MEASUREMENT OF THE VOLCANIC EXPLOSIVITY INDEX (VEI) IN REAL TIME

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INTRODUCTION / BACKGROUND

Explosive, ash-producing, volcanic eruptions represent a major natural hazard, and have resulted in significant loss of life, large economic losses, and infrastructural disruptions throughout Earth history.

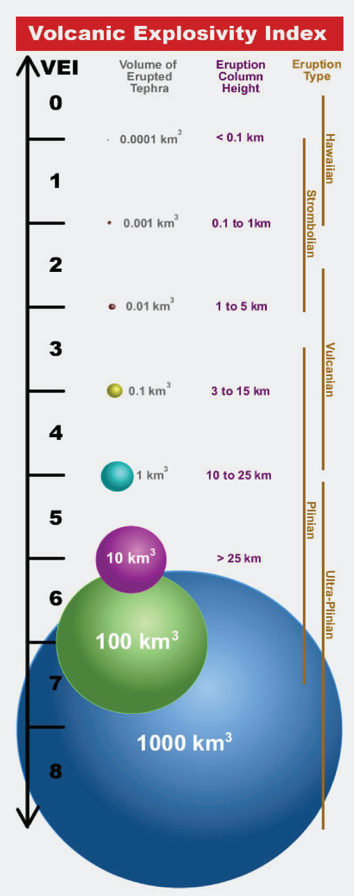
The ability to estimate the potential impact an eruption could have on aviation, infrastructure, and ultimately climate is becoming increasingly critical in the modern world.

As such, a real-time measure of the explosivity and thus potential impact of future eruptions would be useful.

The "Volcanic Explosivity Index" (VEI) was developed by Newhall and Self (1982), and is a semi-quantitative scale, spanning integral values from 0 (gentle) to 8 (colossal). Eruptions are assigned values based primarily on estimated volume of ejecta, with consideration also given to eruption duration and column height

VEI, established by Newhall and Self (1982), involves qualitative descriptions, volume of ejecta, column height, eruption duration, and several other descriptive factors. However, column height is not indicated beyond 25 km, or a VEI of 5 in the original VEI determination scheme.

Beyond this, volume of ejecta to the nearest order of magnitude is the only basis for classification of eruptions. Volume of ejected material is difficult to measure after an eruption has concluded; it is impossible to determine while an eruption is ongoing.



COLUMN HEIGHT AS AN INDICATOR

Column height is the primary indicator of stratospheric ash injection and is controlled by the total volume of ejecta, eruption duration and volume flux.

There is an indication of a relation between column height and vent velocity which suggests that column height can be used as a proxy for eruption energetics.

Determining eruption duration or volume of ejecta is particularly difficult during an ongoing eruption, while maximum eruption column height can be well observed, in real-time, from satellite and ground-based monitors.

Thus, VEI can be calculated for all eruptive phases of actively erupting volcanoes based on this simple, observable parameter rather than having to wait until the eruption has ceased, to estimate total volume of ejecta.

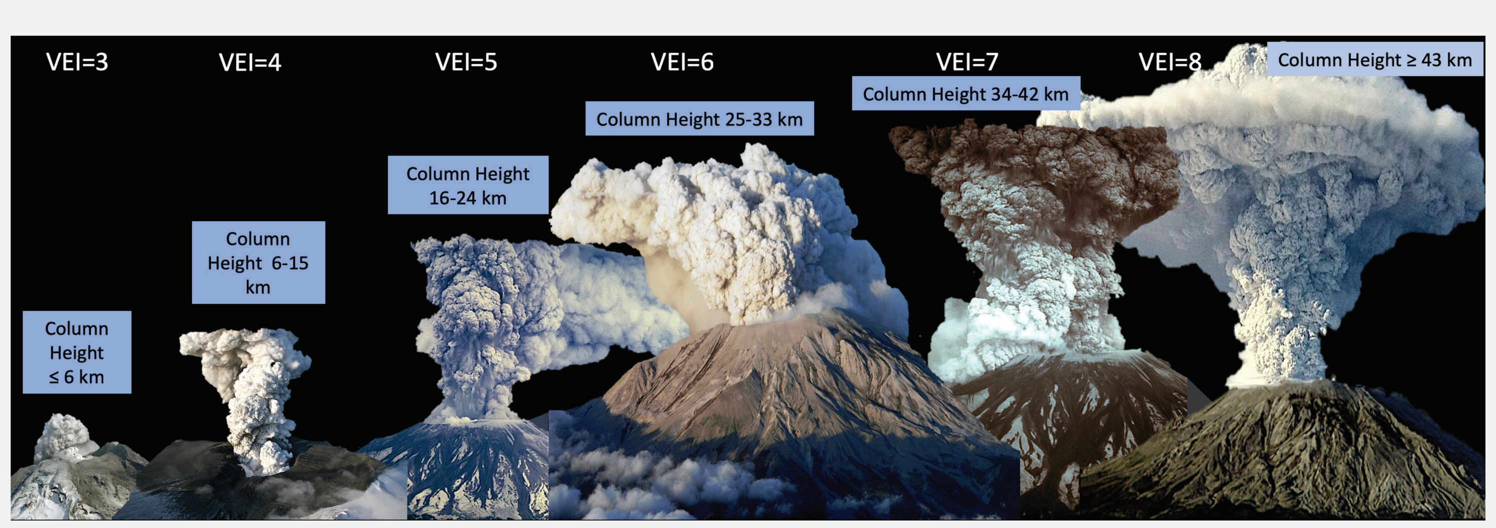


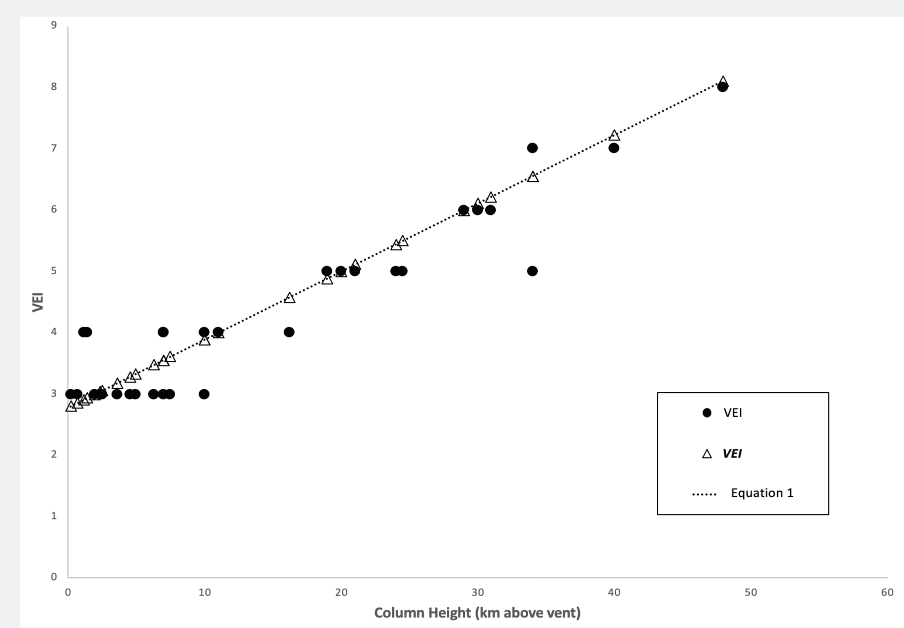
Image displaying the range of column heights (in km) that volcanic eruptions can have and their corresponding VEI values. Famous volcanoes were chosen as examples for the range of VEI values used in this study: VEI 3 to 8. Volcanoes used (from left to right): Mount Redoubt: Alaska, Eyjafjallajökull: Iceland, Mount St Helens: USA, Mount Pinatubo: Philippines, Mount Tambora: Indonesia, and Mount Toba: Indonesia.

A QUANTITATIVE DETERMINATION OF VEI

Developed a simple way to calculate VEI based solely on column height, which represents the various other parameters (e.g. duration and total volume of ejecta) used in characterizing explosive eruptions.

This value is related to a directly observational quantity (column height) to use as a proxy for decompression rate at or near the vent , where critical processes of syn-eruptive bubble nucleation, fragmentation, and ash formation take place.

In calculating VEI based on column height, we have calibrated the index to the explosivity index developed by Newhall and Self (1982), not recreating the already widely accepted scale but rather devising a method for real-time assessment.



Linear regression line y = 0.1079x + 2.805) with an r2 value of 0.9988, fit to the previously established VEIs for the eruptions listed in Table 1, using the scale range of Newhall and Self (1982). The previous VEIs assigned are denoted with the black shaded circles. The open triangles result from applying the simple empirical relation below.

$$\boldsymbol{VEI} = \frac{H_c+25}{9}$$

With this new ***VEI*** determinant, it is now also possible to relate to decompression rate at the vent (Toramaru, 2006).

Previous studies have related VEI to energy (kinetic and thermal) (Pyle, 1995), magnitude (based on erupted mass) and intensity (based on erupted mass flux) to characterize eruptions (Pyle, 2000).

There is no direct relationship between the magnitude and intensity for eruptions (due to variations in duration), as was assumed in the common usage of the original VEI scale (Newhall and Self, 1982).

Both magnitude and intensity scales rely on factors influenced by the mass (or mass flux) of the eruption, which cannot be fully determined while the eruption is taking place.

For the purposes of creating an easy and reliable measurement of VEI that can be assessed in real time, we do not include mass or mass flux in the formulation.

It can be easily converted to energy after-the-fact (Toramaru, 2006), but our main focus is on a real-time assessment.

ERUPTION	Hc (km)	VEI	***VEI***
Nevado del Ruiz (1985)	0.2	3	3
Fuego (Feb. 2002)	0.7	3	3
Asama (1783)	1	4	3
Pelee (1902)	1	4	3
Redoubt (2009)	2	3	3
Aoba (2018)	2	3	3
Dukono (1550)	3	3	3
Etna (2002)	4	3	3
Irazu (1963)	5	3	3
Montserrat (2004)	5	3	3
Sangay (1976)	6	3	3
Grimsvotn (1996)	6	3	3
Augustine (2006)	7	3	4
Eyjafjallajökull (2010)	7	4	4
Kelud (1990)	7	4	4
Popocatepetl (1996)	8	3	4
Spurr (1992)	10	4	4
Soufriere Hills (1999)	10	3	4
Laki (1783)	11	4	4
Fuji (1707)	16	4	5
Soufriere Hills (1979)	19	5	5
El Chichon (1982)	19	5	5
Agung (1963)	20	5	5
St. Helens (1980)	21	5	5
Galunggung (1822)	24	5	5
Askja (1875)	24	5	5
Pintatubo (1991)	29	6	6
Katmai (1912)	30	6	6
Krakatau (1883)	31	6	6
Vesuvius (1631)	33	5	6
Tambora (1815)	34	7	7
Lake Taupo (186 AD)	40	7	7
Toba (~73,000 BC)	48	8	8

Eruptions with known eruptive column heights (above the vent) and previously assigned VEI compared with newly calculated ***VEI*** (Indicated in italics) based solely on column height. Note that the ***VEI*** scale bottoms out at 2.8 with the simple relation above, so it is only pertinent for eruptions of VEI 3 or greater. For future eruptions, even more advanced observation methods (e.g. Flower and Kahn, 2017; McNeal et al., 2017) may make greater precision possible.

RESULTS

ERUPTION	HC (KM)	***VEI***
Dukono (Jan. 2016)	1.2	3
Krakatau (Sept. 2018)	1.8	3
Sarychev Peak (Oct. 2018)	2.0	3
Ebeko (Jan. 2018)	2.5	3
Sangeang Api (Oct. 2018)	2.5	3
Turrialba (May 2016)	3.0	3
Agung (Nov. 2017)	3.0	3
Ebeko (Oct. 2018)	3.5	3
Popocatepetl (July 2017)	4.0	3
Sinabung (Nov. 2017)	4.2	3
Aoba (Oct. 2017)	4.6	3
Mayon (Jan. 2018)	5.0	3
Fuego (Jan. 2017)	5.5	3
Mnt Soputan (Oct. 2018)	6.9	4

It is possible, on the basis of accurately measured eruption column heights, to distinguish between eruptions with the same integral VEI, such as Redoubt and Montserrat, both with VEI 3, but could be indicated as VEI 3.0 and 3.3, respectively, reflecting a difference in eruption energetics.

The simple relation can be applied to recent (mostly smaller) eruptions that have not yet been assigned VEIs. For those eruptions that have been previously assigned VEIs, our new method of assigning VEI produces consistent values and enables the crucial ability for real-time calculation, during the volcanic eruption. A few of these recent eruptions, with column heights and newly calculated ***VEI***, are indicated in the Table to the left.

Eruption column height and volume of ejected of material have a direct relation (Virgil et al., 1990), so including both in the VEI calculation would over-determine the problem.

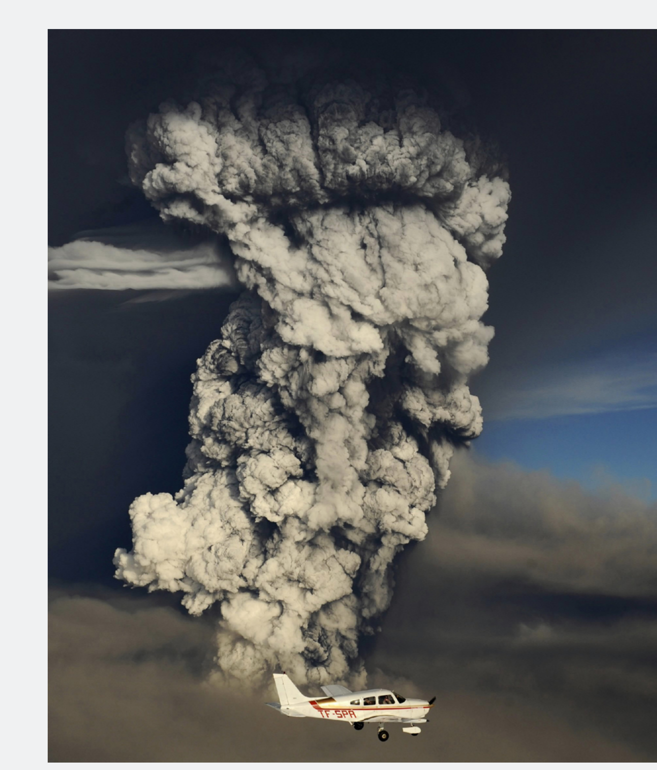
Recent eruptions observed by satellite remote sensing. Some recent eruptions have not yet had a VEI assigned in the semi-quantitative "traditional" way, but we can calculate a specific VEI on the basis of well-observed column heights. Column heights (above the vent) were obtained from the Global Volcanism Program (2018) database. More column heights from recent eruptions can be found using this online resource to determine VEI.

CONCLUSION AND DISCUSSION

This new approach's primary practical strength is in the ability to assign VEI values to future eruptions while the eruption is taking place, in real time, rather than after the fact. This should be an important step in enhancing hazard prediction and preparation.

This quantitative index can be applied to past eruptions, yielding comparable results relative to previously assigned values, but based on consistent, objective measurement criteria.

This quantitative determination of VEI, is not applicable to less explosive eruptions (VEI<3) and to eruptions of future flood basalts that may involve low elevation, high volume fire fountaining of tephra.



The empirical formulation developed in this study is based solely on eruption column height because other important factors involved in explosive eruptions such MER, duration, and vent area are factors controlling column height.

One advantage of basing VEI on column height alone is that eruptions can be quickly characterized, without the need for extensive subsequent fieldwork to estimate the total volume of ejecta.

The new scale will enable immediate response in various sectors of concern (agriculture, aviation, emergency response, etc.) to prepare for what is to come.

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