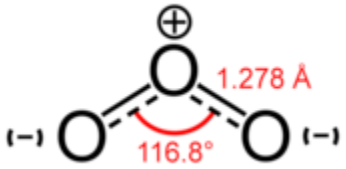
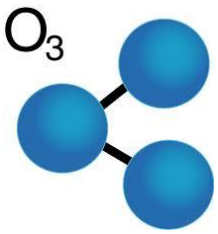
GF 3022 Contenidos de hoy

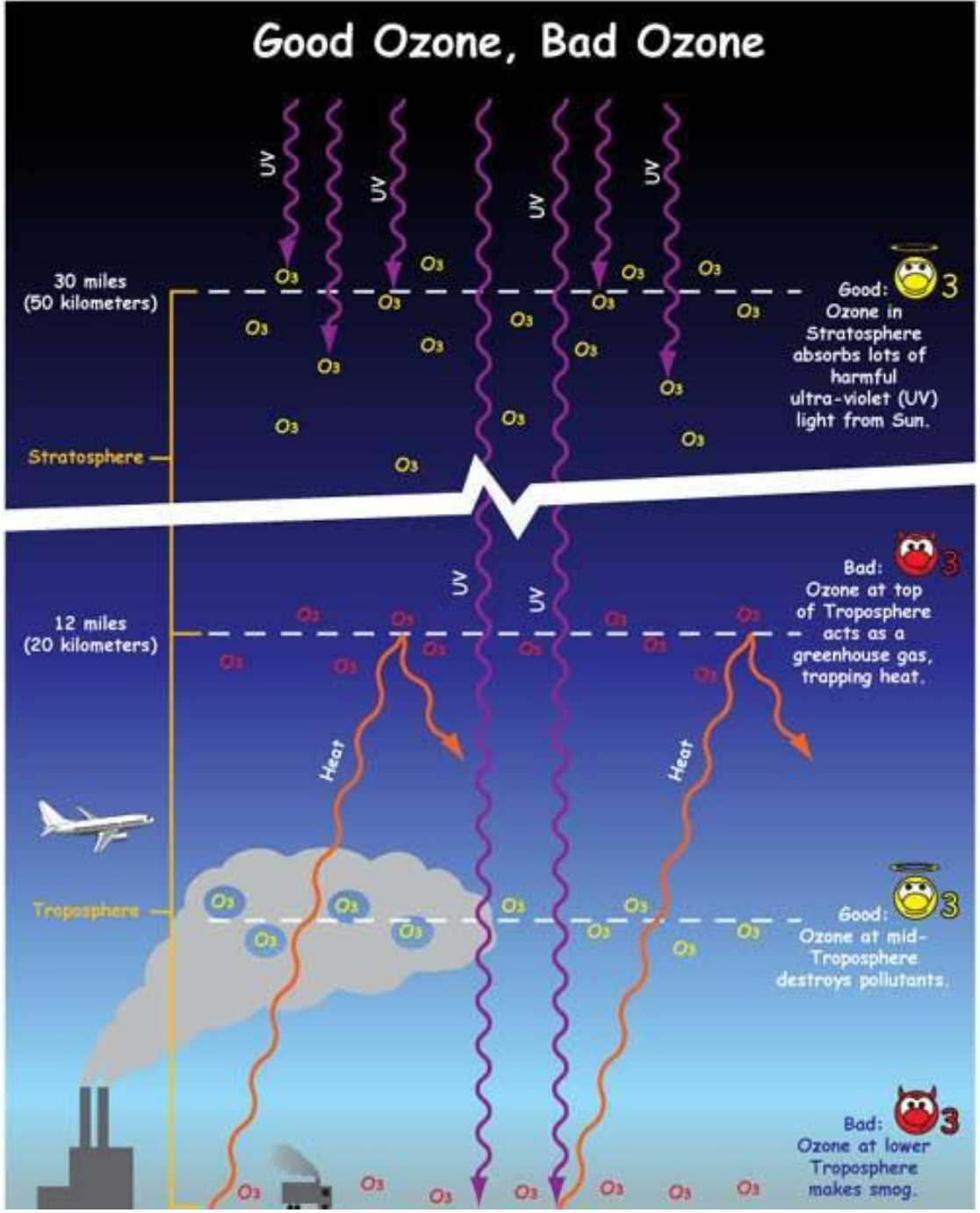


- **Ozono atmosférico**
  - **Importancia e impactos**
  - **Distribución global**
  - **Tendencias**
  - **Ozono y formación de OH**
  - **Formación de ozono en la estratósfera y la tropósfera**
- **Contaminación fotoquímica**
  - **Historia**
  - **Rol pivotal de los óxidos de nitrógeno**
  - **Típico de atmósferas contaminadas**
  - **Origen de los oxidantes**

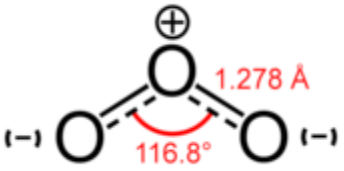
¿Por qué nos interesa el ozono?



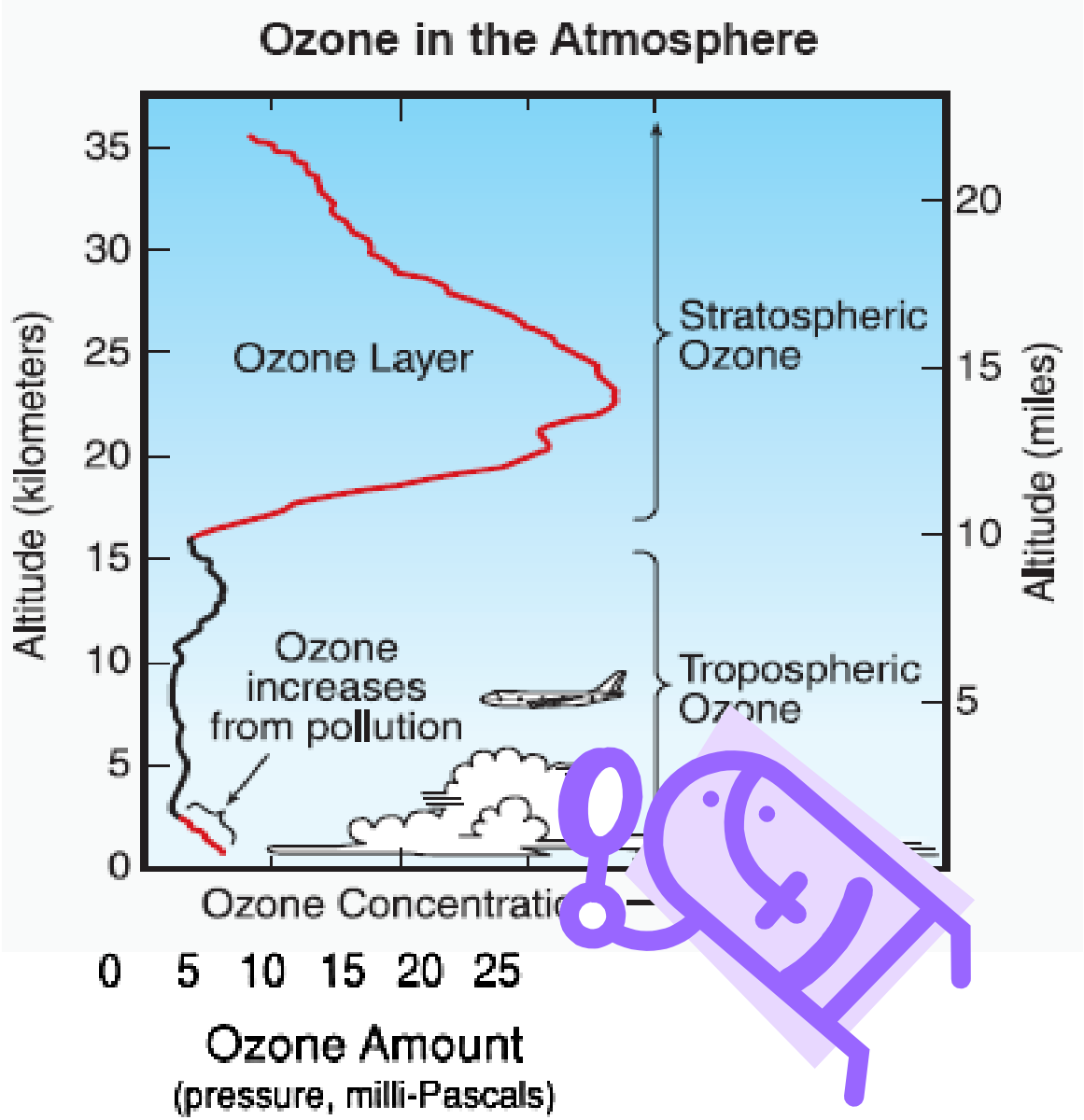
- **Define la dinámica estratosférica**
- **Filtra la radiación UV de alta energía**
- **Es un efectivo gas de efecto invernadero**
- **Es precursor del principal oxidante atmosférico (OH)**
- **Es fitotóxico e irritante**



http://spaceplace.nasa.gov/ozone/en/



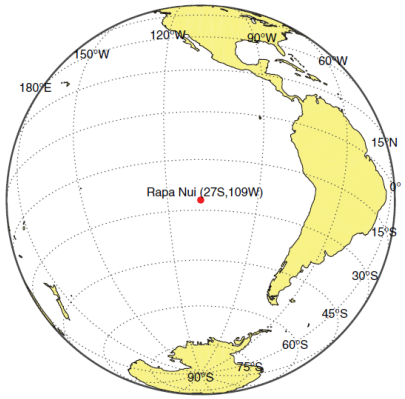
¿Dónde está el ozono?

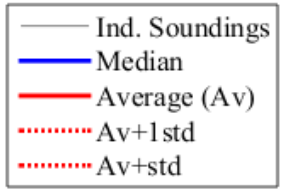


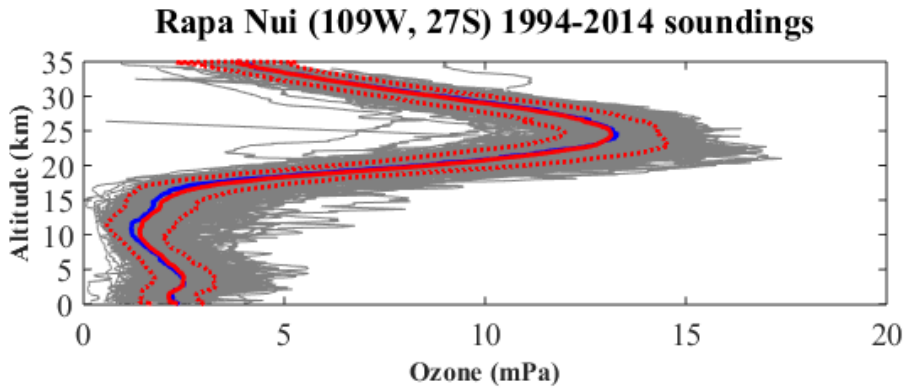
ıe	• Contains 90% of Atmospheric Ozone • Beneficial Role: Acts as Primary UV Radiation Shield • Current Issues: – Long-term Global Downward Trends – Springtime Antarctic Ozone Hole Each Year
ıe	• Contains 10% of Atmospheric Ozone • Harmful Impact: Toxic Effects on Humans and Vegetation • Current Issues: – Episodes of High Surface Ozone in Urban and Rural Areas

http://www.esrl.noaa.gov/

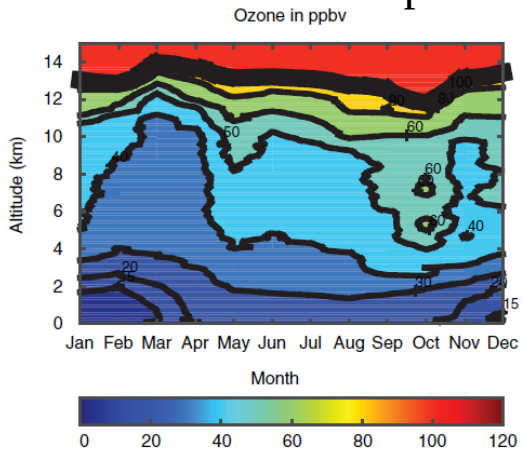
Ozono en Rapa Nui

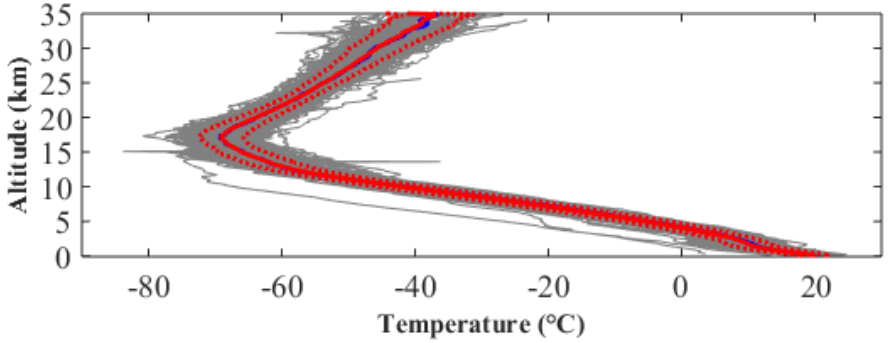






Estacionalidad en la tropósfera (ppbv)

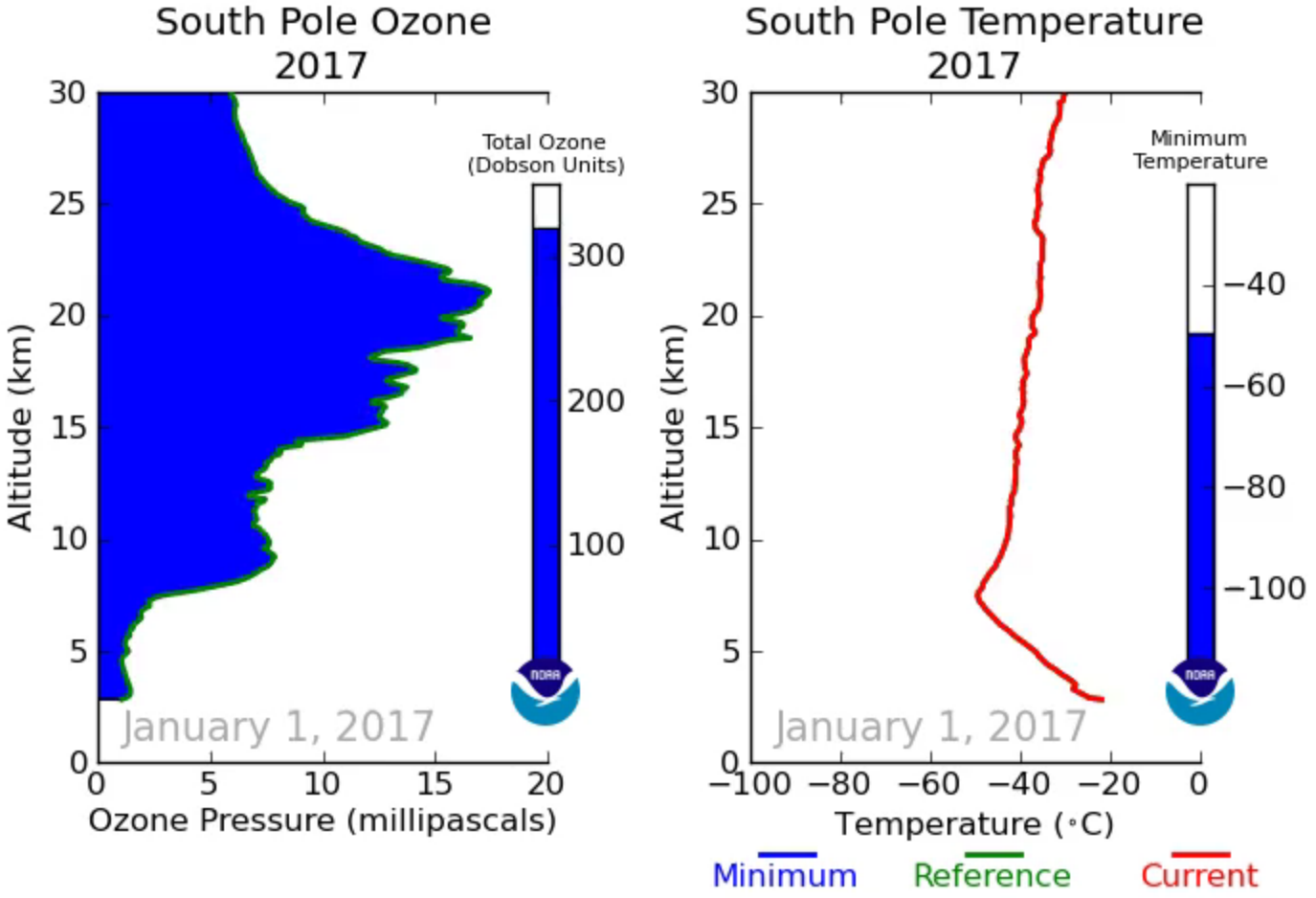




Gallardo et al, 2016. http://www.tellusb.net/index.php/tellusb/article/view/29484

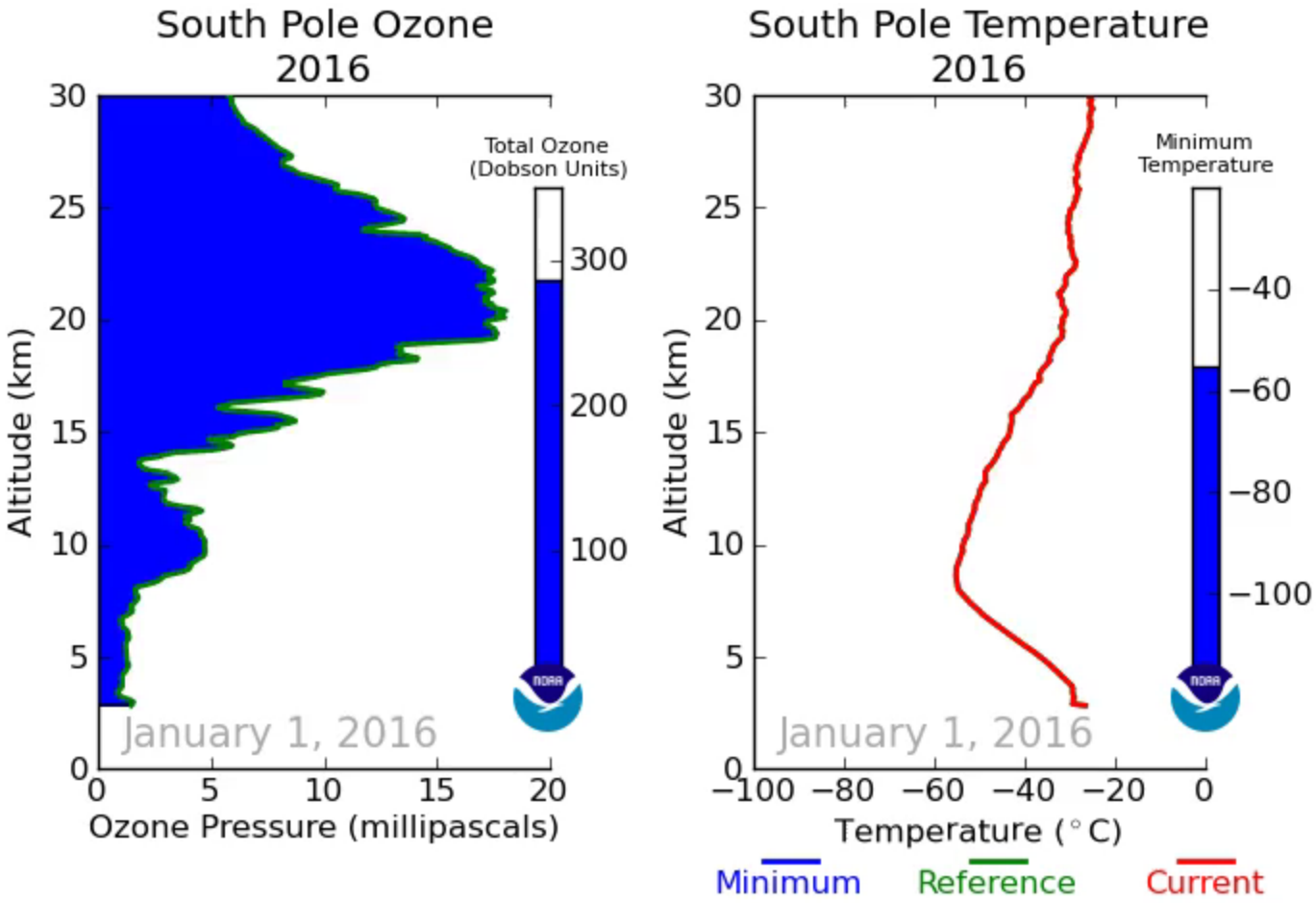
Más datos en: http://www.cr2.cl/recursos-y-publicaciones/datos-ozonosonda/

Ozono sobre Antártica (2017)

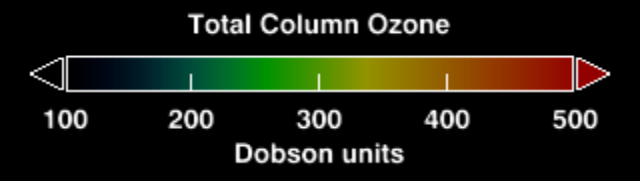


http://www.esrl.noaa.gov/gmd/dv/spo_oz/movies/index.html

Y sobre Antártica (Agente dinámico)

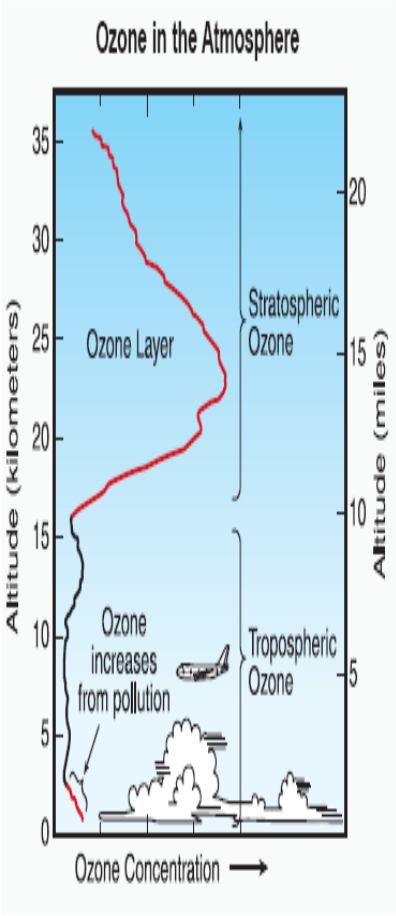


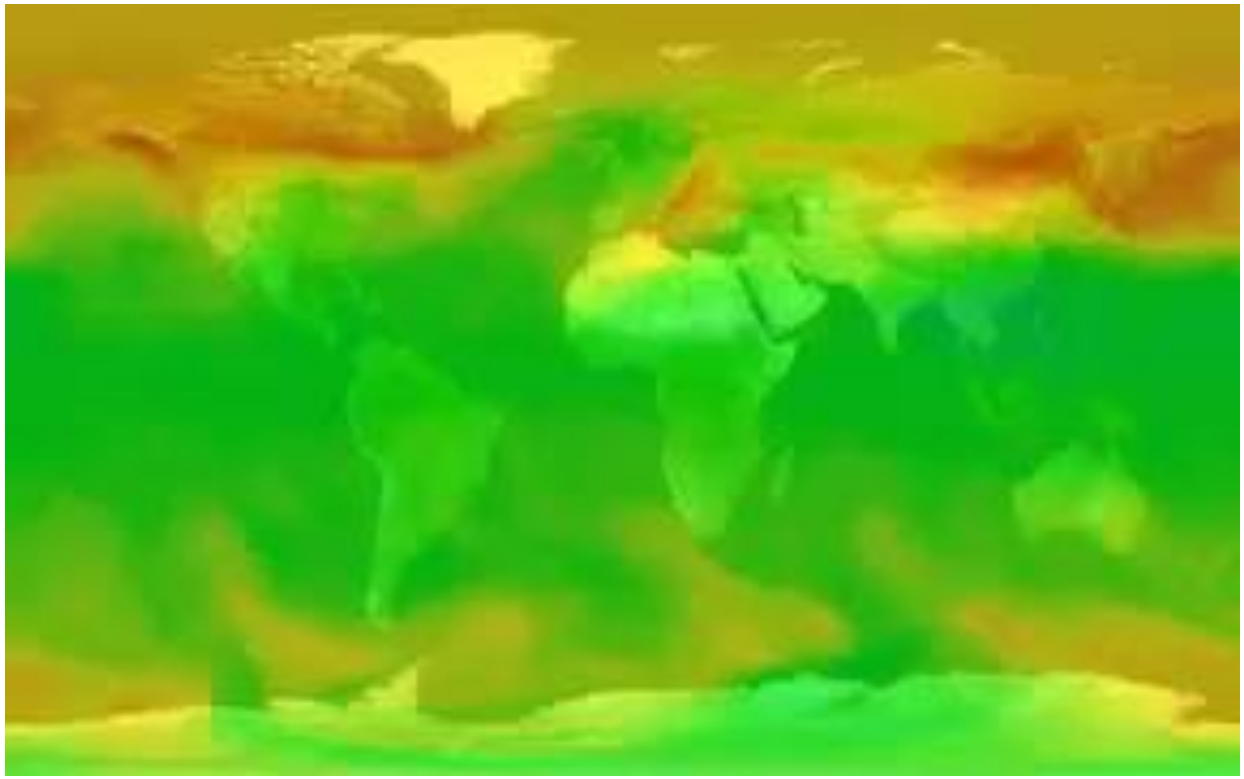
http://www.esrl.noaa.gov/gmd/dv/spo_oz/movies/index.html



Ozono total

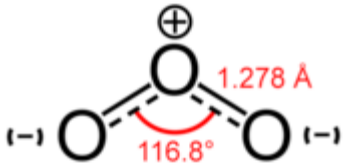
NASA/Goddard Space Flight Center Scientific Visualization Studio



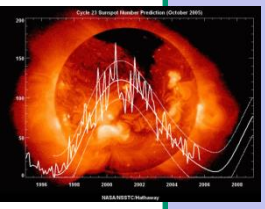


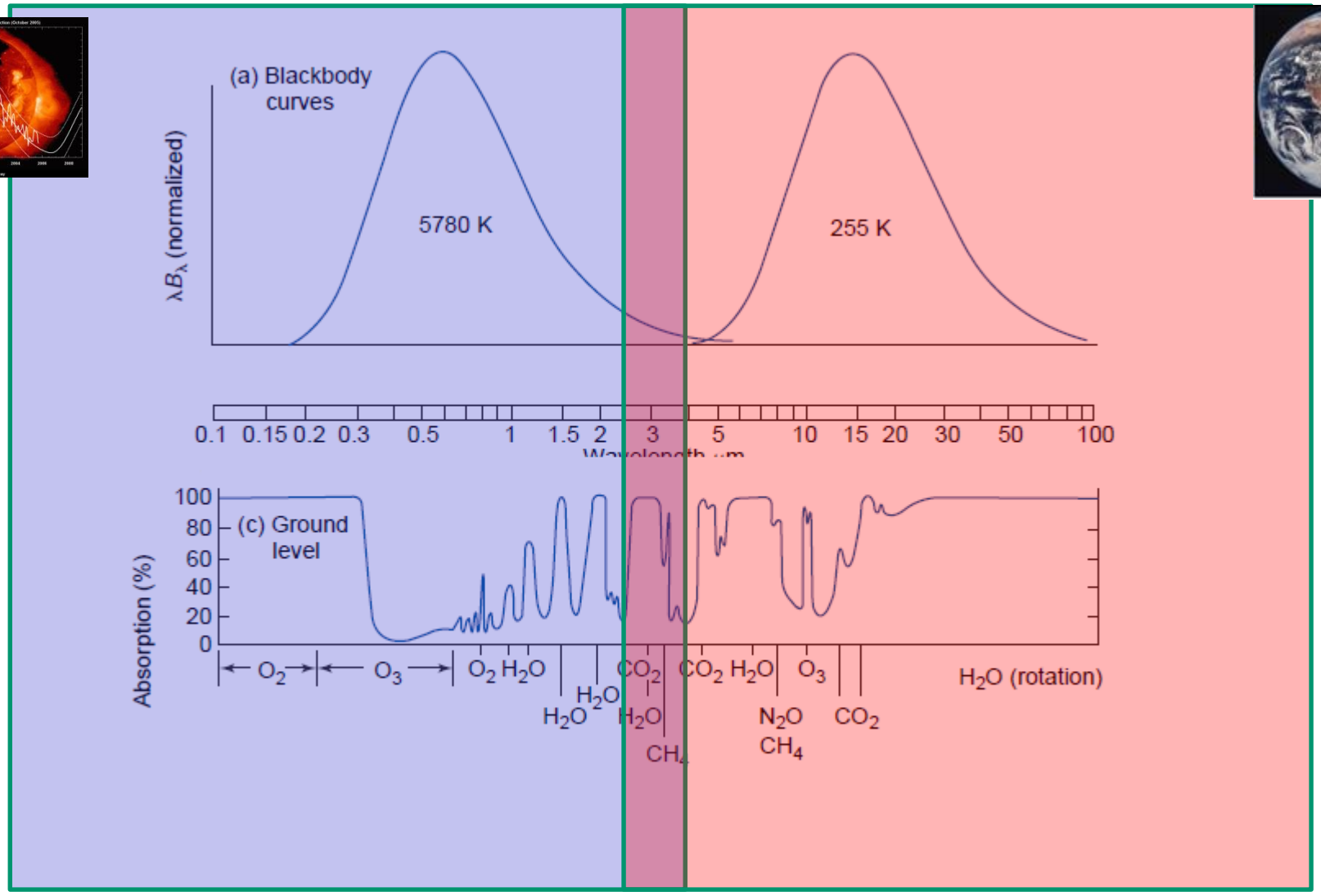
Ver animación en: http://svs.gsfc.nasa.gov/vis/a000000/a002900/a002904/

Hay más ozono en el hemisferio iluminado

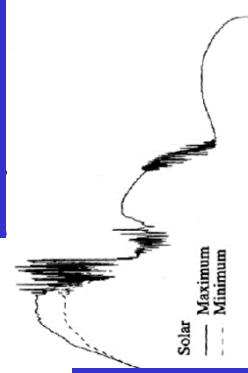


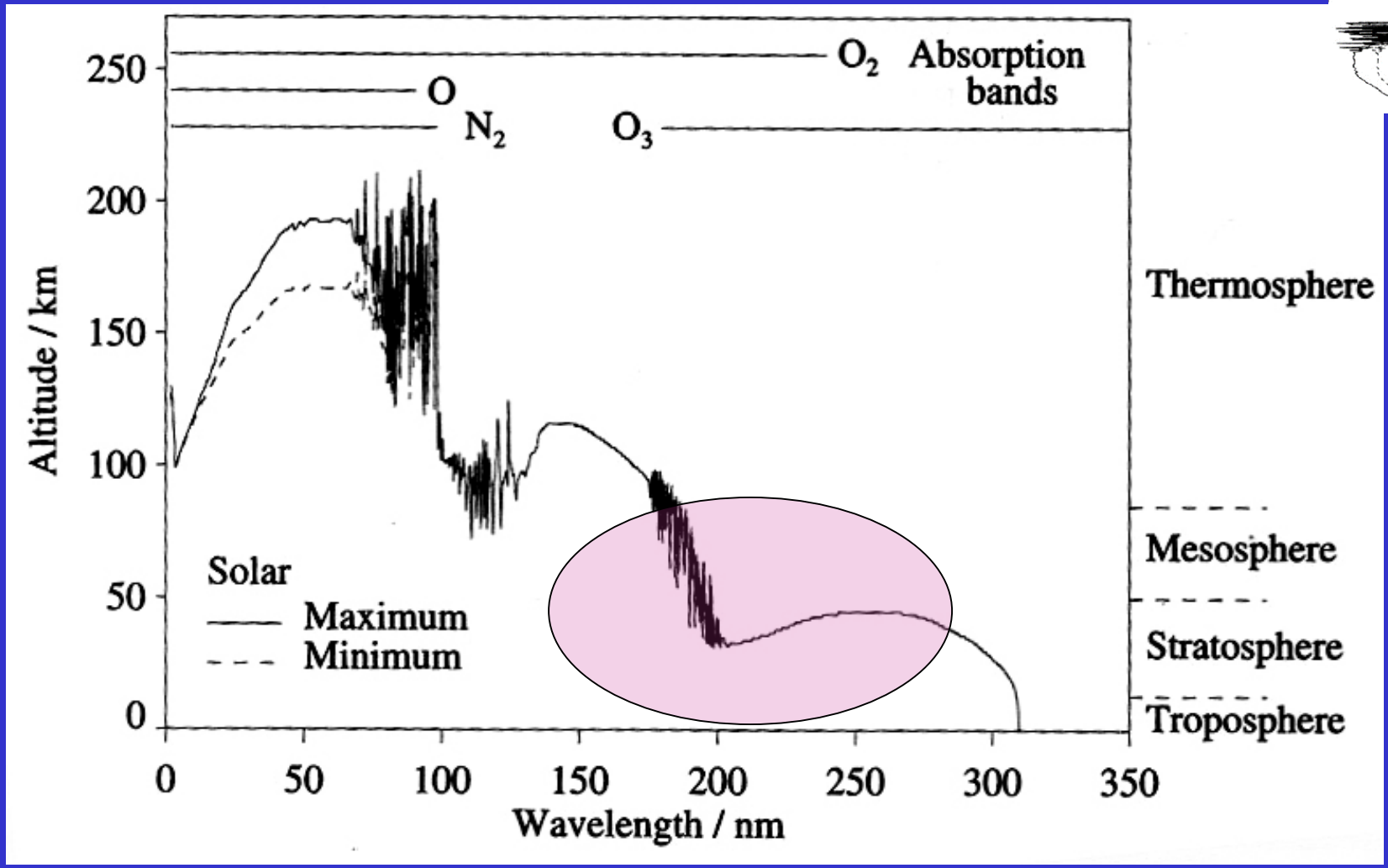
Radiación absorbida en la atmósfera





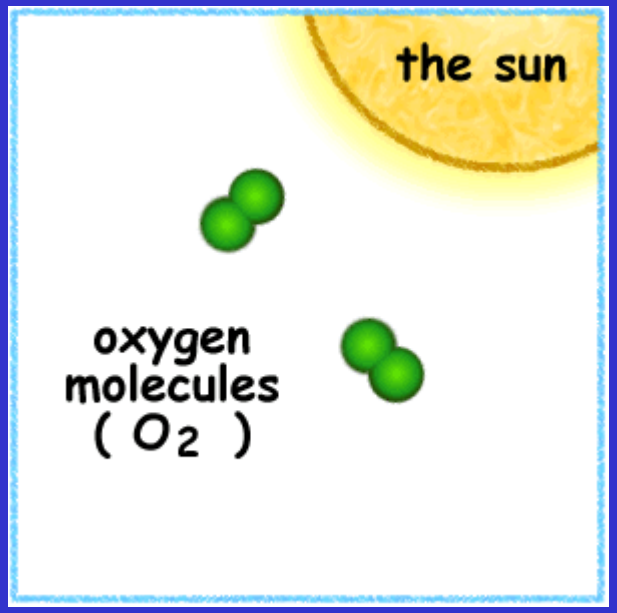
Absorción de radiación UV



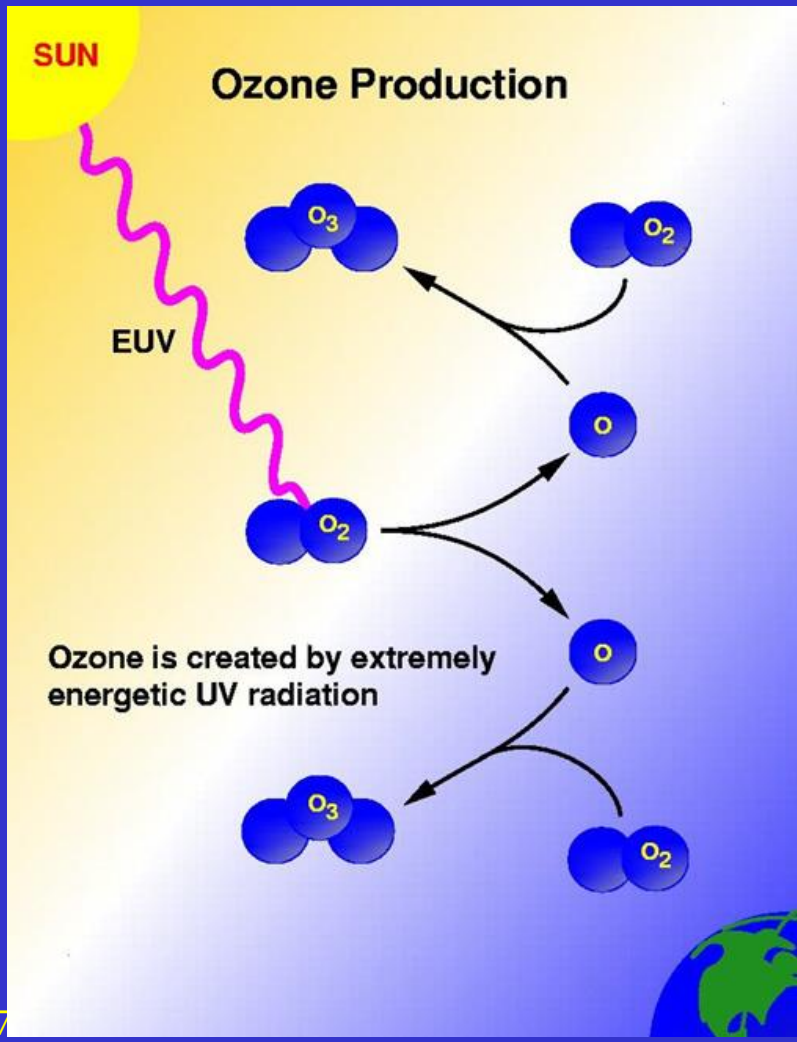


http://lasp.colorado.edu/~bagenal/3720/CLASS5/5Spectroscop

Formación de ozono estratosférico

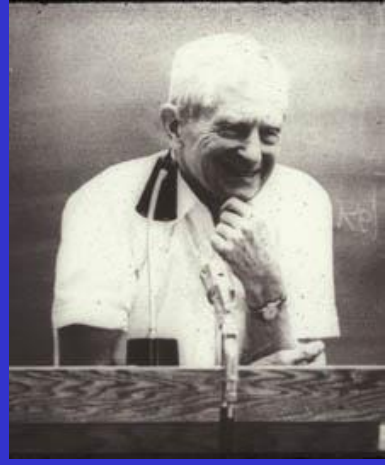


$$O_2 + h\nu \rightarrow O + O,\ \lambda < 0.24\,\mu m$$
$$O_2 + O \rightarrow O_3$$



http://www.theozonehole.com/ozonecreation.htm

Ciclo de Chapman



Production:

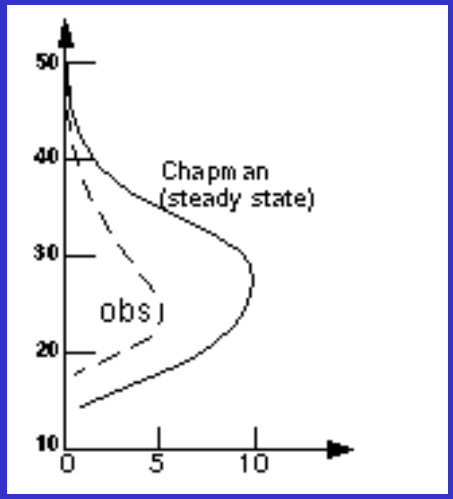
$O_2 + h\nu \longrightarrow O + O \quad (\lambda < .242\ \mu m)$

$O + O_2 + M \longrightarrow O_3 + M$

Destruction:

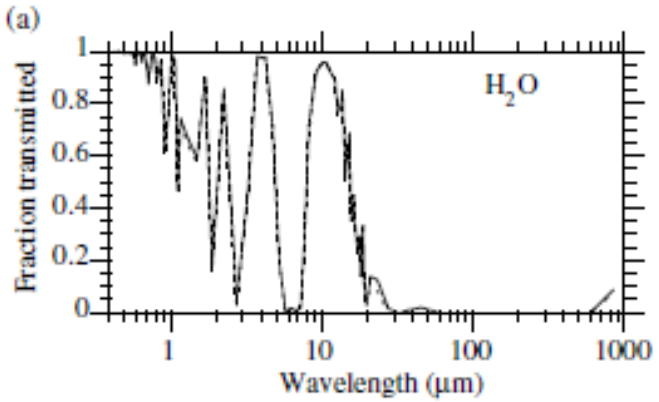
$O_3 + h\nu \longrightarrow O + O_2 \quad (\lambda < .320\ \mu m)$

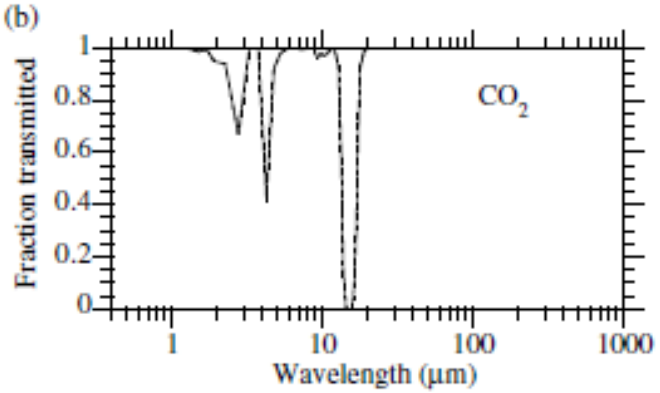
$O + O_3 \longrightarrow 2\ O_2$

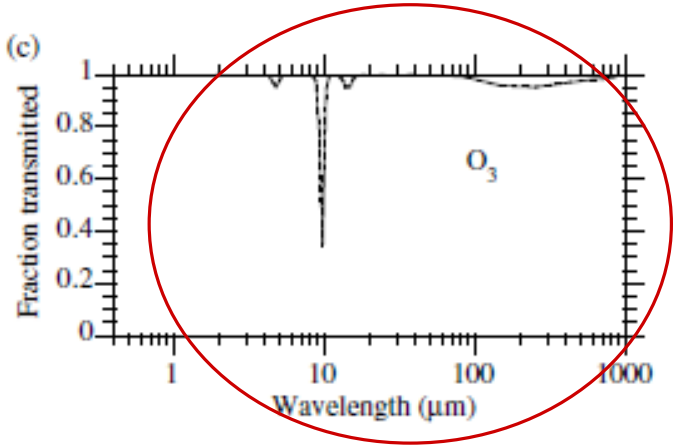


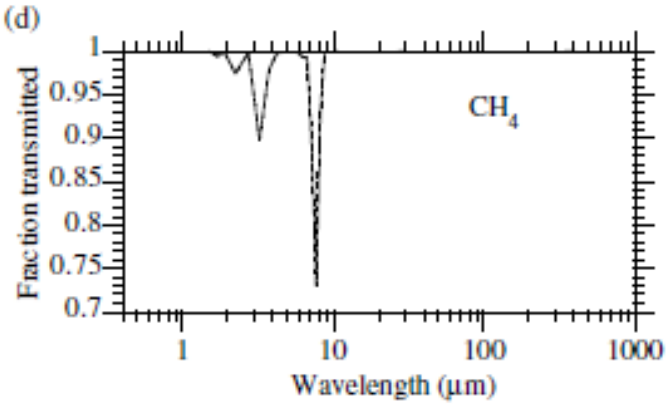
Sydney Chapman, "A Theory of Upper-Atmospheric Ozone," *Memoirs of the Royal Meteorological Society* **3**(26), 103-25 (1930).

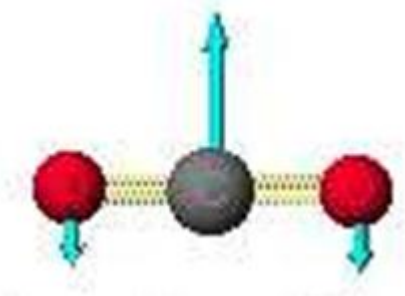
Gases de efecto invernadero: el ozono es un eficaz gas de efecto invernadero

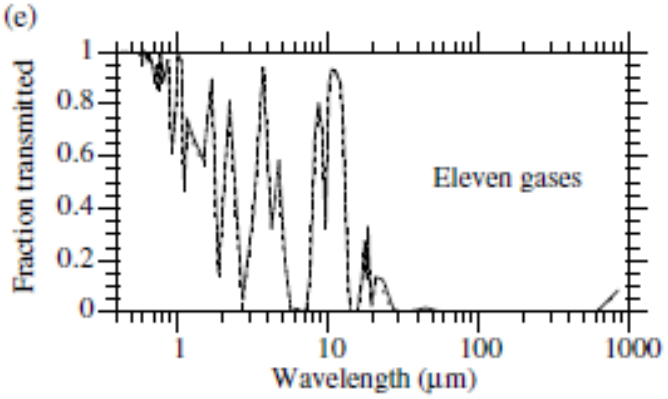






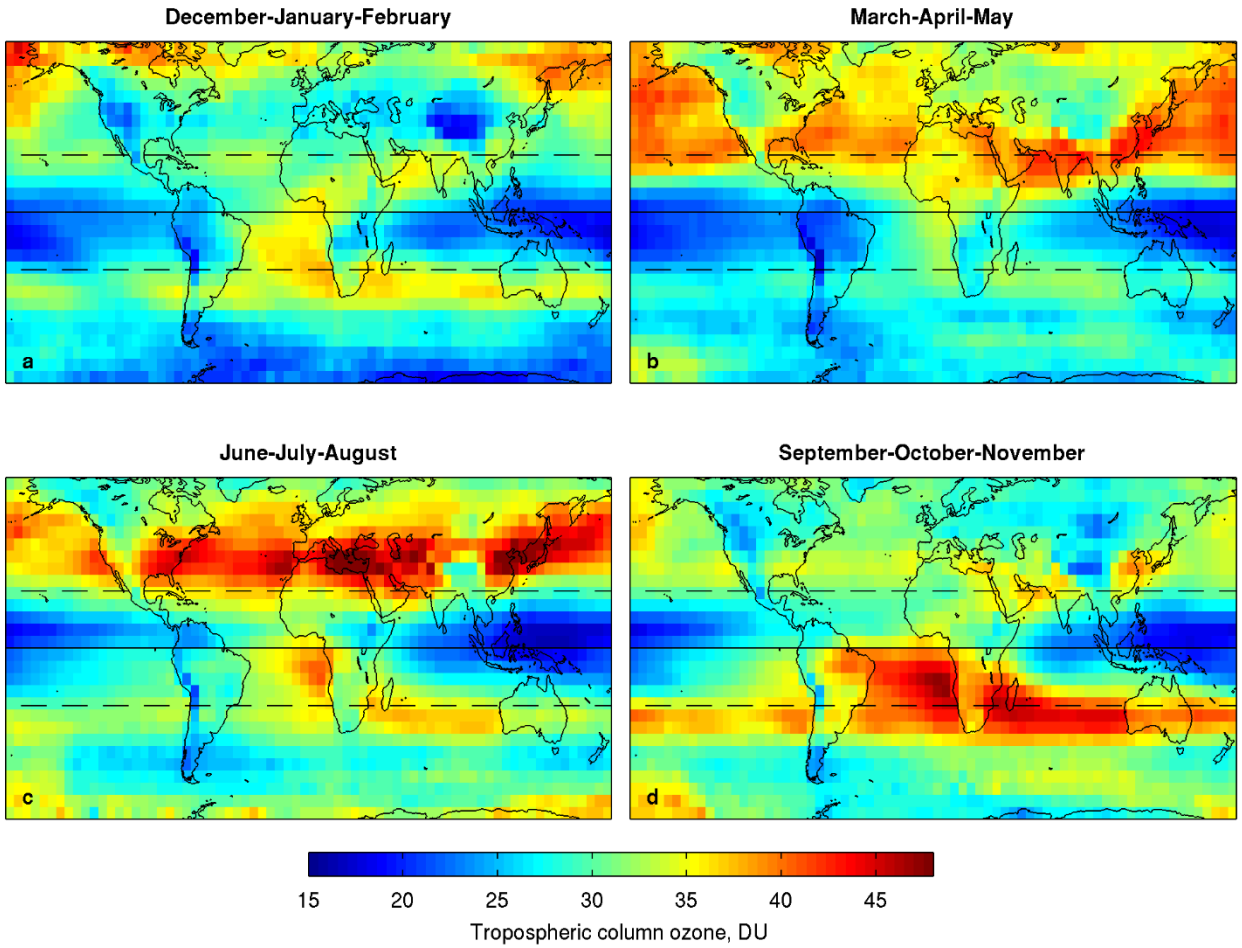






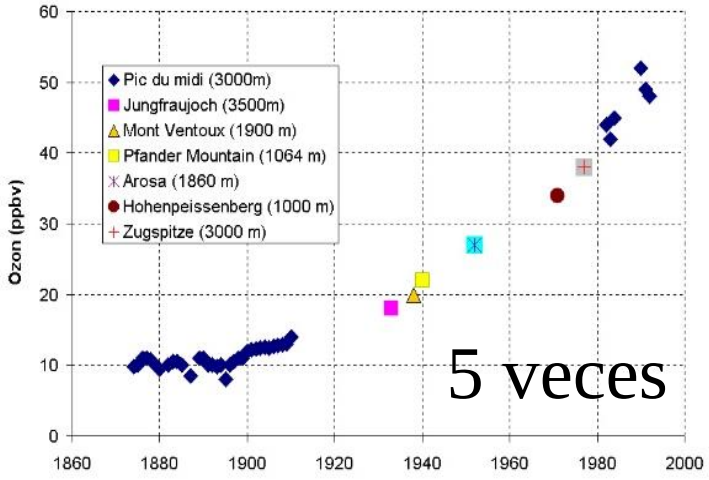
Jacobson, 2005

Ozono en la tropósfera (~10% del total)



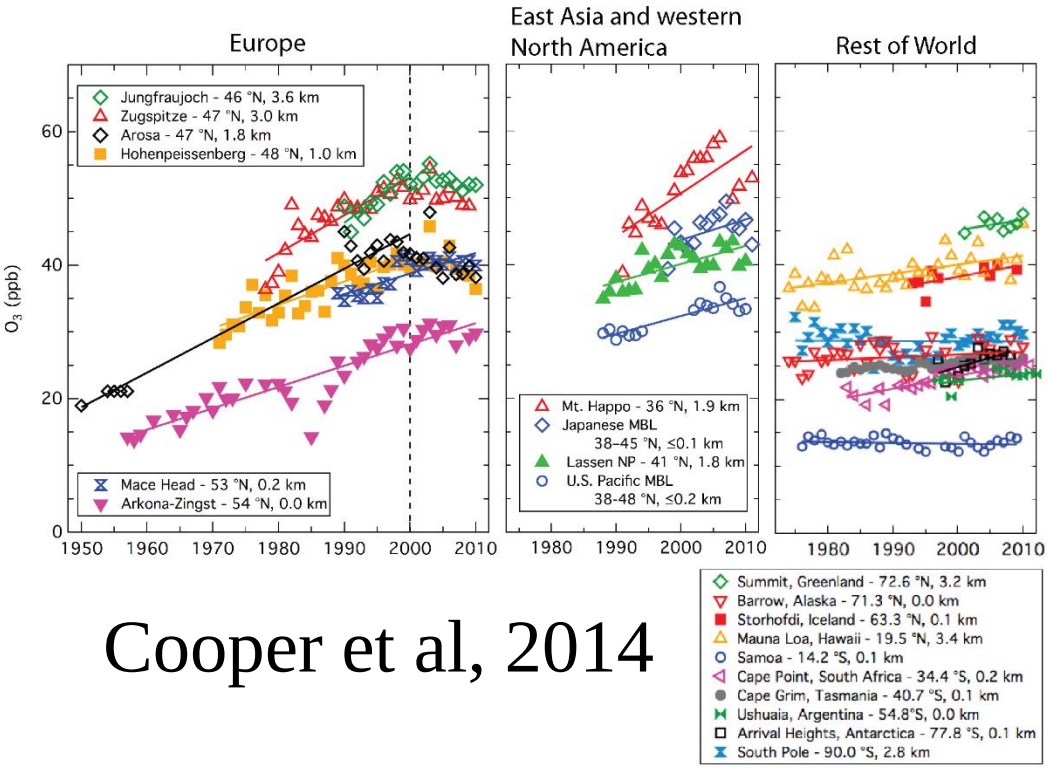
Cooper, O.R., et al., *Global distribution and trends of tropospheric ozone: An observation-based review.* Elementa: Science of the Anthropocene, 2014. **2**(1): p. 000029.

El ozono aumenta en la tropósfera



Marenco et al., 1992

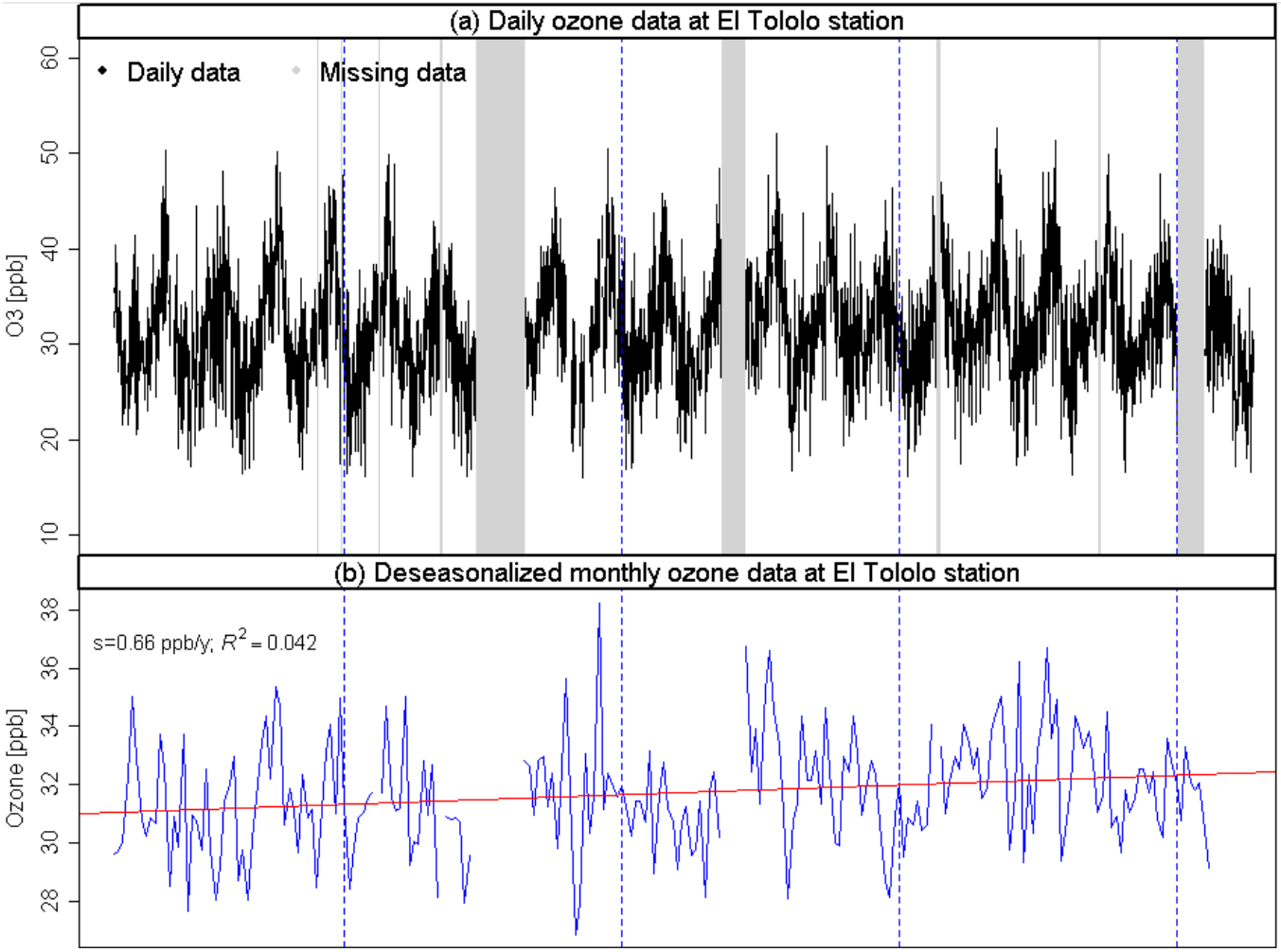
~0.6-7 ppb/década

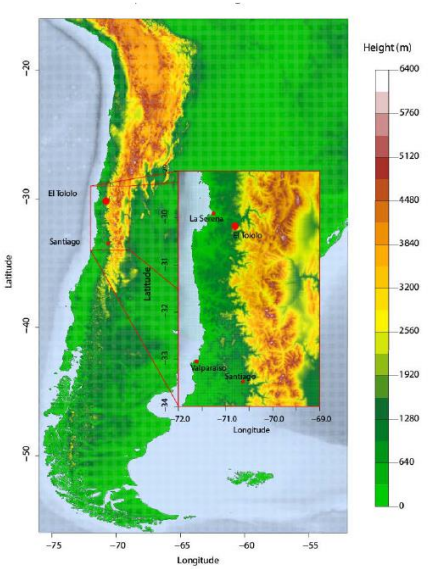


Lugares no directamente impactados (“background”)

Cooper et al, 2014

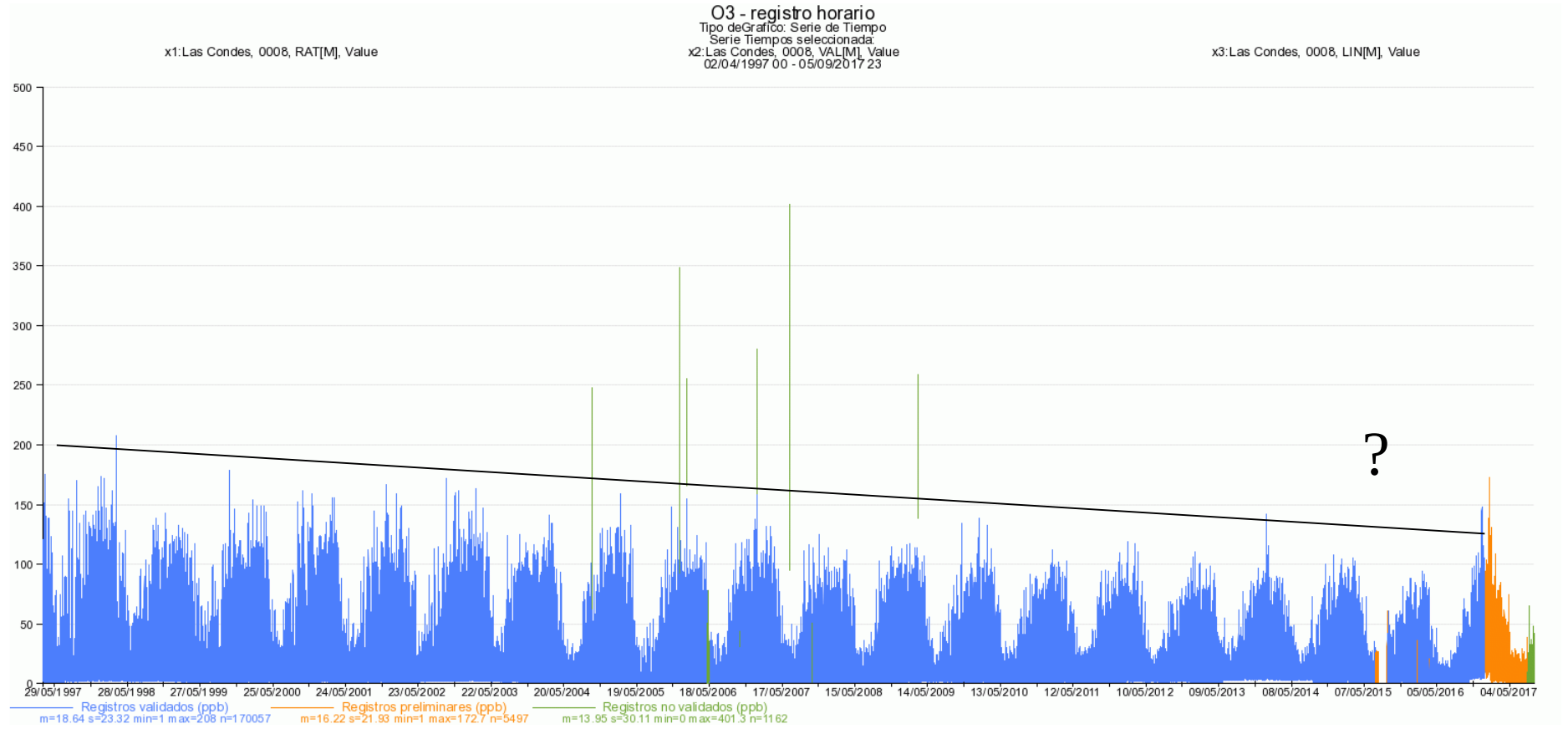
Ozono en Tololo (0.7 ppb/década)





Anet, J. G., Steinbacher, M., Gallardo, L., Velásquez Álvarez, P. A., Emmenegger, L., and Buchmann, B.: Surface ozone in the Southern Hemisphere: 20 years of data from a site with a unique setting in El Tololo, Chile, Atmos. Chem. Phys., 17, 6477-6492, https://doi.org/10.5194/acp-17-6477-2017, 2017.

Ozono en Santiago (0-500 ppbv)

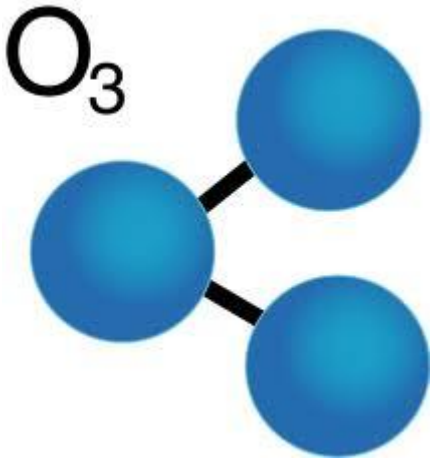


Ver Monares et al, 2017

http://sinca.mma.gob.cl/

¿Por qué preocupa el ozono en la tropósfera?

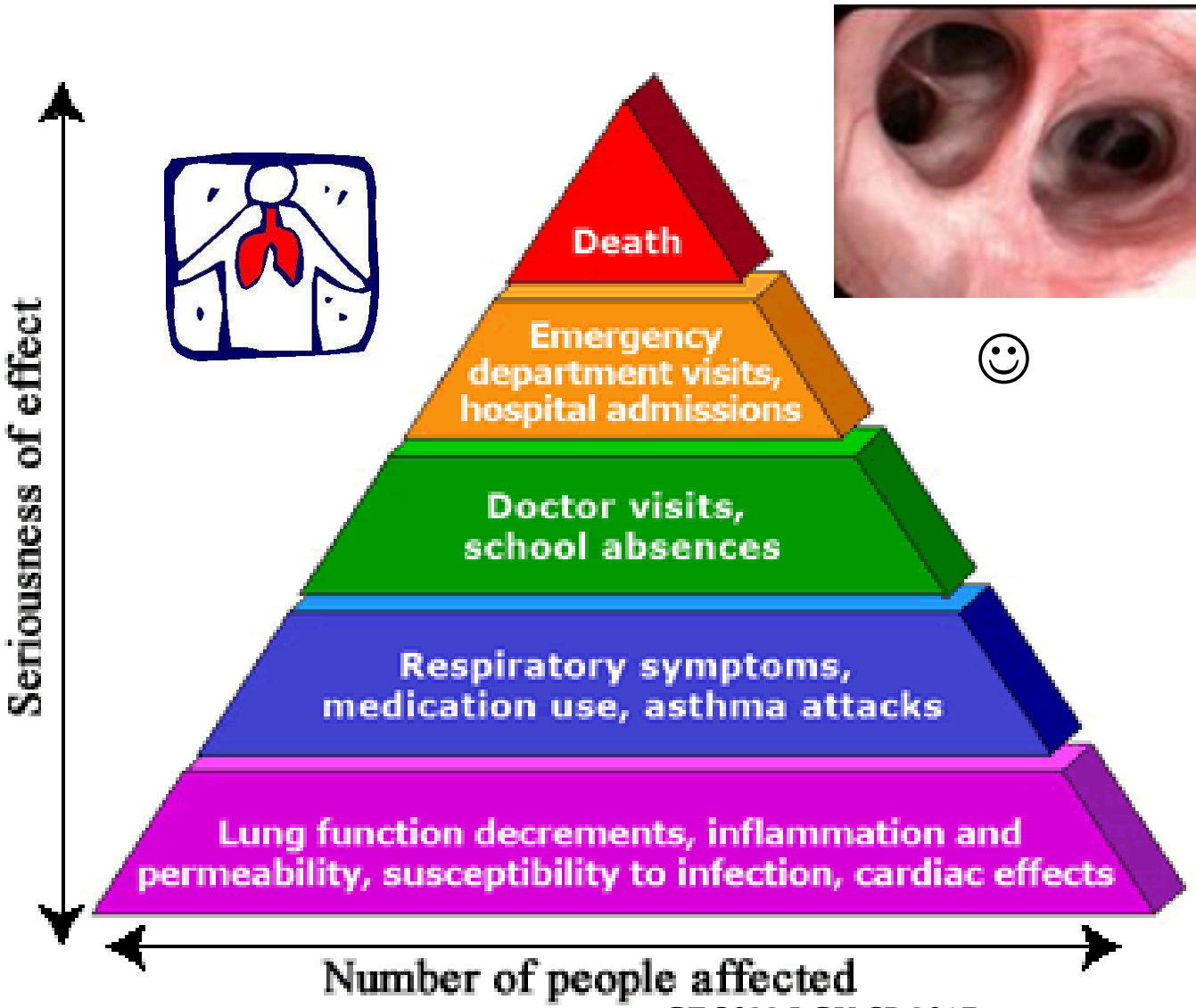
Sólo constituye un 10% del total de ozono en la atmósfera pero:

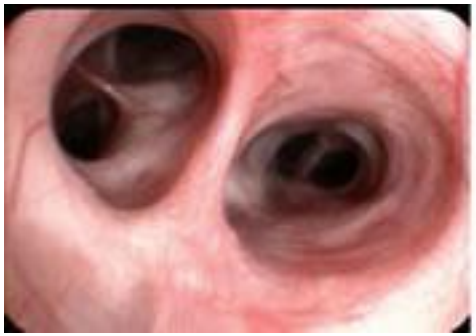


- En exceso es dañino para la salud de las personas y de la vegetación
- Es un gas de efecto invernadero
- Su presencia determina la capacidad de autolimpieza (oxidativa) de la atmósfera

https://www.ucar.edu/learn/1_7_1.htm

Efectos sobre la salud humana



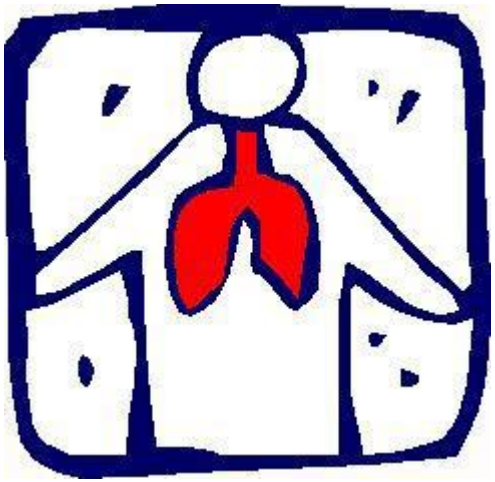


☺ ☹

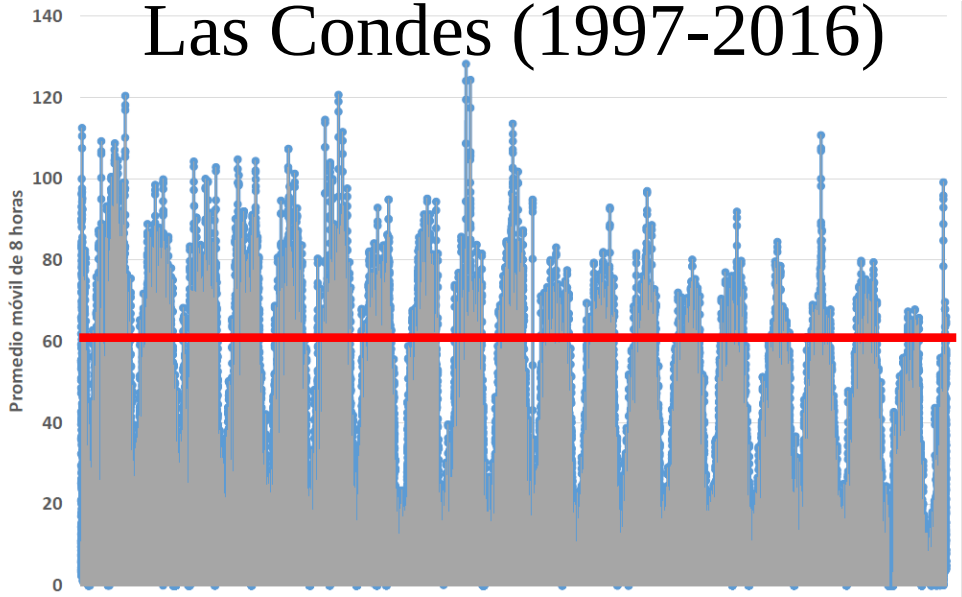
https://www.epa.gov/ozone-pollution/health-effects-ozone-pollution

¿Cuánto ozono es demasiado?

Where	Concentration	Averaging Period
USA	0.08 ppmm 0.12 ppmm	8 hours 1 hour
EU	120 µg/m3	8 hours
WHO	100 µg/m3	8 hours
Chile	120 µg/m3 o 61 ppbv	8 hours



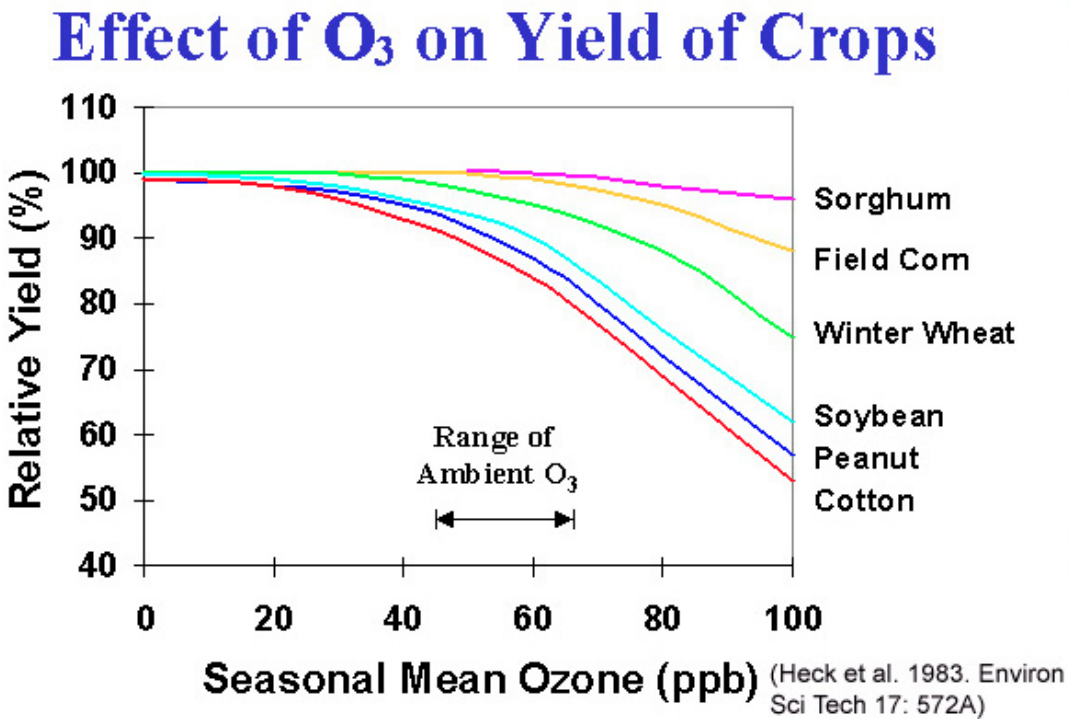
Las Condes (1997-2016)

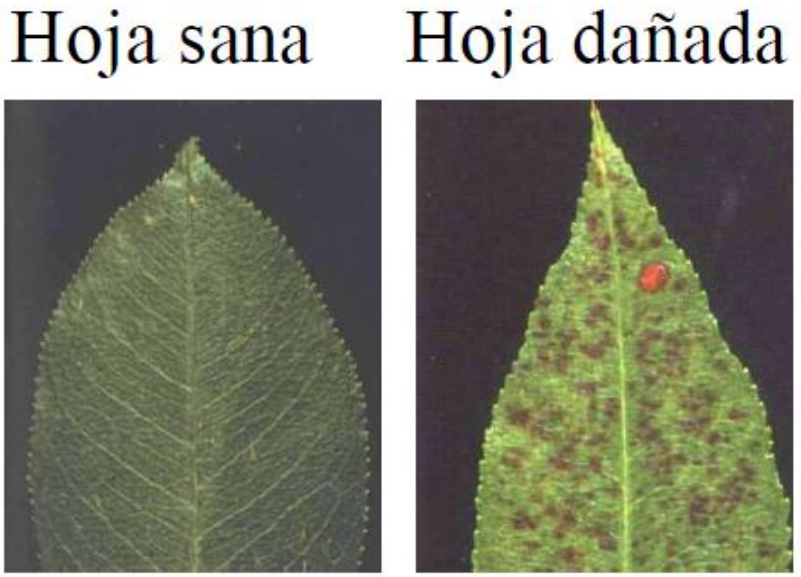


¡¿Disminuyendo?!

IGAC book, chapter 1

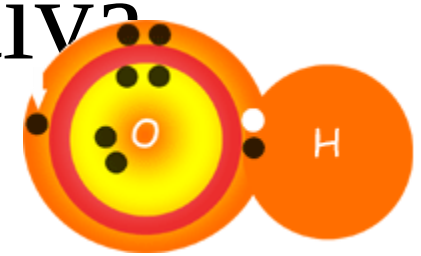
Efectos sobre la vegetación

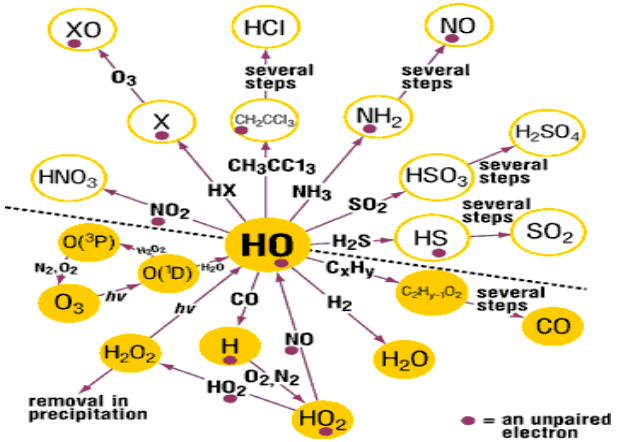




http://www.ars.usda.gov/Main/docs.htm?docid=12462

Ozono y capacidad oxidativa
Radical hidroxilo





$$O_3 + h\nu \rightarrow O + O_2 \quad (\lambda < 310\ \text{nm})$$

$$O + O_2 + M \rightarrow O_3 + M$$

$$O + H_2O \rightarrow \underline{2OH} \quad 3\%$$

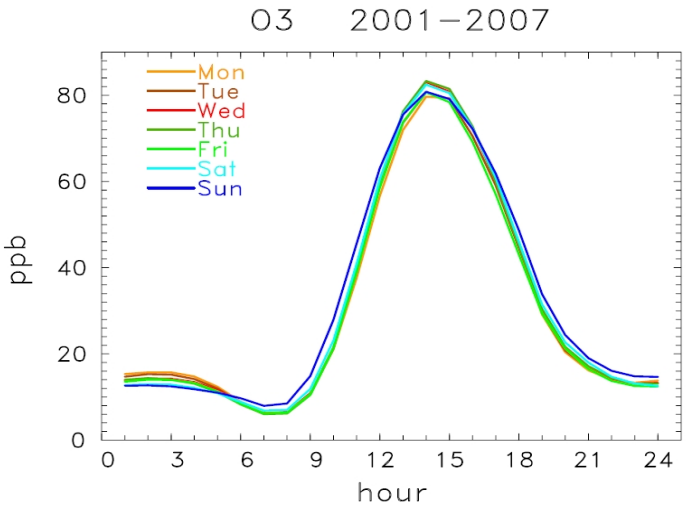
El radical OH es el “detergente” de la atmósfera...
el agente que le da su carácter oxidativo

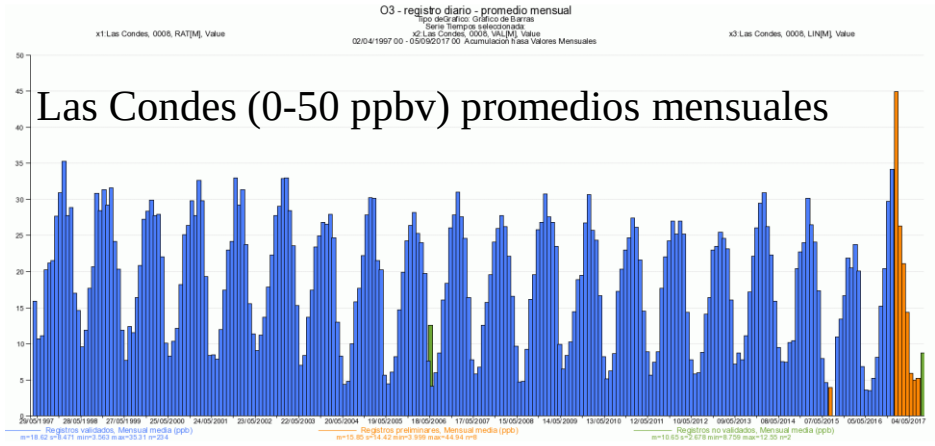
- A escala global, los principales sumideros de OH son:
  - CO (~40%)
  - HC (~45%) {OC (~30%), CH4 (~15%)}
  - O3, HO2, H2 (~15%)

http://www.atmosphere.mpg.de/enid/24y.html

Contaminación fotoquímica

Ciclo diario y semanal en Ciudad de México





¿Cómo se forma el ozono?

$$O(^3P) + O_2 + M \rightarrow O_3 + M$$

En la estratósfera:

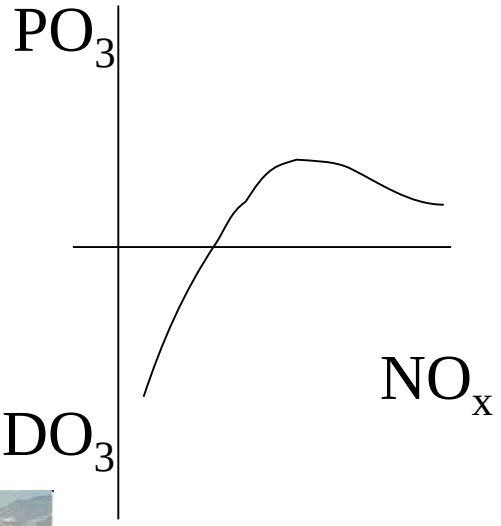
$$O_2 + h\nu \rightarrow O + O(^3P), \quad \lambda < 240nm$$

En la tropósfera, ese O(P) viene únicamente de:

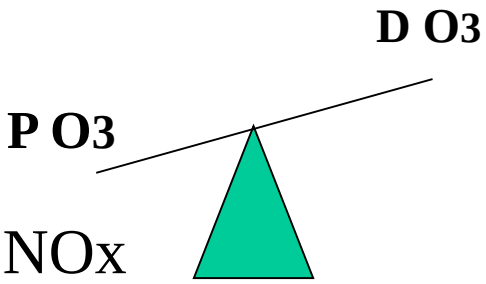
$$NO_2 + h\nu \rightarrow NO + O(^3P), \quad \lambda < 420nm$$

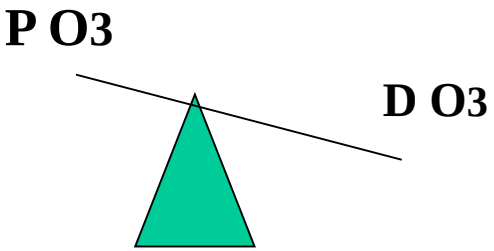
¿De qué depende la formación/destrucción de ozono en la tropósfera?

- En presencia de radiación solar y óxidos de nitrógeno (NO_x), la oxidación de CO, CH_4 y COV da lugar a la formación de ozono
- En ausencia de NO_x, los mismos procesos conllevan a la destrucción de ozono



Rol de los óxidos de nitrógeno





$$CO + OH \rightarrow H + CO_2$$
$$H + O_2 \rightarrow HO_2 + M$$
$$HO_2 + NO \rightarrow OH + NO_2$$
$$NO_2 + h\nu \rightarrow NO + O(P), \quad \lambda < 420nm$$
$$O(P) + O_2 + M \rightarrow O_3 + M$$

Neto :

$$CO + 2O_2 + h\nu \rightarrow CO_2 + O_3$$

$$CO + OH \rightarrow H + CO_2$$
$$H + O_2 \rightarrow HO_2 + M$$
$$HO_2 + O_3 \rightarrow OH + 2O_2$$

Neto :

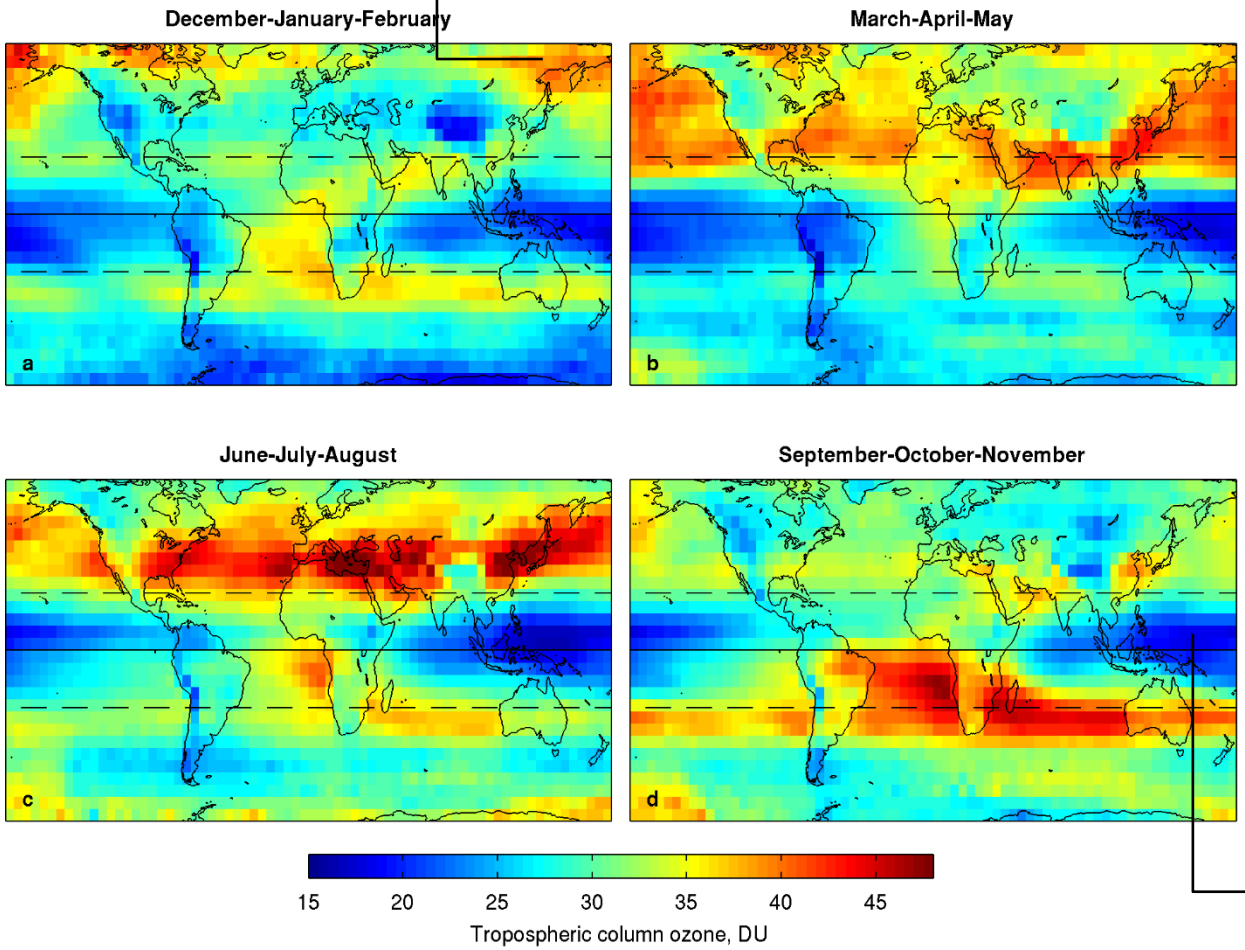
$$CO + O_3 \rightarrow CO_2 + O_2$$

D O3

P O3

NOx

Prevalece la producción pues hay NOx

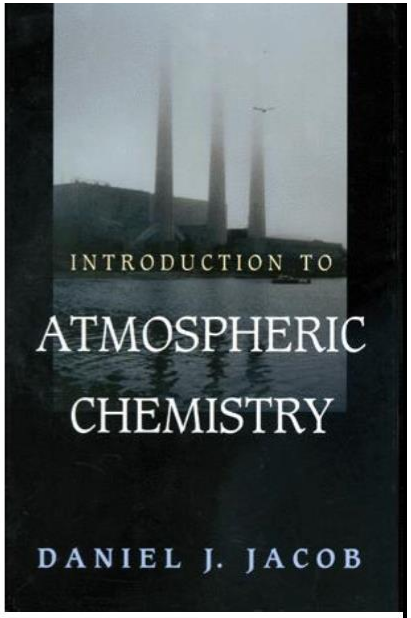


Prevalece la destrucción pues NO hay NOx

P O3

D O3

Lecturas



- Chap 12. Jacob, D.J.,

Introduction
to Atmospheric Chemistry,
266 pp.,
Princeton University Press, 1999.

- Disponible en internet

(http://acmg.seas.harvard.edu/publications/jacobbook/index.html)

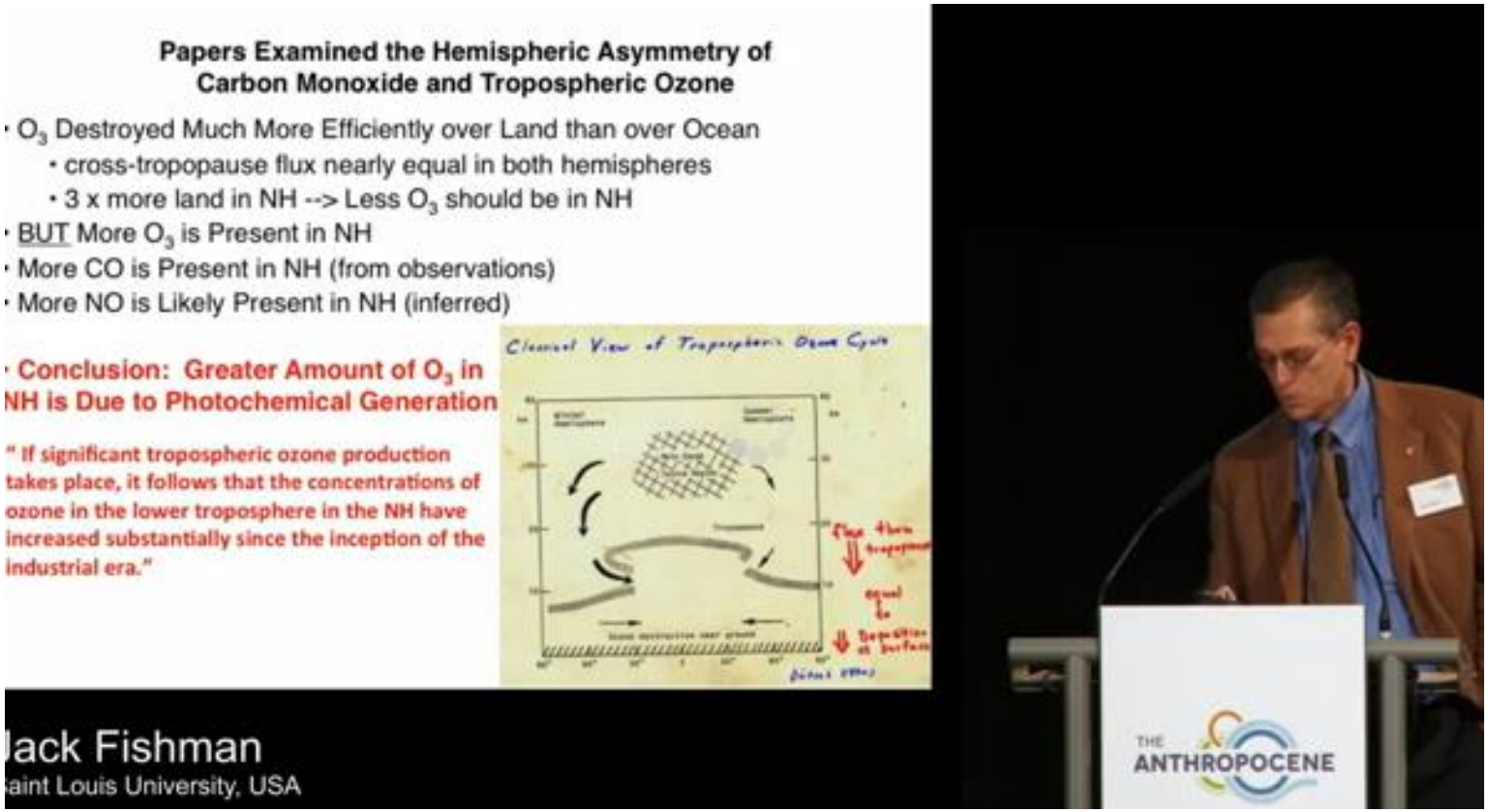
También sobre OH:

http://www.igac.noaa.gov/newsletter/igac21/Sep_2000_IGAC_21.pdf

Jacobson, 2002; 2012
http://www.stanford.edu/group/efmh/jacobson/POLbook/POLbook.html
http://www.stanford.edu/group/efmh/jacobson/POLbook2/index.html

Continuará…

Ver: https://www.youtube.com/watch?v=n_gw5gKJtGM



Jack Fishman homenajeando a Paul Crutzen