Volcanic Tephra ejected in south east Asia is the sole cause of all historic ENSO events. This natural aerosol plume has been intensified by an anthropogenic plume in the same region in recent decades, which has intensified some ENSO events and altered the Southern Oscillation Index and Niño 3.4 SST characteristics.

1. Abstract

ENSO events are the most significant interannual perturbation of the climate system. Previous attempts to link ENSO with volcanic eruptions failed because only large eruptions across the globe which typically inject tephra into the stratosphere, were considered. I have analysed all volcanic eruptions in South Eastern Asia (SEA), about 1981 to 1974 and 1985 to 1994 (44), the months with positive convection typically over 23% of all eruptions in the Global Volcanism Program database since 1500 occurring here and with 5 volcanoes listed in the literature to have erupted nearly continuously for 200 years. SEA is also the region where the convective arm of the thermally direct Walker Circulation occurs driven by the intense equatorial solar radiation which creates the high surface temperature. The volcanic tephra plumes intercept some of the solar radiation by absorption/scattering which cools the surface and heats the atmosphere creating a temperature inversion compared to periods without the plume. This reduces convection and causes the Walker Circulation and Trade Winds to weaken. This reduced wind speed causes the central Pacific Ocean to warm creating convection there and further weakening the Walker Circulation.

With the reduced wind stress the western Pacific warm pool migrates east. This creates an ENSO event and the volcanic aerosol plume reduces, typically when the SE Asian monsoon commences, and convection is re-established over SEA and the Pacific warm pool migrates back to the west. Correlations of SEA tephra and the ENSO indices are typically over 0.89 at p < 0.05 at 5c below. It is clear that the level of activity varies hugely. Tephra from volcanic eruptions such as Pinatubo and Krakatoa are the natural and historic source of aerosols in the SEAP Area.

2. The Eight Great Aerosol Plumes - Jan and Sep (NASA Giovanni - Terra AOD)

The South East Asian Aerosol Plume: The Cause of All El Niño Events

The natural and historic SEAP: The SEAP Area (4d) is the most tectonically active area in the tropics with the USGS earthquake database showing 25% (5 of 20) of the major earthquakes (magnitude ≥ 8) in the world since 1900 occurred in the SEAP Area and the Global Volcanism Program’s database showing that from 1500 to 2016 over 23% of all volcanic eruptions occurred in the region. The number of significant (4a), volcanic eruptions and the volume of tephra ejected in the SEAP Area through the last century (4b) and it is clear that the level of activity varies hugely. Tephra from volcanic eruptions such as Pinatubo and Krakatoa are the natural and historic source of aerosols in the SEAP Area. The anthropogenic and recent SEAP: Is one of eight, continental scale, aerosol, plumes (2) which now occur annually. It can be seen on the monthly mean AOD data from the NASA Giovanni System. Two areas are used to describe the SEAP the SEAP Area, its location, and the Central and Southeast Asian (CSEAP) Area where it is most intense (4c)

3. Interannual Variation - SEAP Oct 2005 and 2006 (NASA Giovanni - Terra AOD)

The graphs 5f to 5l show that higher levels of VEIT result in:

- Increased Niño 3.4 SST levels;
- Lower SIO levels;
- Increased HadCRUT4 global temperatures.

4. The South East Asian aerosol plume (SEAP)

The major anthropogenic sources of aerosols are biomass burning driven by an increasing population needing agricultural land and living space as well as commercial activity and gas flares in the oil industry. NOAA (National Oceanic and Atmospheric Administration) USA estimates SE Asia flares 4.03 billion cubic metres of gas per year.

The correlation of volcanic eruptions for over 140 years, extensive anthropogenic aerosols from four satellite datasets and the MERRA-2 reanalysis with ENSO, where the aerosol source is known, means that the SEAP to ENSO relationship is causal.

5. El Niño / ENSO Events, Tephra and Aerosols

El Niño events are closely linked with changes in the Walker Circulation (5a), especially the Trade Winds. The literature, NASA, NOAA, IPCC and UN/EMERGO office state in reports or on their websites that El Niño events start when the Walker Winds in the central and western Pacific Ocean relax or reverse. The Trade Winds form the lower limb of the Walker Circulation a “Direct thermally driven zonal overturning circulation in the tropical high into an anomalous position which perturbs the storm tracks in that hemisphere around the globe. This forces the regional sub tropical high into an anomalous position which perturbs the storm tracks in that hemisphere around the globe. This creates: conditions conducive to forest fires in the SEAP Area; a denser agricultural land and living space as well as commercial activity and gas flares in the oil industry. NOAA (National Oceanic and Atmospheric Administration) USA estimates SE Asia flares 4.03 billion cubic metres of gas per year.

6. Mechanism

The SEAP absorbs, retransmits, and reabsorbs solar radiation as the correlations of AOD with CLR and atmospheric temperature shows a large fraction of aerosol plumes are in the lower atmosphere and therefore the surface is “Cooling because reduction of sunlight overwhelms any increased downward energy emitted by volcanic cloud”. This reduction in surface solar radiation (aerosol related dimming) reduces the energy available to drive convection in the SEAP Area (5a). The omega, measured in Pa/s, is negative for rising air and the AI/AOD correlations are positive as an increase in AI implies a decrease in the radiation reaching the surface; and positive feedback driving the climate more deeply into an El Niño state.

The reduced convection then forces the Walker Circulation to relax and reduces the Trade Wind speed as with lower or no convection over the SEAP Area there is no wind to drive the Trade Winds into the Walker and Hadley Circulation. The relaxation of the Trade Winds causes the SST to rise in the Niño areas as there is a strong negative correlation (-0.90 to -0.04 (p < 0.01) annual average/interannual difference) between the Trade Wind speed and SST in the Niño 3.4 area. The reduction of convection in the SEAP area reduces rainfall in the region and this is reinforced by the weaker Trade Winds which transport less water vapour into the region.

The other effects during El Niño events are created by changes in the global circulation and wind systems which all arise from the reduction in convection over the SEAP Area (the maritime continent) and the relaxation of the Trade Winds. For example, drought in SE Asia (SEAU) is also caused by the SEAP. An estimate of the surface radiative forcing of the SEAP is shown at 10 pm page 2 where a reduction of 20% of the radiation without the plume is shown. It is clear that the greatest surface radiation now fall at the edges of the plume and that these regions will now drive the Hadley Circulation. This forces the regional sub-tropical high into an anomalous position which perturbs the storm tracks in that hemisphere around the globe.

7. Conclusions

1. All El Niño/ENSO events are triggered and sustained by aerosol regional dimming by the South East Asian aerosol Plume (SEAP).

2. The correlation of volcanic eruptions for over 140 years, extensive anthropogenic aerosols from four satellite datasets and the MERRA-2 reanalysis with ENSO, where the aerosol source is known, means that the SEAP to ENSO relationship is causal.
The South East Asian Aerosol Plume: The Cause of All El Niño Events

This natural aerosol plume has been intensified by an anthropogenic plume in the same region in recent decades which has altered the Southern Oscillation Index and Niño 3.4 SST characteristics.

8. The Southern Oscillation Index and SST in the Niño 3.4 Area

The Southern Oscillation Index is defined by the Australian Bureau of Meteorology as: "The Southern Oscillation Index, or SOI, gives an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean. The SOI is calculated using the pressure differences between Tahiti and Darwin. Sustained negative values of the SOI lower than −7 often indicate El Niño episodes. Sustained positive values of the SOI greater than +7 are typical of a La Niña episode."

The graphs show the changes in the averages of the SOI and SST in the Niño 3.4 area from 1950 to 1979 and from 1980 to 2016. Changes in the SOI can only be caused by either the pressure in Darwin increasing or the pressure in Tahiti falling or both occurring simultaneously as in an ENSO event. Changes in the SST in the Niño 3.4 area must be driven by a relaxation of the Trade Winds. These significant changes are indicative of a move to a more ENSO prone period and this is entirely consistent with the increases in both the natural and anthropogenic elements of the SEAP described at section 4 on page 1. The third graph shows the seasonal relationship between the SOI and rainfall in the CSEAP Area which is also consistent with the SEAP causing ENSO events.

9. The Seven Stages of an ENSO Event

9.1 The volcanic and/or anthropogenic South East Asian Plume commences

9.2 The SEAP intercepts solar radiation warming the atmosphere and cooling the surface - creating a temperature inversion

9.4 The reduced convection forces the Trade Winds to relax which causes the SST in the central Pacific Ocean to rise

9.5 The higher SST creates convection in the central Pacific and further weakens or reverses the Trade Winds and Walker Circulation establishing an ENSO event

9.6 The SEAP collapses at the onset of the SE Asian Monsoon in November - December which enables convection to be re-established

9.7 The ‘normal’ Walker Circulation is re-established forcing the Pacific warm pool west again and the ENSO event ends

10. Acknowledgements

Data, information and images were sourced from:
- NASA: Analyses and visualizations used in this poster were produced with the Giovanni online data system using NASA satellite data and MERRA-2 reanalysis; National Oceanic and Atmospheric Administration; Australian Bureau of Meteorology; Hadley Centre and the University of East Anglia for the HadCRUT4 temperatures.
- Google Earth; Global Volcanism Program, Smithsonian Institution; Australian Bureau of Meteorology; National Oceanic and Atmospheric Administration; MERRA-2 project.
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11. Conclusions

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For more information on aerosol plumes: www.keithpotts.net.au