CO_2 Suppression, Land Use Change, and Anthropogenic Forcing: Impacts on Isoprene and the Chemical Composition of the Troposphere

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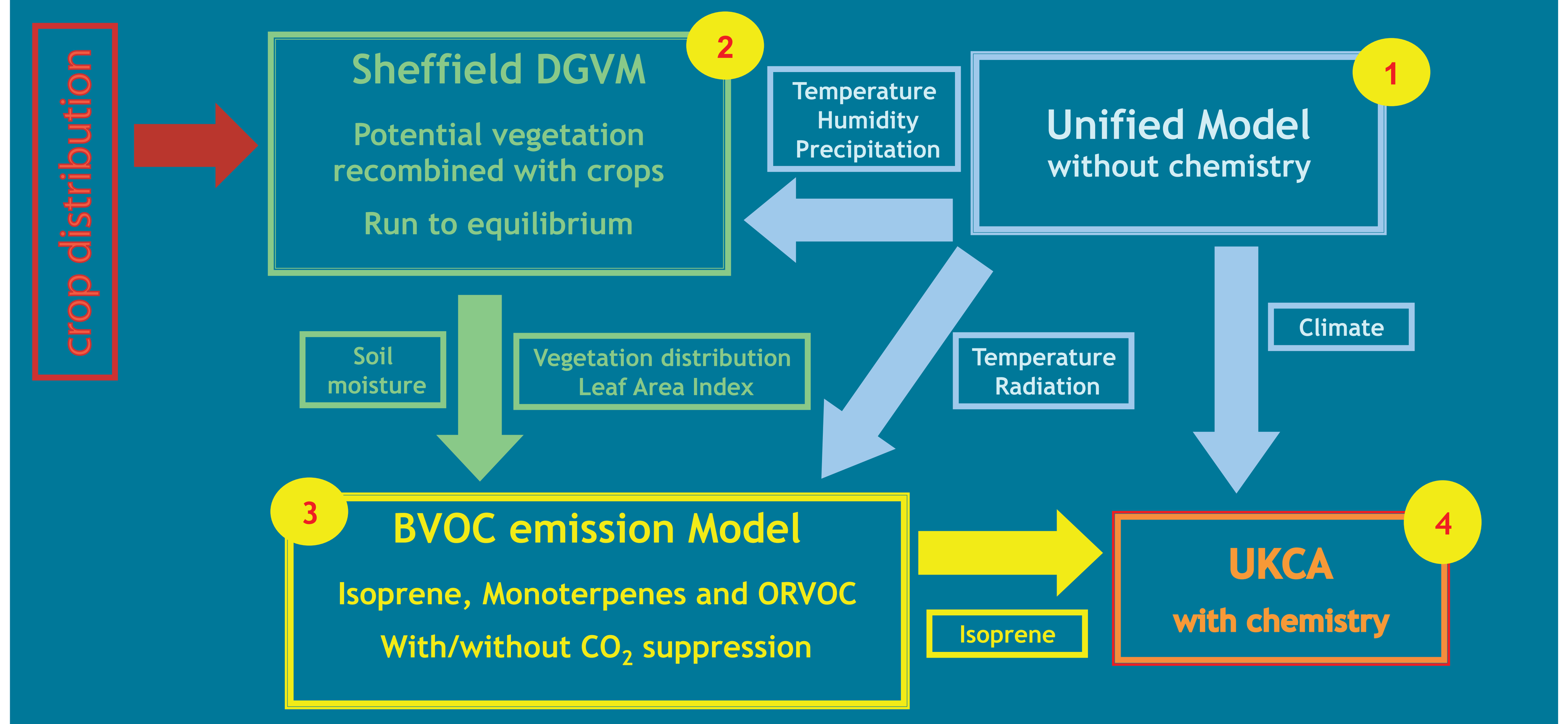
Abstract

Emissions of trace gases from the terrestrial biosphere play a significant role in determining the oxidising capacity and composition of the troposphere,[1] and are modified both by natural processes and anthropogenic activity. Isoprene constitutes more than half of biogenic volatile organic compound (BVOC) emissions globally, and its emission is dependent on climate and a range of vegetation properties, particularly the distribution and density of forests[2-4]. The human influence on the biosphere is global[5], and yet studies of anthropogenic impacts on vegetation distribution, and there BVOC emissions, have thus far been idealised[6,7] or regional[8]. Simulated natural vegetative responses show that future climate will likely affect isoprene emissions[3,4,9-11], and therefore surface ozone[11,12]. Here, we show that policy decisions about land use exert a significant effect on global isoprene emissions and tropospheric ozone concentrations. Our simulations show that future (2100) global isoprene emissions decrease by 35% when we account for future anthropogenic land use change. We find that in tropical and sub-tropical regions, replacement of forests by expanding cropland elevates near surface ozone concentrations by over 50%. These changes are sufficiently large to feedback onto crop health and reduce crop productivity significantly. Our results demonstrate that a crucial part of modelling future atmospheric composition (and its resulting implications for human health, crop health, and climate) is the anthropogenic influence on biogenic emissions.

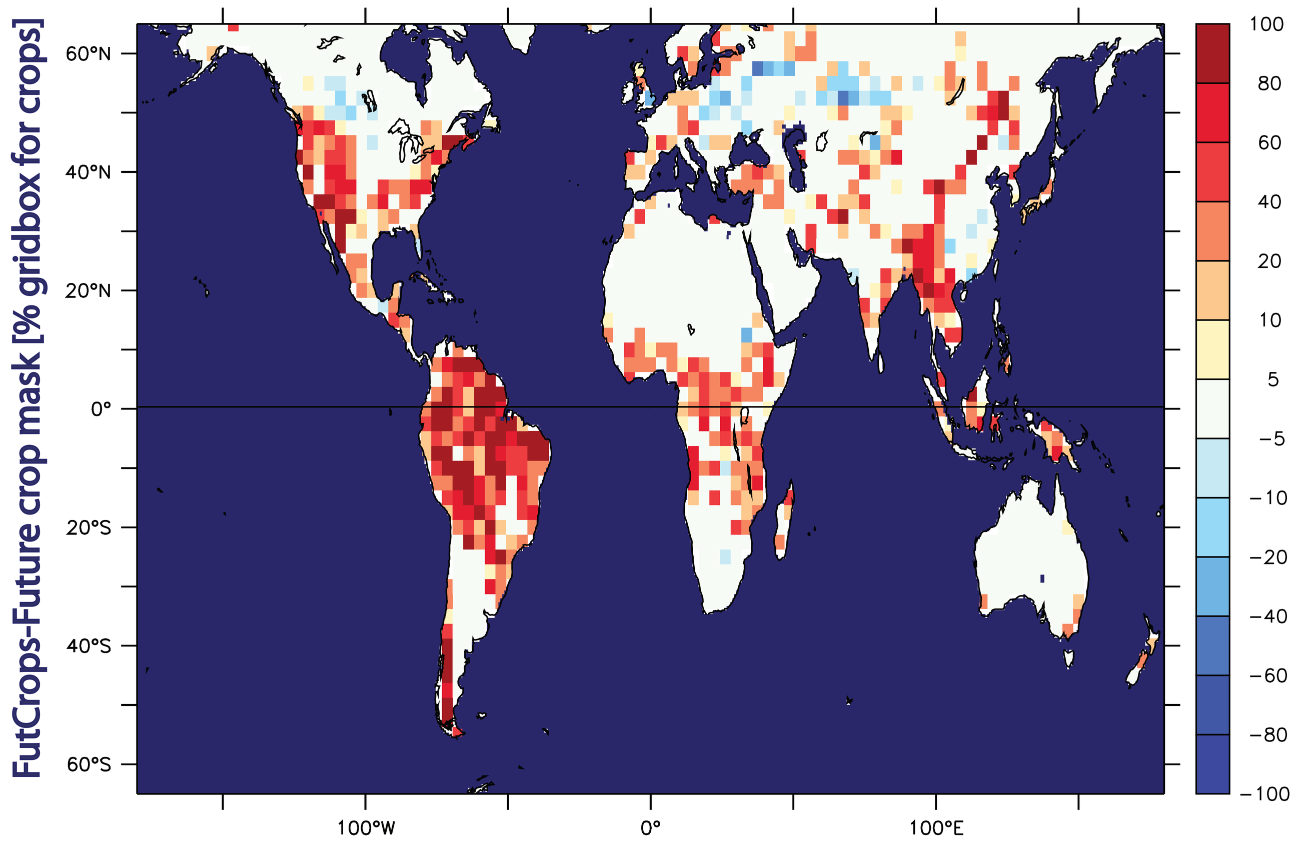
Experimental Setup



In this scheme:

- Crops are estimated using the IMAGE Model[13,14] and are used as input into the SDVGM[15,16] and then the VOC emissions model[17]
- The UM is forced with SSTs and sea ice[18-20]
- UKCA is a sub-model chemistry within the UM[21,22]
- Present day emissions are from IIASA[23,24]
- Future emissions are from the Royal Society report on Ground Level Ozone[25]

Crop Distribution



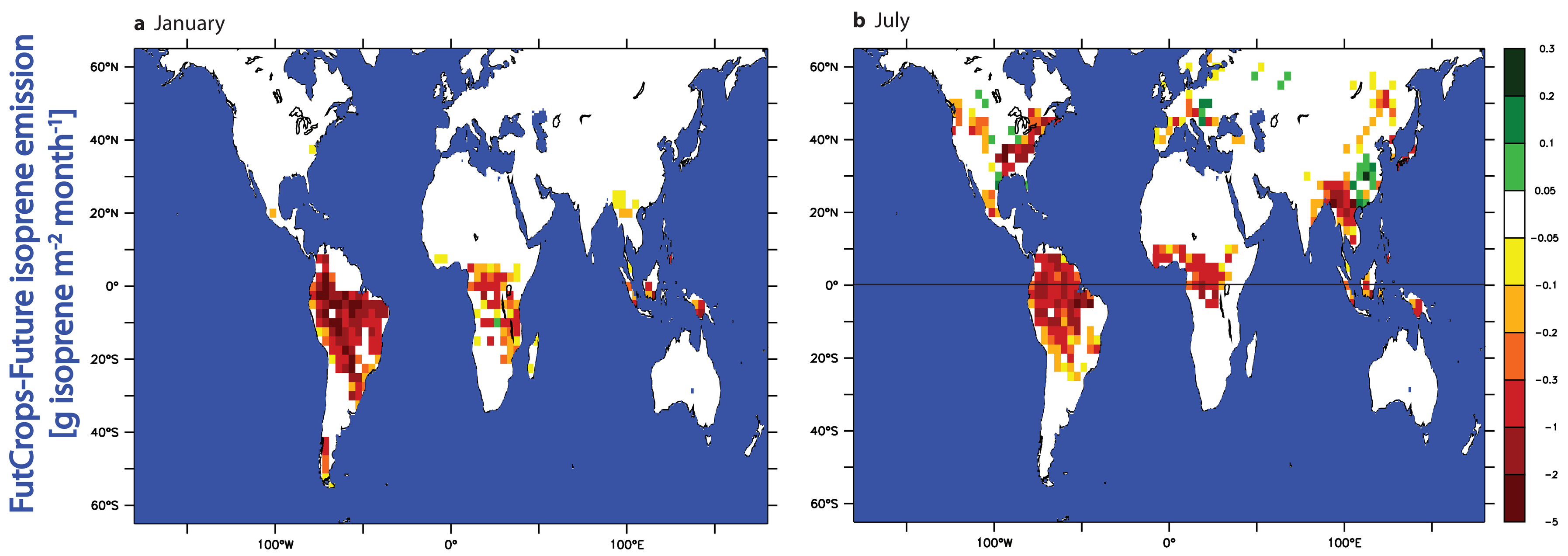
Present (1992) and future (2100) crop distribution were estimated by the Integrated Model to Assess the Global Environment (IMAGE) economic and policy model and compiled for input into a dynamic global vegetation model. We employed the SRES A1B scenario.

The fraction of land dedicated to growing crops increases most in:

- South America (425%)
- the western United States (123%)
- central Africa (209%)
- southeast Asia (141%)

Globally, the land area used for crops increased by 97%

Isoprene Emission



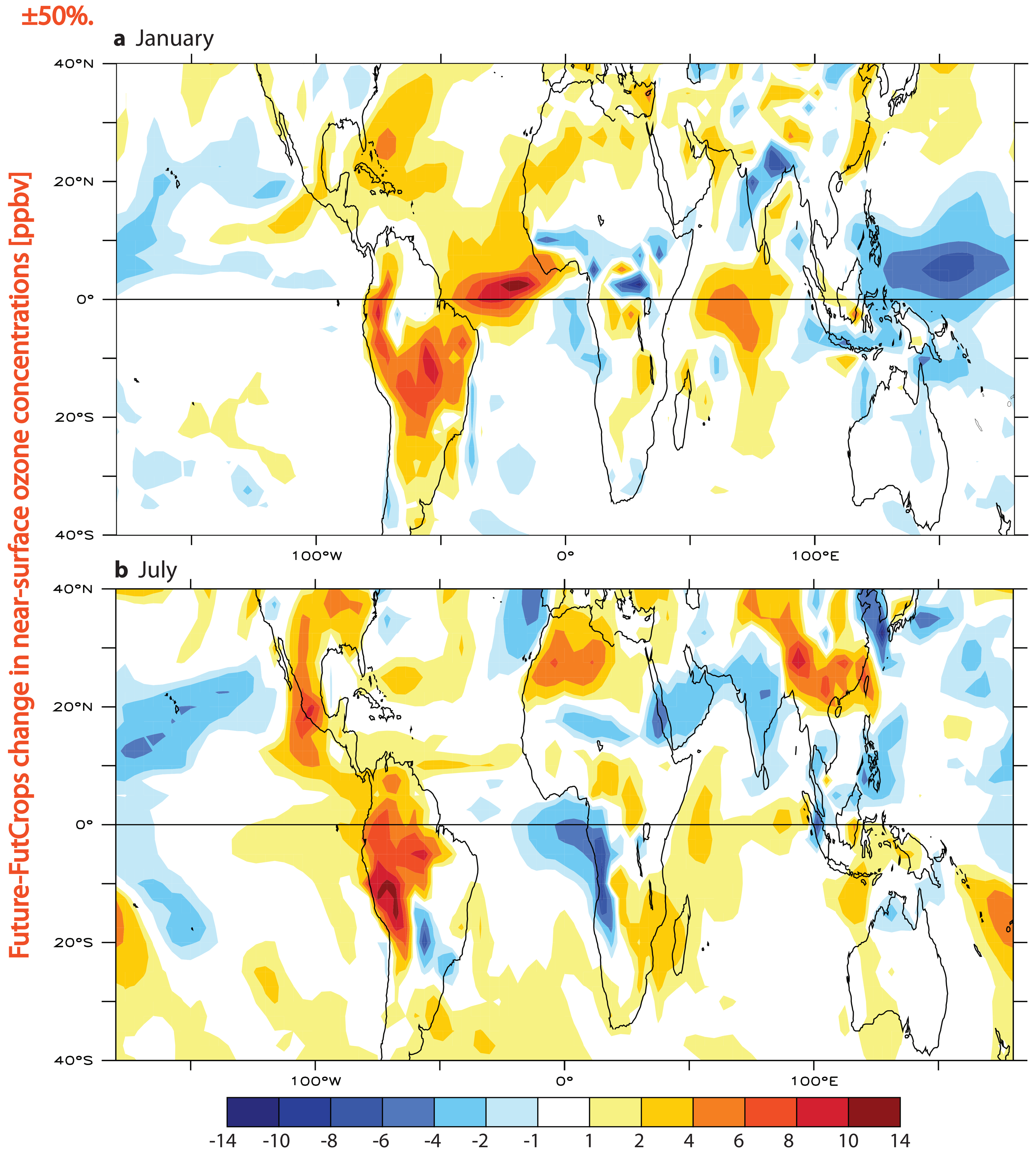
When forests (high emitter) are replaced by agricultural land (very low emitter), we calculate reduced global isoprene emissions of 314 Tg C yr^{-1}. This is equivalent to a 35% decrease compared to the calculation without crop changes (413 Tg C yr^{-1}). Emissions from current isoprene 'hotspots' are dramatically reduced:

- the Amazon (-57%)
- central Africa (-26%)
- south eastern United States (-27%)
- Southeast Asia (-16%).

With anthropogenic land use, annual isoprene emissions drop by 35%

Change in Ozone

The change in crop distribution leads to an increase in regional ozone of up to 50% (over 10 ppbv in 'hotspot' regions) compared with the Future simulation. In January, the largest changes are modelled over the Amazon, the tropical Atlantic, and the tropical Pacific. In the Amazon, dramatic reductions in isoprene flux due to cropland expansion generate elevated ozone concentrations by both reducing isoprene ozonolysis and reducing NOx sequestration to form organic nitrate species. As a result of the latter, NOx concentrations rise by 150% over the Amazon. The strong link between isoprene chemistry and nitrate species is demonstrated by the signal over the tropical oceans, where relative changes of ±70% in PAN concentrations lead to changes in NOx concentrations of ±50%.

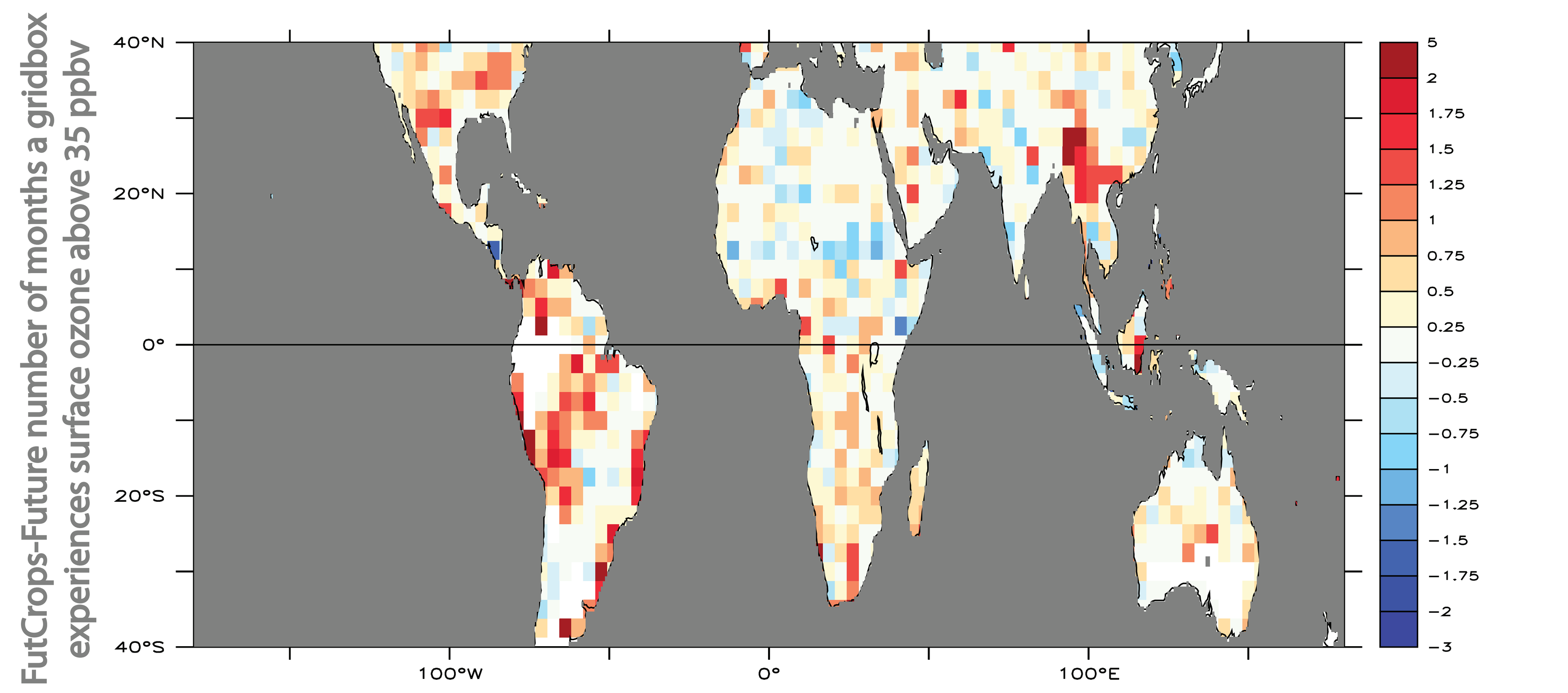


The change in four-year average surface ozone due to cropland expansion is significant

In July, with the peak growing and emitting season in the northern hemisphere, the terrestrial ozone signal shifts northwards. Significant ozone changes (over 10 ppbv) are modelled over North America, the Mediterranean, China, and the Amazon.Over North America and China, where isoprene emissions decrease with anthropogenic land use change, regional NOx concentrations increase by 40% and 90%, respectively. In the cleaner areas of southern China and South East Asia, where NOx levels are lower, PAN formation decreases, and local ozone production increases. The signal over Northern Africa is linked to elevated ozone concentrations in the Mediterranean, again via the formation and transport of nitrate species such as PAN.

Additional Ozone Exposure

In these simulations, the inclusion of anthropogenic land use change leads to increases in ozone over the very areas where cropland is projected to expand in the future. The productivity of crops begins to decline after acute exposures to concentrations above 35 ppbv[26], and the geographical area exposed to this concentration increases in the model when land use change is included. The figure below shows the change in the number of months that a gridbox is exposed to monthly mean ozone concentrations above 35 ppbv for an average model year between the FutCrops and Future runs. Zero values indicate gridboxes that were either exposed to ozone greater than 35 ppbv for the same number of months, or which never attain ozone values of that level. Three regions show a marked increase in the duration of exposure: the southern and eastern United States, Southeast Asia, and the Amazon. In these three regions cropland is predicted to expand; here exposure to ozone has the potential to damage the productivity of crops. It demonstrates the potential strength and significance of the feedbacks between crop expansion, ozone elevation, and crop health and productivity.



Average annual exposure to ozone above 35 ppbv increases up to two months yr^{-1} in some places, potentially reducing crop productivity

CO_2 Suppression

A FutCrops run that includes CO_2 suppresion is nearly identical to that without, and so is not shown. In January, the ozone signal above the continents of South America, Africa, and Australia is exacerbated by the additional reduction in isoprene emissions. In July the same occurs, with near surface ozone increasing in the south eastern United States, central Afirca, and southeast Asia, but there are two exceptions. In both southern South America and east Asia, the reduction in isoprene emissions reduces ozone production by lowering the recycling flux of NO to NO_2 via reaction with RO_2 radicals. In essence, both regimes have been VOC-limited, and the reduction of isoprene emissions in the area reduces local ozone concentrations.

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