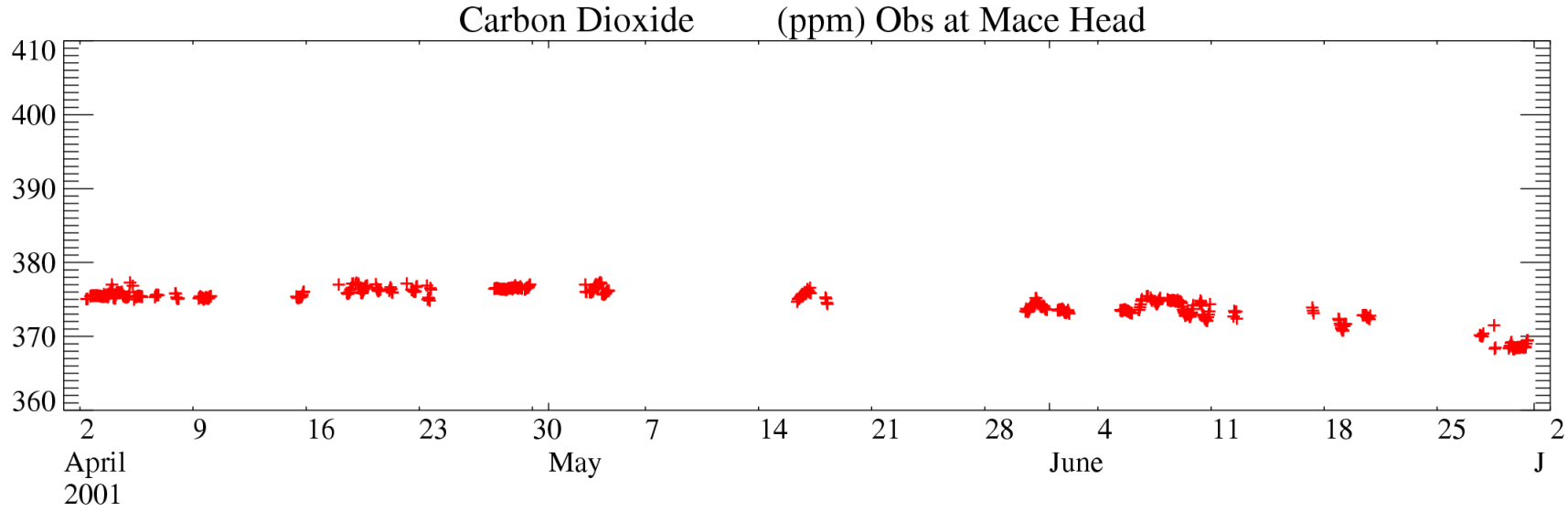
Baseline Concentration Methodology (4): Classifying Mace Head Observations



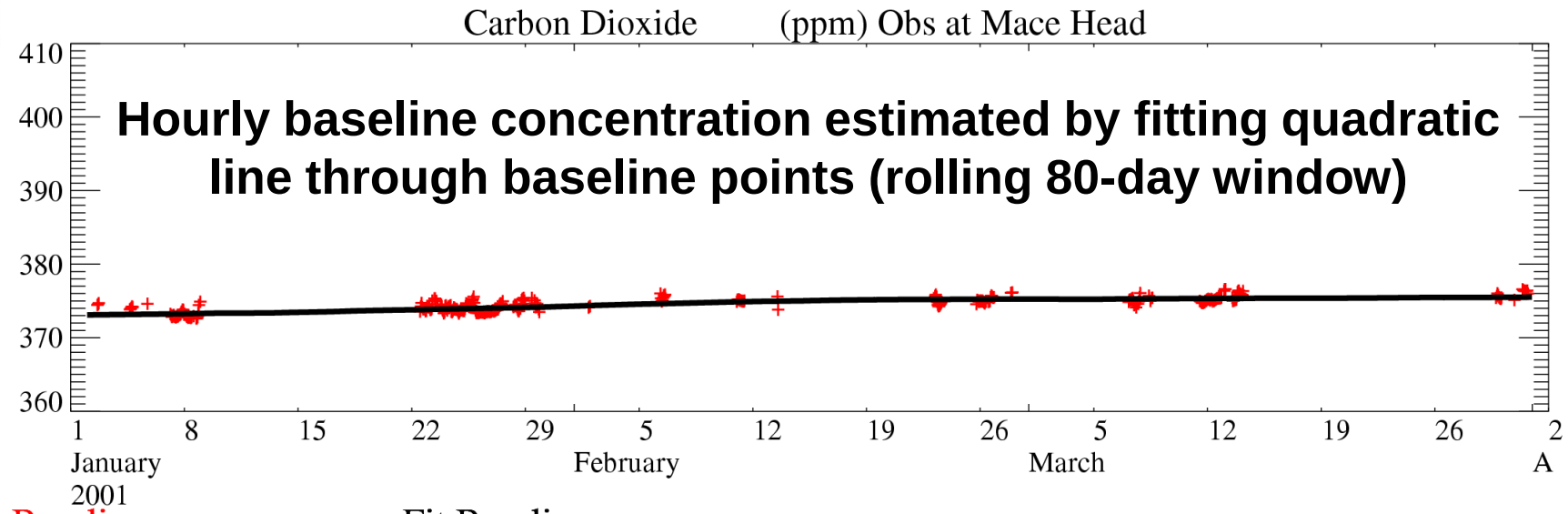


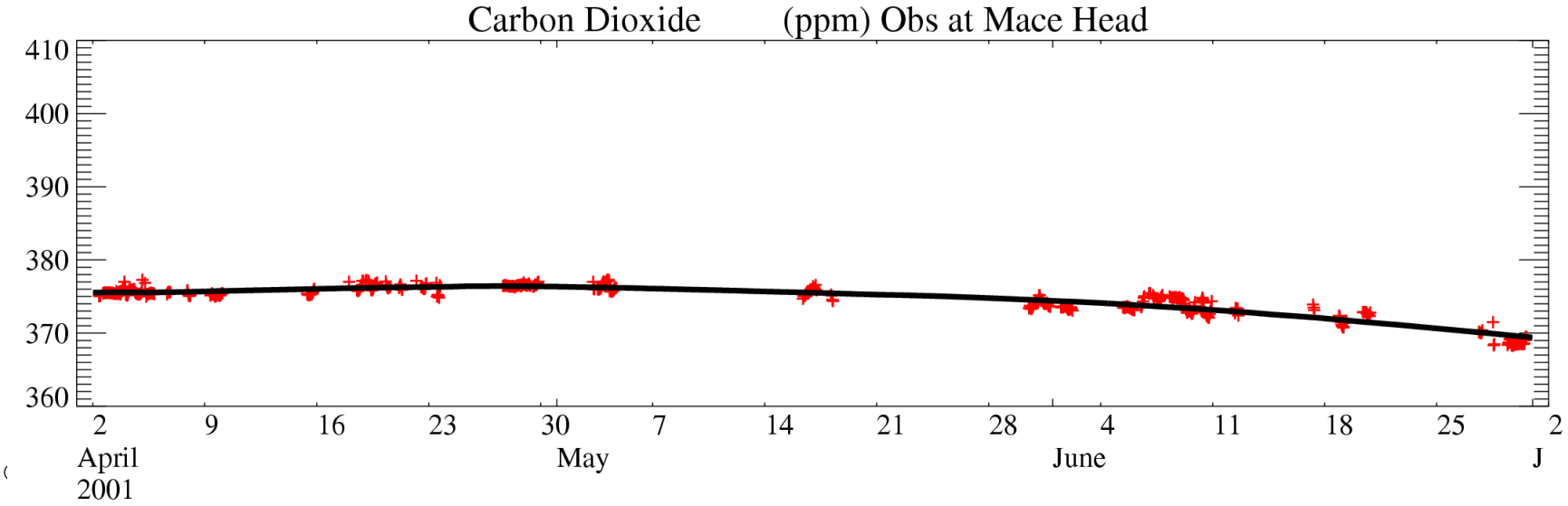
Baseline Concentration Methodology (5): Classifying Mace Head Observations





Baseline Concentration Methodology (6): Classifying Mace Head Observations

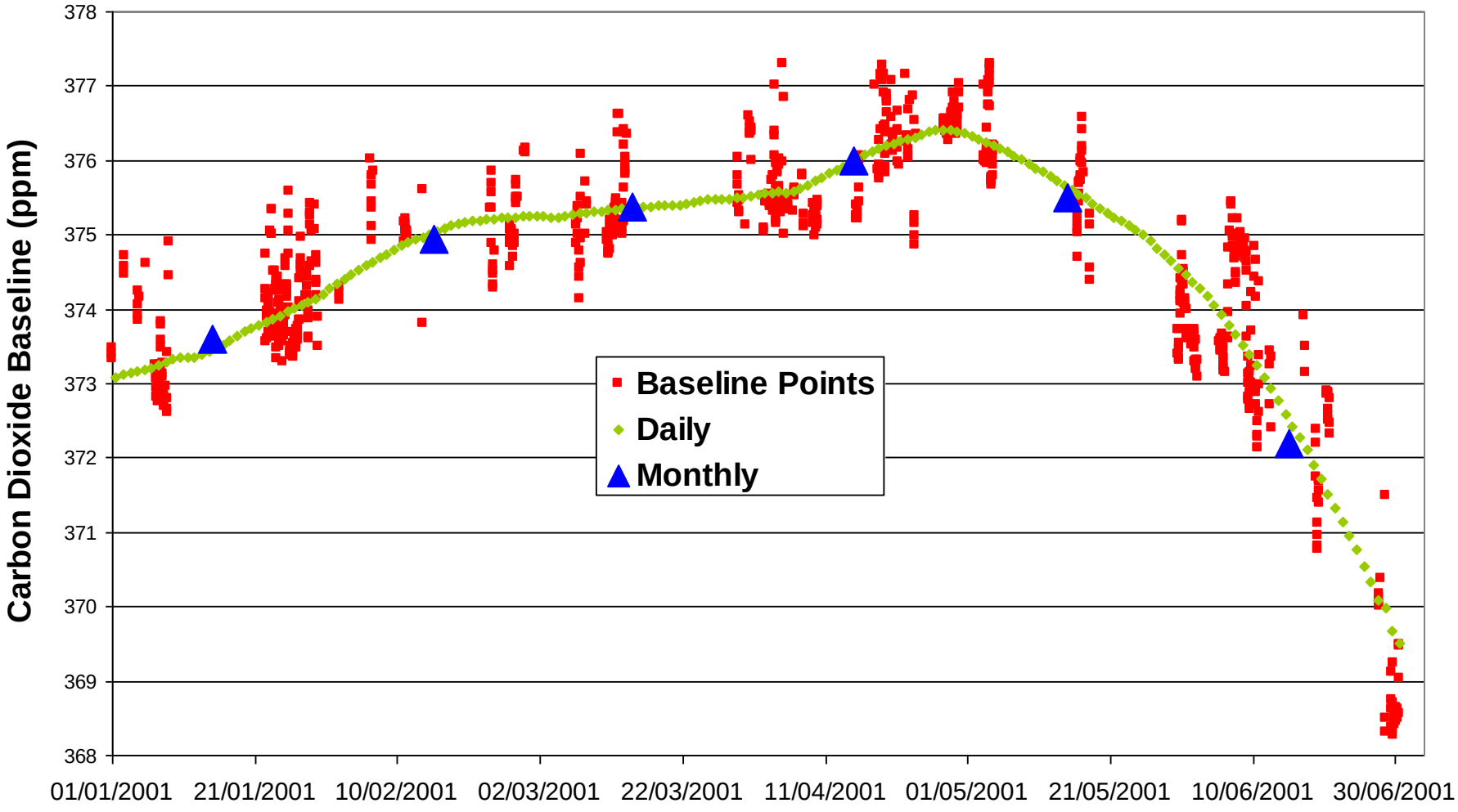




Baseline Concentration Methodology (7):

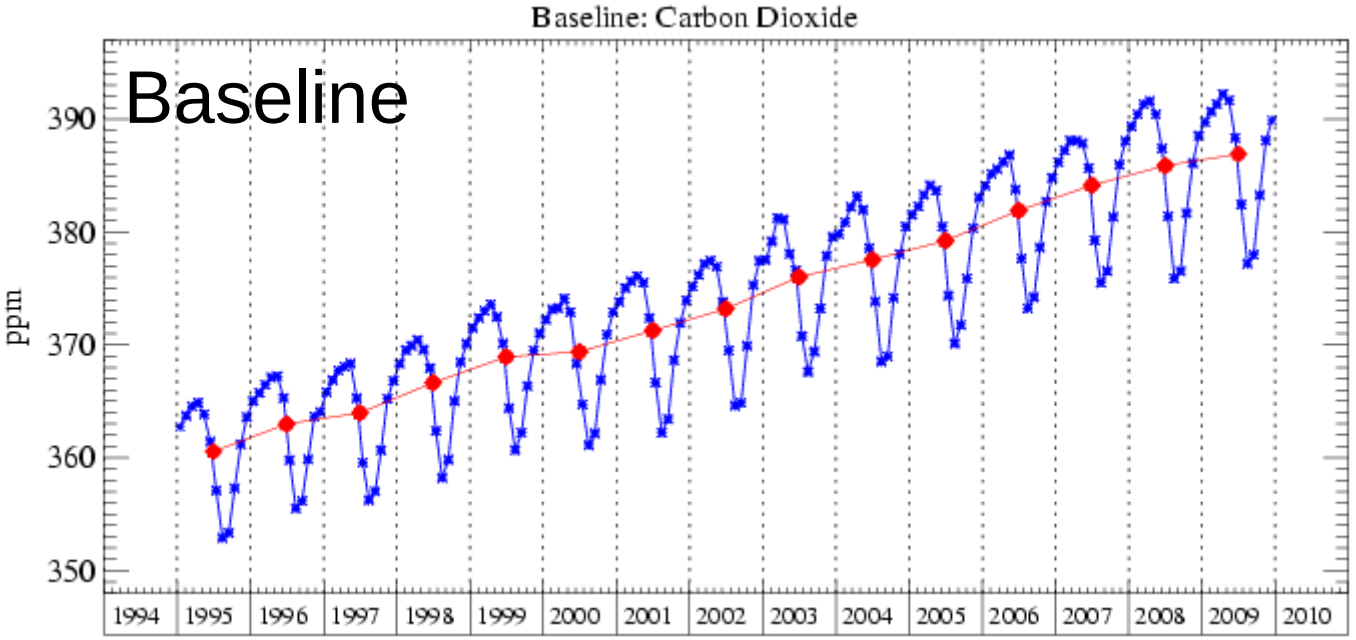
Classifying Mace Head Observations

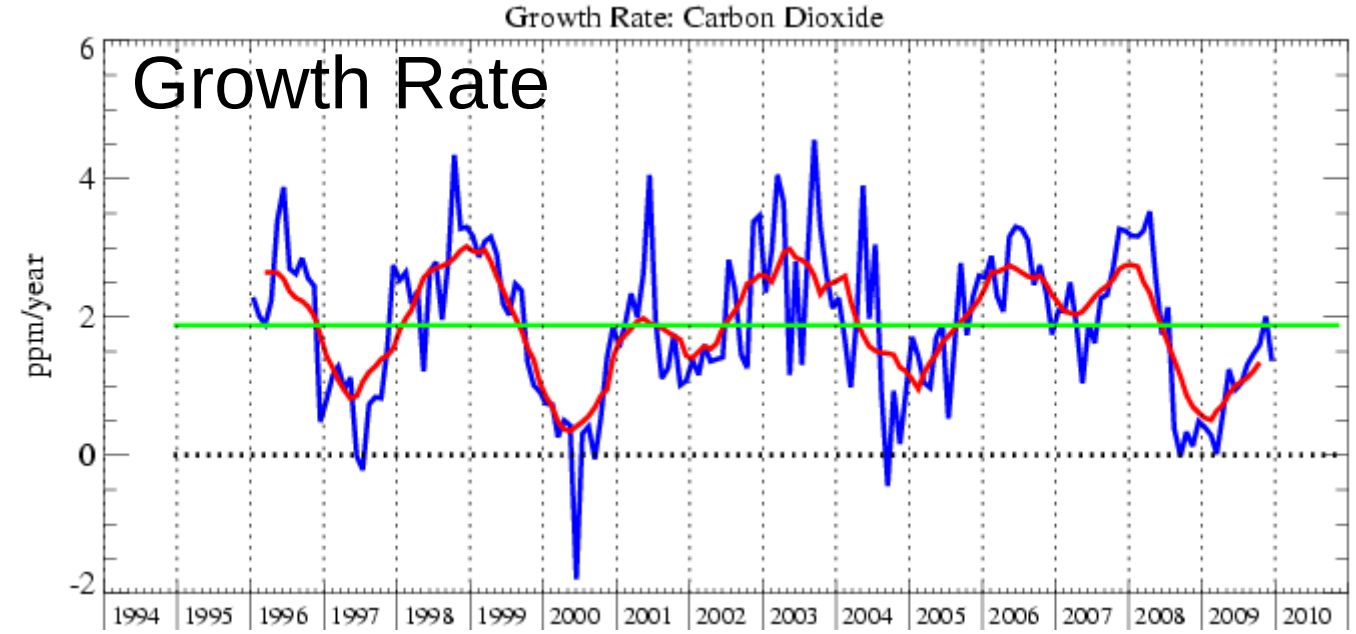
Monthly Baseline = Average of daily values



Met Office

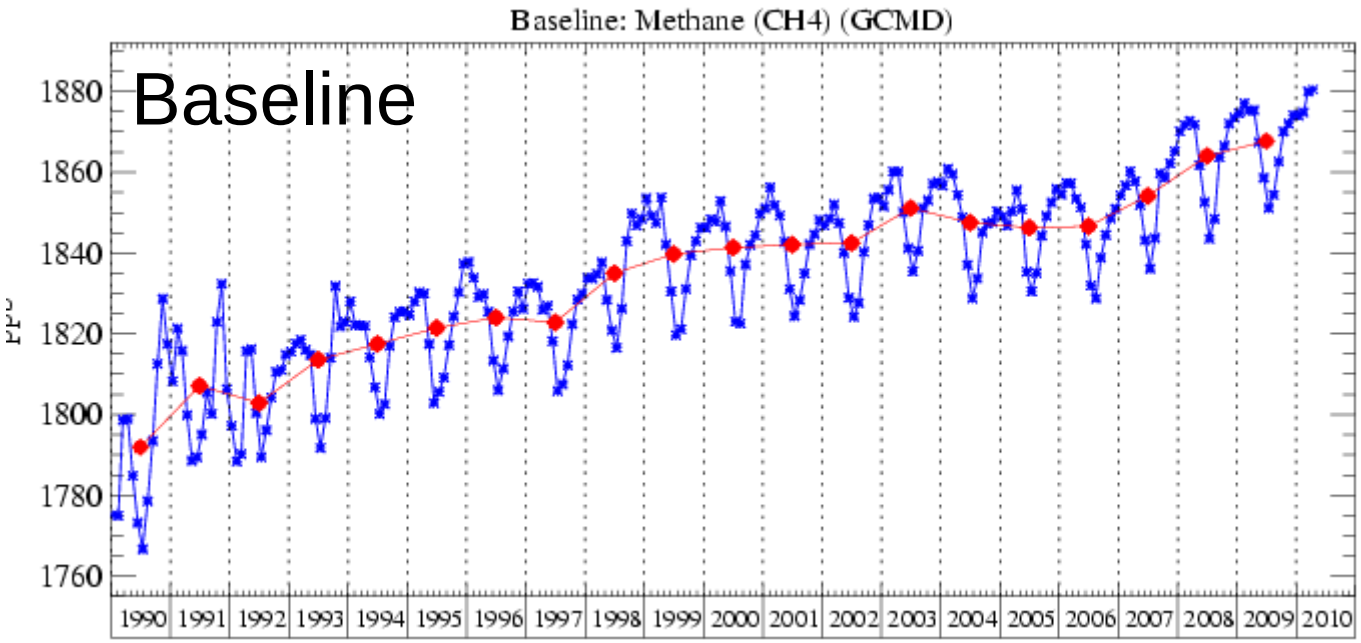
Mid-latitude baseline concentration of Carbon Dioxide (ppm)

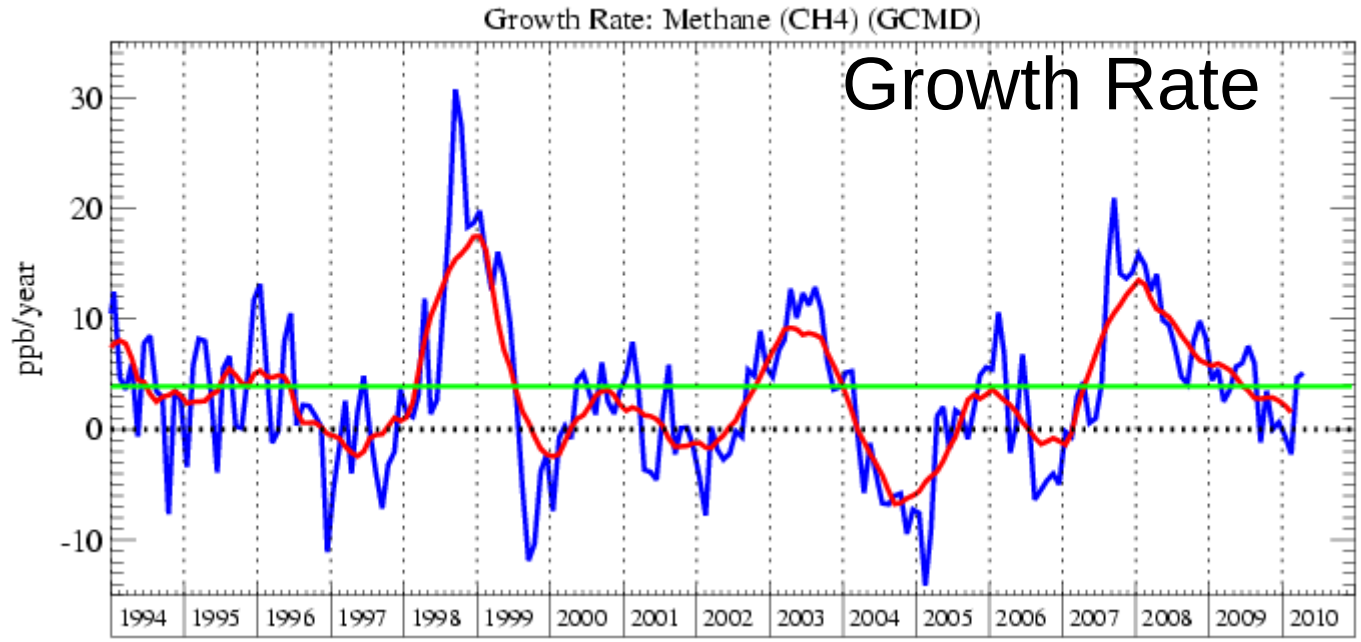




Met Office

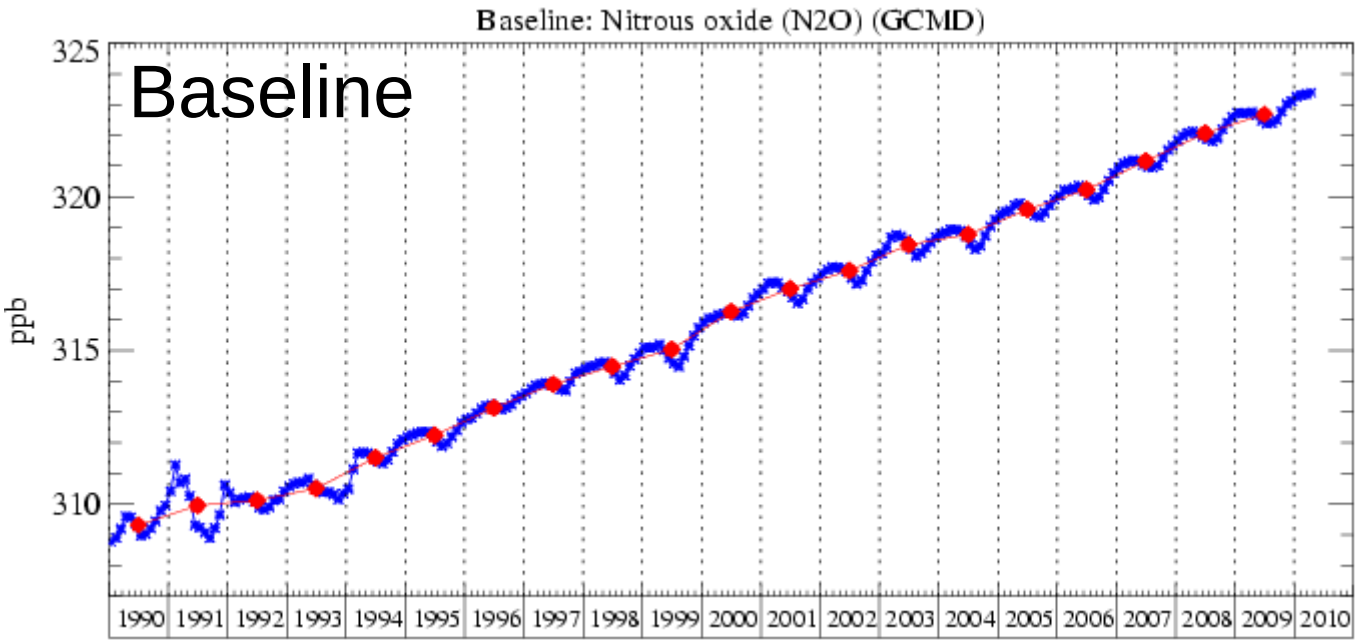
Mid-latitude baseline concentration of Methane (ppb)

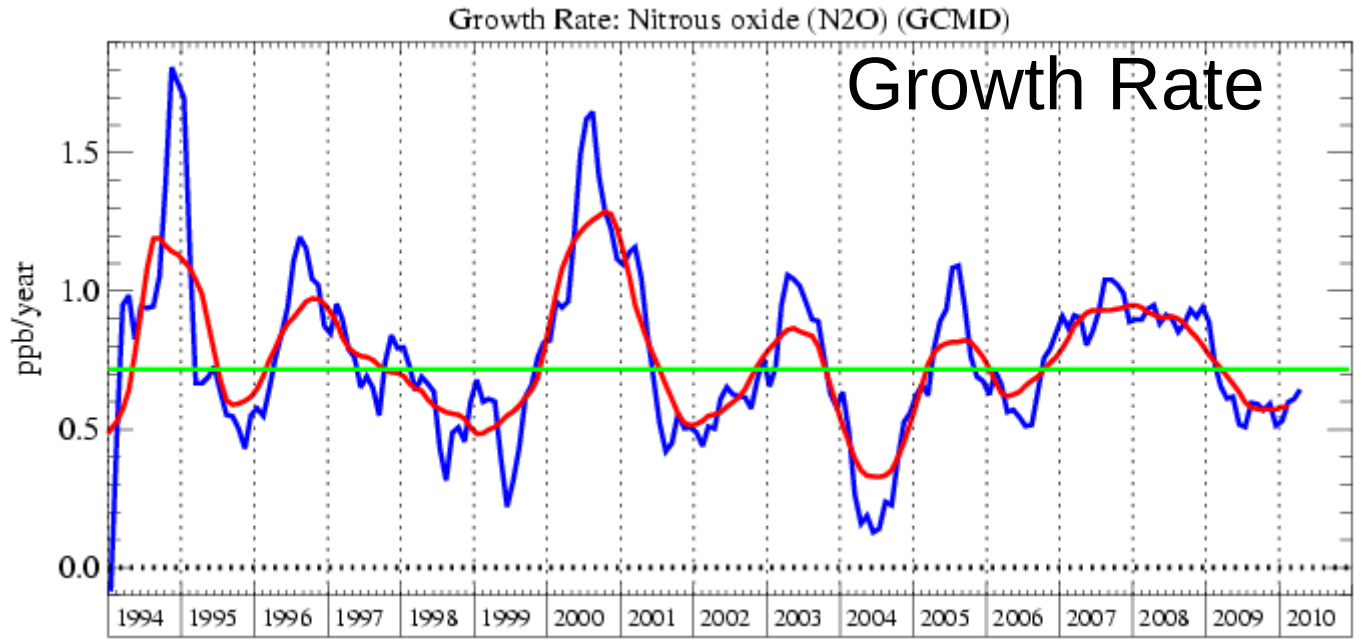




Met Office

Mid-latitude baseline concentration of Nitrous Oxide (ppb)



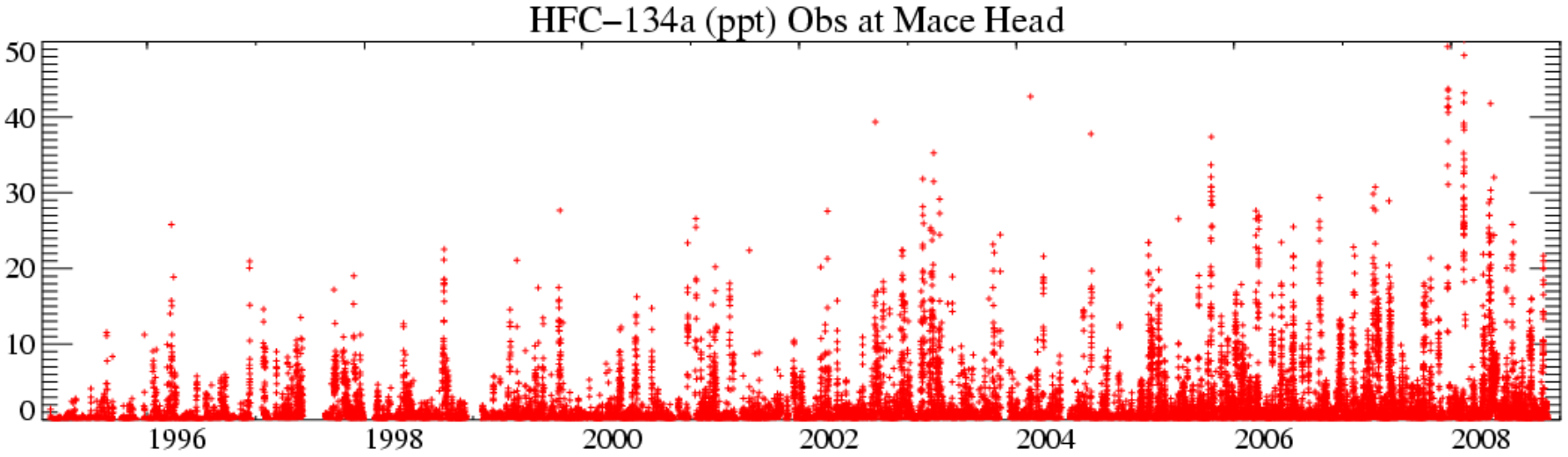


Estimating regional emissions from above baseline concentrations

Estimating Regional Emissions: Inverse Modelling

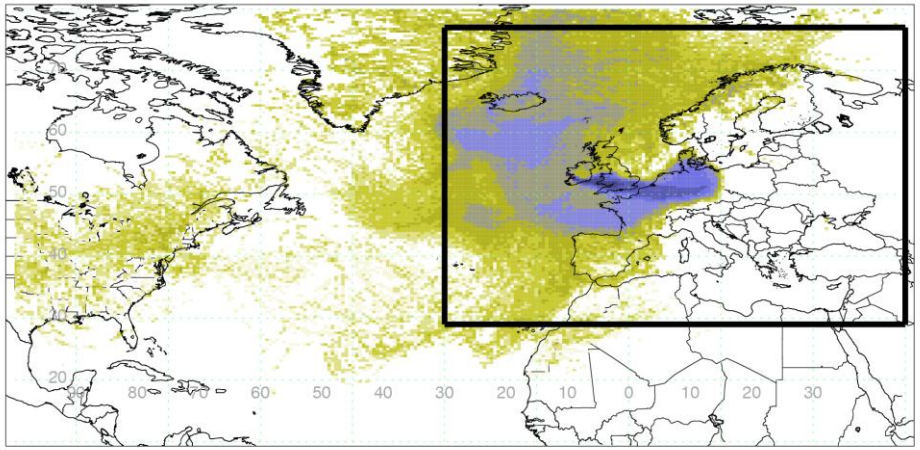
Aim: **Generate emission estimates from 'polluted' (above baseline) observations.**

Subtract the baseline concentration from each observation.



Inversion Technique

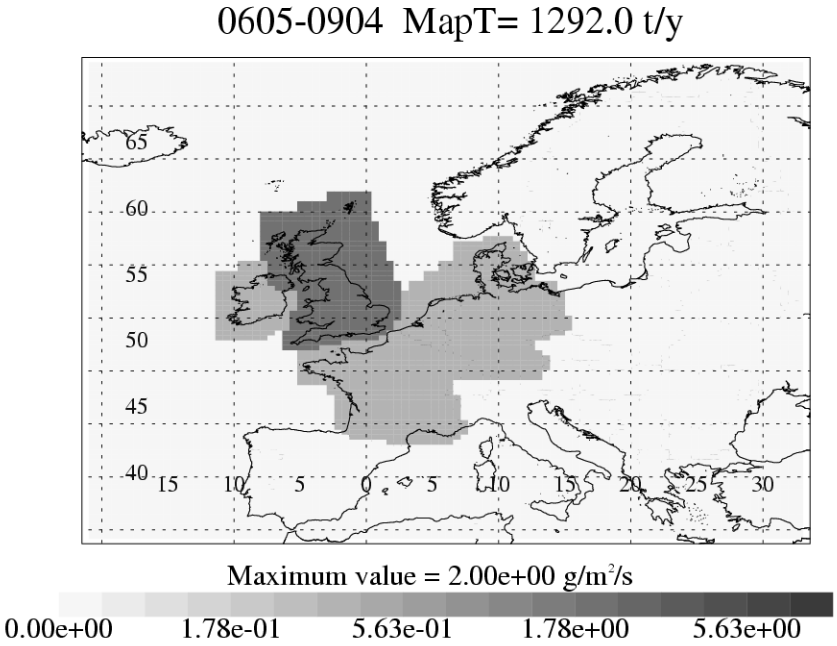
Air Origin Map = Matrix **A**
(N^{o} times x N^{o} grids)

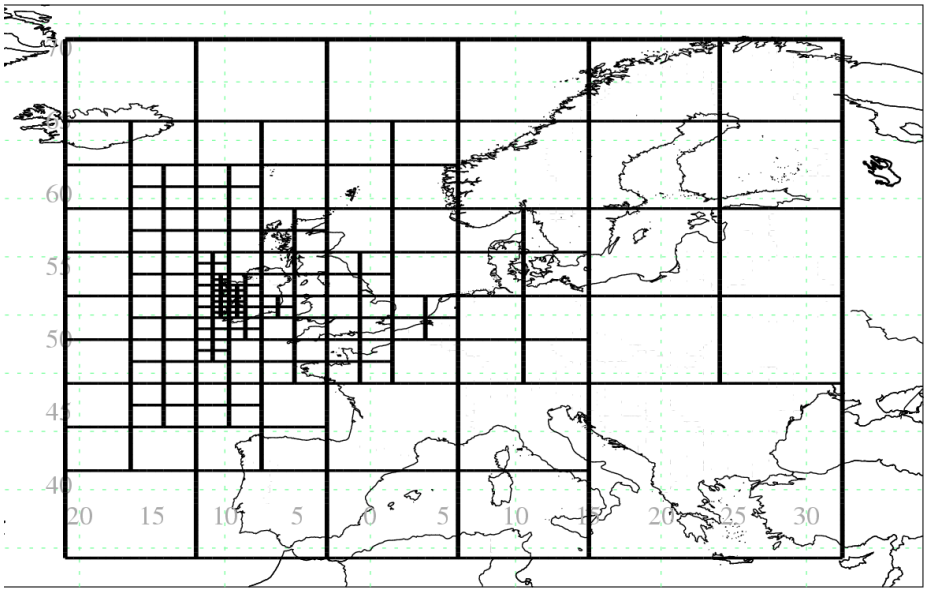


Measurement - Baseline = **m**
Emission Map = **e** (the solution)
Relationship: **A e** = **m**
Problem: Minimise **m** - **A e**

- Remove observations that have a strong **local** influence.
- Scale emissions (**iteration**) to obtain **best-fit** statistical match between model time-series and observations.
- No prior information – **Random** initial guess.
- Solve for each **3-yr** period stepping monthly e.g. Feb'89 – Jan'92, Mar'89 – Feb'92, …
- Solve **multiple** (52) times, each time start from different random initial guess.
- Apply random '**noise**' to observations (different for each inversion).

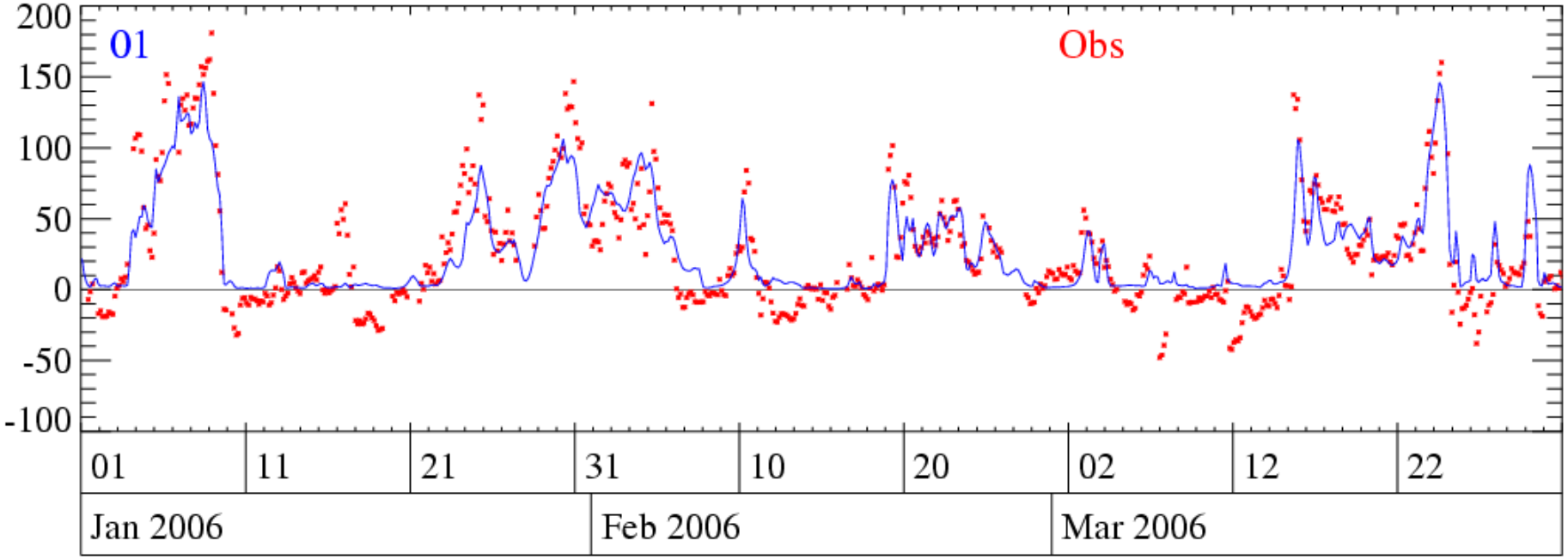
Inverse Modelling: Footprints and resolved areas



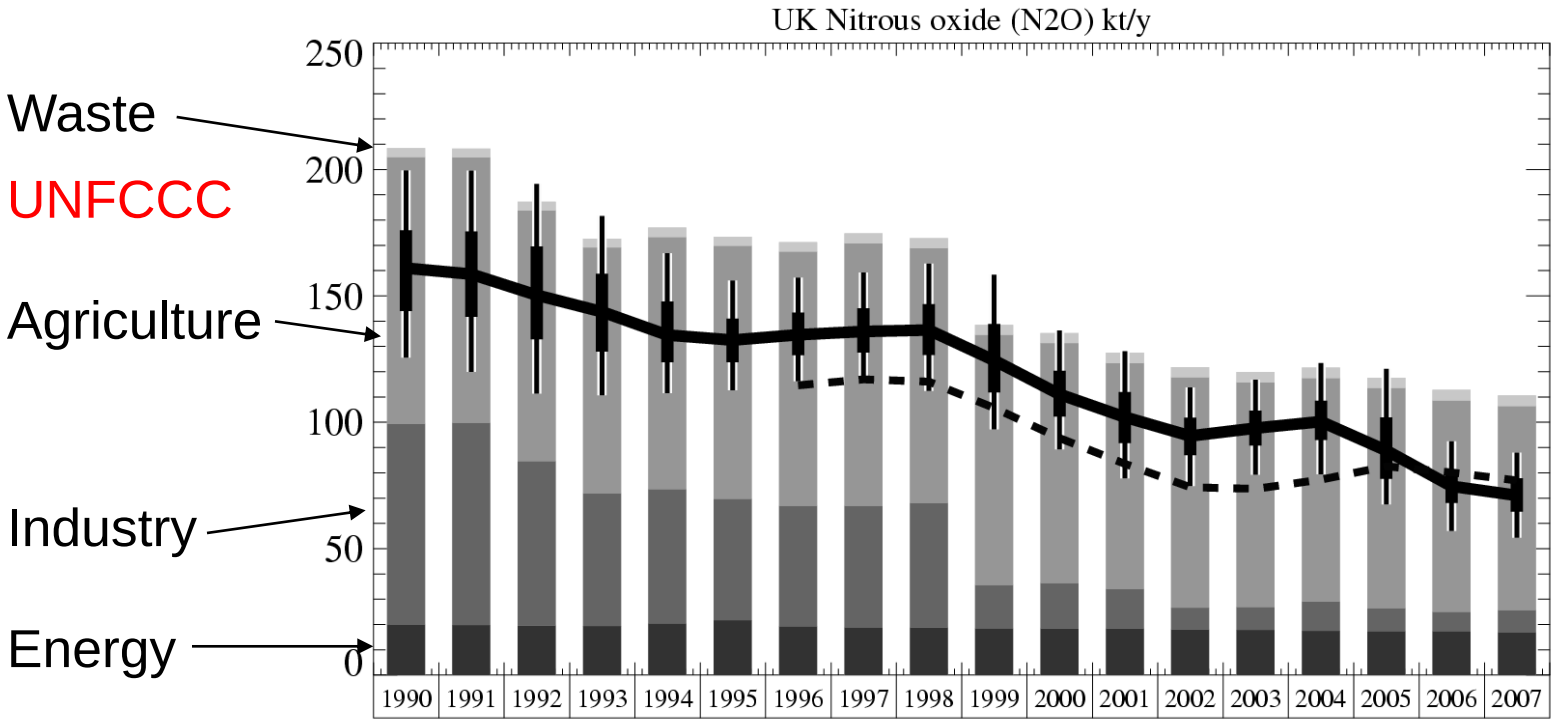


Model Solution Vs Observation

‘Best-Fit’ Model (Blue) and Observation (Red)
Time-series for methane (ppb) Jan-Mar 2006

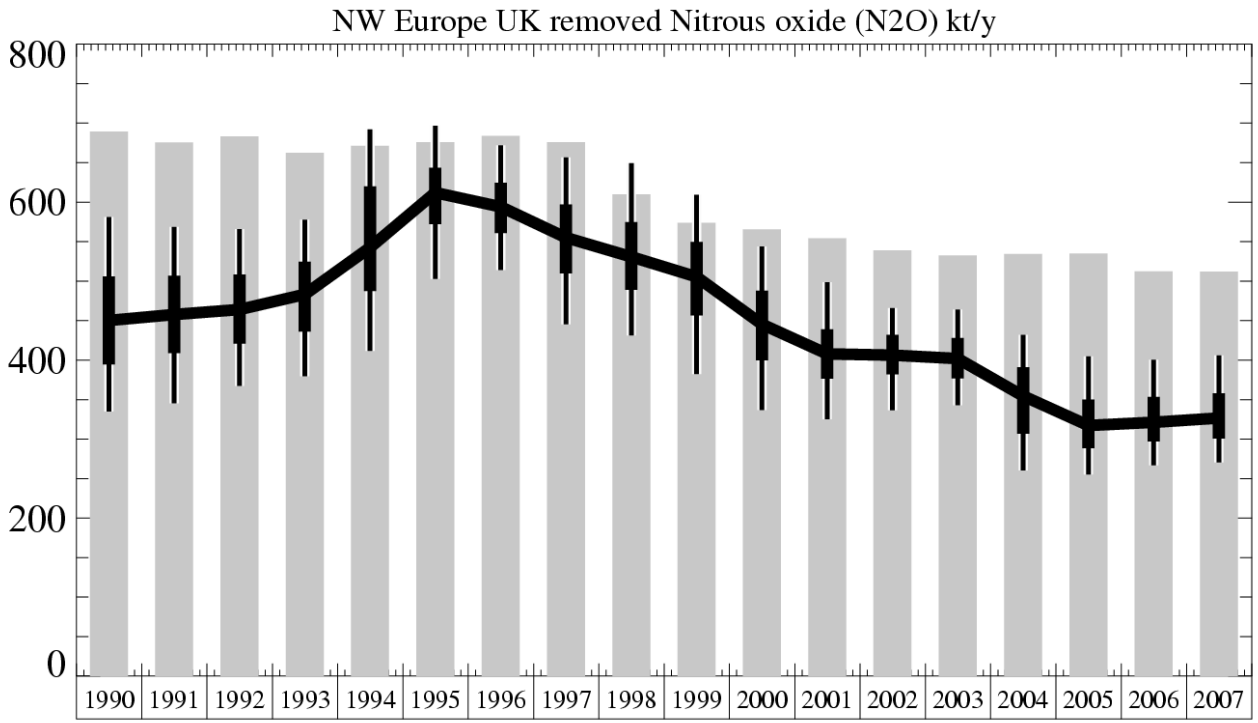


Emission estimates for N_2O for the UK.



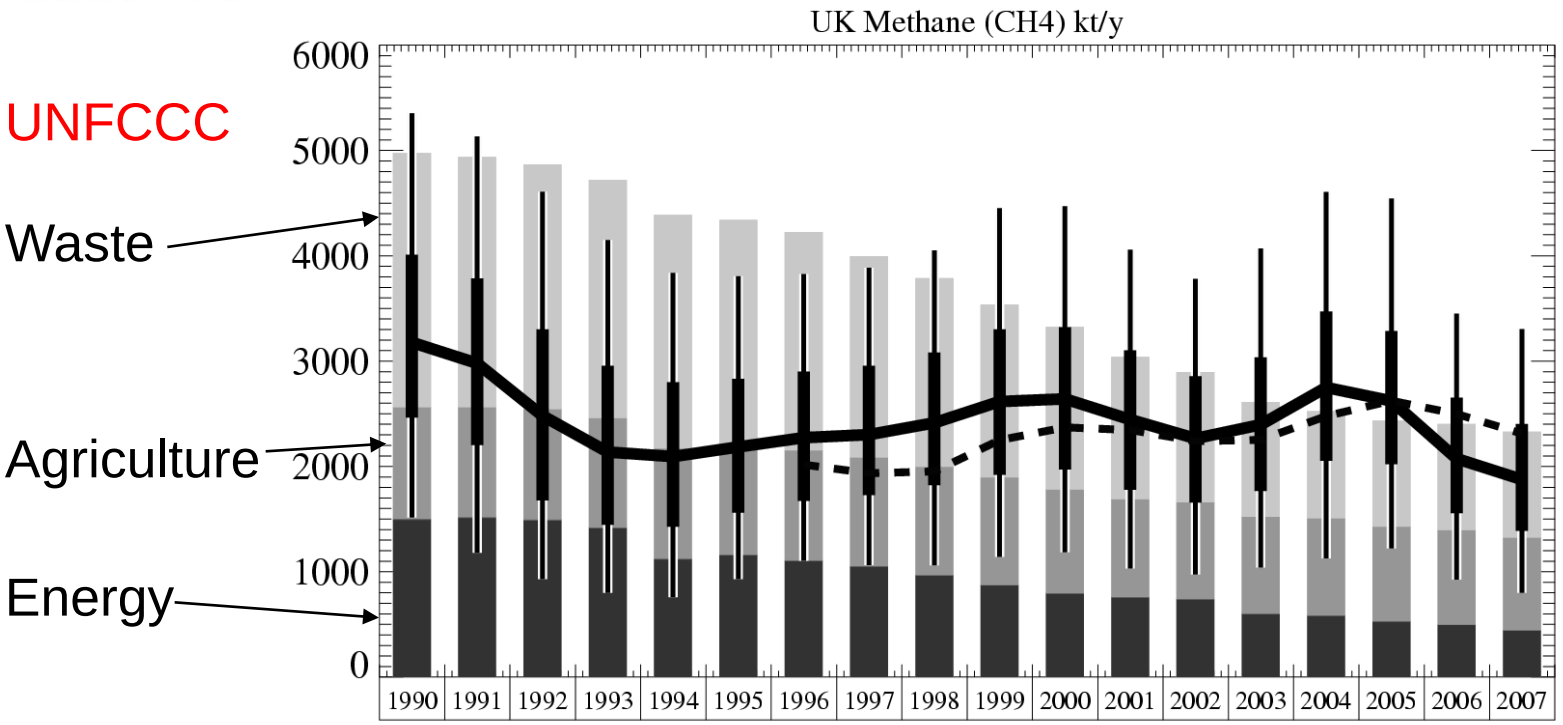
Annual NAME-inversion results using ERAI (UKMO) are shown as a solid (dashed) line with uncertainty bars showing the median, 5th, 25th, 75th and 95th percentiles.

Emission estimates for N_2O for NWEU with UK removed.



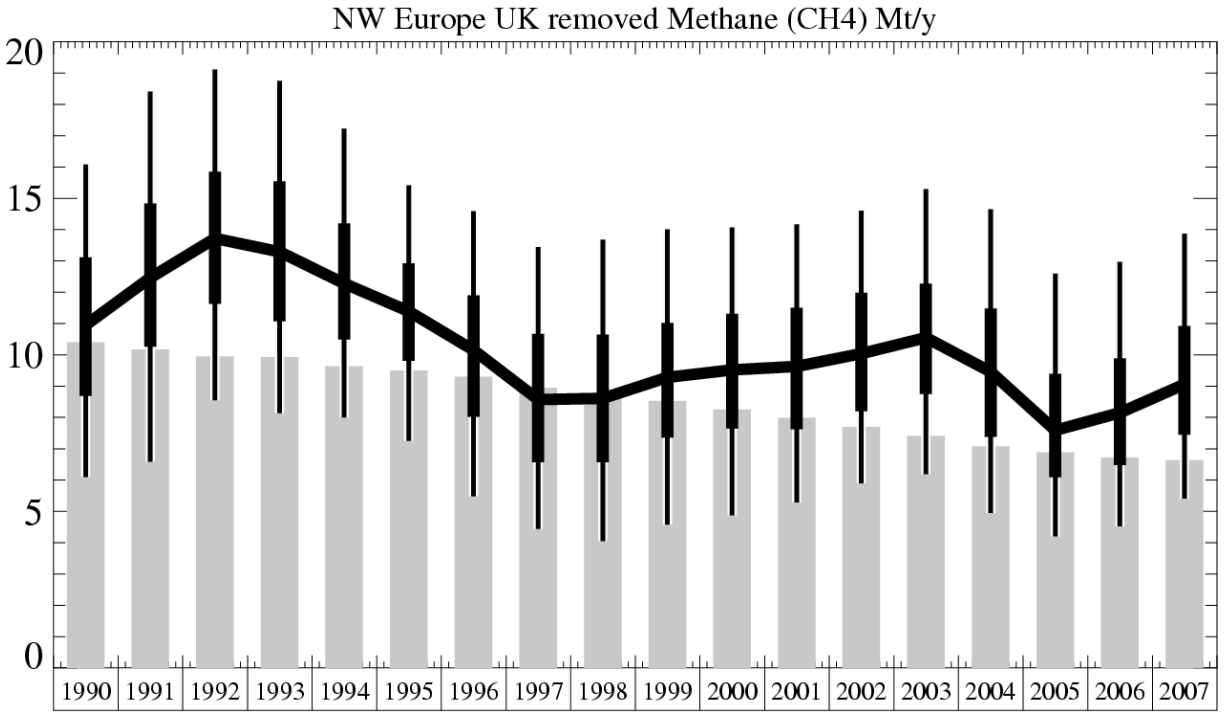
Annual NAME-inversion results using ERAI are shown as a solid line with uncertainty bars showing the median, 5th, 25th, 75th and 95th percentiles. UNFCCC inventory estimates are shown as columns.

Emission estimates for CH_4 for the UK.



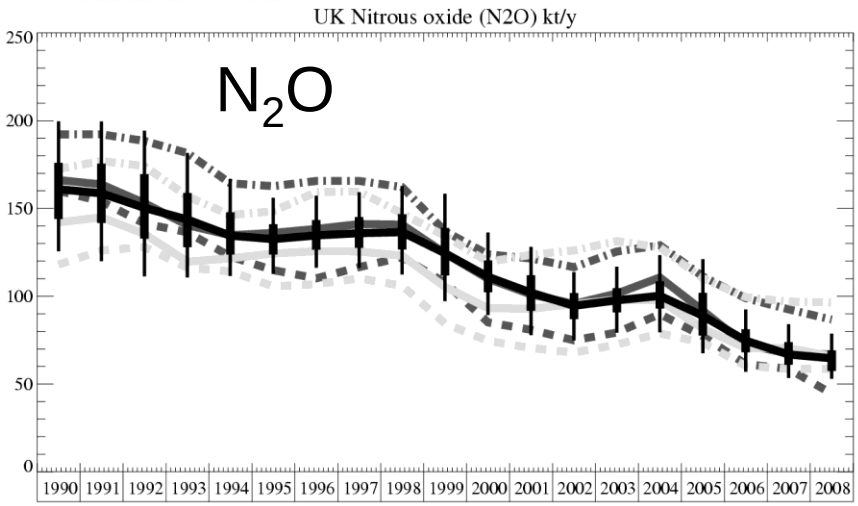
Annual NAME-inversion results using ERAI (UKMO) are shown as a solid (dashed) line with uncertainty bars showing the median, 5th, 25th, 75th and 95th percentiles.

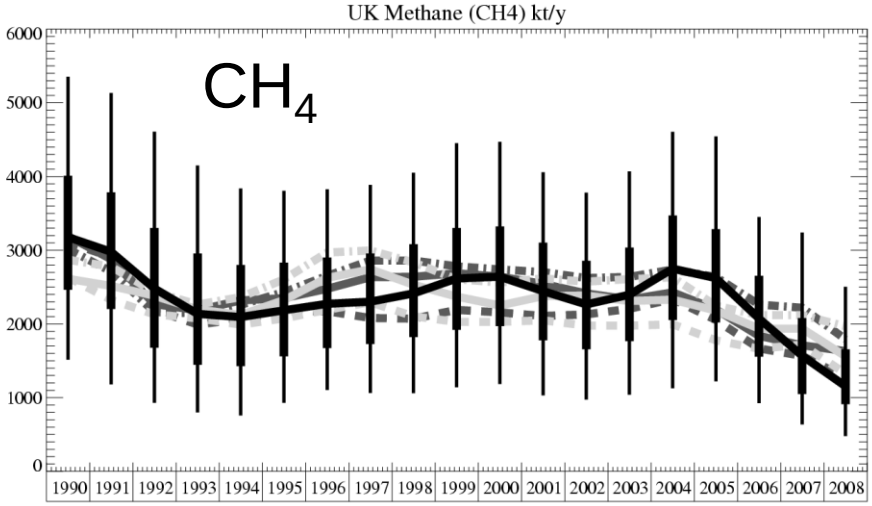
Emission estimates for CH_4 for the NWEU with UK removed.



Annual NAME-inversion results using ERAI are shown as a solid line with uncertainty bars showing the median, 5th, 25th, 75th and 95th percentiles. UNFCCC inventory estimates are shown as columns.

Sensitivity Analysis





Whisker plot = same as previous slides.
Previous plots show impact of using different 3-D meteorology.

Dark grey – Consider systematic bias (1σ) in baseline both -ve and +ve.

Light grey – Consider impact of solving over a larger domain together with systematic bias (1σ) in baseline.

Summary

- Methodology described that enables baseline concentrations of trace gases to be estimated.
  - Regionally polluted observations are removed.
  - Growth rates in baselines estimated.
- Inversion technique to estimate UK emissions compared to UNFCCC.
  - N_2O results trend agrees well, NAME-inversion results lower.
  - CH_4 results post 2000 agree within uncertainty limits.
  - NAME-inversion CH_4 results in 1990s are lower than inventory. Overall (1990 to 2007) model results show 24% UK decline compared to inventory decline of over 50%.
  - Inventory CH_4 decline attributed mainly to reductions in land-fill and coal mining emissions.
  - If model results used then UK still met Kyoto commitment (12.5%) but by smaller margin (14.3% compared to reported 17.3%).