COL/CE/06

Retrieval, Analysis and Visualization of Multiple, Heterogeneous Radar Data Using Intelligent Agents

FY 2005 Proposal to the NOAA HPCC Program

September 9, 2004

| Title Page | Proposed Project | Budget Page |

Principal Investigator: **Kurt Hondl**

Line Organization: National Severe Storms Laboratory
Routing Code: NOAA/ERL
Address:

NSSL
1313 Halley Circle
Norman, OK 73069

Phone: (405) 366-0433
Fax: (405) 366-0472
E-mail Address: Kurt.Hondl@noaa.gov

Other Collaborators

V. Lakshmanan
lakshman@ou.edu

Stephan Smith
Stephan.smith@noaa.gov

Proposal Theme: **Technologies for Collaboration, Visualization, or Analysis**

Funding Summary:

Kurt Hondl	Dr. James F. Kimpel	Jon Domstead
Meteorologist	Director	Administrative Officer
NOAA/OAR/NSSL	NOAA/OAR/NSSL	NOAA/OAR/NSSL

Retreival, Analysis and Visualization of Multiple, Heterogeneous Radar Data Using Intelligent Agents

Proposal for FY 2005 HPCC Funding

Prepared by: Kurt Hondl and V Lakshmanan

Executive Summary:

The National Severe Storms Laboratory serves as the National Weather Radar Test bed with a variety of meteorological radars. There is no way currently to combine data from all of these multiple, heterogeneous, radars into a single 3D grid of radar reflectivity or shear. Since the nation has spent millions of dollars in deploying all of these radars, it is essential to devise a way to combine information from all of these radars. In this proposal, we seek funding to design software that is capable of dealing with these asynchronous, un-coordinated radars belonging to completely different radar networks and building a coherent model of the atmosphere. This will be achieved by treating each radar beam as an intelligent agent, and having each of the beams collaborate to build a 4D model of the atmosphere as it is being scanned.

Building a 4D aging grid of data from the various radars that form the national network of radars in real-time involves high-performance computing because of the large amounts of high-resolution data that will need to be ingested from TDWRs, WSR-88Ds, CASA radars and polarimetric radars. We require Internet-II to get around bandwidth constraints of ingesting all of these radars' data in real-time. We use intelligent agents, an emerging technology, in an innovative manner. XML and NetCDF are proven, self-describing data formats.

This project's scope is broad – it is a colloborative effort among multiple line offices and an University and involves the successful hand off of research efforts into operations. It will directly impact National Weather Service Forecast Offices immediately in the form of TDWR data, and in the next three years as CASA and polarimetric radars come on-line. It leverages off successful experience combining data from multiple, unsynchronized WSR-88Ds that was achieved in HPCC FY2002 project, and builds off HPCC-funded CRAFT network.

Problem Statement:

The initial test bed for Collaborative Adaptive Sensing of the Atmosphere (CASA) radars is in Oklahoma. CASA is a $11million dollar Engineering Research Center funded by the National Science Foundation. CASA radars which will be placed on cell-phone towers across the country aim to complement NEXRAD data by sensing 0-3km. We at NSSL developed the capability to distribute Terminal Doppler Weather Radar (TDWR) via LDM to interested users. The NEXRAD prototype polarimetric radar is located on the NSSL campus. By 2007, the national network of 88D radars will have been upgraded to polarization capability. NSSL also has the world's first phased array radar that has been converted for full-time meteorological use.

A traditional, Doppler weather radar (See Figure 1) scans the atmosphere with a continuous, circular motion. Having made a complete circular scan at a single tilt, the radar changes its tilt angle and sweeps the atmosphere at a different tilt angle. As the radar sweeps through the different azimuths and elevations, it receives the reflected data. Because of the mechanical aspect of the radar antenna movement, traditional radars are limited to scanning the radar volume only once every 5-6 minutes. Being 10cm radars, these radars have a long range, but are defeated by the earth's curvature and can not observe the atmosphere below 3km adequately at farther ranges.

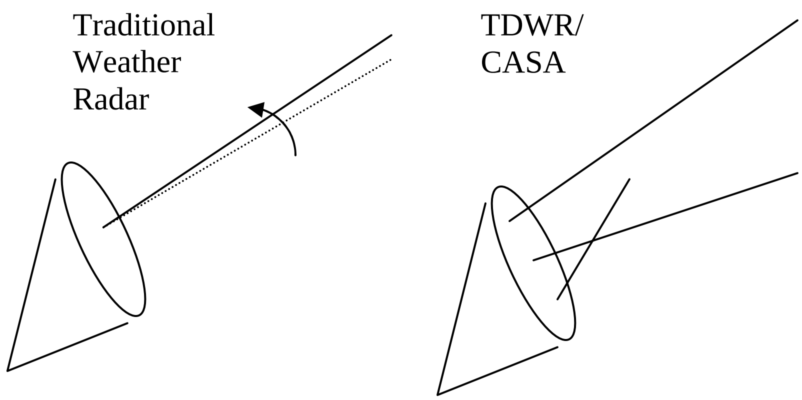

Figure 1: A traditional weather radar scans the atmosphere continuously. A CASA radar will be a phased array radar and can send out beams in different directions at the same time. A TDWR radar jumps between tilt angles.

The TDWR network is comprised of 5 cm wavelength radars that are mechanical scanning. Each TDWR is set up to follow its own scanning strategy as it scans the various elevation angles to observe its radar volume. In addition, the TDWR range gate sampling interval can change between scans.

The CASA radars are 3cm wavelength and have smaller effective ranges but can observe altitudes very close to the ground due to their shorter effective range. They, however, are not constrained to follow any smooth scanning strategy. Although the initial CASA radars are mechanical scanning radars, the plans are to develop phased array versions in the near future.

Phased Array radars form their beams electronically, and can send out multiple pulses, in different azimuths and different elevation angles interspersed (this is referred to as beam multiplexing). Thus, phased array radars can simultaneously scan different storms.

Today's radar visualization techniques are built assuming that the radar senses 2D slices of the atmosphere. Current meteorological algorithms and 3D visualization tools assume that consecutive radar beams are adjacent to each other in space. These tools and techniques would be completely bewildered when faced with randomly arriving radar beams in 3D space. Since the visualization tools possess no history, they would not maintain any knowledge of earlier scans – in a CASA radar where each location is not scanned regularly, this would prove haphazard.

The solution is to develop, from the ground up, an algorithm processing and visualization strategy capable of dealing with radar data from all of these sources *<u>and place them into a common, constantly updating 3D grid in real-time</u>* and to do so using modern, scalable, state-of-the-art techniques. Thus, the data above 3km in the grid would come from the WSR-88D network, while data below 3km could be filled in through the CASA network. Downstream applications would not care – they could deal with the 3D grid as given to them.

Proposed Solution:

Central to this proposal (See Figure 2) is a FY2002 HPCC project "Integrated Visualization and Analysis of Multi-radar and Satellite Data". We will leverage on the capability to integrate asynchronous radar beams from WSR-88Ds that was built in that FY2002 project. In that project, all the individual radars were WSR-88Ds (i.e. their behavior was pretty predictable). In the heterogeneous radar network that is available now, each of the radar systems have different scanning strategies.

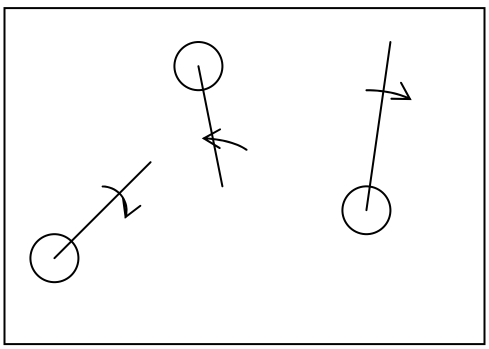

Figure 2: We are leveraging off a FY2002 HPCC project (represented schematically above) that created software to visualize radar data from multiple, unsynchronized, radars.

In FY2002, we created (with funding from the NOAA HPCC program) a technique for visualizing data from multiple NEXRAD radars. One of the challenges we had to overcome is that radars within the NEXRAD network are not synchronized. First, the clocks of the radars are not in sync. More troubling for visualization software that wishes to integrate data from multiple radars, the radar scanning strategies are not synchronized. Thus, a radar in Nebraska might be in precipitation mode, scanning 11 tilt angles every 5 minutes while the adjacent radar in Kansas might be in clear-air mode scanning just 5 angles every 10 minutes.

We created software to build a 3D grid of the most up-to-date data where each range gate from each radar contributed to the knowledge at multiple points within the 3D dynamic grid. Because some of the data might be 10 minutes old, while other data might be only a few seconds old, the range gate data from the radars needs to be adjusted based on time-synchronization with the resulting 3D grid to move to the position that the echo is anticipated to be in. This adjustment is different for each point in the 3D grid. At any one point of the 3D grid, there could be multiple radar estimates, from each of the different radars. We solved this problem using intelligent agents. Each range gate of the radar acts as an intelligent agent that monitors the movement of the storm at the position that it is currently in, and finds a place in the resulting grid based on time difference. Then, at the next time instant, the range gate migrates to its new position in the grid. When new data is received from the source radar (at the new position of the range gate), the intelligent agent updates itself with the new value. When new storm motion estimates are available, the agent updates itself with the new motion vector. When multiple agents all have an answer for a given point in the 3D grid, they collaborate to come up with a single value following strategies specified by the end-user.

This creates a flexible, scalable system that is not bogged down even by a hurricane. This technique of using an intelligent agent for each range gate with data from every radar in a given domain was proven to be robust and scalable even during Hurricane Frances in Florida. The intelligent agents (about 1.3 million of them at one point) all collaborated flawlessly to create the high-resolution mosaic of data (See Figure3) from five different radars in Florida. The Hurricane Frances image was made possible through a FY2004 HPCC proposal “Enabling Communication of WDSS-II Dynamic Severe Storm Grid Data over a Network” that enabled the Storm Prediction Center to use this multi-radar system in real-time over sections of the United States.

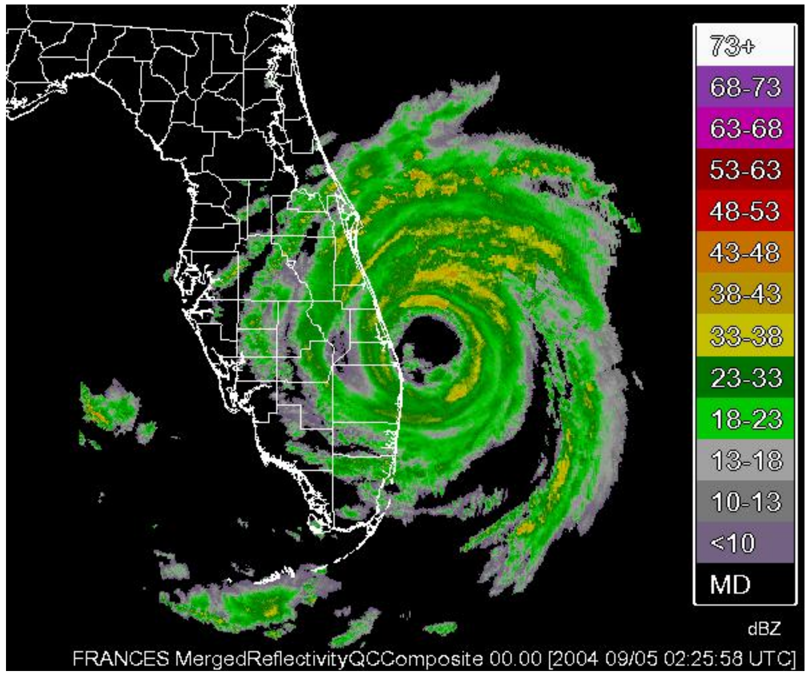

Figure 3: Image of hurricane Frances consisting of combined data from five WSR-88D radars (KMLB, KAMX, KBYX, KTBW, and KJAX). Images were created from the latest available WSR-88D data every 60 seconds (at 1km x 1km x 1km resolution).

We propose to use the same intelligent agent methodology to solve this heterogeneous radar problem. Each of the radar beams (regardless of the radar network it comes from) will be an intelligent agent imbued with the ability to know where it impacts the final result, in what direction it should move with time, when it ceases to be useful, and when it should update itself with new values. The challenge here is to imbue the intelligent agent with all of this information appropriately. In traditional radar data, the task of programming the intelligent agents was made much simpler by the fact that the radars behave in anticipatable ways (i.e. scanning strategies or Volume Coverage Patterns). Because CASA and TDWR radars are much less anticipatable, the intelligent agent has to be that much more intelligent. These radars’ intelligent agents have to operate in a domain with a lot more uncertainty.

The individual scans from each of the radars will be written out in self-describing NetCDF and distributed with XML meta-tags for messaging purposes. (The FY2002 HPCC project created a XML-based messaging system to communicate intermediate and final results between the algorithm server and visualization workstations). It is doubtful, though, that a 30km 45-degree slice of the atmosphere from a CASA radar is of much use to anybody – the utility comes in that information being able to round off the information that comes from the WSR-88D network. We will do this so that in the future, other techniques of integrating these radars into a coherent picture can be attempted by other researchers.

The intelligent agents will collaborate to build a constantly updating 3D earth-relative grid. The grid will be of constant resolution in latitude-longitude-height space, and the value of each point in this 3D grid will be set through active collaboration by the various agents. This 3D grid will also be written out in a self-describing NetCDF format such that it can be incorporated into existing radar analysis algorithms. Meta-data will be created in XML and used for XML-based messaging.

Finally, we will develop a visualization interface that uses OpenGL texture rendering to enable quick and interactive analyses of the constantly updating 3D grid. This will involve traditional examination tools such as cross-sections, but also innovative techniques such as “interactive views” and “fly-throughs”. In an interactive view, changes that the user makes to one view are reflected in other views. For example, if the user draws a pole through the 3D grid in one view, another view might show the vertical cross-section updating on the fly. In a fly-through, the user interacts with the view as if (s)he were flying through the storm and seeing the radar-observed data closest to the nose of the airplane.

Analysis:

The software created with this project will directly impact the mission of the National Weather Service – to protect the lives and property of the people of the United States – through improved severe weather forecasts and warnings. The current NEXRAD network can not see below 3km adequately; whereas the CASA can see very close to the ground. The TDWR network provides high resolution coverage of urban areas. The combination of these three networks is much more important than the sum of the different pieces. The proposed project will combine the data from the different radar networks into a common 3D grid making use of all the available data.

This software solution will be designed for easy transfer to research and operational institutions inside NOAA. The software that we created with FY2002 HPCC funding for example has already been made available to the research community (See http://forum.nssl.noaa.gov/ for researchers and forecasters already using the earlier HPCC-funded project). All that is needed is a high performance network capable of receiving the real-time data, and appropriate PC computers for data analysis and visualization. The software developed will integrate seamlessly into such a hardware framework.

Performance Measures:

The performance of this project will be measured by the ability of the developed system to continuously create and maintain in real-time coherent 3D views of the atmosphere in response to a real-time stream of data received from the WSR-88D network, polarimetric radar, phased array radar and TDWR during a severe storms situation with non-collocated storms. We believe that such a coherent 3D view updated frequently will provide the forecasters with increased knowledge of the dynamic severe weather environment. Potential long-term impacts of using the proposed software include improved verification statistics, and enhanced mesoscale discussions from visual analysis of the severe storm grid.

Milestones

- Receive award notification (tentative) – February 1, 2005
- Development of intelligent agents for other radars – April 15, 2005
- Development of visualization interface – May 15, 2005
- Test during severe weather season – May 15 – June 15, 2005
- Continue to refine data and interface – August 1, 2005

Deliverables

We will develop software to ingest data from WSR-88Ds, TDWR, CASA radars and phased array radars and place them into a 3D grid, combining data from these heterogeneous radar networks in an optimal manner in real-time. Individual packets of beams will be tagged with XML meta data and distributed in self-describing NetCDF format. The beams will be combined optimally into a self-describing, earth-relative NetCDF format and tagged with XML meta data. They will be made available for visualization and analysis through an OpenGL visualization system. We will deliver an effective software system that takes advantage of the latest IT infrastructure and technology.