Ozone, UV and effects

Bases Científiques del Canvi Ambiental

Màster en Canvi Ambiental:

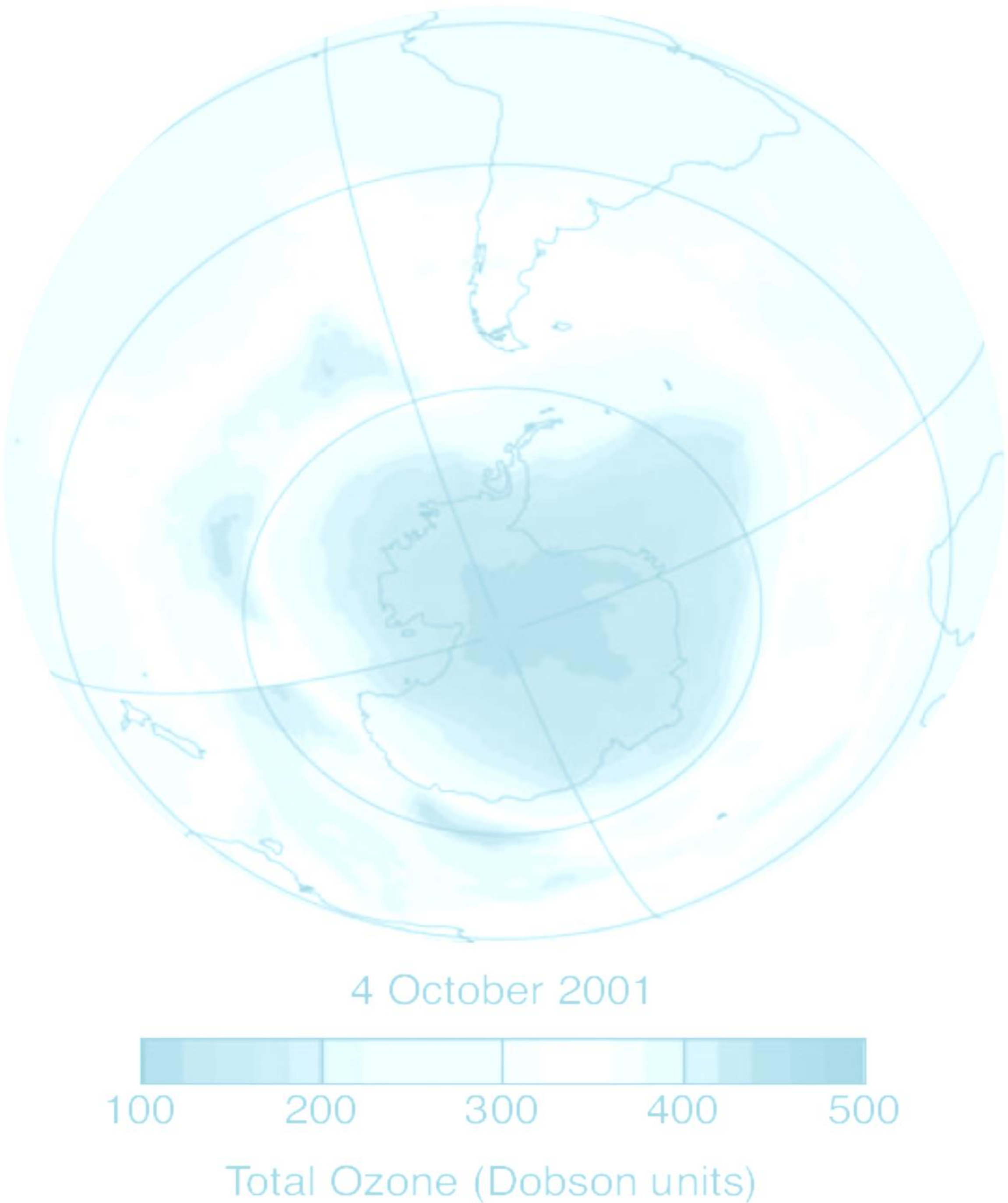
Anàlisi i gestió

17/22 desembre 2020

Josep-Abel González

Departament de Física

Universitat de Girona



4

Effects of UV

Effects

HUMANS
Skin
Immune system
Eyes

NATURAL TERRESTRIAL ECOSYSTEMS, CROPS, FORESTS

AQUATIC LIFE

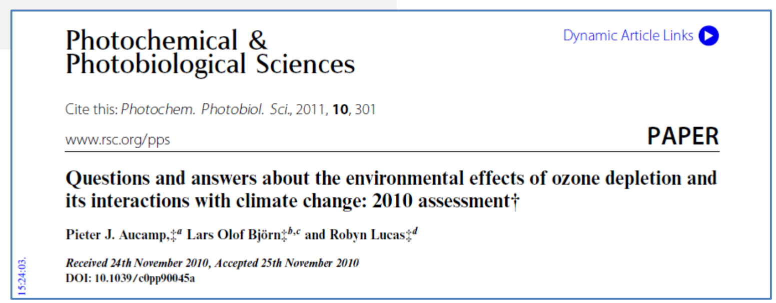
ENVIRONMENTAL PROCESSES AND SYSTEMS

FOOD SECURITY

AIR QUALITY

MATERIALS

RADIATION AUGMENTATION FACTOR



Photochemical & Photobiological Sciences
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www.rsc.org/pps

PAPER

Questions and answers about the environmental effects of ozone depletion and its interactions with climate change: 2010 assessment†

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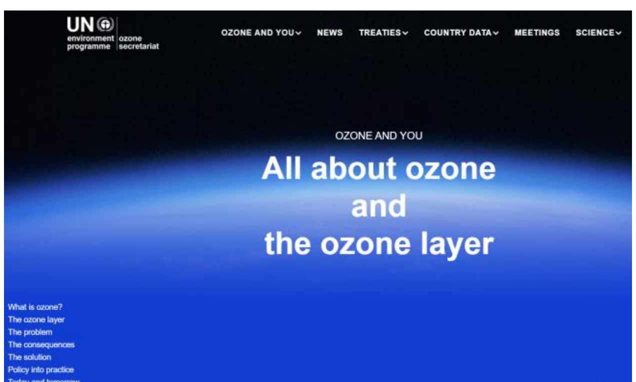
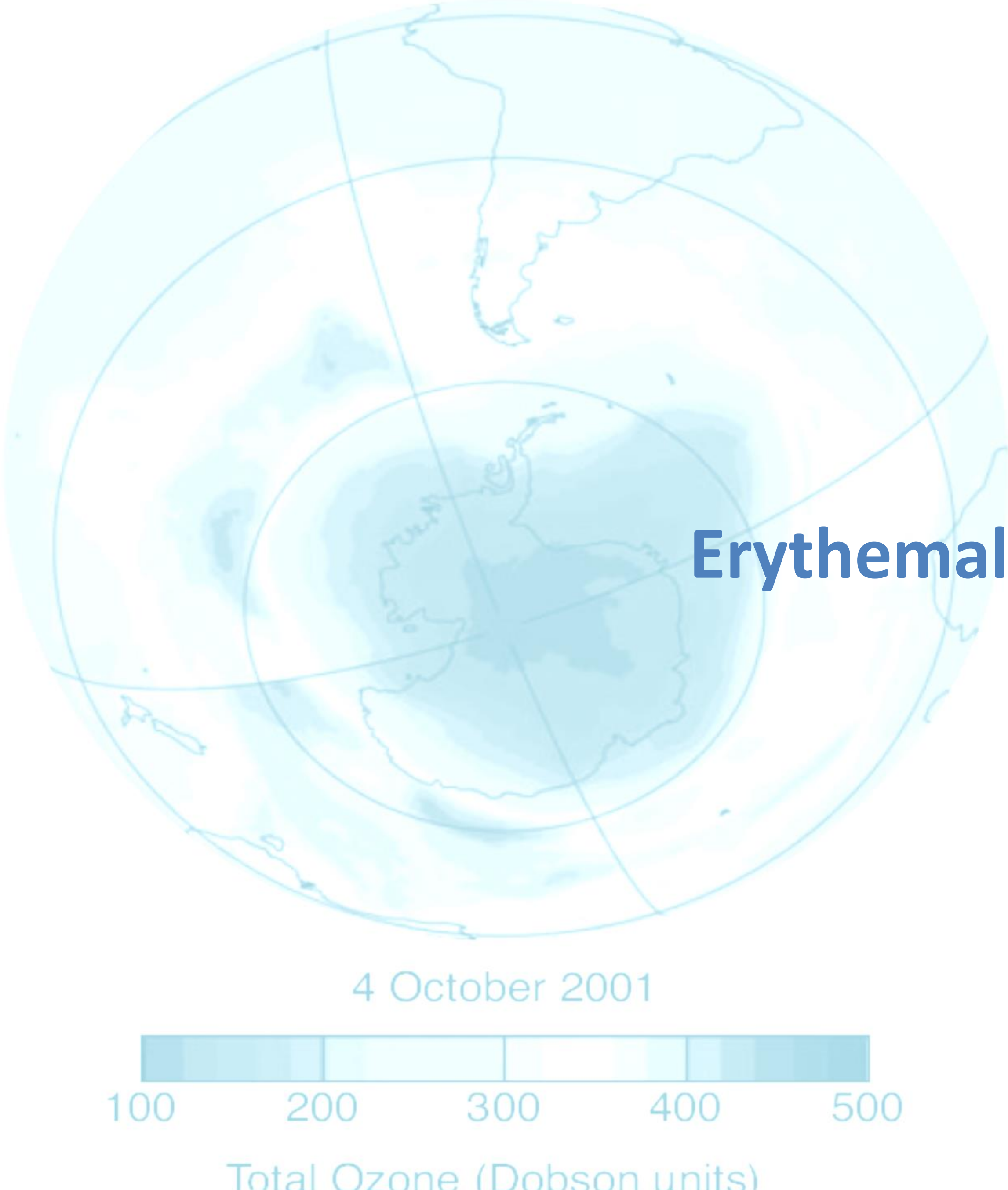


[Ozone and You | Ozone Secretariat (unep.org)]

5

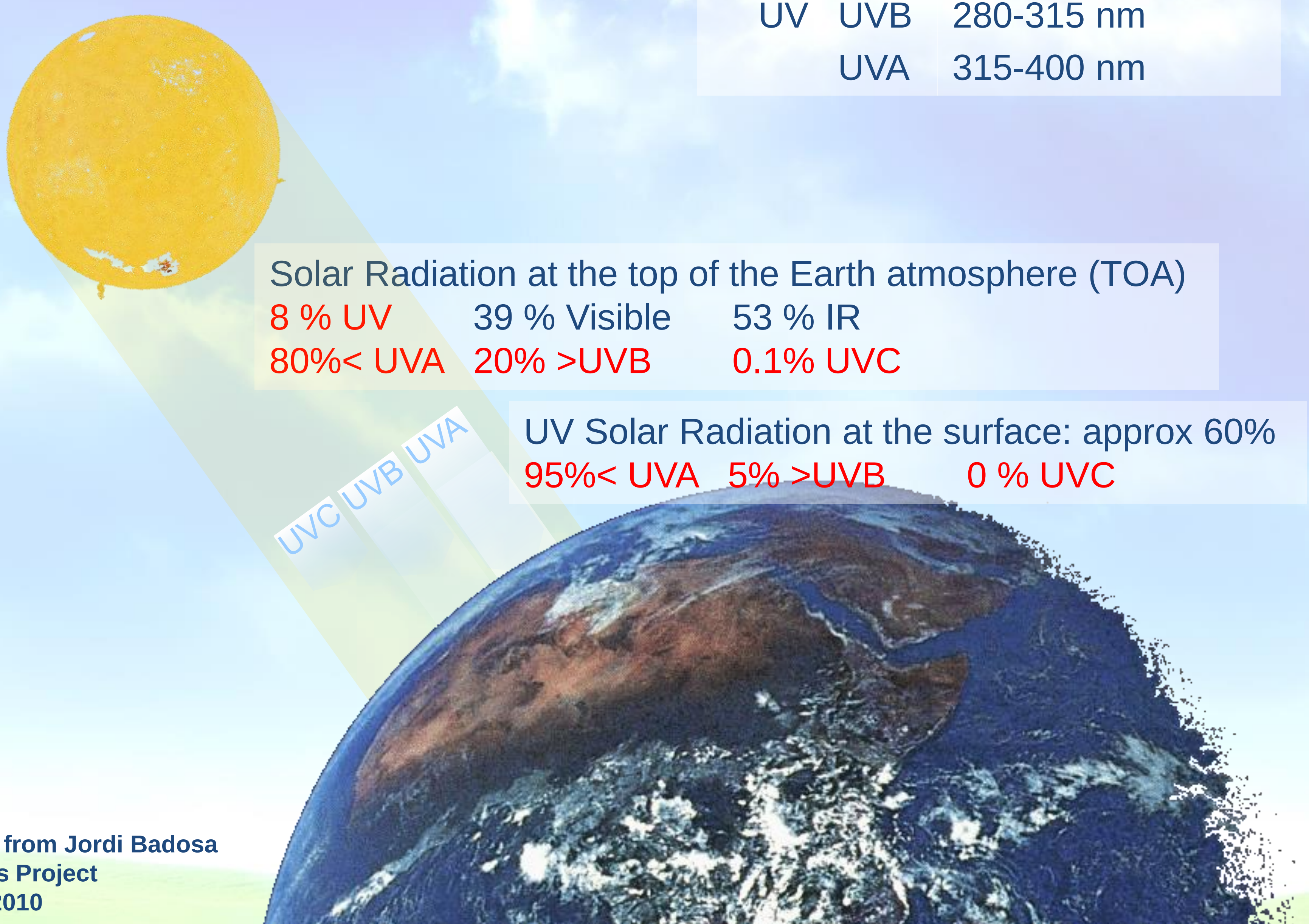
UV radiation

Erythemal effect - UV Index



Solar Ultraviolet Radiation

	UVC	200-280 nm
UV	UVB	280-315 nm
	UVA	315-400 nm



Solar Radiation at the top of the Earth atmosphere (TOA)

8 % UV	39 % Visible	53 % IR
80%< UVA	20% >UVB	0.1% UVC

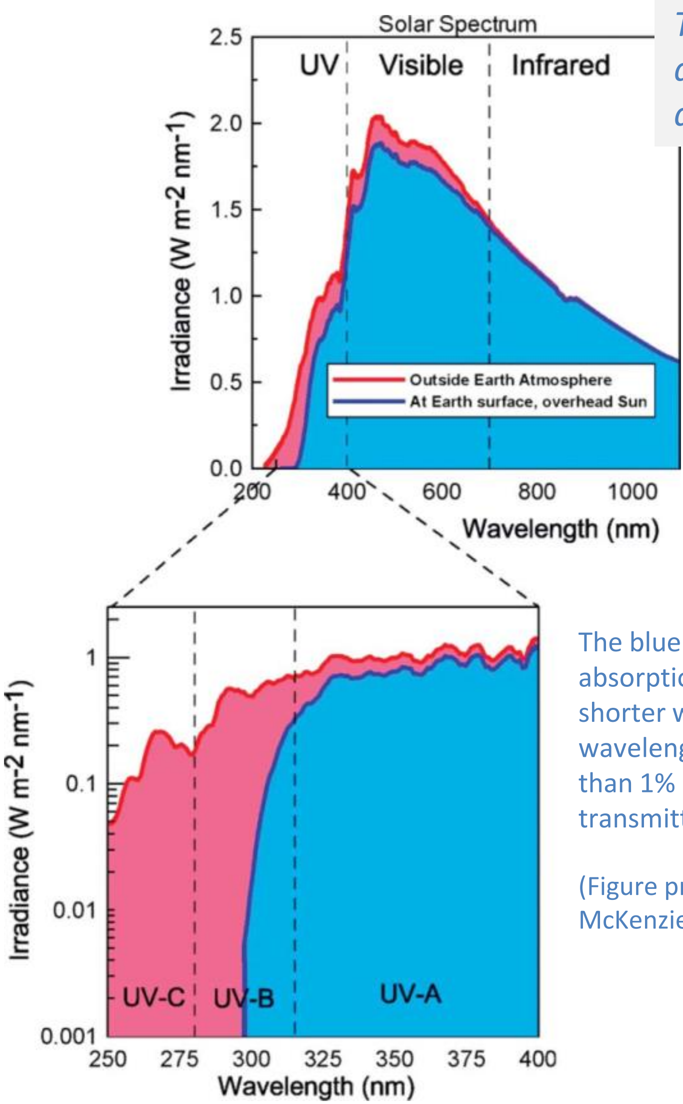
UV Solar Radiation at the surface: approx 60%

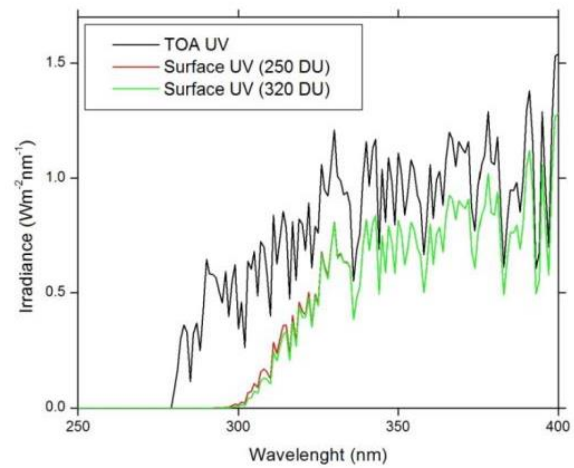
95%< UVA	5% >UVB	0 % UVC

Adapted from Jordi Badosa
ClimSeas Project
15 July 2010

The relationship between ozone and solar ultraviolet radiation

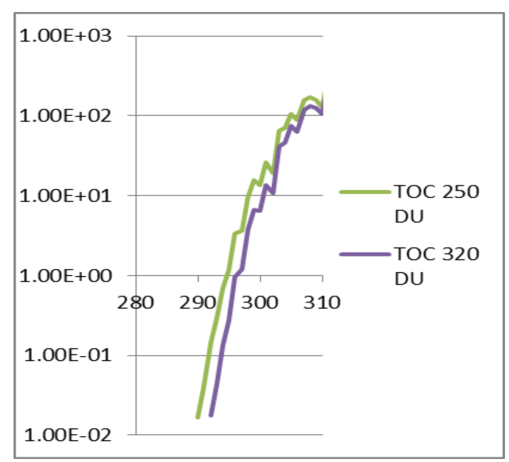
There is an inverse relationship between the total column ozone and the amount of harmful UV radiation transmitted through the atmosphere since ozone absorbs some of the UV radiation.





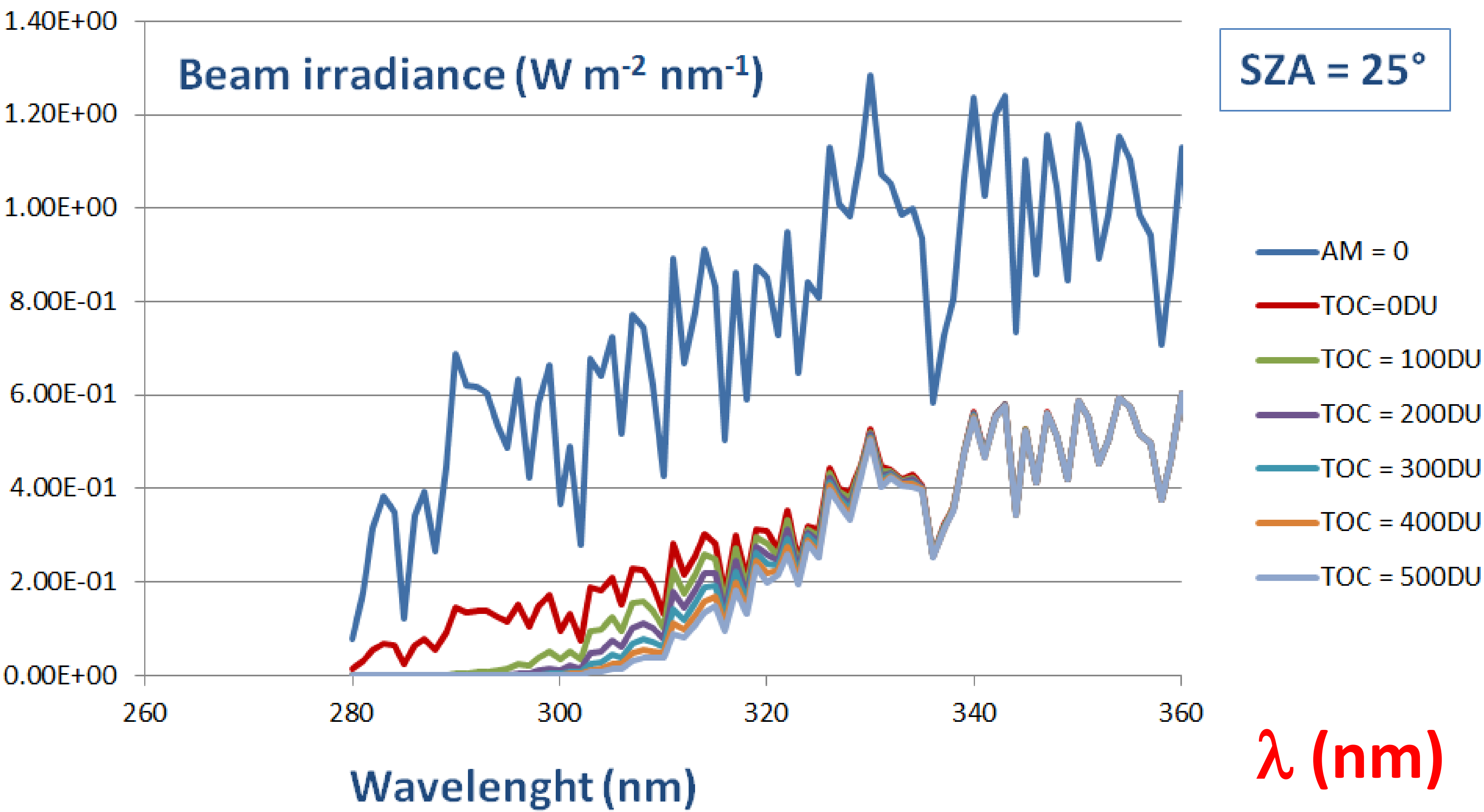
The blue area shows that ozone absorption increases rapidly at shorter wavelengths so that at wavelengths less than 300 nm, less than 1% of the radiation is transmitted.

(Figure provided by Dr R. L. McKenzie, NIWA, New Zealand.)

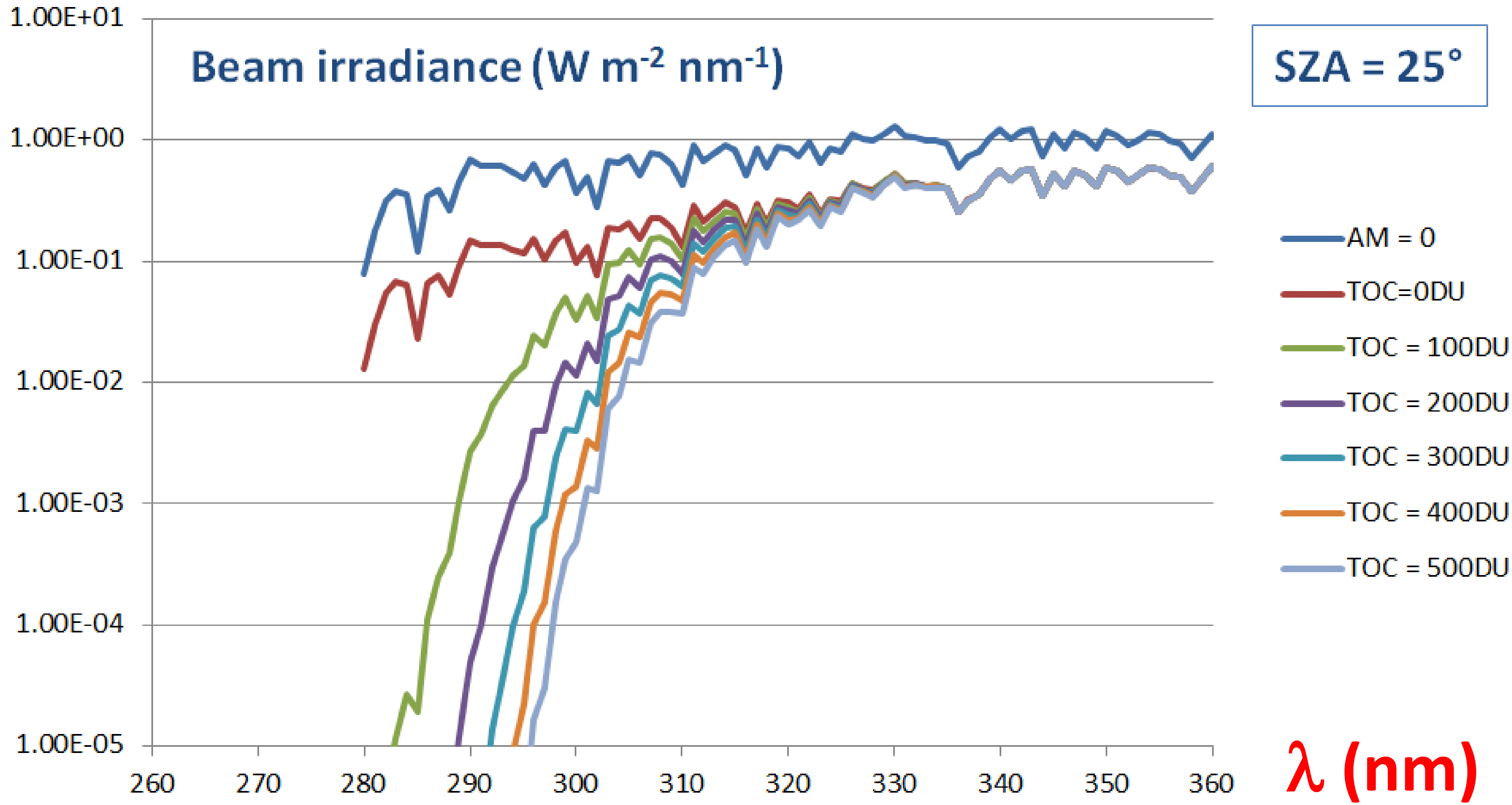


...in detail

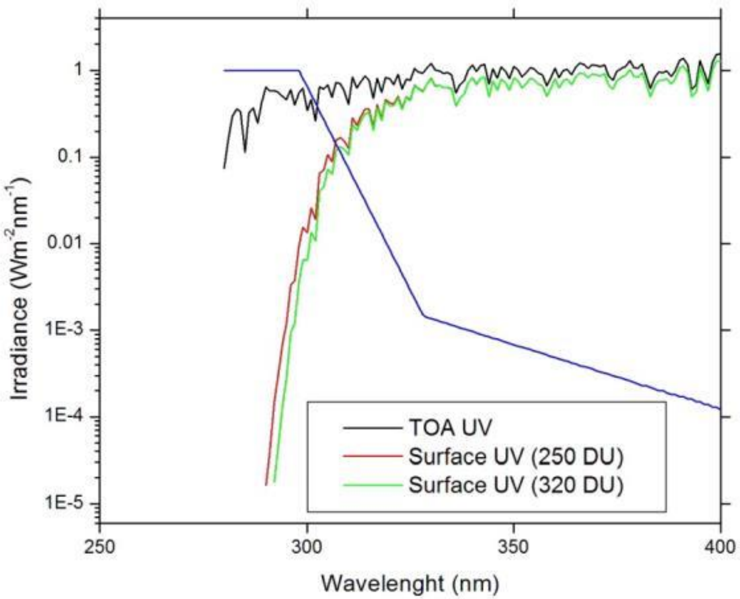
(radiation computed with a RT model)

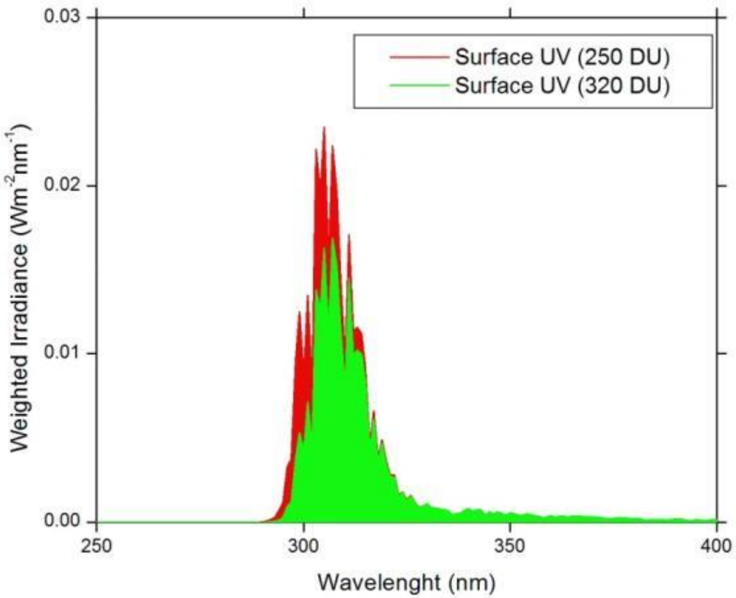


...in log scale
(radiation computed with a RT model)



The erythemal weighted radiation (UVE)





$$UVE = \int_{280}^{400} CIE(\lambda)E(\lambda)d\lambda$$

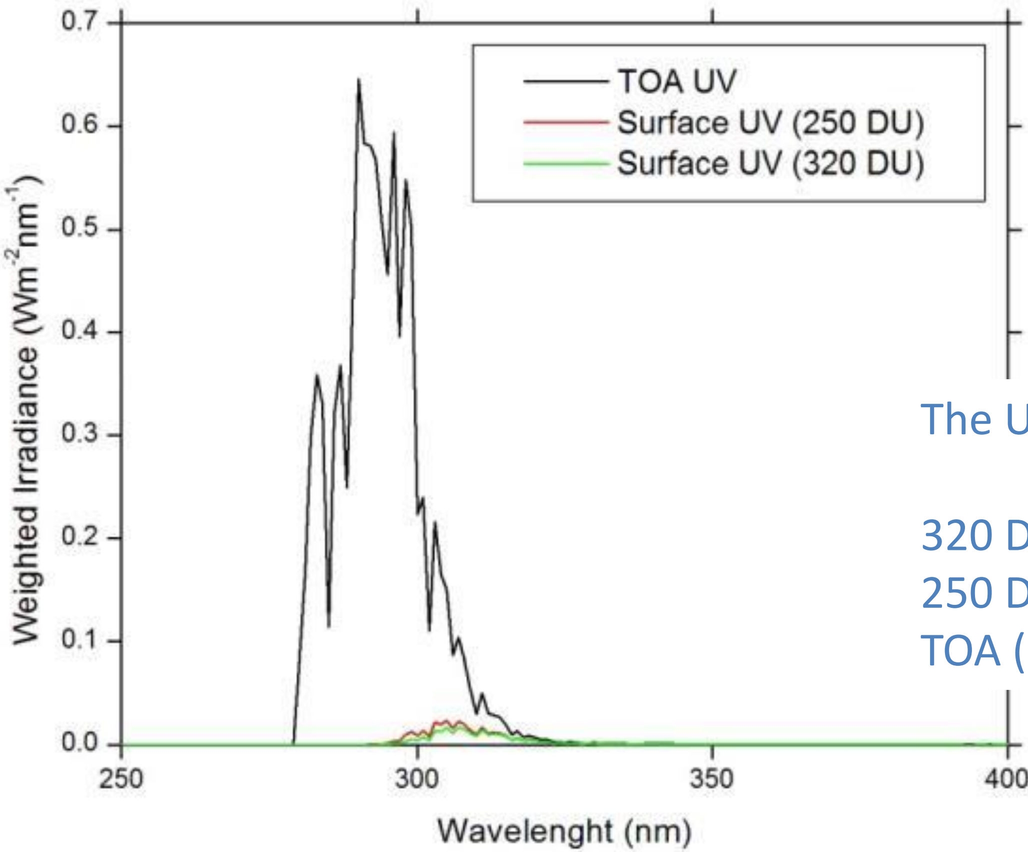
The CIE action spectrum is a model for the susceptibility of the caucasian skin to sunburn (erythema). It is proposed by McKinlay and Diffey (1987).

What is the solar UV Index?

The solar UV Index (UVI) describes the level of solar UV radiation relevant to human sunburn (erythema).

$$UVI = 40 \times UVE$$

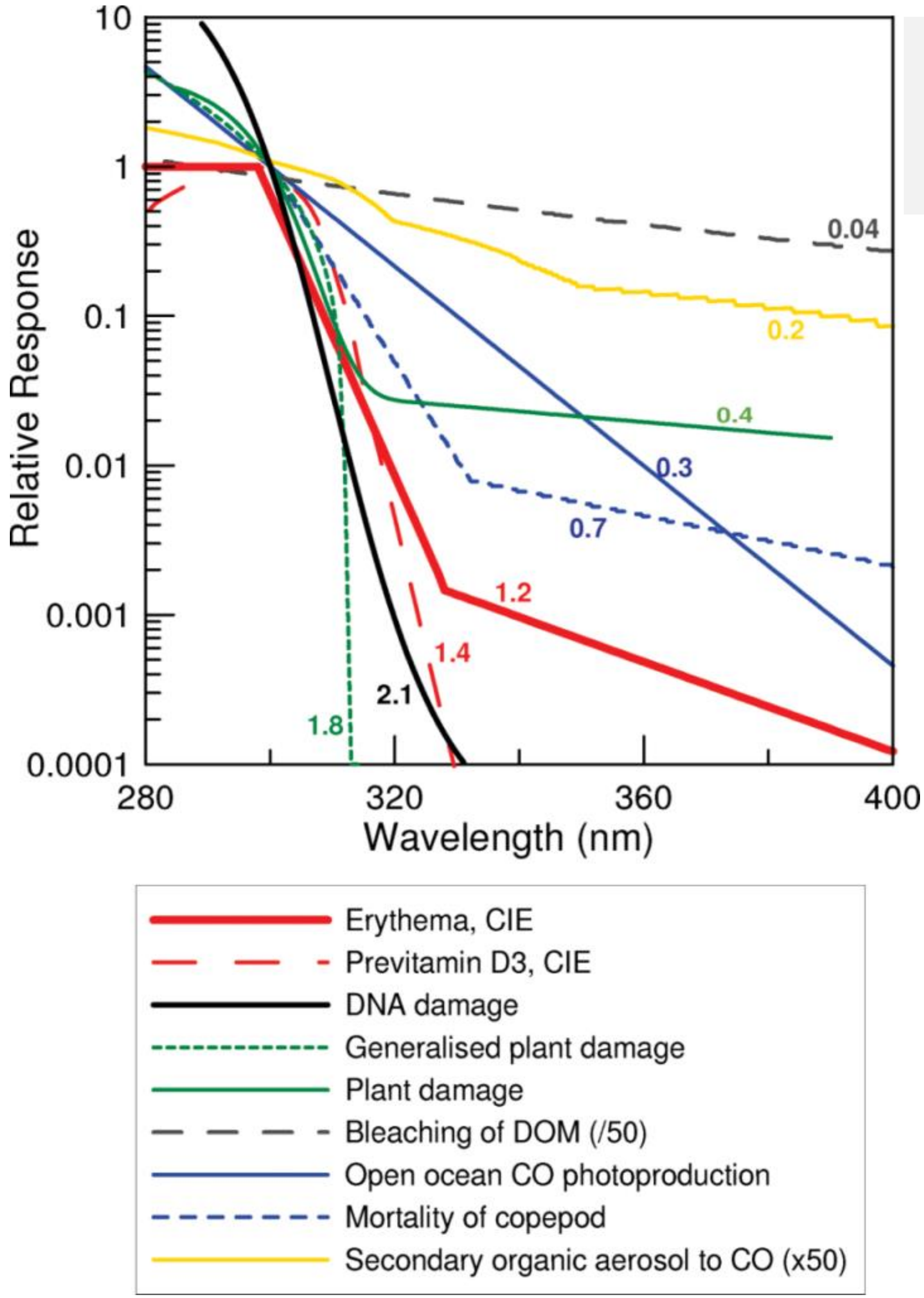
$$UVI = 40 \times \int_{280}^{400} CIE(\lambda)E(\lambda)d\lambda$$



The UVI ranges usually from 0 to 16

320 DU → UVI = 9.9
250 DU → UVI = 13.3
TOA (0 DU) → UVI = 392

Radiation Amplification factor



For small changes in ozone:

$$RAF = -\frac{\Delta E/E}{\Delta O/O}$$

For larger changes:

$$\frac{E_2}{E_1} = \left(\frac{O_2}{O_1}\right)^{-RAF}$$

O means Total Ozone Column (*TOC*)

Table 2 RAFs for action spectra calculated on the basis of daily integrals for latitude 30°N. This is an update of Table 1.1 in ref. 103

Effect	RAF Jan. (290 DU)	RAF July (305 DU)
Exponential decay (14 nm per decade)	1.00	1.01
UV-B (280–315 nm)	1.25	0.99
UV-A (315–400 nm)	0.03	0.02
Erythema (CIE, standard reference)	1.1	1.2
Erythema (from tuneable laser)	1.6	1.5
Squamous skin cancer in humans (SCUP)	1.2	1.2
US Industrial Safety Standard (ACGIH)	1.4	1.5
Cataract using whole pig lens	1.3	1.1
Visual sensitivity in insect	0.1	0.1
Previtamin D3 (CIE)	1.7	1.4
DNA damage (Setlow)	2.2	2.1
DNA damage in alfalfa	0.5	0.6
Generalised plant damage (Caldwell, truncated at 313 nm)	2.2	1.8
Plant damage (extended to 390 nm)	0.3	0.4
Phytoplankton *Phaeodactylum*	0.3	0.3
Phytoplankton *Prorocentrum*	0.4	0.4
Phytoplankton	0.8	0.8
Inhibition of photosynthesis in phytoplankton	0.3	0.3
Damage to freshwater cladoceran (*Daphnia*)	0.72	0.74
Bleaching of dissolved organic matter (DOM)	0.04	0.04
Baltic Sea photoammonification	0.2	0.2
Photoproduction of CO from tropical savanna litter	0.3	0.3
Coastal ocean biologically labile photoproduction	0.2	0.2
Open ocean CO photoproduction	0.3	0.3
Mortality of copepod *Boeckella gracilipes*	0.6	0.7
DNA damage in embryos of sea urchin	0.1–0.2	0.1–0.2
Inhibition of hypocotyl growth in *Arabidopsis*	1.6	1.3
Inhibition of photosynthesis in kelp (depth dependent)	0.1–0.4	0.1–0.4
Secondary organic aerosol to carbon monoxide	0.2	0.2
Secondary organic aerosol to formic acid	0.2	0.2
Material: PVC, 2.5% TiO_2, approximated as $\exp(-0.058\lambda)$	0.3	0.3
Material: Rigid sheets, approximated as $\exp(-0.082\lambda)$	0.4	0.4
Material: Mechanical pulp, approximated as $\exp(-0.110\lambda)$	0.08	0.08
$O_3 \rightarrow O_2 + O(^1D)$	1.5	1.4
$H_2O_2 \rightarrow 2OH$	0.3	0.3
$NO_2 \rightarrow NO + O(^3P)$	0.02	0.02
$HNO_3 \rightarrow OH + NO_2$	0.8	0.8
$NO_3^-(aq) \rightarrow NO_2(aq) + O^-$	0.6	0.5
$CH_2O \rightarrow H + HCO$	0.5	0.4
$CH_2O \rightarrow H_2 + CO$	0.2	0.1
$CH_3COCH_3 \rightarrow CH_3CO + CH_3$	1.5	1.5

Photochemical & Photobiological Sciences

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Ozone depletion and climate change: impacts on UV radiation

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NCAR UCAR | National Center for Atmospheric Research
Atmospheric Chemistry Observations & Modeling

Search

- Modeling
- Master Mechanism
- TUV
- WRF-Chem

QUICK TUV CALCULATOR

This web page runs the *5.3* version of the TUV model. You can run the model for a specified latitude, longitude and time (input option 1), or for a given solar zenith angle (input option 2). In either case, you must also specify the additional parameters in the second column. Also, you may select to print out the photolysis rates and/or the solar actinic flux spectrum at a given altitude above the surface (output option 1), or the erythemal UV and/or solar irradiance at that altitude (output option 2). For any problem, or to send comments, email TUV administrators.

Wavelength

Start:	End:	Increments:
280	420	140

◉ **INPUT OPTION 1**

LATITUDE (deg): 41.962
LONGITUDE (deg): 2.829
DATE (YYYYMMDD): 20201222
TIME (hh:mm:ss, GMT): 12:00:00

○ **INPUT OPTION 2**

SOLAR ZENITH ANGLE (deg): 0

OTHER INPUT PARAMETERS

OVERHEAD OZONE COLUMN (du): 300
SURFACE ALBEDO (0-1): 0.1
GROUND ELEVATION (km asl): 0.115
MEASUREM. ALTITUDE (km asl): 0.115

Clouds

Opt. Depth:	Base:	Top:
0.00	4.00	5.00

Aerosols

Opt. Depth:	S-S Alb:	Alpha:
0.235	0.990	1.000

Sunlight

Direct beam:	Diffuse down:	Diffuse up:
1.0	1.0	0.0

○ **OUTPUT OPTION 1 (for Atmospheric Science)**

☐ MOLECULAR PHOTOLYSIS FREQUENCIES (s-1)
☐ ACTINIC FLUX, SPECTRAL (quanta s-1 cm-2 nm-1)

◉ **OUTPUT OPTION 2 (for Biology)**

☑ IRRADIANCE, WEIGHTED (W m-2)
☐ IRRADIANCE, SPECTRAL (W m-2 nm-1)

RADIATION TRANSFER MODEL

◉ Pseudo-spherical 2 streams (faster, less accurate)
○ Pseudo-spherical discrete ordinate 4 streams (slower, more accurate)

GO!

RESET

ACOM: Quick TUV (ucar.edu)

INPUT

```
INPUT PARAMETERS:

RADIATION SCHEME:              2  streams

w-grid:           141    280.0000         420.0000
equally spaced z-grid
z-grid:            81   0.1150000         80.00000
 measurement point: index            1  altitude=   0.1150000
idate =       20201222  esfact(1) =     1.033511
air temperature: USSA, 1976
air concentrations: USSA, 1976
ozone profile: USSA, 1976
DATAE1/SUN/susim_hi.flx
DATAE1/SUN/atlas3_1994_317_a.dat
DATAE1/SUN/neckel.flx
DATAE1/SUN/sao2010.solref.converted
aerosols:  Elterman (1968) continental profile
lat=    41.96200      long=     2.829000      ut=     12.00000
solar zenith angle =      65.45741
```

OUTPUT

```
WEIGHTED IRRADIANCES (W m-2)
 (with normalized action spectra)

   1 UV-B, 280-315 nm                            2.495E-01
   2 UV-B*, 280-320 nm                           6.210E-01
   3 UV-A, 315-400 nm                            1.998E+01
   4 vis+, > 400 nm                              9.861E+00
   5 Gaussian, 305 nm, 10 nm FWHM                8.346E-03
   6 Gaussian, 320 nm, 10 nm FWHM                9.890E-02
   7 Gaussian, 340 nm, 10 nm FWHM                2.093E-01
   8 Gaussian, 380 nm, 10 nm FWHM                2.853E-01
   9 RB Meter, model 501                         7.091E-02
  10 Eppley UV Photometer                        1.662E+01
  11 PAR, 400-700 nm, umol m-2 s-1               3.381E+01
  12 Exponential decay, 14 nm/10                 9.514E-02
  13 DNA damage, in vitro (Setlow, 1974)         3.820E-04
  14 SCUP-mice (de Gruijl et al., 1993)          3.714E-02
  15 SCUP-human (de Gruijl and van der Leun,     7.763E-02
  16 Standard human erythema (Webb et al., 20    3.471E-02
  17 UV index (WMO, 1994; Webb et al., 2011)     1.388E+00
  18 Erythema, humans (Anders et al., 1995)      1.143E-04
  19 Occupational TLV (ACGIH, 1992)              7.328E-03
  20 Phytoplankton (Boucher et al., 1994)        8.007E-04
  21 Phytoplankton, phaeo (Cullen et al., 199    4.537E-04
  22 Phytoplankton, proro (Cullen et al., 199    3.843E-04
  23 Cataract, pig (Oriowo et al., 2001)         1.020E-01
  24 Plant damage (Caldwell, 1971)               2.063E-02
  25 Plant damage,Flint&Caldwell,2003,orig.      2.775E-01
  26 Plant damage,Flint&Caldwell,2003,ext390     4.236E-01
  27 Previtamin-D3 (CIE 2006)                    4.807E-02
  28 NMSC (CIE 2006)                             7.120E-02
  29 Ebola virus inactivation                    1.208E-01
```

×40

… SARS CoV-2 virus

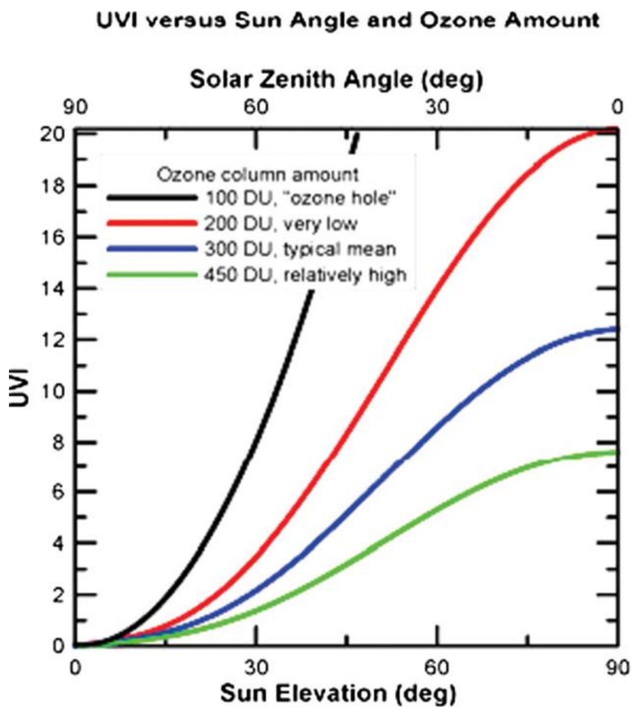
What determines the level of solar UV-B radiation at a specific place?

The Sun is the source of the UV radiation reaching Earth. UV radiation is partly absorbed by the components of Earth's atmosphere. The amount of UV radiation that is absorbed depends mainly on the length of the path of the sunlight through the atmosphere.

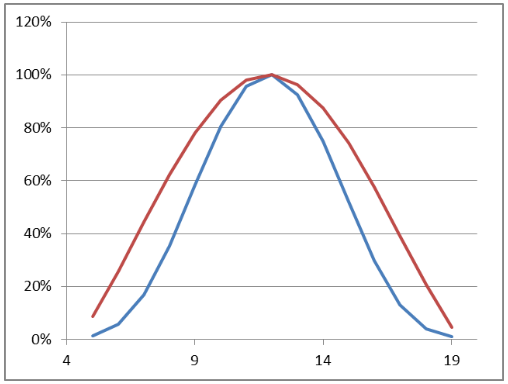
The quantity of solar UVB radiation received by an object is affected by the surroundings. UV radiation is both absorbed and reflected From clouds and water, and is reflected by snow and shiny surfaces in towns.

(Photograph provided by Dr P. J. Aucamp, Ptersa, South Africa.)

The effect of solar altitude



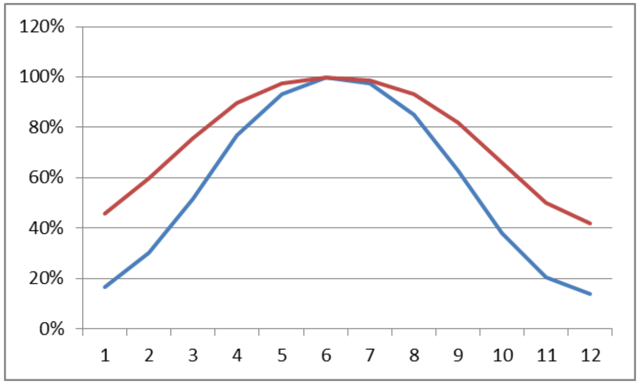
Variation of the UV Index with the solar elevation. The colored lines represent different ozone concentrations measured in Dobson units (DU).
(Figure provided by Dr R. L. McKenzie, NIWA, New Zealand.)



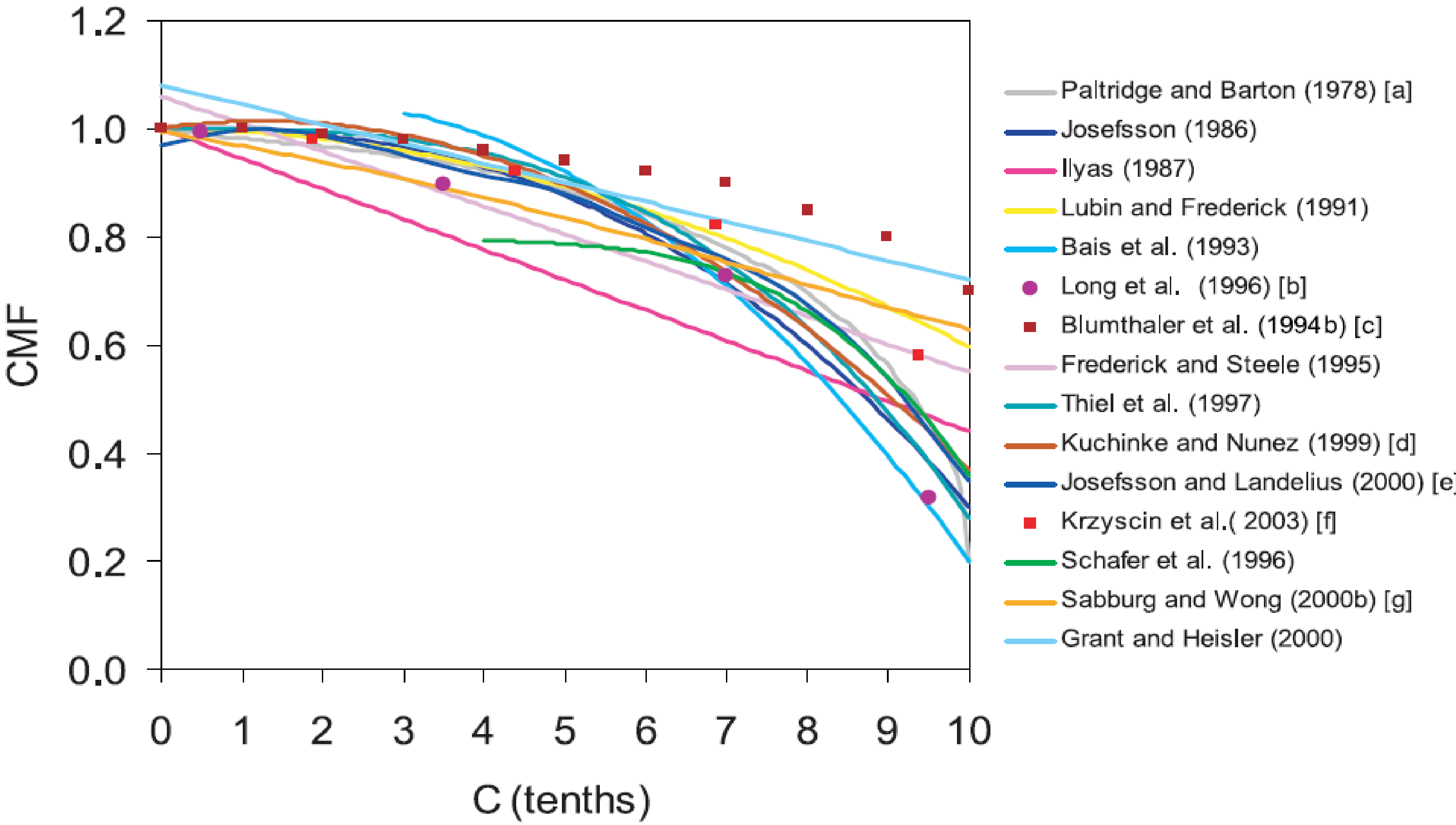
Daily evolution
(relative to noon)

UVE
Solar radiation

Yearly evolution
(relative to noon)



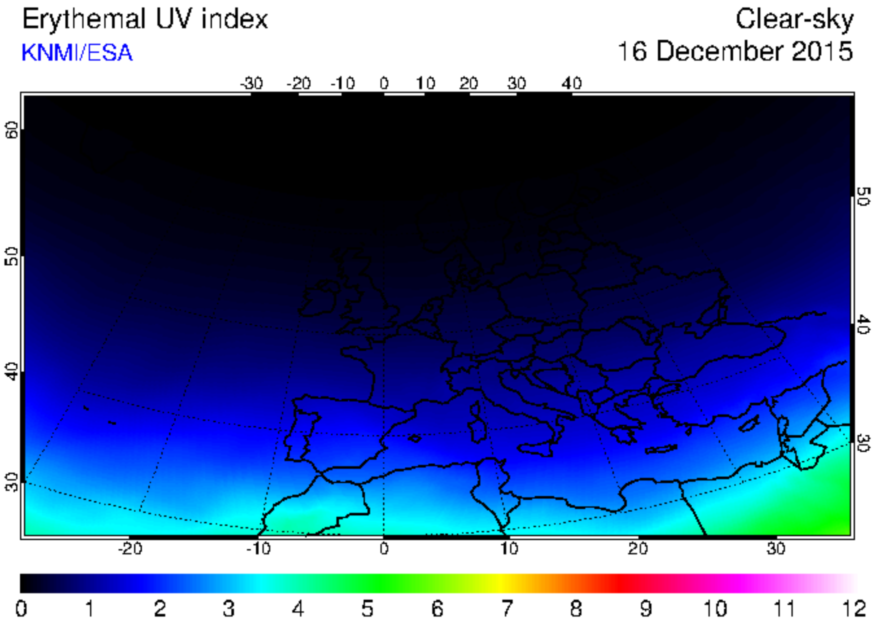
Clouds and UV radiation

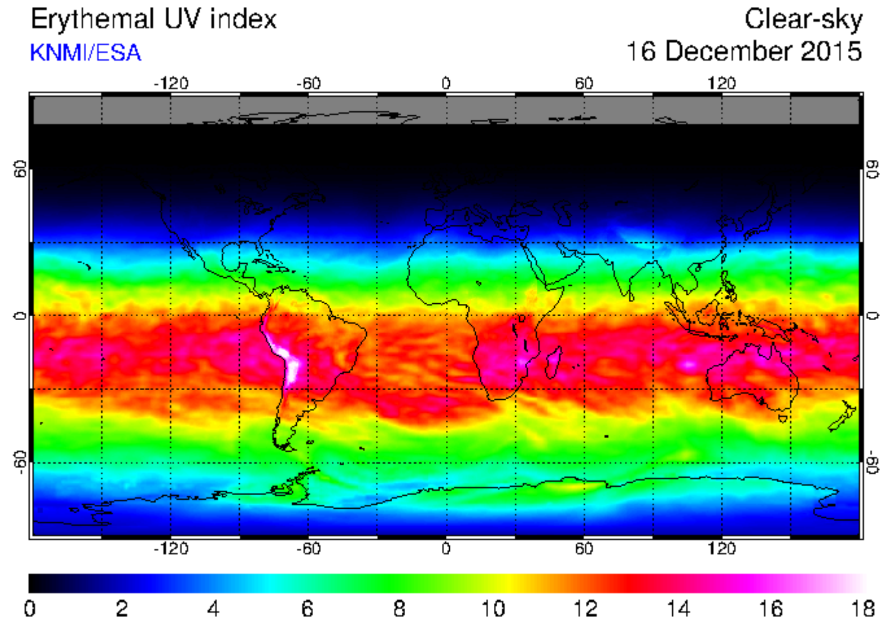


Empirical studies of cloud effects on UV radiation: A review
Calbó, J. Pagès, D, and González, J.A (2005) Reviews of Geophysics.

How does the UV index vary with location and time?

The combination of total ozone, aerosols, clouds, air pollution, altitude, surface reflectivity and solar zenith angle (that is determined by the geographical position, season and time of the day) are the main factors resulting in variation in the UV Index.





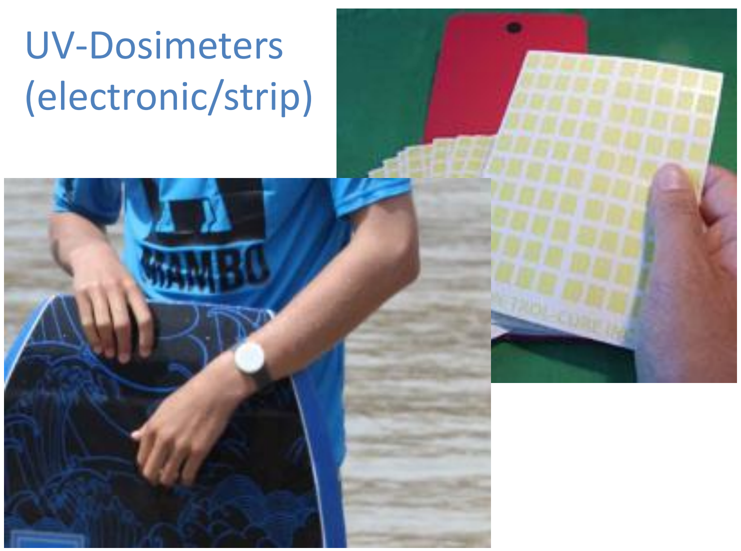
http://www.temis.nl/uvradiation/UVindex.html

How we measure UVB radiation levels at surface?

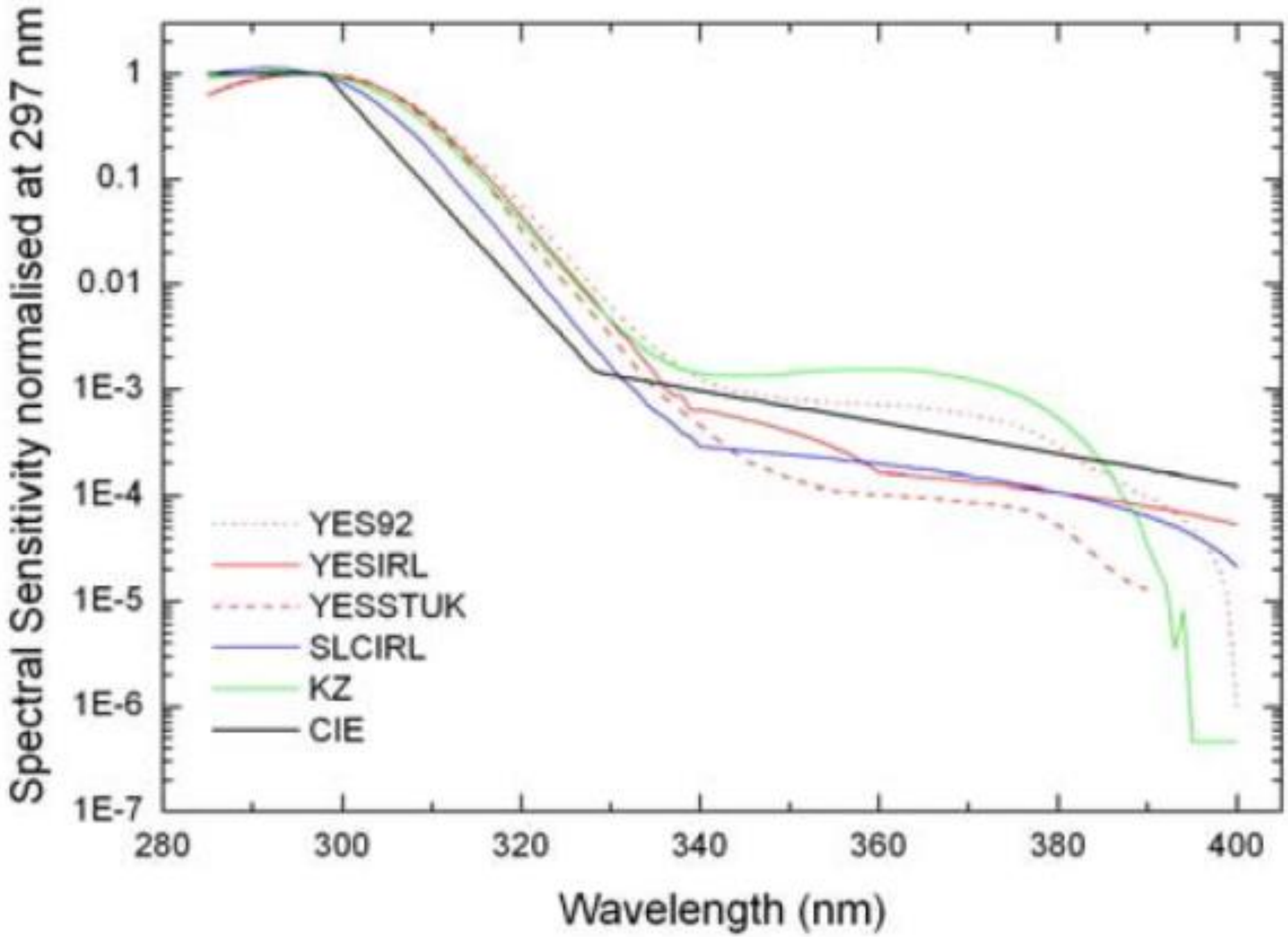
Spectroradiometers

Broadband radiometers

UV-Dosimeters (electronic/strip)



The spectral response of some broadband UVE instruments



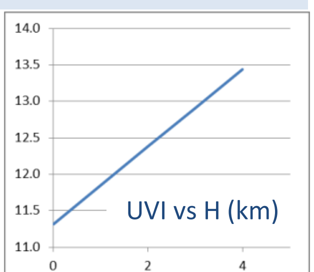
UV forecast

Solar altitude

Total ozone column

Cloudiness (and aerosol)

Location altitude
and surface albedo



→

Radiative transfer
model / parametrization
TUV
UVSPEC
SBDART
...

→

UVE / UVI

meteo.cat | Servei Meteorològic de Catalunya

Comarca	Capital	UVI màxim	UVI previst	Temps previst
L'Alt Camp	Valls	1	0	
L'Alt Empordà	Figueres	1	0	
L'Alt Penedès	Vilafranca del Penedès	1	0	
L'Alt Urgell	La Seu d'Urgell	1	0	
L'Alta Ribagorça	El Pont de Suert	1	0	

METEOCAT → http://www.meteo.cat/prediccio/uvi

AEMET → http://www.aemet.es/es/eltiempo/prediccion/radiacionuv

AEMet

Agencia Estatal de Meteorología

http://www.aemet.es/es/eltiempo/observacion/radiacion/ultravioleta?datos=mapa

Solar Ultraviolet Radiation

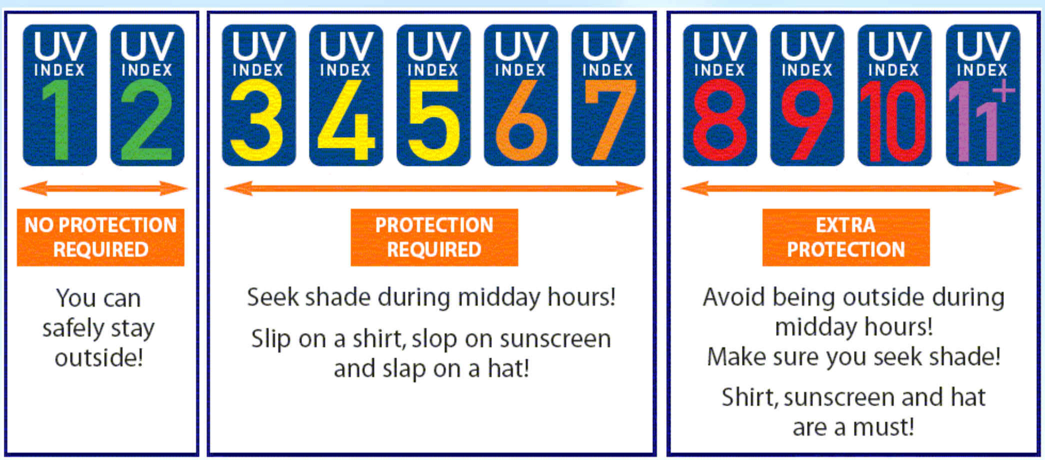
The use of UVI

An international consensus has been reached about the use of UVI

LOW	< 2
MODERATE	3 TO 5
HIGH	6 TO 7
VERY HIGH	8 TO 10
EXTREME	11+

Coded scale

Advise



Basic sun protection messages

- Limit exposure during midday hours.
- Seek shade.
- Wear protective clothing.
- Wear a broad-brimmed hat to protect the eyes, face and neck.
- Protect the eyes with wrap-around design sunglasses or sunglasses with side panels.
- Use and reapply broad-spectrum sunscreen of SPF 15/30+ liberally.
- Avoid tanning beds.
- Protect babies and young children: this is particularly important.

Credit: Jordi Badosa

UVI forecast

6

The Protection of the Ozone Layer

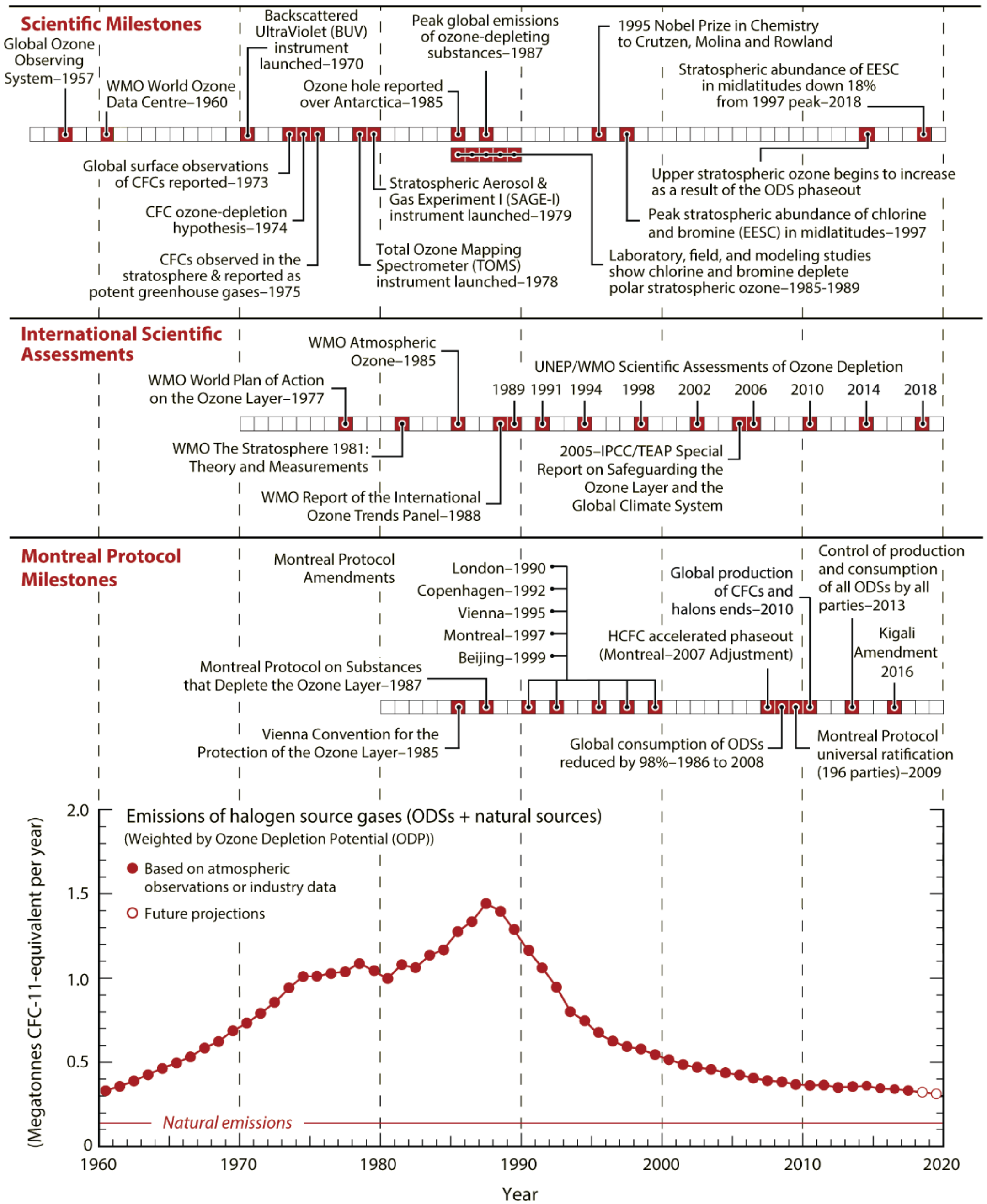
ODS substitution

CFC --
USADOS en
refrigerantes
acondicionadores
aerosoles
plásticos expansibles
limpieza

HCFC ---
TRANSITORIOS
menor potencial de agotamiento (vida más corta)
sustitución difícil en algunos casos (tratamiento de asma)
como halones (extinción del fuego)

HFC ---
aún tienen potencial de efecto invernadero → Kigali 2016
refrigeración y acondicionamiento

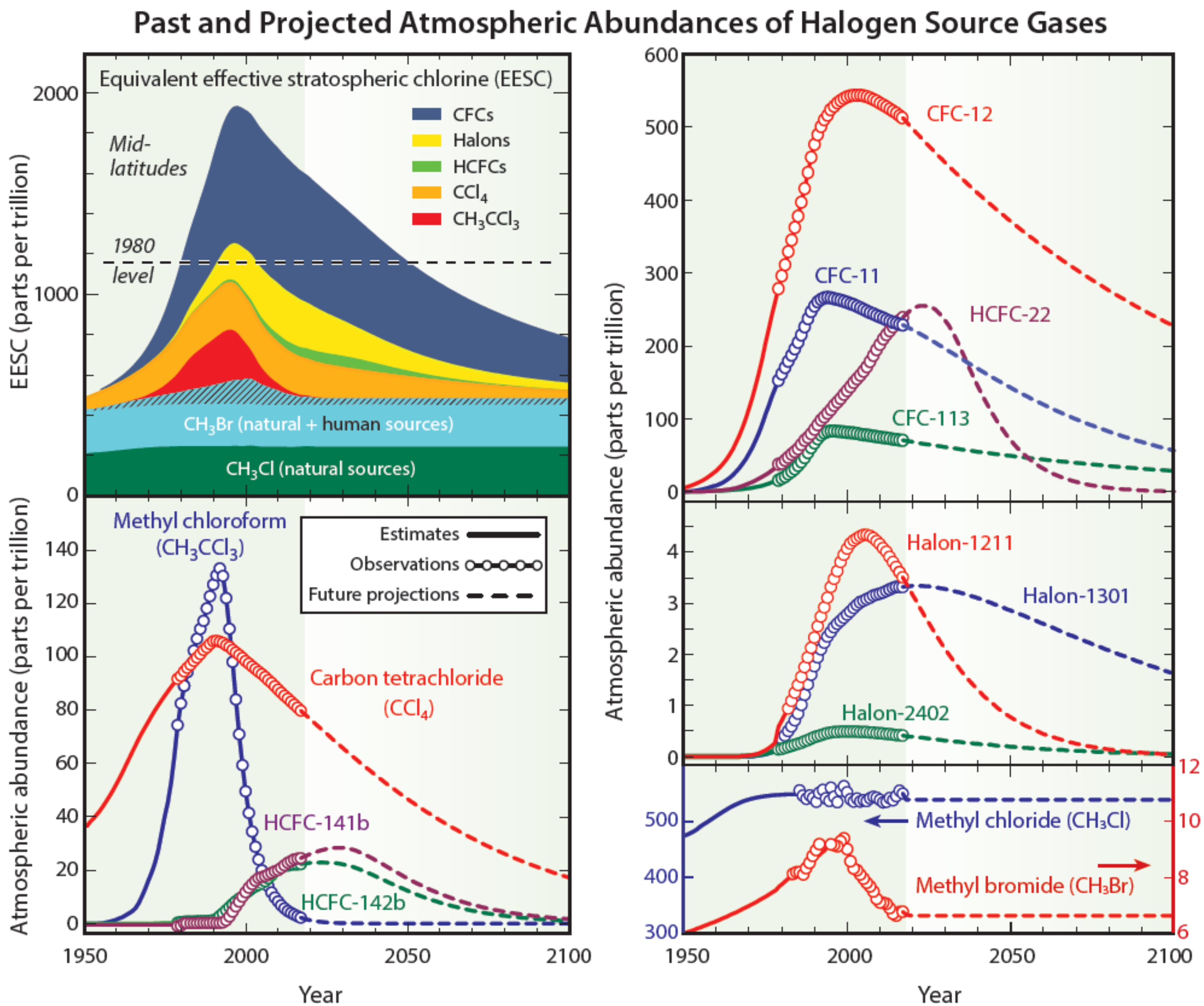
Milestones in the History of Stratospheric Ozone Depletion



Year	Policy Process	Scientific Assessment
1981		The Stratosphere 1981: Theory and Measurements. WMO No. 11.
1985	**Vienna Convention (20 countries)**	Atmospheric Ozone 1985. Three volumes. WMO No. 16.
1987	**Montreal Protocol (43 countries)**	
1988		International Ozone Trends Panel Report 1988. Two volumes. WMO No. 18.
1989		Scientific Assessment of Stratospheric Ozone: 1989. Two volumes. WMO No. 20.
1990	London Adjustment and Amendment	CFC elimination scheduled to 2000
1991		Scientific Assessment of Ozone Depletion: 1991. WMO No. 25.
1992		Methyl Bromide: Its Atmospheric Science, Technology, and Economics (Montreal Protocol Assessment Supplement). UNEP (1992).
1992	Copenhagen Adjustment and Amendment	CFC elimination scheduled to 1996
1994		Scientific Assessment of Ozone Depletion: 1994. WMO No. 37.
1995	Vienna Adjustment	
1997	Montreal Adjustment and Amendment	
1998		Scientific Assessment of Ozone Depletion: 1998. WMO No. 44.
1999	Beijing Adjustment and Amendment	
2002		Scientific Assessment of Ozone Depletion: 2002. WMO No. 47.
2006		Scientific Assessment of Ozone Depletion: 2006. WMO No. 50.
2007	Montreal Adjustment	
2010		Scientific Assessment of Ozone Depletion: 2010. WMO No. 52.
2011	23rd Meeting of the Parties	
2014		Scientific Assessment of Ozone Depletion: 2014. WMO No. 55
2016	28th Meeting of the Parties (Kigali, Rwanda)	**(~ 200 countries)**
2018		Scientific Assessment of Ozone Depletion: 2018

Are the control measures in the Montreal Protocol working?

Yes, the Montreal Protocol has been very successful.



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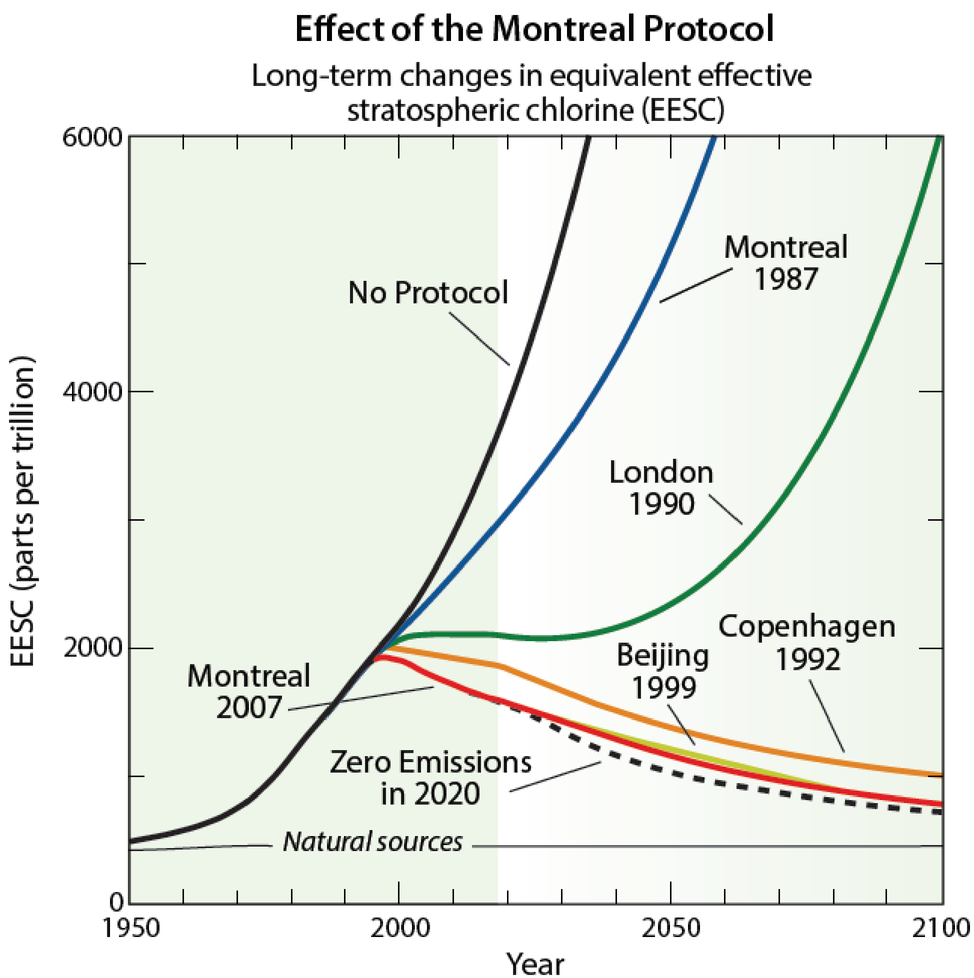
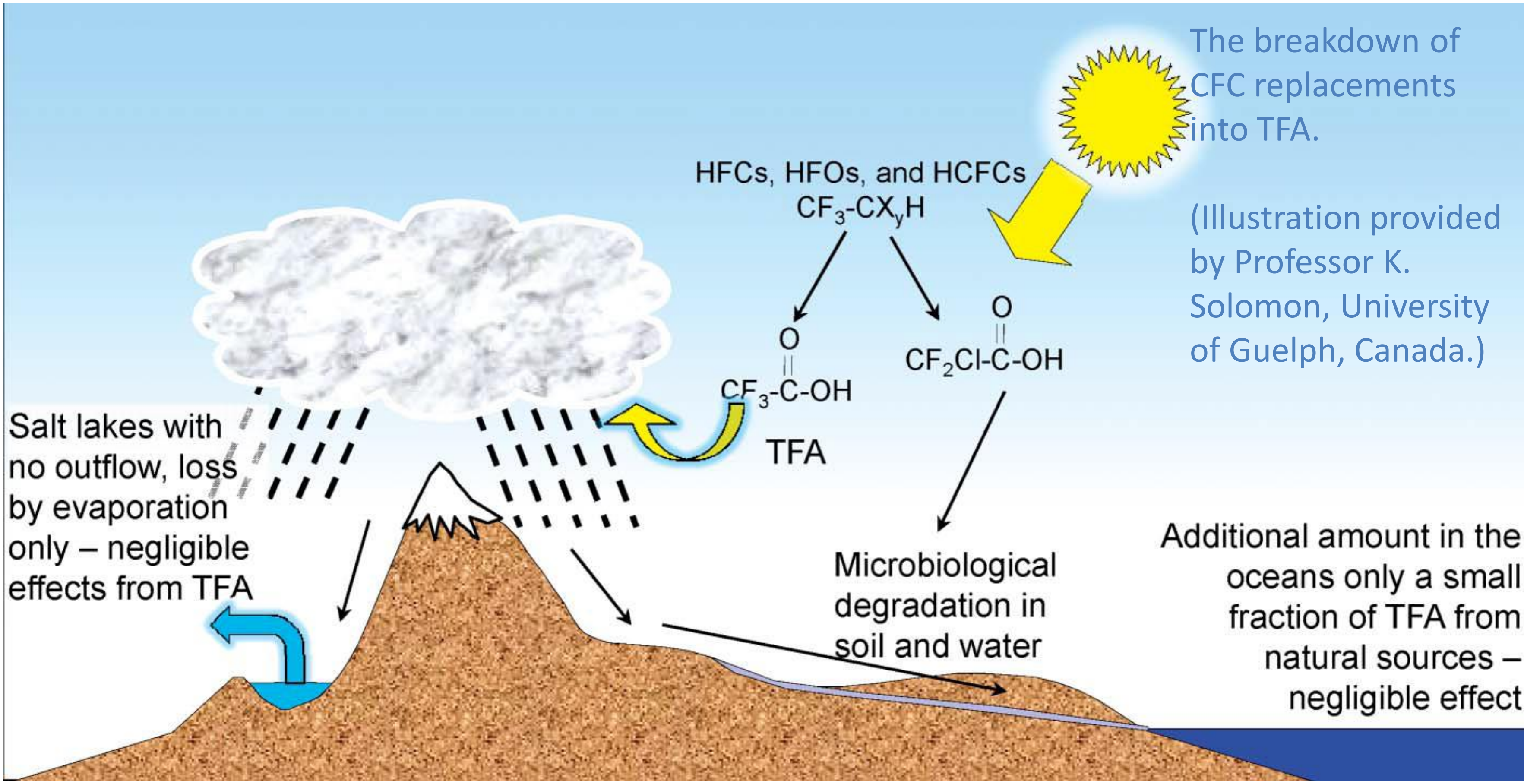


EESC: Equivalent Effective Stratospheric Chlorine

What risks do the breakdown products of HFCs and HCFCs present to humans and the environment?

The main breakdown product, trifluoroacetic acid (TFA), and other related short-chain fluorinated acids are presently judged to present a negligible risk to human health or the environment.

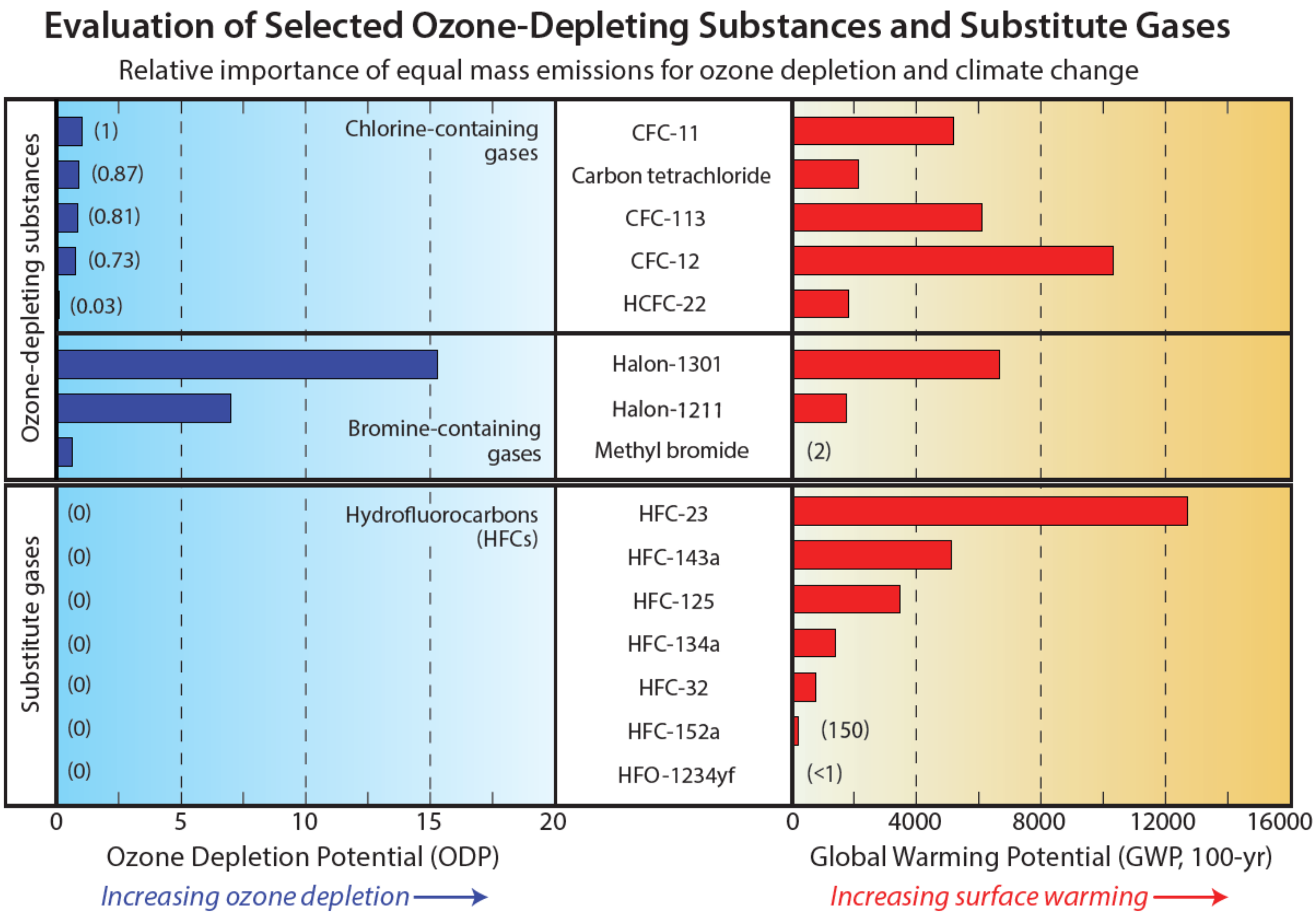


The breakdown of CFC replacements into TFA.

(Illustration provided by Professor K. Solomon, University of Guelph, Canada.)

Ozone Depleting potential *vs* Global Warming potentialWP

GWP = Global Warming Potential



2018 Update

EL PAÍS 40!

INTERNACIONAL

EUROPA EE UU MÉXICO AMÉRICA LATINA ORIENTE PRÓXIMO ASIA ÁFRICA FOTOS OPINIÓN BLOGS TITULARES »

CAMBIO CLIMÁTICO ›

Acuerdo mundial para reducir un potente gas de efecto invernadero

Cerca de 200 países pactan recortar el uso de hidrofluorocarbonos entre un 80% y un 85% a mediados de siglo

la Repubblica.it | Archivio

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immobiliare.it MIGLIAIA DI ANNUNC

Sei in: Archivio > la Repubblica.it > 2016 > 10 > 17 > La Terra più fresca di 0,...

La Terra più fresca di 0,5 gradi grazie all'accordo di Kigali

ROMA. Una riduzione del riscaldamento globale di 0,5 gradi Celsius grazie al venir meno di una quantità di emissioni di gas climalteranti pari al volume di anidride carbonica prodotto globalmente nel corso di due anni. È questo il risultato che la comunità internazionale si attende dall'accordo per la messa al bando dei gas refrigeranti Hfc siglato a Kigali da 197 nazioni. L'intesa prevede lo stop entro il 2024 all'utilizzo degli idrofluorocarburi, gas con una

el Grup Tradueix-nos EL PUNT AVUI+ Identifica't

s, 14 desembre 2016

SECCIONS EDICIÓ IMPRESA EL PUNT AVUI TV MÉS

LOCAL SOCIETAT TERRITORI PUNT DIVERS POLÍTICA ECONOMIA CULTURA COMUNICACIÓ OPINIÓ IN ENGLIS

MEDI AMBIENT KIGALI - 16 octubre 2016 2.00 h

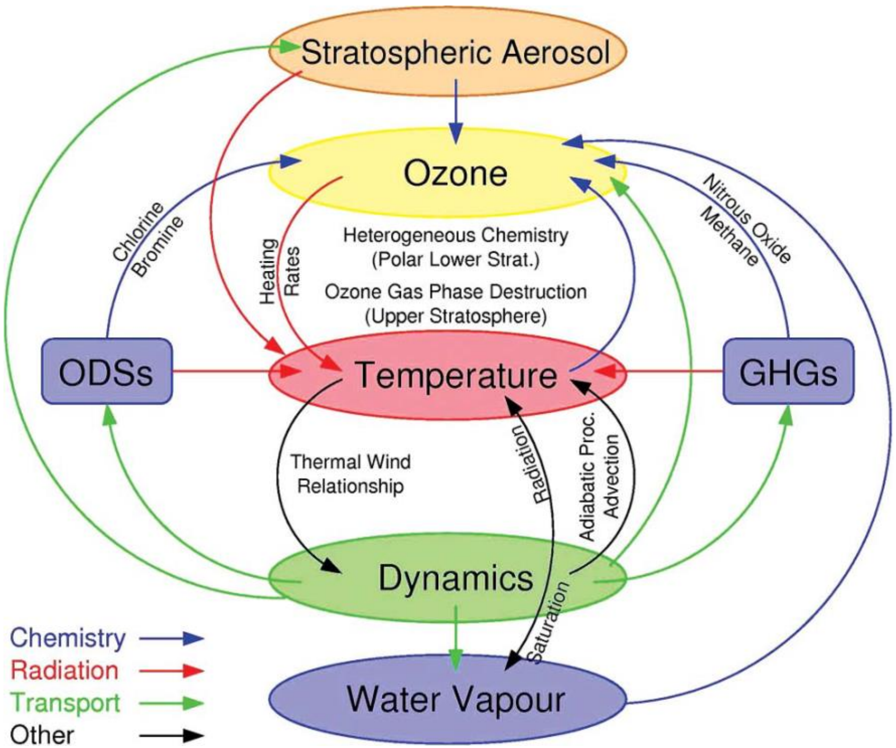
Acord internacional per a la reducció progressiva dels gasos HFC

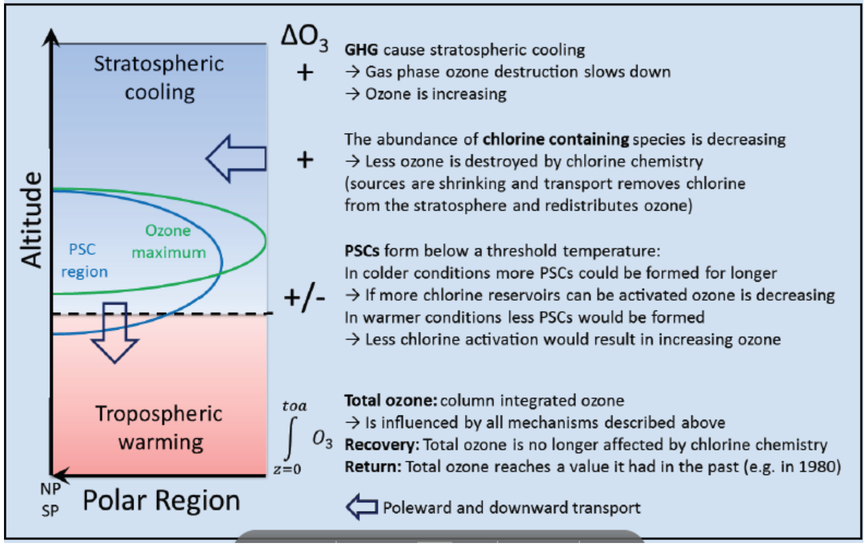
- Considerats molt nocius per al clima, es troben en aerosols i aparells d'aire condicionat i refrigeració
- El text, firmat a Kigali, modifica el protocol de Montreal del 1987

UNEP Climate and Clear Air Coalition
http://www.ccacoalition.org/hfcville

Is ozone depletion affected by climate change?

Climate change affects ozone depletion through changes in atmospheric conditions that affect the chemical production and loss of stratospheric ozone. The interactions are complex. Climate change is expected to result in decreased temperatures in the stratosphere. This will tend to speed up ozone recovery outside Polar regions, but slow down the recovery in Polar regions.



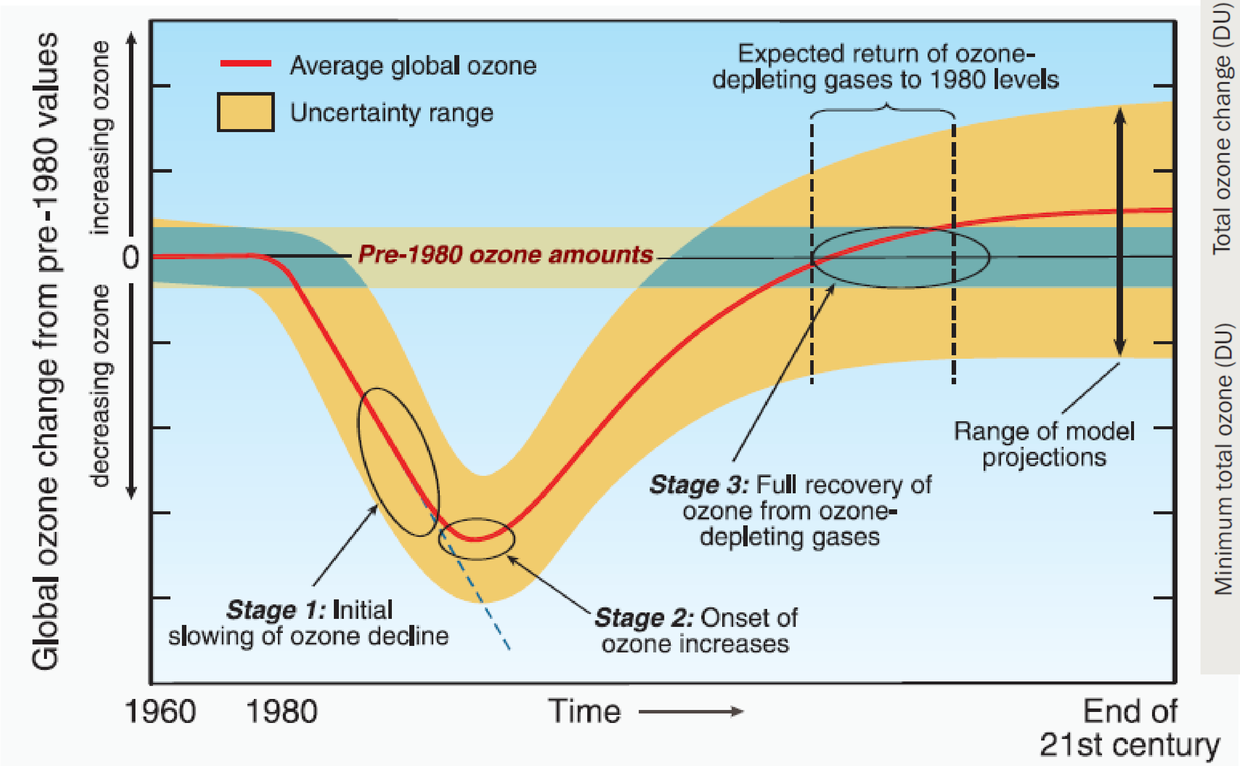


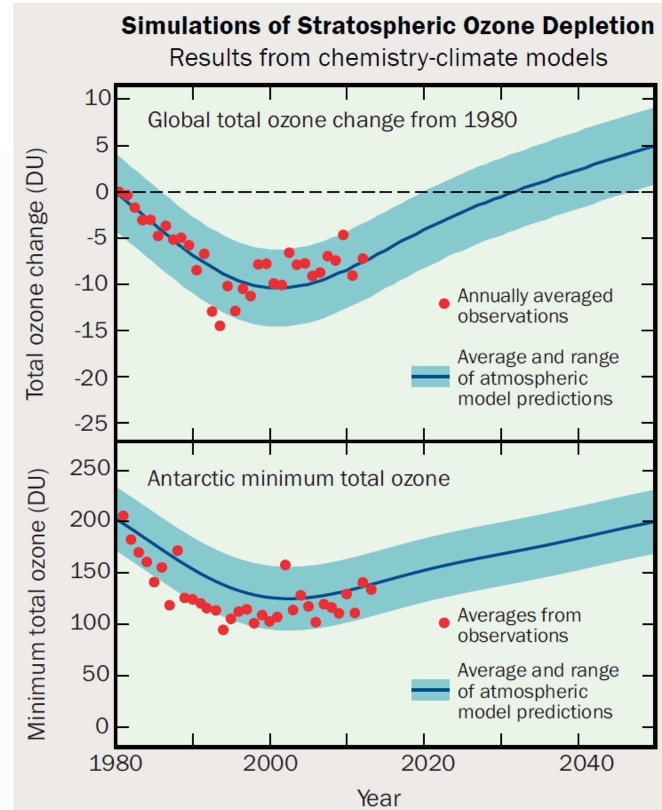
- **Changes in atmospheric circulation** → facilitates insertion of CFC into the stratosphere
- **Colder stratosphere** → less destruction at low latitudes
- **Lower temperature in polar regions** → more PSC will delay the ozone recovering

... Climate Change is also affected by ozone hole

Ozone + ODS + Substitutes → ±13 % influence on CC

The ozone layer evolution (observations and forecasting)





The world avoided

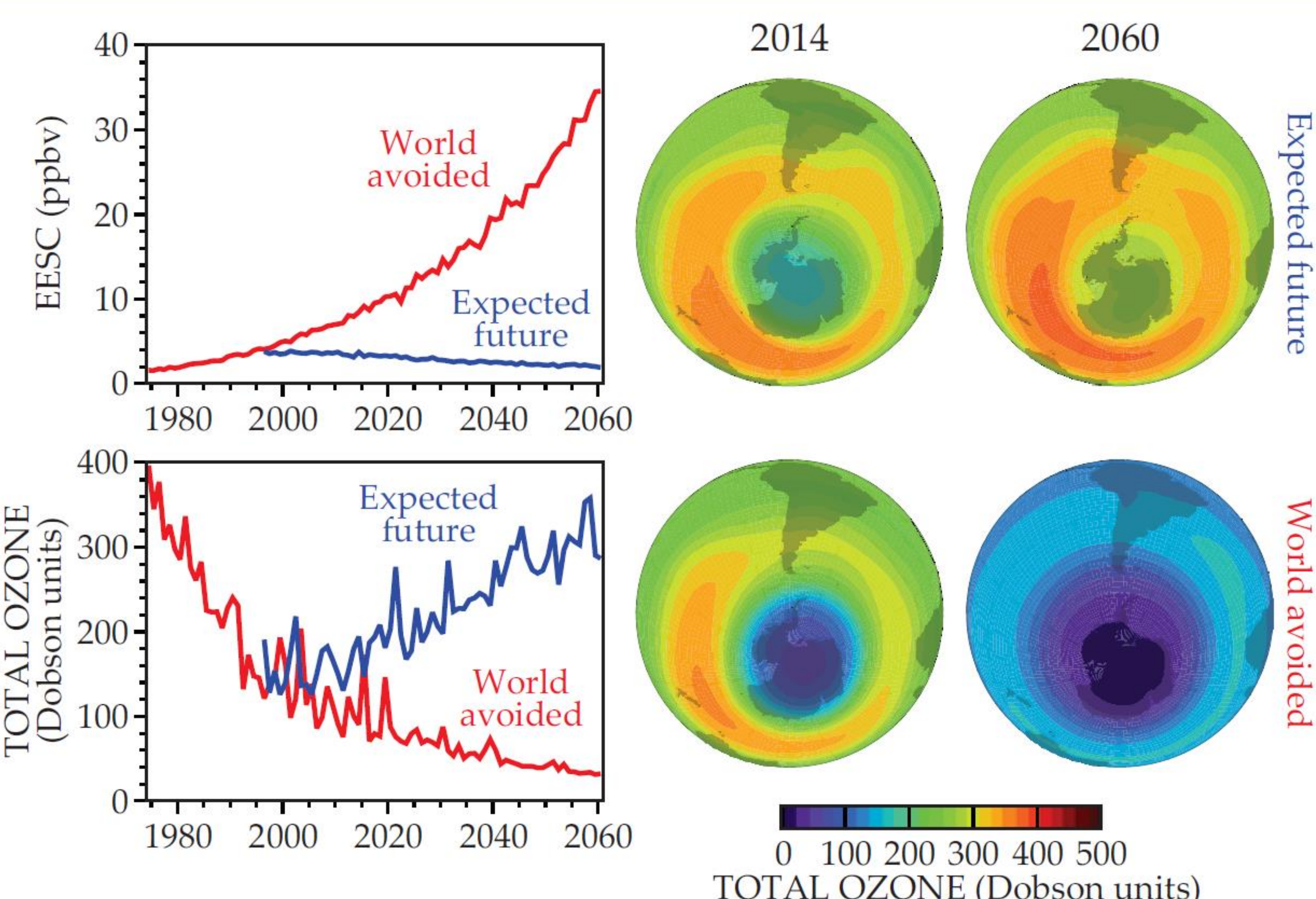
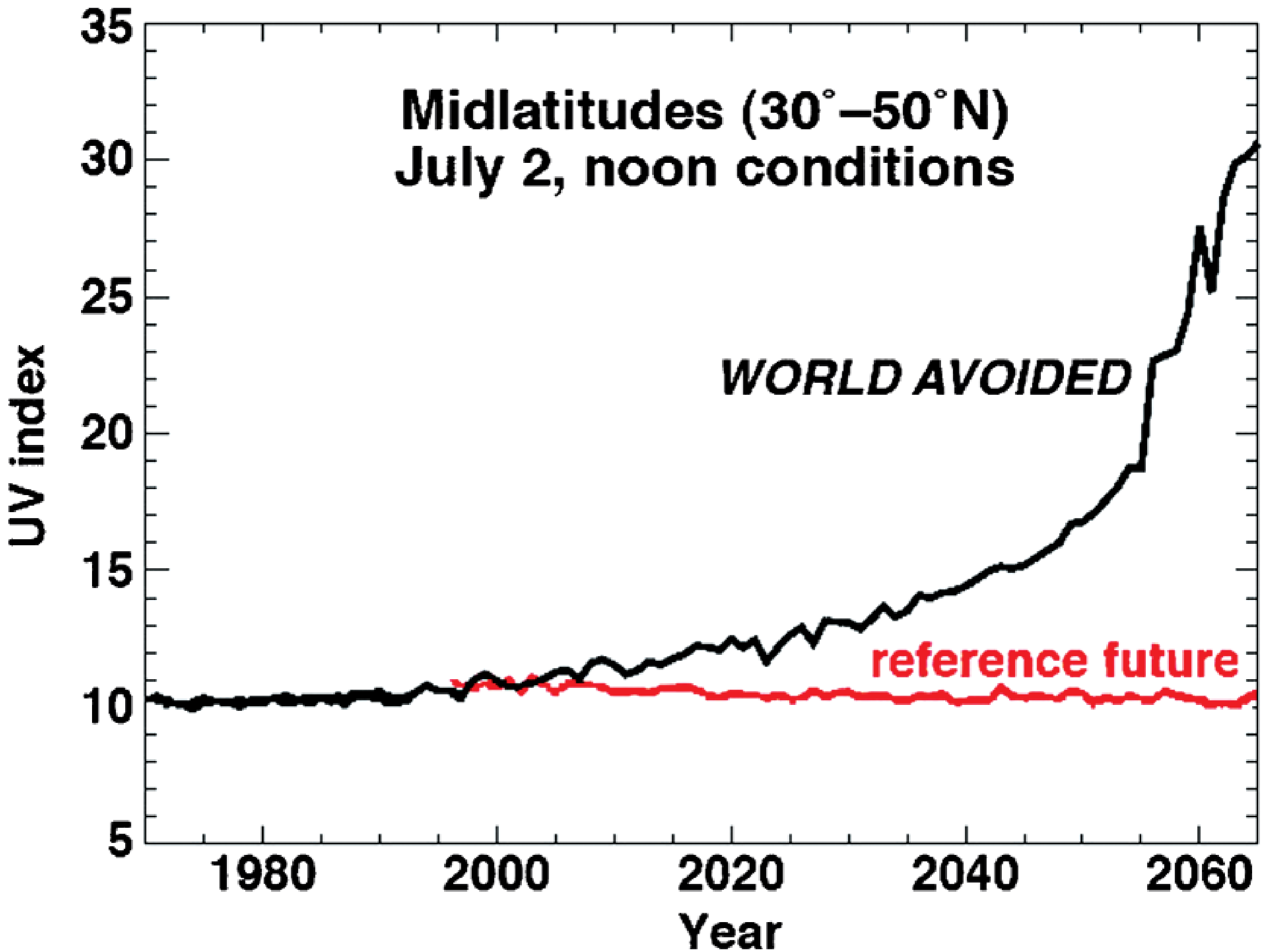


Fig 5. Douglas et al (2014)

UV radiation changes. *The Montreal Protocol has had a large influence on UV-B radiation.*



Prediction of the UV Index indicating what could have happened in the absence of a Montreal Protocol.
(Reproduction of Fig. 5.11 in the Scientific Assessment Report 2010.)

http://www.youtube.com/watch?v=aKHcHmg4WKY

Executive Summary

https://www.esrl.noaa.gov/csd/assessments/ozone/2018/executivesummary/

Highlights

Recommended Citation

The Assessment documents the advances in scientific understanding of ozone depletion reflecting the thinking of the many international scientific experts who have contributed to its preparation and review. These advances add to the scientific basis for decisions made by the Parties to the Montreal Protocol. It is based on longer observational records, new chemistry-climate model simulations, and new analyses. Highlights since the 2014 Assessment are:

Actions taken under the Montreal Protocol have led to decreases in the atmospheric abundance of controlled ozone-depleting substances (ODSs) and the start of the recovery of stratospheric ozone. The atmospheric abundances of both total tropospheric chlorine and total tropospheric bromine from long-lived ODSs controlled under the Montreal Protocol have continued to decline since the 2014 Assessment. The weight of evidence suggests that the decline in ODSs made a substantial contribution to the following observed ozone trends:

The Antarctic ozone hole is recovering, while continuing to occur every year. As a result of the Montreal Protocol much more severe ozone depletion in the polar regions has been avoided.

Outside the polar regions, upper stratospheric ozone has increased by 1–3% per decade since 2000.

No significant trend has been detected in global (60°S–60°N) total column ozone over the 1997–2016 period with average values in the years since the last Assessment remaining roughly 2% below the 1964–1980 average.

Ozone layer changes in the latter half of this century will be complex, with projected increases and decreases in different regions. Northern Hemisphere mid-latitude total column ozone is expected to return to 1980 abundances in the 2030s, and Southern Hemisphere mid-latitude ozone to return around mid-century. The Antarctic ozone hole is expected to gradually close, with springtime total column ozone returning to 1980 values in the 2060s. [ES Sections 1 and 3]

The Kigali Amendment is projected to reduce future global average warming in 2100 due to hydrofluorocarbons (HFCs) from a baseline of 0.3–0.5 °C to less than 0.1 °C. The magnitude of the avoided temperature increase due to the provisions of the Kigali Amendment (0.2 to 0.4 °C) is substantial in the context of the 2015 Paris Agreement, which aims to keep global temperature rise this century to well below 2 °C above pre-industrial levels. [ES Section 2]

There has been an unexpected increase in global total emissions of CFC-11. Global CFC-11 emissions derived from measurements by two independent networks increased after 2012, thereby slowing the steady decrease in atmospheric concentrations reported in previous Assessments. The global concentration decline over 2014 to 2016 was only two-thirds as fast as it was from 2002 to 2012. While the emissions of CFC-11 from eastern Asia have increased since 2012, the contribution of this region to the global emission rise is not well known. The country or countries in which emissions have increased have not been identified. [ES Section 1]

Sources of significant carbon tetrachloride emissions, some previously unrecognised, have been quantified. These sources include inadvertent by-product emissions from the production of chloromethanes and perchloroethylene, and fugitive emissions from the chlor-alkali process. The global budget of carbon tetrachloride is now much better understood than was the case in previous Assessments, and the previously identified gap between observation-based and industry-based emission estimates has been substantially reduced. [ES Sections 1 and 5]

Continued success of the Montreal Protocol in protecting stratospheric ozone depends on continued compliance with the Protocol. Options available to hasten the recovery of the ozone layer are limited, mostly because actions that could help significantly have already been taken. Remaining options such as complete elimination of controlled and uncontrolled emissions of substances such as carbon tetrachloride and dichloromethane; bank recapture and destruction of CFCs, halons, and HCFCs; and elimination of HCFC and methyl bromide production would individually lead to small-to-modest ozone benefits. Future emissions of carbon dioxide, methane, and nitrous oxide will be extremely important to the future of the ozone layer through their effects on climate and on atmospheric chemistry. Mitigation of nitrous oxide emissions would also have a small-to-modest ozone benefit. [Figure ES-9, ES Section 5]