THE IMPORTANCE OF INTER-REGIONAL STANDARDS AND COORDINATION FOR DETECTION, PHYTOSANITARY ALERT AND TIMELY CONTROL OF PESTS OF QUARANTINE SIGNIFICANCE

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Abstract: Concerns about the early detection and control of citrus pests are similar to those faced five years ago for the arrival of *Phakospora pachyrhizi,* Asian Soybean Rust (ASR). Even for the trained monitor, ASR is very difficult to detect in early stages of infection, and once it is easy to detect, it is too late to control without loss. As with ASR, early detection is the essence of successful quarantine and/or management of most invasive pests. The most valuable data can be provided by an alert cadre of first detectors trained and coordinated around specific monitoring protocols for a pest; a prepared and qualified laboratory to provide a timely diagnostic triage of negative samples and tentative confirmation of provisional first finds; and a common platform for extension messages about local risk and control options.

It is often the case that risk of introduction and establishment of insect pests and plant pathogens is best assessed by looking at the prevalence of the pest in source regions, rather than in the region of concern. Often, critical and timely management decisions about whether to spray or not, or to attempt eradication or not, requires information about where the greatest density of the pest is located and understanding the factors involved in its movement.

Growers typically find a pest or disease once it has reached high enough density to be easily detected on their farms. In the absence of real-time information on the local scale about pest presence/absence/movement, growers are often advised to practice multiple precautionary blanket pesticide sprays and/or scheduled area-wide sprays, regardless of the actual risk level of the farm

The timely detection and control protocol developed to address ASR introduction to the United States in late 2004, provides an exampliary model for citrus pests. Training and coordination of first detectors emphasized very early detection. To facilitate access to information, the USDA developed a real-time tracking tool that growers can consult via the internet. The tool, called the integrated pest management Pest Information Platform for Extension and Education (ipmPIPE), has a work platform for first detectors where they input data, manipulate maps, assess pest and climate model information, and post messages for growers and their advisors. The outputs are available to the public and include real-time maps of pest location, model projections of likely spread, and remarks about risk and control recommendations. Education and outreach to growers encouraged them to visit the website (www.sbrusa.net) frequently to determine their risk at any time. The Economic Research Service has documented that approximately 75 million acres of soybeans were not sprayed in 2005 based on the information provided by the ipmPIPE.

The source and movement of citrus pests impacts growers in Florida, Texas, California, the Caribbean, and Mexico. Understanding patterns of movement of vectors and pathogens across the regions is vital to knowing what management strategies to apply in any specific location. Attacking citrus quarantined pests and pathogens on a regional level will have the greatest likelihood of success. An ipmPIPE system is being designed for citrus in Mexico and the U.S., the strengths of which will be presented as a concept. **Keywords:** Monitoring, First Detectors, Early Detection, Plant Pest Diagnostics, Integrated Pest Management

Introduction

This paper discusses monitoring and early detection activities for pests that are in low numbers, but are established and need constant risk-based information for timely and effective control. In addition to formal surveys for exotic pests, such as APHIS's Cooperative Agriculture Pest Survey, the United States Department of Agriculture (USDA) has strengthened domestic monitoring and detection programs to help manage established invasive organisms. The Asian Soybean Rust (ASR) event will be used to show the components of this integrated system and how it works, from early detection, through diagnostics, risk analysis, extension and to management. The intent is to show how this system can be expanded geographically and how it can be instrumental in management of industry-threatening citrus diseases in North and Meso- America.

Phytosanitary alerts – reaching the diagnostic community. There is no time more crucial to keep the diagnostics community well informed, than when there is a newly introduced exotic pest. Diagnosticians communicate among themselves, prepare Standard Operating Procedures, train technicians and stock supplies when they know a surge of samples may be imminent. In the U.S., the National Plant Diagnostic Network (NPDN) (www.NPDN.org), with skilled diagnosticians in every state, creates a passive expert monitoring system (Cardwell and Hoffman, Stack et al.). First detectors of exotic pests are usually observant generalists, gardeners and farmers; not trained exotic pest surveyors. In 2008, the general public, extension agents, industry and grower representatives brought over 85,000 samples to the 61 NPDN member labs to be processed (Table 1). When diagnosticians are on the lookout for an exotic or invasive pest, triggered by a phytosanitary alert, the protocol is to test for that organism on all hosts and indicate when it is not detected (Table 2). When an exotic or invasive pest is known to be in a region, the NPDN has the ability to alert a network of first detectors, and quickly prepare to recognize and report presumptive positive finds. Every NPDN Regional Center serves several roles: regional coordination, hub laboratory for high consequence diagnostics, information brokers between network labs and APHIS during high consequence outbreaks (Figures 1-4). All PDN diagnosticians are trained in confirmation and communications protocols in the event of a presumptive positive for an exotic or re-emerging high consequence species, and they have call lists for the State Plant Health Directors and State PROs of every state and territory.

The NPDN also has a series of first detector training modules to heighten awareness about the importance of early detection, how to notice something new, how to submit a sample to the closest diagnostic laboratory, how to use digital diagnostic protocols, and the art and science of diagnosis (http://cbc.at.ufl.edu/). Pest-specific modules can be added as needed.

NPDN was instrumental in training field specialists in how to find and tentatively identify Asian Soybean Rust and has managed over 70,000 samples since the arrival of the disease. However, let us start at the beginning of the ASR history.

First Detector Training – the Asian Soybean Rust example. In the fall of 2004, aerobiological models indicted that hurricane Ivan (indicated that it could, or predicted that it would – your choice) could bring *Phakospora pachyrhizi* from South America, introducing Asian Soybean Rust (ASR) to the continental United States (Figures 5 and 6). The disease had spread rapidly from its insertion point in Paraguay in 2001, eventually covering most of sub-equatorial Brazil by 2002. Aerobiologists predicted that as long as infection remained south the equator, the inter-tropical convergence zone would preclude aerial spread northward. By 2003, however, there were reports of field-to-field contagion reaching well north of the equator and in June 2004, infected soybean foliage was confirmed in Colombia. In September, hurricane Ivan formed off of the coast of Colombia.

Hurricane Ivan struck the U.S. Gulf Coast on September 16th 2004. On November 6th, the first find was confirmed in Louisiana by a first detector who had just gone through NPDN first detector training. A phytosanitary bulletin was released. By December 3, 2004, there were 20 confirmations by trained first detectors in eight states outlining the periphery of the hurricane impact zone (Figure 7).

When ASR was discovered in the US in November of 2004, models showed (as was widely believed) that it would overwinter on kudzu along the Gulf of Mexico coast. Growers across the soybean belt in the Midwestern States were beginning to purchase and hoard fungicides, planning to spray the following growing season dispite the absence of information indicating that there was a need to do so. They feared that ASR would spread cataclysmically, as it had in South America (Christian and Sherm, 2007).

The USDA and the Cooperative Extension Service recognized the need to provide geographic and temporal information about where infection could be found and its projected pathways of spread. The first technical challenge was how to find the first infection foci in 80 million acres? A plan was devised whereby sentinel plots would be planted from south to north, as soon as the risk of frost receded. These plots would be planted about 10 days before commercial planting, with a susceptible early maturing variety; and would be monitored closely every week by trained detectors. The USDA with its partners in the Cooperative Extension Service, located within the Land Grant Universities across the country, and Universities in Canada, developed a plan for planting and intensive monitoring of sentinel plots for the purpose of ASR tracking and diagnostics . Field scouts and diagnosticians had to know what to do if they suspected that they had found soybean rust.

In 2006, Mexico joined the sentinel plot monitoring systems (Figure 8).

Sentinel plots have been funded by the USDA, the United Soybean Board (USB), and the North Central Soybean Research Program (NCSRP), the University of Chiapas, Secretaria Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA), the University of Guelph, and the Canadian Food Inspection Agency (CFIA). The USDA program involves 35 states and the USB/NCSRP program includes 15 states; a total of 35 states have sentinel plots for monitoring ASR with a peak number of 690 plots from 2005-2008. Five Canadian provinces and four Mexican states are also involved in the monitoring. A single ASR monitoring protocol has been developed for the USB/NCSRP, USDA, and Canadian and Mexican plots. Data from all sentinel plots are uploaded to the integrated pest management Pest Information Platform for

Extension and Education (ipmPIPE) website. All data collected from the sentinel plots is input in a standardized template into the Information Technology platform for integration (Isard. et al, 2006). The IT platform is comprised of three articulated stages (Figure 9), a standardized input based on standard monitoring protocols (Figure 10), a work platform to integrate data with plant and pathogen growth models and spread functions for extension specialists to formulate risk and management communications (Figures 11 - 16), and finally a standardized output that provides the interface for the user clientele to observe up-to-date maps and expert commentary (Figure 17)

ipmPIPE as a model monitoring system – overview. In addition to the more passive surveillance systems represented by first detectors and diagnostic laboratories, there is another, coordinated system of Cooperative Extension associated with the Land Grant University System that is also designed for early first detection with emphasis on integrated pest management (IPM) and controls (Cardwell & Hoffman, 2009).

IT Integration platform. There are three important functions of the Information Technology (IT) platform that became the ipmPIPE sentinel program for monitoring soybean rust (Isard et al, 2006). The primary function is to provide extension agents, crop consultants, growers and other clients with effective decision support information for managing crop risks. For this reason and because the pathogen can only over-winter in subtropical regions, southern and Mississippi Valley states have higher numbers of sentinel plots relative to their soybean acreages than states in other regions. The second function is to quantify the timing and amount of spore production in over-wintering and growing season source areas, an important input for the soybean rust aerobiology prediction system (Isard, et al., 2005). A third function of the sentinel plot system is to collect data to validate and adjust epidemiological models which in turn are used by extension specialists to formulate their risk recommendations (Isard, et al., 2006).

Models. Mathematical and aerobiological models supplement and focus monitoring and surveillance to narrow the search parameters to manageable dimensions (Cardwell & Hoffman, 2009). Aerobiology is the study of the physical process of movement of organisms from one geographic location to another by floating, soaring or flying (Isard, et al., 2005). For the purpose of surveillance advisories, the probability of arrival of any given invasive organism to a new location can be forecast once host availability and climate variables are integrated with the knowledge of the biology of the organism. An unknown source of origin can be estimated by a trace backwards of atmospheric pathways from a point source of infection. The most widely used atmospheric transport model for aerobiological applications is the National Oceanic and Atmospheric Administration (NOAA's) HYSPLIT (hybrid single-particle Lagrangian integrated trajectory model) (Isard, et al, 2006; Cardwell & Hoffman, 2009). These models can be quite accurate in tracking region-to-region movement. In 2007, a HYSPLIT trajectory indicated that a northerly air current pushed soybean rust spore-laden air into Mexico (Figures 18 and19). A phytosanitary alert was issued in Mexico and the first finds of ASR in that season were announced within two weeks (Pers Comm, Ing. Francisco Ramirez y Ramirez).

Public interface – Extension outreach for pest control. Whether a pest is under regulatory management or is an endemic reoccurring problem, the mitigation and control is almost always up to the growers. Therefore, providing tools that help with timing of control applications is a goal of the plant sciences community and Integrated Pest Management. By capturing and integrating real-time data from distributed surveillance and monitoring networks into smart models, it is possible to become quite specific about control recommendations within a region. Information about the source and timing from which new infection/infestation will arrive, coupled with the crop phenology and meteorological data can feed models that make very accurate predictions, help refine scouting, and result in reduced number of inefficacious pesticide sprays.

Other examples. Within a year of establishing the soybean rust PIPE, the system was expanded to include another invasive pest, soybean aphid. Soybean aphid re-emerges every year around the Great Lakes and the bloom may be heavy or light depending on environmental conditions. Although the standardized input and integration platform are the same for soybean aphid workers, the entomologists preferred a different representation of aphid outbreak based not only on location, but also density of the pest. Although growers are not encouraged to spray based on the density graphics, they are an indicator of when to intensify scouting. Diseases are the number one cause of legume crop loss according to Crop Insurance actuary data. All pest and diseases of specialty legumes, peas, lentils, garbanzo, cowpea, chickpeas, etc. are being monitored in sentinel plots in 15 States, Sonora, Mexico, and Alberta, Canada. Therefore, the community of legume scientists decided there was a need to monitor for a variety of causal agents (Schwartz, et al., 2009). For instance, Cucurbit Downy Mildew has the classic south to north spread every year out of the tropics into Canada. This is being tracked and monitored in sentinel plots from Florida to Maine. Growers depend on this website to make management decisions (Gugino, et al., 2009). Also, Pecan – Nut Casebearer, reappears throughout pecan producing states based on cumulative degree-days after the last freeze. The Pecan PIPE is being built across 9 U.S. states and Mexico to manage this destructive endemic pest (Harris, et al., 2008)).

Conclusions. Whether a pest or pathogen is reintroduced each year from an outside source, or is endemic and outbreak severity varies based on climate and plant phenology; if there is spatial or temporal uncertainty to be managed, real-time information can help. Where citrus is concerned, Meso- America and the Caribbean have a real and serious set of uncertainties that require analysis and management. Citrus is in critical danger due to insect vectors and diseases; the Citrus Tristeza Virus and its brown citrus aphid vector, *Toxoptera citricida*, Citrus Leprosis Virus and the false spider mites, *Brevipalpus phoenicis* and *B. californicus,* found in Mexico and the US, Huonglongbing disease and its vector, *Diaphorina citri*, all are threatening and dangerous phytosanitary problems (Bitancourt, 1940; Manjunath, et al, 1998; Michaud, 1998; Saavedra de Dominguez, et al, 2001). All are in the region or on their way. All are affected by seasonal growth flushes of the host, and the vectors most likely migrate on the prevailing air currents which, as shown in figures 20-26, are quite dynamic. A HYSPLIT trajectory of hurricane Ike in September of 2008 (Figures 20-24) shows clearly how, aerobiologically, the Caribbean to California is one contiguous region. Northerly fronts and Pacific hurricanes provide the opposite effect (Figure 25). Even if area-wide sprays occur in

California, it can never be sure of eradication as long as appropriate controls are not also occurring in the Caribbean. The Caribbean could be re-infected from Florida. Mexico has influences to and from the four cardinal directions around it (Figure 26).

Probably the only hope of successfully managing the problems that citrus growers face in the Americas will be to develop comprehensive pan-regional tool sets that will allow us to understand pest movement, potential for continuous re-introduction, timing of crop vulnerability, source locations, and optimum control targets.

A coordinated network of diagnostic laboratories from the Caribbean to California would provide a greater capacity to conduct assays on both plant and insect vector tissues, increasing capacity to handle large numbers of samples, quickly eliminating negatives, and improving throughput of confirmatory diagnostics on positive samples. A citrus PIPE could provide tools for, tracking of infectious vectors, modeling directional spread and host plant vulnerability, regulatory outreach, and extension recommendations for growers.

The solution is to develop a set of common protocols from the Caribbean to California, for data capture, data integration, and a working map-based interface that promotes fine scale, informed management (Figure 27). Modeling tools can be available to citrus workers in every State and Country; crop phenology can be fine-tuned to the farm level with meteorological predictors of growth flush. To this end, I propose that NAPPO take the Mexican Sistema Coordinado de Operaciones para el Manejo de Plagas Reglamentadas y su Epidemiología (SCOPE)and North American ipmPIPE information systems and expand these programs to create an open and coordinated Citrus pan-regional pest and disease management system. A pan-regional diagnostic network, where all clinicians are trained in the same diagnostic protocols and data sharing technologies, would assure that the information systems contained accurate information.

It is a big job, but, as was shown with Asian Soybean Rust, it can be done. The framework for the needed regional collaboration is in place, but in need of further development and leadership. Without this coordination, I believe that the citrus industry of North America is in for a long, painful decline.

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Table 1. National Plant Diagnostic Network 2008 Sample Type, Distribution, and National Data Repository Submission Numbers from the Western (WPDN), North Central (NCPDN), Southern (SPDN), Great Plains (GPDN) and North East (NEPDN) Diagnostic Laboratories								
Region (# of labs)	Samples Processed	Pathogen	Insect	Weed	Nematode	Other	Repository Submissions June 1 2008- April 1, 2009	CERIS reported submissions 2008
WPDN (17)	268,635	166,667	79,390	2,015	10,944	8,151	26,169	20,266
NCPDN (8)	17,910	6,916	2,319	219	5,152	1,651	12,186	10,335
SPDN (14)*	33,574	15,721	2,568	680	9,762	2,824	17,484	23,172
GPDN (9)	15,957	10,618	2,062	404	990	0	15,692	15,898
NEPDN (13)	9,136	4,217	830	178	435	0	7,918	10,335
Totals (61)	345,212	345,649	87,169	3,496	27,283	12,626	79,449	85,186

- VI and GA not reporting at this time

Table 2. Proportion of Samples Confirmed, Suspected, Inconclusive, Not Detected by the North East (NEPDN), North Central (NCPDN), Southern (SPDN), Great Plains (GPDN), and Western (WPDN) Plant Diagnostic Network Laboratories					
	Confirmed	Suspected	Inconclusive	Not Detected	Total
NEPDN	4703	2225	276	714	7918
NCPDN	7279	1997	614	2296	12186
SPDN	8880	3112	2189	3303	17484
GPDN	6878	2657	985	5172	15692
WPDN	23568	930	339	1332	26169
Totals	27740	9991	4064	11485	53280
Proportion	0.52	0.19	0.08	0.22	1

Figure 1. The National Plant Diagnostic Network (NPDN) is Administered by Five Regional Centers Located in Universities

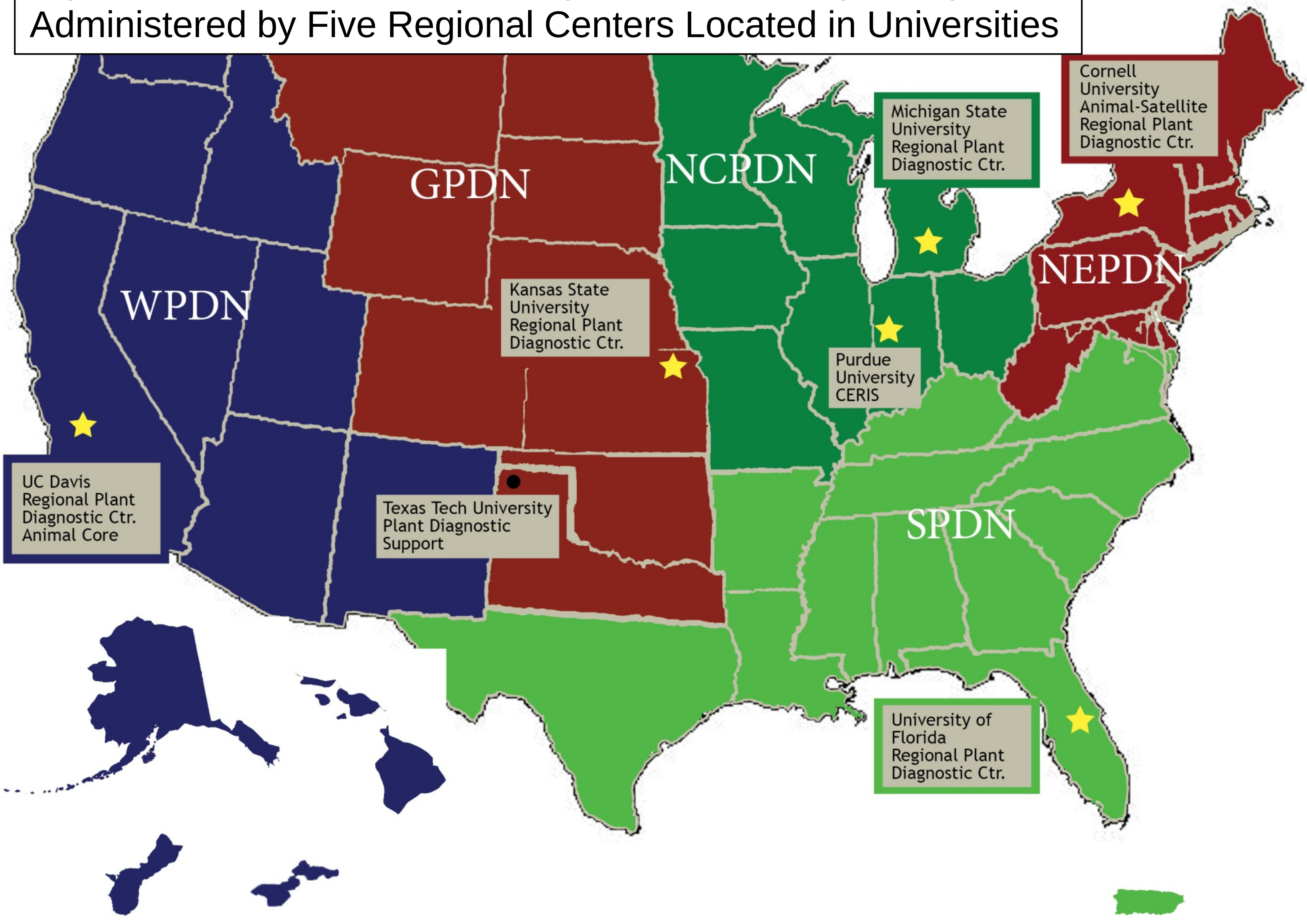


Figure 2. Regional Diagnostic Centers Push Data into Central Repository in NAPIS, at Purdue University

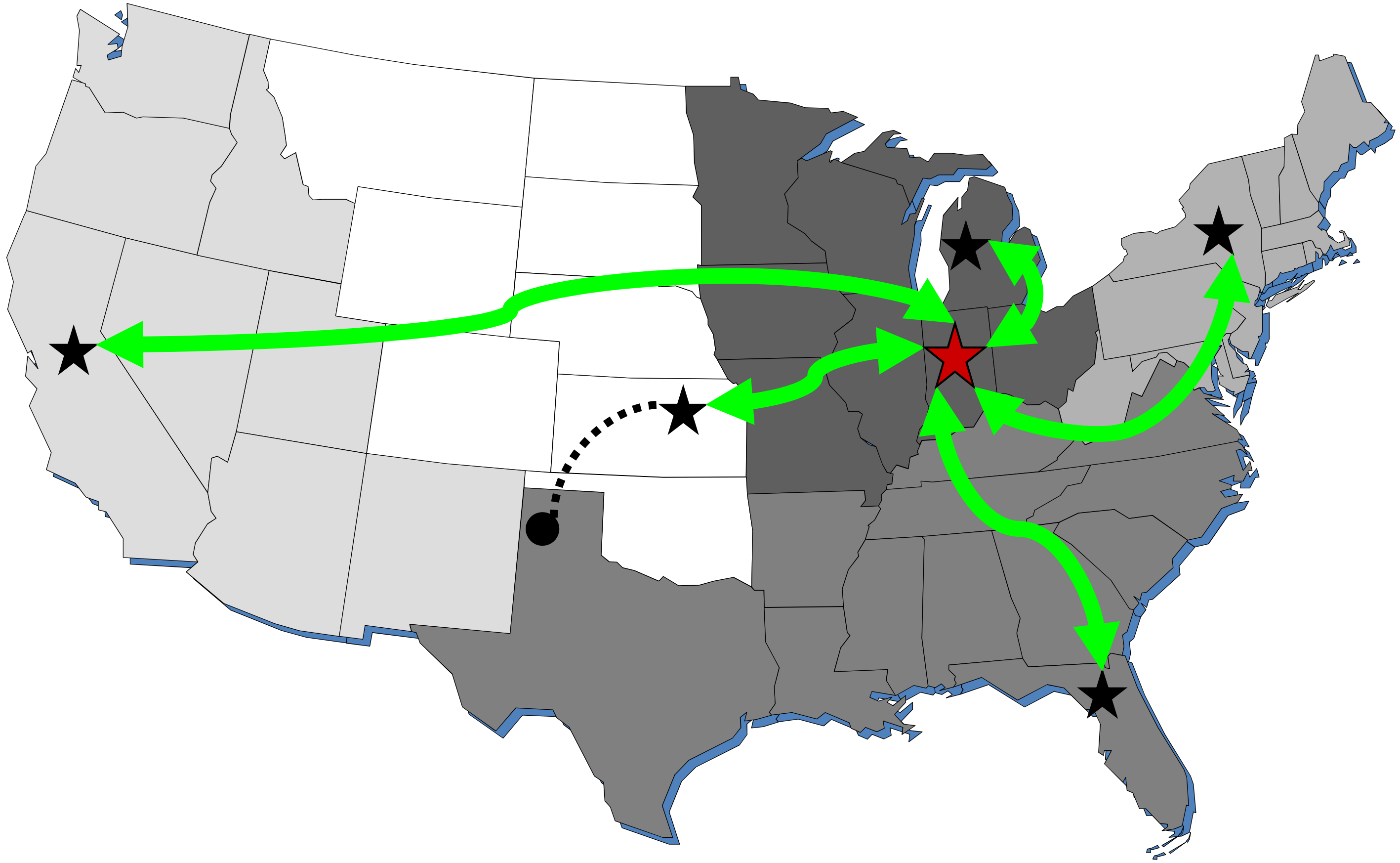


Figure 3. Regional Diagnostic Centers Serve As Central Point for Information Flow from within the State

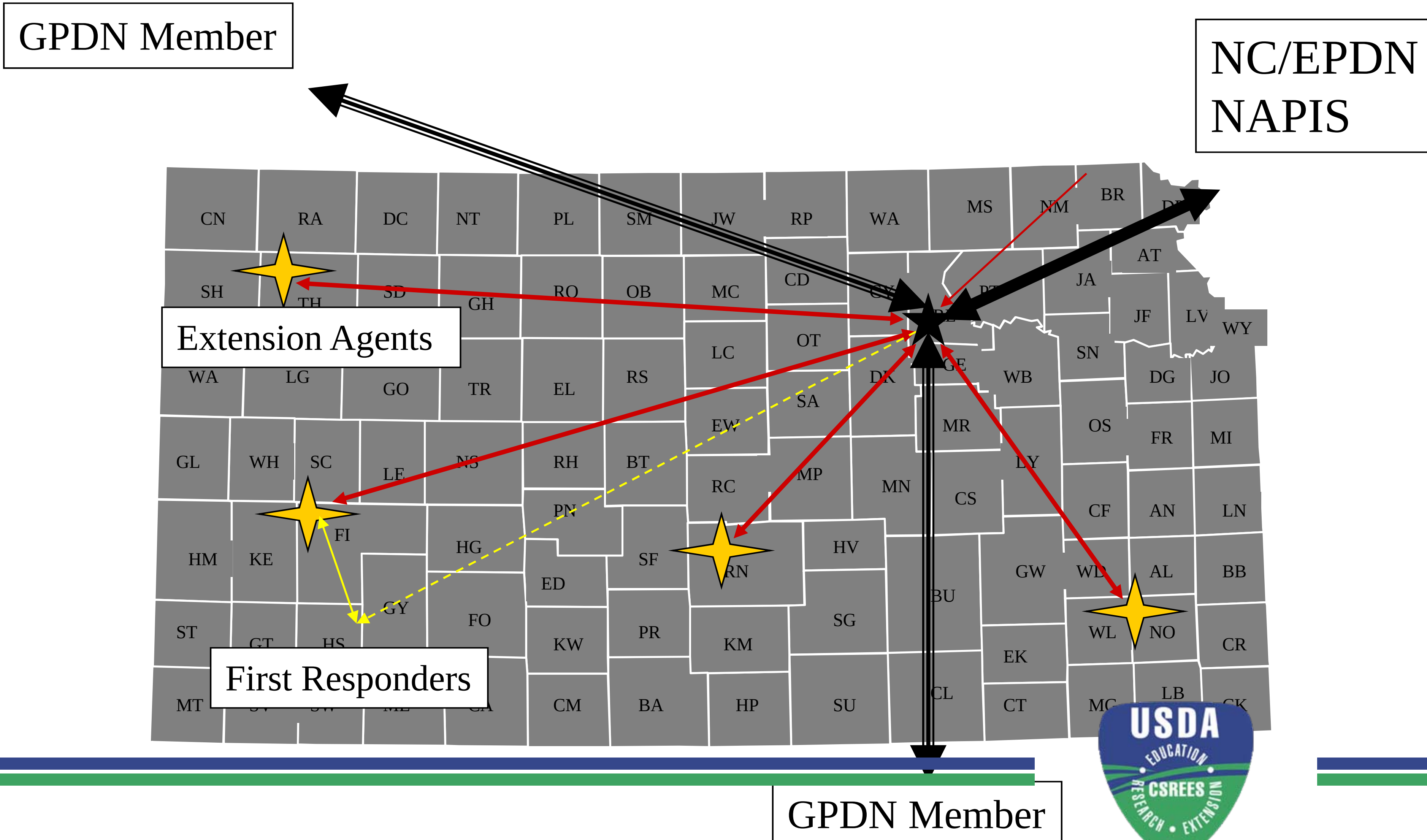


Figure 4. Each NPDN Regional Center Serves as a Central Hub for Advanced Diagnostics & Information Flow Creating Expanded Capacity for High Consequence Events and Rapid Turn-around for Diagnostics

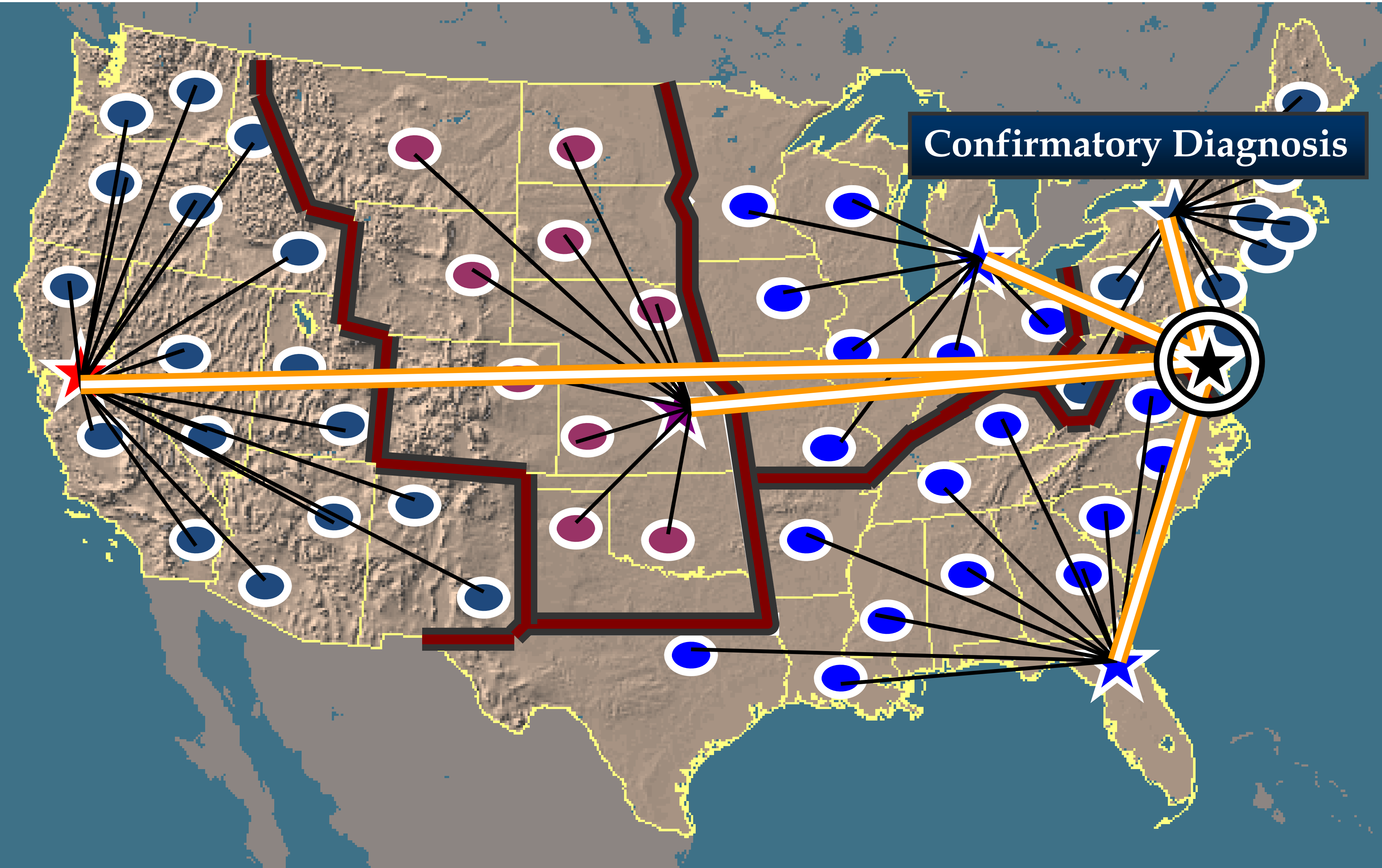


Figure 6. Arrival of Hurricane Ivan September, 2005, Brought an Unwelcome Guest

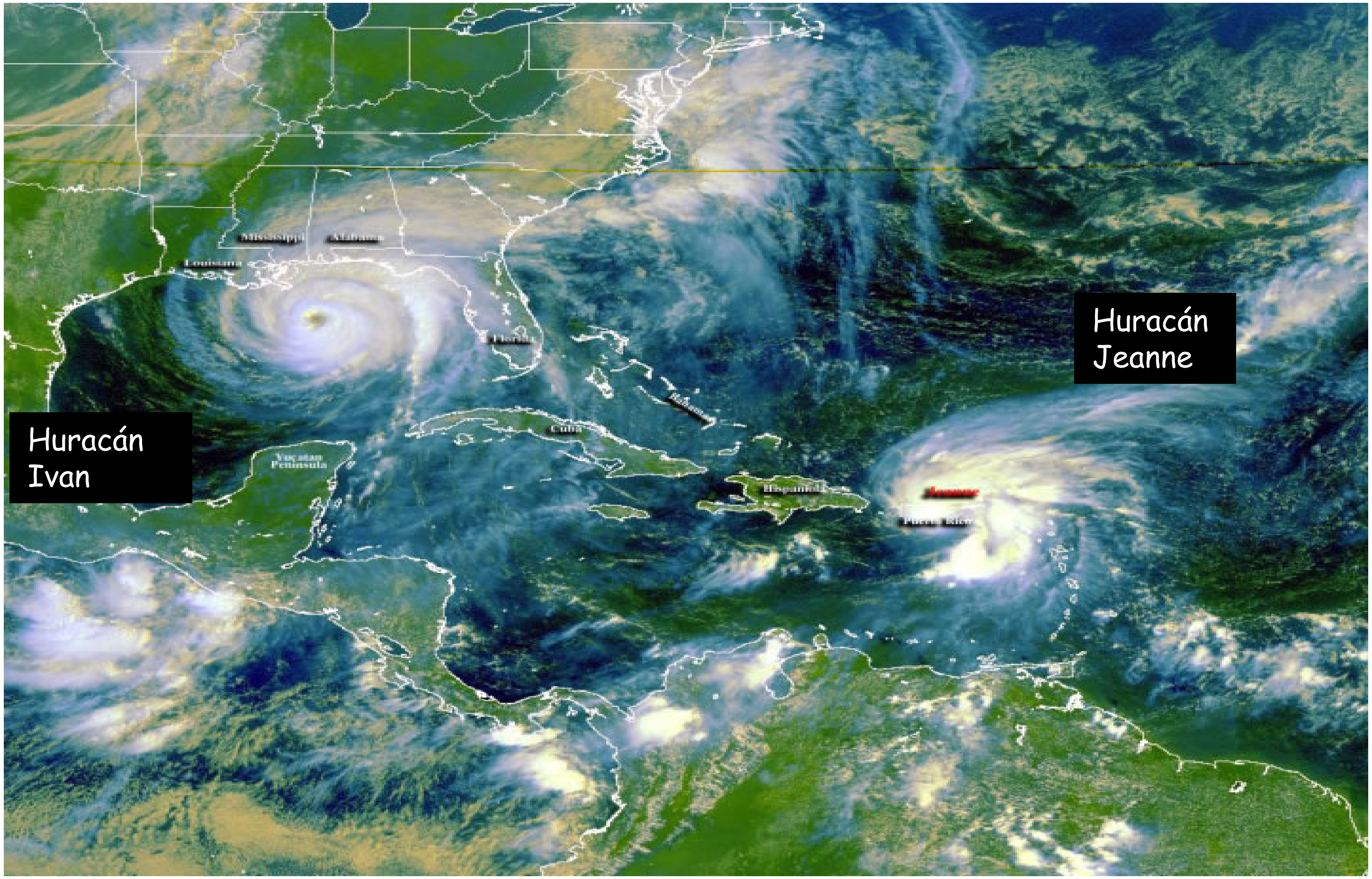


Figure 7. Models predicted Soybean Rust Spore Delivery on Hurricane Ivan

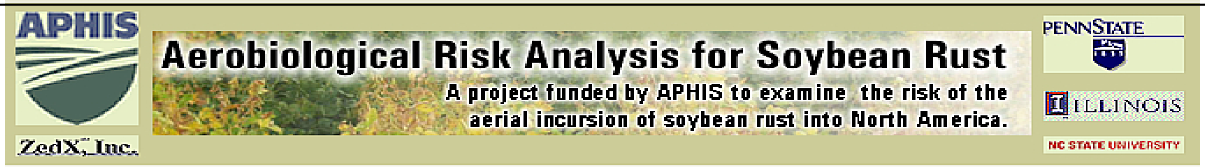


Figure 7. Rust Incursion into Southeastern U.S. Defined by the Hurricane Impact Zone

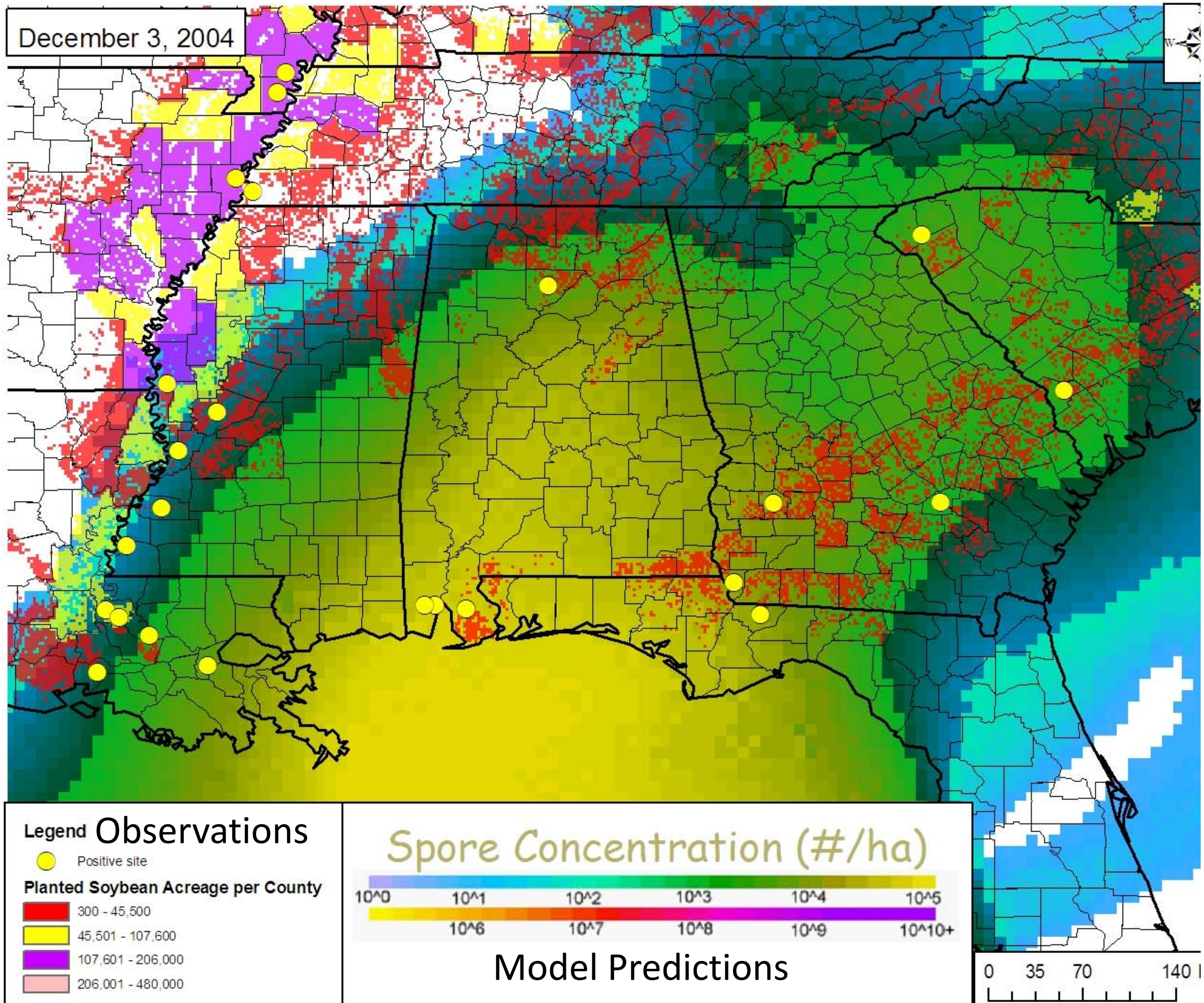
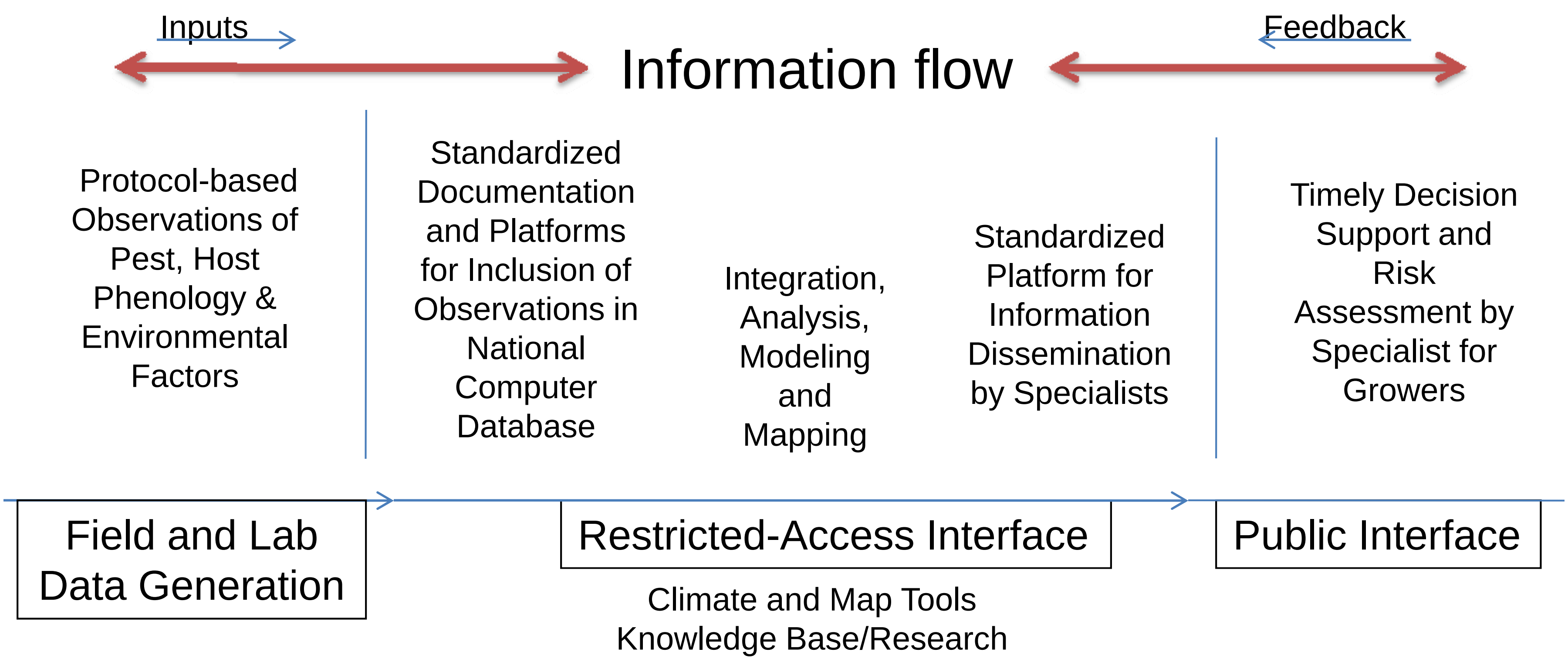


Figure 8. Sentinel Plot Monitoring

First Detector Training, Florida

Scouting in Chiapas, Mexico

Figure 9. Pest Information Platform for Extension & Education (PIPE)



People and computers linked by “state-of-the-art” Information Technology

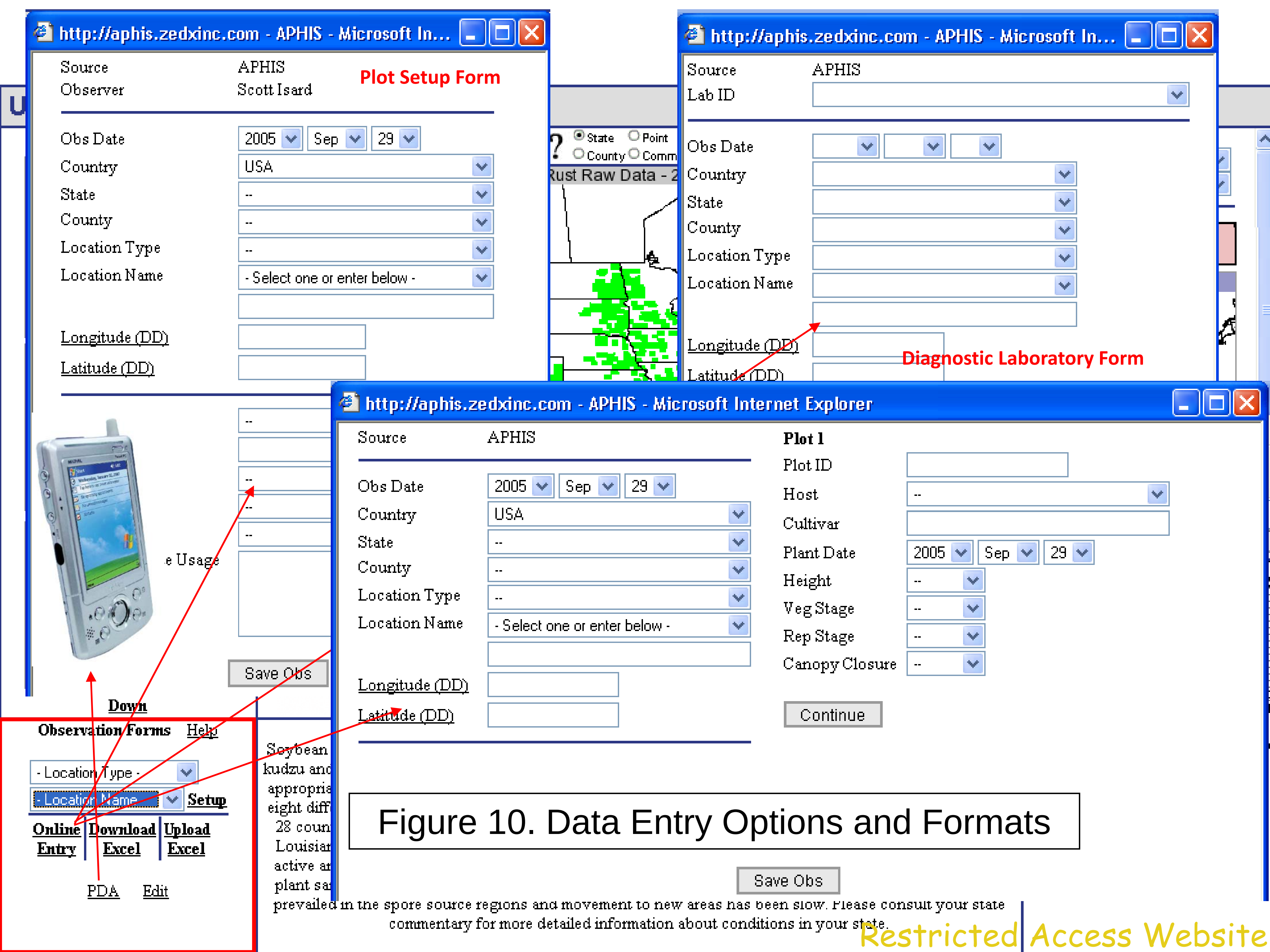
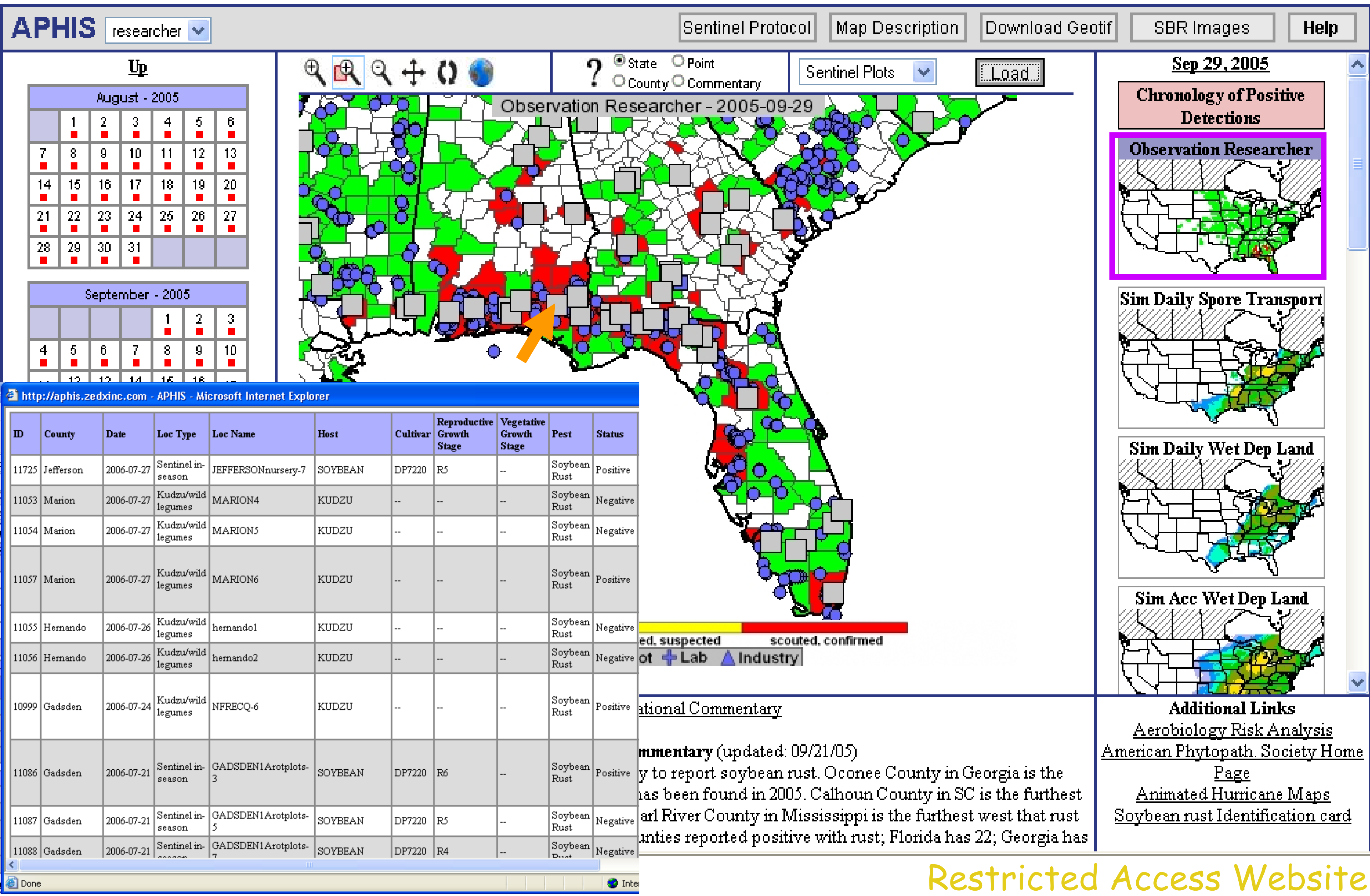


Figure 10. Data Entry Options and Formats

Figure 11. Data manipulation and access



ID	County	Date	Loc Type	Loc Name	Host	Cultivar	Reproductive Growth Stage	Vegetative Growth Stage	Pest	Status
11725	Jefferson	2006-07-27	Sentinel in-season	JEFFERSONnursery-7	SOYBEAN	DP7220	R5	--	Soybean Rust	Positive
11053	Marion	2006-07-27	Kudzu/wild legumes	MARION4	KUDZU	--	--	--	Soybean Rust	Negative
11054	Marion	2006-07-27	Kudzu/wild legumes	MARION5	KUDZU	--	--	--	Soybean Rust	Negative
11057	Marion	2006-07-27	Kudzu/wild legumes	MARION6	KUDZU	--	--	--	Soybean Rust	Positive
11055	Hernando	2006-07-26	Kudzu/wild legumes	hernando1	KUDZU	--	--	--	Soybean Rust	Negative
11056	Hernando	2006-07-26	Kudzu/wild legumes	hernando2	KUDZU	--	--	--	Soybean Rust	Negative
10999	Gadsden	2006-07-24	Kudzu/wild legumes	NFRECQ-6	KUDZU	--	--	--	Soybean Rust	Positive
11086	Gadsden	2006-07-21	Sentinel in-season	GADSDEN1Arotplots-3	SOYBEAN	DP7220	R6	--	Soybean Rust	Positive
11087	Gadsden	2006-07-21	Sentinel in-season	GADSDEN1Arotplots-5	SOYBEAN	DP7220	R5	--	Soybean Rust	Negative
11088	Gadsden	2006-07-21	Sentinel in-	GADSDEN1Arotplots-7	SOYBEAN	DP7220	R4	--	Soybean	Negative

Restricted Access Website

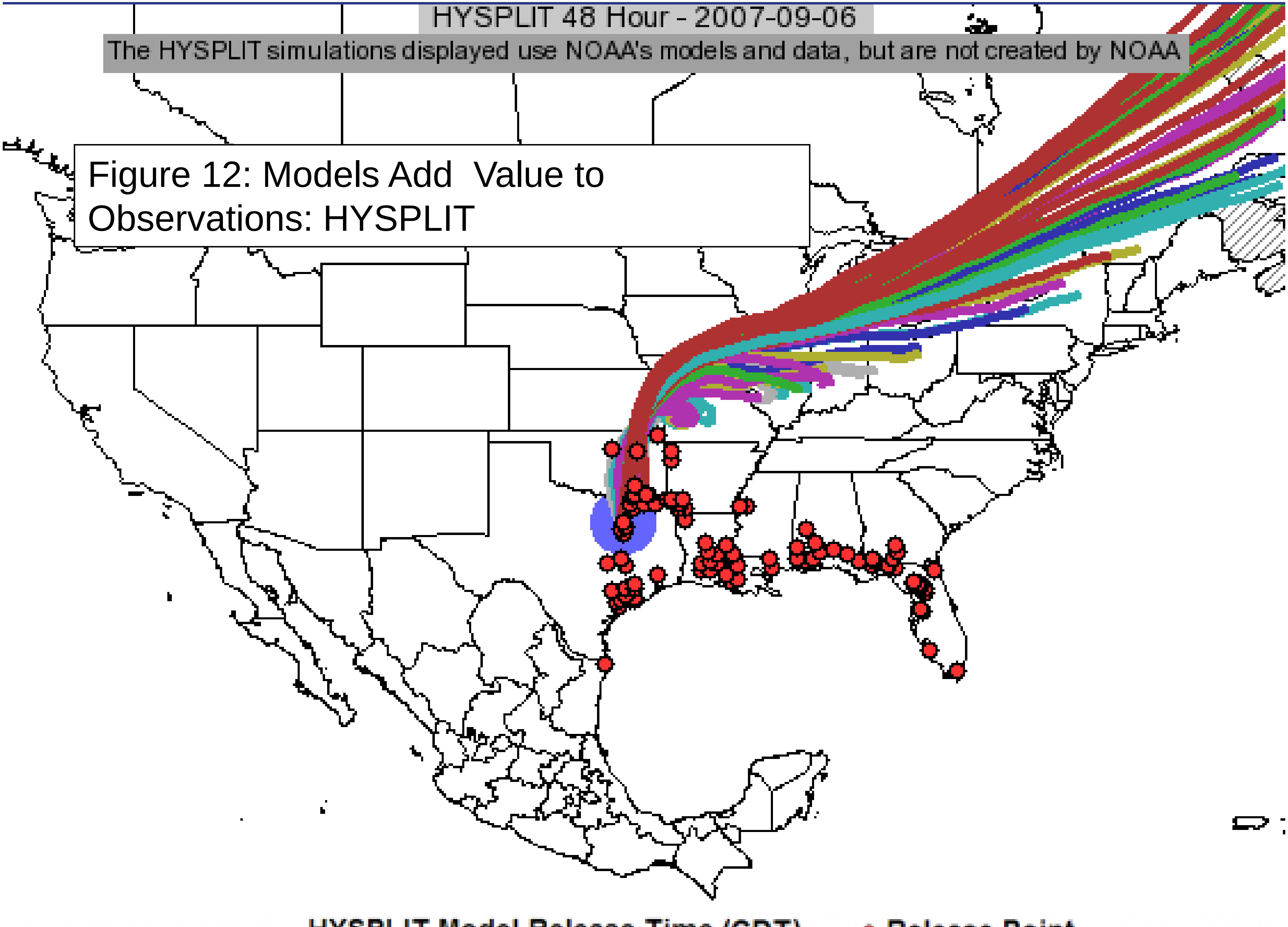


Figure 12: Models Add Value to Observations: HYSPLIT

Figure 13. Models Add Value to Observations: Wet Deposition of Spores, Sept 2007

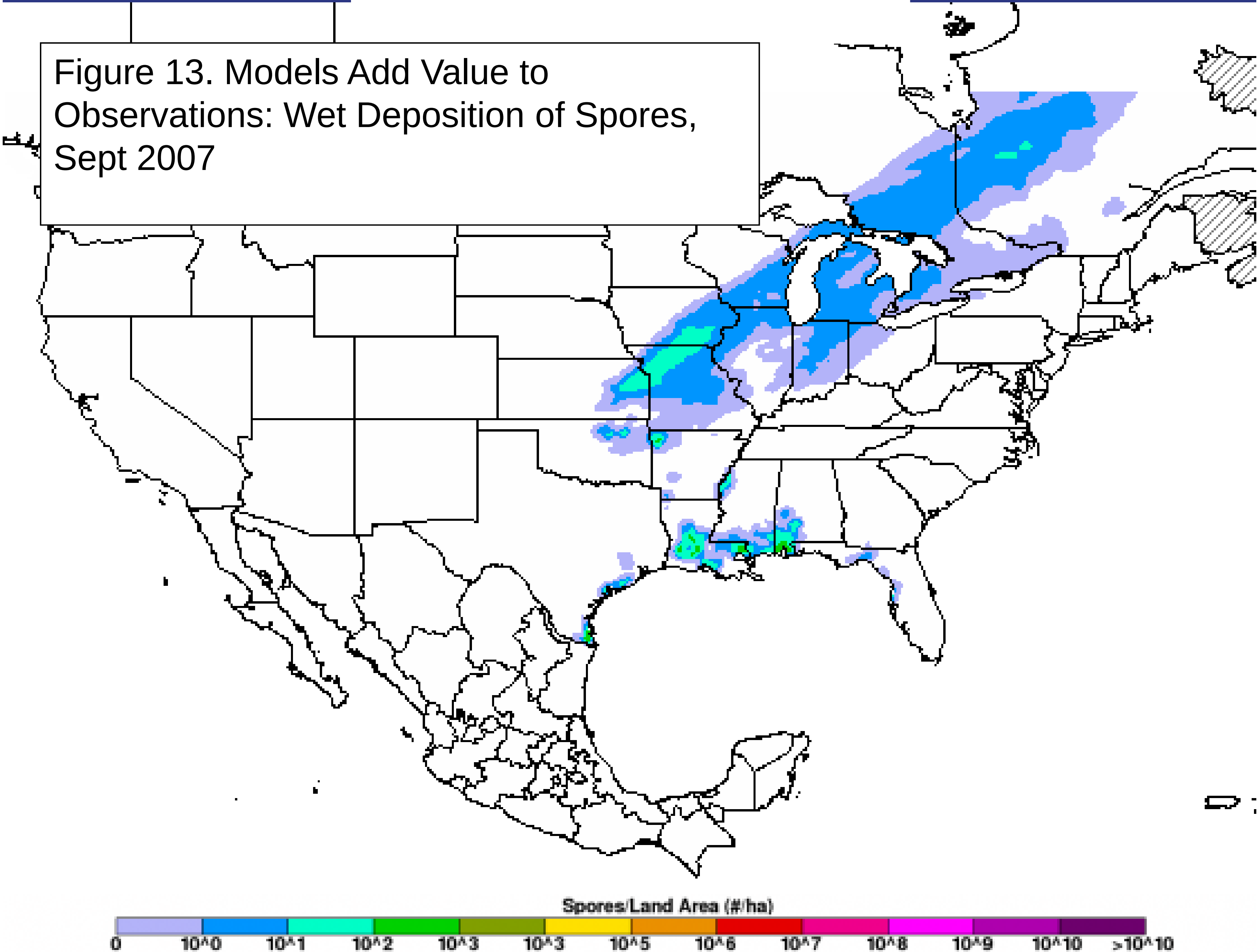


Figure 14.Models Add Value to Observations: Ensemble risk evaluation

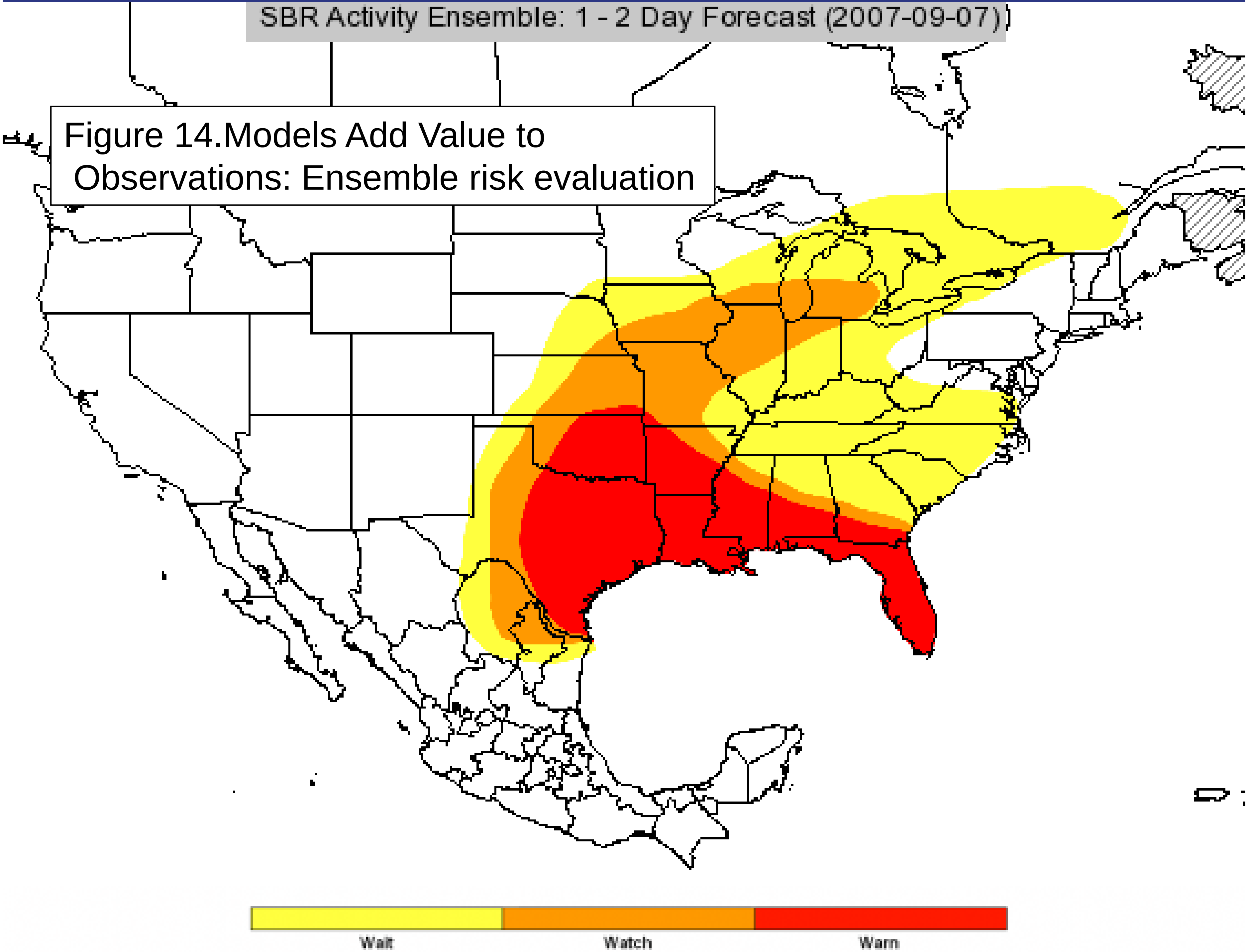


Figure 15. Models Add Value to Observations: Simulated Disease Severity

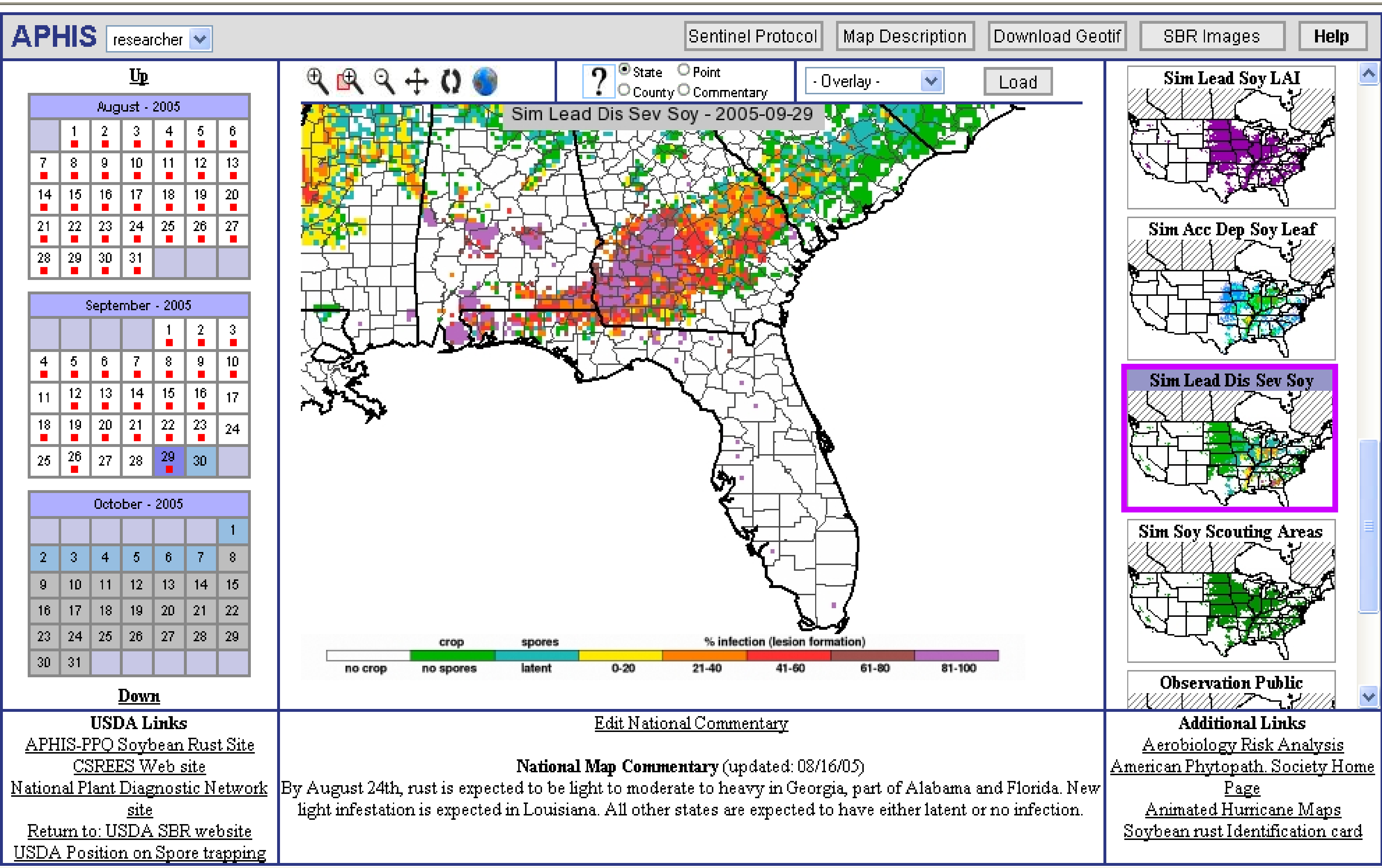


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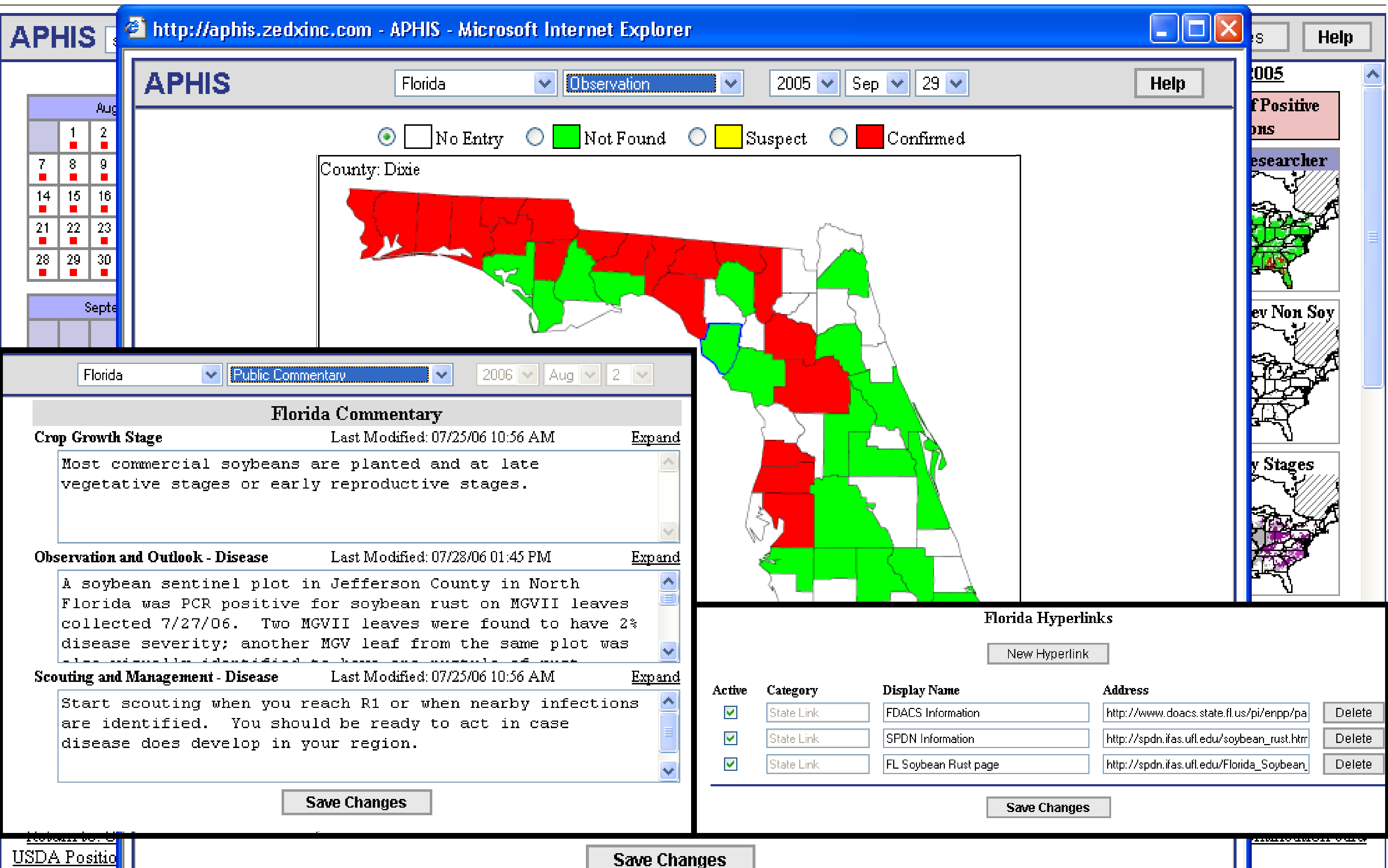
Figure 16. Communications Tools for Specialists; Maps and Text Upload



Restricted Access Website

IAMS
Ensemble Forecasting
Historical Risk Assessment
Epidemiology
Spore Exposure
Canopy Escape
Spore Deposition
Infection Timeline
Spore Trapping
PIPE
Blog
Ragweed
International Collaboration
Forecasting Model
Discussion Group
UG99 - TKKS Wheat Stem Rust
Risk of Incursion
Preparing for Incursion
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Figure 17. Soybean Sentinel Plot Systems From 2006-2008.

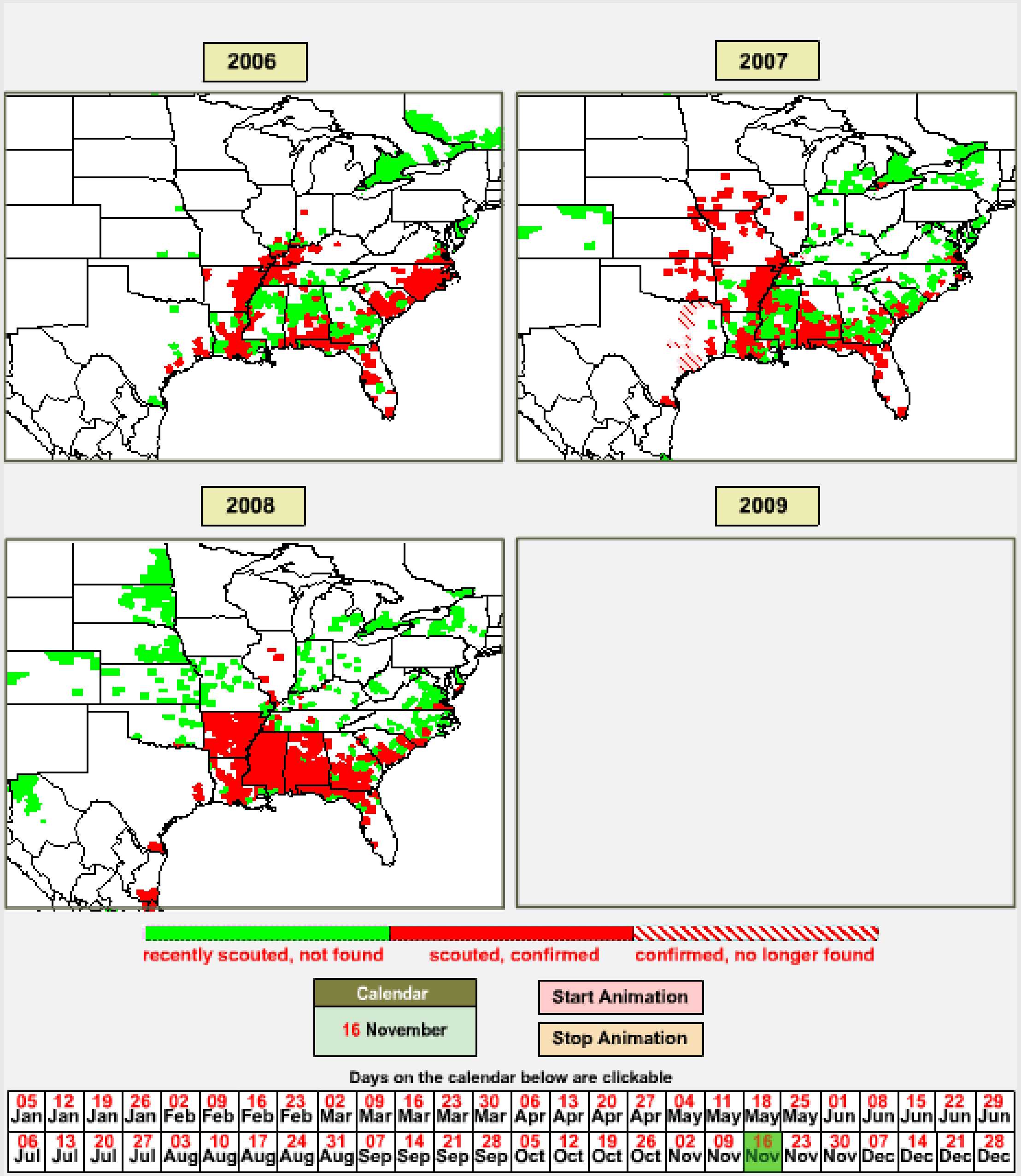


Figure 18. Simulated Transport (HYSPLIT) and Daily Wet Deposition on October 9th, 2007

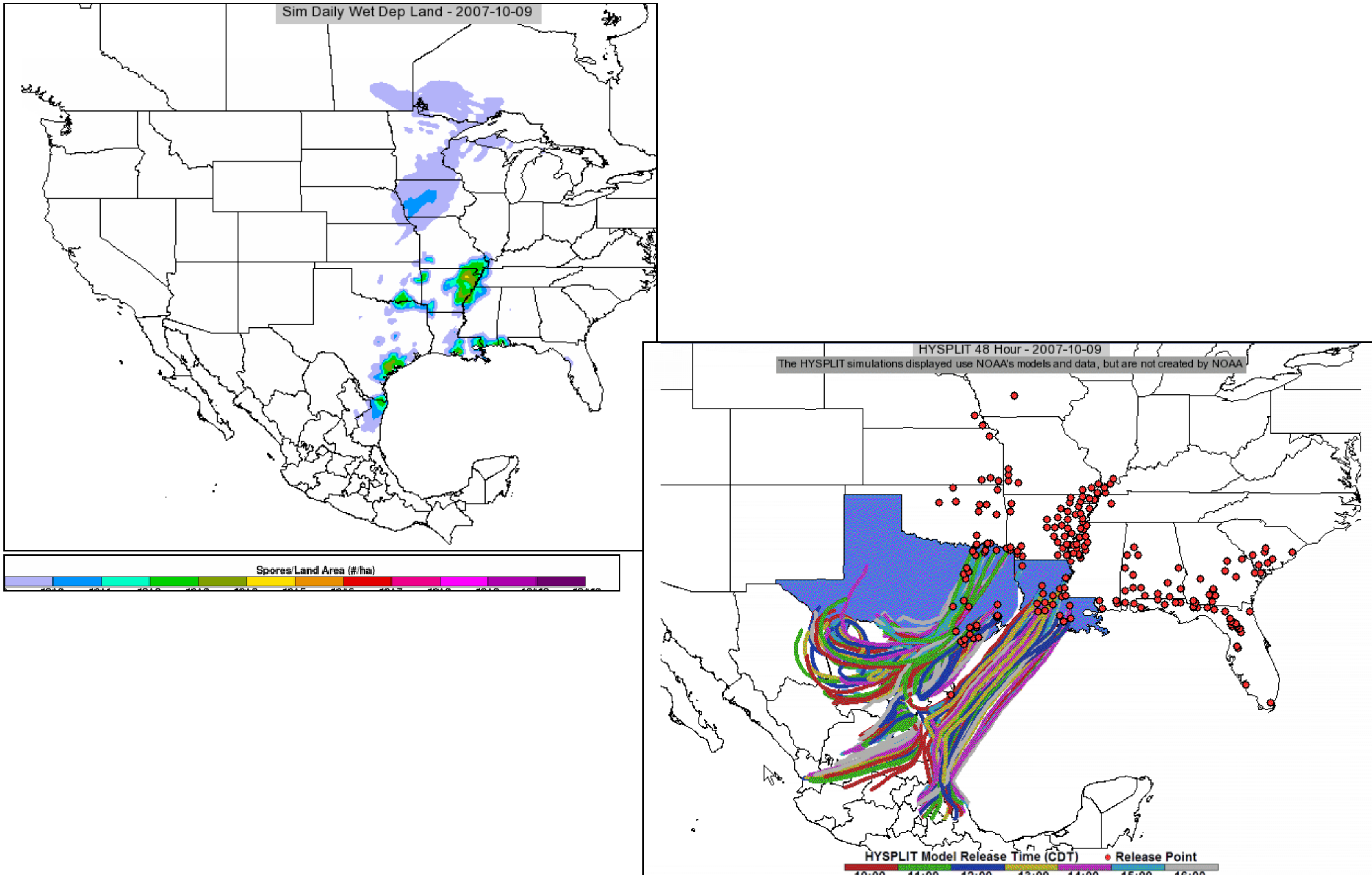


Figure 19. Simulated Transport (HYSPLIT) and Daily Wet Deposition on October 11th, 2007

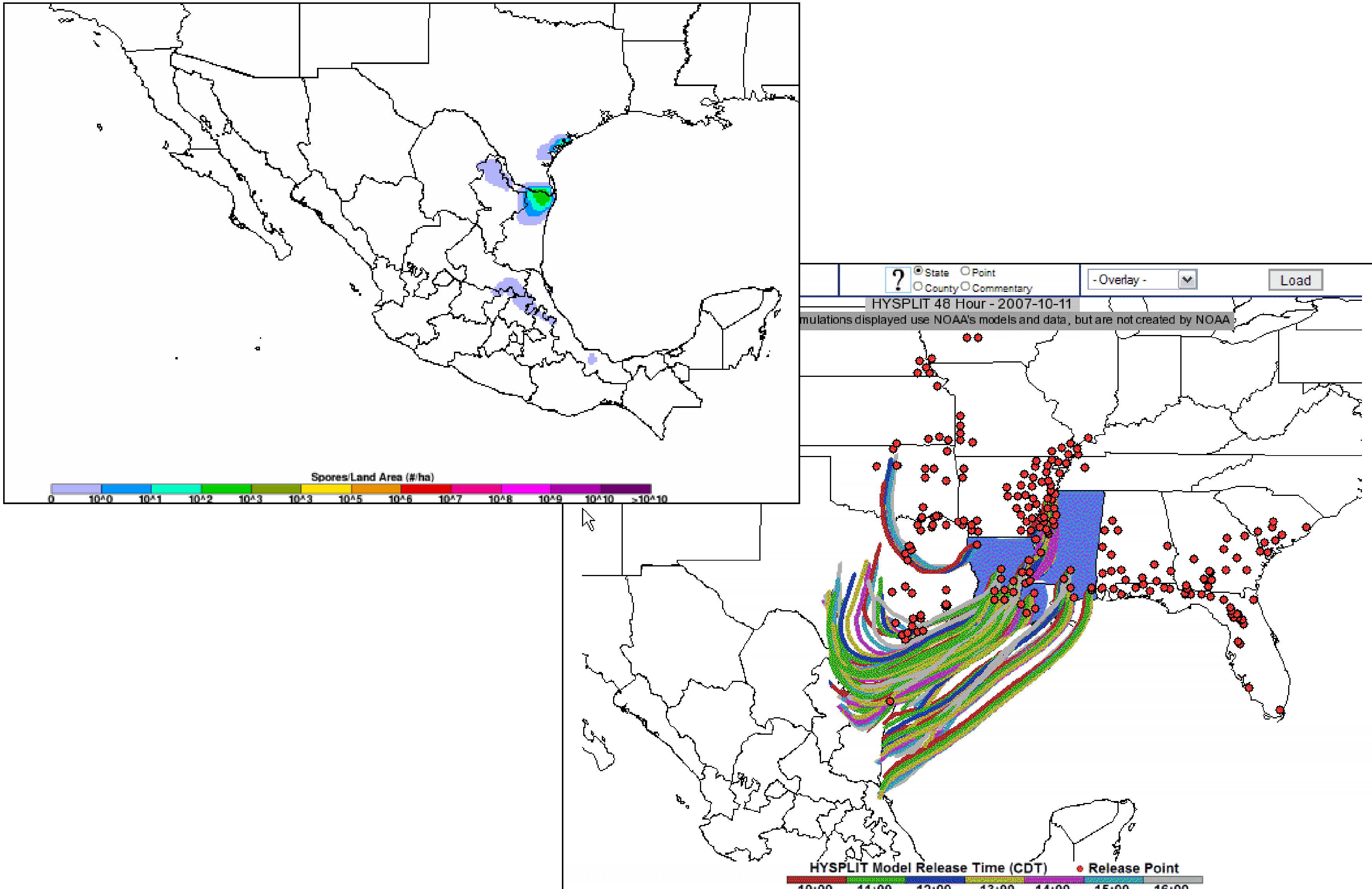
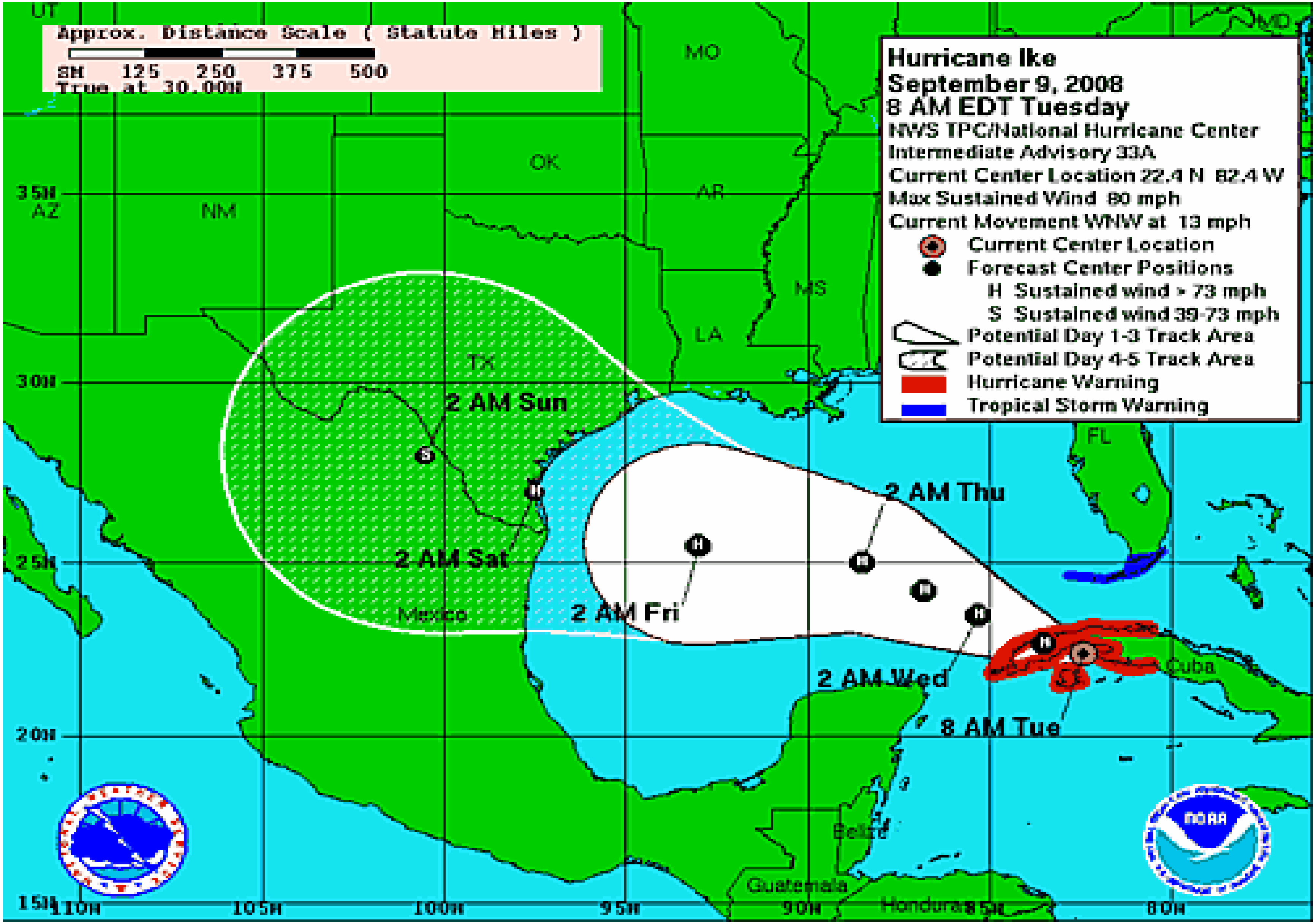


Figure 20. Posible Trayectoria de Huracan Ike



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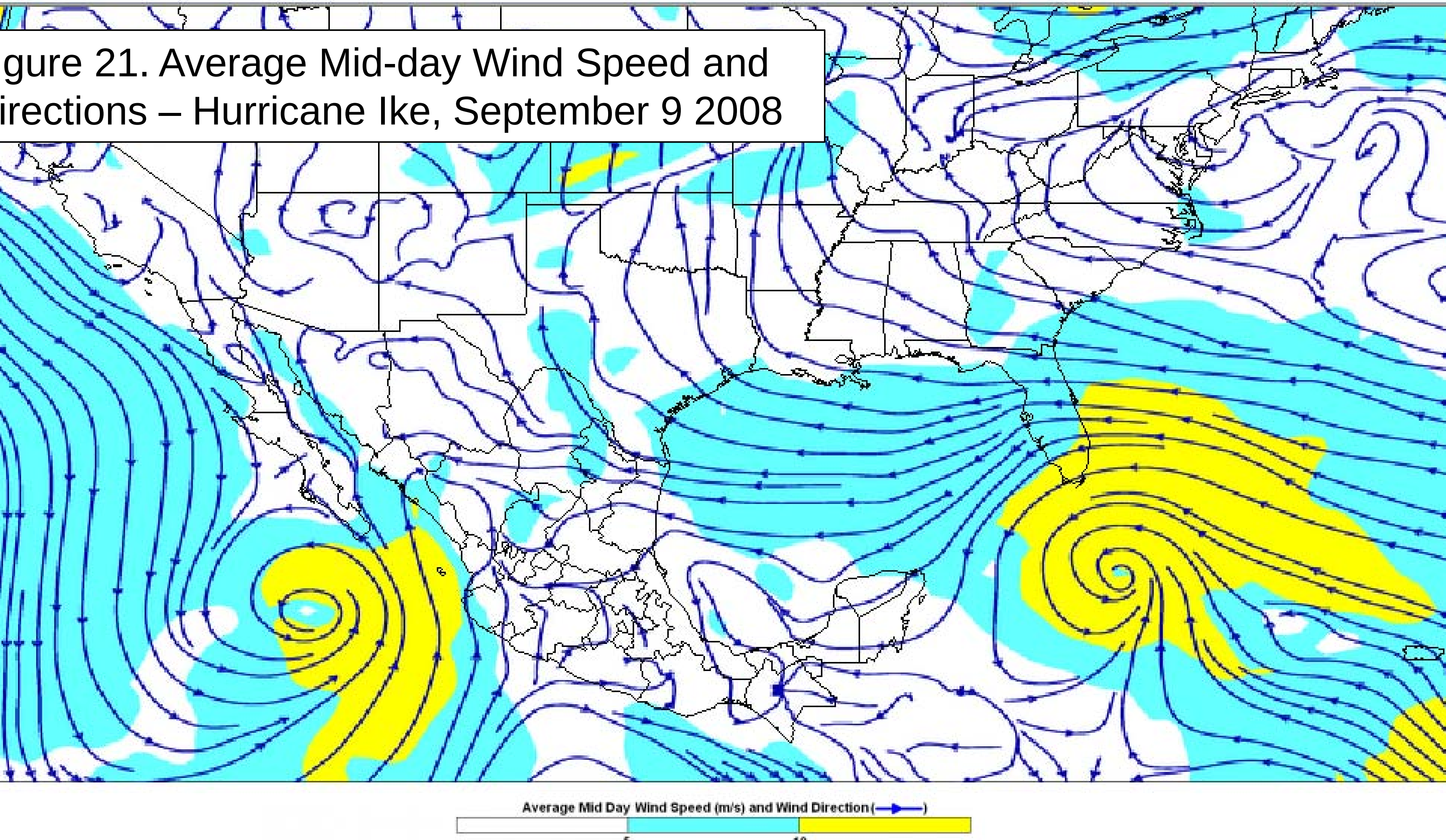
gure 21. Average Mid-day Wind Speed and irections – Hurricane Ike, September 9 2008



Soybean Rust Research Forecast (issued: 2008-09-08)

rent Conditions

Current Conditions September 8th

High pressure situated over Appalachia is keeping most of the South dry this afternoon with the exception of some isolated thunderstorms, especially over the Florida Peninsula. Western and Central portions of Texas are currently observing heavy rain and strong storms associated with a cold front over the central U.S.

Risk Area: Spore transport, deposition, and survival are all currently notable throughout the state of Texas as the disturbance moves though, putting them at risk for the spread of the

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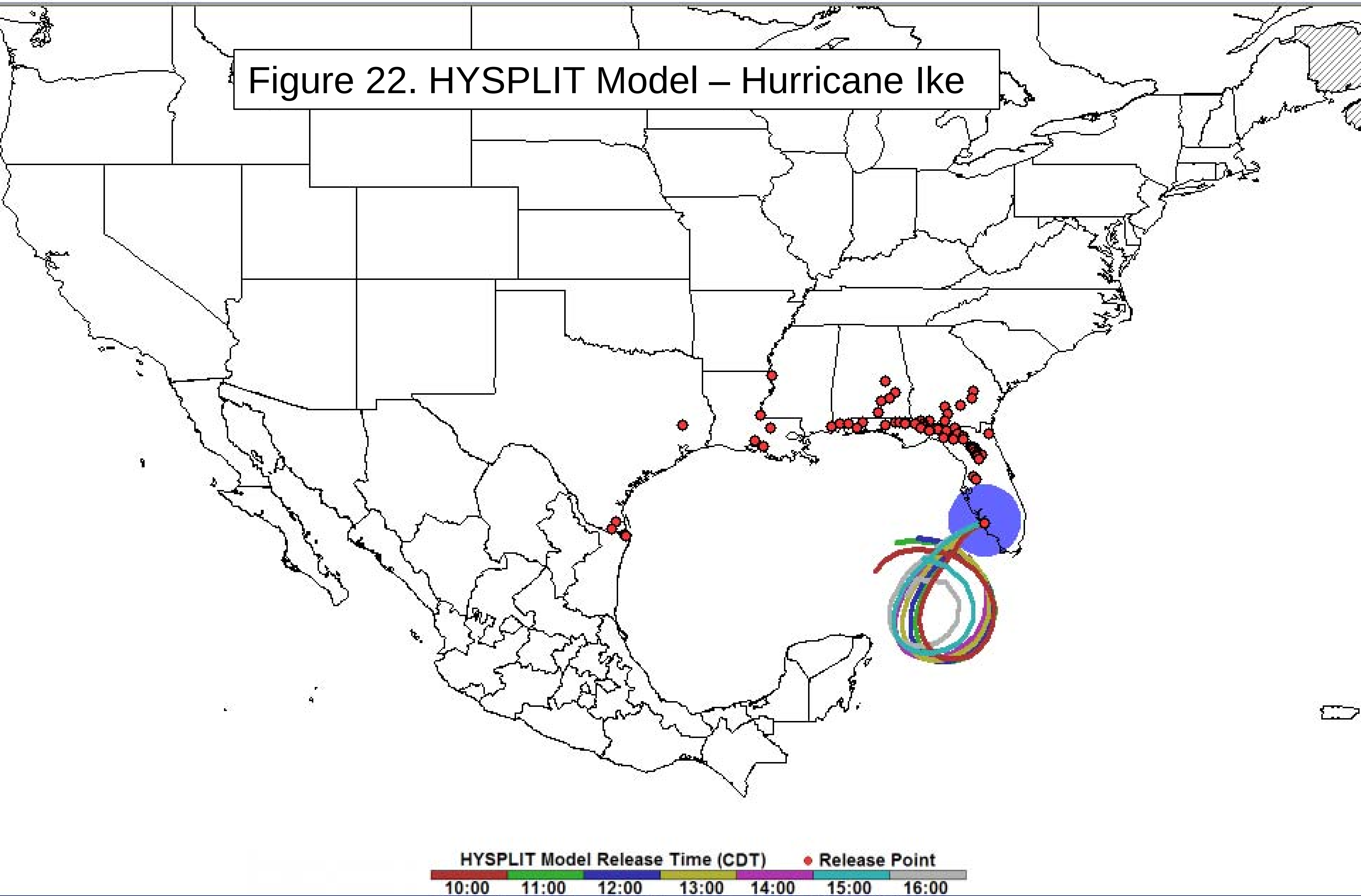
Figure 22. HYSPLIT Model – Hurricane Ike



United States Soybean Rust Commentary (updated: 09/08/08)

September, soybean rust was reported from Holmes County, Florida and from Ashley County, Arkansas on soybeans. Rust was also reported once again in Liberty County, Texas o
dzu. On 6 September, soybean rust was reported in Issaquena County, Mississippi. On 5 September, soybean rust was reported in Elmore (soybean) and Bullock and Pike counties
(kudzu) in Alabama, and in Coffee and Toombs Counties in Georgia.

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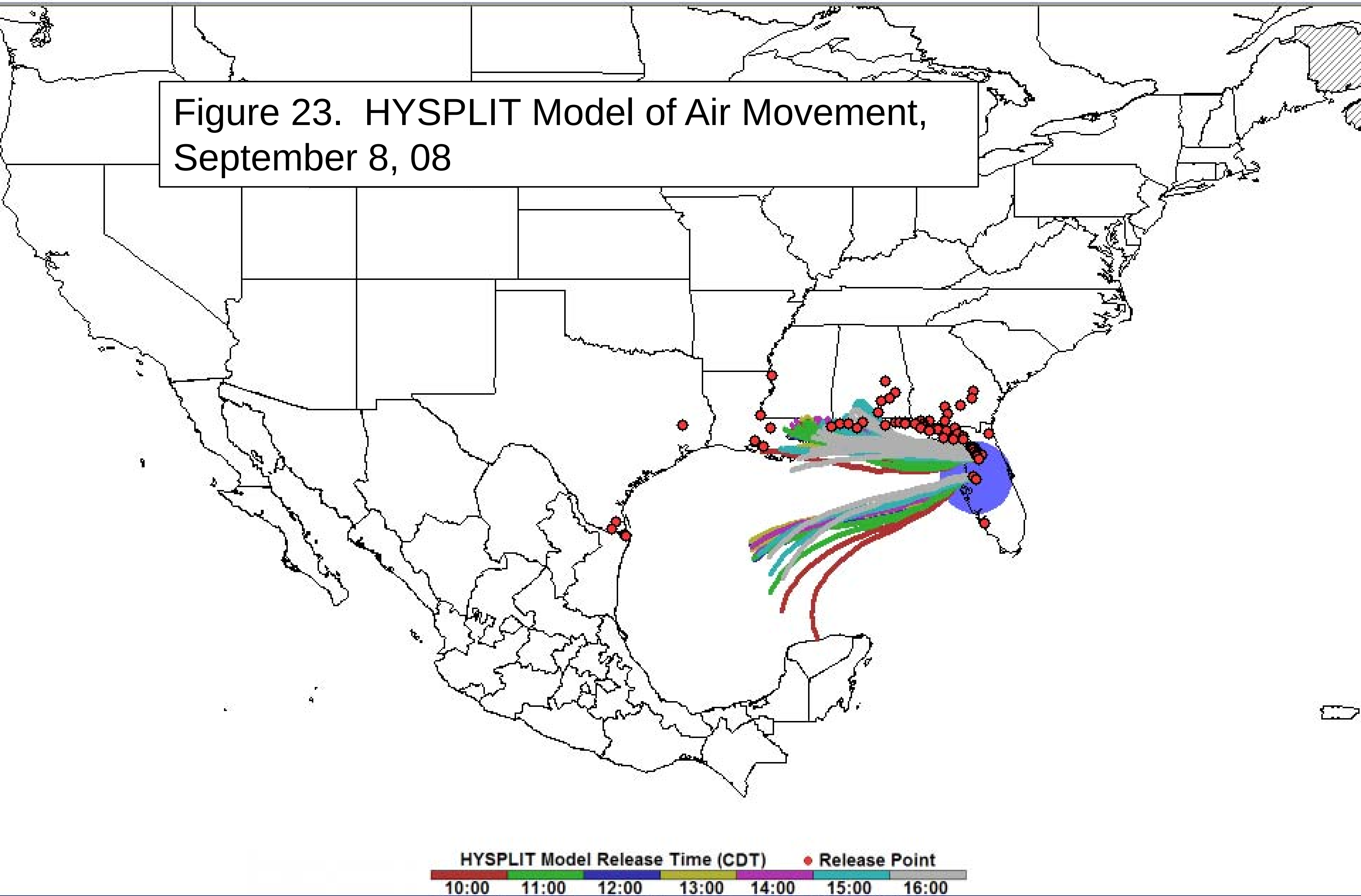
Figure 23. HYSPLIT Model of Air Movement, September 8, 08



United States Soybean Rust Commentary (updated: 09/08/08)

September, soybean rust was reported from Holmes County, Florida and from Ashley County, Arkansas on soybeans. Rust was also reported once again in Liberty County, Texas o udzu. On 6 September, soybean rust was reported in Issaquena County, Mississippi. On 5 September, soybean rust was reported in Elmore (soybean) and Bullock and Pike counties (kudzu) in Alabama, and in Coffee and Toombs Counties in Georgia.

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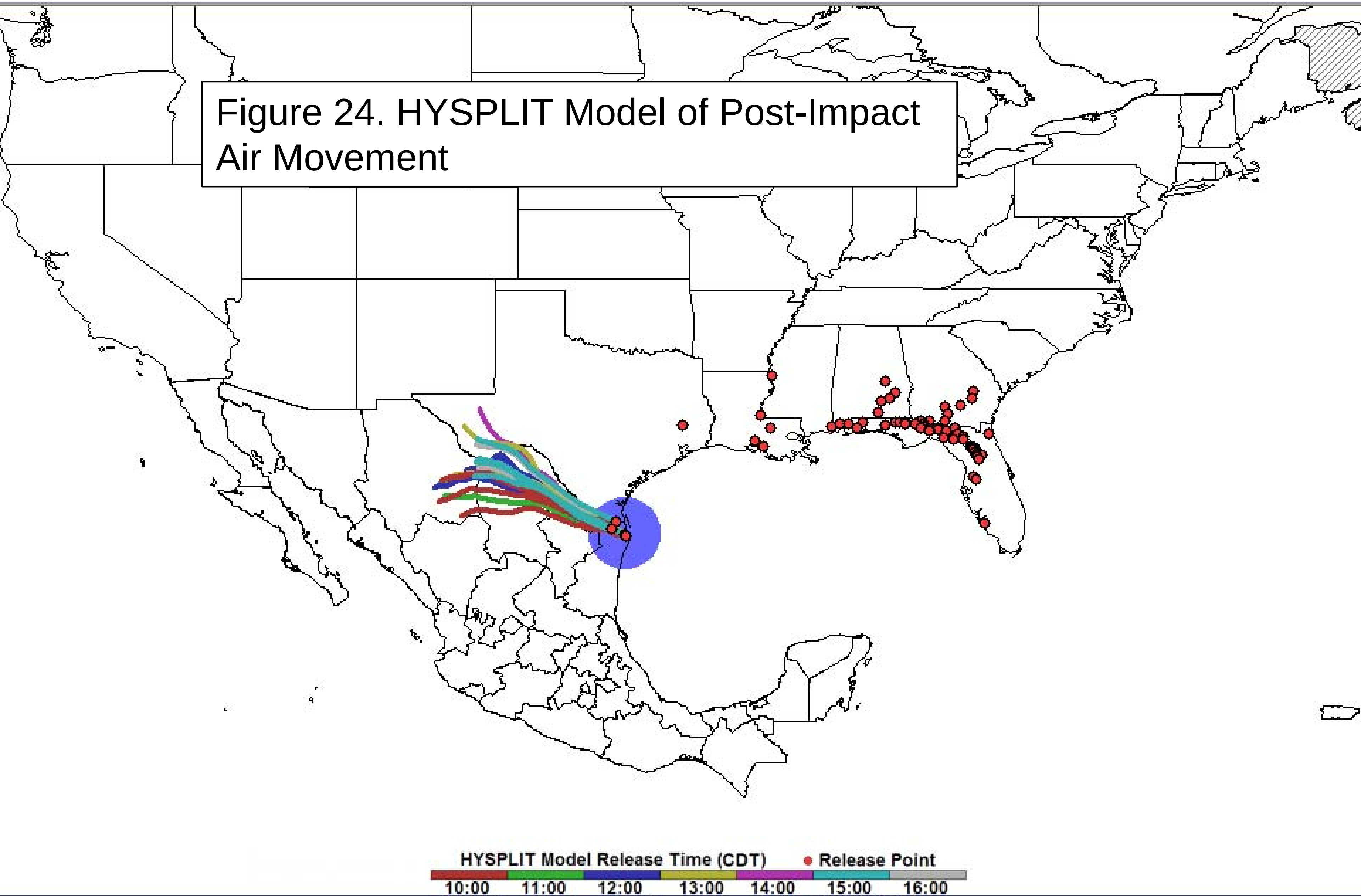
Figure 24. HYSPLIT Model of Post-Impact Air Movement



United States Soybean Rust Commentary (updated: 09/08/08)

September, soybean rust was reported from Holmes County, Florida and from Ashley County, Arkansas on soybeans. Rust was also reported once again in Liberty County, Texas o
udzu. On 6 September, soybean rust was reported in Issaquena County, Mississippi. On 5 September, soybean rust was reported in Elmore (soybean) and Bullock and Pike counties
(kudzu) in Alabama, and in Coffee and Toombs Counties in Georgia.

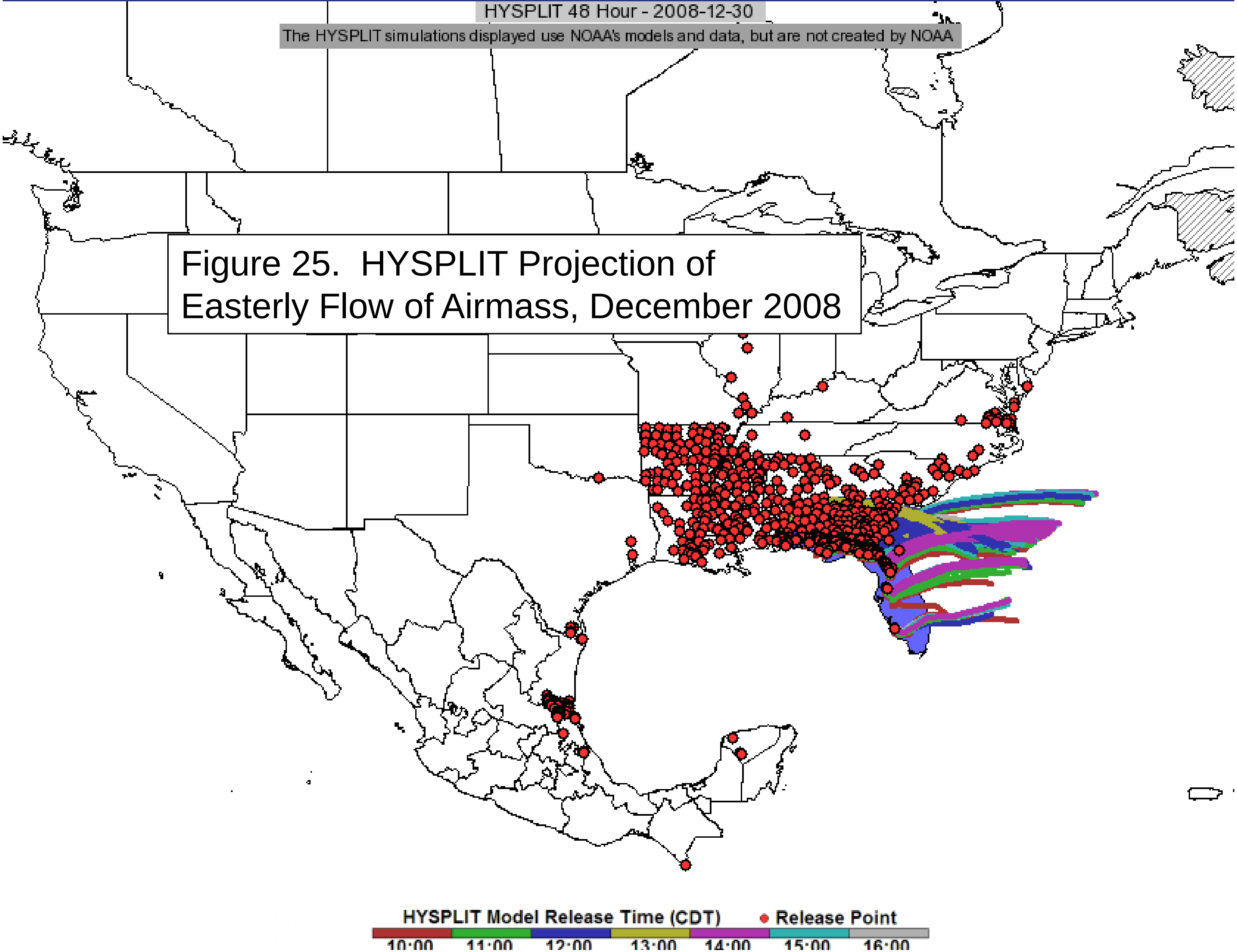


Figure 25. HYSPLIT Projection of Easterly Flow of Airmass, December 2008

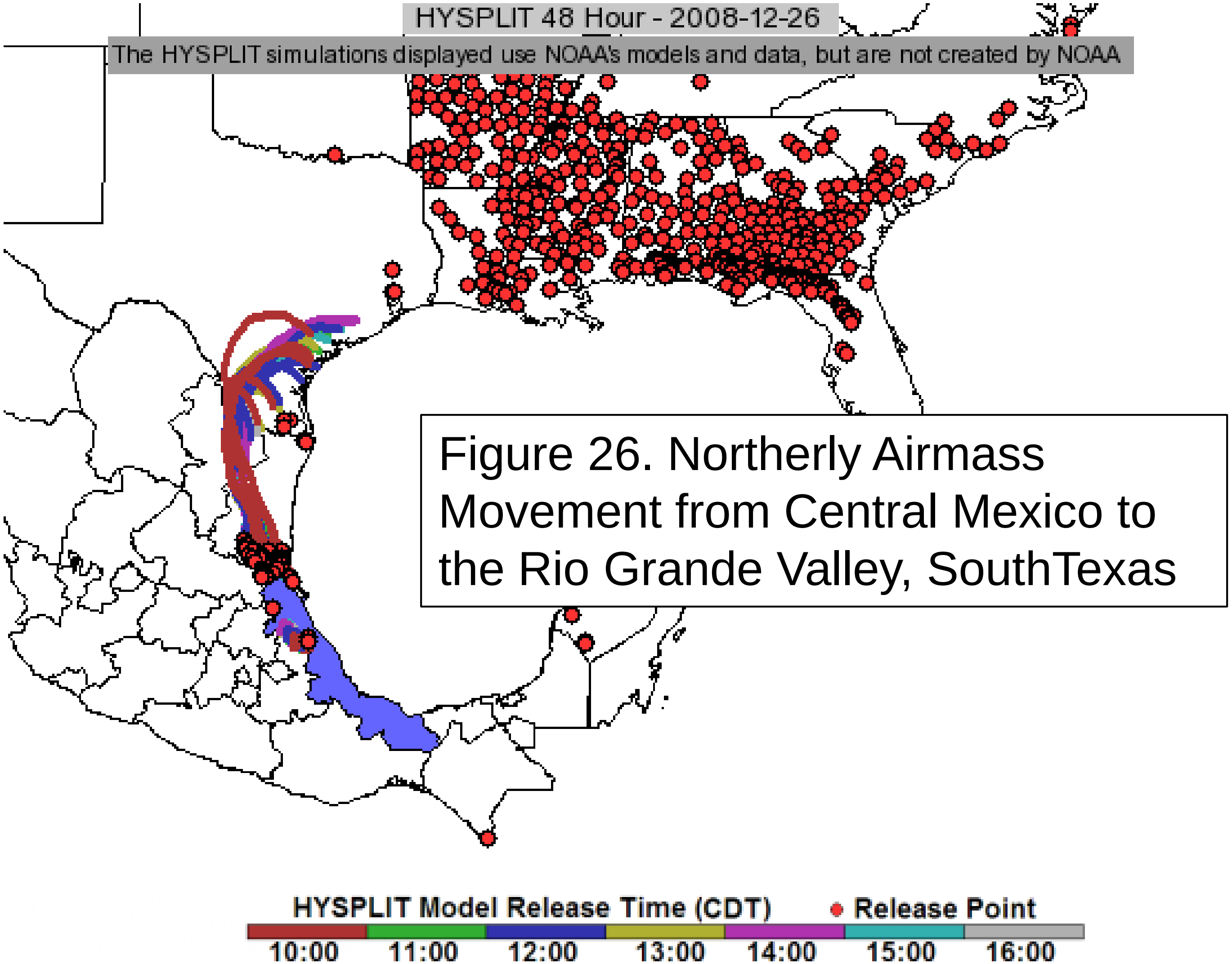


Figure 26. Northerly Airmass Movement from Central Mexico to the Rio Grande Valley, SouthTexas

Figure 27. Meso-American Scale Coordination in Control of Citrus Diseases Is Called For