GFDL CLIMATE MODELING RESEARCH HIGHLIGHTS

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

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TAKE HOME POINTS

- The Sahel region of Africa experienced severe droughts and famine in the late 20th century.
- The late 20th century Sahel drought likely resulted from changes in sea surface temperatures over large areas — changes that GFDL research indicates are consistent with a combination of natural climate variations and human-induced atmospheric changes (increasing greenhouse gases and aerosols).
- The GFDL CM2 models project a drier Sahel in the future, due primarily to increasing greenhouse gases.

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

SAHEL DROUGHT: PAST PROBLEMS, AN UNCERTAIN FUTURE

Droughts are a recurring environmental problem in the Sahel region of Africa - the semi-arid area to the south of the Saharan Desert and north of the rainforests of Central Africa and the Guinean Coast.

Generally receiving less than 500mm (20 inches) of rain a year, the Sahel experiences sizable rainfall variations, year-to-year and decade-to-decade. Following a relatively wet period in the 1950s, the region endured a severe drying trend into the early 1980s, during which annual rainfall amounts dropped by 40%. Large-scale famine ensued. Since the early 1980s there has been partial recovery, but future prospects are uncertain.

Using state-of-the-art global climate models, researchers at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) have investigated both the causes of past Sahel drought and produced projections of potential 21st century trends [Held, *et al.* (2005)].

► Modeling The Late 20th Century

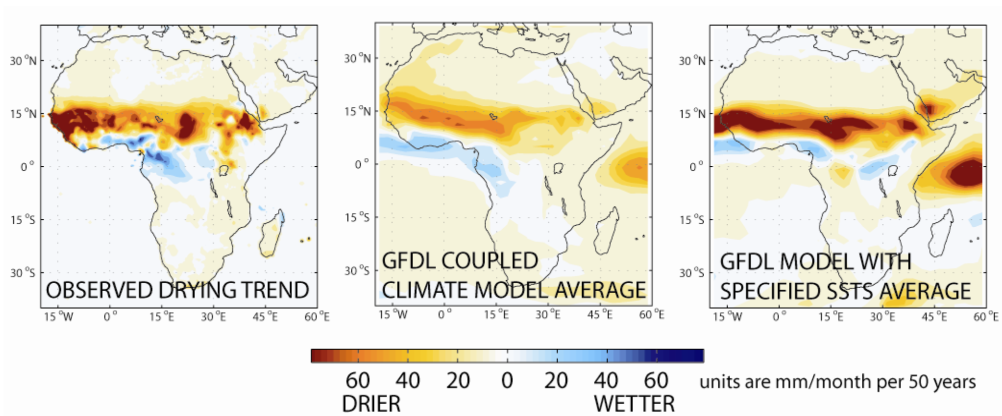
The observed late 20th century pattern of reduced wet season Sahel rainfall *(below left)* appears as a band between 5° and 15°N latitude. Similar patterns of African drought also are seen when averaging the results of eight 20th Century simulations conducted with the GFDL CM2 coupled climate models *(below center)*, though the average GFDL coupled model trend is about half of the observed.

When using the same atmosphere and land model components and specifying sea surface temperatures (SSTs) to vary as was observed, the strength of the modeled 50-year Sahel drying trend more closely matches observations *(below right).* This high level of agreement indicates that SSTs variations likely are responsible for the major Sahel rainfall changes.

Though the average 1950-2000 drying trend seen in the eight CM2 model runs is less severe than the observed, individual coupled

(continued on next page)

[Below] Trends in July-Aug.-Sept. (wet season) rainfall over the period 1950 to 2000. Blue areas trend towards more rain, and brown areas toward a drier climate. *(Left)* The observed trend over land computed from the CRU-TS_2.1 data set [Dai *et al.,* 2004]. *(Center)* The average trend simulated in an eight member ensemble of GFDL CM2 coupled atmosphere-ocean model runs. *(Right)* The average trend simulated in a ten member ensemble of GFDL atmosphere-land model runs with observed sea surface temperatures (SSTs).



From the IPCC Summary For Policymakers...*

"Relevant quotes from the IPCC AR4 SPM will be added to this document shortly after the IPCC releases the report (scheduled for 2 February 2007)."

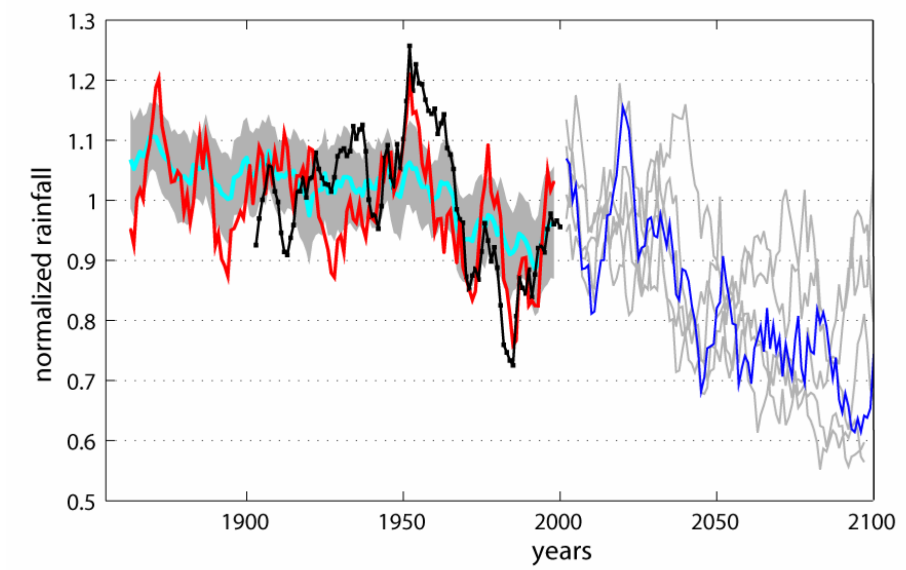
"Please check back then."

*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

model realizations display striking similarity to the observed late 20th century time series and drying pattern (for example, in the figure to the right, compare the black line [observations] and red line [one of the eight model simulations]).

These GFDL model results are consistent with the hypothesis that the late 20th century Sahel drought was a combination of an externally forced trend and internal variability. Averaging the eight individual experiments yields the ensemble mean climate response depicted as a light blue line in the figure to the right. The late 20th century ensemble mean drying trend in the model simulations is attributable to anthropogenic (*i.e.* human-induced) factors; partly due to an increase in atmospheric aerosols and partly due to an increase in greenhouse gases.



[Above] 5-year running means (July–Aug.–Sept.) of Sahel rainfall, normalized so its average value over 1901–2000 is equal to 1.0. Black curve = observations. Thick light blue line = historical CM2 ensemble mean (n=8). Red line = CM2 simulation that most resembles the observed 1950-2000. The gray area represents ±1 standard deviation within the ensemble. The six curves for 2000-2100 are projections for thee future emissions scenarios, one each from CM2.0 and another from CM2.1. The dark blue line shows results from the CM2.0 SRES A1B experiment. See Held et al. (2006) for details.

► Projections for the 21st Century

As depicted in the figure to the right, the GFDL CM2 models project a drier Sahel in the future, primarily due to increasing greenhouse gases. If this projection of long term rainfall reductions occurs, Sahel droughts would be more frequent and severe than in the 20th century.

However, the GFDL model result of an approximately 25% reduction in Sahel rainfall by year 2100 is not common among those generated at other climate modeling research centers.

Until we better understand which aspects of the models account for the different responses in the Sahel region to warming of SSTs, and devise more definitive observational tests, we advise against basing assessments of future climate change in the Sahel on the results from any single model in isolation. In the interim, given the quality of CM2's simulation of the spatial structure and time evolution of the 20th century Sahel rainfall variations, we believe that its prediction of a dramatic 21st century drying trend should be considered seriously as a possible future scenario.

► Some Related References

Dai, et al., (2004), The recent Sahel drought is real, *International Journal of Climatology, Vol.* 24, pages 1323–1331.

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, 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. [LINK]

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

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. [LINK]

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

For more information on this topic, including high resolution graphics and animations, please see
"SAHEL DROUGHT: PAST PROBLEMS, AN UNCERTAIN FUTURE"
links at
http://www.gfdl.noaa.gov/research/climate/highlights

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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 CM2.0 and CM2.1 coupled models used to conduct the simulations are representative of the state-of-the-art in global climate modeling [Delworth et al. (2006)] . 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"). We also present results here (right side of first figure) from a model consisting of only atmosphere and land components; sea surface temperatures and sea ice coverage are specified and not simulated by that 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 seven atmospheric greenhouse gas levels, volcanic aerosols, black and organic carbon aerosols, tropospheric sulfate aerosols, ozone, solar irradiande and land surface changes). 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 [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 CM2 figures displayed here, we show results from what are known as the SRES B1, A1B and A2 emissions scenarios. In the related animations, we show CM2.0 results from what is 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 Sahel rainfall exhibits a climate change response that is clearly visible in the graphics.

When multiple simulations are conducted using the same climate forcing scenario, the group of simulations is referred to collectively as an ensemble and each individual simulation may be called an ensemble member or realization. Ensemble members starts from different initial conditions, and therefore have differing realizations of internal variability (sometimes called "noise"). When analyzing the results of a single realization, it can be difficult to determine to what extent a particular trend is a response to climate forcing changes (i.e., the trend is a climate change "signal") as opposed to simply being a result of the model's internal variability (i.e., the trend is a result of naturally occurring variations, such as that associated with El Niño or other quasi-oscillatory phenomena). Averaging the results of multiple ensemble members yields an ensemble average or ensemble mean that is more representative of the climate change signal (the average response to the changes in climatic forcings). In this way, ensembles can be used to help isolate a model's "forced" climate change signal from the noise of "unforced" year-to-year variations that arise from internal variability. This method of using multi-member ensembles to aid in the identification and attribution of modeled climate changes to climate forcing variations becomes more powerful as the number of ensemble members grows larger.

The figures shown here have been documented in peer-reviewed scientific journals [Held et al. (2006)]. The animations are derived from the model simulations described in that paper.

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

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.

- ○ Dai, et al., (2004) *International Journal of Climatology, Vol.* 24, pages 1323–1331.
- ⌂ 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.*
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[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 greenhouse gases, aerosols, solar irradance, and surface albedo changes, are those things that cause variations in radiative forcings.