Standardisation of the USGS Volcano Alert Level System (VALS): analysis and ramifications

Introduction

Within the last decade significant levels of standardisation have been introduced into protocols and procedures that deal with emergency and disaster management. Notably, following the catastrophic Indian Ocean tsunami of 2004, the UN Secretary-General called for the development of a global early warning system (EWS) for all natural hazards and communities. Certainly, the scope of the disaster, with the tsunami causing loss of life in 14 countries, pointed to the need for a readily translatable, easily understood alert system that could be disseminated quickly via diverse communication media. More often, however, standardisation has been the goal and product of nation-state planning; a trend accelerated in post-9/11 United States (U.S.) and Europe as part of the drive toward increased 'securitisation'. Whereas warning systems and response measures associated with natural hazards have historically emerged from local and regional networks, now a more explicit, top-down demand for cross-contextual protocols has become the norm. These protocols benefit those responsible for management of a standardised warning system, insofar as it enables scientists, for example, to 'constrain work practices and define, describe, and contain representations of nature and reality' (Fujimura 1987, p.205). Protcols also establish political control and legal accountability, particularly during dynamic situations such as natural hazard crises however, a number of difficulties have also ensued (Hogle 1995; Timmermans and Berg 1997; Timmermans and Epstein 2010). These relate to the simplification of what are complex volcanic events and systems, such that more targeted response efforts are hindered, but also to an accompanying shift away from the description (and explanation) of particular events towards a set of warning icons and words that lend themselves to very particular (that is, aviation) communities.

Globally, volcano alert level systems (VALS; also referred to as status levels, condition levels, or colour codes) are used to provide warnings and emergency information in relation to volcanic unrest and eruptive activity, typically based upon forecasts arising from observation, monitoring and data analysis. VALS are a key sub-system within a volcano early warning system, and address the development and communication processes of warnings both prior to and during a hazard 'event,' which can occur in the form of fall deposits (ash), to flow processes (lahars and pyroclastic flows), to volcanic gases, earthquakes and tsunamis. Typically, scientists assess the state of the volcano to forecast future behaviour and assign an alert 'level' – thereby anticipating a 'linearised' set of physical processes (i.e. that follow a linear progression) – that provides public and civil authorities a framework that can be used to gauge and coordinate their response to a developing volcano emergency. In 1985, the United Nations Disaster Relief Organisation (UNDRO) published the report 'Volcanic Emergency Management' outlining one of the first examples of a VALS, described as 'Stages of Alert of Volcanic Eruption' (UNDRO 1985, p.54). The report provided strong guidance in relation to limiting panic during volcanic crises via public announcements, decided prior to any emergency, with the public made aware in advance of arrangements for information provision. These details vary according to locality, region and country, according to different 'political and social structure of the community and the technical means available. It is therefore difficult to lay down any detailed guidelines for public information and warning' (UNDRO 1985, p.55). Due to the recognised importance of local contingency two key consequences arise: first, the majority of operational VALS have remained localised; second, published analytical and evaluative material that addresses the VALS concept has, since 1985, been sparse, and limited, to grey issued by volcano observatories, institutions and individuals, despite the fact that volcano alert levels have been implemented and used around the globe for many decades.

In recent decades, however, standardisation within VALS at a national level has taken place, allowing adaptation better tailored to the type of volcanism encountered, and making provision for consistency of warnings enacted by civil authorities required to take action and facilitate national policies for emergency management. VALS in a number of countries (including Japan, New Zealand, the Philippines and the U.S.) have been standardised at a national level so that a single VALS is used for all ground-based volcanic hazards. Yet, there are variances in the way VALS are being standardised. In the U.S., for example, two standardised VALS are now in place; a textually-based version for ground hazards, and another for aviation hazards that uses colours. New Zealand, also uses two standardised VALS; one designed for hazards expected at frequently active volcanoes, and the other for restless and reawakening volcanoes. Both VALS are numerically-based using six levels ranging from 0 to 5 (GNS 2010). Notably, both the U.S. and New Zealand VALS are based upon the current activity of a volcano, and neither advocate action nor provide advice to users involved in crisis management and mitigation. In sharp contrast, the Japanese VALS addresses the measures to be taken by specifying areas of danger, indicating extent of evacuation, and outlining the expected volcanic activity (Japan Meteorological Agency 2010). Advice on mitigatory action or evacuations to civil authorities or emergency managers is also commonly incorporated within VALS used in developing countries. On the basis of the above examples alone, it becomes apparent that designing and using a standardised VALS involves complex issues that require decisions on: the nature of the information is provided; the style of warning (for example, based upon current or forecast activity); the requirement for a separate aviation alert level system; and whether or not recommendations of mitigatory actions should be included. The World Organisation of Volcano Observatories (WOVO) notes that, although there is often worldwide interest in the status of a volcano, 'with the exception of colour codes for aviation, currently there is no standardised international volcano alert levels system' (WOVO 2008). This, it observes, is due to the 'wide variation in the behaviour of individual volcanoes and in monitoring capabilities, and different needs of populations, including different languages and symbolism of colours or alert levels' (WOVO 2008). The WOVO recognises the importance of local contingency, but also the fact that there is a growing demand, most notably from the aviation sector, for a standardised tool that can be deployed regardless of which airspace pilots are flying through. Consequently, the standardisation of VALS and its effectiveness is in the interest of all institutions seeking ways to improve the effectiveness of their VALS and for new volcano observatories looking for best practices in launching new VALS. Standardisation of VALS across different countries has been a topical issue within the volcanological community, discussed throughout the 1990s with the support of IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior), in the context of establishing a degree of common knowledge and understanding with regard to volcanoes that demonstrate similar behaviours and eruptive styles, and how this might – in turn – lead to the development of more comparable VALS. The development of fruitful commonality has, however, proved to be evasive; a key point of contention being the criteria used in raising and lowering alert levels.

This paper takes as its focus VALS standardisation as it has emerged in relation to addressing the volcanic threat in the U.S.. Specifically, it analyses the development by the United States Geological Survey (USGS) of a standardised volcano alert level system (VALS); including its design, terminology, and operational procedures. The USGS monitors 169 active volcanoes characterised by a wide range of eruptive styles and located in six different tectonic settings. It has also gained experience of volcanic crises around the world via the Volcano Disaster Assistance Program (VDAP) (Ewert et al. 2007), and continues to work closely with Russia's Kamchatka Volcanic Eruption Response Team (KVERT). Within the United States, the USGS supports five relatively well-funded volcano observatories located in regions of significant volcanic hazard, high population or important infrastructure; these operate in Alaska (AVO), the Cascades (north-western U.S.) (CVO), Hawaii (HVO), Long Valley (LVO) now the California Volcano Observatory - CalVO), and Yellowstone (Idaho, Montana, Wyoming) (YVO) (Fig. 1). In 2004 the VALS developed by Alaska Volcano Observatory (AVO) was adopted by the International Civil Aviation Organisation (ICAO) as the international warning system for volcanic ash, becoming the first 'globally standardised' VALS. In 2006, the USGS adopted two standardised VALS, one for ground-based hazards and the other for aviation ash hazards, replacing extant VALS that had been locally developed at each volcano observatory (Gardner and Guffanti 2006). This rationalisation of VALS provides a unique opportunity to examine and analyse the ramifications of upward scalability of VALS and to critically evaluate their effectiveness - at different scales - to communicate a warning.

Research conducted during 2007-2008, adopting a multi-sited ethnographic study (Marcus 1995) at all five USGS volcano observatories, forms the basis of the critical analysis that addresses how, and with what impact, the USGS standardised VALS emerged.[ii] First, the 'scaling-up' of existing locally-contingent VALS, as the basis for national-level VALS, is examined, before looking at how the resultant warning system, which offers a highly simplified categorisation of volcanic activity and no mitigatory advice, has been adopted and used by particular communities. Most crucially, the paper examines how the standardised set of protocols has in turn become subject to a 'scaling-down,' or local contingency, insofar as their implementation 'on the ground' has proceeded in accordance with existing institutional practices and procedures. To provide some context for this discussion, however, a brief outline of how observatories proceeded to develop their own warning systems follows. Quotes used in the text are anonymous to protect interviewee identity. So that the context of the quote is clear, however, the observatory or federal agency of the interviewee is named, or it is stated if the data source is from documents filed under the United States Freedom of Information Act (U.S. FOIA).

Difference and diversity in the US volcano observatories

The USGS has been involved with volcanic hazards since its formation in 1879, but this became a key area of interest in 1912, when Thomas A. Jaggar founded the Hawaiian Volcano Observatory (HVO) (Heliker et al. 1968). In 1974, the Disaster Relief Act (subsequently amended in 1988 and known as the Stafford Act), was enacted in response to severe tornadoes earlier in the year, prompting institutional efforts to provide early warning protocols across the U.S.. As a forerunner of more recent efforts at standardisation, in 1977 the USGS developed procedures for providing warnings for all the hazards for which it had been given responsibility. It drew on the research and experience of other government agencies in meteorology and hydrology to establish a three-tiered system increasing in severity from: a 'notice of potential hazard', to a 'hazard watch', to a 'hazard warning'. Only the Director of the USGS could issue warnings (Hill et al. 2002, p.33). In practice, however, the typical four day delay in getting the Hazard Warning signed off by the USGS Director illustrated that the bureaucratic process was too long to make the warning useful (LVO senior scientist 1; 22/05/08 and VHP manager 6; 21/05/08). Not until the 1980s did three major volcanic crises lead to three newly established volcano observatories (Alaska, Cascades, and Long Valley) shaping the early use and development of warning systems so as to meet their own needs, rendering their implementation more locally-specific than was originally intended.[iii]

The 1980 eruption of Mount. St. Helens in the Cascades Range was the deadliest and most economically destructive volcanic event in the history of the U.S.. Critically, the event coincided with the expansion of media news channels, both local and national, which provided a new, communicative context with which scientists were able to engage. Between June 1980, and October 1986, during which time Mount. St. Helens continued to erupt in the form of a dome-building phase punctuated frequently by dome explosions, scientists worked to develop warnings as far as three weeks in advance for 19 out of 21 explosions (Bailey and USGS 1983). This gave many scientists confidence in their ability to provide more detailed advisories than were required (HVO senior scientist 5; 16/06/08), and the alert levels issued grew from only written information statements, to a VALS with an 'extended outlook advisory', a 'volcano advisory', and a 'volcano alert', labelled from one to four for increasing severity and targeted primarily at Federal Agencies (US Forest Service 1992, pp.20-22). In response, emergency managers throughout the Cascade mountain range developed appropriate actions for each level.

From May 1980, Long Valley caldera (15km by 30km) in eastern-central California began a long phase of unrest, generating serious concern amongst USGS scientists that volcanic activity might occur. The eruptive characteristics of calderas were, and still are, inadequately understood (Newhall and Dzurisin 1988; Troise et al. 2006). The town of Mammoth Lakes, a ski resort popular with Californians, is located on the rim of Long Valley caldera and at the time was developing into a major international resort with populations that swelled to more than 40,000 during peak weekends in the ski season (Hill 1998). At the time, many businesses and investors felt that negative publicity associated with the restless state of the volcano could ruin this growth potential, making management of the volcanic crisis very difficult (Hill 1998, p.401). On October 11, 1983, as a consequence of bad feeling within the Mammoth Lakes community, the official 1977 USGS 3-tiered warning system was dropped to only one tier (see Federal Register v.48, n197[iv]): that is, 'a formal statement by the director of the USGS that discusses a specific geologic condition, process, or potential event that poses a significant *threat* to the public, and for which some *timely* response would be expected', (Hill et al. 2002, p.33) (author's emphasis).

Unable to operate on the basis of a single level warning system, Long Valley Observatory (LVO) has developed and changed its VALS more than any other USGS volcano observatory. The first VALS, introduced in 1991, was based on the USGS Parkfield earthquake prediction experiment, which used an alphabetic scheme of five alert levels from E to A in ascending order of concern, so that 'E' reflects weak unrest and 'A' reflects a warning for volcanic eruption (Bakun et al.` 1987; Bakun 1988). This system was adapted for volcanic hazards at LVO because it was the only formal alert level system the USGS used in California (Hill et al. 1991). Following significant levels of volcanic unrest during the 1990s it became clear via the media, however, that most people had no idea what a 'D-level' alert meant, other than it seemed serious and intimidated visitors to the region, and therefore was detrimental to business. In June

1997, the alphabetic VALS was converted to a four level colour VALS of Green, Yellow, Orange and Red (Fig. 2). In addition, distinctive shapes were used for the colour VALS that could be identified when using black and white print, and faxing. The shapes used were designed to match those used in the state to signify increasing difficulty of pistes, allowing skiers to more intuitively recognise the level of severity of a volcano warning (LVO senior scientist 1; 22/05/08/ and VHP manager 4; 23/05/08). As with the VALS adapted from the USGS Parkfield earthquake prediction experiment, there were detailed sub-levels and stand-down criteria, including at the red alert level.

At the Alaska Volcano Observatory (AVO), yet other user groups and spatial areas of risk became crucial to the development of the observatory and the VALS. In 1986, Augustine Volcano in Alaska's Cook Inlet erupted, generating clouds that disrupted regional air traffic (Casadevall et al. 1994). Volcanologists at the USGS office in Alaska worked with the University of Alaska Fairbanks Geophysical Institute (UAFGI), and the Alaska Division of Geological and Geophysical Surveys (DGGS), to forecast volcanic activity and advise the Federal Aviation Authority (FAA) and U.S. Air Force. By March 1986, this cooperation was formalised in the form of AVO charged with having responsibility for monitoring the four major Cook Inlet volcanoes: Augustine, Spurr, Redoubt and Iliamna. Then, in 1989, the eruption of Redoubt on December 15th, 1989, led to a Boeing 747 aircraft losing power in all four of its engines and dropping 4km in altitude before reigniting the engines just 1km above the nearby mountain peaks (Brantley et al. 1990). Whilst no casualties resulted, damage to the relatively new aircraft was estimated at USD80million (Steenblik 1990). This costly event widely affected commercial and military aircraft operations in the vicinity of Anchorage, causing the re-routing or cancellation of flight operations. This, in turn, seriously impacted the Anchorage economy since Ted Stevens Anchorage International Airport handles more international air freight (by dollar value) than any other airport in the U.S., and remains one of the largest cargo hubs in the world (Airport-technology 2010). Staff at the then small AVO began working with the FAA to develop a specific VALS for large ash plumes and ash clouds with the potential to impact aircraft, and introduced its colour code for aviation during the February 1990 eruption of Mount Redoubt. Unlike the VALS used by the Long Valley and Cascades volcano observatories, the AVO VALS needed to specifically communicate ash hazards as quickly as possible predominantly to the aviation community.

With this goal in mind, the AVO Scientist-in-Charge and the Volcanic Hazard Program Team Chief Scientist decided upon a simple colour-based traffic light system given the extensive use and simplicity of road traffic light systems around the world, along with an increasing use of colours in volcanic risk management ~~already used across South America that had proved successful with local populations~~ (AVO senior scientist 8; 22/04/08), and was renamed as the 'aviation colour code for concern' by AVO.

With increased monitoring capabilities at AVO came recognition of increasing diversity of volcanic behaviour, which led to a number of modifications in the colour VALS. Following the 1996 Akutan volcano seismic crises, the VALS 'description' category (Keith 1995, p.5) was split into 'intensity of unrest at volcano', and 'forecast' (Waythomas et al. 1998, p.33). By 1998, however, the original colour code VALS were back in use suggesting that the forecasting element may have been too specific, making the alert level criteria too restrictive, and implying that volcanic activity could be forecast more accurately than actually possible in a majority of cases. On October 6th 2004, the Cascade volcano observatory (CVO) adopted the AVO colour VALS for ash, incorporating it into an updated VALS. In 2003, however, CVO staff working on the volcanic eruption response plans for Mount. Baker and Glacier Peak were asked by their workgroup stakeholders whether it would be possible to change the names of the alert levels to those used by the National Weather Service (NWS) for flood and tsunami warnings: 'Advisory', 'Watch' and 'Warning' (CVO user – emergency manager 3; 13/04/08). It was felt by the CVO scientists that 'a change to [National] Weather Service alert titles would prevent confusion during volcano crises and that a single alert scheme would be more useful for educating the public about hazard alert levels' (U.S. FOIA).

Hawaii Volcano observatory, by way of contrast, had never developed a VALS. High levels of activity at Kilauea, including its constant eruption from 1983 to the present, facilitated close relationships between the observatory and the local agencies (Tilling et al. 1987). Islanders have experienced numerous volcanic crises and emergency responders have developed sophisticated communication and responsive procedures within their communities (HVO user – emergency manager 1; 24/06/08), without the use of a VALS.

Within two decades, the USGS's Volcano Hazards Program (VHP) had evolved in response to a number of crises and warning systems changes, few of which were the result of in-depth consultation or design. For the most part, these systems were driven by perceived local need, usually over a short time frame. Yet pressures to adopt a national aviation VALS, and user demands for the CVO VALS to comply with National Weather Service terms suggested that nationalisation of VALS was worthy of discussion, which would require consultation with the USGS's external partners and VALS stakeholders. Within USGS management there was growing concern at having different conventions within the VHP, whilst promoting uniformity for aviation VALS. The question of standardisation was certainly being considered at observatory level; these discussions, however, were to be overtaken by federal decision-making, and a top-down series of directives.

Scaling-up VALS in a post-9/11 United States

Following 9/11, U.S. Congress passed the Homeland Security Act (2002), creating the Department of Homeland Security (DHS) in an effort to improve coordination between the different federal agencies that deal with law enforcement, disaster preparedness and recovery, border protection and civil defence. This led, in the same year, to the launch of Homeland Security Advisory System - a colour coded terrorism risk advisory scale created to accommodate the Presidential Directive to provide information relating to terrorist acts to federal, state, and local authorities and the public (US Department of Homeland Security 2010) - and the establishment of a national emergency warning system (EAS). In 2004, one year after discussion and vetting, the National Incident Management System (NIMS) was also accepted for all federal departments, including the U.S. emergency management agencies, as a national-level policy for incident management in order to enable effective and efficient incident management and coordination through provision of a flexible, standardised incident management structure (Department of Homeland Security 2008, p.1). To do this, three key elements were developed: the Incident Command System (ICS), Multiagency Coordination Systems (MACS), and Public Information that provided standardisation through consistency of terminology and commonality of established organisation structures (e.g. the Joint information Centres; JICs). Crisis management was now tailored to address the terrorist threat and, as a consequence, policies to standardise systems for procedures and warnings across a multi-hazard platform dominated the period from 2002.

In 2004, the International Civil Aviation Organisation (ICAO) incorporated the AVO colour VALS into its ‘Handbook on the International Airways Volcano Watch’, with one modification (the removal of height thresholds associated with particular alert levels) (ICAO 2004). By September 2005, the AVO colour code of concern VALS was formally adopted in principle by ICAO to provide notification of the status of a volcano for the purpose of supporting operational decisions to issue warnings globally. ICAO specifies that ‘the colour code [alert level] describes conditions at / near the volcanic source circa the time of eruption and is not intended to describe the hazard potential of the drifting ash cloud itself at locations distant from the volcano or after the volcano has stopped erupting’ (ICAO 2005, p.5-9). In contrast, no consensus had, at this time, been built for an internationally standardised VALS for ground-based hazards.

At an observatory level, it became clear that VALS stakeholders were not only diverse, but required different information across a range of temporal and spatial scales. At an institutional level it was argued by USGS staff that the multiple VALS within the VHP presented a fragmented appearance, lacked consistency, and complicated the role the overseas VDAP team when advising about the adoption of a VALS at different volcanoes. The U.S. President himself, it was argued, wanted to have a simple system whereby he could quickly visualise and understand the relative danger levels associated with a hazard (VHP manager 6; 21/05/08).

In 2003, the VHP team Chief Scientist formed a 'standardisation committee', instructed to determine whether a single alert level notification scheme could be developed to cover all possible volcanic hazard scenarios, and if no generally-applicable system could be determined, what the alternative options were (CVO manager; 07/05/08). The committee comprised a representative member from each volcano observatory along with the USGS Project Chief of the World Volcanic Activity and Aviation Hazards project. The requirements to comply with other federal agency alert systems and adhere to the U.S. Emergency Alert System (EAS) and Common Alert Protocol (CAP) meant that warnings must be compatible between alerting technologies (using an XML-based data format) to simplify warning activation and increase a warning's effectiveness (AVO collaborator 2; 17/04/08). The single most contentious aspect of the entire process, however, were questions related to the design of the VALS. For example; how many VALS and alert levels would be needed? should they be based upon words or colours? would a focus on volcanic activity or forecast behaviour be most appropriate?, what criteria would best define the different alert levels. At the same time, the extant aviation VALS was under discussion for adoption by the International Civil Aviation Organisation (ICAO), thereby restricting potential designs for a standardised VALS.

In May 2004, based upon discussions with Cascadian coordination groups that bring together the different stakeholders involved in a potential volcanic crisis, a white paper written by the standardisation committee reviewed the feasibility of a single unified VALS for all U.S. volcanoes (Gardner *et al.* 2004).[v] In October of that year, however, as the white paper awaited sign-off at CVO by the VHP team Chief Scientist, Mount. St. Helens began erupting, leaving CVO personnel no choice but to use the established CVO VALS that was familiar to stakeholders. During this resulting hiatus, debate over the design of a standardised VALS continued, with suggestions for the form it should take became more diverse as stakeholder input increased.

During 2004 and 2005, discussion driven by members of the standardisation committee, particularly those that worked within the aviation sector (CVO manager; 07/05/08 CVO senior scientist 2; 09/05/08), resulted in concerns over the adoption of a single VALS; 'the sticking point was one colour really can't capture activity in the way that is relevant to both ground and aviation' (VHP manager 1; 22/05/08). Email correspondence from AVO senior management to the VALS standardisation committee in September 2005 (U.S. FOIA) outlined concerns that – in the proposed single VALS - ground hazard users and the public would use the colour code instead of the National Weather Service descriptive terms, which could create confusion. The driver that led to the division of the proposed single VALS into two separate alert level systems appears to have been the need to provide a separate tailored product for aviation stakeholders; perhaps understandable given their financial investment in the VHP (particularly at AVO) and their different requirements. A pilot needs to access warning information quickly due to the high velocities of commercial aircraft, whereas for ground hazard stakeholders a lead-time is preferred so as to educate and inform those who need to know.

In March 2006, after three years of long and complex discussions, an agreed standardised VALS was implemented as a dual system. The ground hazard VALS reflects the level of activity / conditions at the volcano, and on-going or expected hazardous volcanic phenomena, using National Weather Service terminology, while an aviation colour code (VALS) (adopted by ICAO) is based upon the initial colour VALS developed by AVO in 1990 (Figs. 3 and 4).[vi]

For most eruptive activity, the 'alert-level term' and 'code colour' change together (e.g. Yellow and Advisory). Because some volcanic eruptions generate hazards that affect ground and aviation communities differently, however, the VHP decided that in these cases the alert level and colour code can move independently so as to provide flexibility in accommodating end members in the spectrum of volcanic activity;

> For example, an eruption of a lava flow that threatens a community but produces no significant ash might warrant a volcano alert level of Warning but an aviation colour code of Orange. On the other hand, an eruption that produces a huge cloud of volcanic ash that does not drift over inhabited areas might warrant a volcano alert level of Watch and an aviation colour code of Red (Gardner and Guffanti 2006, p.4).

Whilst this created flexibility in the use of the VALS, there were concerns that this might lead to inconsistencies between its operation at different volcano observatories, which could create confusion for the public and other stakeholders. The final decision to split the VALS was not unanimous. A quote from one of the key scientists involved in the process at CVO summarises the strong influences on the final form and its adoption:

> We didn't have a completely blank slate to work with. We couldn't hatch our own system from scratch. We were working in the context, and the context was that there is this colour code that the

aviation industry had adopted and there was this National Weather Service code that not only a lot of ground-based managers adopted, but apparently also wanted us to use, and so given those two things I don't really see that we have a choice (CVO scientist 3; 07/05/08).

The pressure to accommodate aviation demands due to the financial benefits that the aviation sector provided to the VHP was of key importance at a time, post-9/11, when all federal agencies were experiencing the Bush Administration's squeeze on funding resources (CVO manager; 07/05/08 and LVO senior scientist 1; 22/05/08).

AVO was the first observatory to adopt the new mandated VALS since they already operated the aviation code, and on 1st October 2006, CVO adopted the new VALS as the reduced level of activity at Mount. St. Helens meant that the VALS could be changed without confusing stakeholders. No formal notices about the change in VALS were issued, and there was minimal coverage by the media (CVO user – media; 13/05/08), which is perhaps a reflection of the public's lack of interest in VALS. Later in 2006, HVO, LVO and YVO adopted the VALS, although LVO were less keen to adopt a new VALS having just redesigned their own alert level system in 2002 (LVO senior scientist 1; 22/05/08). Each observatory had responsibility for educating the public and other stakeholders about the standardised VALS, and to aid this a USGS Fact Sheet was produced and disseminated to stakeholders and the public online and via printed sheet (Gardner and Guffanti 2006).

The four key requirements established by the USGS for the standardised VALS were to: '1) accommodate various sizes, styles, and duration of volcanic activity; 2) work equally well during escalating and de-escalating activity; 3) be equally useful to both those on the ground and those aviation; and 4) retain and improve effective existing alert notification protocols' (Gardner and Guffanti 2006, p.1). These requirements focus on hazard assessment, in light of a volcano's activity, and do not address issues of risk (such as risk evaluation or risk maps) which are typically completed by emergency and disaster management (Federal, State, or local) in close collaboration with the USGS. Additionally there was pressure for the VHP to adopt the commonly known and used National Weather Service (NWS) terminology (also adopted for tsunami warnings in the U.S.). Volcanic hazards, however, are very different from meteorological ones, and the NWS bases its warnings on probabilities. Since the frequency of recorded volcanic activity is typically insufficient to allow comparably accurate probabilistic models, the NWS terms in the VALS are used in a way that is different to that when applied to meteorological hazards.

In summary, the key factors that led to the standardisation of the USGS VALS were only marginally related to the current scientific understanding of volcanic behaviour and hazards, and how to best represent these in a warning, and more driven, ultimately, by the social context of the post 9/11 U.S., which shaped the broader emergency management policy. Prior to 9/11, the USGS volcano observatories were able to use their scientific understanding of the volcanoes for which they were responsible to design appropriate VALS that, had evolved over time to incorporate local cultural aspects, such as the piste difficulty level shapes at Mammoth Lakes, to make their VALS more relevant to local stakeholders and vulnerable population. The latter, however, also include those in the air or further afield, whose vulnerability to volcanic activity is better addressed through scaling-up of VALS standardisation, which is beneficial for national and international stakeholders such as the U.S. Government, ICAO, and national emergency managers, although less pertinent to local communities.

Scaling-down VALS

It is through the practical application of the standardised VALS that it becomes apparent that local contingency unravels even the best efforts at standardisation. Three key issues contribute to the breakdown of standardisation in practice: first, the diversity of volcanic behaviour and hazards, including spatially and temporally; second, the pluralistic social and institutional contexts of the different volcano observatories; and third, differential abilities to effectively communicate a warning.

A wide range of hazards can be sourced at a volcano, whether it is active or not; potentially occurring at geographically distinct locations and at different times. All of these hazards, except for ash, are excluded from the standardised VALS, which relates only to the occurrence of eruptive activity at a volcano and not to associated hazards. Observatories have, therefore, developed independent alert level systems for different hazards that require specifically tailored warning systems. The problem of sulphur dioxide gas release in Hawaii, for example, has resulted in the development of two volcanic gas warning systems: one operated by the Hawaii Civil Defense authorities (Hawaii State Dept. of Health and County Civil Defense 2008) and a second by the USGS with the Hawaii Volcanoes National Park (Hawaii Volcanoes National Park 2008). At Long Valley volcanic gases also have an important focus, being one of the volcanic hazards that has recent taken lives in the caldera. In 2006, three ski patrol staff succumbed to carbon dioxide poisoning when they fell into a hole melted in overlying snow by a fumerole (LVO user – Mammoth Lakes town 2; 4/06/08 and LVO user – emergency manager 1; 03/06/08). Consequently, Long Valley caldera is monitored for carbon dioxide, particularly around Horseshoe Lake where, in 1990, the gas resulted in the death of trees across an area of 170 acres (Sorey et al. 1996), (LVO senior scientist 1; 22/05/08). Similarly, lahars present a distinctive and serious threat at some U.S. volcanoes since they can travel at velocities up to 80kmph down valleys towards populated areas, usually facilitating a warning that provides emergency managers with less than an hour in which to evacuate vulnerable populations (Scott et al. 2001). As a result, rapid warning systems have been specifically designed for lahars (Lockhart and Murray 2004). At CVO this is a significant concern since large lahars have occurred in the past on many of the Cascade volcanoes, travelling significant distances (sometimes greater than 100km) across what is now densely populated or industrialised land.

Whilst the standardised VALS was intentionally designed to allow the flexibility required by different observatories to cater for specific volcanoes and their hazards by de-coupling the two sets of warnings, in practice this was experienced differently according to the observatories' historical legacy. HVO, for example, which had no prior institutional experience of using a VALS, had to assign active but non-erupting volcanoes an alert level and discuss them at science meetings, which they had never done before. One HVO scientist said 'all of a sudden we are debating about what colour [alert] Mauna Loa *should be* rather than *focusing on the science* and what it means' (HVO scientist 2; 27/06/08) (author's emphasis). When assigning Mauna Loa an alert level conflict arose because, although it had shown signs of unrest in recent years, staff who had worked at other observatories felt it did not warrant a Yellow / Advisory alert level since it gave little scope to issue a higher alert level should further abnormal activity occur. There was clear conflict between those scientists at HVO who had worked with VALS before, and understood the strategic nature of how VALS can be used in a given context, and those that had no experience with them and relied on the description of the VALS as a strict criterion for assigning an alert level (HVO scientist 2; 27/06/08).

Each volcano, then, has its own behaviour patterns or 'character' as the scientists described it (CVO scientist 9; 05/05/08), making it difficult to use standardised monitoring parameters to determine the volcano's level of activity: 'I have been a sceptic about this standardisation all along,' one noted,

> mainly because I look out across the globe and see so many different situations and scenarios, that I think it could be difficult, that it might not be informationaly sound and correct to try and cookie cutter something that applies in every situation [to] every volcano everywhere. Now many of my colleagues completely disagree with me on this […]. I always feel like modern society needs to box everything into organised cubicles and have something that applies to everything. I'm just not sure that this really lends itself [to that process] (AVO senior scientist 1; 10/04/08).

The great majority of scientists interviewed actually identified with this problem, but also defended the use of the standardised VALS as the best possible solution to the problem of issuing volcano warnings at U.S. volcanoes, given constraints of time and resources. That is, despite concerns about the standardised VALS, a majority of staff felt that it is useful, regardless of its design or operation, because without it information cannot be easily communicated or disseminated. The following quote from a CVO scientist on the standardisation committee captures the dilemma of using a simple VALS to communicate complex messages:

> It's a very tricky business; any time you try to communicate a complex message in a simple way, it's very, very difficult. You still have to do it, it is still necessary, it's still important, but it's difficult because volcanoes are so complex and diverse and situations are so different, it's just fundamentally different if you have a volcano doing a certain thing within reach of a large population centre, or not, whether you are intensively monitoring a volcano or whether it is out in the middle of the Aleutians

> and you have very little monitoring. It's very hard to standardise, because the situations you are trying to describe in a single colour or single alert level can just be so varied (CVO senior scientist 1; 16/05/08).

With regard to communication, however, the users interviewed emphasised that clarity is very much lacking in relation to what a particular alert level means within a specific context, as by itself an alert level 'can be vague' (LVO user – emergency manager 1; 03/06/08). Stakeholders want to know why there was a change in alert level and seek further, specific, information; they are 'not just going to look at red and evacuate'. (HVO user – emergency manager 1; 24/06/08). VALS do not relate to a number of volcanic hazards that can cause a great deal of concern; therefore, the 'alert level itself is less important as to what they have to do in response to about it' (CVO scientist 6; 30/04/08). Although messages accompanying volcano alert levels have been used at U.S. volcano observatories since the 1980s, so as to provide more contextual information, these messages are becoming standardised in the form of communication products referred to as the Volcanic Activity Notice (VAN) and Volcano Observatory Notices for Aviation (VONA) that are computer generated by a scientist populating pre-assigned data fields.

VALS, then, impinge upon and interact with a number of complex scientific, social and institutional issues. Figure 5 provides a summary of these issues in relation to each U.S. volcano observatory, and details how the standardised VALS has so far been adapted to cope with them. It can be seen that in practice a number of variables of a scientific, social and institutional nature have contributed to the adaptation of the standardised VALS; the very act of adaptation highlighting limitations to the effectiveness of the 'scaled-up' standardisation, since this process is inevitably undertaken in order to address local contextual factors.

In Conclusion: to standardise or not?

This paper has identified a number of advantages and disadvantages for local and national users in relation to the development of local and nationally standardised VALS, which are summarised in Figure 6. Using a local system provides greater flexibility with regard to adapting to local needs (both hazard-related and socially focused) and integrates the VALS into the management processes of the crisis. Local systems are, however, becoming increasingly constrained by nationally standardised disaster protocols such as the National Incident Management System (NIMS) and Common Alerting Protocol (CAP). Dependence on common terminology for each alert level may help streamline communications but equally can be misleading as a standardised VALS cannot provide the specific information that a locally developed VALS can. Limitations in the ability of a standardised VALS to provide diversity and pluralism suggest that there may not be enough flexibility in the design. It is clear that designing one standardised VALS (even with two separate systems) to accommodate all possible contingencies in all possible circumstances at all U.S. volcanoes is difficult. The principle of 'one size fits all' does not apply to VALS, which need to be adaptable so as to reflect changes in a particular volcano's behaviour and its impact on the local population, and this is better accomplished when considered from a holistic perspective that allows incorporation all possible variables, some of which may not be apparent prior to the development of a volcanic crisis situation.

Whether the standardised VALS work at different scales and for different stakeholders may be a reflection of the drivers underpinning the standardisation process. It is clear that in the U.S. case, the design of the standardised VALS was led by social, political, and economic circumstances that followed from 9/11 and the implementation of national policies (NIMS and CAP) rather than the scientific needs specific to each U.S. volcano. As a result, implementing the standardised VALS has been challenging for three reasons: first, the diversity and uncertain nature of volcanic hazards at U.S. volcanoes, occurring at a range of different temporal and spatial scales, have resulted in the development of specific warning systems designed to address specific hazards and the related requirements of local stakeholders, making the standardised VALS redundant in a number of volcanic crisis situations. Second, the dual standardised VALS operates within plural social and institutional contexts in which prior historical VALS were already embedded, posing challenges in the ability of the standardised VALS to respond to local knowledge and context, which time and again has proven to be vital element in the handling of volcanic crises in the U.S.. Third, the contingencies of local institutional dynamics, which change over time and from place to place, may hamper the ability to communicate effective warnings. Nevertheless, a need for standardisation is recognised, and a number of positive aspects for the USGS, policy makers, government and other stakeholders, arising from the adoption of a standardised VALS, have been identified. In addition, a standardised VALS has proven to be more applicable for the aviation sector, which requires a standard format that it can relate to across the U.S. and its territories, and is also more suited to emergency managers operating under standardised emergency procedures following the implementation of the NIMS.

From the perspective of the USGS, most of the staff interviewed felt that the standardised VALS has generally worked well resulting in a number of benefits, but also some drawbacks for the Volcano Hazard Program team (Fig. 7). From a managerial or policy perspective, it could be argued that the standardised VALS works well operationally, since all the observatories use it to relay the status of volcanic activity. From a stakeholder perspective, however, it lacks the capability to: provide details about specific hazards associated with a particular restless or erupting volcano; differentiate between temporal and spatial elements of a specific hazard; or provide guidance on what action or response to take, which is left to the stakeholders to decide. Notwithstanding this, neither the data, nor the experience, are available to fully balance the long term benefits against the drawbacks of a standardised VALS that has not long been in place.

Although consistency is frequently identified as a key justification for standardisation, in the context of VALS consistency is dependent not on its standardisation, but on the flexibility provided through the many communication products (e.g. VANS, VONA'S, and information statements) and networks developed between the scientists and the users. These products facilitate the essential need for follow-up effective communication of additional information to clarify the designation of, or changes in, an alert level, whichever VALS is used, that are of particular value to stakeholders. This paper has established that while it is not possible to completely exclude local requirements in a standardised VALS, due to variances in hazards, social contexts, and institutional practices within each observatory, it is through the development and effective utilisation of communication products, as implemented at the USGS, that a standardised VALS can operate successfully.

In future, efforts to standardise VALS at national and international scales look likely to proceed rapidly in response to the requirements of 'global' clients such as the aviation industry. Yet, there have been real challenges in getting the ICAO aviation code adopted globally. It is still only used within the U.S. and although on paper it has been accepted for global use, operationally it has not, so far, been actively adopted outside of the U.S.. Whether or not all countries that host active volcanoes will be pressured by ICAO in the future to comply with the U.S. VALS remains to be seen, but policy implementation at such a scale will undoubtedly generate some interesting challenges. The USGS VALS case study that forms the basis of this paper highlights the fact that balancing the needs of local, national, and international users when standardising a VALS is both a difficult and complex process, but one that is made significantly easier through the use of communication products between different stakeholders that facilitate the transfer of tailored and specific information. Perhaps adopting a less prescriptive VALS that is scalable and flexible for the use of local users via standardised communication products that may help accommodate local contingency yet, adhere to national policy. Using such a VALS may facilitate greater and more practical levels of seamless communication so as to overcome the diversity of physical and social complexities involved in generating effective volcanic warnings.

[ii] The observatories are: the Alaska Volcano Observatory (AVO), Cascades Volcano Observatory (CVO), Hawaiian Volcano Observatory, Long Valley Observatory (now California Volcano Observatory - CalVO), and the Yellowstone Volcano Observatory (YVO). The collaborative partners are: University of Alaska, Fairbanks (UAF), Alaska Division of Geological and Geophysical Surveys (ADGGS), University of Washington (UW), University of Hawaii, Hilo (UHH), University of Utah (UU), Yellowstone National Park (YNP).

[iii] Semi-structured interviews were completed with a number of actors involved in the VALS: scientists within the USGS Volcano Hazard Program (VHP), including volcanologists, seismologists, glaciologists and chemists; with users of the VALS at other federal agencies; and with collaborative partners, such as Universities and State officials. There are a diverse range of VALS users, ranging from emergency managers to land owners (U.S. Forest Service, National Monuments, private land) who are generally local, to partner organisations (collaborative universities and institutes), state geologists, and the National Weather Service (NWS), which are regionally at state-level, and the aviation sector (VAACs and Air Traffic Control), which are national. The interviews provide insights into the personal perspectives of the variety of scientists and users involved in the design and implementation of the VALS. This is complemented by ethnographic observational data on the interactions between these different perspectives in practice, and document analysis on the historical emergence and stabilisation of these policies. Data are also derived from the archive released under the Freedom of Information Act (U.S. FOIA), including emails of different staff within the VHP that discuss the standardisation of the VALS.

[iv] The Federal Register is available online, but only since 1994. Access to v.48. n197 from October 11, 1983 can only be provided by Federal depository libraries within the U.S.. Outside the U.S., some major libraries may also carry the Federal Register.

[v] Still in effect (to date of writing), the official (bureau-level) USGS hazard notifications system can only issue a formal hazard warning, although no official warnings have been issued since the 1984 eruption of Mauna Loa, Hawaii on March 29th (email correspondence from Menlo Park scientist to standardisation committee in March 2003, U.S FOIA archives).

[vi] The odd thing is that the NWS terms that usually describe meteorological hazards are not used to describe the ash hazards influenced by meteorological systems, but the ground hazards (AVO collaborator 3; 17/04/08).

Figure1

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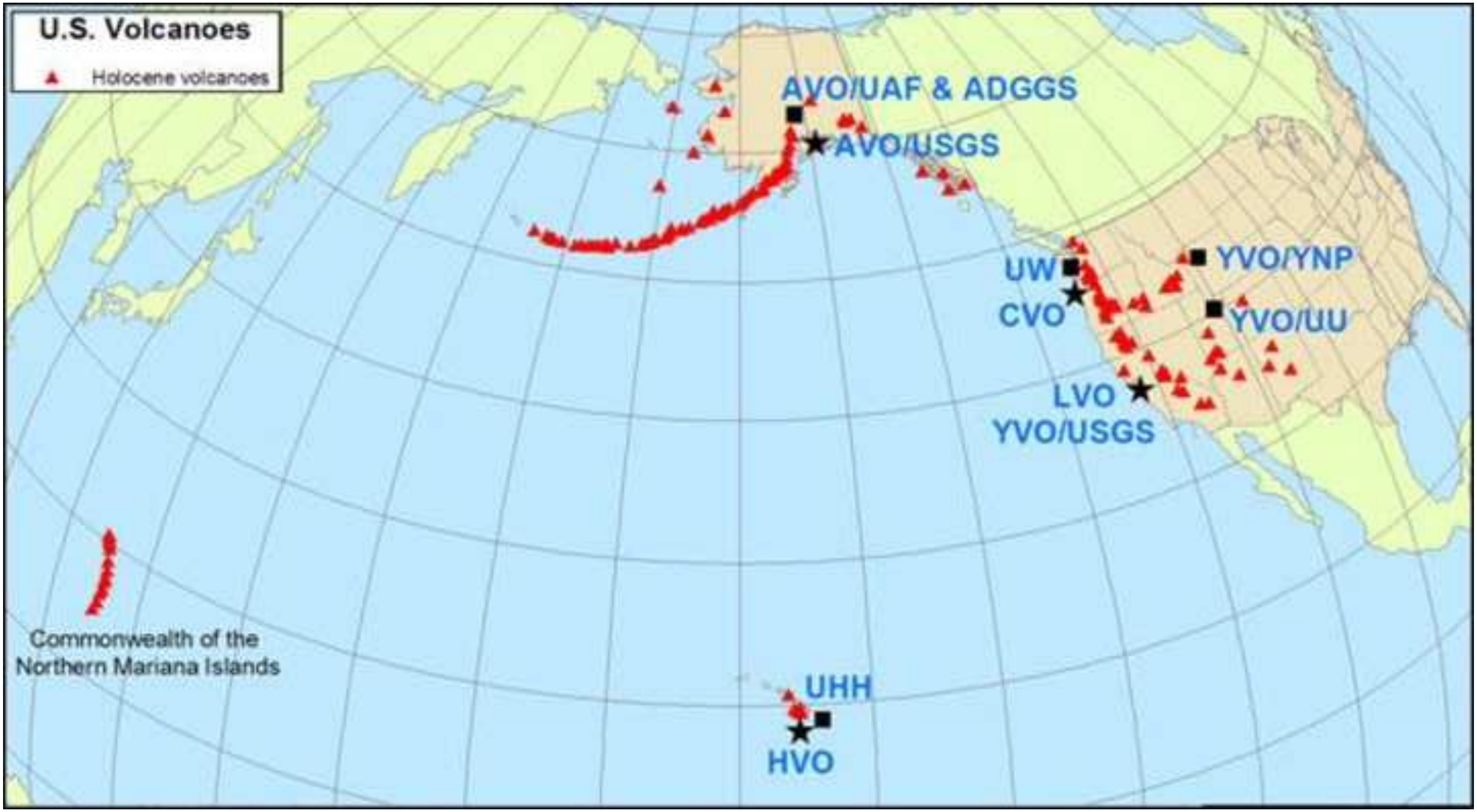

Figure

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CONDITION	USGS RESPONSE[1]	ACTIVITY LEVEL	RECURRENCE INTERVALS[2]
GREEN – No immediate risk	Normal operations plus information calls to local and other authorities for weak through strong unrest as appropriate	Background or quiescence	Most of the time
		Weak Unrest	Days to weeks
		Minor Unrest	Weeks to months
		Moderate-to-Strong Unrest	Months to years
YELLOW (WATCH)	Full call-down and EVENT RESPONSE	Intense Unrest	Years to decades
ORANGE (WARNING)	Full call-down and EVENT RESPONSE (if not already in place under YELLOW)	Accelerating intense unrest: Eruption likely within hours to days	Decades to centuries
RED (EUPTION IN PROGRESS)	Full call-down and EVENT RESPONSE (if not already in place under YELLOW or ORANGE) Daily or more frequent updates on eruption levels	LEVEL 1: Minor eruption	Centuries
		LEVEL 2: Moderate explosive eruption	Centuries
		LEVEL 3: Strong explosive eruption	Centuries
		LEVEL 4: Massive explosive eruption	Centuries to millennia

Figure

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Volcano Alert Levels Used by USGS Volcano Observatories

Alert Levels are intended to inform people on the ground about a volcano's status and are issued in conjunction with the Aviation Color Code. Notifications are issued for both increasing and decreasing volcanic activity and are accompanied by text with details (as known) about the nature of the unrest or eruption and about potential or current hazards and likely outcomes.

Term	Description
NORMAL	Volcano is in typical background, noneruptive state or, *after a change from a higher level,* volcanic activity has ceased and volcano has returned to noneruptive background state.
ADVISORY	Volcano is exhibiting signs of elevated unrest above known background level or, *after a change from a higher level,* volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
WATCH	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway but poses limited hazards.
WARNING	Hazardous eruption is imminent, underway, or suspected.

Figure

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Aviation Color Code Used by USGS Volcano Observatories

Color codes, which are in accordance with recommended International Civil Aviation Organization (ICAO) procedures, are intended to inform the aviation sector about a volcano's status and are issued in conjunction with an Alert Level. Notifications are issued for both increasing and decreasing volcanic activity and are accompanied by text with details (as known) about the nature of the unrest or eruption, especially in regard to ash-plume information and likely outcomes.

Color	Description
GREEN	Volcano is in typical background, noneruptive state or, *after a change from a higher level,* volcanic activity has ceased and volcano has returned to noneruptive background state.
YELLOW	Volcano is exhibiting signs of elevated unrest above known background level or, *after a change from a higher level,* volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
ORANGE	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway with no or minor volcanic-ash emissions [ash-plume height specified, if possible].
RED	Eruption is imminent with significant emission of volcanic ash into the atmosphere likely **OR** eruption is underway or suspected with significant emission of volcanic ash into the atmosphere [ash-plume height specified, if possible].

Figure

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Observatory	HVO	AVO	CVO	LVO	YVO
Scientific issues	• On-going activity • Fairly predictive behaviour • Slow moving lava flows • Chance of explosive behaviour	• Reasonably predictive behaviour • On-going activity • Consistent hazards	• Reasonably good understanding with some forecasting models • Plenty of case studies to compare • Variety of hazards	• Difficult to interpret • Limited knowledge of caldera behaviour • Wide variety of volcanic hazards	• Highly complex • Usually surficial hazards • Difficult to interpret • Long lead up to eruption expected
Social issues	• Historical memory of activity • Influences land planning • Insurance concerns for home owners	• Not largely populated due to on-going activity and remote location • Affects aviation users, both civil and military	• Often part of a National Park due to natural beauty • Nearby hazardous locations can be highly populated with critical infrastructure • Tend to be fertile farm lands	• Can give long term notice, but volcano may erupt with short notice • Raising awareness for hazards, especially with tourists	• Too active to be populated • Well known due to media documentaries • Popular tourist location
Institutional issues	• Constant communication and awareness between scientists and users • Highly monitored volcano	• Remote locations makes it difficult to monitor • Collaborates with UAF and DGGS partners making decision-making more complex	• Highly monitored • Must liaise with land owners i.e. National Parks and Forest Service • Particularly focused on media interest	• Need to work with local businesses i.e. the ski area • Liaises with land owners and managers i.e. U.S. Forest Service	• Collaboration between different land owners and managers i.e. the National Park • Highly monitored for research • Collaborates with partners and a number of universities on research activities
Adaption of VALS	• Developed alert level system for sulphur dioxide hazards • Not used due to constant eruption of Kilauea volcano	• Focused on aviation users • Not usually concerned with ground hazard alerts	• Developed lahar early warning system (AFMs)	• Gases pose significant hazard • Alert level never changed	• Hydrothermal activity not reflected by VALS

Figure

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Issues	Locally developed VALS (individual USGS observatories)	Nationally Standardised VALS (new standardised system)
Management	Local stakeholders develop close relationships during co-ordination meetings / drills	Streamlines communication within federal agencies, thereby reducing opportunities for confusion
Decision Making	Gears decision to local needs, circumstances and knowledge	Descriptions provide guidelines / criteria, but implications may vary
Communication	Provides flexibility for locally adapted warnings, consequently interpretation likely to be more effective	Provides familiar terminologies for use across different contexts, but associated meanings may be different
Users' needs	Provides flexibility to local community but global users may be confused	Limits flexibility possible, but two systems specific for their users

Figure
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Benefits	Drawbacks
Relatively easy to follow and use in most cases, and appears to work well with the users (until the date of research in 2008)	The VALS cannot be tailored to local needs and local hazards, hence HVO uses an alert level system for SO_2 gas, and LVO could use one for CO_2 levels
Provides flexibility for staff to move from different observatories during a crisis to aid one another	The VALS has hardly been decoupled / split, and therefore it seems the purpose of having the two systems is redundant
Provides consistency across the organisation, which aids media and public response, also helps government and the president's office if there is a crisis	The VALS can be misinterpreted because of the double meanings in some of the levels and because users are used to what a particular alert level means within their local context

Table and figure captions

Fig. 1: The USGS' Volcano Hazard Program (VHP) observatories and their collaborative partners[1] (USGS VHP Website 2008). Image credit: U.S. Geological Survey Volcano Hazard Program

Fig. 2: Summary of Colour-Code Conditions and associated U.S. Geological Survey (USGS) responses for volcanic unrest in Long Valley Caldera and the Mono-Inyo Craters region (Hill et al. 2002, p.2). Image credit: U.S. Geological Survey

Fig. 3: Volcano Alert Levels (Gardner and Guffanti 2006, p.2) Image credit: U.S. Geological Survey

Fig. 4: Aviation Colour Codes (Gardner and Guffanti 2006, p.3) Image credit: U.S. Geological Survey

Fig. 5: Summary of the different influences at each observatory and their impact on how the VALS is used.

Fig. 6: The pros and cons of local and standardised VALS.

Fig. 7: Perceived benefits and drawbacks of the use of the standardised VALS within the USGS

[1] The observatories are: the Alaska Volcano Observatory (AVO), Cascades Volcano Observatory (CVO), Hawaiian Volcano Observatory, the Long Valley Observatory (now California Volcano Observatory, CalVO), and the Yellowstone Volcano Observatory (YVO). The collaborative partners are: University of Alaska, Fairbanks (UAF), Alaska Division of Geological and Geophysical Surveys (ADGGS), University of Washington (UW), University of Hawaii, Hilo (UHH), University of Utah (UU), Yellowstone National Park (YNP).

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