Remote Sensing of the El Hierro submarine volcanic eruption plume

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Introduction

Between October 2011 and March 2012 submarine volcanic eruptions took place at El Hierro (Canary Islands). The event produced plumes of discolored waters due to the discharge of volcanic matter, gases and fluids. Field samples of Chl-a and sulphur reduced species were collected by some oceanographic cruises (Instituto Español de Oceanografía, IEO).

Objective

To characterize the spatio-temporal evolution of waters containing material expelled by the eruption (**Fig. 1**) using remote sensing data supported by oceanographic field samples of Chl-a and sulphur reduced species.

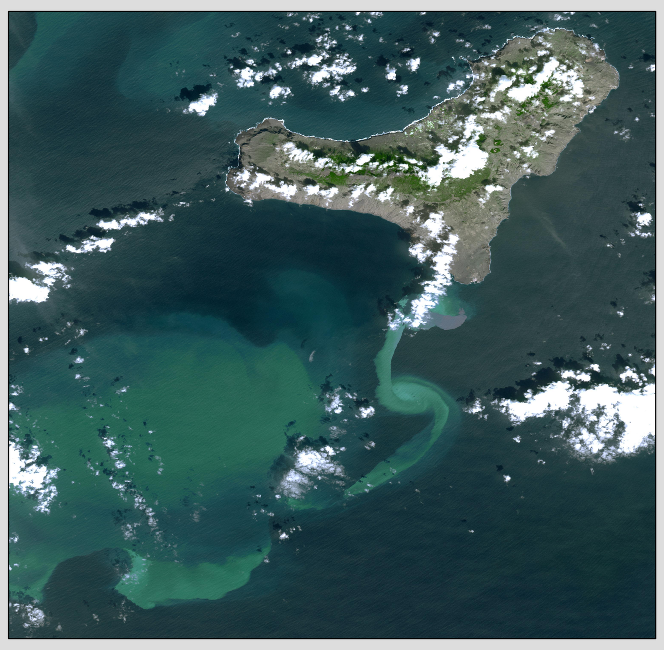


Fig.1.- Aster (Terra) true color image of the volcanic eruption Nov 1, 2011.

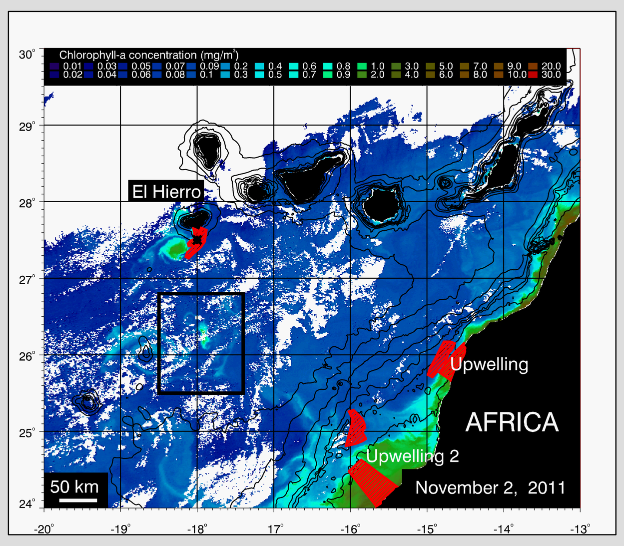


Fig.2.- MODIS-AQUA Chl-a image on Nov 2, 2011, showing the location of the El Hierro volcano and the areas (red shapes) used for STD, NIR-SWIR and MUMM atmospheric correction adjustment and/or comparison. The black box indicates the area where the erupted material and the upwelling converge.

Methods

Level-1A (L1A) granules of MODIS - AQUA satellite were downloaded from *Ocean Color Web* (http://oceancolor.gsfc.nasa.gov/) and processed using SeaDAS 6.4. The selected L2 products were: diffuse attenuation coefficient for downwelling irradiance at 490-nm (Kd490), normalized water leaving radiance (nLw), remote sensing reflectance (Rrs), Shi turbidity index (tindx_shi), Chl-a, SST, backscattering coefficient (b_b) and the parameters required for the Management Unit of the North Sea Mathematical Models (MUMM) adjustment. Three atmospheric correction schemes for satellite imagery were evaluated: SeaDAS standard, NIR-SWIR and MUMM (**Fig. 2**).
5-day syntheses of MODIS SST images and RGB images were created using Rrs. Geostrophic velocities derived from altimeter data were superimposed over RGB and 5-day SST images to describe the distribution of the material expelled by the eruption.
The Rrs spectra were used to characterize types of discolored water plumes of volcanic origin to compare with other water types, leading to a classification schema based on apparent optical properties (Kd490 values and Rrs ratios, Rrs 667nm to Rrs 678nm).

Results

The MODIS-derived Kd490 values verified the moderate intensity of the El Hierro plume since only in some specific situations, the values barely exceed 0.4 m^{-1}. The comparison between the atmospheric correction schemes verified that the SeaDAS standard algorithm was the most suitable (**Fig. 3**). Besides, field oceanographic data verified the high concentration of sulphur in affected waters and confirmed the overestimation by the MODIS algorithm of Chl-a concentration in the volcanic plume (**Fig. 4**). The spreading and transport of volcanic material observed in the sea surface was caused by the predominant currents coupled with different eddies (**Fig. 5**). Derived Rrs spectra over the plume described a great variability throughout the event (**Fig. 6**). Comparisons of spectral shapes from clear, coastal upwelling and the El Hierro waters revealed differences between them (**Fig. 7**). Similarities were found with other submarine eruptions in the SW Pacific (Mantas *et al.* 2011) and with sulphide events at the Namibian coast (Ohde & Mohrholz 2011) (**Fig. 8**). The classification scheme based on Rrs spectra analysis separated water types according to turbidity (high, moderate, low) and Chl-a and non-Chl-a dominated (**Fig. 9**).

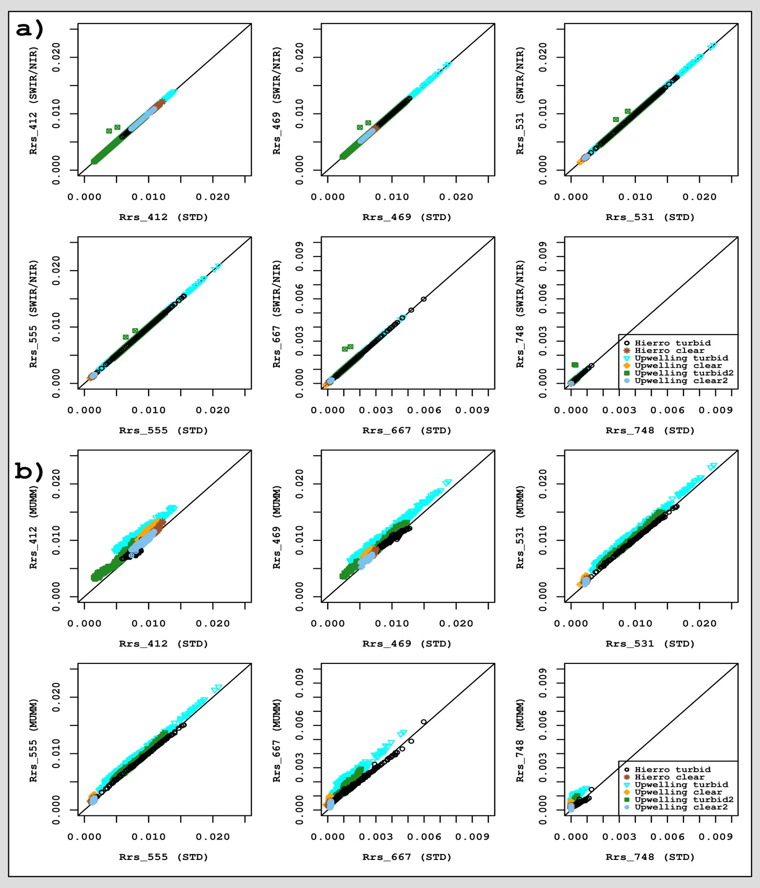


Fig.3.- Scatter plots of remote sensing reflectance at different wavelengths for a) NIR-SWIR vs. STD and b) MUMM vs. STD atmospheric corrections corresponding to areas and date shown in Fig. 2.

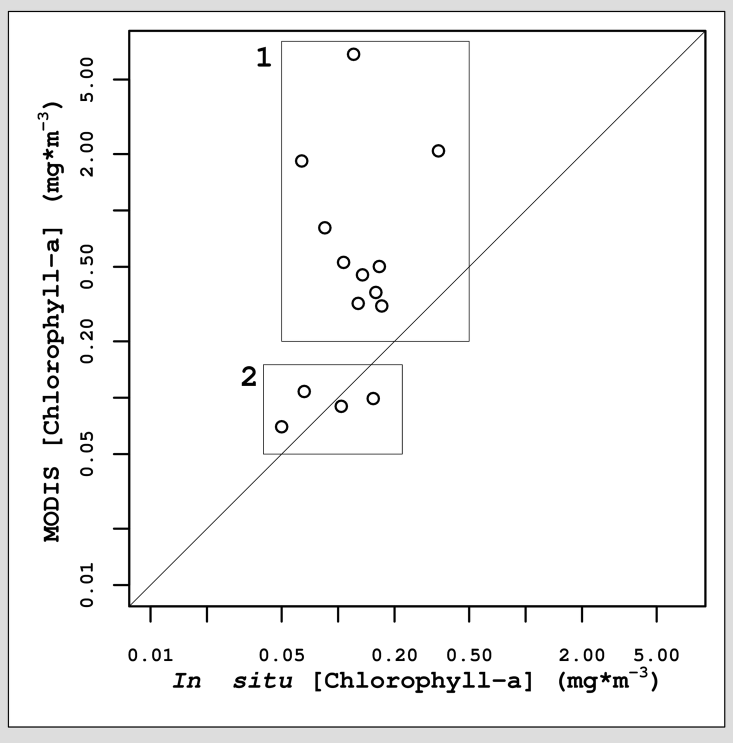


Fig.4.- Scatter plot of in situ Chl-a vs. MODIS Chl-a. Square 1 corresponds to data over the volcanic plume and square 2 corresponds to data over unaffected waters.

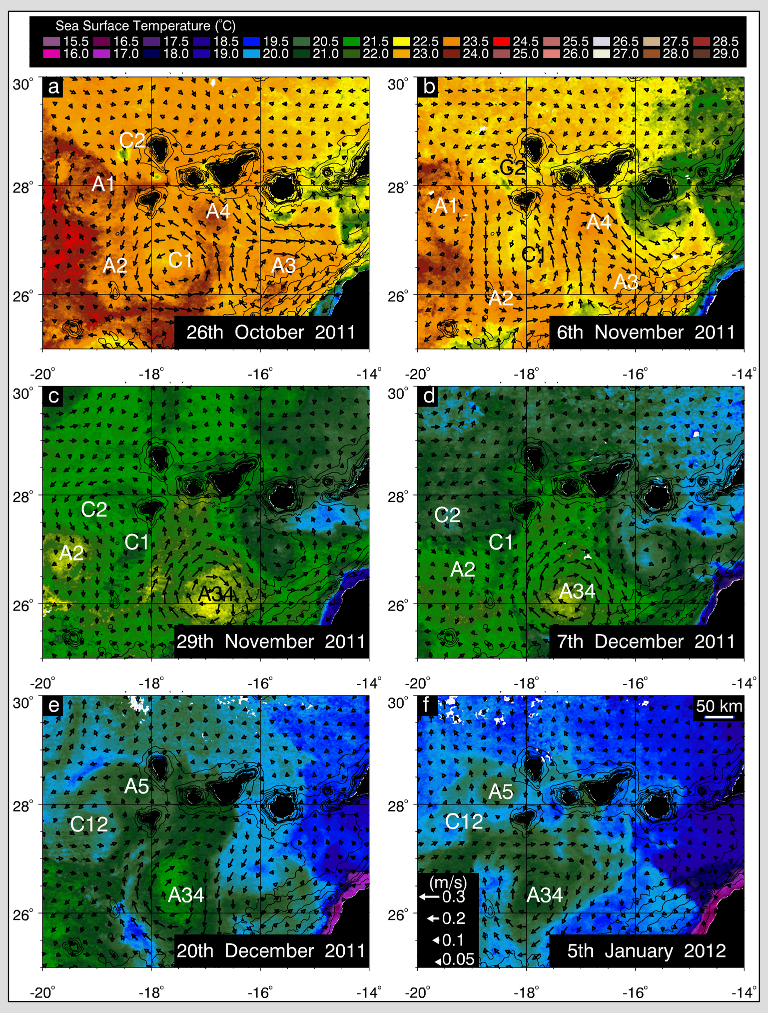


Fig.5.- 5-day SST maps and geostrophic current fields derived from altimeter data (**C**=cyclonic eddy, **A**=anticyclonic eddy).

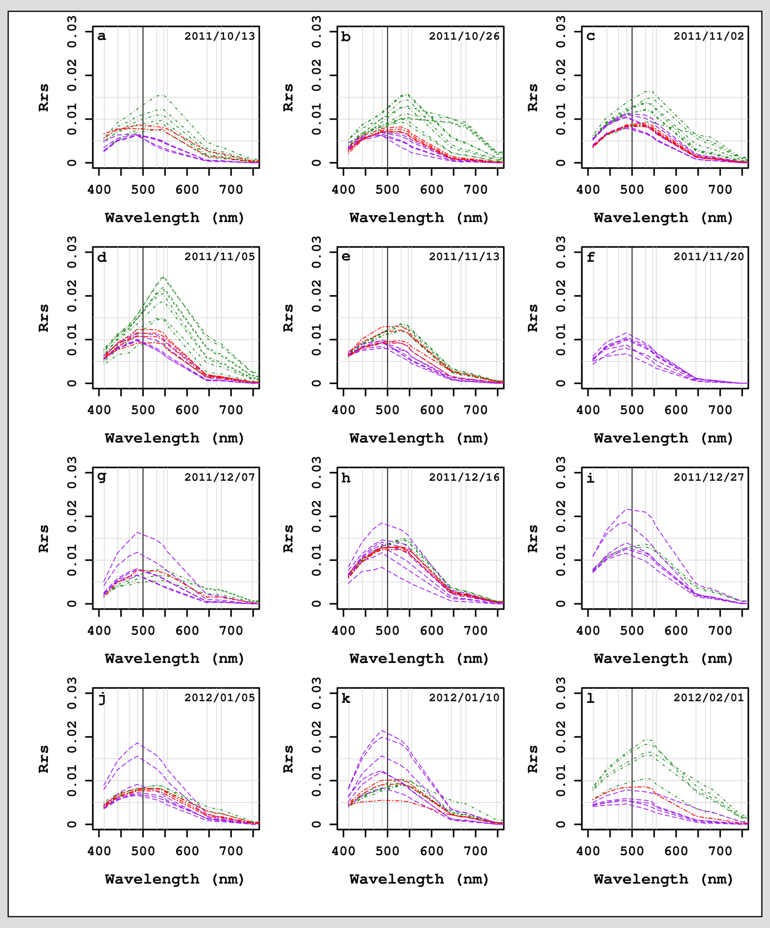


Fig.6.- Spectral of remote sensing reflectance showing variability over the volcanic plume on several dates. Green curves: Kd490 ≥ 0.15; red curves: 0.13 ≤ Kd490 < 0.15; purple curves: Kd490 < 0.13.

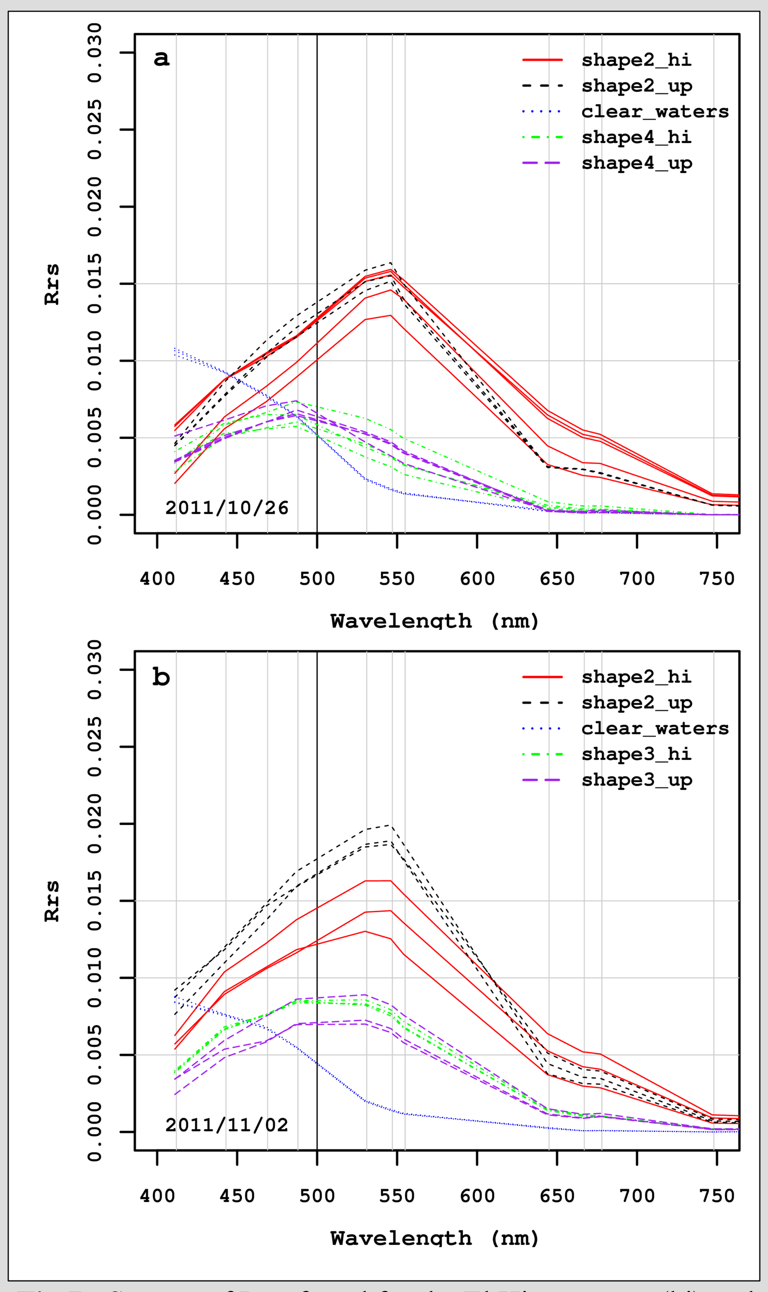


Fig.7.- Spectra of Rrs found for the El Hierro event (hi) and coastal African upwelling (up).

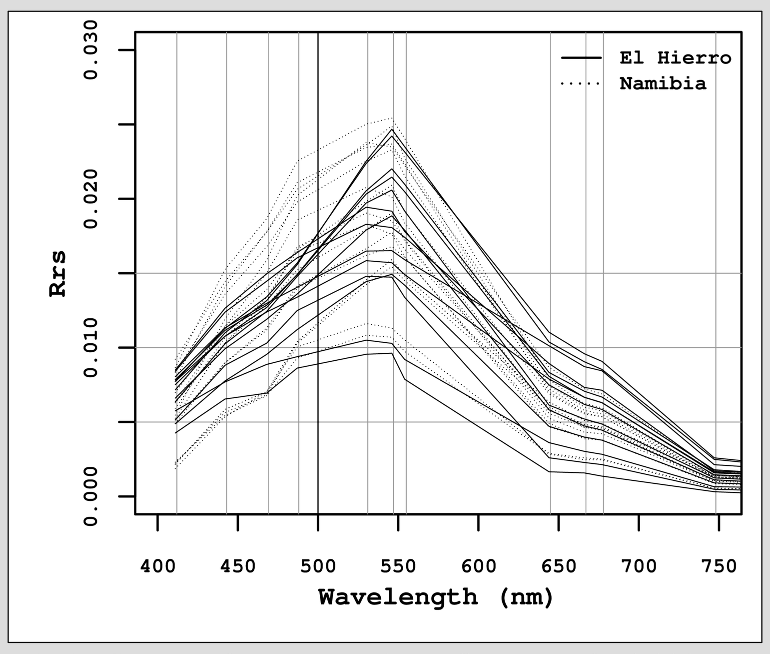
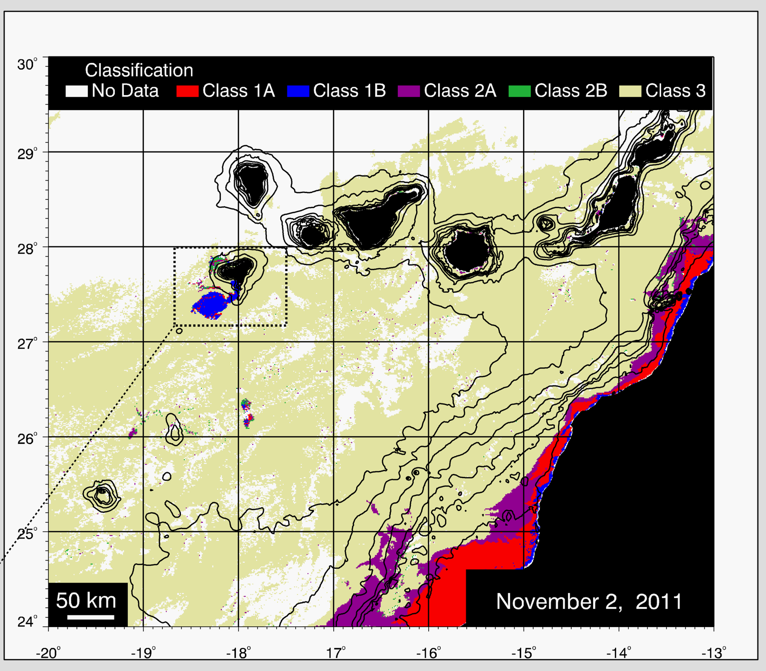


Fig.8.- Spectra of remote sensing reflectance of sulphide events off the Namibian coast and the El Hierro eruption.



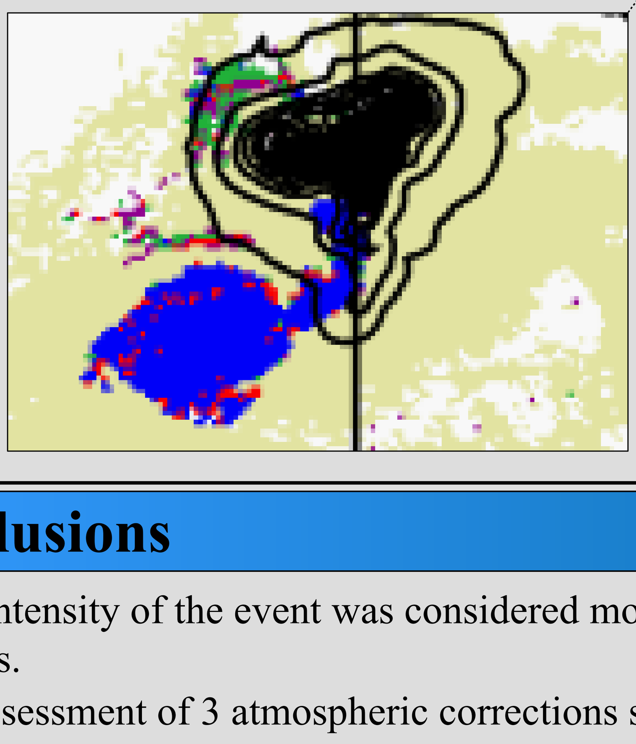


Fig.9.- Example of classification scheme for Nov 2, 2011. Class 1A: turbid Chl-a dominated. Class 1B: turbid not Chl-a dominated. Class 2A: moderate turbid Chl-a dominated. Class 2B: moderate.

Conclusions

- The intensity of the event was considered moderately turbid according to the Kd490 and b_b values.
- An assessment of 3 atmospheric corrections showed the SeaDAS standard MODIS algorithm to be the most suitable approach.
- Field data (low Chl-a reported over the advected plume) confirmed the failure of MODIS Chl-a algorithms for discolored waters.
- The advection of the volcanic plume was strongly related to the presence of eddies.
- Rrs spectra led to the classification of different water types present in the area, allowing their comparison with other similar events.
- The classification schema permitted the characterisation and tracking of the event. The areas classified as **Chl-a dominated** waters increased along the spread plume.

References

Mantas,V., A.Pereira, & P. Morais. 2011. "Plumes of discolored water of volcanic origin and possible implications for algal communities. The case of the Home Reef eruption of 2006 (Tonga, South-west Pacific Ocean)." Rem. Sens Environment 115: 1341-1352.

Ohde, T. & V. Mohrholz. 2011. "Interannual variability of sulphur plumes off the Namibian coast." Int.J.Remote Sensing 32(24):9327-42.doi:10.1080/01431161.2011.554455.

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