Volcanoes and lunar cycles: towards using tidal stresses to forecast eruptions

[Girona et al., 2018]

AOGS 15th Annual Meeting; 8 June 2018

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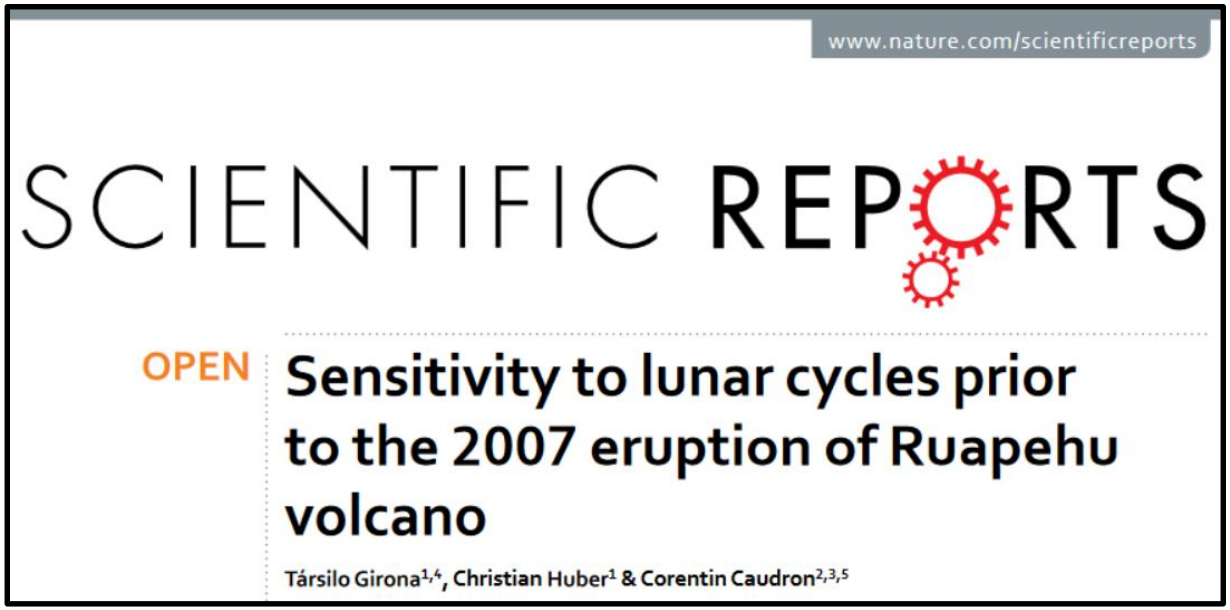
Volcanoes and lunar cycles: towards using tidal stresses to forecast eruptions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Sensitivity to lunar cycles prior to the 2007 eruption of Ruapehu volcano

Társilo Girona[1,4], Christian Huber[1] & Corentin Caudron[2,3,5]

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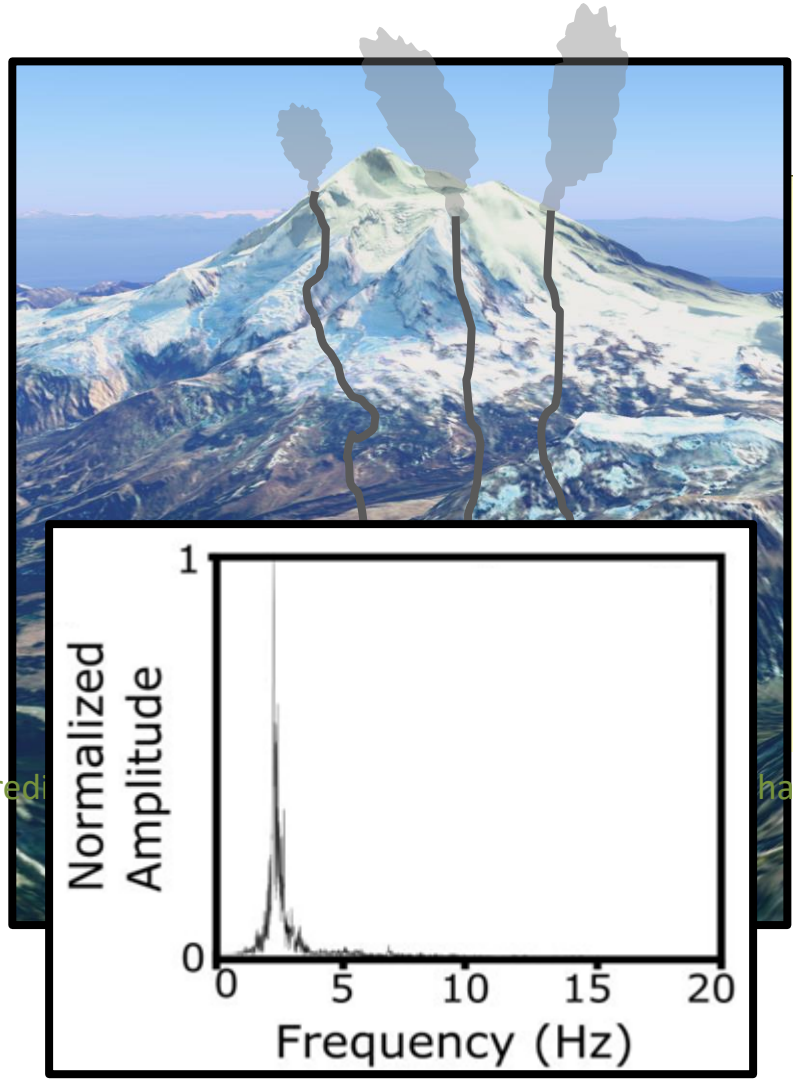
HYPOTHESIS: tidal stresses can modulate volcanic tremor



[credi haMU]

- **Lunisolar gravitational forces induce tidal stresses**

  ⇩

  ~ 1 kPa << 0.1 – 1 MPa

  [e.g., Dzurisin, 1980; Sparks, 1981]

- **Cannot (likely) trigger eruptions…**

  … but (likely) affects the motion of fluids (magma and gas)

  [e.g., Shimozuru, 1980; Sottili et al., 2007]

- **May affect geophysical signals**

  TREMOR

  [e.g., Connor et al., 1988; Custodio et al., 2003; Bredemeyer and Hansteen, 2014; Tolstoy, 2015]

RESEARCH QUESTION

1. Is volcanic tremor sensitive to tidal stresses?

2. How do the response of tremor to tides depend on the internal conditions of a volcano?

Method
Results
Model

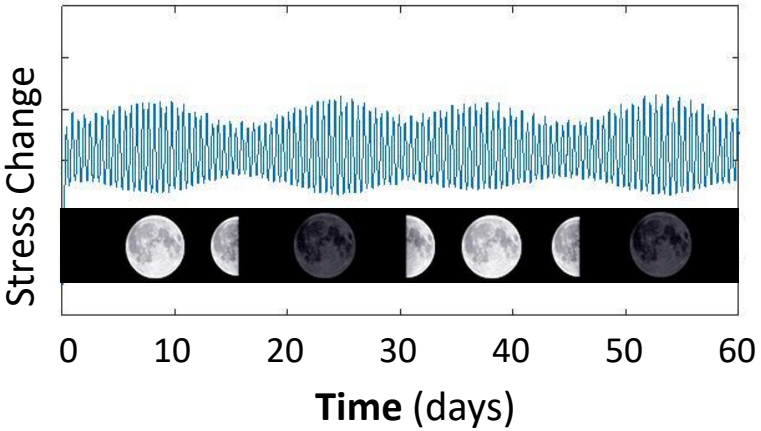
Ruapehu (New Zealand)

2006 and 2007

[credit: Google Earth]

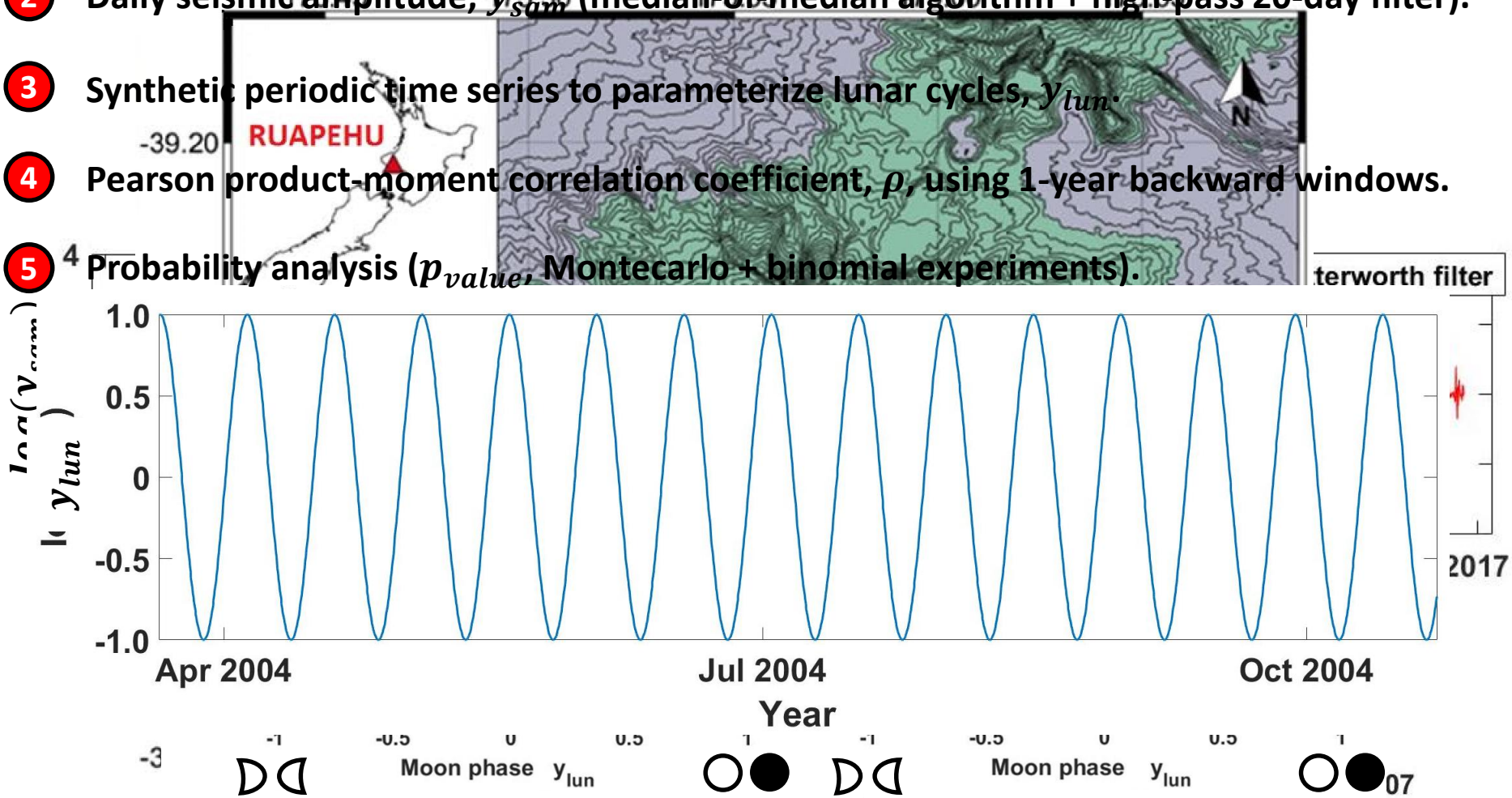
- Br
- Co

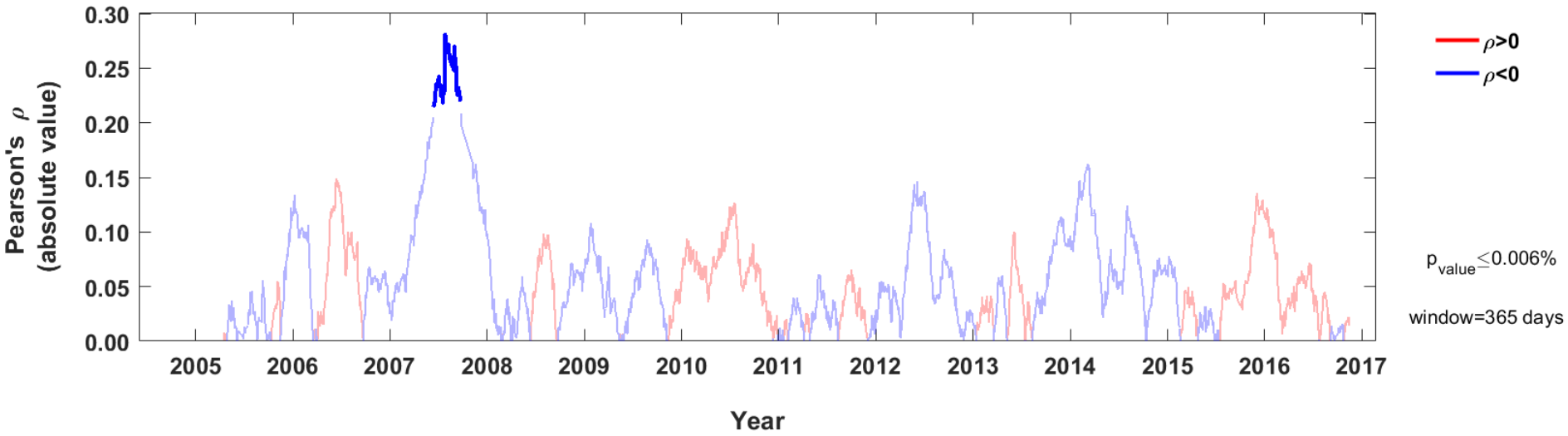
Fortnightly tides

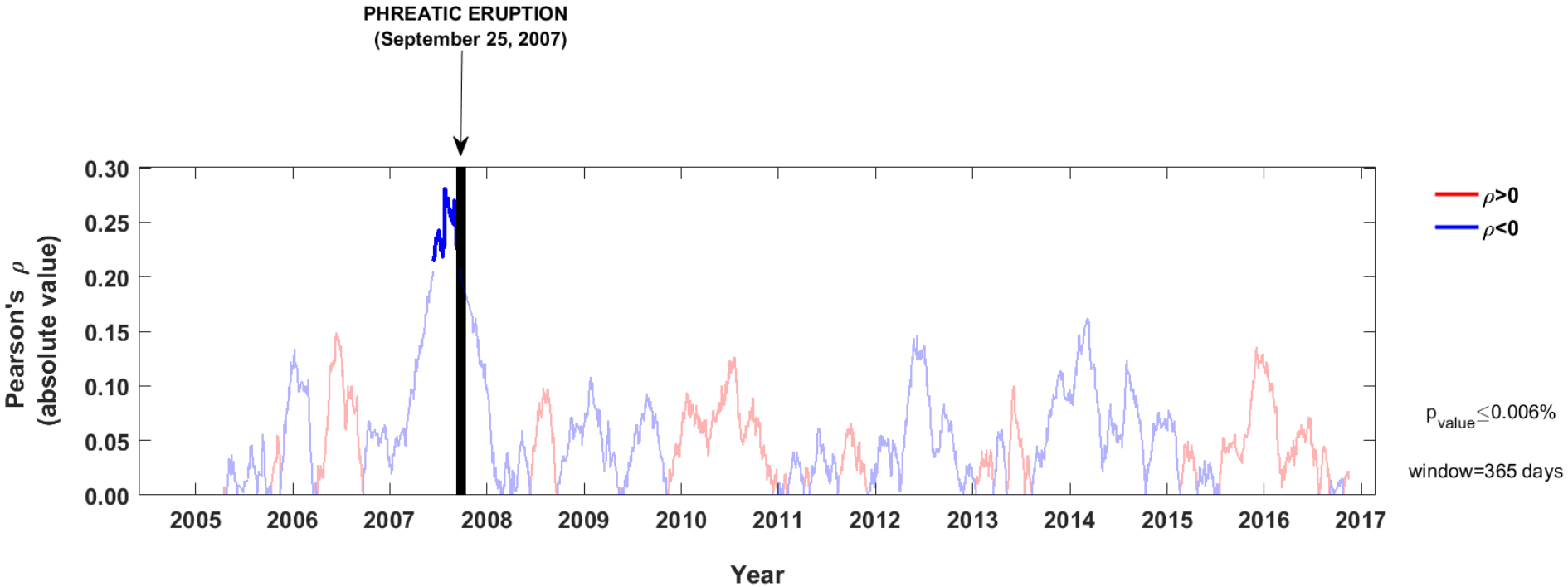


Data processing and analysis

1. Seismic data (2004-2016; DRZ Station Geonet-GNS; 700m to crater; z-component).
2. Daily seismic amplitude, y_{sam} (median-of-median algorithm + high-pass 20-day filter).
3. Synthetic periodic time series to parameterize lunar cycles, y_{lun}.
4. Pearson product-moment correlation coefficient, ρ, using 1-year backward windows.
5. Probability analysis (p_{value}, Montecarlo + binomial experiments).




0.30
0.25
0.20
0.15
0.10
0.05
0.00
Pearson's ρ
(absolute value)
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year
ρ>0
ρ<0
p_value≤0.006%
window=365 days



Days with significant correlation: N =102 (2.3%) [confidence level: 4σ ; $|\rho|\geq 0.21$; $|\rho|_{max}=0.28$]

Probability of obtaining 1 day with $|\rho|\geq |\rho|_{max}$= 4.8e-07

Probability of obtaining 102 days (or more) with $|\rho|\geq 0.21$: 6.1e-188

Tremor and lunar cycles were significantly correlated from 9 to 15 months prior to the 2007 phreatic eruption !!!

Why were tremor and lunar cycles correlated prior to the 2007 eruption?

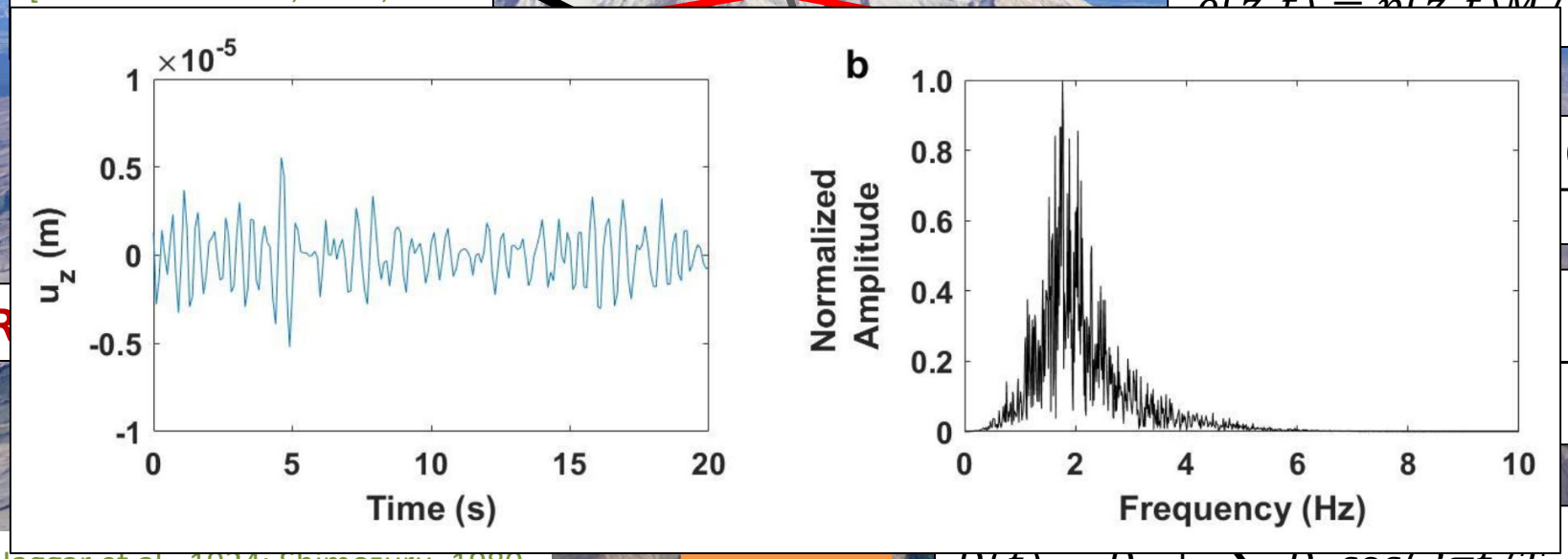
$$-\frac{\partial p(z,t)}{\partial z} = \frac{\mu}{\kappa} v(z,t) + \frac{\rho(z,t)}{\kappa^*} v(z,t)^2 + \frac{\rho(z,t)}{\varphi}\left(\frac{\partial v(z,t)}{\partial t} + \frac{v(z,t)}{\varphi}\frac{\partial v(z,t)}{\partial z}\right)$$

$$\frac{\partial \rho(z,t)}{\partial t} + \frac{1}{\varphi}\frac{\partial[\rho(z,t)v(z,t)]}{\partial z} = 0$$

$$\rho(z,t) = p(z,t)M/R_gT$$

Porous gas flow

[Christenson et al., 2010;



$(t)]$

$- t_n)$

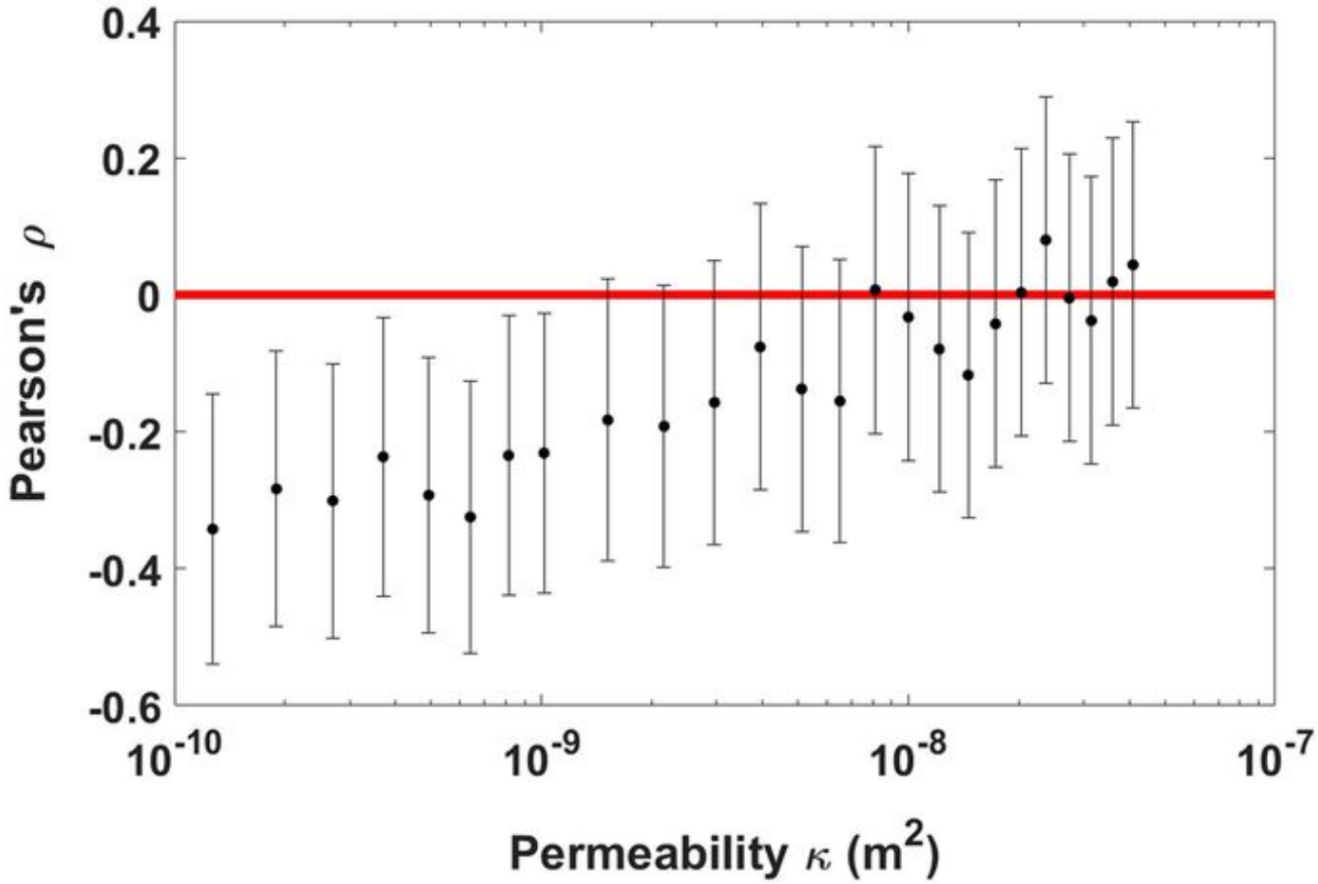
[Jaggar et al., 1924; Shimozuru, 1980
Bredemeyer and Hansteen, 2014]

$$D(t) = D_0 + \sum_i D_i \cos(2\pi t/T_i + \delta)$$

[credit: Google Earth]

[e.g., Girona et al., 2018; Girona et al., submitted]

Why were tremor and lunar cycles correlated prior to the 2007 eruption?



Because the permeability of the cap decreased

RESEARCH QUESTIONS

1 Is volcanic tremor sensitive to tidal stresses?

- **R1**: **Tremor of Ruapehu is not generally modulated by tides, except when the volcano was in a critical state.**

2 How do the response of tremor to tides depend on the internal conditions of a volcano?

- **R2**: **Tremor responds to tides when the shallow cap is plugged and therefore when the volcanic interior was pressurized → FORECASTING TOOL?**