The Antarctic Ozone Hole: unequivocal detection of the onset of ozone recovery ?

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about me

Jos de Laat (PhD, MSc)

- research scientist at Royal Netherlands meteorological Institute (KNMI)

- department of satellite observations (group of Pieternel Levelt, Ronald van der A)
  - OMI + TROPOMI satellite missions
  - Data assimilation of total ozone columns

Involvement in WMO Ozone Assessment 2014

- co-author of chapter 3 on Polar Ozone
- **responsible for section on Antarctic ozone (recovery)**

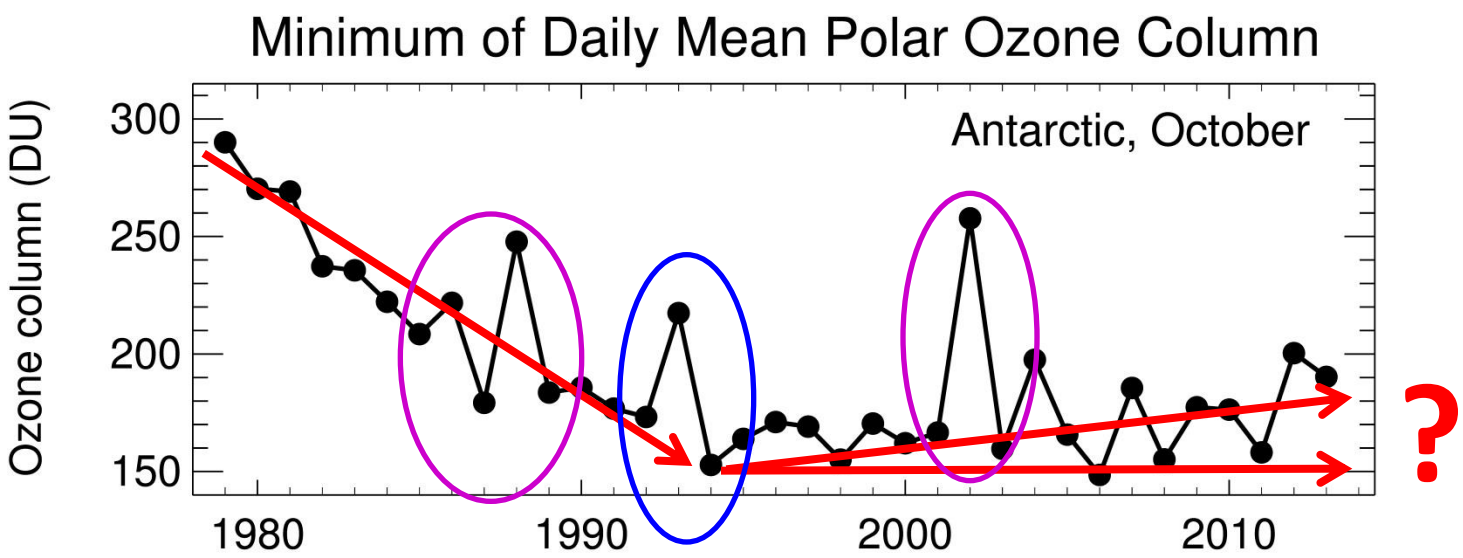


Figure ADM 4-1. High-latitude time series of the minimum daily average total column ozone amount in Dobson units (DU) with October Antarctic values in the bottom panel. Values are those poleward of the 63° equivalent latitude contour. For further details see Figure 3-5 of Chapter 3.

Source: WMO Ozone Assessment 2014

Antarctica

- **Ozone decreased during 1980s – 1990s**
- **Ozone stabilized since mid 1990s**
- **Has there been an post-2000 increase in Antarctic ozone or are we just looking at noise?**
- **Considerable year-to-year variability**
- **… warm winters, volcano …**

Recovery of stratospheric ozone in the Antarctic Ozone Hole

- Stratospheric ozone is affected by both chemistry and dynamics

- Chemistry & ODS: **small slow** but **gradual steady** changes (EESC# change 1-1.5%/year)

- Dynamical effects can be **large** and change **fast** from year to year (+ sub-year; 10's %)
    - Mixing (air physically entering the vortex)
    - Variations in vortex size and location
    - Changes in composition due to changes in chemistry due to changes in temperature due to variations in inner vortex dynamics

Key issue: how to disentangle chemistry from dynamics?

#EESC = Equivalent Effective Stratospheric Chlorine

Antarctic ozone recovery detection methods

Accounting for "dynamics"

[1] Statistical modelling: regression methods

MULTIVARIATE: Salby et al., 2011, 2012; Kuttippurath et al., 2013; de Laat et al., 2015
EOF analysis: Knibbe et al., 2014

[2] Physical modelling (CTM/CCM/GCM etc.)

Solomon et al., 2016

Basic problem either way: recovery is inferred, not obtained from observations themselves

- Inference means making assumptions:
    - How good do we understand effect of dynamics on ozone?
    - How good is our model (statistical/physical)? What is "good" here ?

Criticism of multivariate regression methods [Kramarova et al., 2014; Kuttippurath et al., 2015; de Laat et al., 2015; Varai et al., 2015]

Antarctic ozone recovery detection methods

Critiquing current methods

- ignore structural uncertainties (systematic errors)
- ambiguities on what metric to use
  - *total ozone, ozone hole area, ozone mass deficit ???*
  - *Time average: minimum column, 21-30 Sep, lowest average for 30 consecutive days, Sep, Oct, Sep-Oct, Jul-Dec ???*
  - *Area average (> 60°S/70°S/80°S), vortex average (PV-based or (potential) temperature-based vortex edge), vortex core ???*
- understanding of coupling dynamics and Ozone Hole is relatively poor

[Kramarova et al., 2014; Kuttippurath et al., 2015; de Laat et al., 2015; Varai et al., 2015]

➔ Let's think carefully about methods and metrics before going on adventure!

metrics

total ozone, area, ozone mass deficit?

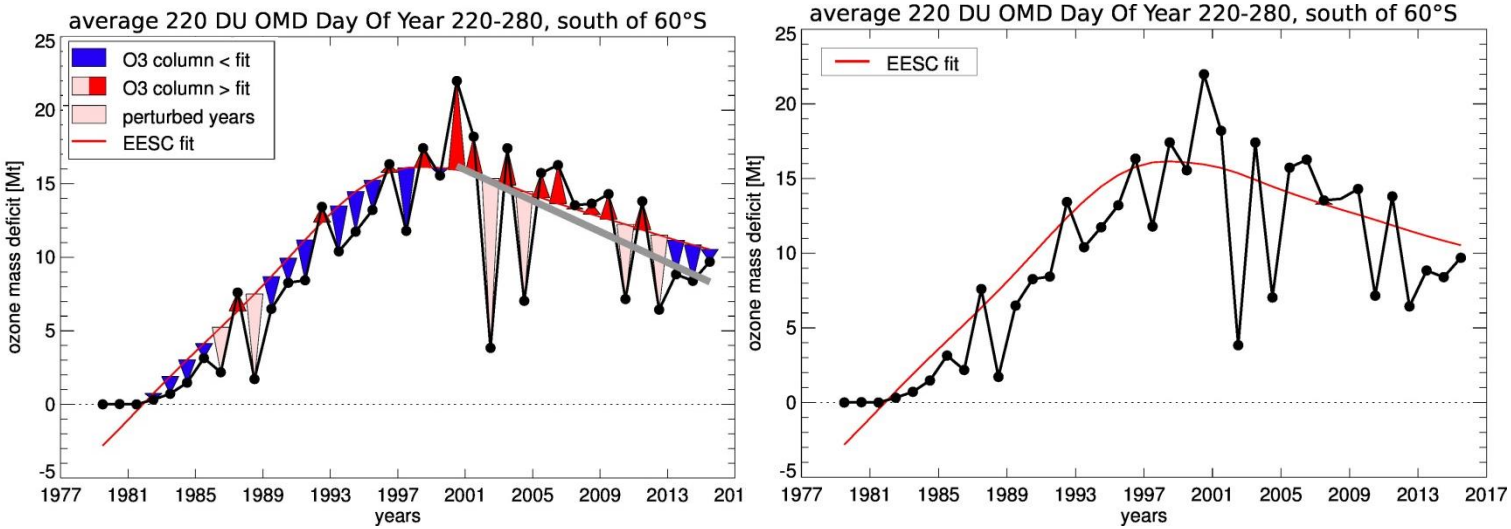
[1] Area is not (very) sensitive to actual amount of ozone depletion (219 or 119 DU = same) ➔ **reject**

[2] Average total ozone requires definition of area and period ➔ **reject**

[3] Ozone Mass Deficit (OMD)
OMD = total mass below threshold total ozone column, typically 220 DU

- no area to be defined
- depends on actual amount of ozone (219 or 119 DU total column does matter)
- time: daily OMD (average daily OMD)
    - Start can be any time
    - Only need end time
        - stop when catatytic ozone chem ceases (= after first week of Oct/DoY 280)

average daily OMD DOY 220-280



Multi Sensor Reanalysis 2 (MSR-2) Van der A et al. 2010, 2015
Assimilation of all possible/available UV/VIS satellitemeasurements

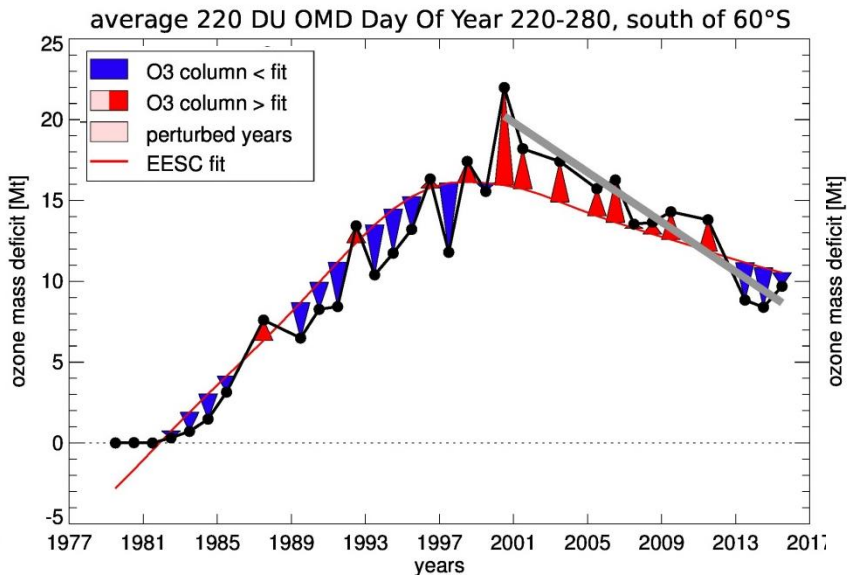
EESC vs OMD: $R^2 = 0.71$

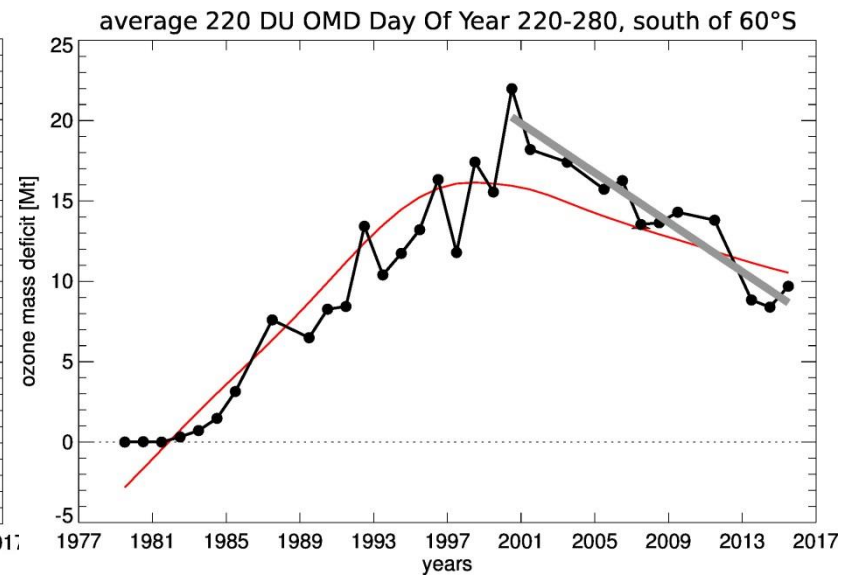
Post year-2000 trend:

-0.52 ± 0.50 Mt/year (± 2.1σ)

For comparison average ozone post year-2000 trend 0.99 ± 2.34 DU (trend significance = 0.8σ)

average daily OMD DOY 220-280: remove PSC-limited years





PSC-limited years

=

1986
1988
2002
2004
2010
2012

EESC vs OMD: $R^2 = 0.87$

Post year-2000 trend:

-0.77 ± 0.17 Mt/year (trend significance 9.8σ)

Accounting for PSC-limited years: remove them !!!

A PSC-limited year is determined based on MERRA reanalysis and reduced PSC volume (negative PSC volume anomalies)

For comparison average ozone post year-2000 trend 2.09 ± 0.91 DU (trend significance = 4.6σ)

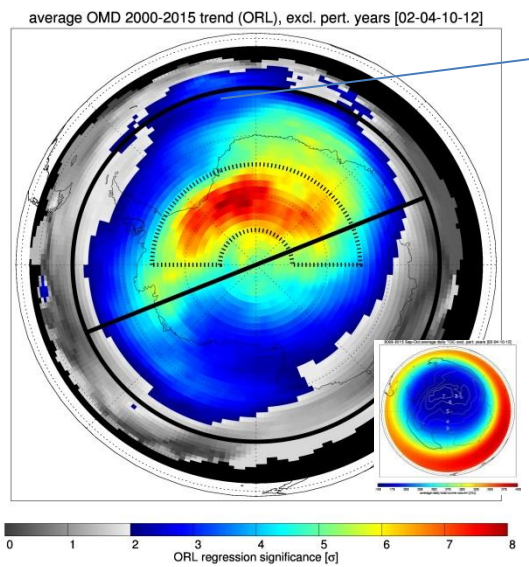
average daily OMD DOY 220-280

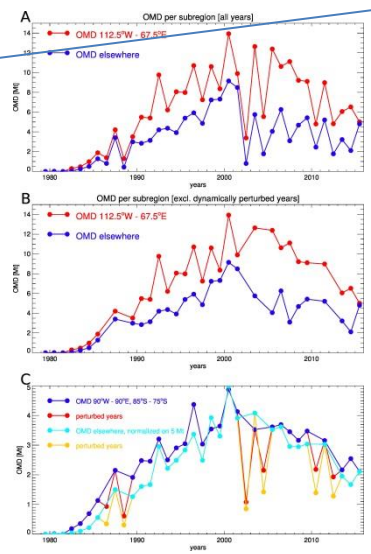
Sensitivity to start year of trend calculation (PSC-limited years removed):

Post year-2001 trend -0.64 ± 0.20 Mt/year (trend significance 6.3σ)
Post year-2003 trend -0.70 ± 0.16 Mt/year (trend significance 8.5σ)

What about mixing?

Post year-2000 shift/change in vortex position/location Hassler et al. [2011]





Vortex core (dotted area):
0.148 ± 0.036 Mt/year
(trend significance 8.2σ)

Vortex edge (anywhere else):
0.663 ± 0.073 Mt/year
(trend significance 9.1σ)

mixing appears not very relevant for the Anarctic vortex as a whole

average daily OMD DOY 220-280

Other processes we looked at:

- Pre-vortex ozon levels

- Assimilation (no sunlight during winter = no UV/VIS satellite measurements & isolated vortex)
  ➔ assimilation model returns slowly to climatology, which depends on ODS

Both cannot explain persistent post year-2000 trend in average daily OMD

conclusions

[1] daily OMD is the "best" metric to determine ozone recovery in Antarctic vortex

[2] few assumptions needed: end date (early October) and OMD threshold column (220 DU)

[3] accounting for vortex dynamics: remove PSC-limited years (MERRA PSC volume based)

[4] highly significant post year-2000 average daily OMD trends (after excluding PSC-limited years)

- trend significance 6σ-10σ = P < 0.00003 / 0.000000000002 (= silly)
- robustness: structural trend uncertainty = "a few sigma"
- spatially coherent trends: vortex dynamics appear unimportant for vortex as a whole
- excellent correlation with EESC (1979-2015 excl. PSC-limited years: R^2 = 0.85-0.90)

[5] by far the best/most significant <u>observation-based</u> trend/recovery levels up till now

[6] **<u>results are predominantly observation-based</u>**

no need for statistical/physical modelling, it is in the data …

Paper has been submitted to JGR

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That's all

Questions?