Quantifying the Effects of Downward Longwave Radiation on Low Clouds (An Update)

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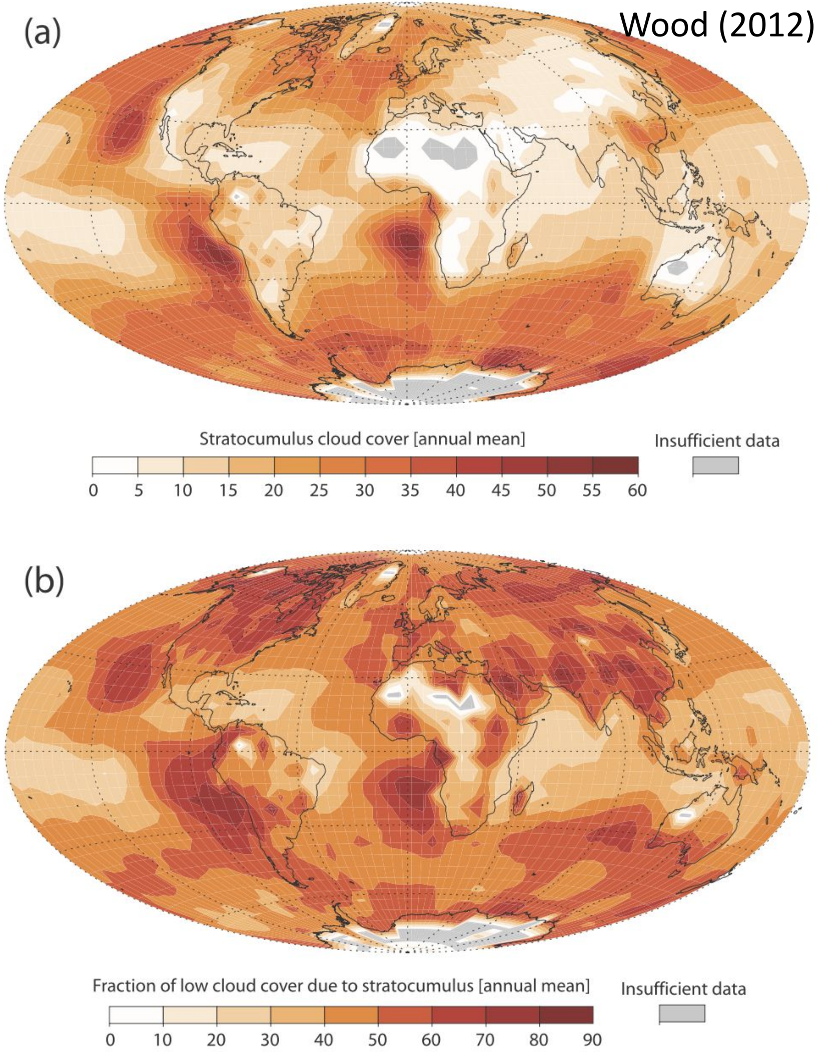
Low Marine Cloud Climatology

Low marine clouds (Sc) cover a large area of the world's oceans in regions of subsidence and cool SSTs

Vital to understanding Earth's energy budget:

- **high albedo**
- **warm emission temperatures**

Wood (2012)



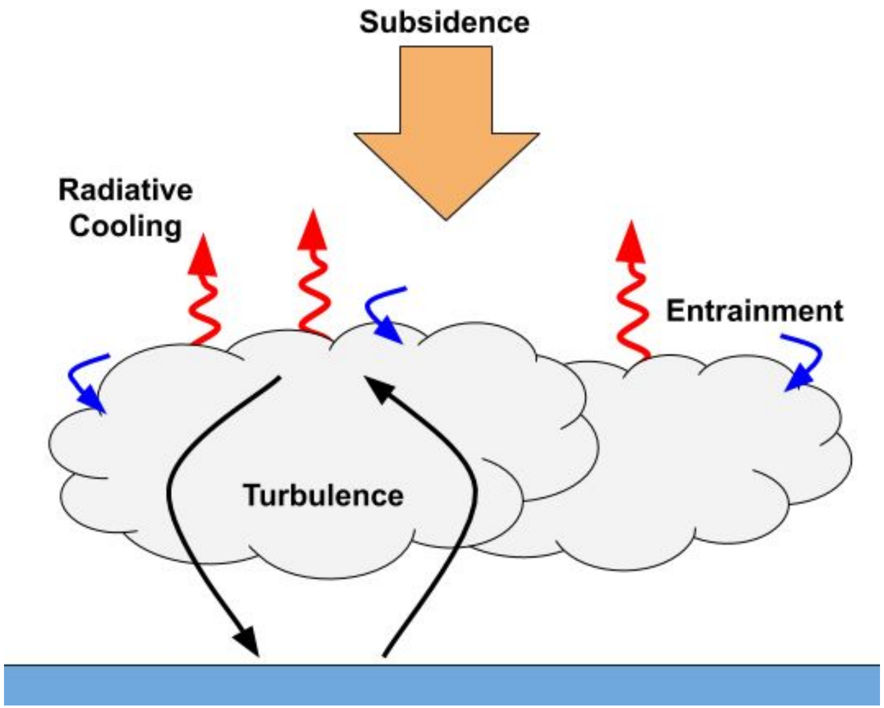
What Sustains Low Marine Clouds?

LW cooling at cloud top

Turbulence driven from LW cooling at cloud top and rising plumes from the sea surface

Entrainment of dry air at cloud top

Strong capping inversion

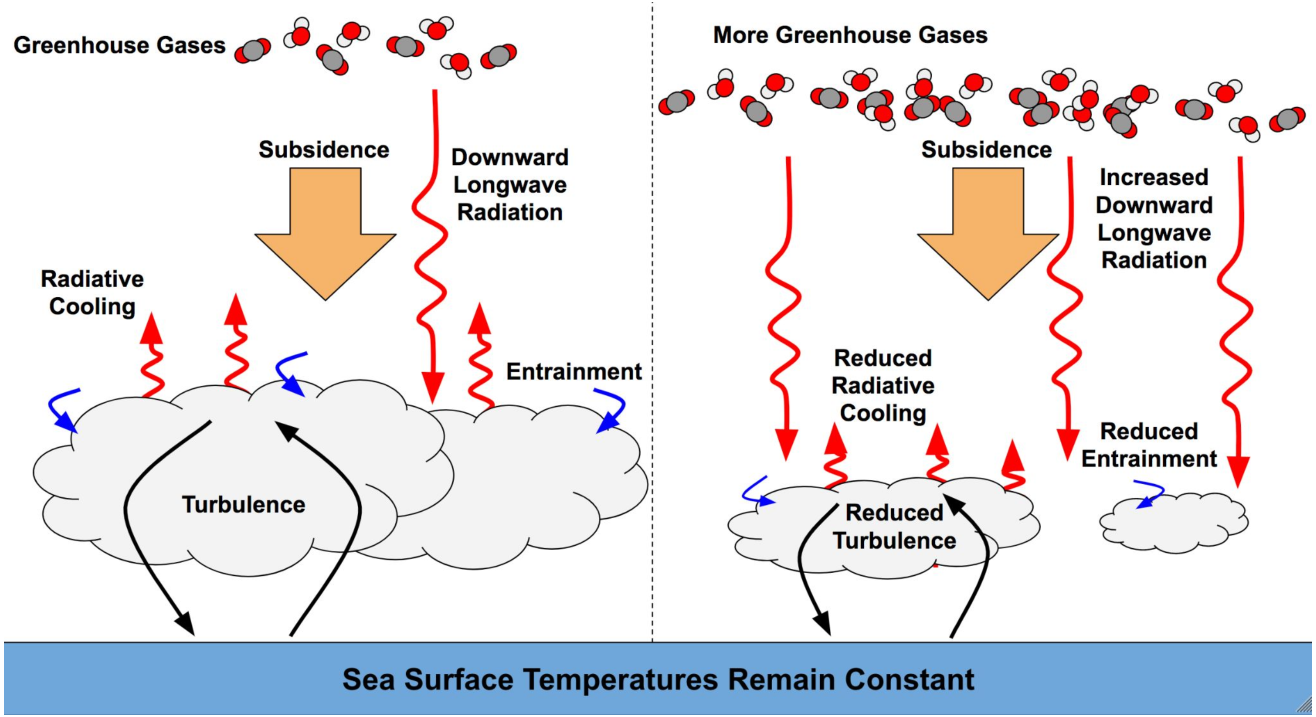


Motivation - How does increased LW↓ affect low clouds?

Greenhouse gases are increasing

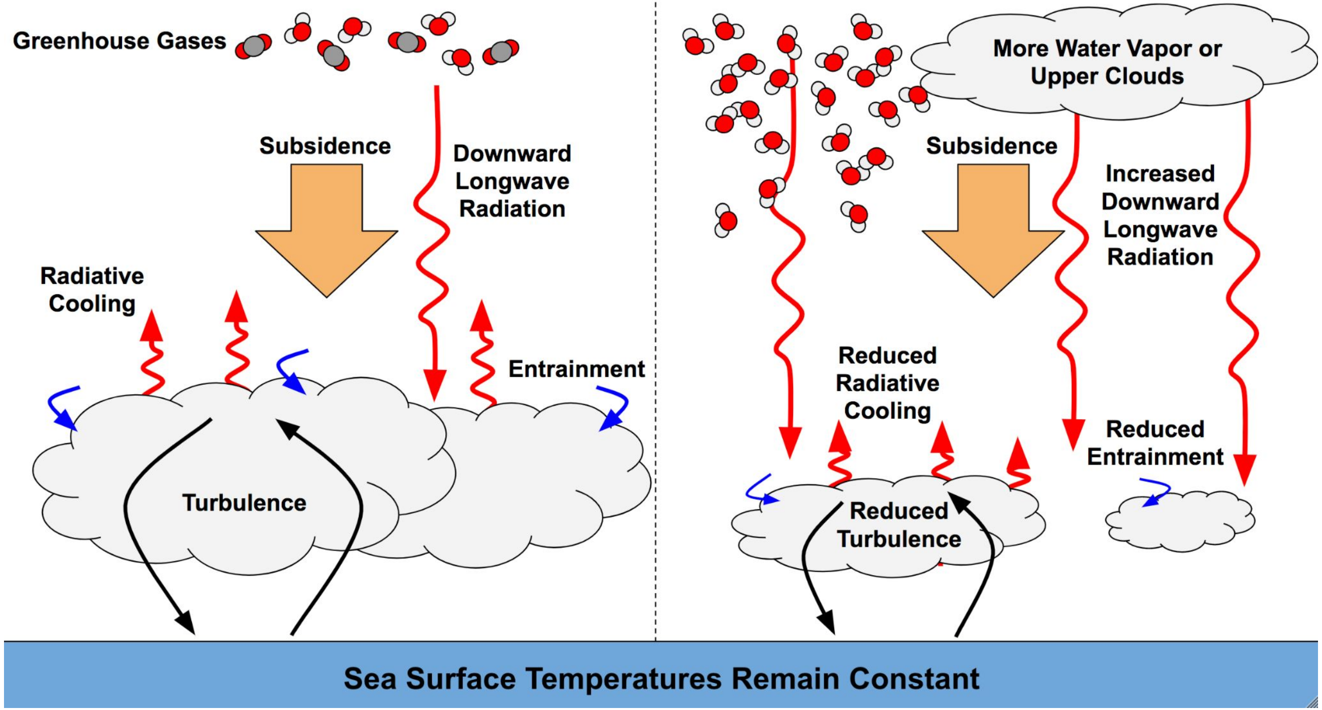
LW emission in the free troposphere above cloud tops comes from lower heights

A change in LW↓ at cloud top will affect the amount of radiative cooling at cloud top



Motivation - How does increased LW↓ affect low clouds?

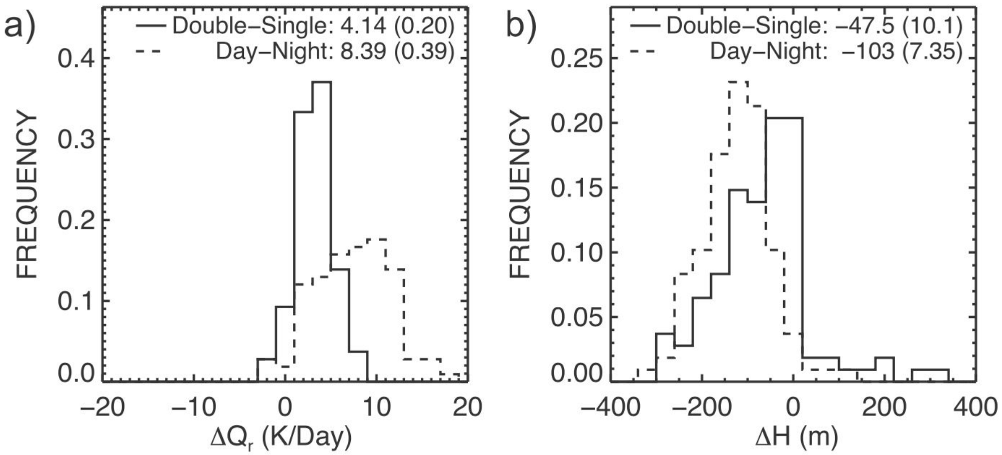
We can use upper layer clouds and free tropospheric humidity as proxies for increased GHGs



Research so far

Low cloud response to increasing GHGs has been modeled in LES (Schneider et. al 2019)

Observational study showed free tropospheric clouds increase LW↓ on cloud tops and reduce CT cooling (Christensen et. al 2013)



Solid line = difference between Double and Single cloud layers

CERES Data Products Used

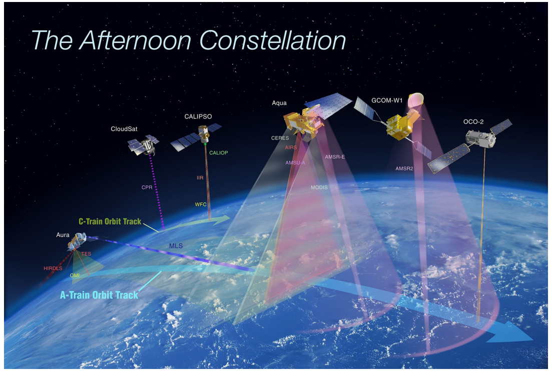
Datasets were needed with:

- Vertical irradiance profiles (MODIS, CALIPSO & CloudSat)
- Ability to observe multilayer clouds (CALIPSO & CloudSat)
- Low cloud contributions to LW↑ and SW↑ at TOA (FBCT)
- TOA LW Clear Sky (SYN1deg)

A-Train Integrated CALIPSO, CloudSat, CERES, and MODIS Merged Product (C3M)

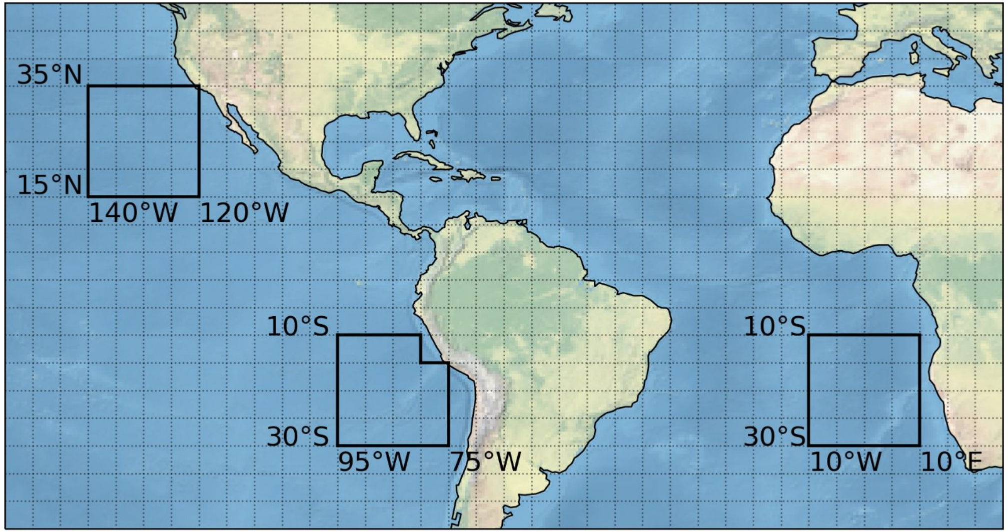
Flux by Cloud Type Daily (FBCT)

CERES_SYN1deg_Ed4A (SYN1deg)

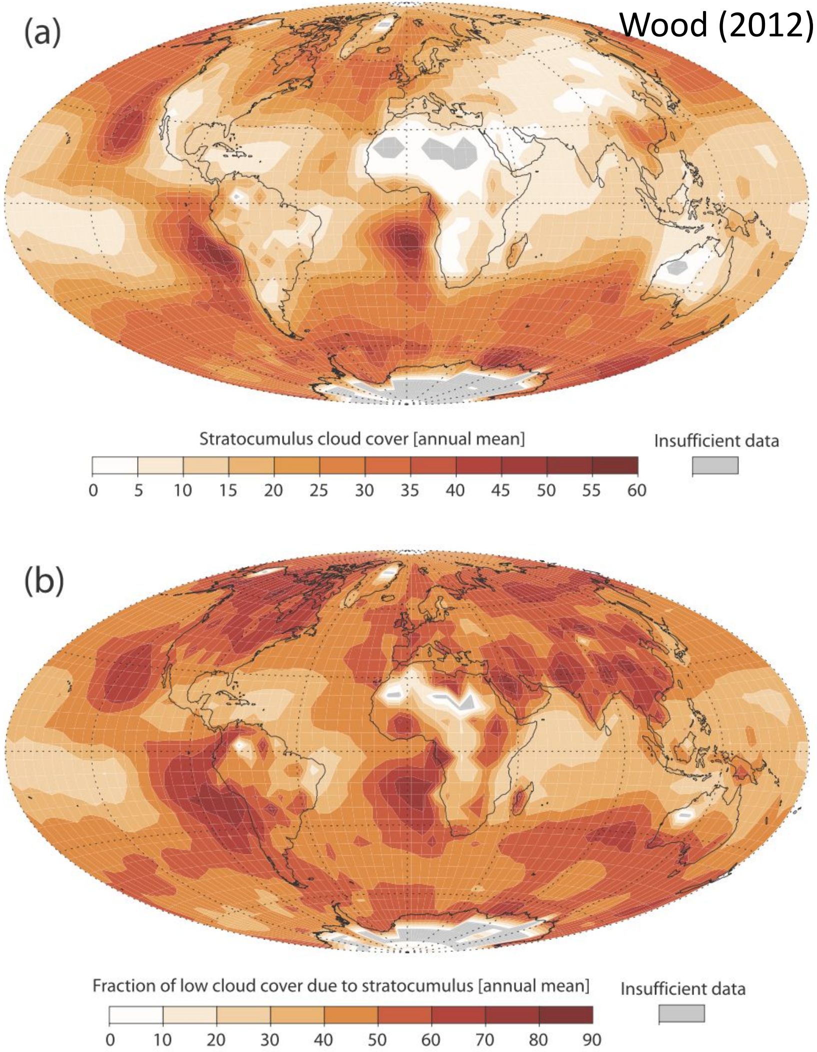


Low Cloud Regions

- Daily data from: 1/1/2007 – 12/31/2010 (4 full years of C3M)
- Night-time only footprints



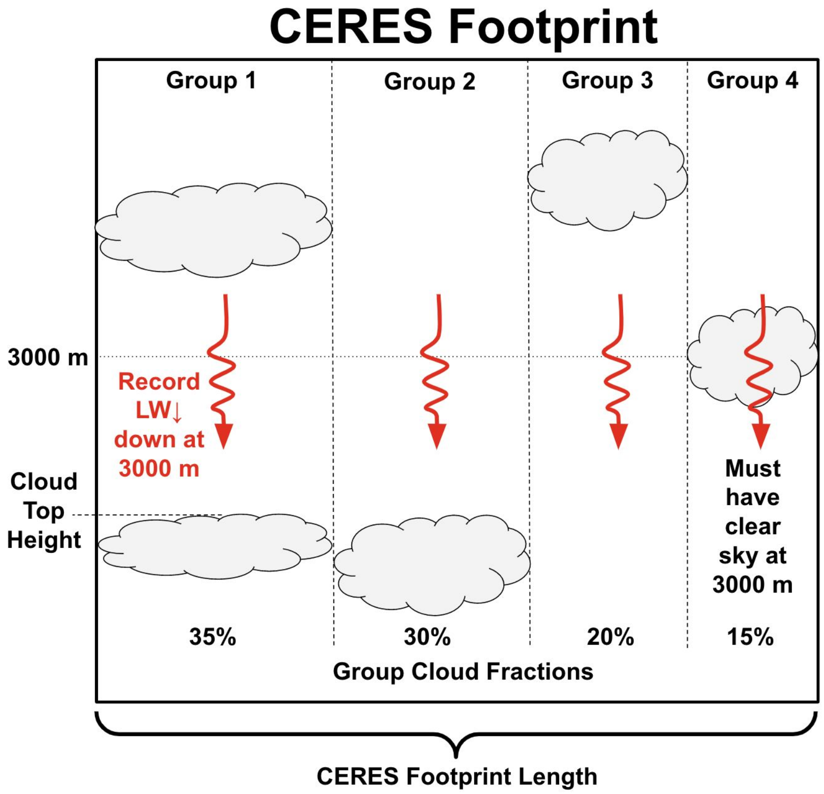
Wood (2012)



C3M: Organizing Cloud Properties

Low cloud top heights were recorded for each cloud group (0-16 groups, 0-6 layers)

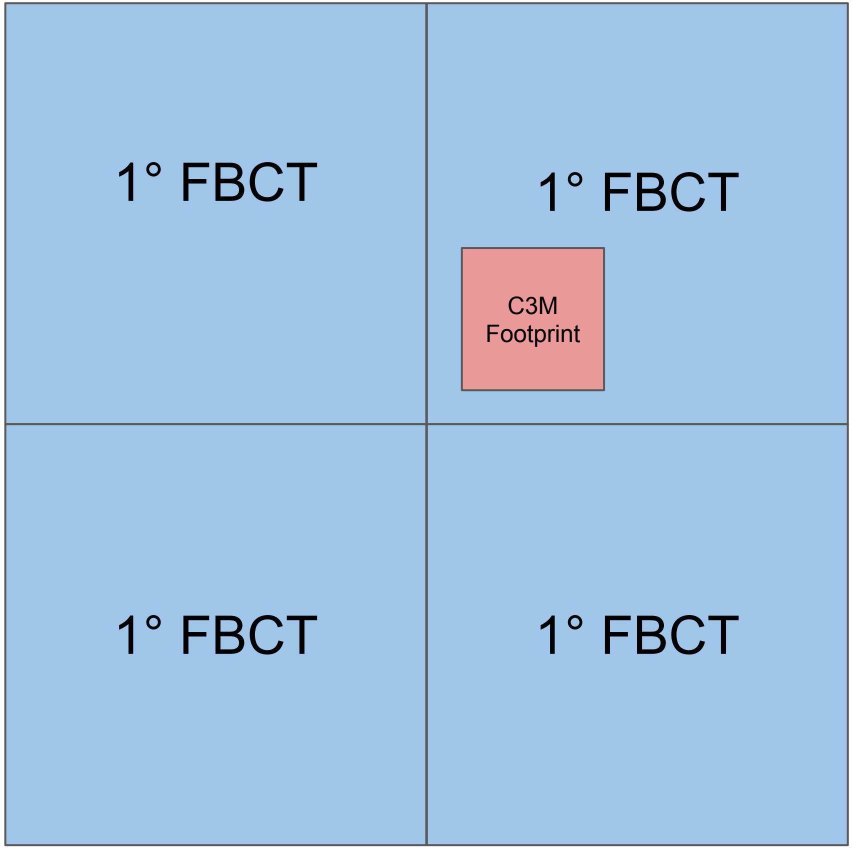
Each group's cloud top height below 3,000m was weighted by each its cloud fraction to produce a footprint average



FBCT and SYN1deg aligned to C3M

FBCT and SYN1deg aligned spatially to C3M using a K-d tree nearest neighbor search

Due to the instantaneous nature of C3M, FBCT and SYN1deg are then temporally interpolated to the C3M observations



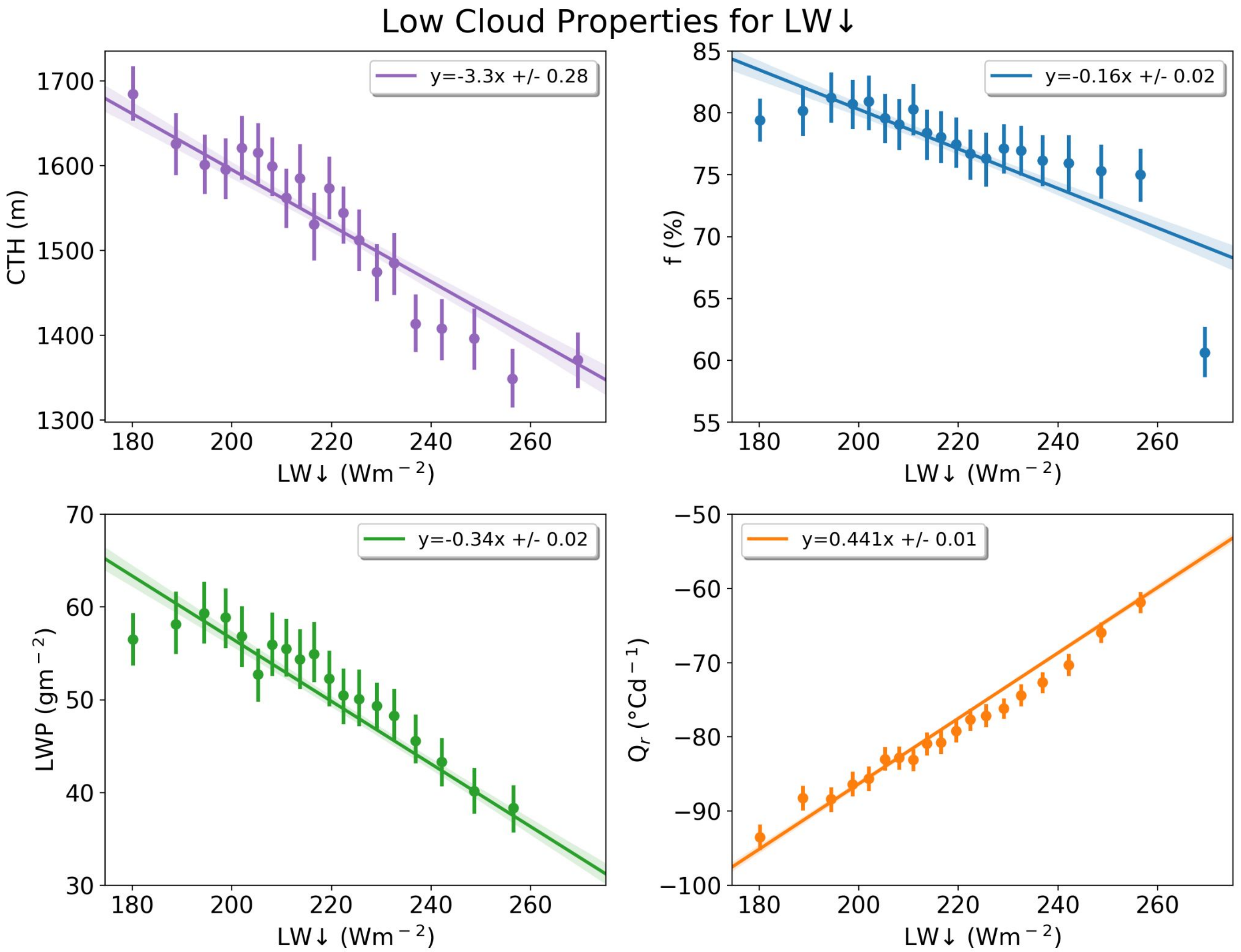
not to scale

Results

Changes in low cloud properties due to LW↓

Decreases in cloud top height, fraction, and liquid water path with LW↓

Increases in Qr with LW↓

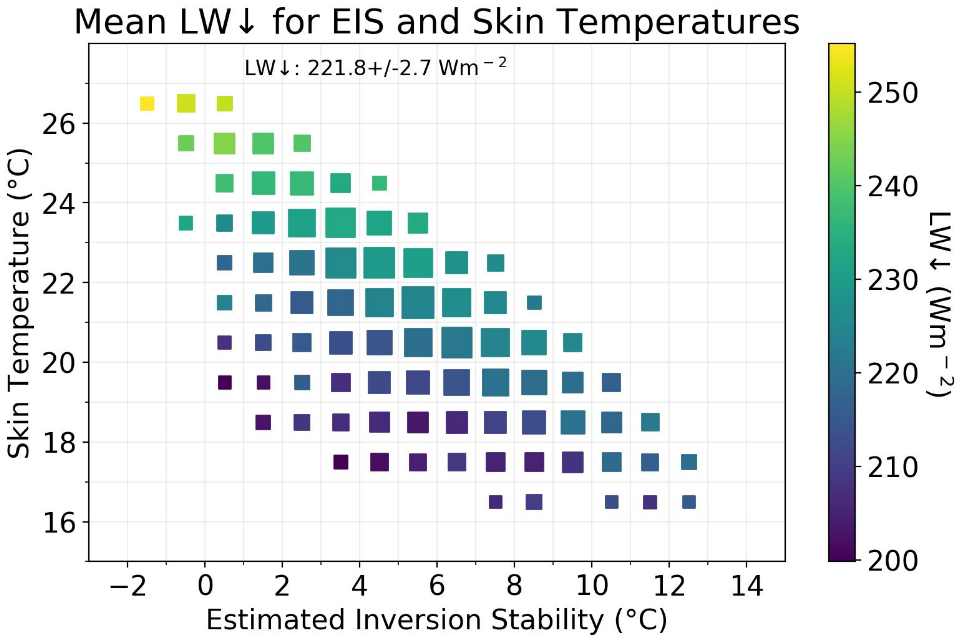


Constraining for Meteorology

EIS and skin temperature are strong controlling factors on low cloud properties

To control for these influences, cloud properties were binned by EIS and skin temperature in 1°C x 1°C bins

Cloud properties: CTH, f, Q_r, LWP, SWCRE, LWCRE, NETCRE

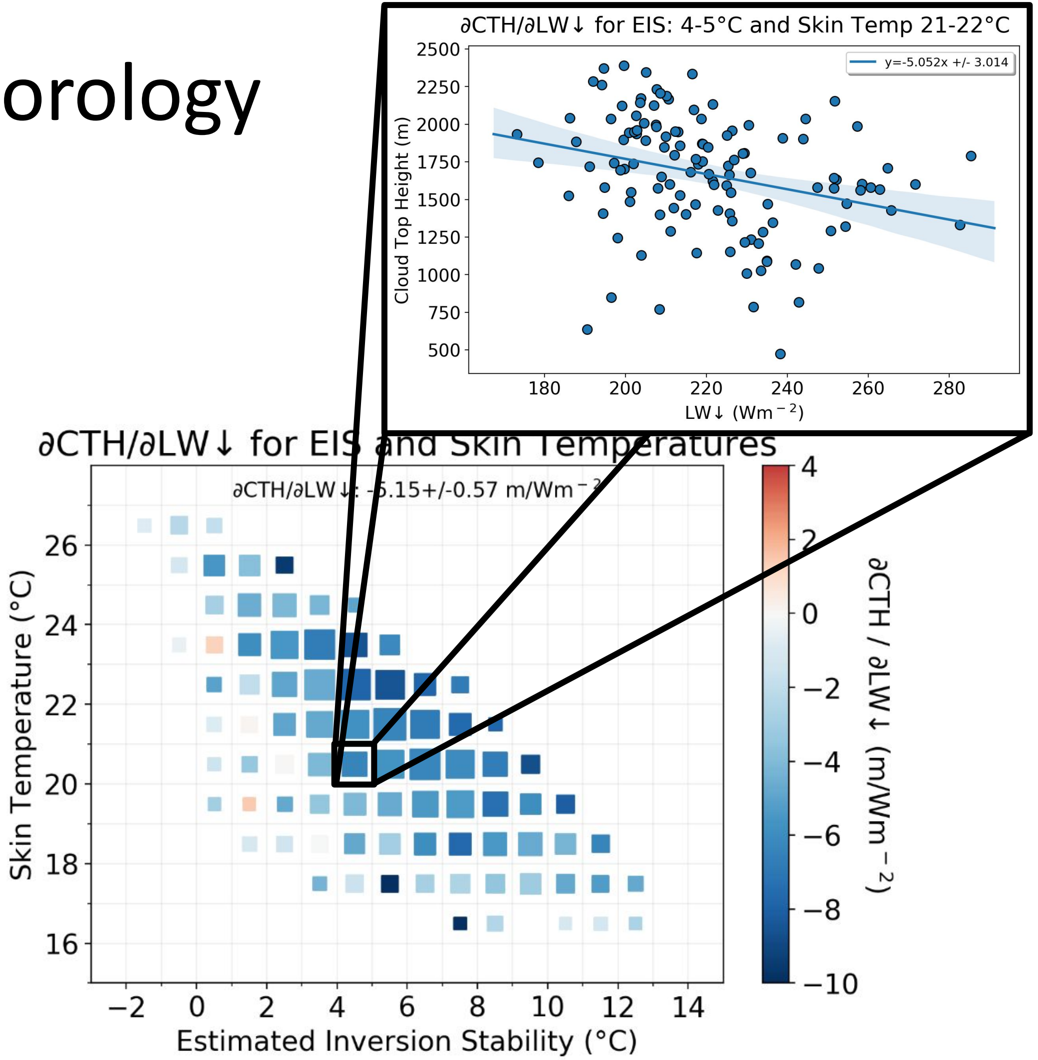


Size of the square is proportional to the number of observations within the bin. 45-328 obs. per bin

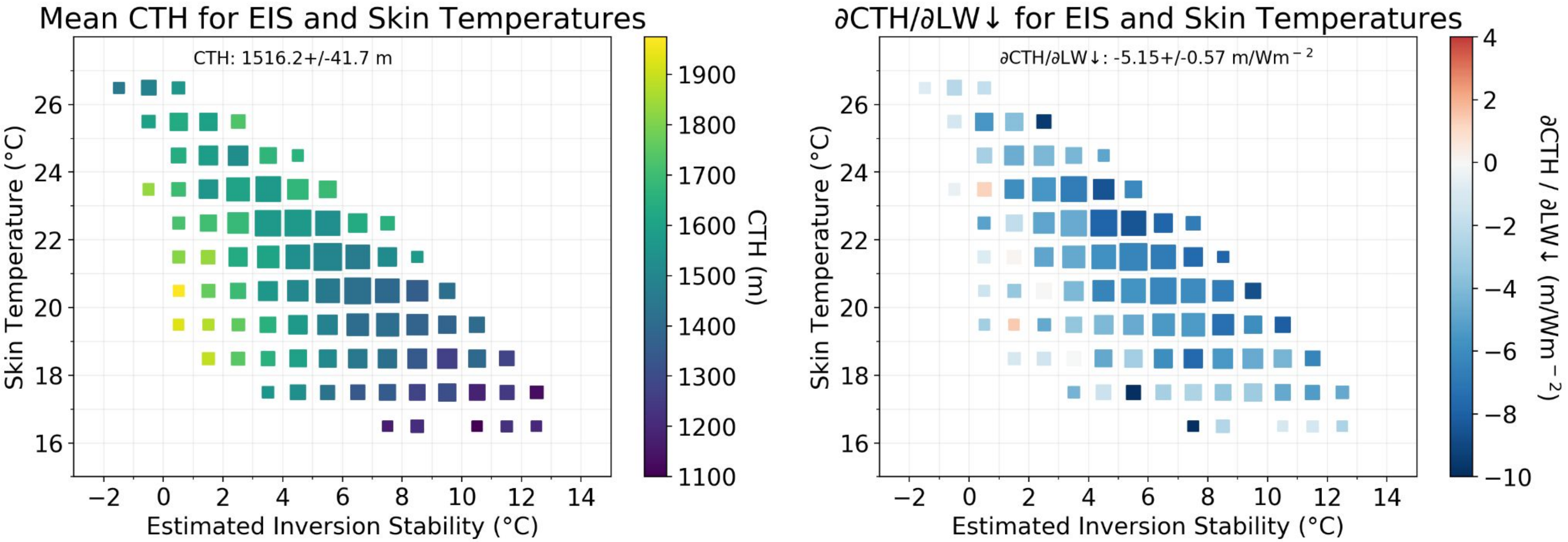
Constraining for Meteorology

The linear regression between each cloud property and LW↓ was calculated for each 1° x 1° EIS and skin temperature bin

The regression coefficients were then matched to a colorbar for each cloud property

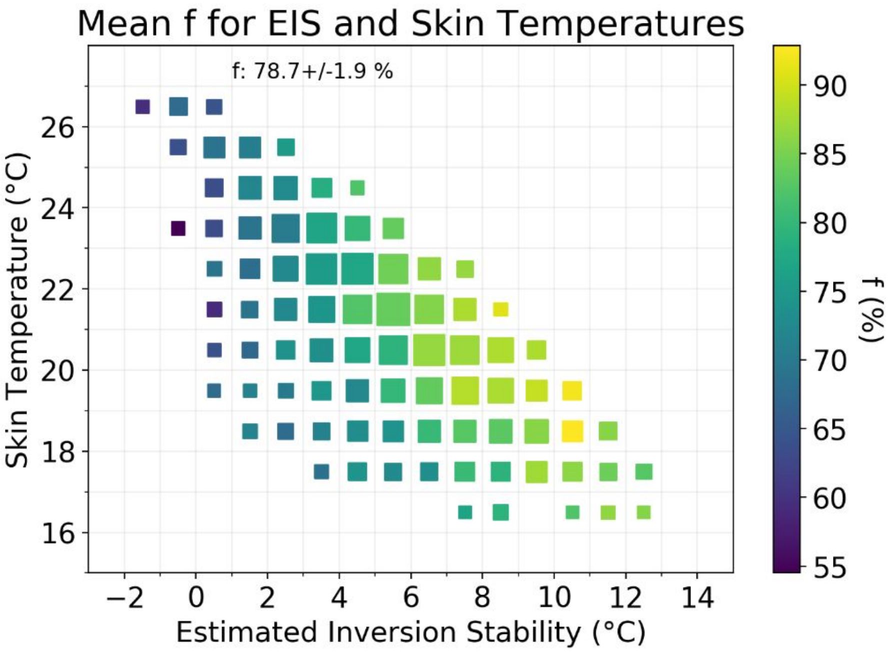


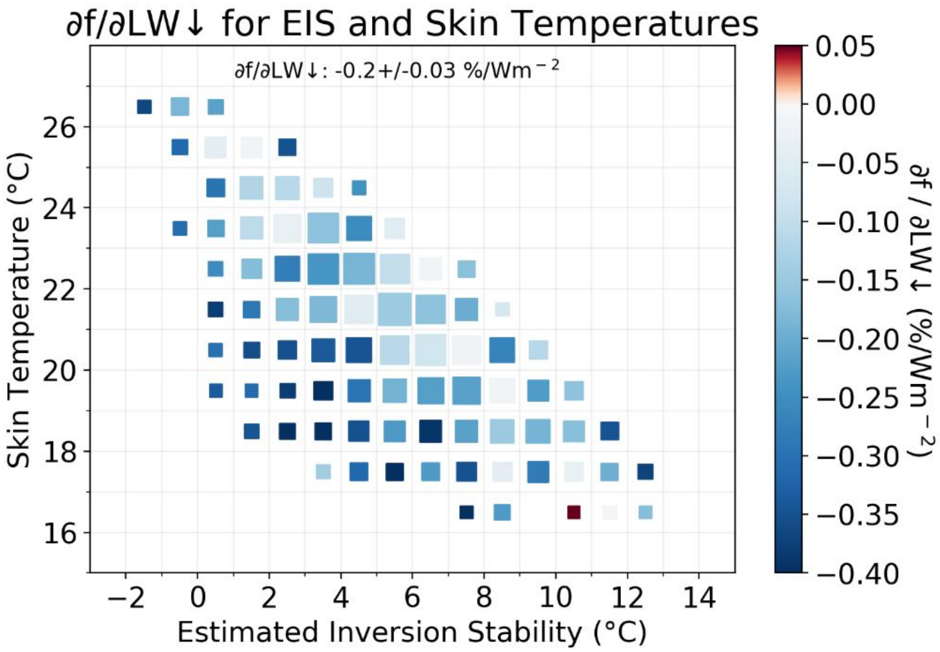
∂CTH/∂LW↓



With increased LW↓, cloud top heights change by: -5.15 +/- 0.57 m/Wm^{-2}

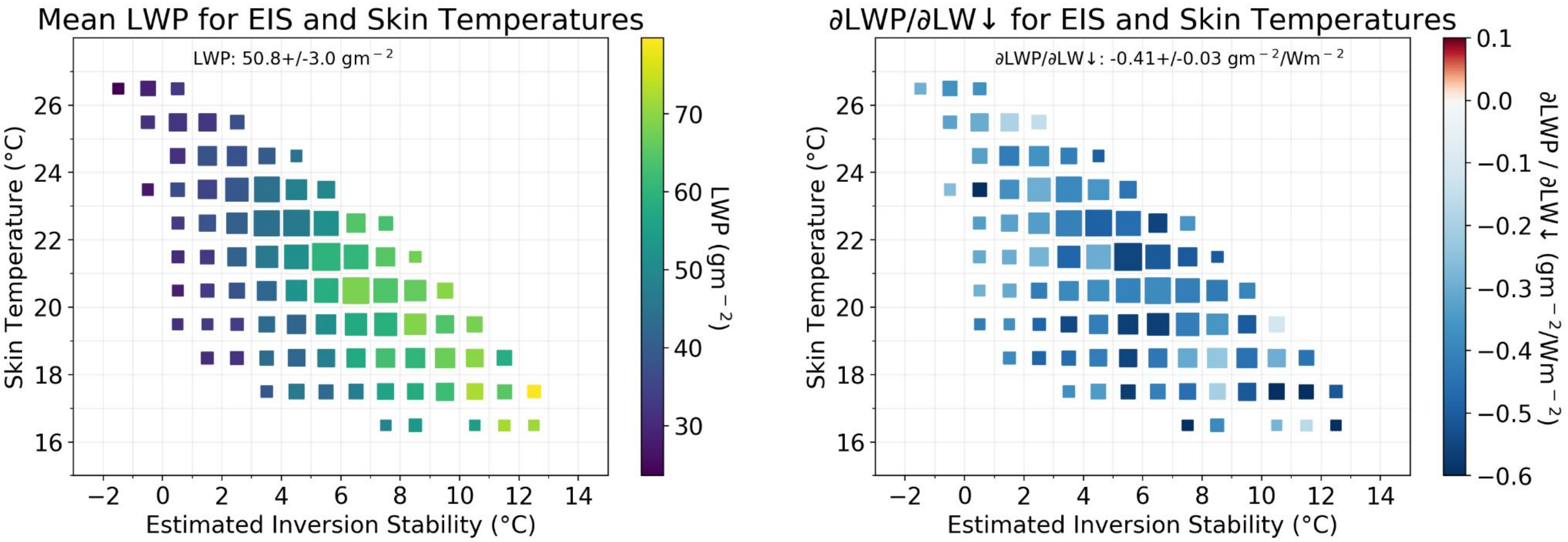
∂f/∂LW↓





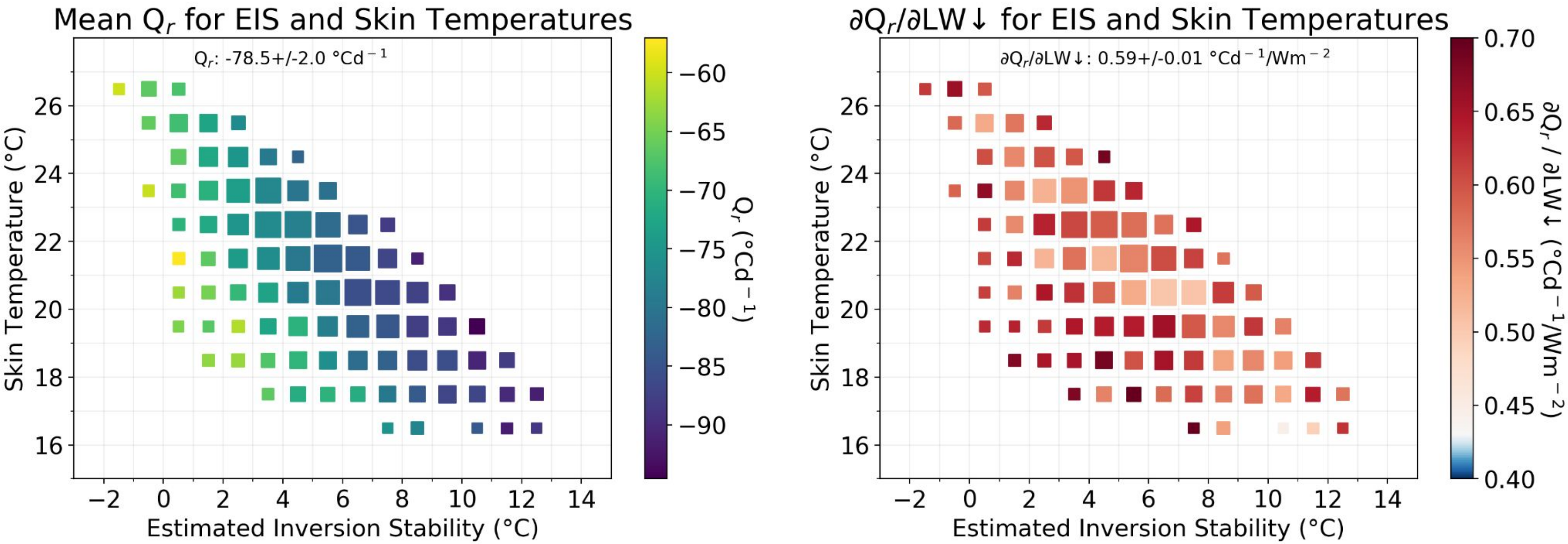
With increased LW↓, cloud fraction changes by: -0.20 +/- 0.03 $\%/Wm^{-2}$

∂LWP/∂LW↓



With increased LW↓, liquid water path changes by: -0.41 +/- 0.03 gm^{-2}/Wm^{-2}

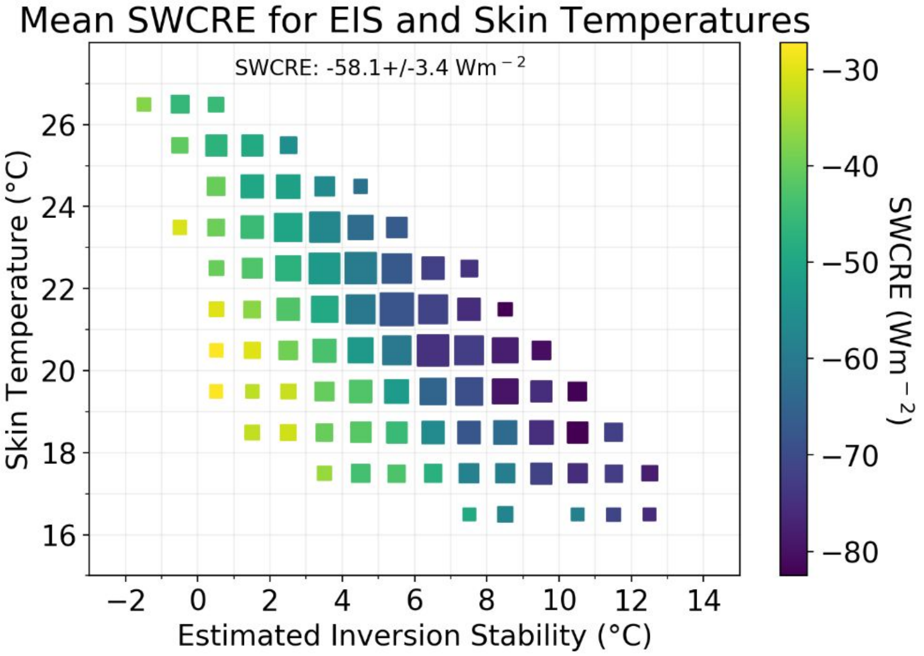
$\partial Q_r/\partial LW\downarrow$

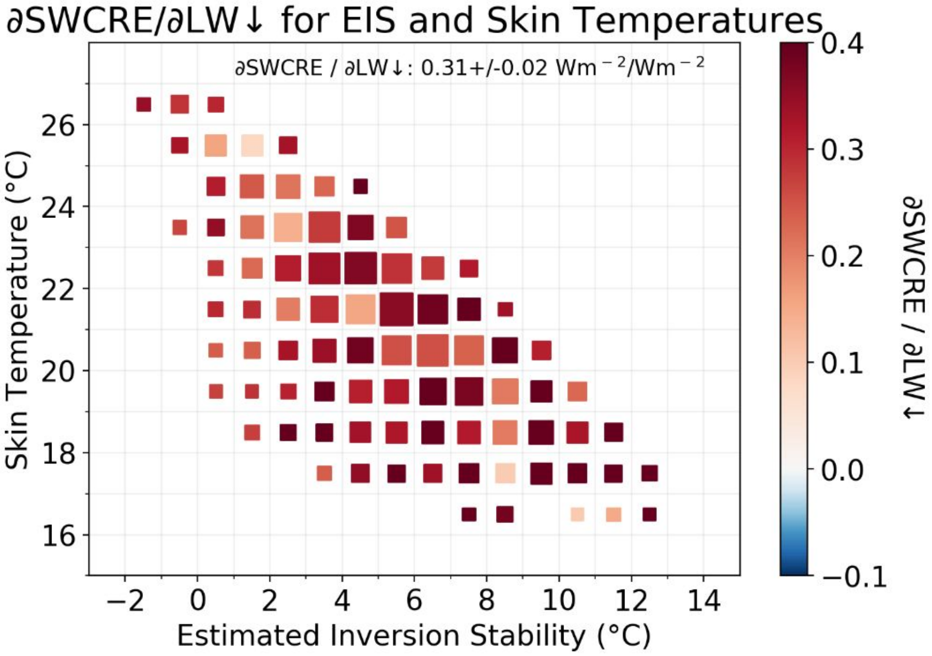


With increased LW↓, boundary layer heating rate changes by: 0.59 +/- 0.01 Cd^{-1}/Wm^{-2}

∂SWCRE/∂LW↓

$$SWCRE = Sof(\alpha_{CLR} - \alpha_{CLD})$$





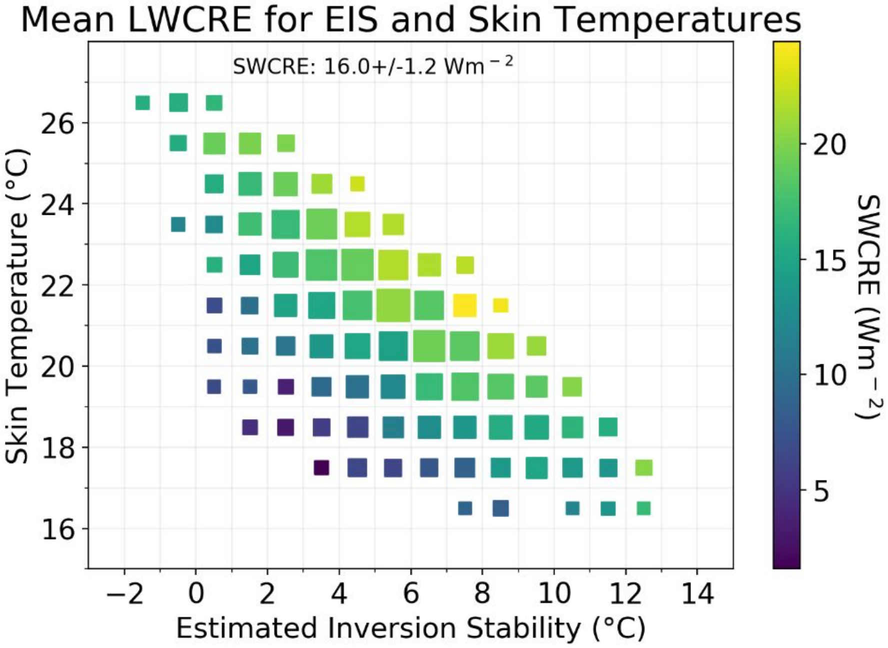
With increased LW↓, SWCRE changes by: 0.31 +/- 0.02 Wm^{-2}/Wm^{-2}

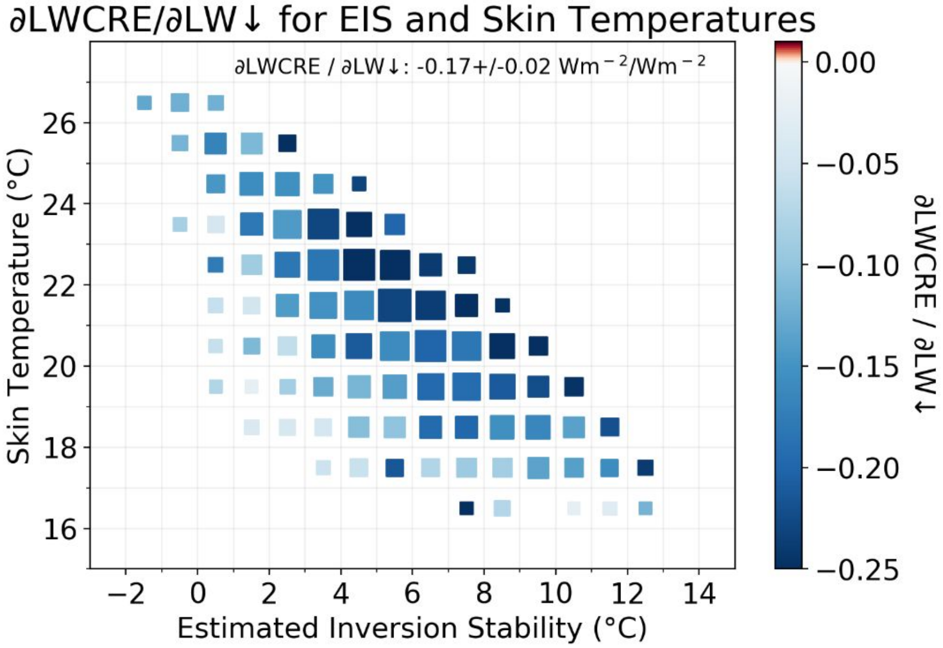
∂LWCRE/∂LW↓

$$LWCRE = fB_s(g_{clr} - g_{free}(1 - 4\Gamma CTH/T_s))$$

$$g_{clr} = LW_{clr}/B_s$$

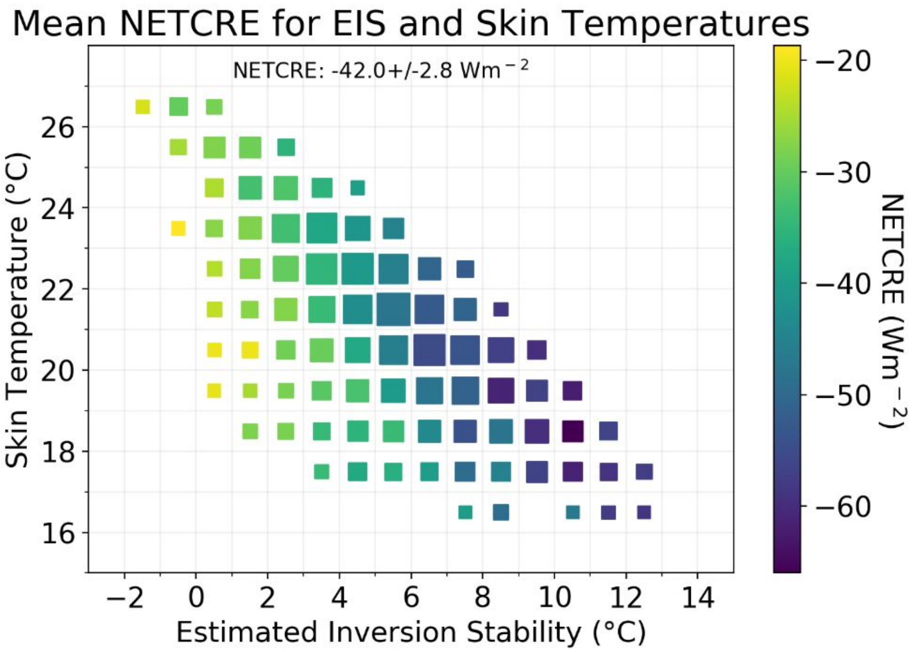
$$g_{cld} = LW_{cld}/B_s$$

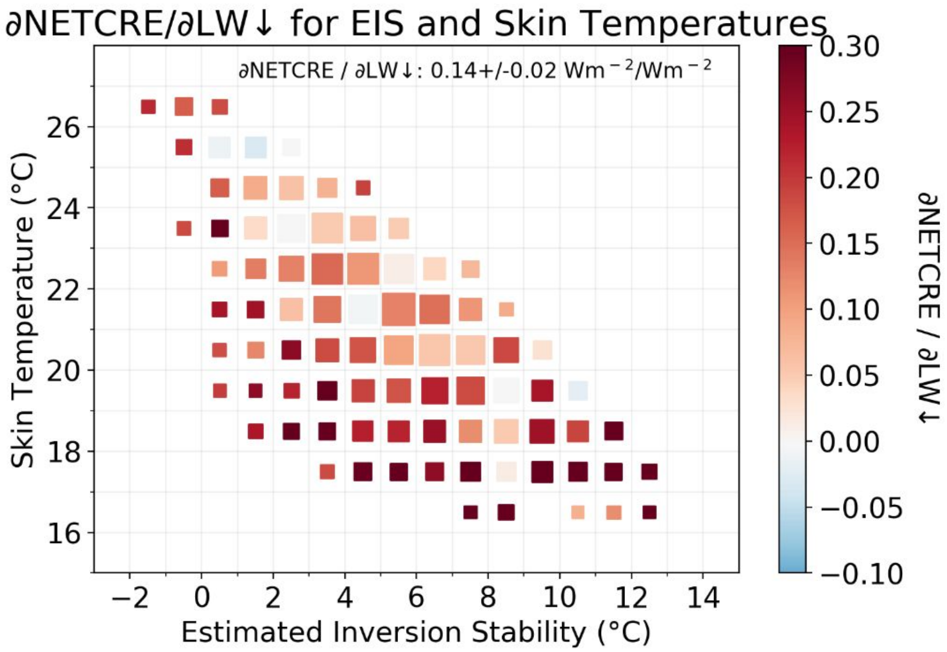




With increased LW↓, LWCRE changes by: -0.17 +/- 0.02 Wm^{-2}/Wm^{-2}

∂NETCRE/∂LW↓





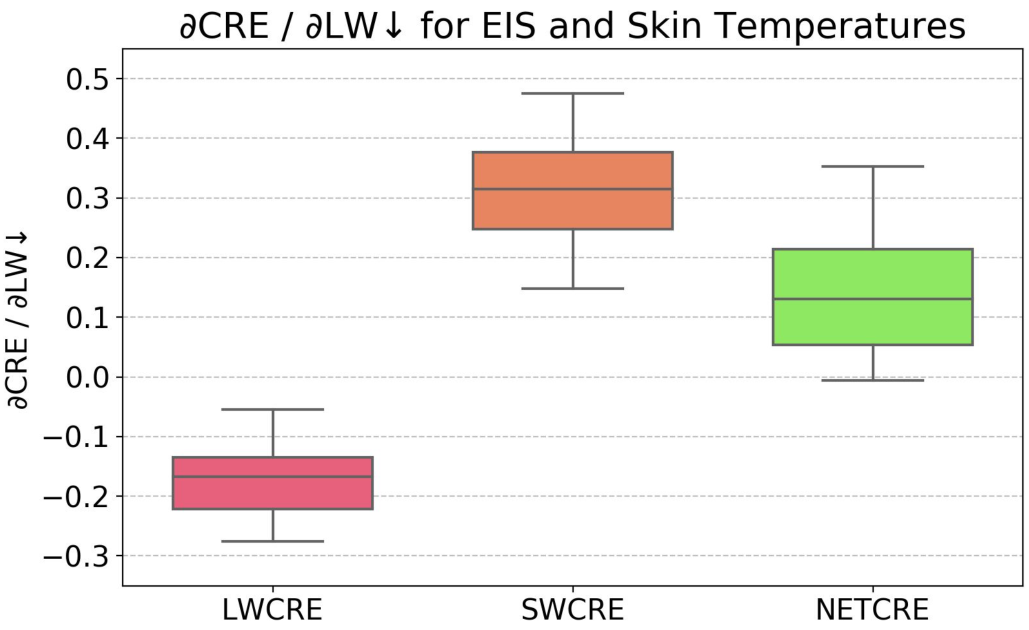
With increased LW↓, NETCRE changes by: 0.14 +/- 0.02 Wm^{-2}/Wm^{-2}

∂CREs/∂LW↓

∂LWCRE/∂LW↓: negative for all 1°x1° EIS & Skin temperature bins

∂SWCRE/∂LW↓: positive

∂NETCRE/∂LW↓: almost always positive



Conclusion

Increased GHGs

↓

Increases LW↓ at cloud top

↓

Reduces Q_r at cloud top

↓

Reduces f, LWP, CTH

↓ ↓

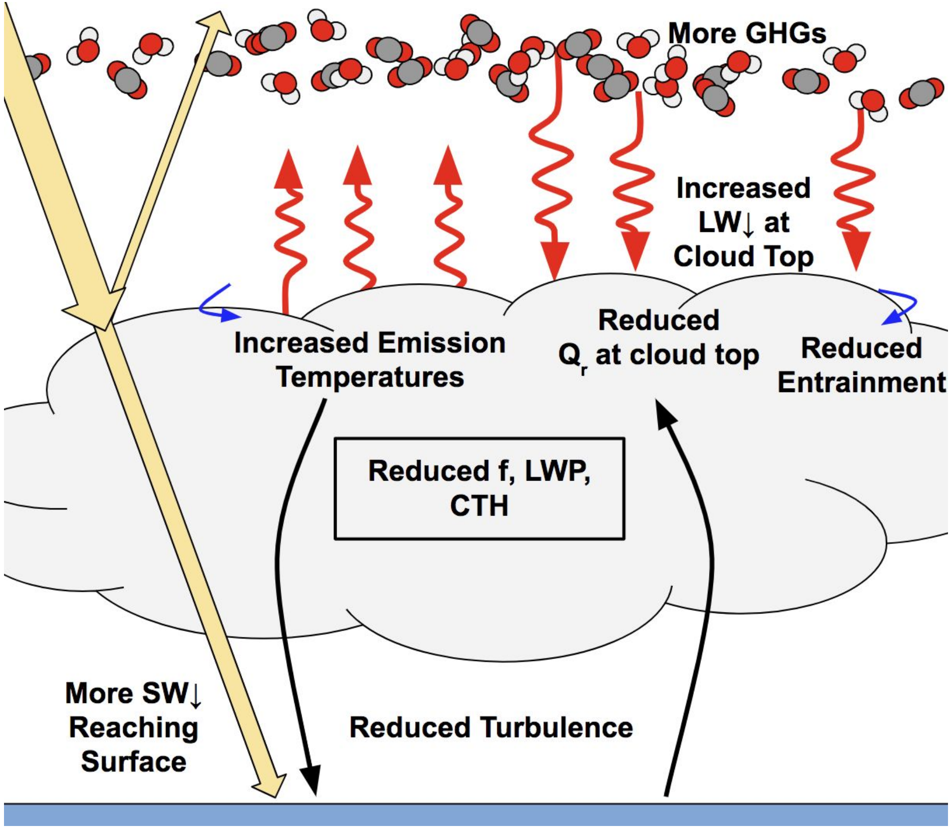
Increases SWCRE | Decreases LWCRE

↓ ↓

Increases NETCRE

↓

Allowing more SW↓ to reach the surface



Questions?