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A New Method for Accurate Remote Measurement of Tropical Cyclone Intensities

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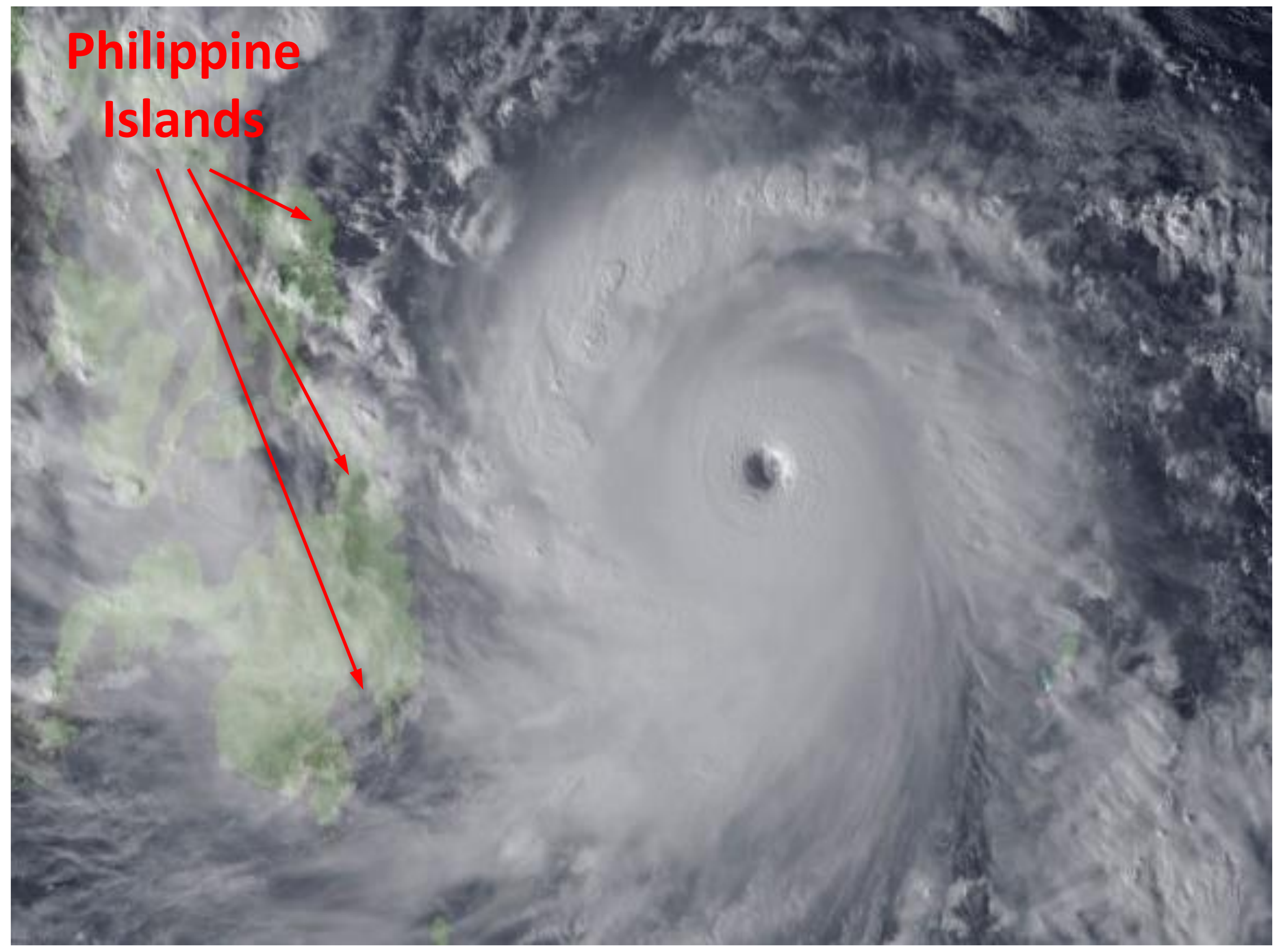
P. C. Joss[1,2] (joss@space.mit.edu), A.T. Stair[2] (ats@visidyne.com), J. G. DeVore[2] (devore@visidyne.com), G. E. Bingham[3] (Gail.Bingham@sdl.usu.edu)

(1) A Tale of Two Storms

To illustrate the importance of tropical cyclone intensity, consider two storms. The figure below shows super typhoon Haiyan on 7 November 2013, a day before landfall when it was category 5 and still intensifying.



Haiyan made landfall near Tacloban, the Philippines, on 8 November 2013. The U.S. Joint Tropical Warning Center (JTWC) did not recognize that the storm was still intensifying as it approached landfall. The local populace was complacent because of its experience with prior typhoons that were weaker.

Haiyan's intensity was underestimated:
- Confirmed death toll ~ 4,000
- Estimated death toll ~ 10,000
- Property losses estimated at $12 billion

Tropical cyclone Phailin made landfall near Gopalupur, India on 12 October 2013. The JTWC reported on 11 October that Phailin was an extremely intense category 5 storm. The government of India evacuated 800,000 people from the coastline at great expense. When Phailin made landfall, it was substantially weaker (low-end category 4).

Phailin's intensity was overestimated:
- Resources were squandered
- The populace may be complacent the next time a severe tropical cyclone approaches

(2) The Problem/Opportunity

Tropical cyclones (TCs, also known as hurricanes and typhoons in different regions) are the world's most disastrous natural phenomenon, having sustained surface winds up to ~ 225 mph and producing catastrophic losses via coastal storm surge and inland freshwater flooding due to torrential rains. TCs have caused humankind millions of deaths and trillions of dollars in property losses:

- 1900: the "Galveston Hurricane" killed 10,000 people, the greatest loss of life from a natural disaster in U.S. history.
- 1970: Typhoon Bhola killed 600,000 people in Bangladesh, the greatest loss of life from a natural disaster in world history.
- 2013: Hurricane Sandy caused over $68 billion in damage along the U.S. East Coast, the greatest property destruction from a natural disaster in world history.

Strong TCs usually originate far from land, making direct (in situ) intensity measurements difficult. Improved capability for space-based, worldwide measurements of the intensities of major TCs is badly needed.

The empirically based Dvorak technique (and its modifications) are generally used to categorize storm intensity in the absence of reports from ships or ocean buoys. Hurricane hunter aircraft are used **only** in the Atlantic basin and the northeast Pacific Ocean.

The modified Dvorak technique often experiences at least 20% errors in deriving maximum sustained surface winds. A dangerous category 3 TC could be misjudged as a much weaker category 1 storm, or vice versa.

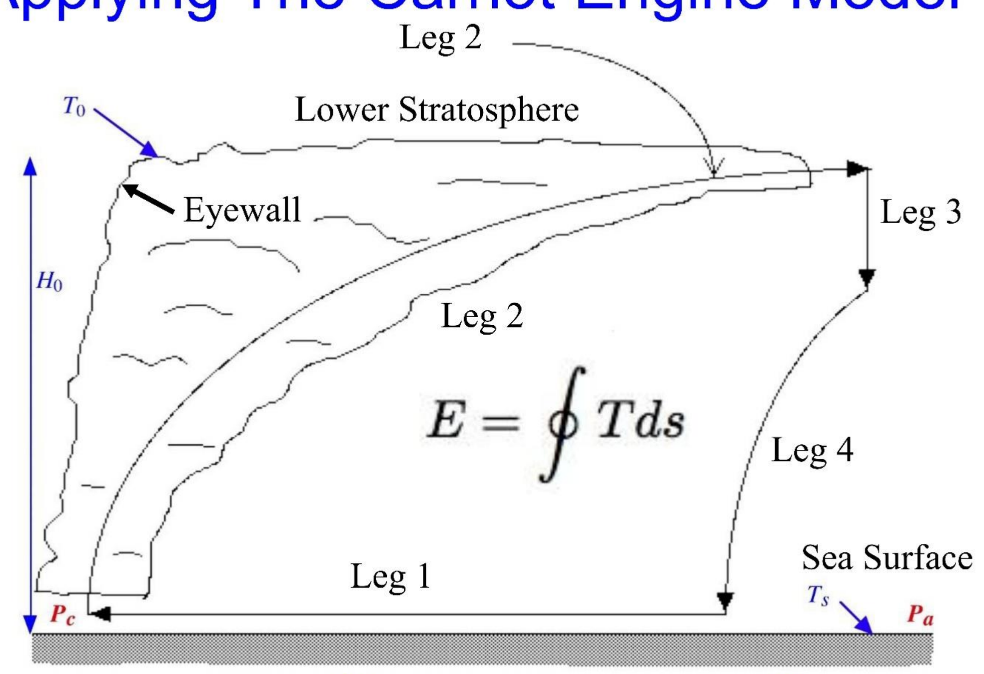
The scatterometry technique of the CYGNSS constellation of 8 satellites, to be launched in 2016, cannot measure the peak surface winds of the strongest TCs (category 4 and higher).

In the near future, NOAA/AOML (Atlantic Oceanic and Meteorological Laboratory) is planning to run their NWP model using the higher accuracy in measured TC intensities that will be achievable with the new approach discussed in the next section (§ 3).

(3) A New Approach

Prof. K. Emanuel (MIT) developed the accepted theory that the global thermodynamics of a TC are equivalent to those of a Carnot engine, as illustrated below:

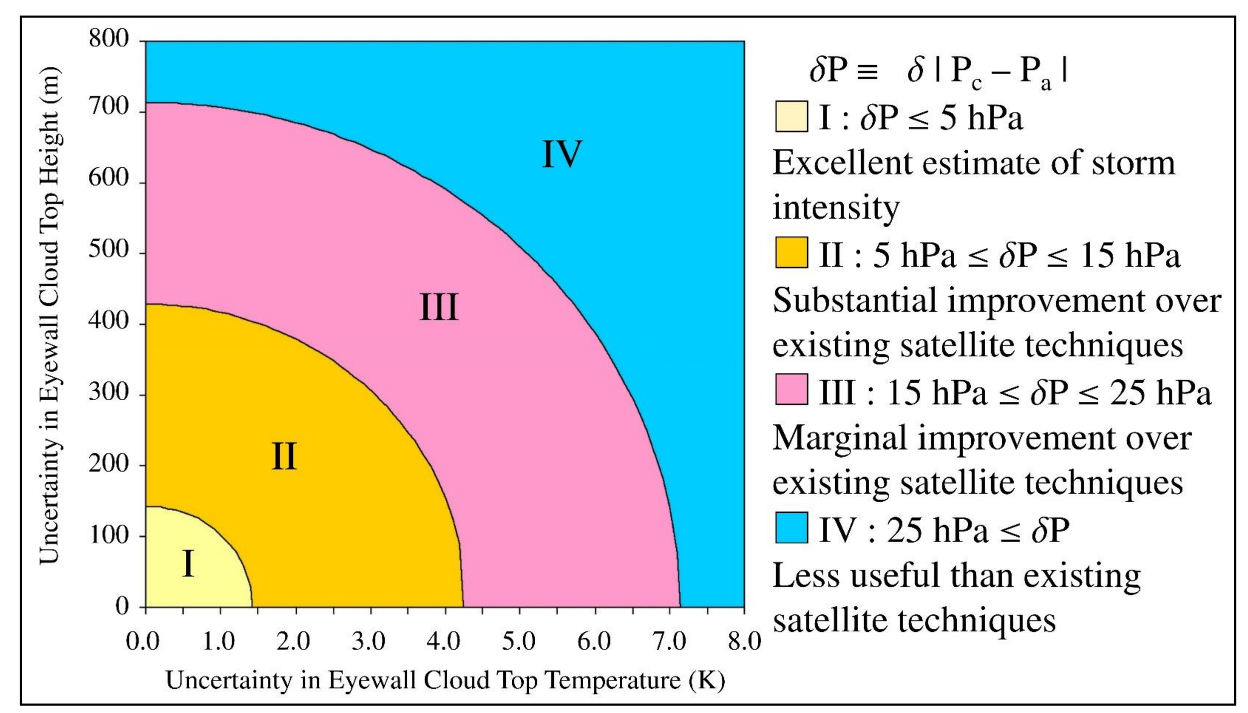
Applying The Carnot Engine Model



(1) Measure the height, H_0, and temperature, T_0, of the cloud tops in the eyewall (along Leg 2). (2) Utilize the known ambient sea level pressure, P_a, and sea surface temperature, T_s (3) Apply the laws of thermodynamics to deduce: (4) P_c, the sea level pressure at the storm's center (at the start of Leg 2).

The Carnot cycle operates between the warm ocean and the cold stratosphere to power the storm's strong surface winds and intense rainfall. Strong TCs develop a distinct eye, surrounded by an "eyewall" of thick clouds above the region of strongest sea-level winds.

The Carnot engine model was subsequently extended with input from Prof. Paul C. Joss (MIT, Visidyne). The model relates simultaneous measurements of the altitude, H_0, and temperature, T_0, of the eyewall cloud tops to the storm's central sea-level pressure, P_c, which then relates directly to the peak surface wind speeds. The plot below relates the precision of the measure-ments of H_0 and T_0 to the uncertainty in P_c.



(4) The CyMISS-D (Daytime) Project

The Cyclone Intensity Measurements from the ISS (CyMISS) project was selected by the Center for the Advancement of Science in Space (**CASIS**[4]) to demonstrate the application of the Carnot engine model to the improvement of the accuracy of TC intensity measurements (CASIS manages the U.S. National Laboratory on the ISS). The initial, daytime only, concept is to measure the altitudes of the cloud tops within the eyewall of a TC using visible image pseudo-stereoscopy from the International Space Station (ISS); the temperatures of the cloud tops will be measured simultaneously via thermal radiometry from the Advanced Baseline Imager (ABI) on GOES-R and the Advanced Himawari Imager (AHI) on Himawari-8. A given TC will be observable from the ISS every ~4 to 12 hours.

Stereoscopic altitude determinations of eyewall cloud tops have previously been demonstrated at lower accuracy (±500 m, Zone III) by NASA investigators (Rodgers et al., 1983). CyMISS visible image pseudo-stereoscopy is designed to achieve ~100 to 200 m altitude accuracy, and the simultaneous thermal radiometry should achieve temperature measurements with ±1 K accuracy. The resultant uncertainty in the TC central sea-level pressure retrieval should be ~5 mb, corresponding to an uncertainty in the peak sustained surface winds of ~20 knots, and thereby achieve a substantial improvement over existing satellite-based techniques (i.e., the modified Dvorak methods).

- CyMISS measurements will improve the GOES-R Hurricane Intensity Estimate (HIE-modified Dvorak).
- CyMISS measurements will complement CYGNSS measurements for strong TCs (categories > 3).

(5) Summary

This daytime-only demonstration of a new approach to obtain more accurate measurements of the intensities of strong TCs can be deployed in a year (~$4M; partner needed). CASIS provides seed money and also covers launch and ISS costs (equivalent to ~$7.5M).

A constellation of 4 small CubeSats with visible cameras and star sensors will reduce the daytime intervals between observations to ~2 to 5 hrs, providing timely up-dates for NWP models that are initialized every 6 hrs.

For both night and day capability, the CubeSats would be equipped with LWIR cameras and star sensors.

[1] Massachusetts Institute of Technology
77 Massachusetts Avenue, Bldg. 37-607
Cambridge, MA 02139

[2] Visidyne, Inc.
111 South Bedford St., Suite #103,
Burlington, MA 01803

[3] Space Dynamics Laboratory
1695 Research Park Way
Logan, UT 84341

For more information contact
A. T. Stair (ats@visidyne.com) 781-273-2820
[4] Duane Ratliff (dratliff@iss-casis.org) 321-253-5104