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ARTICLES

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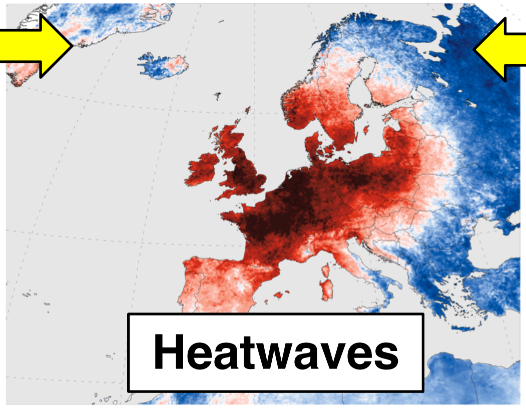
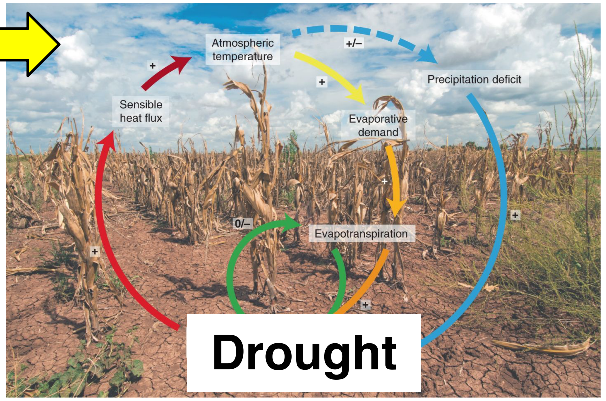
# How do vegetation feedbacks during drought exacerbate ozone air pollution extremes?

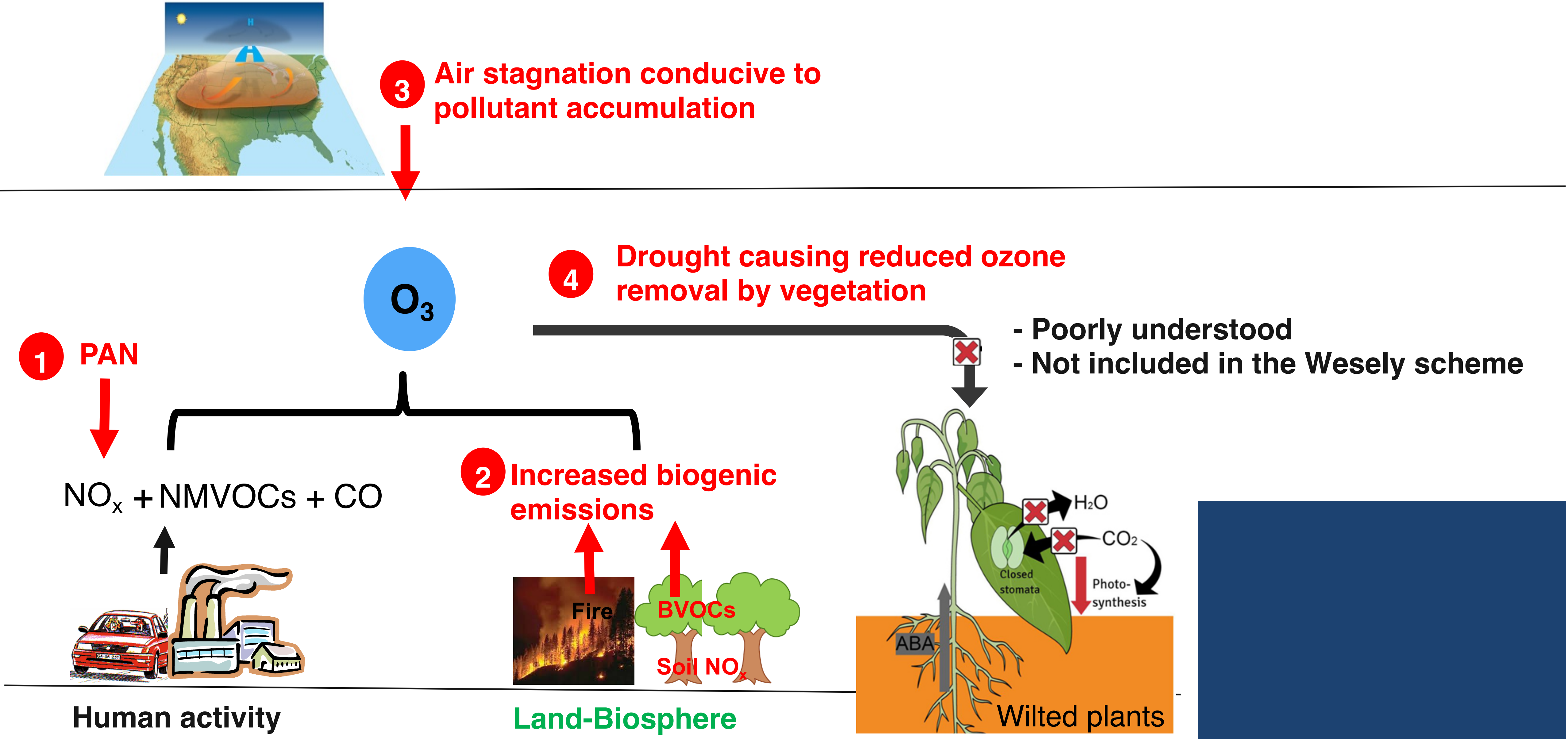
Meiyun Lin[1,2] ✉, Larry W. Horowitz[2], Yuanyu Xie[1,2], Fabien Paulot[2], Sergey Malyshev[2], Elena Shevliakova[2], Angelo Finco[3], Giacomo Gerosa[3], Dagmar Kubistin[4] and Kim Pilegaard[5]

Presented by Meiyun Lin (Princeton/NOAA GFDL)

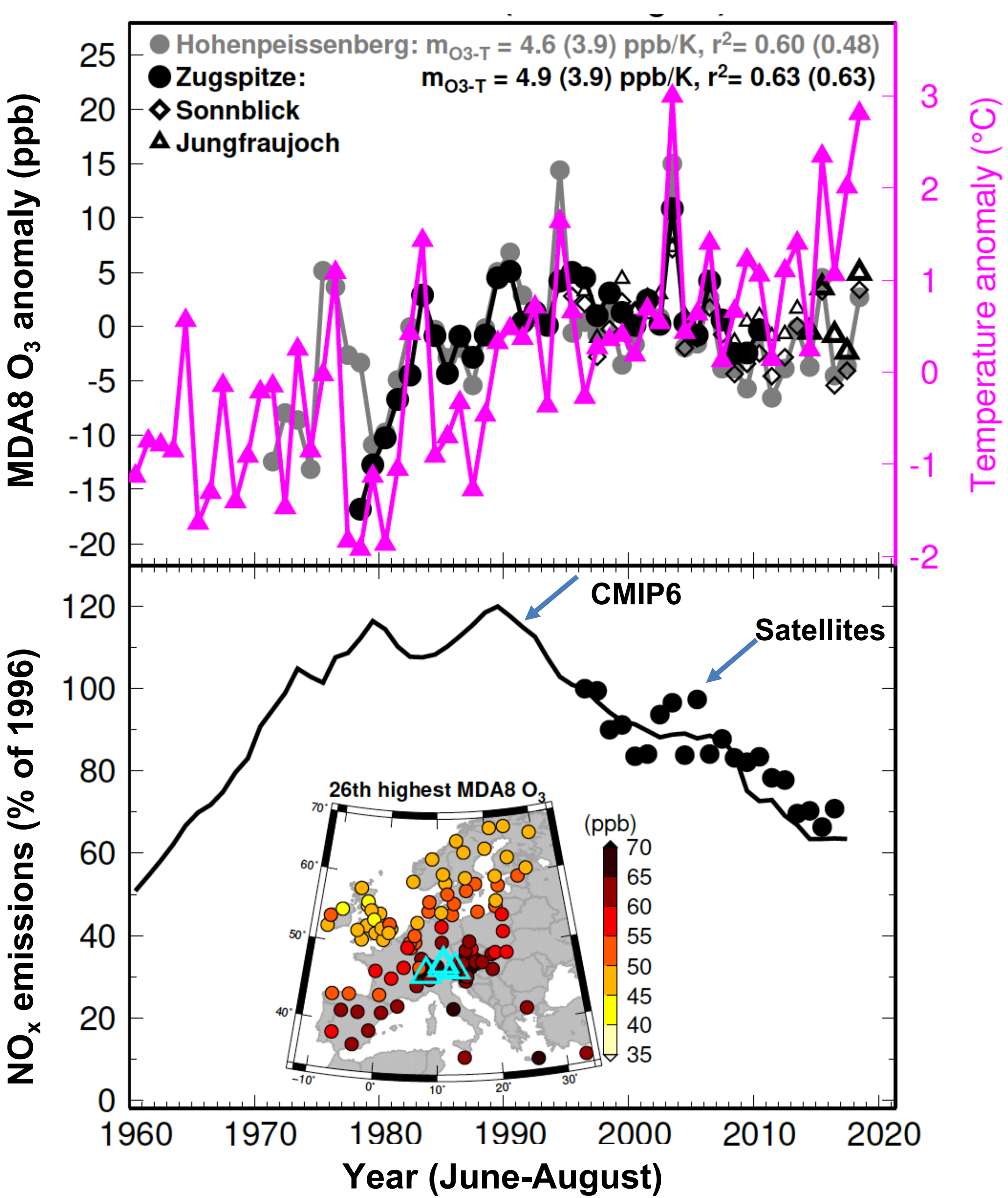



# How does ozone air quality respond to hot and dry spells?



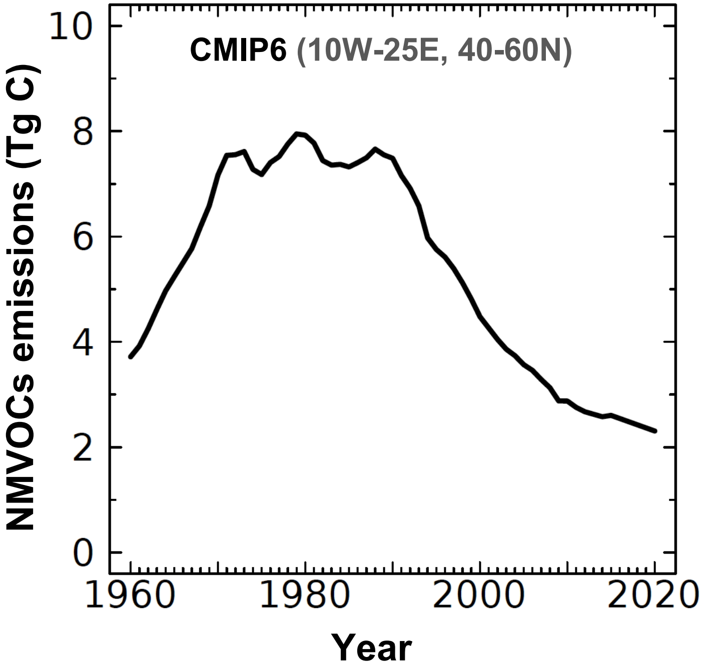
# Why is ozone pollution persisting in Europe despite stringent controls on regional precursor emissions?



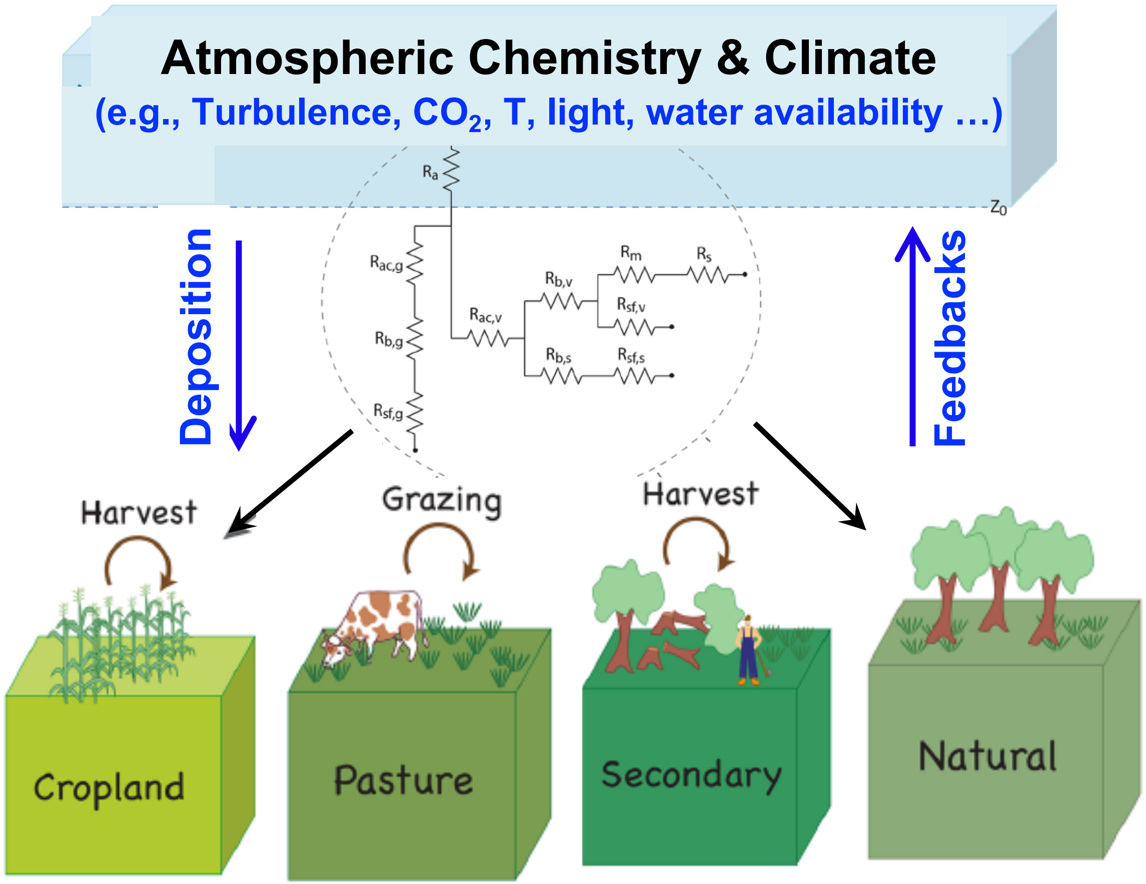

- The trend of $O_3$ does not mimic that in $NO_x$+VOCs emissions
- Observed $O_3$ increases with rising temperature
- Long-standing challenges in modeling EU $O_3$ trends

[e.g., Lelieveld2000; Fusco2003; Lamarque2010; Koumoutsaris2012; Parrish2014]

**→ Unknown "climate penalty" feedback mechanism?**



# New, interactive dry deposition scheme in GFDL Earth System Models

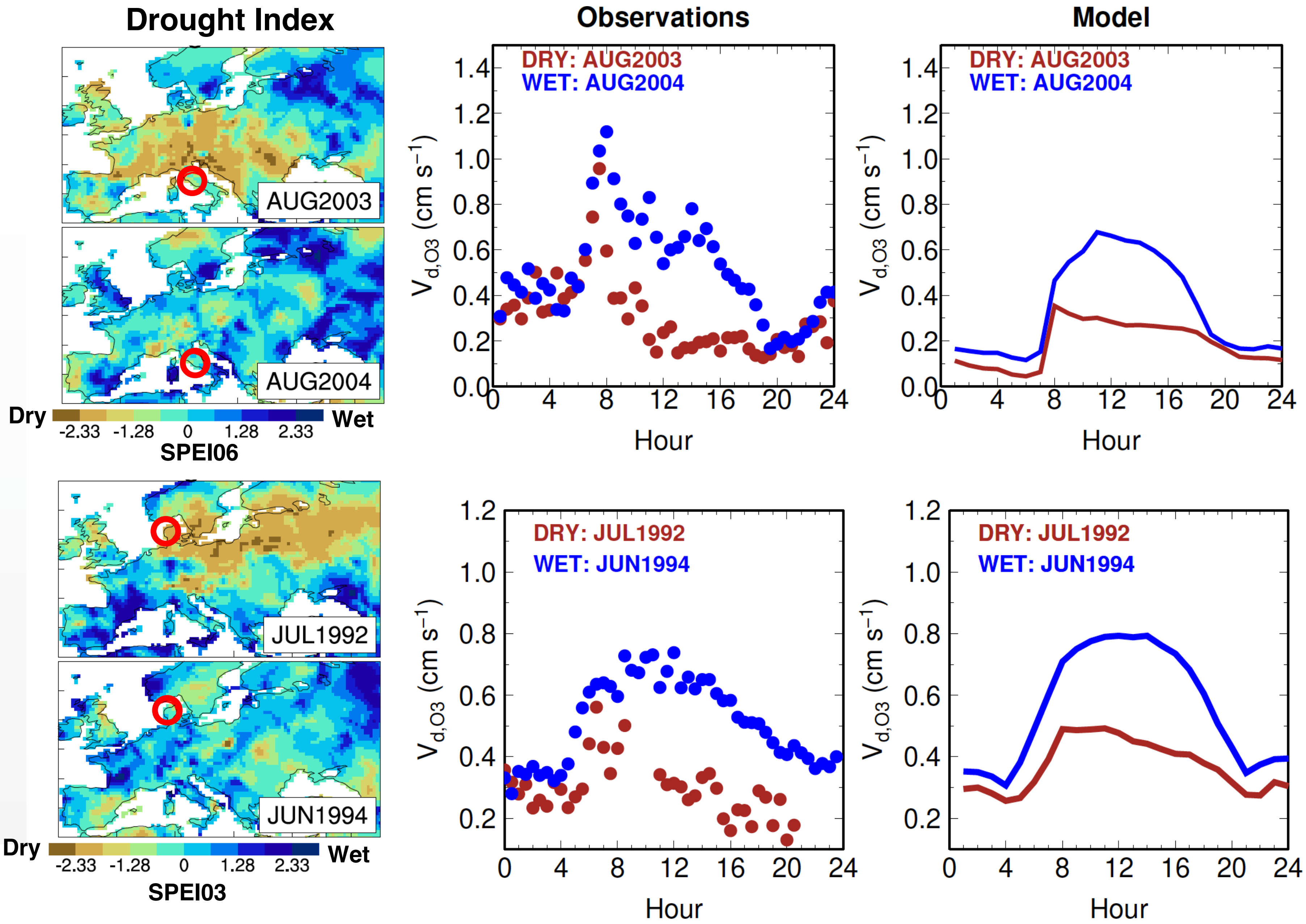



- **Incorporated into GFDL's dynamic vegetation land models** [Shevliakova et al., 2009; Paulot et al., 2018]
- **Stomatal deposition responds mechanistically to photosynthesis (*$A_n$*), soil water availability ($\varphi_w$), vapor pressure deficit (*$D_s$*), and atmos. $CO_2$ concentration (*$C_i$*).**

$$R_{stom} = \frac{\sqrt{\frac{M(O_3)}{M(H_2O)}}}{g_s(H_2O)} \qquad g_s(H_2O) = max\left(\frac{m\bar{A}_n}{(C_i - \Gamma_*)(1 + D_s/D_0)}, g_{s,min}\right) \cdot \psi_i \cdot \psi_w \cdot LAI$$

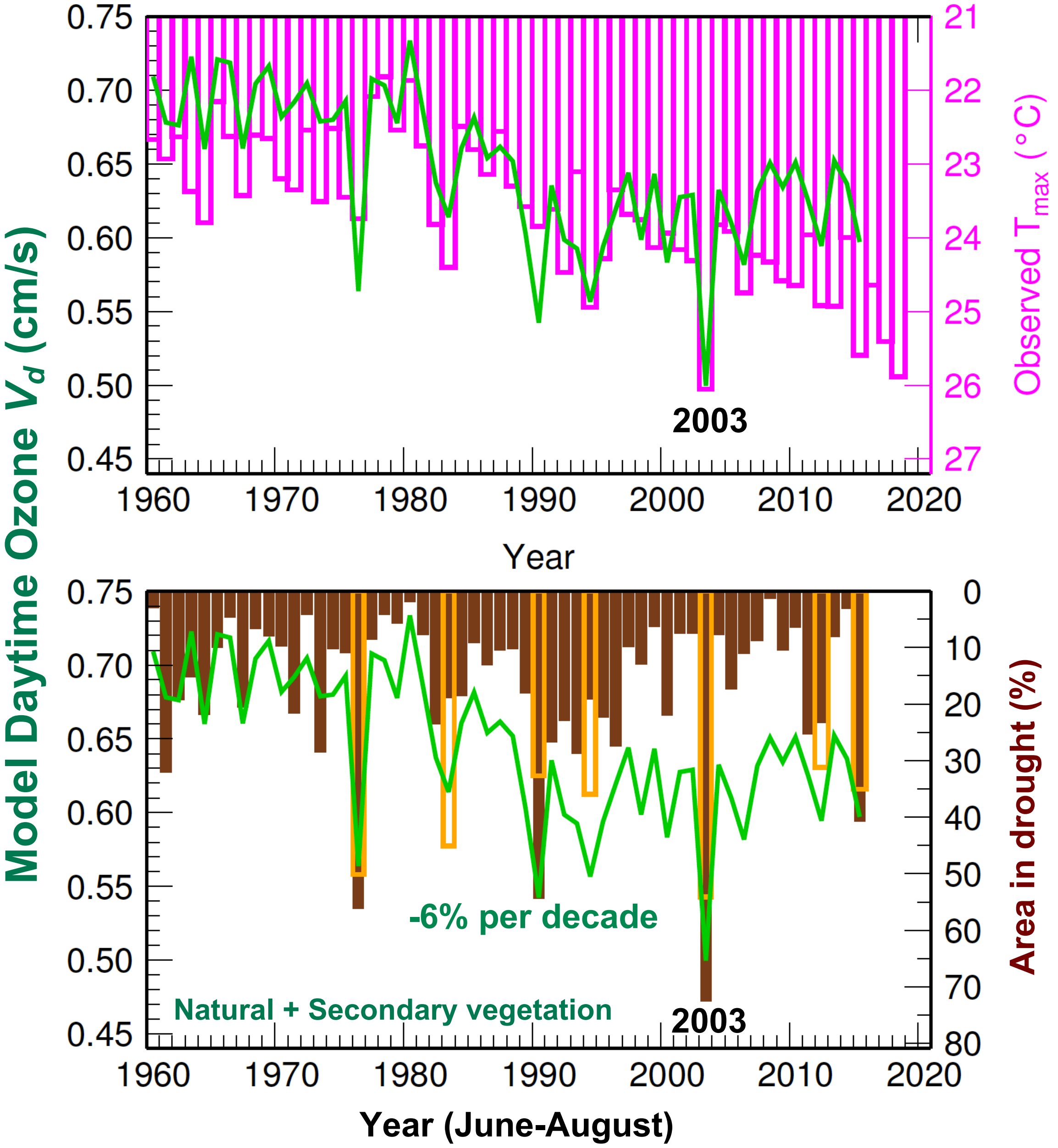
Read Lin M. et al. (Global Biogeochemical Cycles, 2019) for more model details and evaluation

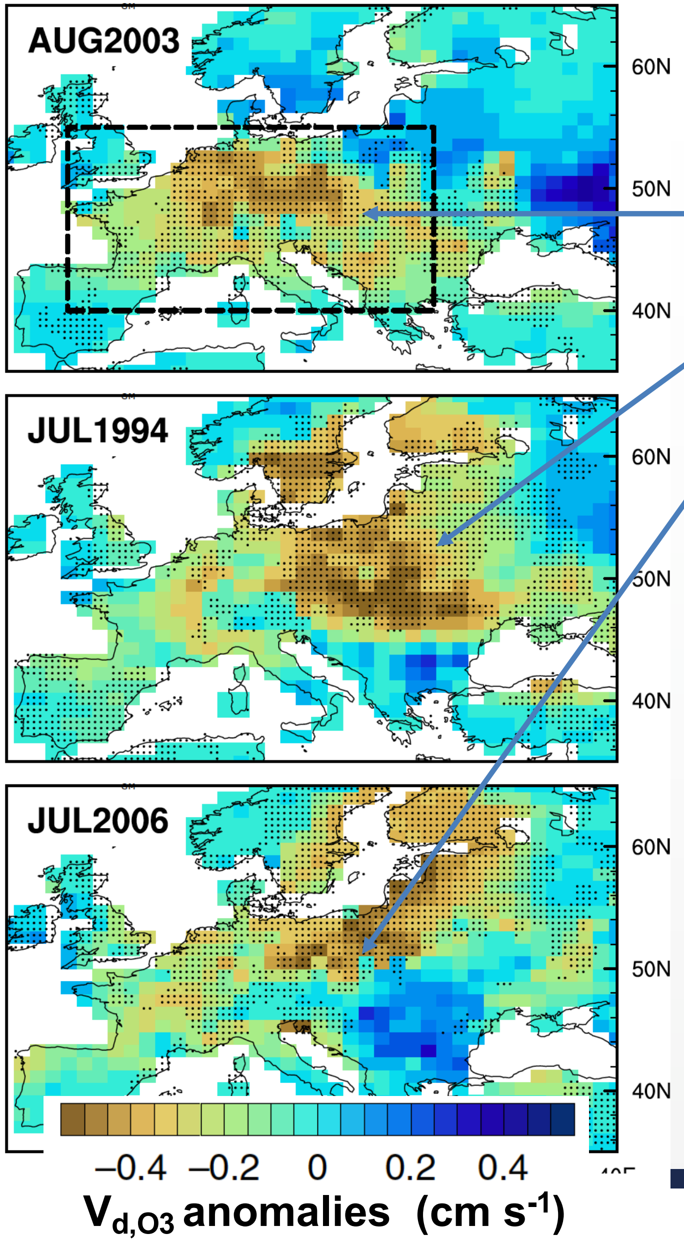
# Observed and modeled reductions in $O_3$ removal by forests during drought




Lin M. et al.
(Nature Climate Change, 2020)

# Declining ozone removal by drought-stressed vegetation since 1980

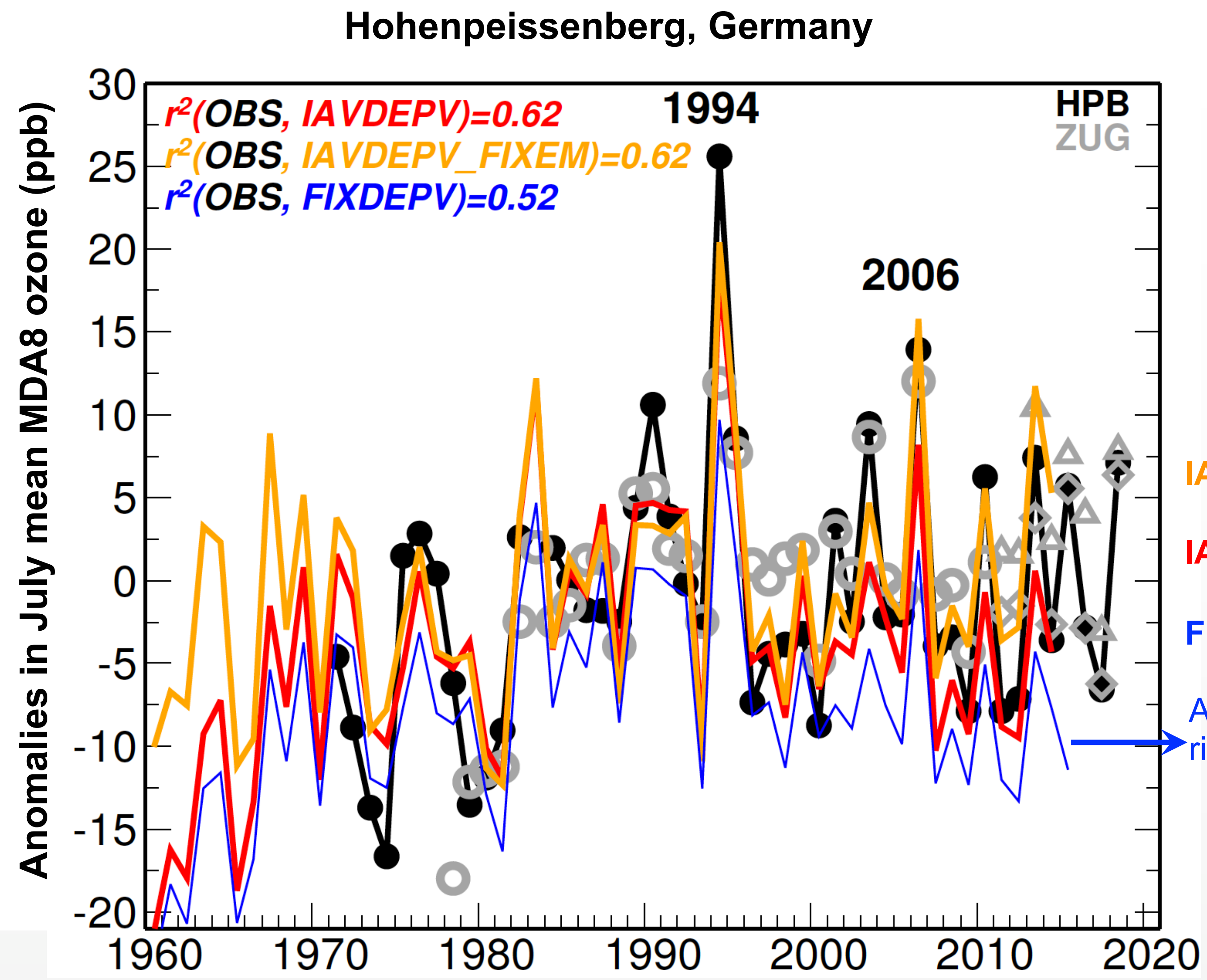



**Dots indicate area in drought**

Lin M. et al.
(Nature Climate Change, 2020)

# Impacts on surface ozone air quality




**IAVDEPV_1980EMIS**: Under 1980 high emission conditions

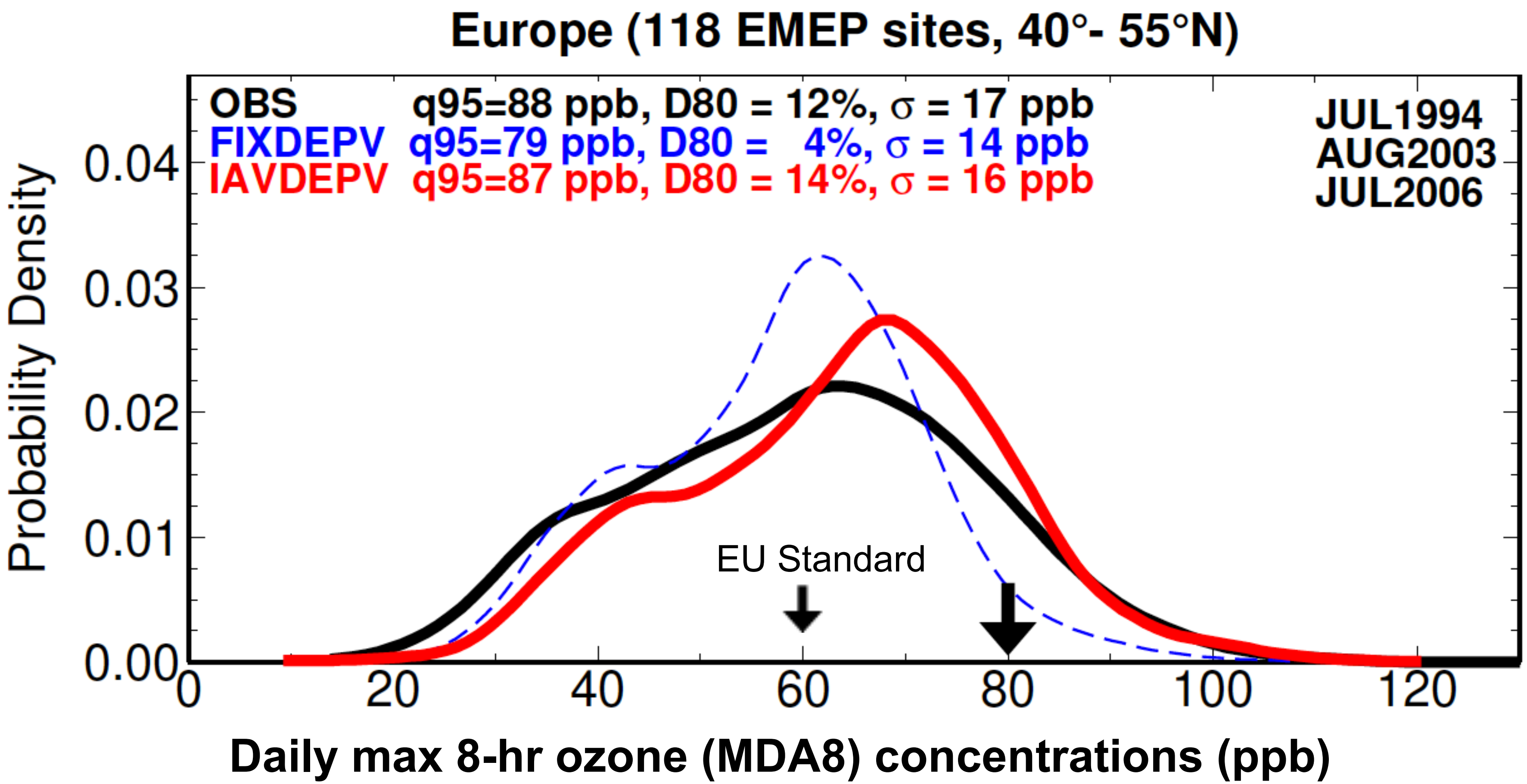
**IAVDEPV**: Ozone $V_d$ varying with climate and vegetation state

**FIXDEPV**: Ozone $V_d$ held constant at 1960 levels;

Already includes the impact of rising BVOC emissions (MEGAN)

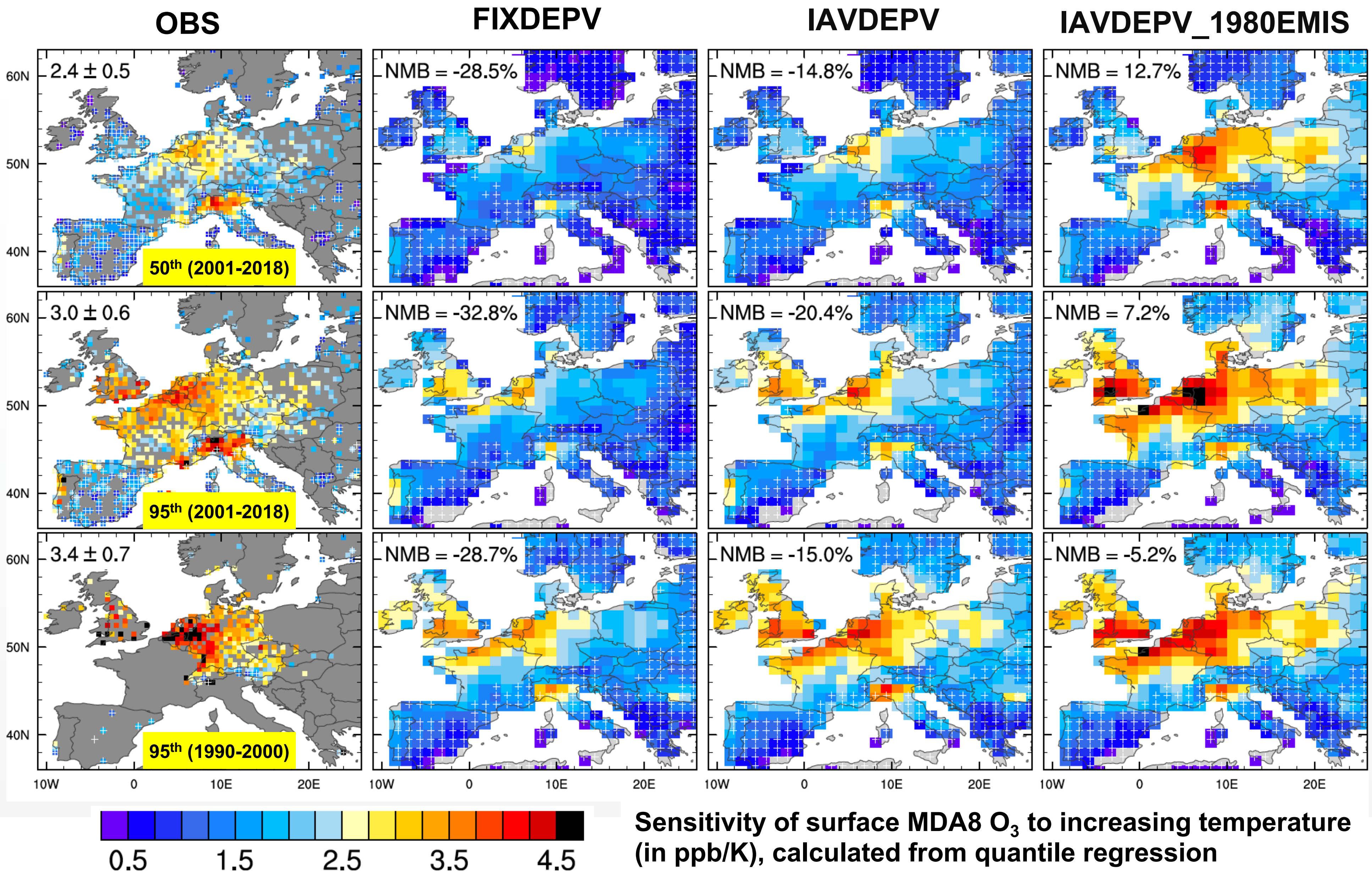
Lin M. et al. (Nature Climate Change, 2020)

# Reduced removal by drought-stressed plants worsens $O_3$ air pollution extremes



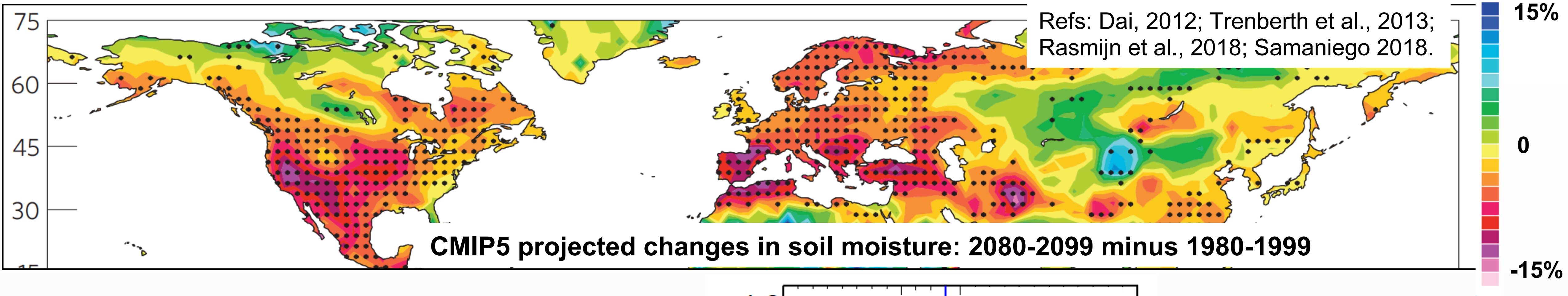

- **Accounting for vegetation feedbacks (IAVDEPV) leads to a three-fold increase in high-$O_3$ events above 80 ppb (D80)**

# Vegetation feedbacks exacerbate climate penalty on $O_3$ air pollution extremes



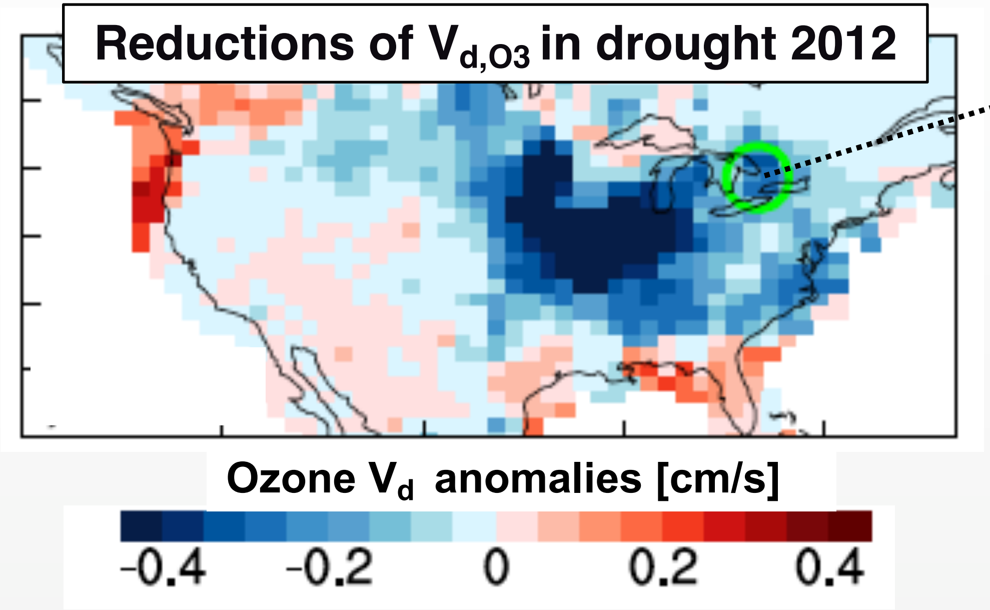

Sensitivity of surface MDA8 $O_3$ to increasing temperature (in ppb/K), calculated from quantile regression

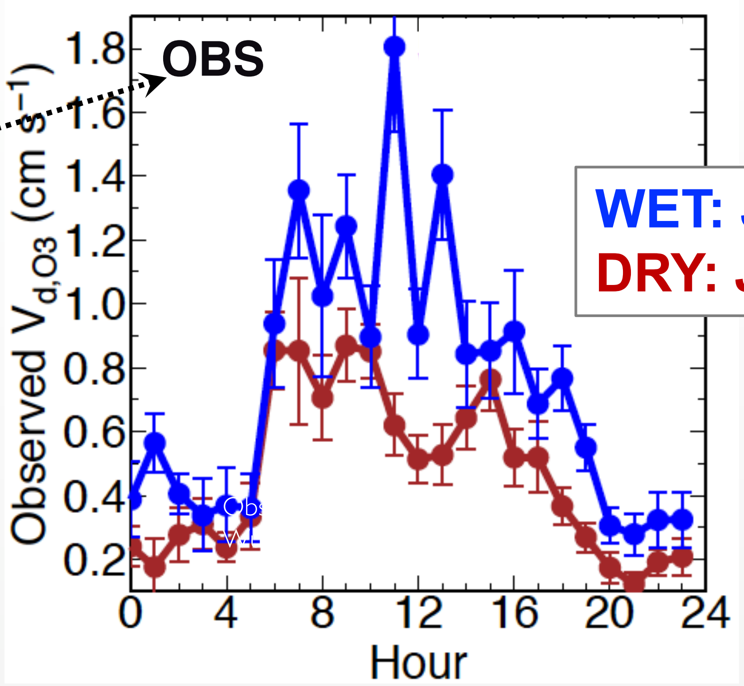
# Increasing drought under global warming




Refs: Dai, 2012; Trenberth et al., 2013; Rasmijn et al., 2018; Samaniego 2018.

CMIP5 projected changes in soil moisture: 2080-2099 minus 1980-1999

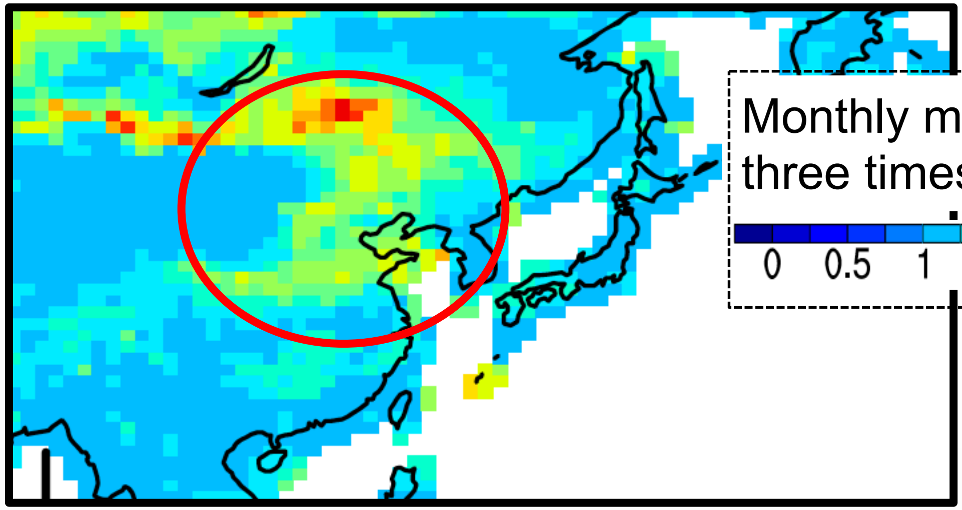



Lin M. et al.
(Global Biogeo. Cycles, 2019)

**The ozone climate penalty may be underestimated in current CCMs not accounting for land-biosphere feedbacks during drought.**

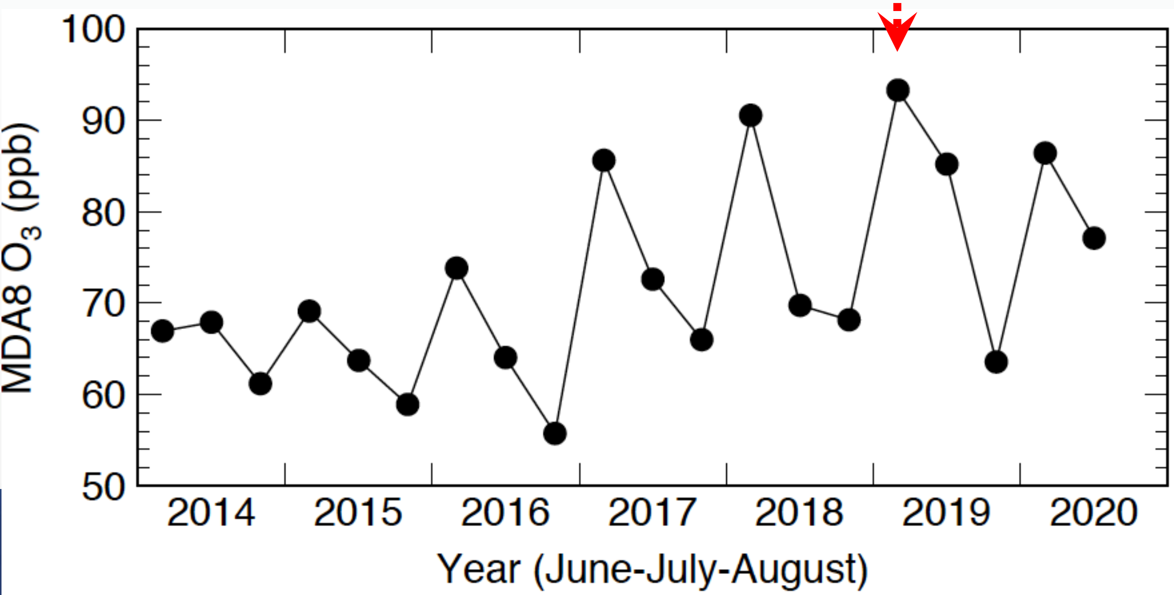
# Potential influence of drought-stressed vegetation on ozone extremes in China?



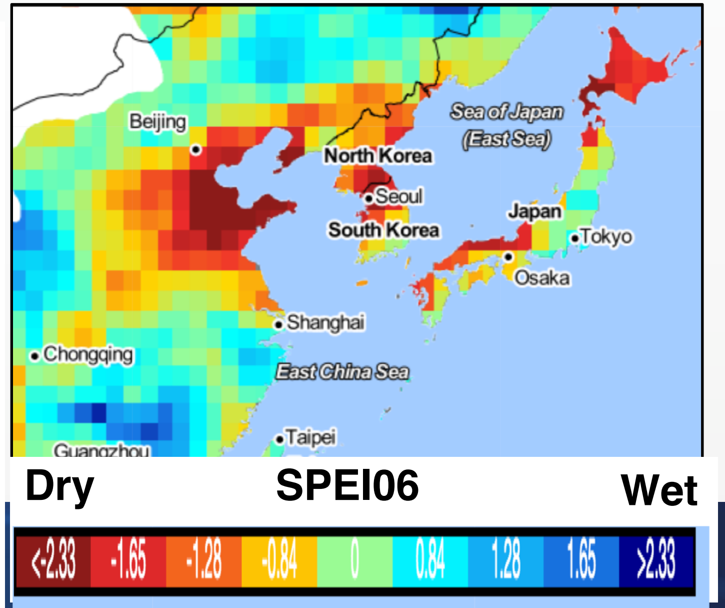
Monthly mean $V_{d,O3}$ over forests for the highest years is two to three times that of the lowest. (Lin et al., GBC2019)



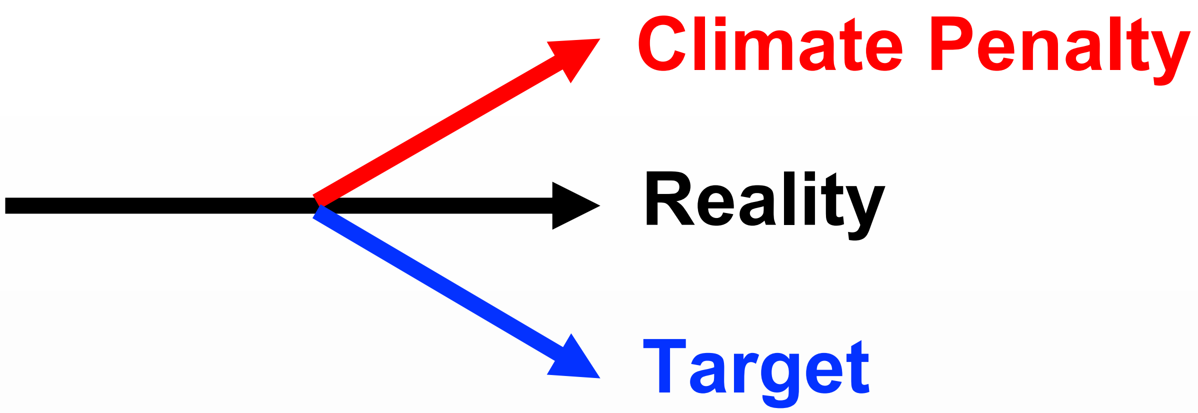
June2019 $O_3$




June2019 Drought Index



# TAKE-HOME MESSAGES




- **Accounting for land-biosphere feedbacks during drought is central to determining extreme pollution events in Europe and other midlatitude populated regions.**

- **The ozone climate penalty may be significantly larger than estimated by current generation CCMs since these models typically do not include the drought-vegetation feedbacks.**

- **As hot and dry summers are expected to increase over the coming decades, effective emissions policies must consider the drought-vegetation feedbacks**

Lin M. et al. (Nature Climate Change, 2020)

# For more information, please read the papers:

Lin, M. et al. (2020): ***Vegetation feedbacks during drought exacerbate ozone air pollution extremes in Europe***. Nature Climate Change, DOI:10.1038/s41558-020-0743-y (PDF)

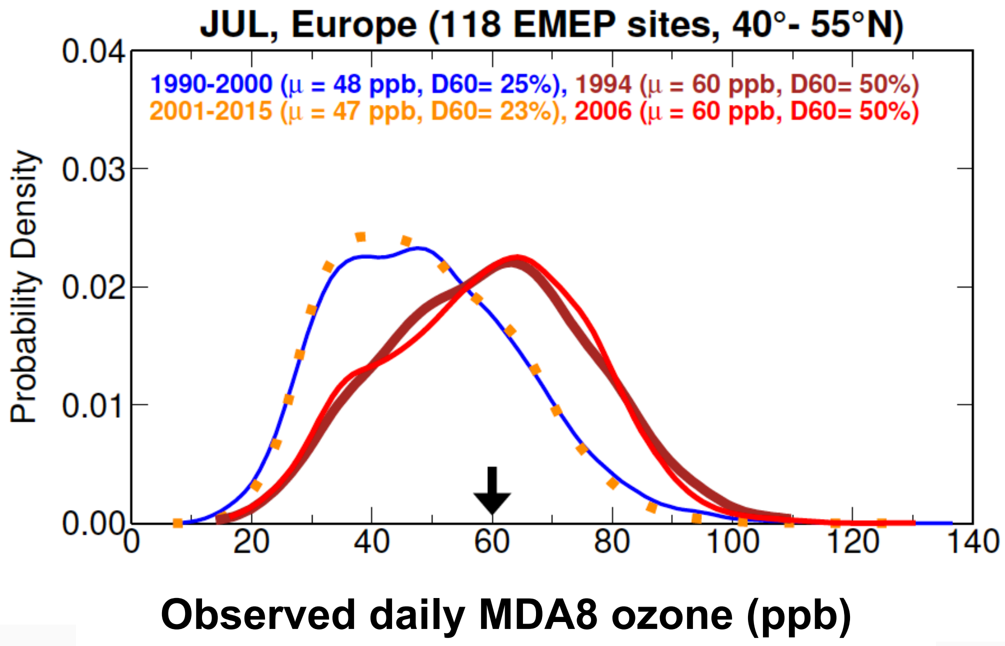
Lin, M. et al. (2019): ***Sensitivity of ozone dry deposition to ecosystem-atmosphere interactions: A critical appraisal of observations and simulations.*** *Global Biogeochemical Cycles*, **33(10)**, 1264-1288, DOI:10.1029/2018GB006157 (PDF)

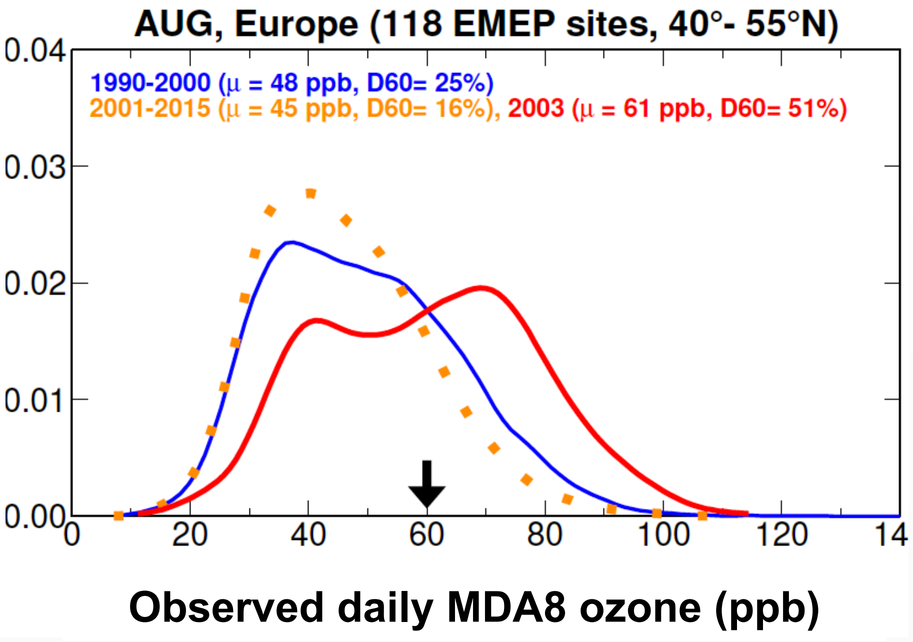
Lin, M. *et al.* (2017): ***U.S. surface ozone trends and extremes from 1980 to 2014: Quantifying the roles of rising Asian emissions, domestic controls, wildfires, and climate,*** *Atmospheric Chemistry and Physics, 17,* 2943–2970, *doi:* 10.5194/acp-17-2943-2017 (PDF)

Twitter: @Meiyun_Lin

**Observations and multi-decadal global model simulations used in these studies are fully available upon request to Meiyun.Lin@noaa.gov**

# Changes in surface ozone distribution in Europe



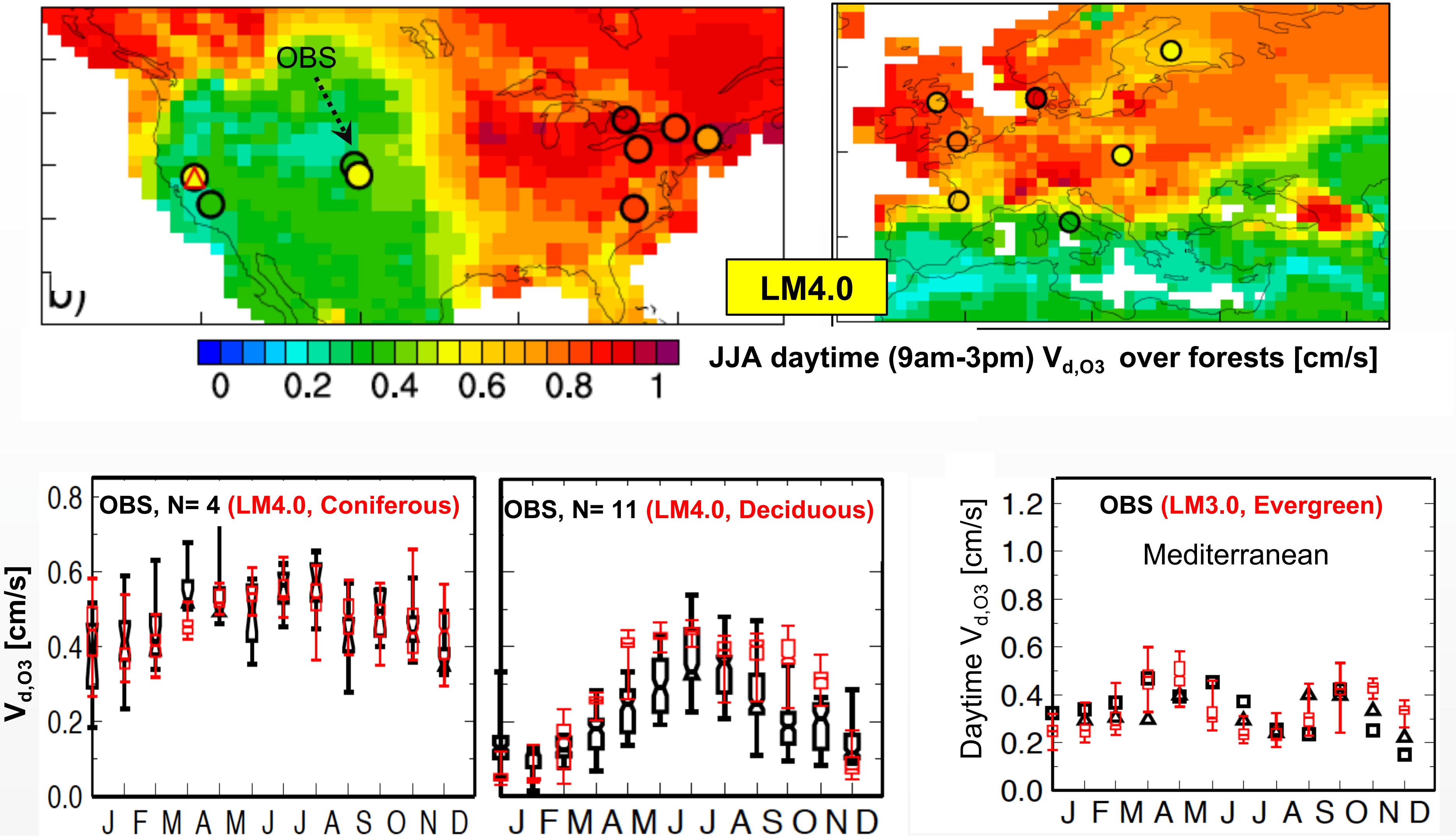




- Little change btw **1990-2000** and **2001-2015** despite precursor emission controls
- Substantial upward shifts during the historic heatwaves and drought of July 1994, August 2003, and July 2006, with events above the EU target (D60) double to triple the long-term average exceedances



Lin M. et al. (Nature Climate Change, 2020)

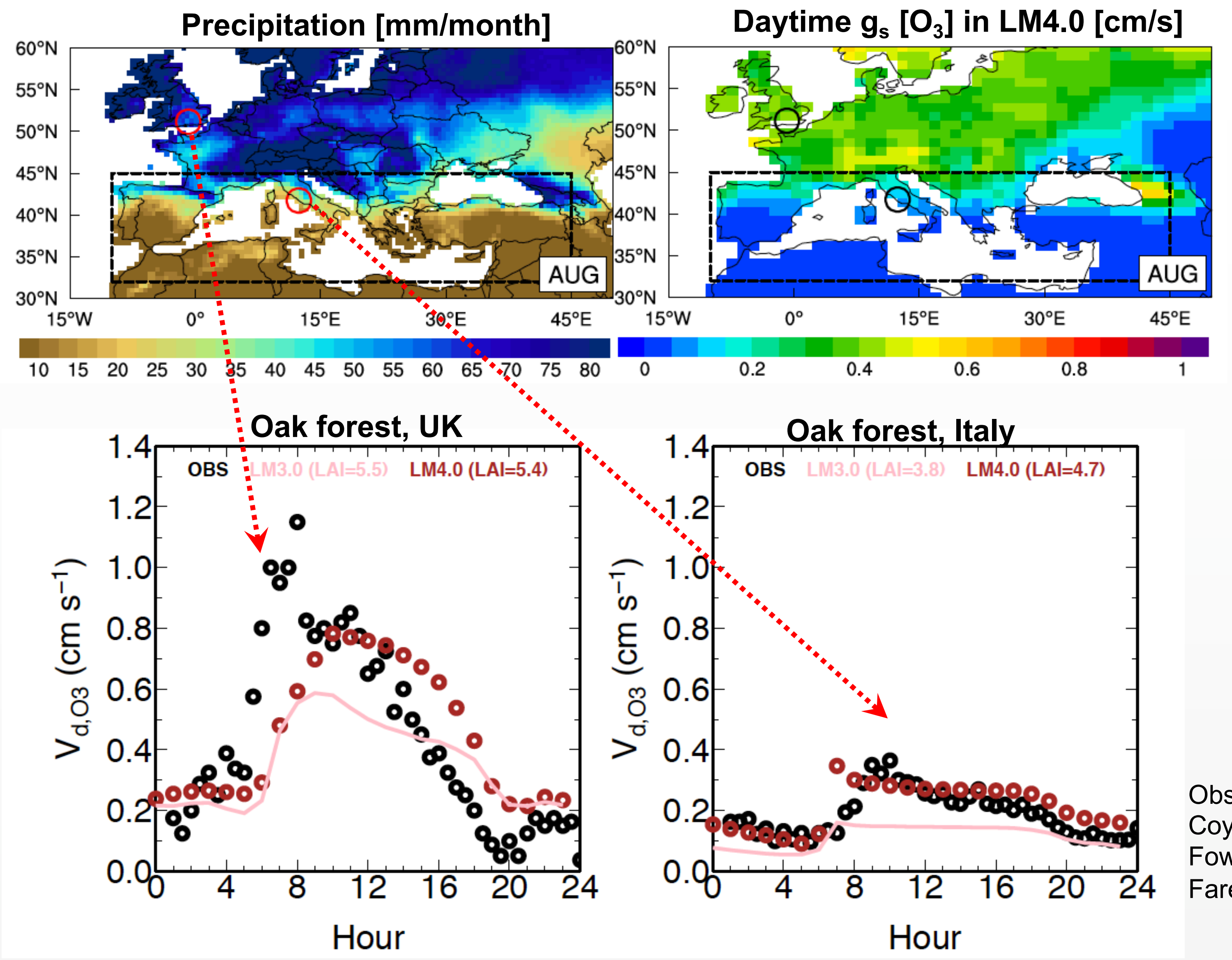
# Observed versus modelled ozone dry deposition velocities ($V_{d,O3}$)




- *Observations are compiled at 41 locations from 26 literature sources published during 1990-2018.*

Lin M. et al. (Global Biogeochemical Cycles, 2019)

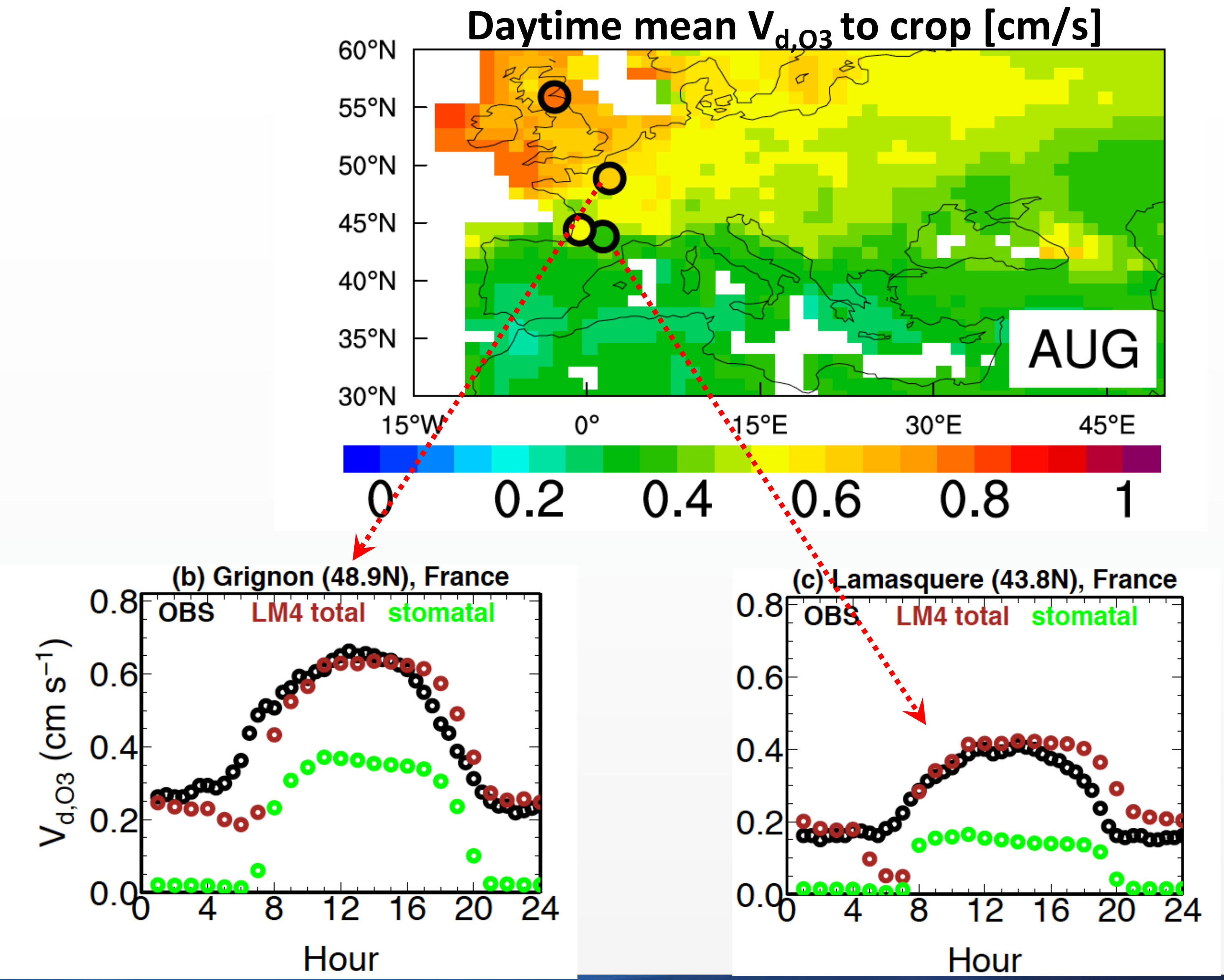
# Reduced $O_3$ deposition over forests in Mediterranean summer climate




Observations:
Coyle et al. (2006)
Fowler et al. (2009)
Fares et al. (2014)

Lin M. et al. (Global Biogeochemical Cycles, 2019)

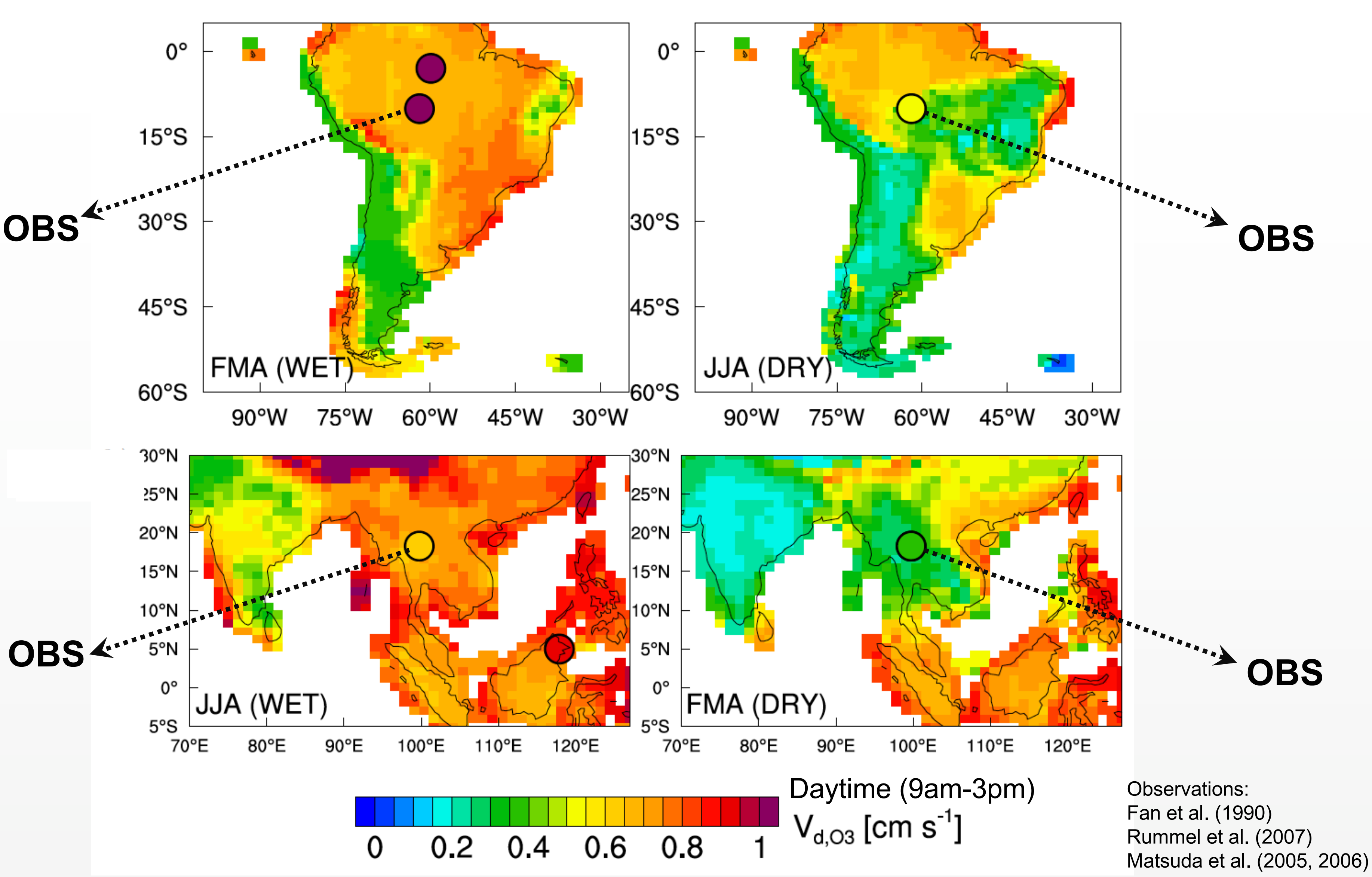
# Reduced $O_3$ deposition over crops in Mediterranean summer climate




Observations:
Coyle et al. (2009)
Stella et al. (2011)

Lin M. et al. (Global Biogeochemical Cycles, 2019)

# Ozone deposition over tropical forests during wet vs. dry season




Observations:
Fan et al. (1990)
Rummel et al. (2007)
Matsuda et al. (2005, 2006)

Lin M. et al. (Global Biogeochemical Cycles, 2019)