Top-down estimation of N_2O Emissions

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Top-down method applied to N_2O

- Atmospheric concentrations of N_2O to constrain surface-atmosphere flux
- Mass balance approach – change in atmosphere balanced by sum of sources and sinks
- Fluxes spatially and temporally resolved
- Can only constrain net flux – separation of “natural” versus “anthropogenic” not possible as this is only an abstract distinction

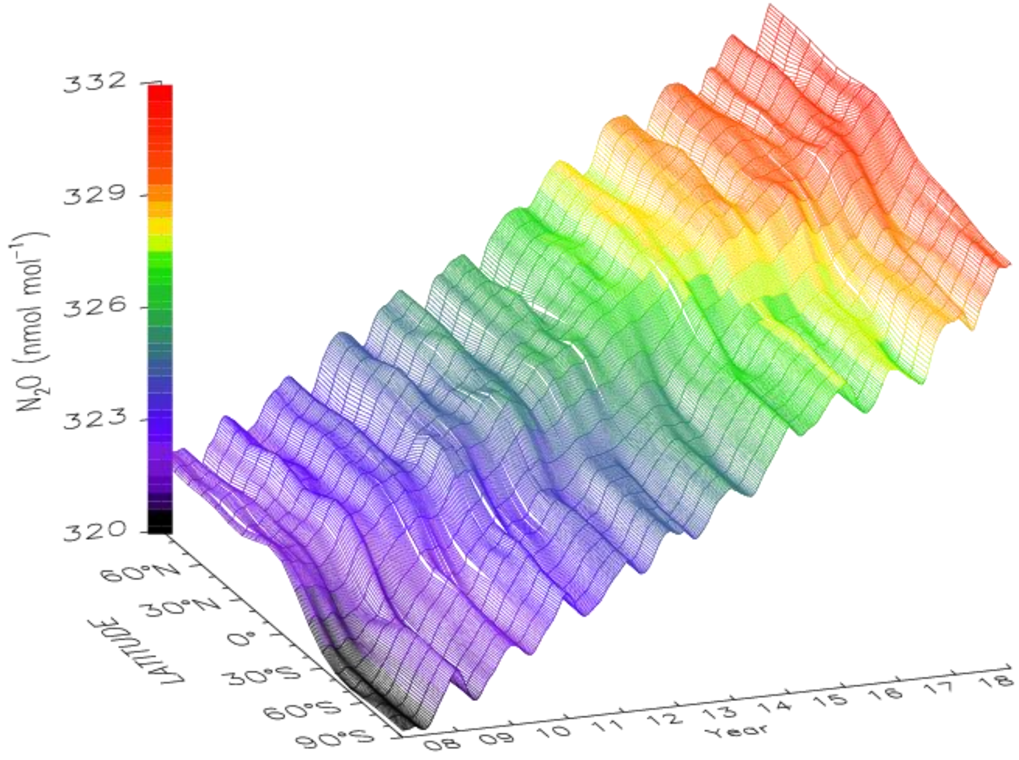
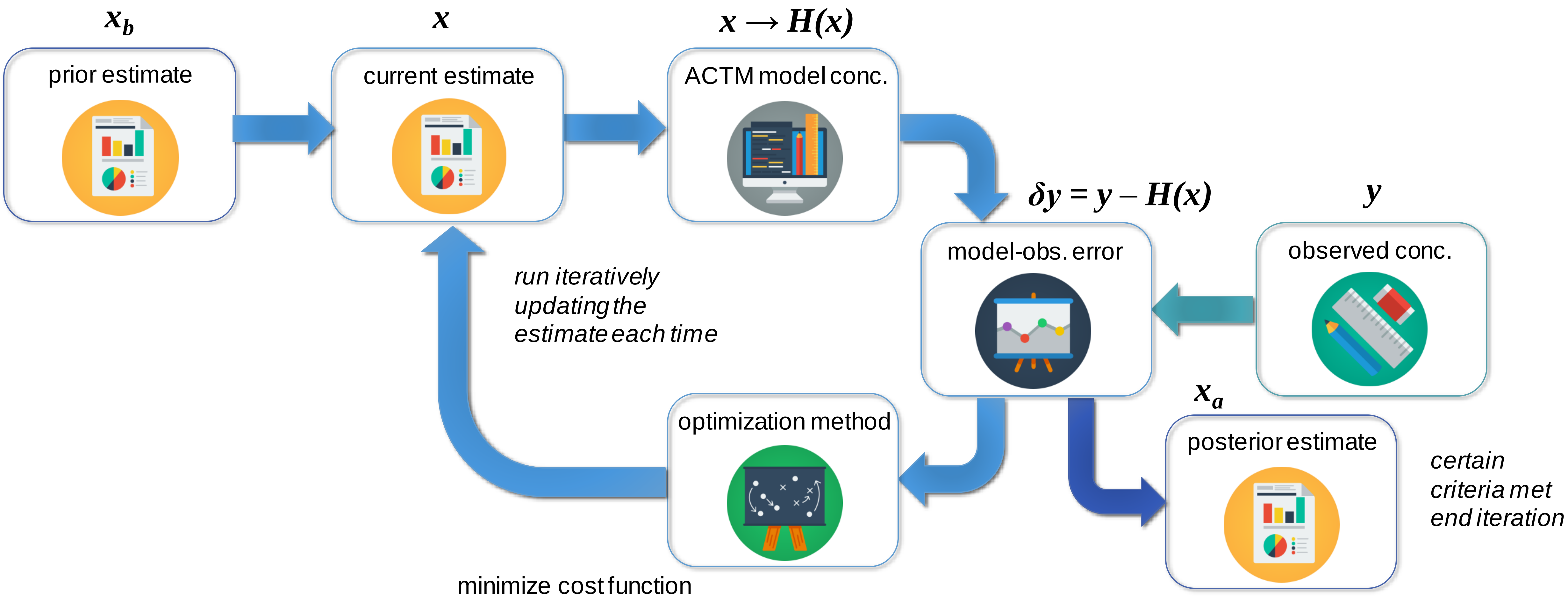


Figure courtesy of E. Dlugokencky (NOAA)

Atmospheric inversion in a nutshell

Provides a rigorous method to relate atmospheric concentrations to fluxes



minimize cost function

$$2J(x) = (x - x_b)^T B^{-1} (x - x_b) + (y - H(x))^T R^{-1} (y - H(x))$$

Example:

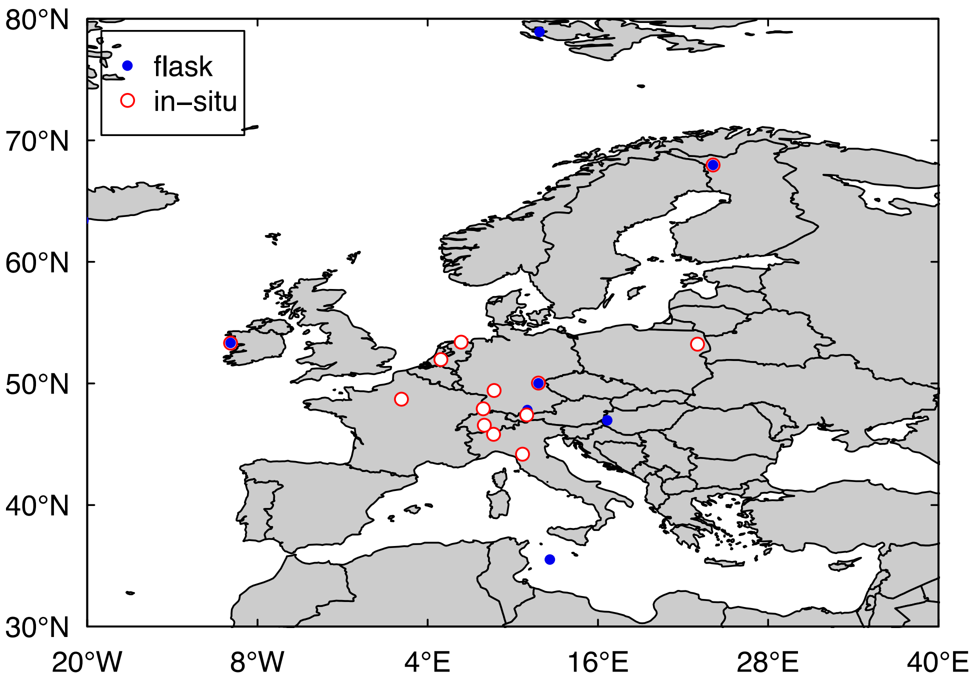
VERIFY inversion for Europe

Prior information (first estimate)

Sources	Method/Model	Resolution/Coverage
Agricultural		
direct and indirect emissions from soils, manure management	EDGAR based on IPCC Tier 1 + 2 approaches (emission factors)	0.1 degrees, monthly Global
Non-agricultural		
energy, industry, waste, transport	EDGAR based on IPCC Tier 1 + 2 approaches (emission factors)	0.1 degrees, monthly Global
Natural		
unmanaged soils	OCN land-surface model (not VERIFY product)	1 degrees, monthly Global
biomass burning (wildfires)	GFED satellite based burnt area and emission factor (not VERIFY product)	0.25 degrees, monthly Global
ocean	PlankTom ocean model (not VERIFY product)	1 degrees, monthly Global

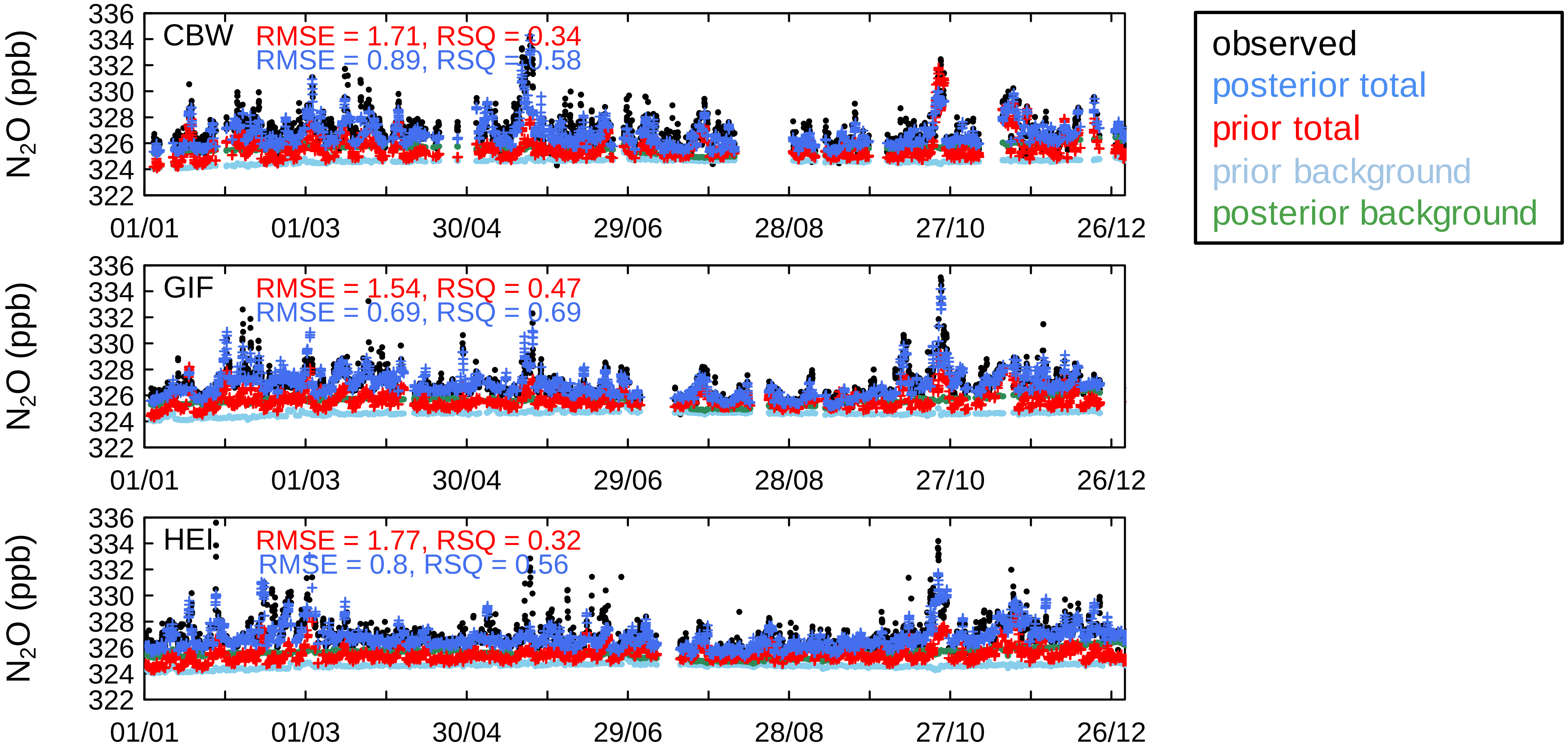
Observation sites

- Core network: sites selected that have quasi-continuous measurements over inversion period (2005-2017)
- Observations from different labs calibrated/adjusted to same scale
- Includes:
  - 13 in-situ sites with 1 observation per hour
  - 7 discrete sample sites with 2-4 observations per month



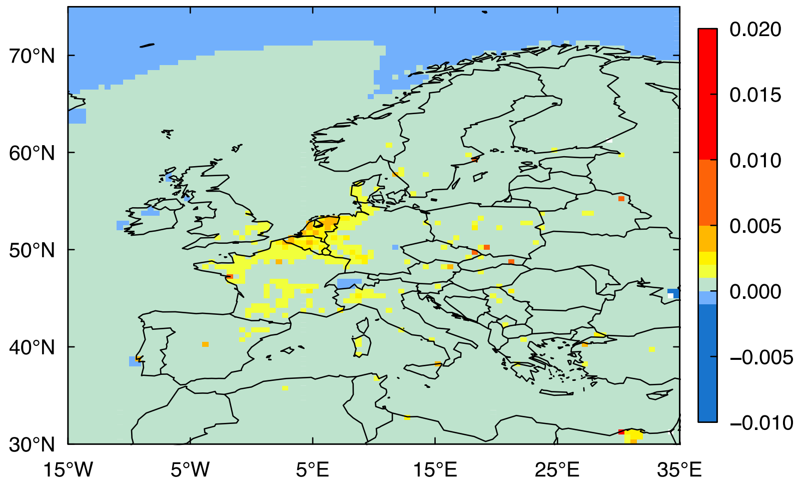
Atmospheric concentrations

Comparison of modelled and observed N_2O at example sites

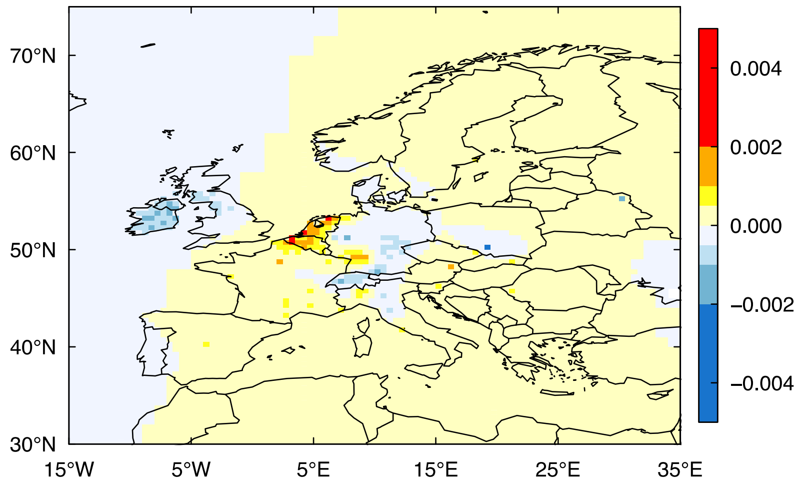


Posterior emissions

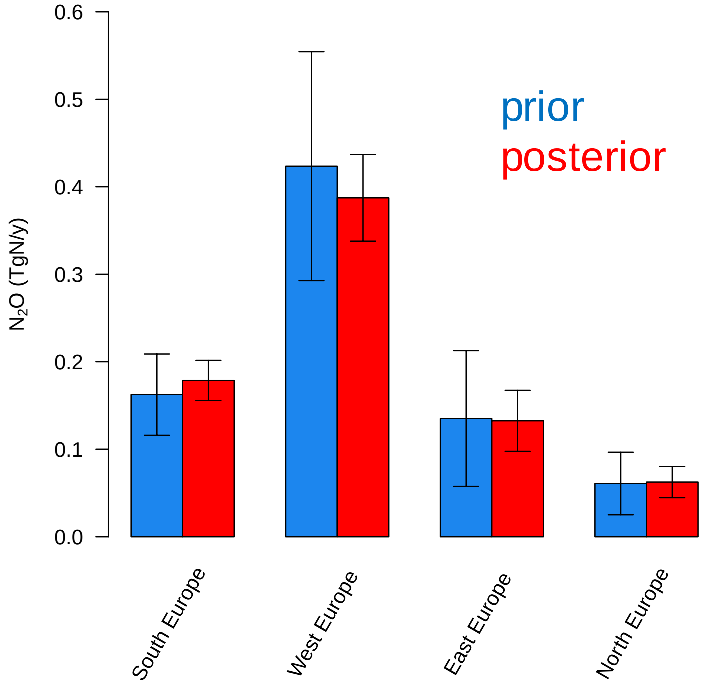
Posterior annual mean N_2O (gN/m²/day)



Posterior-prior annual mean N_2O (gN/m²/day)



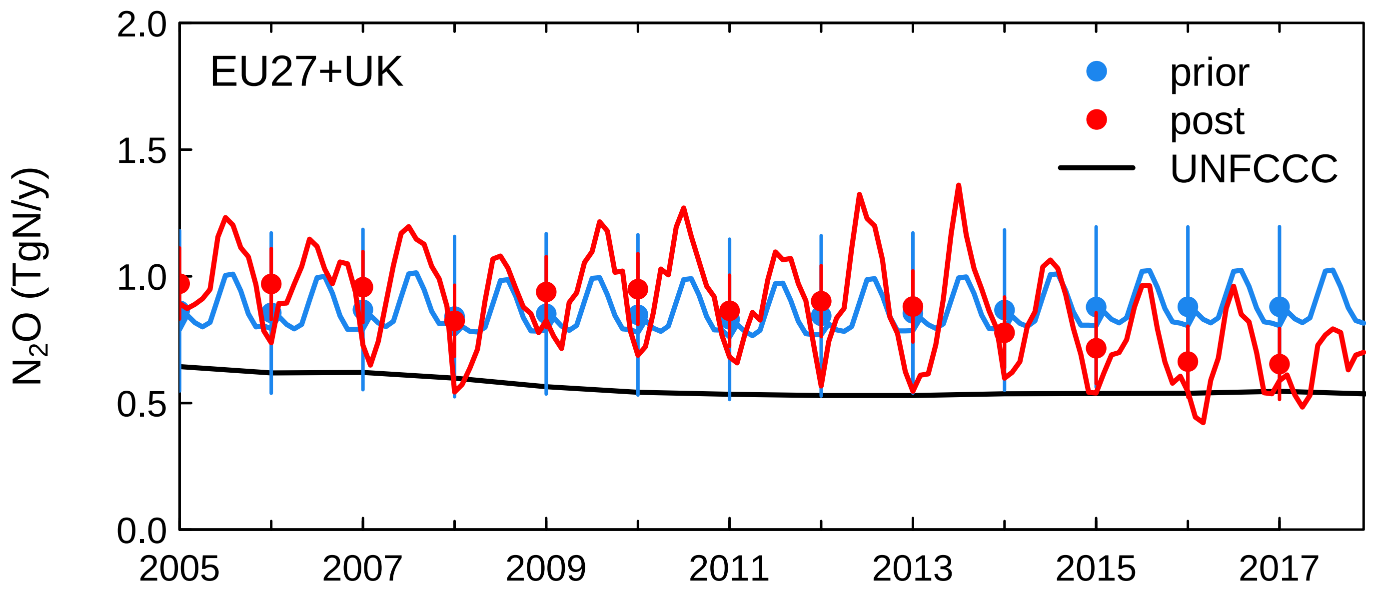
Annual mean emissions (TgN/y)



- Area integrated emissions broadly consistent with the prior (based on EDGAR-v5.0 plus natural sources)
- Significant uncertainty reduction especially in West Europe

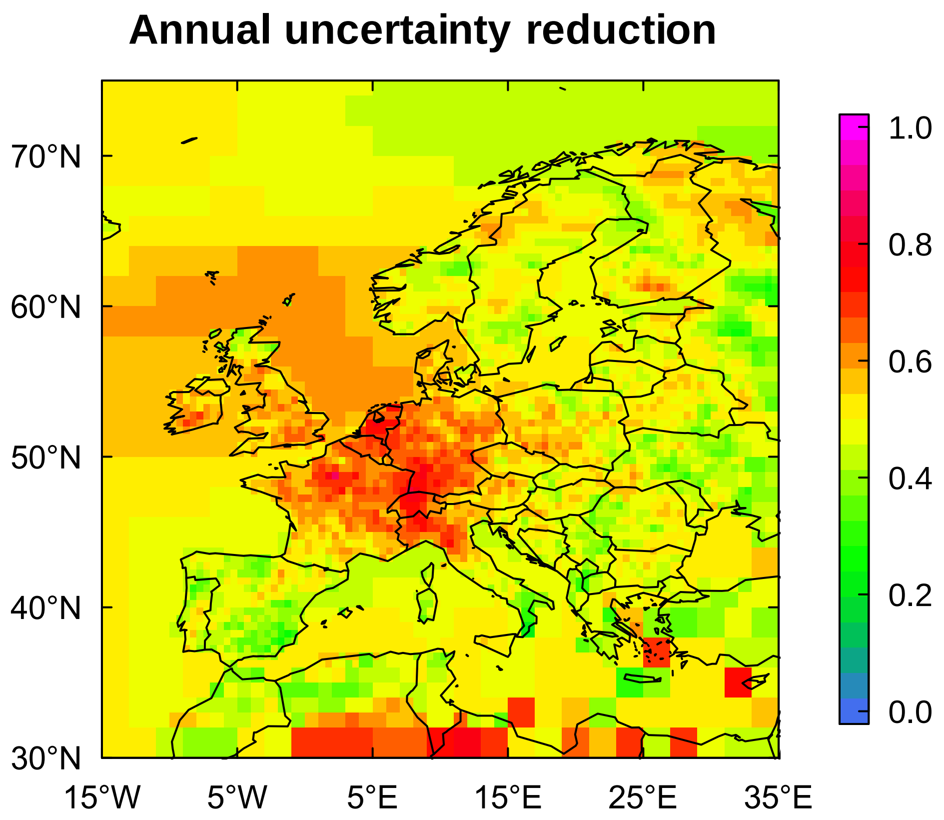
Emission time series

- Comparison UNFCCC EU27+UK and inversion (FLEXINVERT)
- Inversion shows larger seasonal variability (meteorological effect on anthropogenic emissions not in UNFCCC or prior)
- Prior and posterior higher than UNFCCC (posterior 51% larger than UNFCCC)
- Posterior shows decrease from 2013 (close to UNFCCC in 2017)



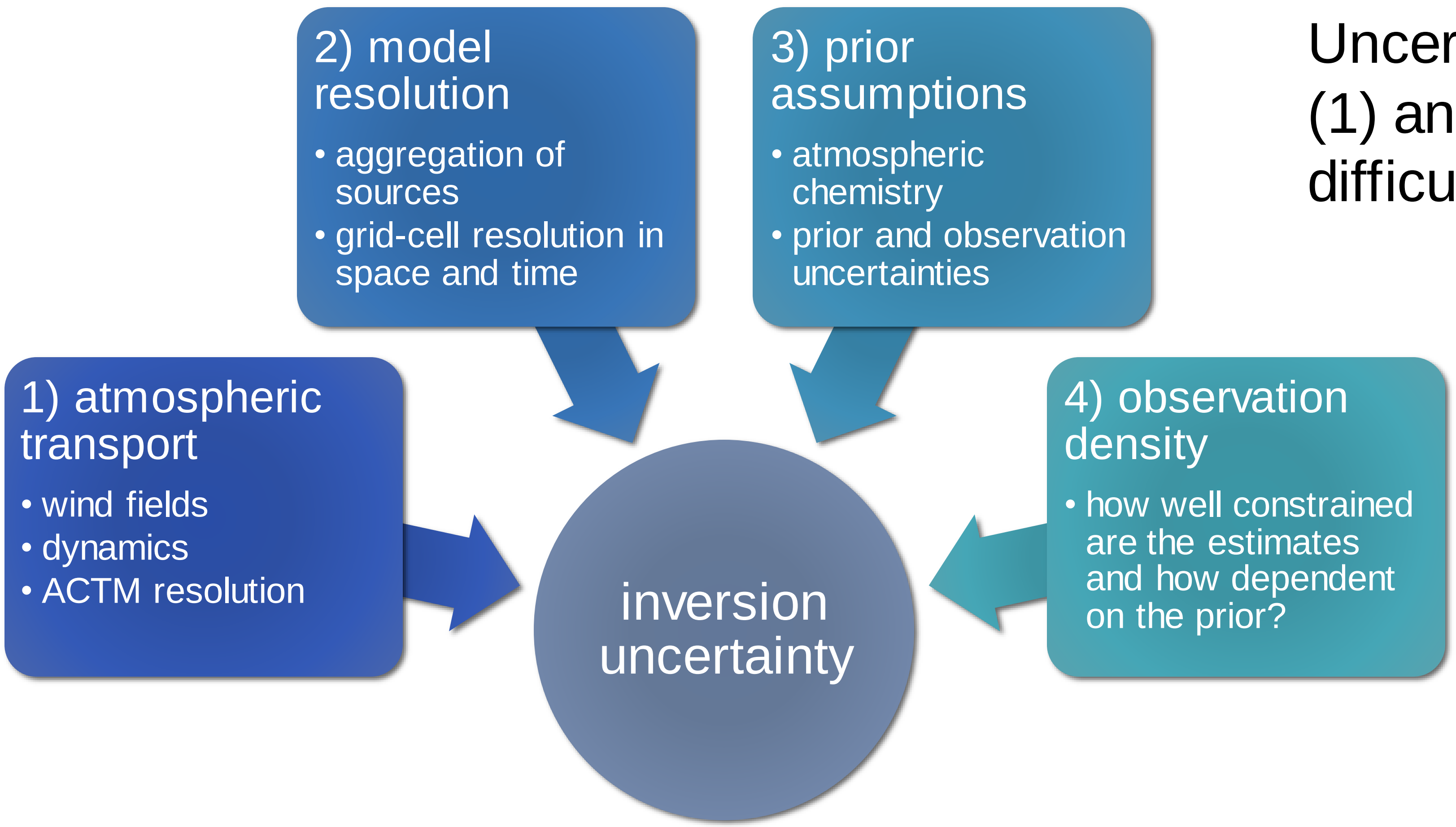
Posterior uncertainty

- Posterior uncertainty can be calculated from the inversion
- Only random uncertainty considered, does not account for systematic uncertainty (e.g. model transport)
- Uncertainty reduction (1 – epos/eprior) indicates how much independent (observation) information constrained the emissions



General remarks…

Sources of uncertainty in inversions



Uncertainties from (1) and (3) are more difficult to quantify

Dependence of inversion on prior estimates

Inversion estimates can be described as a weighting between the true and the prior fluxes:

$$\mathbf{x}_{\mathrm{post}} = \mathbf{A}\mathbf{x}_{\mathrm{true}} + (\mathbf{I} - \mathbf{A})\mathbf{x}_{\mathrm{prior}}$$

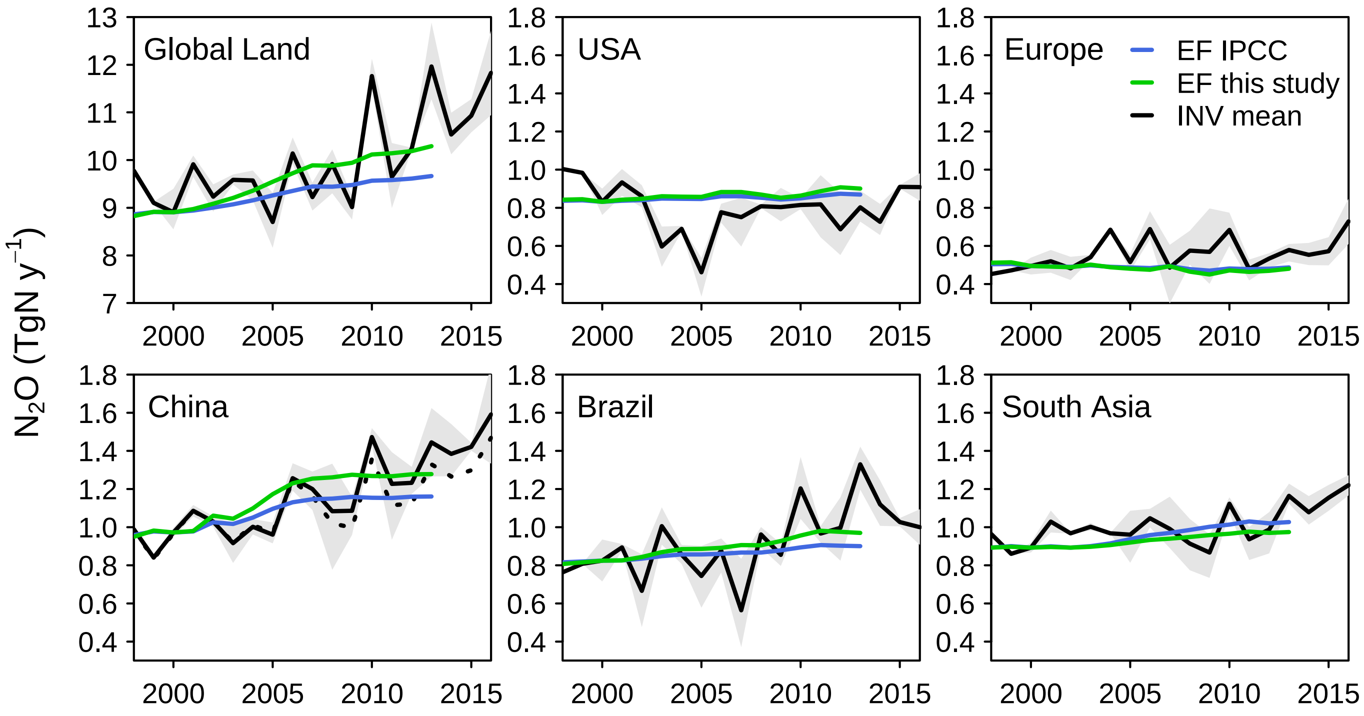
where $\mathbf{A}$ is Averaging Kernel (comes out of Bayesian statistics)

$$\mathbf{A} = (\mathbf{H}^{\mathrm{T}}\mathbf{R}^{-1}\mathbf{H} + \mathbf{B}^{-1})\mathbf{H}^{\mathrm{T}}\mathbf{R}^{-1}\mathbf{H}$$

depends on atmospheric transport ($\mathbf{H}$), observation uncertainties ($\mathbf{R}$) and prior flux uncertainties ($\mathbf{B}$)

What we can learn from TD: 1

- Long-term trends (dominated by anthropogenic emissions)
- Meteorological effects on N_2O fluxes from soil and water

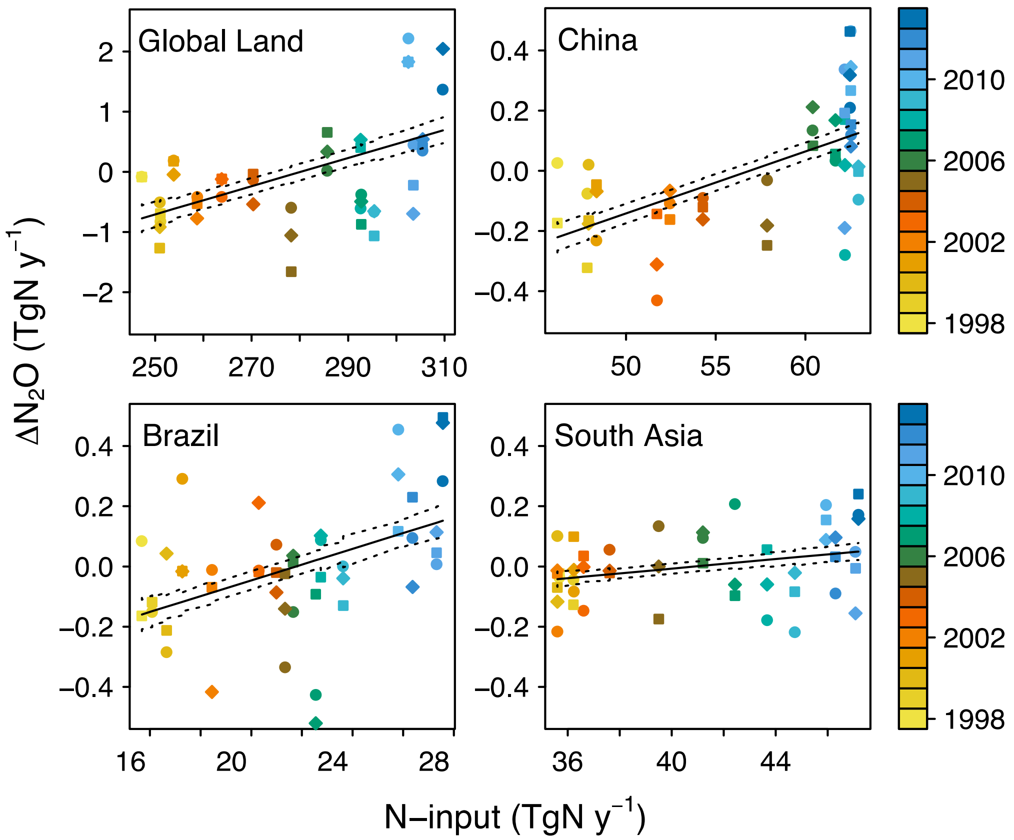


Note: offset added to EF estimates to match TD in year 2000

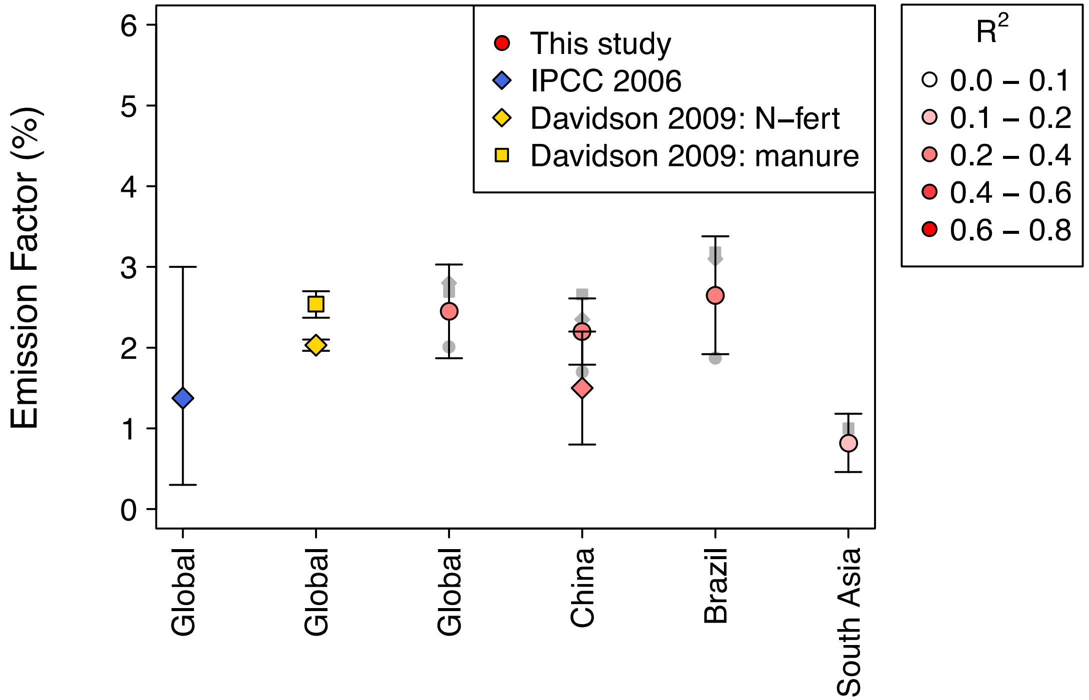
What we can learn from TD: 2

- Total emission factors (total N_2O emitted relative to total N-input)

Change in N_2O from TD versus N-input



Comparison of EFs TD versus BU



What we can learn from TD: 3

- Dedicated observations can constrain large point sources and their EF

Observations of N_2O from fertilizer plant with aircraft measurements

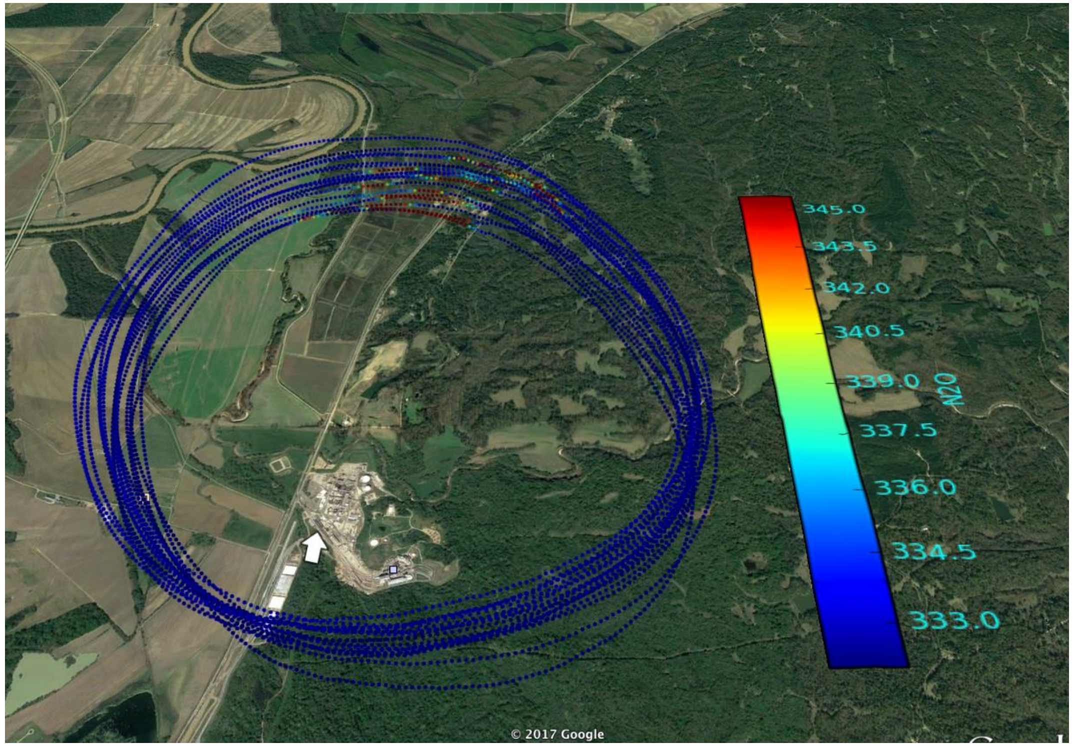


Figure courtesy of E. Kort (Univ. Michigan)

Summary and conclusions

- At European scale TD (inversion) estimates suggest average 0.29 TgN/y (51%) (2005-2017) larger total N_2O source compared to UNFCCC reporting
- TD estimates appear to significantly reduce the uncertainty
- TD estimates larger seasonal and interannual variability compared to prior
- TD can provide information on long-term trends (if these are of magnitude detectable by observation network)
- TD can provide estimates of total EF (direct + indirect) at large scales
- At small scales focused atmospheric measurements can help constrain large point sources (e.g. nitric acid plant)