Establishing process-oriented constraints on chemistry-climate models for projecting ozone air quality over the next century

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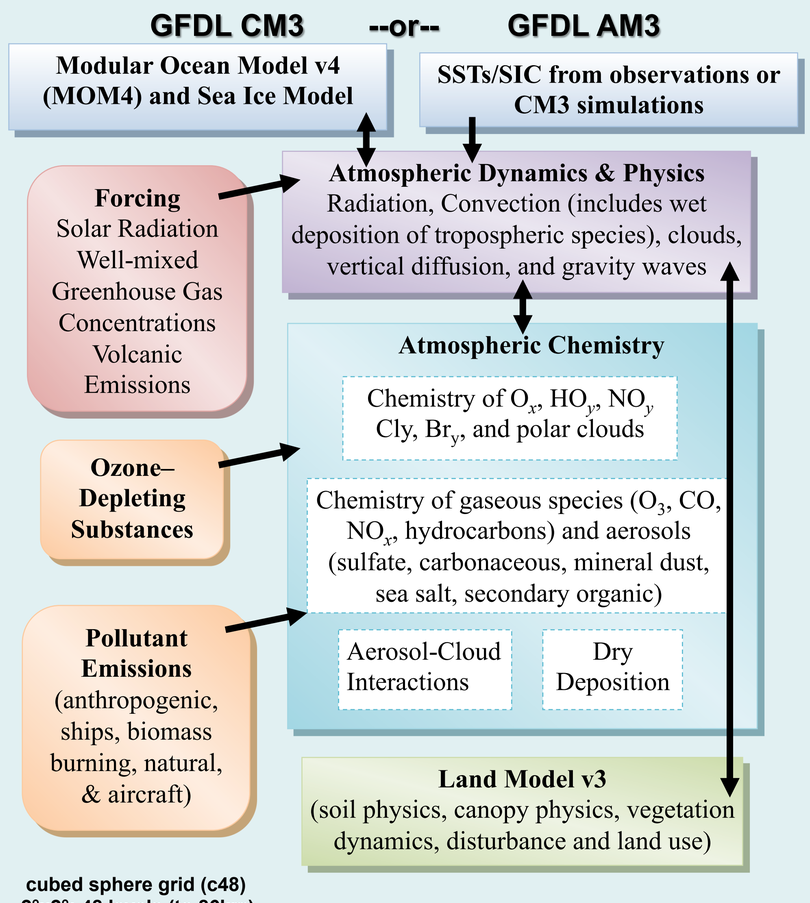
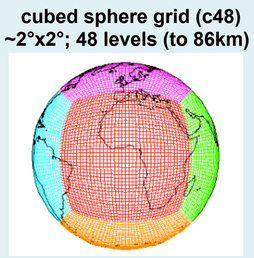
1. GFDL Chemistry-Climate Model

Donner et al., 2011; Golaz et al., 2011; Naik et al., in prep.



cubed sphere grid (c48) ~2°x2°; 48 levels (to 86km)

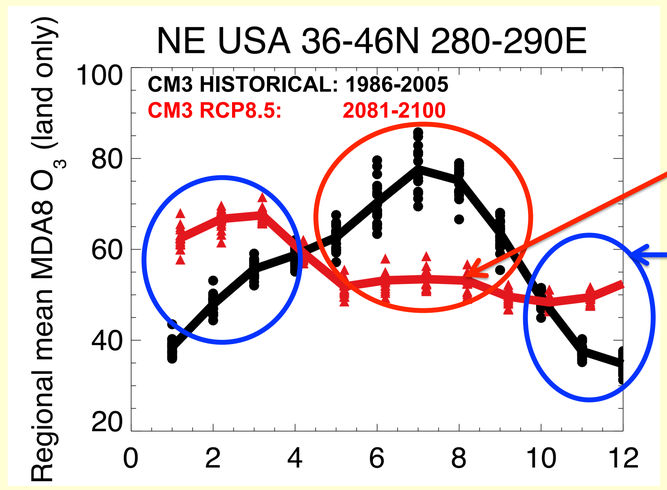


→ Over 6800 years CM3 CMIP5 simulations

→ AM3 nudged high-res. (c180,~0.5°x0.5°); analysis focused on the May-June 2010 NOAA CalNex field campaign

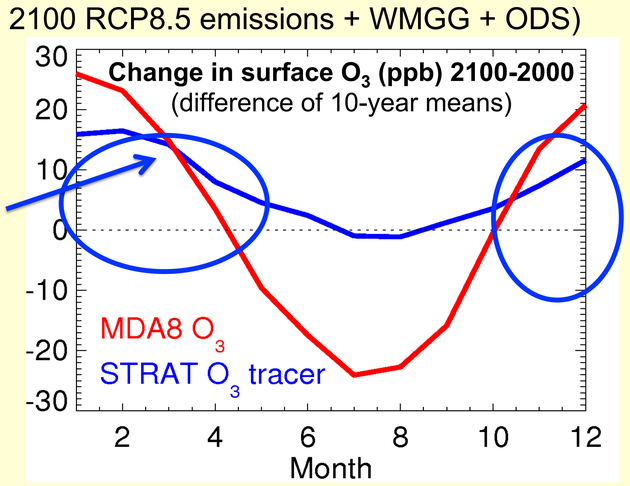
2. Reversal in surface O_3 seasonal cycle over NE USA by 2100?

AM3 ACCMIP simulations (10 years each with decadal average SSTs):
1) 2000 SSTs (+ 2000 emissions + WMGG + ODS)
2) 2100 SSTs (+ 2100 RCP8.5 emissions + WMGG + ODS)



N. Amer. NO_x decreases (>3x by 2100)

Strat. O_3 recovery+ climate-driven increase in STE? [*e.g., Butchart et al.*, 2006; *Hegglin & Shepherd*, 2009; *Kawase et al.*, 2011; *Li et al.*, 2008; *Shindell et al.* 2006; *Zeng et al.*, 2010]



- **Extreme warming with aggressive NO_x controls implies shift in regional vs. background O_3.**
- **How well represented are surface O_3 impacts of (1) strat-to-trop O_3 transport and (2) climate warming, particularly in light of base-state biases?**

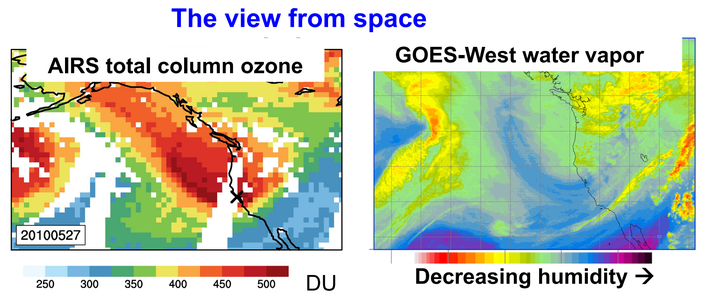
→ Below are first steps to evaluate key processes in GFDL AM3/CM3

3. Influence of stratospheric intrusions on surface O_3

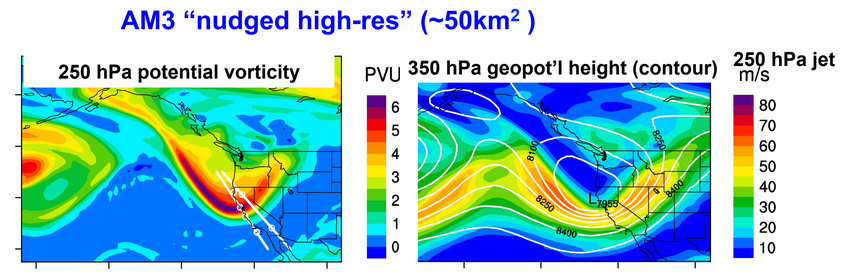
Western U.S is a particularly active region for deep stratospheric intrusions in present climate [*Sprenger and Wernli*, 2003]
Spring 2010 NOAA field campaign provides a wealth of *in situ* data to evaluate AM3 (pressure-dependent nudging to reanalysis winds)

Evaluation of upper level dynamics associated with a deep stratospheric O_3 intrusion (21:00UTC May 27, 2010)

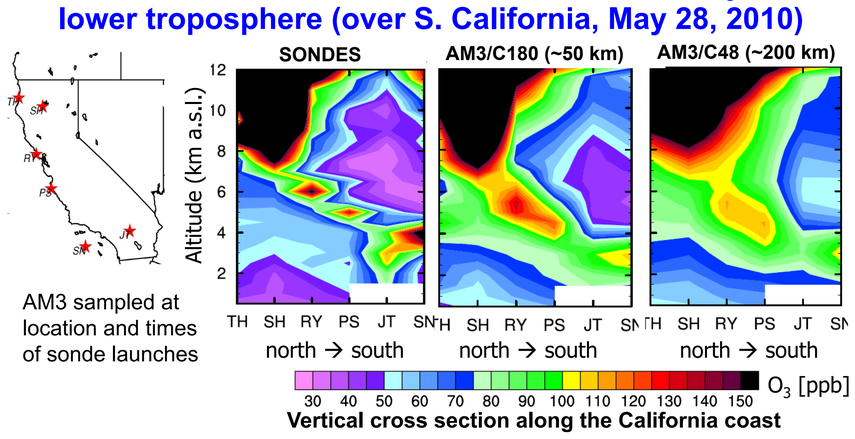
The view from space



AM3 "nudged high-res" (~50km²)

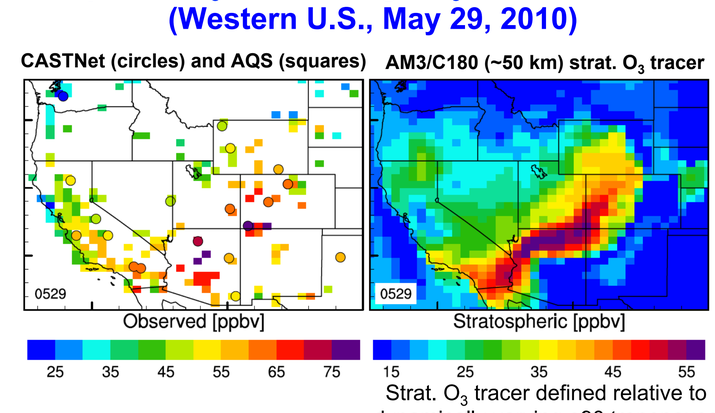


Evaluation of subsidence of stratospheric O_3 to lower troposphere (over S. California, May 28, 2010)



AM3 sampled at location and times of sonde launches

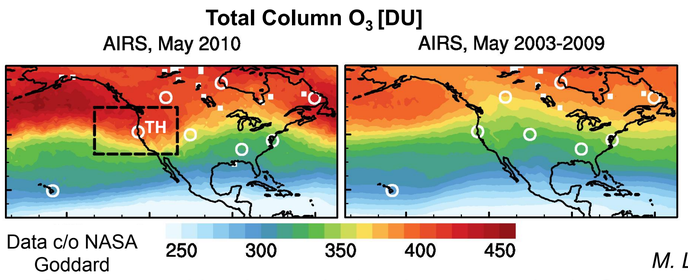
Stratospheric O_3 leads to high-O_3 events in surface air (Western U.S., May 29, 2010)

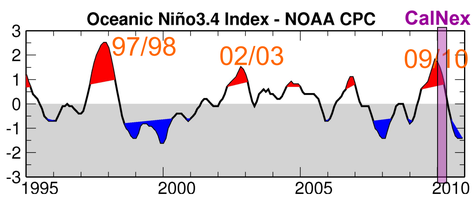


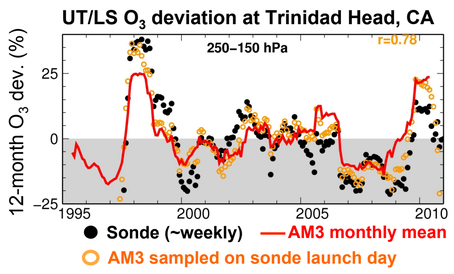
Strat. O_3 tracer defined relative to dynamically varying e90 tropopause [*Prather et al.*, 2011]

M. Lin et al., to be submitted to JGR, CalNex special issue

How typical is spring 2010?







M. Lin et al., in prep.

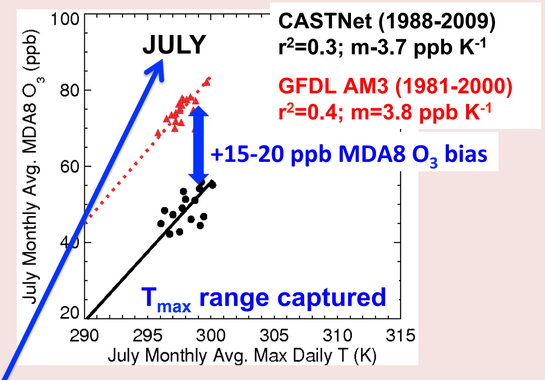
→ Consistent with prior work showing tropospheric O_3 varies with ENSO via STE and transport [*e.g., Langford et al.*, 1998; *Ziemke & Chandra*, 2003; *Koumoutsaris et al.*, 2008]

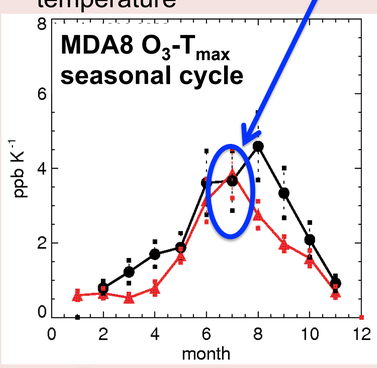
4. O_3-temperature relationships

Evaluation of monthly mean MDA8 O_3 vs. T_{max}

AM3 model driven by observed sea surface temperatures and sea ice for 1981-2000

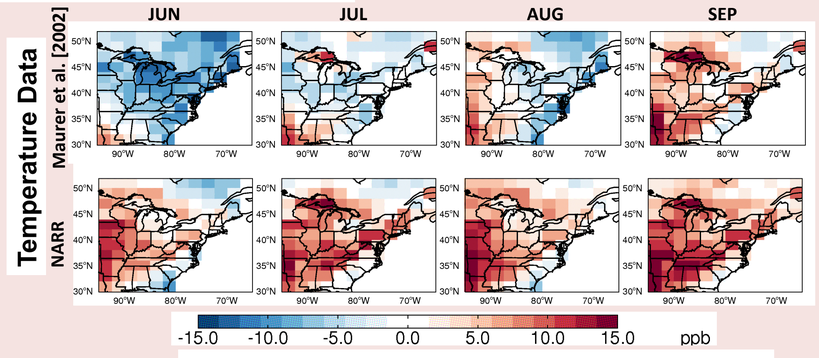
We average over all NE USA CASTNet sites (one value per year for each month) to isolate the regional response of O_3 to temperature





Despite MDA8 O_3 bias, sensitivity to year-to-year variations in T_{max} is broadly reproduced by GFDL AM3 over NE USA.

We estimate impacts of T_{max} biases on MDA8 O_3 biases, assuming a regional mean relationship of 3 ppb K^{-1}:



MDA8 O_3 bias due to temperature bias
→ up to 10-15 ppb; not major driver in NE USA

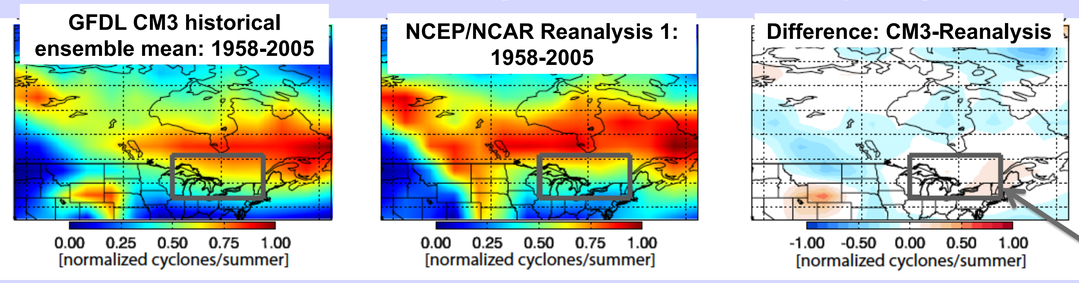
Rasmussen et al., 2012

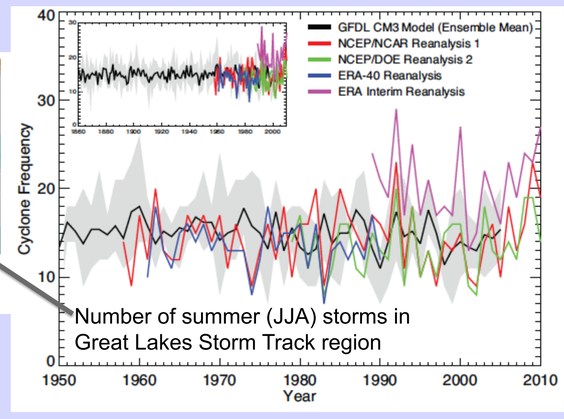
Does a model's ability to capture observed O_3-T relate to its O_3 response to climate warming? (Future work)

5. Summertime cyclone frequency over NE USA

Leibensperger et al. [2008] show a strong anti-correlation in summer between (a) number of migratory cyclones over Southern Canada/ NE U.S. and (b) number of stagnation events and associated NE USA high-O_3 events. These stagnation episodes are a major driver of the observed surface O_3-T correlation over the NE USA [*e.g., Jacob et al.*, 1993]. Following *Leibensperger et al.* [2008], we diagnose cyclones from 6-hourly sea level pressure with MCMS software from Mike Bauer, (Columbia U/GISS).

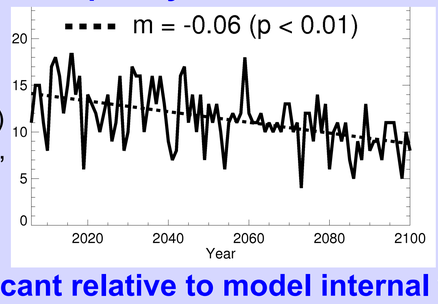
Evaluation of summertime cyclone location and frequency





Changes in storm frequency under an extreme climate warming scenario

Number of storms each summer (JJA) in GFDL CM3, RCP8.5



Relationship between high-O_3 events and storms [Leibensperger et al., 2008]

Decrease in storms per summer in GFDL CM3 by 2100 under RCP8.5

Additional high-O_3 events due to impact of climate warming on storm frequency

$$\left(-4\left[\frac{\text{exceedances}}{\text{cyclone}}\right]\right)\cdot\left(-6\left[\frac{\text{cyclones}}{\text{summer}}\right]\right)=+24\left[\frac{\text{exceedances}}{\text{summer}}\right]$$

A. Turner et al., in prep

→ Trend significant relative to model internal variability (875 year control simulation; 100-year "chunks": 0.06 < p <0.88; -0.01<m<0.02 a^{-1})

→ Not clear yet whether this finding is robust across models [*e.g., Lang and Waugh*, 2011]

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