Project CyMISS
Tropical Cyclone Measurements from the ISS

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Acronyms and Terminology (I)

- **Tropical Cyclones** (TCs):
  - The generic name for large, violent weather systems that originate over the world's tropical oceans
  - Known as "hurricanes" or "typhoons" in different parts of the world
- **TC Categories:**

Category	Wind Speed (mph)	Storm Surge (feet)	Damage
1	74-95	4-5	Minimal
2	96-110	6-8	Moderate
3	111-130	9-12	Extensive
4	131-155	13-18	Extreme
5	155 +	18 +	Catastrophic

Measurement Range

- **Cat 3 to 5 cause 93% of the loss of lives and property damage**

Acronyms and Terminology (II)

- The **eye** is the clear, calm region at the center of a TC
- The **eyewall** is the region surrounding the eye where the most violent winds and torrential rainfall of a TC are found. **ECT** is the abbreviation for Eyewall Cloud Top.
- **NWP Codes** = Numerical Weather Prediction codes: Computer programs that use current atmospheric conditions to forecast the weather
- **CyMISS** (Tropical Cyclone Measurements from the International Space Station) an on-going Visidyne project, peer-reviewed by NASA, and funded by CASIS (Center for the Advancement of Science from Space)

TROPICAL CYCLONES (aka, Hurricanes and Typhoons)
The Most Destructive Natural Forces on Earth

1970- Bangladesh: Killed ~600,000 people- greatest loss of life from a natural disaster in world history

2005- Katrina: ~$143 billion in damage, greatest property destruction from a natural disaster in history;

2012-Sandy: ~$75 billion in property losses along the US east coast

~20 major TCs per year worldwide, causing ~$26 billion in property damage and ~10,000 deaths yearly

Current Practice

- Only indirect methods, such as techniques based on comparisons of storm cloud patterns as seen from weather satellites (modified Dvorak), are widely available to estimate TC intensities
  - Hurricane hunter aircraft are used only in the Atlantic basin and northeastern Pacific oceans
- Current methods frequently experience errors in excess of ±20% in maximum surface wind speeds and damage is an exponential factor, ~$1.4^{3 \text{ to } 9}$ (can be an order of magnitude**)**
- New space-based technologies such CYGNSS primarily address weaker TCs and are complimentary to our approach

Track Forecasts are better but Little Improvement on Intensities

Dr. Peter P. Neilley, Senior VP of Global Forecasting Services

The Weather Company - Published: Aug 24 2015 06:00 AM EDT

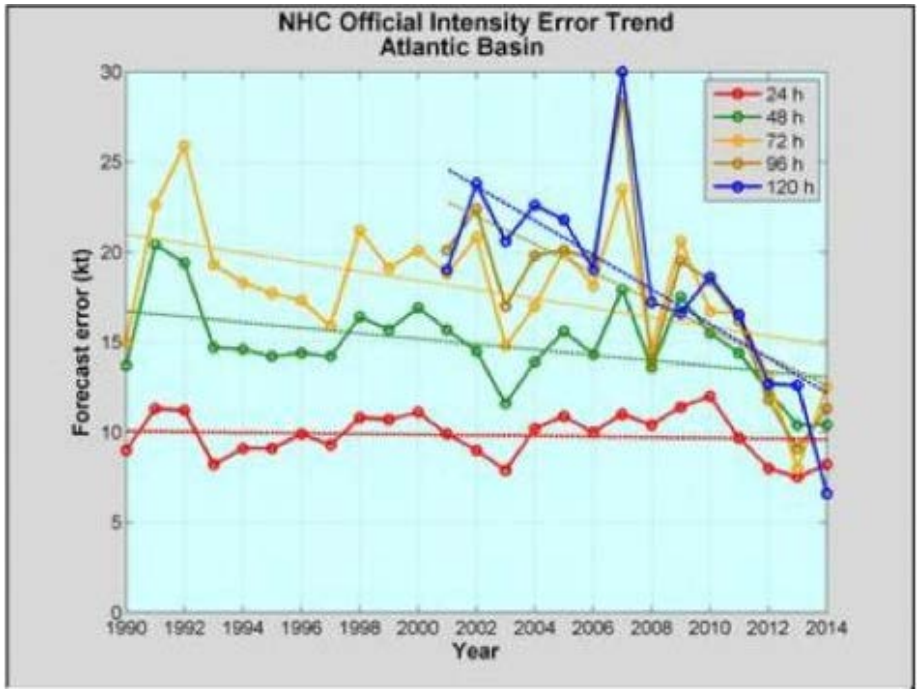


Figure 2. Ten year trends in the errors of Atlantic tropical storm and hurricane intensity forecasts. (Courtesy NOAA, National Hurricane Center)

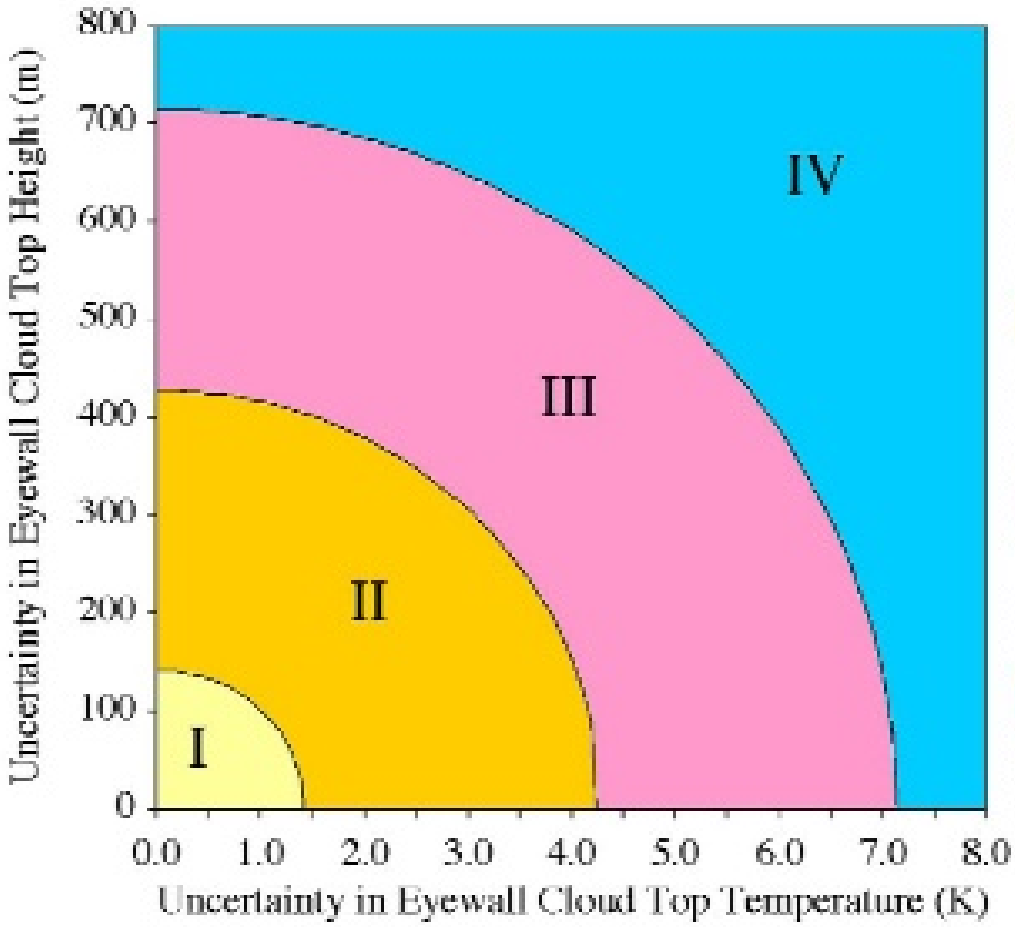
Figure 2. "Knowing where a hurricane is going is one thing, but it's also important to know how strong it will be when it gets there. Unfortunately, up until recently, that part of the story was not so good. This figure shows the trends in NHXэσ ability to predict the strength of the winds near the center of a hurricane. It shows that between 1989 and 2010, there was very little improvement in the ability to predict the strength of the storms and nowhere near the rate of improvement in track forecasts. The two-day-ahead hurricane intensity forecasts over that period improved only about 15 percent and **hardly made any gains against the one-day-ahead forecasts".**

Our Approach

- Prof. Kerry Emanuel/MIT developed the accepted theory of how a TC derives its energy from the warm, moist air above tropical oceans – a Carnot Engine
  - Initial work was down as a consultant to Visidyne, Inc. with participation by Prof Paul Joss/MIT, also as a consultant; part of the RAMOS Science Team led by Dr. A. T. Stair
- Our Technique: Based on Emanuel's model
  - With space-based sensors we simultaneously measure the altitude and temperature of the tops of the clouds above the eyewall ("eyewall cloud tops," or ECTs) with high resolution and accuracy; stereo (parallax) for altitude.
    - These measurements plus the ocean surface temperature determine the peak surface wind speeds of a TC to high accuracy
    - Retrieving the Central sea level pressure with an accuracy of less than +/- 5 hPa (hectopascals) are possible, see next VG/Nomogram
  - Published results from two major field experiments, the latest (2013) by Emanuel et al, have validated the approach but with much less accuracy
  - Visidyne is working closely with NOAA's leading laboratory on hurricane research, AOML (Atlantic Oceanic Meteorology Laboratory, Director: Dr Bob Atlas

Measurements with Errors Less Than 500 m in altitude and a Few Degrees in Temp Will Significantly Improve Tropical Cyclone Knowledge/Predictions

The Carnot Cycle concept has been validated in published papers for Zone III (600 m altitude accuracy)



$\delta P \equiv \delta \mid P_c - P_a \mid$

I : $\delta P \leq 5$ hPa
Excellent estimate of storm intensity

II : 5 hPa $\leq \delta P \leq$ 15 hPa
Substantial improvement over existing satellite techniques

III : 15 hPa $\leq \delta P \leq$ 25 hPa
Marginal improvement over existing satellite techniques

IV : 25 hPa $\leq \delta P$
Less useful than existing satellite techniques

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Retrieval of Altitude by Stereo

- Measuring ECT features, simultaneously, by two satellites allows one to use parallax to retrieve the third dimension (altitude). Measurements using one satellite with sequential measurements are being explored with CyMISS.
  - The altitude accuracy is dependent upon the pointing knowledge in inertial coordinates and the spatial footprint size at the ECT.
  - Current ISS measurements are lacking in accurate point knowledge. Consequently, Visidyne is lobbying Congress for support in the NOAA/OAR/AOML budget to put a “calibrated” infrared camera with a star sensor on the ISS

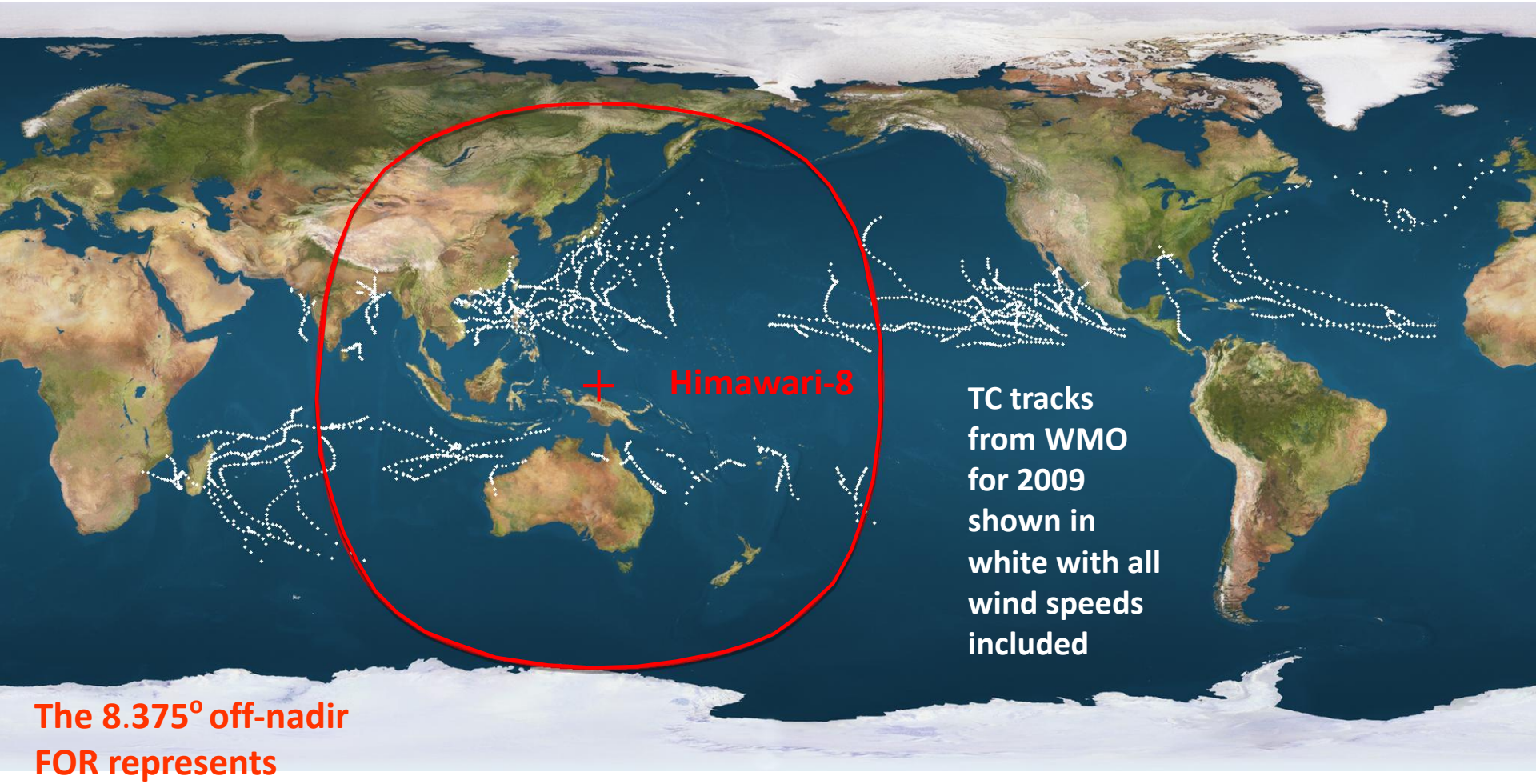
- To get near-simultaneous temperature measurements CyMISS is exploring the use of the new geostationary weather satellite, Himawari-8, located over the Western Pacific (GOES R is scheduled to be launched in November, 2016)

Tropical Cyclone Measurements from the ISS (CyMISS)

- Visidyne is actively engaged with the ISS astronauts who are taking measurements of major tropical cyclones (TC) on a regular basis. Took almost 2 years to establish the routine use of our designated protocol.

- Measurements of the ECT temperatures are being made, nearly simultaneously.

GEO Satellite 8.375 Degrees Off-Nadir Fields-of-Regard (FOR) and Tropical Cyclones



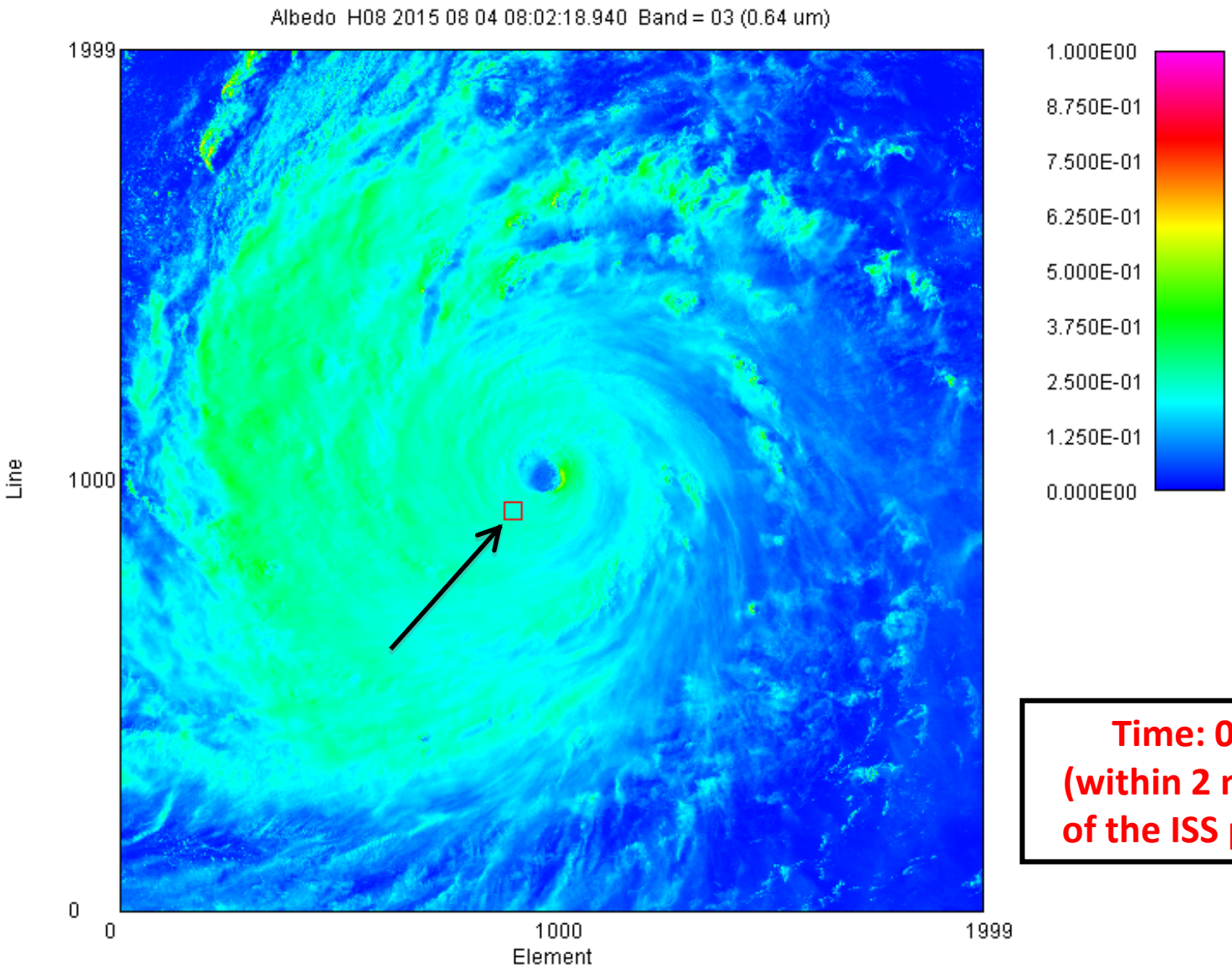
The 8.375° off-nadir FOR represents approx the max angle useable for stereo/parallax

GEO Horizon = 8.7°

Satellite	Lat (deg)	Long (deg)	Alt (km)	Max Nadir Ang (deg)
H-8	0.0	140.7	35786.0	8.375

Himawari-8 TC Soudelor Data, Visible Band 3 (0.64 µm)

The red box shows the region selected for temperature measurements



Time: 08:02 (within 2 minutes of the ISS photos)

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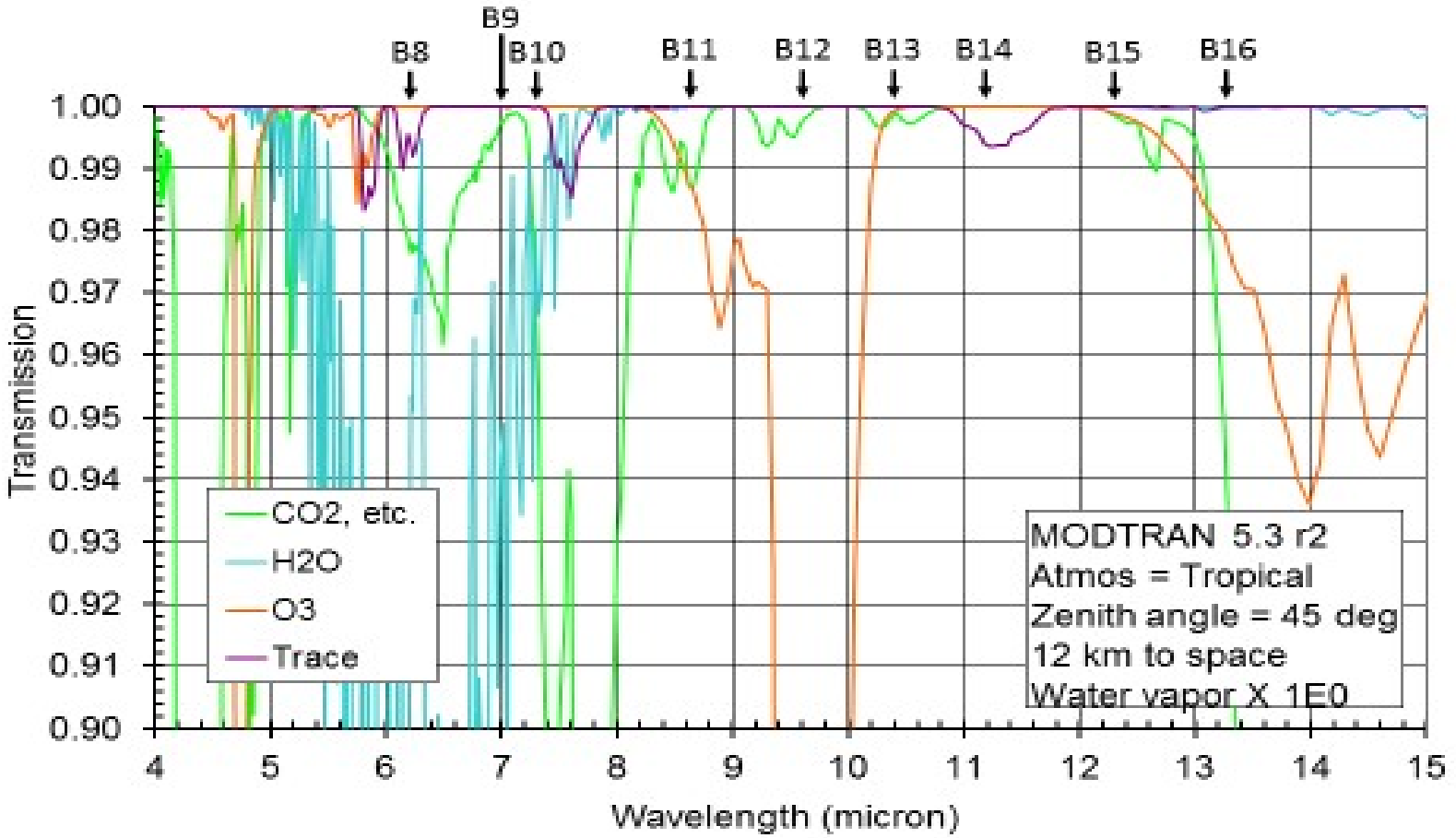
MODTRAN calculation of the transmission of the tropical atmosphere above 12 km, which is taken as an altitude characteristic of eyewall cloud tops

The colored curves show the transmissivities of various molecular atmospheric components. The black arrows indicate the locations of Himawari 8 AHI LWIR bands.

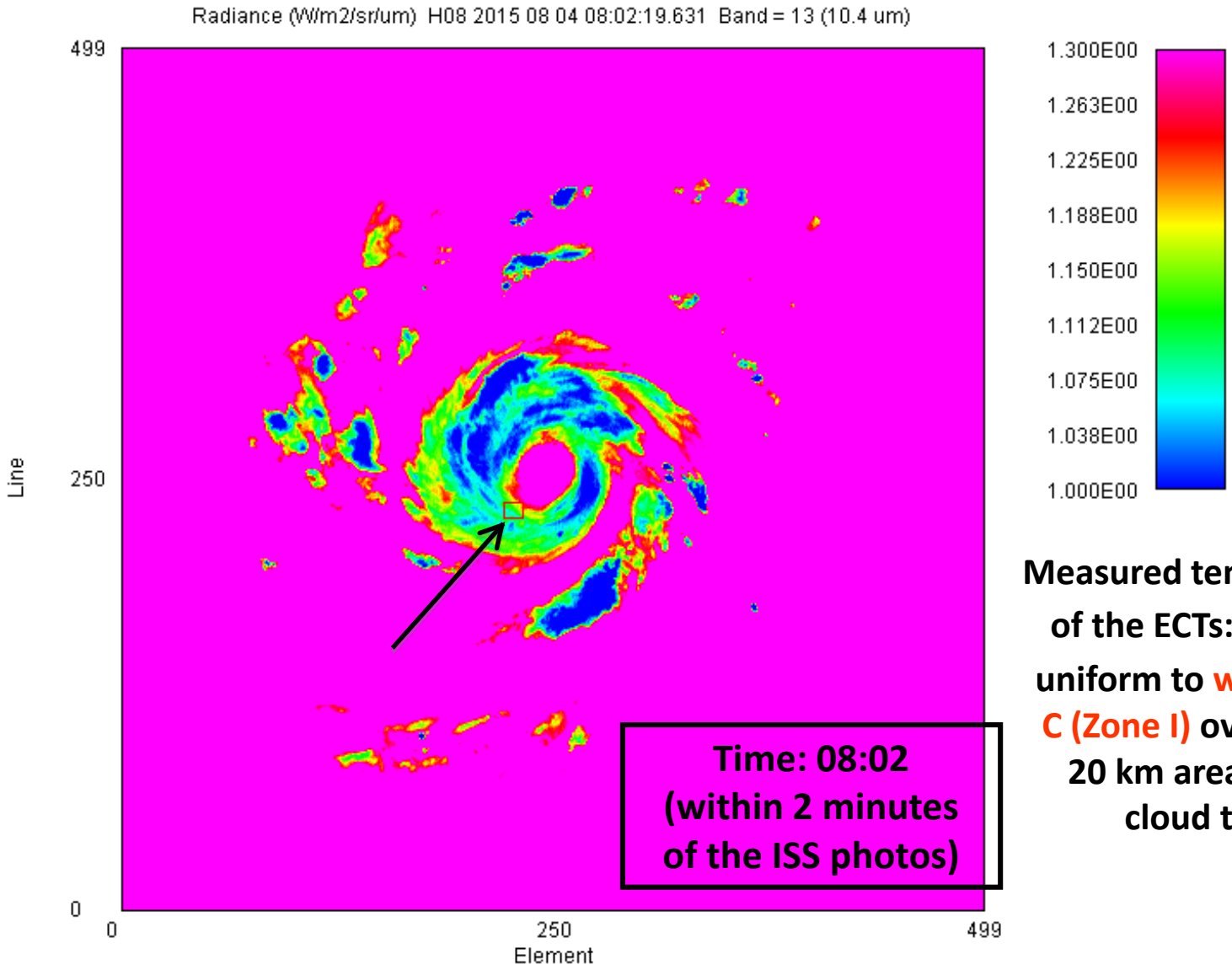


Comparison of Temperatures in the Selected Cloud Top Region Retrieved in Bands 11, 13, 14, and 16.

Comparison of temperatures in the selected cloud top region retrieved in bands 11, 13, 14, and 16.				
Quantity	Band 11 (8.6 μm)	Band 13 (10.4 μm)	Band 14 (11.2 μm)	Band 15 (13.3 μm)
Time	08:02:18.396	08:02:19.369	08:02:19.369	03:02:19.019
# values	10 X 10	10 X 10	10 X 10	10 X 10
Ave Temp (K)	204.31	204.15	203.08	203.45
Stand. Dev. (K)	1.13	1.06	0.92	0.77
Stand. Dev. of Mean (K)	0.11	0.11	0.09	0.08
Maximum (K)	207.51	207.27	206.03	205.65
Minimum (K)	202.50	202.29	201.65	202.10

Himawari-8 Thermal Band 13 (10.4 µm) Radiance (W/m²/sr/µm)

The red box shows the region selected for temperature measurements



Measured temperature of the ECTs: –39° C, uniform to within ±1° C (Zone I) over a 20 x 20 km area of the cloud tops

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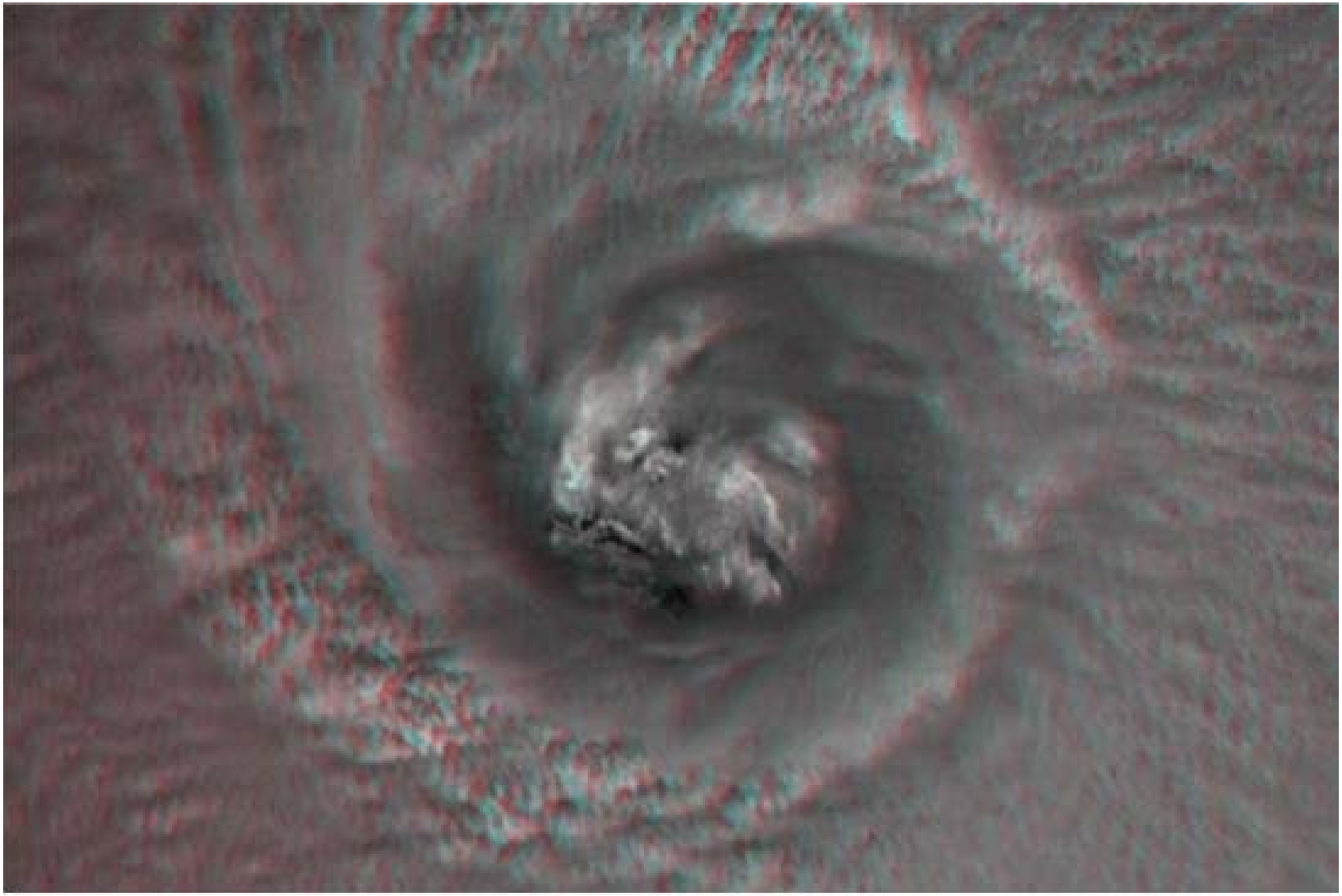
Anaglyph 3D Image of Typhoon Atsani (August 19, 2015)



View of the eye and eyewall of Typhoon Atsani, expanded to a scale of 225 x 150 km and reprojected to approximate an overhead view. The 3D information is obtained by the parallax effect – making use of the changing angle from the ISS to the storm during its overpass on August 19, 2015.

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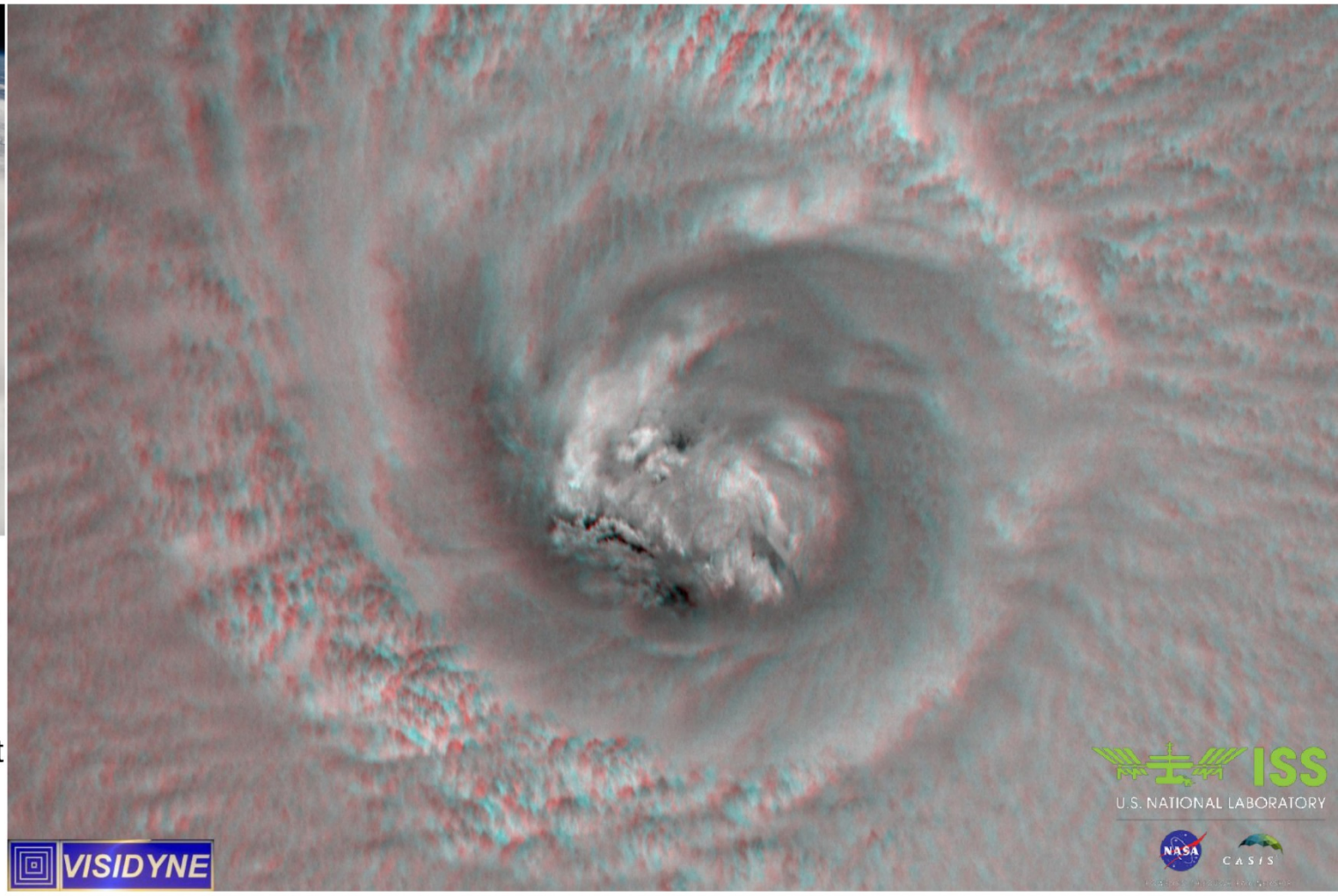
Anaglyphic Stereo Image of Super Typhoon Atsani

Original Image
by Astronaut Kimiya Yui

Tropical Cyclone Project
(aka CyMISS)
supported by CASIS
*www.iss-**casis**.org*



"Looking into the Eye of a Hurricane"

View of the eye and eyewall of Typhoon Atsani, reprojected to approximate an overhead view. The 3D information is obtained by the parallax effect – making use of the changing angle from the International Space Station to the storm during its overpass on 19 Aug 2015.

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POCs: Prof Emeritus Paul Joss, MIT/VI and Dr A. T. Stair, VI