Inverse Modelling of Carbonyl Sulfide (COS) and Emission Budget Analysis

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Utrecht University

European Research Council
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WAGENINGEN
UNIVERSITY & RESEARCH

100years
1918 — 2018

Motivation

- Constrain global COS emission budgets with inverse modelling
- Why?

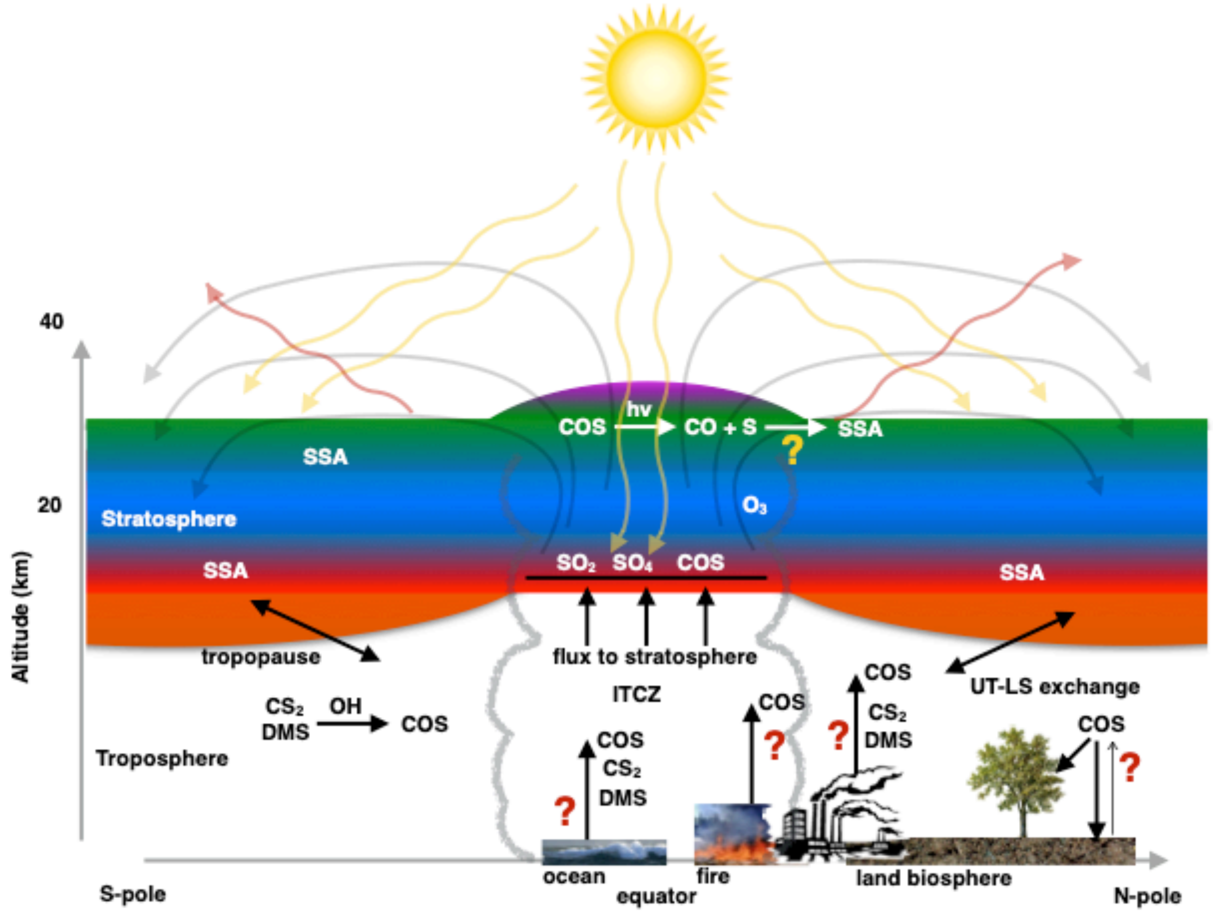
  (a) COS can inform about gross primary productivity [GPP] and ecosystem photosynthesis

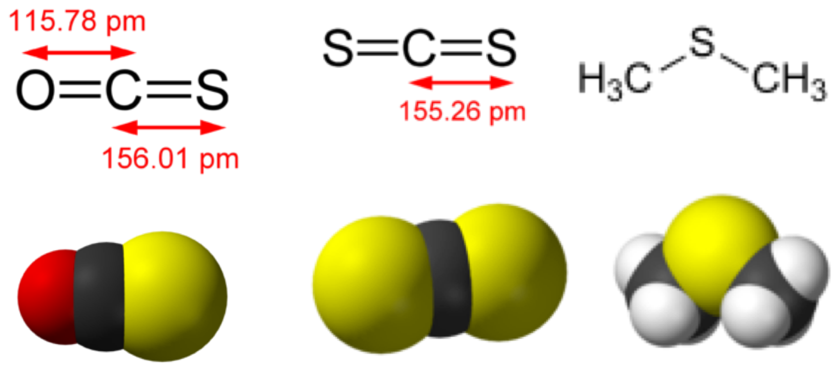
  (b) The budgets of COS remain an open question
- How?

  (a) Implement sources and sinks of COS & precursors, and model the global COS distribution

  (b) Use TM5-4DVAR to mathematically minimize the difference between model and atmospheric observations

COS, CS2 and DMS in the atmosphere

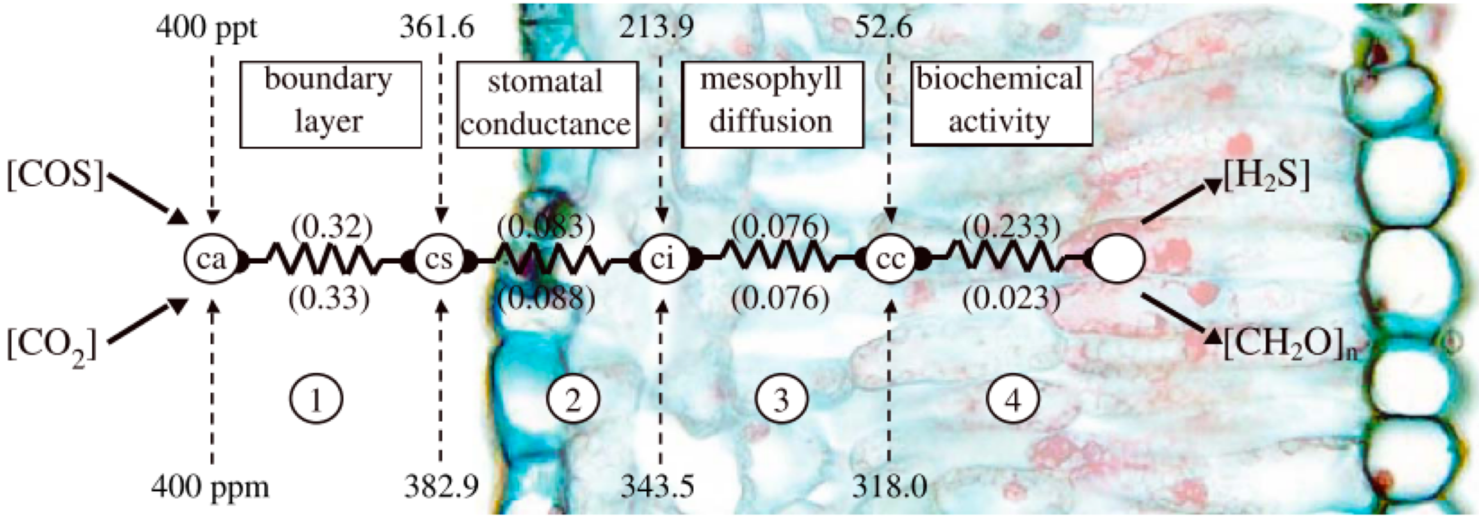




COS lifetime : ~2.5 years
CS2 lifetime : ~15 days
DMS lifetime : ~1.2 days

CS2 and DMS can be oxidized quickly to contribute to COS formation in the atmosphere.

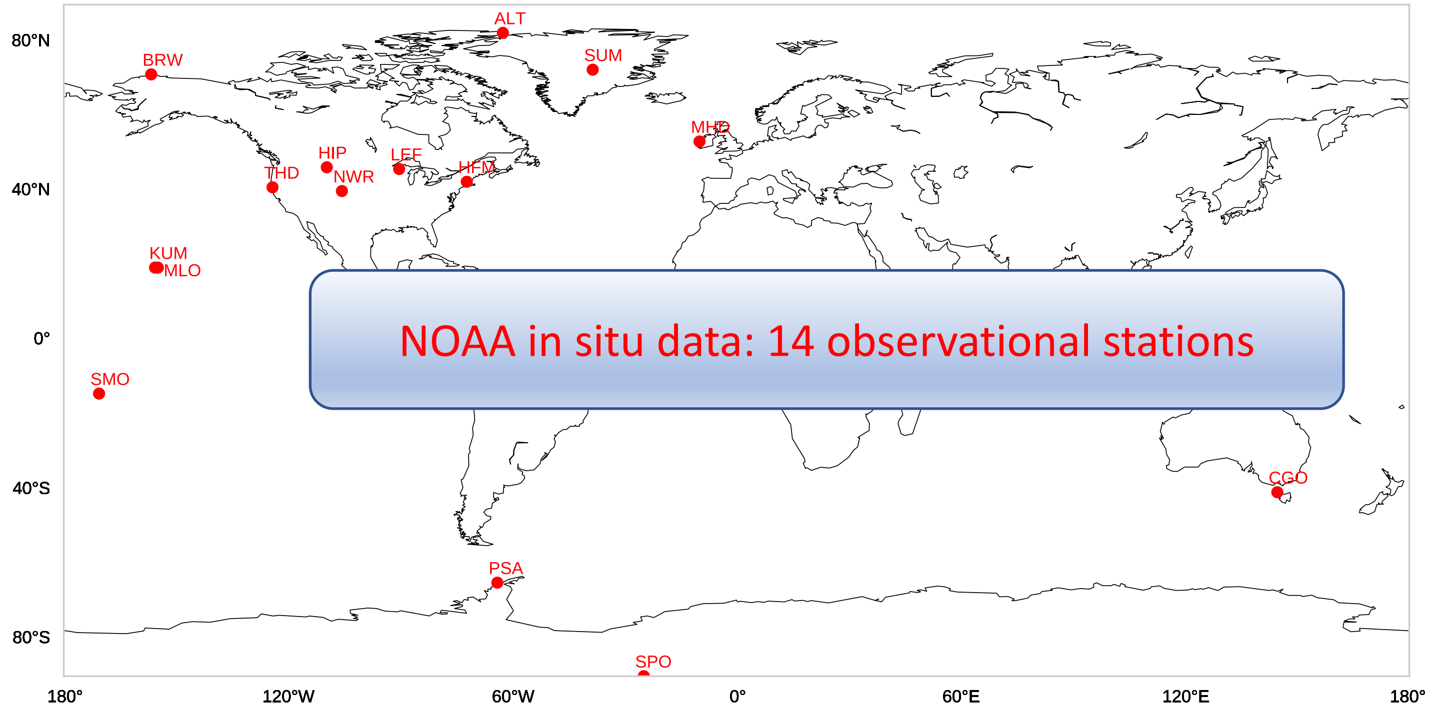
Main sink: COS uptake by a leaf



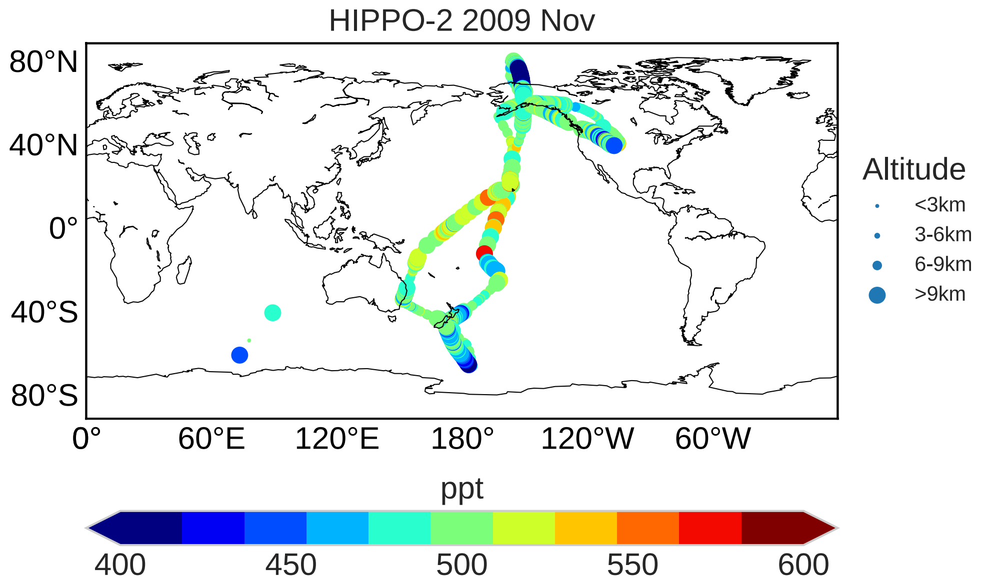
(Berry et. al 2013)

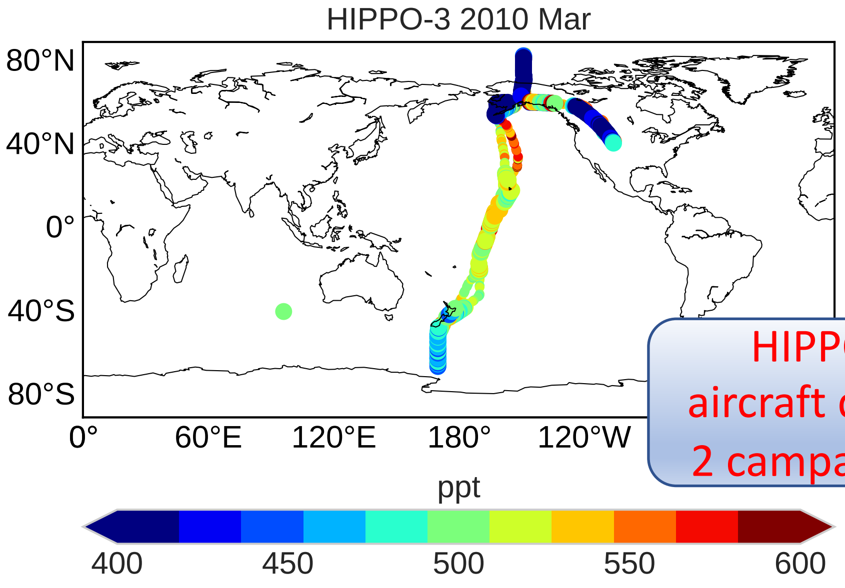
- CO_2 is taken up by a leaf via photosynthesis and emitted via respiration
- COS is only taken up by a leaf
- 1 ppt = 10^{-6} ppm, so measurement of COS is challenging

Observational data sets: NOAA, HIPPO and TES



NOAA in situ data: 14 observational stations

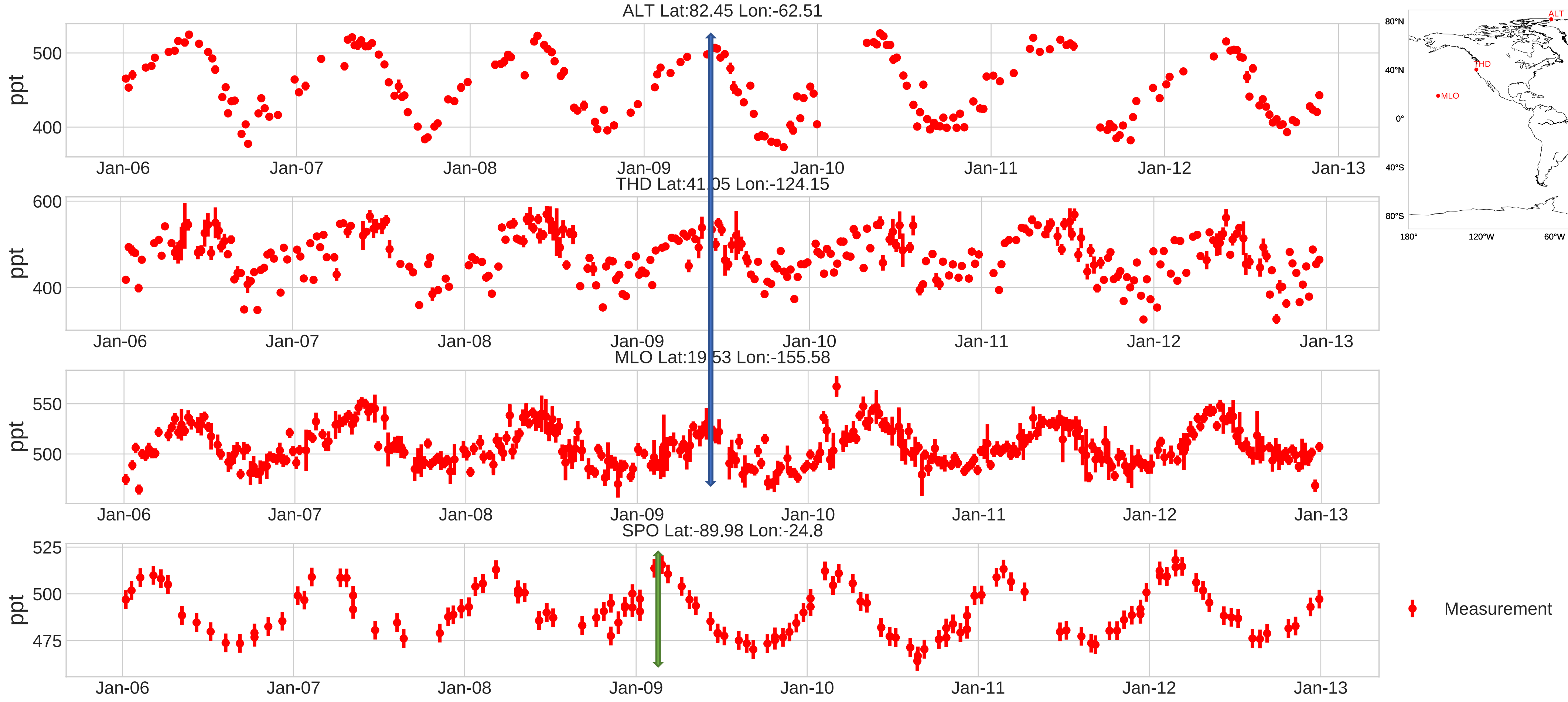


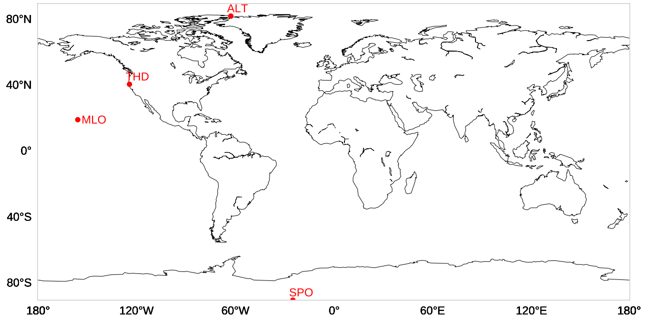


HIPPO aircraft data: 2 campaigns

- TES: nadir satellite data product that provide COS measurement in tropical regions

Measurements on selected NOAA stations





- Measurements shown on 4 sites
- Lagging of seasonal cycle at SPO the South Pole

(Montzka et. al 2007)

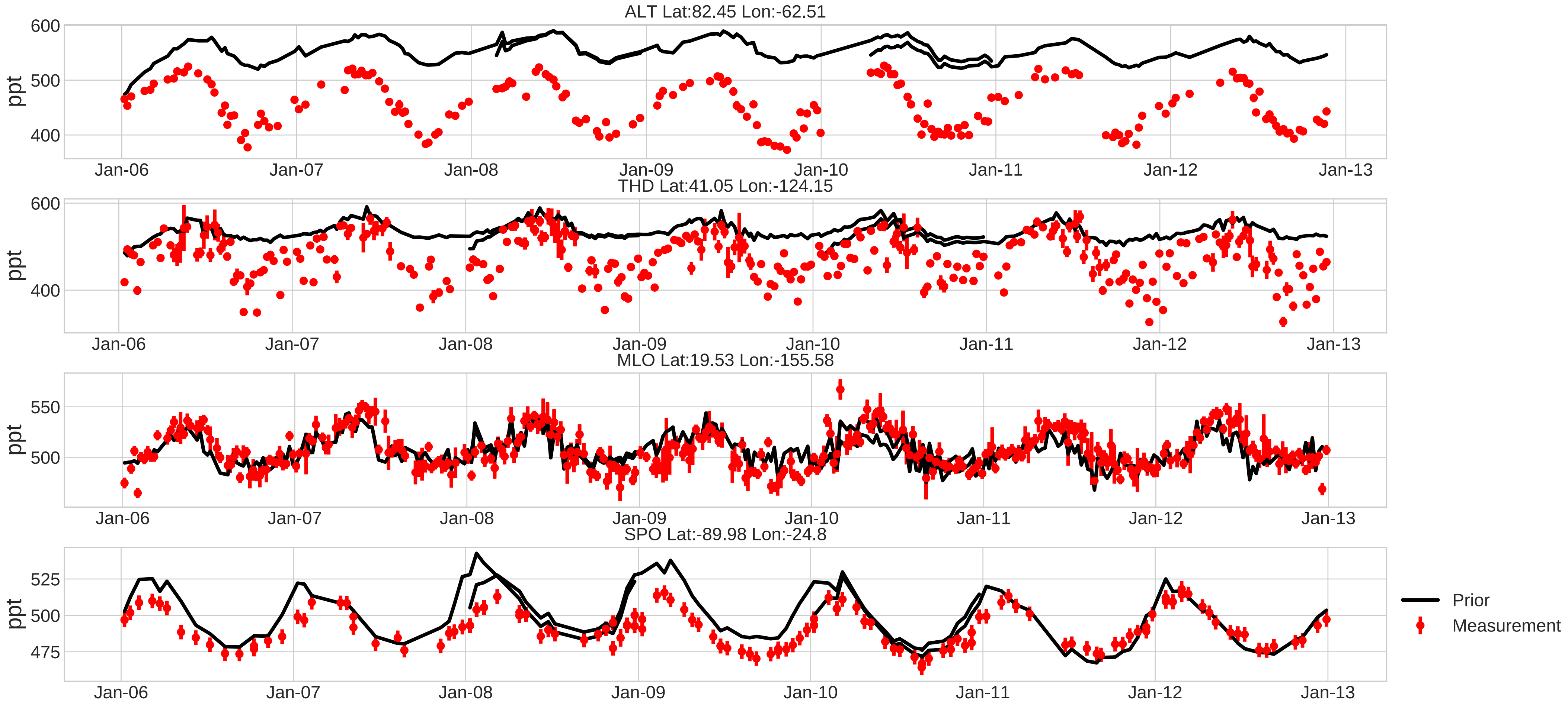
Global COS budgets: Berry2013

COS Global Budget (Gg S /year)	Berry2013	Prior of this study
Direct COS flux from oceans	39	40
Indirect COS flux as CS2 from oceans	81	81
Indirect COS flux as DMS from oceans	156	156
Direct anthropogenic flux	64	155
Indirect anthropogenic flux from CS2	116	188
Indirect anthropogenic flux from DMS	1	6
Biomass burning	136	136
Additional ocean flux	600	-
Anoxic soils and wetlands	-	-
Sources	1193	762
Destruction by OH	-101	-101
Destruction by O	-	-
Destruction by photolysis	-	-40
Uptake by plants	-738	-898
Uptake by soil	-355	
Sinks	-1194	-1039
Net total	-2	-277

- Major updates on anthropogenic, biosphere and biomass emissions, and COS photolysis
- Net total prior is –277 Gg S /year
- Add 277 Gg S /year can close the budgets

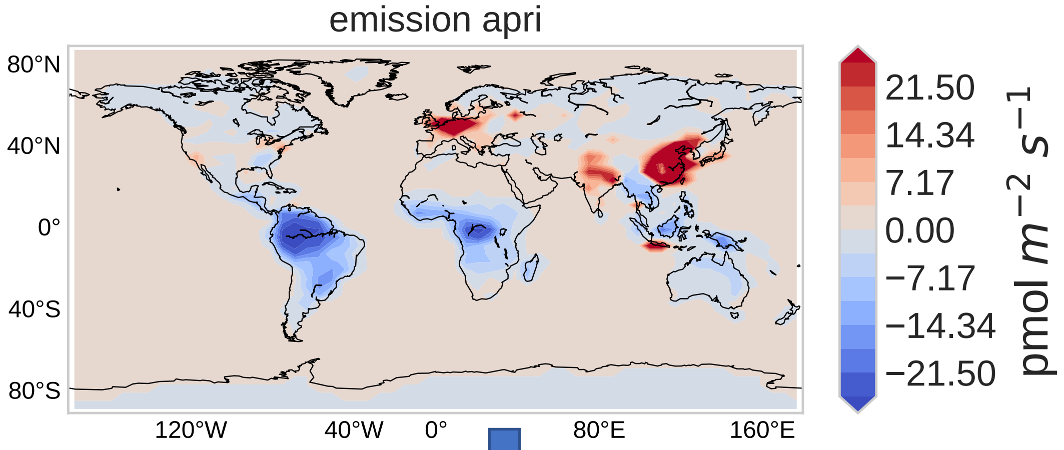
(Berry et. al 2013, Zumkehr et. al 2018.)

Prior simulation on selected NOAA stations

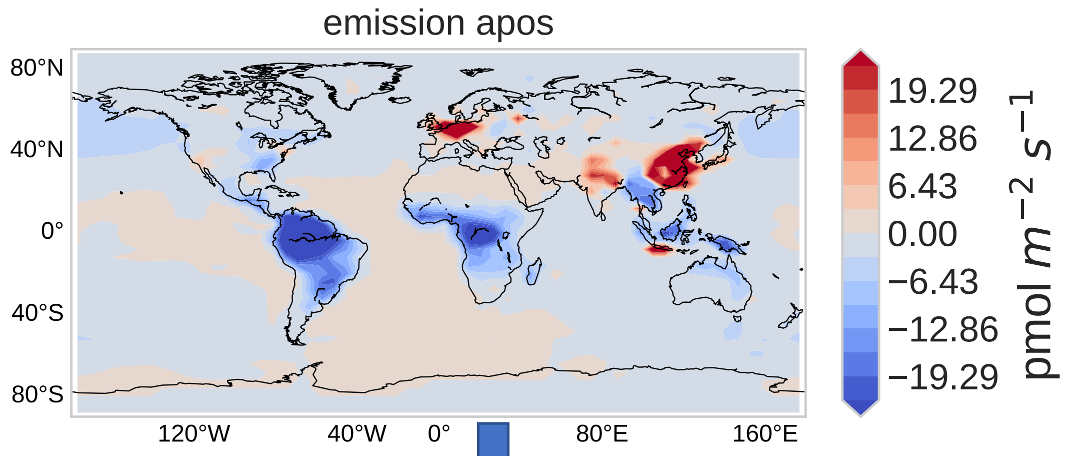


- Measurement (Red), prior simulation (Black)
- weaker seasonal cycle capture with prior emissions

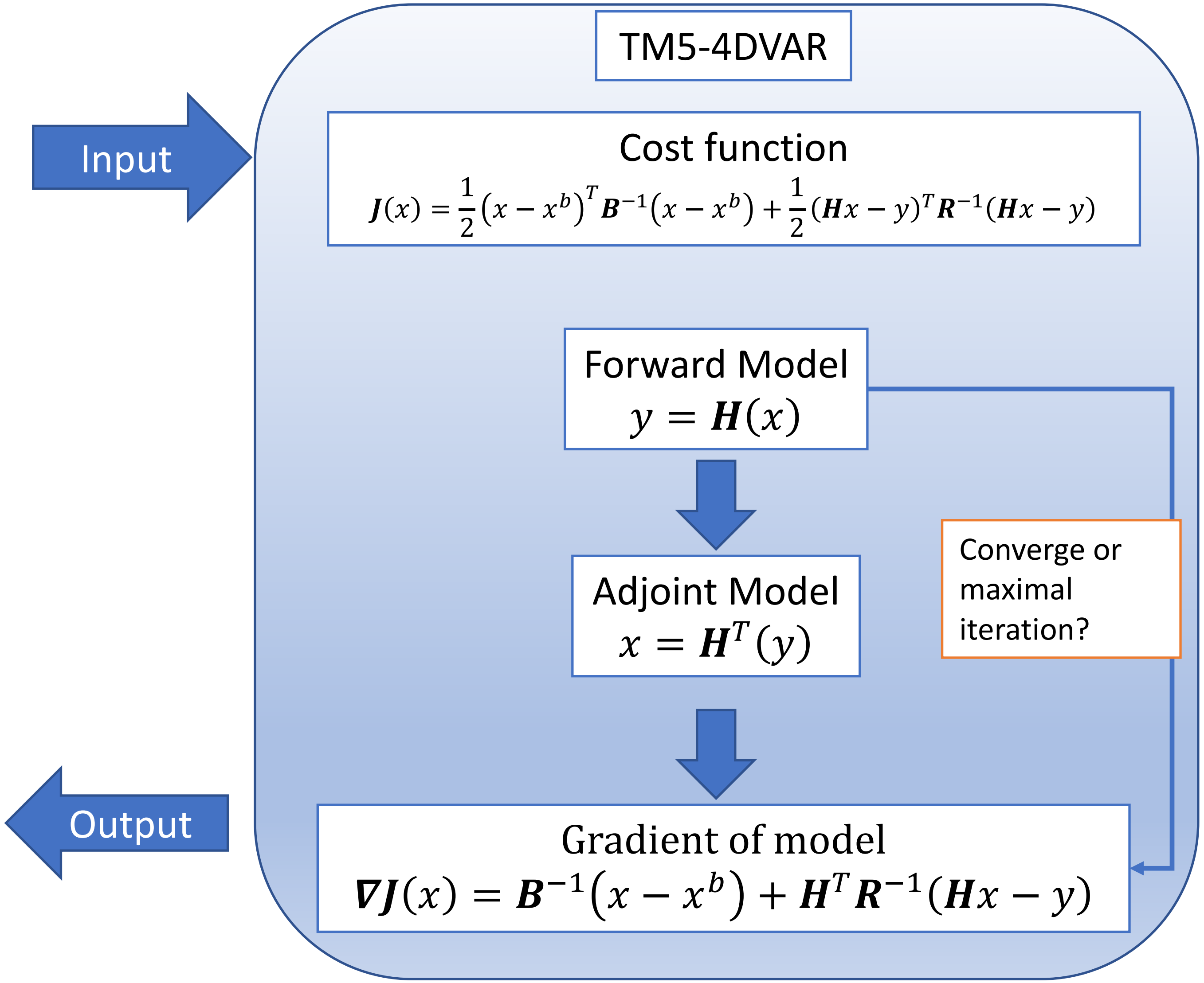
COS inverse modelling framework



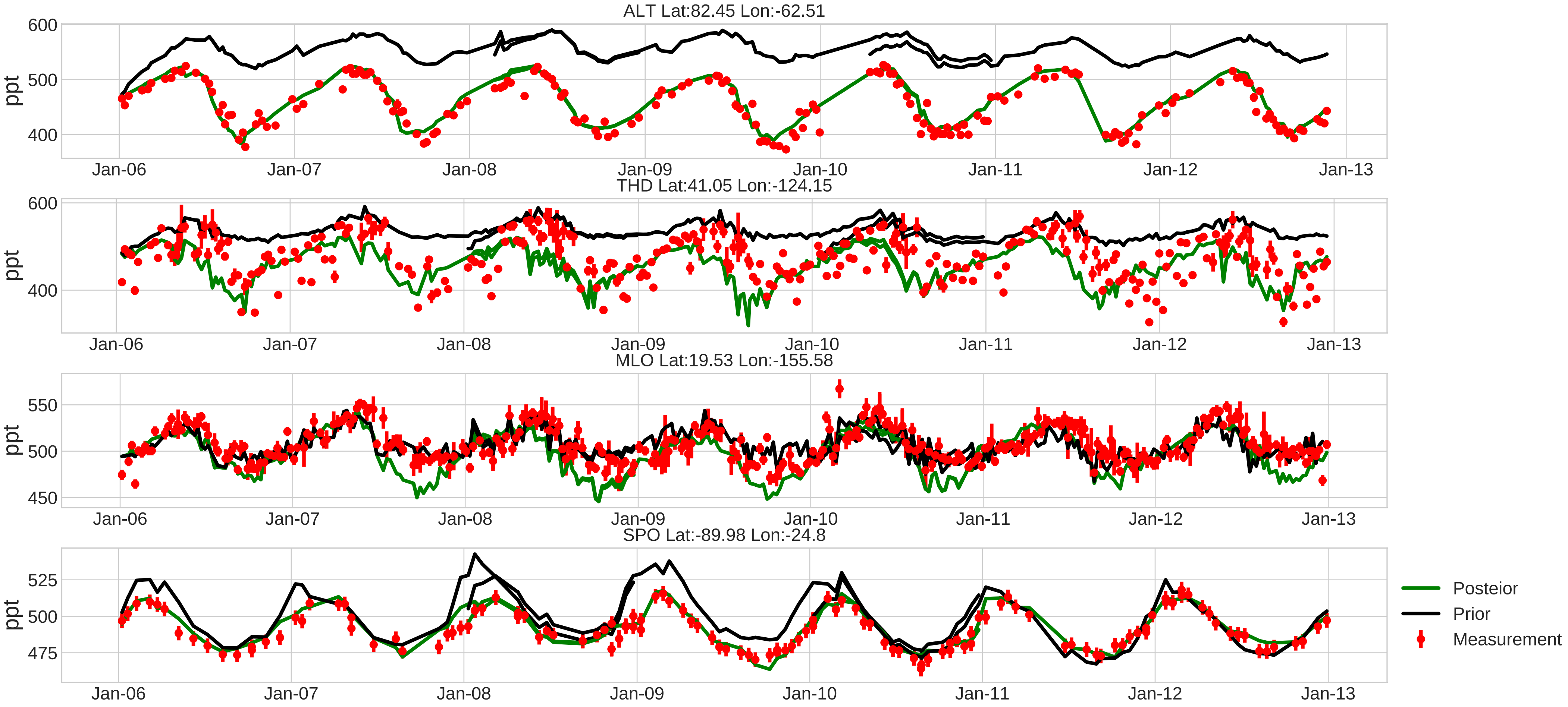
NOAA Observational constraints



HIPPO aircraft for validation

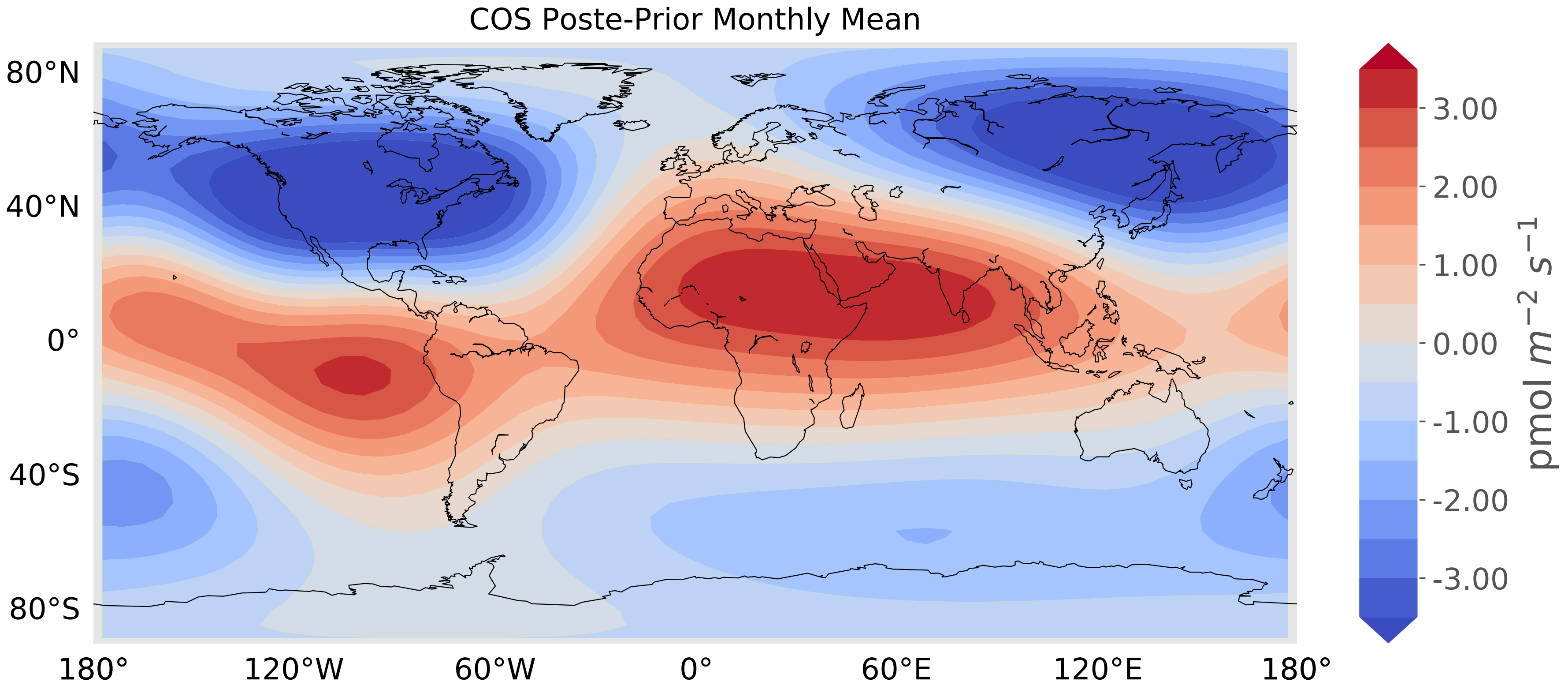


Posterior simulation on selected NOAA stations



- Measurement (Red), prior simulation (Black) and posterior simulation (Green)
- Posterior simulation captures seasonal cycle very well

Where could be the missing emissions?

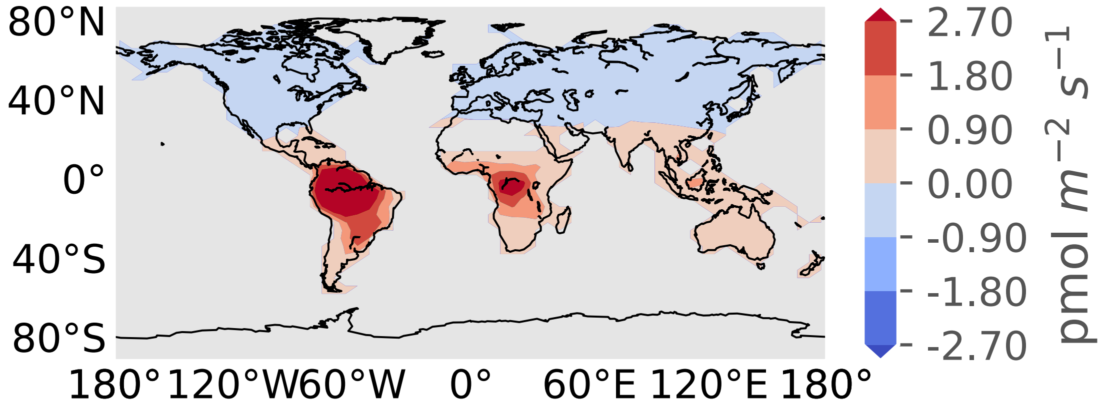


- We close the budget by adding 277 Gg S/year globally uniformly
- only optimize this uniform emission flux: 0.51 pmol m^{-2} s^{-1}
- Spatial correlation = 4000 km

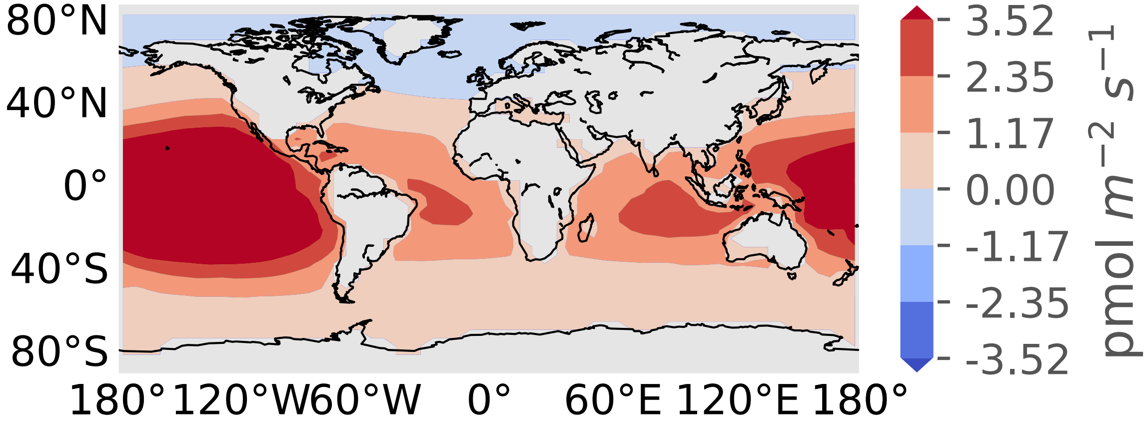
What could be the missing emissions?

- Example of inversion based on prior emissions
- What to optimize?
  - COS : ocean, biosphere
  - CS_2 : ocean

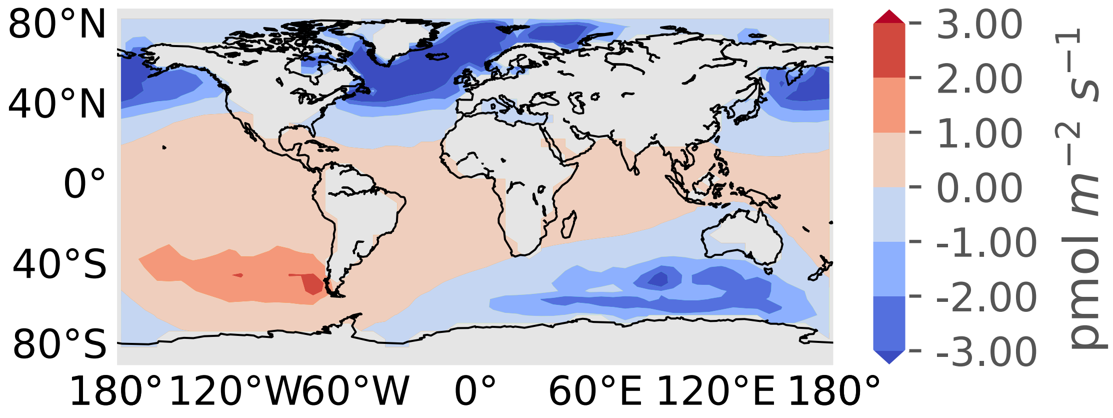
COS Biosphere Poste-Prior



CS2 Ocean Poste-Prior

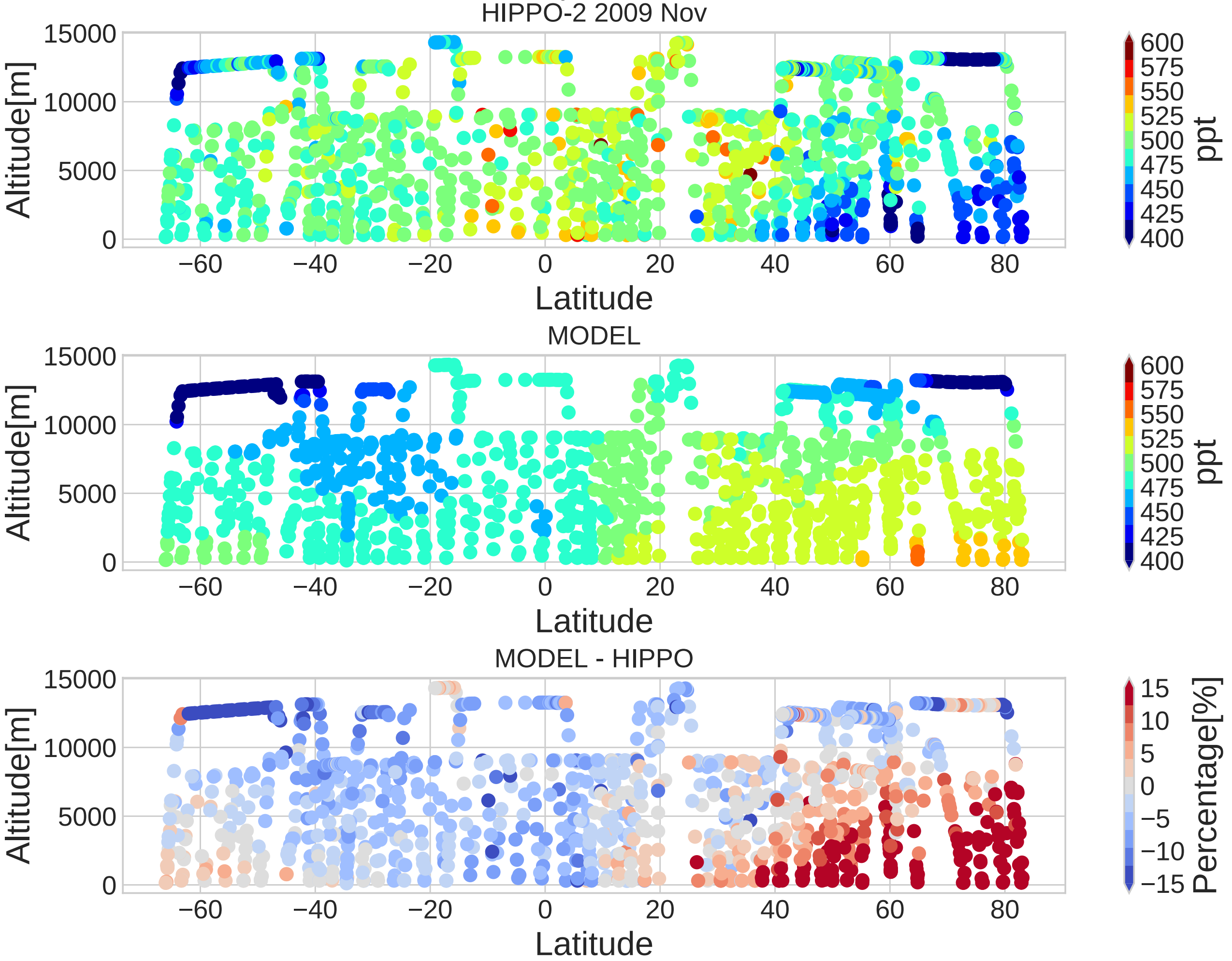


COS Ocean Poste-Prior

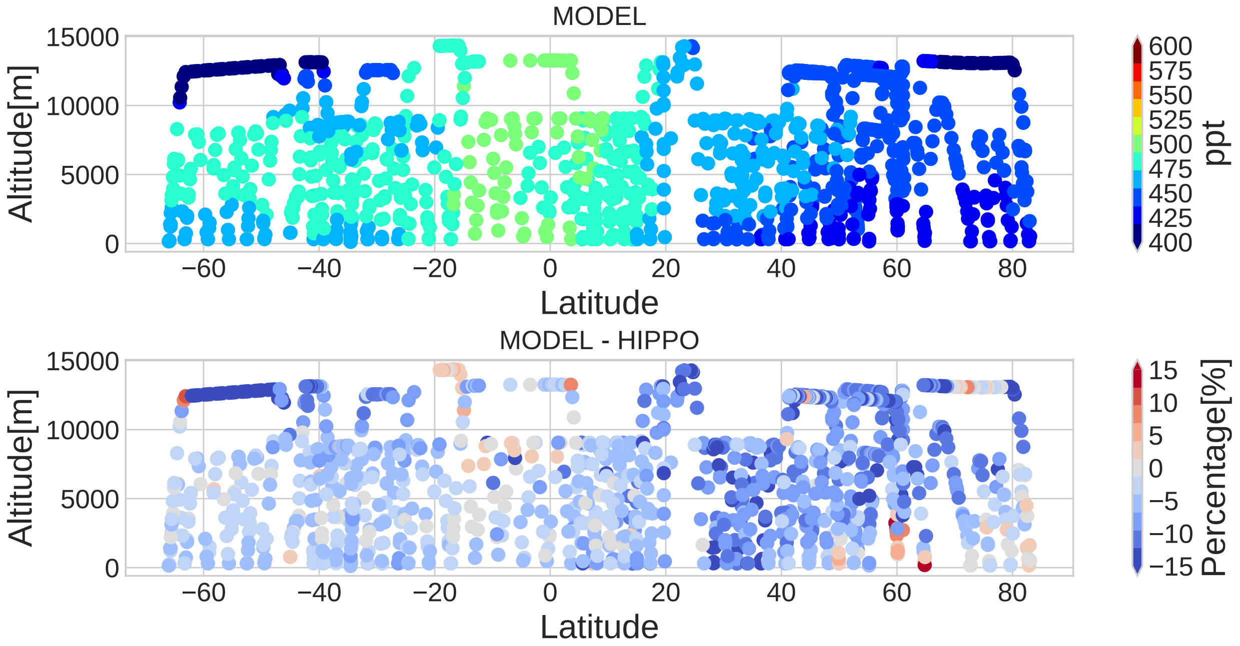


TM5 model validation with HIPPO-2:2009-Nov

Model with prior emission



Model with posterior emission

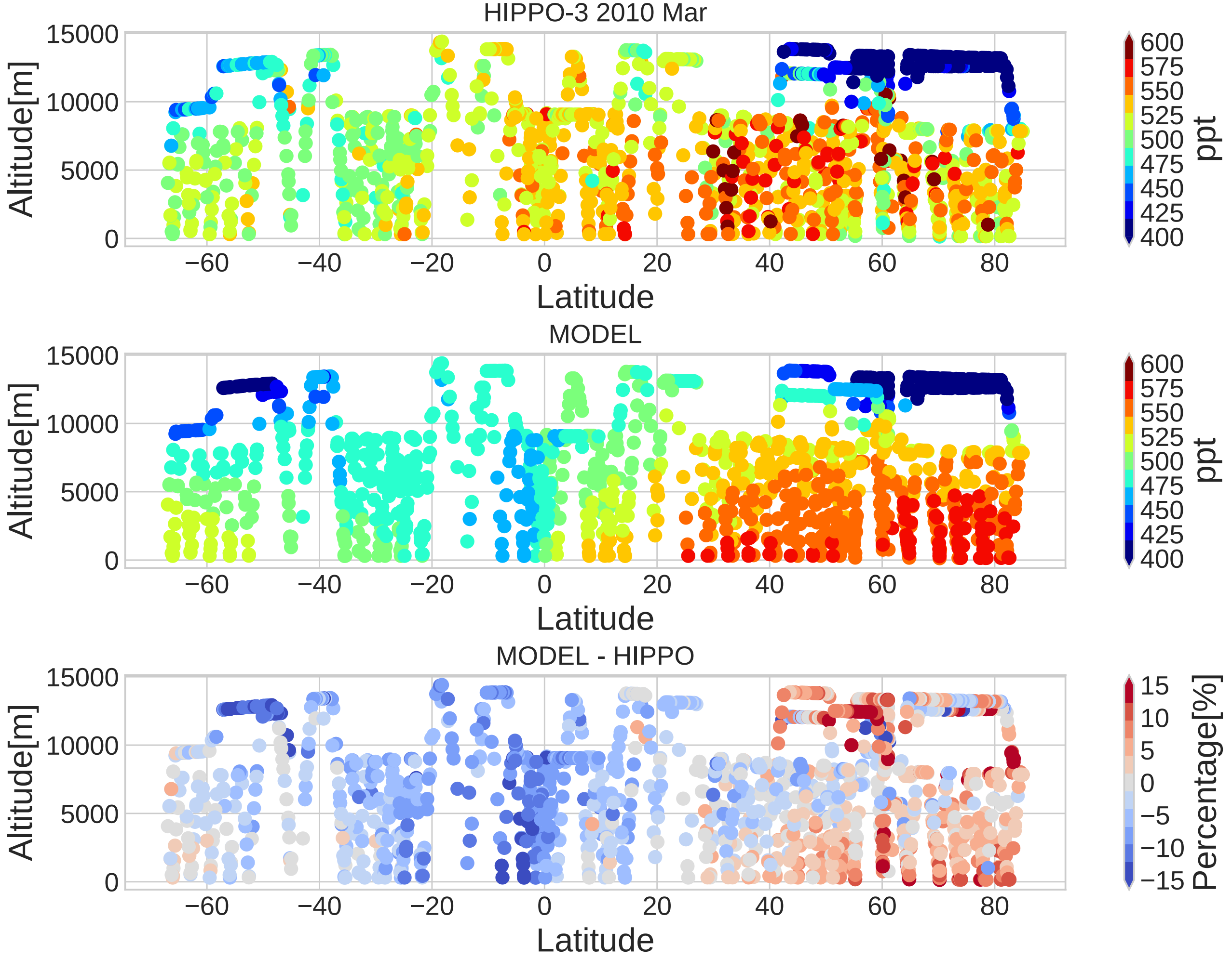


Model-prior is much higher than HIPPO observation in NH

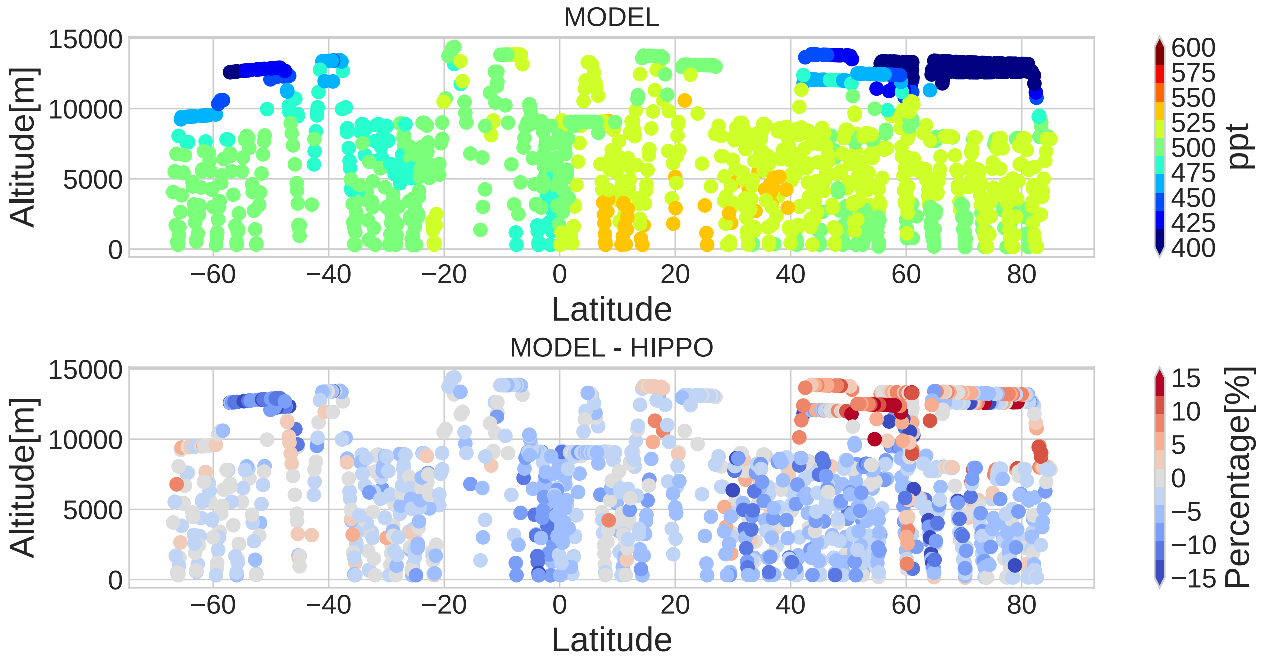
Model-posterior reduced errors (RMSE from 42.6 ppt to 40.0 ppt) and lower than HIPPO

TM5 model validation with HIPPO-3:2010-Mar

Model with prior emission



Model with posterior emission

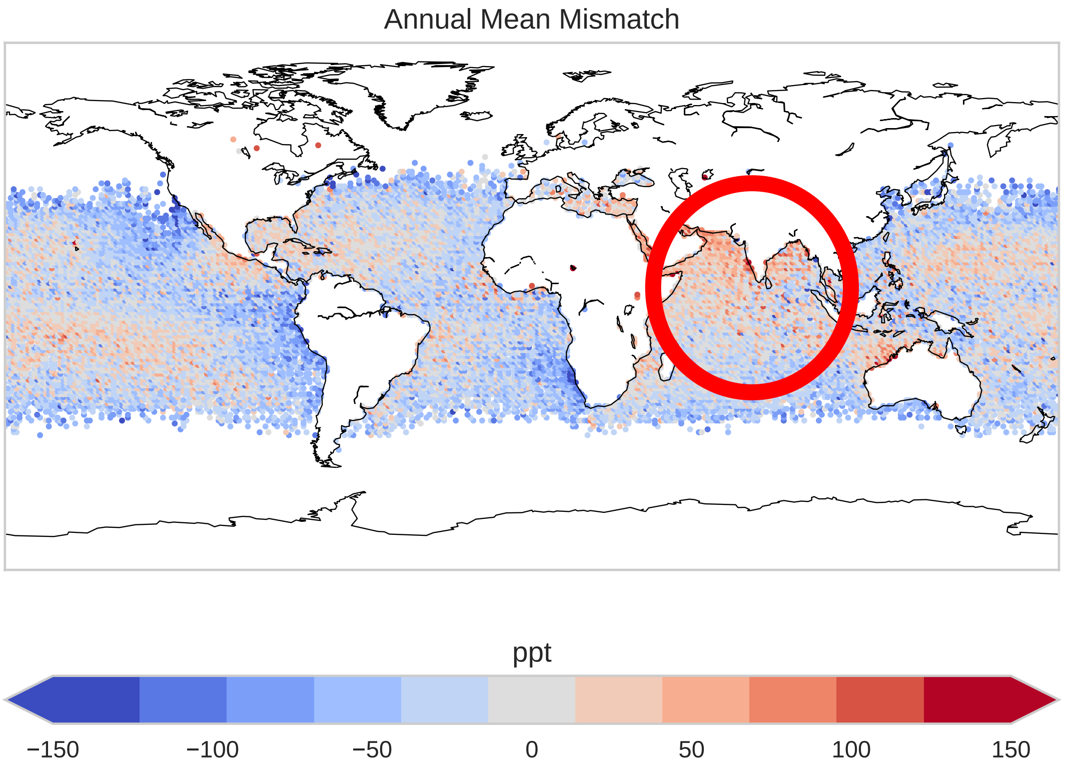


Model-prior is much higher than HIPPO observation in NH

Model-posterior reduced errors (RMSE from 33.1 ppt to 28.8 ppt) and lower than HIPPO in troposphere

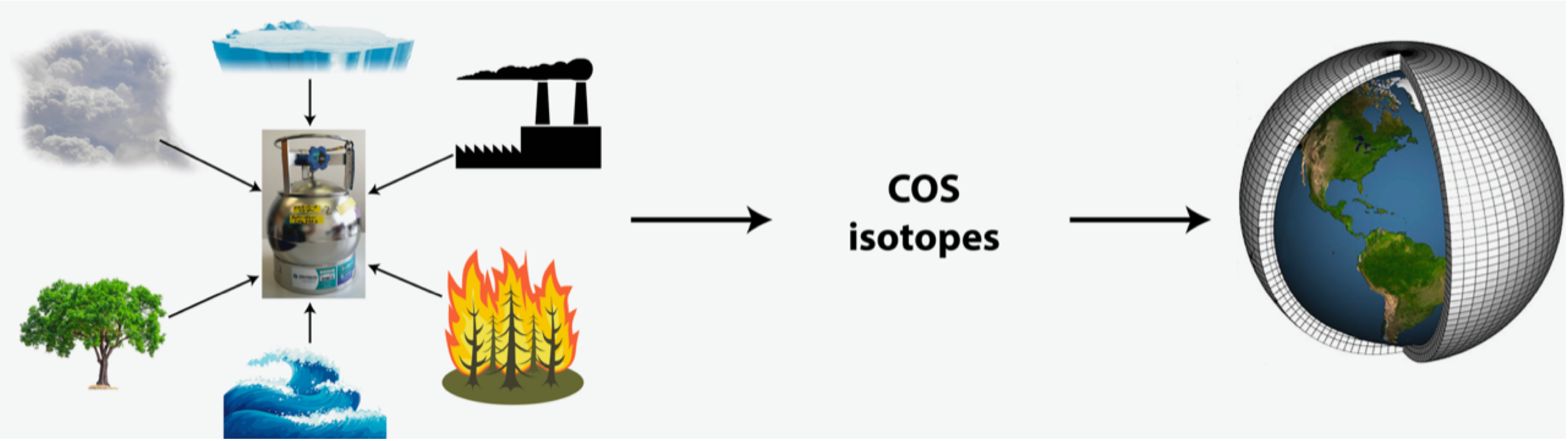
Model validation with TES satellite data

- Mismatch = TM5 profile mean – TES profile mean
- TES data is quite noisy
- Some patterns over tropical oceans
  - higher simulation over Indian Ocean



Outlook

- Future work 1: satellite date to constrain COS in TM5-4DVAR
- Future work 2: on COS isotope inverse modelling (→ Sophie's measurements, Juhi's poster)



Conclusions

- We have implemented a new inverse model for COS-CS_2-DMS based on TM5-4DVAR
- Inversions reveal useful information on budgets about where and what could be possible missing emissions
- The validation with independent data HIPPO reduced RMSE

Acknowledgements

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