Cirrus Cloud Thinning (CCT)

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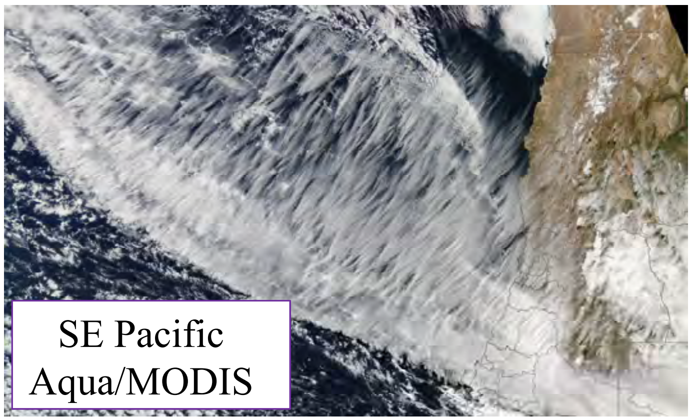
NOAA ERB meeting
6-8 Nov. 2023, Boulder, CO, USA

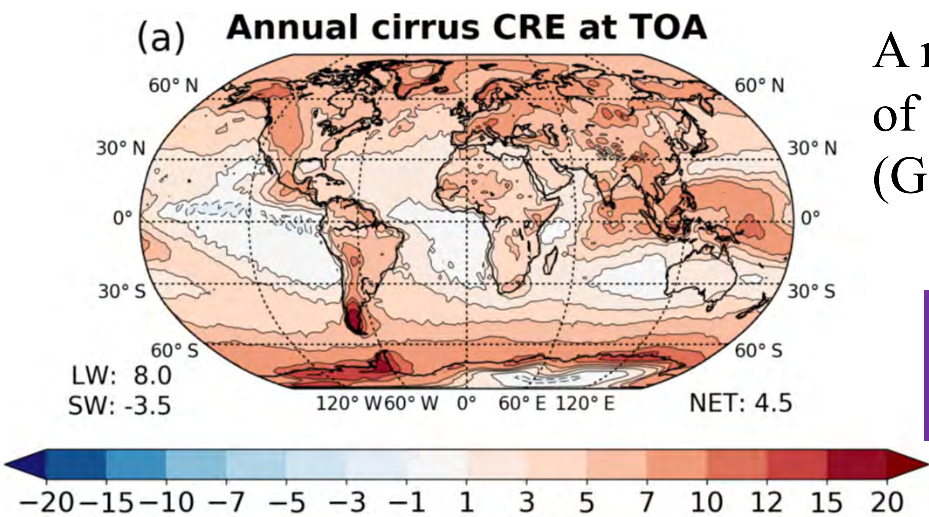
DRI Climate Engineering Research

- **Project 1: Cirrus Cloud Thinning**
  - Goal: Improving the representation of cirrus clouds in global climate models

- **Project 2: Urban cooling strategies**
  - Goal: Quantifying the impacts of irrigation and white rooftops in urban heat islands

Cirrus Clouds

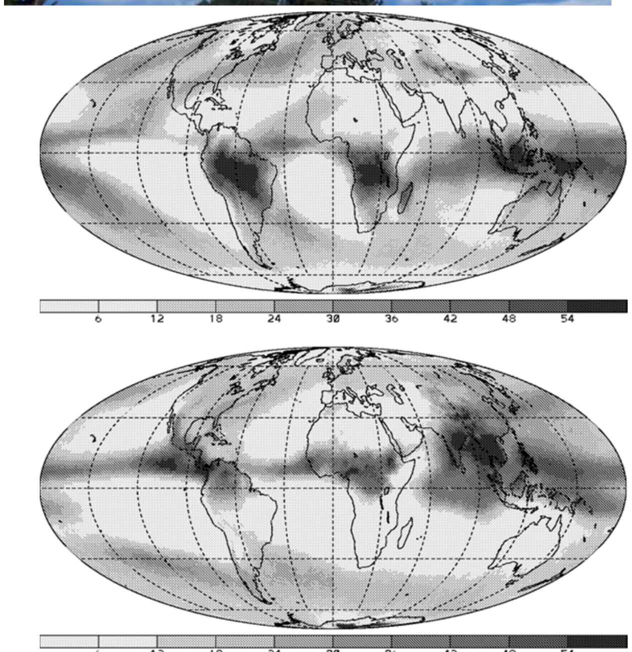




Cirrus clouds cover about **20-25%** of the earth's surface on global annual averages and about **60-80%** in the tropics.

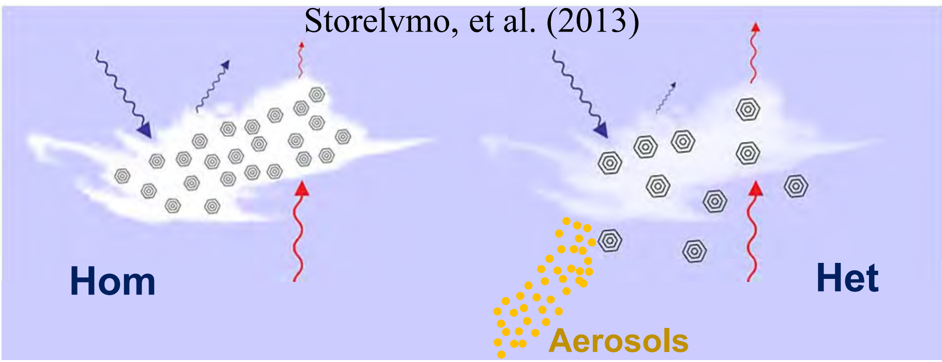
A net **warming** effect of ~ **5 W m^{-2}** (Gasparini et al., 2016)

Still lots of uncertainties!



High cloud amount (%) for DJF and JJA from 1987 to 1995 (Stubenrauch, et al., 2006).

Homogeneous (hom) vs. Heterogeneous (het)



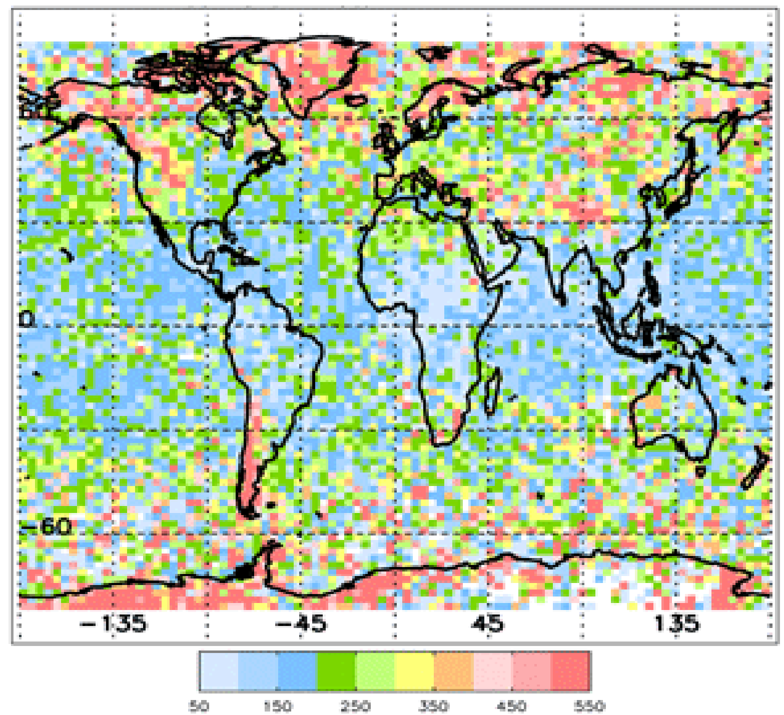
- One source of this **uncertainty**: contribution of hom and het.
- **Hom cirrus:**
  - higher ice particle number concentration
  - smaller ice particles
  - optically thicker

The **iridescence** indicates the presence of very small ice crystals (< 10 microns) that can scatter sunlight through diffraction.

Cirrus Cloud Thinning (CCT)

- **CCT: transition from hom to het cirrus**.
- **Het:**
  - regarded as the main ice production process
  - garnered substantial attention through both field campaigns and GCM simulations (e.g., Cziczo, et al., 2013).
- New **global-scale satellite retrievals** from CALIPSO by Mitchell et al. (2018): **hom process is far more important than previously recognized**.
- What does this imply?
  The **effectiveness of CCT might surpass previous estimates**, considering that the cooling efficacy of CCT depends on the fraction of hom cirrus.

Ice particle number concentration N_i (L^{-1})



Mitchell et al. (2018)

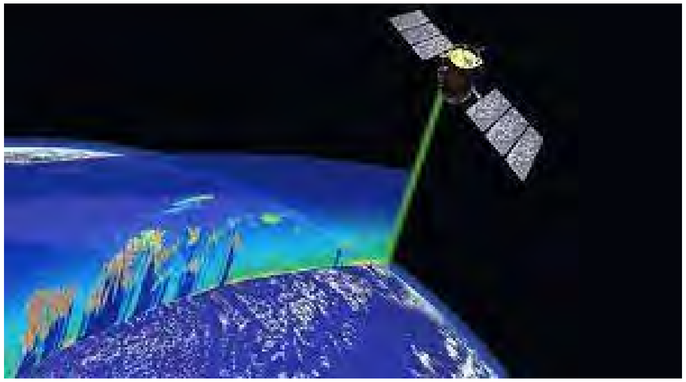
Part 1

Developing a CALIPSO Cirrus Retrieval

- Building on the Mitchell et al. (2018), we developed a satellite retrieval to quantify hom and het cirrus clouds on a global scale,

- The data from **Infrared** Imaging Radiometer (IIR) channels at 12 µm & 10.6 µm is used to calculate **optical properties**.

- The ice number concentration (N_i), ice water content (**IWC**), and effective diameter (D_e) are retrieved using equations based on Erfani and Mitchell (2016).

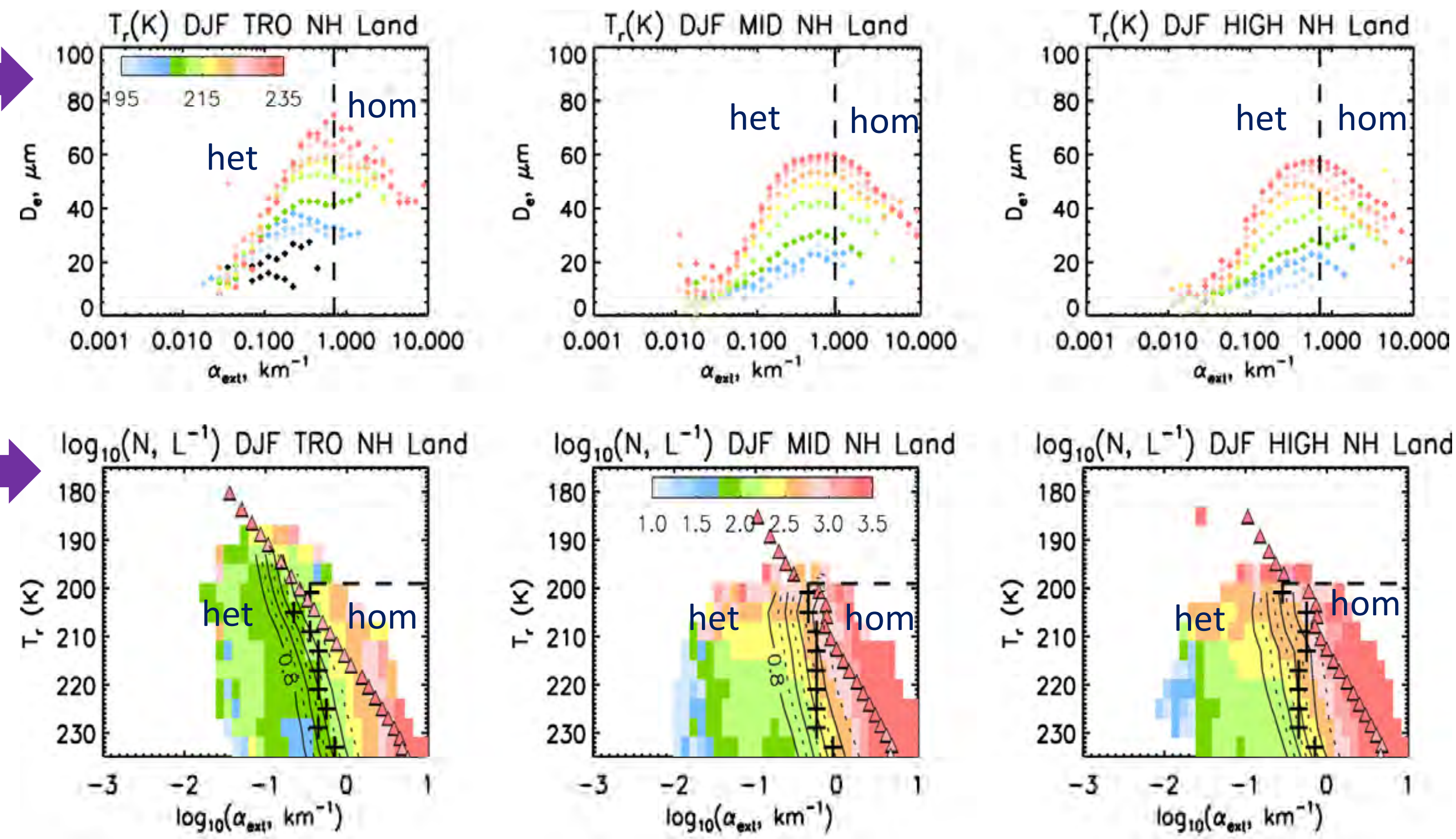


Mitchell et al. (2023); paper in preparation

Part 1

Results of CALIPSO Cirrus Retrieval

- The **peak D_e** value (dashed line) marks the **het-hom transition.** (Hom and het **separated** by a cloud visible extinction coefficient (α_{ext}) value of ~ **0.5 km^{-1}**)
- Higher N_i from hom results in lower D_e due to vapor competition effects.
- **The bottom right regions are strongly affected by hom.**



Black "+" signs: D_e maxima

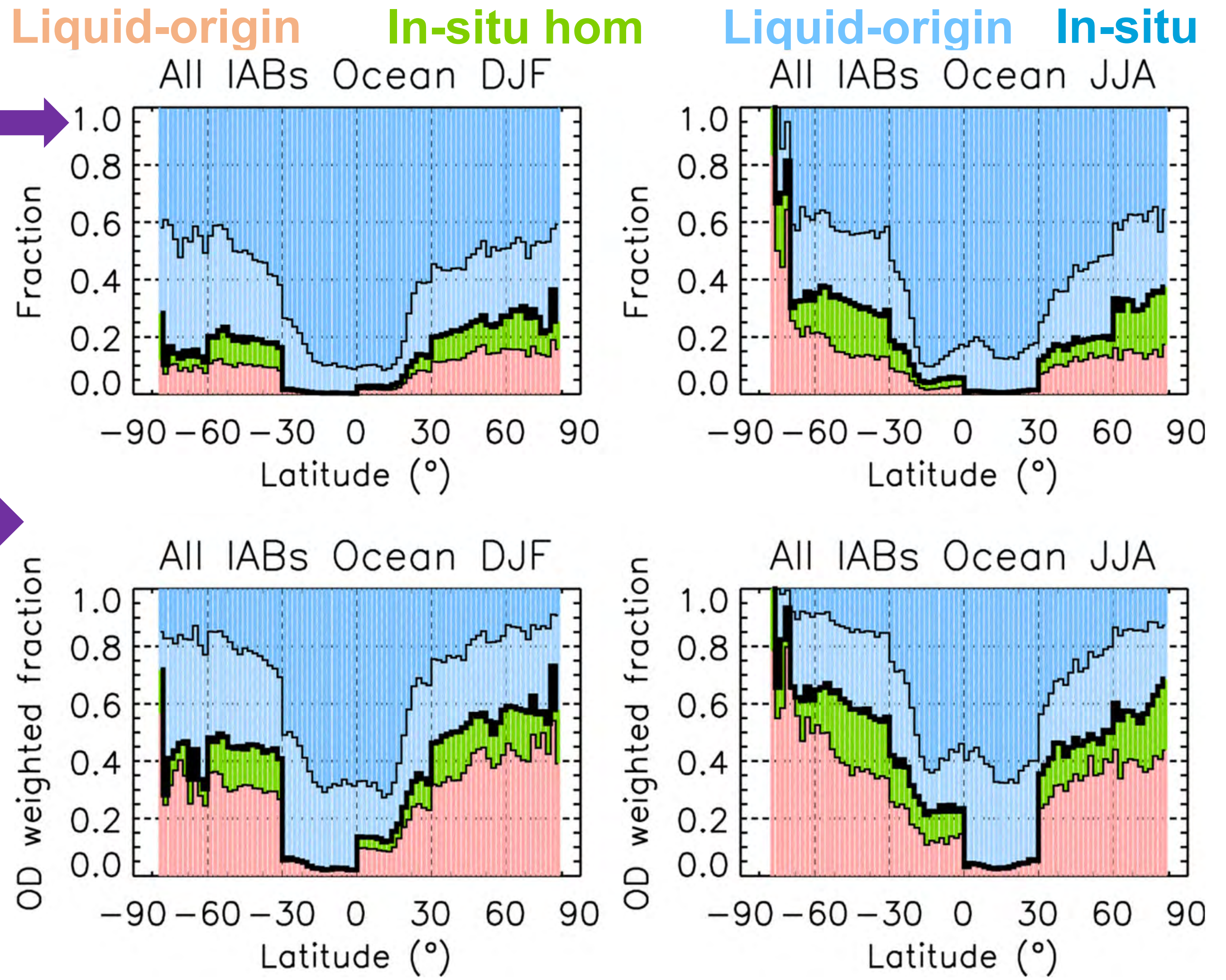
Mitchell and Garnier (2023); paper in preparation

Part 1

- **Zonal means of frequency of hom cirrus** shown by the thick black histogram

JJA: Jun. to Aug.; DJF: Dec. to Feb.

- **Hom fraction weighted by cloud optical depth (COD)** as a measure of the radiative impact of cirrus clouds
- Outside the tropics during winter (CCT is most effective), **COD-weighted hom fraction** tends to be > **50%.**
- This indicates that hom cirrus clouds contribute substantially to the earth's radiation budget.



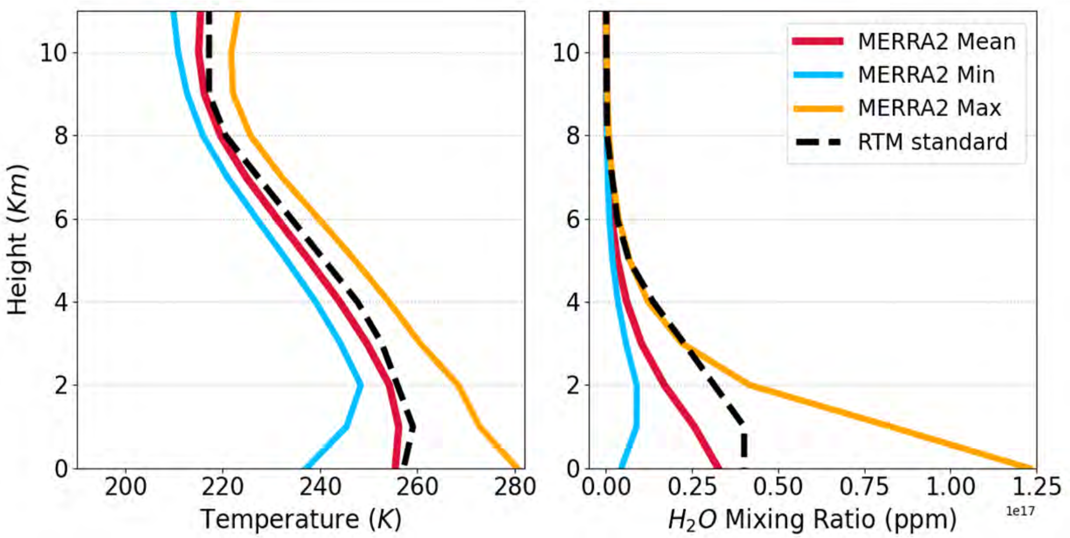
Mitchell and Garnier (2023); paper in preparation

Part 2

Radiative Transfer Model (RTM)

Model setup

- library for Radiative transfer (**libRadtran**; Emde et al., 2016)
- Solver: one-dimensional Discrete Ordinate Radiative Transfer model (**DISORT**) with **6 streams**.
- The spectral wavelength range: **longwave (LW):** from 3.1 µm to 100 µm
- **Meteorological** profiles: **MERRA2** data averaged for **Arctic night**.
- The RTM location and time: latitude 70°N and Arctic night (LW only).



Erfani and Mitchell (2023); paper in preparation

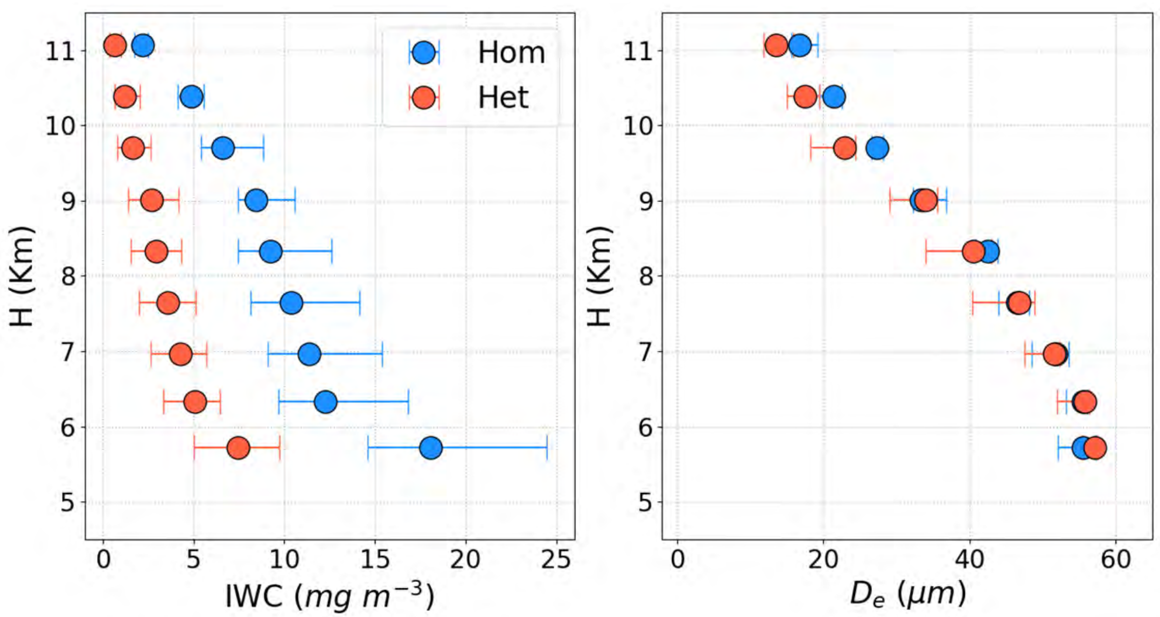
Part 2

Creating cloud profiles as RTM inputs

- **CALIPSO retrievals** of **hom** and **het IWC** and $\boldsymbol{D_e}$ are used as **inputs of RTM** to simulate radiative properties of cirrus clouds.
- For each hom and het, the IWC and D_e **"profile"** from ~ 5.7 km to 11.1 km is **divided into 4 clouds each** having a thickness of ~ 1.3 km (representative for cirrus) but with different cloud base and top heights.

CALIPSO retrievals over Arctic land during winter

Markers: median values; Error bars: 25th and 75th percentiles

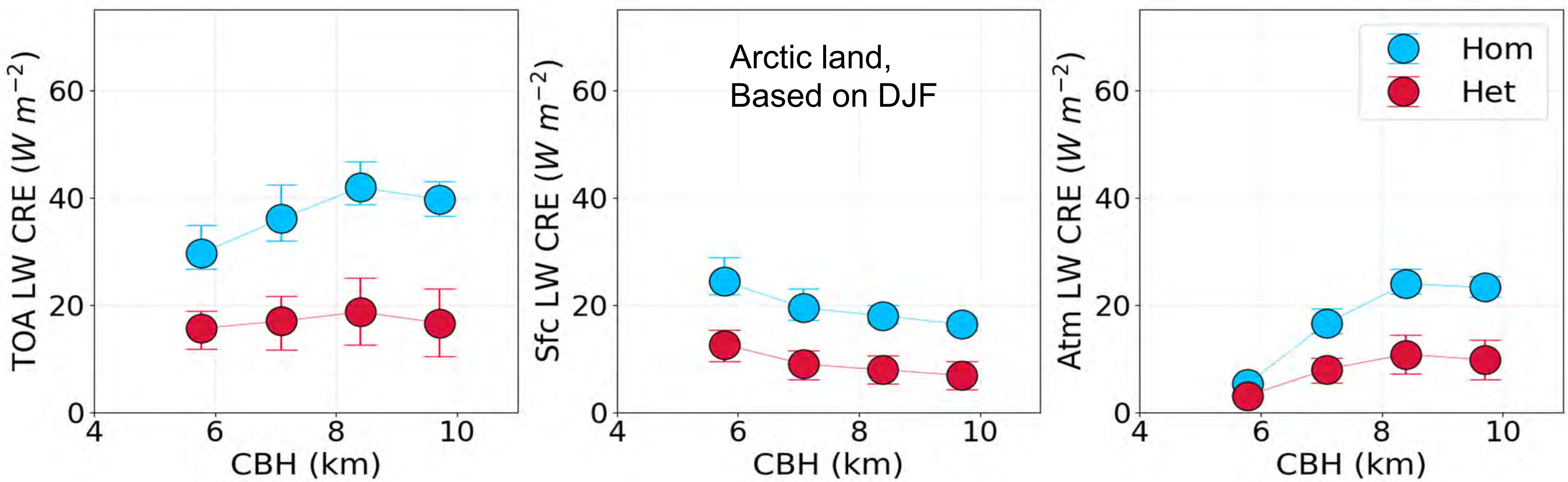


Erfani and Mitchell (2023); paper in preparation

Part 2

RTM Results

- Under cirrus **overcast** conditions **without low clouds**, a transition from all-hom to all-het cirrus clouds during "**Arctic night**" (i.e., no SW radiation) could result in a **significant surface cooling** with a change in cloud radiative effect (ΔCRE) of ~ **-10 W m^{-2}**.
- Considering the fraction of hom cirrus (e.g., **0.3**) for the Arctic night, the **overall surface cooling is: ΔCRE ≈ -3 W m^{-2}.**



CBH: cloud base height

Erfani and Mitchell (2023); paper in preparation

Part 3

Ongoing:
Using CALIPSO Retrievals in a GCM

- Community Atmosphere Model, Version 6 (**CAM6**)
- Resolution: ~**1 deg**.
- Cloud microphysics scheme: Morrison-Gettelman version 2 (**MG2**)

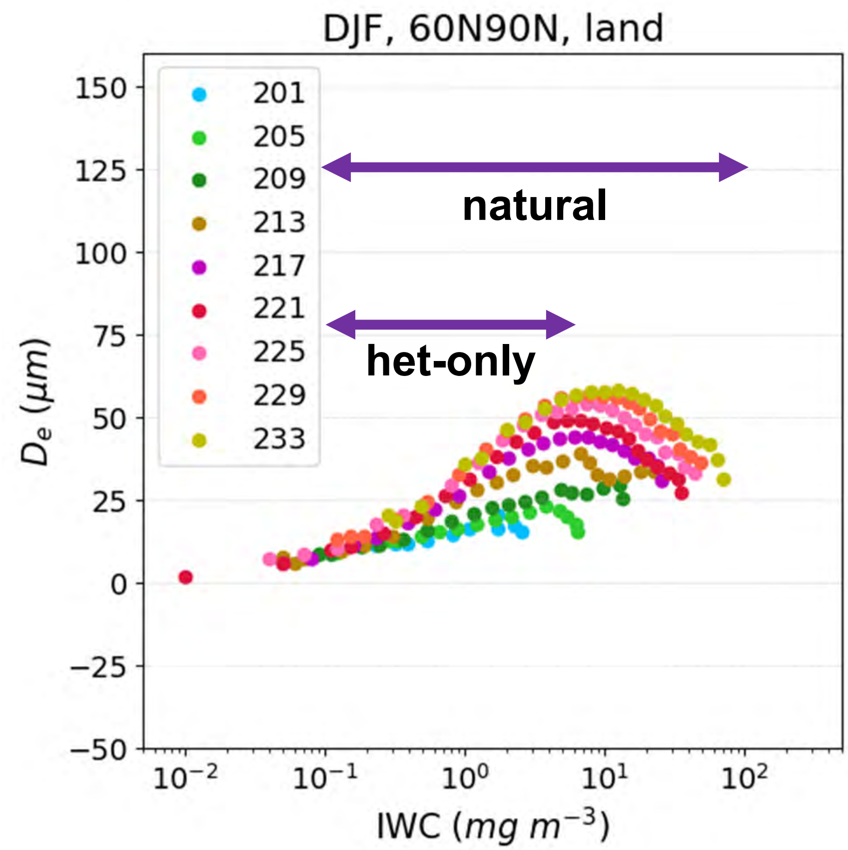
#	Experiment name	Run period (years)	Description
1	CTRL	20	Baseline CAM6 simulation
2	Het-only	20	Implementation of het cirrus from CALIPSO
3	Natural	20	Implementation of both het and hom cirrus from CALIPSO

Part 3

Ongoing:
Implementing CALIPSO retrieval in CAM6 microphysics scheme

- Estimating **De as a function of CALIPSO IWC** for each **temperature** range, **latitude** band, **season**, and **surface** type (land or ocean) (look-up table).

Only one example →

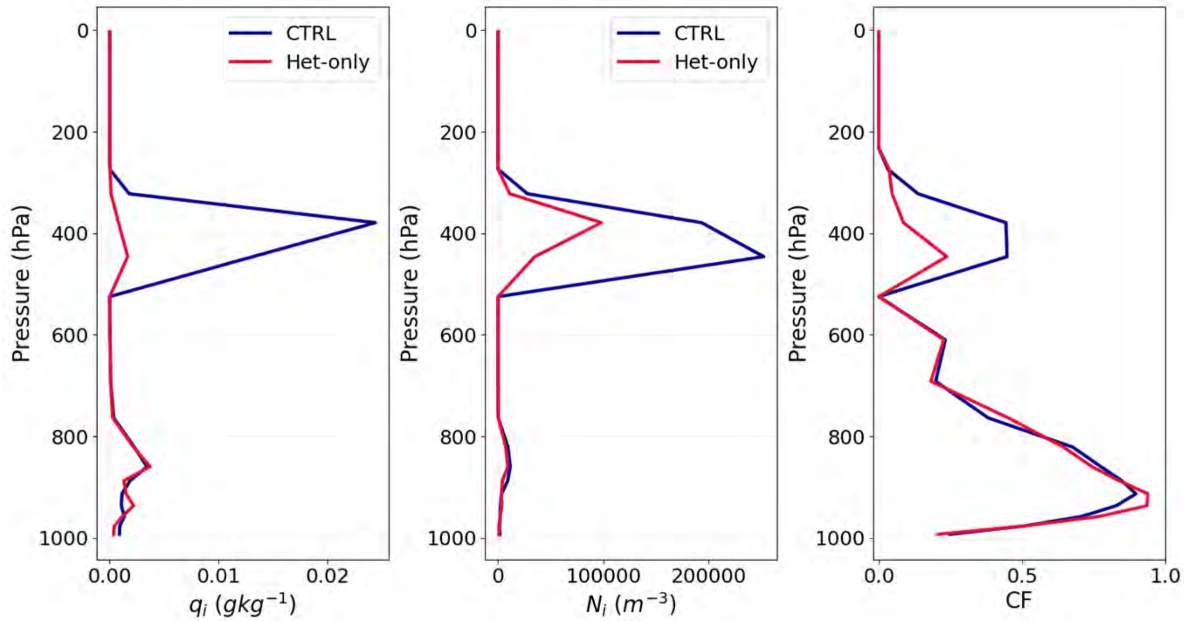


- This is done separately for "het-only" and "natural" simulations.
- Ultimately, **terminal ice fall velocity** is computed, causing **a change in IWC**, cloud cover, and cloud lifetime.

Part 3

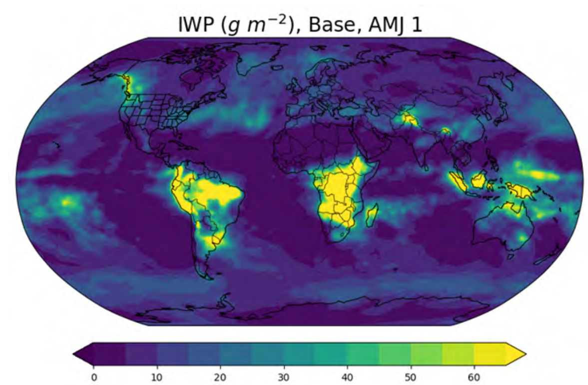
Preliminary Results

- From **Single**-column CAM6 (**SCAM**) for an Arctic campaign (MPACE)
- With our parameterization for het-only conditions, **faster fallspeed** and consequently, **lower IWC and cloud cover** is achieved.



Next step:

Conducting CAM6 on a **global scale** to **comprehensively** assess the impact of CCT within a complex atmospheric system.



CTRL

CCT Summary

- Part 1: The new CALIPSO satellite retrieval shows that het cirrus clouds are the most common type (55-80%, depending on latitude, season, and surface type). Outside the tropics in winter, hom cirrus clouds contribute more than 50% of the estimated radiative impact of cirrus clouds.
- Part 2: Based on the RTM results, a transition from hom to het cirrus clouds (due to natural causes or due to CCT) could result in a significant cooling during the Arctic/Antarctic night (no SW) with a ΔCRE of ~ -3 W m^{-2} at the surface in the absence of low clouds.
- Part 3: Currently, we are working to implement the CALIPSO retrieval into a GCM, called CAM6, to better represent hom cirrus clouds in GCMs for a more accurate simulation of climate and CCT.

Science deliverables:

- Mitchell, D. L., A. Garnier, and S. Woods, 2023: Advances in CALIPSO (IIR) Cirrus Cloud Property Retrievals. Part I: Methods and Testing. In preparation for J. Atmospheric Chemistry and Physics.
- Mitchell, D. L., and A. Garnier, 2023: Advances in CALIPSO (IIR) Cirrus Cloud Property Retrievals. Part II: Global Estimates of the Fraction of Cirrus Clouds affected by Homogeneous Ice Nucleation. In preparation for J. Atmospheric Chemistry and Physics.
- Erfani, E., and Mitchell, D., 2023: Constraining a radiative transfer model with satellite observations: implications for cirrus clouds thinning. In preparation for J. Atmospheric Chemistry and Physics.
- 16 conferences and seminars.

Summary of Urban Heat Island

- We are estimating cooling intensities, their process-based understanding and unintended impacts.
  - *Air quality: Temperature dependent pathways* are likely to decrease
  - Less mixing (hence more concentration) are related to fewer clouds increasing solar radiation, hence *increasing photochemical reaction* pathways.
  - *Less mixing can lead to more pollutant concentrations* at the surface
  - *High albedo strategies have been related to increase photon activity that increase photochemical reactions.*
- We are adding Phoenix and other cooling strategies (urban trees –NOAA-NIHHIS and WRCC-Heat Lab assignment).
- Applications: Aiming to develop useful and usable products for urban sustainability strategies.

- **Science deliverables:**
  - Mejía, J. F., Henao, J., and Saher, R.: The effect of removal of all non-functional turf in Las Vegas: tradeoffs between water conservation, excessive heat, and storminess, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-17481, https://doi.org/10.5194/egusphere-egu23-17481, 2023.
  - Mejia et al. The impacts of cooling adaptation and mitigation strategies on the heat index and clouds, AGU Fall Meeting, 2023 (talk).
  - Mejia et al. "Understanding urban cooling strategies benefits and tradeoffs in contrasting cities under different climate regimes: LV and Phoenix (arid, semi-arid Southwest) and Houston (wet Southeast). Pub in preparation for Urban Climate.

Thank you very much!

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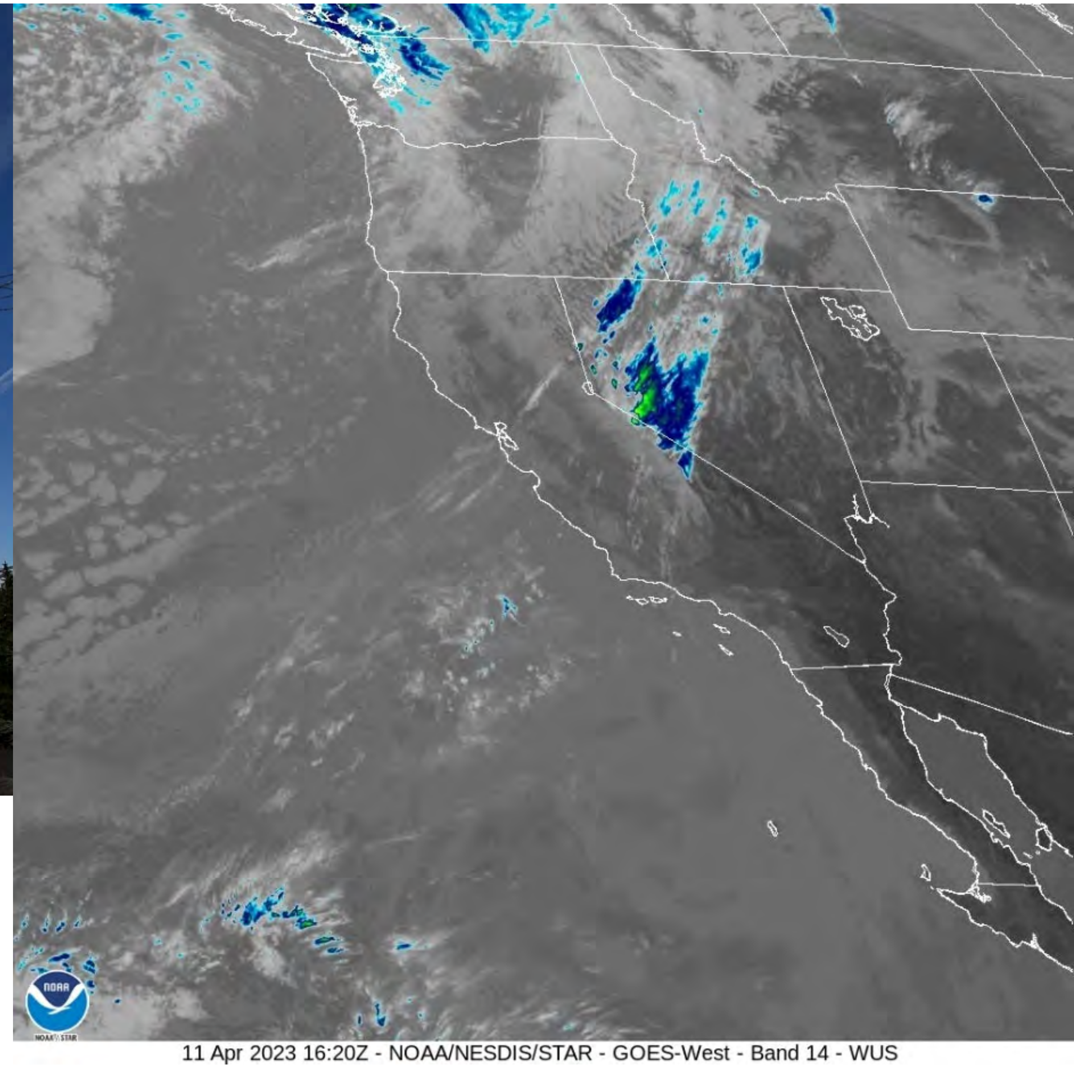
John Mejia: john.mejia@dri.edu

Additional Slides

CCT Conferences

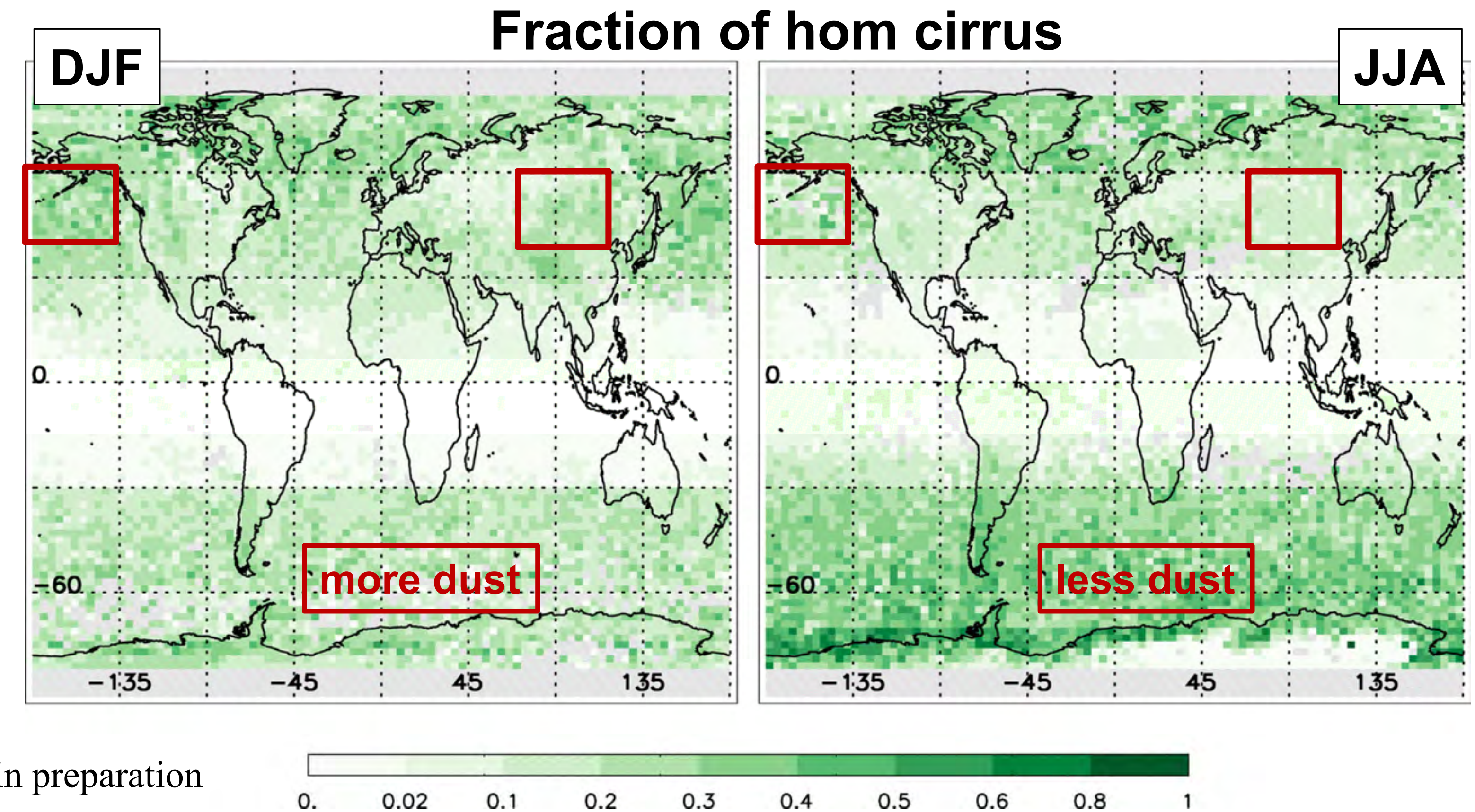
- Dmitruk, Gwendolyn, Anne Garnier and David Mitchell, 2022: Reigniting CCT: Satellite retrieval-model integration. Poster presentation, Gordon Research Conference on Climate Engineering, Sunday River, Maine, 26 June – July 1, 2022.
- Erfani, E., and Mitchell, D. (2023). Constraining a radiative transfer model with satellite observations: implications for cirrus clouds thinning. Gordon Research Conference (GRC) on Radiation and Climate, Lewiston, ME, 23-28 Jul. 2023, (poster).
- Mitchell, D. L., J. Mejia and A. Garnier, 2022: How realistic are explicit CCT simulations in climate models? Poster presentation, Gordon Research Conference on Climate Engineering, Sunday River, Maine, 26 June – July 1, 2022.
- Mitchell, D. L., A. Garnier and J. Mejia, 2022: Evidence of relatively high contributions of homogeneous ice nucleation over land during winter at mid-to-high latitudes, with comparisons against global climate model predictions. AMS Collective Madison Meeting, 16th Conference on Cloud Physics, Madison, WI, 8-12 August 2022.
- Mitchell, D. L. and A. Garnier, 2022: An improved CALIPSO (IIR-CALIOP) cirrus cloud retrieval of ice particle number concentration, effective size and ice water content with observations relevant to extreme weather. AMS Collective Madison Meeting, 17th Conference on Polar Meteorology and Oceanography, Madison, WI, 8-12 August 2022.
- Mitchell, D. L., and A. Garnier, 2022: A reformulated CALIPSO (IIR-CALIOP) retrieval for cirrus cloud ice particle number concentration, effective diameter, and ice water content, NASA CloudSat-CALIPSO Science Team Meeting, Fort Collins, Colorado, 12-14 September 2022.
- Mitchell, D. L., A. Garnier, J. Mejia, and Sarah Woods, 2022: Advances in CALIPSO (IIR) cirrus cloud retrievals and comparisons with WACCM6 predictions. Atmosphere Model Working Group (AMWG) winter meeting, National Center for Atmospheric Research (NCAR), Boulder Colorado, Feb. 2022.
- Mitchell, D. L., and A. Garnier, 2022: On the Contribution of Homogeneous Ice Nucleation to Arctic Cirrus and INP Implications. QuIESCENT Arctic Workshop, Trondheim, Norway, 1 April 2022.
- Mitchell, D. L. and Garnier, A., 2023: Characterizing two types of cirrus clouds that differ in nucleation mechanism and radiative effect, based on a new CALIPSO retrieval. Atmosphere Model Working Group (AMWG) winter meeting, National Center for Atmospheric Research (NCAR), Boulder Colorado, 30 Jan. – 1 Feb. 2023. Mitchell, D. L., and A. Garnier, 2023: Characterizing two types of cirrus clouds that differ in nucleation mechanism and radiative effect, European Geophysical Union, Vienna, Austria, 23-28 April 2023.
- Mitchell, D. L., and E. Erfani, 2023: Food for thought on cirrus cloud thinning (CCT), GeoMIP Modeling Research Consortium (GMRC), University of Exeter, Exeter, England, 4-6 July 2023.
- Mitchell, D. L., 2023: CCT Breakthrough? Poster presentation at the 13th GeoMIP Meeting, University of Exeter, Exeter, England, 4-6 July 2023.
- Mitchell, D. L., and A. Garnier, 2023: Describing domains for heterogeneous and homogeneous ice nucleation in cirrus clouds using a new CALIPSO satellite remote sensing method, International Association for Meteorology and Atmospheric Science (IAMAS)/International Union of Geophysics and Geodesy (IUGG), Session M25 Cloud Nucleation Studies, Berlin, Germany, 11-19 July 2023.
- Mitchell, D. L., and E. Erfani, 2023: Can Cirrus Clouds Cool the Polar Regions During Winter? Results from Satellite Remote Sensing and Radiation Transfer Modeling, International Association for Meteorology and Atmospheric Science (IAMAS)/International Union of Geophysics and Geodesy (IUGG), Session M07 Earth System Response to Solar Radiation Modification, Berlin, Germany, 11-19 July 2023.
- Mitchell, D. L., and A. Garnier, 2023: Characterizing two types of cirrus clouds that differ in nucleation mechanism and radiative effect, International Association for Meteorology and Atmospheric Science (IAMAS)/International Union of Geophysics and Geodesy (IUGG), Session M23 Cloud-Radiative Interactions, Berlin, Germany, 11-19 July 2023.
- Mitchell, D. L., and A. Garnier, 2023: Global Estimates of the Fraction of Cirrus Clouds affected by Homogeneous Ice Nucleation, Workshop "Clouds Containing Ice Particles", Joh. Gutenberg Univ. Mainz, Mainz, Germany, 23-26 July 2003.
- Mitchell, D. L., and A. Garnier, 2023: Investigating Cirrus Cloud Formation Processes from Combined CALIPSO Lidar and IIR Observations, CloudSat/CALIPSO Science Team Meeting, Washington D.C., 10-12 October 2023.



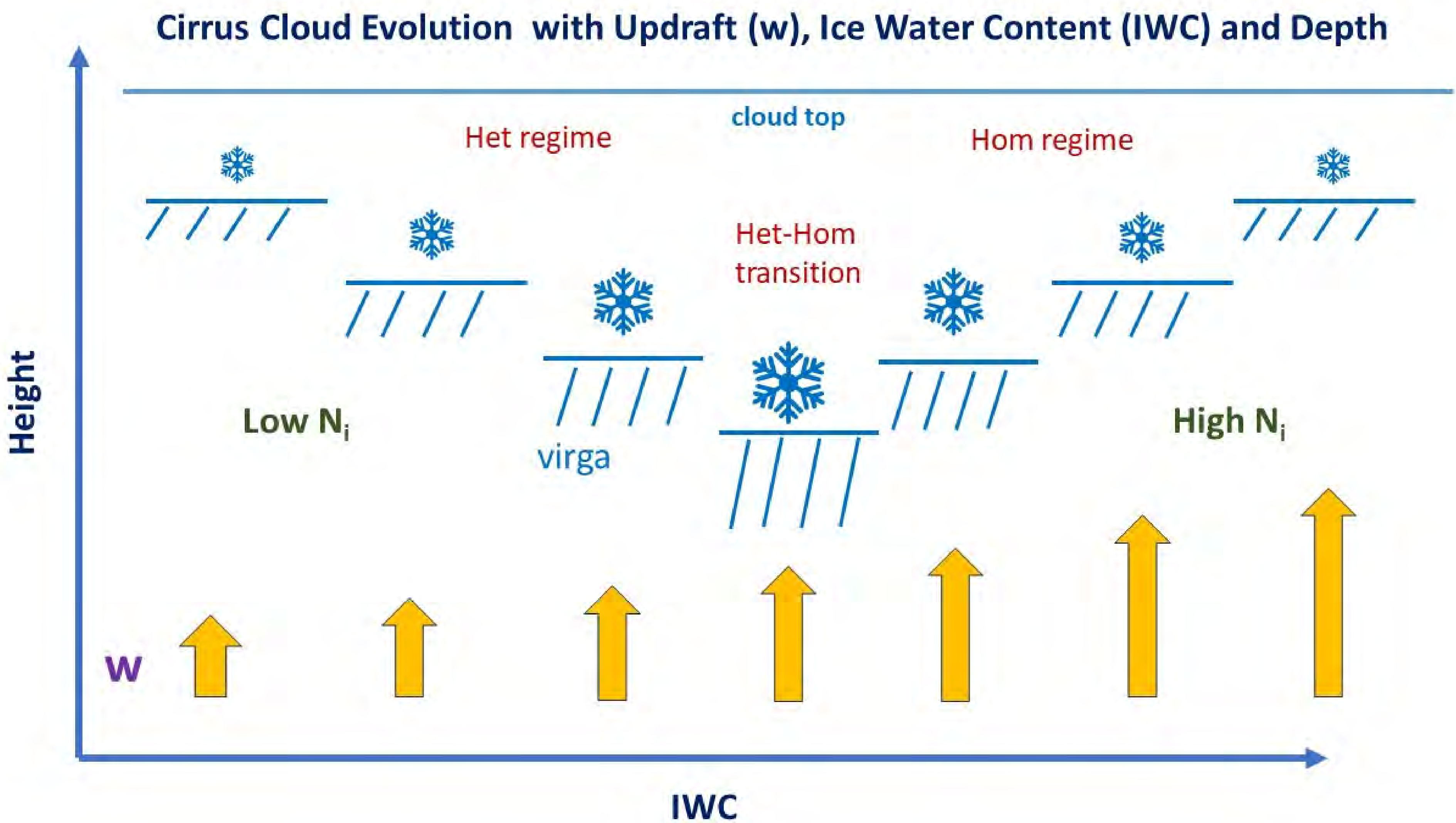
Upper panel: A wave cloud example of hom cirrus, forming over the Sierra Nevada mountains next to Reno, Nevada, that are associated with a warm front on 11 April 2023. Right panel: GOES-18 satellite image (11.2 µm channel) of these cirrus wave clouds taken about 10 minutes before the photo was taken, revealing their extensive coverage.

Global Distribution of Hom Cirrus

- Seasonal changes in dust concentration is inversely proportional to hom fraction.
- Possible evidence of dust events as natural CCT experiments.



Mitchell et al. (2023b); paper in preparation



Mitchell et al. (2023b); paper in preparation

Project 2: Urban cooling strategies in Las Vegas and Phoenix: synergies and tradeoffs

John Mejia et al.

Desert Research Institute

NOAA ERB meeting, 6-8 Nov. 2023, Boulder, CO, USA

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION · NOAA · U.S. DEPARTMENT OF COMMERCE

The simulation scenarios

Xeriscaping
(**No irrigation**)

or "Baseline" or "near present"

Q:/Cooling Las Vegas?

Realistic watering
(**Irrigation**)

6 days, 3 times 5 min irrigation periods
1-hour apart (cycle and soak approach).

The most progressive and comprehensive water conservation measures in the US.
Prohibiting the use of water to irrigate unused, decorative grass in Las Vegas by the end of 2026

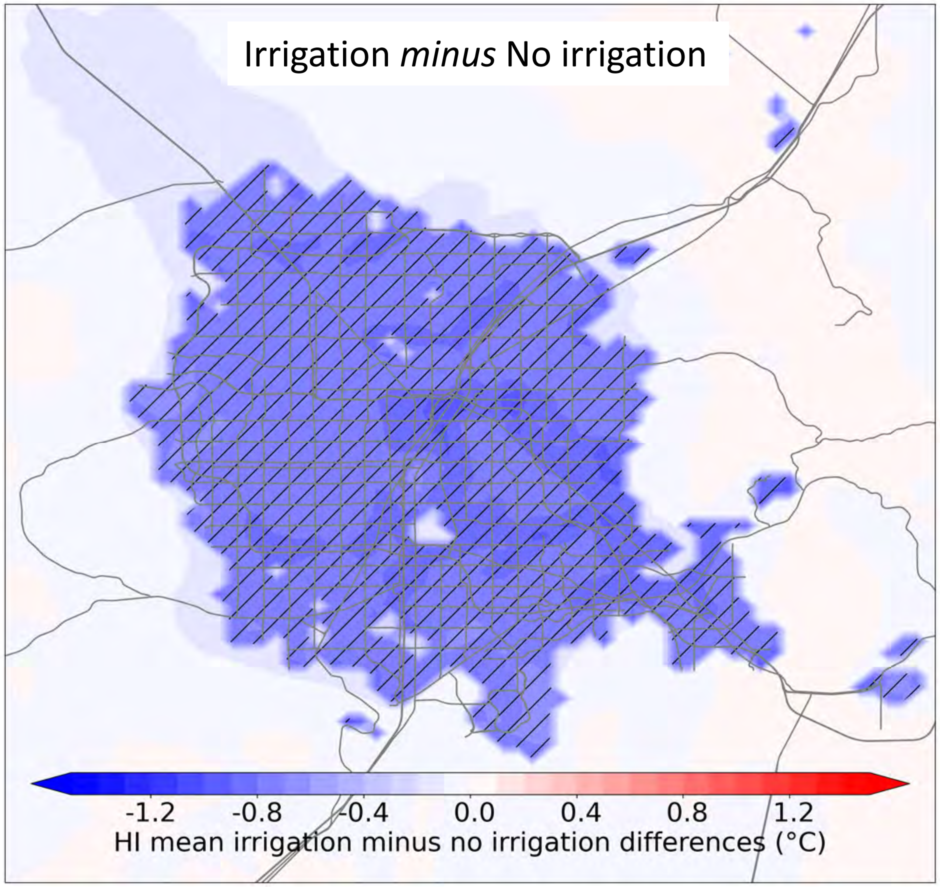
Las Vegas Valley Water District
https://www.lvvwd.com/

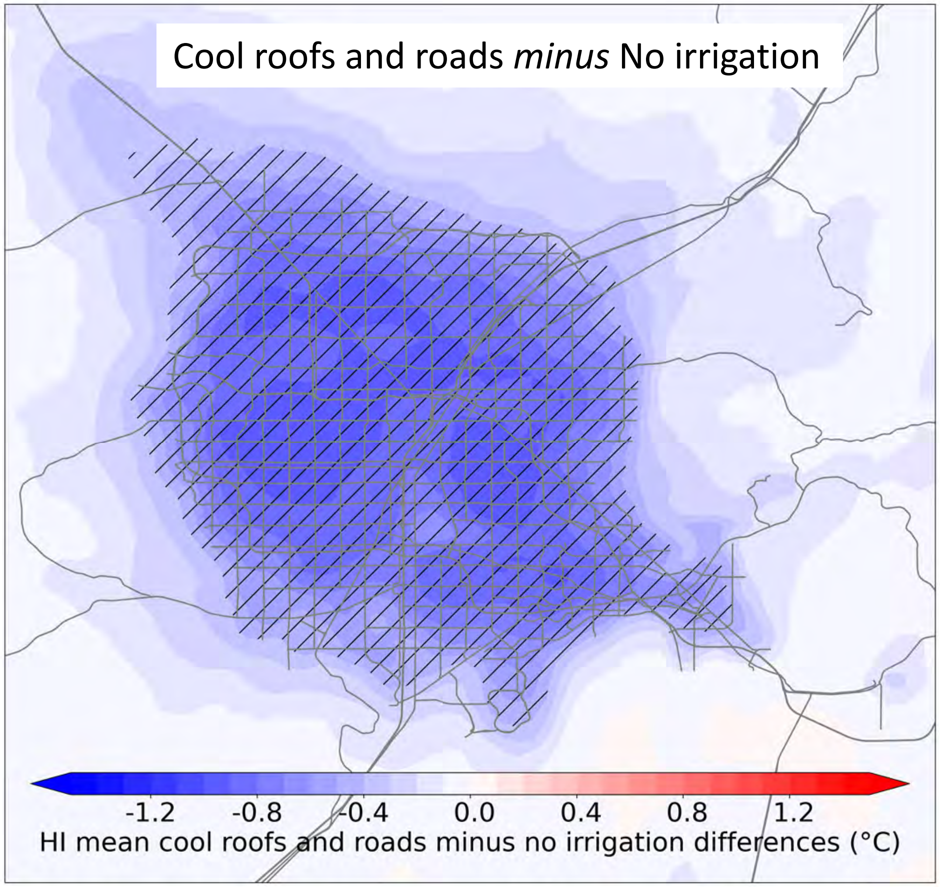
Mejia et al., Removal non-functional turf in Las Vegas, EGU-23.

Q:/ Cooling Las Vegas?

Cool "white" roofs (0.8) and roads (0.55)

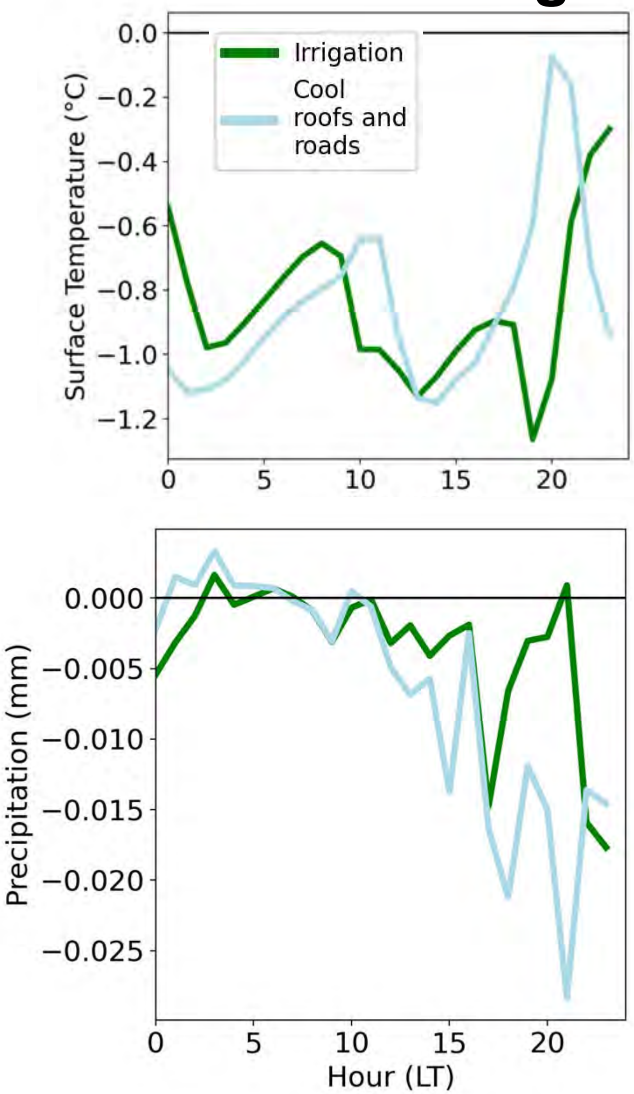
Heat Index



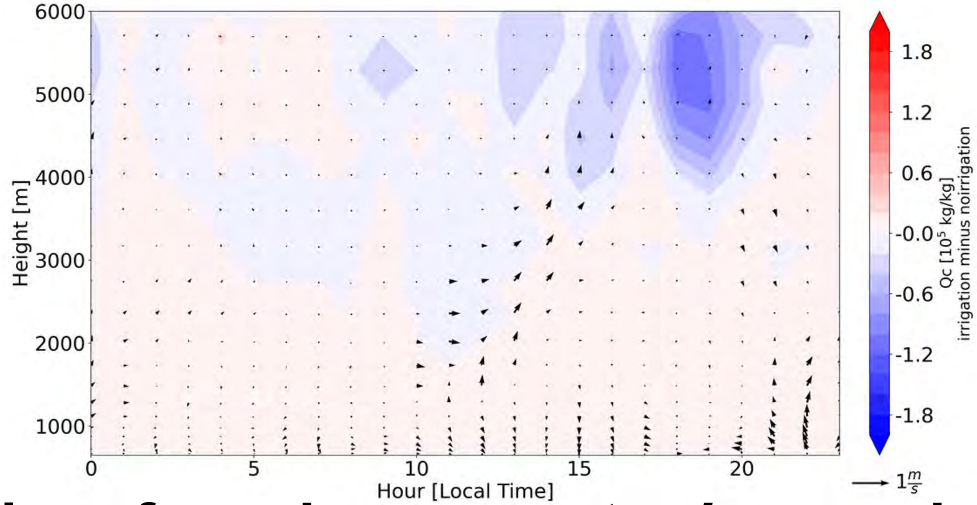


Mejia et al., Removal non-functional turf in Las Vegas, EGU-23.

Relative to no irrigation



Irrigation minus no irrigation



Cool roofs and pavement *minus* no irrigation