Probing the relationship between formaldehyde column concentrations and soil moisture using mixed models and attribution analysis

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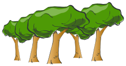
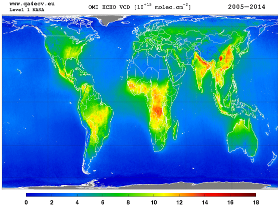
Image by J. K. Holopainen (Tree Physiology, 2011)

Using formaldehyde as a proxy of isoprene emissions

Volatile Organic Compounds **VOC** —Oxidation→ Formaldehyde **HCHO**

↑ Emissions

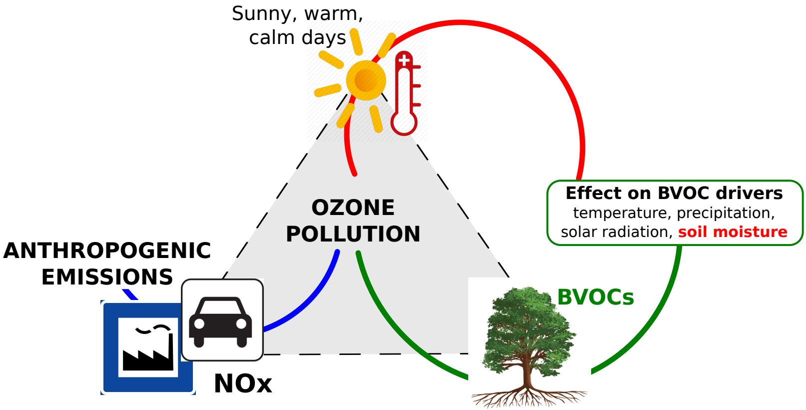
Remote sensed OMI-HCHO

On ∼100-km scale, HCHO is mainly sensitive to isoprene emissions (Marais et al., 2012; Stavrakou et al., 2018)

Among biogenic volatile organic compound (BVOCs) emitted by vegetation, isoprene is the most abundant (Guenther et al., 2012)

Isoprene emissions and water stress

Why do we care about this relationship?

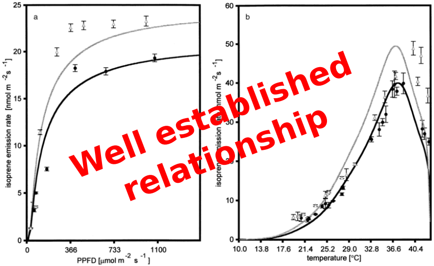


Isoprene emissions affect levels of ozone, methane and particulate matter (Pacifico et al., 2009). Climate change may alter isoprene emissions by modifying the occurrence and intensity of severe stresses that influence plant functioning (Niinemets, 2010).

Isoprene emissions and response to abiotic factors

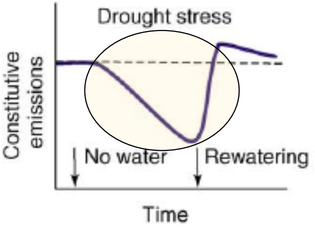
Radiation, temperature and water avaialbility

Radiation and temperature dependence



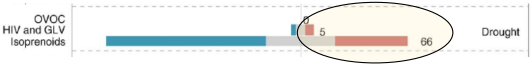
Zimmer et al. (2000)

Water stress dependence



Niinemets (2010)

Under water stress, emissions decrease or increase?



Peñuelas and Staudt (2010)

No. papers reporting BVOC emission increase, decrease or no-change in response to drought

Selected observational global datasets

Variable and dataset	Period	Resolution	Reference
OMI-HCHO (vQA4ECV, L3)	2005–2016	0.25°	De Smedt et al. (2018)
CRU Temperature (v4.03)	1901–2018	0.50°	Univ. East Anglia CRU (2020)
CRU Precipitation (v4.03)	1901–2018		
Standardised Precipitation-Evapotranspiration Index (SPEI, v2.6)	1901–2018	0.50°	Vicente-Serrano et al., 2010
GLEAM Root-Zone Soil Moisture (v3.3b)	1978–2018	0.25°	Martens et al. (2017)
Copernicus Leaf Area Index (LAI)	2005–2017	0.50°	Verger et al. (2015)
MODIS C6 Aerosol Optical Depth (AOD) (L3, Terra and Aqua)	2002–2017	0.05°	Levy et al. (2013)
FLUXCOM Latent Heat	2001–2015	0.50°	Jung et al. (2019)

All data re-mapped to a 2.5° horizontal resolution

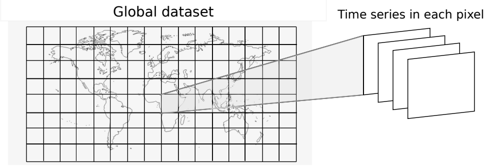
Period for analysis: 2005–2016 → Availability of OMI-HCHO observations

Color legend: Aquiring Discarded

Linear mixed-effects (LME) model

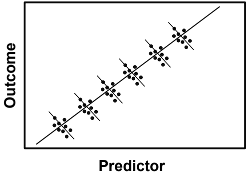
How to deal with non-independence in the data?

Both spatial and temporal levels of dependence in the dataset



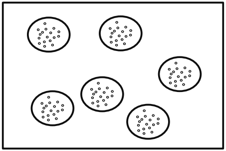
ALTERNATIVE 1

By applying a simple linear regression at each pixel, the model is noisy and does not use all information



ALTERNATIVE 2

By aggregating data at the pixel level, the model is less noisy but some information is lost



Linear mixed-effects models are a trade-off between these two alternatives that account for both **fixed** (variation explained by explanatory variables) and **random** (not explained by explanatory var.) **effects**

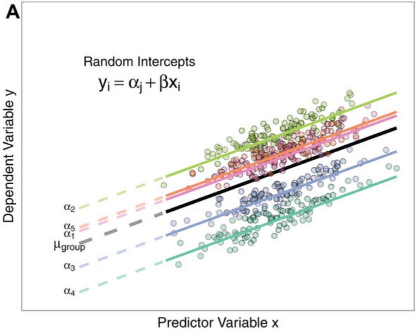
Linear mixed-effects model

Random intercept model

$$Y_{HCHO} = \underbrace{\text{fixed part}}_{\alpha + \beta_1 X_1 + \cdots + \beta_q X_q} + \underbrace{\text{random part}}_{\text{Site-level variability}} + \underbrace{\epsilon}_{\text{Residuals}}$$

In the fixed-effect part, the contribution of the explanatory variables and their interactions is accounted and described using linear regression models.

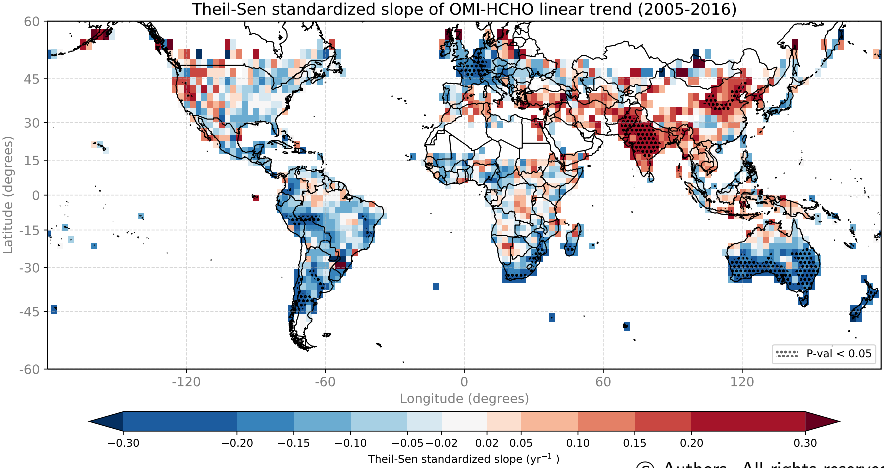
The random intercept model assumes that the variation around the intercept is normally distributed with a certain variance



Linear annual trend in formaldehyde

OMI-HCHO version QA4ECV, Level 3 (period: 2005–2016)

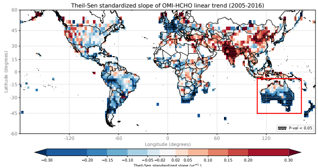
By applying a LME model, HCHO does not show an overall trend at the global scale, while robust trends emerge at the regional scale

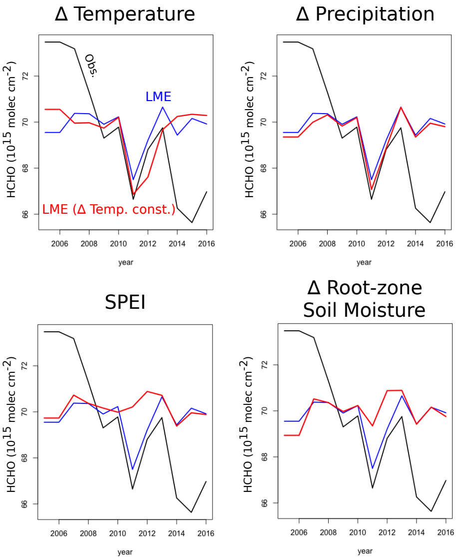


LME model and temporal contribution analysis

Regional scale: Australia

- Accounting for only climatic drivers, the LME model (blue line) does not reproduce the observed regional trend in HCHO (black line)
  $\Rightarrow$ Need to add other explanatory variables!
- When keeping constant the contribution over years of one explanatory variable at-a-time (red line), SPEI and root-zone soil moisture show an important contribution





Conclusions and perspectives

- Formaldehyde column concentrations show no overall trend at the global scale, but robust trends at the regional scale
- Including only climatic drivers, the linear mixed-effects model explains more than 50% of the observed variance of formaldehyde. However, to correctly reproduce the observed trend, some information is still missing (as observed for Australia)
- Over Australia, the Standardised Precipitation-Evapotranspiration Index (SPEI) and the root-zone soil moisture show important temporal contributions

Next steps

Include as explanatory variables:

- Leaf Area Index (LAI) to account for trends in biomass;
- Burned fraction to account for trends in wildfires, which are an important source of formaldehyde;
- Aerosol Optical Depth to account for anthropogenic sources of formaldehyde.

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