Atmospheric research in the Arctic: current projects and future challenges

Hélène Angot

Atmospheric Research Laboratory: http://instaar.colorado.edu/arl/index.html
Group Leader: Detlev Helmig

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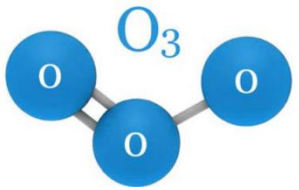
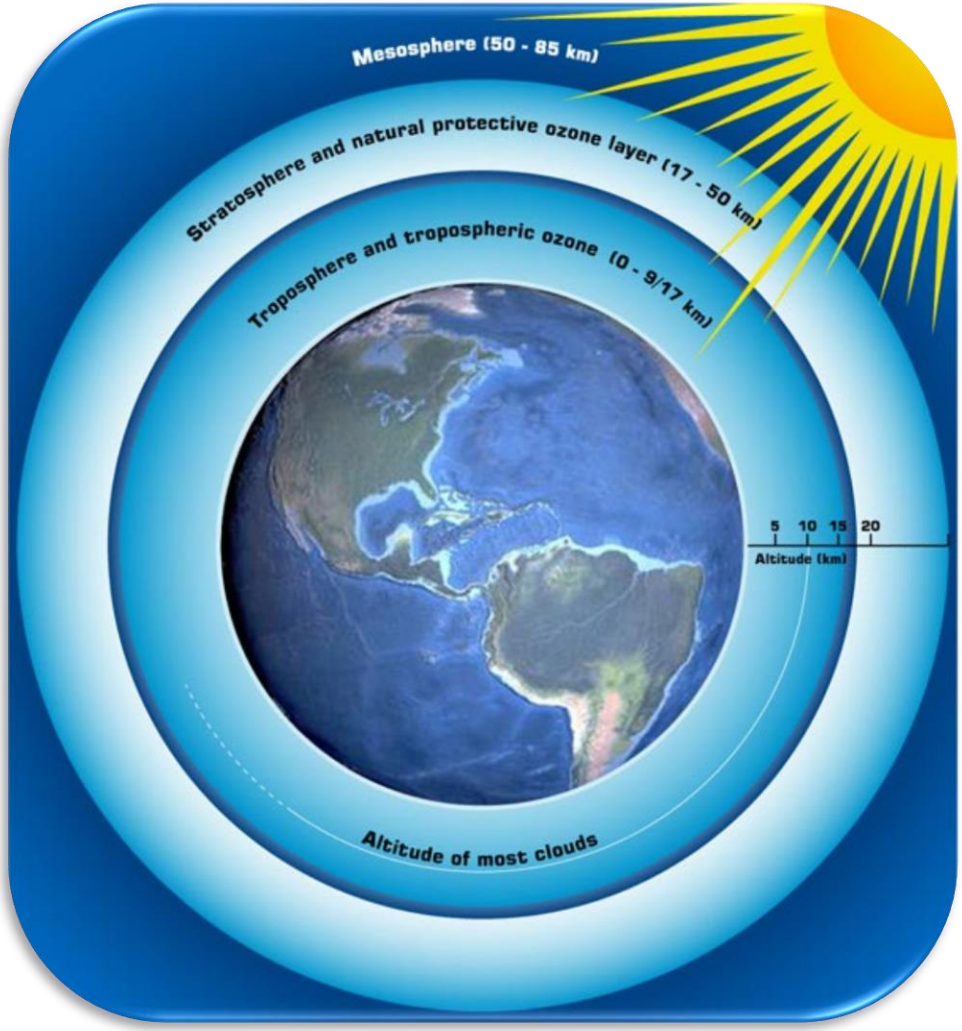
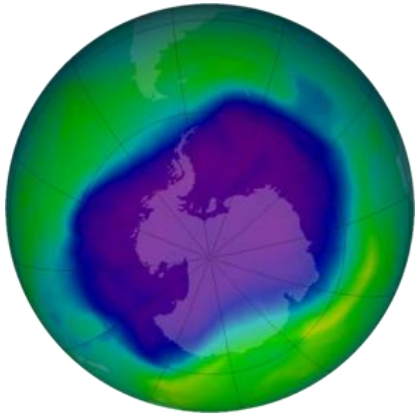


Atmospheric research in the Arctic: current projects and future challenges

Introduction: Ozone



- Stratospheric O_3: Protective layer



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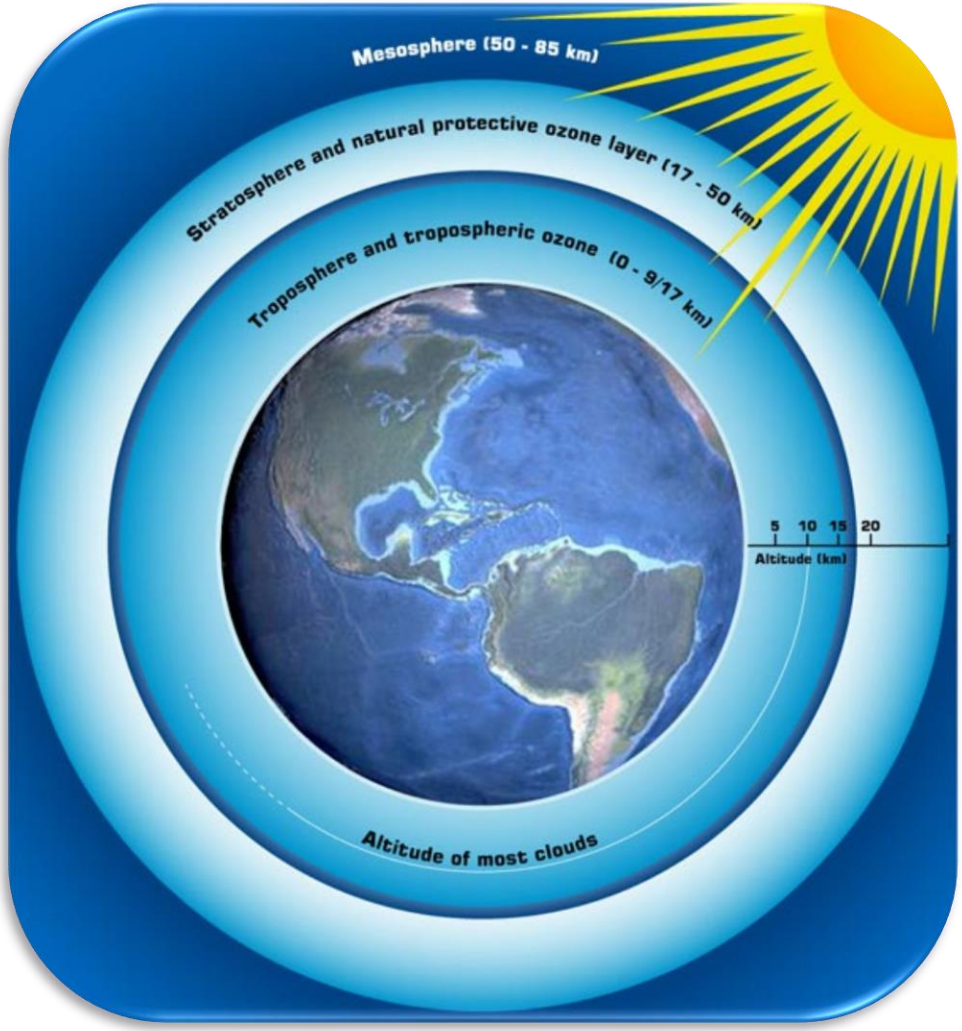
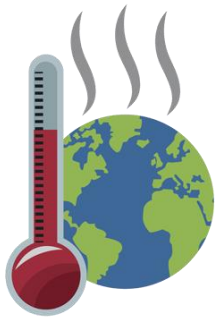


- Tropospheric O_3:

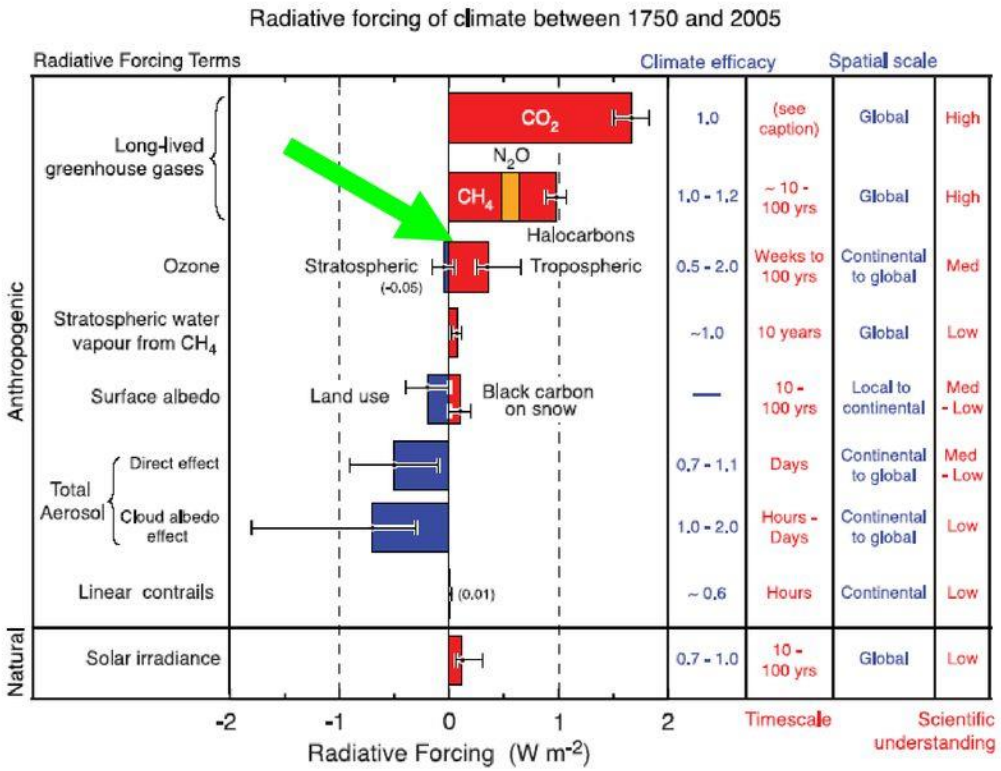
- ✓ **Climate pollutant**
- ✓ **Air pollutant**

Introduction: Ozone

- Tropospheric O_3: **climate pollutant**



Radiative forcing from tropospheric O_3

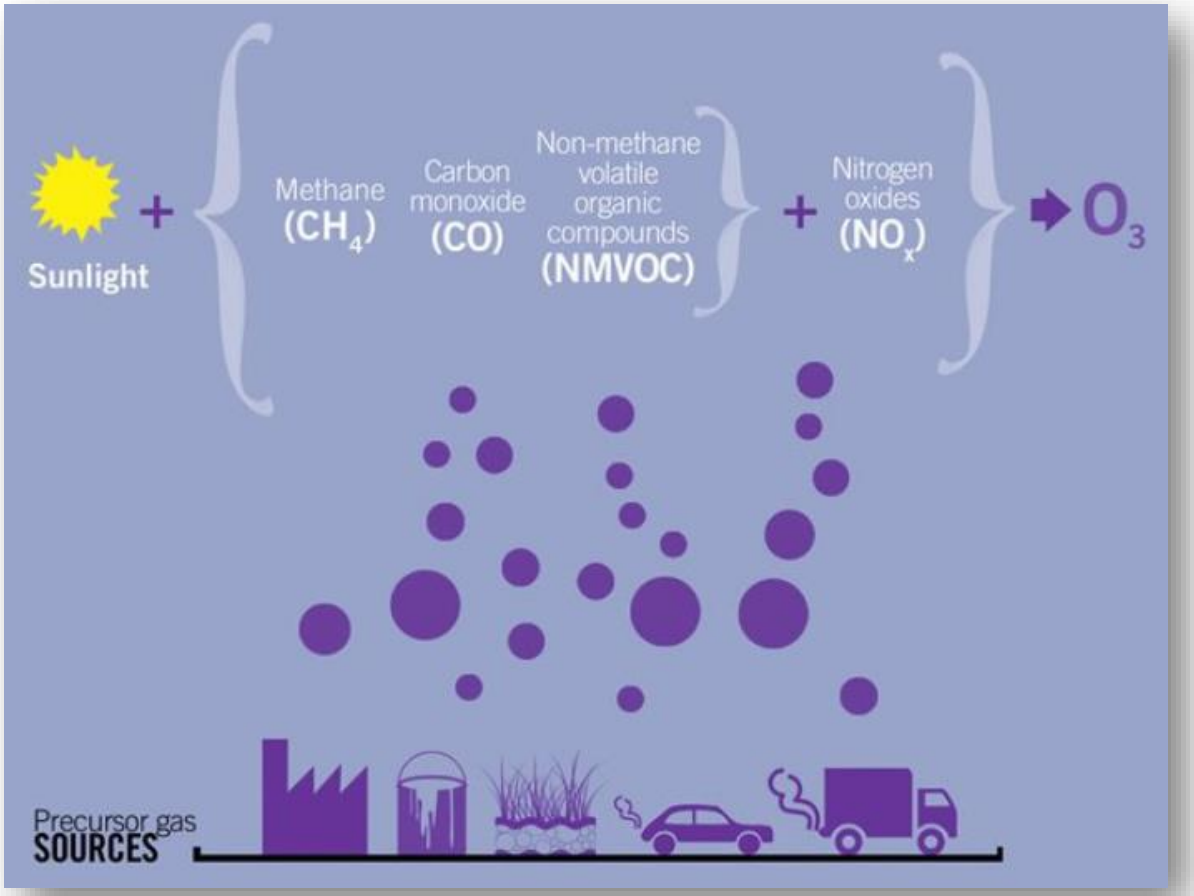


Forster et al. (2007)
IPCC-AR4
WG1 Chapter 2

Introduction: Ozone

- Tropospheric O_3: **<u>secondary</u> air pollutant**

Not emitted directly but instead forms when precursor gases react in the presence of sunlight.



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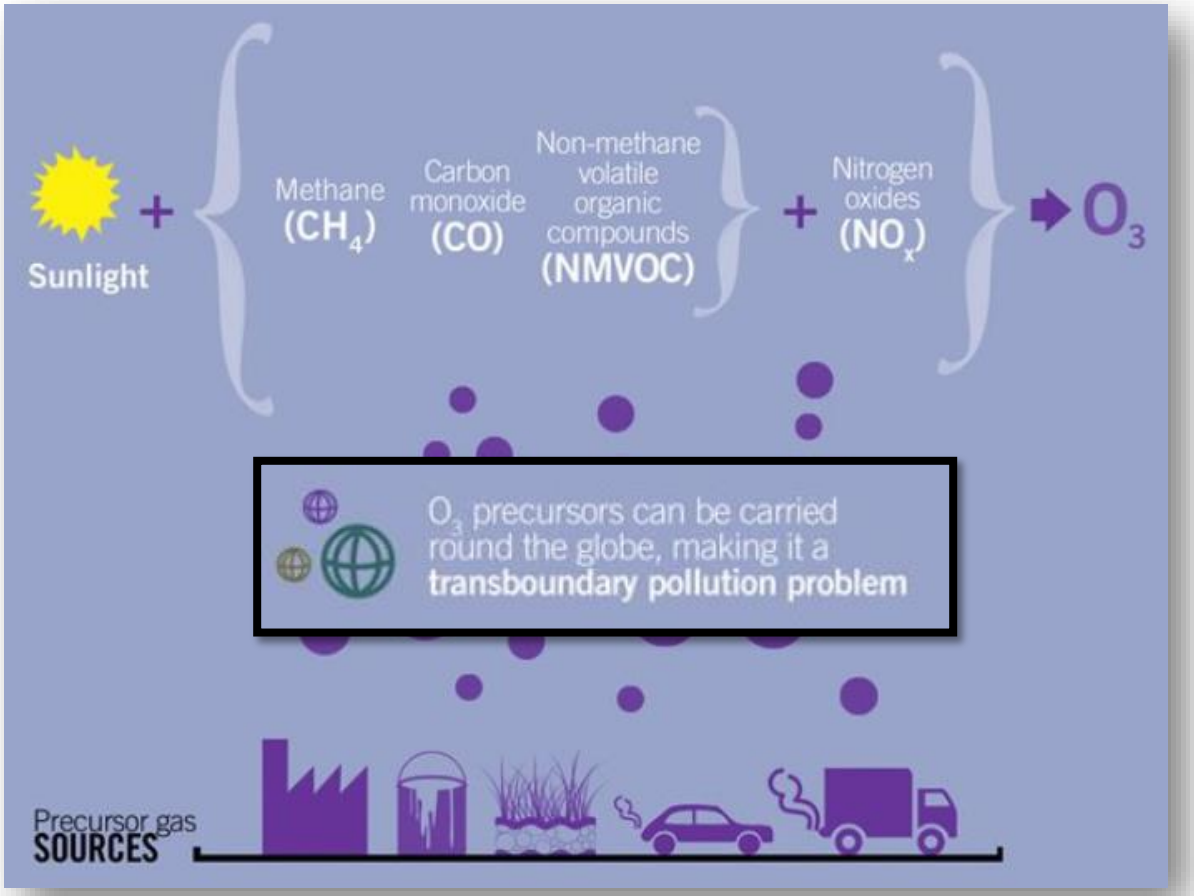


Introduction: Ozone

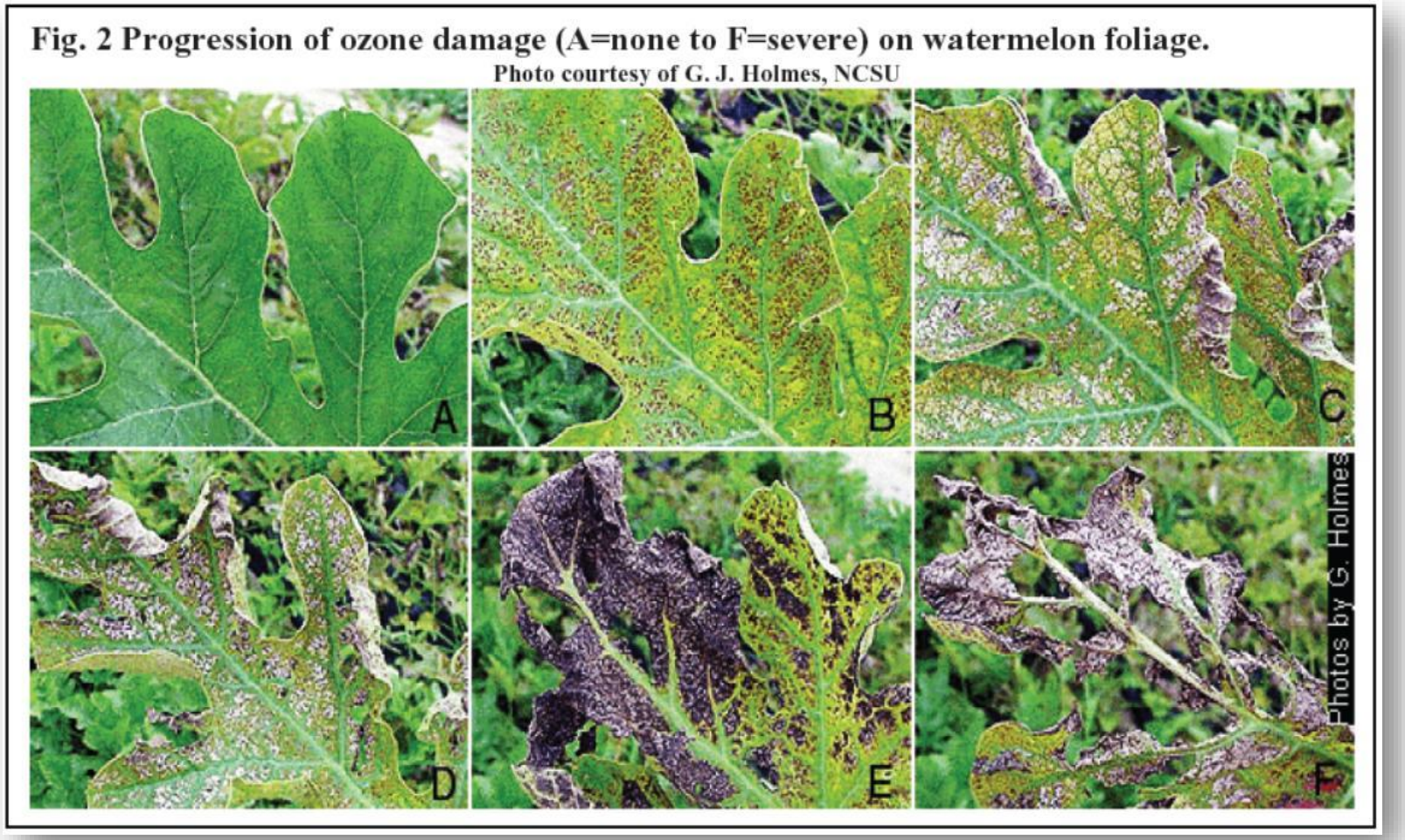
- Tropospheric O_3: **health effects**

Introduction: Ozone

- Tropospheric O_3: **damage to vegetation**

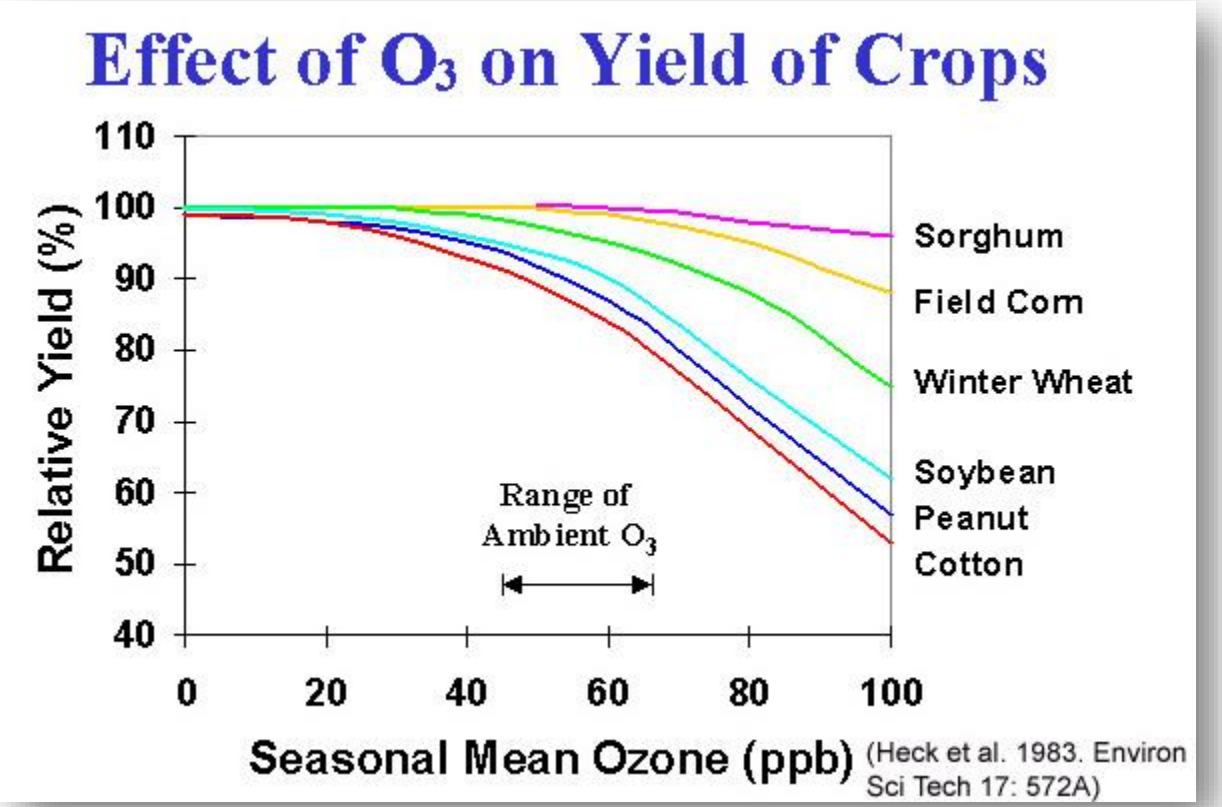
Introduction: Ozone

- Tropospheric O_3: **damage to vegetation**
  - ✓ Leaf injury



Introduction: Ozone

- Tropospheric O_3: **damage to vegetation**
  - ✓ Crop yield reductions



Introduction: Ozone

- ❑ Tropospheric O_3: **damage to vegetation**
- ✓ Carbone sequestration reduction

Tellus (2004), 56B, 230–248
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TELLUS

Effects of ozone on net primary production and carbon sequestration in the conterminous United States using a biogeochemistry model

By B. FELZER[1]*, D. KICKLIGHTER[1], J. MELILLO[1], C. WANG[2], Q. ZHUANG[1] and R. PRINN[2], [1]*The Ecosystems Center, Marine Biological Laboratory, 7 MBL St., Woods Hole, MA 02543, USA;* [2]*Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139, USA*

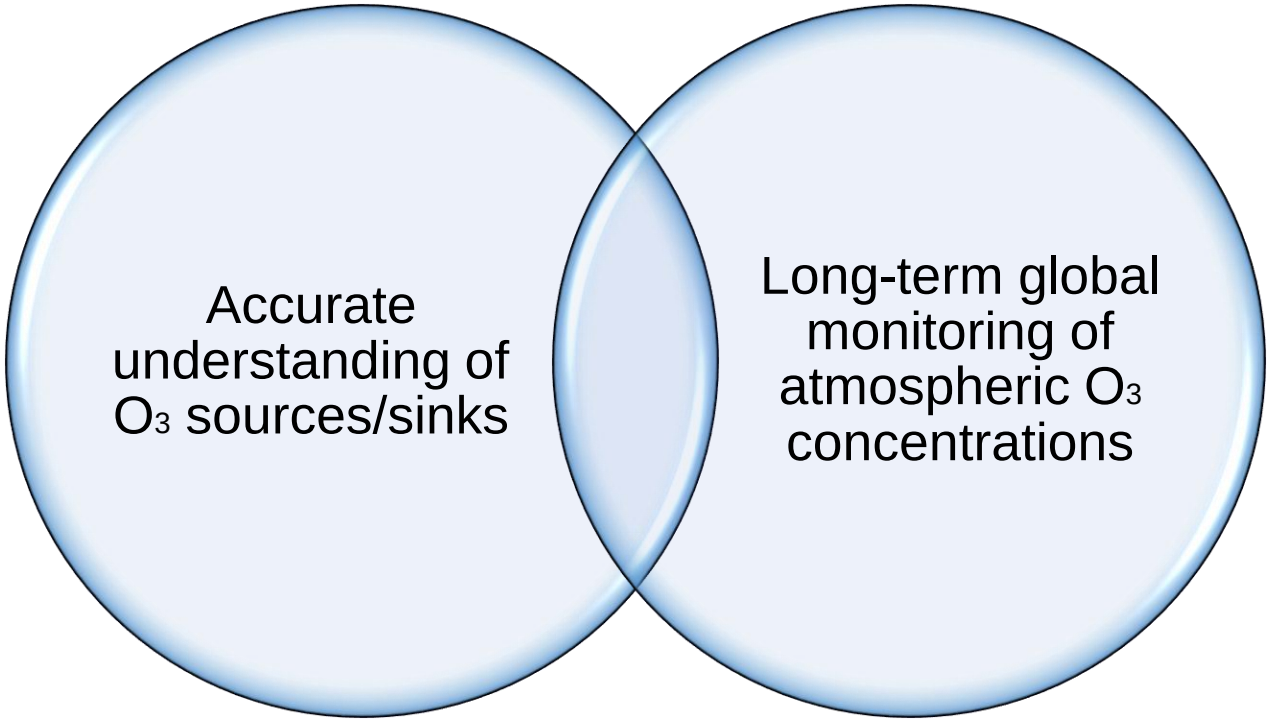
(Manuscript received 7 October 2002; in final form 25 November 2003)

ABSTRACT

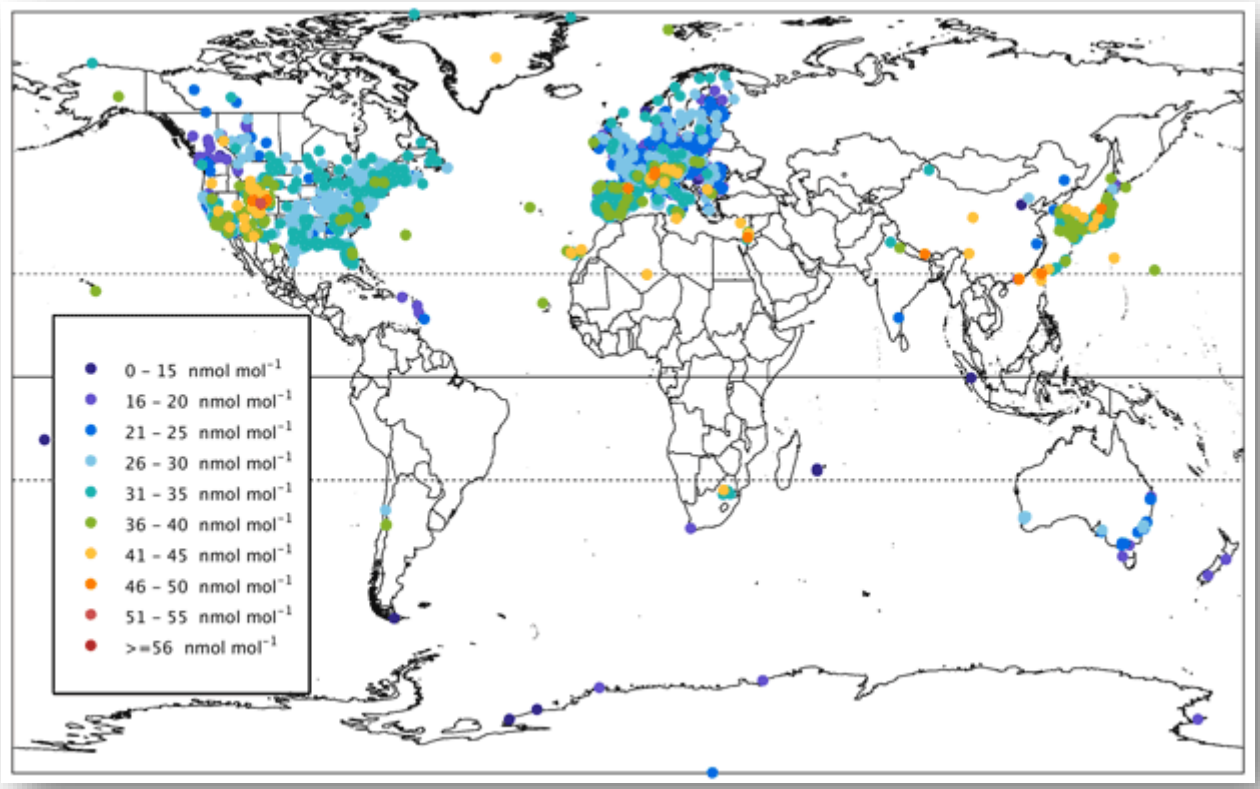
The effects of air pollution on vegetation may provide an important control on the carbon cycle that has not yet been widely considered. Prolonged exposure to high levels of ozone, in particular, has been observed to inhibit photosynthesis by direct cellular damage within the leaves and through possible changes in stomatal conductance. We have incorporated empirical equations derived for trees (hardwoods and pines) and crops into the Terrestrial Ecosystem Model to explore the effects of ozone on net primary production (NPP) and carbon sequestration across the conterminous United States. Our results show a 2.6–6.8% mean reduction for the United States in annual NPP in response to modelled historical ozone levels during the late 1980s-early 1990s. The largest decreases (over 13% in some locations) occur in the Midwest agricultural lands, during the mid-summer when ozone levels are highest. Carbon sequestration since the 1950s has been reduced by 18–38 Tg C yr^{-1} with the presence of ozone. Thus the effects of ozone on NPP and carbon sequestration should be factored into future calculations of the United States' carbon budget.

Introduction: Ozone

- Radiative forcing
- Health effects
- Damage to vegetation

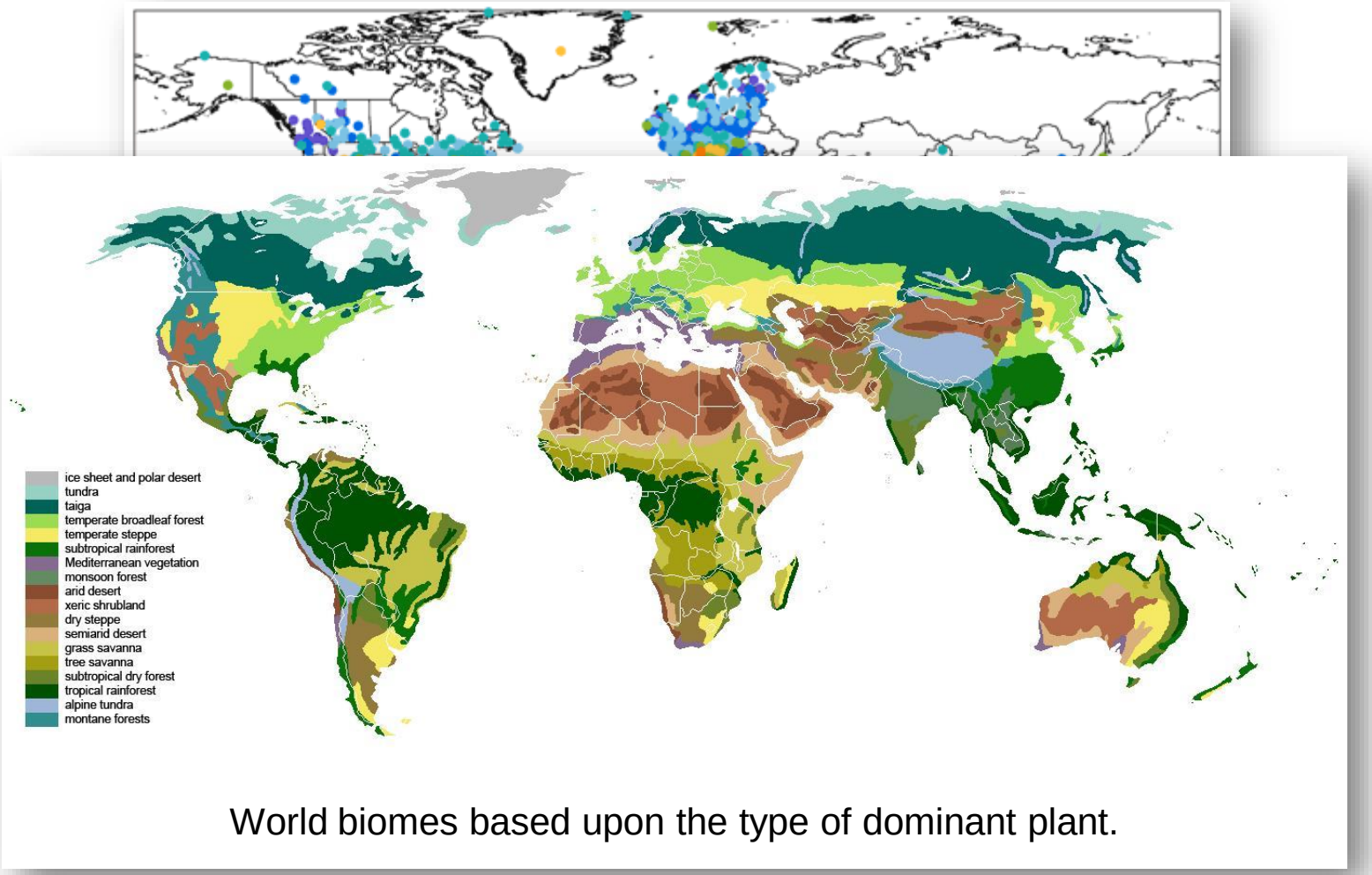


Existing monitoring stations



Global daytime average O_3 (nmol/mol) at 2702 non-urban sites in Dec-Jan-Feb for the 2010-2014 period (Gaudel et al., 2018).

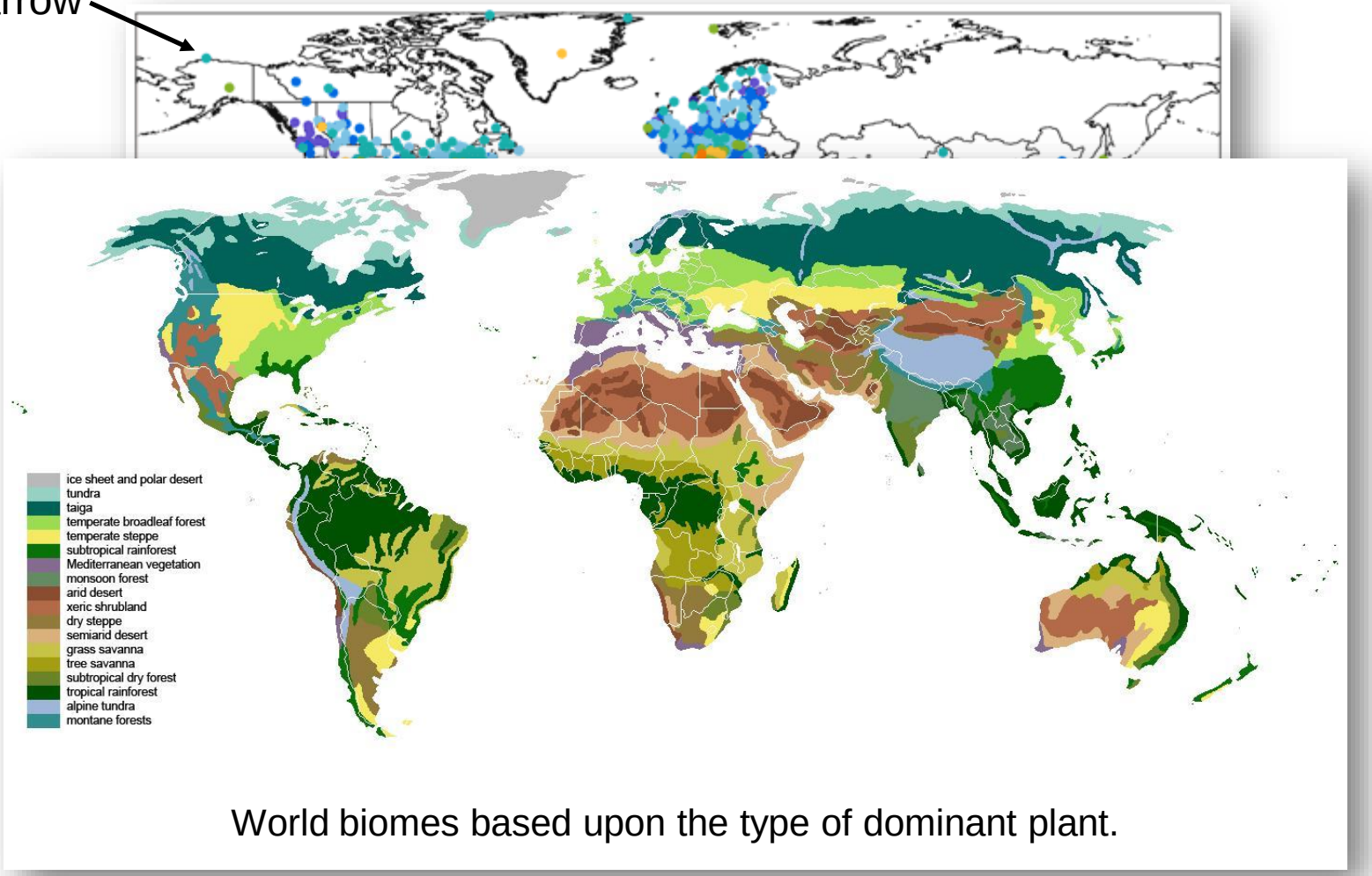
Existing monitoring stations



World biomes based upon the type of dominant plant.

Existing monitoring stations

Barrow



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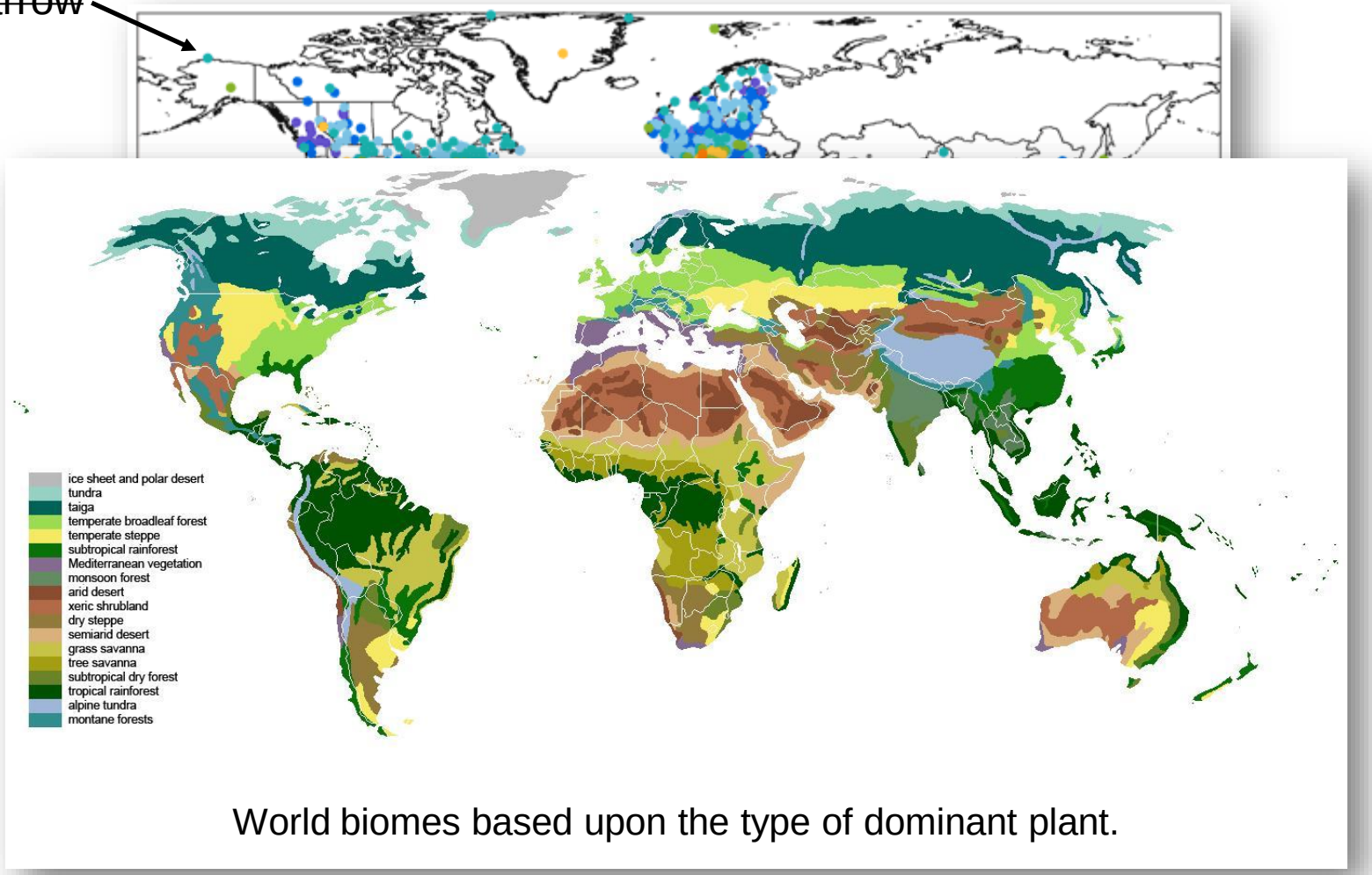

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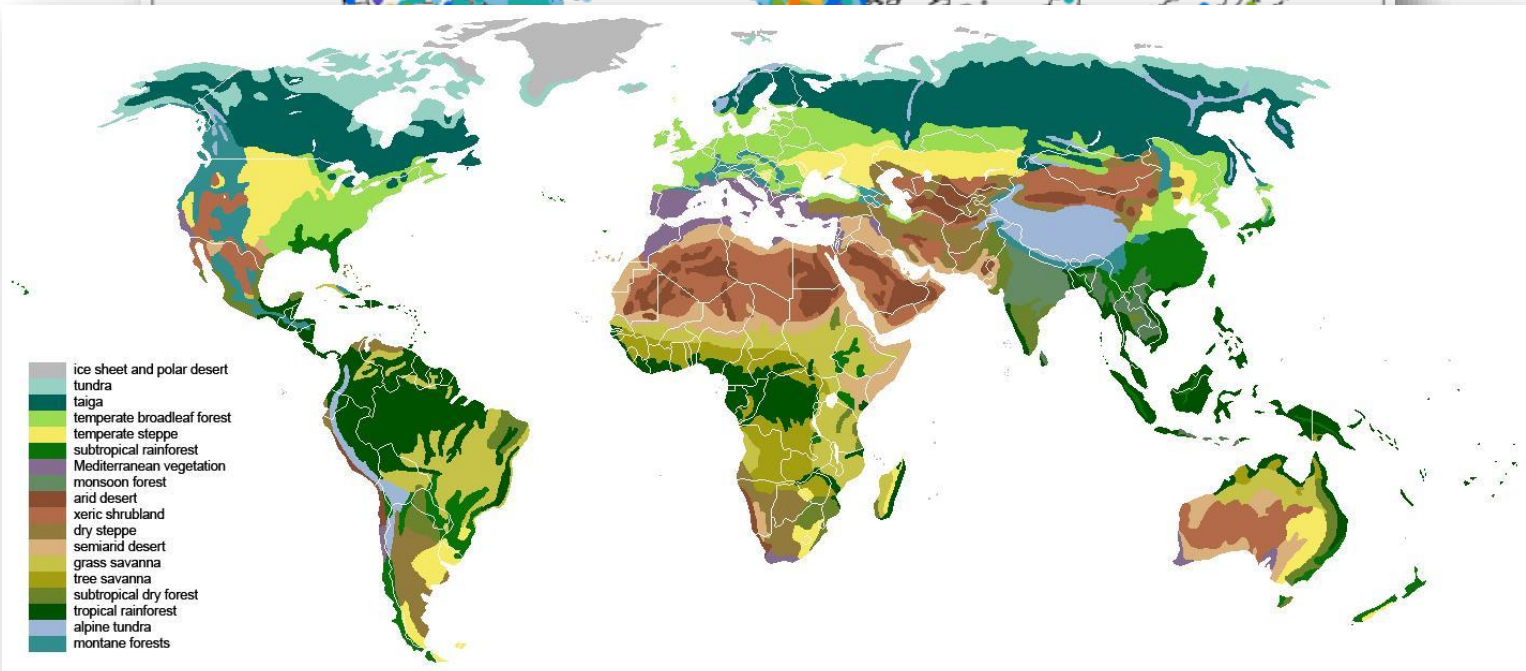
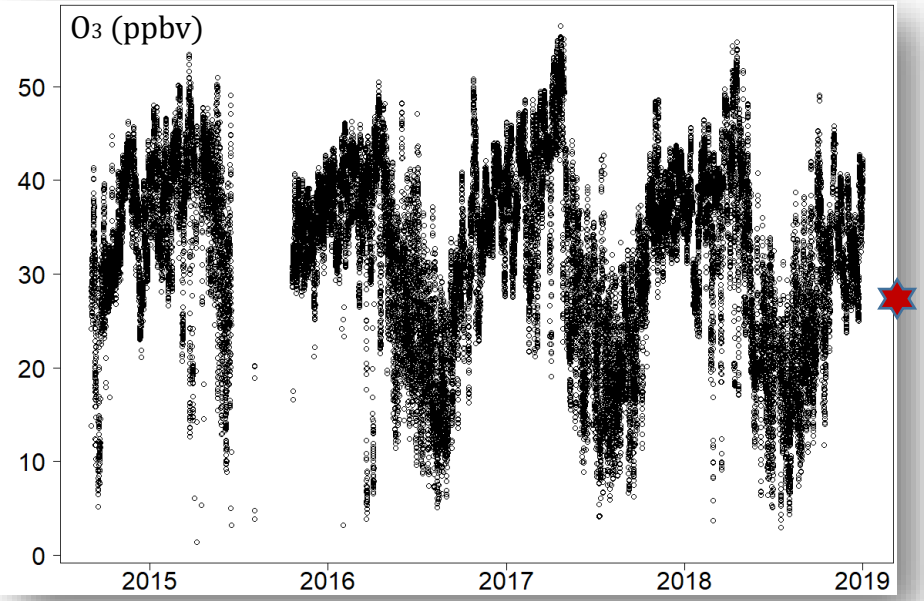


World biomes based upon the type of dominant plant.

O_3 record at Toolik Field Station

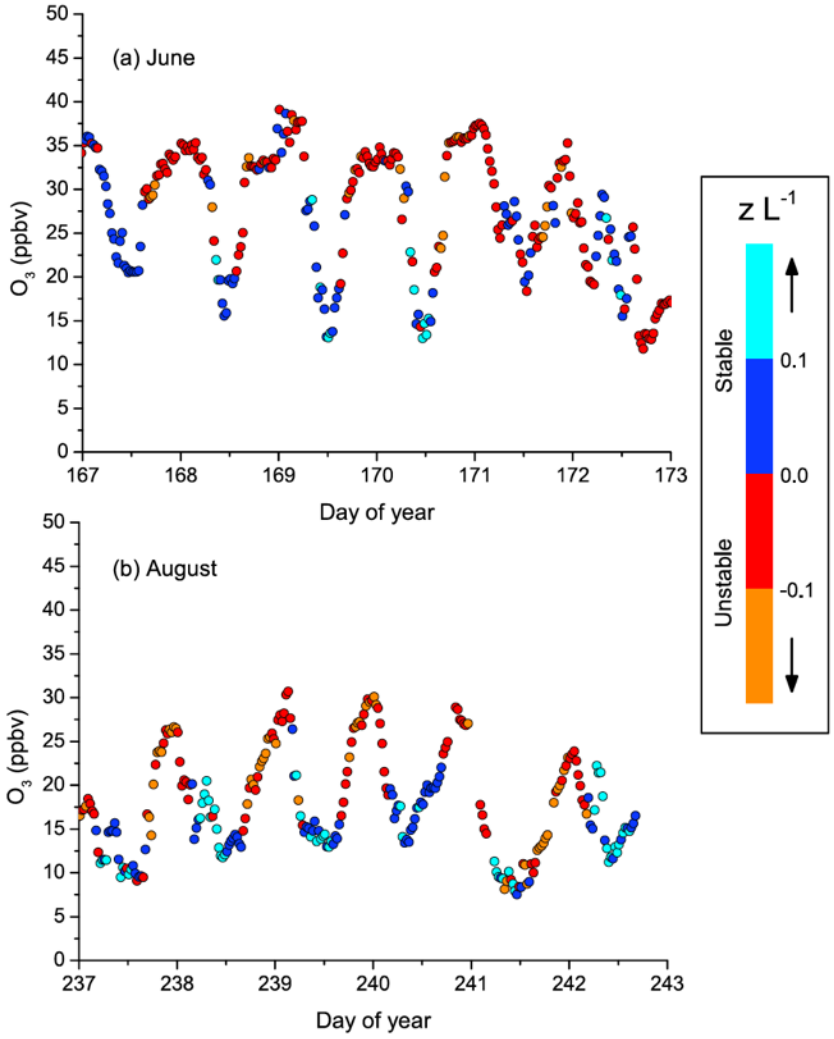
- 2007-2013: A synthesis of existing and new observations of air-snowpack exchanges to assess the Arctic. Sept 2010-Aug 2011 O_3 record.
- 2013-2018: Soil-snow-atmosphere exchanges of mercury in the interior arctic tundra.
- 2017-2020: Biogenic volatile organic compounds and the fate of ozone in the changing Arctic.

Sept 2014-present O_3 record.



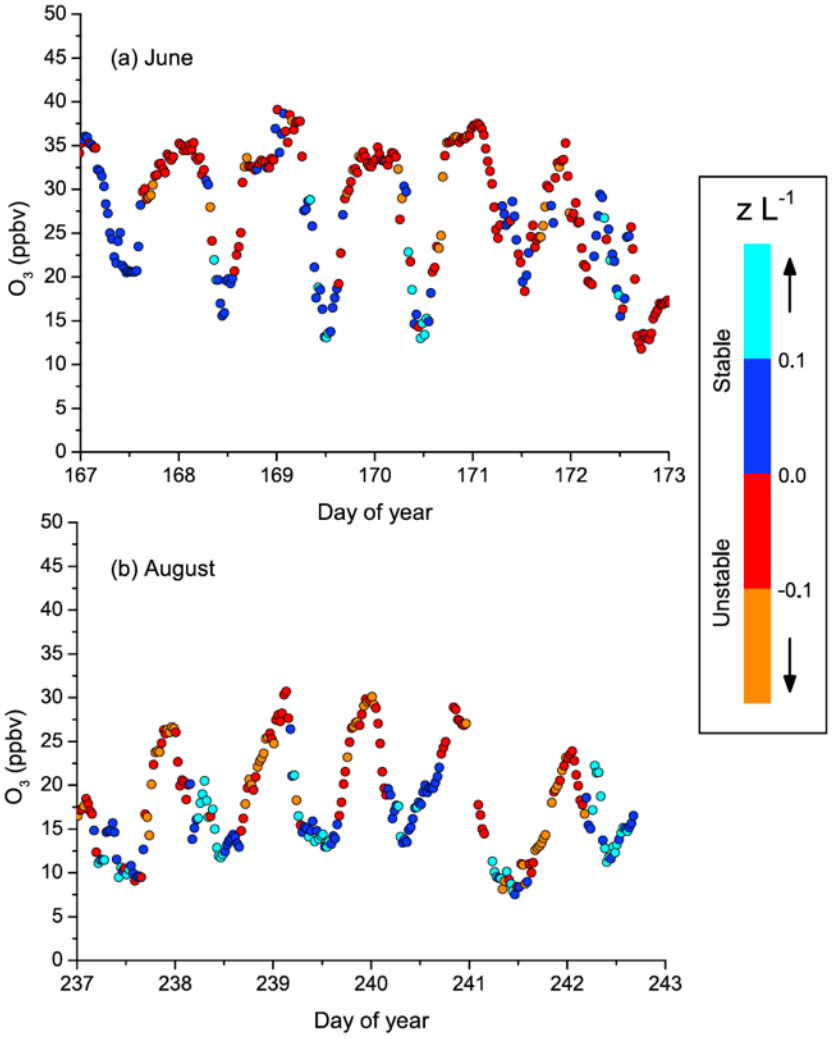
Summer 2019:
field campaign ends

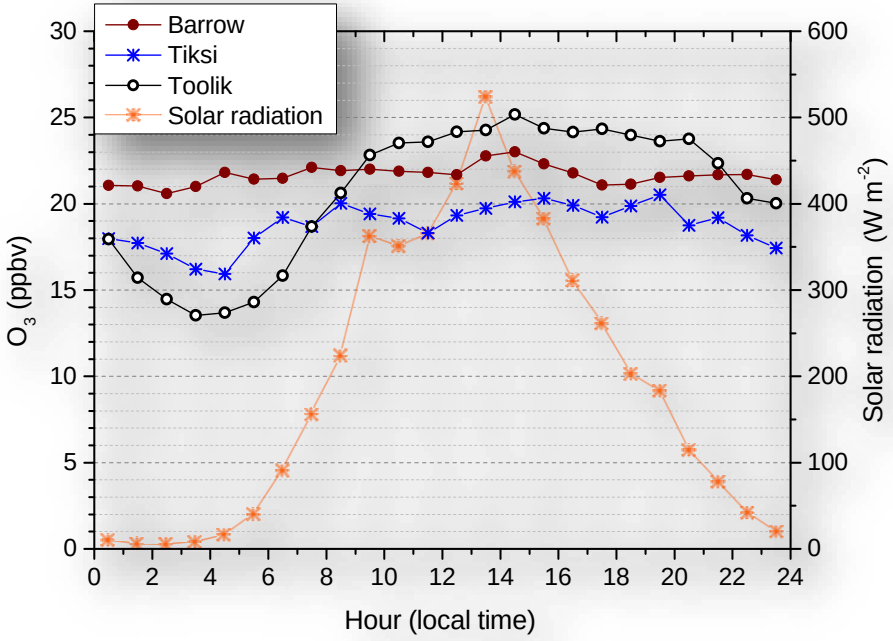
Summertime O_3 record at Toolik Field Station



Van Dam et al., JGR, 2016

Summertime O_3 record at Toolik Field Station





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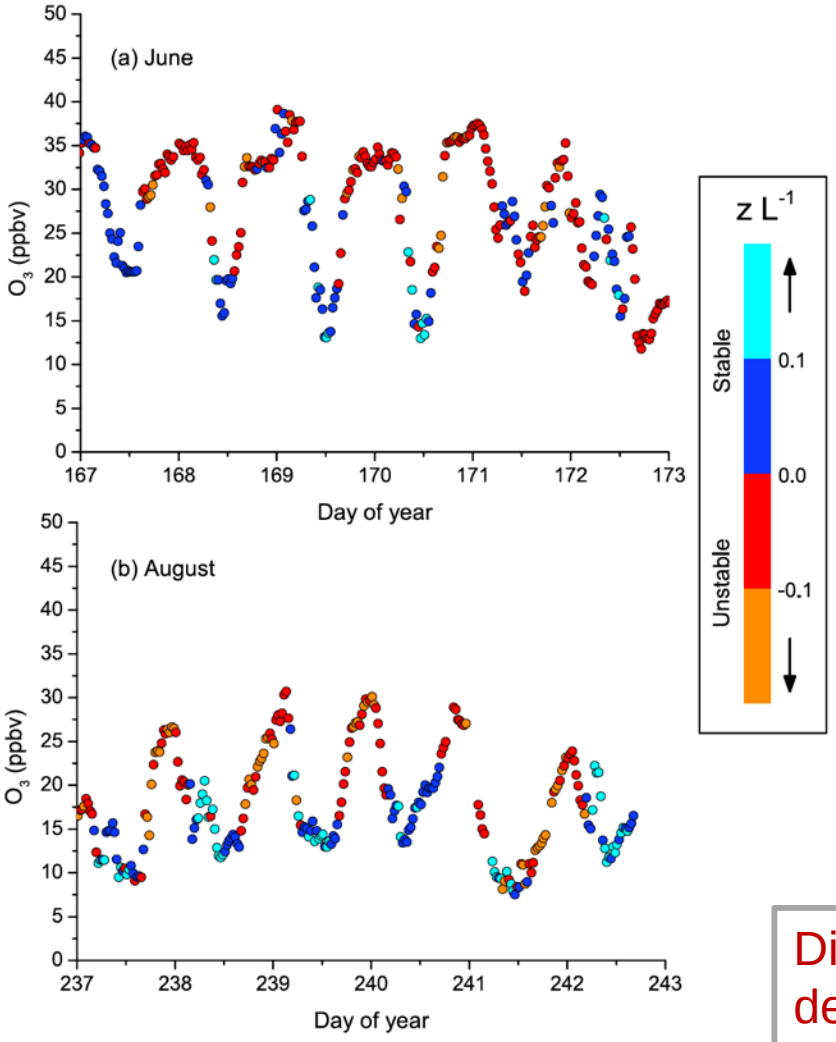
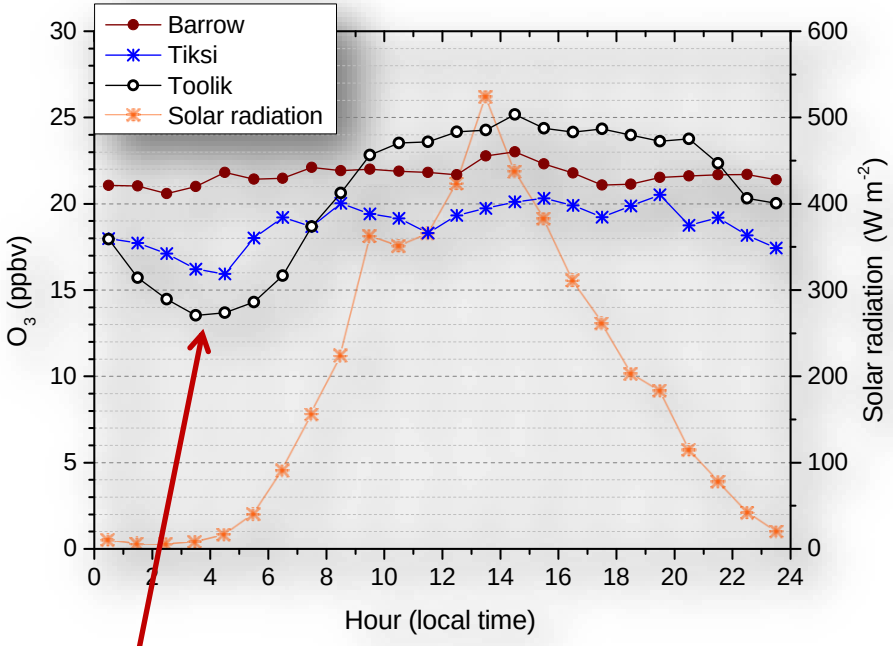


Van Dam et al., JGR, 2016



Diurnal cycles are mostly driven by nighttime destruction - NOT daytime photochemical production.

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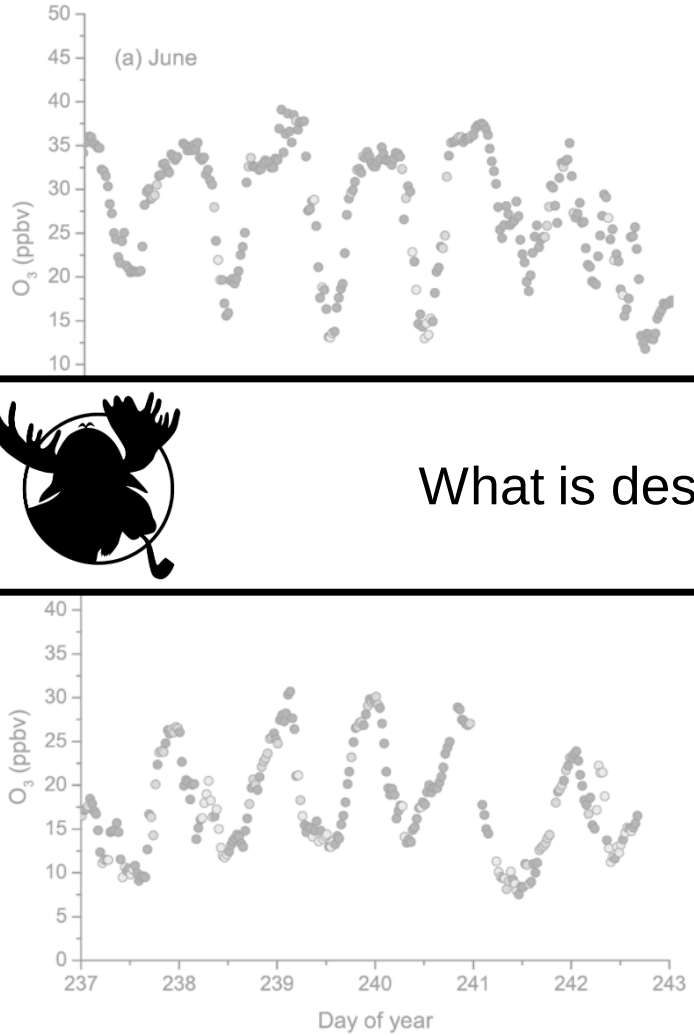

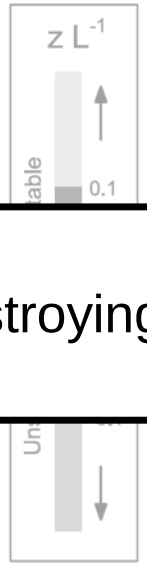

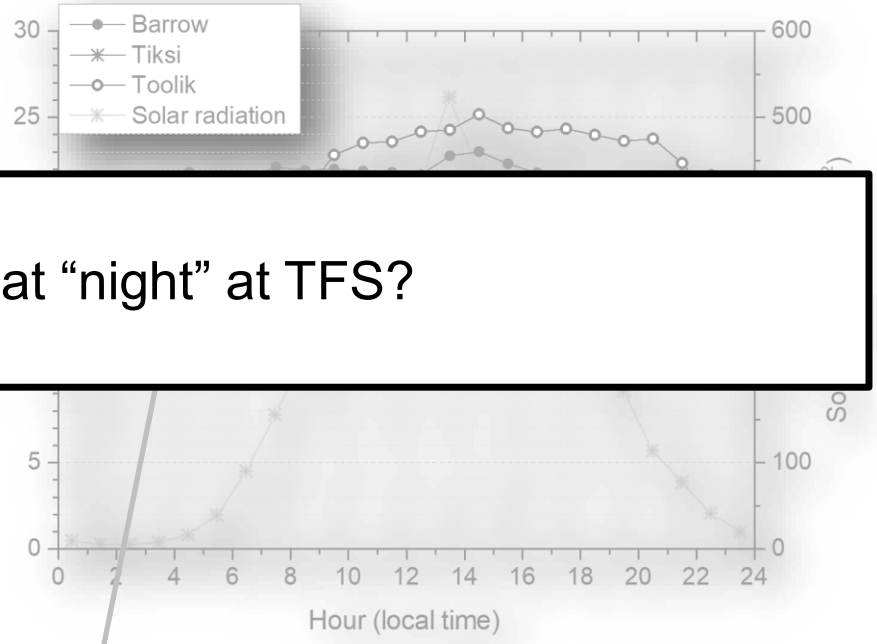

What is destroying O_3 at "night" at TFS?

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Van Dam et al., JGR, 2016

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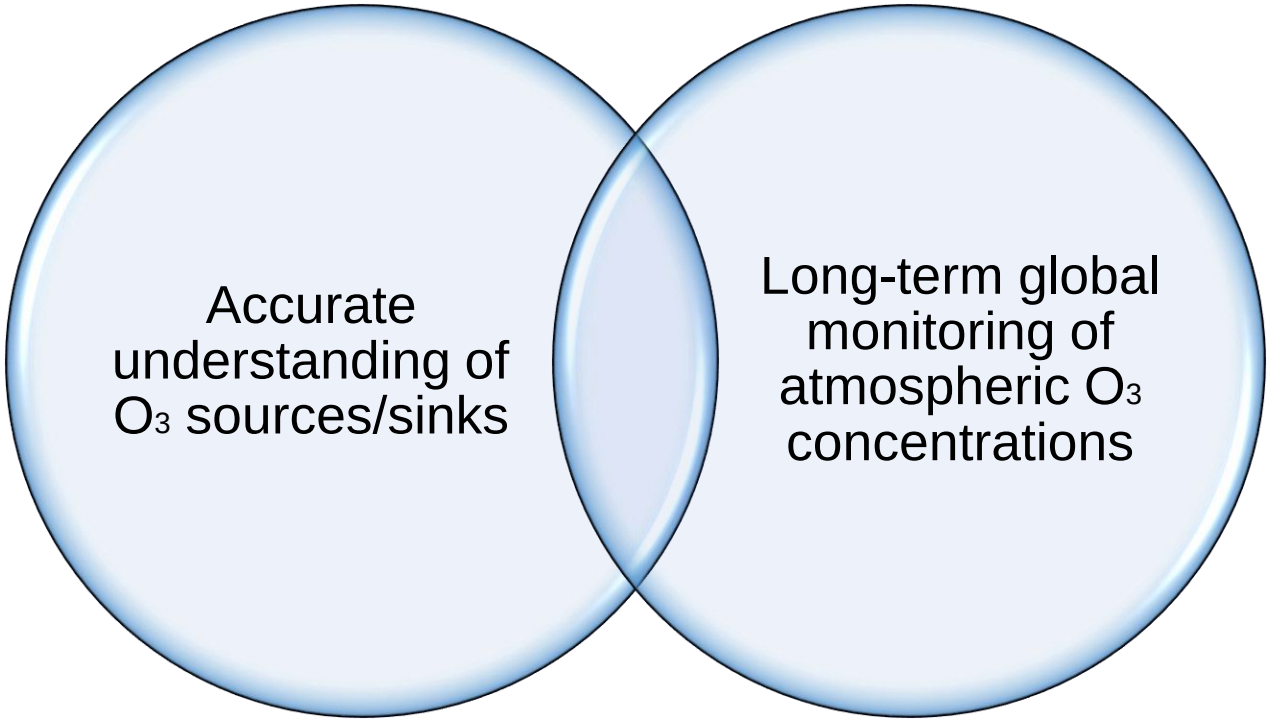
- Health effects
- Damage to vegetation



What's destroying O_3 at night?

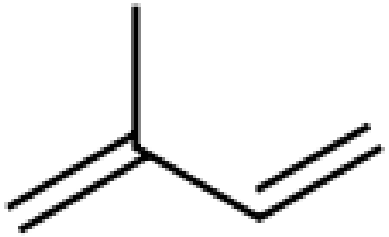
What's destroying O_3 at night?

Biogenic volatile organic compounds and the fate of ozone in the changing Arctic

- Detlev Helmig, Univ. of Colorado, P.I.
- Dylan Millet, Univ. of Minnesota, co-P.I.
- Lu Hu, Univ. of Montana, co-P.I.

Biogenic organic compounds

Biogenic organic compounds (BVOCs):



Isoprene (C_5H_8)

Biogenic organic compounds

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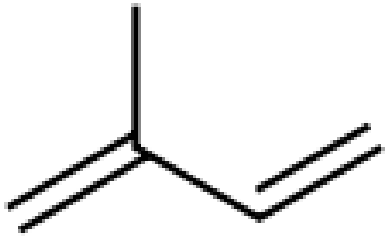
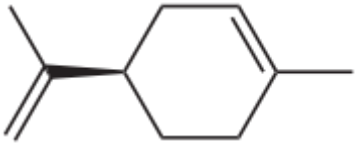
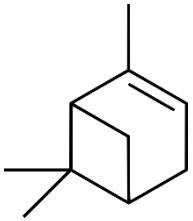


Isoprene (C_5H_8)

Monoterpenes ($C_{10}H_{16}$): consist of 2 isoprene units



Limonene



α-pinene

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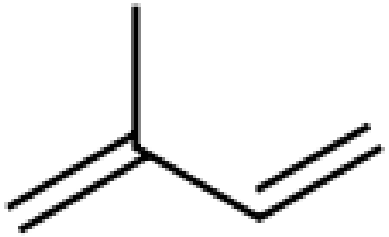

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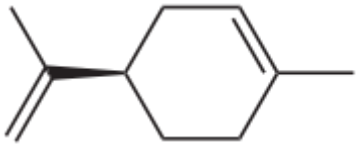

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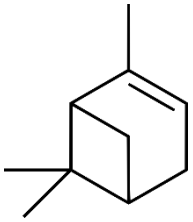
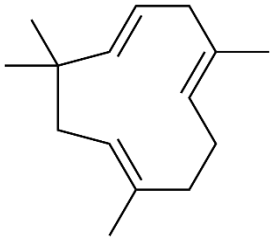
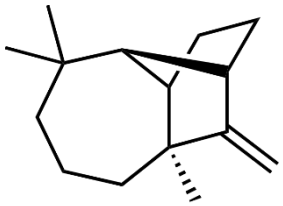


α-pinene

Sesquiterpenes ($C_{15}H_{24}$): consist of 3 isoprene units



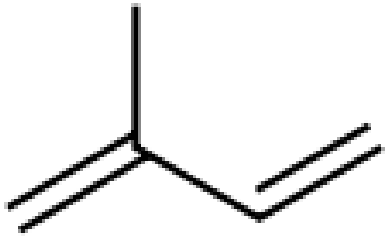
Humulene



Longifolene

Biogenic organic compounds

Biogenic organic compounds (BVOCs):



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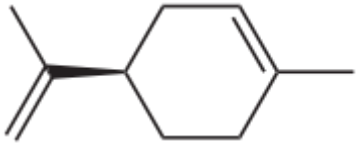

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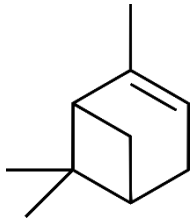

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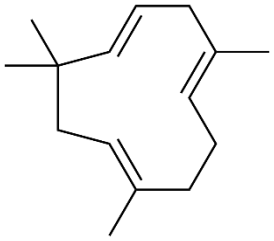

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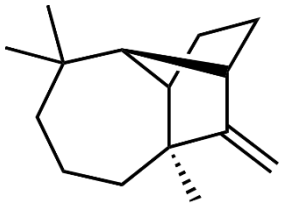
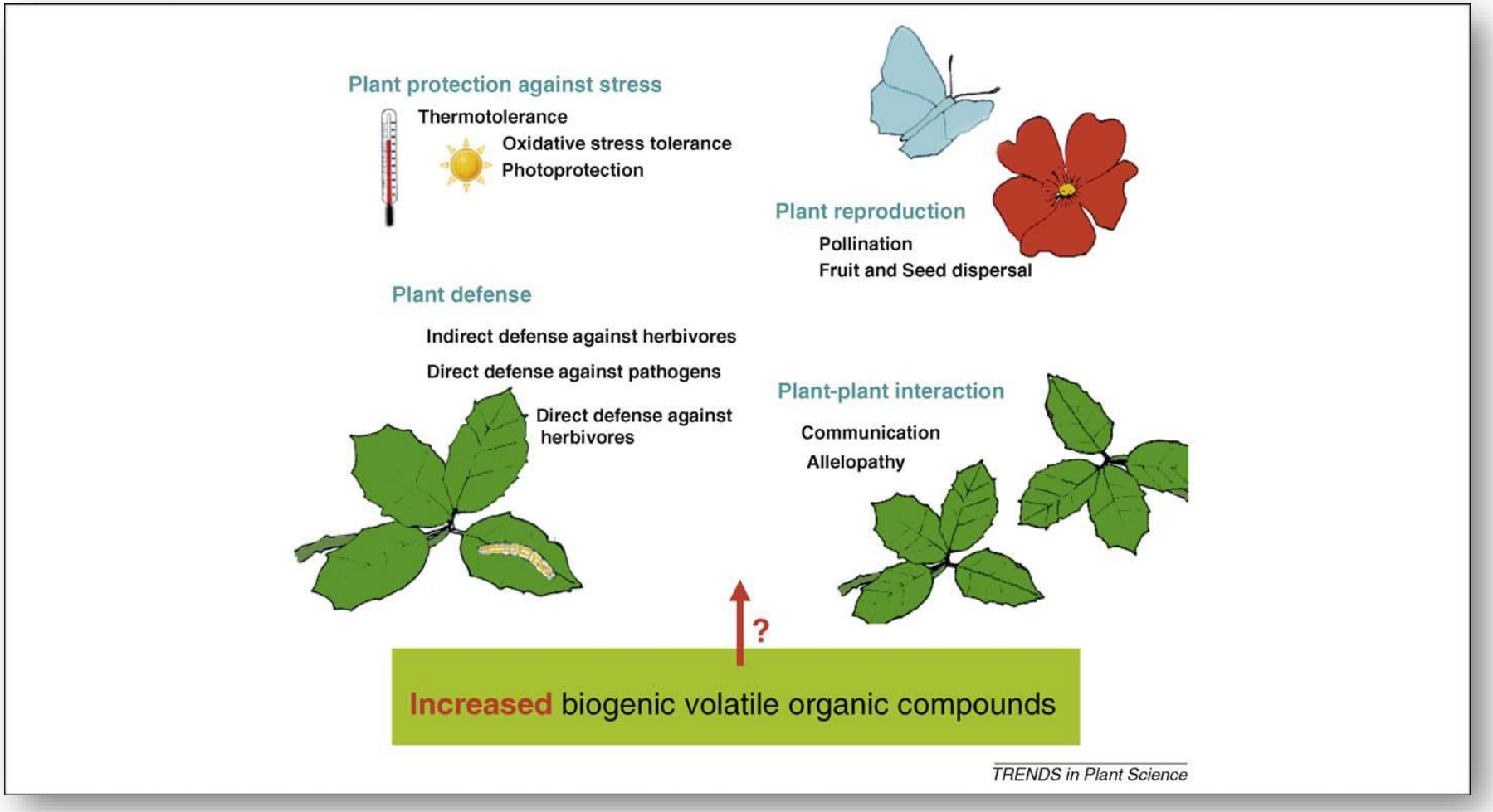


Longifolene

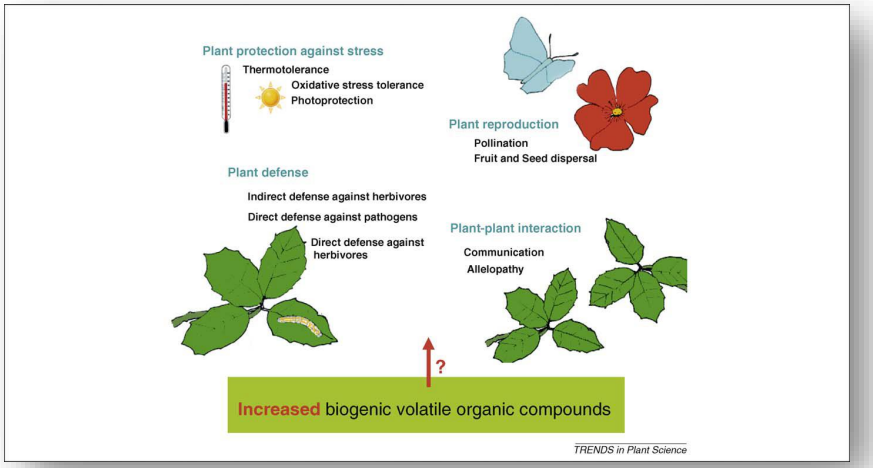
Biogenic organic compounds

BVOCs produced by plants are involved in plant growth, reproduction and defense.



Peñuelas and Staudt, 2010

Biogenic organic compounds



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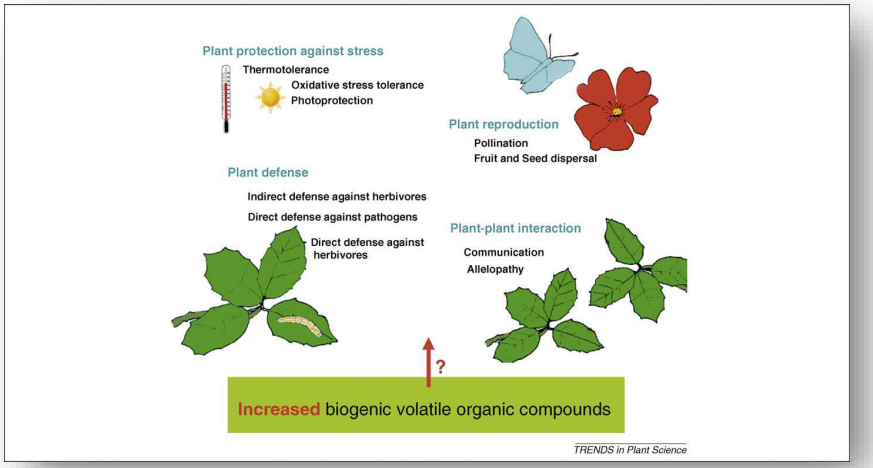
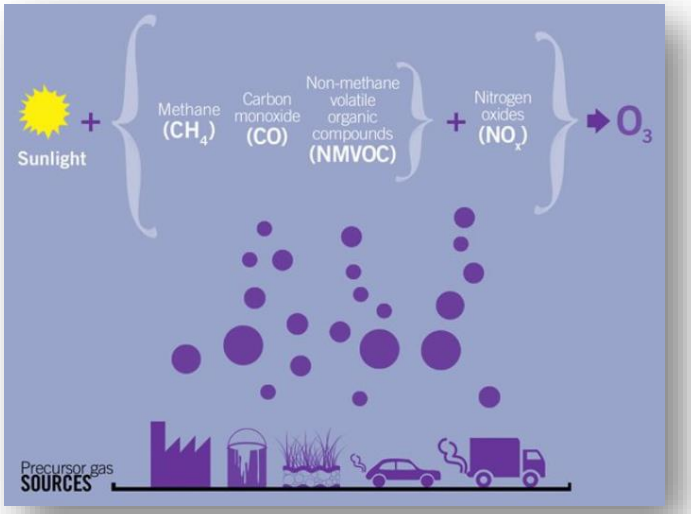
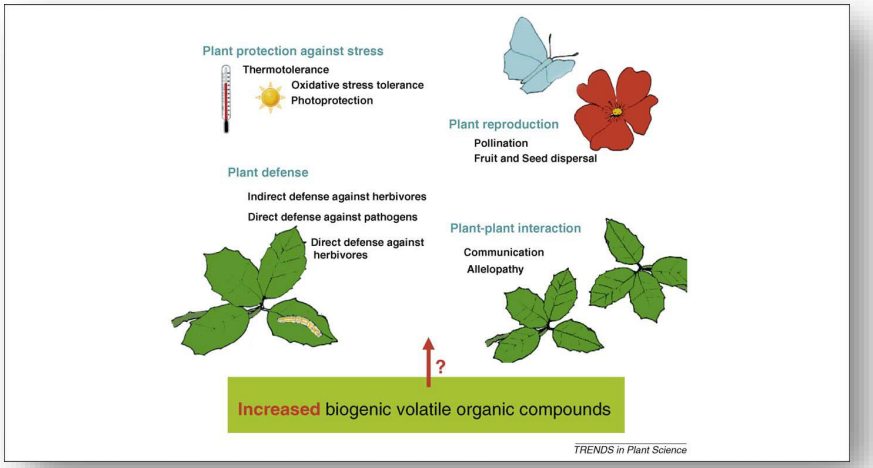


Formation of photochemical oxidants such as O_3



Biogenic organic compounds



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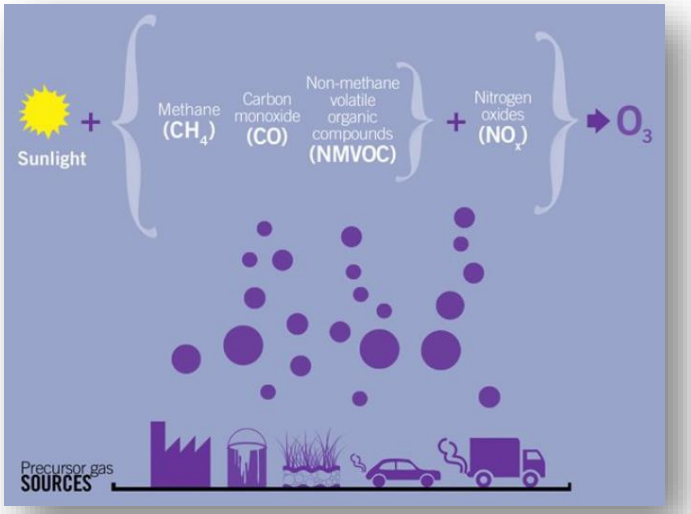
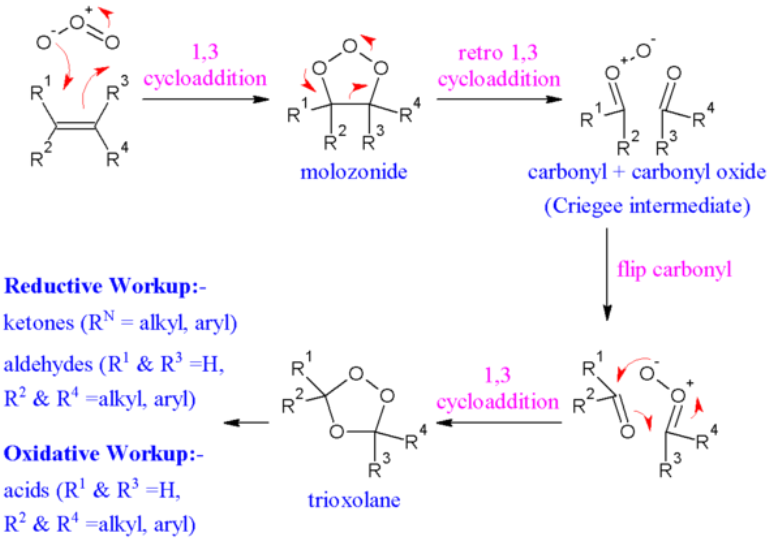
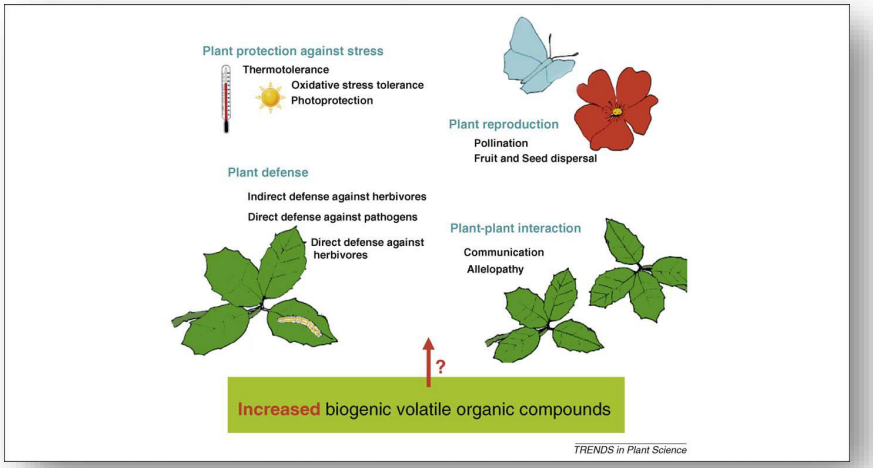


Ozonolysis (**destruction**)

Addition of O_3 to C=C double bonds



Biogenic organic compounds



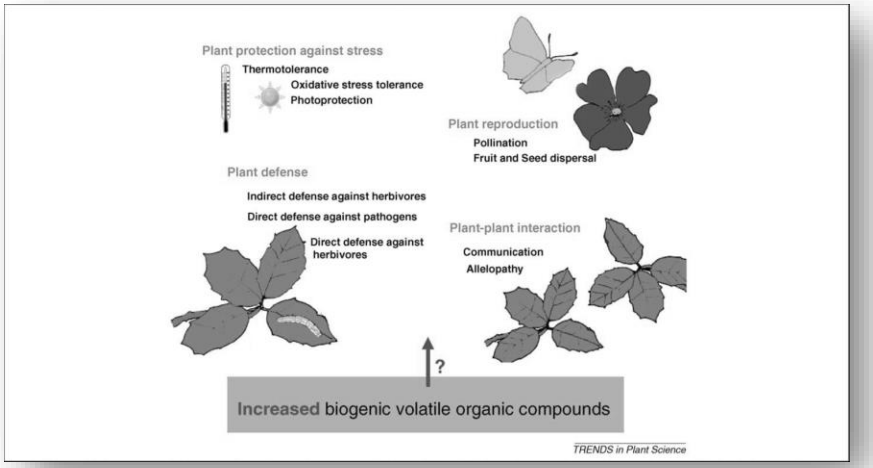
Ozonolysis (**destruction**)

O_3-reactive BVOCs

Less O_3-reactive BVOCs:
Isoprene, limonene, β-pinene

Highly O_3-reactive BVOCs:
α-pinene, α-terpinene, 2-carene, α-phellandrene, α-humulene, β-caryophyllene

Biogenic organic compounds



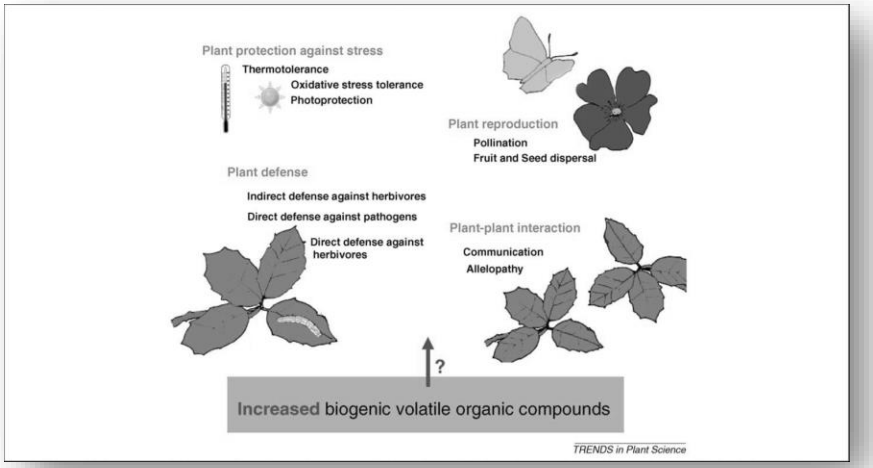
Ozonolysis (**destruction**)

1. Are these BVOCs emitted at Toolik?

Less O_3-reactive BVOCs:
Isoprene, limonene, β-pinene

Highly O_3-reactive BVOCs:
α-pinene, α-terpinene, 2-carene, α-phellandrene, α-humulene, β-caryophyllene

Biogenic organic compounds



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2. Why do we observe a destruction of O_3 *at night*?

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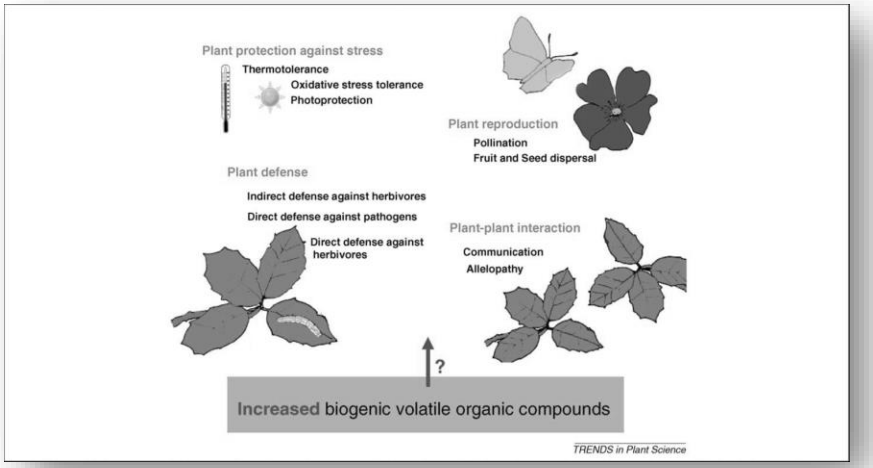

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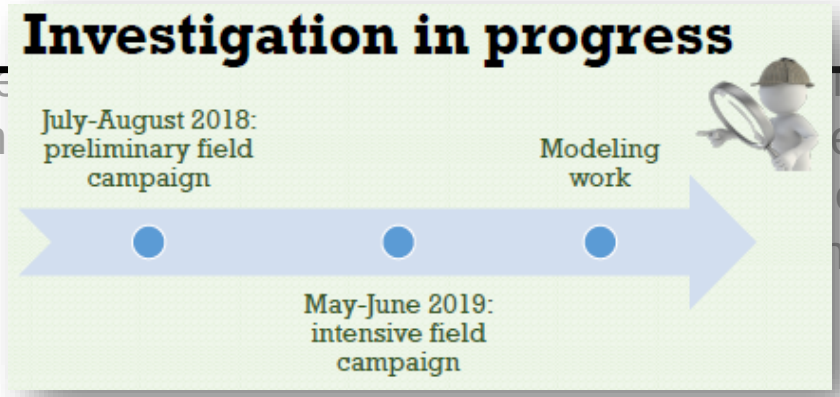


Are these BVOCs emitted at Toolik?

Enclosure systems

1. Sample collection

Different types of tundra species

Tundra emissions automatically collected on solid adsorbent cartridges

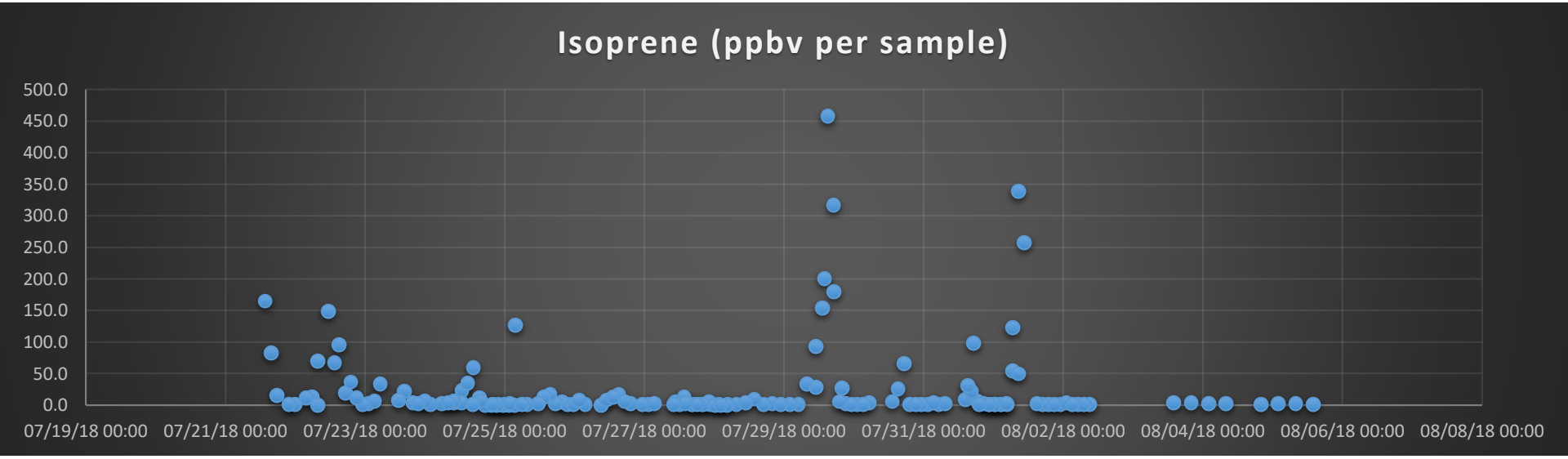
2. Laboratory analysis

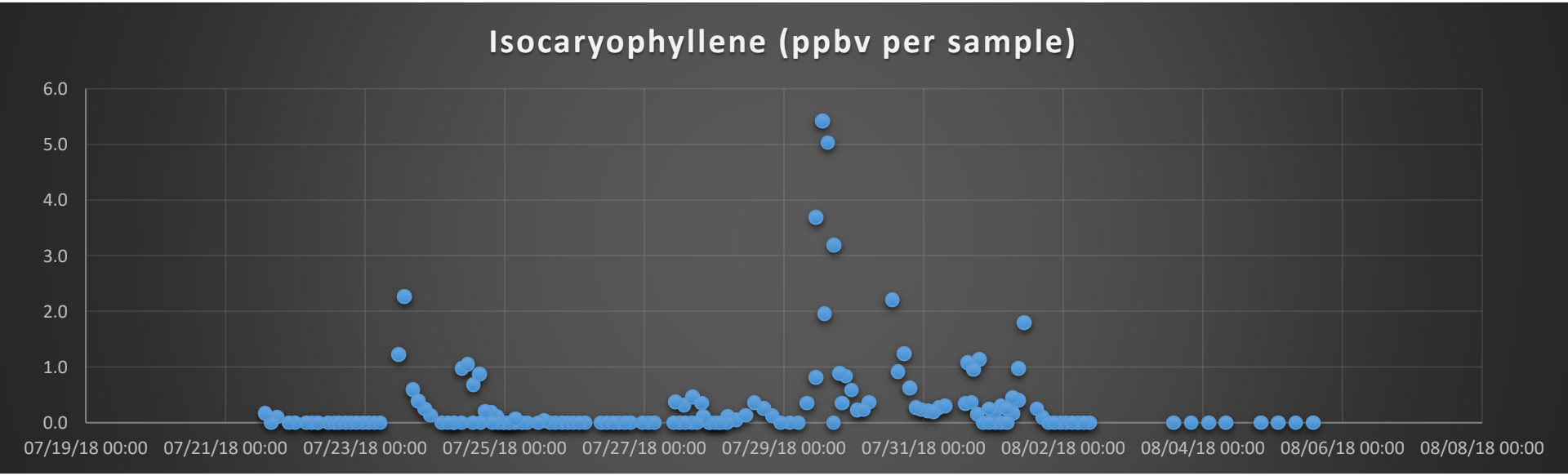
Solid adsorbent cartridge

Thermal desorption (ATD-400)

Spectroscopy analysis (GC/MS/FID)

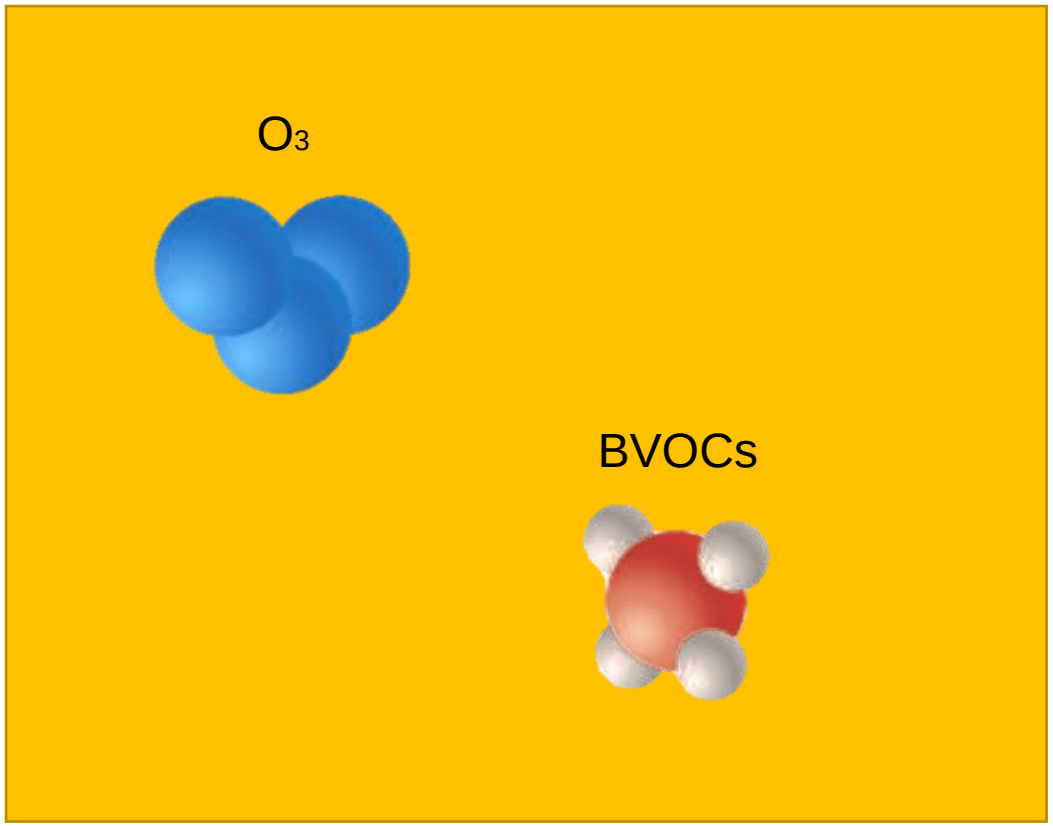
Are these BVOCs emitted at Toolik?





Why do we observe a destruction of O_3 at night?

Box model



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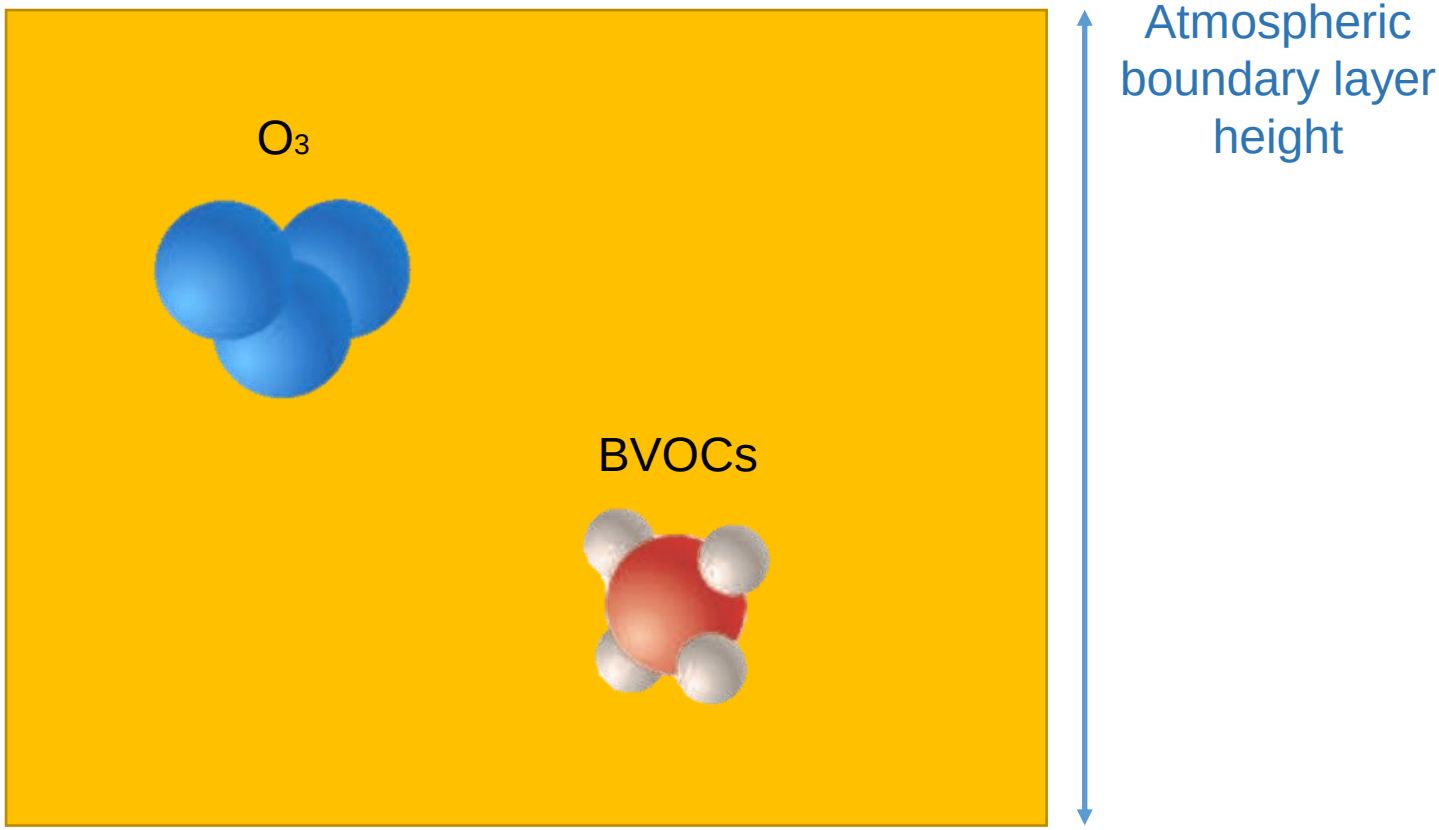

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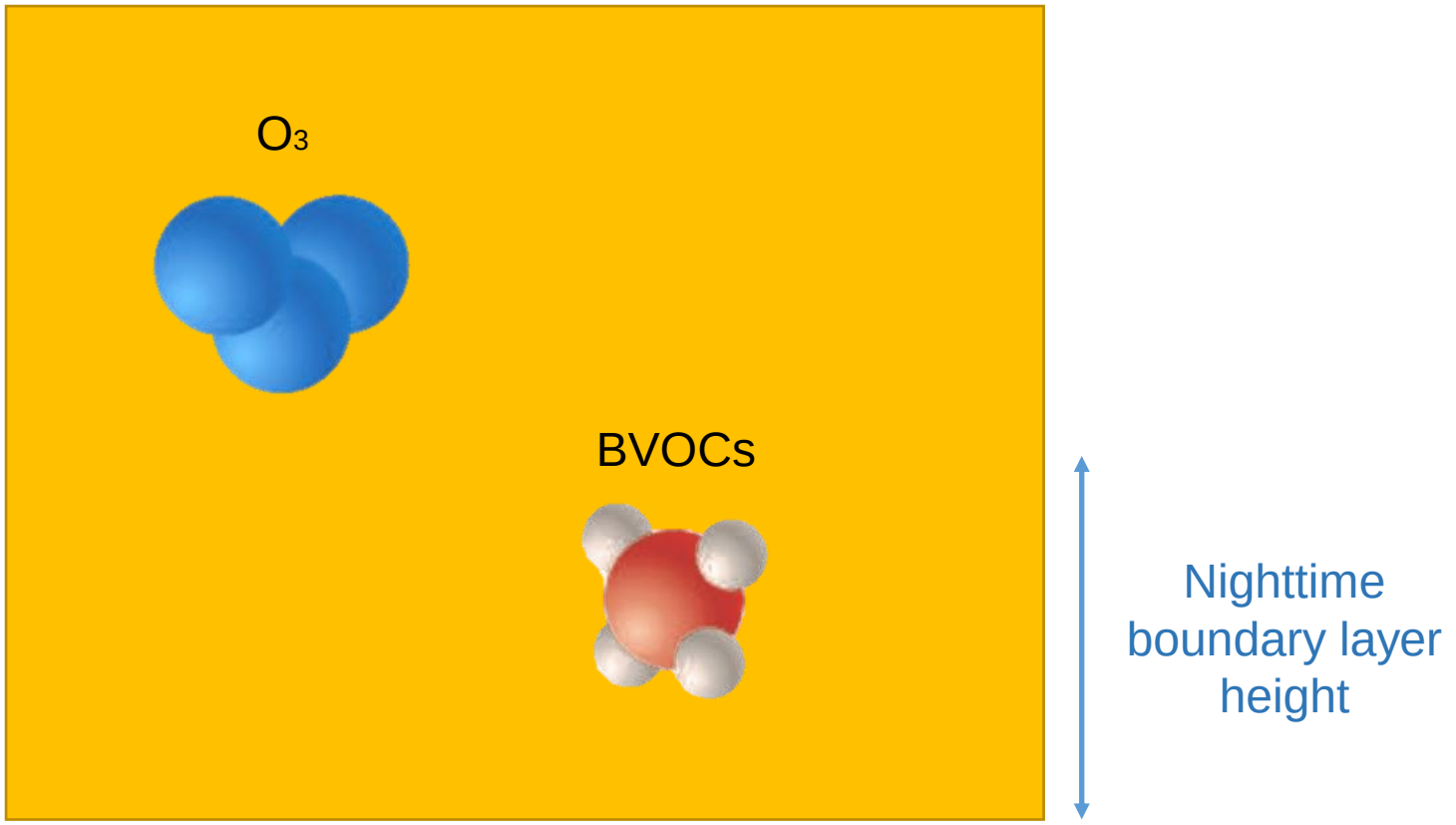

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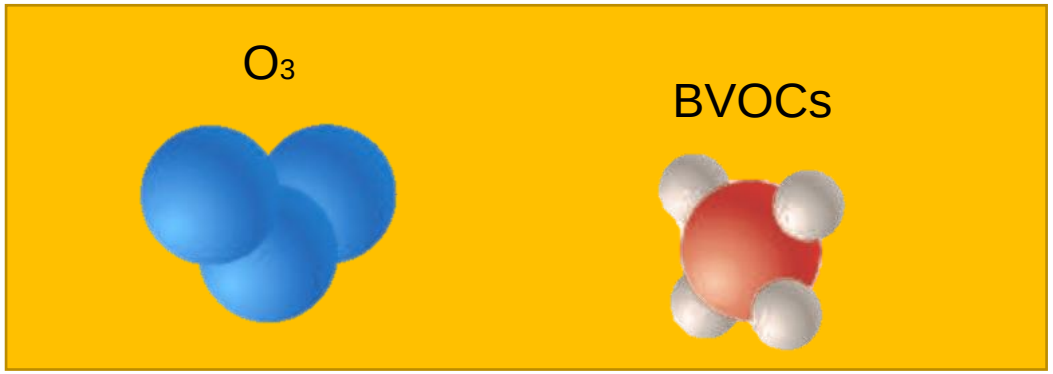
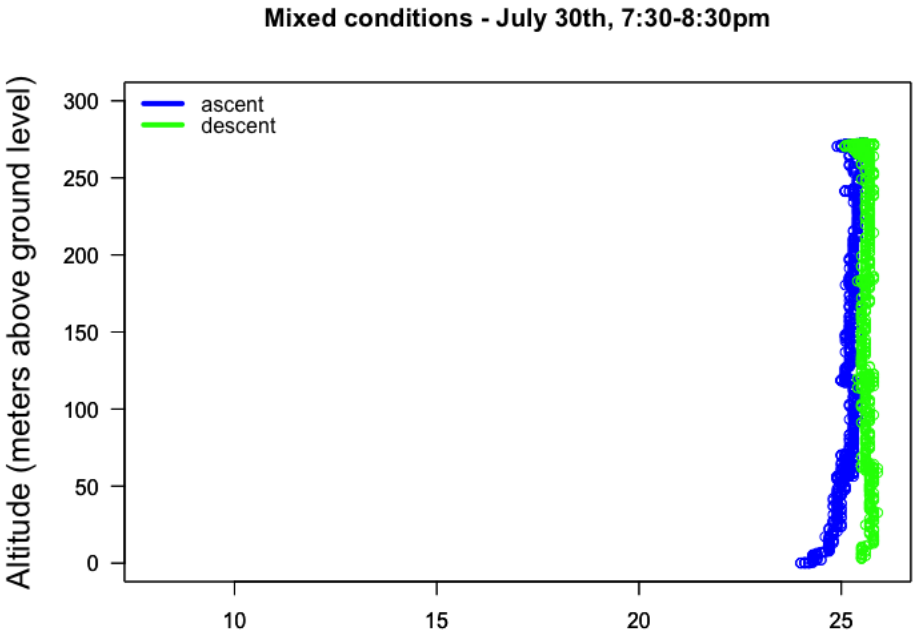
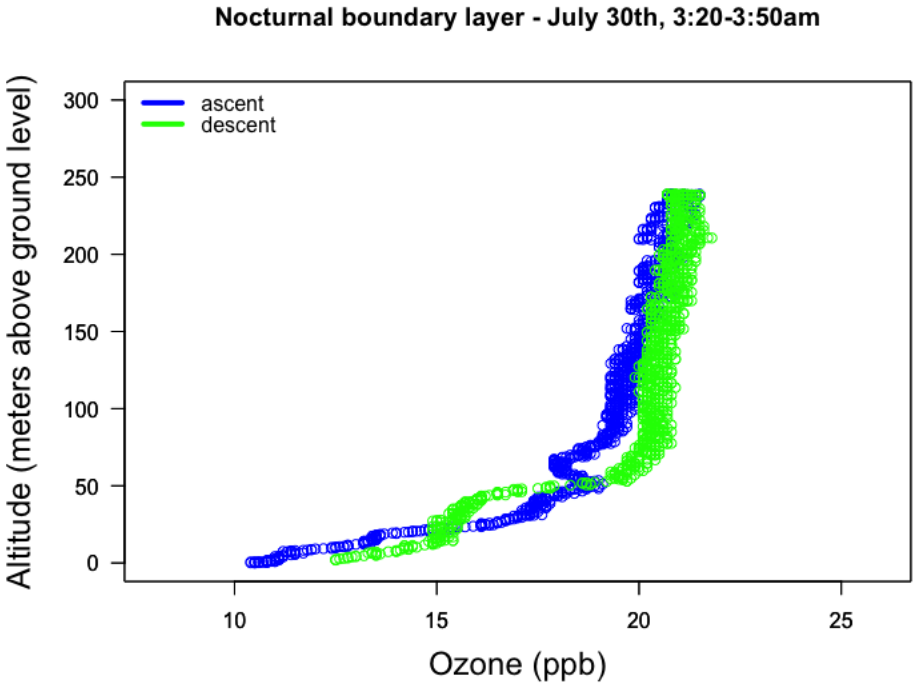


Nighttime boundary layer height

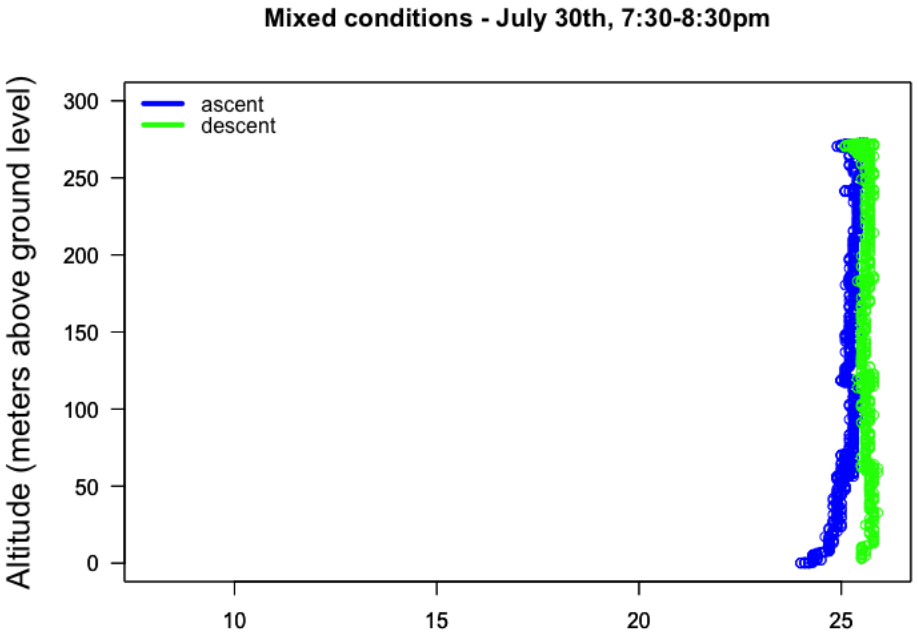
$$Concentration = \frac{N_{molecules}}{Volume \times N_{Avogadro}}$$

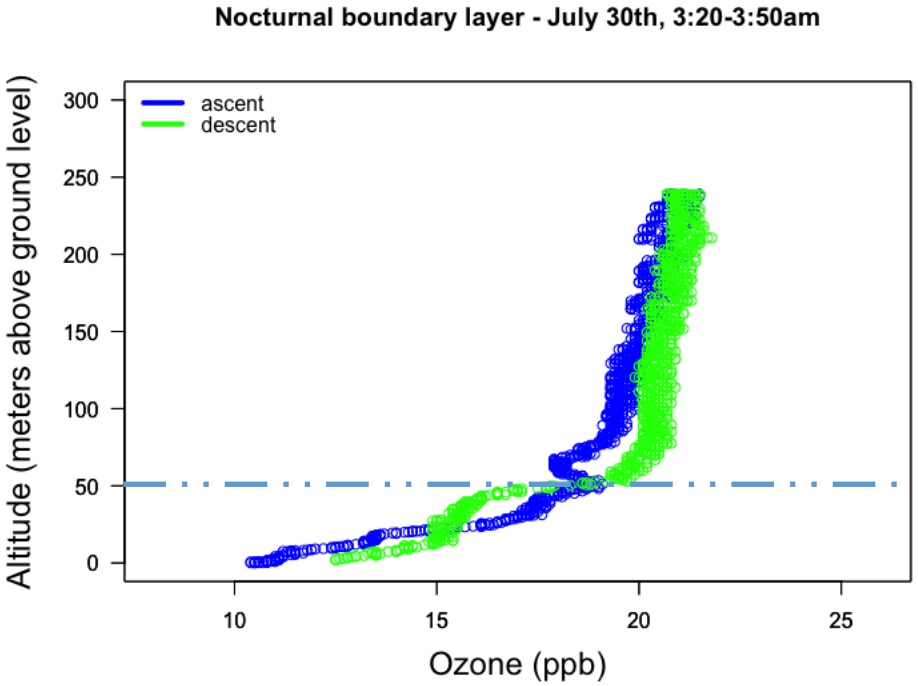
Tethered balloon





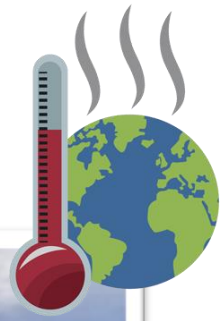
Tethered balloon



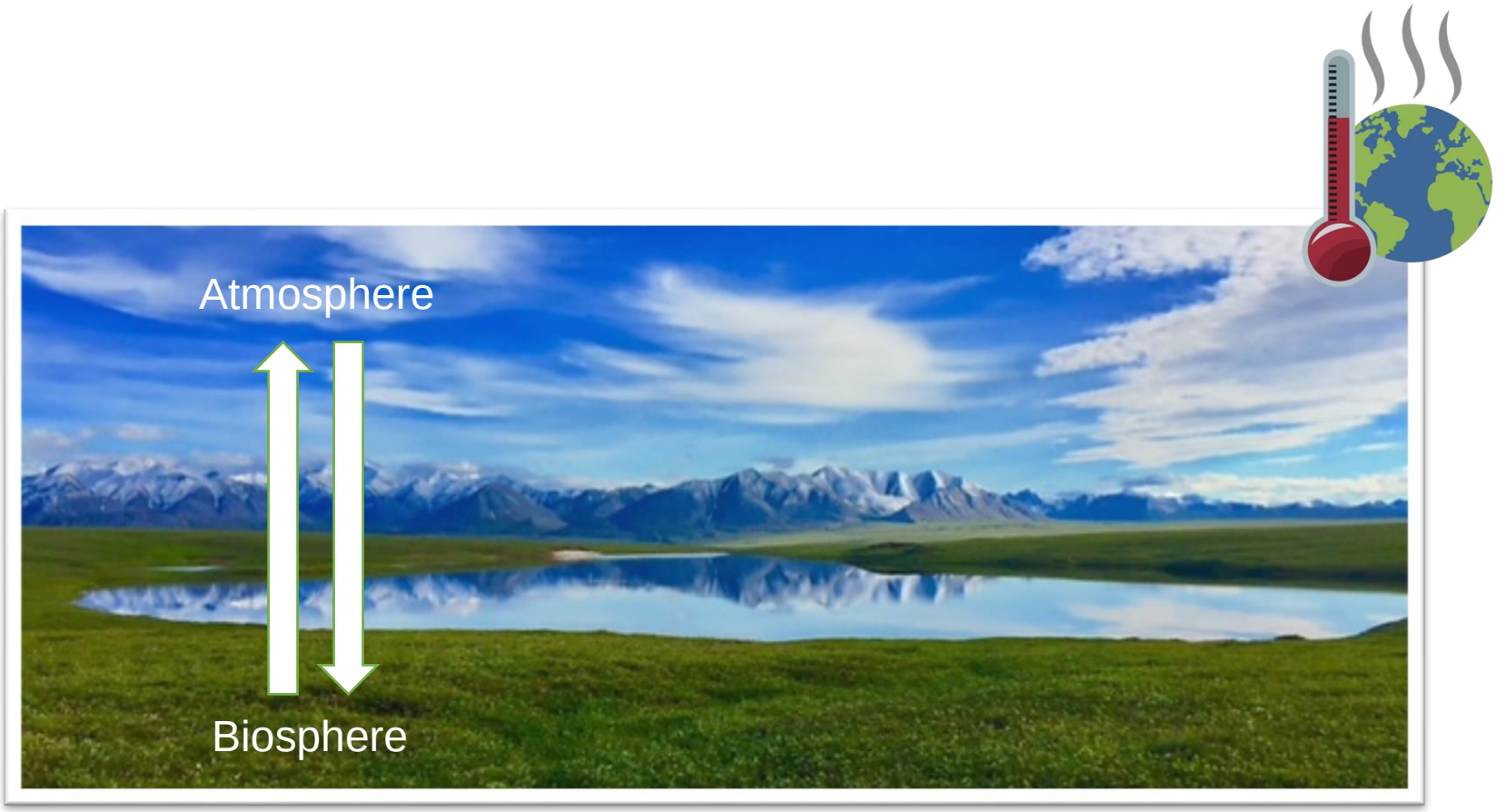


Future challenges

Future challenges

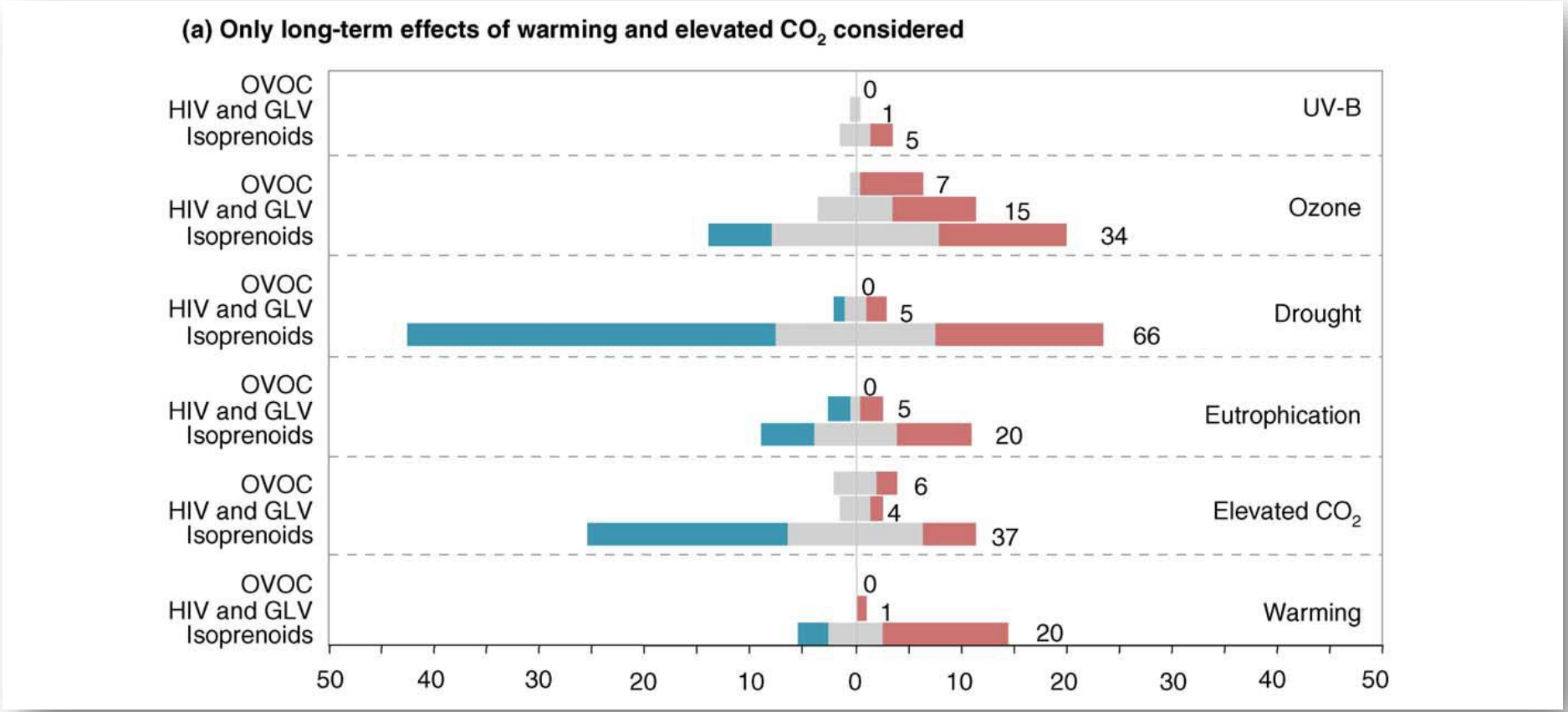


Future challenges



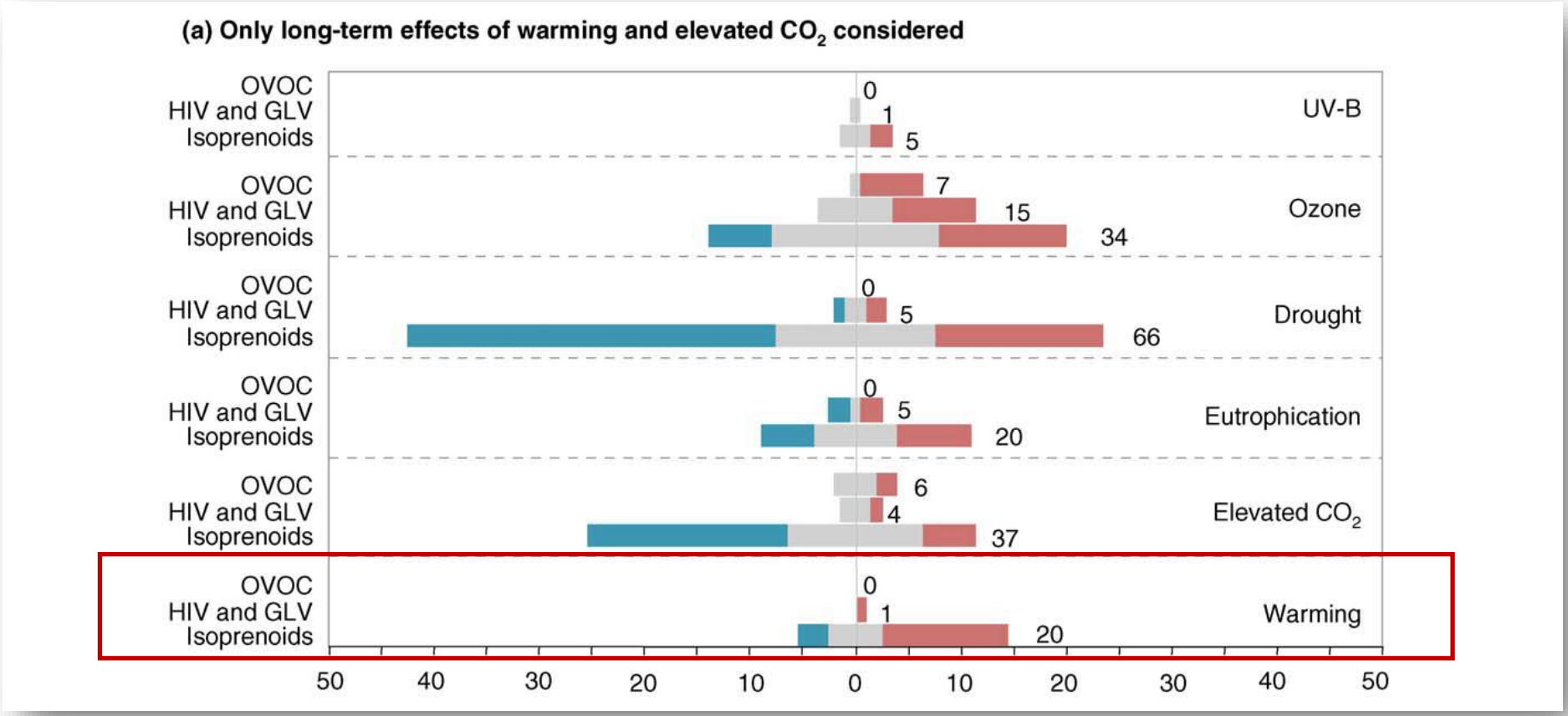
Sensitivity to length of the growing season?
Change in abundance of plants with high terpenes emission capacity?

Future challenges



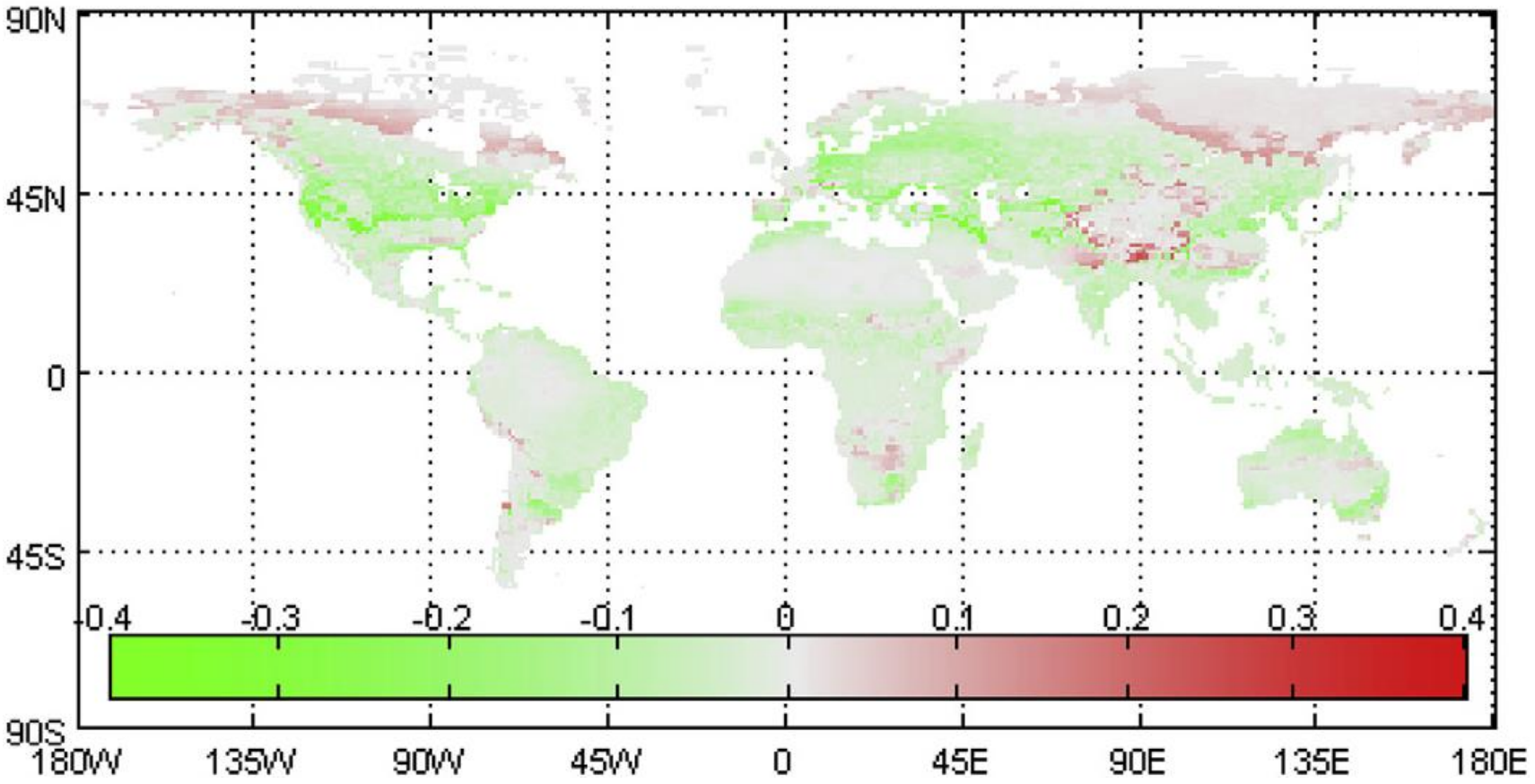
Peñuelas and Staudt, 2010

Future challenges



Peñuelas and Staudt, 2010

Future challenges

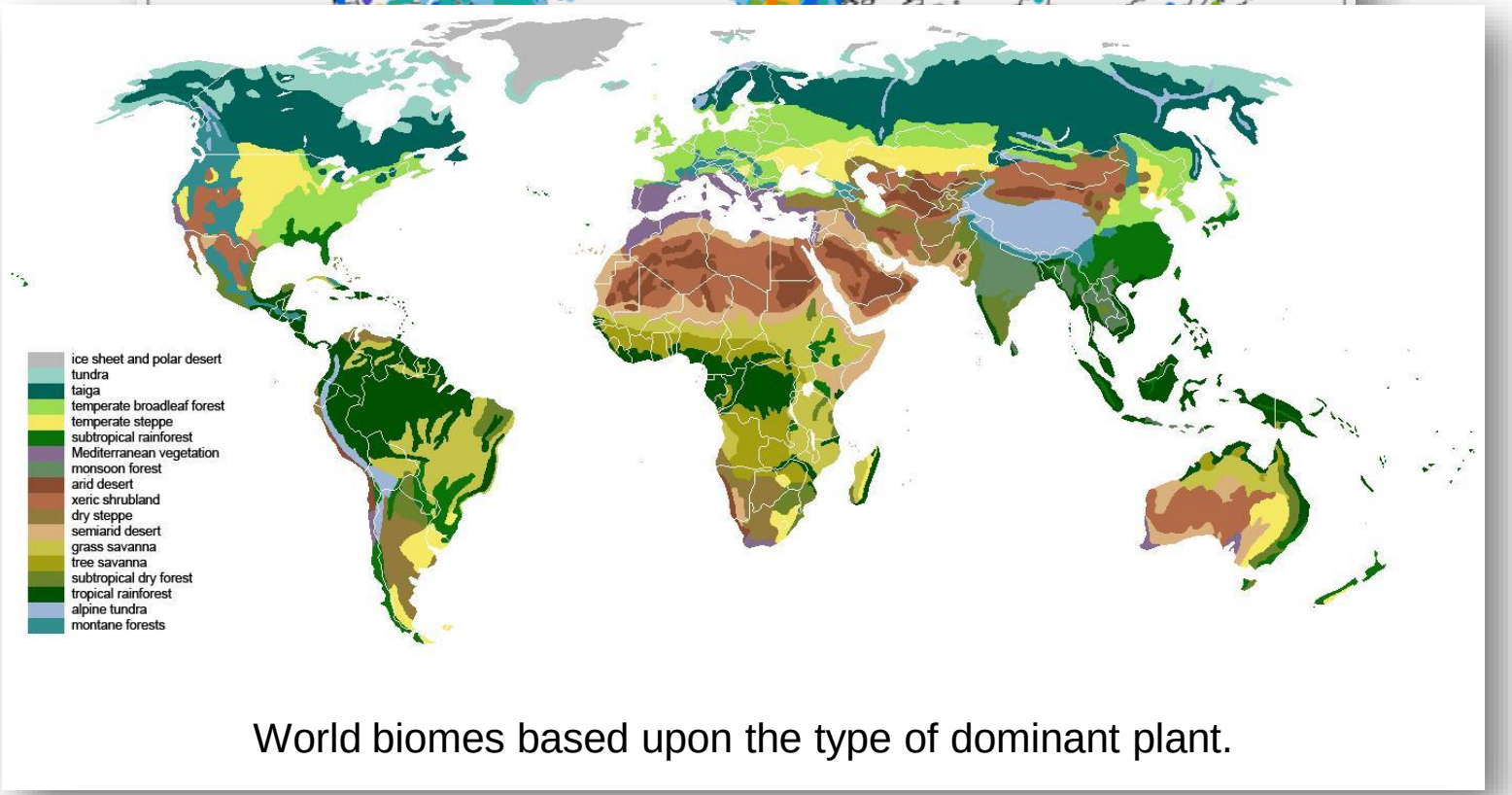


Δ 2100-2000 emissions (in gC/yr/m^2) of monoterpenes
under a RCP 4.5 emission scenario.

Hantson et al., 2017

Existing long-term monitoring stations

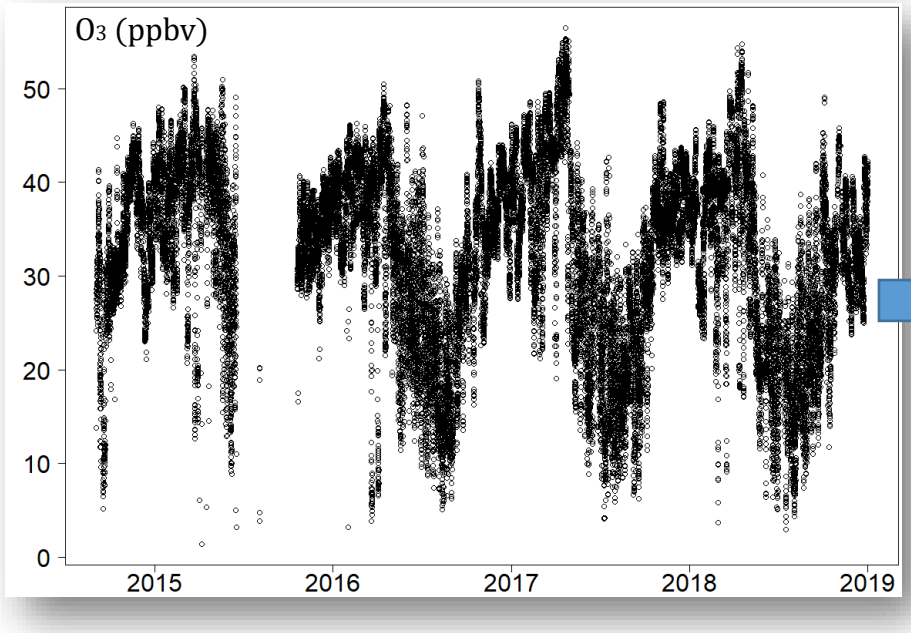
Barrow



World biomes based upon the type of dominant plant.

Future challenges

1. Long-term O_3 monitoring



Future challenges

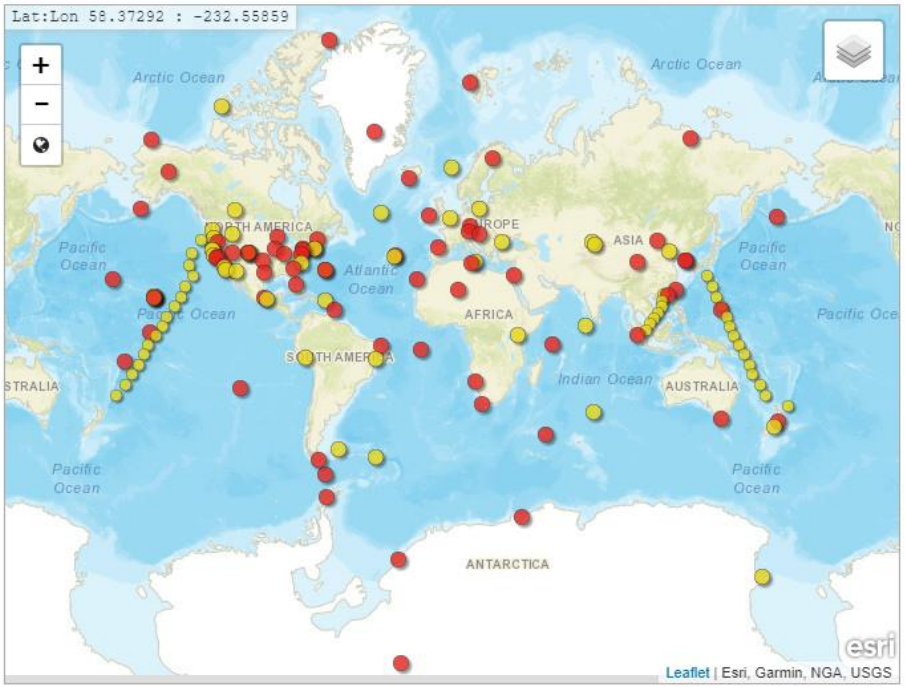
1. Long-term O_3 monitoring
2. Long-term BVOCs monitoring

Global Greenhouse Gas Reference Network

Reference Network ▾ Pro

Cooperative Air Sampling Network

The NOAA/ESRL/GMD CCGG cooperative air sampling network effort began in 1967 at Niwot Ridge, Colorado. Today, the netwo is an international effort which includes regular discrete samples from the NOAA ESRL/GMD baseline observatories, cooperative fixed sites, and commercial ships. Air samples are collected approximately weekly from a globally distributed network of sites. Samples are analyzed for CO_2, CH_4, CO, H_2, N_2O, and SF_6; and by INSTAAR for the stable isotopes of CO_2 and CH_4 and for many volatile organic compounds (voc) such as ethane (C_2H_6), ethylene (C_2H_4) and propane (C_3H_8). Measurement data are use identify long-term trends, seasonal variability, and spatial distribution of carbon cycle gases.



Flask Sampling Newsletters

- Dec 2018
- Oct 2017
- Oct 2016
- May 2013
- May 2012
- April 2011
- May 2010
- April 2009
- May 2008
- May 2007
- May 2006

Thank you for your attention

The crew:

Detlev Helmig

Brendan Blanchard

Jacques Hueber

Helene Angot