P6.14 ADVANCES IN THE PROVISION OF WARNINGS FOR VOLCANIC ASH FOR AVIATION IN THE AUSTRALIAN REGION

Rodney Potts* and Mey Manickam
Bureau of Meteorology Research Centre, Melbourne, Victoria, Australia

1. INTRODUCTION

Volcanic ash presents a significant hazard to aviation and in recent years ICAO has established arrangements for provision of warnings regarding volcanic ash under the International Airways Volcano Watch (IAVW) (ICAO 2001). These arrangements include provision of Volcanic Ash Advisories (VAA) that give information on the erupting volcano and the analysed and forecast boundaries of the associated volcanic ash cloud. The VAA's are provided by designated Volcanic Ash Advisory Centers (VAAC) and are based on an initial report or detection of a volcanic eruption or ash cloud, an analysis of satellite data to identify and track the ash cloud, and a forecast of the movement of the ash derived from upper level winds and an atmospheric dispersion model. The VAA message is prepared in the agreed format and disseminated to the aviation industry. The process must be completed in a timely manner so that aircraft likely to be affected by the ash cloud can take appropriate avoidance measures. The Darwin VAAC, which is operated by the Bureau of Meteorology, has responsibility for the volcanically active area that includes the southern Philippines, Indonesia and PNG.

There are a number of complex issues in the preparation of warnings for volcanic ash. Firstly, there are many volcanoes in the Darwin area of responsibility and most are remote and not monitored in real-time, with the result that initial reports of volcanic eruptions or ash clouds may be delayed. Secondly, the discrimination of volcanic ash from water/ice clouds in satellite data and delineation of the observed ash boundary remains problematic with current data and processing techniques. This necessitates intensive manual analysis of available satellite data with resultant time and resource implications. Thirdly, there are uncertainties in the output from ash dispersion models. These arise from uncertainties in the wind field in the underlying atmospheric model, the source term for initialising the dispersion model and the concentration that presents a risk to aircraft. Hence, delineation of the forecast 'threat area' is problematic. Finally, the VAA is quite detailed and its preparation can be manually intensive. During busy operational periods this can cause undue pressure for operational staff.

* *Corresponding author address*: Rodney Potts, Bureau of Meteorology Research Centre, GPO Box 1289K, Melbourne, VIC, 3001, Australia.
Email: r.potts@bom.gov.au

All these factors cause delays and increase the potential for errors in the provision of advice that is of critical importance to aircraft operating in regions where there are active volcanoes.

With these issues in mind there is ongoing effort in the Bureau that is designed to improve the efficacy of the advisory service that is provided. This includes improved use of satellite data for detecting volcanic eruptions and tracking ash clouds, improved utilization of the volcanic ash dispersion model output and streamlining the warning preparation process. In this paper we briefly examine the operational uncertainties, using the Indonesian Ruang eruption of 25 September 2002 as a case study, and describe efforts directed at using available guidance in a more integrated and streamlined way for preparation of the volcanic ash advisory and a corresponding graphical product.

2. RUANG VOLCANO ERUPTION OF 25 SEPTEMBER 2002

The Ruang volcano is located in the Sangihe Islands of Indonesia at 2.28°N 125.425°E and has an elevation of 725 m. On 25 September 2002 at approximately 0340 UTC the volcano erupted to a height of approximately 20 km. Conditions at the time were clear and the evolution of the ash plume was well observed in satellite data, including the hourly GMS5 satellite data (Tupper etal 2004). Winds over the volcano at the time of the eruption were from the east in the layer up to 18 km and most of the ash plume moved to the west. A very thin and barely visible layer of ash and SO_2 in the layer 18-20 km did move to the east (Tupper etal 2004) but for the purposes of this discussion is not considered further.

2.1 Satellite Observations

Satellite data has proved of considerable value for the detection and tracking of volcanic ash clouds and there have been improvements in the utilisation of these data to support the volcanic ash warning service. In particular the use of multispectral data and the reverse absorption technique as described by Prata (1989a,b) has been of value for improving the discrimination of volcanic ash from water/ice clouds (Potts 1993, Tupper etal 2004). There are still limitations however, as well discussed by Simpson et al (2000, 2001), Prata etal (2001) and Tupper etal (2004), and further research and development is required.

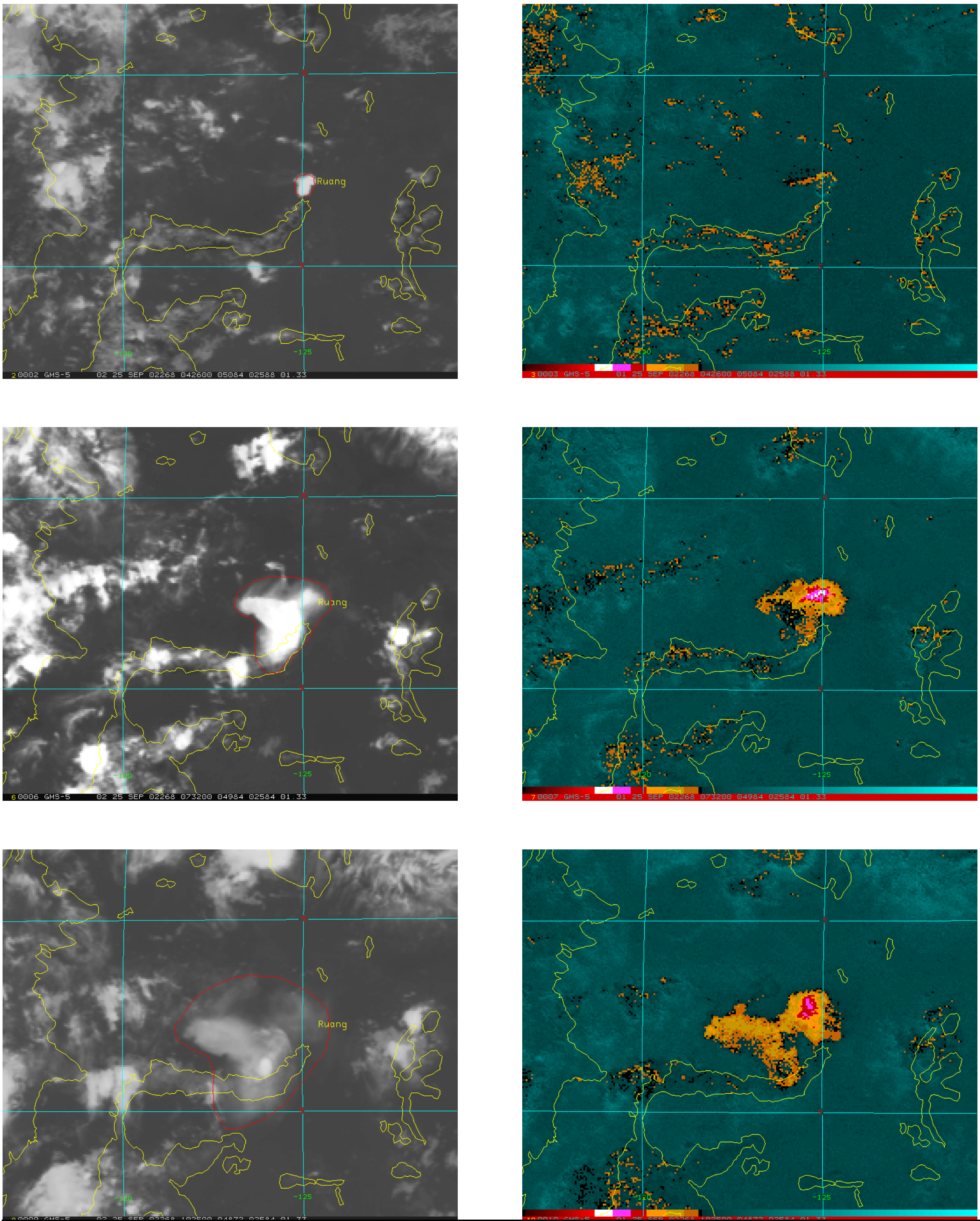


Figure 1. GMS satellite imagery for Ruang volcano eruption that occurred at 0345 UTC, 25 September 2002. IR1 and IR1-IR2 imagery for (a,b) 25/0430 UTC, (c,d) 25/0730 UTC and (e,f) 25/1030 UTC. (see text)

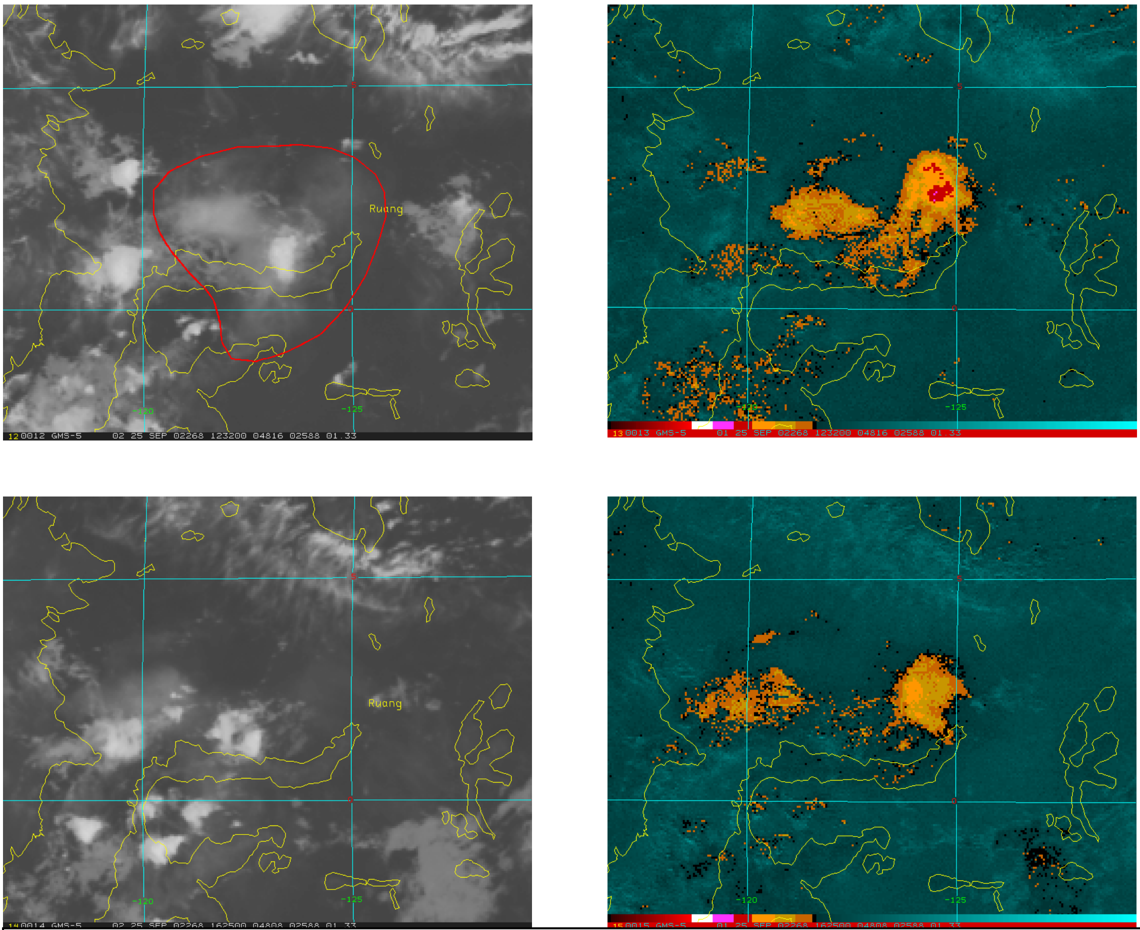


Figure 1…cont. GMS5 IR1 and IR1-IR2 imagery for (g,h) 25/1230 UTC and (i,j) 25/1630 UTC.

In the Darwin VAAC hourly geostationary satellite data from GMS5 (now defunct) and more recently GOES9 has been fundamental to improvements in warnings for volcanic ash in the region. AVHRR satellite data from the NOAA polar orbiting satellites are also very important though these data are available less frequently.

For the Ruang eruption Fig.1 shows the IR1 (BT_{11}) and the corresponding IR1-IR2 (BT_{11}-BT_{12}) images from GMS5 for the times 0430, 0730, 1030, 1230 and 1630 UTC. The IR1-IR2 images show positive differences in blue and negative differences in orange and red. The latter indicates the possible presence of ash and a well defined signature is evident near the centre of these images. The additional speckled areas of negative differences in the IR1-IR2 images are 'false alarms' that have been discussed elsewhere (Potts and Ebert 1996, Tupper etal 2004) and techniques have been developed to eliminate or minimise this.

For this event it was possible to track a 'visible' boundary for the ash cloud up to 1230 UTC from a loop of the hourly visible, IR1 and IR1-IR2 imagery and Fig.1 shows the manually analysed boundary up to this time.

Discriminating ash from water/ice clouds can be difficult in visible and IR imagery and although the IR1-IR2 image may show a well-defined ash signature it does not identify the full extent of the ash as shown in Fig 1. For this event the IR1-IR2 data showed the presence of ash for around 40 hours following the eruption but delineation of the ash boundary, or 'threat area', became problematic after just 9 hours. When there is active convection in the area and extensive water/ice cloud present then uncertainties in delineating the analysed and forecast threat areas increase greatly.

2.2 Dispersion Model Output

Guidance on the dispersion of volcanic ash clouds is provided by the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler and Hess, 1998). The model uses pre-processed NWP

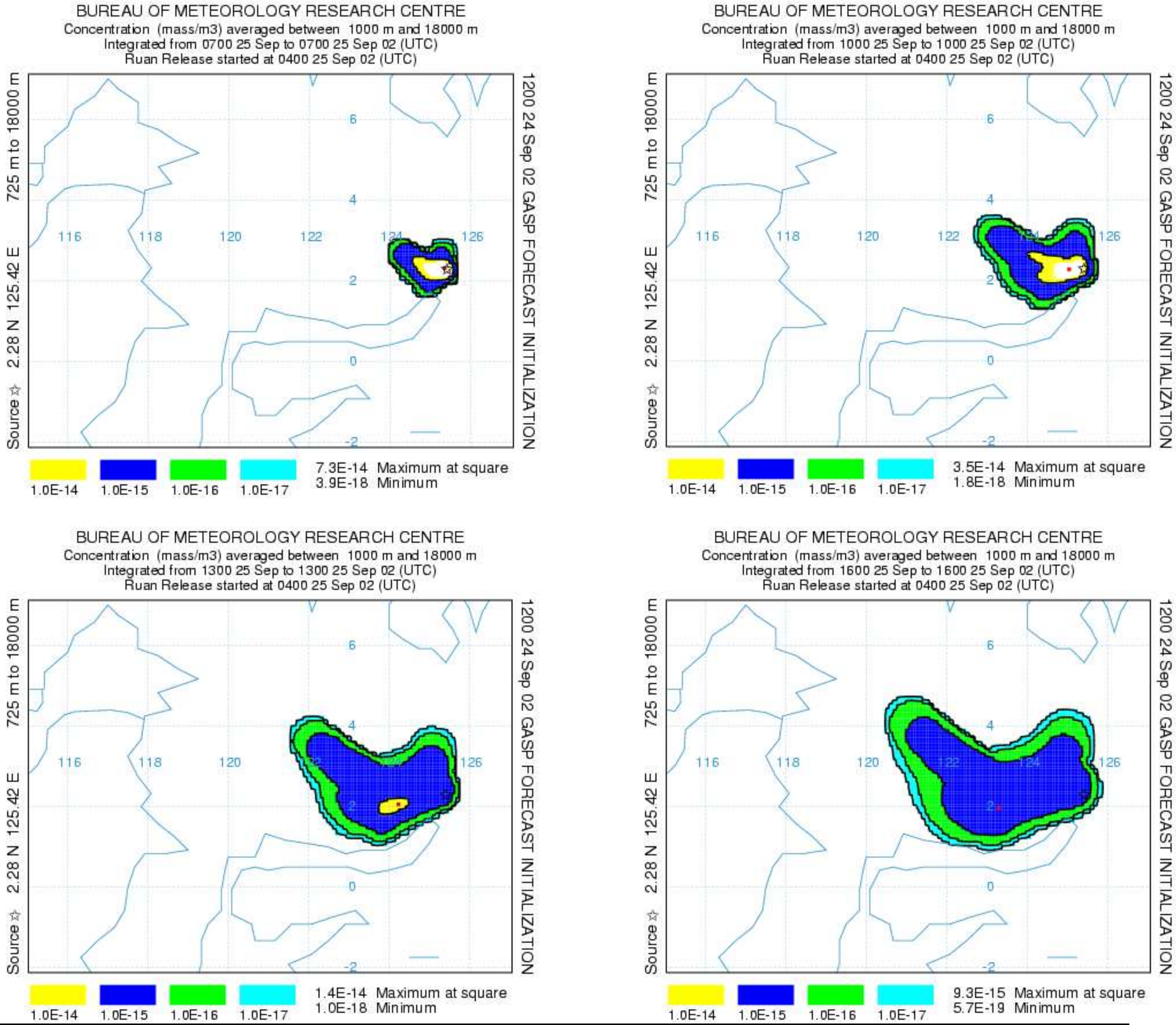


Figure 2. HYSPLIT dispersion model output for Ruang eruption at 0345 UTC, 25 Sep 2002. (see text)

model fields from the Bureau's global model (GASP) (Seaman etal 1995) or tropical regional model (TLAPS) (Puri etal 1992) that are generated routinely at 12 hour intervals. The time of the eruption, the height and the duration are set by the forecaster and the dispersion model is run with other system parameters set to default values. Model output is then used as guidance for delineating the forecast ash boundary or 'threat area'. With improved NWP models and dispersion models this guidance has proved of great value in preparing the VAA. However, there are still uncertainties.

Fig.2 shows the integrated concentration from the surface to 18 km for the Ruang eruption given by the dispersion model. The model run was based on the eruption starting at 25/0345UTC, a nominal emitted mass of unit 1 and a line source centred on the volcano. It was run using the GASP forecast wind fields from the 24/1200UTC NWP model run, as these would have been available at the time of the eruption. Output is shown at 3-hour time steps for the period 25/0700UTC to 25/1600UTC.

Comparison of the forecast ash boundary shown in Fig 2 with the analysed ash boundary shown in Fig 1 shows general agreement but the extent of the analysed ash is significantly greater. Such differences can arise because the forecast wind field from the underlying NWP model is not representative of the true wind field. There are also uncertainties in the source term with difficulties in estimating the height of the eruption in an operational environment and a lack of information about the 3-dimensional mass distribution of ash. Here we assumed a uniform line source but in reality there is horizontal spreading of the plume in the early stages, due to the internal dynamics of the eruption, and this will contribute to greater spreading of the plume than the model predicts. Finally the nominal ash concentration that presents a risk to aircraft is not well known. If the defined 'threat area' is based on a low concentration threshold from the dispersion model then the area may be very extensive after a period of 18-24 hours. This may impact many airways in the region and the selection of alternate routes that avoid the area may result in onerous and unnecessary costs to airlines. Conversely, if the defined 'threat area' is based on a high concentration threshold the area that is hazardous to aircraft may not be fully covered.

Operational forecasters must provide relevant information on the presence of volcanic ash in the VAA products and given the uncertainties described here the satellite data and dispersion model output must be used in an integrated way to provide the best assessment of the analysed and forecast ash boundary or 'threat area'.

3. THE DARWIN VOLCANIC ASH WARNING PREPARATION SYSTEM (VAWS)

The Volcanic Ash Warning Preparation System (VAWS) is a user interface that has been developed to enable more integrated use of available satellite data and dispersion model output and to streamline the generation of the VAA text message. The system also generates a graphical product that is consistent with the text product and provides a framework that will simplify the operational implementation of improved analysis and prediction components.

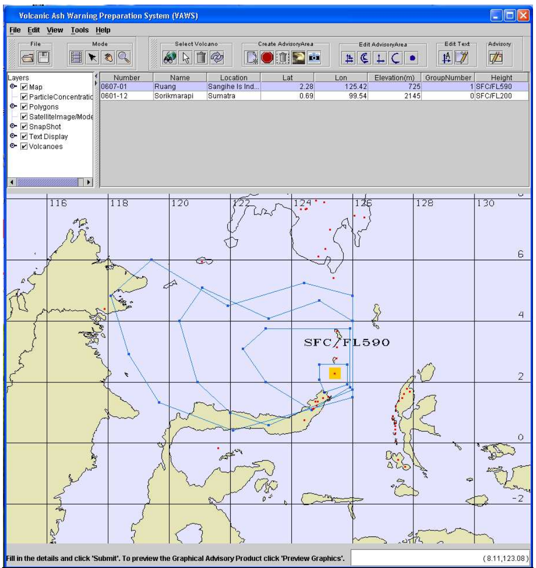


Figure 3. Graphical interface for Volcanic Ash Warning Preparation System.

The VAWS interface includes a graphics window that shows the coastlines and all volcanoes in the region, a table for the display of relevant volcano details, a layer manager and a toolbar, as illustrated in Fig 3. Full roam and zoom capabilities are available in the graphics window and the user can select the volcano of interest, using the mouse or a text based search, and add the volcano to the volcano table. The forecaster can then define the analysed and forecast threat areas for 0 hr, +6 hr, +12 hr and +18 hr using the mouse. The VAA product is generated in a two-step process. The operator selects the 'Advisory' icon on the toolbar and this generates a text dialogue that shows all the required fields for the VAA (Fig 4). Most of these fields are filled automatically using details derived from the graphical interface and remaining fields, such as the information source, are

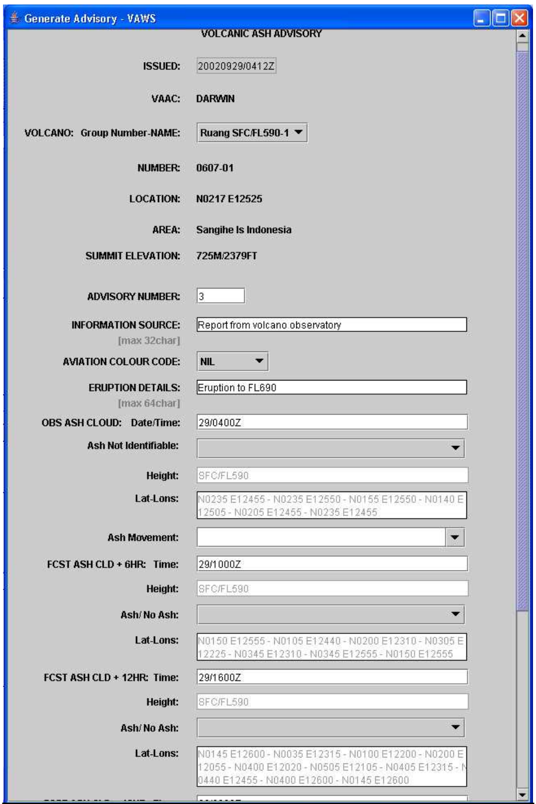
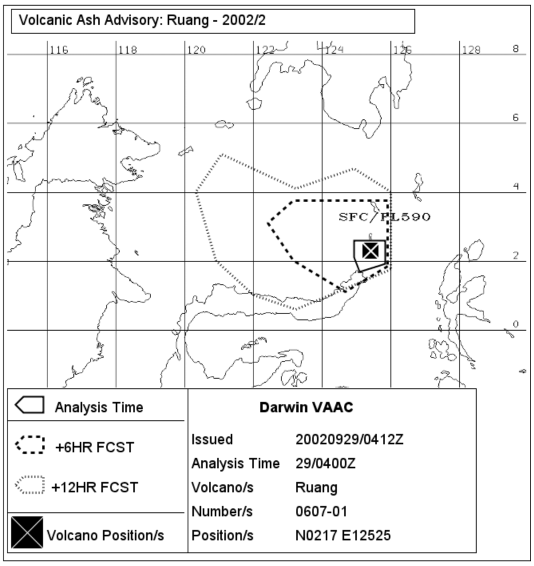


Figure 4. Text dialogue for preparation of VAA message.

completed manually. The output products are then previewed and submitted for dissemination. The products include the VAA in text format and a corresponding graphical product (Fig 5) that was developed in liaison with regional aviation industry representatives. The output products are archived together with system files that store relevant information for each advisory and for the system status. Provision is made in the system for cases where it may not be possible to discern the ash boundary in satellite data, cases where there may be two or more layers from a given volcano moving in different directions and situations where more than one volcano is active at a given time.

In the development of the user interface several design criteria have been adhered to. These include platform independence; a responsive graphical interface; the need to integrate the system within the Bureau's operational infrastructure (Kelly, etal, 2004); the ability to display satellite data, NWP data and output from the ash dispersion model using a concept of layers; and, the need to archive relevant information for training purposes and for ongoing research and development.



In the first stage of development the focus has been to streamline the preparation of the VAA message and to generate a corresponding graphical product. The latest version of the VAWS system allows for the display of satellite data and dispersion model output within the graphics window and this will be implemented for operational use in the near future.

3.1 OPERATIONAL EXPERIENCES

Operational use of the stage-one VAWS system started in Dec 2003 and over 250 VAA's have been generated and disseminated in the period up to 1 August 2004. Following feedback from operational forecasters a number of upgrades have been provided to improve operations and functionality. The system has streamlined the preparation of the VAA message, reduced the potential for errors, and feedback from forecasters has been positive. Feedback from the aviation industry on the format of the graphical product has also been positive. It is consistent with the text product and satisfies the need, expressed by flight planning personnel and pilots, for a concise and simple product that shows the variation of the ash boundary with time. The simple format also means the product remains legible when faxed to pilots at briefing stations that may have limited facilities.

4. CONCLUSIONS

The Volcanic Ash Advisories (VAA's) issued by the Darwin VAAC are based on an initial report or detection of a volcanic eruption or ash cloud, an analysis of satellite data to identify and track the ash cloud, and a forecast of the movement of the ash derived from upper level winds and an atmospheric dispersion model. Uncertainties in the guidance means the forecaster must use them in an integrated way to generate output products for the aviation industry. This process, together with preparation of the VAA, can be manually intensive and time consuming with the resultant delays and potential for errors.

The Volcanic Ash Warning Preparation System (VAWS) is a person-machine user interface that has been developed to streamline preparation of the VAA text product and automatically generate a corresponding graphical product. It enables satellite data and dispersion model outputs to be used in a more integrated way to delineate the analysed and forecast threat areas. The system will also provide a stable framework that simplifies the operational implementation of improved analysis and prediction components. The system has been in operational use since December 2003 and feedback from forecasters and the aviation industry has been positive.

Although there have been advances in the use of satellite data and the dispersion model to improve the guidance available to forecasters, further research and development is required. There is a need for better detection of volcanic ash in satellite data including identification of the ash boundary. There is also a need to determine the uncertainties in the forecast ash boundary from dispersion models and to develop ways to present information about the uncertainty to the aviation industry.

5. REFERENCES

Draxler, R.R. and G.D. Hess, 1998: An Overview of the Hysplit_4 Modeling System for Trajectories, Dispersion, and Deposition, *Aust. Met. Mag.*, **47**, 295-308.

ICAO, 2001: Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds. ICAO Doc 9691-AN/954, First Edition-2001.

Kelly J., A. Donaldson, C. Ryan, J. Bally, J. Wilson and R. Potts, 2004: The Australian Bureau of Meteorology's next generation forecasting system. 20th IIPS Conference, AMS.

Potts, R.J., 1993: Satellite observations of Mt Pinatubo ash clouds. *Aust.Met.Mag.*, **42**, 59-68.

Potts R.J., and E. Ebert, 1996: On the detection of volcanic ash in NOAA AVHRR infrared satellite imagery. Proceedings of the 8th Australasian Remote Sensing Conference. Canberra, 25-29 March 1996.

Prata, A.J., 1989a: Infrared radiative transfer calculations for volcanic ash clouds. *Geophys.Res.Letters*, **16**, 1293-1296.

Prata, A.J., 1989b: Observations of volcanic ash in the 10-12 m window using AVHRR/2 data. *International Journal of Remote Sensing*, **10**, 751-761.

Prata A.J., G.J.S. Bluth, W.I. Rose, D.J. Schneider and A.C. Tupper, 2001: Comments on "Failures in detecting volcanic ash from a satellite based technique". Remote Sens. Environ, **78**, 341-346.

Puri K., N.E. Davidson, L.M. Leslie and L.W. Logan, 1992: The BMRC tropical limited area model. Aust. Met. Mag., **40**, 81-104.

Seaman R., W. Bourke, P. Steinle, T. Hart, G. Embery, M. Naughton and L. Rikus, 1995: Evolution of the Bureau of Meteorology's Global Assimilation and Prediction System. Part 1: Analysis and initialisation. Aust. Met. Mag., **44**, 1-18.

Simpson J.J., G. Hufford, D.Pieri and J.Berg, 2000: Failures in detecting volcanic ash from a satellite based technique. Remote.Sens.Environ., **72**, 191-217.

Simpson J.J., G.Hufford, D.Pieri and J.S. Berg, 2001: Response to "Comments on 'Failures in detecting volcanic ash from a satellite based technique'". Remote.Sens.Environ., **78**, 347-357.

Tupper A., S. Carn, J. Davey, Y. Kamada, R. Potts, F. Prata and M. Tokuno, 2004: An evaluation of volcanic cloud detection techniques during significant eruptions in the western 'Ring of Fire'. *Remote Sensing of Environment*, **91**, 27-46.