



**Frequency of Deep Convective Clouds  
and Global Warming**

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Held, I.M. and B.J. Soden (2006) “Robust Responses of the Hydrological Cycle to Global Warming”,  
J.Climate, v.19, 5686-5699

“... the major Climate Models predicted that the Hadley circulation will decrease by  $-5\%/K$  of global warming”



## The frequency of Severe Storms

Almost all climate models predict that the intensity of the tropical circulation will slow down with global warming.

Observation from SSMI and Topex/Poseidon indicate that precipitation has been increasing with global warming at a rate consistent with the Clausius-Clapeyron relationship

The climate models are inconsistent with the observations.

What do we see in the AIRS data?



## Outline

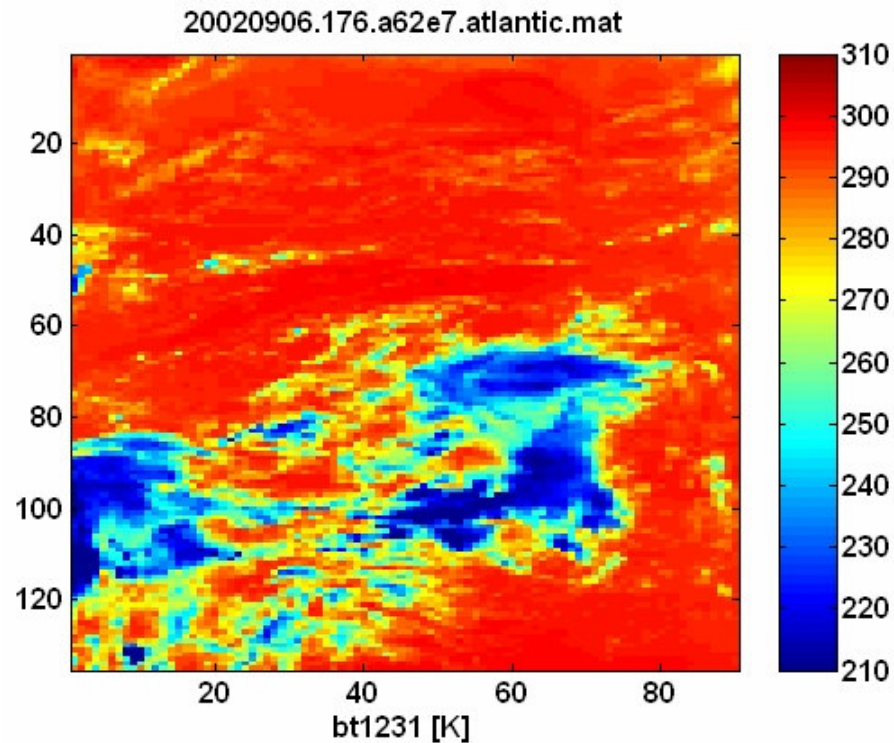
Deep Convective Clouds (DCC)

Do we expect the frequency of DCC to increase with global warming?

Correlated observations?



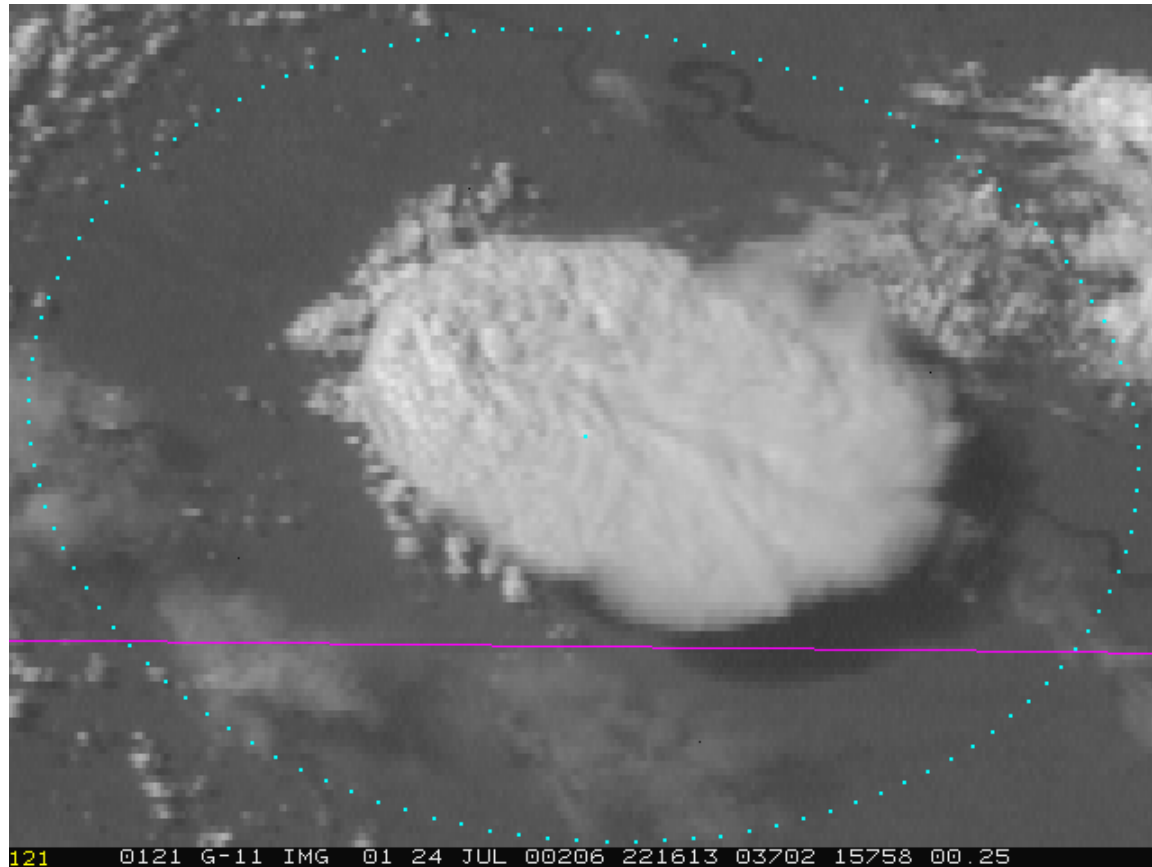
DCC are very obvious in AIRS, AMSU and AMSRe data



as areas were no temperature, moisture and precipitation retrievals are possible due to the extremely thick clouds.



DCC were discovered using GOES data.  
Reynolds (1986) and Purdom (1991) correlated  
DCC with severe storms and extreme precipitation



movie credit:  
J.Prudom

The green dots are a 15 km footprint H. H. Aumann **JPL**



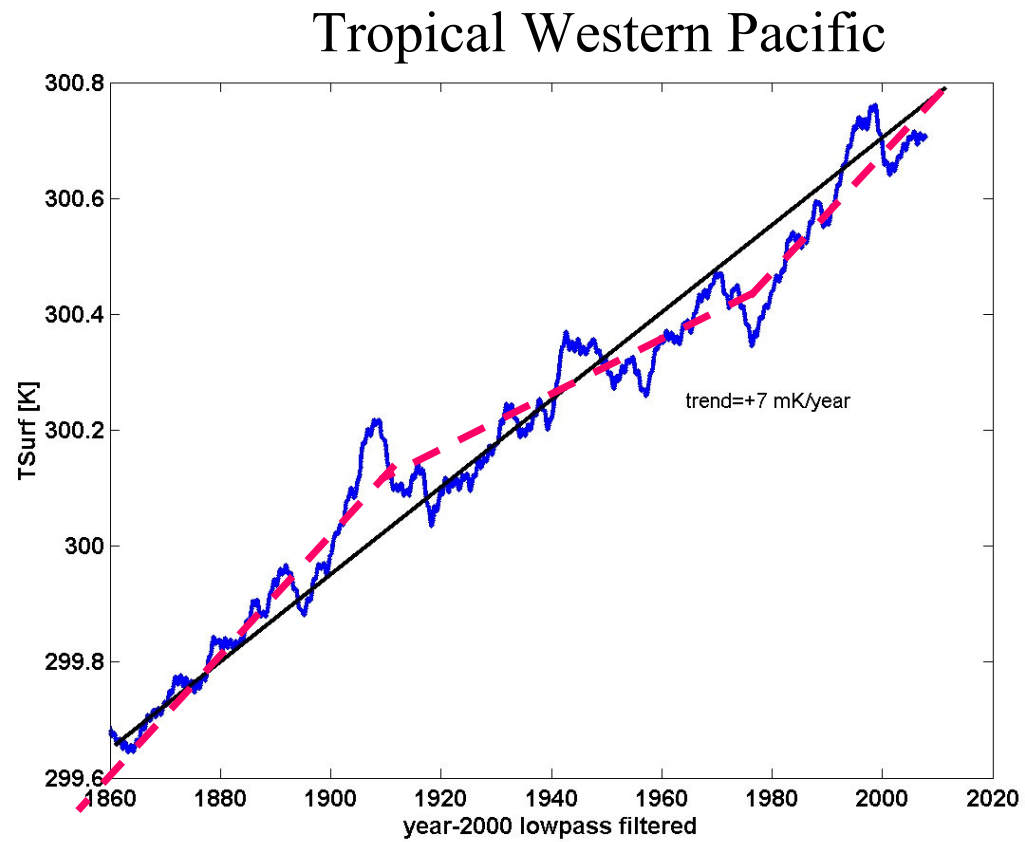
Does the frequency of severe storms increase or decrease with global warming?

We use the frequency of DCC to find out

If we can characterize DCC as a process which occurs with a frequency which is a function of the mean zonal surface temperature, we can use the established multi-decadal trend of global warming to predict the multi-decadal trend in DCC frequency.



Expected changes with global warming  
+0.13 K/decade based on IPCC (2007)







DCC are identified in the AIRS data as every footprints over non-frozen land or ocean where the 1231  $\text{cm}^{-1}$  window channel brightness temperature is 210 K or less.

In the tropical oceans this definition corresponds to cloud tops higher than 100 mb, i.e. penetrating through the tropopause.

Typically 10,000 DCC are identified globally each day, almost all within  $\pm 30$  degree latitude. About 7000 per day are in the tropical oceans ( $\pm 30$  degree latitude).



We analyze the data in terms of the DCC frequency, i.e. the count divided by the number available spectra.

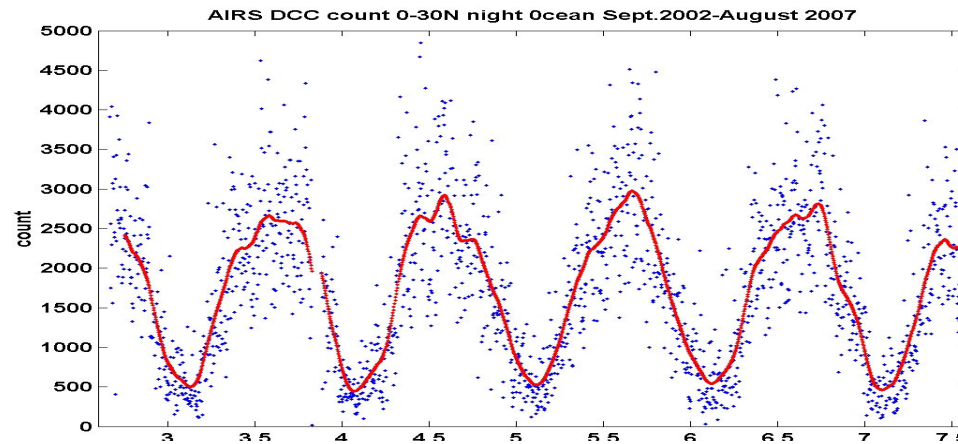
The DCC frequency for the tropical oceans is approximately 1%, almost day/night independent for the 1:30 pm EOS Aqua orbit.

The IASI DCC frequency (9:30 am orbit) is consistent with AIRS

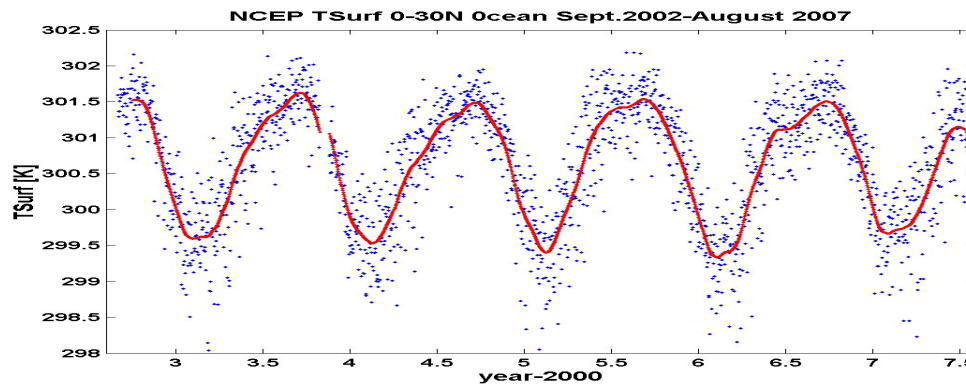


DCC count is highly correlated with the mean zonal SST

DCC  
count



Zonal  
mean  
TSurf



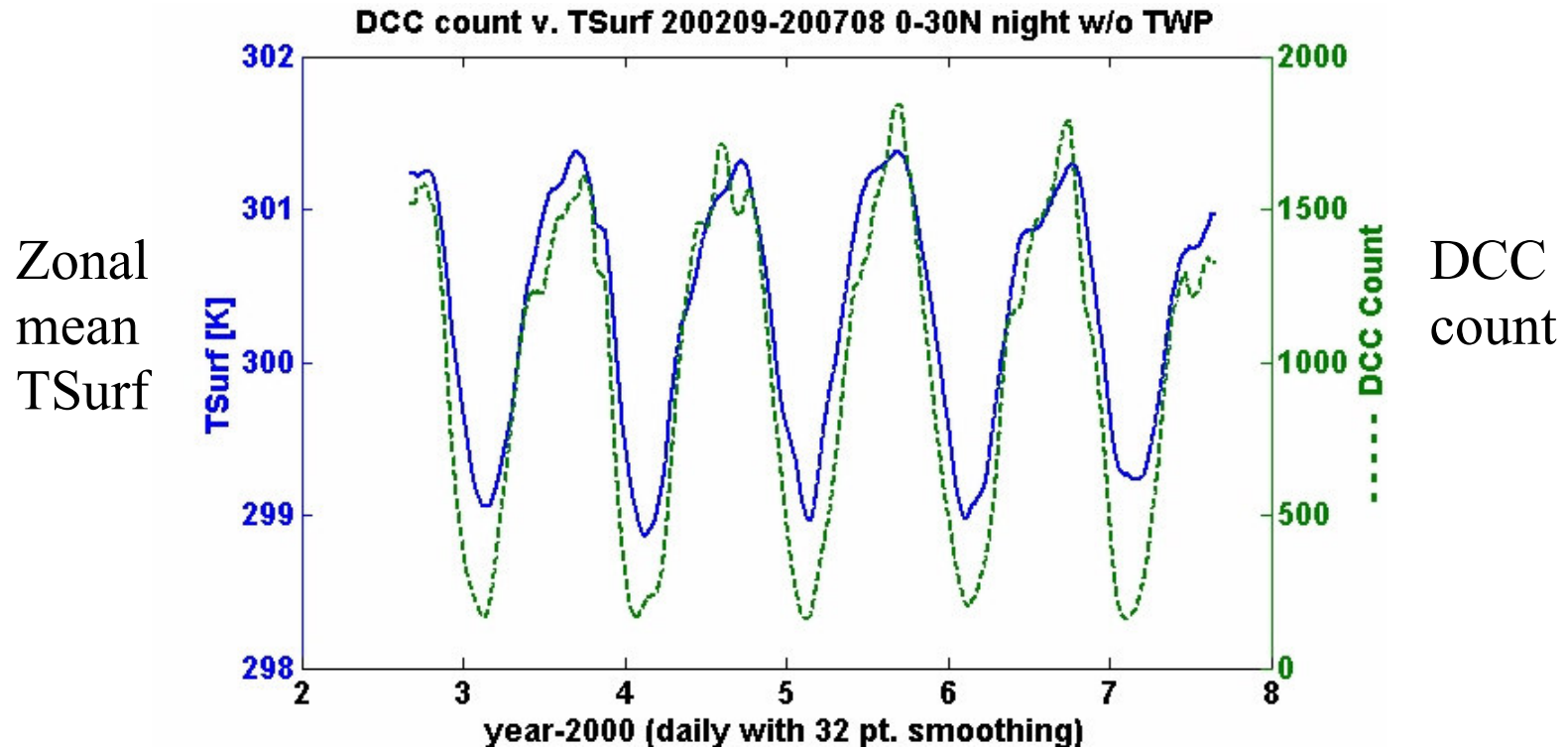
For night 0-30N the correlation is 0.62

Aumann et al. 2007 GRL

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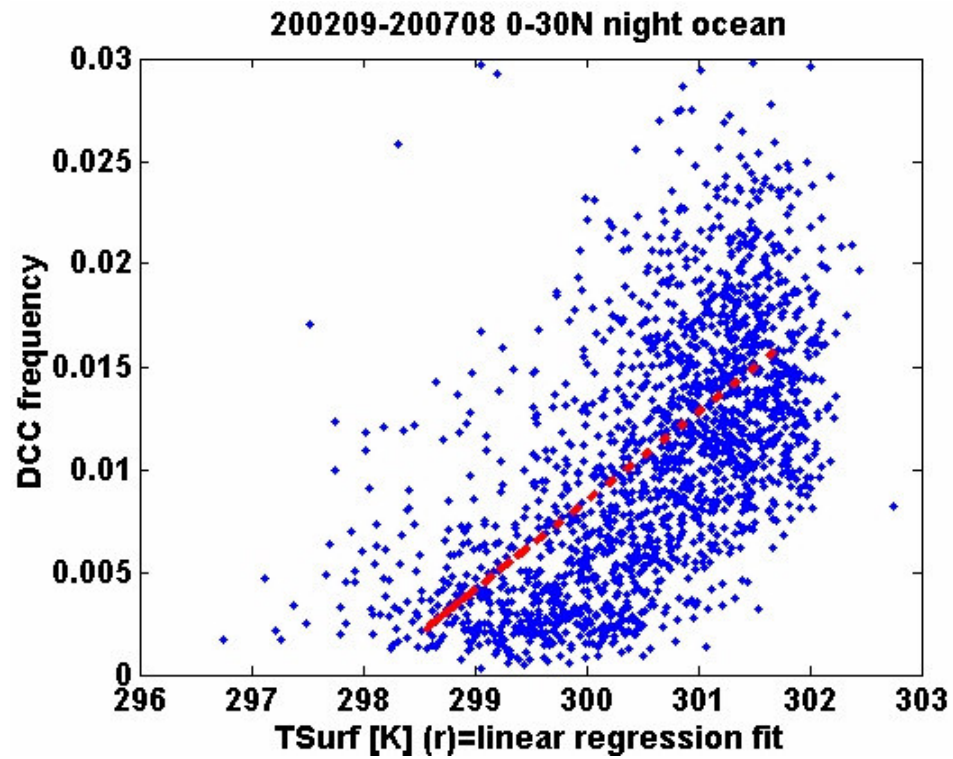
For night 0-30N the correlation is 0.62

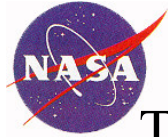
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DCC frequency correlation with T<sub>Surf</sub> results in a DCC frequency sensitivity of 48%/K





The DCC frequency sensitivity uncertainty was evaluated by breaking up the data into four independent groups.

	Five year mean DCC frequency	DCC frequency/TSurf correlation	sensitivity [fraction/K] with TWP		Five year mean DCC frequency	DCC frequency/TSurf correlation	sensitivity [fraction/K] without TWP
0-30N day	0.0085	0.611	0.45		0.0058	0.603	0.56
night	0.0105	0.622	0.48		0.0066	0.610	0.52
0-30S day	0.0062	0.661	0.48		0.0027	0.591	0.37
night	0.0073	0.678	0.29		0.0035	0.592	0.35



## Expected changes with global warming

The mean DCC frequency sensitivity is  $(+45 \pm 15) \text{ \%}/\text{K}$

Global warming is  $(+0.13 \pm ?) \text{ K}/\text{decade}$

predicted increase in DCC frequency

$(+45 \pm 15) \text{ \%}/\text{K} * 0.13 \text{ K}/\text{decade} = (+6 \pm 1.5) \text{ \%}/\text{decade}$

This rate is 6 times faster than the increase in water vapor predicted by applying the Clausius Clapeyron relationship.



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What other evidence is there to support our result?





Rosenlof et.al (2001, Climate) shows that stratospheric water vapor has increased by 10%/decade over the past 50 years.

The 6%/decade increase in the DCC frequency provide a mechanism for an increased break in the tropopause and water vapor injection into the lower stratosphere.



## Expected changes in DCC with global warming

Vecchi and Soden (2007) note that the decrease in the mean strength of the tropical convections in climate models

“should not be interpreted as a reduction in the frequency of intense precipitation events;

intense precipitation events become more frequent in GFDL CM2 as the climate warms.....

and ... the frequency of the most intense rain events increases”.

**DCC are correlated with the most intense rain events**

## Conclusions

We predict the frequency of Deep Convective Cloud to increase with multi-decadal global warming much faster than the 1.5%/decade measured for precipitation.

Severe storms will increase at the same rate as DCC, since the two are synonymous.

The temperature sensitivity of the DCC frequency appears to explain the observed increase in stratospheric water vapor over the past 50 years.

The predicted increase in the frequency of DCC with global warming agrees qualitatively with the increase in the frequency of the most extreme rain rate seen in the GFDL CM2 model with global warming

International TOVS Study Conference, 16<sup>th</sup>, ITSC-16, Angra dos Reis, Brazil, 7-13 May 2008.  
Madison, WI, University of Wisconsin-Madison, Space Science and Engineering Center,  
Cooperative Institute for Meteorological Satellite Studies, 2008.