Using temporal composites to understand tropical cirrus development

George Horner, Edward Gryspeerdt

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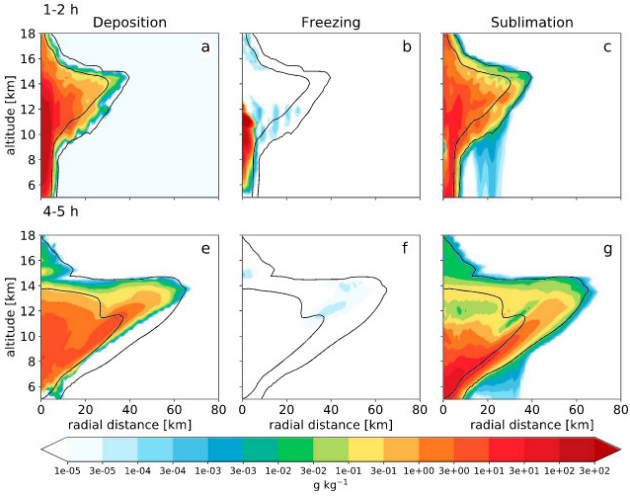
Measuring cirrus processes

In models, measuring process rates is straightforward.

In observations, we need to measure timescales

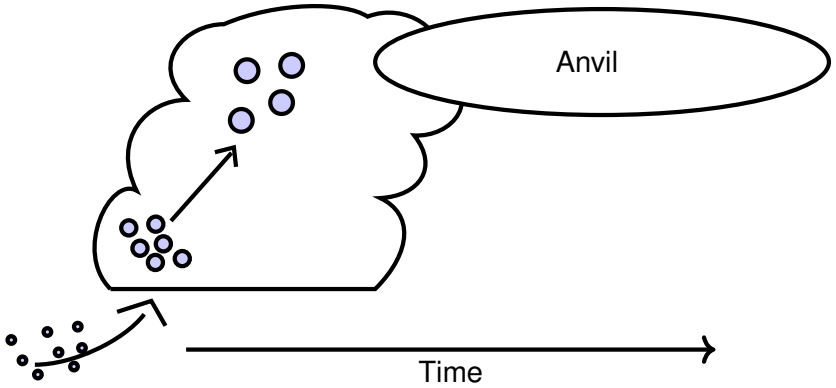
- Related to rates of change

Many of the detailed measurements we like (CloudSat, CALIPSO, EarthCARE) have a long revisit time...



Gasparini et al, 2019

Convective clouds



An ideal situation for a time-based/trajectory analysis!

Background - Aerosols and convection

Observation-based estimates of aerosol forcing have a problem...

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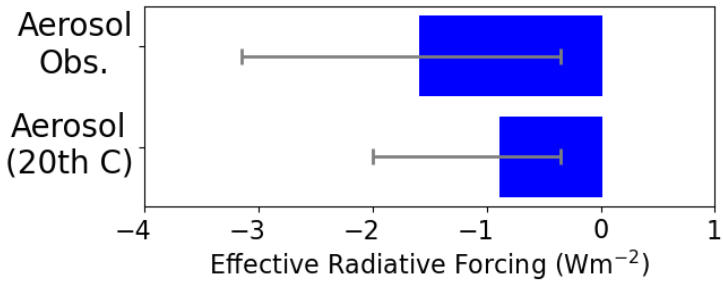

When you add up the estimates, they are too negative (too much cooling)

Background - Aerosols and convection

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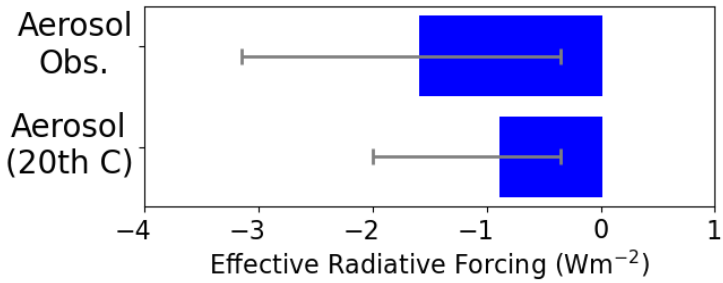

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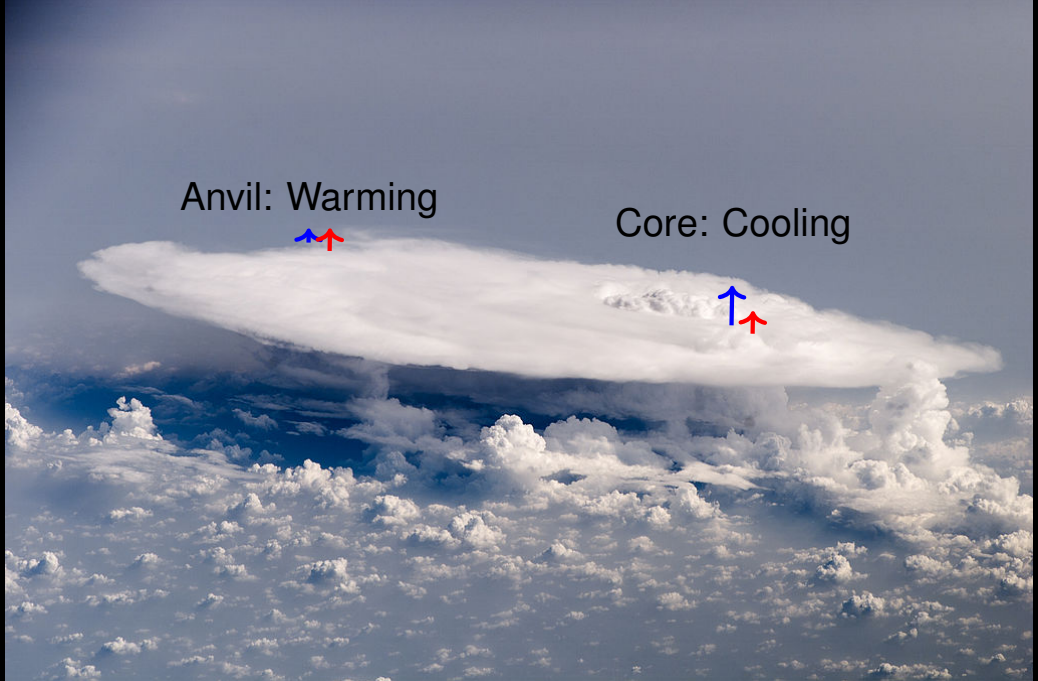
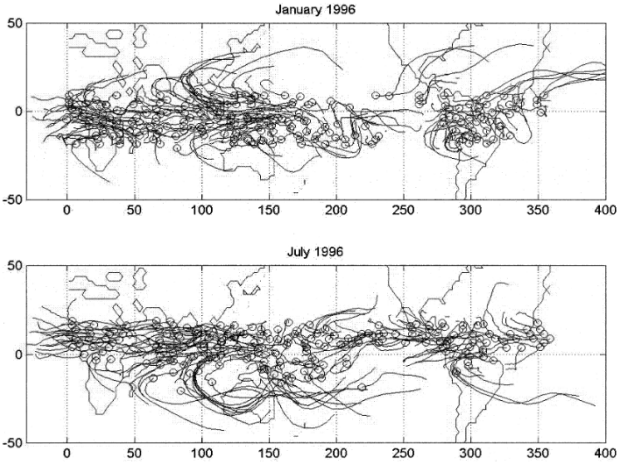
Is there a “missing warming”?


Anvil: Warming
Core: Cooling

Trajectories

Run a trajectory model from identified convection!

- How long do you run the trajectory model for?
- What happens when trajectories overlap?
- How do you know if they overlap?



Luo and Rossow, 2004

Time since convection

Imagine wind blowing south, away from some convection

How far away from this convection is any particular point?

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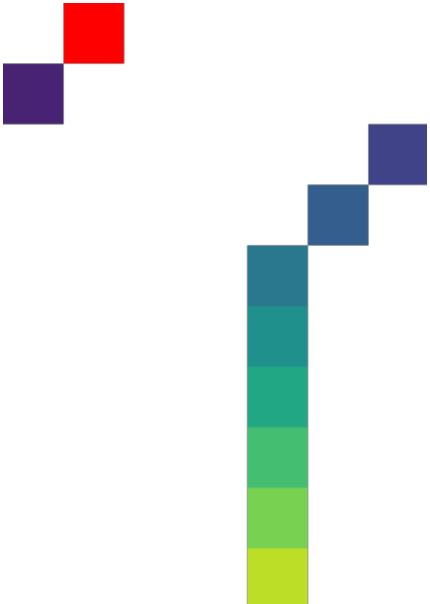

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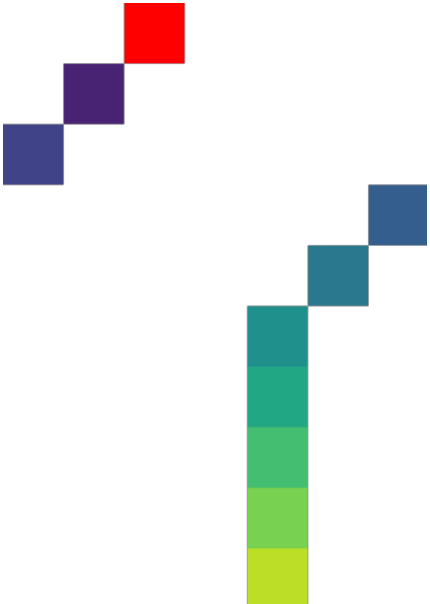

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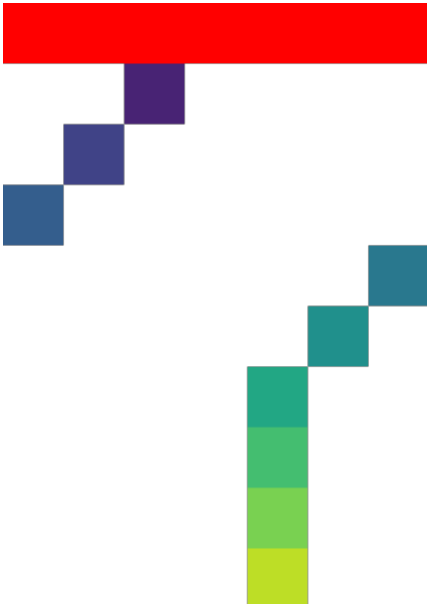

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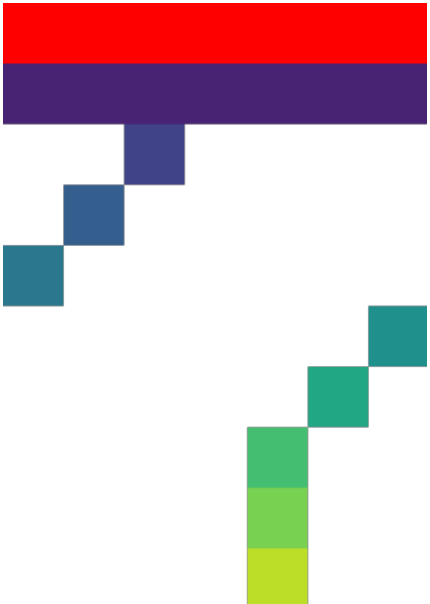

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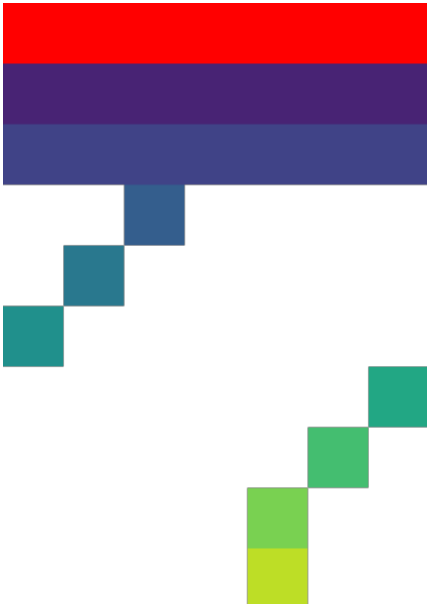

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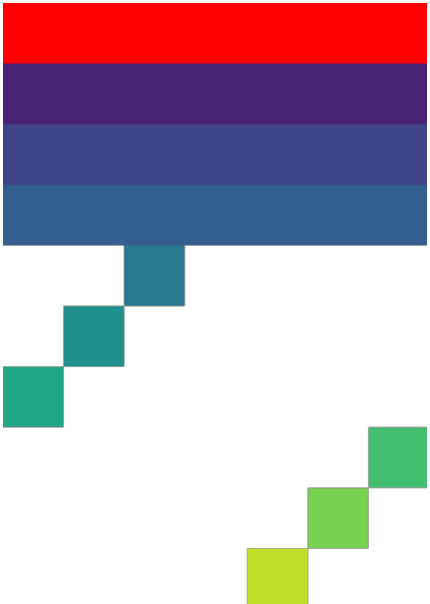

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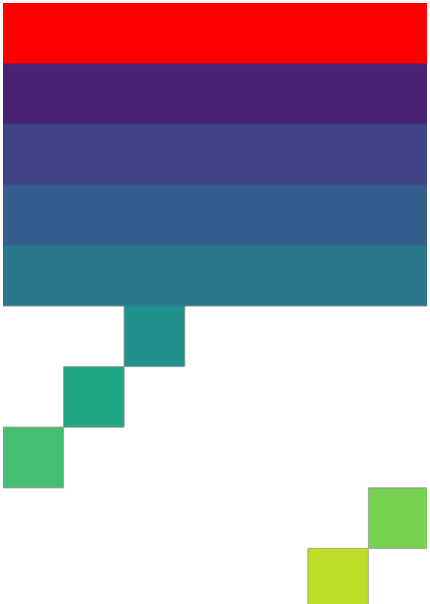

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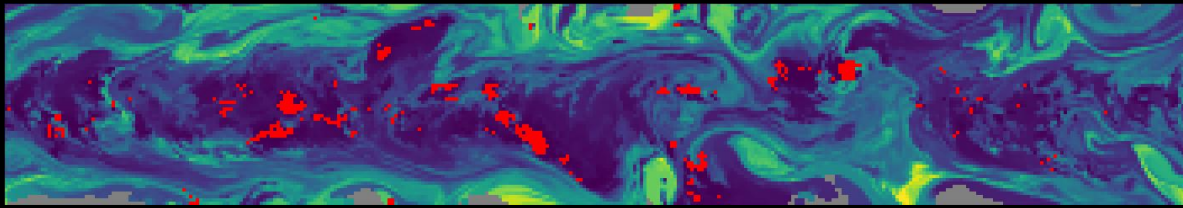
This map is “time since convection”

A more complex case



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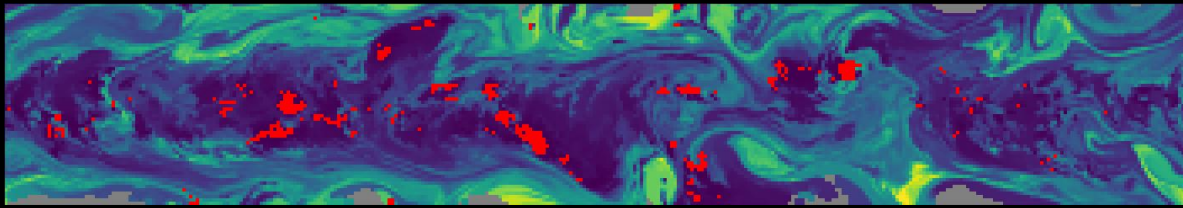
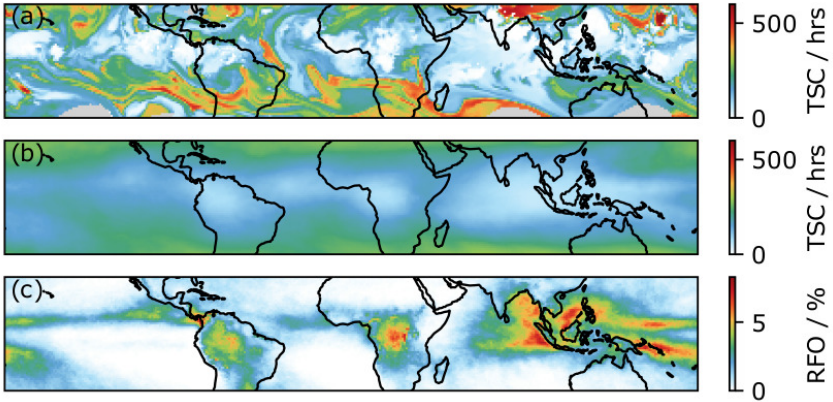


Not aiming to specifically track the convection

- Identify convection with ISCCP
- Advect “convection” with ERA5 winds (approx 200-300hPa)

TSC distribution



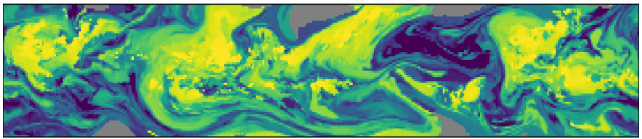
Calculated only in the tropics, time since convection is

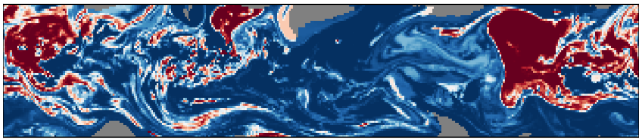
- Lowest near convection
- Not a simple function of convective occurrence
- Not just a function of latitude

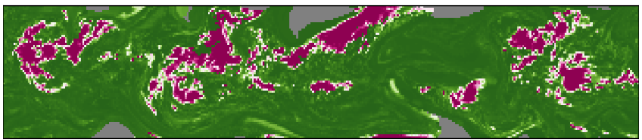
Tracking properties - ’Flags’

In addition to tracking time since convection, we can track

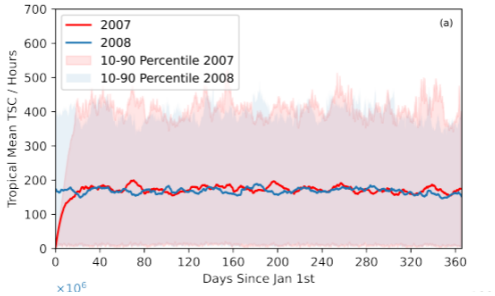
- Properties of initial convection
  - Land vs. ocean, convective strength
- Evolution of the air parcel
  - Detrained vs insitu formed cirrus

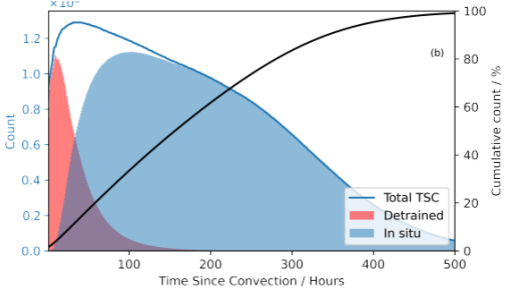






The TSC distribution

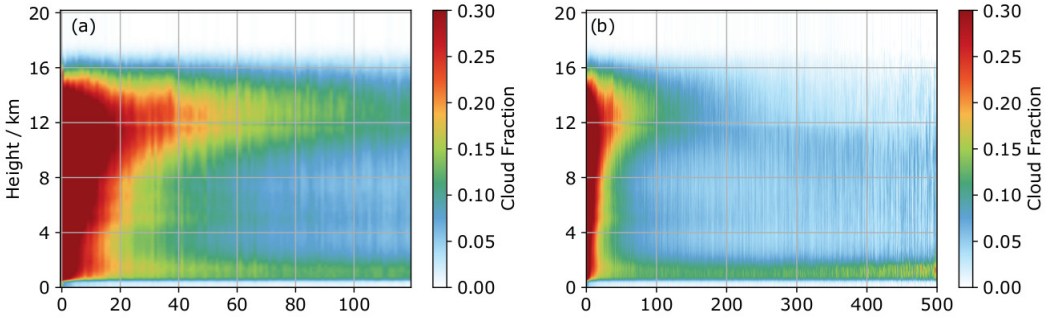




The “time since convection” method has a bias towards new convection/low TSC

- Despite this, many cases at high TSC (5% “older” than 20 days)

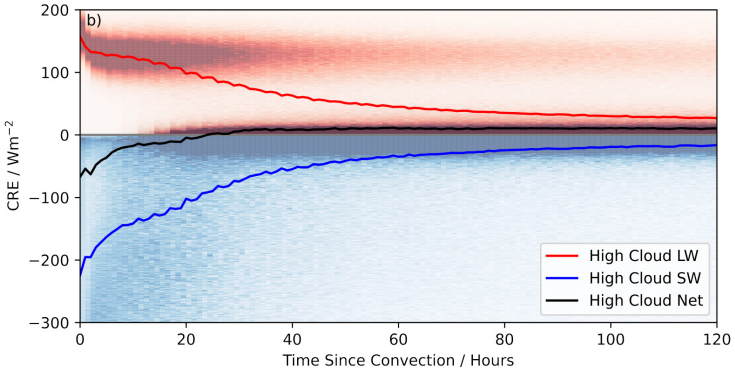
Cloud profiles



CloudSat/CALIPSO/DARDAR shows clouds are a strong function of TSC

- Clear anvil development near convection
- Continued development even at longer times
- Not just a function of latitude

CRE as function of TSC

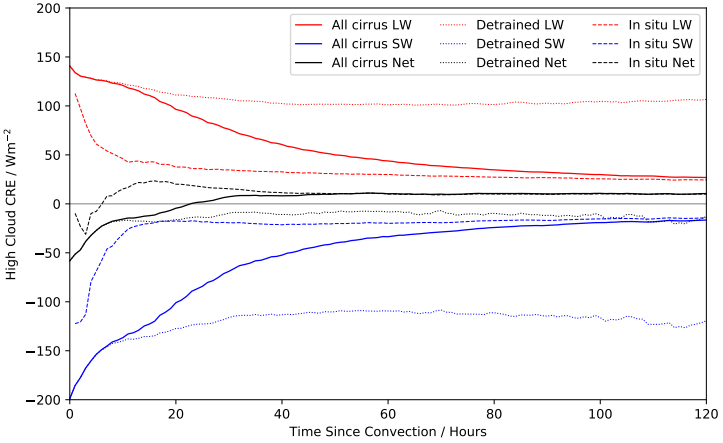


Cloud radiative effect is a strong function of TSC

- Cooling near convection
- Warming further away

CRE - cloud radiative effect - (cloudy - clear sky)

CRE as function of TSC



CRE - cloud radiative effect - (cloudy - clear sky)

Cloud radiative effect is a strong function of TSC

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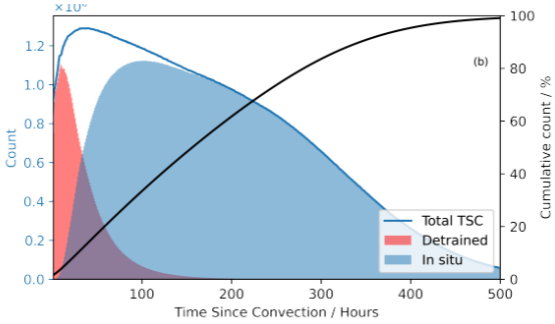
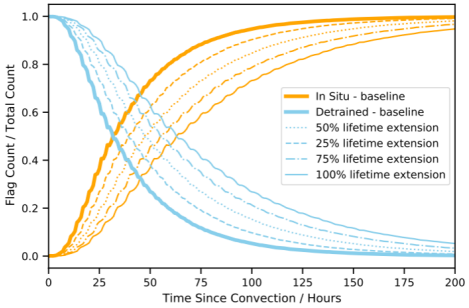
Due to a switching from detained to insitu clouds

- Cloud types have near constant CRE
- High cloud CRE is a function of anvil cloud lifetime

Extending cirrus lifetime?





What if detrained cirrus lived longer?

- No change in circulation (the TSC distribution)
- No change in cirrus properties (CRE)

Horner and Gryspeerdt, ACP, accepted

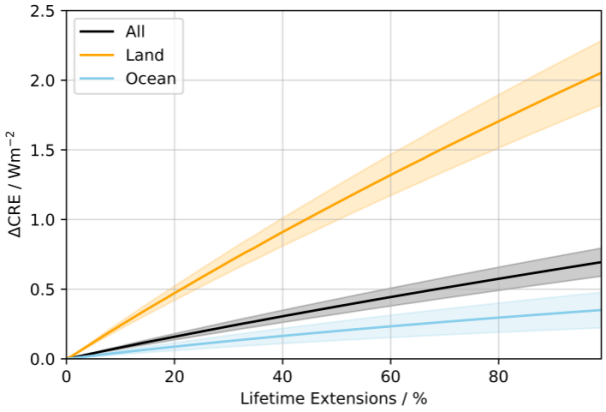
Radiative impact of lifetime change

Extending lifetime has a bigger impact over land

- Due to the diurnal cycle
- Land cirrus more strongly warming

Very large changes needed for a significant forcing

- Is a 50% increase in detrained cirrus lifeitime plausible?



How does convective strength affect cirrus CRE?

How does initial CTP affect cirrus CRE?

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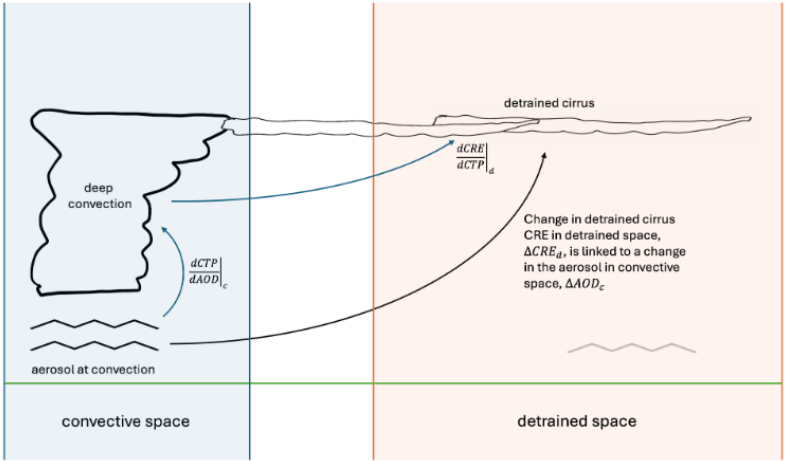


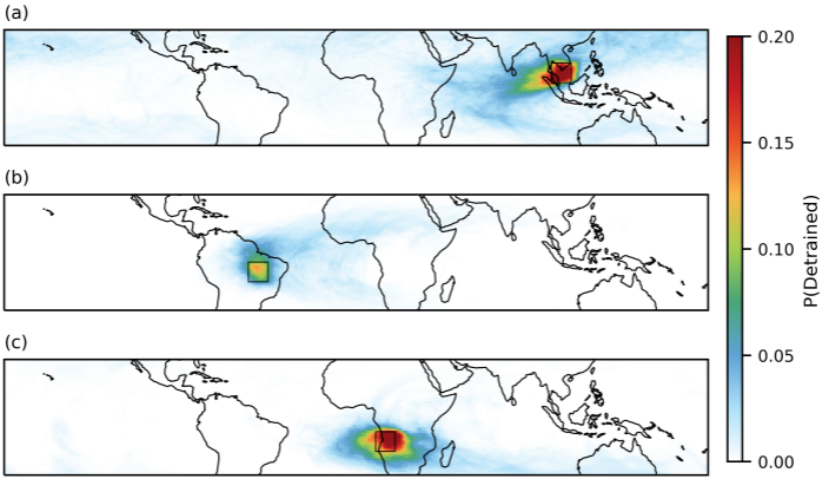
How does convection in one place affect cirrus CRE in another?

George Horner, PhD Thesis, Imperial College, 2024

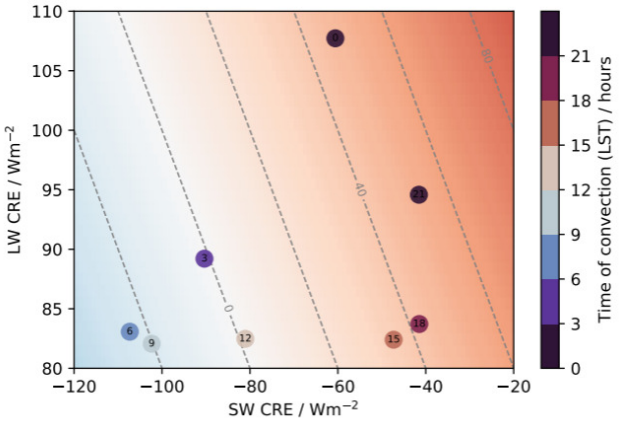
Mapping cirrus sources

Where do you find detrained cirrus originating from a region?

How does detrained lifetime change with region?



The diurnal cycle and CRE



The time-integrated CRE depends strongly on the time of convective initiation

- Not just changes in the SW CRE

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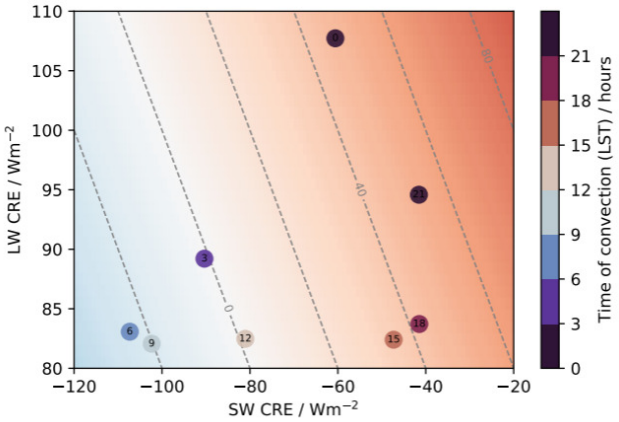

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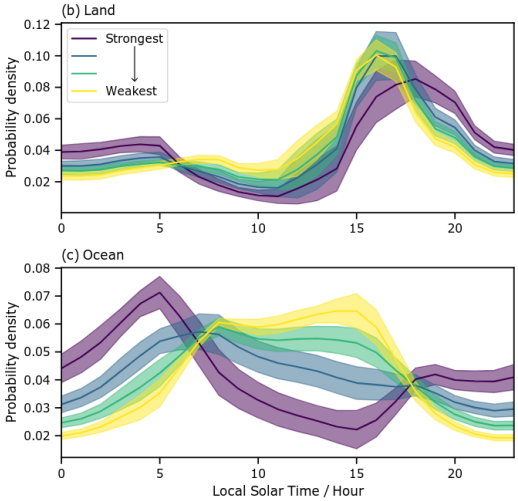
Large impacts in shifting the time of convection during daylight

- Morning convection has the strongest cooling effect
- Evening the strongest warming

The impact of the diurnal cycle

The timing of convection shifts with the maximum CTP

- Significant variations over land and ocean
- Produces CRE “changes” (stronger convection more warming)
- Causality less clear



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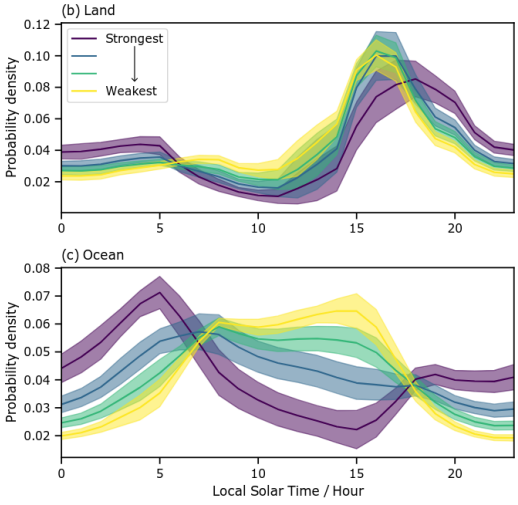
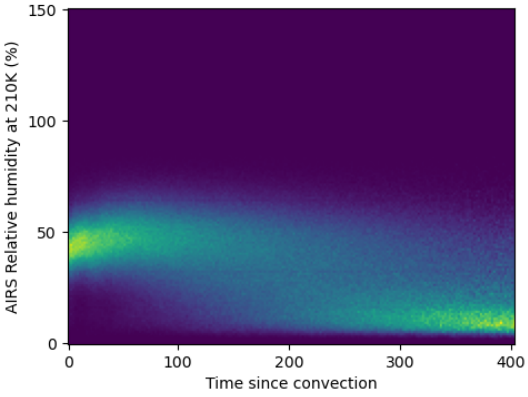
Perhaps a better measure of convective strength?

- INCUS?
- Precip-based measure?



Future questions

- Radiative heating
- Relative humidity
- Aerosol evolution
- Other data sources (e.g. aircraft)



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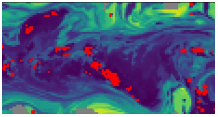

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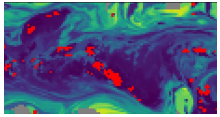

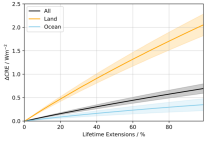

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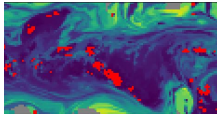

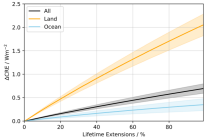

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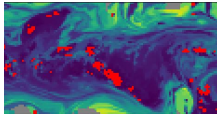
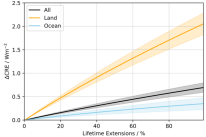
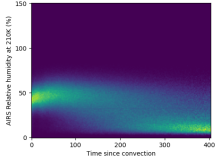
  - Difficult to isolate for other covariation
- Can composite wide variety of sparse data
  - Does it work for your data/question/model?
  - Is "old air" important?
  - Horner et al, ACP, 2024 (10.5194/acp-23-14239-2023)







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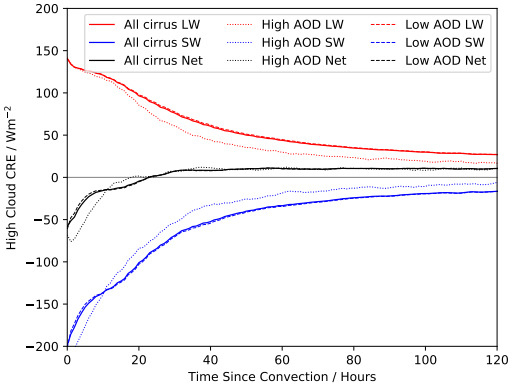
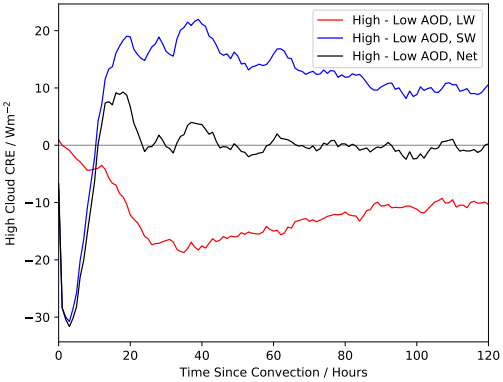
What about aerosol...?





Aerosol impact on convection is uncertain, but if aerosol increase cirrus lifetime...

- Stronger SW and LW CRE
- Slight warming further from convection
- Large enough to be the “missing warming”?

High cloud CRE