SATELLITE APPLICATIONS TO TROPICAL CYCLONE FORECASTING

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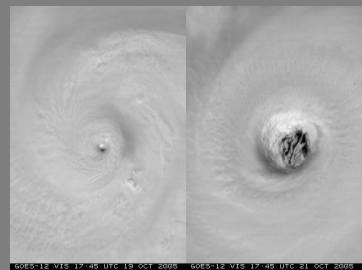
NOAA/NESDIS/RAMMB

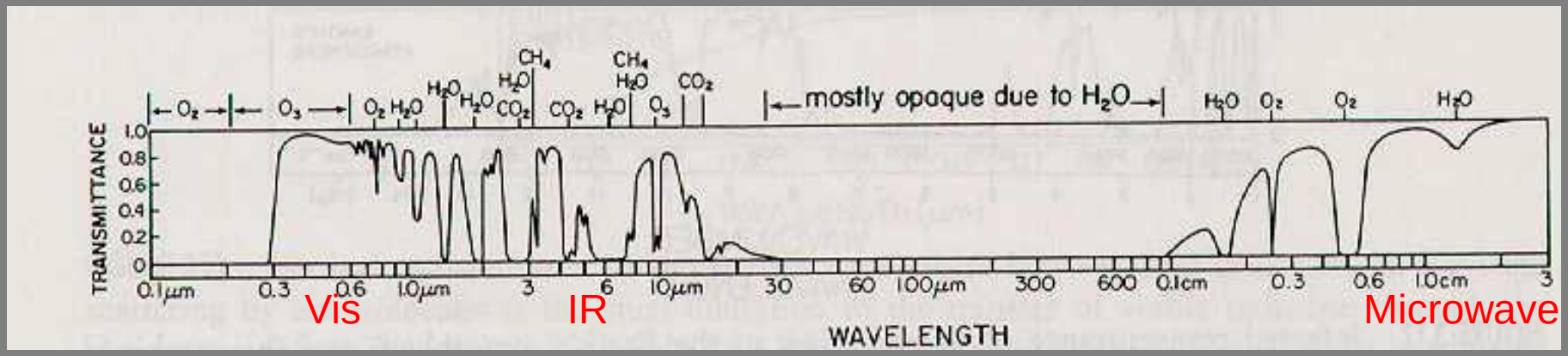
NCAR Hurricane Workshop
February 22-23, 2010

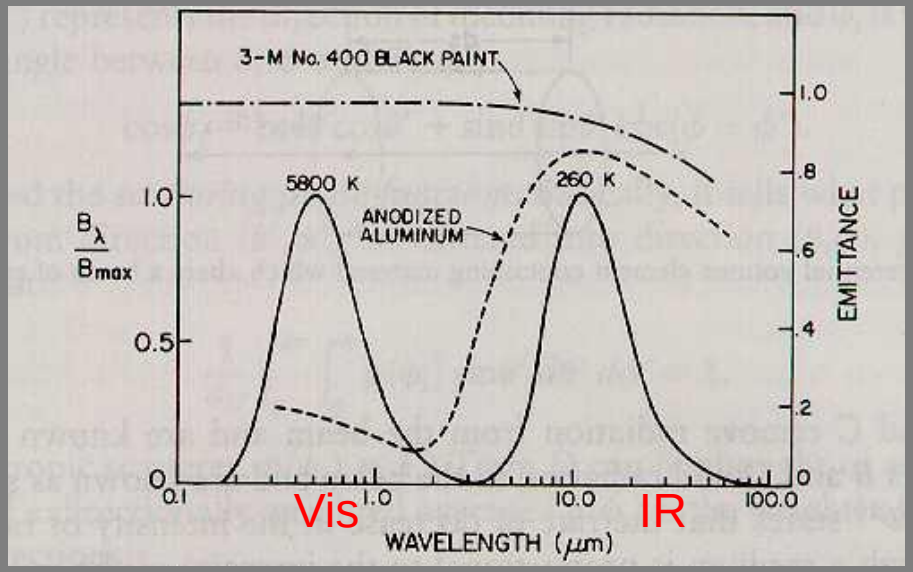


Outline

- Very brief review of satellite remote sensing
- Satellite applications to tropical cyclone analysis and forecasting
- Future satellite systems

The Electromagnetic Spectrum





(From Kidder and Vonder Haar, 1995)

<u>Visible</u>: Reflected, scattered incoming solar

<u>IR</u>: Emitted from earth, ocean, atmosphere
Even thin clouds are nearly opaque

<u>Microwave</u>: Penetrates through most clouds
Polarization important
Low emissivity over land

Satellite Orbits and Sensors

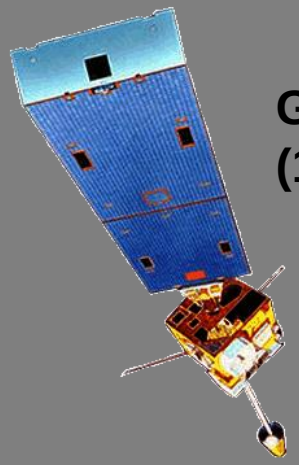
- Geostationary
  - GOES, Meteosat, MT-SAT, INSAT, FY-2x
    - IR and visible imagers, IR sounders
- Low-earth orbit (LEO)
  - POES, Met-Op, DMSP (operational)
  - Terra/Aqua, TRMM, COSMIC, many others
    - IR, vis, μ-wave imagers, sounders
    - Radio occultation
    - Lightning detection
    - Active instruments
      - Ocean surface winds, altimetry, radars

Instrument Resolution

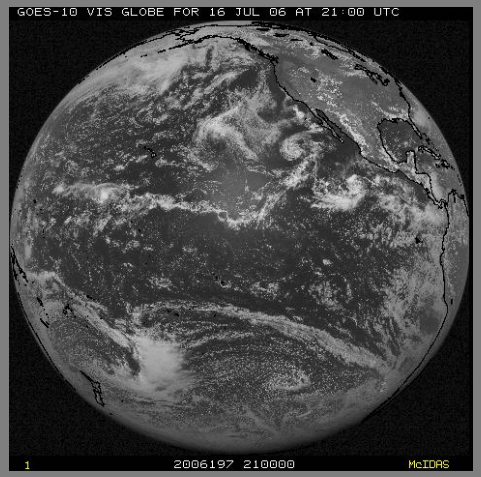
	Horizontal	Vertical (Spectral)	Temporal
Geo Vis	1 km	N/A	1-30 min
Geo IR	4-10 km	~3 km	1 – 60 min
Leo Vis	.25-1 km	N/A	6-12 hr
Leo IR	.5-1 km	1-3 km	6-12 hr
Leo microwave	5-100 km	2-3 km	6-12 hr

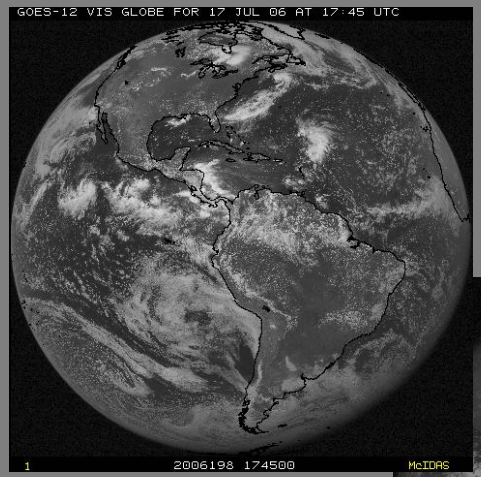
GOES Constellation (mid-2010)

Operational

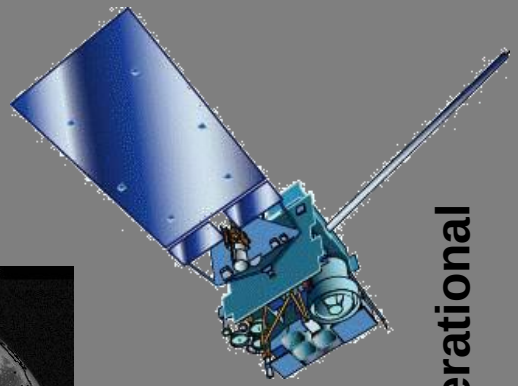


GOES-11
(135W)

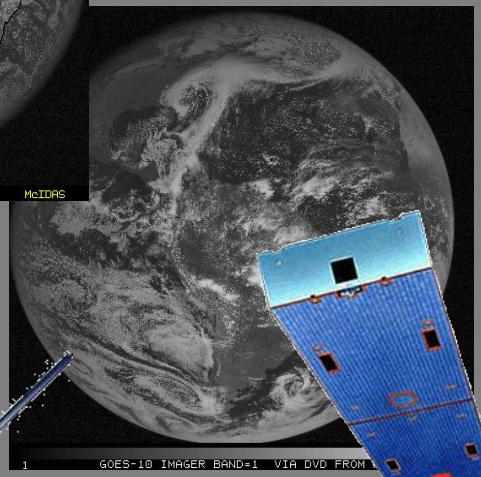


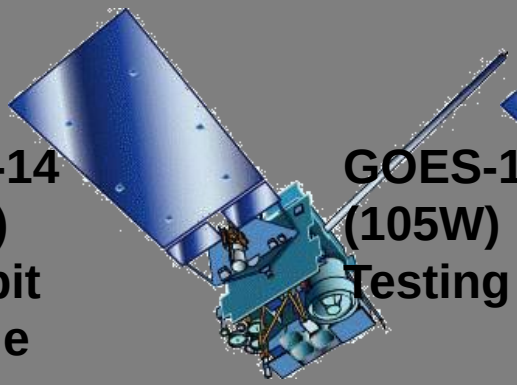


GOES-13
(75W)

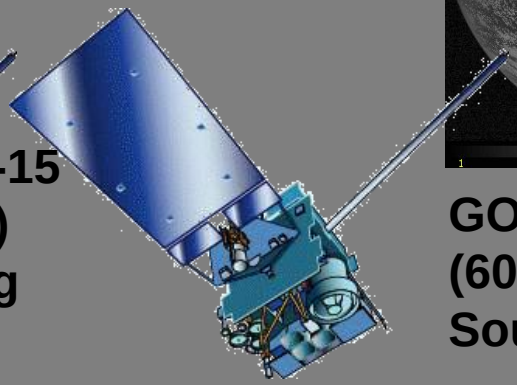


Operational

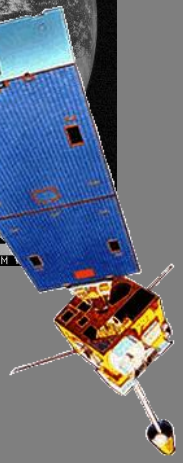




GOES-14
(105W)
On-orbit
Storage

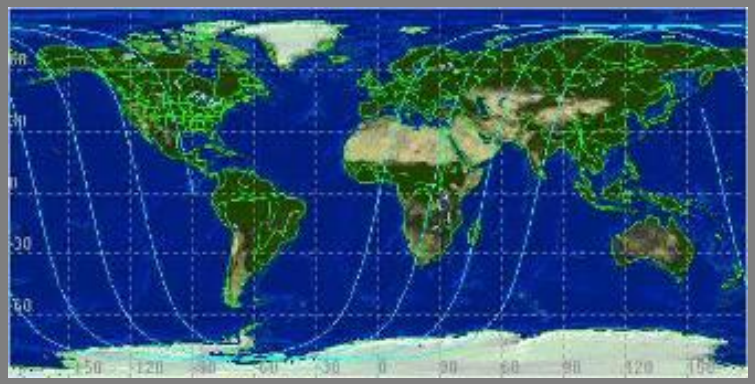


GOES-15
(105W)
Testing



GOES-12
(60W)
South America

NOAA POES Satellites

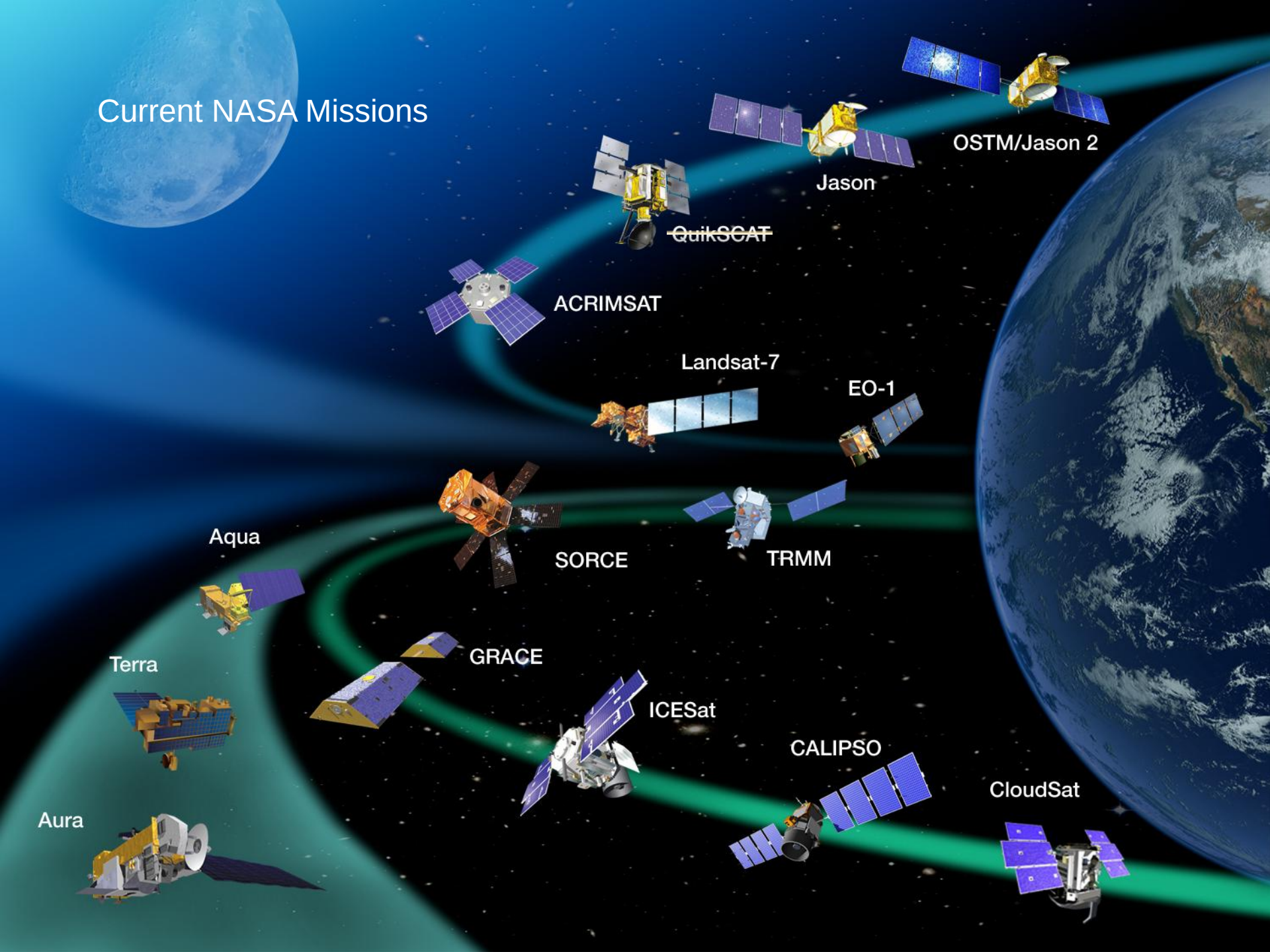


2 p.m. Orbit

10 a.m. Orbit

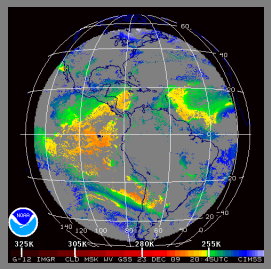
- Two polar operational satellites; one in morning and one in afternoon sun-synchronous orbit
- Launch upon failure of imager or sounder
- Continuity of operations since early 1960s
- Since May 2007, NOAA using EUMETSAT satellite operationally for mid-morning orbit through NOAA/EUMETSAT partnership

Current NASA Missions

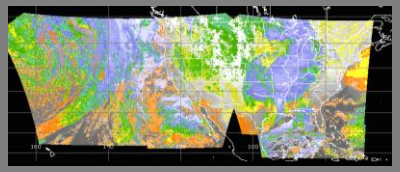


Sample Uses by Instrument

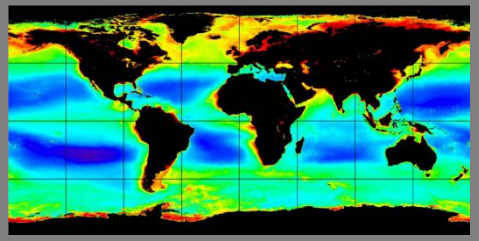
GOES Imager



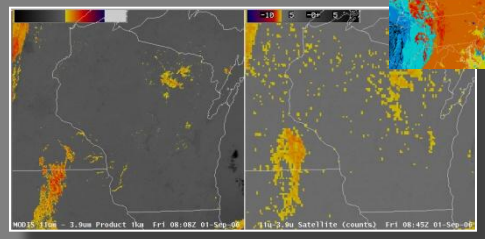
GOES Sounder



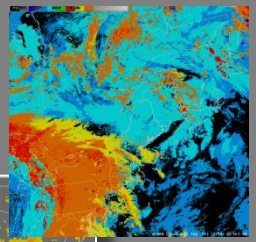
SeaWIFS



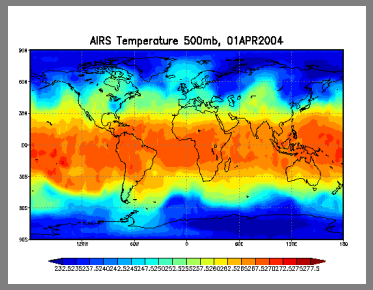
MODIS



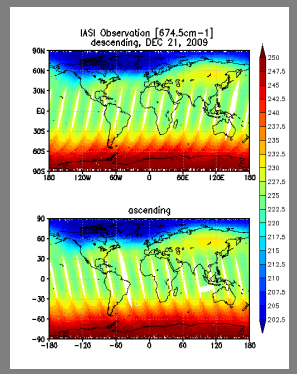
AVHRR



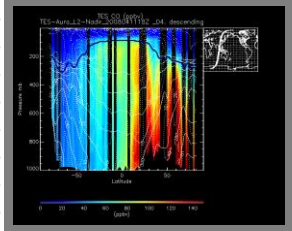
AIRS



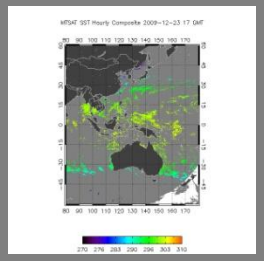
IASI



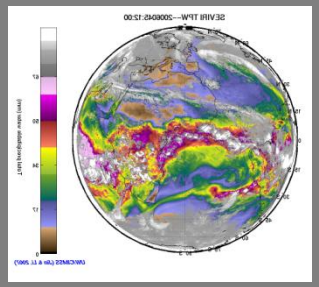
TES



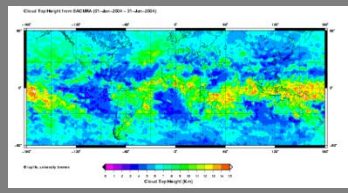
MTSAT



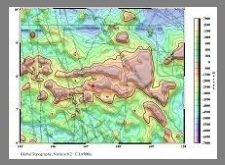
SEVIRI



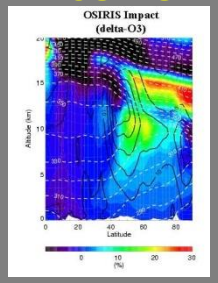
SCIAMACHY



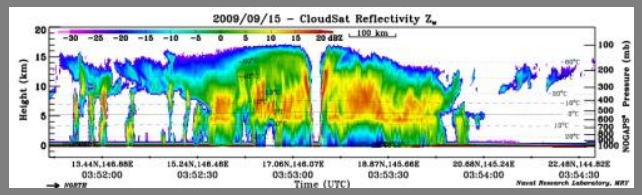
Jason 2



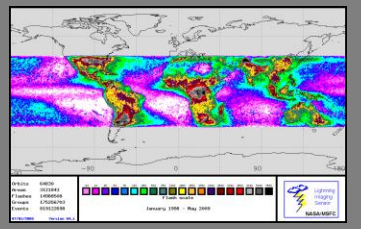
OSIRIS



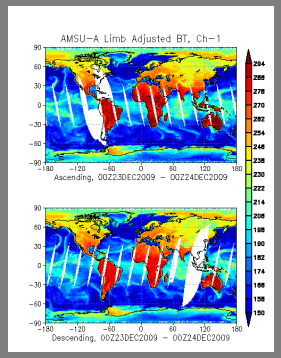
CALIPSO/CloudSat



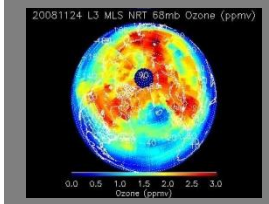
TRMM



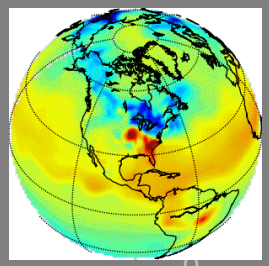
AMSU



MLS



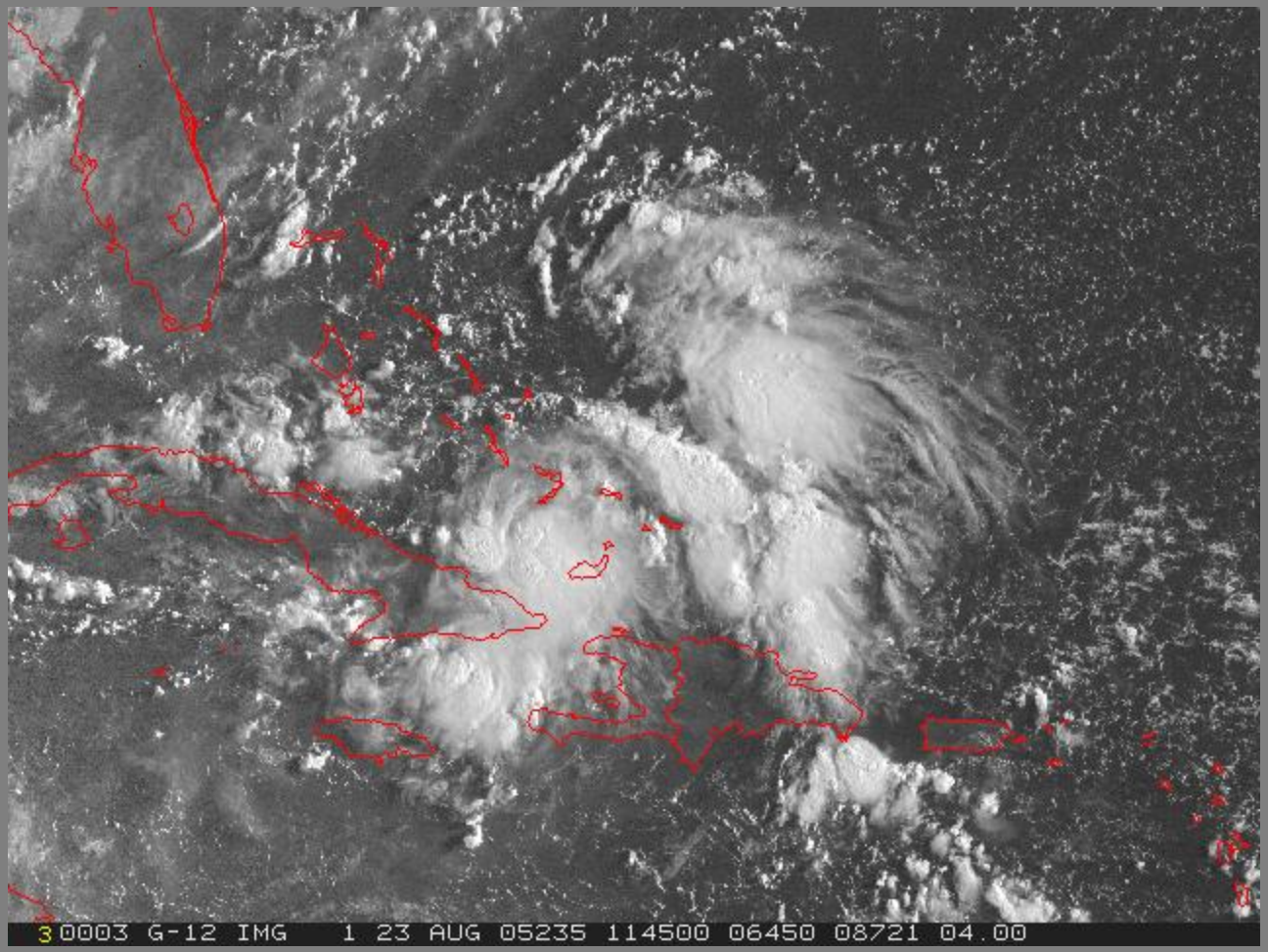
OMI/TOMS/GOME-2



Satellite Data Utilization in Hurricane Forecasting

- Monitoring cloud clusters that may form TCs
- Center location, intensity, structure estimation
  - Vis/IR Dvorak techniques, microwave methods
- Synoptic feature identification
  - Feature track winds, WV imagery
- Sea surface temperature and ocean heat content products
- Assimilation into numerical models
  - Atmosphere and ocean
- Model evaluation/verification
  - Synthetic imagery from model field input to radiative transfer routines
- Predictors in statistical intensity forecast models
  - Oceanic heat content from satellite altimetry
  - GOES data for convective analysis
  - Microwave imagery
  - Lightning data on GOES-R using proxy ground based systems

Monitoring TC Formation

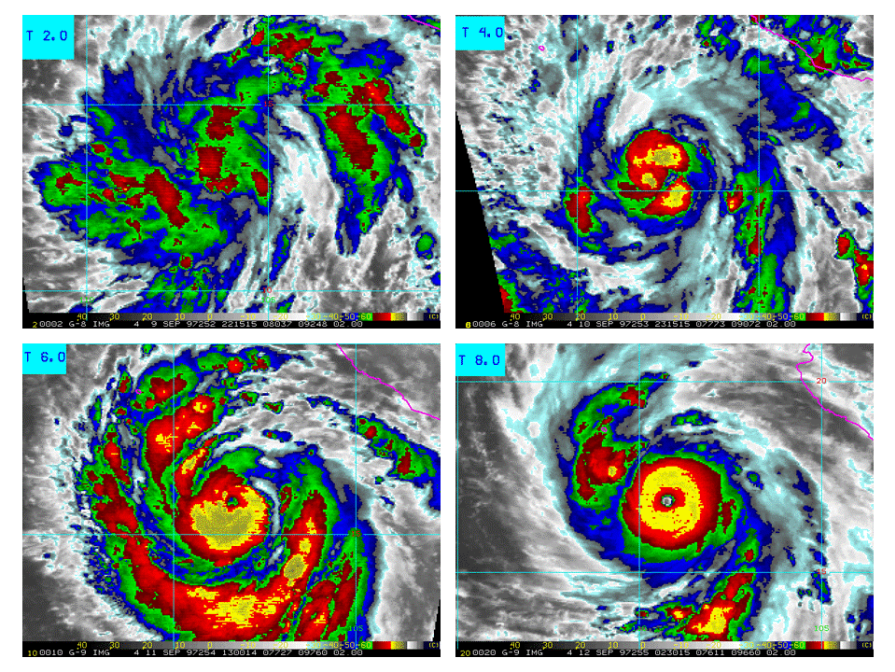


<u>TC definition from NHC glossary of terms :</u>

A warm-core non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined center.

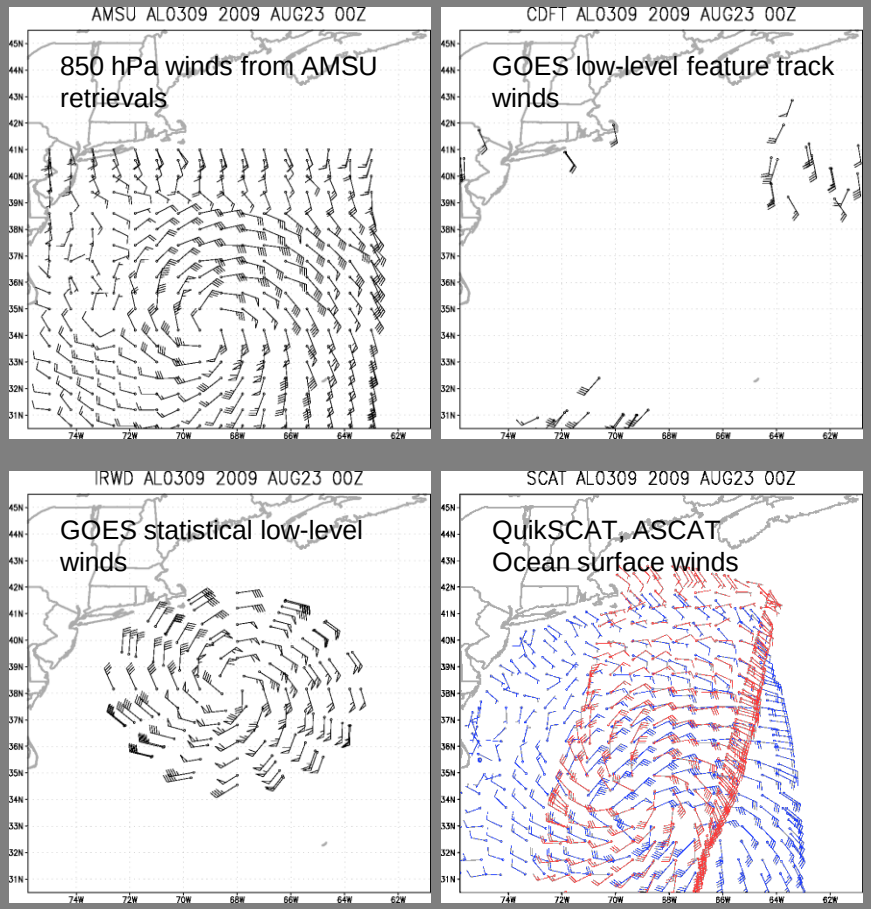
The Dvorak Technique

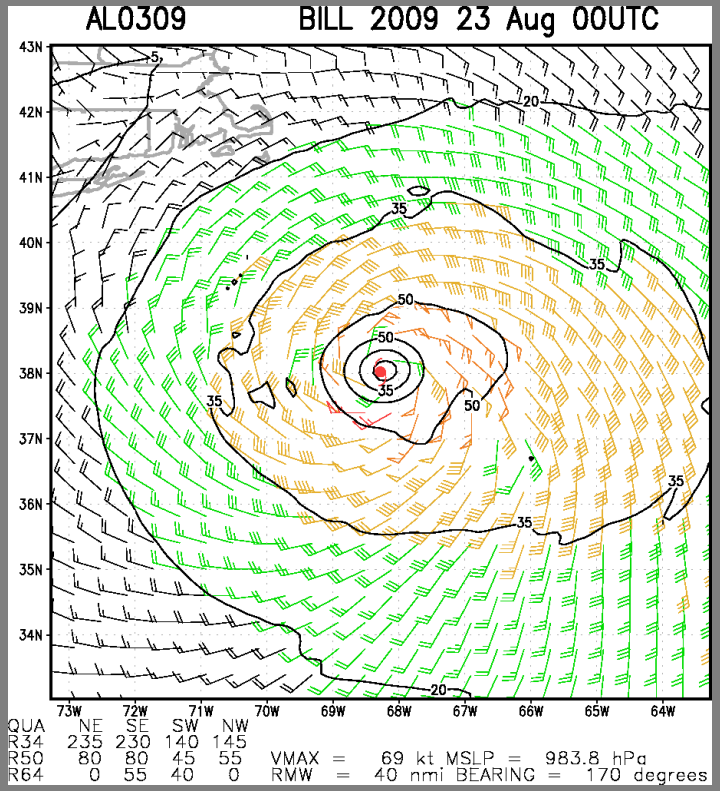
- Based on pattern recognition
- Relates intensity to T-number (1 to 8)
- Vis and IR techniques
  - Partially subjective
- Still the cornerstone for TC intensity estimates in most basins



Wind Structure Analysis

Hurricane Bill 00 UTC 23 Aug 2009

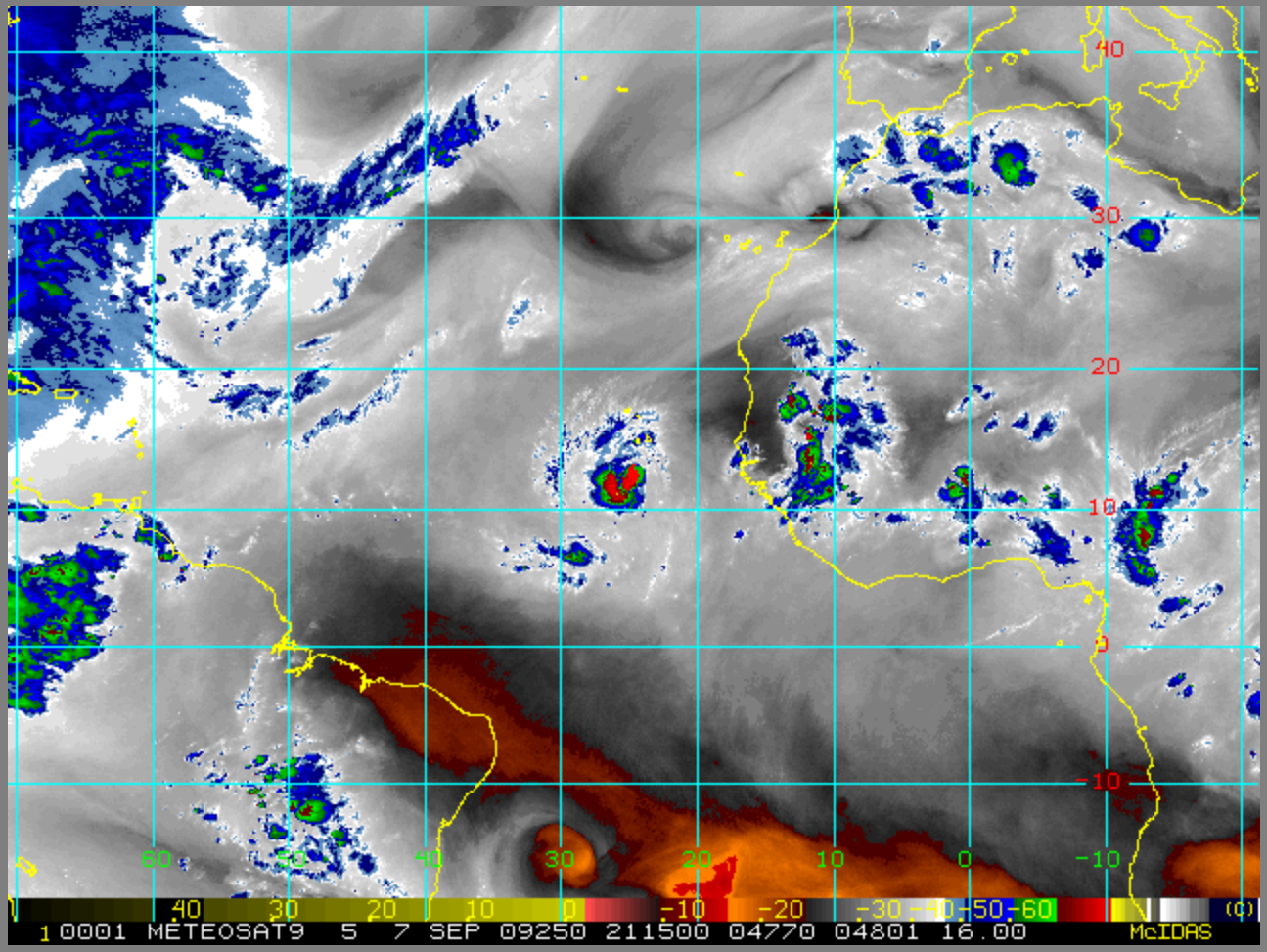




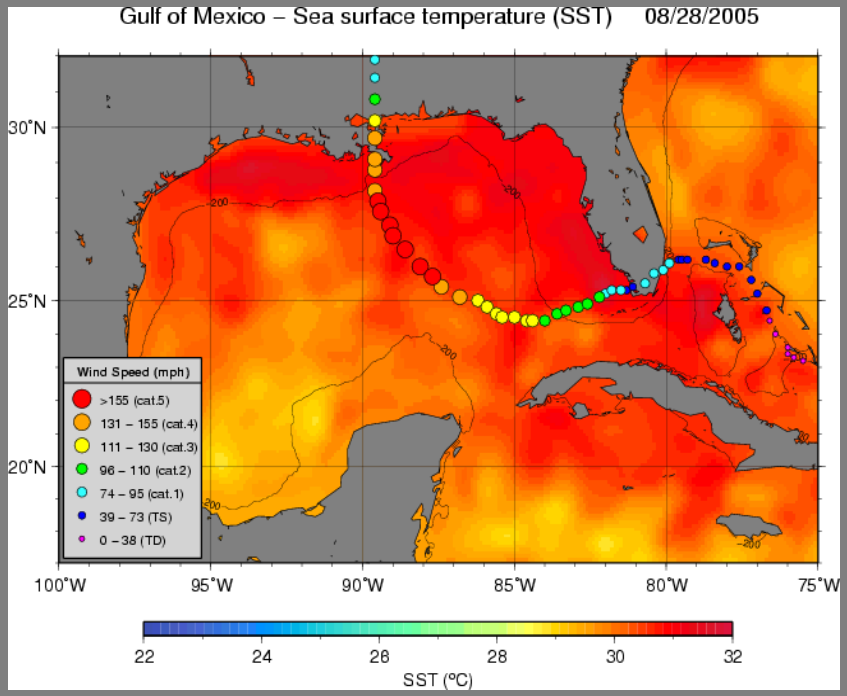
Objective Analysis

Synoptic Feature Analysis

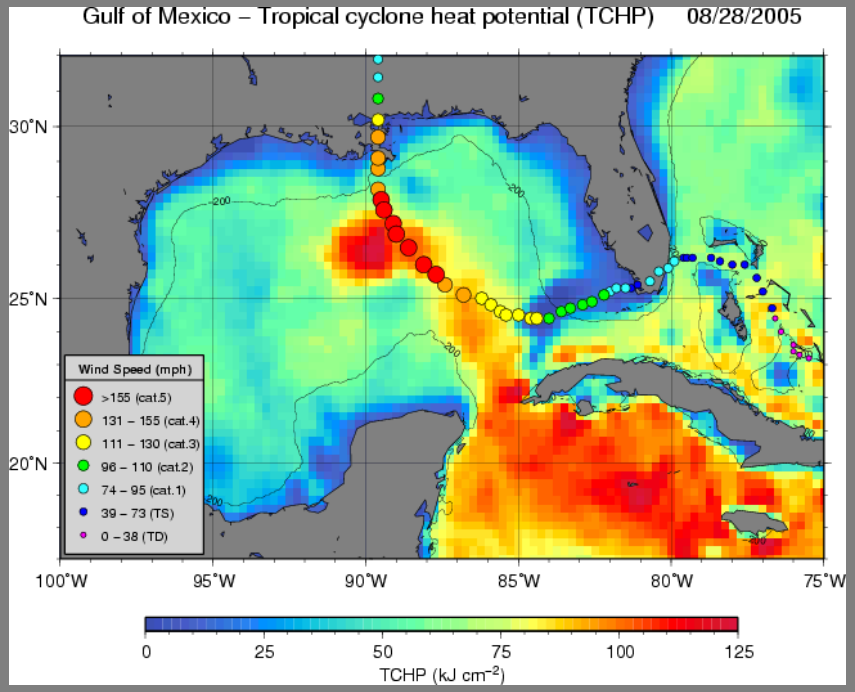
MeteoSat WV Imagery
Hurricane Fred Sept 2009



Satellite-Based Ocean Products



Microwave SST Analyses

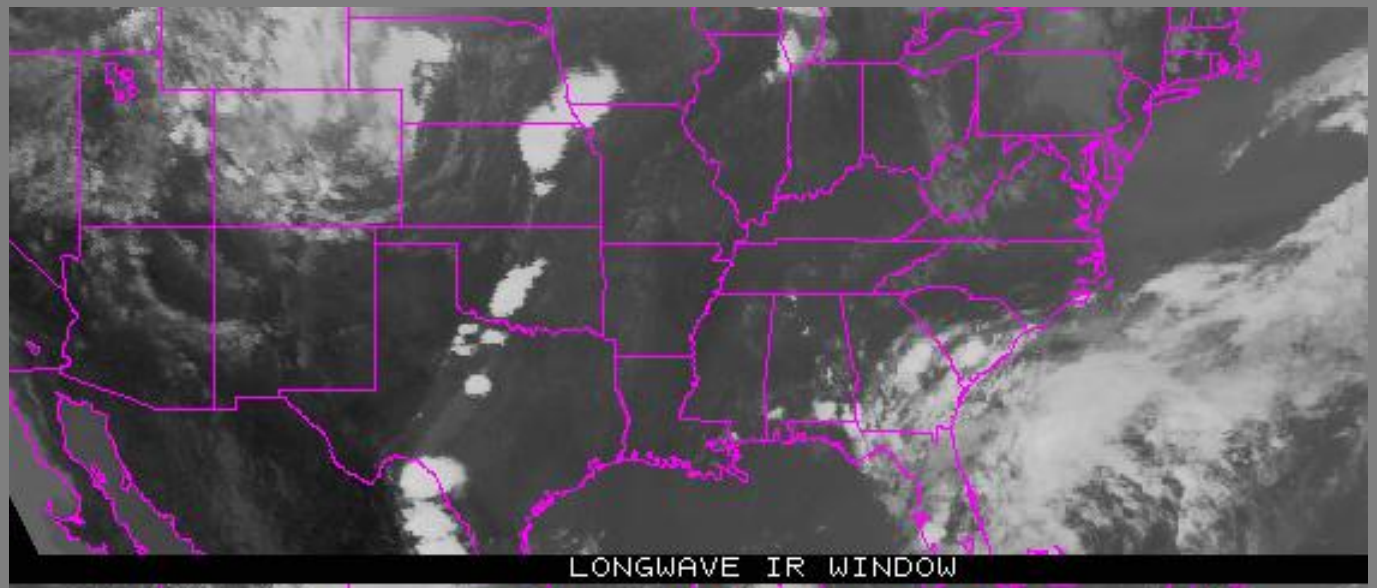


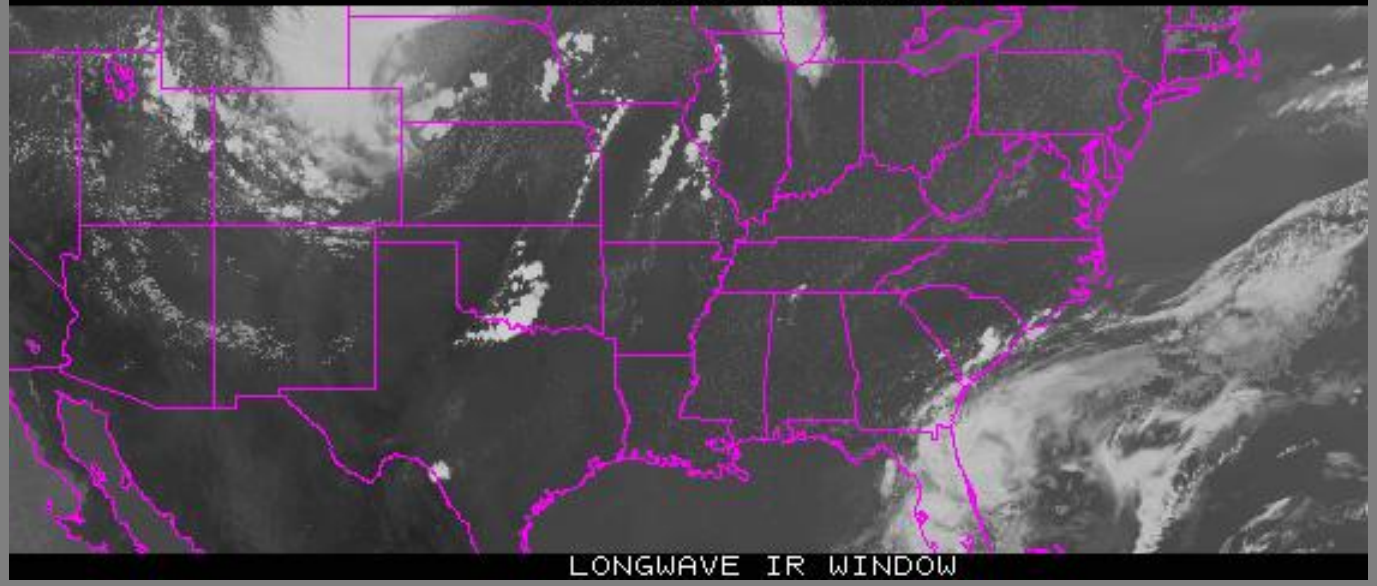
Oceanic Heat Content from satellite altimetry

Synthetic Imagery for Model Evaluation/Verification

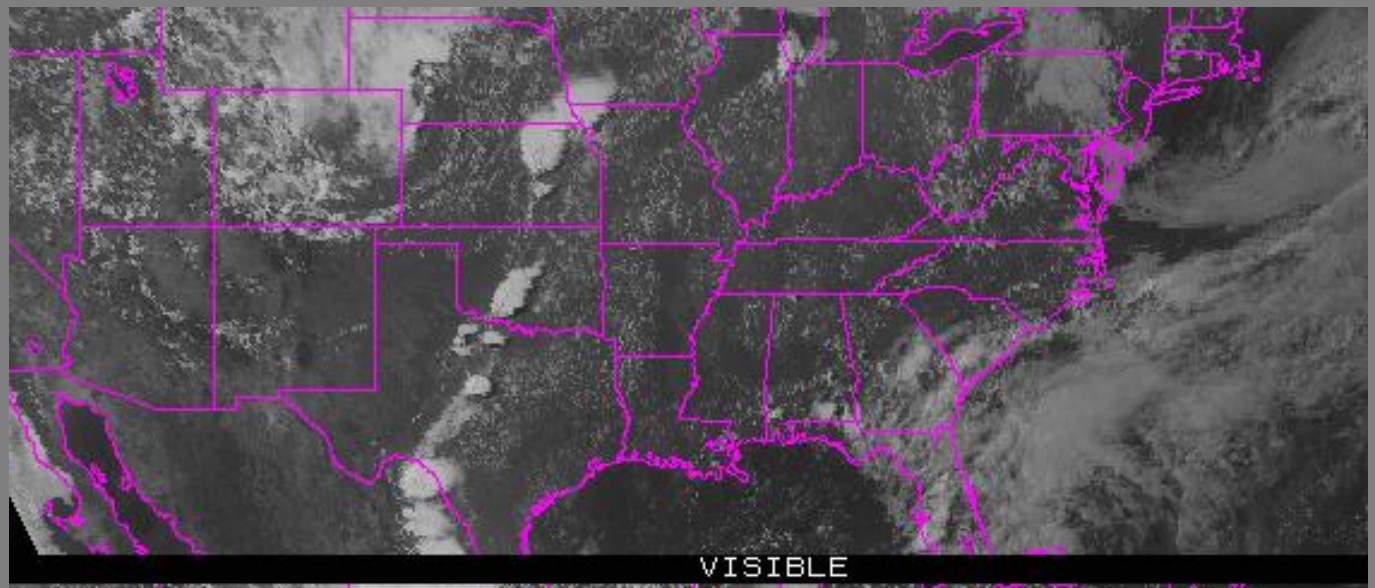
- Use model fields as input to forward radiative transfer models
  - Part of most data assimilation procedures
- Also useful for comparison with real observations
  - Verification in “radiance” space
- Preparation for product development from new sensors
  - GOES-R advanced baseline imager

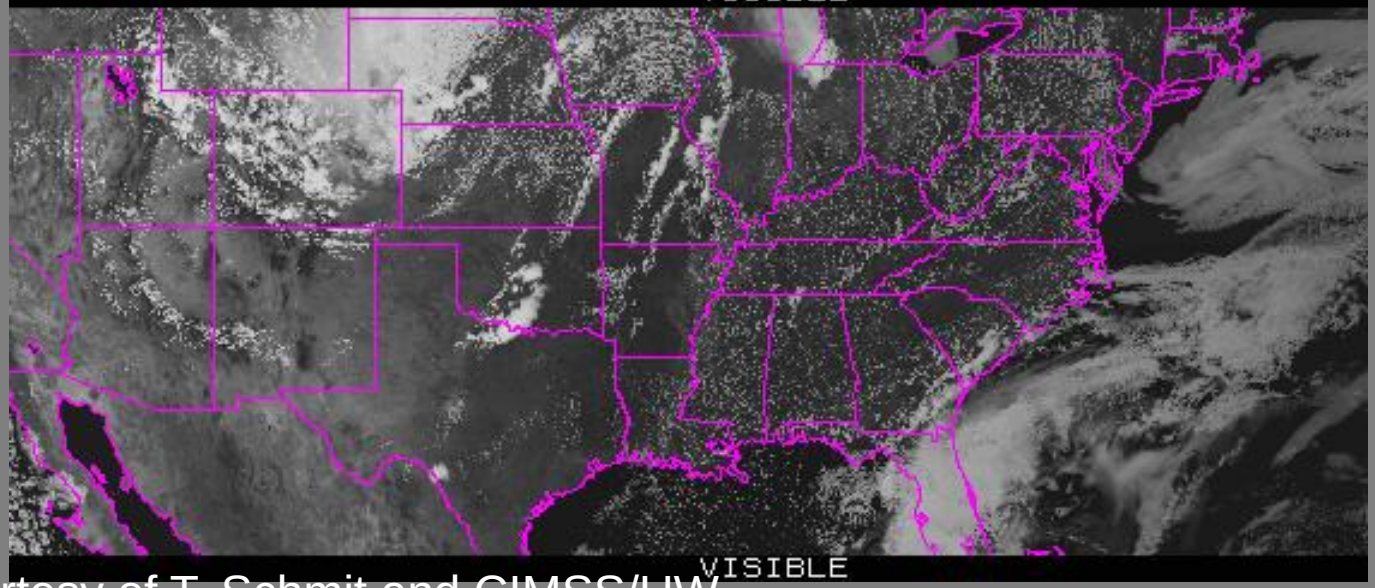
Real, Simulated GOES IR



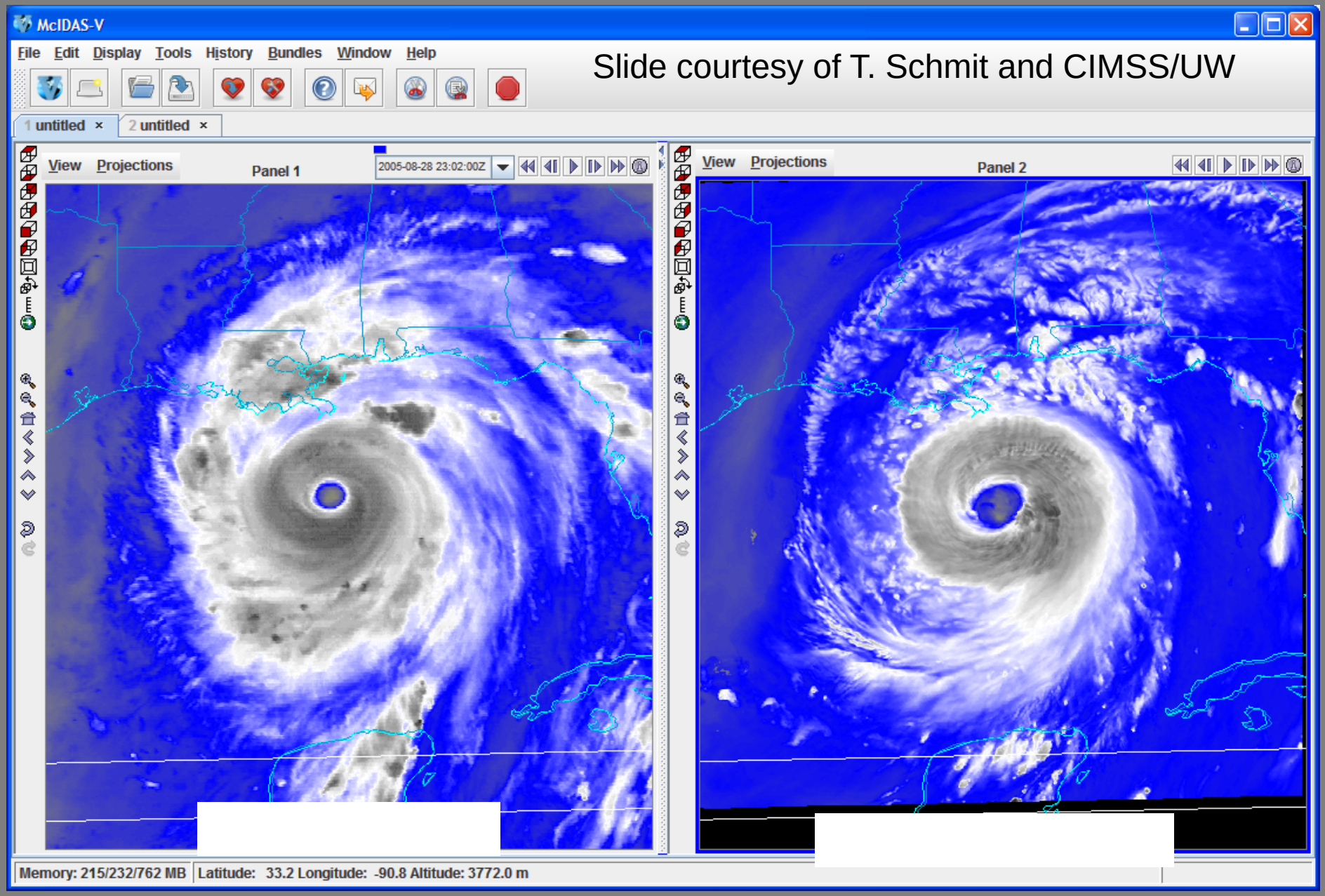


Real, Simulated GOES Vis

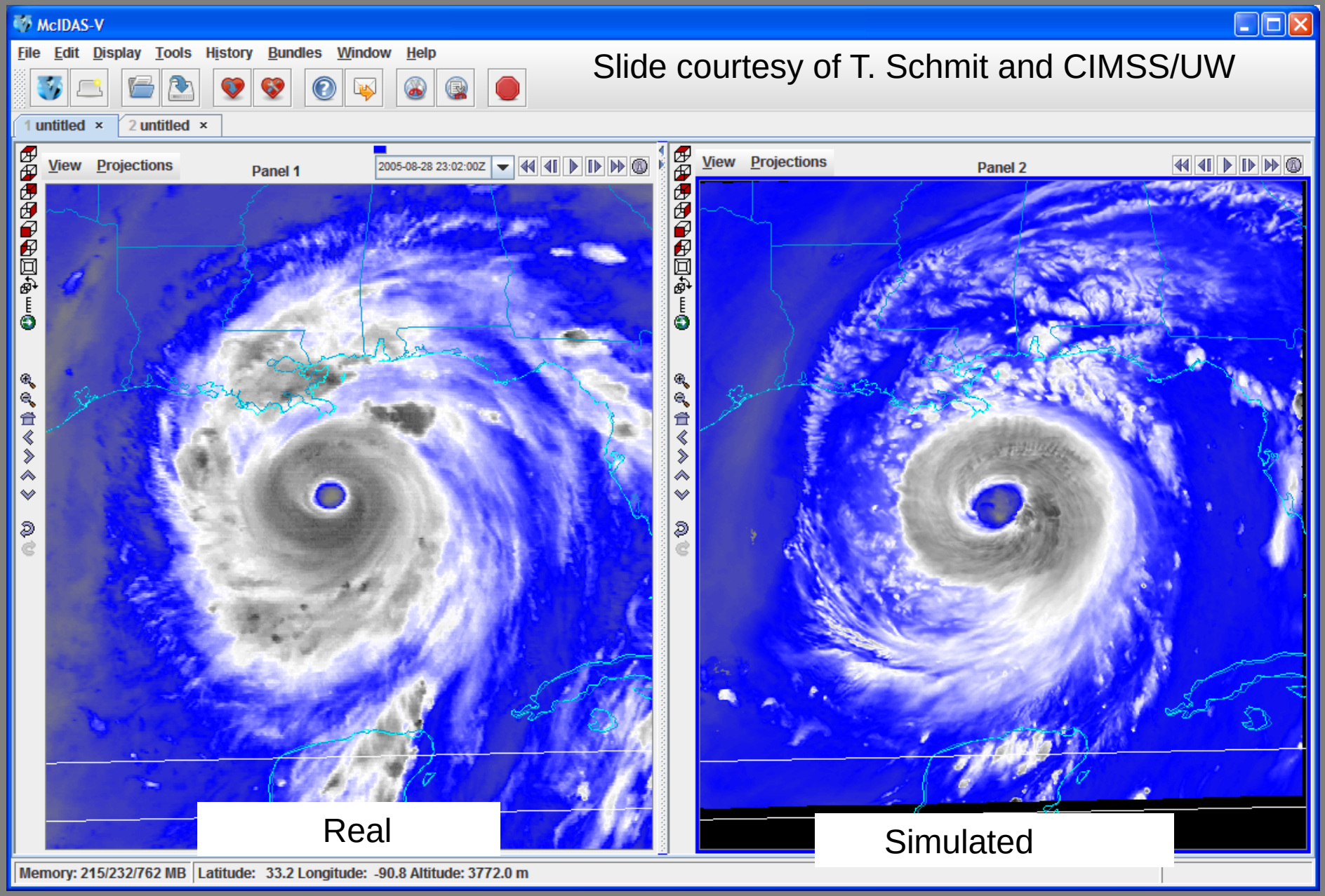




Slide courtesy of T. Schmit and CIMSS/UW

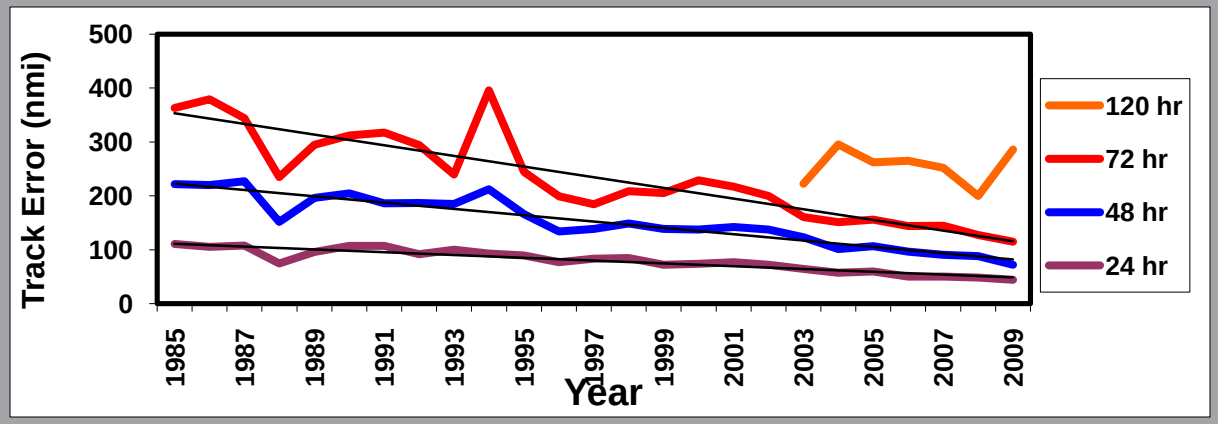


One image is simulated, the other observed from current GOES Imager. Shown in McIDAS-V.

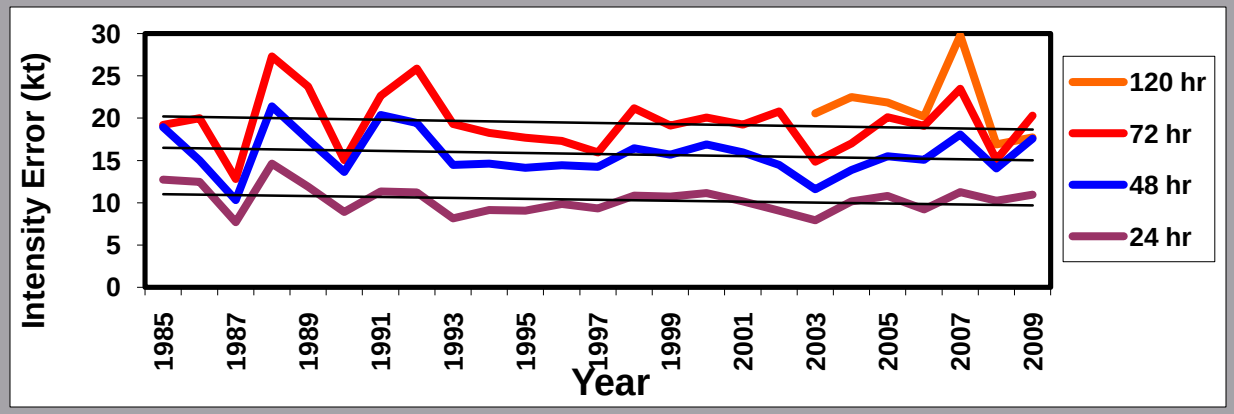


One image is simulated, the other observed from current GOES

Long Term Trends in NHC Tropical Cyclone Forecast Errors – Track vs. Intensity



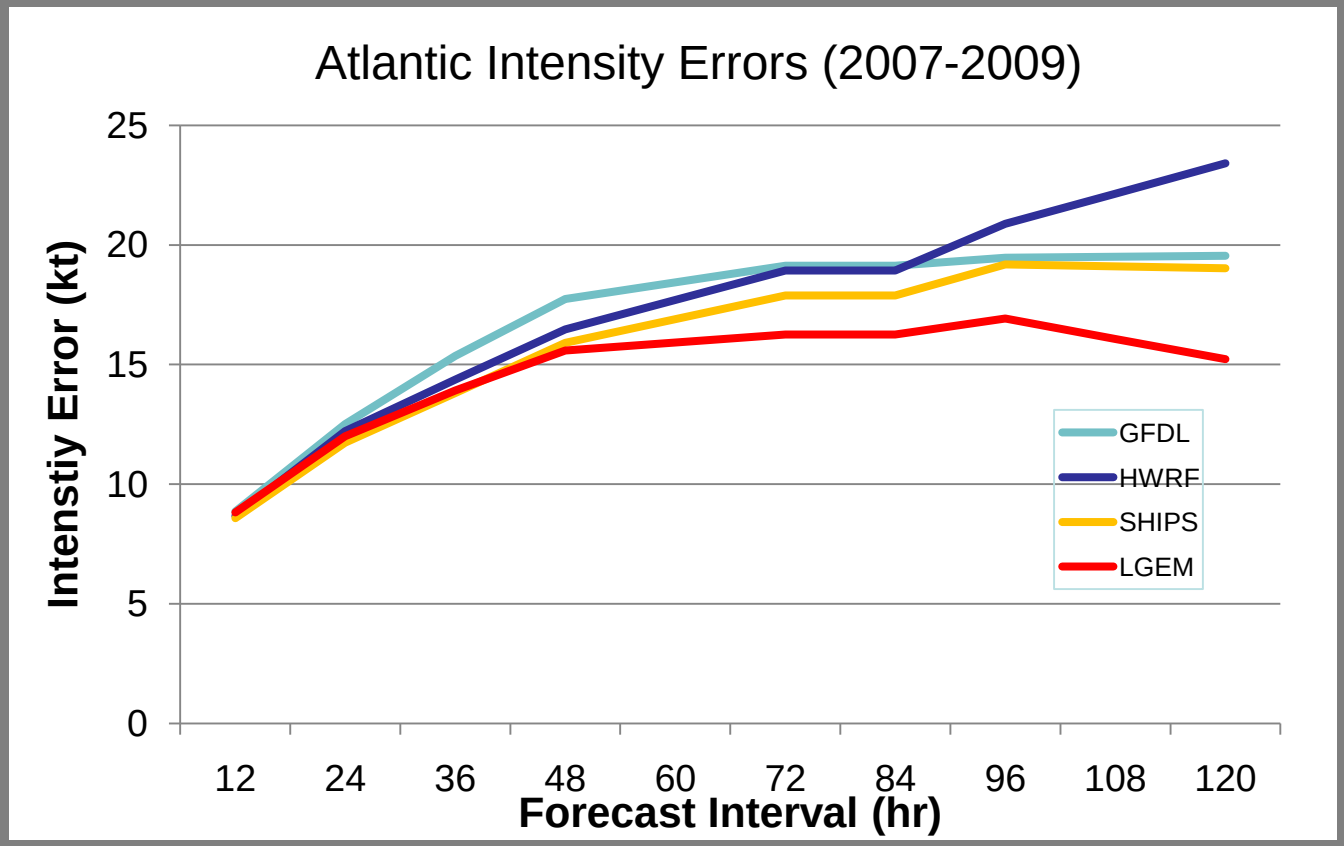
48 hr Track Improvements ~3.7% per year



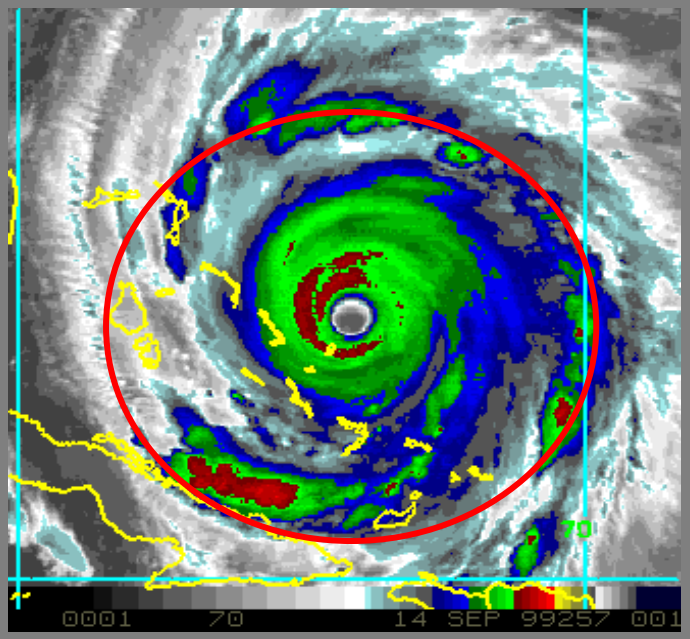
48 hr Intensity Improvements ~0.6% per year

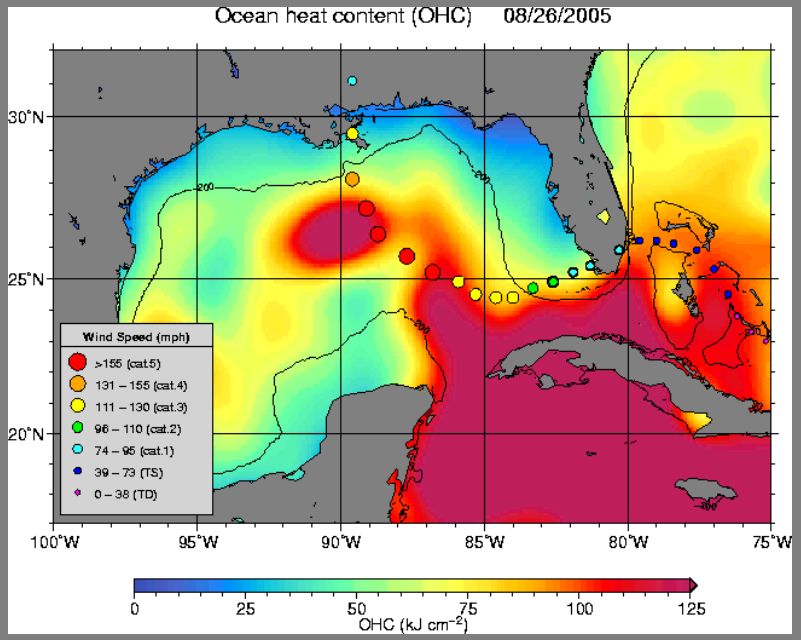
Intensity changes involve wider range of scales and physical processes than track and are much harder to predict .

Operational Hurricane Intensity Forecast Guidance Model Performance



Satellite Predictors in SHIPS/LGEM

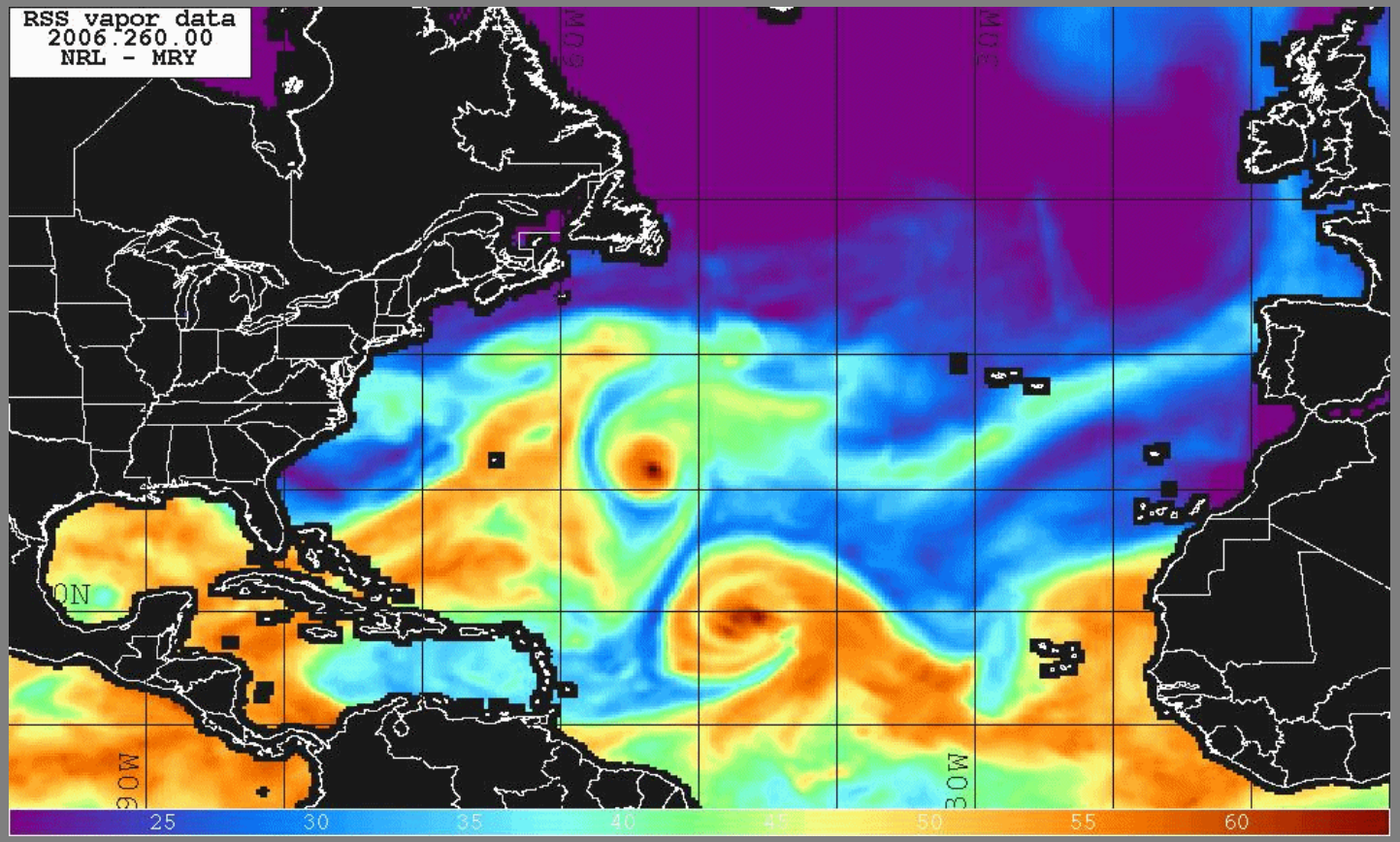




1. GOES cold IR pixel count
2. GOES IR T_b standard deviation
3. Oceanic heat content from satellite altimetry (TPC/UM algorithm)

Cold IR, symmetric IR, high OHC favor intensification

New SHIPS/LGEM Predictors from satellite Total Precipitable Water (TPW) products



- 0-100 km average TPW
- Percent 400-600 km area with TPW < 45 mm

Ring structure in 37 GHz Microwave imagery precursor to rapid intensification

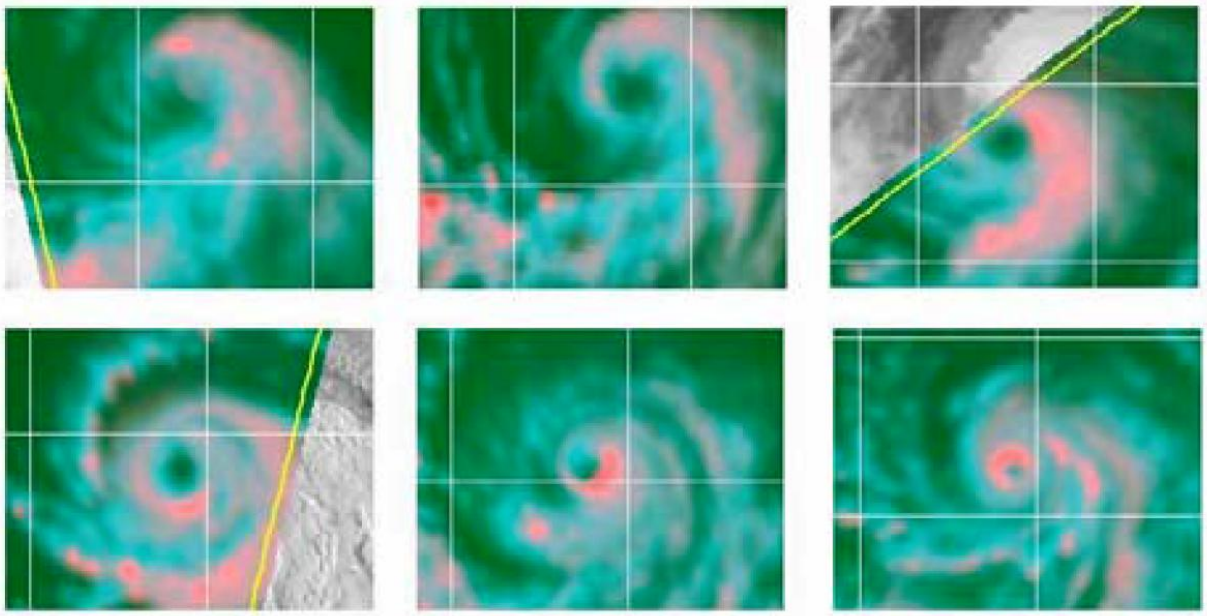


Figure 7. 2004 Hurricane Ivan, showing a rapid improving trend in organization, while increasing in intensity from 50 kt to 115 kt in a 36-hour period

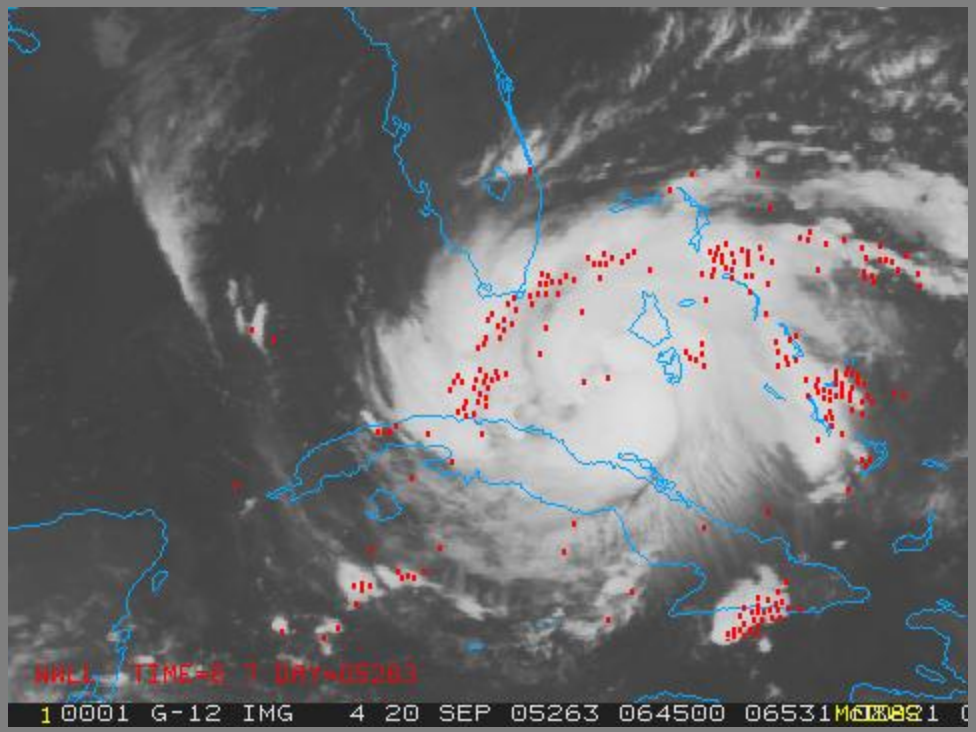
From Kieper, 2008: AMS tropical conference

Next Generation Operational Satellite Systems

- GOES-R series (~2015)
  - 16 channel advanced baseline imager
  - Lightning mapper
- Meteosat Third Generation (~2015)
  - Multi-channel imager
  - Lightning mapper
  - Hyperspectal IR sounder
- NOAA polar satellites
  - NPOESS
    - Fairytale wedding ends in divorce
  - Joint Polar Satellite System (JPSS) (~2014?)
    - NOAA-NASA joint venture (similar to GOES)
    - Advanced imagers and sounders

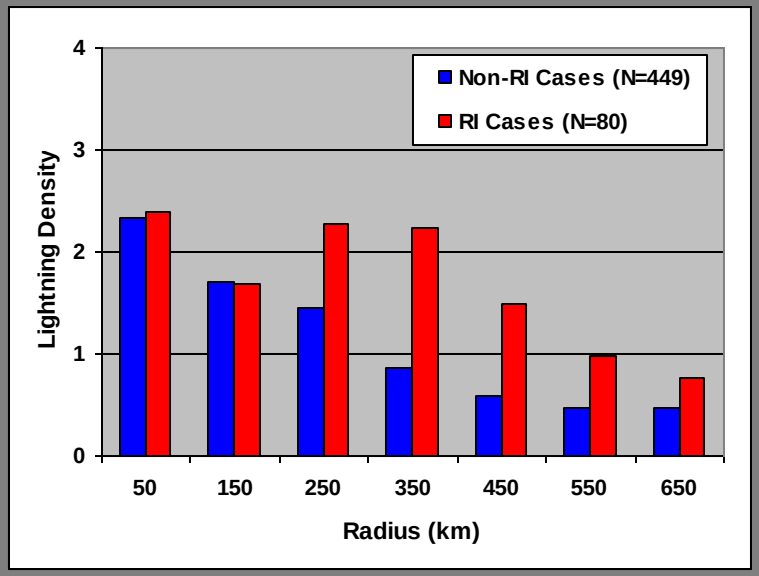
Lightning and Tropical Cyclone Intensity Change

- Ground-based lightning networks proxy for GOES-R
- WWLLN provides global data
- All 2005-2008 Atlantic and eastern North Pacific cases analyzed
- Relationship with intensity changes more complex than in previous studies
- Vertical shear influence masks relationship with intensity changes
- Strong predictive signal when shear accounted for

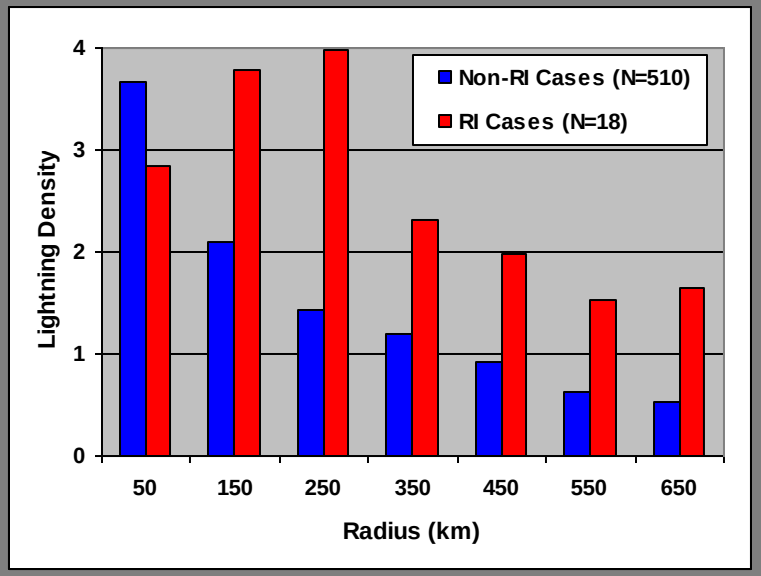


1 hour lightning composites for Hurricane Rita (2005)

Lightning Density for Atlantic RI and non-RI Cases

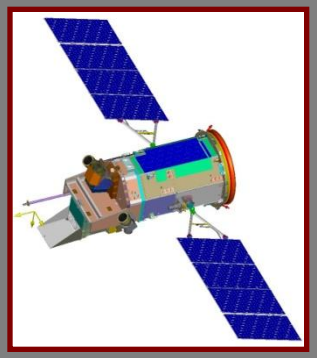


Low Shear



High Shear

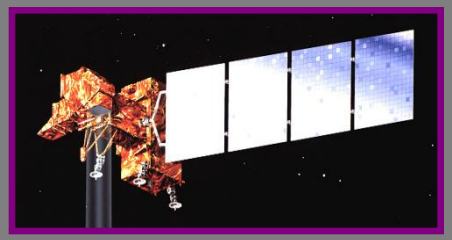
NASA Missions in Formulation and Implementation (tier 1)



GLORY

AQUARIUS

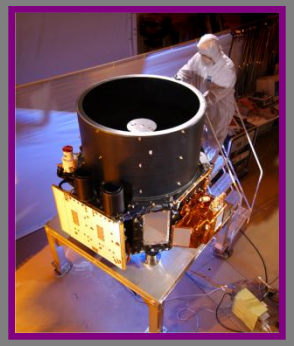
NPP



LDCM

GPM

SMAP



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Summary

- Satellite data have many applications to tropical cyclone forecasting
- Current and future systems provide huge volumes of data
- Considerable work is needed for extracting the information content from the data
  - *Existing data is not fully utilized for tropical cyclone forecasting*
- Promising new developments
  - Total lightning
  - Hyperspectral sounder on a geostationary satellite
  - Advanced imagers and sounders on GOES-R and JRSS