Where does snow become rain with atmospheric warming?

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*=Now at Travelers' Insurance

*Funding from NASA (*Grant 80NSSC20K1727*) and CIRES graduate research fellowship awarded to MTM.*

Part 1: Published Paper

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An Observational Constraint for Future Greenland Rain in a Warmer Atmosphere

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Key Points

- Warming alone applied to spaceborne-radar observations provides a useful constraint on future Greenland rain occurrence
- Rain could double with 2.3°C of near-surface warming
- Projected 21st century warming makes rain possible at all elevations and in all months

Strategy: Use spaceborne radar observations from CloudSat to build up local statistics over time to map and understand precipitation phase sensitivity to warming alone.

Be conservative and simple:

1) Detect precipitation with attenuated CloudSat reflectivity: >0 dBZ in each column, mask out the five vertical bins (240 m each) above the ice sheet surface
2) Snow-rain threshold: near-surface air temperature > 2°C (Sims & Liu, 2015, Jennings et al. 2018)

Let's look at these methods for one example CloudSat granule.

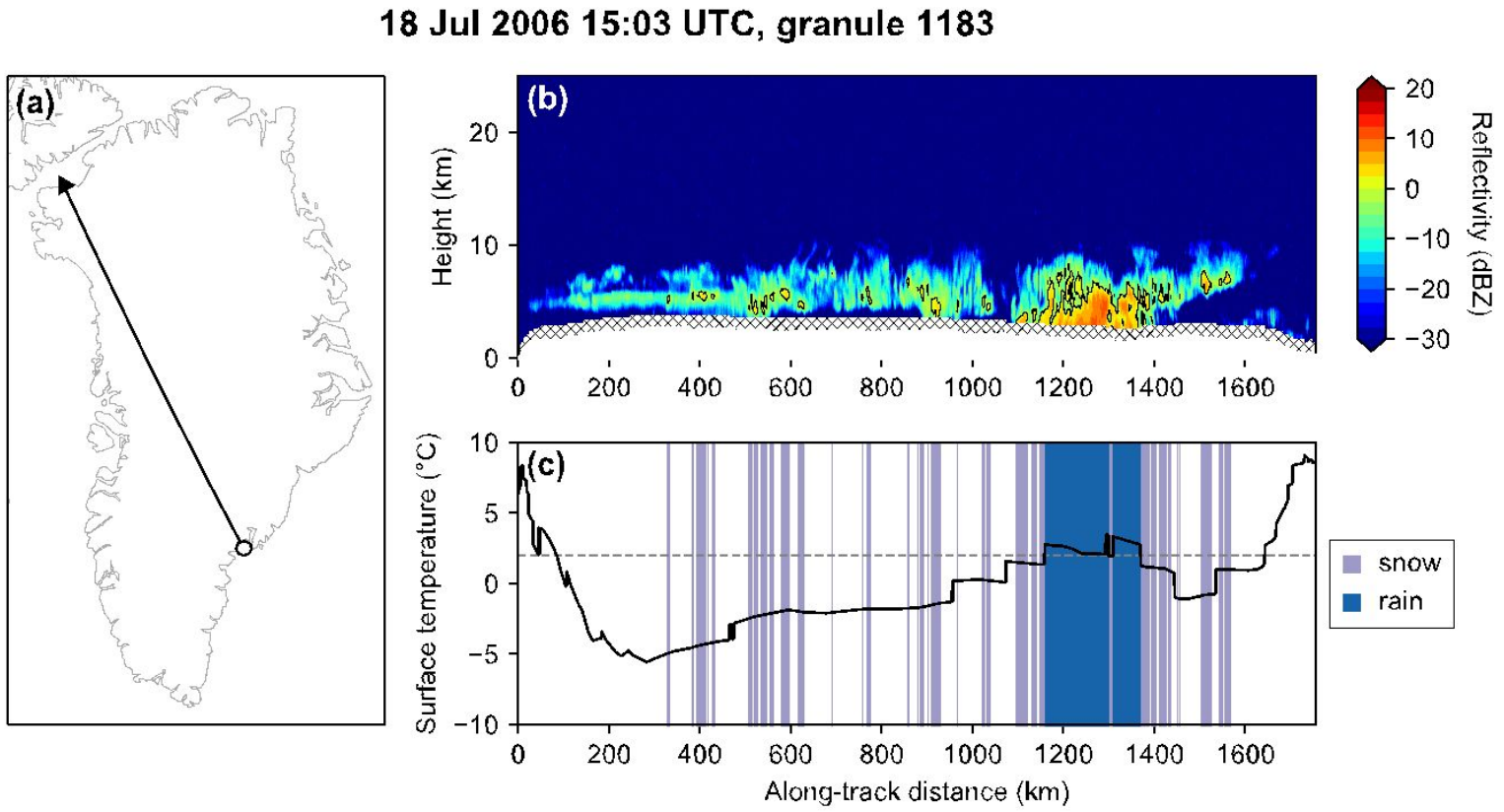


Figure from Thompson-Munson et al. 2025 GRL Supplement

Present-day observations consistent with rain are **rare**, occurring only along the coasts and during summer.

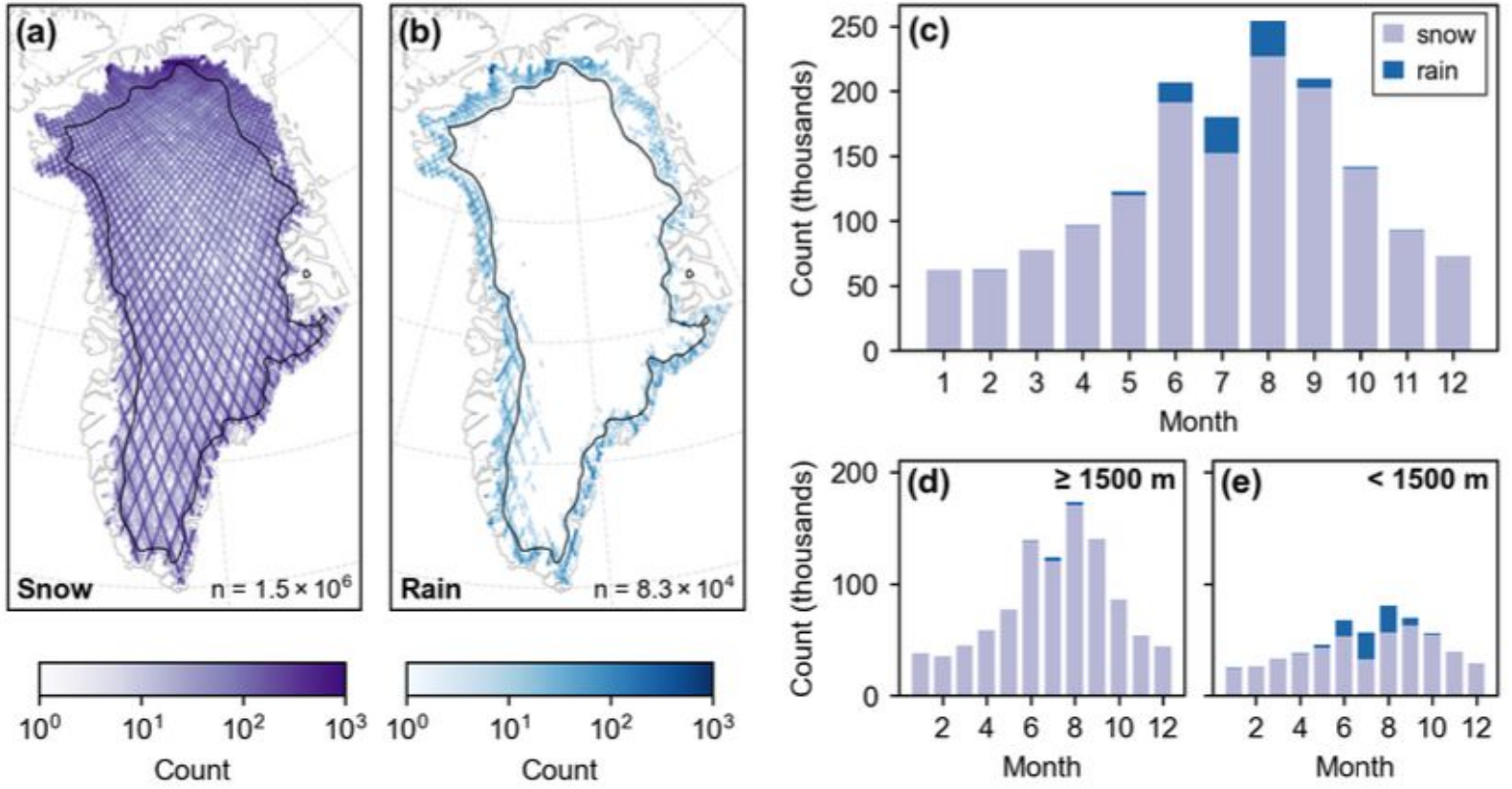
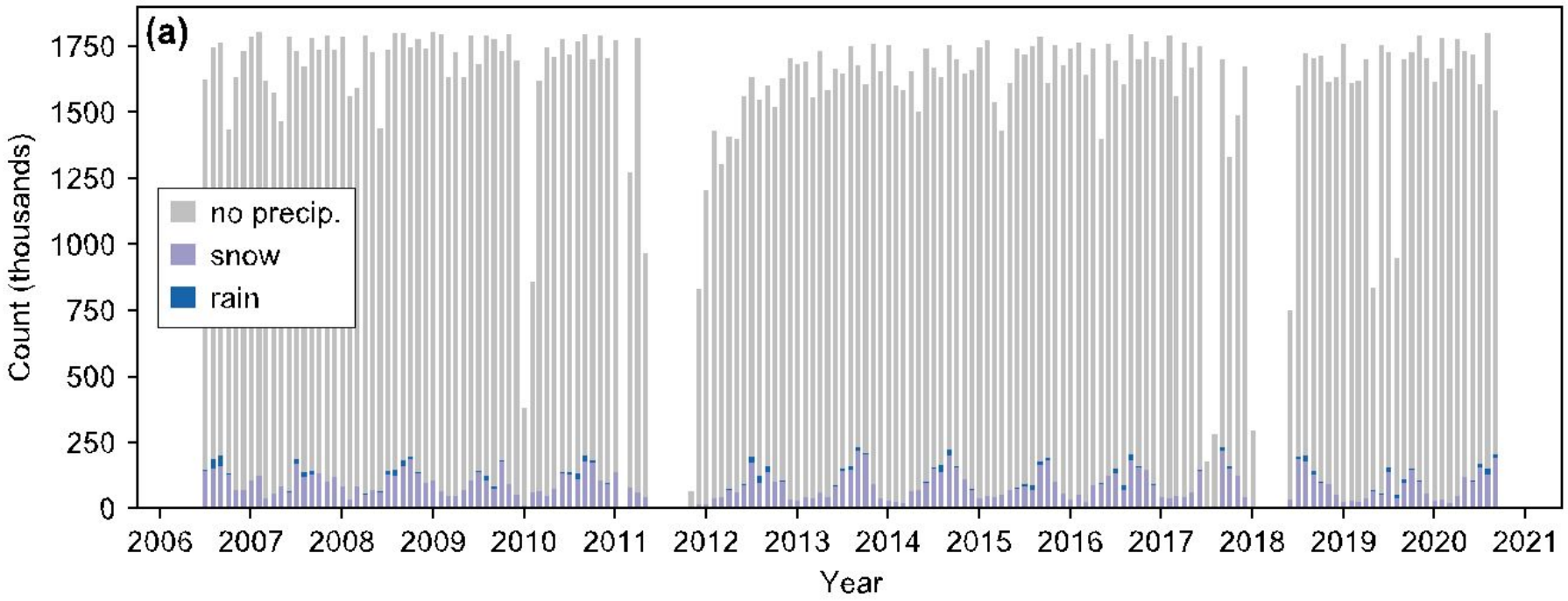
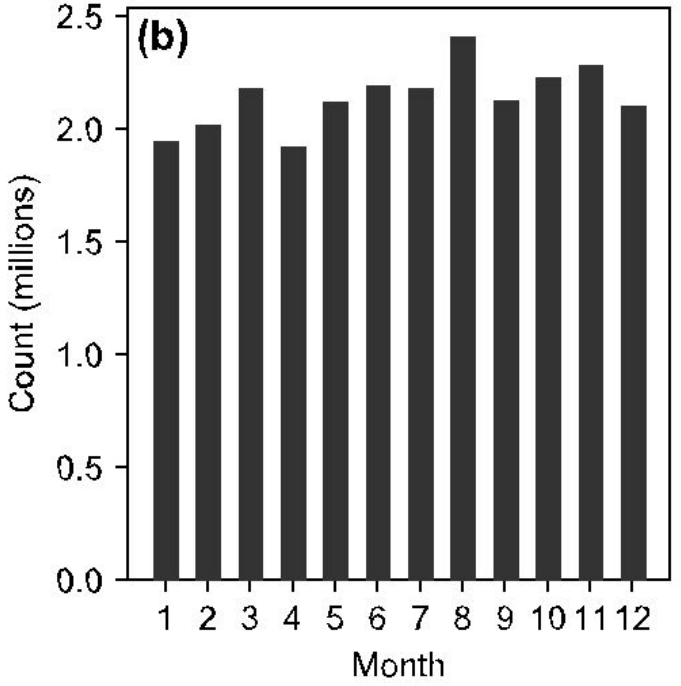


Figure 1. Spatial and temporal distribution of snow and rain CloudSat observations over the period 2006 to 2020. (a) snow count map. **(b)** rain count map. For **(a)** and **(b)**, the black line corresponds to the 1500-m surface elevation contour and the total count of observations is shown in the lower right. The concentration of observations along specific tracks results from CloudSat's orbit. **(c)** Stacked bar graphs showing the monthly count of rain and snow at all locations. **(d)** as in (c) but for high elevations (≥1500 m) only, **(e)** as in (c) but for low elevations (<1500 m) only.

Thompson-Munson et al. 2025 GRL

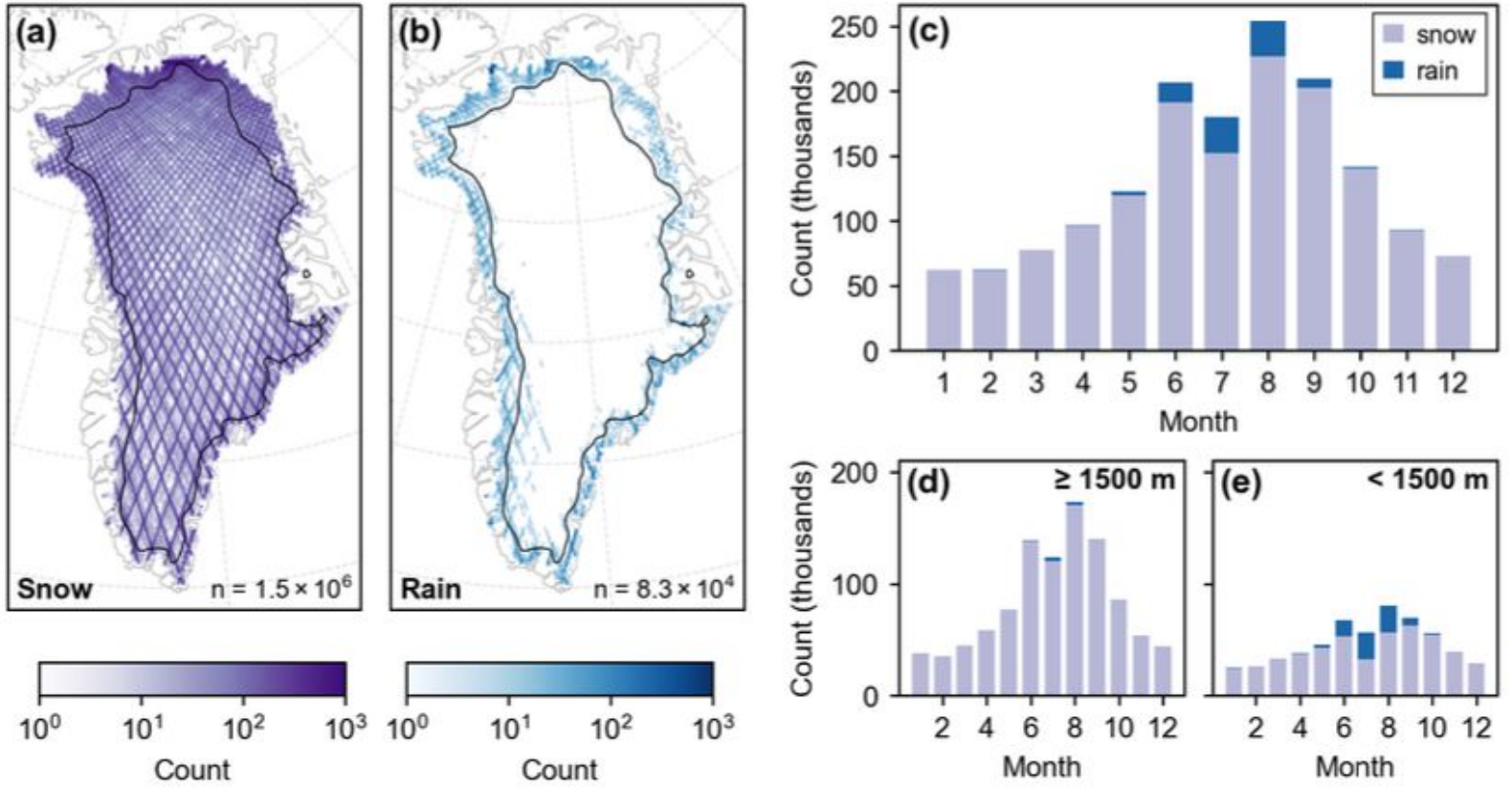
The CloudSat legacy profile-by-profile over Greenland





Thompson-Munson et al. 2025 GRL Supplement

The CloudSat observed distribution serves as the foundation for assessing the potential for rain increases **due to atmospheric warming alone**.



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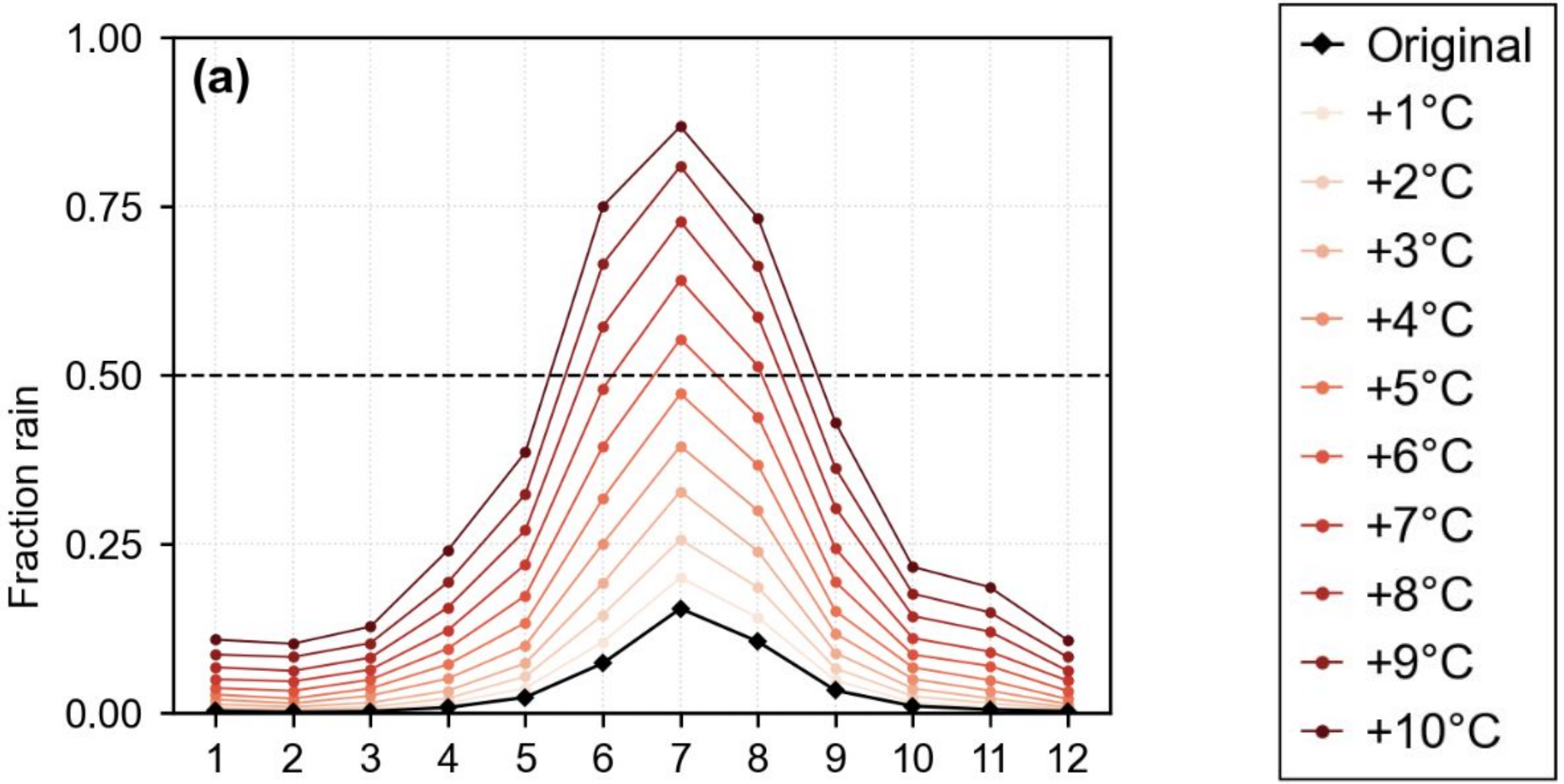
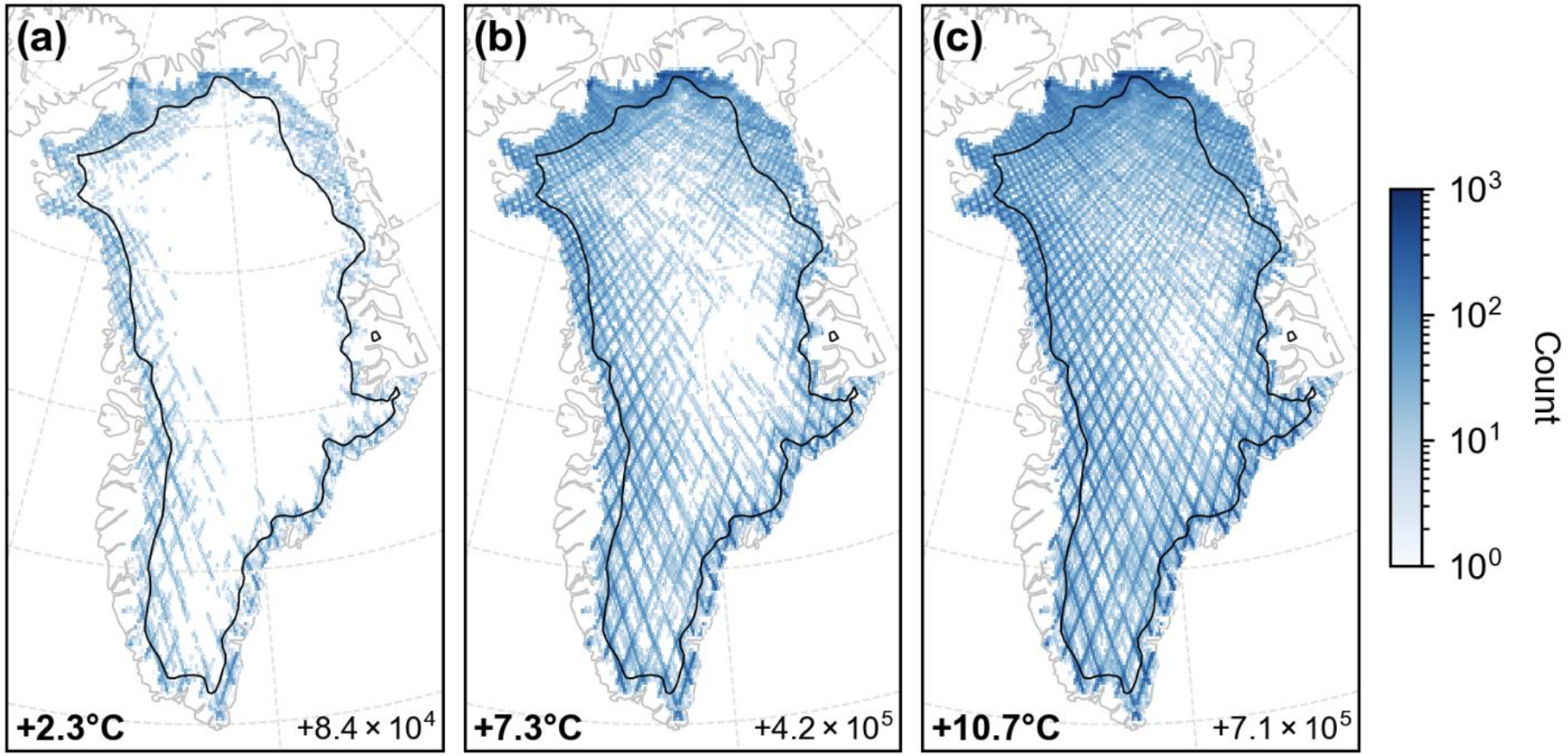
Thompson-Munson et al. 2025 GRL

Fraction of Greenland precipitation consistent with rain with different warming levels



Fraction of Greenland precipitation consistent with rain under different warming levels

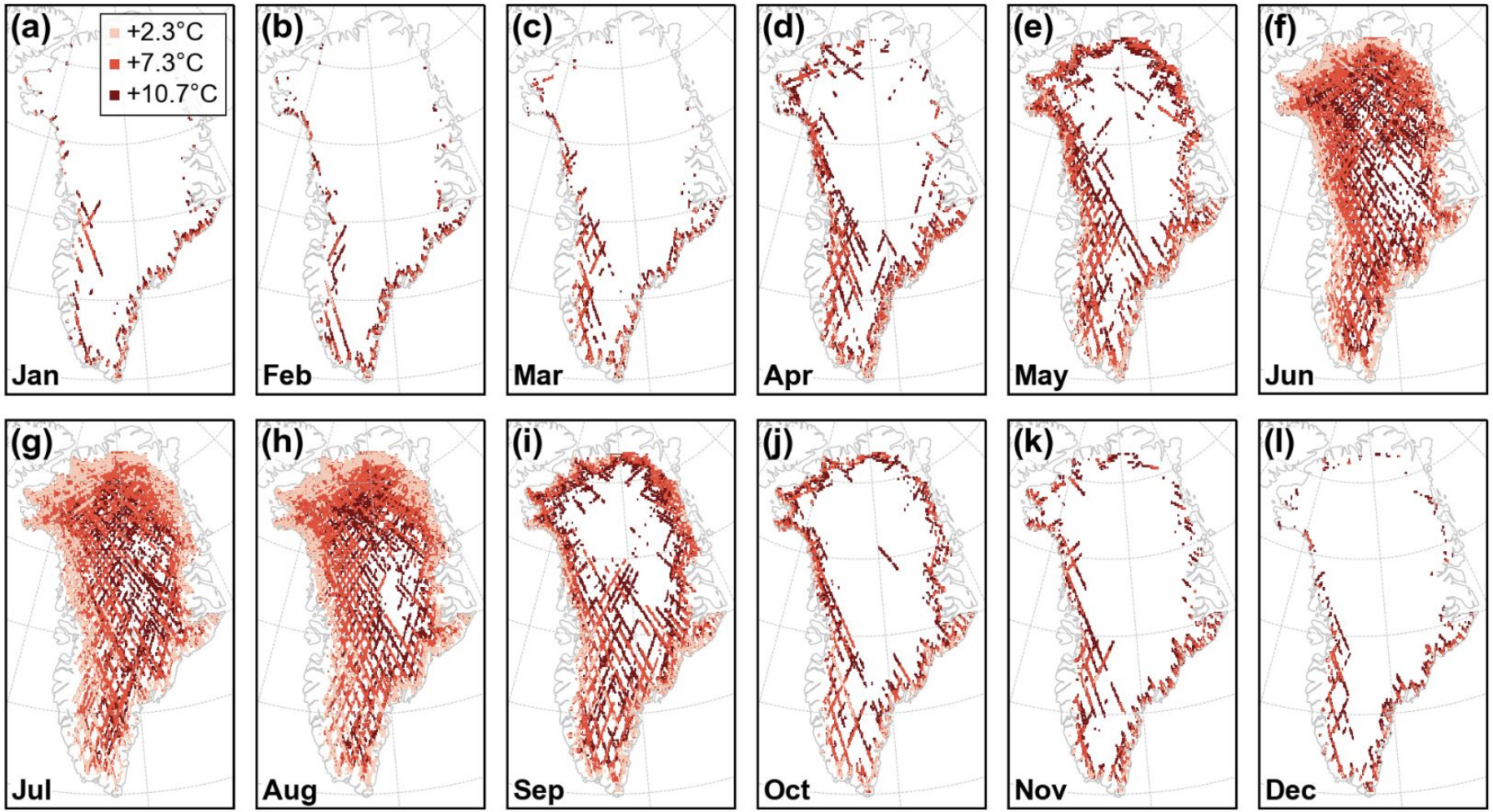


Rain doubles

Rain 50% of precipitation

Rain 50% of precipitation

Fraction of Greenland precipitation consistent with rain under different warming levels



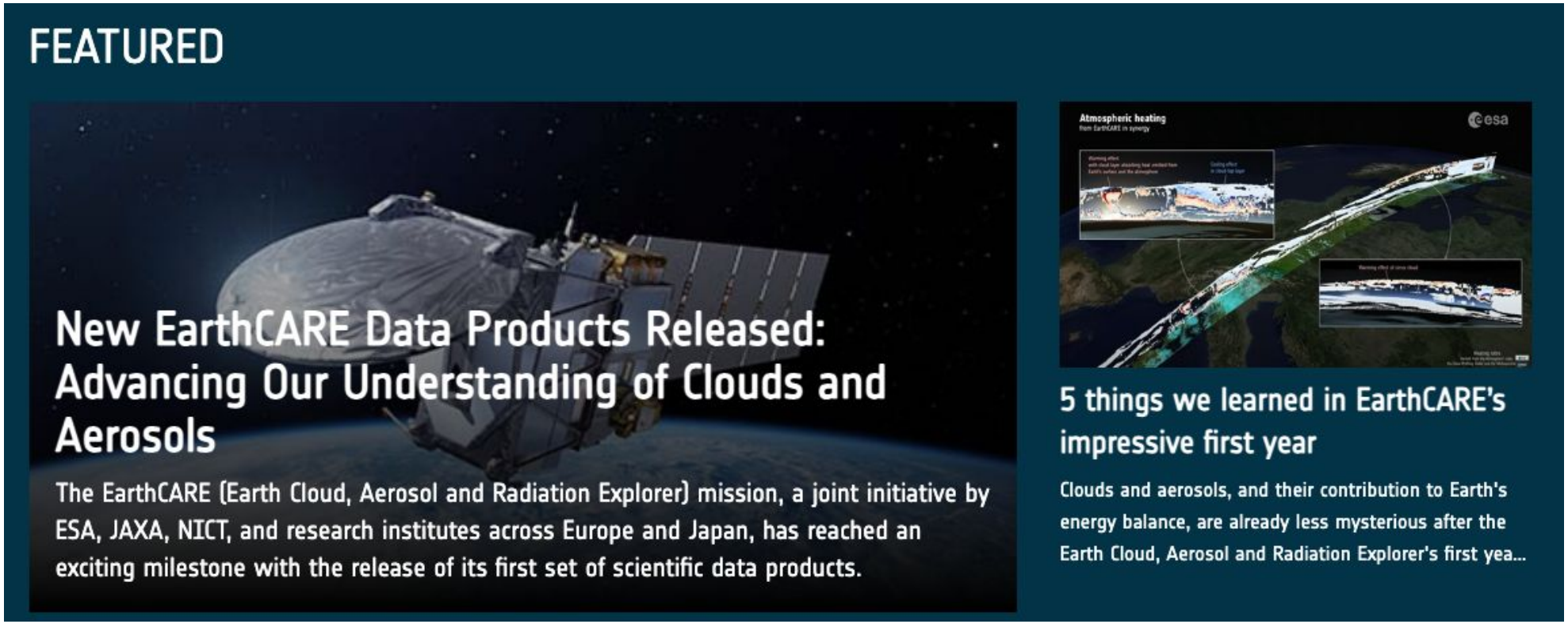
Three Key Points – Thompson-Munson et al. 2025 GRL

1) **Warming alone** applied to **spaceborne-radar** observations provides a useful constraint on future **Greenland rain** occurrence.

2) Rain could **double** with 2.3°C of near-surface warming

3) Projected 21st century warming makes **rain possible at all elevations and in all months**

Launch of EARTHCare (European/Japanese satellite)! New spaceborne radar and lidar observations available…



Featured yesterday (June 9, 2025 at https://earth.esa.int/eogateway/missions/earthcare

Part 2: CESM2 Snow to Rain Transition

Strategy: Use CESM2 Large Ensemble 6-hourly MOAR outputs to build up local statistics over time to map and understand the location of the snow-to-rain transition.

Be conservative and simple:

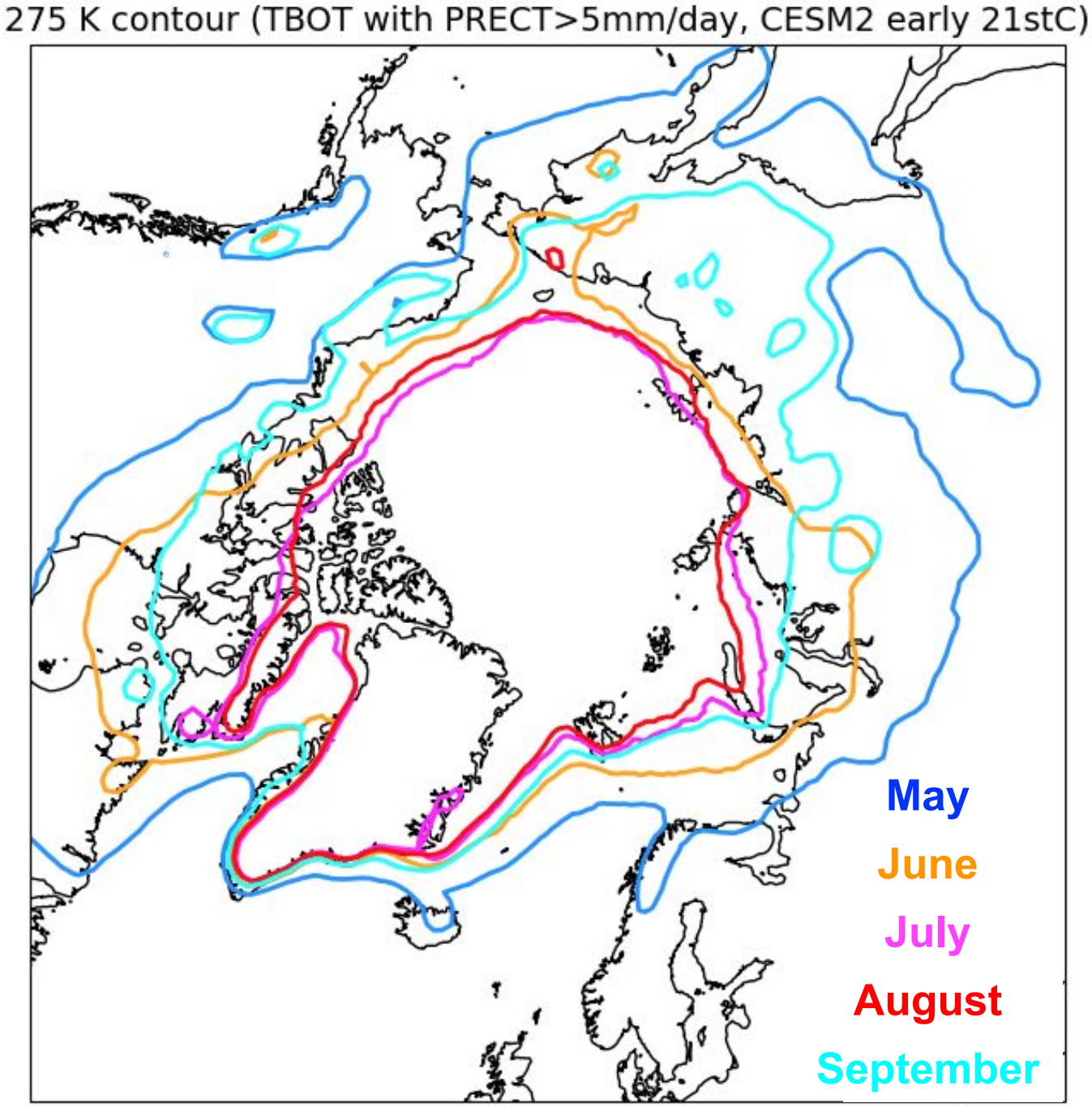
1) large (> 5 mm/day) precipitations events detected in 6-hourly averages
2) snow-rain threshold: air temperature > 2°C (or > 0°C extra slides)
3) Early 21st century (2000-2009) vs. late 21st century (2085-2094)

<u>Science Questions:</u>

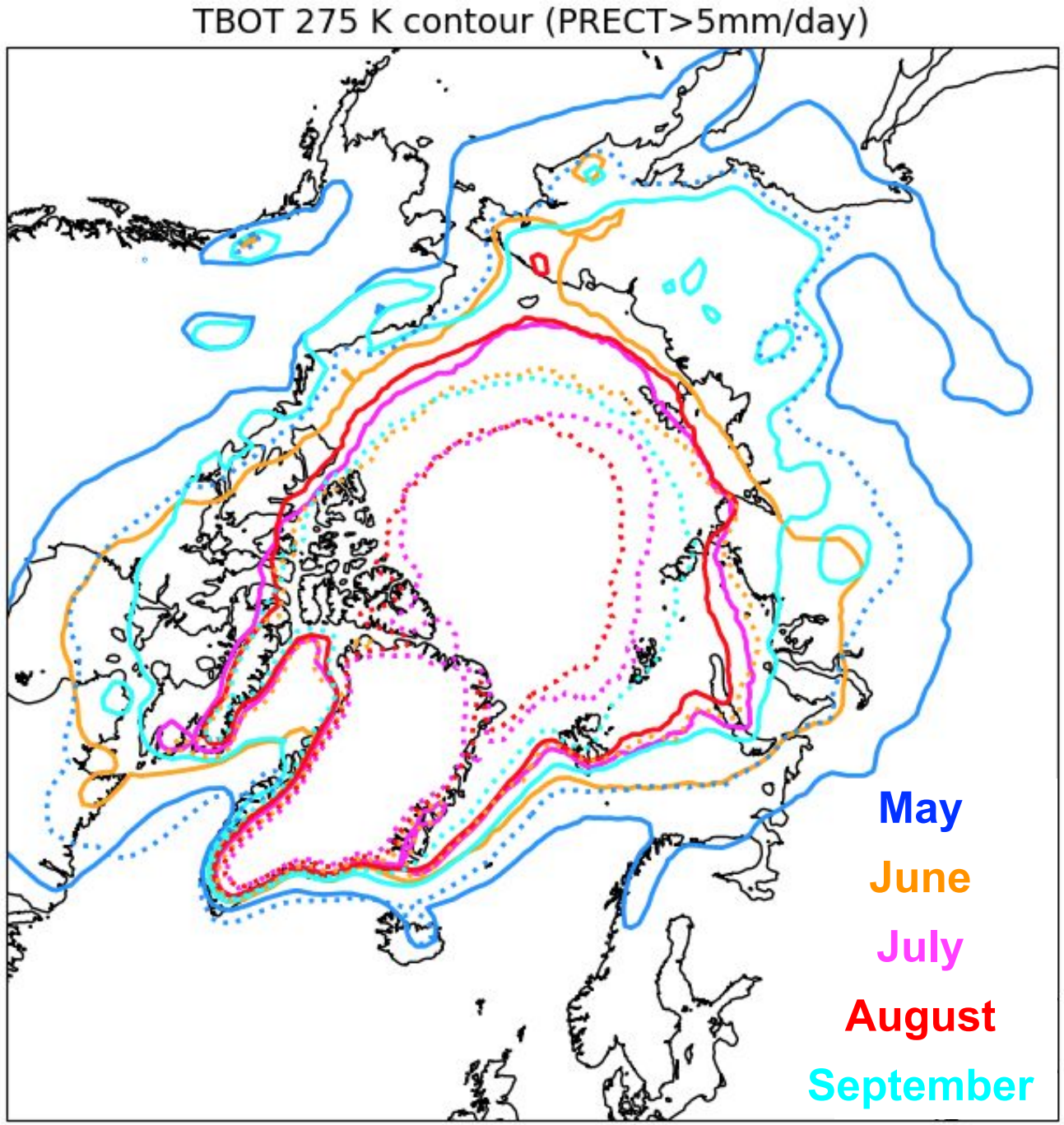
Where is the location of the SNOW->RAIN transition in the atmosphere?

What processes control this transition?

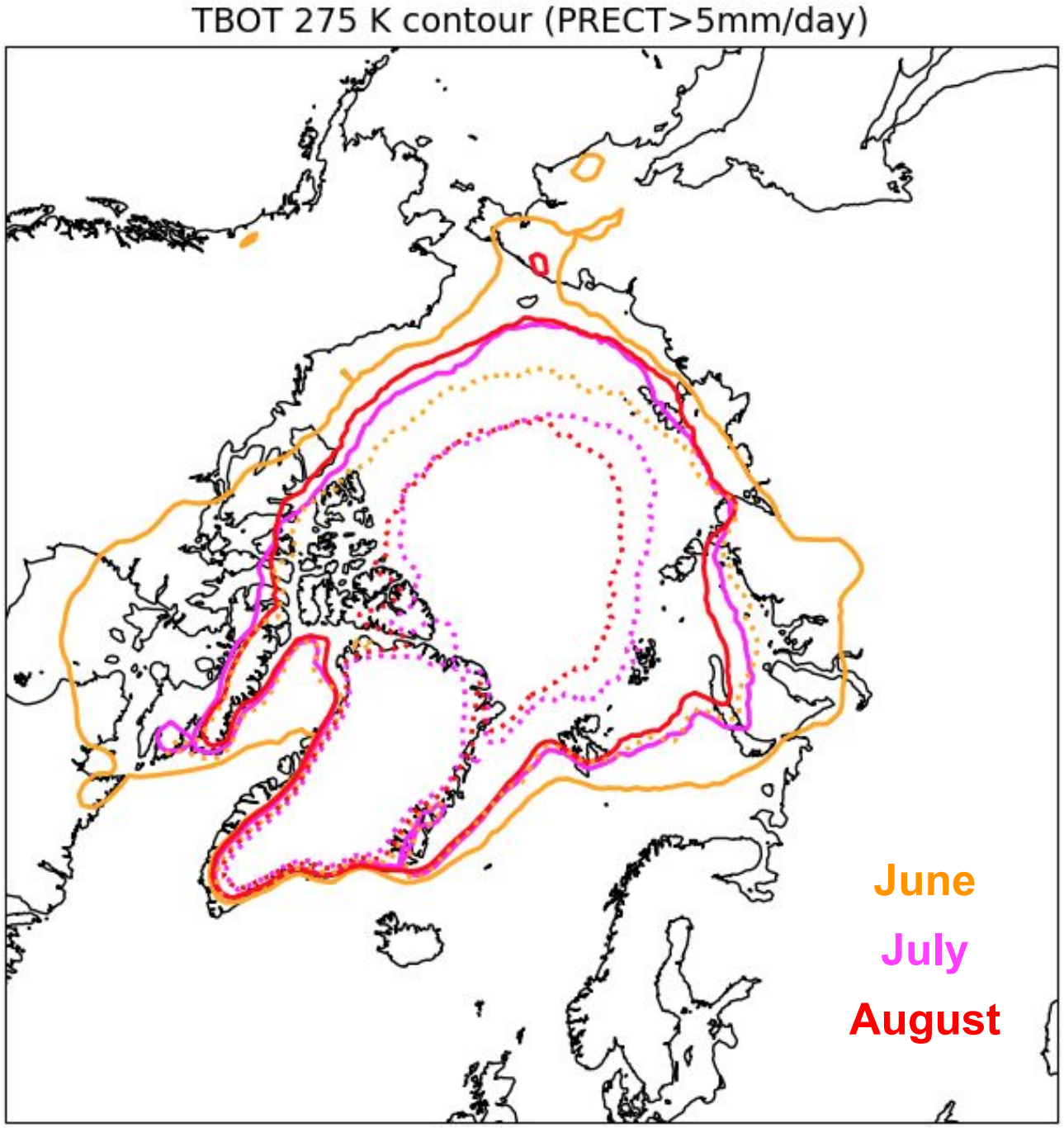
Where is the early 21st century SNOW->RAIN transition in the atmosphere in CESM2?



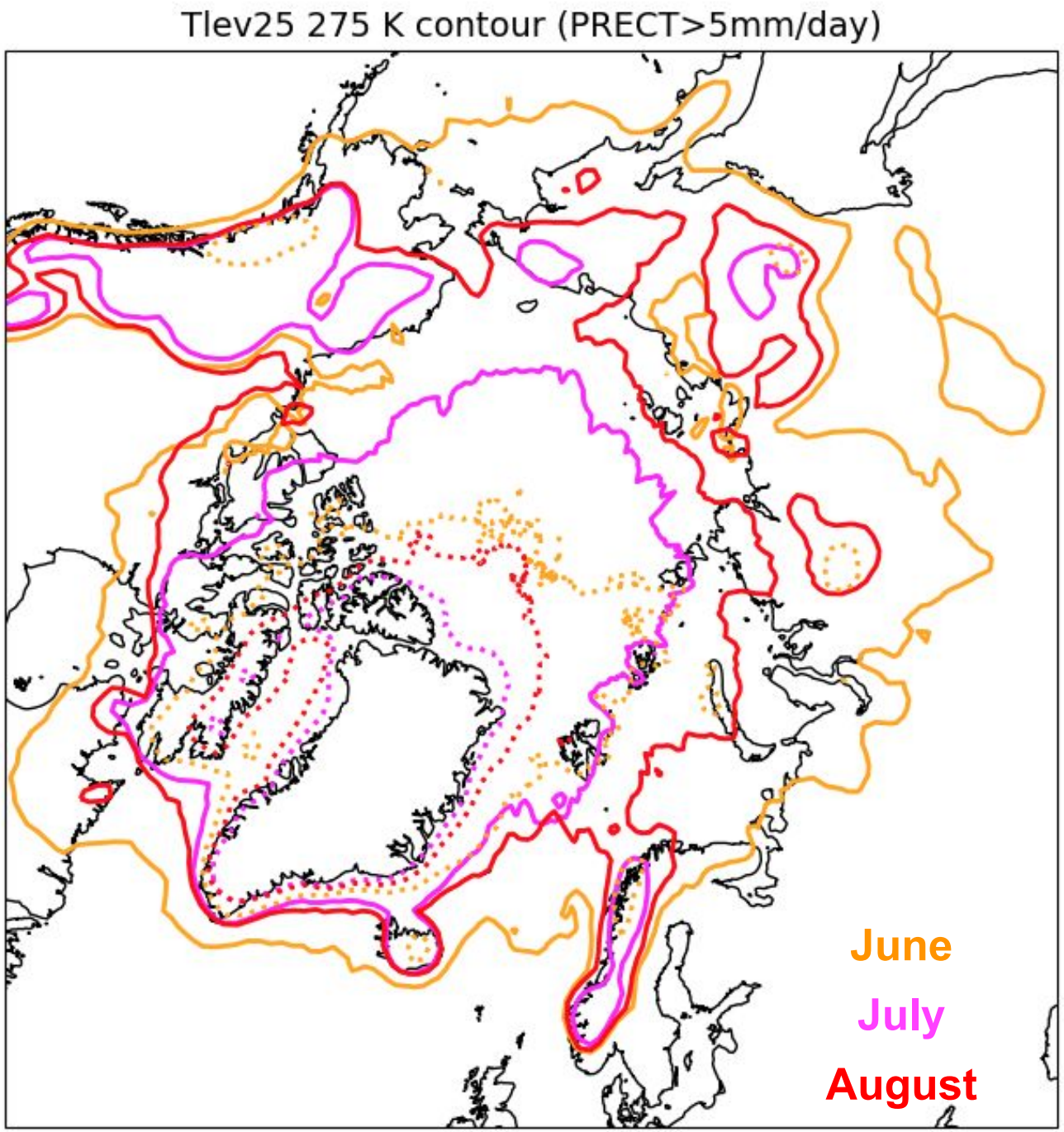
Where is the early (solid) and late (dashed) 21st century SNOW->RAIN transition in the atmosphere in CESM2?



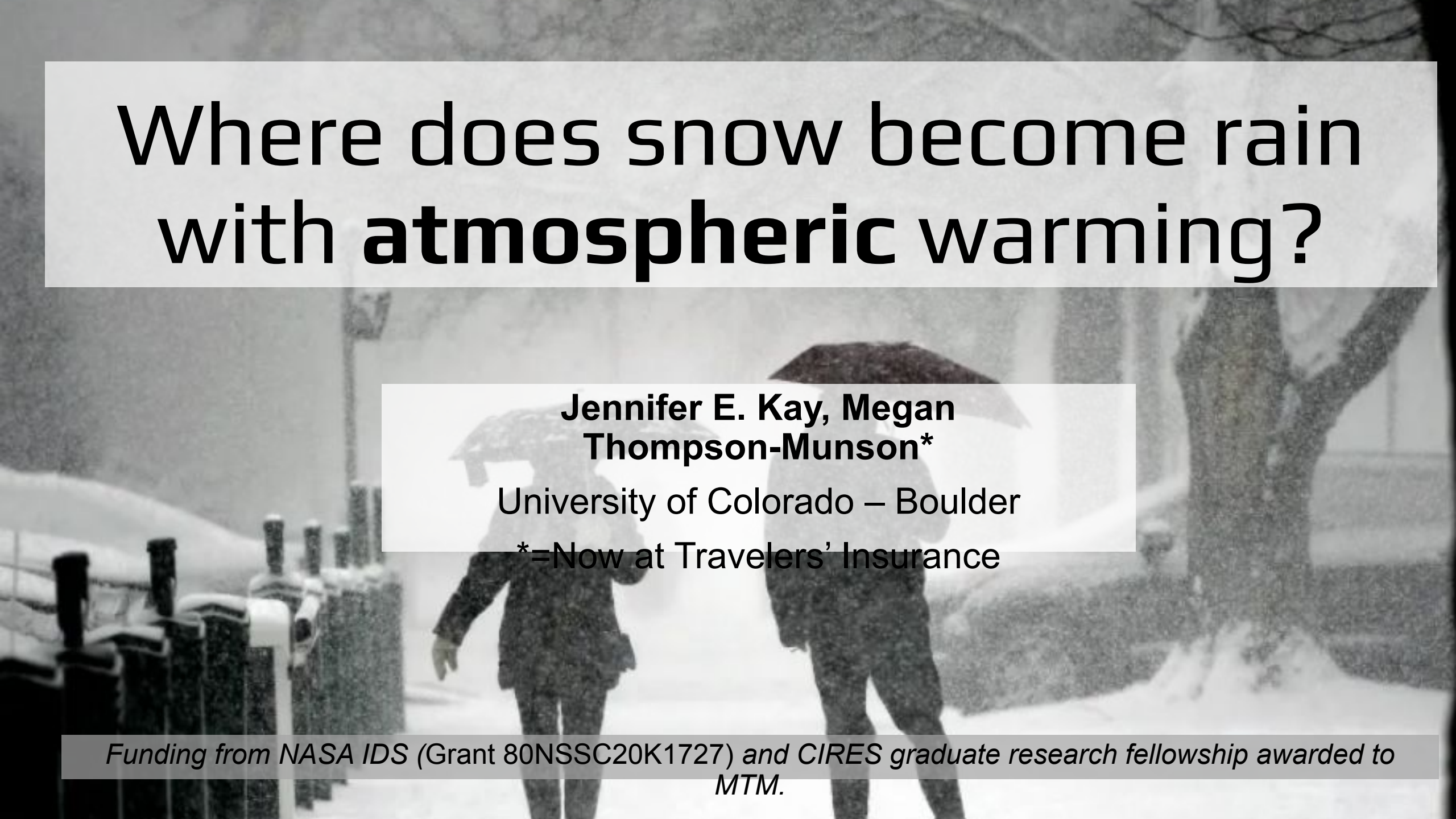
The near-surface air temperature (TBOT) affected by the surface and sea ice (ocean latent heat)



What about at ~1200 meters above the ground surface in the atmosphere (T, lev25)?



Where does snow become rain with **atmospheric** warming?



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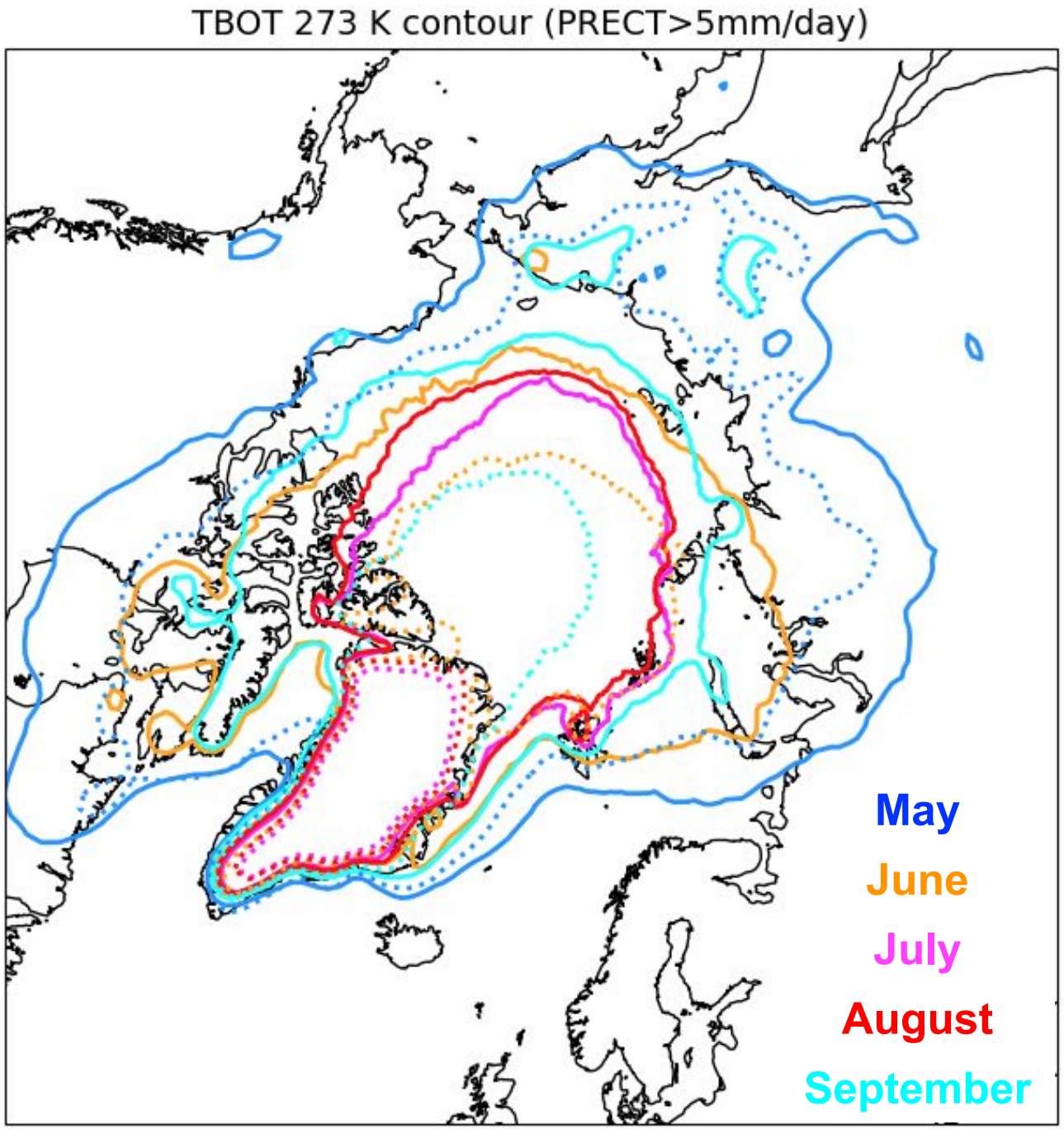

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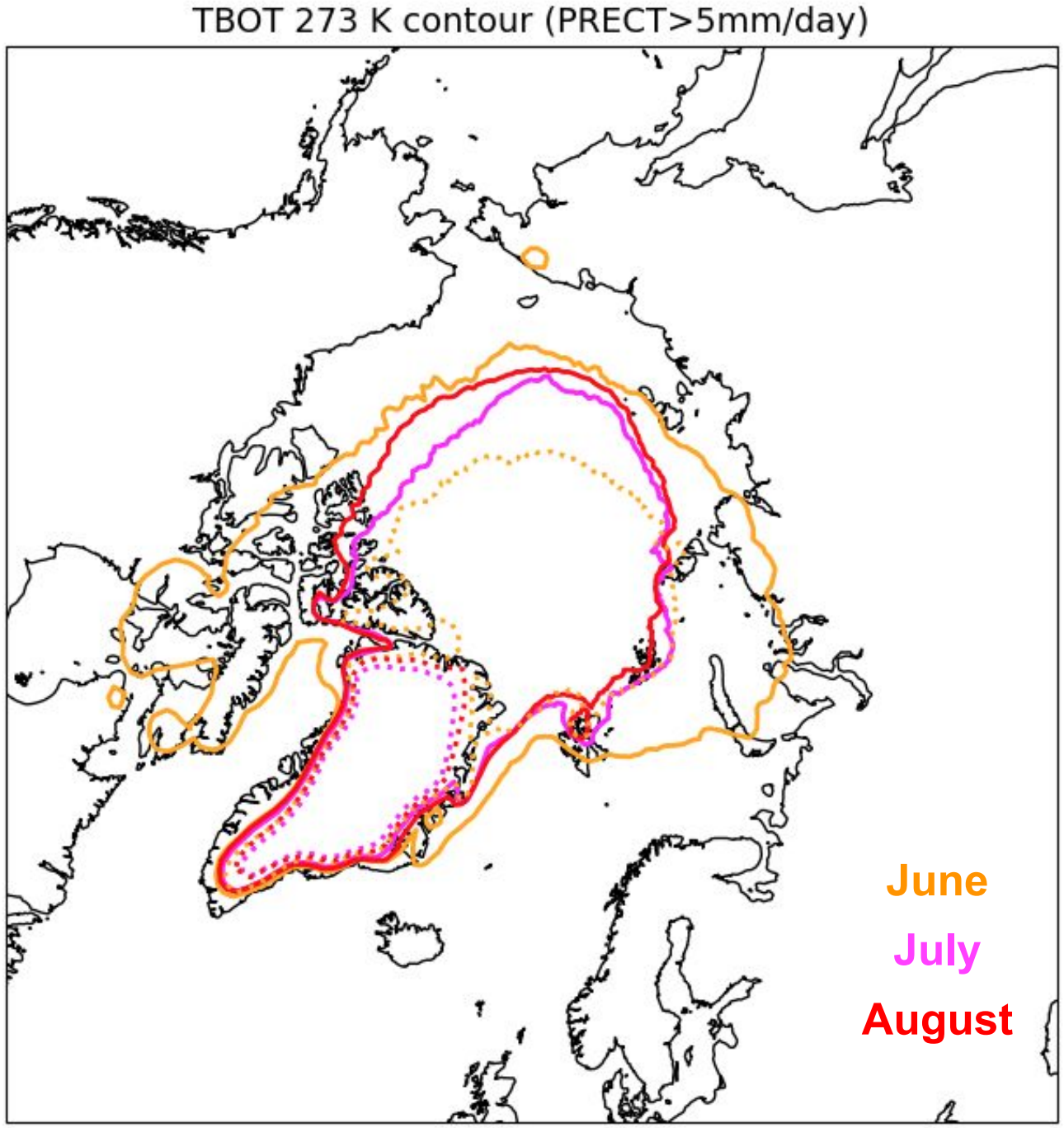

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