Estimating US methane emissions using GOSAT observations

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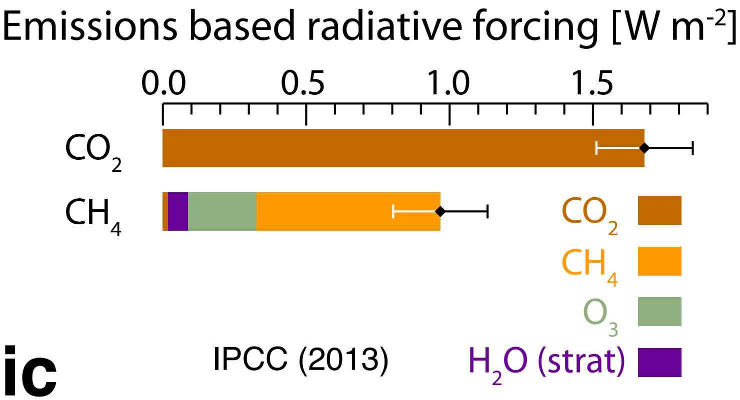
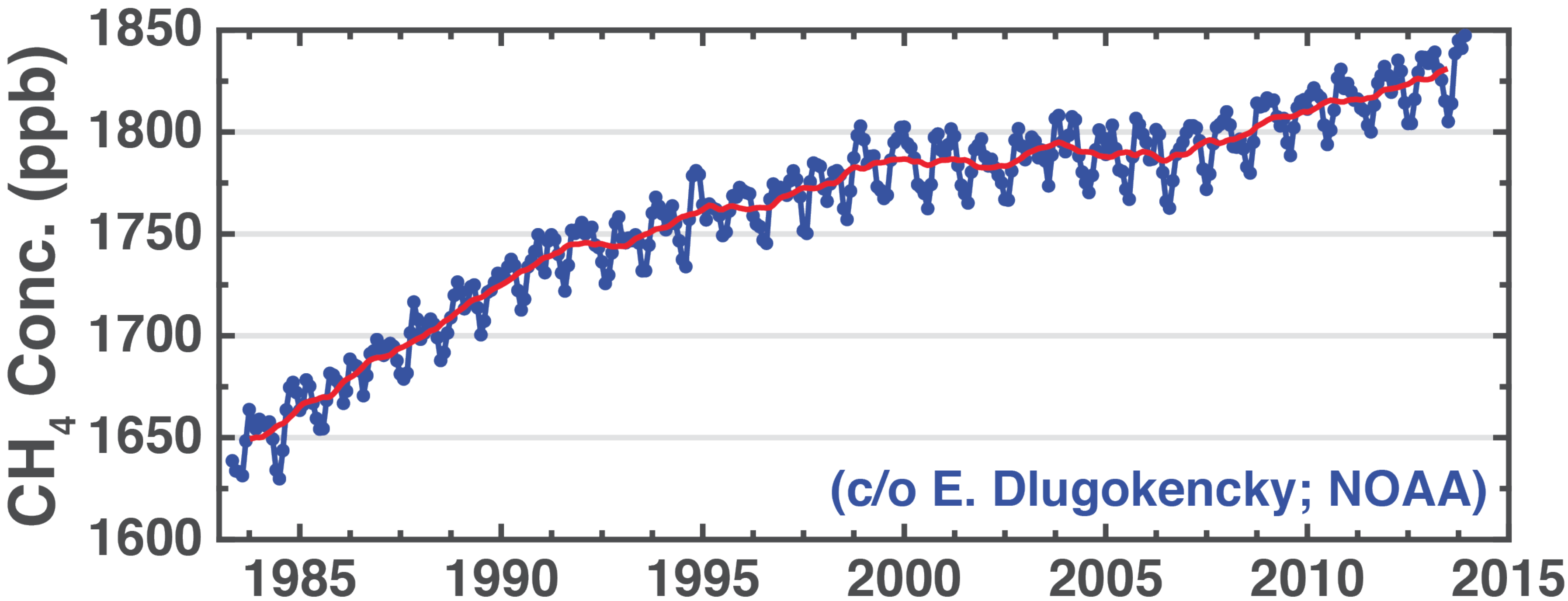
Why do we care about atmospheric methane?

1) Methane is a potent greenhouse gas

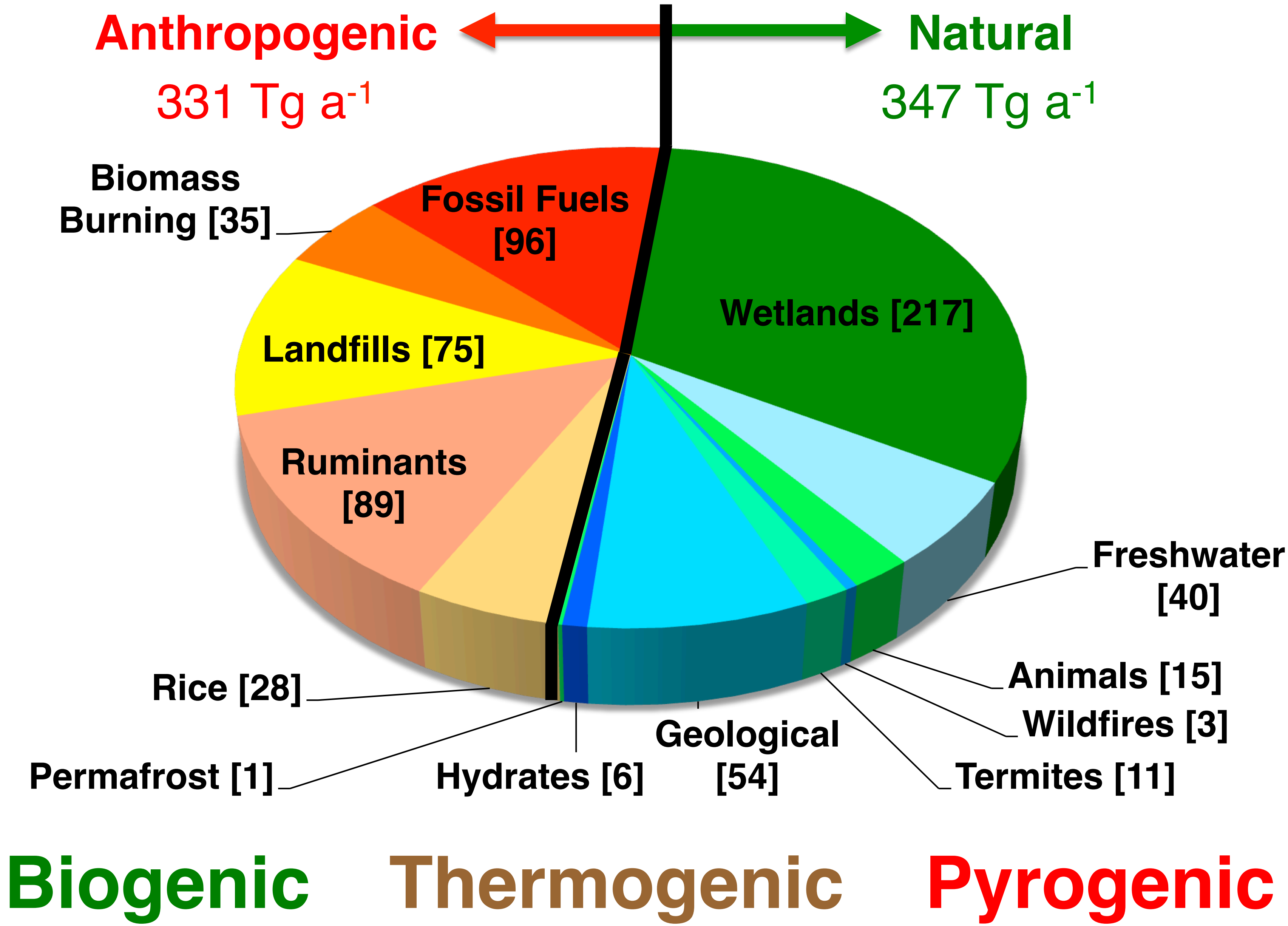
- 2nd only to CO_2



2) Recent trends in atmospheric methane are not well understood



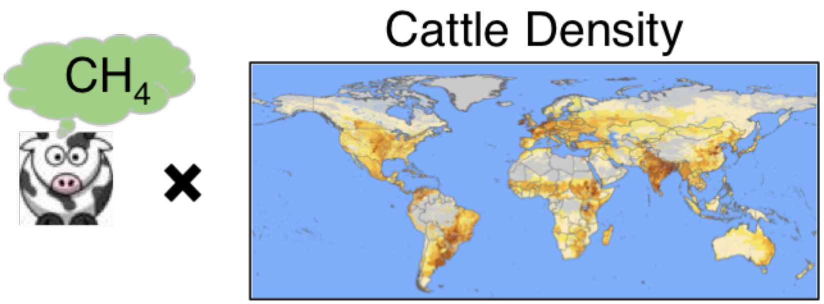
Global methane emission sources



Kirschke et al. (2013) & IPCC (2013)

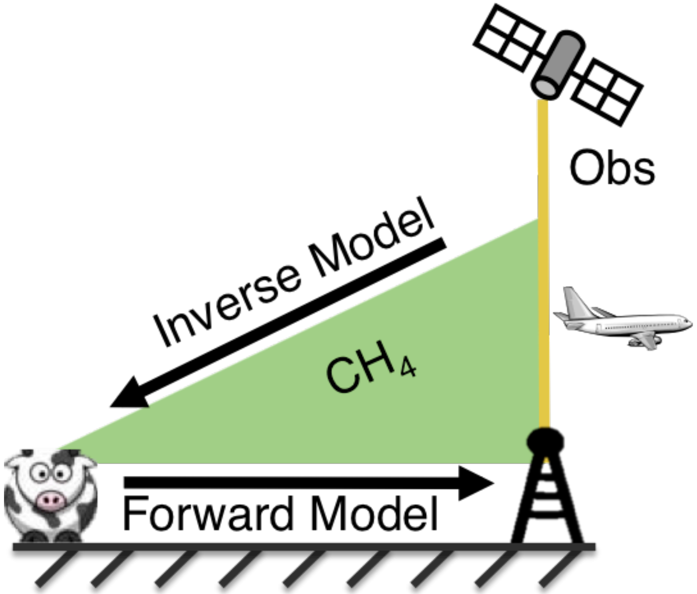
Methods of estimating methane emissions

Bottom-up



= Global map of cattle emissions

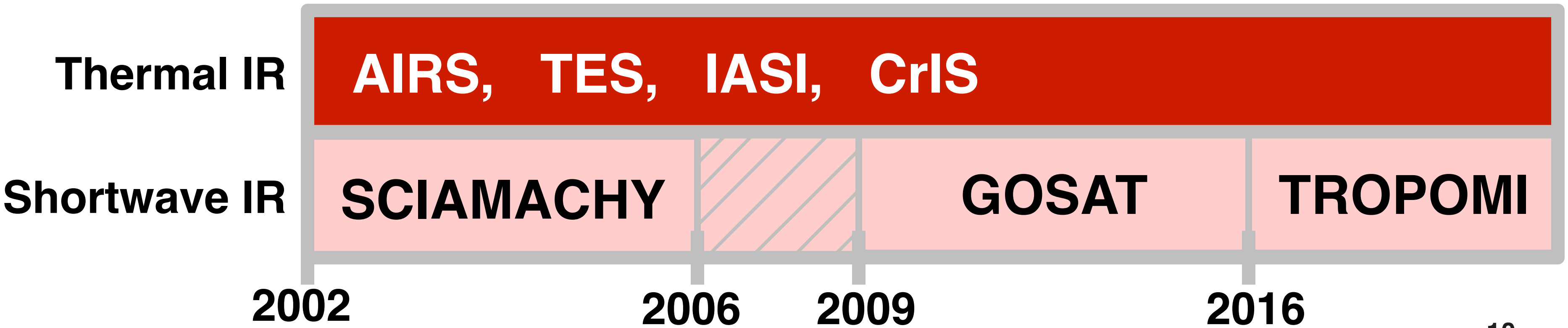
Top-down

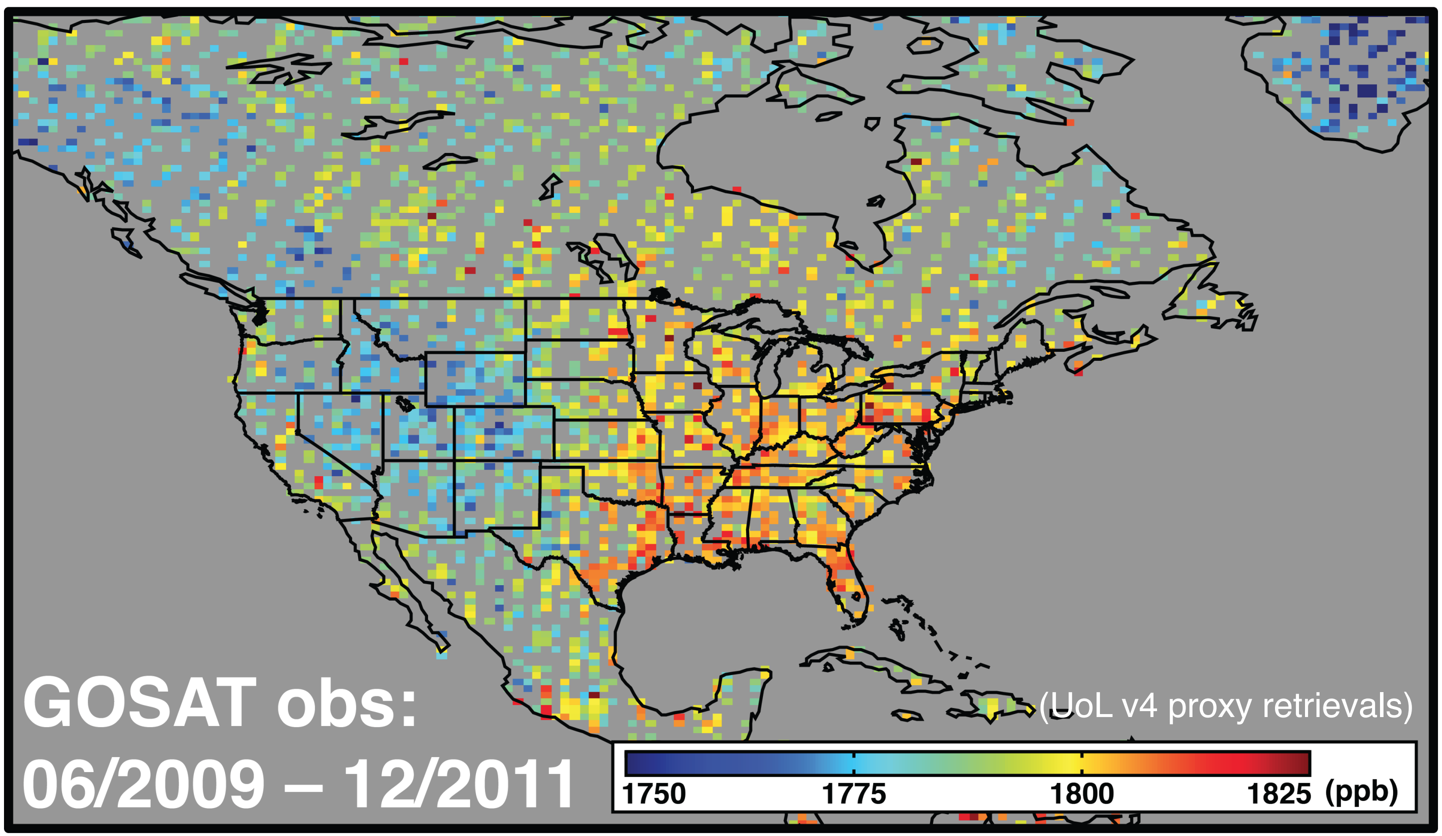


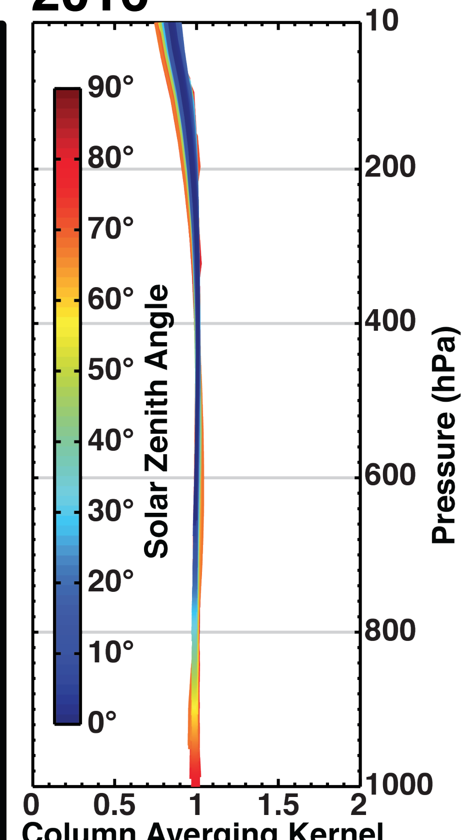
Satellites provide dense spatial coverage but have large uncertainties

Retrievals of methane from observed radiances

Satellites Observing Methane

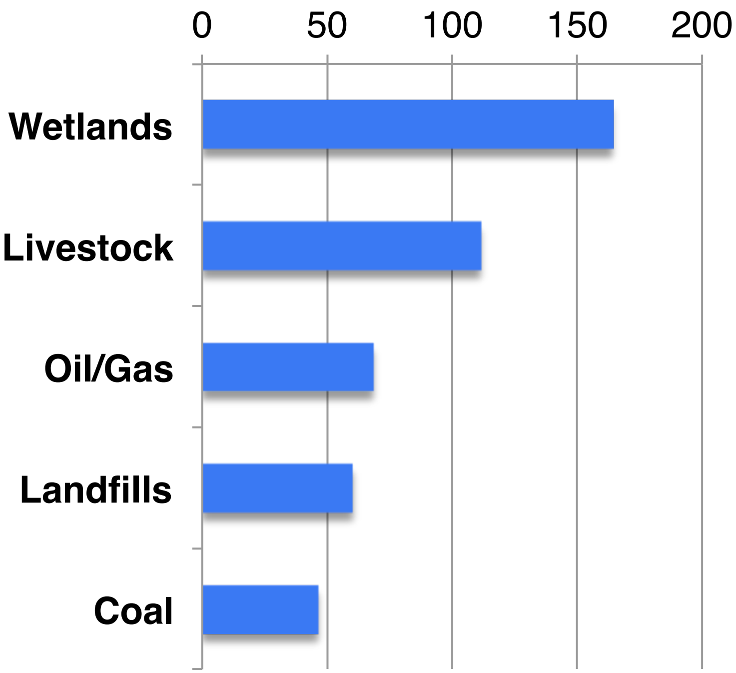




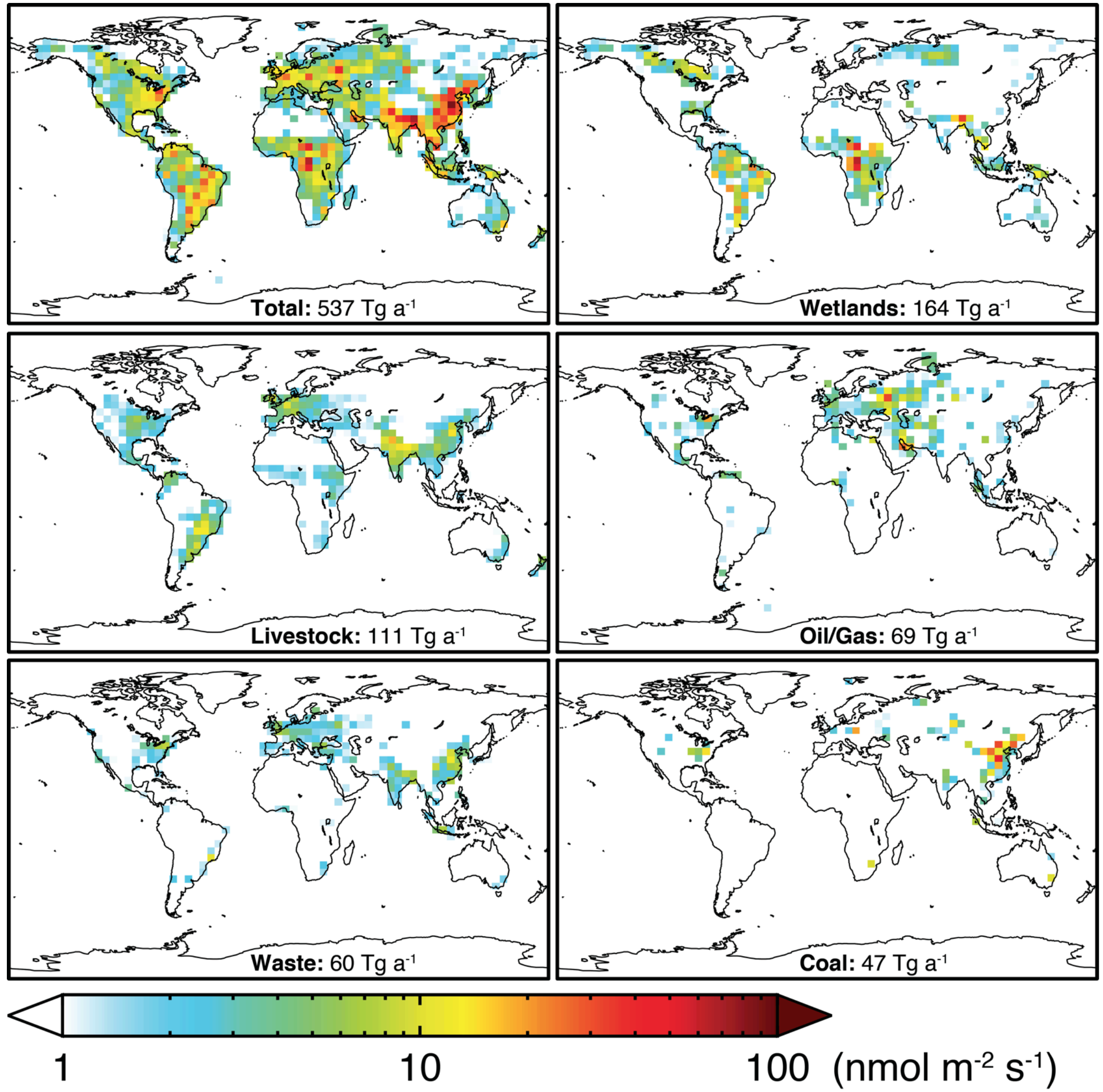


Prior emissions from EDGARv4.2 + LPJ + GFED3

Major Sources ($Tg\ yr^{-1}$)

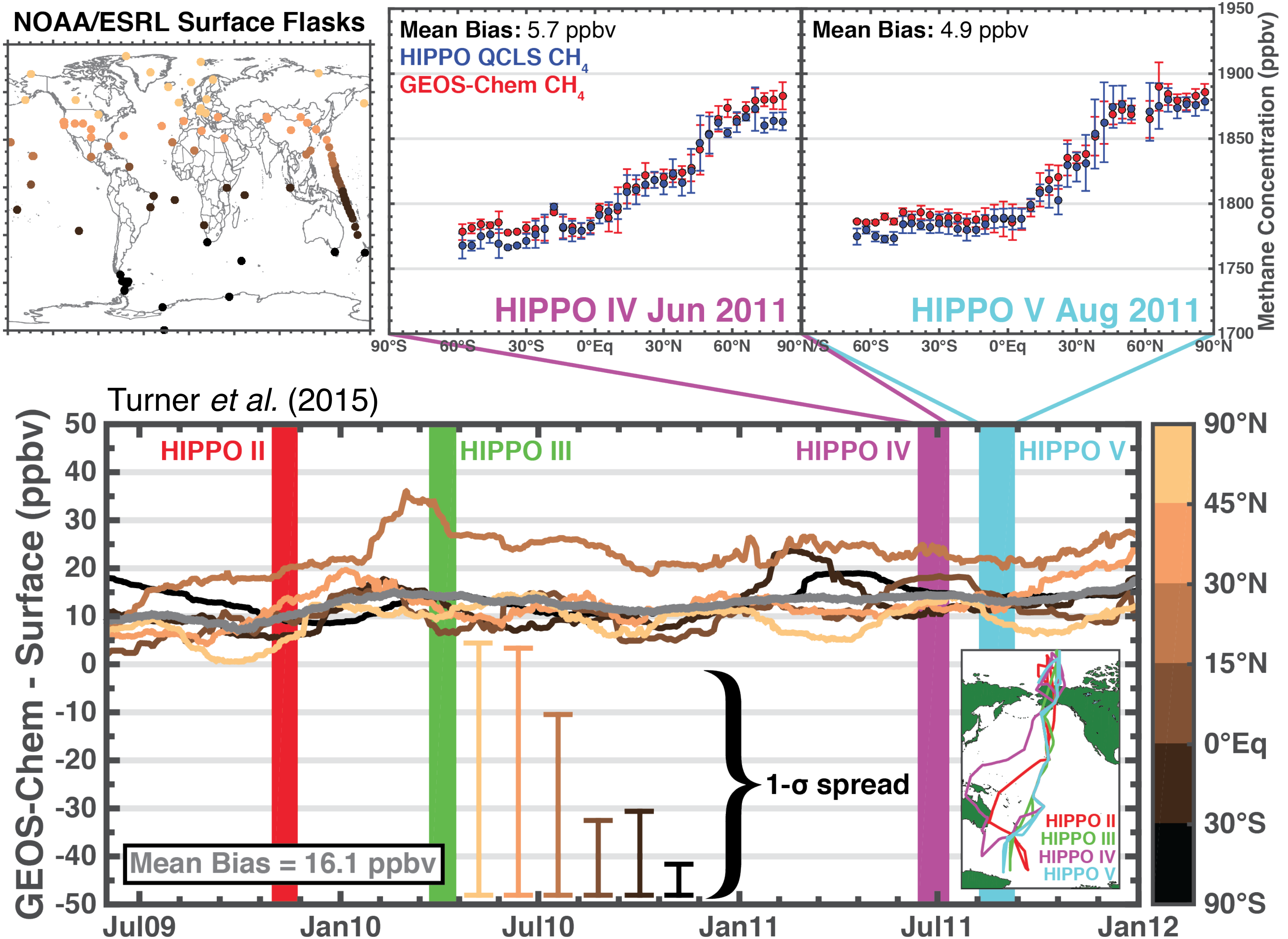


Total: 537 $Tg\ yr^{-1}$

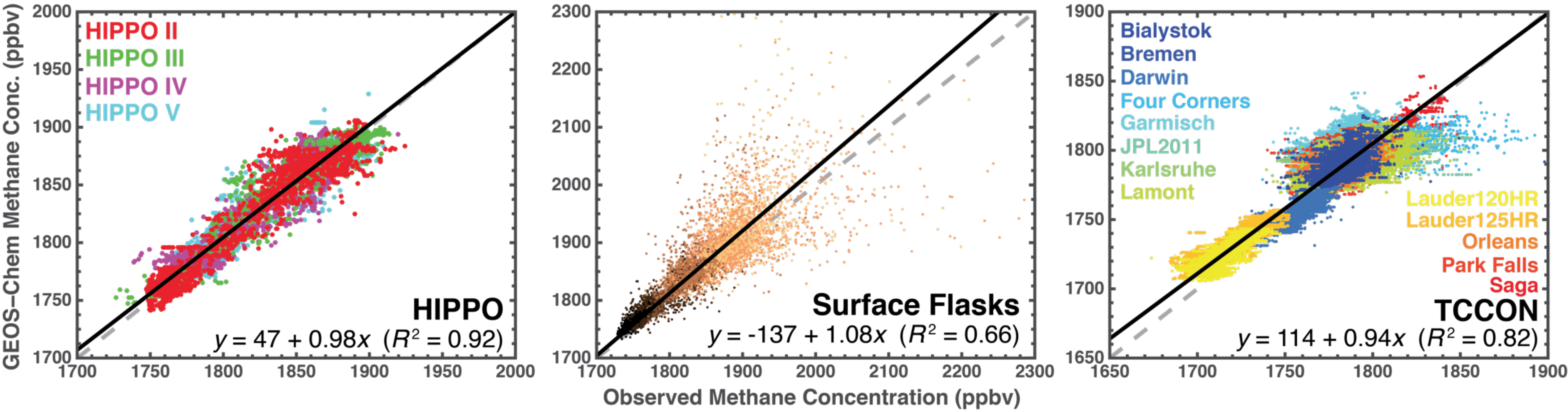


Turner *et al.* (2015)

Model compares well with observations



Model compares well with observations

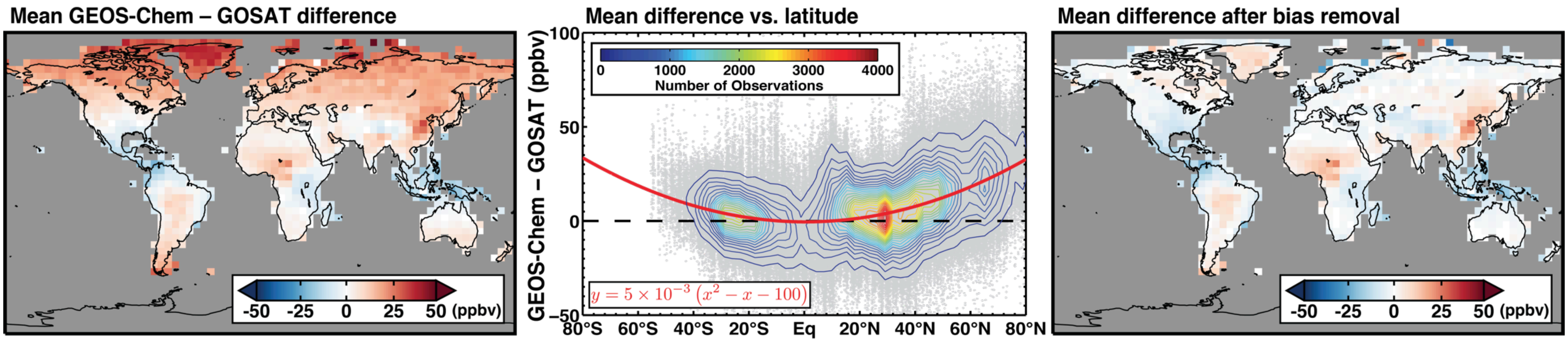


- **Latitudinal gradient and seasonal cycle are represented**
  - Compared to HIPPO, NOAA/ESRL, and TCCON

- **Captures surface, free trop, and total column background**

Turner *et al.* (2015)

Identifying a GOSAT/GEOS-Chem bias



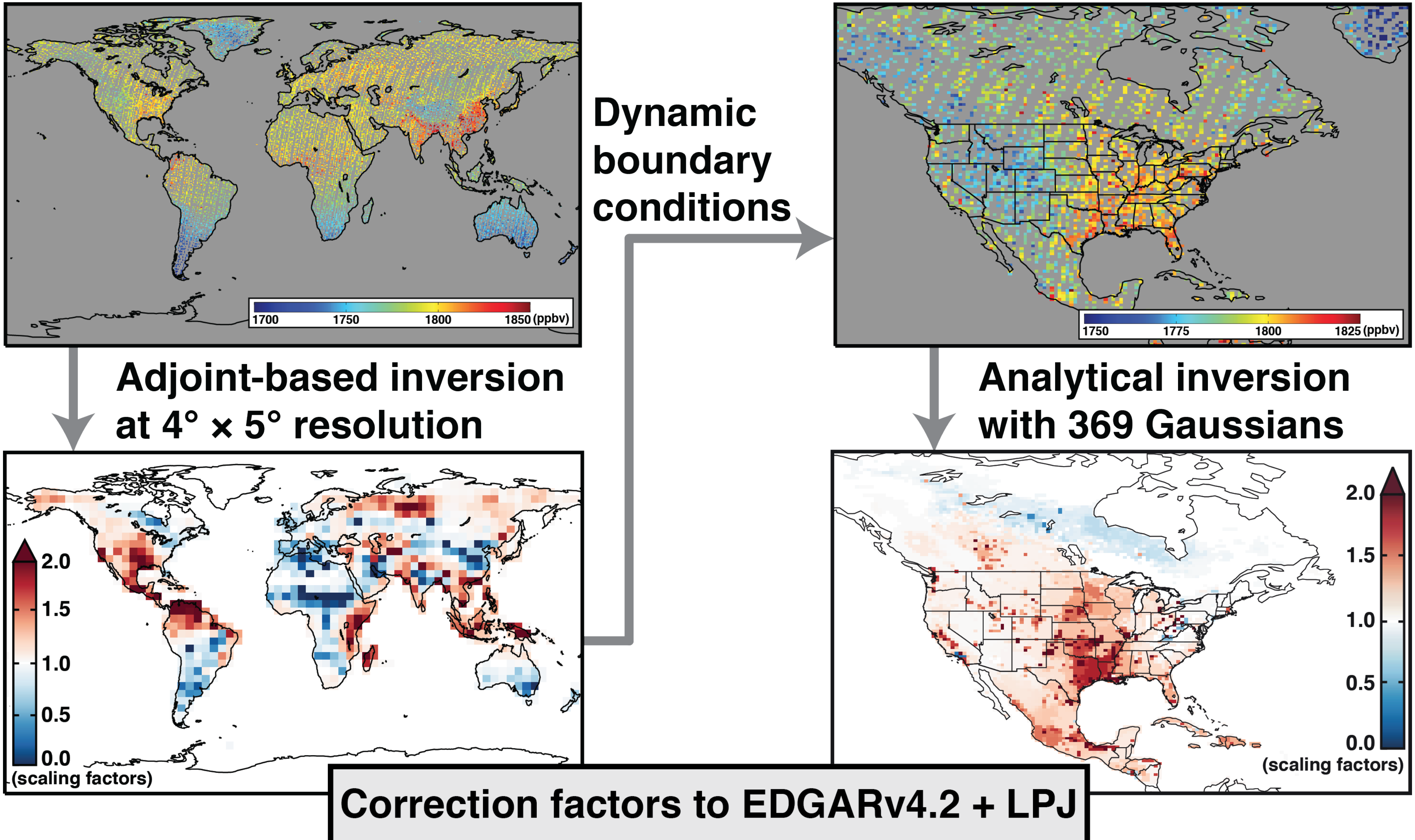
- **Model/satellite comparison identifies a high-latitude bias**
  - Latitudinal bias not seen in surface, aircraft, or column comparison

- **Remove bias before estimating methane emissions**
  - Bias is either due to the model stratosphere or GOSAT retrievals

Observations are ready for inversion!

Turner *et al.* (2015)

General inversion framework: 2009–2011 GOSAT data

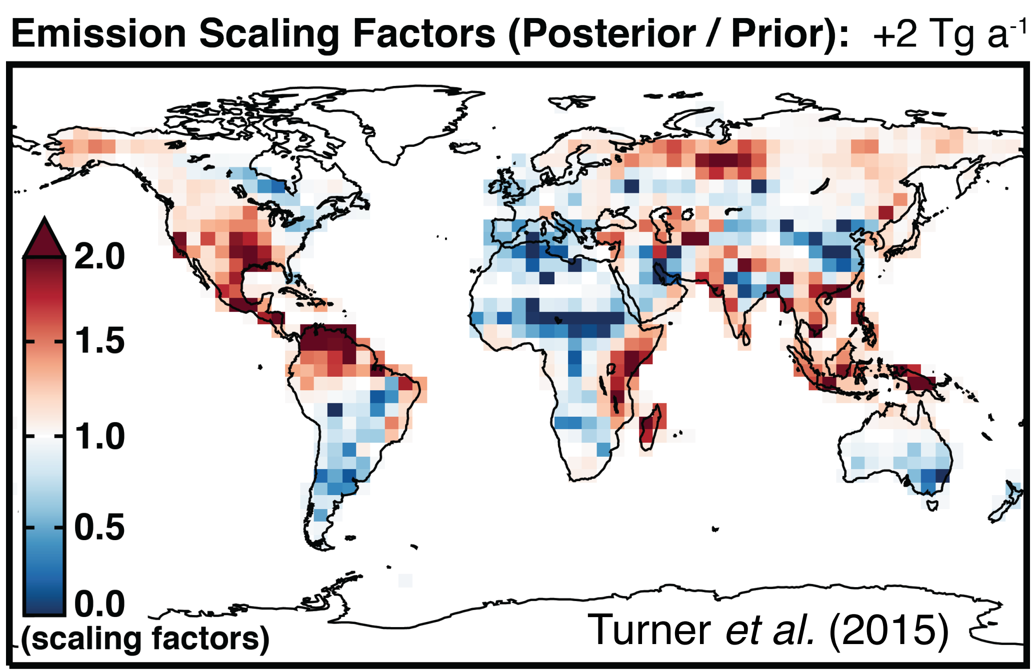


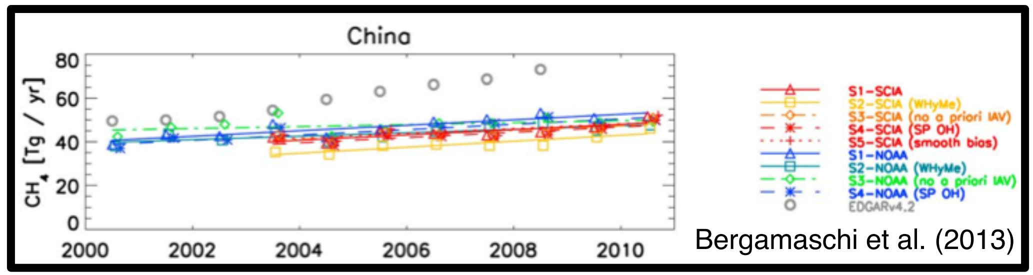
Global inversion provides dynamic BCs for North America

Turner *et al.* (2015)

Global inversion results

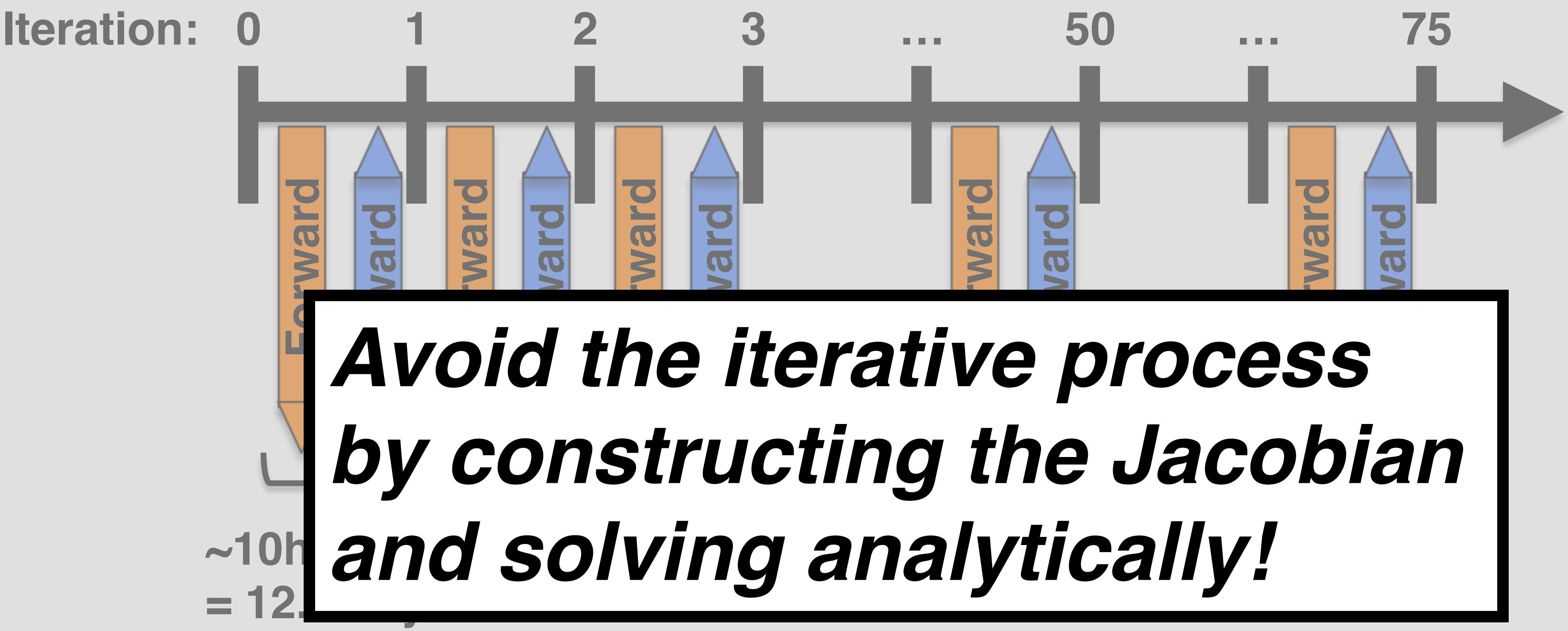
- **Overestimate of Chinese methane emissions**
  - Consistent with previous work (e.g., Bergamaschi et al. 2013, Bruhwiler et al. 2014, Schwietzke et al. 2014)





- **Underestimate in South-Central US emissions**
  - Will further investigate using Nested North American simulation

Adjoint is not ideal for long time horizons at hi-res



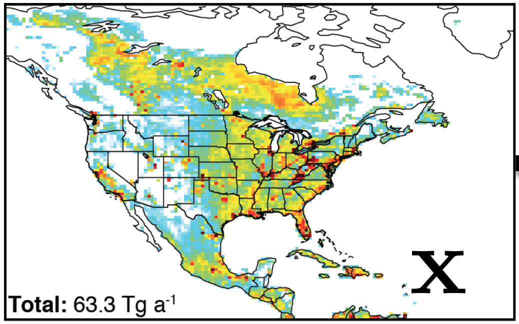
Avoid the iterative process by constructing the Jacobian and solving analytically!

Simulation Walltime: 2.6 years

Estimating methane emissions at high resolution

Spatial error correlations are important at fine spatial scales!

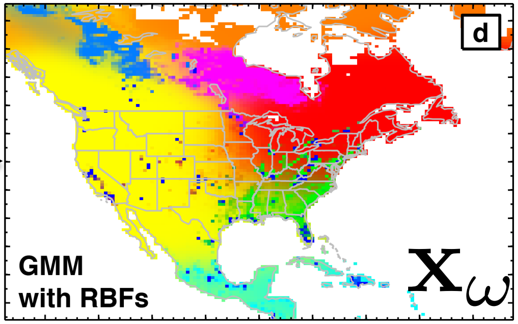
Native resolution ½° × ⅔° state vector x (n = 7366)



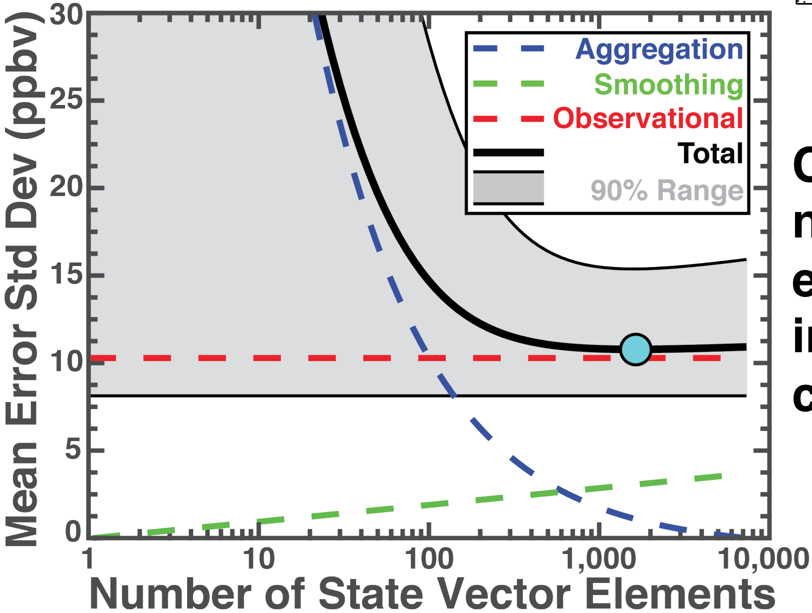
Aggregation Matrix: Γ_ω

$$\mathbf{x}_\omega = \Gamma_\omega \mathbf{x}$$

Reduced-resolution state vector x_ω (here n = 8)



Posterior error depends on choice of state vector dimension



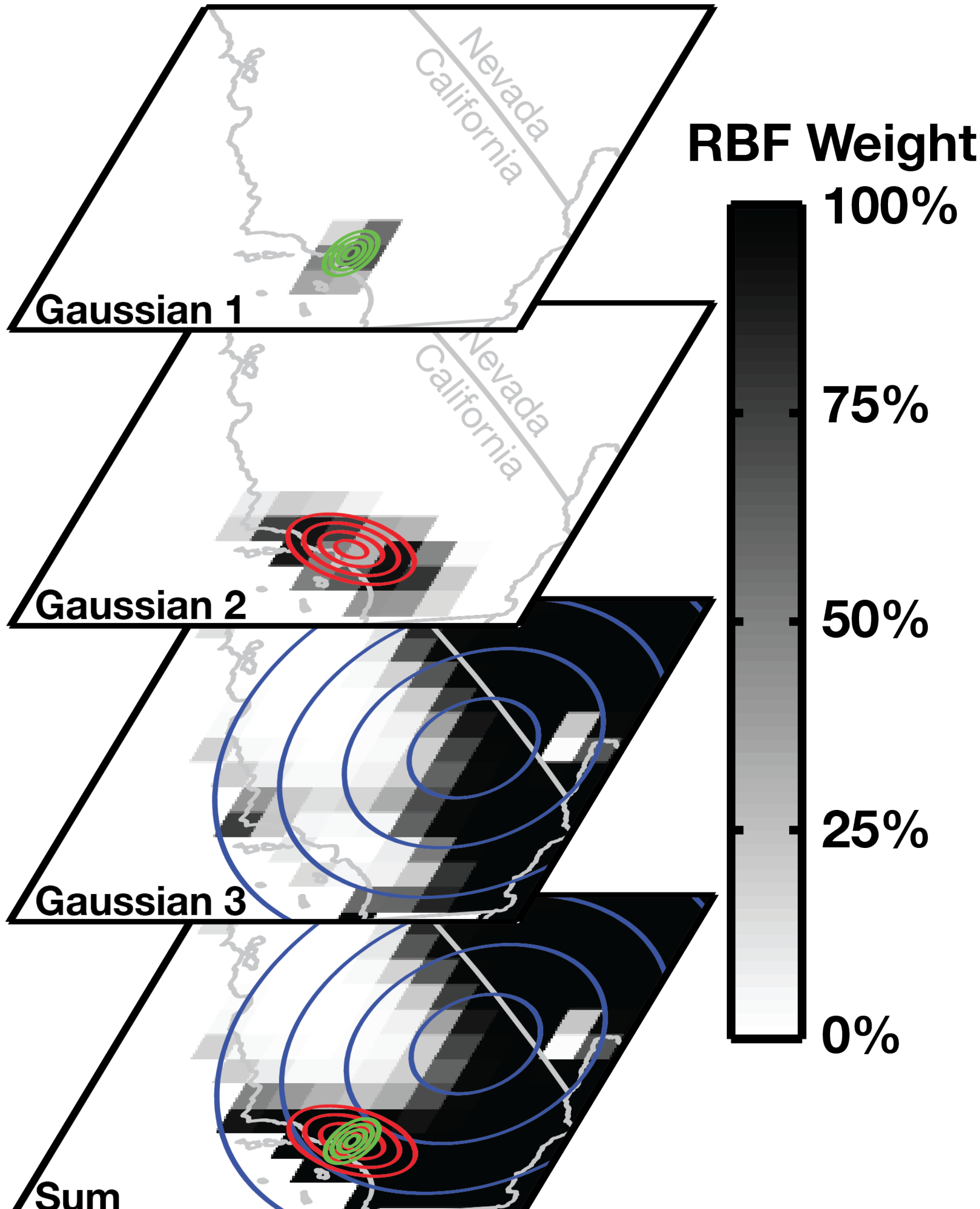
Choose n = 369 for negligible aggregation error; allows analytical inversion with full error characterization

Optimal size must balance aggregation and smoothing error

Turner and Jacob (2015)

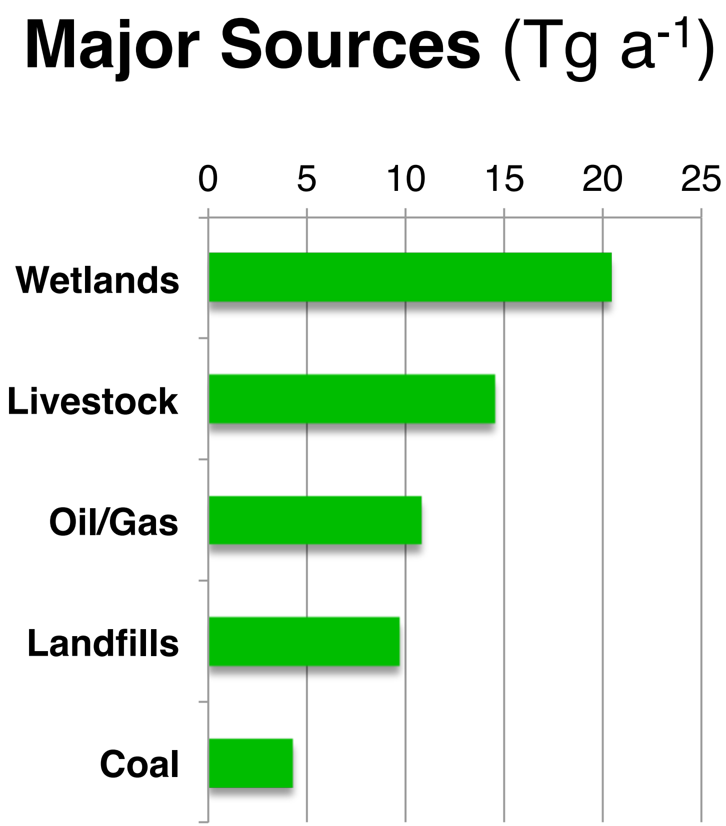
Radial Basis Functions retain high resolution

- **Decompose the state vector into Gaussians**
  - Group based on correlated prior emission patterns
- **Retain high resolution**
  - Coarsen weak or uniform signals



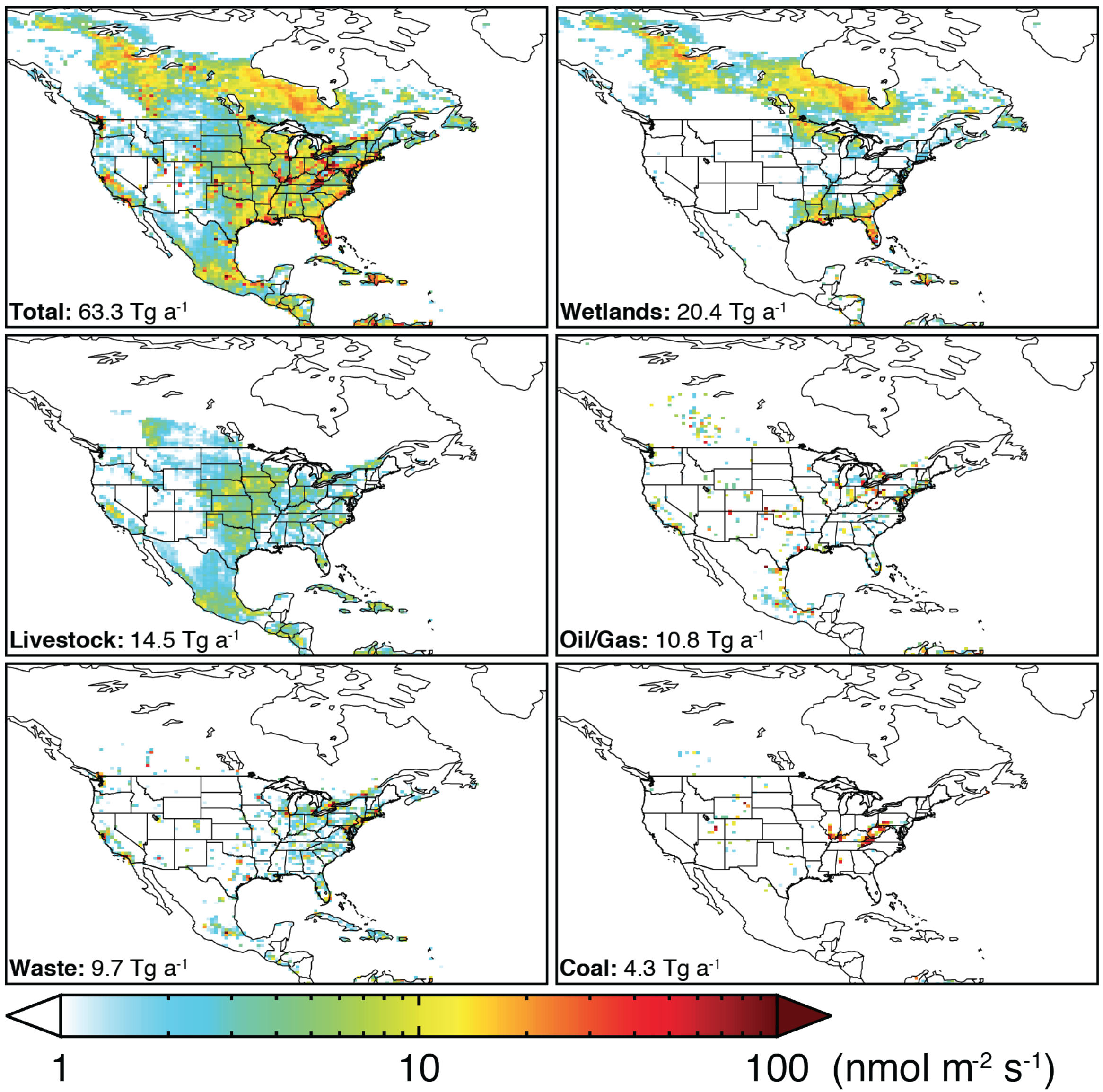
Turner and Jacob (2015)

Prior methane emissions from EDGARv4.2 + LPJ



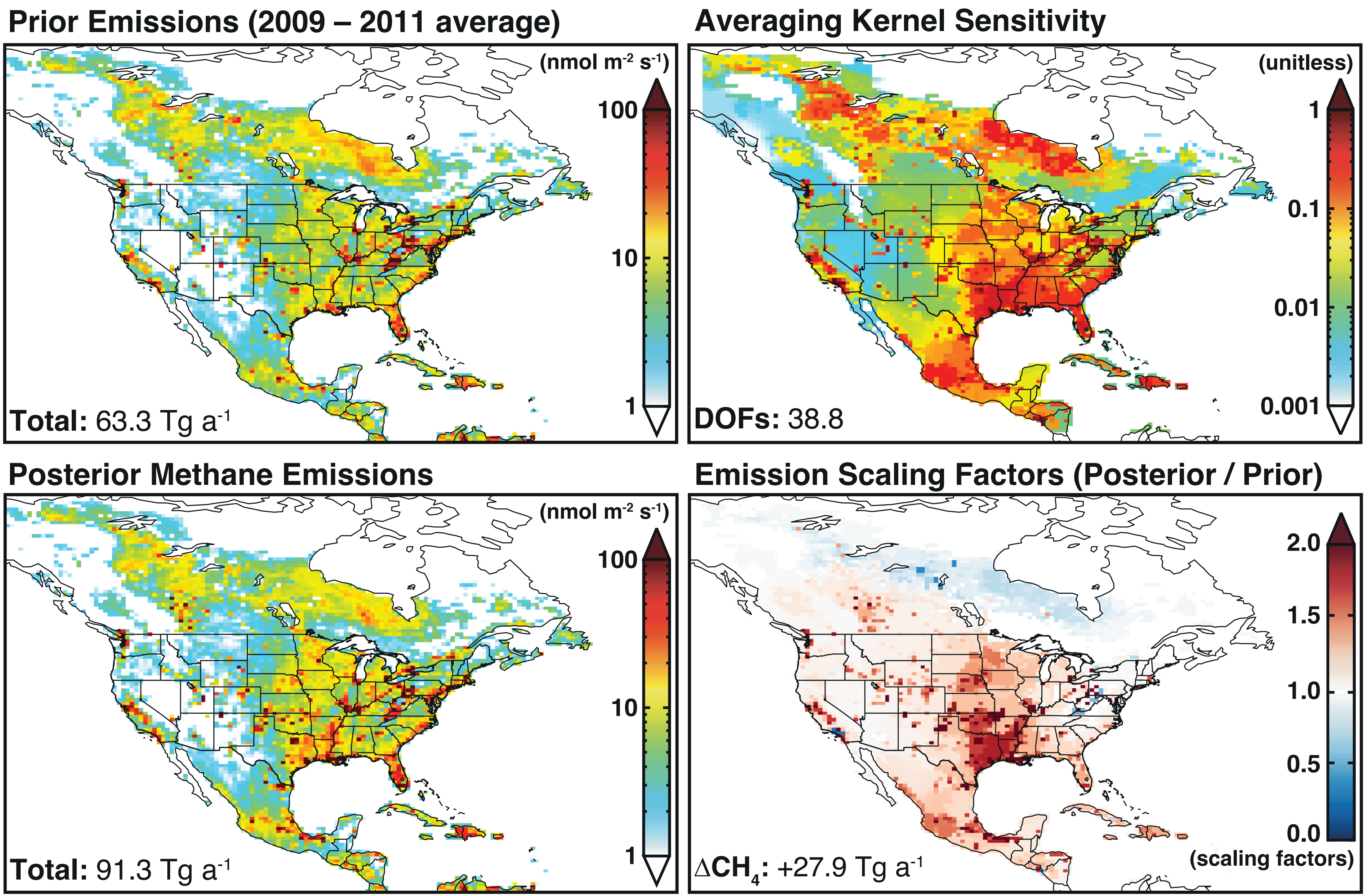
Total: 63/537 Tg a^{-1}

North America **Global**



Turner *et al.* (2015)

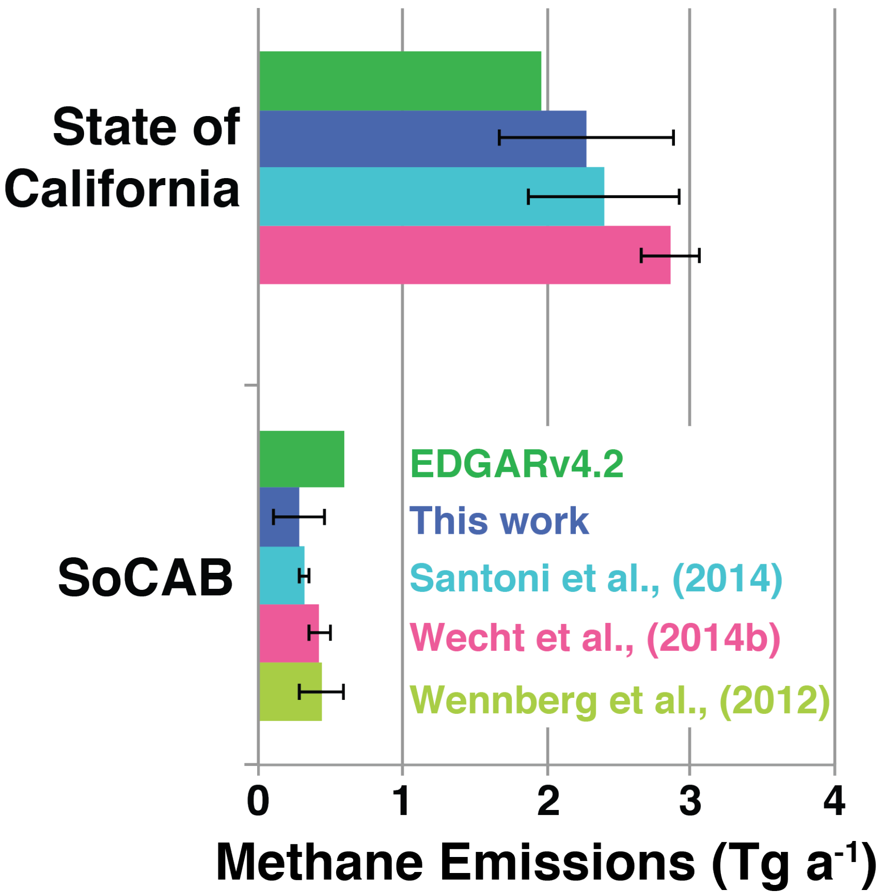
Constraining North American methane sources

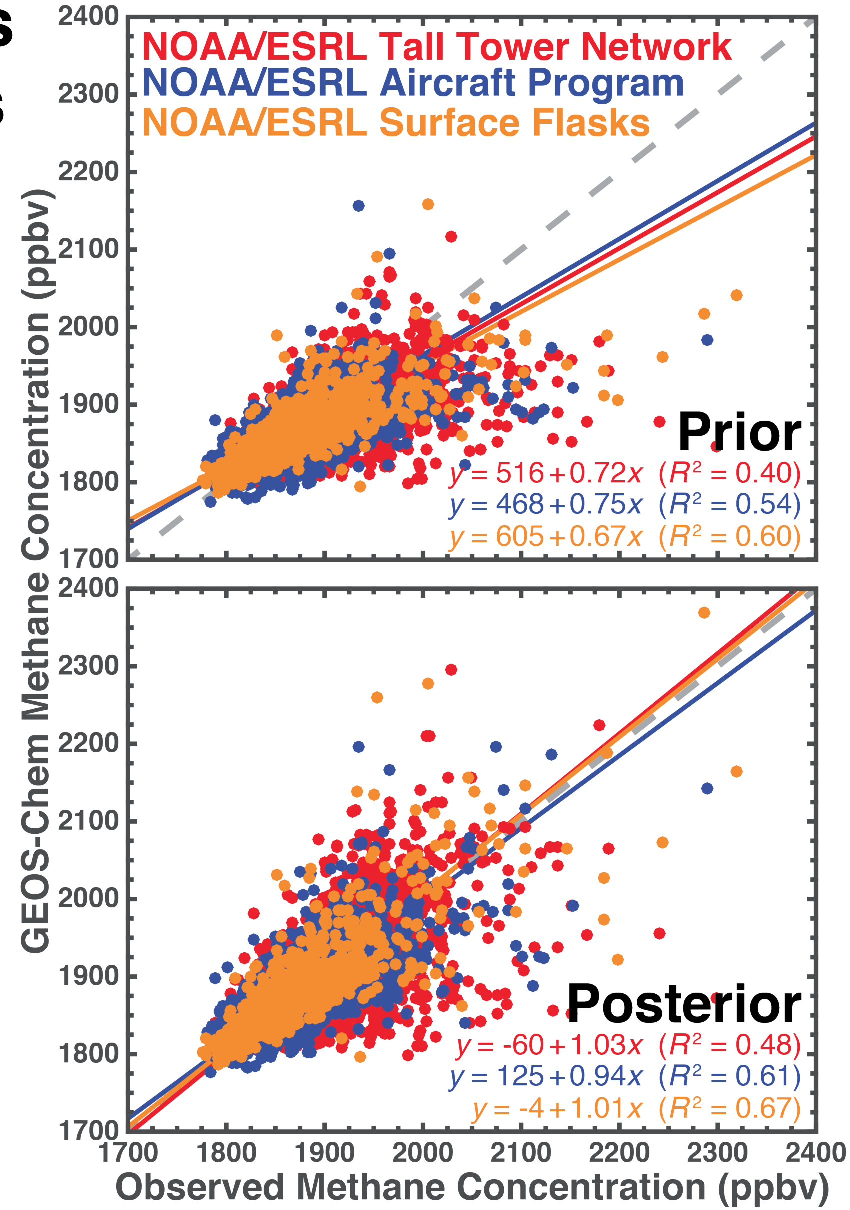


Turner *et al.* (2015)

Does this posterior inventory improve things?

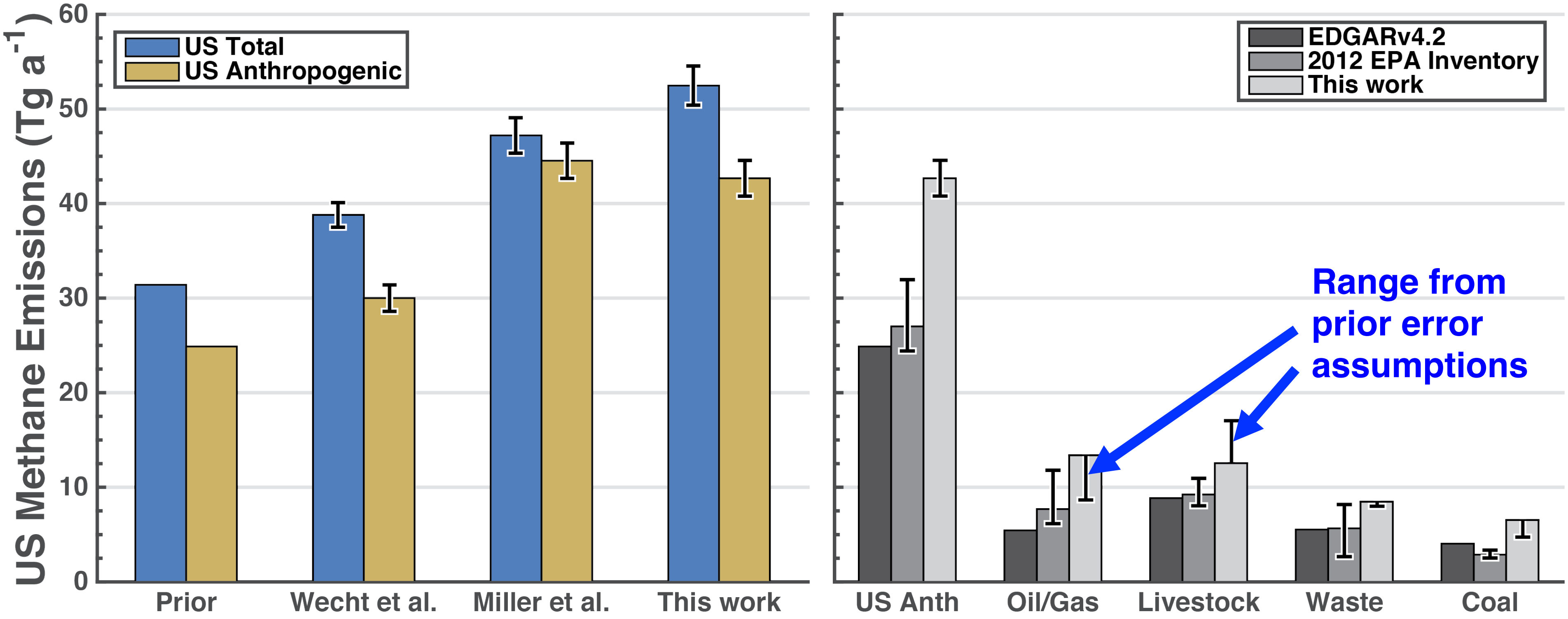
- **Consistent emission estimates with regional and local studies**
  - Improves comparison with independent observations!





Turner *et al.* (2015)

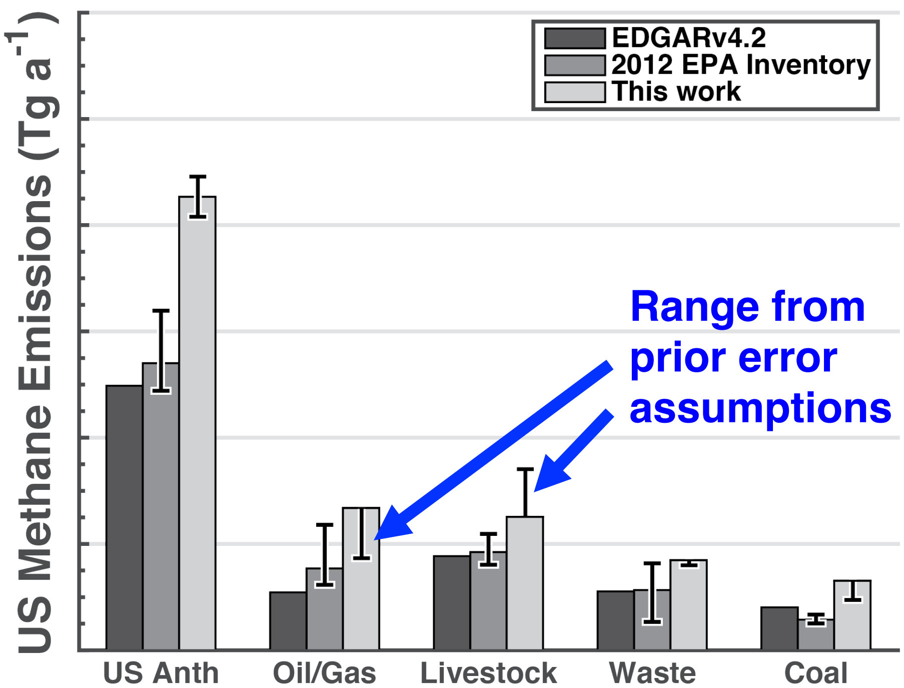
US methane emissions and source attribution

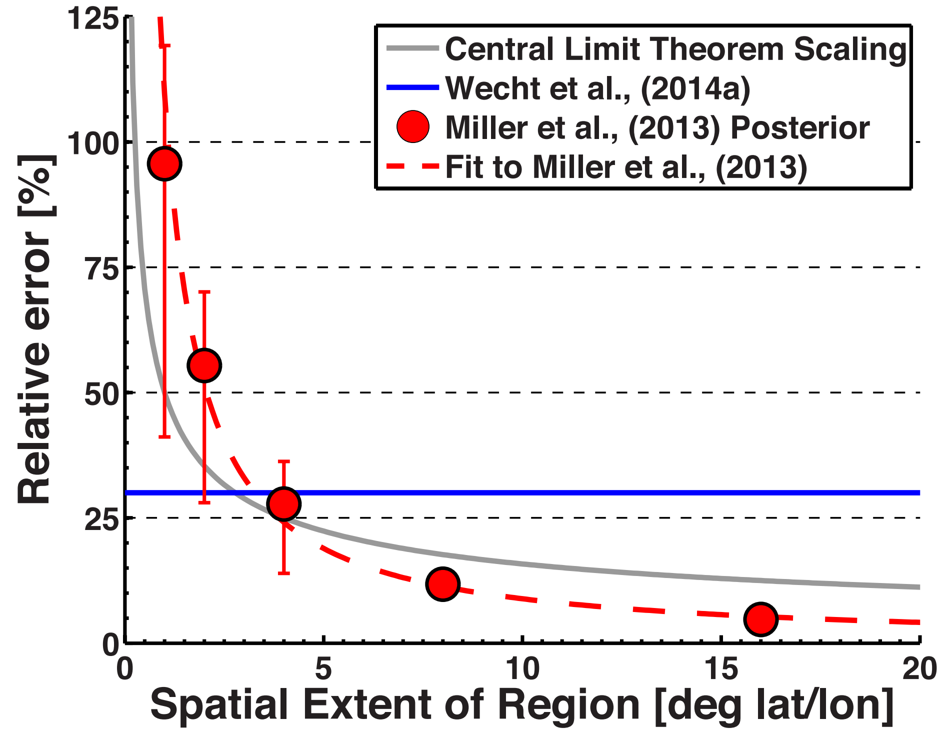


- **US emissions are a factor of 1.5 larger than the US EPA**
- **Livestock + Oil/Gas are the largest underestimated sources**
- **Attribution is sensitive to assumption about the prior error**

Turner *et al.* (2015)

US methane emissions and source attribution



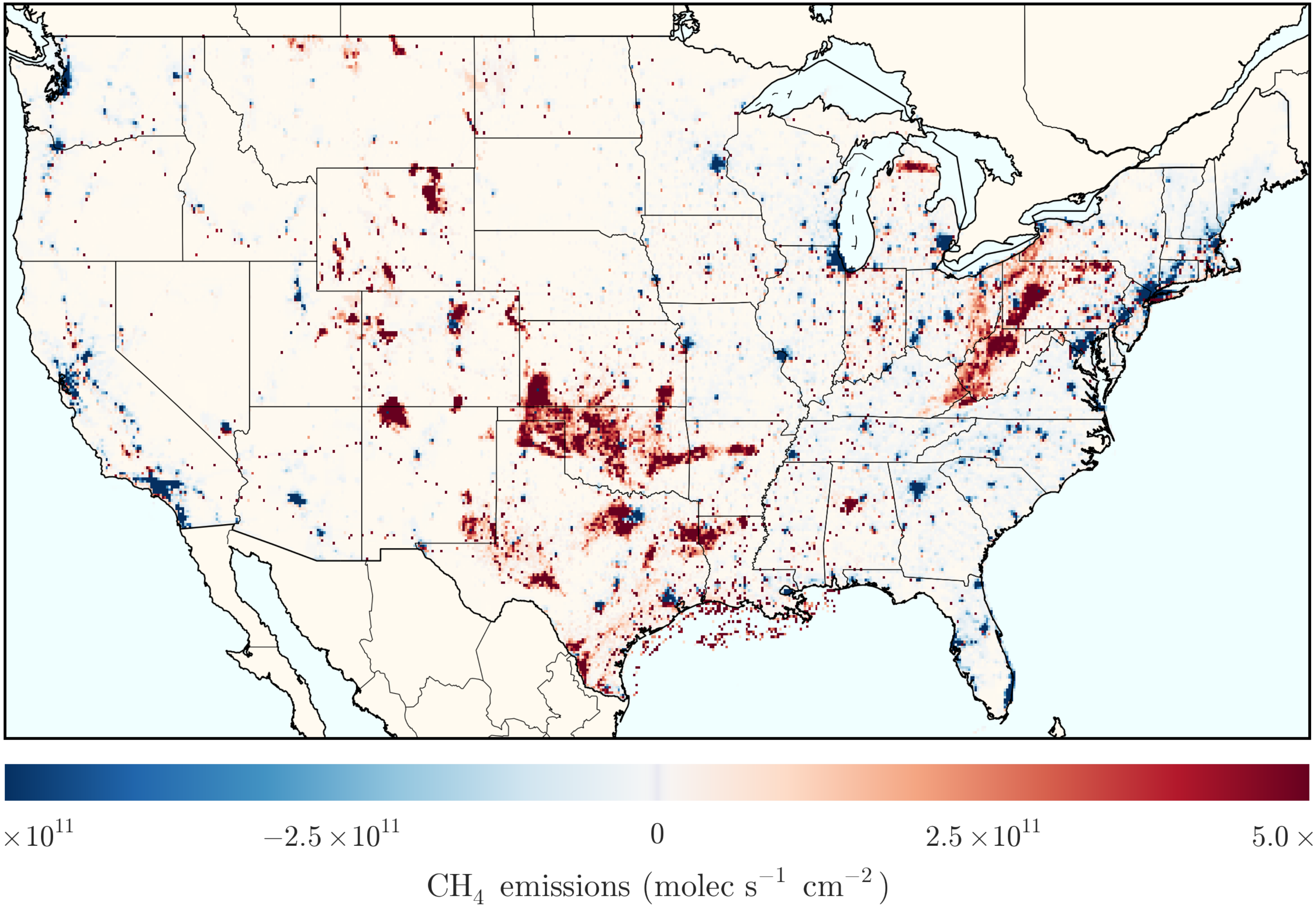


- **Partitioning between oil/gas and livestock is dependent on specification of prior error**
  - Prior error like Wecht et al. (2014a) yields more livestock emissions
  - Prior error like CLT (more similar to Miller et al.) yields balance between oil/gas and livestock

Turner *et al.* (2015)

Development of a gridded EPA methane inventory

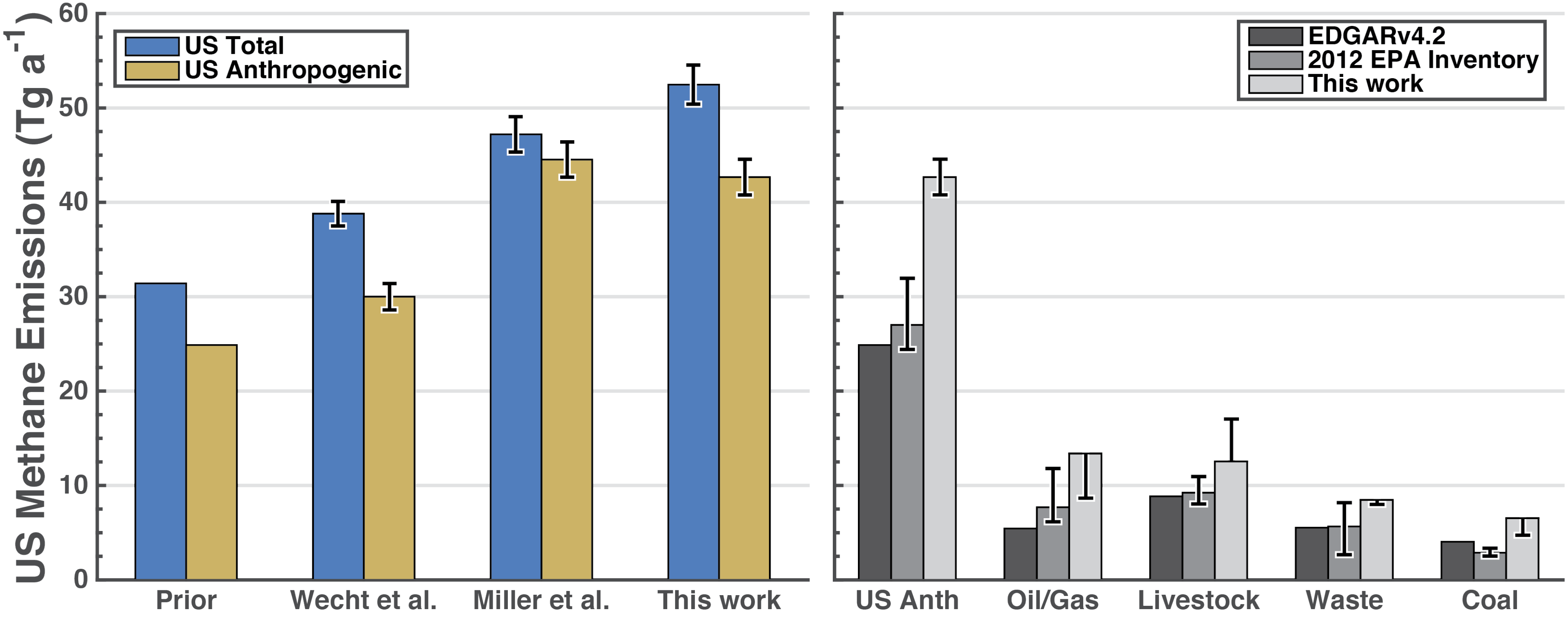
EPA – EDGAR v4.2 CH_4 emissions from natural gas systems



Improves potential of inversions to test and improve the EPA inventory

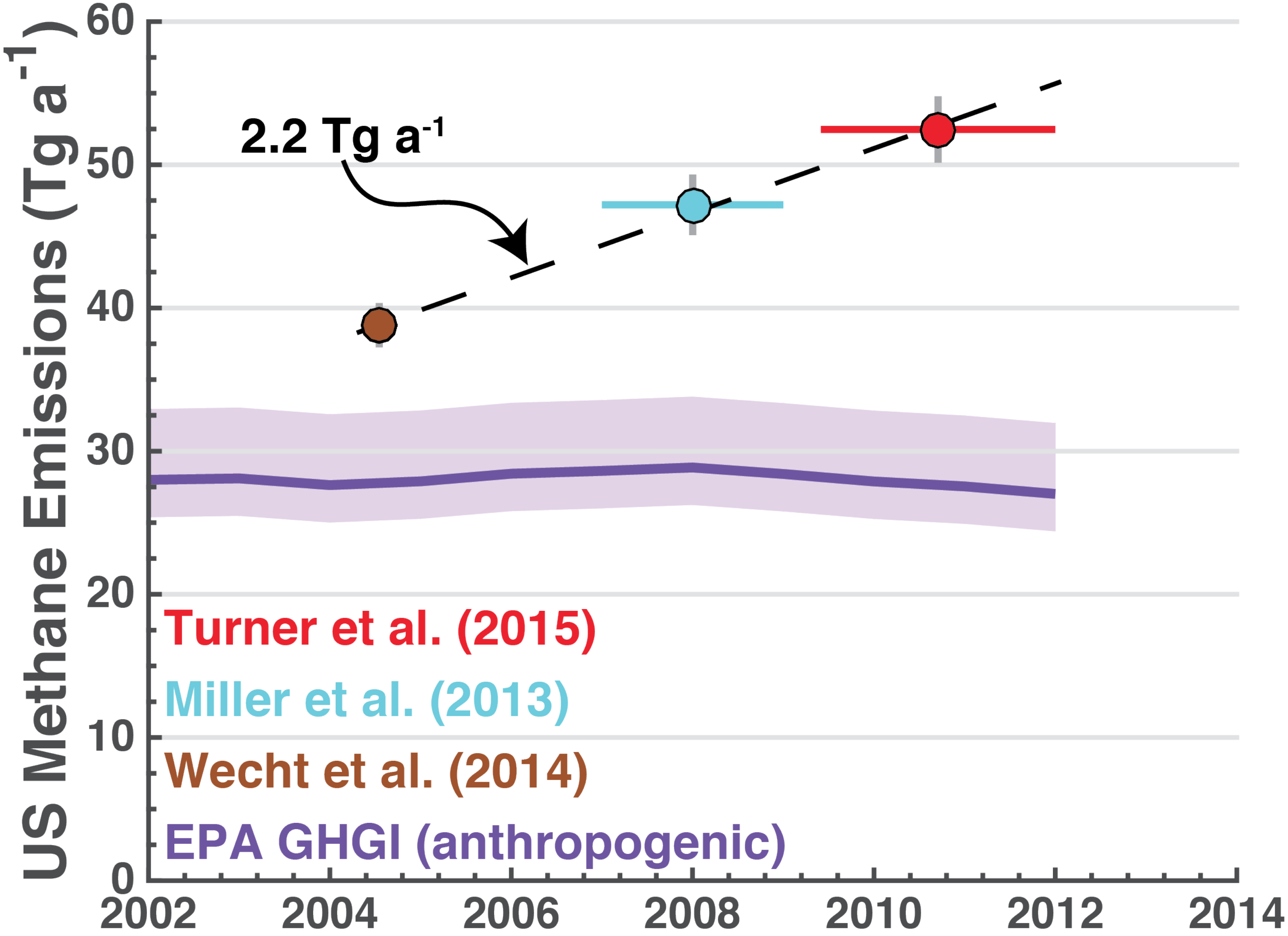
Maasakkers *et al.* (in prep)

Trend in US methane emissions?



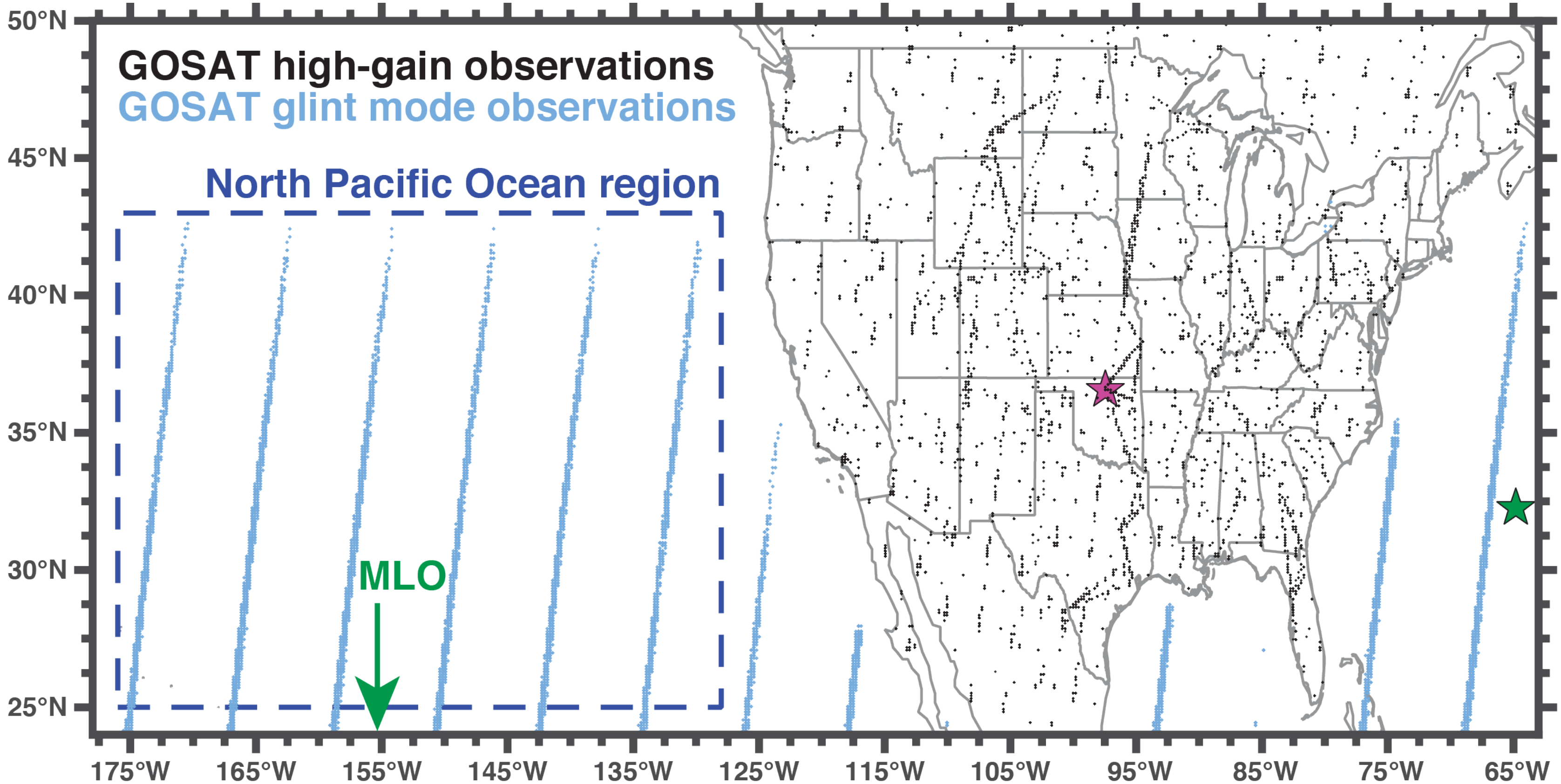
- **What about the difference in magnitude between Wecht et al., Miller et al., and Turner et al.?**

Trend in US methane emissions?



Top-down studies point to an increase in US methane, not seen in bottom-up estimates

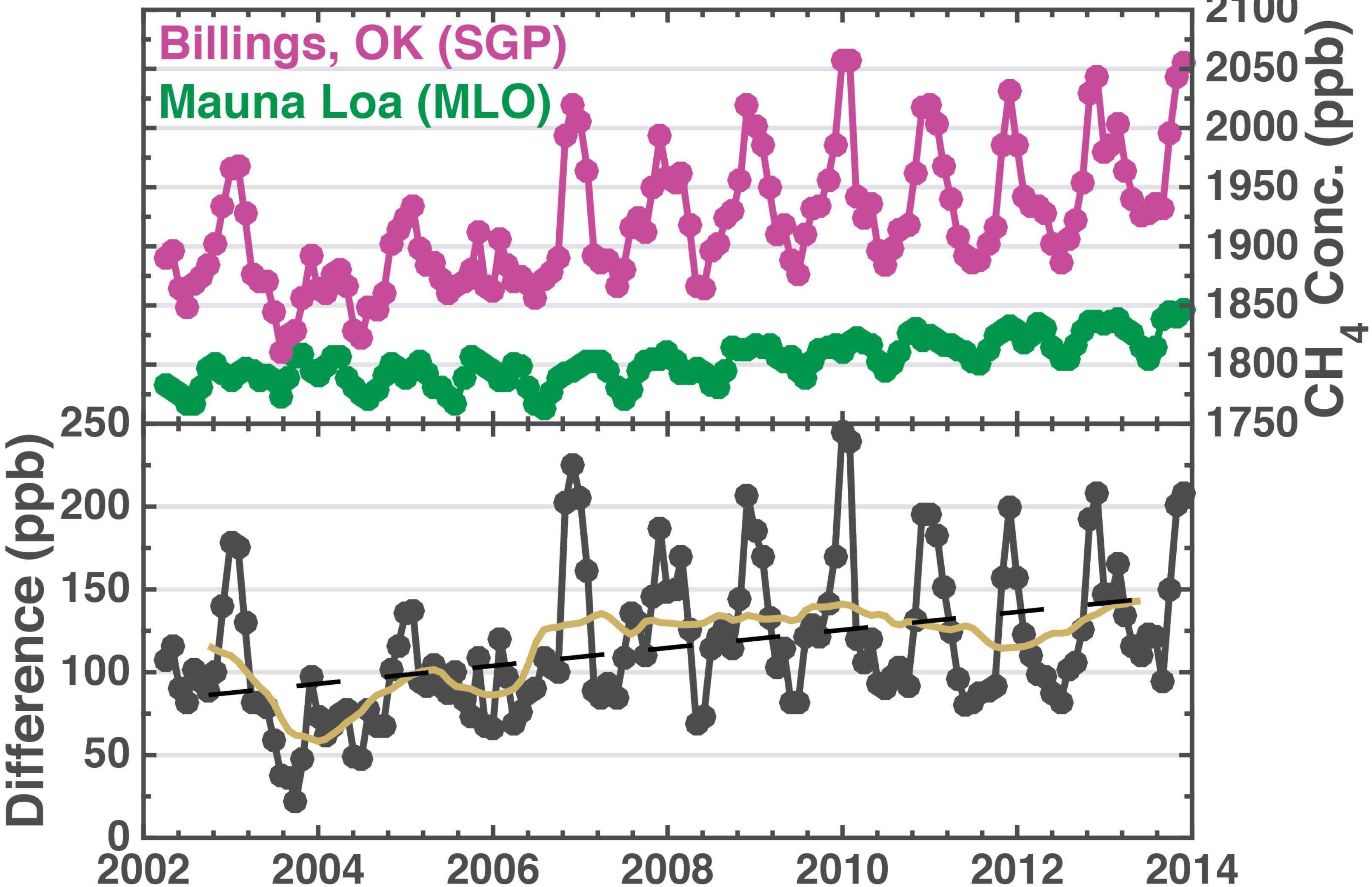
What data do we have to corroborate this trend?



- Surface observations from the NOAA/ESRL flask network
- Nadir-mode observations from the GOSAT satellite
- Glint-mode observations from the GOSAT satellite

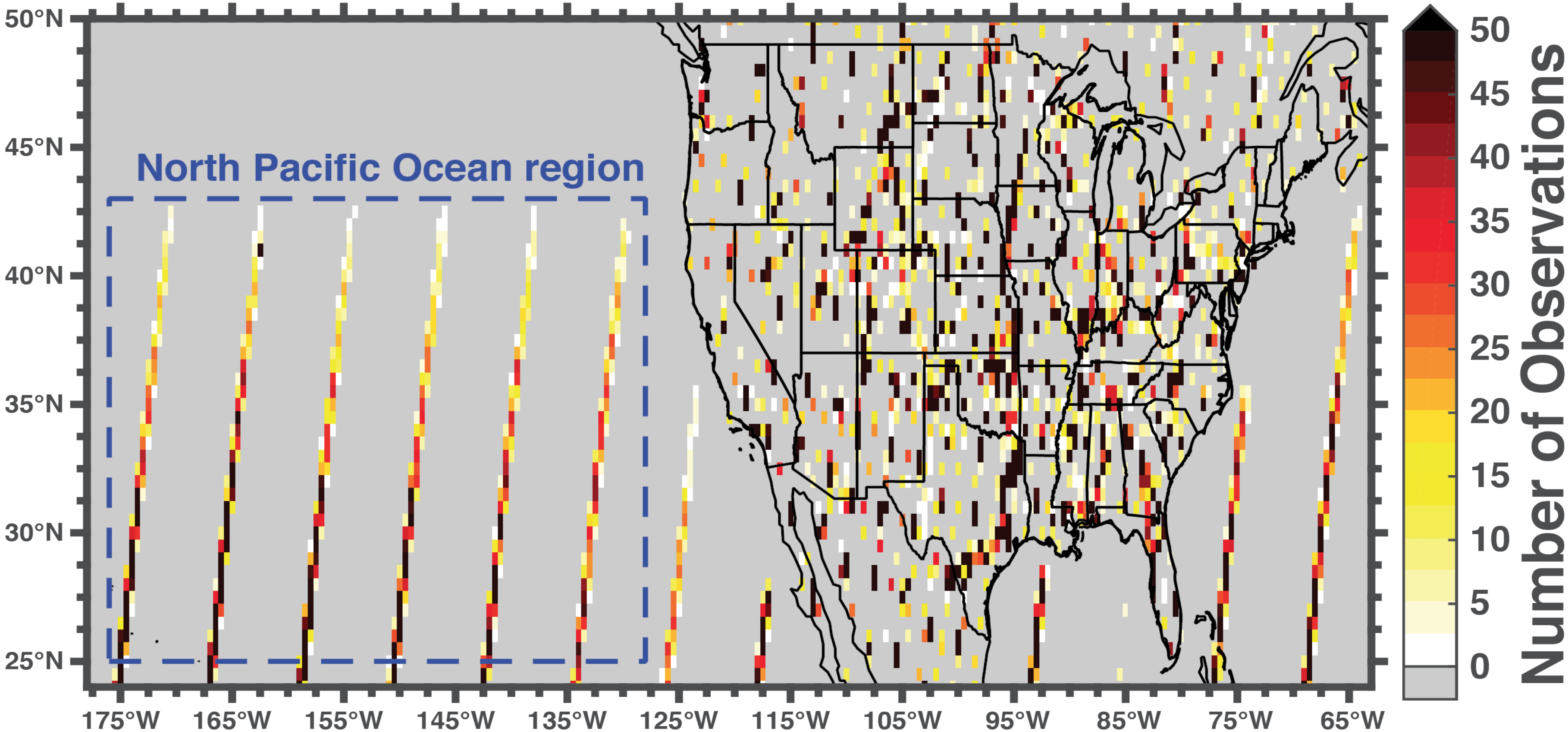
Increasing difference in NOAA/DOE observations

Coincides with increase in US methane emissions seen by top-down studies



(data c/o S.C. Biraud & E. Dlugokencky)

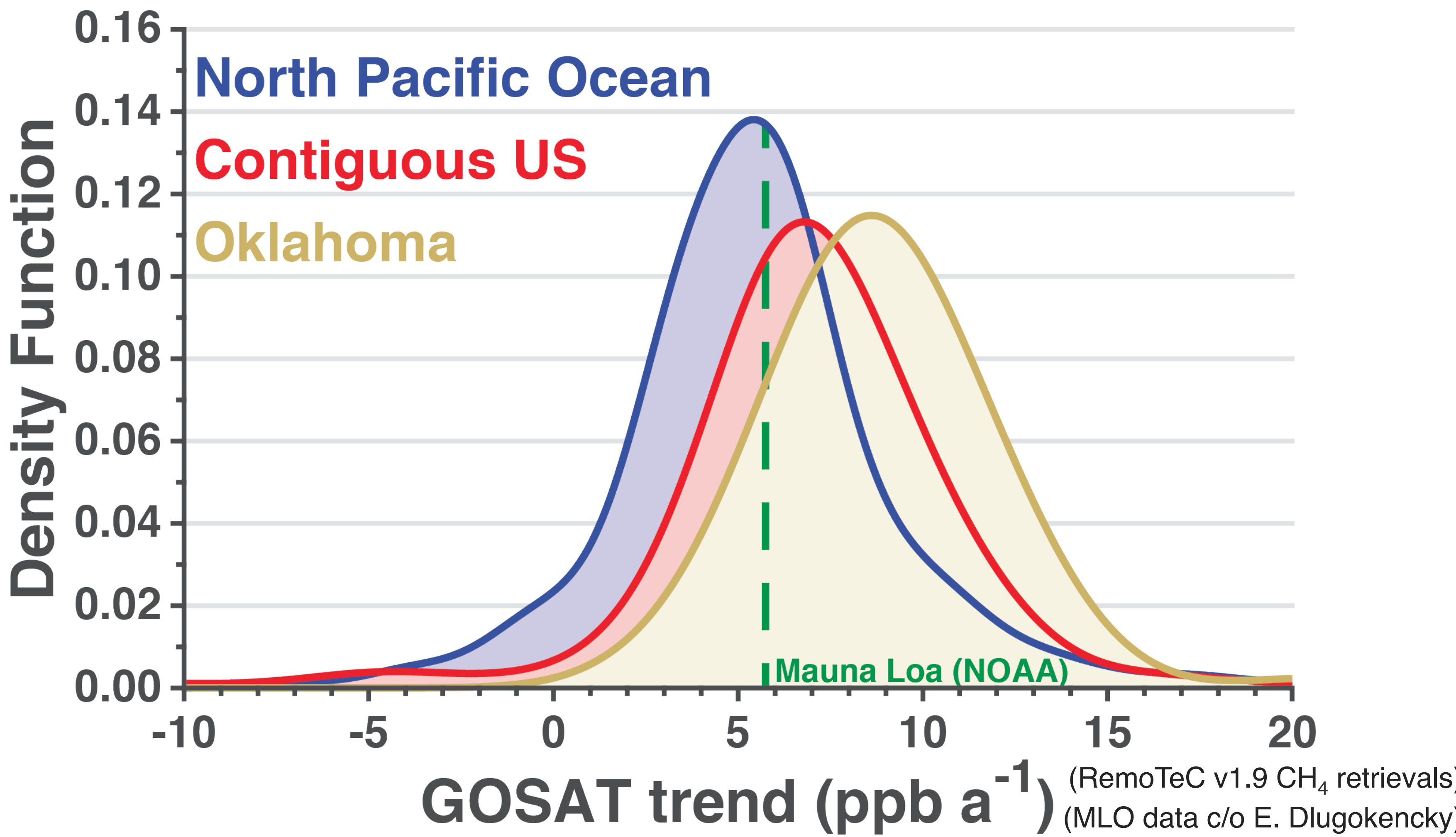
Use GOSAT for regional trend analysis



(RemoTeC v1.9 CH_4 retrievals)

- **Look at trends over locations where GOSAT samples**
- **Compare ocean glint to contiguous US observations**

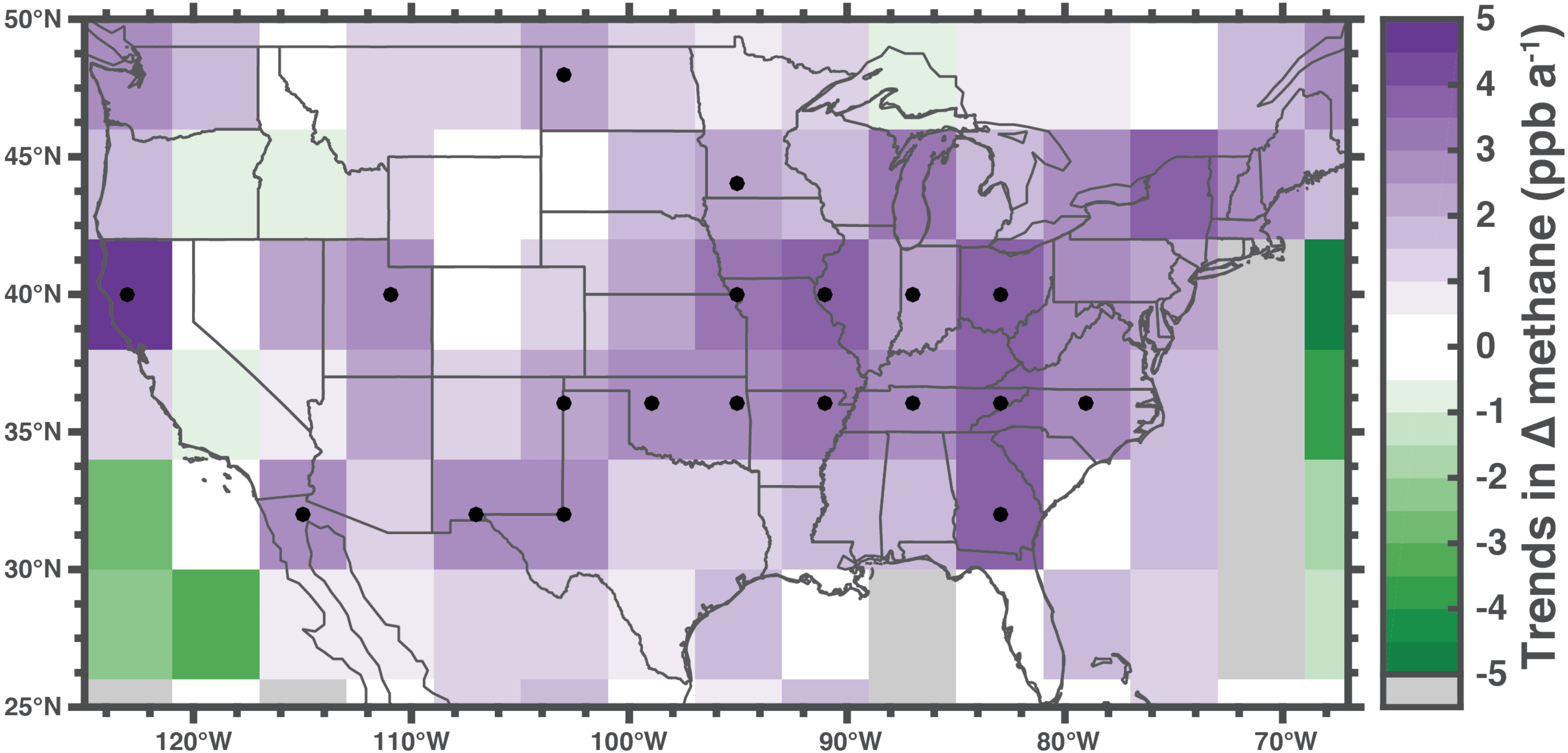
Increasing difference in GOSAT observations



GOSAT and NOAA background are consistent

Contiguous US enhanced from background

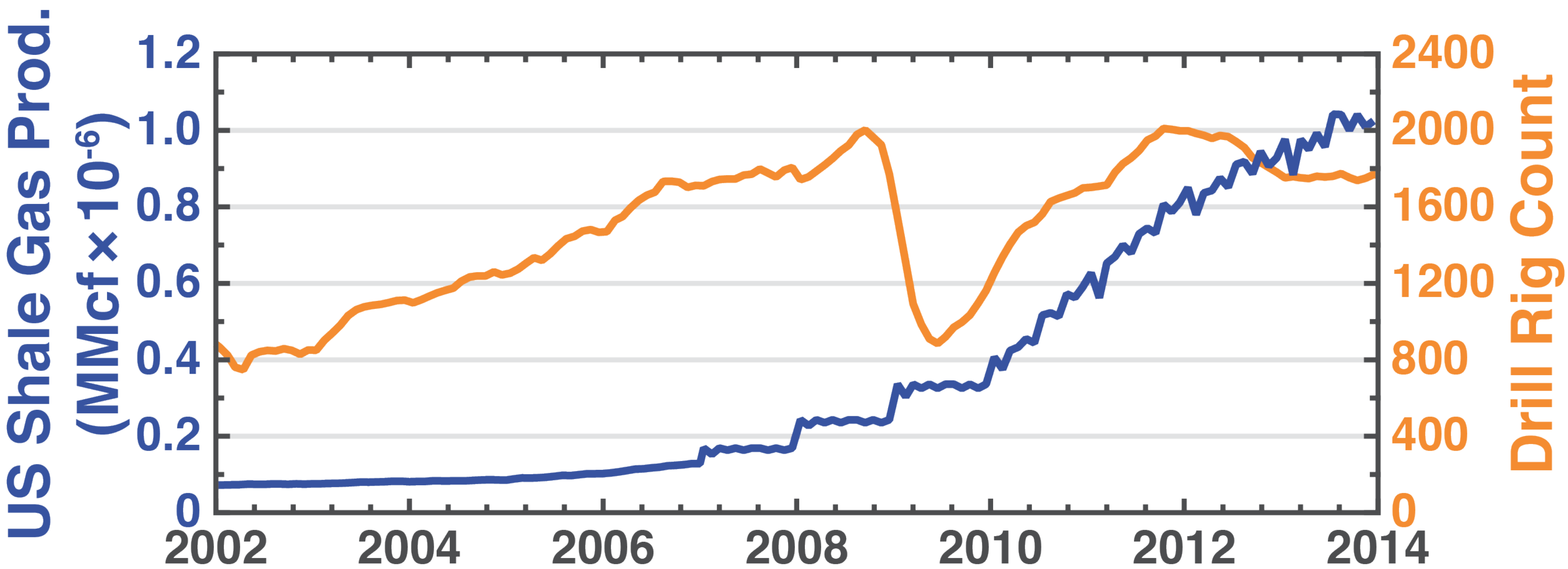
Where do we find regional trends?



(RemoTeC v1.9 CH_4 retrievals)

Increases are coincident with agriculture and oil/gas

Potential cause of the increase in US emissions



(data from EIA, 2015)

- 9-fold increase in US shale gas production from 2002–2014
- 125% increase in active drill rigs from 2002–2014

***Potentially* explained by oil/gas increases**

Summary

- **Space-borne observations can be used to estimate regional methane emissions**
- **US methane emissions have increased more than 30% in the past decade**
  - Likely due to anthropogenic (oil/gas or agriculture) sources
- **Could be a driver in the renewed methane growth**