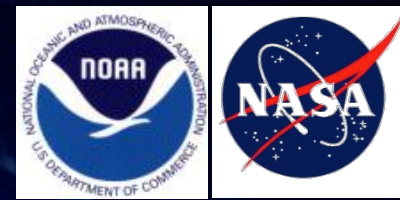# GOES-R Hurricane Intensity Estimation (HIE) Validation Tool Development

Winds Application Team

Tim Olander (CIMSS)
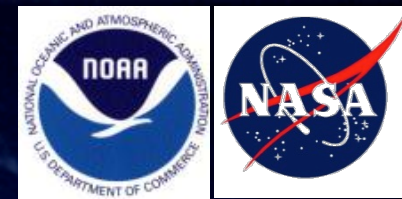Jaime Daniels (STAR)

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OUTLINE

- **Products** (1-2 slides)

- **Validation Strategies** (3-4 slides)

- **Routine Validation Tools** (4-5 slides)

- **"Deep-Dive" Validation Tools** (4-5 slides)

- **Ideas for the Further Enhancement and Utility of Validation Tools** (1-2 slides)

- **Summary**

Products

- The Hurricane Intensity Estimation (HIE) algorithm produces tropical cyclone (TC) intensity estimates using long-wave infrared imagery (GOES-R Channel 13 : 10.1-10.6µm).

- Algorithm specifications
  - Full disk coverage at 2km horizontal resolution for all active TC every 30 min.
  - Accuracy/Precision requirements : 6.5/8.0 m/s

- Project stakeholders include
  - NOAA/NWS/National Hurricane Center (NHC) and Central Pacific Hurricane Center (CPHC)
  - NOAA/NESDIS/Satellite Analysis Branch (SAB)
  - Department of Defense/Fleet Numerical Meteorology and Oceanography Center (FNMOC) and Joint Typhoon Warning Center (JTWC)
  - Various International (WMO) Tropical Forecast Centers including BoM (Australia), Fiji, JMA, India, and MeteoFrance
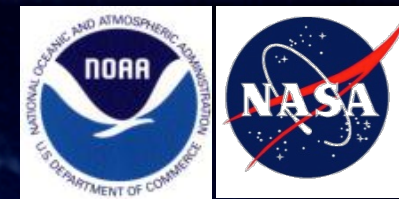
- HIE algorithm output is purely textual (specifically it consists of the current TC intensity in terms of wind speed in m/s). No product displays are required. Examples of output "Tailored Products" are provided.

Current Intensity "Bulletin"

```
              UW - CIMSS
       ADVANCED DVORAK TECHNIQUE
            ADT - Version 7.2.3
     Tropical Cyclone Intensity Algorithm

          ----- Current Analysis -----
   Date : 12 SEP 1999       Time : 124500 UTC
   Lat : 22:59:26 N         Lon : 66:12:49 W

          CI# /Pressure/ Vmax
          6.5 / 934.8mb/127.0kt

    Latitude bias adjustment to MSLP : -0.2mb
  Estimated radius of max. wind base on IR : 31.4km

       6hr-Avg T#       Adj T#        Raw T#
          6.3             6.5           7.1

  Eye Temp : 18.6C          Cloud Region Temp : -74.2C

  Scene Type : EYE

  Positioning Method : MANUAL

  Ocean Basin : ATLANTIC
  Dvorak CI > MSLP Conversion Used : ATLANTIC

  Tno/CI Rules : Constraint Limits : 1.5T/6hr
                      Weakening Flag : OFF
            Rapid Dissipation Flag : OFF
  *****************************************************
```
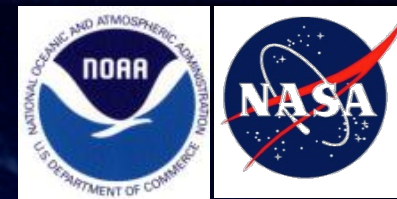
History File Listing

| Date	Time (UTC)	CI	Final/MSLP MSLP /BiasAdj/	Lat/Vmax (kts)	Fnl Tno	Adj Raw	Ini Raw	Cnstrnt Limit	Wkng Flag	Rpd Wkng	Cntr Region	Mean Cloud	Scene Type
1999SEP08	151500	3.0	1000.0/	+0.0 / 45.0	3.0	3.0	3.0	NO LIMIT	OFF	OFF	-15.86	-27.61	SHEA
1999SEP08	161500	3.0	1000.0/	+0.0 / 45.0	3.0	3.0	3.1	0.1T/hour	OFF	OFF	-6.16	-28.89	SHEA
1999SEP08	171500	3.0	1000.0/	+0.0 / 45.0	3.0	3.0	2.5	0.1T/hour	OFF	OFF	-5.56	-33.82	IRRC
1999SEP08	181500	3.0	1000.0/	+0.0 / 45.0	2.9	2.9	2.5	0.1T/hour	WKN	OFF	-19.96	-36.52	IRRC
<records deleted from listing>													
1999SEP11	031500	4.6	975.2/	-2.0 / 79.6	4.6	4.6	4.6	NO LIMIT	OFF	OFF	-58.76	-71.83	UNIF
1999SEP11	064500	4.7	974.0/	-1.5 / 82.2	4.7	4.8	4.8	NO LIMIT	OFF	OFF	-47.06	-68.08	EMBC
1999SEP11	074500	4.8	972.0/	-1.6 / 84.8	4.8	5.0	5.0	NO LIMIT	OFF	OFF	-59.86	-70.36	EMBC
1999SEP11	084500	4.8	972.2/	-1.4 / 84.8	4.7	4.5	4.5	NO LIMIT	WKN	OFF	-46.46	-69.65	UNIF
1999SEP11	094500	4.8	972.1/	-1.5 / 84.8	4.6	4.5	4.5	NO LIMIT	WKN	OFF	-62.46	-69.24	UNIF
1999SEP11	104500	4.8	972.2/	-1.4 / 84.8	4.6	4.8	4.8	NO LIMIT	WKN	OFF	-64.36	-68.35	EMBC
1999SEP11	114500	4.8	972.2/	-1.4 / 84.8	4.7	4.8	4.8	NO LIMIT	WKN	OFF	-60.96	-67.65	EMBC
<records deleted from listing>													
1999SEP12	214500	6.1	945.7/	+0.2 /117.4	6.0	6.0	6.0	NO LIMIT	ON	OFF	19.14	-67.50	EYE
1999SEP12	224500	6.1	945.6/	+0.2 /117.4	6.0	6.0	6.0	NO LIMIT	ON	OFF	19.24	-70.46	EYE
1999SEP12	234500	6.1	945.6/	+0.2 /117.4	6.0	6.0	6.0	NO LIMIT	ON	OFF	19.24	-69.12	EYE
1999SEP13	004500	6.1	945.7/	+0.3 /117.4	6.0	6.0	6.0	NO LIMIT	ON	OFF	19.74	-71.65	EYE
1999SEP13	014500	6.1	945.7/	+0.3 /117.4	6.0	6.0	6.0	NO LIMIT	ON	OFF	20.54	-68.80	EYE
1999SEP13	024500	6.1	945.7/	+0.3 /117.4	6.0	6.0	6.0	NO LIMIT	ON	OFF	21.44	-69.21	EYE
1999SEP13	064500	6.4	938.1/	+0.5 /124.6	6.2	6.4	6.4	NO LIMIT	OFF	OFF	19.14	-69.40	EYE
1999SEP13	074500	6.4	938.1/	+0.5 /124.6	6.3	6.4	6.4	NO LIMIT	OFF	OFF	18.84	-69.23	EYE
1999SEP13	084500	6.4	938.2/	+0.6 /124.6	6.4	6.6	6.6	NO LIMIT	OFF	OFF	19.44	-70.73	EYE
<records deleted from listing>													

Validation Strategies

- Initial HIE Validation suite was delivered 15 December 2010.
  - No feedback or comments have been provided by reviewers as of yet.

- HIE intensity estimates (stored in HIE history files) can be validated against two different "ground truth" data sets either in real-time of post-storm, depending on the data set used in the process.
  - In situ aircraft reconnaissance measurements of maximum wind speed.
    - May not be available for part or all of the storm lifetime, depending on where the storm track is located.
  - "Working" and "Final" Best Track storm intensity history.
    - Available for entire storm lifetime, but may not be based entirely on in situ data.
    - Working Best Track is available in real-time during the storm lifetime. It may not be accurate due to bad observational data, inaccurate Dvorak estimates, or TC forecaster error.
    - Final Best Track are made available after extensive analysis of all in situ observations, estimates from remote sensing methods/applications, and TC forecast methodology have been examined.
  - "Ground Truth" data can be easily obtained via NOAA "Family of Services" or FTP sites (such as NOAA/NHC)

Routine Validation Tools
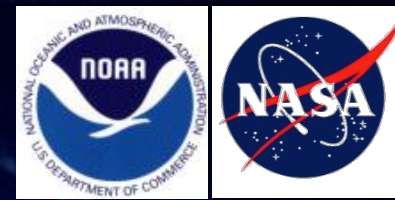
- Datasets will include the HIE history file output for each storm being analyzed. The history files will be compared directly to the in situ aircraft reconnaissance measurements of TC intensity or the Best Track intensity for the storm in question.

- The HIE validation suite will produce statistical comparisons of the HIE intensity estimates and the validation data. The statistical analysis will be provided in terms of wind speed (in m/s) precision and accuracy metrics as well as additional error metrics utilized at operational NOAA TC forecasting and analysis centers.

- HIE Validation analysis suite submitted/proposed has already been used by an operational TC forecast center (NOAA/SAB) to verify the ADT/HIE, so it is already familiar to organizations who wish to validate the HIE.

- Output products are ASCII text files derived using a series of C programs and shell scripts. No proprietary software is currently used.

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Routine Validation Tools
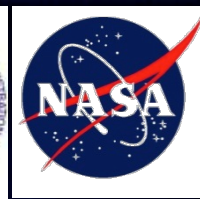
- Current intensity validation statistical output example
  - Intensity statistical error analysis versus 'ground truth" (either reconnaissance and/or NHC Best Track information)
  - Accuracy and precision measurements are displayed for the storm in question
  - Categorical differences in ADT differences from "ground truth" can provide quick overview of any intensity estimate biases
  - Output layout mirrors output parameters as utilized in operations by NOAA/SAB

```
INTENSITY ERRORS  (wind speed : m/s)
            bias    rmse     aae    stdv    cnt
ADT:07L     2.04    7.33    5.61    7.04     23


ADT-BestTrack Intensity Differences
 dCAT   ALL    TD    TS   H12   H35
 <-20    0     0     0     0     0
  -20    0     0     0     0     0
  -15    1     0     0     0     1
  -10    1     0     0     0     1
   -5    4     0     1     1     2
    0    9     0     1     6     2
   +5    4     0     0     1     3
  +10    2     0     0     0     2
  +15    2     0     0     0     2
  +20    0     0     0     0     0
 >+20    0     0     0     0     0
        23     0     2     8    13
```

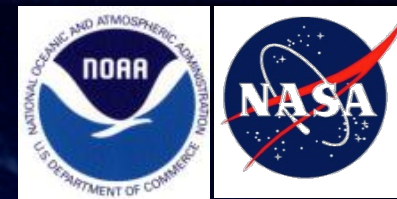| dCAT	ALL	TD	TS	H12	H35
<= 2.5:	39.1%	0.0%	50.0%	75.0%	15.4%
<= 7.5:	73.9%	0.0%	100.0%	100.0%	53.8%
>10.0:	17.4%	0.0%	0.0%	0.0%	30.8%

"Deep-Dive" Validation Tools

- Further statistical analysis comparisons will be derived versus various operational tropical cyclone forecast center intensity estimates
  - Manual/Subjective Dvorak Technique estimates will also be compared to automated HIE estimates to note/define biases and/or derive baseline accuracy threshold for Dvorak-based methodologies
    - NOAA/Satellite Analysis Branch (SAB) and NOAA/NHC/Tropical Analysis and Forecast Branch (TAFB), as well as the Joint Typhoon Warning Center (JTWC) currently perform manual Dvorak TC intensity estimates
  - Methods to obtain real-time "ground truth" measurements of intensity and current operational Dvorak estimates would need to be outlined
  - Output will be created using any graphical software package since data is based upon simple ASCII data files
- Analysis of HIE automated storm center determination algorithm will also be provided
  - Proper determination of storm center plays large role in intensity accuracy
  - Graphical displays can easily show impact of improved position over forecast
 - Statistical analysis can provide accuracy of each different location method

- Graphical timeline example of HIE analysis versus observational data and/or TC forecast center Dvorak estimates

  - Allows for quick analysis of the accuracy of the HIE performance versus subjective Dvorak estimates and/or "ground truth"

  - Plots can be provided in real-time or in post-storm analysis mode

  - SAB Dvorak estimates and NHC Best Track are displayed here

**Timeline of HIE and SAB intensity estimates versus NHC Best Track**

ADT/SAB Tropical Cyclone Intensity Estimates
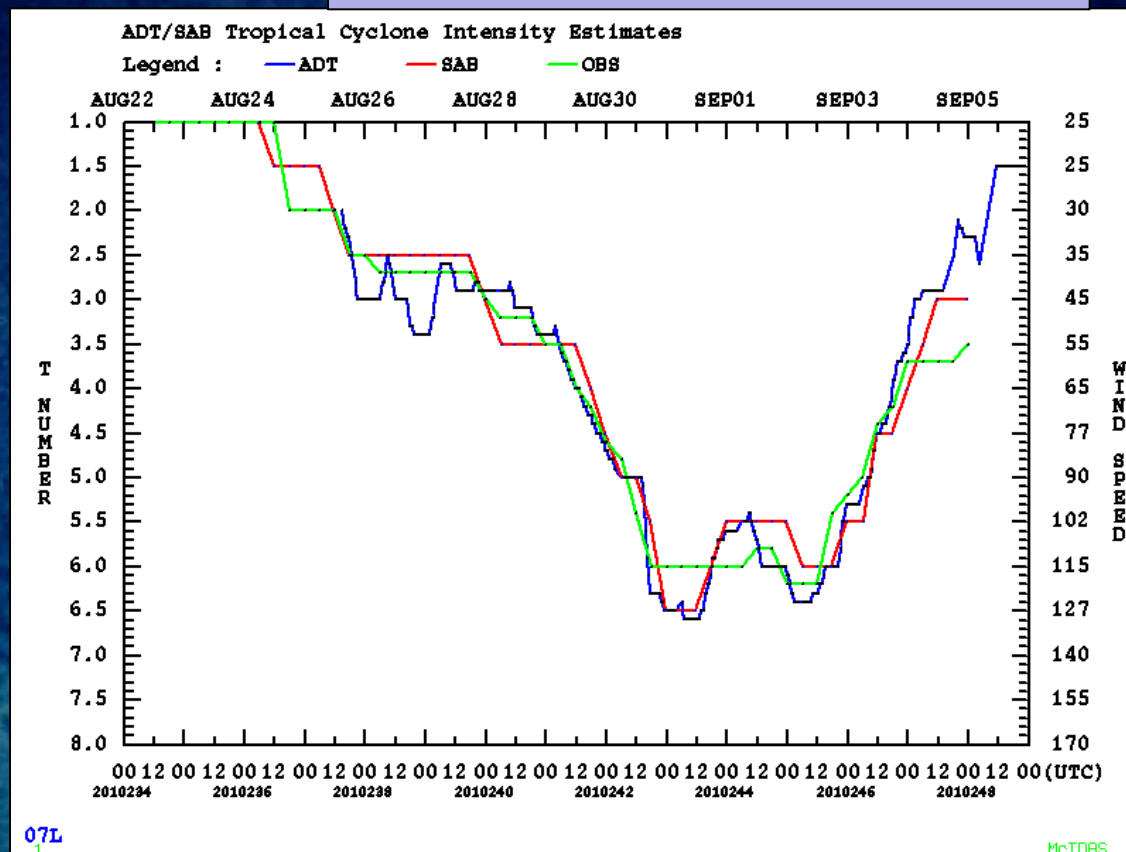
Legend : ADT SAB OBS
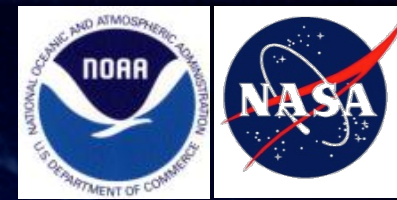
- Histogram of HIE and operational center intensity estimates differences from "ground truth"

  – Provides easy display of errors between the two methodologies

  – Can easily identify any biases in intensity differences in either set of estimates

  – HIE versus SAB Dvorak intensity differences from NHC Best Track are shown in the graph to the right
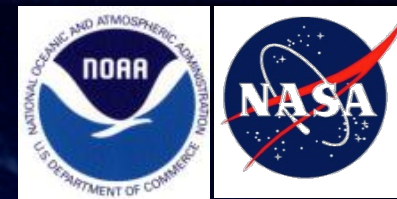
**Histograms of HIE and SAB intensity estimates differences versus NHC Best Track**

ADT vs. NHC Best Track 07L 2010 Atl
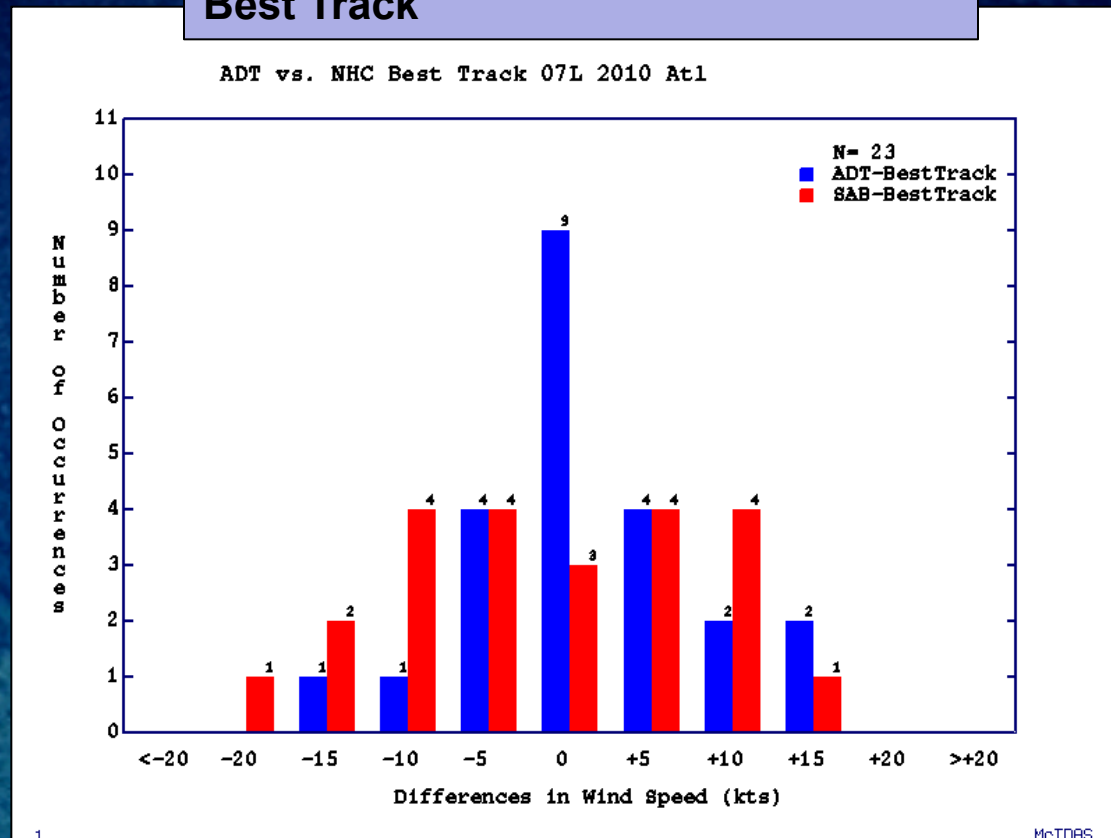
- Display HIE automated storm center position versus "ground truth" and forecast interpolation positions
  - Provides visual method to determine accuracy of automated storm center selection position
  - Can be used to assess accuracy of current storm forecast from issuing TCFC
  - Can be compared to aircraft reconnaissance, if available

Example of image displaying storm center location information.

Reconnaissance

HIE Determined

Forecast Interpolation

G-12 IMG IR (BD ENH) 26 AUG 05 09:15
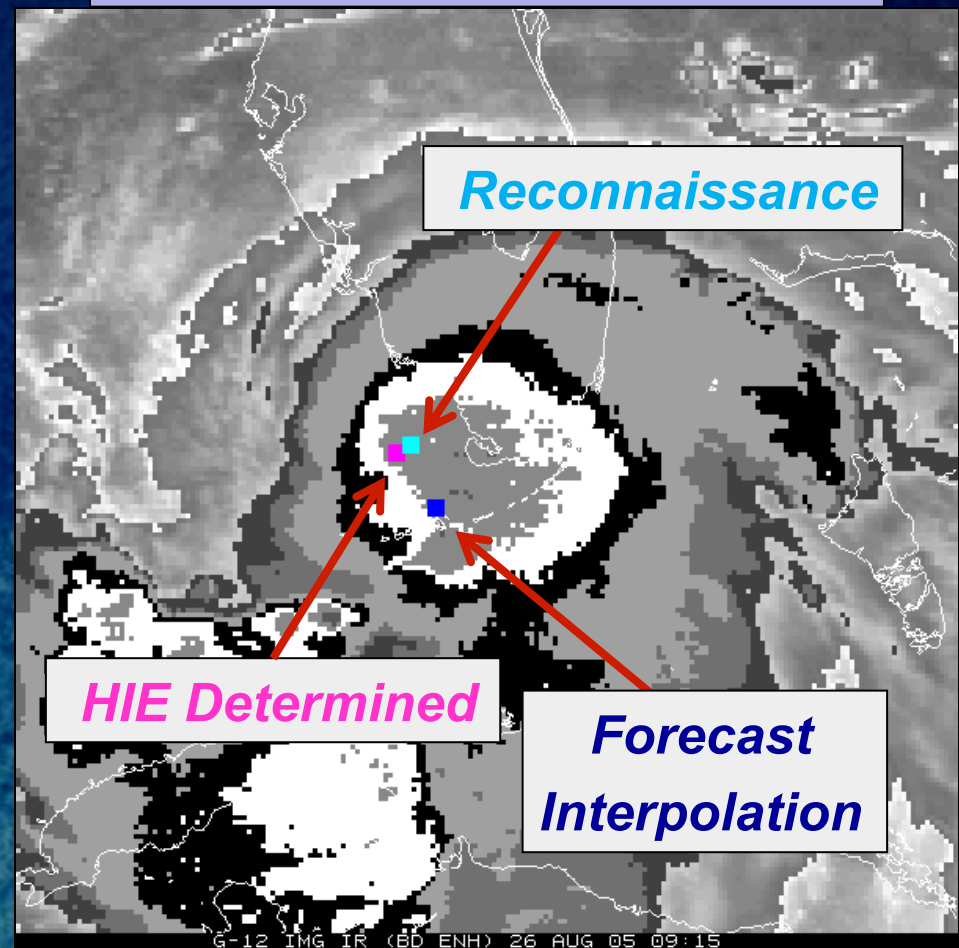
"Deep-Dive" Validation Tools

- Current intensity validation statistical output example

  - Storm center positioning error analysis versus 'ground truth" (either reconnaissance and/or NHC Best Track information)

  - Accuracy and precision measurements are displayed for the storm in question or for entire ocean basin and season

  - Comparisons with manual positions from TCFC can be output, if available

  - Output layout mirrors output parameters as utilized in current operations by NOAA/SAB

```
POSITIONING ERRORS (distance in nmi)
 OVERALL     bias     rmse      aae      stdv      cnt
SAB:LAT      0.00     0.17     0.12     0.17      118
SAB:LON     -0.07     0.24     0.17     0.23      118
SAB:DIST                      13.86               118
ADT:LAT      0.04     0.22     0.17     0.22      118
ADT:LON     -0.05     0.31     0.22     0.31      118
ADT:DIST                      18.16               118


 Estimated Position Error (nmi) by Fix Method
 Method    Num (%)         ADT      SAB
FORECAST    77 ( 65%)      20.1     14.9
SPIRAL      29 ( 24%)      16.8     13.9
COMBO       12 ( 10%)       8.9      7.2
EXTRAP       0 (  0%)       0.0      0.0
OVERALL    118             18.2     13.9
```
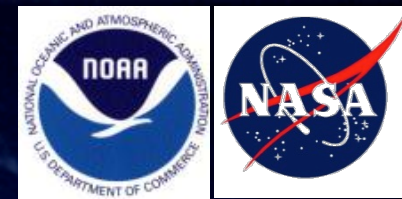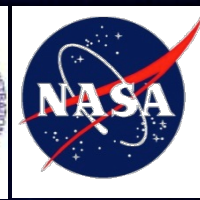
- Graphical and textual information could be sent to a webpage to allow for immediate, real-time viewing and investigation of HIE performance versus in situ measurements and/or additional subjective estimates of current tropical cyclone intensity and automated positioning accuracy

- Statistical analysis of different tropical cyclone stages (formation, mature, dissipation) and HIE scene types (Curved Band, Central Dense Overcast, Eye, Shear, etc.) could be derived in real-time to allow HIE users to be aware of algorithm precision and accuracy during specific TC analysis situations.
    - Analysis could also be derived for individual basins (North Atlantic, East/Central Pacific) and storm seasons to indicate any additional precision and accuracy errors users should be aware of

Summary

- Validation of HIE intensity estimates are conducted versus either in situ aircraft reconnaissance measurements of TC maximum wind speed measurements or Best Track storm information provided from an official TC forecast center.

- The HIE validation suite has already been utilized by an official, operational TC forecast center (NOAA/SAB) to verify the ADT/HIE against their Dvorak intensity estimates. The layout and information provided was specifically defined to meet their specifications for intensity estimate validation and is familiar to this and other TC forecast centers (and HIE project stakeholders).

- HIE Validation results are easy to interpret and can be presented either textually or graphically (and can easily be implemented into any graphical display program).