Global Warming and an Enhanced Hydrologic Cycle

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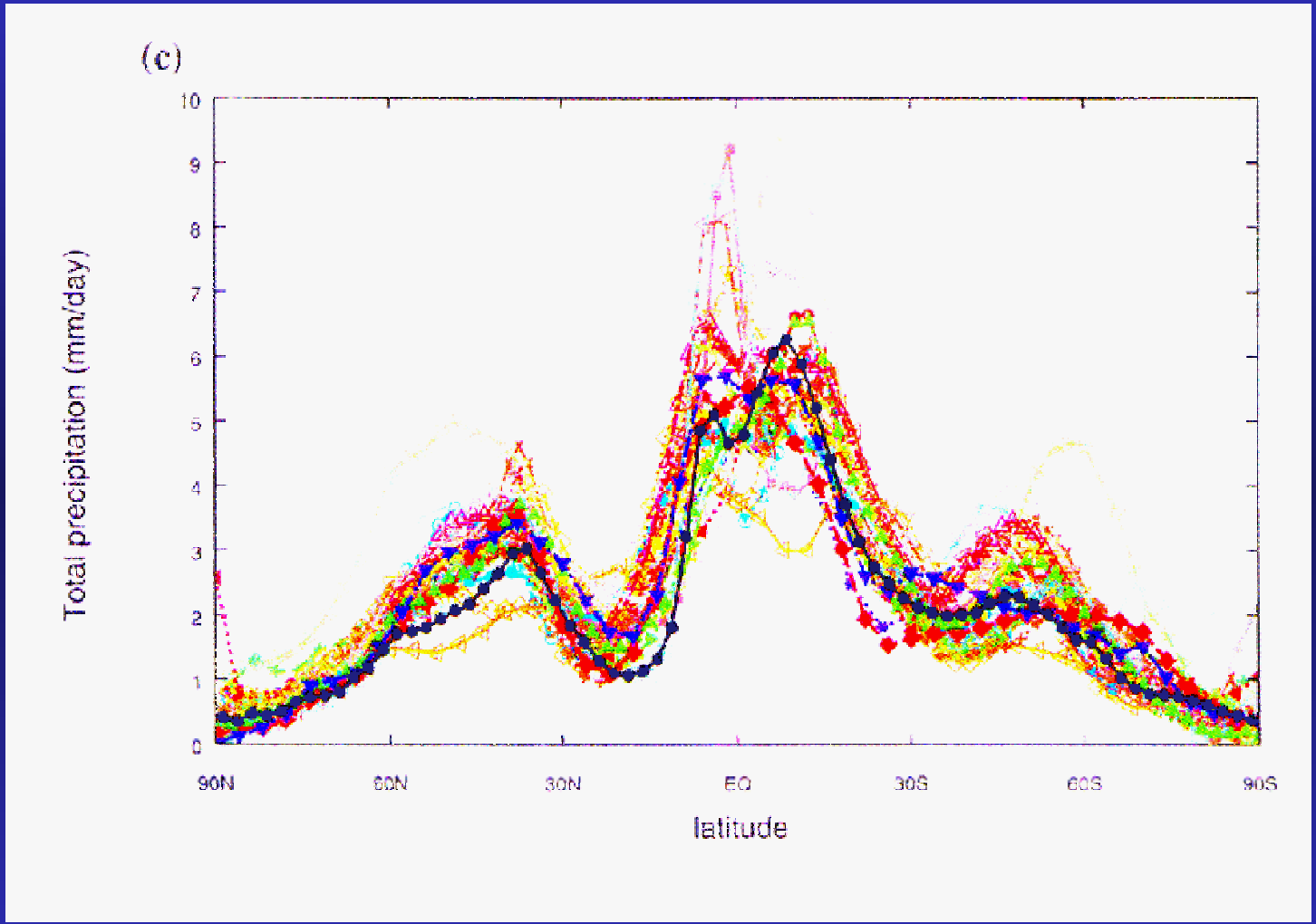
Precipitation is Difficult to Simulate in a GCM because:

- Process occurs below the spatial and temporal resolution of most GCMs
- Precipitation process is not fully understood
- Numerical instabilities may arise with small moisture amounts
- Parameterization of other factors (e.g., topography, circulation, clouds, boundary-layer interactions, evapotranspiration, dynamics) can adversely affect precipitation simulations

Zonally-Averaged Global Precipitation by 31 GCMs



Gates (1999)

Global Precipitation Estimates

Model	January	July
GFDL	3.13 in.	3.35 in.
GISS	3.89 in.	4.06 in.
NCAR	3.76 in.	4.24 in.
UKMO	3.54 in.	3.93 in.

Global Precipitation Estimates

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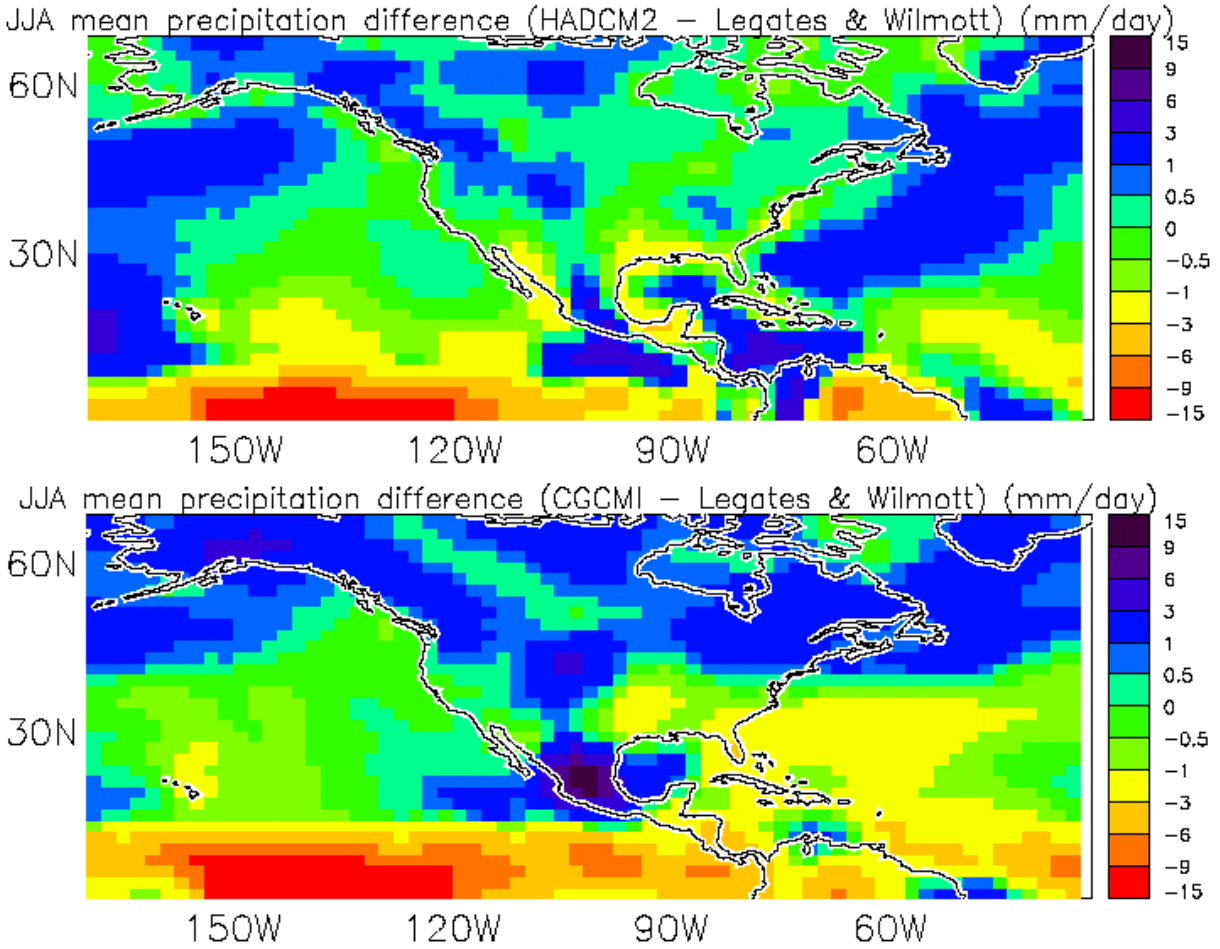
UKMO	3.54 in.	3.93 in.
Observed	**4.37 in.**	**3.44 in.**

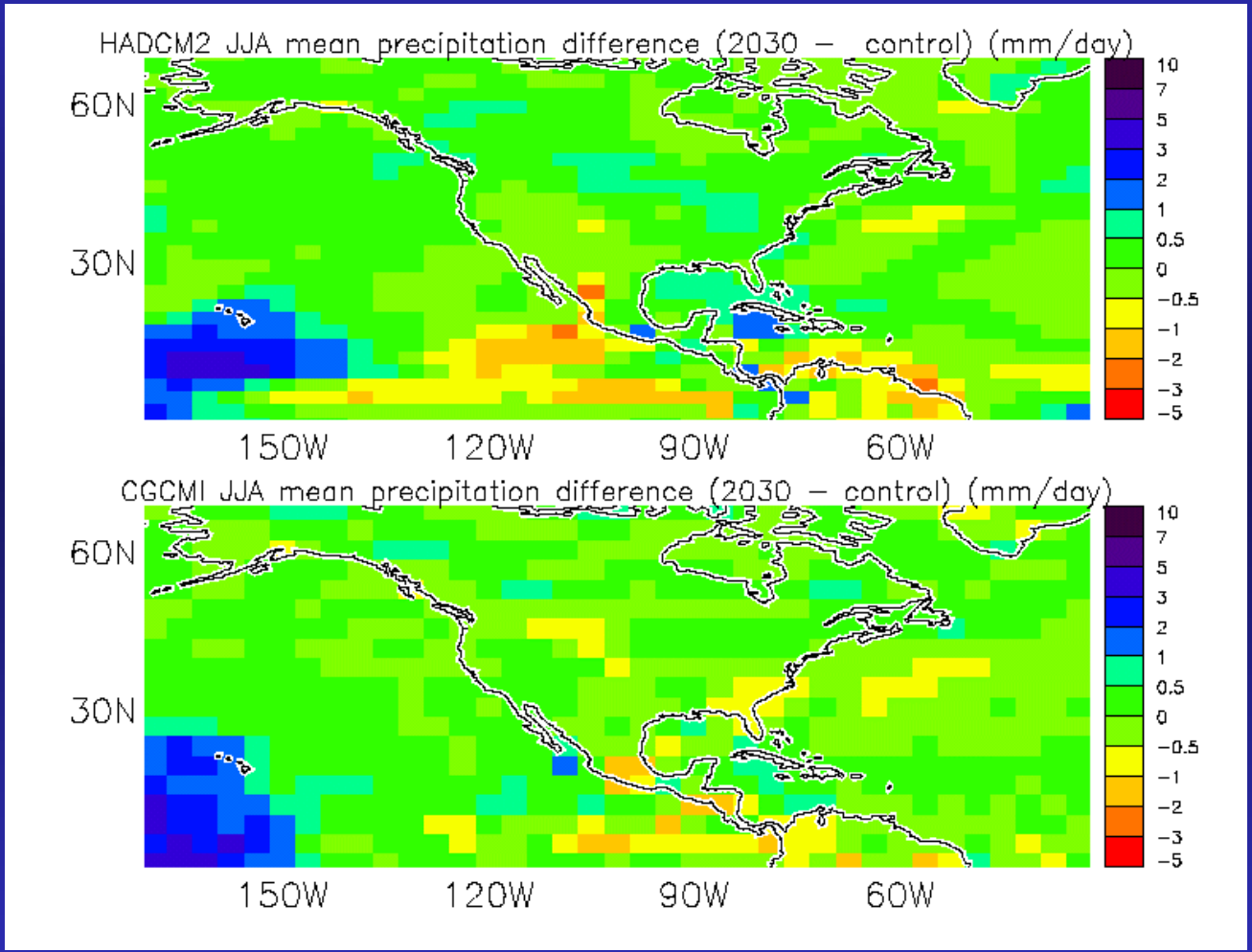
Model minus Observed: Precipitation



Summer

Doherty and Mearns (2000)

Prognostications for 2030: Precipitation



Summer

Doherty and Mearns (2000)

Contribution of Precipitation to the Energy Balance

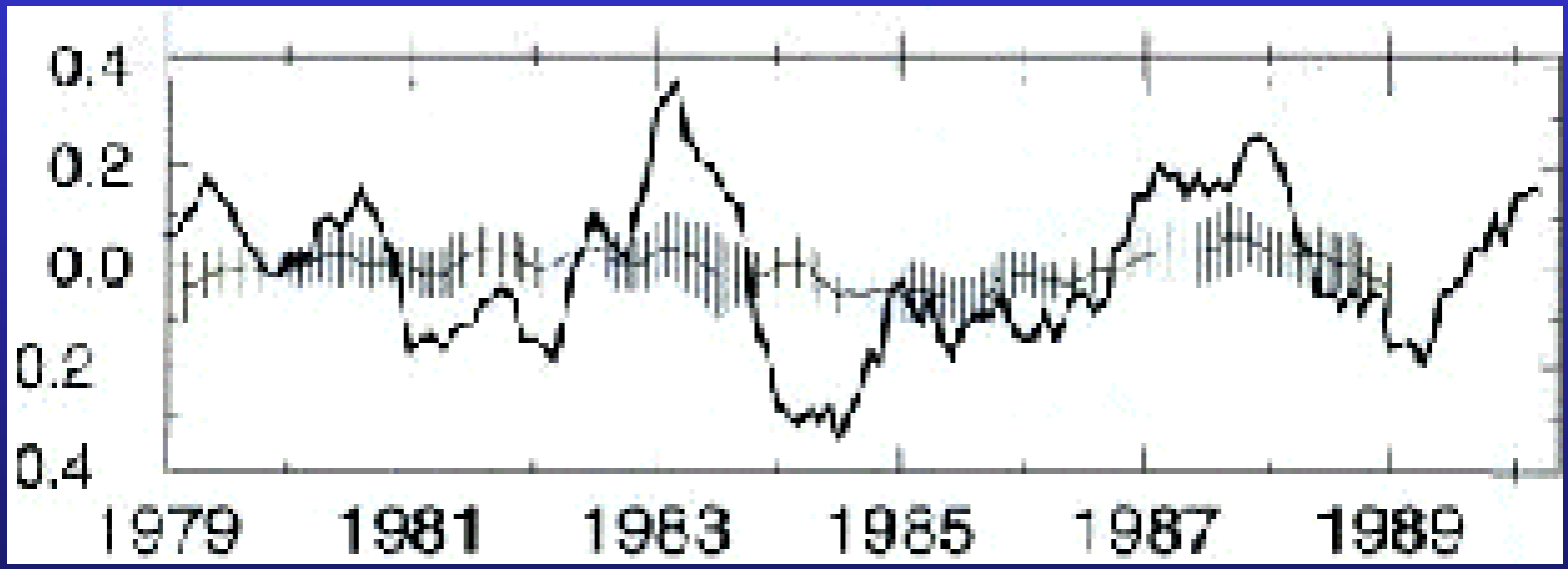
$$\Delta P \, (\rho_w \, L \, g) / (C_p \, p) = \Delta T$$

$$(0.001 \text{ m}^3/\text{m}^2)\ (1025 \text{ kg m}^{-3})\ (2.5\text{x}10^6 \text{ J kg}^{-1})\ (9.8 \text{ m s}^{-2})\ (1004.67 \text{ J kg}^{-1} \text{ K}^{-1})^{-1}\ (0.8 \text{ x } 101325 \text{ N m}^{-2})^{-1}$$

1 mm of rainfall = 0.31°C in air temperature

or

0.1 inch of rainfall = 0.79°C in air temperature



"Thus, not only do the GCMs differ with respect to the observations, but the models also lack coherence among themselves. It is noted, however, [t]hat *even the extreme models exhibit markedly less precipitation variability than observed*…Moreover, the diversity of models considered here requires that this error not be sensitive to the differing physical parameterizations between existing GCMs. Rather, if the GCMs are in error, this deficiency would presumably reflect a *more fundamental flaw common to all models*."

Soden (2000)
Journal of Climate

An Enhanced Hydrologic Cycle?

"Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events."

IPCC SAR Summary for Policymakers (1996)

But from the IPCC Scientific Assessment (1996):

"In the few analyses available, there is *little agreement* between models on the changes in storminess that might occur in a warmed world. Conclusions regarding extreme storm events are obviously *even more uncertain*."

An Enhanced Hydrologic Cycle?

"Global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur … in many different regions."

IPCC TAR Summary for Policymakers (2001)

An Enhanced Hydrologic Cycle?

"There is no firm evidence that climate has become more variable over the last few decades."

IPCC Summary for Policymakers, 1990

"There is no evidence that extreme weather events, or climate variability, has increased in a global sense, through the 20th century, ... data and analyses are poor and not comprehensive."

IPCC SAR, 1996

"Variability in much of the Northern Hemisphere's midlatitudes *has decreased* as the climate has become warmer. Some computer models also project decreases in variability."

Karl *et al.,* 1997

Changes in Precipitation Intensity?

"These data suggest that the precipitation regimes in the United States are changing disproportionately across the precipitation distribution. The proportion of total precipitation derived from extreme and heavy events is increasing relative to more moderate events."

Karl and Knight, 1998

Bulletin of the American Meteorological Society

Changes in Precipitation Intensity?

In the Midwest, heavy event frequencies from 1896-1906 were higher for all ten-year periods except 1986-96.

"Interpretation of the recent upward trends must account for the possibility of *significant natural forcing* of variability on century timescales…Attribution of the cause of the recent upward trend should consider potential natural forcing factors that may make a significant contribution. There is *no implication* in these results that the upward trends will necessarily continue."

Kunkel *et al.*, 1999
Journal of Climate

Changes in Precipitation Intensity?

Examination of heavy precipitation frequencies: high frequencies observed during the late 19th and early 20th centuries, a minimum in 1920s and 1930s, and a general increase to the 1990s.

"Frequencies at the beginning of the 20th Century were nearly as high as during the late 20th Century… suggesting that natural variability *cannot be discounted* as an important contributor to the recent high values."

Kunkel *et al.*, 2003

Geophysical Research Letters

An Increase in Flood and Droughts?

"Two general patterns emerge; trends are most prevalent in the annual minimum to median flow categories and least prevalent in the annual maximum category."

"Hydrologically, these results indicate that the conterminous US is getting wetter, but less extreme."

Lins and Slack, 1999

Geophysical Research Letters

An Increase in Flood and Droughts?

"Over the 20th century (1900 to 1995), there were *relatively small increases* in global land areas experiencing severe drought or severe wetness. In many regions, these changes are dominated by inter-decadal and multi-decadal climate variability, such as the shift in ENSO towards more warm events. In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades."

IPCC TAR, 2001

Changes in Storm Intensity & Frequency?

"There has been *no trend* in North America-wide storminess or in storm frequency variability found in the record of storm tracks for the period 1885-1996 … It is not possible, at this time, to attribute the large regional changes in storm climate to elevated atmospheric carbon dioxide."

"[Model] projections of North American storminess shows *no sensitivity* to elevated carbon dioxide. It would appear that statements about storminess based on [model] output statistics are unwarranted at this time."

"It should also be clear that little can or should be said about change in variability of storminess in future, carbon dioxide enriched years."

Hayden, 1999

Journal of the American Water Resources Association

Report of the Water Sector for the US National Assessment

Changes in Storm Intensity & Frequency?

"Changes globally in tropical and extra-tropical storm intensity and frequency are dominated by inter-decadal to multi-decadal variations, with *no significant trends* evident over the 20th century. Conflicting analyses make it difficult to draw definitive conclusions about changes in storm activity, especially in the extra-tropics."

IPCC TAR, 2001

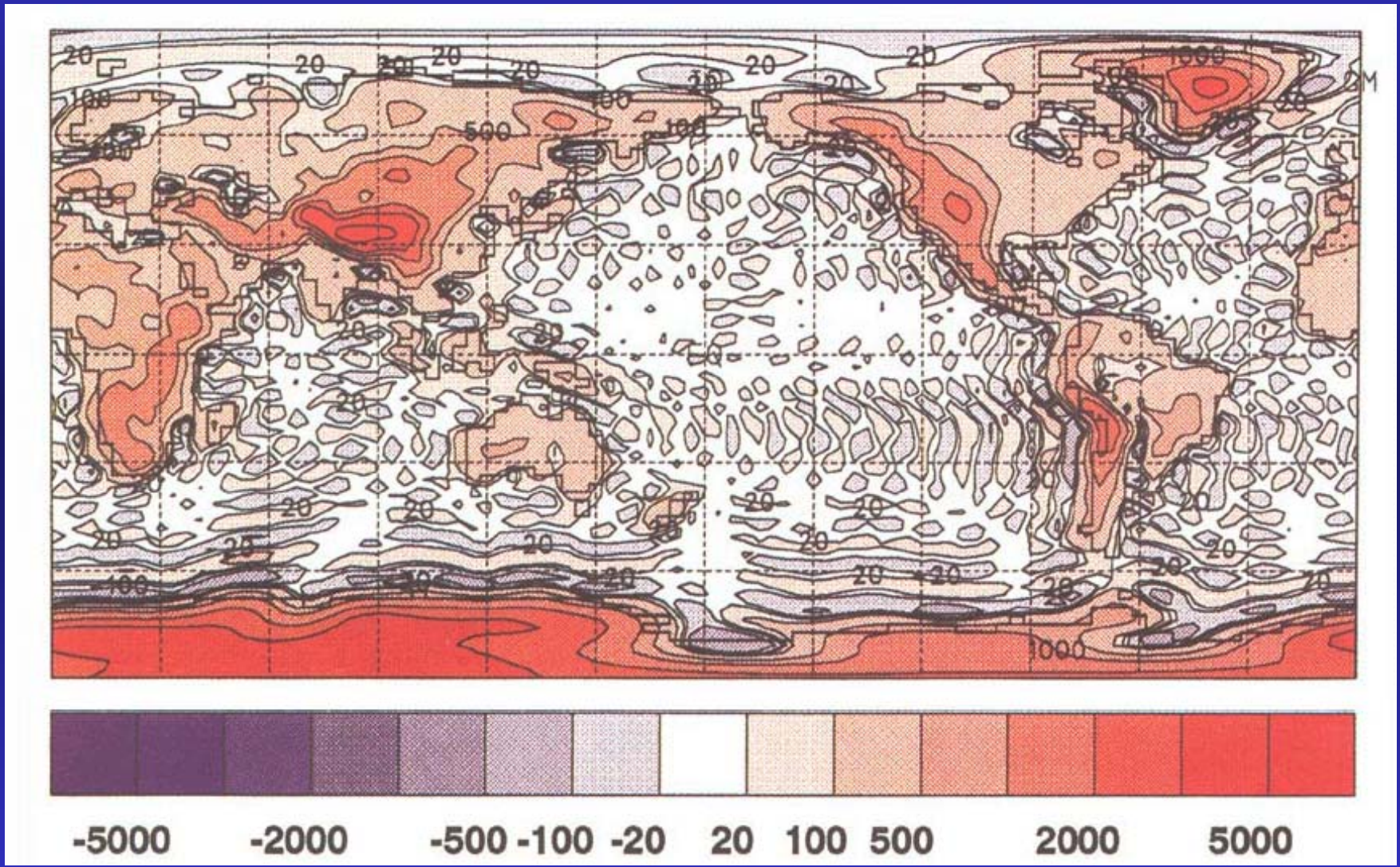
Changes in Storm Intensity & Frequency?

"Doubled CO_2 leads to a ***marked decrease in the occurrence of intense storms*** [in the extratropics]… one exception is over the South Pacific where there is a suggestion of an increased incidence of cyclones at the intense end of the spectrum. Reductions in average cyclone central pressure that have been used in other studies to promote the possibility of enhanced storminess under greenhouse warming, are more likely the result of ***global-scale sea level pressure falls*** rather than any real increase in cyclone circulation strength."

Sinclair and Watterson, 1999

Journal of Climate

Surface Elevation (m) Represented in an R30 Climate Model (2.25 of Latitude by 3.75 of Longitude)



Lindberg and Broccoli, 1996

Changes in Tropical Storm Frequencies?

"In the two regions where reasonably reliable records exist (the North Atlantic and the western North Pacific), substantial multidecadal variability (particularly for intense Atlantic hurricanes) is found, but there is *no clear evidence* of long-term trends."

Henderson-Sellers *et al.,* 1999
Bulletin of the American Meteorological Society

"There have been various studies investigating the potential effect of long-term global warming on the number and strength of Atlantic-basin hurricanes. The results are *inconclusive*."

Goldenberg *et al.,* 2001
Science

Changes in Tropical Storm Frequencies?

"While it is not yet clear how the numbers and tracks of hurricanes will change, projections are that peak windspeed and rainfall intensity are likely to rise significantly."

US National Assessment, 2001

"It is emphasized that the popular belief that the region of cyclogenesis will expand with the 26°C [sea surface temperature] isotherm is a fallacy. The very modest available evidence points to an expectation of little or no change in global frequency."

Henderson-Sellers *et al.,* 1999

Bulletin of the American Meteorological Society

Summary

- Changes in Precipitation Totals?
  - Yes, but below measurement bias and variability
- Changes in Frequency and Intensity?
  - No, with agreement from IPCC TAR (2001)
- Changes in Flood and Drought Frequencies?
  - No, with agreement from IPCC TAR (2001)
- Changes in Extratropical Storm Frequencies?
  - No, with agreement from IPCC TAR (2001)
- Changes in Tropical Storm Frequencies?
  - No, with agreement from IPCC TAR (2001)

An Enhanced Hydrologic Cycle?

"It is likely that the observed trends toward an intensification of precipitation events will continue. Thunderstorm and other intensive rain events are likely to produce larger rainfall totals. Projections [for hurricanes] are that peak windspeed and rainfall intensity are likely to rise significantly."

US National Assessment, 2001

An Enhanced Hydrologic Cycle?

"Global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur … in many different regions."

IPCC TAR Summary for Policymakers (2001)

Where is the *Proof* for an Enhanced Hydrologic Cycle?

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