U52A-0024

Instantaneous Rain Rates in Satellite Observations and a General Circulation Model

Eric M. Wilcox

Princeton University Program in Atmospheric and Oceanic Sciences, and
NOAA Geophysical Fluid Dynamics Laboratory
P.O. Box 308, Princeton NJ 08542-0308
ph: (609) 452-6500 x6995; email: ewilcox715@yahoo.com; web: /www.gfdl.noaa.gov/~emw/

The response of rain rates to increasing greenhouse gas forcing

The rising concentration of atmospheric greenhouse gases is likely to result in a greater amount of precipitation globally. This change is a consequence of increases in both the saturation vapor pressure of the atmosphere and the rate of surface evaporation, which act to increase the amount of water vapor. The global increase in precipitation is expected in order to balance the increase in evaporation. It has been argued that the increase in precipitation will be realized as an increase in the frequency of heavy rain events (exhibiting high rain rates) at the expense of gentle rain events, because the convergence of moisture at the base of precipitating storms will rise with increasing water vapor amounts[1]. Such changes have been found in records of precipitation[2]. In order to assess whether the frequency of severe flood events will increase as well, it is necessary for climate prediction models to properly simulate the frequency distribution of rain rates averaged over small spatial scales (such as over the 300 km grid cells of coarse grid models) and small time scales (such as 0.5 hours to a few days). **As shown here, climate models do not appear to properly capture the frequency distribution of rain rates exhibited by the present climate state. This issue must be settled before quantitative predictions of changes in flood frequencies can be made.**

Rain rates as observed by SSM/I satellites and as simulated in the GFDL AM2 general circulation model

As a first step toward assessing whether modern general circulation models are capable of predicting future changes in precipitation intensity, the frequency of occurrence of precipitation as a function of rain rate is examined in a model and compared with satellite observations. The frequency of occurrence of rain rates from 0 to 10 mm hr^{-1} are examined in combined observations from two SSM/I instruments on separate satellite and compared with output from two separate global simulations using the GFDL AM2 atmospheric general circulation model.

SSM/I observations

The Special Sensor Microwave Imager (SSM/I) instruments are passive radiometers in the microwave, sensitive to the presence of precipitating water and ice. Data from Jan. 1 1998 through Dec. 31 2001 from two SSM/I instruments are combined here. Each is mounted on a separate polar orbiting, sun-synchronous satellite. Rain rate is retrieved using the Goddard Profiling Algorithm. The rain rate retrievals are instantaneous, except in a small portion of the observing area where the two satellite swaths overlap within a three hour period. In such cases the two observations are averaged. The horizontal resolution of the satellite data is approximately 25km, however these data have been averaged over the grid cells of the AM2 general circulation model so that the spatial scales of the model output and the satellite observations are comparable.

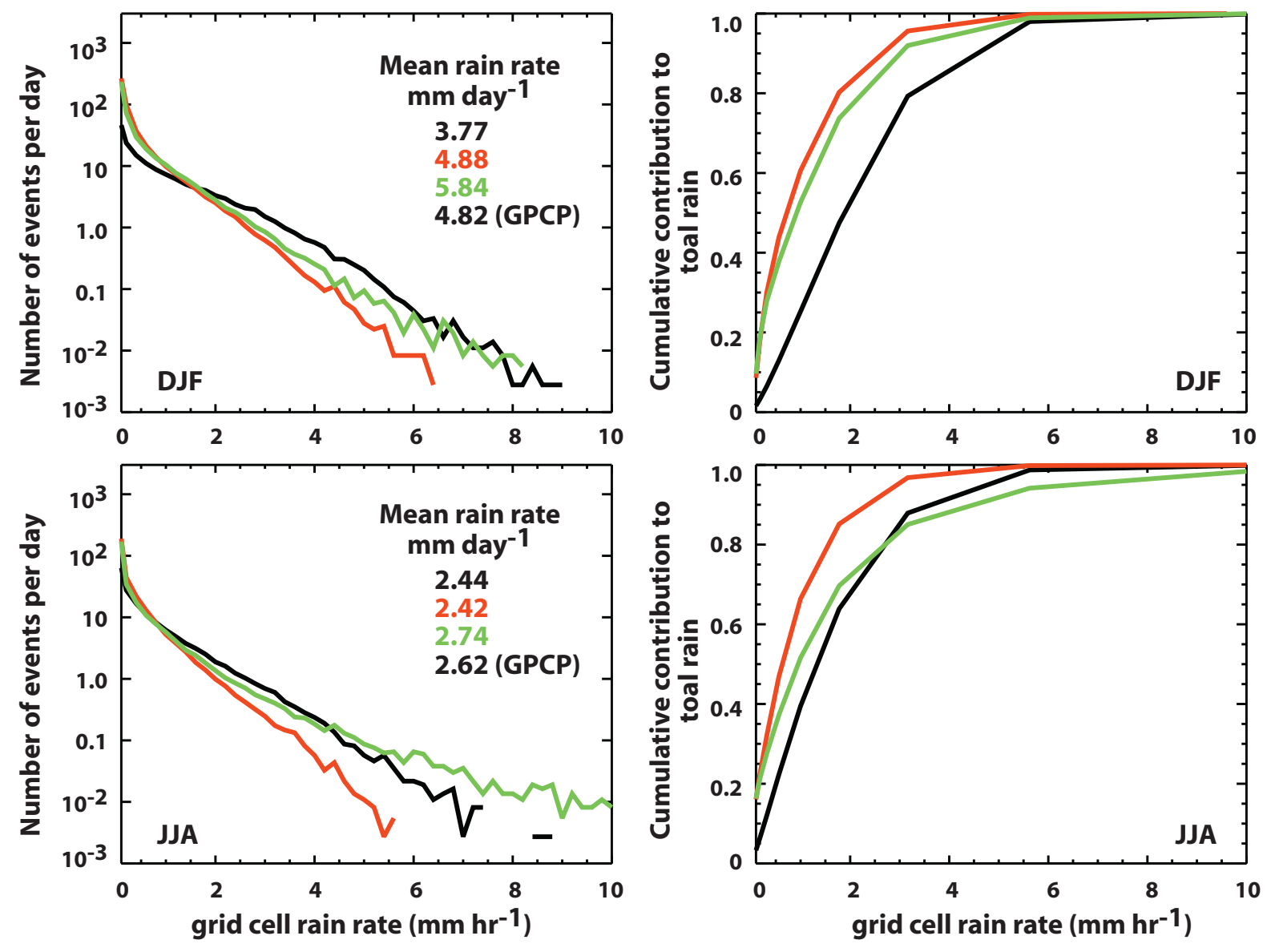
AM2 simulations

The GFDL AM2 model is a global atmospheric general circulation model suitable for climate change studies[3]. It uses a rectangular grid dynamical core with grid cell spacing of 2.5° X 2°. Simulations are initialized with arbitrary initial conditions and driven with observed monthly mean SST beginning Jan. 1 1997 and running through Dec. 31 2001. The atmosphere is coupled to a fully interactive land surface model. Output from 1998 through 2001 is used in the analysis. The rain rates are single time step values (i.e. 30 minute averages) sampled once every 3 hours.

Two separate simulations are performed using different convection parameterizations:

- Relaxed Arakawa and Schubert (**RAS**) scheme[4]. This scheme simulates an ensemble of convective updrafts.
- **Donner** scheme[5]. In addition to convective updrafts, this scheme simulates mesoscale convective structures and updraft velocities in narrow and mesoscale convection.

Northern Pacific Ocean



Over the Northern Pacific Ocean rain rates are generally lower than over the tropical oceans or summertime continents because cumulus convection is not as dominant. Thus the frequency of rain rates higher than 4 mm hr^{-1} is lower than in the other regions. The difference between the two model runs is small because the weak role of convection here.

Frequency distributions of rain rate are averaged over the period Jan. 1 1998 through Dec. 31 2001 for the regions indicated by the rectangular boxes on the map.

Black lines are satellite observations.
Red lines are AM2 simulation using RAS convection scheme.
Green lines are AM2 simulation using Donner convection scheme.

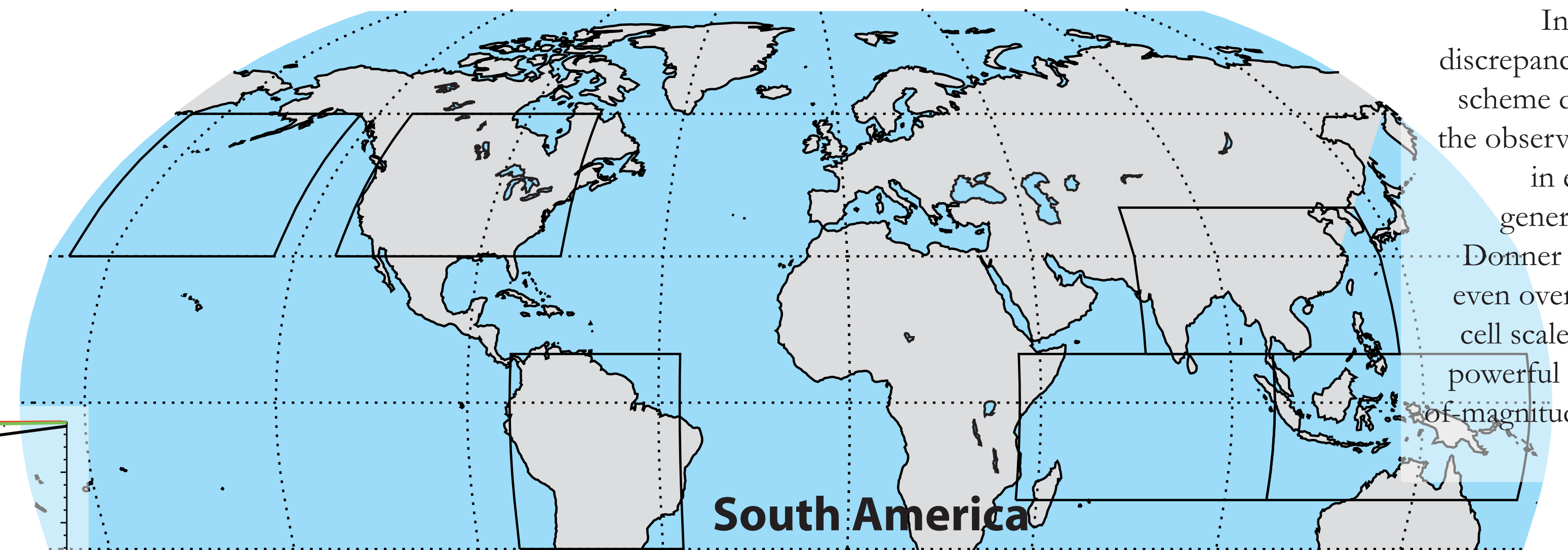
Left panels are the number of events occurring per day within the region as a function of rain rate.

Right panels are the same data presented as the cumulative contribution to total rainfall as a function of rain rate. They indicate the fraction of total rainfall attributable to rain rates lower than the indicated value.

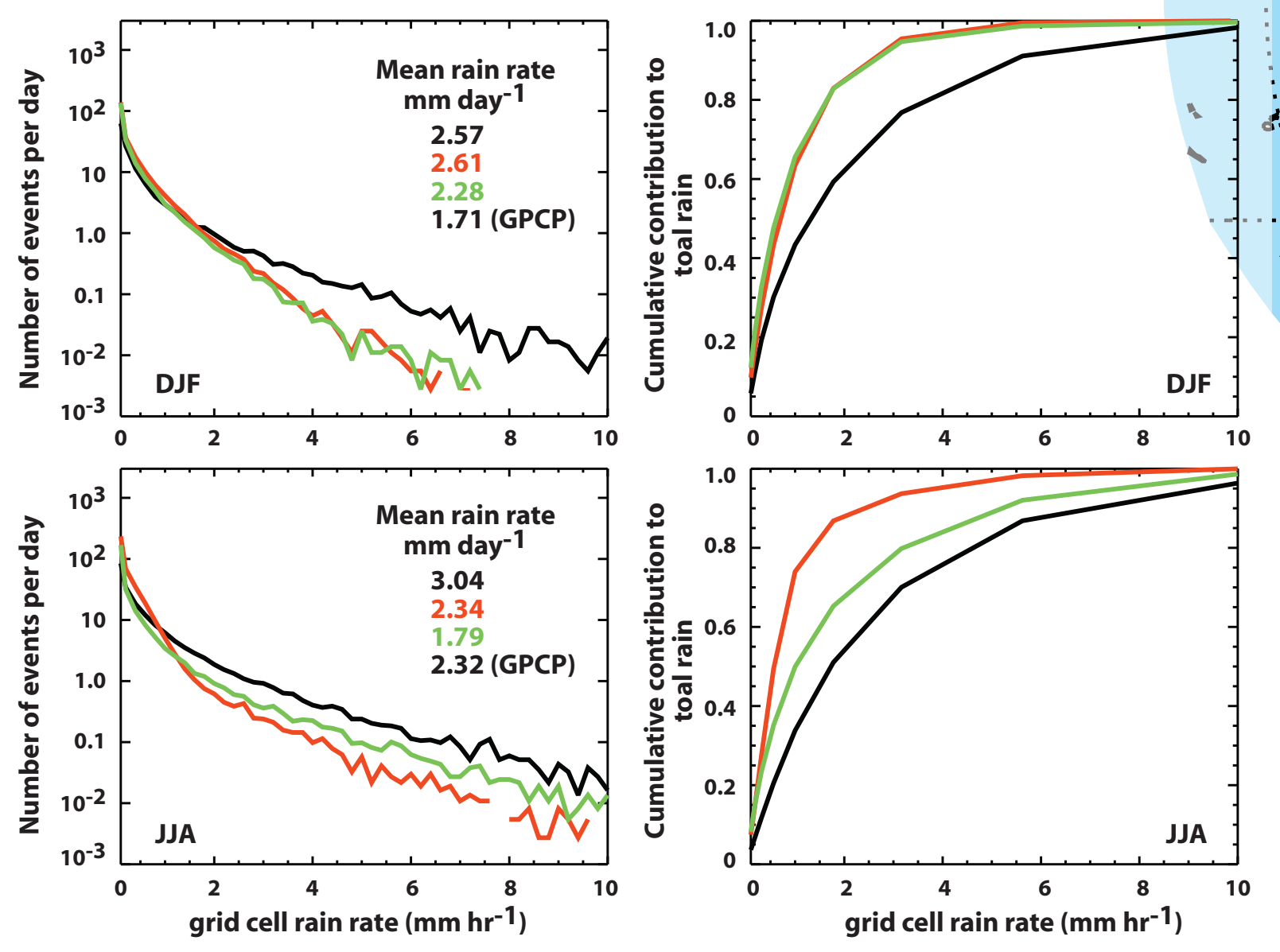
Upper panels are Northern Hemisphere winter (DJF).

Lower panels are Northern Hemisphere summer (JJA).

Inset tables indicate the seasonal and regional mean rain rate from each source in addition to the Global Precipitation Climatology Project (GPCP) value.

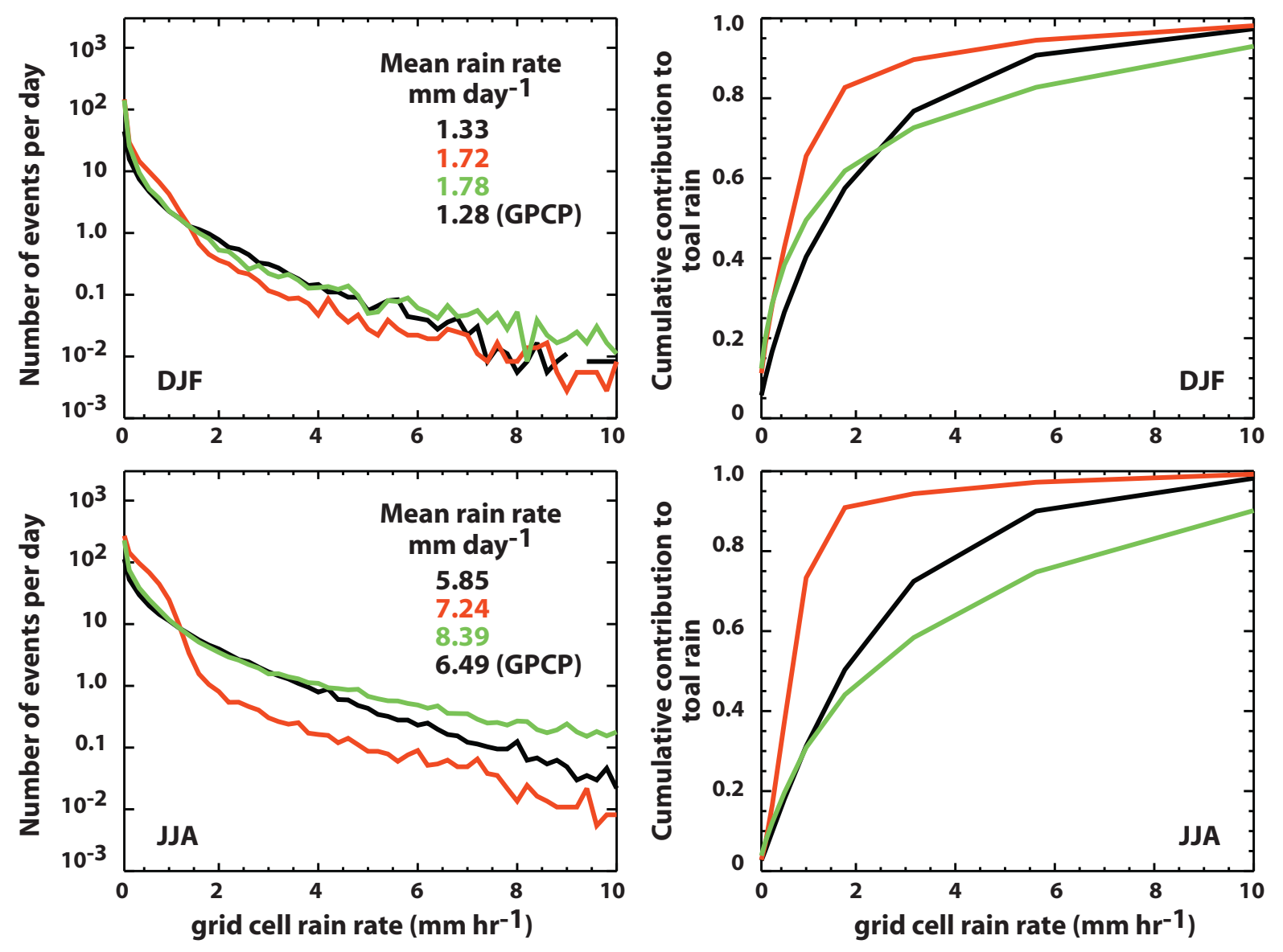


North America



North American rain rates are higher in the observations than they are over the North Pacific because of the greater impact of cumulus convection over the land surface. Both model convection schemes underestimate the frequency of heavy rain events, although they do a better job during the summer season when convection is more active.

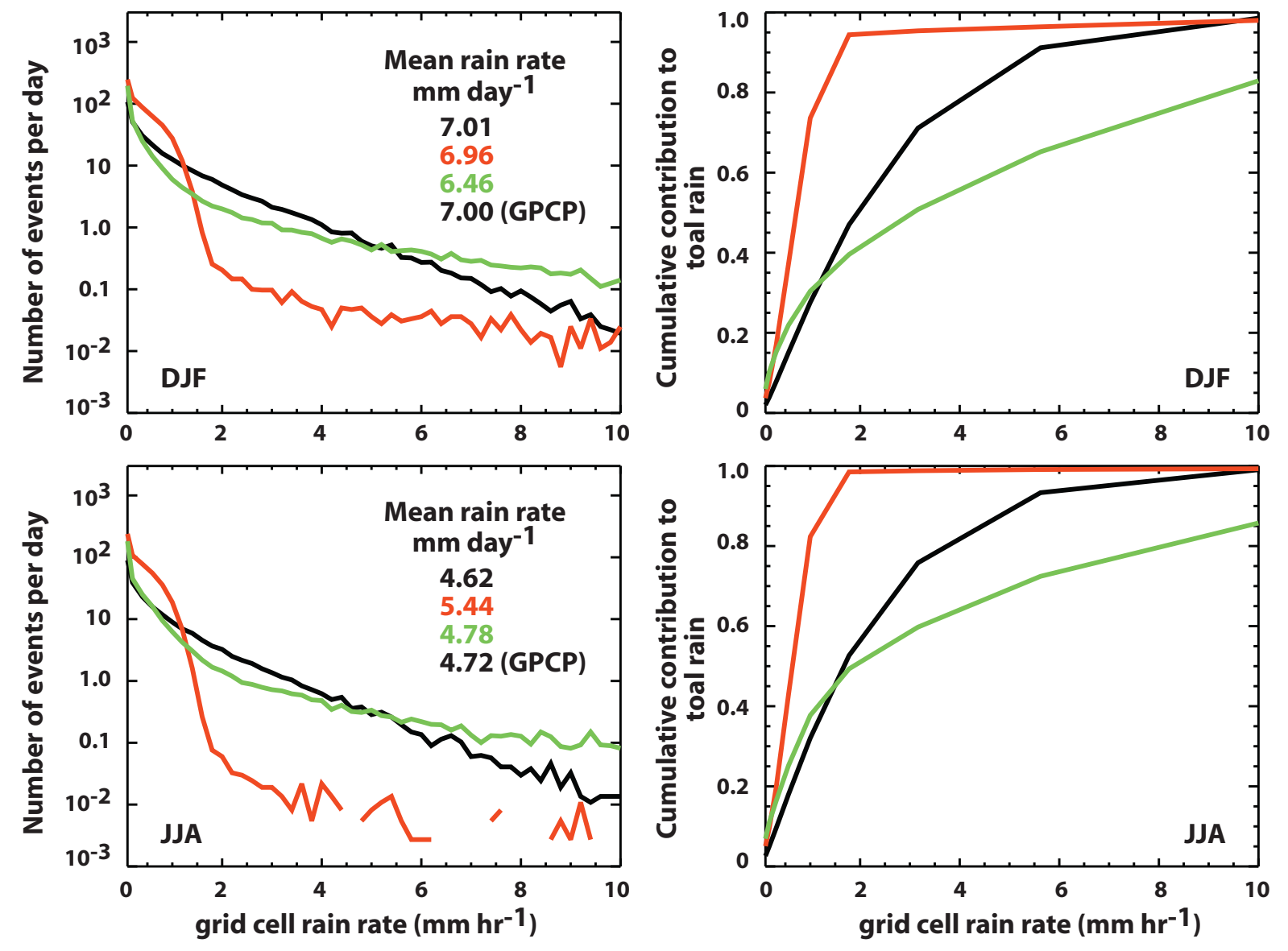
South Asia



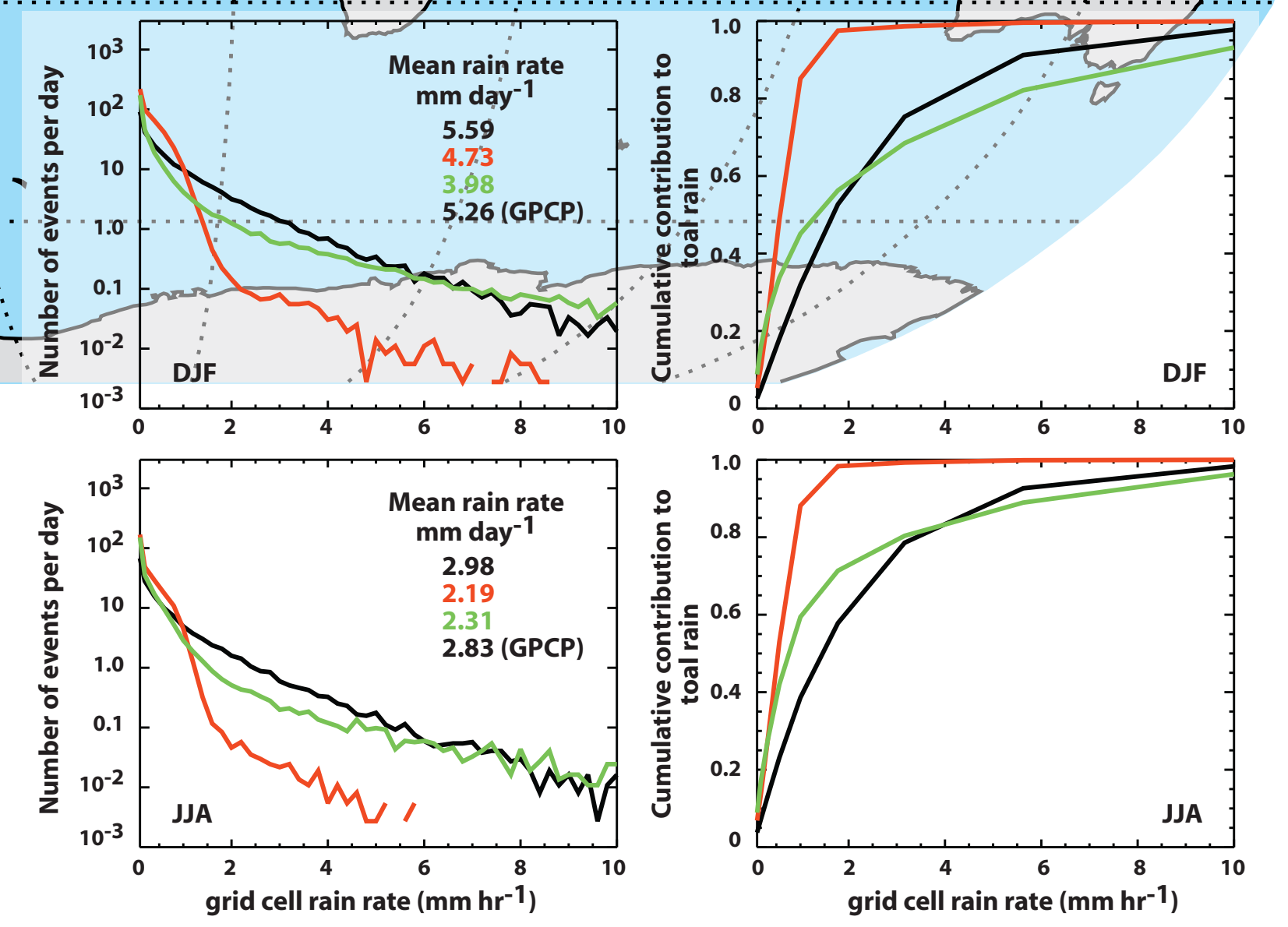
Success in simulating rain rate distributions over South Asia depends on the season. Both model convection schemes perform reasonably well in winter, however summer monsoon rains show differences similar to those in the tropics.

The deep convective regions of South America, the Tropical Indian Ocean and the Warm Pool reveal the greatest discrepancies in rain rate distributions. The RAS convection scheme drastically underestimates heavy rain events. While the observations suggest that as much as 40% of rain occurs in events of greater than 2 mm hr^{-1}, the RAS scheme generates virtually all of its rain at lower rain rates. The Donner scheme approaches the observed distribution, and even over-compensates in some cases. Note that high grid-cell scale convective rain rates are associated with large and powerful storms, including cyclones. Accounting for order-of-magnitude discrepancies in the frequency of such events is crucial for evaluating impacts of future changes.

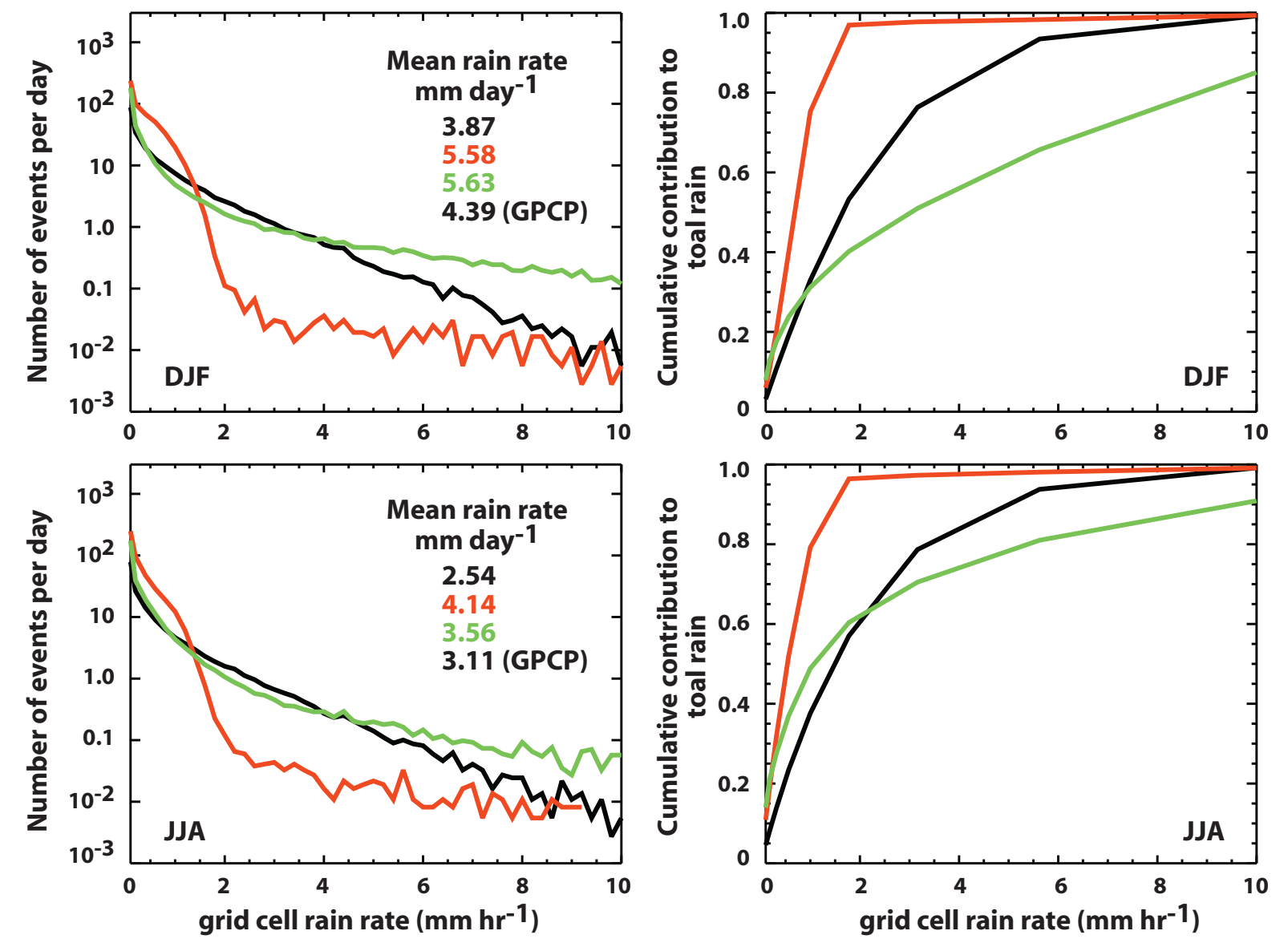
The Warm Pool



South America



Tropical Indian Ocean



In regions such as the North Pacific Ocean, where cumulus convection plays a subordinate role to larger baroclinic eddys, the GFDL AM2 model reproduces the frequency distribution of short-time-scale rain rates reasonably well.

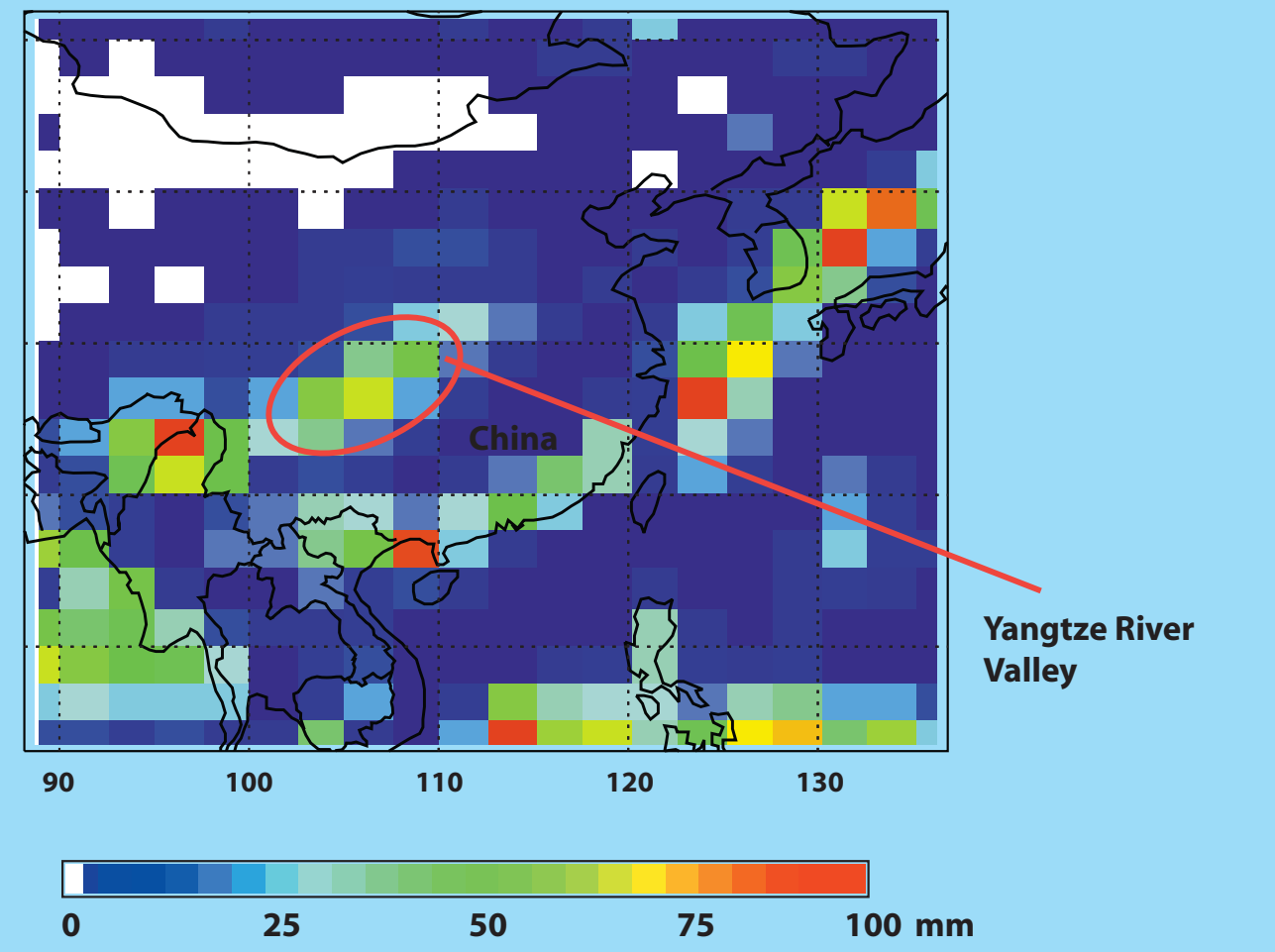
Where cumulus convection dominates, i.e. the tropics and summertime continents, differences in the formulation of convection lead to order-of-magnitude differences in the frequency of intensely falling rain. Candidates for the source of the discrepancy include the effects of mesoscale structures within convective systems and the formulation of the convective closure. Sensitivity tests are being constructed to clarify the issue.

The frequency of potential flood events

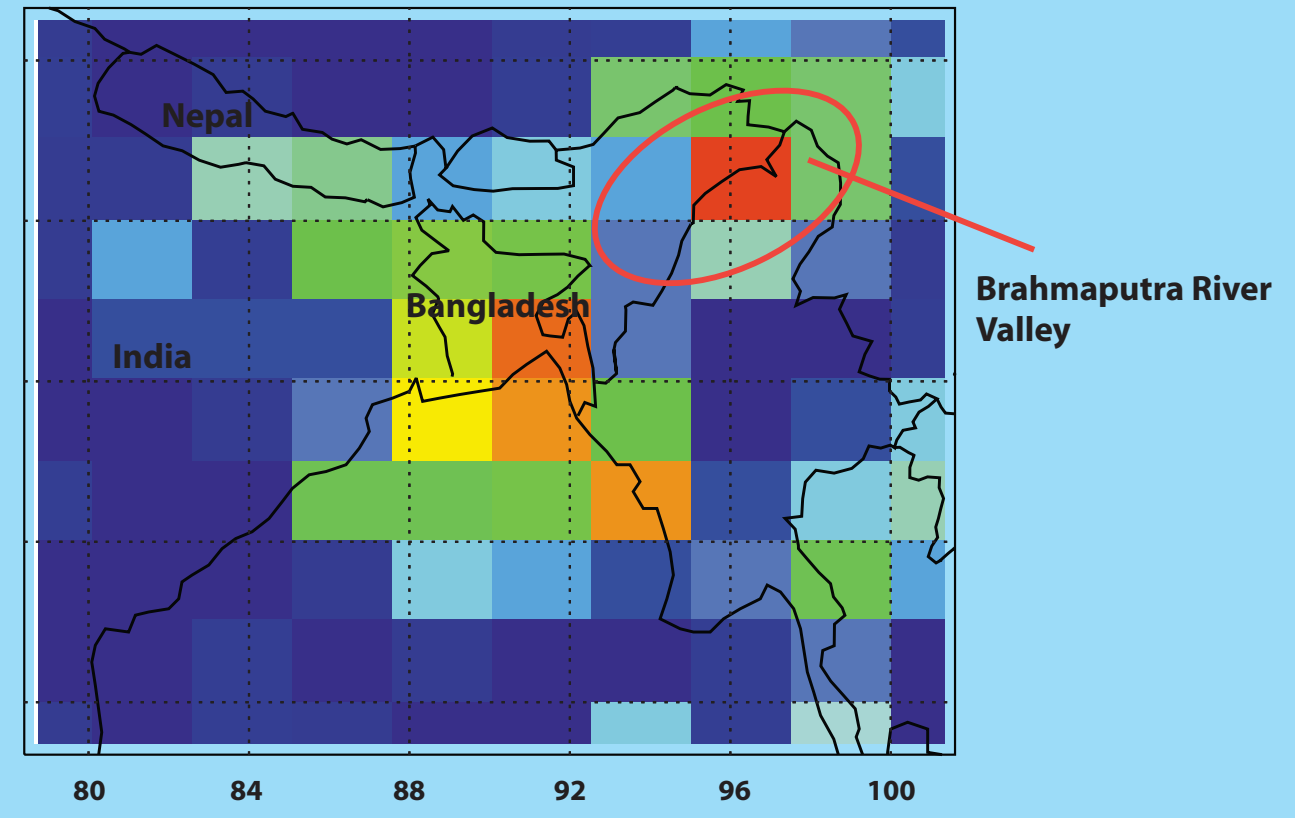
That future climate change may result in an increase in the frequency of severe flood events is of great concern. In urban and rural areas alike, such events can have grave impacts on the wellbeing of residents. In urban areas, where waterways are largely managed, predictions of changes in the frequency of flood events may help guide future management projects. Floods, of course, depend on much more than simply heavy rainfall. Other important characteristics may be topography, soil conditions, and river flow. Furthermore, it may not be sufficient that rain be heavy over just the period of a single GCM time step (usually 30 minutes).

Two examples of heavy rain events observed by SSM/I instruments during the Asian summer monsoon season are shown here. Both caused flooding of major river systems, resulting in hundreds of deaths and thousands of displaced persons. The data have been averaged over AM2 model grid cells and then accumulated over 4-day increments. Each event includes at least one grid cell where the 4-day accumulation of rain is between 70 and 100 mm and collocated with a major river valley. Note that other grid cells in the surrounding regions also exhibited high 4-day accumulations, though they may not have been located properly to contribute to large scale flooding.

4-day accumulation of rain
Aug. 9-12, 2002



4-day accumulation of rain
July 5-8, 2002



Number of South Asia grid cells exhibiting 4-day accumulations in excess of 100 mm (JJA, 1998-2001)

SSM/I observations	924
AM2/RAS	1317
AM2/Donner	12085

If we assume that extreme 4-day accumulations are a necessary condition for a flood event and evaluate the frequency of this condition over summertime South Asia in the AM2 model (see table above), we find the surprising result that the RAS convection scheme agrees reasonably well with the observations for the frequency of 4-day accumulations in excess of 100 mm. This occurs even while RAS underestimates the frequency of instantaneous rain over 2 mm hr^{-1} by as much as an order of magnitude (see figures to the left). The Donner scheme overestimates the frequency of extreme 4-day accumulations by an order of magnitude.

Proper assessment of the ability of models to capture the frequency of potential flood events requires better constraints on the spatial and temporal qualities of threatening rain events.

References:
[1] *Trenberth, K. E., Climatic Change, vol. 42, pp.327-339, 1999.*
[2] *Karl, T. R., Nature, vol. 377, pp. 217-220, 1995.*
[3] *GFDL Global Atmos. Model Development Team, under revision, J. Climate, 2003.*
[4] *Moorthi, S and Suarez, M. J., Mon. Wea. Rev., vol. 120, pp. 978-1002, 1992.*
[5] *Donner, L. J., J. Atmos. Sci., vol. 50, pp. 889-906, 1993.*

***Acknowledgments**: Funding has been provided by a fellowship from the NOAA Postdoctoral Program in Climate and Global Change. Leo Donner and Stephen Klein assisted with the GFDL AM2 simulations. Satellite precipitation measurements were provided by the TRMM Science Team and The NASA/Goddard DAAC.*