Impact of increased melting level height

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Graduate Seminar

ATMS-790

April 5th, 2021

Article : Prein and Heymsfield (2020)

Figures included in this presentation are from the following article unless indicated.

nature climate change

ARTICLES

https://doi.org/10.1038/s41558-020-0825-x

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Increased melting level height impacts surface precipitation phase and intensity

Andreas F. Prein ✉ and Andrew J. Heymsfield

The global near-surface temperature increased by ~0.155 K per decade during 1979–2012, which resulted in decreasing snow and increasing rain events, retreating mountain glaciers and more frequent and intense rainfall extremes. Although surface temperature increases are well studied, less attention is given to the associated changes in the tropospheric thermal structure, such as melting level height, which affects cloud microphysics and surface precipitation. Here we use observations and reanalyses to show that the melting level height increased by 32 ± 14 m per decade over global land areas during 1979–2010, consistent with a warming atmosphere. This causes a transition from snow to rain, the enhanced melting of hail and an increased depth of warm cloud layers (cloud base to melting level distance). Warm cloud layers with a depth beyond ~3.5 km result in an intensification of extreme precipitation at twice the rate of the atmospheric moisture increases. Days with such environments increased by 25% per decade in populated regions, such as the eastern United States.

Outline

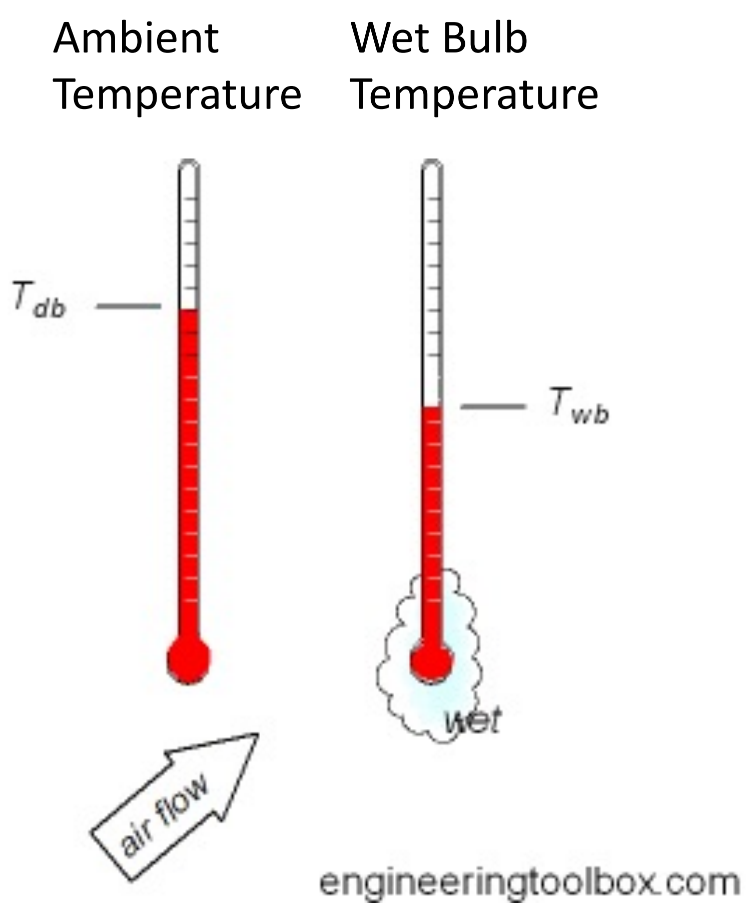
- Introduction
- Datasets
- Results
- Conclusion

Global Surface warming increased ~1°C since 1850

- The warming of global near surface (land and sea) reached ~1°C since pre-industrial era (IPCC special report, 2017)
- Many regions and seasons have faced the greater warming than global average and warming over land is higher than over the ocean (IPCC special report, 2017)
- Tropospheric thermal structure might impact the melting level height
- Lower atmospheric temperatures directly influences the formation, composition, and dynamics of clouds and surface precipitation.

Wet bulb temperature

- **Latent heat** is the energy absorbed by or released from a substance during a phase change
- Evaporation is a cooling process that absorbs latent heat, therefore **the more evaporation the more cooling.**
- The wet-bulb temperature is the lowest temperature that results after complete evaporational cooling at constant pressure.
- Through the wet cloth, air blows and as water evaporates the bulb is cooled (Remember as you get out of swimming)



Melting Level: 0°C Wet Bulb Temperature

- Author defines the **melting Level height** as the height of the **zero-degree wet bulb temperature** above the surface

- ML height is crucial for the phase change of the hydrometeors

- Precipitation rate at the surface depends on the phase and size of hydrometeors which determine their fall speed.

- The rainfall intensities is higher for larger drops that evaporate little during the fall.

Objective

To quantify the change in ML height and examine the impact on the precipitation phase and intensity.

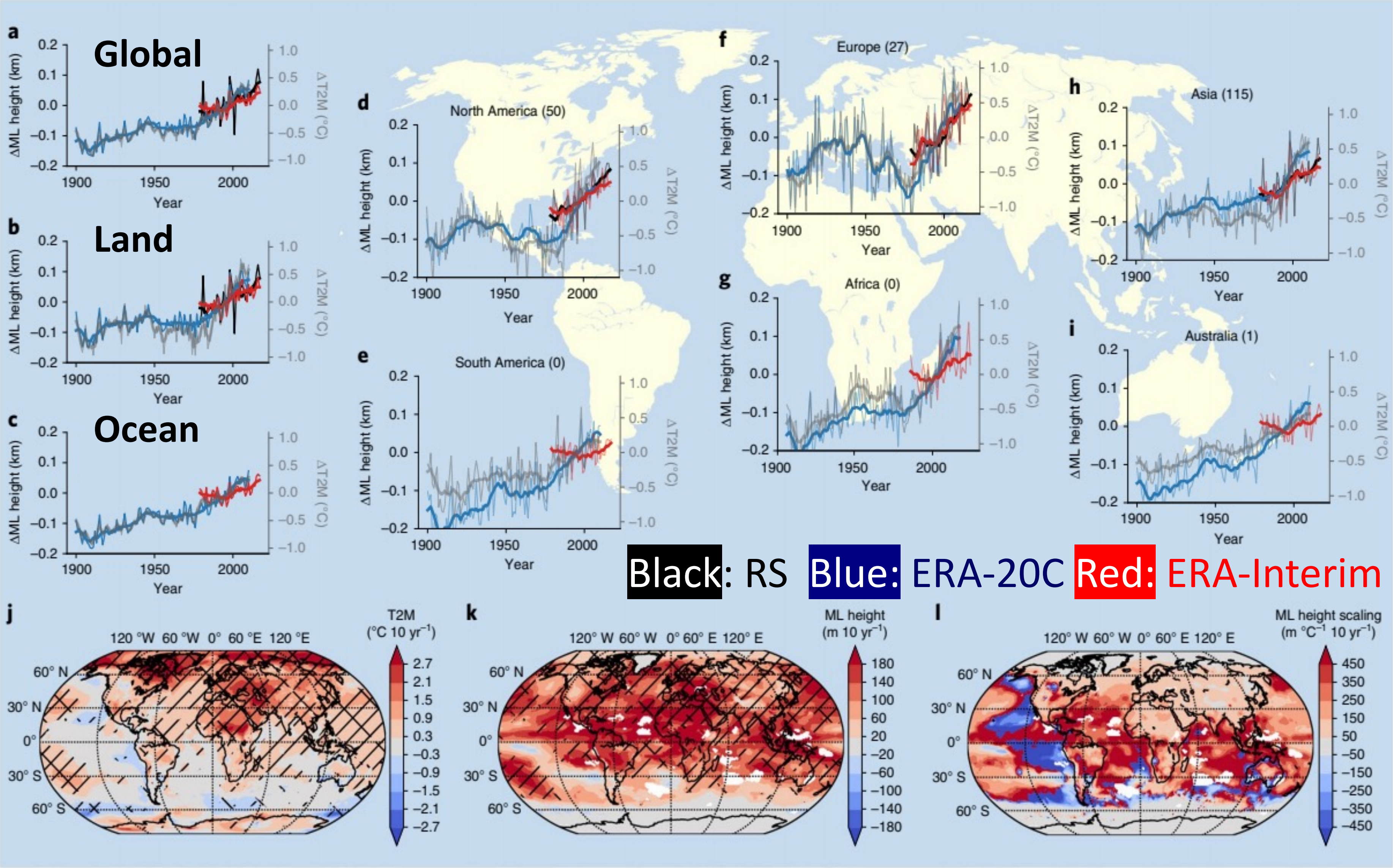
Datasets

- Radiosonde (RS) data (Observational)
- Reanalysis data
  - ERA-Interim: Since 1979 (~80km horizontal resolution, 60 vertical resolution)
  - ERA-20C: 1900-2010 (~125km horizontal resolution, 91 vertical resolution)
- Gauge based and gridded precipitation records
  - Global Historical Climatology Network
  - 3-hourly (0.1° gridded globally, since 1979)
- US and Australian hail observations

Results: ML height increased significantly since 1979

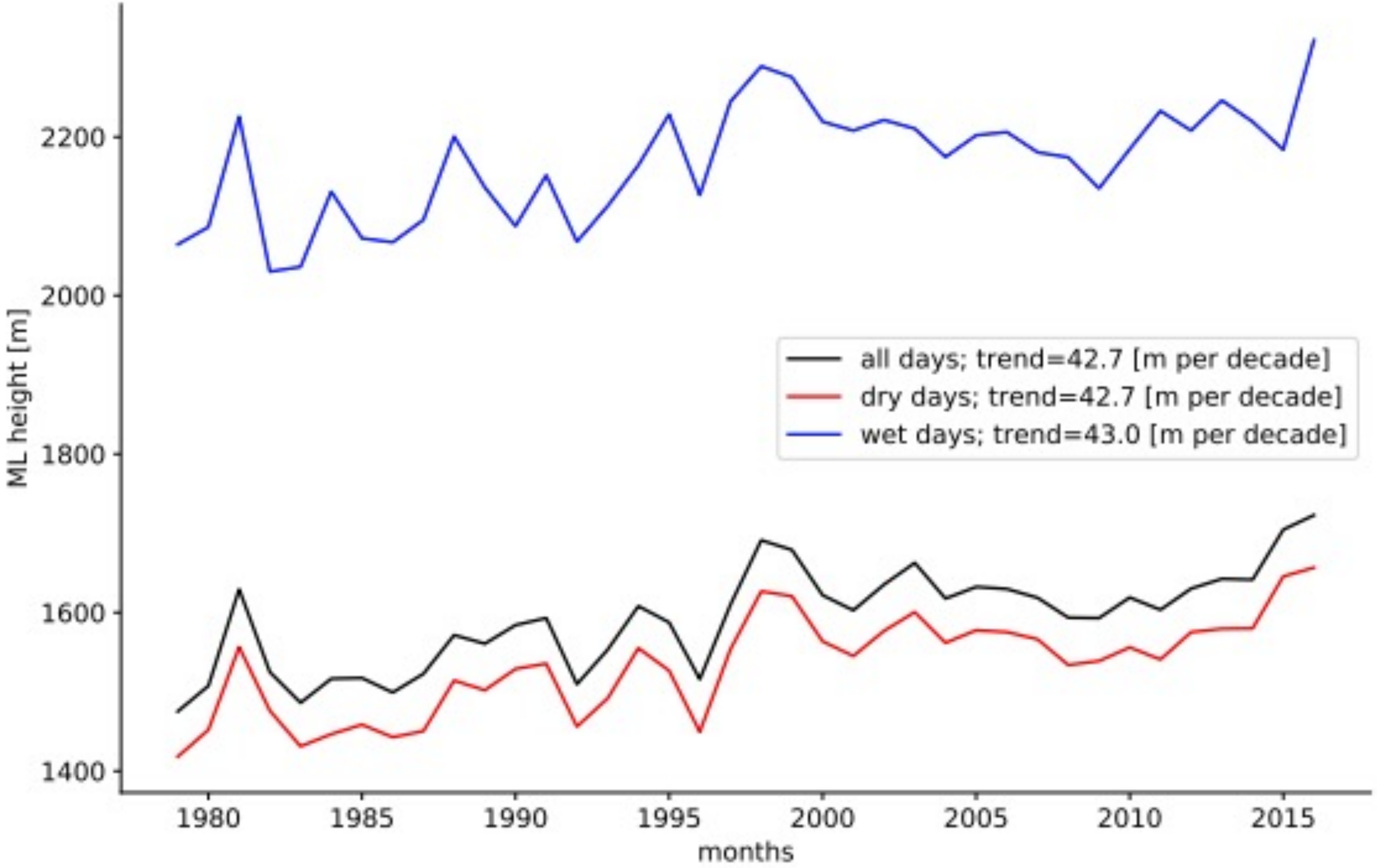
Annual average ML changes since 1900

- ML height increased by 32±14 m dec^{-1} over land
- ML height increase correlates well with 2m air temperature
- Over Northern Hemisphere mid to high latitudes, ΔML is 65 m dec^{-1} during June-November
- Globally, ΔML is 206±90 mK^{-1} per degree surface warming



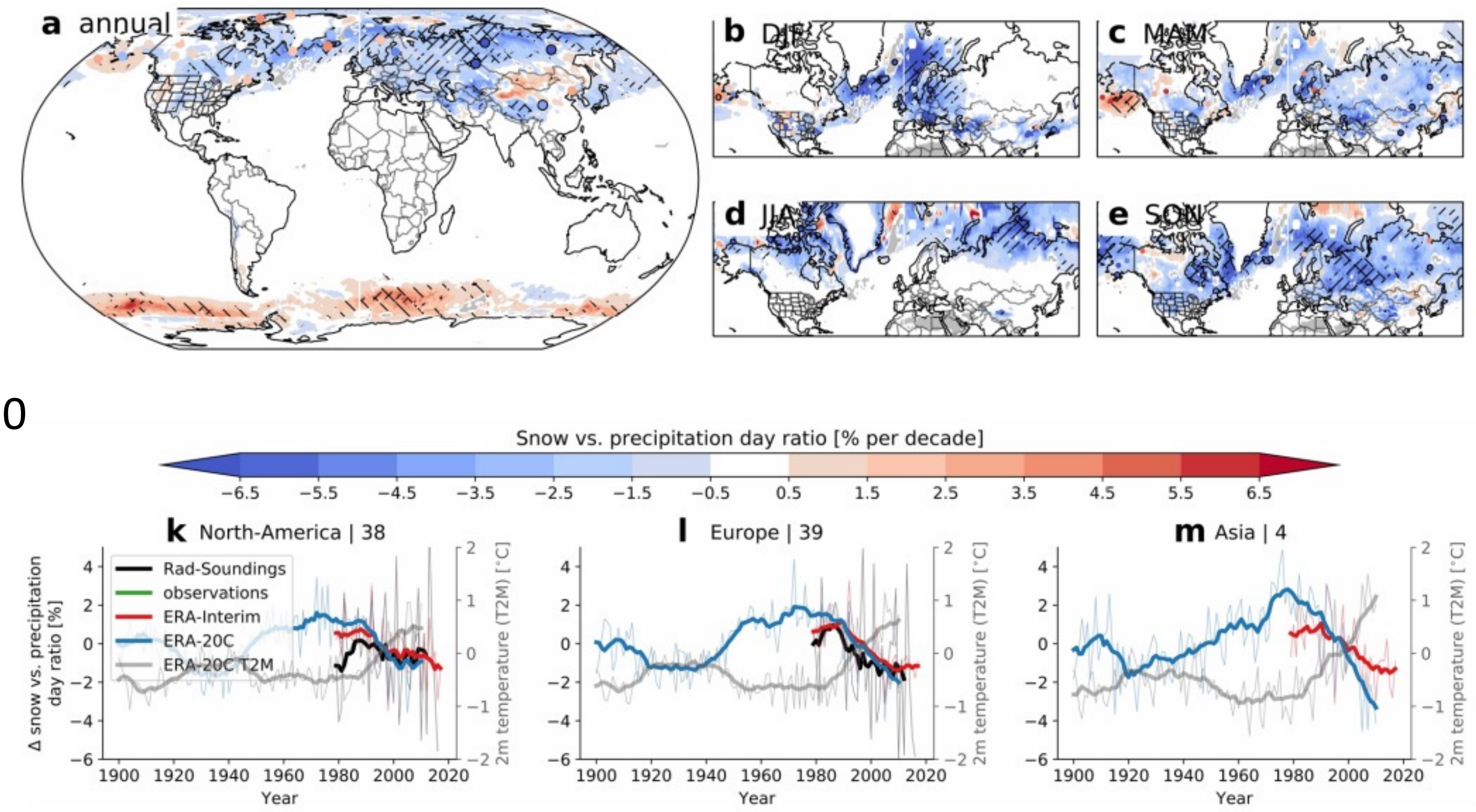
Similar ML height trends

Threshold to differentiate dry and wet days is 1mm day^{-1}



Expected consequence: Significant reduction of snow events and corresponding increase in rain events

Linear trend of snow to precipitation-day ratio



Significant decreases between 1979 and 2010

- **North America:** $-0.5\pm0.4\%\mathrm{dec}^{-1}$
- **Europe:** $-1.0\pm0.2\%\mathrm{dec}^{-1}$
- **Asia:** $-1.4\pm0.6\%\mathrm{dec}^{-1}$

WCL and C-C Equation

- **Warm Cloud Layer (WCL):** distance between cloud base height and ML height

- WCL depth influences warm rain processes which impacts the liquid water content in the cloud and the precipitation rates at the surface

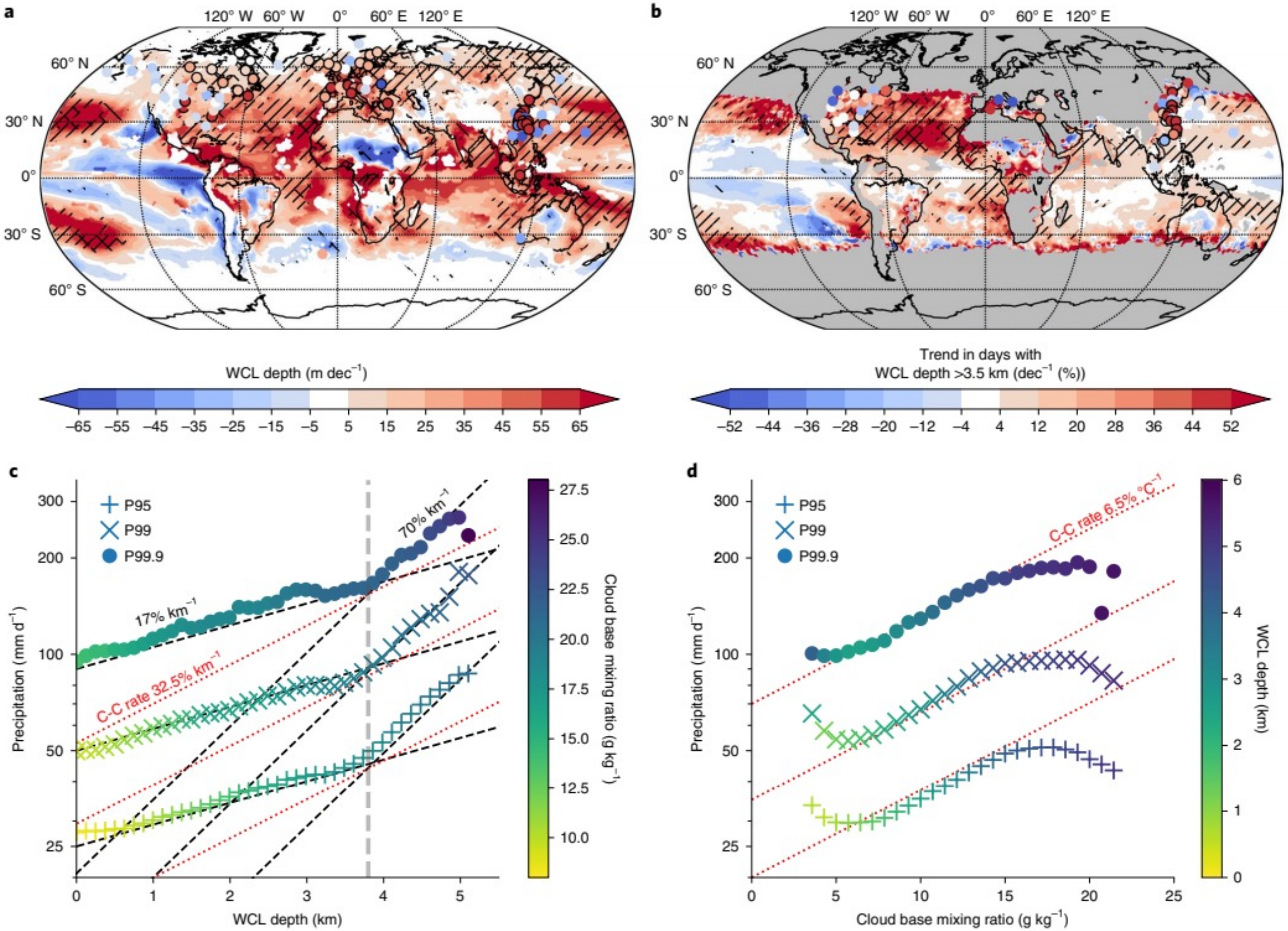
- **Clausius-Clapeyron (C-C) equation**: Relates vapor pressure to temperature in a system.

$$e_s\,(T) = 0.6112 \exp\left(\frac{17.67\,T}{T + 243.5}\right)$$

  - T: Temperature
  - e_s: Saturation vapor pressure

Potential Consequence: Increasing trend of WCL depth since 1979

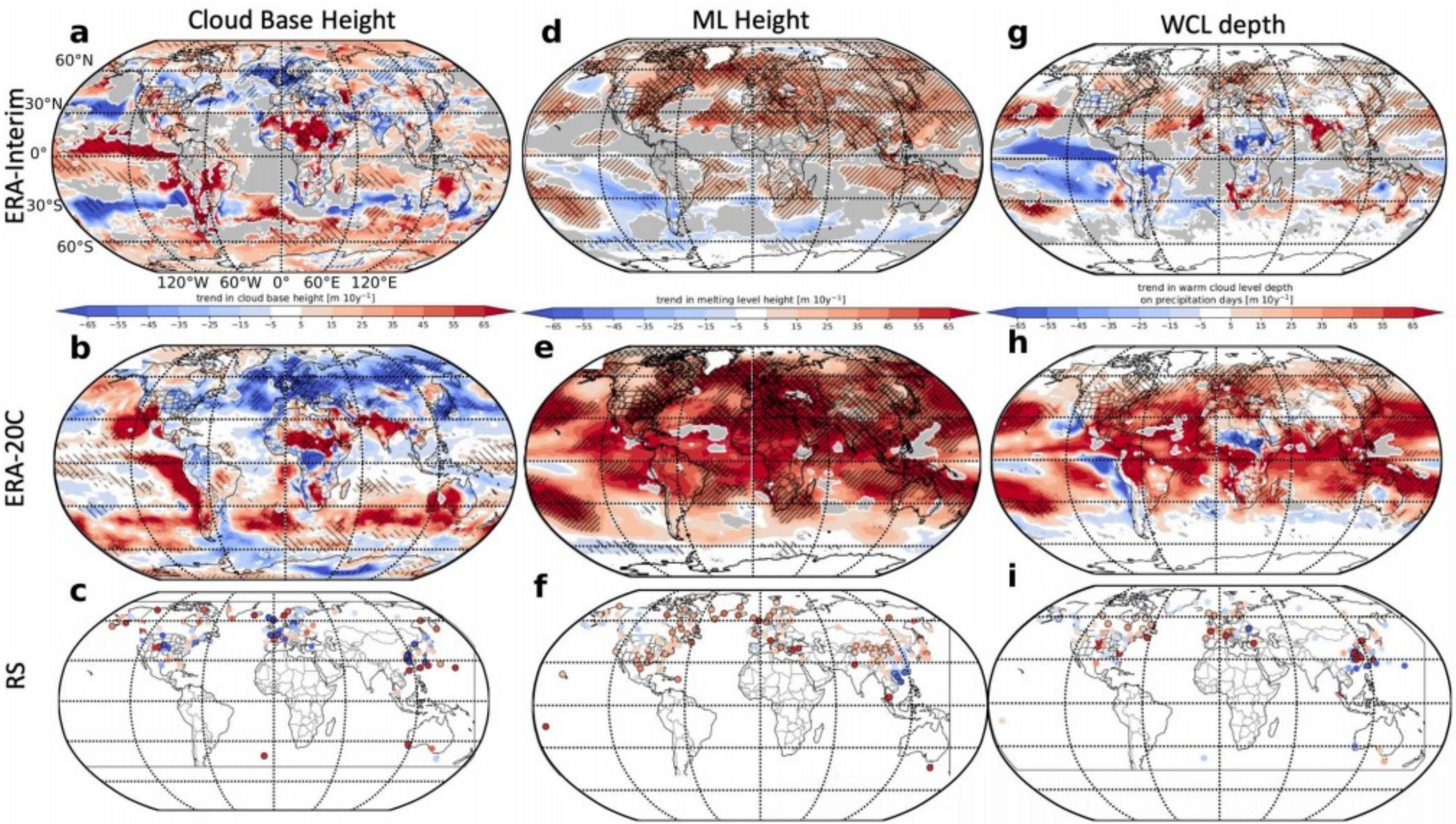
- Global WCL depth increased by 15±12 m dec^{-1} on days with more than 1 mm of precipitation
- **Number of days with WCL > 3.5km increased** by **25% dec^{-1}** over eastern US
- Environment with WCL > 3.3 km relates to flash flood events due to enhanced rainfall efficiency
- For **WCL < 3.5 km = 17% km^{-1}** rise in rainfall
- For **WCL > 3.5 km = 70% km^{-1}** rise in rainfall



WCL change is mainly driven by increase in ML height

WCL changes is mostly due to ML rather than cloud base height (Extended Fig. 4)

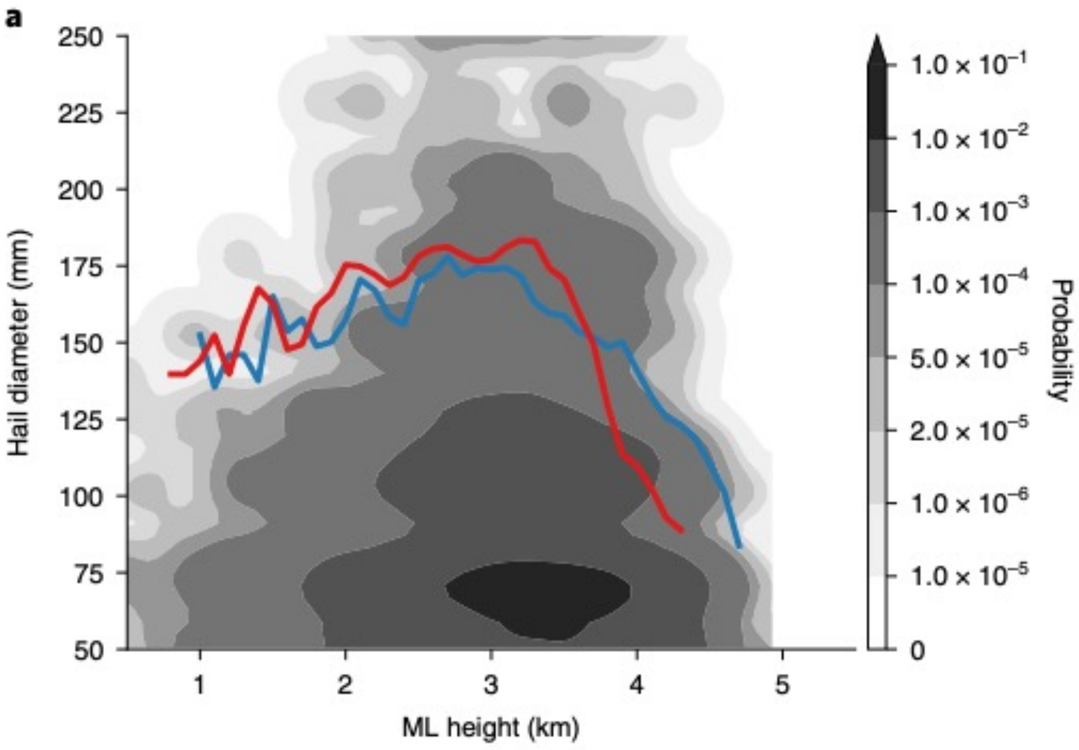
- Cloud base height is less systematic and more uncertain

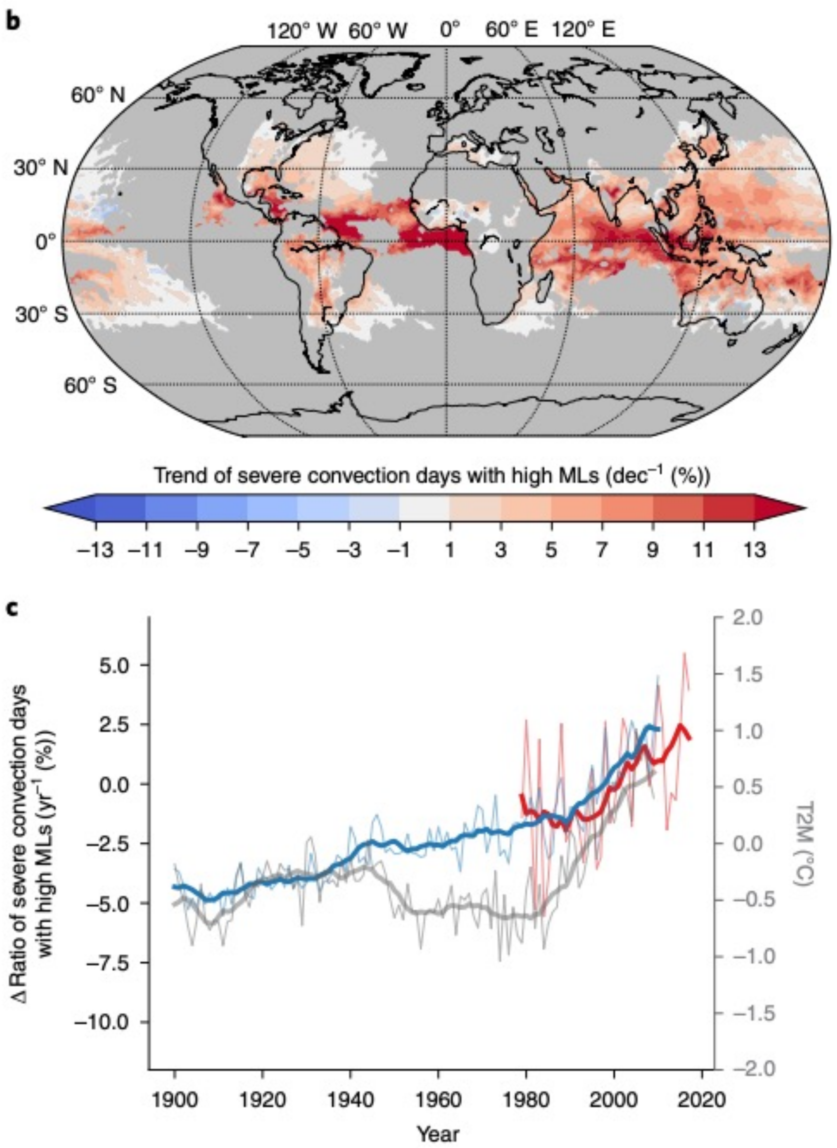


Increase in ML height reduces the risk of damaging hail due to melting over tropics and sub-tropics

- **Damaging hail with max diameter > 50mm rarely occurs** if ML height is 4.5 or 3.8 km (ERA20C or ERA-Interim)

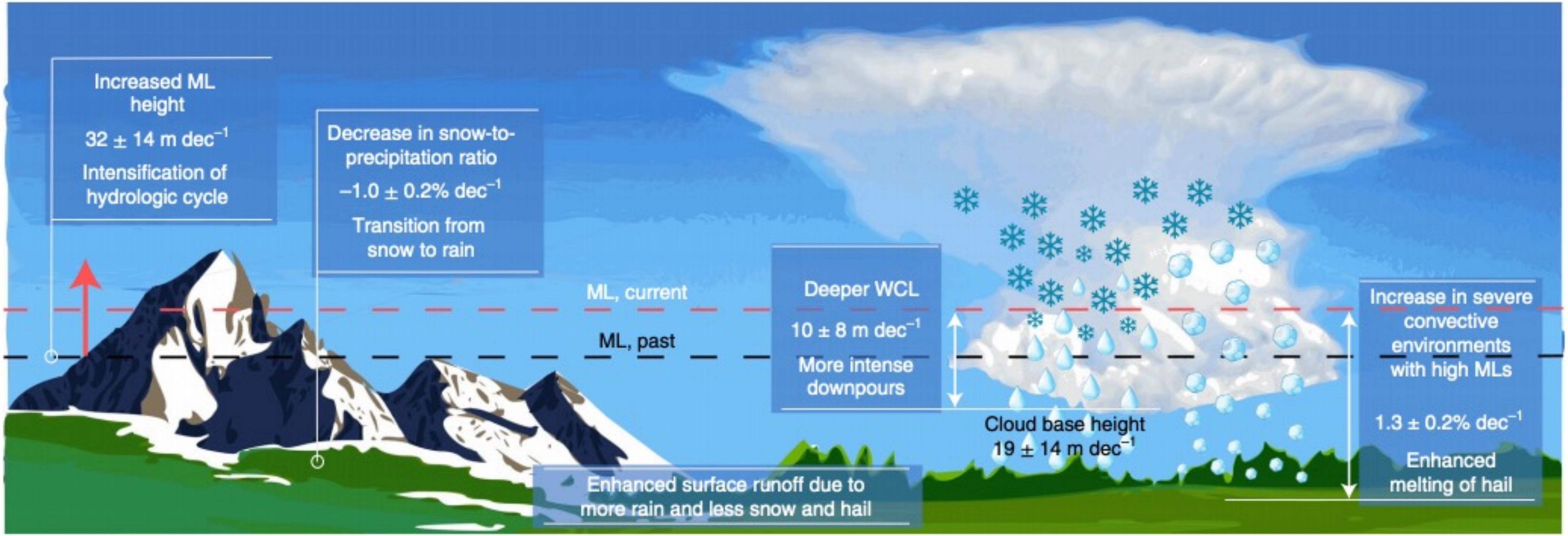
- This is due to an **increase in days with severe convection environments** with ML height > 4.5 or 3.8 km





Relative to all severe convective days over the global land regions the **days with severe convection environment and high ML height** increased significantly by 1.3±0.2%

Conclusion: Climate change results in increasing ML height which accelerates the hydrological cycle



Climate change could result in an intensification of precipitation beyond the rate of atmospheric moisture increase

Freezing Level Height

- **The summer FLH tends to increase by 2.3 m/yr over** over high land of China and Tibetan Plateau since 1970 to 2010 (Wang et al., 2014).

- **Increase in summer FLH** by 10 m **rises equilibrium snow line** altitude by 3.1 to 9.8 m resulting in **reduction of glacier mass balance by 7 to 38 mm** (Wang et al., 2014).

- Recently, Adhikari and Mejia (2021) found that **the FLH is higher by 136.21 ± 18.82 m** during the polluted days compared to relatively cleaner environment over the southern slope of the Himalayas.

- Also, during the polluted days the central Himalayan region experienced heavier precipitation (Adhikari and Mejia, 2021).

Thank you

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