UNIVERSITY OF TORONTO

AN NSERC CREATE PROGRAM
IACPES
INTEGRATING ATMOSPHERIC CHEMISTRY AND PHYSICS FROM EARTH TO SPACE

The sensitivity of summer time surface ozone concentrations to dry deposition in the United States

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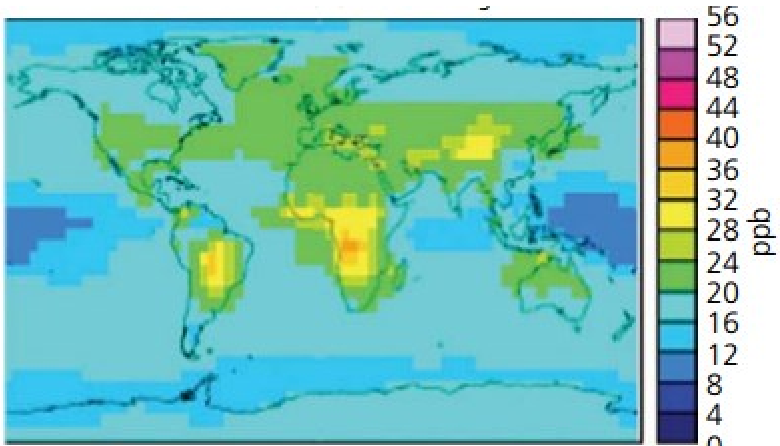
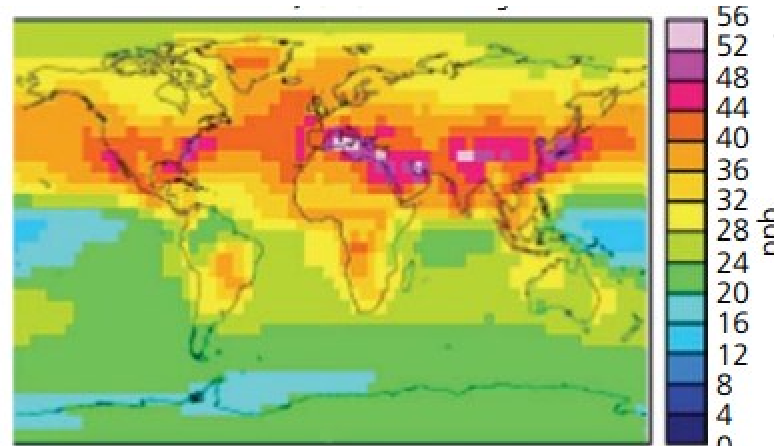
Department of Chemistry, University of Toronto

Acid Rain Conference 2015, Rochester, NY., October 22nd, 2015

Why study surface ozone?



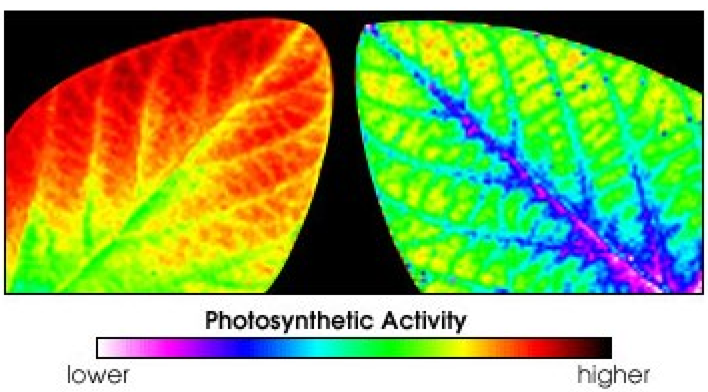
Pre-industrial surface ozone



(1)

Present-day surface ozone

Leaves Grown in
Low Ozone Environment vs High Ozone Environment



(3)

Ozone disruption of photosynthesis

(2)

Ozone damage to vegetation

(1) The Royal Society, 2008. (2) Gerald Holmes, UDA-ARS Air Quality Program. (3) Kim et al., *Applied Optics,* 2001.

Ozone in CASTNET

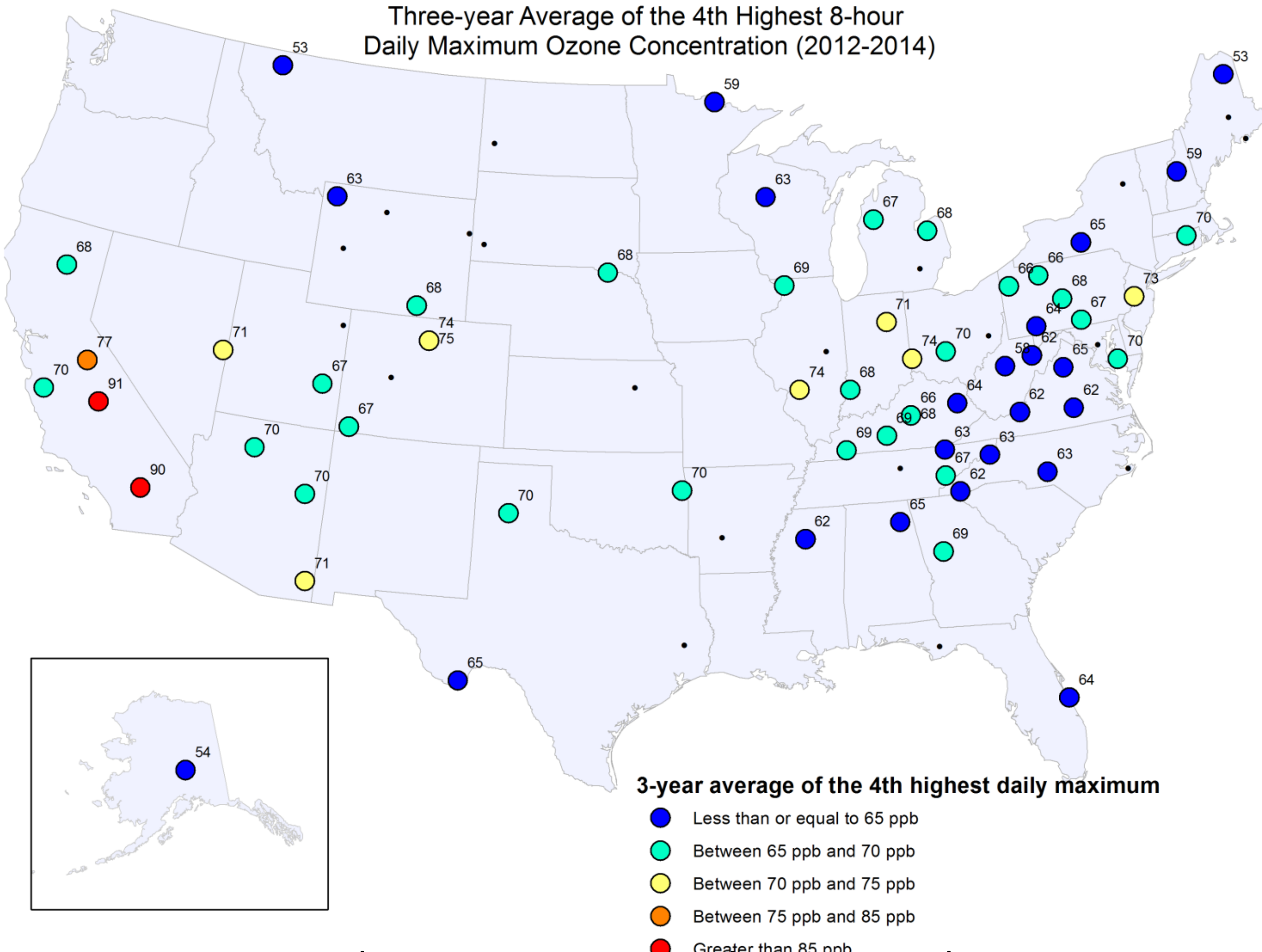
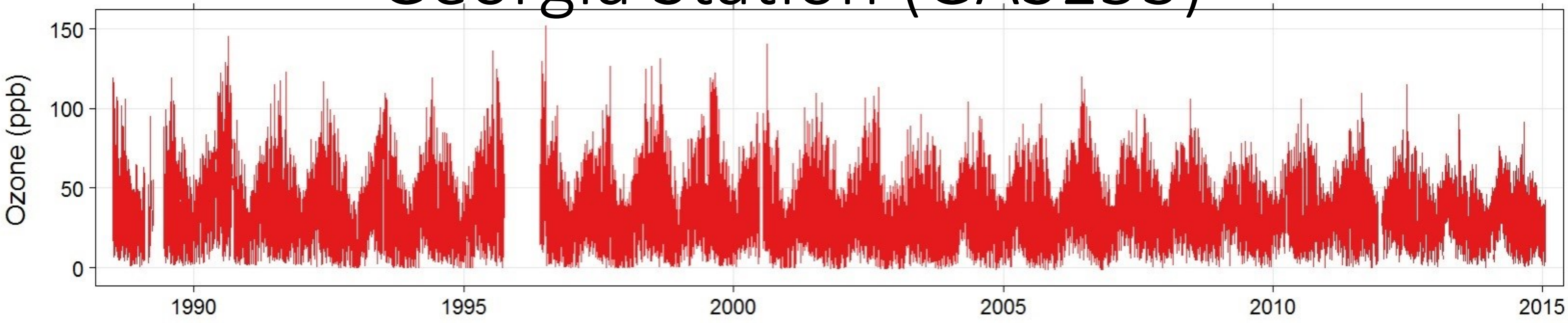


Image: U.S. Environmental Protection Agency Clean Air Markets Division
Clean Air Status and Trends Network (CASTNET)

Ozone in CASTNET
Georgia Station (GAS153)



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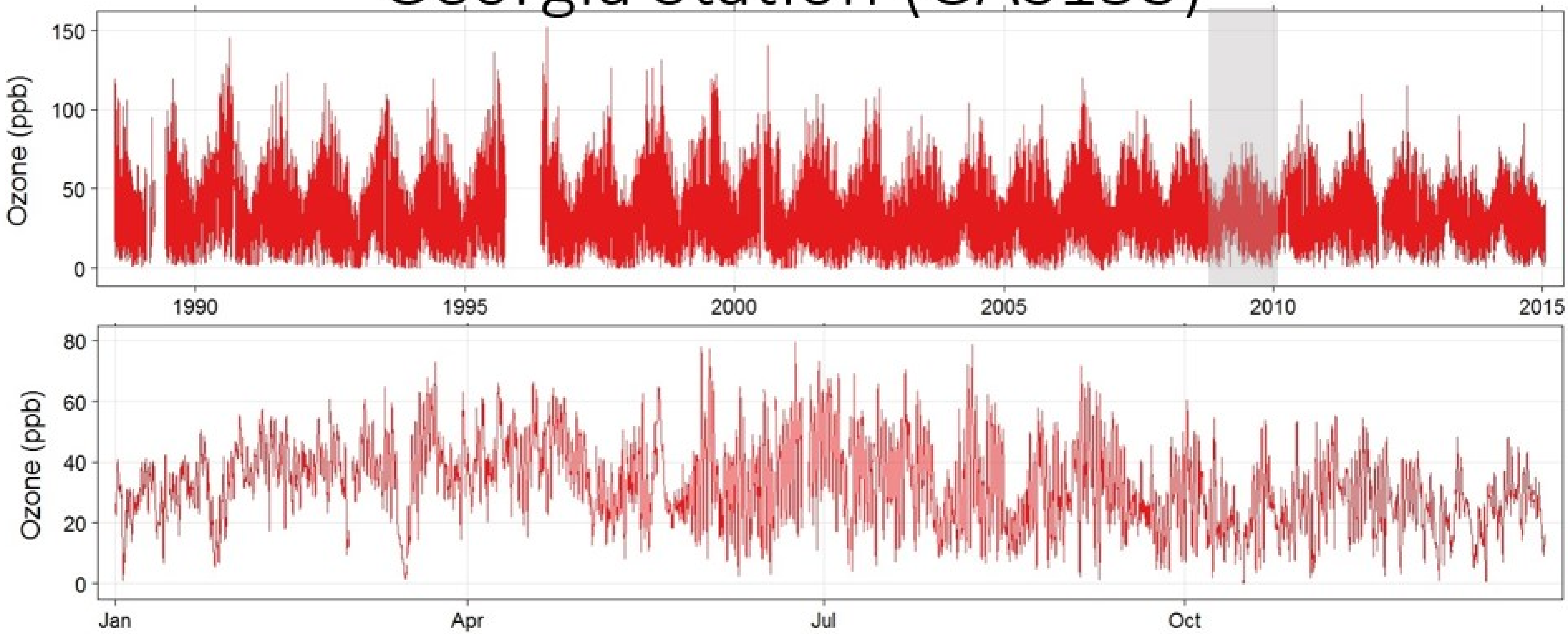

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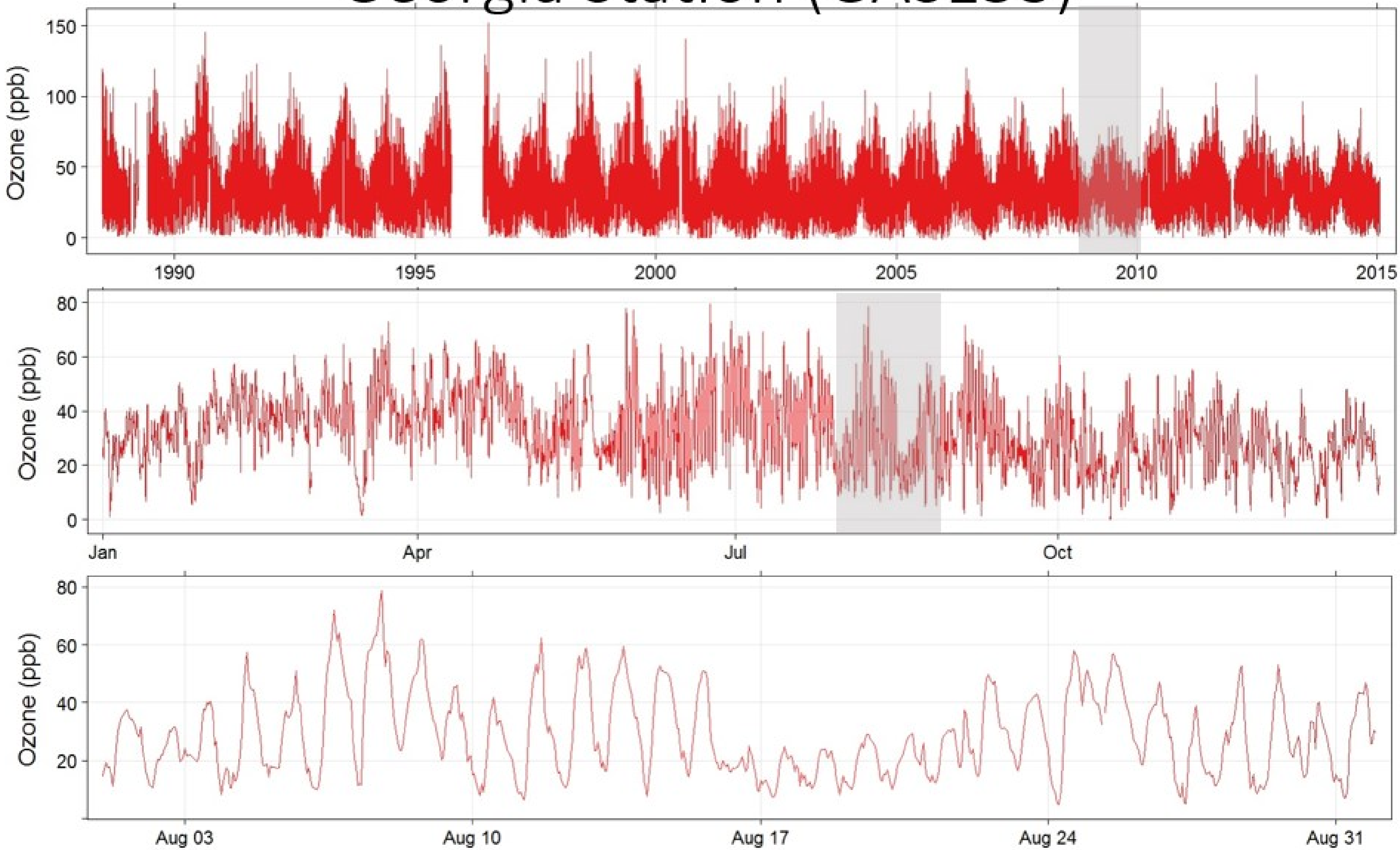
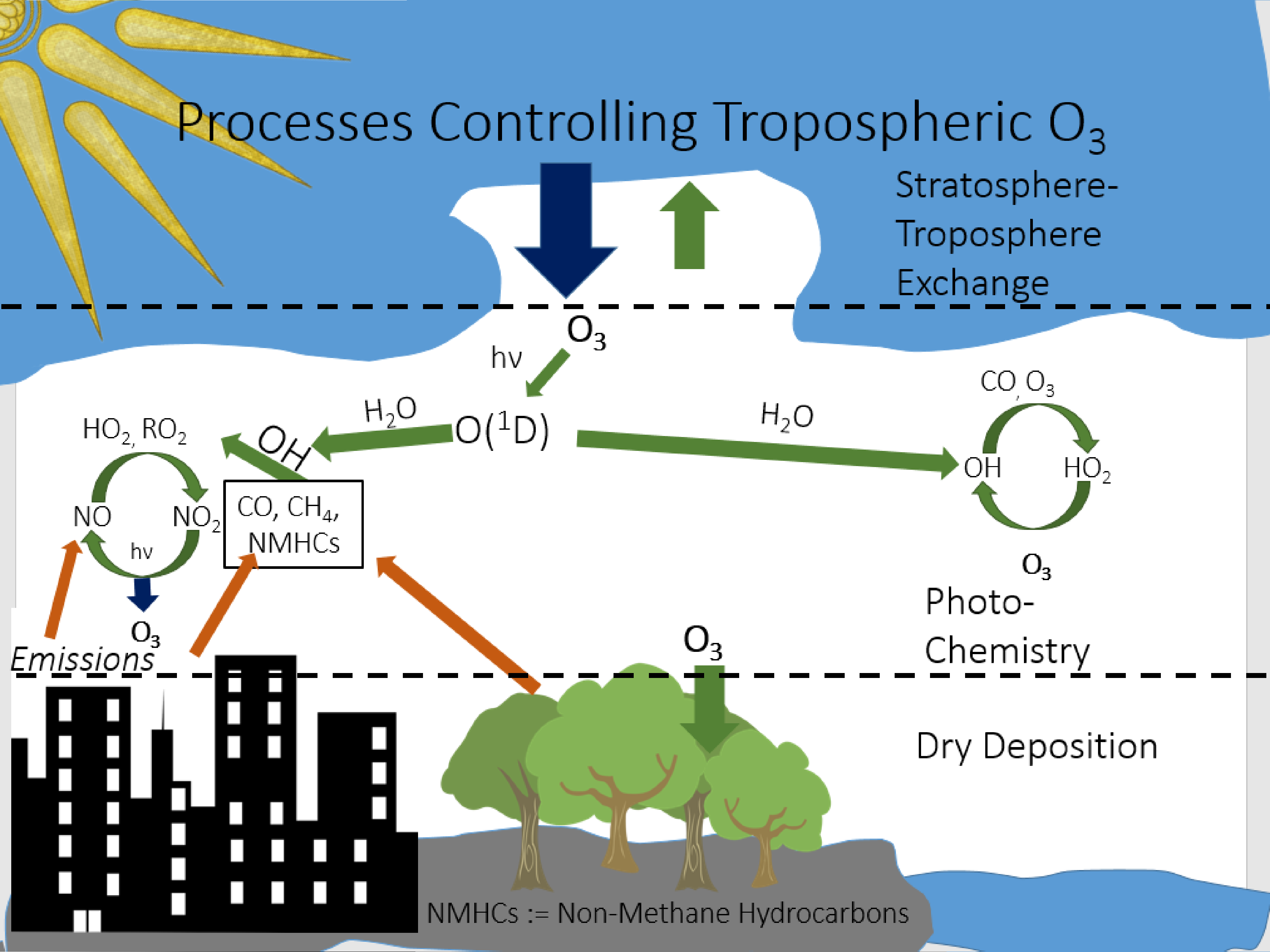
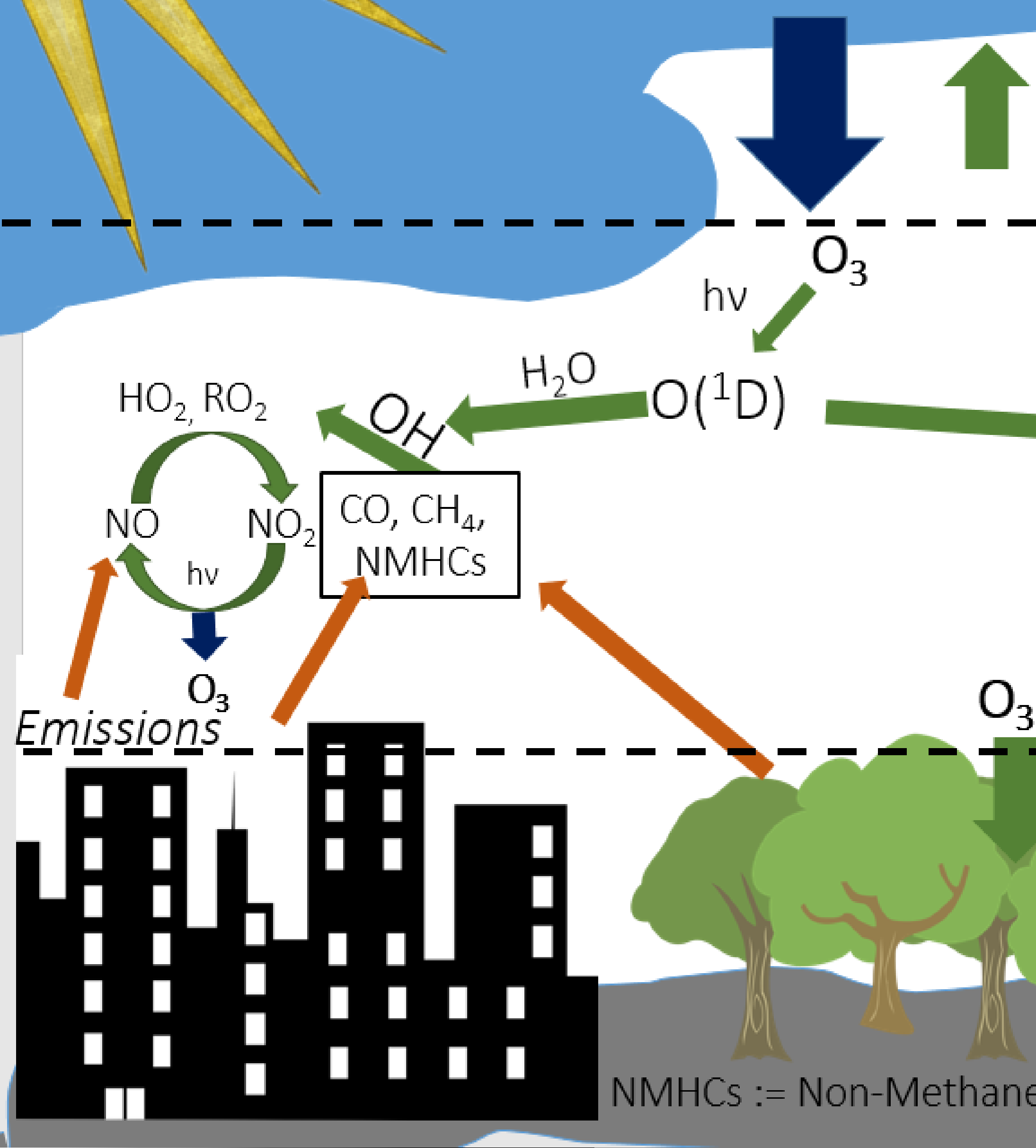




Processes Controlling Tropospheric O_3
Stratosphere-Troposphere Exchange
O_3
hν
$O(^1D)$
H_2O
OH
H_2O
HO_2, RO_2
NO
NO_2
hν
O_3
CO, CH_4, NMHCs
CO, O_3
OH
HO_2
O_3
Photo-Chemistry
Emissions
O_3
Dry Deposition
NMHCs := Non-Methane Hydrocarbons

Processes Controlling Tropospheric O_3



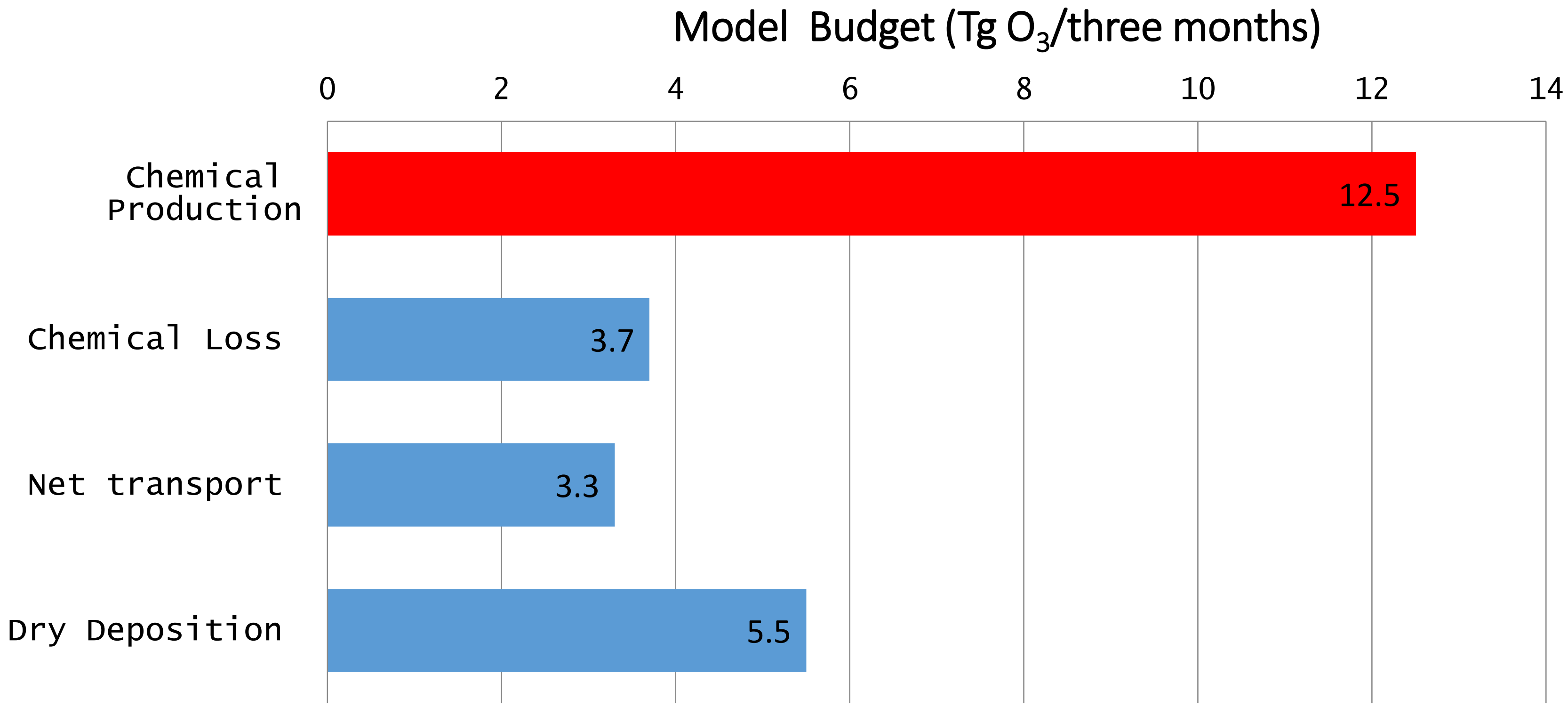
S-T E: Governed by mixing

Chemistry: O_3 production is non-linear, dependent on emissions and meteorology

Deposition: Highly dependent on surface composition

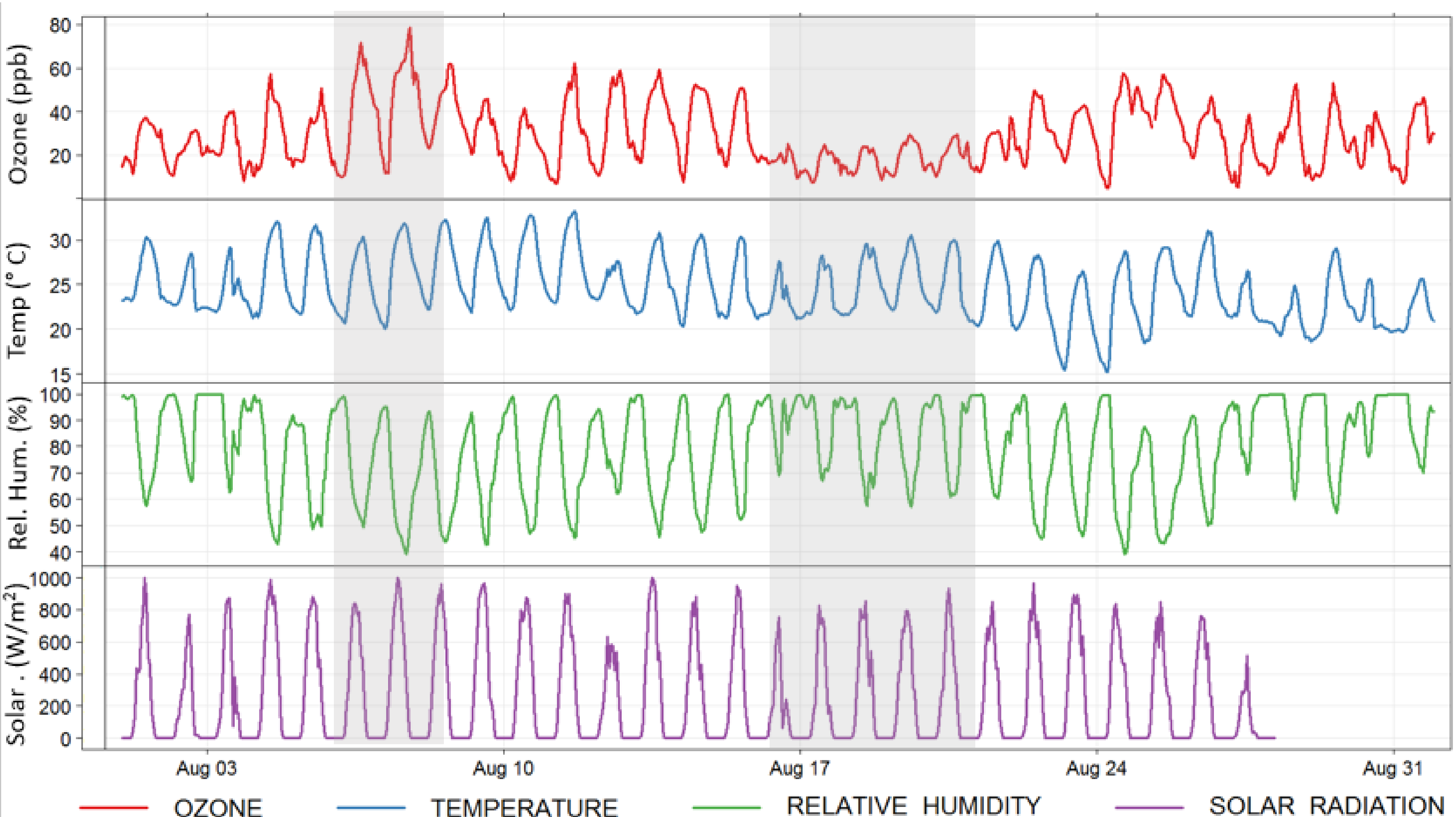
North American PBL Ozone Budget

Summer-time planetary boundary layer (984–934 hPa) ozone budget over the Southeast and Midatlantic United States (95–75∘W and 28–40∘N)



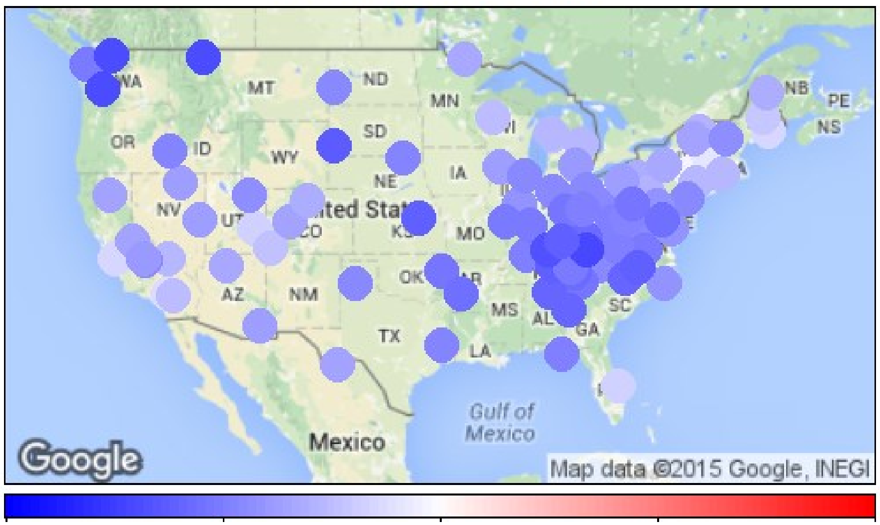
Racherla and Adams, *The response of surface ozone to climate change over the Eastern United States*, Atmos. Chem. Phys., 8, 871–885, 2008.

Data in CASTNET
Georgia Station (GAS153)



Meteorological Controls on Ozone

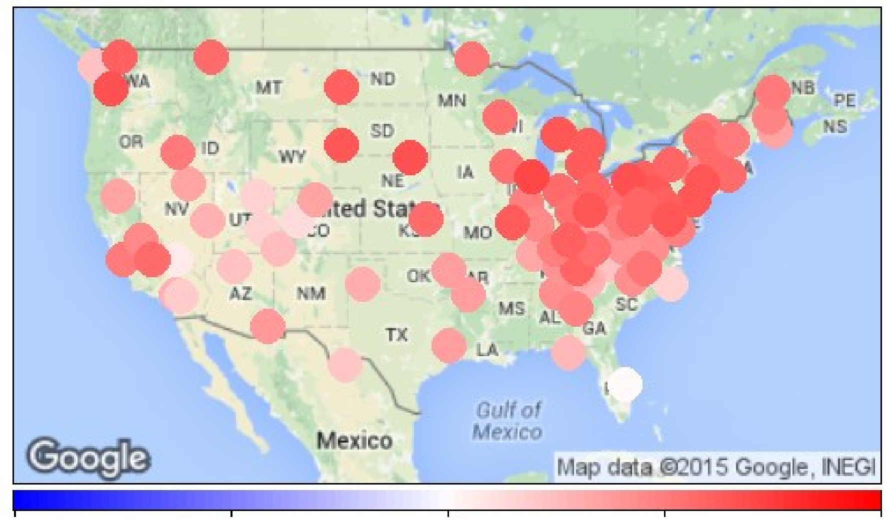
Summer p(RH,Ozone)



1.0 -0.5 0.0 0.5 1.0

p(Relative Humidity,Ozone)

Summer p(T,Ozone)

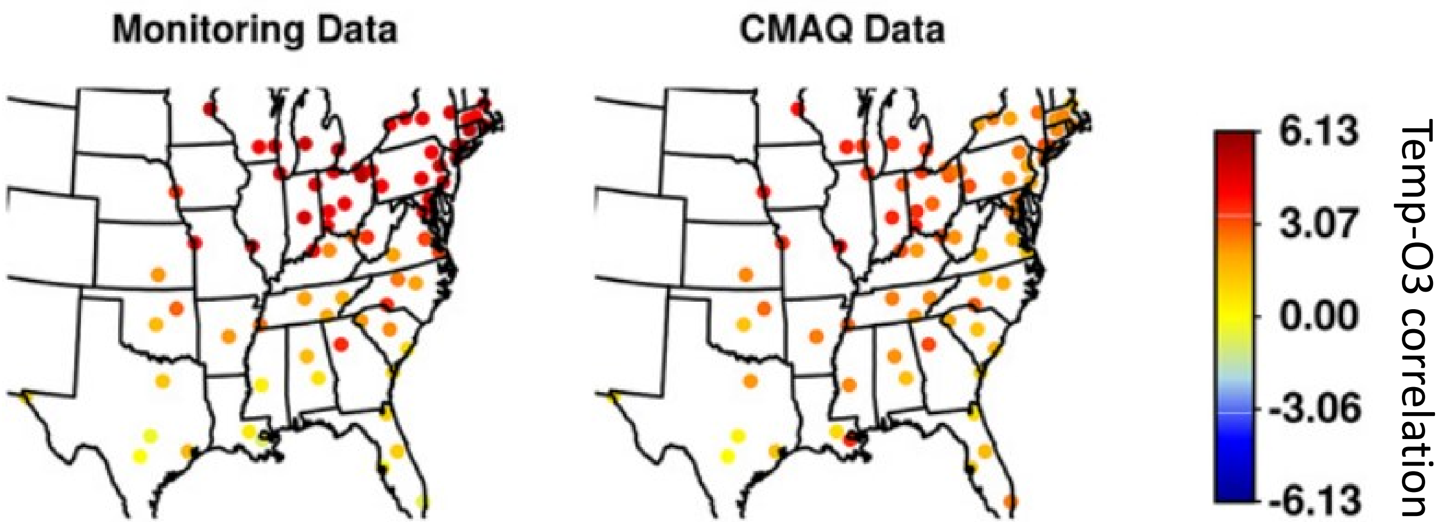


-1.0 -0.5 0.0 0.5 1.0

p(Temperature,Ozone)

Summer (June, July, August) observed midday (12-4pm) Pearson's correlation coefficient of ozone versus relative humidity a) and b) temperature from 1987 to 2015 at CASTNET stations.

Ozone-Met Correlations in CMAQ

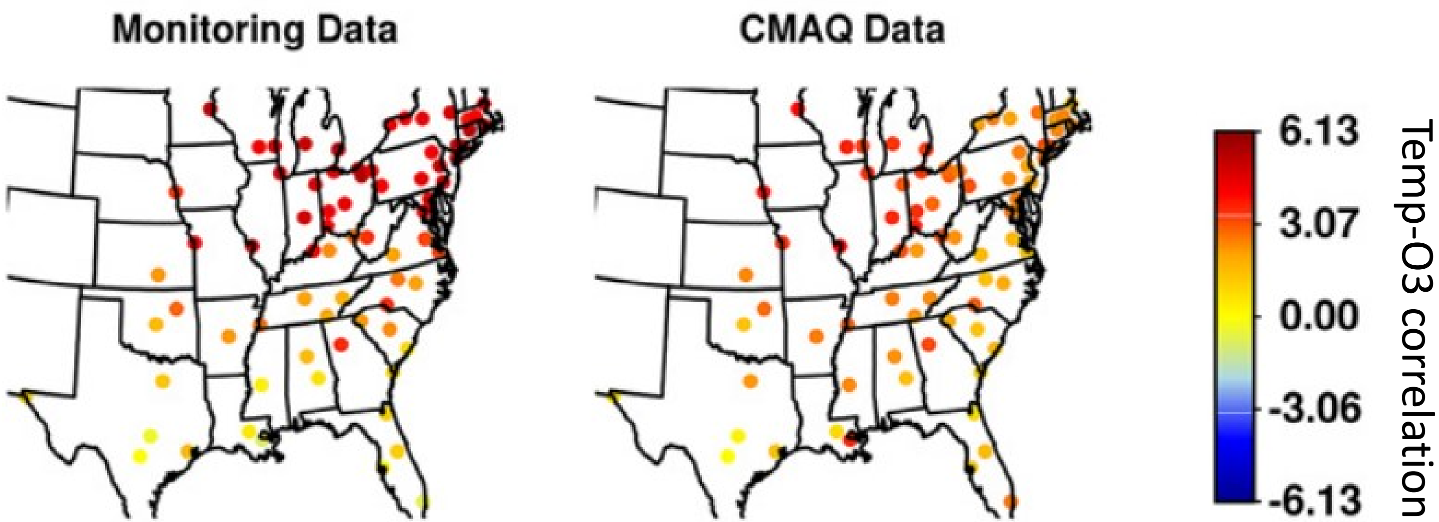


May 1st-September 30th

Temperature-O_3 correlation reasonable well captured by model

Davis et al., *Atmos. Env.* , 2011.

Ozone-Met Correlations in CMAQ



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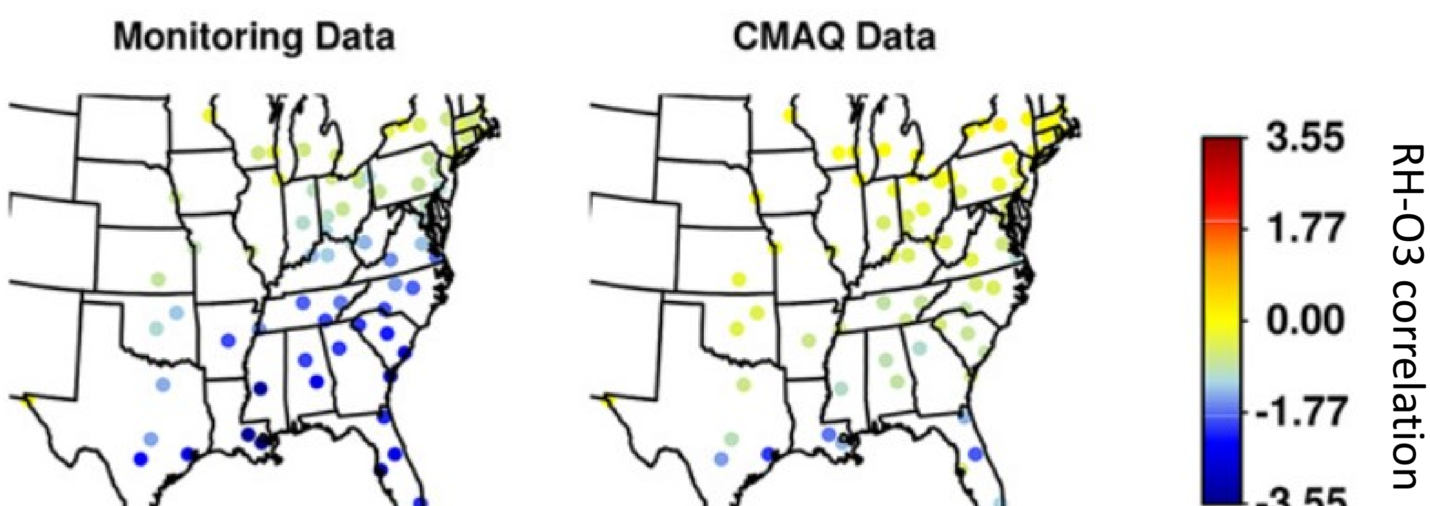
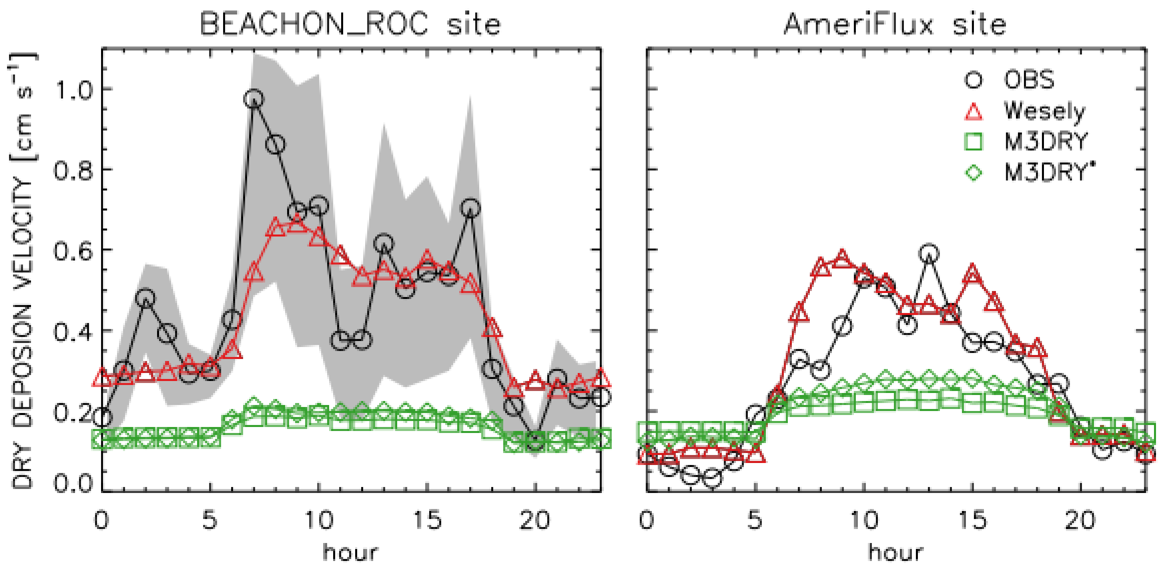


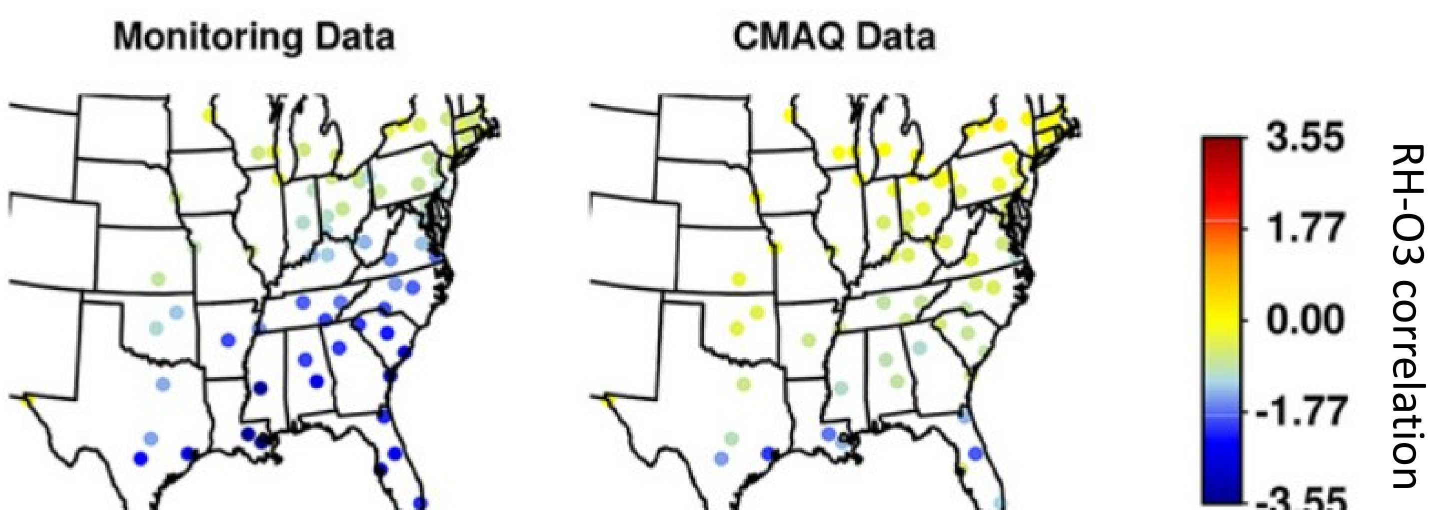
Relative Humidity-O_3 correlation poorly captured by model.

Davis et al., *Atmos. Env.* , 2011.

Ozone-Met Correlations in CMAQ



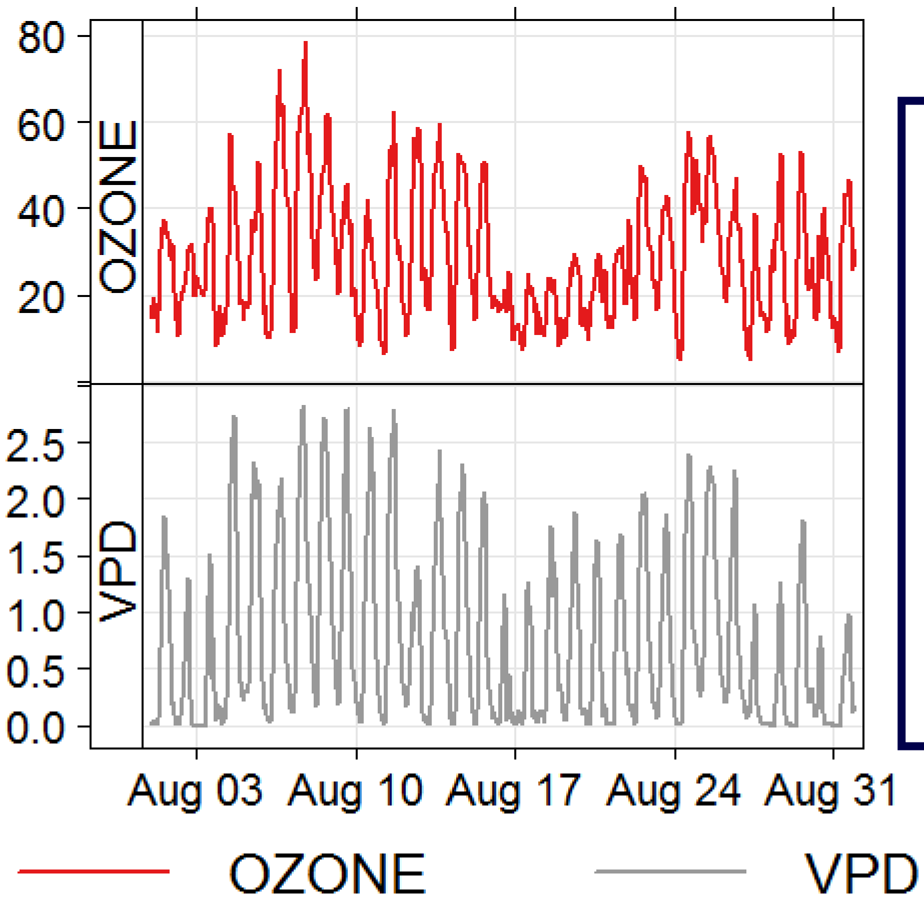
A comparison of the simulated and observed hourly mean O_3 dry deposition velocities. M3DRY is the deposition scheme used in CMAQ. Wesely is a popular alternative.



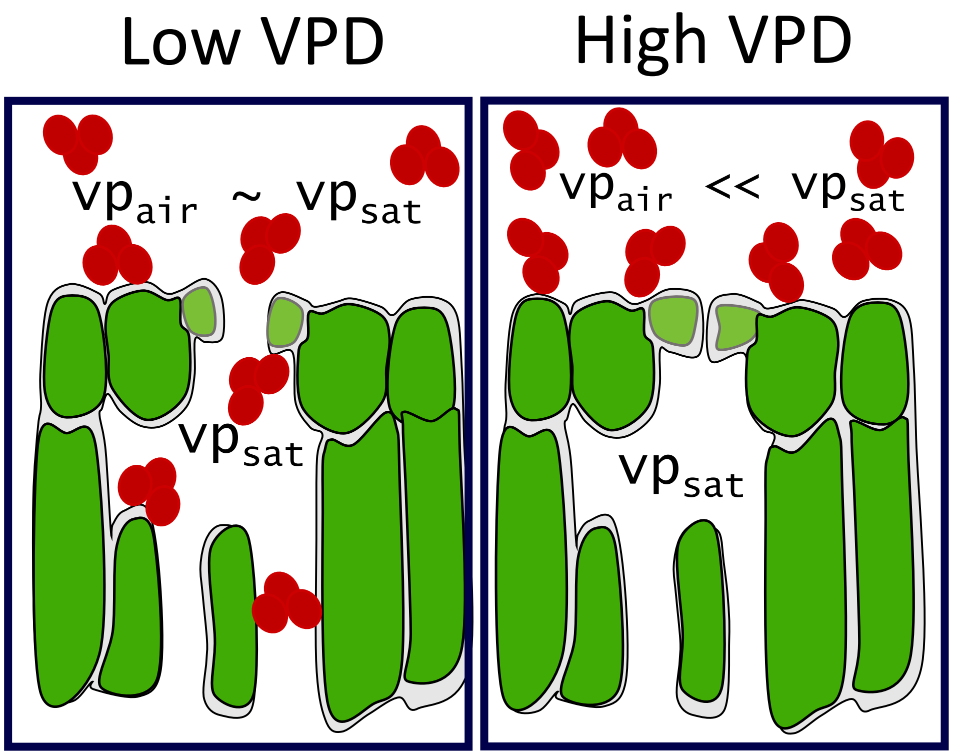
Relative Humidity-O_3 correlation poorly captured by model.

Park et al., *ACP*, 2014. Davis et al., *Atmos. Env.* , 2011.

Ozone-Met Correlations: Role of Deposition?



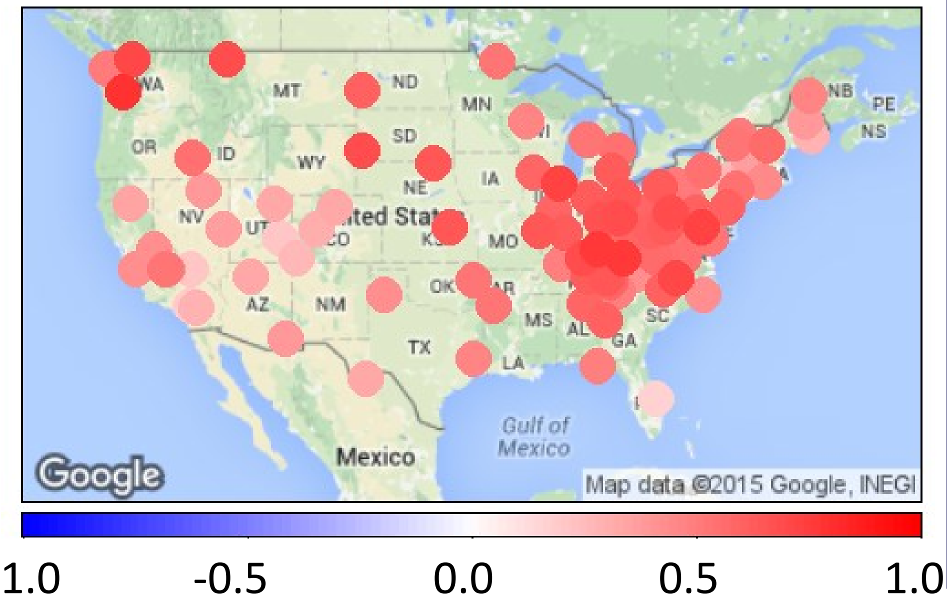
Georgia Station (GAS153), 2009



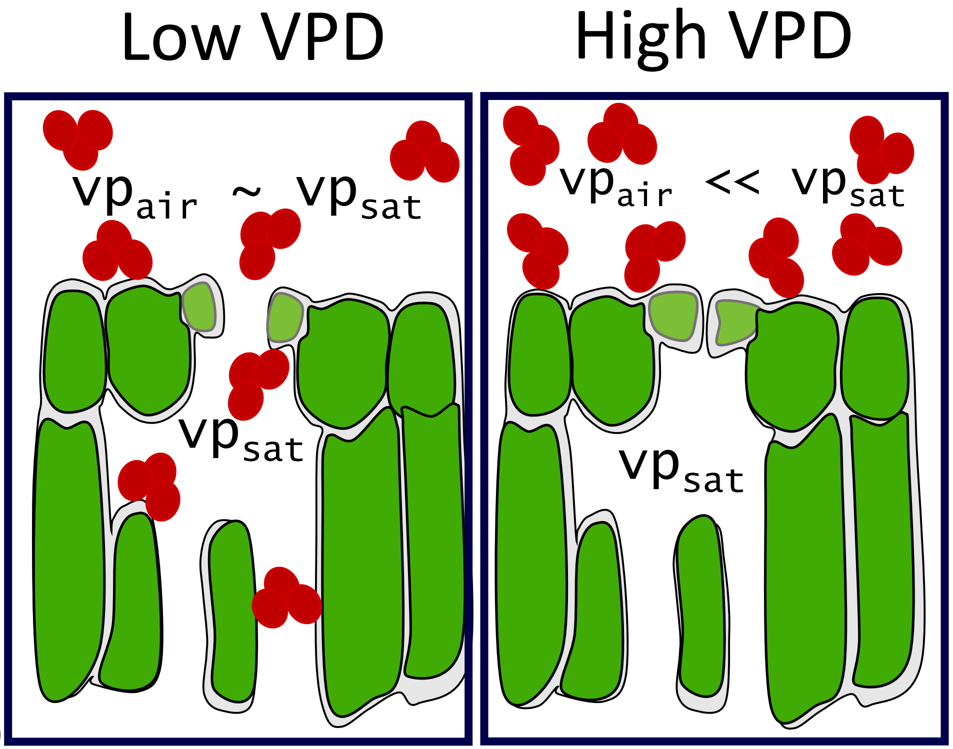
Vapour Pressure Deficit (VPD) = vp of H_2O in air – saturated vapour pressure

Ozone-Met Correlations: Role of Deposition?

Summer p(VPD,Ozone)



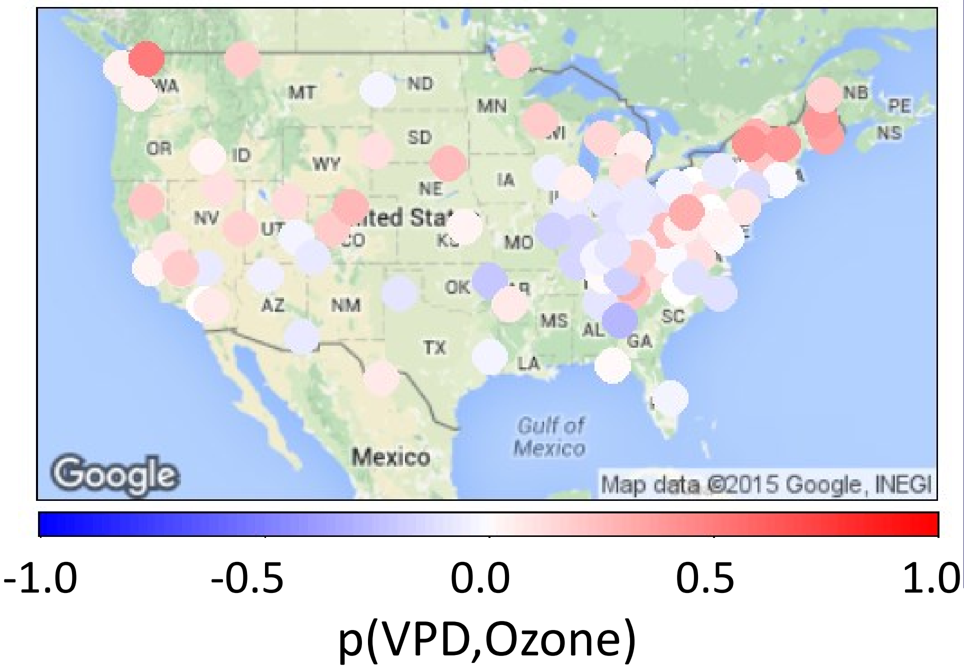
p(VPD,Ozone)

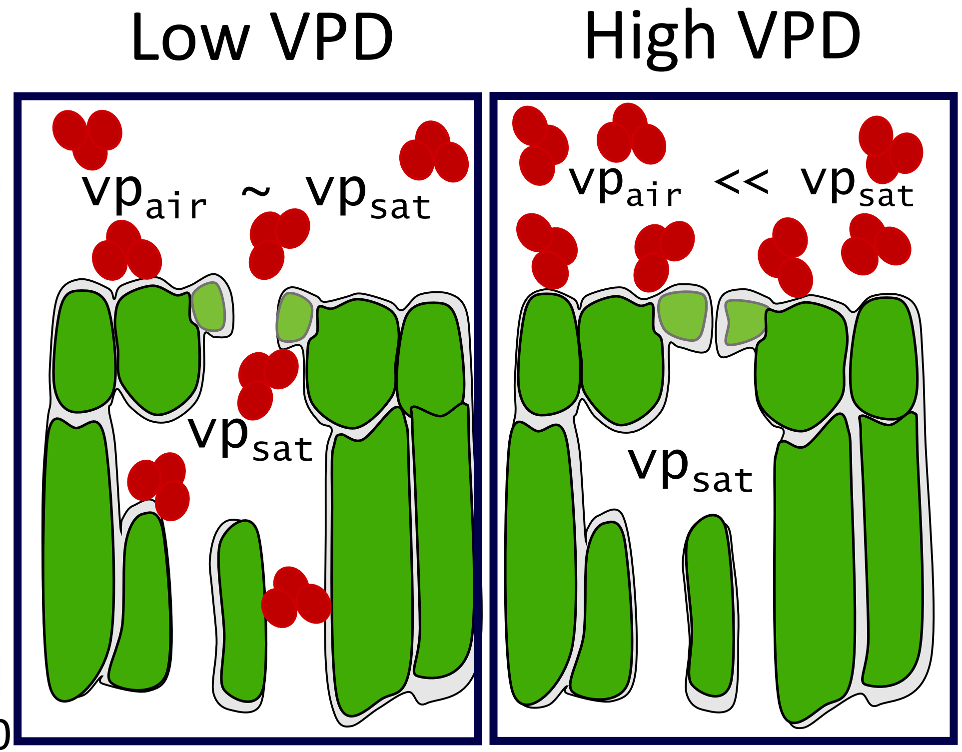


Afternoon VPD and afternoon ozone are well correlated at most CASTNET sites in the summer. The correlation is stronger on average that that of temperature or relative humidity.

Ozone-Met Correlations: Role of Deposition?

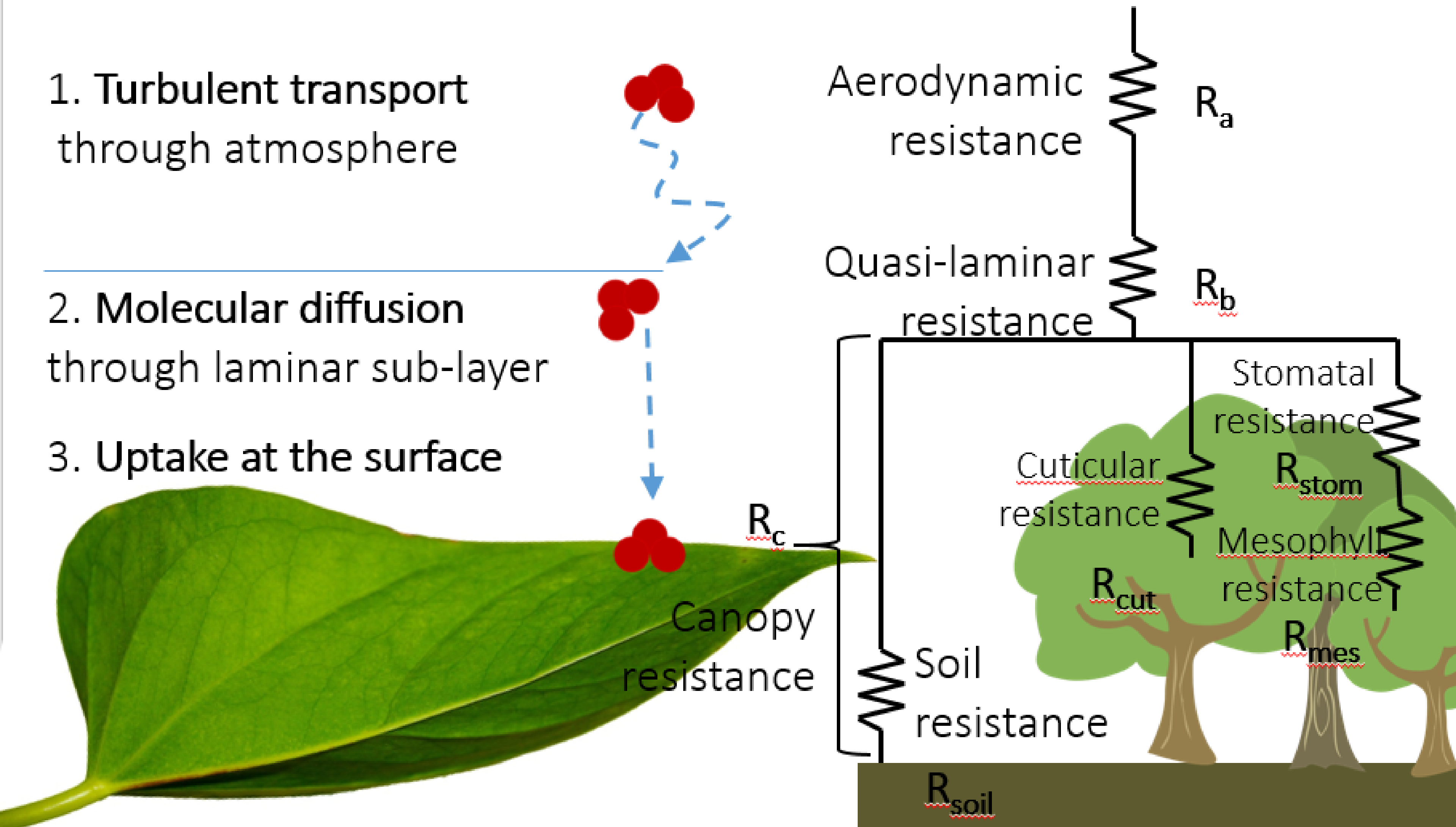
Winter p(VPD,Ozone)





Afternoon VPD and afternoon ozone are poorly correlated at most CASTNET sites in the winter.

Modelling Dry Deposition A Resistance Approach



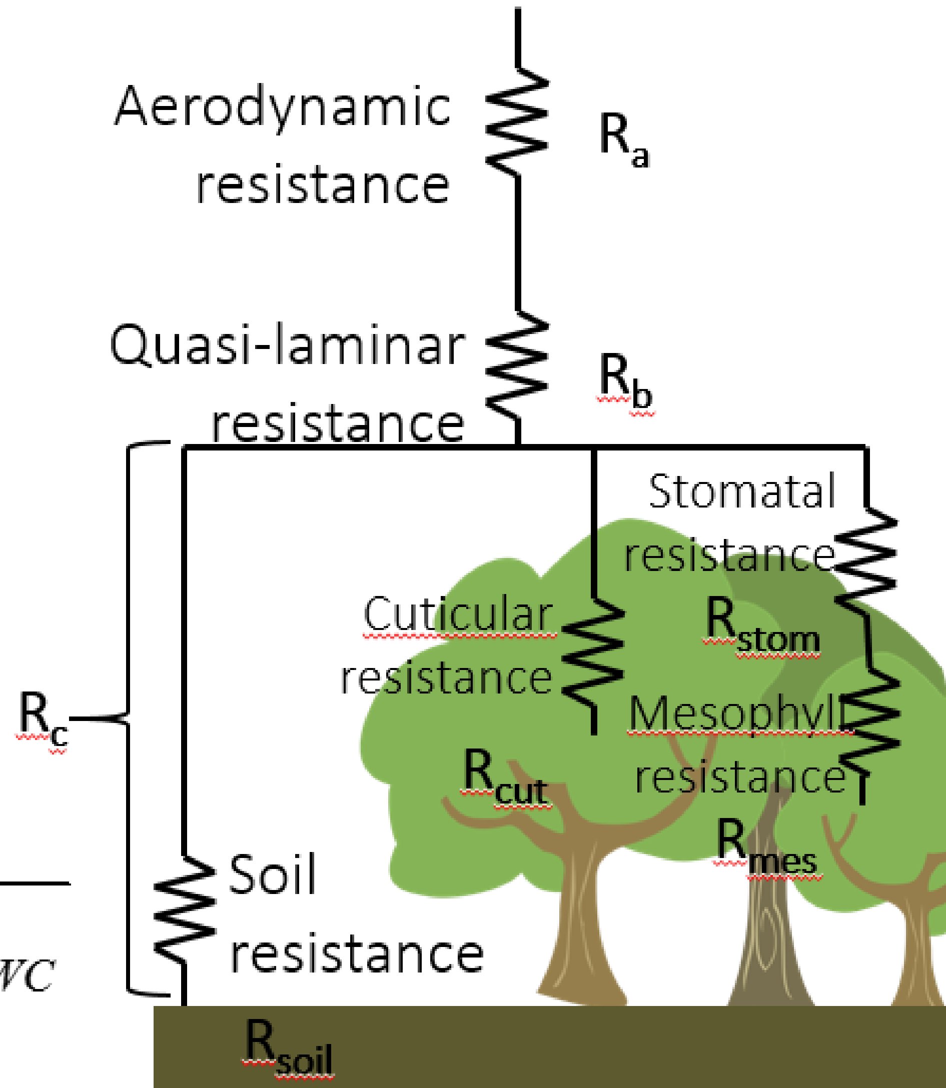
Modelling Dry Deposition
A Resistance Approach

$$V_d = \frac{1}{R_a + R_b + R_c}$$

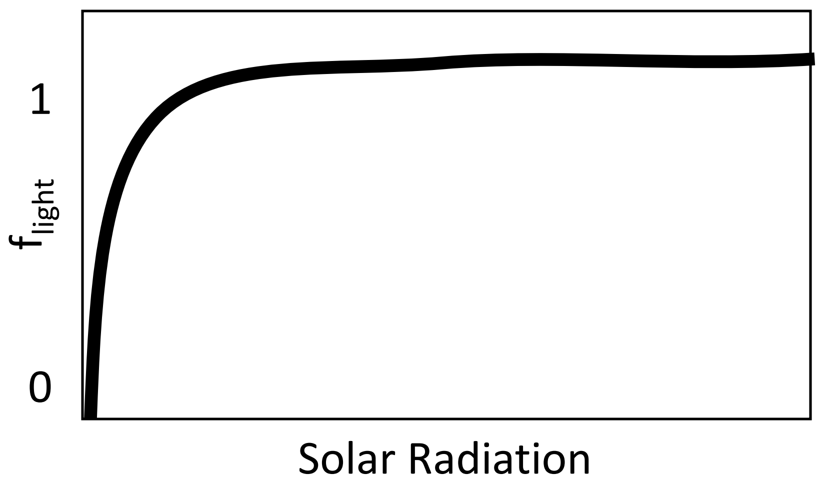
$$R_c = \frac{1}{R_{stom} + R_{mes}} + \frac{1}{R_{cut}} + \frac{1}{R_{soil}}$$

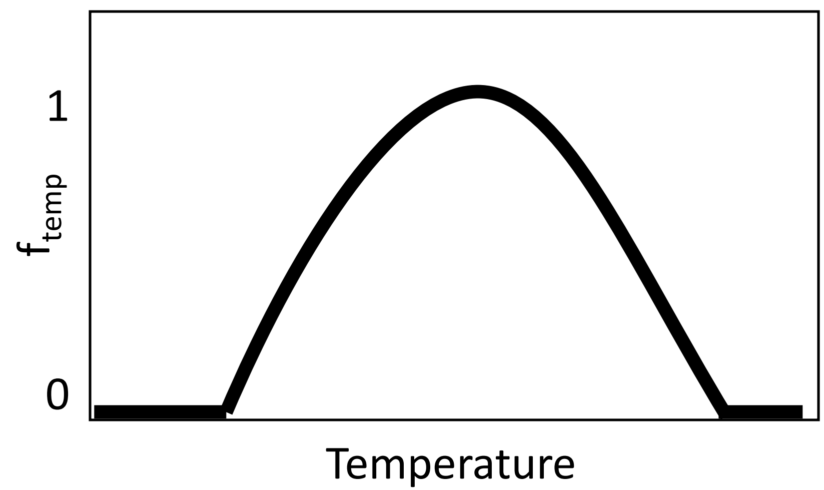
Jarvis multiplicative approach:

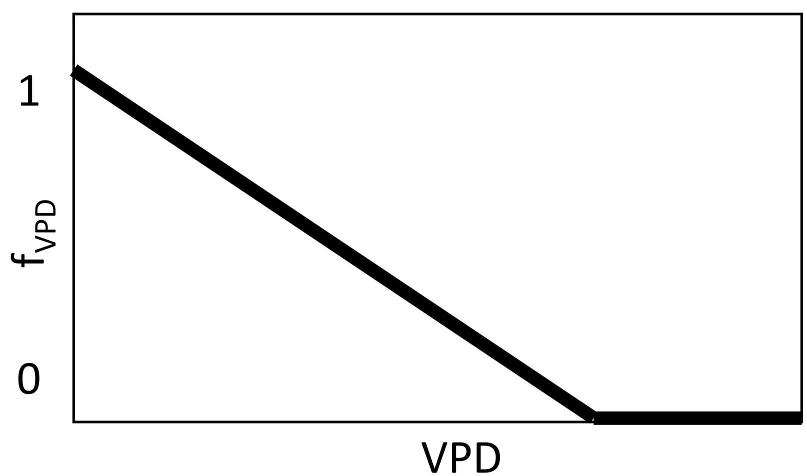
$$R_{stom} = \frac{R_{\min}}{f_{phen} f_{light} f_{Temp} f_{VPD} f_{SWC}}$$



Modelling Dry Deposition Jarvis Approach

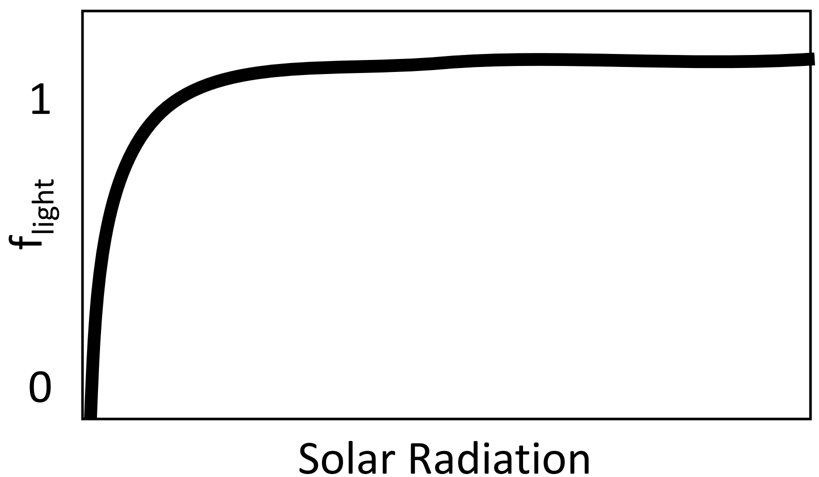


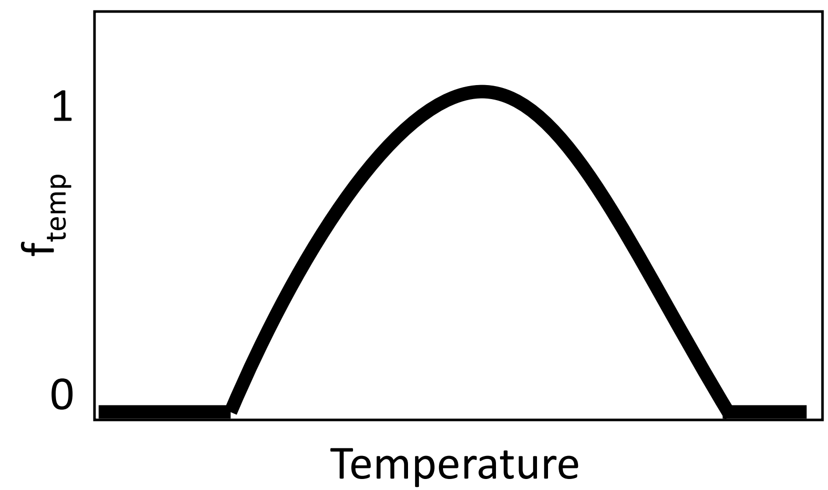


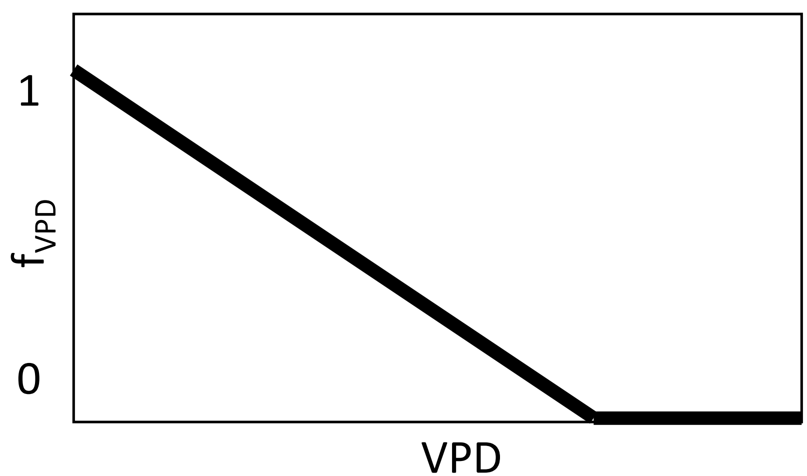


$$R_{stom} = \frac{R_{\min}}{f_{phen} f_{light} f_{Temp} f_{VPD} f_{SWC}}$$

Modelling Dry Deposition
Jarvis Approach





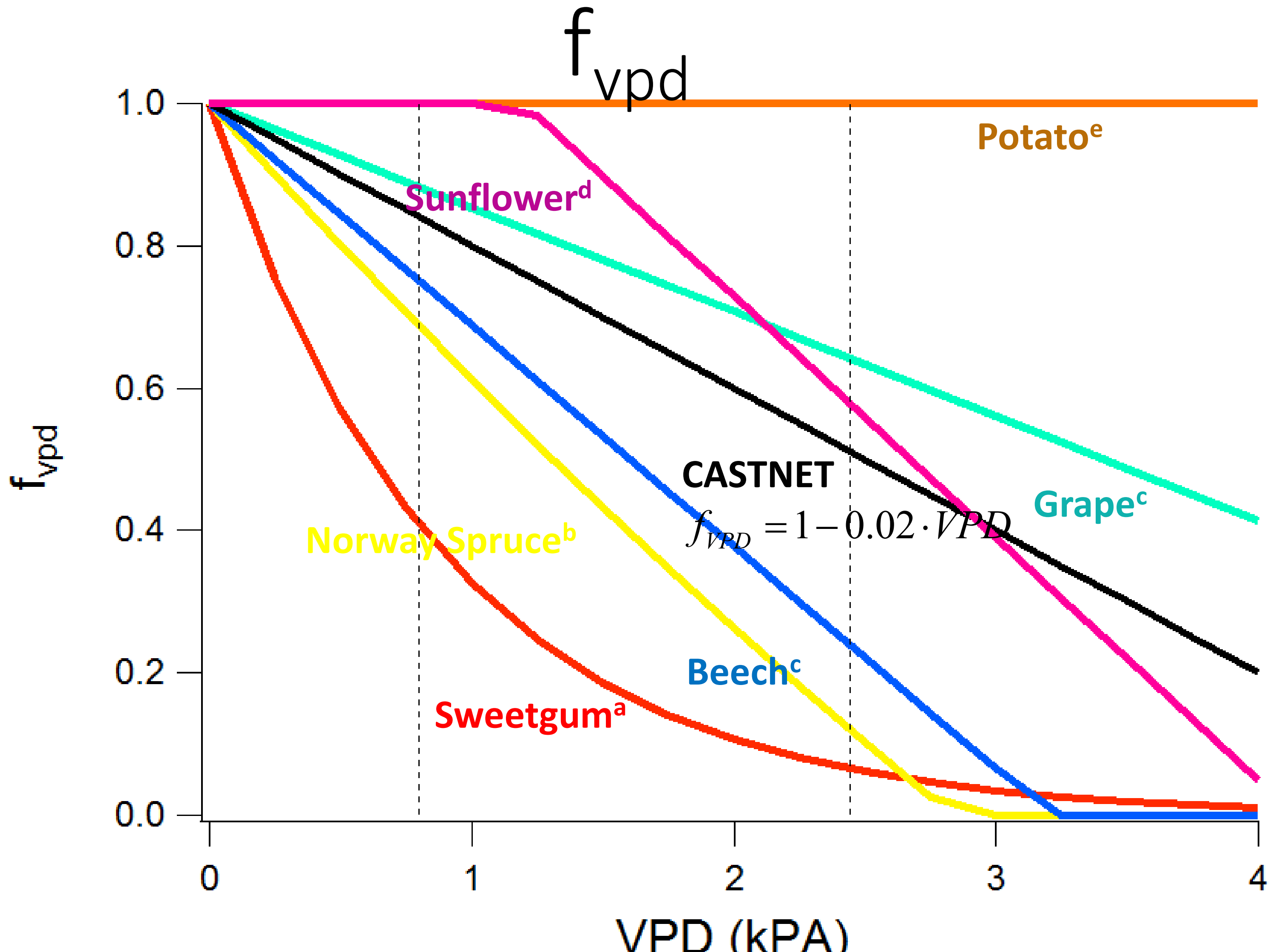


$$R_{stom} = \frac{R_{\min}}{f_{phen} f_{light} f_{Temp} f_{VPD} f_{SWC}}$$

CASTNET

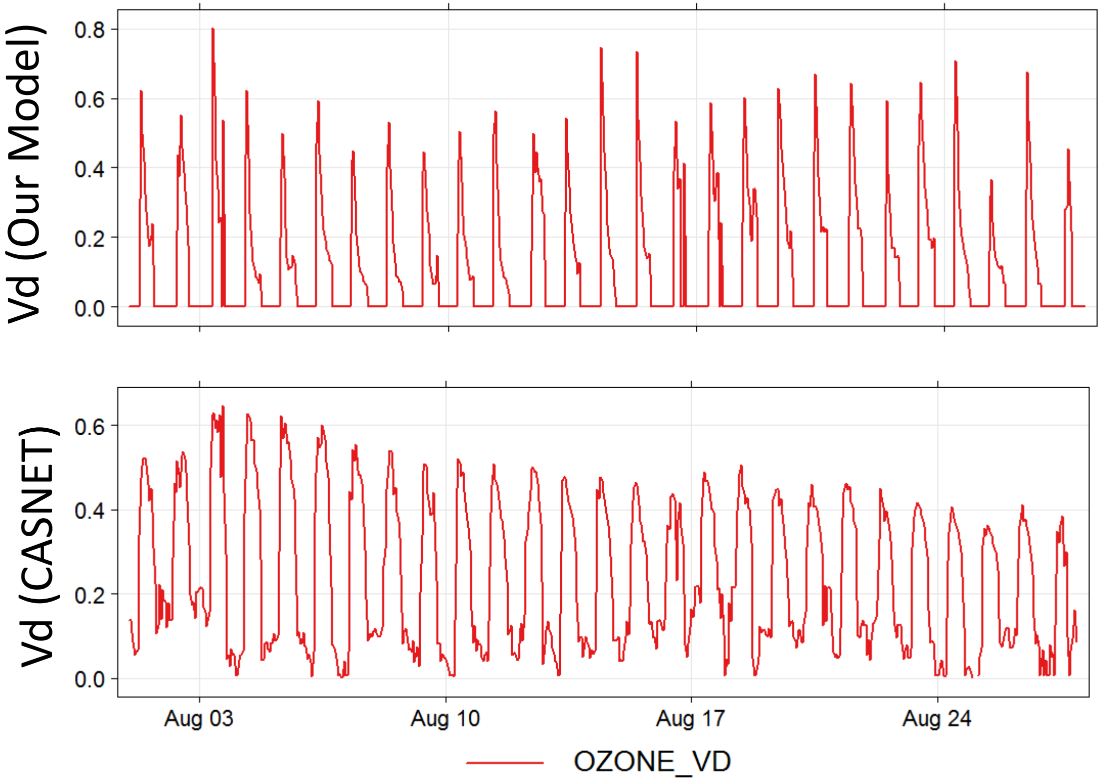
$$f_{VPD} = 1 - 0.02 \cdot VPD$$

Modelling Dry Deposition

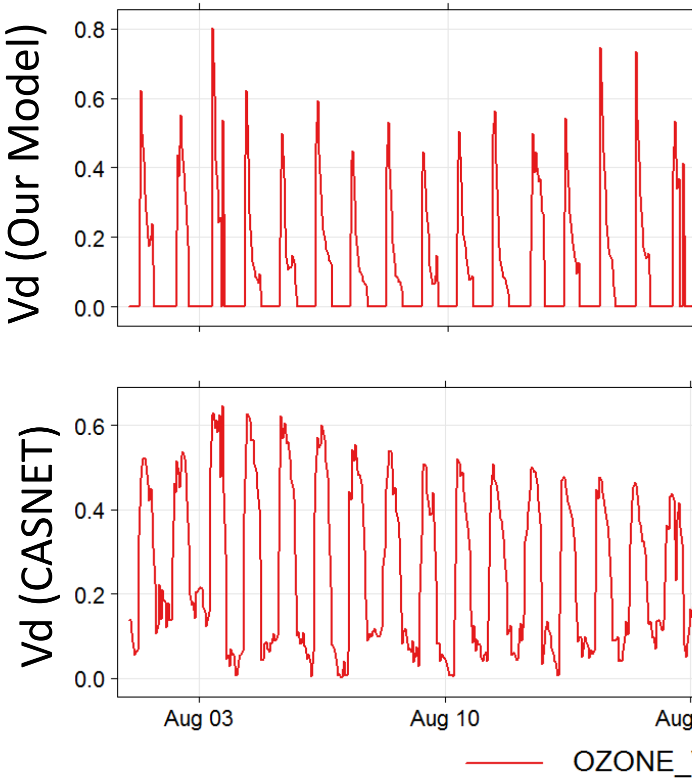


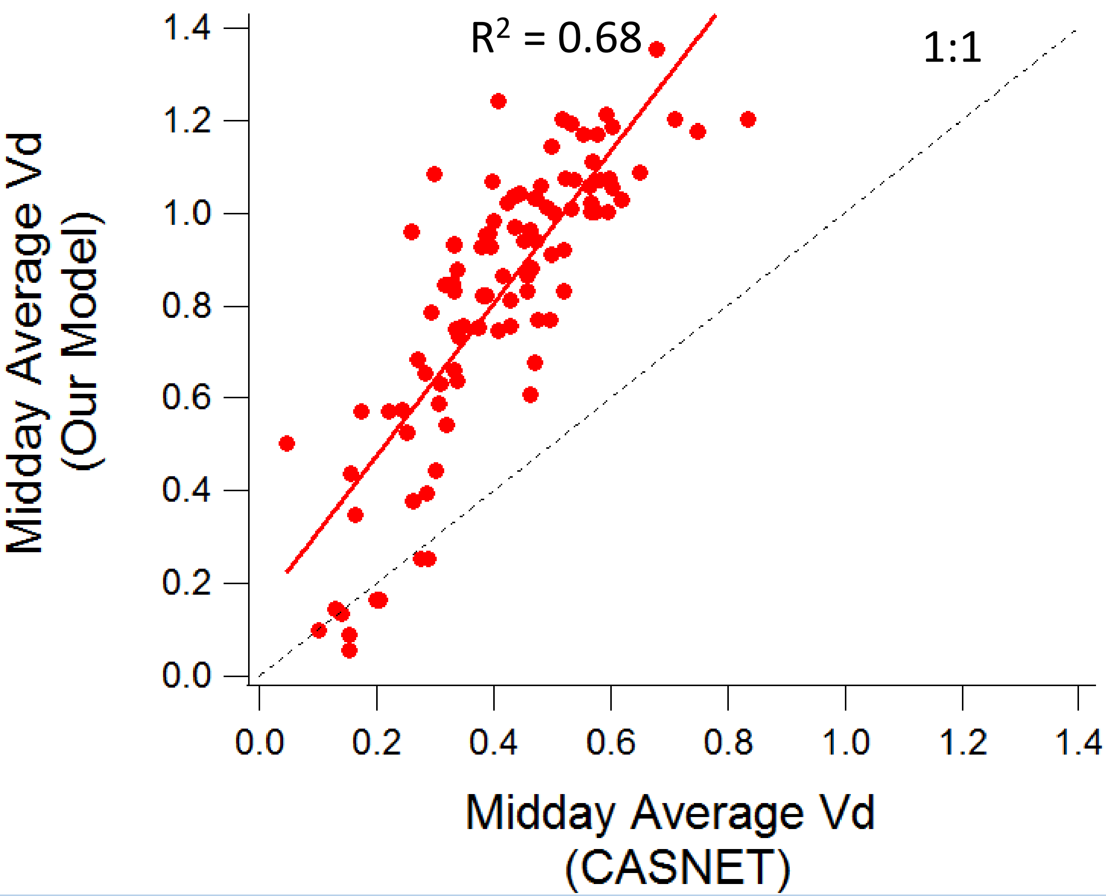
(a) *Gunderson, 2002. (b)* Karlsson , 2000. (c) Buker,2007. (d) Emberson, 2000. (e) Pleijel, 2002.

Does our model work?



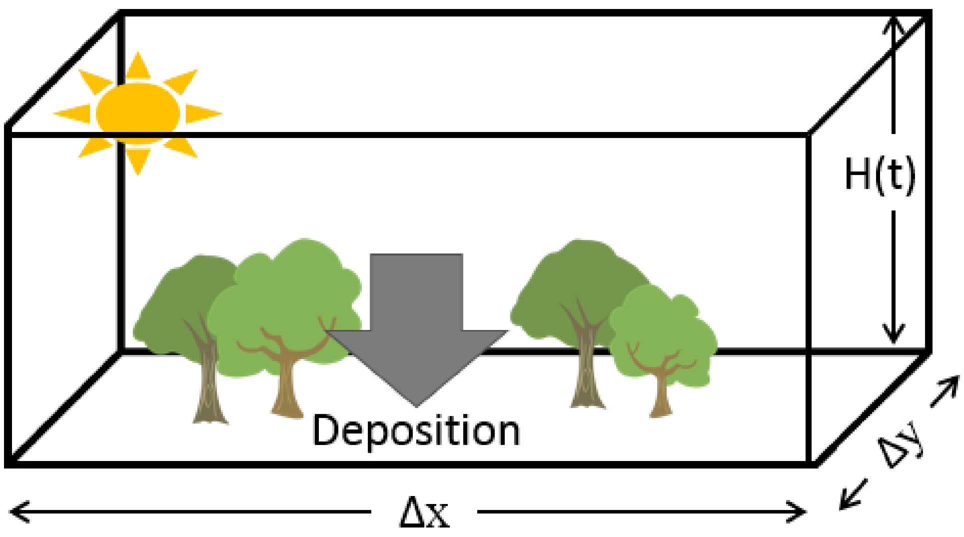
Does our model work?





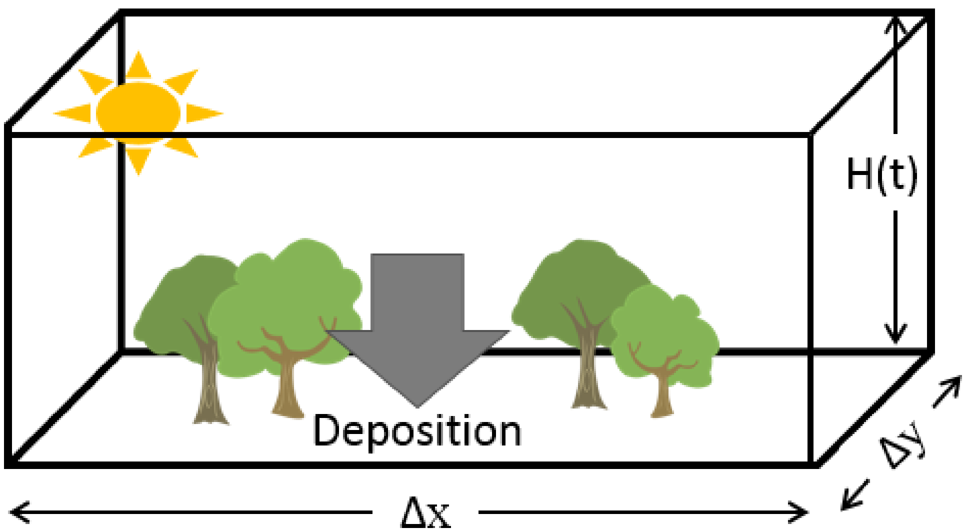
Affect of Dry Dep on Summer Ozone

$$\left.\frac{d[O_3]}{dt}\right|_{dep} = -\frac{V_d[O_3]}{H(t)}$$

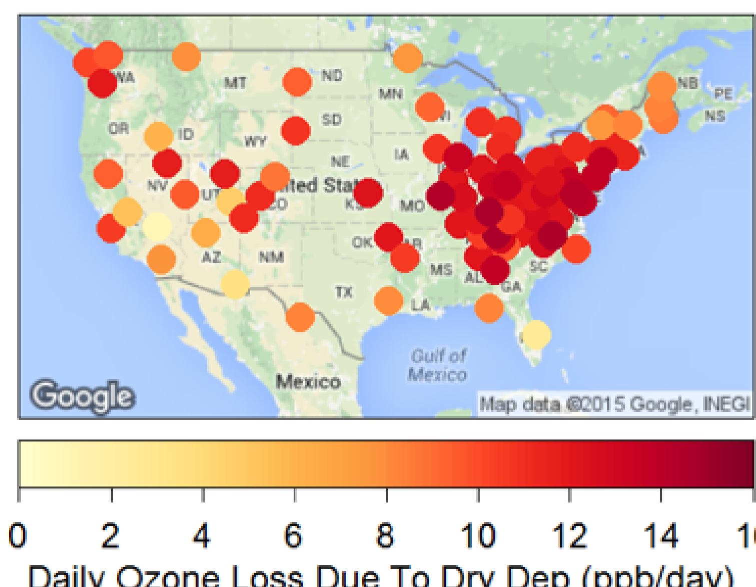


Affect of Dry Dep on Summer Ozone

$$\left(\frac{d[O_3]}{dt}\right)_{dep} = -\frac{V_d[O_3]}{H(t)}$$



Low VPD

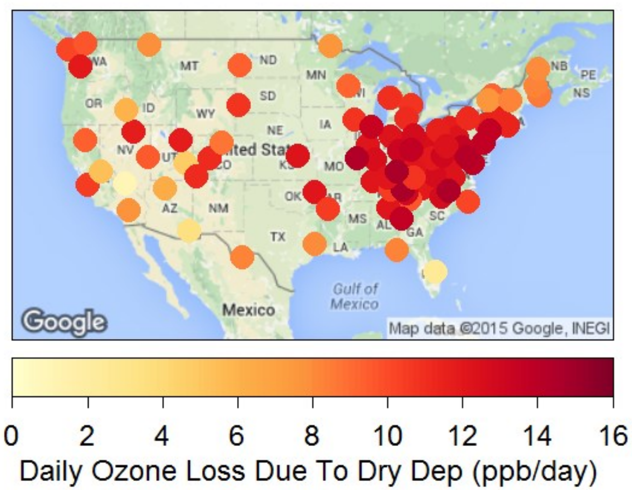


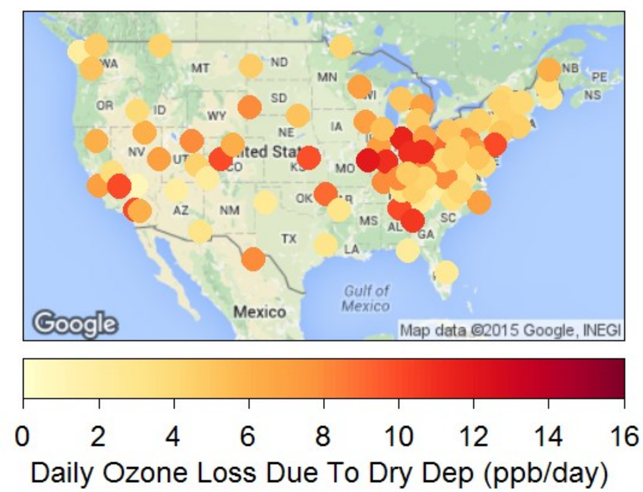
Affect of Dry Dep on Summer Ozone

(humid)
Low VPD

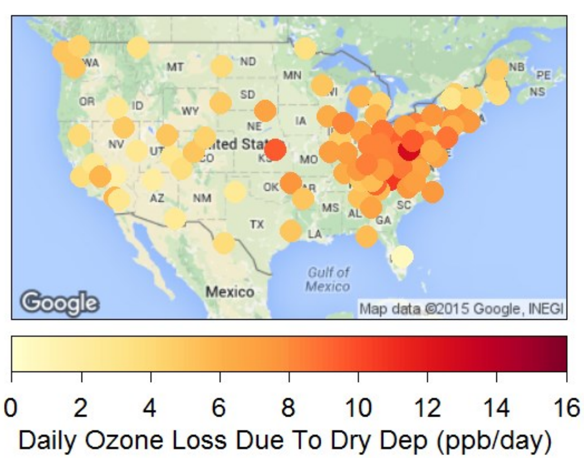
(dry)
High VPD

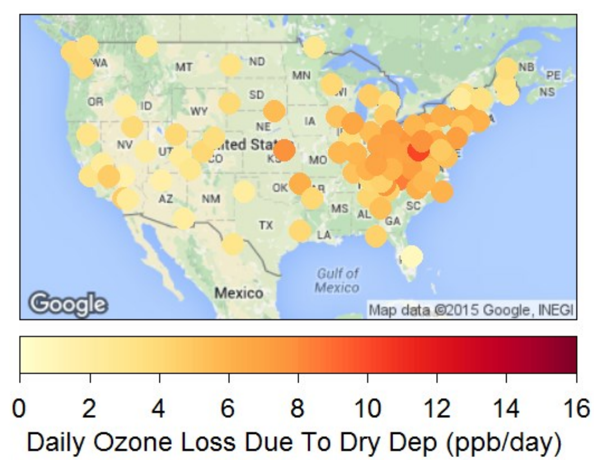
Our Model's Deposition Values





CASTNET's Deposition Values



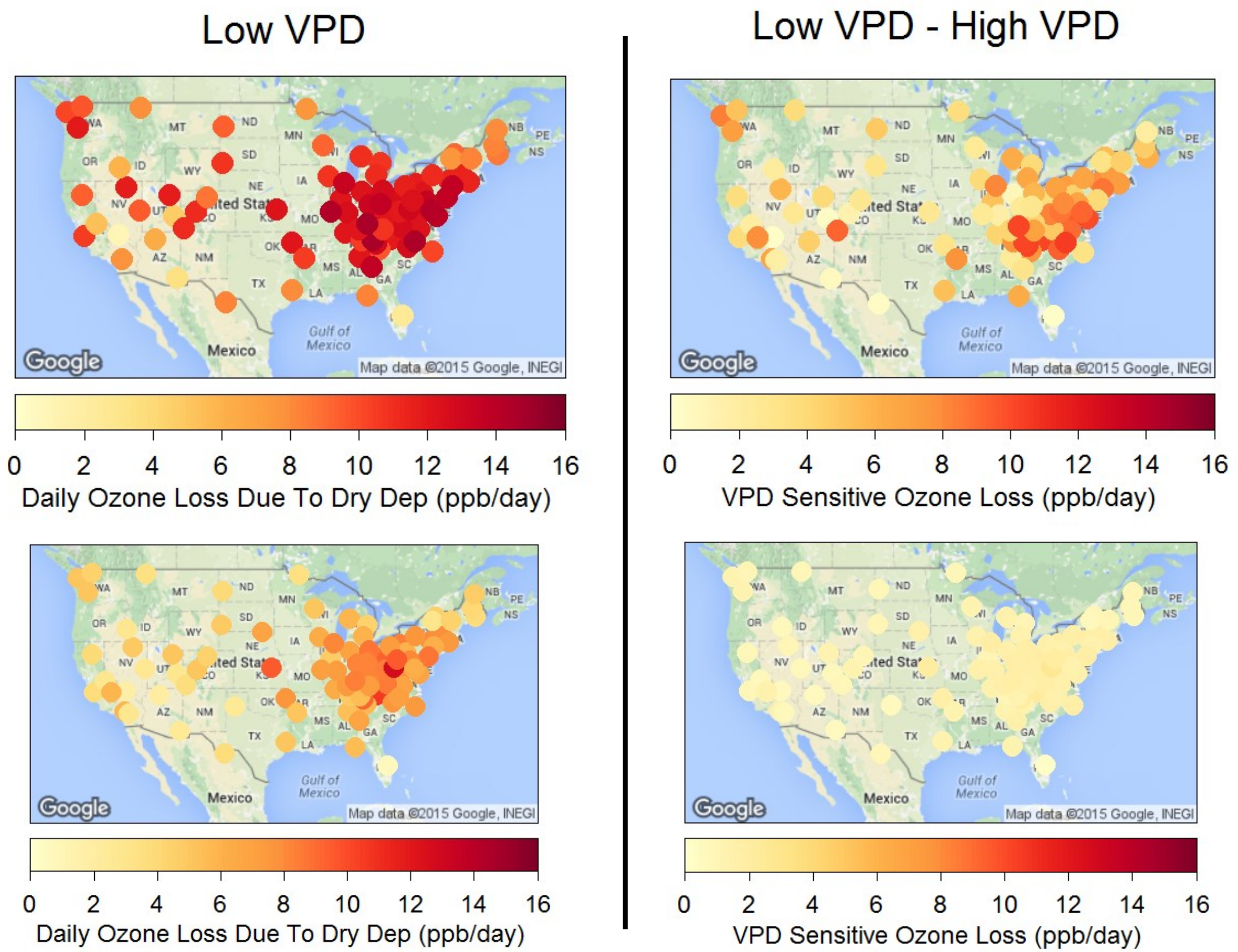


75th precentile humidity for site vs 25th precentile humidity for site

Affect of Dry Dep on Summer Ozone

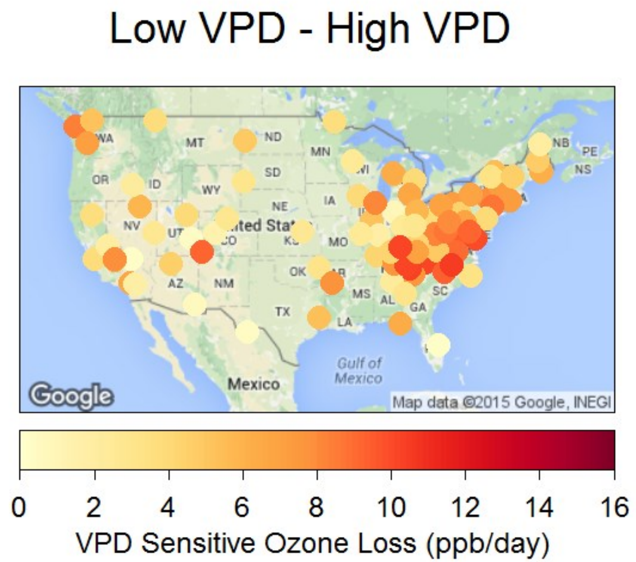
Our Model's Deposition Values

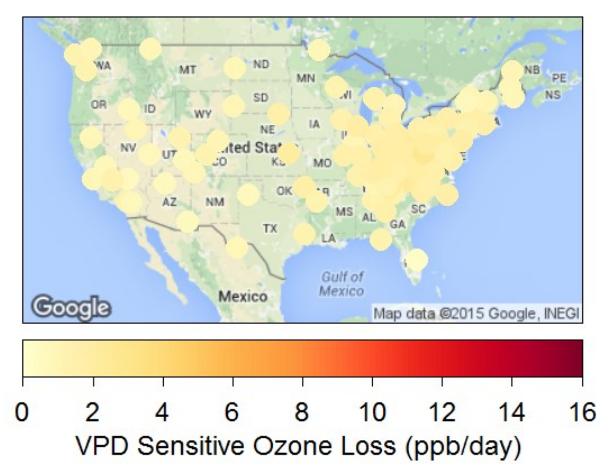
CASTNET's Deposition Values

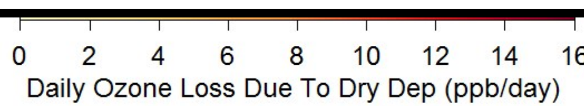


Affect of Dry Dep on Summer Ozone

- Vieno et al. (2010) associated a heat wave with an extra 20 to 35 ppb of ozone due to the loss of the dry dep. sink
- Royal Society (2008) found 'turning off' deposition lead to a 19% increase in daily mean ozone concentrations
- Emberson et al. (2013) found European exceedance days tripled under drought stressed conditions







Conclusions

- Midday Ozone and VPD are well correlated at most CASTNET sites during the summer
- Deposition of ozone to vegetation is sensitive to VPD for many species of plants
- The VPD-sensitive ozone sink can result in 5-12ppb differences in day-to-day ozone concentrations
- But: Ozone fluxes are highly sensitive to stomatal resistance parameterization choices

Limitations/Future Work

- We don't have a good characterization of what the boundary height is doing which is really essential for deposition modelling.
- **Ongoing: We're currently implementing our species-dependent Jarvis scheme into GEOS-Chem**
- Currently: We're mapping the entire canopy onto a single representative leaf. Comparisons to real measurements are tricky.
- **Future: We're planning more detailed canopy modelling in conjunction with field campaign flux measurements.**
- Currently: We're assuming well watered vegetation (no drought stress) and no surface wetness effects as well as static species composition and LAI throughout time (not great assumptions)