cap in Greenland. For data collection, the researchers set up a weather station to relay observations and dug fox holes and additional cylindrical columns in the snow to take measurements of the "history" of the snow pack. Measurements included temperature, density, and O-18 isotope concentration of the snow and ice. Anderson said they discovered that while the ice cap on the edges of Greenland is melting more each summer, the cap in the center is actually getting thicker, as a result of more precipitation falling in recent years.

Anderson also described his research on sea ice, which has shown that the summer thickness and extent of polar sea ice have been decreasing, with a greater decrease in the thickness than in the extent, which has decreased only slightly, but not uniformly. The Beaufort Sea area has been melting earlier in recent springs, while the area north of Greenland has been melting slower and later. Last year was unusual, with the ice along the north coast of Asia melting very early and the ice in Hudson Bay melting very late. The delayed Hudson Bay melting was symptomatic of the unusually cool summer over most of eastern North America.

Anderson concluded his presentation by listing opportunities to use polar ice research data, such as studying atmospheric correlations (e.g., El Niño weather patterns and the Arctic Oscillation), and applications in numerical modeling and in biology (mainly whale migration patterns). In the future he also intends to address annual freeze patterns.

—John Roth
Omaha–Offutt chapter

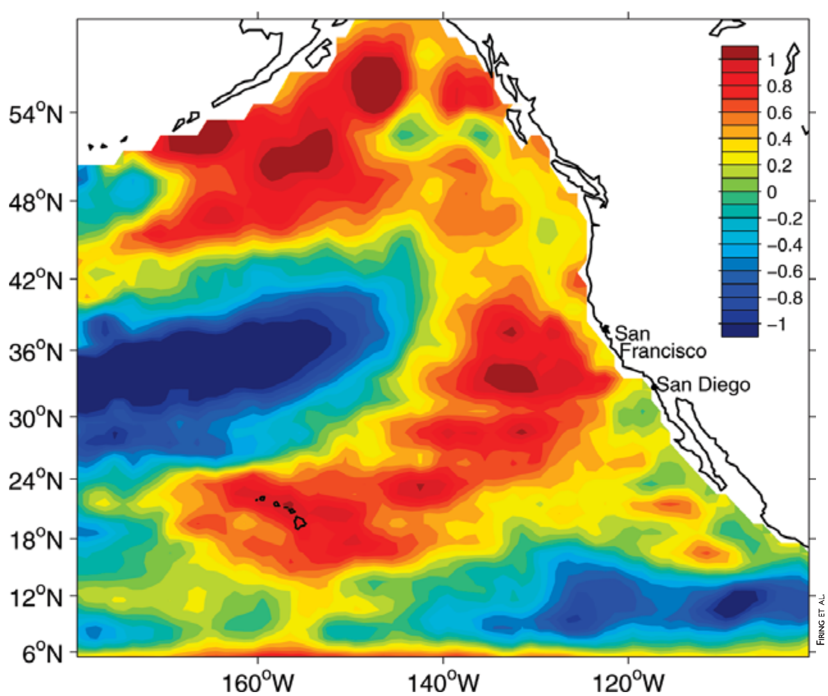
PAPERS OF NOTE

Interdecadal Sea Level Fluctuations at Hawaii

Interdecadal sea level fluctuations at Hawaii are correlated with sea surface height (SSH) variations over a significant portion of the North Pacific (see figure) as a result of common forcing by large-scale, low-frequency atmospheric modulations. These atmospheric modulations, rather than oceanic Rossby wave propagation, are the main connection between Hawaii sea level and sea level at California, or Hawaii sea level and tropical variability such as El Niño–Southern Oscillation (ENSO).

Over the past century, tide gauges in Hawaii have recorded interdecadal sea level variations with 10–25-yr time scales and peak-to-trough changes of ~5 cm. The Hawaii record is similar to long sea level records at San Francisco and San Diego, California. Unlike the California records, however, it does not have a clear dependence on ENSO. We addressed the questions of what forces interdecadal Hawaii sea level and how it is related to other interdecadal variability.

The Hawaii sea level record was compared to other oceanic and atmospheric variables, including SSH from the Topex/Poseidon altimeter, dynamic height from the *World Ocean Atlas* and from the Hawaii Ocean Time-series, surface winds and pressure from the NCEP re-



Regression (at zero lag) of Topex/Poseidon sea surface height anomaly on Hawaii sea level. The data have been smoothed with an annual Gaussian filter.

analysis, scatterometer winds from the World Ocean Circulation Experiment (WOCE), the Southern Oscillation Index, and the Pacific North America index (PNA), which represents midlatitude atmospheric variability and its teleconnections to tropical ENSO variability. After finding correlations between interdecadal Hawaii sea level and SSH, dynamic height, local wind and pressure patterns, and the PNA, we attempted to reproduce the Hawaii sea level signal using a simple model forced by NCEP wind stress curl, and including mode-one Rossby wave propagation.

This model was not able to explain a significant portion of interdecadal Hawaii sea level variability. Forcing with WOCE wind stress data, however, showed some promise of better results, suggesting a return to the problem when there is a longer time series of accurate satellite-based wind stress available.—YVONNE L. FIRING (UNIVERSITY OF HAWAII AT MANOA), MARK A. MERRIFIELD, THOMAS A. SCHROEDER, AND BO QIU. *"Interdecadal Sea Level Fluctuations at Hawaii," in the November* Journal of Physical Oceanography.

KELVIN–HELMHOLTZ INSTABILITY IN AN ANVIL CLOUD

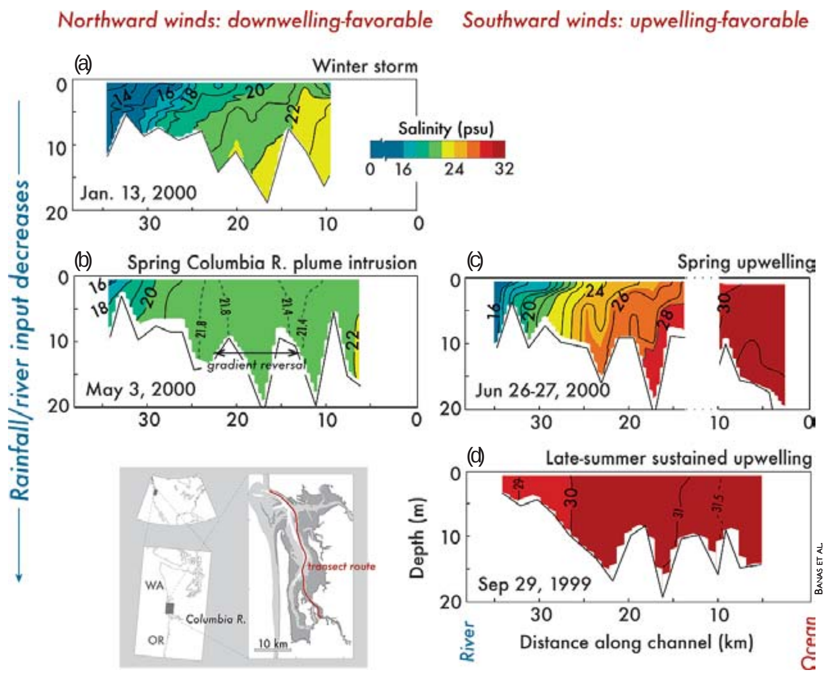
Although previous studies associate large-amplitude shear instability with Kelvin–Helmholtz billow clouds along frontal zones, to our knowledge, until now, no large-amplitude Kelvin–Helmholtz billows have been documented inside a tropical convective anvil. They were documented with the University of Miami 95-GHz cloud radar over Miami on the evening of 21–22 July 2002.

The billows lasted more than 3 h, suggesting that internal anvil circulations helped continuously regenerate the instability, even more than an hour after the demise of all deep convection. At times, the shear layer was small enough to be contained within a single radar gate (30 m). In addition to the main shear axis along which the Kelvin–Helmholtz instability developed, several identifiable weaker shear layers existed in the anvil, evident in the Doppler spread, especially of the aged anvils. The analysis demonstrates that the frequent assumption of an anvil as a well-mixed layer is not always valid. Hence, models built on this assumption will need to be reevaluated.—Jacob M. Petre (The Pennsylvania State University) and Johannes Verlinde. *"Cloud Radar Observations of Kelvin–Helmholtz Instability in a Florida Anvil,"* in the October Monthly Weather Review.

Questioning Assumptions about Estuary Balance

Analytic theories of estuarine circulation almost always assume a steady balance between salt flushed seaward by river flow and salt returned to the estuary by tidal and baroclinic circulations. Real estuaries, however, are often forced by environmental changes too rapid to be followed in near-equilibrium: large changes over a few days in river input, local wind stress, sea level, ocean water properties, and tidal range are all well documented. In a new study of Willapa Bay, Washington, these transients actually drown out the mean for much of the year, suggesting a general analytic approach that emphasizes, rather than averages away, such unsteadiness.

Willapa is the largest in a chain of small, relatively unstudied estuaries on the U.S. Pacific Northwest coast (the Columbia River being the dramatic exception) that have large tidal ranges (in Willapa, 50% of total volume is intertidal) and highly seasonal river input. In addition, wind shifts on the 2–10-day time scale of synoptic weather patterns force shifts between coastal upwelling and downwelling (and thus salinity changes of several ppt) in all seasons. The Columbia River plume, furthermore, episodically fills the nearshore waters of Washington during downwelling conditions. As a result of this complex forcing, over the course of one year Willapa occupies most of the possible states of a partially mixed estuary (see figure).



Salinity sections down the main channel of Willapa Bay (map, lower left) on four days in 1999 and 2000. (a) During high winter riverflows the bay is well-stratified, a classic partially mixed estuary. (b) Often, however, high-flow events are accompanied by intrusions of the Columbia River plume, which erase all stratification in the outer estuary and can even reverse the salinity gradient between river and ocean. (c) In spring, plume intrusions alternate on the 2–10-day scale with fair-weather upwelling, which rapidly reestablishes salinity gradients. (d) In late summer, when upwelling is sustained and river flow close to zero, these gradients vanish again, and the bay becomes a lagoon or tidal embayment.

The relationship between these hydrographic variations and the underlying circulation—the overall estuary–ocean exchange rate—is not direct, however. By regressing the rate of change of estuarine salt storage to the axial salinity gradient, we calculated an effective horizontal diffusivity, parameterizing all up-estuary salt flux, as a function of river flow, and then compared this diffusivity to the value that would maintain a steady salt balance. For most of the year, there is a net loading of salt into the estuary; the compensating net loss comes during high-flow winter storms. This disequilibrium is made possible by the strength of lateral tidal stirring, which is independent of river flow and the salinity field. Thus, the variability of Willapa's salinity and other properties turns out to be evidence of an exchange circulation not unexpectedly variable but unexpectedly constant across changing forcing.—N. S. Banas (University of Washington), B. M. Hickey, P. MacCready, and J. A. Newton. *"Dynamics of Willapa Bay, Washington: A Highly Unsteady, Partially Mixed Estuary,"* in the *November* Journal of Physical Oceanography.

Cyclones with Multiple Warm Front–like Zones

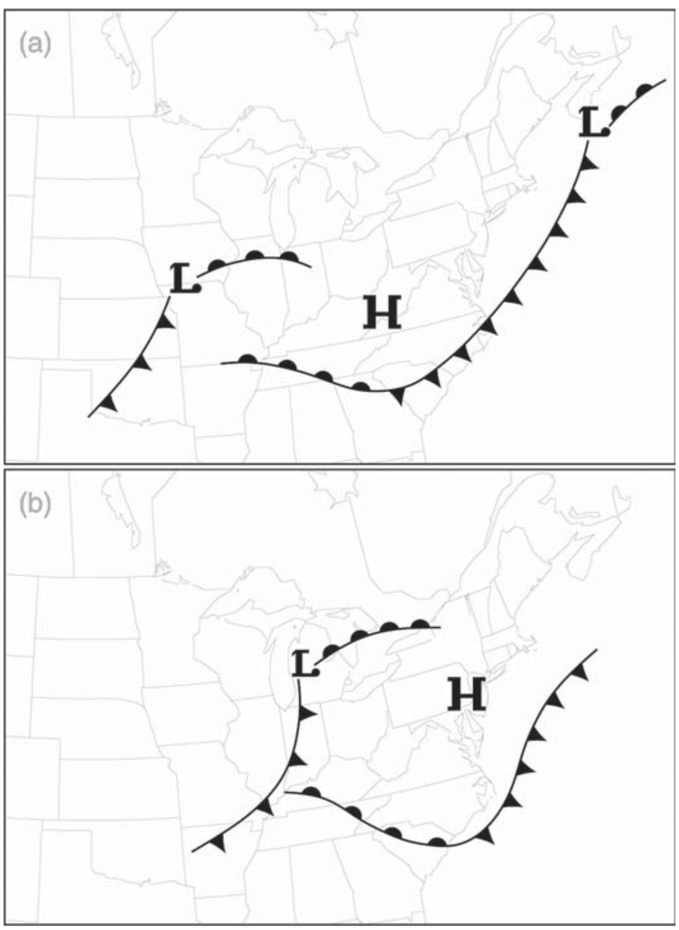
Forecasters at the Storm Prediction Center have long observed extratropical cyclones over the central United States with two or more warm front–like baroclinic zones. These baroclinic zones can serve as a focal point for the development of severe convective storms, yet research on these baroclinic zones has not been performed. Our climatological study shows the frequency with which various mechanisms lead to these structures.

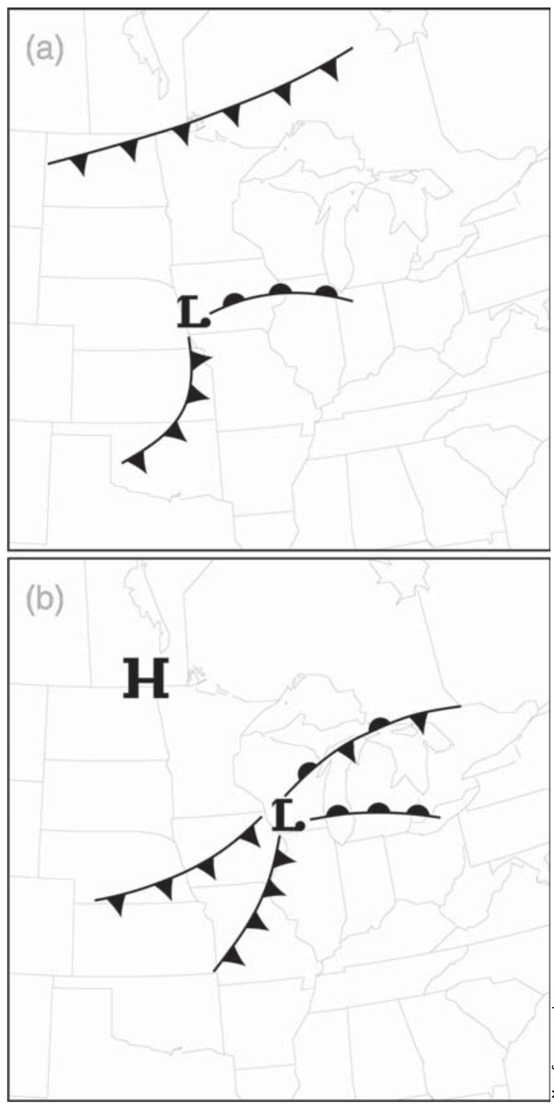
We examined 108 cyclones over two years (1982 and 1989) and found that 42% have multiple baroclinic zones. Ninety-four percent of all baroclinic zones were coincident with a significant dewpoint temperature gradient, and 81% of all baroclinic zones possessed a wind shift of at least 20°, suggesting that these baroclinic zones were significant airmass and airstream boundaries.

Although cyclones with multiple baroclinic zones formed in a variety of ways, two synoptic patterns dominated. Thirty-eight percent of cyclones with multiple baroclinic zones formed as a cold or stationary front from a previous cyclonic system was drawn into the circulation of a cyclone center, forming the southern baroclinic zone. Twenty-two percent of cyclones with multiple baroclinic zones formed as a cold front to the north of the cyclone center was drawn into the circulation of the cyclone, forming the northern baroclinic zone. In cyclones with multiple baroclinic zones, 58% of the southern baroclinic zones were associated with reports of severe weather. Despite the increased potential for severe convective storms along these southern baroclinic zones, 51% were not identified on the surface analyses made at the National Meteorological Center (now the National Centers for Environmental Prediction).

Fig. 1 (below). Schematic illustration of the attachment of the southern baroclinic zone.

Fig. 2 (at right). Schematic illustration of the attachment of the northern baroclinic zone.





Metz, Schultz, and Johns

CAMELS ARE QUIETER, TOO

After examining global satellite images from the last 50 years, Andrew Goudie of the University of Oxford, England, has come to a conclusion: it's dusty out there. Goudie's research, presented in August at the International Geographic Congress in Glasgow, Scotland, shows that about 3 billion tons of dust is blowing through the sky each year. Of particular concern are dust storms that originate in the Sahara Desert in Africa. Goudie found that such storms now occur 10 times more frequently than they did 50 years ago. He attributes much of this increase to the replacement of camels with autos as the new method to cross the desert—what Goudie has coined "Toyota-isation" due to the many Toyota Land Cruisers that are used for this purpose. "If I had my way, I would ban them from driving off-road," Goudie says. He explains that the activity of the autos takes away a layer of lichen or algae that normally covers the sand and prevents it from blowing away.

The results of this study yield two important implications. First, a single conceptual model of cyclone structure and evolution, like the Norwegian cyclone model, is inadequate to explain the observed variety of cyclones in the central United States. This evidence indicates forecasters and research scientists must be alert to the potential for weather systems that differ from previously published research. Second, the importance of performing manual analyses of the surface data in real time and recognizing these baroclinic zones cannot be overstated, given their association with severe convective storms.—NICHOLAS D. METZ (OKLAHOMA WEATHER CENTER RESEARCH EXPERIENCES FOR UNDERGRADUATES/VALPARAISO UNIVERSITY), DAVID M. SCHULTZ, AND ROBERT H. JOHNS. *"Extratropical Cyclones with Multiple Warm Front–like Baroclinic Zones and Their Relationship to Severe Convective Storms," in the October* Weather and Forecasting.

RADAR VORTEX DETECTION: SIGN OF TORNADOES?

Mesoscale vortices—vertically rotating columns of air that can extend to 10 km in diameter and over 10 km deep—are often associated with severe weather phenomena such as tornadoes (a smaller, but stronger vortex). However, in comparing approximately 100,000 radar-detected mesoscale vortices with ground truth tornado reports, we find that only a very small percentage (<5%) of all vortex detections are associated with the occurrence of a tornado. The results are very much dependent on how vortices are determined algorithmically: tornadic percentage increases to approximately 10% as the criteria for defining a vortex detection as a mesocyclone detection become more strict; however, many tornadic events are only associated with weaker detections, and are "missed" when the detection threshold is increased.

Early mesocyclone research suggests that as many as 50% of radar-detected mesocyclones in supercell-type thunderstorms are tornadic. More recent research suggests this number ranges between 20% and 30%. Some research using much larger datasets even suggests that as few as 2% of all mesocyclone detections are tornadic.

This range of results may seem excessive, but must be taken in the light of significant changes over the years in the criteria for "detecting" a mesocyclone. The criteria for a mesocyclone detection were often set high so that vortices not associated with the primary mesocyclone did not contaminate the results. In constructing our dataset of mesocyclones, we used a radar algorithm that uses much lower threshold criteria and more robust diagnosis techniques to produce a detection. However, the mesocyclone detection algorithm (MDA) is designed to pick up vortices that are not necessarily associated with a classic tornado-producing mesocyclone. Thus, a detection dataset produced by the MDA will contain more than just "mesocyclone" detections.

This research involves two years worth of data from six Southern Plains radars. The primary goal is to better determine the relative proportion and characteristics of tornado-producing mesocyclones, and what are the best criteria to use when classifying vortex detections as mesocyclones. The large detection datasets used here may not be large enough to produce long-term statistics. As the mesocyclone dataset increased in size with the addition of the second year of data, the percentage of detections classified as tornadic decreased. This decrease may well continue for even larger datasets, resulting in the possibility that less than 2% of the mesocyclone detections produced by the MDA are tornadic using the lowest reasonable classification threshold. Using the highest, no more than 10% to 12% of detections are likely to be tornadic. Repeating this work with a much larger dataset several years from now could provide very interesting results.—THOMAS A. JONES (UNIVERSITY OF OKLAHOMA/UNIVERSITY OF ALABAMA IN HUNTSVILLE), KEVIN M. MCGRATH, AND JOHN T. SNOW. *"Association between NSSL Mesocyclone Detection Algorithm-Detected Vortices and Tornadoes," in the October* Weather and Forecasting.

ECOSYSTEMS SERVING AS A CLIMATE MEMORY MECHANISM

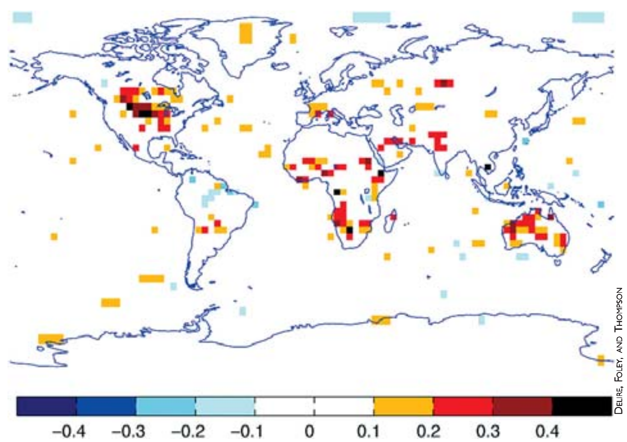
With a fully coupled atmosphere–biosphere model, we show that vegetation dynamics (i.e., the changes in vegetation cover over time, such as changes in forest and grass cover) may be capable of producing long-term variability in the climate system, particularly through the hydrologic cycle and precipitation. We find that dynamic interactions between the atmosphere and vegetation enhance precipitation variability on land at time scales from a decade to a century. These interactions introduce persistent precipitation anomalies in several ecological transition zones: between forest and grasslands in the North American Midwest, in southern Africa, and at the southern limit of the tropical forest in the Amazon basin; and between savanna and desert in the Sahel, Australia, and portions of the Arabian Peninsula (see figure).

Until now, interannual to interdecadal variability was mainly attributed to the interaction between atmospheric and oceanic processes, with the ocean acting as the "memory" of the climate system. Here, we show that terrestrial ecosystems, because they operate on time scales of years to centuries, can also provide a memory to the climate system, causing important variations of climate and ecological conditions on interannual to interdecadal time scales.

To show this, we performed two simulations of the global climate, with fixed climatological sea-surface temperatures: one including vegetation as a dynamic boundary condition and the other keeping vegetation cover fixed. The comparison of the simulated precipitation fields and their power spectra shows that vegetation dynamics enhances the long-term variability of the precipitation. Slow changes in the vegetation cover, resulting from a "red noise" integration of high-frequency atmospheric variability, are responsible for generating this long-term variability.

Decadal variability of precipitation has been documented in the Sahel and the U.S. Midwest. Observations and models suggest that vegetation dynamics play an important role in the Sahel, while the causes in the Midwest are still a matter of debate. Our results indicate that vegetation feedbacks might play a role.

We have only considered natural ecosystems in our study. To analyze how current terrestrial vegetation affects climate variability, we should include managed ecosystems as well as processes affecting the functioning of terrestrial ecosystems—like soil erosion or natural disturbances—that are not represented in this model. —CHRISTINE DELIRE (UNIVERSITY OF WISCONSIN—MADISON/UNIVERSITÉ MONTPELLIER II), JONATHAN A. FOLEY, AND STARLEY THOMPSON. *"Long-Term Variability in a Coupled Atmosphere–Biosphere Model," in the 15 October* Journal of Climate.



Regions where precipitation anomalies persist for more than 1 yr (shown by the lagged autocorrelation coefficient of the yearly precipitation time series for the dynamic vegetation simulation with a 1-yr time lag).

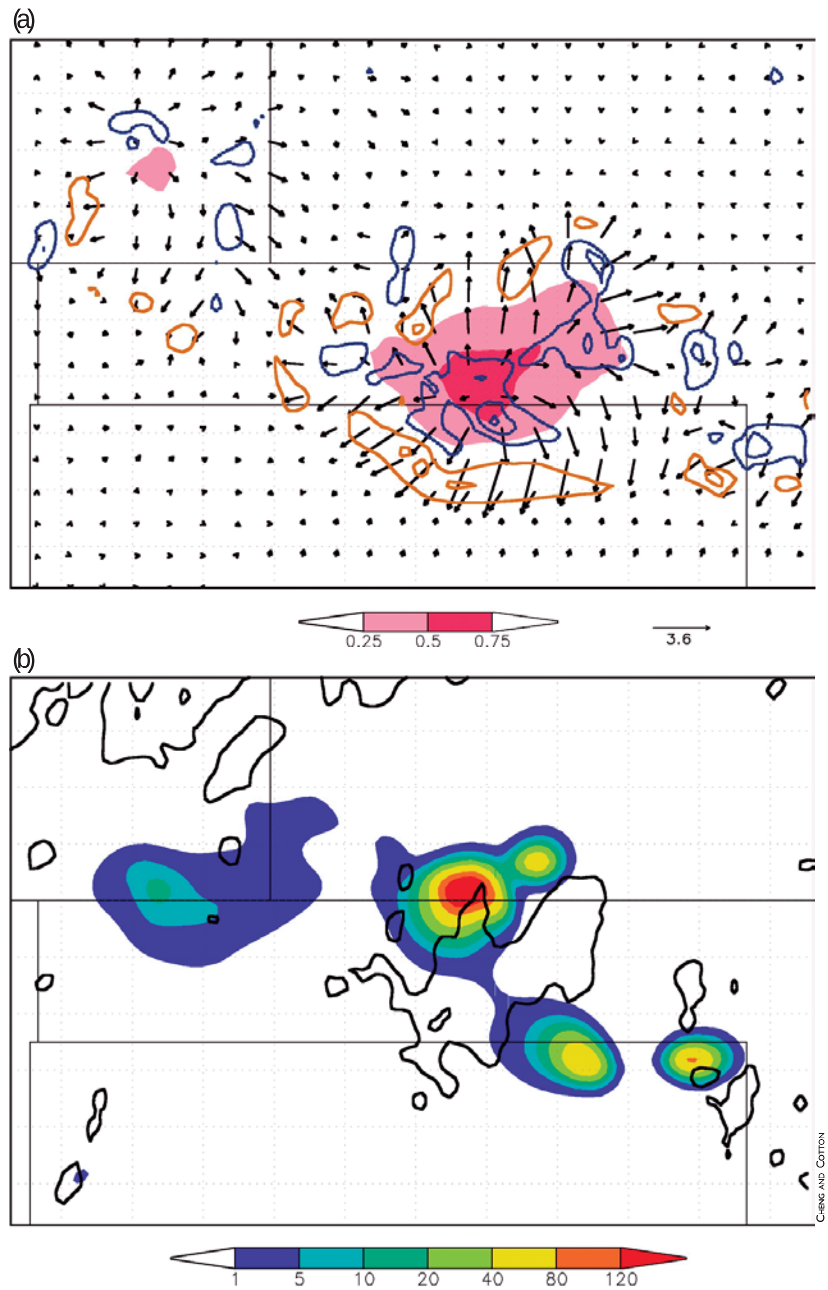
GENESIS OF MESOSCALE CONVECTIVE SYSTEMS ABOVE UNEVEN SOIL MOISTURE CONDITIONS

Heterogeneities in vegetation type, soil type, or soil moisture can induce physiographically forced mesoscale circulations through sensible heat flux gradients at the surface. These mesoscale circulations can provide regions of convergence, triggering deep convection. Convection often organizes itself on the mesoscale, leading to convective systems (MCSs) hundreds of kilometers across, which produce a large part of the precipitation in the central United States in summer. Our studies show that the location of these systems may be affected by soil moisture heteorogeneity.

We examined the sensitivity of a simulation of the genesis of a mesoscale convective system to the initial soil moisture distribution. In the initialization of this cloud-resolving simulation, we used antecedent precipitation to make the soil moisture distribution heterogeneous. In the sensitivity experiments, we 1) removed the fine-scale features of the soil moisture distribution, 2) used homogeneous soil moisture initialization, and 3) displaced a soil moisture anomaly from its initial location.

Most of the experiments produced qualitatively similar results, producing a quasicircular cloud shield, indicating the importance of large-scale dynamics. However, the soil moisture distribution affected where convection was likely to occur. For the case examined, a wet soil moisture anomaly suppressed convection, but convection preferentially occurred on the periphery of the wet soil moisture anomalies due to the mesoscale circulations there. Sensitivity experiments also showed that soil moisture with grid spacing of 40 km may be adequate to initialize a cloud-resolving model for MCS simulations.

Because of the negative feedback between convection and soil moisture in this case, we surmise that the soil moisture gradient will be reduced with time for cases like the one in this study. Because the MCS case studied here was weakly forced by its large-scale environment, it would be of interest in future studies to test the effects of small-scale soil moisture anomalies on large-scale environments with differing strengths.—William Y. Y. Cheng (Colorado State University) and William R. Cotton. *"Sensitivity of a Cloud-Resolving Simulation of the Genesis of a Mesoscale Convective System to Horizontal Heterogeneities in Soil Moisture Initialization," in the October* Journal of Hydrometeorology.



Results from a selected numerical experiment in the cloud-resolving grid: (a) anomalous vertical velocity at the lowest level above ground (in contour intervals of 2 cm s^{-1}) with orange (blue) representing upward (downward) motion and anomalous sea level pressure in shading (hPa), superposed with anomalous horizontal wind vector (m s^{-1}) due to heterogeneous soil moisture distribution during the pre-MCS genesis phase (at model hour 6). (b) Precipitation rate (mm h^{-1}) in shading superposed with contour of initial volumetric soil moisture at 50% saturation at model hour 9.75 during the MCS genesis phase.