A CloudSat perspective of the atmospheric water cycle and precipitation: Recent progress and grand challenges

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*"Water is the next oil."**

The WCRP/GEWEX Grand Science questions

1. ***How can we better understand and predict precipitation variability and changes?*** ***PREDICTION***
2. ***How do changes in land surface and hydrology influence past and future changes in water availability and security?*** ***TERRESTRIAL WATER CYCLE***
3. ***How does a warming world affect climate extremes, especially droughts, floods, and heat waves, and how do land area processes, in particular, contribute?*** ***EXTREMES IN A WARMING WORLD***
4. ***How can understanding of the effects and uncertainties of water and energy exchanges in the current and changing climate be improved and conveyed?*** ***IMPROVED UNDERSTANDING***

We must meet the challenge of understanding how the water cycle will change and whether the changes are predictable.

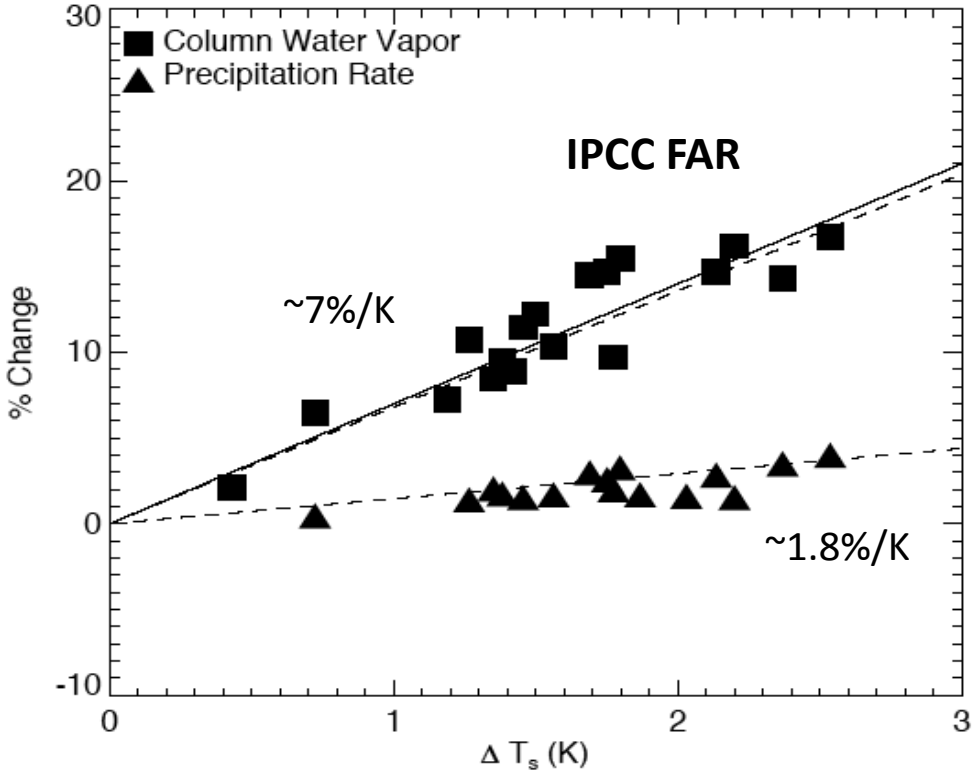
***Conclusion of a USA National Security report on risks associated with changing climate.**

Outline of this talk

- What we know/don’t know about the changes to the water cycle (precipitation) in a warming world.
- A challenge: snowfall
- Precipitation is just one component of an inter-related set of climate processes
- A complication: aerosols
- Observational systems: a vision for the future.
- Summary

What we know/don’t know about the changes to the water cycle (precipitation) in a warming world.

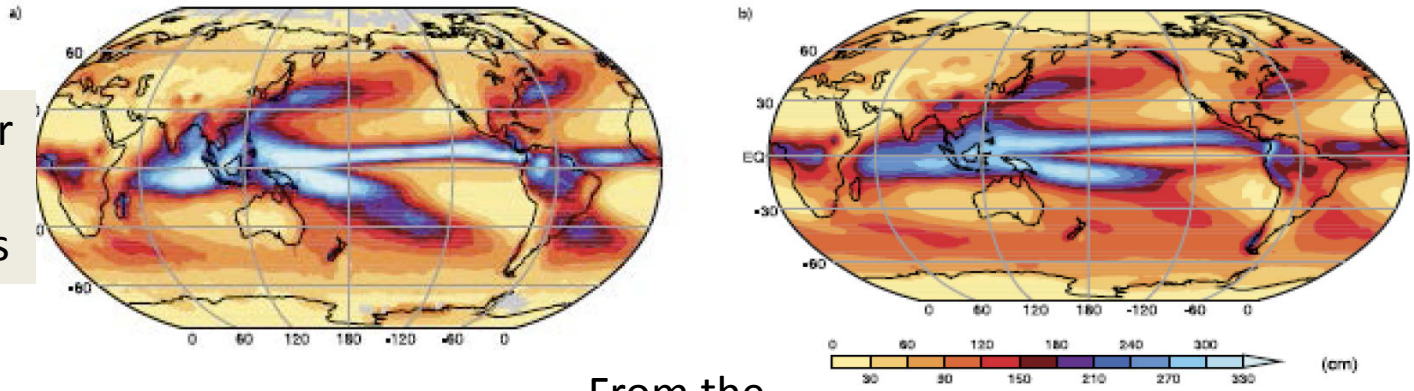
The global-average accumulation of precipitation: Its change in a warming world is predictable



E.g. Allen and Ingram, 2002
Stephens et al., 2009

This global rise of 2%/K is highly predictable to the extent that water vapor rise of 7%/K is predictable. It is a consequence of energy balance PLUS basic physics in the way the water molecule absorbs (& emits) energy –Stephens and Hu (2010)

Annual (or seasonal) Precip obs



Model ensemble

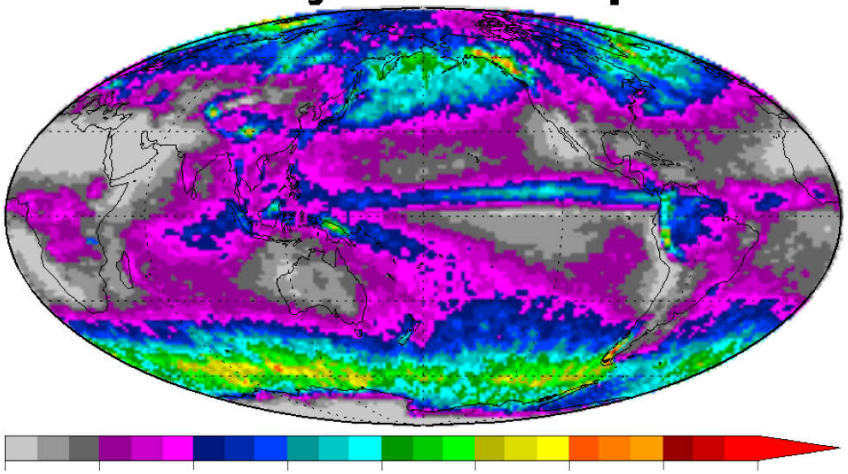
From the IPCC FAR

In a climate modeling context, usually only **accumulation** is considered. But for many reasons

- The **frequency and duration** (how often) matters
- The **intensity** (the rate when it does rain) matters
- The **phase**: snow or rain also matters

accumulation over Δt = Σ freq of occurrence X intensity when raining

Probability of Precipitation



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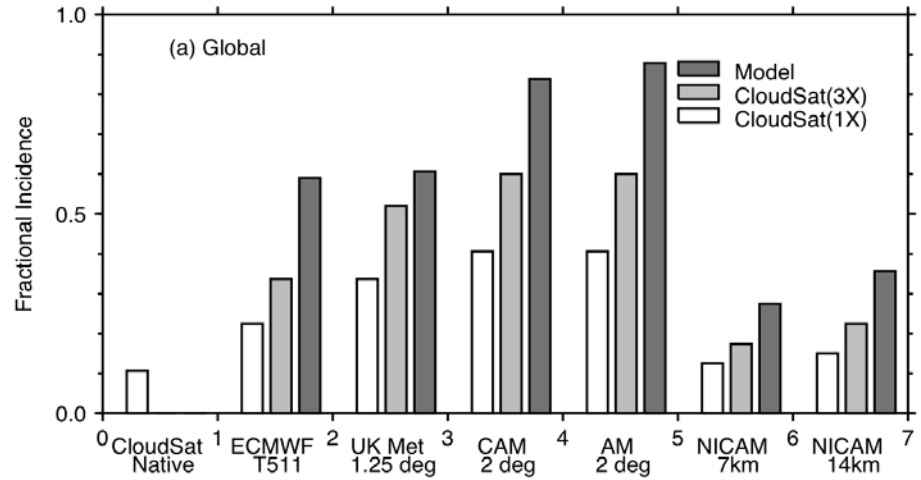
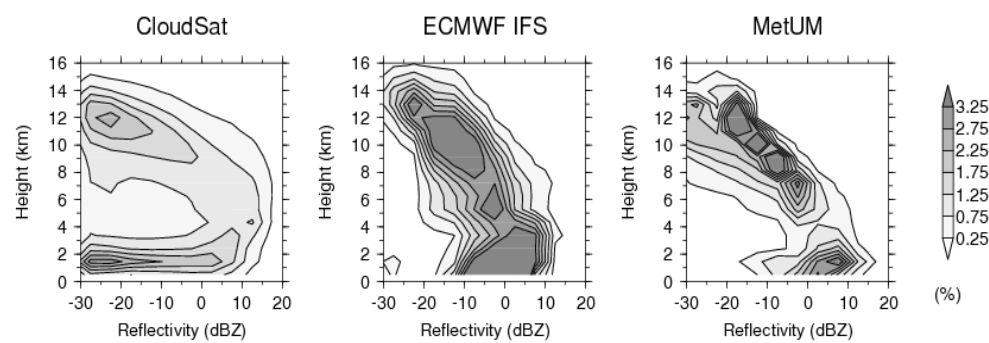
Dreary state of precipitation in global models

Graeme L. Stephens,[1] Tristan L'Ecuyer,[1] Richard Forbes,[2] Andrew Gettlemen,[3] Jean-Christophe Golaz,[4] Alejandro Bodas-Salcedo,[5] Kentaroh Suzuki,[1] Philip Gabriel,[1] and John Haynes[6]

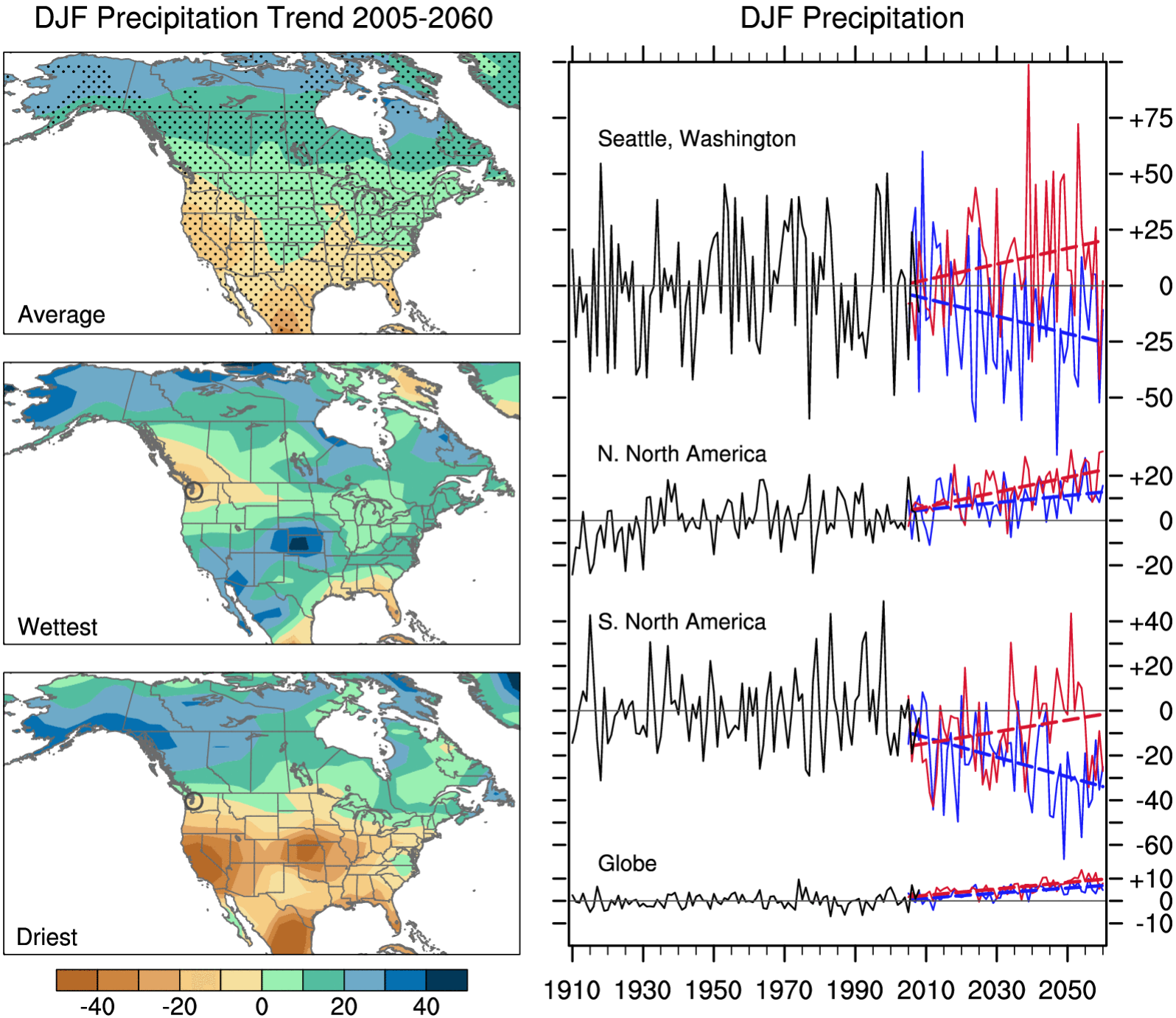
We now have definitive information about the global occurrence of precipitation (from CloudSat) and now we definitively can state that models globally produce precipitation too frequently



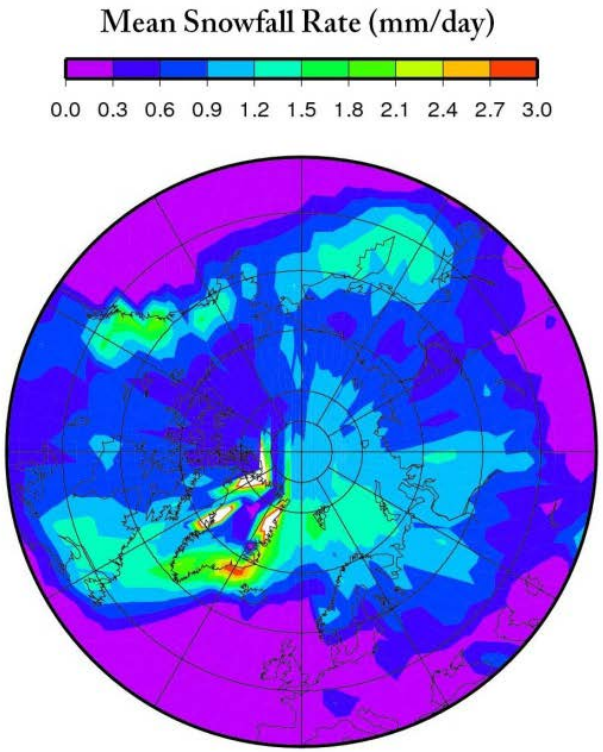


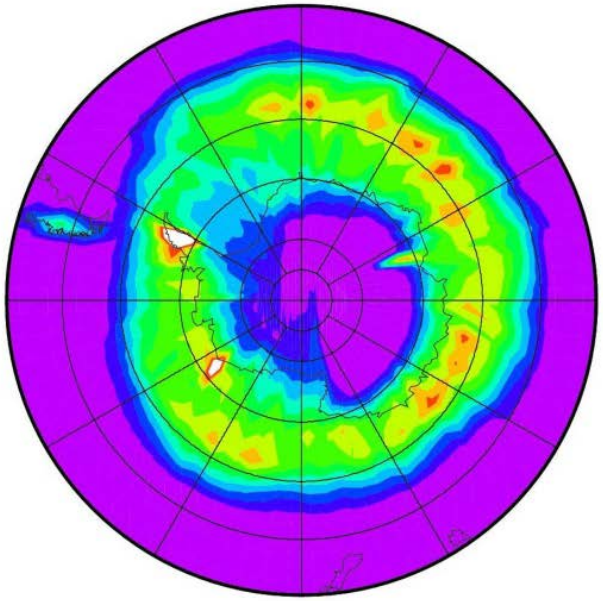
Constrained		Too frequent		Too light
accumulation over Δt	=	Σ freq of occurrence	X	intensity when raining

Deser et al., 2012



A challenge: snowfall





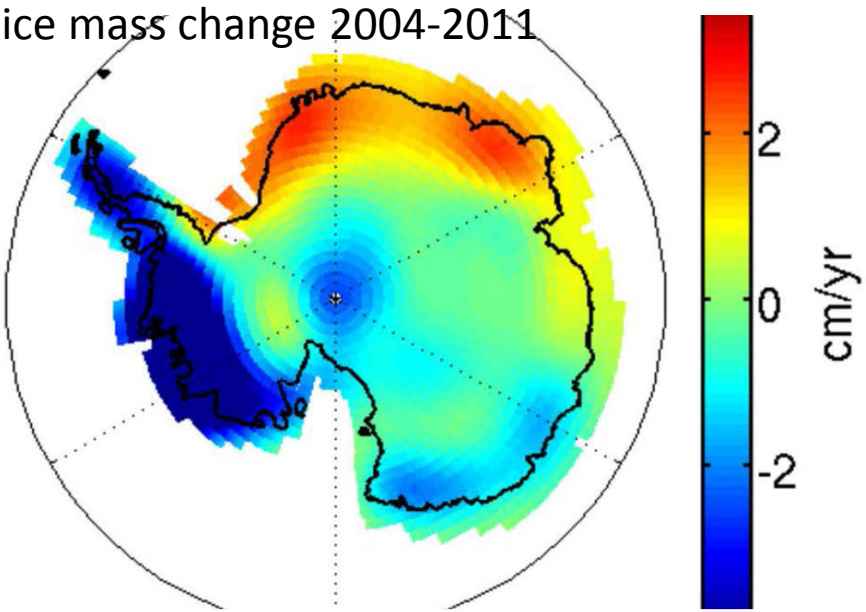
Snowfall observations: CloudSat provides the 1st real spaceborne observations

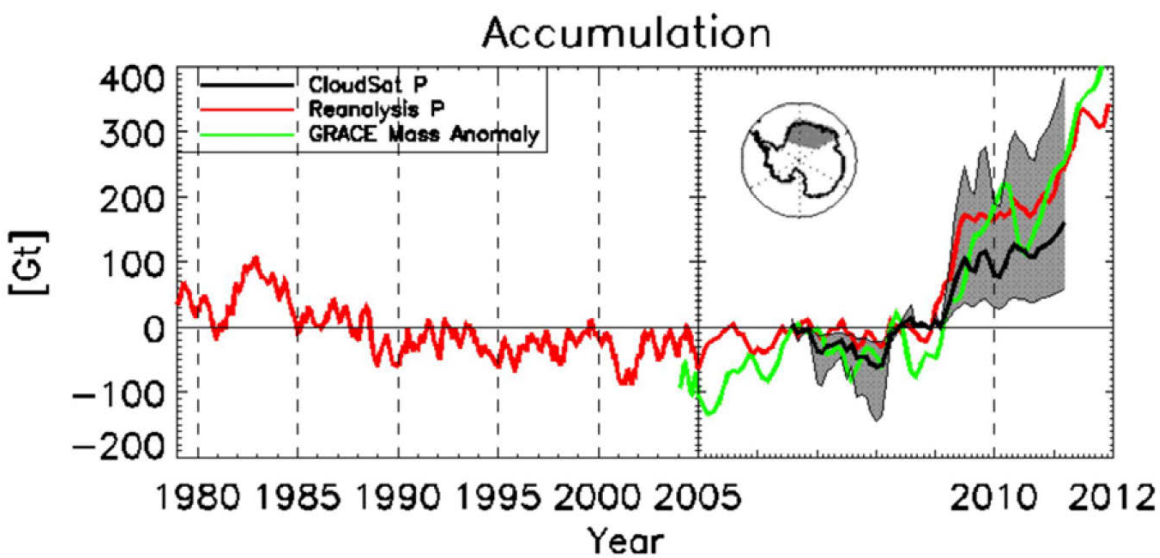
CloudSat global snowfall product – the only real global product but how good is it?

A challenge to retrieve and a challenge to validate.

Connecting CloudSat snowfall to GRACE ice mass changes

GRACE ice mass change 2004-2011





Boening et al., 2012; GRL

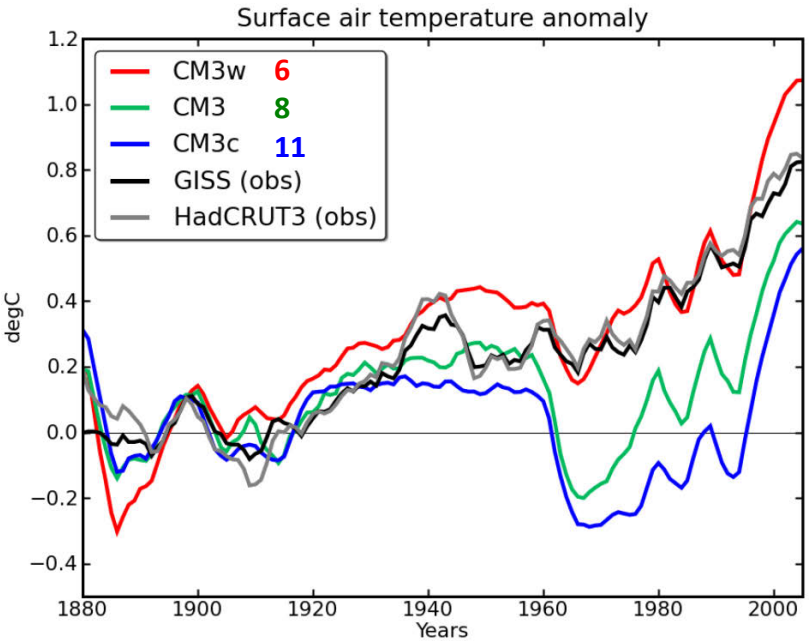
The mass increase (red) is equivalent to about 10% of the annual sea level rise.

The mass increase is consistent with CloudSat snowfall accumulation.

The ice mass gain through snowfall is a consequence of the change in circulation and storm trajectory in 2009/2010

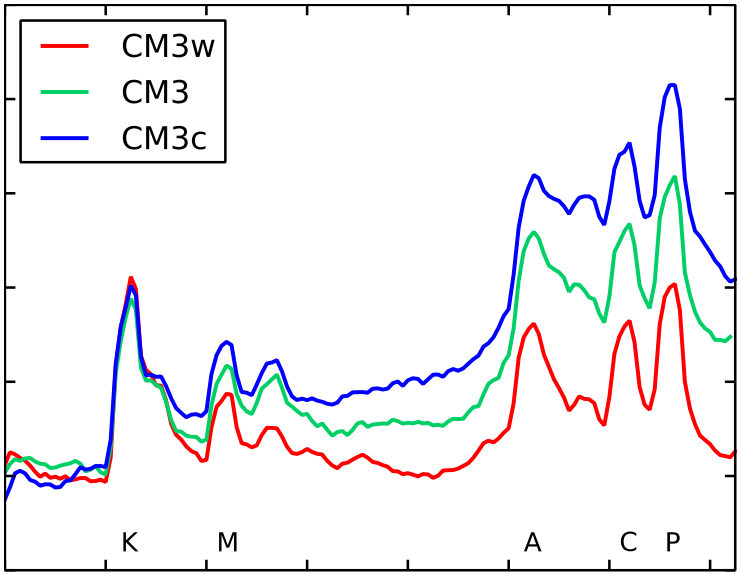
Precipitation is just one component of an inter-related set of climate processes

The cloud-albedo climate problem is really a cloud-rainfall problem



6µm threshold =less low cloud

11µm threshold = more low cloud (closer to reality)



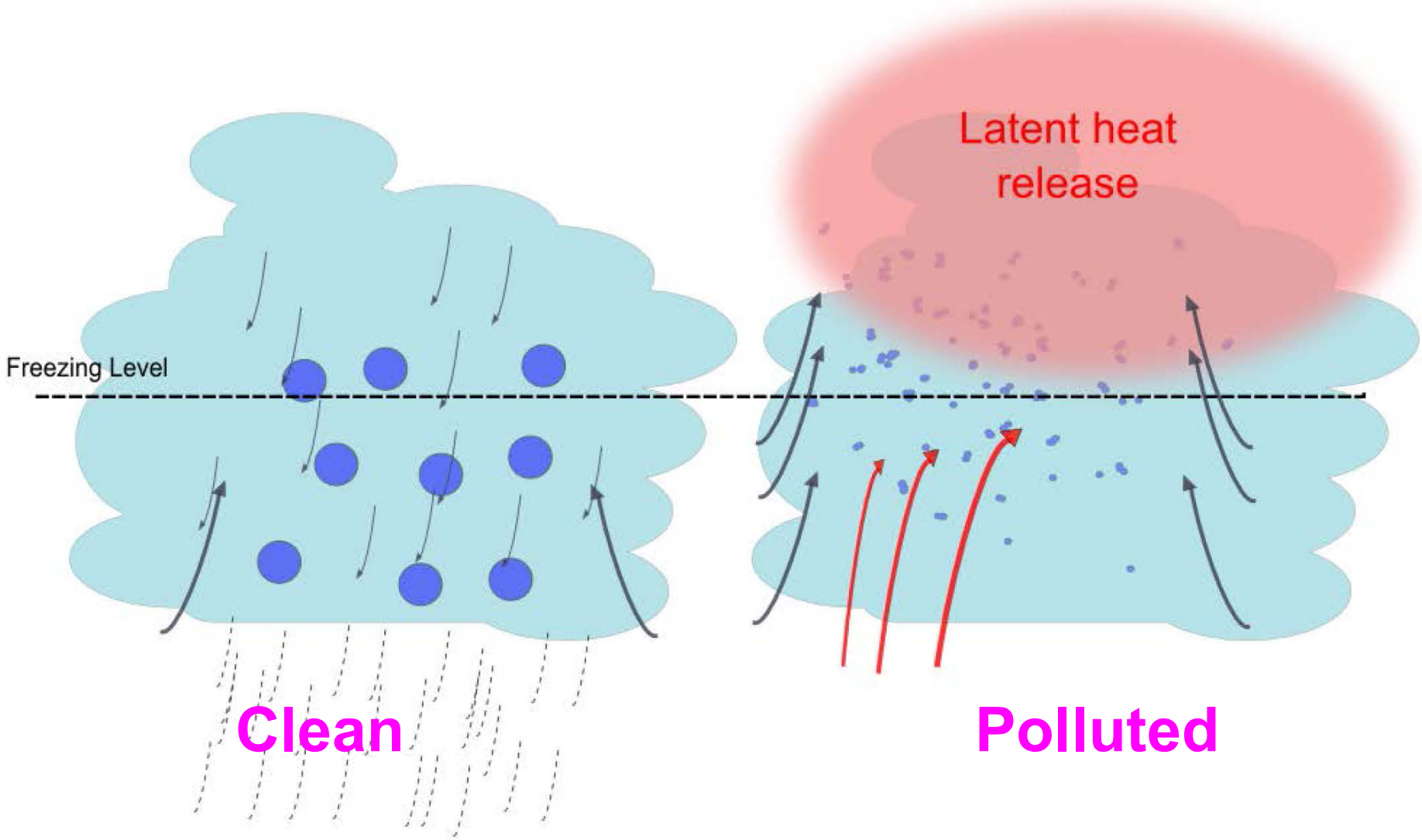
Golaz, Suzuki & Stephens, in prep

The 'climate sensitivities' of current generation Earth system models are acutely sensitive to processes that change the albedo of the system and precipitation is a key process in this change.

This example of the effect of low cloud changes on the simulated warming over the 20th century illustrates the sensitivity to how rainfall is produced in models that affect clouds and the amount of reflected sunlight

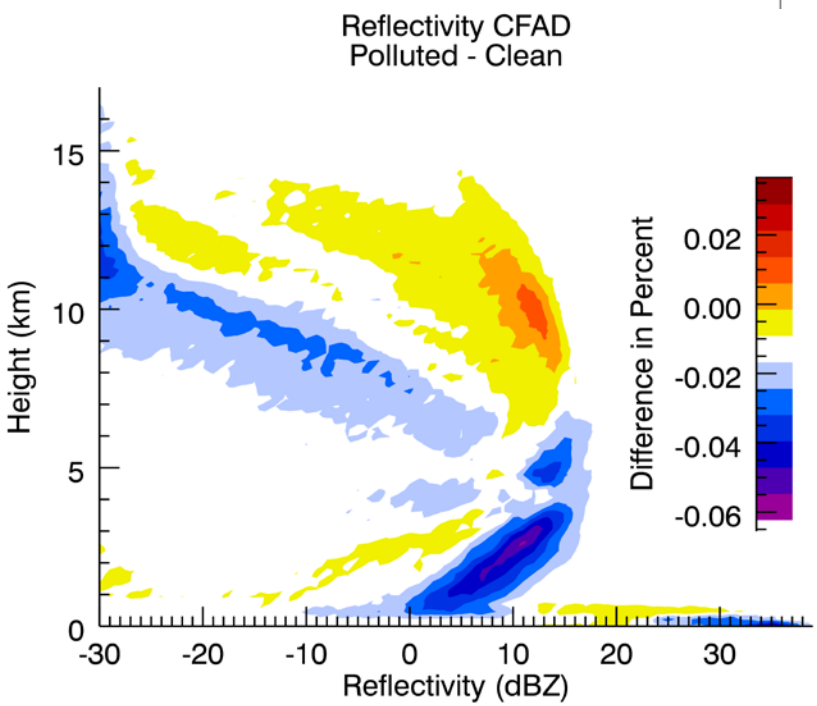
A complication: aerosols

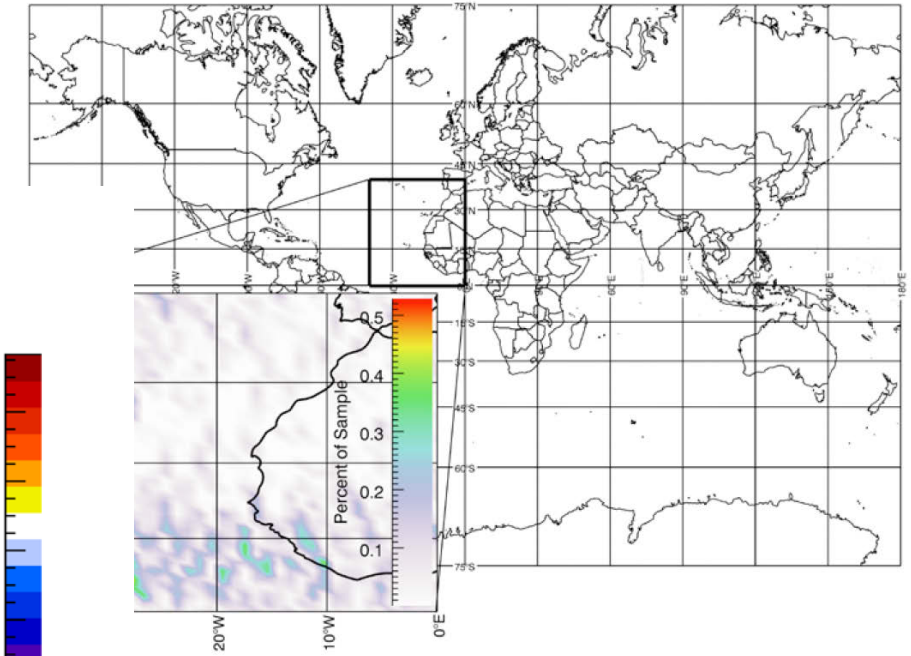
Convective storm invigoration by aerosol



More aerosol => Suppressed drop collection => more cloud water lofted => more freezing and release of latent heat

Aerosol and convection





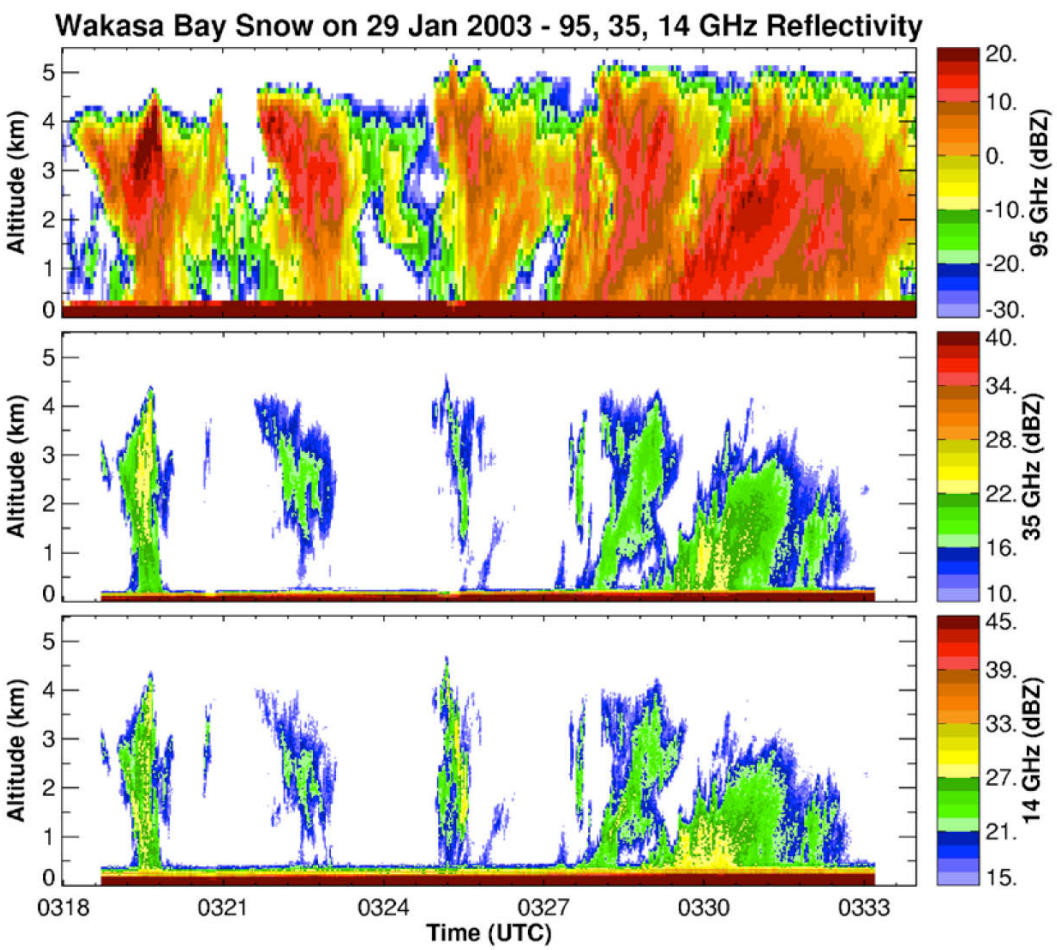
Storer et al. 2012

CloudSat observations combined with aerosol data from an ECMWF aerosol-assimilation forecast shows distinct reveal that storms with aerosol loading reach higher and have more ice mass (higher radar reflectivity value), consistent with the invigoration hypothesis.

Observational systems for precipitation: a vision for the future.

Vision for the Future:

3-frequency (14, 35, 94 GHz) radar + aerosol is the optimum observing system for precipitation:



- Ka/W band is optimum choice for observing snowfall.
- Ka/W/doppler is optimum for cloud and precipitation processes.
- Ku/Ka is optimum for monitoring convective precipitation.
- Ku/Ka/W is optimum for relating cloud to precipitation.
- W/aerosol is optimum for aerosol-cloud interaction.

Summary

Global-mean precipitation - is controlled by Earth's energy balance and is a quantifiable consequence of the water vapor feedback. Predictability rests on the degree to which the water vapor feedback is predictable.

Regional scale - to a significant extent, changes are shaped by atmospheric circulation changes but we do not know the extent to which regional scale changes are predictable. The impacts of changes to atmospheric circulation on regional scale water cycle changes can be dramatic.

Process-scale - significant biases to the CHARACTER of precipitation (frequency and intensity) is related to how the precipitation process is parameterized in models.

Aerosol - We still do not know the extent to which the water cycle is influenced by aerosol but anecdotal evidence is building. The character of precipitation is affected by the way aerosol influence clouds and thus affects the forcing of the climate system through the albedo effect.

Observations - we still have a way to go and need to approach the problem in a more integrated way (tie clouds, aerosol and precipitation together and then link to soil moisture, etc). Globally our capabilities seriously lag behind the science and model development.