Update on carbon monoxide inversions

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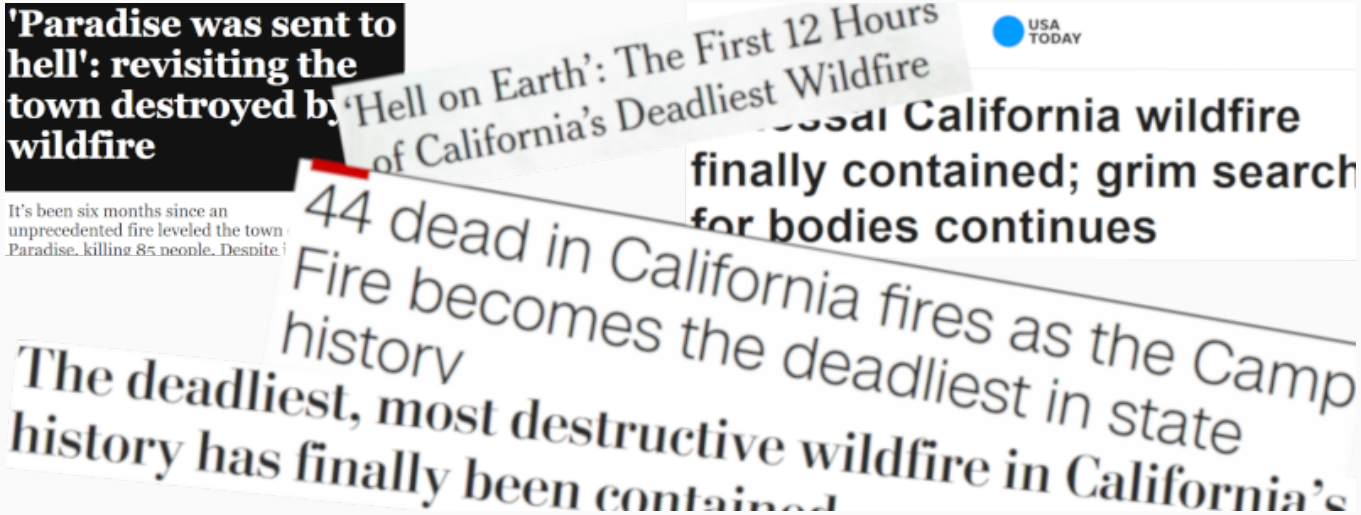
Outline

Californian Fires

The bigger plan

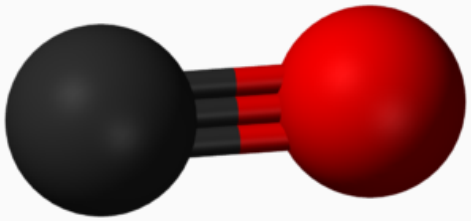
- **Use high-spatial-resolution satellite data**
- Extend the chemical scheme of the model for using satellite data products for multiple species
- Perform inversions using data from multiple satellites instruments

Californian wild fires

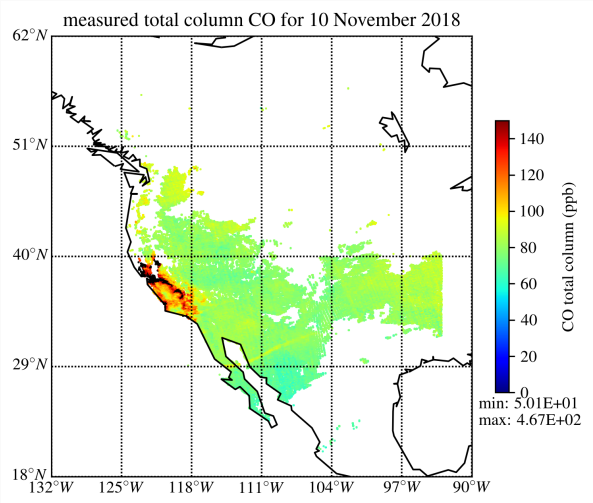


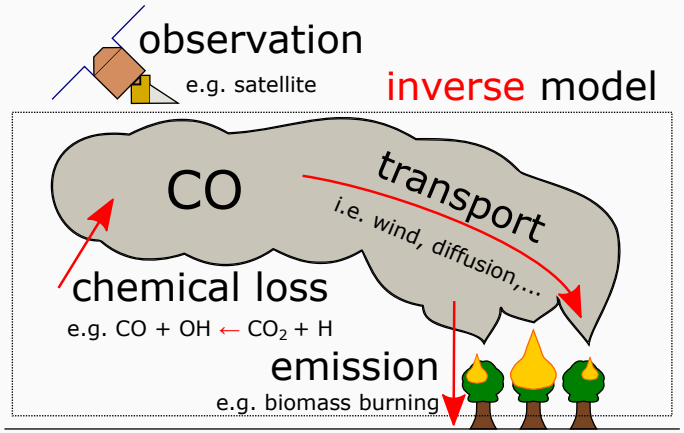
- Warmer and dryer than usual $\rightarrow$ wildfires more likely
- November and December 2018: major burning events
- Focus on Camp and Woolsey fires, raging in the weeks after November 8th
  - Devastated area about $1000\,\mathrm{km}^2$
  - Direct damage: 88 dead, burned land and structures, forced evacuation of multiple towns
  - Indirect damage due to pollution

Objective and Motivation



Retrieve CO emissions from biomass burning events in California using TROPOMI observation in the TM5 4DVAR model.





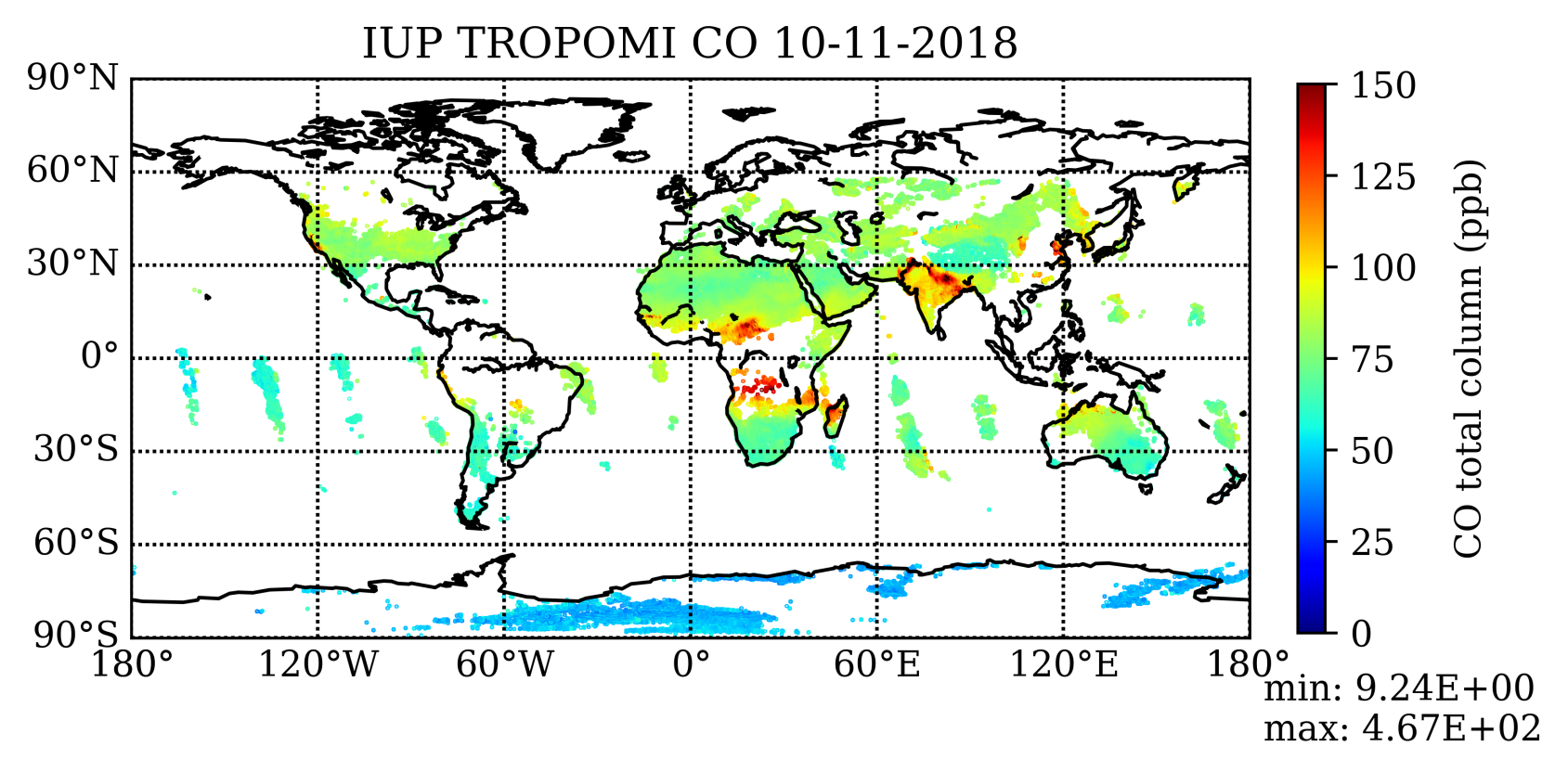
Images: Fire: Mark McKenna / Zuma Press, LA-Times; S5P: ESA

TROPOMI observations

- **TROPO**spheric **M**onitoring **I**nstrument onboard of **S**entinel-**5** **P**recursor
- Daily global coverage
- Local overpass time 13:30
- High resolution (up to $7 \times 7\,\mathrm{km}^2$)
  - $\rightarrow$ Still useful for $1^\circ \times 1^\circ$ model boxes: lower error, chance to have at least some cloud free pixels
- Especially sensitive to troposphere/boundary layer

Image: ESA

Satellite observations



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Satellite data courtesy of Oliver Schneising and Michael Buchwitz of IUP Carbon and Greenhouse Gas Group

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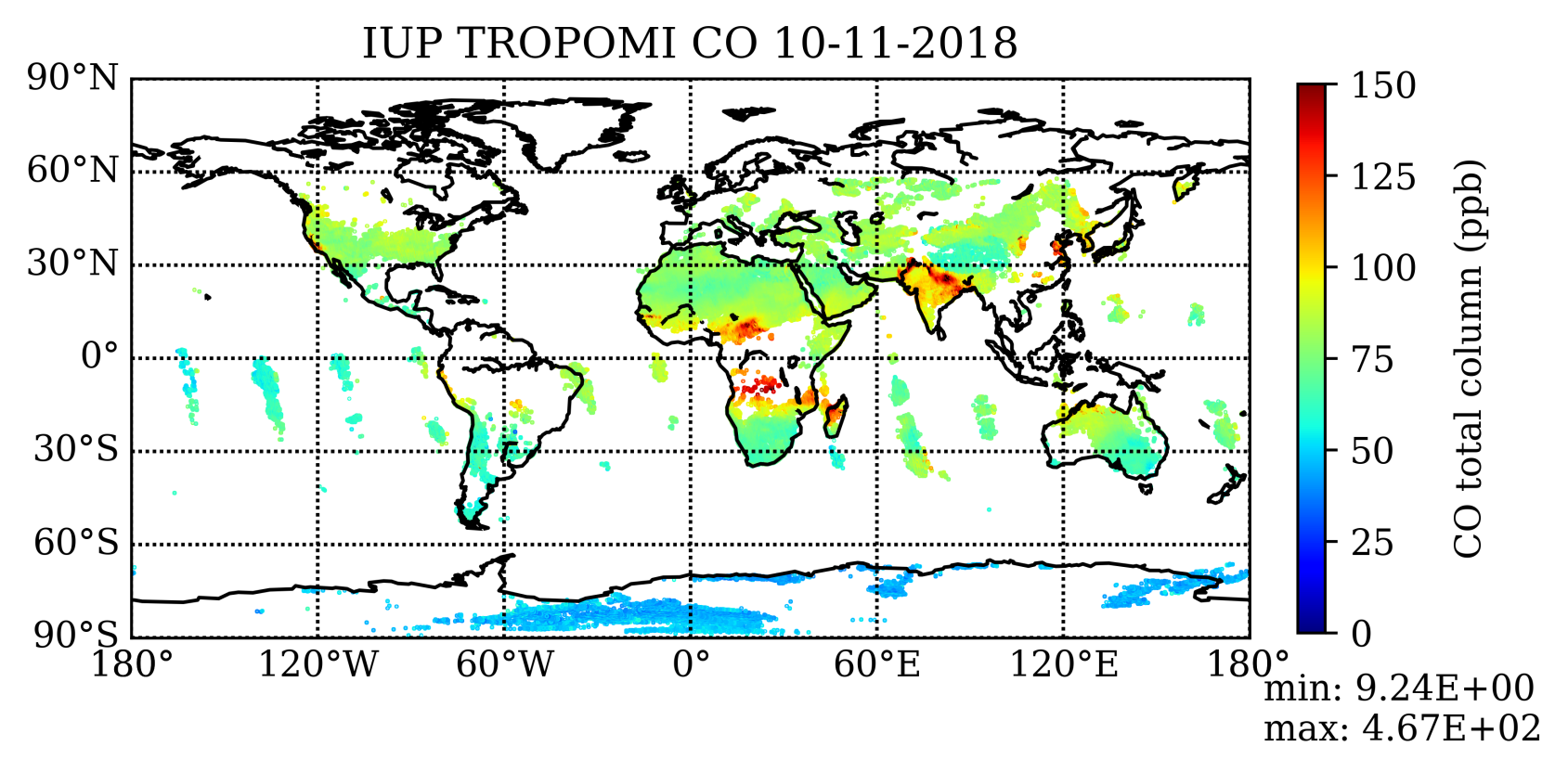

- Given: TROPOMI CO total column observation
- Wanted: Location and temporal development of emissions

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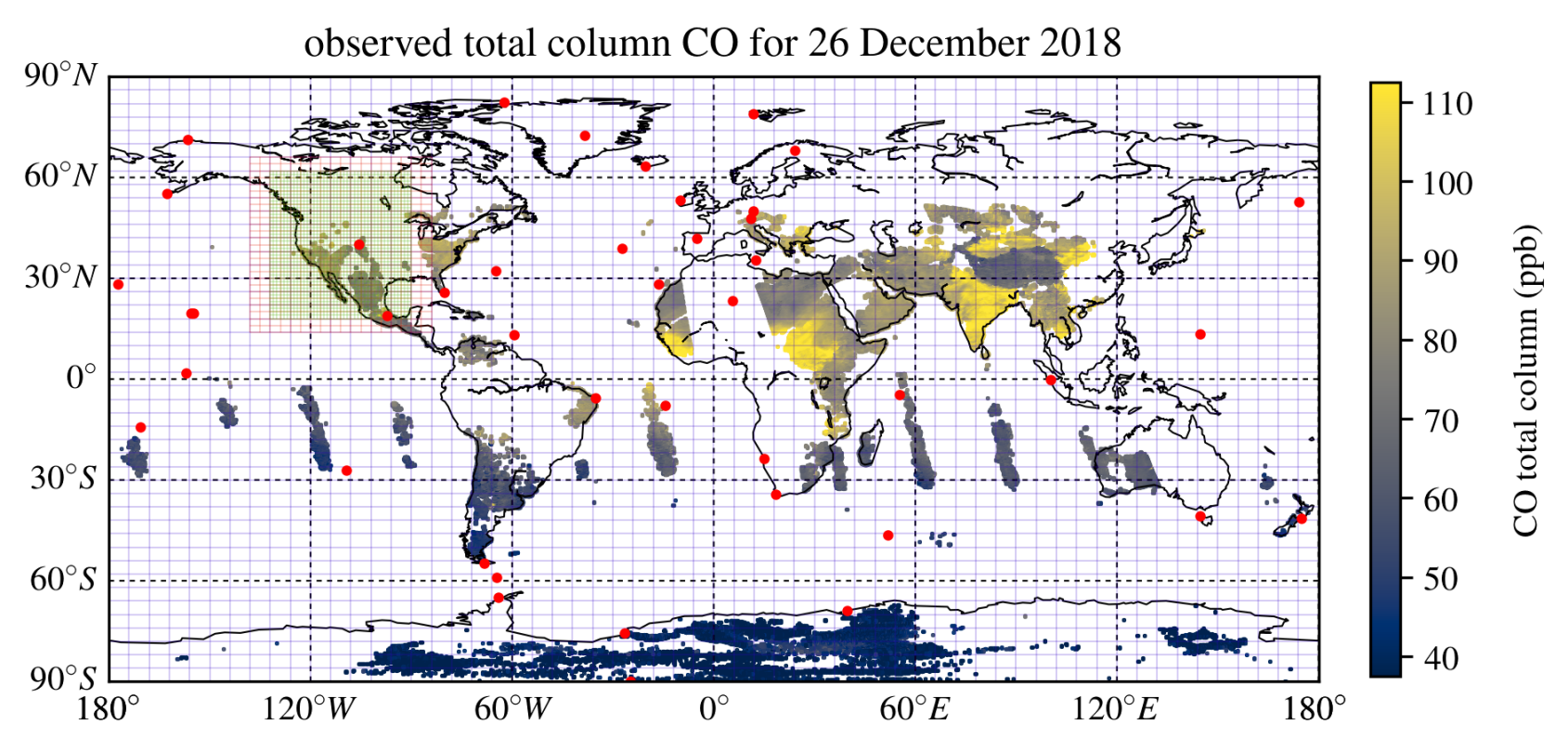
- M1qN3 optimizer
- Zoom over California

Zooming, flask measurements and satellite observations



Spin-up

- Start from TM5MP full chemistry fields
- Spin-up inversion for 5 months to flasks and global ~~IASI~~ TROPOMI observations on $6^\circ \times 4^\circ$
- 3 month main inversion period around 2 week time of interest

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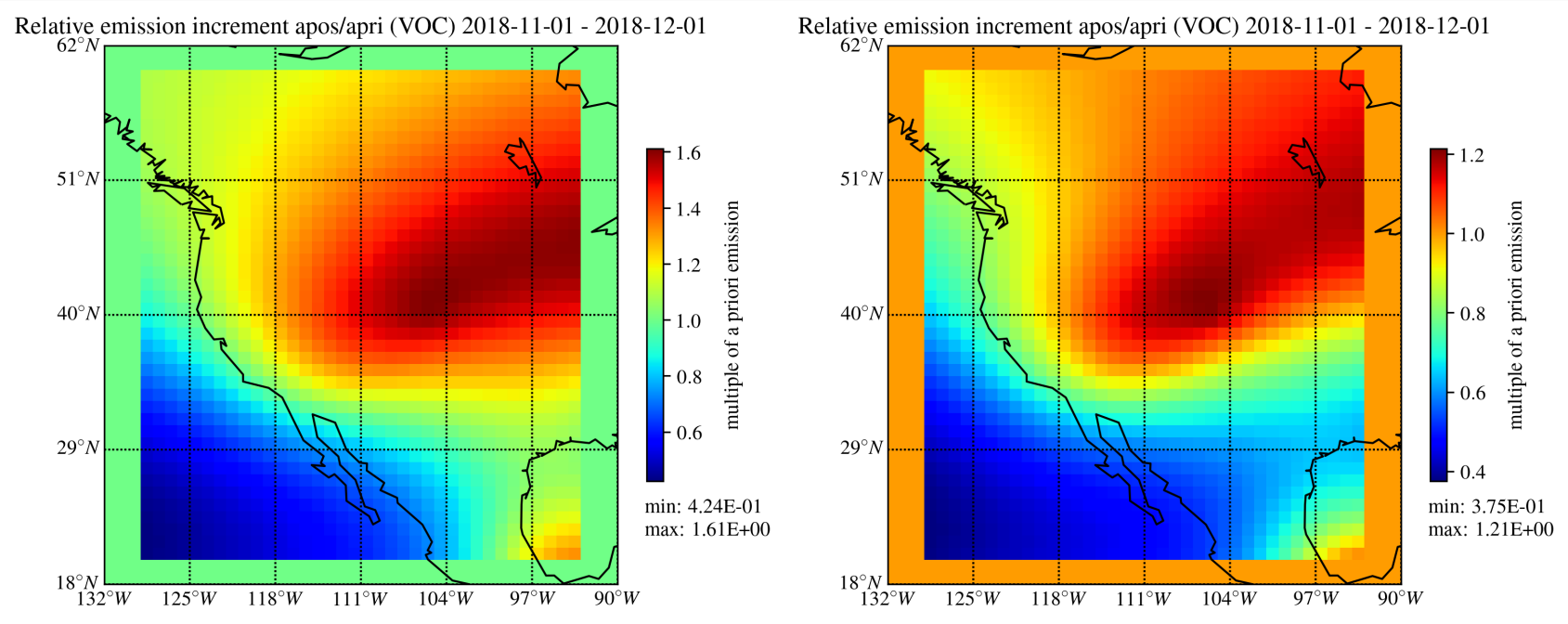
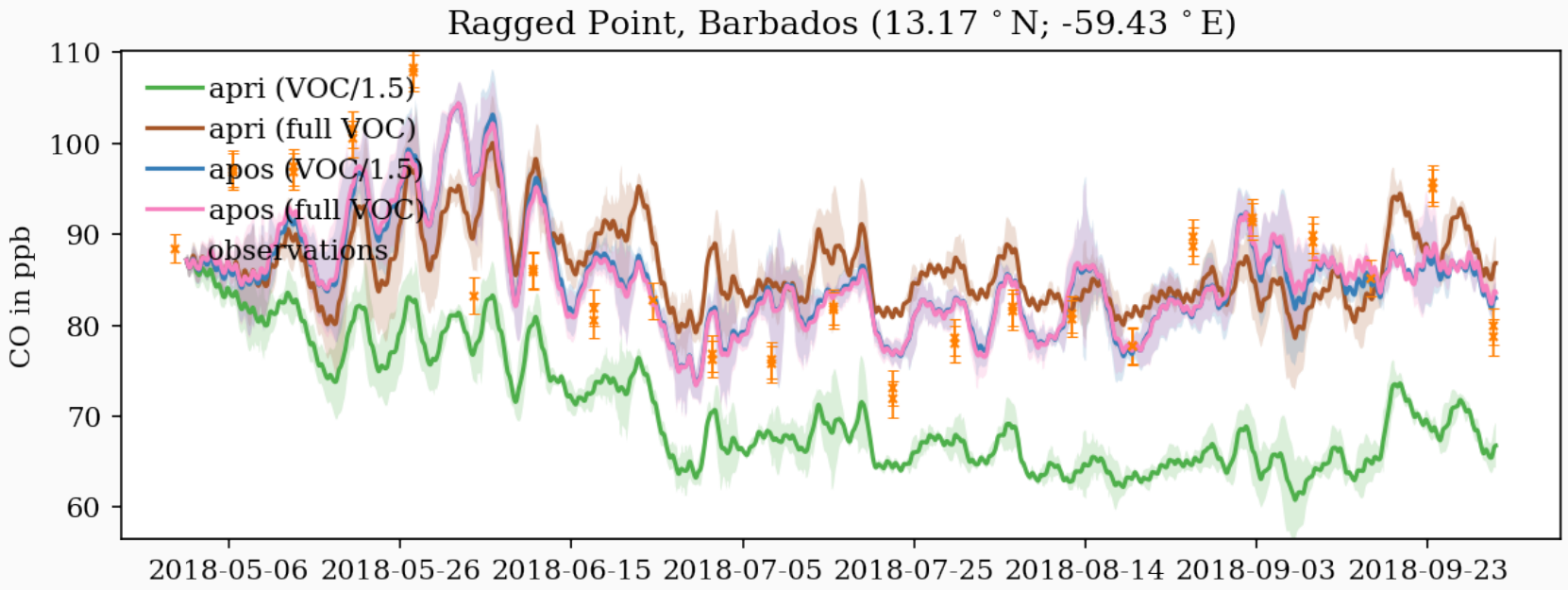
$\rightarrow$ Spin up works as intended

Aliasing between biomass burning and VOC emissions

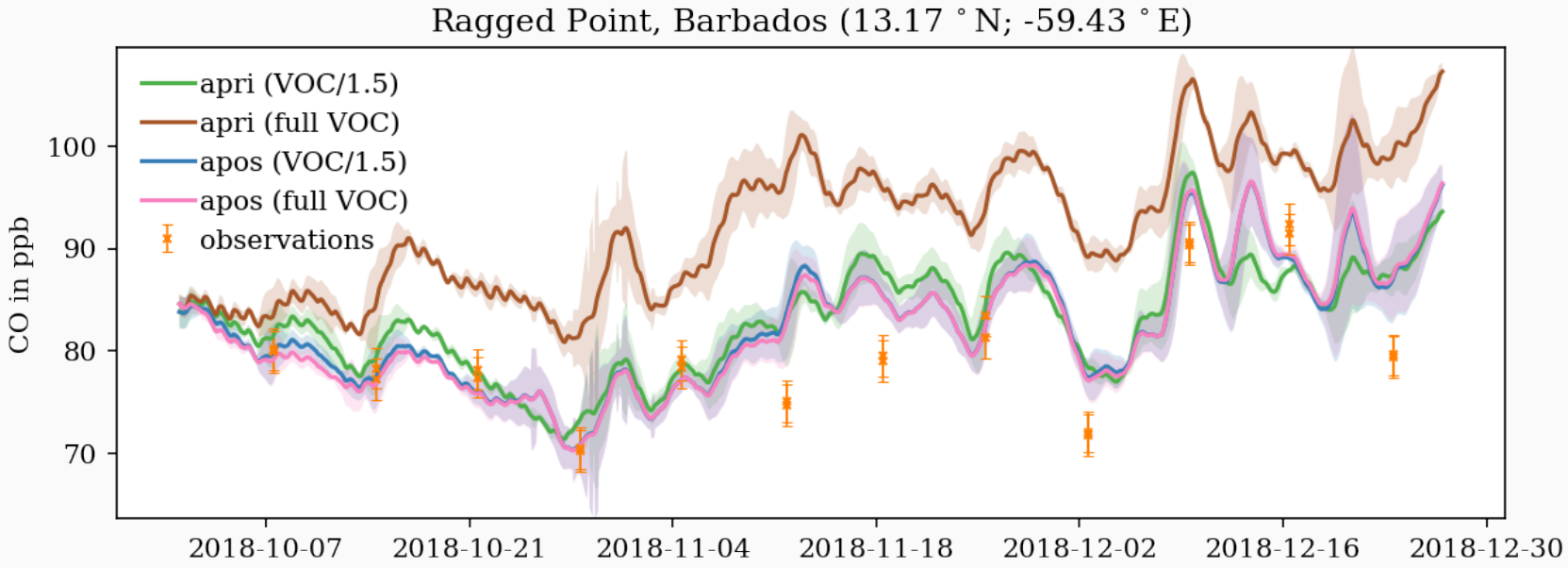


- Identical setups except for BB prior (left: GFED, right: FINN)
- Simultaneous inversion of BB CO and CO from VOC/CH_4
- A posterior production from VOC/CH_4 strongly affected by a priori biomass emissions $\rightarrow$ simultaneous inversion not feasible

RPB - NH-summer



RPB - NH-winter



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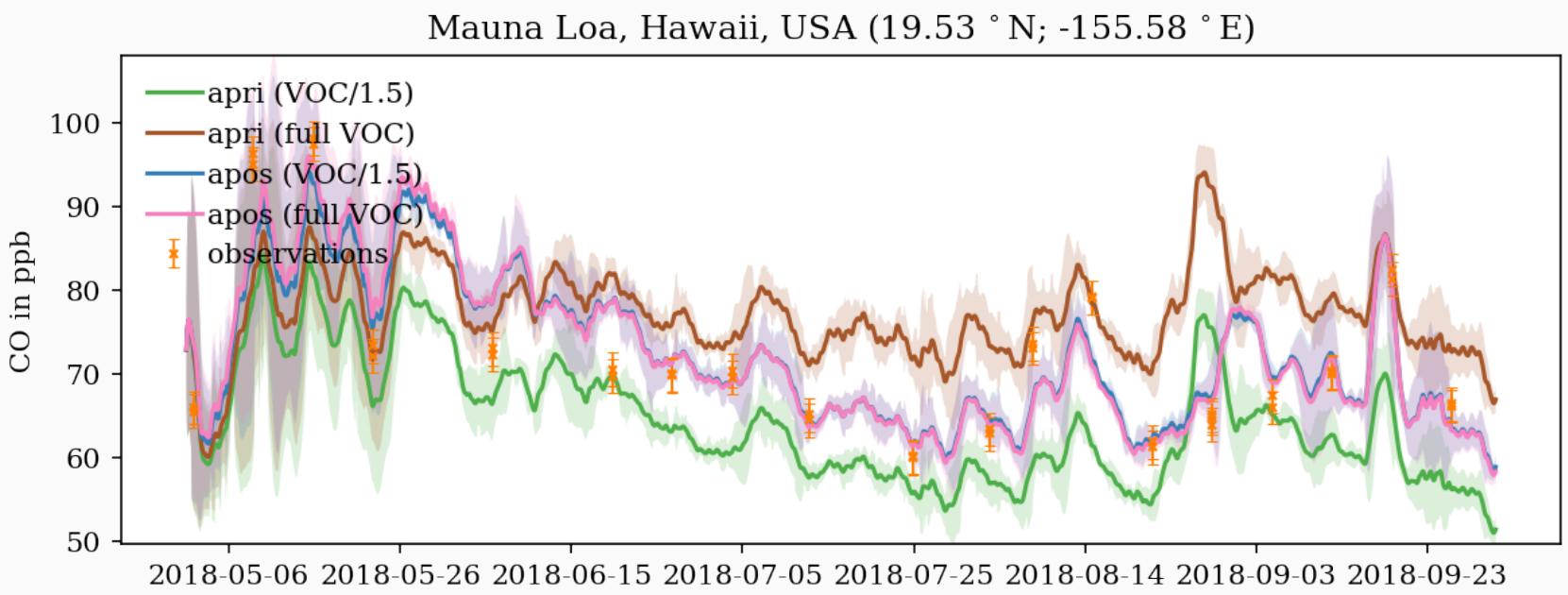

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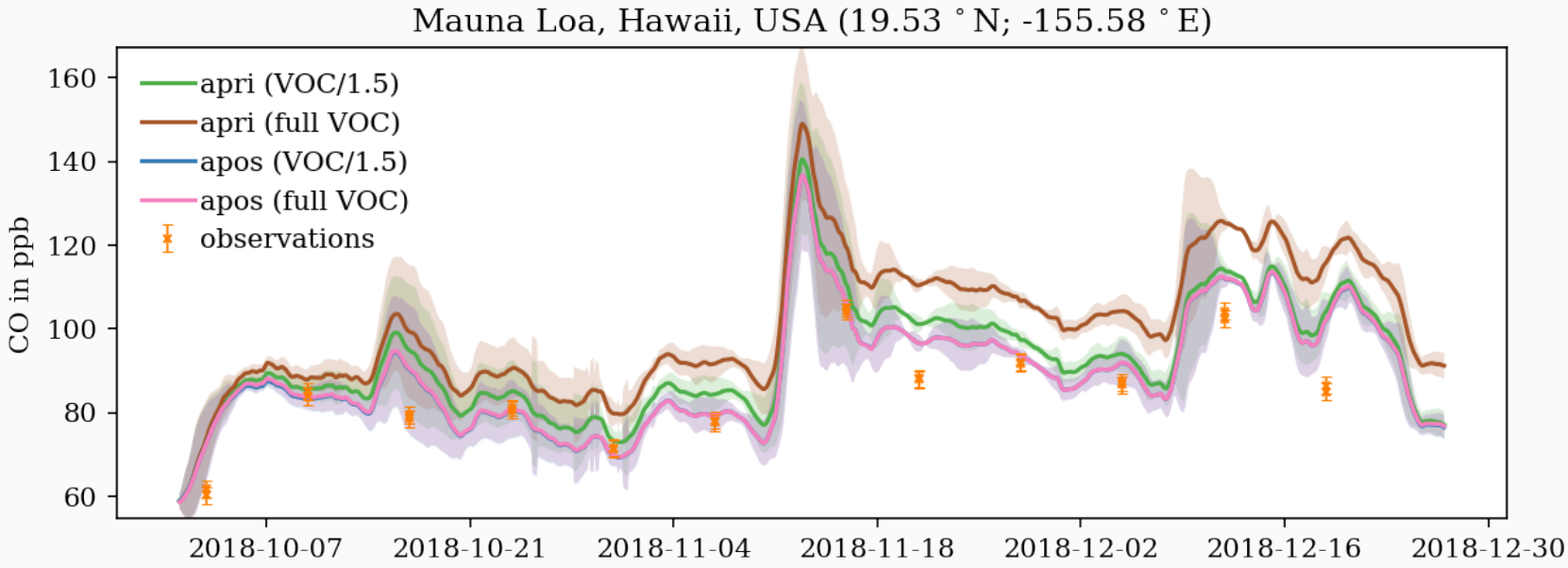

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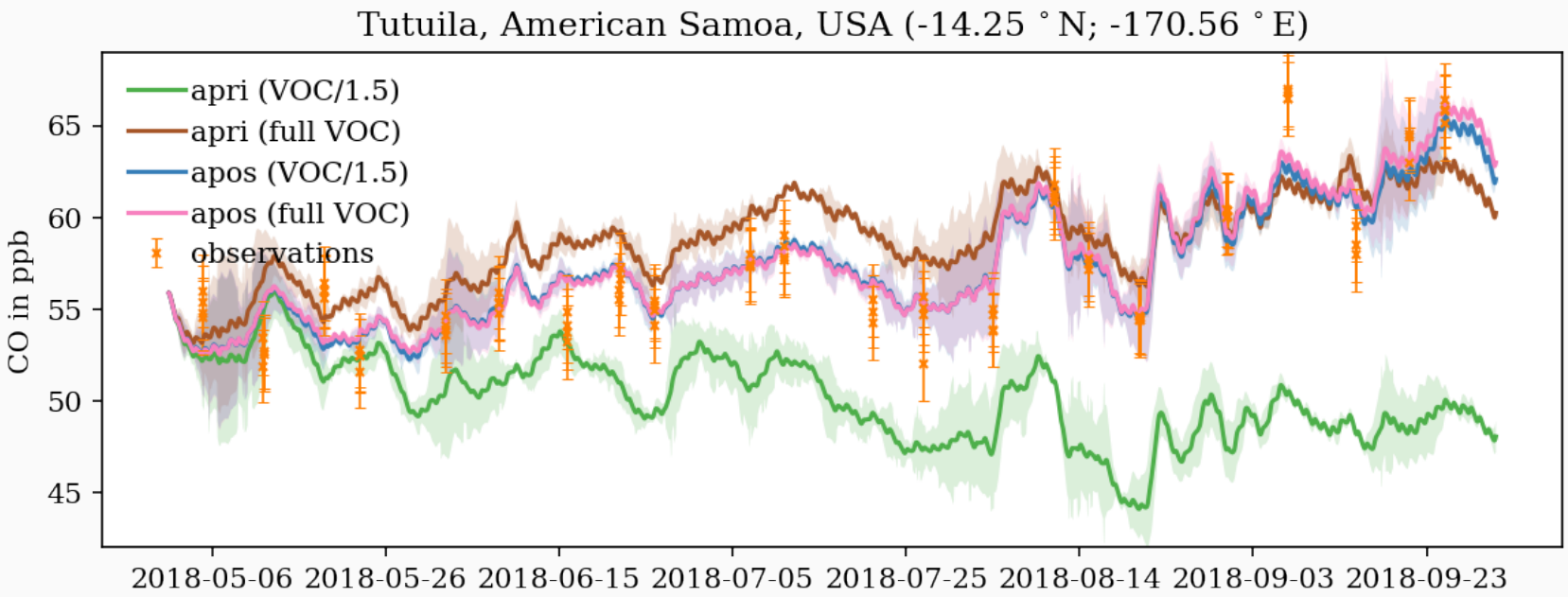

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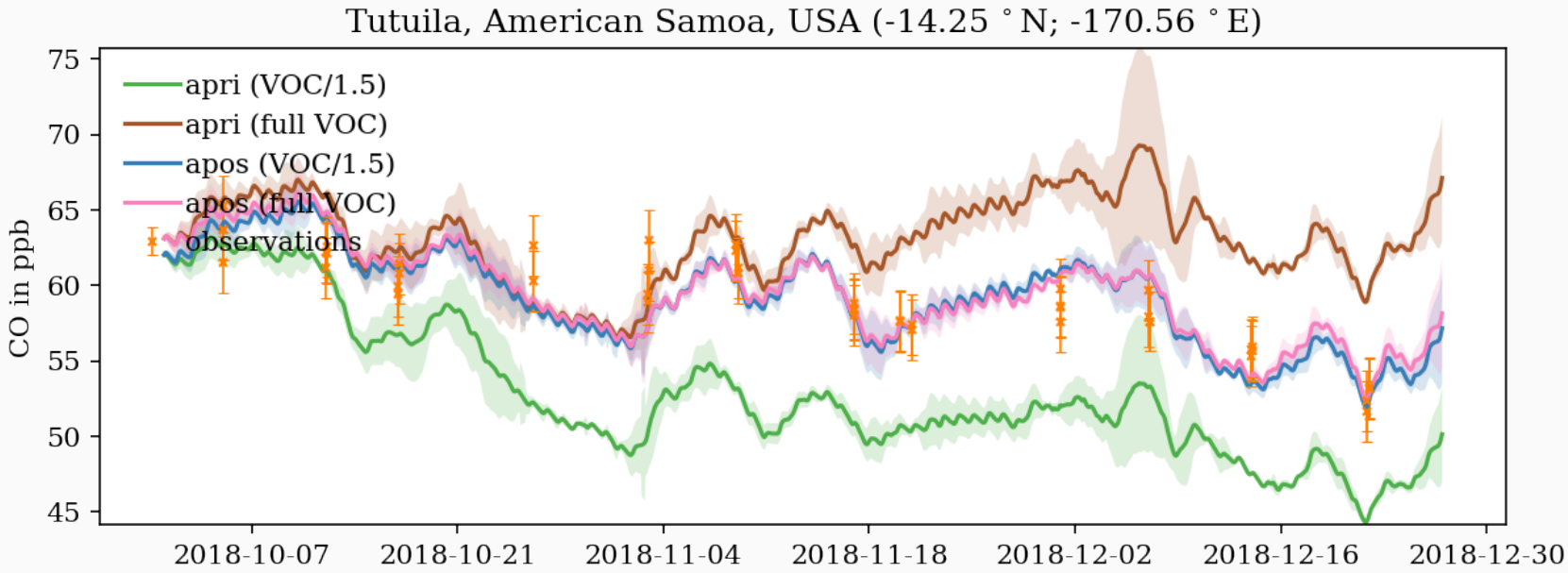

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- Consider more complex chemistry, like HCHO

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- Collaboration with Prof. Dr. Maarten C. Krol, one of the model's original creators, and other students working on related topics

The bigger plan

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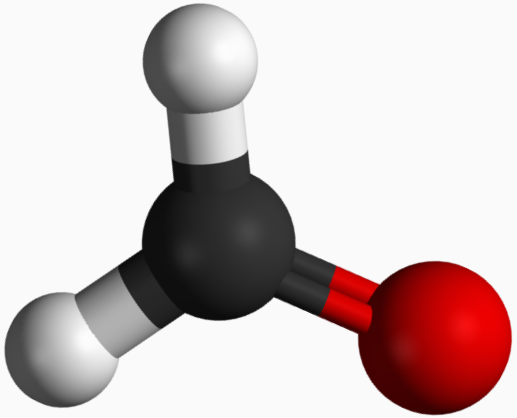
Formaldehyde (HCHO)



- Volatile, colorless and toxic gas
- Intermediate species in oxidation of CH_4 and VOCs to CO
  - Specifically, proxy species for the isoprene produced by plants
  - As such part of and proxy for the natural/biogenic CO source
- Shortlived, lifetime of a few hours in the sunny atmosphere

Extended inversion scheme

Problem:

- CO from biomass burning looks the same as CO from natural sources
- Collocated sources

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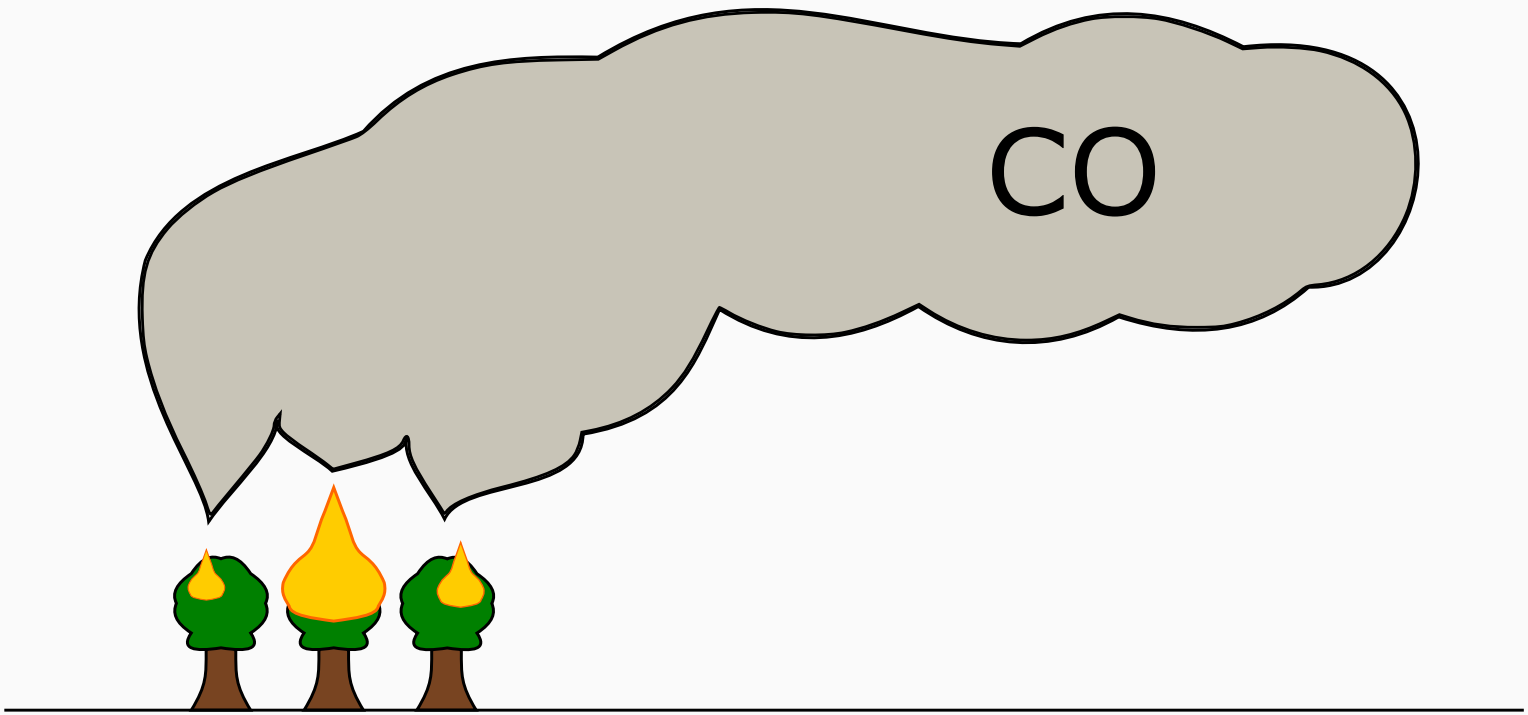

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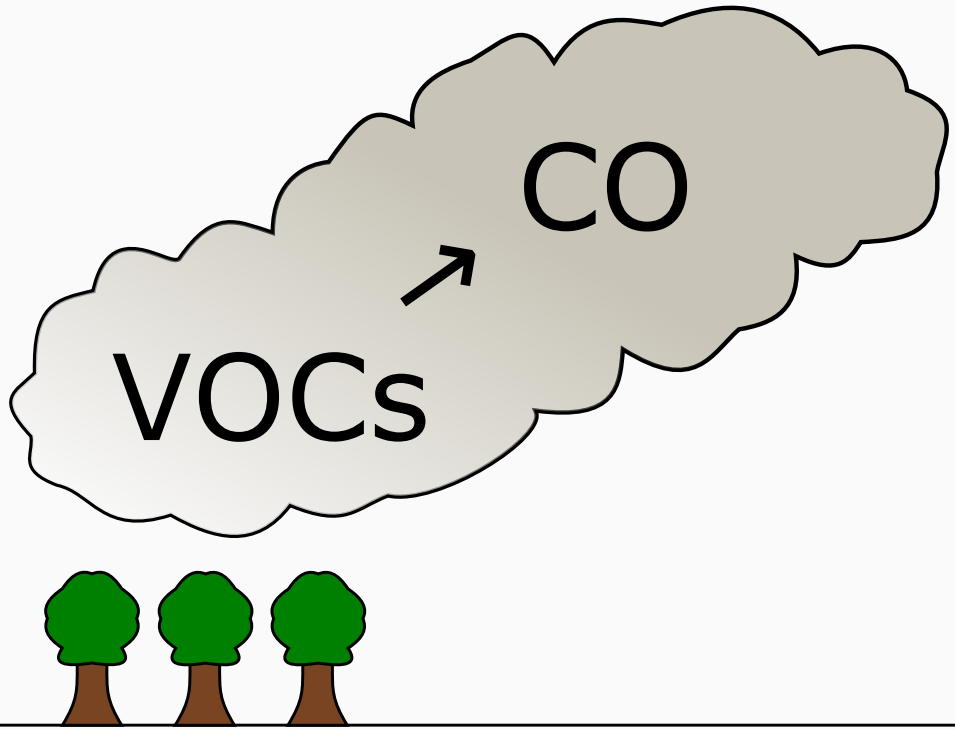

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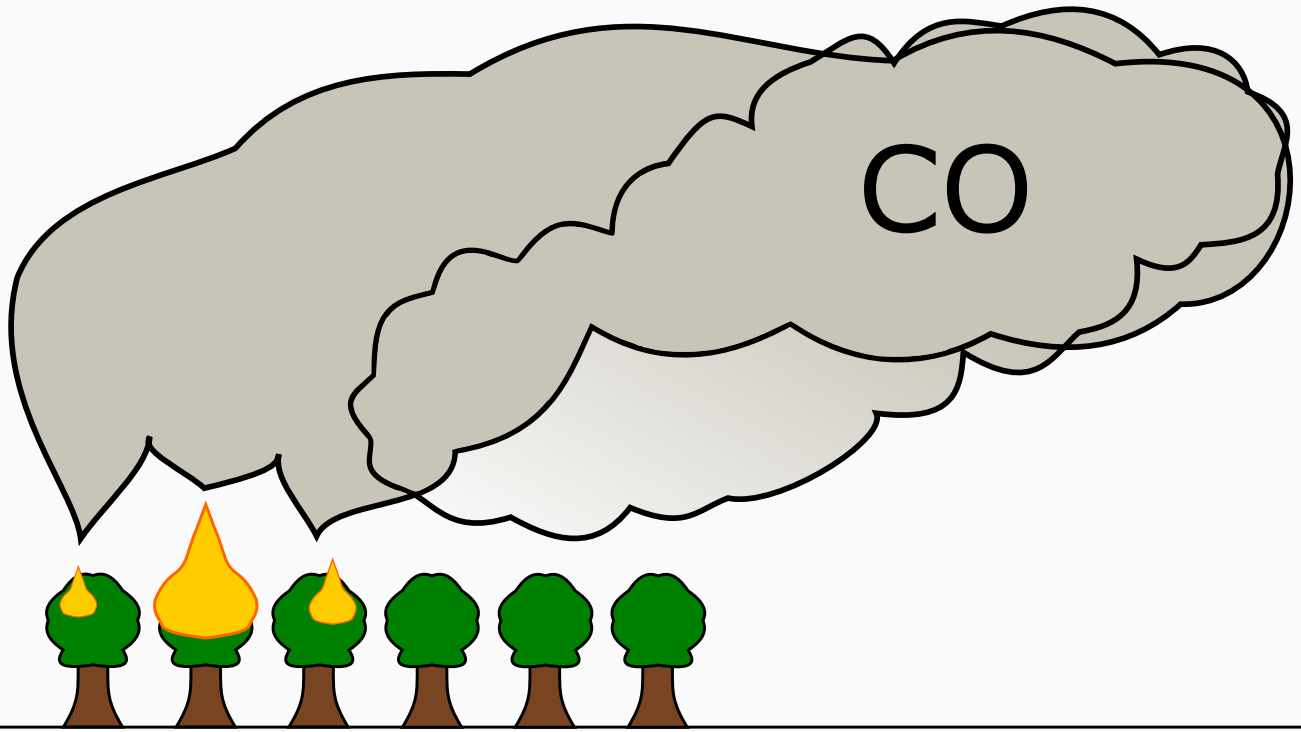

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Solution:

- Use observations for CO **and** HCHO
- HCHO sufficient proxy for the whole natural source

$\rightarrow$ If ambient and local HCHO are known, the biogenic source can be estimated and distinguished from the biomass burning source

Extended inversion scheme (2)

Multiple approaches:

- Extend the currently very simplified CO chemistry in TM5-4DVAR to include HCHO

$\rightarrow$ Solving more complex chemistry $\rightarrow$ severely increased computation time

- Create look-up tables for loss and production of CO and HCHO under different ambient conditions
  - Use TM5MP to get loss rates..
  - .. either use a simplified scaling approach
  - .. or do a dedicated HCHO inversion

Scaling approach

$$P_{\mathrm{CO}} \propto P_{\mathrm{HCHO}} = L_{\mathrm{HCHO}} \cdot [\mathrm{HCHO}]_{\mathrm{TM5}} \cdot \mathrm{scaling\_factor}$$

- P_{HCHO}: Biogenic source of HCHO to be used in the inversions
- L_{HCHO}: Chemical loss rate of HCHO, to be taken from TM5MP
- $[\mathrm{HCHO}]_{\mathrm{TM5}}$: Current concentration of HCHO, to be taken from TM5MP and compared to satellite observations to obtain $\mathrm{scaling\_factor}$

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- $\mathrm{scaling\_factor} = [\mathrm{HCHO}]_{\mathrm{obs}}/[\mathrm{HCHO}]_{\mathrm{TM5}}$
- Varies in time and space
- Each grid box has its own factor, default 1
- Updated whenever there is a measurement or monthly, to be tested

Dedicated HCHO inversion

Multiple challenges for HCHO inversions:

- Generally short, but variable lifetime
- Pronounced diurnal cycle
- Little, but non-negligible transport
- Diurnal cycle in vertical distribution of precursors
- Fast chemistry, highly depended on exact ambient conditions (sun, OH, lots of other VOCs)

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Acknowledgments

- The computations were performed on the HPC cluster Aether at the University of Bremen, financed by DFG in the scope of the Excellence Initiative.
- The PhD position is paid for by the University Bremen.
- The travel expenses were covered by the BremenIDEA program of the University of Bremen.
- Special thanks to the TM5 community, especially Maarten Krol and Sourish Basu for provision of and help with the TM5-4DVAR model.

- ... and of course thank You for your attention