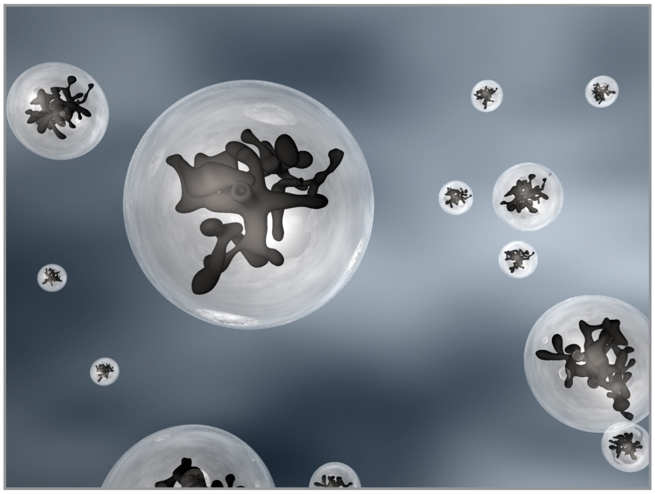
2012 Research Accomplishments

The U.S. Department of Energy's (DOE) Atmospheric System Research (ASR) program seeks to advance process-level understanding of the key interactions among aerosols, clouds, precipitation, radiation, dynamics, and thermodynamics, with the ultimate goal of reducing the uncertainty in global and regional climate simulations and projections. These research highlights represent key ASR accomplishments in 2012.

More Like Shades of Gray: The Effects of Black Carbon in Aerosols

Scientific Question. Every day, the incomplete combustion of fossil fuels, biofuels, and biomass forms black carbon particles in the atmosphere. Once deposited in the Arctic, these black carbon particles darken the surface of snow and ice, increasing the amount of the sun's energy converted to heat rather than reflected back to space. At a larger scale, sunlight absorbed by atmospheric black carbon is also converted into heat and increases temperatures, affecting atmospheric circulation and cloud development. What researchers want to know is how much heating takes place and how that change affects global climate.



Black to the Core. ASR-funded scientists are combining field and laboratory measurements to understand more about the physical properties of aerosols containing black carbon and how they impact global warming.

Through measurements in the field and in the laboratory, ASR research projects in the last year have advanced the understanding of the impacts from black carbon aerosol in the following ways:

- In examining how the amount of black carbon aerosol and the size of snow grains affect heat generation at the Earth's surface, researchers confirmed model predictions and found that the larger the grains of snow, the more heat was generated by the black carbon contamination.
- Research into the different physical characteristics of individual black carbon particles mixed together with other components—commonly modeled as a light-absorbing inner core surrounded by a non-absorbing shell—revealed that many particles are actually shaped differently.
- Measurements of black carbon in the atmosphere around urban centers in California indicate that when black carbon mixes with other atmospheric components, the particle's ability to absorb light and generate heat is significantly less pronounced than often simulated in global climate models.

Impact. Various ASR research efforts coupled laboratory and field measurements to yield a better understanding of the concentrations and physical characteristics of aerosols containing black carbon. The research confirmed that black carbon contamination on snow contributes to near world-wide melting of ice, which exacerbates global warming. Using sophisticated instruments, scientists also determined that black carbon particles can adopt a range of internal configurations, which may affect their ability to absorb sunlight and heat the atmosphere. Finally, measurements at specific locations showed that black carbon's influence on light absorption may need to be modeled differently. When combined, the ASR-funded research demonstrates that a more accurate representation of the physical characteristics of black carbon in models can greatly affect the calculated influence of black carbon on global warming and supports development of more effective ways to mitigate the impacts of black carbon.

Method. To determine the effect of black carbon and snow grains on heating, researchers generated snow in the laboratory and measured the effects of adding various amounts of black carbon. To learn more about the structure of black carbon, scientists used the single particle soot photometer, or SP2, one of the few instruments that can quantitatively characterize black carbon down to individual particles. Two of the projects also used observations from a large field measurement campaign funded by DOE, the Carbonaceous Aerosols and Radiative Effects Study, as the basis for their analyses.

References:

Cappa, CD, et al. 2012. "Radiative Absorption Enhancements Due to the Mixing State of Atmospheric Black Carbon." *Science* 337: 1078, doi:10.1126/science.1223447.

Hadley, OL, and TW Kirchstetter. 2012. "Black-carbon reduction of snow albedo." *Nature Climate Change Letters*: doi:10.1038/NCLIMATE1433.

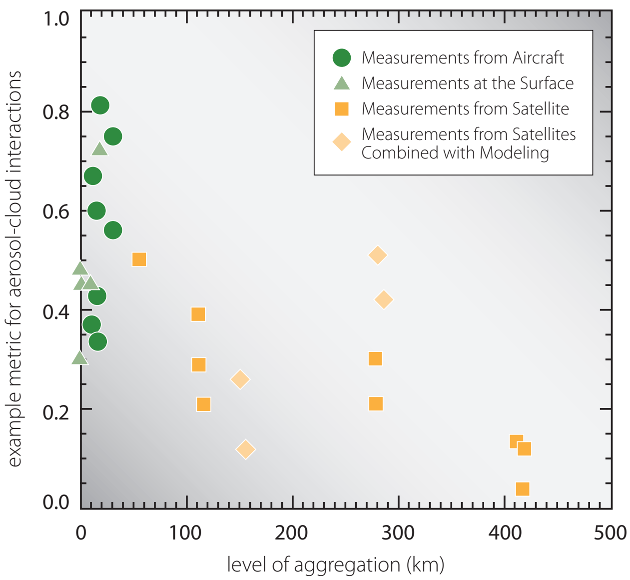
Sedlacek, AJ, et al. 2012. "Determination of and evidence for non-core-shell structure of particles containing black carbon using the Single-Particle Soot Photometer (SP2)." *Geophysical Research Letters* 39: L06802, doi:10.1029/2012GL050905.

Scale Shows True Weight of Aerosol Effects on Clouds

Scientific Question. Aerosols—tiny airborne particles from sources like pollution or desert dust—can increase the brightness of clouds, changing how much of the sun's energy is reflected or radiated back to space compared to how much is trapped in the atmosphere. Some current climate change estimates are based on models that combine or aggregate aerosol and cloud observations in such a way as to lose important details contained in the observations. Now, researchers funded by the ASR Program have demonstrated that such aggregated data result in computed values, or metrics, of aerosol-cloud interactions that are very different than those derived from disaggregated data. Comparisons of metrics from the two types of data yield a range of values that are often treated as equivalent when, in fact, they may have physically different interpretations.

Impact. Disaggregated data represent very specific processes on the fairly small scale of cloud drop formation, while aggregated data represent the full range of processes and feedbacks associated with larger-scale aerosol, cloud, and meteorological conditions. Using this range of metrics in climate models is responsible, in part, for the large uncertainty associated with the impacts of aerosol-cloud interactions on Earth's energy balance. The current research sheds light on over-simplification in the existing range of published metrics and raises the question as to what the range of metrics actually represents.

Based on an understanding of biases revealed in this study, the authors have proposed approaches that combine distributions of small-scale observations, which retain variance in the measured property, with process-scale models. Such approaches include combining multiple available passive and active satellite-based sensors with airborne and ground-based measurements,



Differing Values. Derived from aircraft and surface observations, which represent disaggregated data, differ from those derived from satellite-based data, which represent data aggregated at a range of levels. Currently, many climate change models treat the two types of data the same.

process-scale modeling, and extrapolating results using disaggregated data. These approaches will lead to more appropriate use of observations in models of future climate, thus improving the accuracy of the models.

Method. To explore the causal relationship between aerosol and cloud properties, the researchers used satellite-based data; ground-based data from the Atmospheric Radiation Measurement (ARM)Mobile Facility at Pt. Reyes, California; and output from the Weather and Research Forecasting model. As observations become more aggregated, the original range of values was reduced and the relationship between the aerosol and cloud properties changed. At the fine scale, the specific causal changes were easier to isolate (change x in aerosol equals change y in cloud). However, these causal changes become obscured by many other processes operating at the aggregated scale.

Values derived from aircraft and surface observations, which represent disaggregated data, differ from those derived from satellite-based data, which represent data aggregated at a range of levels. Currently, many climate change models treat the two types of data the same.

Reference:

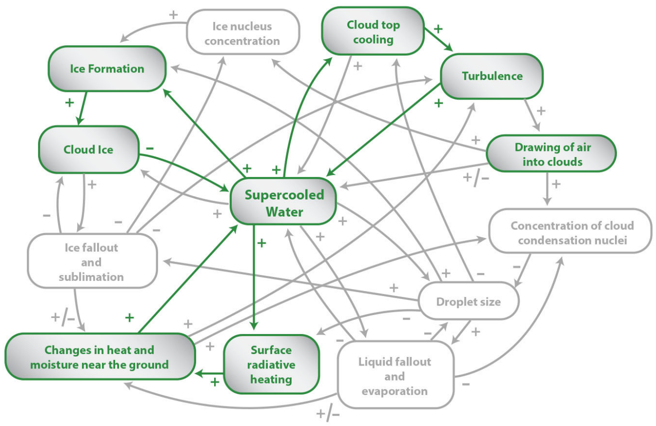
McComiskey, A, and G Feingold. 2012. "The scale problem in quantifying aerosol indirect effects." *Atmospheric Chemistry and Physics* 12: 1031–1049, doi:10.5194/acp-12-1031-2012.

The Complexity of Arctic Clouds

Scientific Question. Scientists refer to clouds containing both ice and supercooled water as "mixed-phase" clouds. In the Arctic, these clouds occur frequently during all seasons, and can persist for many days at a time. This persistence is remarkable given the inherent instability of ice-liquid mixtures. How is this possible?

Scientists funded by ASR have identified complex buffering processes that allow mixed-phase clouds to persist in the Arctic long after they would have dissipated in other environments. These processes, including the formation and growth of cloud droplets, limited cloud ice formation, movement of radiation through the tops of clouds, turbulence, and possible contributions from heat and moisture changes near the ground, all participate in an interconnected web of interactions that support the resilience of mixed-phase clouds.

Impact. The ability to identify and characterize complex interactions that influence the formation and life cycle of mixed-phase clouds is critical to improve the accuracy of computer models that predict future climate. This is especially true for the Arctic, which is particularly sensitive to climate change. Mixed-phase clouds play a critical role in modulating Arctic energy flow. As little as a 5% shift in the frequency of occurrence between these clouds and clear conditions could have a profound influence on important Arctic climate indicators,



Arctic Climate Feedbacks. The processes that allow mixed-phased clouds to persist in the Arctic are surprisingly complex and could impact the accuracy of climate models.

including sea-ice concentration, freshwater runoff, and productivity and diversity in marine and terrestrial environments.

Method. The research team reviewed the scientific literature on Arctic mixed-phase clouds and assembled important findings from recent DOE field studies and individual research projects on this topic. From this comprehensive review, they developed a conceptual model that more closely represented observations of mixed-phase clouds within the Arctic environment. The refined model allowed the team to describe complex feedbacks among various local processes that combine to sustain the resilient clouds.

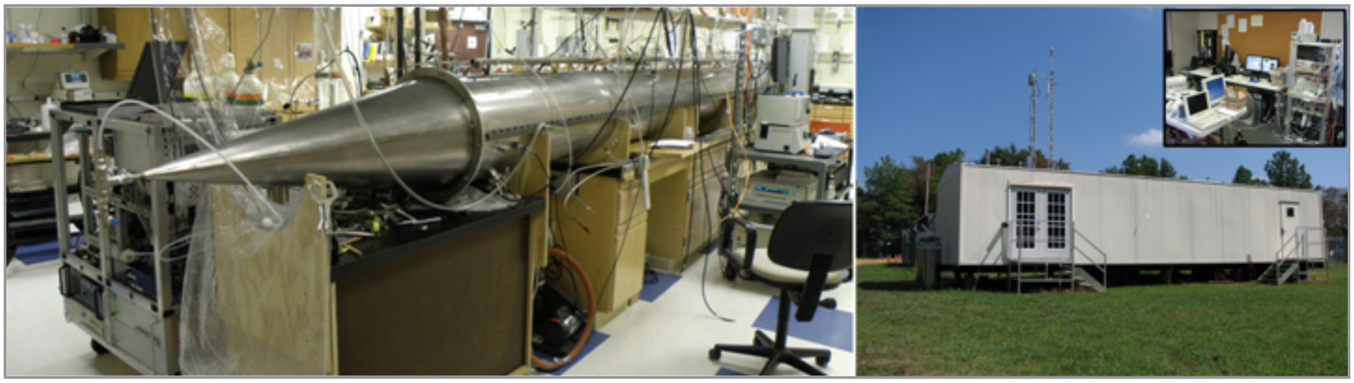
Reference:
Morrison, H, G de Boer, G Feingold, J Harrington, M Shupe, and K Sulia. 2012. "Resilience of persistent Arctic mixed-phase clouds." *Nature Geoscience* 5: 11–17, doi:10.1038/ngeo1332:

Probing the Birth of New Particles

Scientific Question. On local to global scales, newly formed particles contribute significantly to the concentration of atmospheric particles. In general, particles influence climate by affecting the balance of atmospheric radiation, both directly through scattering and absorbing incoming solar radiation and indirectly through impacts on cloud properties and lifetimes. However, the process of particle formation has long puzzled scientists. Currently, researchers model particle formation based on the interactions of only sulfuric acid and water, key components of these particles, but theory and observations simply do not match. Then too, modeling requires access to sophisticated computers, which can be costly.

Now researchers funded by ASR have proposed two conceptually new approaches that build on field measurements, laboratory experiments, and theoretical computations. Both approaches tackle the problem of modeling particle formation by looking at the process as a series of acid-base chemical reactions that now include interactions with amines and ammonia. By identifying key steps in the series, these approaches can quantitatively predict formation rates and concentrations of newly formed particles, while keeping the computational cost low enough to be suitable for inclusion in large-scale atmospheric models.

Impact. Particle formation plays an important role in predicting aerosol impacts on climate. Realistic assessment of these impacts in large-scale atmospheric simulations depends heavily on particle formation models that not only accurately predict formation rates but require less use of costly computing resources. These two new models provide a framework to better understand how these particles form, and incorporate the complex role of amines and ammonia, which has now been shown to be essential for new particle formation.



The Flow of Particles. ASR researchers used complex equipment such as this flow tube (left) and outdoor measurement facilities (right) to determine the series of steps needed to form particles in the atmosphere, resulting in more accurate models.

Method. Scientists developed the two approaches from different vantage points. One approach involved experiments in a laboratory flow tube in which gaseous chemicals and water vapor interact to form particles. Scientists then measured how the particles were distributed in the vapor using a mobility scanner that determined particle sizes. In the other approach, researchers combined real-world observations from intensive field measurement campaigns in Atlanta and Mexico City with laboratory experiments. Using new instruments developed for this effort, scientists measured a number of previously inaccessible quantities, including the concentrations of reacting vapors and of particles down to sub-nanometer sizes. In both cases, researchers found that, by using the new data and identifying the key series of steps needed to form particles, they were able to capture the necessary complexity of particle formation in a simple model.

References:

Chen, M, et al. 2012. "Acid–base chemical reaction model for nucleation rates in the polluted atmospheric boundary layer." *Proceedings of the National Academy of Sciences*: doi:10.1073/pnas.1210285109.

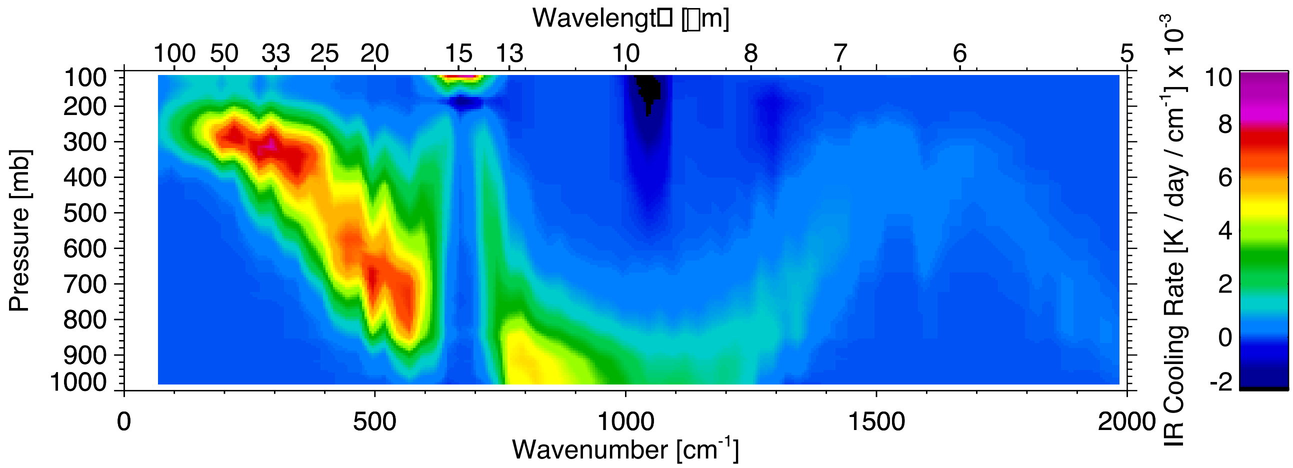
Dawson, ML, et al. 2012. "Simplified mechanism for new particle formation from methanesulfonic acid, amines, and water via experiments and ab initio calculations." *Proceedings of the National Academy of Sciences*: doi:10.1073/pnas.1211878109.

Looking at the Full Spectrum for Water Vapor

Scientific Question. Absorption and emission of infrared radiation by water high in the atmosphere helps cool the earth and fuels the updrafts and downdrafts that can lead to cloud formation. Until recently, technology limitations prevented scientists from collecting data in one of the most important subsections of the infrared scale, the far-infrared. Lacking such data, global climate models cannot accurately simulate the movement of heat through the atmosphere.

A two-phased field measurement effort, called the Radiative Heating in Underexplored Bands Campaign, or RHUBC, used newly developed spectrometers to gather radiation data across the entire infrared scale. Using these data, researchers sponsored by ASR were able to improve radiative transfer calculations—the portion of global climate models that simulate how radiant energy moves through the atmosphere.

Impact. Earth's climate is driven by the total incoming solar energy versus outgoing infrared energy, as well as how this radiant energy is distributed within the atmosphere. The ASR studies demonstrated and then confirmed that improved radiative transfer calculations can result in significant changes in how climate models



Radiative Cooling Across the Full Infrared Spectrum. The far-infrared (the left half of the figure, from 15 to 1000 microns) plays a key role in heat transfer in the atmosphere, but scientists could not measure it, and model calculations were consequently very uncertain. Field observations from newly developed spectrometers, followed by ASR modeling studies, have improved and confirmed advances in radiative transfer calculations.

predict temperature, humidity, cloud amount, and radiative cooling in the middle and upper troposphere in all regions of the globe, from the tropics to the poles. Studies like this illustrate the importance of using accurate treatments of radiation within global climate models and provide motivation for different modeling groups to improve this aspect of their models—especially since there are large discrepancies among the radiation treatments in various models. The RHUBC analysis also identified smaller second-order effects, such as temperature effects on water absorption, that are still deficient in the radiative transfer model and need to be improved.

Method. Scientists used data from the first RHUBC campaign on the North Slope of Alaska to revise radiative transfer calculations and test them in a climate model. Compared to the observations, the revised calculations improved model results for water vapor absorption in the far-infrared part of the spectrum by a factor of two. Scientists then used data from the second field measurement campaign, conducted at 17,500 feet in northern Chile's Atacama Desert, where the water vapor amount was five times drier, to evaluate how the revised radiative transfer calculations stood up under different conditions. Data from the second test largely confirmed the improvement in the original calculations.

References:

Turner, D, et al. 2012. "Ground-based high spectral resolution observations of the entire terrestrial spectrum under extremely dry conditions." *Geophysical Research Letters* 39: L10801, doi:10.1029/2012GL51542.

Turner, D, A Merrelli, D Vimont, and E Mlawer. 2012. "Impact of modifying the longwave water vapor continuum absorption model on community Earth system model simulations." *Journal of Geophysical Research* 117: D04106, doi:10.1029/2011/JD016440.

Mlawer, E, V Payne, J-L Moncet, J Delamere, M Alvarado, and D Tobin. 2012. "Development and recent evaluation of the MT_CKD model of continuum absorption." *Philosophical Transactions of the Royal Society* A 370: 2520--2556, doi:10.1098/rsta.2011.0295.

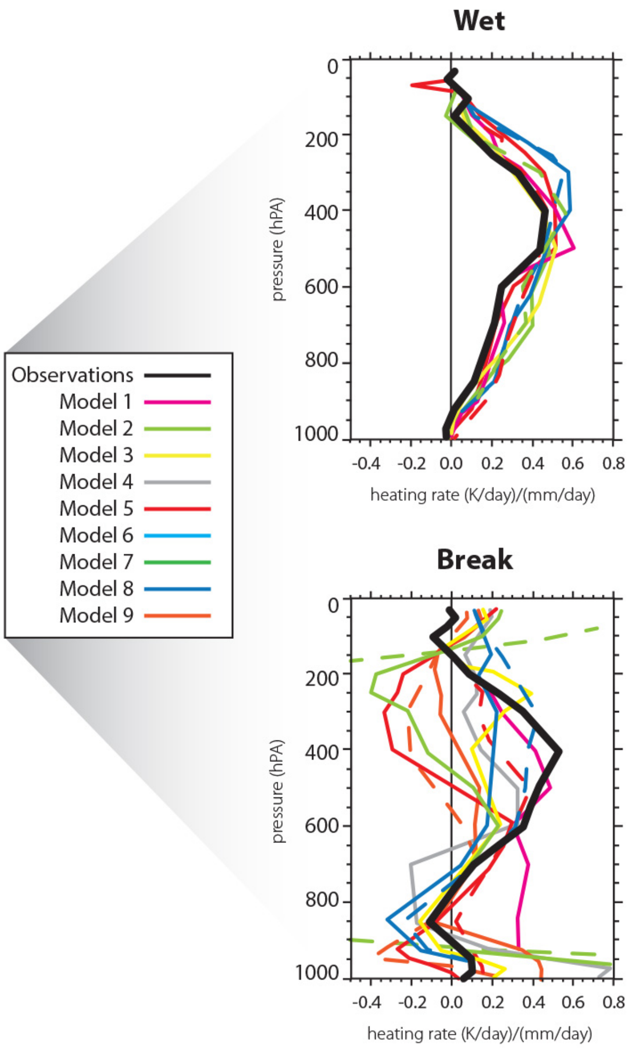
Oreopoulos, L, et al. 2012. "The continual intercomparison of radiation codes: Results from phase I." *Journal of Geophysical Research* 117: D06118 doi:10.1029/2011JD016821.

Modeling from a Tropical State of Mind

Scientific Question. Scientists have long known that global climate models struggle to accurately simulate tropical storms and the clouds they produce in different kinds of meteorological states. Research funded by ASR has shown that tropical weather patterns can be classified into eight such states, including two monsoon states (active monsoon and break monsoon). Additional ASR research comparing a range of global climate models with observations indicated that the models have more trouble simulating the break monsoon. In simulating the drier conditions of the break monsoon, global climate models gave completely different results about whether it is stormy, the time of day the storms occur, and other important factors. With these limitations in mind, researchers used smaller-scale cloud process models to provide insights into possible ways to improve the global models.

Impact. Understanding how global climate models simulate tropical weather and clouds allows scientists to pinpoint and resolve areas of concern. For example, researchers found that models in which storm development is more sensitive to atmospheric humidity are more likely to simulate the break monsoon accurately. Cloud-scale modeling also provided insight into several of the physical processes important to tropical weather patterns, such as the effects of downdrafts, the cold pools of air they create, and the broad shields of anvil clouds that accompany some storms. These types of information lead to more robust models of tropical weather patterns, which regulate global climate and influence the severity and duration of precipitation not only in the tropics but also as far away as the United States.

Method. To identify the states of tropical weather, scientists started with information from a meteorological analysis, which combines available observations with weather prediction models to identify shorter-term



Coming to Agreement. Researchers funded by ASR have determined that tropical weather patterns include several states, including wet and break monsoons. Further research is helping identify ways to improve global climate models, which tend to agree with observations on how storms heat the atmosphere in the wet monsoon state but struggle to accurately model storms in the break monsoon state.

weather patterns over a large area. They input these data into a neural network—a statistical way of dealing with lots of disparate data to find recurring patterns. They centered their area of analysis on Darwin, Australia, because of its strategic location for observing tropical weather variations and because of the availability of extensive DOE ground-based observations at the ARM site there. They then looked for atmospheric states in which cloud properties were stable over time and distinct from every other state.

To compare the ability of various global climate models to simulate these tropical atmospheric states, scientists then used data from a large DOE field experiment called the Tropical Warm Pool-International Cloud Experiment, or TWP-ICE, to compare results against observations of actual tropical weather. Data from the field experiment also made cloud-scale modeling possible and helped scientists to identify potential ways to improve the global models.

References:

Evans, SM, RT Marchand, TP Ackerman, and N Beagley. 2012. "Identification and analysis of atmospheric states and associated cloud properties for Darwin, Australia." *Journal of Geophysical Research* 117: doi:10.1029/2011JD017010.

Lin, Y, LJ Donner, J Petch, P Bechtold, J Boyle, SA Klein, T Komori, and C Schumacher. 2012. "TWP-ICE global atmospheric model intercomparison: Convection responsiveness and resolution impact." *Journal of Geophysical Research* 117: doi:10.1029/2011JD017018.

Del Genio, AD, J Wu, and Y Chen. 2012. "Characteristics of Mesoscale Organization in WRF Simulations of Convection during TWP-ICE." *Journal of Climate* 25(17), 5666, doi:10.1175/JCLI-D-11-00422.1.

Mrowiec, AA, C Rio, AM Fridlind, AS Ackerman, AD Del Genio, OM Pauluis, AC Varble, and J Fan. 2012. "Analysis of cloud-resolving simulations of a tropical mesoscale convective system observed during TWP-ICE: Vertical fluxes and draft properties in convective and stratiform regions." *Journal of Geophysical Research* 117: doi:10.1029/2012JD017759.

For more information, contact:

http://asr.science.energy.gov

Ashley Williamson
DOE Program Manager
301-903-3120
ashley.williamson@science.doe.gov

Sally McFarlane
DOE Program Manager
301-903-0943
sally.mcfarlane@science.doe.gov

DOE/SC-ASR-13-003