Pollution tracks in clouds provide direct observational evidence for weak cloud water response to aerosols

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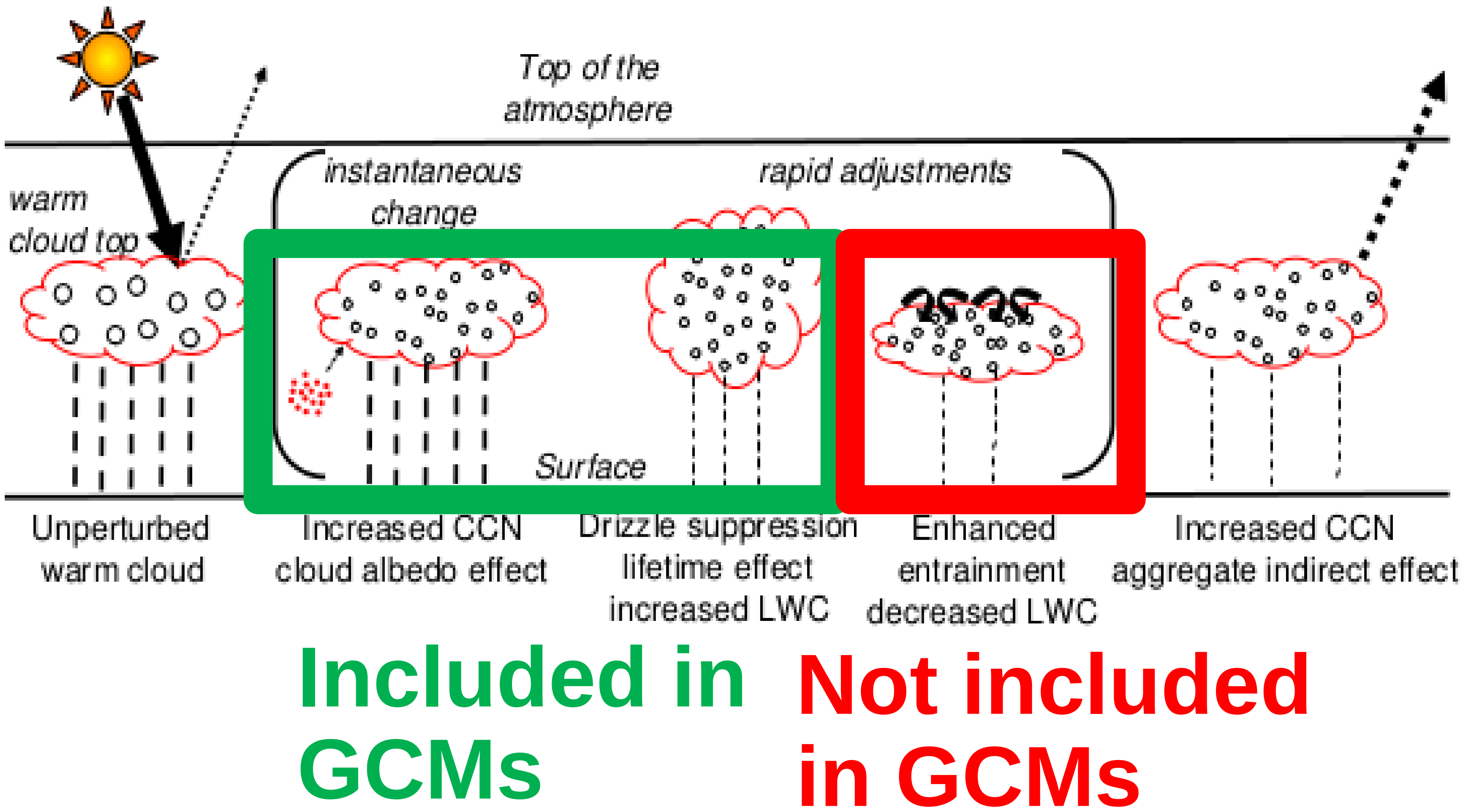
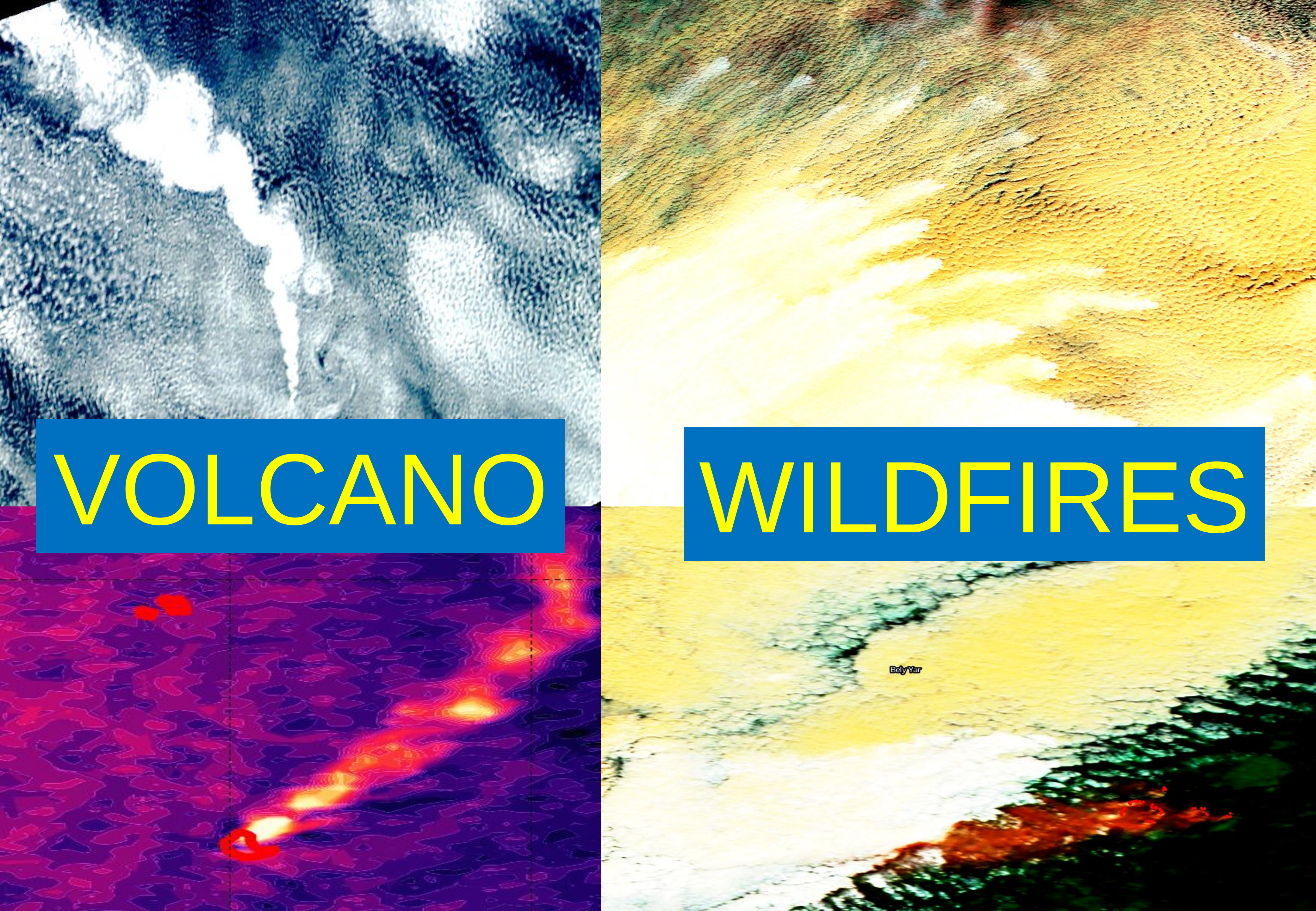
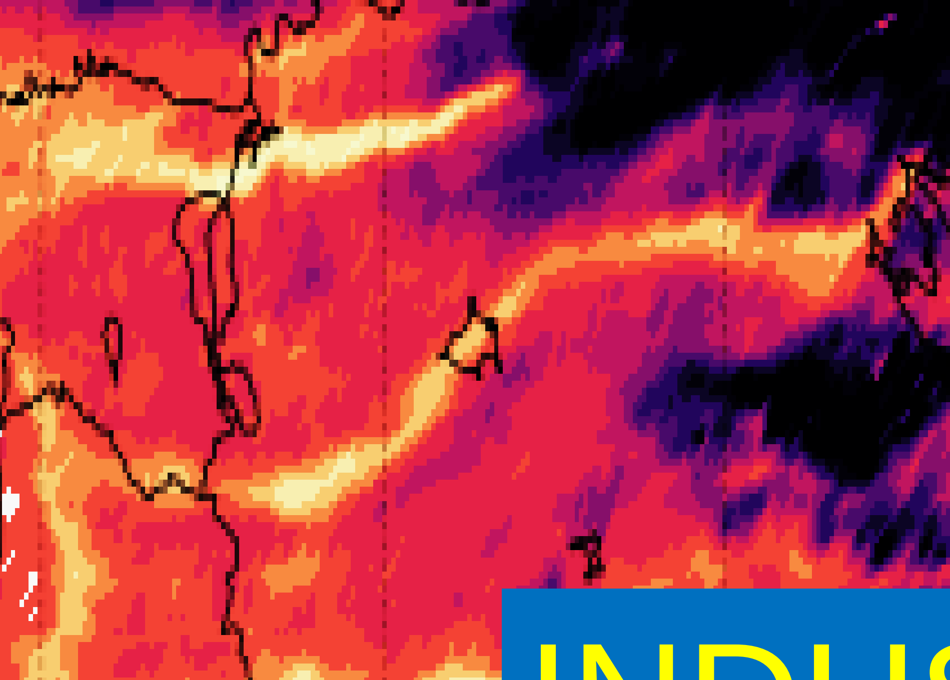
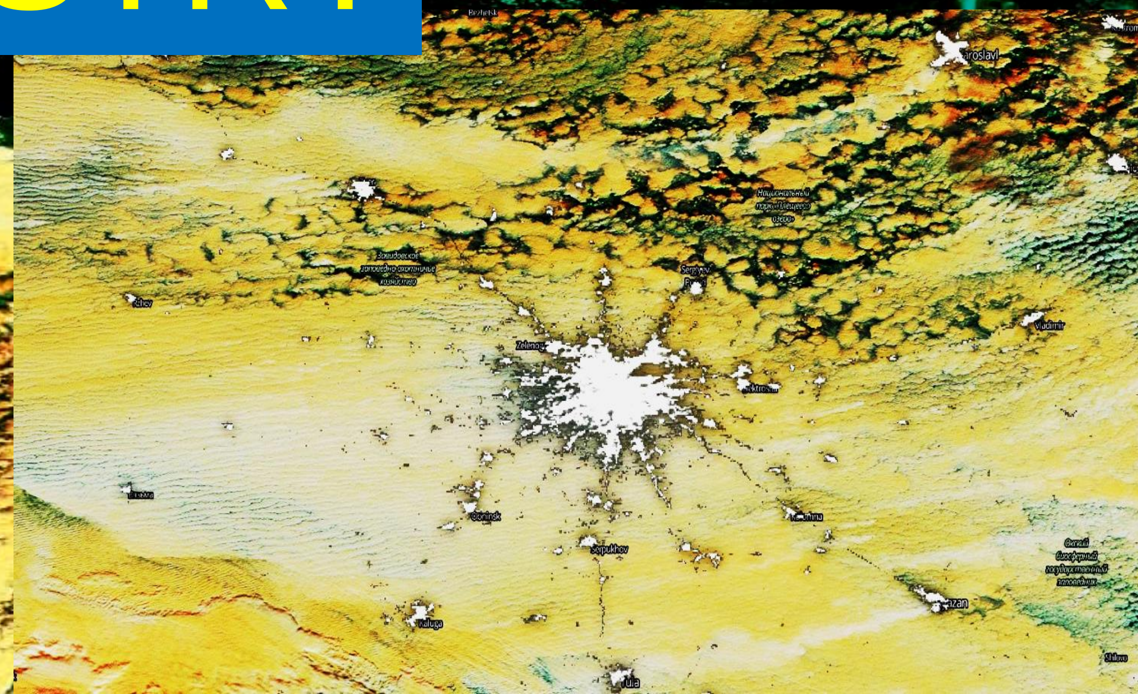
Need to revise unidirectional cloud water increases in GCMs



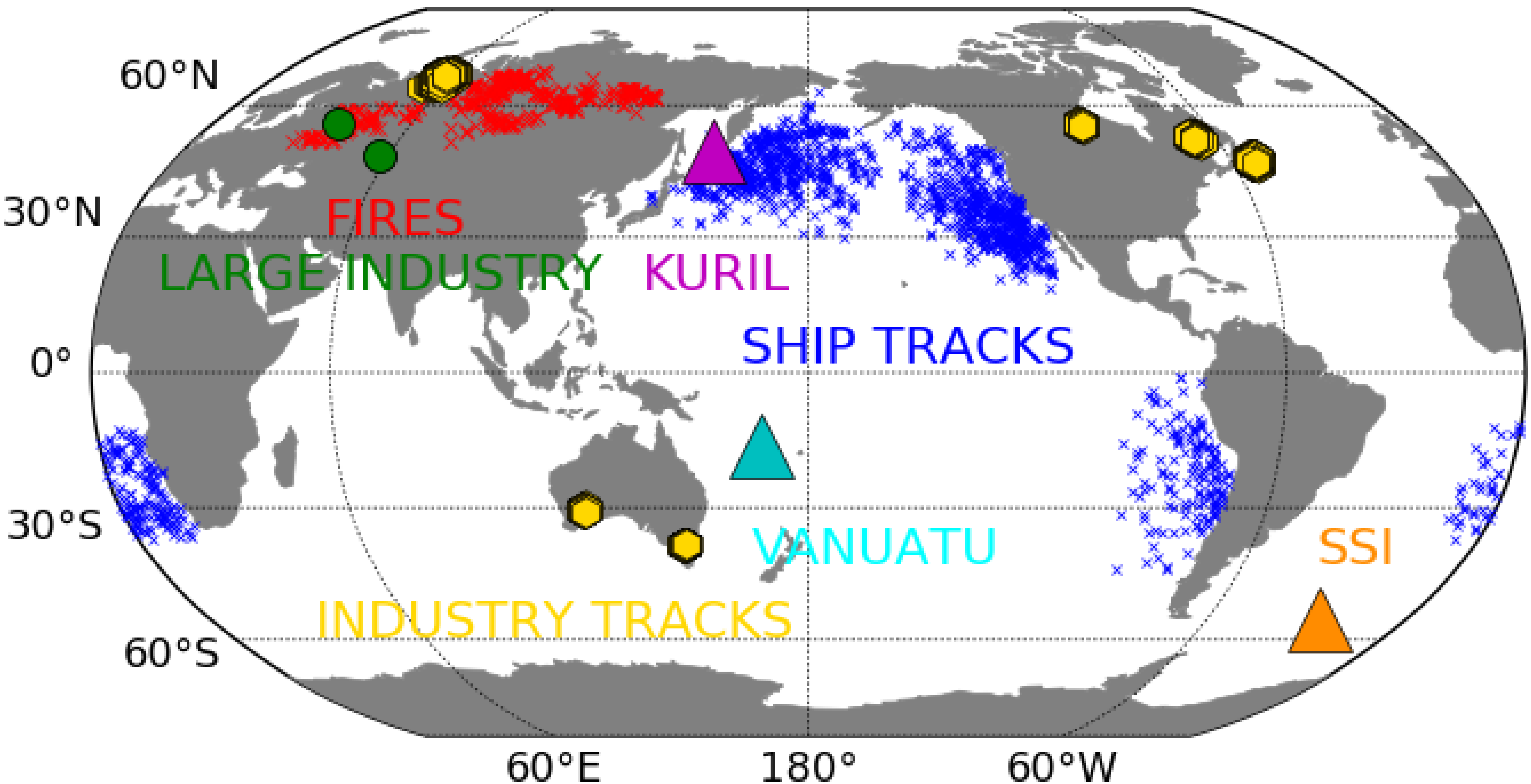

VOLCANO
WILDFIRES
Bely Yar



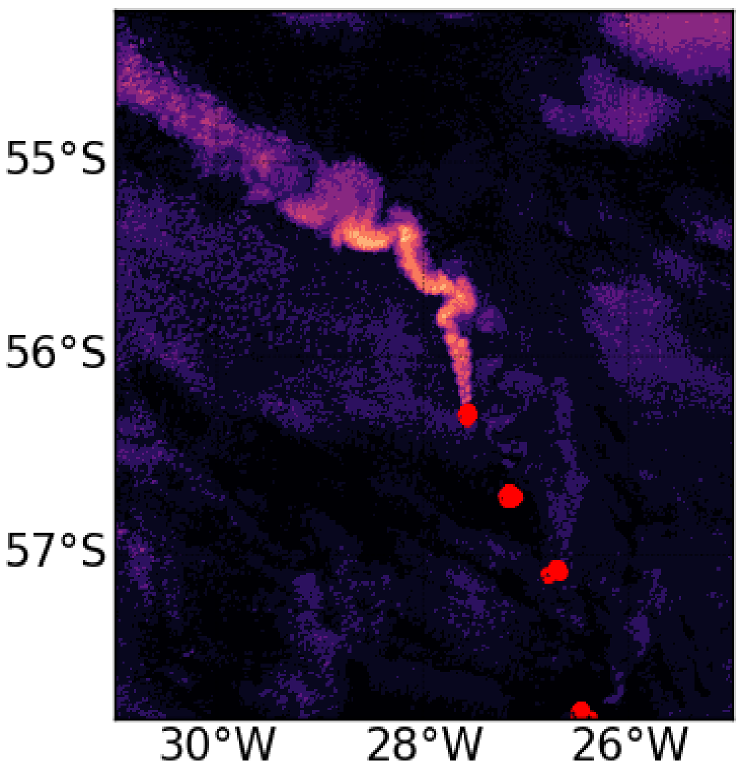
INDUSTRY

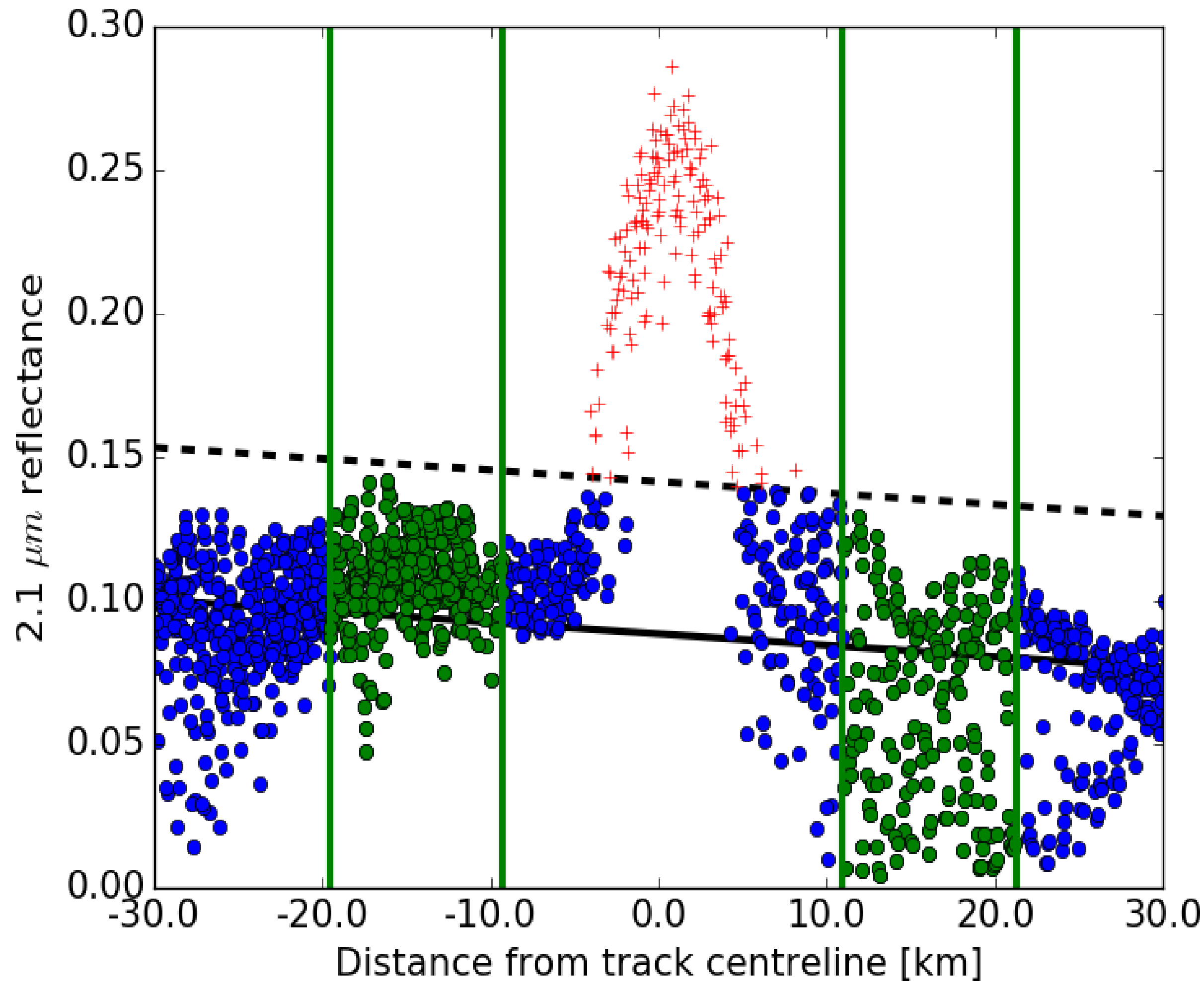


Locations of sampled pollution tracks

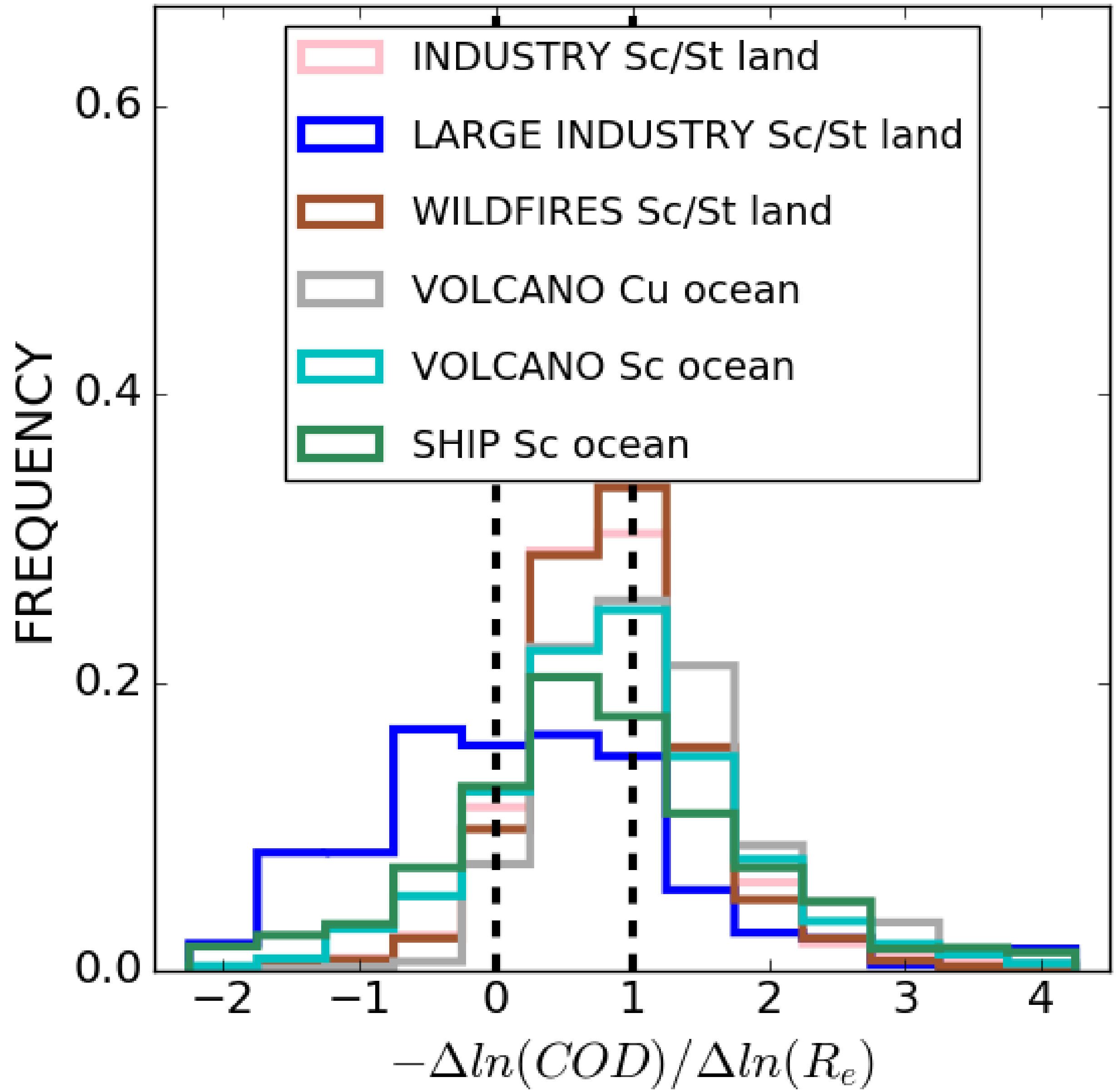


Selecting polluted/unpolluted pixels from MODIS data

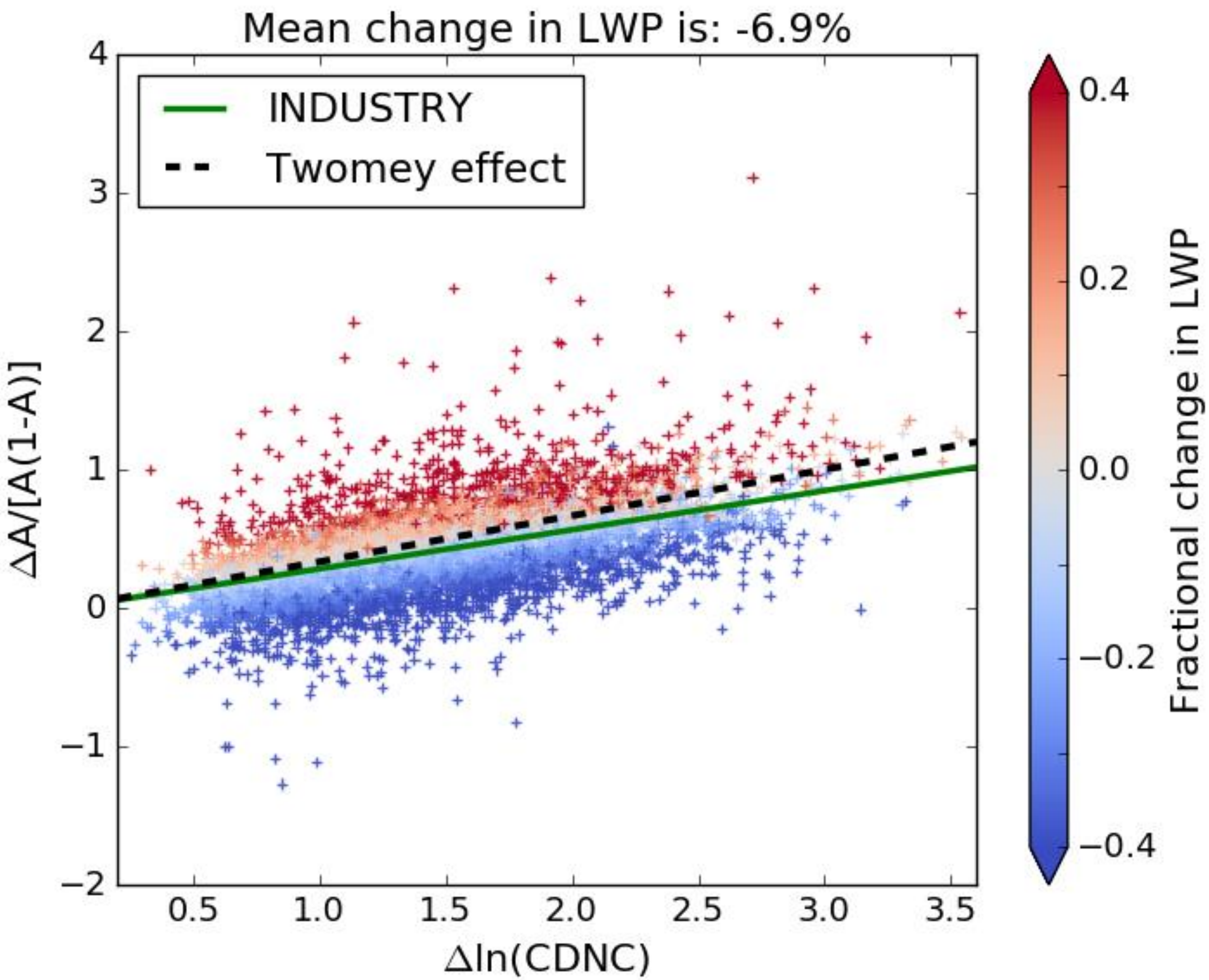




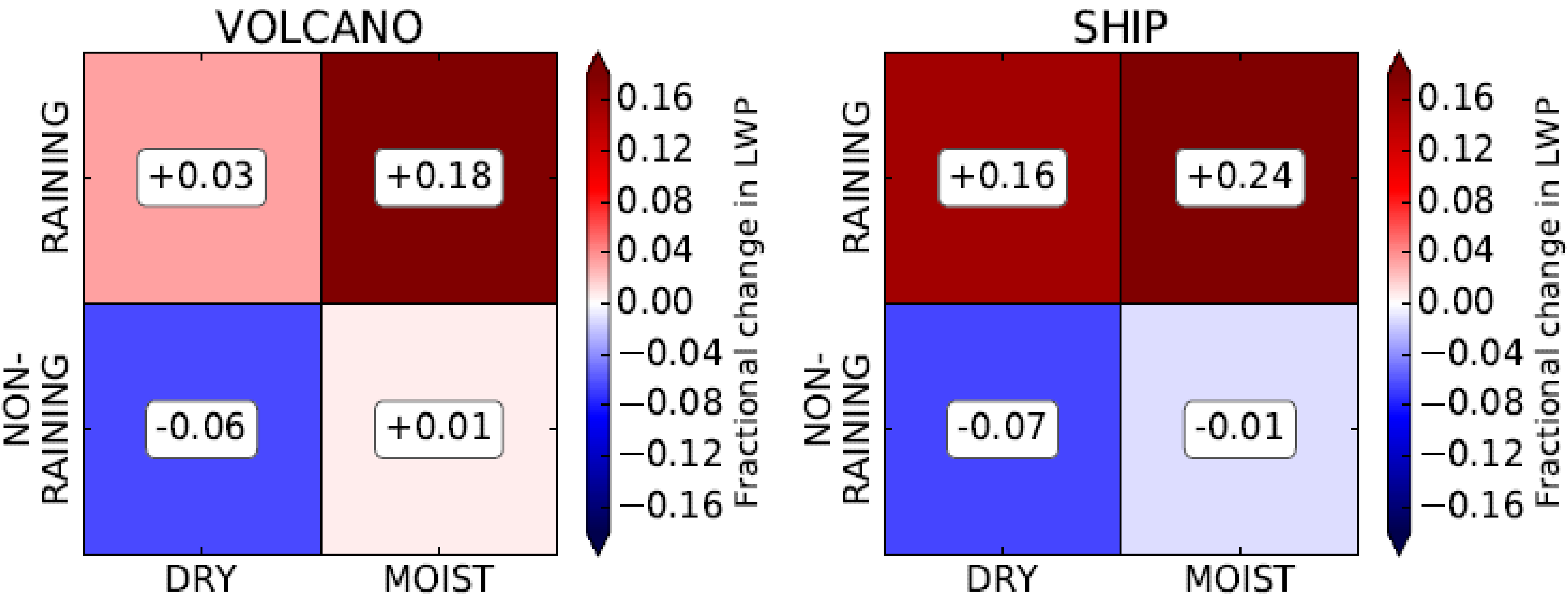
Diversity of cloud responses



Total aerosol indirect effect could be weaker than the Twomey effect

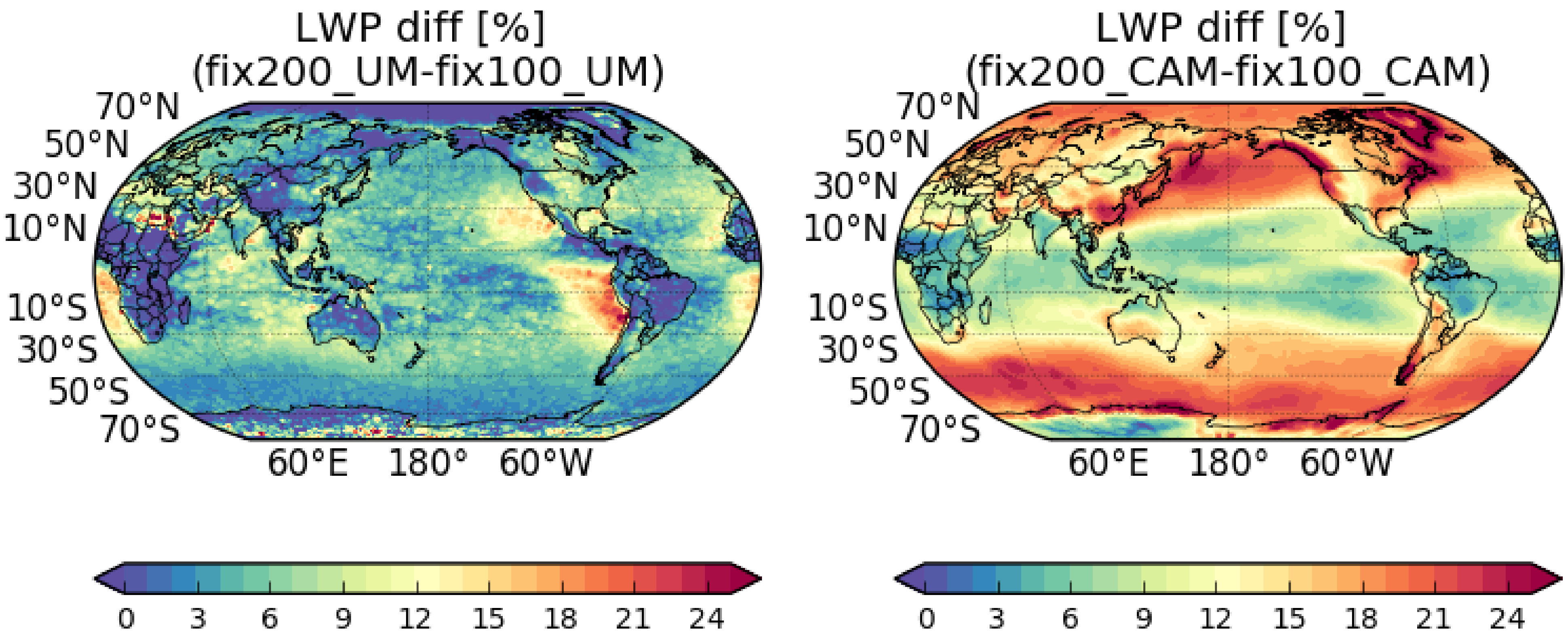


Enhanced entrainment drying vs. supression of precipitation

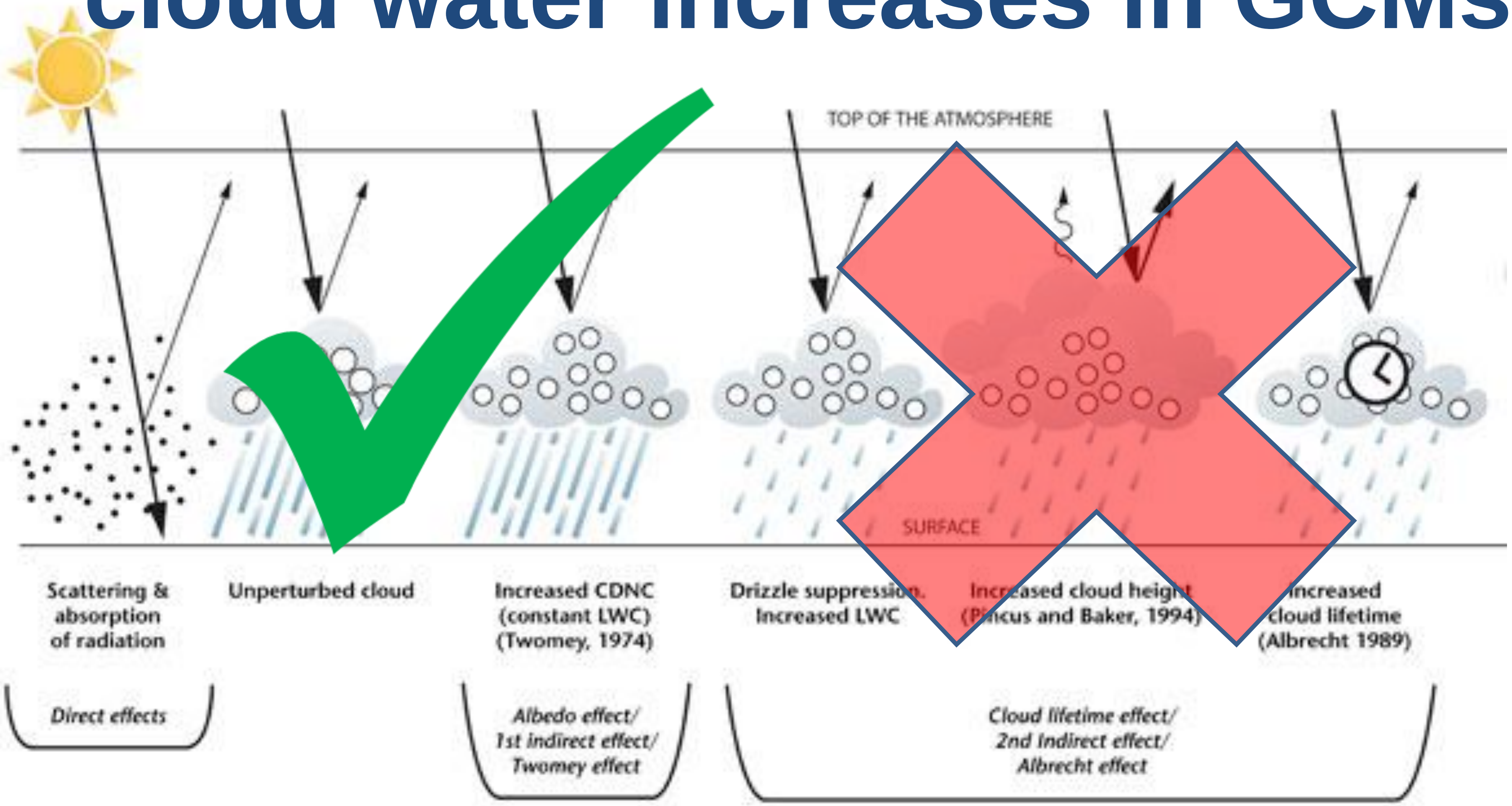


(Toll et al. 2017, GRL)

Unidirectional cloud water increases in GCMs



Need to revise unidirectional cloud water increases in GCMs



Relevant for aerosol forcing!

Irrelevant for aerosol forcing?

Conclusions

- Unidirectional cloud water increases in GCMs are not in agreement with pollution track observations
- GCM-based estimates of aerosol indirect forcing are overly negative

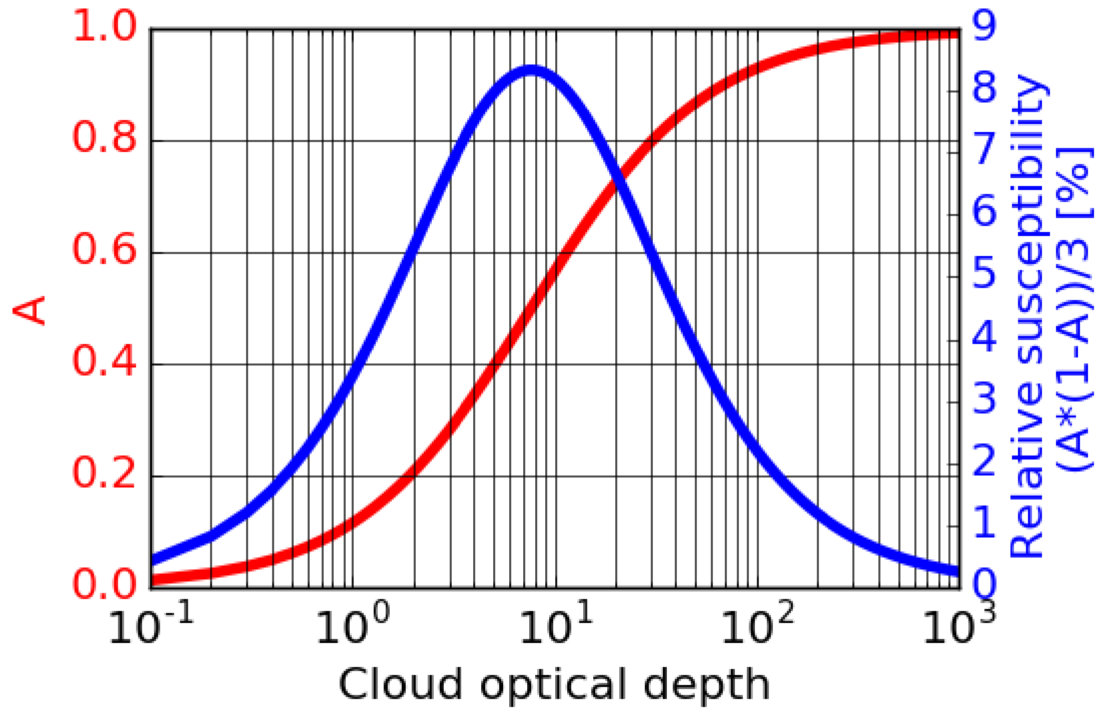
MODIS data

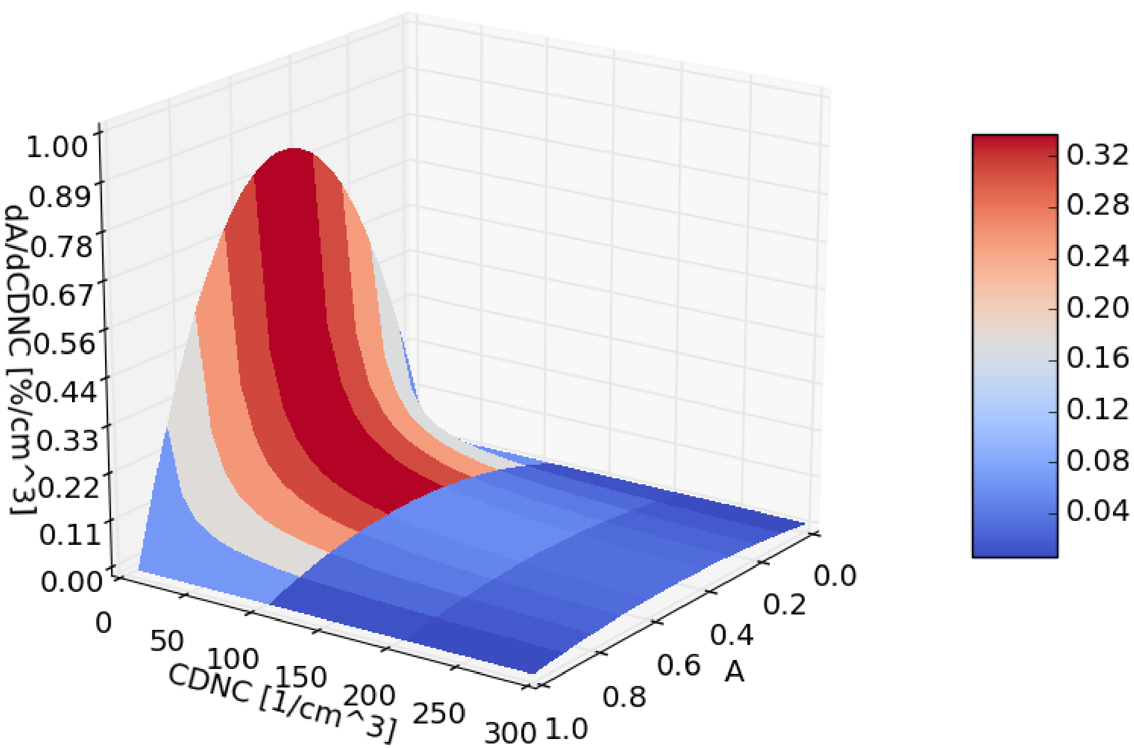
- Collection 6 L2 data (1km resolution)
- Data screening: single-layer clouds only, removed ice and mixed phase retrievals
- Cloud albedo from MODIS data (LWP, Re, SZA) using BUGSRAD two-stream code (Stephens et al., 2001)
- CDNC estimated from MODIS data: $CDNC \sim k\ COD^{1/2}\ Re^{-5/2}$ (Brenguier et al., 2000)

Twomey effect

$$A = \frac{0.13\tau}{1 + 0.13\tau}$$

(Lacis and Hansen, 1974)

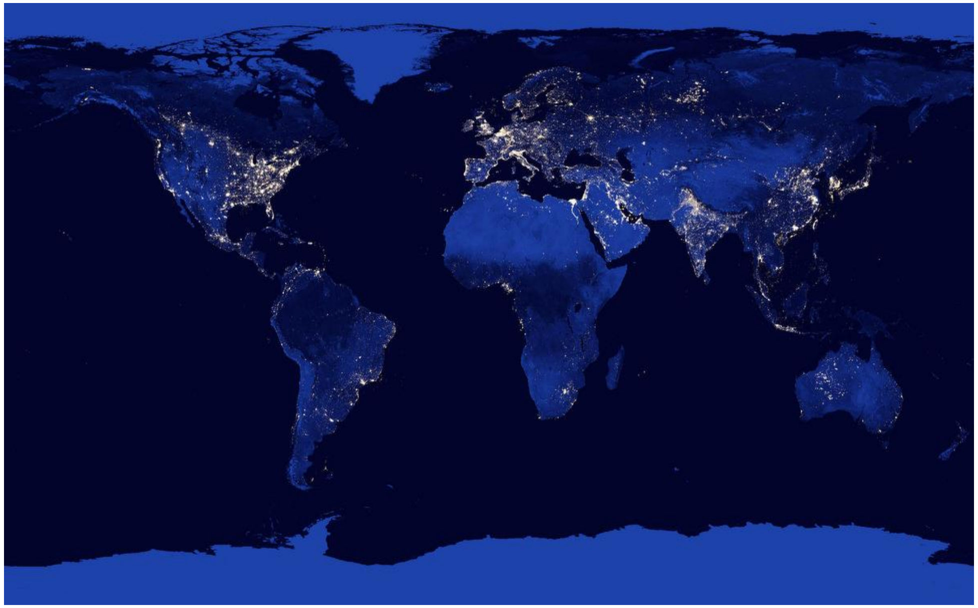




$$\frac{\partial A}{\partial CDNC} = \frac{A(1-A)}{3CDNC}$$

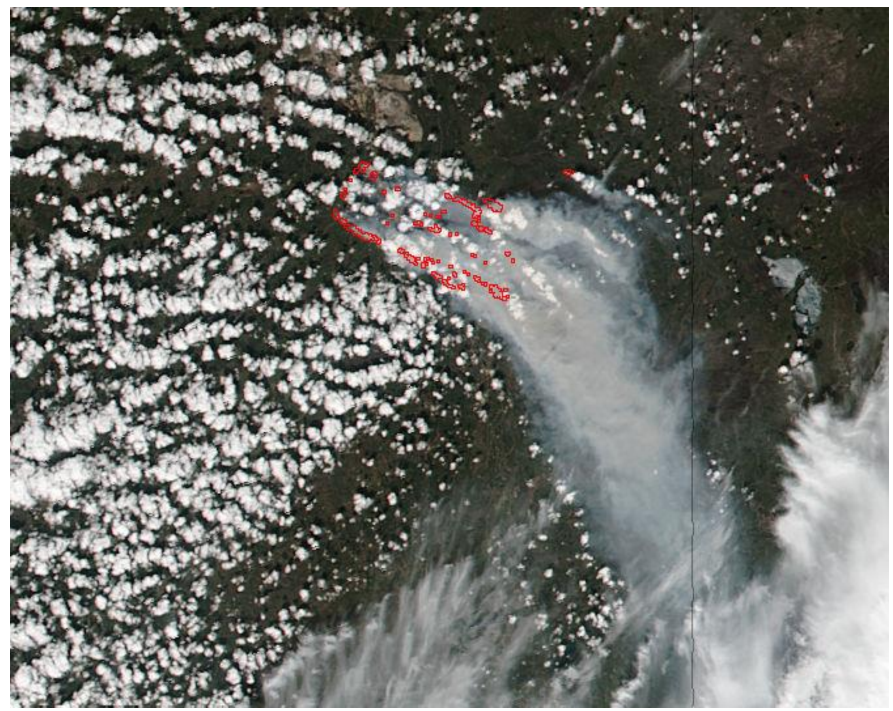
$$\frac{\Delta A}{\frac{\Delta CDNC}{CDNC}} = \frac{A(1-A)}{3}$$

(Twomey, 1991)



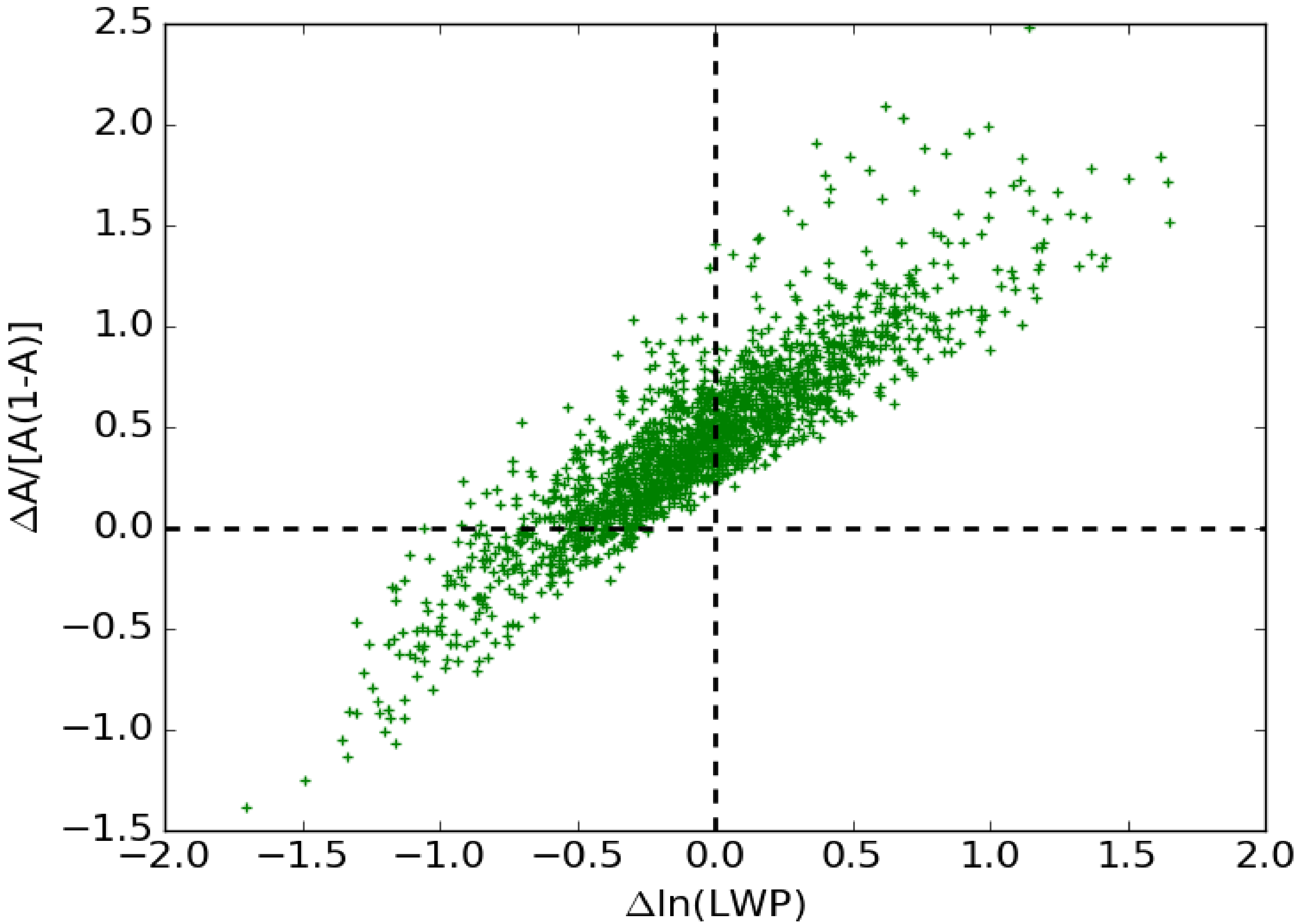
NASA GIBS to find tracks from MODIS images

Earth at night for industry tracks

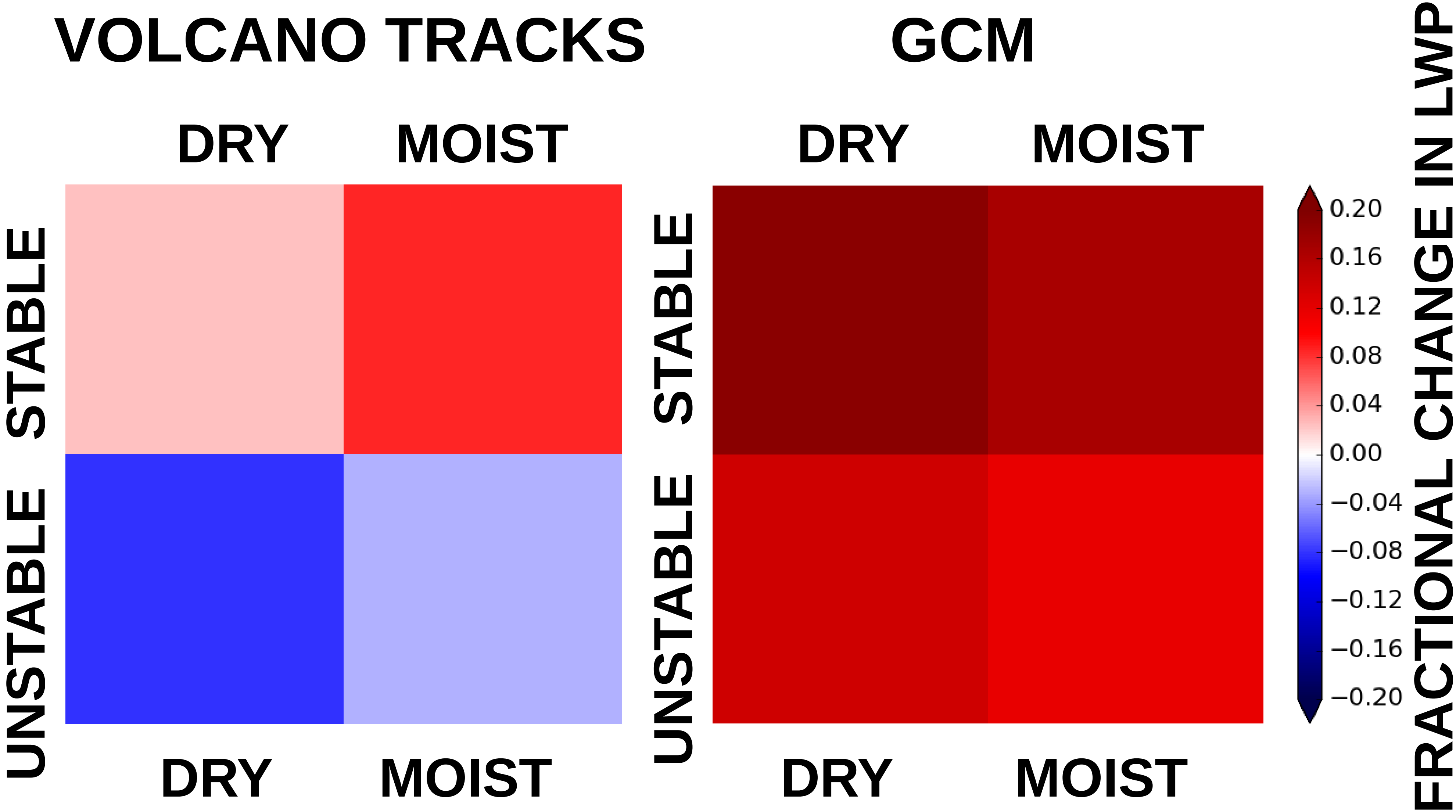


Fire products for wildfire tracks

ΔLWP mainly determines ΔA, many data points with ΔA<0



Disagreement with GCM data



$$\frac{\mathrm{d}\ln R}{\mathrm{d}\ln E} = \left[\frac{\mathrm{d}\ln C}{\mathrm{d}\ln CDNC} + \frac{\mathrm{d}\ln R_c}{\mathrm{d}\ln \tau}\left(\frac{\mathrm{d}\ln LWP}{\mathrm{d}\ln CDNC} - \frac{\mathrm{d}\ln R_{eff}}{\mathrm{d}\ln CDNC}\right)\right]\frac{\mathrm{d}\ln CDNC}{\mathrm{d}\ln CCN}\frac{\mathrm{d}\ln CCN}{\mathrm{d}\ln E}$$

$$\frac{\mathrm{d}\ln \tau}{\mathrm{d}\ln CDNC} = \left(\frac{\mathrm{d}\ln LWP}{\mathrm{d}\ln CDNC} - \frac{\mathrm{d}\ln R_{eff}}{\mathrm{d}\ln CDNC}\right)$$

(Ghan et al., 2016)

$R - cloud \quad radiative \quad forcing$ $\quad LWP - liquid \quad water \quad path$

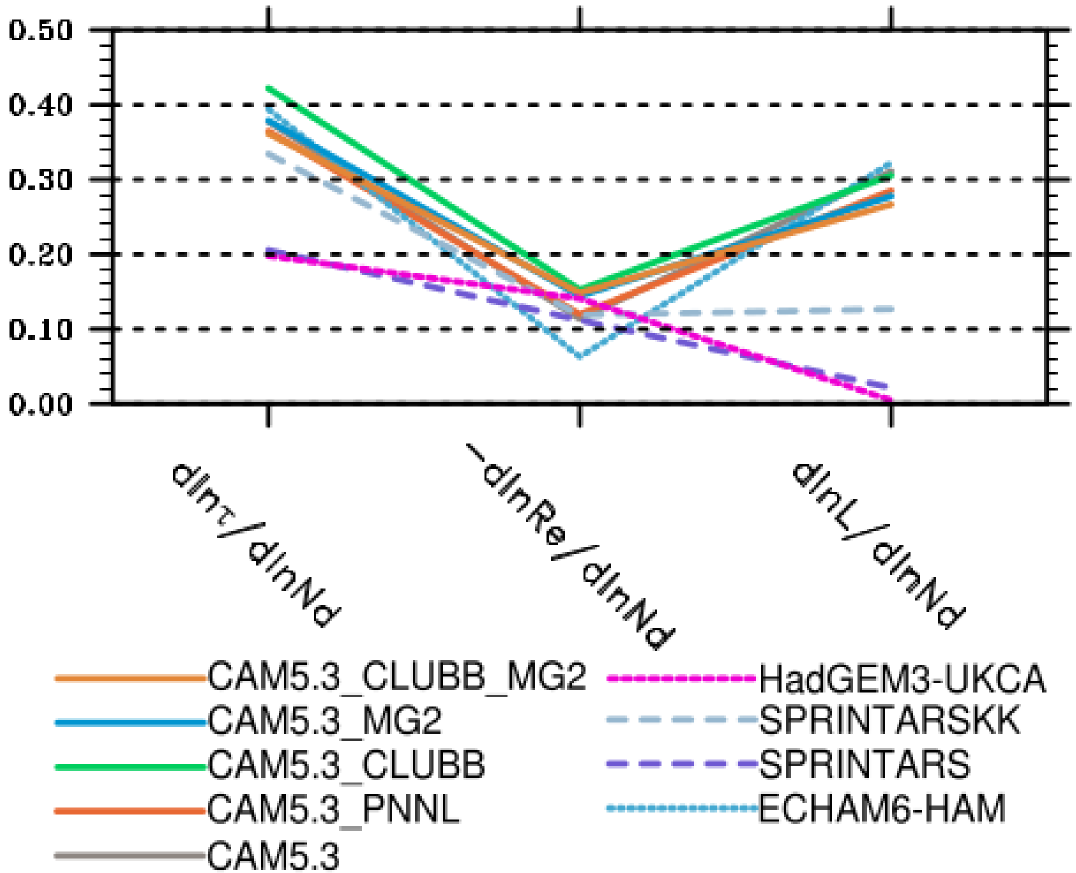
$C - cloud \quad fraction$ $\quad \tau - cloud \quad optical \quad depth$

$CDNC - cloud \quad droplet \quad number \quad concentration$

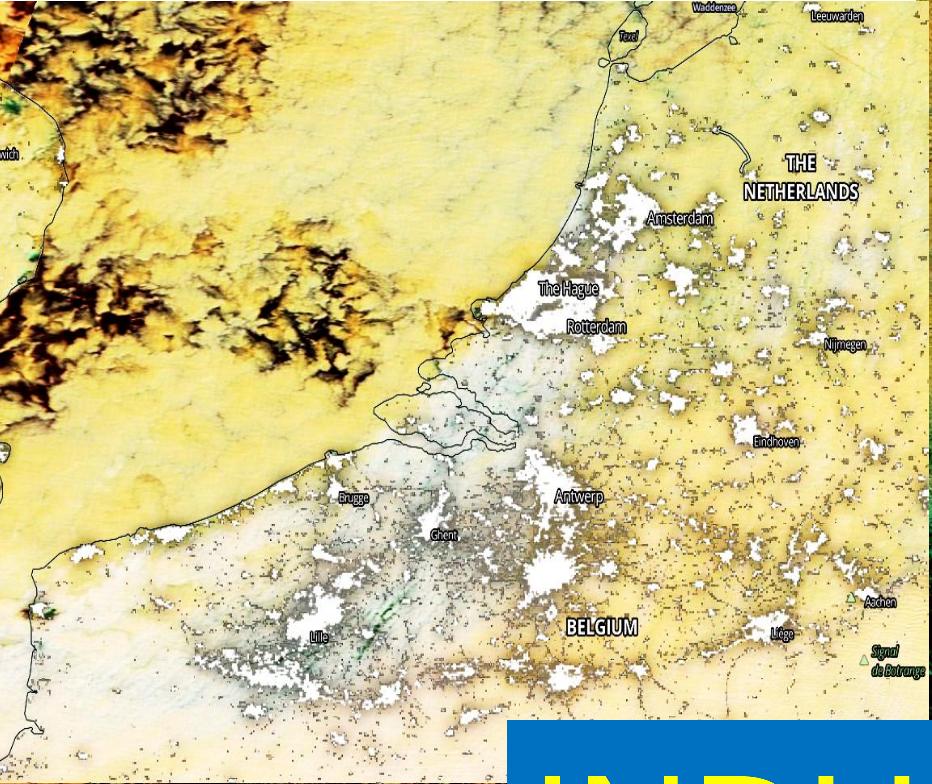
$R_{eff} - cloud \quad droplet \quad effective \quad radius$ $\quad E - emission$

$CCN - cloud \quad condensation \quad nuclei \quad concentration$

Diversity of LWP changes in GCMs



(Ghan et al., 2016)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