Satellite-based Global Estimate of Ground-level Fine Particulate Matter Concentrations

Aaron van Donkelaar[1], Randall Martin[1,2], Lok Lamsal[1], Chulkyu Lee[1] and Xiong Liu[3]

Atmospheric Composition Constellation
June 2009

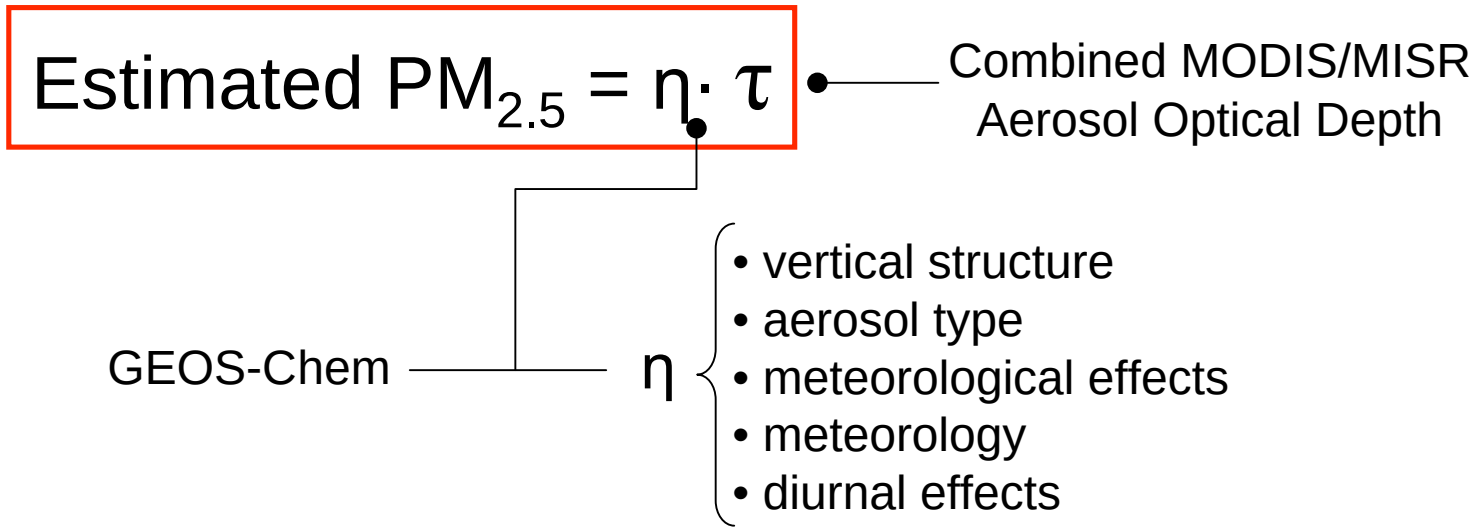
[1]Dalhousie University [2]Harvard-Smithsonian [3]NASA Goddard

Approach

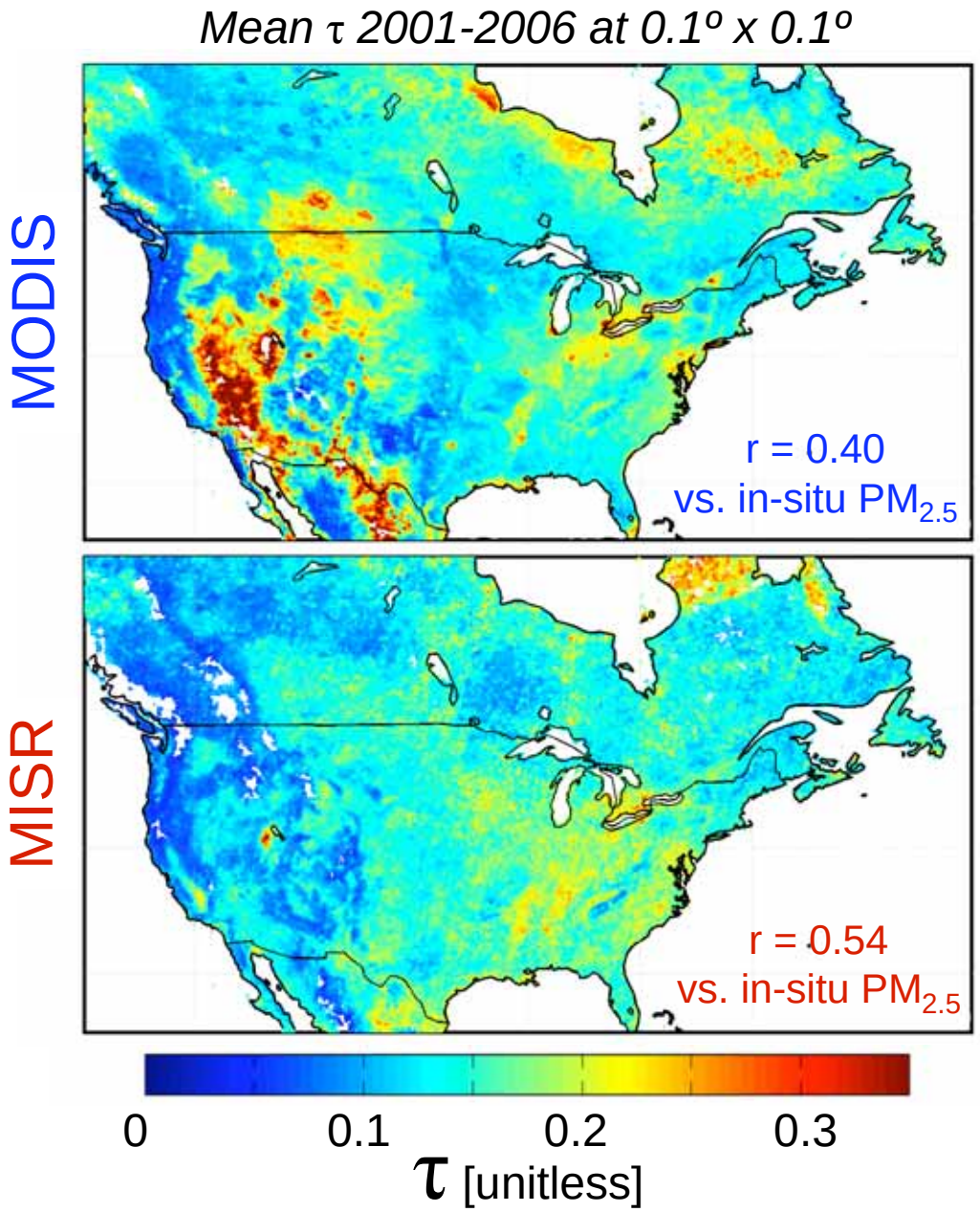
We relate satellite-based measurements of *aerosol optical depth* to $PM_{2.5}$ using a global chemical transport model

---

Following *Liu et al.*, 2004:



MODIS and MISR τ



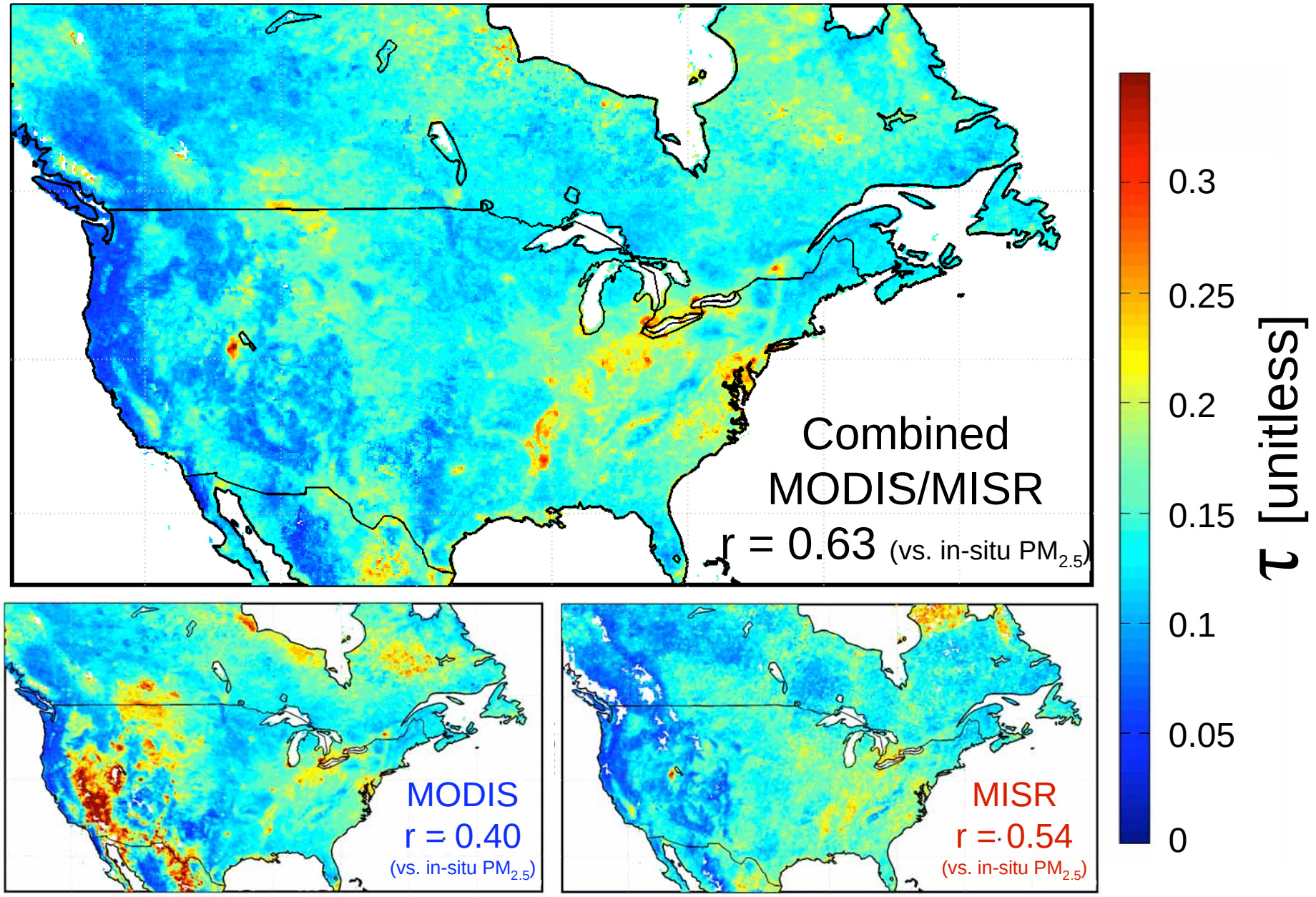
MODIS τ

- 1-2 days for global coverage
- Requires assumptions about surface reflectivity

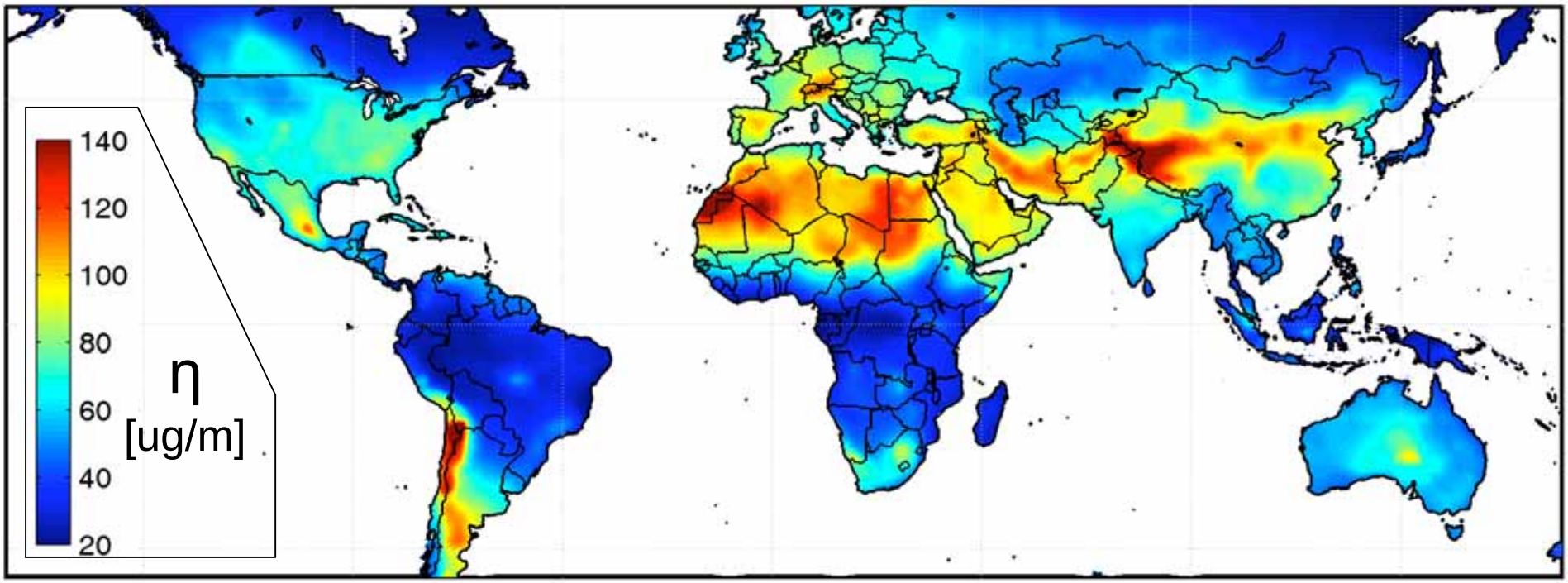
MISR τ

- 6-9 days for global coverage
- Simultaneous surface reflectance and aerosol retrieval

Combining MODIS and MISR improves agreement



Global CTMs can directly relate $PM_{2.5}$ to τ

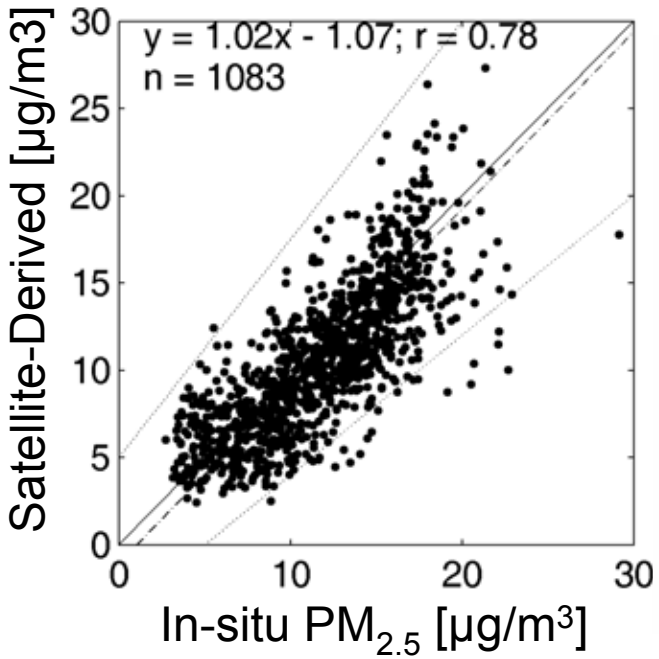


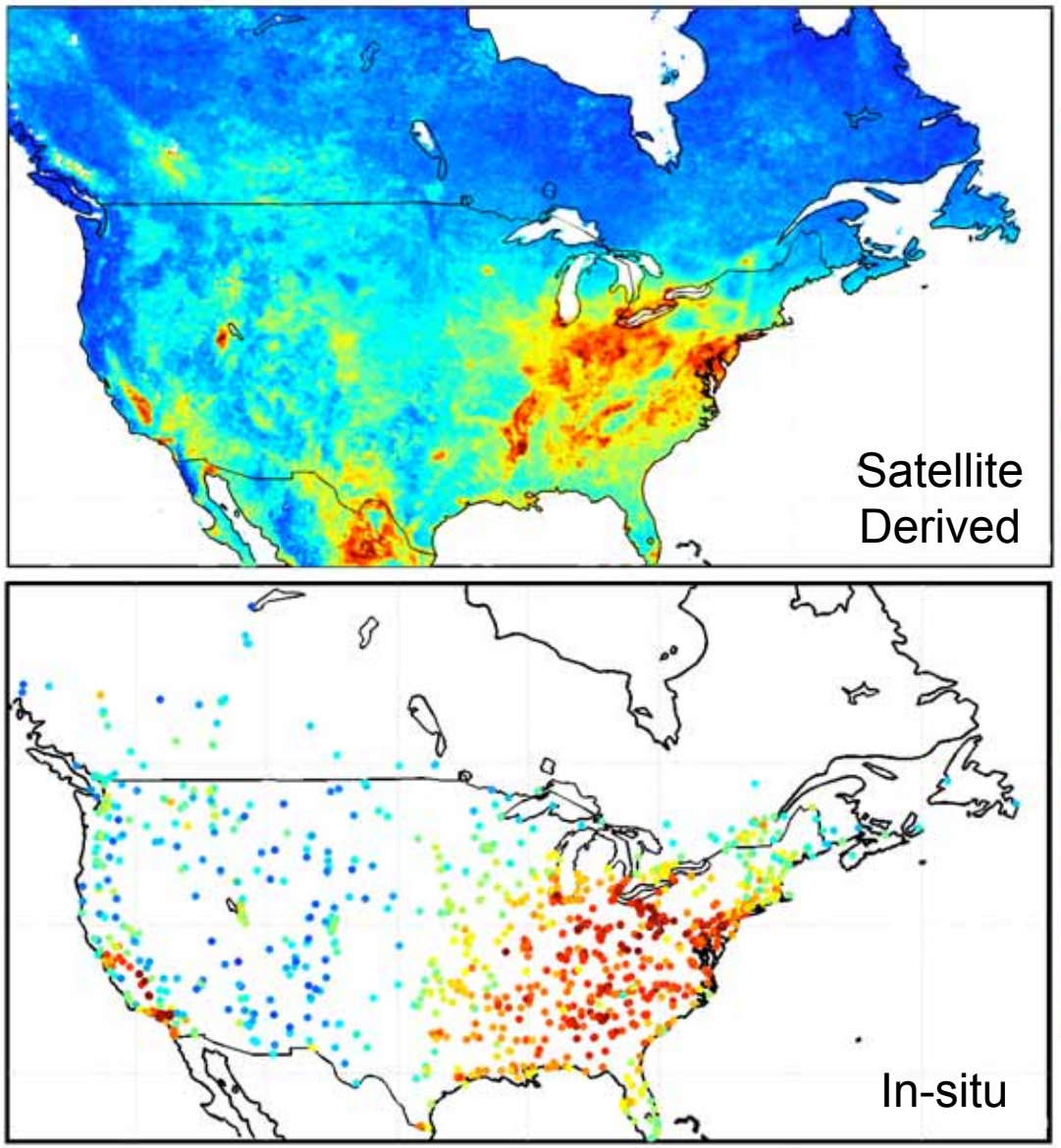
GEOS-Chem

- Detailed aerosol-oxidant model
- 2º x 2.5º
- 54 tracers, 100's reactions
- Assimilated meteorology
- Year-specific emissions
- Dust, sea salt, sulfate-ammonium-nitrate system, organic carbon, black carbon, SOA

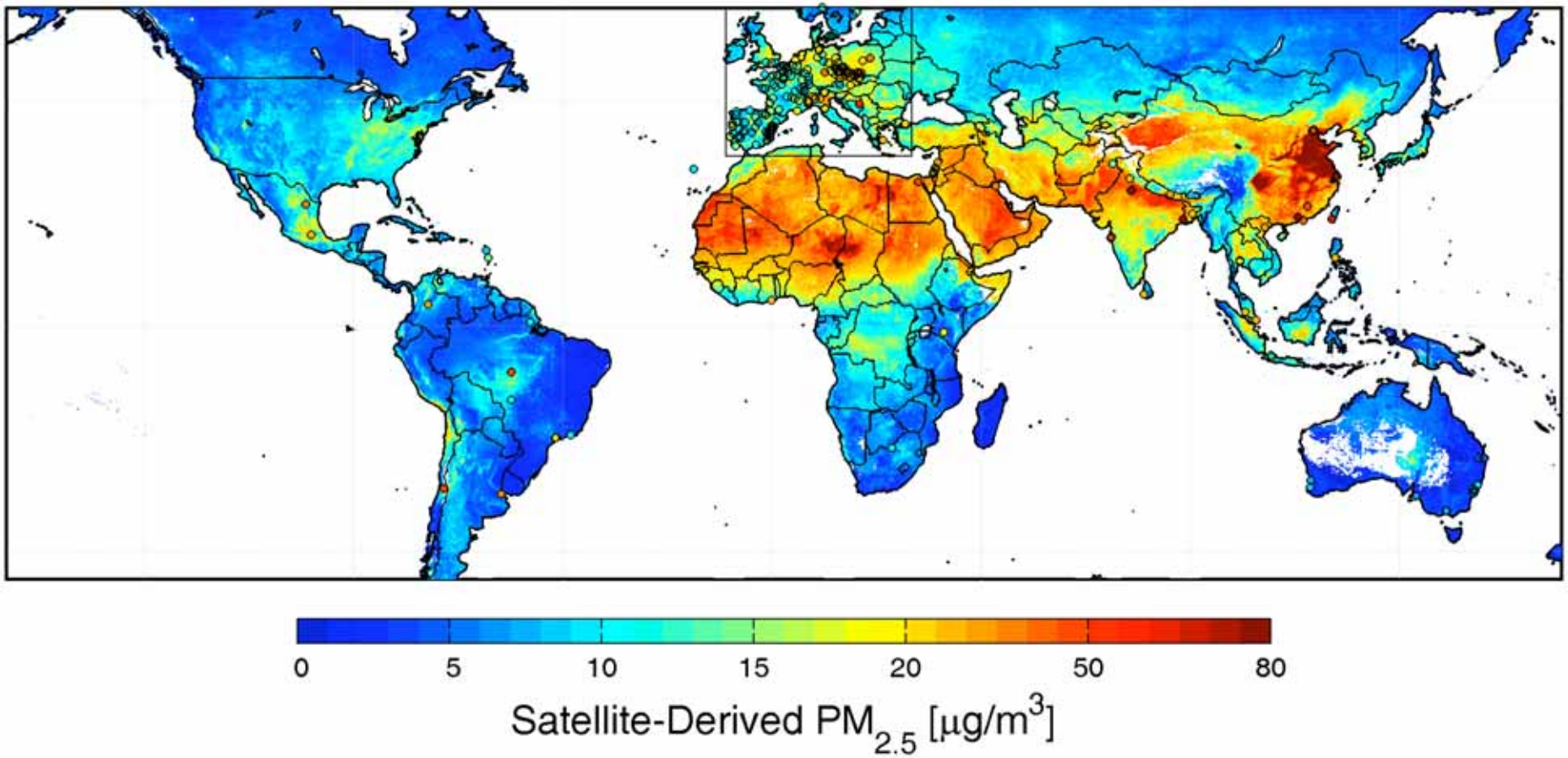
Significant agreement with coincident ground measurements over NA

	r
MODIS τ	0.40
MISR τ	0.54
Combined τ	0.63
Combined $PM_{2.5}$	0.78





Method is globally applicable



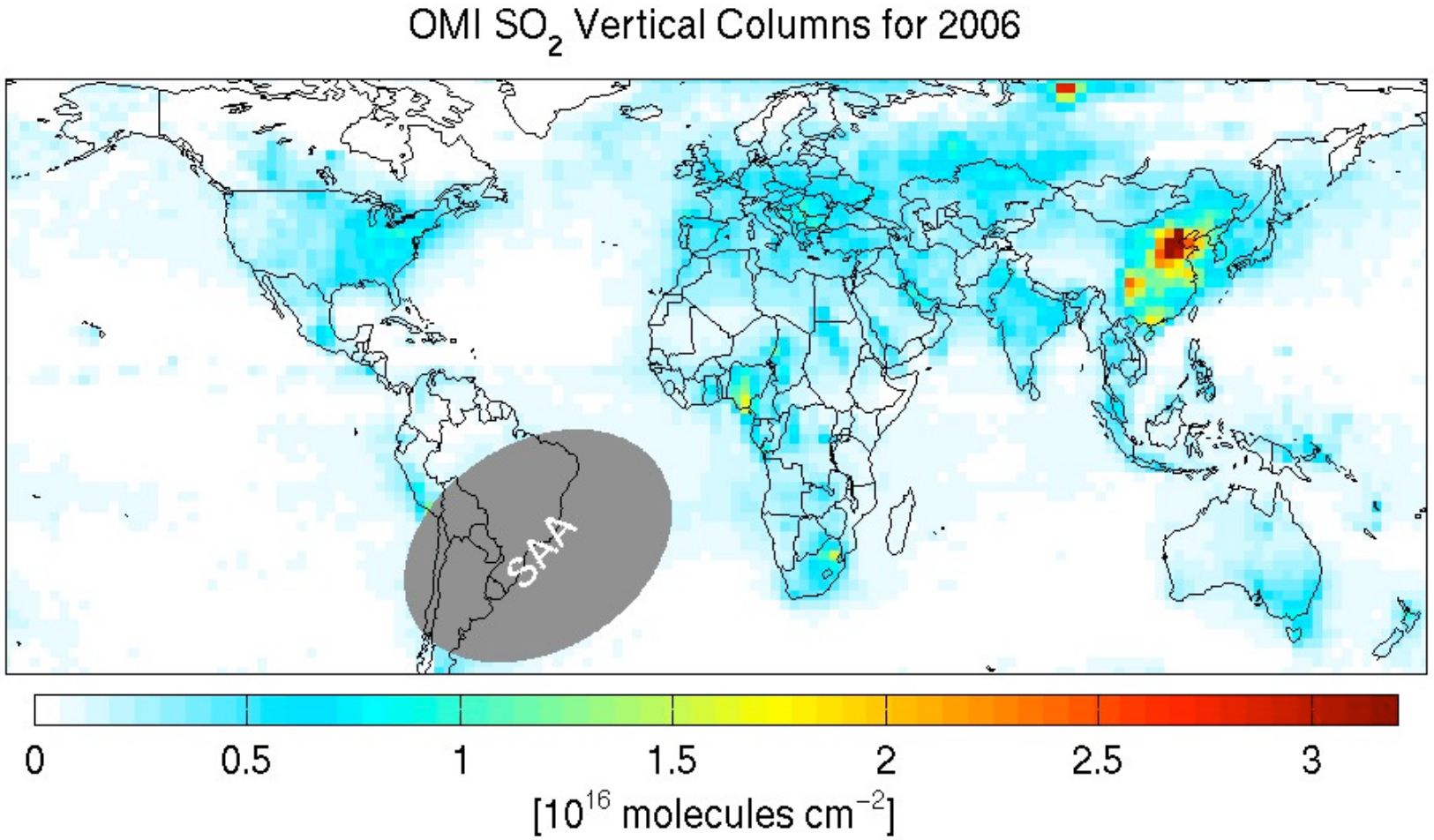
- Annual mean measurements
  - Outside Canada/US
  - 297 sites (107 non-EU)

- r = 0.75 (0.76)
- slope = 0.89 (0.96)
- bias = 0.52 (-2.76) µg/m^3

Insight into Aerosol Sources/Type with Precursor Observations

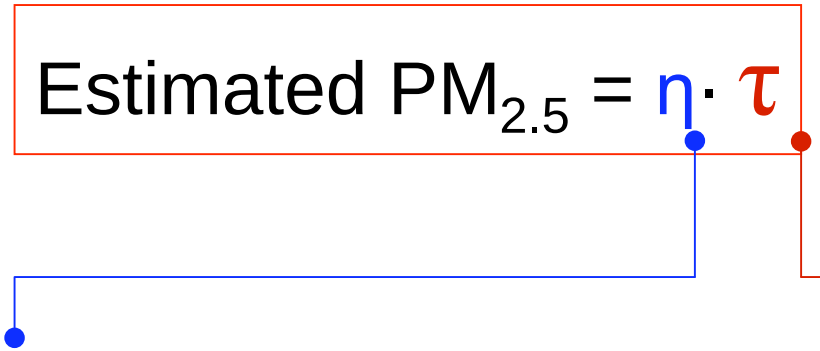
OMI SO_2 Retrieved with Local Air Mass Factor
Improves Agreement of OMI SO_2 versus Aircraft Observations (INTEX A & B)

Orig: slope = 1.6, r=0.71
New: slope = 0.95, r=0.92



Lee et al., JGR, submitted

Coincident $PM_{2.5}$ error has two sources



Model

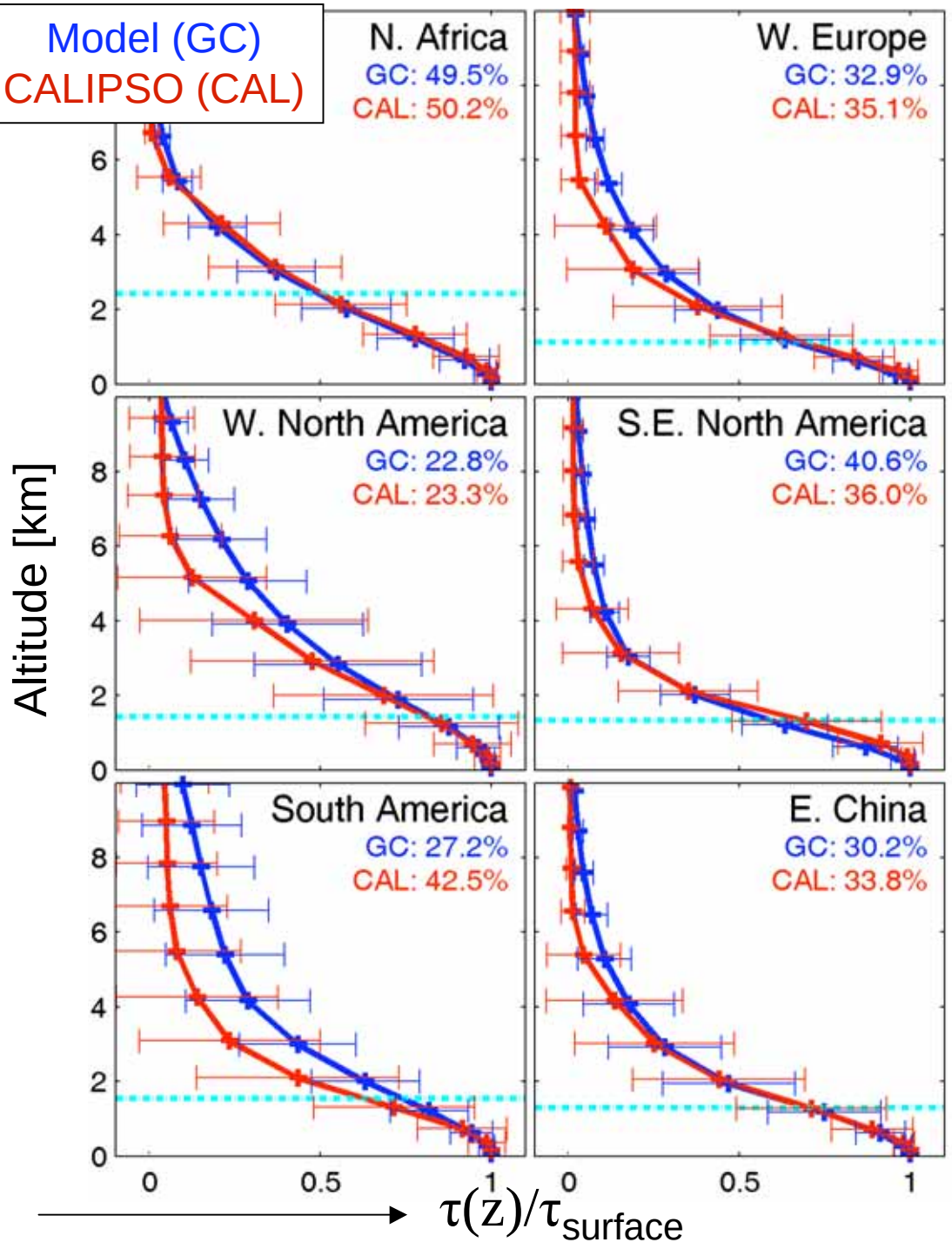
- Affected by aerosol optical properties, concentrations, vertical profile, relative humidity
- Most sensitive to vertical profile [*van Donkelaar et al., 2006*]

Satellite

- Error limited to 0.1 + 20% by AERONET filter
- Implication for satellite $PM_{2.5}$ determined by η

CALIPSO allows profile evaluation

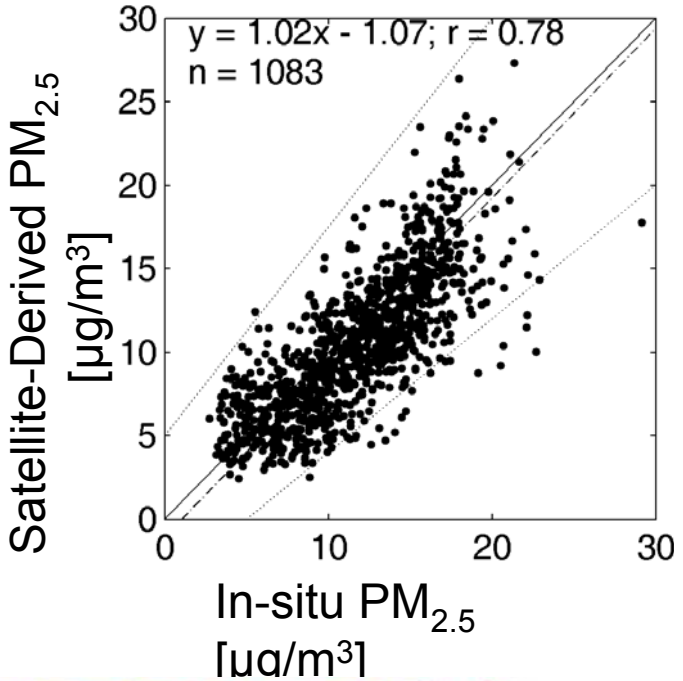
- Coincidently sample model and CALIPSO extinction profiles
  - Jun-Dec 2006
- Compare % within boundary layer

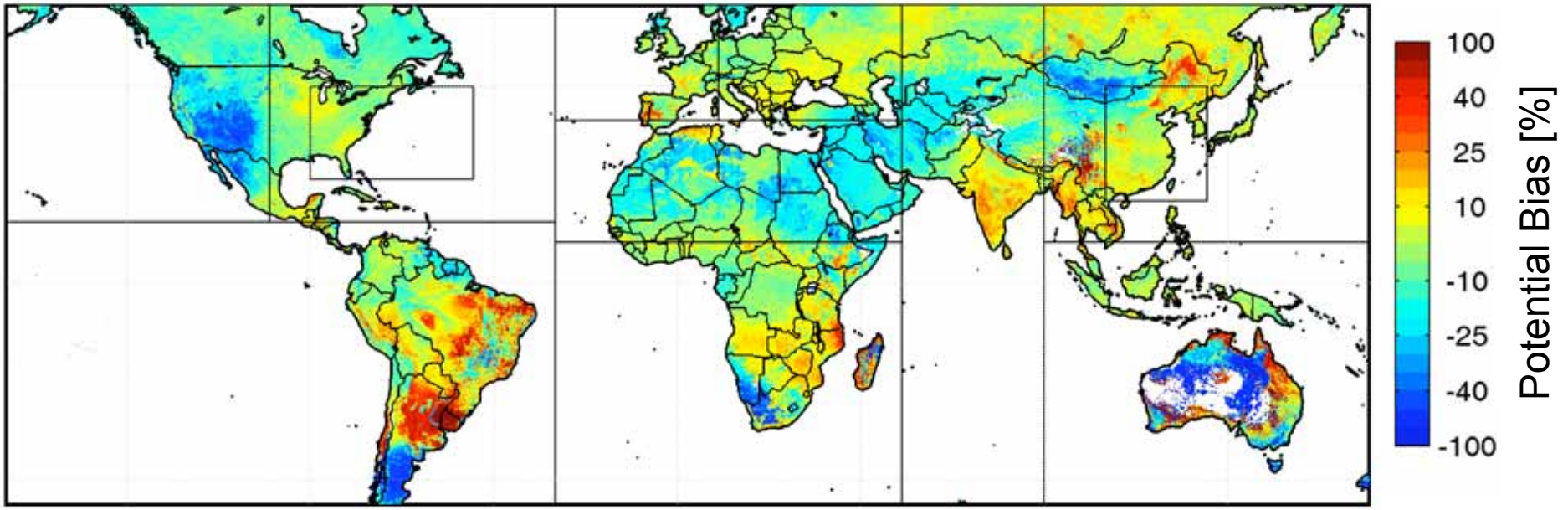


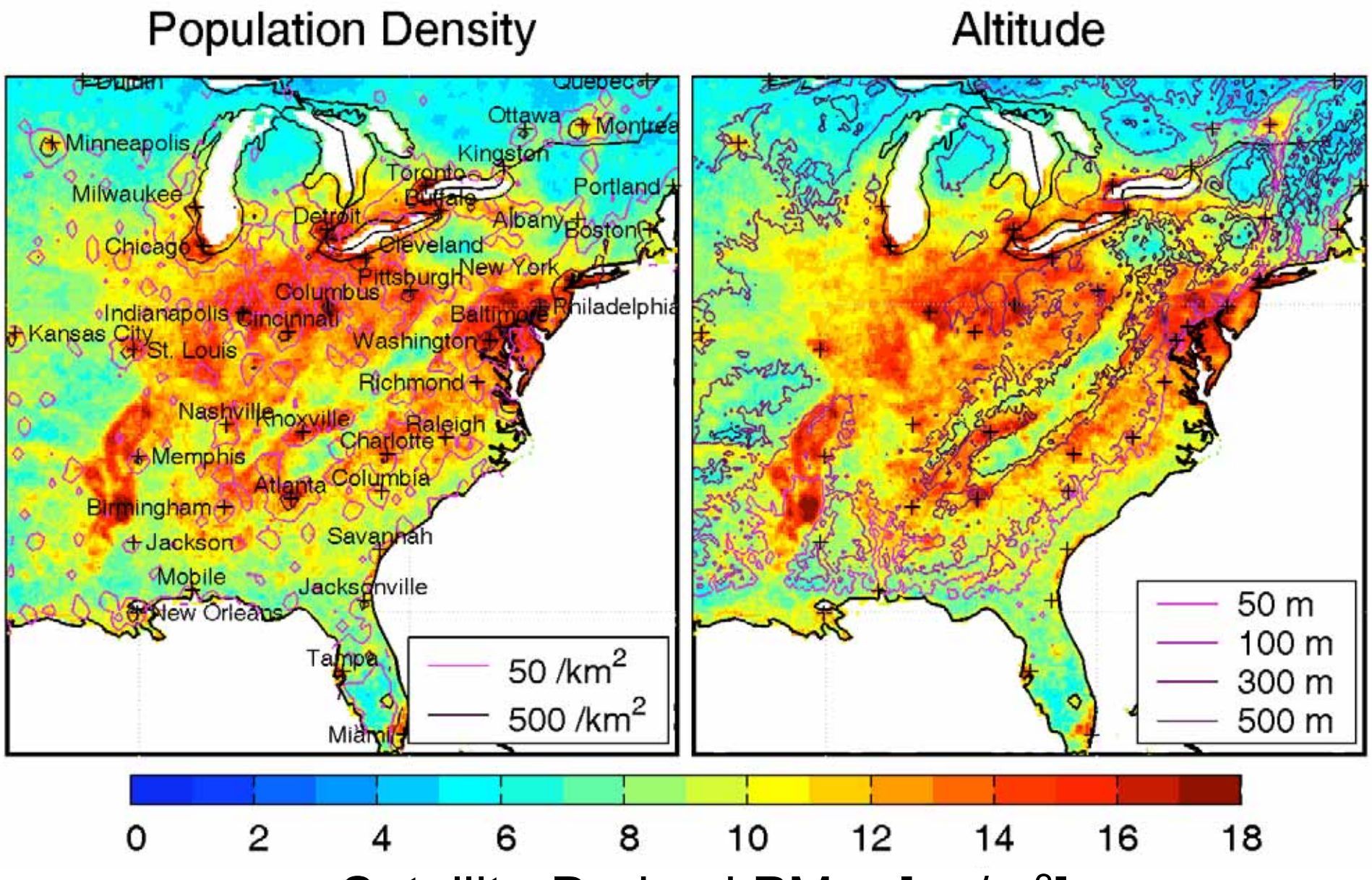
Optical Depth from TOA / Optical Depth at surface

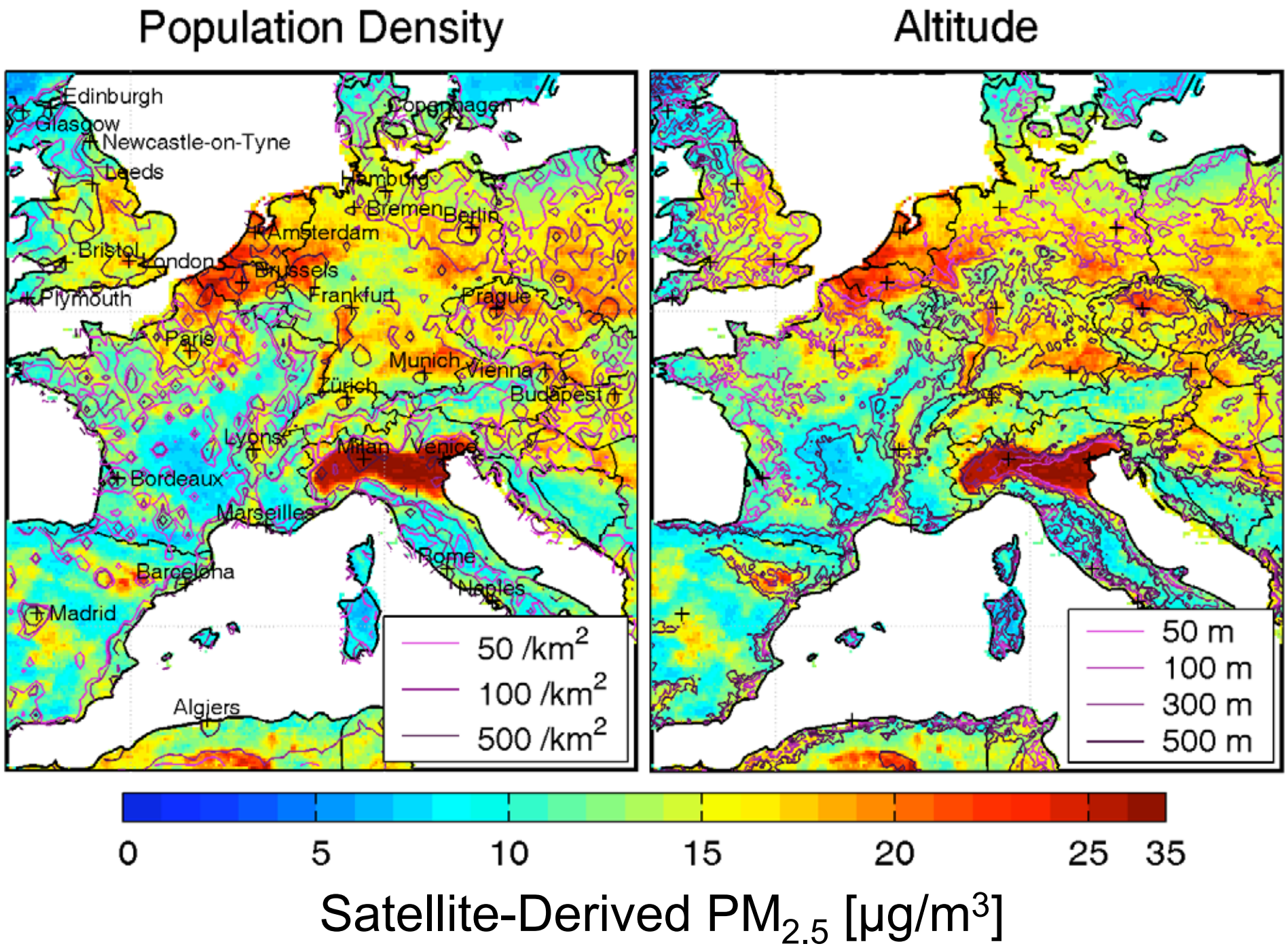
Potential for profile and τ bias define error

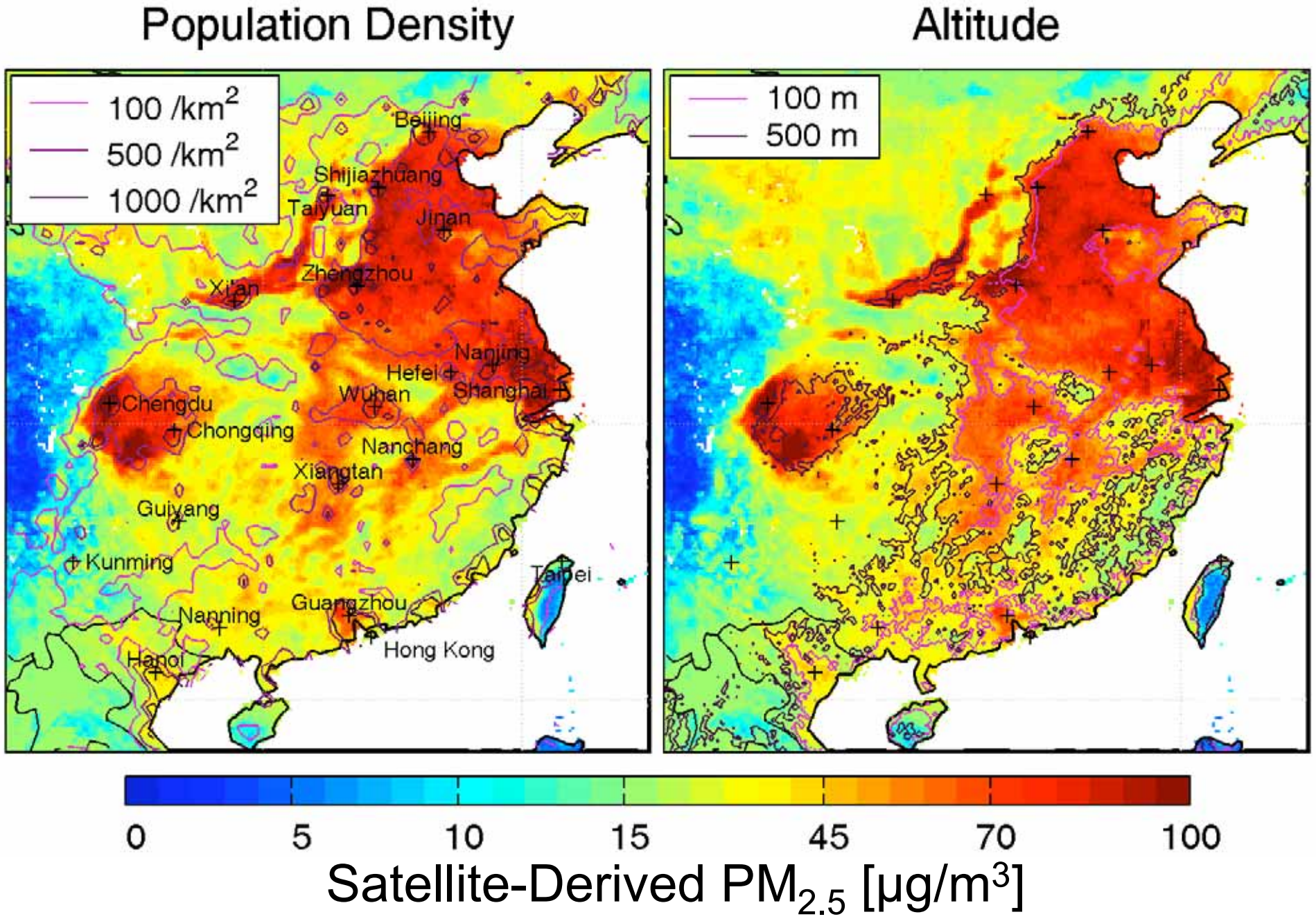
- Vary satellite-derived $PM_{2.5}$ by profile and τ biases
  - 99.8% within ±(5 μg/m^3 + 25%) of original value
- Contains 98.0% of NA data





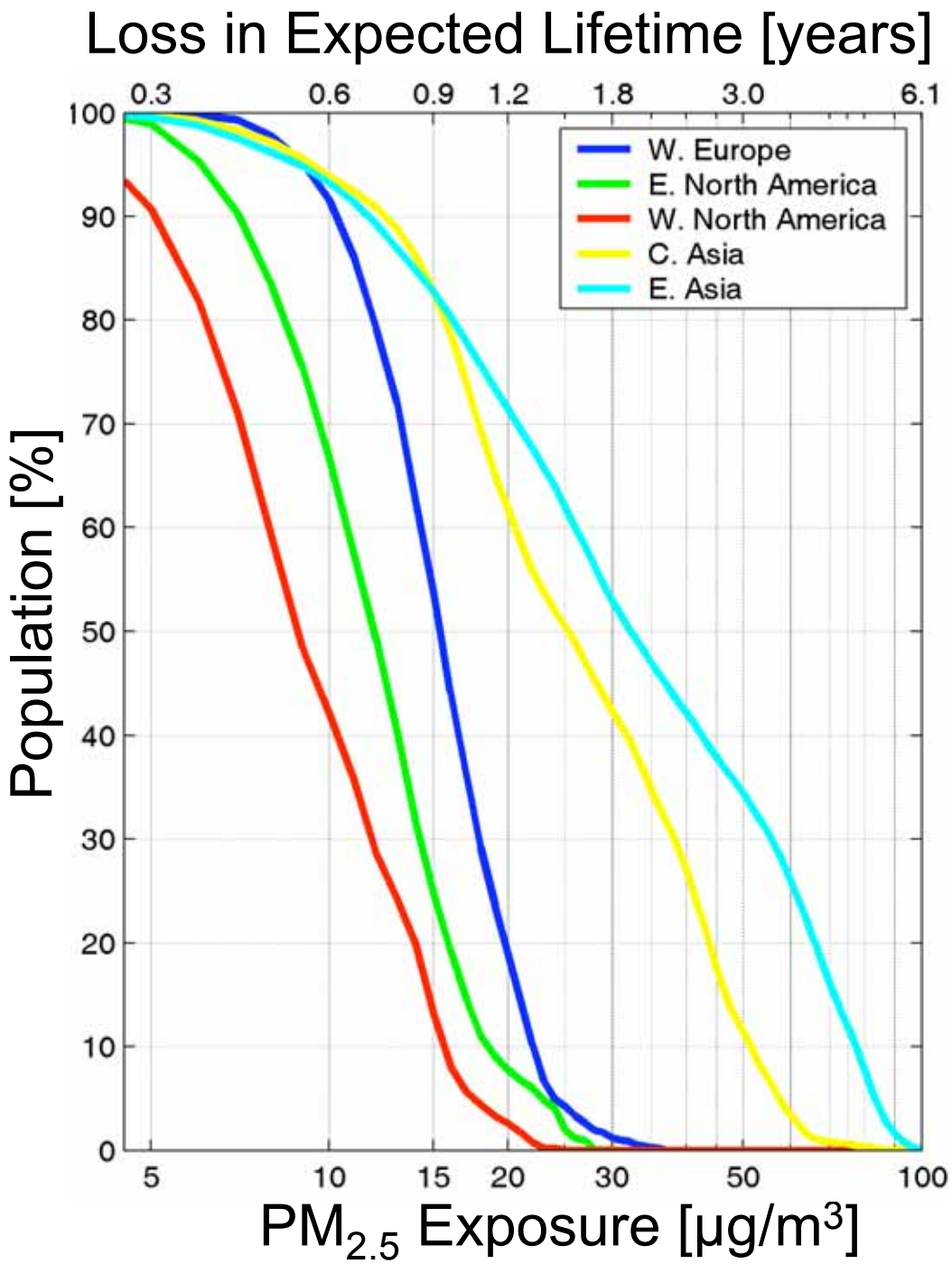

Population Density
Altitude
Minneapolis
Milwaukee
Chicago
Detroit
Toronto
Buffalo
Ottawa
Montreal
Quebec
Kingston
Portland
Albany
Boston
Cleveland
Pittsburgh
New York
Columbus
Indianapolis
Cincinnati
Baltimore
Philadelphia
Kansas City
St. Louis
Washington
Richmond
Nashville
Knoxville
Raleigh
Charlotte
Memphis
Atlanta
Columbia
Birmingham
Jackson
Savannah
Mobile
Jacksonville
New Orleans
Tampa
Miami
50 /km2
500 /km2
50 m
100 m
300 m
500 m
0
2
4
6
8
10
12
14
16
18
Satellite-Derived PM2.5 [µg/m3]


Population Density
Altitude
Edinburgh
Glasgow
Newcastle-on-Tyne
Leeds
Copenhagen
Hamburg
Bremen
Berlin
Amsterdam
Bristol
London
Brussels
Frankfurt
Prague
Plymouth
Paris
Munich
Vienna
Zürich
Budapest
Lyons
Milan
Venice
Bordeaux
Marseilles
Rome
Naples
Barcelona
Madrid
Algiers
50 /km2
100 /km2
500 /km2
50 m
100 m
300 m
500 m
0
5
10
15
20
25
35
Satellite-Derived PM2.5 [µg/m3]


Population Density
Altitude
100 /km2
500 /km2
1000 /km2
100 m
500 m
Beijing
Shijiazhuang
Taiyuan
Jinan
Zhengzhou
Xi'an
Nanjing
Hefei
Shanghai
Wuhan
Chengdu
Chongqing
Nanchang
Xiangtan
Guiyang
Kunming
Taipei
Guangzhou
Nanning
Hong Kong
Hanoi
0
5
10
15
45
70
100
Satellite-Derived PM2.5 [μg/m3]

High global impact of $PM_{2.5}$

- Using 0.61±0.20 years lost per 10 μg/m^3 [*Pope et al.*, 2009]
- Satellite-$PM_{2.5}$ + population map + lost-life relationship →
  - Global estimate of decreased life expectancy due to $PM_{2.5}$ exposure
- 10% of eastern North Americans lose ~1 of life expectancy from $PM_{2.5}$
- 40% of eastern Asia exposed to > 40 μg/m^3



Significant Spatial Correlation in Satellite-derived and In-Situ AQHI

(OMI-derived NO_2 and O_3, MODIS/MISR-derived $PM_{2.5}$)

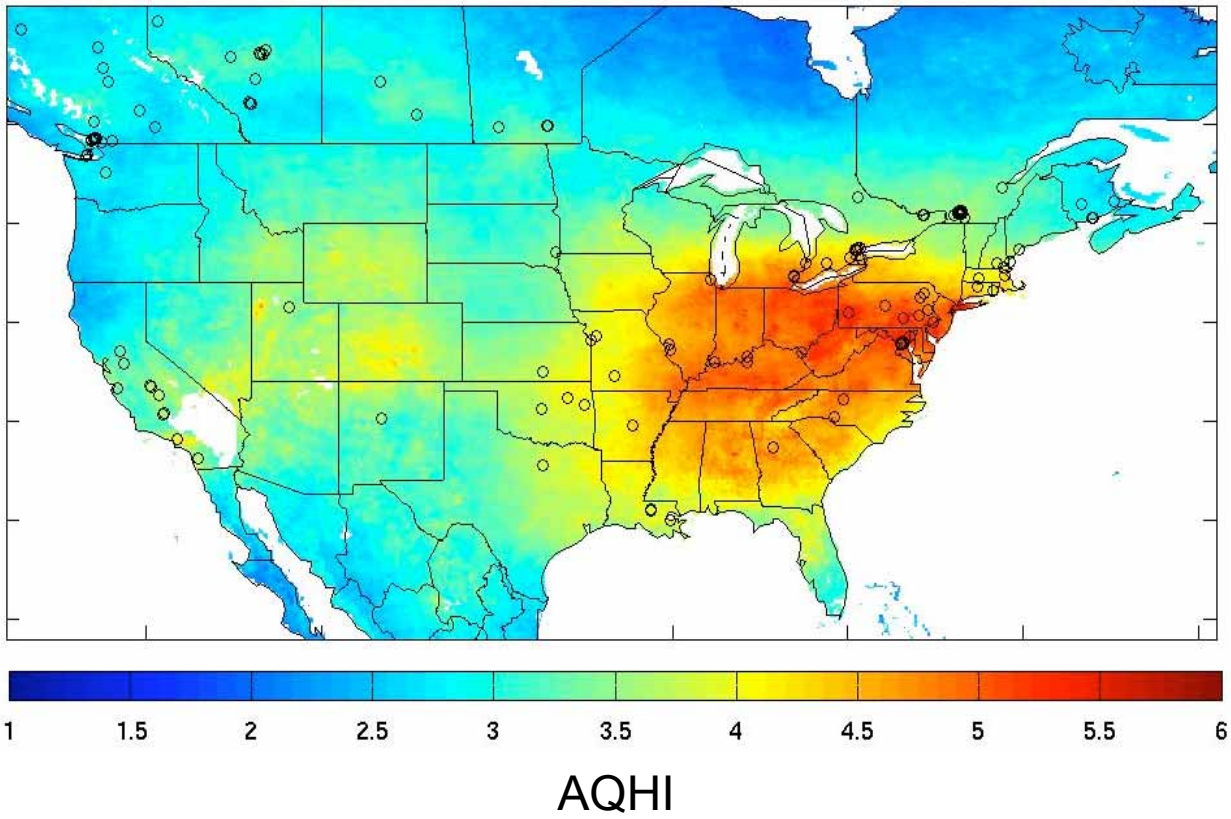
Combined effect from numerous species → Use Canadian AQHI

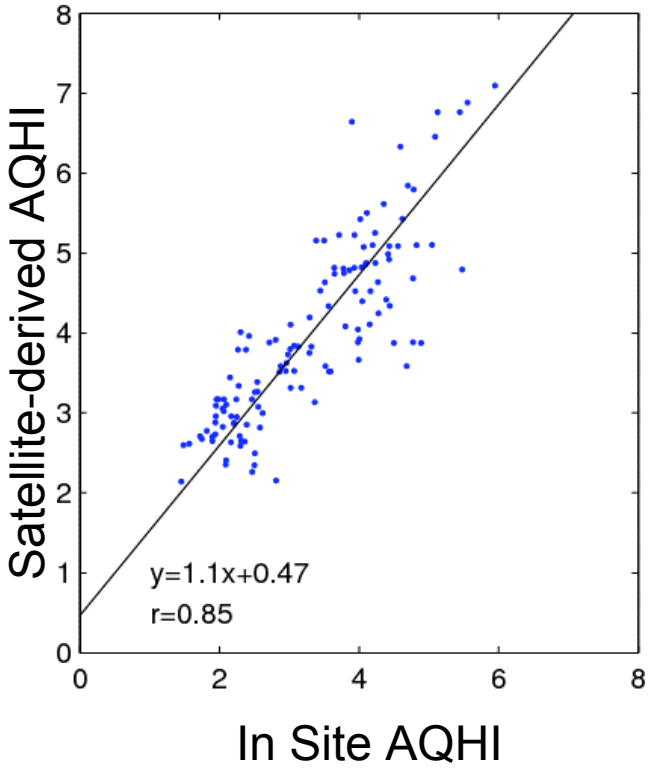
(Stieb et al., JAWMA, 2008)

$$AQHI \approx 0.09 \times NO_2\ (ppbv) + 0.05 \times PM_{2.5}\ (\mu/m^3) + 0.05 \times O_3\ (ppbv)$$

AQHI ≈ Excess Mortality Risk (%)

Mean values over June – August 2005 for North America





Summary

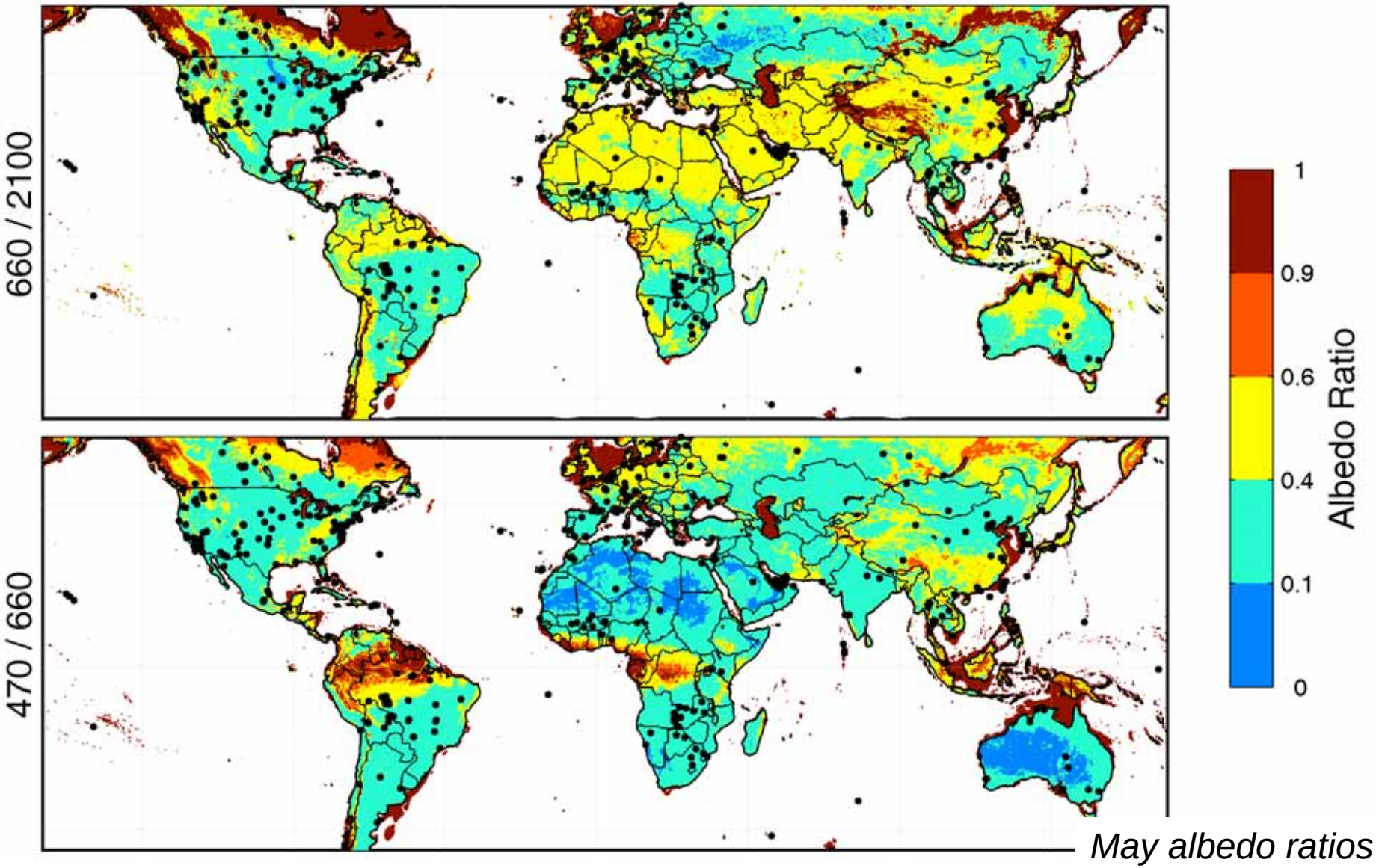
- Satellite-derived $PM_{2.5}$ asset to global air quality monitoring
- Quantifiable Error
  - Coincident: ±(5 μg/m^3 + 25%)
  - Sampling: ±(2 μg/m^3 + 10%)
- Potential for health studies
  - Combined with satellite NO_2 and O_3

Additional Slides

Evaluate Monthly Mean Satellite τ with AERONET by Region

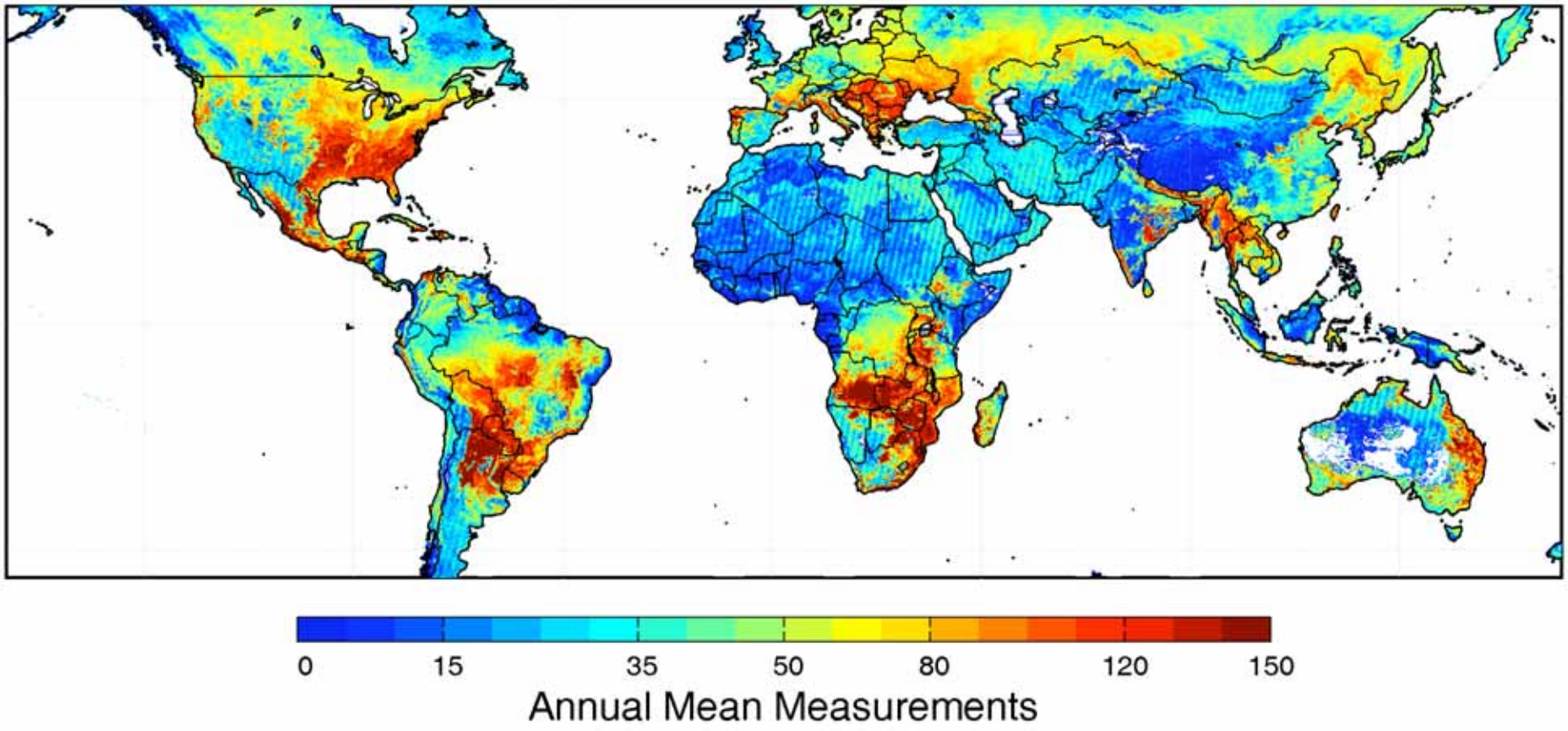
Regions Determined with MODIS Albedo Ratios

Reject Retrievals for Regions with Error > 0.1 or 20%



May albedo ratios

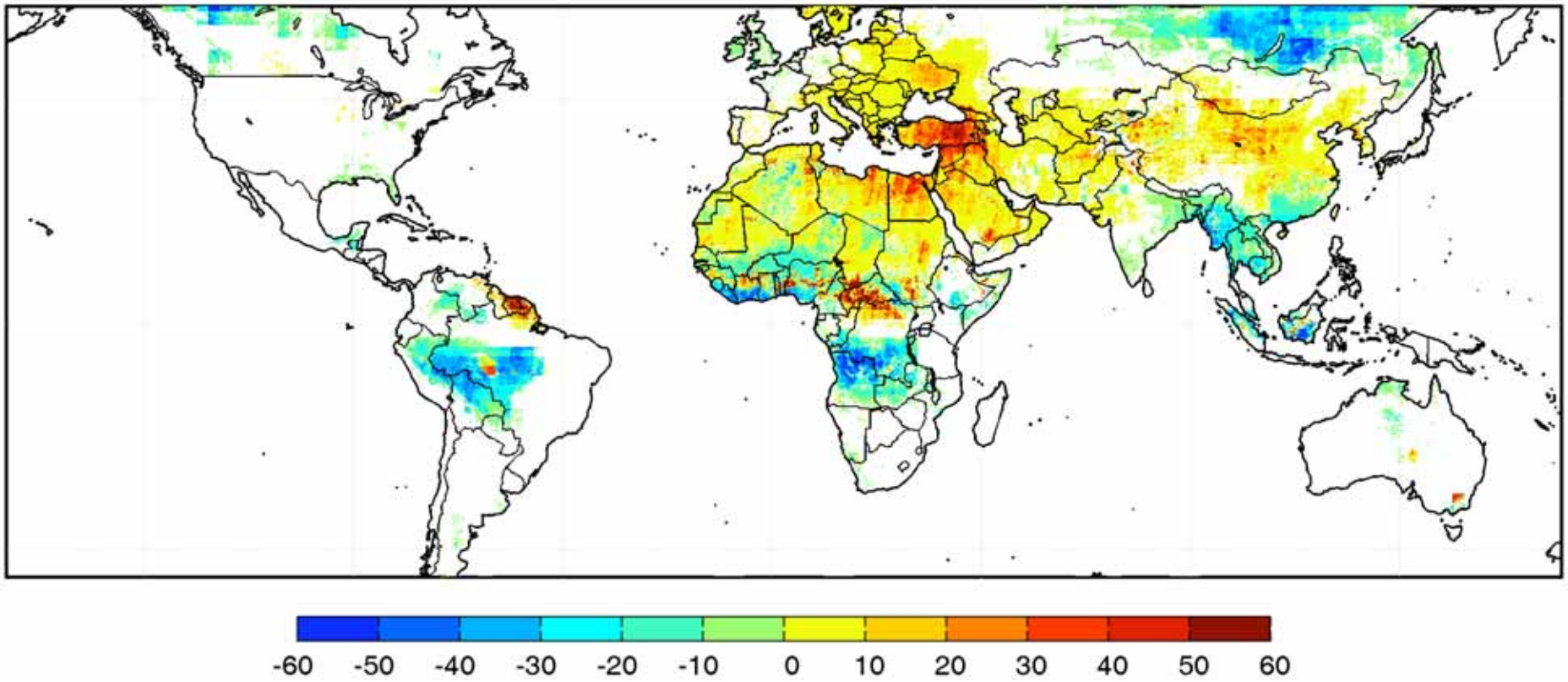
Sampling frequency varies with region



- Potential loss of representativeness relative to annual mean

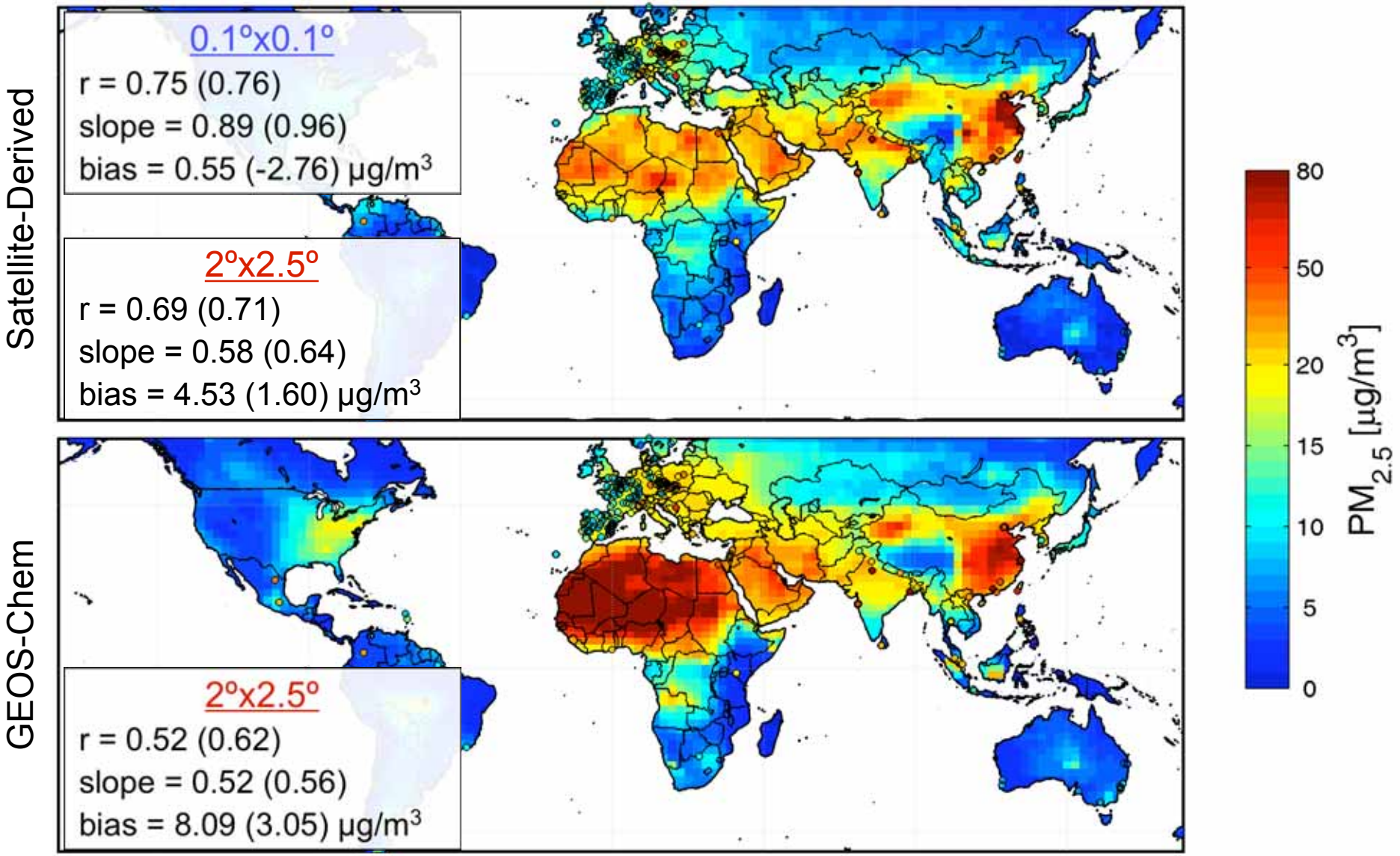
Sampling error is regional

- Compare continuous and coincident model results
- Plot sampling-induced error in excess of ±2 μg/m^3



$$\text{Sampling-Induced Error} = \frac{\text{Annual } PM_{2.5} - \text{Coincident } PM_{2.5} \pm 2\ \mu g/m^3}{\text{Annual } PM_{2.5}}$$

In-situ agrees better with satellite-derived $PM_{2.5}$



- Annual mean measurements
  - 298 sites (108 non-EU)