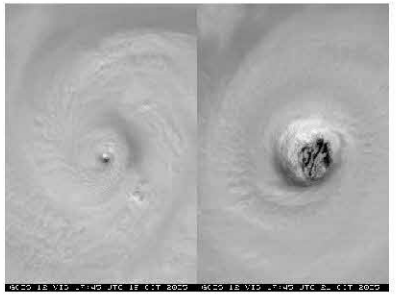
Tropical Cyclone Intensity Prediction

Mark DeMaria
NOAA/NESDIS/StAR, Fort Collins, CO

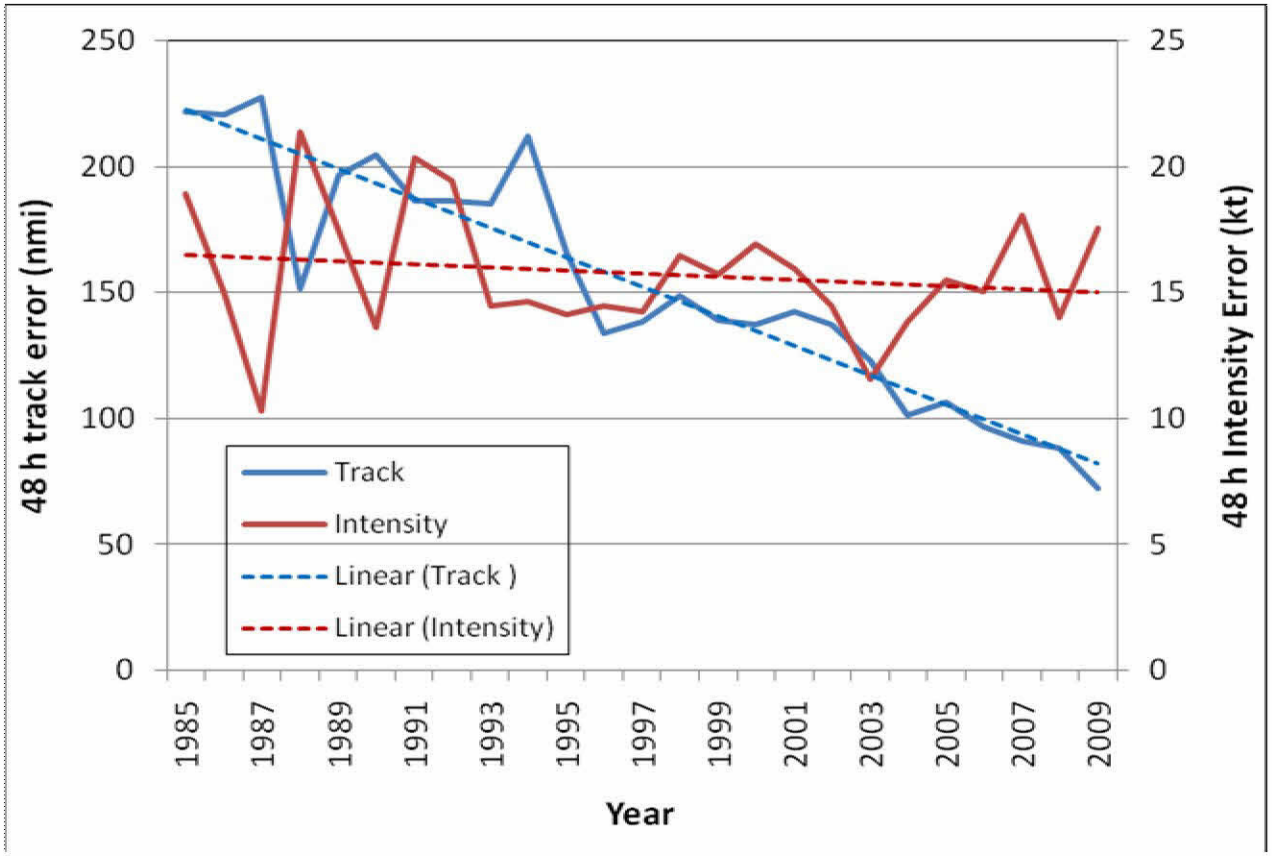
OCONUS Proving Ground Meeting
Honolulu, Hawaii
July 28-30, 2010



Outline

- Background on Tropical cyclone Intensity Forecasting
- NHC Proving Ground products
- Suggestions for additional products
  - West Pacific statistical intensity models
  - TPW input to statistical models
  - Multi-sensor, RGB and lightning products for center tracking
  - Synthetic ABI data from numerical models

NHC 48 h Atlantic Track and Intensity Errors 1985-2009



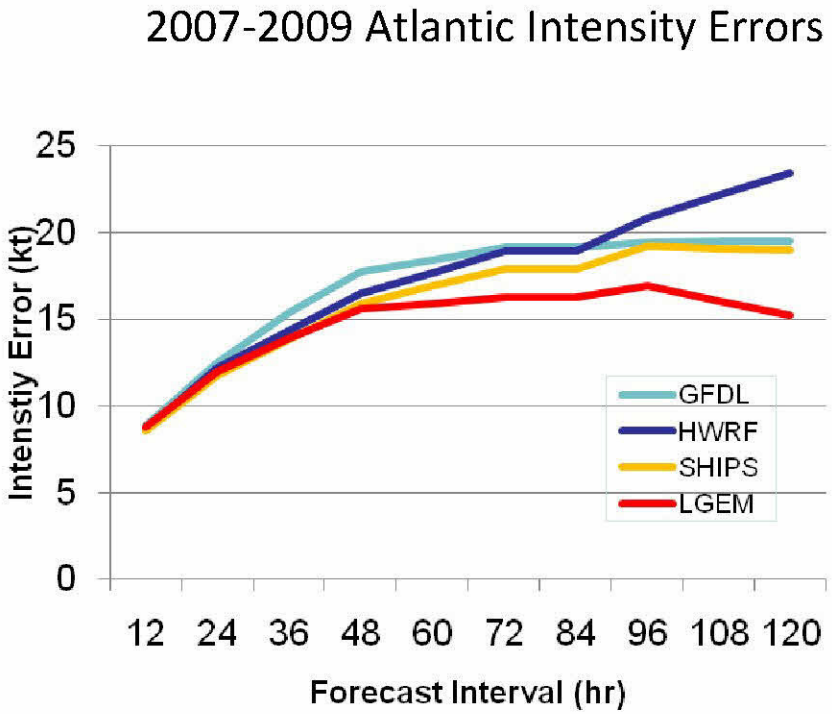
Track 63% Improvement in 24 yr

Intensity 9% Improvement in 24 yr

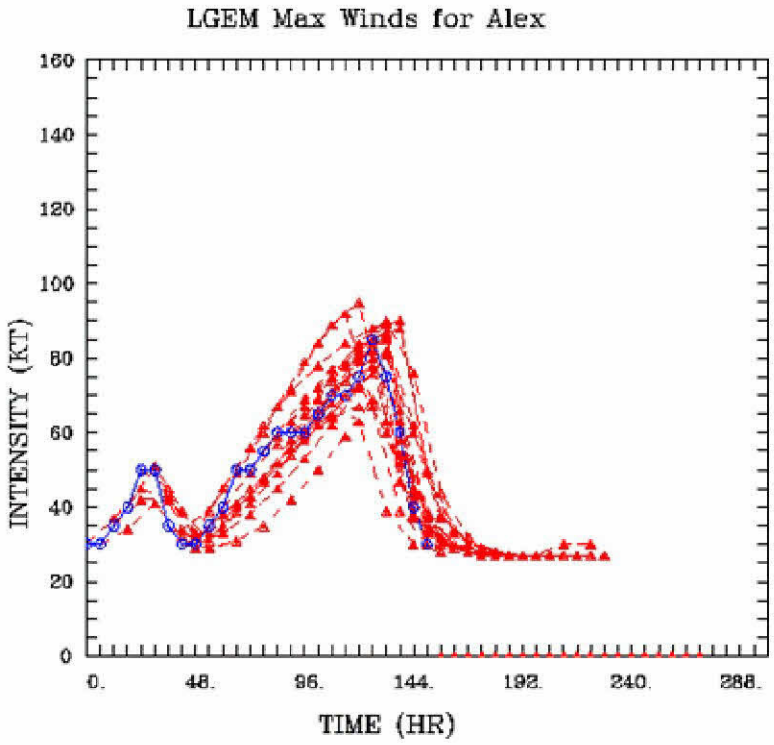
HFIP Goals: 20% in 5 yr, 50% in 10 yr

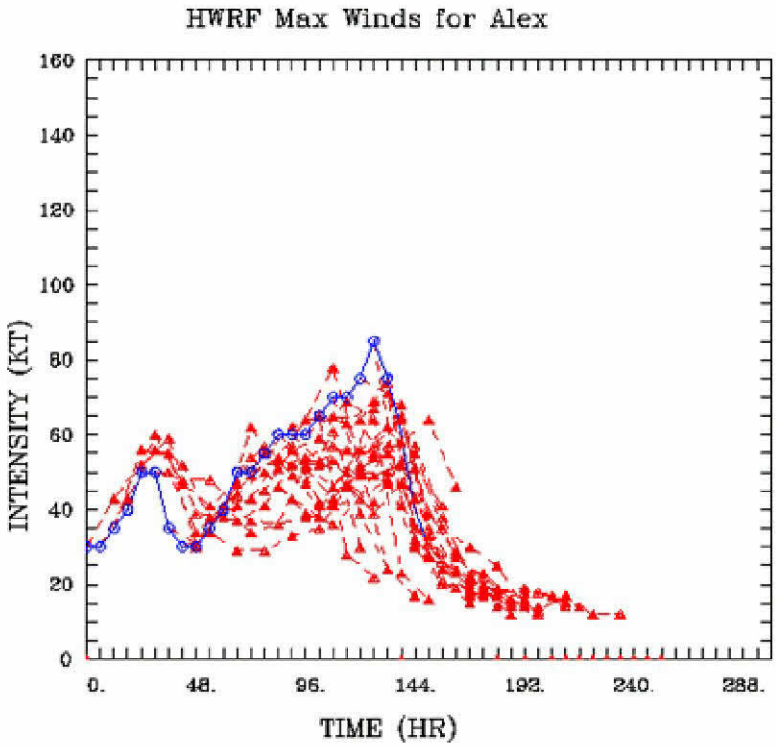
Operational Intensity Forecast Models

- GFDL and HWRF
  - 3-D coupled ocean atmosphere models
  - Since 1995 and 2007
- SHIPS and LGEM
  - Statistical-dynamical models
  - Since 1991 and 2006



LGEM and HWRF Forecasts for Hurricane Alex 2010

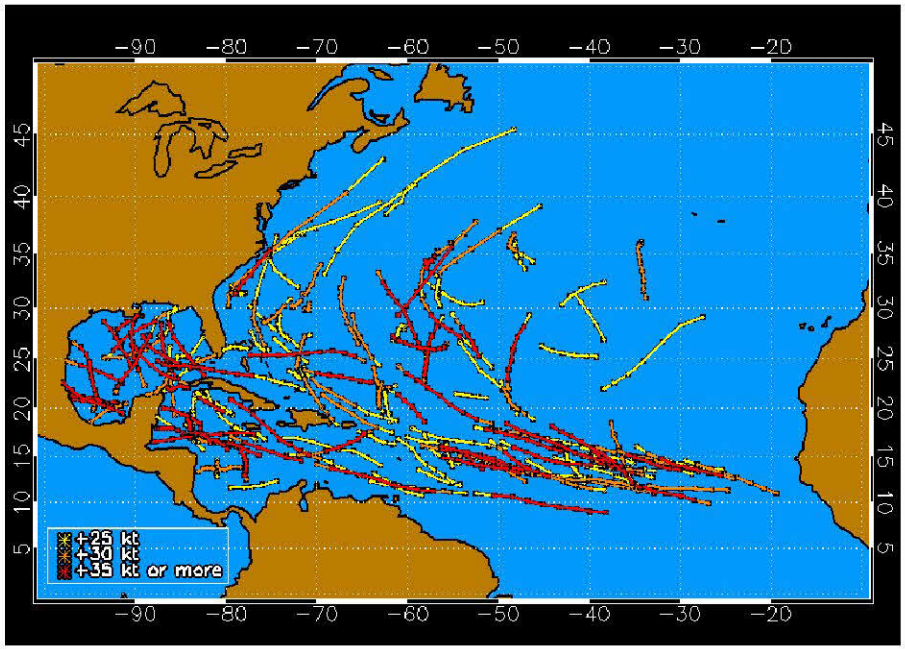


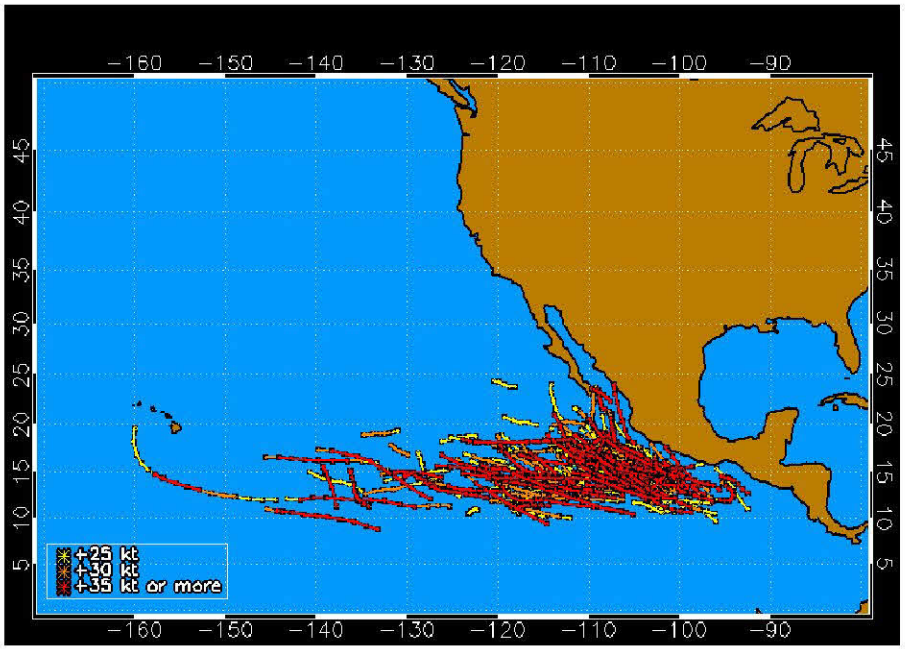


Rapid Intensification

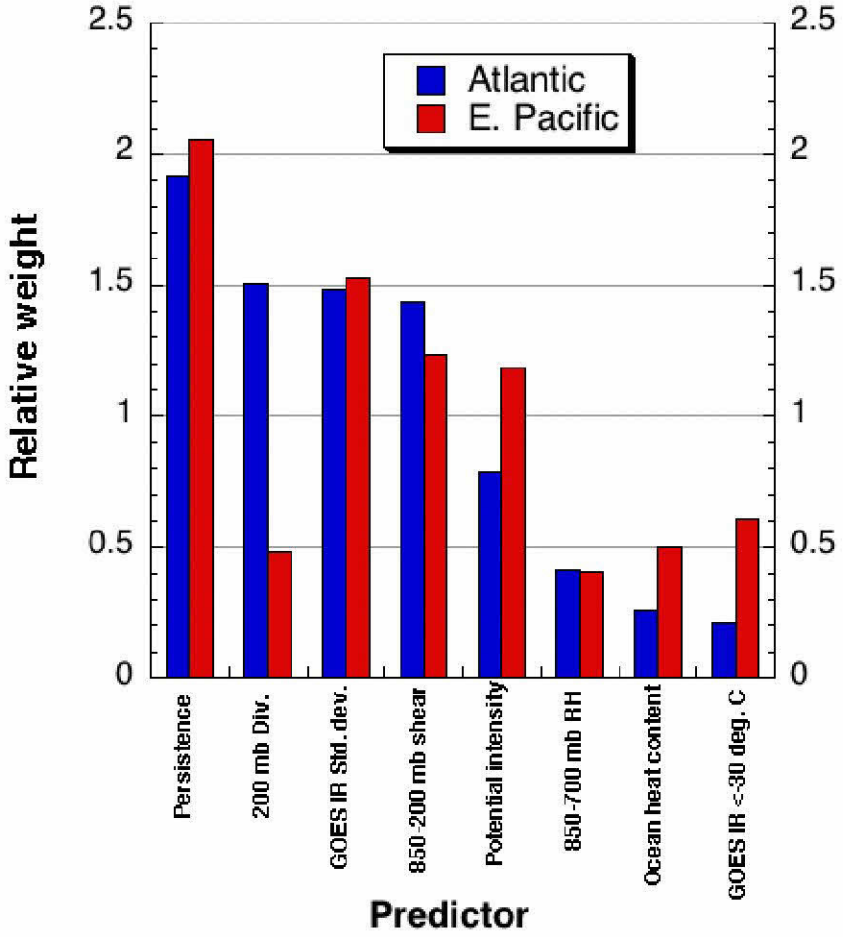
- Increase of maximum sustained winds of 30 kt or greater in 24 hour
  - ~90th percentile of Atlantic TC intensity change
- Important forecast problem
- No deterministic models do very well
- Operational Rapid Intensity Index (RII) developed to provide probabilistic RI forecast

Rapid Intensification Locations 1989-2006





RII Discriminant Analysis Weights (1995-2008 developmental sample)

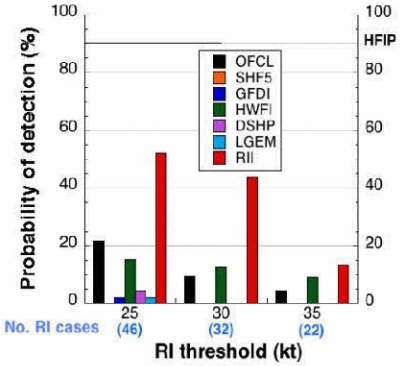


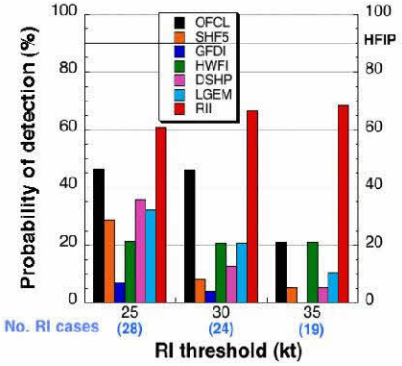
Operational Model RI performance (2008 and 2009)

Atlantic basin

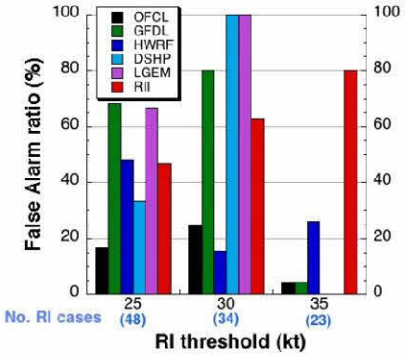
E. Pacific basin

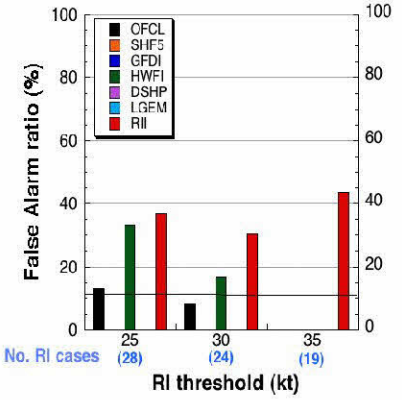
Probability of detection



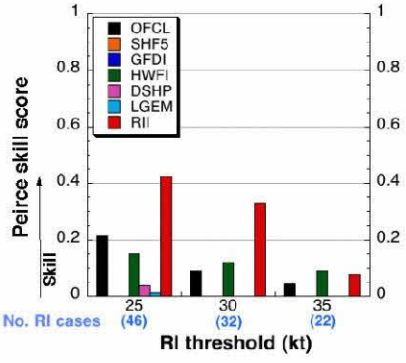


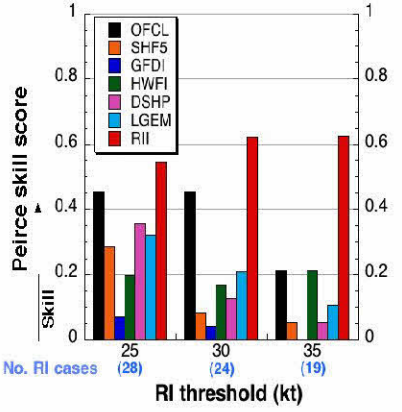
False alarm ratio





Peirce skill score





Example of Operational RII Product

```
  ** 2010 E. Pacific RI INDEX EP042010      CELIA 06/23/10  18 UTC **
         ( 30 KT OR MORE MAX WIND INCREASE IN NEXT 24 HR)

12 HR PERSISTENCE (KT):  25.0 Range:-20.0 to  35.0 Scaled/Wgted Val:  0.8/  1.7
850-200 MB SHEAR (KT) :   4.0 Range: 15.2 to   1.6 Scaled/Wgted Val:  0.8/  1.0
D200 (10**7s-1)       :  -0.2 Range:-10.0 to 129.0 Scaled/Wgted Val:  0.1/  0.1
POT = MPI-VMAX (KT)   :  50.7 Range: 44.8 to 134.3 Scaled/Wgted Val:  0.1/  0.1
850-700 MB REL HUM (%):  77.2 Range: 64.0 to  88.0 Scaled/Wgted Val:  0.6/  0.1
% area w/pixels <-30 C:  98.0 Range: 26.0 to 100.0 Scaled/Wgted Val:  1.0/  0.4
STD DEV OF IR BR TEMP :   9.4 Range: 35.4 to   2.7 Scaled/Wgted Val:  0.8/  1.2
Heat content (KJ/cm2) :  44.0 Range:  0.0 to  67.0 Scaled/Wgted Val:  0.7/  0.6

Prob of RI for 25 kt RI threshold=    42% is   3.3 times the sample mean(11.8%)
Prob of RI for 30 kt RI threshold=    40% is   5.1 times the sample mean( 8.1%)
Prob of RI for 35 kt RI threshold=    36% is   6.8 times the sample mean( 5.7%)
Prob of RI for 40 kt RI threshold=     1% is   0.3 times the sample mean( 4.1%)
```

NHC Proving Ground

Operations Plan

for the
GOES-R Proving Ground
portion of the
National Hurricane Center 2010 Hurricane Season PG Experiment

Program overview by:

John L. Beven, NOAA/NCEP/NHC
Michael Brennan, NOAA/NCEP/NHC
Renate Brummer, CIRA/CSU
Mark DeMaria, NOAA/NESDIS/STAR/RAMMB
Jason Dunion, NOAA/OAR/AOML/HRD
Jiann-Gwo Jiing, NOAA/NCEP/NHC
John Knaff, NESDIS/STAR/RAMMB
Bonnie Read, NESDIS/GPO
Christopher Velden, CIMSS/UW

Product developers contributed the material regarding their respective products.

Goals of NHC Hurricane Season PG Experiment

- Demonstrate identified GOES-R surrogate products in real-time at NHC during the 2010 hurricane season
- Ensure that NHC forecasters can use and get familiar with GOES-R surrogate products
- Evaluate products and provide valuable feedback to GOES-R Program Office

NHC Products Demonstrated

- **Official GOES-R Baseline product**
  - Hurricane Intensity Estimate (HIE) -- CIMSS

- **GOES-R Decision Aids**
  - Red-Green-Blue (RGB) Air Mass Product -- CIRA/RAMMB
  - RGB Dust Product -- CIRA/RAMMB
  - Saharan Air Layer (SAL) Product -- HRD + CIMSS
  - Super Rapid Scan Imagery – CIRA + NHC + CIMSS
  - Rapid Intensity Index (RII) -- CIRA/RAMMB

Hurricane Intensity Estimate (HIE)

{Basically, the ADT}

- **Real-time validation of GOES-R HIE during 2010 Atlantic Hurricane season**
  - **Will utilize MSG SEVERI data**
  - **Automatically initiated upon official NHC declaration of tropical cyclone event (depression or greater strength)**
  - **Utilizes current ADT version (v8.1.1 w/MW)**
  - **Estimates derived every 15 minutes until storm reaches 60°W**
  - **Real-time HIE estimates available via dedicated webpage at UW-CIMSS:**

http://cimss.ssec.wisc.edu/tropic2/real-time/adt/goesrPG/adt-PG.html

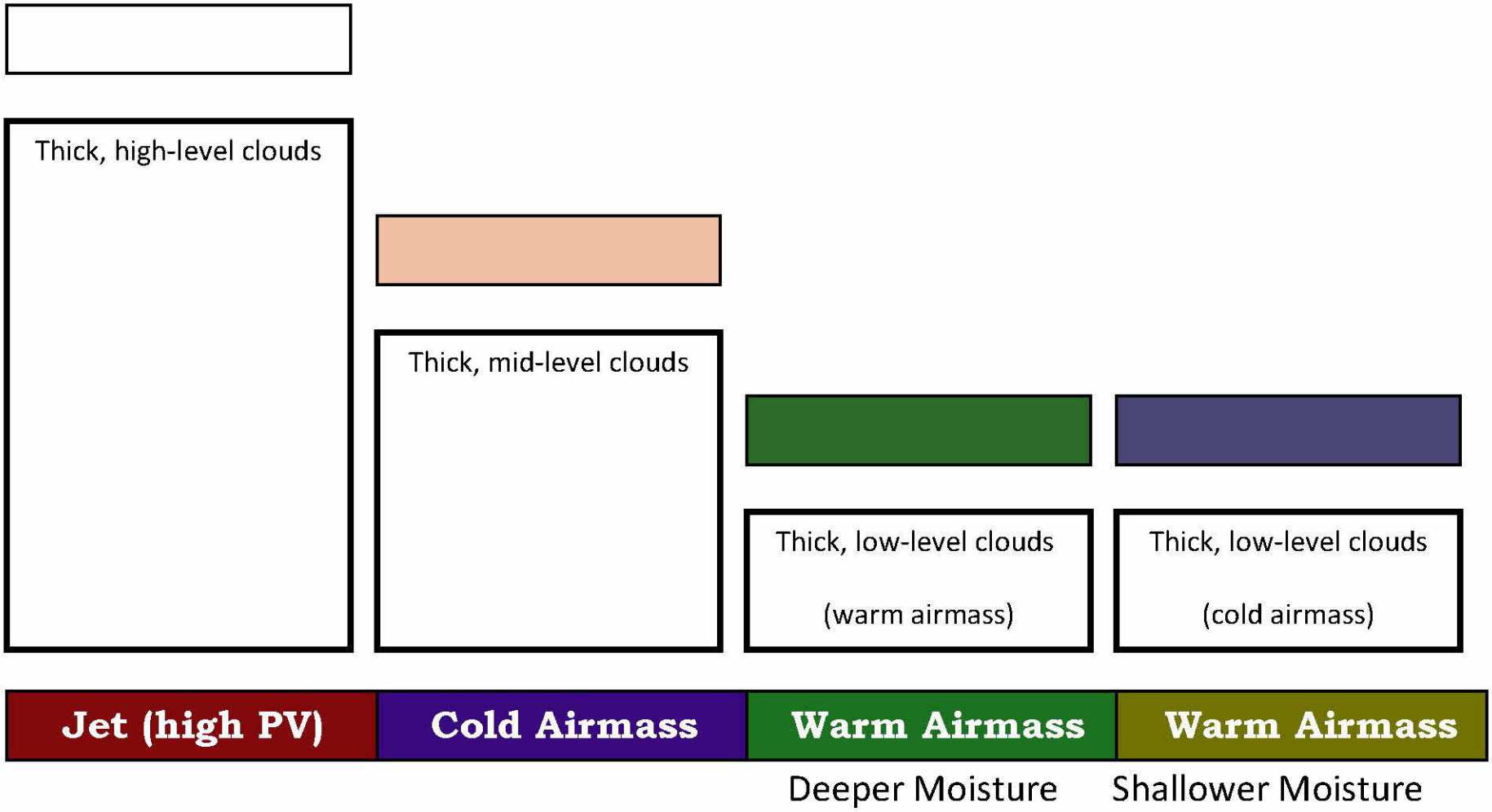
NHC Product Introduction

- Hurricane Intensity Estimate (HIE)
  - Red-Green-Blue (RGB) Air Mass Product
  - RGB Dust Product
- Saharan Air Layer (SAL) Product
- Super Rapid Scan Imagery
- Rapid Intensity Index (RII)

Red-Blue-Green (RGB)
Air Mass Product

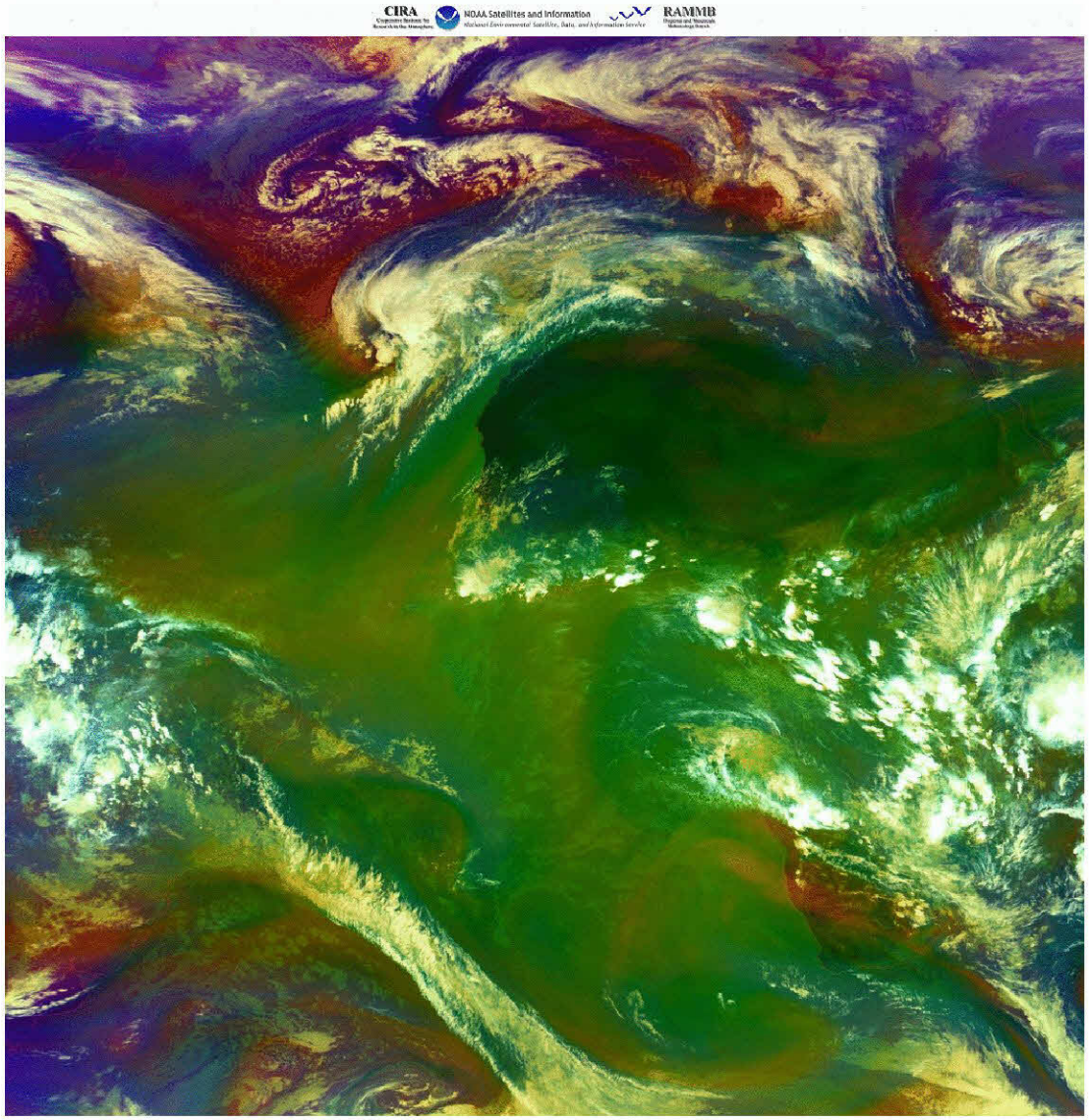
- Duplicates current EUMETSAT product
  - Can leverage their training and examples
- Combines MSG
  - Ch 5 (6.25µm), 6 (7.35µm), 8 (9.66µm), 9 (10.8µm)
  - **R = Difference WV6.25 - WV7.35 (-25 to 0 K)**
  - **G = Difference IR9.66 - IR10.8 (-40 to +5 K)**
  - **B = Channel WV6.25 (243 to 208 K)**

RGB Airmass Product
Interpretation of Colors



RGB Air Mass Product

1. Detect the position of jet streams and areas of dry descending stratospheric air with high PV (red areas)
2. Discriminate tropical air masses (i.e., rich-ozone tropical air mass vs. low-ozone polar air mass)
3. Discriminates subtropical air masses (dryer subtropics vs. moister tropics)
4. Detect typical WV features like cold lows, deformation zones and wave features
5. Clouds heights can also be inferred by brightness



More Information from EUMESAT:

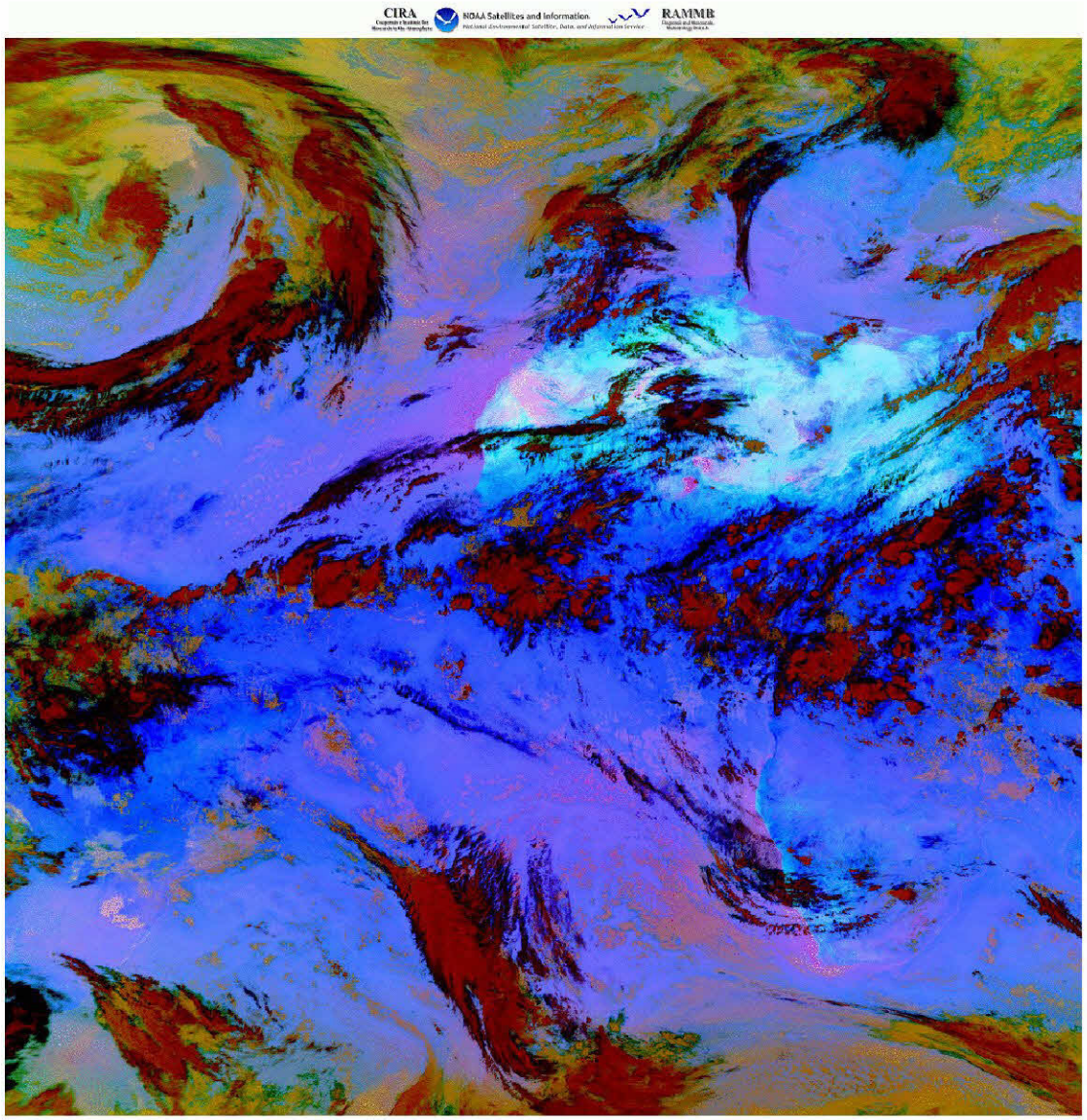
http://oiswww.eumetsat.org/IPPS/html/MSG/RGB/AIRMASS/

Red-Blue-Green (RGB)
Dust Product

- Duplicates current EUMETSAT product
  - Can leverage their training and examples
- Combines MSG
  - Ch 7 (8.7µm), 8 (9.66µm), 9 (10.8µm), 10 (12.0µm)
  - **R = Difference IR10.8 – IR12.0 (-2 to 4 K)**
  - **G = Difference IR10.8- IR8.7 (0 to +15 K, γ=2.5)**
  - **B = Channel IR10.8 (261 to 289 K)**

RGB Dust Product

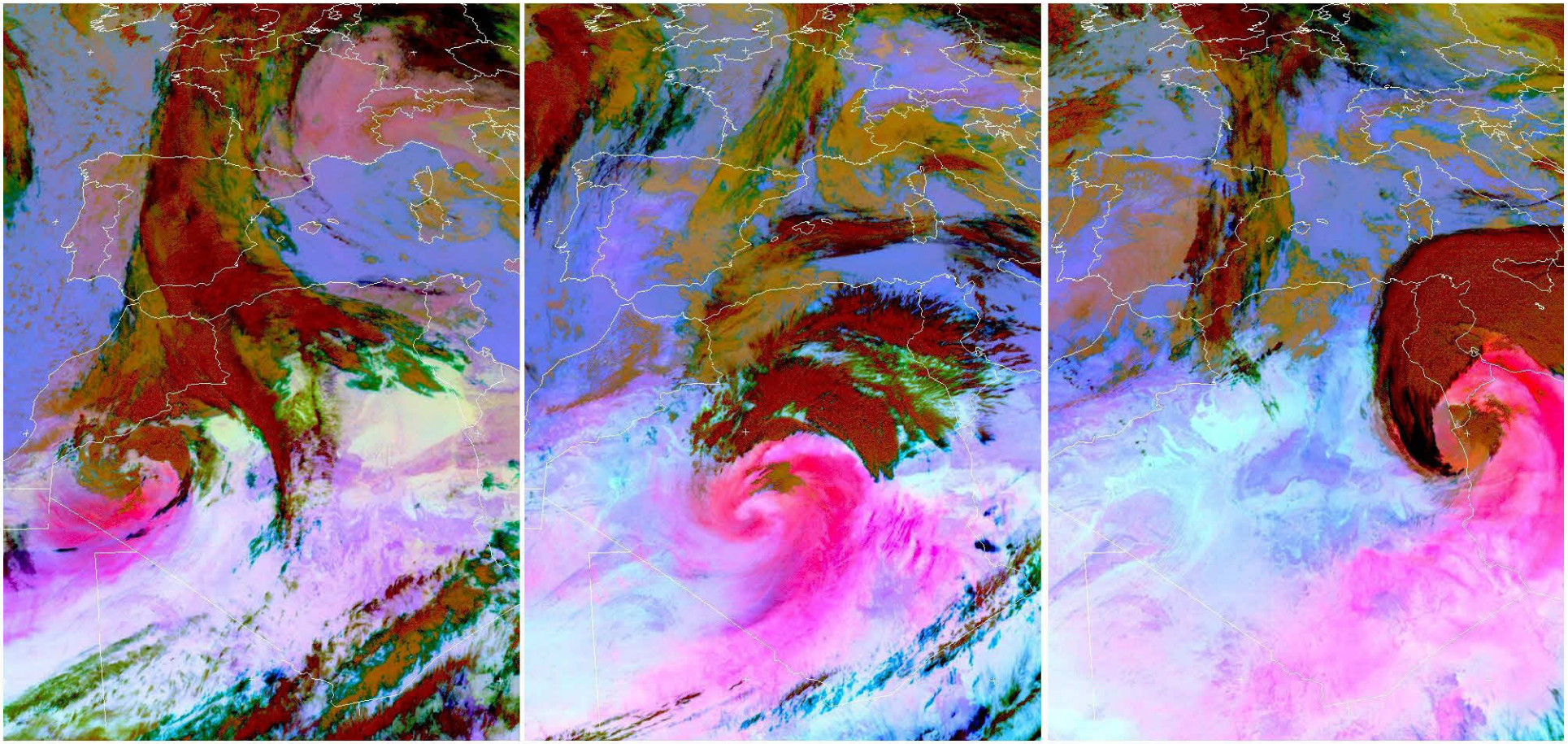
1. Dust appears as purple, pink or magenta
2. Generally thicker dust clouds appear as dark magenta or purple
3. Animation helps to confirm moving features



More information from EUMETSAT:

http://oiswww.eumetsat.org/IPPS/html/MSG/RGB/DUST/

RGB Dust Product Example: Day



20 Feb 18:00 UTC 21 Feb 12:00 UTC 22 Feb 12:00 UTC

NHC Product Introduction

- Hurricane Intensity Estimate (HIE)
- Red-Green-Blue (RGB) Air Mass Product
- RGB Dust Product
- ➢ Saharan Air Layer (SAL) Product
- Super Rapid Scan Imagery
- Rapid Intensity Index (RII)

Split Window SAL Tracking Satellite Imagery

- Split window (12-11 µm) imagery used for detecting dry and/or dusty air in the lower to middle levels of the atmosphere

- Product Utility:

  -Monitoring synoptic-scale interactions between dry layers (e.g., the Saharan Air Layer) and tropical cyclones

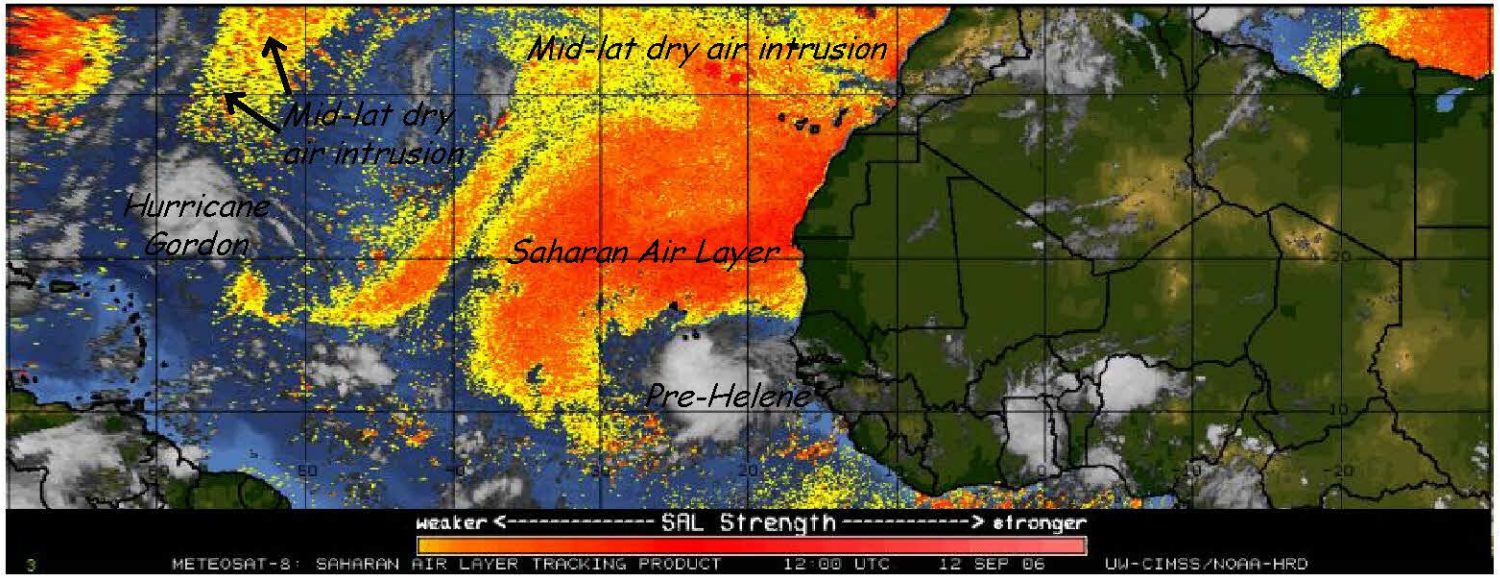
  -Monitoring large-scale movements of mid-latitude dry air intrusions and Saharan Air Layer outbreaks that routinely impact local weather in the tropical North Atlantic

- Current GOES & METEOSAT algorithm uses pixel value (0-255) differencing of the split window channels

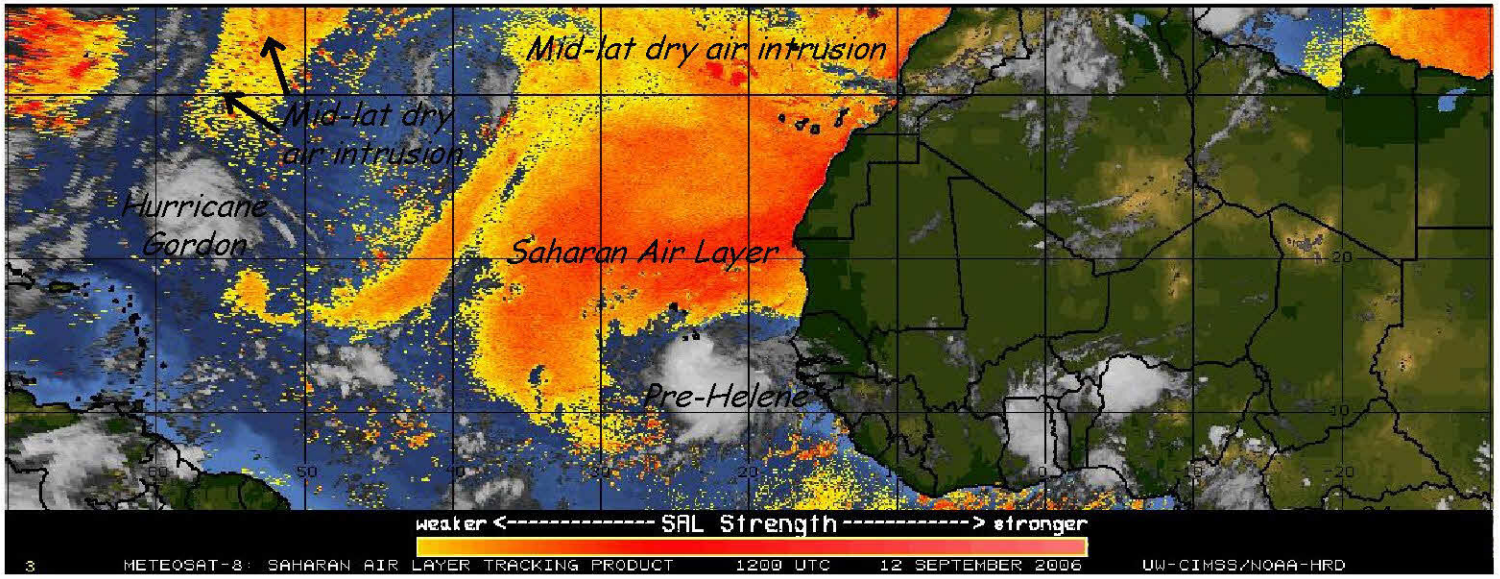
- Experimental version uses brightness temperature (K) differencing of the split window channels and provides ~5x more horizontal gradient information

Split Window SAL Tracking Satellite Imagery (Meteosat)

Current *pixel value* split window algorithm

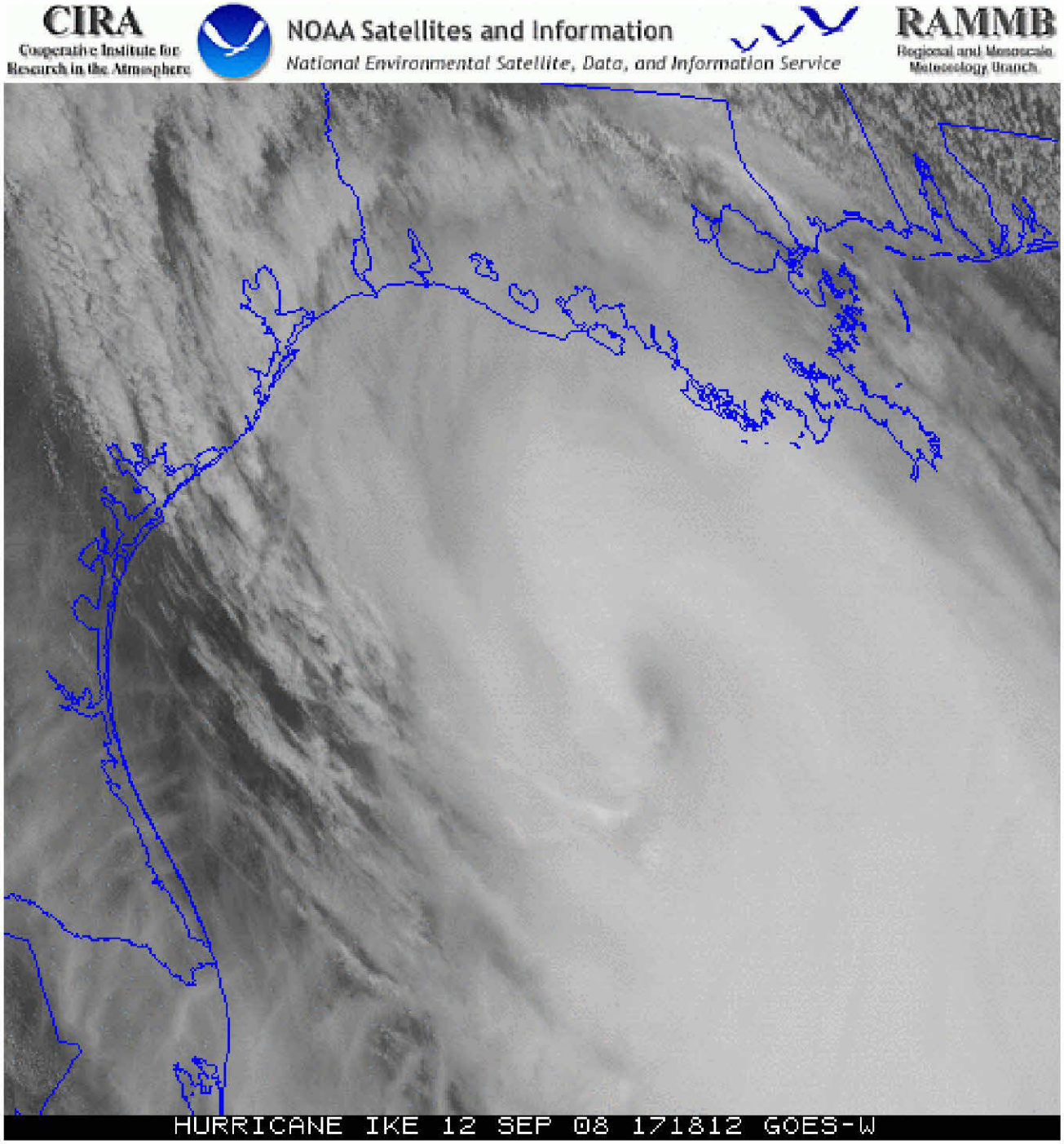


Experimental *brightness temperature* split window algorithm



NHC Product Introduction

- Hurricane Intensity Estimate (HIE)
- Red-Green-Blue (RGB) Air Mass Product
- RGB Dust Product
- Saharan Air Layer (SAL) Product
- **Super Rapid Scan Imagery**
- Rapid Intensity Index (RII)



Super Rapid Scan Imagery

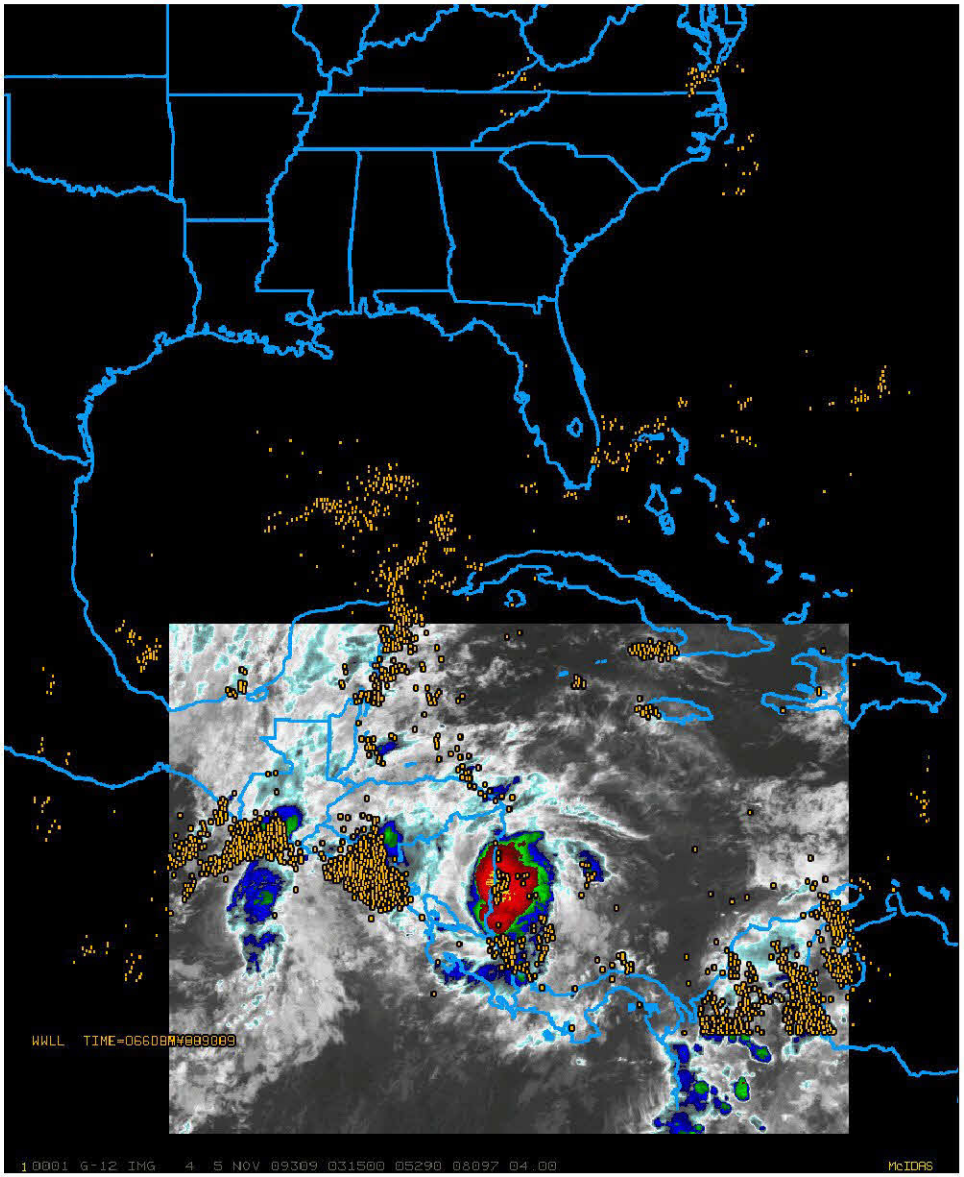
Hurricane Ike
12 September 2008
1718 UTC to 2250 UTC

NHC Product Introduction

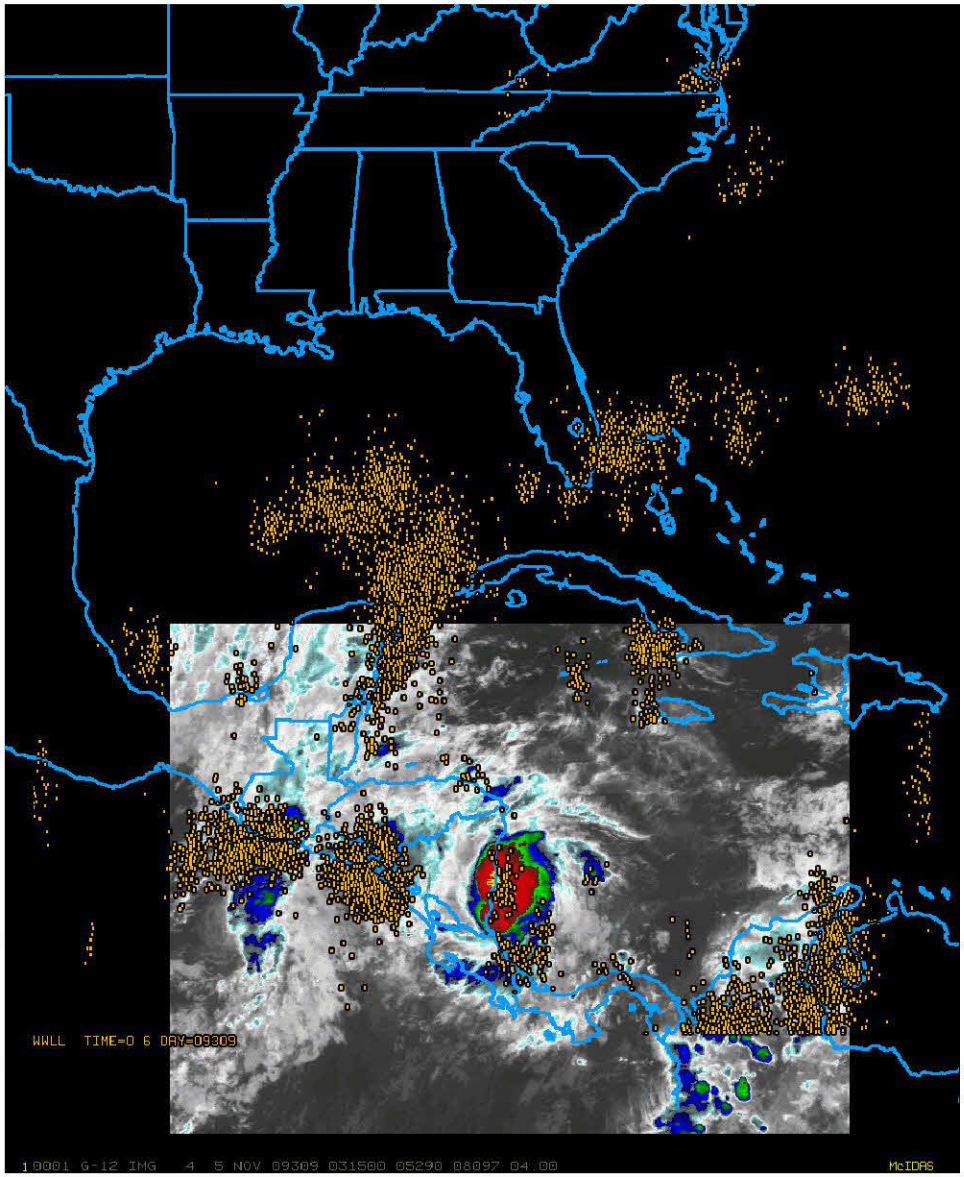
- Hurricane Intensity Estimate (HIE)
- Red-Green-Blue (RGB) Air Mass Product
- RGB Dust Product
- Saharan Air Layer (SAL) Product
- Super Rapid Scan Imagery
- **Rapid Intensity Index (RII)**

Lightning-Based Tropical Cyclone Rapid Intensity Index (RII)

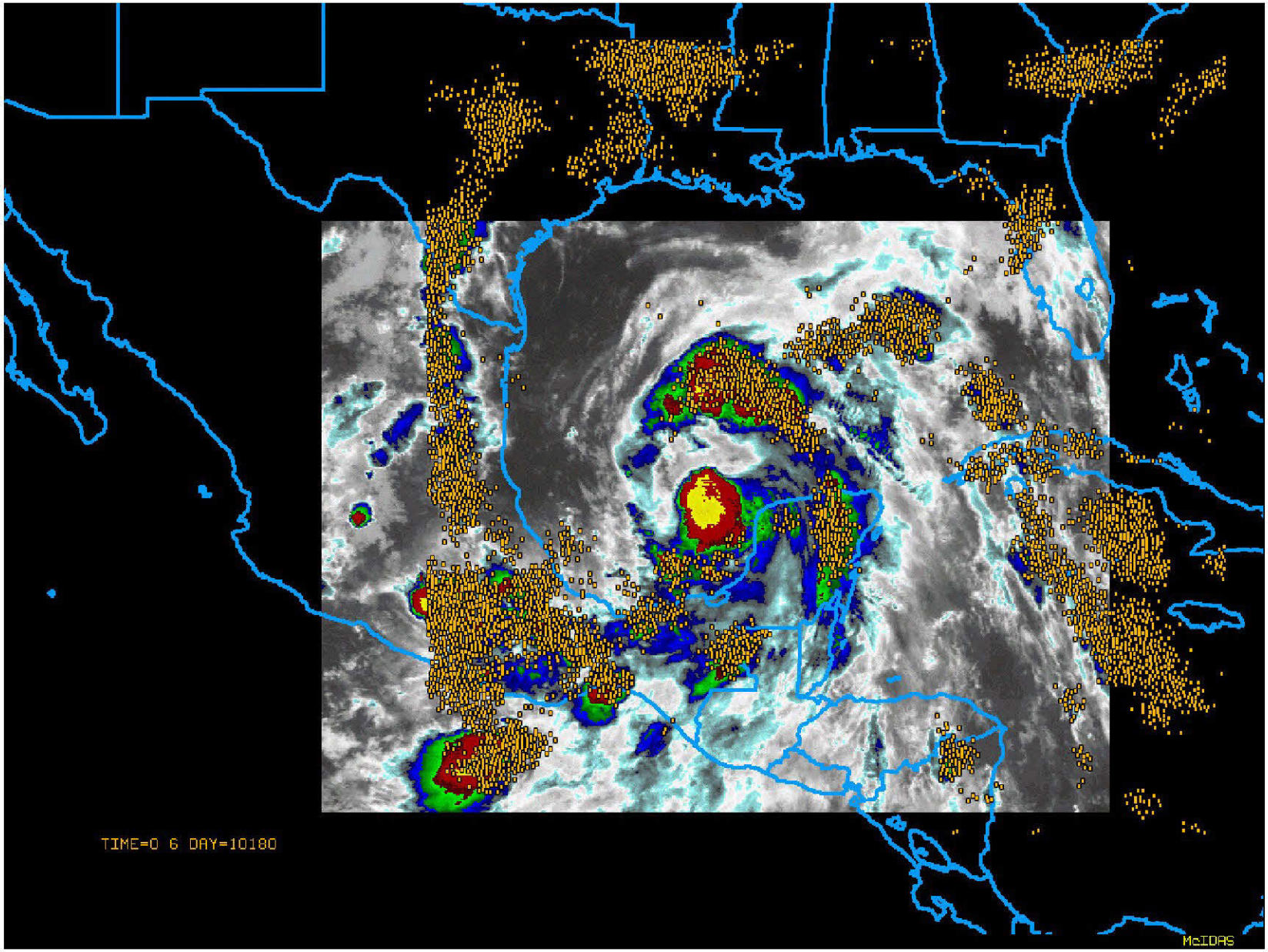
- Ground-based lightning data used as a proxy for GOES-R GLM
- NHC real-time rapid intensity index (RII)
  - Input from GFS model, GOES imagery, oceanic heat content analyses, Reynolds SST, persistence
  - Discriminant analysis provides probability of max wind increase of at least 30 kt in 24 hr
- Experimental version adds lightning density input
  - 6 hr storm-relative composites
  - 2005-2009 developmental sample from WWLLN
  - Real time in 2010 from Vaisala GLD360 feed at CIRA
  - Text product distributed from CIRA
  - Analogous to text product for operational RII



WWLLN



VAISALA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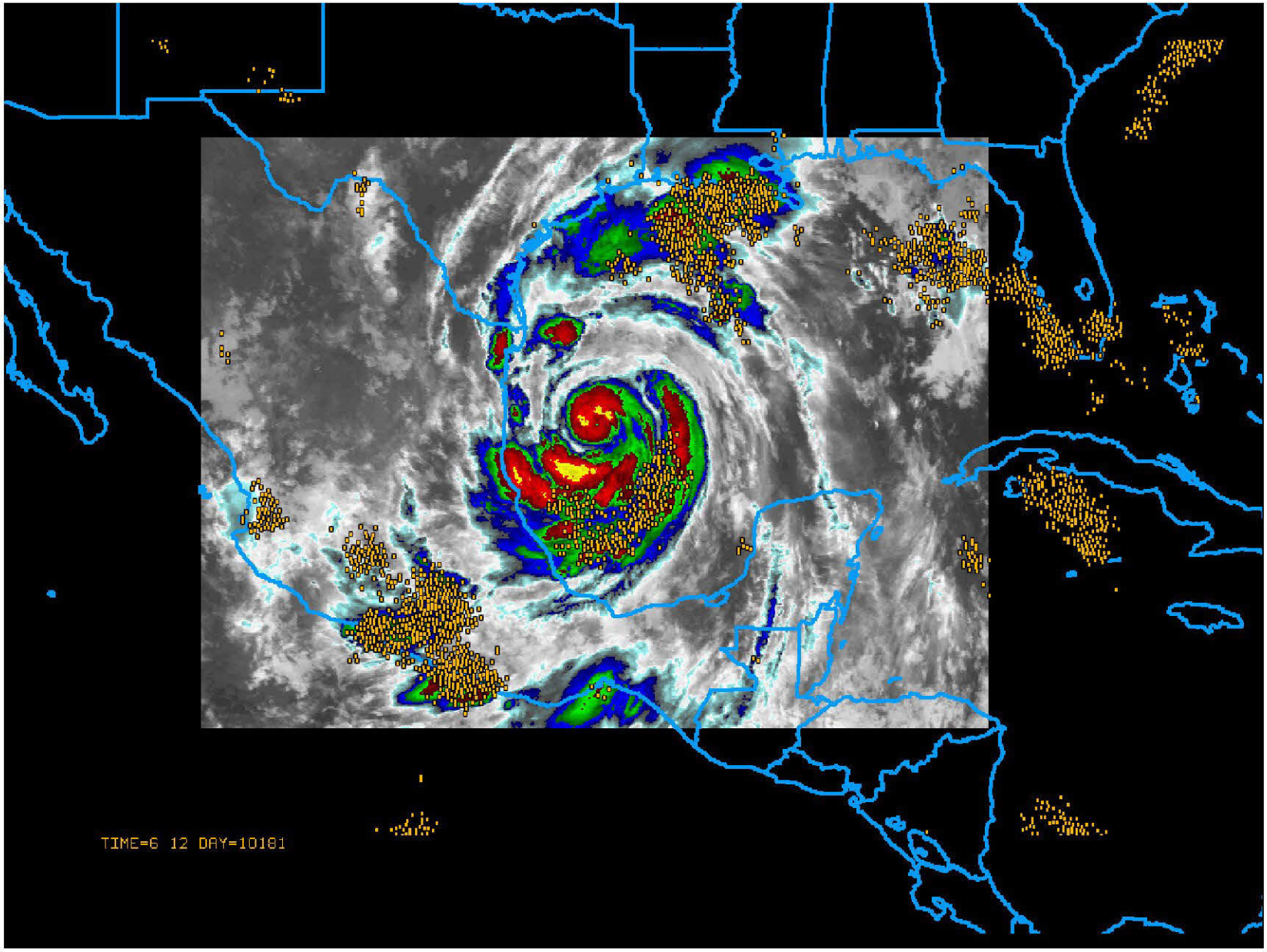
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```
                  *   ATLC RAPID INTENSITY INDEX TESTS        *
                  *      GOES DATA AVAILABLE                  *
                  *      OHC  DATA AVAILABLE                  *
                  *  AL01        AL012010  06/30/10  00 UTC   *

++++++++ SECTION 1, COPY OF OPERATIONAL RII ++++++++

   ** 2010 ATLANTIC RI INDEX AL012010 AL01       06/30/10  00 UTC **
         ( 30 KT OR MORE MAX WIND INCREASE IN NEXT 24 HR)

 12 HR PERSISTENCE (KT):   5.0 Range:-45.0 to  30.0 Scaled/Wgted Val:  0.7/  1.4
 850-200 MB SHEAR (KT) :   6.5 Range: 26.2 to   3.2 Scaled/Wgted Val:  0.9/  1.0
 D200 (10**7s-1)       :  61.0 Range:-21.0 to 140.0 Scaled/Wgted Val:  0.5/  0.7
 POT = MPI-VMAX (KT)   :  69.0 Range: 33.5 to 125.5 Scaled/Wgted Val:  0.4/  0.3
 850-700 MB REL HUM (%):  81.8 Range: 56.0 to  85.0 Scaled/Wgted Val:  0.9/  0.5
 % area w/pixels <-30 C:  92.0 Range: 17.0 to 100.0 Scaled/Wgted Val:  0.9/  0.1
 STD DEV OF IR BR TEMP :  10.9 Range: 30.6 to   3.2 Scaled/Wgted Val:  0.7/  1.2
 Heat content (KJ/cm2) :  44.6 Range:  0.0 to 130.0 Scaled/Wgted Val:  0.3/  0.0

 Prob of RI for 25 kt RI threshold=    44% is   3.5 times the sample mean(12.6%)
 Prob of RI for 30 kt RI threshold=    33% is   4.1 times the sample mean( 8.1%)
 Prob of RI for 35 kt RI threshold=    21% is   4.1 times the sample mean( 4.8%)
 Prob of RI for 40 kt RI threshold=    20% is   6.4 times the sample mean( 3.4%)

++++++++ SECTION 2, RII WITH LIGHTNING DATA ++++++++
                  FOR GOES-R PROVING GROUND

AL01       Initial vmax, lat, lon:    65.   23.0   -94.4

 Prob of RI for 30 kt RI threshold=    28%,  no lightning input, exper. algorithm
 Prob of RI for 30 kt RI threshold=    33%, with lightning input, exper. algorithm

Recent Lightning Density History  (Strikes/km2-year)
Date/Time    Inner core (0-100 km)  Rainband (300-400 km)
10 0630 00      0.5                    40.7
10 0629 18      2.0                     4.5
10 0629 12      0.0                    15.4
10 0629 06      0.0                    53.7
10 0629 00      0.0                    80.0
10 0628 18      0.0                     2.0
10 0628 12      2.5                     0.5
10 0628 06      5.3                     0.6
10 0628 00      0.0                     2.3
10 0627 18      0.0                     9.9
10 0627 12      0.0                    12.3
10 0627 06      0.0                    15.7
10 0627 00     47.2                    82.1

Sample mean:  21.5                    14.7

 Note: Inner core lightning <  sample mean favors RI
       Rainband lightning   >  sample mean favors RI
```

Sample Text Output

Lightning-Based Rapid Intensity Forecast Algorithm

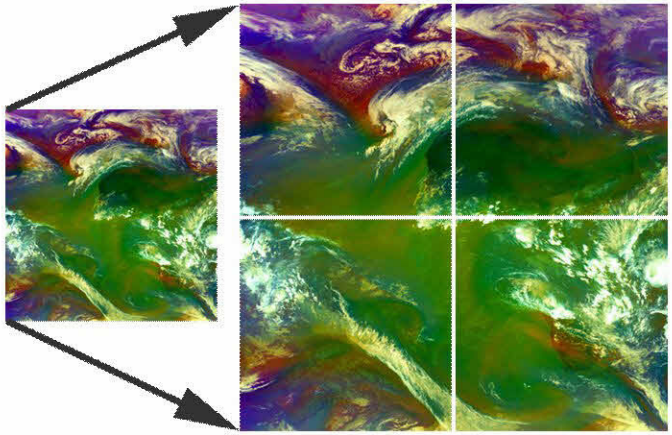
Hurricane Alex
30 June 2010 00 UTC

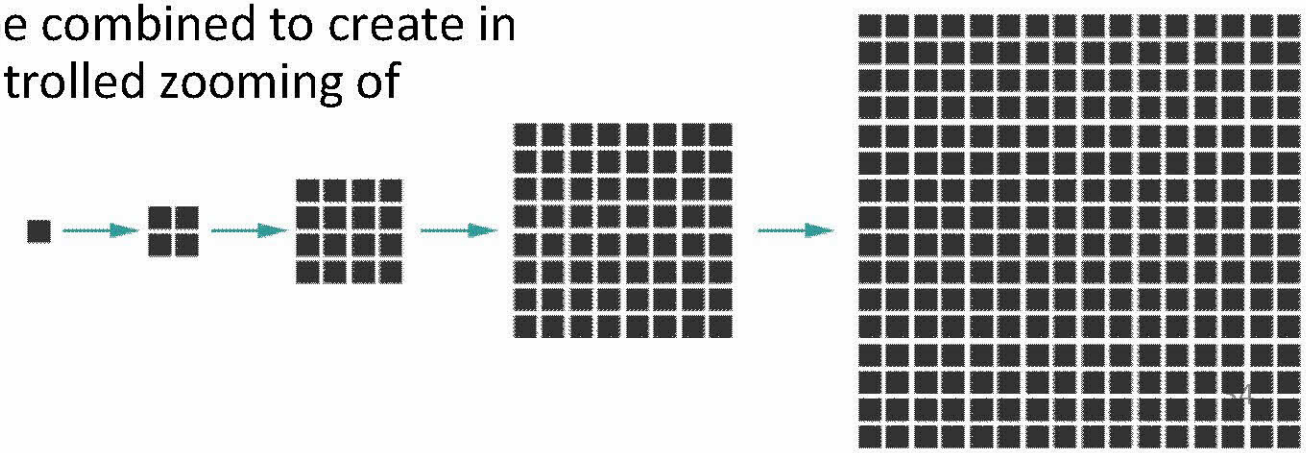
NHC Proving Ground Product Demonstrations

- HIE → Web
- RGB Air Mass → GoogleEarth
- RGB Dust → GoogleEarth
- SAL → GoogleEarth
- SRSO → NAWIPS and Web
- RII → Web

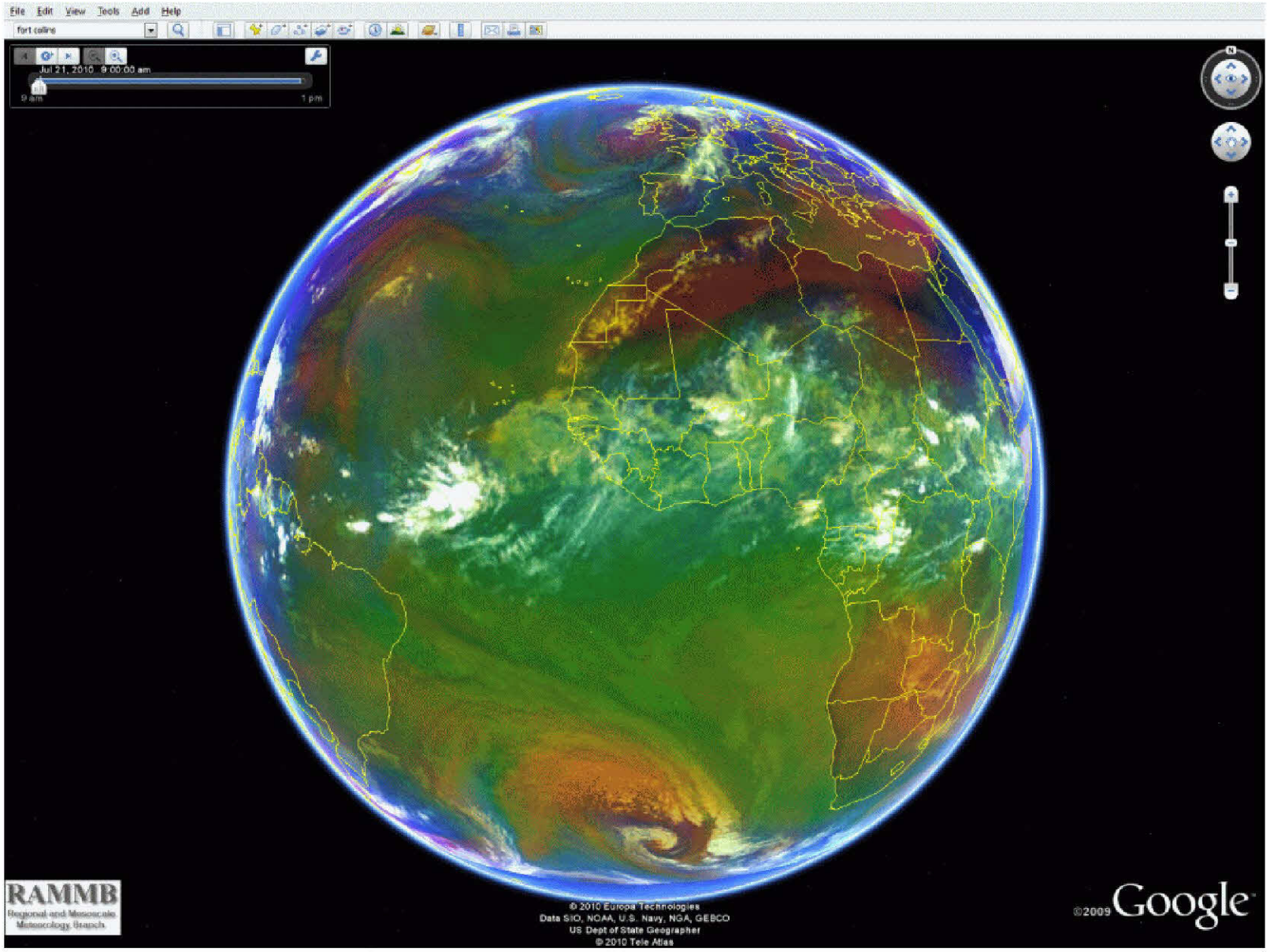
Tiling or "Super-Overlays"

- Cut original hi-res image into four "tiles"
- Resample hi-res original image to make file size smaller.
- Google Earth only downloads tiles defined at current zoom-level, reducing necessary data transfer.
- E.g., for a 4096 x 4096 pixel image:
  - Tile size = 256 x 256 pixels (for small file size), and 5 separate zoom levels of tiles
  - 341 image tiles in total per original image, each re-sampled to 256 x 256 pixels.
- Time and tiling can be combined to create in KML 2.2 via user-controlled zooming of image loops.





POC: Kevin Micke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Regional and Mesoscale Meteorology Branch
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US Dept of State Geographer
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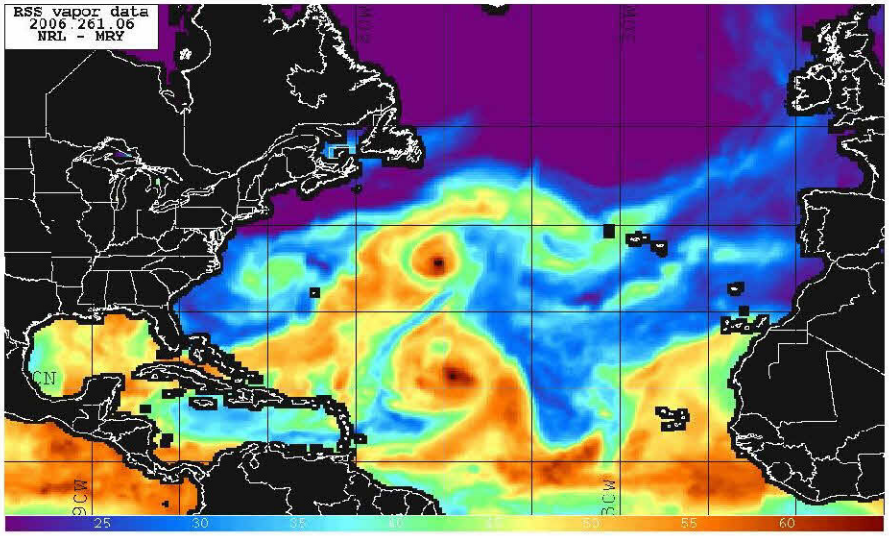
Possible Additional TC Products

- West Pacific statistical intensity models
- TPW input to statistical models
- Multi-sensor products for center tracking
- Multi-platform storm structure analysis
- Synthetic ABI data from numerical models

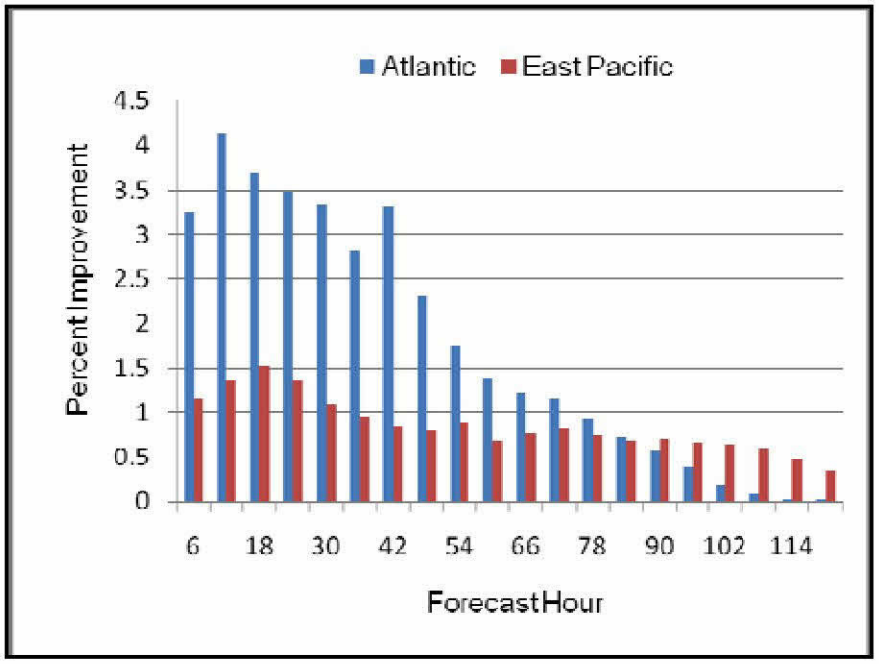
West Pacific Statistical Intensity Models

- STIPS model is analogous to SHIPS for the Atlantic and east Pacific
- No LGEM or Rapid Intensity Index
  - Both under development at CIRA with NOPP/HFIP funding
  - Could be a framework for adding lightning and TPW data

TPW Input to Statistical Intensity Models



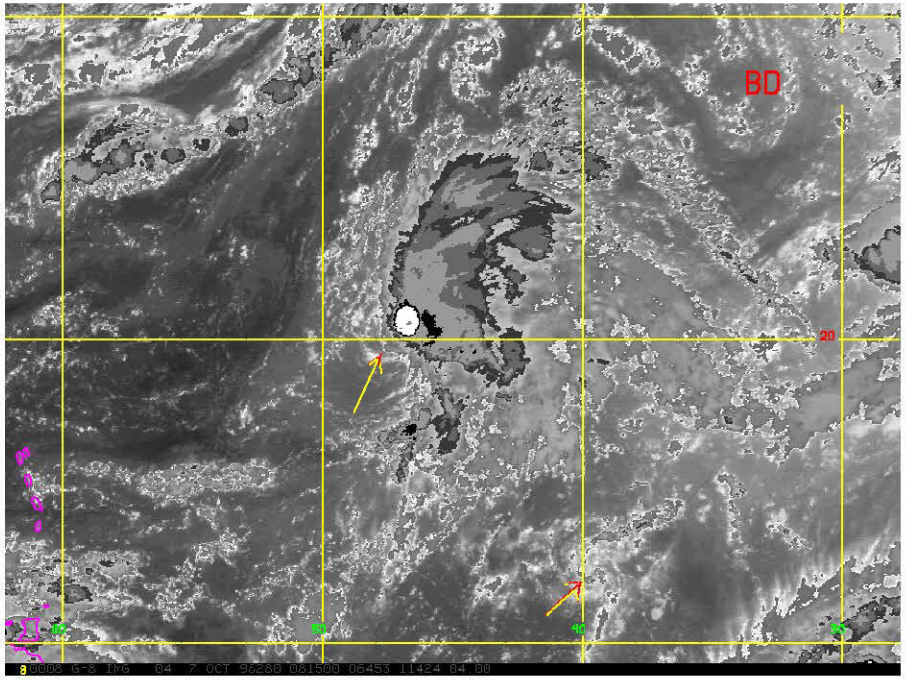
Blended TPW product



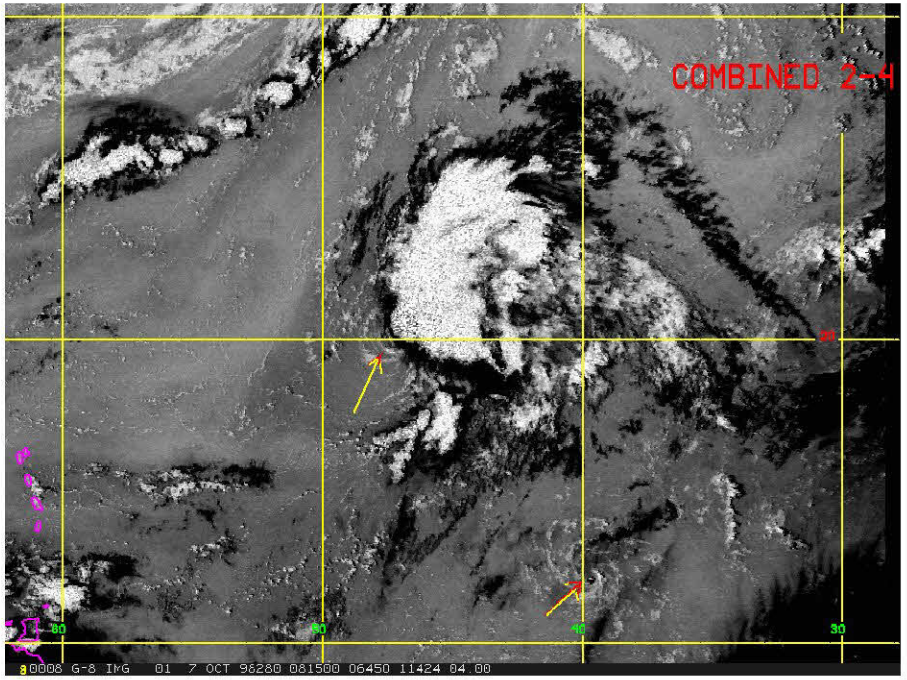
Percent Improvement in Dependent SHIPS model forecasts with TPW and lightning input

From Knaff et al., 2010, AMS Tropical Conference

Multi-Spectral Imagery for Center Fixing



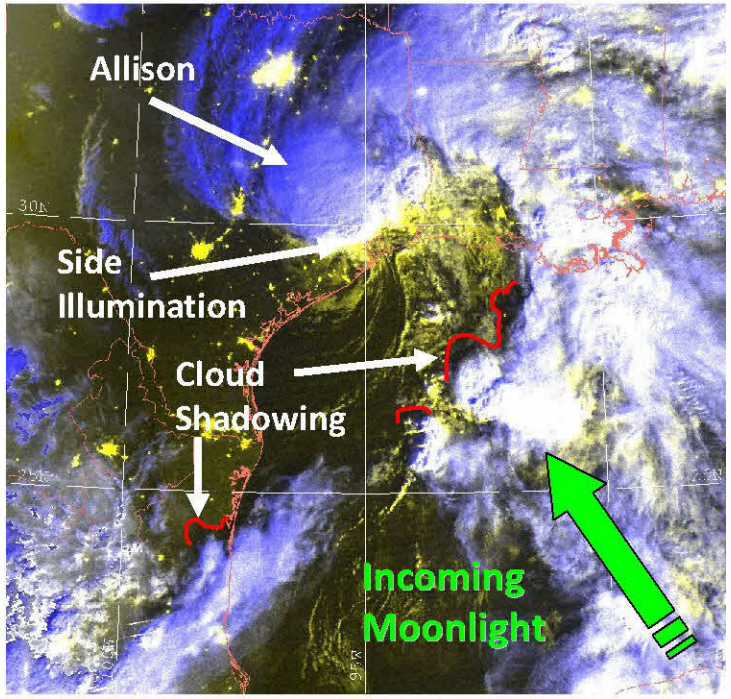
GOES Channel 4



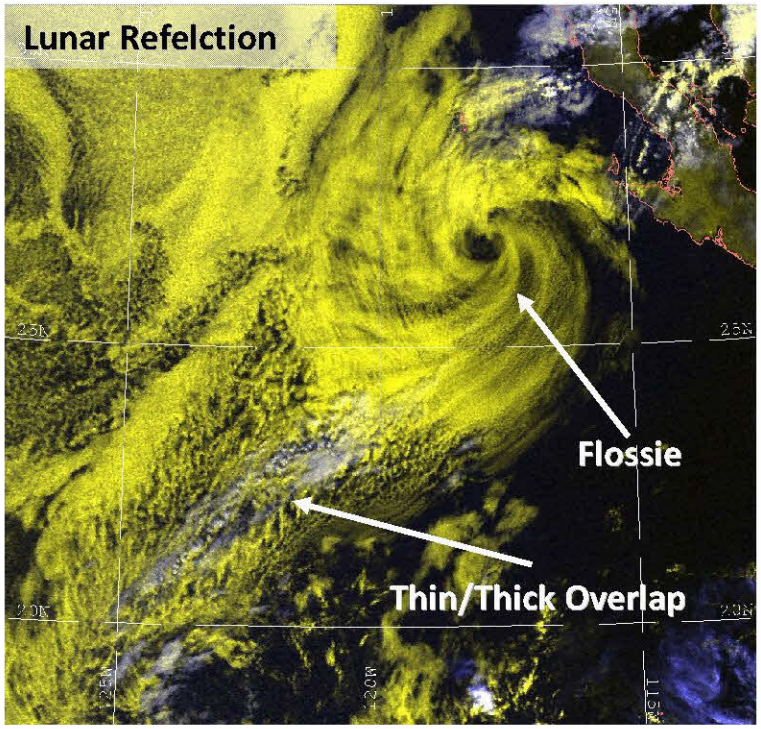
Combined Channel 2 and 4

- Many more possibilities with ABI
- Use principal component analysis to guide RGB recipes

Multi-Platform Center Fixing Incorporation of Night-time "Vis"



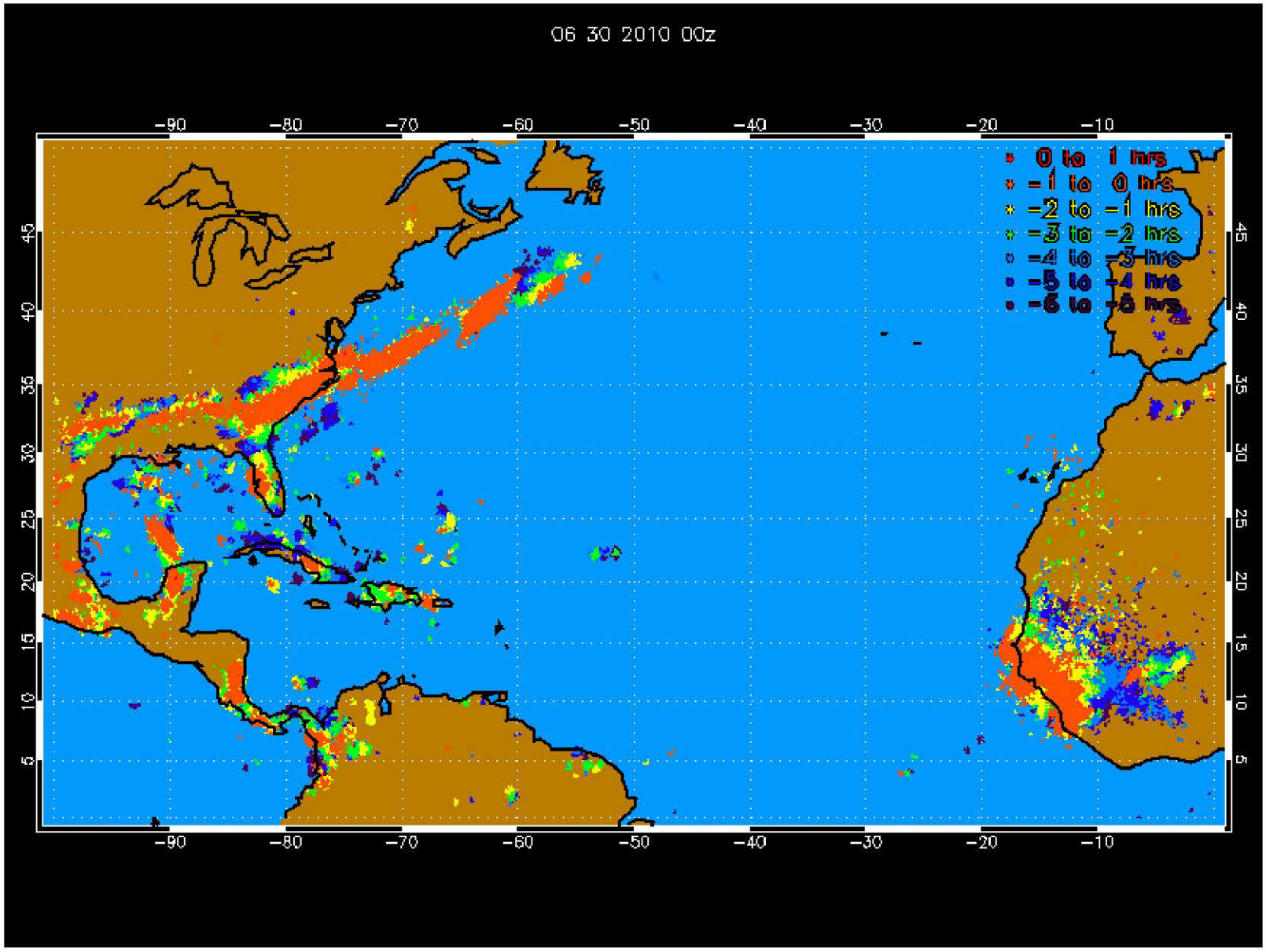
Cloud heights can be derived from lunar shadows and viewing geometry in a way equivalent to thedaytime approach (e.g., Prata and Grant, CSIRO Tech Rep. 2001).



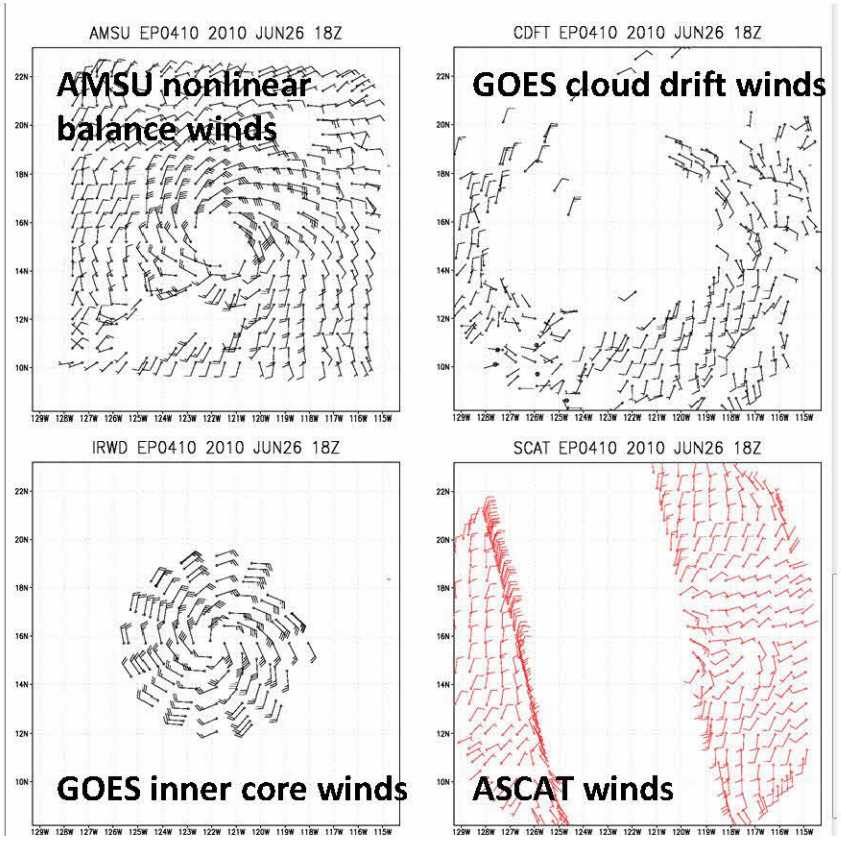
Thin-over-Thick Cloud overlap detection (e.g., Pavolonis and Heidinger, JAM 2004) can be applied to lunar reflection and split-window observations.

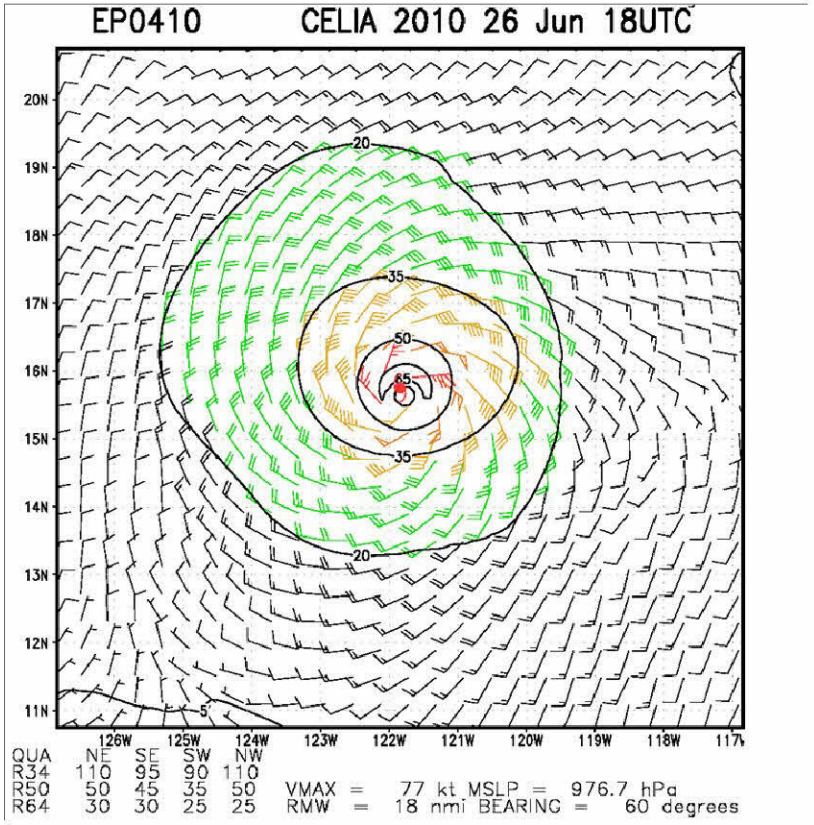
Slide courtesy of Steve Miller, CIRA

Lightning Time History Provides Information on Mesoscale System Location and Motion



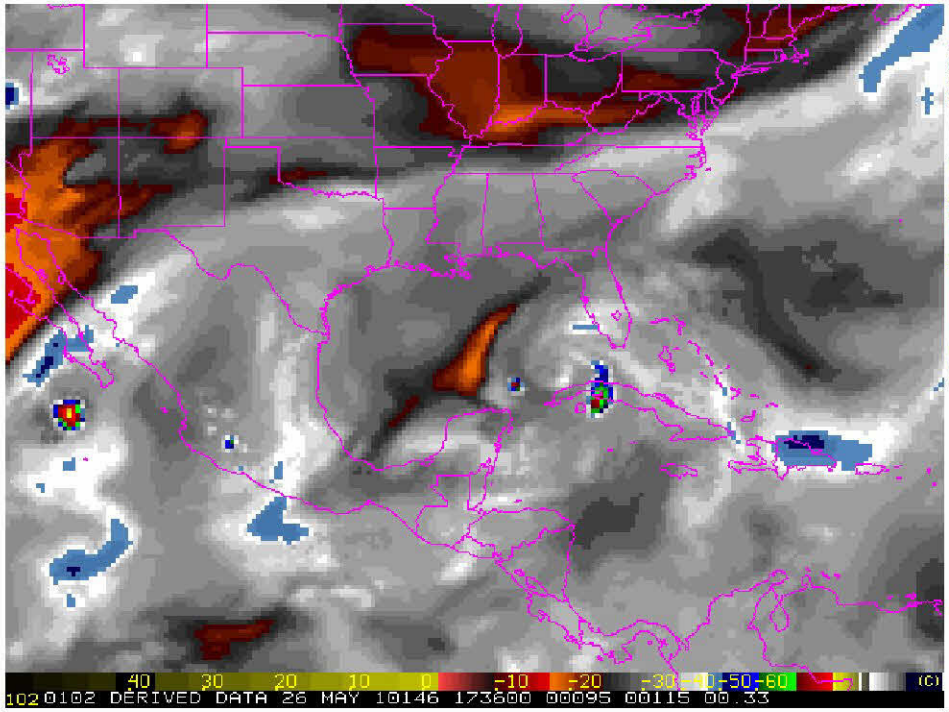
Multi-Platform Storm Structure Analysis



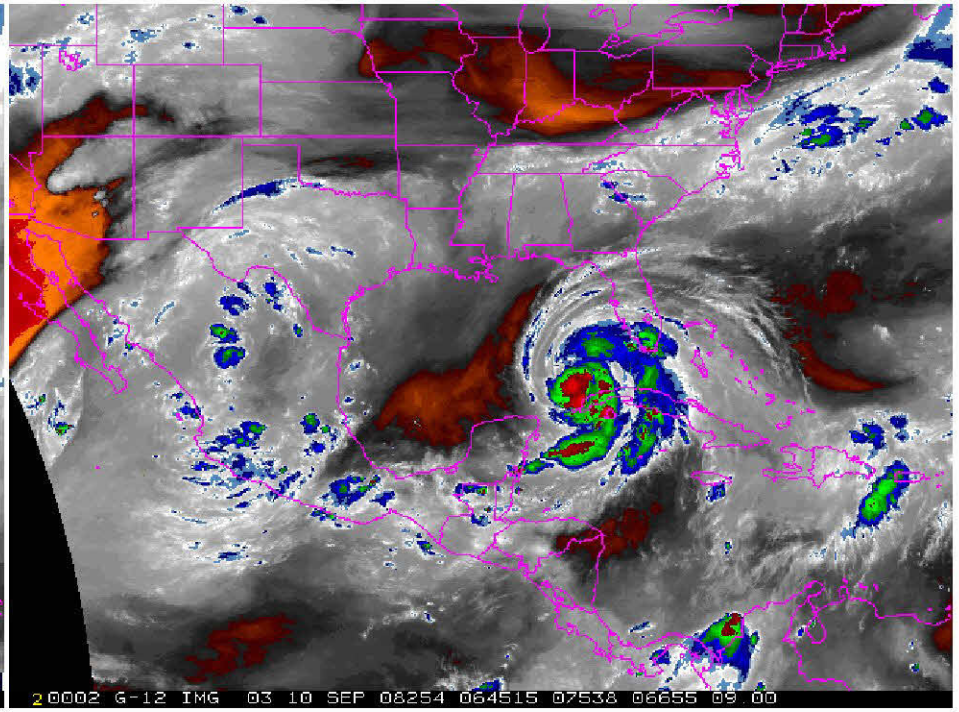


Example of Simulated IR Imagery from HWRF Model Hurricane Ike (2008)

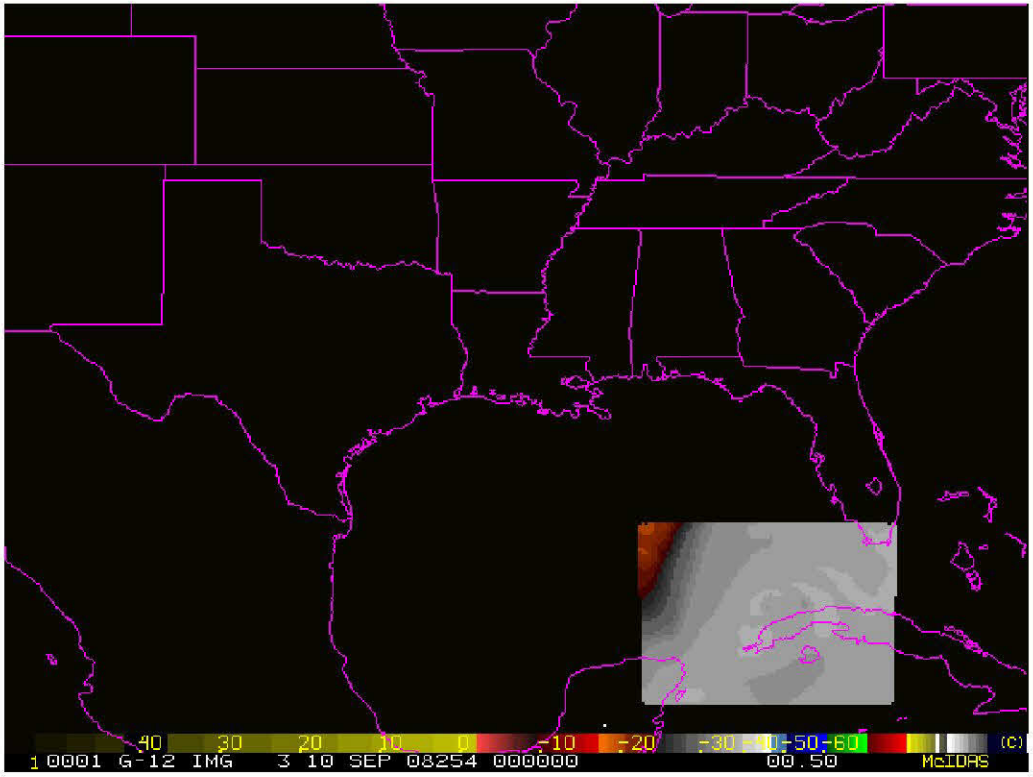
Band 3 Loop Simulated



Band 3 Loop Real



Simulated GOES Channel 3 from HWRF Inner Mesh for Hurricane Ike (2008)



Summary

- Tropical Cyclone intensity forecast skill lags track skill
- Rapid intensity forecasting is very difficult but very important problem
  - GOES-R GLM and ABI have large potential for improving RII
- NHC proving ground starting next week
  - HIE, RGB, Rapid Intensity and rapid scan products
- Additional GOES-R TC products under development
- Suggestions for Pacific region
  - HIE, Basic RGB, rapid intensification, center fix and wind structure products, Synthetic ABI, Rapid scan imagery