Substantial cloud brightening from shipping observed in subtropical low clouds

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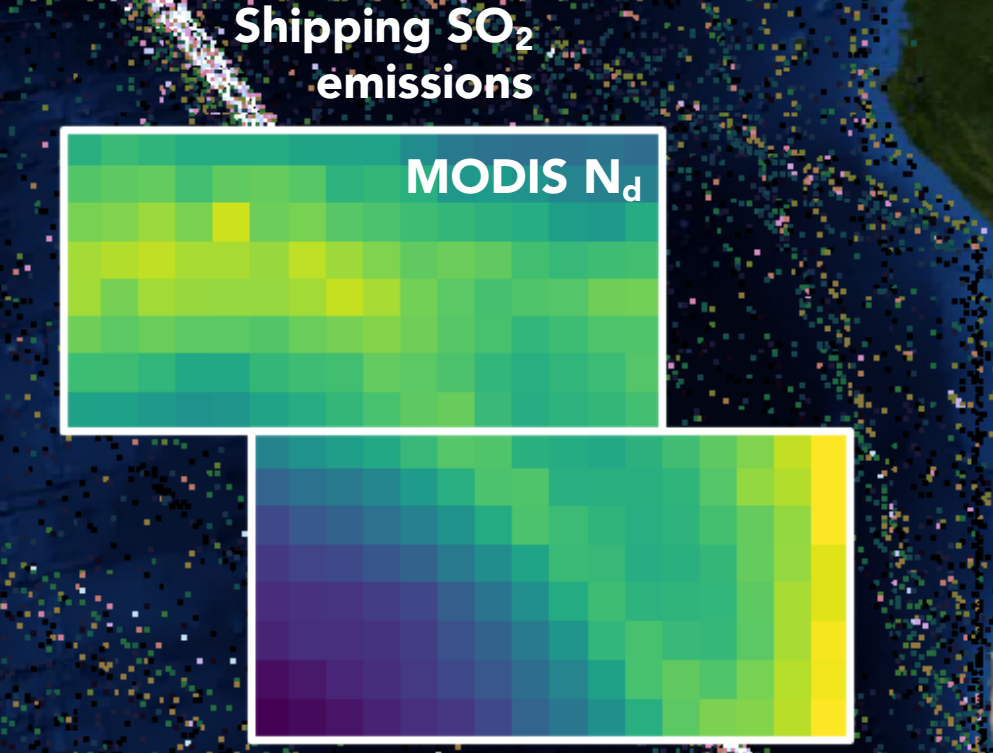
AMS Annual Meeting
January 15th, 2020



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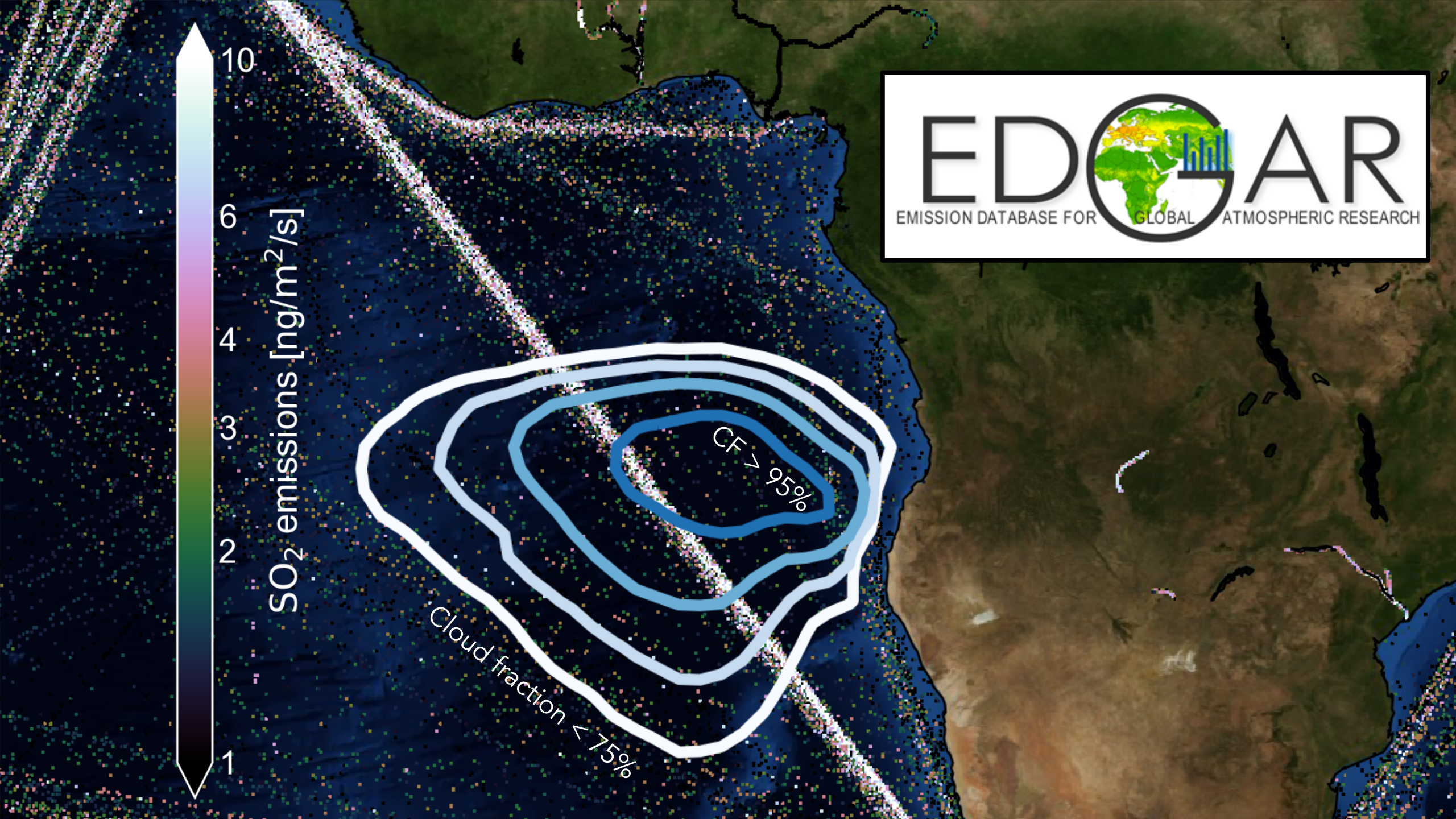

10
6
4
3
2
1
SO_2 emissions [ng/m^2/s]
CF > 95%
Cloud fraction < 75%
EDGAR
EMISSION DATABASE FOR GLOBAL ATMOSPHERIC RESEARCH

Conover (1966), JAS

- "It appears that **cloud enhancement to increase the albedo about 20 per cent over large areas would be artificially possible** under certain limited existing conditions by generating cloud liquid through the introduction of Aitken nuclei."

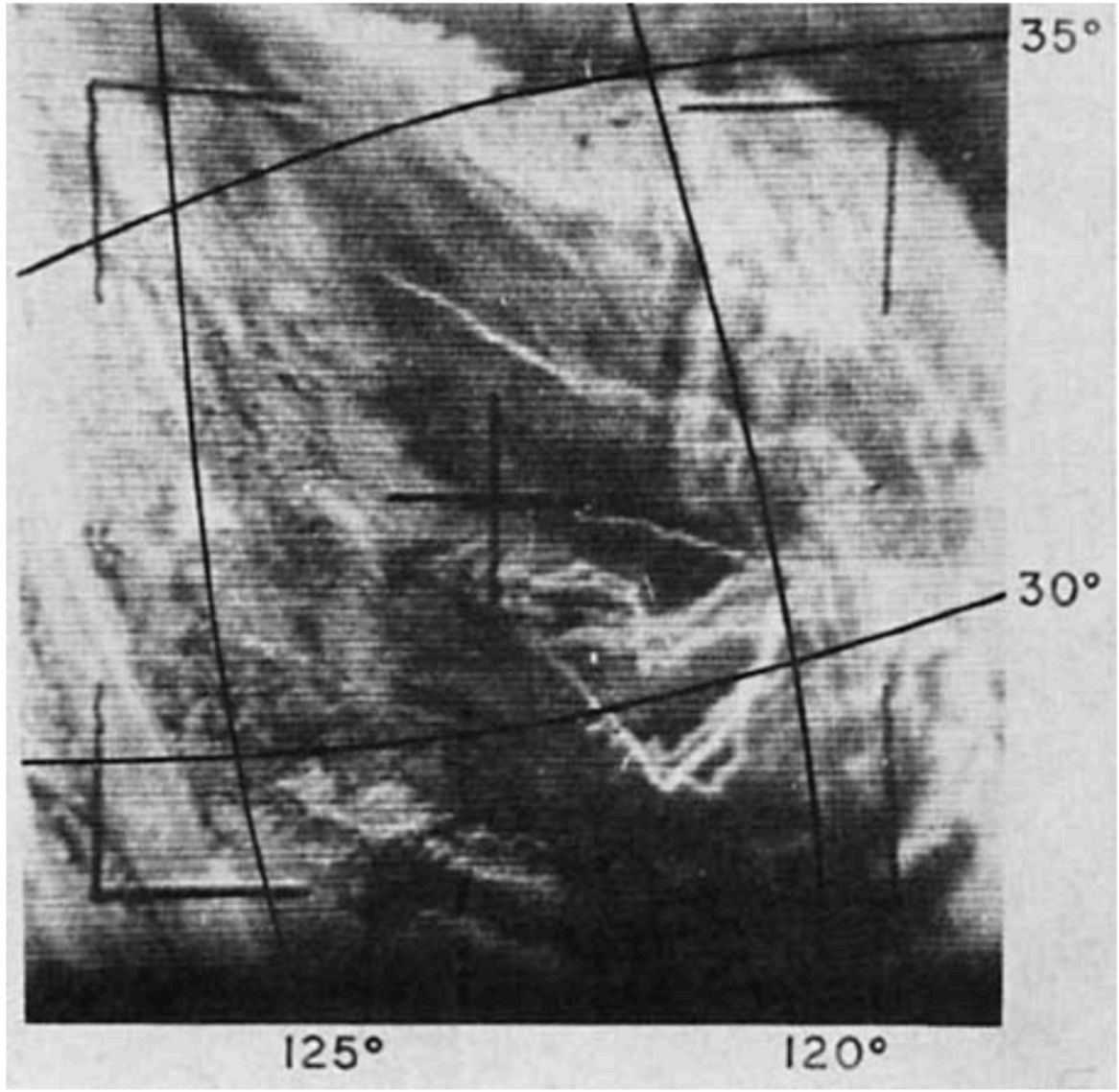
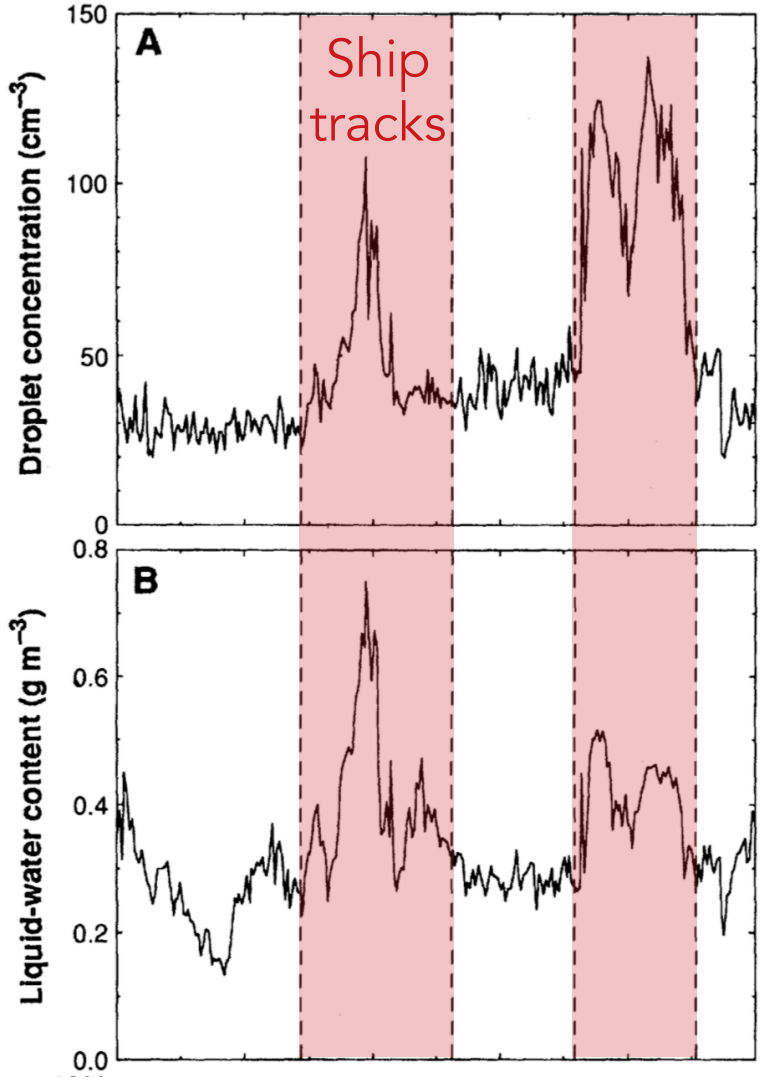
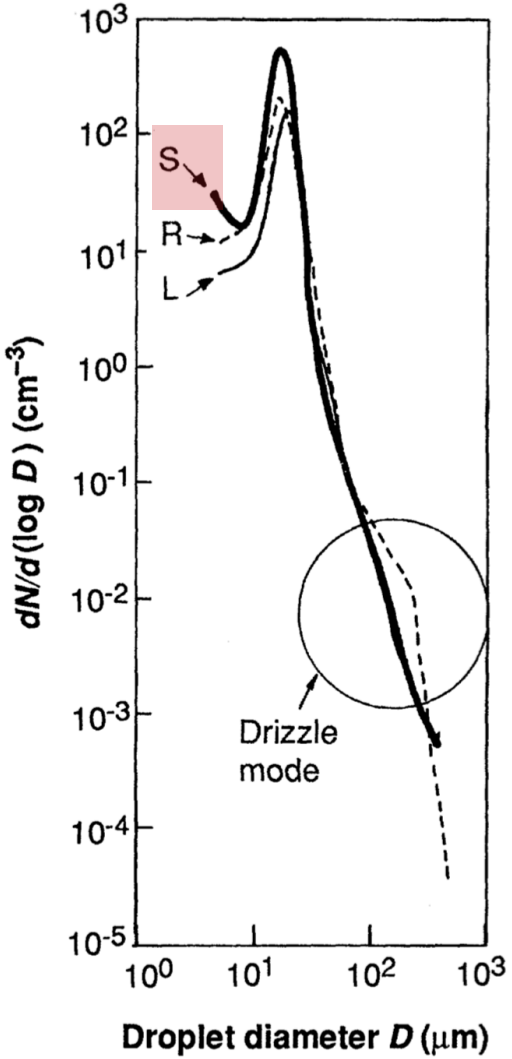


FIG. 2. Family of anomalous lines. California coast and islands south of Santa Barbara are shown on the right. Case 4.

Ship tracks as a "natural" experiment for ACI hypotheses





Twomey effect:

- More aerosol leads to more cloud droplets of smaller size for same amount of water

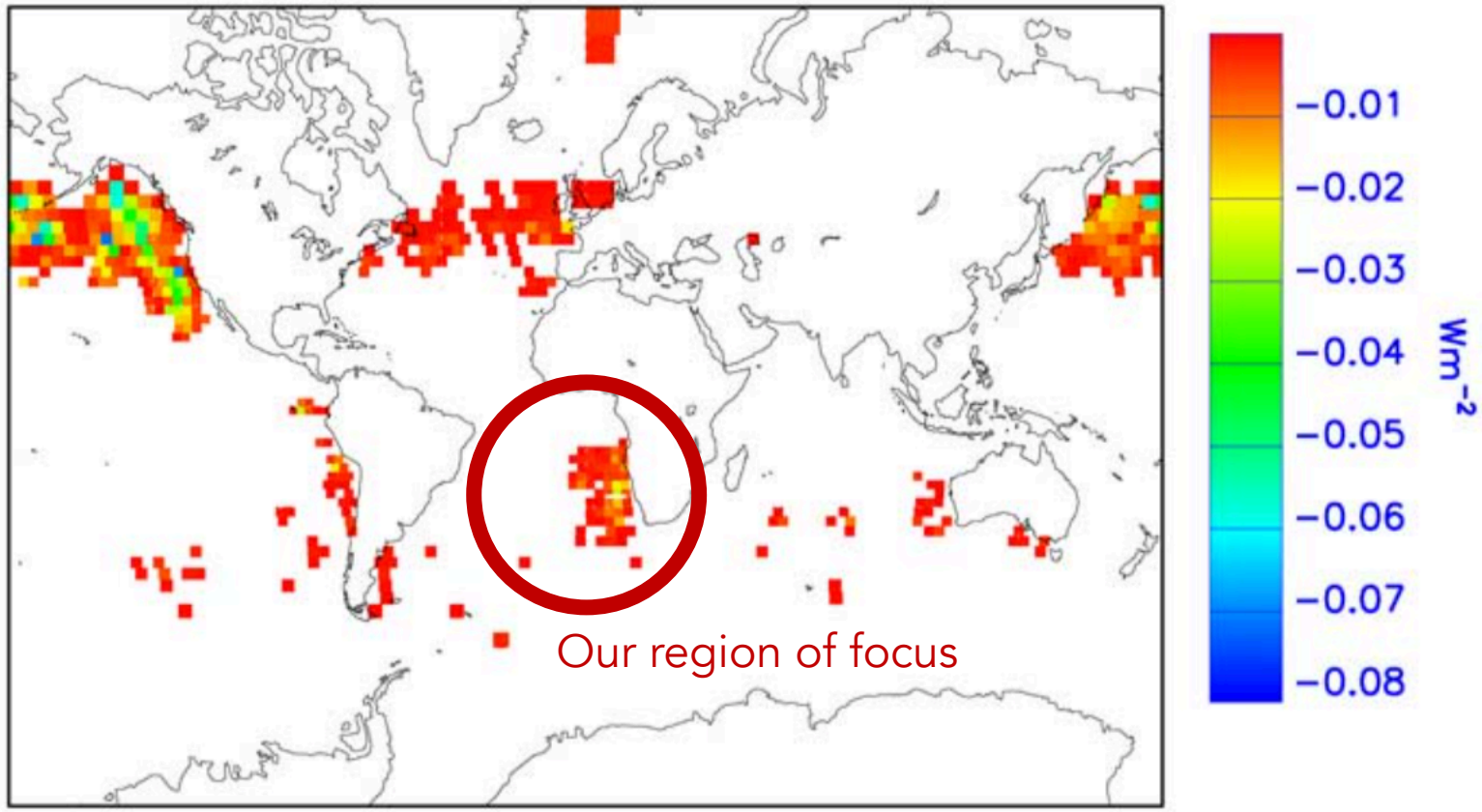
Cloud adjustments:

- Precipitation suppression increases cloudiness
- Enhanced entrainment drying decreases cloudiness

Radke et al. (1989), Science

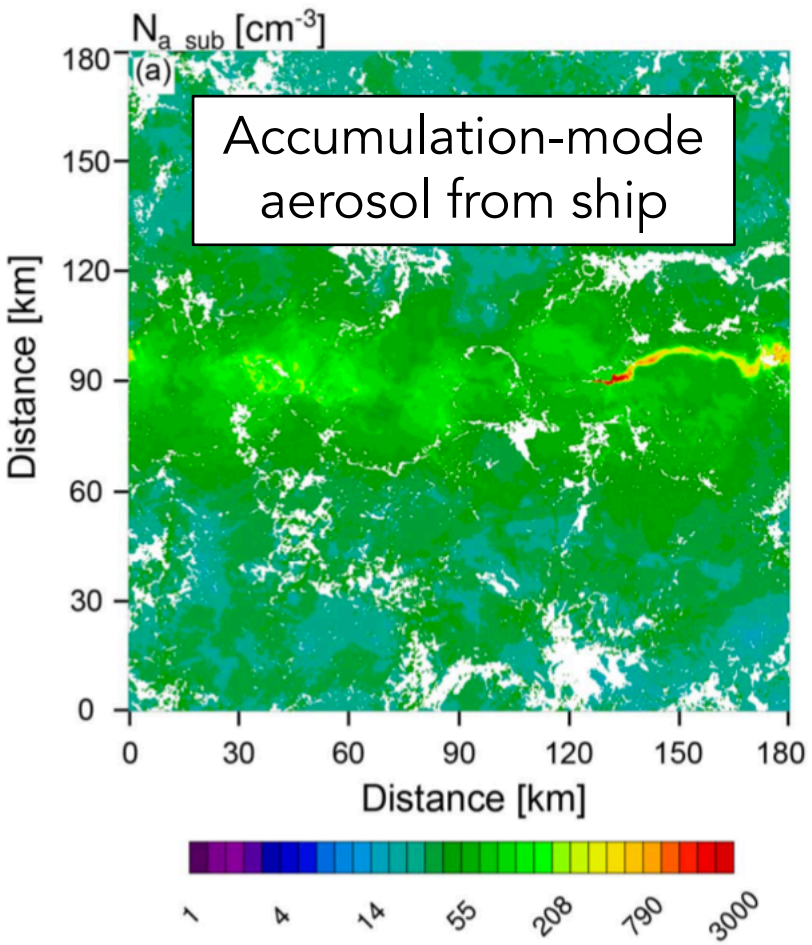
Do ship tracks matter globally?

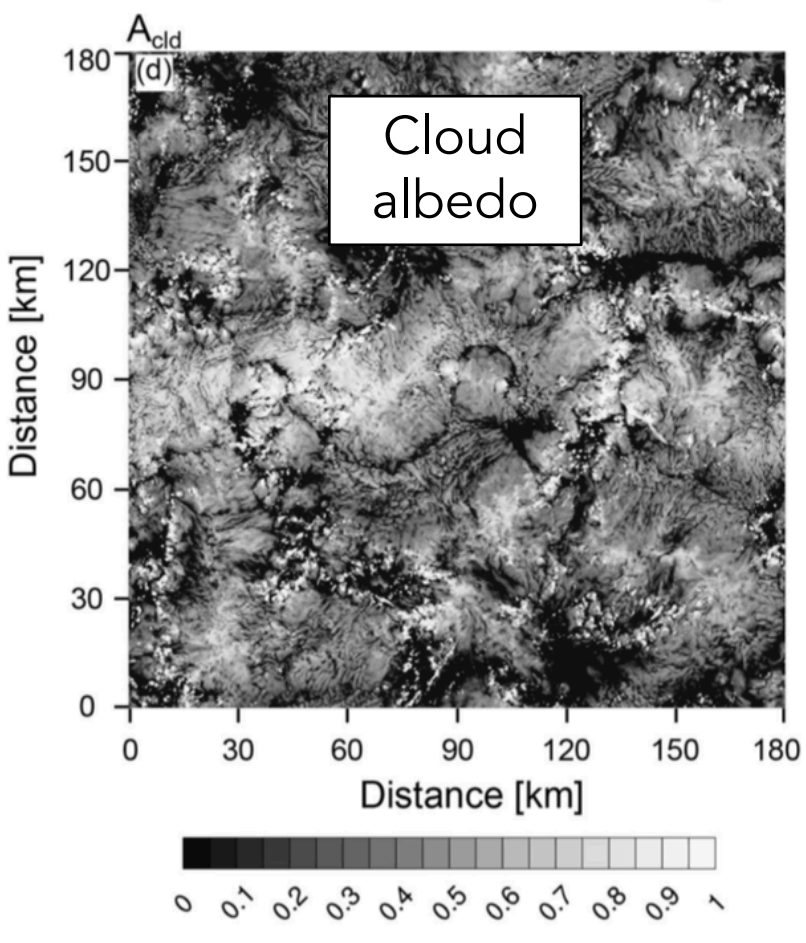
- Global ERF_{ACI} estimate from one year's worth of ship track data of -0.0005 W/m^2
- But model spread of ERF_{ACI} ranges from -0.06 to -0.6 W/m^2...



Schrier et al. (2007), GRL; Capaldo et al. (1999), Nature; Lauer et al. (2007), ACP

Shipping perturbations may not be readily visible given natural cloud variability

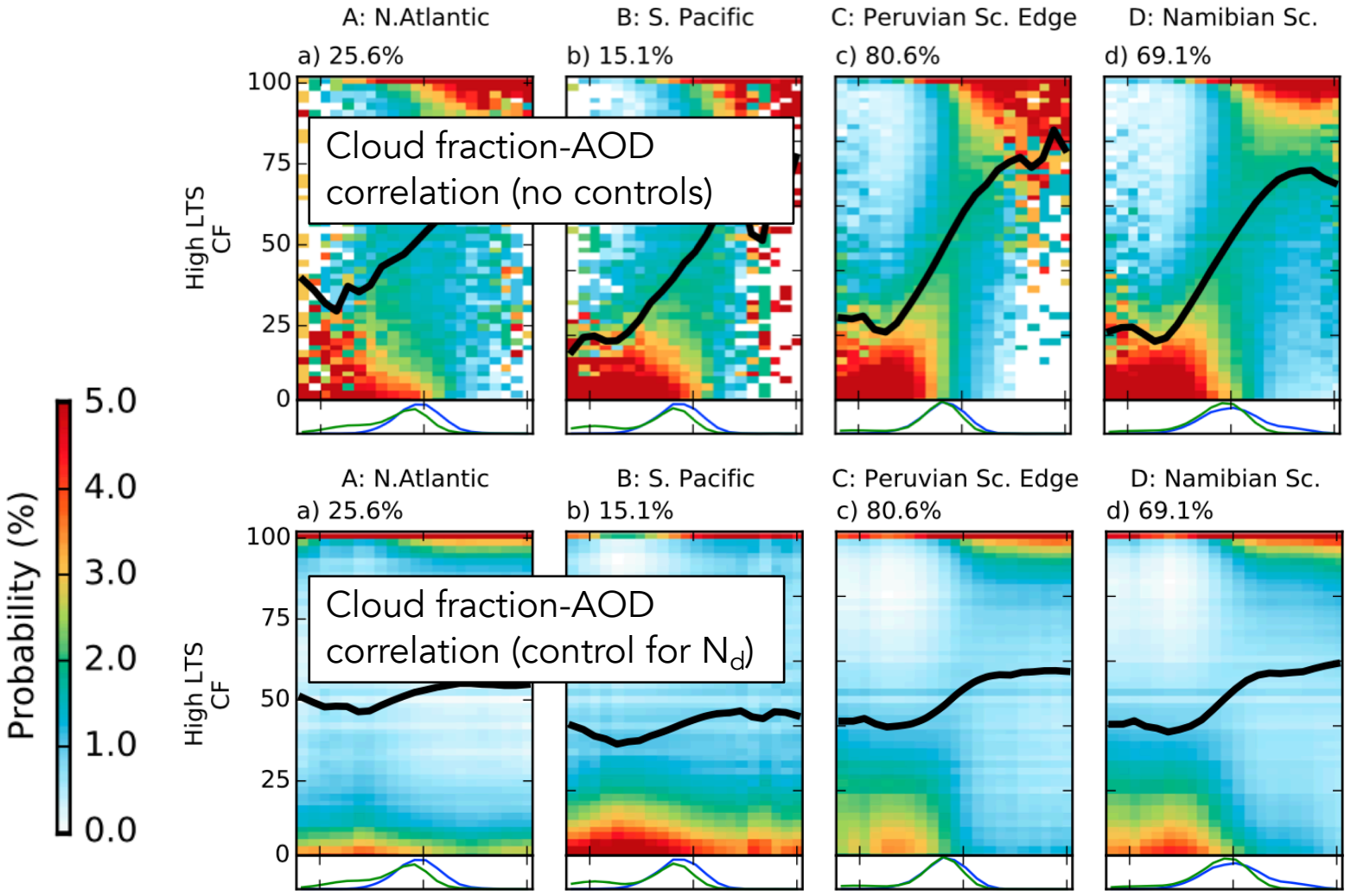




Possner et al. (2018), ACP

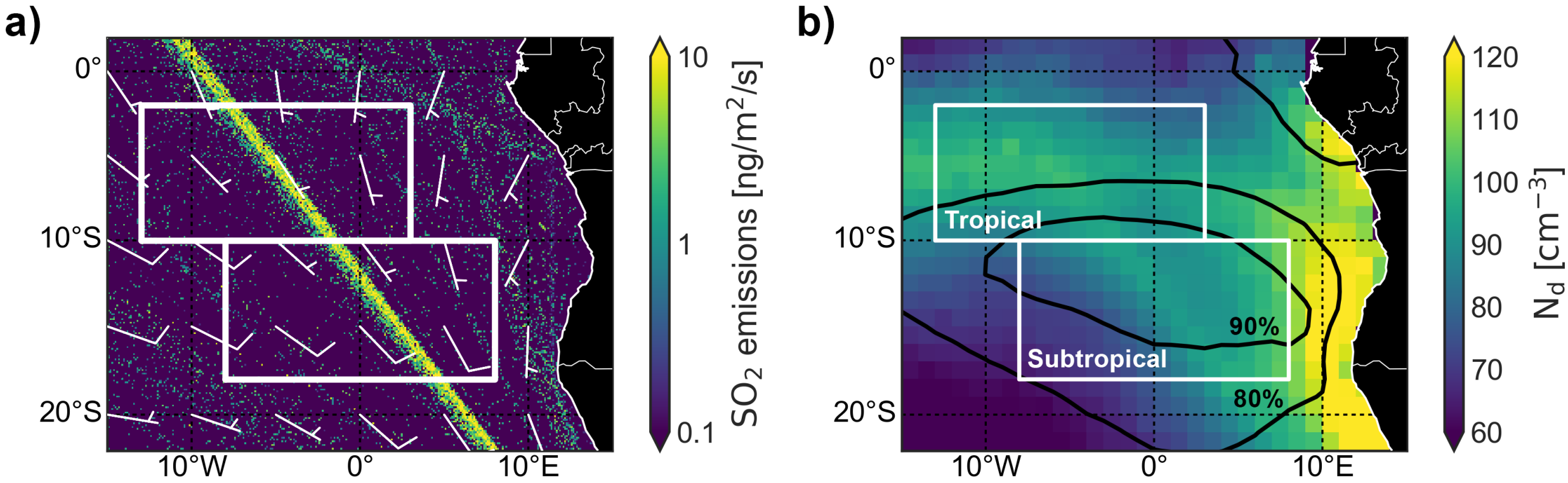
So why bother with shipping?

- **Disentangling the effects of meteorology** versus aerosol effects is notoriously difficult
- "Natural" experiments offer cases with relatively **clear causality**



Gryspeerdt et al. (2016), JGR:A

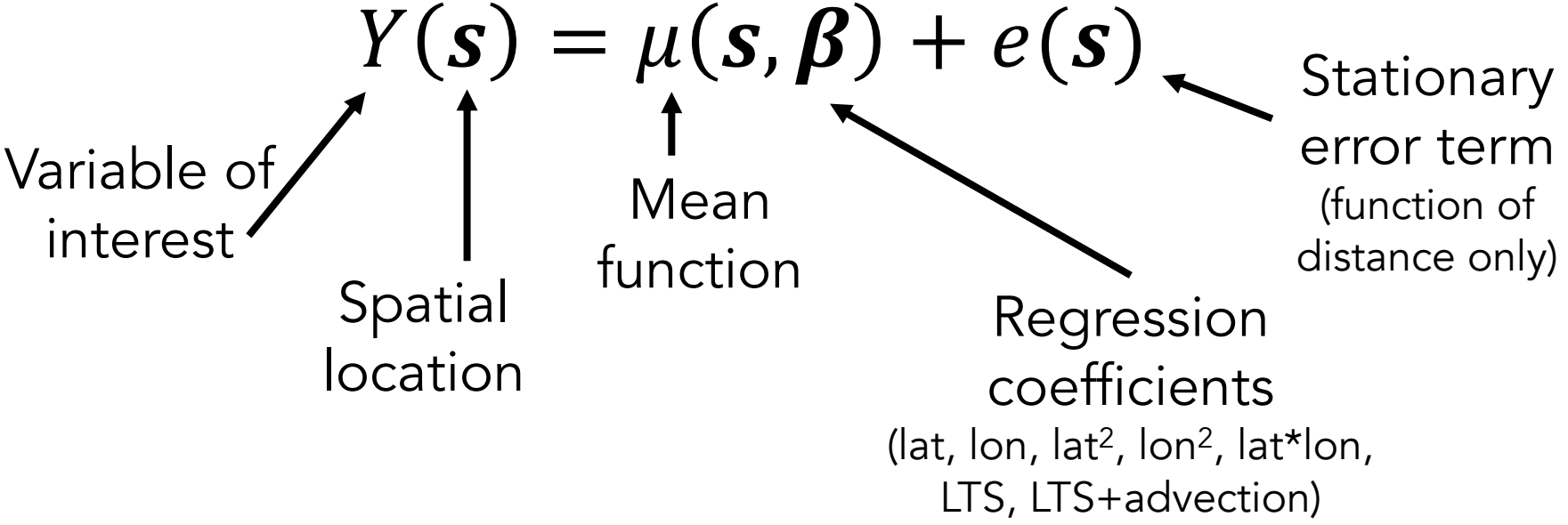
Southeast Atlantic: Ideal setup?



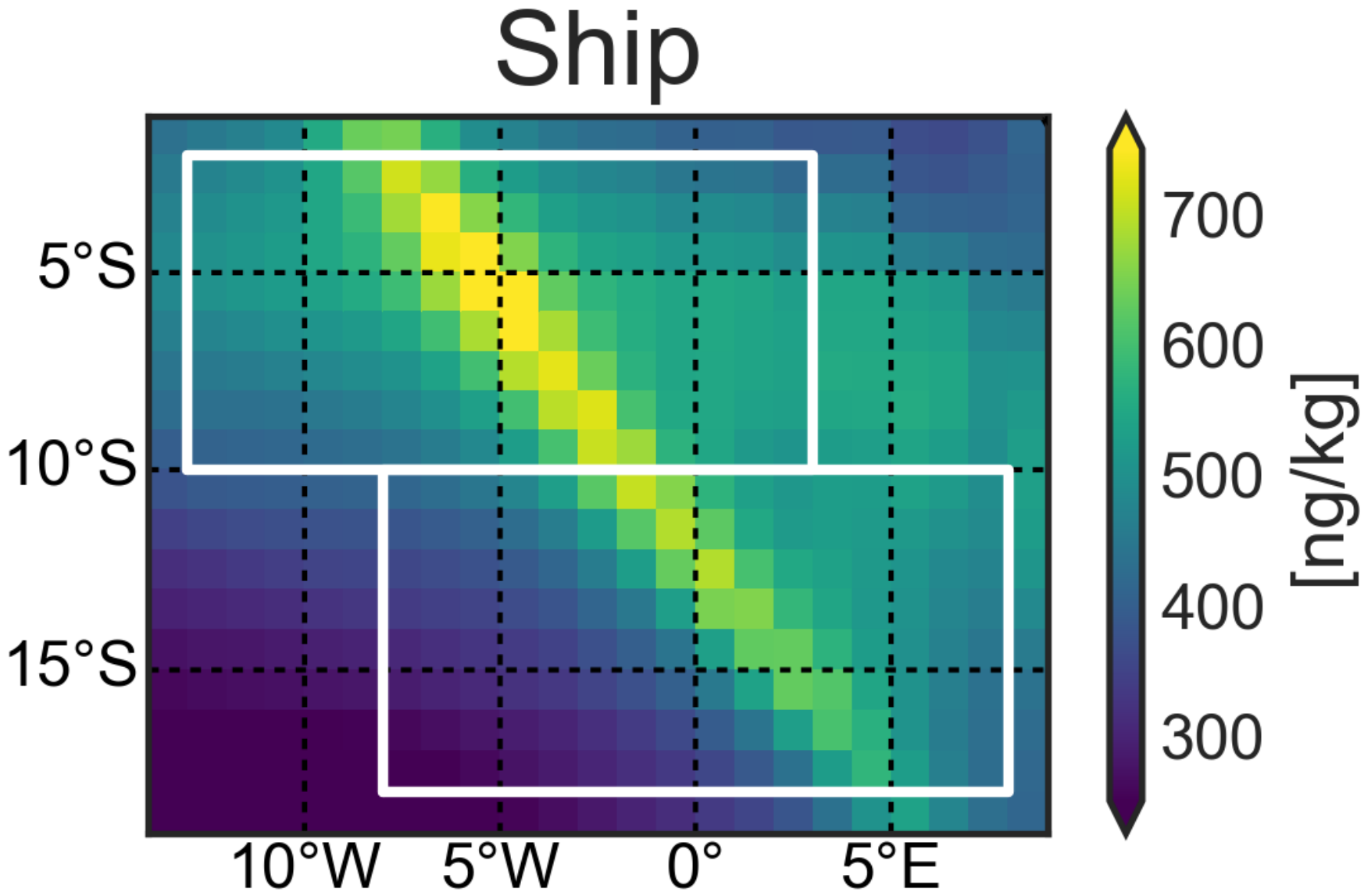
**All data is for austral spring (September-October-November) climatology from 2003-2015*

Universal kriging

- Geostatistical method that provides the best linear unbiased predictor for a spatial model composed of some underlying mean spatial trend and a stationary "error" pattern



Example: MERRA-2 surface [SO_4]



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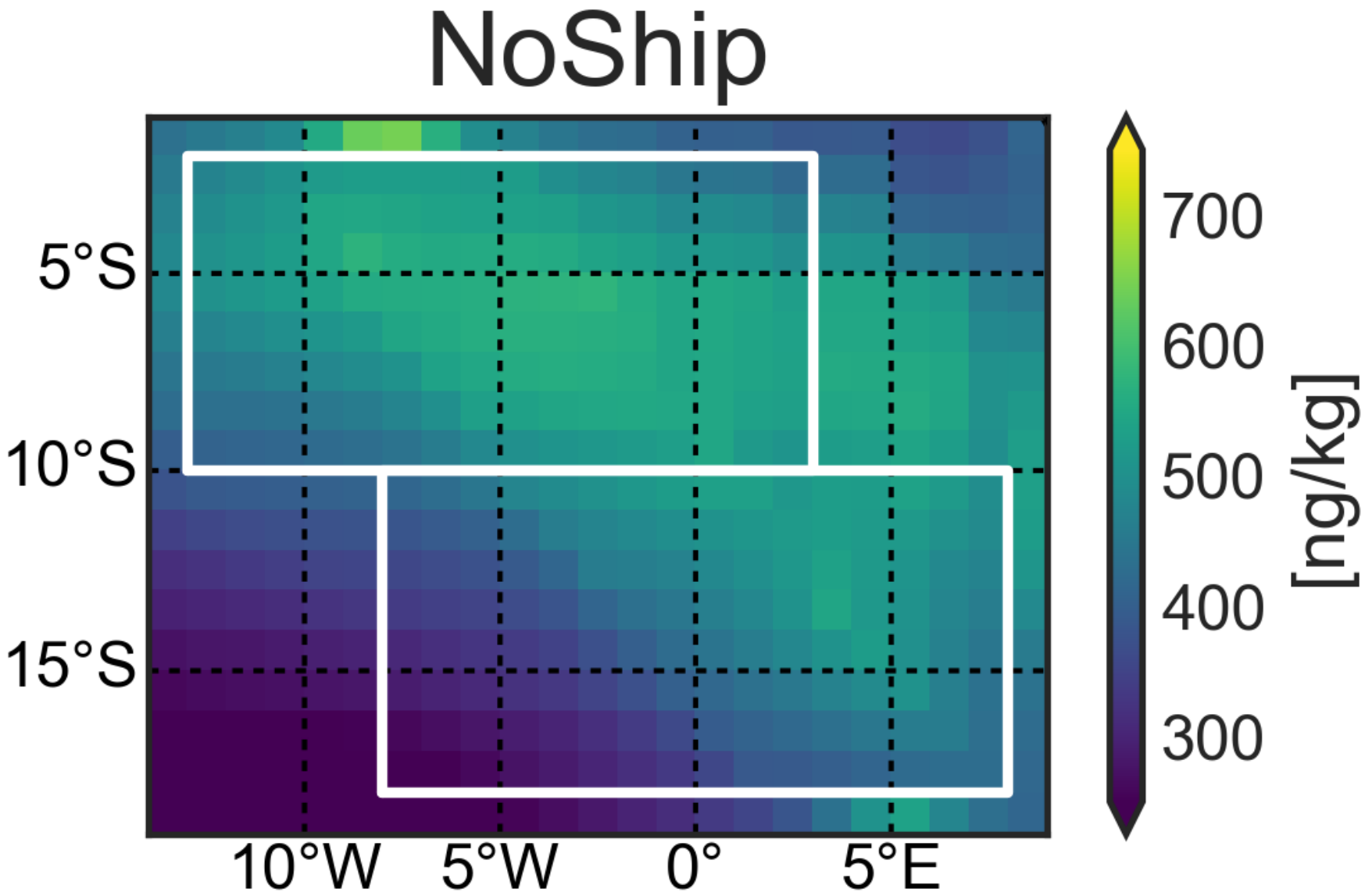

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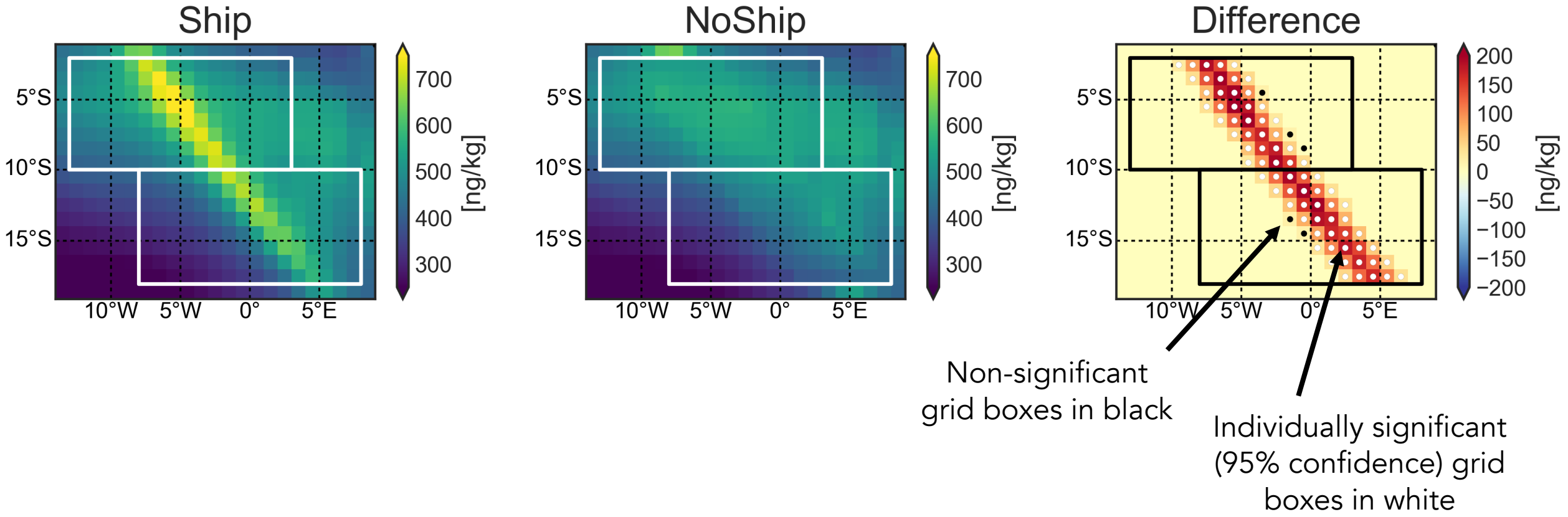
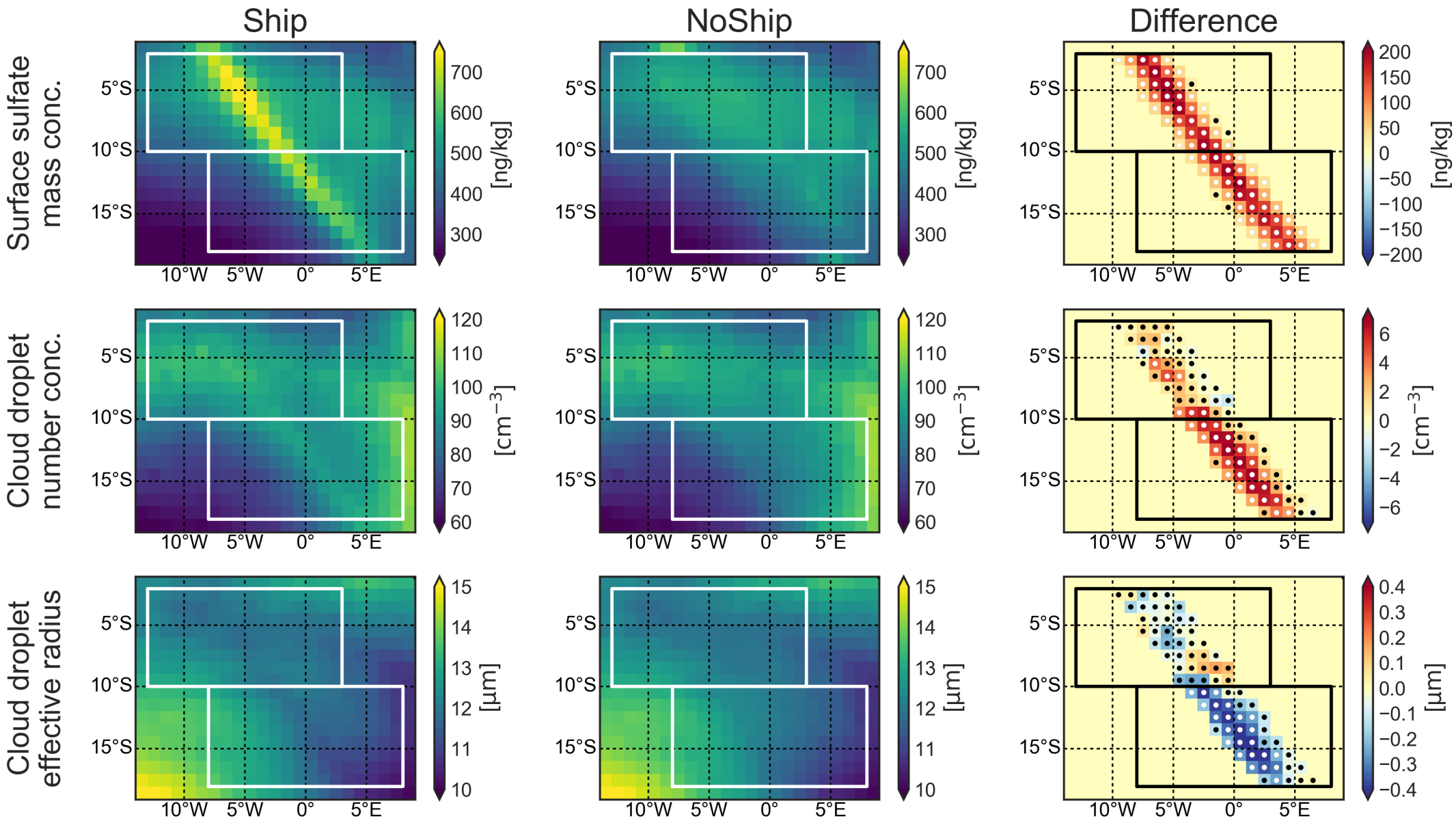
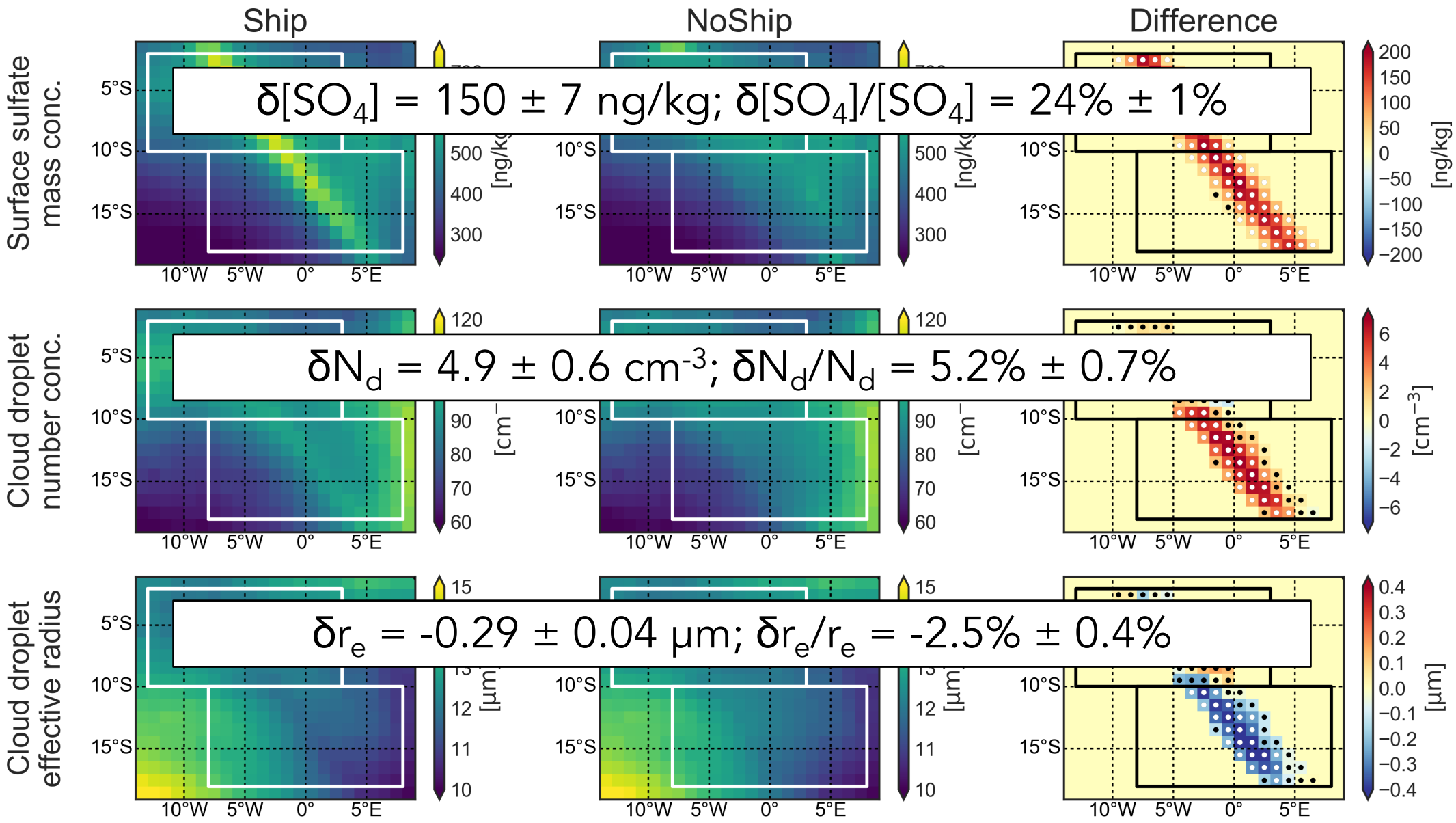


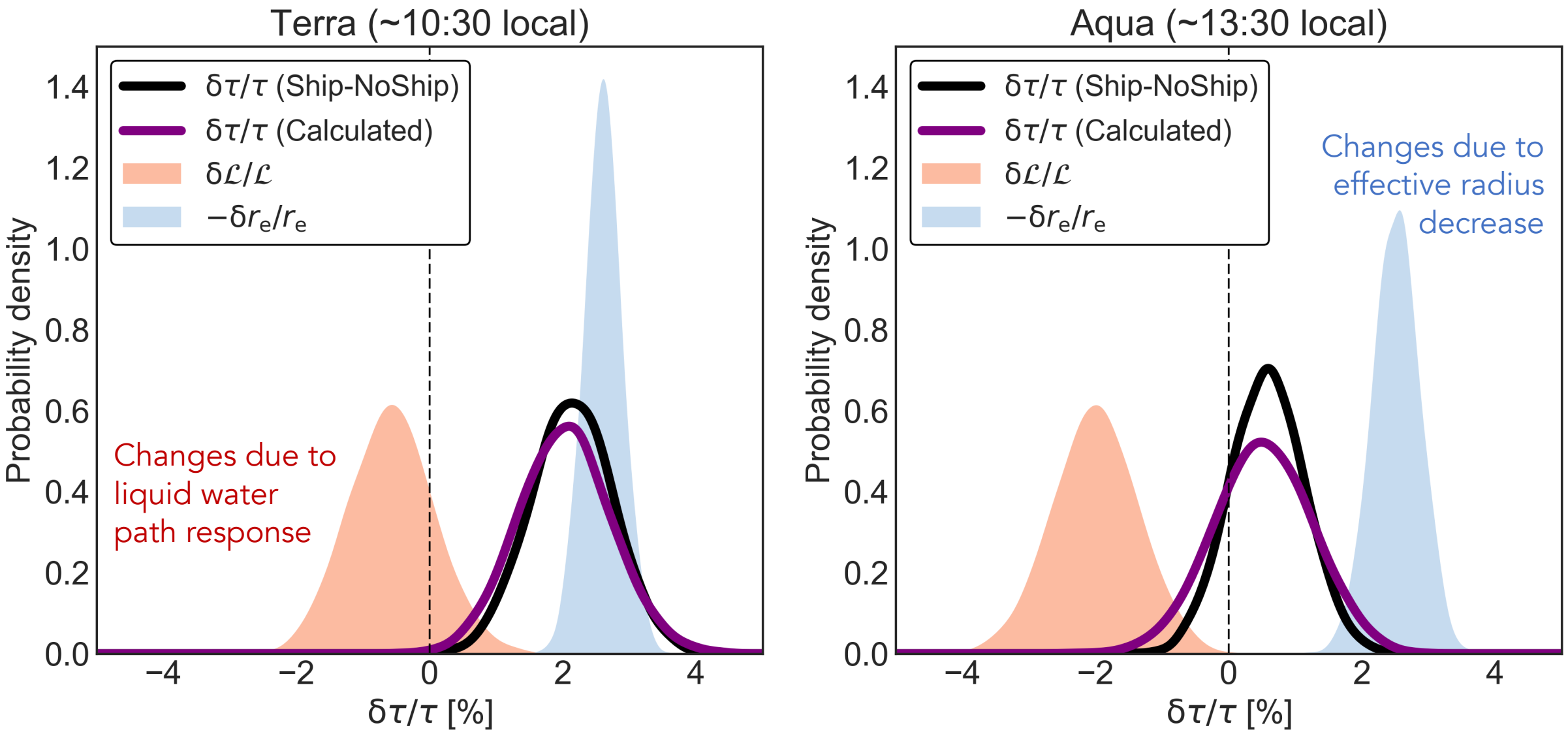


*N_d & r_e from MODIS/Aqua



*Values for southern/stratocumulus-dominated region only

Cloud optical thickness (τ) changes

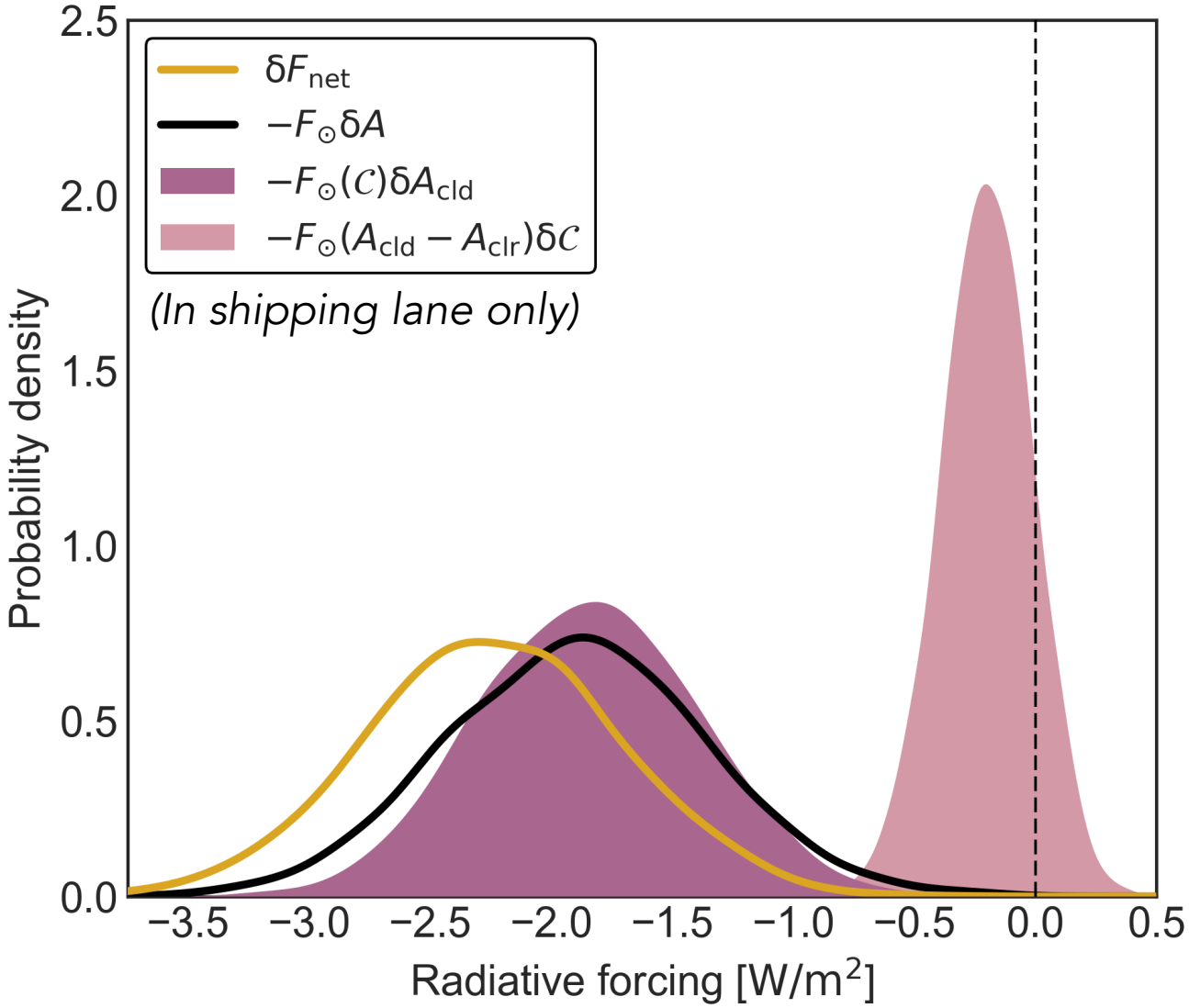


Albedo decomposition

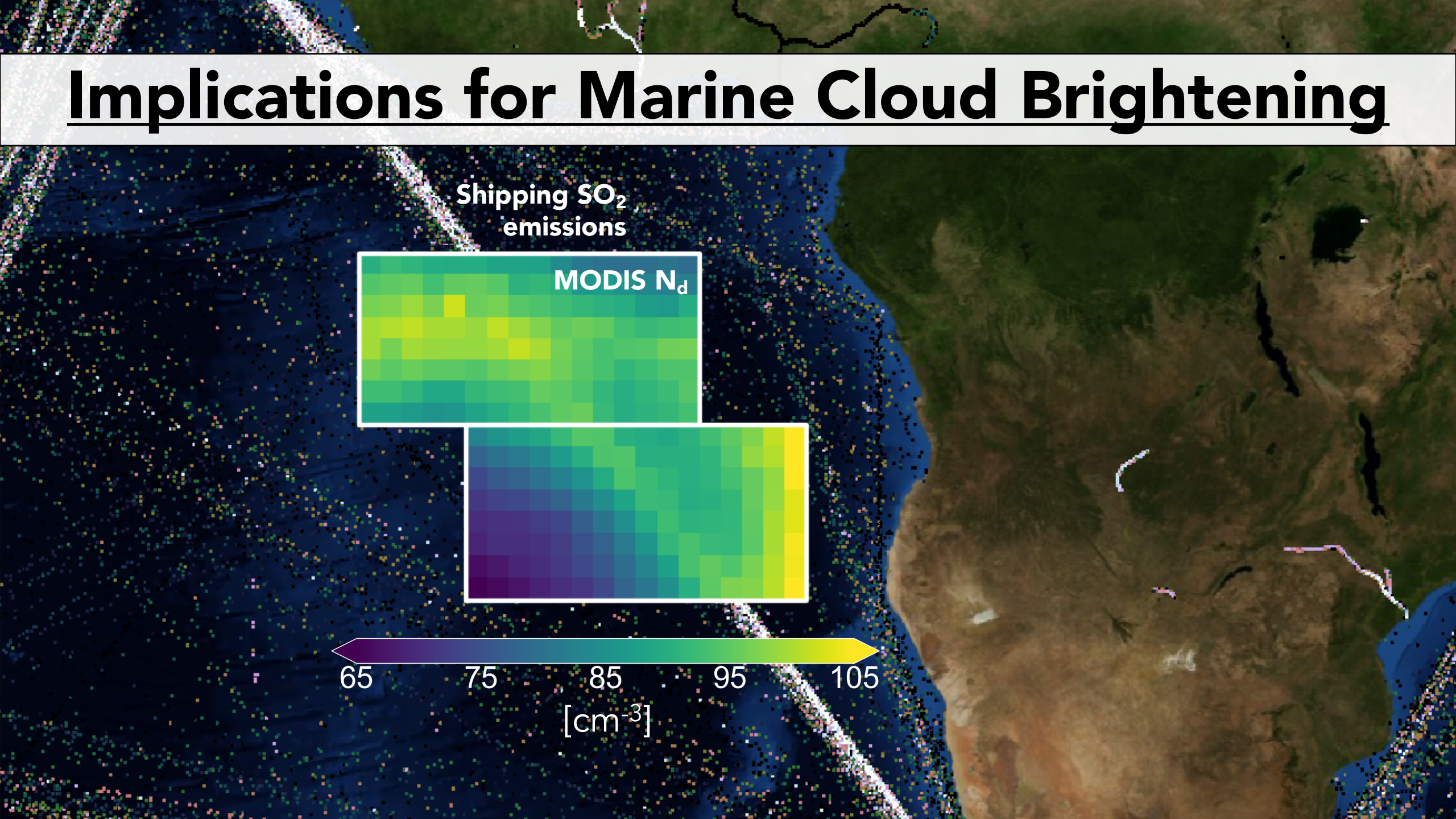
- CERES total albedo (***A***), clear-sky albedo (A_{clr}), and cloud fraction ($\mathcal{C}$) used to estimate cloud albedo (A_{cld})

- **Total albedo change** broken into components from changes in **cloud brightness** versus **cloud fraction**

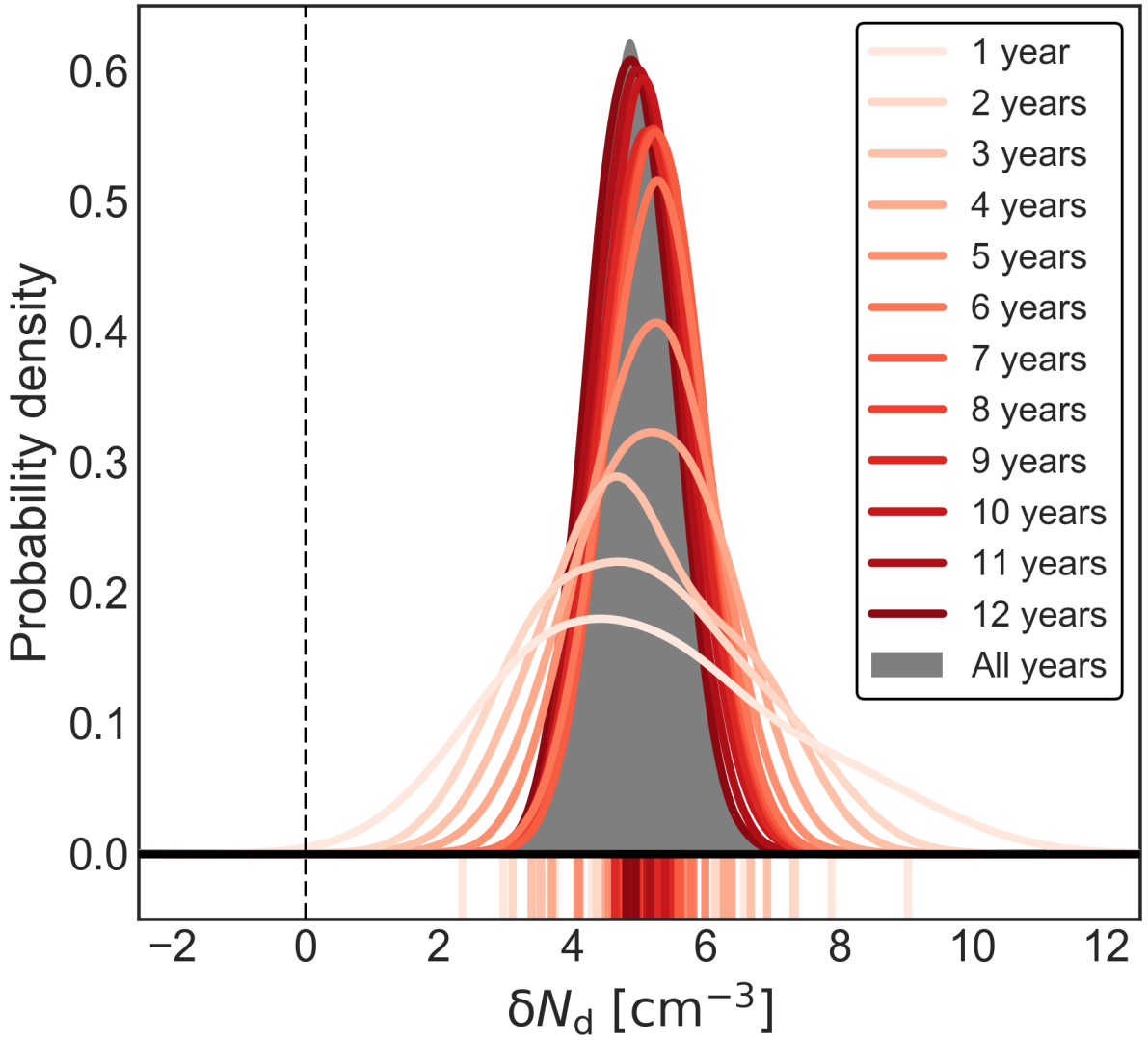
- CERES **net flux** tested directly

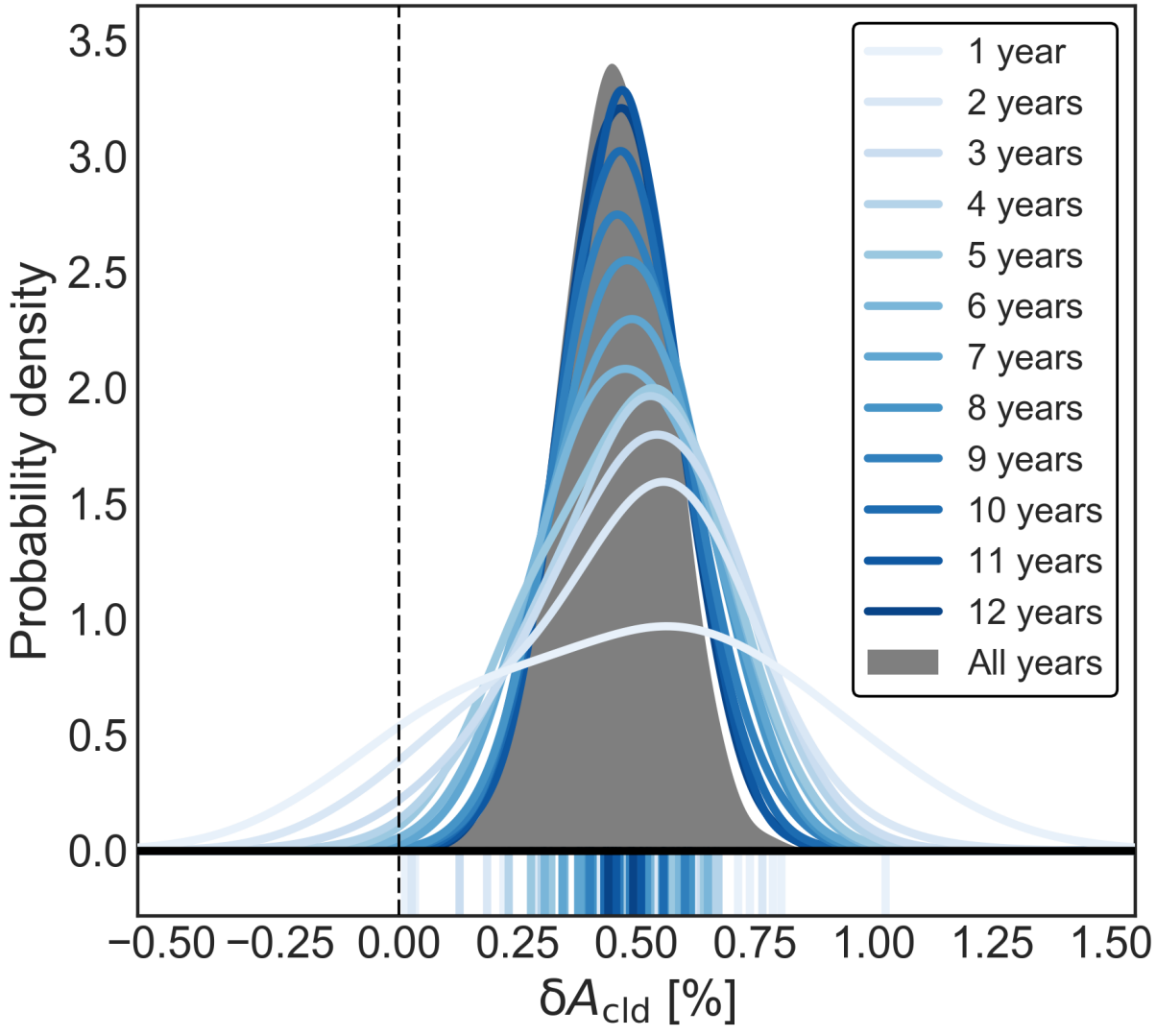


Implications for Marine Cloud Brightening

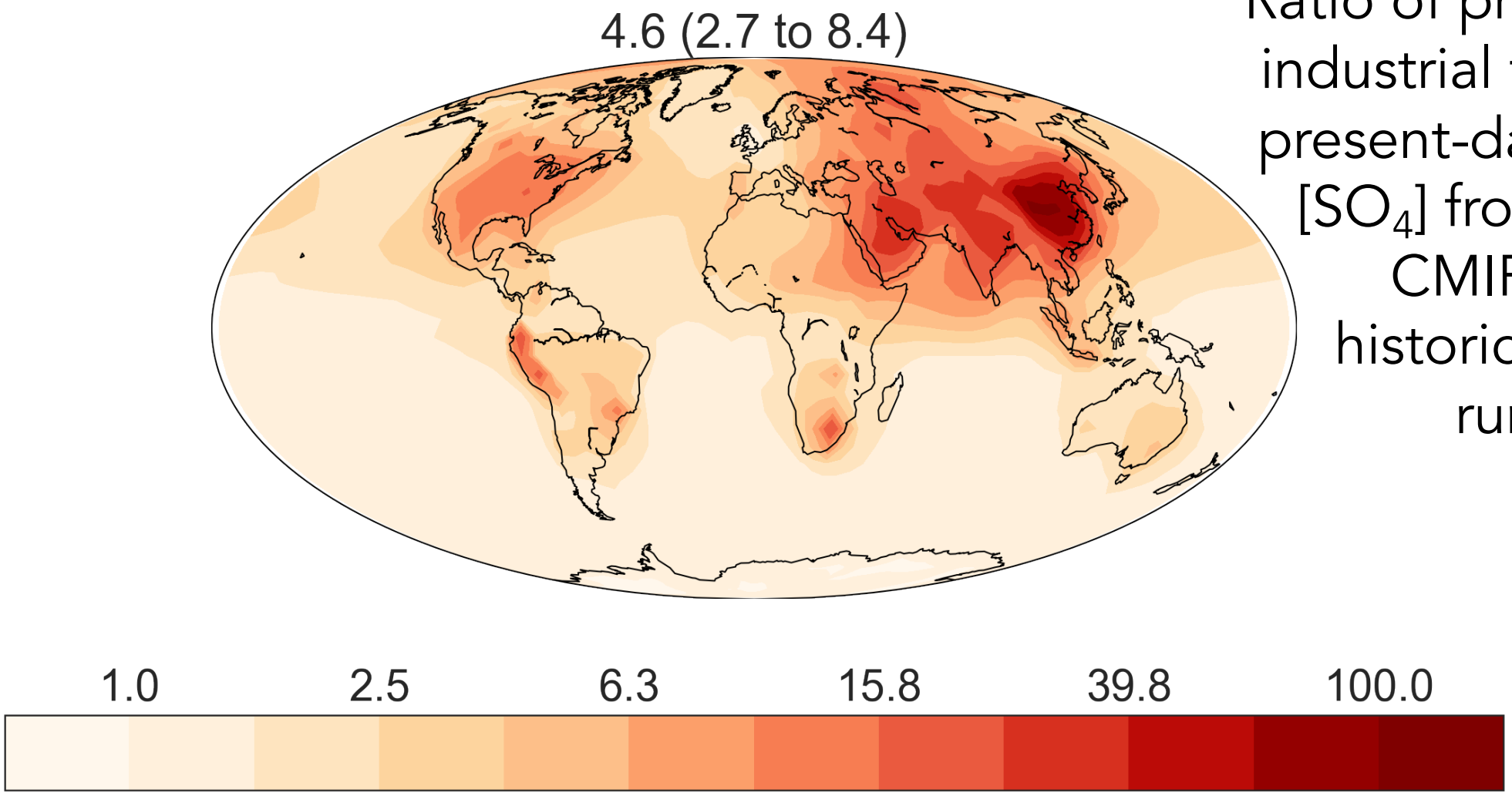


It takes ~5-6 years for signal to become clear

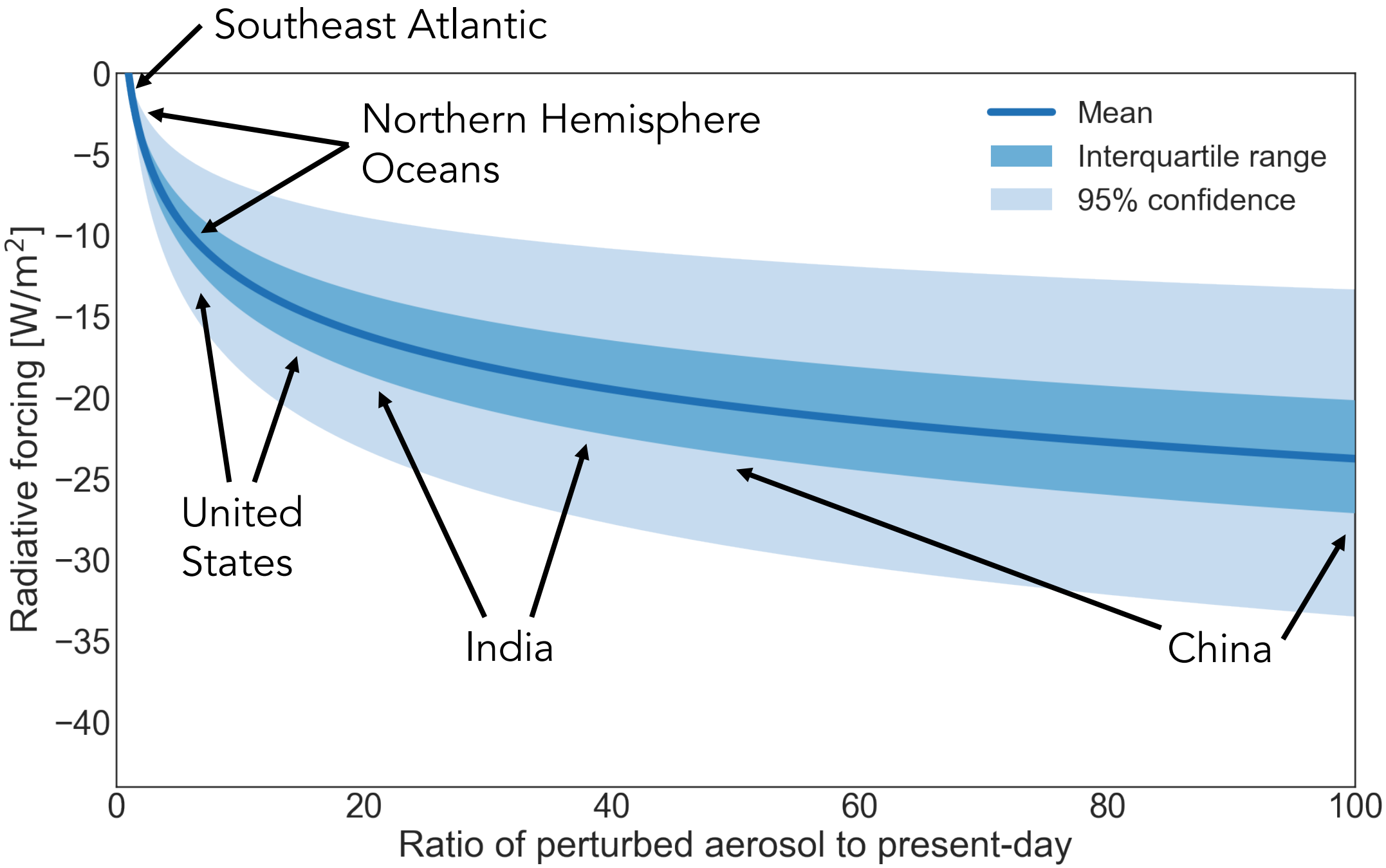




Historical aerosol changes



Ratio of pre-industrial to present-day $[SO_4]$ from CMIP6 historical runs


Southeast Atlantic
Northern Hemisphere Oceans
Mean
Interquartile range
95% confidence
Radiative forcing [W/m^2]
0
−5
−10
−15
−20
−25
−30
−35
−40
United States
India
China
0
20
40
60
80
100
Ratio of perturbed aerosol to present-day

Earth and Space Science Open Archive:
https://www.essoar.org/doi/abs/10.1002/essoar.10501145.1

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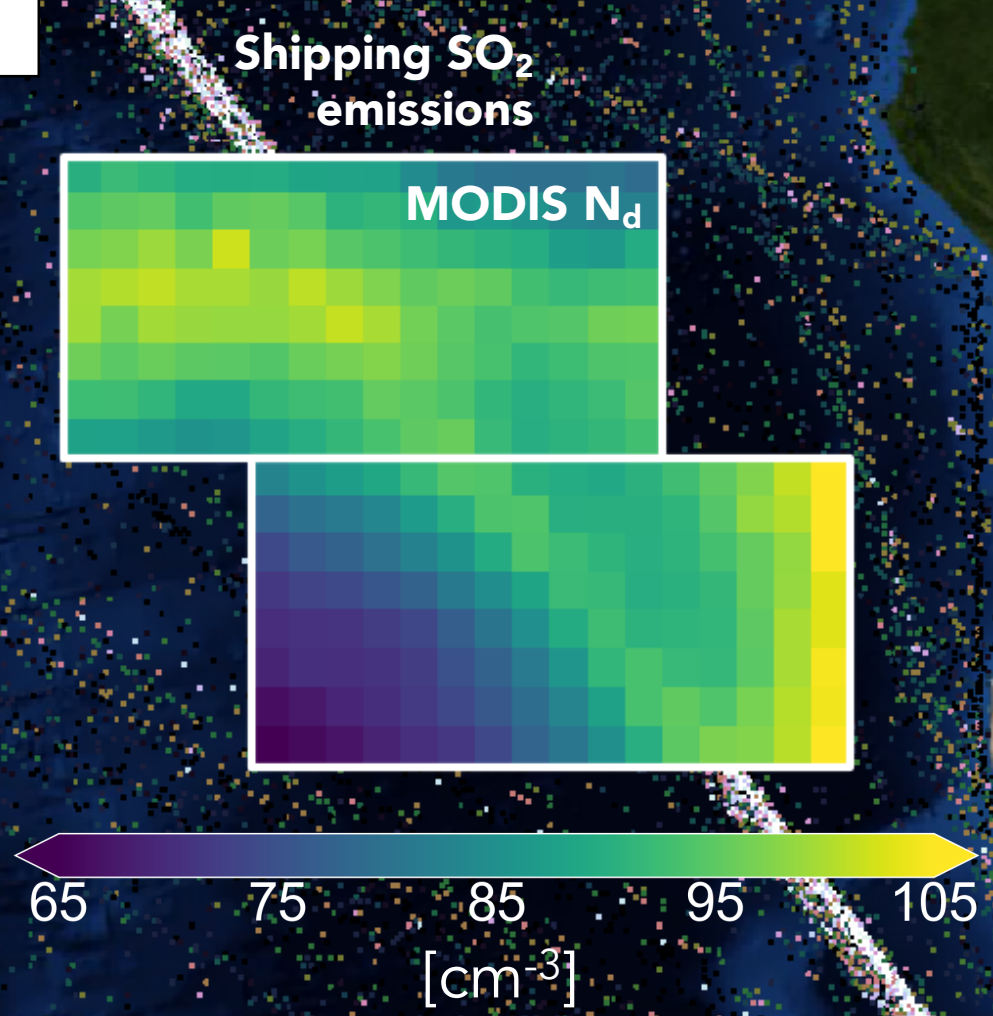


Summary & conclusions

- First unambiguous detection of climate-relevant cloud radiative effects due to international shipping emissions
- Total albedo increase dominated by cloud brightening, not by changes in fractional cloudiness
- Liquid water path adjustments offset brightening from the Twomey effect
- Could be an ideal test for aerosol-cloud interactions in climate models

Extra slides

ANNEX 6

RESOLUTION MEPC.280(70)
(Adopted on 28 October 2016)

EFFECTIVE DATE OF IMPLEMENTATION OF THE FUEL OIL STANDARD IN REGULATION 14.1.3 OF MARPOL ANNEX VI

Current fuels have been limited to 3.5% (by mass) since 2012, 4.5% prior

THE MARINE ENVIRONMENT PROTECTION COMMITTEE,

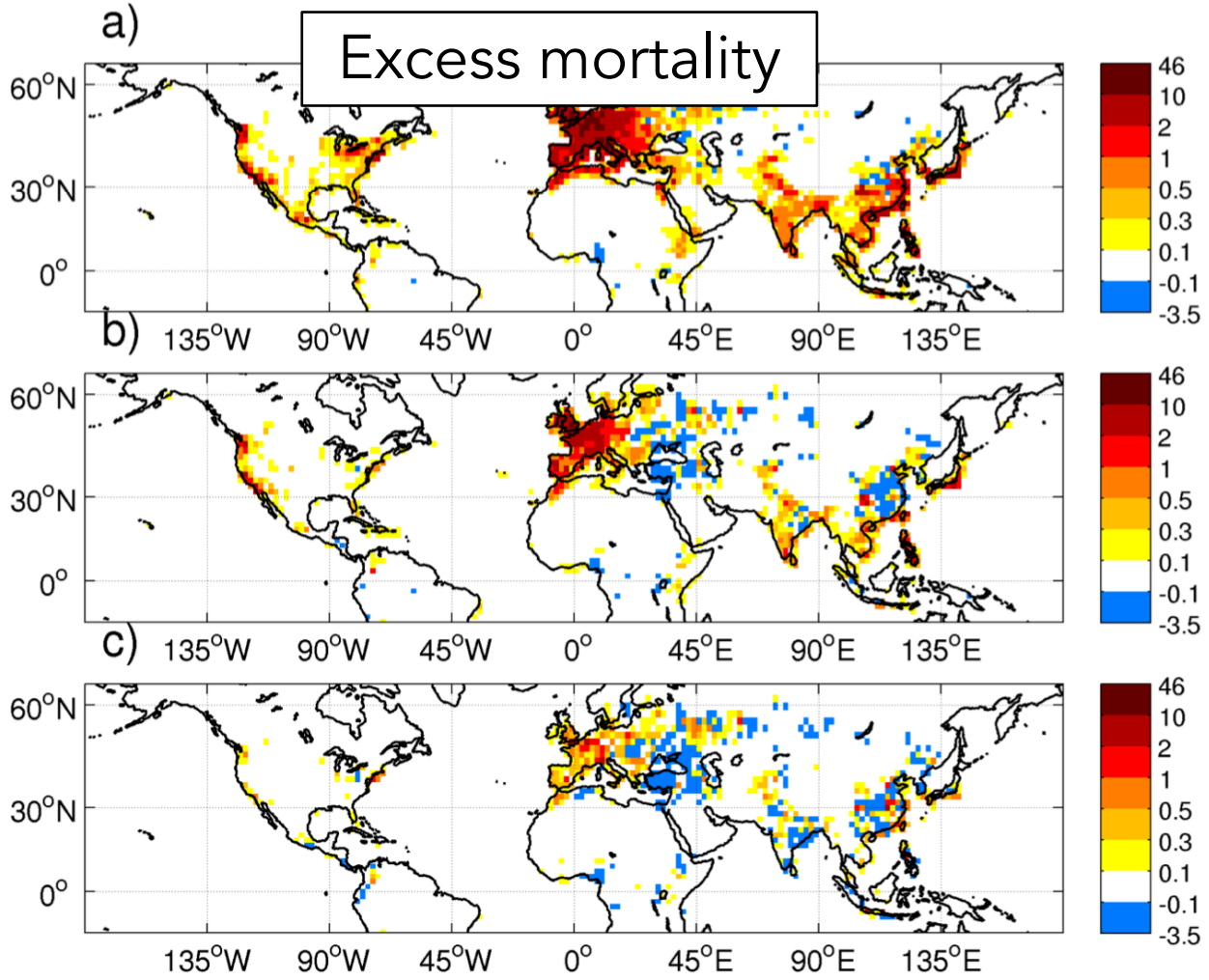
RECALLING Article 38(a) of the Convention on the International Maritime Organization concerning the functions of the Marine Environment Protection Committee conferred upon it by international conventions for the prevention and control of marine pollution from ships,

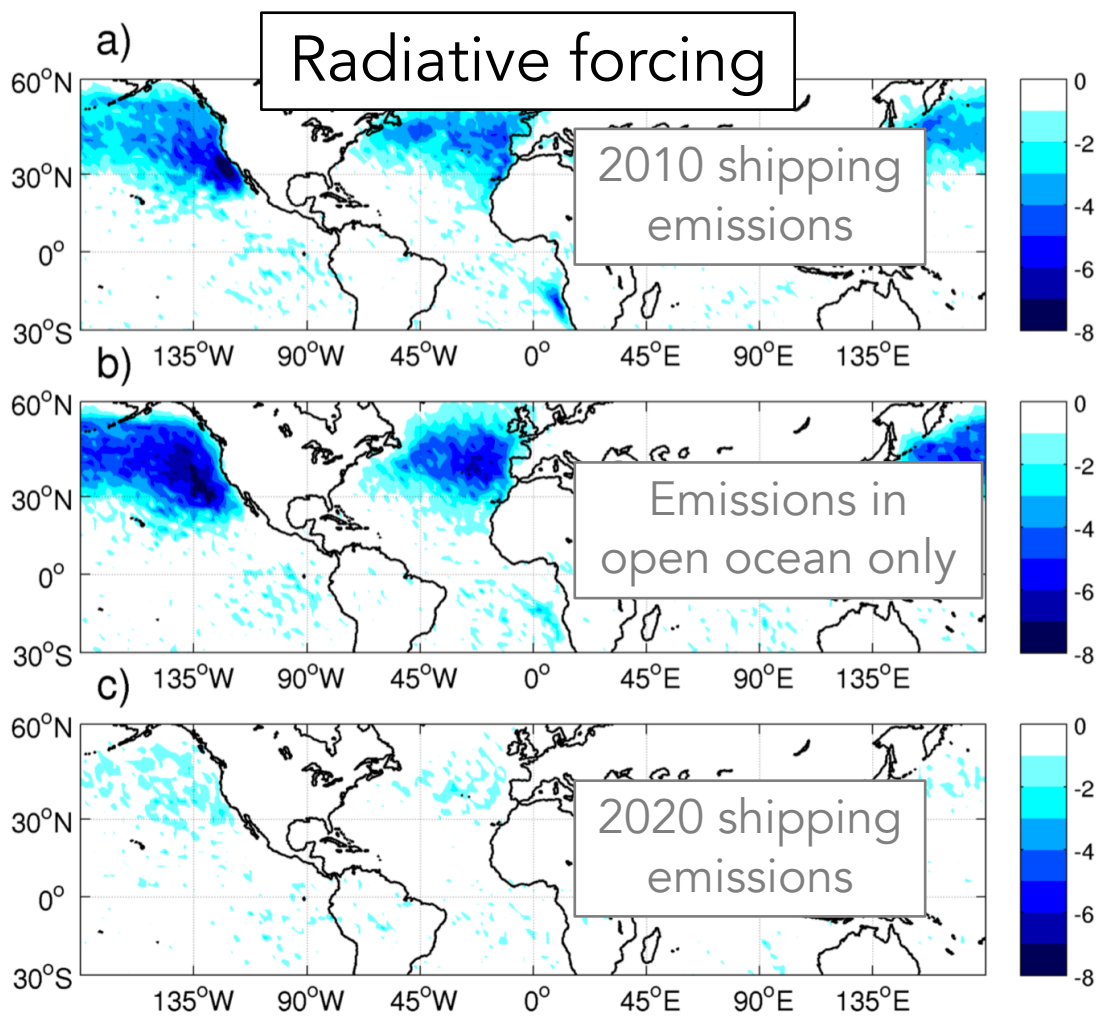
RECALLING ALSO that the revised MARPOL Annex VI entered into force on 1 July 2010,

RECALLING FURTHER that regulation 14.1.3 of MARPOL Annex VI stipulates that the sulphur content of any fuel oil used on board ships shall not exceed 0.50% m/m on or after 1 January 2020,

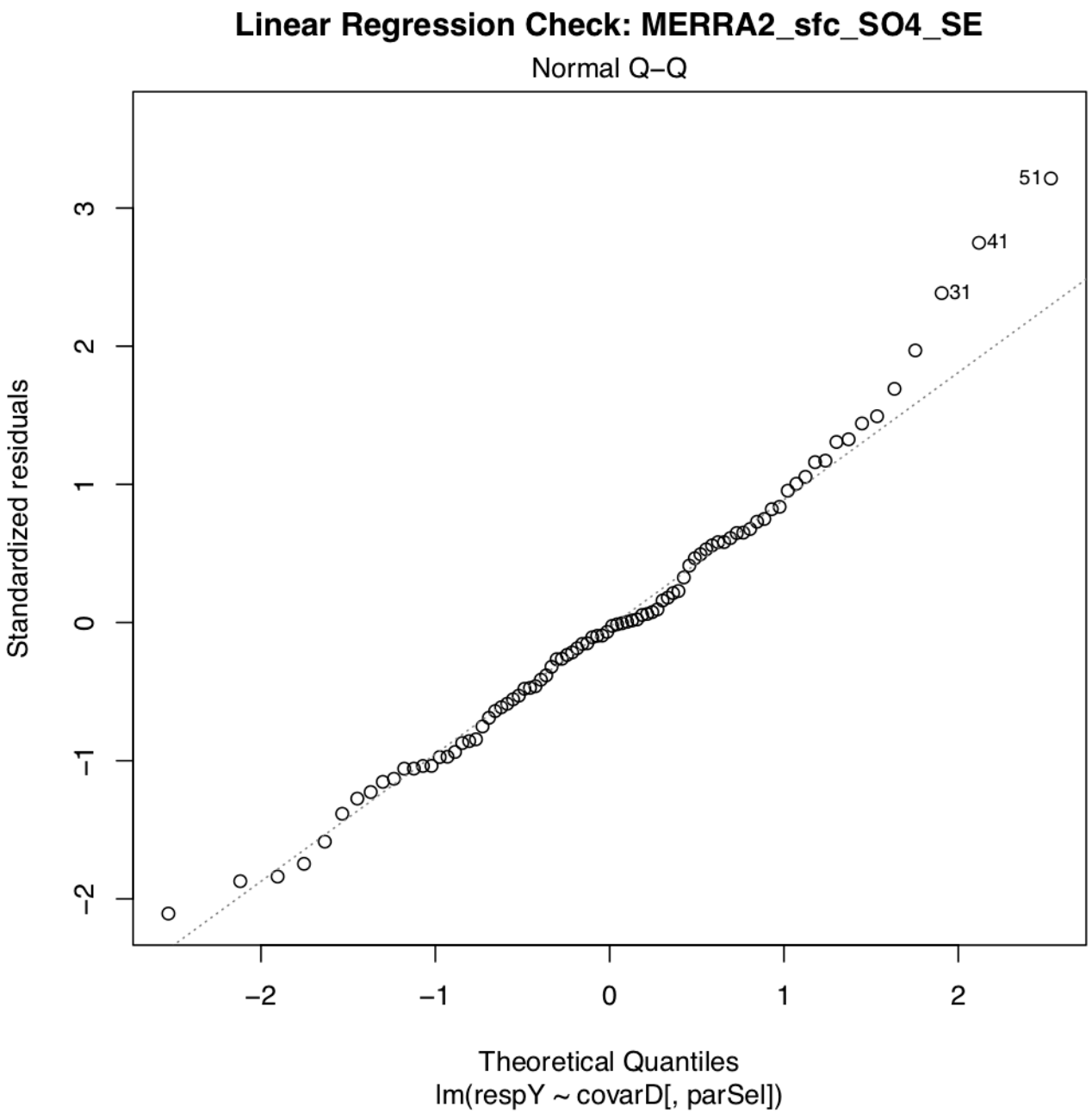
RECALLING that regulations 14.8 to 14.10 of MARPOL Annex VI require that a review shall be completed by 2018 to determine the availability of fuel oil to comply with the fuel oil standard

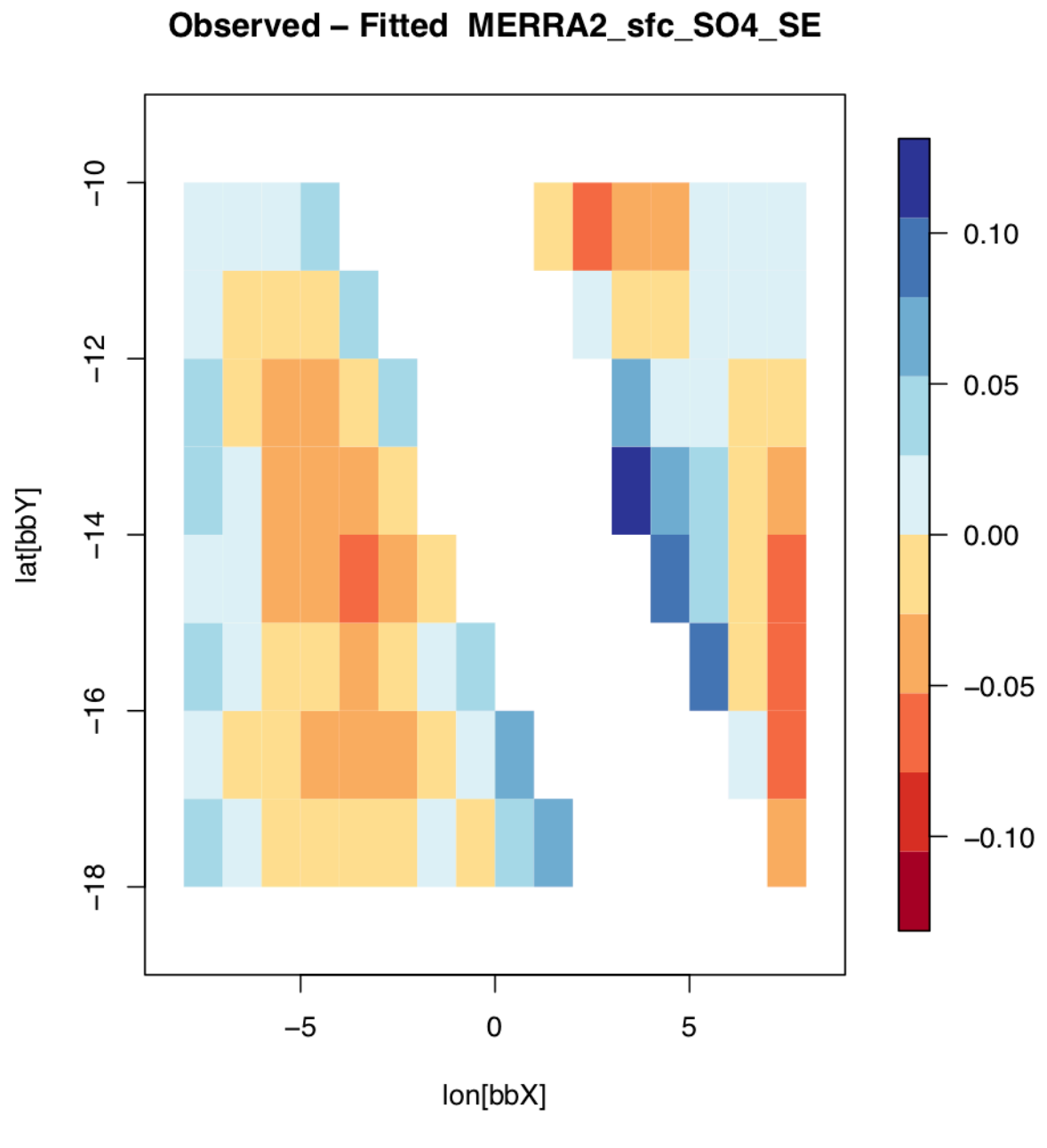
Proposal to use global shipping fleet for geoengineering

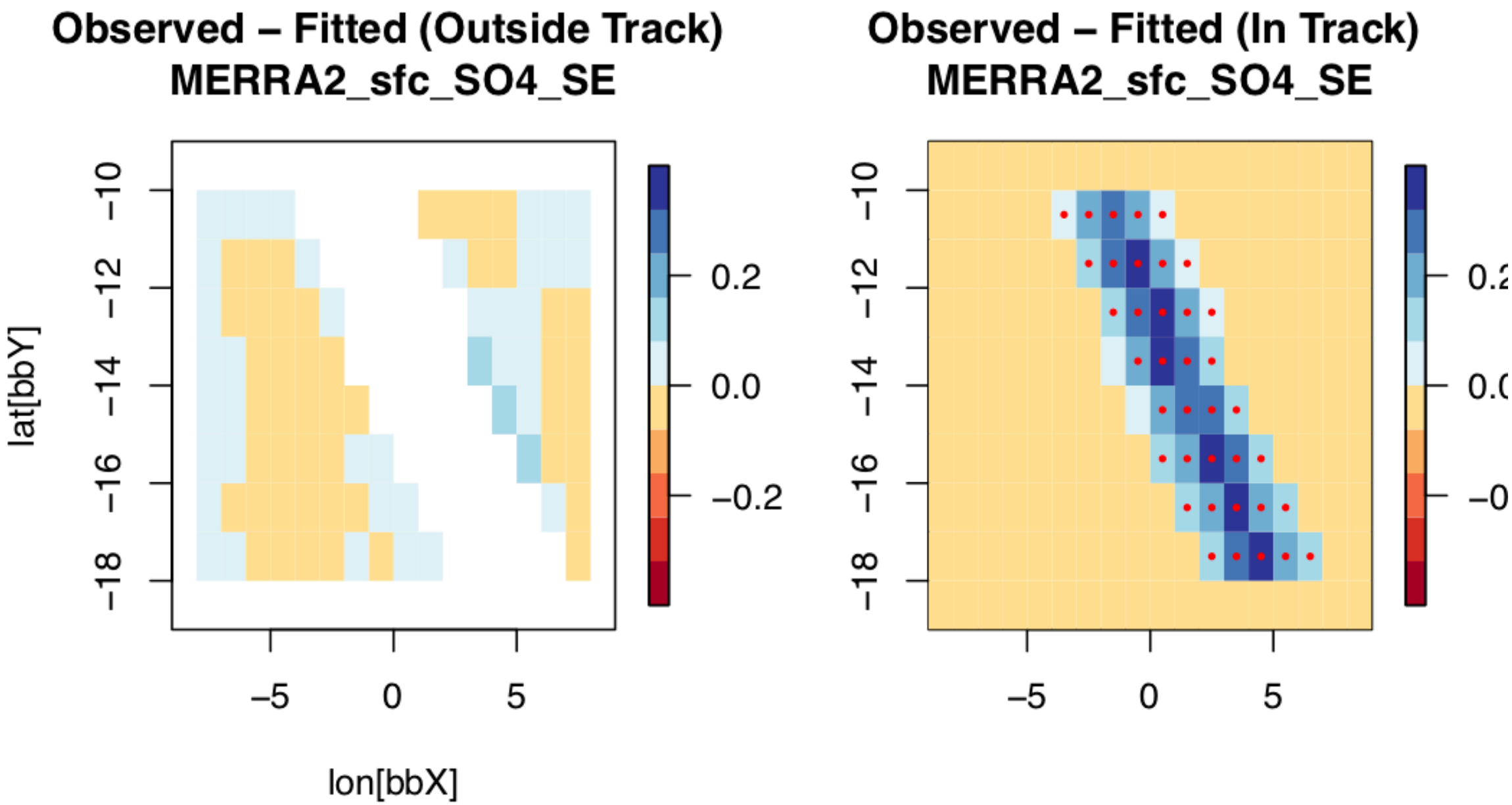




Partanen et al. (2013), ACP


Linear Regression Check: MERRA2_sfc_SO4_SE
Normal Q–Q
Standardized residuals
Theoretical Quantiles
lm(respY ~ covarD[, parSel])
51
41
31
3
2
1
0
−1
−2
−2
−1
0
1
2


Observed – Fitted MERRA2_sfc_SO4_SE
lat[bbY]
lon[bbX]
−10
−12
−14
−16
−18
−5
0
5
0.10
0.05
0.00
−0.05
−0.10


Observed – Fitted (Outside Track)
MERRA2_sfc_SO4_SE
lat[bbY]
−10
−12
−14
−16
−18
−5
0
5
lon[bbX]
0.2
0.0
−0.2
Observed – Fitted (In Track)
MERRA2_sfc_SO4_SE
−10
−12
−14
−16
−18
−5
0
5
0.2
0.0
−0