Climate versus emission drivers of U.S. ozone variability and trends

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1. Motivation

Major changes in observed baseline tropospheric ozone over northern mid-latitudes:

- An overall increase over the past 20-30 years[1-4].

- A tendency for ozone pollution season to begin earlier in spring[5]

- A pattern dominated by slow or no growth in the 2000s[2,4]

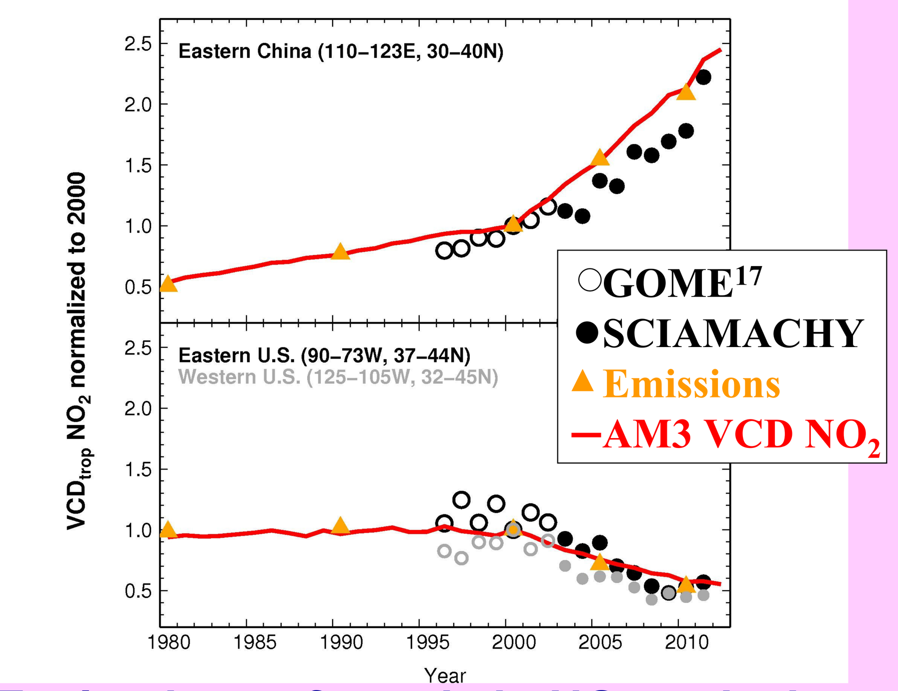
However, the rate of ozone increases is highly uncertain (due to large interannual variability, short record, and sparse in situ sampling). **Unraveling the drivers of historical ozone variability and trends necessitates process-level understanding on daily to multi-decadal time scales:**

→ Crucial for improving seasonal forecasts and designing ozone abatement strategies;

→ Provide insights into how tropospheric ozone will respond to a warming climate.

2. The GFDL AM3 Model Hindcasts (in the CCMI framework)

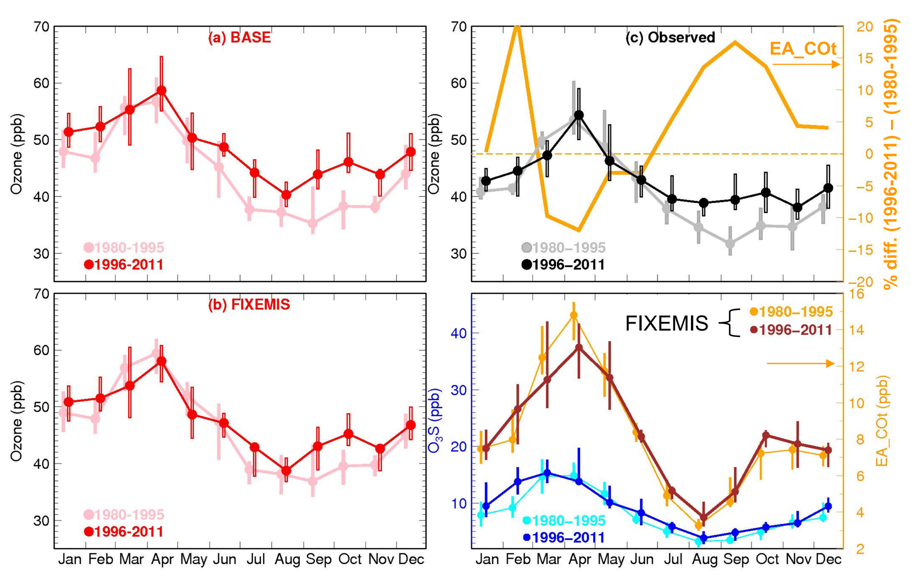
Experiment	Period	Meteorology	Forcings (radiation)	CH_4 (chemistry)	Aerosol and O_3 precursors	Fire emissions
BASE	1978-2012	Nudged to NCEP U&V [6-7]	Historical	Historical	Historical[8] and RCP 8.5 beyond 2005	Historical[9-10]
PRB	1978-2012	as BASE	Historical	Historical	Shut off over NA; as BASE elsewhere	Historical
FIXEMIS	1978-2012	as BASE	Historical	2000	Fixed	Fixed
IAVFIRE	1978-2012	as BASE	Historical	2000	Fixed	Historical
IAVASIA	1978-2012	as BASE	Historical	1980	Varying in Asia only	Fixed
IAV_CH4CHEM	1978-2012	as BASE	Historical	Historical	Fixed	Fixed
AMIP	1950-2012	Forced to obs. SSTs & sea ice	Historical	2000	Varying aerosols; fixed O_3 precursors	Fixed



Evaluations of trends in NO_x emissions

3. Footprints of changing atmospheric circulation at Mauna Loa Ozone Observatory

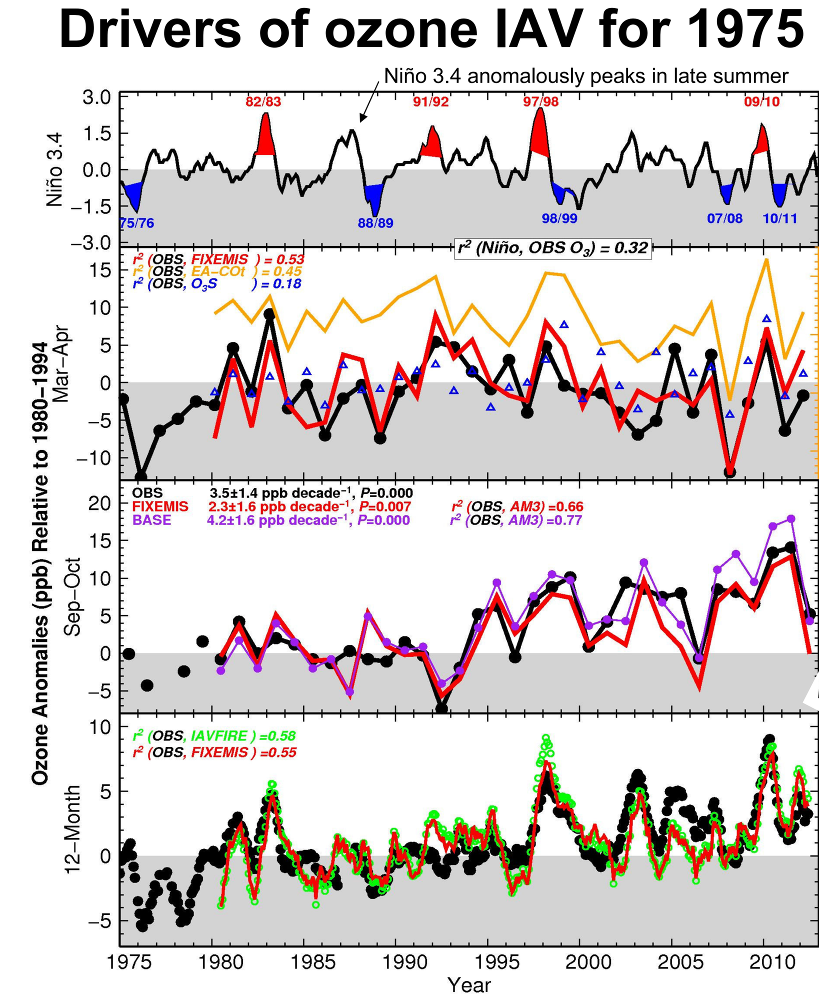
The changing ozone seasonal cycle



- Increase in fall for MLO while in spring for NH mid-latitudes
- **Spring**: Weakened Eurasian airflow offsets O_3 increases from rising Asian emissions
- **Fall**: Enhanced Eurasian airflow augments O_3 increases with rising Asian emissions
- No significant trends in NA_COt and O_3S[7]

→ Will CCMI multi-models agree?

Drivers of ozone IAV for 1975 to 2012

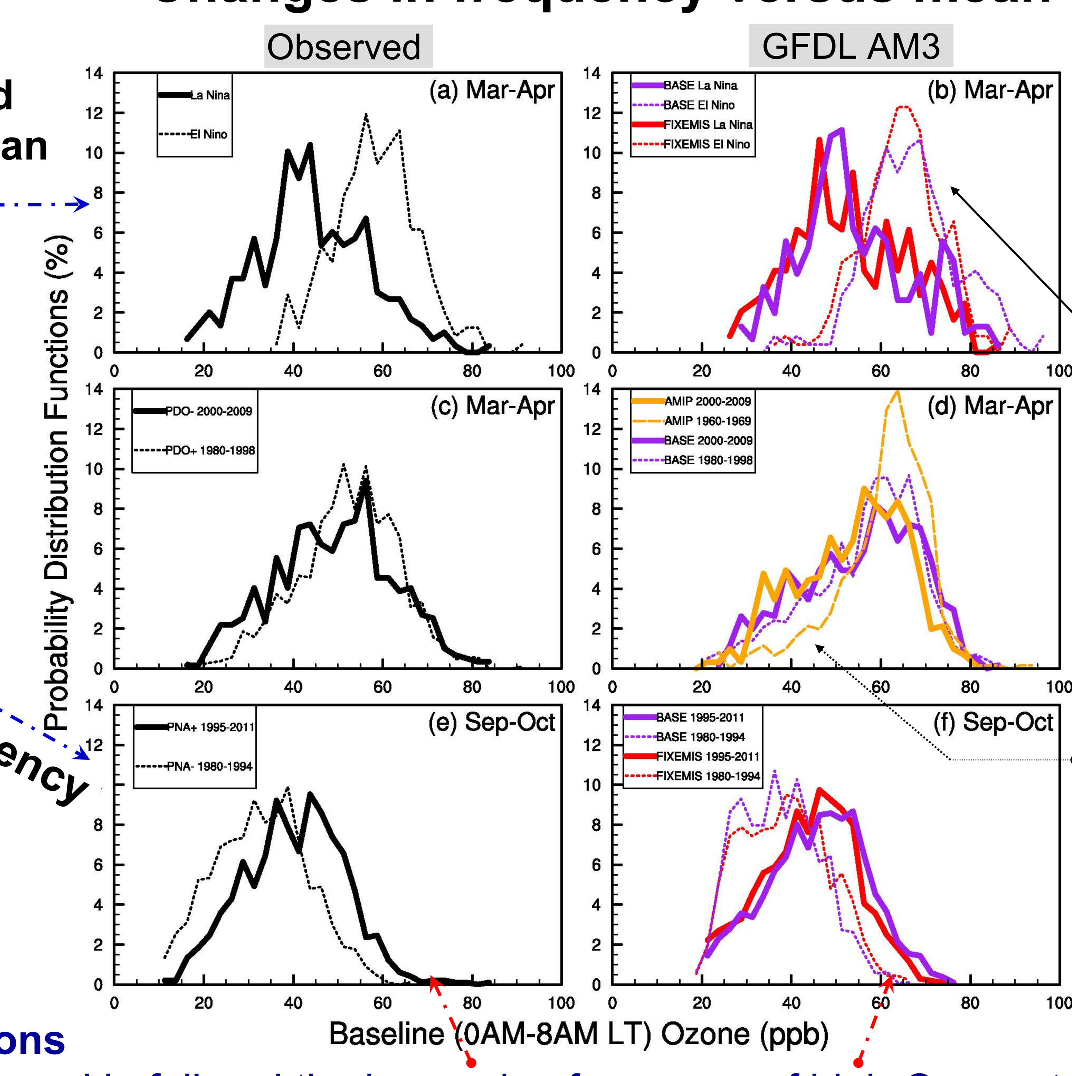


- Wildfire emissions are not the major driver of O_3 IAV
- **Increasing mean O_3 in spring following El Niño conditions**
- AM3/FIXEMIS captures the mid-1990 abrupt increase observed in fall and the increasing frequency of high-O_3 events

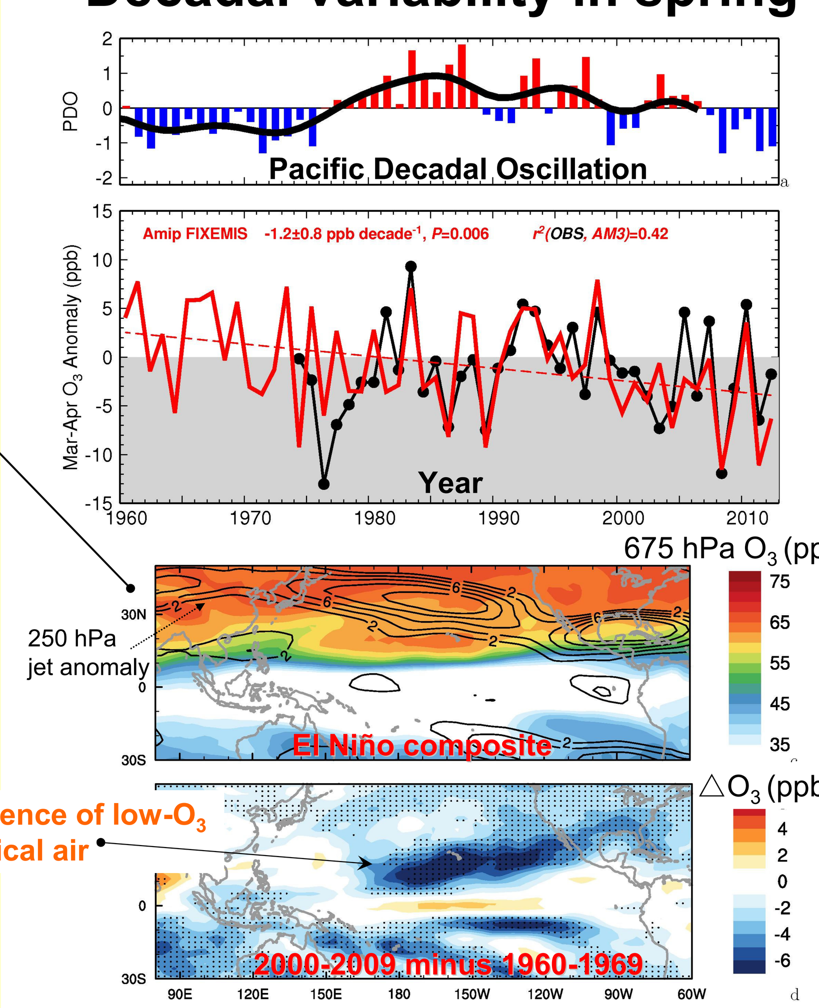
Changes in frequency versus mean

ENSO-related changes in mean

Shifts in tails PNA (low-frequency variability)

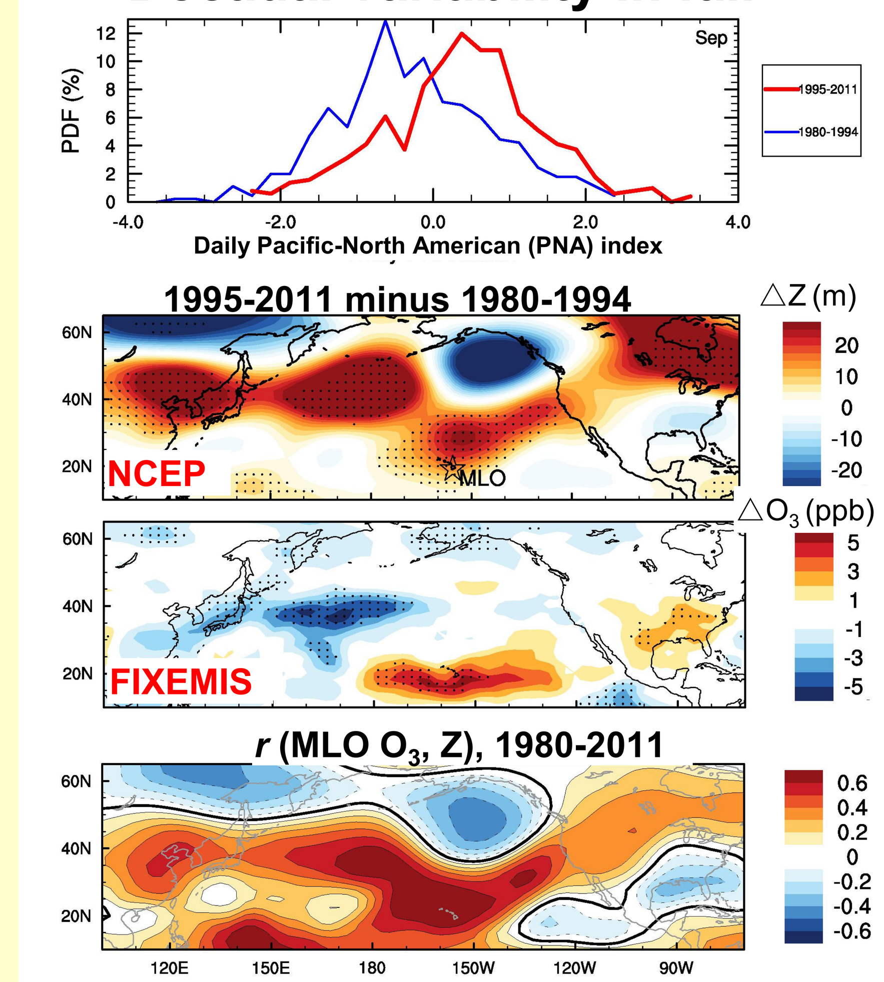


Decadal variability in spring



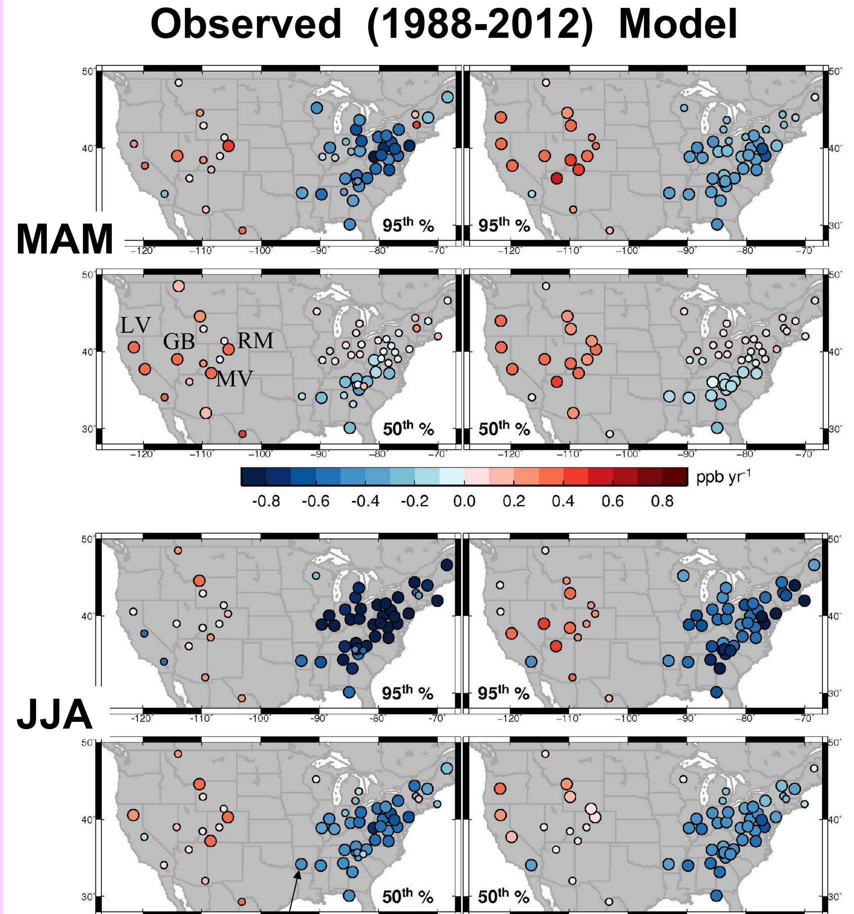
Recent NH tropical expansion[14-16] combines with PDO negative[12-13] in the 2000s to reduce transport of mid-latitude air to MLO?

Decadal variability in fall

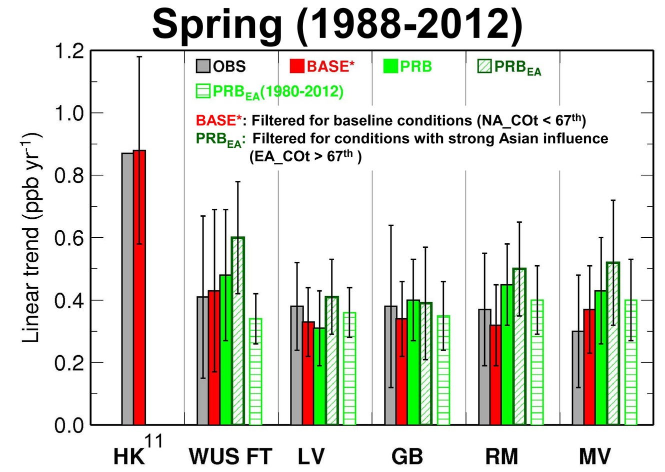


Increasing frequency of the PNA pattern towards its positive phase leads to more frequent transport of Asian pollution towards MLO

4. Model evaluations of U.S. O_3 trends



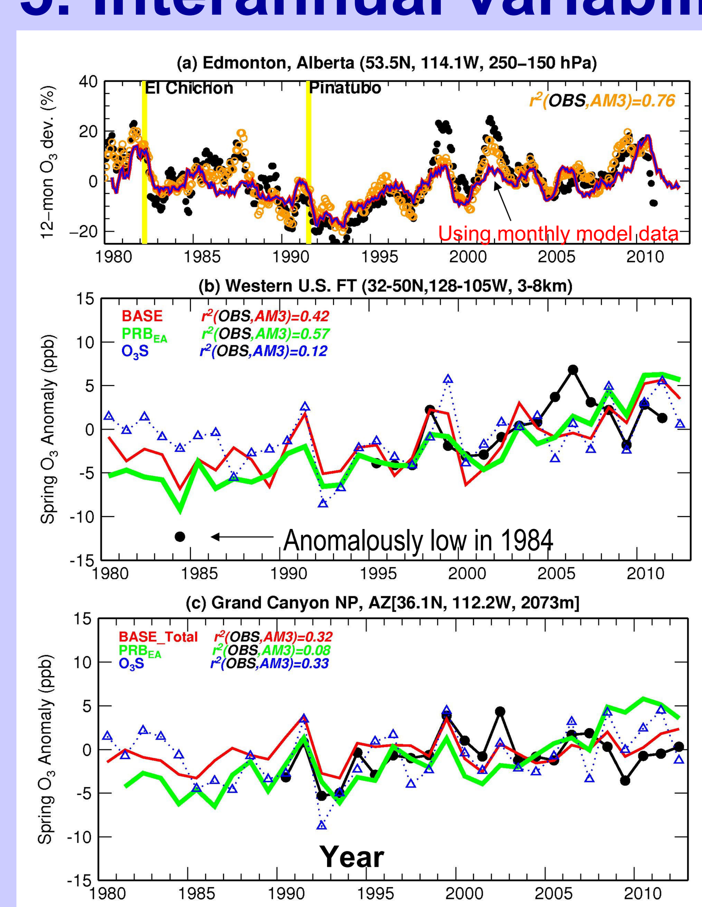
Larger circles indicate statistically significant trends ($P<0.05$)

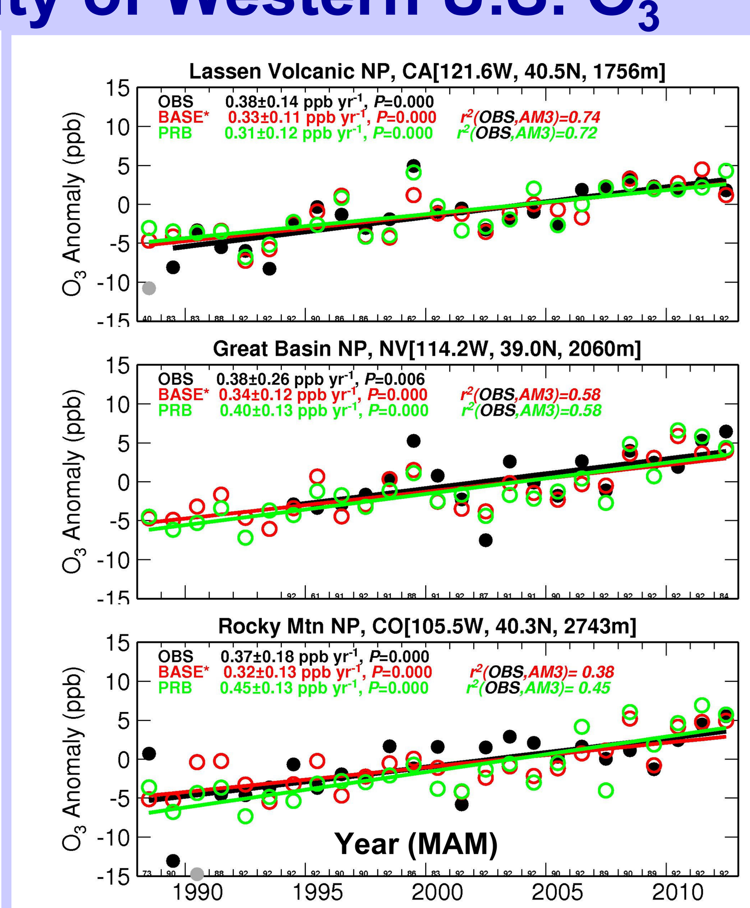


- AM3 captures the opposing sign in the western vs. eastern U.S.
- Greater trends simulated for the western U.S. when the influence of Asian pollution is stronger
- Regional CO tracers are useful for baseline filtering in coarse-res. global models

→ Recommend this approach for CCMI model analysis

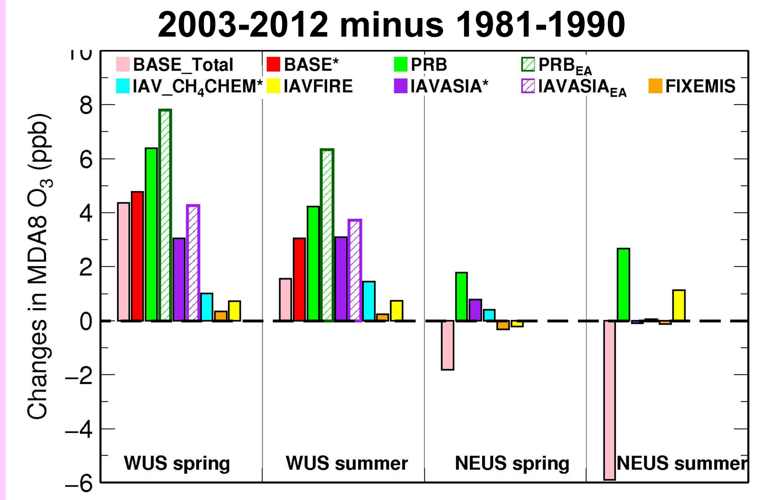
5. Interannual variability of Western U.S. O_3

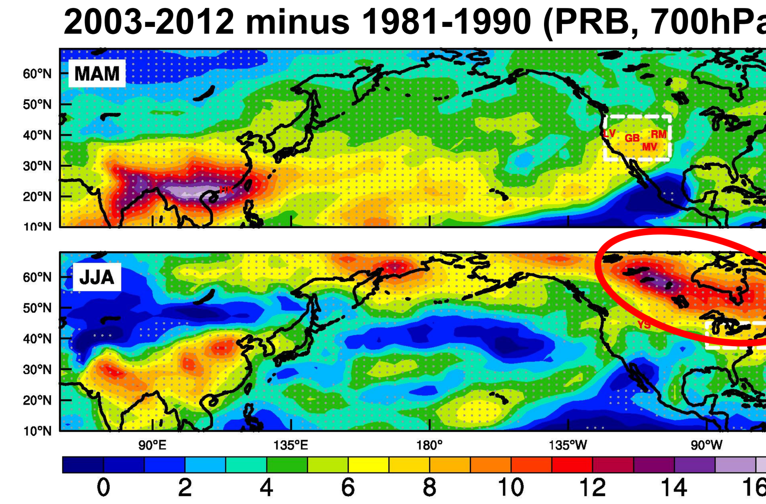




- **Climate variability modulates WUS O_3 through stratospheric influence**
- The model suggests that trends in the FT started in 1990s rather than 1980s
- **No signs of leveling off in springtime O_3 at remote sites in the 2000s**

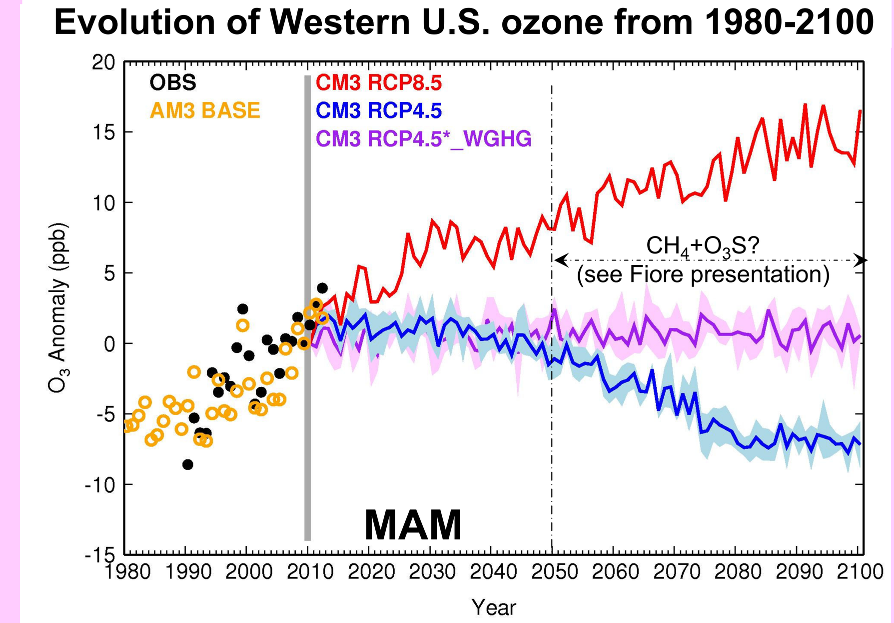
6. Rising Asian emissions drive most present-day O_3 increases



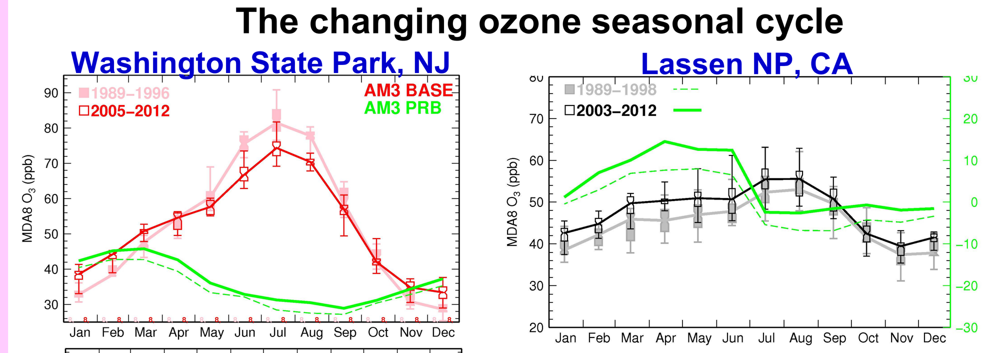


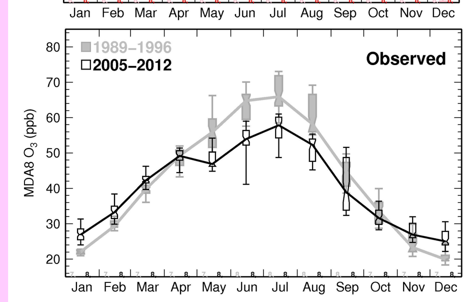
Increases from boreal fires w/ implications for a warming climate?

Evolution of Western U.S. ozone from 1980-2100



The changing ozone seasonal cycle





- AM3 captures the seasonal shift despite high biases
- Reduced local titration contributes to winter O_3 increases

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