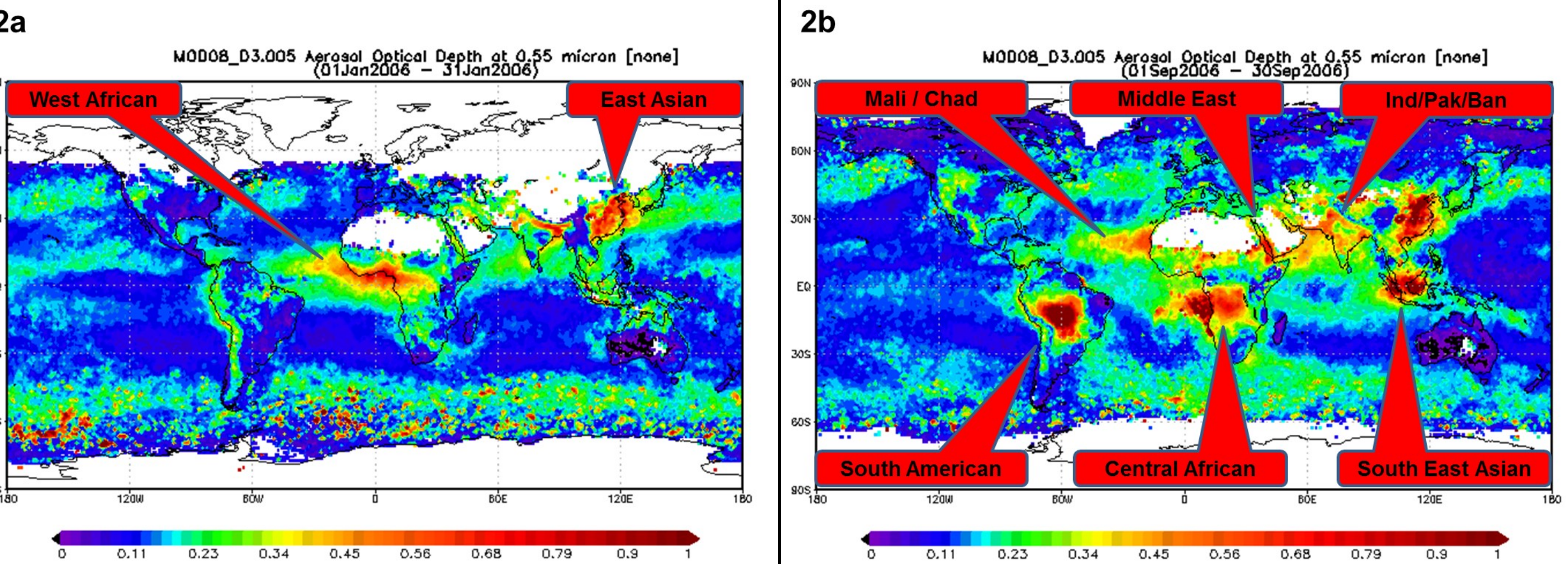


The South East Asian Aerosol Plume - Causing All El Niño Events

1. Abstract

Apparitions of eight continental scale aerosol plumes occur each year in the regions shown in 2a and 2b. Seven plumes only exist for a few months in the same season each year whilst the East Asian Plume is visible all year. The Aerosol Optical Depth (AOD) of all the plumes varies hugely interannually as 3a and 3b show with studies showing the surface radiative forcing of the South East Asian aerosol Plume (SEAP) as $-150W/m^2$ and $-286W/m^2/AOD$. I show that the SEAP, created by volcanic aerosols (natural) and biomass burning and gas flares in the oil industry (anthropogenic), is the sole cause of all El Niño events, the greatest interannual perturbation of the atmospheric circulation system. The SEAP creates an El Niño by absorbing solar radiation at the top of the plume which heats the upper atmosphere and cools the surface. This creates a temperature inversion compared to periods without the plume and reduces convection. With reduced convection in SE Asia, the Maritime Continent, the Trade Winds blowing across the Pacific are forced to relax as their “exit” into the Hadley and Walker Cells is constrained. The reduced Trade Wind speed causes the Sea Surface Temperature (SST) to rise in the central tropical Pacific Ocean

2. The Eight Great Aerosol Plumes - Jan & Sep 2006 (NASA Giovanni - Terra AOD)

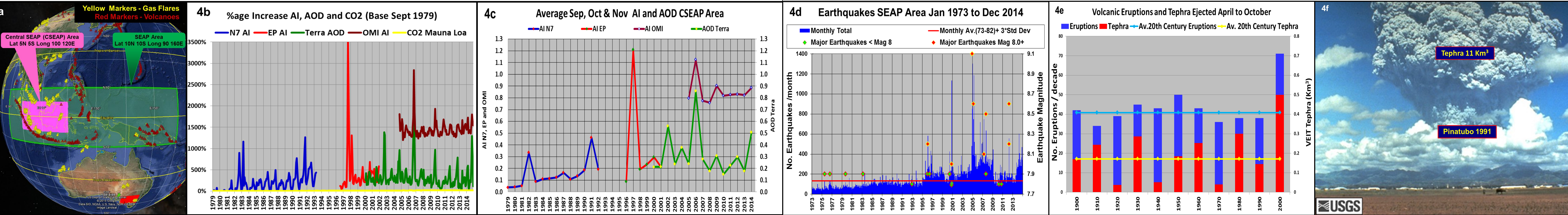
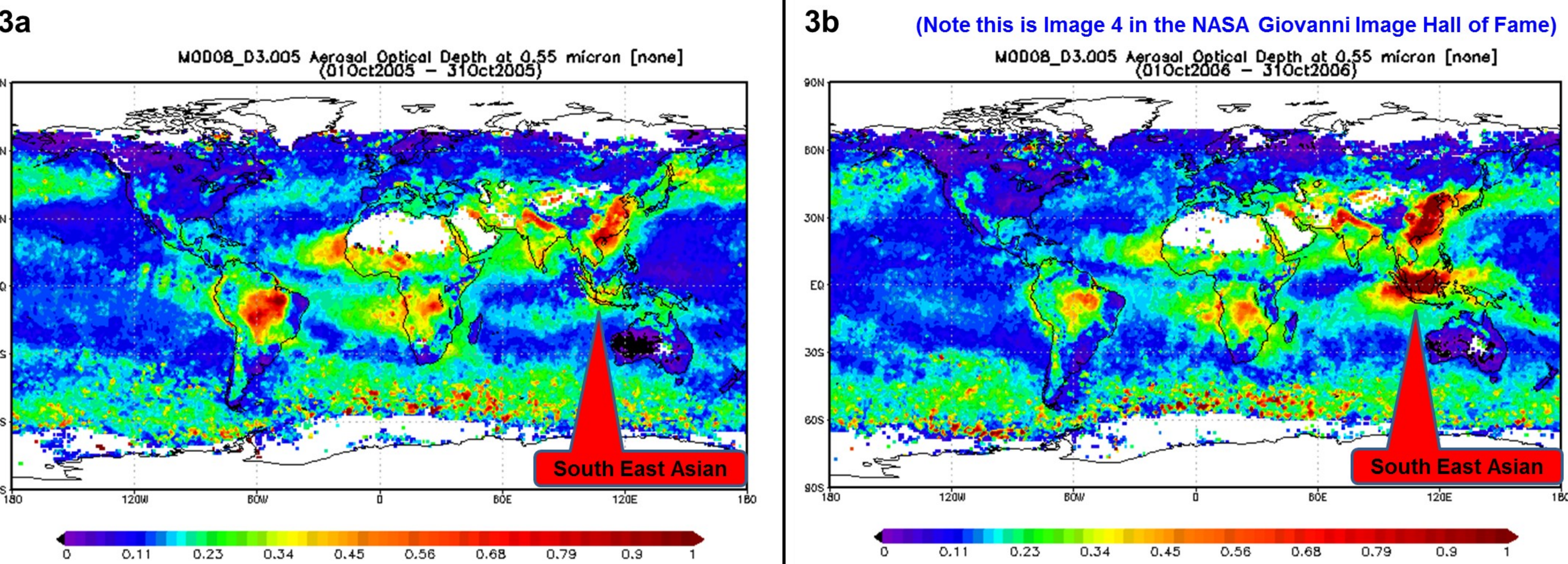


4. The South East Asian aerosol Plume (SEAP)

The anthropogenic SEAP: Is one of eight aerosol plumes which 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 SEAP (CSEAP) Area where it is most intense (4a). The increase in the monthly AI/AOD of the CSEAP Area since 1979 (4b) demonstrates the peak anthropogenic aerosol emission season is SON, the end of the dry season in SE Asia, and was very high in 1997, 2002, 04, 06, 09 and 14 compared with the intervening years. 3b shows the extent of the October 2006 extreme apparition of the SEAP. This paper first focuses on Sep, Oct, Nov (4c) because the anthropogenic SEAP is at its most intense and will therefore have its greatest effect in this season. The maximum AOD and AI for the CSEAP Area was 1.282 (Oct 2006) and 1.811 (Sept 1997). The AI of the CSEAP Area grew from 0.050 in Sep 1979 to 0.297 in 1992 and to 0.396 in 2000 a 491% and 687% increase respectively in

as there is a strong negative correlation between wind speed and SST. The warmer SST in the central Pacific Ocean creates convection in the region which further reduces the Trade Wind speed and may ultimately cause the Walker Cell to reverse – a classic El Niño. Having established the ability of such extreme aerosol plumes to create El Niño events I then show how the South American, West African and Middle East plumes and the SEAP create drought in the Amazon, Spain, Darfur and Australia as well as causing the extremely warm winter in Europe in 2006-07. The effects are created by the plumes reducing convection in the region of the plume which reduces local rainfall and forces the regional Hadley Cells into anomalous positions which create persistent high pressure cells in the mid latitudes. This perturbs the mid latitude storm tracks, creating persistent high and low pressure systems around the World at those latitudes, giving rise to extreme events caused by the winds blowing persistently from one direction. Finally, I will suggest which plumes may be causing the high pressure ridge in the NE Pacific and the USA which is causing the severe drought in California.

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



5. El Niño / ENSO Events, Aerosols & Tephra

El Niño events are closely linked with changes in the Walker Cell (8a) - especially the Trade Winds. The literature, NASA, NOAA, the IPCC and the UK Met Office state in reports or on their websites that El Niño events start when the Trade Winds in the central and western Pacific Ocean relax or reverse. The Trade Winds form the lower limb of the Walker Cell a “Direct thermally driven zonal overturning circulation in the *atmosphere* over the tropical Pacific Ocean, with rising air in the western and sinking air in the eastern Pacific” (IPCC). As the Walker Cell is directly thermally driven the heat must be applied *at the Earth’s surface in SE Asia* - the SEAP Area - to drive the convection and as the variation in solar radiation at the top of atmosphere cannot explain the reduction in surface heating and the relaxation of the Trade Winds the reduction in heat must be caused by aerosols in the atmosphere. **First:** I show the correlations of the AI and AOD of the CSEAP Area and the various indices used to monitor ENSO events identified in the IPCC Assessment Report 5 (AR5), shown in red, as well as other parameters in 5a and 5b. They demonstrate that when an aerosol plume exists in the SEAP Area in SON from 1979 to 2014:

- ◆ The level of (OLR) increases - implying a decrease in the radiation reaching the surface;

- ◆ The air temperature at 650hPa increases showing the plume warms the upper atmosphere;
- ◆ Convection in the CSEAP Area reduces and the Sea Surface Temperature (SST) of the SEAP Area reduces;
- ◆ The Trade Winds relax;
- ◆ The SST in the Niño Areas 1+2 and 3.4 increases as does the Oceanic Niño Index; and
- ◆ The Southern Oscillation Index (SOI) decreases.

Second: Table 5c shows the relationship between: volcanic tephra in the SEAP Area; Niño 3.4 SST; the SOI and CSEAP Area omega. Tephra (4f) data was calculated from the Volcanic Explosivity Index (VEI) data, VEI Tephra (VEIT), deskewed, segmented, averaged/segment and then correlated with the segmented averages of the other parameters from 1870, 1876 and 1948 respectively to 2014. Graphs of VEIT, SST and SOI are at 5j and 5l.

Third: The maps 5e to 5i (NCEP Reanalysis) show the anomalies caused by the SEAP by deducting years of low SEAP AOD (2000, 01 and 05) from years of high AOD (2002, 04 and 06) in SST, SLP, omega, wind speed and OLR.

Fourth: The graphs 5j to 5l show the Niño 3.4 SST increases with higher VEIT and CSEAP AI and AOD and the SOI decreases with increased VEIT. Graphs of AI and AOD with omega and OLR are shown at 8b and 8c.

5a	Sept Oct Nov – Correlations									
	AOD	AI	AI	AI	AI	AI	AI	AI	AI	AI
1	SST SEAP Area	-0.74	-0.68	-0.85	-0.62	-0.41	-0.02			
2	Rainfall CSEAP Area	-0.57	-0.40	-0.88	-0.52	-0.38	0.04			
3	NOAA Interp'd OLR	0.86	0.64	0.99	0.77	0.60	0.33			
4	NOAA T. Wind Index	-0.60	-0.69	-0.97	-0.68	-0.76	-0.29			
5	SST Niño 3.4	0.61	0.86	0.91	0.55	0.61	0.34			
6	SST Niño 1 and 2	0.69	0.47	0.96	0.86	0.76	0.28			
7	Oceanic Niño Index	0.62	0.50	0.90	0.56	0.57	0.29			
8	SOI	-0.70	-0.64	-0.85	-0.63	-0.45	-0.09			
9	CSEAP Area Omega	0.89	0.57	0.96	0.87	0.56	0.38			
10	Temp CSEAP Area 650 hPa	0.77	0.35	0.75	0.78	0.54	0.73			

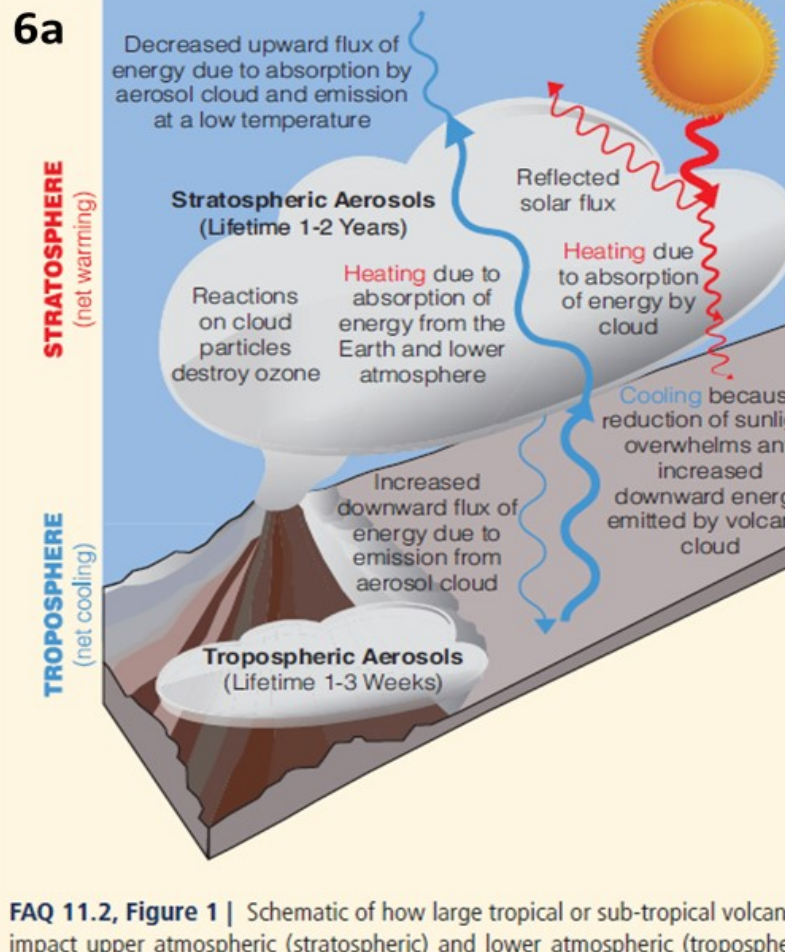
5c	Correlations of VEIT with Indices & Parameters shown			
	Index	Correlation Apr to Oct (Skew/Kurtosis)	Correlation Annual (Skew/Kurtosis)	VEIT Area Period
	Niño 3.4 SST	0.94 (0.07/-2.40)	0.84 (1.72/3.10)	10S-1N; 100-151E 1870 – 2014
	SOI	-0.80 (0.05/-1.26)	-0.85 (0.13/-0.41)	10S-1N; 110-160E 1876 – 2014
	Omega (400 hPa) (CSEAP Area)	0.98 (-0.34/0.27)	0.89 (0.30/-0.57)	10S-1N; 102-151E 1948 – 2014

5d Legend for all Correlation Tables				
Significance	< 0.10	< 0.05	< 0.02	< 0.01
IPCC ENSO Indices				

6. Mechanism

The SEAP absorbs, re-radiates and reflects solar radiation as the correlations of AI/AOD with OLR and air temperature at 650hPa show. Fig. 6a (IPCC AR5) shows volcanic aerosol plumes and states that the effect on 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 regional dimming*) reduces the energy available to drive convection in the CSEAP Area (5a, 5b (9)). Omega, measured in Pa/s, is negative for rising air and the AI/AOD correlations are positive as an increase in AI/AOD reduces convection. 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 “exit” for the Trade Winds into the Walker and Hadley Cells. The relaxation of the Trade Winds causes the SST to rise in the Niño areas as there is a strong negative correlation ($-0.88/-0.93$ ($p < 0.01$)) annual average/Inter annual difference) between 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. This creates: conditions conducive to forest fires in the SEAP Area; a denser aerosol plume; and positive feedback driving the climate more deeply into an El Niño which only ends with the start of the south east Asian monsoon in November. 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 Australia (SEAus) is caused by the SEAP as described on page 2. An estimate of the surface radiative forcing of the SEAP is shown at 8d where a reduction of 20% of the radiation without the plume is shown. It is clear that the greatest surface radiation now falls at the edges of the plume and that these regions will drive the Hadley Cells thereby forcing them into anomalous positions.



7. Conclusions

1. El Niño/ENSO events are triggered and then sustained by aerosol regional dimming by the South East Asian aerosol Plume (SEAP).
2. The ENSO correlations with volcanic eruptions for 145 years and with extensive biomass burning during the satellite era where the source of the aerosols is known means that either the relationship of SEAP to ENSO is causal or the correlations are coincidental.

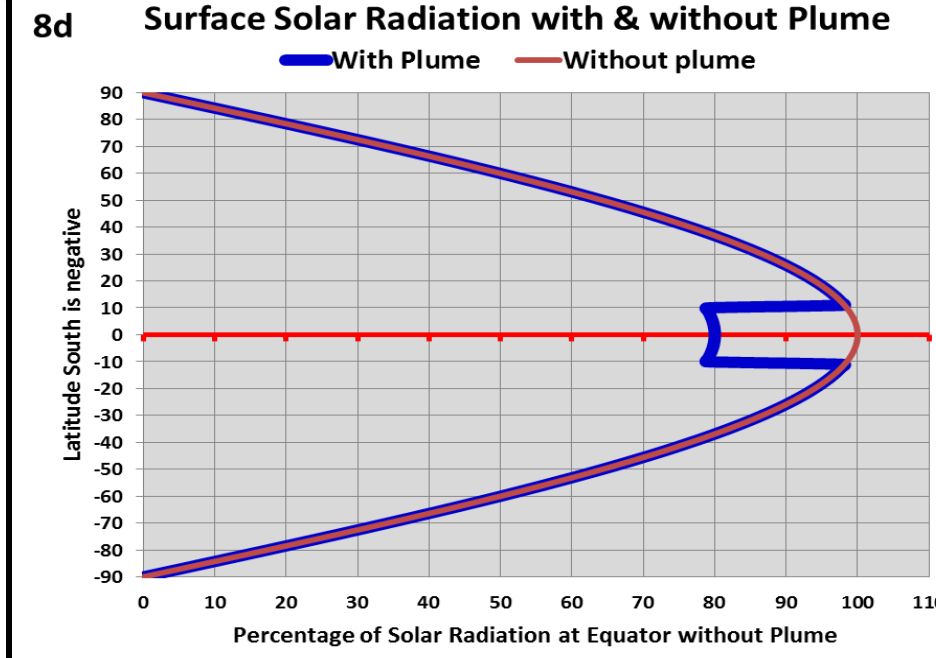
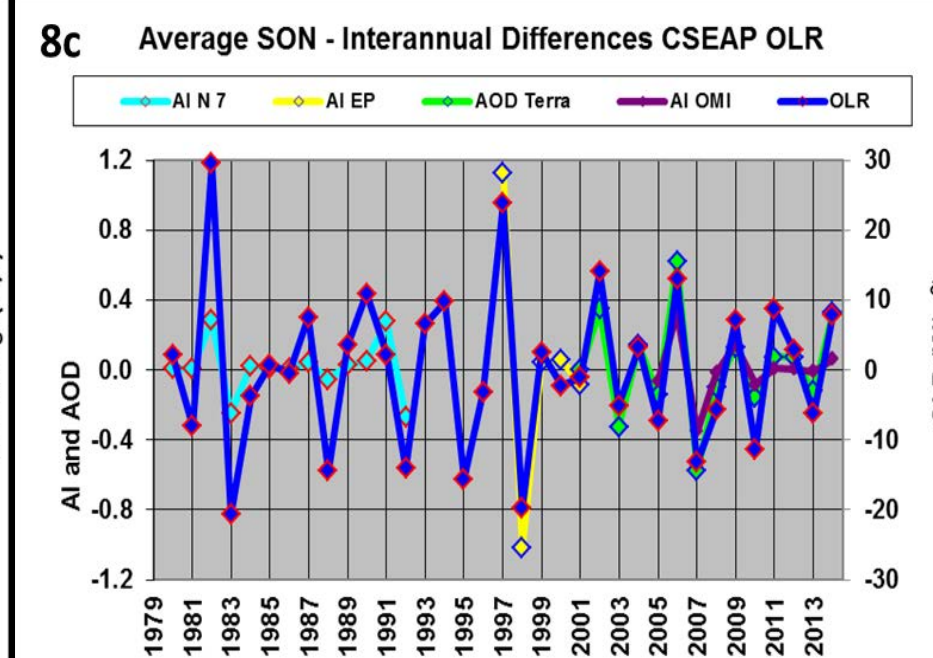
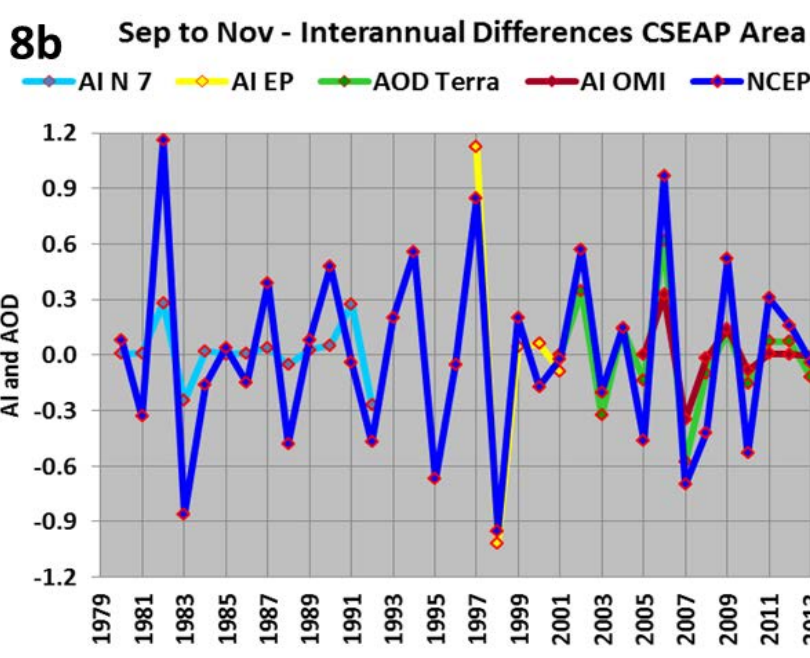
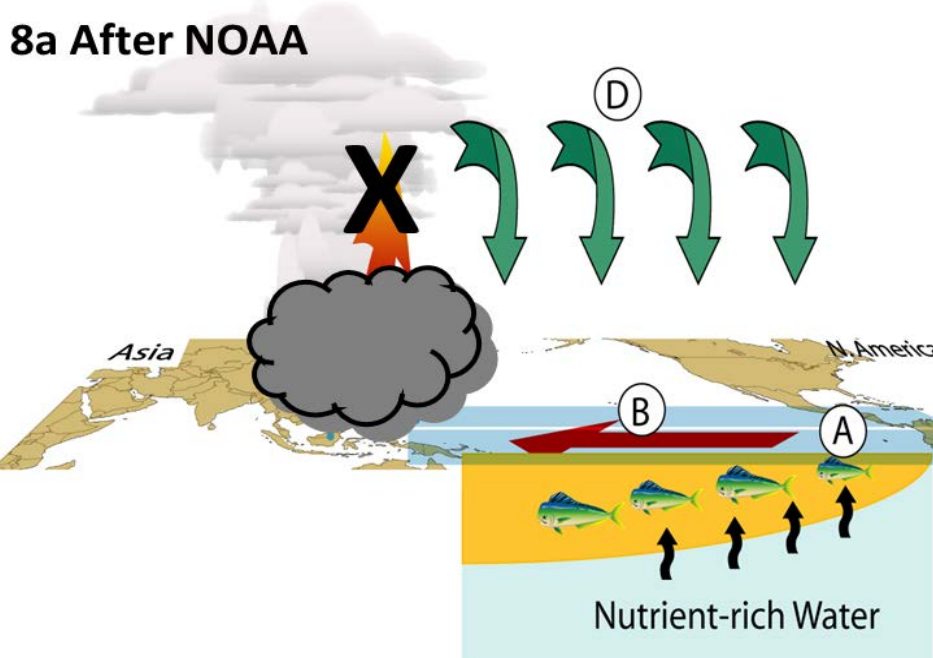
8. Acknowledgements

Data and information was sourced from:

- NASA: Analyses and visualizations used in this poster were produced with the Giovanni online data system;
- National Oceanic and Atmospheric Administration;
- NOAA and the NCEP / NCAR reanalysis data set;
- IPCC Assessment Report 4 (AR4) and 5 (AR5);
- Google Earth;
- Global Volcanism Program, Smithsonian Institution;

- US Geological Survey;
- Australian Bureau of Meteorology; and
- UK Met Office.

AI / AOD Aerosol Index / Aerosol Optical Depth
OLR Outgoing Longwave Radiation
SON September, October and November
Presented at
AGU Fall Meeting
San Francisco 14 to 18th December 2015
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Drought in California, the Amazon, Darfur, Spain & Australia

Extreme aerosol plumes and convection are negatively correlated as the literature and the IPCC suggest. In the Technical Summary in Assessment Report 4 (AR4) p.53 and in AR5 p.623 the IPCC states that:

- Absorbing aerosols can affect the large-scale atmospheric circulation systems;
- Changes in aerosols may have affected precipitation and other aspects of the hydrologic cycle more strongly than other anthropogenic forcing agents; and
- Aerosols are distributed unevenly and can heat and cool the climate system in patterns that can drive changes in the weather and several studies suggest significant effects on precipitation; and

Tosca et al in GRL in 2015 conclude that aerosols in the tropics reduce convection and convective rainfall.

Applying this understanding of the connection between aerosols and drought via the major atmospheric circulation

systems to the five regions below we find in order of increasing complexity (numbers refer to sections below) in:

- The Amazon (5): the South American aerosol plume directly reduces convection which reduces rainfall;
- Darfur (4): the Middle East aerosol plume created by the gas flares in oil fields creates the same effects;
- Spain (3): the West African Plume moves the northern Hadley Cell north creating an anomalous blocking high pressure system over the Mediterranean and the Iberian Peninsula which reduces rainfall;
- Australia (2): the South East Asian Plume moves the southern Hadley Cell south creating an anomalous blocking high pressure system over south eastern Australia which reduces rainfall; and
- California (1): the West African Plume perturbs the northern circulation systems in Dec, Jan, Feb (DJF) creating high pressure over the USA and north east Pacific Ocean and reducing DJF + Mar (DJFM) rainfall in California.

1. Drought in California - in the Boreal Winter - Caused by the West African Plume or the East Asian Plume or both Combined?

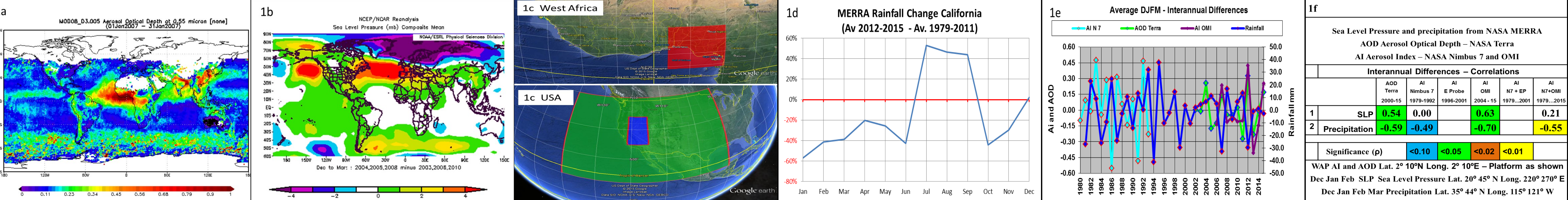
Panel 3 below shows the West African aerosol Plume (WAP, 1a) creates high pressure over the Mediterranean Sea and Spain and thus drought in Spain. 1b, created by deducting the years of low AOD from the high years AOD of the WAP in the NCEP Reanalysis sea level pressure data, shows the anomaly created by the plume which includes a region of high pressure in the NE Pacific similar to the region the literature describes as being the cause of the Californian drought. Similar anomalous high pressure can be seen in panel 2 (2b) causing drought in SE Australia. Statistically significant correlations (1f) are obtained when the AI/AOD of the West African Plume is correlated with:

- Pressure over the USA in DJF using the regions in 1c. In the same season the pressure in the green region and rainfall in the blue region in California correlate at -0.73 ($p < 0.01$) using NCEP pressure data and rainfall from 1948 to 2015 and at -0.69 ($p < 0.01$) using NCEP pressure and MERRA rainfall from 1979 to 2015; and

2. Rainfall in California in the smaller blue region in 1c in DJFM.

1d shows the rainfall change in 2012-15 (blue region 1c) and 1e the detrended WAP AI/AOD and rainfall in DJFM. The WAP and other tropical aerosol plumes move the Hadley Cells and this creates anomalous blocking high pressure systems in the mid latitudes which perturb the storm tracks, creating persistent high and low pressure systems around the globe as 1b and 2b show. These persistent regions of high/low pressure alter the atmospheric circulation systems and the winds which can create regional droughts or floods and large variations in temperature.

Conclusion: Apparitions of the extreme aerosol plumes which exist in the boreal winter, the West African Plume and the East Asian Plume, should be investigated to determine which one, or both in combination, create(s) the drought in California by modifying the major atmospheric circulation systems.

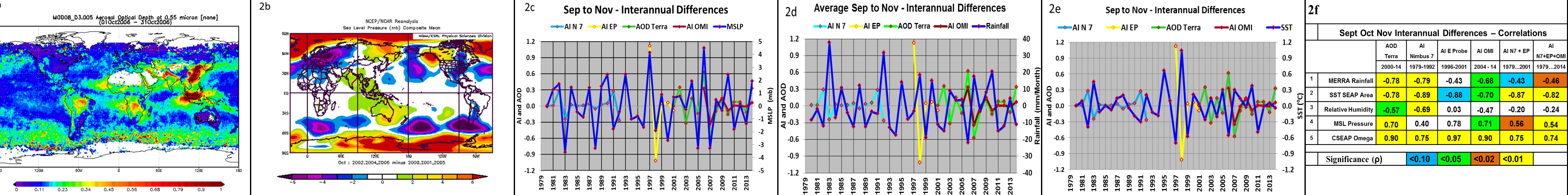


2. Drought in South Eastern Australia - September to November - Caused by the South East Asian Plume (SEAP)

The Centre for Australian Weather and Climate Research stated in Technical Report 026 that the main drivers of the “millennium” drought in South Eastern Australia (SEAs) from 1997 to 2008 in the southern spring were El Niño events and high pressure over SEAs. Page one has shown that El Niño events are caused by the South East Asian Plume (SEAP) and it only remains to show that the SEAP causes the anomalous high pressure over SEAs and a reduction in rainfall in the southern spring to demonstrate that the cause of drought in SEAs is the SEAP. Fig 4a on page one shows the areas used in the analysis. 2a shows the SEAP in October 2006. 2b shows the anomalously high sea level pressure over SEAs created by subtracting the low aerosol loading years of the SEAP, 2000, 2001 and 2005, from the high years, 2002, 2004 and 2006, using the NCEP reanalysis data.

2c shows the detrended AI/AOD and NCEP MSLP over SEAs (30° 35°S and 140° 147.5°E). 2d shows the detrended AI, AOD and MERRA Rainfall in SEAs (33° to 39°S and 140° to 149°E). 2e shows the SEAP reduces the SST in the SEAP Area and 2f shows the correlations of AI/AOD and the parameters of drought in SEAs.

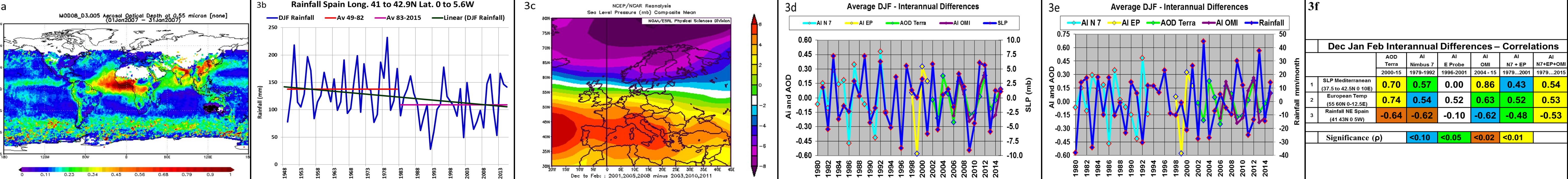
The SEAP creates drought in SEAs by: **First**, cooling the sea surface in the SEAP Area, the source of rainfall in SEAs, thereby reducing evaporation and the available water; and **Second**, the SEAP moves the regional Hadley Cell into an anomalous position creating a blocking high pressure system over SEAs (2b) which forces cold fronts to the south and away from the land. This combination of lower humidity and fewer cold fronts results in drought.



3. Drought in Spain - in the Boreal Winter - Caused by the West African Plume

3a shows the West African Plume and 3b the reduction in rainfall in NE Spain using NCEP reanalysis data for the area 41° to 42.9°N, and 0° to 5.6°W from 1948 to 2015. The cause of the reduction in rainfall has been attributed by Vicente-Serrano and López-Moreno in 2006 in the Int. Journal of Climatology to an increase in the number of anticyclonic days in Winter with Figure 5 in the paper showing Spain covered by higher than average pressure in winter during these days. NCEP Reanalysis data in 3c, created by subtracting the years of low WAP AOD from the years of high WAP AOD to show the MSLP anomaly during years of high AOD, shows the anomalous high pressure over much of SW Europe and the Mediterranean Sea during the boreal winter. This pattern is similar to the pattern in 2b over SEAs which suggests that the model of equatorial, continental scale, aerosol plumes moving the Hadley Cells to anomalous positions is correct. Areas used in the analysis are shown in Google Earth at 3g to the right.

3d shows the SLP over the Mediterranean and the AI and AOD of the WAP which are in phase whilst 3e shows the MERRA rainfall over NE Spain and the WAP AI/AOD which are in antiphase. 3f shows the statistically significant correlations. Two factors have increased the size of the WAP in recent decades: the increased population in West Africa requiring an increase in tropical agriculture with its attendant biomass burning and land clearing to provide living space; and oil production with the flaring of associated gas. Nigeria flared an estimated 14.6 billion cubic metres of gas in 2011 - the second largest in the World according to the World Bank.



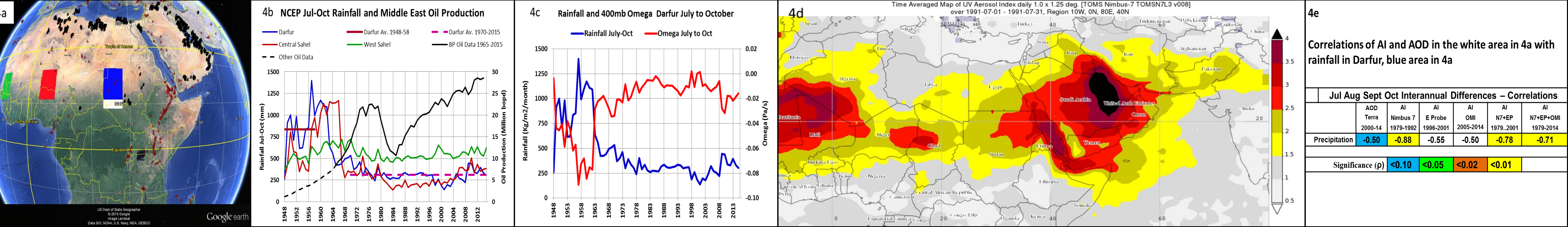
4. Drought in Darfur - July to September - Caused by the Middle East Plume

4a shows the four areas analysed, black pins are oil industry gas flares, red are volcanoes. Precipitation collapsed in Darfur in the 1960's and has never recovered as 4b shows for Darfur (blue) and the central (red) and western Sahel (green). Precipitation occurs in Darfur when the inter-tropical convergence zone (ITCZ) moves to and north of Darfur in the boreal summer and moist air drawn in from the Indian and Atlantic Oceans rises and cools, creating rain. The direct association of convection and drought is shown in figure 4c using NCEP data.

4b also shows the rise of oil production in the Middle East from BP and other sources which coincides with the fall in rainfall in Darfur. The connection between Middle East oil production and Darfur is, of course, the aerosols carried on the prevailing winds from the Middle East to Darfur. 4d using 1991 data from the Nimbus 7 satellite when the Kuwait oil fields were burning after the first Gulf War shows this trajectory clearly. AI/AOD is from white area in 4a.

The Middle East aerosol plume crosses the Arabian Peninsula to the west and south, is forced north into the Red Sea by the Somali/Ethiopian highlands and resumes a south westerly trajectory to Darfur after rounding the northern tip of the highlands. 4c shows the negative correlation ($-0.97 p < 0.01$) between omega (400 mb) and rainfall in Darfur (data from NCEP) and, applying the same arguments that apply in the Amazon, the aerosol plume reduces convection which inhibits the northern movement of the ITCZ and thus reduces rainfall (4e).

The drought then spread west across the Sahel from Darfur as 4b shows with the central Sahel drying about 4 years after Darfur and the West Sahel 8 years later. The aerosol plumes reducing the central and west Sahel convection and rainfall are, of course, the dust plume derived from the drier eastern Sahel (Darfur) and the aerosols from the gas flares in the north African oil fields which are all carried to the Sahel on the prevailing winds.



5. Drought in the Amazon Dry Season - August to October - Caused by the South American Plume

The connection between drought and aerosols is most simply demonstrated in the Amazon where the source of the aerosol plume and the drought are co-located. The South American aerosol Plume (5a) reduces convection as the literature suggests and, using the area in 5b, 5c shows using detrended data from the NCEP reanalysis.

The connection of omega (vertical pressure velocity) and precipitation is shown in 5d also using detrended NCEP data which correlate at -0.87 ($p < 0.01$) and aerosols and precipitation in 5e again using detrended data. 5f shows the correlations of detrended AI and AOD with omega and precipitation.

