GFDL CLIMATE MODELING RESEARCH HIGHLIGHTS

The National Oceanic and Atmospheric Administration (NOAA)
Geophysical Fluid Dynamics Laboratory (GFDL) - Princeton, NJ

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WILL THE WET GET WETTER AND THE DRY DRIER?

TAKE HOME POINTS

- In response to increasing greenhouse gas levels, climate models project an increase in the amount of water evaporating and precipitating over the Earth — a strengthening of the global hydrologic cycle.
- Precipitation is projected to increase in the near-equatorial regions, which tend to be wet in the present climate.
- In subtropical land areas—places that are already relatively dry—precipitation is projected to decrease during the 21st century.
- Mid-latitude storm track are projected to move poleward along with the poleward edge of the subtropical dry zones.

Contact Info:

For this topic:

Isaac Held
GFDL Weather & Atmospheric Dynamics Group
email: Isaac.Held@noaa.gov
phone: 609-452-6512

Gabriel Vecchi
GFDL Climate Diagnostics Group
email: Gabriel.A.Vecchi@noaa.gov
phone: 609-452-6583

GFDL media inquiries:
Maria Setzer
email: Maria.Setzer@noaa.gov
phone: 609-452-6643

GFDL main phone:
609-452-6500

Research Highlights, Graphics & Animations
www.gfdl.noaa.gov/research/climate

Warming of the global climate is expected to be accompanied by a reduction in rainfall in the subtropics and an increase in precipitation in subpolar latitudes and some equatorial regions. This pattern can be described in broad terms as the wet getting wetter and the dry getting drier, since subtropical land regions are mostly semi-arid today, while most subpolar regions currently have an excess of precipitation over evaporation.

Though clearly a feature of a warming global climate, this characterization of the changing precipitation pattern cannot be applied to every locale, but should instead be thought of as a large-scale tendency that can be modified by local conditions in some cases.

As seen in the map below, the drying is projected to be strongest near the poleward margins of the subtropics (for example, South Africa, southern Australia, the Mediterranean, and the south-western U.S.), a pattern that can be described as a poleward expansion of these semi-arid zones.

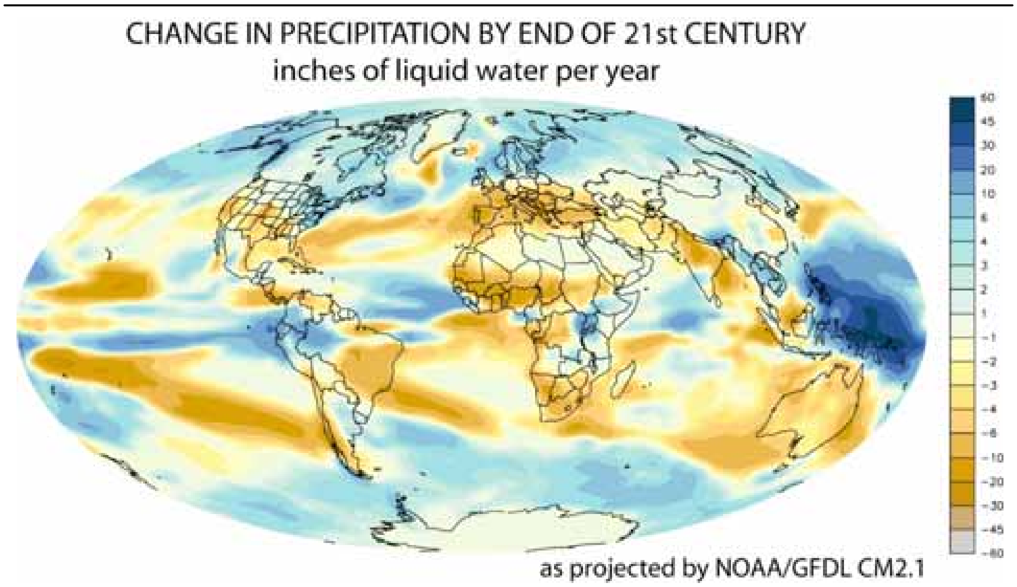
This large-scale pattern of change is a robust feature present in nearly all of the simulations conducted by the world's climate modeling groups for the 4th Assessment of the Intergovernmental Panel on Climate Change (IPCC), including those conducted at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL). It is also evident in observed 20th century precipitation trends.

► How the atmosphere responds

As the atmosphere warms, it is capable of holding more water vapor, and computer climate models as well as observations indicate that the atmosphere's water vapor

(*continued on next page*)

[Below] The change in annual average precipitation projected by the GFDL CM2.1 model for the 21st century. These results are from a model simulation forced according to the IPCC SRES A1B scenario [IPCC, 2000] in which atmospheric carbon dioxide levels increase from 370 to 717ppm. The plotted precipitation differences were computed as the difference between the 2091 to 2100 ten-year average minus the 1971 to 2000 30-year average. (Note the irregular contour intervals.)



From the IPCC Summary For Policymakers...*

"Long-term trends from 1900 to 2005 have been observed in precipitation amount over many large regions. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia."

"Increases in the amount of precipitation are very likely in high-latitudes, while decreases are likely in most subtropical land regions..., continuing observed patterns in trends."

*Reference:
Intergovernmental Panel on Climate Change (IPCC) WG1 Fourth Assessment Report, Climate Change 2007: The Physical Science Basis, Summary For Policymakers.

Available online at www.ipcc.ch

is increasing and will increase further.

The reason that the subtropics are relatively dry and higher latitudes relatively wet is that the water vapor that evaporates in the subtropics (roughly the band from 20° to 40° latitude in both the Northern and Southern Hemispheres) is continually being transported to higher latitudes by the atmosphere before it falls as rain or snow. As the amount of water vapor in the atmosphere increases, this transport increases, pulling more water out of the subtropics and depositing in subpolar latitudes (roughly the zone between 50° and 70° latitude in each hemisphere.

Combined with wind pattern changes that cause the entire atmospheric circulation to be displaced polewards as the climate warms, these atmospheric climate change responses result in especially strong drying tendencies near several subtropical regions This is seen in the graph to the far right as a decrease of 3 to 4 inches of annual precipitation centered near 35 latitude in both hemispheres. This pattern of large-scale precipitation changes also can be seen in animations and graphics found at http://www.gfdl.noaa.gov/research/climate/highlights

► Some Related References

Delworth, *et al.*, (2006): GFDL's CM2 global coupled climate models - Part 1: Formulation and simulation characteristics, *Journal of Climate*, Vol. 19, No. 5, pages 643-674. [LINK]

Held and Lu, (2007): On the plausibility of drying in the Sahel associated with global warming, submitted to *Journal of Climate.*

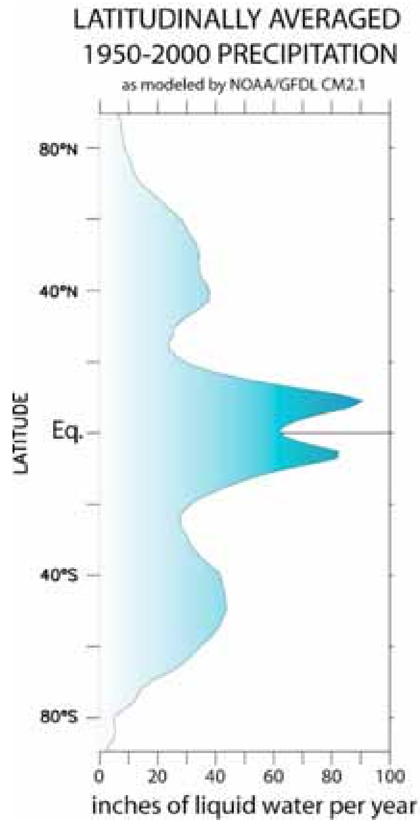
Held and Soden, (2006): Robust responses of the hydrological cycle to global warming, *Journal of Climate*, Vo. 19, No. 21, pages 5686-5699. [LINK]

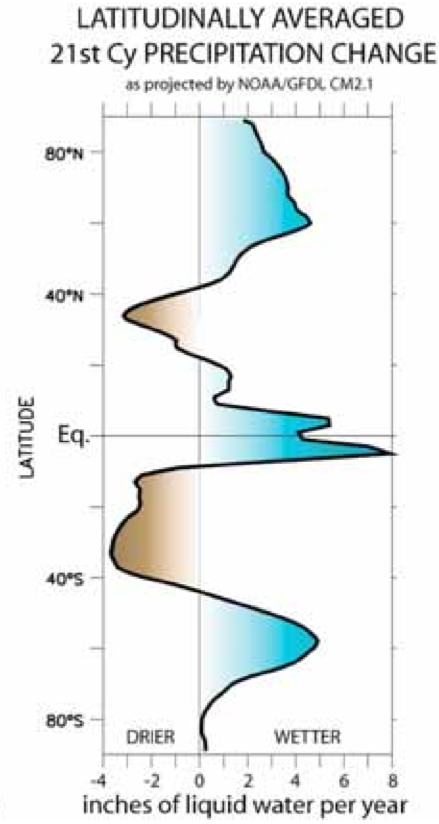
IPCC (Intergovernmental Panel on Climate Change) (2000): Special Report on Emission Scenarios. Cambridge University Press, U.K. (http://www.grida.no/climate/ipcc/emission/)

Lau, *et al.* (2006): Attribution of Atmospheric Variations in the 1997-2003 Period to SST Anomalies in the Pacific and Indian Ocean Basins, *of Climate*, Vol. 19, No. 15, pages 3607-3628. [LINK]

Lu, *et al.* (2007): Expansion of the Hadley Cell under global warming, submitted to *Journal of Climate*.

For more GFDL CM2.1 references, see http://nomads.gfdl.noaa.gov/CM2.X/references





[Above Left] Annual precipitation amounts averaged around the Earth along each latitude circle, as simulated by the GFDL CM2.1 model over the period 1951-2000. Notice the strong precipitation near the Equator, and the relative minima in precipitation near 20°S and 20°N - latitudes in the subtropical dry zones.

[Above Right] 21st Century precipitation changes as projected by the GFDL CM2.1 model, averaged around the Earth along each latitude circle. The precipitation changes are computed as differences between the 2081-2100 twenty-year average and the modeled 1951-2000 fifty-year average (the values shown to the left).

Notice that latitude zones receiving relatively high amounts of precipitation in the late 20th century simulation (left), such as the near-equatorial tropics and the high latitudes centered at 60°N and 60°S, show a pronounced increase in 21st century precipitation (right). Also note that decreases in precipitation are projected for the subtropical dry regions - particularly on their poleward flank. The projected changes are in response to increasing greenhouse gases and changing aerosols based on a "middle of the road" estimate of future emissions. This scenario is denoted as IPCC SRES A1B; for details see IPCC [2000]. General information about the GFDL CM2.1 model can be found in Delworth *et al* [2006]

For more information on this topic, including high resolution graphics, please see "WILL THE WET GET WETTER & THE DRY DRIER" links at http://www.gfdl.noaa.gov/research/climate/highlights

NOAA GFDL

US Department of Commerce
National Oceanic & Atmospheric Administration
Geophysical Fluid Dynamics Laboratory
Princeton University Forrestal Campus
201 Forrestal Road, Princeton, NJ USA 08540

Phone................609-452-6500
Web...................www.gfdl.noaa.gov
Data Portal........nomads.gfdl.noaa.gov

About GFDL

Located in Princeton, New Jersey, the Geophysical Fluid Dynamics Laboratory (GFDL) develops and uses mathematical models and computer simulations to improve our understanding and predictions of the behavior of the atmosphere, the oceans, and climate. Over its 50-year history, GFDL has set the agenda for much of the world's research on the modeling of global climate change and has played a significant role in the World Meteorological Organization and Intergovernmental Panel on Climate Change (IPCC) assessments, as well as the US Climate Change Research Program (US CCSP).

The multi-year effort that culminated in the GFDL CM2.1 global climate model used in the research presented here was truly a lab-wide endeavor, and one that supports the National Oceanographic and Atmospheric Administration's (NOAA's) strategic goal to *"Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond."*

For more background information about GFDL, see...
http://www.research.noaa.gov/organization/backgrounders06/gfdl.html

Supplementary Information

Some Fine Print:

More About These GFDL Climate Model Experiments

The Geophysical Fluid Dynamic Laboratory's CM2.1 coupled model used to conduct the simulations presented herein are representative of the state-of-the-art in global climate modeling. The CM2 models became GFDL's workhorse models for computer modeling studies of decadal to century time scale climate variability and change in 2004, and their results figure prominently in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) and the US Climate Change Science Program (US CCSP) reports. The CM2 global climate models consist of atmospheric, land, ocean and sea ice components that interact with each other (hence the term "coupled model").

Regarding the climate forcing[1] scenarios used in the model simulations, for the years up to year 2000, the models include most of the major climate forcing factors that were observed to change in the real world (*e.g.,* changes in atmospheric greenhouse gas levels, volcanic aerosols, soot, tropospheric sulfate aerosols, land surface changes, etc.). The GFDL CM2.0 and CM2.1 models have been shown to be credible at reproducing the decade to decade variations in global mean surface air temperature observed during the 20th century [Delworth et al. (2006), Knutson et al. (2006)].

To explore a range of "If ... Then" future scenarios, several different 21st century emissions scenarios have been used at GFDL and other climate modeling centers. In the figures displayed here, and in the related animations at www.gfdl.noaa.gov/research/climate/highlights we show results from what are known as the SRES A1B emissions scenario - one with a mid-level increase in 21st century greenhouse gas levels [IPCC, 2000]. We display results from the A1B scenario not because it is considered any more or less likely to resemble the emissions scenario that actually will occur in the coming decades, but rather because, even as a "middle of the road" emissions scenario, the model's precipitation exhibits a large-scale climate change response that is clearly visible in the graphics.

The graphics and animations are derived from the above described model simulations documented in GFDL authored papers referenced herein.

Model output files from some experiments shown here can be freely downloaded from the GFDL Data Portal (nomads.gfdl.noaa.gov).

[1] A climate forcing (or more properly, a radiative forcing) is the result of a process that directly changes the energy balance of the climate system by altering the balance between incoming solar radiation and outgoing longwave and shortwave radiation. It does not include the effects of feedbacks. A positive forcing tends to warm the surface of the Earth and a negative forcing tends to cool the surface. Forcing agents, such as clouds, greenhouse gases, aerosols, and surface albedo changes, are those things that cause variations in radiative forcings.

References:

⌂ symbols identify papers available for viewing online from the GFDL Online Bibliography web page: http://www.gfdl.noaa.gov/reference/bibliography/

○ symbols indicate non-GFDL references.

⌂ Delworth, *et al.,* (2006), GFDL's CM2 global coupled climate models - Part 1: Formulation and simulation characteristics, *Journal of Climate*, Vol. 19, No. 5, pages 643-674.

⌂ Held, et al., (2005): Simulation of Sahel drought in the 20th and 21st centuries. *Proceedings of the National Academy of Sciences*, Vol. 102, No. 50, page 17891-17896.

⌂ Held and Lu, (2007): On the plausibility of drying in the Sahel associated with global warming, submitted to *Journal of Climate.*

⌂ Held and Soden, (2006): Robust responses of the hydrological cycle to global warming, *Journal of Climate*, Vo. 19, No. 21, pages 5686-5699

○ IPCC (Intergovernmental Panel on Climate Change) (2000): Special Report on Emission Scenarios. Cambridge University Press, U.K. (http://www.grida.no/climate/ipcc/emission/)

○ IPCC (Intergovernmental Panel on Climate Change) (2007): Climate Change 2007: The Physical Science Basis, Summary for Policymakers. (published online 2 Feb 2007 at http://www.ipcc.ch/)

⌂ Knutson, *et al.,* (2006): Assessment of Twentieth Century Regional Surface Temperature Trends using the GFDL CM2 Coupled Models, *Journal of Climate*, Vol. 19, No. 9, pages 1624-1651.

⌂ Lau, *et al.* (2006): Attribution of Atmospheric Variations in the 1997-2003 Period to SST Anomalies in the Pacific and Indian Ocean Basins, *of Climate*, Vol. 19, No. 15, pages 3607-3628.

⌂ Lu, *et al.* (2007): Expansion of the Hadley Cell under global warming, submitted to *Journal of Climate.*

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GFDL scientist contacts for this topic:

Isaac Held, NOAA/GFDL
Gabriel Vecchi, NOAA/GFDL