Surface temperature dependence of the frequency of severe storms in the tropical oceans[1]

Hartmut H. Aumann

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

Abstract

The analysis of five years of data from the Atmospheric Infrared Sounder (AIRS) is consistent with an increase in the frequency of extreme Deep Convective Clouds (DCC) in the tropical oceans increases by about 50% per 1 K of warming of the zonal mean surface temperature. With the current 0.13K/decade rate of global warming, this implies a 6%/decade increase in the frequency of DCC and, through correlation, severe storms. Since we define extreme DCC as deep convective clouds with cloud top temperature of 210 K or colder, i.e. clouds which penetrate the tropopause and inject water vapor into the lower stratosphere, an increase in the frequency of DCC with global warming also increases the amount of water vapor in the stratosphere. This increase is consistent with observations over the past 50 years.

Key words: Deep Convective Clouds, Infrared temperature sounding hyper-spectral climate cloud feedback

Introduction

Higher temperatures of the oceans associated with global warming should result in an increase in the amount of water vapor, which should manifest itself as an increase in the fractional cloud cover. However, the analysis of 22 years of data from eleven HIRS instruments on the NOAA/ATOVS weather satellites between 1978 and 2003 revealed no significant trend in the low or high cloud fraction for the tropical oceans (Wylie et al. 2005). High clouds in that study were defined as cloud tops above 400 hP, which are referred to as Deep Convective Clouds (DCC) by Rong Fu et al (1990) and correspond to cloud top temperatures colder than 240 K. Since no change is detectable in the frequency of 240 K cloud tops, we focused on cloud tops colder than 210 K. These clouds should be referred to as extreme DCC, but in the following we refer to them as just DCC. We treat the DCC as a process and analyze the temperature dependence of the frequency of this process in the tropical oceans.

Approach

The analysis used data from the first five years of the Atmospheric InfraRed Sounder (AIRS) (Chahine et al. 2006). AIRS is a infrared hyperspectral imager on the EOS Aqua spacecraft, which covers the 3.7-15.4 micron infrared spectral region with 13 km nadir footprints. AIRS was launched into polar 705 km altitude orbit on May 4, 2002 and has been in routine data gathering mode essentially uninterrupted since September 2002. Global coverage is achieved twice each day. The 1:30 PM ascending node and the altitude of the EOS Aqua orbit are

---

[1] ITOVS #16 Angra Dos Reis, Brazil May 2008

accurately maintained to minimize confusion of diurnal variability with climate trends. Each day AIRS generates about 3.7 million spectra.

Results

Every spectrum over where the brightness temperature in the 1231 cm-1 window channel is less than 210 K at non-frozen land or ocean position is identified as a DCC. The spectra selected with this simple threshold invariable show the very pronounced spectral characteristics of cirrus ice in the 11 micron window region (Aumann et al. 2006b). On average about six thousand DCC are identified globally each day, almost all within 30 degrees of the equators. While this seems like a large number, it corresponds to only about 0.5% of all spectra in the tropical ocean latitudes. The temperature of the southern and northern tropical oceans goes through a seasonal cycle between 294 K and 302.5 K. Correlated with this seasonal cycle is the frequency of DCC (Aumann et al. 2007). This correlation, shown in Figure 1 for the 0-30N oceans, is used to determine the temperature sensitivity of the DCC frequency.

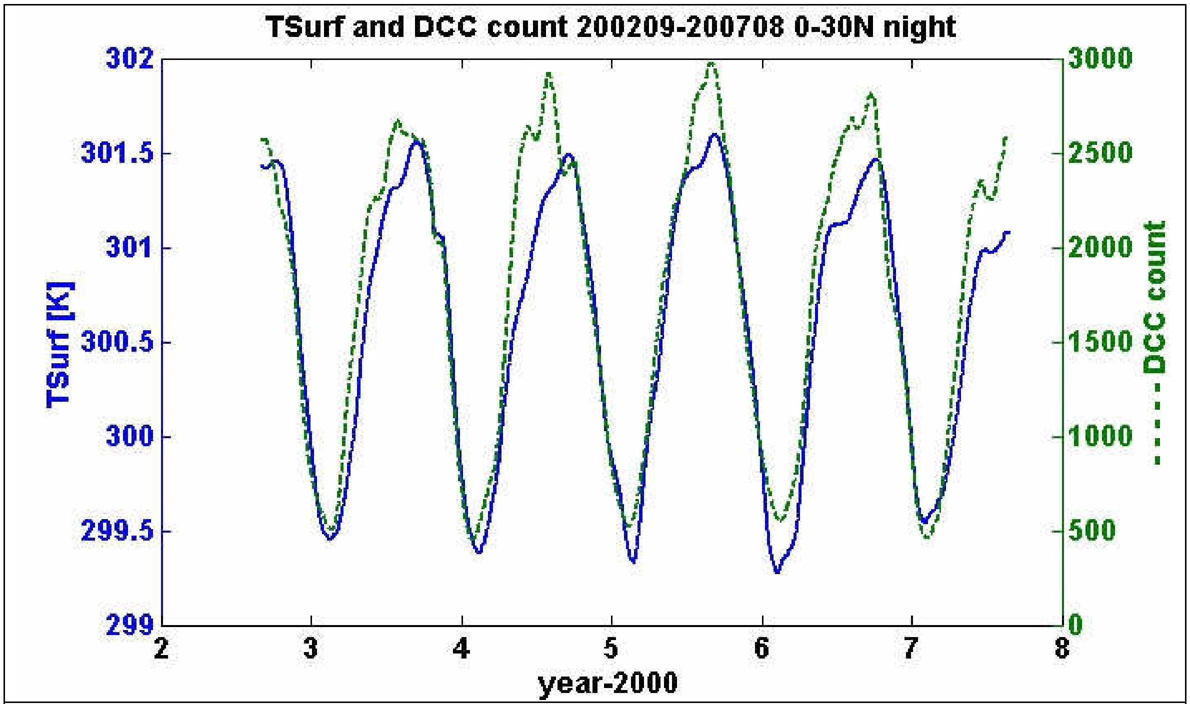


Figure 1. The strong correlation between the mean zonal SST (solid line) and the count of DCC (broken line) can be used to determine the temperature sensitivity of the DCC frequency.

For each of the 1788 days between 2002/09/01, the first day of routine AIRS data availability, and 2007/08/31 we counted the DCC in four independent groups: The 0-30N and 0-30S tropical ocean zones, and for each zone we separate the day time overpasses (at 1:30 PM, ascending orbit) from a night time overpasses (at 1:30 AM local time, descending orbit). Figure 2 shows the correlation between the daily count of DCC for the night overpasses of the 0-30N latitude zone, and the mean SST in that zone. This is not the SST associated with the DCC, which is considerably warmer than the zonal mean SST. A very similar high correlation between the zonal mean SST and the DCC count can be seen in the other three groups.

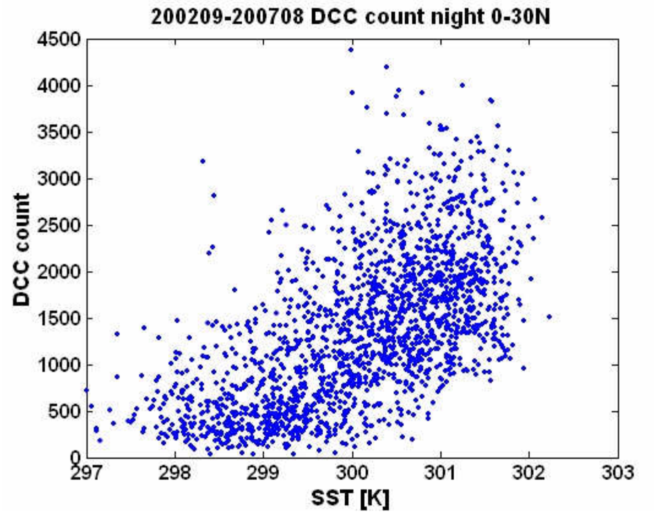


Figure 2. The 0-30N latitude night data show a correlation of 0.62 between the DCC count and the mean zonal SST. Each dot represents the count of DCC at night for the 0-30N zone, plotted as function of the mean surface temperature of the zone.

Inspection of Figure 2 shows that the typical count is 1500 and that the count increases by 2000 as the temperature increases by 3 K from 298 to 301K, i.e. about 670/K. The DCC count divided by the mean number of spectra is the DCC fractional frequency sensitivity, i.e. the back-of-the-envelope estimate results in a temperature sensitivity of 670/1500/K= 0.45/K. Table 1 summarizes the results for the four groups using linear regression. For the 0-30N night data this results in a sensitivity of 0.51/K, i.e. the frequency increases by 51% if the SST increases by 1 K in the 299 to 301 K range.

1788 day with TWP	DCC count / SST correlation	mean zonal SST	mean DCC count	sensitivity [fraction/K]
0-30N day	0.59	300.3	1113	0.58
night	0.62	300.2	1287	0.51
0-30S day	0.57	298.9	638	0.46
night	0.59	298.8	804	0.58

Table 1. Summary the DCC trends of the four tropical ocean groups including the TWP

The correlation between the DCC count and the SST ranges from 0.57 to 0.62 for the four groups. Although the mean SST in the 0-30S zone is 0.4 K lower than 0-30N, there is no obvious N/S effect in the temperature sensitivity of the DCC frequency.

Discussion

In our study we focused on extreme DCC with cloud tops colder than 210 K, corresponding to a pressure level of 150 hP and less. These high clouds are found in only about 0.5% of the spectra in the tropical ocean latitudes, while 35% of the tropical oceans are covered with clouds above 400 hP (Wylie et al. 2005). These extreme DCC penetrate the tropopause and inject water vapor into the lower stratosphere.

We have treated the DCC as a process, with a temperature dependent frequency. The derivation of a 0.5/K temperature sensitivity of the frequency of this process has implications in the context of long-term global warming. Using the nominal global warming rate of +0.13 K/decade (IPCC 2007), the frequency of DCC increases at the rate of 0.5/K*0.13K/decade= 6%/decade.

As the frequency of DCC increases by 6%/decade with global warming, the amount of water vapor injected into the stratosphere also increases. Assuming a linear correlation between the DCC frequency and the amount of water vapor injected into the stratosphere, a 6%/decade increase in the stratospheric water vapor would be expected. This is reasonably consistent with the observation by Rosenlof et al. (2001) that the stratospheric water vapor mixing ratio has increased steadily over the past half century at the rate of 10%/decade.

The association of cloud formations with cloud tops colder than 210 K with heavy rainfall, lightning, crop damaging hail and tornadoes goes back to Reynolds in 1980 and infrared data from the first geosynchronous satellites (Reynolds, D. W. 1980). Our finding suggests that the frequency of severe storms will increase with global warming at the rate of 6%/decade. A recent re-analysis of SSMI data (Wentz et al. 2007) shows that precipitation over the oceans has increased by 1.5% per decade during the past 19 years. The increase in the total precipitation may be associated with the increase in the frequency of DCC, but precipitation associated with DCC, while hevay, does not play a dominant role in the total precipitation.

Conclusions

Five years of data from the Atmospheric Infrared Sounder are used to argue that the frequency of Deep Convective Clouds in the +/-30 degree tropical zone increases by 50% per degree of increase in the zonal mean surface temperature from the current mean tropical ocean temperature. Assuming global warming at the 0.13 K/decade rate, the frequency of DCC, and by correlation the frequency of severe storms in the tropical oceans, will increase by 6% per decade. This rate is consistent with the observed increase in stratospheric water vapor.

Acknowledgements

This work was carried out at Caltech's Jet Propulsion Laboratory under contract with NASA.

References

Aumann, H. H., David Gregorich and Sergio M. DeSouza-Machado (2006b) “AIRS Observations of Deep Convective Clouds”, SPIE Photonics Conference 13-17 August 2006 San Diego, CA, paper 6301-20.

Aumann, H. H., David Gregorich, S. Broberg and D. Elliott.(2007) “Seasonal Variability of SST, Water Vapor and Convective Activity in the Tropical Oceans” GRL, VOL. 34, L15813, doi:10.1029/2006GL029191

Chahine, Moustafa T, Thomas S. Pagano, Hartmut H. Aumann, Robert Atlas, Christopher Barnet, John Blaisdell, Luke Chen, Murty Divakarla, Eric J. Fetzer, Mitch Goldberg, Catherine Gautier, Stephanie Granger, Scott Hannon, Fredrick W. Irion, Ramesh Kakar, Eugenia Kalnay, Bjorn H. Lambrigtsen, Sung-Yung Lee, John Le Marshall, W. Wallace McMillan, Larry McMillin, Edward T. Olsen, Henry Revercomb, Philip Rosenkranz, William L. Smith, David Staelin, L. Larrabee Strow, Joel Susskind, David Tobin, Walter Wolf and Lehang Zhou. "The Atmospheric Infrared Sounder (AIRS): Improving Weather Forecasting and Providing new Data on Greenhouse gases", BAMS, (2006) 87, 911-926.

Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S.,D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Chapter 3.

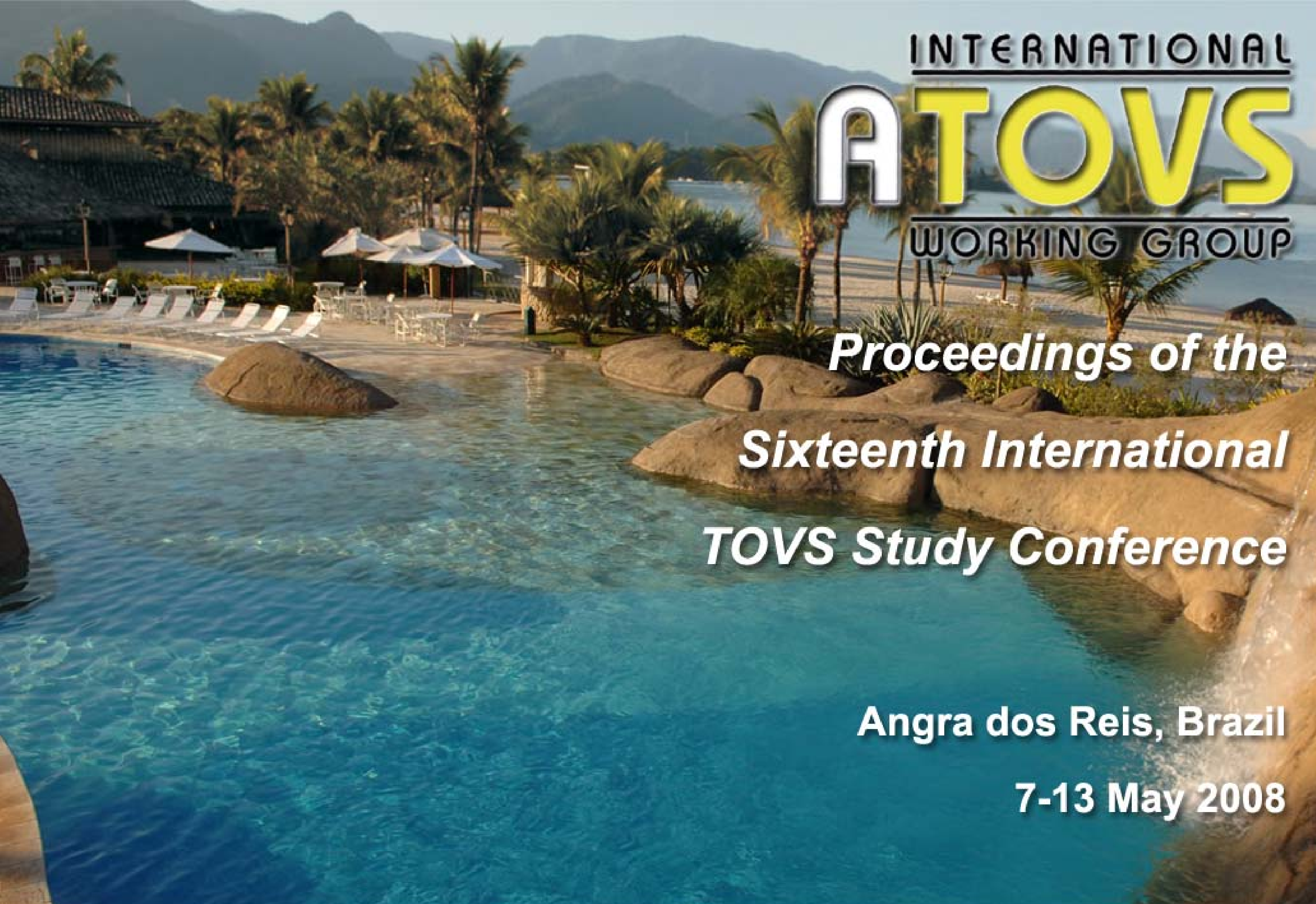
Fu, Rong, A.D. Del Genio, and W.B. Rossow (1990) "Behavior of Deep Convective Clouds in the tropical Pacific Deduced from ISCCP Radiances", J.Climate, Vol.3. pp.1129-1152.

Reynolds, D. W. (1980) "Observations of Damaging Hailstorms from Geosynchronous Satellite Digital Data", Monthly Weather Review V.108, 337-348.

Rosenlof, K.R., S.J. Oltmans, D. Kley, J.M. Russel III, E-W. Chiou, W.P. Chu, D.G. Johnson, K.K. Kelly, H.A. Michelsen. G.E. Nedoluha, E.E. Rernsberg, G.C. Toon and M.P. McCormick (2001), "Stratospheric water vapor increases over the past half-century", GRL, 28, 7, pp 1195-1198.

Wentz , F.J., L. Ricciardulli, K. Hilburn and C. Mears (2007) "How Much More Rain Will Global Warming Bring?" Science v.317, 233-235.

Wylie, D.P., D.L. Jackson, W.P. Menzel and J. Bates (2005), "Trends in global cloud cover in two decades of HIRS observations". J. Climate, Vol.18, pp.3021-3031.



INTERNATIONAL ATOVS WORKING GROUP

Proceedings of the Sixteenth International TOVS Study Conference

Angra dos Reis, Brazil

7-13 May 2008

Sharing ideas, plans and techniques to study the earth's weather and climate using space-based observations