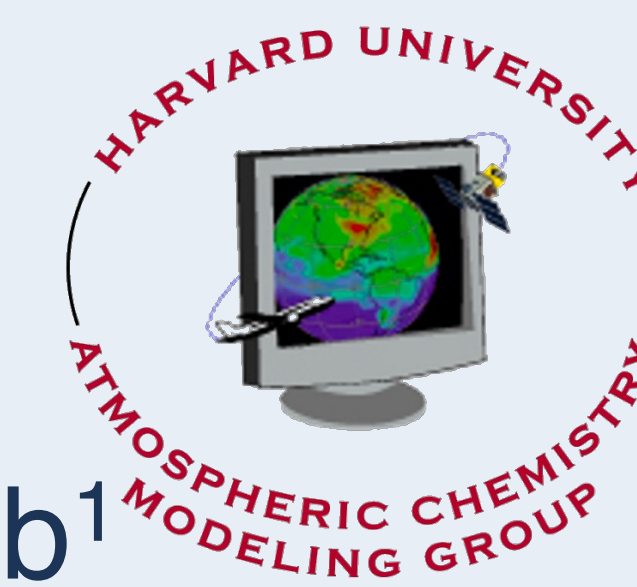# Global Fine-Resolution Analytical Inversion of TROPOMI Methane Observations Enabled by the Stretched-Grid High-Performance GEOS-Chem Model

Dandan Zhang[1], Daniel J. Varon[2], Melissa P. Sulprizio[1], Elizabeth W. Lundgren[1], Nicholas Balasus[1], Lucas Estrada[1], and Daniel J. Jacob[1]
[1]Harvard University, [2]Massachusetts Institute of Technology

Constrain Methane Emissions with Analytical Inversion

using the Integrated Methane Inversion (IMI) model

- Exploit satellite observations
- Detailed uncertainty characterization
- BUT, computationally demanding with massive sensitivity simulations

Computational cost (# of sensitivity simulations) { Spatial domain, Spatial resolution }

- Limiting global inversion to ~200 km
- Incapability of fine-resolution regional inversion for
  - Global mass conservation
  - OH sink optimization

Global Adaptive Fine Resolution Enabled by Stretched GCHP

Massively parallel scalability over thousands of cores, stretched-grid enables 25-km resolution with computational economy
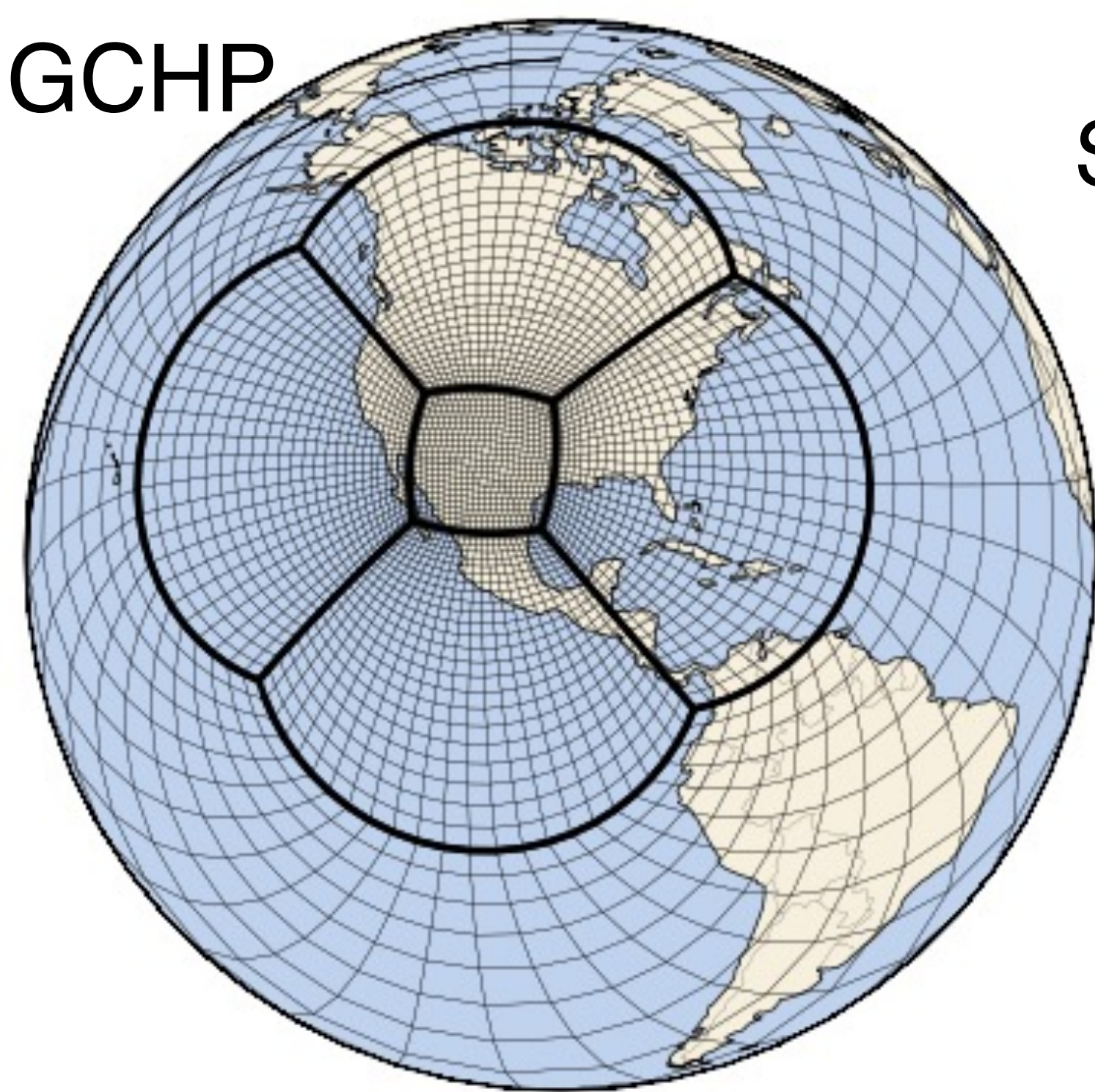
GCHP
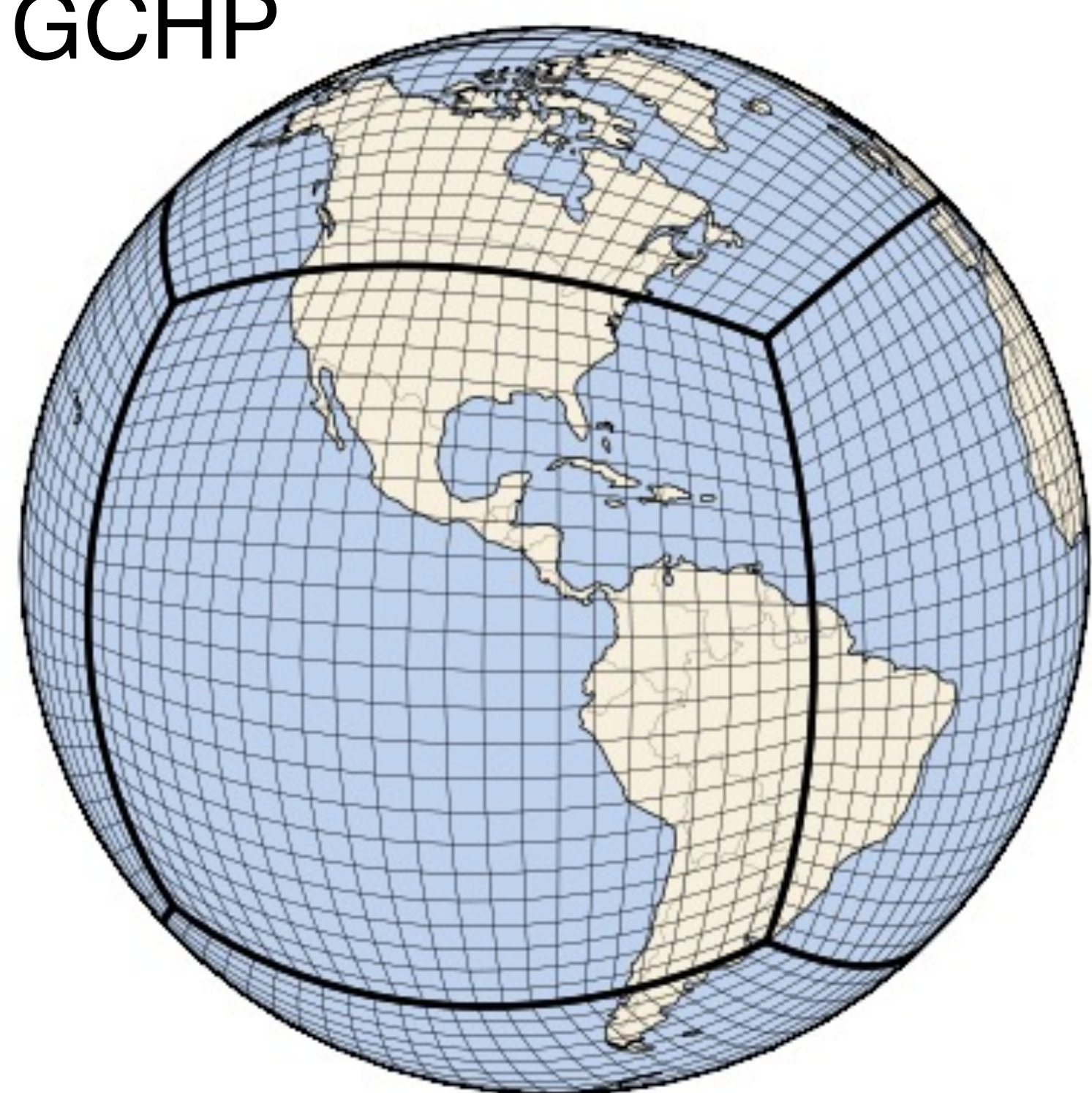
GCHP simulation
- multi-node parallelization
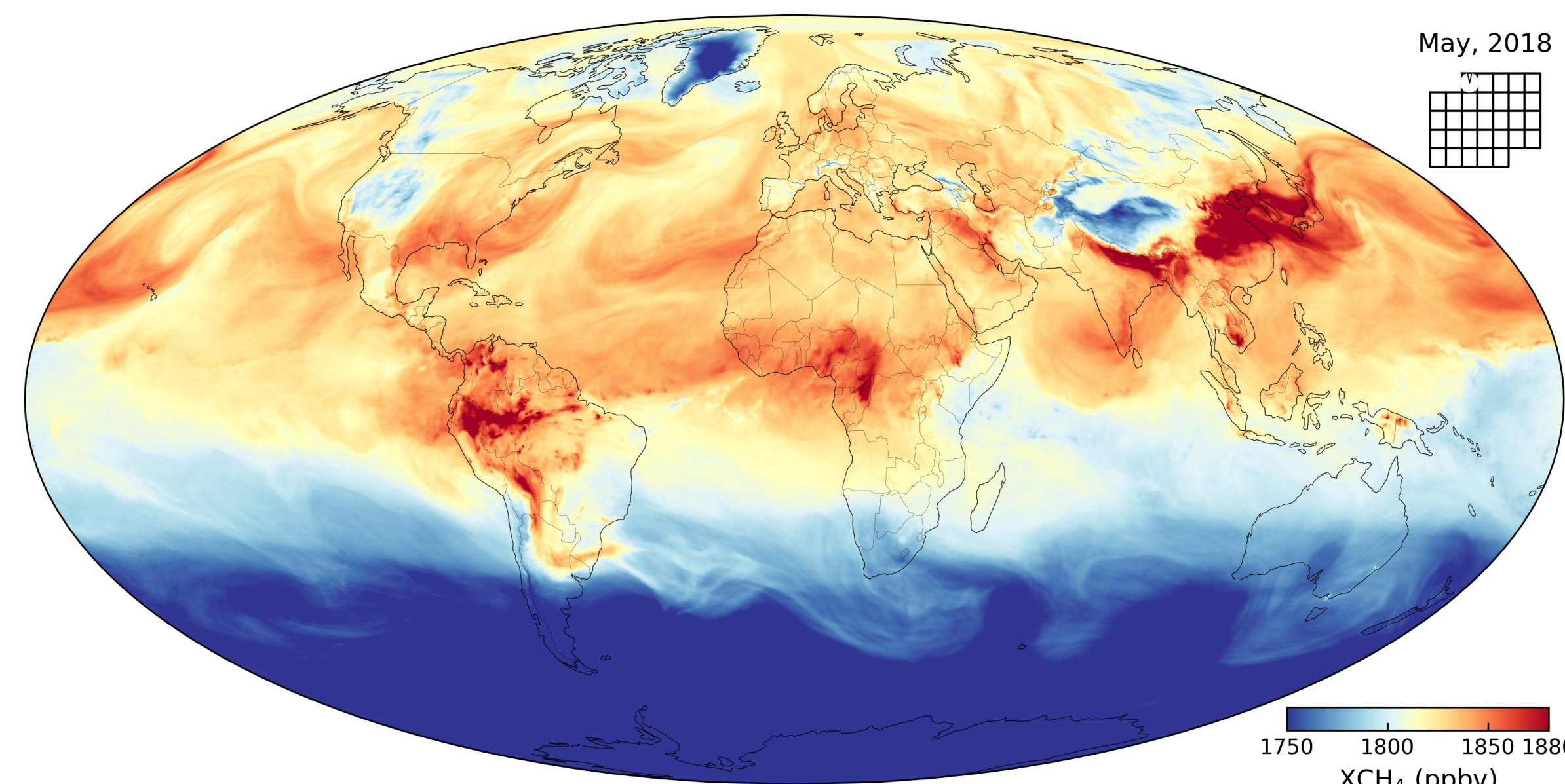Global fine-resolution capability but computationally demanding

Stretched-grid GCHP simulation
- Computational cost of a coarse simulation
- Near-field finer resolution
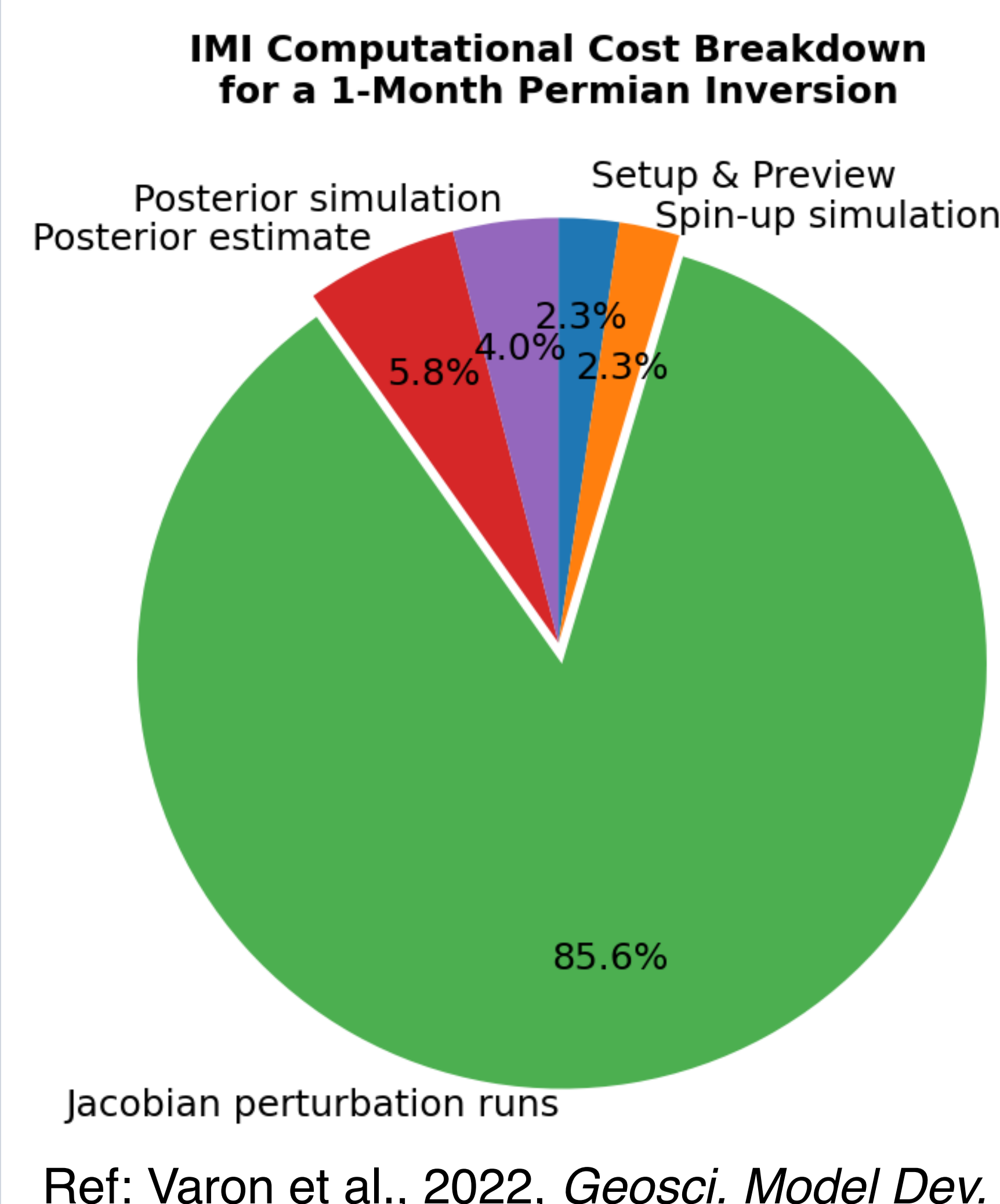- Two-way nesting
- Global mass conservation & OH optimization

Stretched GCHP

Spatial Heterogeneity of Methane Distribution

May, 2018

1750 1800 1850 1880
XCH$_4$ (ppbv)

Constructing Jacobian Sensitivity Dominates Computational Cost

IMI Computational Cost Breakdown for a 1-Month Permian Inversion

Posterior simulation
Posterior estimate

Setup & Preview
Spin-up simulation

2.3%
4.0%
5.8%
2.3%

85.6%

Jacobian perturbation runs

Ref: Varon et al., 2022, *Geosci. Model Dev.*

Jacobian sensitivity matrix (J): $[j_1, \cdots j_i, \cdots j_n]$
Concentration difference upon emission perturbation

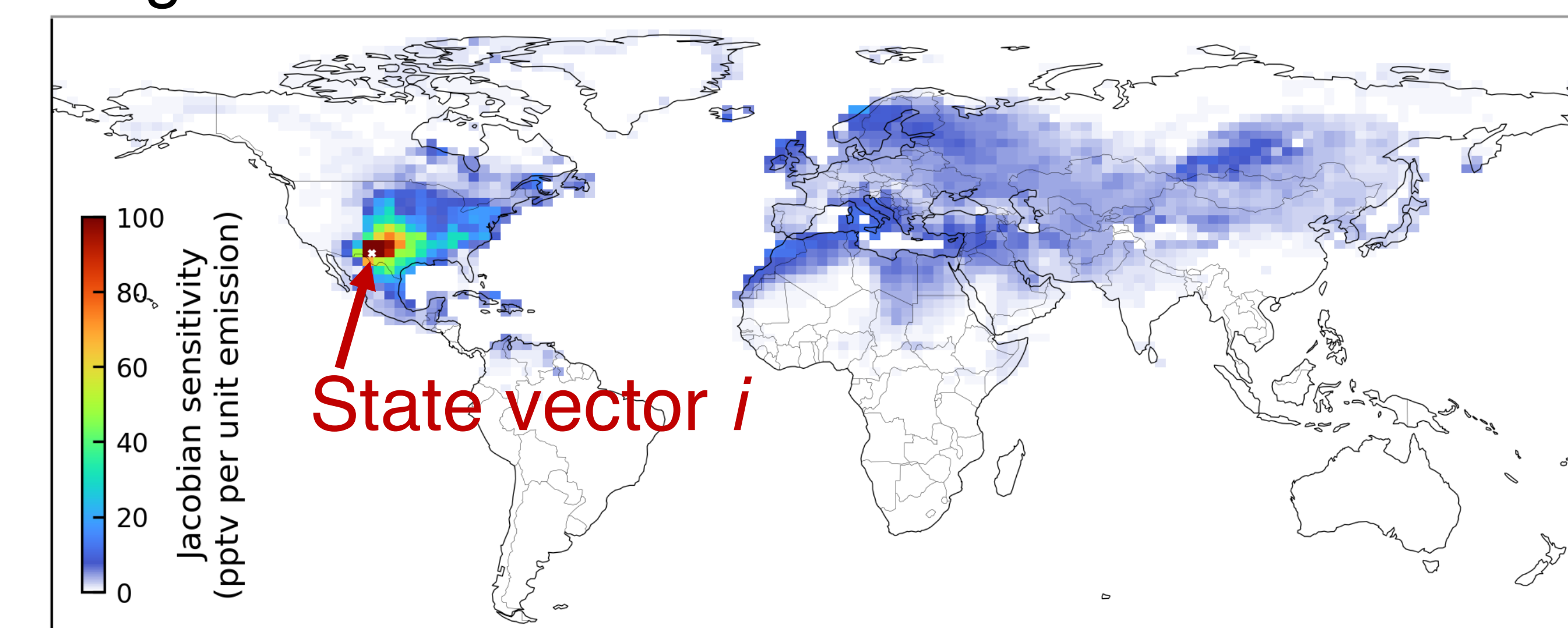Jacobian column for state vector i

n: # of state vector elements

$$j_i = \frac{dy}{dx_i}$$

Concentration difference for all domain pixels (global/regional)

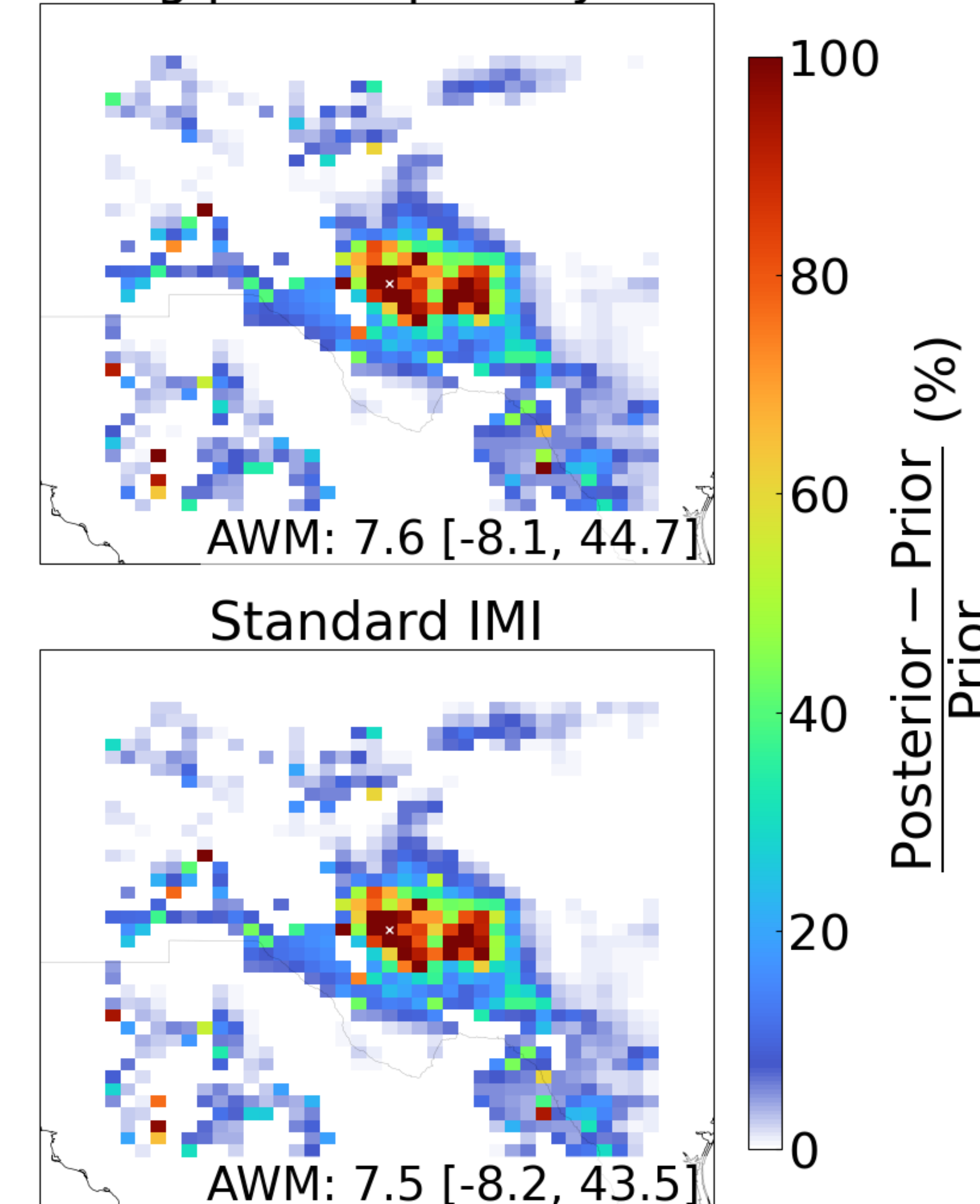Emission perturbation for single state vector i (one pixel)

Single Jacobian Column from GEOS-Chem Model

100
80
60
40
20
0
Jacobian sensitivity (pptv per unit emission)

State vector i

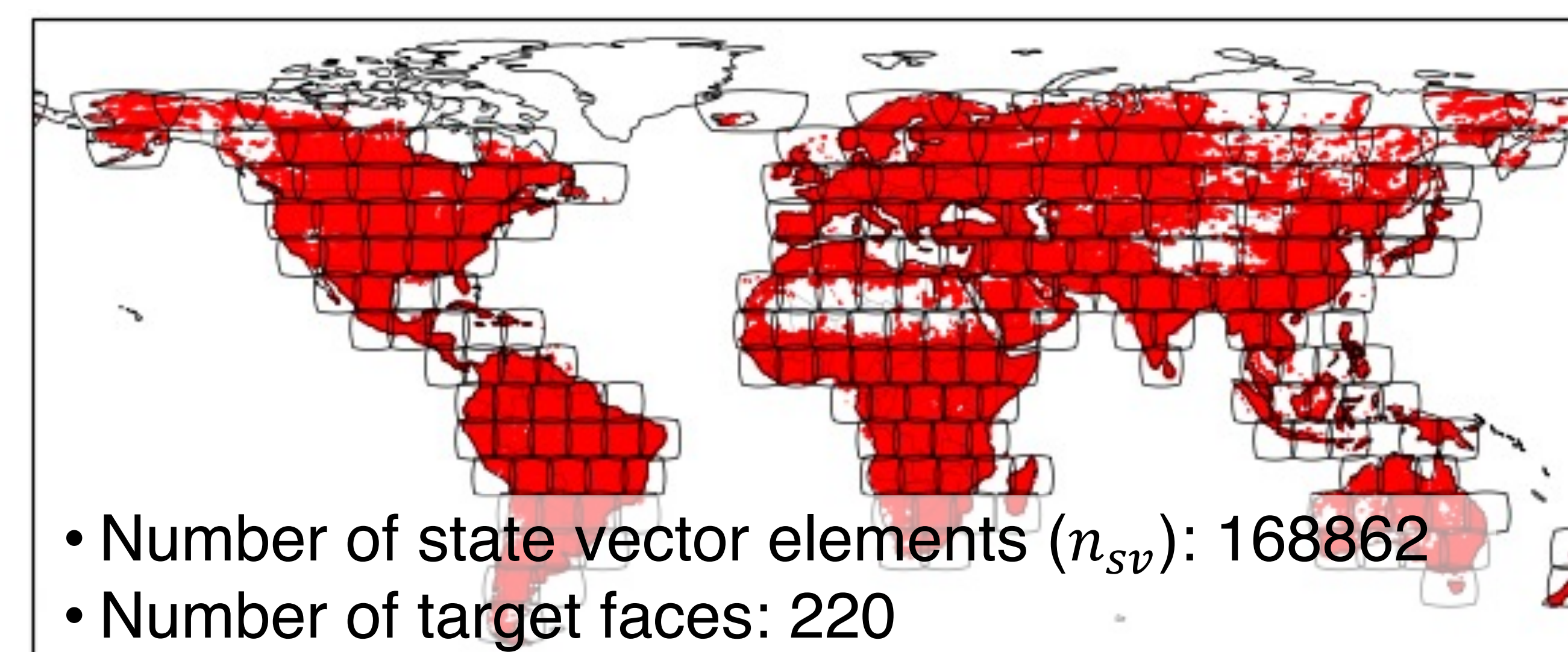## Application of Archived Jacobians for Low-Cost 25-km Inversions

- Constructing global ~25-km Jacobians with x100 less computational cost
  => New capability of global 25-km inversion

- Archiving the 25-km Jacobians at native C36S10 with x100 reduced storage
  => Low-cost regional inversions

State Vector Construction with Ensemble Target Faces

- Number of state vector elements (n_{sv}): 168862
- Number of target faces: 220

IMI using precomputed Jacobian

AWM: 7.6 [-8.1, 44.7]

Standard IMI

AWM: 7.5 [-8.2, 43.5]

100
80
60
40
20
0
$\frac{\text{Posterior} - \text{Prior}}{\text{Prior}}$ (%)

Inset values: area-weighted mean (AWM) with [5th, 95th]