FINNISH METEOROLOGICAL INSTITUTE

Indirect aerosol forcing estimates over southeast and northeast Atlantic marine stratiform clouds

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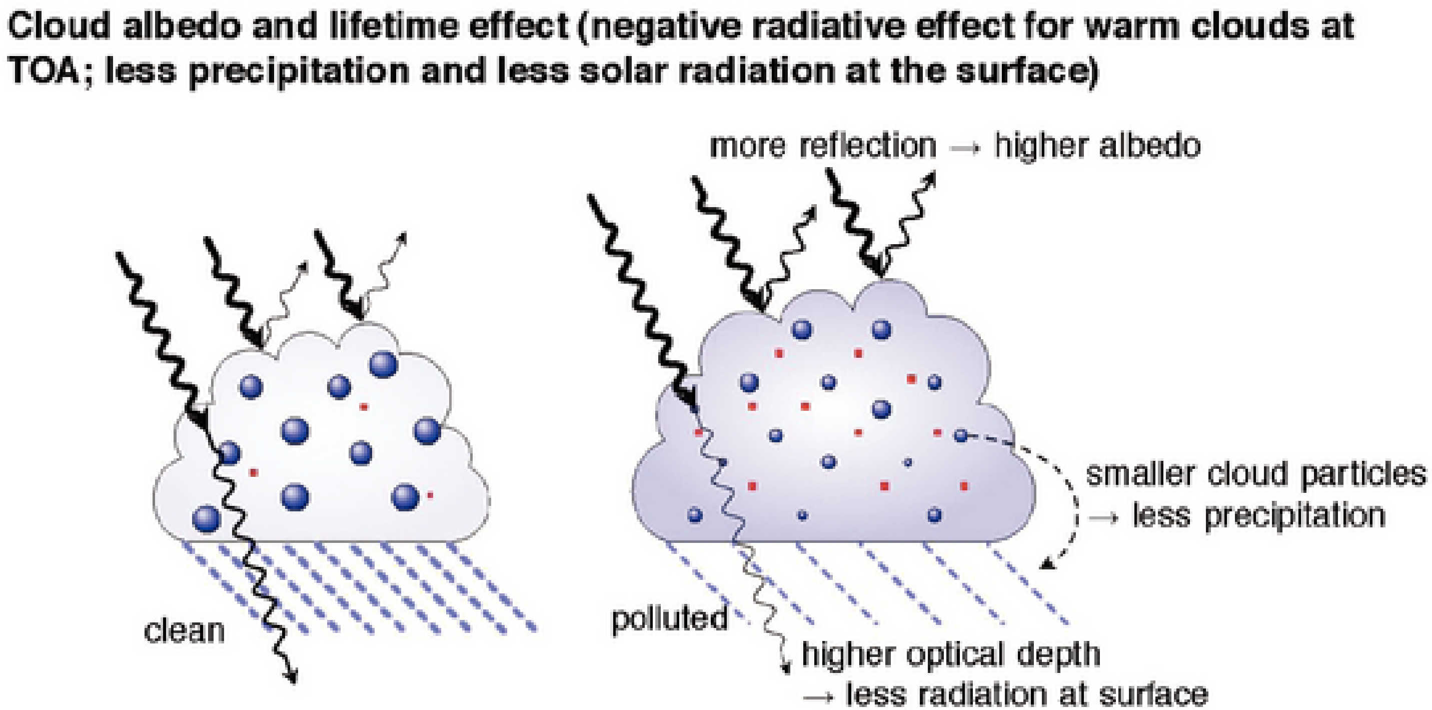
Aerosol Indirect Forcing



Satellite estimates of indirect aerosol forcing are still uncertain – for stratocumulus cloud regime

1. Likely, due to the uncertainties in the strength of slopes of N_d versus AOD and AI
2. Due to not accounting co-variations in large-scale meteorology

Objectives

At a higher resolution of 25kmx25km

1. To evaluate the strength of slopes of N_d versus AI and cloud properties

1. To study the dependency of these slopes on large-scale meteorology

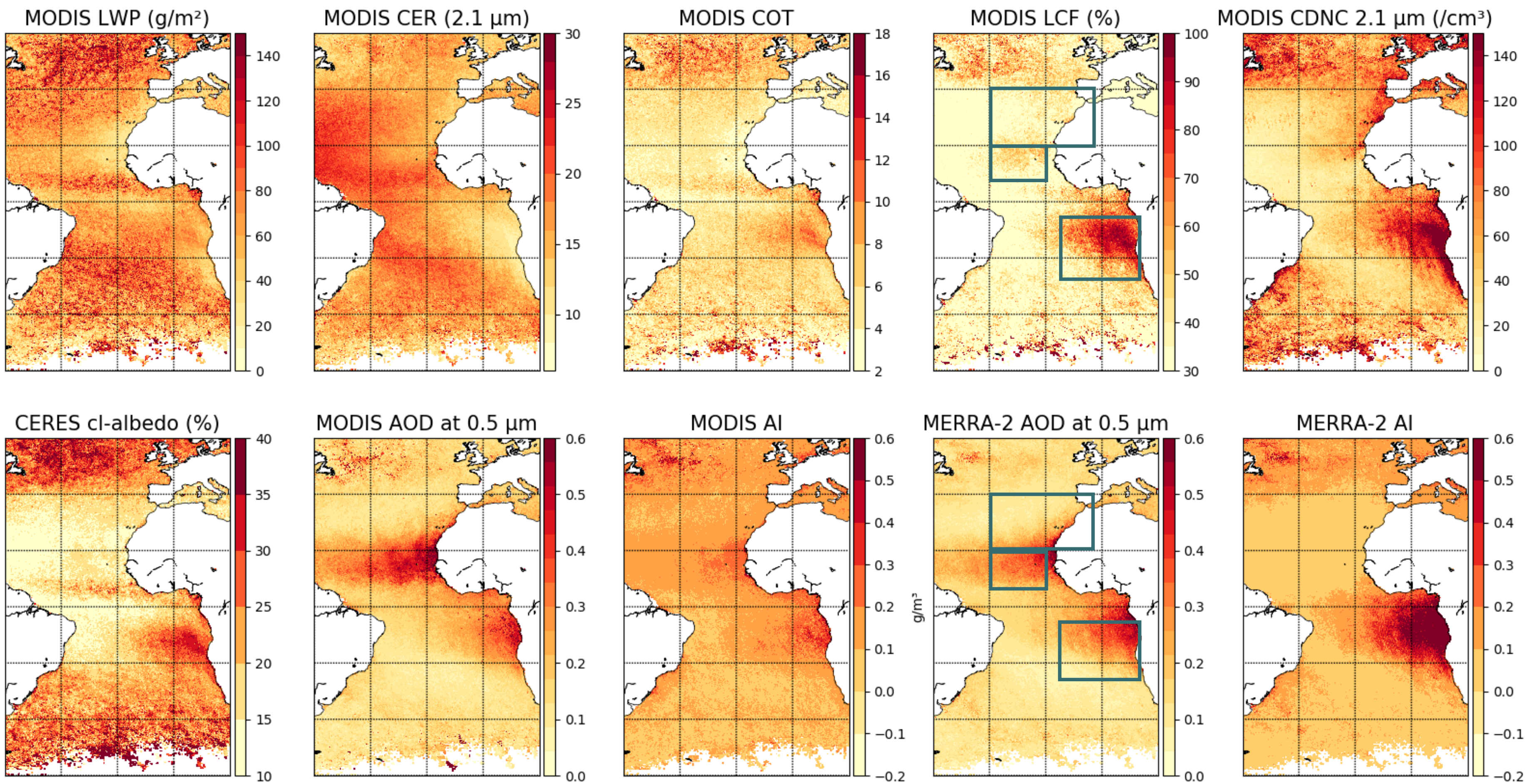
2. To estimate Aerosol indirect forcing - Intrinsic (cloud albedo effect) and extrinsic (cloud lifetime effect) terms

Data and Methodology

- MODIS Aqua C6.1 L2 cloud and aerosol products & OMI-ACA retrieval
- AMSR-2 V8 LWP, SST, and rain rate
- CERES Aqua TOA radiation measurements
- MODIS and CERES data are collocated onto 25km AMSR-2 grid within the time difference of 15 minutes
- MERRA-2 meteorology and aerosol analysis data

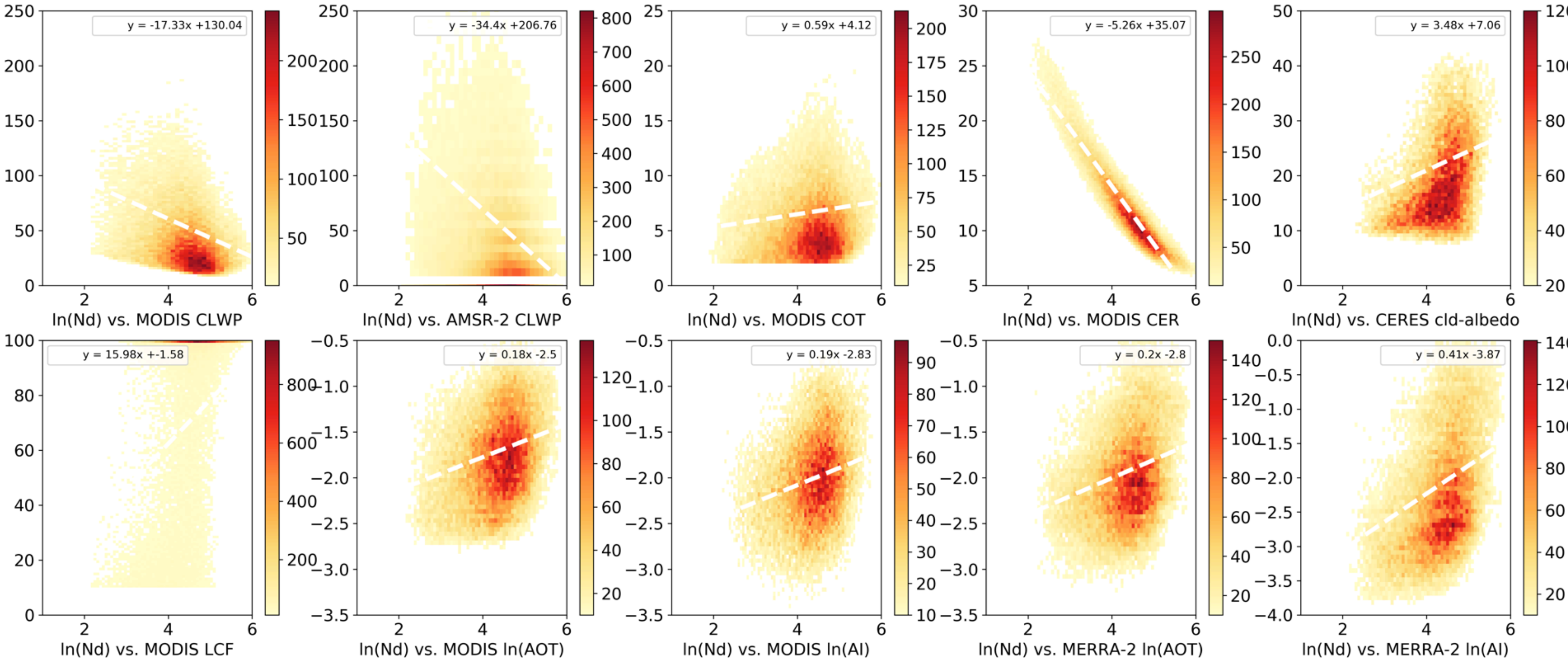
- Study period 06/2015 – 05/2018
- Single layer liquid clouds with ice-free pixels, CTT>273K and ω700> 0
- Cloud droplet #concentration (N_d) is computed following Bennartz and Rausch (2017) using r_e at 3.7 µm and Quaas et al. (2008) using r_e at 2.1 µm.
- Anthropogenic fraction calculated following Bellouin et al. (2013)
- Aerosol indirect forcing is computed following Chen et al. 2014
- Analyzed 25km grid-boxes with LCF>10% and rain rate=0.

Cloud and Aerosol Properties – June - Nov 2015-2018



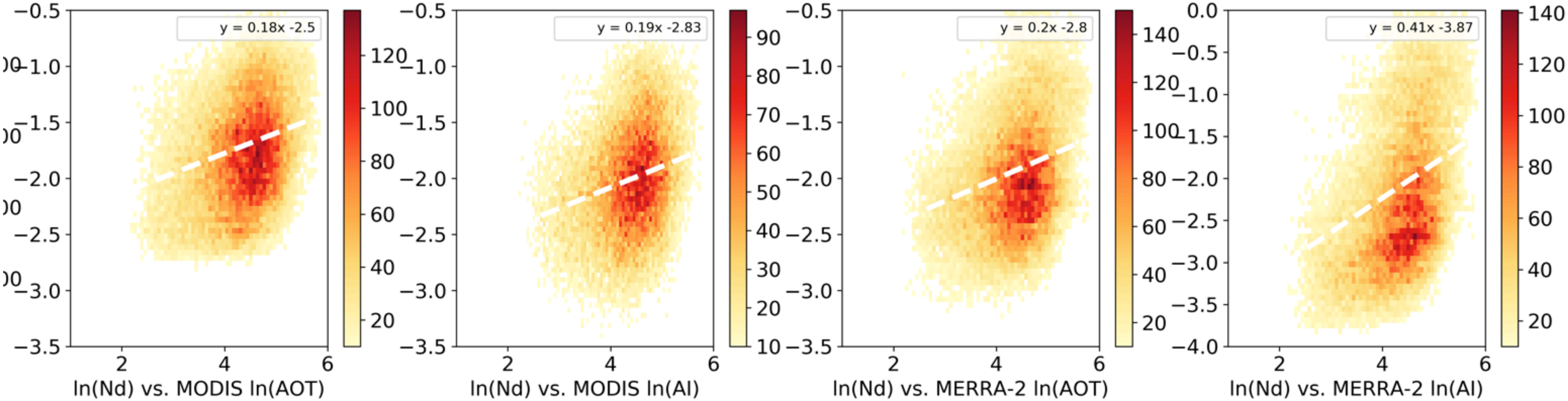
- Southeast Atlantic Sc – Smoke plume
- Northeast Atlantic Sc – Desert dust

Southeast Atlantic Stratocumulus (smoke)
OLS slopes of ln(N_d) versus Cloud and Aerosol parameters

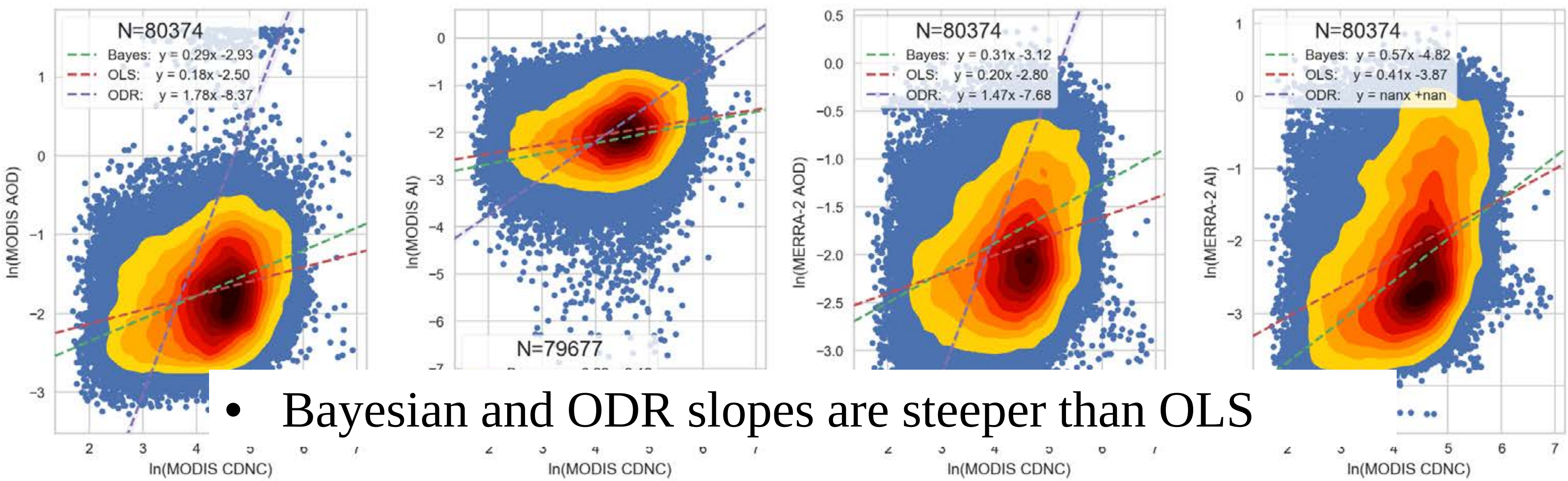


- LWP, CER – Negative slope
- COT, cl-albedo, LCF – Positive slope
- AOD, AI – Positive slope

OLS slopes

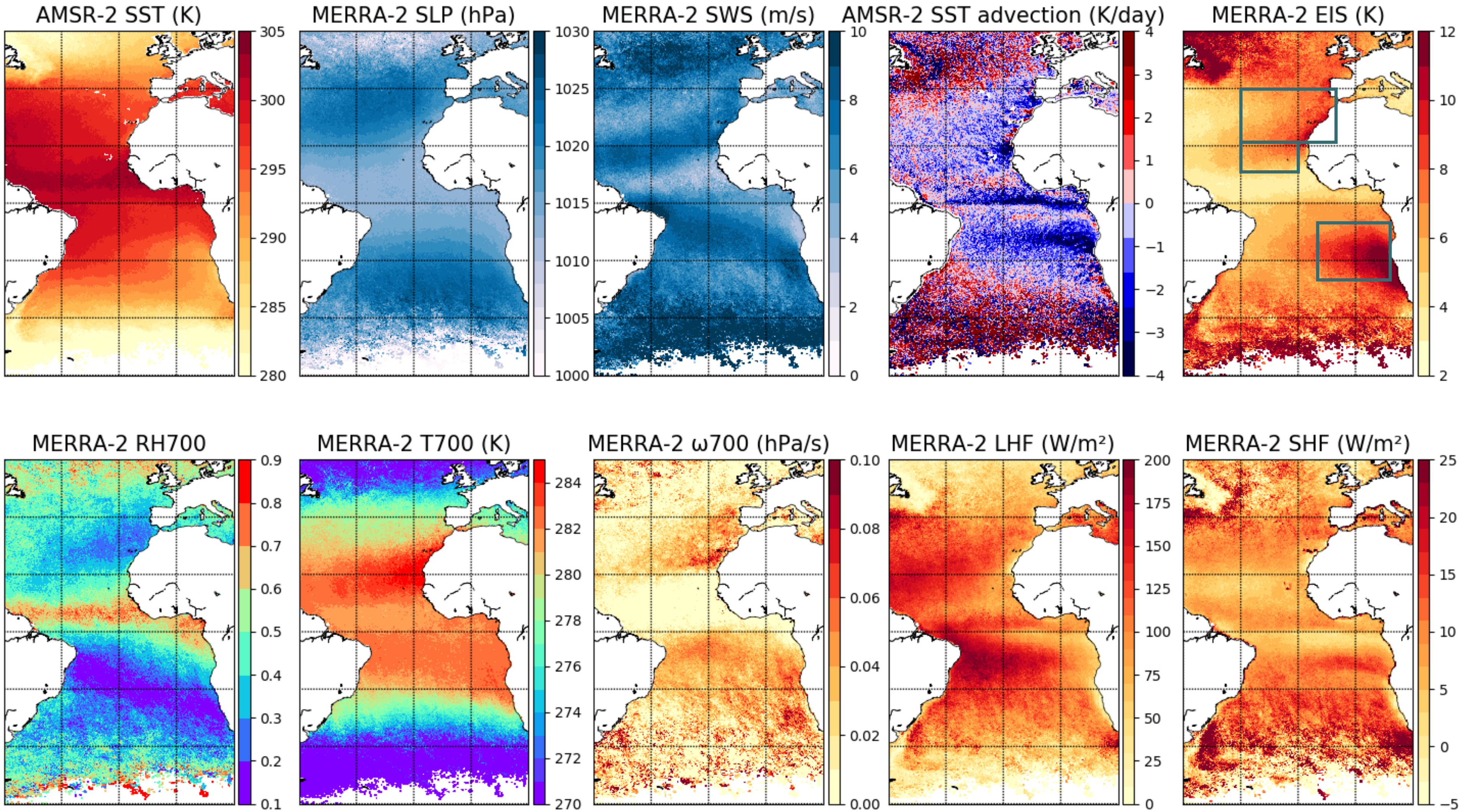


Bayesian & Orthogonal Distance Regression (ODR) slopes



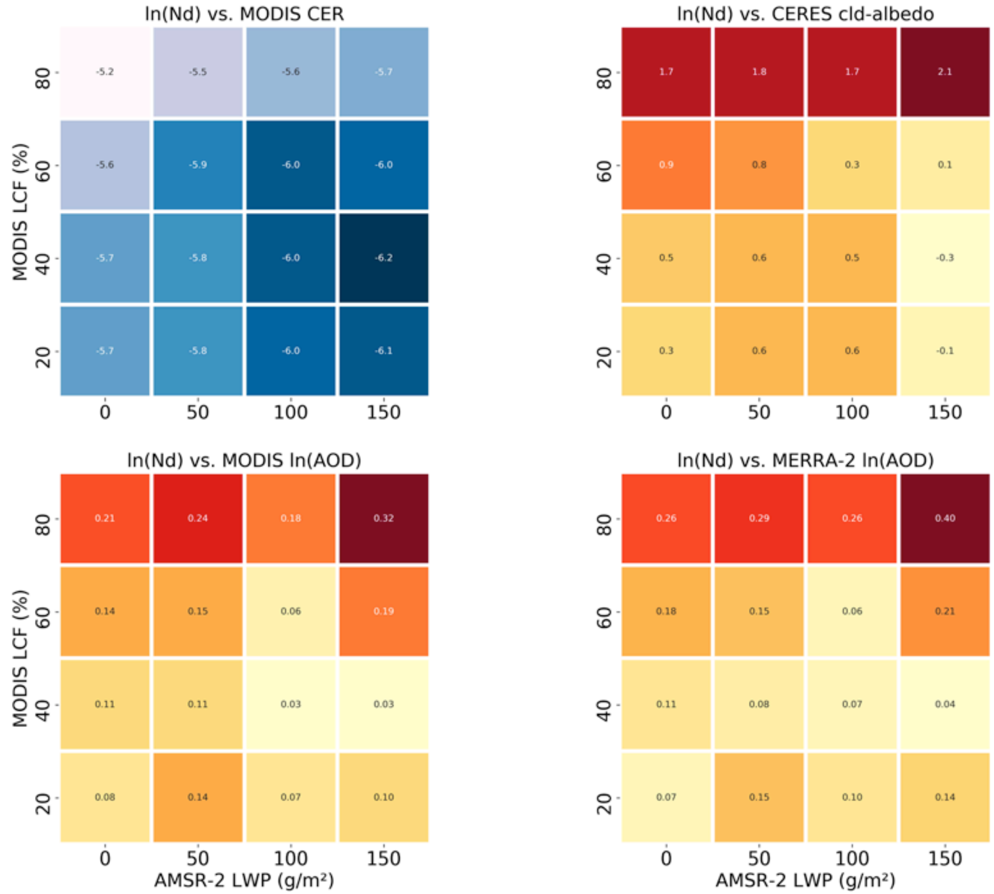
- Bayesian and ODR slopes are steeper than OLS

Large-scale meteorology and surface fluxes – Jun - Nov 2015-2018



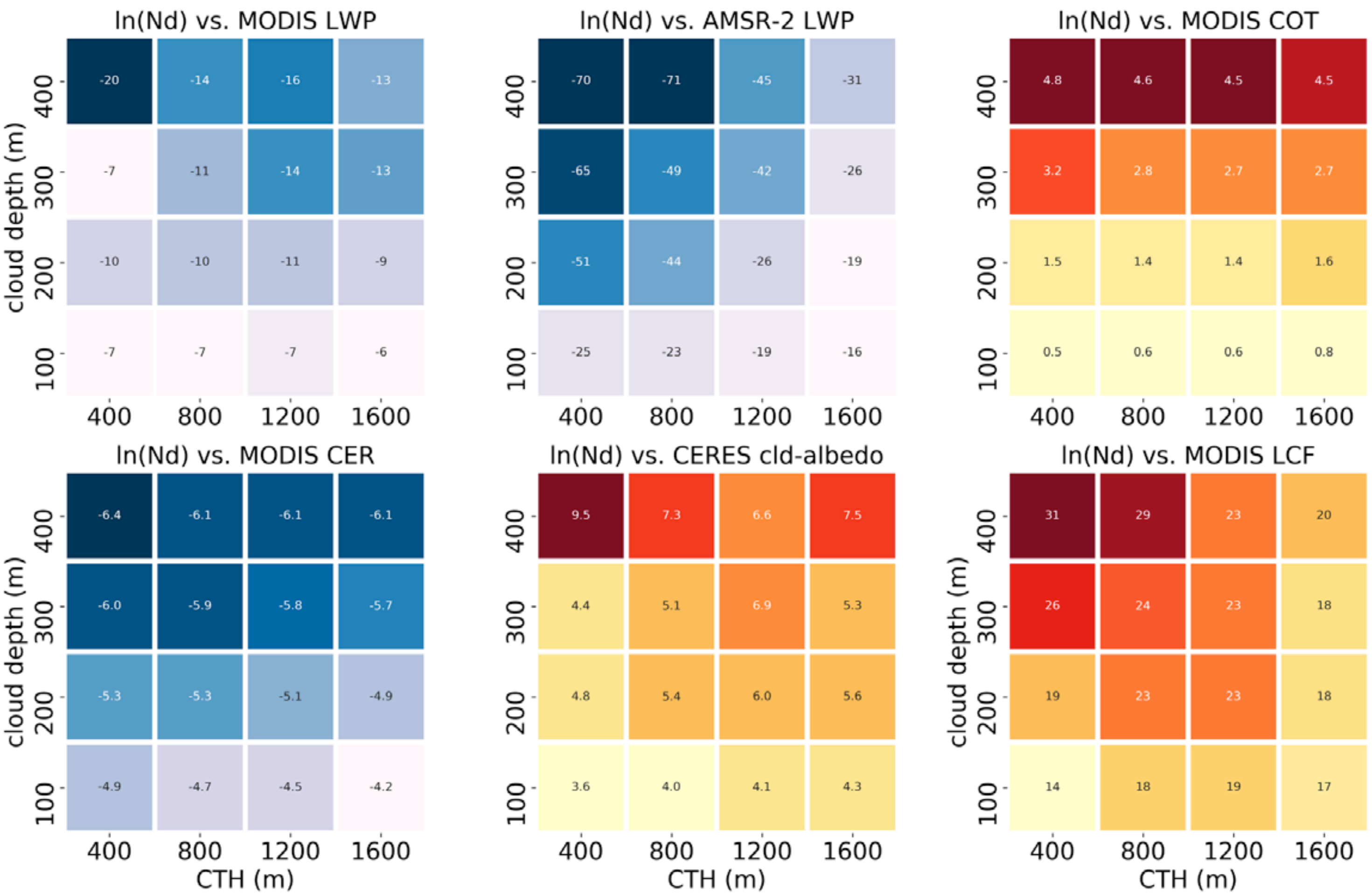
- Cloud amount increase – Cooler SST, increased SLP, SWS, LHF, cooler SST-adv, stronger EIS and w700, drier and warm FT (RH700, T700)
- LWP increase – moist FT RH700

Slopes of ln(N_d) vs. cloud and aerosol parameters Dependency on AMSR-2 LWP and MODIS LCF



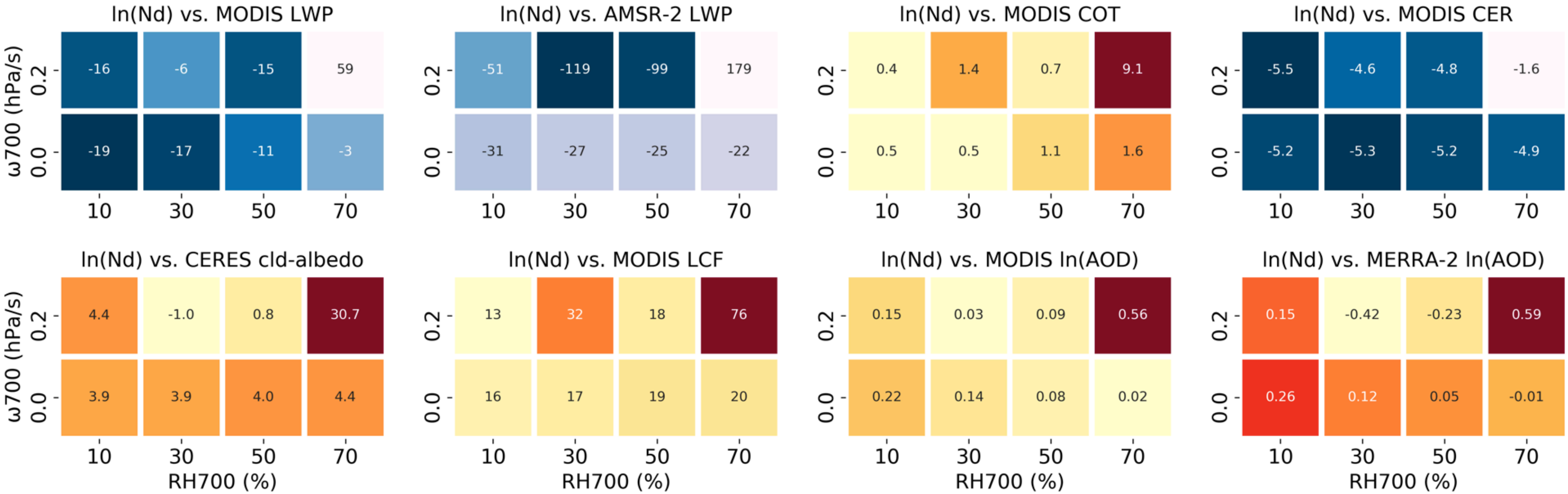
- The relationships are strongest at overcast condition, and increased with increasing LWP

Slopes of ln(N_d) vs. cloud and aerosol parameters
Dependency on CTH and cloud depth



- The negative LWP and CER slopes are steepest when the clouds are thicker and below 1km.
- Similarly, positive LCF, COT, cl-albedo slopes are steepest.
- AOD slopes are steeper either when the clouds are thicker or at higher top height.

Slopes of ln(N_d) vs. cloud and aerosol parameters
Dependency on RH700 and ω700



- N_d versus AOD slopes are steeper for stronger subsidence regime, especially at warmer SST and moist Free-troposphere.
- Similar results obtained for cloud properties aswell, except that N_d versus CER and LCF slopes are steepest at cooler SST.

Aerosol Indirect Forcing computation

Intrinsic Forcing or cloud albedo effect is estimated as

$$\Delta a.\bar{C}_m.\left(\frac{dA_{clr}}{d\ln(AI)} - \frac{dA_{cld}}{d\ln(AI)}\right).\bar{F}^{\downarrow}$$

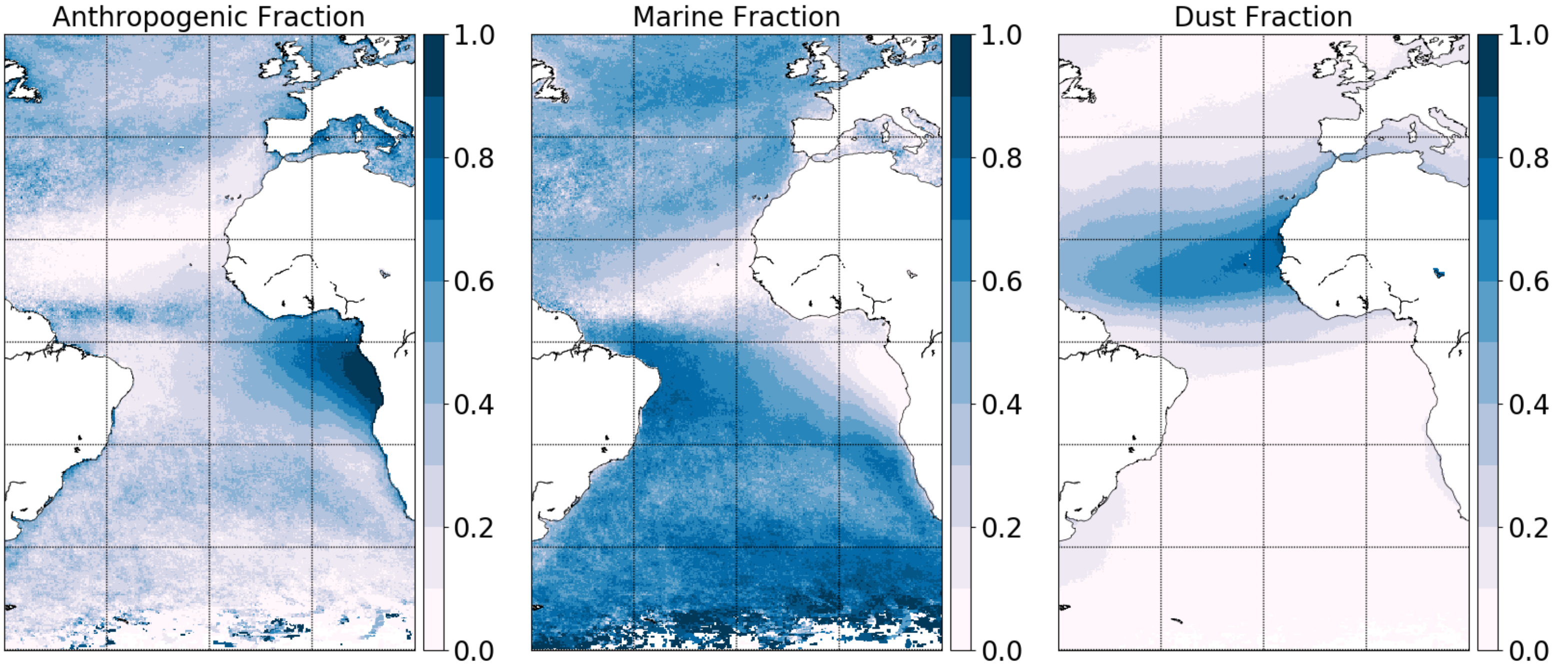
Extrinsic Forcing or cloud lifetime effect is estimated as

$$\Delta a.\overline{(A_{clr} - A_{cld})}.\frac{dC_f}{d\ln(AI)}.\bar{F}^{\downarrow}$$

A is albedo
$F^{\downarrow}$ is incoming shortwave radiation
C_f is cloud fraction

as in Chen et al. 2014

MERRA-2 Aerosol classifications following Bellouin et al. 2013



Jun – Nov (2015-2018)

Anthropogenic – 31%
Marine – 53%
Dust – 16%

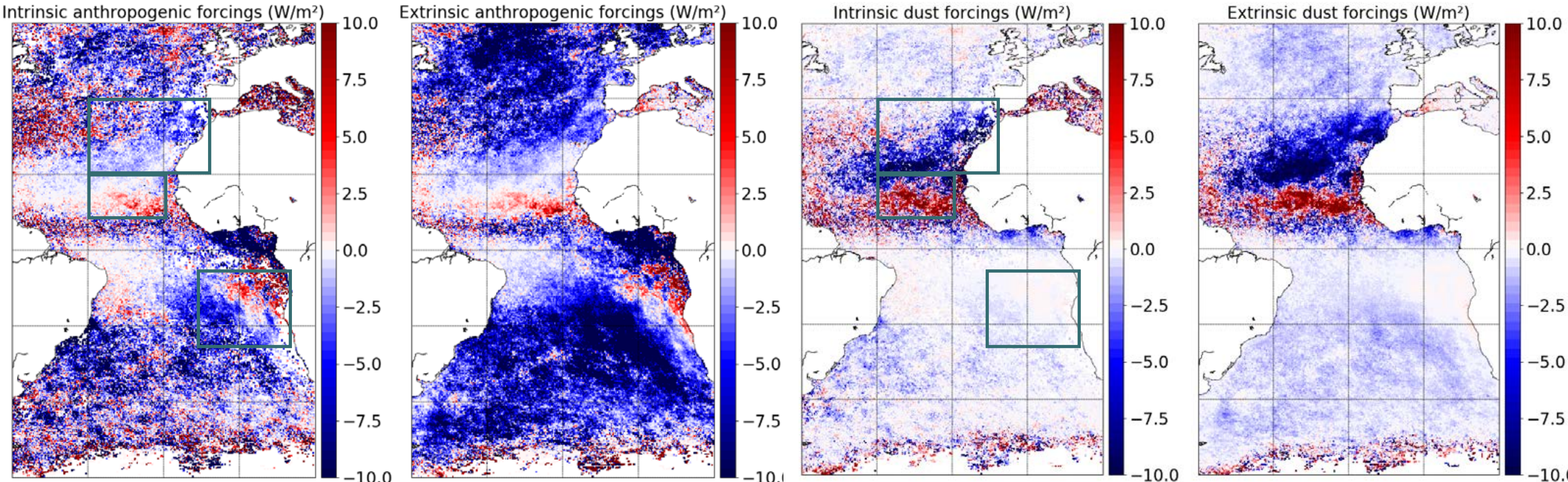
Forcing estimates (Jun – Nov 2015-2018)

Anthropogenic

Cloud albedo | **Cloud lifetime effect**

Dust

Cloud albedo | **Cloud lifetime effect**



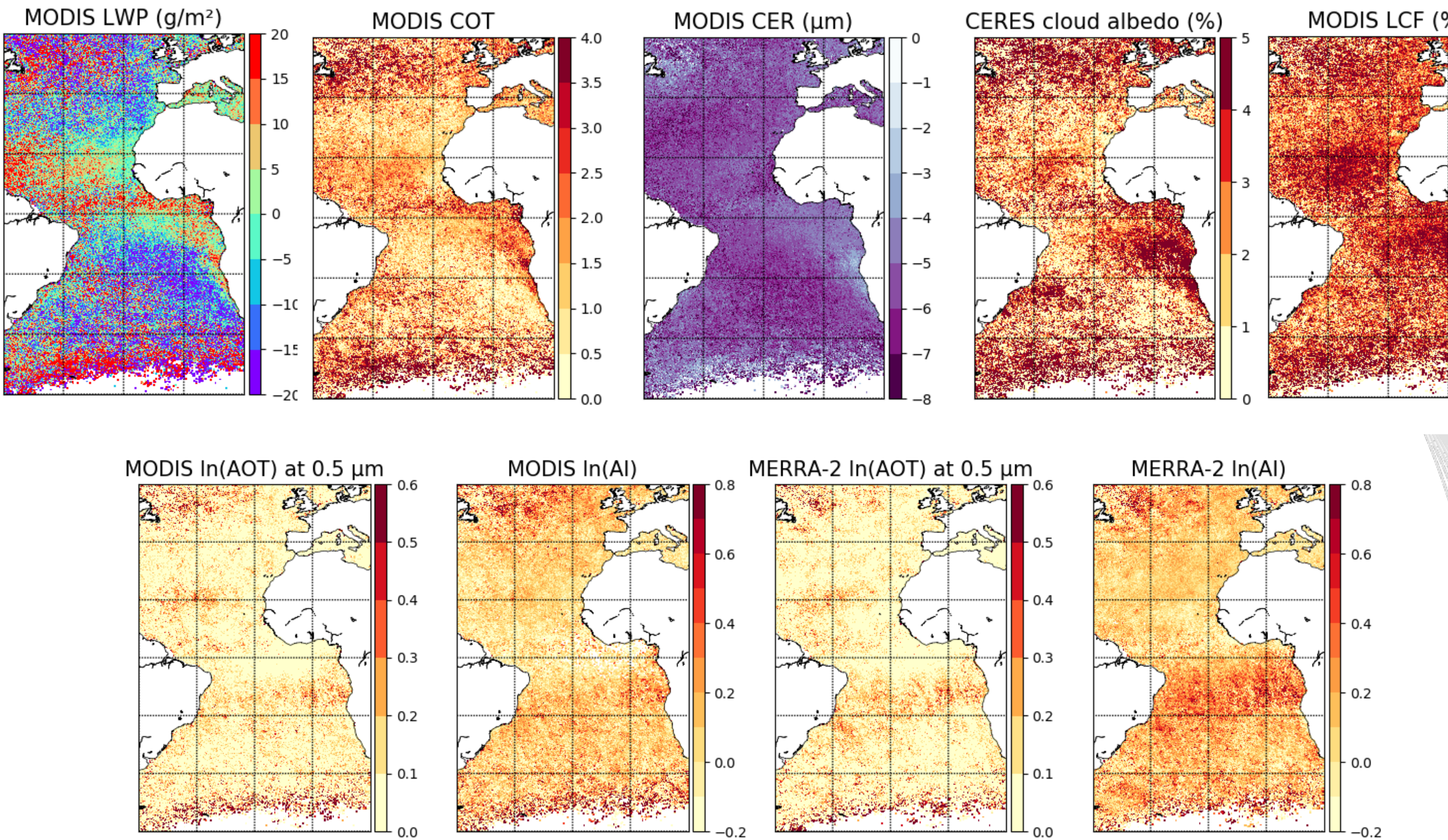
Episodic Smoke and Dust regime → Large positive forcing estimates

Less polluted Sc regime → Large negative forcing estimates

Summary

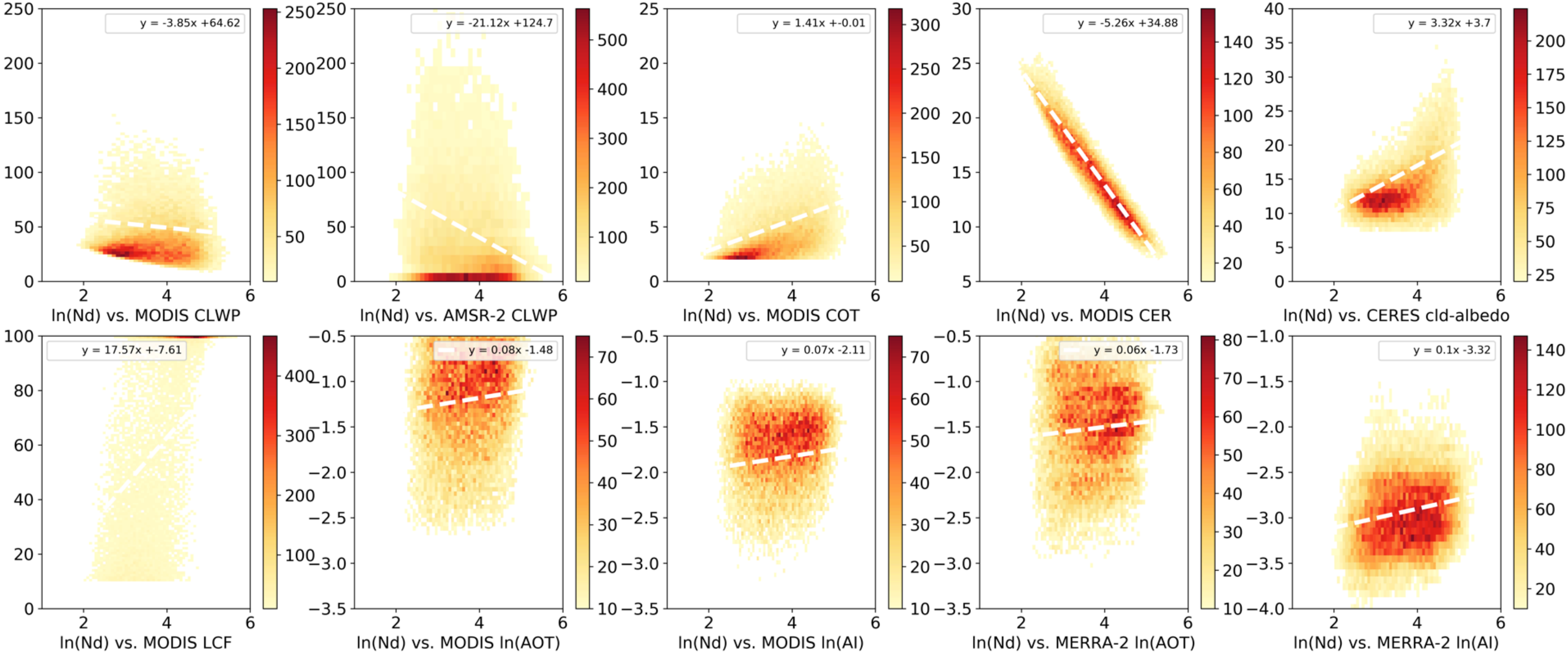
- N_d versus AI slopes are steeper at a higher resolution satellite measurements.
- Also, advanced fitting methods that consider uncertainty in both X and Y axis are recommended over OLS fitting to compute slope
- Compute aerosol indirect forcing based on slopes from advanced regression methods
- Include the effect of meteorology into the forcing computation

Slopes of ln(N_d) versus Cloud and Aerosol Products – 2015-2018

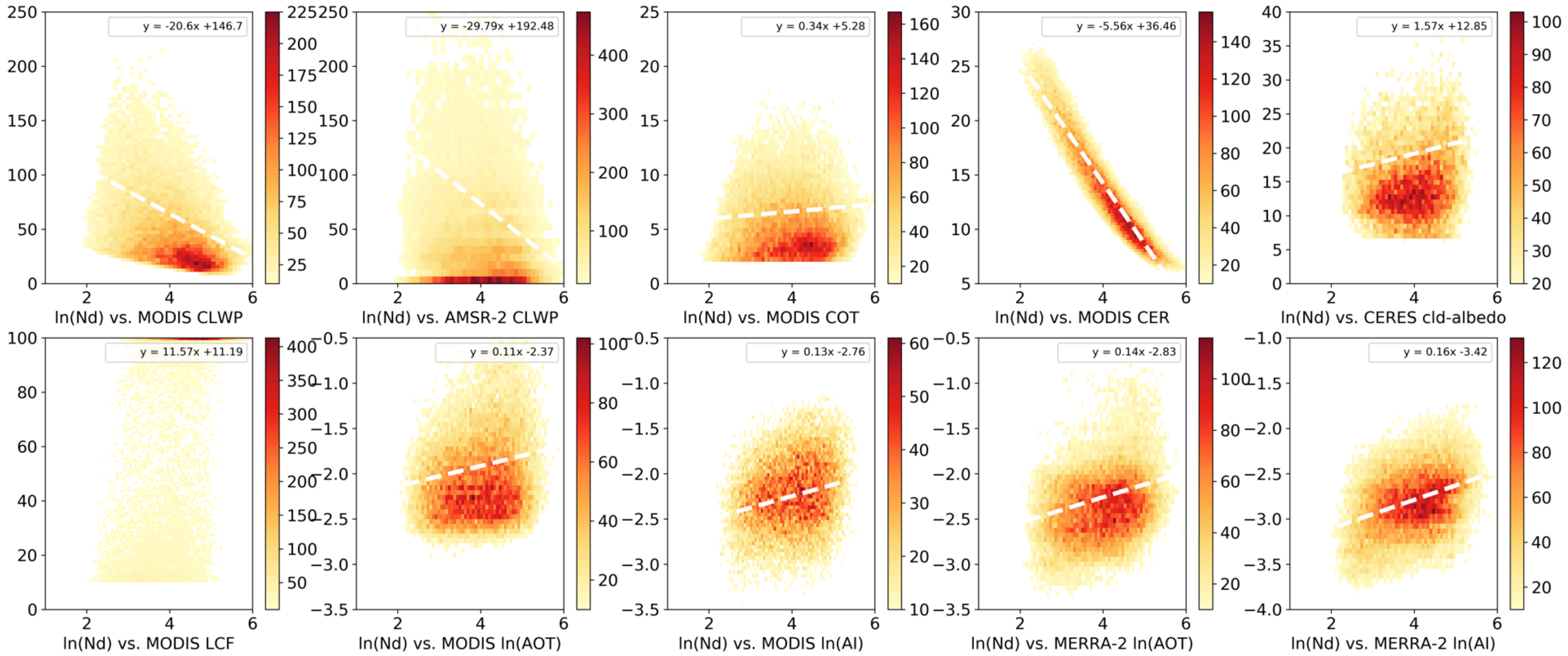


Northeast Atlantic Stratocumulus (dust)

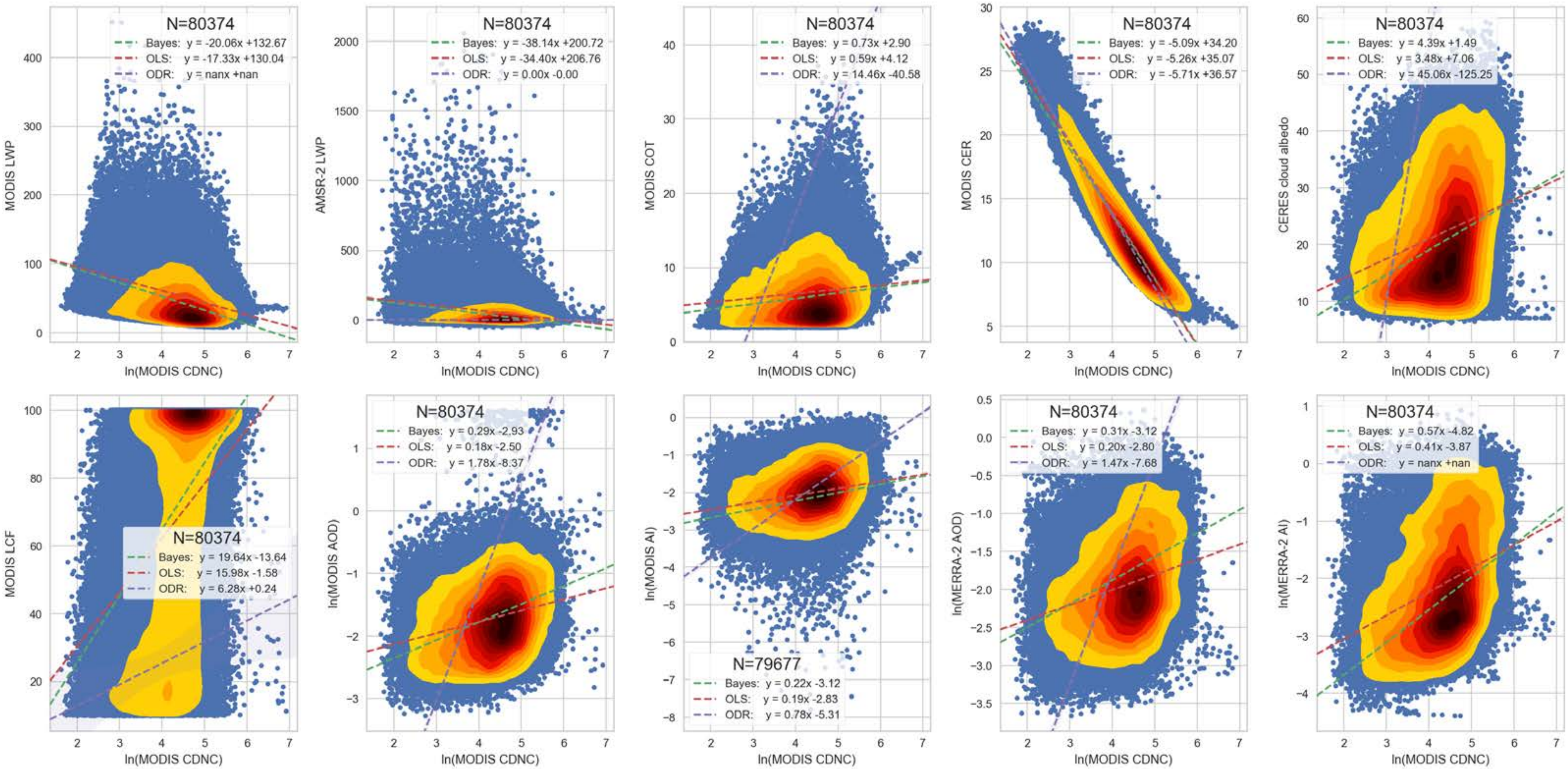
OLS slopes of $\ln(N_d)$ with cloud and aerosol parameters



Northeast Atlantic Stratocumulus (less dust)
OLS slopes of $\ln(N_d)$ with cloud and aerosol parameters

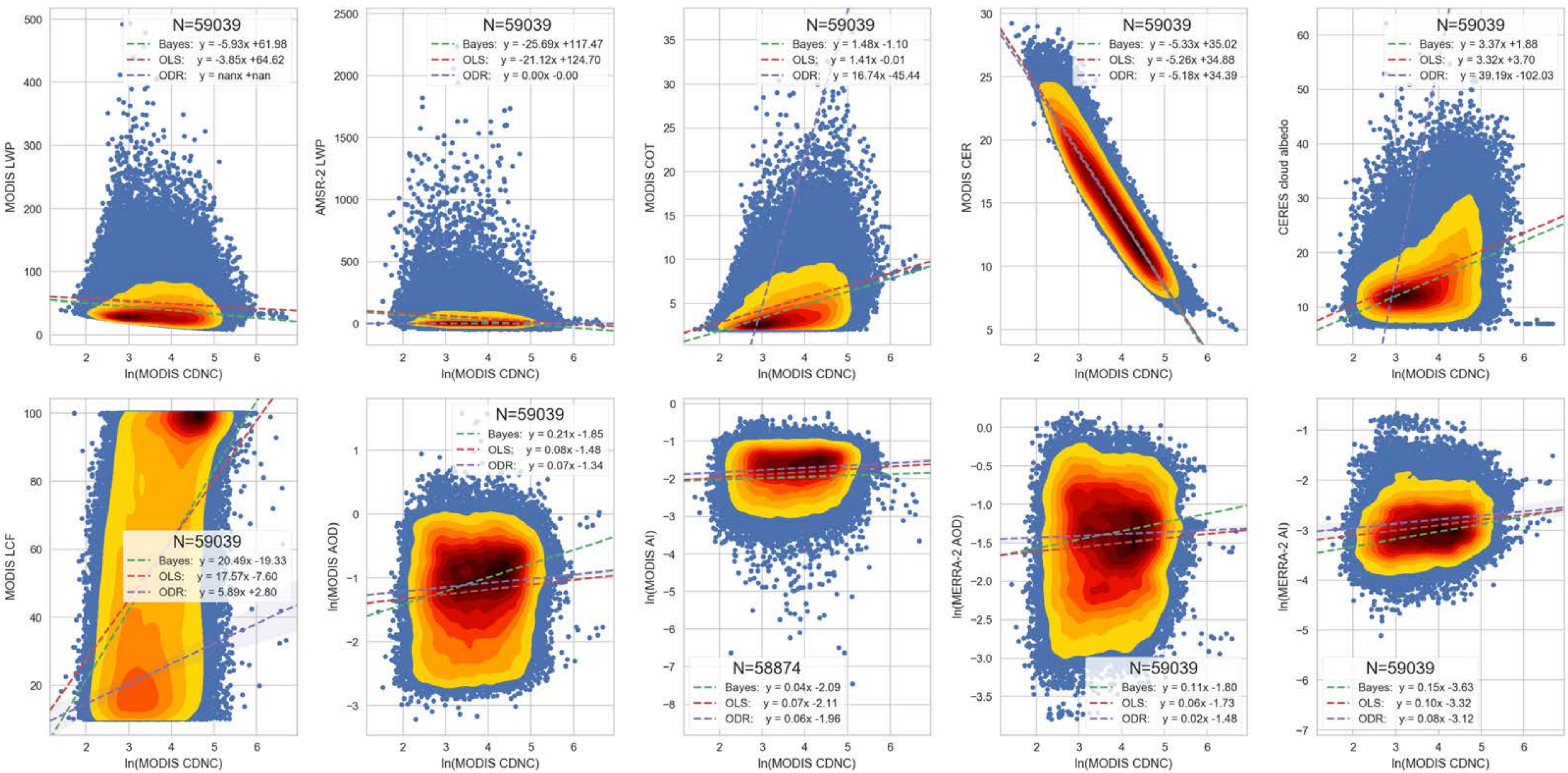


Southeast Atlantic Stratocumulus (smoke) OLS, Bayesian, Orthogonal Distance Regression ODR slopes of $\ln(N_d)$ with cloud and aerosol parameters



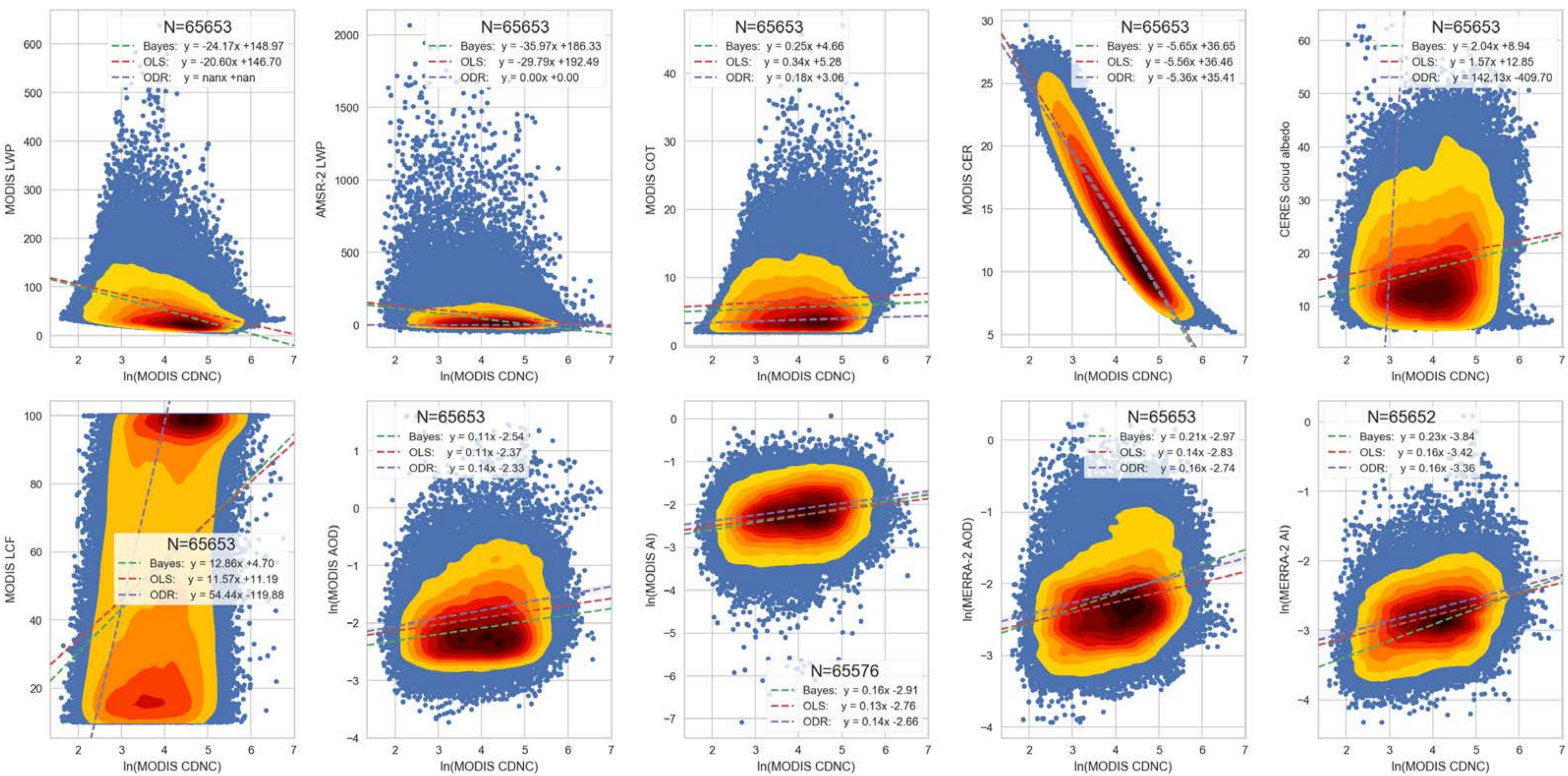
Northeast Atlantic Stratocumulus (dust)

OLS, Bayesian, ODR slopes of $\ln(N_d)$ with cloud and aerosol parameters

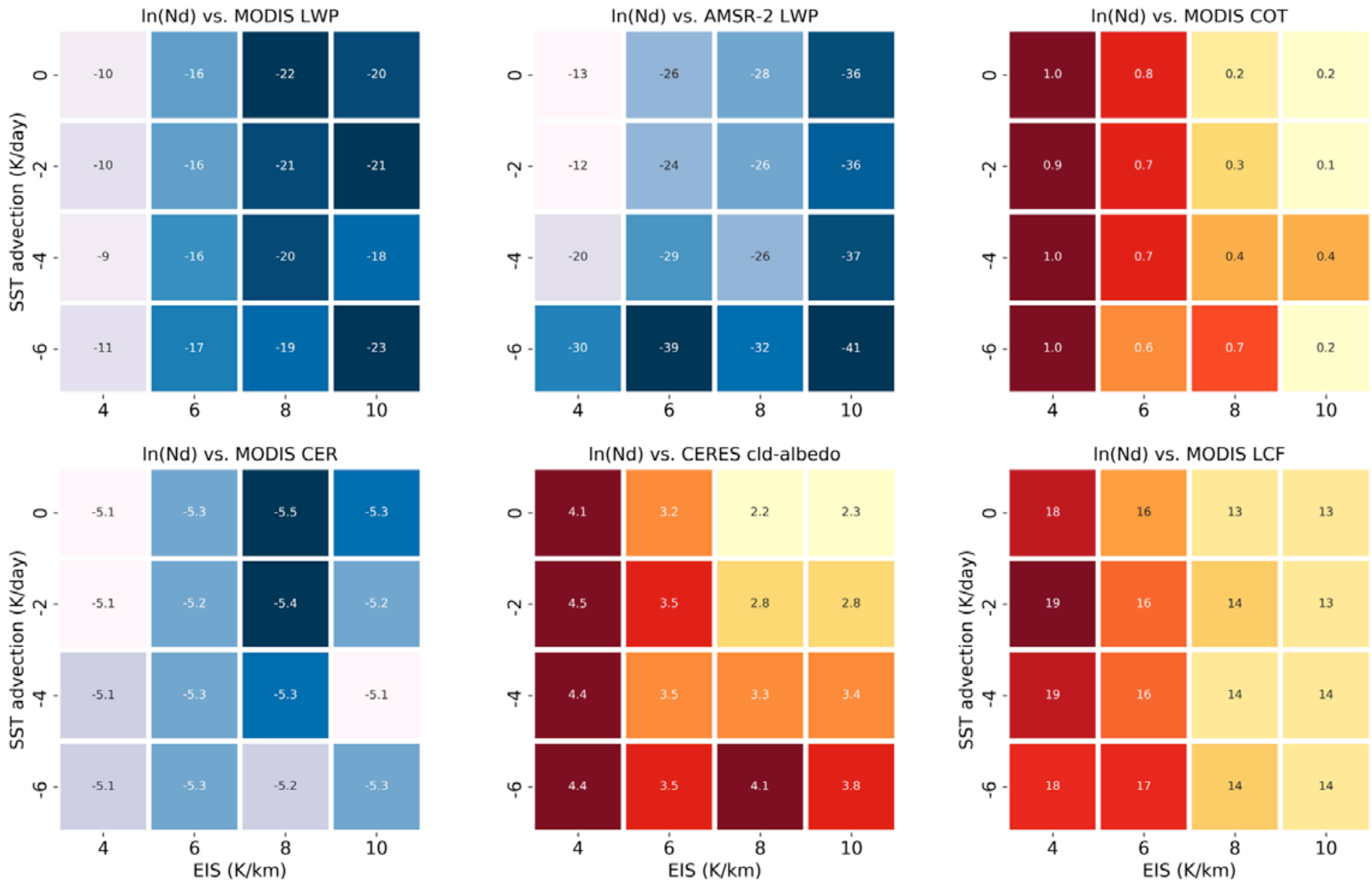


Northeast Atlantic Stratocumulus (less dust)

OLS, Bayesian, ODR slopes of $\ln(N_d)$ with cloud and aerosol parameters



Dependency on EIS and SST advection
Slopes of Ln(Nd) vs. cloud and aerosol parameters

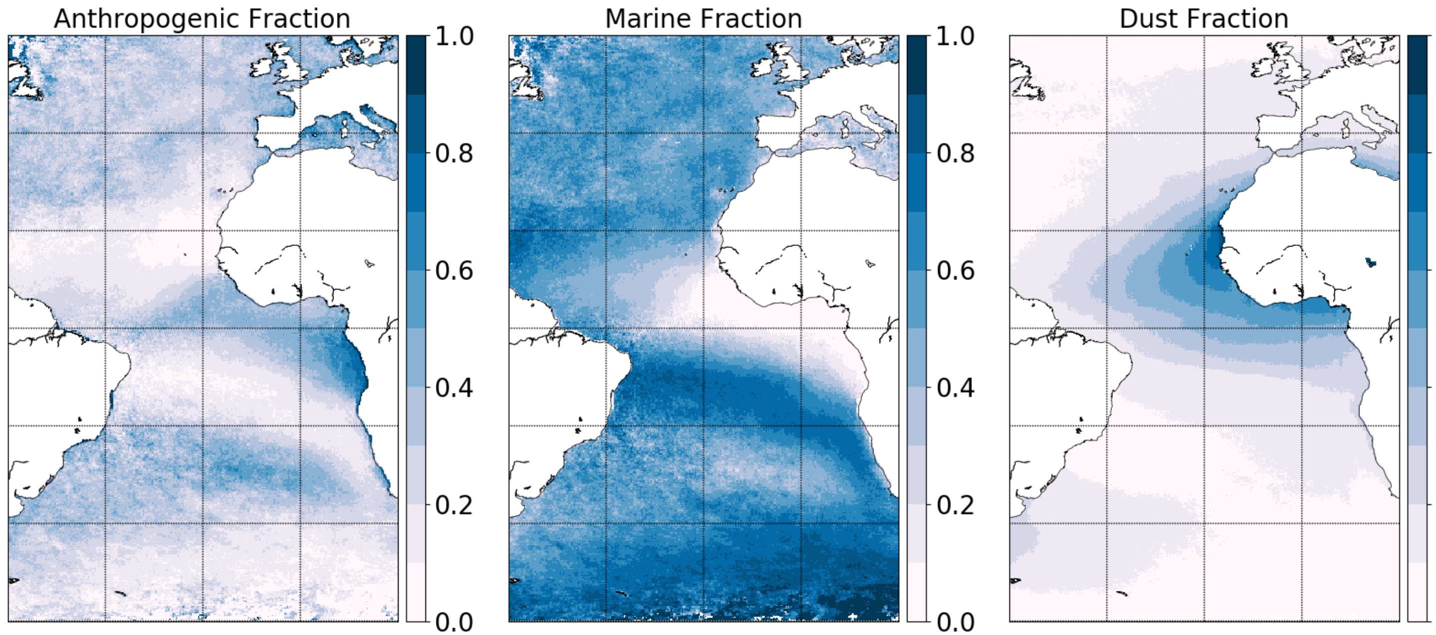


- The negative LWP and CER slopes are steepest when the clouds are thicker and below 1km.
- Similarly, positive LCF, COT, cl-albedo slopes are steepest.
- AOD slopes does not show any dependency on SST-advection or EIS.

MERRA-2 Aerosol classifications following Bellouin et al. 2013

Dec – May (2015-2018)

Anthropogenic – 26%
Marine – 56%
Dust – 18%



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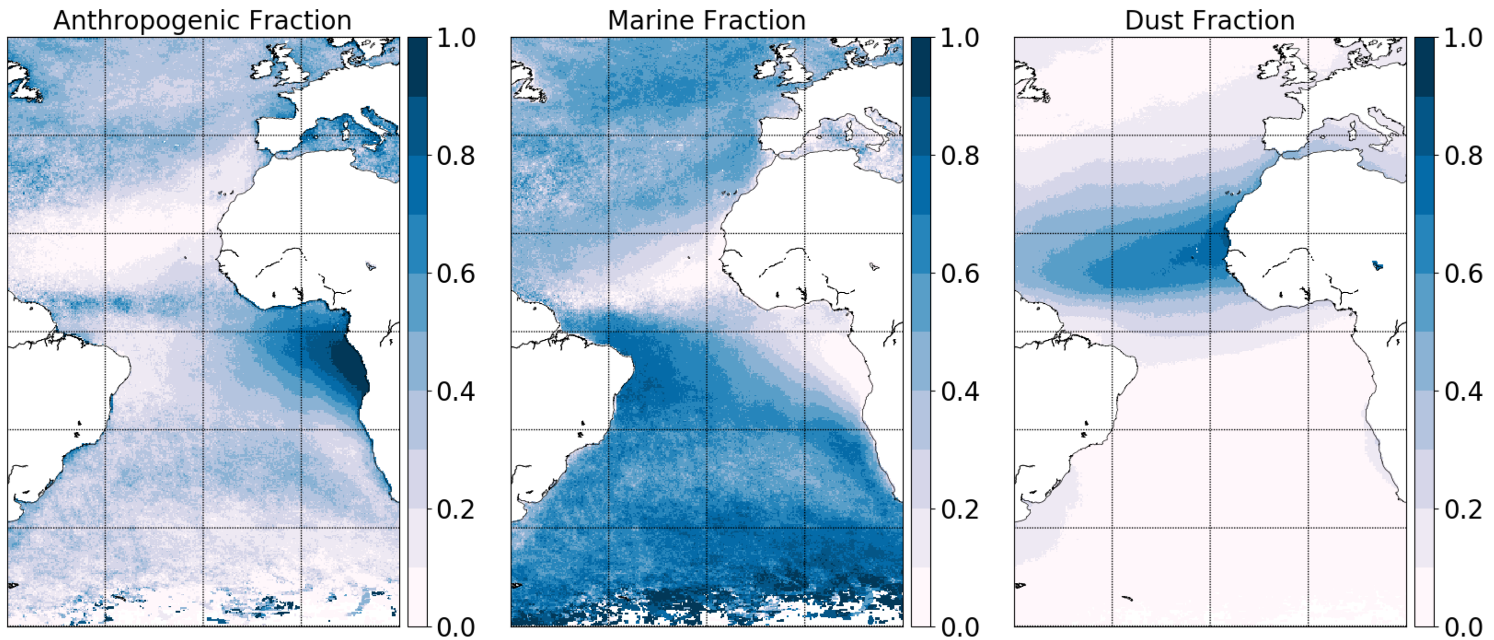
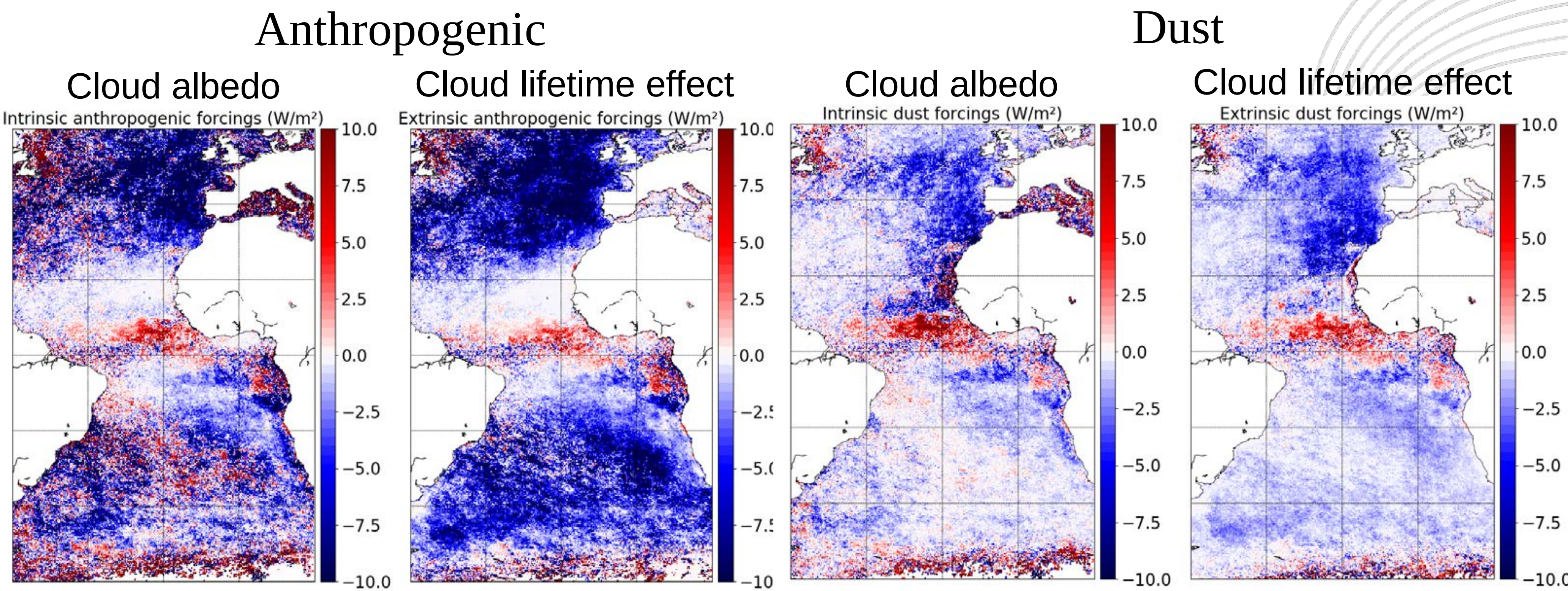


Forcing estimates (Dec – May 2015-2018)



SEA Sc regime → Large negative forcing estimates with means of about -2.45 W/m^2 and -2.97 W/m^2 respectively for cloud albedo and cloud lifetime effect.

NEA dust domain indicates a large positive forcing