

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Summary of Hurricane Gonzalo, October 17th-18th

A hurricane watch was issued by Bermuda Weather Service (BWS) at 11.30pm local time Tuesday 14th October. This was superseded by a hurricane warning issued at 6pm on Wednesday 15th to ensure that this message reached the community that evening so that hurricane preparedness could be started. The BWS director, Kimberley Zuill, had been advising the local Emergency Measures Organisation (EMO) on developments since Monday 13th and along with published press releases, televised press conferences attended by the director of BWS, the Premier and the Commissioner of Police, were broadcast on Wednesday 15th and Thursday 16th. The EMO disseminated alert messages to the community via the local cell phone operators. In addition, Bermuda Weather Service utilised social media (in advance/during/after the event) to supplement the standard forecast/warning products, and keep the local community abreast of any nuances in the forecast updates, including any interesting and notable observations. This proved to be a very effective form of communication to the public and instigated an additional 2500 'likes' on the BWS Facebook page (<https://www.facebook.com/BermudaWeatherService>).

The Causeway was closed from early morning on the 17th and the airport was closed (via NOTAM) through the 17th and into much of the 18th to facilitate the clean-up operation.

Bermuda sustained a direct hit of a category 3 hurricane (100g130kt) on Friday 17th, weakening to a strong category 2 (95g125kt) during Gonzalo's passage into the morning of Saturday 18th. The initial onset brought strengthening tropical storm force easterly winds during Friday morning. These then intensified into the hurricane force category in the afternoon and early evening as moderate to heavy rain set in. The official airfield Vaisala MIDAS wind data was lost at around 7pm as the northern eyewall and strongest easterly winds approached the area. This data was then replaced by wind speed readings from the Causeway ultrasonic sensor, located near the west end of the airfield.

The eye passage occurred around 9.30-10.15pm with winds easing variable, light to moderate across the whole Island. The persistent rain abated in what was essentially a rain-free eye. However, a rare phenomenon was observed in the overcast eye, a light 'salt drizzle', which was likely the vast amounts of sea spray gradually falling under gravity that had been elevated into the boundary layer by the extreme winds and seas. Winds then rapidly strengthened to hurricane force once again from the west late evening and overnight, before gradual easing into Saturday morning. In addition, further mostly moderate rainfall set in.

Remarkably, the highest gusts in the event were recorded in these westerly winds as the main southern eyewall moved across the area at around midnight local time (one would ordinarily expect the strongest winds to be on the right forward quadrant of the hurricane as Gonzalo maintained weak category 3 status). A gust of 98 knots was recorded on the Causeway (sustained at around 80 knots) and 125 knots at St David's AWOS (sustained at 77 knots). During this wind peak, BWS had one of its storm shutters ripped off its south-facing window. So despite Gonzalo weakening from a

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

category 3 to a category 2 during its passage across Bermuda, the strongest winds were recorded as the hurricane exited the area. The gust ratio illustrated in figure 2 varied from 1.44 within the northern eye wall to 1.62 in the southern eye wall. Suggestions as to why this occurred include the interaction of Gonzalo with a dynamic front from the west as it transited Bermuda, and the fact that it was beginning to lose its 'pure' tropical characteristics, slowly becoming more 'sub-tropical' in nature due to increased wind shear and decreasing SSTs.

Hurricane Gonzalo was a long duration event, with sustained tropical storm force winds lasting for as long as 24 hours, and hurricane force winds persisting for approximately 12 hours. The official rainfall amount at the airport for the whole event was 2.85 inches. However, this is likely to be a gross underestimate, due to much of the rain likely blowing over the gauge and not into it.

Despite a significant surge forecast to develop (an estimate of 10ft was used by NHC from a previous event – Hurricane Fabian), coastal flooding was minimal due to the eye passing (CPA) around the time of low tide. High tide occurred around 4.50pm local with an enhanced sea level of approximately 0.5ft, as per data from the NOAA Tide Gauge at Esso Pier on the north side of St George's, see figure 12. However, with the associated storm surge beginning to impact the area at this time, the tide remained high (with in effect no low tide) and a water level differential of as much as 2.5ft was recorded at midnight before the effects of the surge on water levels began to diminish. The cumulative effects of the storm tide had less impact on the Causeway infrastructure than during Fabian, due to the direction of the swell/wind waves, which was more easterly rather than the forecast southeasterly. This is likely to have been due to Gonzalo pushed up against a stubborn high pressure system to the northeast, serving to back the forecast southwest winds into more of an easterly direction.

Main damage impacts across the Island, which were extensive, were further downed trees (in addition to those that came down in TS Fay – worse than perhaps expected due to still saturated ground from a record wet August), downed electricity and utility poles, as well as varied building damage ranging from storm shutter damage to substantial infrastructure damage (loss of roofs/collapsed walls), some of which were due to felled trees. As touched upon earlier, the Bermuda Weather Service itself was not immune from Gonzalo's destruction, sustaining damage to the building. Most notable during the event was water ingress into a comms room and the loss of a storm shutter on the south-facing side of the building. A large number of marine vessels (yachts etc.) were also grounded and damaged, even those stored on land and in 'safe' storm-mooring harbours. At the height of the power outage the vast majority of customers were without power (over 30,000 households). Power was only restored to all customers by the 3rd November, and some other utility (TV and Internet) customers remained without service well into November, as technicians continued to fix issues on a house-to-house basis. The Causeway sustained some damage (mostly superficial wall damage) and was re-opened during the afternoon of Saturday 18th October, along with the airport. However, the two-lane road on the Causeway was limited to one lane traffic for several days post-Gonzalo, so that restoration work on the south-facing roadside walls could be carried out.

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

One of the benefits of the merging of Gonzalo with a weather front over the Bermuda area was that as Gonzalo cleared northeast, the front ushered in dry and sunny weather with just moderate winds, as a ridge of high pressure gradually built in behind the front from the west. This spell of settled weather helped to expedite the restoration efforts and get Bermuda back up and running as quickly as possible.

A wealth of media reports and photos are available on two local news websites - <http://www.royalgazette.com/> and <http://bernews.com/>; type Hurricane Gonzalo into the search boxes. These include press releases/conferences, damage pictures and clean-up efforts, including a visit by the British Royal Navy frigate HMS Argyll, which is routinely on standby in the Caribbean/West Atlantic region during hurricane season for humanitarian assistance.

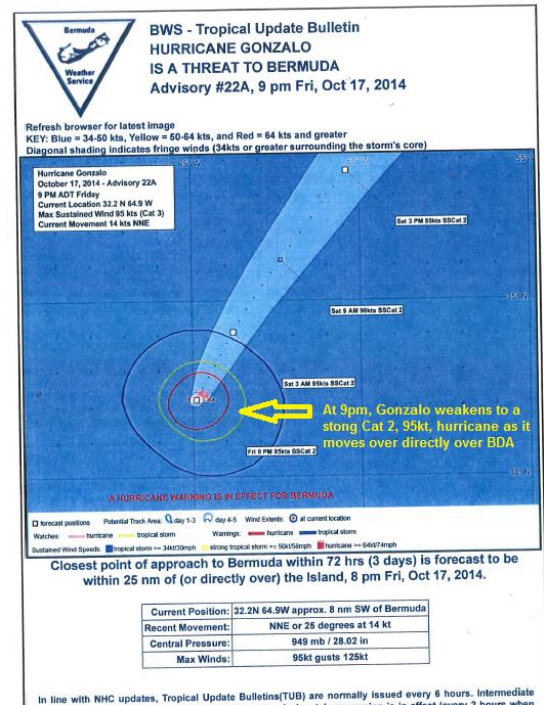
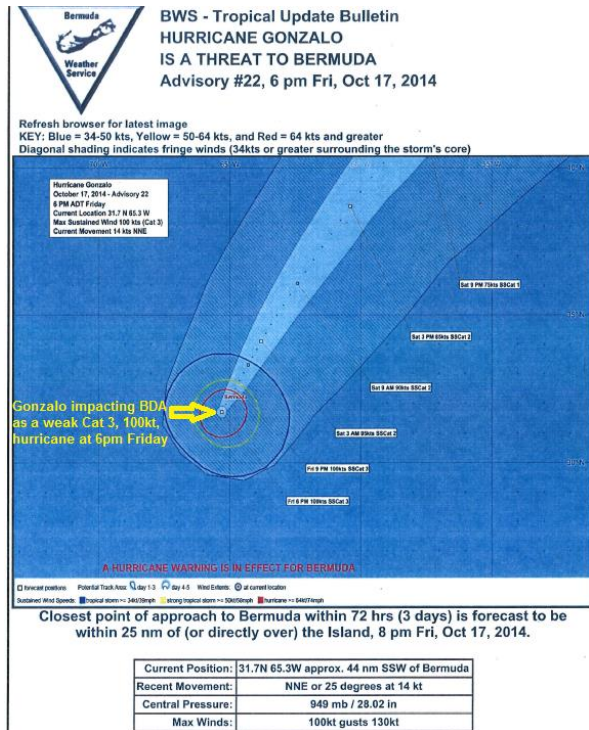
Forecasting

The track and intensity forecasting of Gonzalo for Bermuda was generally very good, with high confidence provided at a long range time scale. Noted subtleties were:

1. Winds direction ahead of the onset of the eye on Bermuda was generally more backed (east rather than southeast) than forecast, and this may have been due to Gonzalo bumping up against the stubborn ridge to the northeast.
2. Another consequence of the stubborn ridge may have been the delay in Gonzalo's onset on by a few hours – noted in the CPA in the few days running up to the event.

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

BWS local products – Figure 1.) Tropical update bulletins (TUBs):



Winds - Table of maximum winds (sustained and gusts) at various locations across Bermuda (ranging from approx. 40ft @ Airport/Causeway to 290 ft at Harbour Radio). Note that official reporting of sustained wind speeds in Bermuda is the 10 minute mean format. The highest gust recorded was at the St David's AWOS, a relatively low level site: 125.4kts or 144.21mph or 230.74kph. Note that the majority of the highest wind velocities were from the WNW/NW during the southern eyewall passage, when Gonzalo was in a continued weakening phase (Cat 3 to Cat 2). The convective bands within this eyewall appeared to generate the increased gust ratio, which caused much of the most significant damage such as snapped trees, downed utility poles, roof damage and storm shutters being ripped off their mountings. Gust ratios increased from approximately 1.4 with the initial northern eyewall to as high as 1.6 with the outgoing southern eyewall. Also worth noting is the fact that there were several anemometer failures during the event, limiting a comprehensive set of forensic data:

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Figure 2.) Table of winds

| Location | Maximum sustained wind | Maximum gust |
|---|---|---|
| LF Wade International Airport (MIDAS – approx. 40ft) | 53.9 knots (108°) @ 2214Z 17th before anemometer failure | 73.1 knots (108°) @ 2214Z 17th before anemometer failure |
| Causeway sensor (ultrasonic – approx. 40ft) | 81 knots (WNW) @ 0250Z 18 th | 98 knots (WNW) @ 0250Z 18th |
| Commissioner’s Point, Dockyard AWOS (approx. 150ft) | 94.3 knots (319°) @ 0250Z 18th | 112.5 knots (323°) @ 0310Z 18th |
| St David’s AWOS (50ft) | 78.3 knots (132°) @ 2320Z 17th | **125.4 knots (326°) @ 0310Z 18th |
| RCC Bermuda Maritime Operations Centre, MarOps (290ft) | N/A | 109 knots in initial easterly winds before anemometer failure (max likely to be higher) |

** 125.4 knots (144 mph) is the highest recorded gust in this event – stronger winds may have been recorded at the most exposed/elevated RCC MarOps site if equipment held.

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Satellite derived wind images – Figure 3.) Ascatsat satellite overpass (0043Z on the 18th) showing the circulation of Hurricane Gonzalo in the Bermuda area – this was near the time of closest point of approach, when Bermuda experienced a direct hit and the eye of the hurricane:

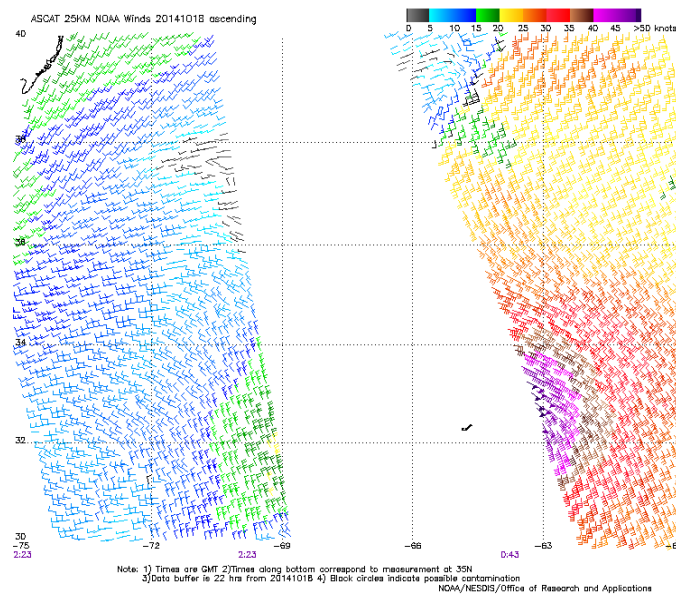
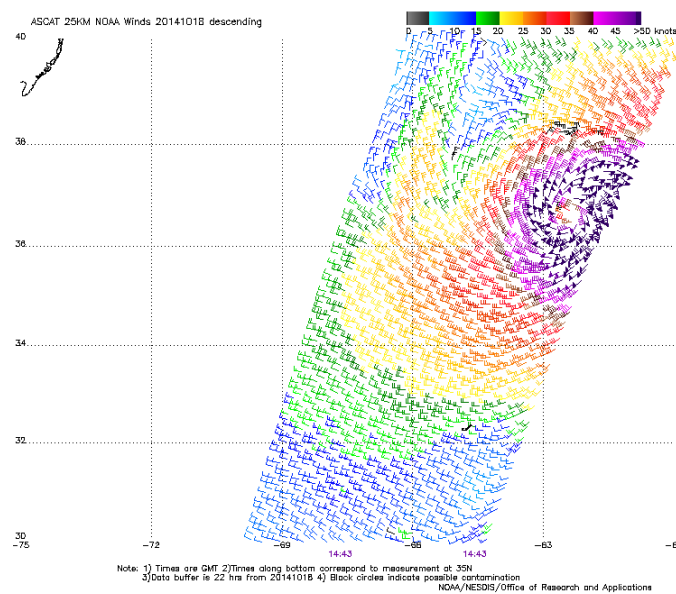
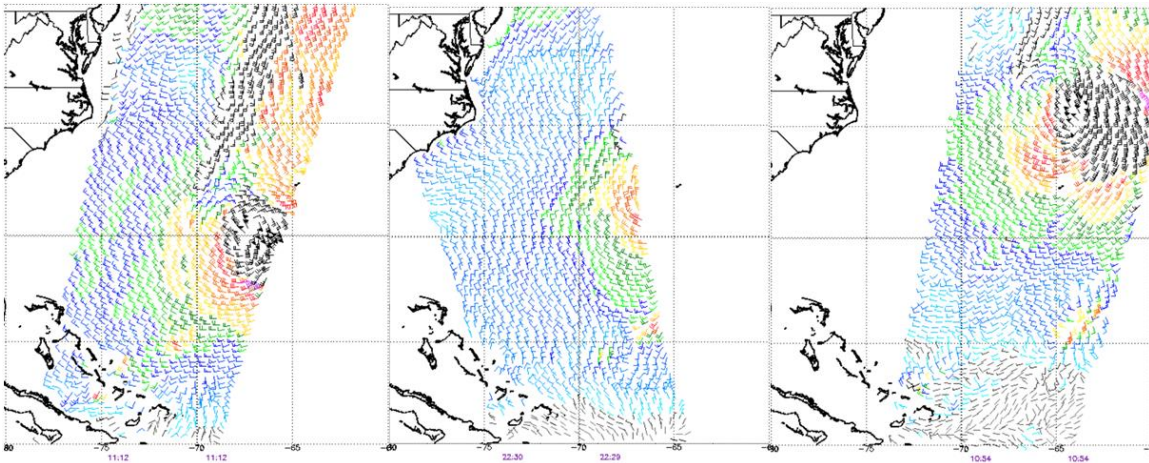


Figure 4.) Further Ascatsat image at around 15Z on the 18th overpasses most of Gonzalo to the northeast of Bermuda:



REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Figure 5.) Further to this, see below for a sequence of Windsat passes showing Gonzalo's steady transition across the Bermuda area:

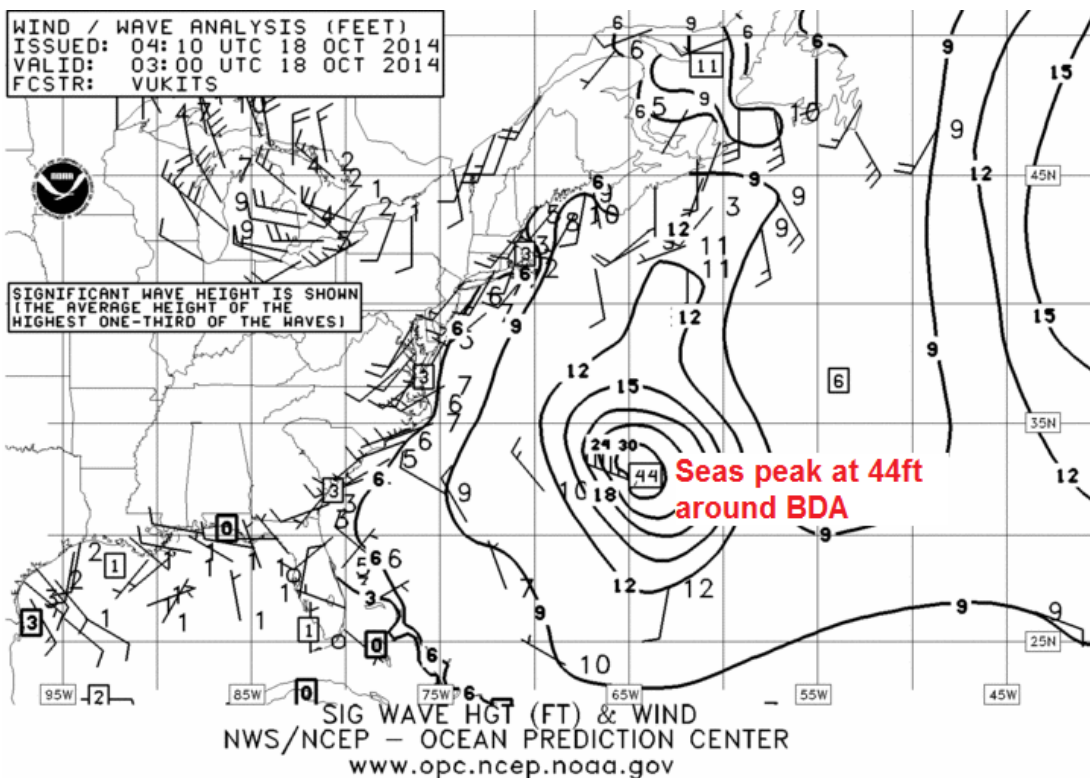


11z on 17th

23z on 17th

11z on 18th

Seas - Figure 6.) Peaked at around 44ft during Gonzalo's passage:



REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Radar imagery -

Figure 7.) Northern eye wall radar image – coincided with strongest easterly winds:

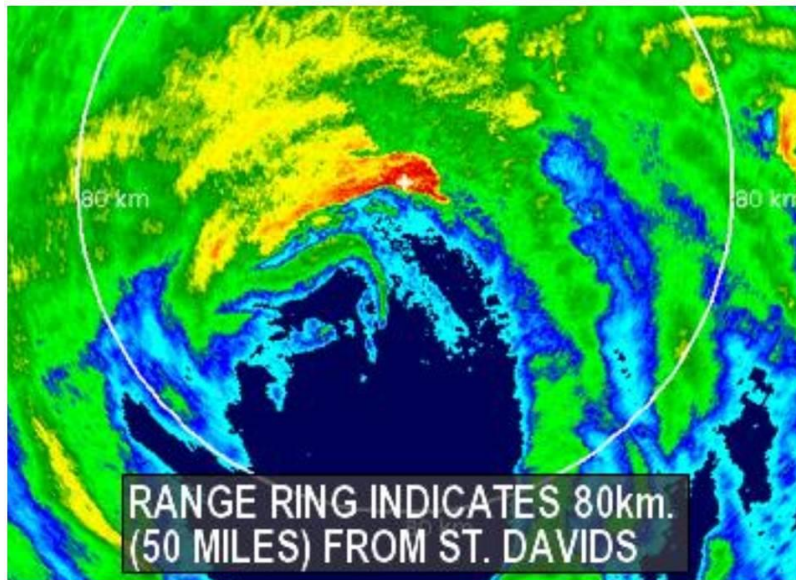
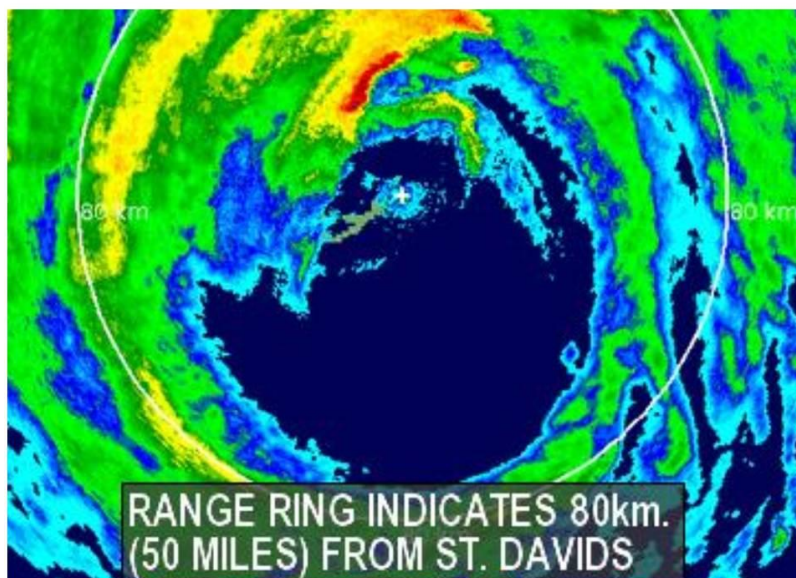


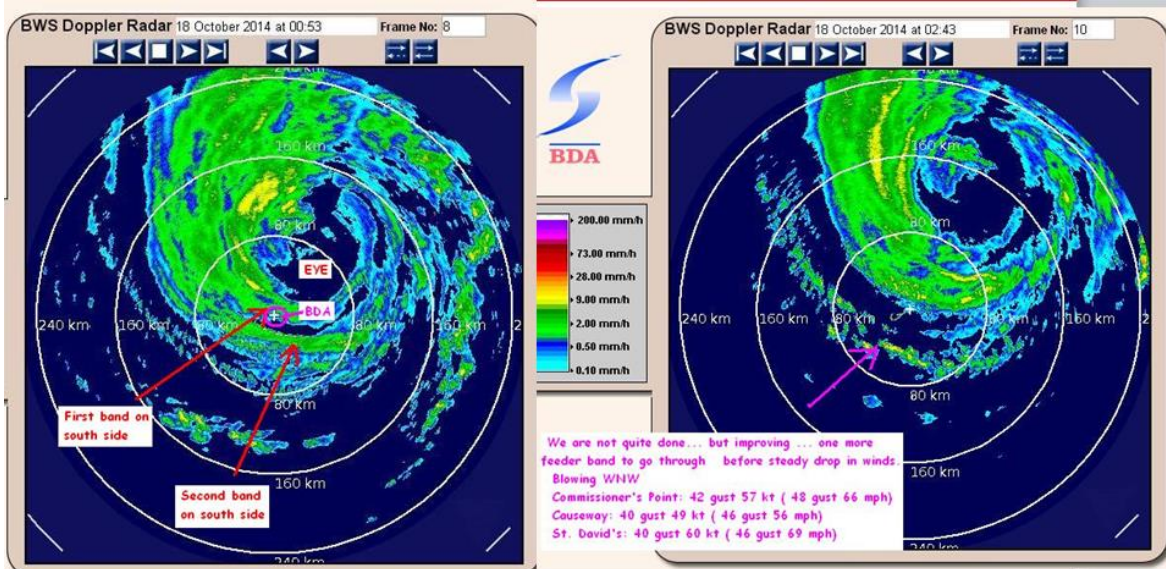
Figure 8.) Northern eye wall clearing, temporary improvement as eye moves in:



Note that the brighter radar echoes (in red) are coincident with a spell of heavy rain reported at the airport between 5pm and 9pm local time.

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Figure 9.) South side – Feeder rain bands & eye wall replacements; transition from Cat 3 to Cat 2 due to cooling sea surface temperatures and vertical windshear – gradual loss of tropical characteristics:



Note that these images were shared on the BWS Facebook page, in order to visually educate and update the local community on radar images that would likely be unfamiliar to them due to the relatively rare nature of a direct hit by a major hurricane.

Radar echoes were not as intense on the south side of the hurricane, despite the stronger winds. This potentially relates to the fact that water vapour imagery suggested some dry air encroaching from the west, limiting the maximum extent of the total precipitable water on the rear eye wall. This adds further weight to the fact that Gonzalo was beginning to lose tropical characteristics at this stage”

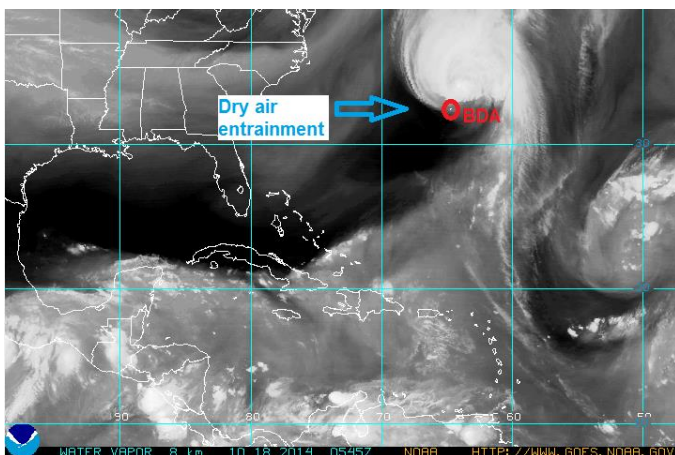


Figure 10.) WV image 0545Z,18th

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Pressure –

Figure 11.) BWS Meteograf trace showing pressure falling to 952.3mb/28.12inches:

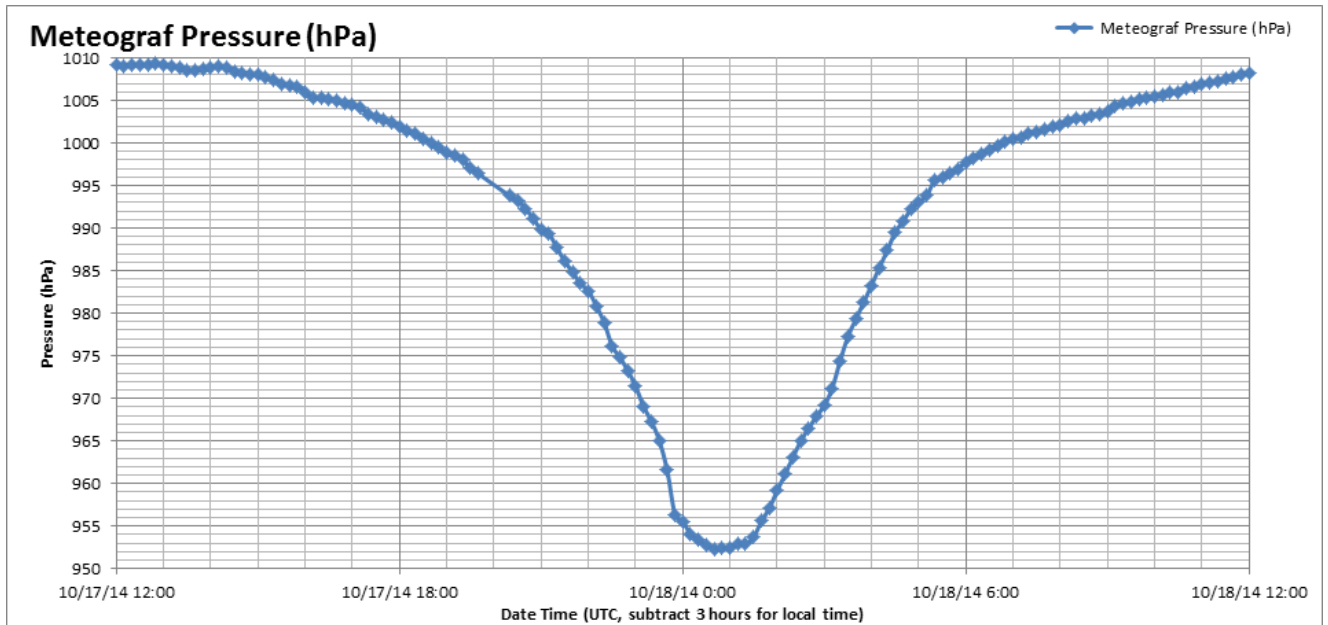
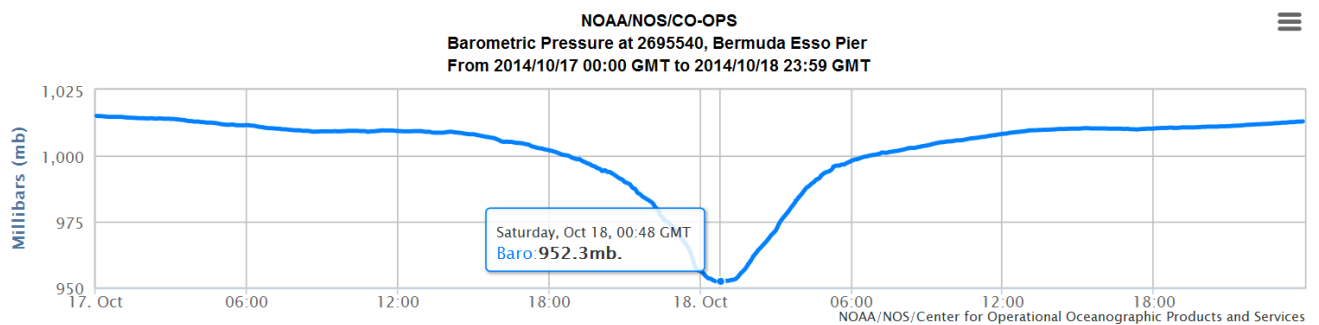
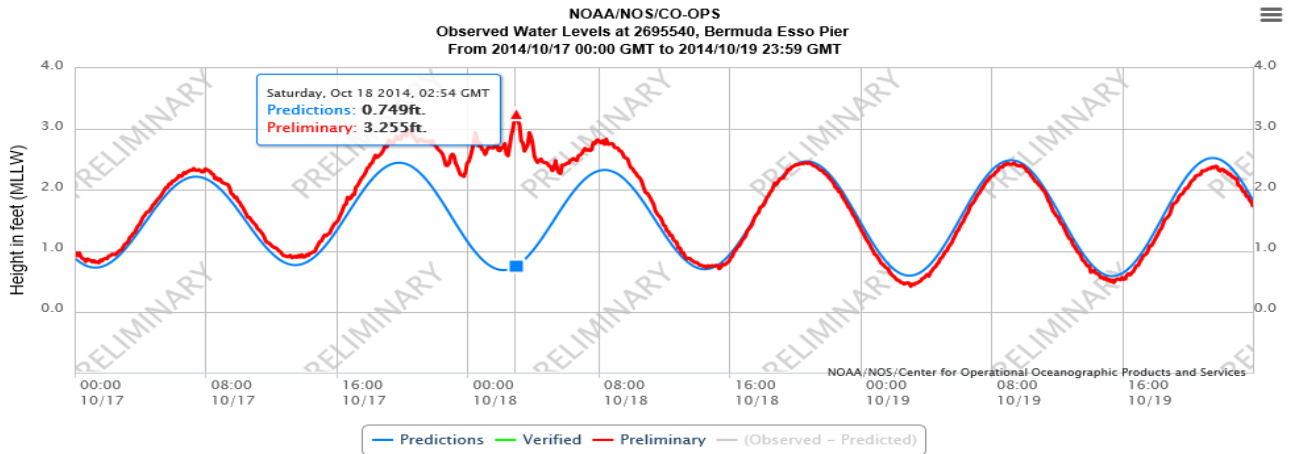


Figure 12.) Pressure trace from NOAA's Esso Pier tide station, pressure again falling to 952.3mb/28.12inches:



REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Tide data - Figure 13.) Lower surge impact due to timing of low tide at closest point of approach:

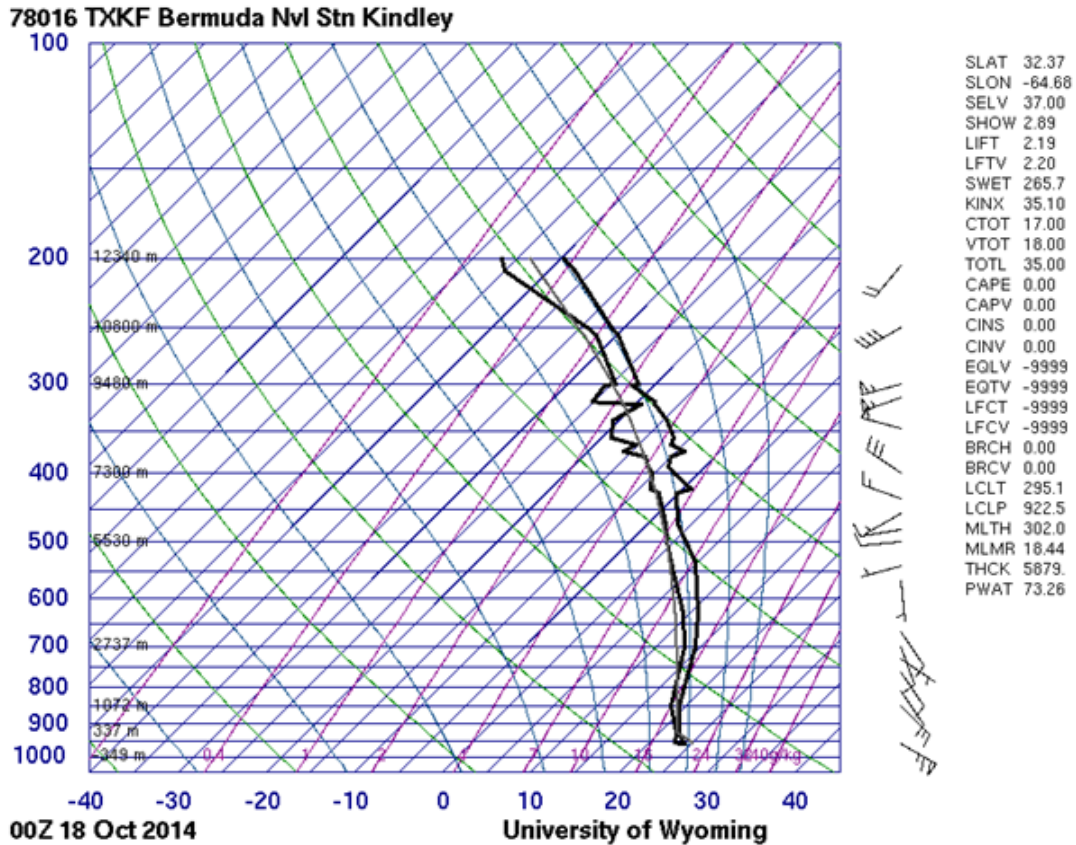


00Z radiosonde balloon launch on the 18th October -

Bermuda Weather Service had the rare opportunity to launch a 00z weather balloon in the eye of hurricane Gonzalo, as can be seen from the skew-t plot on the following page. Note that surface winds had not been qc'ed though and were very likely too high. The best estimate of surface wind speed around the time of balloon launch was around 20 knots. This successful launch garnered a lot of international media attention, as well as becoming a topic of conversation on some online tropical blogs.

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Figure 14.) Skew-t plot for TXKF at 00z 18 Oct 2014 (beware of the erroneous surface wind data, more likely to have been near 20 knots)



REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Webcam pictures - Figure 15.) Port of Bermuda webcam captures the deterioration of local conditions on the 17th October (<http://www.portbermudawebcam.com/>):



REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

Onset/Cessation wind timings - Figure 16.) Timings for onset and cessation of tropical (34kt), storm (50kt) and hurricane force (64kt) winds across the Island and Marine area (25 nautical miles offshore) based on local observations:

Onset/ Cessation Wind Timings

Hurricane Gonzalo onset timing of winds

Based on observations across island

Onset:

■ Tropical Storm Force Winds

- Marine Area: 9 am Friday
- Island: 11 am Friday

■ 50 knot Winds

- Marine Area: 3 pm Friday
- Island: 7 pm Friday

■ Hurricane Force Winds

- Marine Area: 6 pm Friday
- Island: 8 pm Friday

Cessation:

■ Hurricane Force Winds

- Island: 2 am Saturday
- Marine Area: 4 am Saturday

■ 50 knot Winds

- Island: 3 am Saturday
- Marine Area: 6 am Saturday

■ Tropical Storm Force:

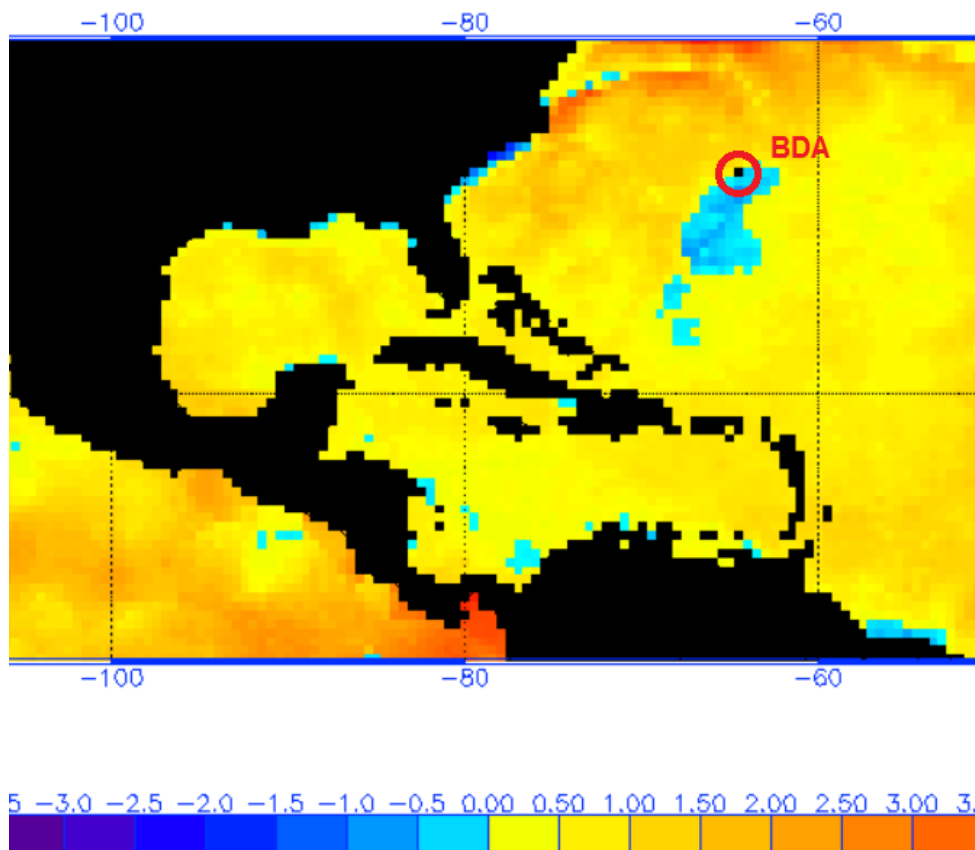
- Island: 6 am Saturday
- Marine Area: 9 am Saturday

The hurricane warning was downgraded to a Tropical Storm warning with the 0530hrs local time update on Saturday 18th October. This was then 'Ended' at 9am and superseded by a small craft warning which ran into Sunday morning, mainly for continued rough seas.

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.

SST anomaly chart – Figure 17.) The NOAA/NESDIS SST anomaly chart for 20th October clearly indicated Gonzalo's path as it approached Bermuda, with the hurricane causing some significant cooling/cold water upwelling in its wake:

NOAA/NESDIS SST Anomaly (degrees C), 10/20/2014



Of further interest with regards to the ocean and SSTs, a local scientific institute, Bermuda Institute of Ocean Sciences (BIOS) was able to send an ocean glider into the path of Gonzalo as it approached Bermuda. Extensive data was collected including the height of underwater waves, which were recorded to be a phenomenal 150ft. For more information on BIOS's glider programme please see the following webpages:

<http://www.bios.edu/news/undersea-glider-studies-hurricane-impact/>
<http://www.royalgazette.com/article/20141022/ISLAND/141029910>

REPORT ON HURRICANE GONZALO FROM BERMUDA - FOR THE 37TH SESSION OF THE WMO REGIONAL ASSOCIATION IV HURRICANE COMMITTEE.**Closing remarks**

Hurricane Gonzalo was the most significant hurricane to affect Bermuda since Hurricane Fabian in 2003. Much like Fabian, the forecast for Gonzalo was mostly excellent with regards both track and intensity at a long lead time. This allowed Bermuda to comprehensively prepare for a direct hit by a major hurricane.

The forecasting, warning and preparedness was exceptional, and can be seen as a model example of how to prepare, endure and recover from a major hurricane.

However, the same cannot be said of Tropical Storm Fay, which was not forecast especially well and had a short lead time to impact in Bermuda. The fact that Fay had such an impact on Bermuda actually helped communicate the further message regarding the Gonzalo forecast/warnings and impact.

Ahead of Fay, there was an air of complacency as the Island had not suffered a direct hit by a strong tropical storm hurricane in a number of years. However, the impacts of Fay brought to the fore the fact that Bermuda can and does suffer significant tropical cyclone impacts now and again. Therefore, the community were on high alert after Fay, and paid extra attention to the watches and warnings associated with Gonzalo. In addition, it was a much stronger tropical cyclone ahead of impact, increasing to a category 4 at one stage, capturing people's attention.

The 'wheels' of the forecasting/warning process ran very smoothly with Gonzalo, with plenty of lead time, allowing the community to prepare well in advance. The televised press conferences added extra weight to the warnings, with the BWS Director, Premier and Commissioner of Police communicating a strong and clear message. This was shared repeatedly with the community via various media outlets. A couple of cell phone text alerts, absent in the lead up to Fay, were disseminated to the public helping to consolidate the message, and capture a larger swath of the community, not necessarily in tune with the more traditional forms of media such as newspapers, TV and radio. Finally, as mentioned earlier, BWS heavily used their Facebook page to provide further updates and advice to the public.

It was this combination of communication channels that undoubtedly led to excellent preparedness by the community and adherence of the strong warnings and guidance. Bermuda is very thankful that no serious injuries or loss of life were incurred as a direct result of Hurricane Gonzalo's impact.

Report published by:

James Dodgson, Deputy Director
Bermuda Weather Service
4pm, 1st December 2014