Impact of Aerosols in ACCESS-1.4

Peter Vohralik, CSIRO

Global Aerosol, Large-scale Circulation and Australian Climate Change,

Development of Chemistry and Aerosols in ACCESS Climate Models

(Contact: peter.vohralik at csiro.au)

Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

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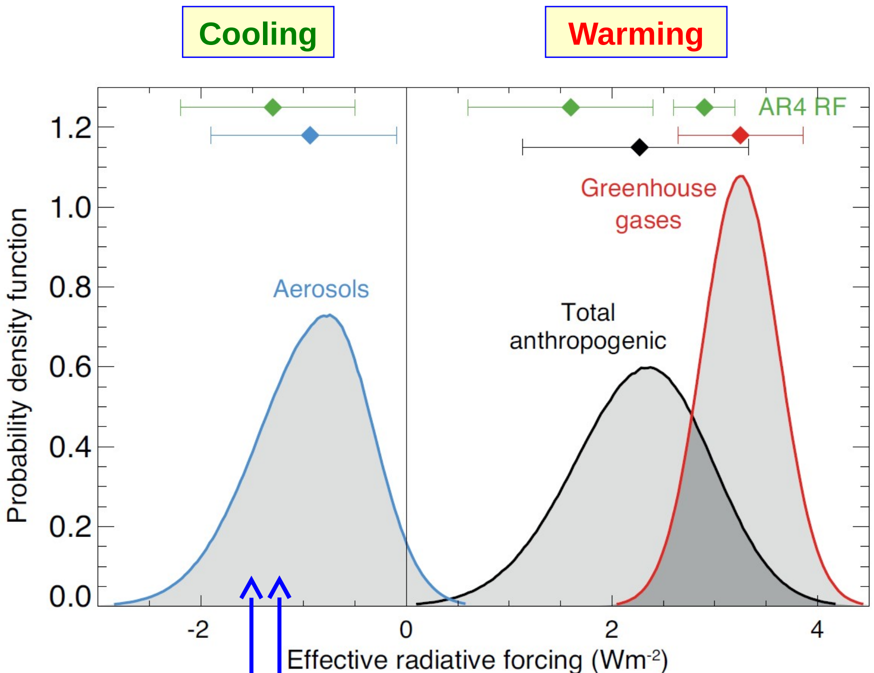
Aerosol Effective Radiative Forcing (ERF)



ACCESS 1.3 and 1.4

-1.5 Wm^{-2}

ACCESS 1.0

-1.3 Wm^{-2}

ACCESS 1.0. UM atmosphere, MOSES land surface, MOM4p1 ocean, CICE sea ice, HadGEM2 origin.

ACCESS 1.3. UM atmosphere, CABLE land surface, MOM4p1 ocean, CICE sea ice, PC2 clouds, HadGEM3 origin.

ACCESS 1.4. Updated version of 1.3. Includes a newer version of CABLE, some physics modifications, bug fixes, improved dust uplift, etc..

All use the CLASSIC Aerosol Scheme.

ACCESS 1.0 & 1.3 used for CMIP5 runs.

ERF calculations for ACCES models (1850 to 2000) obtained using 30-year simulations with fixed SSTs & Sea Ice.

Diagram from “Climate Change 2013: The Physical Science Basis”, Fifth Assessment Report of the IPCC (AR5).

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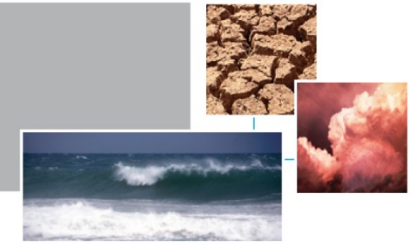
Aerosol Impact over the Historical Period



Quantify aerosol-related changes in ACCESS 1.4

- Simulations with and without Anthropogenic Aerosol Emissions (NoAA)
- 3-member ensembles for ACCESS 1.4, Historical + RCP 8.5, to 2030
- Temperature and precipitation changes considered
- Global-mean energy flows evaluated
- Top of atmosphere (TOA) radiative fluxes assessed
- Initial results are reported here

- Thanks to Leon Rotstayn, Tony Hirst, Julie Noonan, Ashok Luhar, and ACCSP for suggestions, discussions, $, etc.

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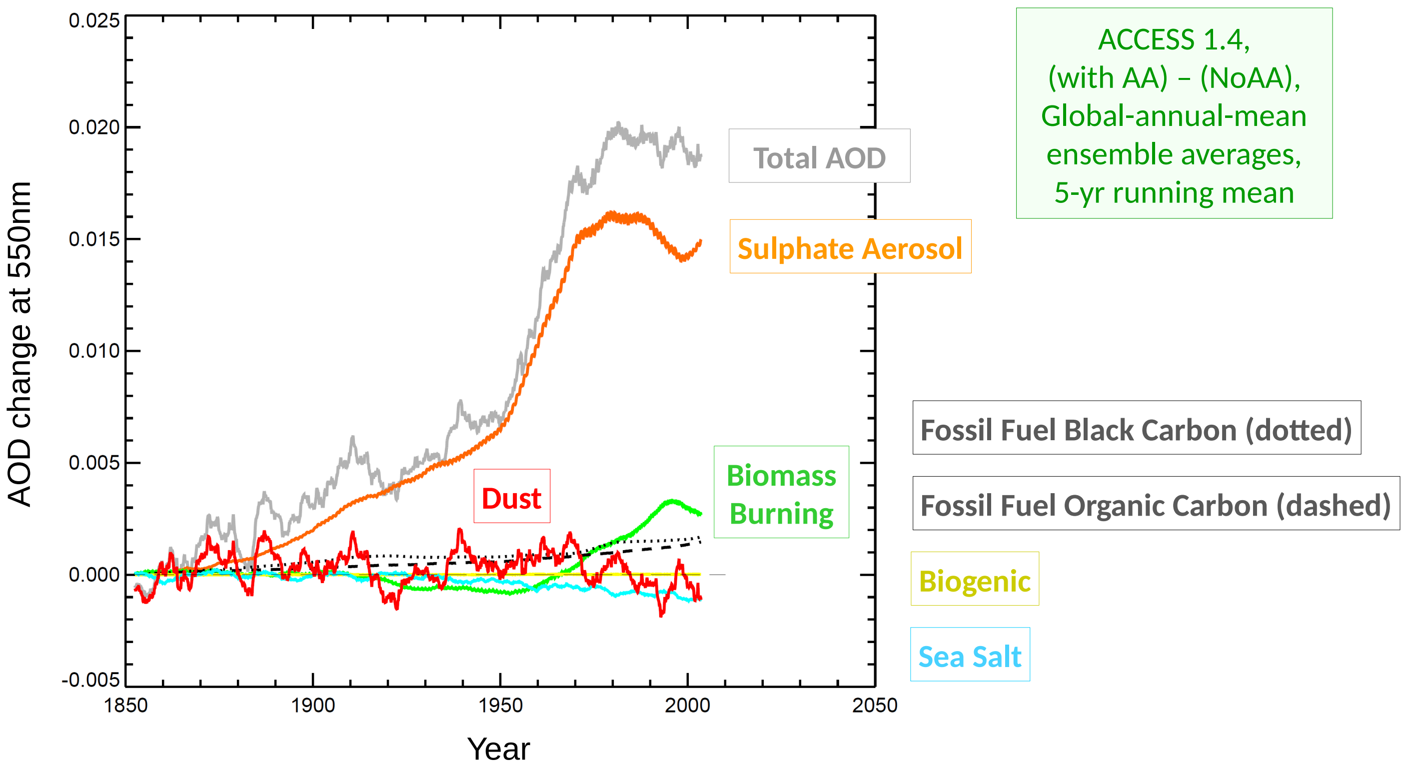
Aerosol Optical Depth (AOD) from Humans

Global-mean AOD change
from Anthropogenic Aerosol Emissions



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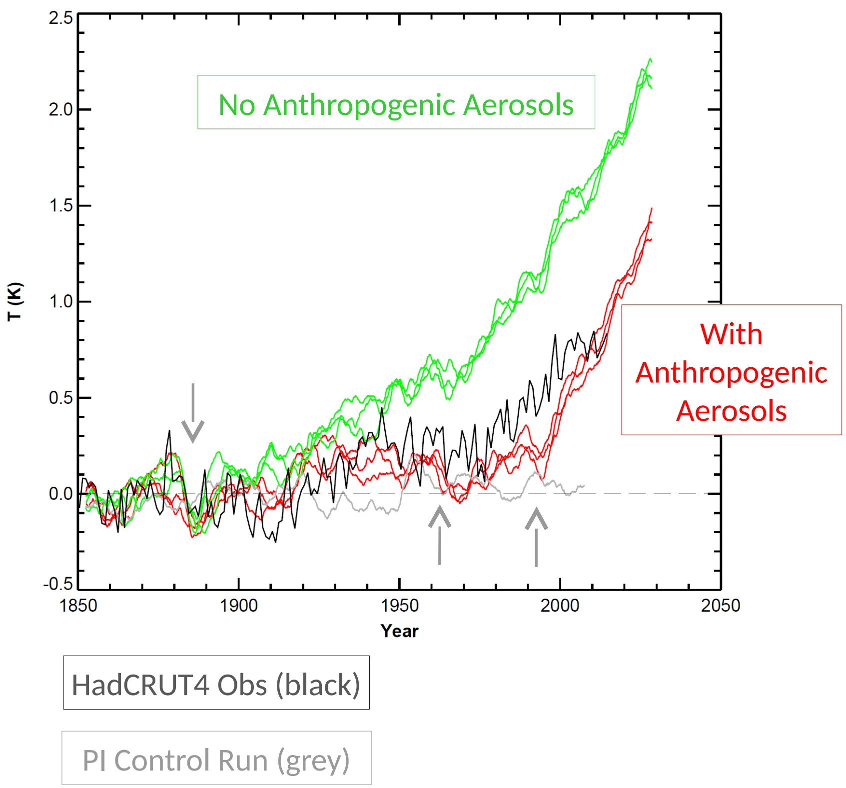
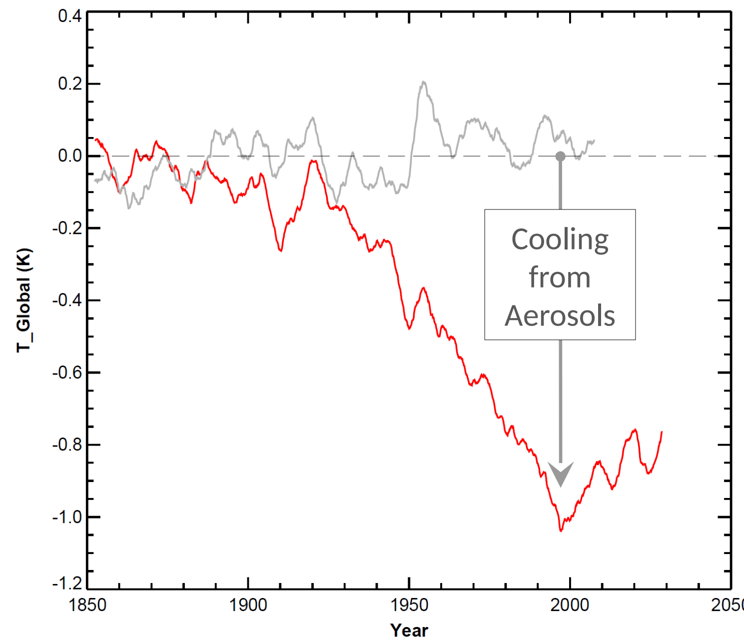
Aerosol Impact on Global-Mean Temperature

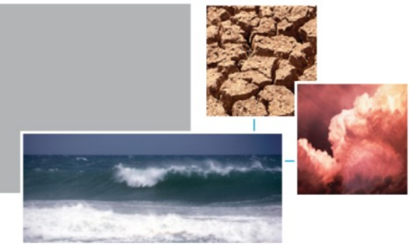
Global-mean Temperature change from Pre-Industrial



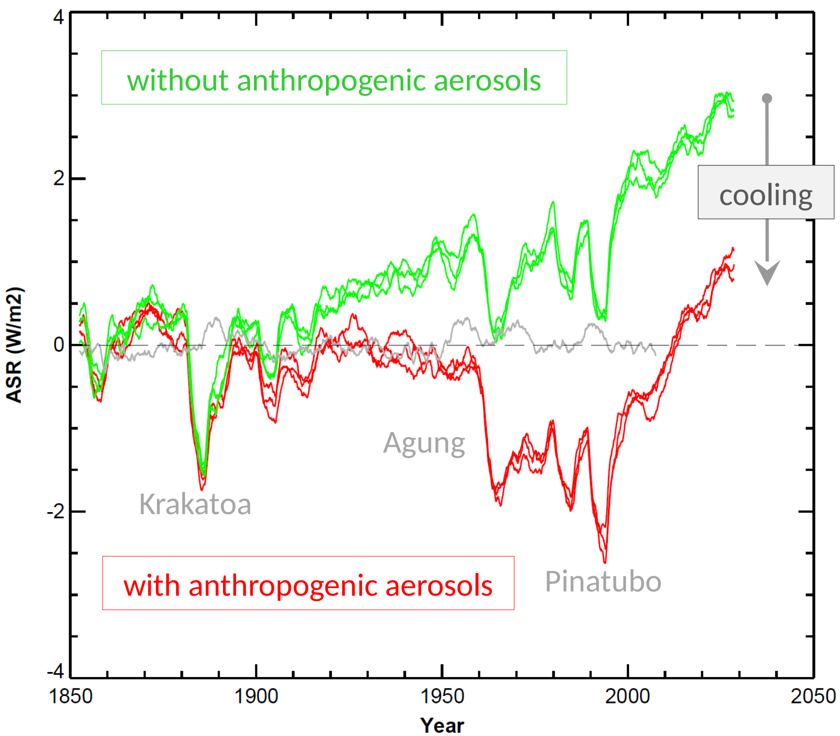
Global-mean Temperature change from Anthropogenic Aerosols



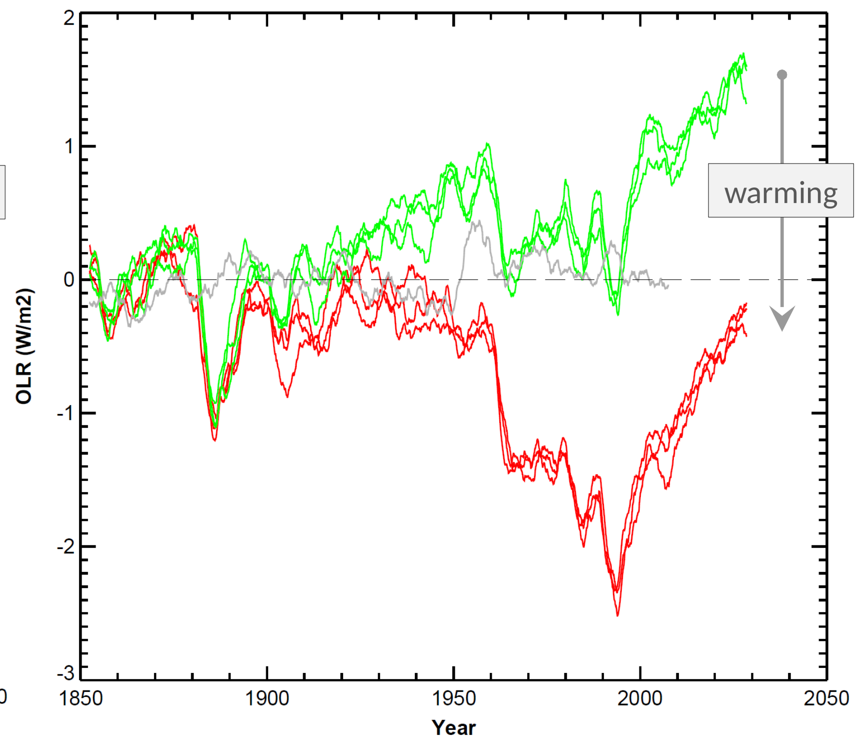
Aerosol Impact on TOA Radiation



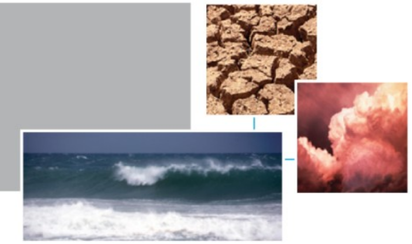
Absorbed Solar Radiation change from PI



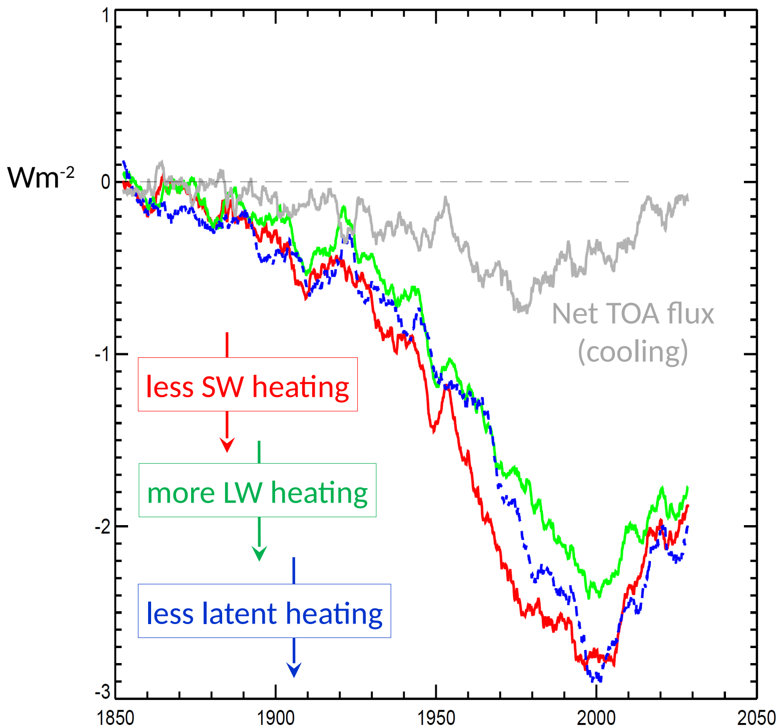
Outgoing Longwave Radiation change from PI



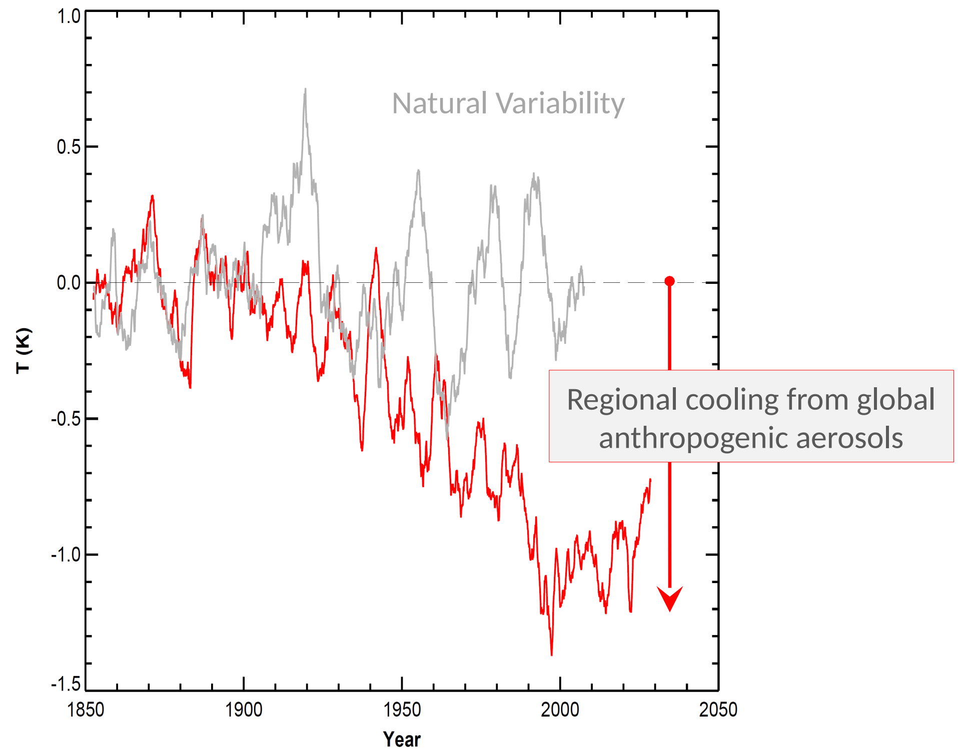
Aerosol Impact on Australian Temperature



Impact of Anthropogenic Aerosol Emissions on global-mean Absorbed SW (red), Outgoing LW (green), Latent Heating (blue), and Net TOA Radiation (grey)



Australian Land Temperature change from Anthropogenic Aerosols



Local aerosol emissions … local forcing … global climate impact … resulting in regional changes

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Earth's Energy Imbalance since 1960

AGU Geophysical Research Letters 10.1002/2014GL062669

Earth's energy imbalance since 1960 in observations and CMIP5 models

Smith et al. (2015), Geophys. Res. Lett., 42, doi:10.1002/2014GL062669.

CMIP5 – solid curves
Obs – dotted curves

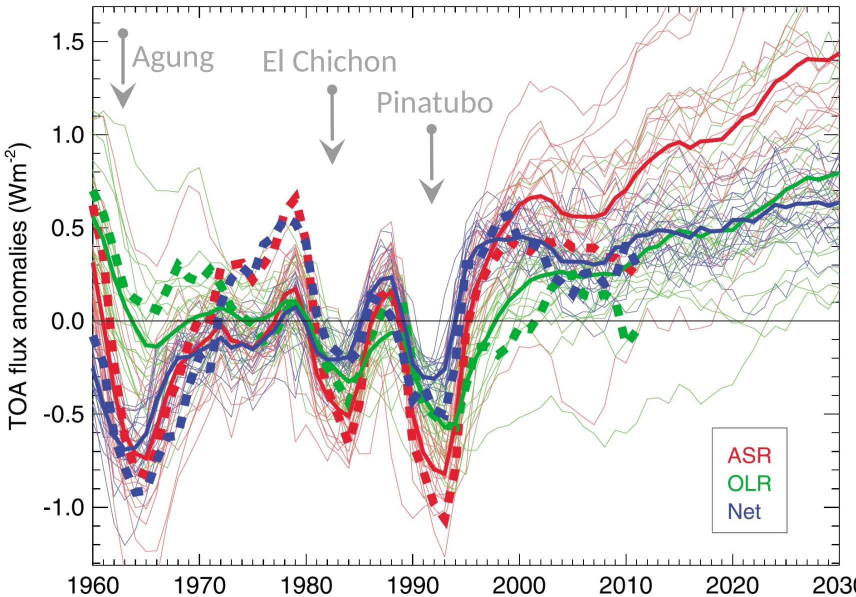

Figure 4. Components of radiative fluxes. Time series of 5 year running mean anomalies (relative to 1960 to 2011) of TOA-absorbed shortwave radiation (ASR, red), outgoing longwave radiation (OLR, green), and net radiation (N = ASR-OLR, blue) in N_O (dashed) and the CMIP5 models (solid, with thick line showing the ensemble mean).

"Since internal variability is largely removed in the ensemble mean of the CMIP5 models, this agreement suggests that much of the multiyear variability in Earth's energy imbalance from 1960 to 2000 was externally forced by the volcanic eruptions of Agung (1963), El Chichon (1982), and Pinatubo (1991), as noted by Trenberth et al. [2014]."

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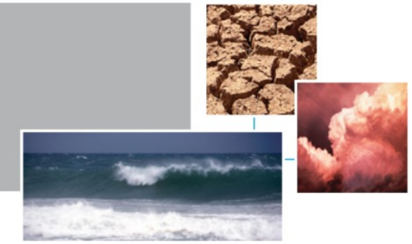
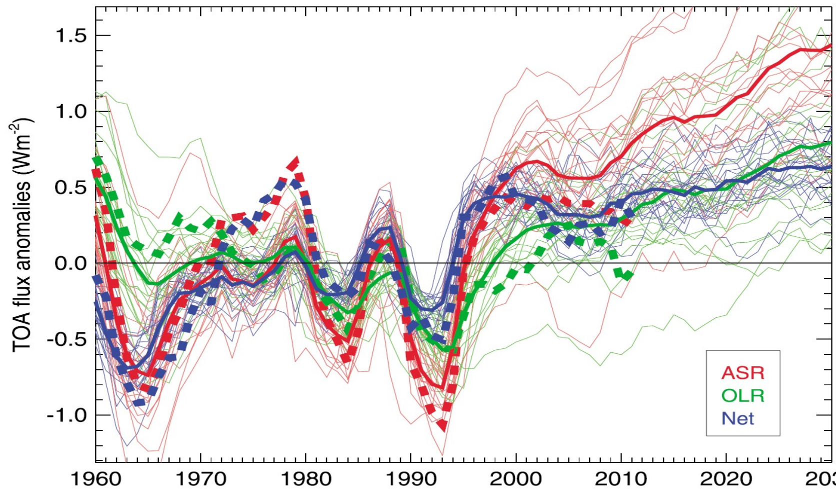
Earth’s Energy Imbalance since 1960





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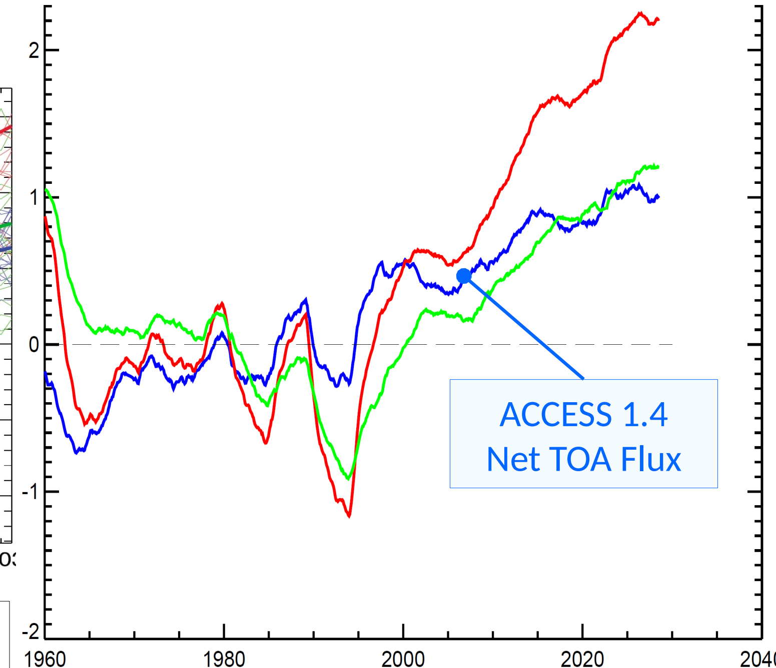
Historical + RCP4.5, Anomalies relative to 1960 to 2011,
mean of 21 CMIP5 Coupled Models
(bold solid curves)

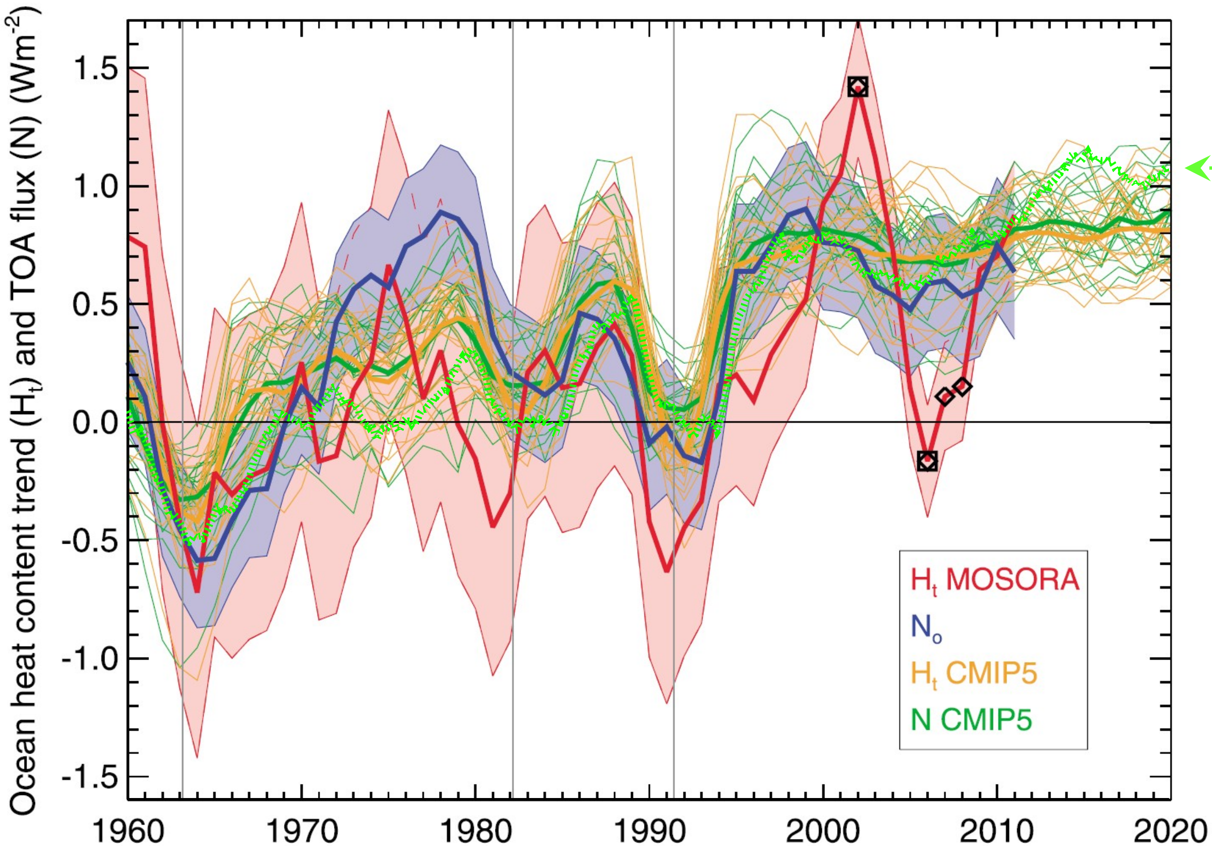
Smith et al. (2015), Geophys. Res. Lett., 42



ACCESS-1.4 Coupled Model,
Mean of 3-member Historical+RCP8.5 Ensemble,
Anomalies relative to PI-Control Simulation,
5 year running mean applied,
Curves shifted to give zero mean for 1960-2011

Earth's Energy Imbalance since 1960

ACCESS-1.4 Coupled Model, Mean of 3-member Historical+RCP8.5 Ensemble,
Net TOA Flux anomalies relative to PI-Control Simulation
(dotted bright green curve, N, 5 year running mean)



ACCESS 1.4
Net TOA flux
(with AA)

Smith et al. (2015),
Geophys. Res. Lett., 42

Figure 3. Earth's energy imbalance. (a) Time series of 5 year running mean N and H_t (as Figure 2, second panel) for 21 CMIP5 coupled model simulations (N in green, H_t in orange, ensemble mean in thick lines) compared with H_t from MOSORA (red) and N_o (blue, see text). …

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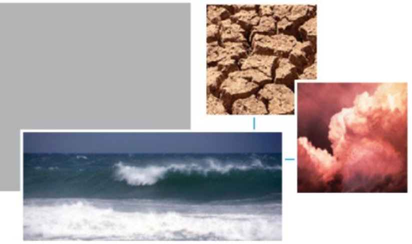
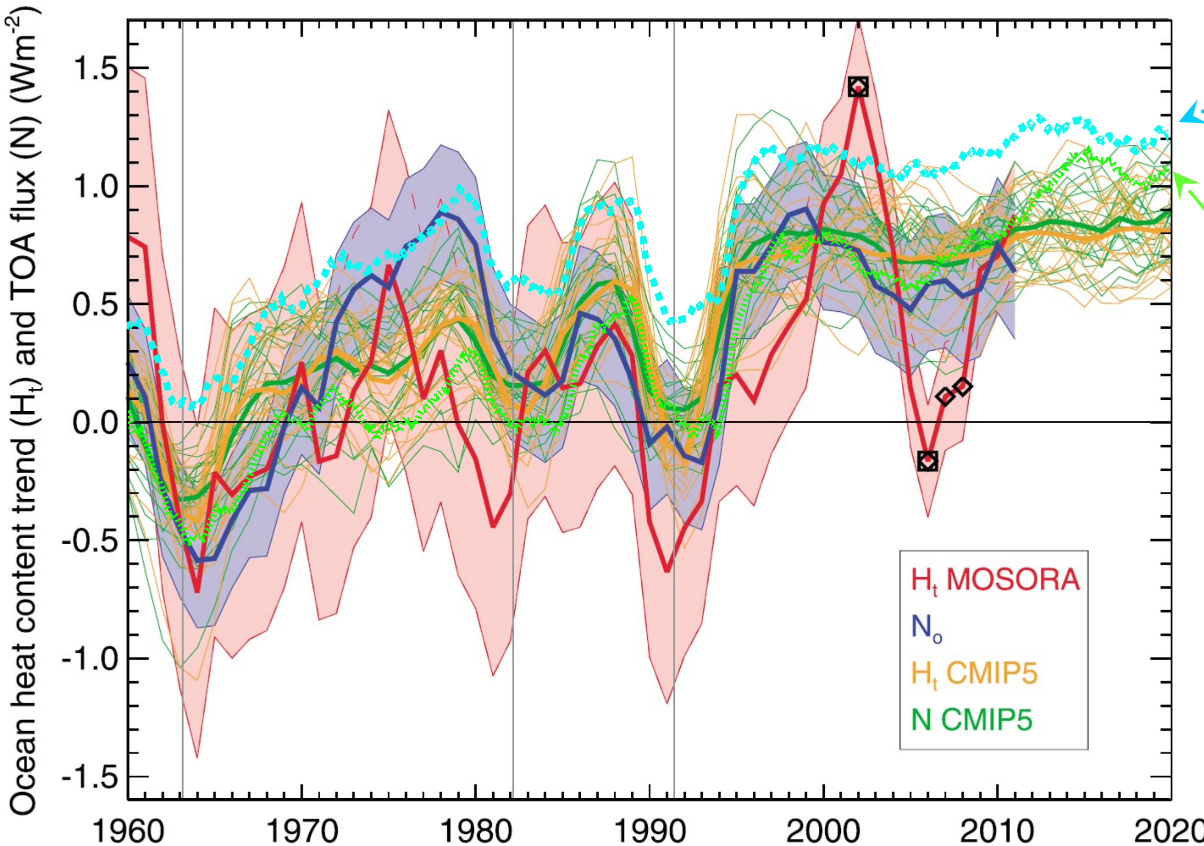
Earth’s Energy Imbalance since 1960



ACCESS-1.4 Coupled Model, Mean of 3-member Historical+RCP8.5 Ensemble,
Net TOA Flux anomalies relative to PI-Control, 5 year running mean,
with (dotted green) and without (dashed blue) Anthropogenic Aerosols



ACCESS 1.4 Net TOA flux (NoAA)

ACCESS 1.4 Net TOA flux (with AA)

Smith et al. (2015), Geophys. Res. Lett., 42

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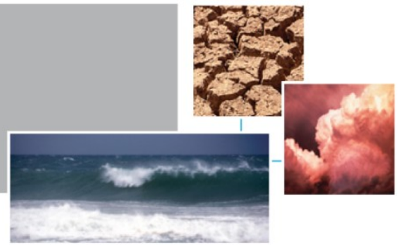
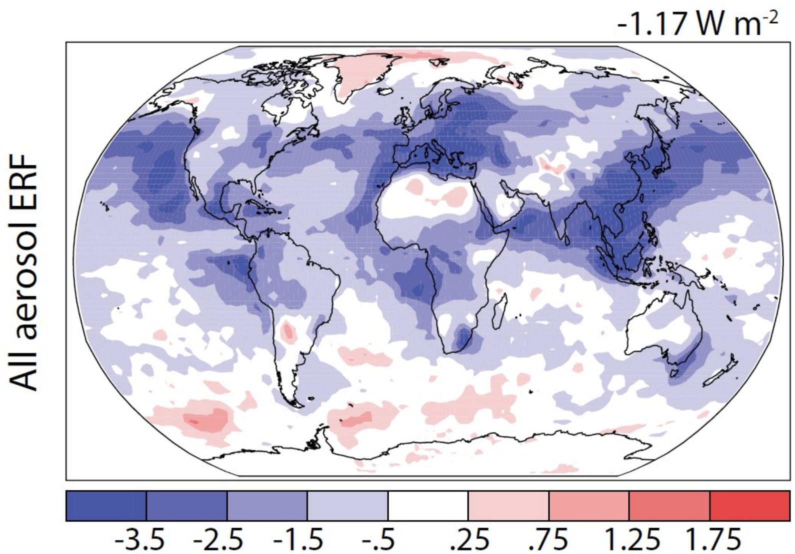
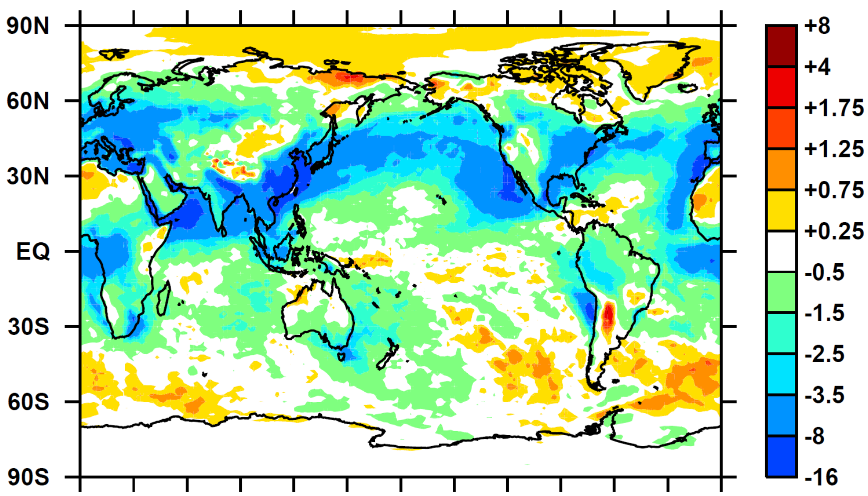
Aerosol Radiative Forcing (Wm^{-2})



Mean Aerosol ERF from ACCMIP models, for 1850 to 2000

(from AR5)



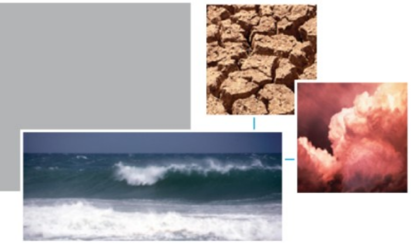


ACCESS-1.4 Aerosol ERF for 1850 to 2000. Global mean value = -1.5 Wm^{-2}

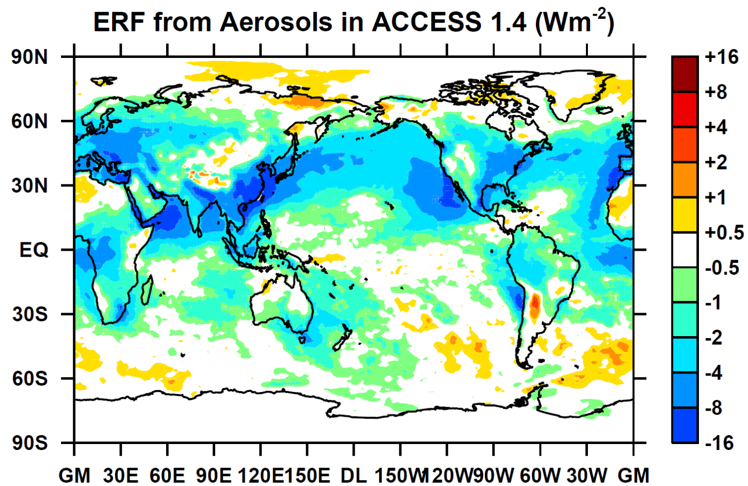
Local cooling and warming caused by anthropogenic aerosol changes since pre-industrial times.

Large cooling (blue) from sulphate aerosols and related cloud changes over (and downwind from) industrial regions of China, Asia and Europe.

Aerosol Radiative Forcing (Wm^{-2})

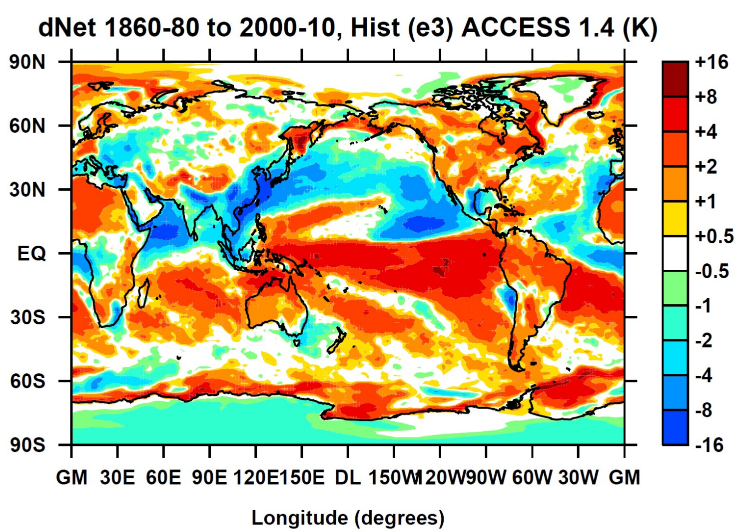


ACCESS 1.4 Aerosol ERF from 1850 to 2000



Blue-green regions show local cooling caused by anthropogenic aerosols.

Change in Net TOA flux from PI to present in a transient Historical run



Signature of anthropogenic aerosol cooling is seen in the TOA Net flux changes from PI to present.

“Dialed-in” GHG forcing is also apparent as the Earth system tries to catch up with accumulating GHGs.

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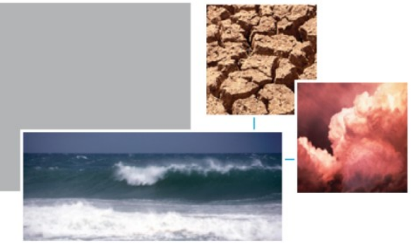
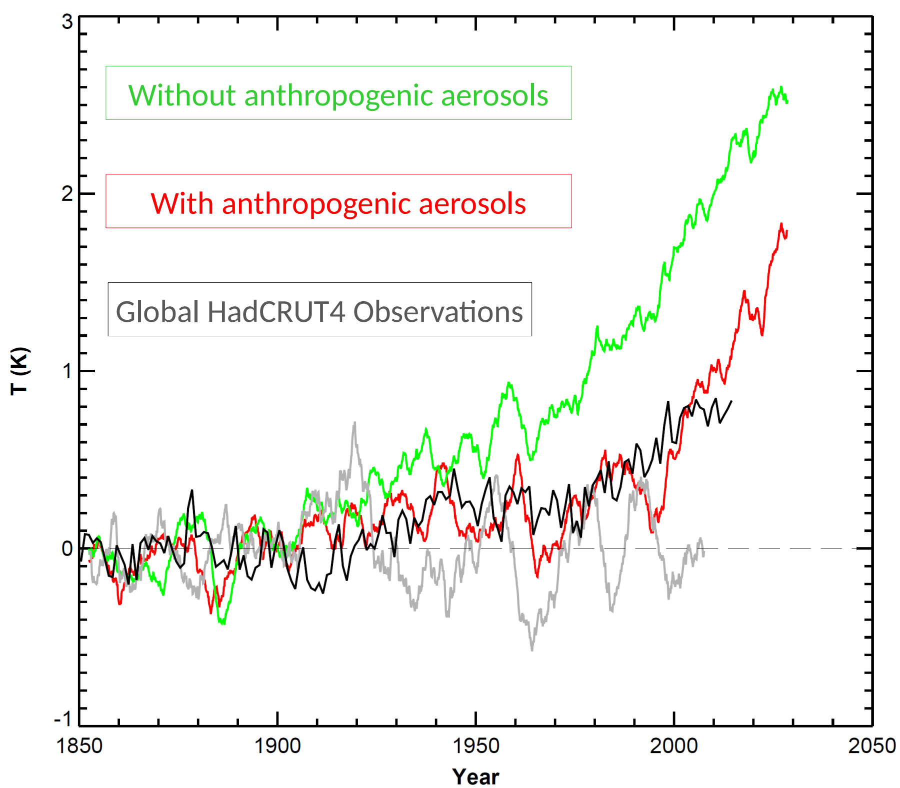
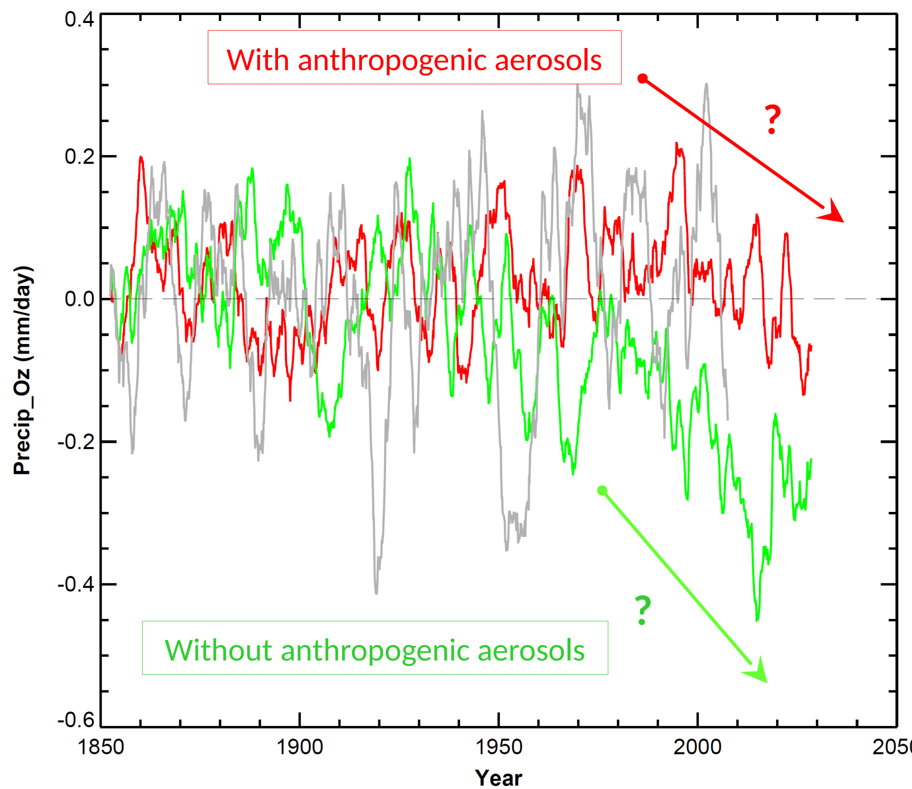
What happens to rainfall over Australia?



Temperature change from pre-industrial over Australian land



Precipitation change from pre-industrial over Australian land and surrounding ocean



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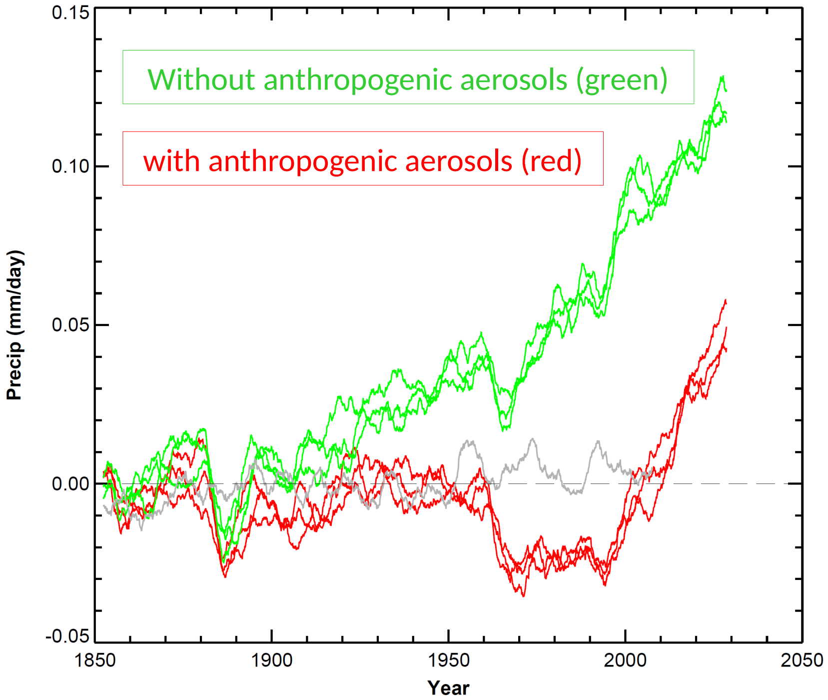
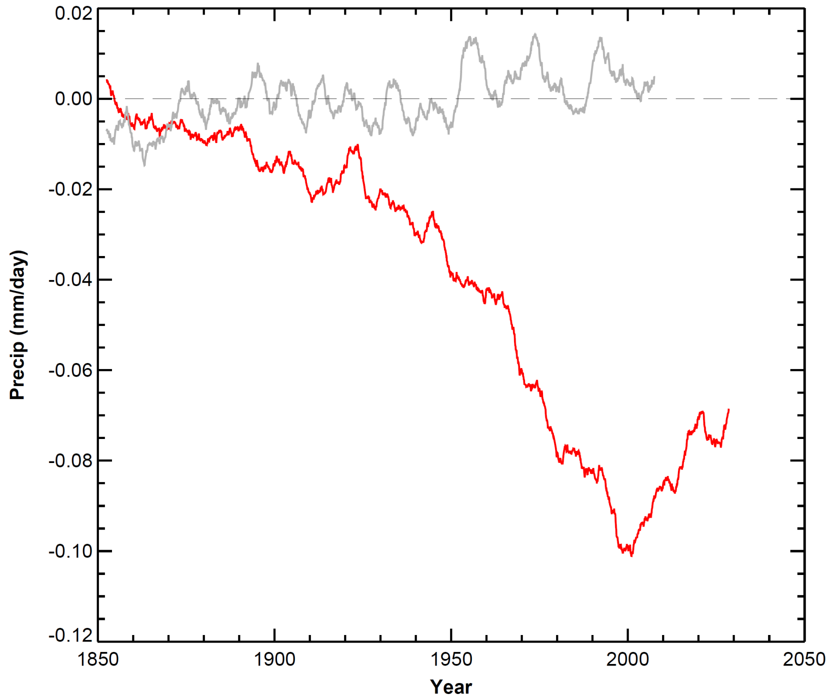
Global Precipitation Changes

Global precipitation change from pre-industrial driven by changes to latent heating rates



Global precipitation change changes caused by including anthropogenic aerosol emissions



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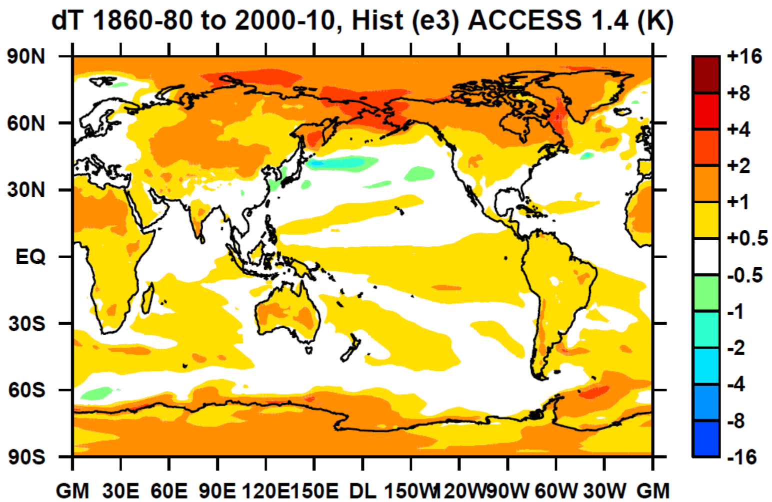
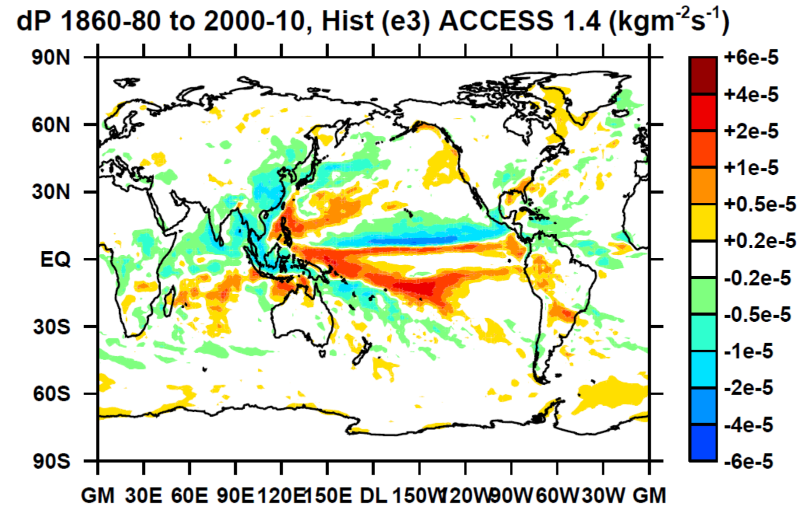
Location of T and Precipitation Changes

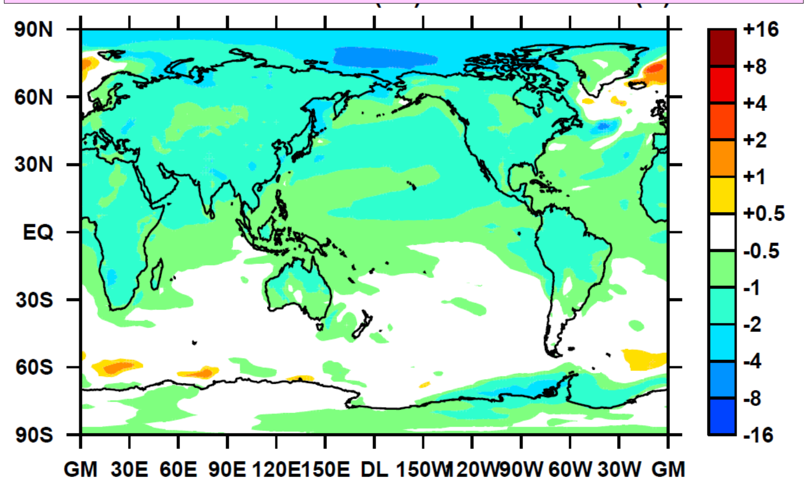
Temperature changes from PI to Present Day



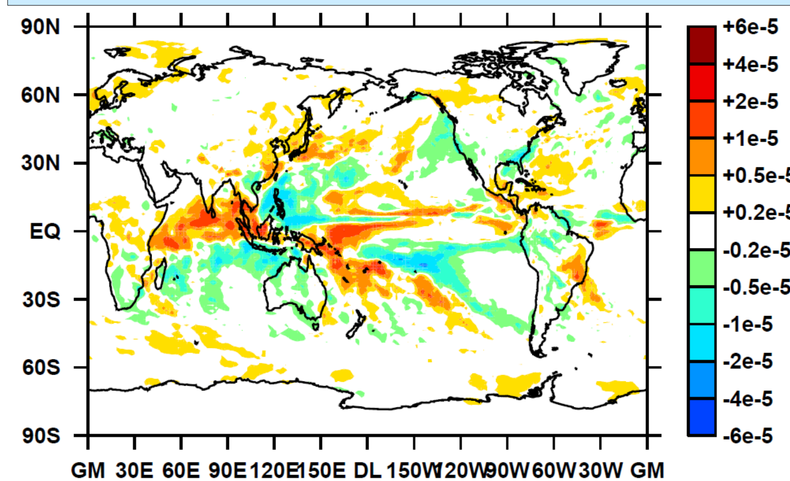
Precipitation changes from PI to present day



Temperature changes from aerosols, 2000-2010



Precipitation changes from 2005 to 2025



Changes are based on one (or two) ensemble member and therefore include substantial interannual variability

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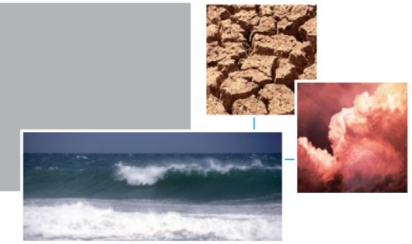
The End.

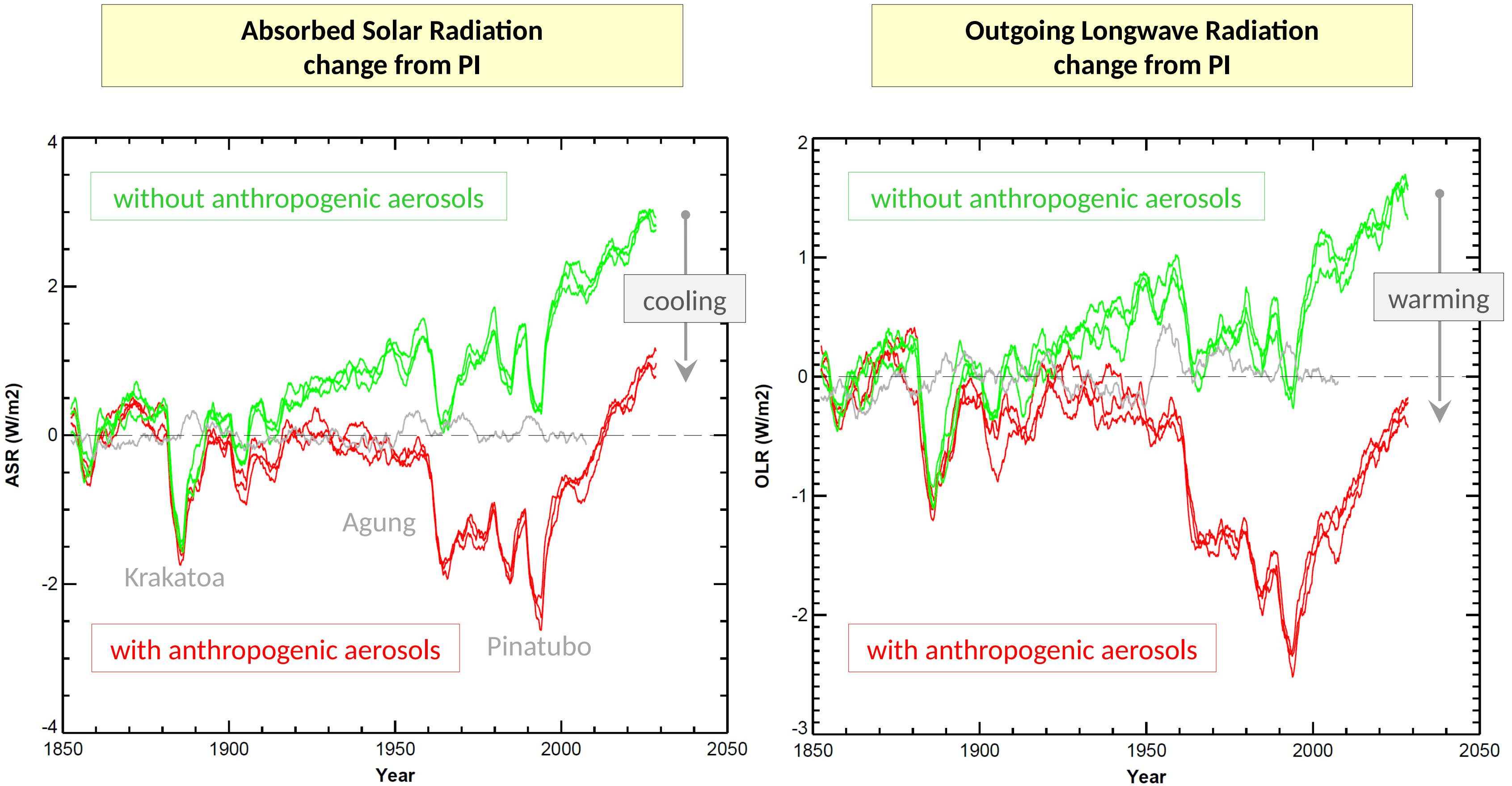
Thank You for Listening

The End.



Additional Slides Follow

Aerosol Impact on TOA Radiation



NoAA = GHGs and volcanoes = **green** ensemble runs = warming mostly from more absorbed SW

Historical = with anthropogenic aerosols = **red** ensemble runs = warming mostly from more trapping of LW

(see Donohoe et al. (2014), PNAS, Shortwave and longwave radiative contributions to global warming under increasing CO2)

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The Changing Balance of Energy Flows

Shortwave and longwave radiative contributions to global warming under increasing CO2

Aaron Donohoe, Kyle C. Armour, Angeline G. Pendergrass, and David S. Battisti

Donohoe et al. (2014), PNAS, 111, 16700-16705

Observations and model simulations suggest that even though global warming is set into motion by greenhouse gases that reduce OLR,
it is ultimately sustained by the climate feedbacks that enhance ASR.

Based on their analysis of current energy flows, Donohoe et al. note that …

“if anthropogenic radiative forcing had acted predominantly in the LW and increased somewhat linearly over the last century, OLR would have recovered within a decade or so, beyond which time global energy accumulation would continue because of enhanced ASR.”

… although, because of tropospheric aerosols …

“the current global energy accumulation is still dominated by decreased OLR.”

… however, Donohoe et al. also note that …

“a transition to a regime of global energy accumulation dominated by enhanced ASR could occur with only 0.5 K global warming above present—by the middle of the 21st century if warming trends continue as projected.”

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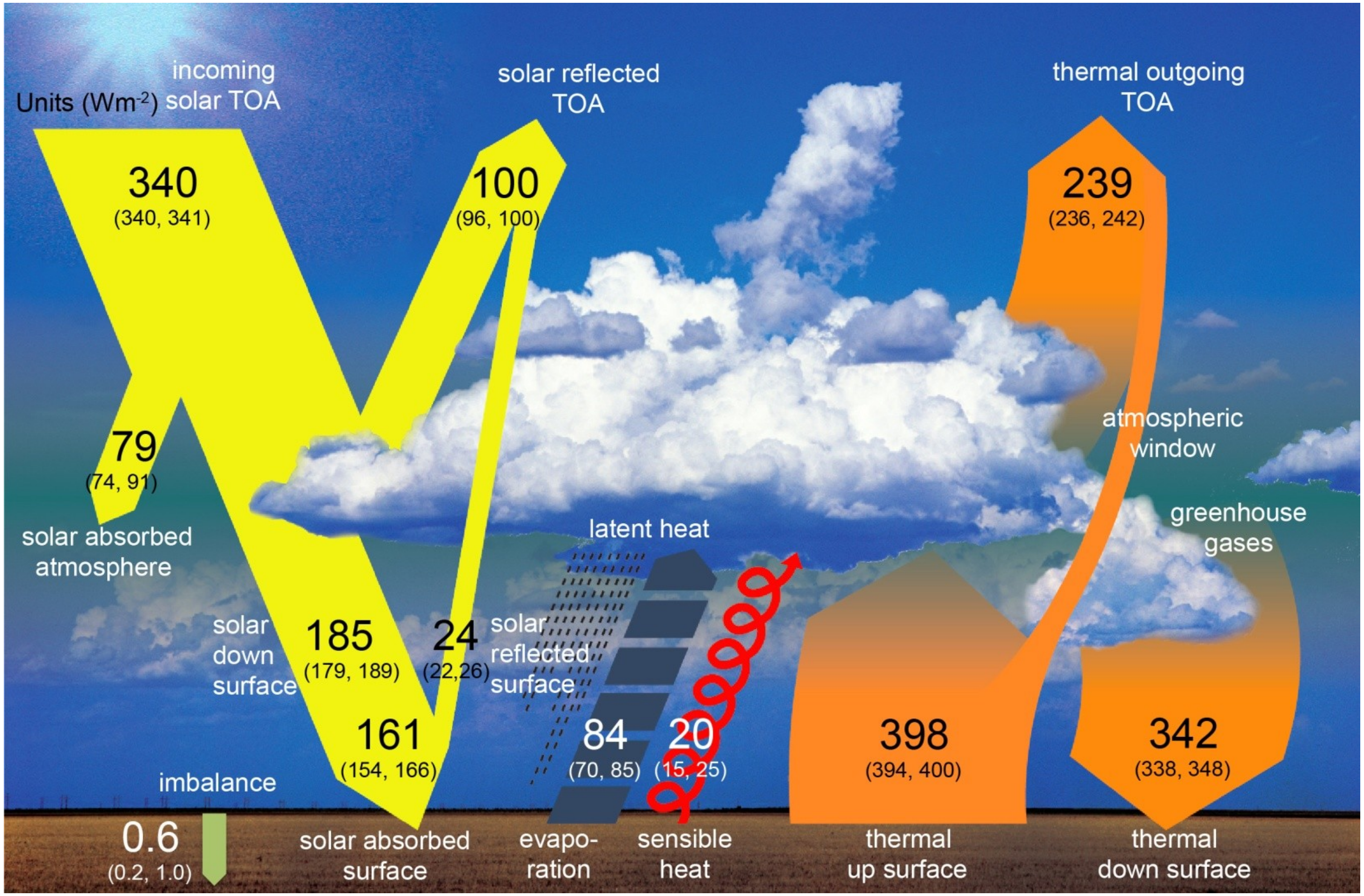
Aerosols, Radiation and Clouds



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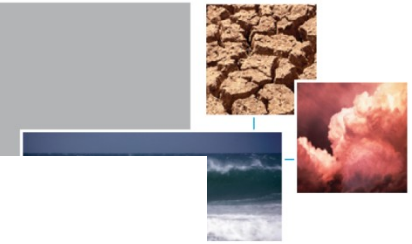
Aerosols, Radiation and Clouds



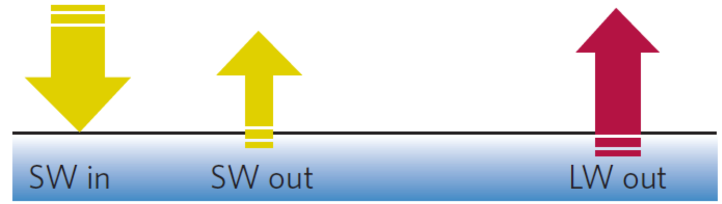
Stephens *et al.* (2012), *Nature Geoscience* 5, 691-696, "An update on Earth's energy balance in light of the latest global observations"

Figure 1
Surface energy balance. Observed and climate model deduced energy fluxes (Wm^{-2}) in and out of the TOA (a) and at the surface (b).

[Results are for 2000-2010]

ACCESS 1.4 (blue), mean of 3-member ensemble, 2000-2010, Historical+RCP8.5

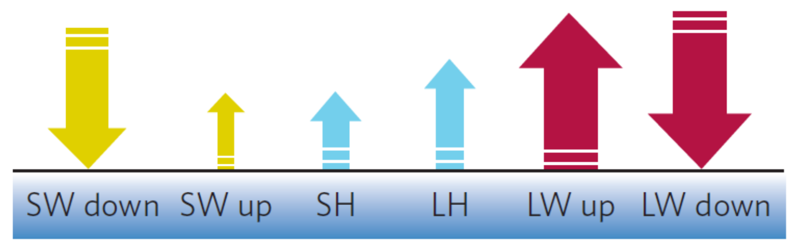
a TOA budget



	SW in	SW out	LW out	TOA imbalance
Observations	340.2±0.1	100.0±2	239.7±3.3	0.6±0.4
ACCESS 1.4	341.7	98.2	243.1	0.66 wrt PI 0.46 absolute PI = -0.21
CMIP5 Min	338.6	96.4	232.4	
CMIP5 (Mean)	(343)	(102.2)	(238.6)	
CMIP5 Max	343.7	106.5	243.5	

Atmosphere (net):
SW absorb 74.2
LW emiss 184.6

b Surface budget



	SW down	SW up	SH	LH	LW up	LW down	Surface imbalance
Observations	188±6	23±3	24±7	88±10	398±5	345.6±9	0.6±17
ACCESS 1.4	194.5	25.1	17.4	91.9	400.9	342.4	0.62 wrt PI 1.57 absolute PI = 0.95
CMIP5 Min	181.9	21.1	17.6	78.4	391.9	326.4	
CMIP5 (Mean)	(190.3)	(24.9)	(20.9)	(85.8)	(397.5)	(339.7)	
CMIP5 Max	196.2	30.3	27.8	93.6	398.1	347.0	

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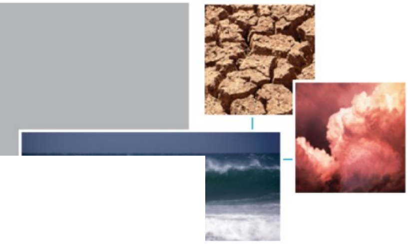
Aerosols, Radiation and Clouds



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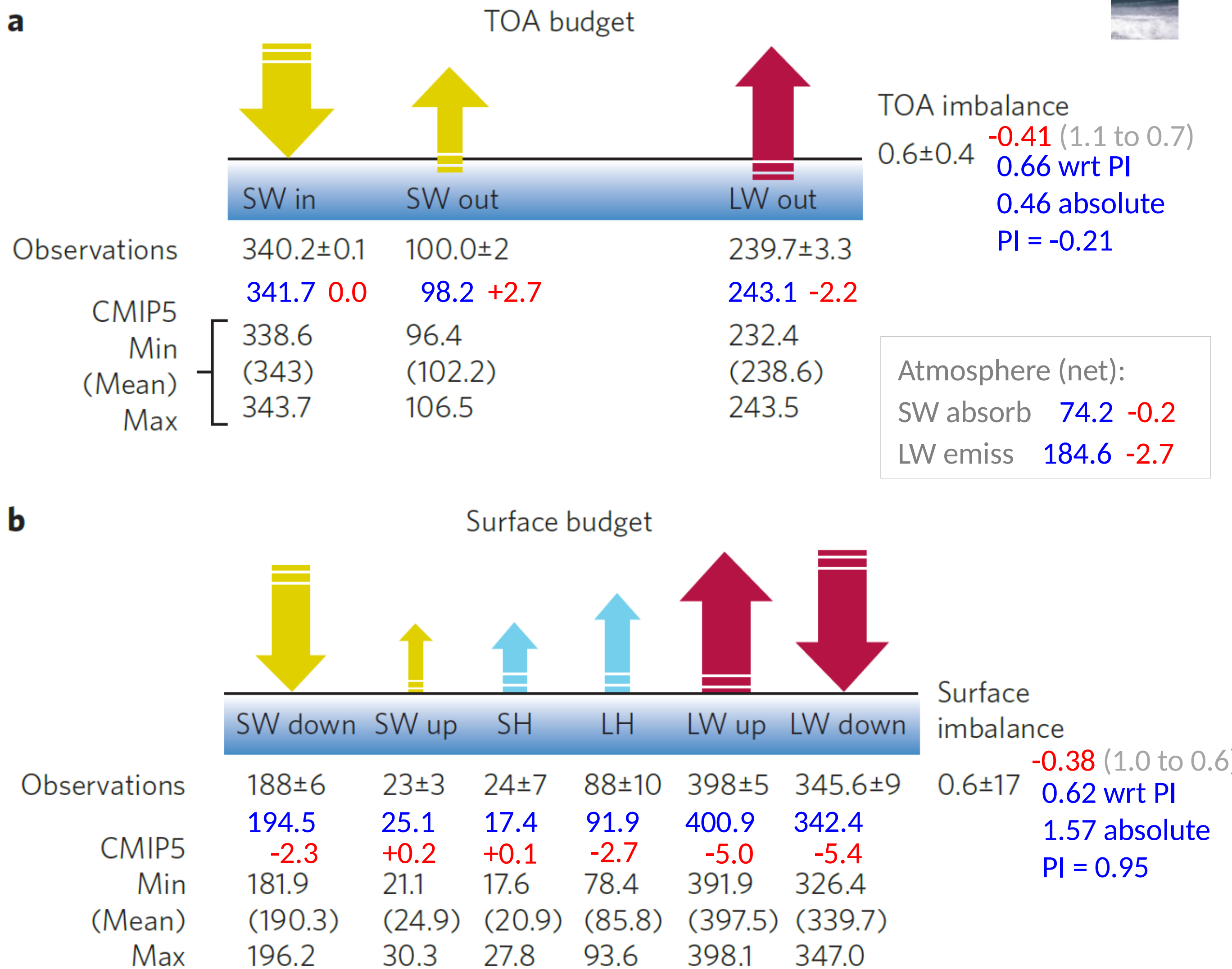
Change caused by anthropogenic aerosol emissions (red)



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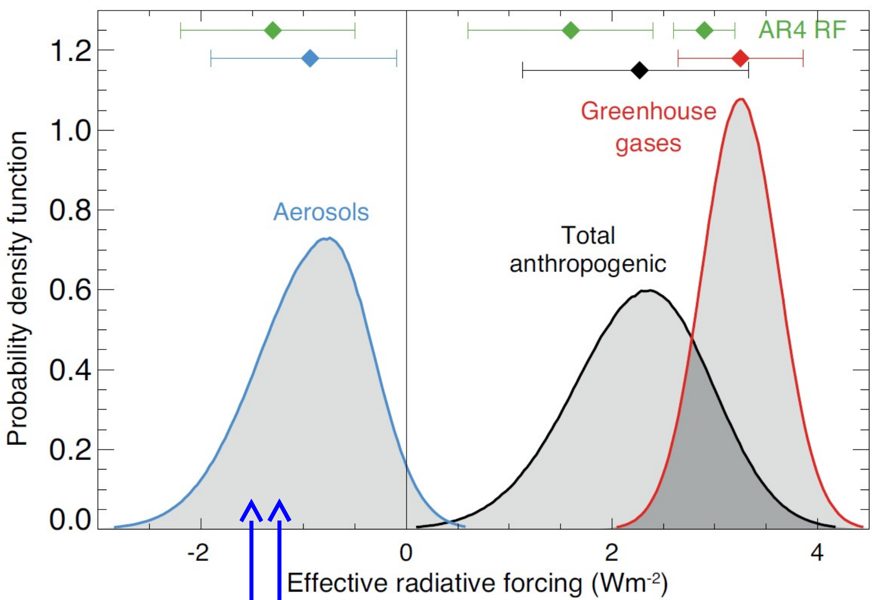
Aerosol Effective Radiative Forcing (ERF)

Cooling **Warming**



ACCESS 1.3 and 1.4

-1.5 Wm^{-2}

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ACCESS 1.4. Updated version of 1.3. Includes a newer version of CABLE, some physics modifications, bug fixes, improved dust uplift, etc..

All use the CLASSIC Aerosol Scheme.

ACCESS 1.0 & 1.3 used for CMIP5 runs.

ERF calculations for ACCES models (1850 to 2000) obtained using 30-year simulations with fixed SSTs & Sea Ice.

Diagram from “Climate Change 2013: The Physical Science Basis”, Fifth Assessment Report of the IPCC (AR5).

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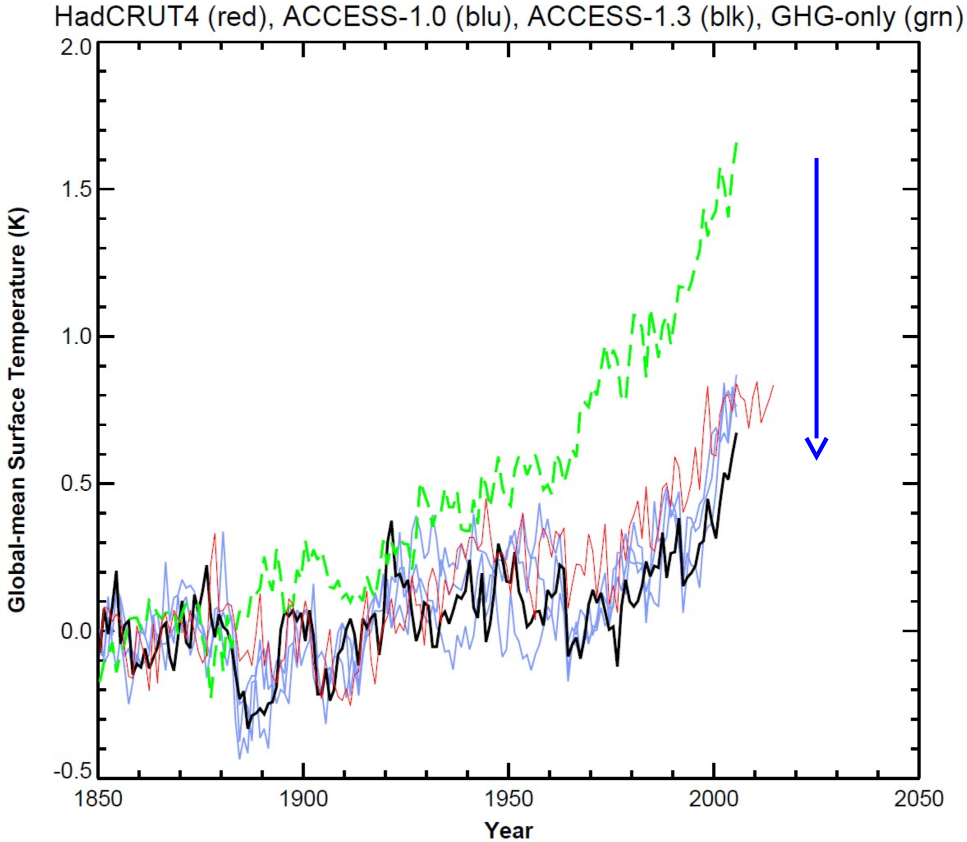
Global-Mean Temperatures in ACCESS



Observations: HadCRUT4 (red).

ACCESS-1.3, Historical (black).

ACCESS-1.3, GHG-only (green).

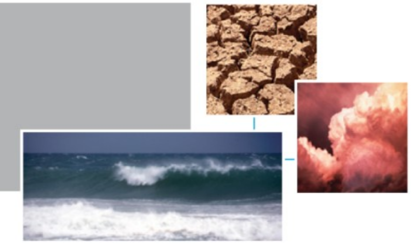
ACCESS-1.0, Historical (mauve), showing a 3-member ensemble.

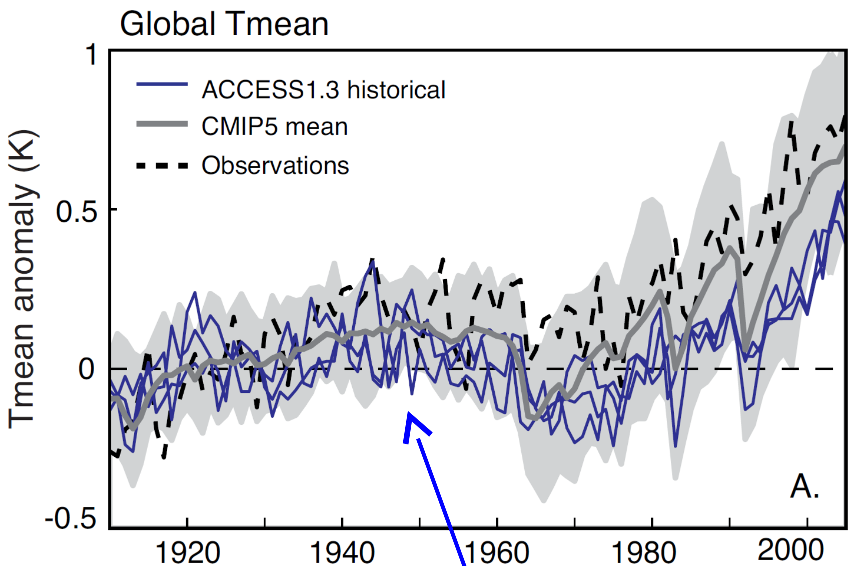
Green to Black ≈ Aerosol impact.

Global-mean temperature anomaly from 1850-1880 mean value.

GHG-only results from the Earth System Grid (ESG) submitted by the ARC Centre of Excellence for Climate System Science at the University of Melbourne (Lewis and Karoly, AMOJ 64 (2014) 87-101.).

Global-Mean Temperatures in ACCESS

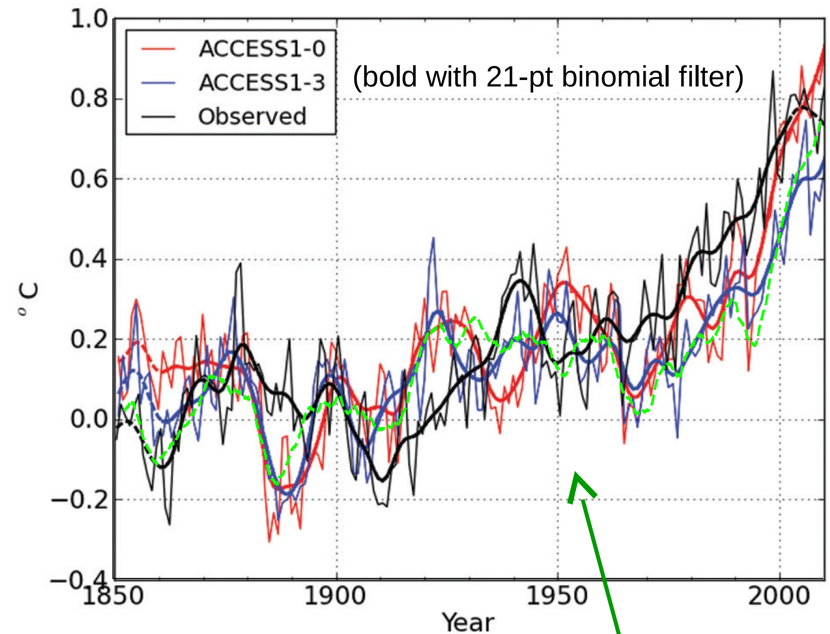




ACCESS 1.3 Coupled Model (blue),
3-member Historical Ensemble,
Global Tmean anomalies

Lewis and Karoly, AMOJ 64 (2014) 87-101

The authors suggest that the reduced warming trend for ACCESS 1.3 between 1950 and 2010 appears to be related to an overly strong response to increases in anthropogenic aerosols.



ACCESS 1.4 Coupled Model (green):
Mean of 3-member Historical+RCP8.5 Ensemble,
Global T anomalies relative to PI-Control,
5 year running mean

Global annual mean surface air temperature anomaly relative to 1880-1920 mean.

Dix et al., AMOJ 63 (2013) 83-99

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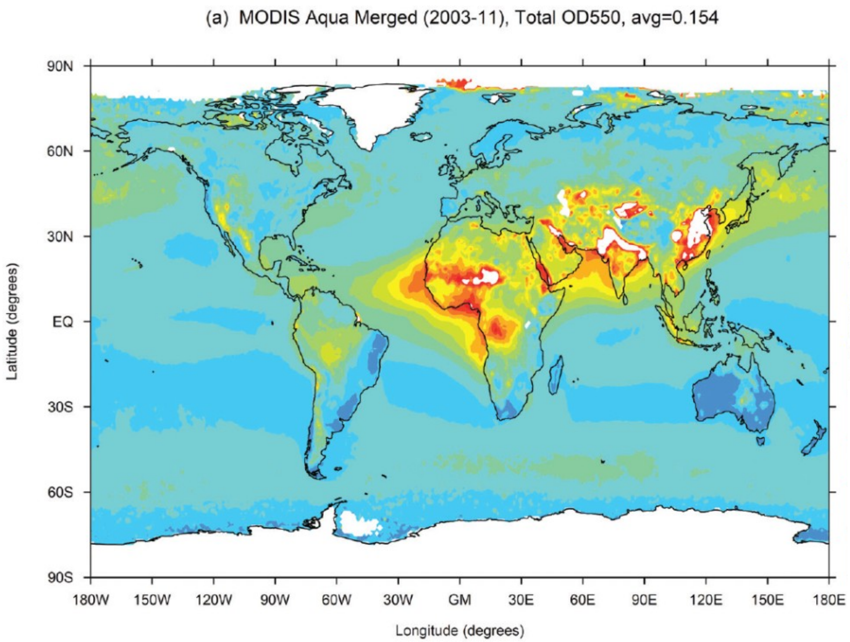
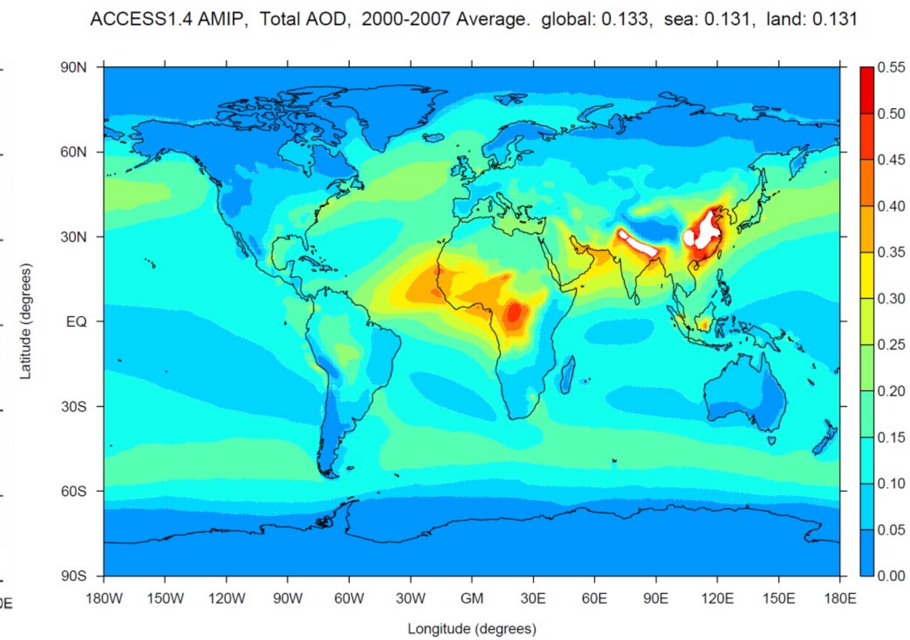
Global Aerosol Distribution

The total aerosol optical depth (AOD) reflects the amount of radiatively-active aerosol in a vertical column.





MODIS satellite and ACCESS-1.4 annual-mean total aerosol AOD features are broadly similar.

Differences to be investigated. Model results show:

- dust transport from Africa to Americas going further south than seen in MODIS
- larger AODs in the North Atlantic and in the Southern Ocean
- smaller AODs over western North and South America
- smaller AODs over Central Asia
- smaller AODs over parts of Indonesia and South Asia, but larger AODs over Borneo

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Does Aerosol ERF scale with AOD change?

Quantity	ACCESS 1.0	ACCESS 1.3	ACCESS 1.4 ESM1	HadGEM2 ES
AOD change at 550nm, (2000 – 1860), 5yr means				
Sulphate	0.0166	0.0151	0.0149	0.015
Biomass Burning	0.0044	0.0024	0.0033	0.0042
Fossil Fuel Organic C	0.0017	0.0012	0.0013	0.0016
Fossil Fuel Black C	0.0021	0.0015	0.0016	0.0021
Sea Salt	0.0011	0.0009	0.0012	0.0007
Dust	0.0004	0.0	0.0038	-
biogenic	0.0	0.0	0.0	0.0
nitrate	n/a	n/a	n/a	n/a
Total AOD Change	0.0263	0.0211	0.0261	0.031
Aerosol ERF (Wm^{-2})	-1.26	-1.58	-1.63	-1.23
Delta-T (5yr means, K) 1858-62 to 1998-02	0.666	0.525	0.494	
D 1860-69 to 1990-99				

ACCESS model runs are for CMIP5 Historical simulations

Dix et. al. (2013), AMOJ 63 (2013) 83-99.

HadGEM2-ES from Bellouin et. al. (2011), JGR 116 (2011) 1-25.

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Temperature increases are consistent with ERF values, although non-aerosol forcings will also be relevant.

Dix et. al. (2013), AMOJ 63 (2013) 83-99.

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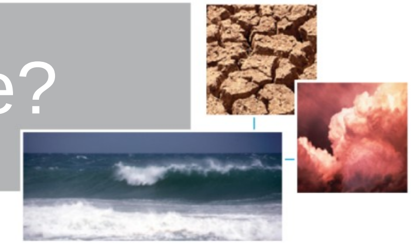

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D[illegible] 1860-69 to 1990-99				

ACCESS model runs are for CMIP5 Historical simulations

ACCESS-1.0 aerosol change is larger than for 1.3.

But ACCESS-1.0 ERF is smaller than for 1.3.

Cloud differences?

Dix et. al. (2013), AMOJ 63 (2013) 83-99.

HadGEM2-ES from Bellouin et. al. (2011), JGR 116 (2011) 1-25.

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The End.

When considering global-means averaged over 2000-2010, Anthropogenic Aerosols:

(*) reduce net Earth system heat uptake by 0.4 Wm^{-2}, from 1.1 Wm^{-2} to 0.7 Wm^{-2}

(*) cool the Earth's surface by 0.9 K, from 1.5 K above PI-Control to 0.6 K above PI-Control

(*) increase outgoing TOA SW by 2.7 Wm^{-2}

(*) reduce outgoing TOA LW by 2.2 Wm^{-2}

(*) lead to a 1.8% increase in the low cloud fraction, from 0.405 to 0.412

(*) lead to a 3.2% increase in the medium cloud fraction, from 0.180 to 0.185

(*) lead to a 1.5% increase in the high-cloud fraction, from 0.324 to 0.329

(*) reduce downward SW at the surface by 2.3 Wm^{-2}

(*) reduce downward LW at the surface by 5.4 Wm^{-2}

(*) reduce net LW emissions from the atmosphere by 2.7 Wm^{-2}

(*) reduce latent heating of the atmosphere by 2.7 Wm^{-2}

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The End.

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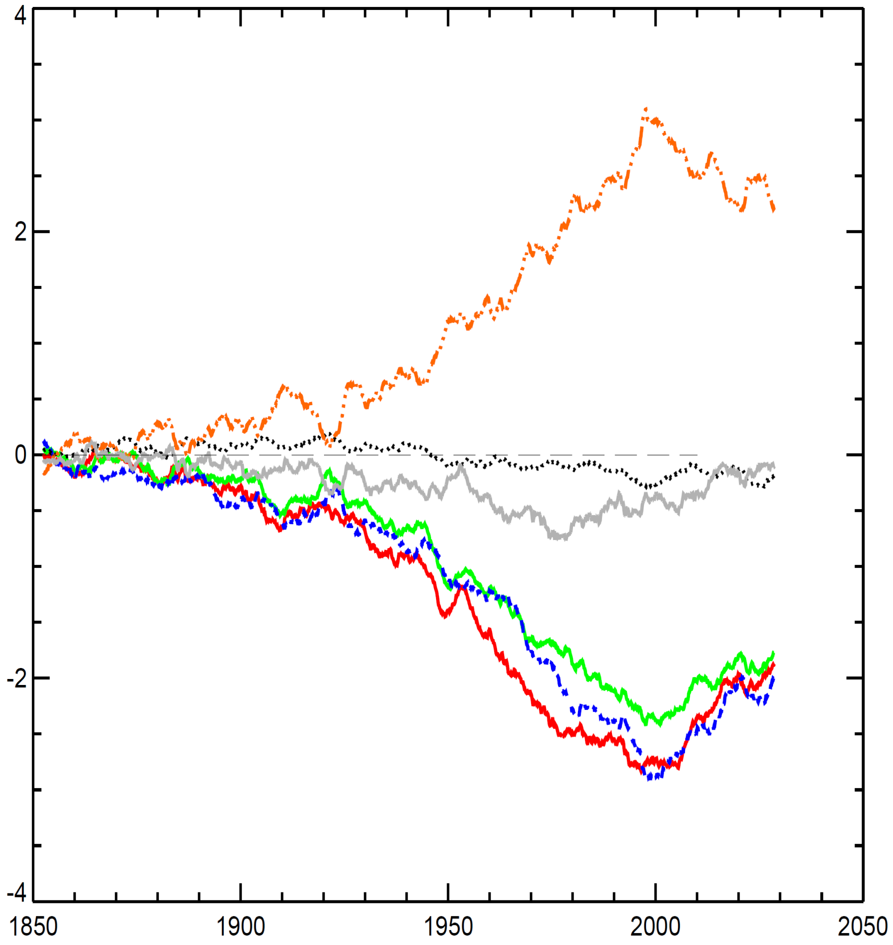

The End.

The End of 19 May 2015 Talk

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