GFDL CLIMATE MODELING RESEARCH HIGHLIGHTS

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

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A TROPICAL ATMOSPHERIC CIRCULATION SLOW-DOWN

TAKE HOME POINTS

- The Walker Circulation is a dominant feature of atmospheric circulation that influences climate across much of the world.
- Theory, observations, and GFDL climate models agree that the Walker circulation weakened by about 3.5% during the past 150 years.
- If, as simulated in GFDL climate models, the Walker Circulation weakens an additional 10 to 15% by 2100, impacts may be seen in features such as large-scale precipitation patterns and nutrient levels in biologically productive tropical oceans.

Many people have heard of El Niño and La Niña - episodic climate phenomena that, though defined by sea surface temperature changes in the tropical Pacific, have far ranging and dramatic affects on weather and climate. But fewer people are familiar with the Walker Circulation— a vast loop of winds that influences climate across much of the globe, and that varies in concert with El Niño and La Niña oscillations.

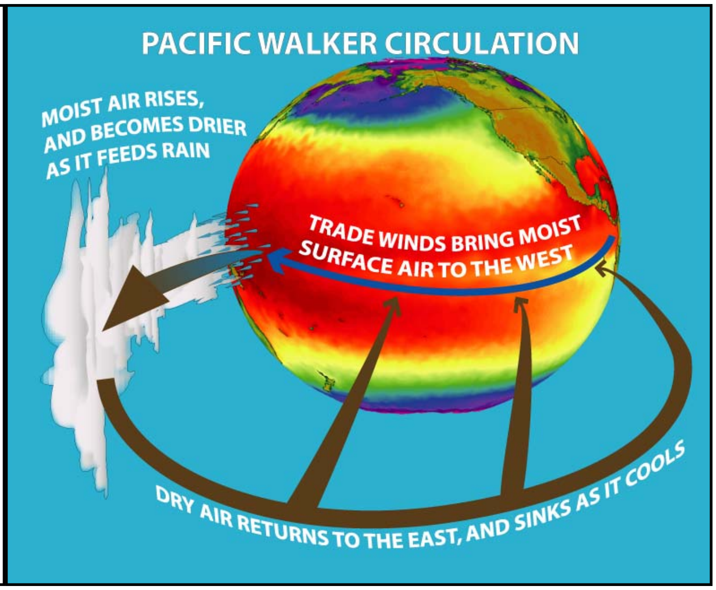
Recently conducted analyses of atmospheric sea level pressure changes indicate that the Walker Circulation slowed by 3.5% since the mid 19th century [Vecchi, *et al.*, (2006)]. Climate model studies conducted at NOAA's Geophysical Fluid Dynamic Laboratory (GFDL) simulate a slow-down similar to that observed and suggest the Walker Circulation could slow an additional 10 to 15% during the 21st century [Vecchi and Soden, (2007)].

The linkage between the Walker Circulation, El Niño and their influence on environmental factors across much of the globe makes studies of past and future changes the strength of the Walker Circulation of importance beyond the confines of the tropics.

► Combining Theory, Observations, & Models

As illustrated in the figure below and described in the accompanying caption, one can visualize the Walker Circulation as a three-dimensional loop of winds spanning roughly half the Earth's circumference. At the surface, trade winds blow across the Pacific westward toward Indonesia, becoming moister and driving surface ocean currents along their path. The humid air rises and produces massive rains in the west. Along the Equator and off the Pacific coast of South America, trade wind driven divergent surface ocean currents draw cooler nutrient rich sub-surface waters up to the surface.

Theory suggests that increases in greenhouse gases should weaken the atmosphere's three-dimensional circulation in the tropics, including the Walker circulation (Held and Soden, 2006). As temperatures rise and more water evaporates from the ocean, the amount of water vapor in the lower atmosphere increases rapidly. But physical processes prevent precipitation from increasing as quickly as the tropical atmosphere's water



[Right] A schematic view of the three-dimensional Walker Cell circulation. The Walker Cell circulation consists of trade winds blowing from east to west across the tropical Pacific Ocean (blue arrow), bringing moist surface air to the west. In the western tropical Pacific, the moist air rises, forming clouds. The rising air becomes drier as much of its moisture falls to the surface as rain. Winds a few miles high blow from west to east, moving the now drier air toward South America. The air descends back to the surface in the eastern tropical Pacific, dry and relatively cloud free, completing the circulation loop. Atmospheric sea level pressures are higher under the dry sinking air in the eastern Pacific than in the more warmer and more humid west.

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

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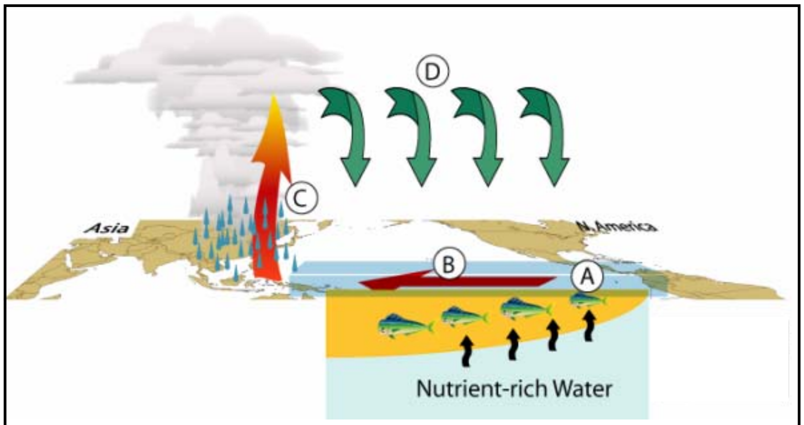
vapor content. Since, over time, the amount of water vapor transported to the upper atmosphere must remain in balance with precipitation, the rate at which moist air rises slows down to compensate. This leads to a slowing of the overall Walker Circulation.

To investigate the sensitivity of the Walker Circulation to climate variations, several different GFDL CM2.1 climate model simulations of the period 1860 to 2000 were examined. Some simulations included the observed increase in greenhouse gases; others included just the natural climate-altering factors of volcanic eruptions and solar variations.

It was found that only when the model included the historical rise of greenhouse gases could it simulate the observed amount of Walker Circulation weakening. Model experiments in which greenhouse gases did not vary in time did not show weakening. This indicates that human-induced climate change is the most plausible explanation for the observed Walker Circulation slow-down over the past 150 years.



[Above] In a warmer climate, (A) evaporation from the warm tropical Pacific Ocean increases strongly and moistens the lower atmosphere. East to west surface trade winds transport the warm moisture laden air to the the western Pacific (C), where the moist air rises and feeds rain, but the rainfall increases more slowly than the atmospheric moisture content. To compensate for the moisture imbalance, the trade winds (B) slow, as does the entire Walker Circulation loop, including the upper level winds (D).

► 21st Century Walker Circulation Projections

Since the GFDL CM2.1 climate model simulations of the past 150 years are consistent with the observed 3.5% weakening of the Walker circulation, it is reasonable to use the model to explore how the circulation might change in the future. GFDL CM2.1 model simulations of "If ... Then" future scenarios of greenhouse and aerosol emissions project the Walker Circulation to weaken by roughly an additional 10 to 15% during the 21st century [Vecchi and Soden, (2007)].

Should a long term 10 to 15% weakening of the Walker Circulation occur significant changes in precipitation patterns, winds and ocean currents may be expected to result over large regions. For example, the reduction of the upward flow of nutrient rich waters in the biologically productive tropical Pacific ocean could impact its marine ecosystem. Also, a weaker Walker Circulation may be linked to increased wind shear in the tropical Atlantic, potentially leading to conditions somewhat less favorable for hurricane development.

Of course, the ability of computed-generated 21st century projections to forecast is limited both by uncertainties in how the atmosphere's composition will change in the future and because the model themselves are imperfect. However, the GFDL CM2.1 model's ability to simulate previously observed Walker Circulation changes can increases one's confidence in its projections of future climate change in the tropics, even as more observations are gathered and models and theories are refined.

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 Soden, (2006): Robust responses of the hydrological cycle to global warming. *Journal of Climate*, Vol. 19, No. 14, pages 3354-3360. [LINK]

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]

Vecchi, et al.,, (2006): Weakening of tropical Pacific atmospheric circulation due to anthropogenic forcing, *Nature,* Vol. 441, pages 73-76, doi:10.1038. [LINK]

Vecchi and Soden,, (2007): Global warming and the weakening of tropical circulation, *Journal of Climate*, (in press).

Wittenberg, et al., (2006): GFDL's CM2 global coupled climate models - Part 3: Tropical Pacific climate and ENSO, *Journal of Climate*, Vol. 19, No. 5, pages 698-722. [LINK]

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

For more on this topic, including high resolution graphics, please see **"A Tropical Atmospheric Circulation Slow-Down"** 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 CM2.1 coupled model used to conduct the simulations is 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").

Regarding the climate forcing scenarios used in the model simulation discussed here, for the years prior to 2000, the model includes 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, solar irradance, volcanic aerosols, black and organic carbon aerosols, tropospheric sulfate aerosols, ozone and land surface changes). Run in this manner, the GFDL CM2.1 model has 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)]

The GFDL CM2.1 model provide a generally realistic simulation of the current tropical Pacific climate. [Wittenberg et al. (2006)]. The observed annual-mean trade winds and precipitation, sea surface temperature, surface heat fluxes, surface currents, Equatorial Undercurrent, and subsurface thermal structure are well captured by the model. GFDL CM2.1 simulates a robust El Nino - La Nina oscillation, with multi-decadal fluctuations in amplitude, an irregular period between 2 and 5 years, and a distribution of SST anomalies that is skewed toward warm events as is observed. The evolution of subsurface temperature and current anomalies is also quite realistic. However, the simulated SST anomalies are stronger than observed and the simulated patterns of tropical Pacific SST, wind stress, and precipitation variability are displaced 20°–30° west of the observed patterns.

To explore a range of "If ... Then" future scenarios, several different 21st century emissions scenarios have been used at GFDL and other climate research centers. The SRES A1B emissions scenario [IPCC (2000)]- one with a mid-level increase in 21st century greenhouse gas levels - was reported on in the Vecchi and Soden [2007] paper. The A1B scenario was shown 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, as a "middle of the road" emissions scenario, its tropical circulation response is generally characteristic of GFDL CM2.1 21 century projections.

Of course, some uncertainties in model projections of future climate remain and stem from the fact that we do not know how the atmosphere's composition will change in the future and because the models themselves are imperfect.

The model experiments from which the figures were derived have been documented in peer-reviewed scientific journals (see references below).

Model output files from some the experiments discussed 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.

⌂ 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.

⌂ 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.

⌂ Held and Soden, (2006): Robust responses of the hydrological cycle to global warming. *Journal of Climate*, Vol. 19, No. 14, pages 3354-3360.

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

⌂ 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.

⌂ Vecchi, et al., (2006): Weakening of tropical Pacific atmospheric circulation due to anthropogenic forcing, *Nature,* Vol. 441, pages 73-76, doi:10.1038.

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