Global Monitoring Division

• Theme 2 – Ozone and Ozone Depleting Substances

Contents:

Overview – Ozone & Ozone Depleting Gases


Halocarbon flask sampling at Mauna Loa


Ozonesonde launch at South Pole


2013 NOAA ATTREX Team

GMD OZWV and HATS Groups

James W. Elkins, Presenter

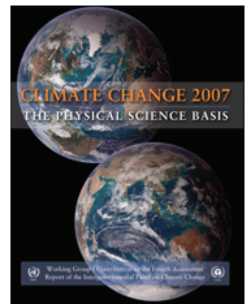
Key Scientific Questions

- Is the Montreal Protocol process successfully reducing the threat to stratospheric ozone posed by ozone depleting substances?
- Is stratospheric ozone recovering as expected?
- How does ozone variability affect the distribution and trends of UV radiation at Earth's surface?

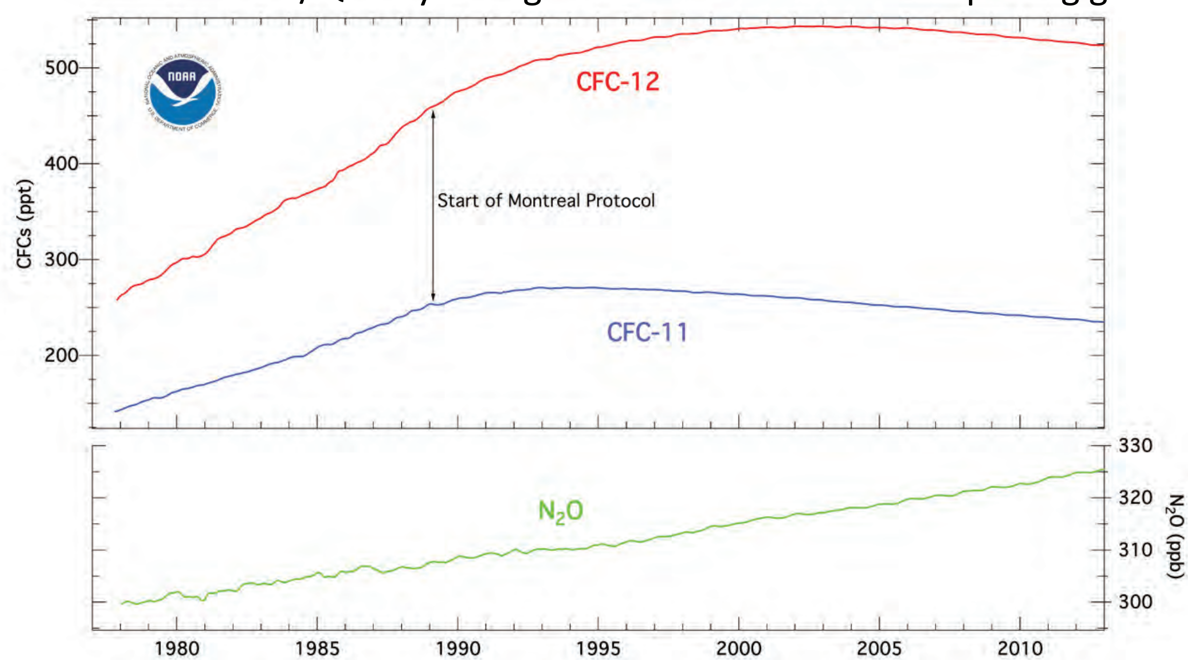
1. Relevance/Motivation of Work

- US Clean Air Act of 1990 (WMO Scientific Assessments of Stratospheric Ozone Depletion)
  - *The Administrators of the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration shall monitor, and not less often than every 3 years following enactment of the Clean Air Act Amendments of 1990, submit a report to Congress on the current average tropospheric concentration of chlorine and bromine and on the level of stratospheric ozone depletion.*

- Other – UN Framework Convention for Climate Change (UNFCCC, June 1992, US ratified in Oct. 1992)
  - Reporting of Science and Technological Results and Advice to the UNFCCC through the International Panel for Climate Change Assessments (IPCC) and other documents.



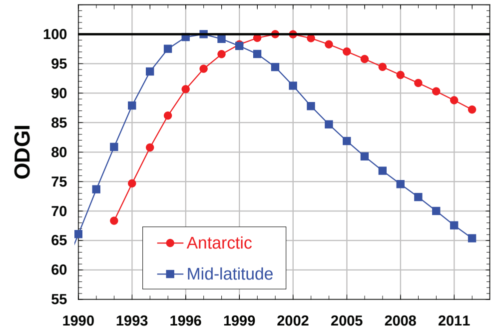
2. Performance/Quality: Long term records of ozone depleting gases.



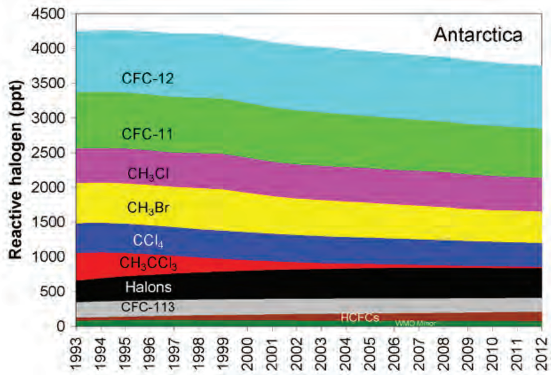
- Global measurements of the CFCs and nitrous oxide (N_2O) began towards the end of 1977. The start of the Montreal Protocol was January 1, 1989.
- Current emissions of N_2O are expected to have a larger impact on future ozone than current emissions of controlled halocarbons. Its global growth rate is 0.7 ppb yr^{-1}.
- Our data are updated once every six months at ftp.cmdl.noaa.gov/hats . See Geoff Dutton's poster.

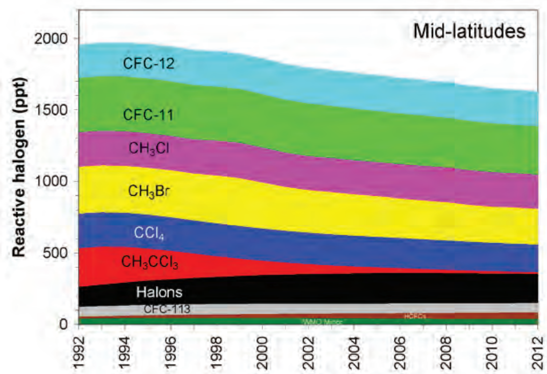
2. (Cont.) The Ozone-Depleting Gas Index (ODGI)

- Guiding the recovery of the ozone layer--GMD's global surface measurements of ozone-depleting substances provide:
  - a measure of ozone-depleting halogen in the stratosphere (as the ODGI) and its changes, and
  - an understanding of processes affecting ozone-depleting halogen (international policy and natural processes, Steve Montzka's Talk)

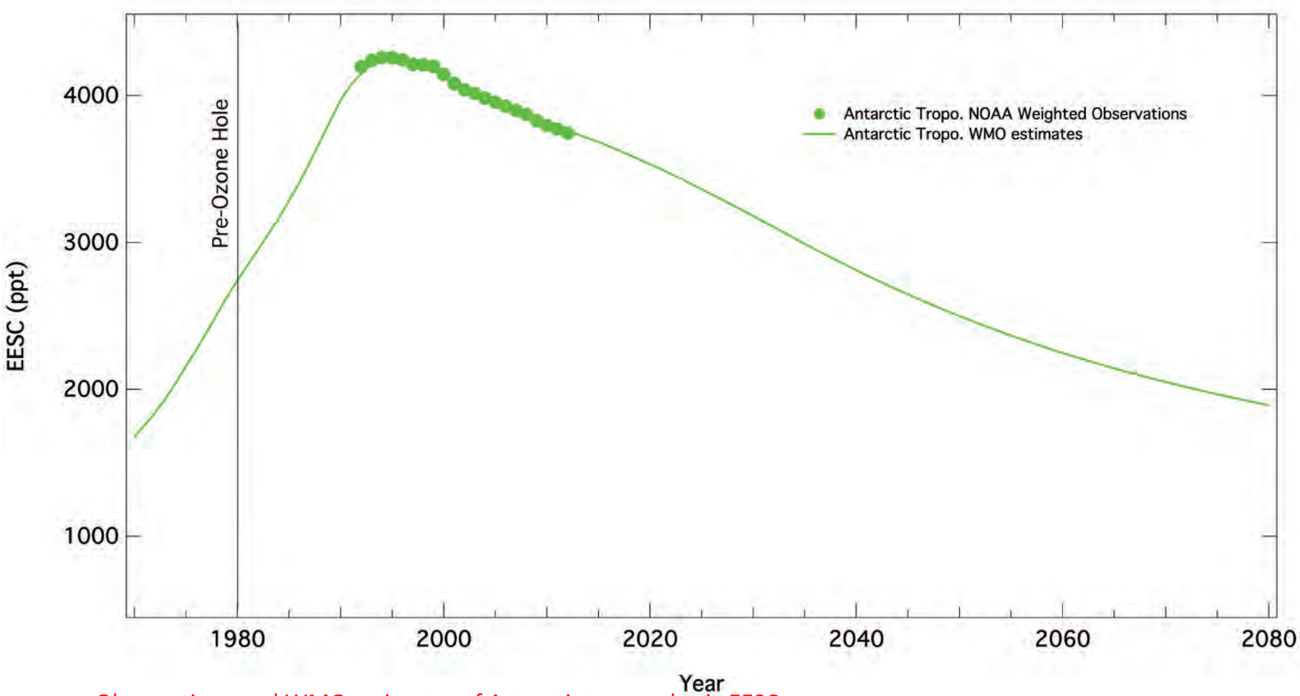


NOAA measures 14 of 16 gases in WMO report, 99% of total Cl & Br.





2. (Cont.) Transport: How stratospheric age affects recovery of the ozone layer?



- Observations and WMO estimates of Antarctic tropospheric EESC.

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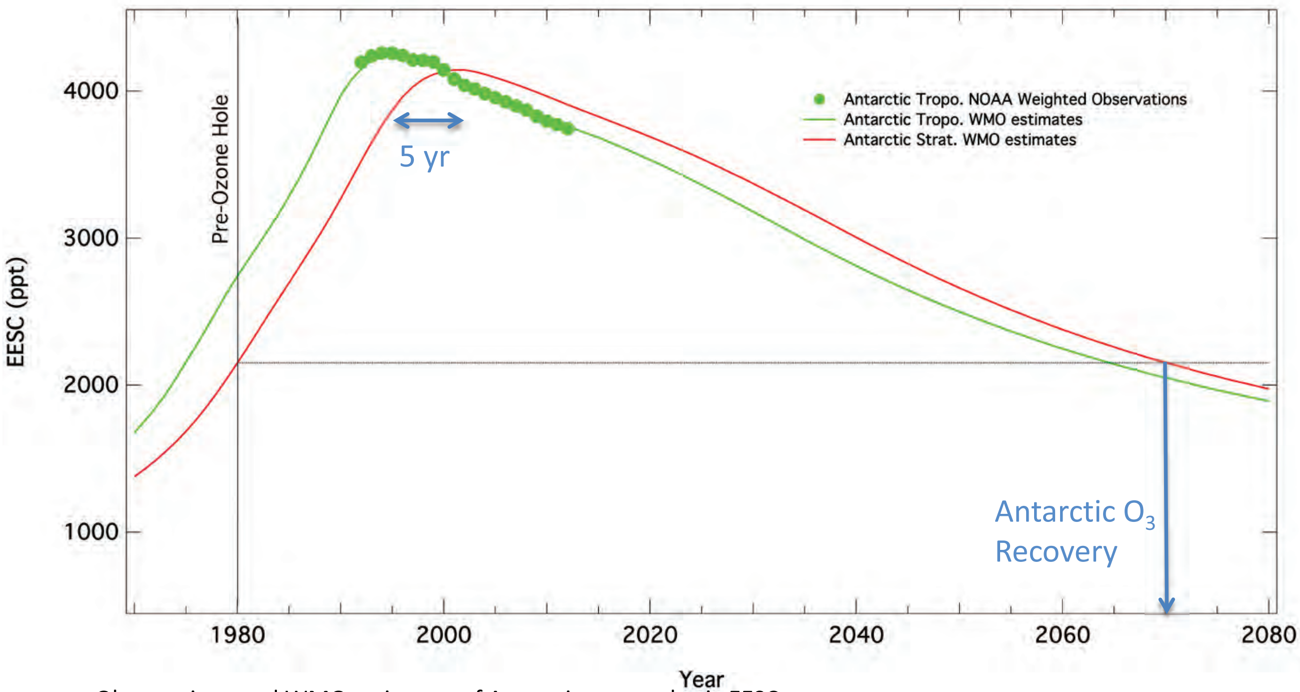

- Observations and WMO estimates of Antarctic tropospheric EESC.
- Tropospheric-stratospheric exchange delays the peak of EESC. 5 y in the polar regions.

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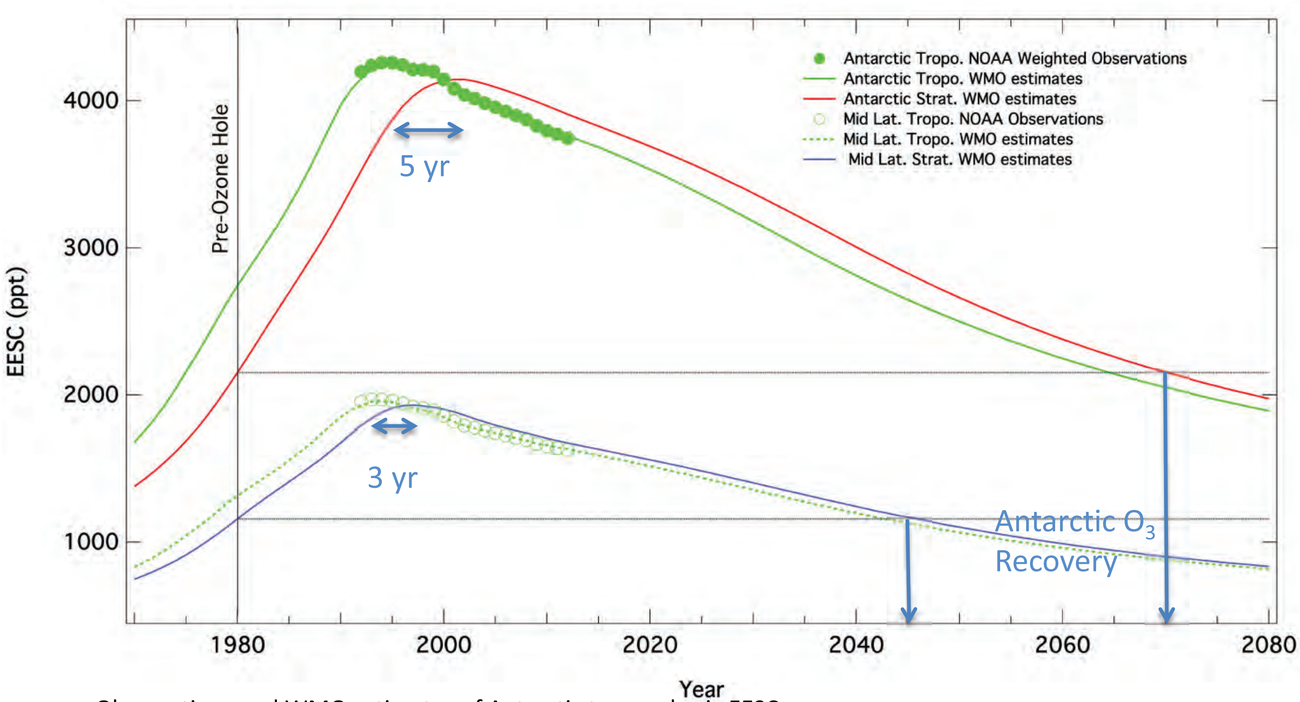
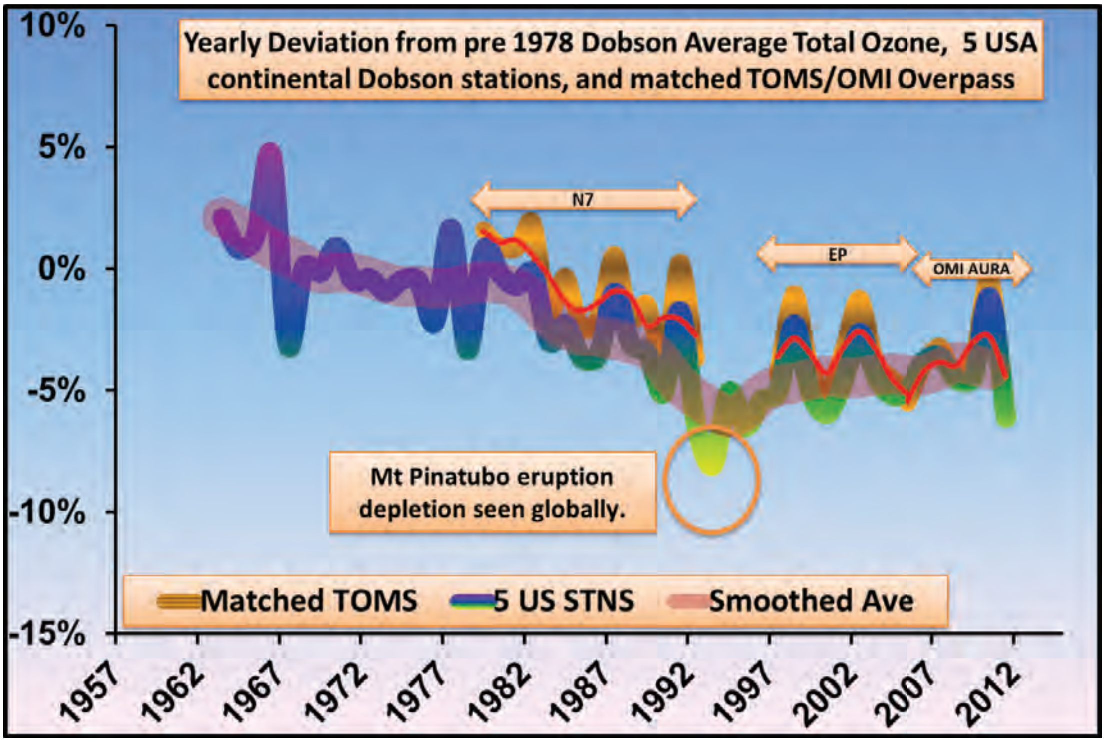


- Observations and WMO estimates of Antarctic tropospheric EESC.
- Tropospheric-stratospheric exchange delays the peak of EESC. 5 yr in the polar regions. 3 yr in the mid-latitudes.
- GCM shows climate increases age, but obs. show increase. Can we monitor this change? (Fred Moore's talk.)

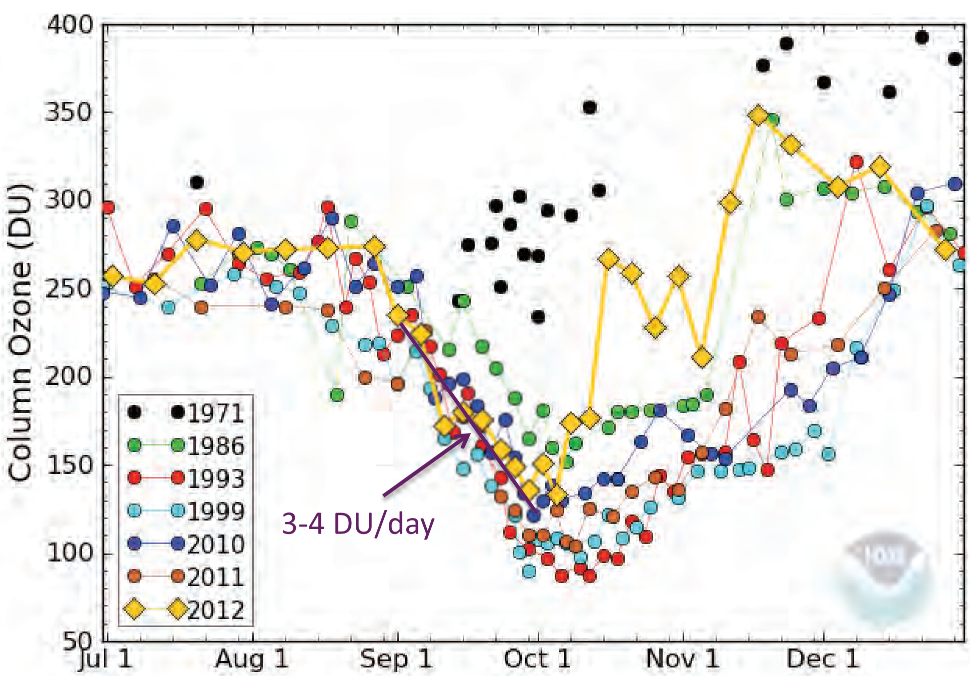
3. (Cont.) Monitoring ozone over time & providing a benchmark for satellites



Dobson Network and satellite record complement each other, sometimes filling gaps.

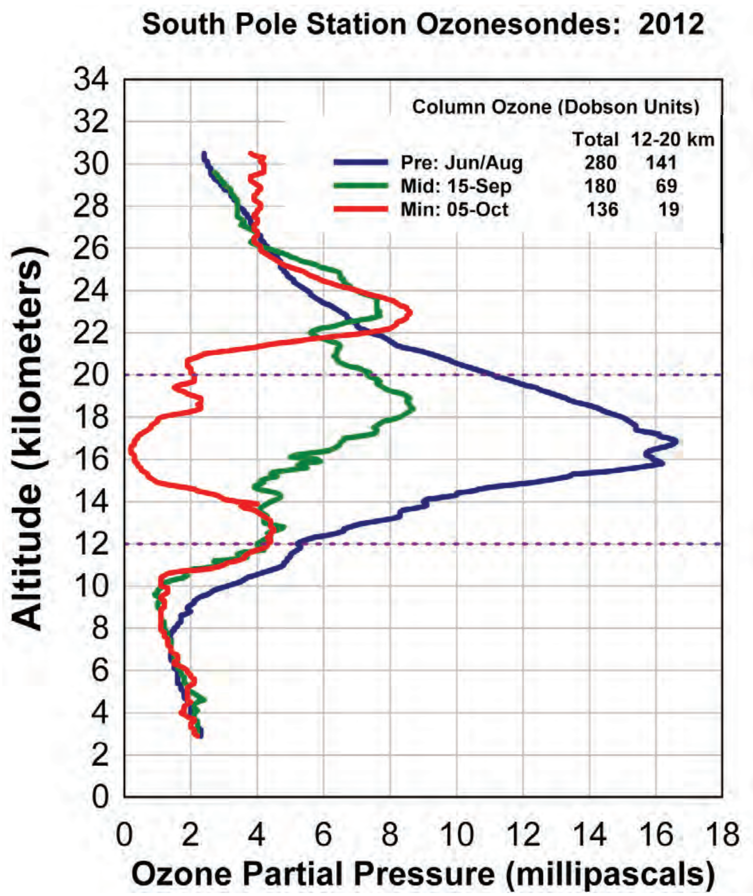
Irina Petro.'s talk & Bob Evans' poster.

2. (Cont.) Total Column Ozone from SPO Ozonesondes



Ozone Recovery over Antarctica: 2012 still within the previous 3-4 DU/day lost rate.

Bryan Johnson's talk



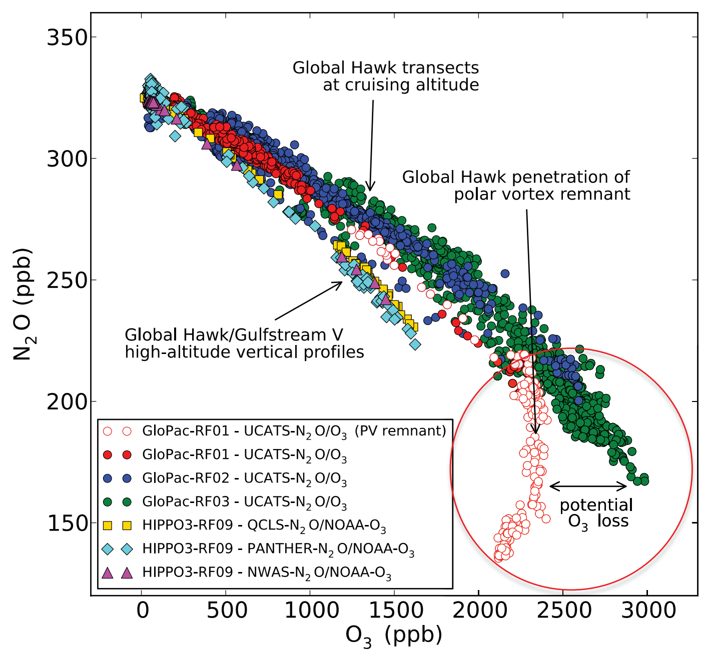
Ozonesonde measurements at South Pole completed 27 continuous years (1986-2012).

2012 minimum total column ozone profile (136 Dobson Units) ranked 24th out of 27 years due to weakened vortex by late September and slightly warmer stratospheric temperatures.

However, the 12-20 kilometer ozone loss rate in early September 2012 was 3.4 Dobson Units/day – the 8th fastest loss rate out of 27 years.

3.Collaboration/Stakeholders: Satellite & airborne validation of trace gases

- Constraints on ODS lifetimes,
- Improve estimates of air movement to allow quantification of ozone depletion in stratospheric air parcels.
- Detected and confirmed ozone loss during HIPPO/GloPac with models.



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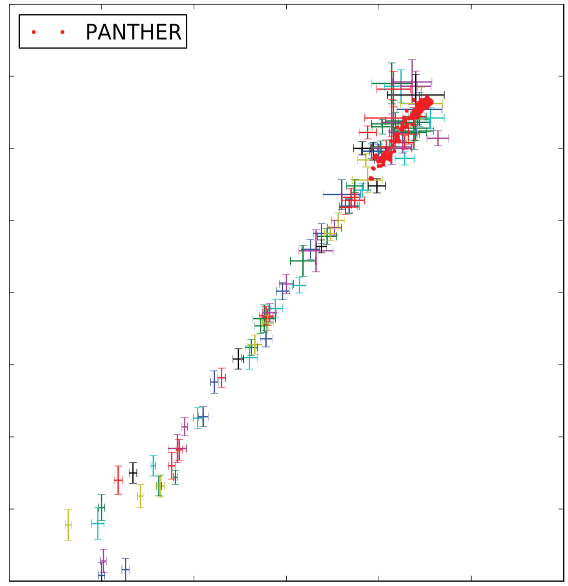

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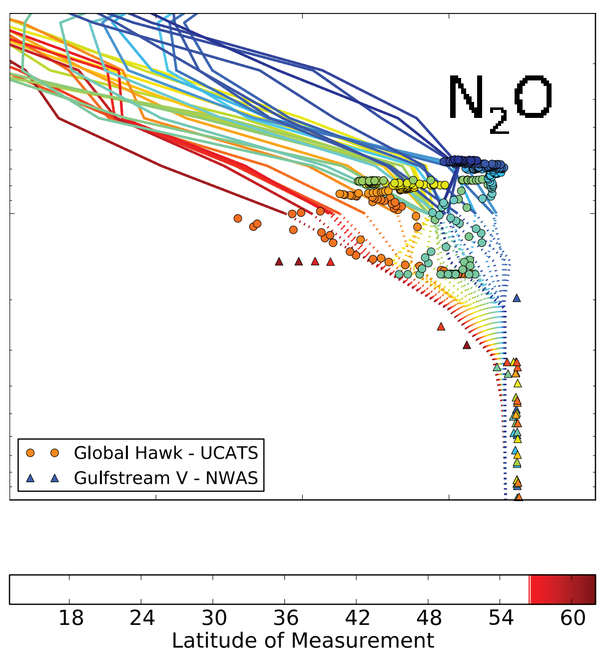
- Detected and confirmed ozone loss during HIPPO/GloPac with models.
- Provide a benchmark that allows as assessment of other platforms where ODSs are measured indirectly (satellites, etc.).
- Compared profiles with ACE, MLS, and TES instruments on satellites (more on Nance poster).



3. Collaborations/Stakeholders (Cont.)

- GMD is the WMO Central Calibration Laboratory for N_2O and other greenhouse gases (CO_2, CH_4, N_2O, SF_6, and CO).
  - Many outside laboratories use our halocarbon and trace gas standards.
- Only two networks provide independent calibration and long term, global measurements of ozone depleting gases on a weekly timescale (NASA's AGAGE and NOAA's GMD).
  - The WMO assessments average the two data sets.
- GMD is the center for the WMO Dobson Network and Calibration Laboratory (data back to the 1960s).
  - It provides independent long term data including Umkehr calculations of trends to compare with NASA satellite record. Ozonesondes are launched from Antarctica, Greenland, US, and the tropics (SHADOZ) and are provided to researchers and governmental agencies.
- GMD Ozone and Ozone Depleting Gases are provided to a number of stakeholders, including WMO Global Atmospheric Watch (GAW), CDIAC, WMO World Greenhouse Gases Data Center, NDACC, many university and government researchers.

4. Summary

- GMD provides high accuracy calibration scales for ozone and ODSs that are recognized internationally as being of the highest quality. Long term trends are shown for these important gases.
- GMD provides independent, high quality, long-term observations of nitrous oxide, halocarbons and ozone on a global scale.
- Transport is important for ozone and total chlorine.
- GMD conducts critical research on the global budgets, emissions (e.g. UNEP Emissions Gap Report, in press), and transport of ozone and ozone depleting gases.

Measurements and analysis of stratospheric ozone

Dr. Irina Petropavlovskikh

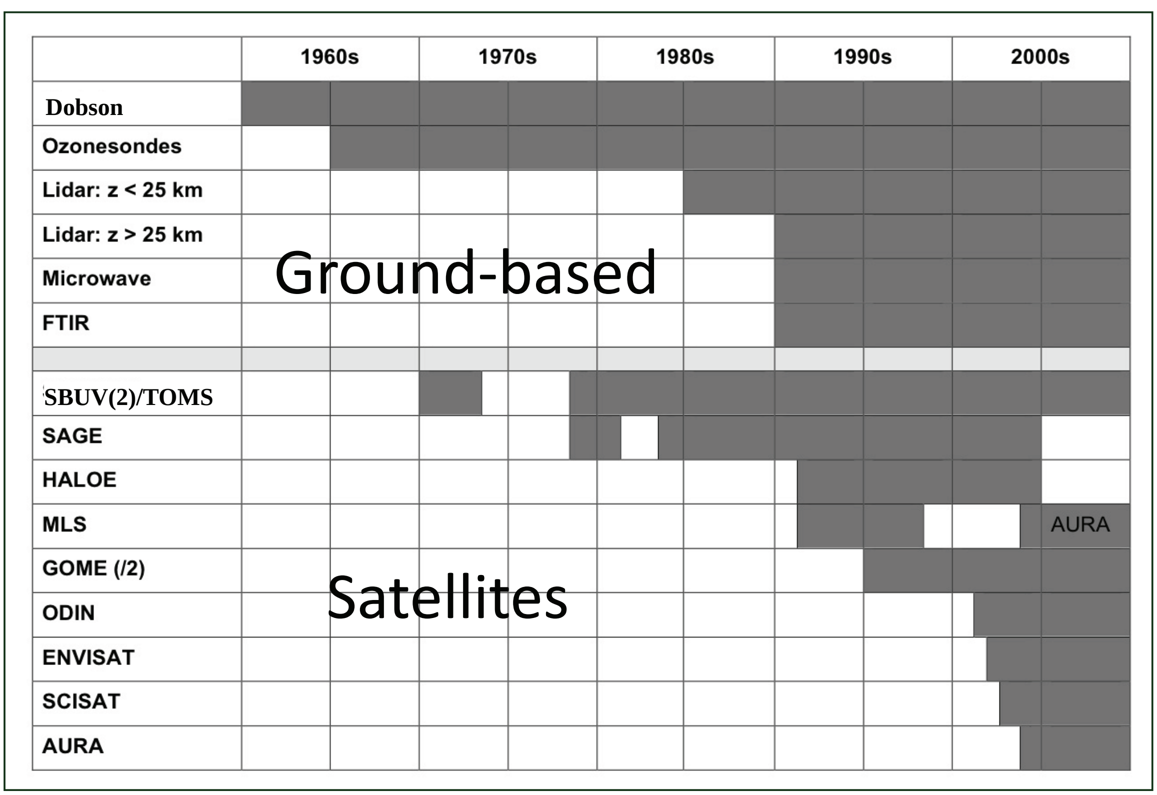
Goals and Science Questions

- **What is the issue?**
  - Stratospheric Ozone recovery following the decline of ozone depleting substances in stratosphere
- **What does it impact?**
  - UV exposure to people and plants, climate forcing, expansion of tropics (change of climate in Boulder?), significant climate changes in the Arctic and Antarctic
- **What are uncertainties in predicting recovery?**
  - Increase in greenhouse gas concentrations, climate changes, change in the meridional transport of ozone-depleting substances (ODS)
  - deliberate injection of stratospheric aerosols

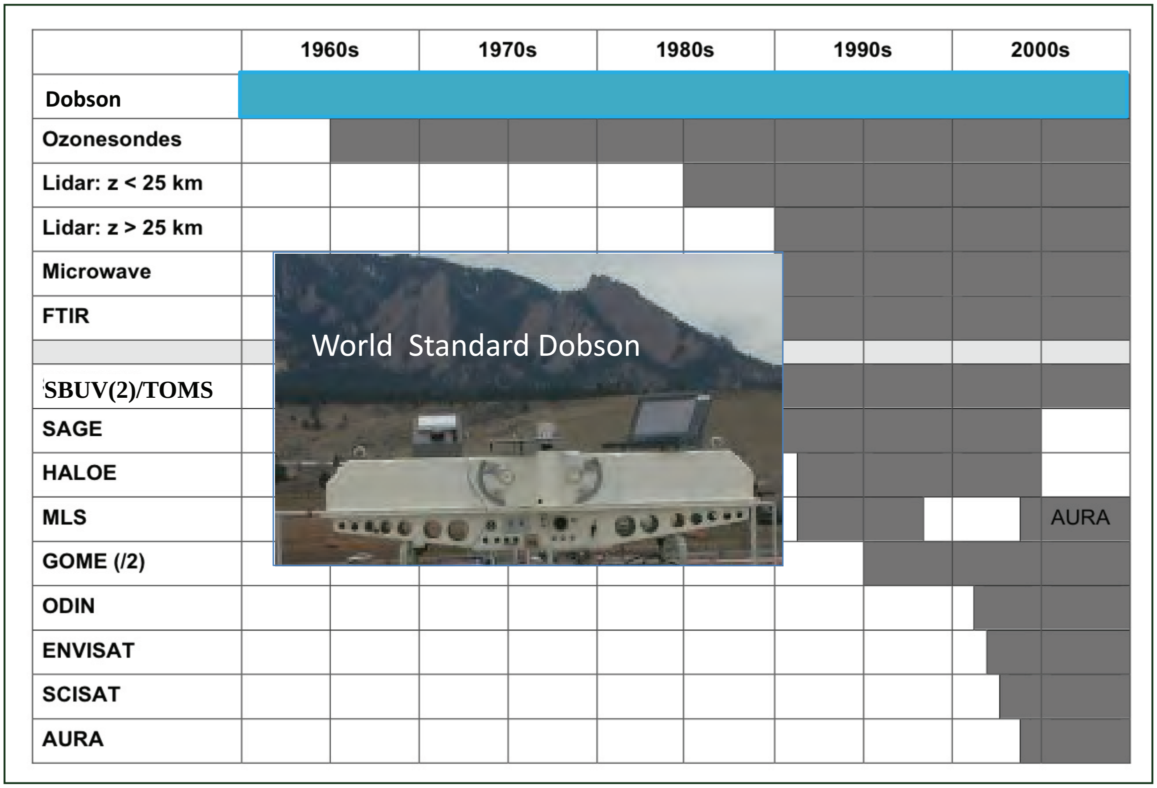
Approaches

- **Long-term** monitoring of ozone profile and column data
- Maintain **calibration** of the WMO Dobson ozone network
- Assurance of **data quality** through calibration and **re-analysis** of data
- Final **archiving** at the WMO data centers
- Provide data for **validation** of NASA and NOAA satellites
- Contribute ozone data and expertise for international **assessments** of current state of atmospheric composition and its long-term changes.
- **Collaboration** with US and international partners

Long-term ozone records

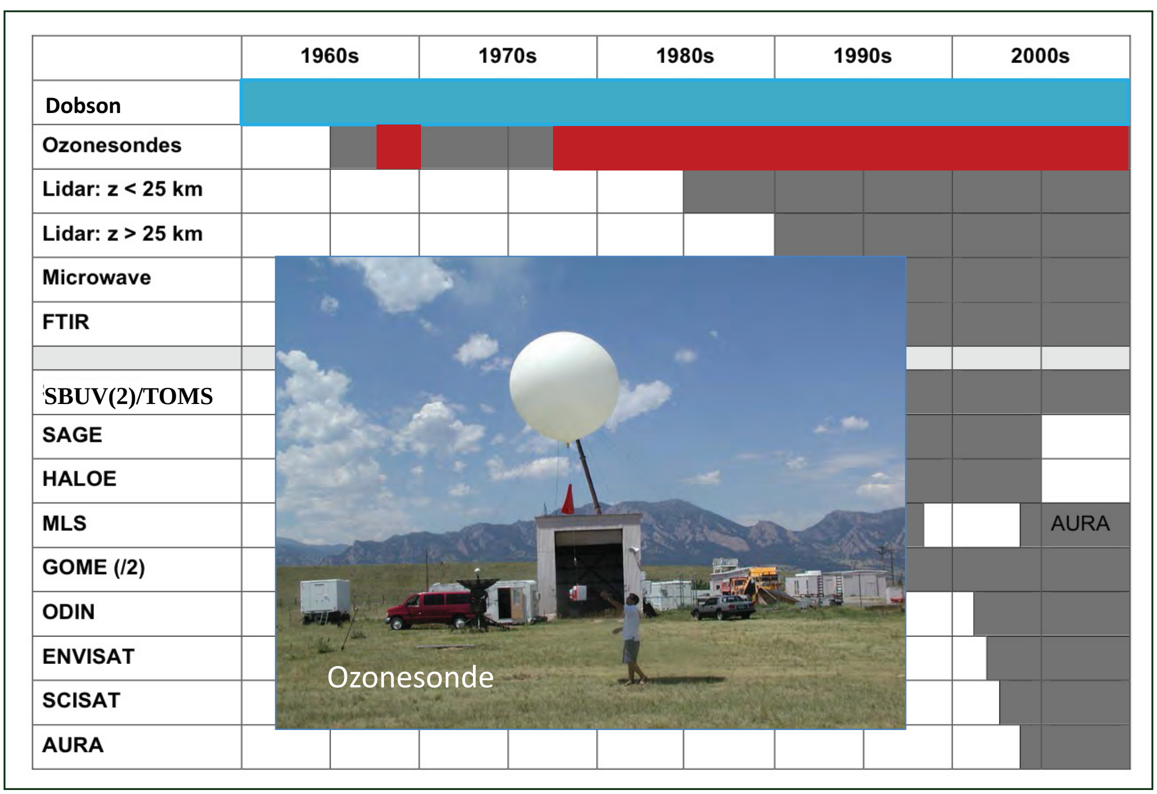


Long-term **GMD** ozone records



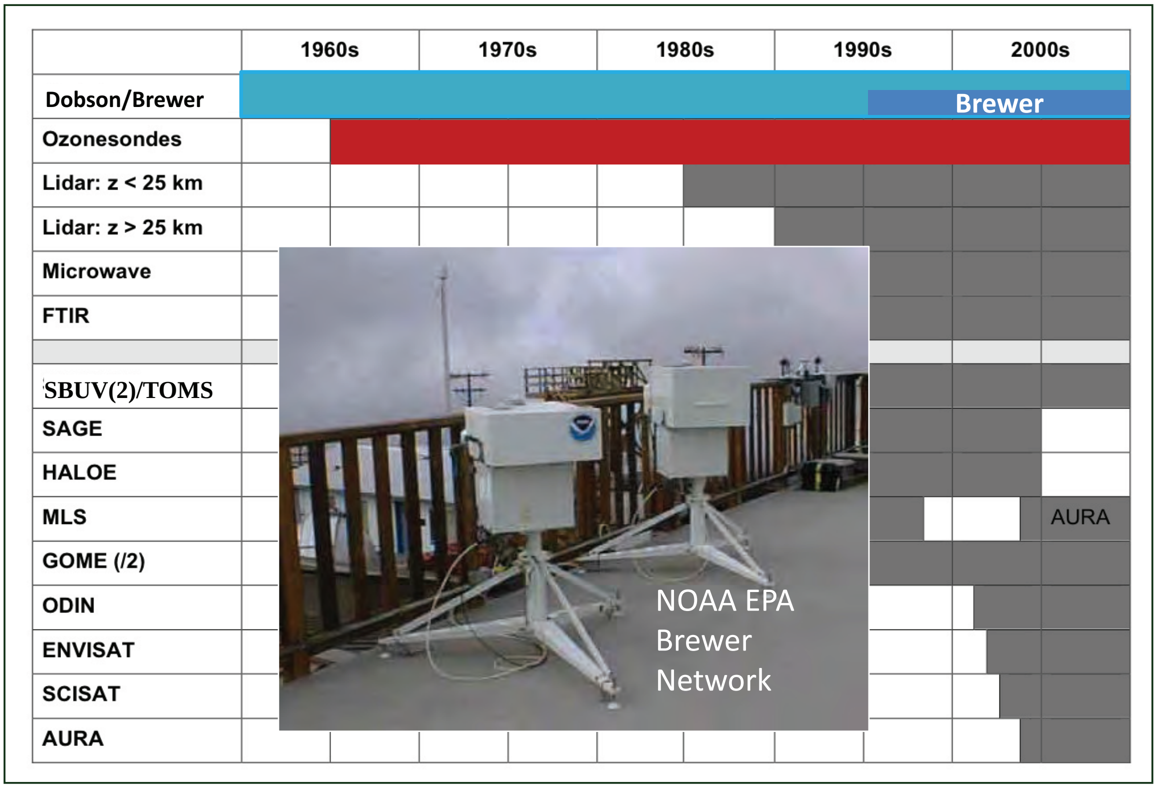
Poster by Bob Evans on Dobson network calibration

Long-term **GMD** ozone records



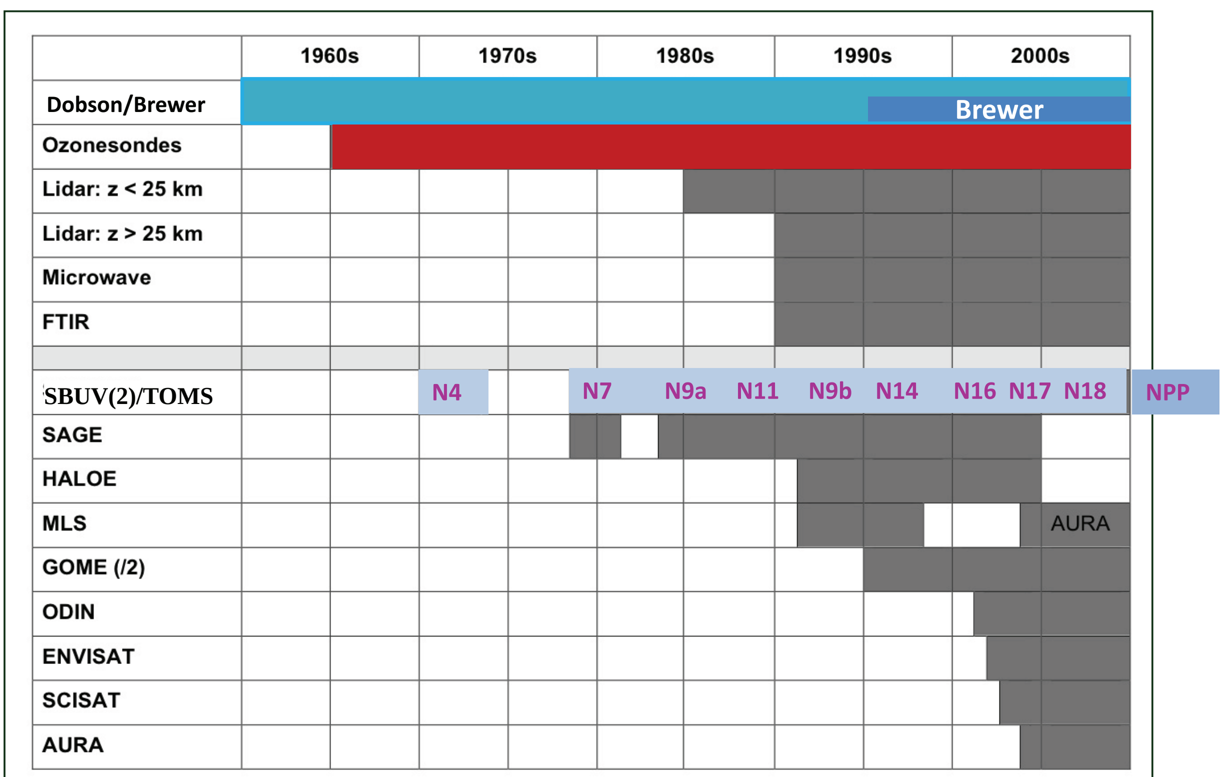
Talk by Bryan Johnson about GMD South Pole ozone records

Newer GMD ozone records

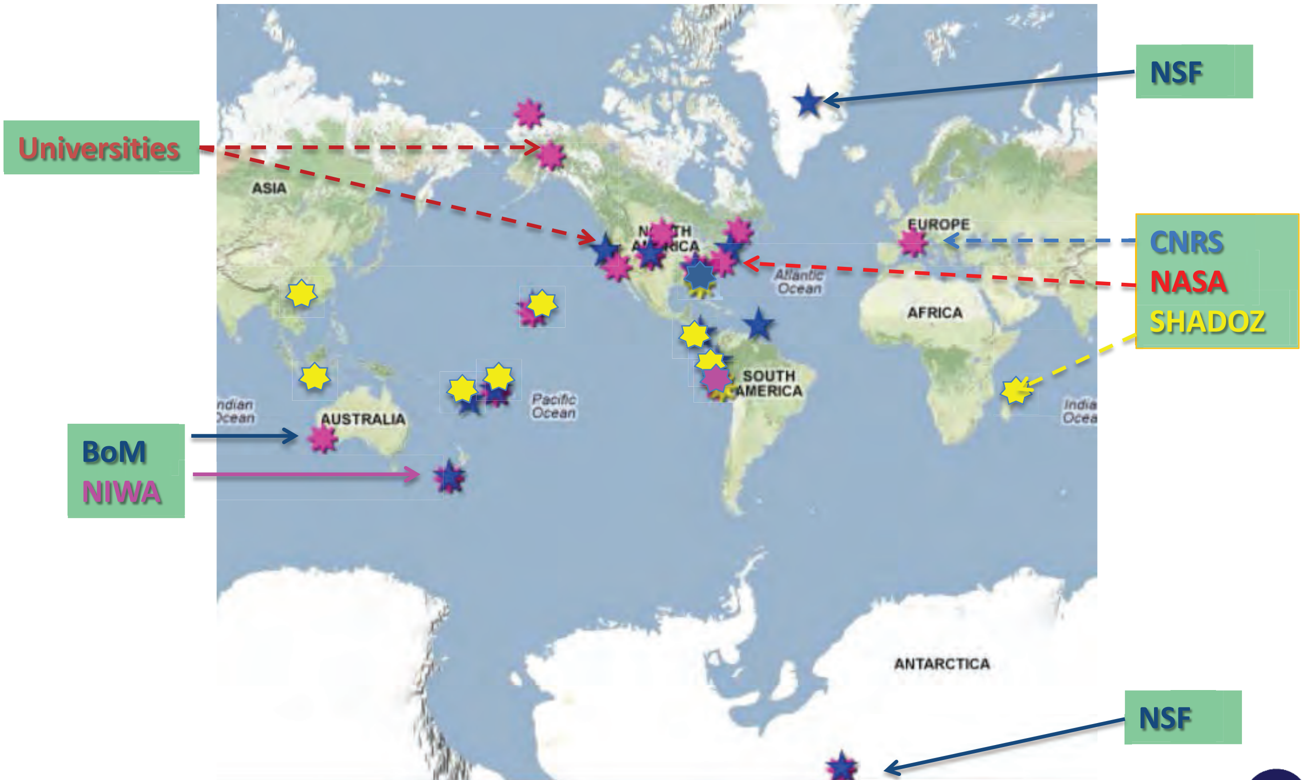


http://esrl.noaa.gov/gmd/grad/neubrew/

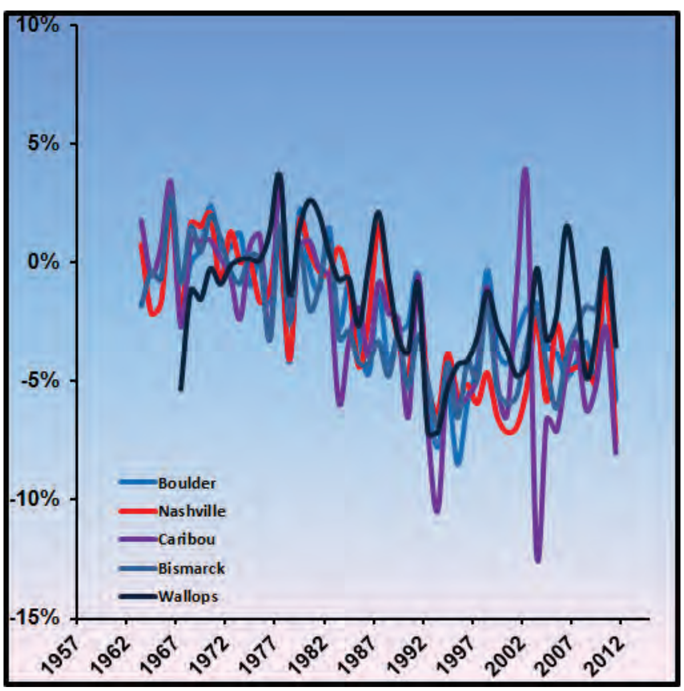
Long-term climate ozone records



GMD Dobson and sonde records & Partners

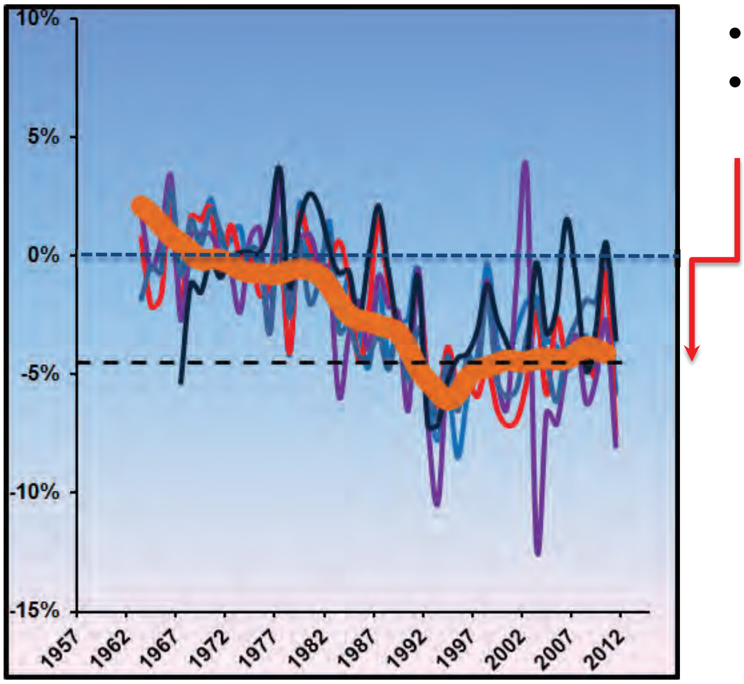


Stratospheric ozone recovery: 5 US stations



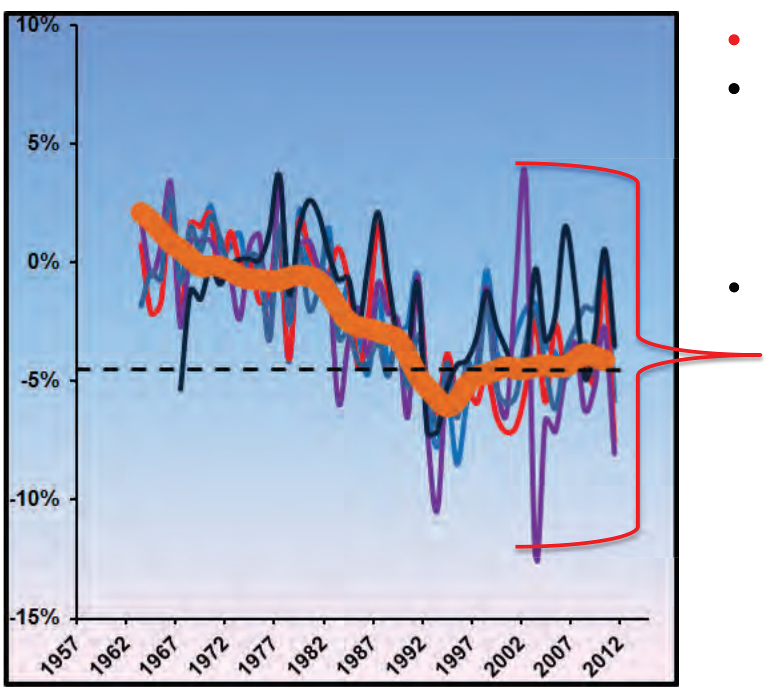
- **62,489**! ozone column measurements at 5 US continental stations beginning in 1962

Stratospheric ozone **recovery**: 5 US stations



- 62,489! ozone column
- NOAA mid-latitude records shows that mean stratospheric ozone levels are still **4%** below 1970s levels

Stratospheric ozone **recovery**: 5 US stations



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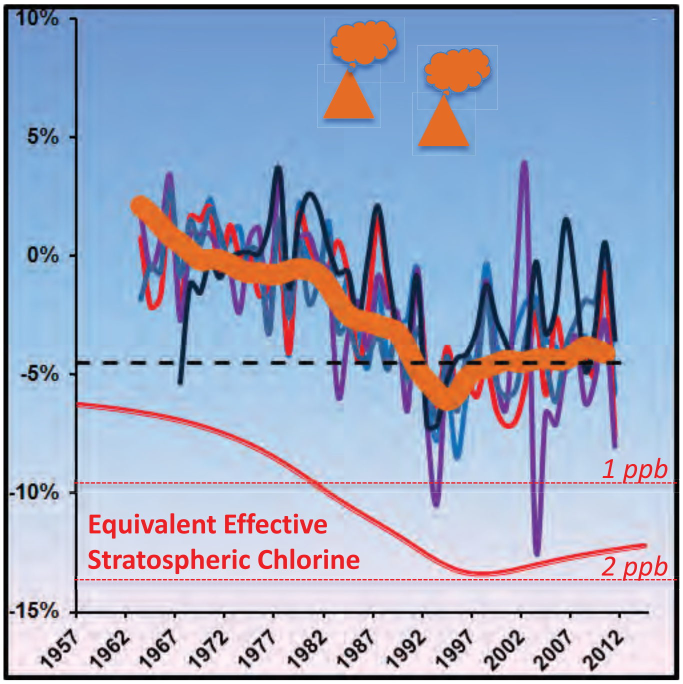
- Increase in inter-annual ozone **variability**

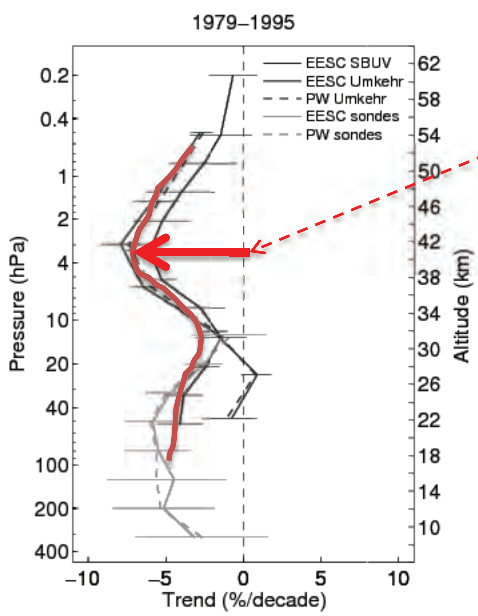
Stratospheric ozone **recovery**: 5 US stations



El Chichón, Pinatubo

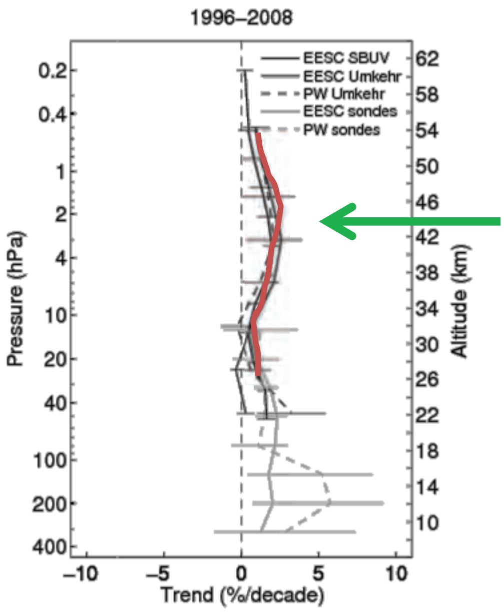
- **62,489**! ozone column
- NOAA middle latitude records shows that mean TO levels are still **4% below** 1970s levels
- Increase in inter-annual ozone **variability**
- **Mechanisms** (Chlorine, volcanic aerosols, transport)
- Long-term effects of **climate change** on future ozone recovery

Mid-latitude stratospheric ozone
2010 WMO Ozone Assessment



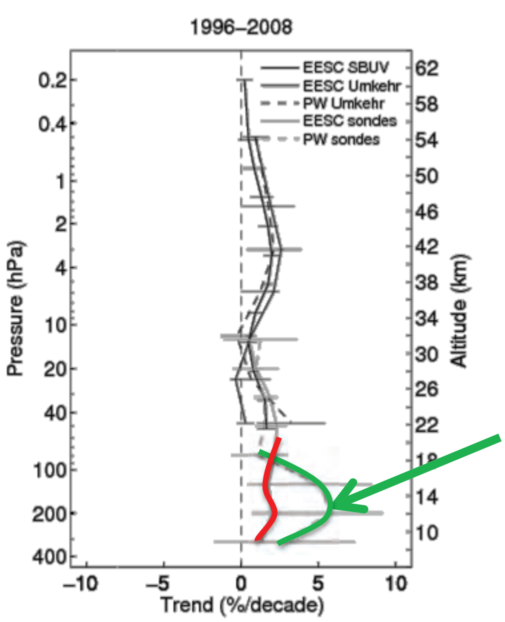
- Ozone **depletion in northern hemisphere 1979-1995**
- **Agreement** between sondes, ground-based, and satellite data

When will ozone recover?
How soon can we detect change?



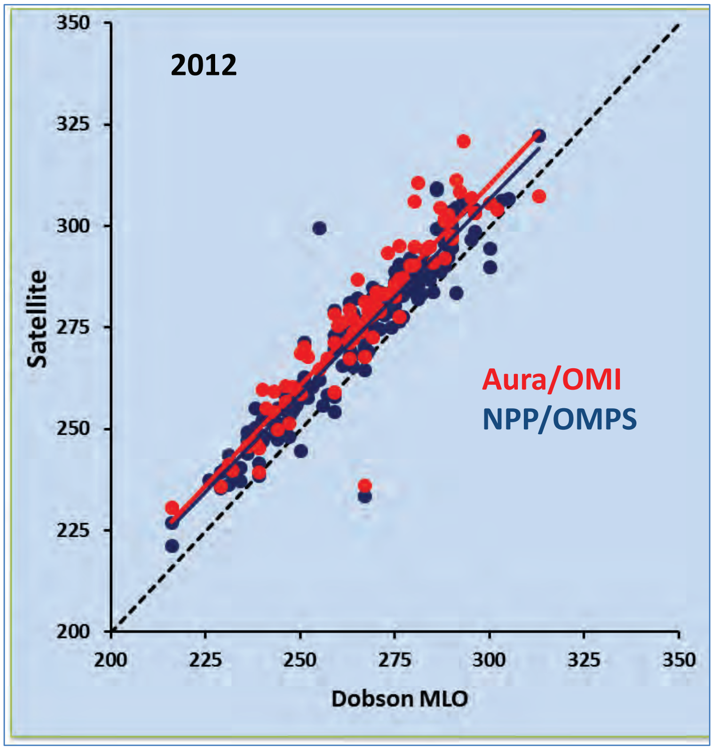
- **Decreasing ozone-depleting substances after 1996**
- Ozone **recovery** at ~2 % per decade above 30 km altitude

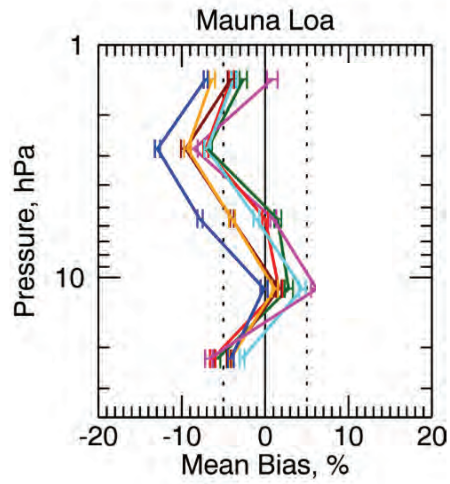
What is driving trends **in the lower stratosphere?**



- **Recovery is not definite**
- High ozone **variability**
- Magnitude and errors depend on **attribution method**
- **ODS or climate ?**
- **Measurement error?**

Validation and detection of Drifts





Satellite merged ozone, 1979-2010
N07 N09 N11 N14 N16 N17 N18

Goals

- **Continue** long-term ozone profile and column records
- **Maintain** high calibration and quality control standards, provide standard to WMO ozone network
- **Validate** long-term and new ozone records
- **Coordinate** with GMD and other climate monitoring networks to improve understanding of climate impacts on ozone: Hilo, American Samoa and SHADOZ
- **Verify** regional and global climate models for attribution – "fingerprints" or patterns techniques (amplitude of change) and trajectories for transport
- **Detect** changes in transport patterns and climatological conditions with respect to impacts on the Arctic ozone
- **Guide** ozone recovery at South Pole and globally

Poster " Monitoring the Earth Ozone layer"

South Pole ozone

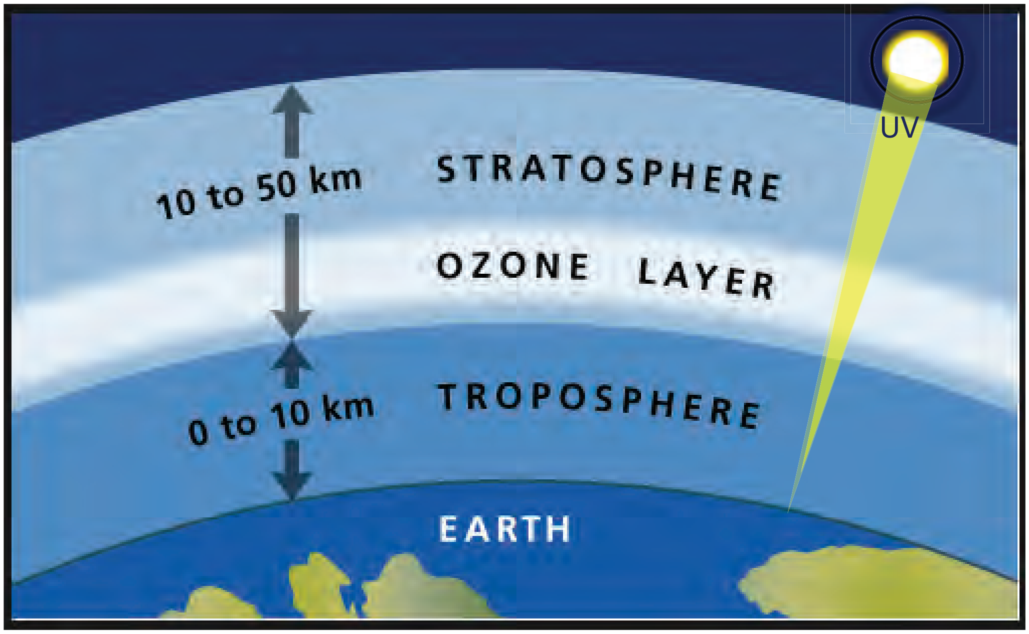
Bryan Johnson

OUTLINE

- Measuring stratospheric ozone at South Pole Station.
  - -- Dobson Spectrophotometer (ground based)
  - -- Ozonesondes (balloon-borne)
  - -- Long term record

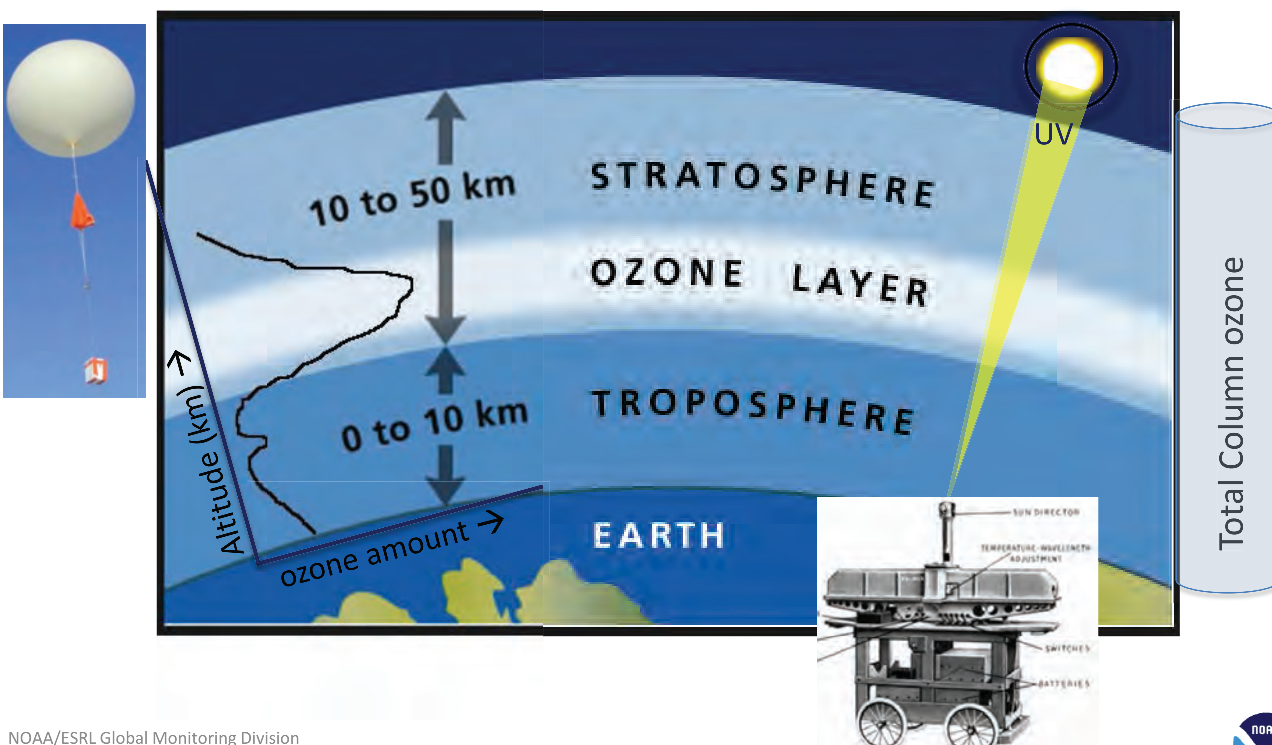
2012 -- October ozone minimum was much higher but loss rates in early September 2012 did not show any indication of ozone recovery.

Stratospheric Ozone

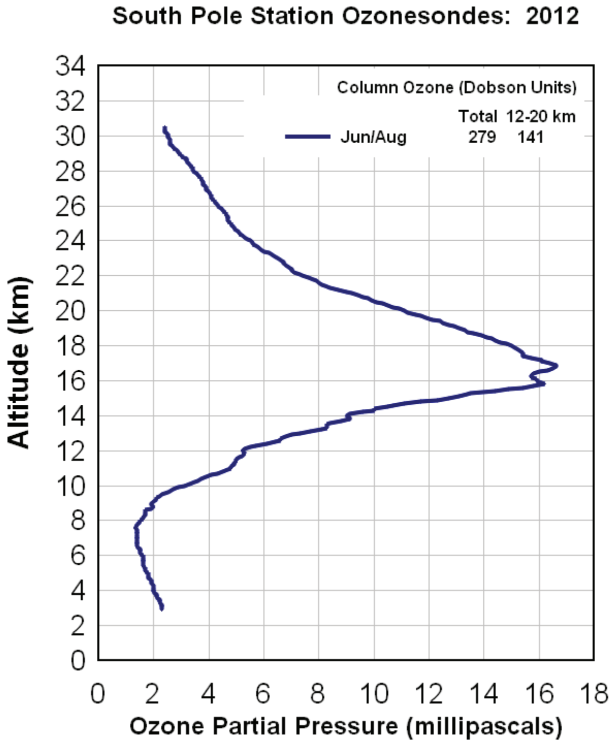


GMD measures stratospheric ozone at South Pole from:

1. Ground-based Dobson spectrophotometer: *51 years 1962-2012*
2. Balloon-borne ozonesondes: *27 years 1986-2012*

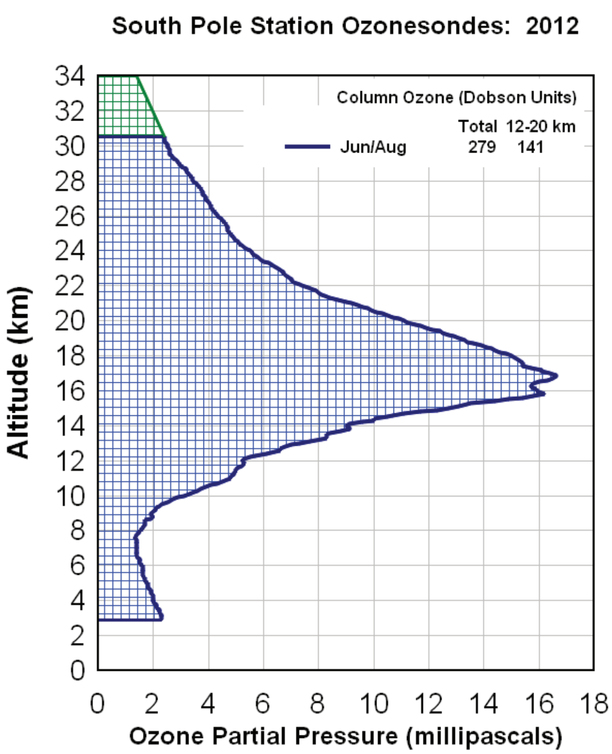


Total Column Ozone (Dobson Units) =
Sum of ozone from surface to burst altitude + Residual amount



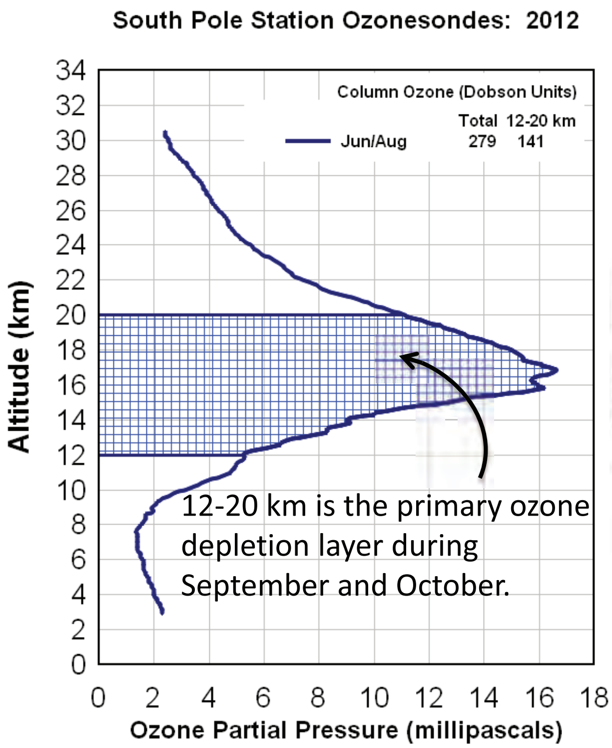
Total Column Ozone of
279 Dobson Units =
0.279 centimeter column of
pure ozone gas at the surface
of the earth.

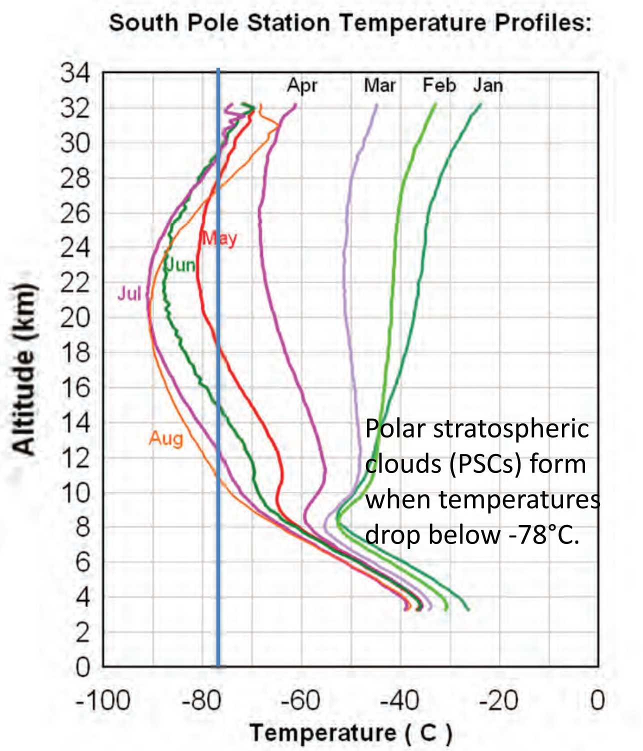
Total Column Ozone (Dobson Units) =
Sum of ozone from surface to burst altitude + Residual amount



Residual Ozone = 21 Dobson Units
Integrated Ozone = 258 Dobson Units
Total Column Ozone = 279 Dobson Units

12-20 km Column Ozone (Dobson Units)
18 km temperature (C)





Balloon-borne ozonesondes

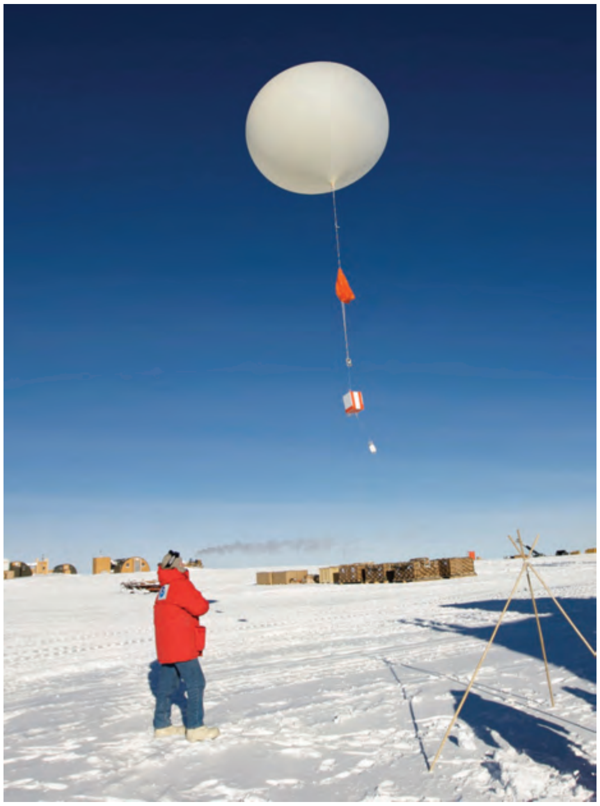
Ozonesonde launch in early September.

Balloon-borne ozonesondes

October (day after strong wind storm).

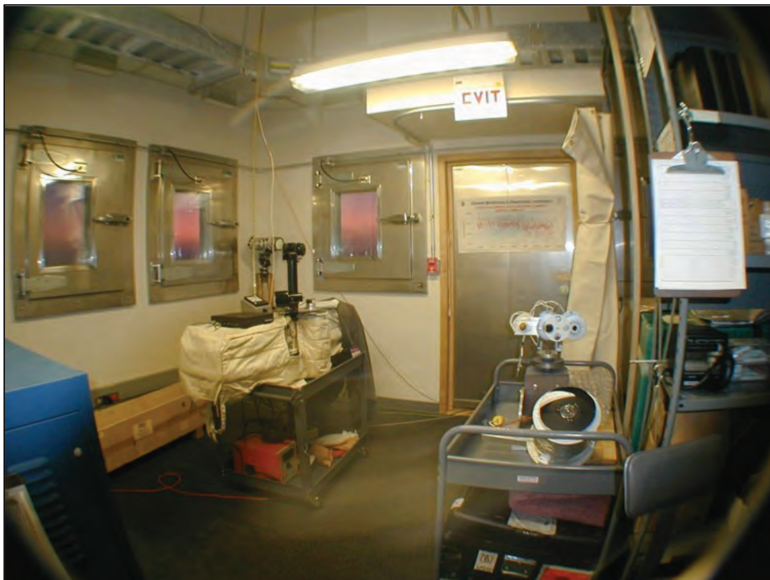
Balloon-borne ozonesondes.

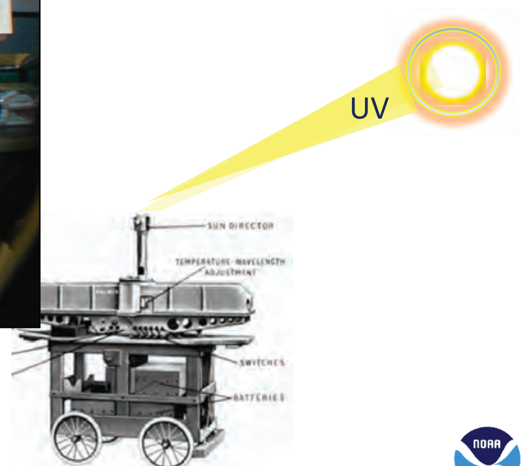
late October.



Ground-based Dobson spectrophotometer.

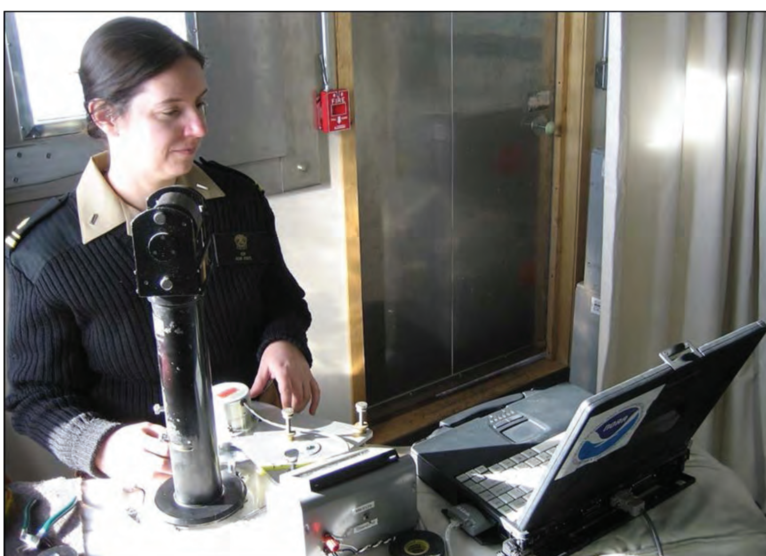
Three observations (measurements of total column ozone) in a 24 hour period - as the view of the sun passes by the 3 windows.

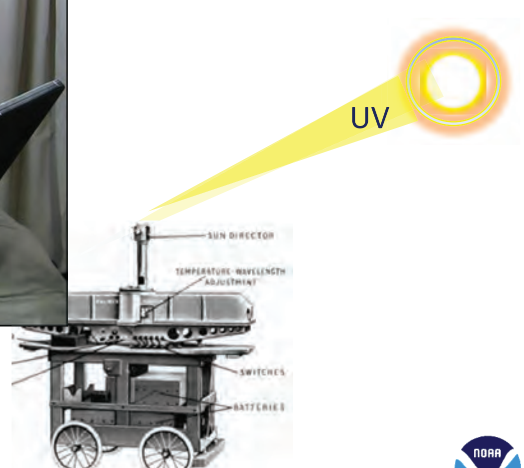




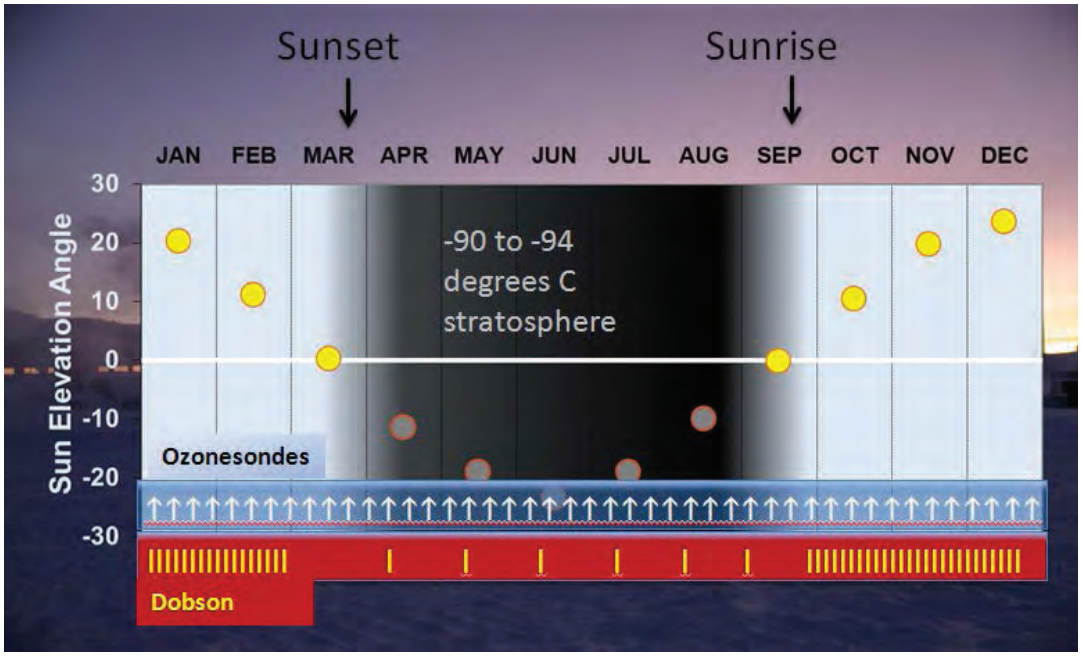
Ground-based Dobson spectrophotometer.

Observation taken by NOAA Corp Officer Amy Cox during winterover 2007-2008.





Summary of South Pole Sun Elevation Angle and Corresponding Ozone Measurements.



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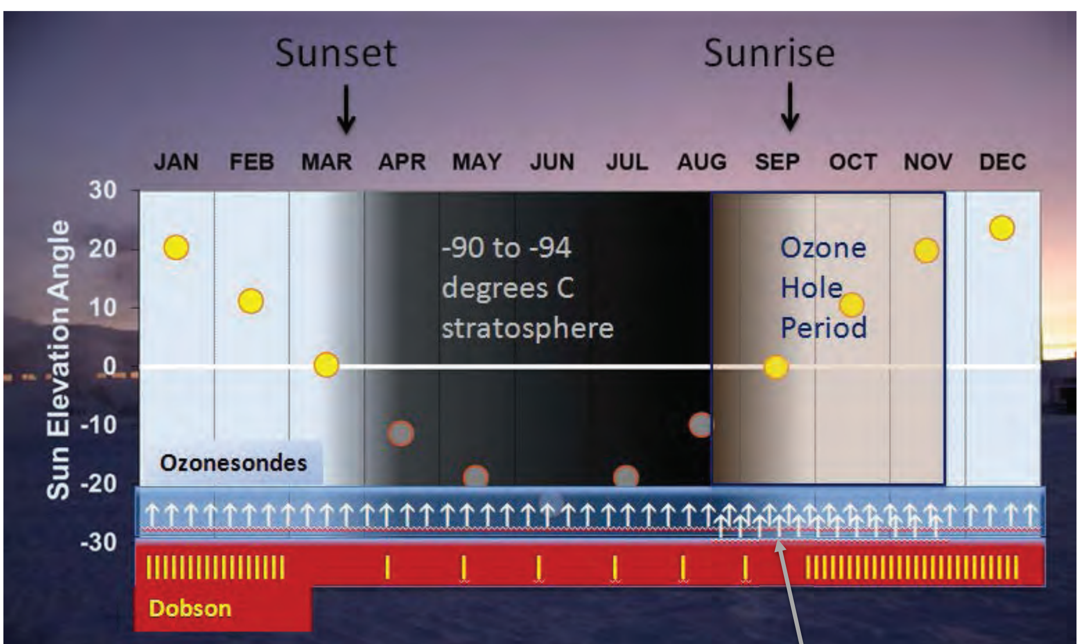
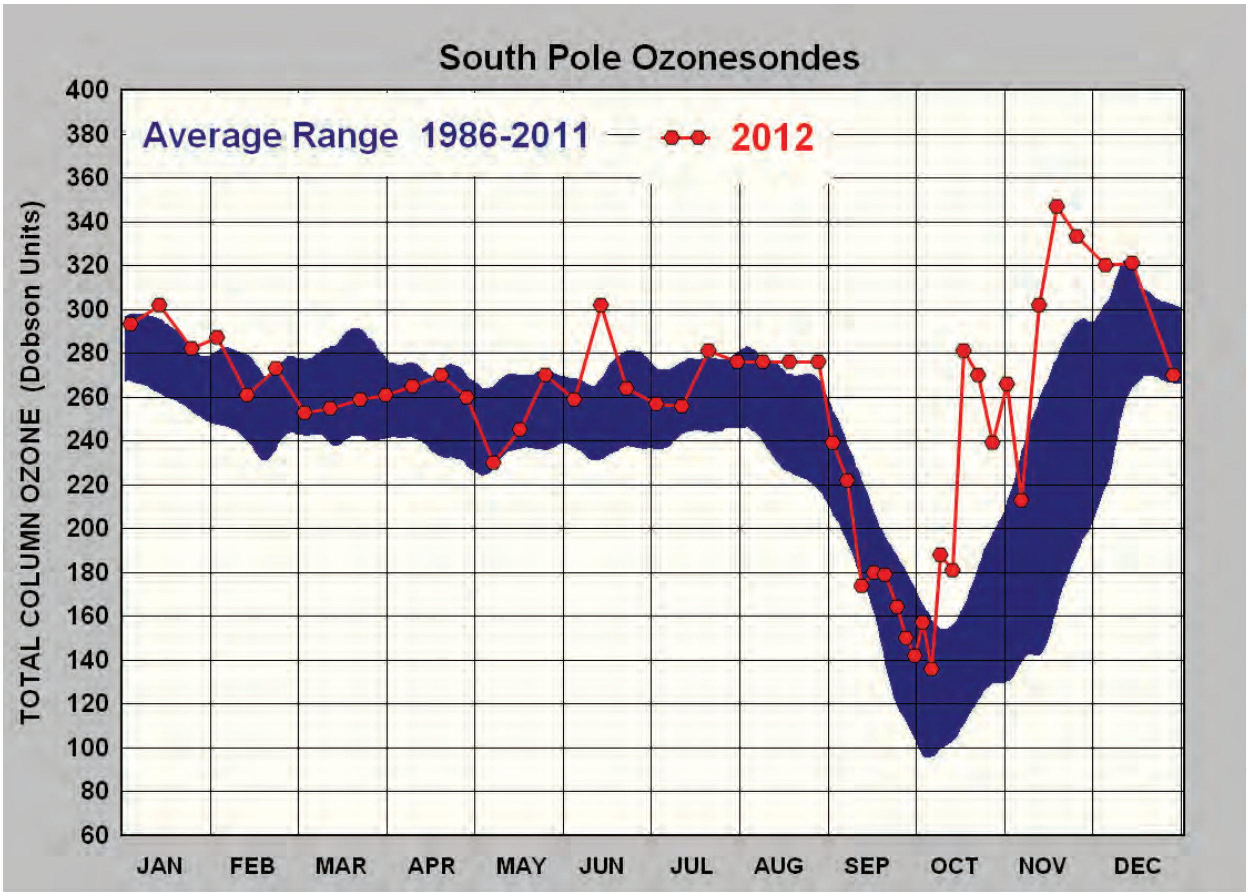
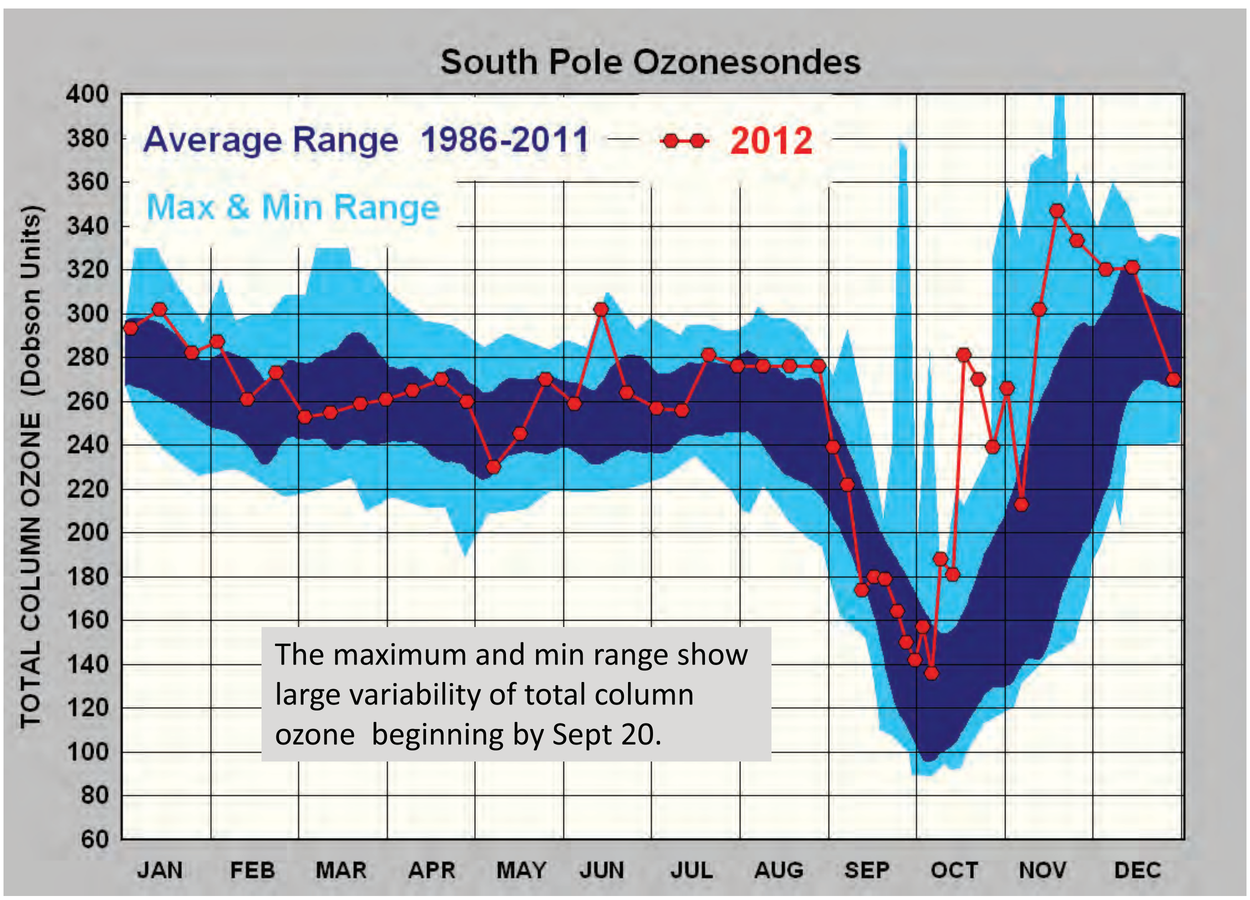


Increased frequency of ozonesonde launches during ozone hole period.


South Pole Ozonesondes
Average Range 1986-2011
2012
TOTAL COLUMN OZONE (Dobson Units)
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


South Pole Ozonesondes
Average Range 1986-2011
2012
Max & Min Range
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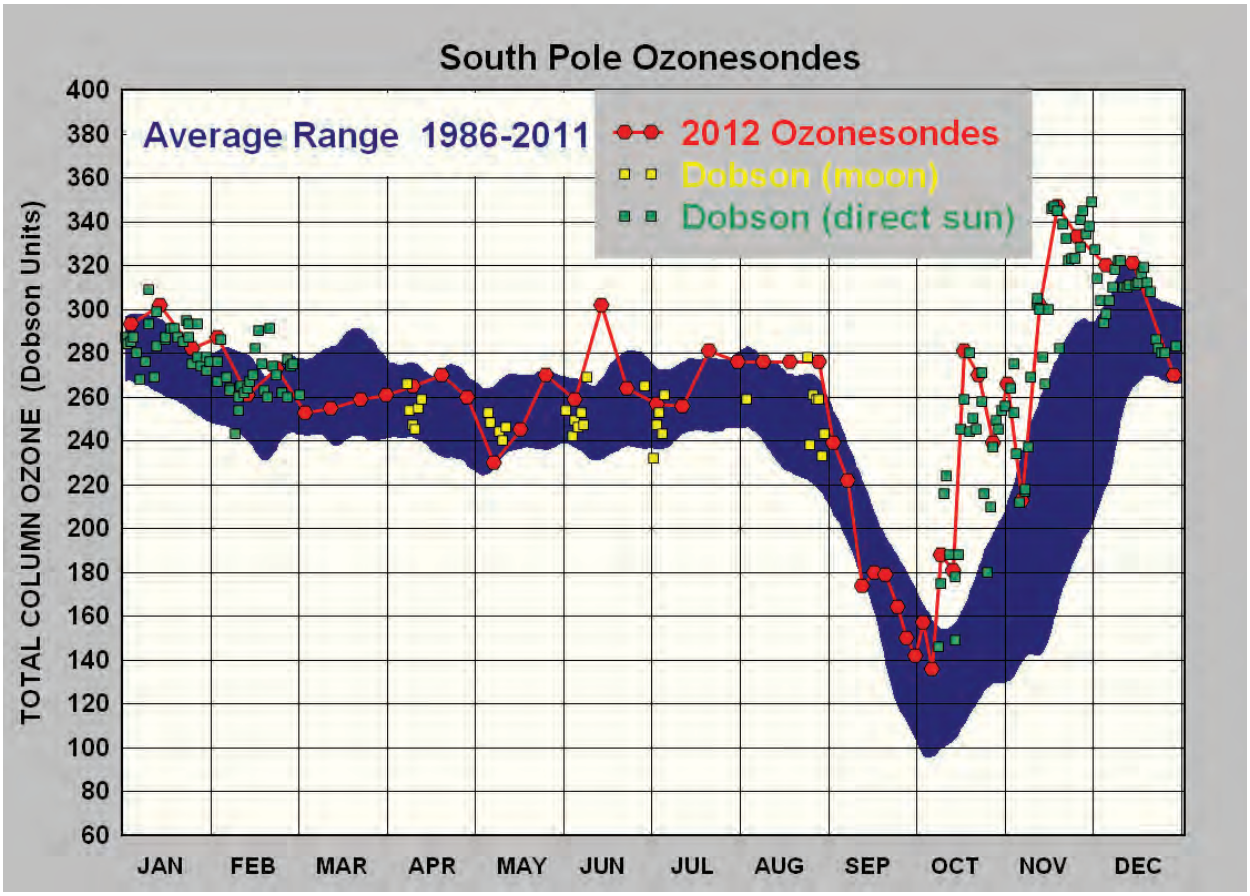
60
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
The maximum and min range show large variability of total column ozone beginning by Sept 20.


South Pole Ozonesondes
Average Range 1986-2011
2012 Ozonesondes
Dobson (moon)
Dobson (direct sun)
TOTAL COLUMN OZONE (Dobson Units)
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
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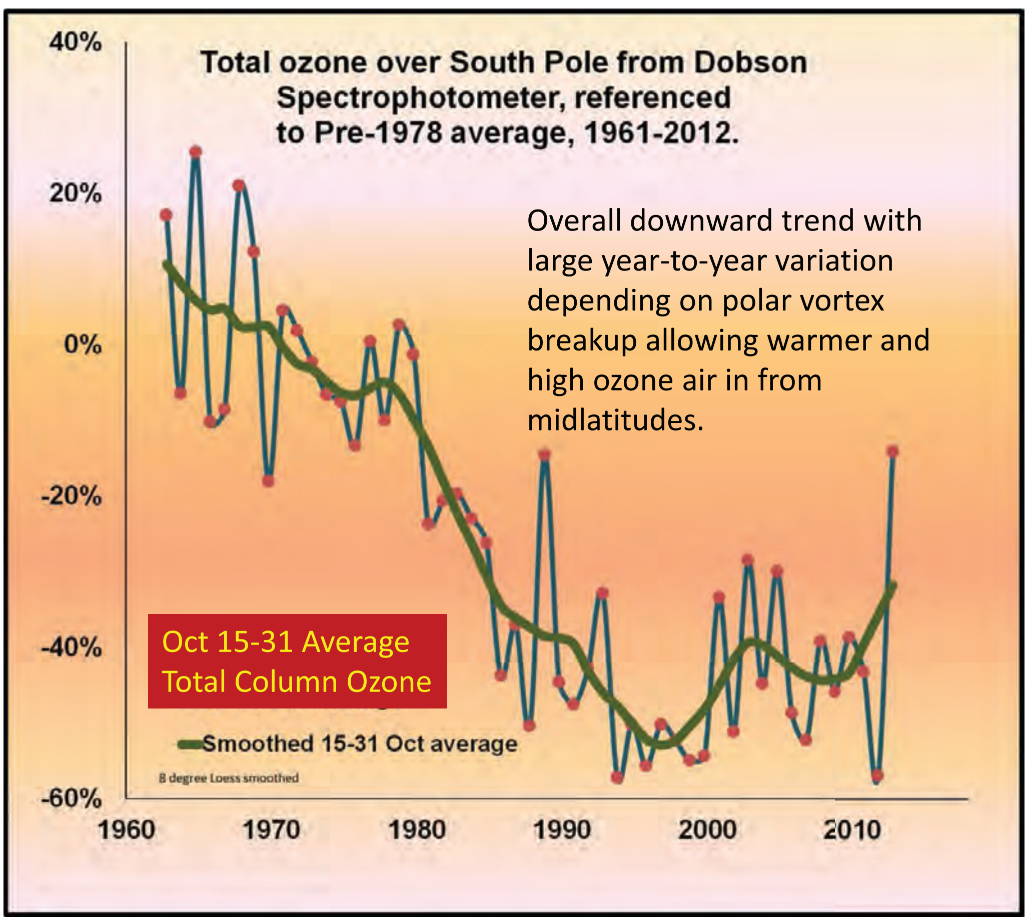
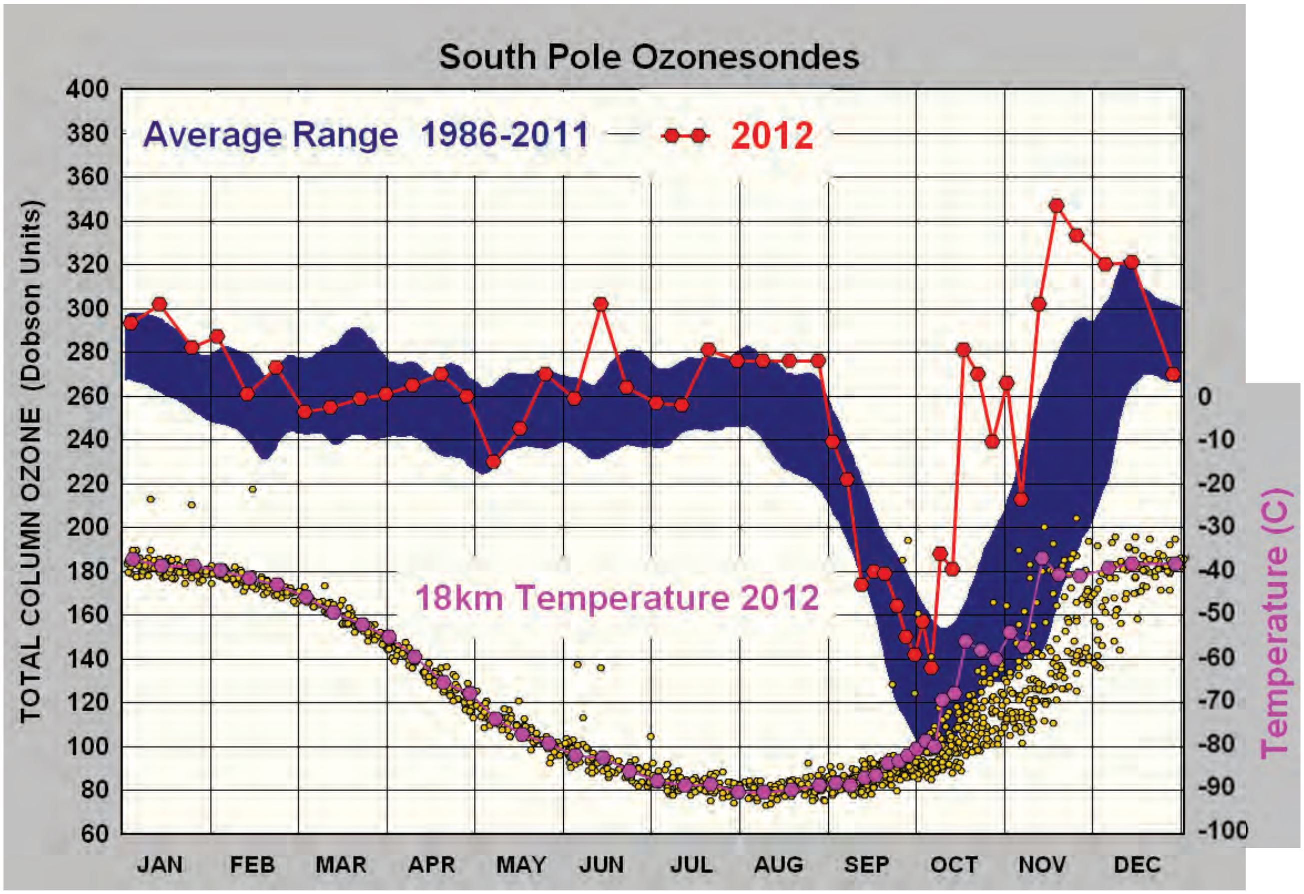

Total ozone over South Pole from Dobson Spectrophotometer, referenced to Pre-1978 average, 1961-2012.
Overall downward trend with large year-to-year variation depending on polar vortex breakup allowing warmer and high ozone air in from midlatitudes.
Oct 15-31 Average Total Column Ozone
Smoothed 15-31 Oct average
8 degree Loess smoothed
40%
20%
0%
-20%
-40%
-60%
1960
1970
1980
1990
2000
2010


South Pole Ozonesondes
Average Range 1986-2011
2012
18km Temperature 2012
TOTAL COLUMN OZONE (Dobson Units)
Temperature (C)
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MAY
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AUG
SEP
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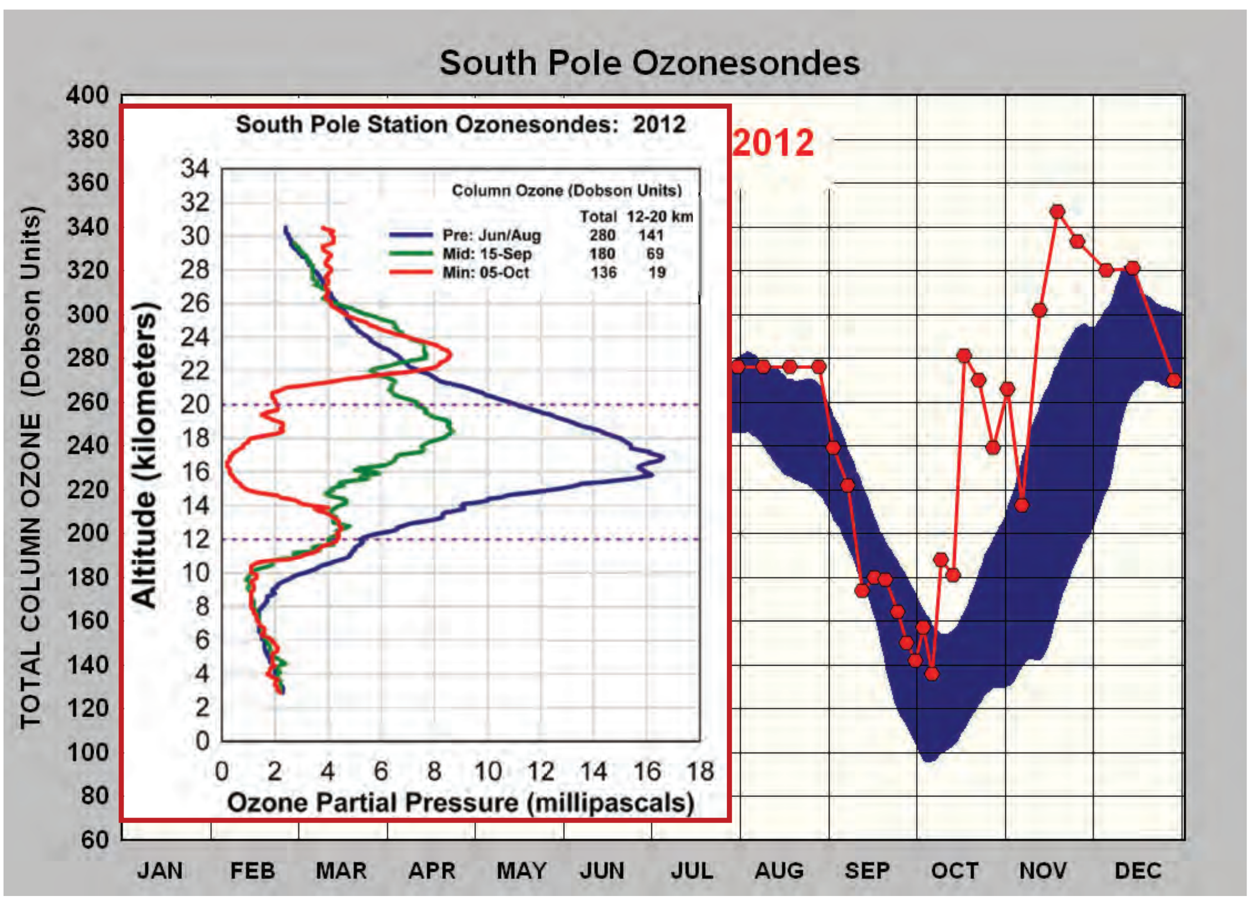
South Pole Ozonesondes
2012
South Pole Station Ozonesondes: 2012
Column Ozone (Dobson Units)
Total 12-20 km
Pre: Jun/Aug 280 141
Mid: 15-Sep 180 69
Min: 05-Oct 136 19
Altitude (kilometers)
Ozone Partial Pressure (millipascals)
TOTAL COLUMN OZONE (Dobson Units)
JAN
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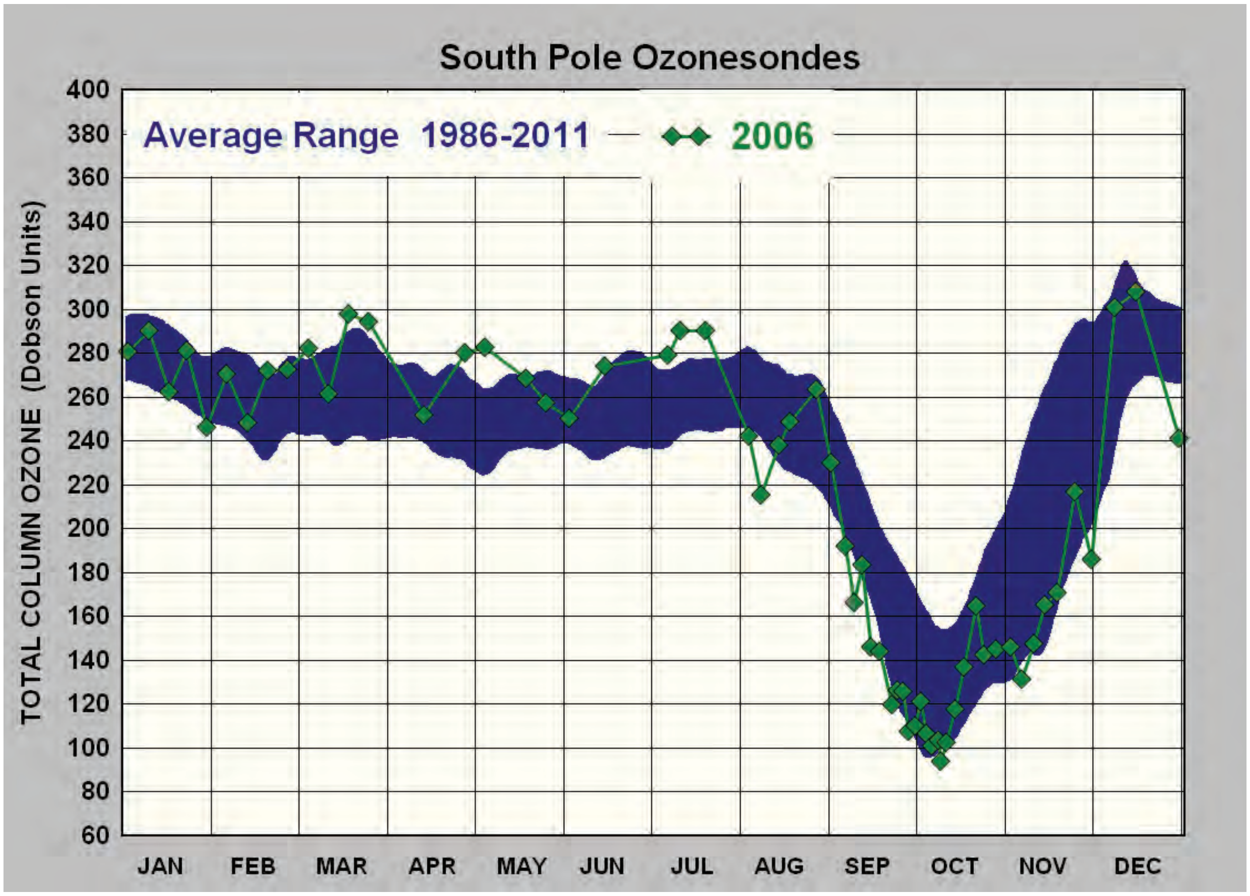
South Pole Ozonesondes
Average Range 1986-2011
2006
TOTAL COLUMN OZONE (Dobson Units)
400
380
360
340
320
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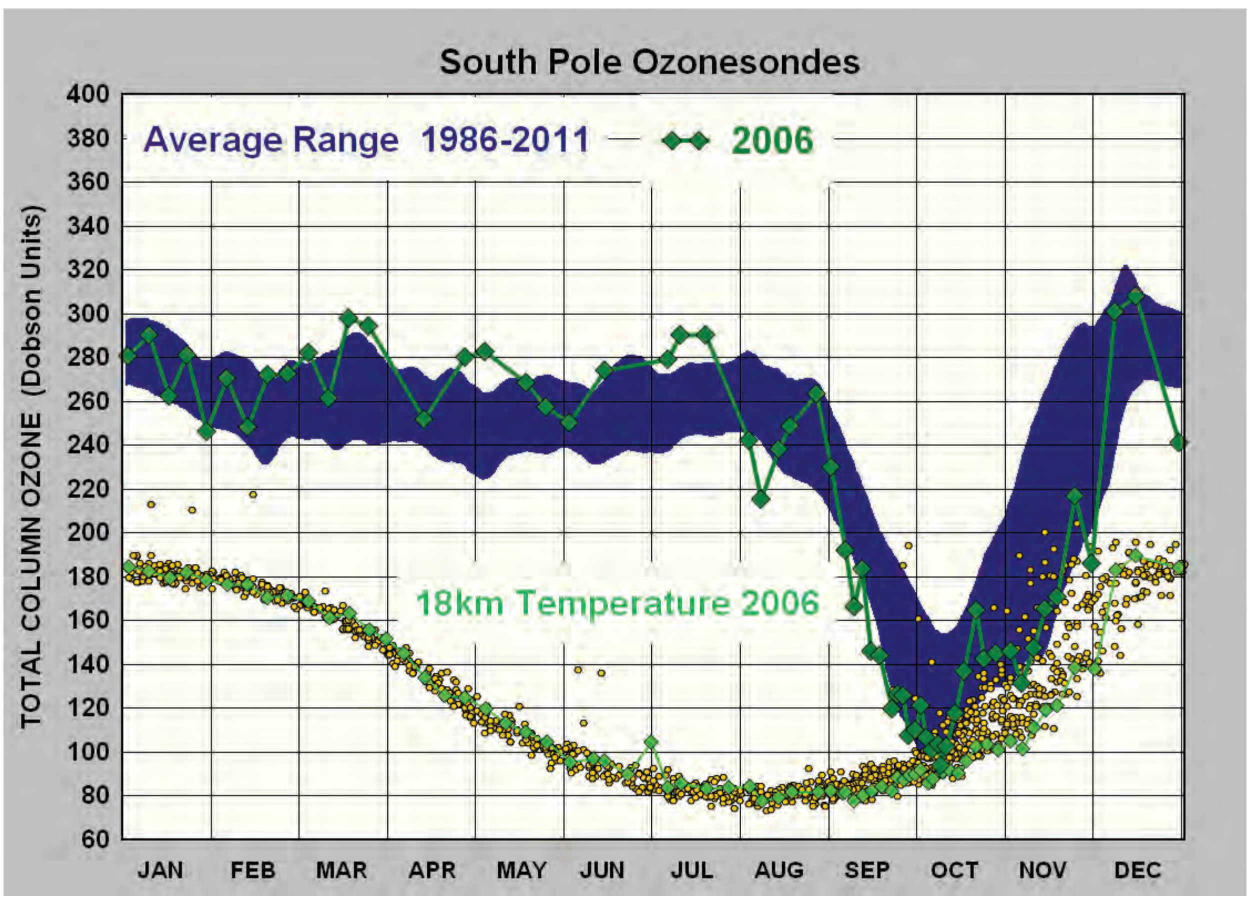
South Pole Ozonesondes
Average Range 1986-2011
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18km Temperature 2006
TOTAL COLUMN OZONE (Dobson Units)
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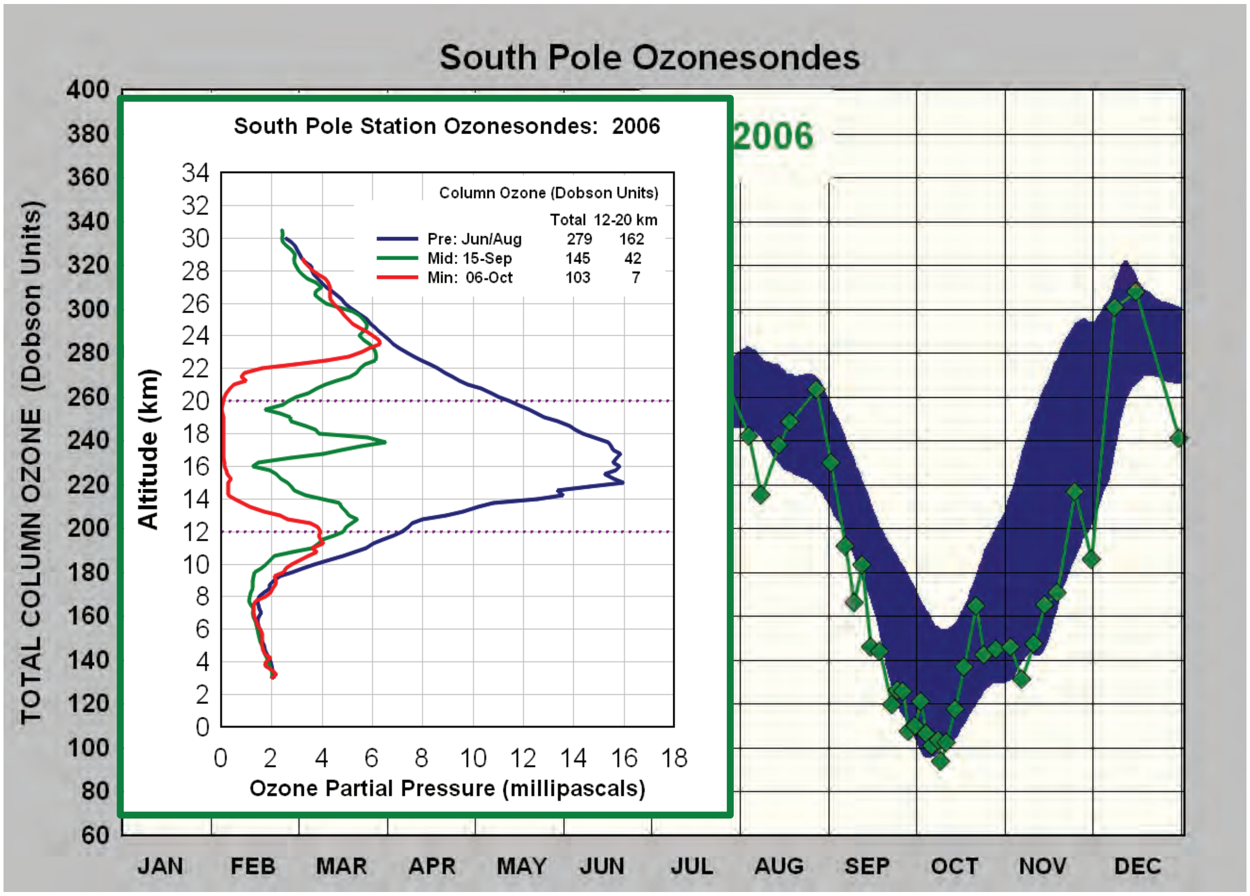
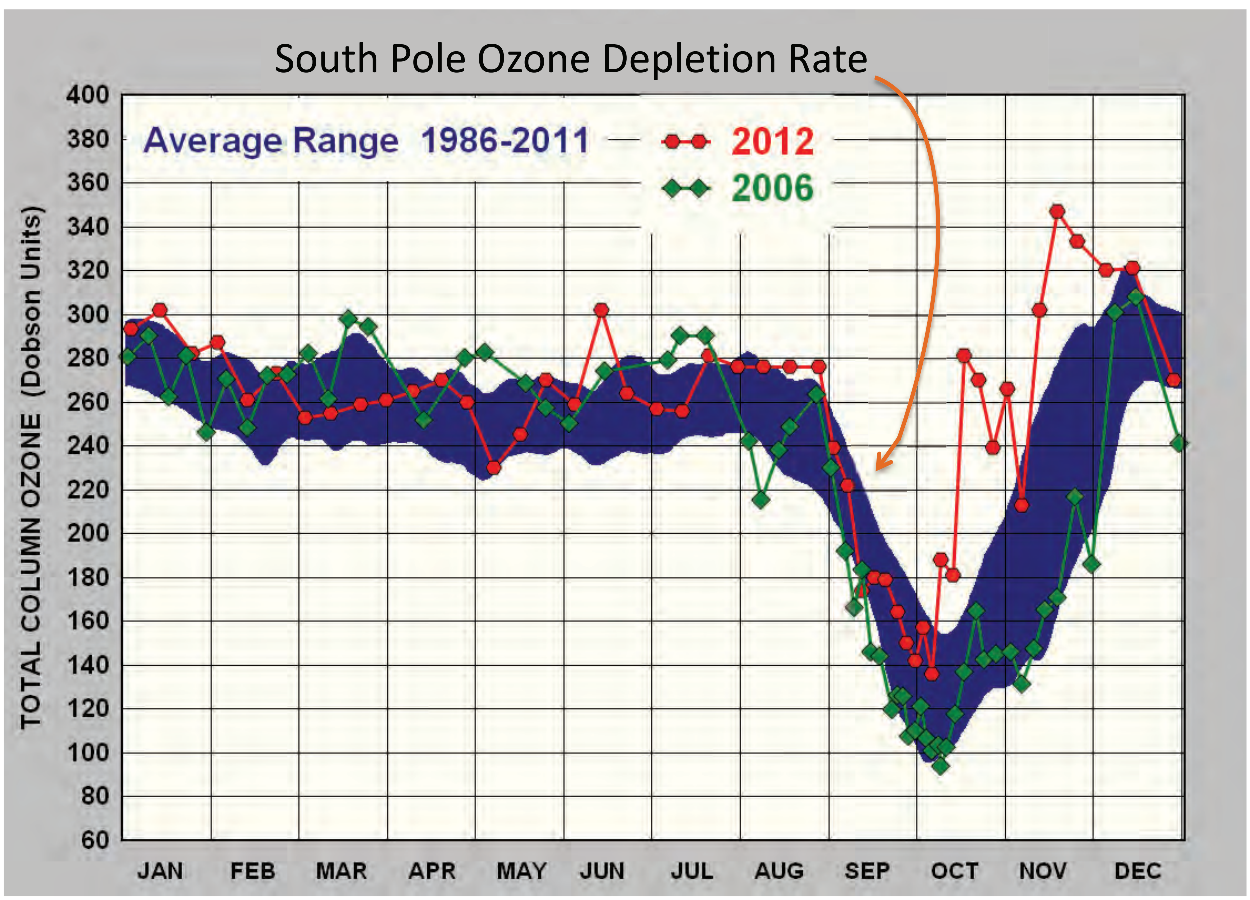
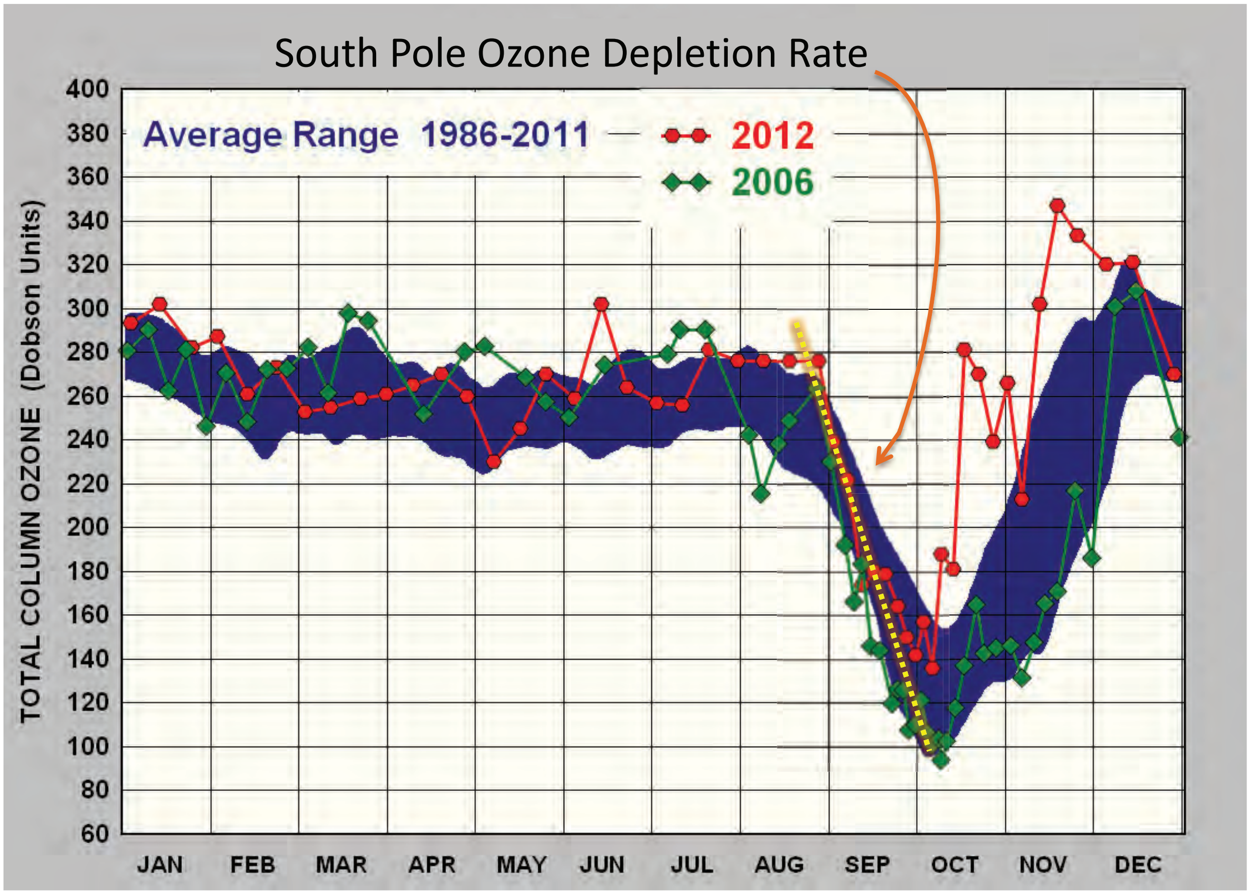


South Pole Ozonesondes
South Pole Station Ozonesondes: 2006
Column Ozone (Dobson Units)
Total 12-20 km
Pre: Jun/Aug 279 162
Mid: 15-Sep 145 42
Min: 06-Oct 103 7
Altitude (km)
Ozone Partial Pressure (millipascals)
2006
TOTAL COLUMN OZONE (Dobson Units)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC



South Pole Ozone Depletion Rate
Average Range 1986-2011
2012
2006
TOTAL COLUMN OZONE (Dobson Units)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC


South Pole Ozone Depletion Rate
Average Range 1986-2011
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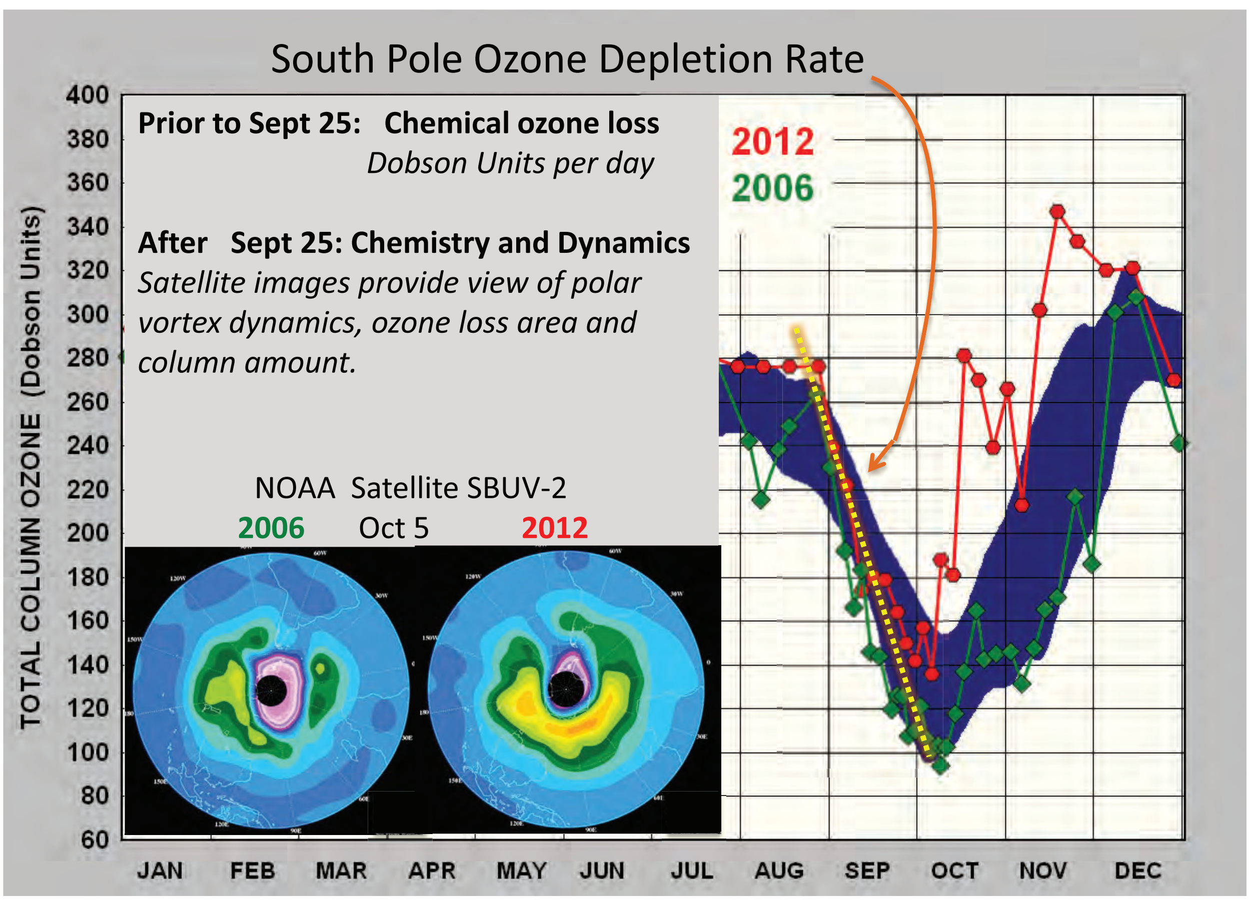
South Pole Ozone Depletion Rate
Prior to Sept 25: Chemical ozone loss
Dobson Units per day
After Sept 25: Chemistry and Dynamics
Satellite images provide view of polar vortex dynamics, ozone loss area and column amount.
NOAA Satellite SBUV-2
2006
Oct 5
2012
2012
2006
TOTAL COLUMN OZONE (Dobson Units)
400
380
360
340
320
300
280
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240
220
200
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120
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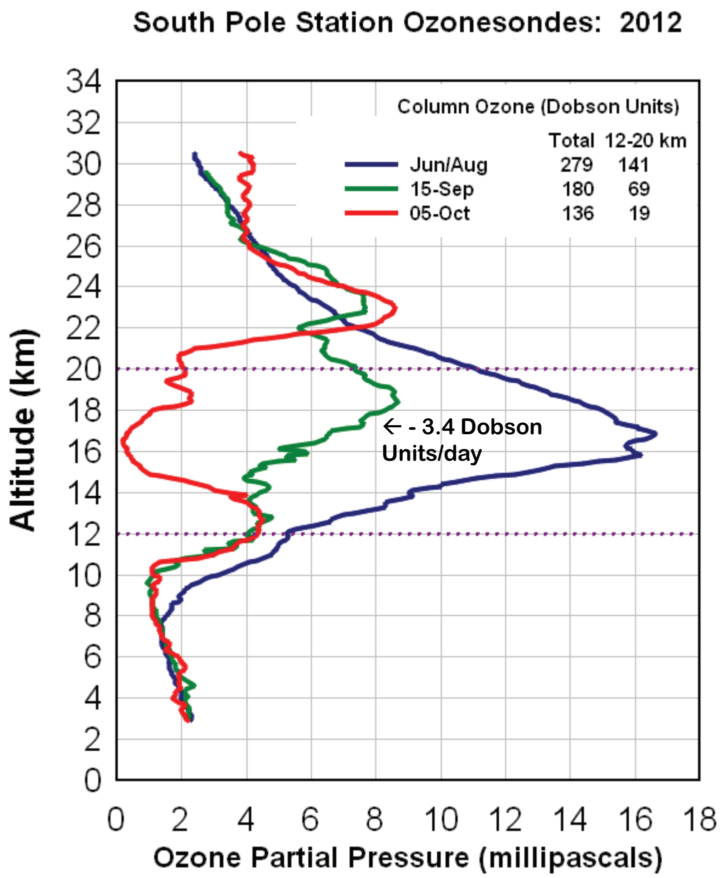
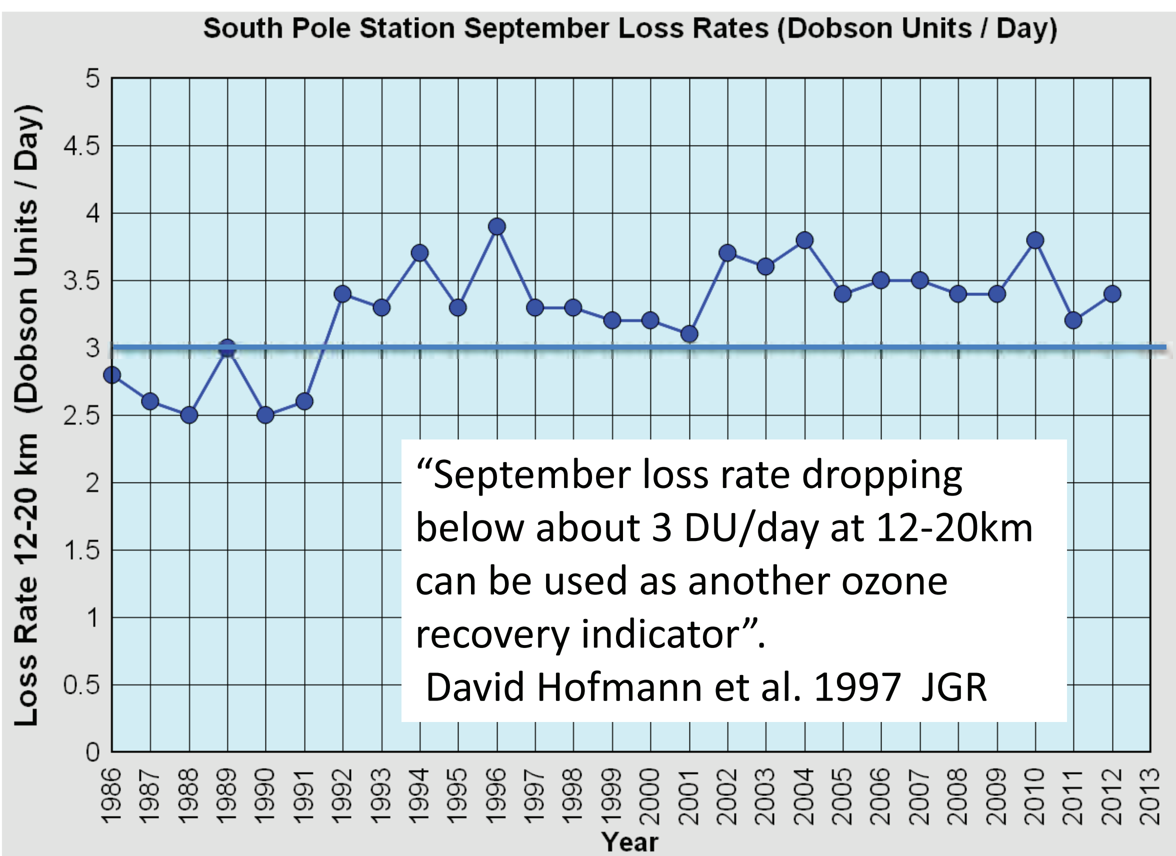
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC



12-20 kilometer ozone loss rate in September 2012 was 3.4 Dobson Units/day .
(**average loss rate compared to 27 year record**)

87% of ozone depleted in the 12-20 kilometer layer.



"September loss rate dropping below about 3 DU/day at 12-20km can be used as another ozone recovery indicator".
David Hofmann et al. 1997 JGR

Summary

GMD monitors stratospheric ozone at South Pole Station:

-- Ground based Dobson Spectrophotometer observations (*51 year record*).

-- Balloon-borne ozonesonde profiles (*27 year record*).

- When to expect first signs of recovery at South Pole:

*"Assuming a lineal relationship between ozone loss rate and Equivalent Effective Stratospheric Chlorine - a reduction of the ozone loss rate at South Pole station will be detectable in **2017-2021 period** " Hassler et al., (2011).*

Stratospheric Transport

presenter: Fred Moore

Stratospheric Transport is Important

- Affects Ozone Production and Depletion
- Affects Climate
- **Stratospheric Trend Analysis** can play and important part
- Current understand is insufficient for making predictions

Outline of Presented Material

- Simple picture of Stratosphere
- Measurement based approach
  - Tracer Data-to-Transport Quantification
- Trend Analysis Example of Predictability
  - Ozone Depletion
- Role of Climate Change
  - Driver and Feedback Mechanisms
- A way forward

Simple Stratosphere

Modeled Concept. | Measurements.

- Brewer Dobson Circulation (BDC) — Age of Stratospheric Air — SF_6 and CO_2
- Chemistry — Ozone — O3; Distribution of Halogens — Halocarbons, etc.; Polar Stratospheric Clouds, HOX, NOX, etc.
- Chemistry coupled to Circulation — measurements cross coupled

- **Learned**
  - Measured Mean Age of Air is NOT a measure of Brewer Dobson Circulation
    - * Coupled BDC + Mixing
  - But BDC, Mixing and more, can be de-convolved and measured by
    - * Adding Stratospheric Halocarbon Measurements
    - * Applying Photolytic Loss estimates (exponentially increacing with altitude)

Transport Quantified from past measurements of Simple Photolytic + Age Tracers.

- From Measurements of N_2O, CFC-12, CFC-113, CFC-11, halon-1211, SF_6 and CO_2

- Mean Age of Stratospheric Air (altitude)
- Vertical Ascent (altitude) in Tropics (or BDC)
- Entrainment (altitude) of Mid-latitude air into Tropics

→ Age Distributions

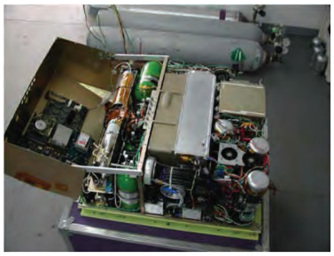
- Stratospheric Lifetime of Halocarbons, N_2O, and SF_6

- Vortex Dynamics:
  - Vortex Formation -> vertical descent and mixing (measure of Mesospheric Flux)
  - Vortex Isolation -> necessary to de-convolve transport from loss in Ozone Studies
- Stratosphere <–> Troposphere Exchange
- Propagating Surface gases to the Tropical Tropopause Layer (entry to the stratosphere)
  - Tropical Convection, Hemispheric Exchange …

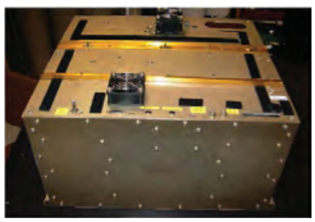
Focused Process Oriented Studies

- Mission Driven
  -> Snap Shot in Time

* Difficult to derive trends from process oriented studies
-> Cost prohibitive !

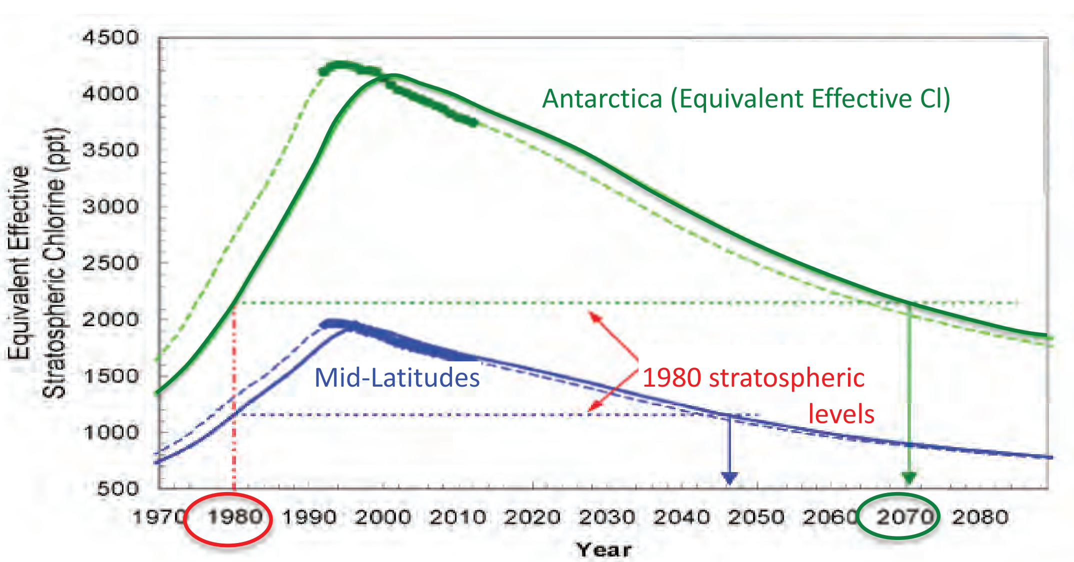






Trend Analysis Example: Ozone Depleting Gas Index. (talk by Steve Montzka)

- Uses Age of Air estimates of Brewer Dobson Circulation and Mixing
  - To Propagate measured surface values of Halocarbons into the Stratosphere
  - To Partition these Halocarbons into reactive Cl + Br that destroy ozone
- Propagate Loading Trend forward in time to estimate
  - When Stratospheric Cl + Br loading will be the same as in 1980
  - When Ozone will recover (around year 2070)



Stratospheric Transport assumed to be Fixed !

Example: Ozone Depleting Gas Index is a Trend Analysis (talk by Steve Montzka)

- Models predict increasing Brewer Dobson Circulation due to Climate Change
- Lifetime of Halocarbons may get shorter
  - Surface trends may be modified
- Partitioning into reactive halogens will change
- Age of Stratospheric Air may change
  -> Lag times between surface trend and Stratosphere may change.
- Ozone Chemistry and Vortex have strong dependencies on Temperature
  -> Relationship between Ozone hole and Ozone Depleting Gas Index?
- Bottom line .... Ozone recovery estimate may shift from 2070
- Need a monitor of Trends in Stratospheric Circulation !

Changes in Stratospheric Circulation are a major Feedback on Climate Change.

Climate Models require accurate description of Stratospheric Circulation:

Stratosphere: O_3
H_2O ~ 30% of ΔT
Tropopause Height
QBO
→ Surface Temperature

Sudden Stratospheric Warming:

Troposphere: Storm track shift (toward the equator)
Storm intensity ("Storminess")
-> Corresponding Water distribution shifts
Lower Pressure across the Atlantic and Pacific at surface

Solomon et. al 2010, 3 decades of H_2O change responsible for ~ 30% of surface ΔT

Scaife et. at. 2011, Change in Stratospheric Winds induce change in Baroclinic Eddy Growth

Butchart et. al. 2011, Strong link between QBO and tropical upwelling and the Vortex

Gerber et. al. 2012, Overview on Impact of Stratospheric Dynamics and Variability

again..

Need a monitor of Trends in Stratospheric Circulation !

- Stratospheric Transport is not fixed … changes on all these time scales
  - Seasonal -> Hemispheric weather driven circulation ...
  - Inter-annual -> QBO, El-Niño ….
  - Episodic -> Sudden stratospheric warming, volcanic, …
  - Climate change -> Driven by tropospheric weather

- Changes on all time scales need to be understood to
  - Quantify causal relationship for each relevant change

- Mission Driven, Focused Process Oriented Studies
  - Important part of our future studies
  - Cost prohibitive for climate time scales with seasonal coverage

Air Core, P. Tans U.S. patent 7,597,014

Pilot program funded by NOAA UAS

- Gas Chromatograph coupling to Air Core
- Balloon Flights out of Boulder (mid-latitude)
- Sky Wisp UAS flight

Affordable:

Air Core cost comparable to O_3 or H_2O Sonde < $2,000

Appropriate for Long Term Monitoring:

One GC calibration errors common across data set

vortex: CO_2, CO, H_2, SF_6, N_2O, CFC-12, O_3, . .

Mid Latitude: SF_6, N_2O, CFC-12, CFC-113, CFC-11, Halon-1211, O_3, H_2O, CO_2

Tropical Pipe: SF_6, N_2O, CFC-12, CFC-113, CFC-11, Halon-1211, O_3, H_2O, CO_2

SF_6, N_2O, CFC-12, CFC-113, CFC-11, Halon-1211, O_3, H_2O, CO_2

Mid Latitude Surf Zone

vortex: CO_2, CO, H_2, SF_6, N_2O, CFC-12, O_3, . .

Troposphere

Photos: Anna Karion and Jack Higgs

Summary

- Stratospheric Transport
  - necessary for both Ozone and Climate Studies

- Stratospheric Transport is not fixed … changes on these time scales of
  - Seasonal
  - Inter-annual
  - Episodic
  - Climate

- Changes on all time scales need to be understood to
  - Quantify causal relationship for each relevant change

- Strat Transport is quantifiable using a specific set of trace gas measurements
  - 20 years of mission oriented airborne studies learning how to quantify transport
  - Each represents a process quantified at a point in time
  - Difficult to do trend analysis with the current data sets

- Pilot Air-Core program Coupled to Gas Chromatograph
  - Cost effective and technically sound
  - Potential for
    - Latitudinal coverage
    - Seasonal coverage
    - Long Term coverage

NOAA's Ozone-Depleting Gas Index

Guiding recovery of the ozone layer

Steve Montzka

Guiding ozone recovery at GMD:

A) Tracking tropospheric changes of ozone-depleting substances and substitute gas concentrations

- GMD's Global and North-American sampling networks
- Characterizing atmospheric responses

B) Deriving stratospheric changes in reactive halogen

- Gauging progress in the decline back to pre-1980 levels

C) Communicating results to a broader audience

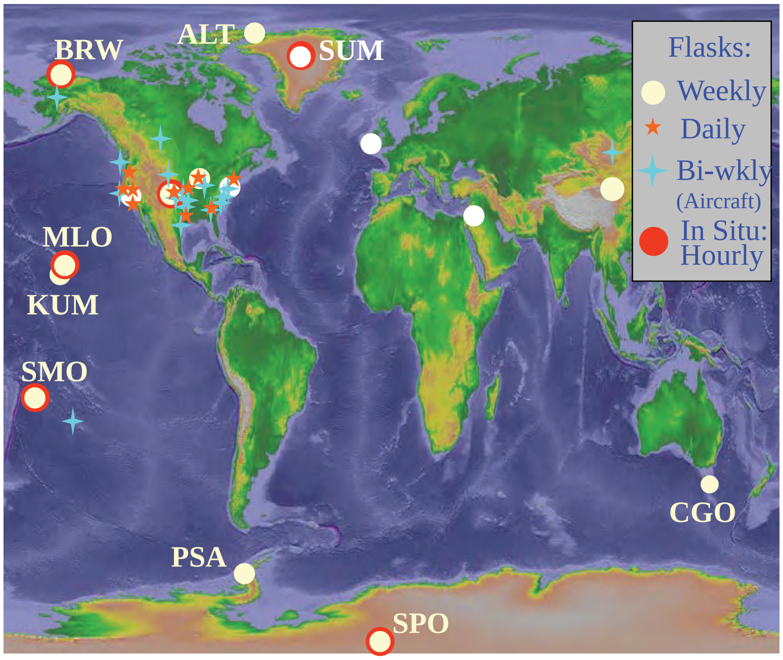
- the Ozone Depleting Gas Index
- Informing Parties to the Montreal Protocol through WMO Scientific Assessments of Ozone Depletion

D) Advancing scientific understanding

- Improving knowledge of sources, sinks, and sensitivities

A) Tracking tropospheric changes

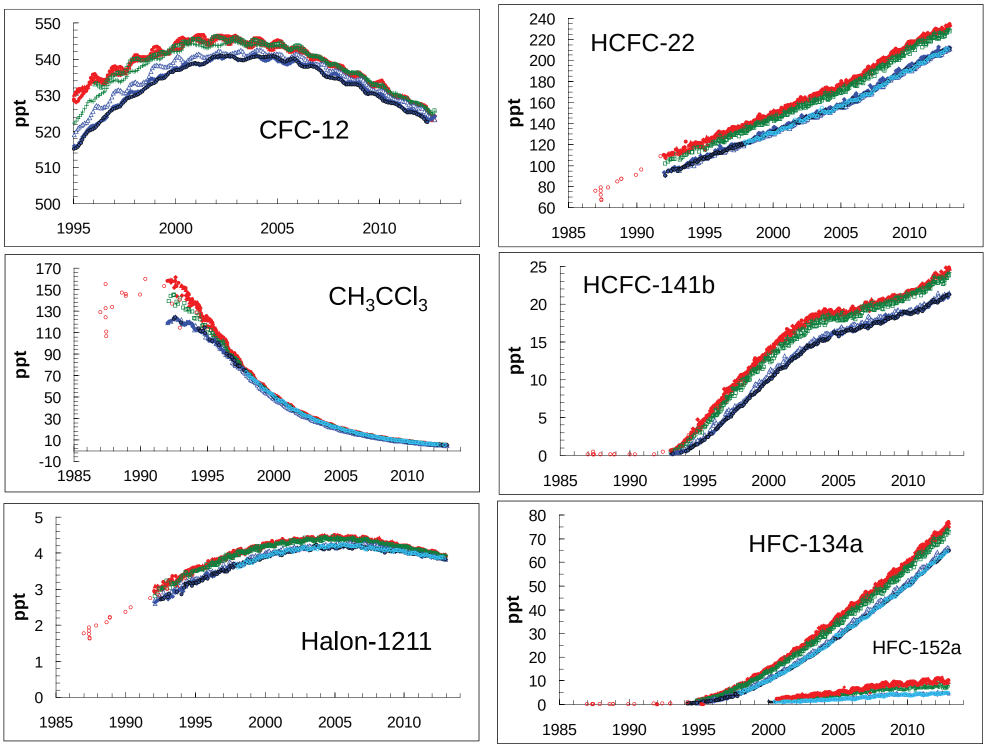
- GMD measures all major ozone-depleting substances*
  - At sites across the globe:



- Approximately 30 chemicals are measured regularly
- With multiple methods (weekly flasks and hourly in-situ instruments; and mass spectrometry and electron capture detection)
- Data records are up to 35-yr long

* and substitute gases

A) Tracking tropospheric changes



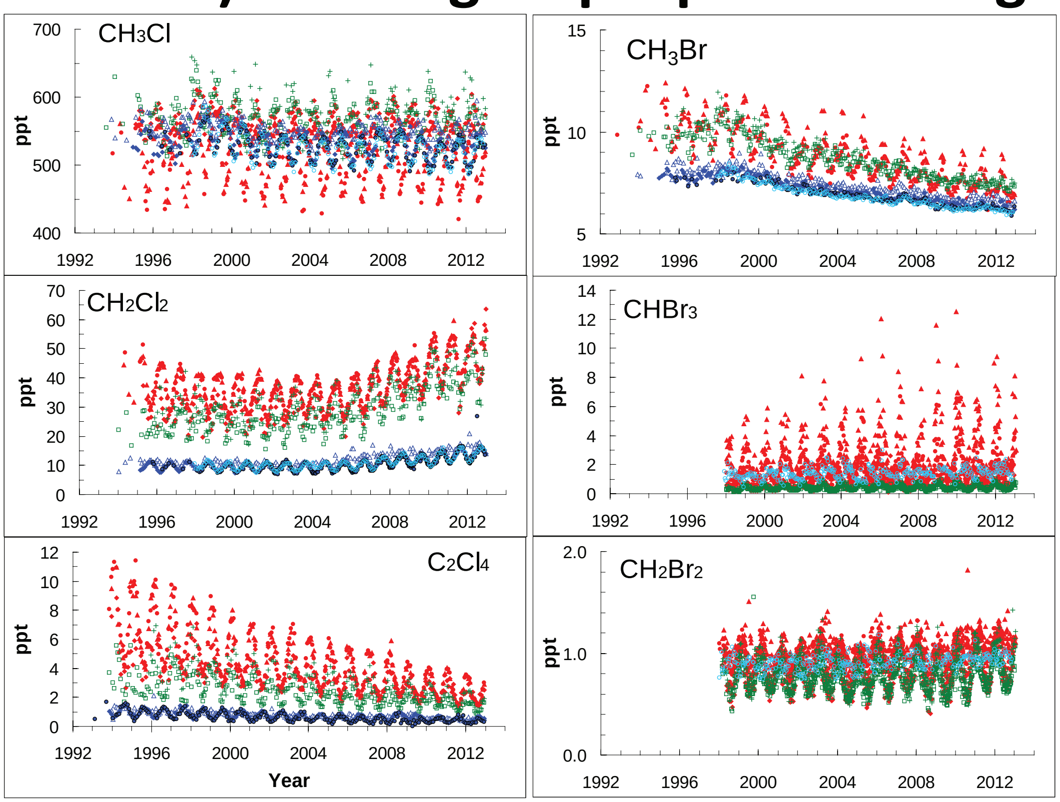
Chemicals controlled by the Montreal Protocol

and significant substitutes (HFCs)

Northern Hemisphere:
red & **green**
Southern Hemisphere:
blue

Recent work diagnosing emission magnitudes, distributions, and lifetimes:
Montzka *et al.*, 2009; Miller *et al.*, 2012; Saikawa *et al.*, 2012; Rigby *et al.*, 2013.

A) Tracking tropospheric changes



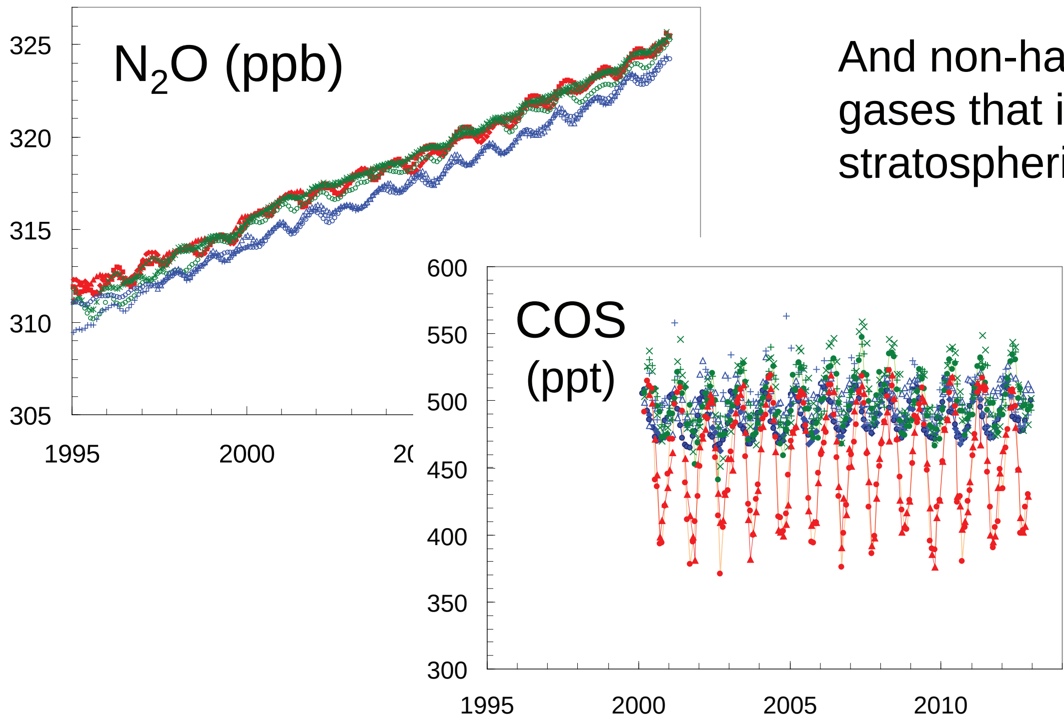
We also accurately track halogenated chemicals having both ***natural*** and ***anthropogenic*** sources—

…of those shown here, only CH_3Br is controlled by the Montreal Protocol

NH: **red** & **green**
SH: **blue**

Montzka *et al.*, 2007; 2011; Xiao *et al.*, 2010; Yvon-Lewis *et al.*, 2009; Hossaini *et al.*, 2012.

A) Tracking tropospheric changes



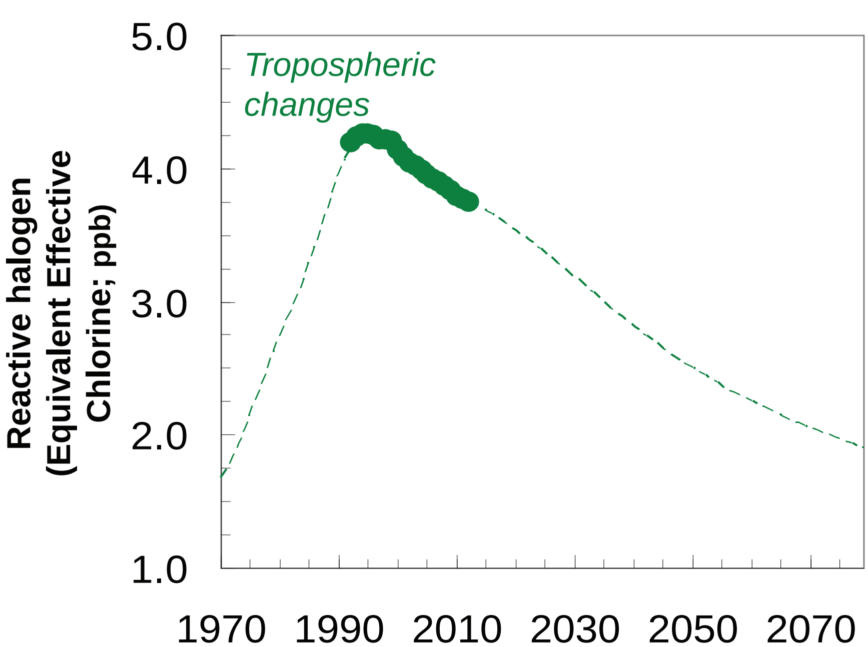
And non-halogenated gases that influence stratospheric ozone

NH: **red** & **green**
SH: **blue**

Montzka *et al*., 2007; 2011; Xiao *et al*., 2010, Yvon-Lewis *et al*., 2009; Hossaini *et al*., 2012.

B) Deriving Stratospheric Changes

- Summarizing tropospheric observations in a way that is relevant for stratospheric ozone (halocarbons only):



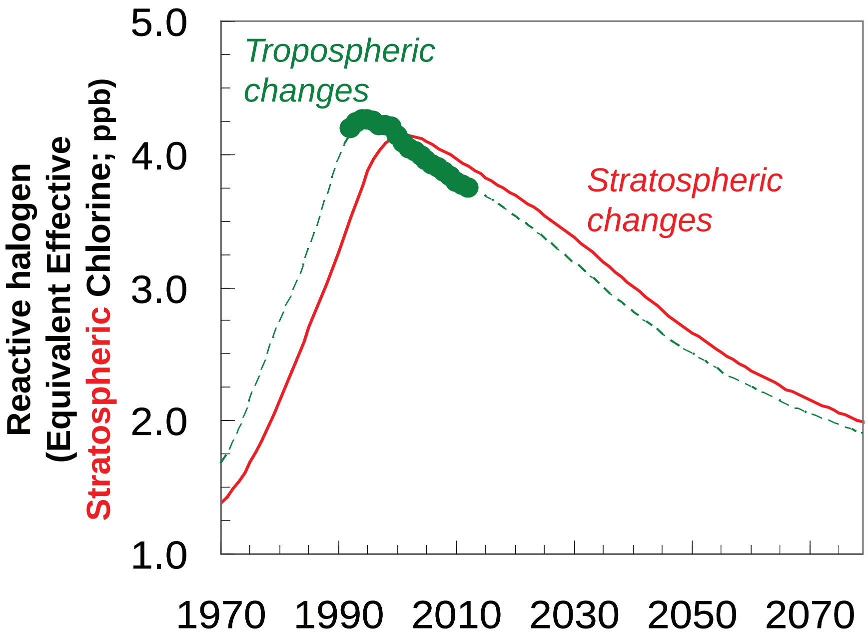
1) With consideration of

→ #'s of bromine and chlorine atoms

→ stratospheric degradation rates

B) Deriving Stratospheric Changes

- Summarizing tropospheric observations in a way that is relevant for stratospheric ozone (halocarbons only):



1) With consideration of

→ #'s of bromine and chlorine atoms

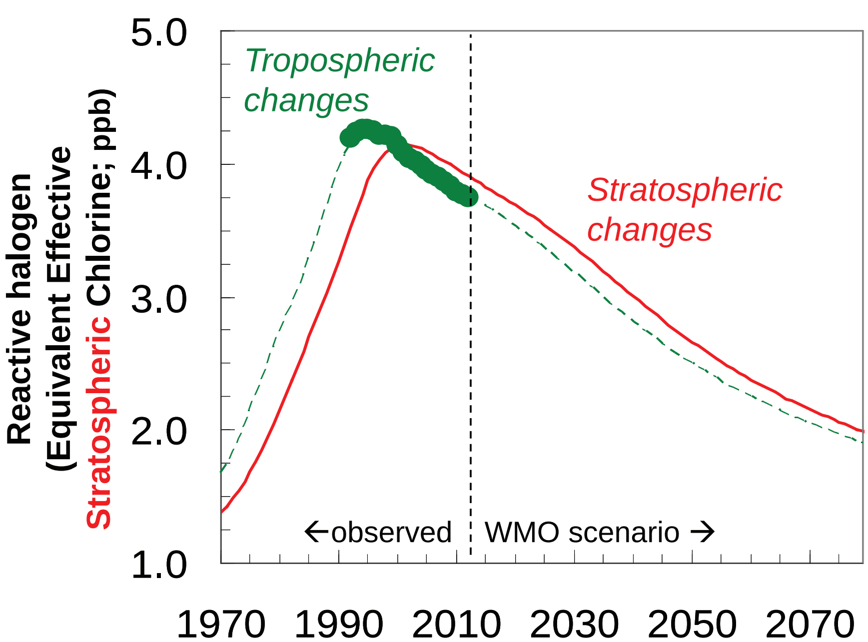
→ stratospheric degradation rates

2) Stratospheric concentrations can be estimated with additional consideration of

→ mixing processes

B) Deriving Stratospheric Changes

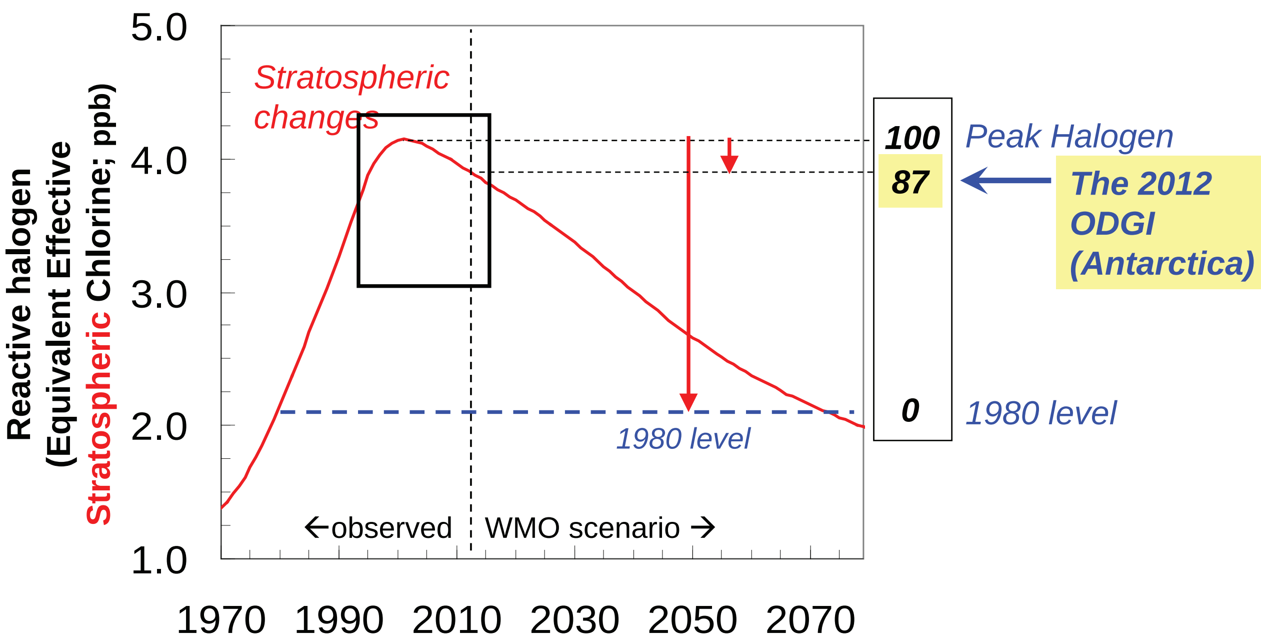
- Summarizing tropospheric observations in a way that is relevant for stratospheric ozone:



B) Deriving Stratospheric Changes

- Gauging our progress towards ozone recovery

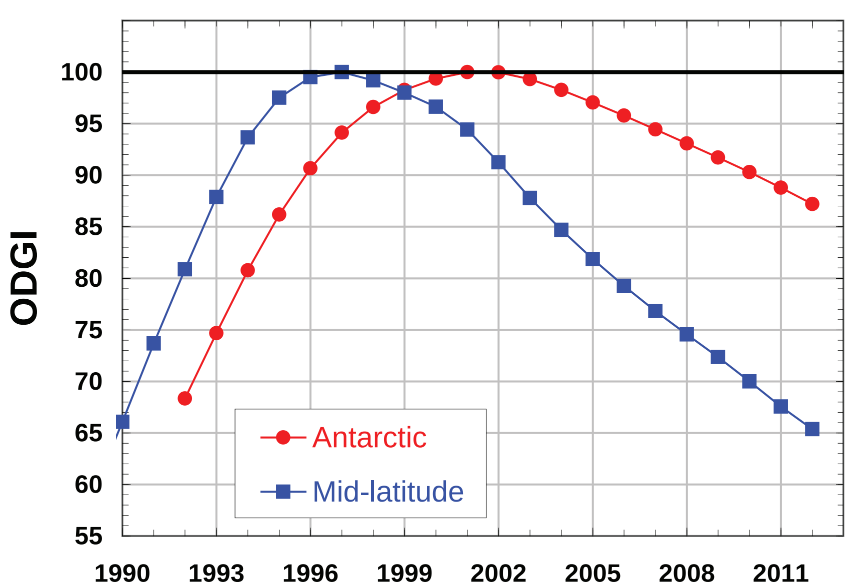
The Ozone Depleting Gas Index:



C) Communicating Results

- Gauging our progress towards ozone recovery

The Ozone Depleting Gas Index:

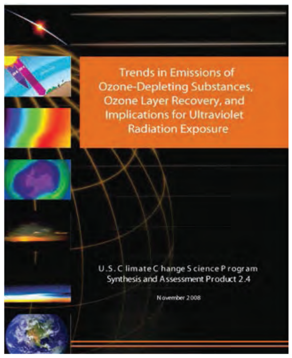


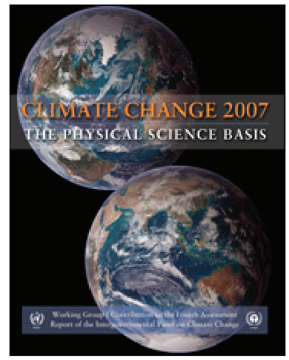
The ODGI is updated annually at http://www.esrl.noaa.gov/gmd/aggi/

In 2012:
- Antarctic ODGI was 87
- Mid-latitude ODGI was 65

C) Communicating Results

- ***Providing expertise*** to national and international Assessments on Ozone and Climate:
  - ***GMD scientists*** have been lead authors, co-authors, contributing authors, and contributors to these Assessments
  - ***GMD data*** are prominent in these Assessments





Also:
•UNEP/TEAP Task force on emissions discrepancies report—Oct 2006
•SPARC Reevaluation of Lifetimes—in process, 2013

D) Advancing Scientific Understanding

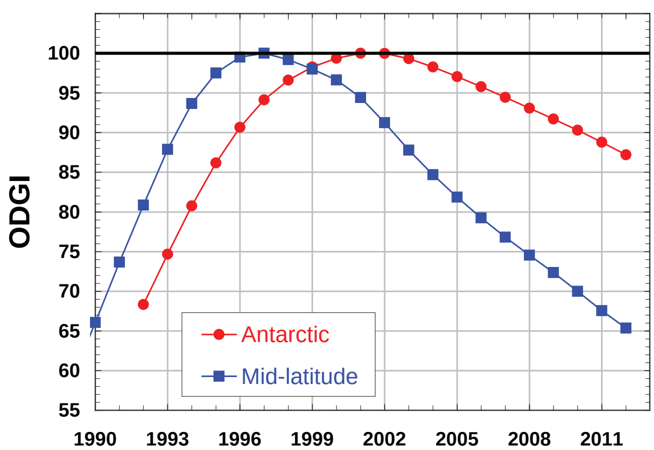
- **On stratospheric processes**
  - Understanding stratospheric transport and loss processes
- **On tropospheric losses**
  - OH concentration and variability derived from CH_3CCl_3 data
- **On anthropogenic emissions**
  - Assessing global responses to international policy
  - Working towards quantifying continental-scale emissions (from US network, and with global modeling; with partners)
- **On gases not controlled by the Montreal Protocol**
  - Quantifying contributions from naturally-emitted chemicals (CH_3Cl, CH_2Br_2, $CHBr_3$, CH_3I,
    N_2O, and COS (carbonyl sulfide))

Summary

Regarding ozone-depleting substances, GMD is:

- ***Tracking tropospheric changes*** of ozone-depleting substances with global and North-American networks
- ***Characterizing atmospheric responses*** to international policy decisions and natural process variations
- ***Guiding ozone layer recovery***
  – By annual updates of the Ozone Depleting Gas Index
  – By providing input to International Ozone Assessments
- ***Advancing scientific understanding***
  – Improving knowledge of sources, sinks, and sensitivities of atmospheric changes to policy decisions

The last five talks have shown how:
GMD plays a central role in the global effort to monitor stratospheric ozone, ozone-depleting gases, and other processes affecting ozone



GMD data are critical for:

– Assessing the effectiveness of the Montreal Protocol to reduce ozone-depleting gases

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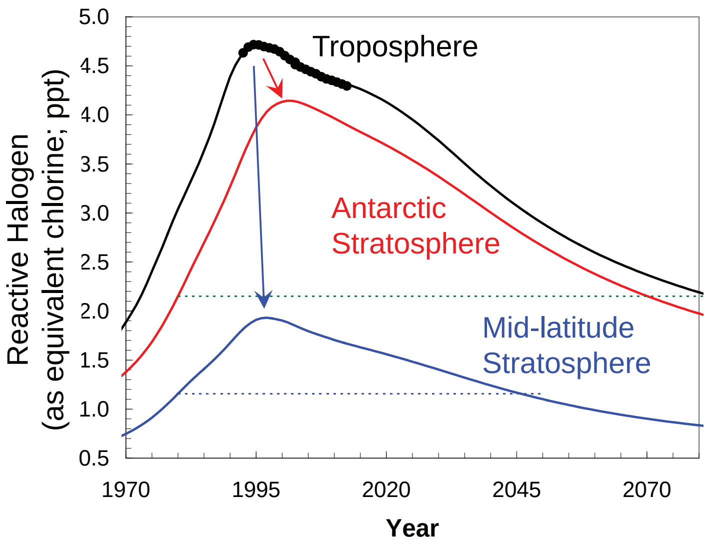

GMD data are critical for:

– Assessing the effectiveness of the Montreal Protocol to reduce ozone-depleting gases
– Improving our understanding of the transport and transformation of these gases

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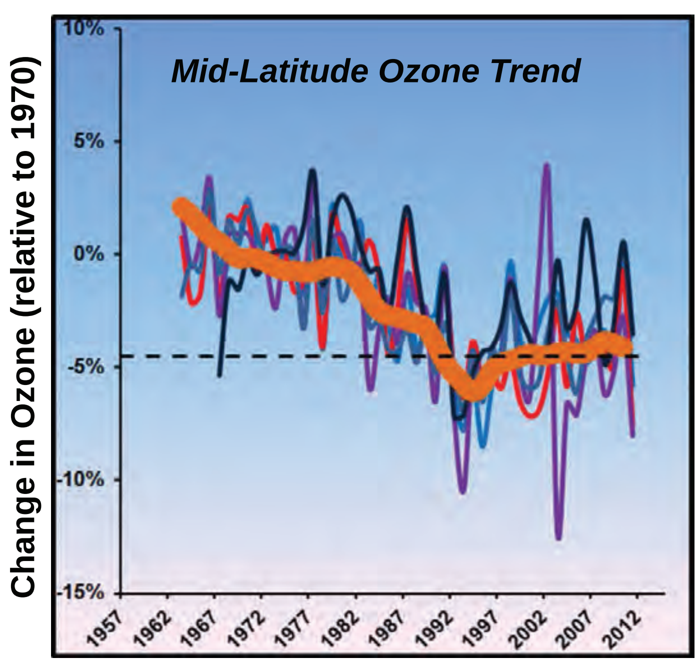

GMD data are critical for:

– Assessing the effectiveness of the Montreal Protocol to reduce ozone-depleting gases
– Improving our understanding of the transport and transformation of these gases
– Tracking and understanding trends for stratospheric ozone in mid-latitudes…

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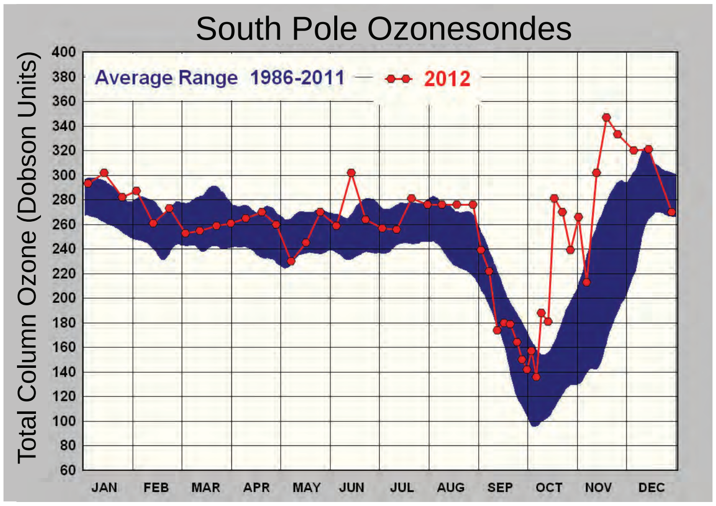

GMD data are critical for:

– Assessing the effectiveness of the Montreal Protocol to reduce ozone-depleting gases
– Improving our understanding of the transport and transformation of these gases
– Tracking and understanding trends for stratospheric ozone in mid-latitudes

...***and for the ozone hole above Antarctica***

The last five talks have shown how:
GMD plays a central role in the global effort to monitor stratospheric ozone, ozone-depleting gases, and other processes affecting ozone

With a focus on:

– ***global-to-regional scale observations*** to assess global changes ***and*** influences from specific processes and regions (*e.g.*, U.S.)
– ***Diagnosing observed changes*** to clarify the relative influence of policy decisions, other human behaviors, and natural processes
– ***To provide the highest-quality, policy-relevant science***

→ Guiding the recovery of the ozone layer by informing Parties to the Montreal Protocol on the progress of recovery…