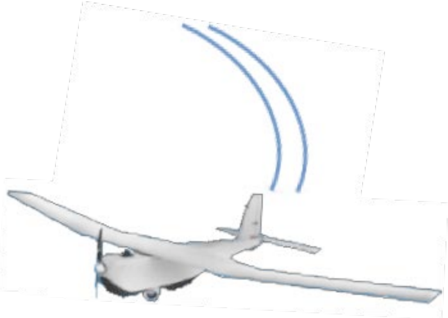
NOAA UAS Program's SHOUT Project: A Case Study for the End-to-end Utilization of High- and Low-altitude Unmanned Aircraft Systems

AMS 2017 Annual Conference:
Special Symposium on Meteorological Observations and Instrumentation

Seattle, WA
January 26, 2017

Presented by:
John Walker

Cherokee Nation Technologies,
Supporting NOAA UAS Program Office



Acknowledgement of Co-Authors

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NOAA:
“America’s Environmental Intelligence Agency”

MONITORING MODELING

OBSERVATIONS ASSESSMENT FORECAST & PRODUCTS

Provide information and services to make communities more resilient

Evolve the Weather Service

Invest in observational infrastructure

Achieve organizational excellence

NOAA UAS Program Vision and Key Roles

Vision

- **UAS observations will become an essential component of the NOAA observing system**

Key Roles

- **Serve as the NOAA subject matter experts for UAS technology and observations**
- **Assist with the research, development, demonstration, and transition to application of select UAS observing strategies**

Why UAS?

- **Efficient, Effective, Economical, and Environmentally friendly**

Where?

- **Missions that are "Dull", "Dangerous", "Dirty", or "Denied"**

UAS Program Science Focus Areas

"SHOUT" Project

High Impact Weather

- ***Can UAS observations enable improved forecasts, scientific understanding and decision support?***

Marine

- ***Can UAS observations provide reliable, timely and affordable environmental intelligence information for resilient coastal communities and healthy oceans?***

Polar

- ***Can UAS observations contribute to NOAA'S Arctic vision and strategy?***

SHOUT:
"Sensing Hazards with Operational Unmanned Technology"

Goal

- Demonstrate and test prototype UAS concept of operations that could be used to mitigate the risk of diminished high impact weather forecasts and warnings in the case of polar-orbiting satellite observing gaps

Objective 1: Data Impact Assessment

- Conduct data impact studies
  - Modeling (Real and Simulated data)
  - Forecaster feedback (Situational Awareness)

Objective 2: Cost Benefit Analysis

- Evaluate cost and operational benefit through detailed analysis of life-cycle operational costs and constraints

Subset of UAS Capabilities

High Altitude Long Endurance (HALE)

- Maximum Altitude 65,000 ft
- Maximum Endurance 25+ hrs
- Maximum Payload Weight 1200 lbs

Medium Altitude Long Endurance (MALE)

- Maximum Altitude 40000 ft
- Maximum Endurance 24 hrs
- Maximum Payload Weight 400 lbs int, 2000 lbs ext

Low Altitude Long Endurance (LALE)

- Maximum Altitude 19,500 ft
- Maximum Endurance 24 hrs
- Maximum Payload Weight 13.5 lbs

Low Altitude Short Endurance (LASE)

- Maximum Altitude 1000 ft (operating altitude, higher capable)
- Maximum Endurance 2 hrs
- Maximum Payload Weight approx 2 lbs

Vertical Takeoff and Landing (VTOL)

•Maximum Altitude 3280 ft (Nominal specs; Capabilities vary!)
•Maximum Endurance 1.4 hr
•Maximum Payload Weight 1.7 lb

Vision of Future
End-to-End UAS Capabilities

Timeline

1) Large-scale / Synoptic Observations

How: HALE UAS

Where: Oceans (Upstream)

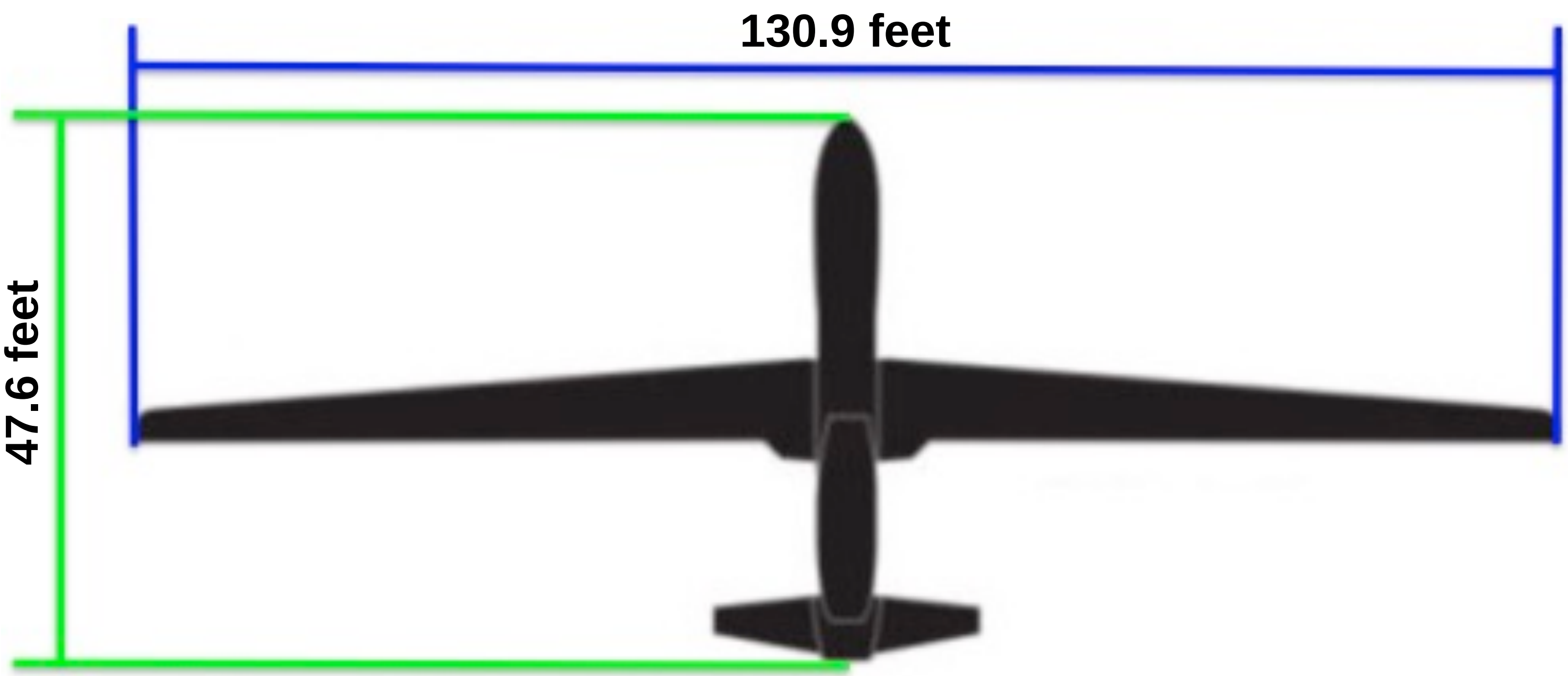
When/Why: Improved global NWP forecasts **DAYS in advance**

Global Hawk AV-6
(Northrop Grumman "RQ-4")

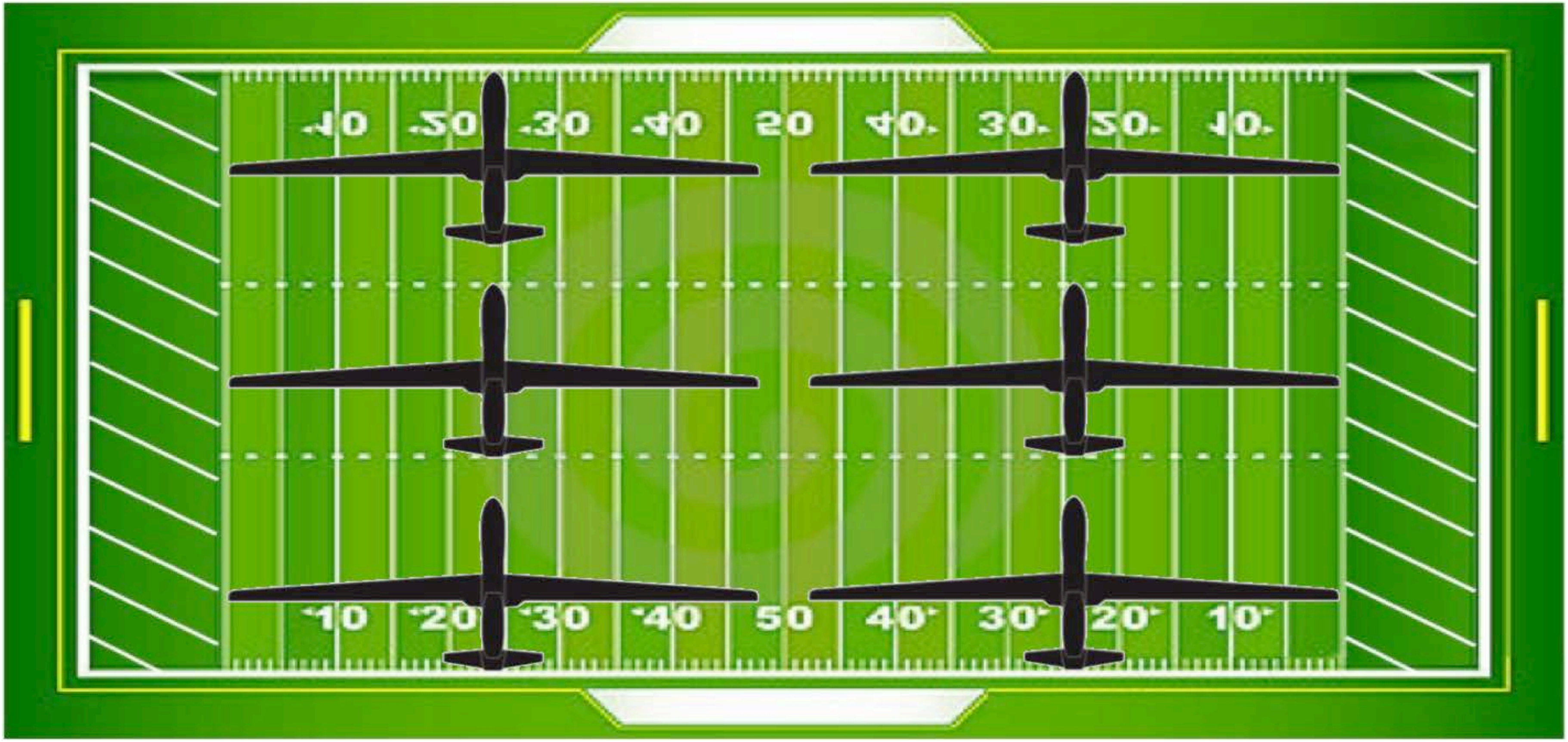
Wingspan: 130.9 ft
Length: 47.6 ft
Height: 15.4 ft

Max Altitude: ~60,000 ft (18.3 km)
Payload: 3,000 lbs
Range: 12,300 nm
Cruising Speed: 357 mph
Maximum Endurance: 32+hrs

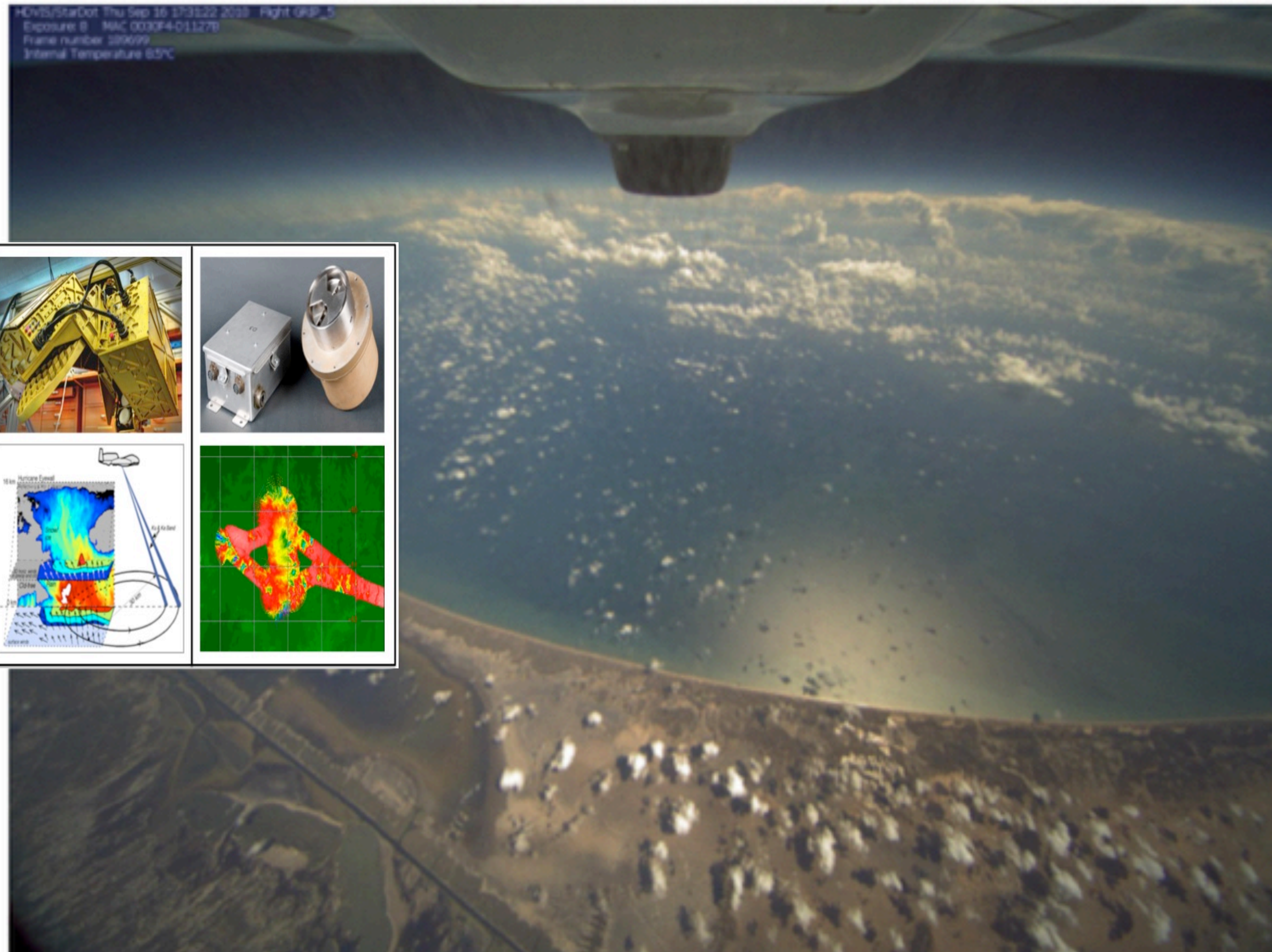
Global Hawk HALE UAS Size

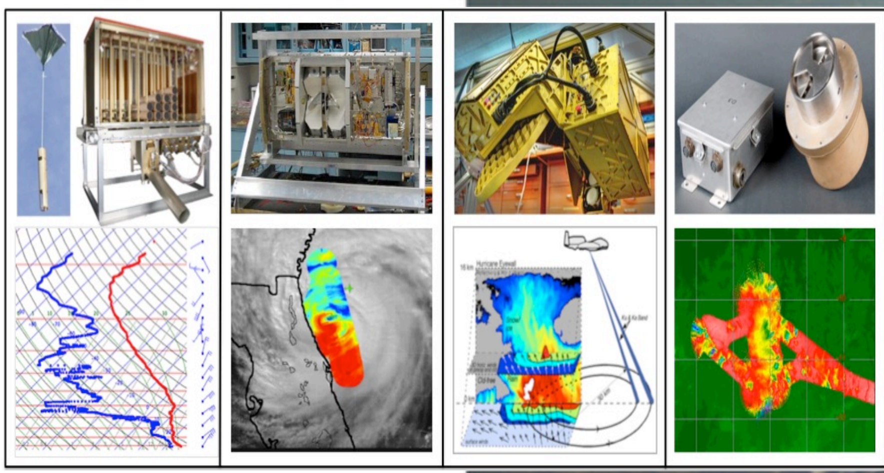


Global Hawk HALE UAS Size



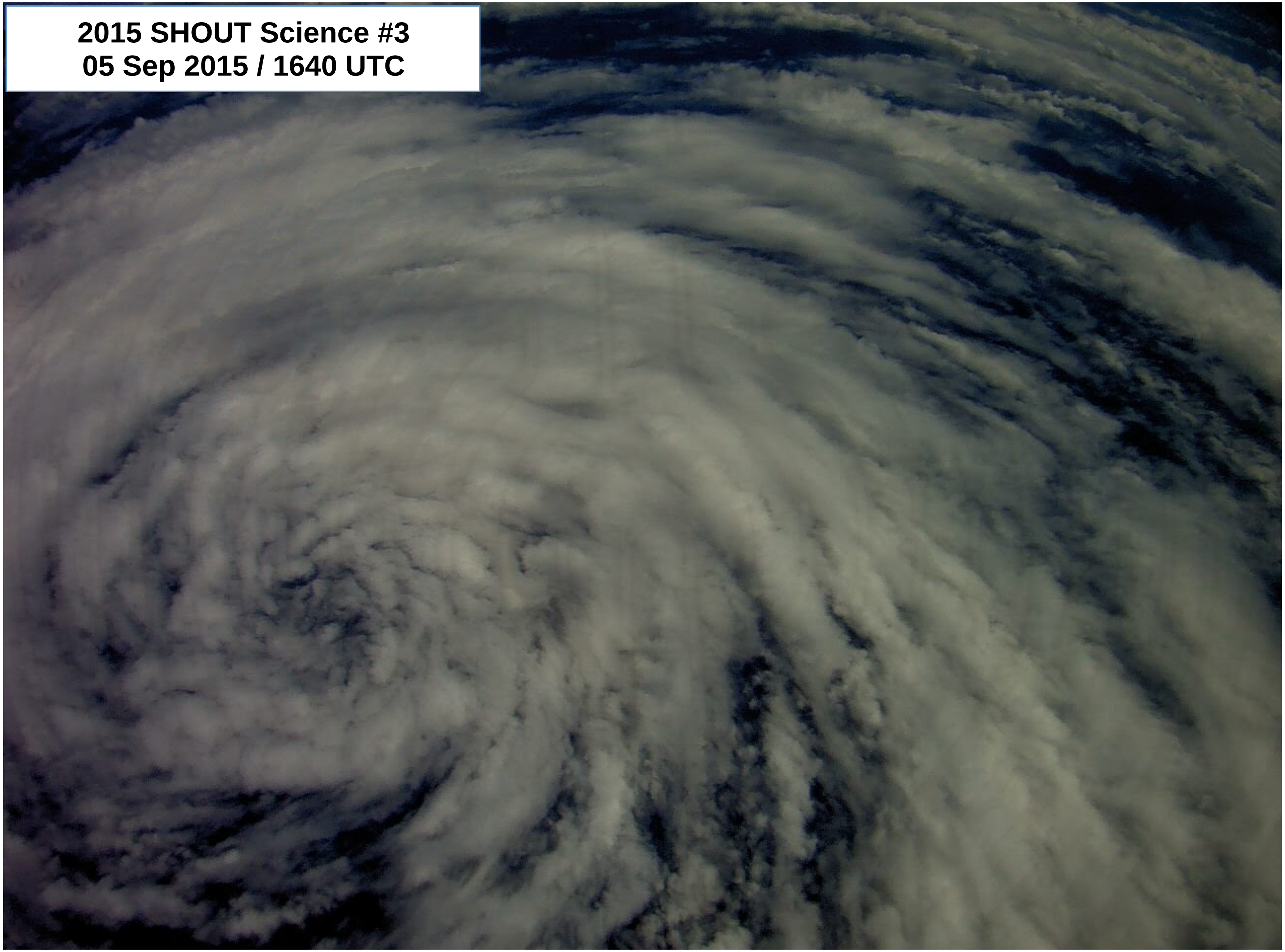
Global Hawk AV6 – Payload Options





Global Hawk AV6 – Daylight Nose Camera: Approaching Fred (05 Sept 2015)

Global Hawk AV6 – HDVIS Camera: Approaching Fred (05 Sept 2015)



Vision of Future
End-to-End UAS Capabilities

Timeline

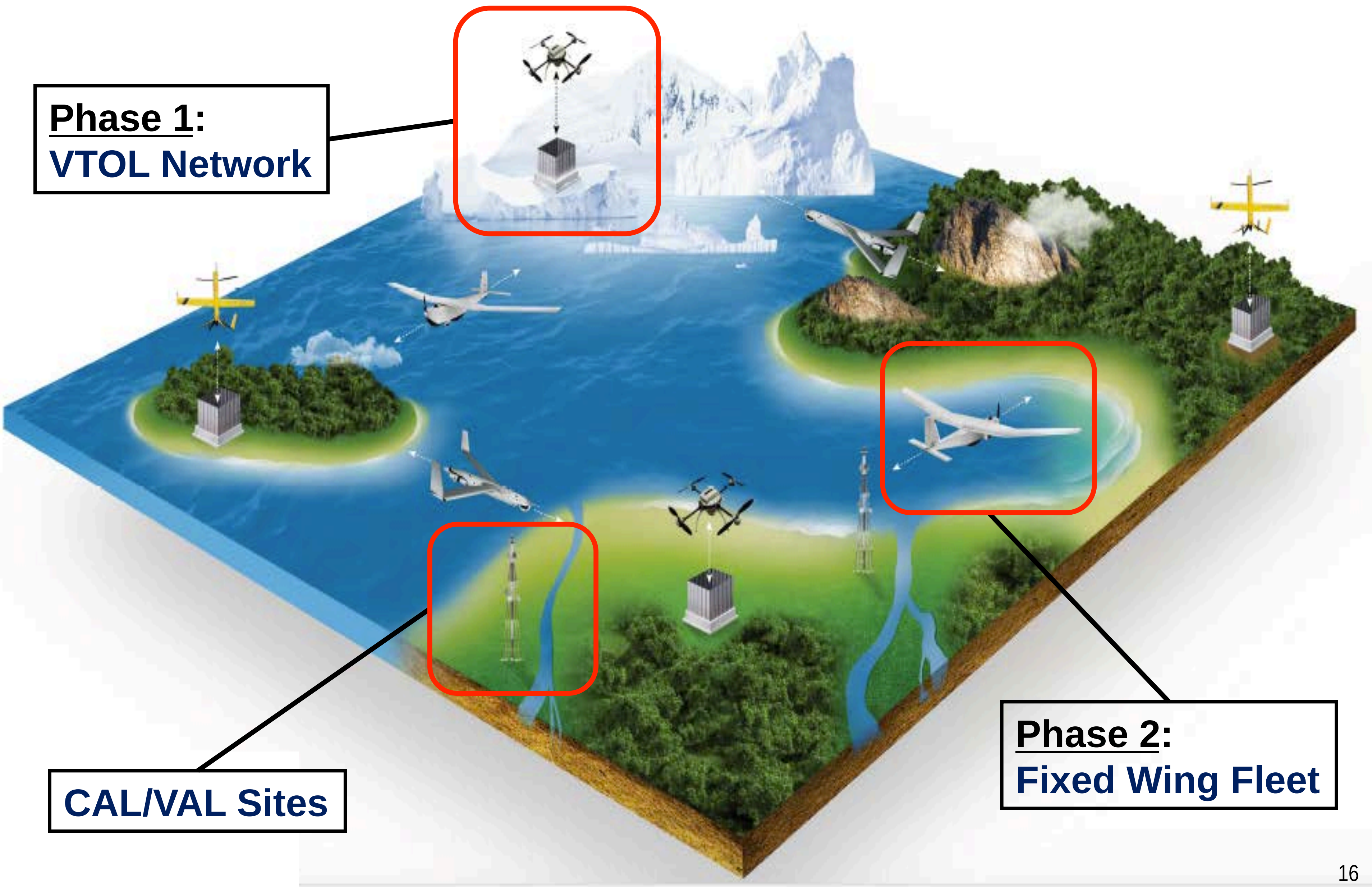
1) Large-scale / Synoptic Observations

How: HALE UAS
Where: Oceans (Upstream)
When/Why: Improved global NWP forecasts **DAYS in advance**

2) Mesoscale Observations

How: LASE / VTOL UAS
Where: Inland (Area of expected impact and/or Slightly upstream)
When/Why: Improved… a) Hi-res NWP models **HOURS in advance**
b) Forecaster “Situational Awareness”

Targeted Autonomous In-situ Sensing and Rapid Response (TAISRR)

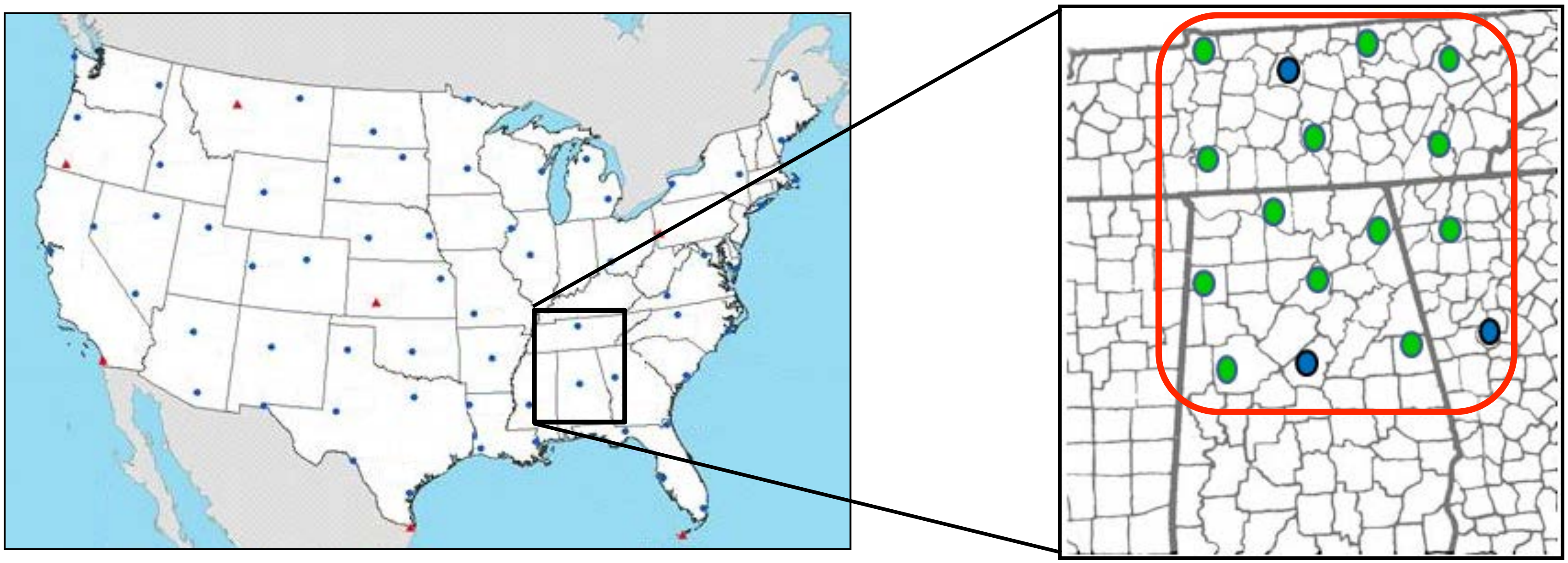


TAISRR: Objective #1

Lower Atmospheric Mesoscale Observations

Current Upper Air Observation Network

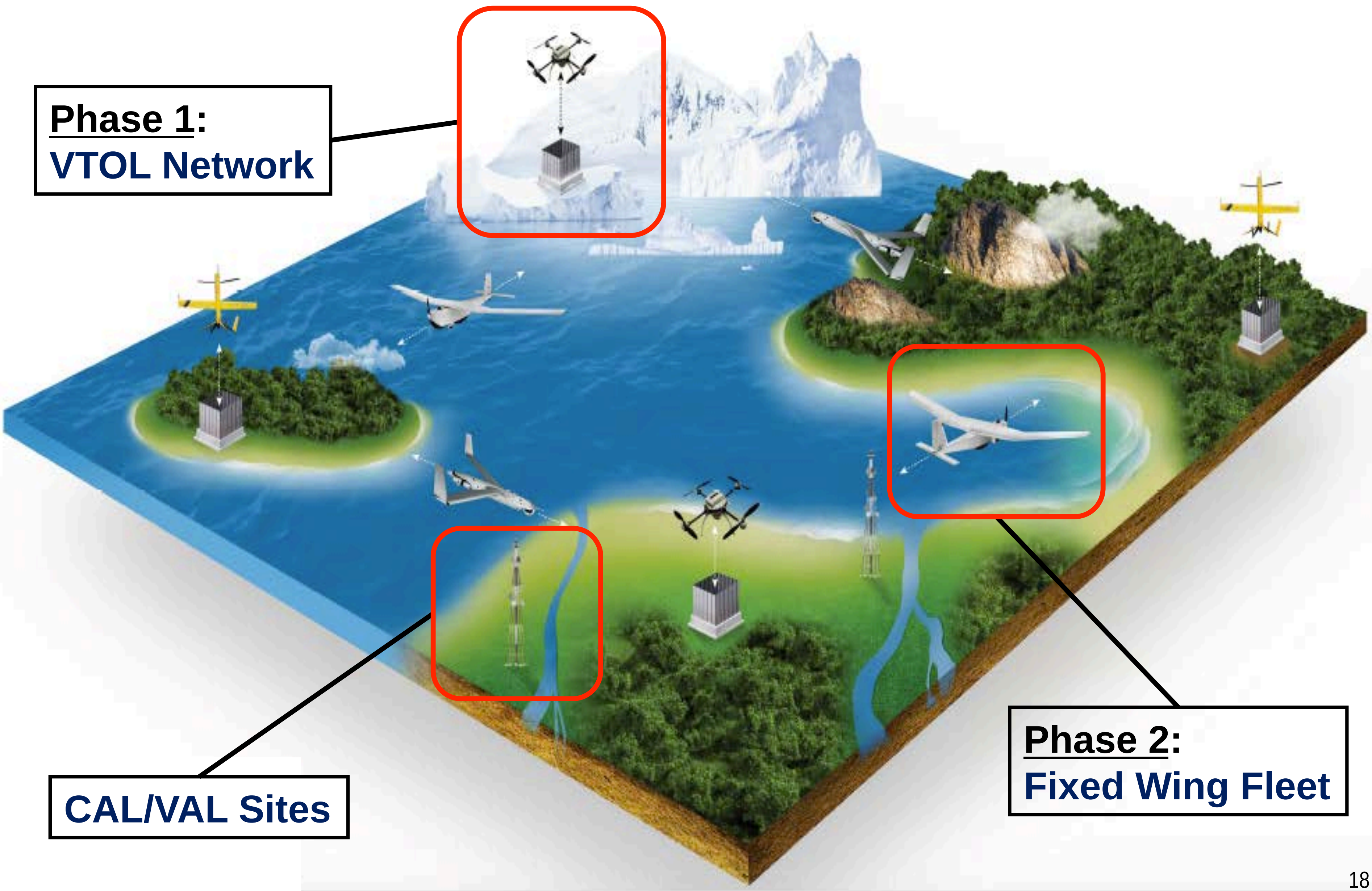
Hypothetical
Regional Network Example

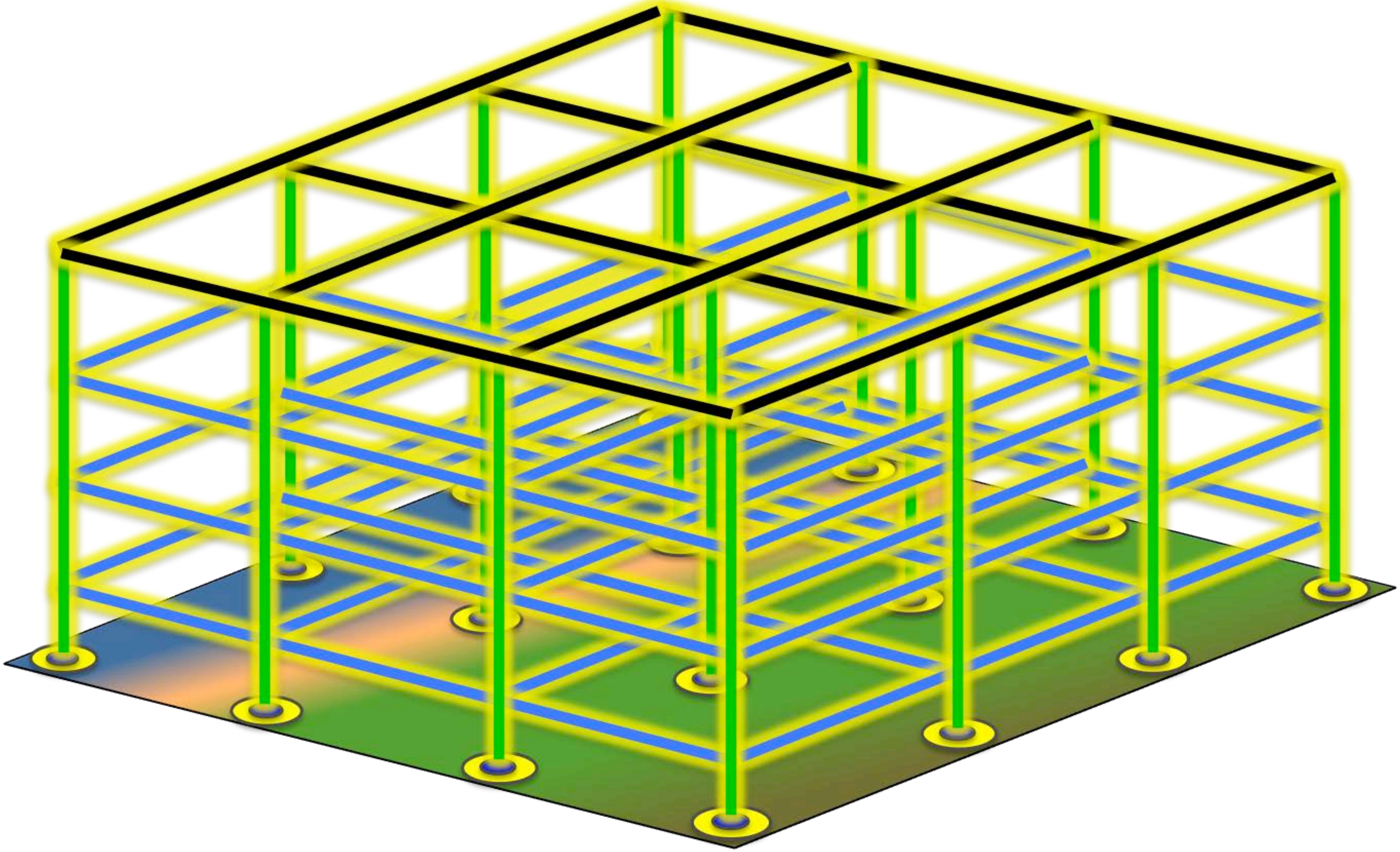


-Full Tropospheric Soundings
-BUT… Sparse network
-AND… Usually only 2x per day!

-Lower 1/2 Tropospheric Soundings
-BUT… Dense network
-AND…Frequency > 1x per hour!

Targeted Autonomous In-situ Sensing and Rapid Response (TAISRR)

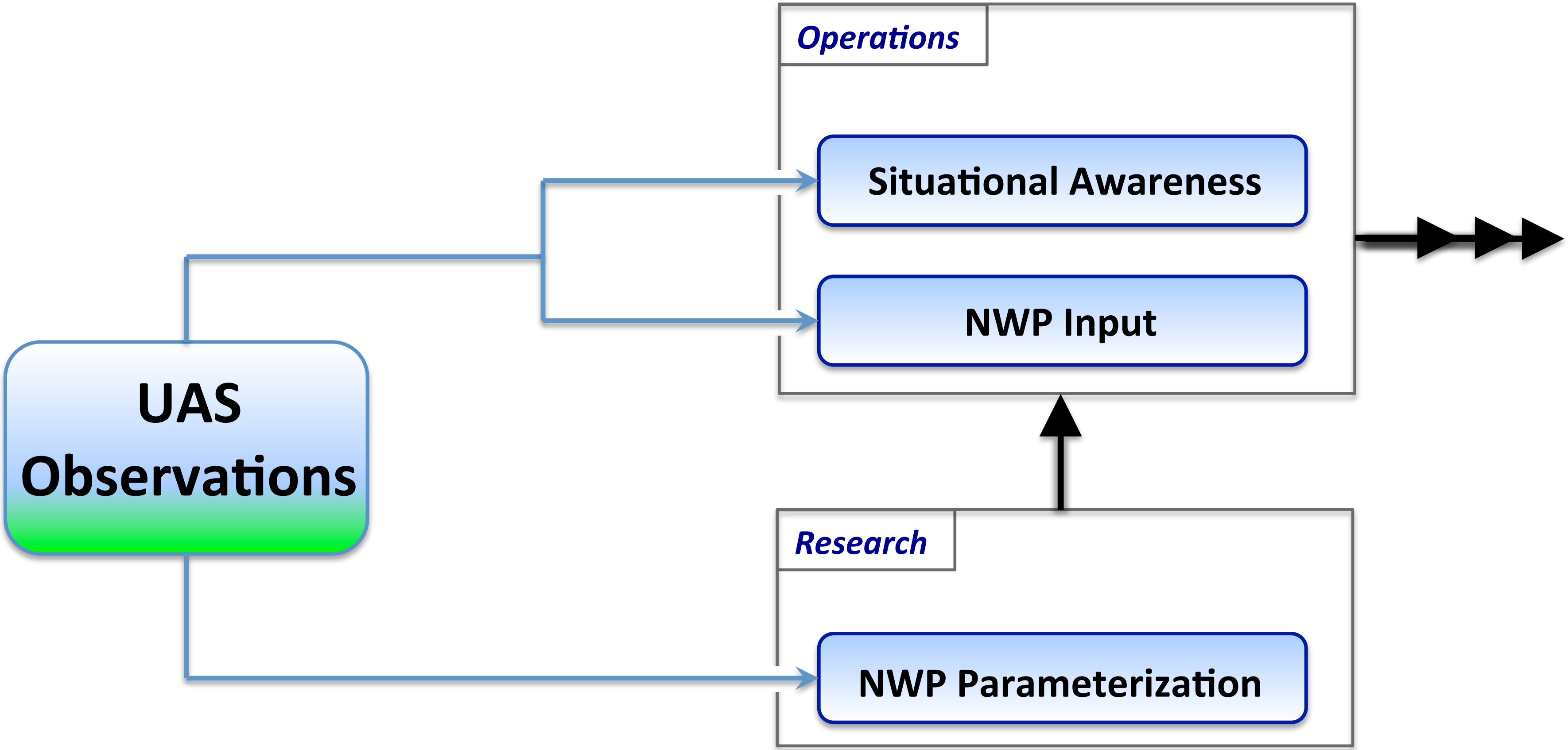




Provides a virtual 3D cube of Atmospheric Measurements

TAISRR: Objective #1

Lower Atmospheric Mesoscale Observations



Vision of Future
End-to-End UAS Capabilities

Timeline

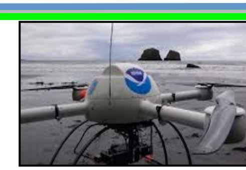
1) Large-scale / Synoptic Observations

How: HALE UAS
Where: Oceans (Upstream)
When/Why: Improved global NWP forecasts **DAYS in advance**

2) Mesoscale Observations

How: LASE / VTOL UAS
Where: Inland (Area of expected impact and/or Slightly upstream)
When/Why: Improved… a) Hi-res NWP models **HOURS in advance**
b) Forecaster "Situational Awareness"

3) Hazard/Damage Assessment Observations



How: LASE / VTOL UAS
Where: Inland (Area where impacts have occurred)
When/Why: NWS and EMA rapid response **HOURS following event**
Damage assessment / Community recovery

TAISRR: Objective #2
Hazard/Damage Assessment

Identified Problem: Often difficult to determine damage type/extent from a ground-based perspective

TAISRR: Objective #2
Hazard/Damage Assessment

Potential Solution: UAS for providing aerial viewpoint

Several Types of UAS-based Imagery

For Example… 2D Orthomosaic:

Sample image courtesy of “Skylab Production”

Progress Toward
Vision of Future
End-to-End UAS Capabilities

Timeline

1) Large-scale / Synoptic Observations

-- SHOUT 2015 (Summer 2015)
-- SHOUT 2016 / El Nino Rapid Response ("ENRR"; Feb. 2016)
-- SHOUT 2016 / Hurricane Rapid Response ("HRR"; Summer 2016)

2) Mesoscale Observations

-- NSSL/OU/CU ("EPIC"; Ongoing collab)
-- ARL ATDD (Ongoing collab)
-- Various labs and universities

3) Hazard/Damage Assessment Observations

-- Numerous NWS WFOs around country
…Charleston, SC … Blacksburg, VA…
…Huntsville, AL … Jackson, MS … etc.

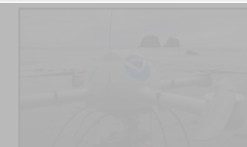
Progress Toward
End-to-End UAS Capabilities

Timeline

1) Large-scale / Synoptic Observations

How: HALE UAS
Where: Oceans (Upstream)
When/Why: Improved global NWP forecasts **DAYS in advance**

2) Mesoscale Observations



How: LASE / VTOL UAS
Where: Inland (Area of expected impact and/or Slightly upstream)
When/Why: Improved… a) Hi-res NWP models **HOURS in advance**
b) Forecaster "Situational Awareness"

February 2016

(Hoping to fold in mesoscale obs in future cases.. Stay tuned!)

3) Hazard/Damage Assessment Observations

How: LASE / VTOL UAS
Where: Inland (Area where impacts have occurred)
When/Why: NWS and EMA rapid response **HOURS following event**
Damage assessment / Community recovery

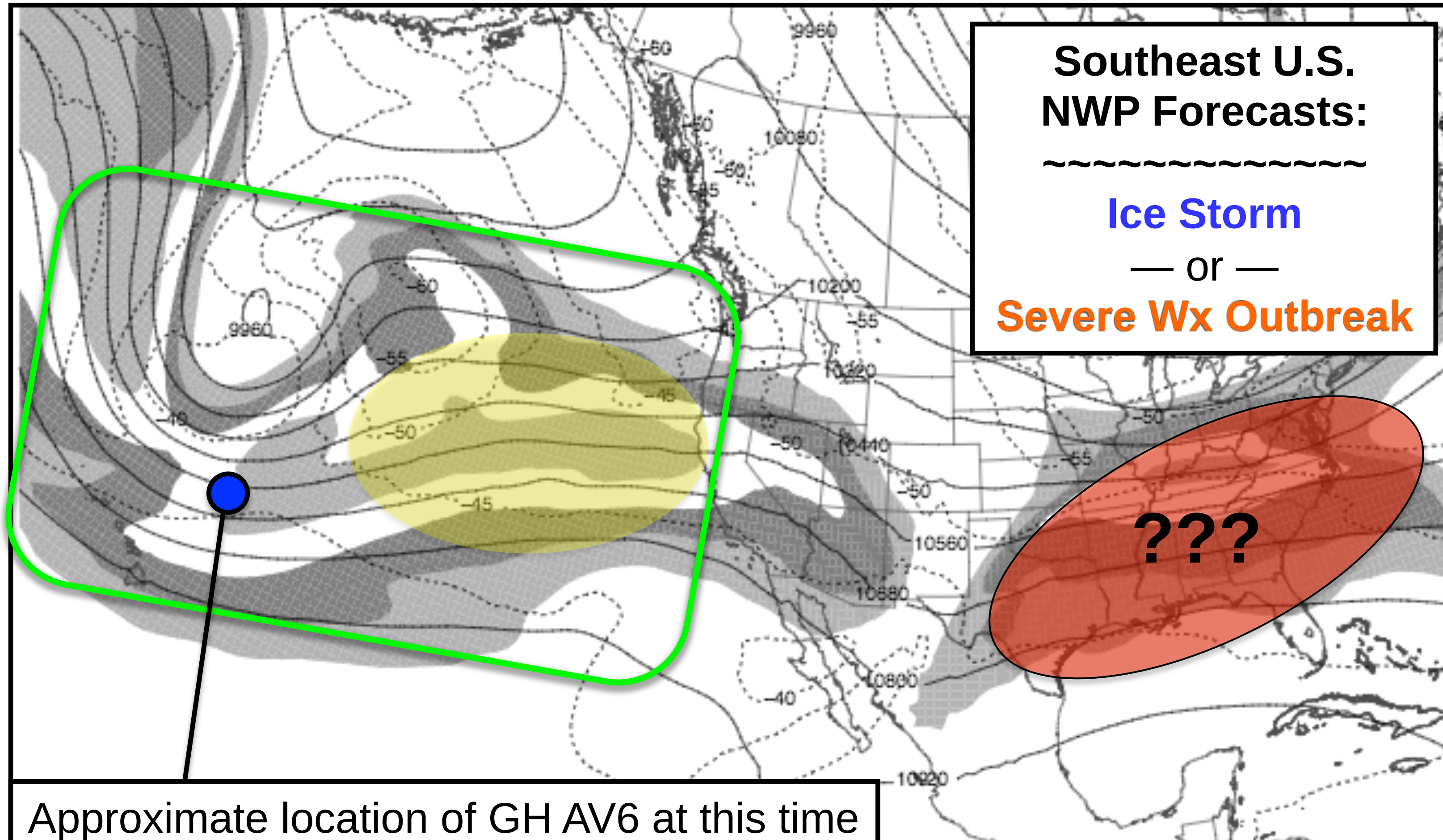
Global Hawk Synoptic Recon Mission

ENRR: February 21-22, 2016

GH Mission: 02/21/16 1517z – 02/22/16 1454z **Duration: 23 hours 37 minutes**

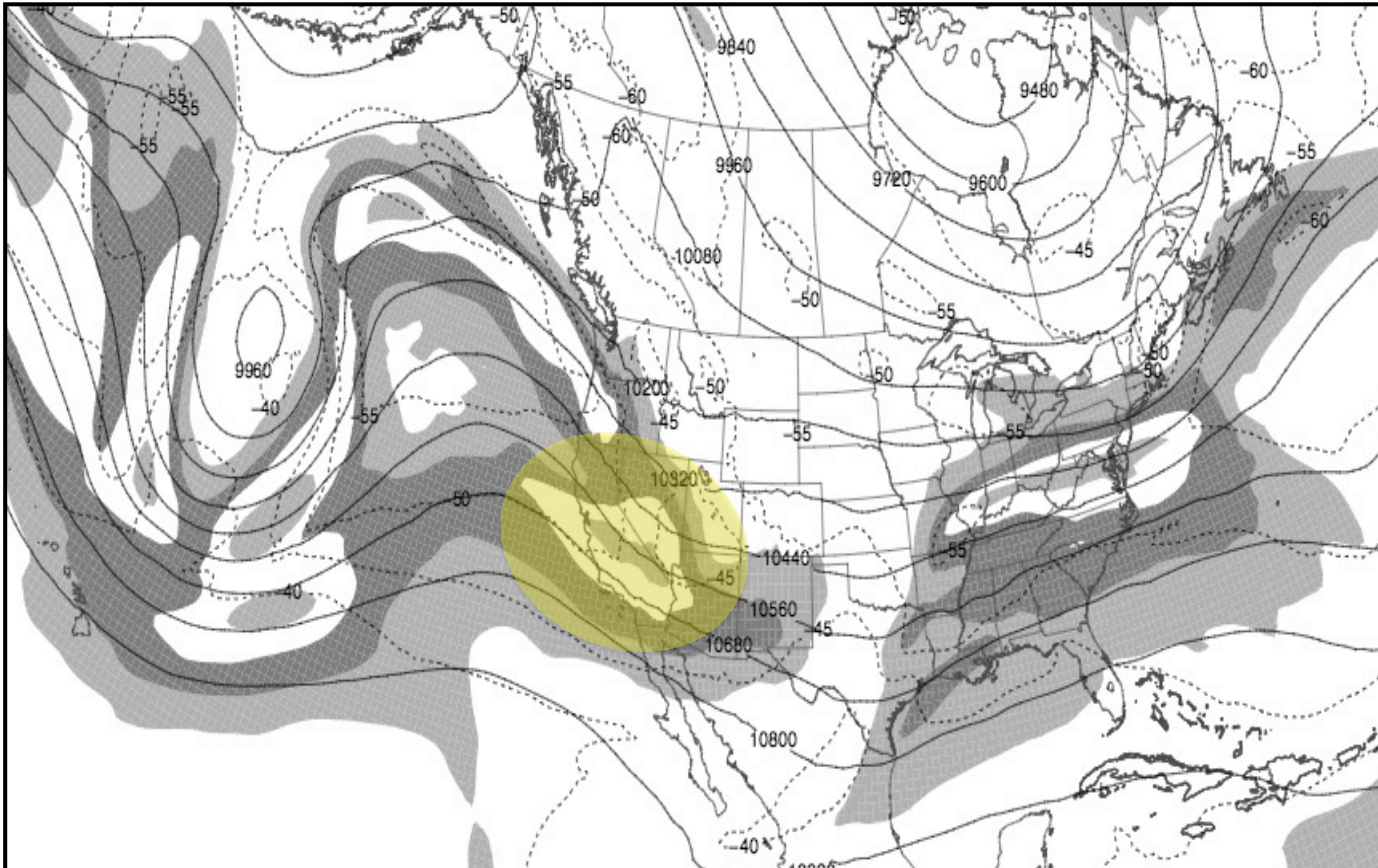
250mb Upper Chart Analysis

Valid: 00z 02/22/16 (~Midpoint of mission flight)



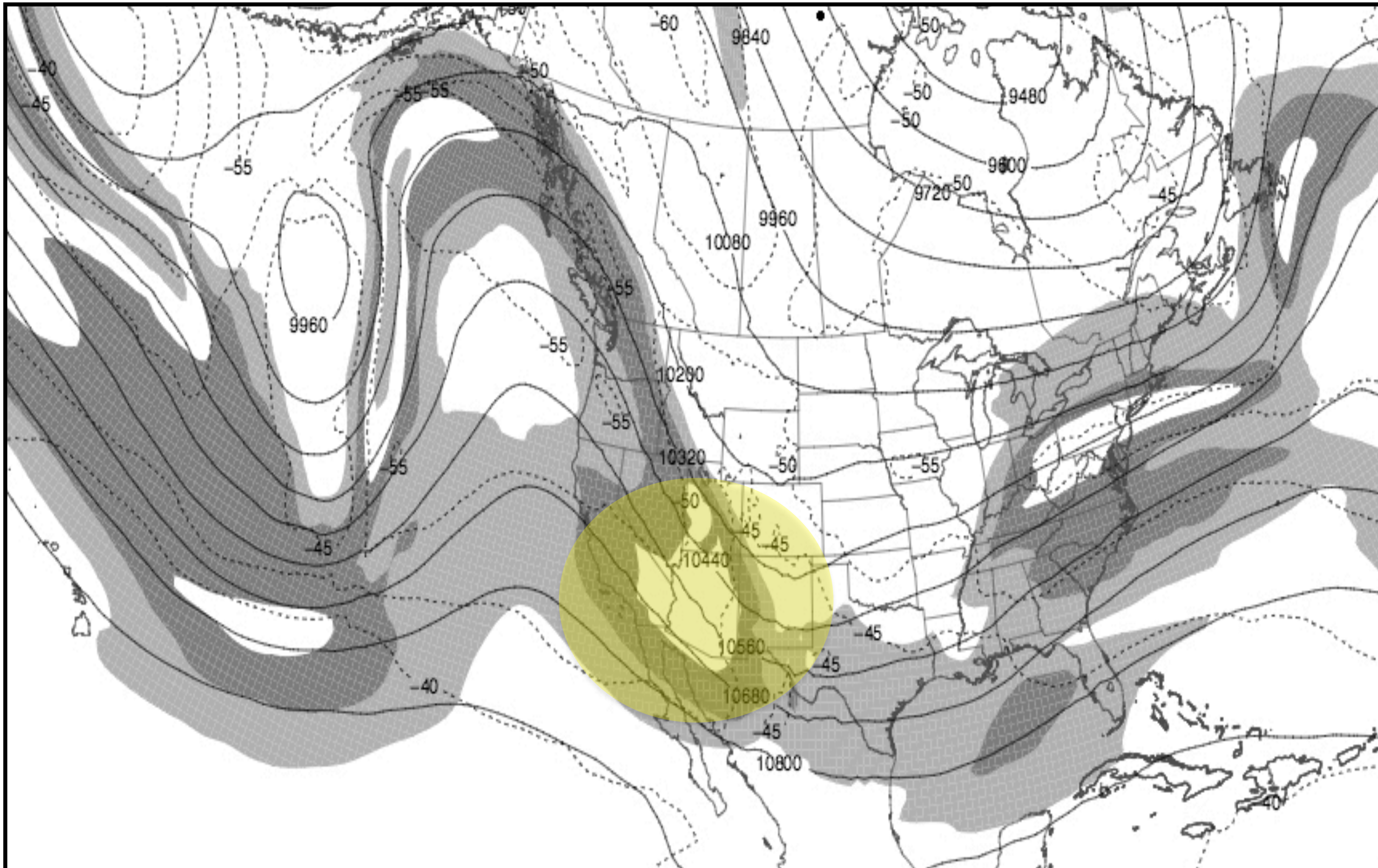
250mb Upper Chart Analysis

Valid: 12z 02/22/16



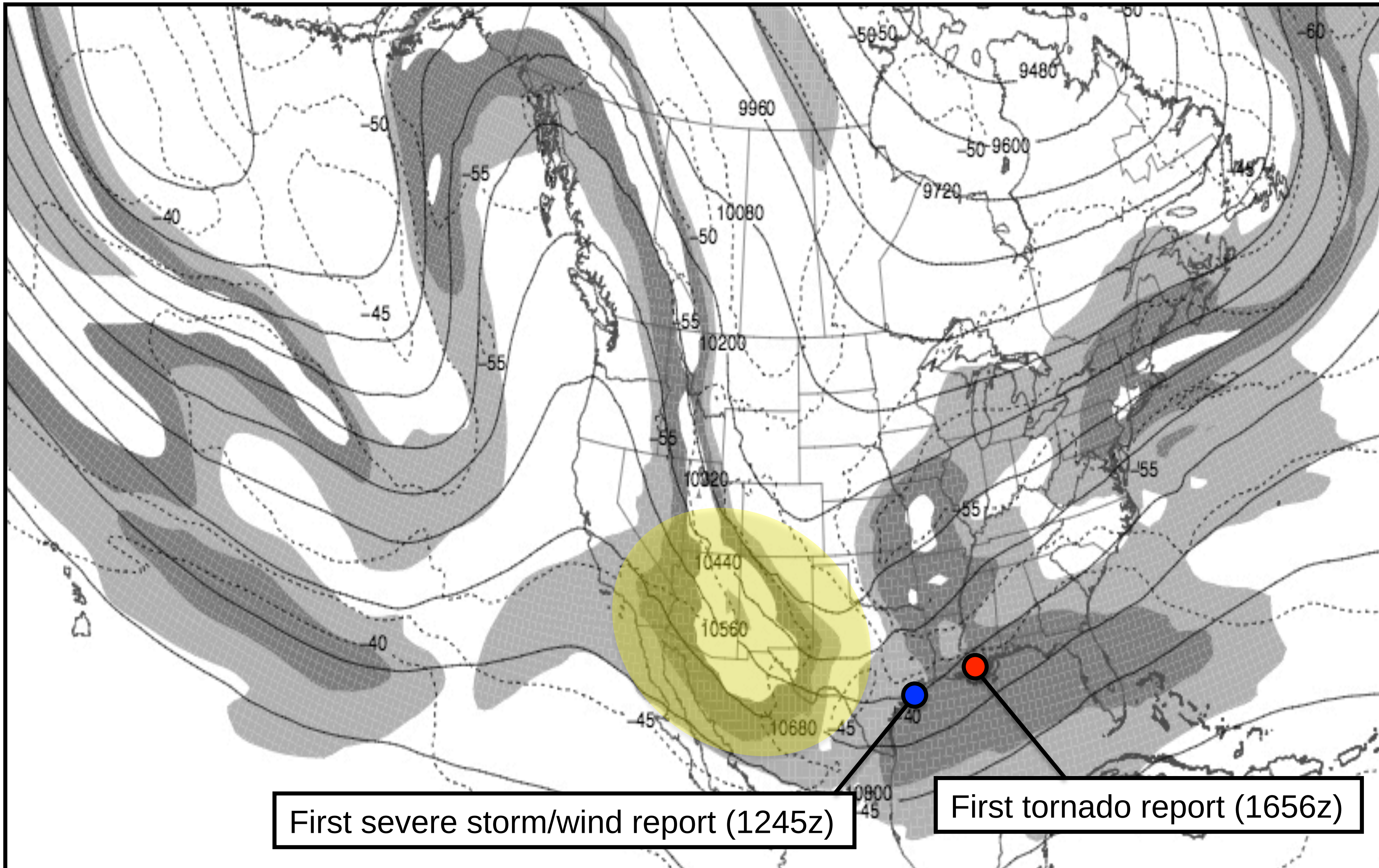
250mb Upper Chart Analysis

Valid: 00z 02/23/16



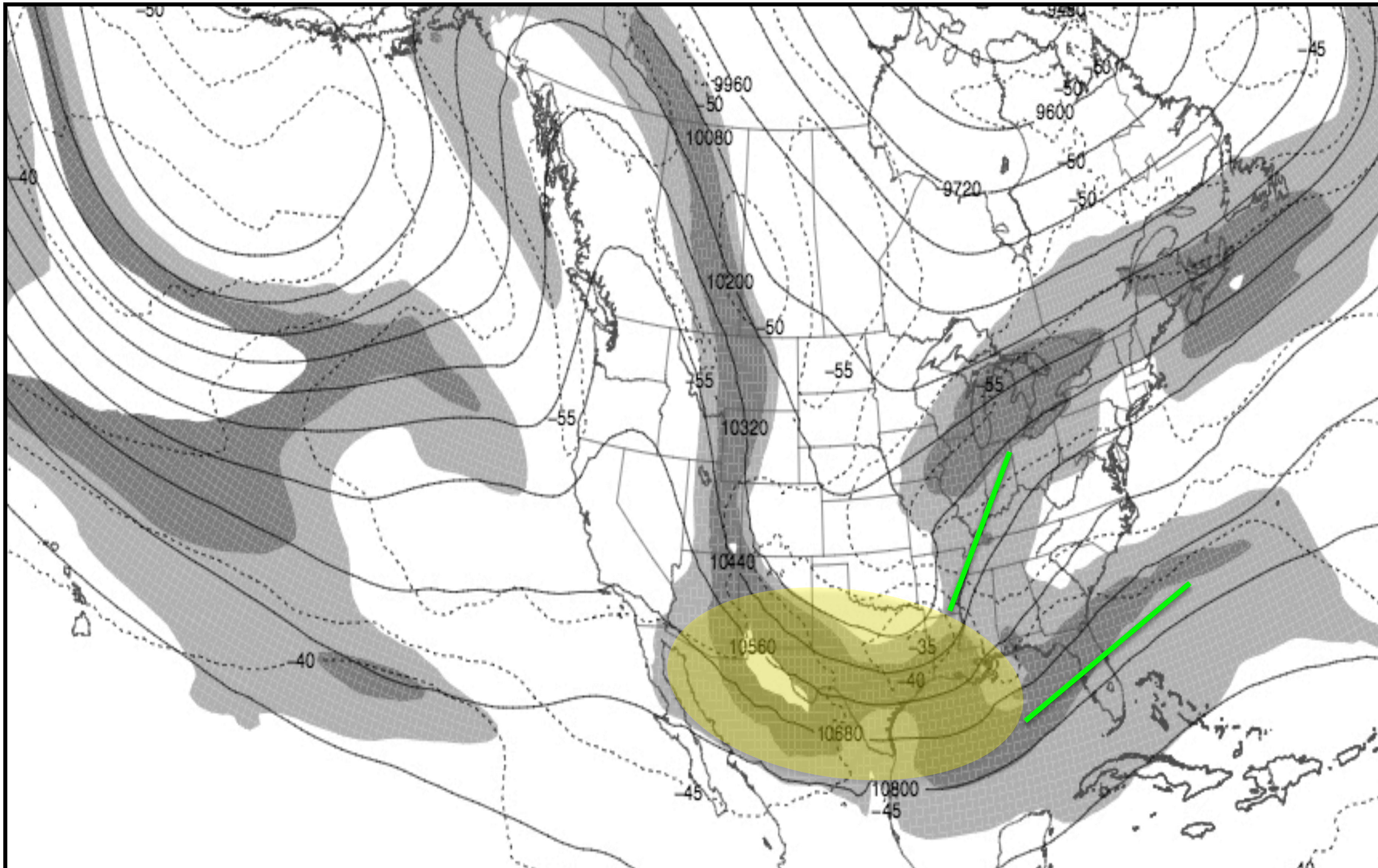
250mb Upper Chart Analysis

Valid: 12z 02/23/16

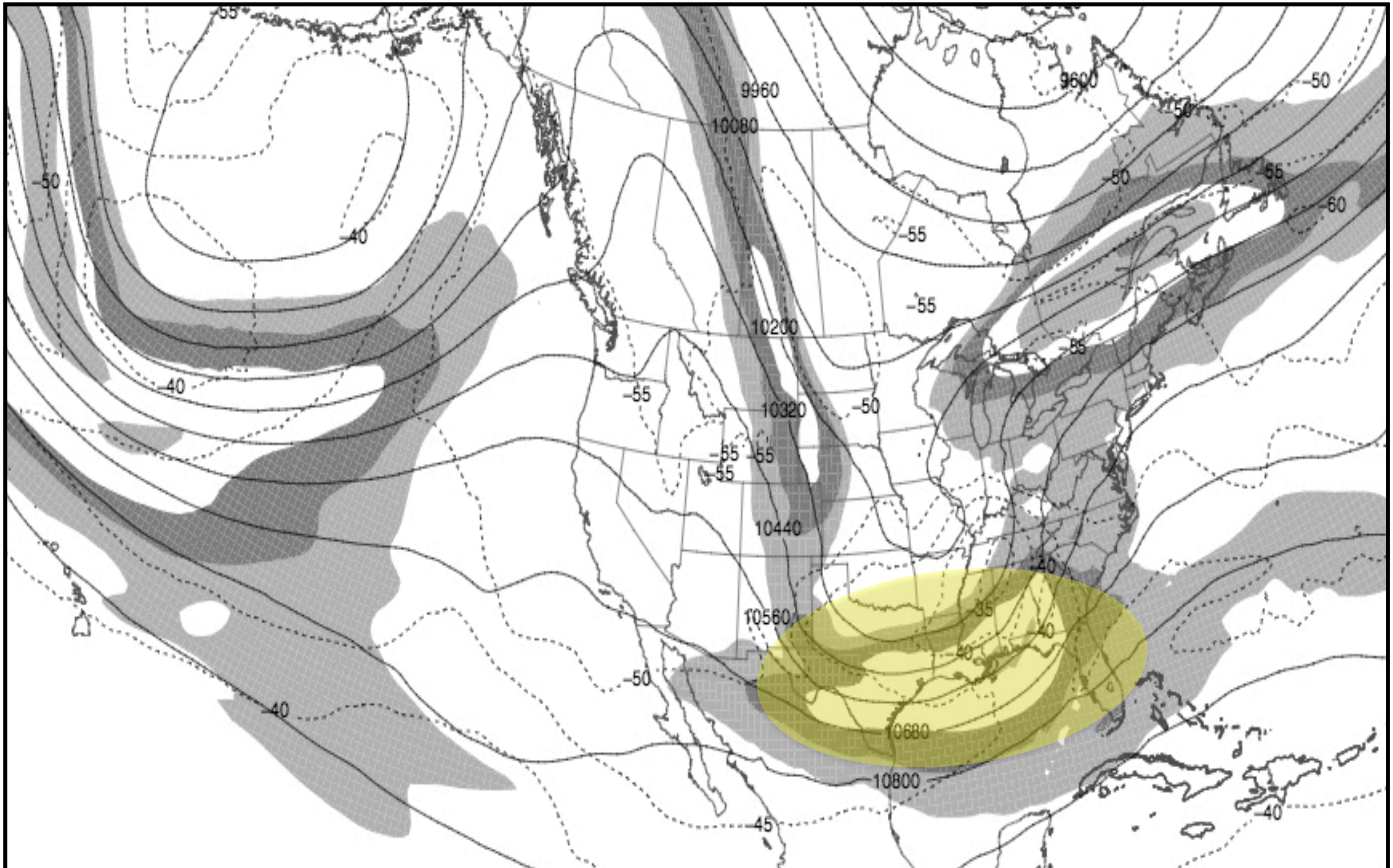


250mb Upper Chart Analysis

Valid: 00z 02/24/16

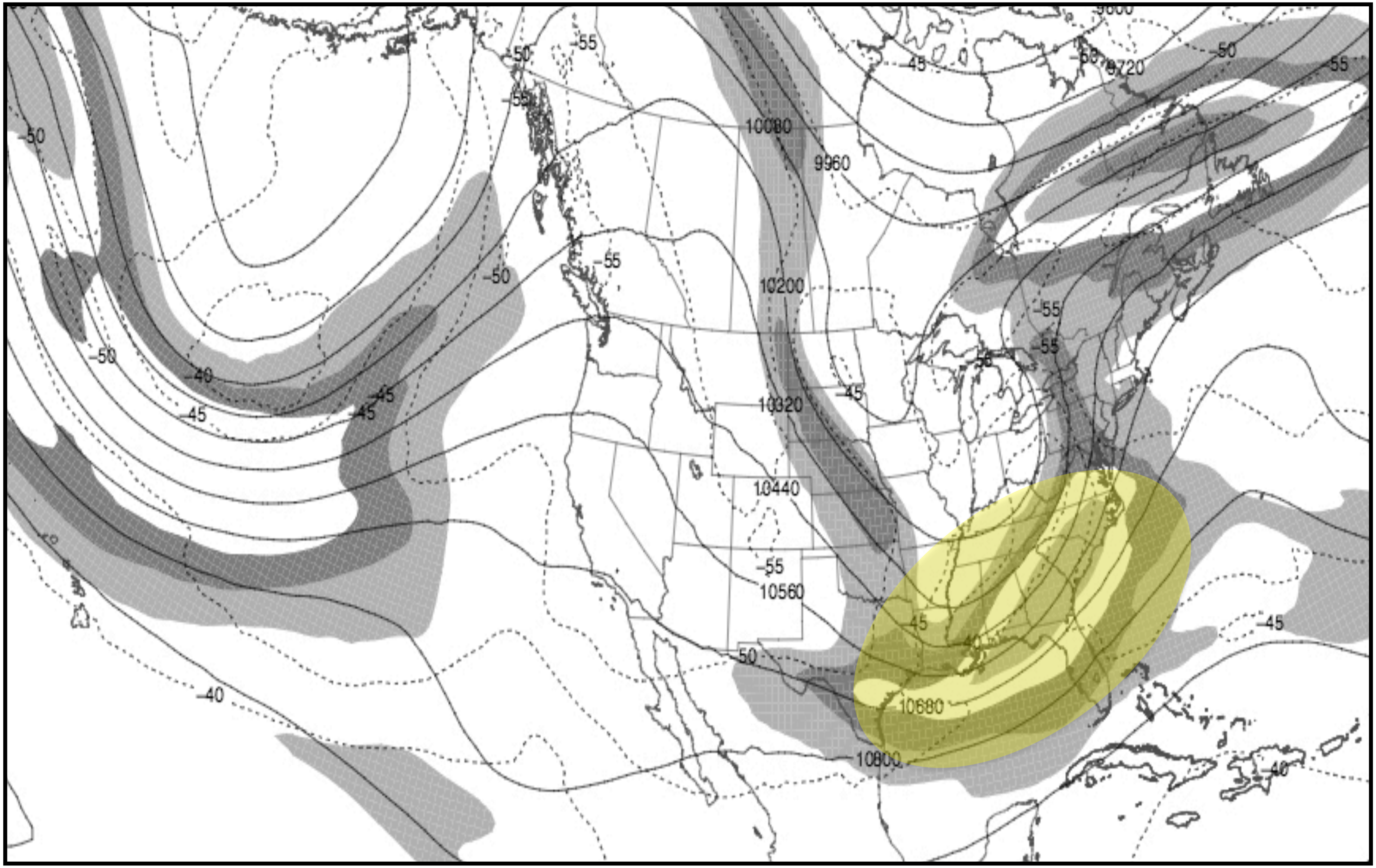


250mb Upper Chart Analysis
Valid: 12z 02/24/16

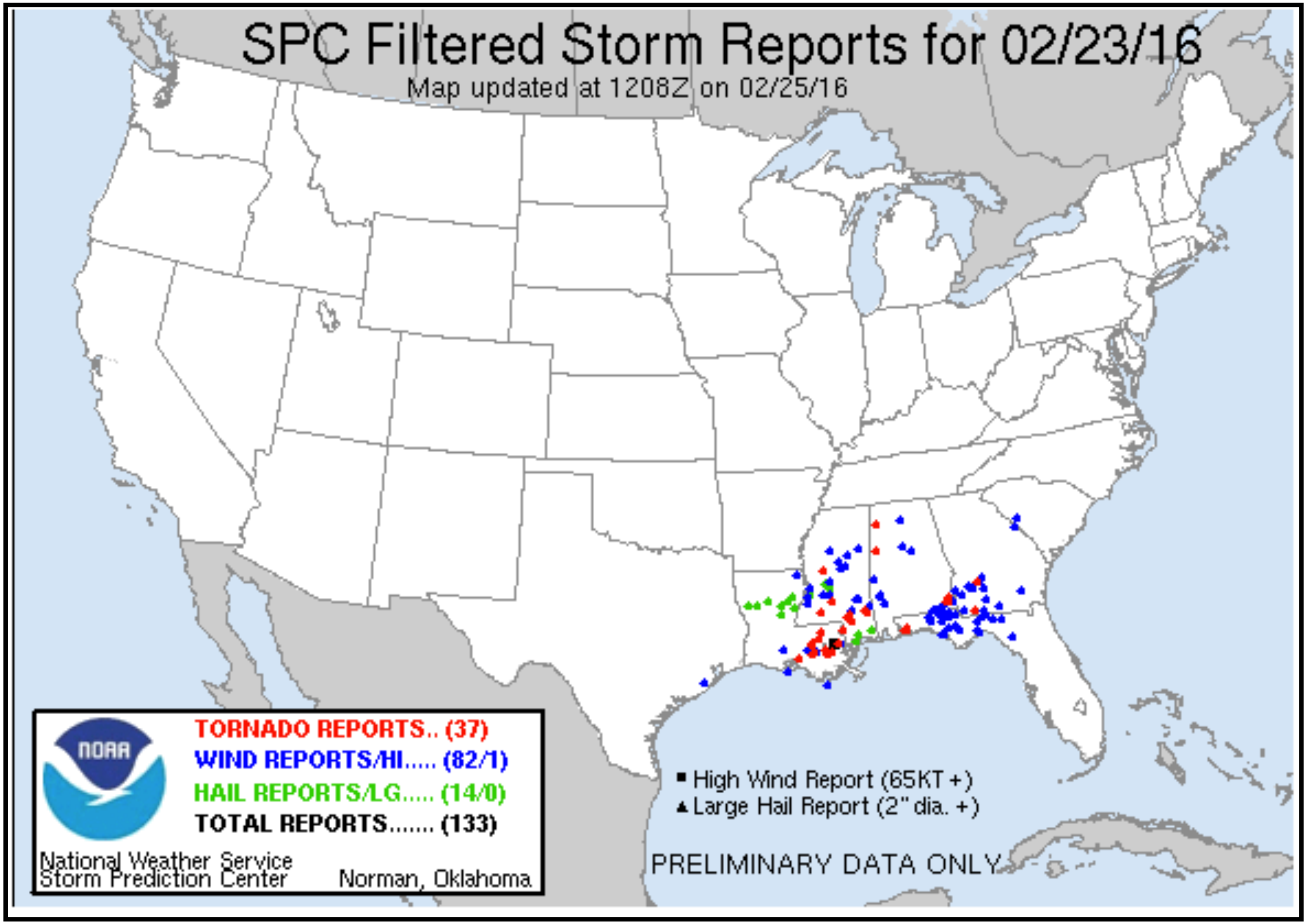


250mb Upper Chart Analysis

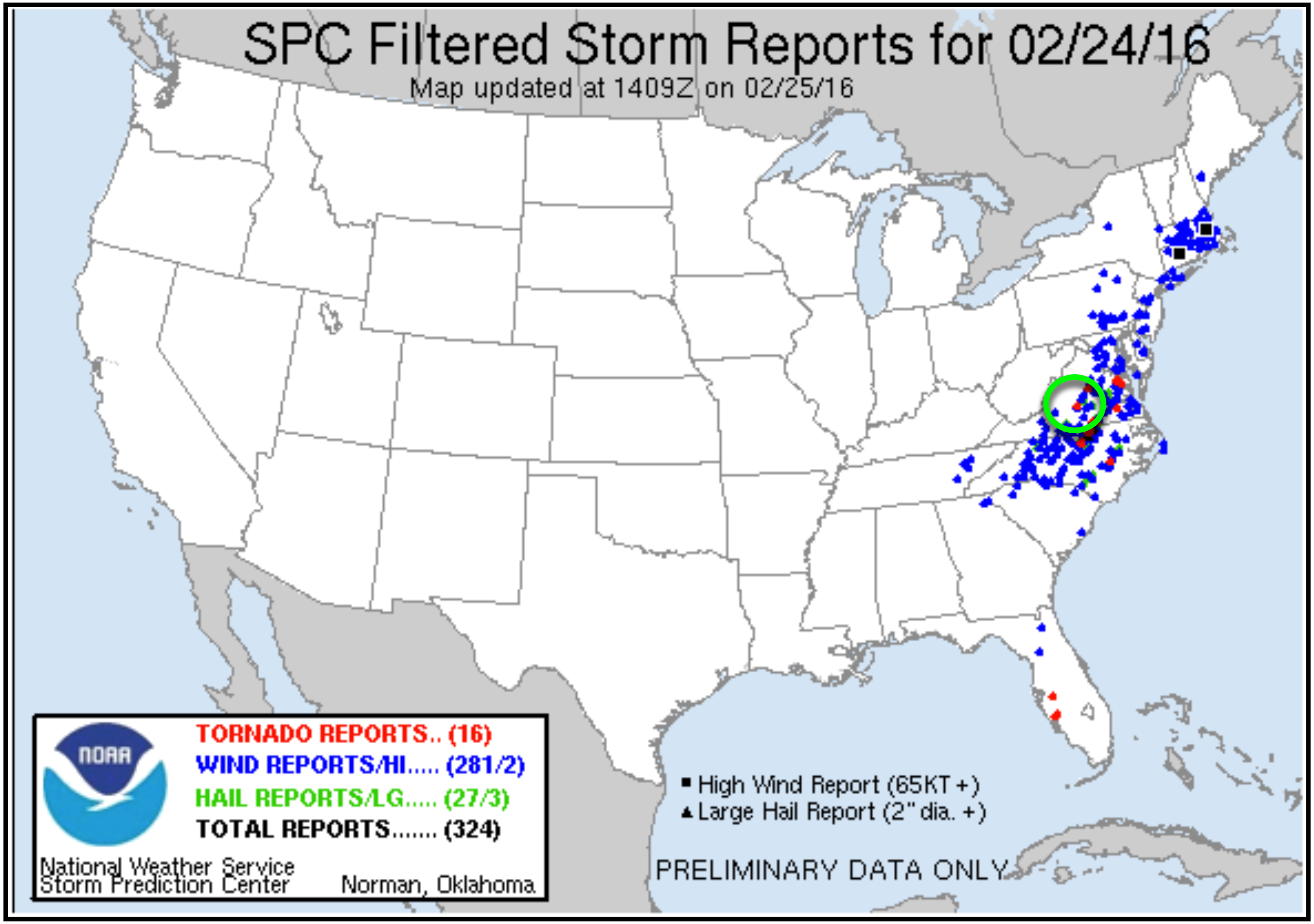
Valid: 00z 02/25/16



NOAA Storm Prediction Center Storm Reports



NOAA Storm Prediction Center Storm Reports



UAS for Hazard/Damage Assessment

UAS Aerial Survey of Storm Damage / NWS Blacksburg
Feb 26, 2016; Appomattox County (near Evergreen, VA)

UAS-based aerial imagery of EF-3 tornado damage path; 26 Feb 2016.

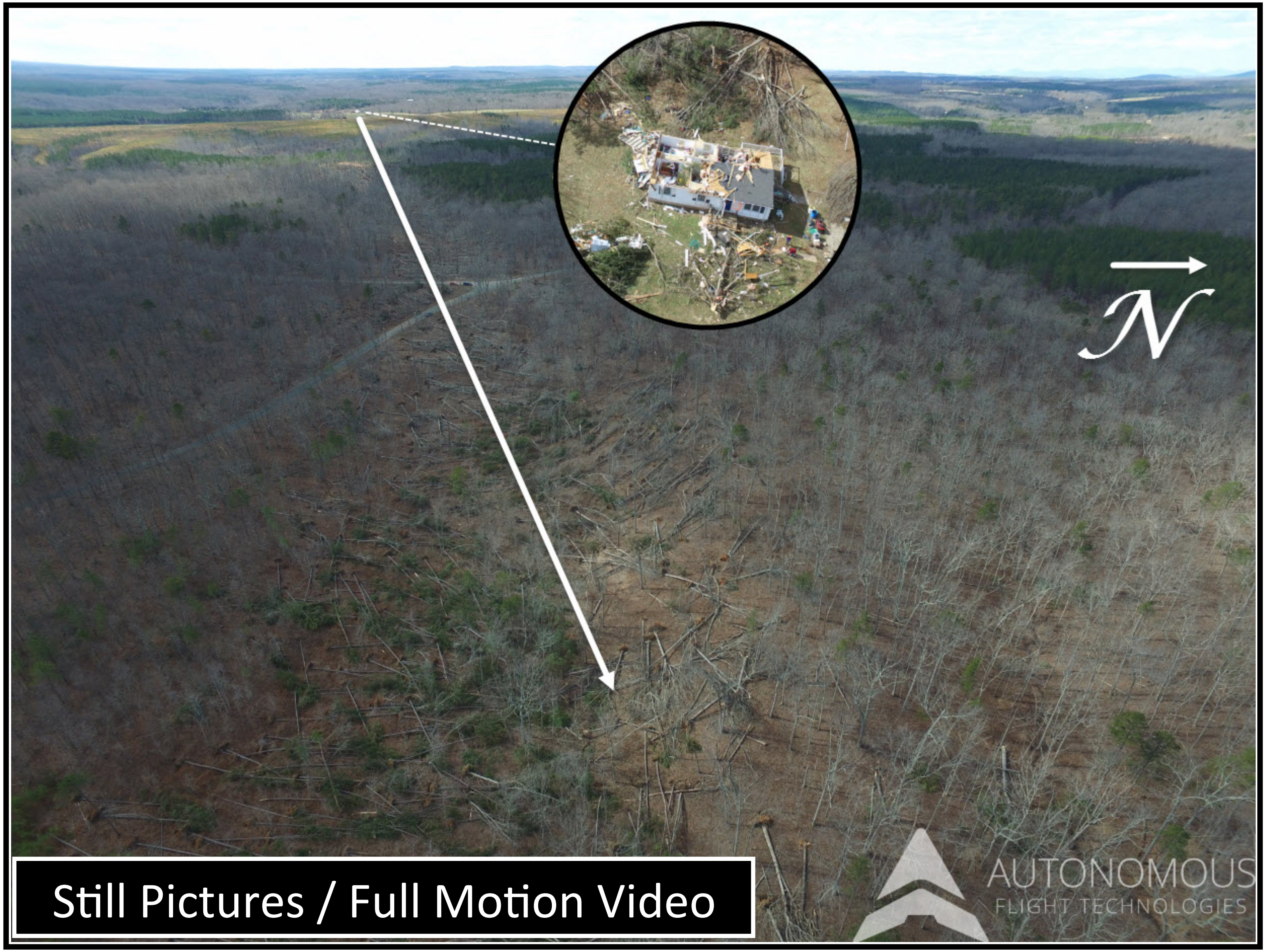
-- Operations coordinated through Appomattox Co., VA EMA.

--Imagery shared with NWS Blacksburg, VA Office

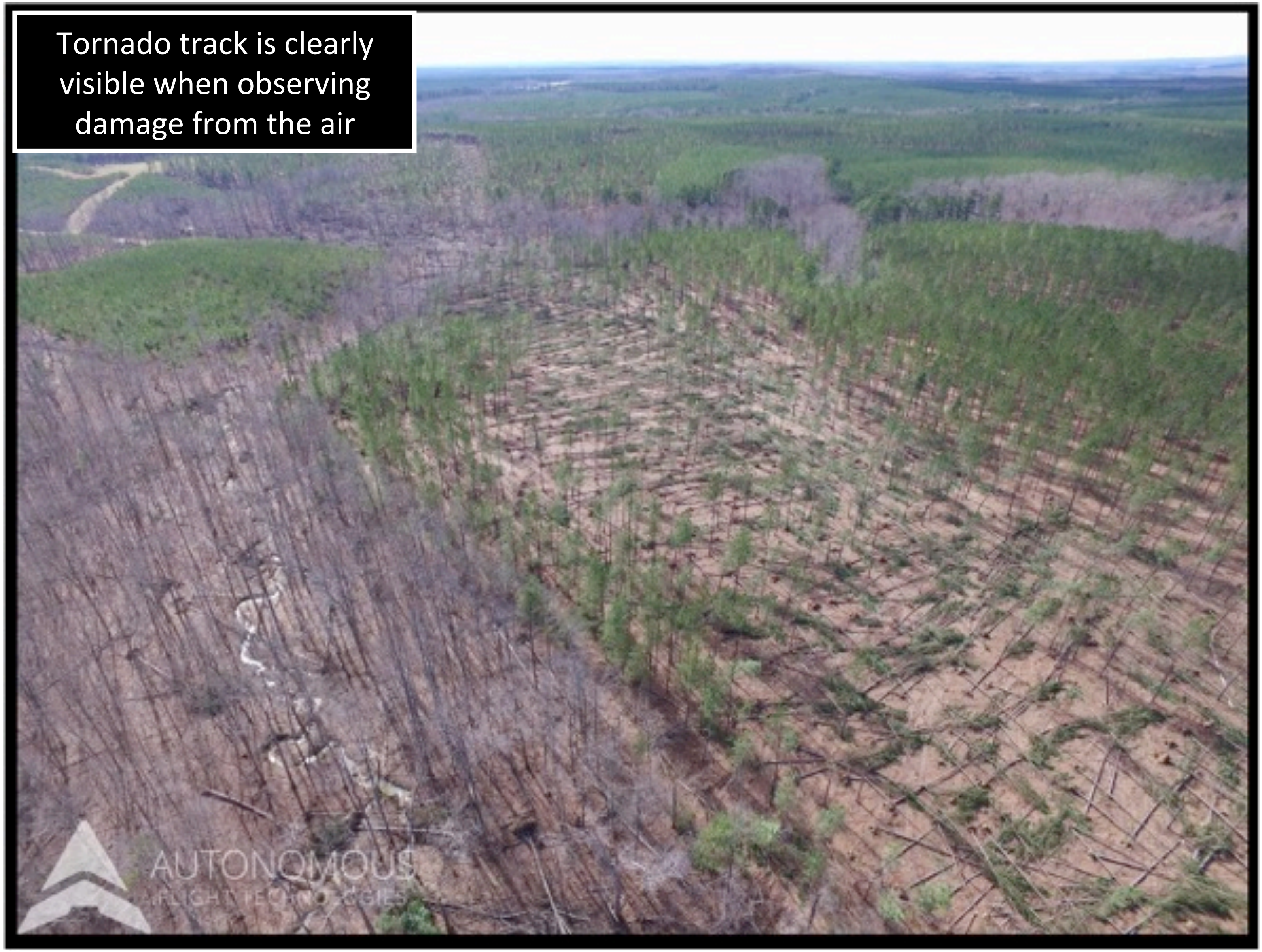
-- Imagery provided courtesy of "Autonomous Flight Technologies, LLC" in Virginia.

**** Operation accomplished through efforts of NWS Eastern Region Drone Team (ERDT) ****

UAS Damage Assessment Imagery:
Appomattox County, VA Tornado / Feb 2016



UAS Damage Assessment Imagery:
Appomattox County, VA Tornado / Feb 2016



UAS Damage Assessment Imagery:
Appomattox County, VA Tornado / Feb 2016

UAS Damage Assessment Imagery:
Appomattox County, VA Tornado / Feb 2016

UAS Damage Assessment Imagery:
Appomattox County, VA Tornado / Feb 2016

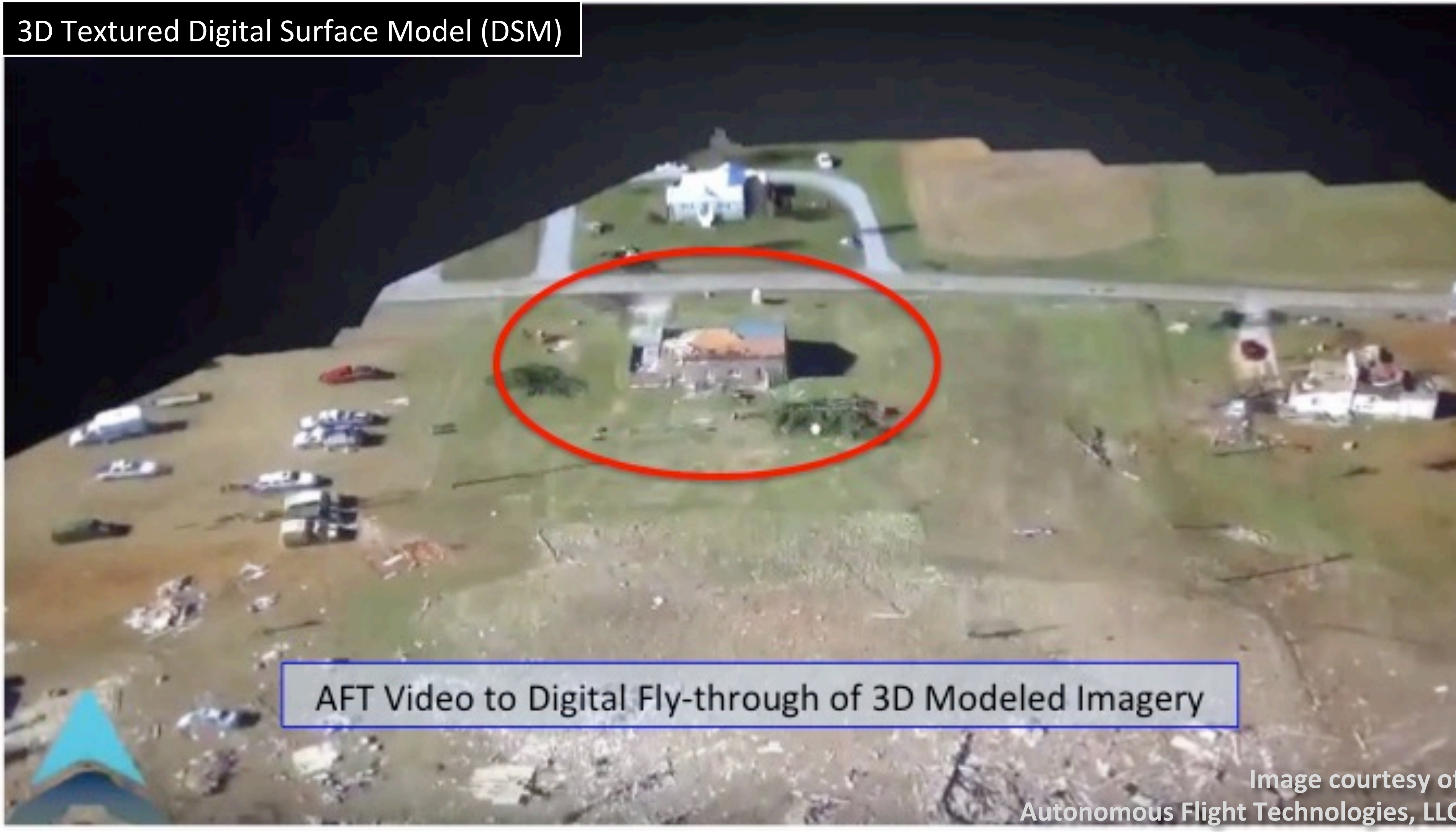
The drone was able to see deep into areas of tangled debris not safely accessible from the ground. Good for determining damage extent, but also good for search and rescue efforts.

UAS Damage Assessment Imagery:
Appomattox County, VA Tornado / Feb 2016

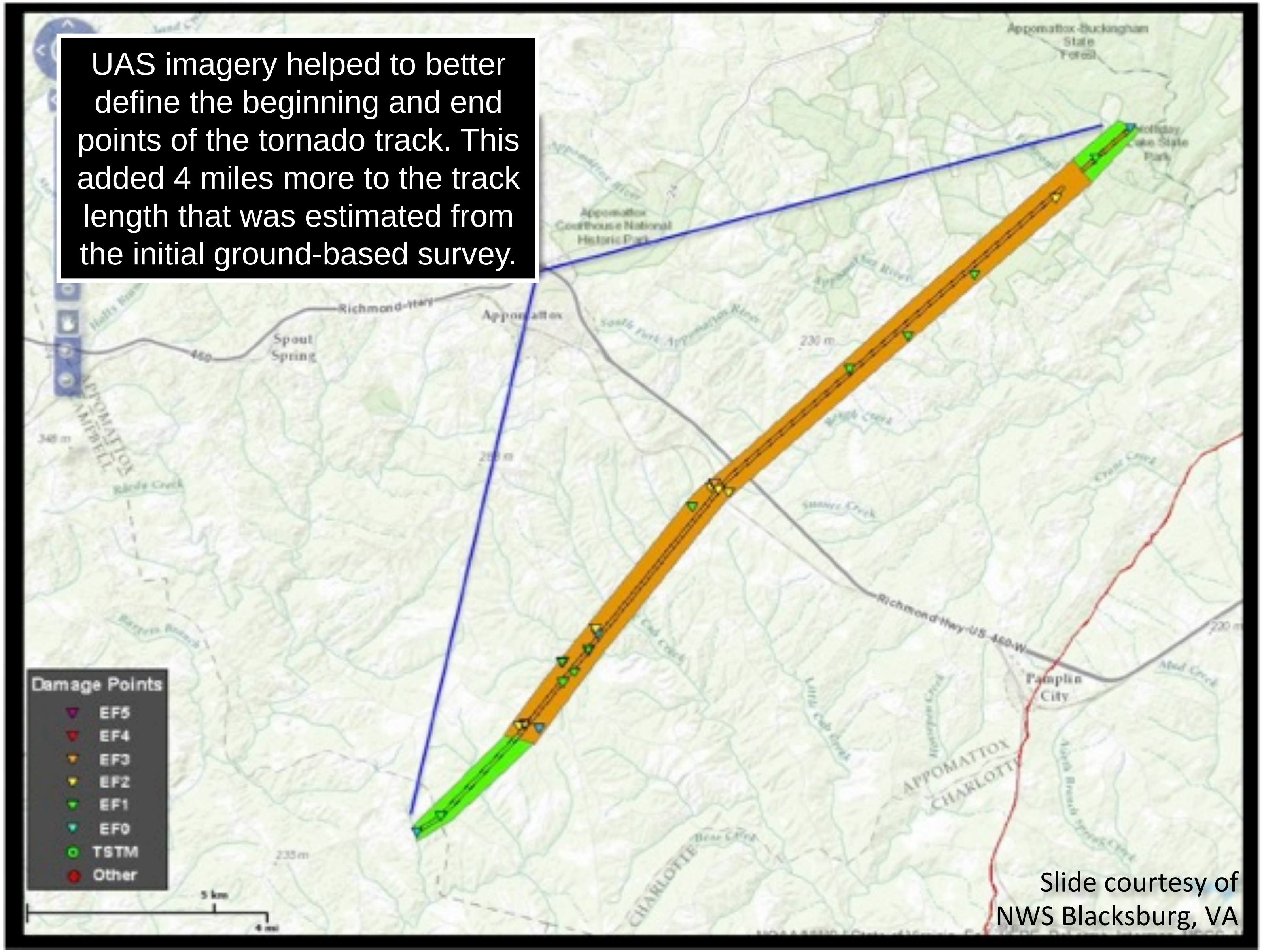
UAS Damage Assessment Imagery:
Appomattox County, VA Tornado / Feb 2016

Orthomosaic "Change Detection":
Pre- and Post-Damage Comparison Overlays

UAS Damage Assessment Imagery:
Appomattox County, VA Tornado / Feb 2016



UAS for Hazard/Damage Assessment



Slide courtesy of
NWS Blacksburg, VA

AMS Recommendation Slide: Observations and Instruments

--- Questions? ---

Timeline

1) Large-scale / Synoptic Observations

How: HALE UAS
Where: Oceans (Upstream)
When/Why: Improved global NWP forecasts **DAYS in advance**

2) Mesoscale Observations

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Damage assessment / Community recovery

NOAA UAS Program's SHOUT Project: A Case Study for the End-to-end Utilization of High- and Low-altitude Unmanned Aircraft Systems

Questions?

For more information, please come see me or contact us at:

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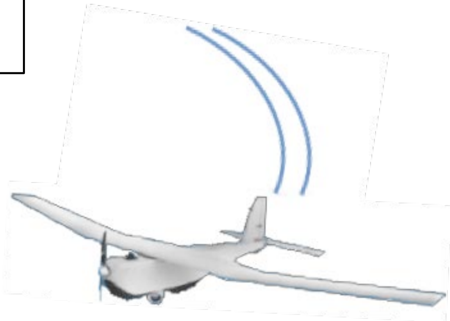
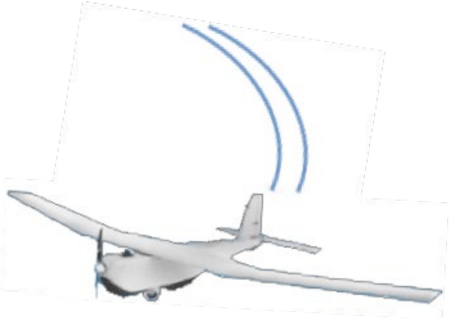
"JC" Coffey: John.J.Coffey@noaa.gov
John Walker: John.R.Walker@noaa.gov

CHEROKEE NATION Technologies



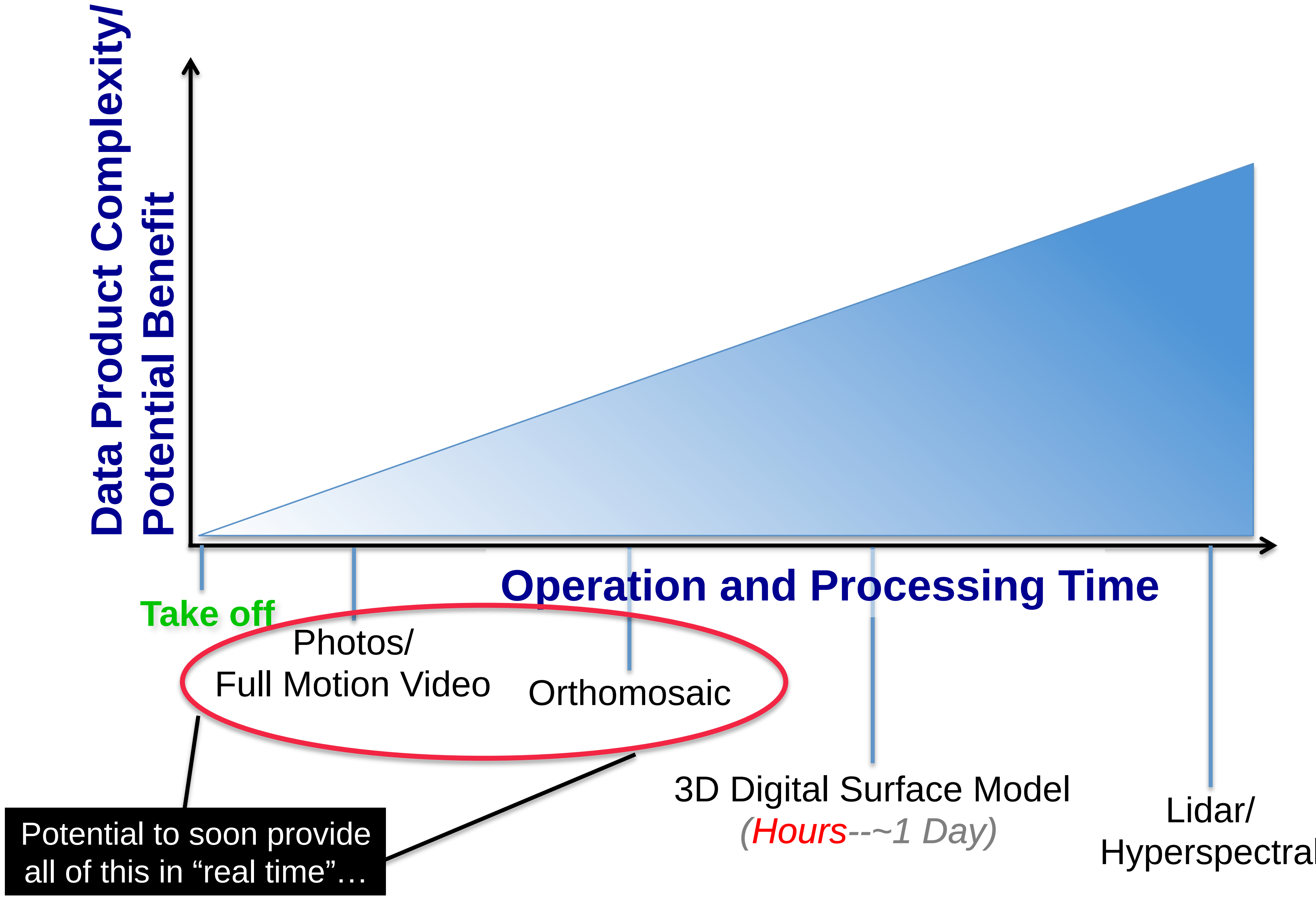
NOAA UAS Program's SHOUT Project: A Case Study for the End-to-end Utilization of High- and Low-altitude Unmanned Aircraft Systems

Backup Slides



CHEROKEE NATION Technologies

Types of UAS-based Imagery



UAS for Rapid Response

Under Development: UAS Data Services Comparison Checklist

Government
Data Services - End Product / Best Value Determination Tool

Purpose: This worksheet provides decision-making guidance when there is a need for a product, such as an aerial photograph, that could be obtained by a commercial company that uses unmanned aircraft systems (UAS). This worksheet should be used to make a best value determination by comparing UAS-obtained products and costs with alternative methods of obtaining the needed product. Contact the Government UAS Program for additional UAS platform or sensor guidance.

Directions: For each option, place a check in the box that applies (Yes or No). Do not fill out the grayed-out boxes. To fill out the "Cost" column, you must obtain a quote from commercial companies. Contact the controlling Government aircraft office for additional guidance.

All Options Should be Considered:	Will the Government Have Operational Control?		Take-Off/Landing Operation Within Park Boundaries		Complies with All Relevant Legal and Policy Requirements[3]		Data Captured Meets Projected Need		Provider for this Option is Available		Cost
Ground-Based Options (e.g. elevated structures, land masses)	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	
Manned Aircraft	[1]		[2]								
Unmanned Aircraft	[1]		[2]								
Other (e.g. kites, balloons, satellites)											

If Unmanned Aircraft meets all requirements and represents the best value to the Government, go to Section 2.

Global Hawk AV6 – Operational Utility

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TROPICAL STORM GASTON DISCUSSION NUMBER   9
NWS NATIONAL HURRICANE CENTER MIAMI FL       AL072016
500 PM AST WED AUG 24 2016

Gaston is being affected by southwesterly vertical shear associated
with a strong mid- to upper-level trough and cut-off low seen in
water vapor imagery near 26n 51w.  The shear has caused the
low-level center to become partially exposed while much of the
deep convection has been shunted to eastern half of the circulation.
In spite of the degraded satellite presentation, dropsonde data
from the unmanned NASA Global Hawk aircraft investigating Gaston
support keeping the intensity at 60 kt.  In fact, additional
observations from the ongoing mission might reveal that the system
is even a little stronger than this estimate.
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HURRICANE GASTON TROPICAL CYCLONE UPDATE
NWS NATIONAL HURRICANE CENTER MIAMI FL       AL072016
1215 AM AST THU AUG 25 2016

...GASTON BECOMES THE THIRD HURRICANE OF THE ATLANTIC SEASON...

Dropsonde data from a NASA/NOAA Global Hawk mission indicate that
Gaston has strengthened to a hurricane.  The maximum winds are
estimated to be 75 mph (120 km/h) with higher gusts.
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UAS for Rapid Response

Potential Solution: UAS for providing aerial viewpoint

National Weather Service (NWS) needs:

- Beginning / End Points of Damage Area
- Width of Damage Area
- Worst Hit Areas
- Where are "boots on the ground" needed for ground survey … How to get there?
- Cause (Tornado, Winds, etc.)
- Rating of Damage (If cause is tornado)
- **Goal**: Thorough and efficient survey of all damaged areas with correct attribution of the natural cause of disaster

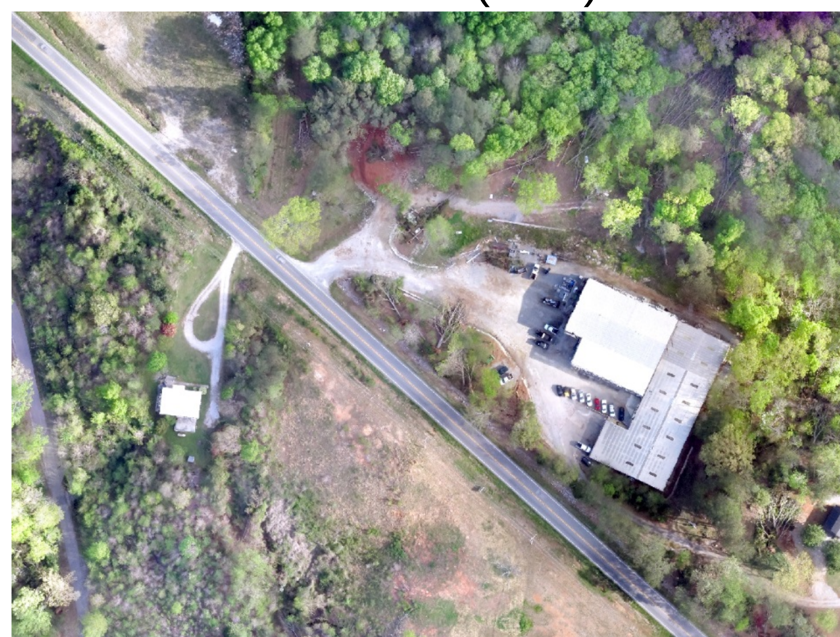
Emergency Management/ First Responders (EM) needs:

- Extent of damage
- Worst Hit Areas
- Where are resources most needed / What types of resources are needed?
- How to direct resources to greatest areas of need?
- **Goal**: Quick assessment of area of affected by disaster; Search and Rescue; Direction of resources; Determination of disaster declaration


Landsat 8 OLI (30m) Resolution


ASTER (15m)


ISERV (4m)


UAS (0.05m / 5 cm)

UAS for Rapid Response

Real World Example: UAS aerial survey of storm damage
Dec 24, 2015; near Charleston, SC

UAS-based aerial imagery of storm damage; 24 Dec 2015.

The "orthomosaic" version of this data (~1.3 cm resolution) provided enough information to NWS Charleston, SC to classify the damage as "tornadic". It was noted that ground-based information, alone, was not sufficient and would have likely led to an inaccurate "straight-line wind" damage classification.

-- Operations coordinated through Berkeley Co., SC EMA.

-- Imagery provided courtesy of "SkyView Aerial Solutions, LLC" in South Carolina.

**** Operation accomplished through efforts of NWS Eastern Region Drone Team (ERDT) ****

UAS for Rapid Response

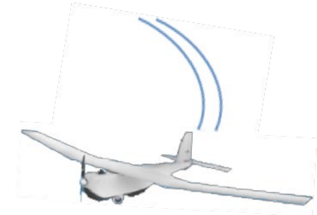
<u>Real World Example:</u> UAS aerial survey of storm damage April 2016; Morgan County, AL

UAS-based aerial imagery of damage produced by a tornado in Morgan County, AL on the evening of March 31, 2016.

-- Operations coordinated through Morgan Co., AL EMA.

-- Imagery provided courtesy of "enrGies" in Huntsville, AL.

Exercise Overview



Primary Objective:

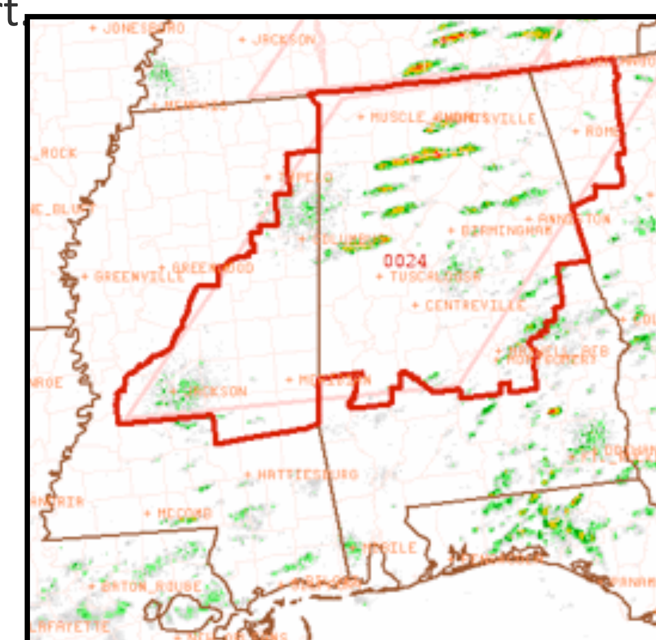
Test the feasibility for transitioning UAS applications from concept into routine rapid response operations, and use identified lessons learned to develop a formal protocol for real-world implementation.

Key Goals/Focus Areas:

- Quickly and effectively obtain info about the scope of an event
  - Use information to expedite communications
  - Test latest technologies, platforms, and payloads
  - Review collection, processing, dissemination procedures
  - Provide near real time and real time access
  - Aid in post hazard damage assessment
  - Assist in allocation and management of resources

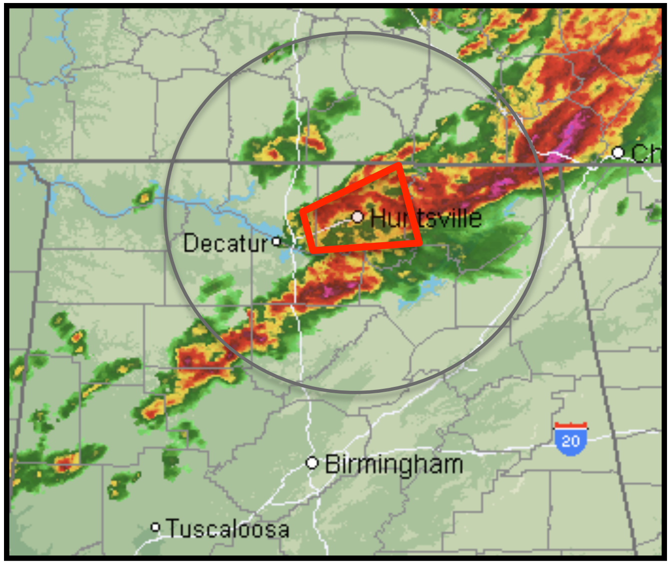
Exercise Scope

- <u>Preface for Fictitious Rapid Response Scenario:</u>
  - In the days leading up to the event, the potential for a severe weather threat was forecast by NWS and communicated to EMA and enrGies.
  - On the day of the event, a tornado watch was in effect across the region; NWS provided updates regarding the potential for a severe weather event, and EMA and Emergency Personnel were put on alert.
  - EMA informed enrGies of the updates and put them on general "stand by" status, in case their services may have been required later in the day.



Exercise Scope

- <u>Emergency Identified and UAS Resource Activated:</u>
  - Storms developed, intensified, and move into the county.
  - NWS issued a tornado warning for one of them.
  - Several minutes later, damage reports began to stream into the EOC and NWS offices from the public and first responders in the Chase Industrial Park area.
  - Once the event was determined to have hit critical mass, EMA decided to activate the UAS team…
  - …enrGies got the call; they quickly ascertained what capabilities were needed, where they needed to deploy, and who they needed to contact (who was expecting them) upon arrival at Incident Command… **<u>The clock started</u>**!



Exercise Scope

- <u>Rapid Response UAS Operation:</u>

➢ 1 VTOL (LM Indago)

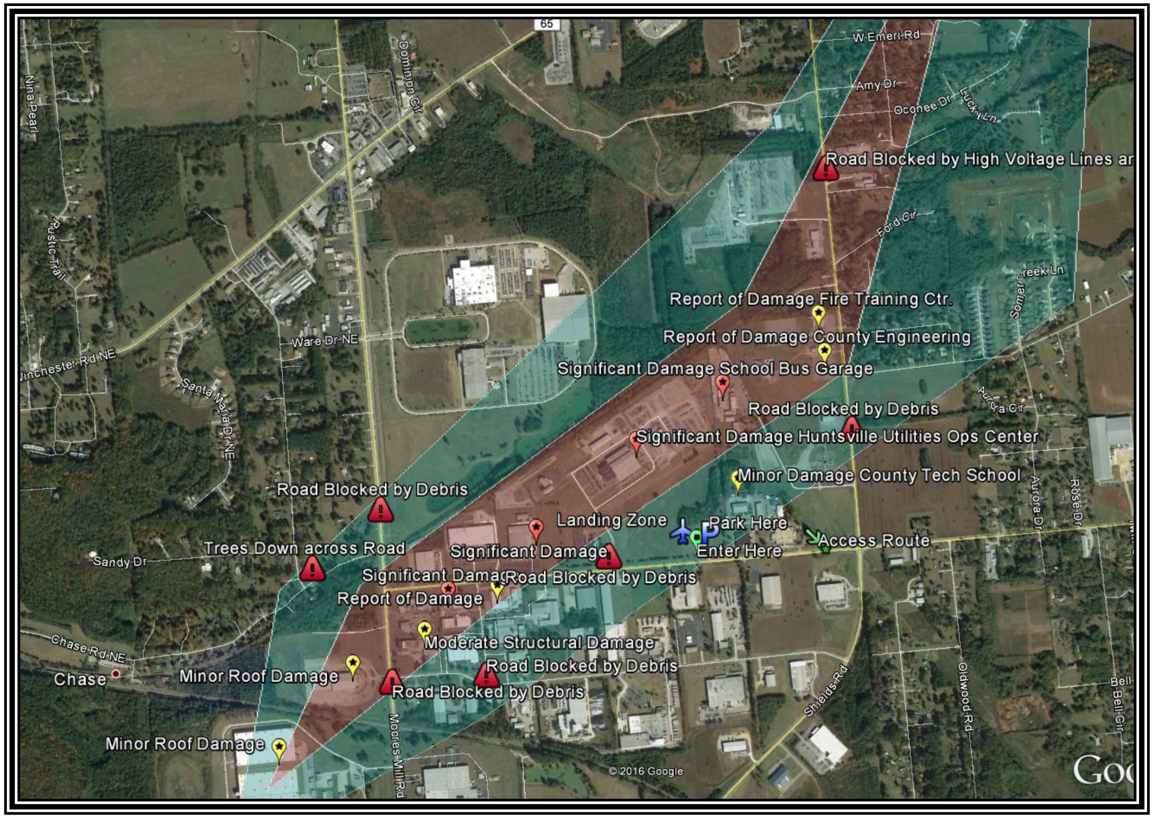
➢ 1 Fixed Wing (sensefly eBee)

➢ EO/IR Still pics and FMV

➢ High-res Orthomosaic

➢ Summary Timeline:

  - 0927 – UAS Activation
  - 0952 – Arrive/Check in with IC
  - 1034 – Flights commenced
  - 1209 – Flights concluded
  - 1436 – Last of survey data processed and distributed



Exercise Conclusion

Photo collage, courtesy of Todd Barron; NWS Huntsville

Huge success!

- ✓ **Real-time FMV imagery to ground team and across town to EOC**
- ✓ **S&R capabilities tested**
- ✓ **High resolution orthomosaic generated on-site and distributed to EMA and NWS**

TAISRR: Objectives in Lower Atmosphere

Objective #1a:

Obtain high temporal/spatial resolution **Meteorological Observations** of lower atmosphere (emphasis on the planetary boundary layer)

- ❑ Near real-time operational forecaster Decision Support System (DSS) examination
- ❑ Input for high-resolution Numerical Weather Prediction (NWP) forecast models

Objective #1b:

Obtain high temporal/spatial resolution **Air Quality Observations** of lower atmosphere for improved analysis and transport/dispersion forecasting

Objective #2:

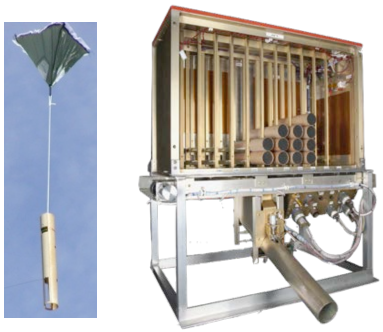
Rapid Response surveillance / **Storm Damage Assessment**

Lower Atmosphere Early Testing

NOAA ARL ATDD Field Testing

SHOUT 2015
Global Hawk Instrumentation

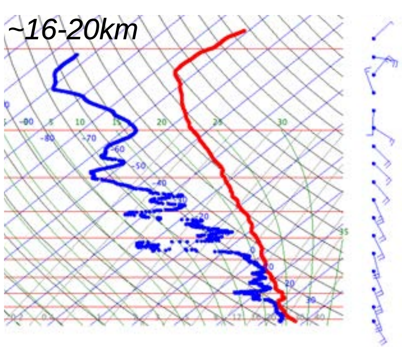
Airborne Vertical Atmospheric Profiling System (AVAPS)



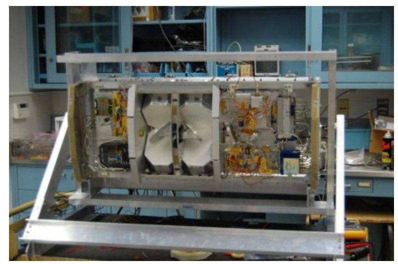
PI: *Terry Hock, NCAR / Gary Wick, NOAA*

Measurements:
- *temperature, pressure, wind, humidity (vertical profiles);*
- *88 dropsondes per flight;*

Resolution:
- *~2.5 m (winds), ~5 m (PTH)*



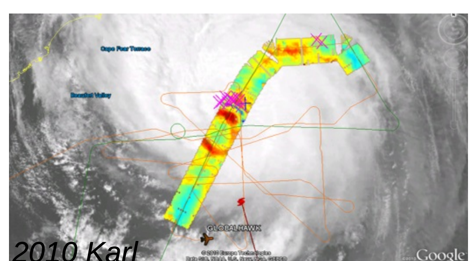
High Altitude Monolithic Microwave Integrated Circuit (MMIC) Sounding Radiometer (HAMSR)



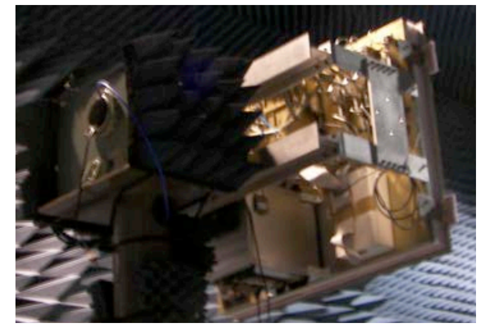
PI: *Dr. Bjorn Lambrigtsen, JPL*

Measurements:
- *Microwave AMSU-like sounder;*
- *25 spectral channels in 3 bands;(50-60 GHz, 118 GHz, and 183 GHz)*
- *3-D distribution of temperature, water vapor, & cloud liquid water;*

Resolution:
- *2 km vertical; 2 km horizontal (nadir)*
- *40 km wide swath*



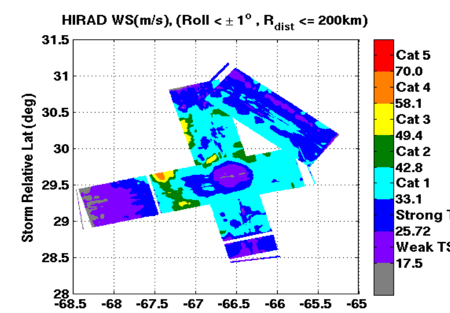
Hurricane Imaging Radiometer (HIRAD)



PI: *Dr. Dan Cecil, NASA MSFC*

Measurements:
- C-band radiometer developed to retrieve ocean surface wind speed and rain rate
- Six selectable frequencies b/w 4 and 7 GHz
- Wide-swath measurements between ± 40 degrees in incidence angle

Resolution:
- *1-3 km horizontal*



SHOUT 2015
Global Hawk Instrumentation

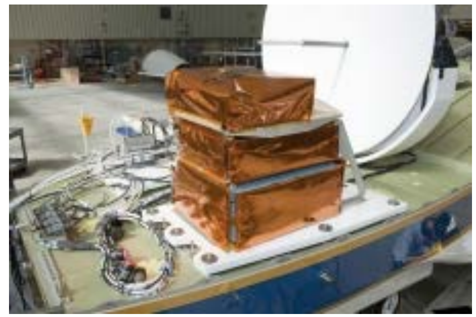
Lightning Instrument Package (LIP)

PI: *Dr. Richard Blakeslee, NASA MSFC*

Measurements:
- *Lightning, electric fields, electric field changes*
- *Air conductivity and vertical electric field above thunderstorms*
- *Provides estimates of the storm electric currents.*
- *Detects total storm lightning and differentiates between intra-cloud and cloud-to-ground discharges*

Resolution:
- *Comprised of a set of optical and electrical sensors with wide range of temporal, spatial, and spectral resolutions*

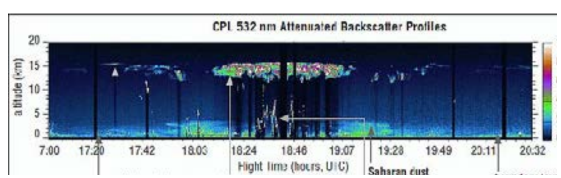
Cloud Physics Lidar (CPL)



PI: *Dr. Matthew McGill, NASA GSFC*

Measurements:
- *Optical depth of clouds and aerosols*
- *Derives cloud phase, cloud particle size, cloud profiles, as well as aerosol, boundary layer, and smoke plume profiles*

Resolution:
- *30 m vertical; 0.1 s temporal for "raw" data / 1.0 s for "processed" (equates to a nominal horizontal spatial resolution of 20 m and 200 m, respectively, for typical high-altitude aircraft speeds of ~200 m/s)*

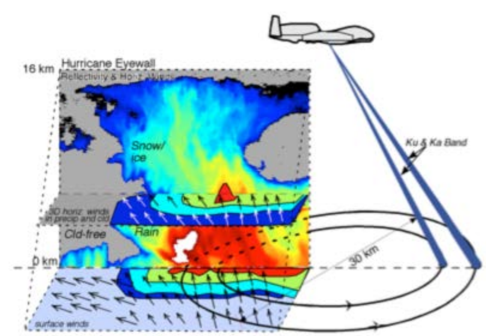


High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

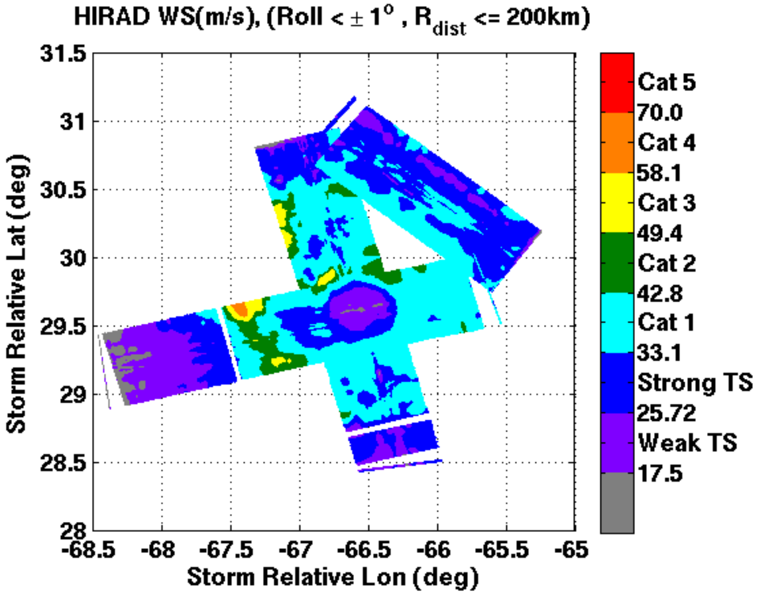
PI: *Dr. Gerald Heymsfield, NASA GSFC*

Measurements:
- *Dual-frequency (Ka- & Ku-band), dual beam, conical scanning Doppler radar*
- *3-D winds, ocean vector winds, and precipitation;*

Resolution:
- *60 m vertical, 1 km horizontal;*

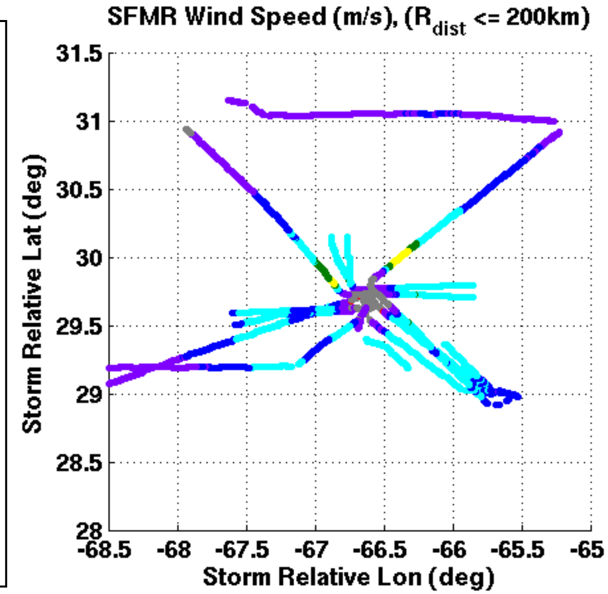


HIRAD Wind Retrievals

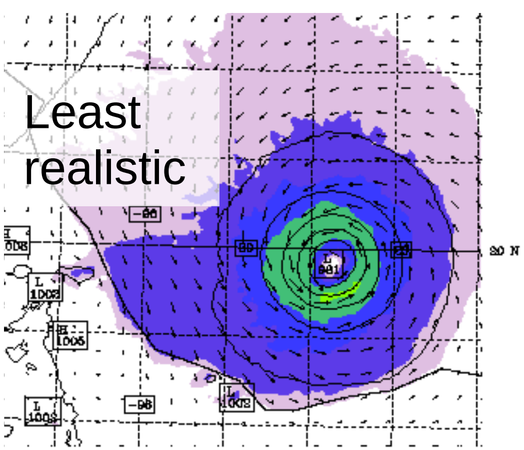


Wide swath from NASA MSFC's HIRAD (left) quickly maps the wind structure of the hurricane.

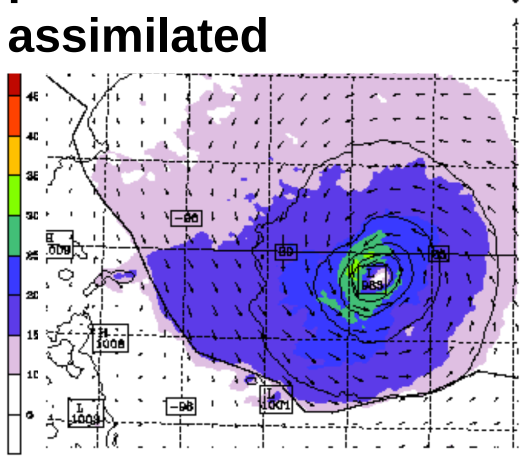
Narrow sampling from operational instruments (right) requires several passes by the aircraft.



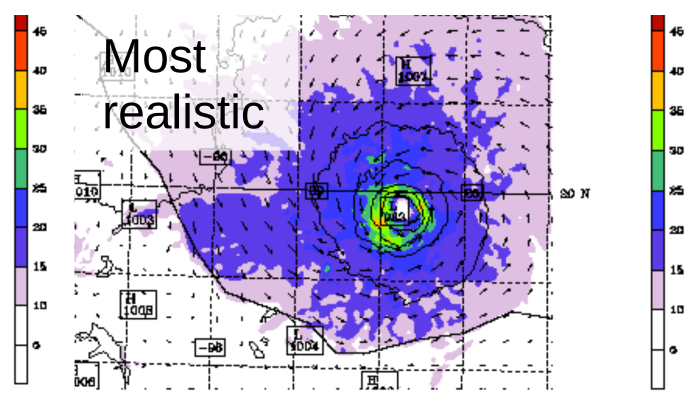
HIWRAP VAD wind assimilated



HIRAD surface wind plus radar VAD wind assimilated



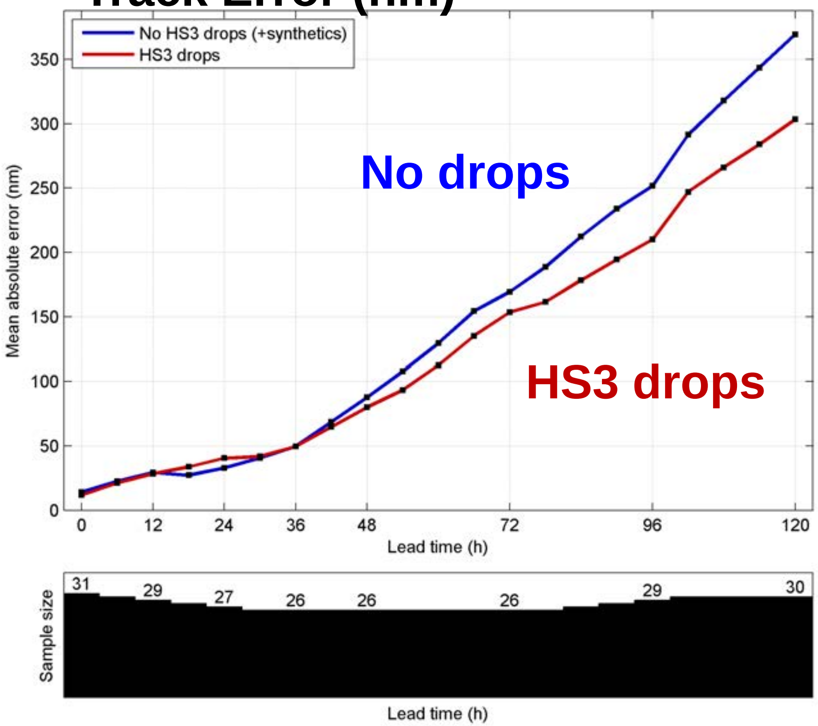
HIRAD surface wind, dropsonde wind, and radar VAD wind assimilated



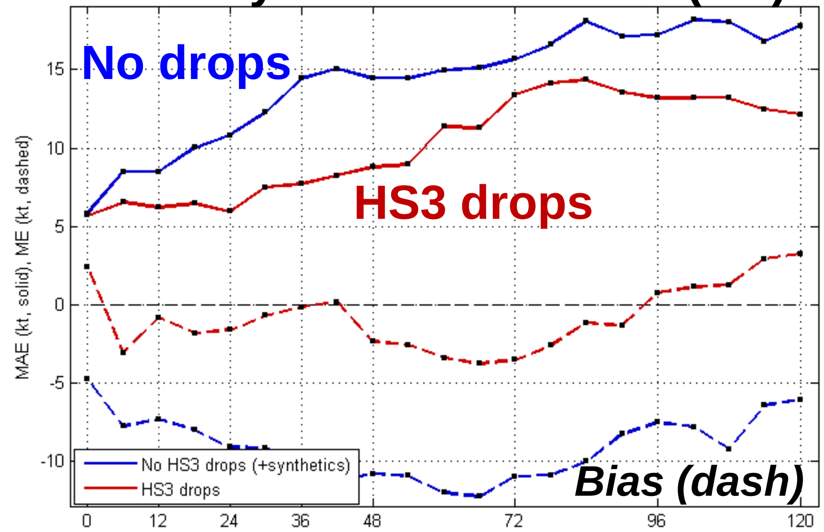
Assimilating HIRAD surface winds gives the forecast model a more realistic wind field

Impact of HS3 Dropsondes for Navy COAMPS-TC Hurricane Nadine Predictions

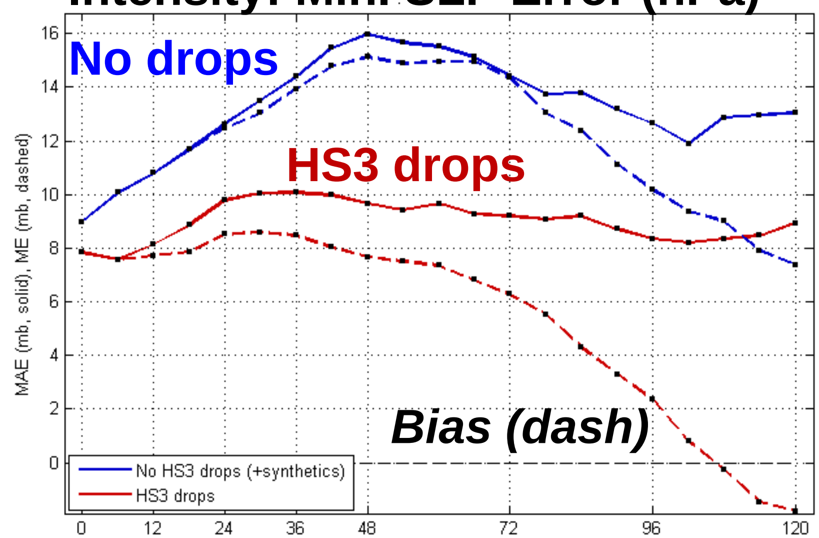
Track Error (nm)



Intensity: Max. Wind Error (kts)



Intensity: Min. SLP Error (hPa)



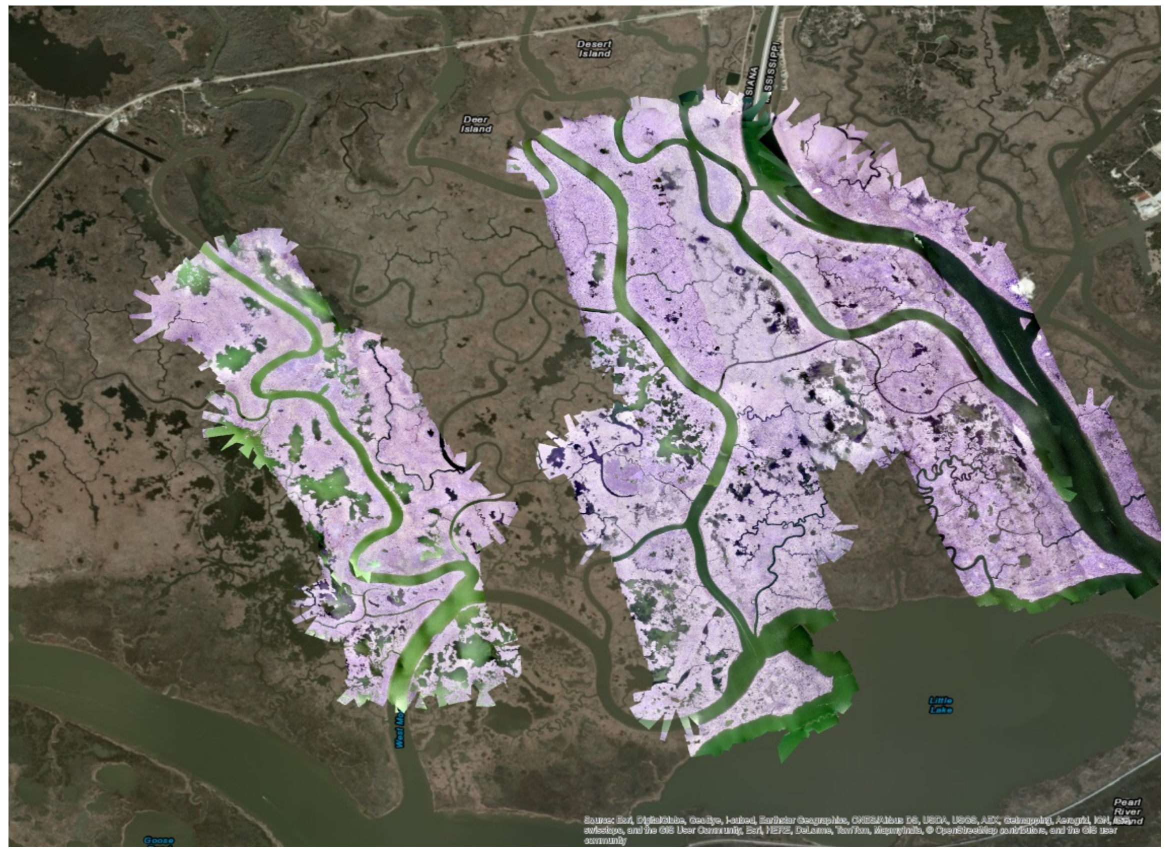
- **Dropsonde impact experiments performed for 19-28 Sep. (3 flights)**
  - **Red: with HS3 drops**
  - **Blue: No drops with synthetics**
- **COAMPS-TC Intensity and Track skill are improved greatly through assimilation of HS3 Drops.**

Slide courtesy of James Doyle / NRL

NWS River Forecast Center (RFC) and National Estuarine Research Reserve System (NERRS) Missions

Grand Bay NERR

Pearl River Coastal Watershed



Change Detection

- Blues
  - March class > December
    - Marsh Vegetation vs Marsh Water
    - Marsh Water vs Water
- Reds
  - March class < December
- White
  - No difference