Tropospheric composition in a warmer climate scenarios of extreme weather & pollution

IN ECHAM5/MESSy

Tamara Emmerichs[1] and Domenico Taraborrelli[1]
IEK-8 Troposphäre, Forschungszentrum Jülich, Jülich, Germany

Tamara Emmerichs,
(t.Emmerichs@fz-juelich.de)

1. Context & Motivation

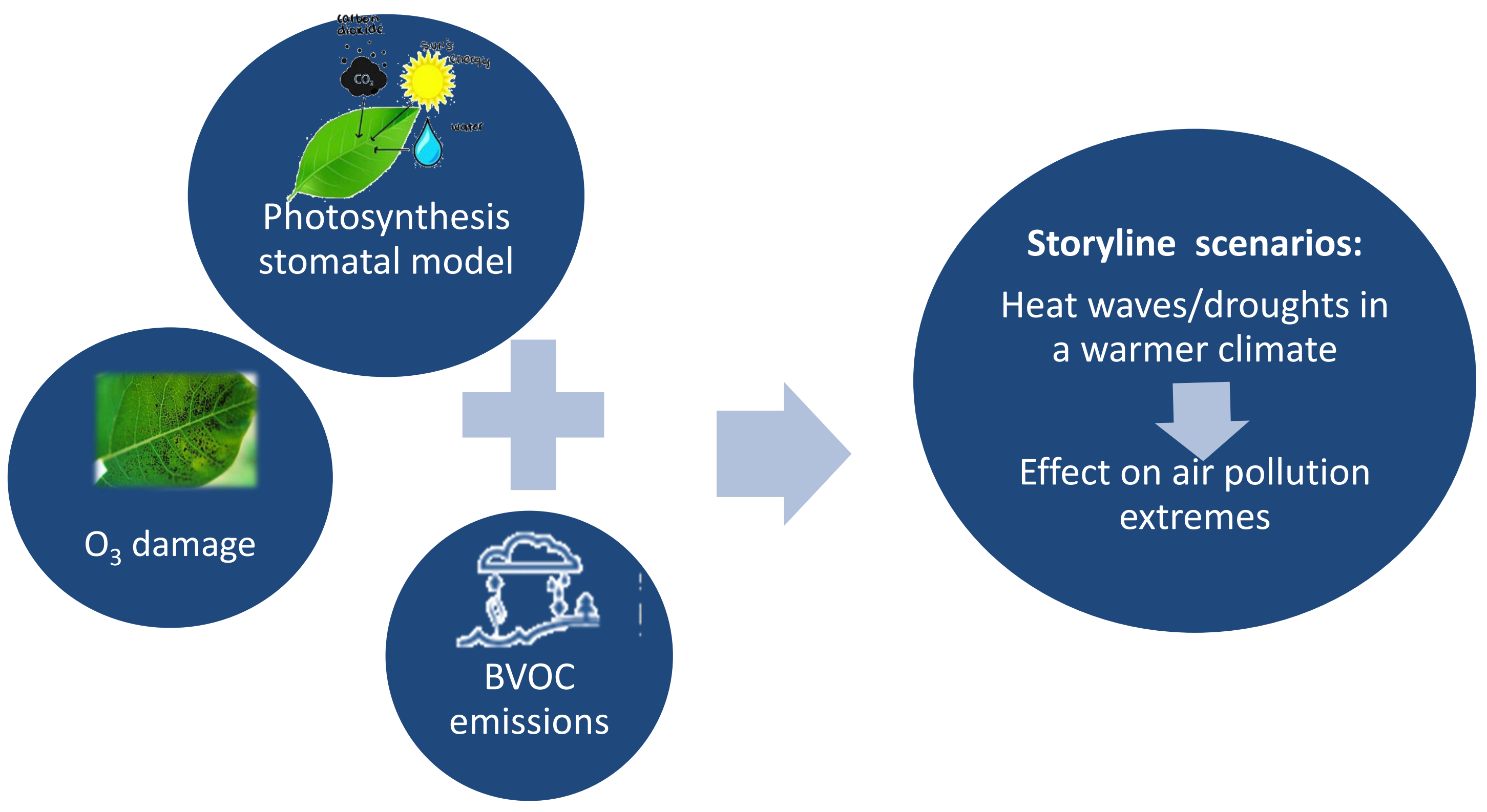
- Meteorological extremes are projected to increase in frequency and intensity because of climate warming (Ridder et al., 2022)
  - Meteorology significantly determines tropospheric composition (e.g. Tawfik et al., 2014), also bidirectional land-atmosphere exchanges (e.g. Fares et al., 2012)
  - ➢ Important implications for air pollution extremes are expected

2. SCENIC project

Storyline **Scen**ar**i**os of Extreme Weather, **C**limate, and Environmental Events along with their Impacts in a Warmer World

Methods:
- Separate dynamic and thermodynamic drivers of extremes
  - Selective nudging of atmospheric winds (dynamics) to reproduce past weather extremes
- CCMI forcing towards +2K & +4K warmer climate

Objectives:
- Complement classical climate simulations
- Make climate change more tangible
- Assess the role of surface-atmosphere exchange for air pollution (thermodynamic aspects)



Photosynthesis stomatal model

O_3 damage

BVOC emissions

Storyline scenarios:

Heat waves/droughts in a warmer climate

Effect on air pollution extremes

3. ECHAM5/MESSy

Model equipment:
Global atmospheric chemistry model (Jöckel et al, 2006)
- Complex atmospheric and aerosol chemistry available
  - Tagging system
- Large set of volatile organic compounds from plant emissions (BVOCs)

Recent and planned developments
- Photosynthesis stomatal model (20 land cover types: IFS Documentation – Cy47r3)
  - Improved soil moisture response
  - O_3 damage function
  - Improved soil moisture stress to BVOC emissions

Soil moisture sensitivity study
Global model simulations with ECHAM5/MESSy (T42L31: 310km, up to 10hPa) & standard chemistry (Jöckel et al., 2016),), nudged (BL free) to ERAinterim

Experiments in (boreal) summer 2018:
a) ref: 'status quo' soil moisture stress
b) wpw: wilting of plants is omitted
c) SM: soil moisture stress is neglected
d) Combi: full consideration of soil moisture stress (to the max. photosynthetic activity, mesophyll and stomatal conductance)

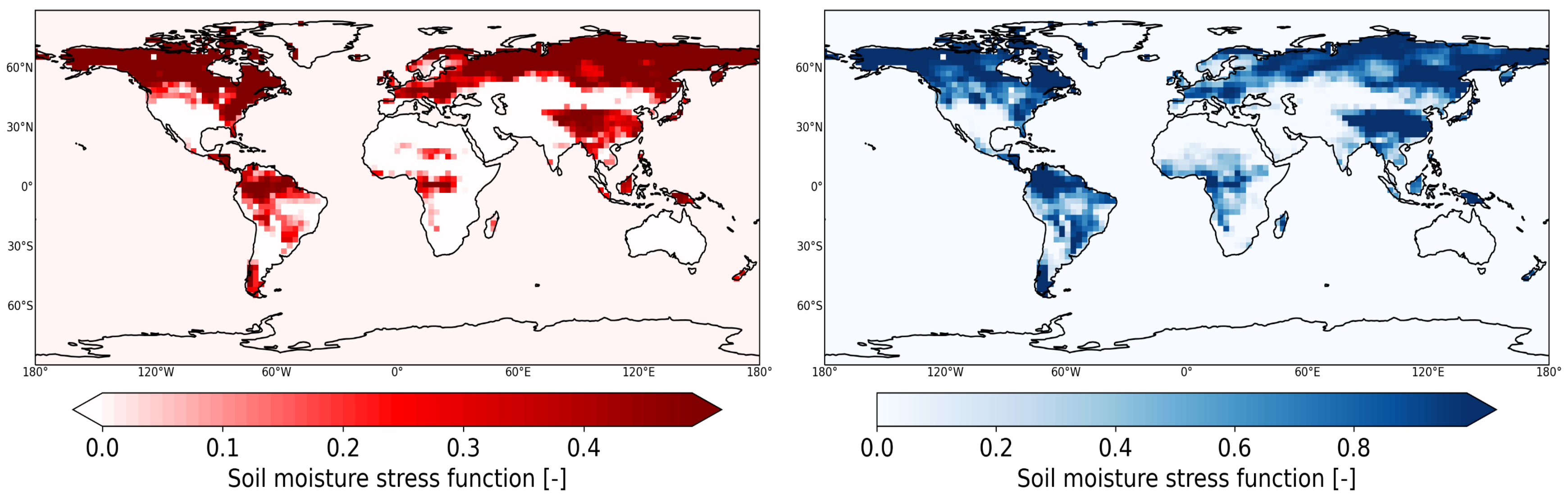
4. Results of soil moisture sensitivity study

Reduced soil moisture stress (Omission of W_{wpw} & entire SM stress, Fig. 1)
- Enhanced evapotranspiration (ET)
  - i. Low change in 'energy-limited regime' (W_s>W_{cr}, Fig. 1)
  - ii. High change in 'soil moisture-limited regime' (Seneviratne et al. ,2010)
  - ➢ Feedback on temperature (T), rel. humidity (RH) and soil moisture (SM)

Omission of wilting point (reduction of SM stress factor by up to ~0.5)
- Direct & indirect change of O_3 dry deposition (Fig. 2)
  - i. Direct change of dry deposition dominates
    - Increase by ~10%, most pronounced in the Amazon
  - ii. Locally different changes
    - Increase dominates (e.g. S U.S: ~↓T,↑RH, ↑SM)
  - ➢ Low increase of surface O_3 (5-10%) widespread ~ favoured precursor emissions
  - ➢ Decrease ~ ↑dry deposition only in Scandinavia & Canada

  (significant correlation: Δddep ~ ΔO_3)

Fig 1.: Regions of soil moisture stress factor changes (left, *wpw-ref*) and absolute values (*ref*) in boreal summer



No SM stress (reduction of SM stress factor by more than 100%)
- more pronounced change patterns (Fig. 3)
  - i. Direct change of dry deposition dominates
    - Increase by ~20%, most pronounced in the tropics
  - ii. Locally different changes
    - Decrease is most significant in very dry regions (e.g. Australia)
    - Increase is more widespread
    - ➢ Strengthen pos. correlation of surface O_3 with dry deposition (e.g. Europe)
    - ➢ Surface O_3 change of +-5-10%

Combined application of soil moisture stress
- Mesophyll and stomata experience additional SM stress
  - Highest relative changes on max. photosynthetic capacity
  - ➢ Stomatal activity overall reduced by up to 30%
  - ➢ Enhance ET limitation by soil moisture ('soil moisture-limited regime')
  - ➢ Significant O_3 increase in different climate regimes (Fig. 3)

Fig. 2: Summer mean change of O_3 dry deposition velocity due to the wilting (*wpw-ref*)

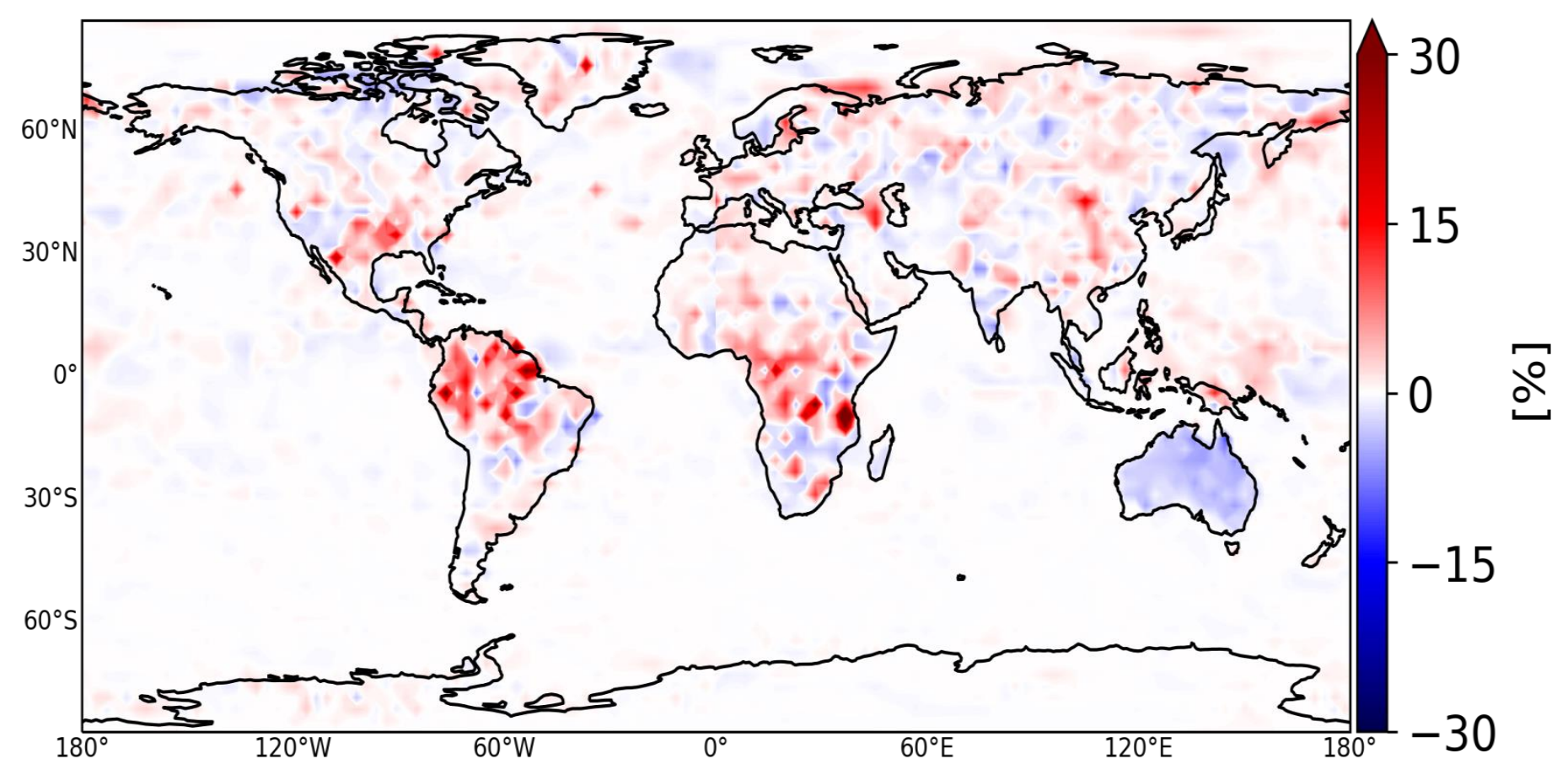
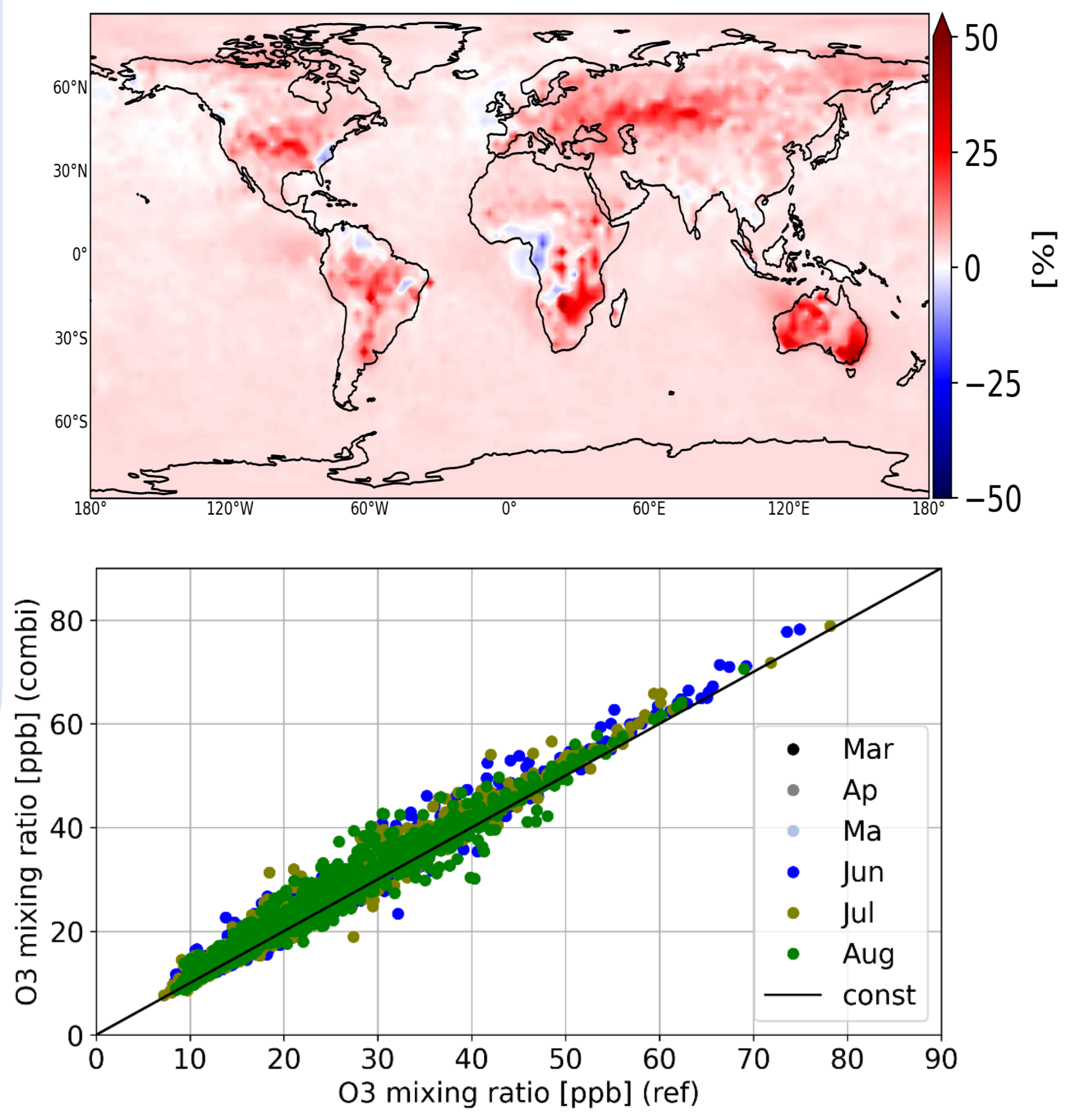


Fig. 3: Surface O_3: Summer mean change (top, *combi-ref*) and *ref~combi* in April-August 2018 (bottom)



5. Conclusion, Outlook and Acknowledgement

- **The Omission of the wilting point** decreases the soil moisture stress which significantly reduces O_3 dry deposition. This is most important in the Amazon.
  - The feedback by the changed transpiration have balancing effects. Thus, the slight increase of the surface O_3 mixing ratio correlates most to the changed relative humidity following the transpiration changes.
    = This soil moisture stress parametrization might be used to avoid shut down of dry deposition (s. Emmerichs et al., 2021).

- **The neglection of the total soil moisture stress** yield stronger impact patterns compared to the omission of the wilting point. The area of 'energy-limited regimes' is significantly increased which correspond to a decrease of dry climate (in the model).

- **The full consideration of soil moisture stress** enhances the limitation of transpiration by soil moisture. By this, the global mean stomatal activity is overall reduced by 30 % reduction which yields a significant increase of surface O_3 , in different climate regimes.

Outlook
The current soil moisture stress parametrization is not adequate (Verhoef et al., 2014) . Therefore, a parametrization for the leaf water potential is implemented to represent the plant response to the water status.

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