Insights on Tropospheric Ozone through the Synergic Use of OMI Satellite Data and UKCA-UKESM1 Model Simulations.

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Tropospheric ozone

- Can affect climate directly through its radiative impact
- Can affect climate indirectly, through the oxidation of aerosol precursors and impact on OH and CH4
- Impact on air quality, crops and ecosystems (at the surface)

SOURCES:	SINKS:
1) photochemical oxidation of volatile organic compounds (VOC) in the presence of nitrogen oxides (NOx) 2) Stratosphere to troposphere transport (STT), larger at mid-latitudes in Spring	1) photolysis in the presence of H_2O 2) dry deposition at the surface (plant foliage, sea water, soil etc.)

AIMS

Understand how well the model reproduces observed ozone (and causes of discrepancies)

Understand the chemical and dynamical processes that drive ozone variability

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Model run: UKCA vn11.5 constrained by ERA-Interim

- Model setup equivalent to the climate-chemistry module in UKESM1 (see Archibald et al., GMD, 2020)
- Typical climate resolution (1.875° x 1.25°, or ~150km), 85 vertical levels with model top at 80km
- Emissions of short lived gases from CMIP6 (historical + SSP3-7.0)
- Interactive emissions of isoprene (from vegetation) and NOx (from lightning)

Observations: monthly gridded datasets

- **OMI** height-resolved ozone: 0-6km, ~6-13km, ~13-20km; 2005-2018, monthly AK and *a priori* data used to sample model data consistently to satellite data (Miles et al 2015, Williams et al 2019); ozonesonde bias correction applied
- **OMI-MLS** ozone tropospheric column [OMI total column – MLS stratospheric column]; 2005-2018, no AK and *a priori* information available (*Ziemke et al.* 2006, 2019)
- **LIS-OTD** lightning flash frequency; 1996-2013 (*Cecil et al.* 2014)
- **Bodecker Scientific** vertical ozone profiles (data from satellites and sondes); 1992-2016. (*Hassler et al. 2018*)

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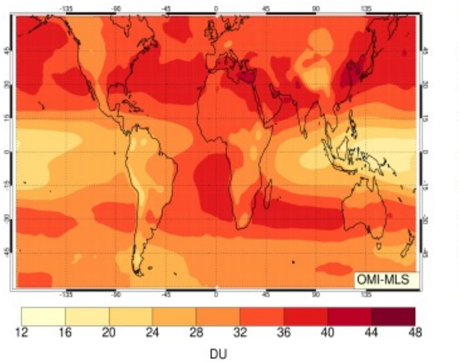
Talk Outline:

- How well does UKCA reproduce observed ozone climatology?
- Sensitivity experiments and comparison with observed lightning flashes to understand causes of UKCA ozone bias
- As part of a NERC multidisciplinary project on the North Atlantic (ACSIS) we investigate North Atlantic ozone interannual and decadal variability:
  - North Atlantic Ozone response to dynamical forcing (Arctic Oscillation)
  - North Atlantic Ozone recent trends (2005-2018)

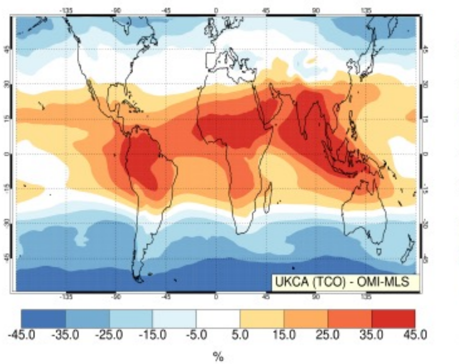
Tropospheric ozone (2005-2018)

Tropospheric column
(surf-tropopause)

Obs



UKCA-Obs %

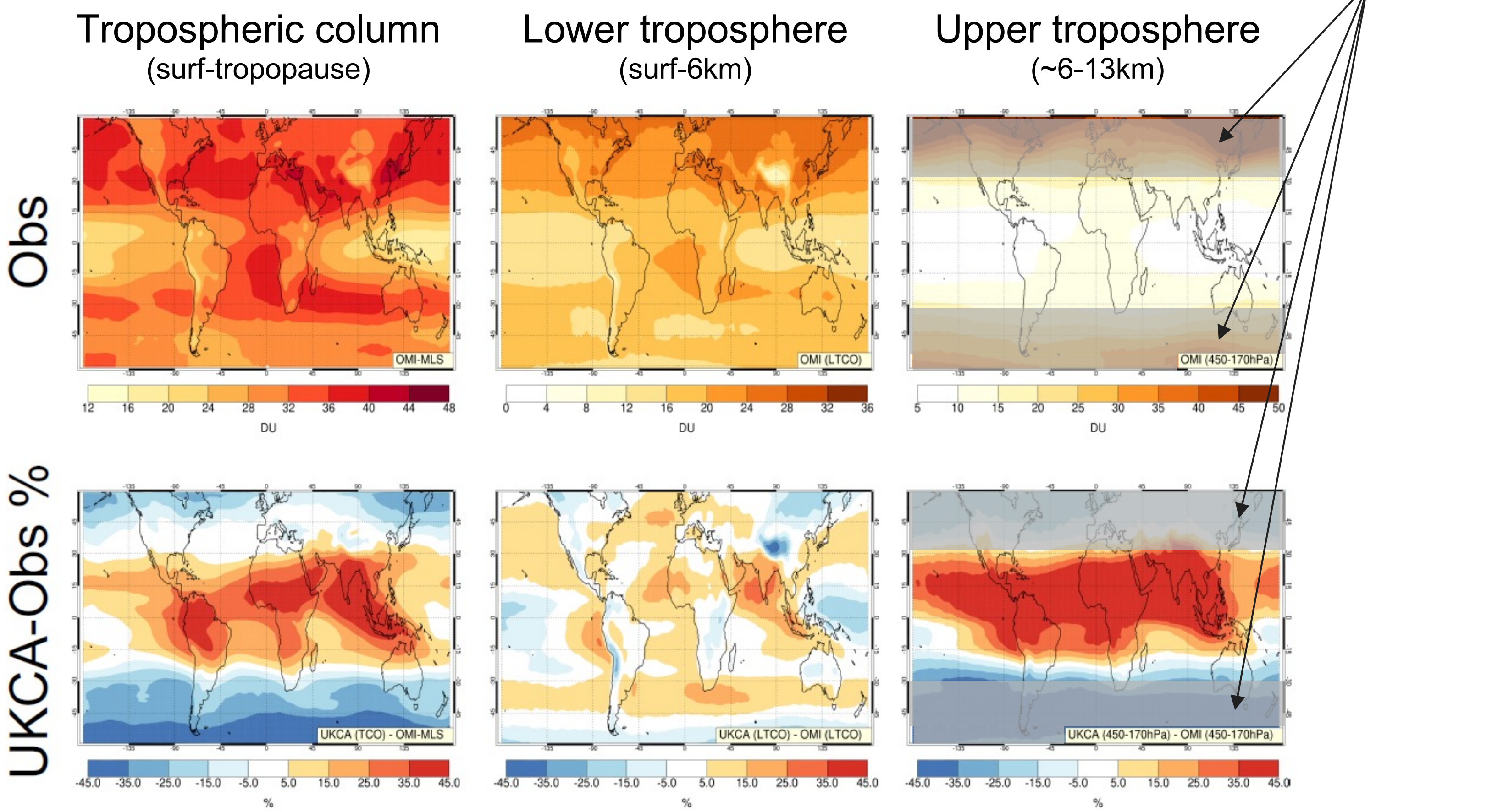


Relative to OMI-MLS, UKCA has a positive bias in the Tropics and a negative bias at mid-latitudes.

Similar results were found in Archibald et al., GMD 2020.

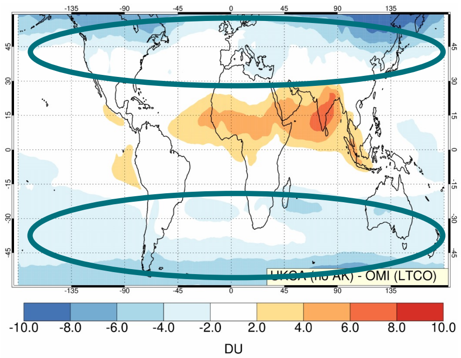
Tropospheric ozone (2005-2018)

Shaded areas include stratospheric sampling



Does UKCA have a mid-latitude low bias?

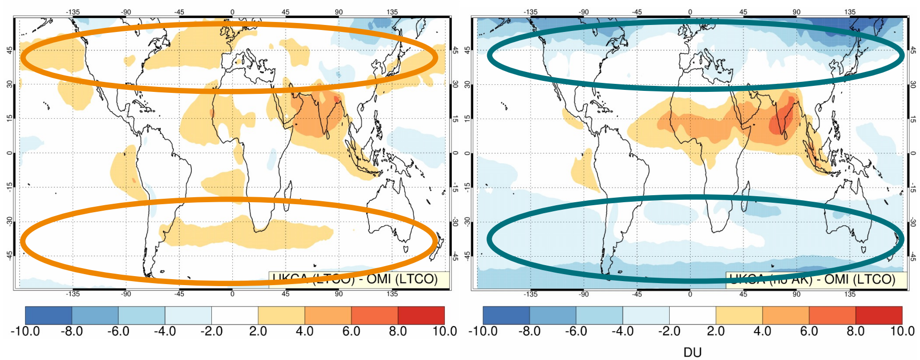
Model data no AK sampling



← When no AK and a-priori information is used to sample model data, a negative bias is found in the mid-latitude lower troposphere, relative to OMI data

Does UKCA have a mid-latitude low bias?

Model data AK sampling | Model data no AK sampling



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← When proper sampling is applied, there is no systematic negative bias at mid-latitudes relative to OMI Lower troposphere data

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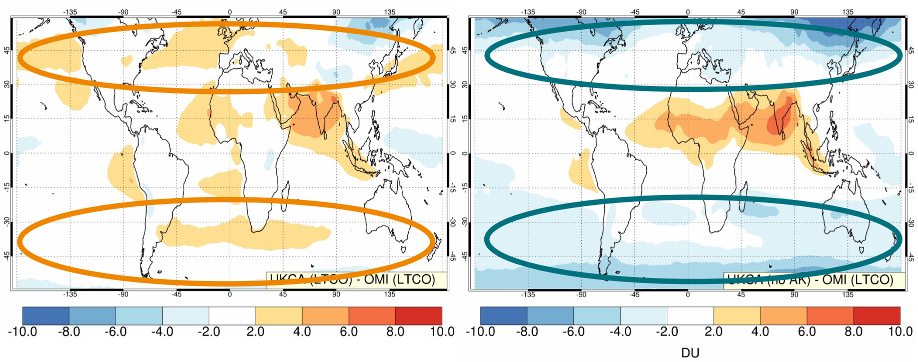

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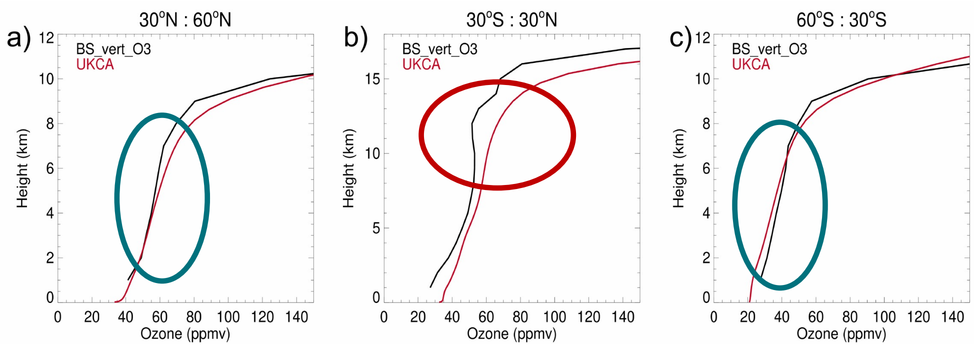
Comparison with Bodecker zonal mean ozone profile



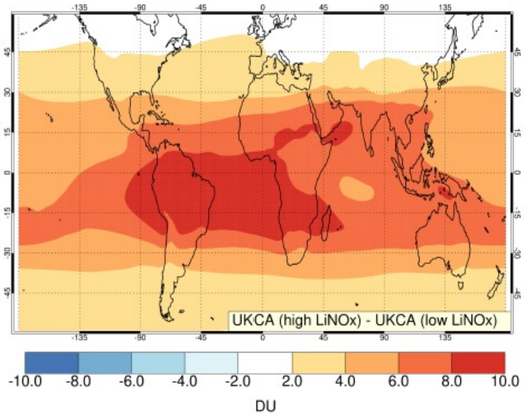
UKCA positive bias in the Tropics is supported by comparison with Bodecker dataset, which shows largest differences in the tropical upper troposphere

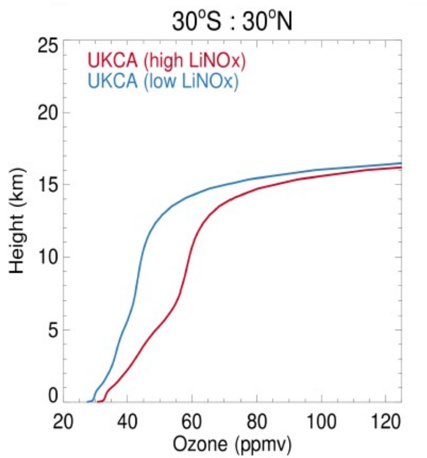
However, the large negative ozone bias at mid-latitudes relative to OMI-MLS is not supported by comparison with Bodecker datasets

What causes the tropical bias in UKCA?

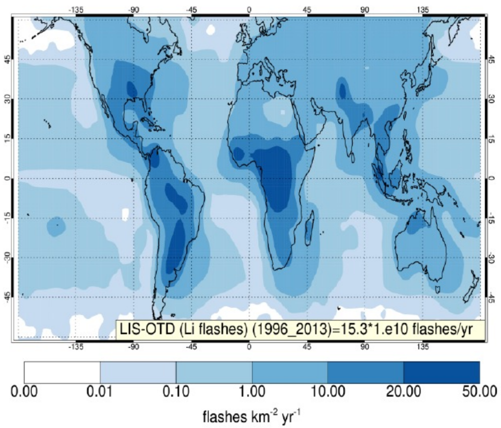
Sensitivity experiments:

	High LiNOx	Low LiNOx
Emissions	7 Tg(N)/yr	2 Tg(N)/yr
O_3 burden 60S:60N	310	260

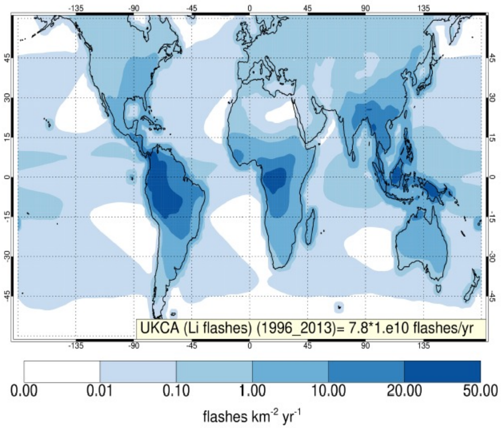




OBS (LIS-OTD)



UKCA



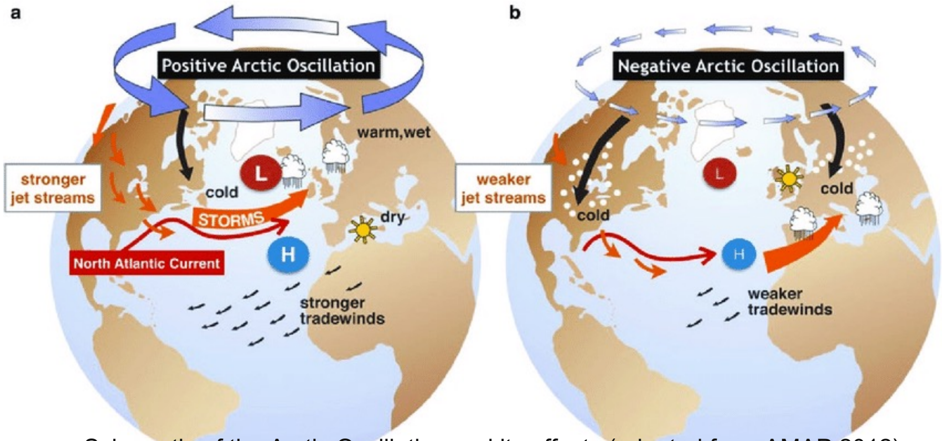
In UKCA:

Ratio of tropical to extra-tropical flashes is too high

Ratio of land/sea flashes is too high

Too much LiNOx is emitted in the Tropics, leading to ozone bias in the tropical upper troposphere

North Atlantic ozone response to Arctic Oscillation



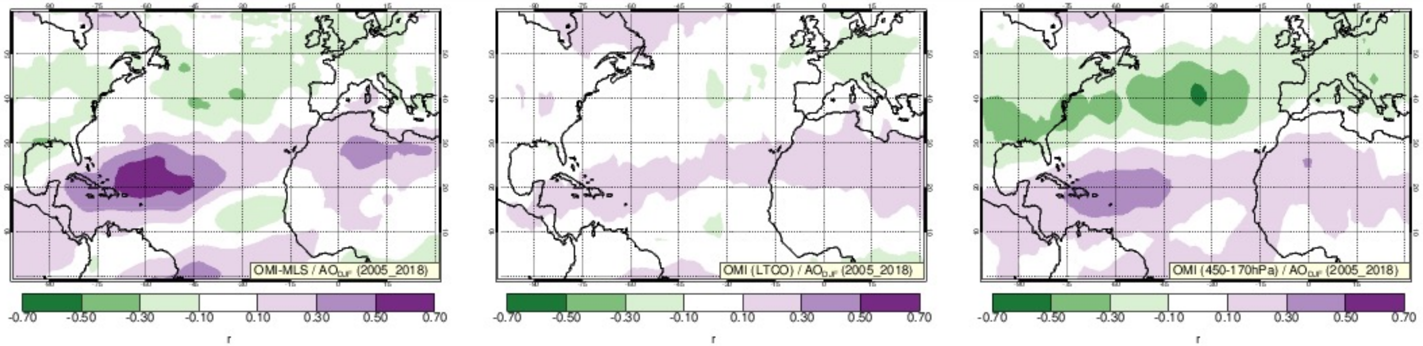
Schematic of the Arctic Oscillation and its effects (adapted from AMAP 2012)

The Arctic Oscillation (AO), similarly to the North Atlantic Oscillation (NAO), affects circulation and transport in the North Atlantic basin

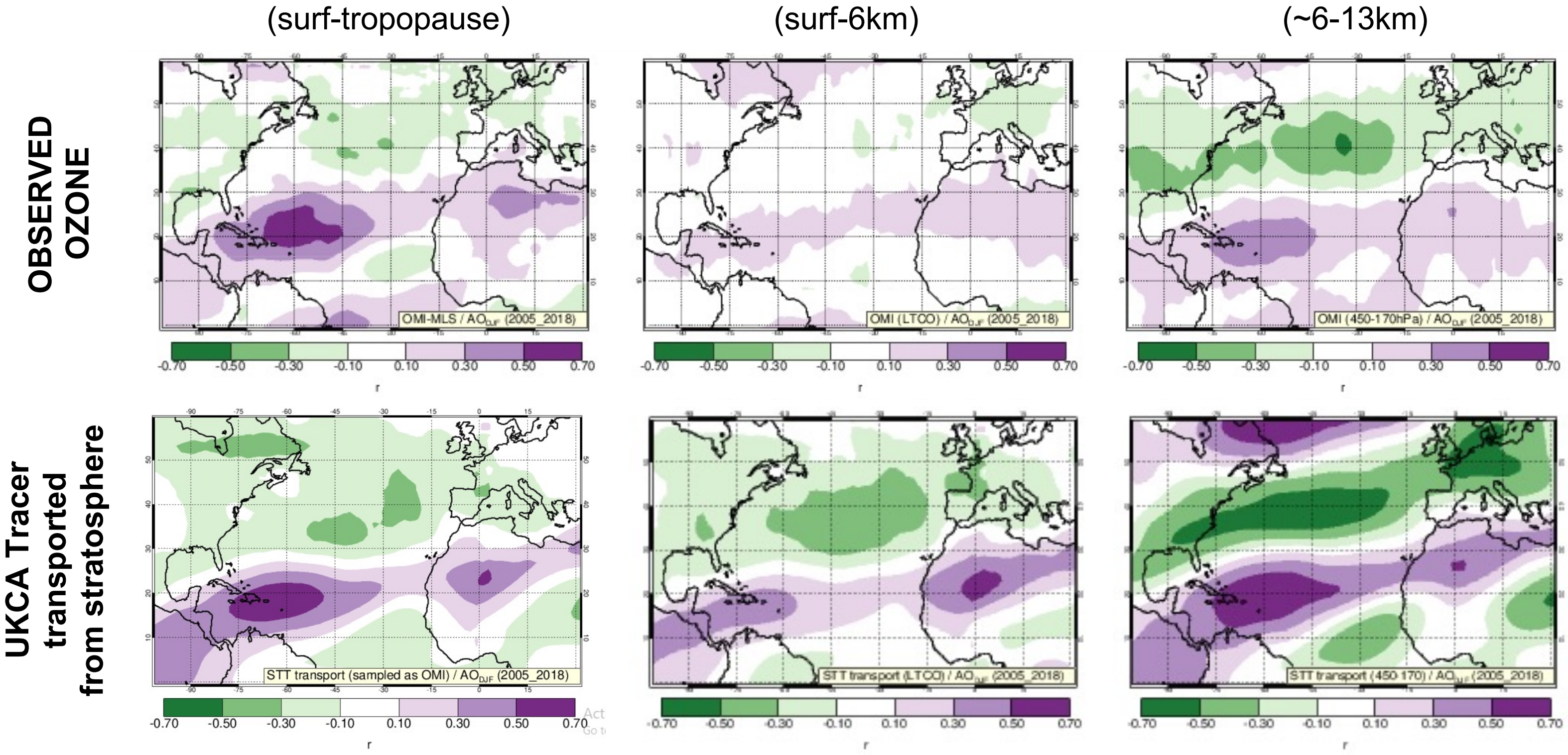
Below we calculate correlation maps between ozone and the AO index in DJF

OBSERVED OZONE

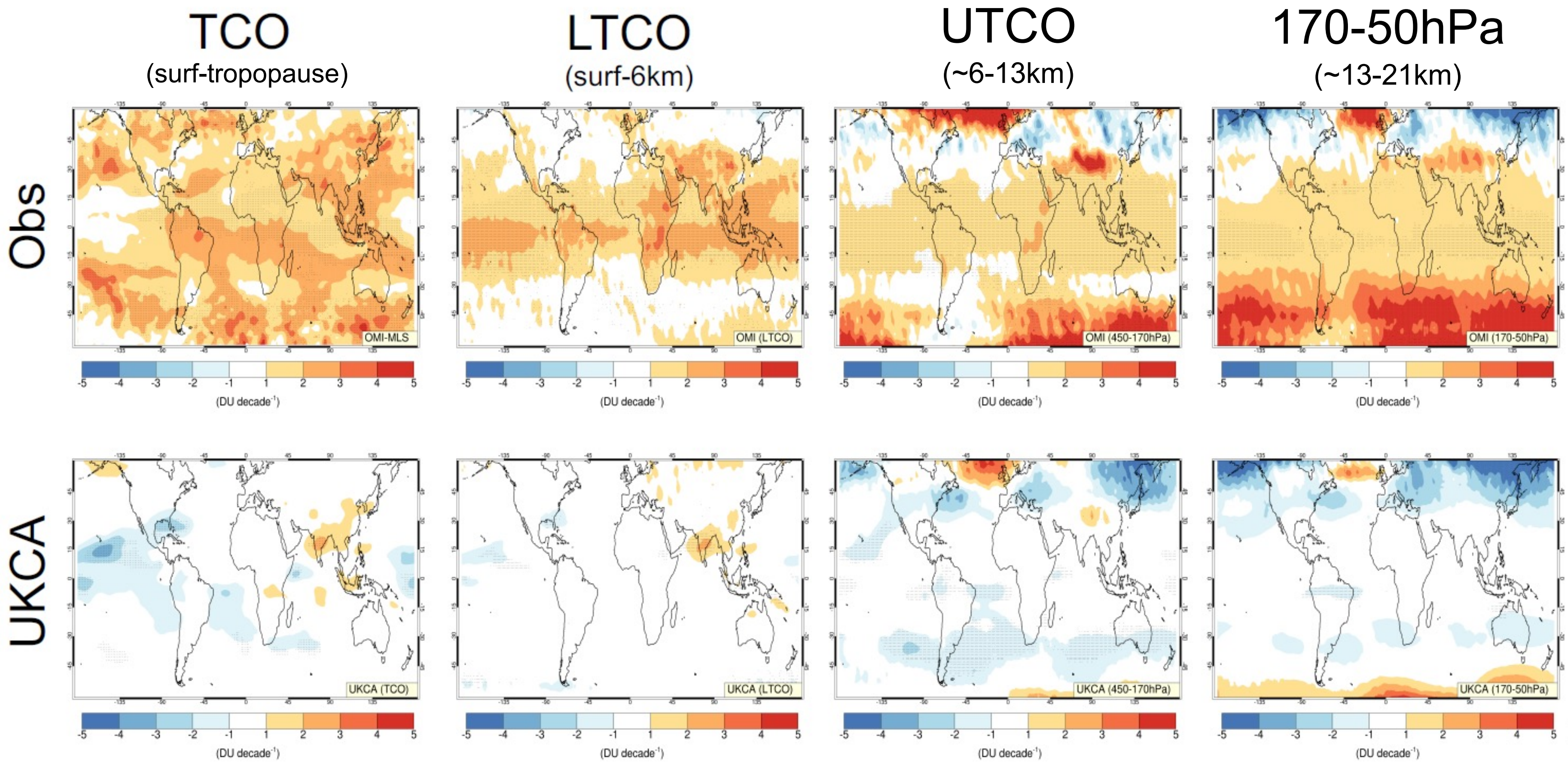
(surf-tropopause) | (surf-6km) | (~6-13km)



What drives ozone response to Arctic Oscillation?

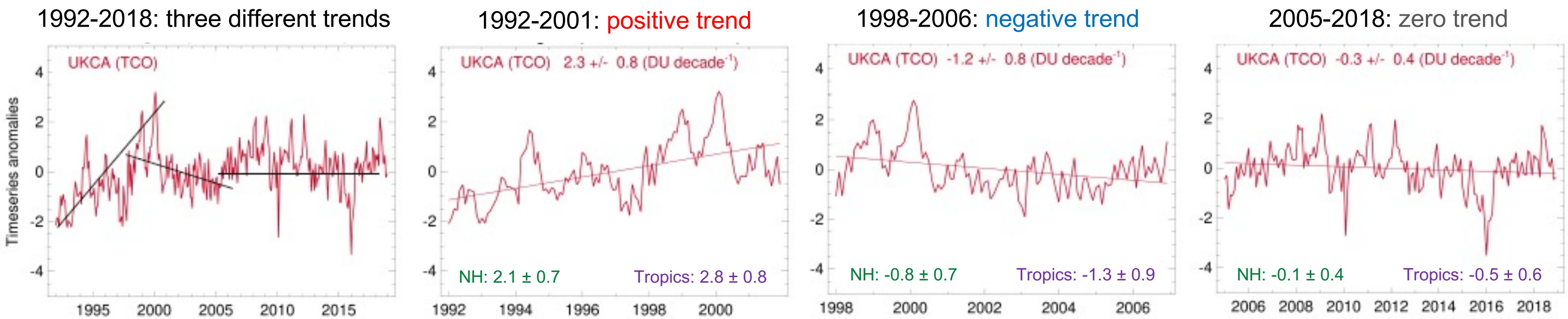


Ozone trends: observed vs modelled



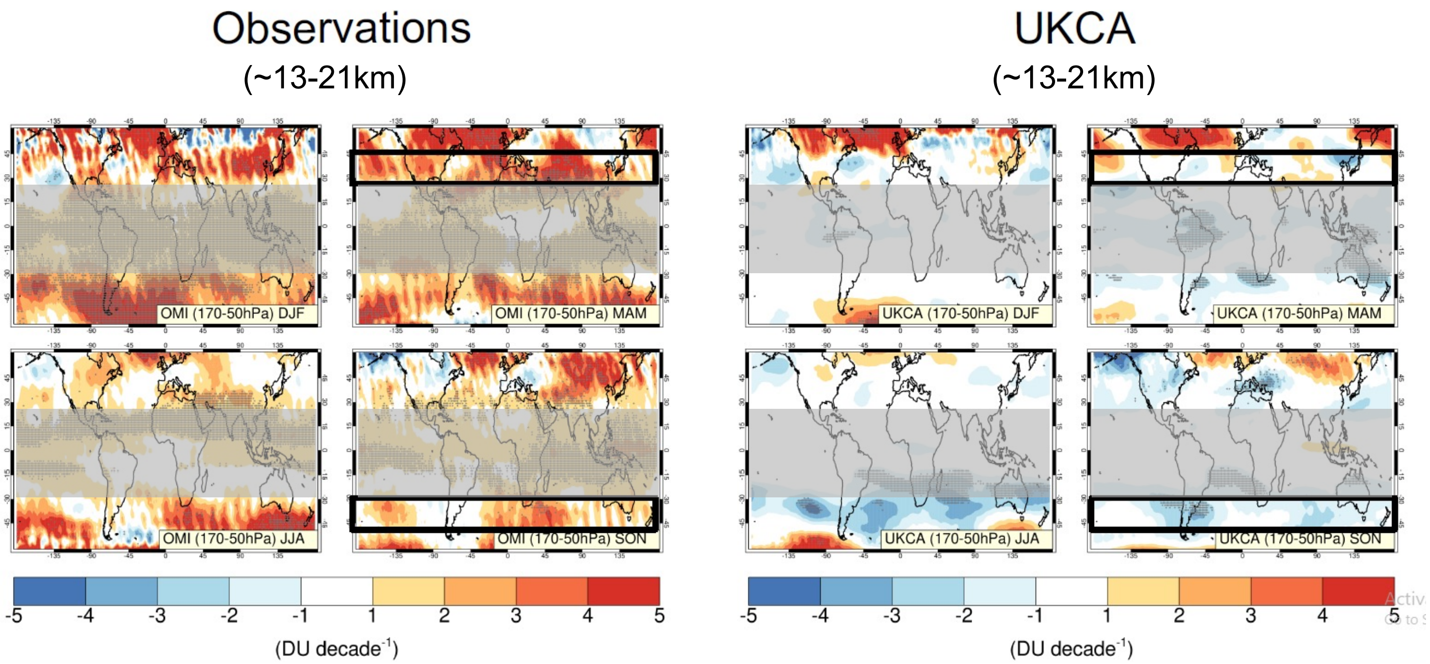
Drivers of UKCA tropospheric ozone trends in the NA

R between TCO(NA) - LiNOx			R between TCO(NA) - isoprene			R between TCO(NA) - NOx			R between TCO(NA) – O3 from STT		
(NA)	(NH)	(Tropics)	(NA)	(NH)	(Tropics)	(NA)	(NH)	(Tropics)	(NA)	(NH)	(Tropics)
0.15	0.40	0.72	0.01	0.13	0.50	-0.12	0.39	0.35	0.77	0.76	0.62



SOURCE	1992-2001 TREND %			1998-2006 TREND %			2005-2018 TREND %		
	NA	NH	Tropics	NA	NH	Tropics	NA	NH	Tropics
LiNOx emissions Tg(N)/yr	0	0	+ 17%	0	0	0	0	0	0
Isoprene emissions Tg/yr	- 5 %	0	+ 14 %	0	0	0	- 10 %	- 8 %	- 9 %
NOx emissions Tg(N)/yr	0	+ 4 %	+ 20 %	- 10 %	+ 10 %	+ 15 %	- 25 %	0	+ 10 %
O3 from STT DU/yr	+ 6 %	+ 6 %	+ 5 %	- 3 %	- 3 %	- 6 %	0	0	0

Seasonal ozone trends in the lower stratosphere (2005-2018)



Observed ozone in the lower stratosphere shows large positive trends in regions and season where STT occurs (black boxes). This would lead to positive trends in ozone transported from the stratosphere

Modelled ozone does not have positive ozone trends in the same regions and seasons, leading to zero trend in ozone transported from the stratosphere

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Summary

- OMI height resolved ozone data, retrieved by the RAL scheme (UK NCEO, ESA CCI), helped to unequivocally identify model biases and the responsible processes.
- Shortfalls in the convection parameterisation scheme leads to discrepancies between modelled and observed lightning flashes. This results in:

    1) positive ozone bias in the tropical upper troposphere

    2) Modelled tropical ozone being overly sensitive to ENSO forcing

- Observed North Atlantic ozone response to Arctic Oscillation can be attributed to changes in stratosphere to troposphere transport during positive/negative AO phases.
- UKCA underestimates tropospheric ozone trends due to an underestimate of lower stratospheric ozone trends (stratospheric ozone contributes to tropospheric ozone trend via stratosphere to troposphere transport).

Extra slides

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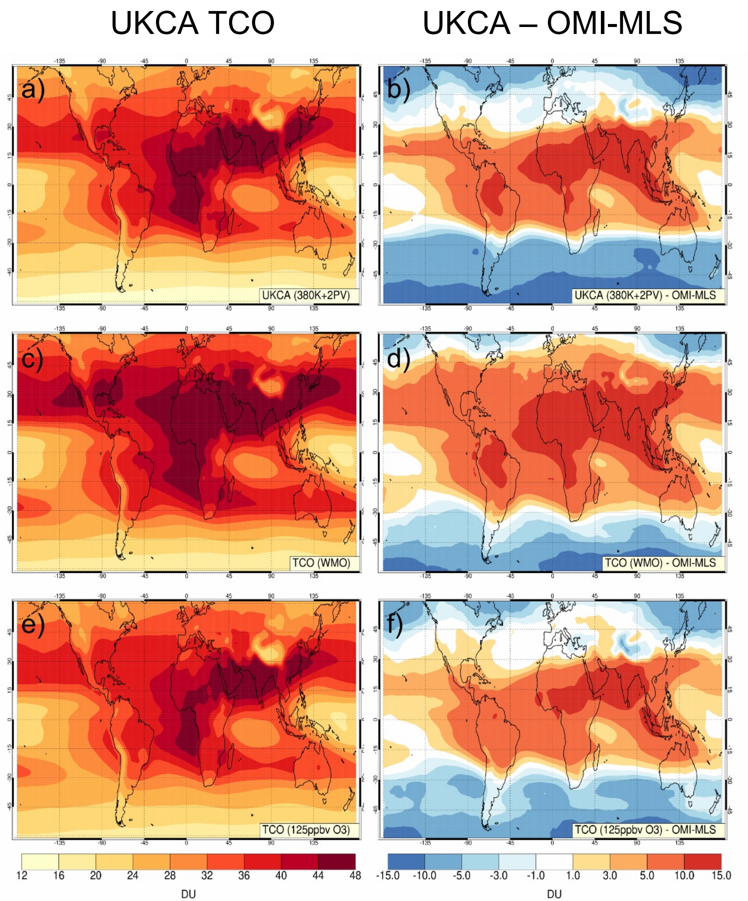
TCO sensitivity to tropopause definition

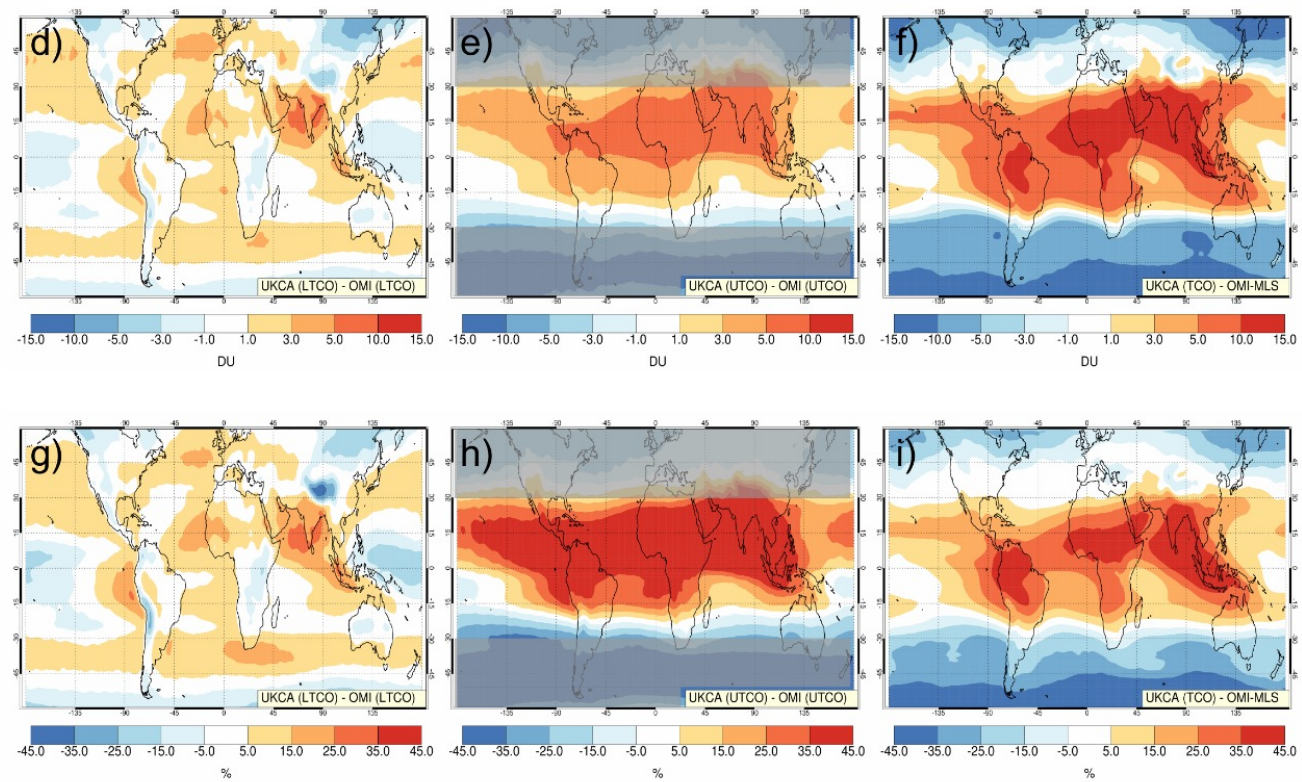


Absolute vs % bias

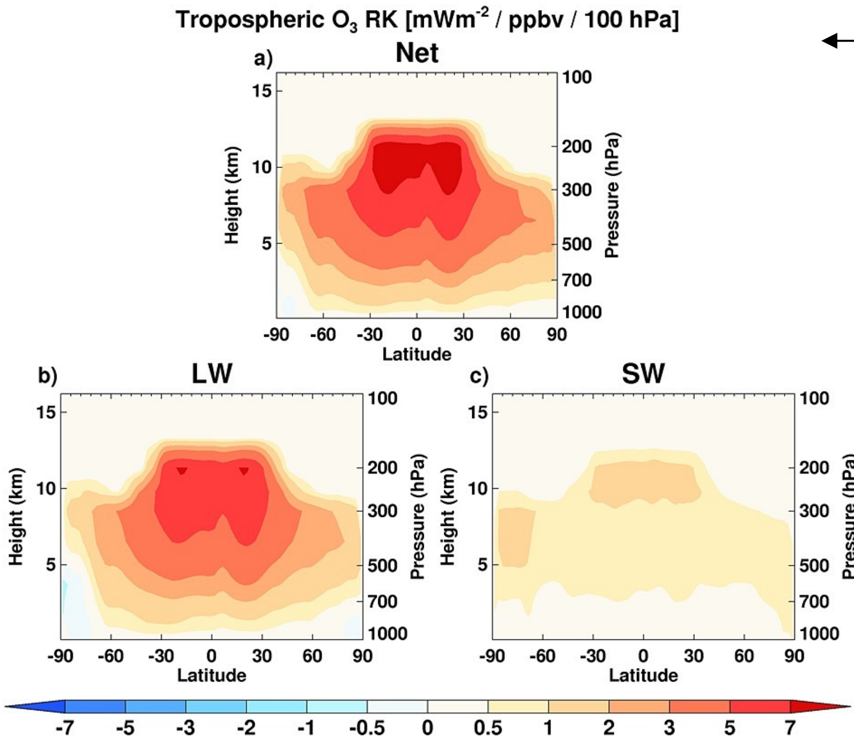
LTCO (surf-6km) | UTCO (~6-13km) | TCO (surf-tropopause)

Absolute

%



Why does it matter?



← Rap et al. 2015 (GRL)

Radiative effect is most sensitive to change in tropospheric ozone in the tropical upper troposphere

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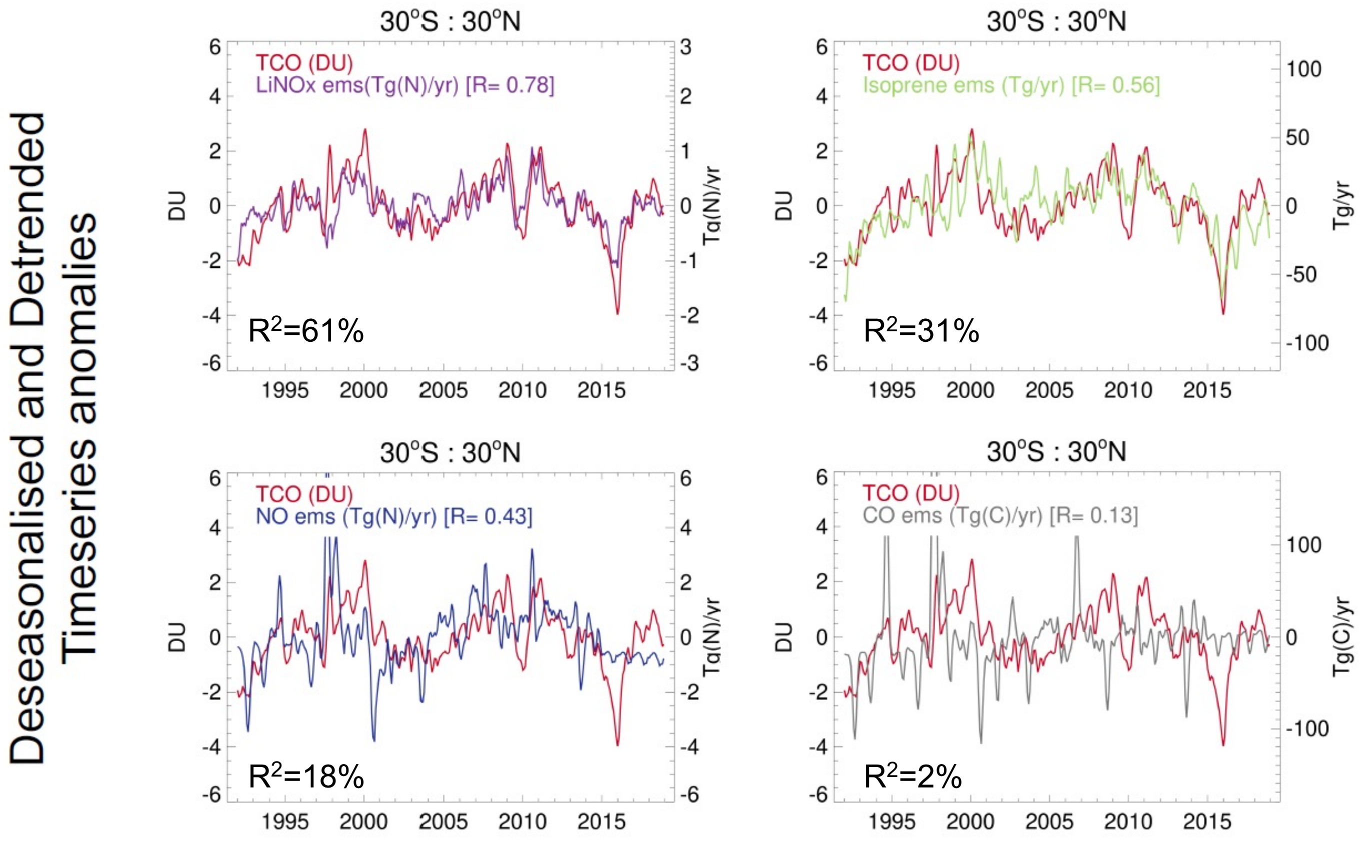
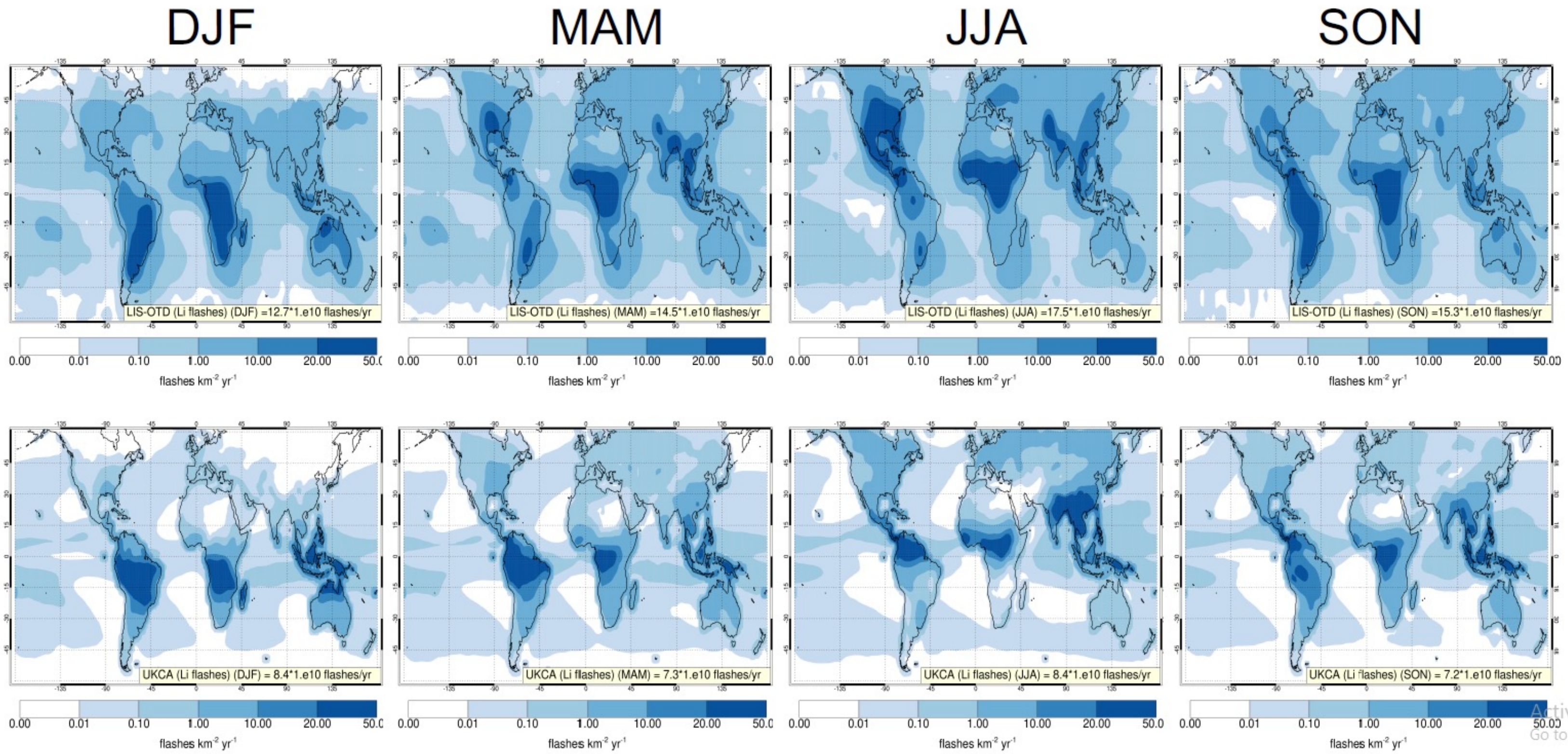
Understanding drivers of tropical ozone in UKCA:



One way to understand how modelled TCO changes in response to changes in modelled emissions is to calculate the temporal correlation coefficient (R) and the coefficient of determination (R^2) between ozone and specific ozone precursor emissions.

Observed vs modelled lightning flashes (1996-2013)



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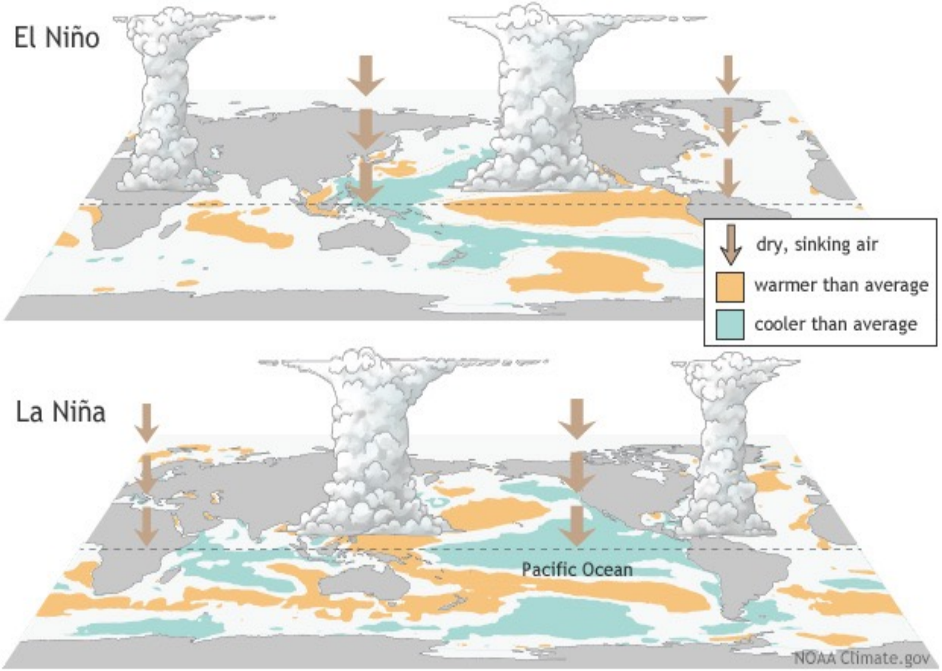
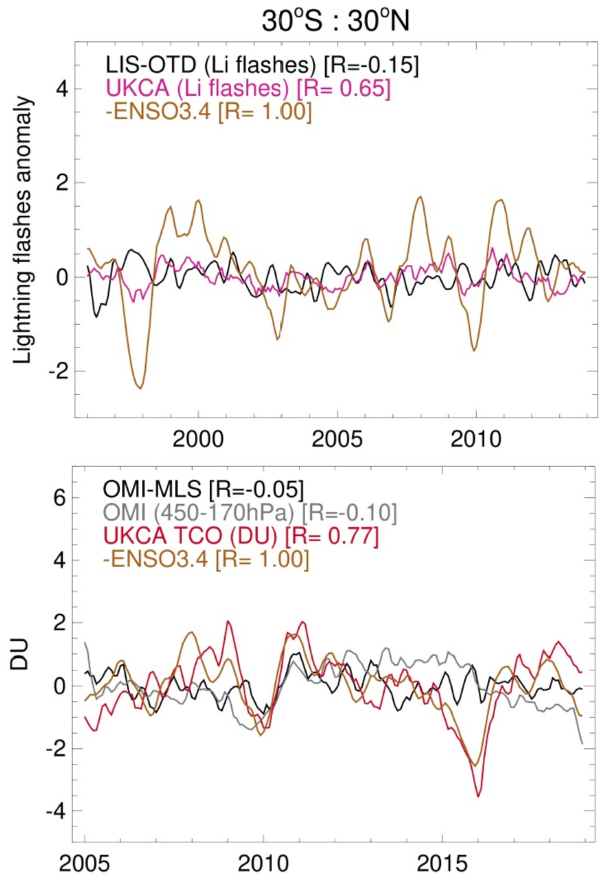
ENSO response: observed vs modelled

ENSO impacts convection and lightning flashes distribution

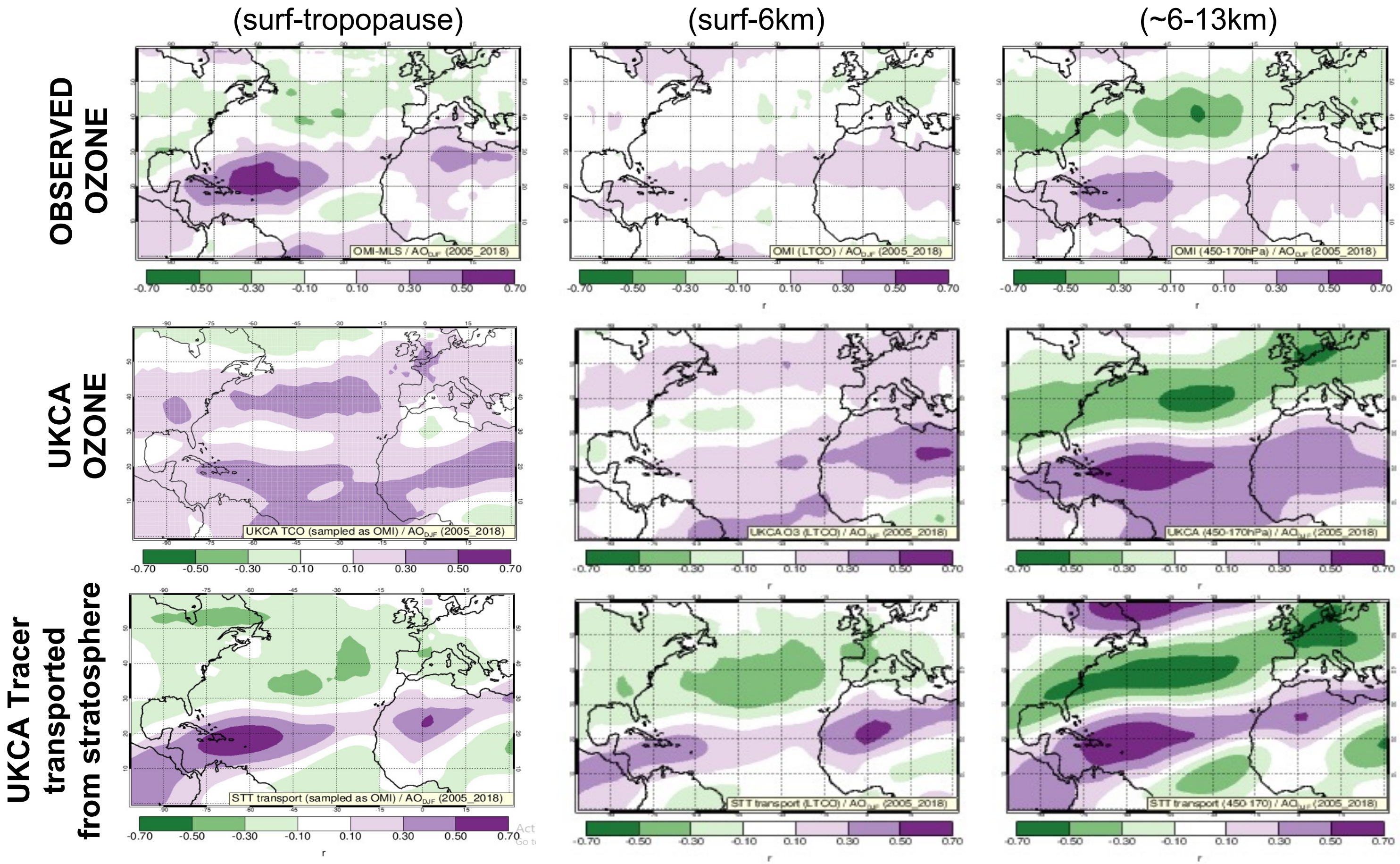
Convection response to ENSO is different in the model



Source: https://www.climate.gov/enso



North Atlantic ozone response to Arctic Oscillation



Tropospheric ozone trends in the North Atlantic (NA)