Assessment of LDRD Project 20080126DR:
Predicting Hurricane Intensification using LANL Lightning Data
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1. OVERVIEW

In the wake of the devastating 2005 hurricane season, government agencies, scientific boards and advisory panels have unanimously called for urgent increases in hurricane research and improvements in hurricane forecast accuracy [*HIRWG*, 2006; *Holland and Lukas*, 2006; *NSB*, 2006; *H.R. 327*, 2009]. In coordination with this national agenda, Los Alamos National Laboratory funded our three-year LDRD project (20080126DR), beginning in October, 2007 with an initial budget of approximately $1M/year. Our project has two broad science and technology grand challenges:

- Perform a real-time 3D mapping of convective events in the hurricane eyewall using a new dual VLF/VHF lightning remote-sensing capability deployed in the Gulf of Mexico.
- Demonstrate that the forecast of rapid hurricane intensification, the sudden **large-scale** transition and reorganization of a vastly multiscale system, can be improved using using a novel model that assimilates real-time knowledge of critical **small-scale** processes—specifically, observations of violent eyewall convection provided by a hurricane lightning imaging system.

These broad S&T challenges underlie the work of three project teams with the following specific goals:

1. The Lightning Mapping Team: Build, test and deploy a new dual-band VLF/VHF lightning mapping array in the New Orleans vicinity; demonstrate a VHF spatial accuracy of 1 km and a range of 200 km, required for high-resolution data assimilation.
2. The Hurricane Modeling Team: Develop a new LANL hurricane model with prognostic cloud electrification and discharge. Study the modeled charge structure in the eyewall and its relationship to hurricane dynamics. Determine why intense lightning activity can be coincident with rapid intensification.
3. The Data Assimilation Team: Develop novel methods of lightning data assimilation based on surrogates for lightning flash rate (e.g. latent heating). Demonstrate a marked improvement in 48 hour hurricane intensity (wind speed) forecast errors using lightning data assimilation.

This project aligns not only with LANL's "predicting emerging environmental threats" Grand Challenge and energy security priorities, but also with (i) a recent National Science Board report calling for a new national hurricane research initiative [*NSB*, 2006]; (ii) a recent NOAA science advisory board report that defines a national hurricane forecast grand challenge [*HIRWG*, 2006]; and (iii) the emerging National Hurricane Research Initiative Act of 2009 (H.R. 327, in committee) which calls for $235M/year for 5 years to establish a new national hurricane research program—administered jointly by NSF and NOAA—with the explicit goals of funding research in "predicting hurricane intensity change" and "improved observations of hurricanes".

2. PROJECT RESEARCH PLAN

(A) Gulf Lightning Mapping Array

Task 1: Develop and test a new Dual Band VLF/VHF Sensor.
Status: Complete.
Summary: The new array sensor consists of a broadband (10 kHz-80 MHz) antenna, a VHF (60/5 MHz) logarithmic power detector, and a VLF/LF (1-500 kHz) waveform detector. The VHF channel is sensitive to VHF power down to -70 dBm, and can be programmed to detect a peak at any chosen time window. The current setup allows a detection of a maximum peak within each 100 microseconds, similar to New Mexico Tech's LMA system. The VHF channel is also capable of continuously recording VHF power waveform at a rate of 1 Mega-sample per second for detailed breakdown process study. The VLF/LF channel is the same as the earlier Los Alamos Sferic Array (LASA) sensors that record the raw field change waveform once triggered. The VHF band provides a detailed 3-d channel structure that depicts the progress of small-scale breakdown processes, while the VLF/LF band provides the large-scale current transportation associated with each of the processes.

Task 2: Establish a Lightning Mapping Array in the Gulf.
Status: 75% complete.
Research Plan: During the project's 1st year we developed a partnership with (1) Louisiana Marine Consortium (LUMCON), (2) Nicholls Sate University, (3) Louisiana State University, (4) Port Fourchon Authorities, (5) Associated Branch Pilots and (6) Chevron, to deploy an eight station array. Internet connectivity was established at 5 sites last year.
Unforeseen Challenges: Legal issues prevented the deployment of sensors on Chevron and Nicholls' sites. Two sensors were destroyed by Gustav on Sept. 1, 2008; two sensors were damaged by Ike on Sept. 12. Assessment of last year's VHF data indicated that RF background noise is too high at 3 sites.
Resolution: We have developed a new cellular modem capability that gives us greater site flexibility. Five new, VHF-quiet sites have been identified; 4 new sensors are under construction. In the coming months we will relocate sensors at noisy sites, and deploy sensors at new sites.

Task 3: Technology Demonstration of VHF Eyewall Lightning Mapping.
Status: 50% complete.
Research Plan: Demonstrate feasibility of VHF eyewall lightning mapping using our new Gulf array.
Unforeseen Challenges: VHF array was not complete last year.
Resolution: We analyzed VHF lightning mapping data of Hurricane Rita landfall from the LDAR array which covers the Houston metropolitan region. Demonstrated utility of eyewall mapping via comparison with Nexrad radar data.

(B) LANL Hurricane Modeling with Cloud Electrification

Task 1: Develop a cloud electrification capability for LANL hurricane model.
Status: Complete.
Summary: Five hydrometeor classes (droplet, rain, ice, snow, graupel); prognostic equations for mass, number density and charge. Cloud electrification is based on the Oklahoma group's work (Mansell et al., 2005). Fundamental microphysical quantity for non-inductive charge transfer is rime accretion rate, RAR. Critical RAR curve determines sign of charging. Discharge occurs when electric field reaches critical level.

Task 2: Investigate the relationship between lightning and rapid intensification
Status: 75% complete.
Research Plan: Simulate the charging processes in the hurricane eyewall. Assess the relationship between intense eyewall convection, lightning activity, and rapid intensification. Demonstrate how disruption of the balance between glaciation of supercooled water (decreased cloud charging) and intense vertical convection (increased cloud charging) can cause sudden bursts of eyewall lighting activity. Determine the dynamical processes, e.g. barotropic instability, vorticity stretching, axi-symmetrization, PV production, that play a role in the observed bursts of eyewall lighting activity.

(C) Lightning Data Assimilation and Forecast Assessments

Task 1: Novel lightning data assimilation approach
Status: 50% complete.
Research Plan: Develop a new lightning data assimilation scheme that combines (1) a surrogate for lightning flash rate, (2) an ensemble Kalman filter, and (3) a novel assimilation approach where model parameters are optimized during the assimilation procedure.

Task 2: Demonstrate improved 48 hour hurricane intensity forecasts using lightning data assimilation.
Status: 25% complete.
Research Plan: Combine (1) Data from new Gulf lightning mapping array, (2) LANL hurricane model with cloud electrification and discharge and (3) New lightning data assimilation procedure to demonstrate a marked improvement in 48 hour intensity forecast skill.
Challenges: It is possible, albeit unlikely, that the 2009 and 2010 Atlantic hurricane seasons do not produce an intense storm in the Gulf.
Resolution: In lieu of new observations, we are proceeding to assimilate and test our 2005 lightning observations of Hurricane Rita.

3. PROBABILITY OF SUCCESS

Task: *Perform a 3D mapping of convective events in the hurricane eyewall using a new dual VLF/VHF lightning remote-sensing capability.*
Probability of Success: 65%
Discussion: Two factors limit the success of this endeavor: (1) The VHF noise background at array sites, and (2) the probability that a hurricane enters the Gulf during the next two seasons.

Task: *Demonstrate that the forecast of rapid hurricane intensification can be improved using a novel model that assimilates knowledge of eyewall convection from lightning observations.*
Probability of Success: 90%
Discussion: We have demonstrated that assimilation of (radar-derived) latent heating observations improves hurricane forecast accuracy, and that eyewall latent heating—intense convection associated with lightning—can cause rapid intensification. It is highly likely that knowledge of eyewall convection derived from lightning data will improve forecast accuracy.

4. KEY ACCOMPLISHMENTS

- Developed and tested a new Dual Band VLF/VHF Sensor.
- Established new partnerships in the New Orleans area to deploy our array, and have partially deployed and tested our lightning mapping array.
- Worked with LANL legal council to draft IA with Nicholls State; pending IA with Chevron.
- Demonstrated the utility of VHF lightning mapping using Houston's LDAR network.

- Developed a cloud electrification capability for the LANL hurricane model.
- Investigated the relationship between lightning and rapid intensification. Showed that eyewall transition and/or perturbation can cause a burst of lightning activity before glaciation removes super-cooled water and charging stops.
- Developed a novel extension of the Ensemble Kalman Filtering method in which key model parameters are included in the optimization procedure.
- Demonstrated that assimilation of (radar-derived) latent heating observations improves hurricane forecast accuracy.
- Four publications in print; 5 other publications in progress.
- Participated in the March, 2009 Monterey lightning workshop sponsored by LANL's IGPP. Contributed to a white paper which articulates the need for a lightning remote sensing and data assimilation program, administered jointly by ONR and NOAA.

5. PARTICIPATING INVESTIGATORS

ISR Division: Christopher Jeffery, Xuan-Min Shao, Nicholas O'Connor (grad student), Brad Henderson, Petr Chylek, Tim Hamlin, Jeremiah Harlin, Tess Light

EES Division: Jon Reisner, Alex Fierro (postdoc), Steve Guimond (grad student).

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6. REQUEST FOR FUTURE BUDGETS

- We request full funding of $1.5M/year for FY10.
- We also request 1-year matching funding for FY10 or FY11, conditional on a successful grant from the emerging National Hurricane Research Initiative Act (program) of 2009 or 2010.

Background: H.R. 327, "National Hurricane Research Initiative Act of 2009", is currently in House committee. This bill calls for $235M/year for 5 years to establish a new national hurricane research program—administered jointly by NSF and NOAA—with the explicit goals of funding research in "predicting hurricane intensity change" and "improved observations of hurricanes".
We request 1-year matching LDRD funds to smoothly transition our project to a new set of S&T challenges and goals, and to smoothly transition our lightning mapping array infrastructure to possible New Mexico Consortium administration.

References

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