Using TROPOMI observations to constrain large scale CO emissions

32nd international TM5 meeting, May 2022

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Outline

Objective and Motivation

Objective

Optimizing carbon monoxide emission estimates in the Northern Hemisphere through inverse modeling based on high-resolution satellite observations

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Abstract.

Carbon monoxide in the atmosphere adversely affects air quality and climate. In this study, we attempt to optimize current bottom-up carbon monoxide emission estimates for the second half of the year 2018 on a global scale with a focus on the Northern Hemisphere through the top down approach of inverse modeling. Observations from the TROPOMI satellite in

- Manuscript in preparation
- How well can we constrain CO with just TROPOMI?

Setup

Model description

- Code at revision 899b16 from "official" repository
  - → Extended to handle new input

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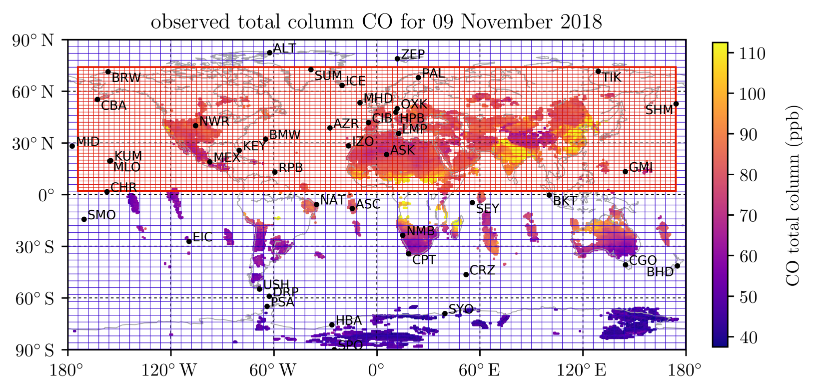
- Zoom over northern hemisphere

Zooming setup and observations



- NOAA flasks
- global TROPOMI observations

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 $7 \times 7\,km^2$)
- Gridded to $0.5^\circ \times 0.5^\circ$ (as shown during last meeting following Miyazaki et al. 2012)
- Especially sensitive to troposphere/boundary layer

Image: ESA

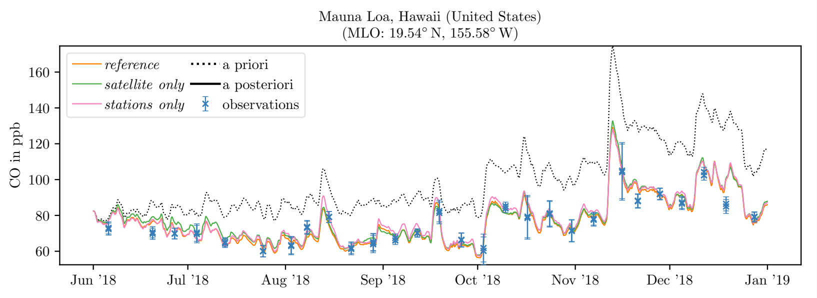
Experiments

3 inversions with different observational input (3 more in manuscript not shown here)

Inversion	Observations	
	satellite	flasks
reference	gridded	yes
satellite only	gridded	no
stations only	none	yes

Results

Good fits in most places



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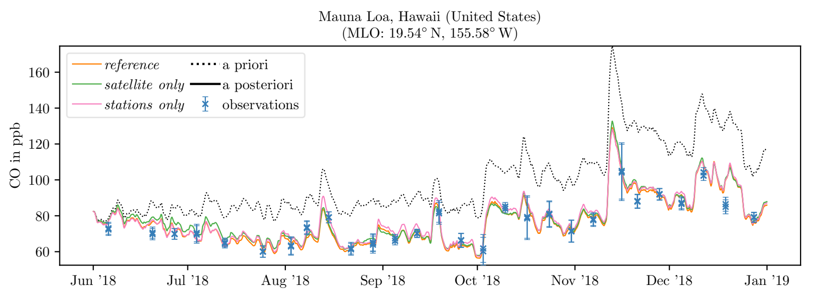

Quantify overall mismatch as $\frac{\sum\left[\frac{(\text{obs}-\text{model})^2}{\text{error}^2}\right]}{\text{number\_of\_obs}}$

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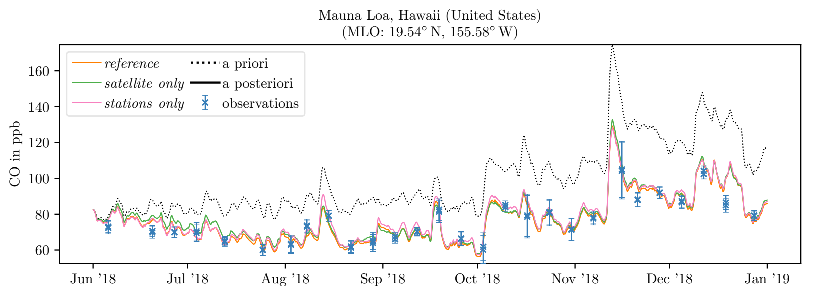

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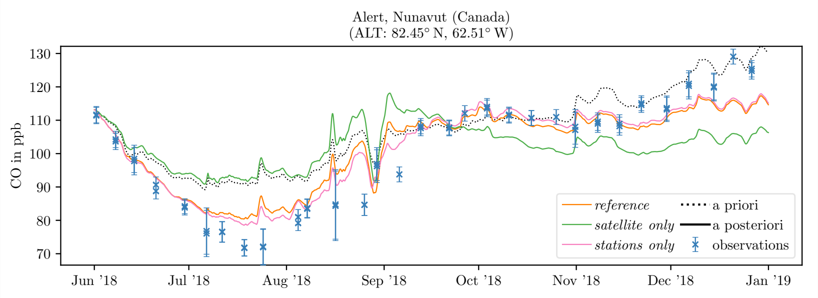
	reference	*satellite only*	*station only*
prior	21.91	21.91	21.91
posterior	3.61	**9.12**	3.26

High northern latitudes problematic, southern ok



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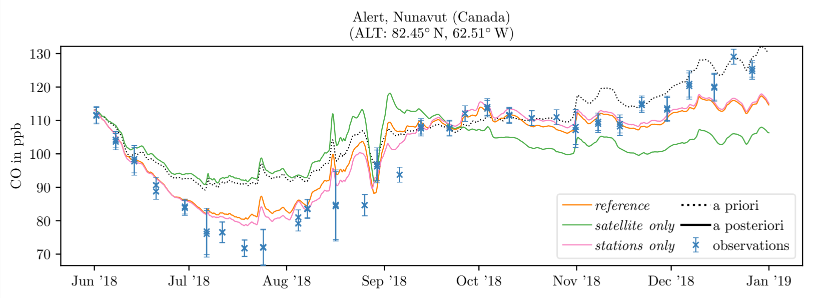
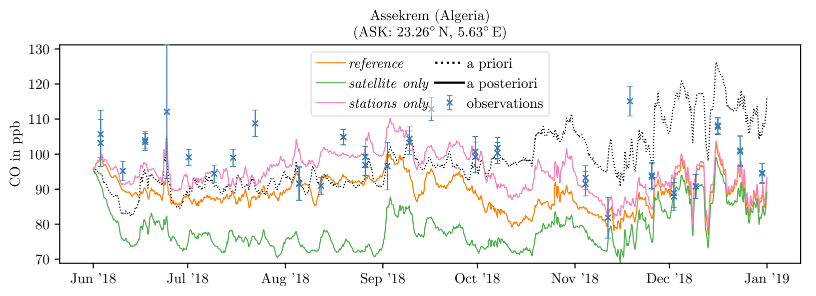


stations		*reference*	*satellite only*	*station only*
all	prior	21.91	21.91	21.91
	posterior	3.61	**9.12**	3.26
$< 55° N$	prior	24.33	24.33	24.33
	posterior	3.59	**7.84**	3.35

Few stations generally problematic



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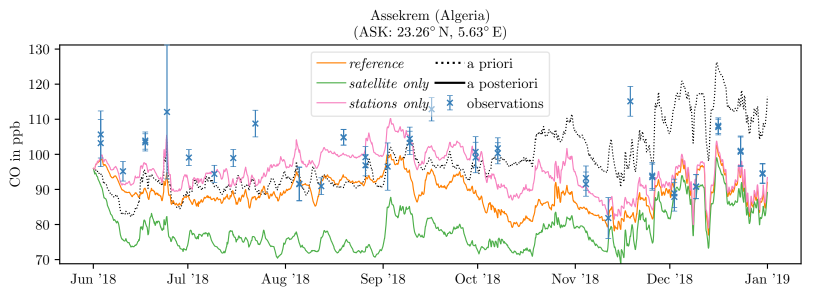

stations		*reference*	*satellite only*	*station only*
all	prior	21.91	21.91	21.91
	posterior	3.61	**9.12**	3.26
excluding ASK, HPB, OXK	prior	22.21	22.21	22.21
	posterior	3.36	**7.62**	3.14

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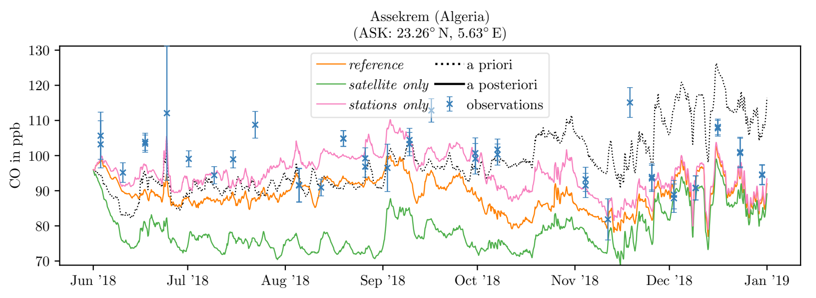

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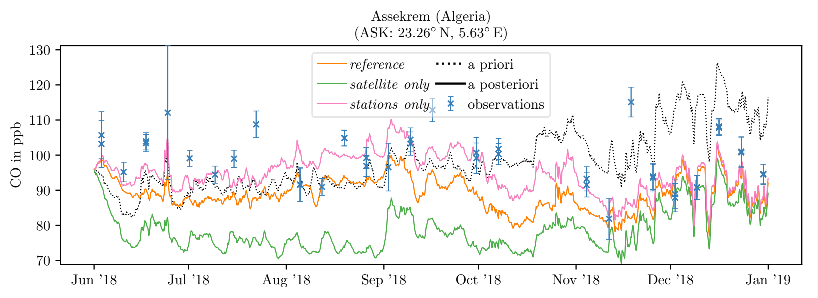

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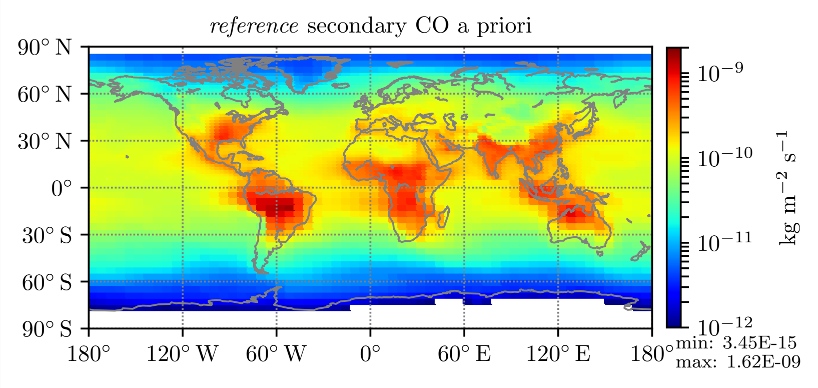
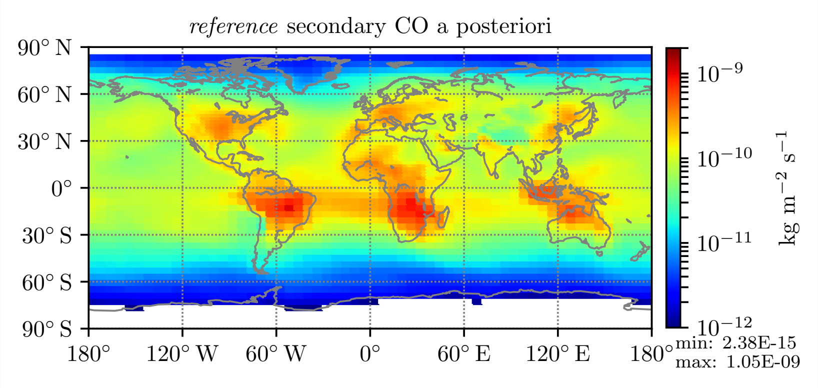
$< 55° N$ and excl. ASK, HPB, OXK	prior	24.92	24.92	24.92
	posterior	3.27	**5.80**	3.20

Emission – A priori



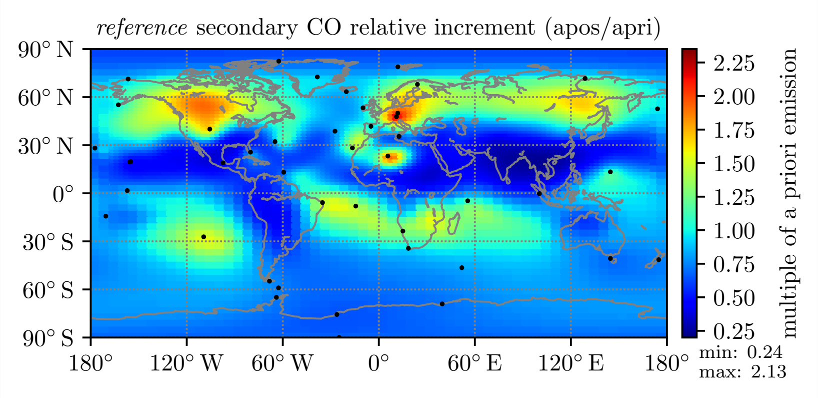
Anthropogenic and biomass burning not shown

Emission – A posteriori



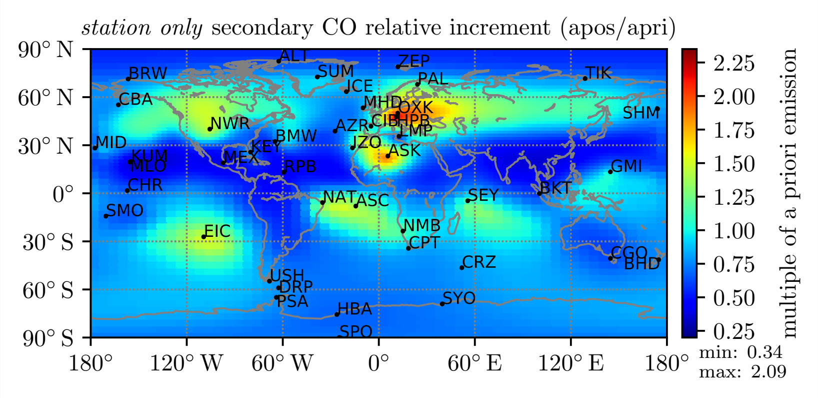
Large decrements over India and China

Emission – Relative increment



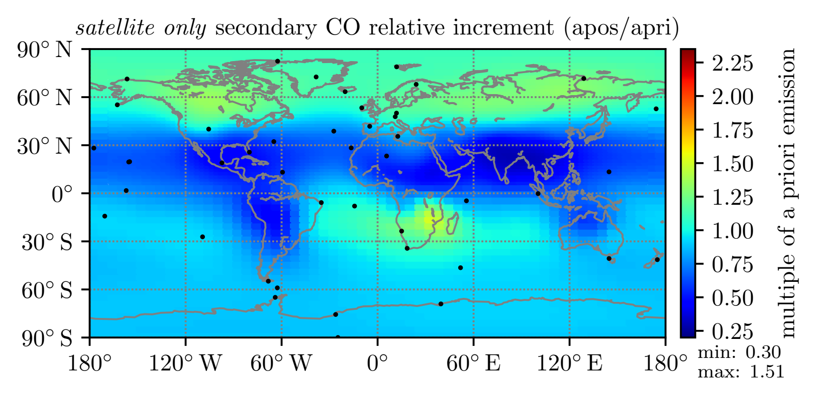
- Asia reduced by up to 75 %
- Some increments appear co-located to stations

Emission – Relative increment



- Without satellite smaller increments overall
- Lower emissions at high north latitudes, higher in Asia
- Clear co-location for ASK, HPB, OXK, EIC, but...

Emission – Relative increment



- ... increments near some stations also found with only satellite
- Broader patterns reserved

Summary & Outlook

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- Technical paper, showcasing TROPOMI (super)observations in TM5-4dvar

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- Technical paper, showcasing TROPOMI (super)observations in TM5-4dvar

$\rightarrow$ $0.5^\circ \times 0.5^\circ$ superobservation as input for inversion with NH in $3^\circ \times 2^\circ$

$\rightarrow$ CO inversion driven only by satellite appears feasible

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- Technical paper, showcasing TROPOMI (super)observations in TM5-4dvar

$\rightarrow$ $0.5^\circ \times 0.5^\circ$ superobservation as input for inversion with NH in $3^\circ \times 2^\circ$

$\rightarrow$ CO inversion driven only by satellite appears feasible

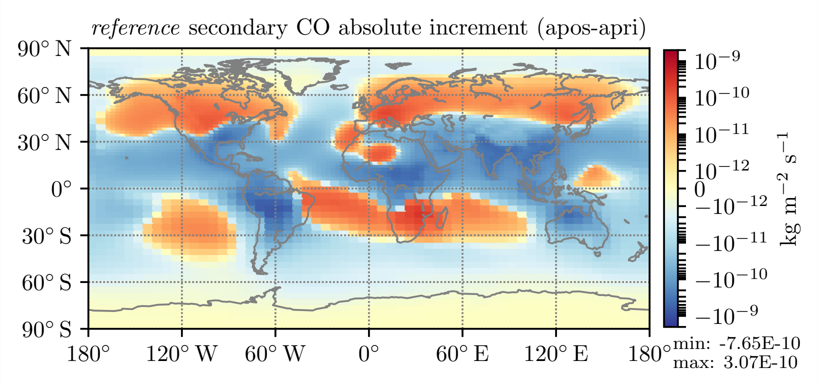
- Scientific paper for Californian (and Siberian?) fires also in the making

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.

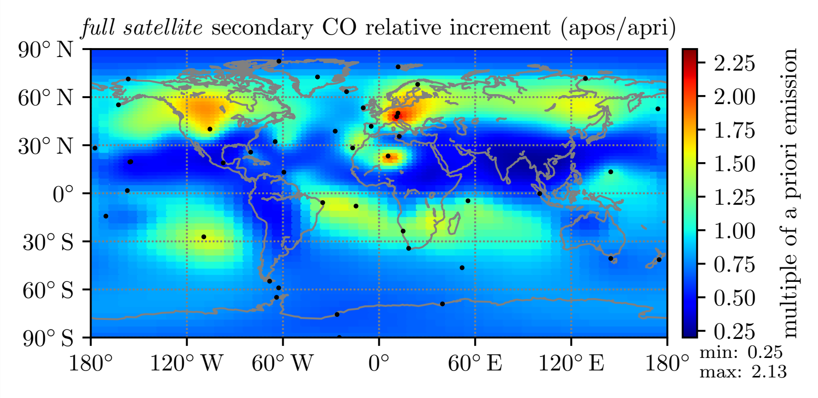
- ... and of course thank You for your attention

Emission – Absolute increment



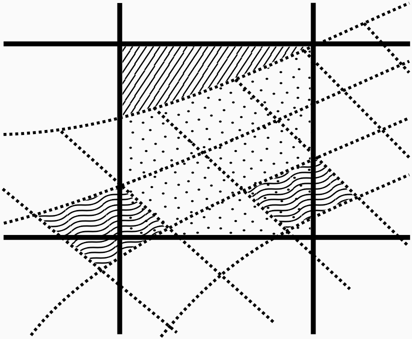
Hard to see differences with log-scale

Emission – Relative increment



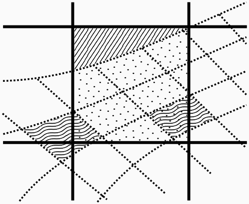
Almost no changes through gridding

The easy approach



- Set up global, regular grid
- Aggregate any observations in a grid cell into a single superobservation based on the location of their center
- How to weigh the observations?

Area-weighting



$$\hat{y}_o = \frac{\sum_{i=1}^{m} w_i \hat{y}_i^o}{\sum_{i=1}^{m} w_i}, \quad (1)$$

- Calculate intersection areas w_i of footprints $\hat{y}_i^o$ with each grid cell
- Get area-weighted mean
- Can also be applied to averaging kernel, pressure levels, time, and a-priori profile...
- ... but not to the observational error

Observational error and overlapping footprints

- Observations can contribute to multiple grid cells
- Inflate their error by $\sqrt{\frac{A_i}{w_i}}$ to keep their weight in the cost function constant, A_i is the total footprint area

$$\sigma = \frac{\sum_{i=1}^{m} \sqrt{\frac{A_i}{w_i}} w_i \sigma_i^o}{\sum_{i=1}^{m} w_i} = \frac{\sum_{i=1}^{m} \sqrt{A_i w_i} \sigma_i^o}{\sum_{i=1}^{m} w_i} \tag{2}$$

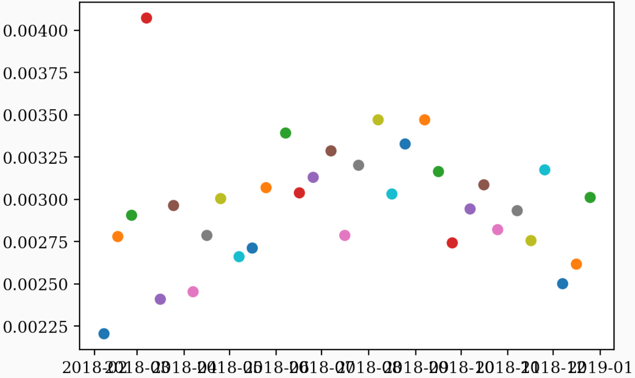
Error deflation and systematic errors

- Many independent observations reduce error by $\sqrt{n}$
- Adjacent satellite observations not independent
- Correlations in errors form assumptions about albedo etc.
- Eskes et. al. 2003 suggest $\sigma_o = \sigma\sqrt{\frac{1-c}{n} + c}$
- Miyazaki et. al. 2012 set $c = 15\%$

Representativeness error

- Handle grid cells on partly covered by observations
- introduce factor $f_{\mathrm{rep}}(\alpha)$ based on the relative coverage $0 \leq \alpha \leq 1$
- Estimate f_{rep} by artificially reducing coverage and comparing the resulting superobservations
- We aggregate f_{rep} into bins of 1 % coverage each
- Only use well covered cells, Miyazaki et. al. 2012 used $\alpha > 90\,\%$, we use $\alpha > 50\,\%$, to accommodate coarser grids

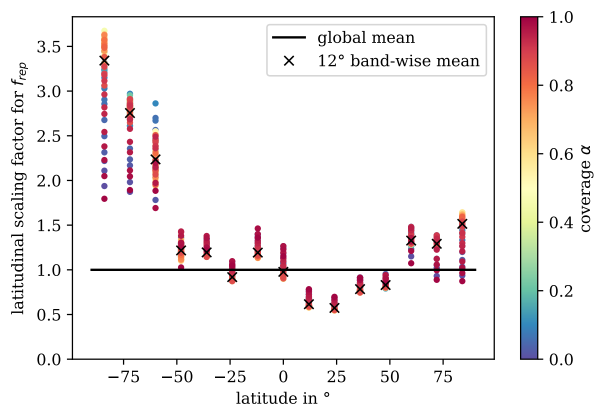
Representativeness error - intra-annual variations



- f_{rep} seems to weakly depend on season, likely due to differences in land mass between NH and SH
- daily variation has similar magnitude $\rightarrow$ use one consistent f_{rep} for the whole year

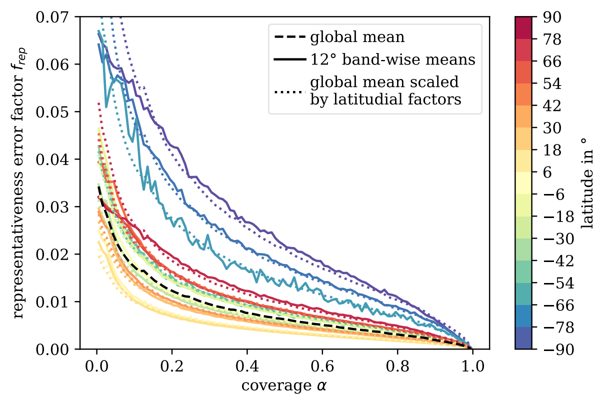
Representativeness error - latitudinal variations

- Magnitude of f_{rep} seems to strongly depend on latitude, likely linked to distribution of oceans and grid cell size



Representativeness error - latitudinal variations

- Magnitude of f_{rep} seems to strongly depend on latitude, likely linked to distribution of oceans and grid cell size
- Shape of f_{rep} appears to be unaffected by latitude



Representativeness error - latitudinal variations

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- Shape of f_{rep} appears to be unaffected by latitude

$\rightarrow$ Calculate global $f_{\mathrm{rep}}(\alpha)$

$\rightarrow$ Recalculated f_{rep} in 12° latitude bands to get scaling factor $\bar{f}_{rep}(\phi)$ to the global curve

$$f_{rep}(\alpha, \phi) = \bar{f}_{rep}(\phi) \cdot f_{\mathrm{rep}}(\alpha) \tag{3}$$

Total superobservation error

- Representativeness error for a specific coverage and latitude, based on the area-weighted observation:

$$\sigma_r = f_{\mathrm{rep}}(\alpha, \phi) \cdot \hat{y}_o. \tag{4}$$

- Total superobservation error by combing inflation through representativeness error and deflation through number of observations:

$$\sigma_s = \sqrt{\sigma_o^2 + \sigma_r^2}. \tag{5}$$