Tropospheric Ozone in the United Kingdom Chemistry and Aerosols (UKCA) model

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Talk outline

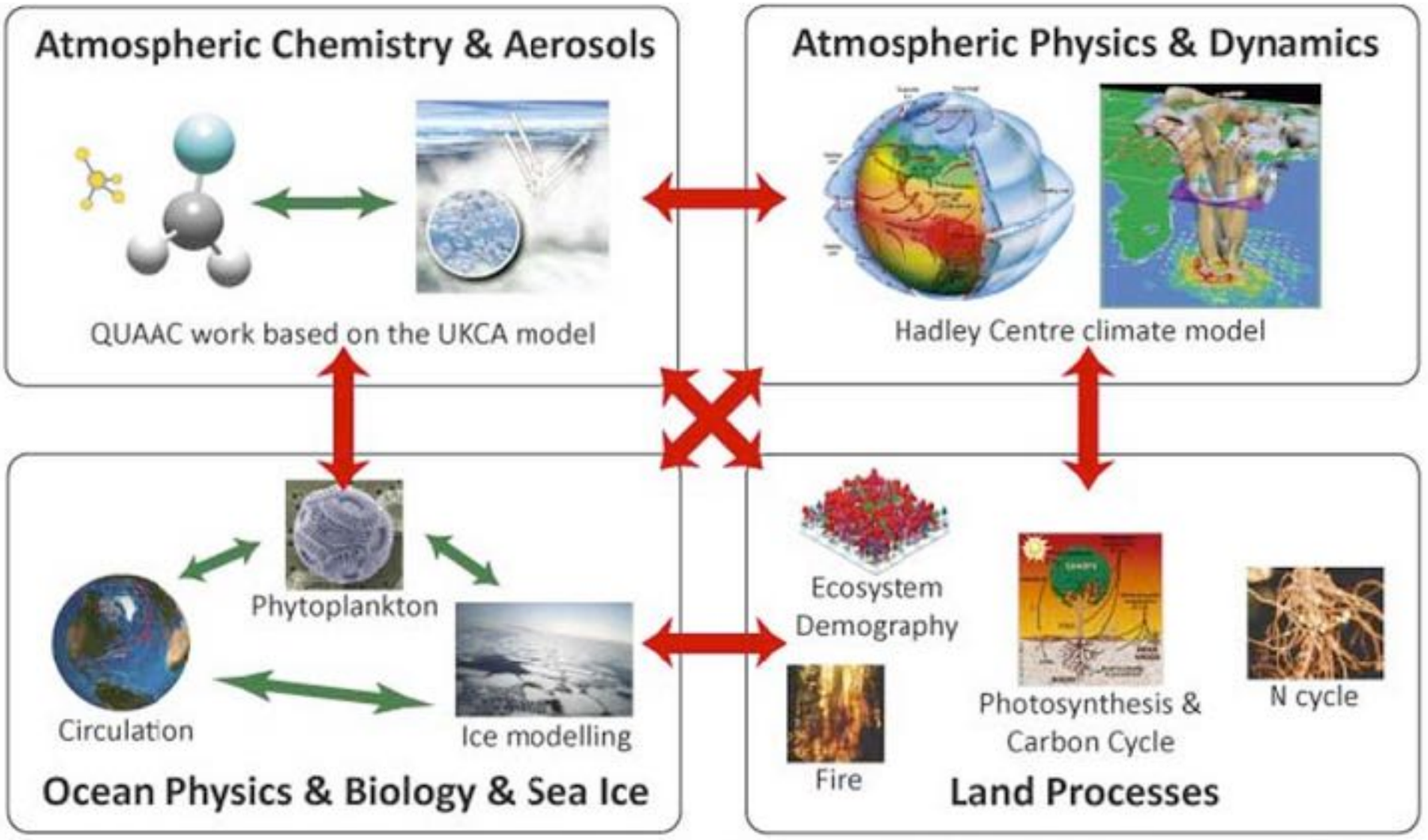
- **Ozone in the troposphere**
  - Is formed from Volatile Organic Compounds (VOC) and nitrogen oxide emissions
  - Is a non-linear system
  - Large levels of NOx cause a decrease in ozone production

- **The UKCA model and what it says about ozone in the present day**
  - Where are **regions** of **ozone production** and **destruction**?
  - How **accurate** are UKCA predictions of **ozone**?

- **Using UKCA to examine how ozone may change in future**
  - **Anthropogenic emissions** of NOx and VOC change
  - Land is used differently - **deforestation changes biogenic** (natural) **emissions**

UK Chemistry and Aerosols project (UKCA)

Model components of Earth System



Earth system modelling within QUEST. Based on a diagram by M. Joshi

- UK Met Office Unified Model (UM) is a weather forecast model run in climate mode - basis for HadGEM/HadES models, next generation UK-ESM1
- Online chemistry - feedbacks between atmospheric composition, radiation and transport

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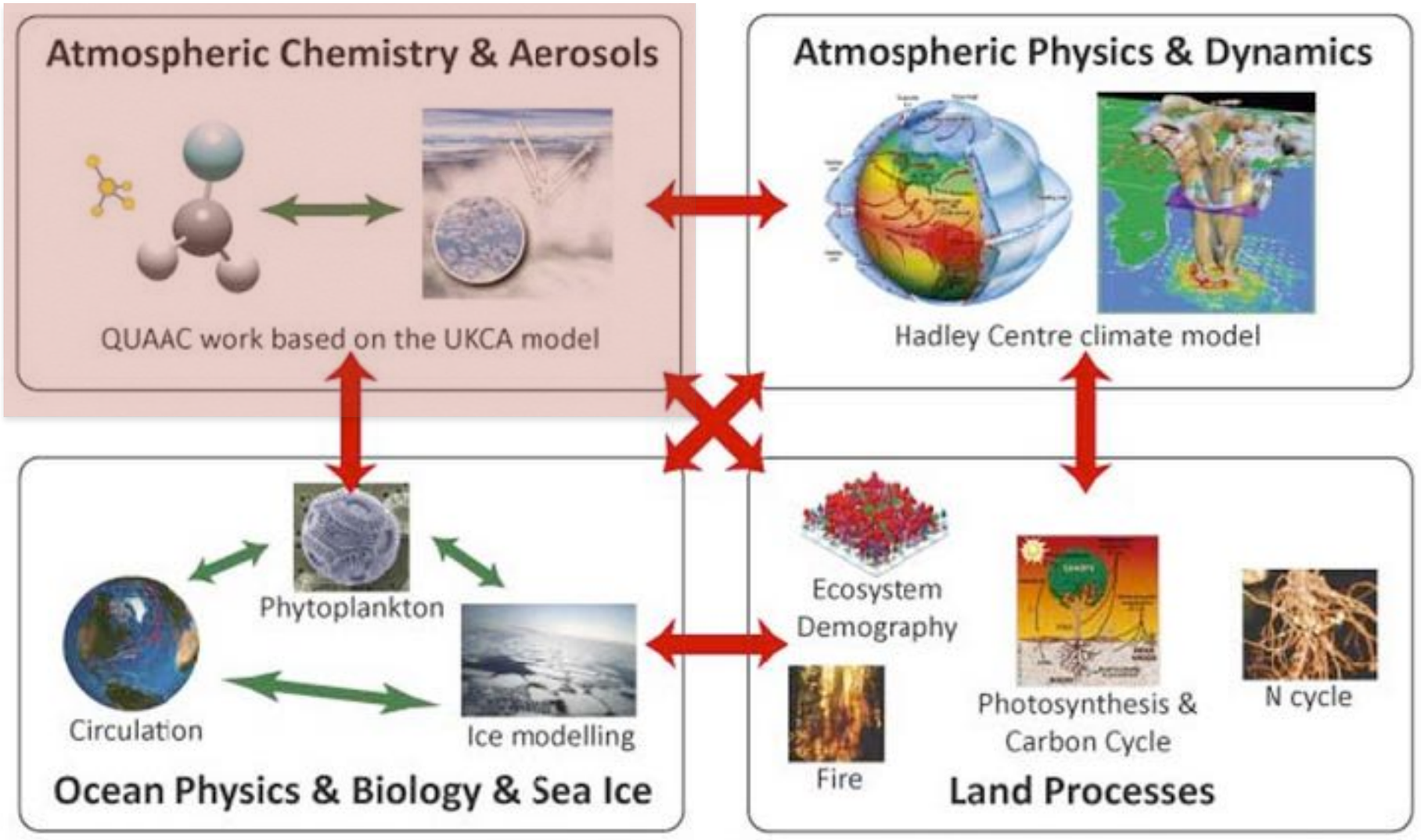

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Ozone in the troposphere

Ozone in the troposphere

- To a chemist, **the atmosphere is an oxidizing environment**

- **Pollution** released into the atmosphere **is slowly degraded by oxidation**

- Viewed a certain way, **the atmosphere is a low temperature combustion system.**

- **Volatile organic compounds are transformed into CO_2**
  - $VOC + O_2 \rightarrow CO_2 + H_2O$
  - **Ozone is can be produced or destroyed during this process**
  - **Ozone affects other pollutants, e.g. NO_2**
- **Ozone**
  - A key component of UK Air Quality
  - Implications for health

Ozone from a chemist's perspective - about in situ production/loss

$$\begin{aligned}
\mathrm{O_3} + h\nu(\lambda < 310\mathrm{nm}) &\rightarrow \mathrm{O_2} + \mathrm{O^1D} \\
\mathrm{O^1D} + \mathrm{H_2O} &\rightarrow 2\mathrm{OH} \\
\mathrm{OH} + \mathrm{VOC} &\rightarrow \mathrm{RO_2} + \mathrm{H_2O} \\
\mathrm{RO_2} + \mathrm{NO} &\rightarrow \mathrm{NO_2} + \mathrm{RO} \\
\mathrm{NO_2} + h\nu + \mathrm{O_2} &\rightarrow\rightarrow \mathrm{O_3} + \mathrm{NO}
\end{aligned}$$

- Local or regional emissions of **volatile organic compounds** (VOC)
- VOC can have industrial or natural sources.
- React with oxidant OH to make **peroxy radicals**, RO2
- Peroxy radicals, **RO2** react with local or regional emissions of **NO** to make **NO2**
- NO2 is **photolysed** rapidly to **make ozone**
- **More ozone is produced than is consumed = ozone production**
- **Ozone production requires sunlight, VOC and NO**

Ozone from a chemist's perspective - about in situ production/loss

$$\mathrm{O_3} + h\nu(\lambda < 310\mathrm{nm}) \rightarrow \mathrm{O_2} + \mathrm{O^1D}$$

$$\mathrm{O^1D} + \mathrm{H_2O} \rightarrow 2\mathrm{OH}$$

$$\mathrm{OH} + \mathrm{VOC} \rightarrow \mathrm{RO_2} + \mathrm{H_2O}$$

$$\mathrm{RO_2} + \mathrm{NO} \rightarrow \mathrm{NO_2} + \mathrm{RO}$$

$$\mathrm{NO_2} + h\nu + \mathrm{O_2} \rightarrow\rightarrow \mathrm{O_3} + \mathrm{NO}$$

Primary pollutants, local emissions

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$$\mathrm{NO_2} + h\nu + \mathrm{O_2} \rightarrow \mathrm{O_3} + \mathrm{NO}$$

Ozone is regenerated and amplified

- Ozone **initiates** and is the **product** of this chemistry.
- When NO and VOC present in sufficient concentration, **more ozone is produced than is consumed = ozone production**
- **Ozone production requires sunlight, VOC and NO**
- **OH product affects lifetime of CH_4**

Ozone from a chemist's perspective - cycle of O3 production

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Ozone from a chemist's perspective - cycle of O3 production

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$$O^1D + H_2O \rightarrow \boxed{2OH}$$

$$OH + VOC \rightarrow RO_2 + H_2O$$

$$RO_2 + NO \rightarrow NO_2 + RO$$

$$NO_2 + h\nu + O_2 \rightarrow O_3 + NO$$

More info on Friday at 0930 !!

- Ozone **initiates** and is the **product** of this chemistry.
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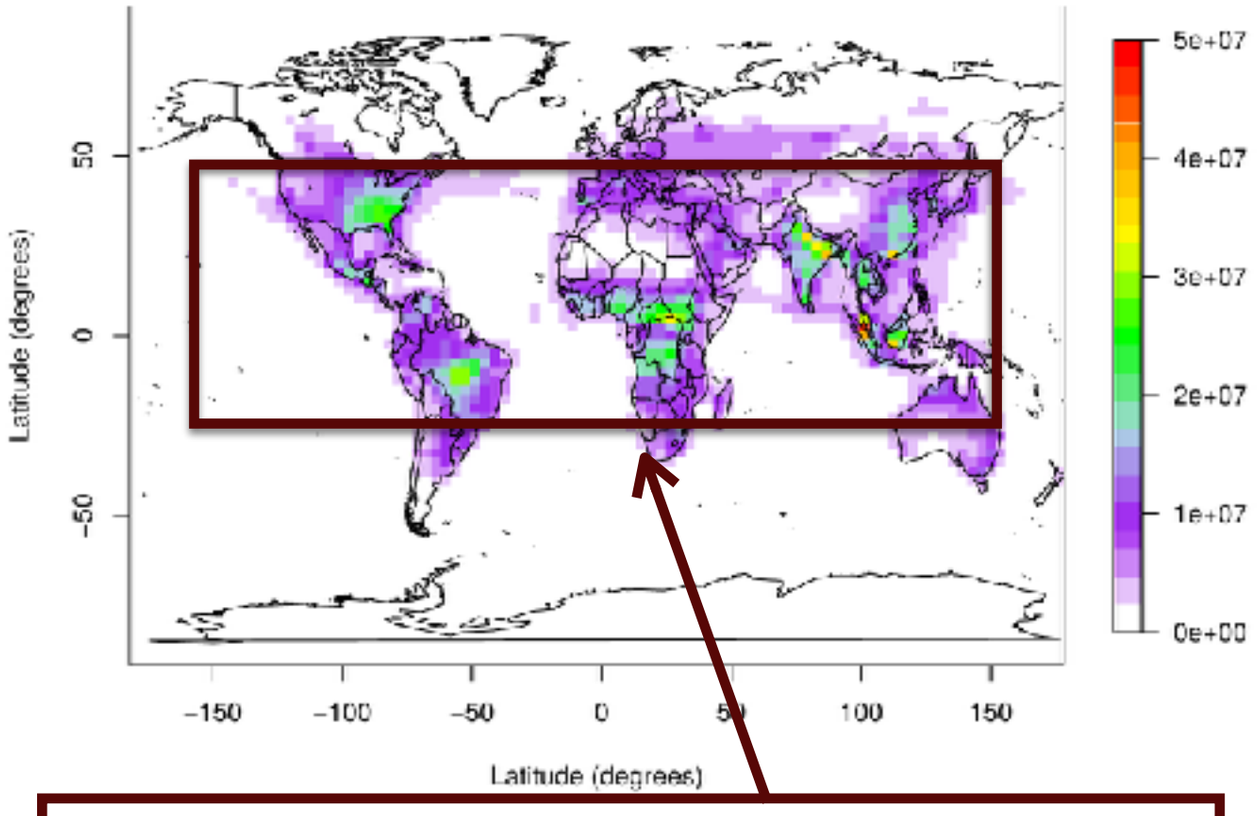
Ozone in the troposphere

Ozone production in UKCA: ozone production/loss

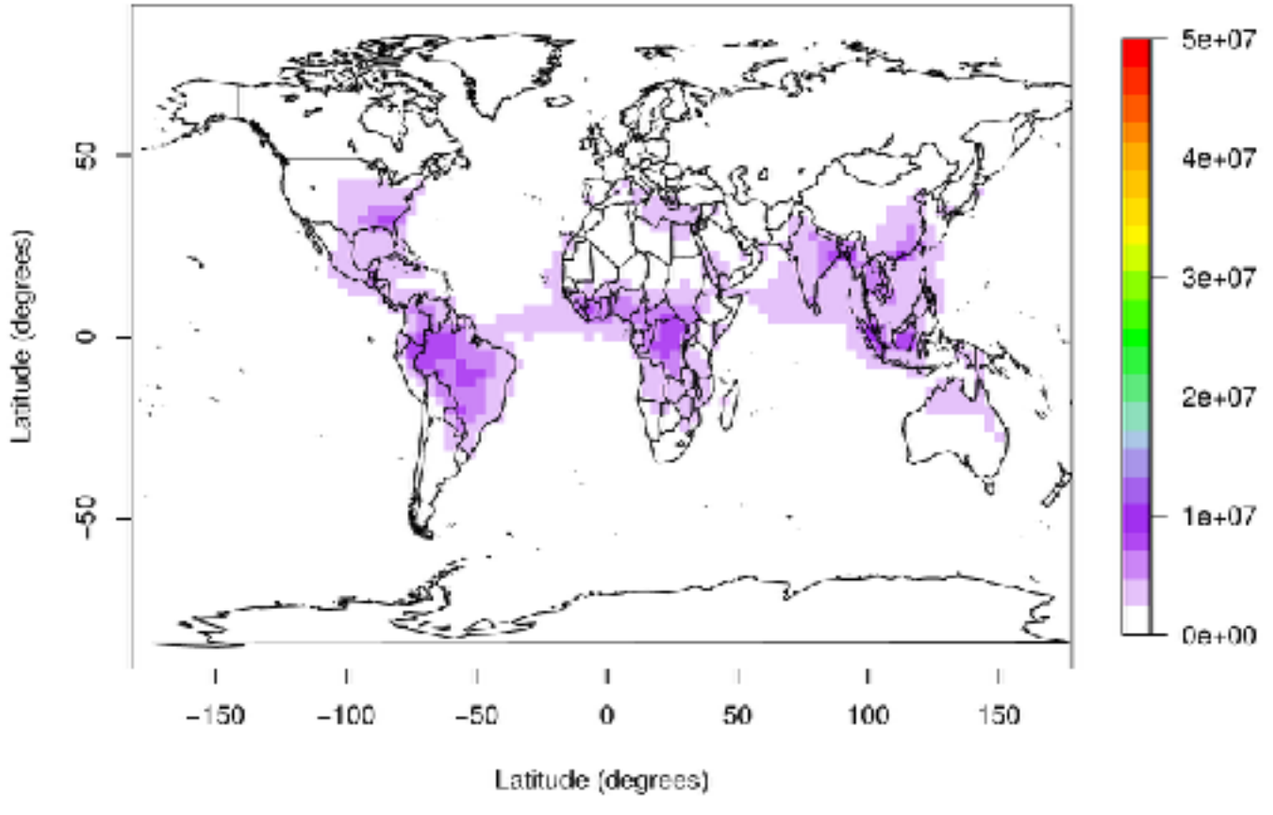
- Ozone is **produced close to the surface** via VOC oxidation
- Some ozone is lost via deposition to the surface (dry deposition)
- Regions with high NOx may not produce as much ozone

Ozone production at surface



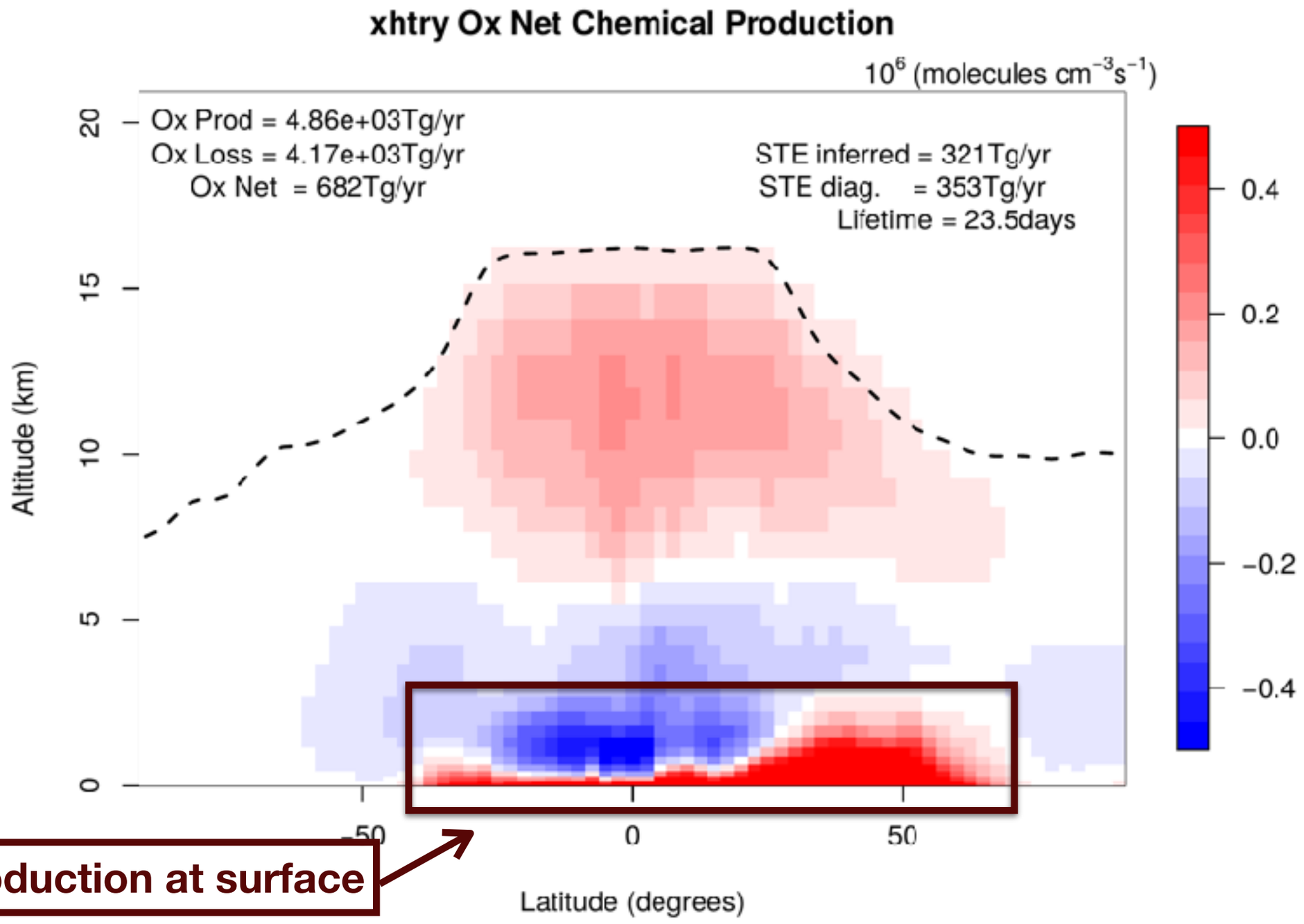
Ozone production in and near to tropics

Ozone loss at surface

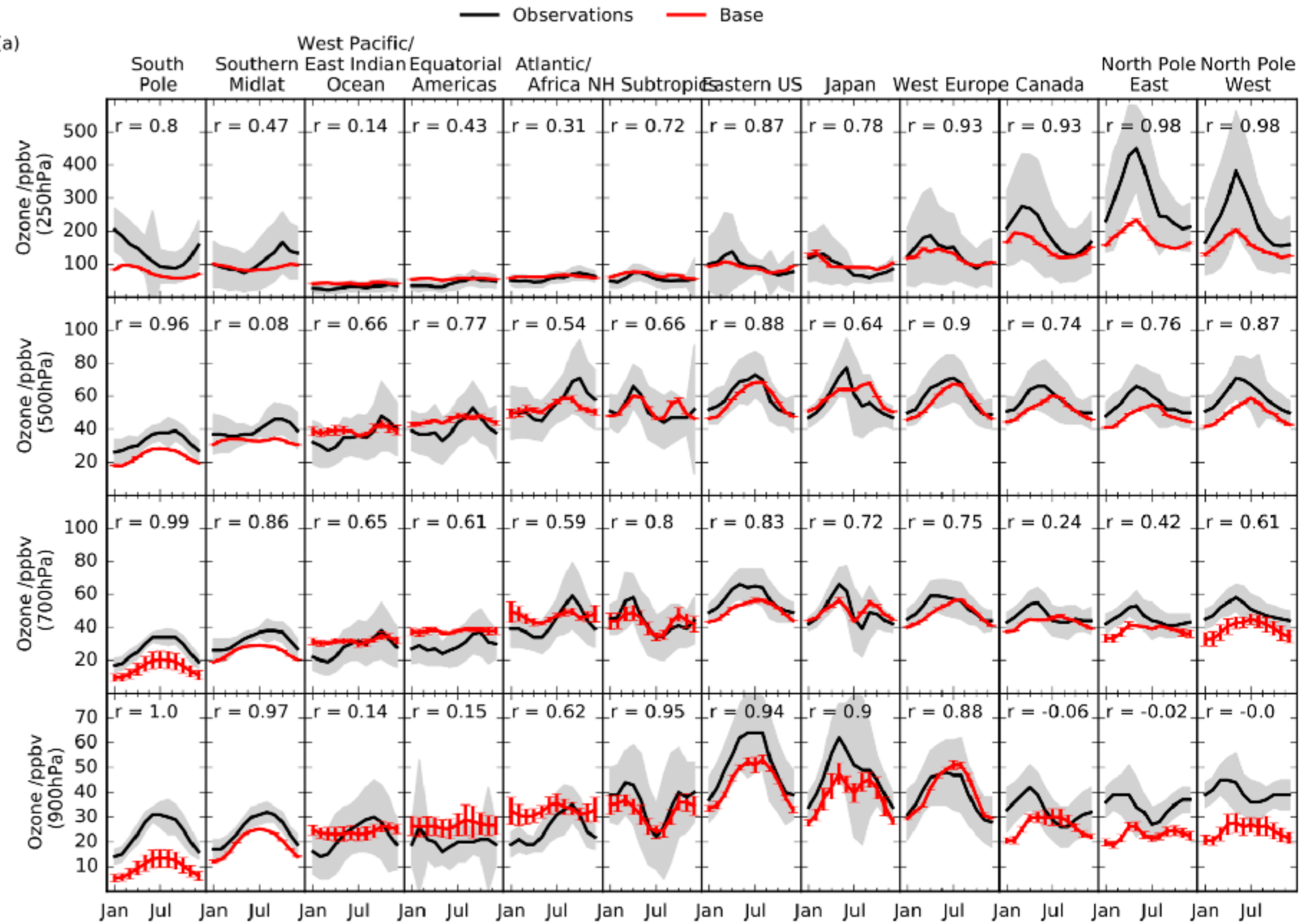


Ozone production in UKCA: ozone production/loss

- There is significant **loss in the mid troposphere** (via HO2 + O3)
- Most global tropospheric ozone is produced in the NH and lost in the tropics



UKCA vs Simone Tilmes' ozonesonde data comparison



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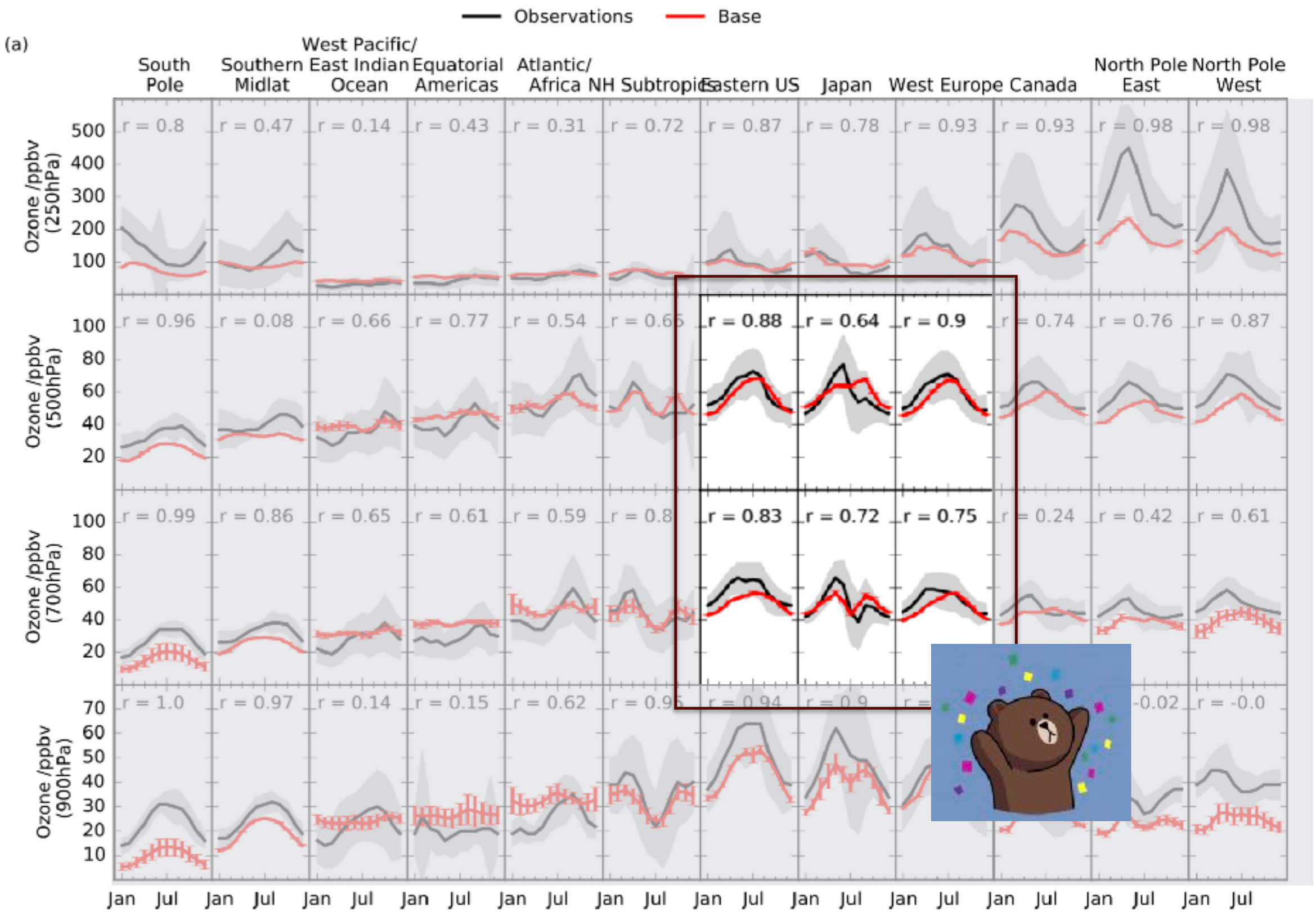

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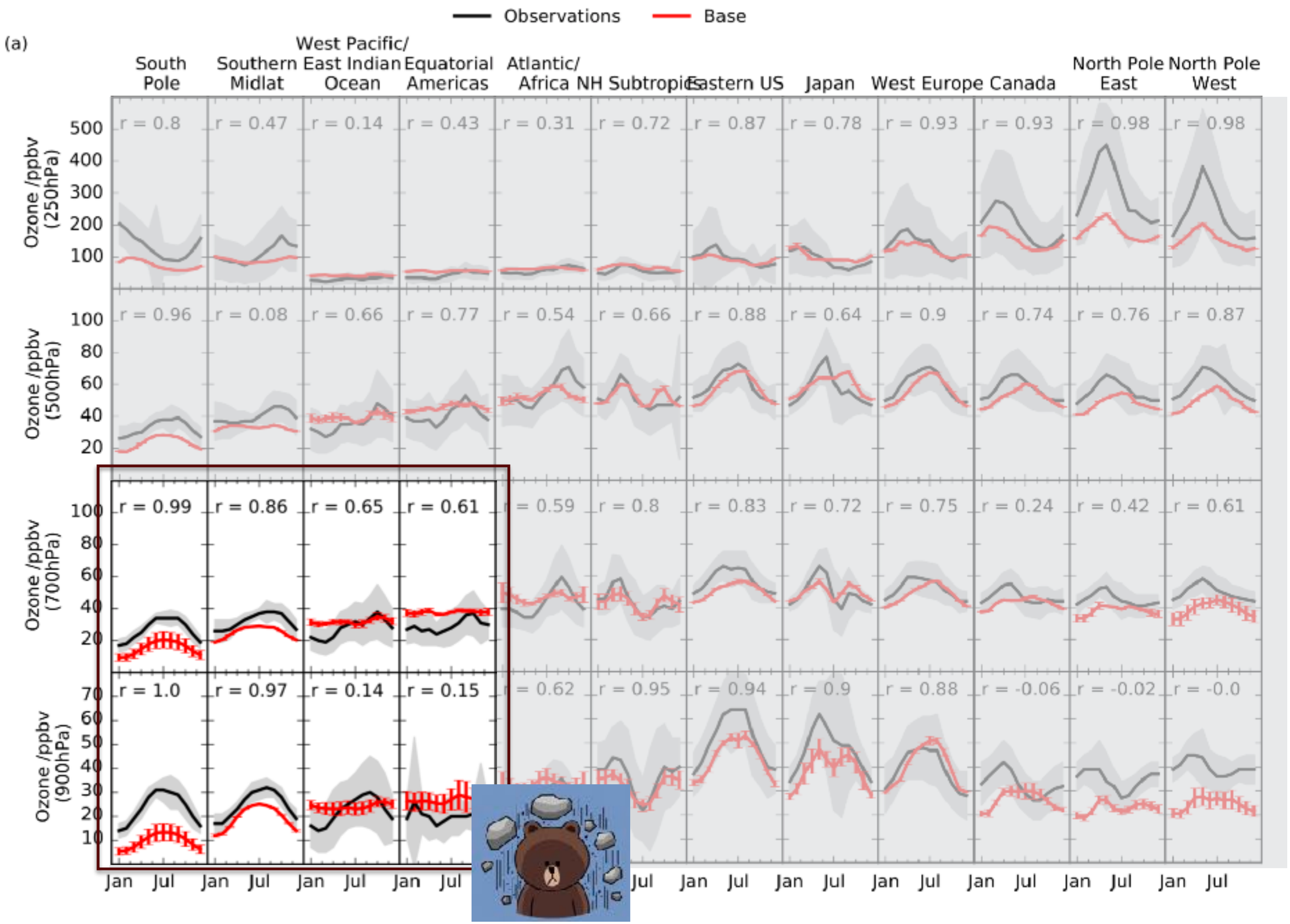


Ozone in future climate:

Vegetation, emissions and chemistry at work

How does ozone respond in future climate?

- Ozone levels in future climate is a wicked problem [***'too important to ignore, too difficult to solve'***]

  - **Anthropogenic emissions** of VOC and NOx will **change**

  - The **temperature** increases - most reactions go faster, **plant emissions increase e.g. isoprene, C5H8 (emitted by trees)**

  - **Land use / land cover** is changing

  - The amount of **water vapour** increases so OH increases

  - What happens to the **atmospheric dynamics** and **transport** of ozone?

Isoprene

- 500 Tg C isoprene emitted annually
- Broad-leafed trees major emitters, crops emit less
- Reacts quickly in the atmosphere in the presence of NOx to produce ozone.

- As **temperature** increases - **plant emissions increase e.g. isoprene, C5H8 (emitted by trees)**

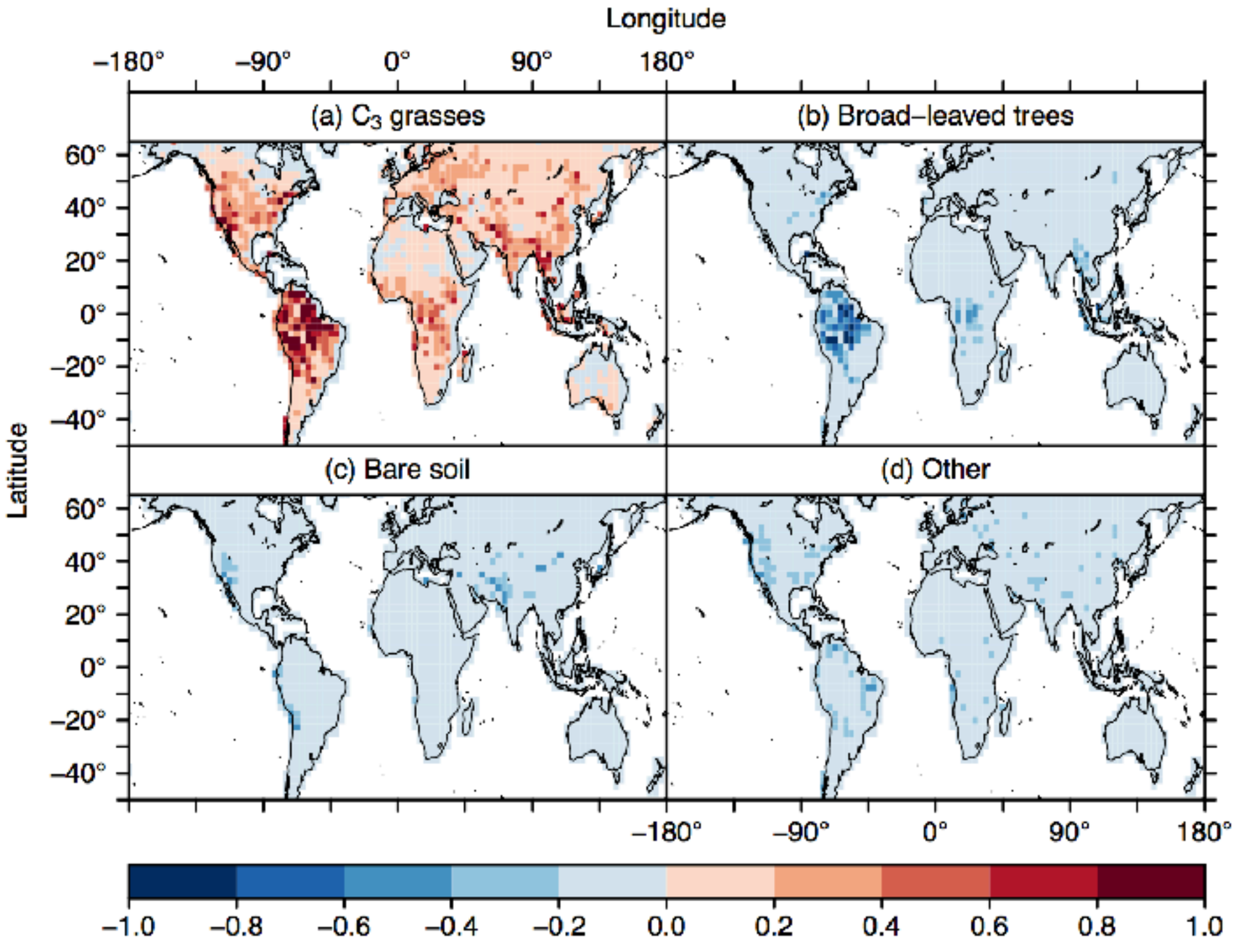
- As CO_2 increases, isoprene emission is inhibited

- **Land use / land cover** is changing - usually replacement of high isoprene emitters with low emitters**.**

- The amount of **water vapour** increases so OH increases

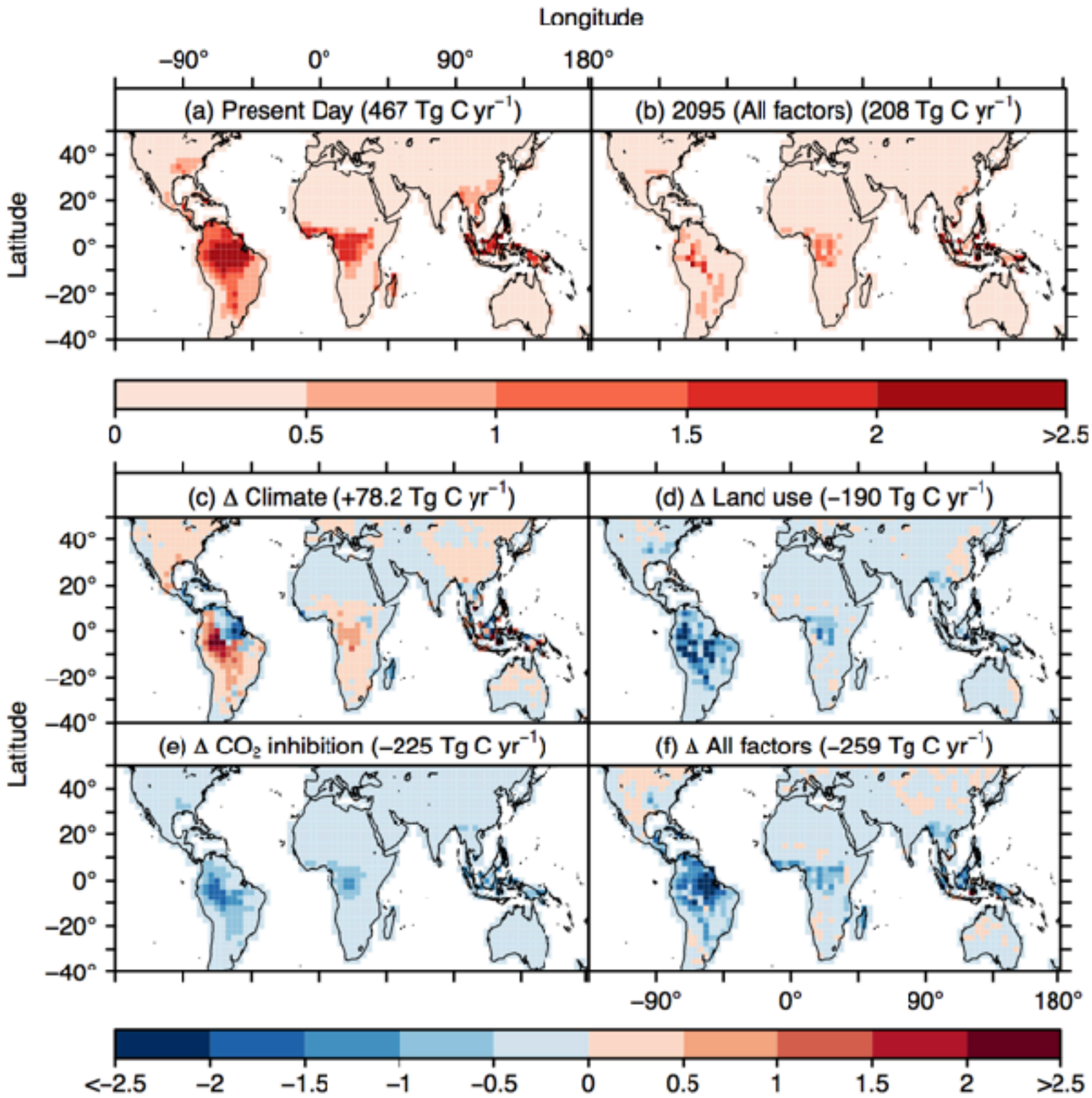
- What happens to the **atmospheric dynamics** and **transport** of ozone?

Land use changes



Change in grid cell fraction in the model in year 2095

Isoprene emissions changes



Change in isoprene emissions in the model year 2095

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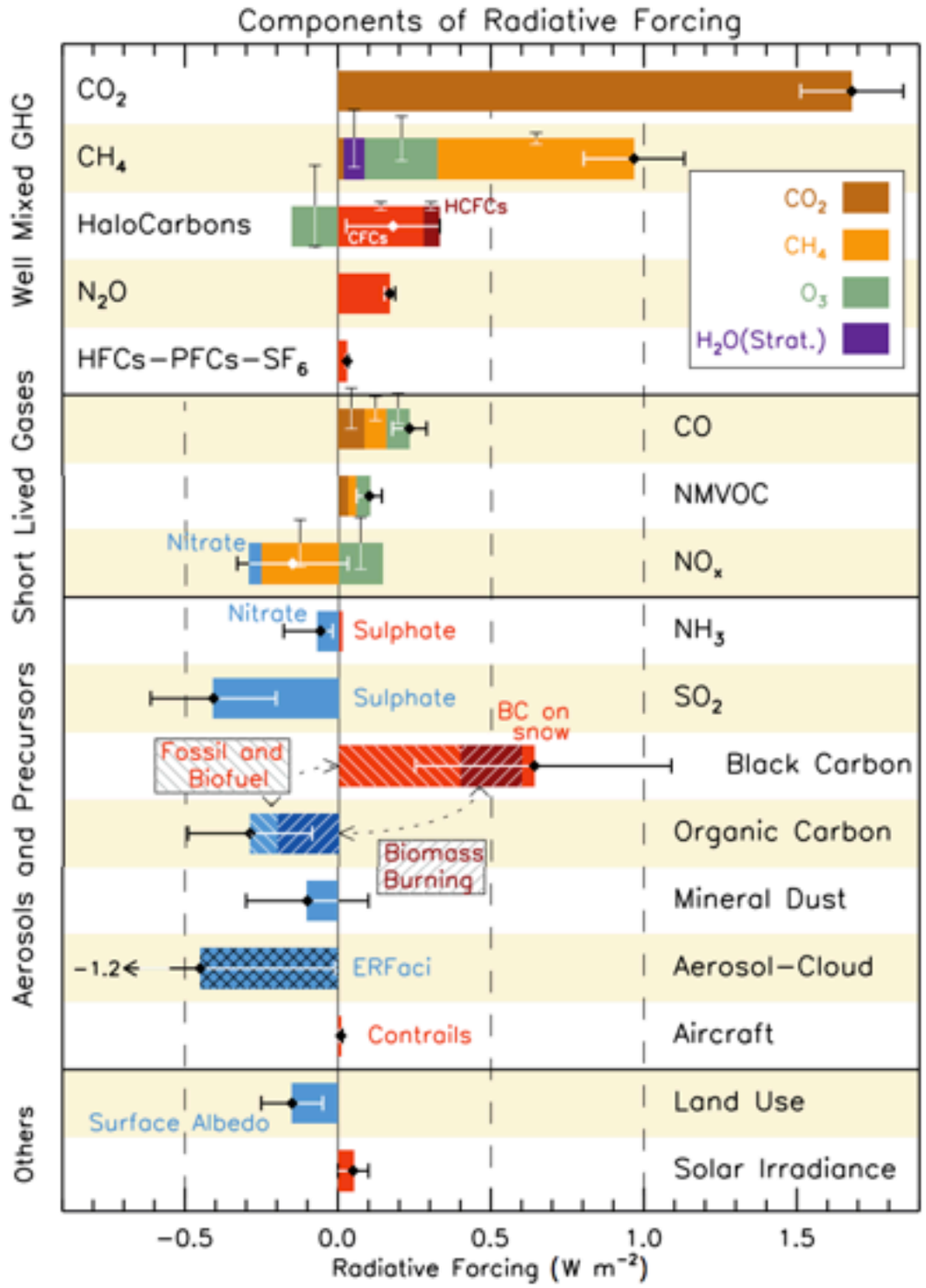
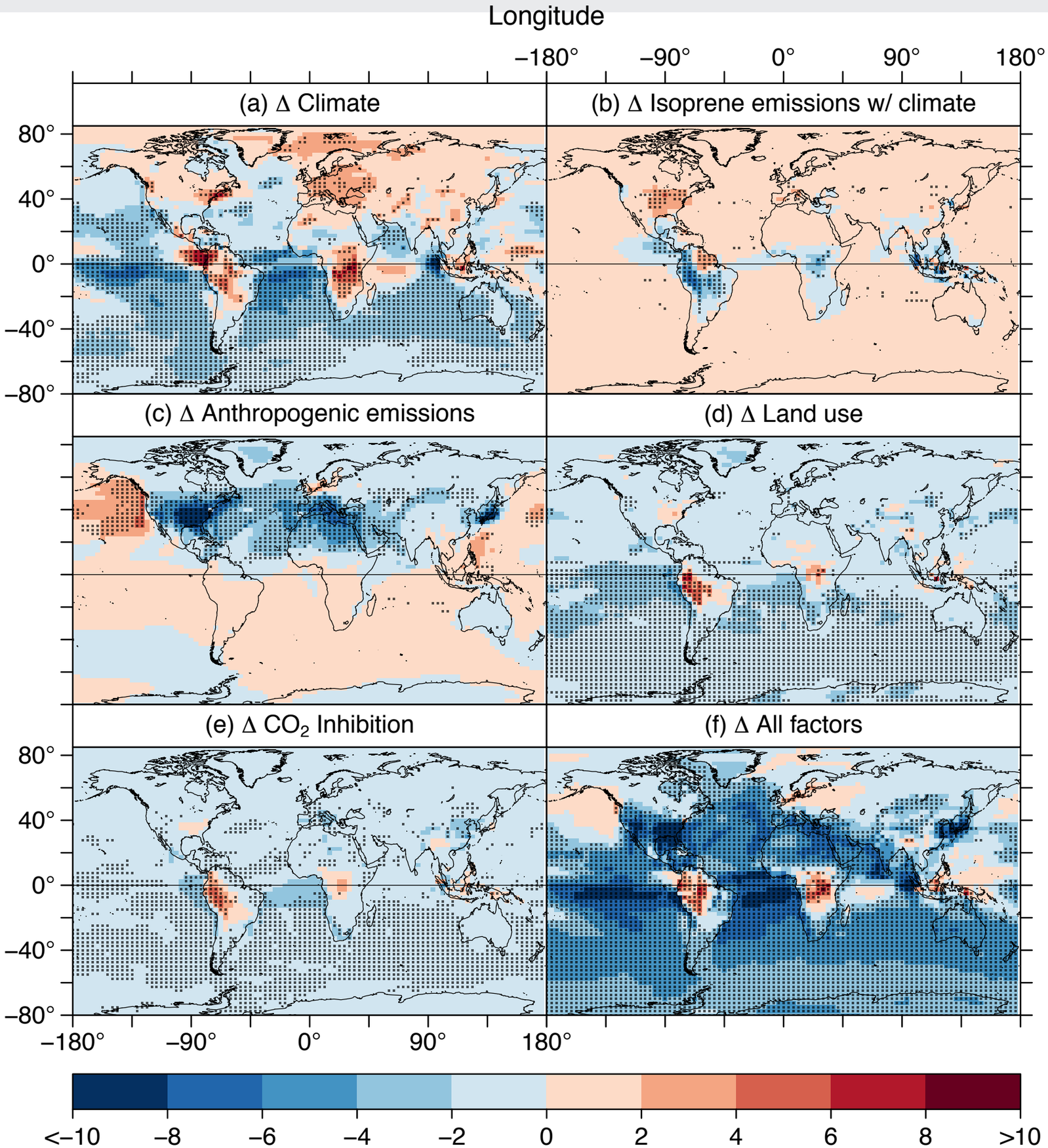
  - **Anthropogenic emissions** of VOC and NOx will **change**
  - The **temperature** increases - most reactions go faster, **plant emissions increase e.g. isoprene, C5H8 (emitted by trees)**
  - The amount of **water vapour** increases so OH increases
  - What happens to the **atmospheric dynamics** and **transport** of ozone?
  - What about **biomass burning**?
  - What about methane? Will anthropogenic emissions increase? Will wetland emissions increase?



How does ozone respond in future climate?



Squire et al., 2015, Atm Chem Phys

- How does ozone respond?
- **Single** perturbations to climate system for each forcer
- Focus on **isoprene (VOC)** from vegetation.
- Then allow perturbations to **interact**
- UM/UKCA N48L60, CheT chemistry,
  - isoprene emissions from MEGAN
  - vegetation distribution from Sheffield Dynamic Vegeation model,
  - other emissions according to IPCC REF B2 scenario

How does ozone respond in future climate?

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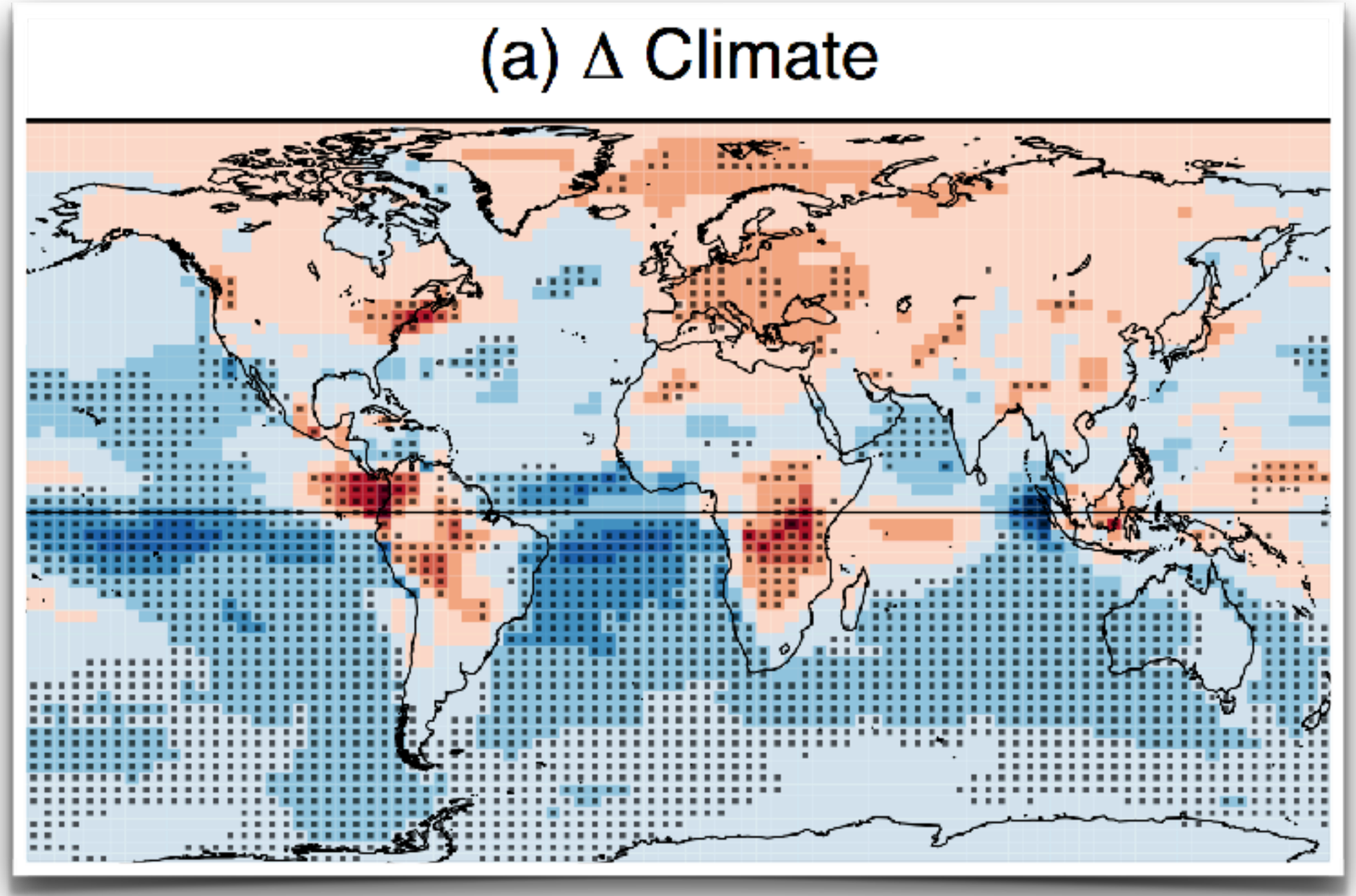

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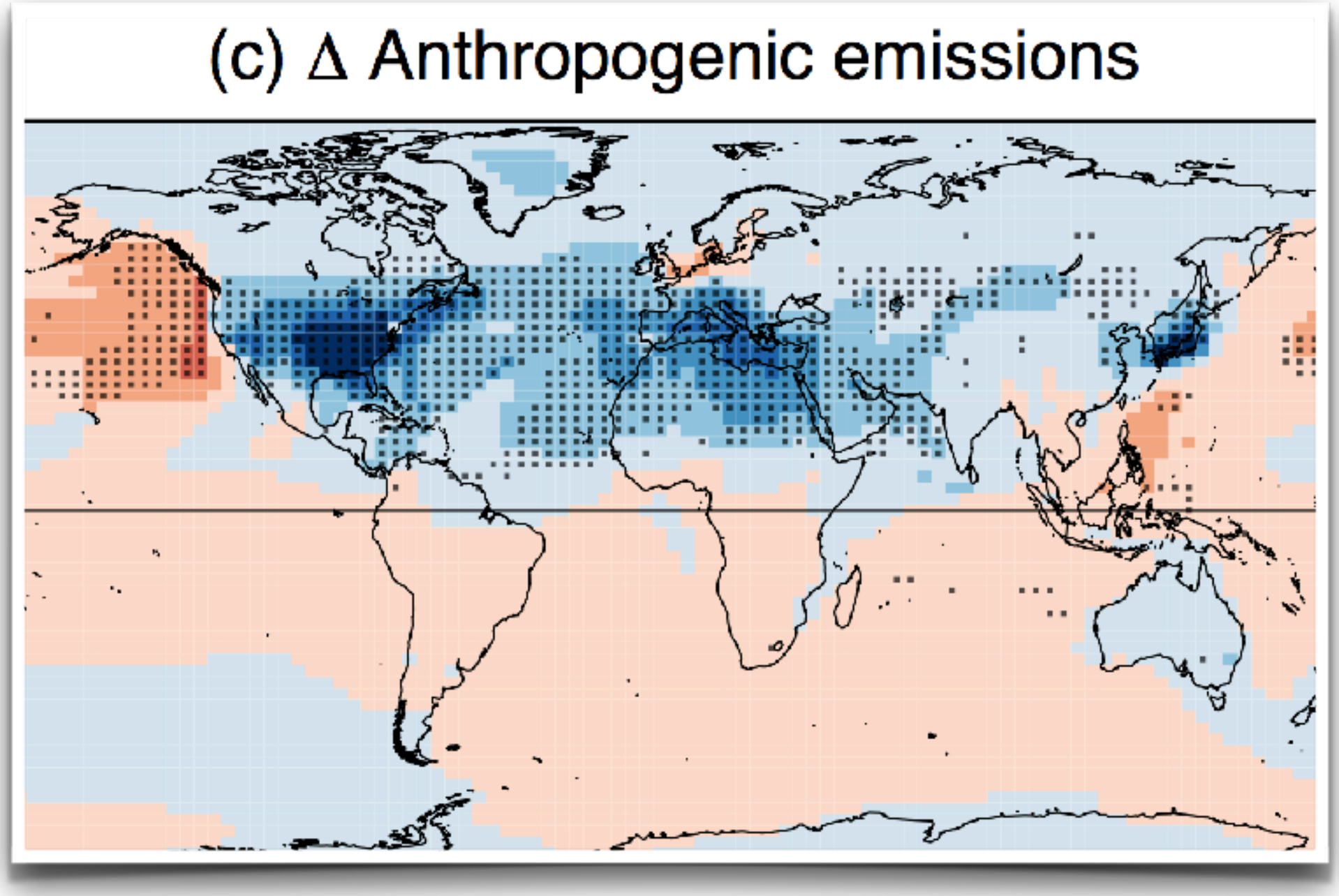

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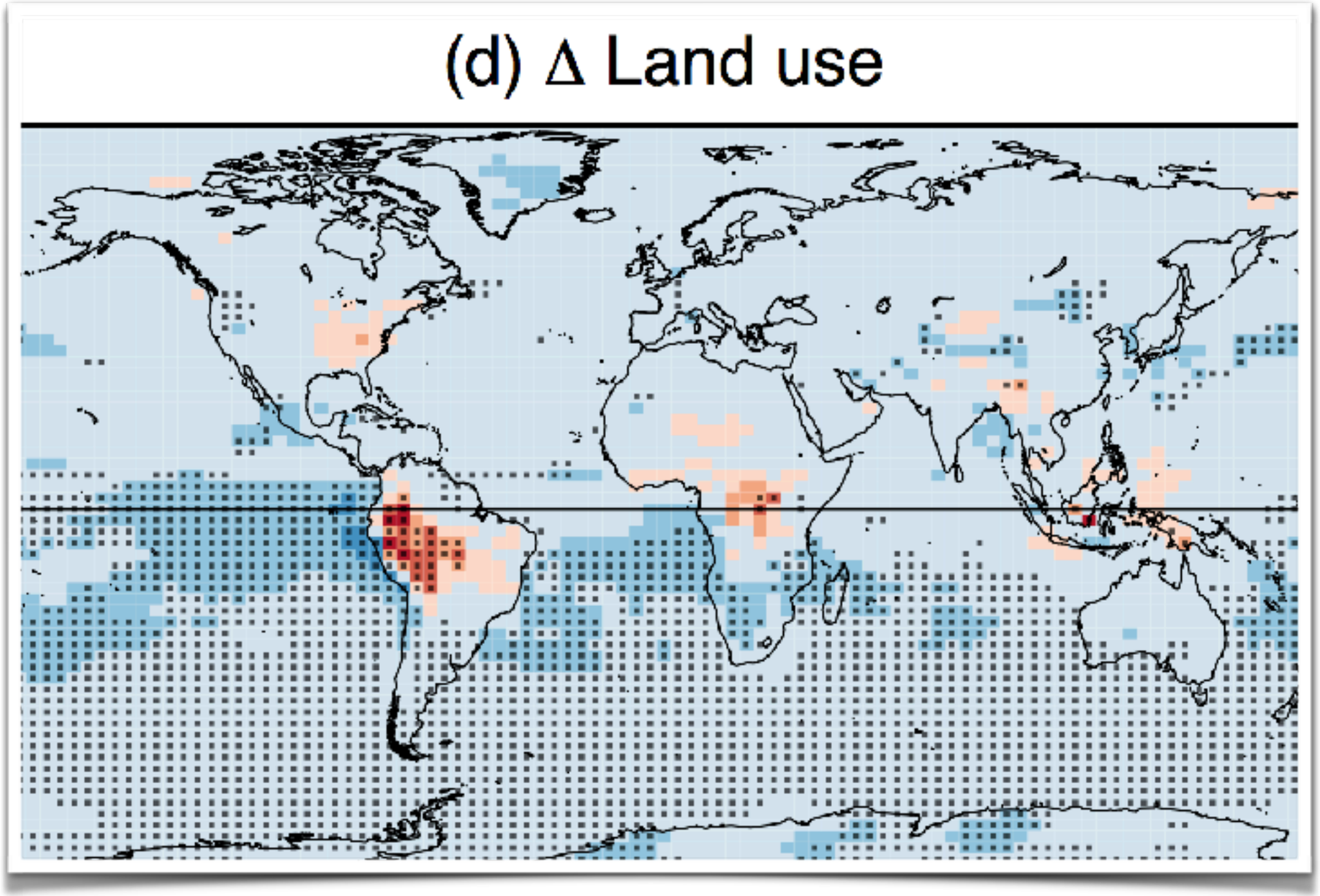
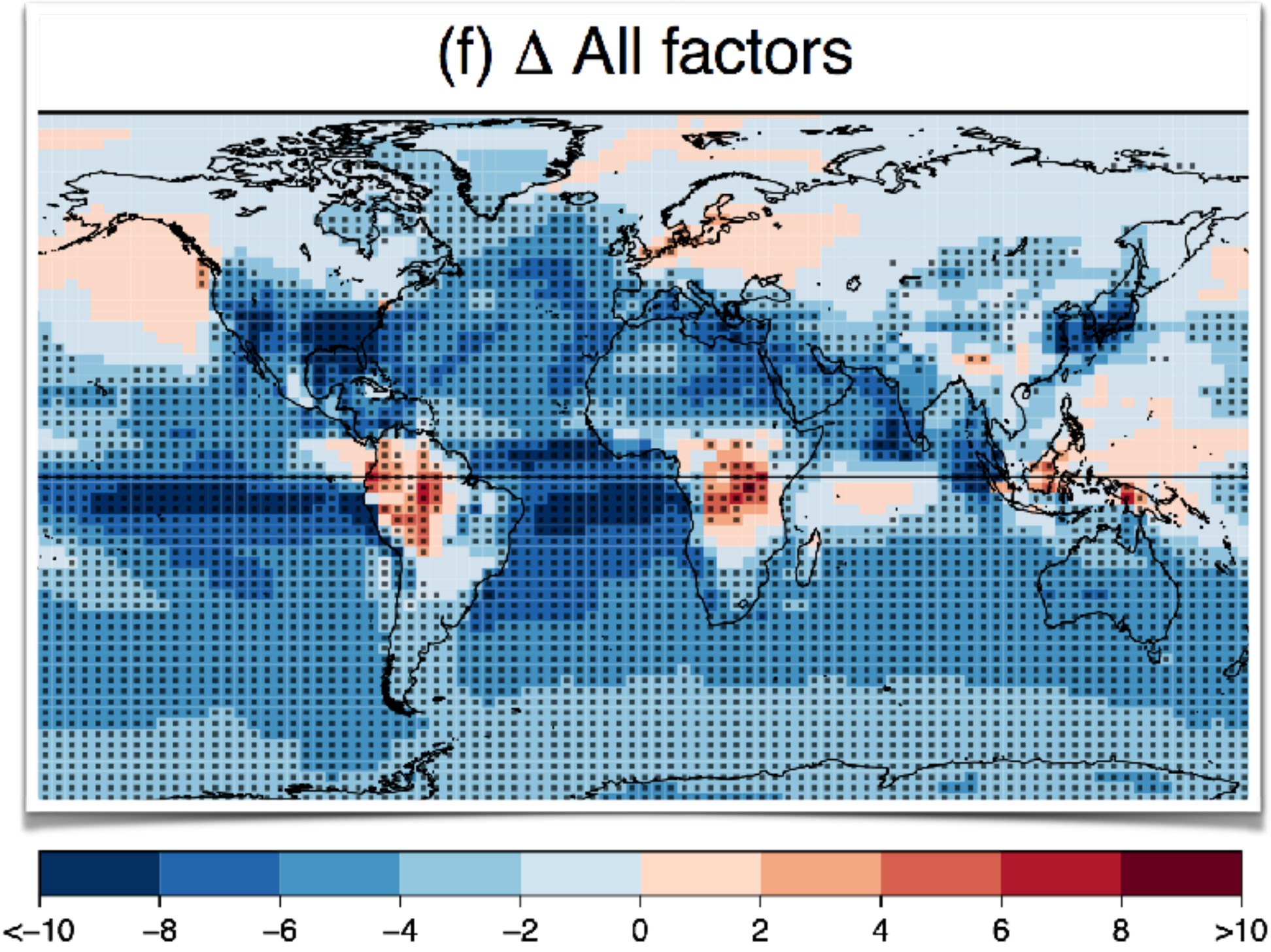


How does ozone respond in future climate?

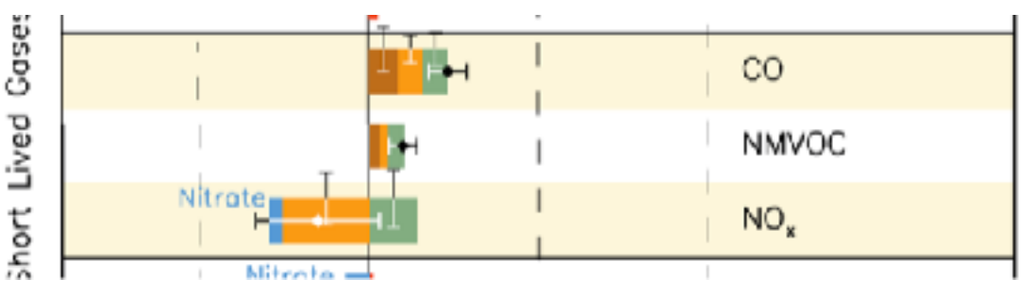
Dots indicate regions of significant change compared to model variability

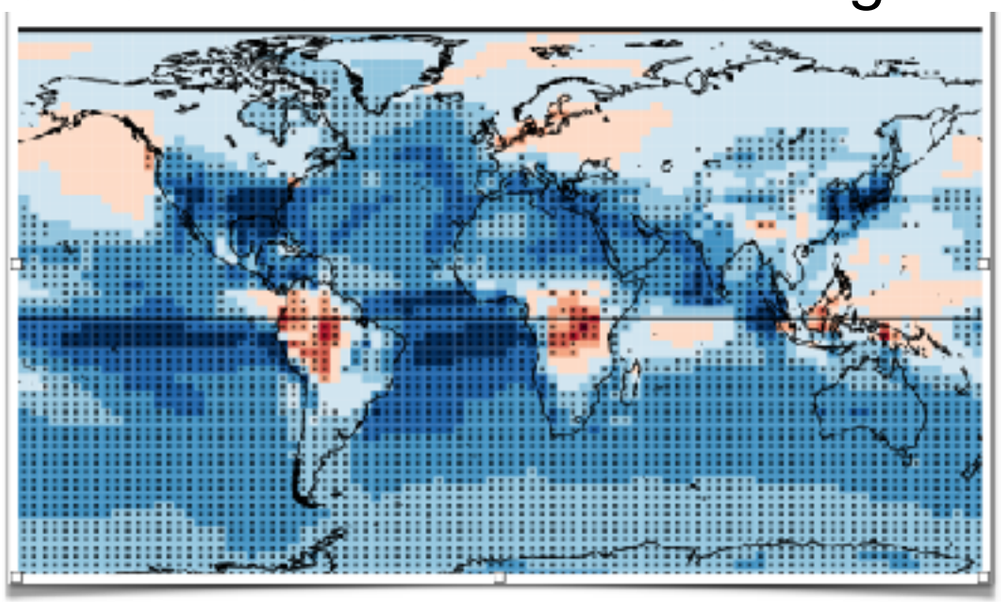


Conclusions

Conclusions

- Ozone in global climate models is challenging
  - While **Emissions, chemistry** have strong effect, **land use change** play a significant role.
  - Strong effects where vegetation cover is changing due to changes to deposition.
- Underpinning emissions estimates and sinks depend crucially on land use and land cover estimates
- Air quality, health, climate connect at local level
  - Long range transport of ozone precursors also important regionally
- Tropospheric ozone burden important to methane lifetime and radiative forcing





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Thank you!

Questions?

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