Using observations to better understand aerosol-cloud-climate interactions

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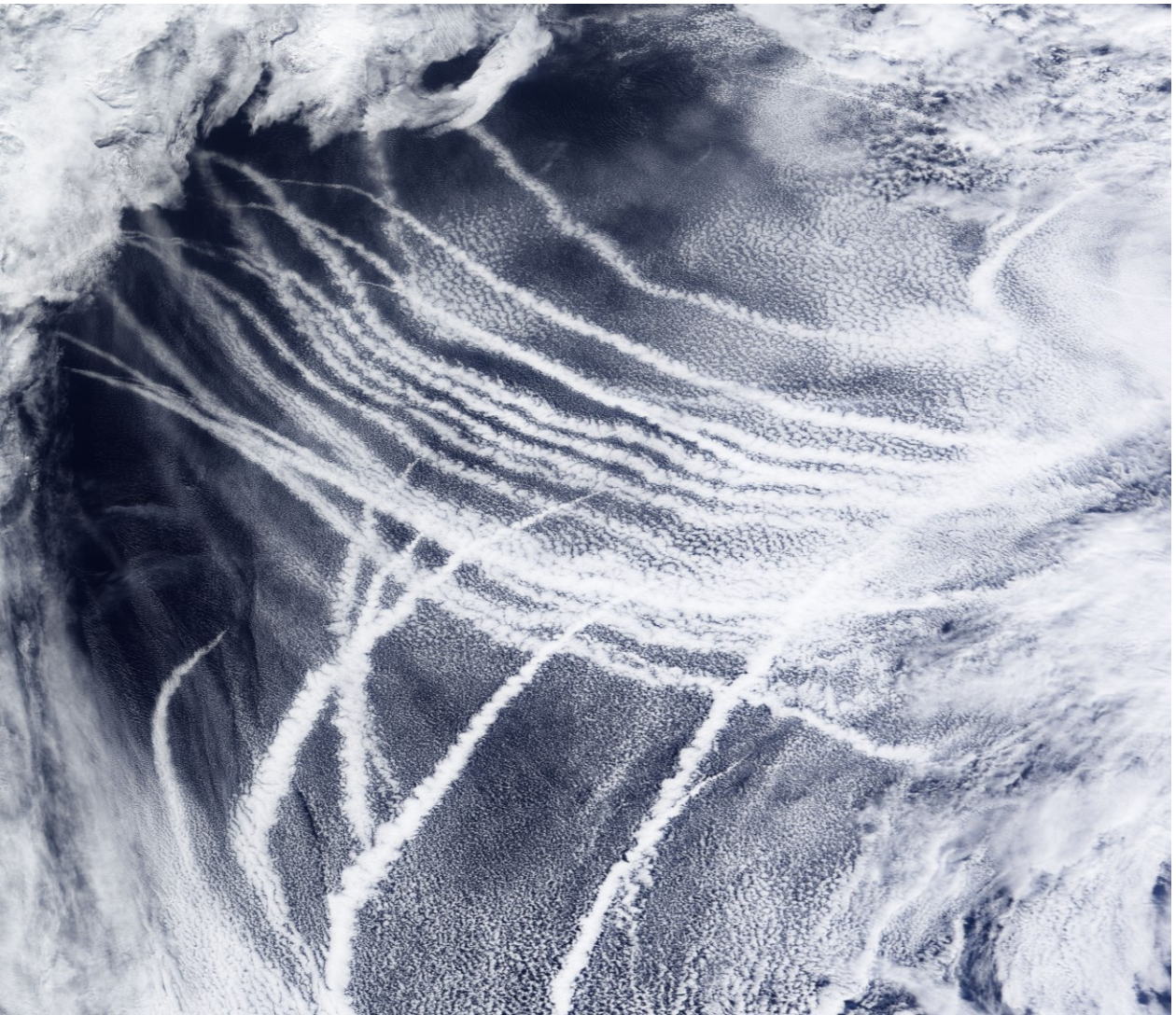
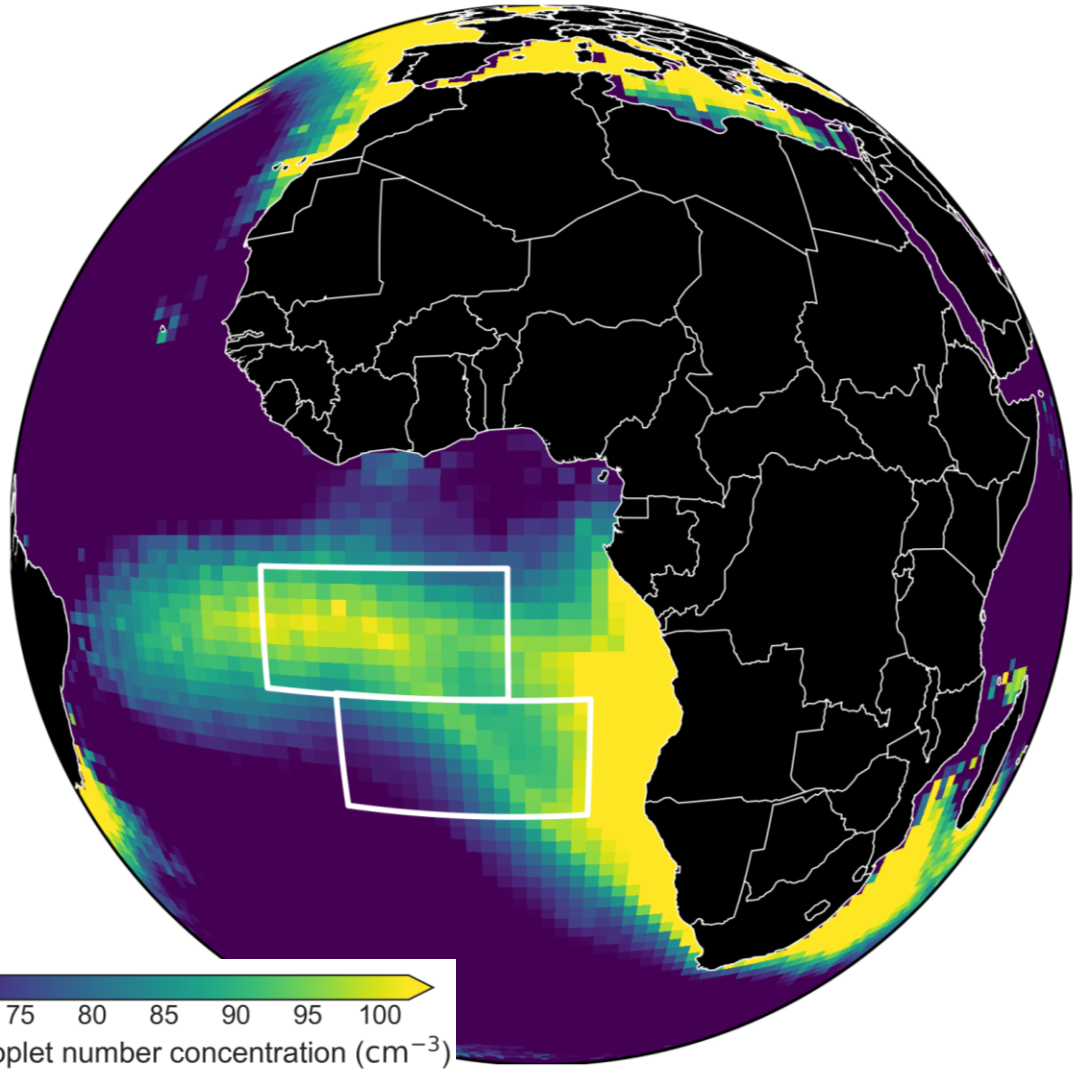
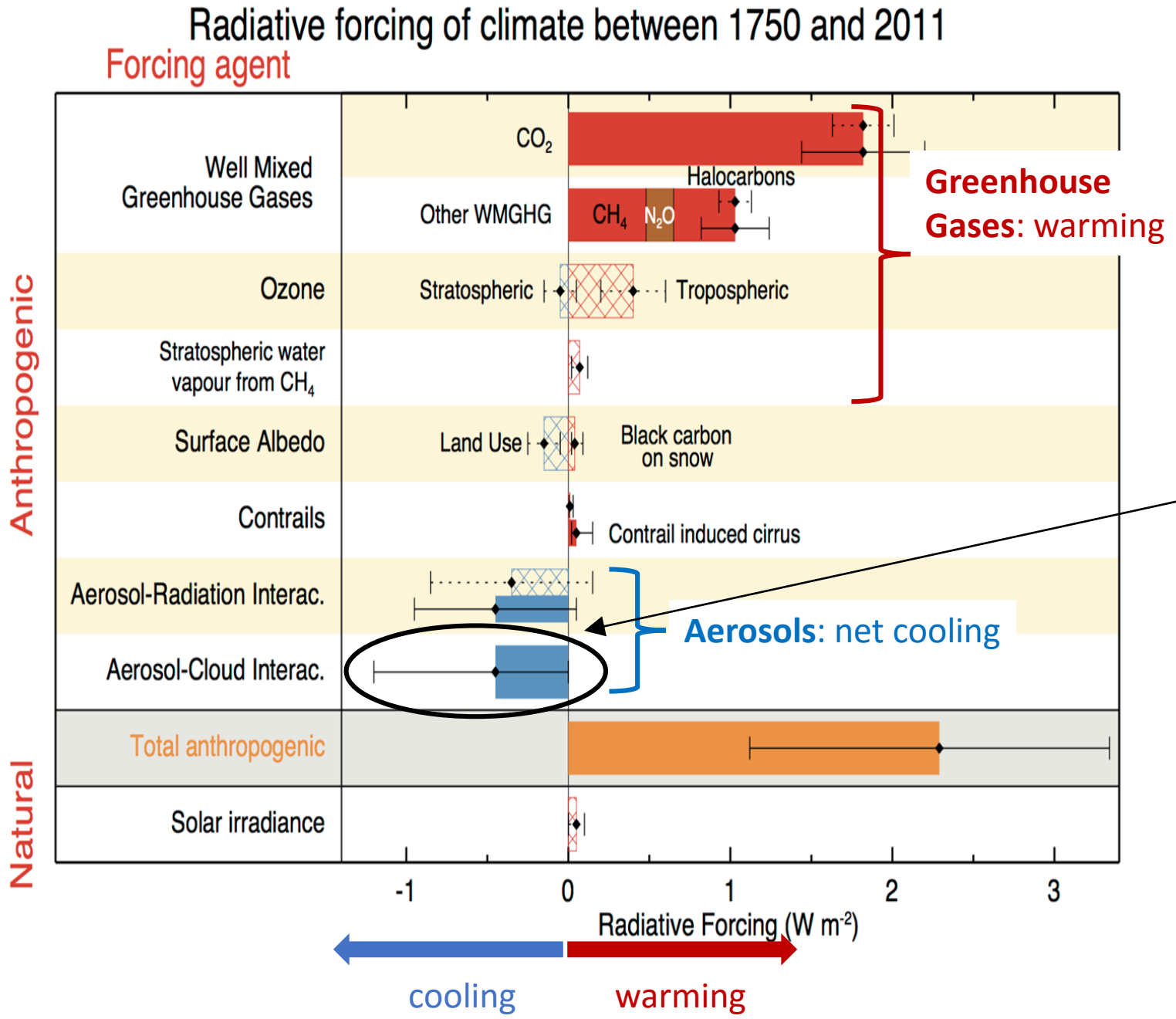






*"There is high confidence that **aerosols and their interactions with clouds** have offset a substantial portion of global mean forcing from well-mixed greenhouse gases. **They continue to contribute the largest uncertainty to the total [Radiative Forcing] estimate.** "*

IPCC 5th Assessment, 2013, Summary for Policymakers p. 13-14.

Anthropogenic radiative forcing, IPCC 2013

Conover (1966), JAS

- First mention of ship tracks in the academic literature

"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."

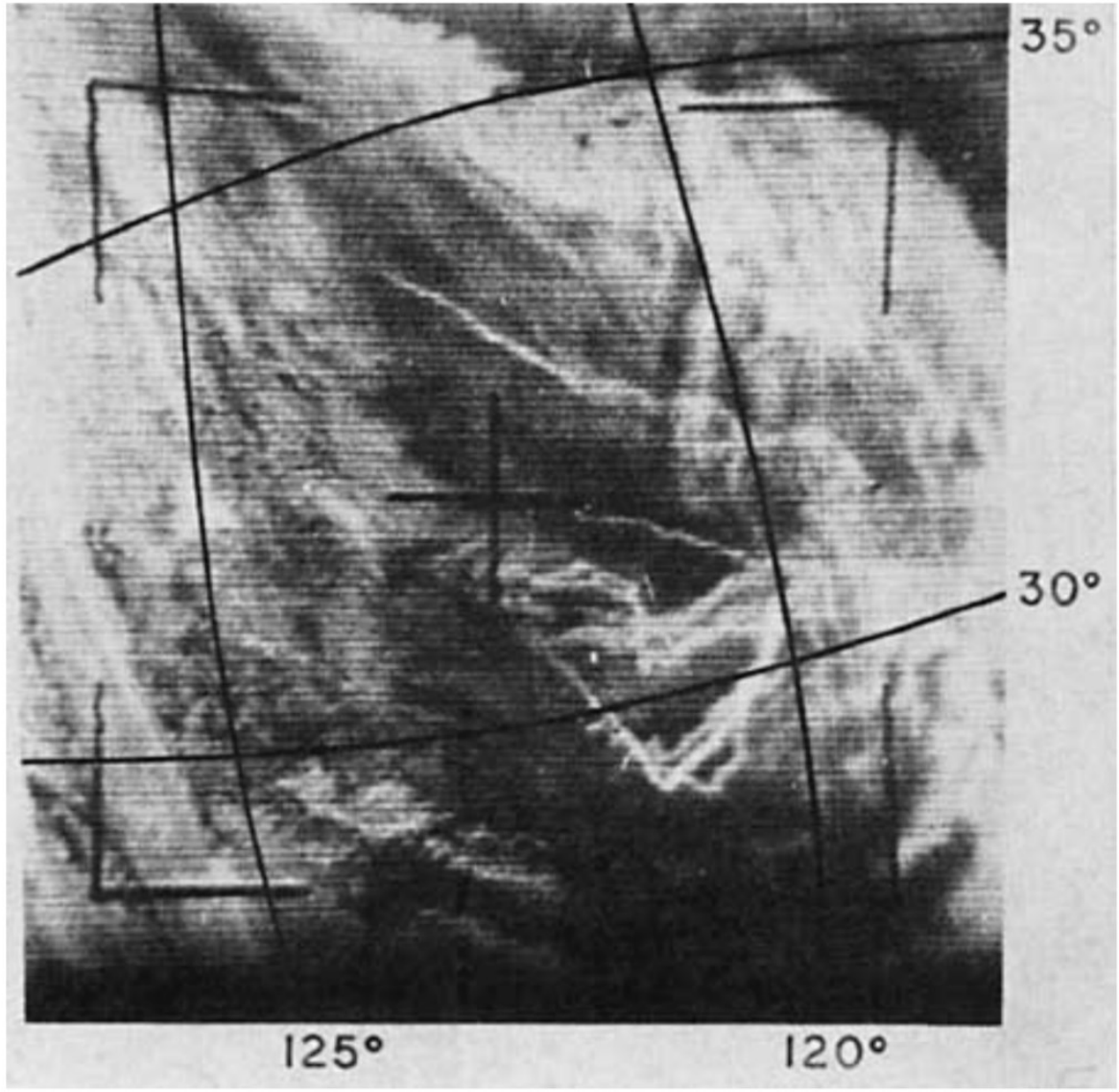
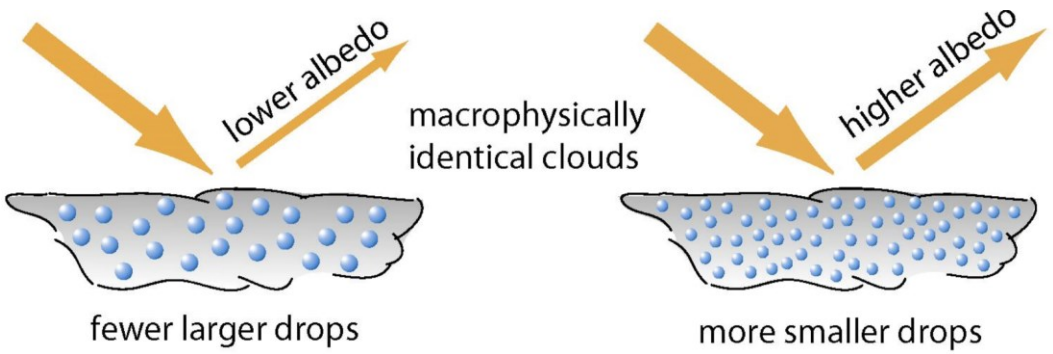


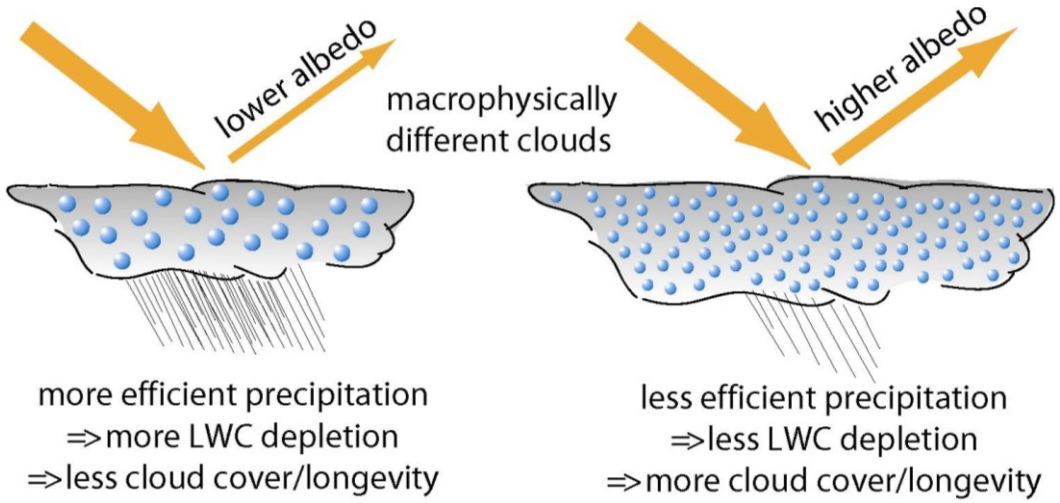
FIG. 2. Family of anomalous lines. California coast and islands south of Santa Barbara are shown on the right. Case 4.

Cloud responses to aerosols

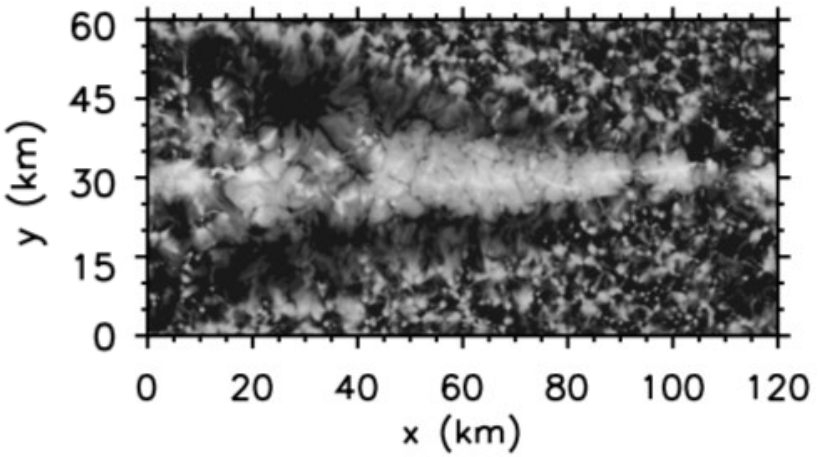
Twomey effect



Cloud adjustments

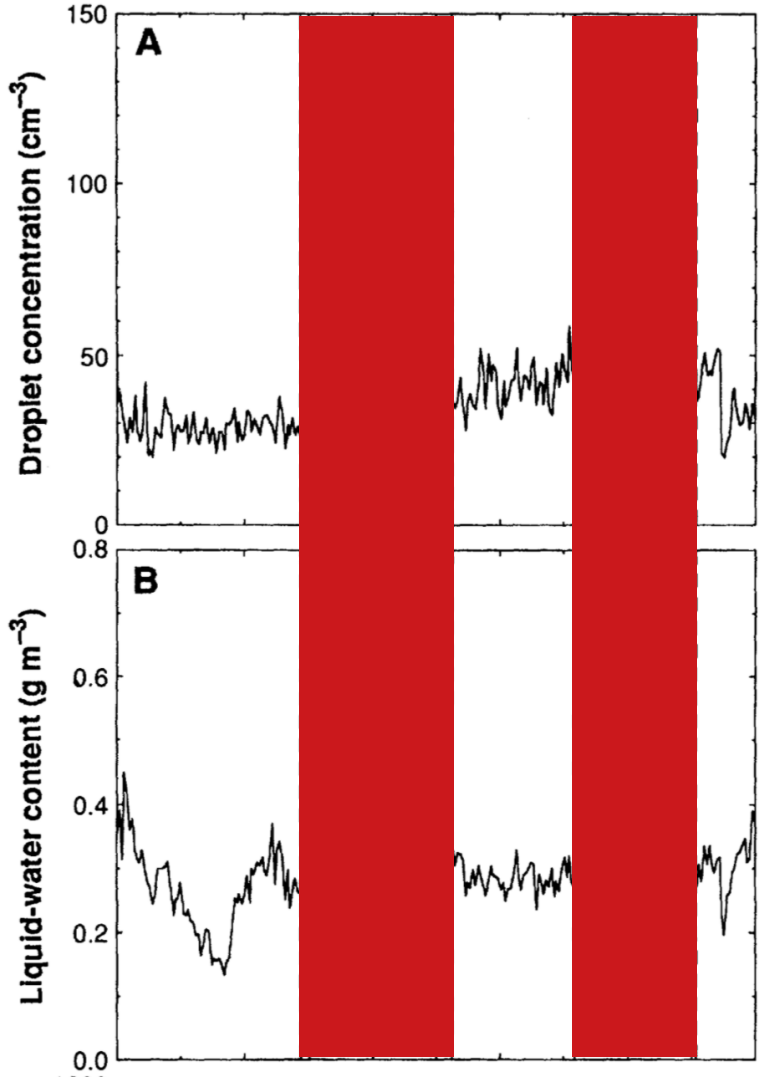


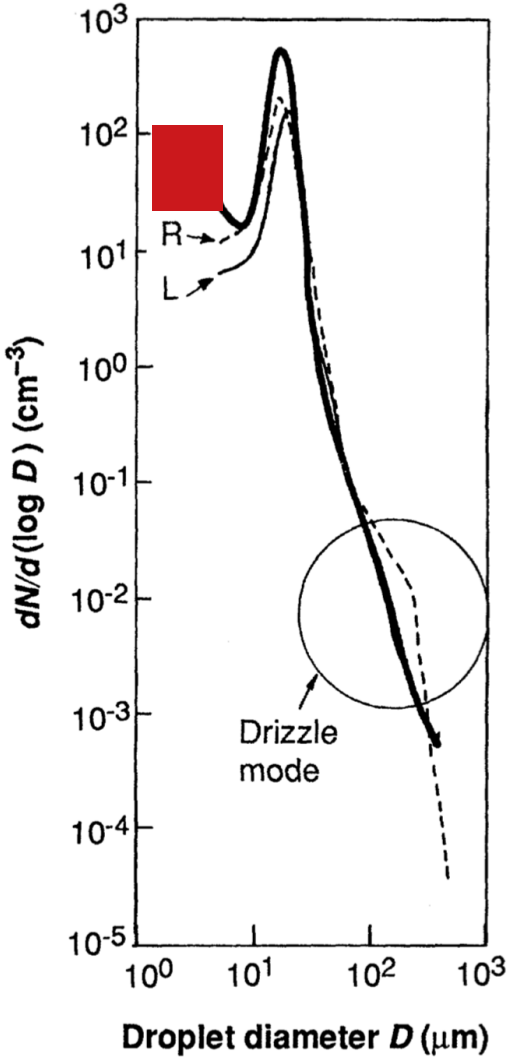
- Perturbed & adjacent clouds can be altered by dynamical responses to initial perturbation



Wang et al., 2011

Ship tracks as a "natural" experiment for ACI hypotheses





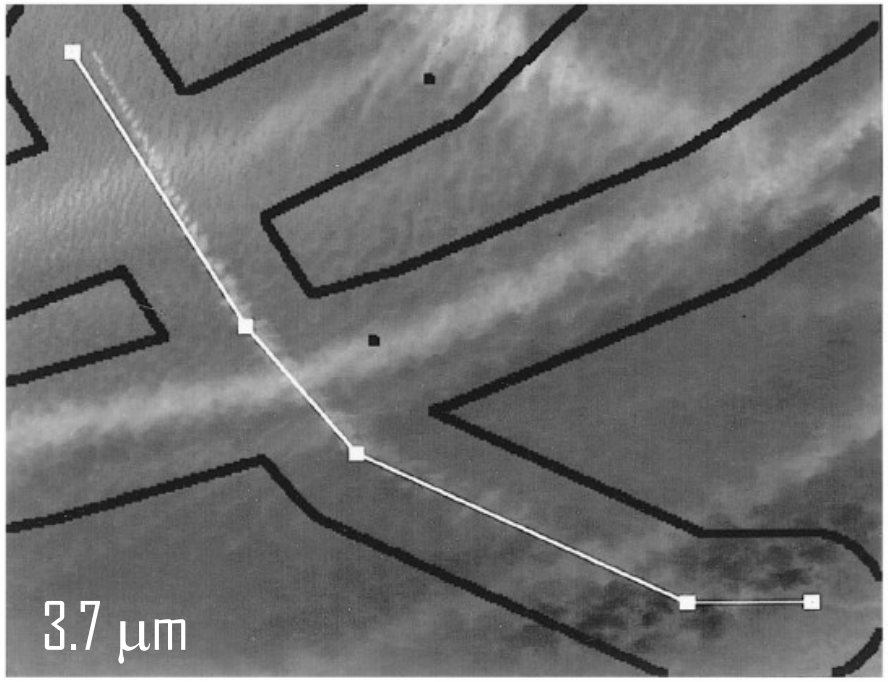
Twomey effect:

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

Cloud adjustments:

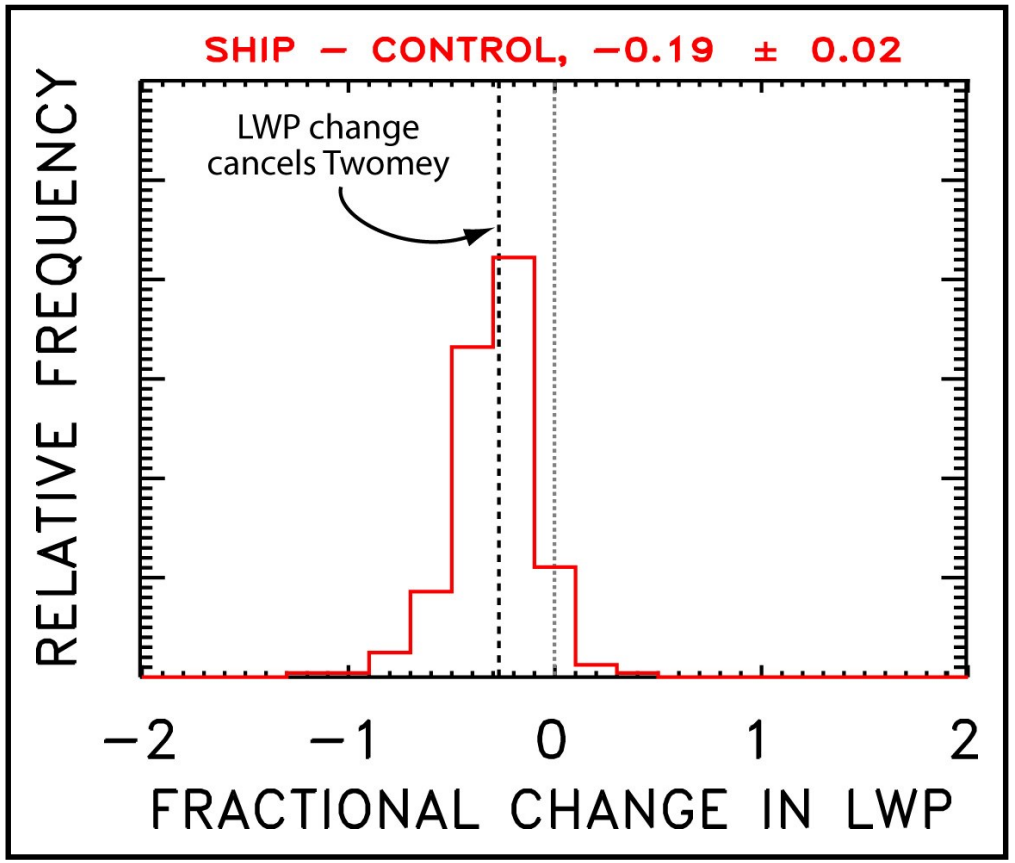
- Precipitation suppression increases cloudiness
- Enhanced entrainment drying decreases cloudiness

Radke et al. (1989), Science



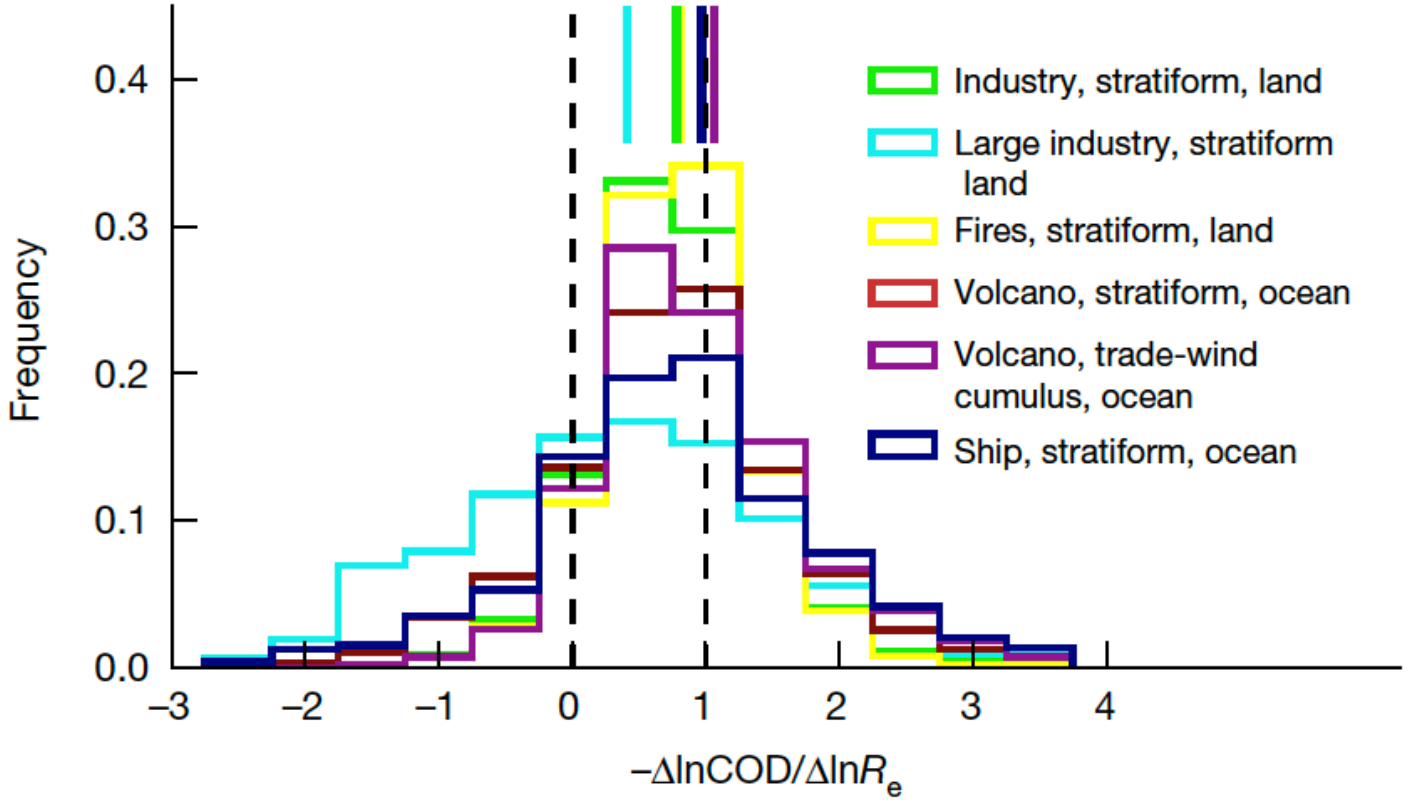
Liquid water content is reduced in many shiptracks

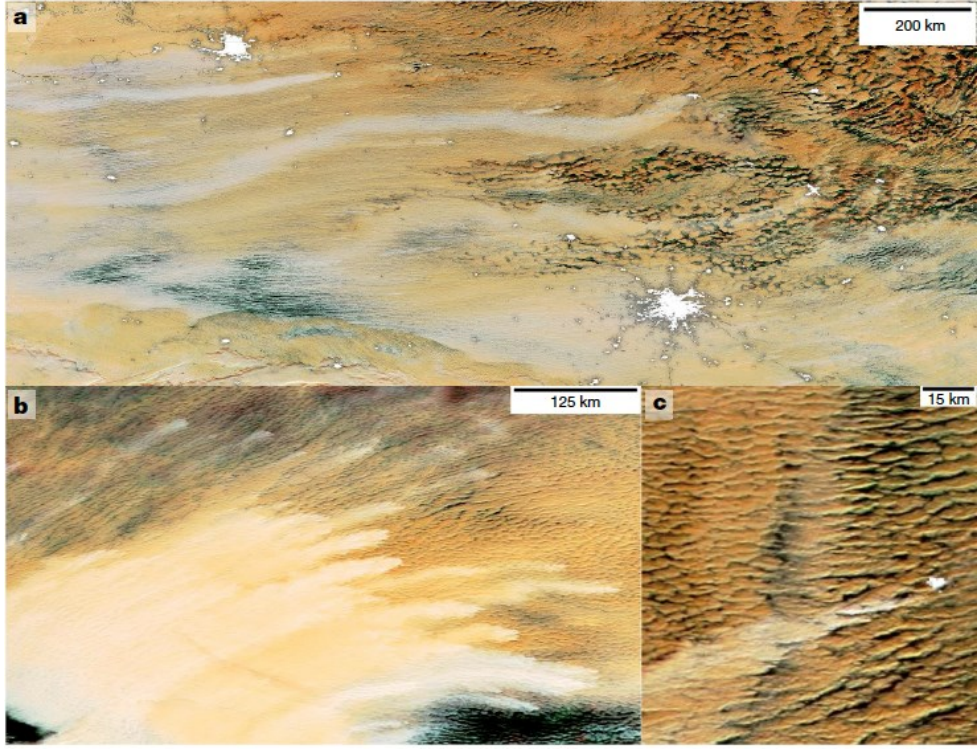
- Cloud droplet size reductions in shipping-perturbed clouds
- Liquid water content in shiptracks is typically reduced compared with surrounding cloud
- Clear refutation of the increased lifetime effect

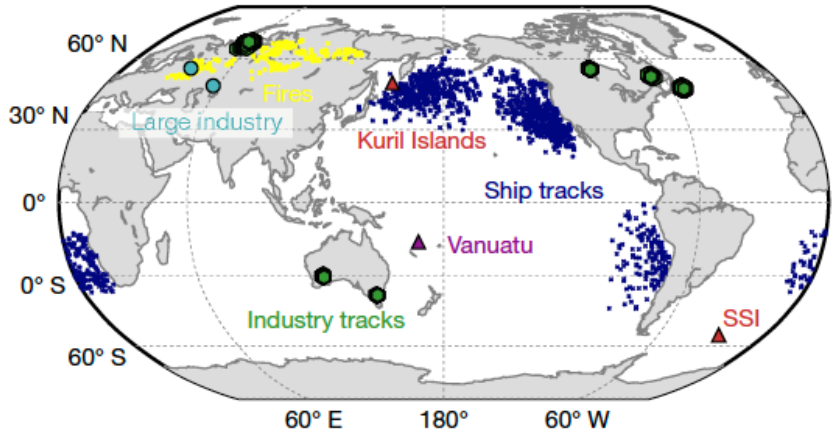


courtesy Jim Coakley, see Coakley and Walsh (2002)

Observations of inadvertent anthropogenic aerosol perturbations





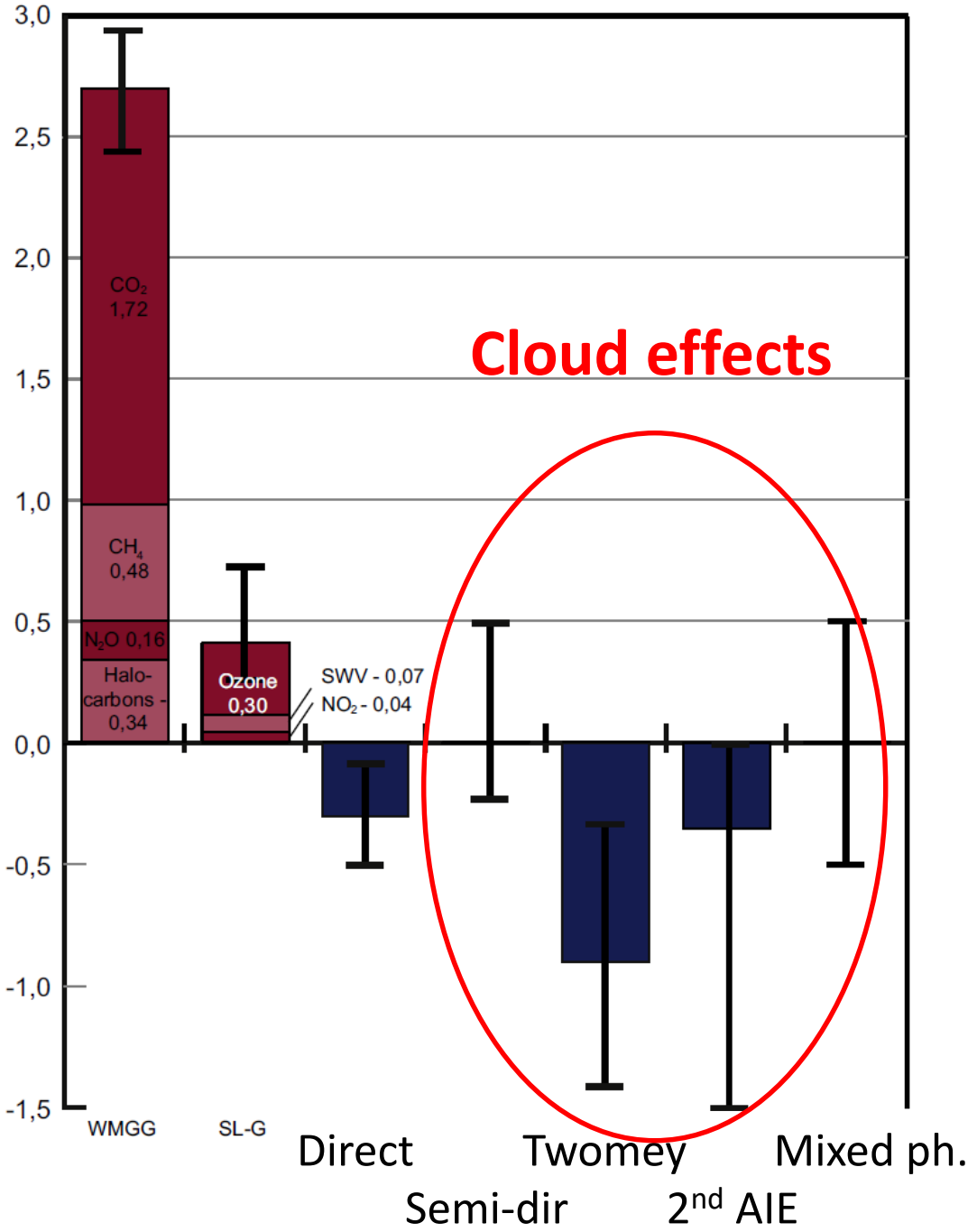


"We estimate that the observed decrease in cloud water offsets 23% of the global climate cooling effect caused by aerosol-induced increases in the concentration of cloud droplets"

Toll, V., Christensen, M., Quaas, J., & Bellouin, N. (2019). Weak average liquid-cloud-water response to anthropogenic aerosols. Nature, 572(7767), 51–55. https://doi.org/10.1038/s41586-019-1423-9

Climate models show increases in liquid water in response to aerosols

- In models, the Twomey effect (reduced droplet size) is enhanced by increased liquid water content due to suppressed precipitation
- Large-scale models poorly capture small-scale mixing responses

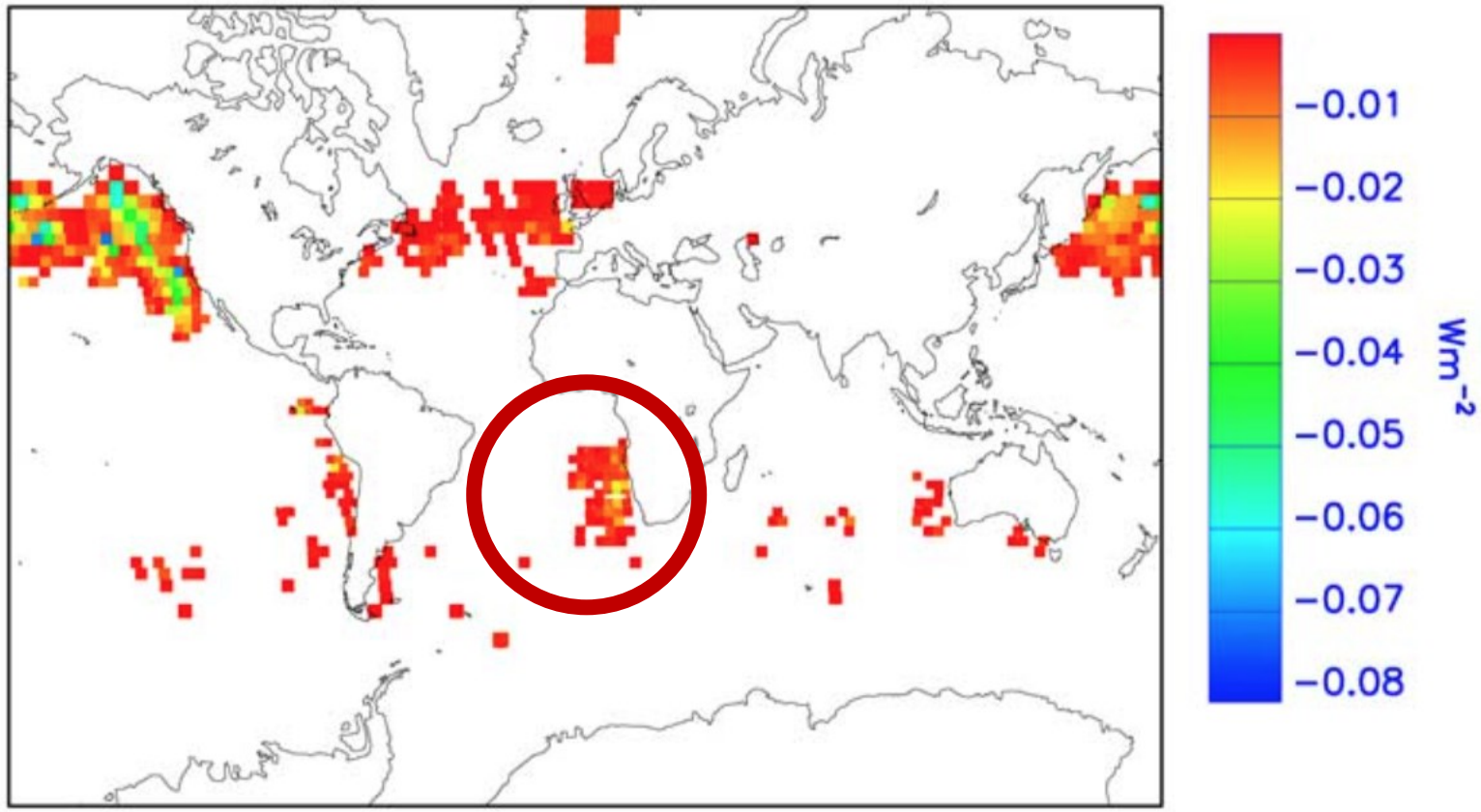


Isaksen, I. S. A., et al., (2009). Atmospheric composition change: Climate–Chemistry interactions. Atmospheric Environment, 43(33), 5138–5192. https://doi.org/10.1016/j.atmosenv.2009.08.003

Do ship tracks matter globally?

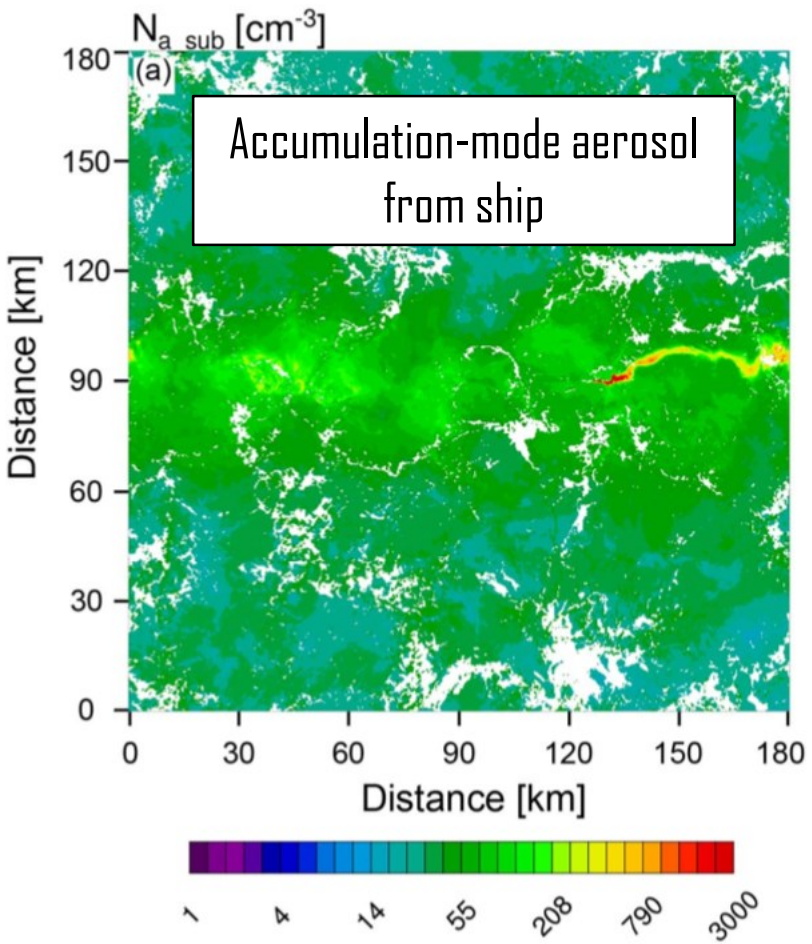
- Global ERF_{ACI} estimate from one year's worth of ship track data of -0.0005 W/m^2

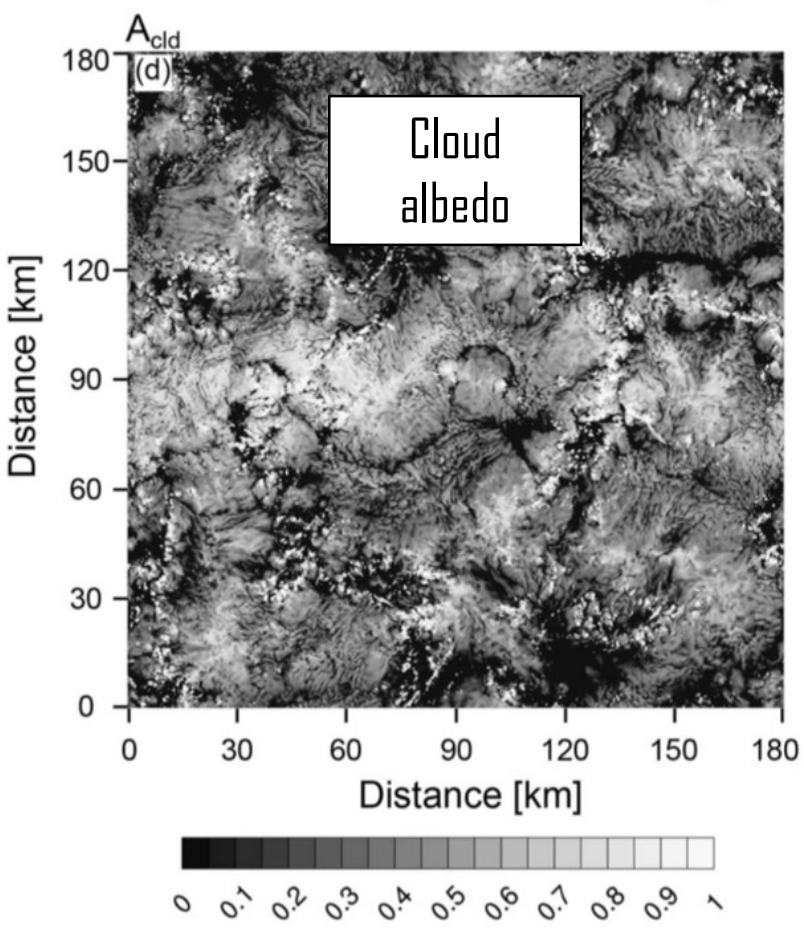
- But model spread of ERF_{ACI} ranges from -0.06 to -0.6 W/m^2...



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

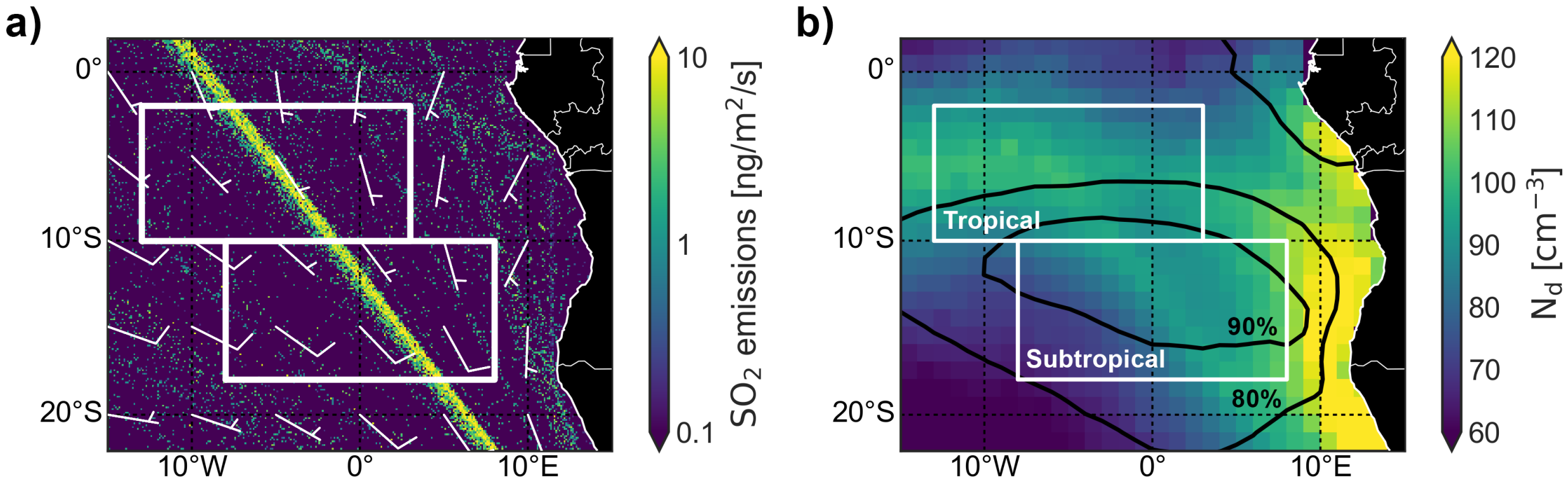
Shipping perturbations may not be readily visible given natural cloud variability





Possner et al. (2018), ACP

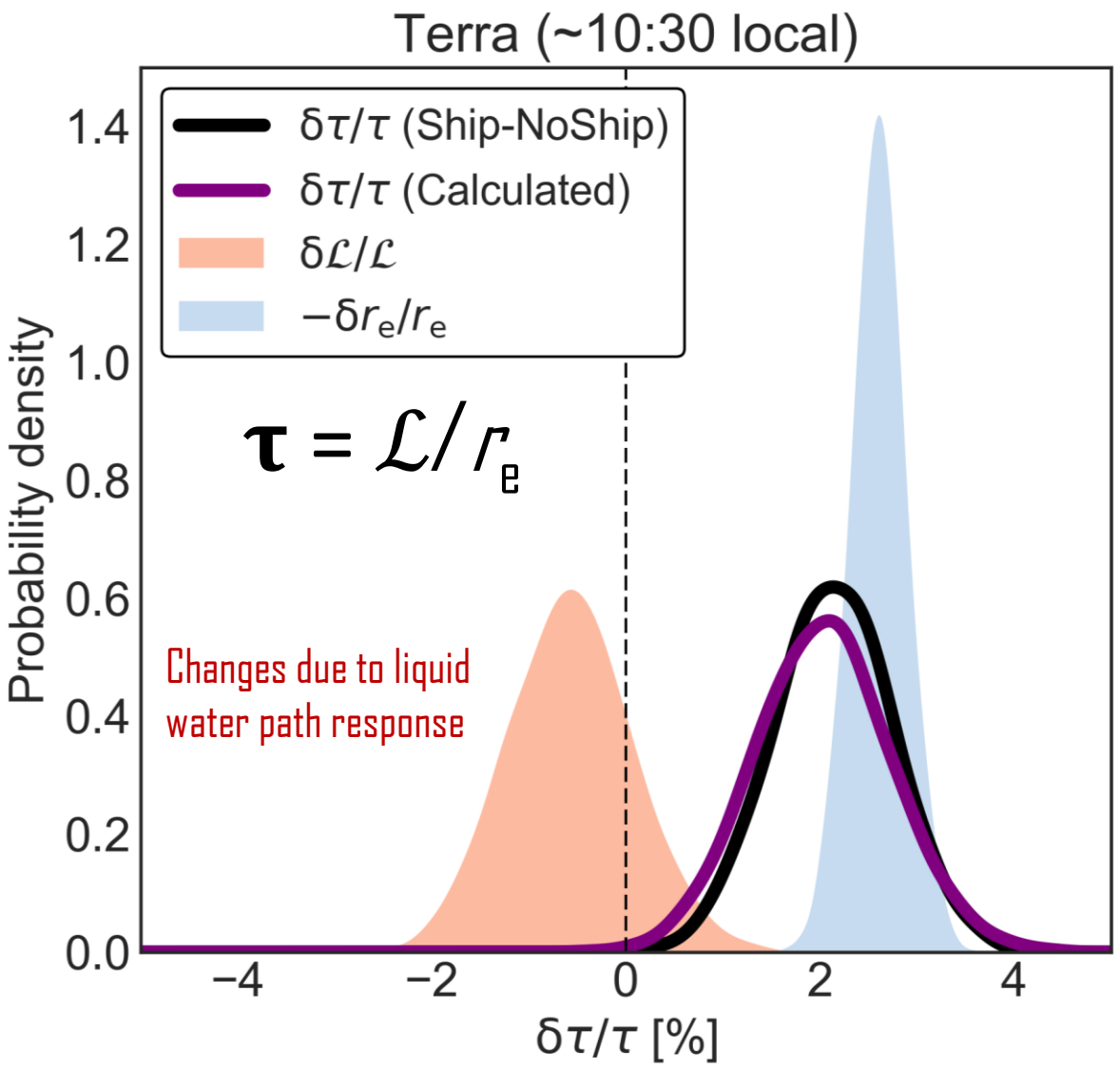
Climatological shipping lane perturbations can be detected

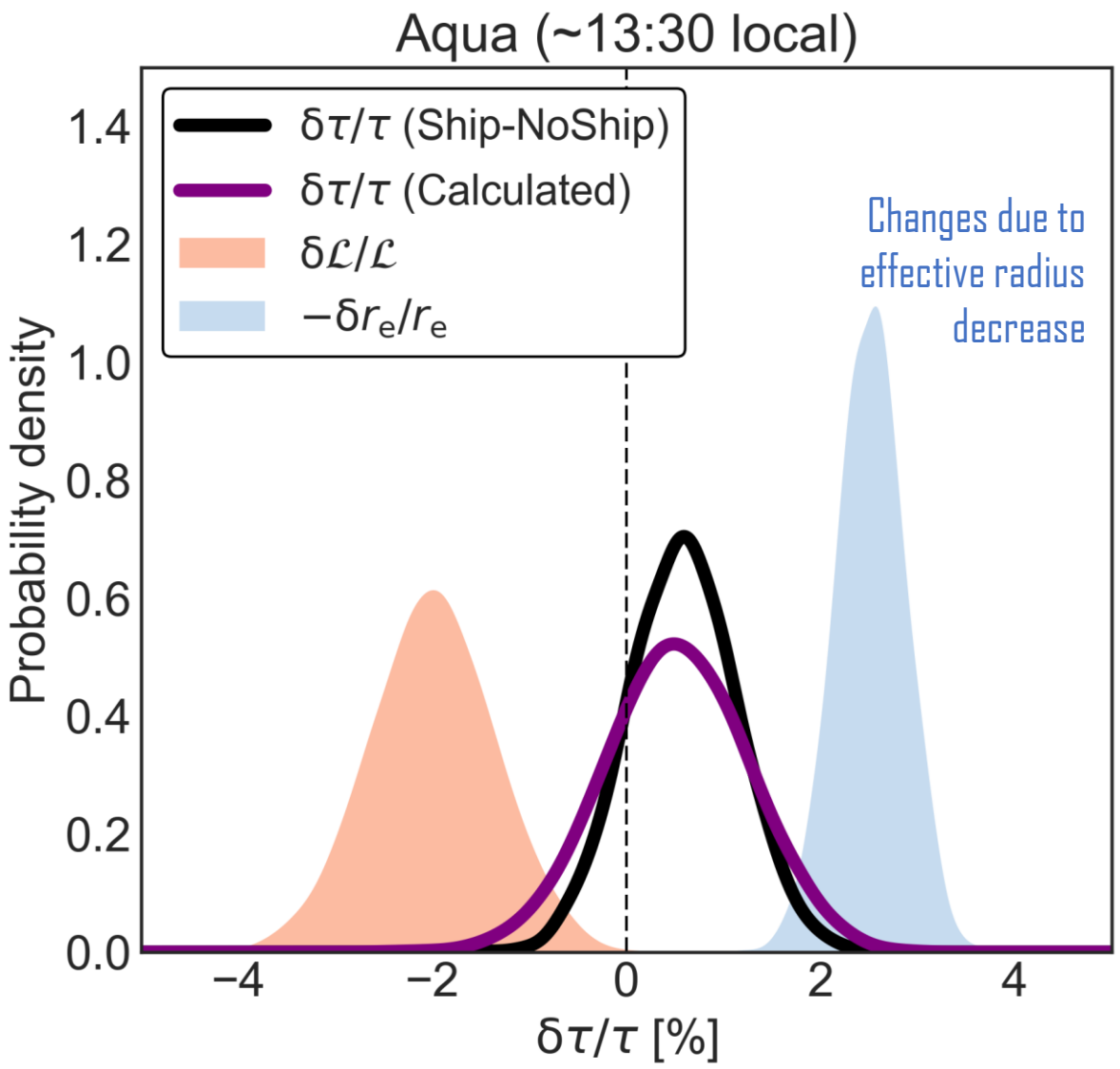


**All data is for austral spring (September-October-November) climatology from 2003-2015*

Substantial Cloud Brightening from Shipping in Subtropical Low Clouds. Diamond, M. S., H. M. Director, R. Eastman, A. Possner and R. Wood, 2020: *AGU Advances*, **1**, e2019AV000111

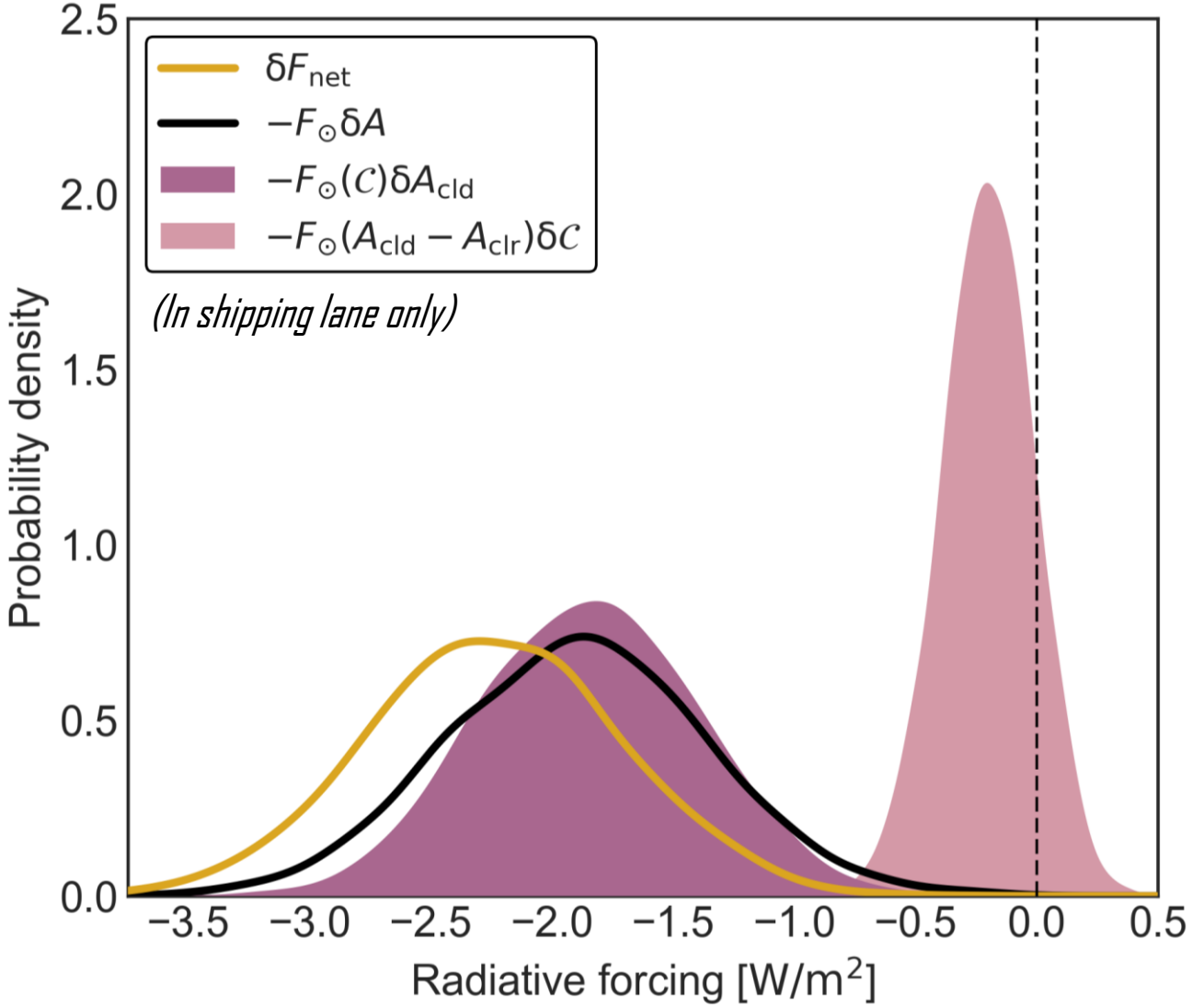
Cloud optical thickness (τ) changes





Brightening can be measured using CERES

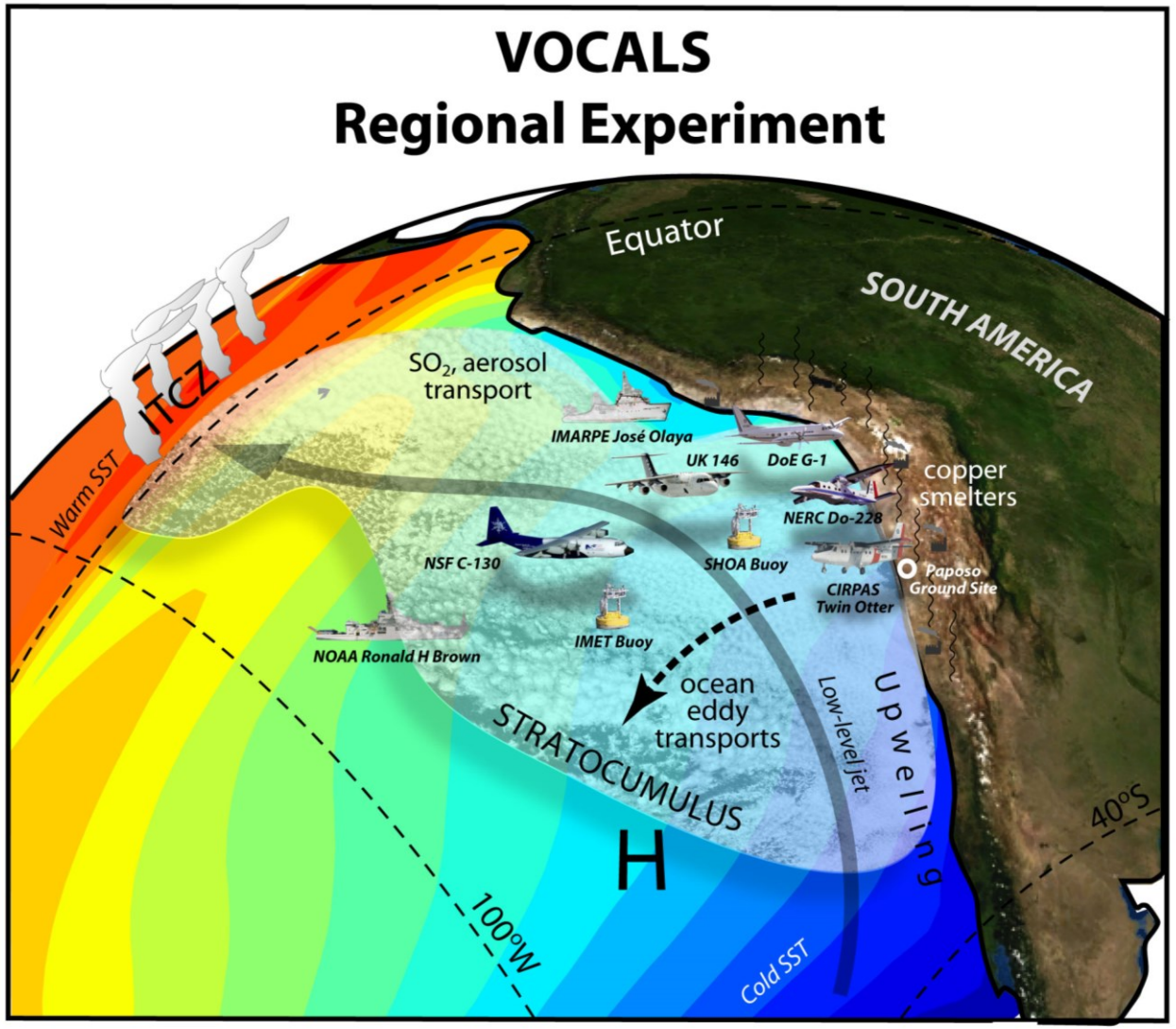
- CERES total albedo (A), clear-sky albedo (A_{clr}), and cloud fraction (C) used to estimate cloud albedo (A_{cld})
- **Total albedo change** broken into components from changes in **cloud brightness** versus **cloud fraction**
- CERES **net flux** tested directly
- 2 W m^{-2} of increased solar reflection in shipping lane
- Can be used as a direct test for climate models.....forthcoming

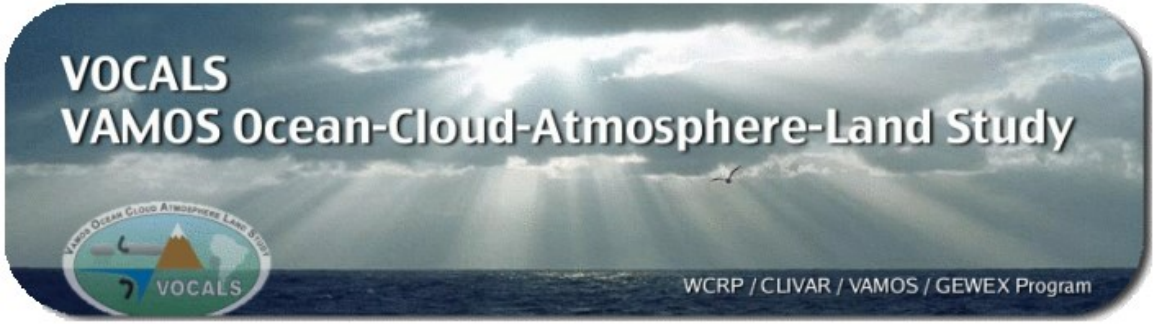


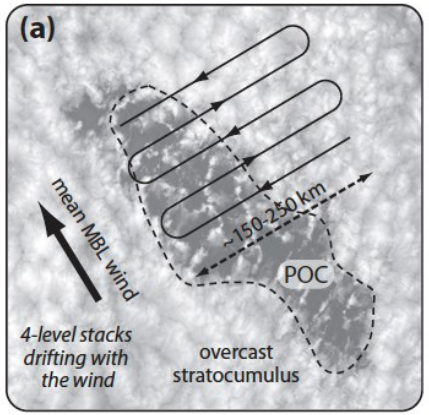
Limitations to satellite observations for testing MCB efficacy

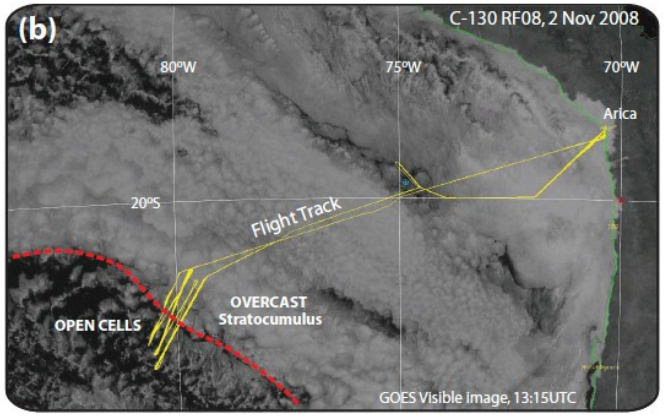
- Commercial shipping emissions are not a good proxy for directly emitted salt particles proposed for marine cloud brightening
- Shipping lane and shiptrack observations limited to specific low cloud and meteorological regimes
- Satellites cannot measure properties of aerosol below clouds
- Satellite measurements need to be augmented with more detailed in situ and airborne remote sensing observations of cloud responses to single and multiple aerosol plumes

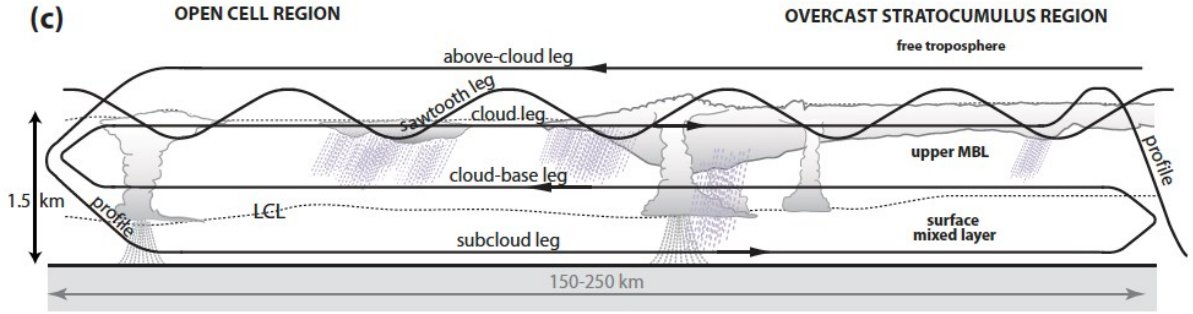
Aircraft campaigns provide fundamental aerosol-cloud process information







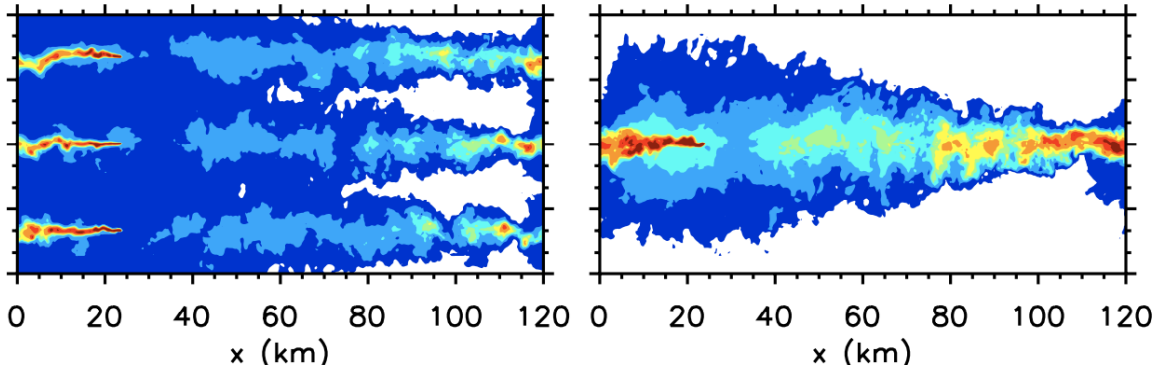




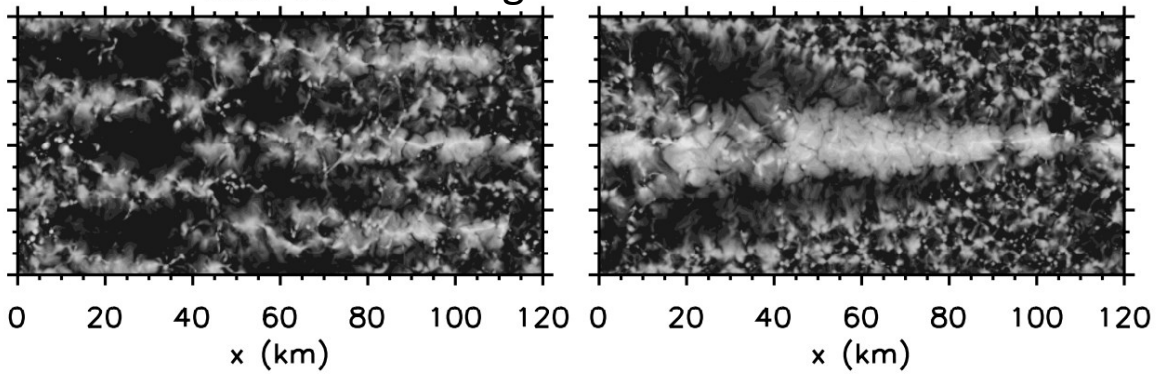
Aerosol-Cloud Interaction Studies

Cloud–scale, high resolution modeling studies

Injected aerosol plumes



Resulting cloud fields

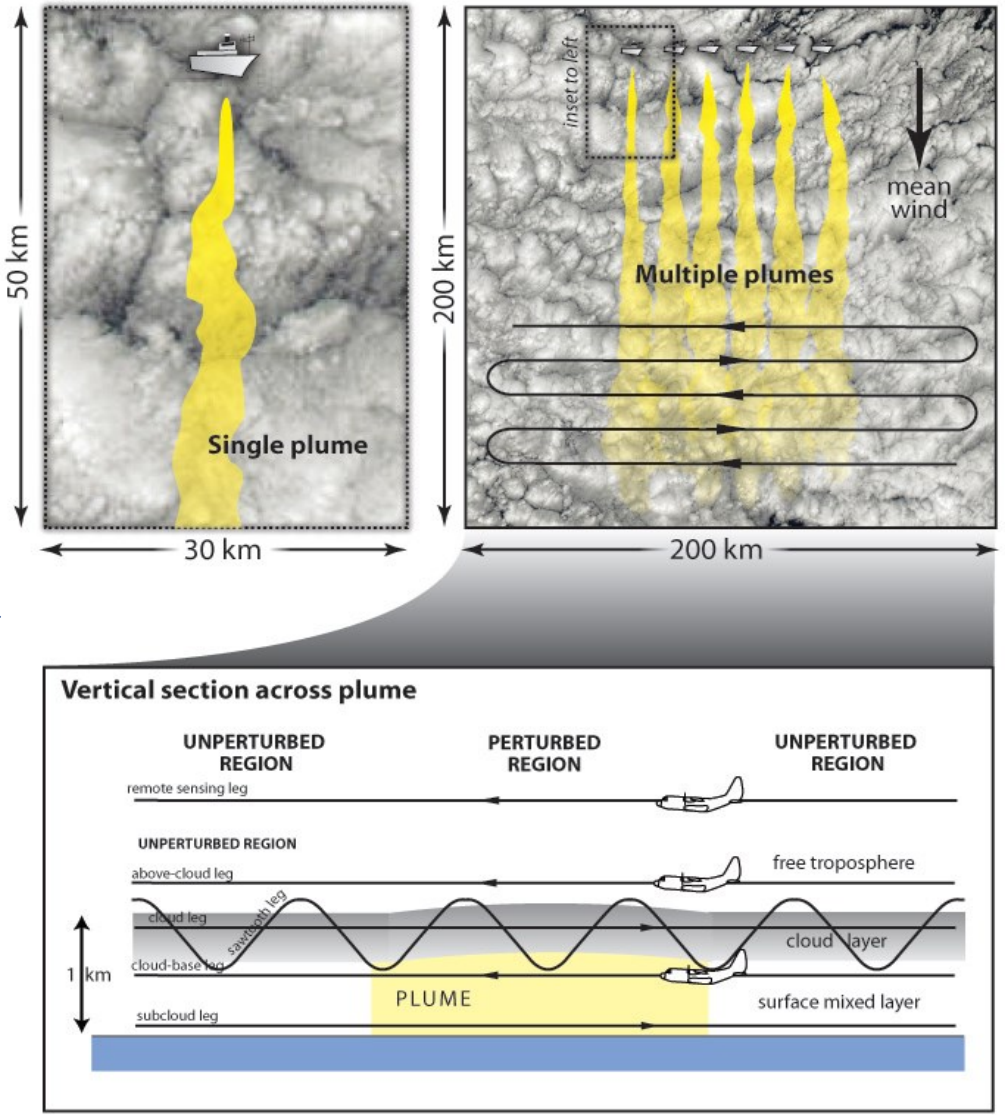


Wang et al., 2011

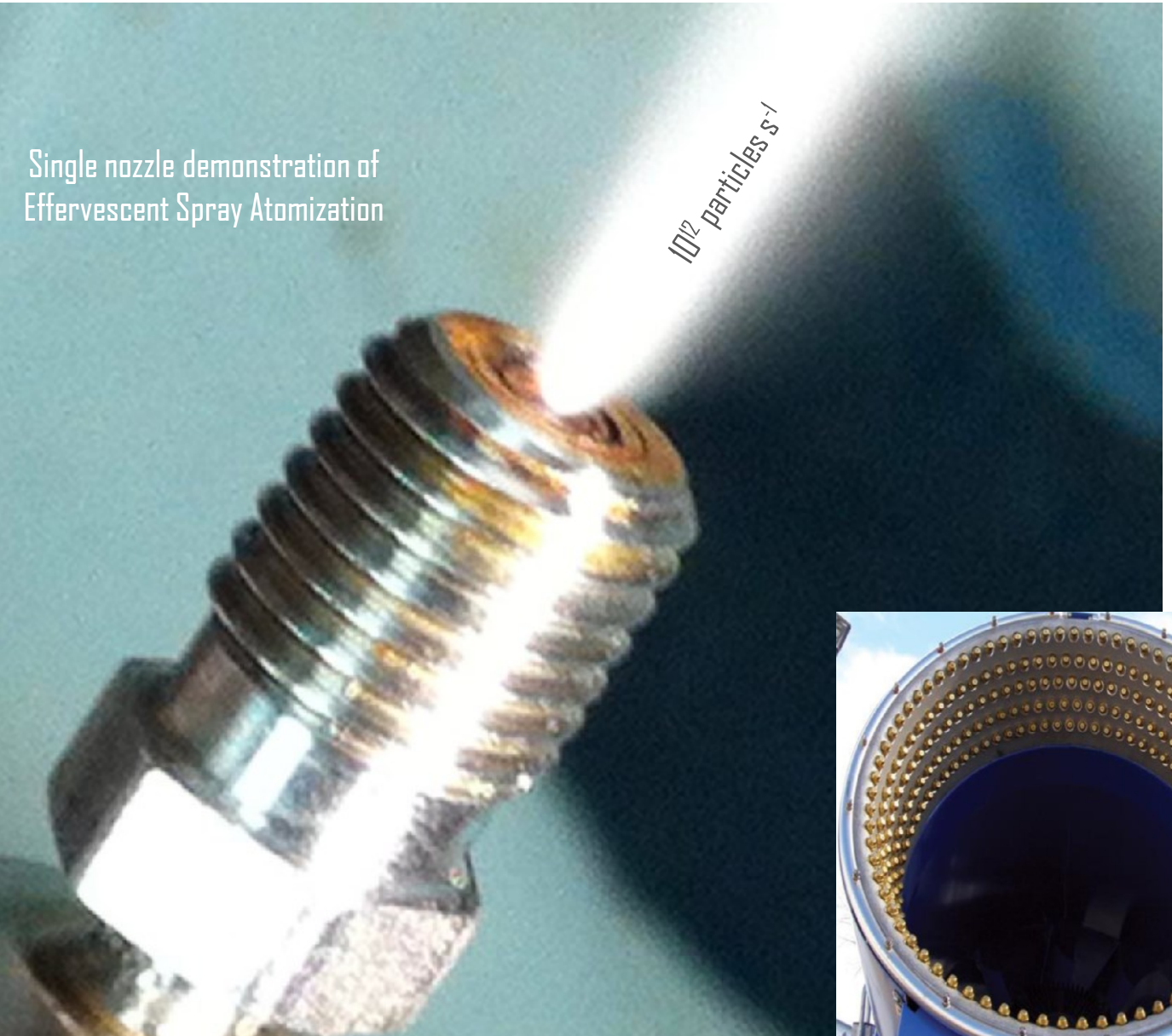
Parameterization development

Single-plume field study

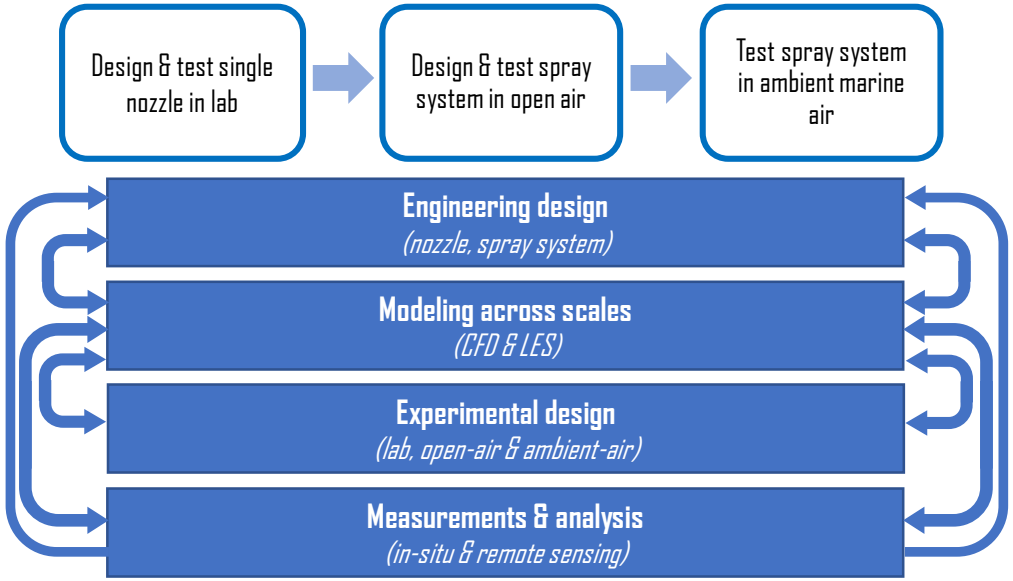
Multi-plume field study



A new Instrument for Cloud Physics Research

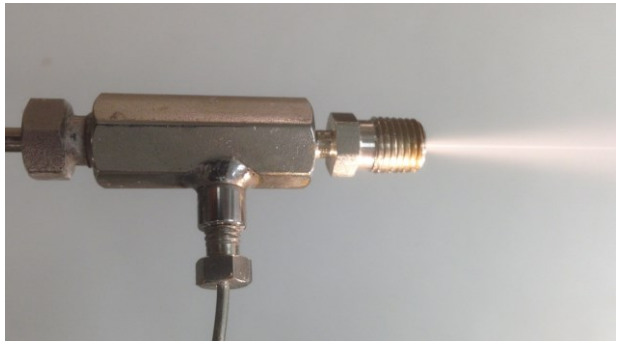


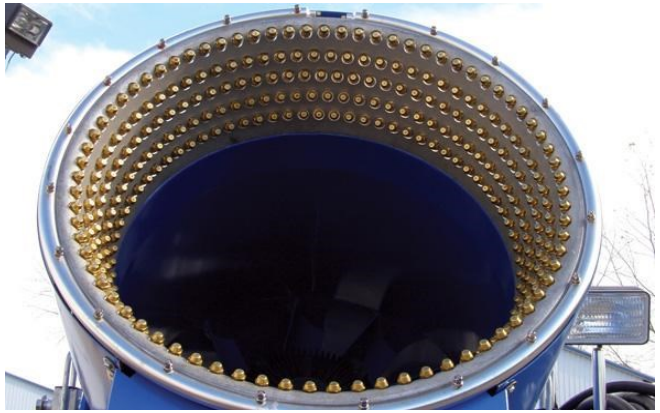
MCB Aerosol Spray System Development



MCB Aerosol Technology development:
A new Instrument for Cloud Physics Research

CFD* modeling ↔ spray system design ↔ lab tests ↔ LES** modeling ↔ open-air tests ↔





Research-grade
spray system

** CFD= Computational Fluid Dynamics*
*** LES = Large Eddy Simulation*

Established research plan with high scientific value

Field testing design is based on prior observational programs designed to understand aerosol impacts on climate

Valuable experimental work

- Addresses a critical gap in understanding climate ("cloud-aerosol effects")
- Helps understand cooling effects that are already occurring, and subject to change
- Materials are benign, effects are localized and temporary (2-3 days)
- Experimental research is based on similar observational field studies

For overview of MCB Project see Sarah Doherty's CCIS Webinar, 27 May 2020

Atmospheric Intervention Research (AIR) Program

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MARINECLOUD — BRIGHTENING PROJECT —

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— BRIGHTENING PROJECT —

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"Old SALTS"