Early Detection of the 5 April 2005 Anatahan Volcano Eruption using the Guam WSR-88D

Timothy P. Hendricks
Senior Forecaster
National Weather Service Forecast Office Guam

Abstract

For more than three years the activity at Anatahan Volcano has produced numerous ash-bearing volcanic clouds that drift around the Mariana Islands. These volcanic clouds are a serious threat to aviation. To effectively mitigate volcanic cloud hazards within the busy flight lines of the western Pacific, warning of eruptions is needed within a few minutes. Although designed to detect water and ice particles, ground-based meteorological radar systems have demonstrated capability to detect volcanic eruptions. The Andersen Air Force Base (PGUA) WSR-88D Next Generation Radar (NEXRAD) proved to be a valuable tool in early detection of the 5 April 2005 Anatahan Volcano eruption. With the volcano within 289 km (180 mi) of the radar, accurate measurement of the eruption clouds height could be discerned in a timely manner. Sounding and satellite observations complemented the NEXRAD imagery, making long-term tracking of the ash clouds feasible. The multiple agency coordination effort was exceptional, resulting in superior products and services to the aviation community, emergency managers and general public.

1. Introduction

The National Weather Service (NWS) Weather Forecast Office (WFO) Guam has to deal with many varied hazards in its 4.7 million square mile area of responsibility. While tropical cyclones are the number-one hazard, there are others such as strong monsoon events, El Niño-induced floods and droughts, earthquakes, grass fires, tsunamis, and high surf events. Over the last three years, volcanic ash and volcanic haze from the Anatahan Volcano, an island only 289 km (180 mi) north-northeast of Guam, have become a concern for emergency managers, meteorologists and the aviation community. Shortly after 1600 UTC 5 April 2005, Anatahan erupted explosively. Reports indicated that the initial volcanic eruption reached heights of approximately 15 km (50,000 ft), producing ash fall on the most populous of the Mariana Islands—Guam, and the Commonwealth of the Northern Mariana Islands (CNMI) of Saipan, Tinian, and Rota.

In a technical report from Michigan Tech University, Rose (1998) stressed the need for real-time radar data near active volcanoes, since volcanic ash is a serious threat to aviation. Rose (1998) also stated that timely information on the eruption's onset and intensity is vital to mitigate the hazards from ash clouds to the aviation community. The Anatahan eruption on 5 April 2005 was unique for it occurred well within the range of the Andersen Air Force Base (PGUA) WSR-88D Next Generation Radar (NEXRAD), located in Mangilao, Guam about 8 km (5 mi) southeast of the weather station.

Over the years, many aircraft encounters with volcanic ash have occurred within minutes or a few hours of an eruption (Johnson and Casadevall, 1994). The best documented encounter occurred with the eruption of the Galunggung volcano in Indonesia in 1982, when a commercial airliner, a Boeing 747, lost power in all four engines. The aircraft fell from 12 km (39,000 ft), finally restarting the engines and recovering around 4 km (12,000 ft) just in time to avoid ditching in the Indian Ocean. Jet aircraft engines can fail within minutes of encountering a volcanic ash plume. Furthermore, volcanic ash is highly abrasive and can severely damage windshields, aircraft turbines, and other internal engine surfaces. Volcanic ash can also clog up essential filters and render navigational equipment useless.

The goal of this paper is to present the chronology of the 5 April 2005 eruption of Anatahan using data from the PGUA WSR-88D and GOES-9 (Geostationary Operational Environmental Satellite). In addition, the multiple agency coordination effort between WFO Guam, the Volcanic Ash Advisory Center (VAAC) in Washington DC, WFO Honolulu, other US agencies, and local emergency and environmental agencies will be discussed.

2. Eruption Chronology

Anatahan Island (16.4N 145.7E) is located in the western North Pacific, and is part of the Mariana Island chain (Fig. 1). Anatahan is uninhabited and remote, located about 80 miles north of Saipan. Prior to 1990, Anatahan was assumed to be extinct, although several other islands along the chain have had recent eruptions. In early May of 2003, Anatahan erupted explosively for the first time in recorded history. The volcano produced another eruption in July 2004, and several other minor eruptions have occurred since July 2004. However, the most recent major eruption, which is the focus of this paper, occurred on 5 April 2005.

Meteorological conditions in the vicinity of Anatahan just prior to the 5 April 2005 eruption could be described as benign, with relatively clear skies and no significant precipitation (Fig. 2). Light rain showers were occurring in the vicinity of Guam, but were not heavy enough to result in radar attenuation, especially across the northern quadrants. The PGUA WSR-88D 1600 UTC Velocity Azimuth Display (VAD) Wind Profile (not shown) depicted northeast trade wind flow to the top of the trade wind inversion, or roughly 2.5 km (8,500 ft). Due to the lack of backscatters or clouds, winds above 2.5 km were not plotted on the VAD Wind Profile. However, the 1200 UTC PGUM sounding (not shown) indicated that winds remained northeasterly through 8 km (27,000 ft), before shifting abruptly from the north. These mid and high level northerly winds would later prove troublesome for the southern Mariana Islands.

Anatahan erupted at approximately 1610 UTC. Within minutes, the PGUA WSR-88D signaled the onset of another major eruption. Since Anatahan is located within the range of the PGUA WSR-88D, early detection of major eruptions of the volcano is not only possible, but is likely. No major eruption has gone unnoticed by WFO Guam. The PGUA 0.5 degree reflectivity at 1616 UTC (Fig. 3) shows a faint echo directly over Anatahan between 20 and 30 dBZ. The elevation of the 0.5 degree beam over Anatahan is approximately 9 km (30,000 ft). Obviously, below the height of the 0.5 degree beam, there are limitations in detecting and observing ash clouds. The Senior Forecaster on duty immediately notified the Washington VAAC and WFO Honolulu, which has responsibility for volcanic ash SIGMETS in the western North Pacific, south of 21N and east of 130E (the western-most extent of the Oakland Flight Information Region (FIR). About one hour later, at 1726 UTC, the PGUA 0.5 reflectivity (Fig. 4) increased to 50 to

55 dBZ over Anatahan. Clearly, the ash cloud reached to at least 9 km (30,000 ft), and continued to climb. Six minutes later at 1732 UTC, the PGUA 1.5 degree reflectivity (Fig. 5) depicted a 40 to 45 dBZ echo over Anatahan. The elevation of the 1.5 degree beam over Anatahan is approximately 15 km (50,000 ft).

A truly beneficial aspect of the National Weather Service Advanced Weather Interactive Processing System (AWIPS) is the ability to superimpose PGUA WSR-88D data with satellite data. Tupper and Kinoshita (2003) describe the complexities of relying on satellite data alone to observe volcanic eruptions. In the tropical western Pacific, volcanic clouds can contain or entrain moisture, making them difficult to distinguish from meteorological clouds. However, the combination of PGUA WSR-88D and GOES-9 infrared (IR) imagery proved to be extremely beneficial in tracking the extent and migration of the ash cloud. The 1725 UTC PGUA/GOES-9 IR combination (Fig. 6) shows the low level plume trailing off the southwest, essentially trapped underneath the trade-wind inversion. A southward drift can be discerned at higher levels. The low level plume is typically not a problem for commercial jets arriving from Japan, Korea, Taiwan or Southeast Asia, as flight levels at descent are commonly near 6 km (20,000 ft) at that range from Guam and Saipan International airports. However, the high level plume is a serious hazard, which was conveyed in Washington VAAC advisories and WFO Honolulu SIGMETS.

By 1802 UTC, the radar signature of the eruption was faint at best. But once again, in combination with the IR imagery, the southward drift of the high level plume was noted. The Senior Forecaster on duty was already anticipating possible ash fall across Tinian and Saipan, and eventually Rota and Guam. Public Volcanic Ash Advisories, or Non-Precipitation Advisories (NPWs), were issued by WFO Guam for Tinian and Saipan initially, with Rota and Guam to follow a few hours later. The lead time was 3 hours. By 2102 UTC, the combination of GOES-9 visual and IR imagery indicated that the leading edge of the high level plume had reached Tinian and Saipan.

3. Coordination Efforts between Multiple Agencies

Tupper and Kinoshita (2003) describe the difficulties ensuring an efficient warning network. First, if meteorologists are not focused on a particular area (because of lack of eruption forewarning), the eruption may be missed entirely or only discovered via satellite analysis in hindsight. This indeed was almost the case during the first major eruption of Anatahan in May 2003. Fortunately, the forecaster on duty noted the anomaly in the satellite data and cross checked it with PGUA WSR-88D data. He then astutely and correctly discounted thunderstorm development and deduced that a volcanic eruption was underway. Second, a smooth relationship between multiple agencies may not exist, which can result in delays of eruption notifications. The forecaster recognized the importance of timely and accurate advisories from the Washington VAAC and promptly issued the appropriate SIGMETS (which were issued by WFO Guam at that time). Third, real-time detection rates can be very low, especially with satellite data as the only remote sensing tool. If convective clouds are in the area of the volcano, it may be impossible to detect the eruption. But, with combination of radar data and satellite imagery, early eruption detection is possible, even with convective clouds.

The coordination effort between WFO Guam, the Washington VAAC, WFO Honolulu, and the Aviation Weather Center (AWC) at Kansas City, MO, was efficient and timely. Meteorological briefings occurred frequently between the aforementioned agencies during this major eruption, which ensured accurate and timely products to our customers, including the aviation community. Air routes from Hawaii and Guam to the Philippines and Hong Kong and between Japan, Guam, Saipan and Australia all pass in the vicinity of Anatahan Volcano. Pilots in flight, as well as those handling flight-planning on the ground, were kept informed of the location and altitudes of the volcanic ash. Frequent coordination and requests for verification occurred among WFO Guam, the FAA, and airline dispatchers. The aviation community was encouraged to consult the latest advisories from the Washington VAAC, SIGMETS issued by WFO Honolulu, Terminal Aerodrome Forecasts (TAFs) issued by WFO Guam, and aviation hazard charts issued by the AWC.

The coordination effort continued well after the 5 April 2005. For the next five months, WFO Guam routinely coordinated with the FAA and airline dispatchers. Pilot reports became a useful tool for diagnosing the depth of the low level plume. The infrequent bursts to higher levels were monitored by the PGUA WSR-88D, with the plume heights verified against pilot reports. Close communications also continued with the Washington VAAC and WFO Honolulu.

Throughout the entire period, WFO Guam was also in close contact with Guam Civil Defense, the Guam Environmental Protection Agency and the CNMI Emergency Management Office. At the request of the CNMI Governor, a National Conference was convened on Saipan to develop a formalized volcanic ash plan. In a collaborative effort between the USGS, FAA, U.S. Air Force, NOAA/NWS, and regional governments, the Interagency Operating Plan for Volcanic Ash Hazards to Aviation in the Pacific Region of the Northern Marianas Island was created, and will soon be included in the latest update of the National Volcanic Ash Plan (Quick, 2006).

4. Summary and Conclusion

In summary, the 5 April 2005 massive, short lived eruption to 15 km (50,000 ft) proved problematic for Tinian and Saipan. Panic-stricken residents bombarded the CNMI Emergency Management Office with phone calls, as motorists used their headlights to drive in the middle of the day, and a strong sulfur odor permeated the air. It was so dark, that streetlights, which operate with automatic sensors, turned themselves on. The volcanic ash left a thin layer of grey soot on vehicles, rooftops and other flat surfaces. The Saipan International Airport was shut down. Fortunately, this eruption was brief. If it had been a continuous major eruption, there would have been much great impact to the population and economy.

Anatahan may be calming down for now, but another eruptive cycle is always a possibility, and with it the potential for another large ash producing eruption. The impacts to all aspects of aviation and local residents are too great to take this threat lightly. This recent massive eruption produced high level ash impacts for local and international flights to and from Saipan. Depending on wind direction, future eruptions could also impact Guam. Flights get cancelled. Air traffic is rerouted and diverted. Locally, large amounts of ash fall result in respiratory problems for children and the elderly, especially on Tinian and Saipan, and prolonged darkened skies tend to promote panic and fear.

In conclusion, interagency communications and technology availability and tools, including NEXRAD data, are the keys to ensuring timely volcanic ash warnings and statements reach the users who most need it. The findings of this research will no doubt improve forecaster situational awareness in the future at WFO Guam and possibly at other locations where volcanic eruptions may occur.

5. Acknowledgements

The author would like to thank Chip Guard (WCM, WFO Guam), Roger Edson (SOO, WFO Guam), Kristine Nelson (MIC, CWSU Anchorage), and Jon Zeitler (SOO, WFO Austin/San Antonio) for providing direction and guidance, as well as several peer reviews.

6. References

Camacho, J.T., Chong, R., and Trusdell, F., 2005: Anatahan Future Outlook. [Available online at http://www.hvo.wr.usgs.gov/cnmi/].

Johnson, R.W. and T.J. Casadevall, 1994: Aviation Safety and Volcanic Ash Clouds in the Indonesia-Australia Region. Proceedings, *1st International Symposium on Volcanic Ash and Aviation Safety*, Seattle, WA, *U. S. Geol. Surv. Bull.*, **2047**, 191-197.

Quick, J.E., 2006: Statement of James E. Quick, Program Coordinator Volcano Hazards Program U.S. Geological Survey, before the U.S. Senate Subcommittee on Commerce, Science, and Transportation on Disaster Prevention and Prediction. [Available online at http://commerce.senate.gov/pdf/quick-031606.pdf]

Rose, W.I., 1998: Using Radar to Detect Ash Clouds. [Available online at http://www.geo.mtu.edu/department/classes/ge404/gcmayber/radar.html]

Tupper, A. C., and Kinoshita, K., 2003: Satellite, Air and Ground Observations of Volcanic Clouds over the Islands of the Southwest Pacific. S. Pac. Study, **23,** 21-46.

7. Figures

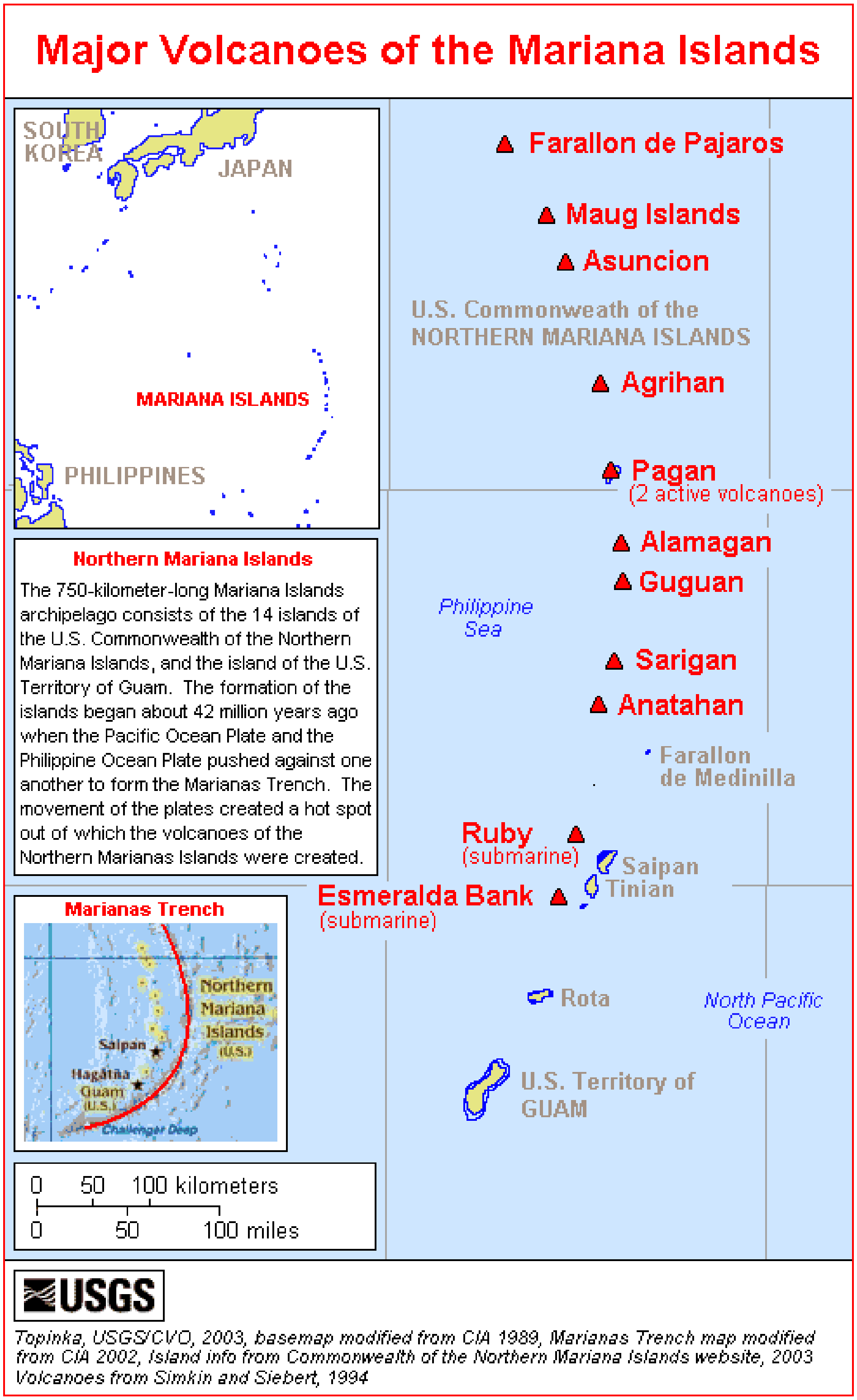

Fig. 1. Major volcanoes of the Mariana Islands (Courtesy USGS).

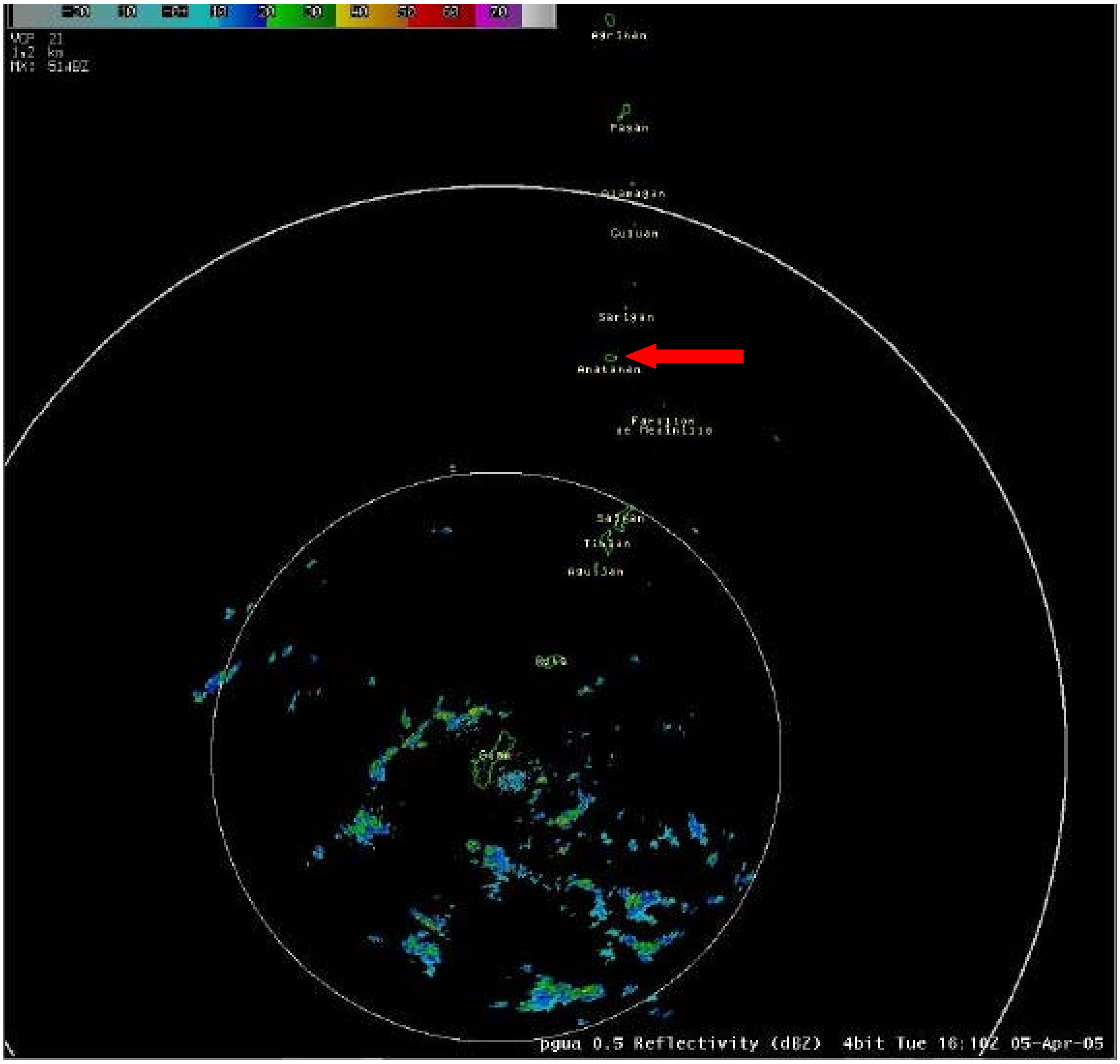

Fig. 2. PGUA 0.5 degree reflectivity image at 1610 UTC 5 April 2005 (0210 LST 6 April 2005) just prior to eruption. The red arrow identifies Anatahan Volcano.

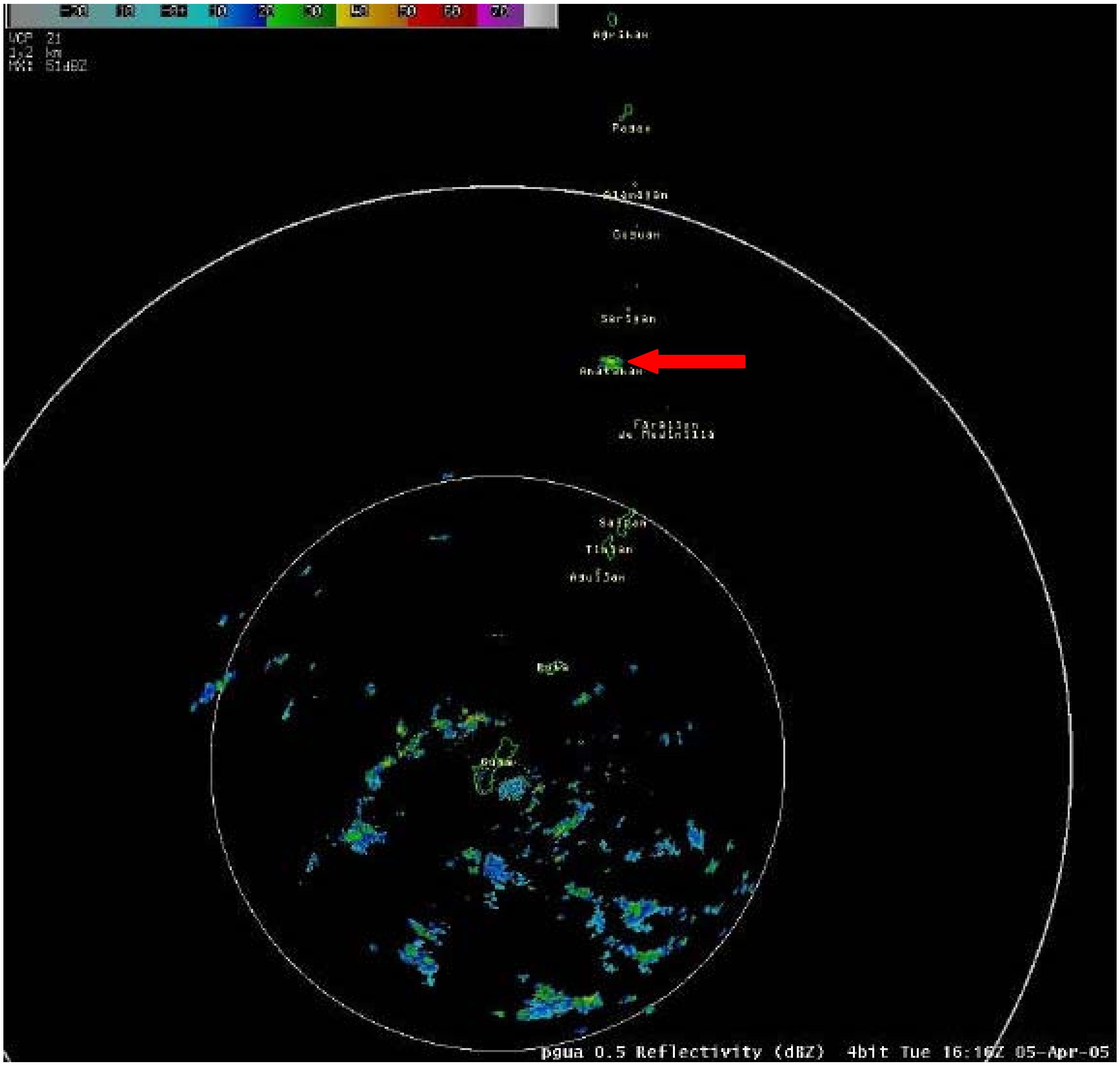

Fig. 3. PGUA 0.5 degree reflectivity image for 1616 UTC 5 April 2005 (0216 LST 6 April 2005). 20 to 30 dBZ echo evident over Anatahan, indicating the onset of the eruption.

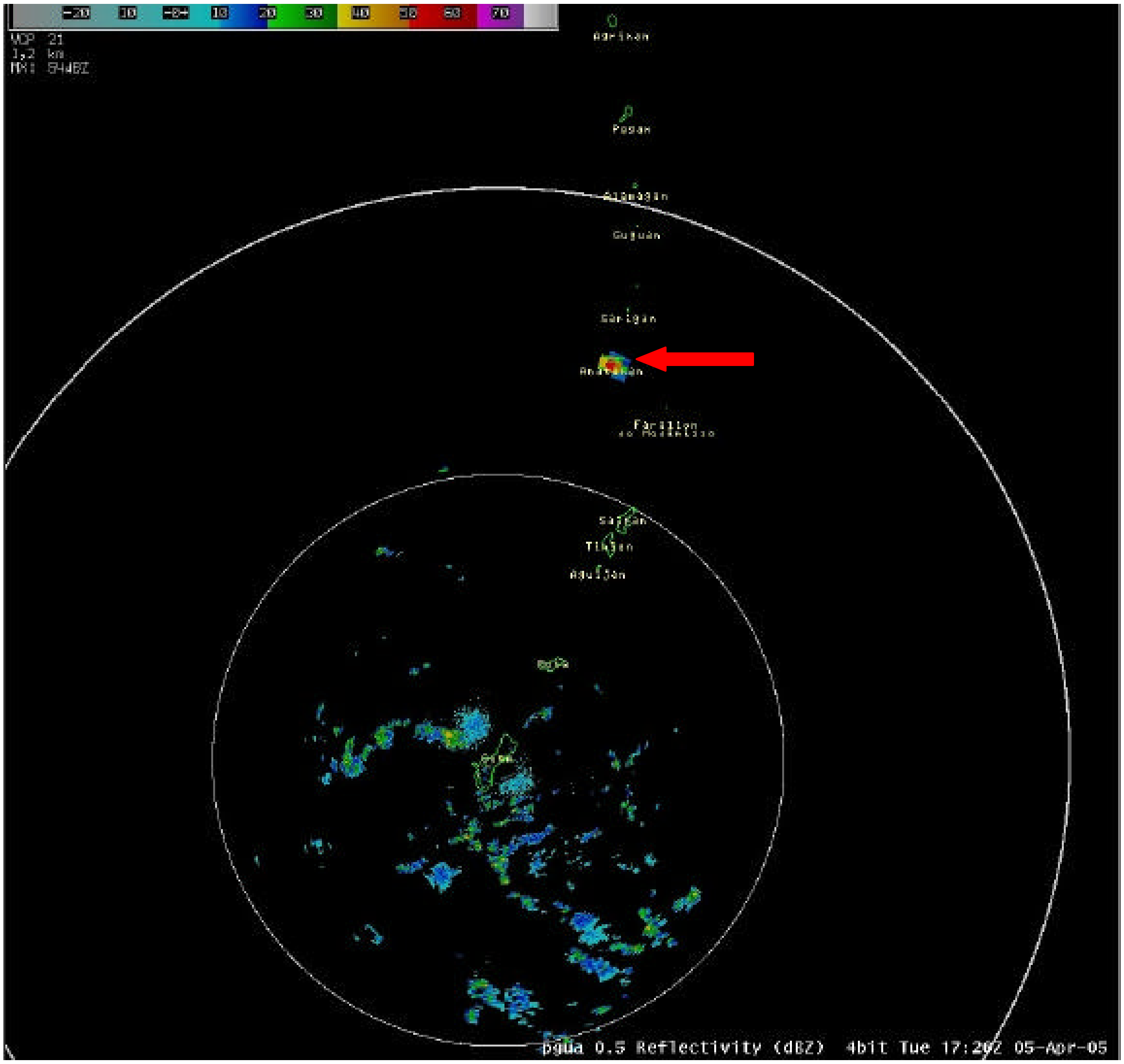

Fig. 4. PGUA 0.5 degree reflectivity image for 1726 UTC 5 April 2005 (0326 LST 6 April 2005). 50 to 55 dBZ observed at 9 km (30,000 ft) over Anatahan.

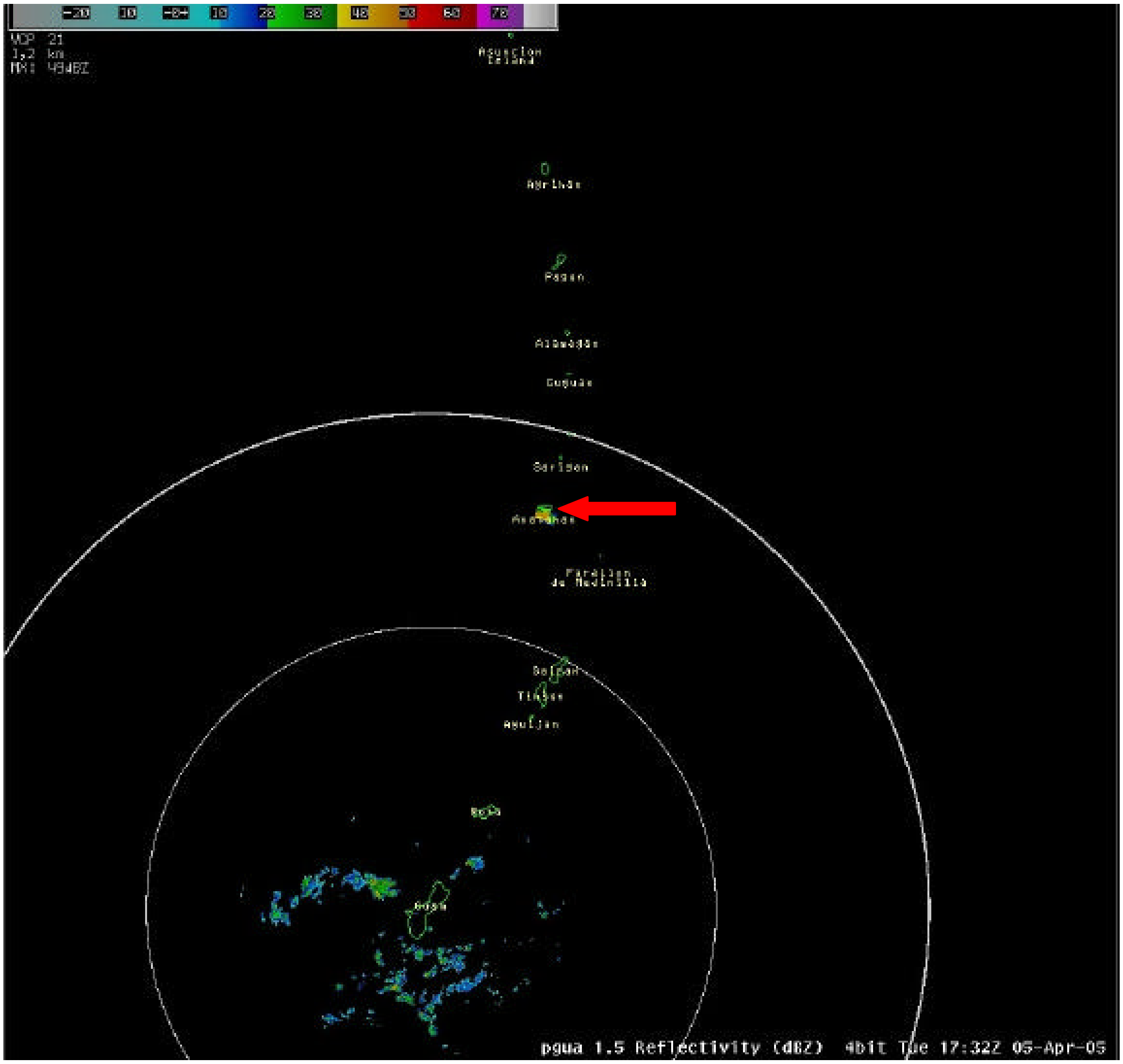

Fig. 5. PGUA 1.5 degree reflectivity image for 1732 UTC 5 April 2005 (0332 LST 6 April 2005). At the peak of the eruption, 40 to 45 dBZ echo to 15 km (50,000 ft) over Anatahan.

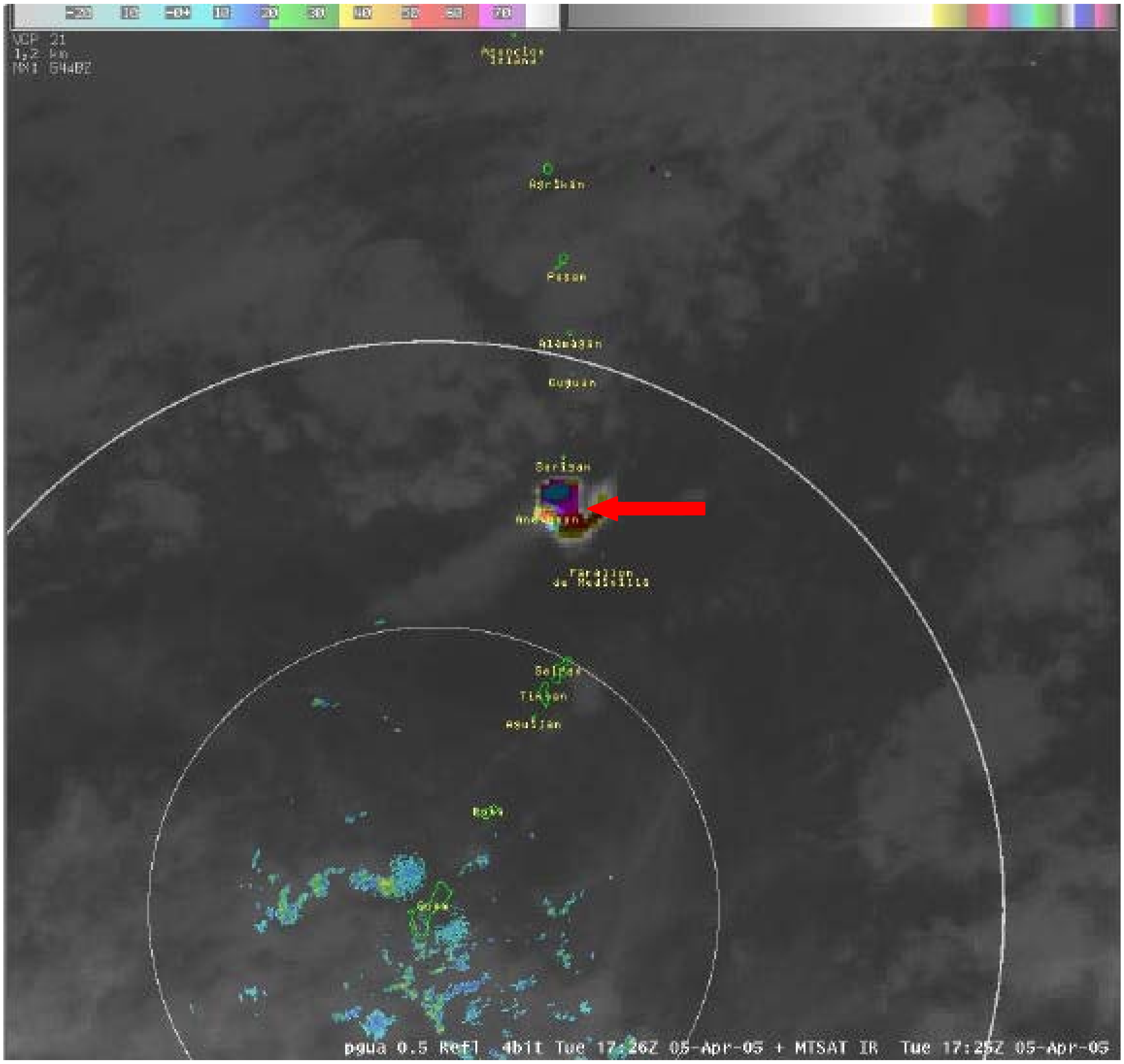

Fig 6. GOES-9 IR and PGUA 0.5 degree reflectivity image for 1725 UTC 5 April 2005 (0425 LST 6 April 2005). The low level plume can be seen trailing off to the southwest under influence of northeast trade winds. Northerly winds aloft are steering the high level plume toward Tinian and Saipan.