

Program Final Report
PFR-10163

Hurrevac eXtended (HVX): Hurricane disaster planning, training, operations for emergency managers

R. G. Hallowell

3 January 2023

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS



DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited.

This material is based upon work supported by the Dept of Homeland Security under Air Force Contract No. FA8702-15-D-001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Dept of Homeland Security.

This report is the result of studies performed at Lincoln Laboratory, a federally funded research and development center operated by Massachusetts Institute of Technology. This material is based upon work supported by the Dept of Homeland Security under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Dept of Homeland Security.

© 2023 Massachusetts Institute of Technology

Delivered to the U.S. Government with Unlimited Rights, as defined in DFARS Part 252.227-7013 or 7014 (Feb 2014). Notwithstanding any copyright notice, U.S. Government rights in this work are defined by DFARS 252.227-7013 or DFARS 252.227-7014 as detailed above. Use of this work other than as specifically authorized by the U.S. Government may violate any copyrights that exist in this work.

Massachusetts Institute of Technology
Lincoln Laboratory

Hurrevac eXtended (HVX): Hurricane disaster planning,
training, and operations for emergency managers

Robert G. Hallowell
Group 21

Final Report PFR-10163
3 January 2023

DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited.

This material is based upon work supported by the Dept of Homeland Security under Air Force Contract
No. FA8702-15-D-0001.

Lexington

Massachusetts

Hurrevac eXtended (HVX): Hurricane Disaster Planning, Training, and Operations for Emergency Managers

Robert Hallowell

HVX Closeout Program #10163

3 January 2023

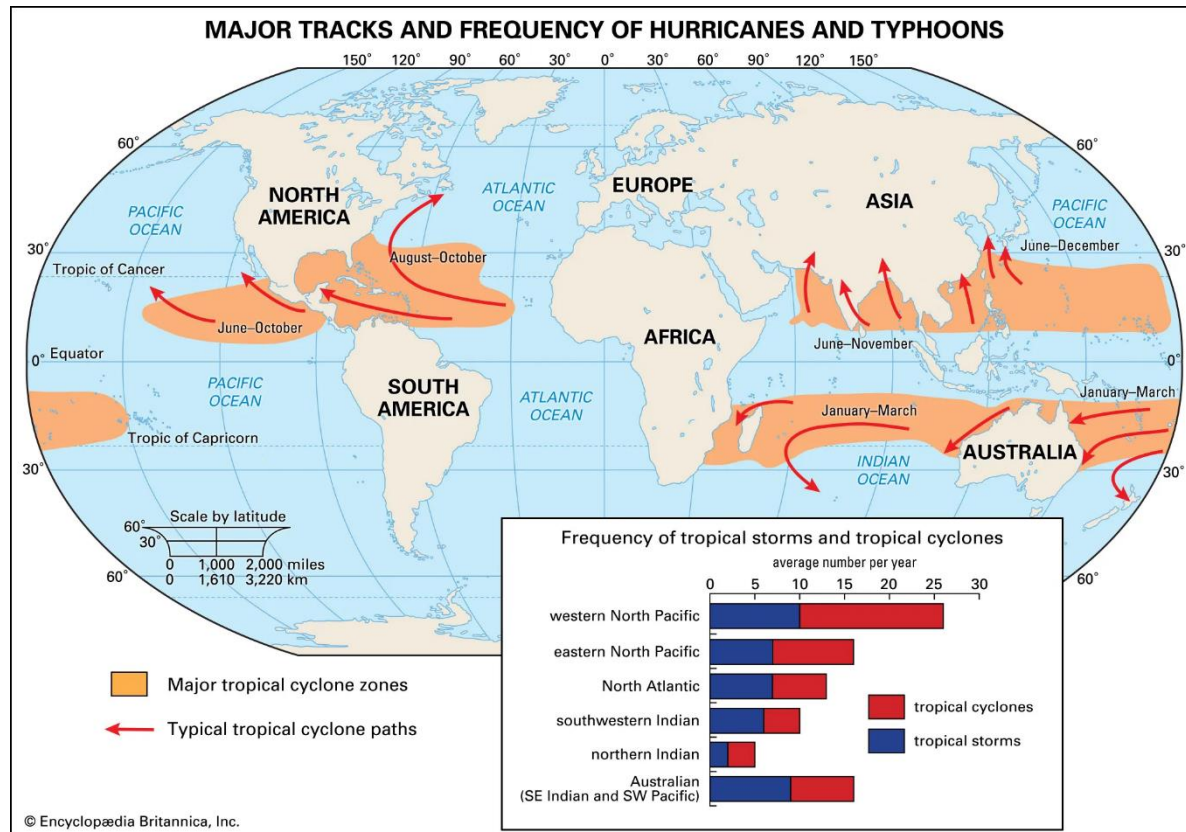


DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited. This material is based upon work supported by the Dept of Homeland Security under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Dept of Homeland Security. © 2023 Massachusetts Institute of Technology. Delivered to the U.S. Government with Unlimited Rights, as defined in DFARS Part 252.227-7013 or 7014 (Feb 2014). Notwithstanding any copyright notice, U.S. Government rights in this work are defined by DFARS 252.227-7013 or DFARS 252.227-7014 as detailed above. Use of this work other than as specifically authorized by the U.S. Government may violate any copyrights that exist in this work.

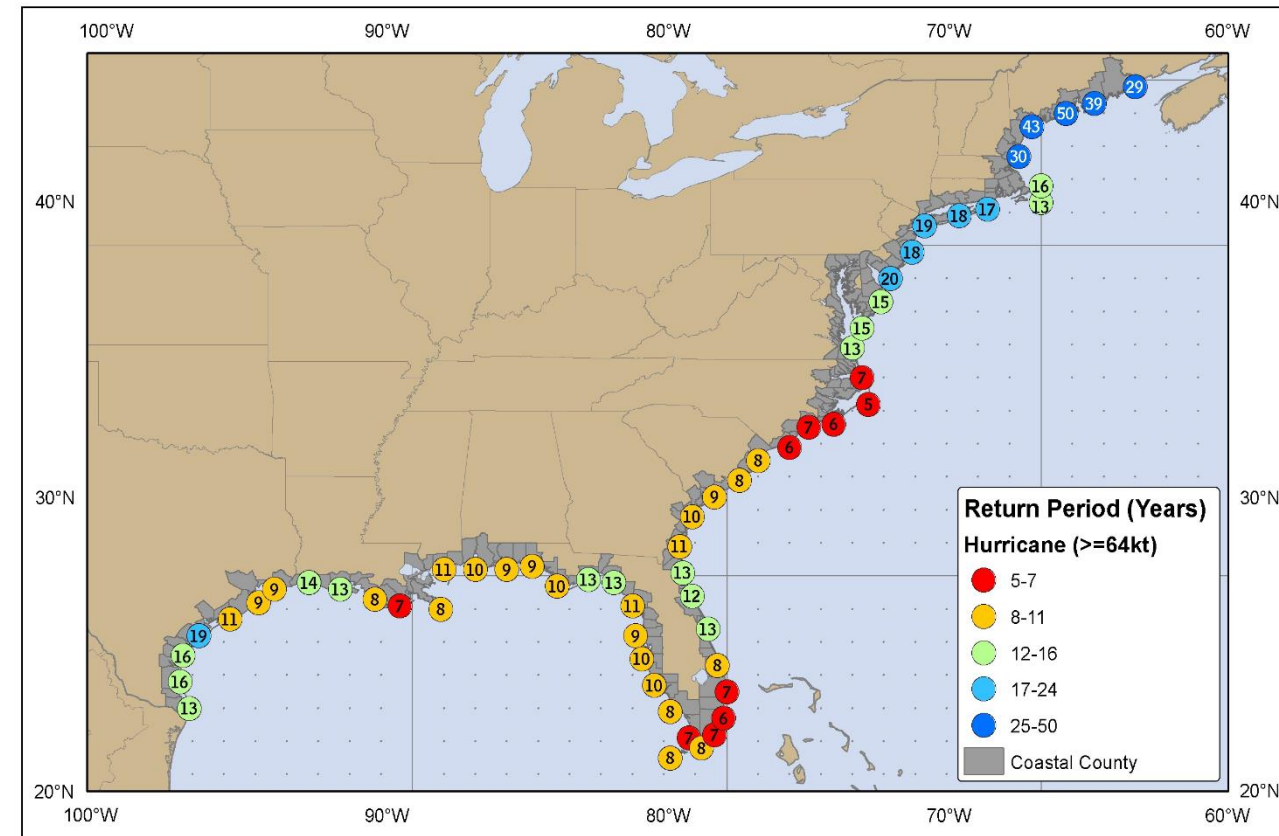


Tropical Cyclone Climatology

Worldwide Tropical Cyclone Tracks and Frequency



Frequency of U.S. Landfalling Hurricanes





- **Landfalling Hurricanes: 125 (1.7 /yr)**
- **Major Hurricane: 370 (5.1 /yr)**
- **Hurricanes: 917 (12.7 /yr)**
- **Named storms: 1,762 (24.5 /yr)**

- **3,274 (55.5 /yr)**

- **\$1.2T (\$33.3B /yr)**



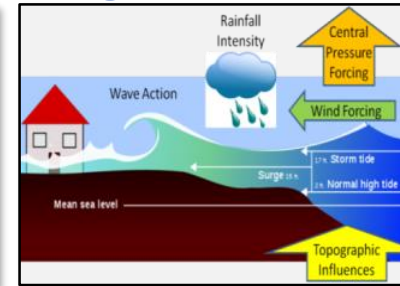


Hurricane Hazards/Impacts

U.S. Hurricane Damages (Top 10 1980–2022)

Name(year)	Damages(\$B)
Katrina (2005)	\$186.3
Harvey (2017)	148.8
Maria (2017)	107.1
Sandy (2012)	81.9
Ida (2021)	78.7
Irma (2017)	59.5
Andrew (1992)	55.9
Ike (2008)	40.2
Ivan (2004)	31.6
Michael (2018)	29.0

Storm Surge



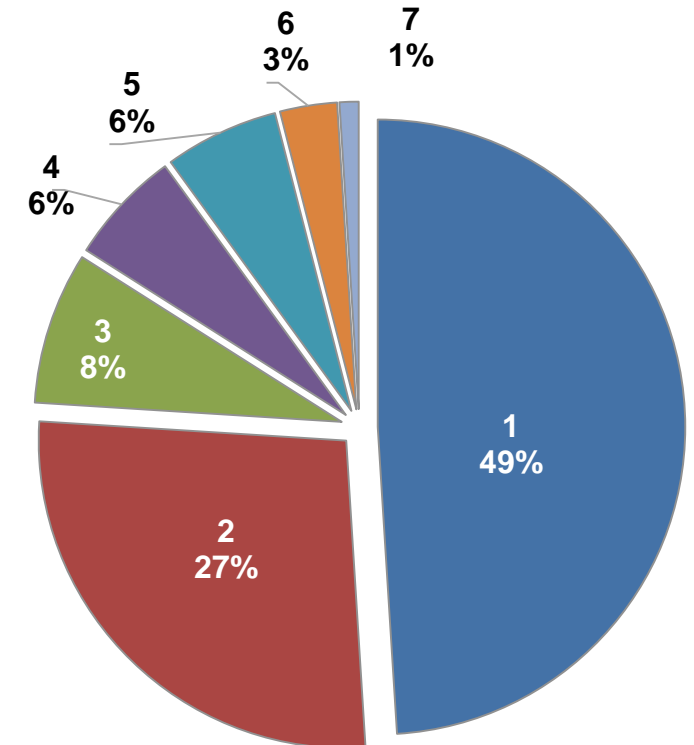
Winds



Inland Flooding



Causes of U.S. Hurricane Fatalities (1960–2012)





Hurricane Evacuations

“I make the best wrong decision that I can make” – Local emergency manager



- Evacuations can take days
- Need to be ordered well ahead of storm, under high forecast uncertainty

As Harvey submerges Houston, local officials defend their calls not to evacuate

By Amy B Wang, Cleve R. Wootson Jr. and Ed O'Keefe August 28, 2017 [Email the author](#)

Governor delays evacuation decision until Friday evening forecast

SEPTEMBER 8, 2017 BY SOUTH CAROLINA RADIO NETWORK

Why the 'tough love' on Hurricane Matthew evacuation?

By Juliette Kayyem, CNN National Security Analyst
Updated 6:50 AM ET, Fri October 7, 2016

How New Orleans' Evacuation Plan Fell Apart

September 23, 2005 - 12:00 AM ET

'People making decisions hesitated'

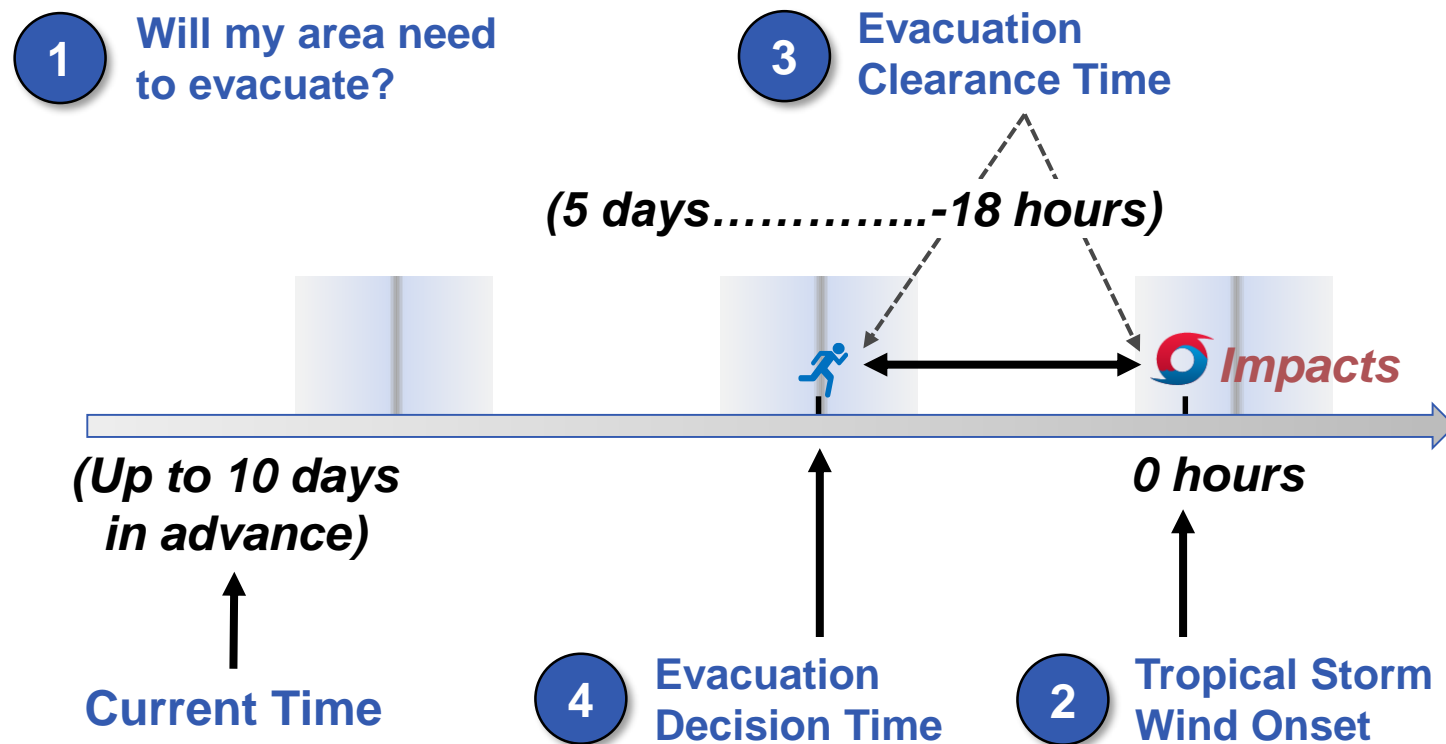
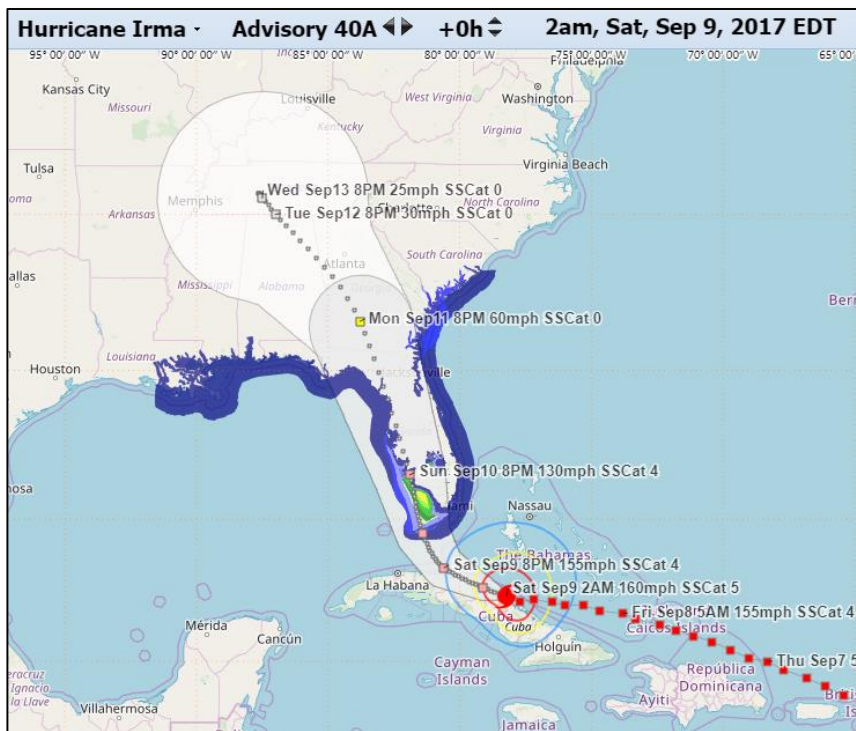
More officials' jobs may fall to Katrina response criticism

Tuesday, September 13, 2005; Posted: 6:28 p.m. EDT (22:28 GMT)

Hurricane evacuation orders are complex, high-impact, high-regret decisions



Hurricane Evacuation Decision Timeline

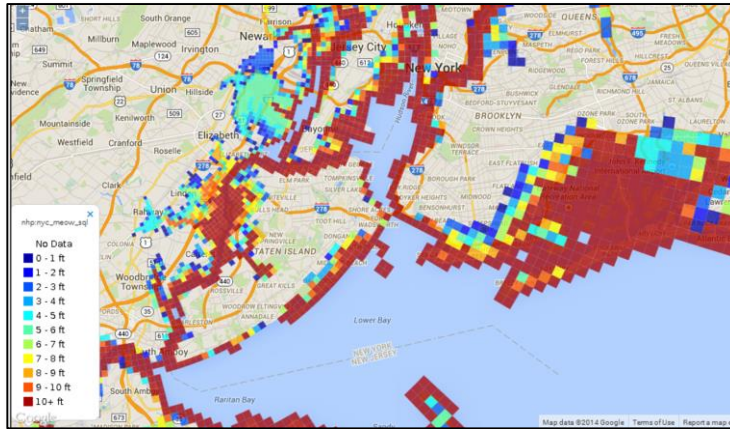


Evacuation decisions require understanding the uncertainty in forecasted timing and impacts

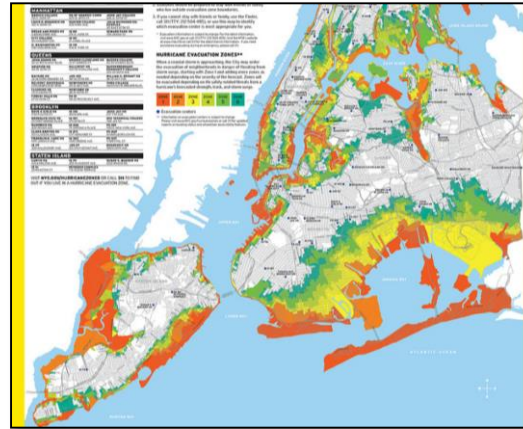


Hurricane Evacuation Decisions

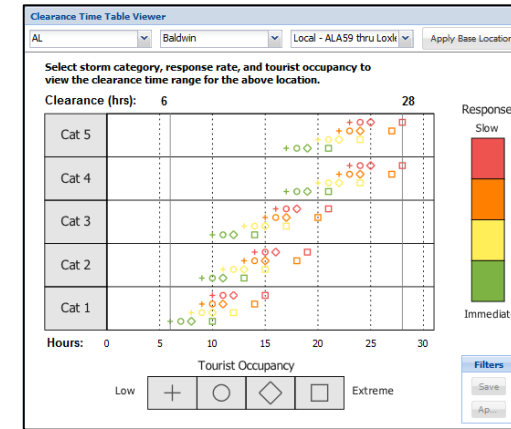
Storm Surge Hazard



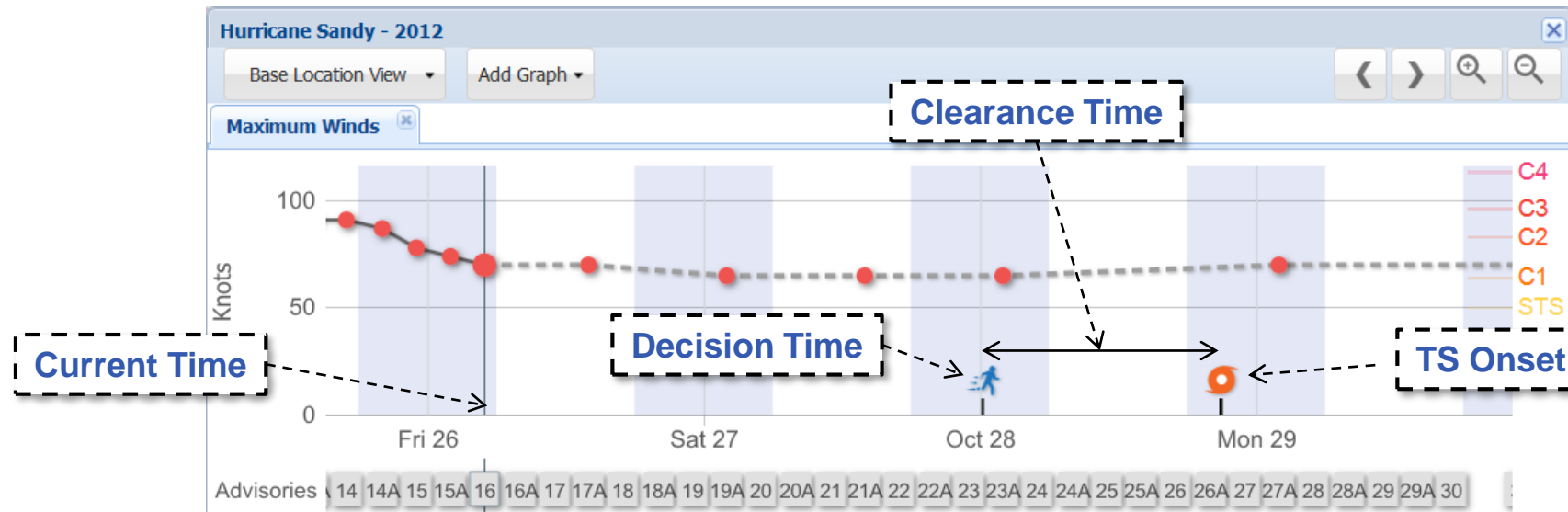
Evacuation Zones



Clearance Times



Storm Forecast





Hurricane Disaster Response Cycle

Continuous Situational Awareness and Decision Support



Monitoring and Modeling



Years: Risk Assessment, Planning and Training



Days / Hours

Evacuation and Mitigation Decisions



Days / Hours

Rapid Response and Resource Allocation



Days / Weeks

Damage Assessment



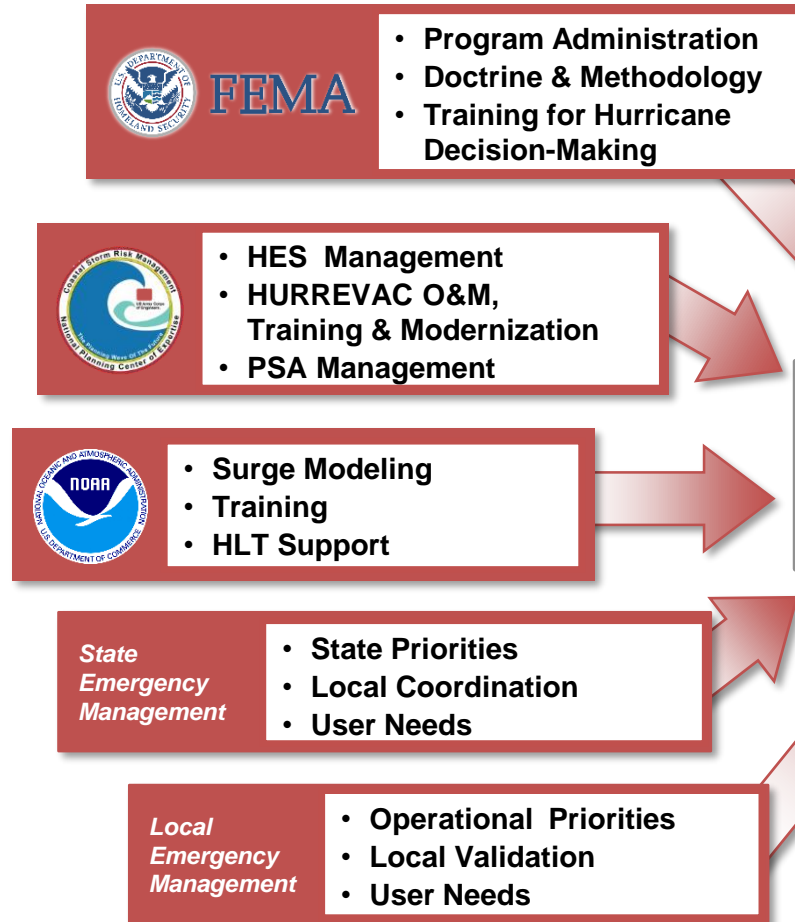
Weeks / Months

Recover and Rebuild



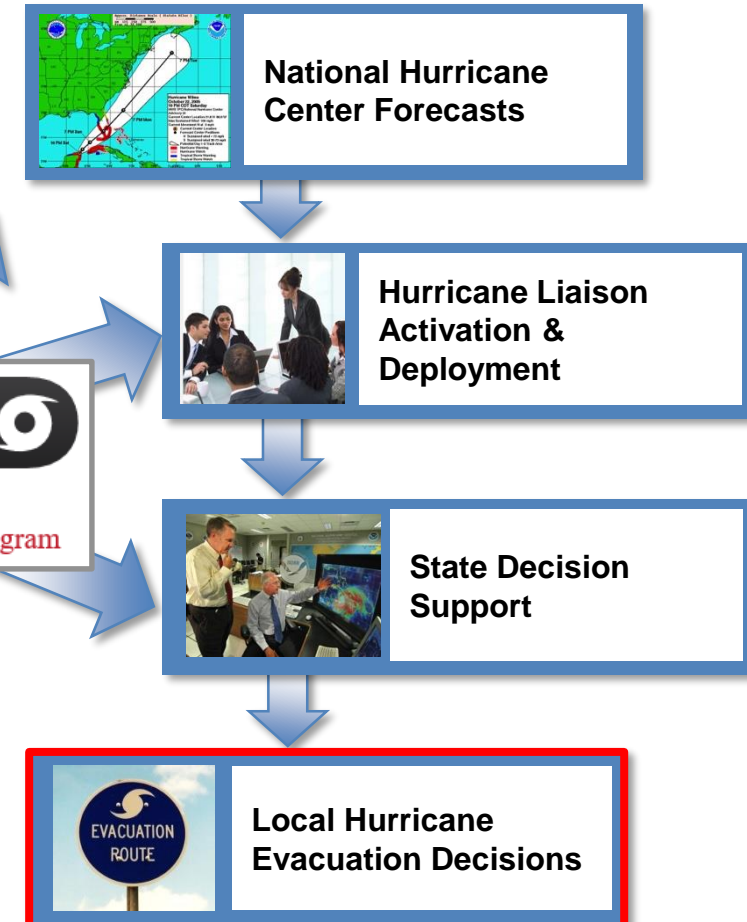
National Hurricane Program*

Planning



NHP
National Hurricane Program

Response



Provide training, operational tools, technical and policy assistance to EMs in support of their hurricane evacuation and response decisions during hurricane threats



HVX Development Timeline

*Stakeholder
Engagement*



Technology Gap Analysis



HVX User Groups



*HVX Transition to
FEMA Vendor*

HVX Operational
(Sea Island Software
hvx.hurrevac.com)



2013

2014

2015

2016

2017

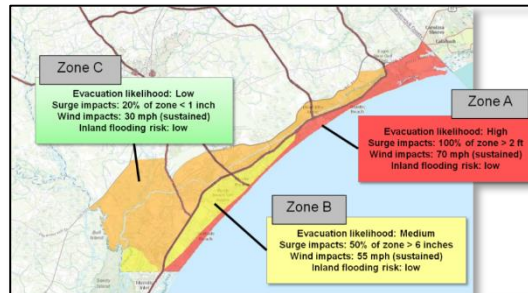
2018

2019

2020

2021

Technology Pilots



HVX Development



Decision platform, gaming tools

“Operational” Prototype



2016, 2017 & 2018 Hurricane Seasons




*HURREVAC Storm
simulation suite – 2022
National Hurricane
Conference “Outstanding
Achievement Award*



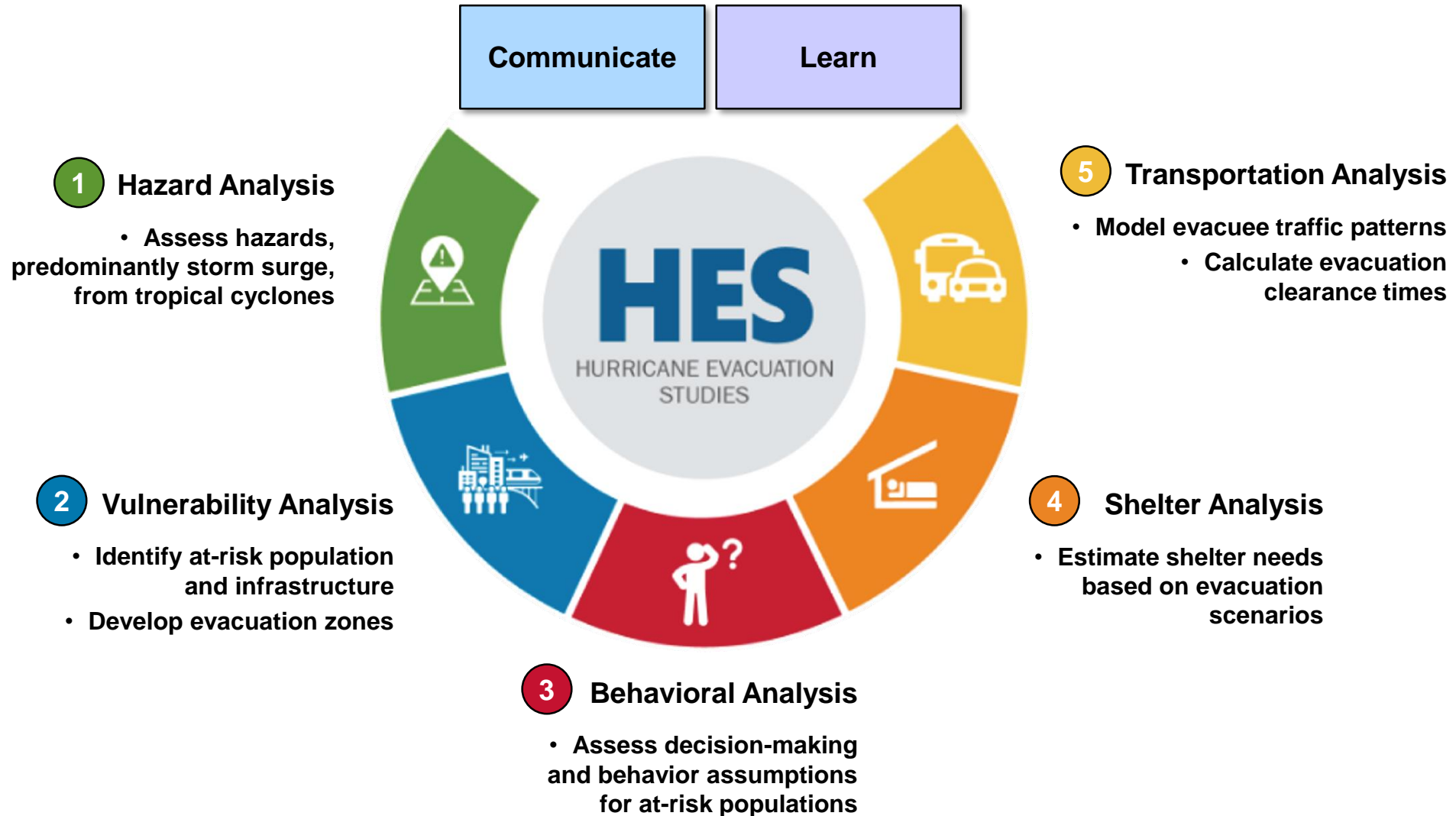
HVX Program Funding History

DHS Science & Technology Directorate Funding FY13 – FY20

 Science and Technology		Phase 1 (Gap Analysis, Technology Pilots)		Phase 2 (Guidance Doc & HES-SUMMIT, HVX Platform)		Phase 3 (HVX pilots and extensions)	Phase 4 (HVX Transition)	Transition (Core system components)	Transition (Training)
		FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20
		(Jun 13 - Sep 13)	(Oct 13 – Sep 14)	(Oct 14 – Mar 16)	(Mar 16 – Apr 17)	(May 17 – May 18)	(May 18 – Apr 19)	(May 19 – Apr 20)	(May 20 – Jul 21)
Performers	MITLL	\$150K	\$400K	\$2,750K	\$1,250K	\$820K	\$832K	\$834K	\$500K
	Sandia	\$150K	\$400K	\$1,000K	0	0	0	0	0
	CSE-Corp	0	0	\$250K	0	0	0	0	0
TOTAL BY PHASE		\$1,100K		\$5,250K		\$820K	\$832K	\$834K	\$500K
TOTAL BY FY		\$300K	\$800K	4,000,000	1,250,000	\$820K	\$832K	\$834K	\$500K
TOTAL PROJECT		\$9,336K (all performers) [\$7,536K MITLL*]							

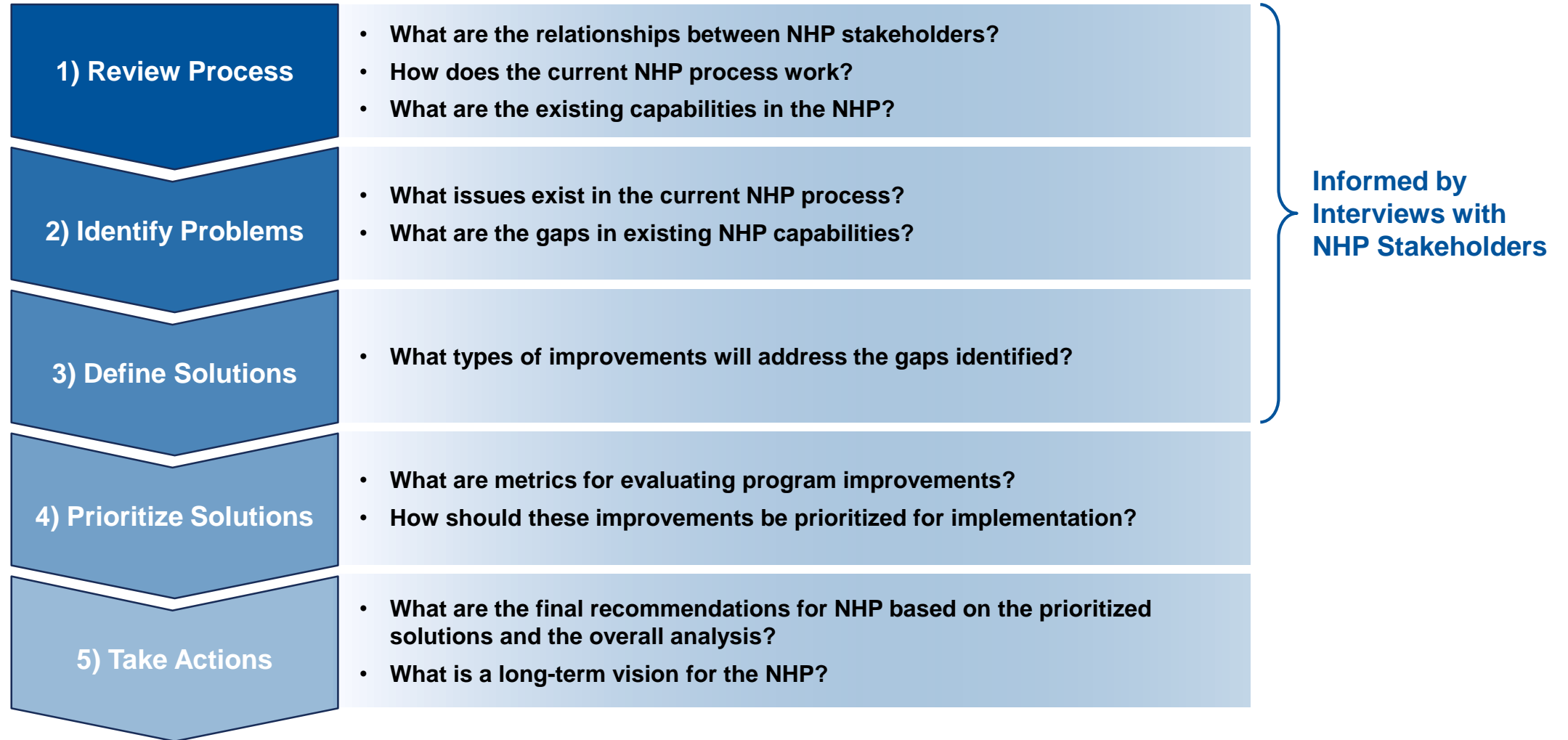


Evacuation Planning Process and Challenges





Analysis Process Overview





Technical Approach

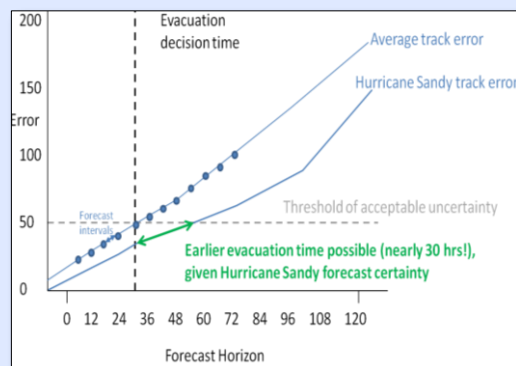
Program Goal: Modernize the “technology” components of the National Hurricane Program (NHP)

Operations Analysis



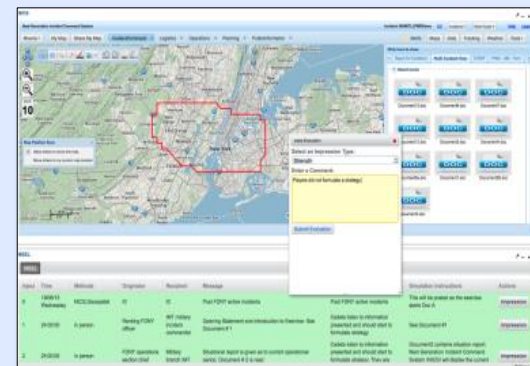
- Interview stakeholders
- Identify gaps

Concept Exploration



- Prototype solutions
- Analyze effectiveness

Technology Development

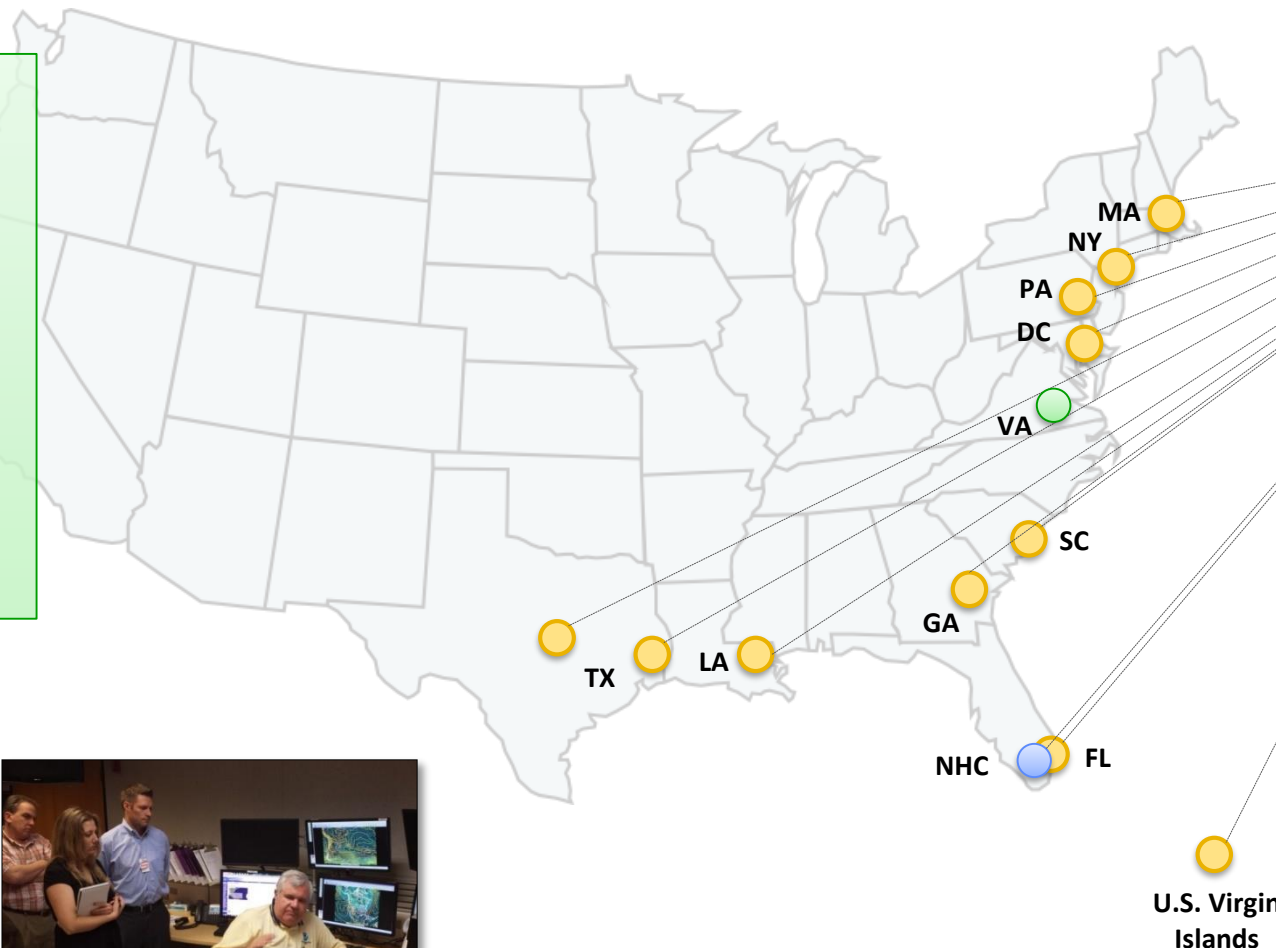


- Build new technology
- Transition to operations



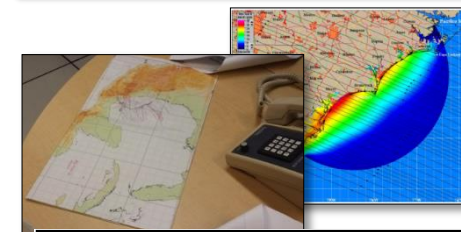
Step 1-3: Stakeholder Interviews

- **Federal**
 - FEMA (HQ & Regions)
 - NWS NHC
 - NWS LFOs
 - USACE
- **State and local level**
 - 17+ Interviews of EMs
- **Sea Island Software**
 - HURREVAC developer



- **Structured interviews**
 - In-person
 - Phone-based
- **NHC Training**
 - L324 @ NHC

The team conducted over 50 interviews



QUESTION 2 - WHAT WOULD BE THE EXTENT OF AN EVACUATION FROM THE STORM?			
STATION	STATION NUMBER	STATION NAME	STATION TYPE
STATION 1	1000	STATION 1	STATION 1
STATION 2	2000	STATION 2	STATION 2
STATION 3	3000	STATION 3	STATION 3
STATION 4	4000	STATION 4	STATION 4
STATION 5	5000	STATION 5	STATION 5
STATION 6	6000	STATION 6	STATION 6
STATION 7	7000	STATION 7	STATION 7
STATION 8	8000	STATION 8	STATION 8
STATION 9	9000	STATION 9	STATION 9
STATION 10	10000	STATION 10	STATION 10
STATION 11	11000	STATION 11	STATION 11
STATION 12	12000	STATION 12	STATION 12
STATION 13	13000	STATION 13	STATION 13
STATION 14	14000	STATION 14	STATION 14
STATION 15	15000	STATION 15	STATION 15
STATION 16	16000	STATION 16	STATION 16
STATION 17	17000	STATION 17	STATION 17
STATION 18	18000	STATION 18	STATION 18
STATION 19	19000	STATION 19	STATION 19
STATION 20	20000	STATION 20	STATION 20
STATION 21	21000	STATION 21	STATION 21
STATION 22	22000	STATION 22	STATION 22
STATION 23	23000	STATION 23	STATION 23
STATION 24	24000	STATION 24	STATION 24
STATION 25	25000	STATION 25	STATION 25
STATION 26	26000	STATION 26	STATION 26
STATION 27	27000	STATION 27	STATION 27
STATION 28	28000	STATION 28	STATION 28
STATION 29	29000	STATION 29	STATION 29
STATION 30	30000	STATION 30	STATION 30
STATION 31	31000	STATION 31	STATION 31
STATION 32	32000	STATION 32	STATION 32
STATION 33	33000	STATION 33	STATION 33
STATION 34	34000	STATION 34	STATION 34
STATION 35	35000	STATION 35	STATION 35
STATION 36	36000	STATION 36	STATION 36
STATION 37	37000	STATION 37	STATION 37
STATION 38	38000	STATION 38	STATION 38
STATION 39	39000	STATION 39	STATION 39
STATION 40	40000	STATION 40	STATION 40
STATION 41	41000	STATION 41	STATION 41
STATION 42	42000	STATION 42	STATION 42
STATION 43	43000	STATION 43	STATION 43
STATION 44	44000	STATION 44	STATION 44
STATION 45	45000	STATION 45	STATION 45
STATION 46	46000	STATION 46	STATION 46
STATION 47	47000	STATION 47	STATION 47
STATION 48	48000	STATION 48	STATION 48
STATION 49	49000	STATION 49	STATION 49
STATION 50	50000	STATION 50	STATION 50

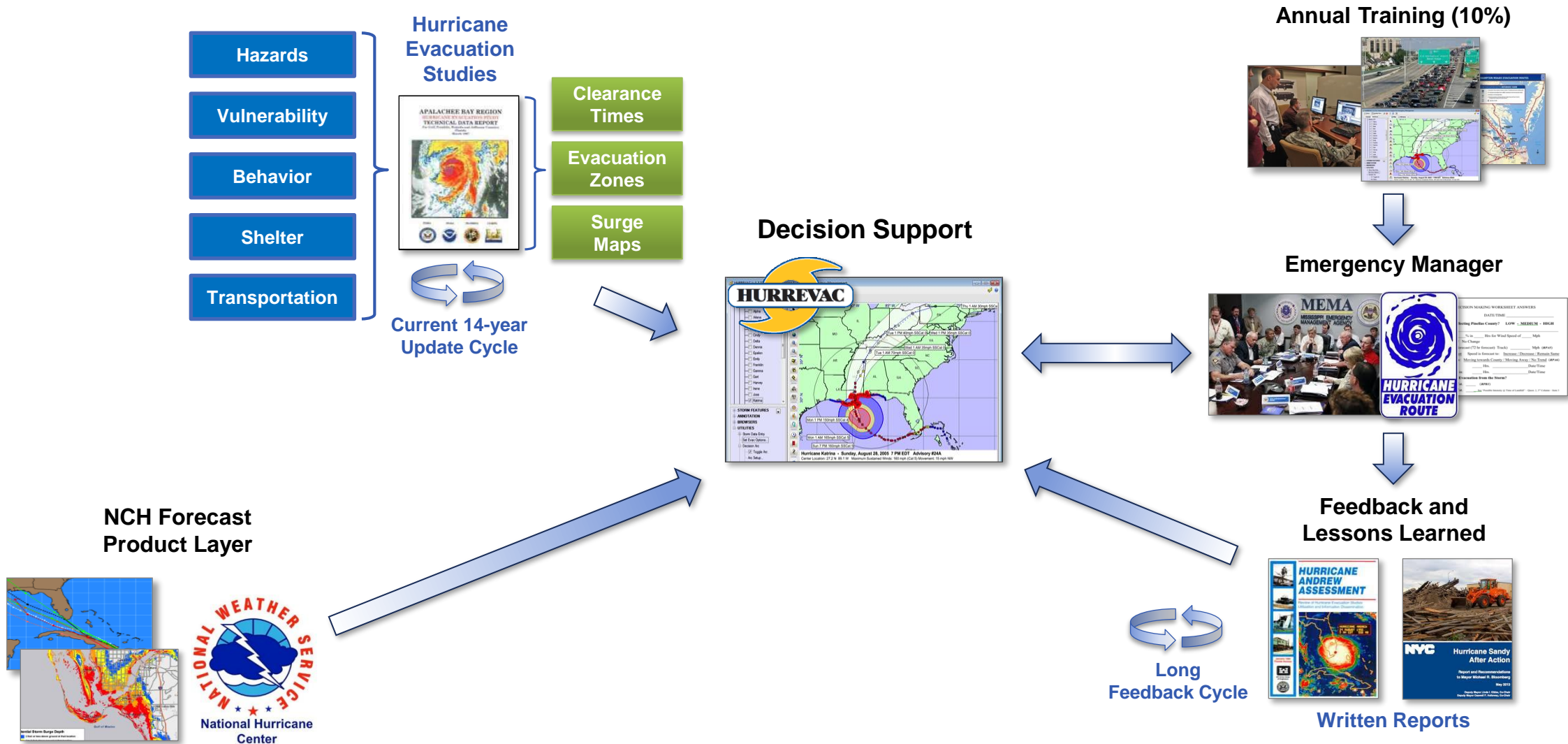


Technology Gap Recommendations

Recommendation	Interviewee Gaps Addressed
Evolve HURREVAC into an integrated decision-support platform	5, 12, 21, 23, 25, 30
Transform weather forecast products into guidance that is directly relevant to local decision-making (EM product layer)	9, 13, 15, 18, 19, 20, 22, 25, 27
Provide more comprehensive and accessible training	8, 14
Improve the efficiency of the Hurricane Evacuation Study (HES) process	1, 2, 10, 11
Establish, document, and share best practices for the NHP	3, 6, 16, 17, 28
Extend the scope of NHP to consider “Mitigation” and “Resilience”	7
Implement a metrics-based improvement process	4, 24

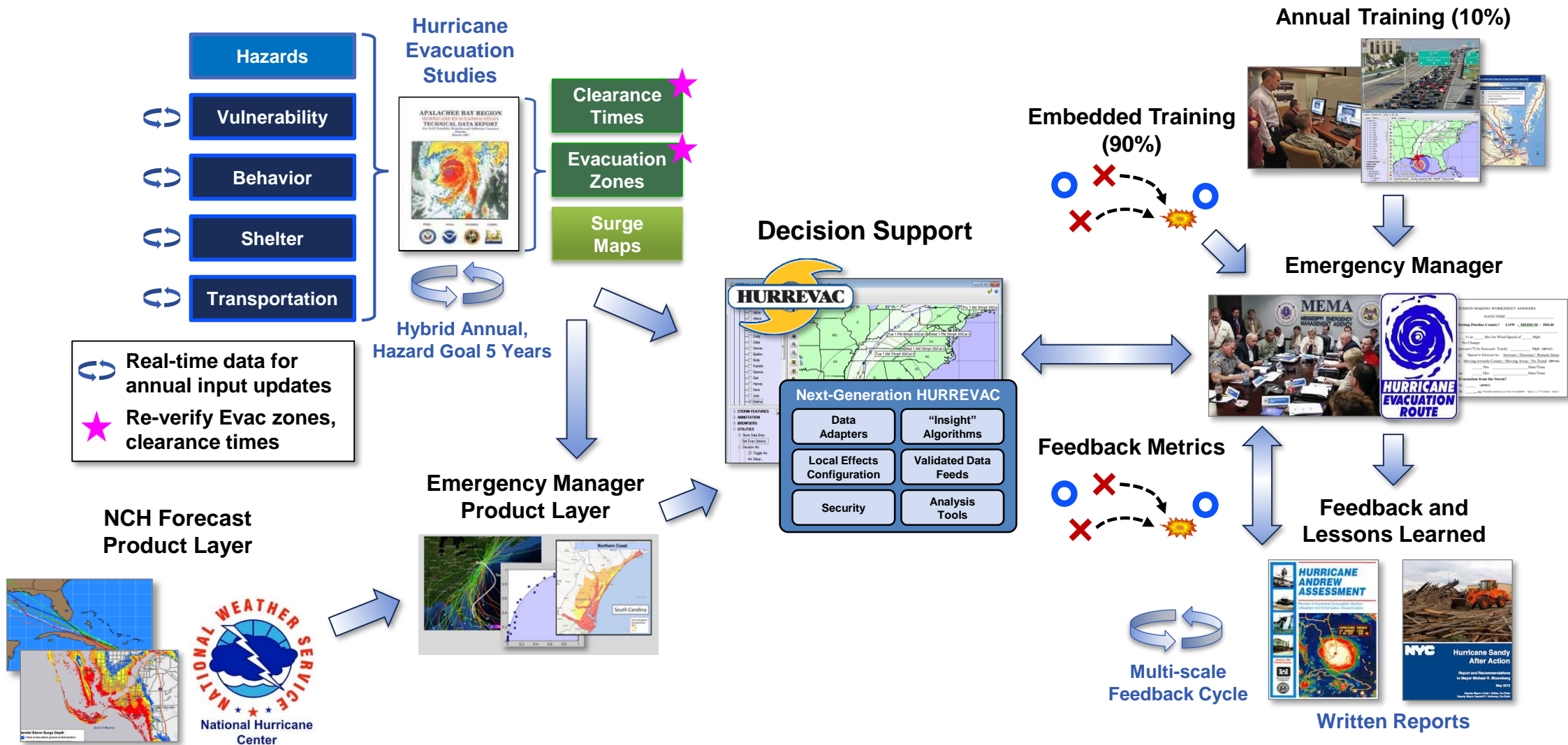


NHP Technology Components (As-is)





NHP Technology Components (To-be)





Next Steps: “Solution Pilots” (FY14)

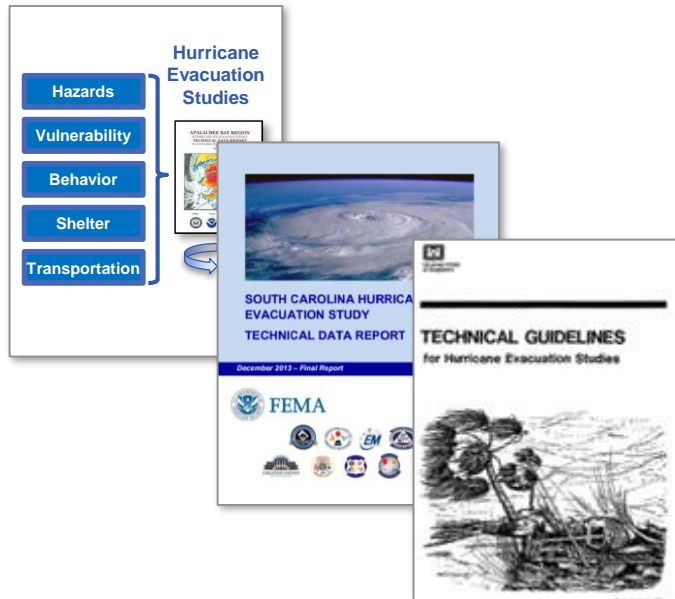
- Further explore recommendations through prototyping
 - Establish pilots with select jurisdictions
 - Learn → prototype → test → gather feedback → repeat
 - Inform solution feasibility and operator acceptance

Pilot Focus	Hypothesis	Exploration Approach
Decision Support Platform	A common decision platform will increase decision effectiveness	<ul style="list-style-type: none">• Identify pertinent data• Integrate data• Explore analytics
Immersive Training	Practicing decisions often will lead to better decisions	<ul style="list-style-type: none">• Develop scenarios• Run exercises• Collect decision data
Best Practices	Collecting and distributing best practices will improve nation’s capabilities	<ul style="list-style-type: none">• Assemble expert panel• Define decision timeline• Validate findings
HES Efficiency	Modular HESs can improve the HES process	<ul style="list-style-type: none">• Centralize HES results• Merge with other data• Prototype decision tools



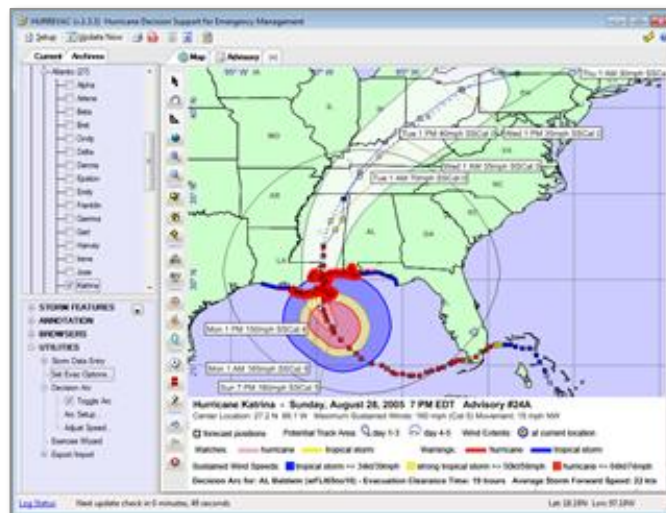
Evacuation Decision Support (before HVX)

Hurricane Evacuation Studies



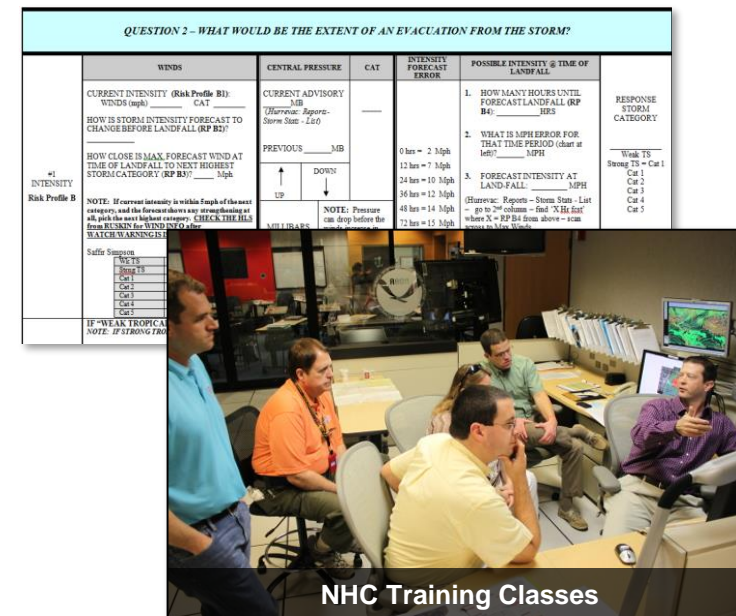
- Paper-based reports
- Telephone behavioral surveys
- Long 2–5 years process

Operational Decision Support



- Legacy Windows-only system, proprietary data formats
- Limited graphical/analytical capabilities

Training / Exercises



- In-person sessions, limited budget
- Train <10% annually
- Separate training for tools & decisions
- Time-consuming exercise creation



Key Architecture-Enabled Transformations

Open Source / Open Standards



OpenStreetMap

- Reduces cost of operations
- Supports rapid inclusion of new products
- Enables diverse contributors and connections

Enable the User

Risk Profile Question Definition

Impact Point or Time	Feature or Characteristic	Relationship	Location
Specific Timeframe	48 hour forecast	Forward speed	Base region Current: Duval County, Florida
	72 hour forecast	Wind probability	
	120 hour forecast	Wind speed	
	120 or 72 hr. forecast	Rainfall	Maximum
	Closest approach	Error cone intersect	Minimum
	Currently	Intensity	Time Until
		Bearing	True/False
		Tide	Value
		Track direction	Category
		Evac. decision time	
		Watches/warnings	
		Tourist Population	
		SS category diff	
Change Over Time	By Advisory		
	From current position to landfall		
	Around closest approach		
	Across several advisories		

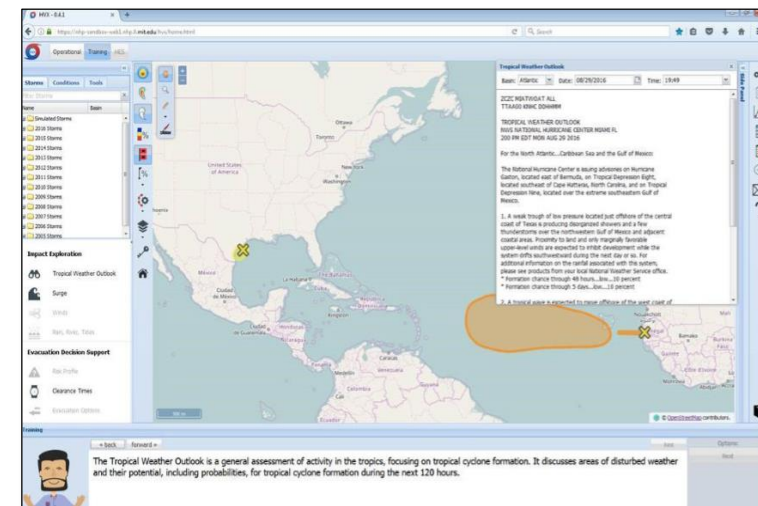
Current Selection

72 hour forecast | Wind speed | Category | Duval County, FL

Cancel Next

- Products that can be easily configured by the user
- Flexibility to visualize the data with simple interfaces

Embed Training



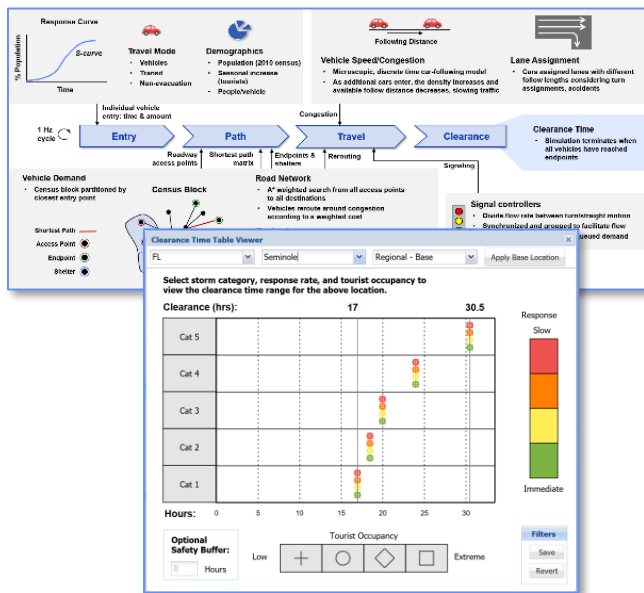
- User trains with same tools with which they respond
- Simulation tools allow user to tailor scenarios to their location

HVX provides a maintainable, sustainable and engaging platform to meet each emergency manager's decision-making needs



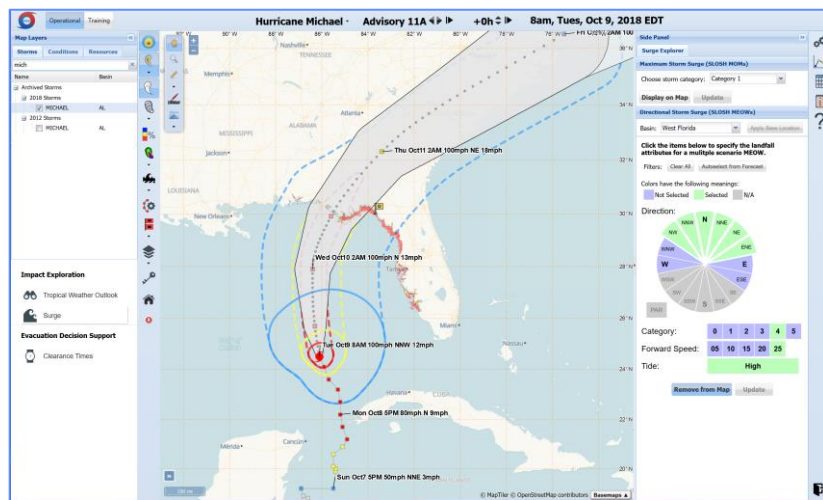
Evacuation Decision Support with HVX

Hurricane Evacuation Studies



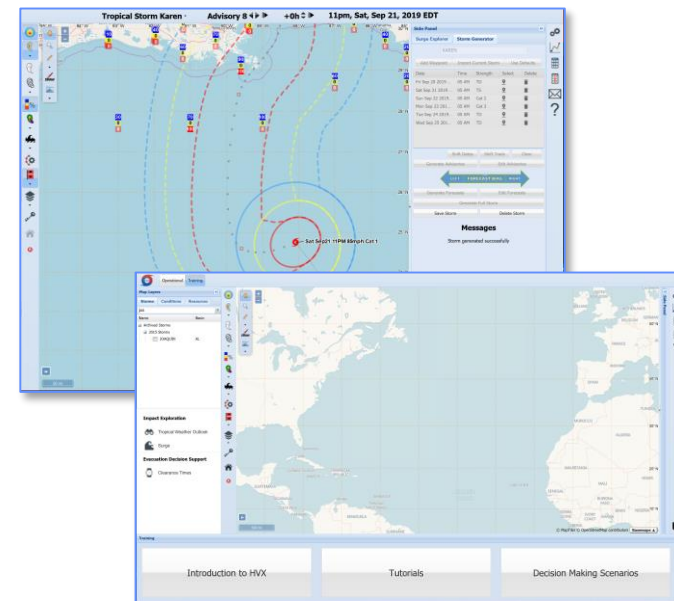
- In-platform graphics
- Standardized transportation model (RTEPM) via portal
- Full HVX-HES integration (pending)

Operational Decision Support



- Anywhere, any time, any device
- Advanced temporal and spatial mapping/analytics
- Surge explorer

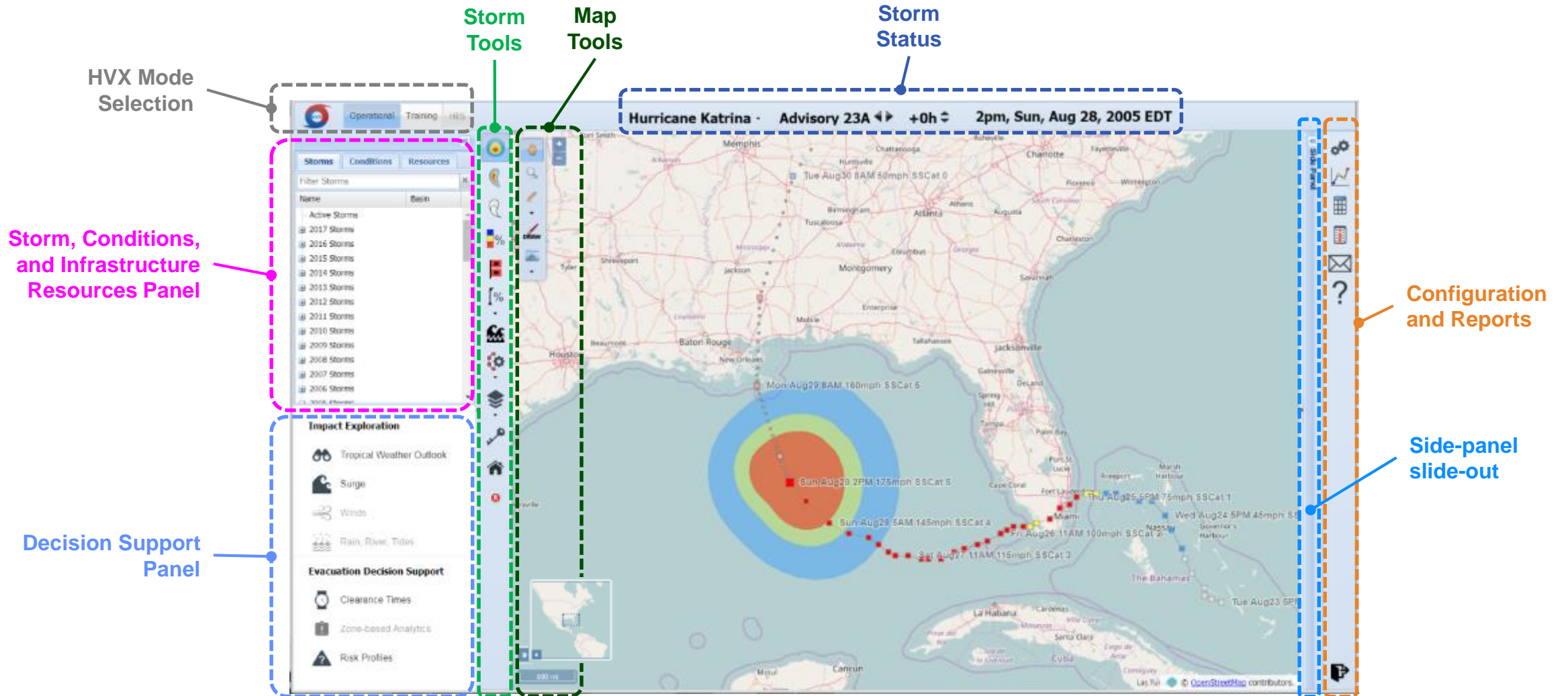
Training/ Exercises



- Embedded training for platform features, product tutorials and decision making – available to all
- Exercise creation tool generates full product suite in minutes



HVX GUI Components







Training Interface

The screenshot displays the HVX Training Interface. The main window features a map of the Eastern United States and the Caribbean. On the left, a sidebar contains a 'Storms' list with filters for 'Active Storms' and 'Name', and an 'Impact Exploration' section with icons for 'Tropical Weather Outlook', 'Surge', 'Winds', 'Rain, River, Tides', 'Clearance Times', 'Zone-based Analysis', and 'Risk Profiles'. The top of the interface has tabs for 'Operational' and 'Training'. Below the map, a 'Training' section contains three modules: 'Introduction to HVX', 'Tutorials', and 'Decision Making Scenarios'. Below these modules are three dashed boxes with instructional text, each with an arrow pointing to a corresponding module.

How to use HVX Interface controls/tools

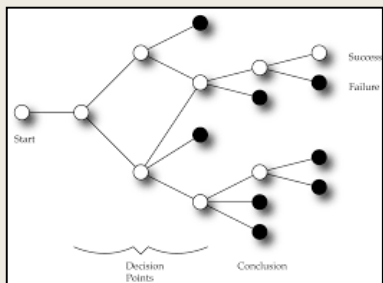
How to use the weather layers, products, tools for decision-making

How to use the weather layers, products, tools for decision-making using simulated storms

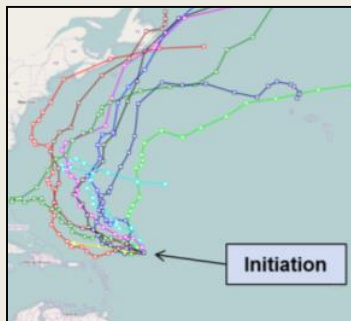


Training Capability Components

Training Module Creator



Storm Track Simulator



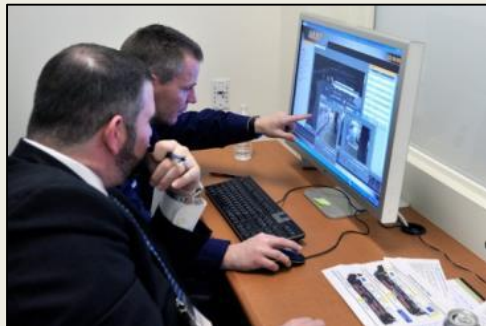
Training Framework



Introduction
to HVX

Tutorials

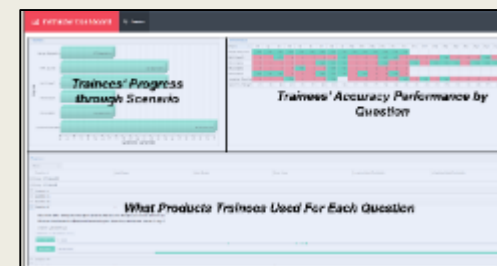
Decision-Making
Scenarios



User/Product Analytics



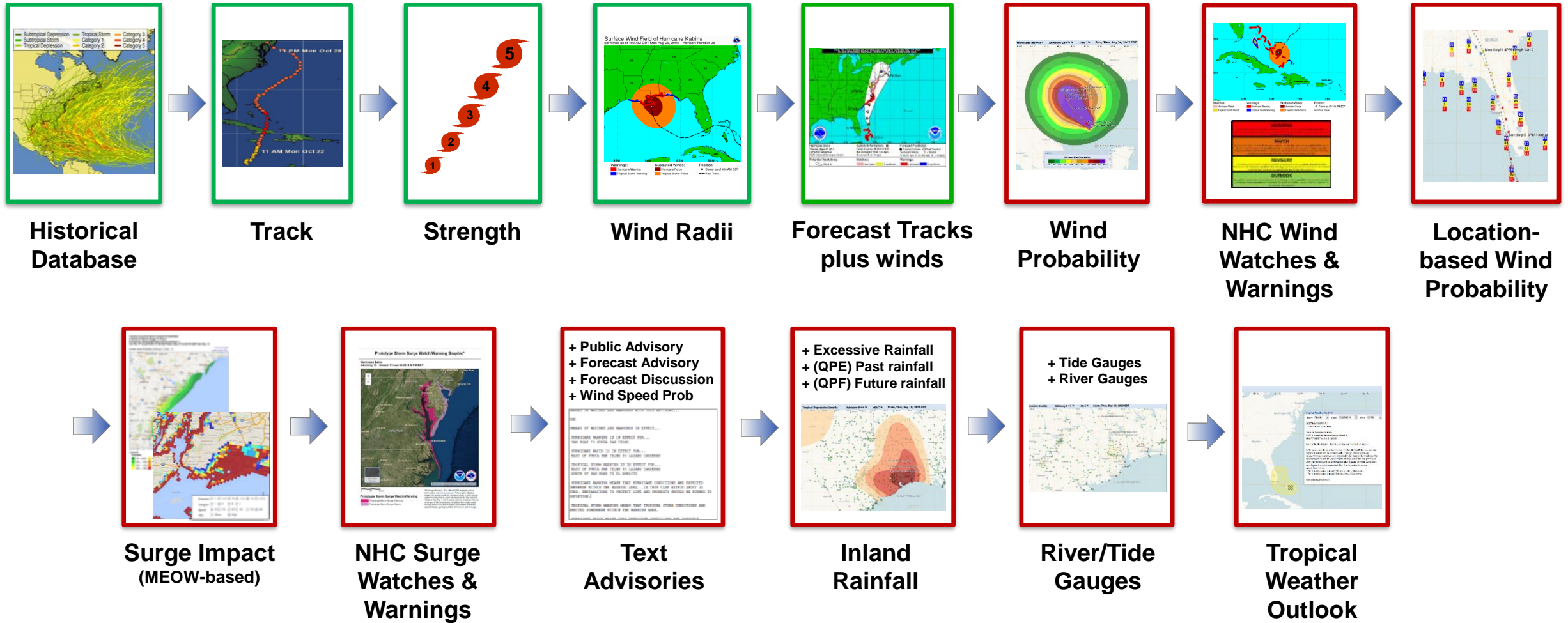
Scoring



Instructor Panel



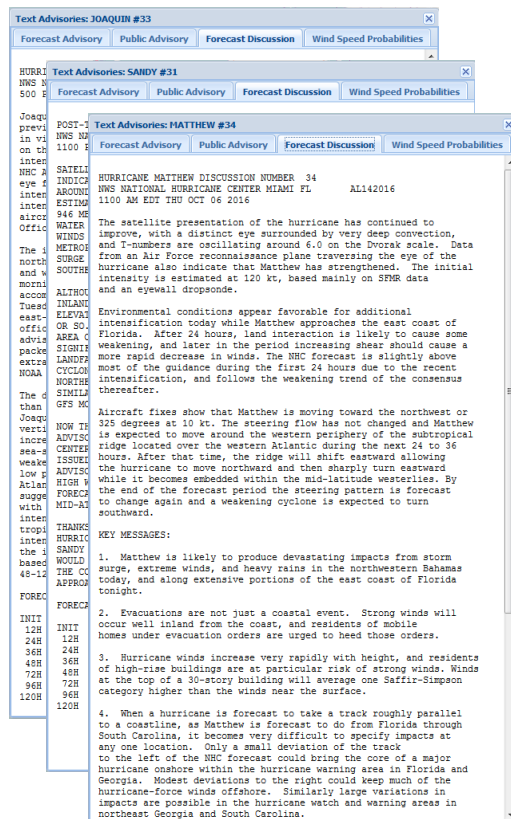
Storm Simulation Components





Simulating Forecast Discussions

Archive of 10K Discussions



Sentence Classification

Bob will **weaken** as it passes over Puerto Rico
Shear aloft will **weaken** Sandy.....

Katrina will **strengthen** over warmer water.....
Warm sea surface temperatures **increase**

The models **diverge** and makes the track.....
A front to the north makes the track **uncertain**

Variable Identification

<storm type> (tropical storm, hurricane, ...)
<name> (Sandy, Matthew, ...)
<strength change> (weaken, strengthen,...)
<uncertainty> (challenge, certain, ...)

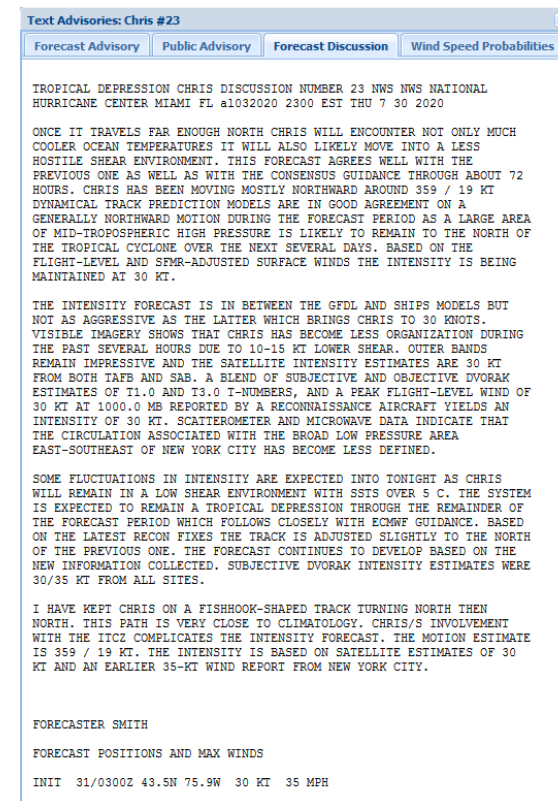
Storm Technical Data

Forecast position is <lat, lon>
Motion estimate is <value>
Forward speed is <value>

Storm Track/Forecast Simulation



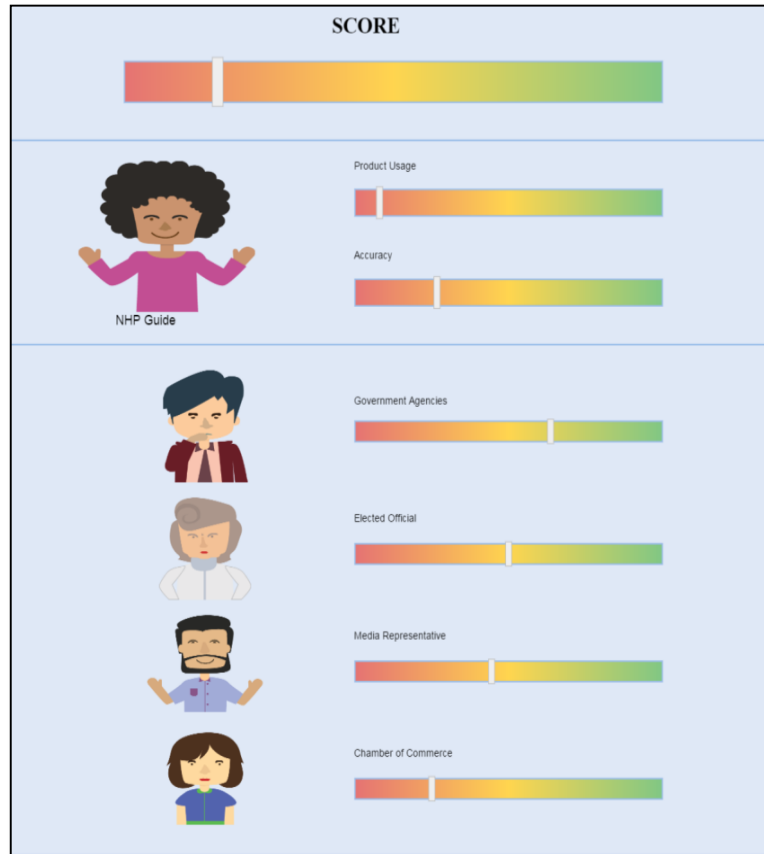
Simulated Discussion



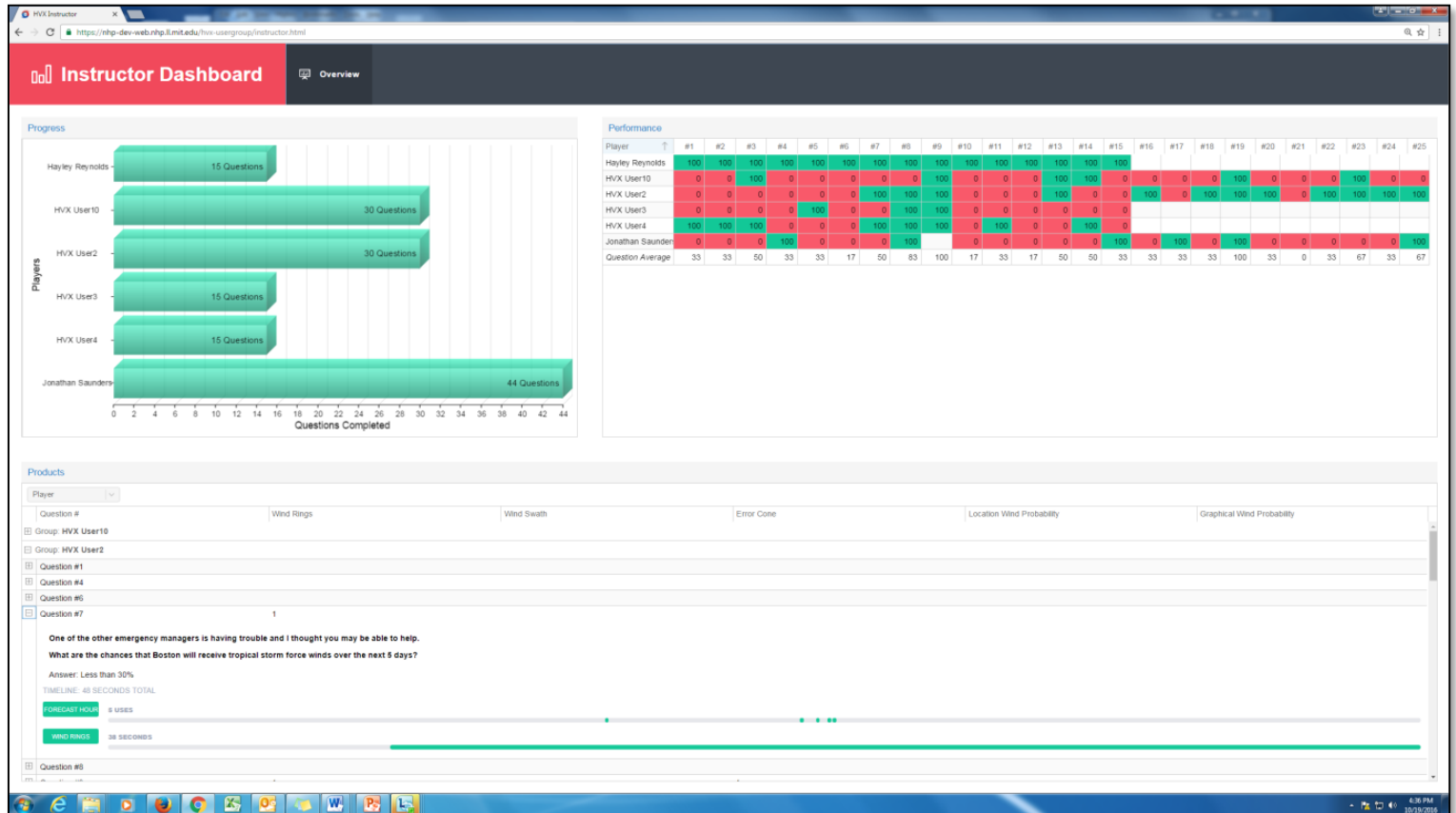


Training User Analytics

Individual Scores



Instructor Screen





HVX-HES Integration

Hazards



Vulnerability



Behavior

Hypothetical Evac. Decision			
	Cat. 1	Cat. 2	Cat. 3
Evac.	42%	53%	68%
Stay	52%	42%	26%
?	6%	5%	6%

Shelter



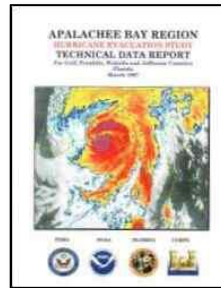
Transportation



Hurricane Evacuation Studies

Update Goal:

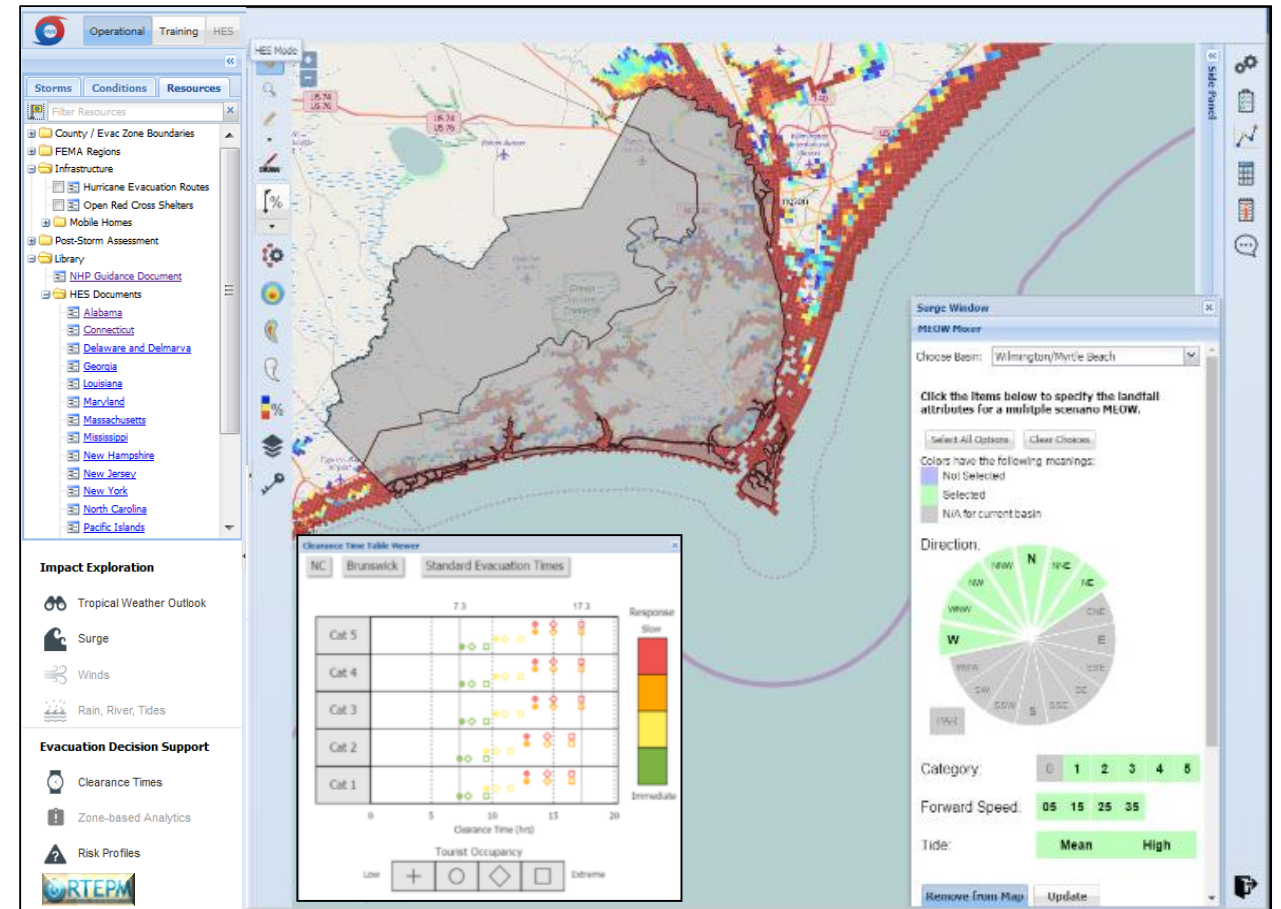
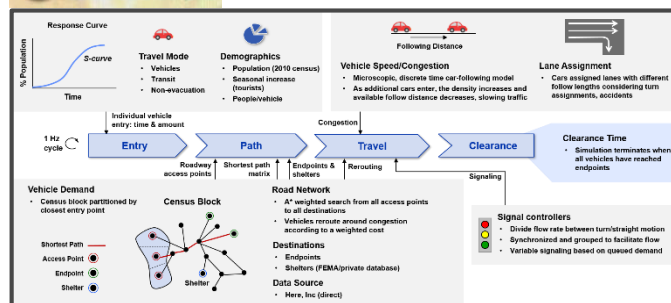
- Full Hazard – Every 5 years
- Hybrid – Annual



Clearance Times

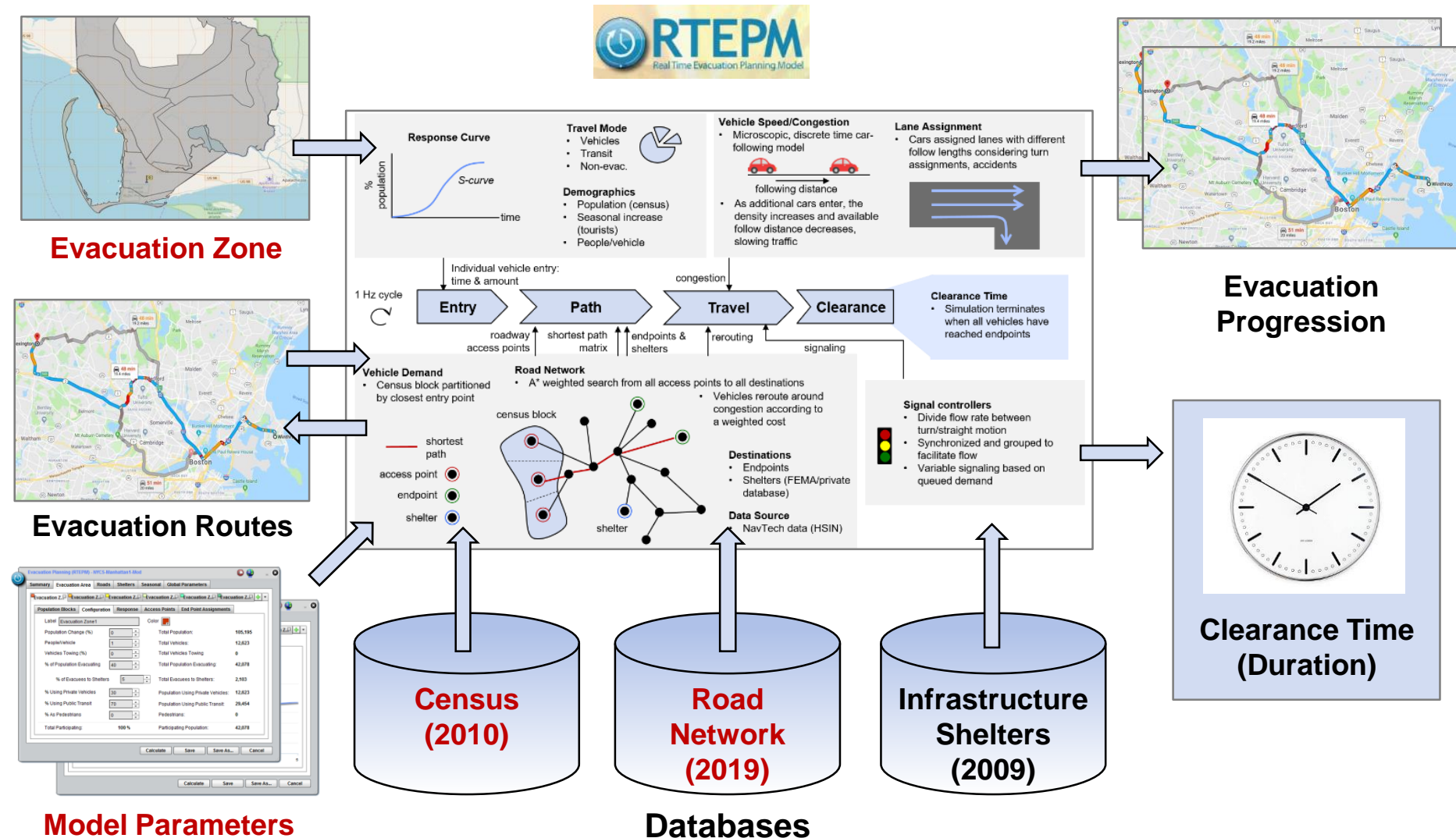
Evacuation Zones

Surge Maps



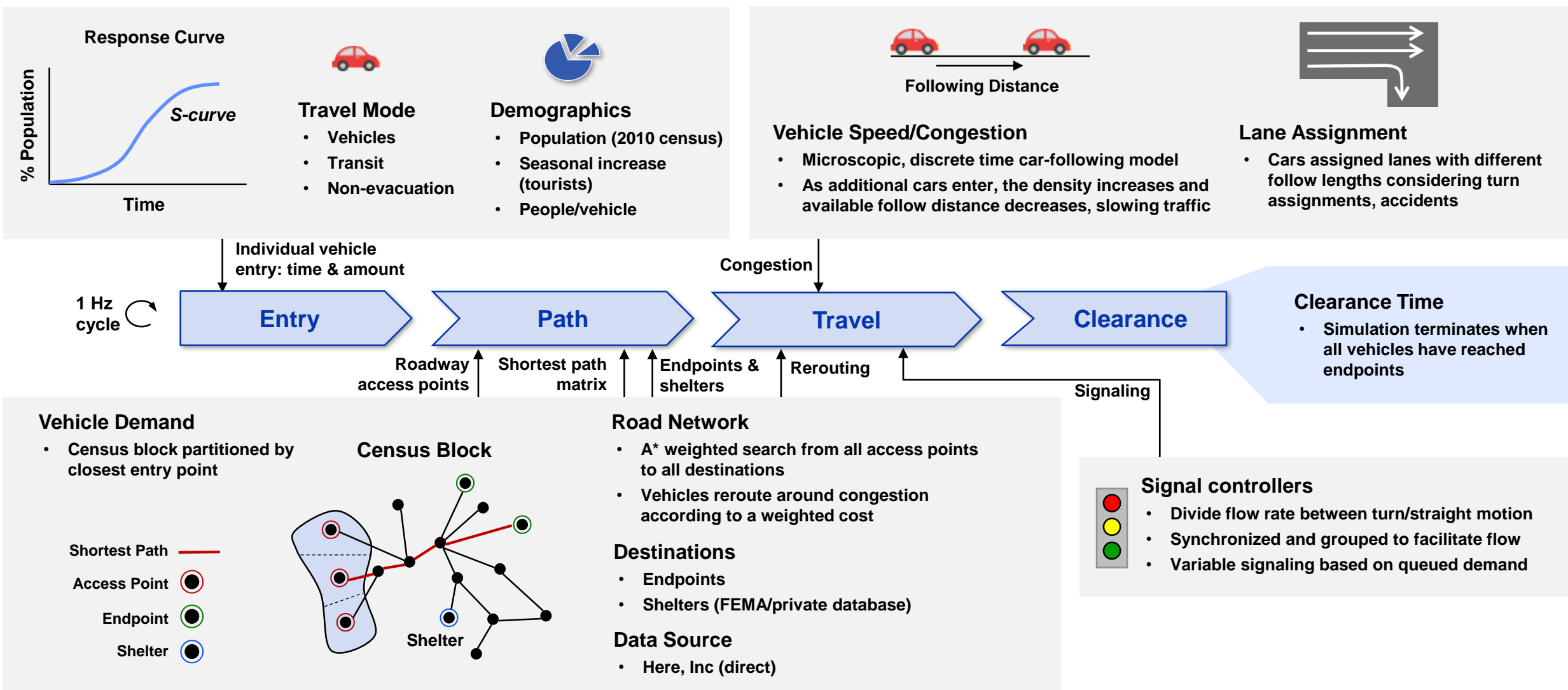


Clearance Time Modeling Architecture





Evacuation Planning Transportation Model





HVX “In the Field” 2016-2019 Hurricane Seasons

HADR staff deployed to FEMA National Response Coordination Center (NRCC) with HVX:

- Hermine (2016)
- Matthew (2016)
- Harvey (2017)
- Irma (2017)
- Maria (2017)



Transition to Web-based HURREVAC (Sea Island Software) Beta 2018:

- Alberto (2018)
- Gordon (2018)
- Lane (2018)
- Florence (2018)
- Michael (2018)
- Olivia (2018)

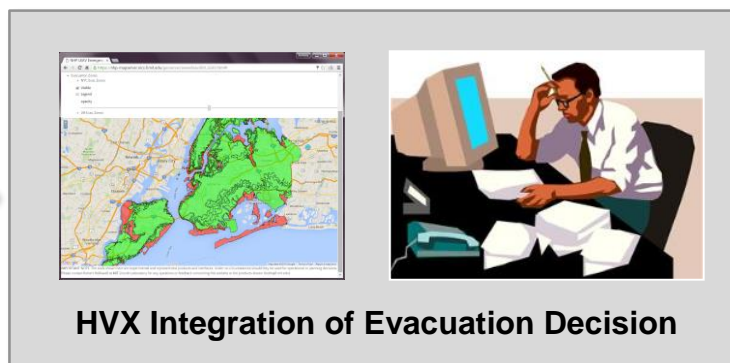
Transition to Operations (2019):

- Dorian (2019)
- Flossie (2019)



(Near-term) Technology Pilots for FY18

Local Evacuation Alert Verification (LEAV)



- Integrated Public Alert & Warning System (I-PAWS)
- NOAA's "Weather Emergency Alert"
- FEMA's Common Alerting Protocol (CAP)

Mass-Care Food & Shelter Estimation App



Impact Area from HVX

Generate needs assessment
from track forecast:

- Shelter
- Meals
- Bedding
- Housing

Category	Item	Quantity	Unit
Food	Food (1000 meals)	1000	meals
	Food (2000 meals)	2000	meals
	Food (3000 meals)	3000	meals
	Food (4000 meals)	4000	meals
Meals	Meals (1000 meals)	1000	meals
	Meals (2000 meals)	2000	meals
	Meals (3000 meals)	3000	meals
	Meals (4000 meals)	4000	meals
Bedding	Bedding (1000 meals)	1000	meals
	Bedding (2000 meals)	2000	meals
	Bedding (3000 meals)	3000	meals
	Bedding (4000 meals)	4000	meals
Housing	Housing (1000 meals)	1000	meals
	Housing (2000 meals)	2000	meals
	Housing (3000 meals)	3000	meals
	Housing (4000 meals)	4000	meals

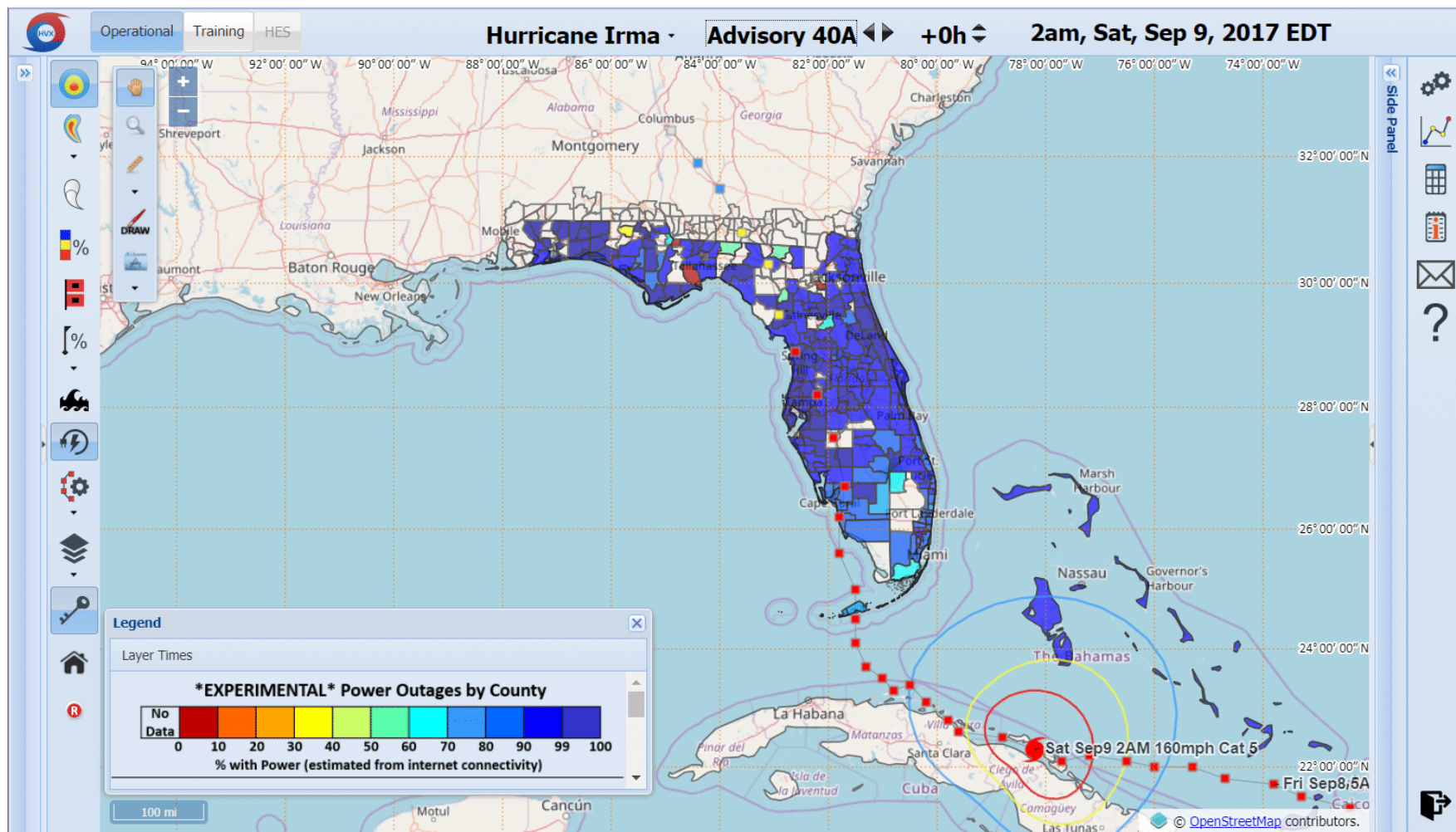
Rules of Practice



MassCare Operations



Integrating External Data: Real-time Power Outages

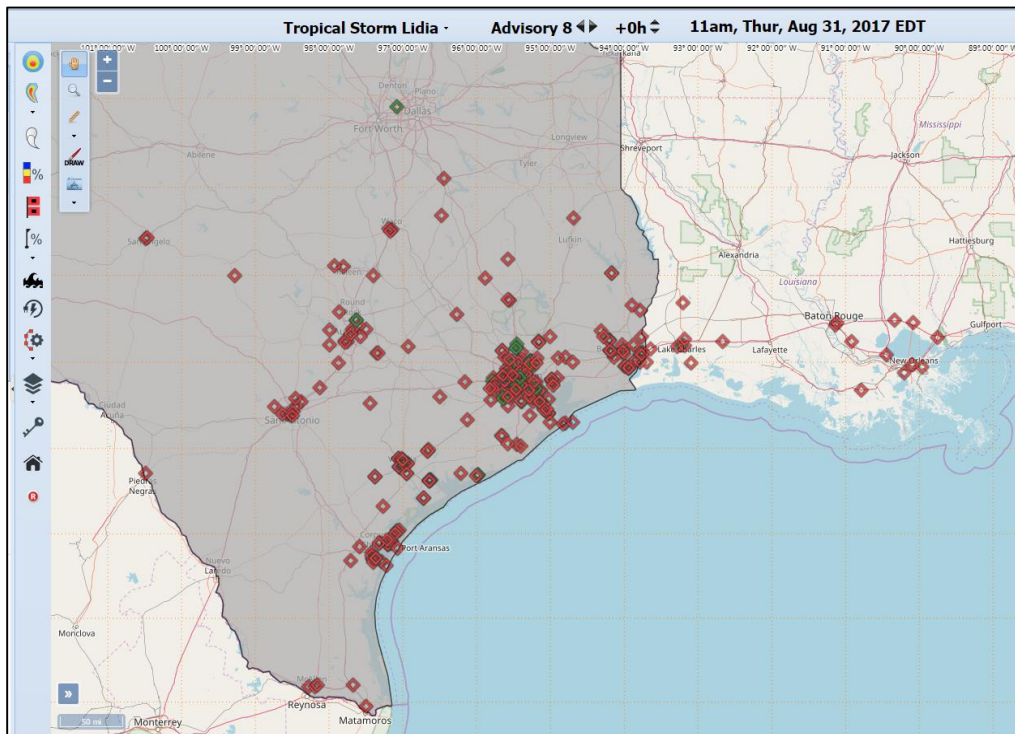


HVX provides a maintainable, sustainable and engaging platform to meet each emergency manager's decision-making needs



Other HVX Add-ons

SABER Business Status



Sears, Costco, Macy's, Walmart,
Walgreens, Target, gas stations,
distribution centers

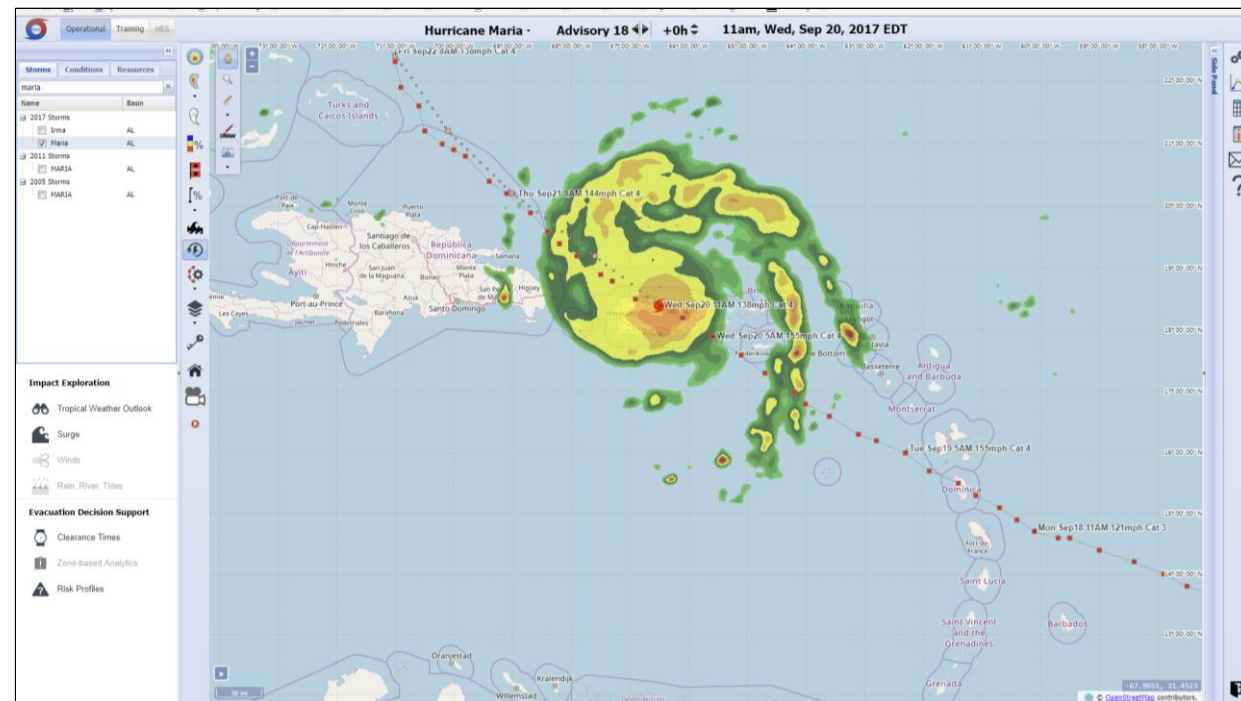


Closed



Open* or Limited Hours

Offshore Precipitation Capability (OPC)

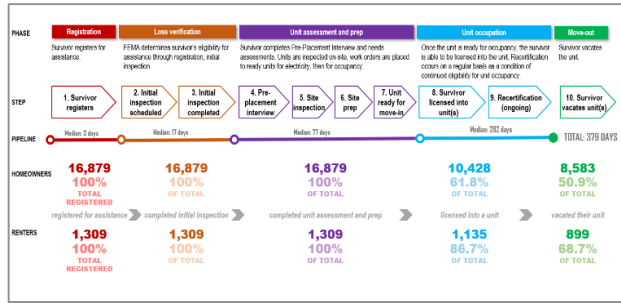


- San Juan lost NEXRAD radar during Maria
- NWS utilized OPC as their backup for weeks

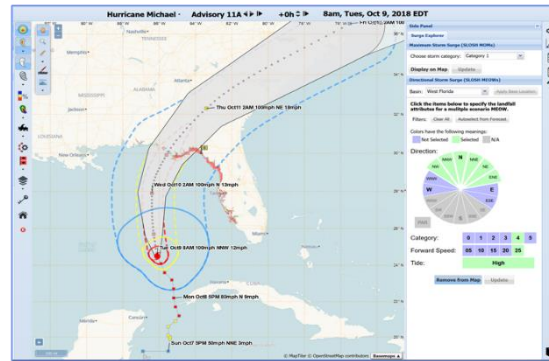


MIT LL Hurricane Related Work

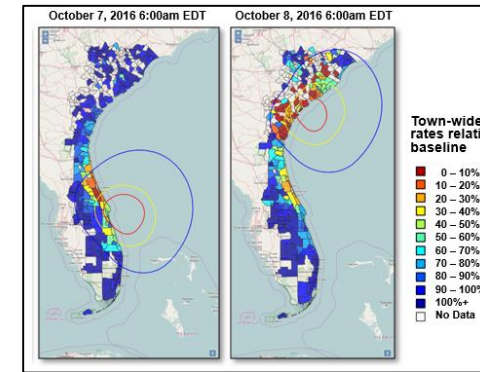
FEMA Direct Housing Assistance Performance Analysis



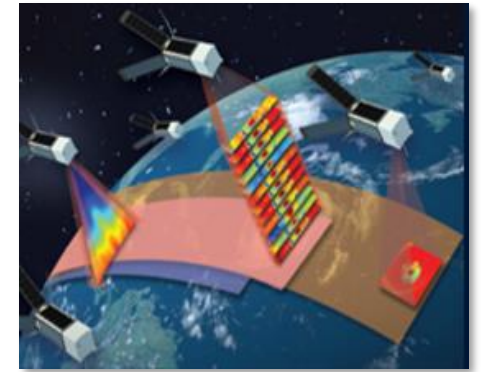
HURREVAC (HVX) Hurricane Evacuation Decision-support Platform



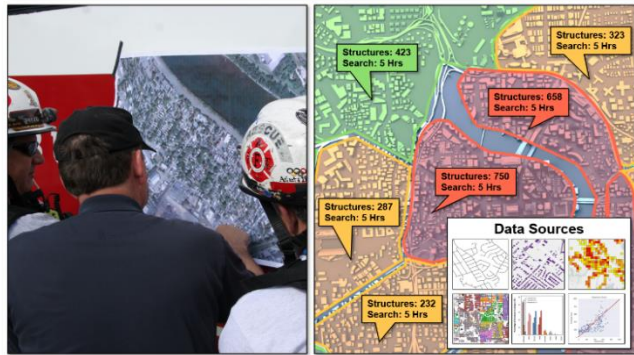
Cyber-Sensing Power Outages



TROPICS Cube-sat Satellite Constellation (Division 9)



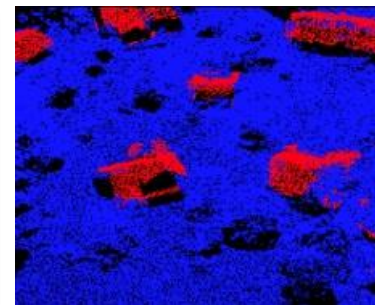
Predictive Analytics for Wide Area Search and Rescue (PAWSAR)



Lidar-based Sensing/Analytics for Damage and Debris Assessment

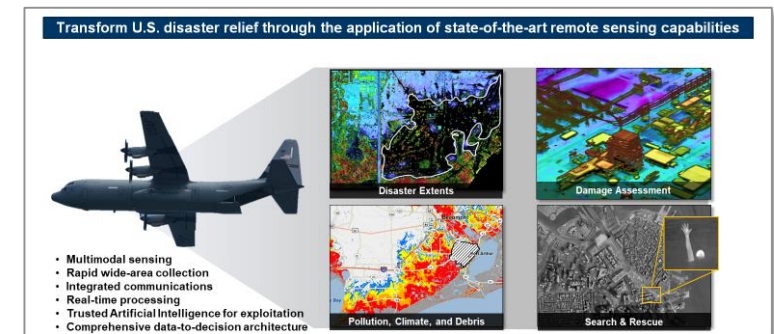


Damage Sensitive Routing



Building Detection

Multi-sensor HADR Remote Sensing Platform Concept

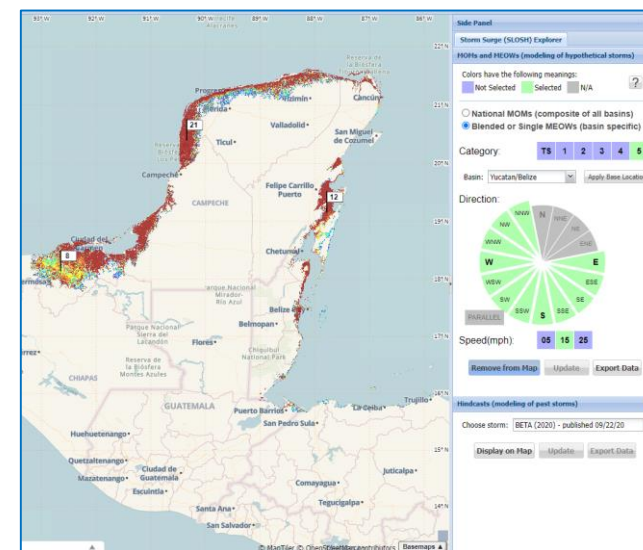
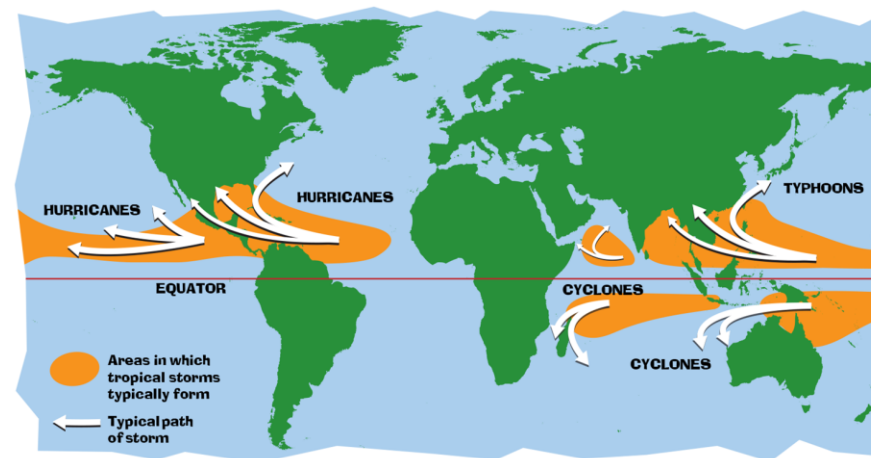




International Use of HURREVAC Platform

National Hurricane Program is domestically funded

- FEMA, USACE, NOAA-NHC
- Over 12K registered emergency managers (US military, federal, state, local, tribal)
- While the system ingests tropical cyclone and weather globally << 1% are international users
 - FEMA Policy/funding restrictions as domestic agency
 - Creating/maintaining a world-wide tailored tropical cyclone dataset out of scope for NHP
- Storm surge modeling created by NOAA-NHC primarily for U.S./territories
 - USAID, however, has funded NHC to perform storm surge modeling for Hispaniola, Yucatan and Belize
 - FEMA has granted temporary access to HURREVAC for these countries – but no long-term agreement





Potential for International Expansion

- **Leverage existing NHP HURREVAC architecture**
 - Extending HURREVAC for international use only requires separate servers and databases
 - Cloud infrastructure makes this straightforward
 - Co-development with NHP benefits from maintenance to existing core software
 - NHP is on board, but they need a partner
- **Expand storm surge modeling**
 - NHC can run storm surge models anywhere in the world
 - Could be enhanced by higher resolution coastal mapping (Lidar scanning)
- **Integrate existing international evacuation planning**
 - India in particular has a robust evacuation plan, others are more limited
- **Modular HURREVAC infrastructure allows tailored extensions, such as:**
 - Evacuation monitoring
 - Post-storm disaster assessment
 - Tsunamis and inland flooding