Solar UV-B radiation and the environmental effects of ozone depletion

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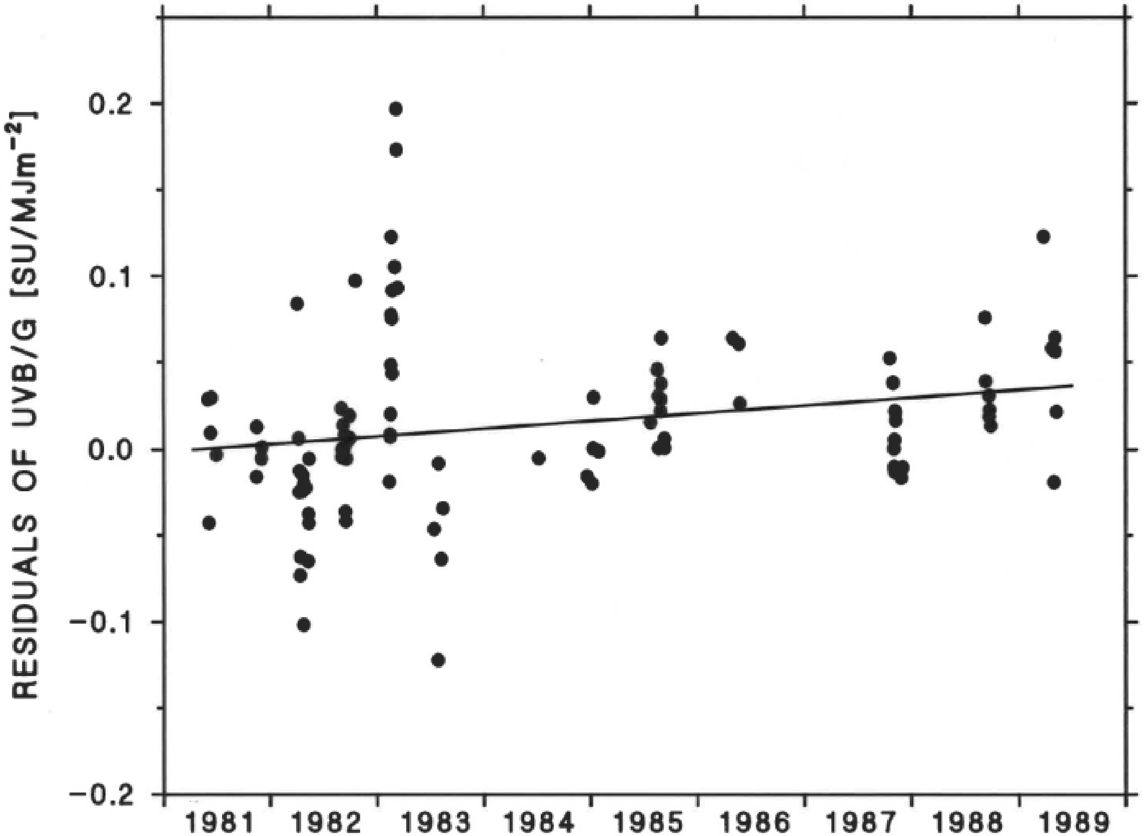
Stratospheric ozone depletion & UV radiation

- **Increase of damaging solar UV-B radiation, with effects on:**
  - **Human health**
  - **Terrestrial and aquatic ecosystems**
  - **Tropospheric air-quality**
  - **Biogeochemical cycles**
  - **Materials**

- **Effects of climate change on stratospheric ozone and UV-B**

- **Effects of climate change on UV-B radiation (directly)**

- **Measurements of UV-B radiation were sparse in the 1980s**
- **Spectral UV-B radiation measurements started after 1990**



Jungfraujoch 1981-1989

Increases in Erythemal irradiance with respect to total SW irradiance

Blumthaler & Ambach 1990, Science

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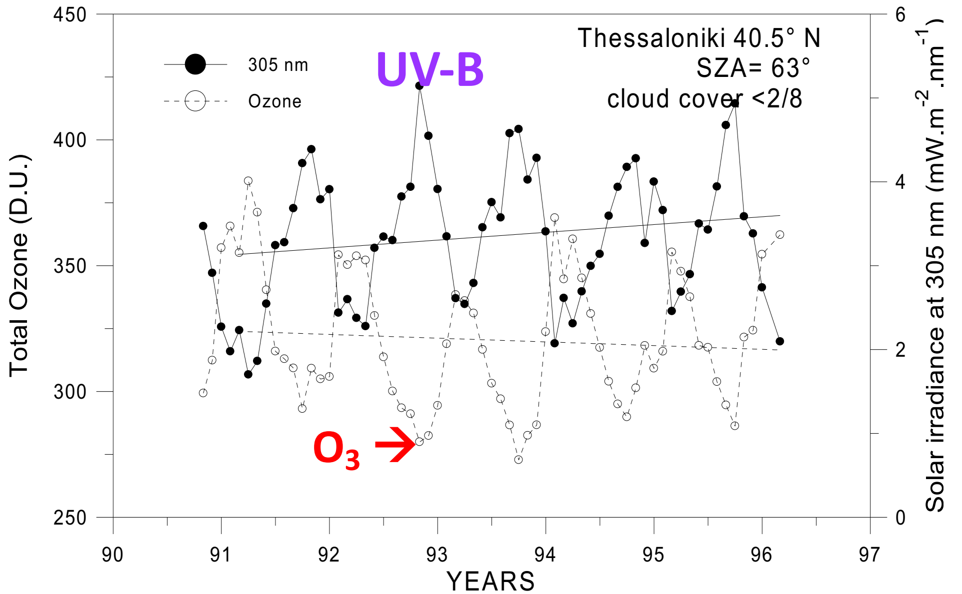
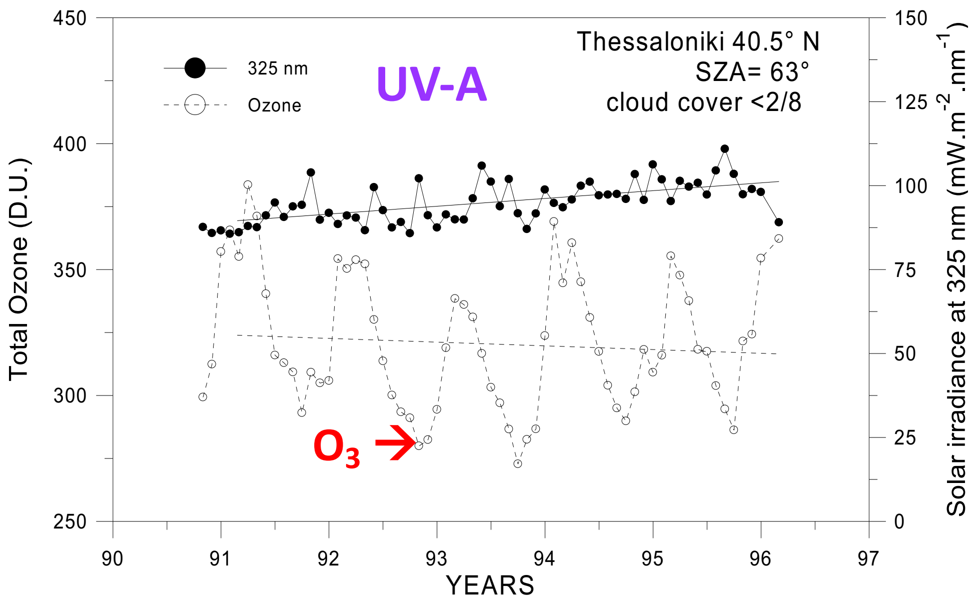




First proof of the inverse relation between Total Ozone and spectral UV-B radiation

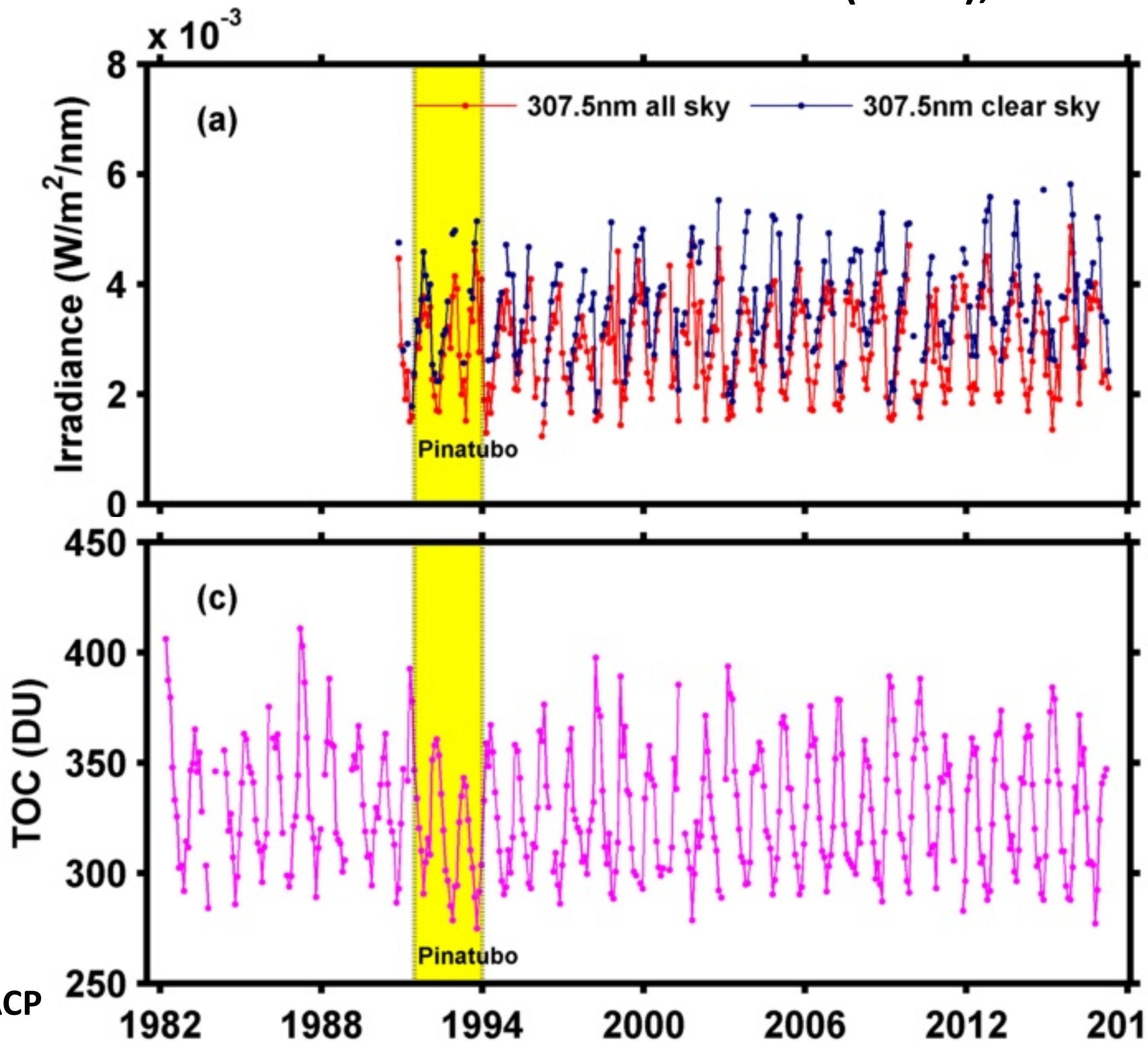
- Total ozone is the dominant factor in “long-term” changes of surface solar irradiance below 320 nm.
- Similar “long-term” variability was found for Thessaloniki, Brussels, Garmisch-P and Reykjavik for all-sky conditions.
- Calculated fractional changes in solar irradiance critically depend on the length of the period of study. A few years are not enough for any reliable conclusions.

Zerefos et al., 1997, GRL

20 years later …

Thessaloniki (40° N); SZA = 64°

307.5 nm
Strong ozone absorption



Update from Fountoulakis et al 2016, ACP

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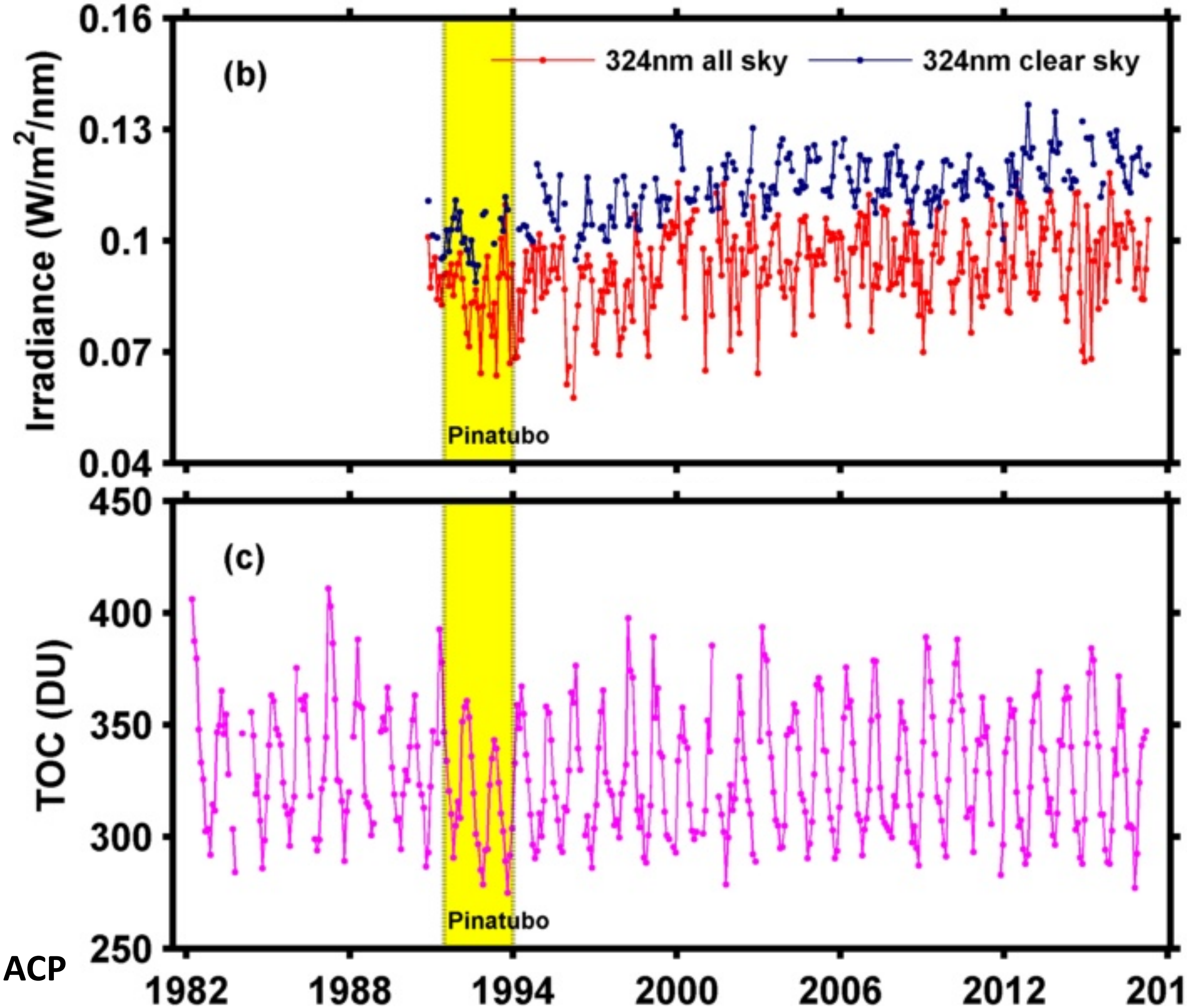
20 years later …

Thessaloniki (40º N); SZA = 64°

324 nm weak ozone absorption



Update from Fountoulakis et al 2016, ACP

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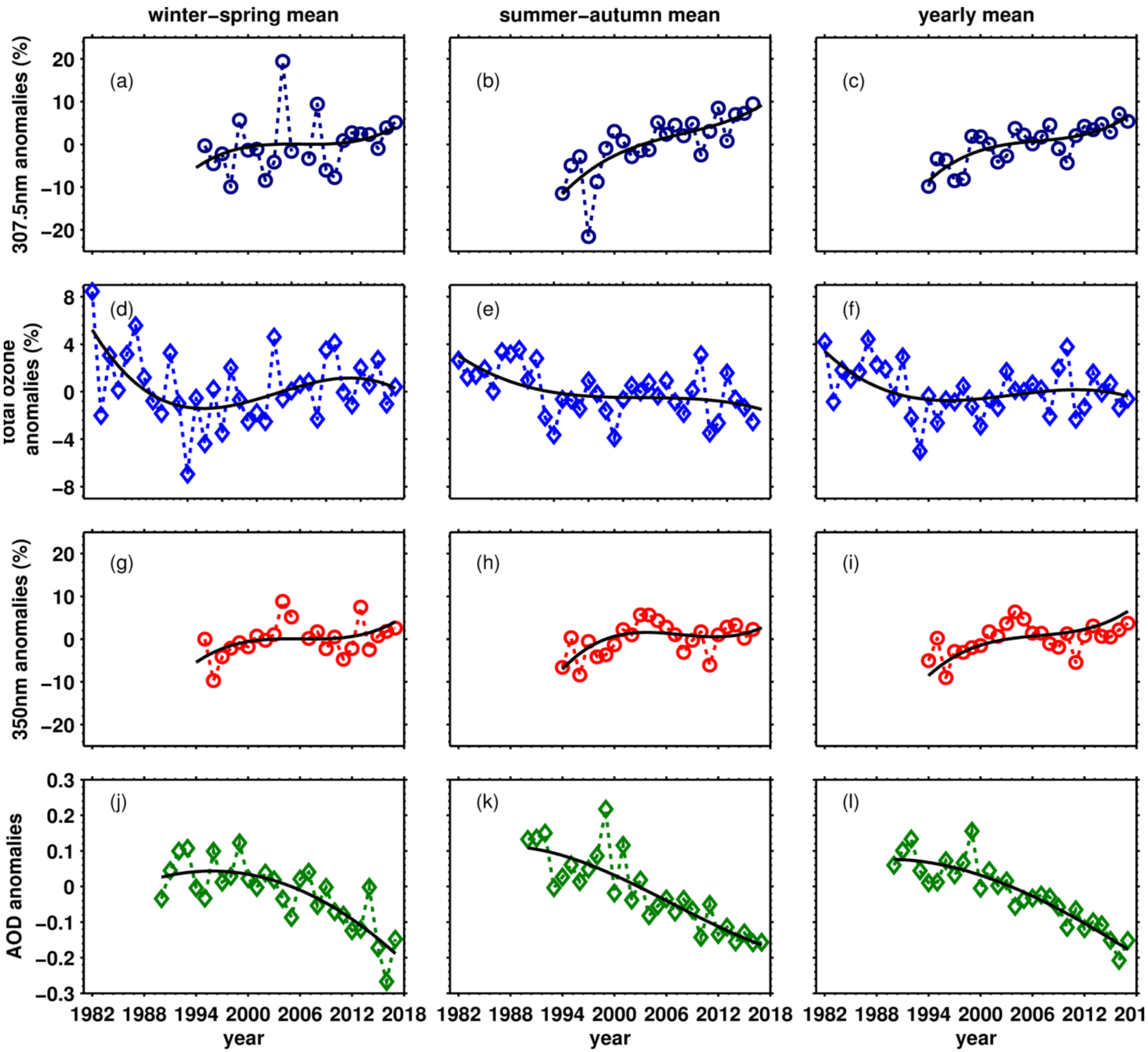
Thessaloniki (40° N); SZA = 64°; Clear skies

1992 – 2017



- UV-B irradiance (307.5 nm) is increasing due mainly to decreasing aerosols. Ozone affects the short-term variations.
- Total ozone has stabilized since ~1990 to about 3% below its values in the early 1980s.
- Increases in UV-A (350 nm) are smaller. Negligible effect of ozone, smaller effect of aerosols
- The aerosol optical depth decreases steadily with higher rates after ~2000.

Update from Fountoulakis et al 2016, ACP

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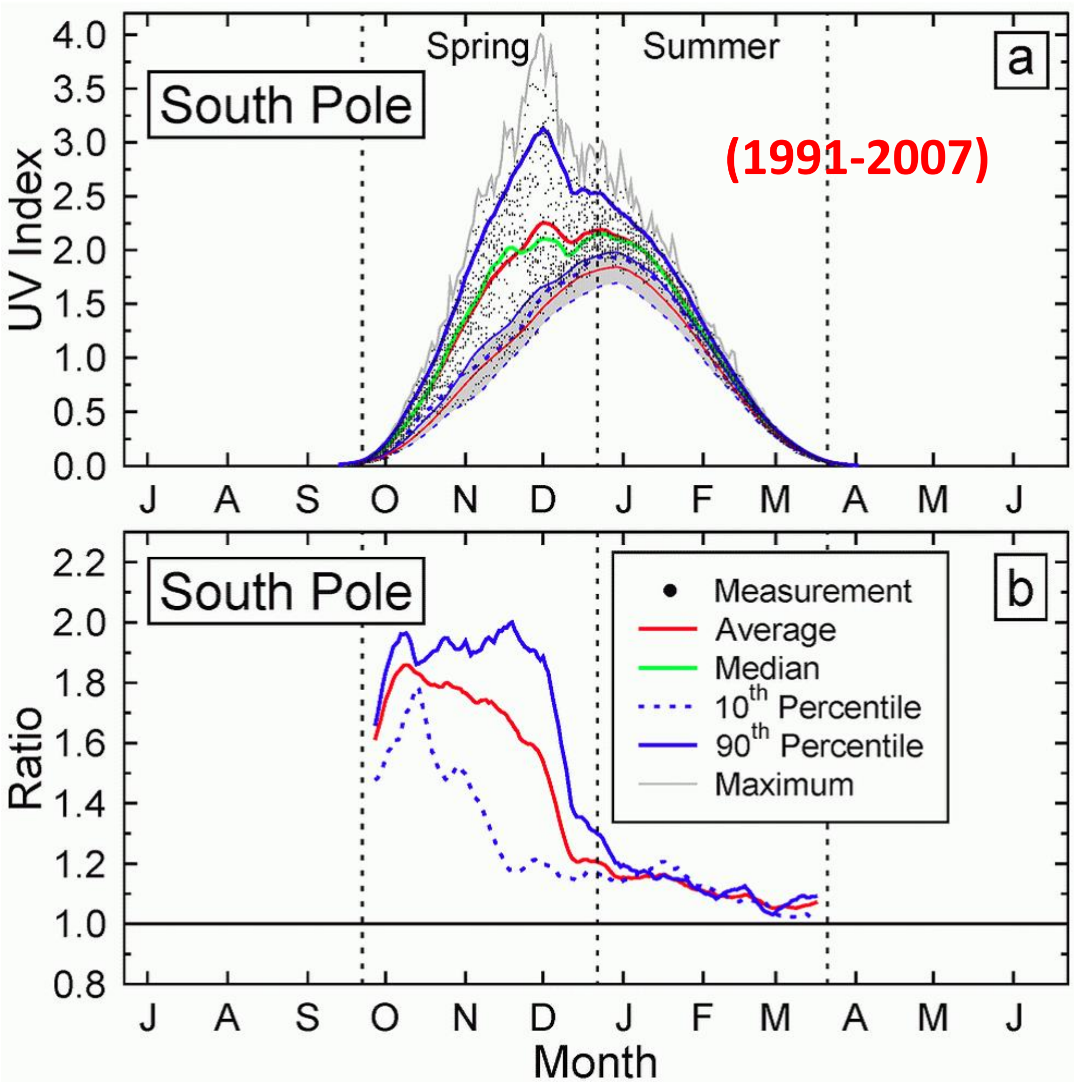
The ozone depletion effect on UV-B is clearly detected in Antarctica



NSF UV Spectral Irradiance Monitoring Network

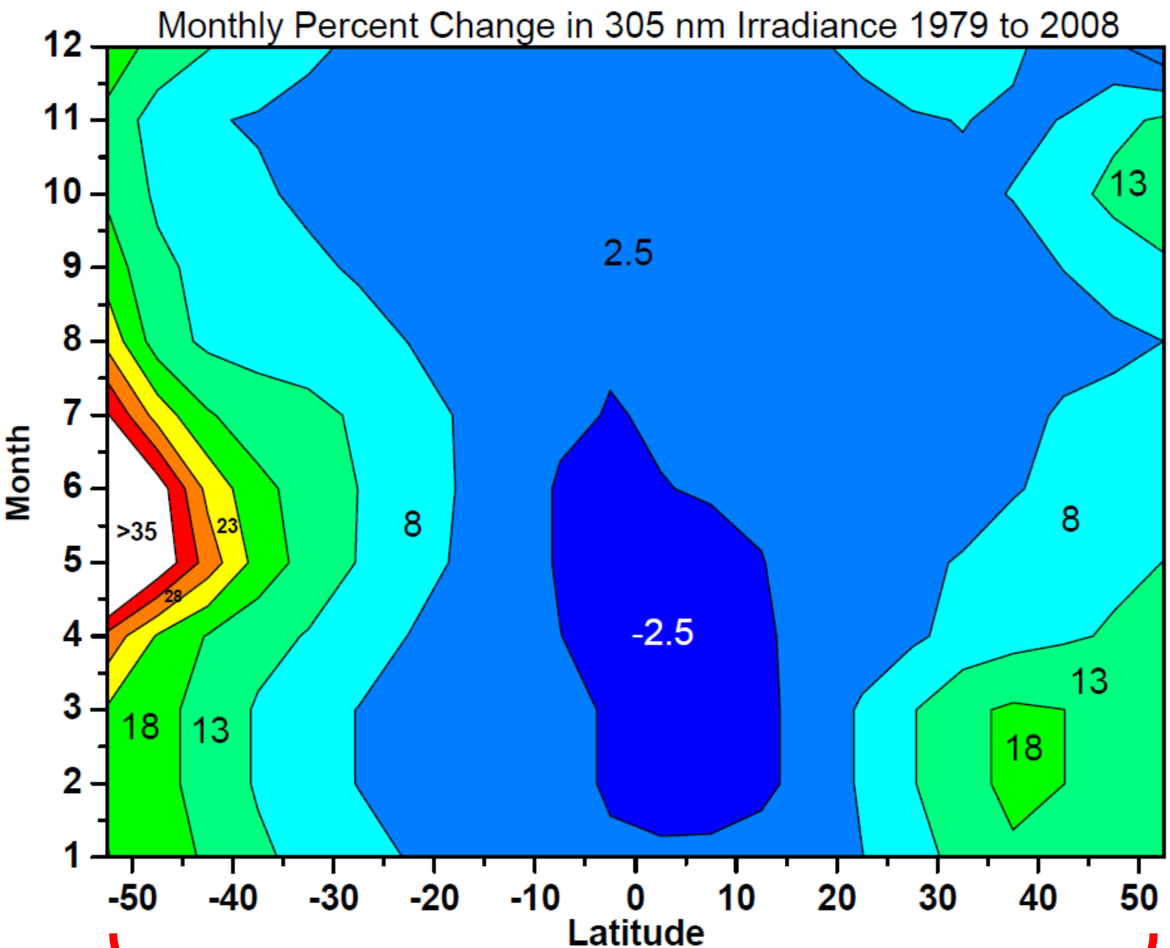
The noontime UV Index measured at South Pole during the ozone hole period (October - November) is:

20 – 80% higher than in summer at comparable solar zenith angles

up to 2 times higher than in the pre-ozone hole period

Station	Lat.	max UVI
Palmer	64 °S	**14.8**
Ushuaia	54 °S	**11.5**
San Diego	32 °N	**12.0**

Bernhard et al., 2010

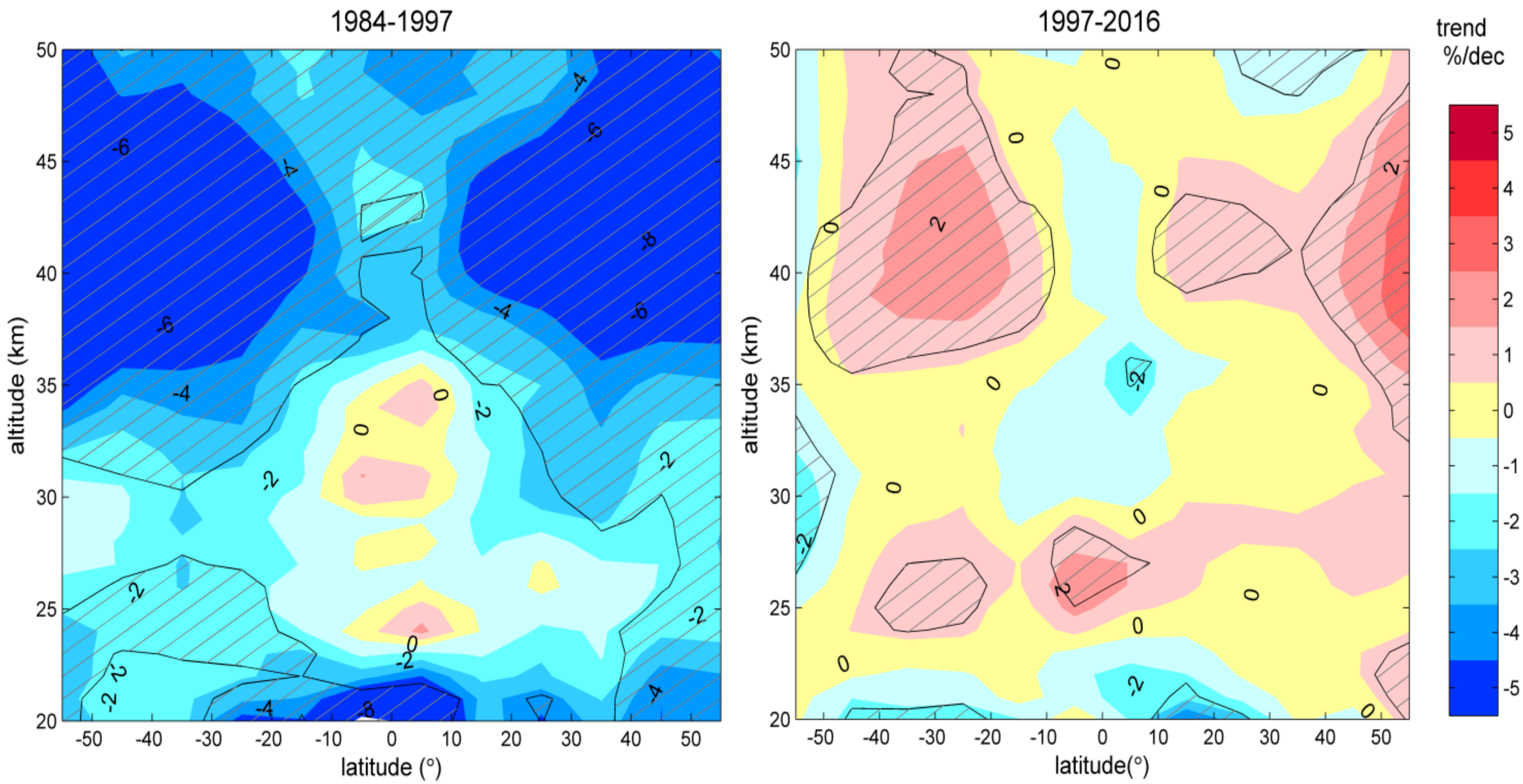


Missing high latitudes > 55°

Changes in UV irradiance at 305 nm in 30 years (1979-2008) estimated from satellite data

- Greatest increases were found at mid-latitudes in the southern hemisphere
- Small decreases or increases in the tropics depending on season
- For erythemal irradiance (UV Index) changes are less than half

Herman J. 2010, JGR



The ozone trend in % per decade for different latitudes for 1984–1997 (left) and 1997-2016 (right). Shaded areas show regions where trends are statistically different from zero at the 95% level.

(Sofieva, V. F. et al.: Merged SAGE II, Ozone_cci and OMPS ozone profiles dataset and evaluation of ozone trends in the stratosphere, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-598, in review, 2017.)

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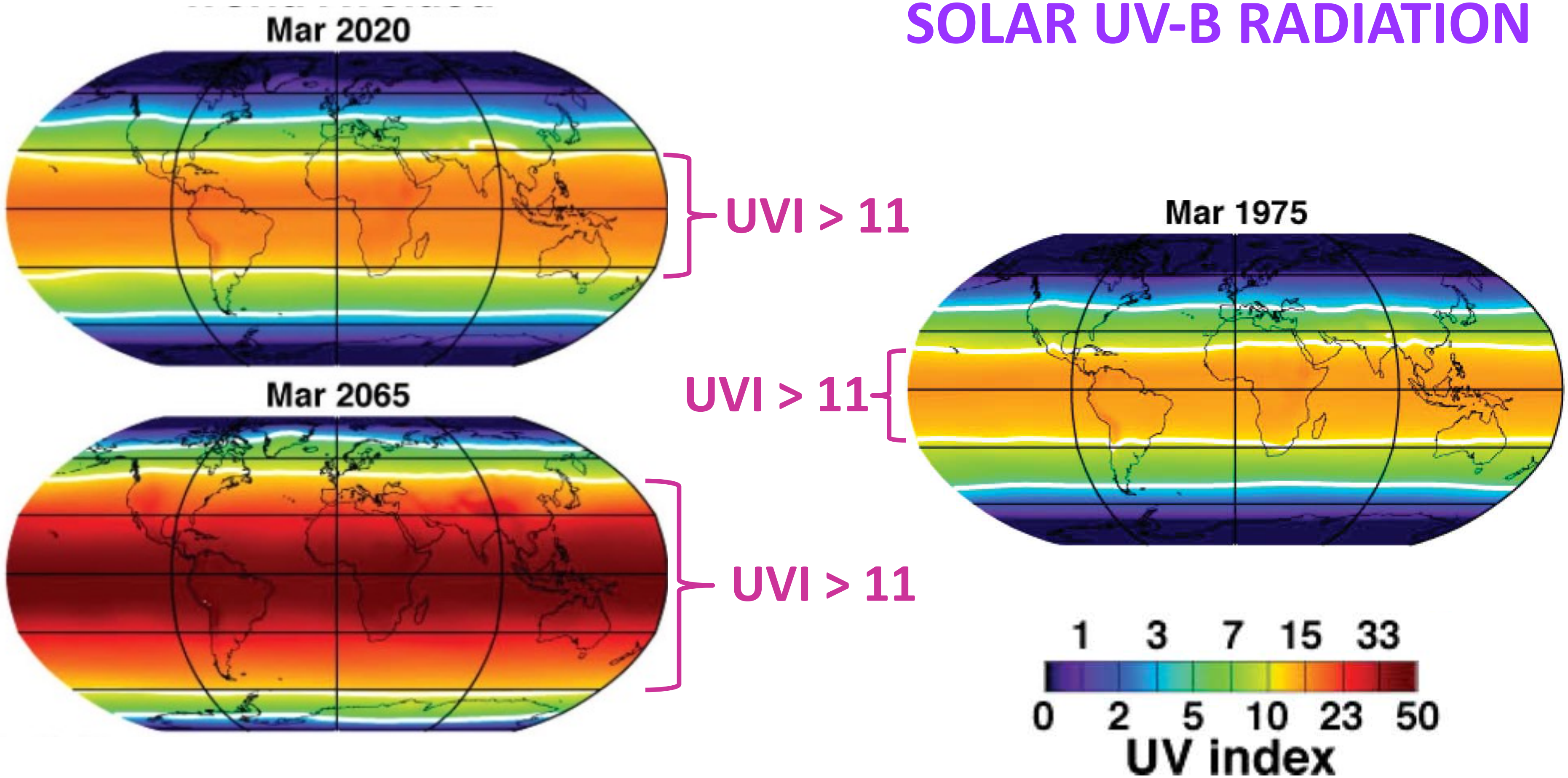
How has the Montreal Protocol affected the UV-B radiation at Earth's surface?

World avoided due to Montreal protocol

SOLAR UV-B RADIATION

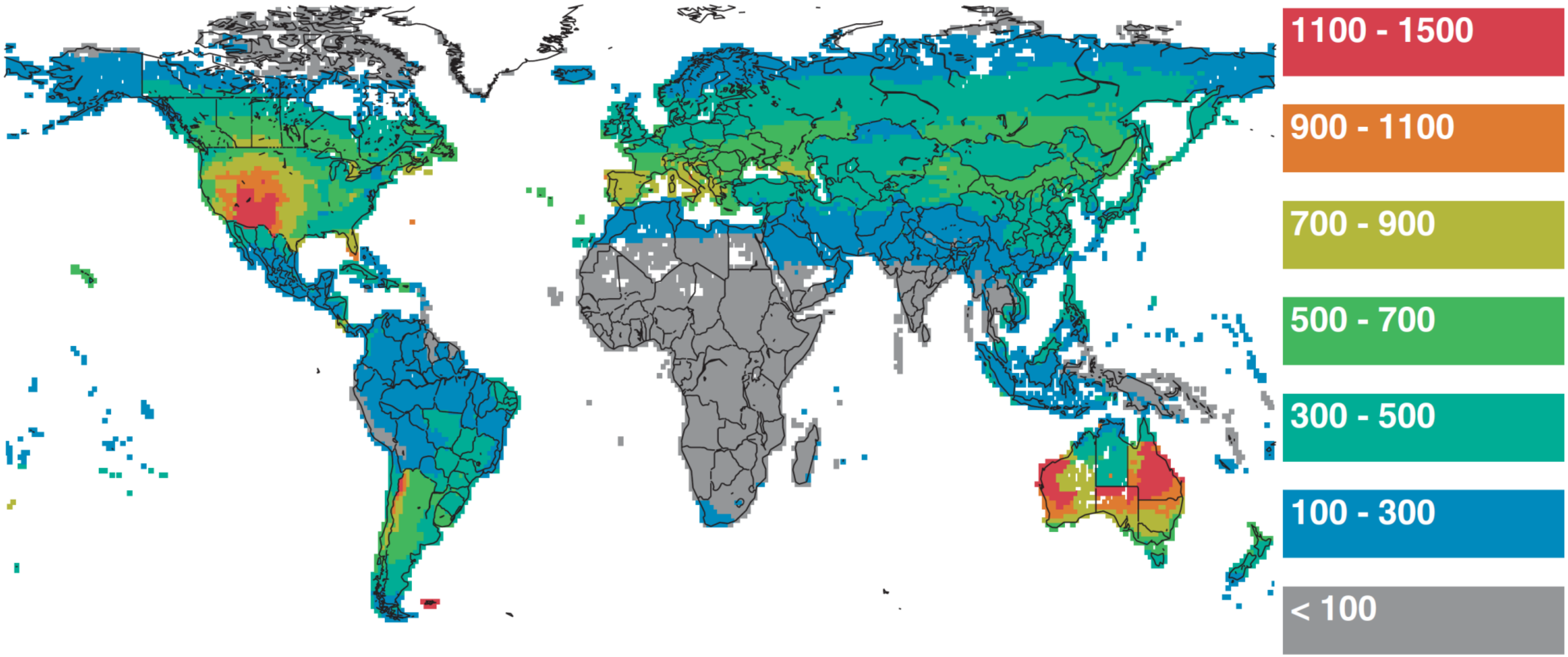


Newman et al., 2011, PPS

World avoided due to Montreal protocol

Projected number of avoided new cases of skin cancer per million people per year for 2030

EXCESS SKIN CANCER

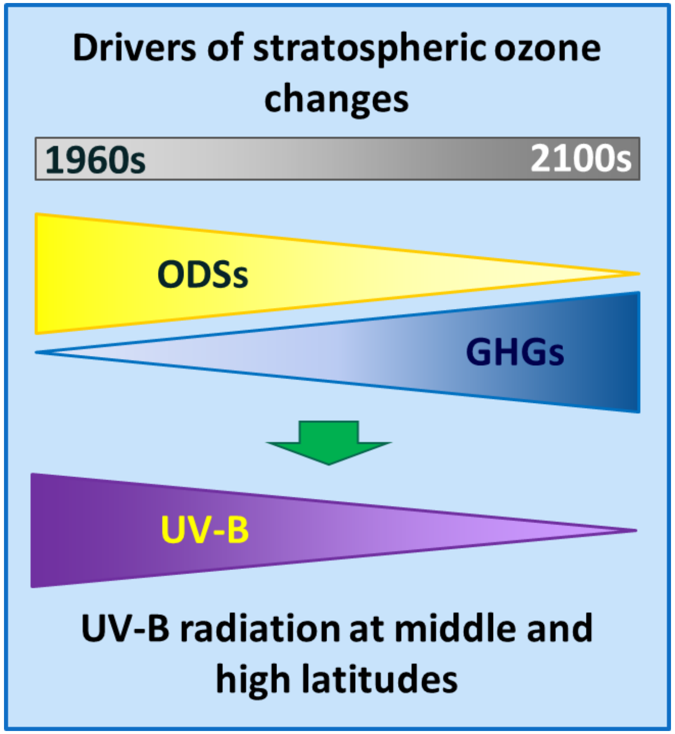


Van Dijk et al., 2011, P&P

UV-B radiation in the future

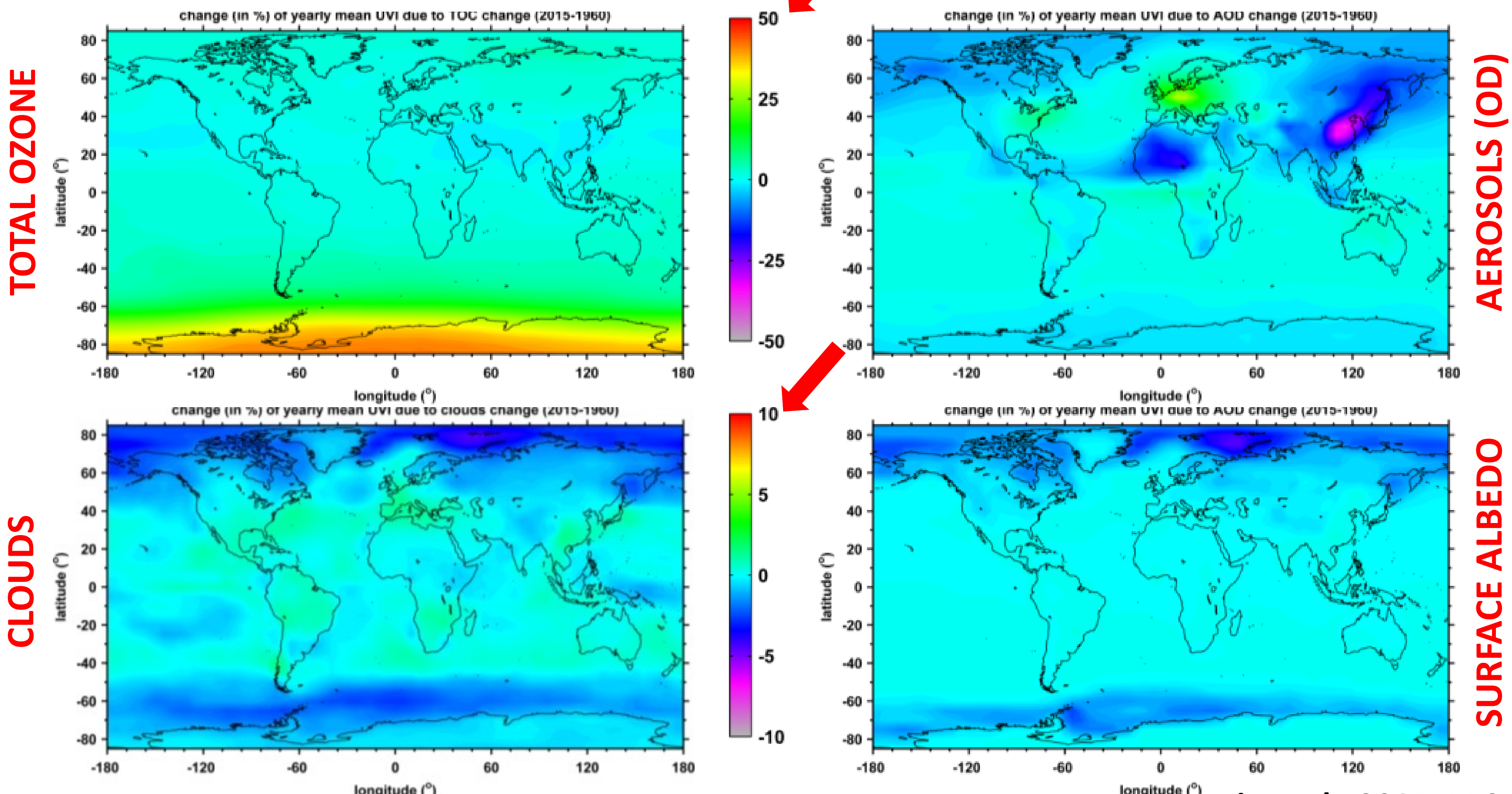
UV-B Radiation, Ozone and Climate Change

- **Outside Antarctica other factors (aerosols, clouds, albedo, air pollution) dominate the variability of UV-B radiation, masking effects of changes in stratospheric ozone.**
- **These factors are influenced strongly by increasing GHGs.**



- **As concentrations of ODSs decrease over the next decades, GHGs will become the dominant driver of stratospheric ozone changes.**
- **UV radiation will decrease in the middle and high latitudes relative to the historical period 1955–1975.**
- **In the tropics, the sign of change depends on the emission scenario.**

Percentage change in **UV Index** from **PAST** to **PRESENT** (1965-1655) to (2010-2020)



Bais et al., 2015, PPS

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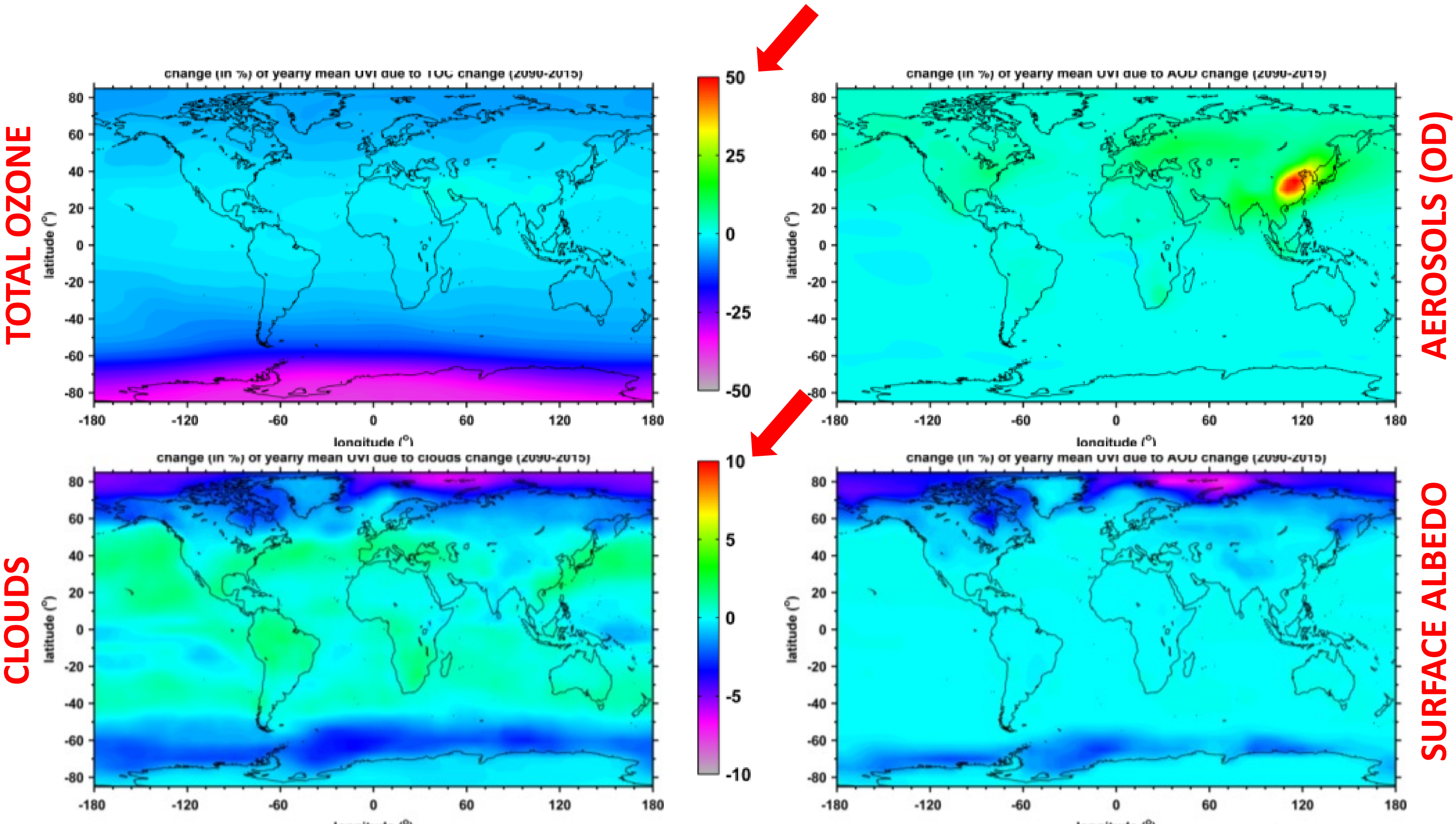
Percentage change in **UV Index** from **PRESENT** to **FUTURE**
(2010-2020) to (2085-2095)



Bais et al., 2015, PPS

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The UNEP's
Environmental Effects Assessment Panel

EEAP progress meeting Stratford-upon-Avon, UK, 11-18 Sept. 2017

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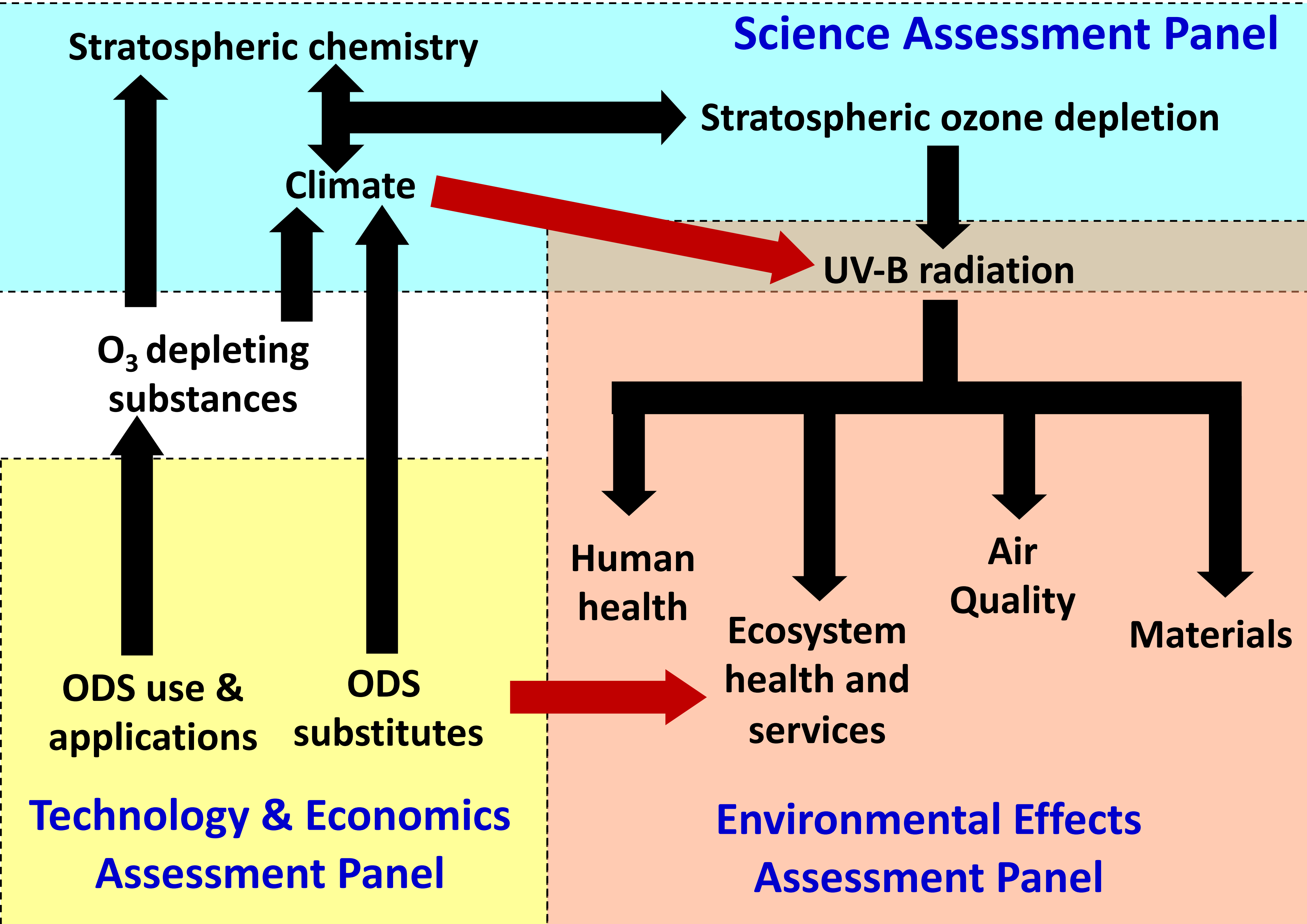
How the 3 Panels complement each other in contributing to the Montreal Protocol

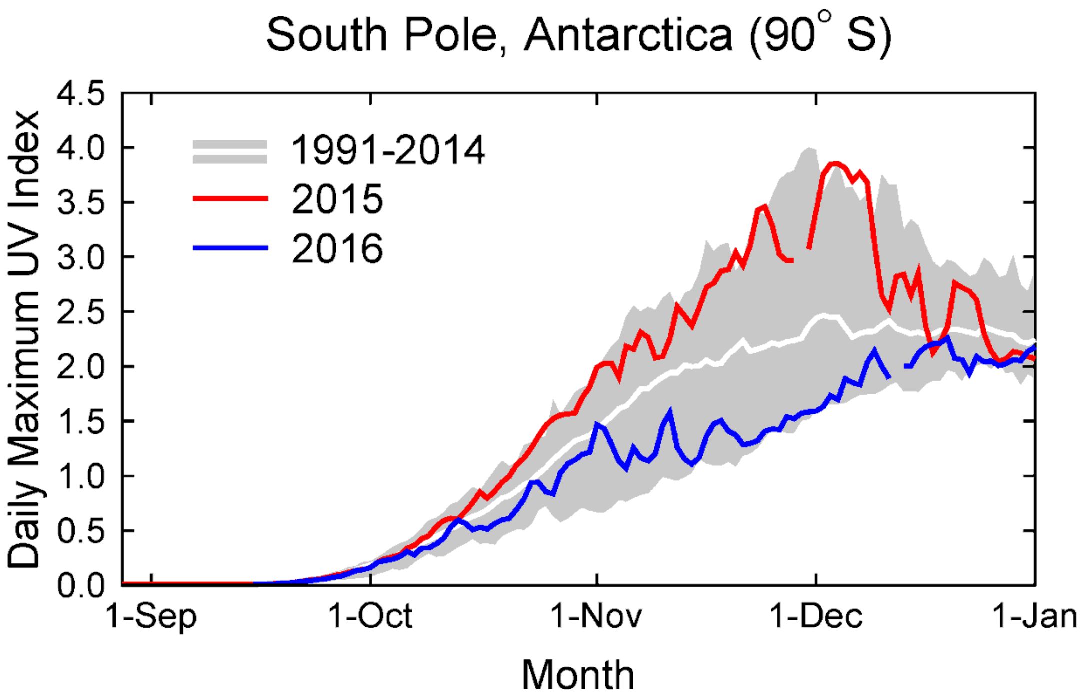


KEY QUESTIONS: PAST, PRESENT AND FUTURE

- **What are the direct and indirect beneficial effects of the Montreal Protocol?**
- **Have the effects of the Montreal Protocol been reflected in measurements of UV-B radiation?**
- **When and where should we expect damaging or beneficial effects of UV-B?**
- **How increasing GHGs modify the ways stratospheric ozone changes (depletion or recovery) affect UV-B radiation?**
- **How has stratospheric ozone depletion been affecting climate in the southern hemisphere? Will the effects be reversed when ozone recovers?**

Recovery of Antarctic Ozone

- **Despite indications of ozone recovery in Antarctica in spring, no effects on UV-B radiation are yet detectable, due to:**



✓ **Strong variation of UV attenuation by ozone, clouds, albedo**

✓ **Weak UV-B intensity in early spring**

<u>NOTE:</u> Delayed ozone recovery in late spring and summer is important for UV-B radiation as the sun gets higher in this period

Human health – key findings

- **Effects on human health from changes in stratospheric ozone are through changes in exposure to solar UV-B radiation.**
- **Exposure of humans to UV-B radiation depends on multiple factors, including individual choices (e.g. relating to sun behaviour, clothing, use of sun protection).**
- **Warmer temperatures as a result of climate change will alter how much time people spend outdoors and thus their exposure to solar radiation across all wavelengths.**
- **While focus remains on exposure to UV-B radiation for risks or benefits to human health, longer wavelengths of solar radiation should also be considered.**

Human health – key findings

Exposure to UV radiation has both risks and benefits

Adverse effects from UV exposure:

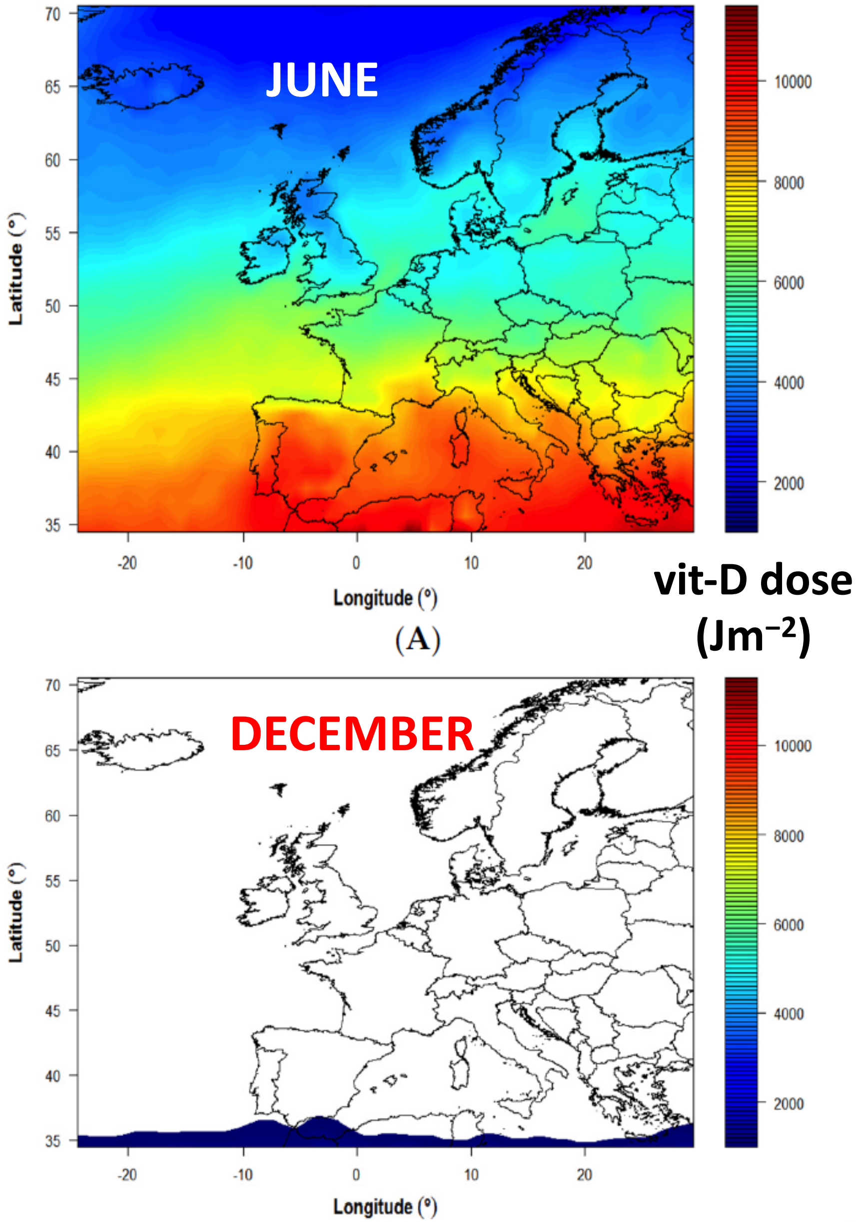
- **Skin cancers,** including cutaneous malignant melanoma and keratinocyte cancers (previously: non-melanoma skin cancers)
- **Eye diseases,** including cataract
- **Immune suppression,** causing reactivation of latent viruses

Possible benefits from UV-VIS exposure:

- **Improved vitamin D status** (known to be primarily from UV-B)
- **Reduced risk of myopia** (short sightedness)
- **Immune suppression** (reducing risk of autoimmune diseases)
- **Benefits for cardio-metabolic health**

Human health - Remarks

- Despite strong public-health programs for effective sun protection risky sun exposure behaviour resulting in sunburn (and ultimately skin cancer) remains common in many countries.
- Such behaviour will continue to influence the health effects from future changes in UV exposure due to changes in ozone and other factors.
- Benefits of exposure of both the skin and eyes to solar radiation (UV-B and longer wavelengths) are still being investigated, and could be of considerable importance.
- Vitamin D deficiency due to reduced UV-B exposure is common, particularly at high-latitude locations. Reliable data for vitamin D levels remain very limited for many regions of the world.



Modeled mean monthly effective dose for pre-vitamin D3 synthesis (2003–2012)

- **Low vitamin D status is common in Europe**

O'Neill et al., 2016, Nutrients

Deficiency limit: 1000 J m^{-2}

- **Dark-skinned ethnic groups in Europe have greater risk of vitamin D deficiency than their white counterparts.**

O'Neill et al., 2016, J. Ster. Biochem.

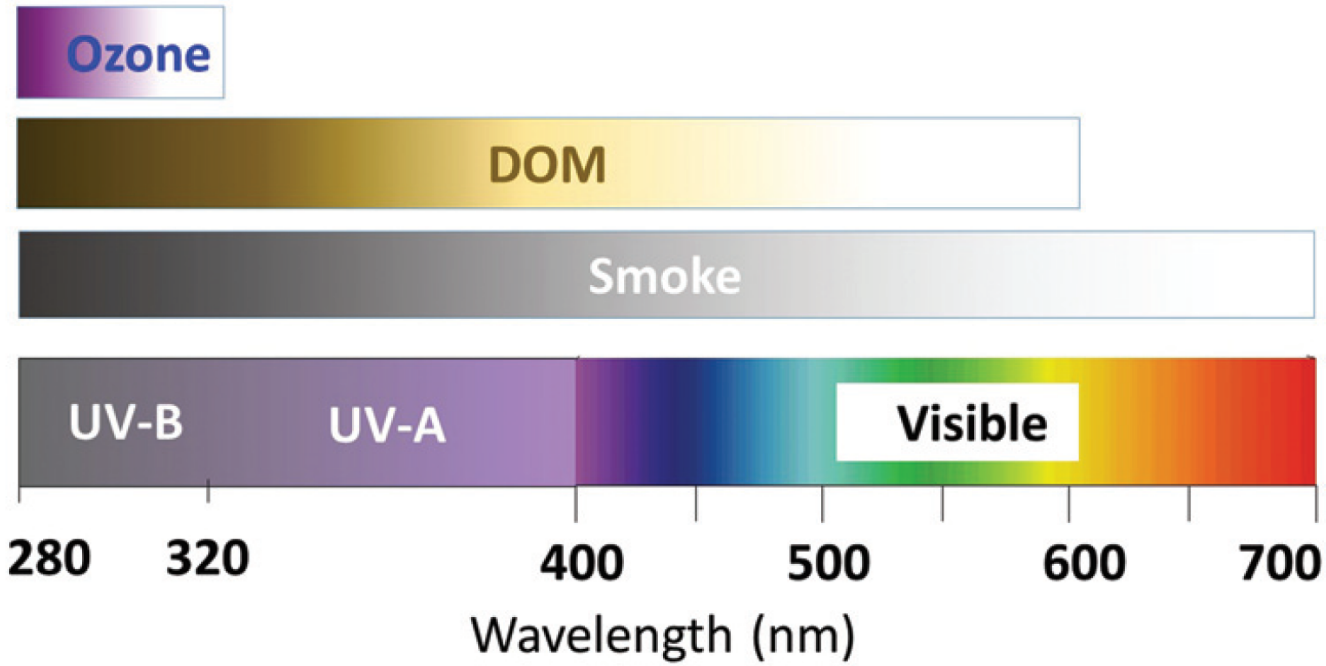
Ecosystem health and services

- **Terrestrial systems are affected by UV radiation and constraints from climate change (water availability, higher temperatures, CO_2)**
  - Ozone-depletion driven climate changes have affected growth and distribution patterns of plants in natural ecosystems in some parts of the Southern Hemisphere.
  - Potential changes in crop yield and food quality in agricultural systems (e.g. faster ripening of some crops by CO_2, and changes in nutrient status)
- **UV radiation effects depend on interacting environmental factors**

Increases the challenge of reliably predicting overall impact of changes by UV-B radiation on natural or agricultural ecosystems

Ecosystem health and services

- **Dissolved organic matter (DOM) selectively absorbs potentially damaging UV radiation in aquatic ecosystems**



Ecosystem health and services

Strong evidence that DOM is increasing in many aquatic ecosystems ("browning"):

- **Increases as much as two-fold in some inland waters**
- **DOM is related to climate change (increases in precipitation, extreme rain events) and other factors (e.g., recovery from anthropogenic acidification, changes in land use)**

Ecosystem health and services

Consequences of reduced penetration of UV radiation into aquatic ecosystems due to "browning"

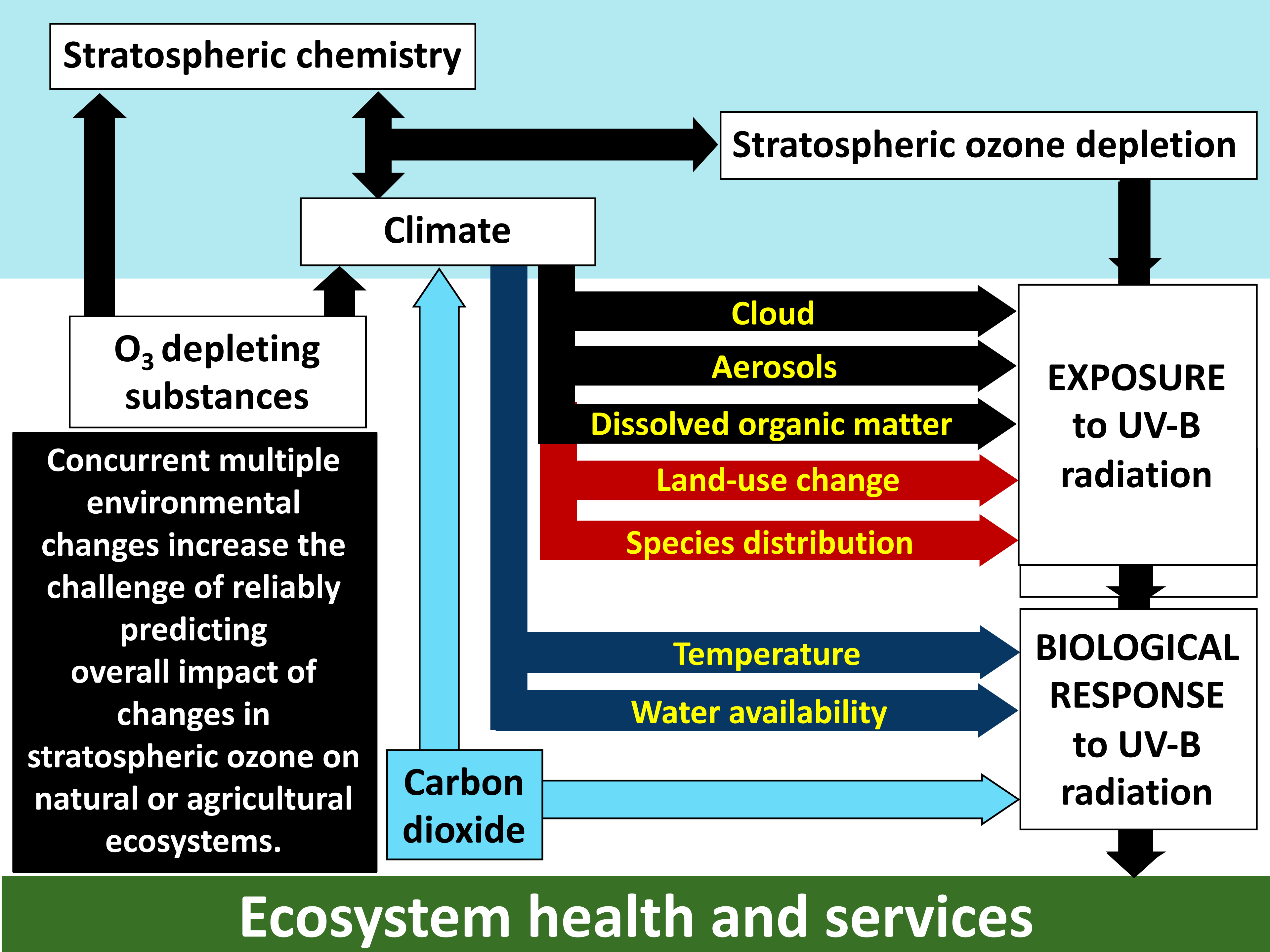
- Increased survival of water-borne human pathogens that would otherwise be inactivated by exposure to solar UV radiation
- Increased survival of pathogens in surface waters increases the risk of infectious disease in humans and wildlife
- Altered behaviour of aquatic organisms affects water quality, aquatic food webs and fishery productivity.
- CO_2 is released by solar UV-B radiation-driven break-down of DOM that enters the aquatic ecosystems
- Reduced UV-B radiation in the future would result to less CO_2 released by terrestrial and aquatic ecosystems

Ecosystem health and services

- **CO_2 is released** by solar UV-B radiation-driven break-down of **DOM** that enters the aquatic ecosystems

- **Future changes in UV-B radiation will affect the released CO_2 by:**
  - **Carbon entering aquatic ecosystems due to "browning"**
  - **Photochemical or biological degradation of dead-plant material in terrestrial ecosystems**

- **Reduced UV-B** radiation in the future would result to **less CO_2** released by terrestrial and aquatic ecosystems


Stratospheric chemistry
Stratospheric ozone depletion
Climate
O_3 depleting substances
Cloud
Aerosols
Dissolved organic matter
Land-use change
Species distribution
EXPOSURE to UV-B radiation
Temperature
Water availability
BIOLOGICAL RESPONSE to UV-B radiation
Carbon dioxide
Concurrent multiple environmental changes increase the challenge of reliably predicting overall impact of changes in stratospheric ozone on natural or agricultural ecosystems.
Ecosystem health and services

Air quality

<u>UV radiation drives the chemistry of the troposphere</u>

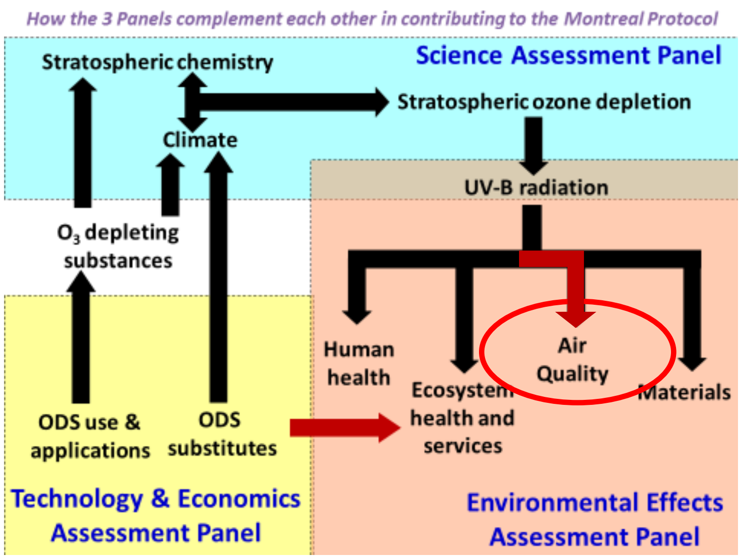
Examples:

1. **Removal of ODS and GHG (e.g. HCFCs, HFCs, CH_4, tropospheric ozone) by OH radicals**
   - UV radiation is an important factor affecting the lifetime of CH_4 and temporal trends in its amounts in the global atmosphere

2. **Formation and destruction of ground-level ozone**
   - Decreasing UV radiation resulting from stratospheric ozone recovery will lead to slower production and slower destruction of tropospheric ozone:
     - small <u>decreases</u> in O_3 in cities
     - small <u>increases</u> in rural O_3 regionally.

Air quality

<u>Substitutes for ODS must be monitored for potential risks</u>:



1. **Formation of persistent compounds, e.g. TFA from HFCs**

At present, amounts of TFA produced from HFCs and HCFCs are small relative to other sources, and therefore unlikely to pose a risk to humans or the environment.

2. **Small but non-zero contributions to urban pollution, for example through the use of volatile organic compounds (hydrocarbons) as ODS substitutes**

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Materials damage

- **Exposure to UV radiation and ambient temperature determine the outdoor service lifetimes of plastics, wood and other construction materials**
- **Increased UV radiation and temperature can shorten replacement time for products used outdoors. The control technologies in use today, or their improved versions, mitigate additional damage, but add to the cost of these products.**

UV-shielding pigments are presently used to stabilize PVC against UV radiation.

UV damage to wood is avoided by surface coatings (paints) or chemical modi-fication of wood.

Main conclusions and research needs

- Projecting future changes in UV-B radiation and effects on health and other ecosystems (including food production) demands that **research is not limited simply to changes in stratospheric ozone.**
- **Climate change will influence UV-B exposure** through changes in ozone but also clouds, aerosols, and DOM and, for human health, changes in behavior.
- **Biological effects on ecosystems** of altered exposure to UV-B **will be further modified by interactions with other factors**, e.g. in temperature, water availability and quality, CO_2.
- The scale and scope of **the necessary research is increasingly under threat** due to the perception of funders that ozone depletion/UV-B are no longer major environmental threats.

Thank you !

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