GOES-R AWG Winds Team: Hurricane Intensity Estimation (HIE) Algorithm

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Outline

- Executive Summary
- Requirements Specification Evolution
- Algorithm Description
- ADEB and IV&V Response Summary
- Validation Strategy
- Validation Results
- Summary

Executive Summary

- The Hurricane Intensity Estimation (HIE) algorithm will generate current estimates of tropical cyclone wind speed using Infrared Window imagery (GOES-R ABI Channel 13).
- Version 4 was delivered in March. Version 5 will be delivered in July.
- ATBD (100%) is due for a June 15 delivery.
- Winds Team Technical Interchange Meeting (TIM) scheduled with Harris for June 24.
- HIE spec changes for accuracy and precision threshold requirements approved after review in April.
- Several validation studies indicate HIE at or very near spec compliance. HIE Version 5, utilizing new analysis techniques, has shown ability to meet spec thresholds.

Requirements

Product	*Accuracy*	*Precision*	*Latency*	*horizontal resolution*
Hurricane Intensity	*6.5 m/s* *(modified from 5.0 m/s)*	8.0 m/s *(modified from 5.0 m/s)*	806 sec	2 km

Qualifiers

Ability for HIE to meet specs is made with the following qualifiers.

- Sensor zenith angle < 65 degrees
- Focus storm is an “active TC” being monitored and forecasted by operational Tropical Cyclone Forecast Centers (producing forecast center points used by the HIE)

Algorithm Description

Algorithm Summary

- The Hurricane Intensity Estimation (HIE) algorithm will generate current estimates of tropical cyclone (TC) intensity globally over the entire lifecycle of the storm.

- Algorithm utilizes Infrared Window imagery (GOES-R ABI Channel 13) which will allow for high spatial and temporal resolution analysis of tropical storm intensity. HIE validation studies using proxy ABI imagery have shown small impacts from expected improved spatial resolution.

- Algorithm has long history of operational use in TC forecast community. Automated estimates obtained by HIE have been shown to be on par with (or better in some cases) than subjective estimates of TC intensity obtained at tropical cyclone forecast centers (TCFCs).

Motivation for Algorithm Channel Selection

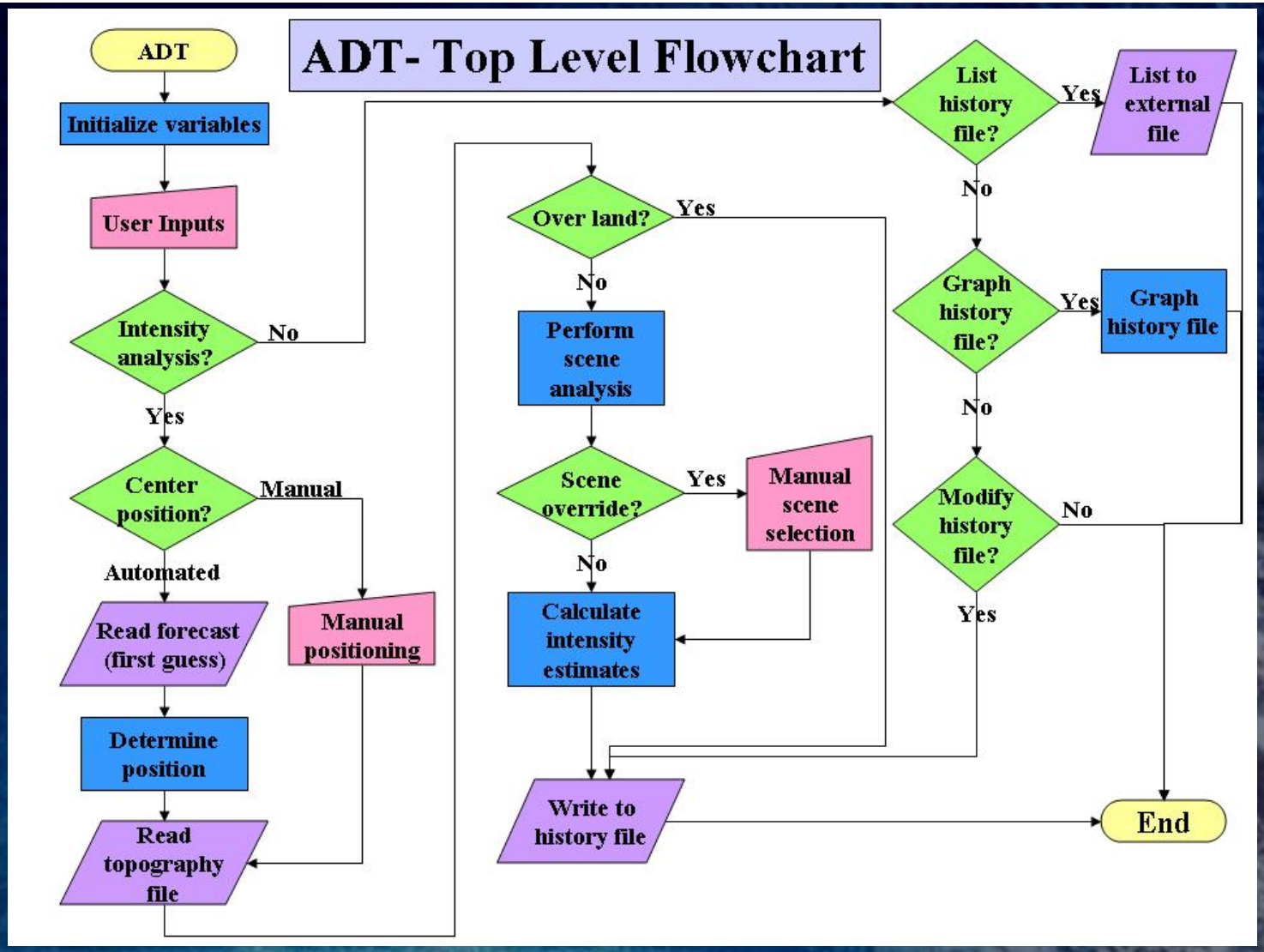
- The use of Infrared Window channel in the HIE algorithm was defined by the historical use of this channel information in the subjective TC intensity estimation routine (Dvorak Technique) and the objective Advanced Dvorak Technique (ADT) on which the HIE was based.

- The HIE has advanced beyond the scope of the subjective technique, but the cloud top and eye temperature information provided by the IR Window channel still serves as the foundation of the HIE technique.

- The GOES-IM and GOES-NOP imagers have provided the 10.7μm Infrared channel information for the current and previous GOES satellites.

- The GOES-R ABI provides multiple IR window channels, however the HIE algorithm will utilize the 10.35μm channel to be closely consistent with the above.

HIE Processing Outline



HIE Output

- HIE Algorithm Output Data in NetCDF4 Format
  - Hurricane intensity estimates can be presented in a variety of methods
    - Current estimate can be output to screen and/or file
    - Prior estimates can be listed and edited

Name	Type	Description	Dimension
HIE	output	Contains 35 values generated by HIE algorithm; current intensity values and various critical measured quantities for determining intensity	35 values/record for each HI throughout the life of the storm

HIE Output

- ATCF output (Tailored Product)
  - » Automated Tropical Cyclone Forecast format of HIE output intensity estimate and various intensity parameters (used and requested by NHC/JTWC)

HIE Output

- "Bulletin" format intensity estimate output (Tailored Product) currently used by heritage ADT algorithm.

```
*****************************************************
                  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
*****************************************************
```

HIE Output

- "Listing" format history file output (Tailored Product) currently used by heritage ADT algorithm.

```
===== ADT-Version 7.2.3 =====
                  --------Intensity------- -Tno Values--  ---Tno/CI Rules---  -Temperature-
            Time        Final/MSLPLat/Vmax   Fnl Adj Ini   Cnstrnt  Wkng Rpd   Cntr   Mean   Scene  EstRMW   Storm Location  Fix
Date        (UTC)   CI  MSLP /BiasAdj/(kts)  Tno Raw Raw    Limit   Flag Wkng Region  Cloud  Type    (km)     Lat     Lon    Mthd
1999SEP08 151500  3.0 1000.0/  +0.0 / 45.0  3.0 3.0 3.0  NO LIMIT   OFF  OFF -15.86 -27.61  SHEAR    N/A    15.81   50.06   FCST
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  SHEAR    N/A    15.86   50.28   FCST
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  IRRCDO   N/A    15.91   50.51   FCST
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  IRRCDO   N/A    15.96   50.73   FCST
<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  UNIFRM   N/A    20.97   60.56   SPRL
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     N/A    21.66   60.42   SPRL
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     N/A    21.49   61.20   SPRL
1999SEP11 084500  4.8  972.2/  -1.4 / 84.8  4.7 4.5 4.5  NO LIMIT   WKN  OFF -46.46 -69.65  UNIFRM   N/A    21.76   61.17   SPRL
1999SEP11 094500  4.8  972.1/  -1.5 / 84.8  4.6 4.5 4.5  NO LIMIT   WKN  OFF -62.46 -69.24  UNIFRM   N/A    21.61   61.52   SPRL
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     N/A    21.69   61.53   SPRL
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     N/A    21.77   61.65   SPRL
<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     36 IR   23.58   68.19   COMBO
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     35 IR   23.52   68.29   COMBO
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     33 IR   23.57   68.61   COMBO
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     33 IR   23.61   68.82   COMBO
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     34 IR   23.66   69.03   COMBO
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     33 IR   23.60   69.25   COMBO
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     28 IR   23.86   70.09   COMBO
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     29 IR   23.91   70.31   COMBO
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     28 IR   23.97   70.54   COMBO
 <records deleted from listing>
```

HIE Algorithm Changes from v80% to v100%

- Added use of “eye score” parameter from polar-orbiting Passive Microwave (PMW) imagers. The eye score parameter is derived external to the HIE algorithm. It aids the HIE algorithm intensity estimation process in TC cases where eye features are not well resolved in the IR Window imagery but apparent in the PMW imagery. Note: HIE will operate without external PMW inputs.

- Algorithm has been further tuned based on statistical analysis of the algorithm with the PMW eye score information (specifically, regression equations used in eye and cloud scenes to derive intensity estimates).

- Integration of HIE quality information “Error Code” values.

ADEB and IV&V Response Summary

- All ATBD errors and clarification requests have been addressed.
- Feedback did not require substantive modifications to the algorithm.

Validation Approach

Validation Approach

- Three HIE validation studies have been conducted to date. None of these include the addition of the PMW (v100%). Validation study using PMW information is currently being run and will be included in ATBD.

- **First** validation study utilized AVHRR and MODIS data to provide ABI-like IR Window data. Homogeneous comparisons of HIE intensity estimates using the simulated ABI data and current GOES imagery during 11 TC events from 2002 – 2006 were validated against in situ aircraft reconnaissance measurements of TC intensity.

- **Second** validation study utilized MSG SEVERI data and model-derived simulated ABI (SABI) data at 15 and 30 minute resolutions to assess impact of improved temporal resolution data on the HIE. Comparisons were performed for 7 TC events between 2006 - 2008 against NHC "Best Track" intensity estimates since in situ aircraft reconnaissance data was not available.

Validation Approach

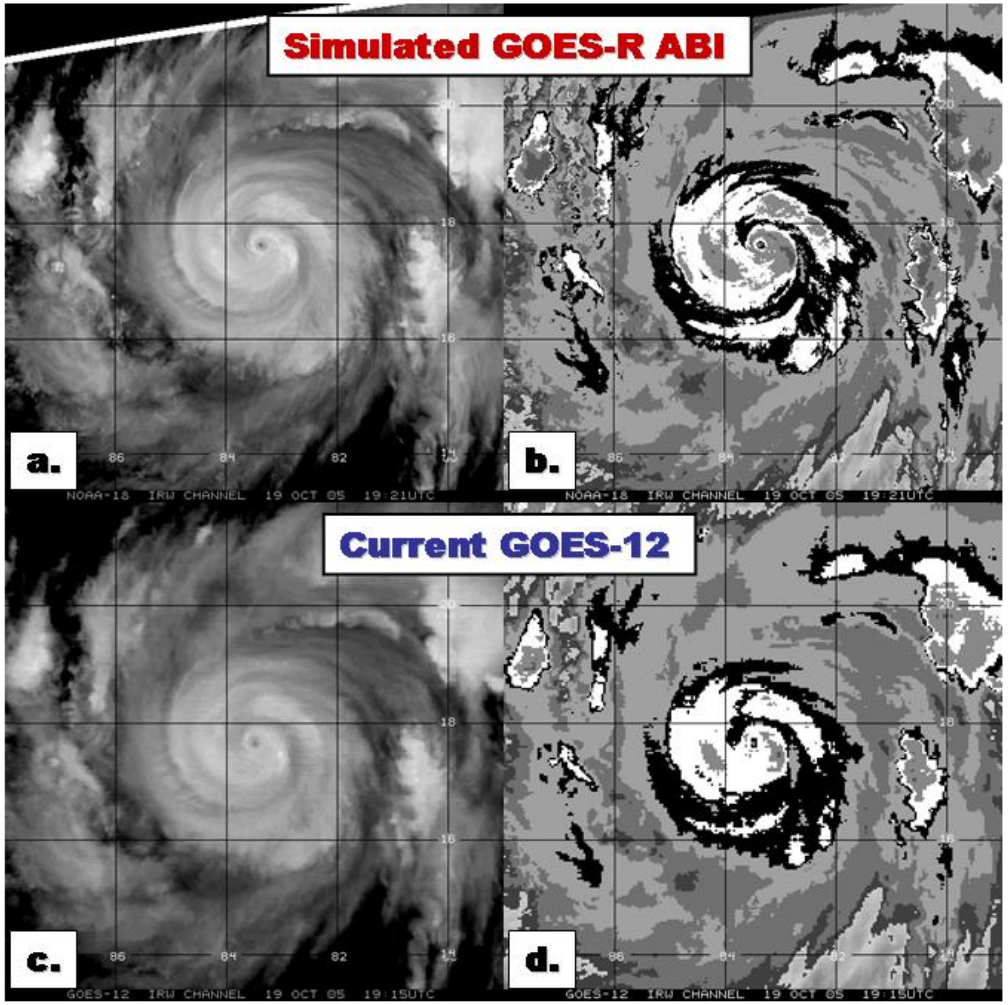
- **Third** validation study utilized current GOES data for 10 storms between 2004 -2008 to assess differences between the CIMSS "offline" and AIT "framework" HIE versions. Statistical comparisons were performed for this data set as a "baseline" study of the HIE using current GOES imagery.

- Proxy datasets were collected and provided by CIRA in first and second studies.

Validation Results

Validation Results: AVHRR/MODIS vs. Current GOES

Simulated GOES-R ABI infrared window (IRW) imagery with a.) black/white contrast stretch and b.) "BD-curve" enhancement versus current GOES-12 IRW imagery with c.) black/white contrast stretch and d.) "BD-curve" enhancement for Hurricane Wilma on 19 October 2005 (19:21 and 19:15UTC, respectively). Contrast stretch/enhancement shows improved capability to capture small eye feature.



Validation Results: AVHRR/MODIS vs. Current GOES

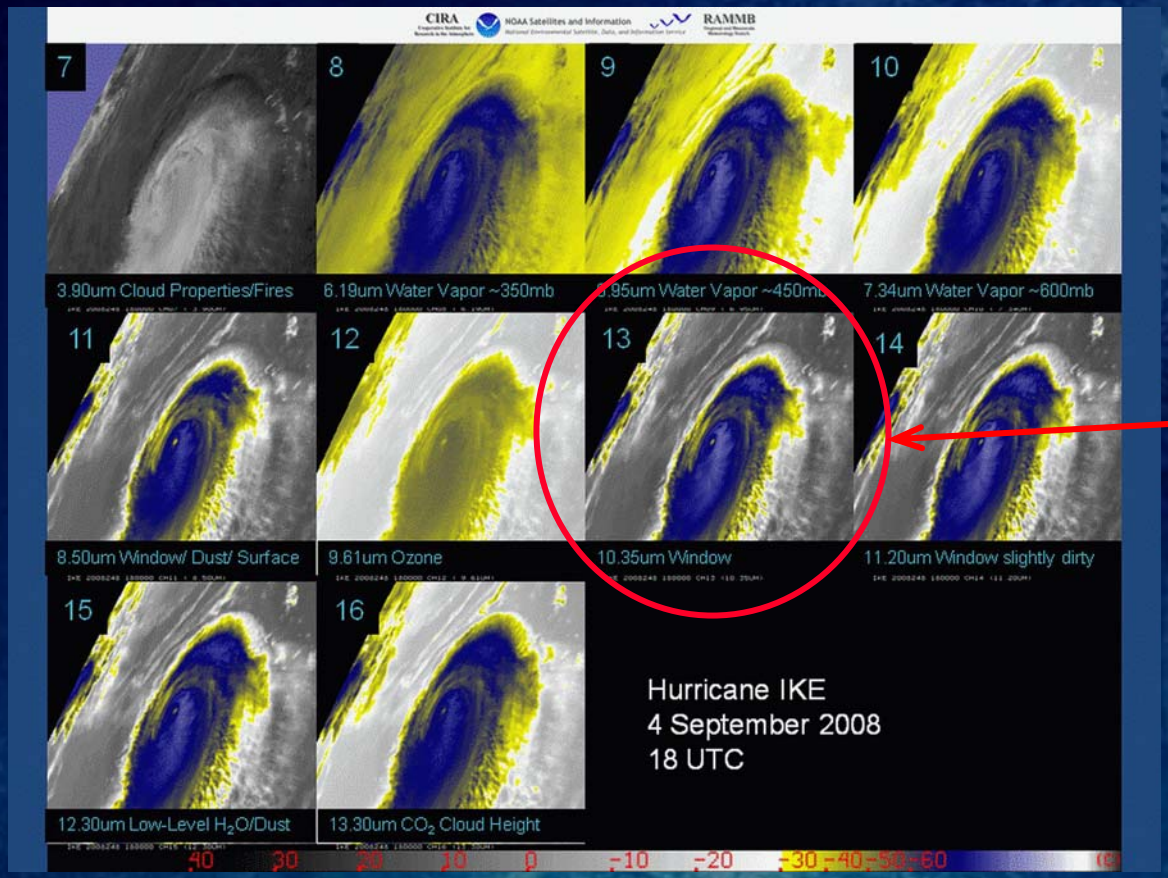
sample size: 42	GOES-ABI		GOES-current	
(units in m/s)	Bias	StdDev	Bias	StdDev
HIE CI#	-2.35	6.49	-3.09	5.22
OpCen	-1.89	6.31	-1.89	6.31

HIE CI# : Intensity estimates from HIE algorithm
OpCen : Intensity estimates from TCFC estimates using Dvorak Tech.

HIE estimates meet TC intensity spec requirements for accuracy and precision

Validation Results: MSG/SABI @ 15/30-minute

- Generate simulated ABI imagery (SABI) from MSG SEVERI IR channels (using the algorithm developed by the AWG) for 7 selected tropical cyclones from 2006-2008 that became hurricanes in the east Atlantic. The resulting IR window channel is used to evaluate the performance of the AWG Hurricane Intensity Estimation algorithm.



***Left:** Example of storm-centered simulated infrared ABI channels 7-16. Imagery is shown for Hurricane Ike on 4 September 2008 at 1800UTC. The IR window channel to be employed by the HIE is Channel 13.*

Slide courtesy of CIRA/RAMMB AWG Tropical Cyclone Project.
John Knaff, Andrea Schumacher, and Mark DeMaria

Validation Results: MSG/SABI @ 15/30-minute

sample size: 2455	30-minute		15-minute	
(units in m/s)	Bias	StdDev	Bias	StdDev
MSG	-0.79	8.34	-0.38	8.20
SABI	-0.28	8.50	-0.01	8.42

MSG : Meteosat Second Generation (MSG) SEVERI data
SABI : Simulated ABI derived from MSG data using ABI coefficients

HIE estimates meet TC intensity spec requirements for accuracy and are very close for precision despite high viewing angle issues (>50°) for most of the data set cases.

Validation Results: Offline vs. Framework HIE

sample size: 529	Offline		Framework	
(units in m/s)	Bias	StdDev	Bias	StdDev
HIE	-5.97	8.17	-6.00	8.32
OpCen	-2.42	6.27	-2.42	6.27

HIE CI# : Intensity estimates from HIE algorithm
OpCen : Intensity estimates from TCFC estimates using Dvorak Tech.

HIE estimates meet TC intensity spec requirements for accuracy and are very close for precision despite using only current GOES data.

Summary

- The ABI Hurricane Intensity Estimation algorithm provides long-standing and proven solutions that will utilize the capabilities offered by the ABI

- Version 4 is delivered. Version 5 and the 100% ATBD are coming in the next two months.

- The HIE algorithm has meet specifications in one validation study and was very close in two others (despite not yet employing latest version, and limitations with the data sets). It is fully expected to meet specifications by final delivery.