Ground based Sensing of Volcanic SO_2 emission

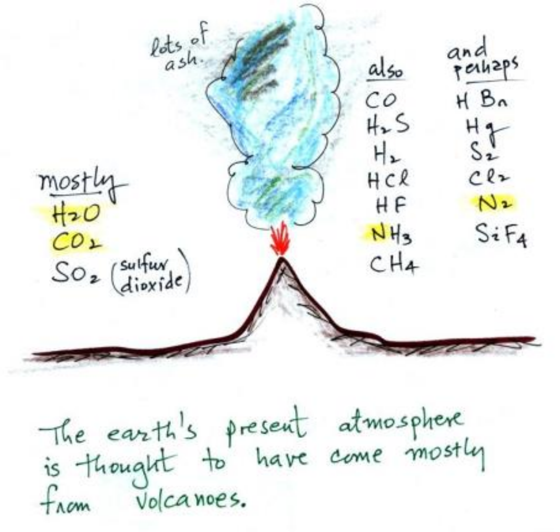
Giuseppe Salerno

Istituto Nazionale di Geofisica e Vulcanologia

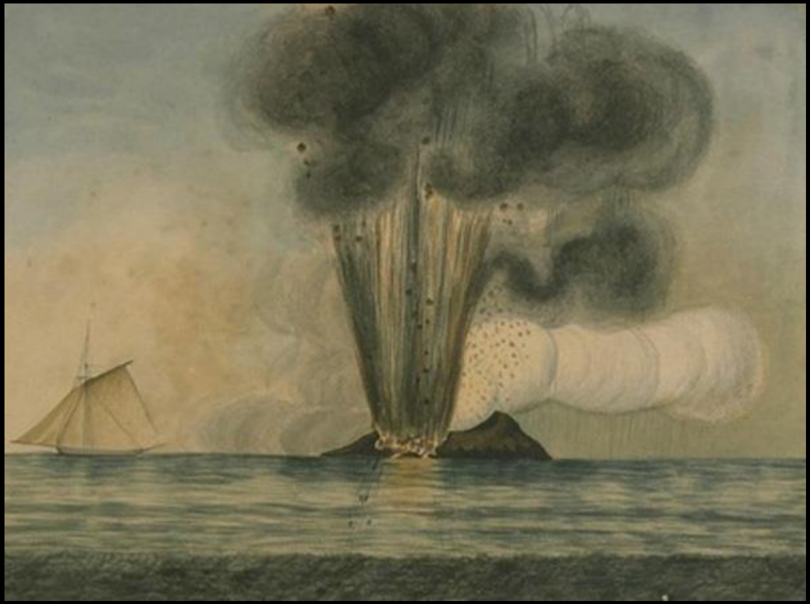
MEDiterranean SUpersite Volcanoes
MED-SUV

Outline

- *from volatiles to gas phase*
- *measuring emission rates of SO_2*
- *case study*
- *conclusion*

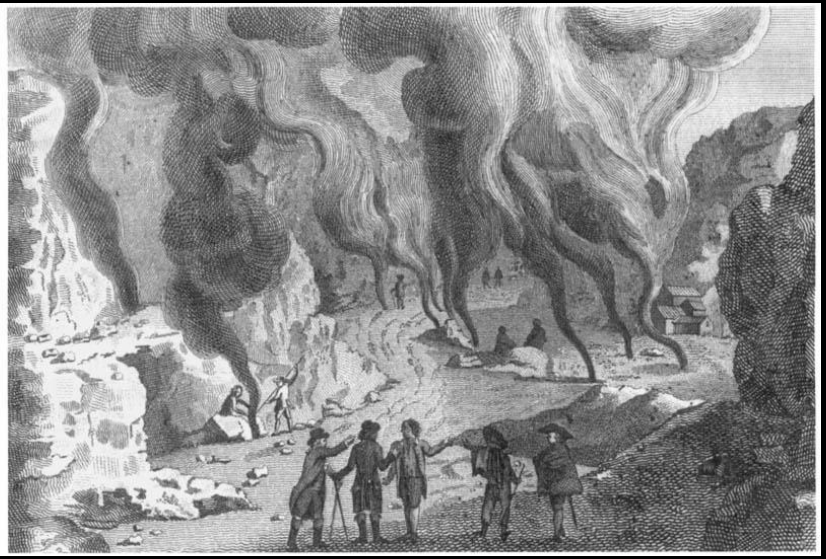


heat and fire has inspired myths and legends



Ferdinandea, Gemmellaro (1831)

gases talk about the longevity of volcanoes



Solfatara, from Bankes's New System of Geography (c.1800)

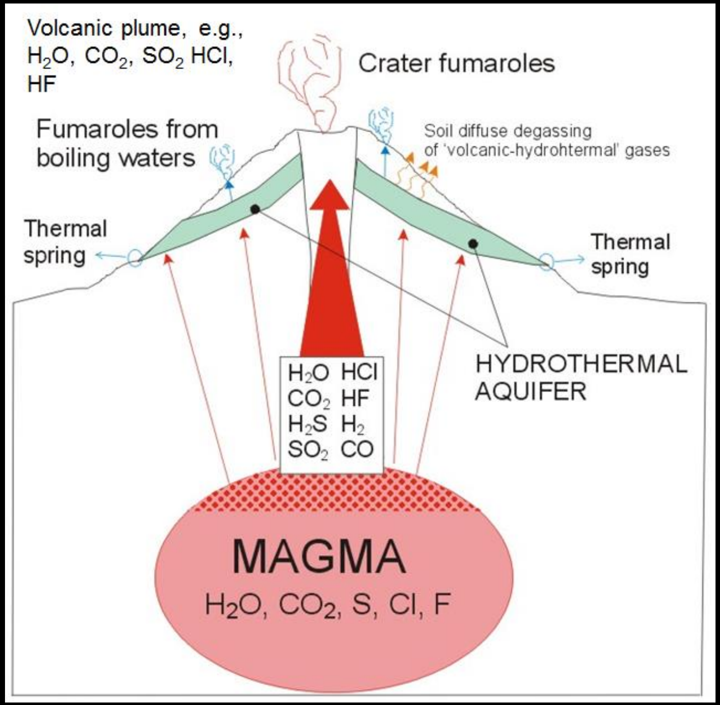
Degassing is the dominant way how active volcanoes dissipate their magma-transport energy

Passive degassing may coexist with active degassing

Passive degassing make up a large fraction of daily mass/energy release

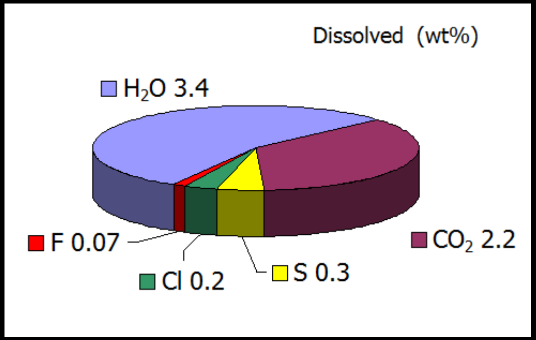
active degassing represents a few percentage of the total SO_2 gas loss, e.g, Stromboli 3-8% (Allard et al, 1994, Mori and Burton, 2009)

from volatiles to gas phase

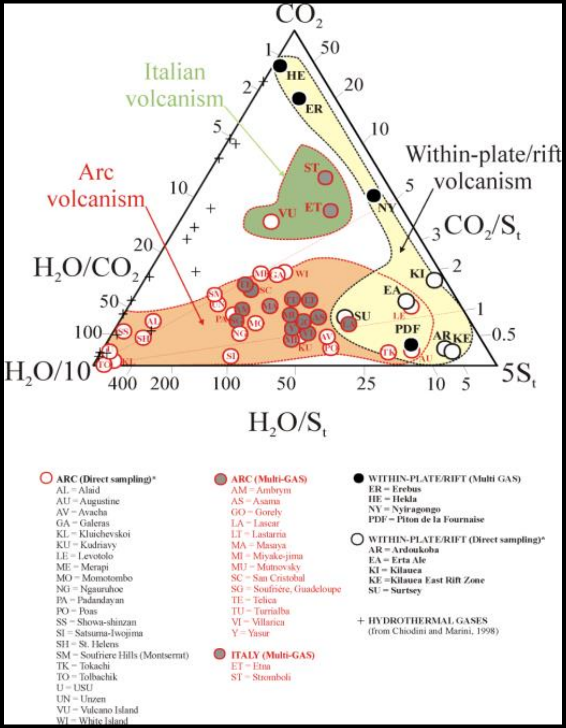


Volcanic gas compositions in volume% concentrations, (*Symonds et. al., 1994*)

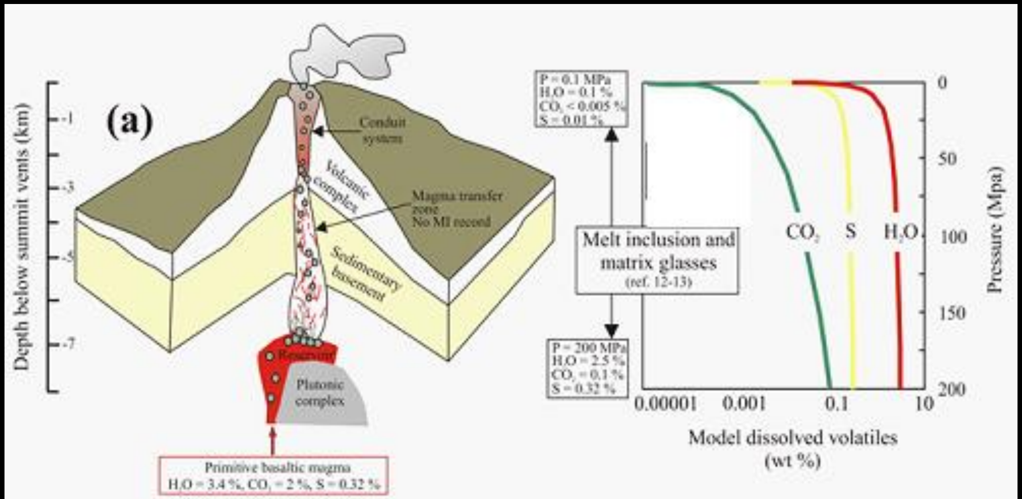
Volcano	Kilauea Summit	Erta` Ale	Momotombo
Tectonic Style	Hot Spot	Divergent Plate	Convergent
Temperature	1170°C	1130°C	820°C
H_2O	37.1	77.2	97.1
CO_2	48.9	11.3	1.44
SO_2	11.8	8.34	0.5
H_2	0.49	1.39	0.7
CO	1.51	0.44	0.01
H_2S	0.04	0.68	0.23
HCl	0.08	0.42	2.89
HF	---	---	0.26



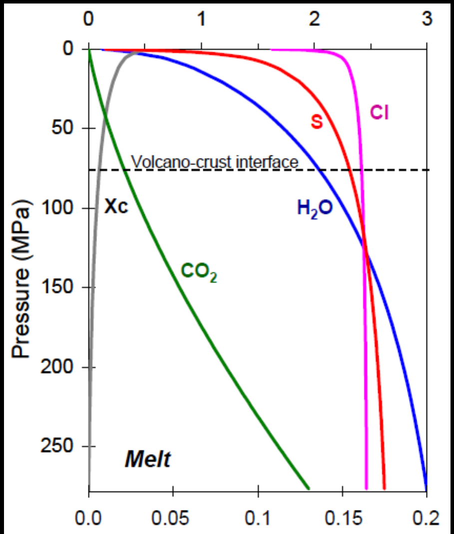
Large compositional differences among different volcanic settings, (*Aiuppa, 2014*)



from volatiles to gas phase



Aiuppa et al., 2004



Allard, 2010

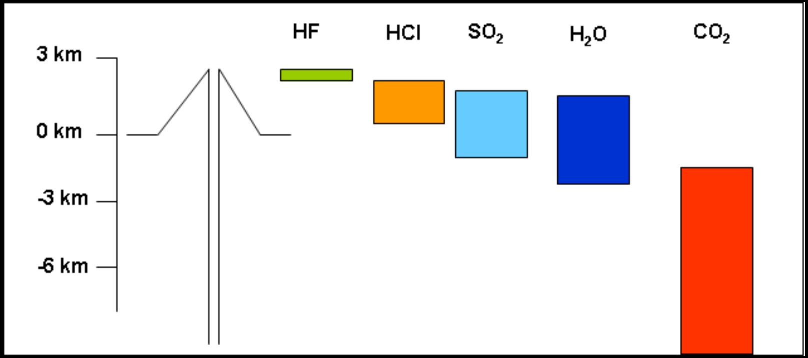
Plume gas composition is controlled by the solubility dependent partitioning between magma and the vapor phase

chemical composition changes during decompression (differing P-solubilities

CO_2 << H_2O < S < Cl< F

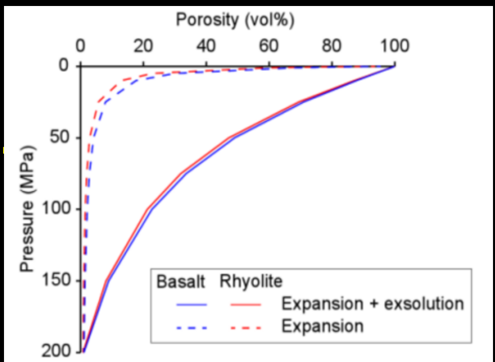
confining pressure (km)

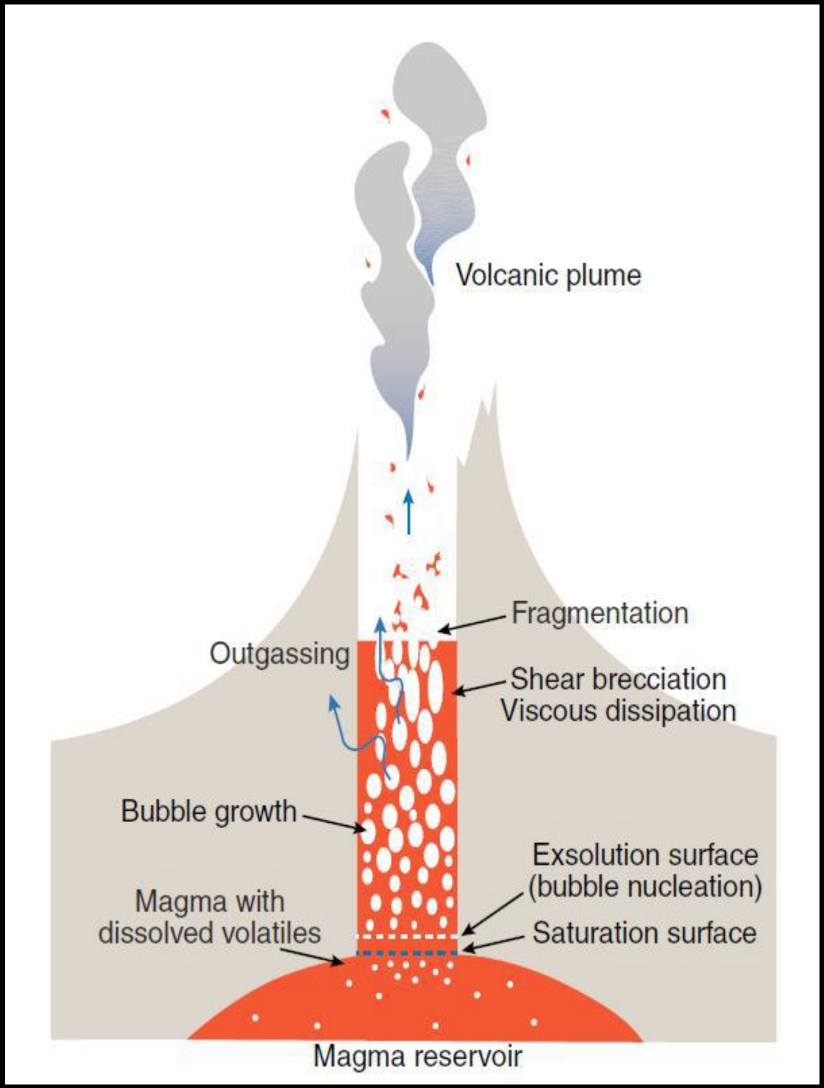
CO_2~20, SO_2~4-5, HCl~2 and HF~<1



from volatiles to gas phase

Burgisser and Degruyter, 2015





Driving force of volcanic eruptions magma fragmentation/ ejection –

Chemical composition changes during decompression

Melt dynamics and crystallization

Bubbling regime

Volatiles are prime drivers of volcanic activity

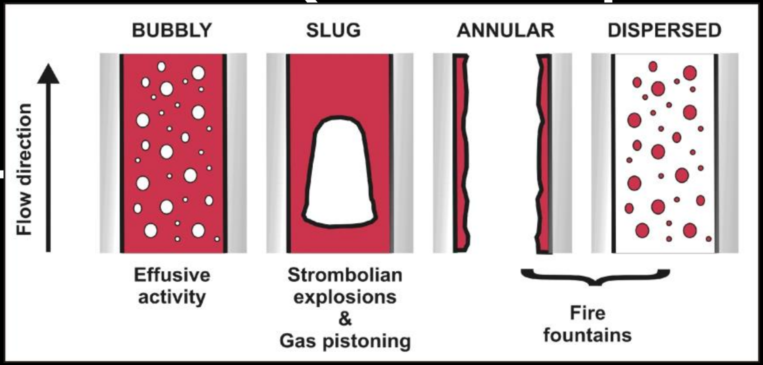
quiescent degassing

Effusive activity

Lava lakes

Strombolian activity

Lava fountain



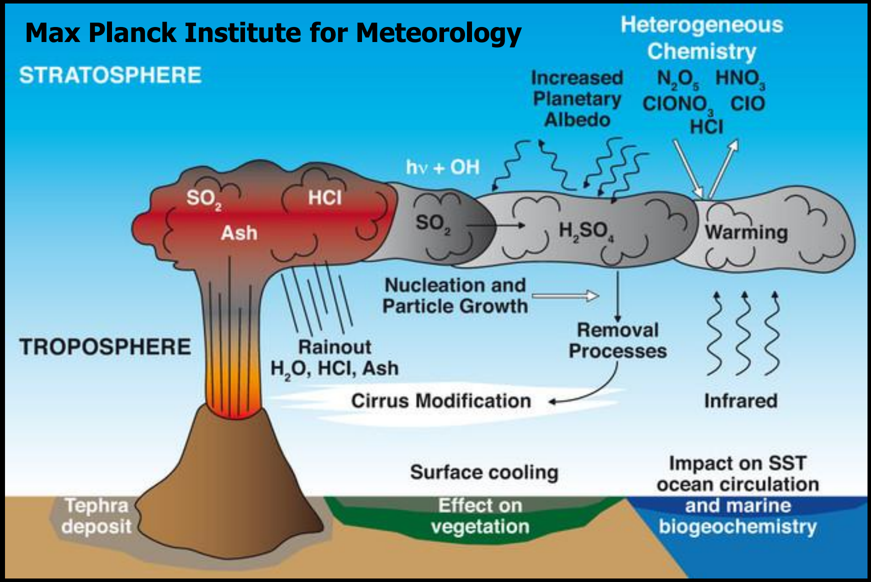
common energy spectrum of basaltic eruptive activities

Sulphur, relevant species in climatic impact

- Sulphur dioxide + water > sulphuric acid
- Aerosol sulphate

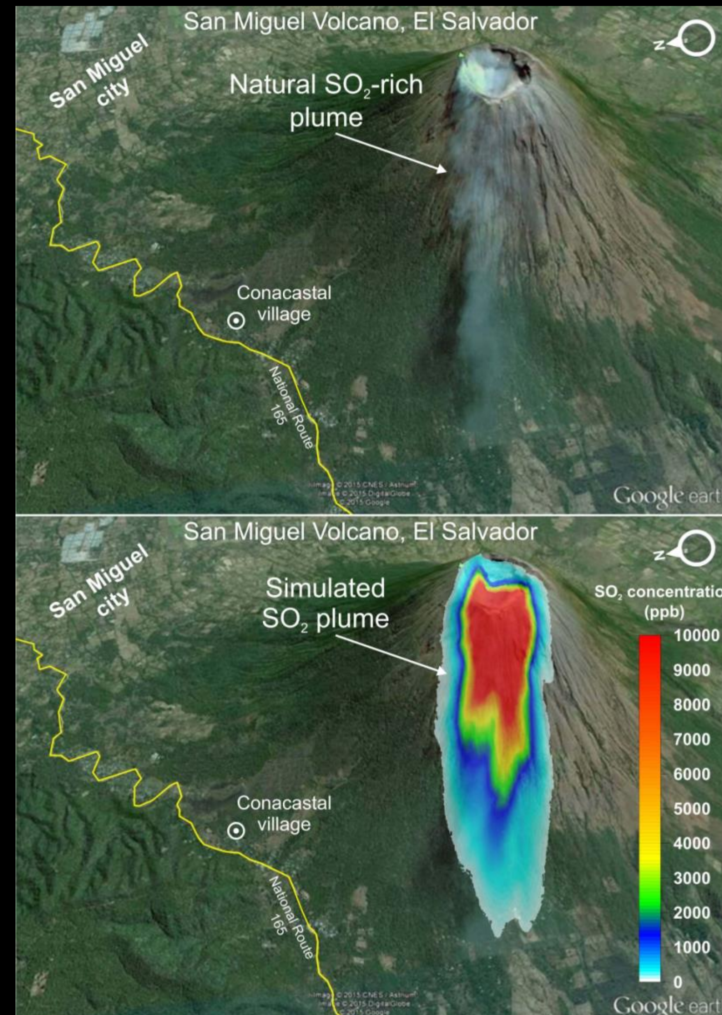
Rise to stratosphere and troposphere

Reflection of sun's radiation:
'radiative forcing'



Environmental and health people impacts

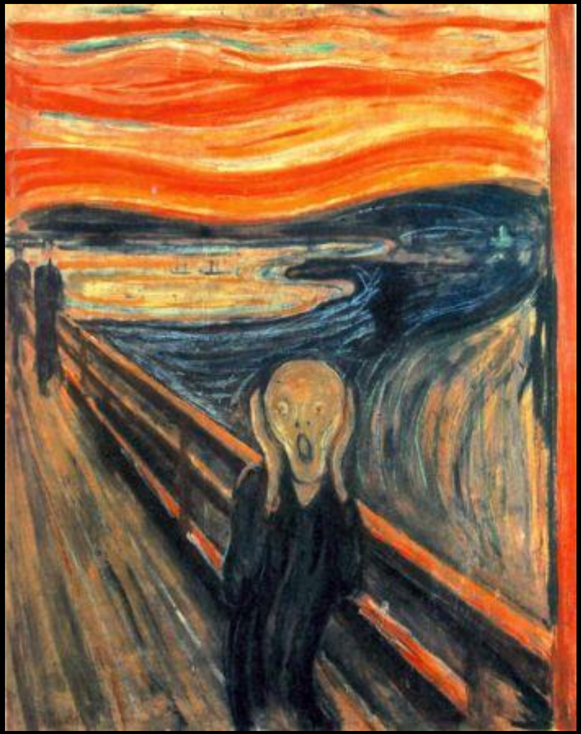
Dieback of trees near Kilauea volcano (Hawai´i) due to high CO2 emission.



UP - Volcanic plume at San Miguel volcano (El Salvador) likely rich in SO_2 as evident by the typical bluish color of this gas; DOWN - Simulated SO_2 concentration in the plume assuming an SO_2 emission rate of 2000 t d^{-1} and wind blowing from the E with velocity equal to 1.05 ms^{-1}.

Granieri et al., 2015

Environmental/climatic impacts, economic, political and demographic change *'volcanic Winter'*

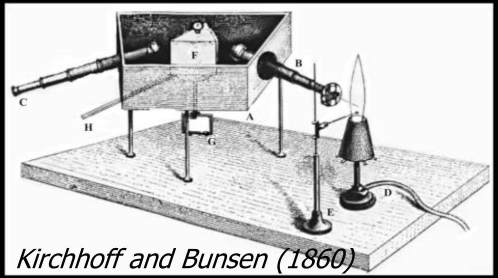


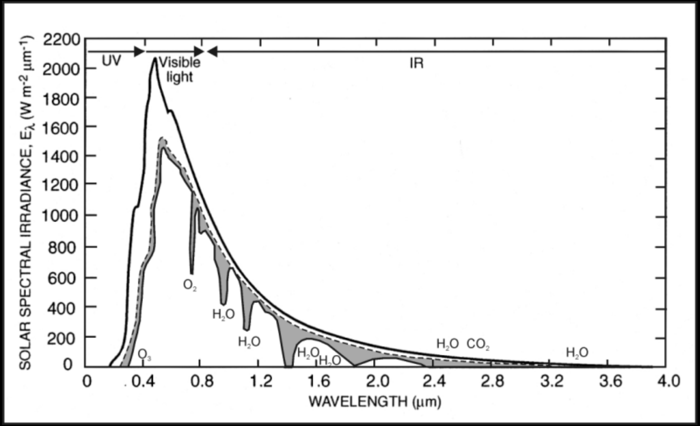
'the scream' Munch (1893), The 1883 Krakatoa eruption created vivid red twilights in Europe

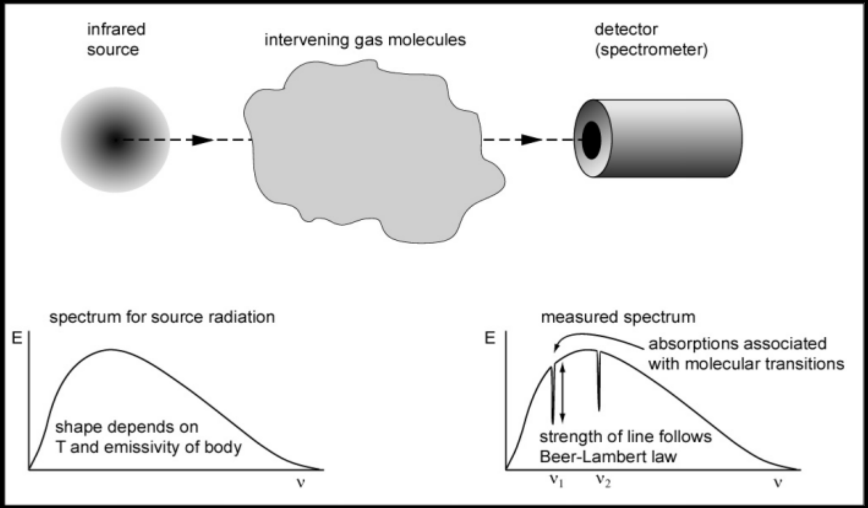
A wave of famine-induced protests and violence spread through Europe in the years following the Tambora eruption 1815(*Oppenheimer, 2015)*.

Ground-based Remote sensing

Open-path ultraviolet spectroscopy







Beer-Lambert:

$$I(\lambda) = I_0(\lambda)\ e^{(-\sigma c l)}$$

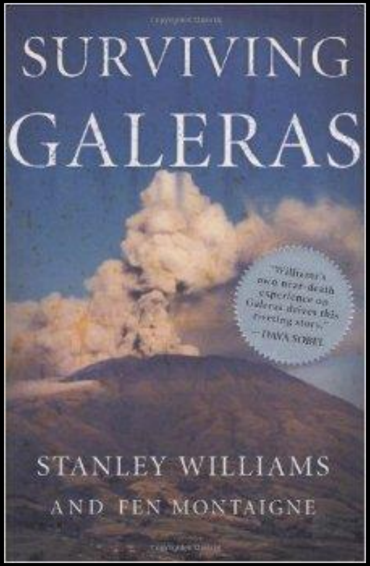
$$T = I(\lambda)/I_0(\lambda)$$

$$A = -\ln(T)$$

Open–Path UV spectra reduced by DOAS using a modelled reference spectrum

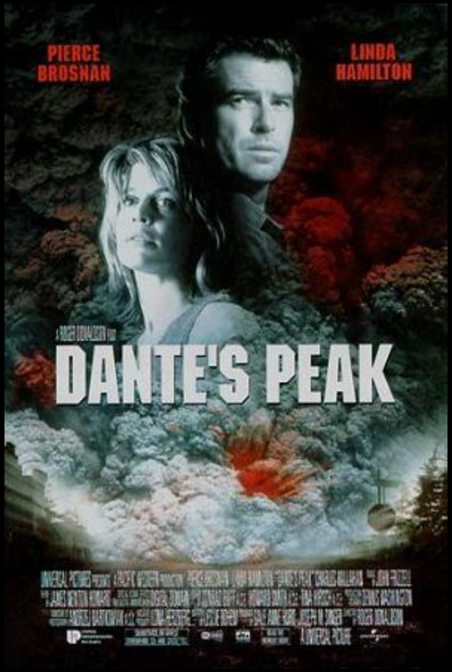
Measuring emission rates of SO_2

A 1993 eruption killed nine people, who had descended into the volcano's crater to sample gases



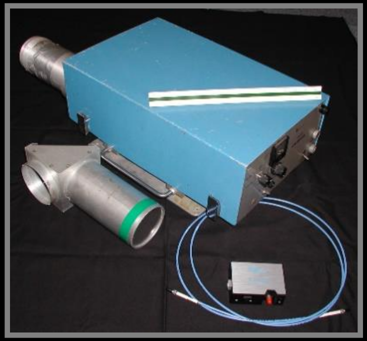
Since late 80s COSPEC, the workhorse of observatories and emblem of modern volcanology

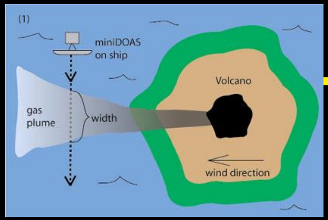
even featured in the 1997 volcano disaster movie *Dante's Peak*

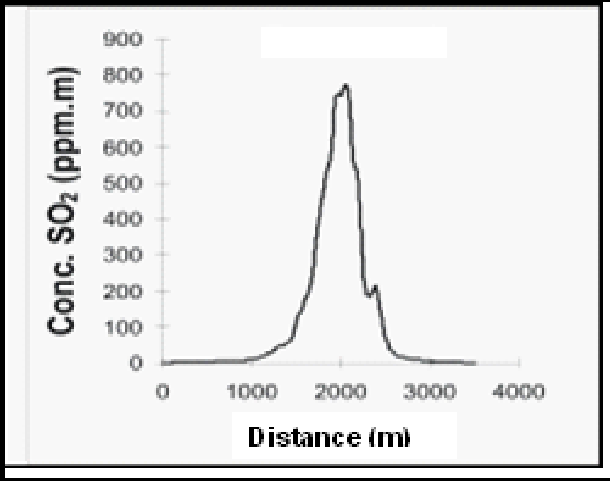


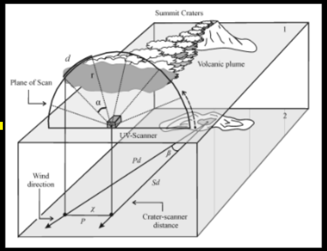
Measuring emission rates of SO_2

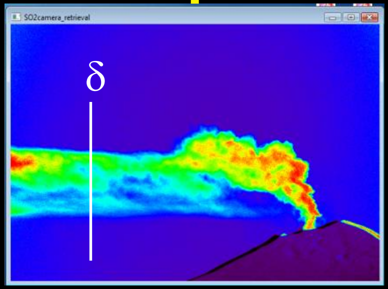
(a) COSPEC/CCD-based spectrometers traverses
(b) Network of ultraviolet scanning spectrometer FLAME
(b) Permanent SO_2Camera system

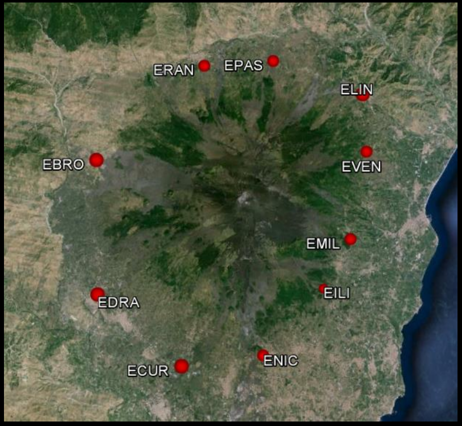




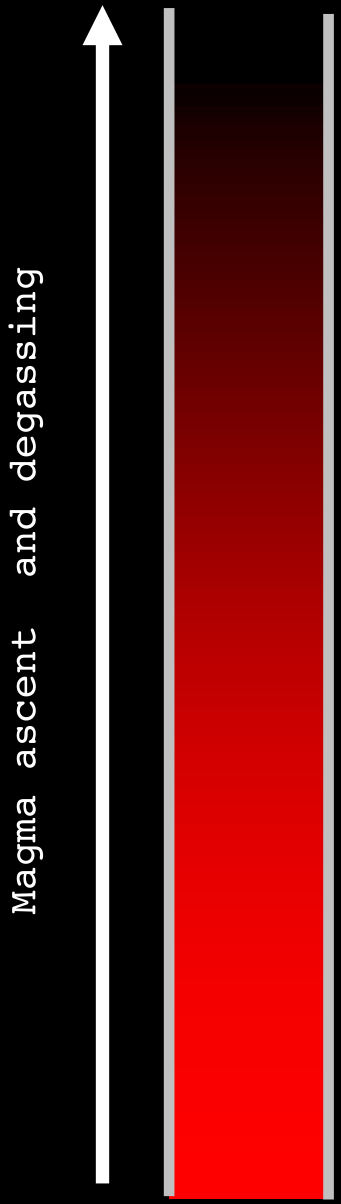




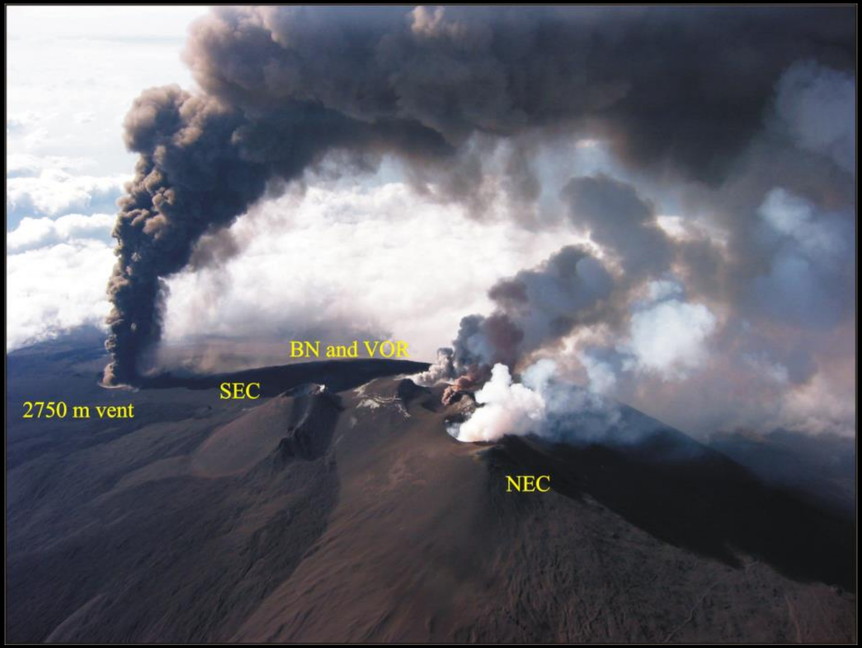




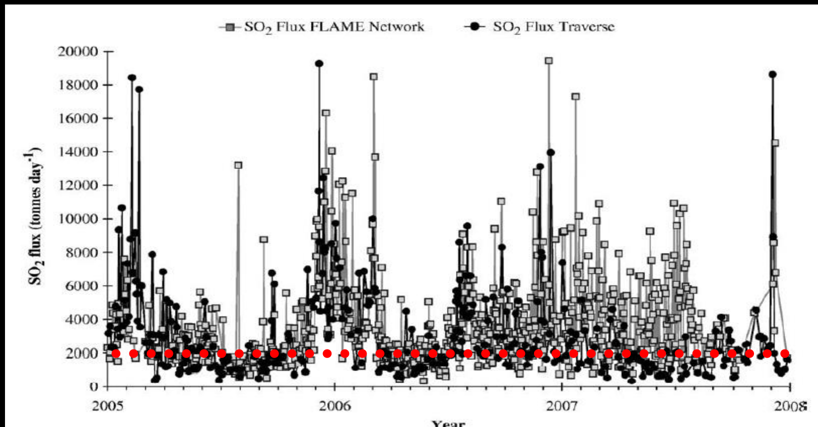
case study



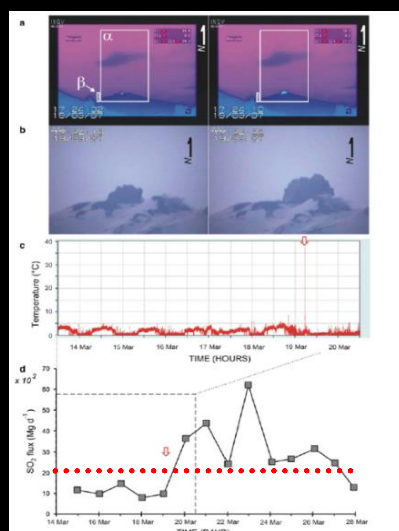
- Dynamics of eruption, style and timing
- magma supply - degassing rate
- mass balance
- climatic impact
- Satelite retrieval



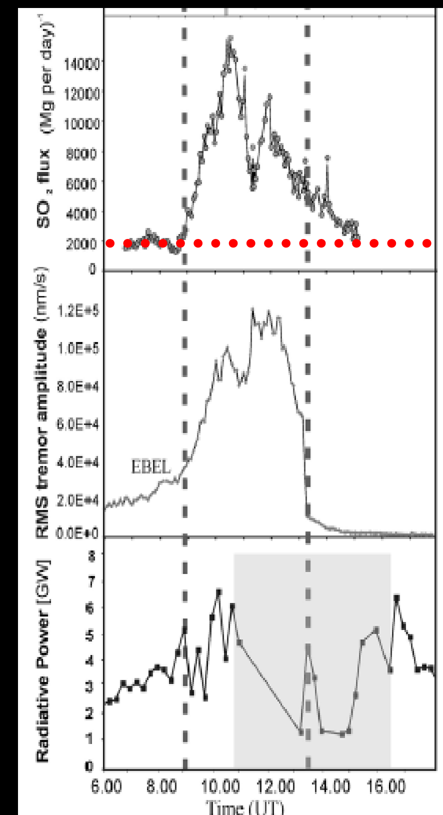
magma supply-degassing rate



Salerno et al., 2009



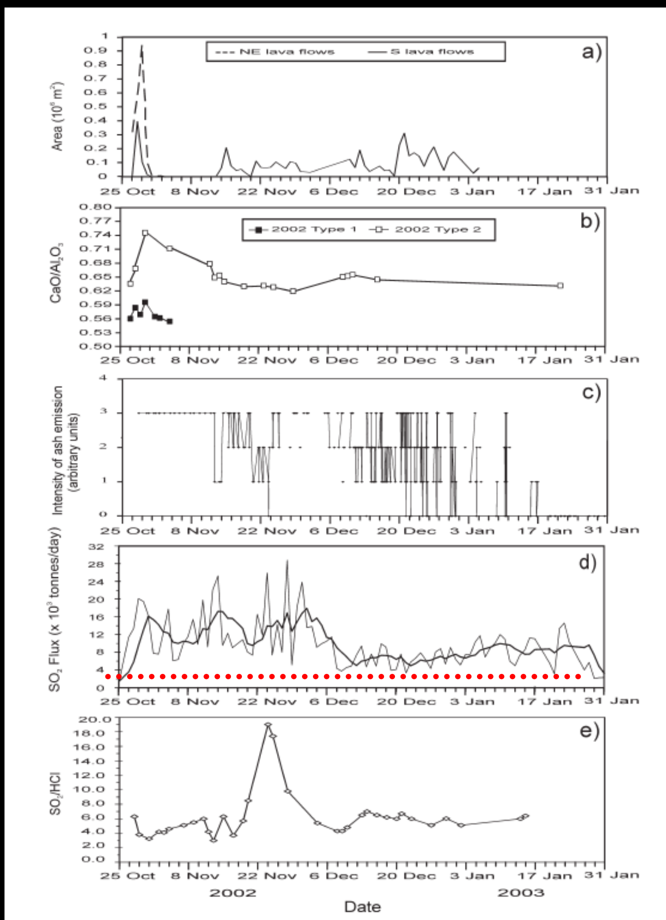
Spring 2007,
Falsaperla et al., 2014

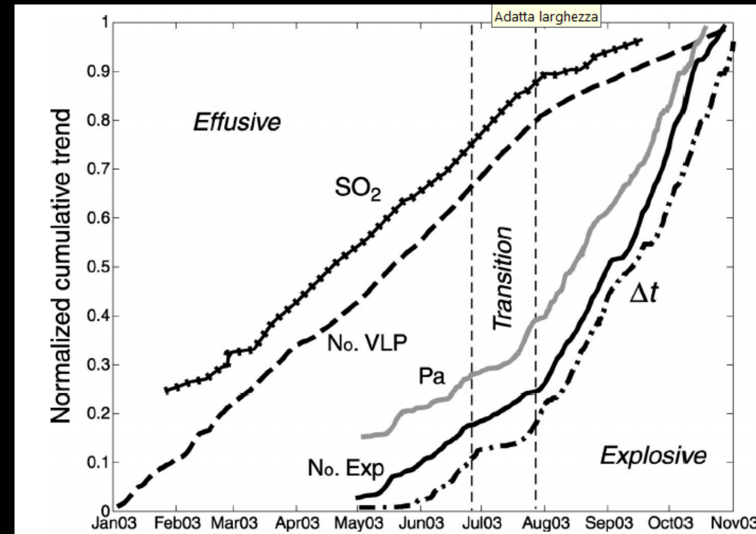


The 11th April 2011 lava fountain episode
Bonaccorso et al,. 2011

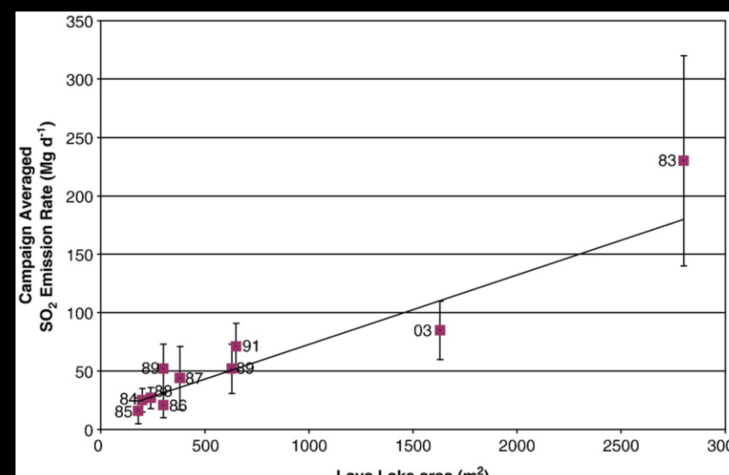
case study

2002-2003 Eruption, *Andronico et al., 2005*





2002-03 Stromboli eruption, *Ripepe et al., 2005*,



Volcanic gas fluxes are controlled by magma fluxes. *Sweeney et al., 2008*; Erebus

- Interpretation of chemical composition

  MultiGas + SO_2 flux = CO_2 & SO_2 Flux Monitoring

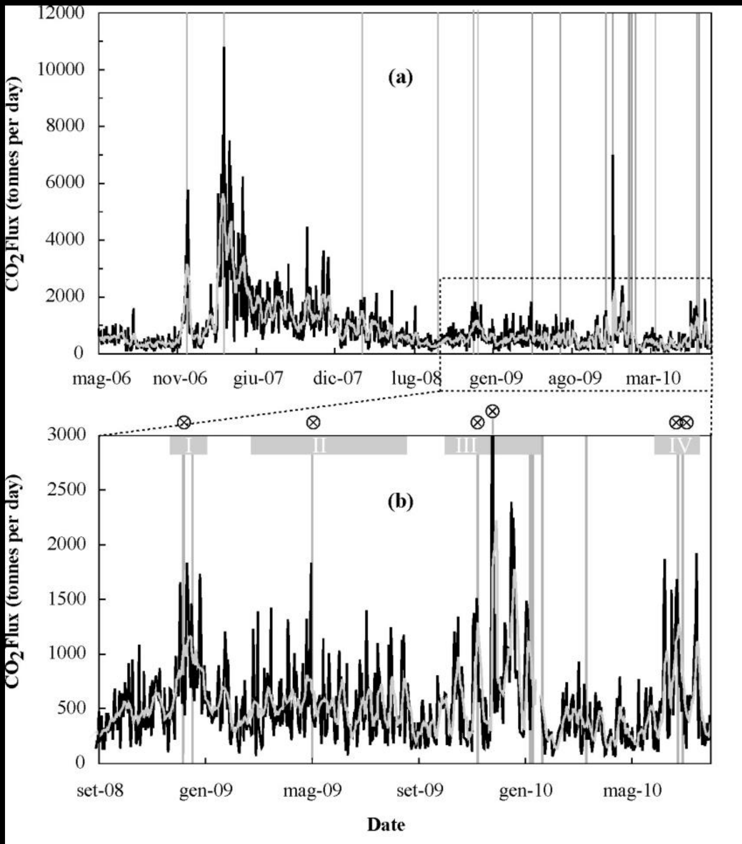
  CO_2/SO_2 ratio increase can be produced by increase in CO_2 or decrease in SO_2

  Fluxes allow unique interpretation of the gas variations

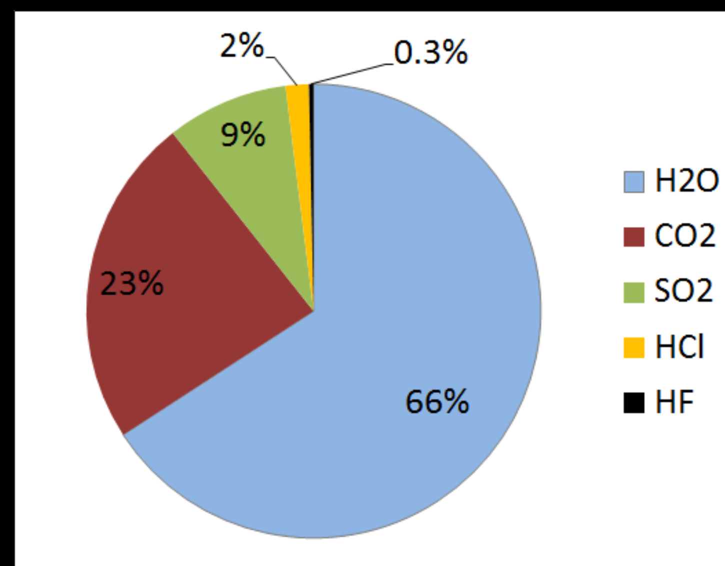
- Computation of total volatile budget

  by using SO_2 emission rates

this reveals degassing from different depths in the Stromboli system (*Aiuppa et al., 2008, 2011)*



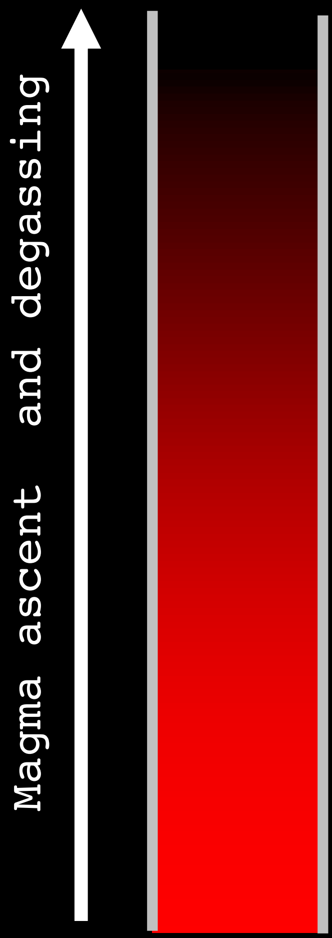
Daily averages of CO2 plume fluxes between May 2006 and July 2010. Major explosions, indicated by the vertical grey lines



Total volatile flux of Mt. Etna between 2005-2011.

Mass balance

Volume of degassed magma from observed SO_2 flux



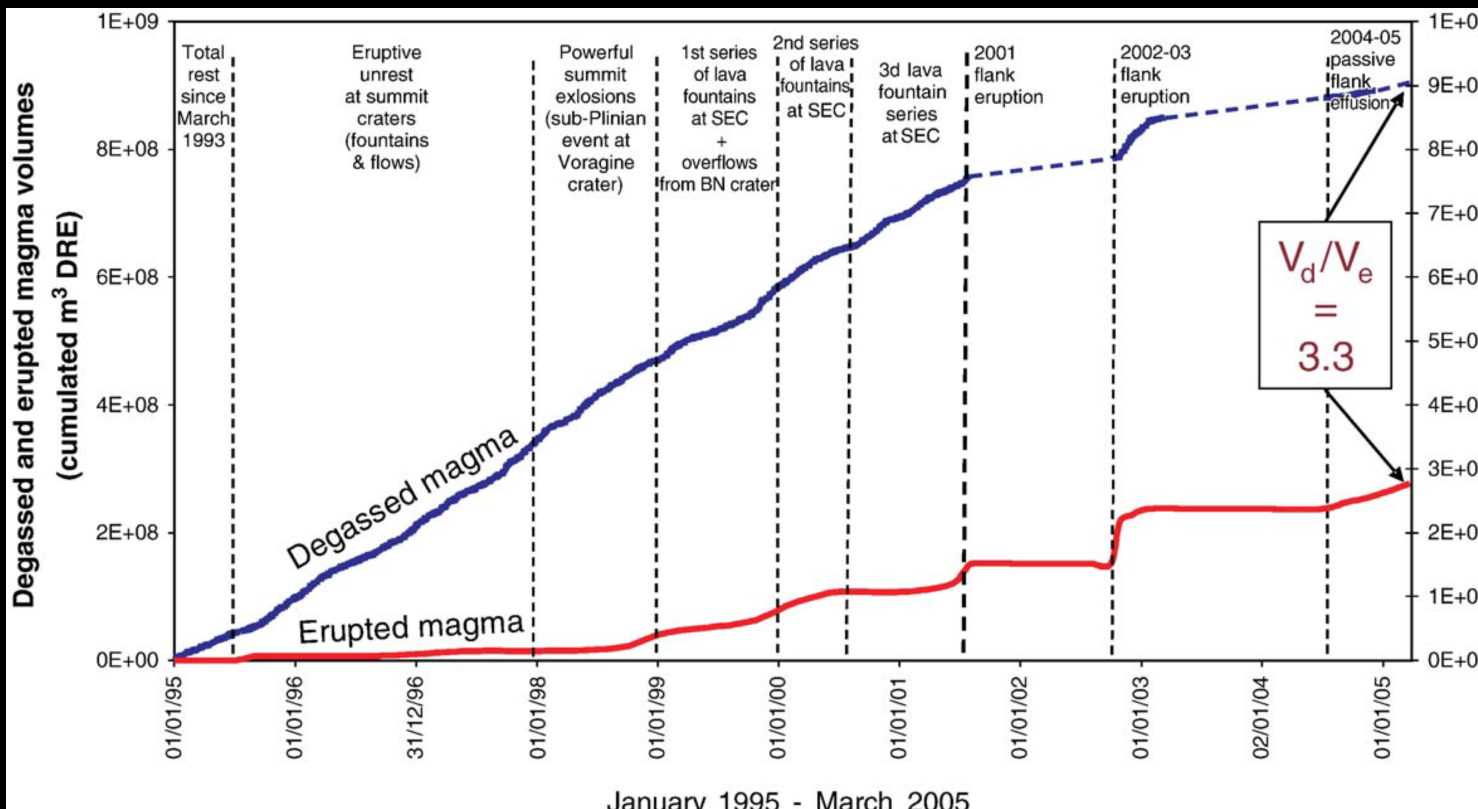
$$Magma\ supply = \frac{1}{2}\ \phi SO_2 \ / \ [\Delta S * \rho m * (1 - x_c)]$$

- ΔS : Mass fraction degassed sulphur (melt inclusions, 0.32 wt%)
- ρm : Magma density,
- $1 - x_c$: Crystal fraction

In quiescent stage Etna ejects ~2500 tonnes of SO_2 per day, which imply

~4800 Kg/s mass of degassed magma and a volume of 1.7 $m^3\ s^{-1}$ or 0.055 km yr^{-1}

Cumulative erupted and degassed magma between 1995 – 2005

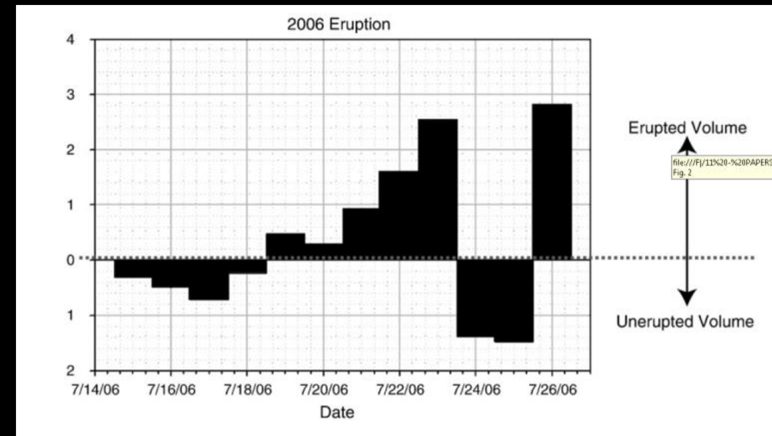


SO_2 flux data, normalised to magma S content, imply differential gas release from prevalently non-erupted magma – Vd/Ve ~ 3.3 (*Allard et al. 2006*)

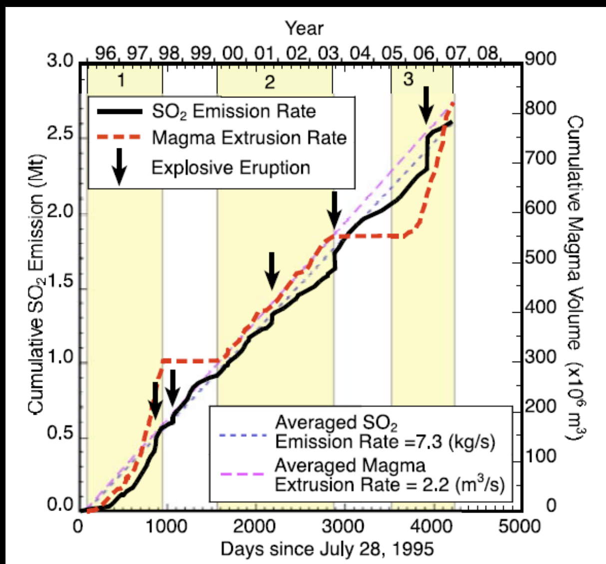
case study

EXCESS DEGASSING FROM VOLCANOES AND ITS ROLE ON ERUPTIVE AND INTRUSIVE ACTIVITY

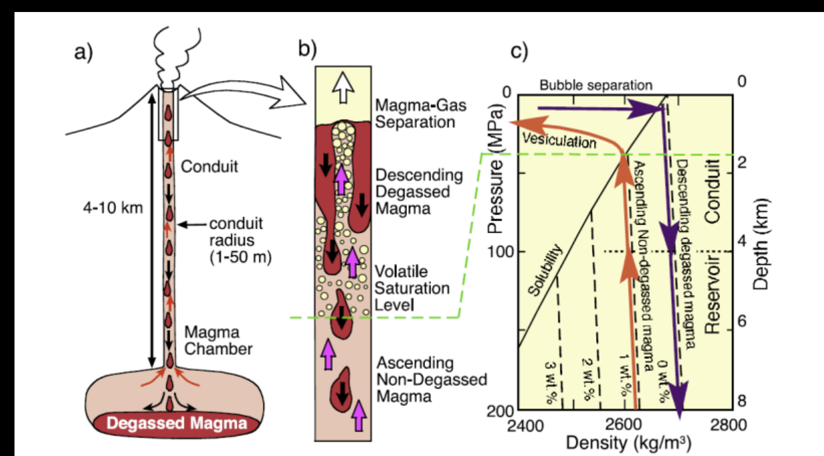
Shinohara, H. (2008), *Rev. Geophys.*, *46*,



Steffke et al., 2011, Etna



Soufriere Hills volcano, Montserrat (Shinohara, 2008)



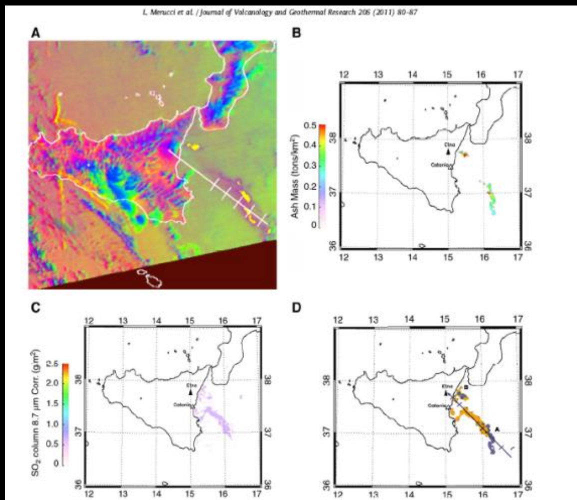
Schematic diagrams of degassing model in a convecting magma column (Shinohara, 2008).

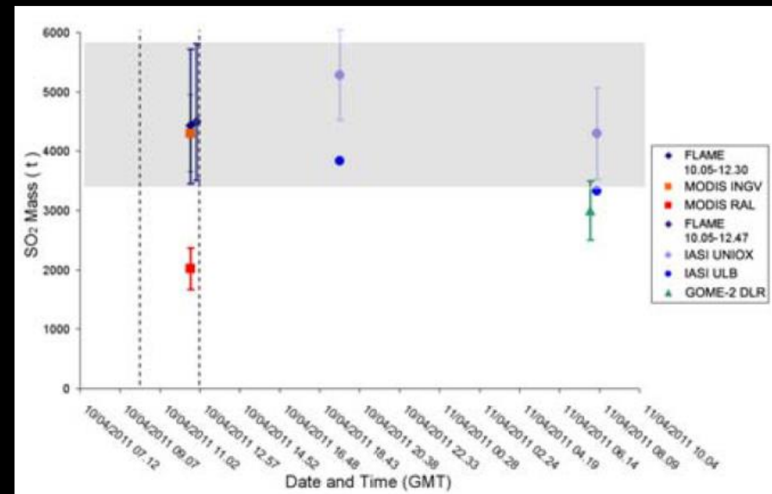
Endogenous growth of persistently active volcanoes

Peter Francis*†, Clive Oppenheimer† & David Stevenson†

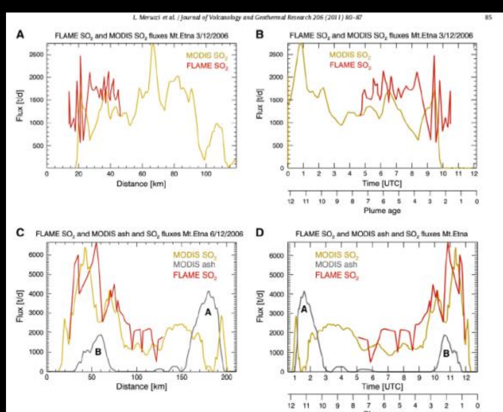
NATURE · VOL 366 · 9 DECEMBER 1993

Satellite-based SO_2 retrieval

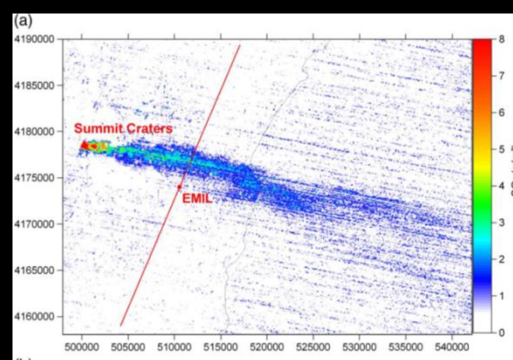


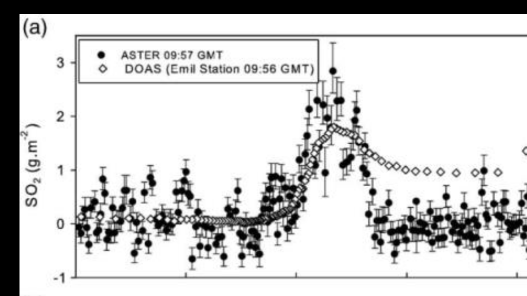


Spinetti et al., 2015



Merucci et al., 2011





Campion et al., 2010

- *PhD: Azzopardi et al., Etna's volcanic SO2 plume dispersion over the Maltese Islands. In review Atm. Env.*

- *Sellitto et al., Synergistic use of Lagrangian dispersion modelling, satellite- and ground-based measurements for the investigation of volcanic plumes: the Mount Etna eruption of 25-27 October 2013, In review ACP*

- *Bachelor of Science: Zanatel 2015, The impact of Mount Etna sulphur emissions in the Central Mediterranean: 14 years of statistic analysis using lagrangian modelling and observations*

Volatiles few % of the total mass of magma

- *engine of eruptions*
- *style and timing of eruptive activity*
- *local to global scale impact*