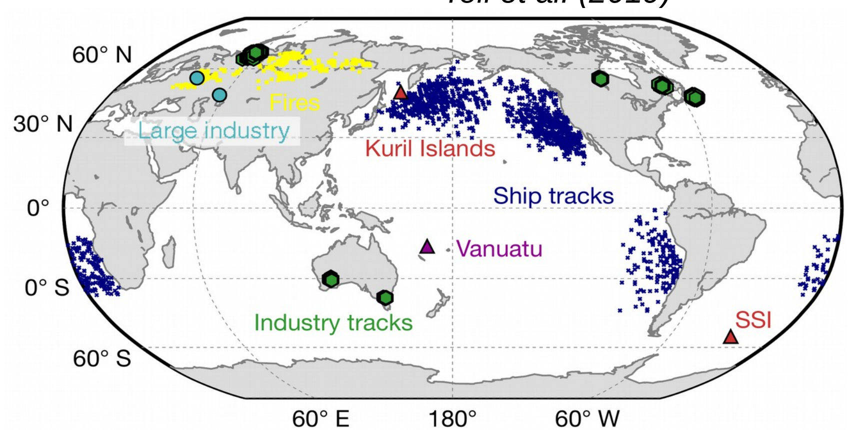
Exploring the cloud water adjustment in deep marine stratocumulus decks

A. Possner, R. Eastman, F. Bender, F. Glassmeier

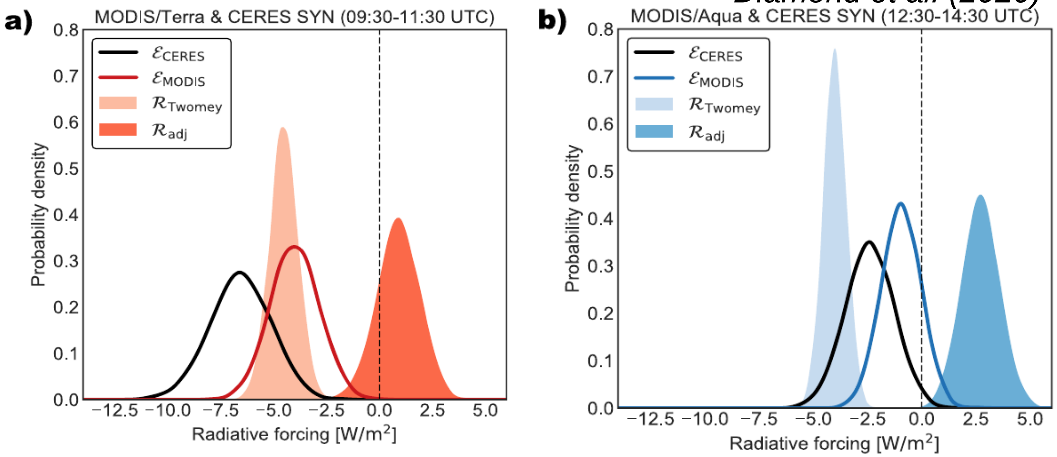
Estimates of cloud adjustment:

1) **Natural Laboratories: cloud adjustment likely small** (Malavelle et al. 2017) **with moderate (< 30%) offset to Towmey forcing** (Toll et al. 2017, Toll et al. 2019, Diamond et al 2020).

Toll et al. (2019)



Diamond et al. (2020)



[Figure comment: Notice diurnal variation in adjustment strength]

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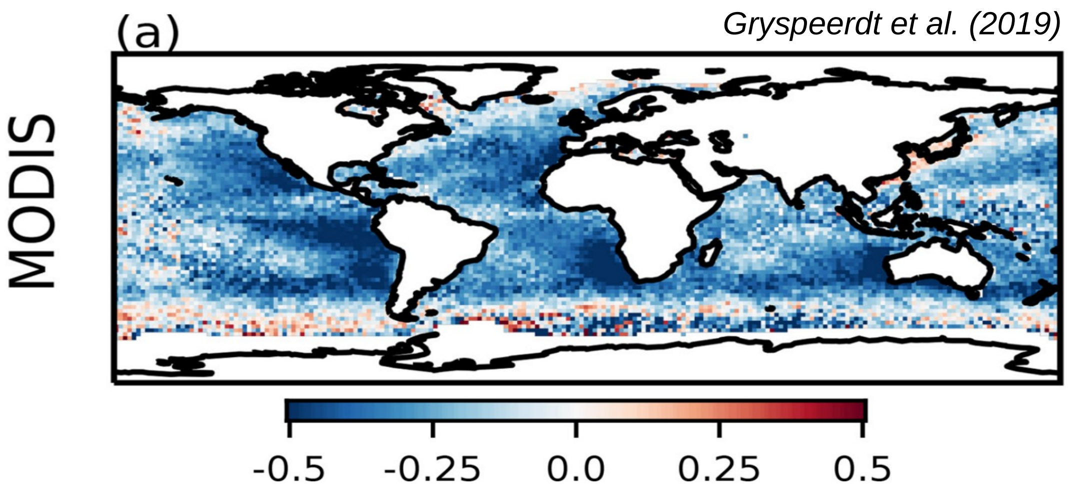
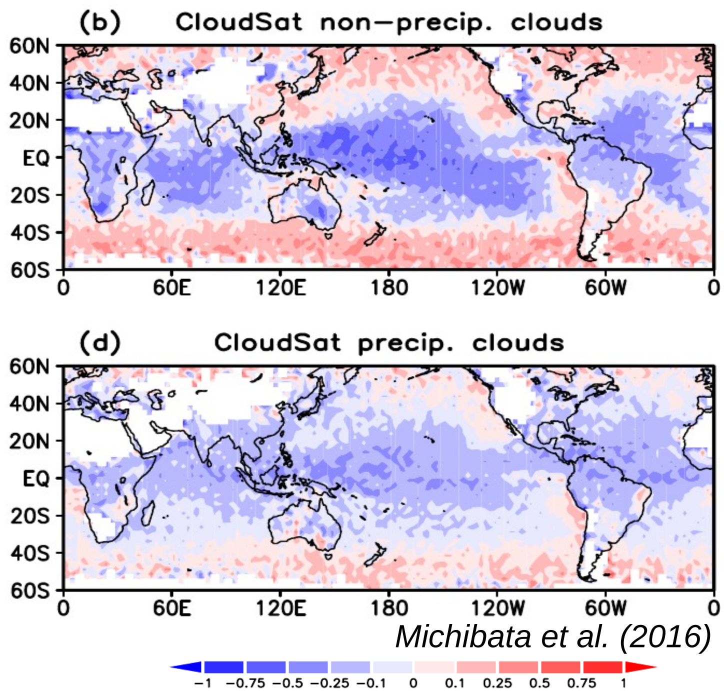


Definition: $s_{lwp} = \frac{\Delta \ln LWP}{\Delta \ln N_d}$



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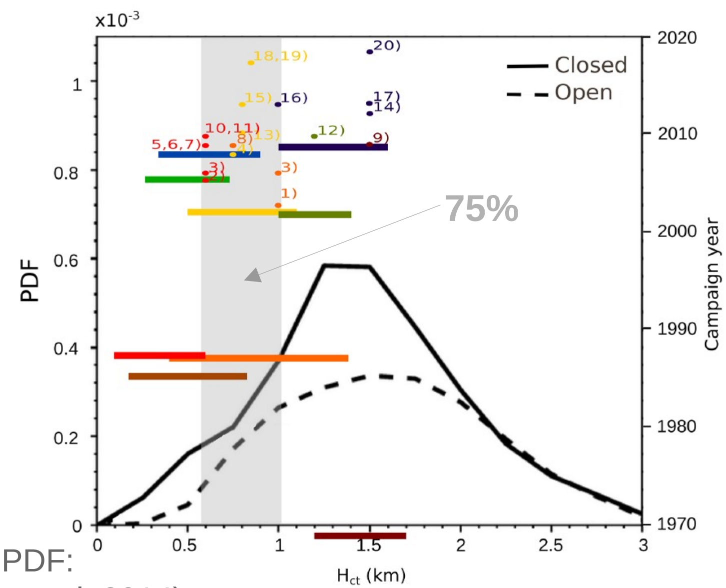
3) **In-situ observations and cloud-resolving model studies: 75% of all high-resolution model studies investigating aerosol-cloud interactions in stratocumulus decks are conducted within narrow range of conditions** (Possner et al. 2020).



[courtesy PDF: Muhlbauer et al. 2014)

Field campaigns:

ATEX (Augstein et al., 1973)
DYCOMS (Lenschow et al., 1988)
FIRE (Albrecht et al., 1988)
ASTEX (Albrecht et al., 1995)
DYCOMS-II (Stevens et al., 2003)
EPIC (Bretherton et al., 2004)
MASE-I (Lu et al., 2007)
MASE-II (Lu et al., 2009)
VOCALS-REx (Wood et al., 2011)

Cloud-resolving simulations:

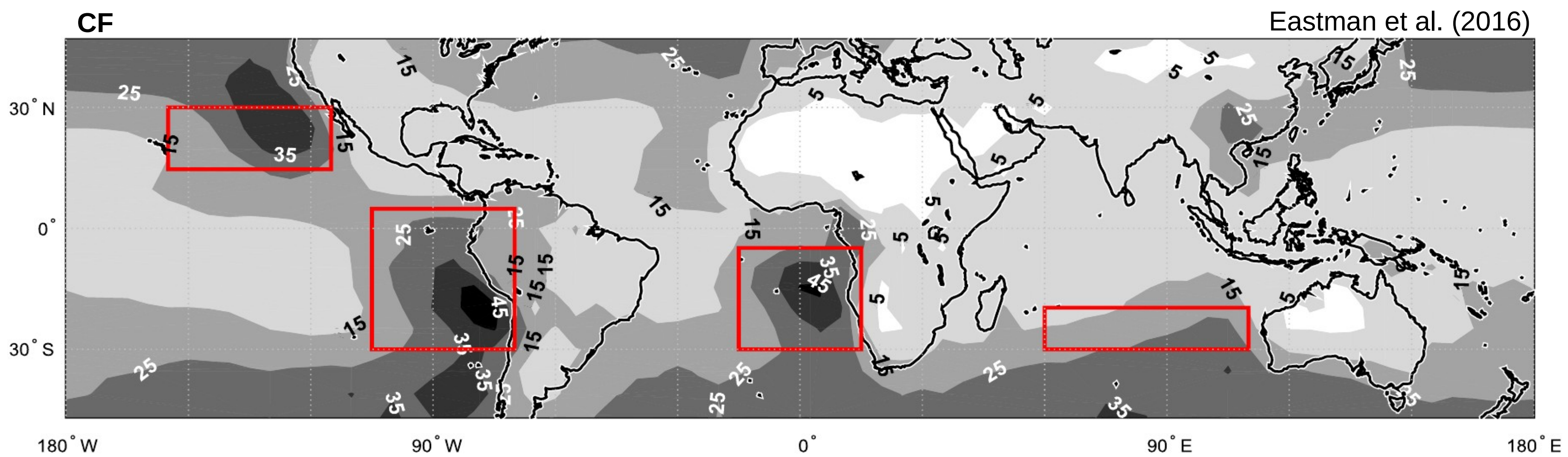
1 Jiang et al. (2002)
2 Johnson et al. (2004)
3 Lu and Seinfeld (2005)
4 Bretherton et al. (2007)
5 Sandu et al. (2008)
6 Hill et al. (2008)
7 Hill and Dobbie (2008)
8 Yi et al. (2008)
9 Xue et al. (2008)
10 Sandu et al. (2009)
11 Hill and Feingold (2009)
12 Caldwell and Bretherton (2009)
13 Ackerman et al. (2009)
14 Mechem et al. (2012)
15 Jenkins et al. (2013)
16 Petters et al. (2013)
17 Berner et al. (2013)
18 Tonttila et al. (2017)
19 Zhou et al. (2017)
20 Possner et al. (2018)

- Summary of published literature (status Sept. 2019) exploring aerosol-cloud interactions in stratocumulus decks during field campaigns and in cloud-resolving models
- **70% of all stratocumulus decks reside in boundary layers deeper than 1 km, but are currently under-represented in the published literature**

=> can we expect cloud adjustment to be invariant of boundary layer depth?

 apossner@iau.uni-frankfurt.de

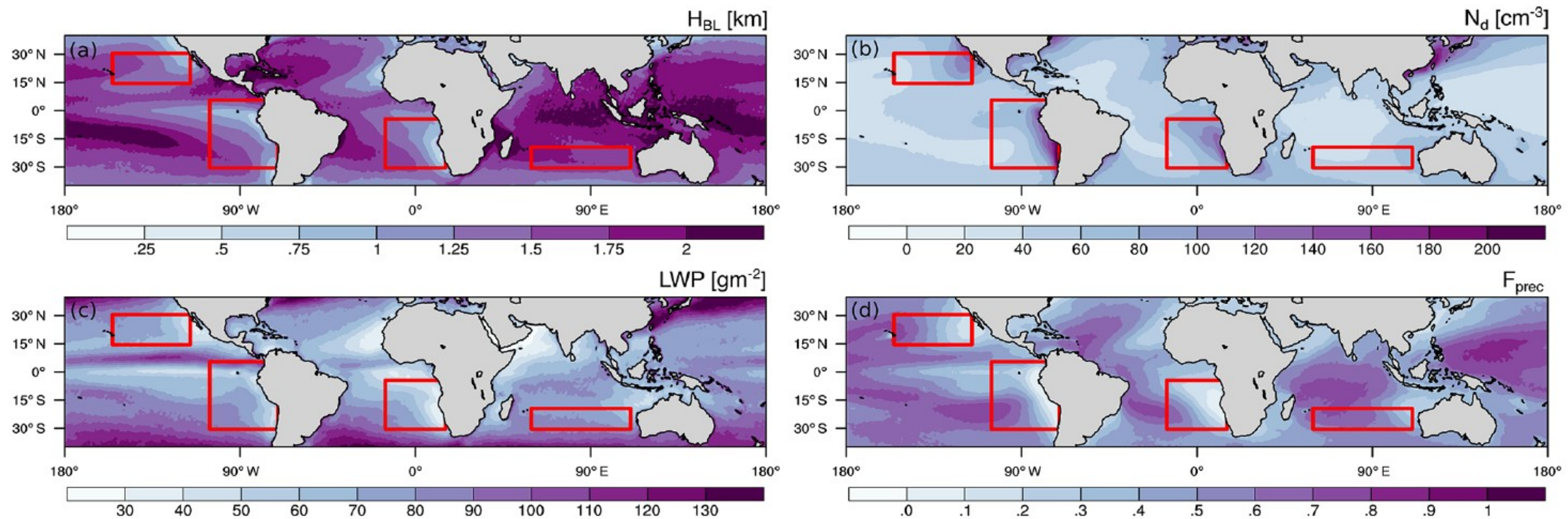
Analysis of boundary layer depth relationships in subtropical stratocumulus decks:



A_{tot}, A_{cld} (estimated), CF	CERES (ed4) *(Kato et al. 2013)*
LWP, R_{eff}, F_{prec} (R_{eff} ≥ 15 µm)	MODIS (C6) *(King et al. 2003, Platnick et al. 2017)*
N_d	MODIS (C6) *(Boers 2006, Bennartz 2007)*
H_{PBL}	CALIPSO *(Eastman & Wood 2016, Eastman et al. 2017)*

- 10-year period (2007-2016)
- In-cloud properties only
- 1º x 1º resolution
- Stratocumulus decks (CF>80%)

Climatologies of stratocumulus decks



Possner et al. (2020)

Gradients to coast line observed in all physical properties:

- Boundary layer deepens away from coast lines (500m to >2km in depth)
- LWP increases with |latitude| and distance to coast
- Strong gradients in N_d observed close to coast and relatively homogeneous elsewhere

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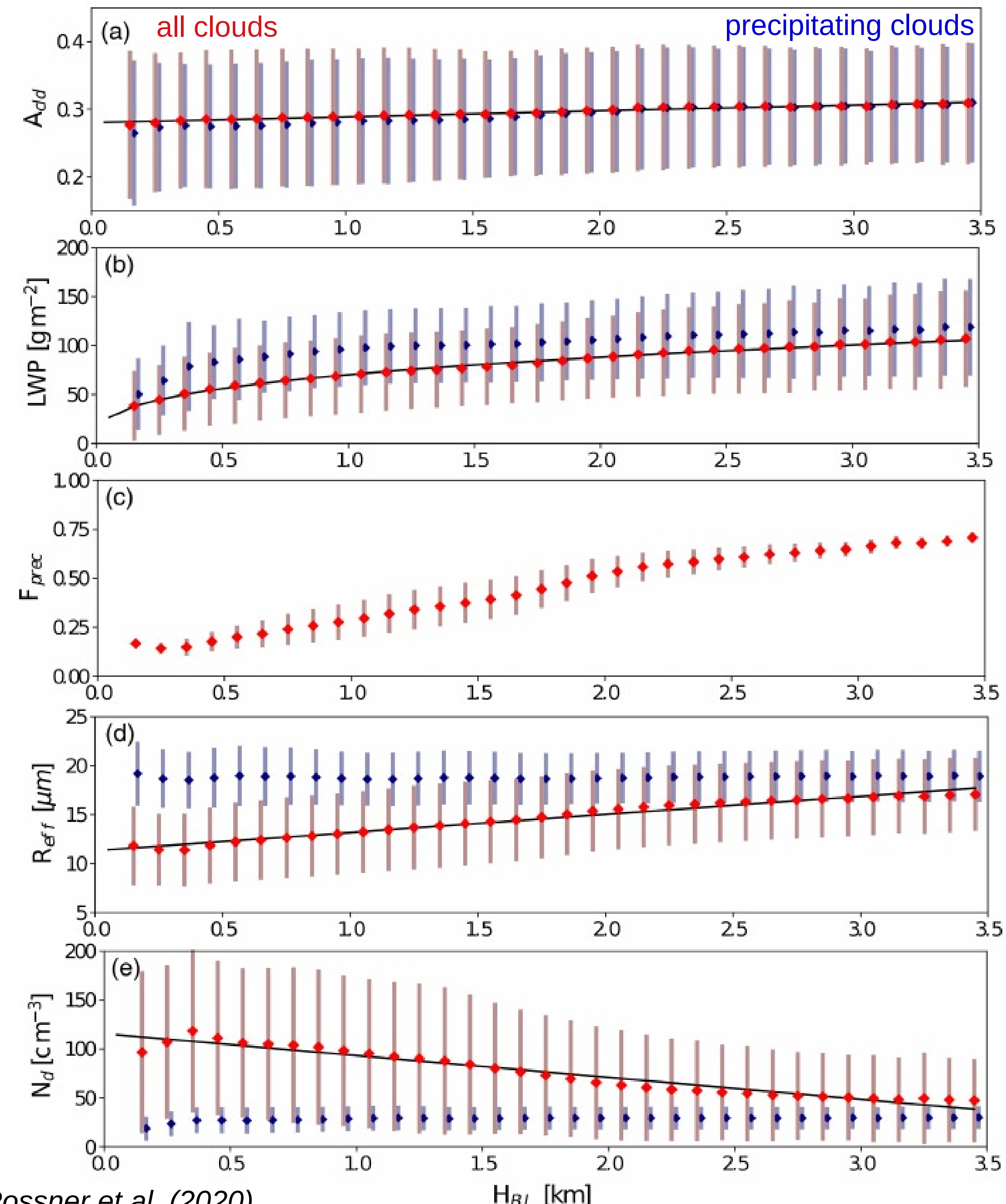
Scaling Relationships with H_{BL}



Possner et al. (2020)

→ cloud albedo scales weakly with H_{BL}

→ $\mathit{ln}\mathrm{LWP} \sim 0.42\ \mathit{ln}H_{BL}$

- In adiabatic clouds (where $\mathit{ln}\mathrm{LWP} \sim 2\ \mathit{ln}H_c$) cloud depth ($H_c$) increases by merely 3m for every 100m increase in H_{BL}
- **LWP-H_{BL} relationship controlled by external factors** (gradients in SST, FT conditions and/or changes in aerosol concentration)
- LWP-H_C relationship constrained by thermodynamics of boundary layer

→ N_d decreases with H_{BL}

- Distance to coast and thus sources of pollution is primary driver of this relationship in the absence of precipitation
- Results confirm precipitation dominant constraint on N_d

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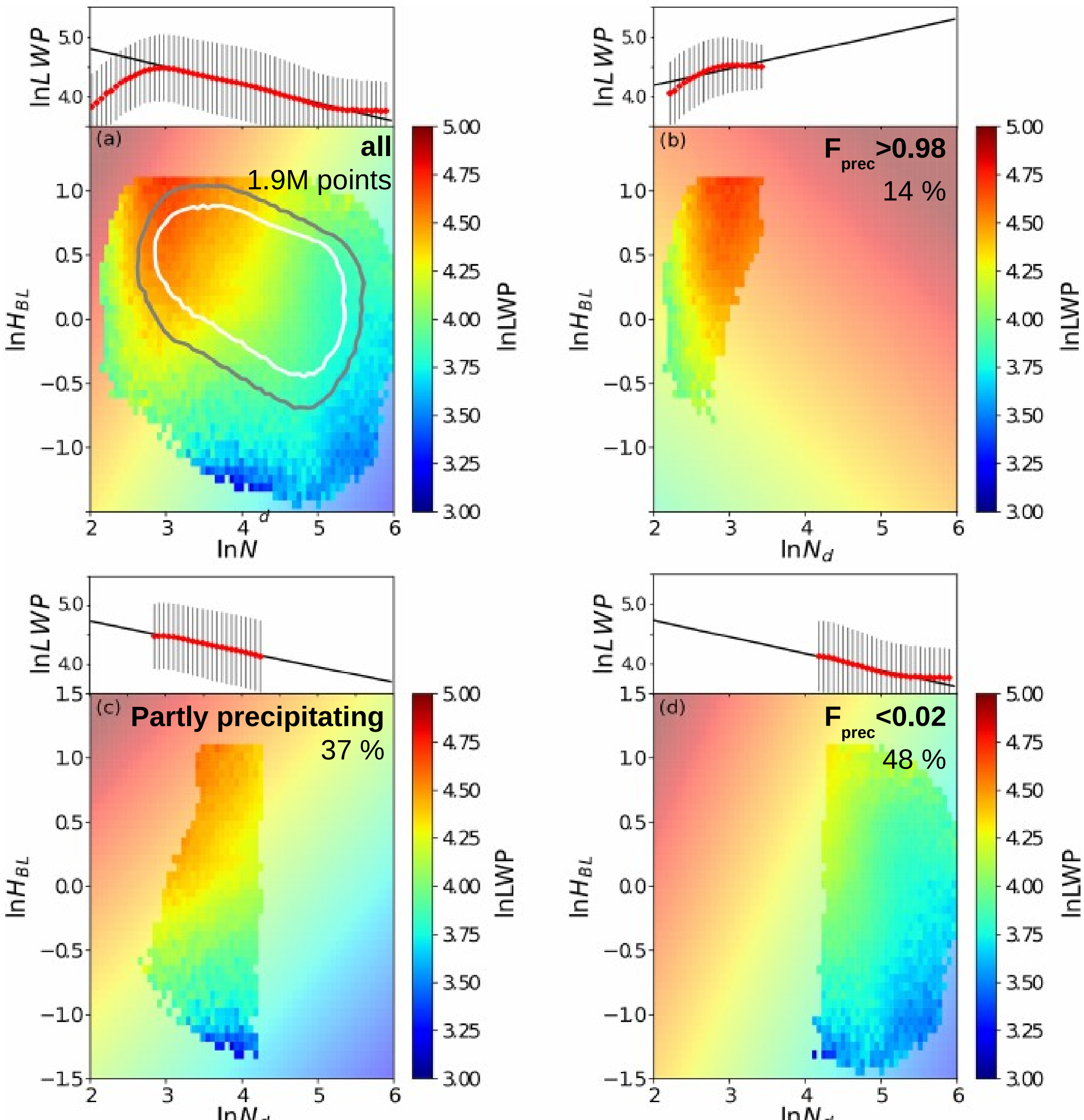
Bi-variate fit of cloud water adjustment



Possner et al. (2020)

<u>Definition:</u> $$s_{lwp} = \frac{\Delta \ln LWP}{\Delta \ln N_d}$$

Suscepti-bility	**all**	**no prec**	**part prec**	**all prec**
s_{lwp} (bivariate)	-0.28	-0.28	-0.23	0.14
s_{lwp} (Gryspeerdt et al. 2019)	-0.33	-0.28	-0.26	0.28

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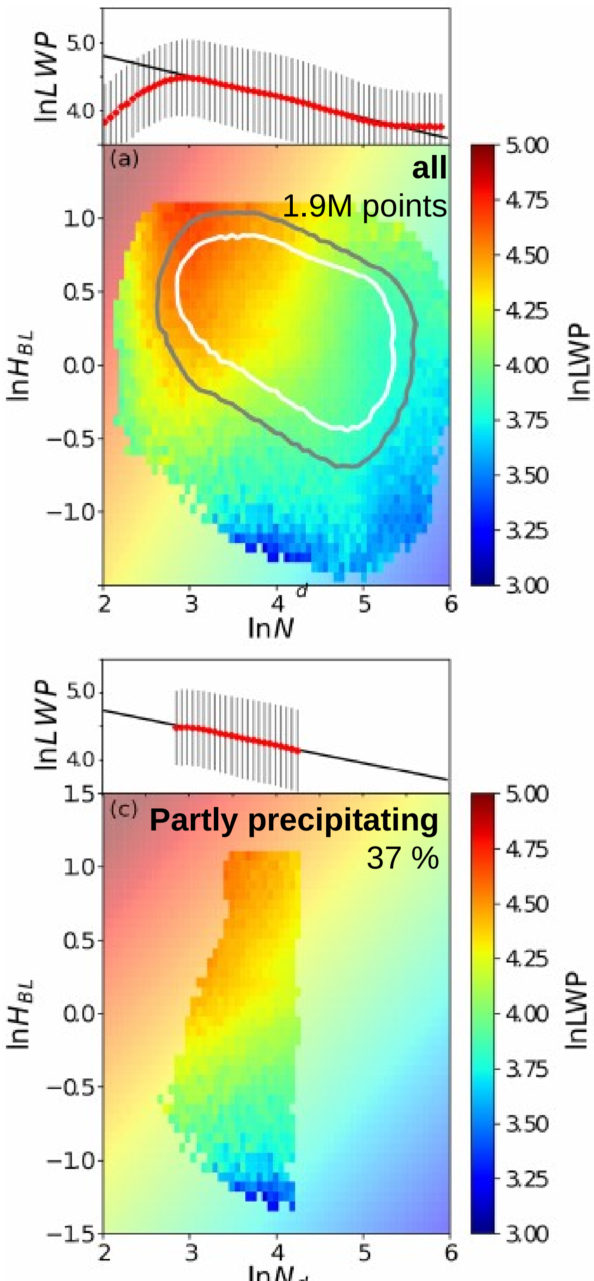

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S_{lwp} of all clouds is dominated by non-precipitating clouds as in Gryspeerdt et al. (2019).

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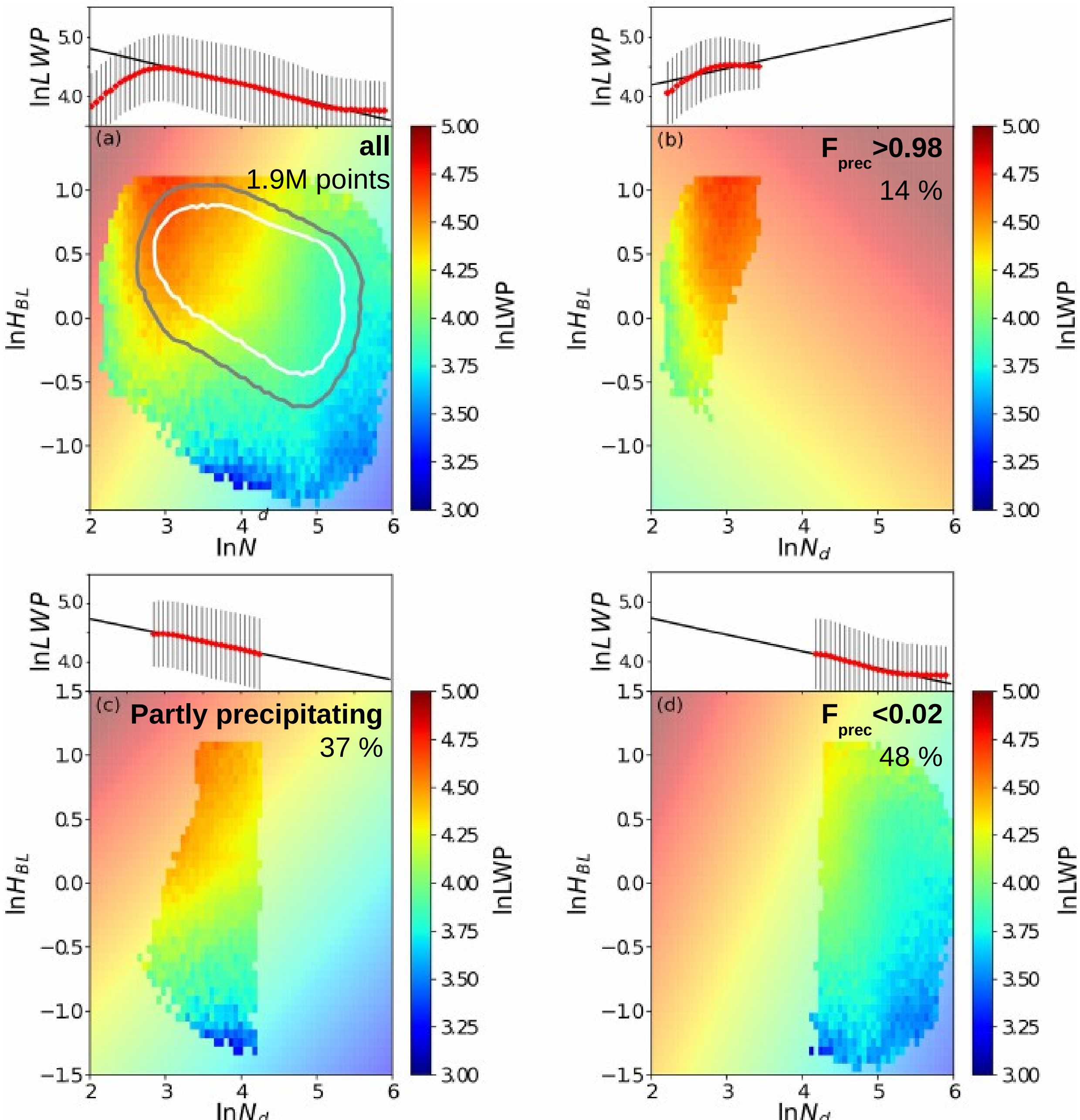

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Taking co-variability with H_{BL} into account only marginally reduces climatological s_{lwp} estimates.

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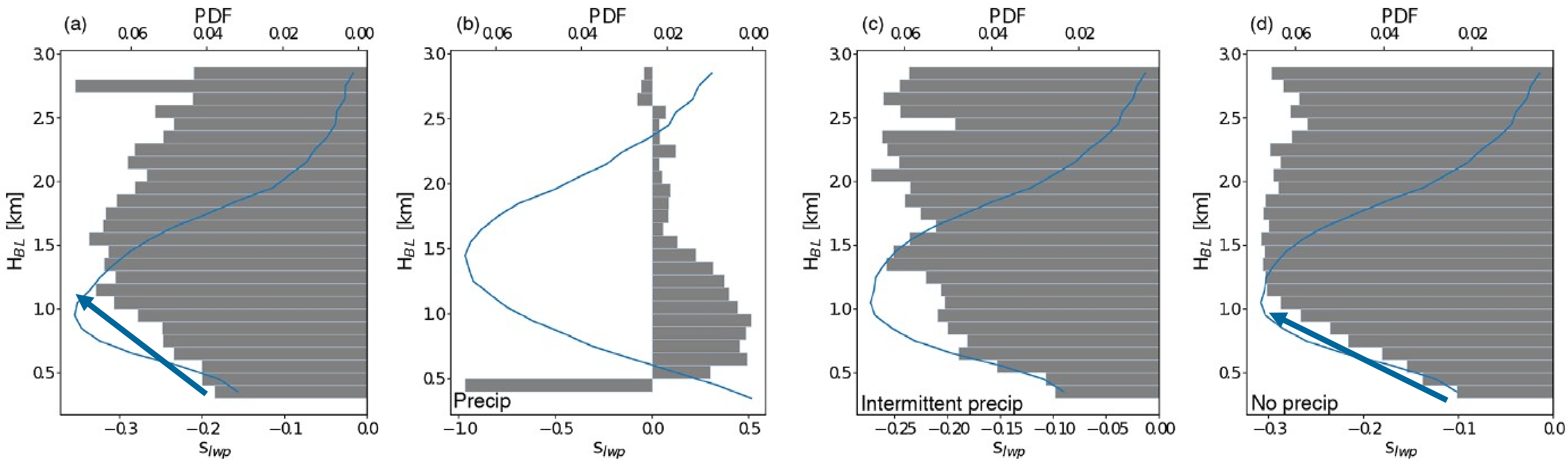
BL depth dependence of s_{lwp}



Possner et al. (2020)

s_{lwp} increases in magnitude from -0.1 for shallow BLs (depth ≤ 300 m) to -0.31 in BLs deeper than 1.1km.

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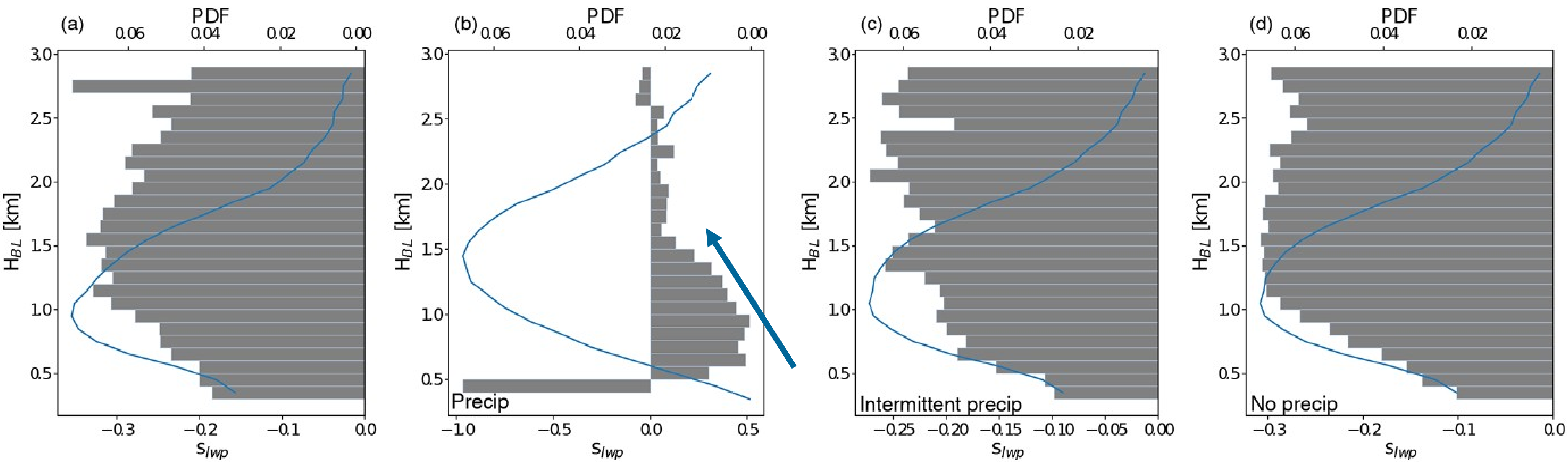
BL depth dependence of s_{lwp}

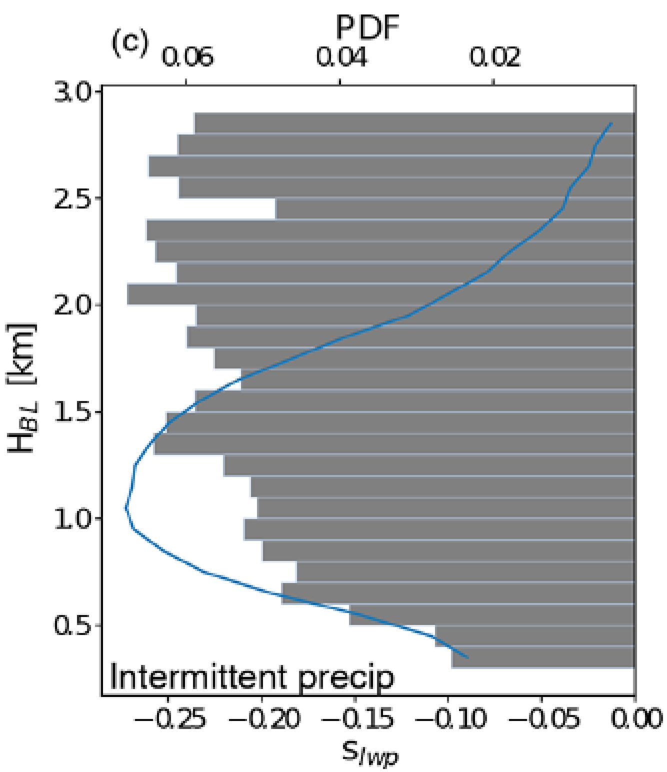


Possner et al. (2020)

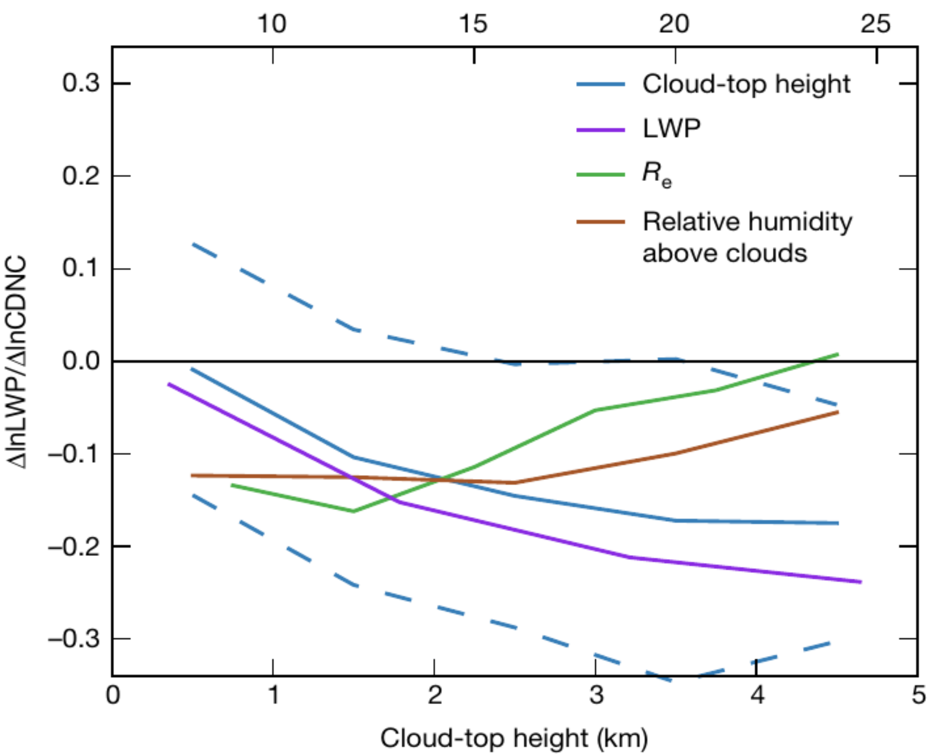
s_{lwp} increases in magnitude from -0.1 for shallow BLs (depth ≤ 300 m) to -0.31 in BLs deeper than 1.1km.

Precipitating stratocumulus are associated with stronger positive LWP adjustments in BLs lower than 1.5km.

- **Change in s_{lwp} with H_{BL} is within 1σ uncertainty of pollution track estimates where s_{lwp} decreases from** -0.01 ± 0.13 **to** -0.13 ± 0.13 **as BL depth increases to 3 km.**



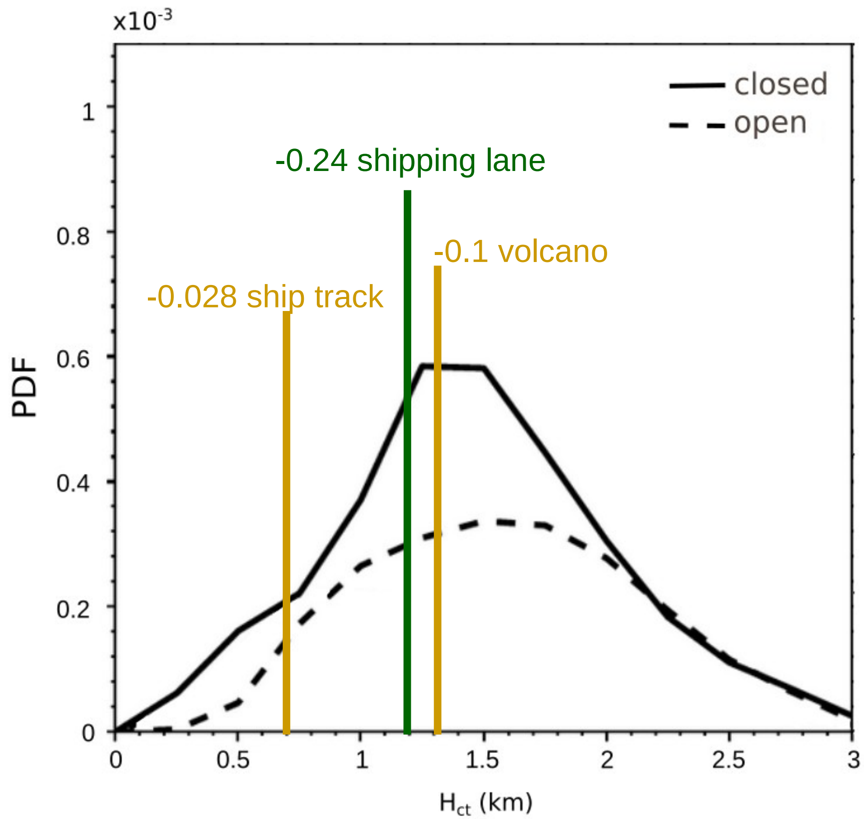
Climatological relationship of regime characterising most stratocumulus regions



Cloud top-height dependence in pollution tracks (Toll et al. 2019)

Context to natural laboratories

- Change in s_{lwp} with H_{BL} is within 1σ uncertainty of pollution track estimates where s_{lwp} decreases from -0.01 ± 0.13 to -0.13 ± 0.13 as BL depth increases to 3 km.
- **Ship track estimate:** s_{lwp} = -0.028 (Toll et al. 2019), **versus shipping lane estimate:** s_{lwp} = -0.24 (Diamond et al. 2020) **also supports that slwp may be larger in deeper BL.**



[courtesy PDF: Fig. 10 in Muhlbauer et al. 2014)

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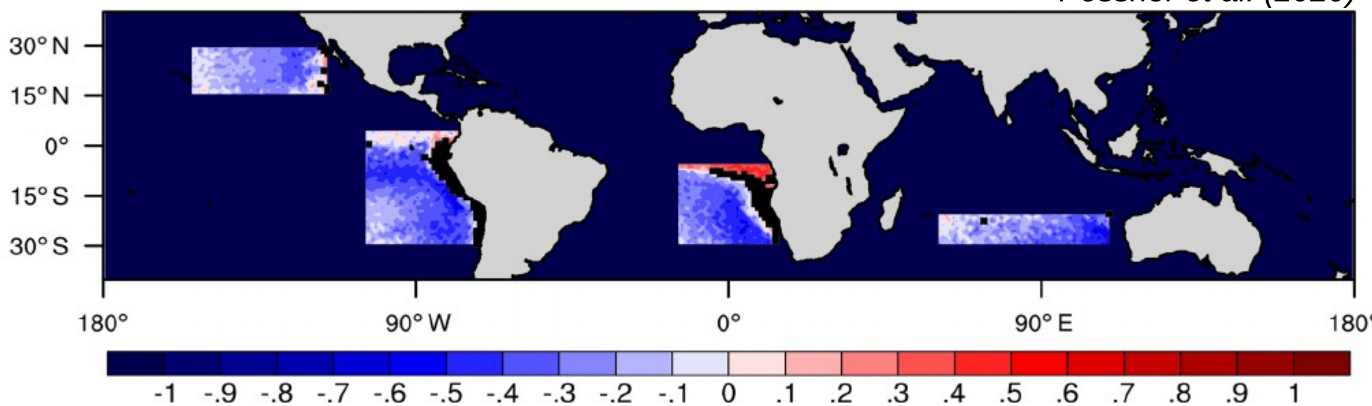

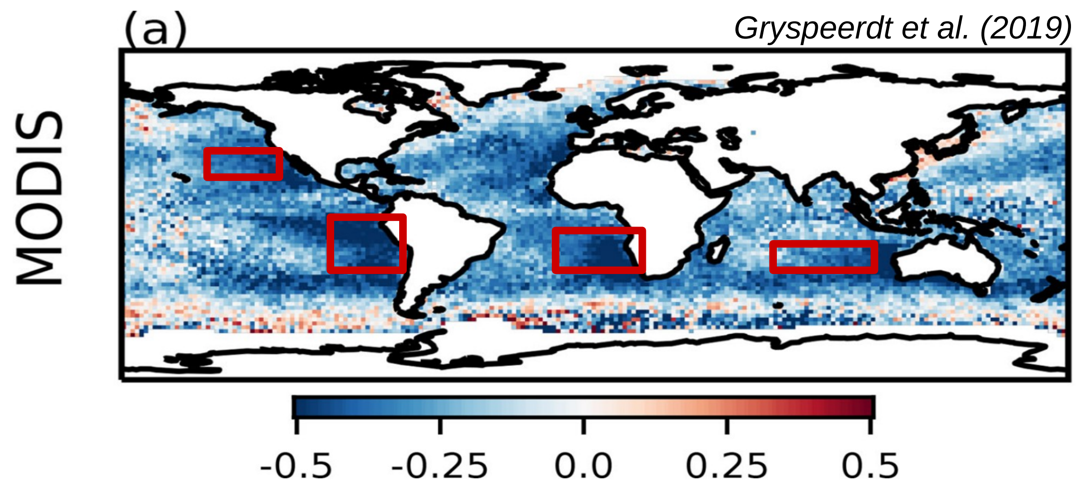

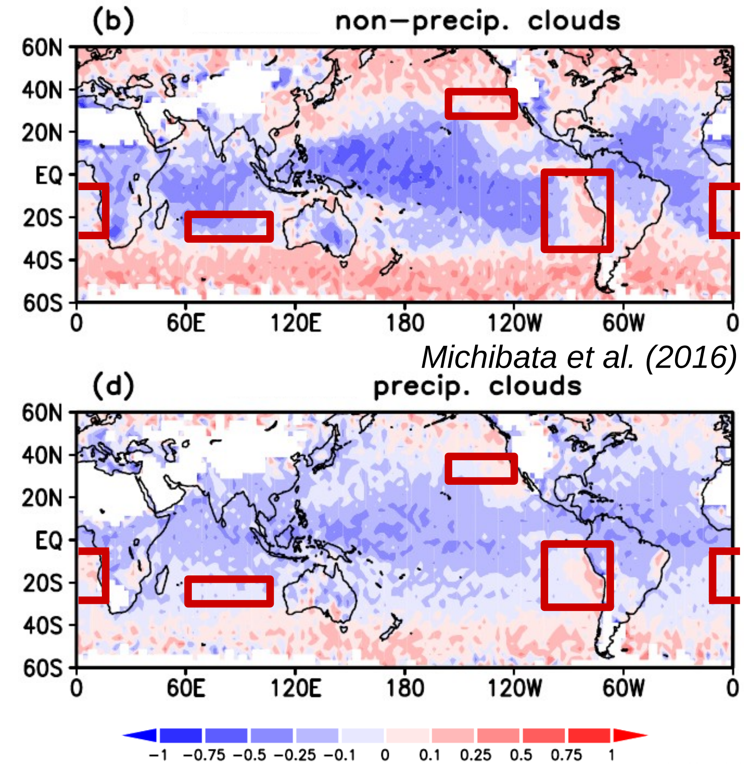

→ 3 diverging estimates of climatological s_{lwp} distribution based on MODIS LWP and N_d retrievals

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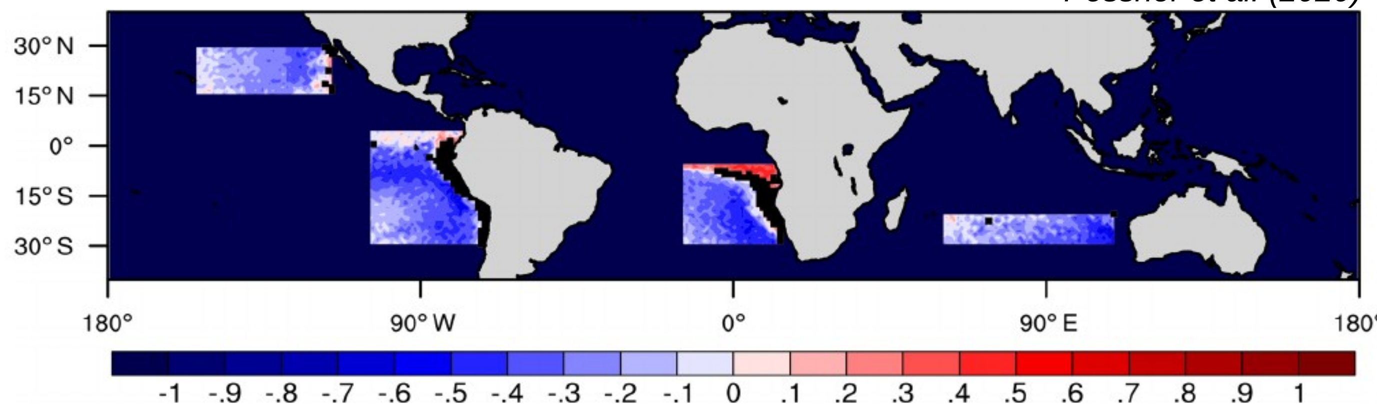
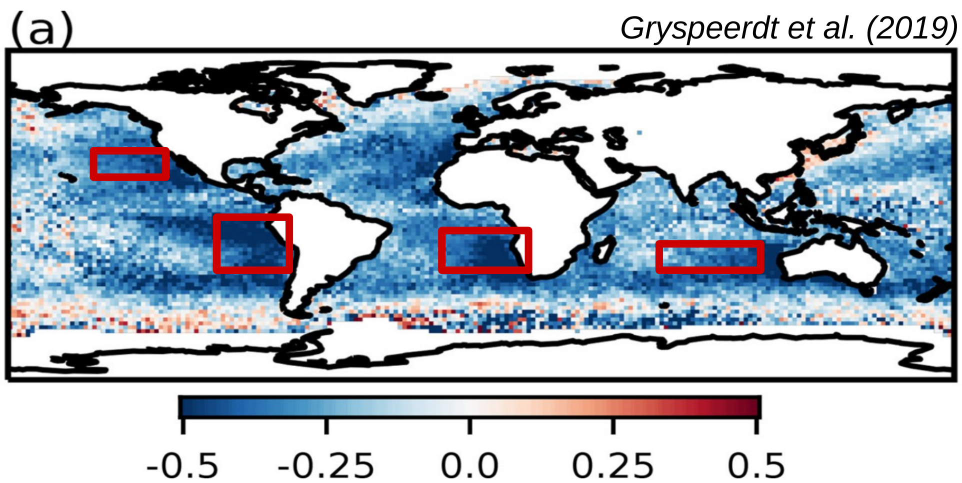
Limitations of remote-sensing based estimates

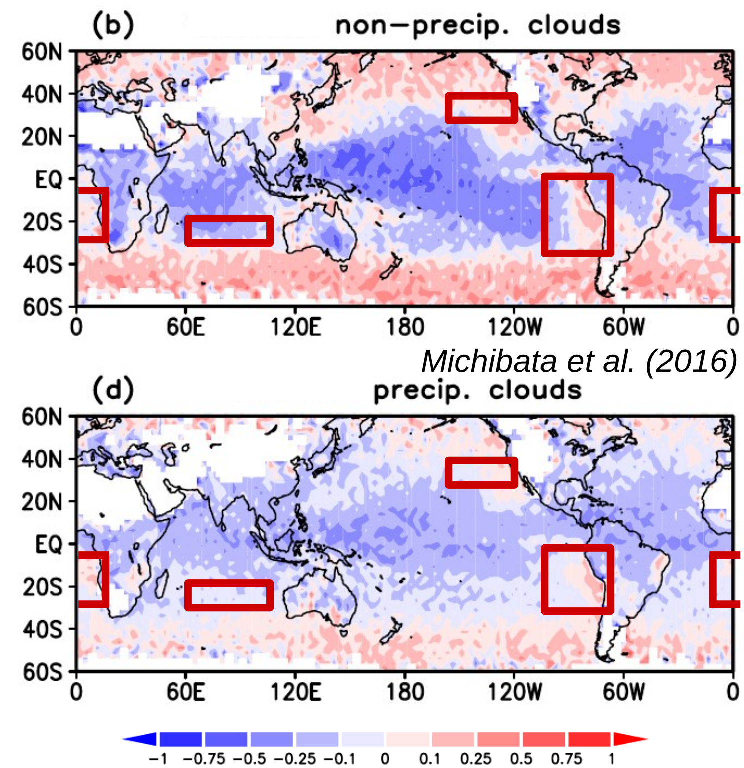
Possner et al. (2020)



Gryspeerdt et al. (2019)

MODIS





Michibata et al. (2016)

→ 3 diverging estimates of climatological s_{lwp} distribution based on MODIS LWP and N_d retrievals

- all estimates consistent in themselves
- different selection and filtering techniques applied with respect to e.g. N_d and precipitation characterisation

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Summary

- Our analysis suggests, consistent with pollution track estimates, that the cloud water adjustment triples in magnitude as the BL deepens from a few hundred meters to 1.2 km in depth.

- Substantial uncertainty remains with remotely-sensed estimates of s_{lwp} which in part seems due to different methodologies in data processing.

- Susceptibility estimates and process verification in deep stratocumulus are currently poorly constrained due to lack of process studies in this depth range.

Thoughts on Way Forward

1) Upcoming analyses and case studies of ORACLES, CLARIFY and LASIC during which deeper BLs were sampled, can help close the gap between in-situ constrained shallow BL and deep BL estimates and help constrain remote-sensing based estimates.

2) Can we agree on “state-of-the-art” approach to quantify cloud water adjustment using low-cloud satellite retrievals? What are advantages and disadvantages of different methodologies and how are estimates effected?

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