Viable Stratospheric Transport Monitoring Program;
Vital to Tracking and Improving our Understanding of Climate Change.

F. Moore, E. Ray, J. Elkins, P. Tans, A. Karion, C. Sweeney

Use atmospheric cartoons to indicate:

#1 Changes in Stratospheric Circulation Track Climate Change in the troposphere.

#2 Changes in Stratospheric Circulation are Measurable.

#3 Motivate a Monitoring Program based on Air-Core measurements.
Acquiring relatively inexpensive data.

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Changes in Stratospheric Circulation are a Major Feed Back on Climate Change.

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Changes in Stratospheric Circulation are a major Feed Back on Climate Change.

Models require accurate description of Stratospheric Circulation:

Stratospheric: O_3
H_20 ~ 30% of ΔT
Tropopause Height
QBO

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

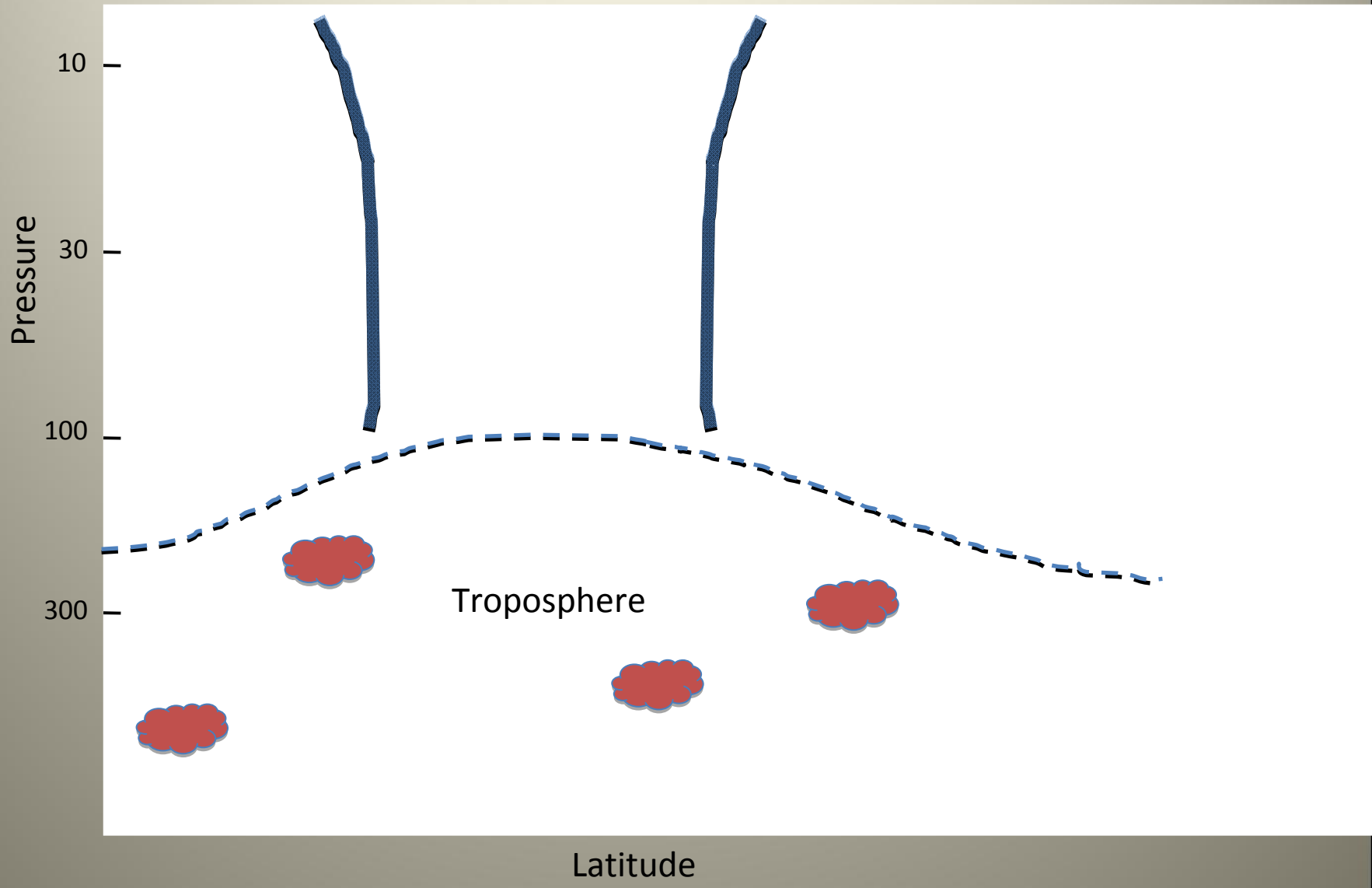
Solomon et. al 2010, 3 decades of H_2O change responsible for ~ 30% of surface ΔT

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.

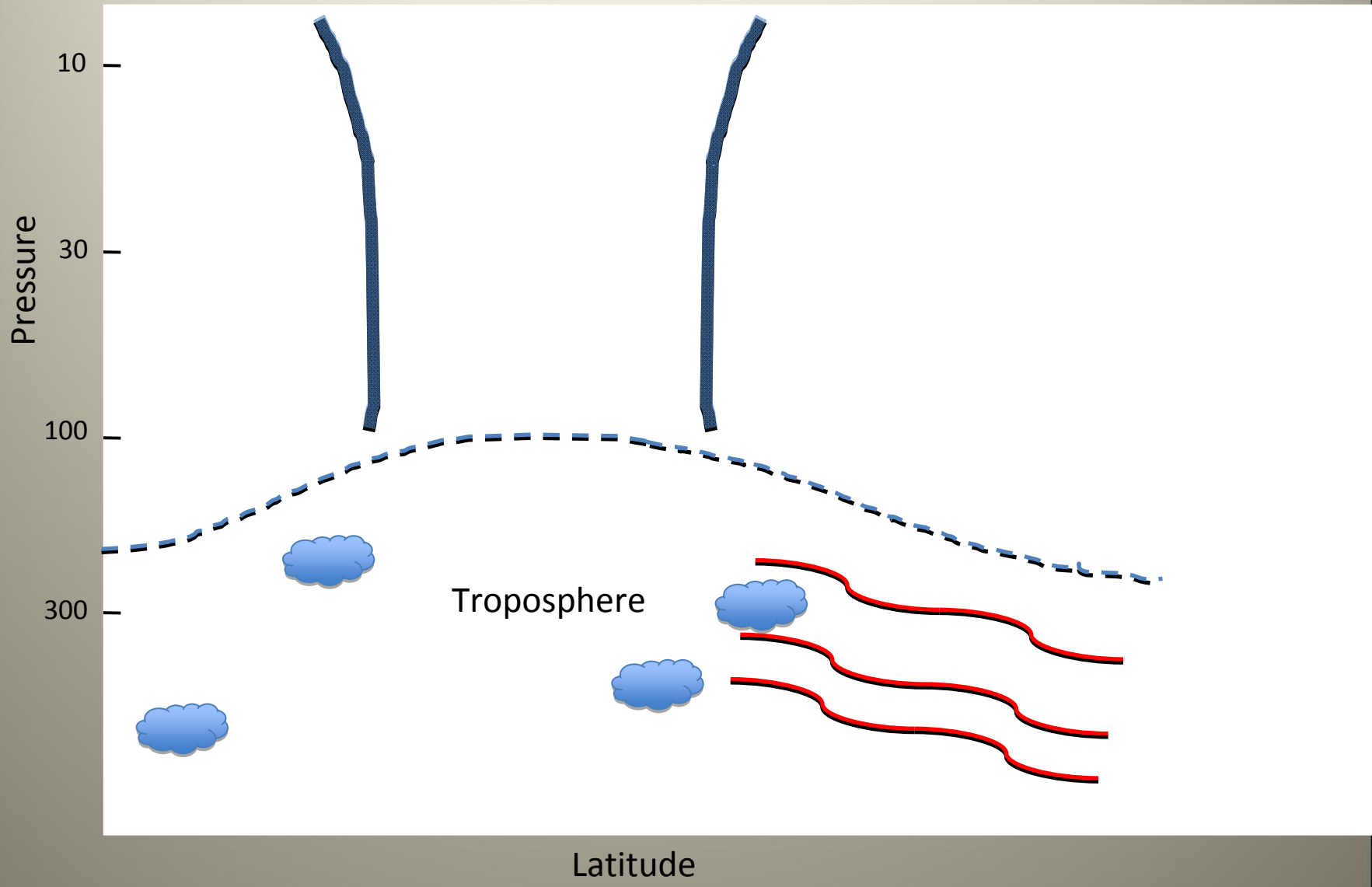
Tropospheric CLIMATE CHANGE to First Order

*Drives Change in Weather in the troposphere.



CLIMATE CHANGE to first order

*drives change in weather in the troposphere. >> Induces Change in Wave Generation



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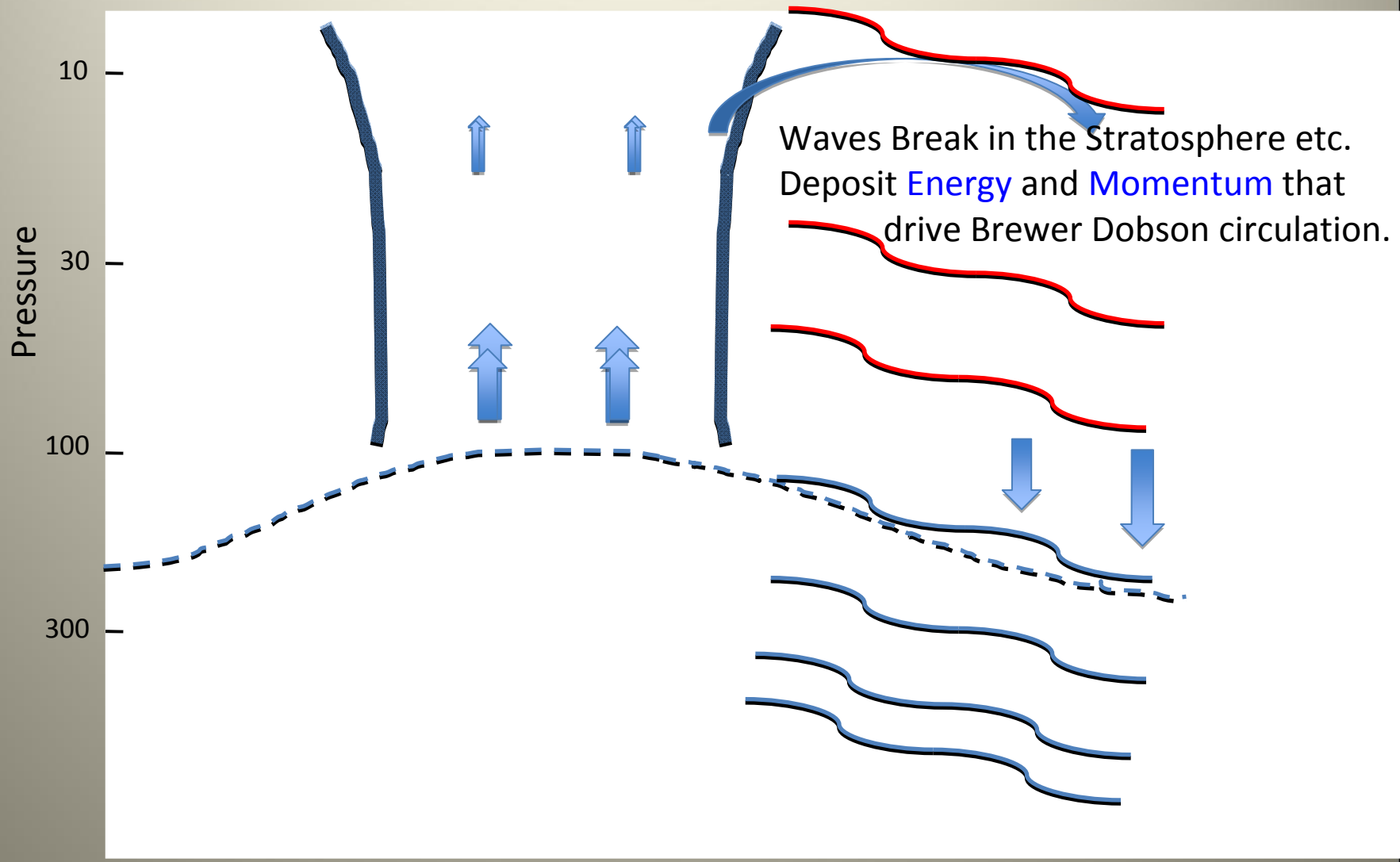

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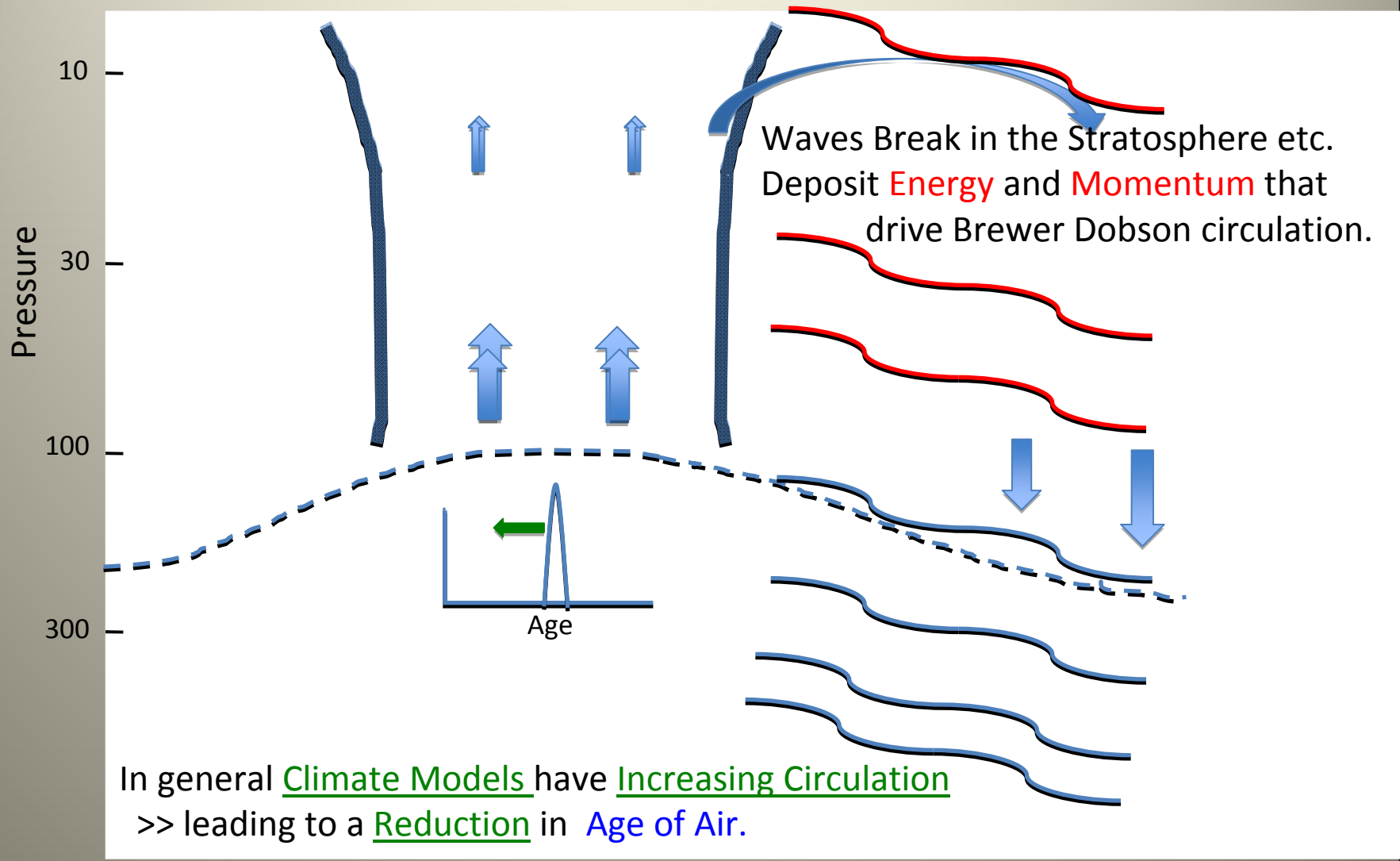

In general Climate Models have Increasing Circulation
>> leading to a Reduction in Age of Air.

CLIMATE CHANGE

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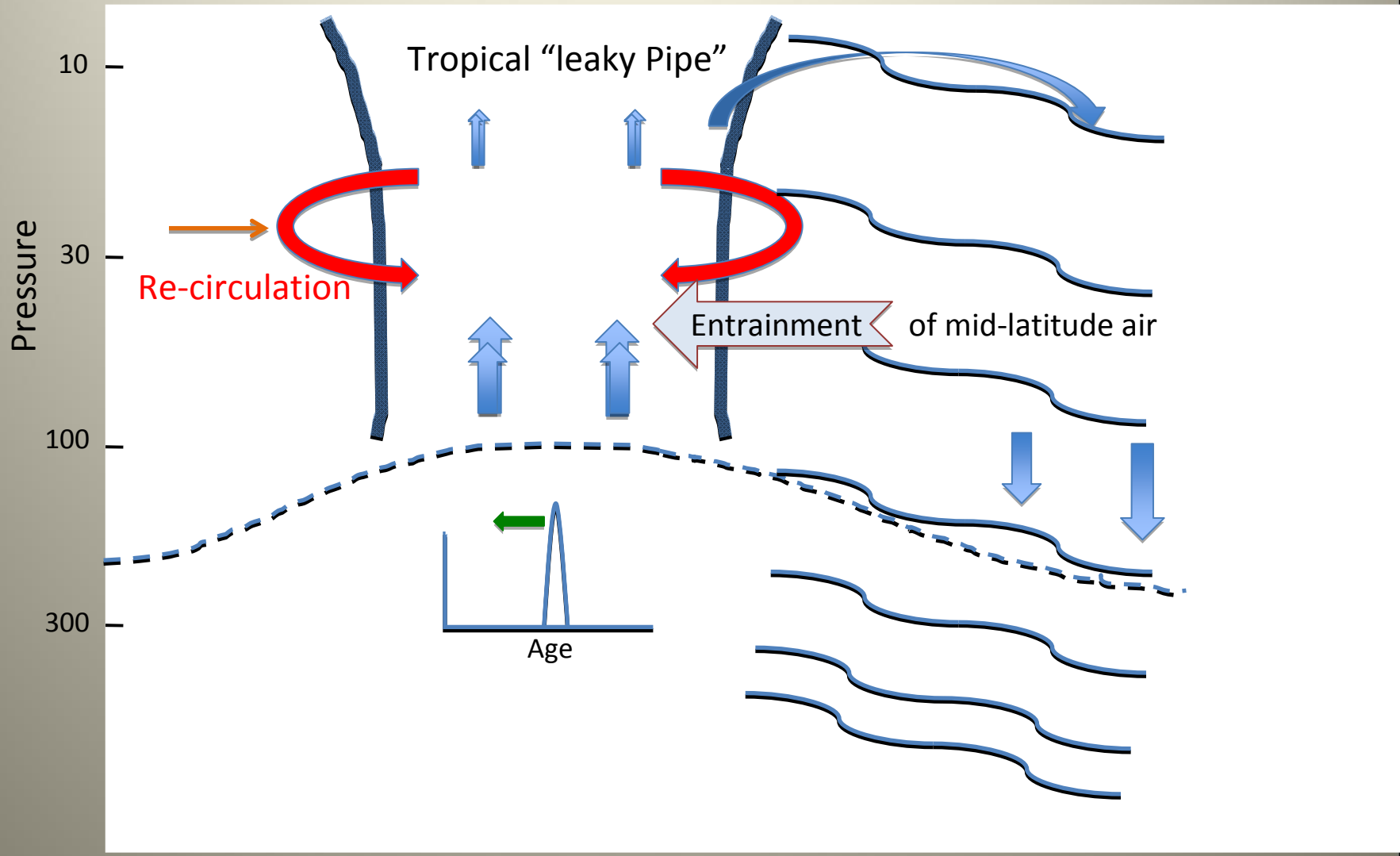
* Drives changes in stratospheric circulation Mean-circulation and Re-circulation



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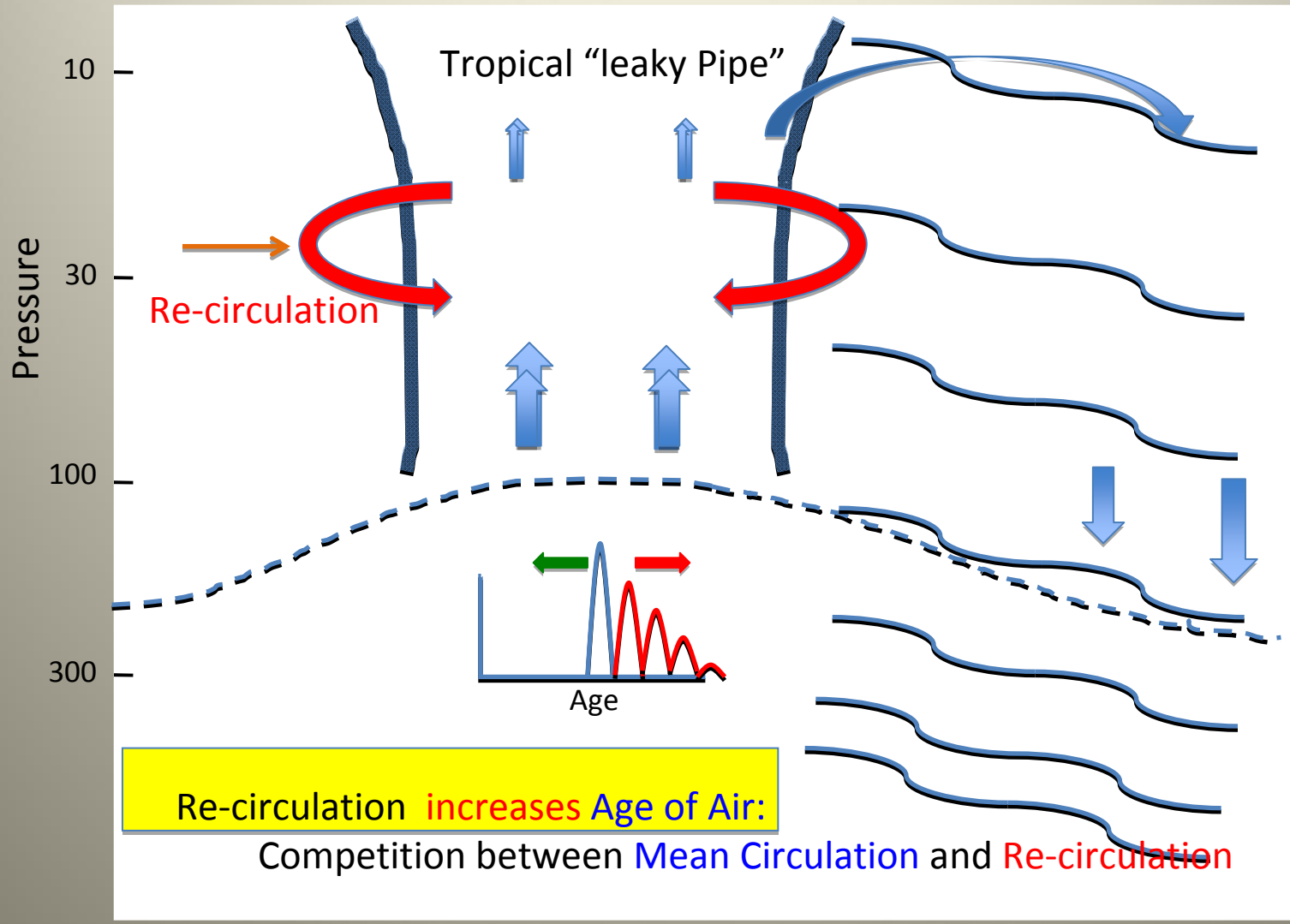

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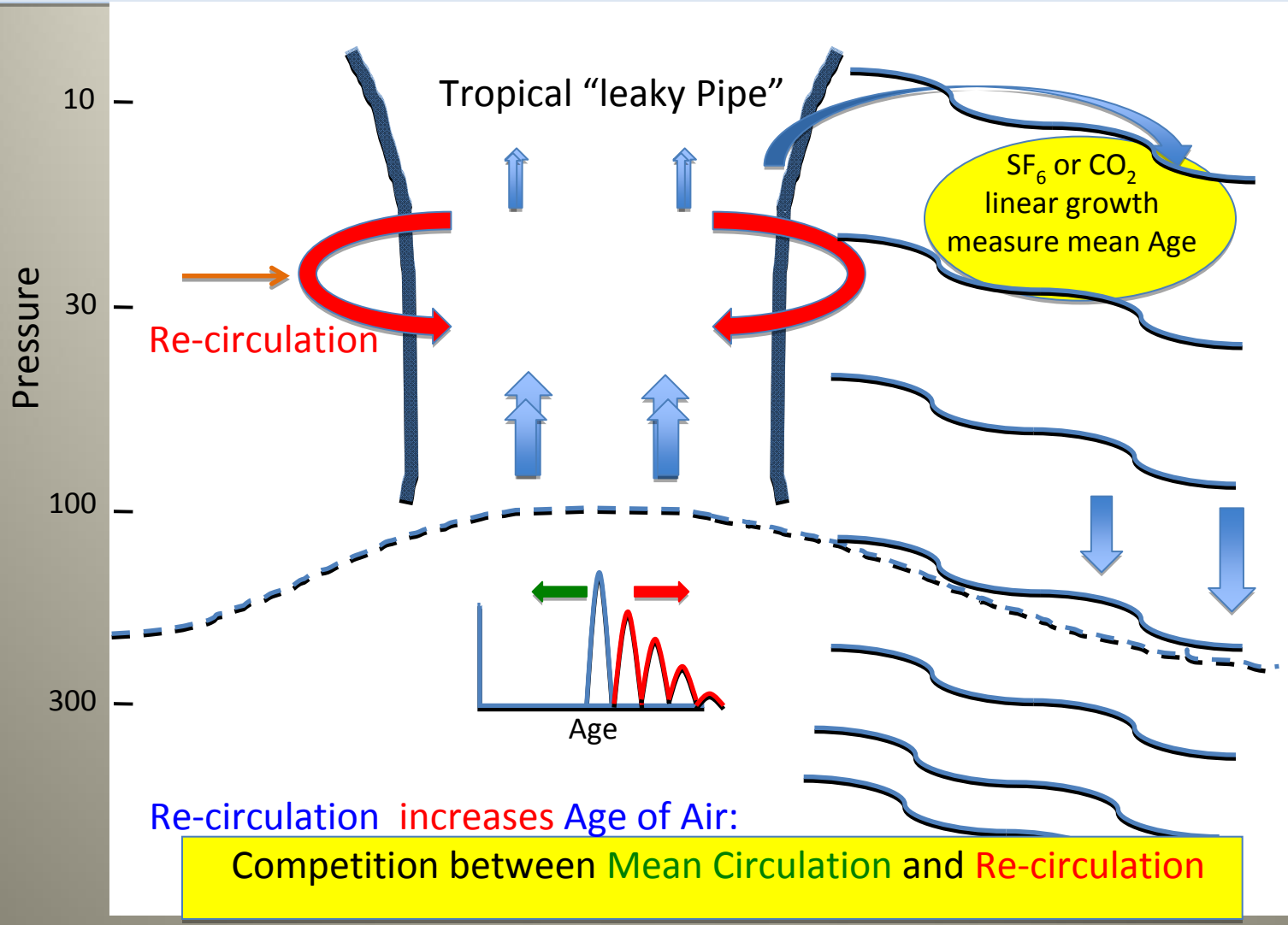
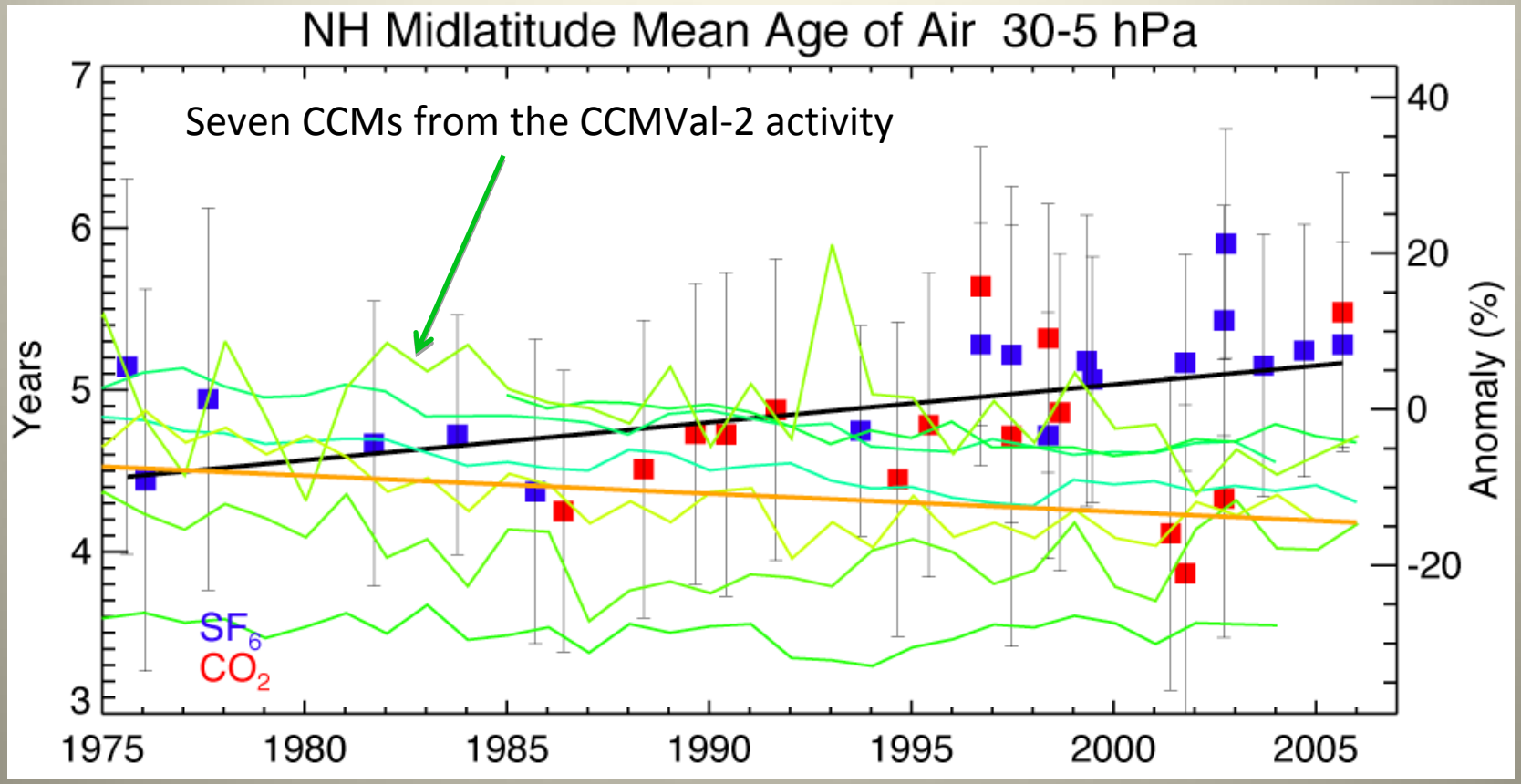


Re-circulation increases Age of Air:

Competition between Mean Circulation and Re-circulation

Stratospheric Mean Age of Air Trend at 25-32 km

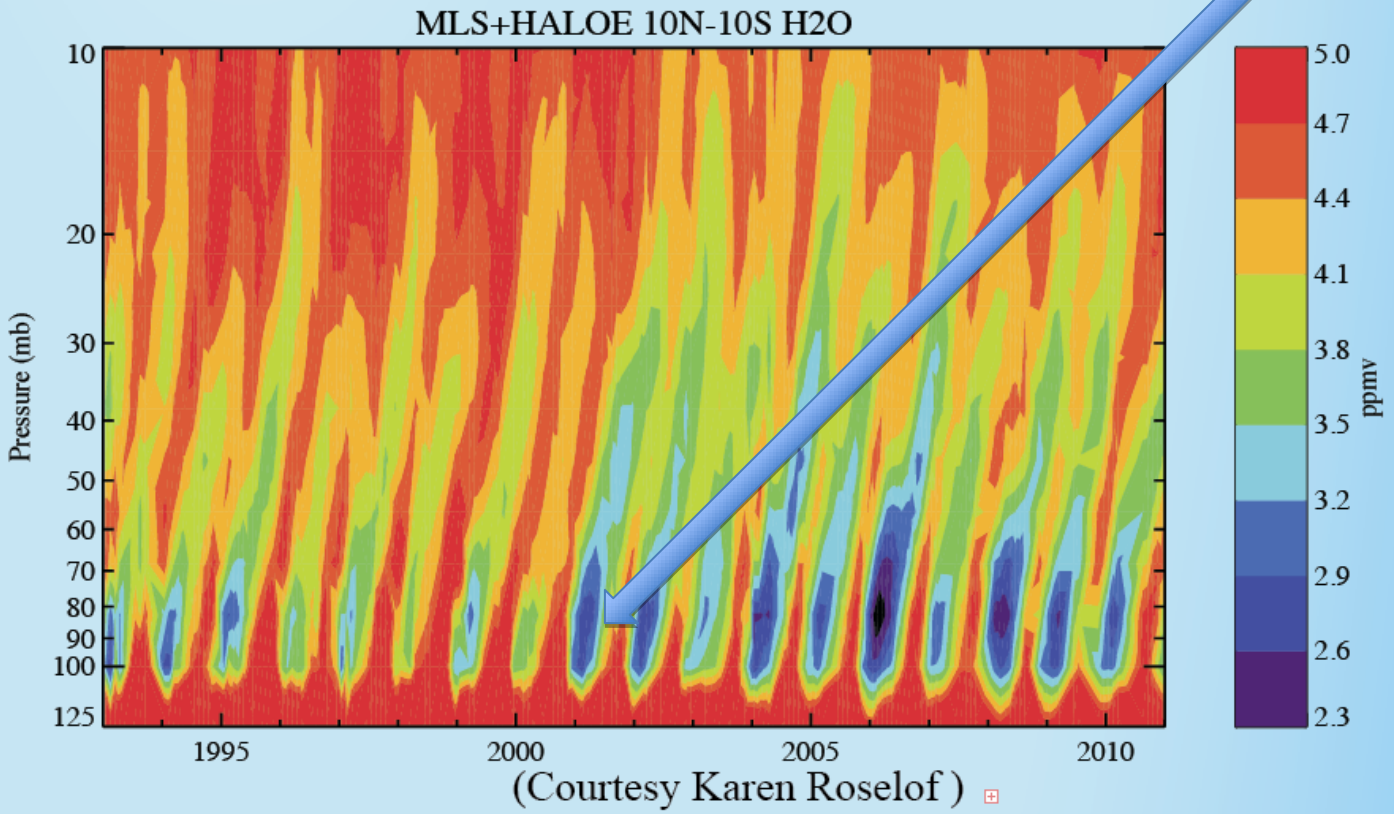


Ray et. al. 2010

Decreasing mean ages caused by an increasing strength of the stratospheric circulation are consistent, robust results in nearly all CCMs.

Stratospheric Mass Flux Changes Implied well below 25 km

Changes in Stratospheric water vapor are clearly evident in satellite data, they imply large changes of mass flux into the stratosphere and these changes can have a big impact on climate forcing.



(Courtesy Karen Roselof)

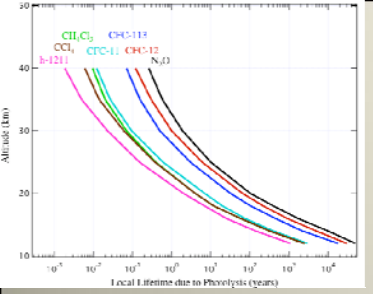
#1 Changes in Stratospheric Circulation Track Climate Change.

Take home message

Stratospheric Circulation Changes are Occurring,

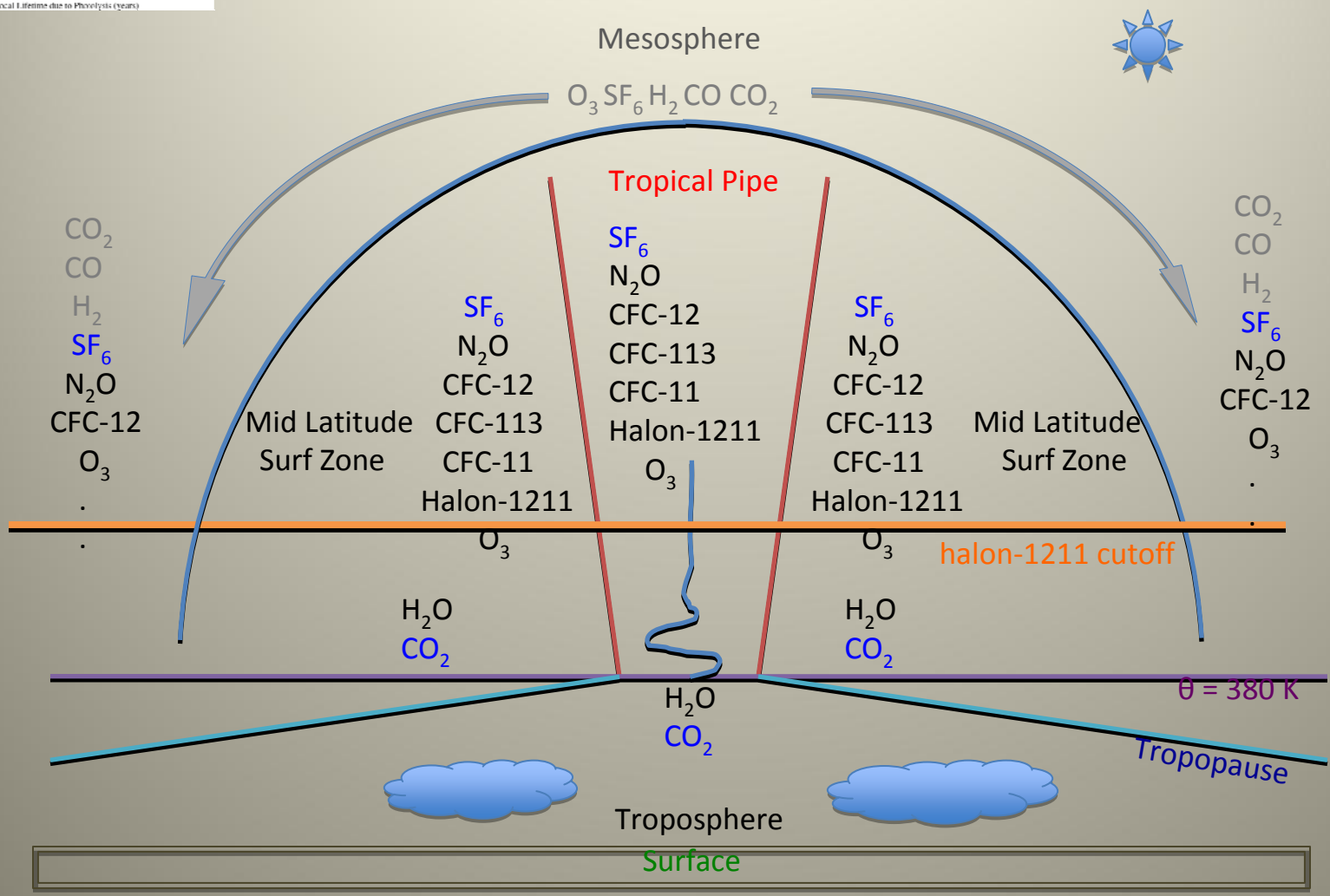
and

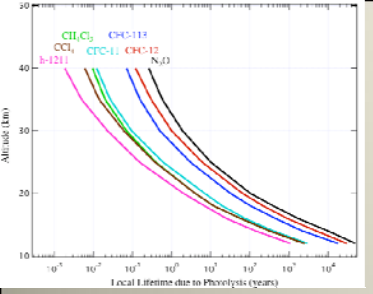
A quality Climate Climate Monitoring program needs a Measurement Based Stratospheric Circulation Program.



Data Set tailored for Stratospheric Circulation

Transport Time Scales from Age Tracers SF_6 or CO_2





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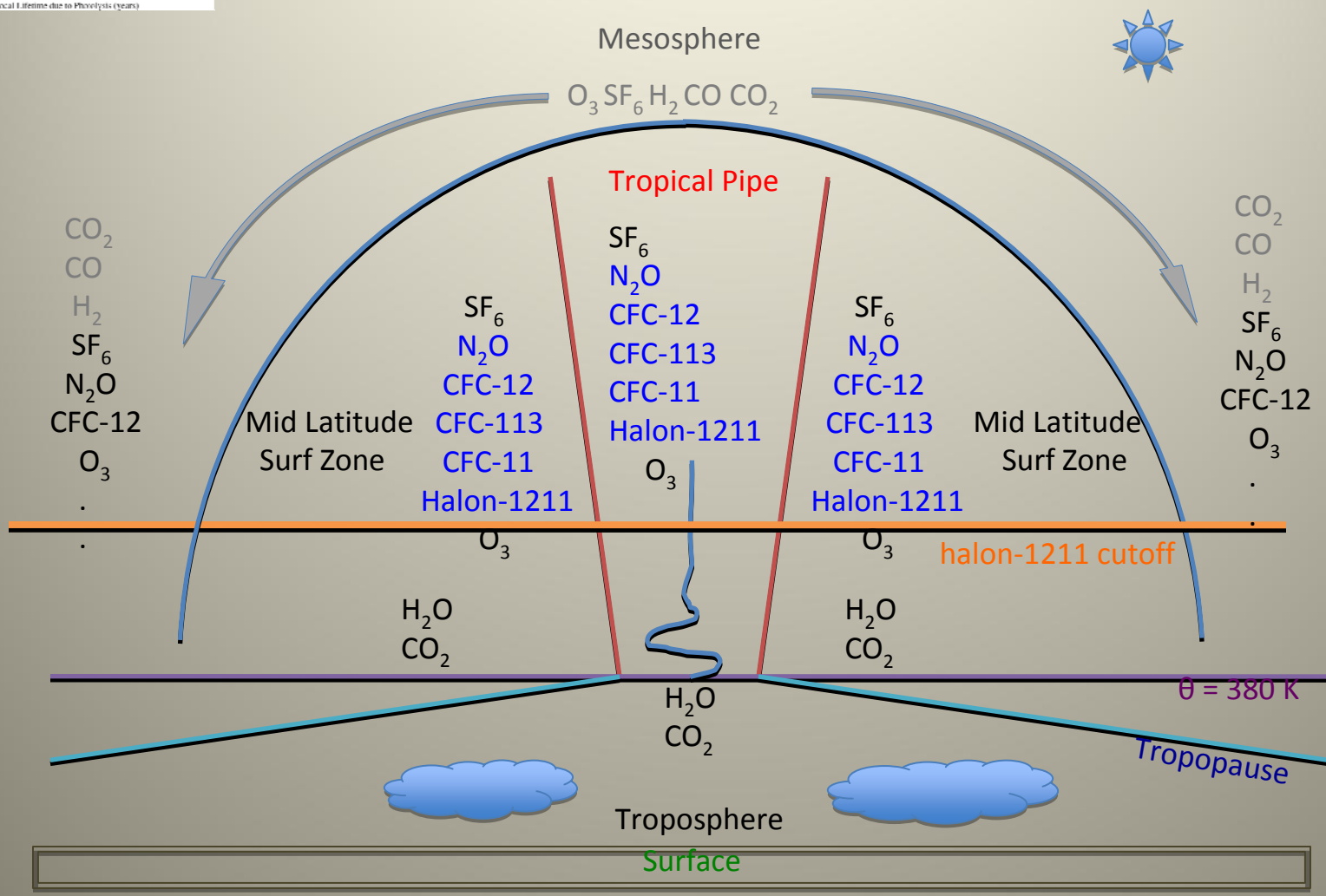

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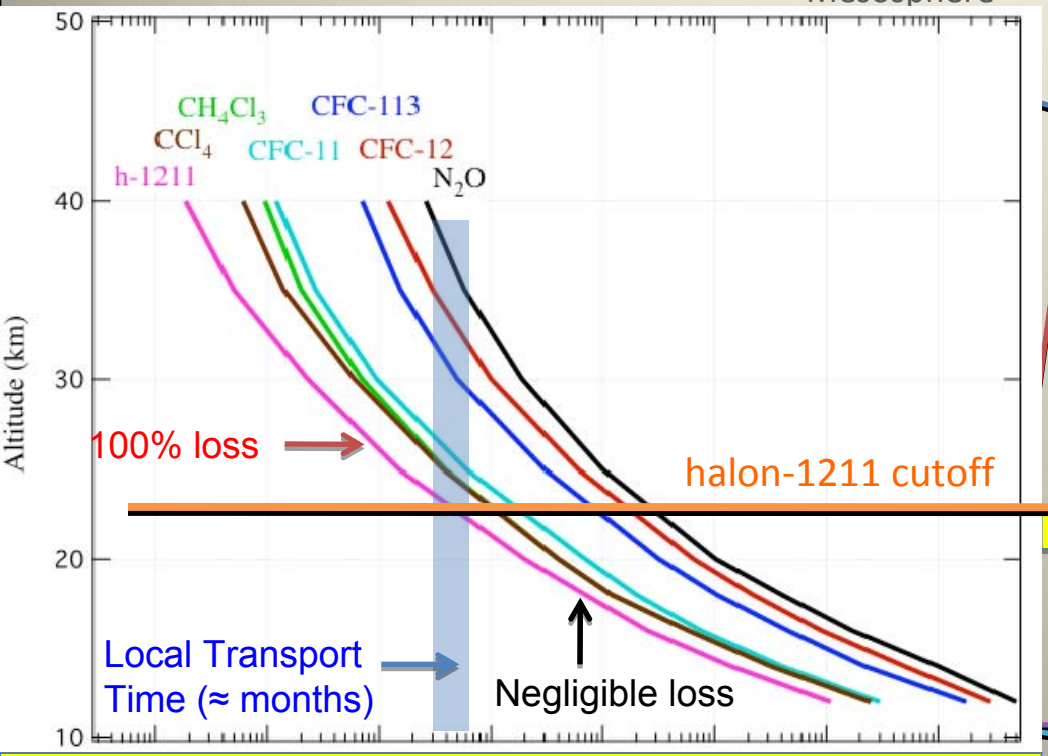
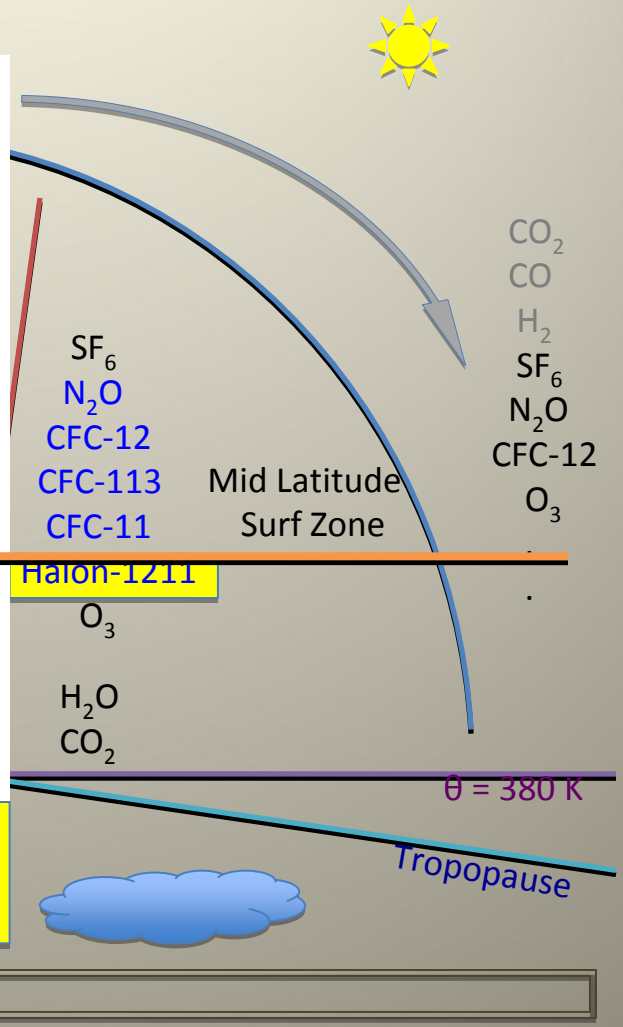


Local Lifetime due to Photolysis (years)
Log scale !



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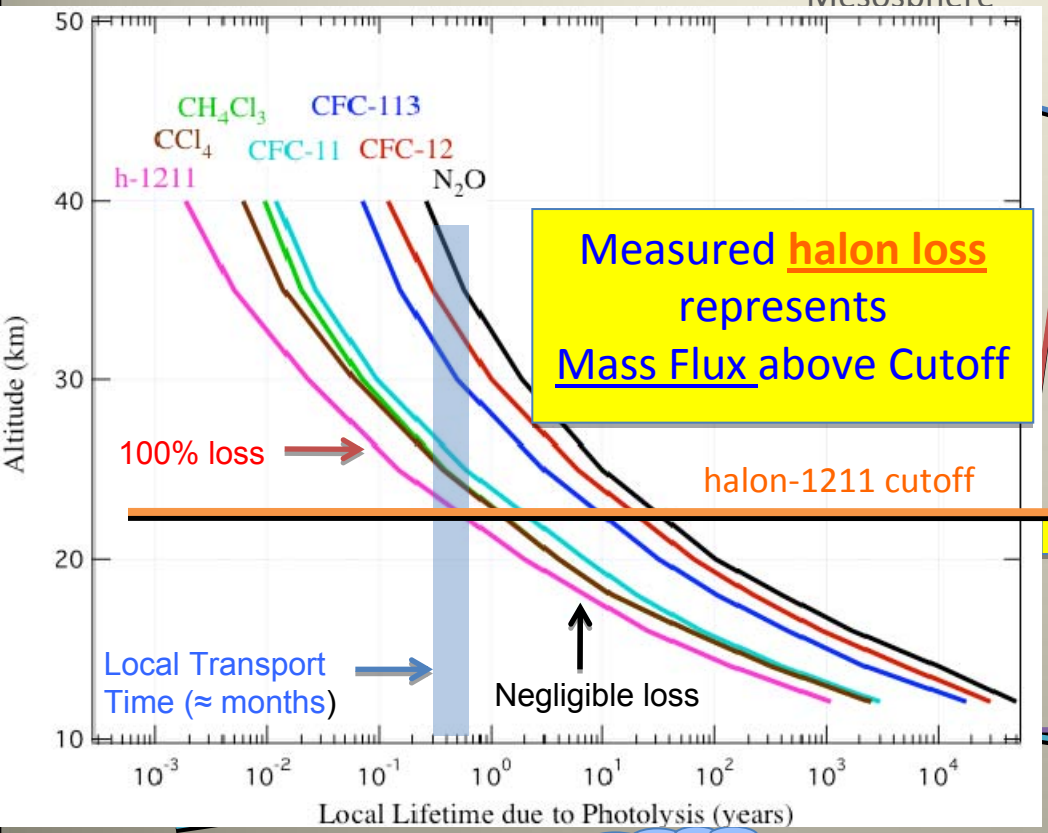

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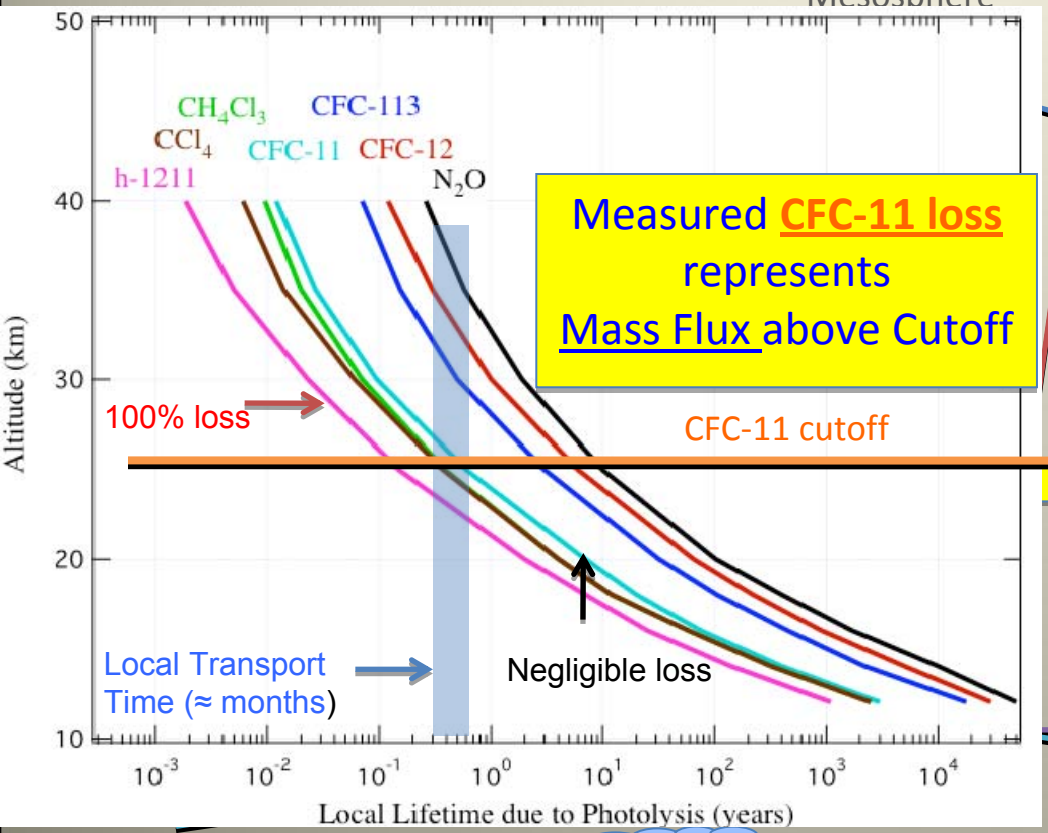
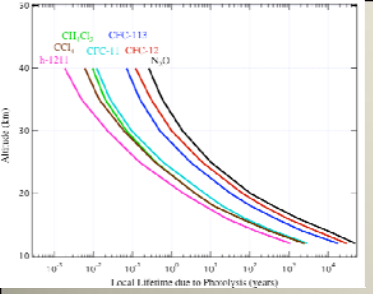


Measured CFC-11 loss represents Mass Flux above Cutoff



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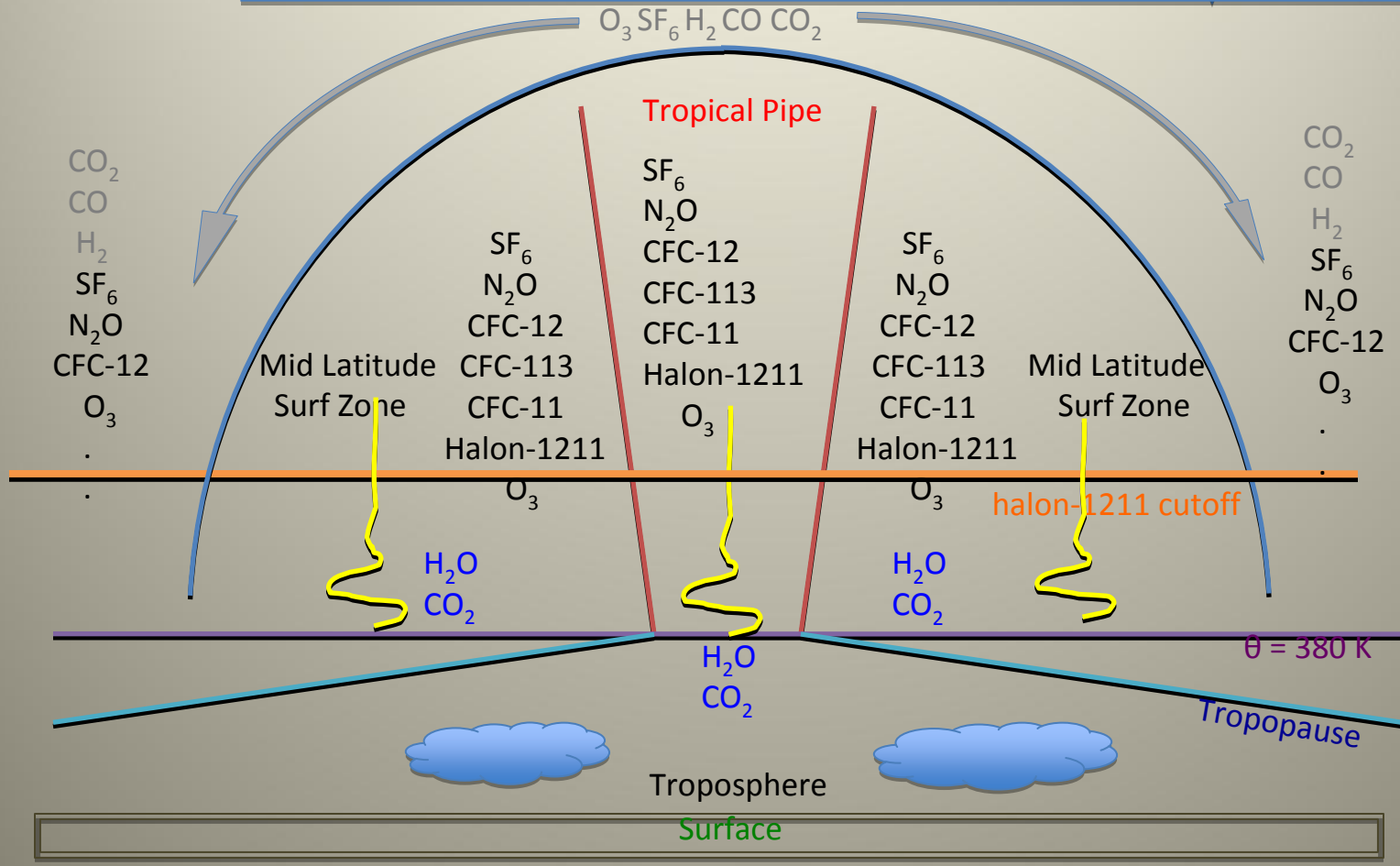
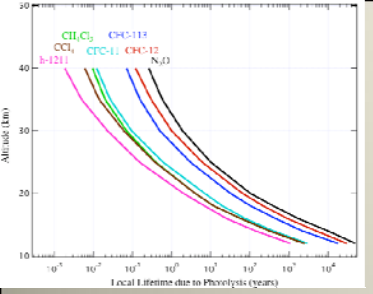
Tape Recorder Tracers add transport info below halon-1211 Cutoff Attenuation and Phase Lag.





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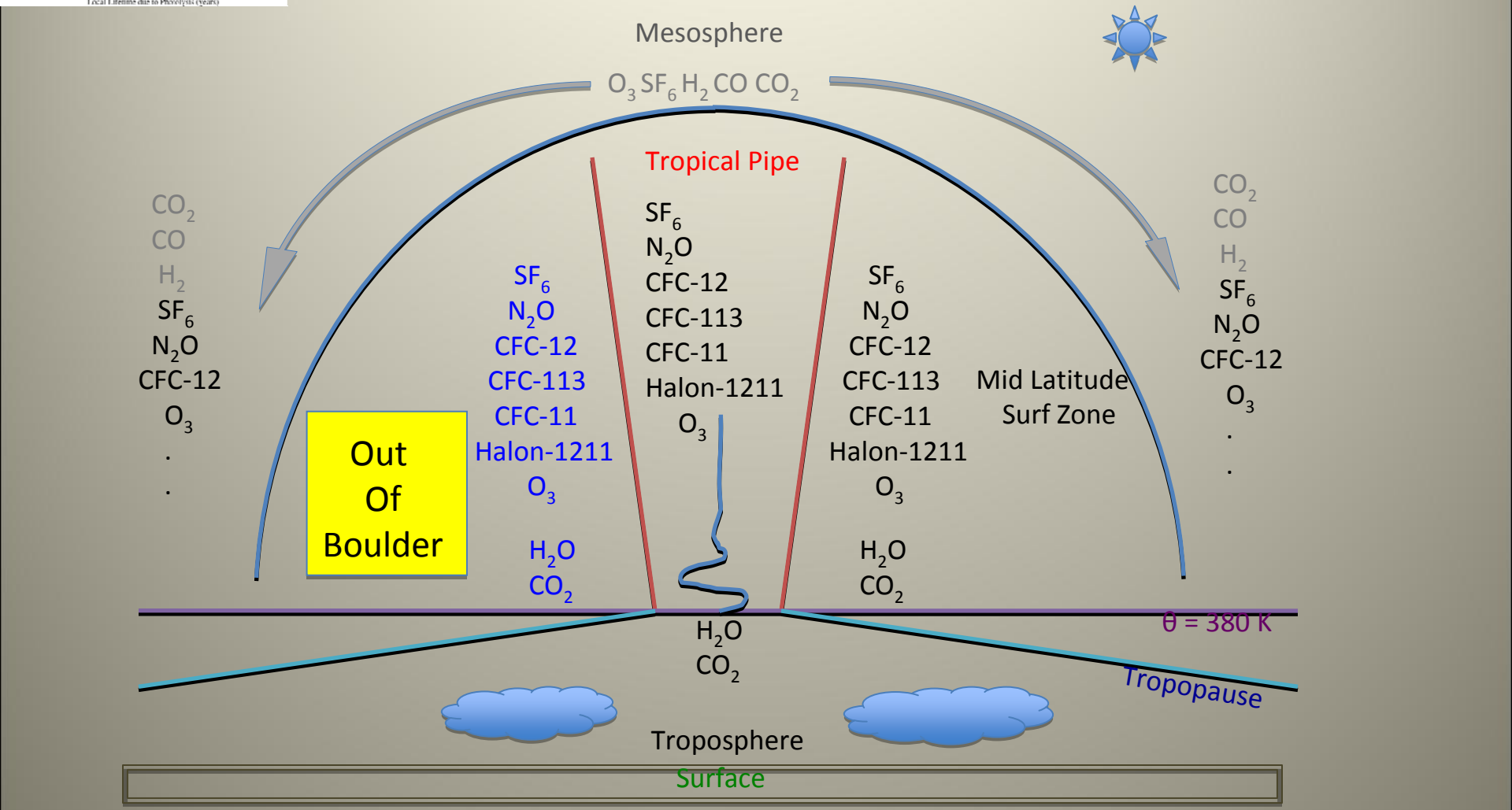

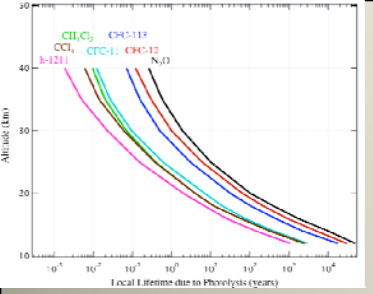

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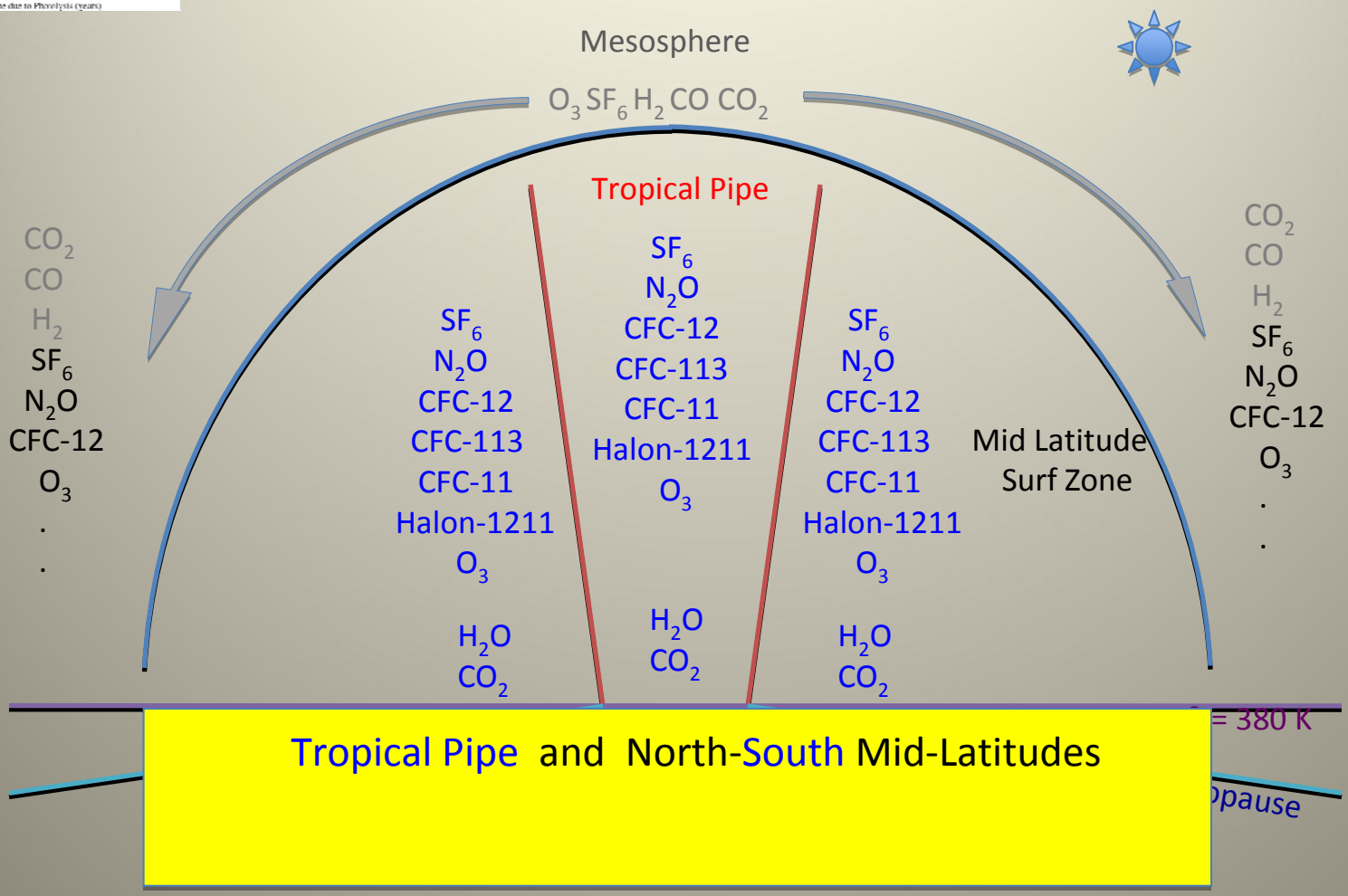

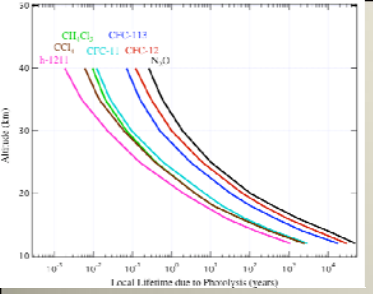

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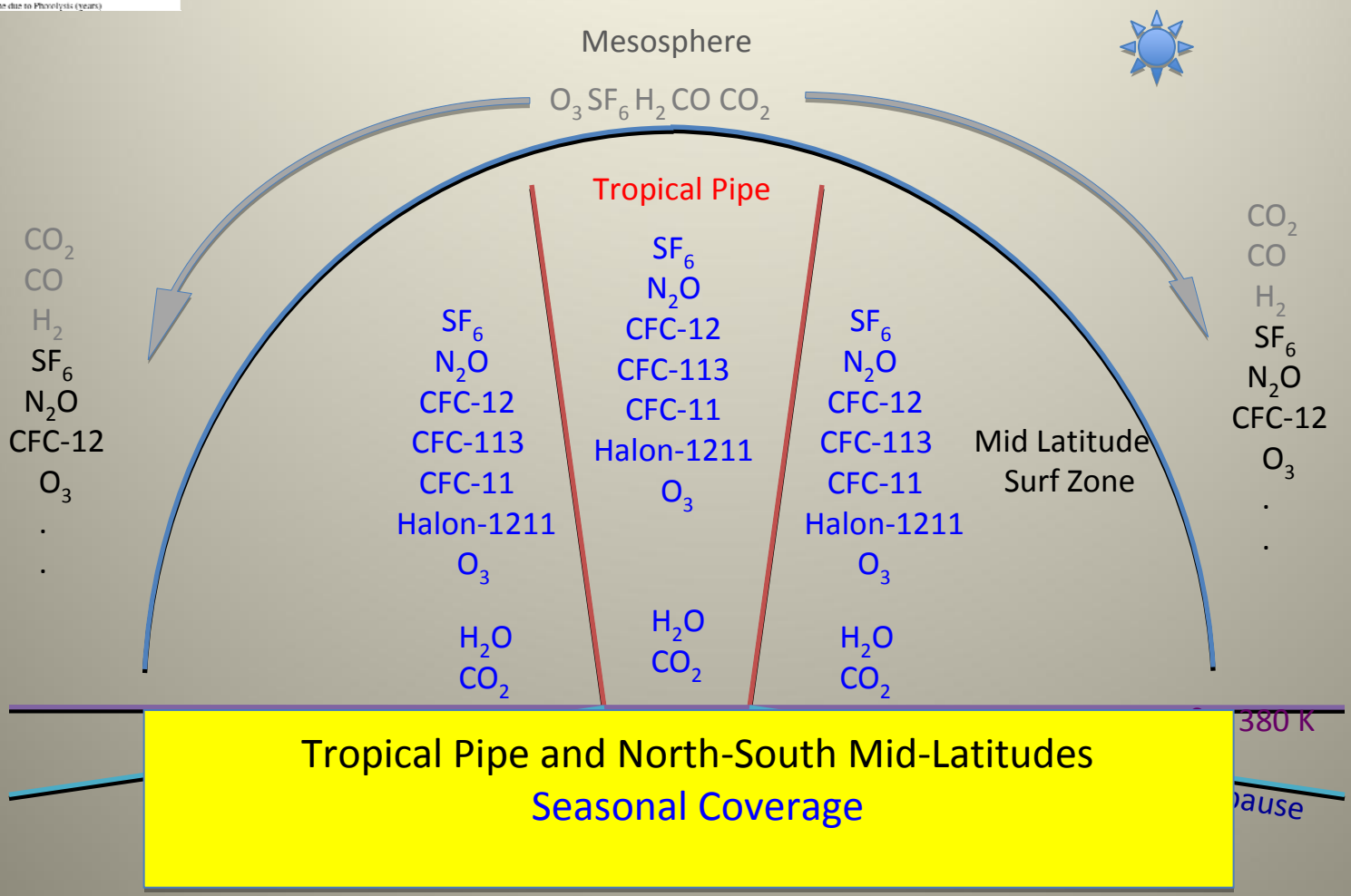

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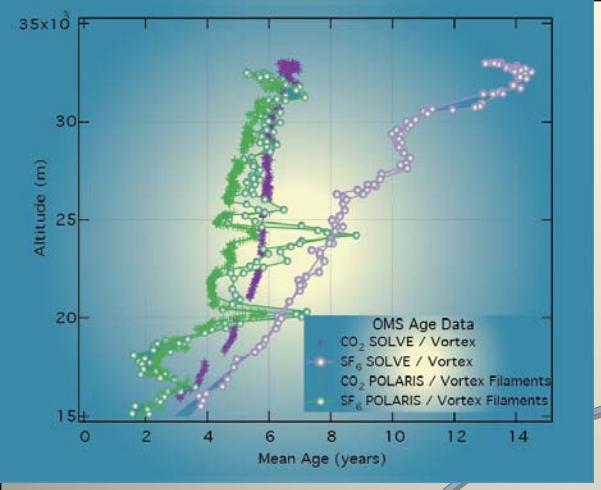


Mesosphere Mass Flux

O_3 SF_6 H_2 CO CO_2

Tropical Pipe

CO_2
CO
H_2
SF_6
N_2O
CFC-12
O_3
.
.

SF_6
N_2O
CFC-12
CFC-113
CFC-11
Halon-1211
O_3

H_2O
CO_2

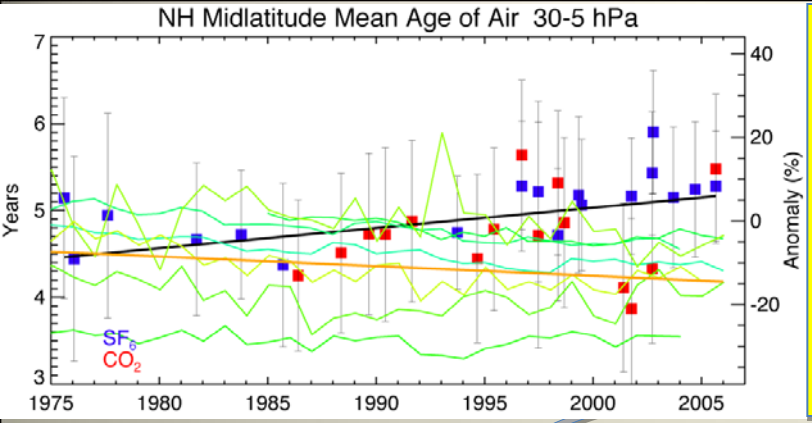
SF_6
N_2O
CFC-12
CFC-113
CFC-11
Halon-1211
O_3

H_2O
CO_2

Mid Latitude
Surf Zone

CO_2
CO
H_2
SF_6
N_2O
CFC-12
O_3
.
.

Tropical Pipe , North-South Mid-Latitudes, and Polar Seasonal Coverage

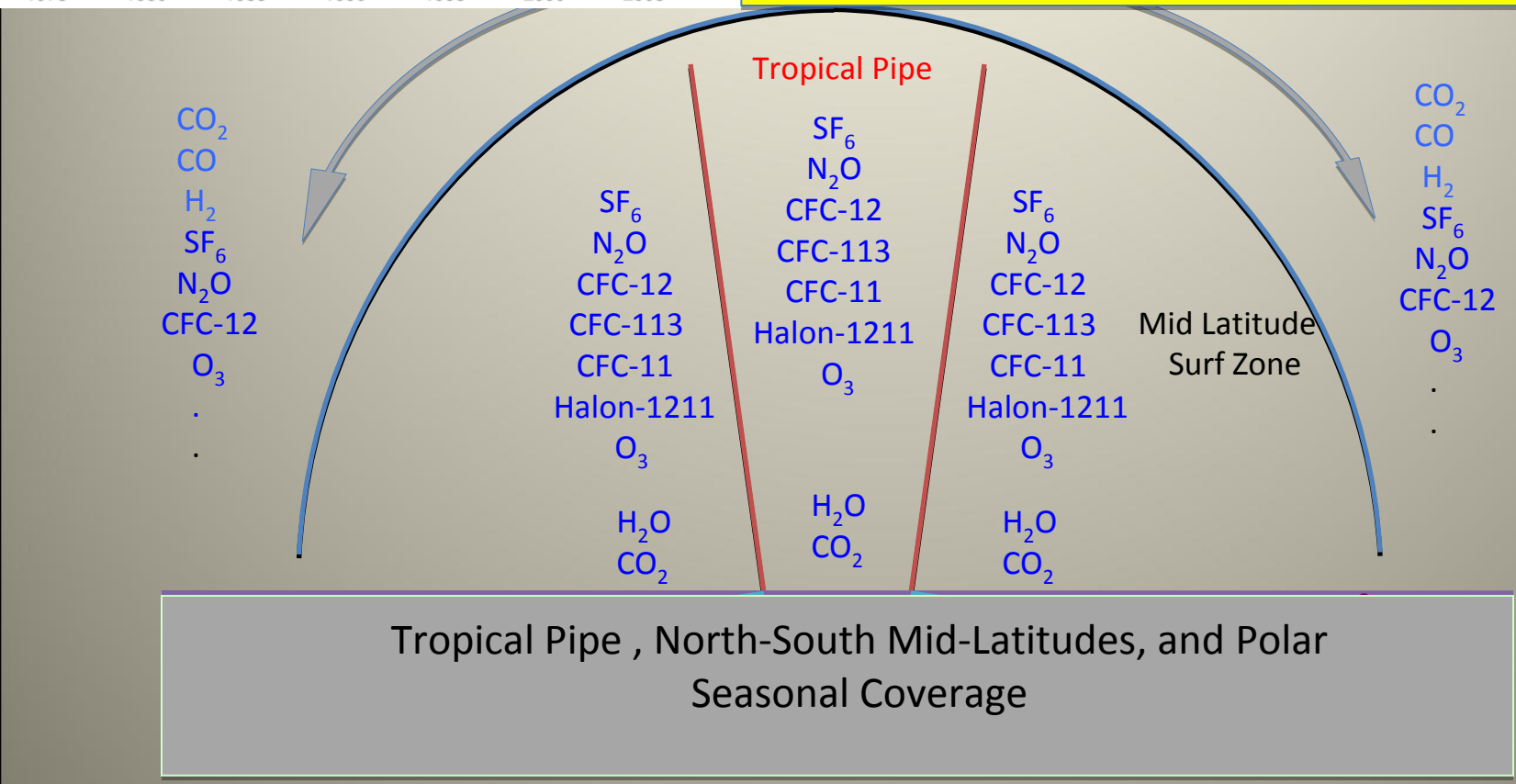


Very Expensive:

Each LACE GC data point cost > $100,000

Not Optimized for Long Term Monitoring:

Independent calibration errors from multiple programs



Tropical Pipe , North-South Mid-Latitudes, and Polar Seasonal Coverage

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

Fly Air Core out of Boulder

Analyze by one GC in Boulder.

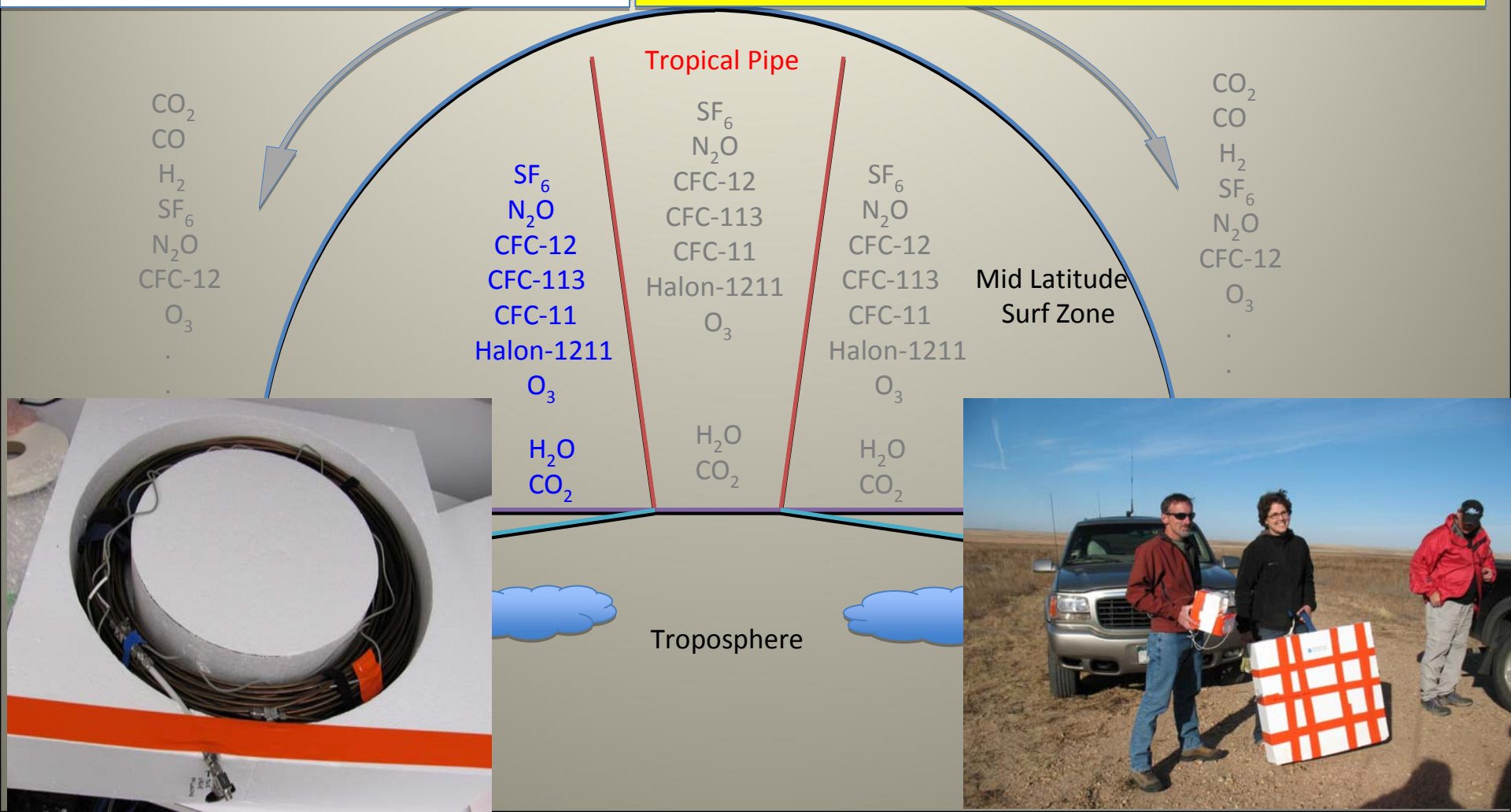
Photos: Anna Karion and Jack Higgs

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



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

Air Core coupled to an Auto Sampler
(Modified Mini -PFP)
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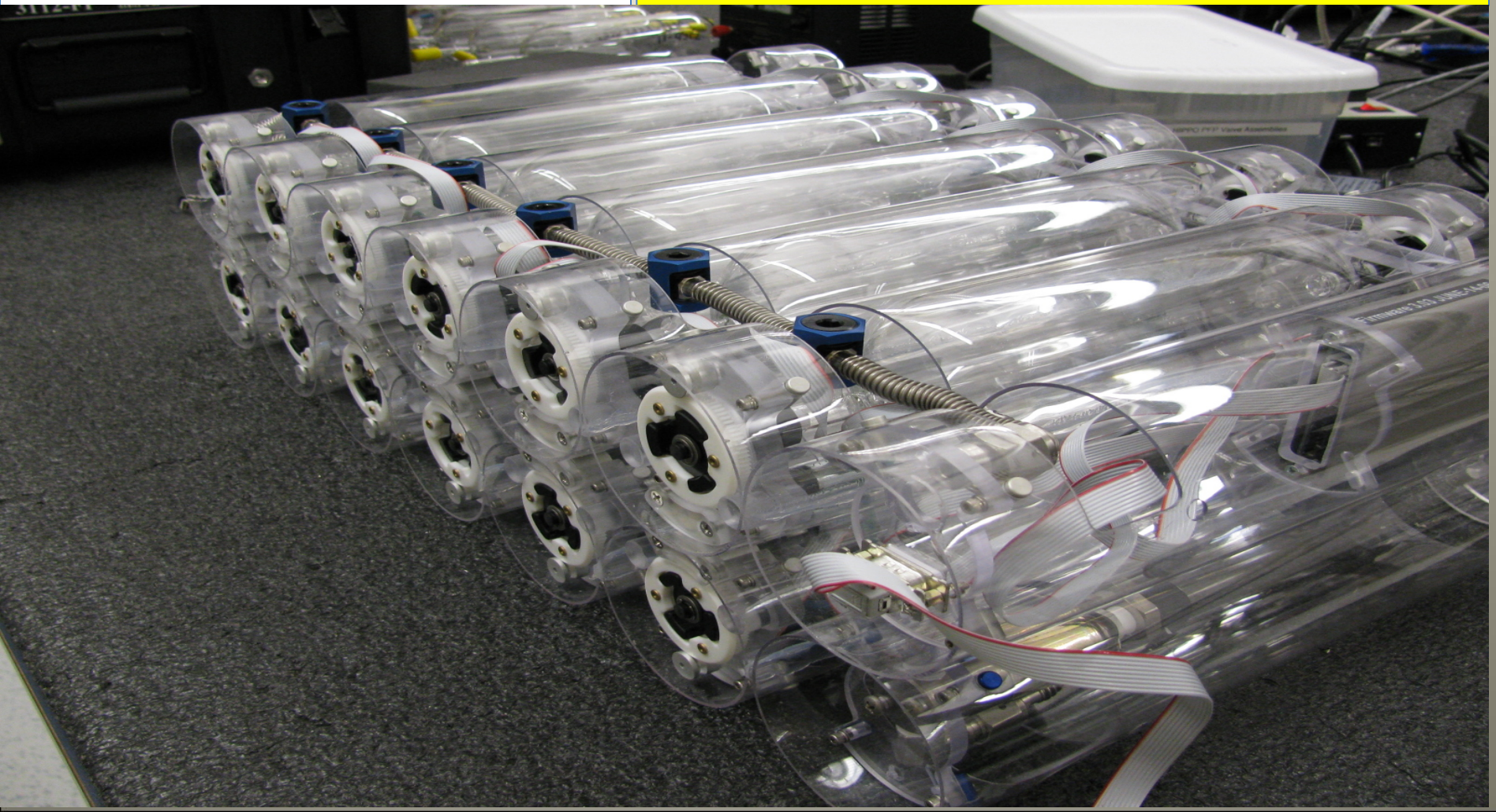

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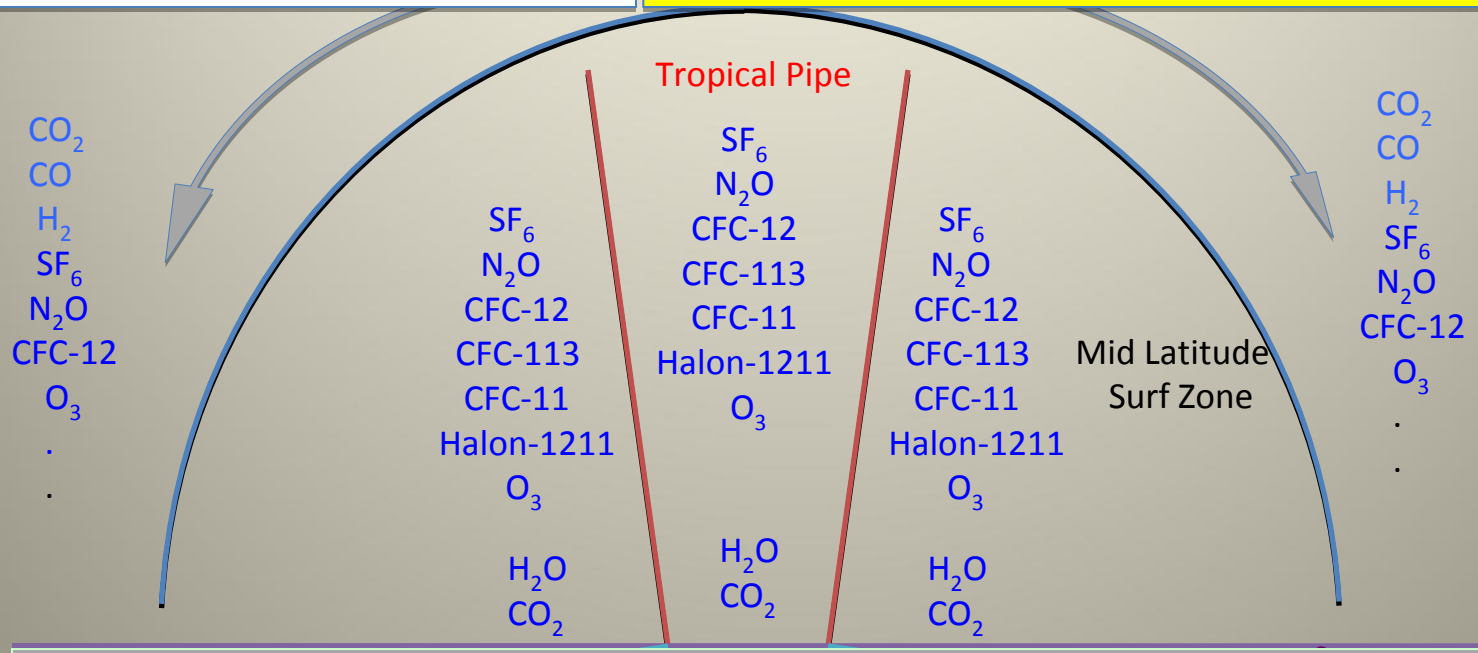

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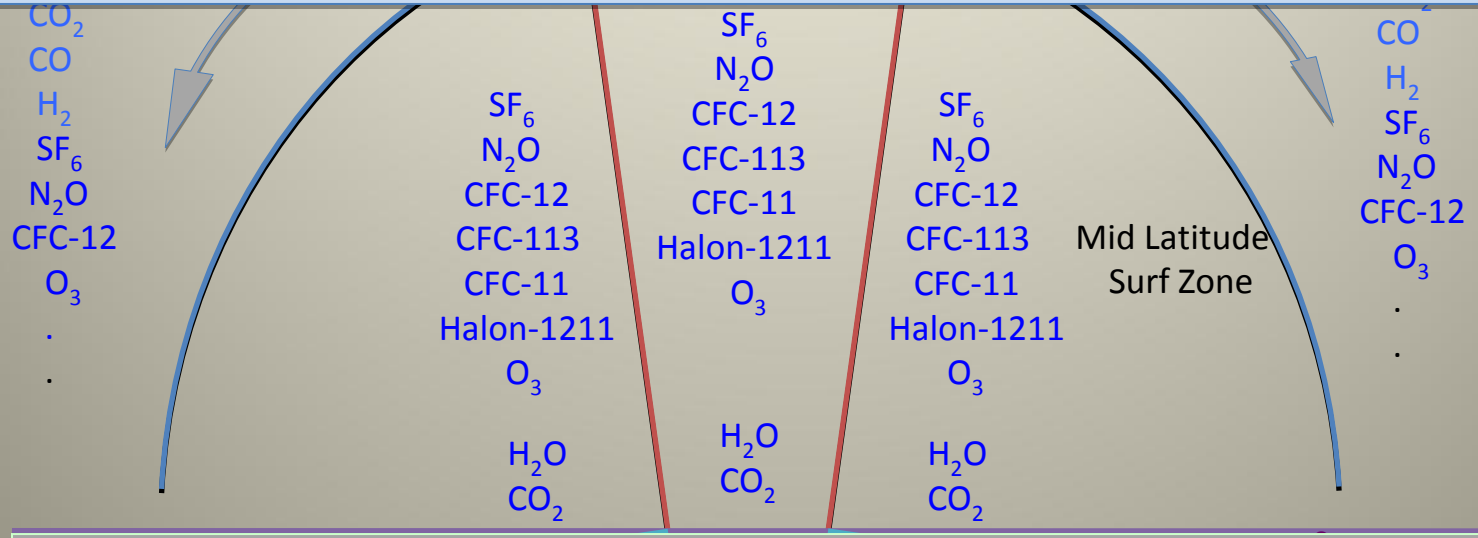

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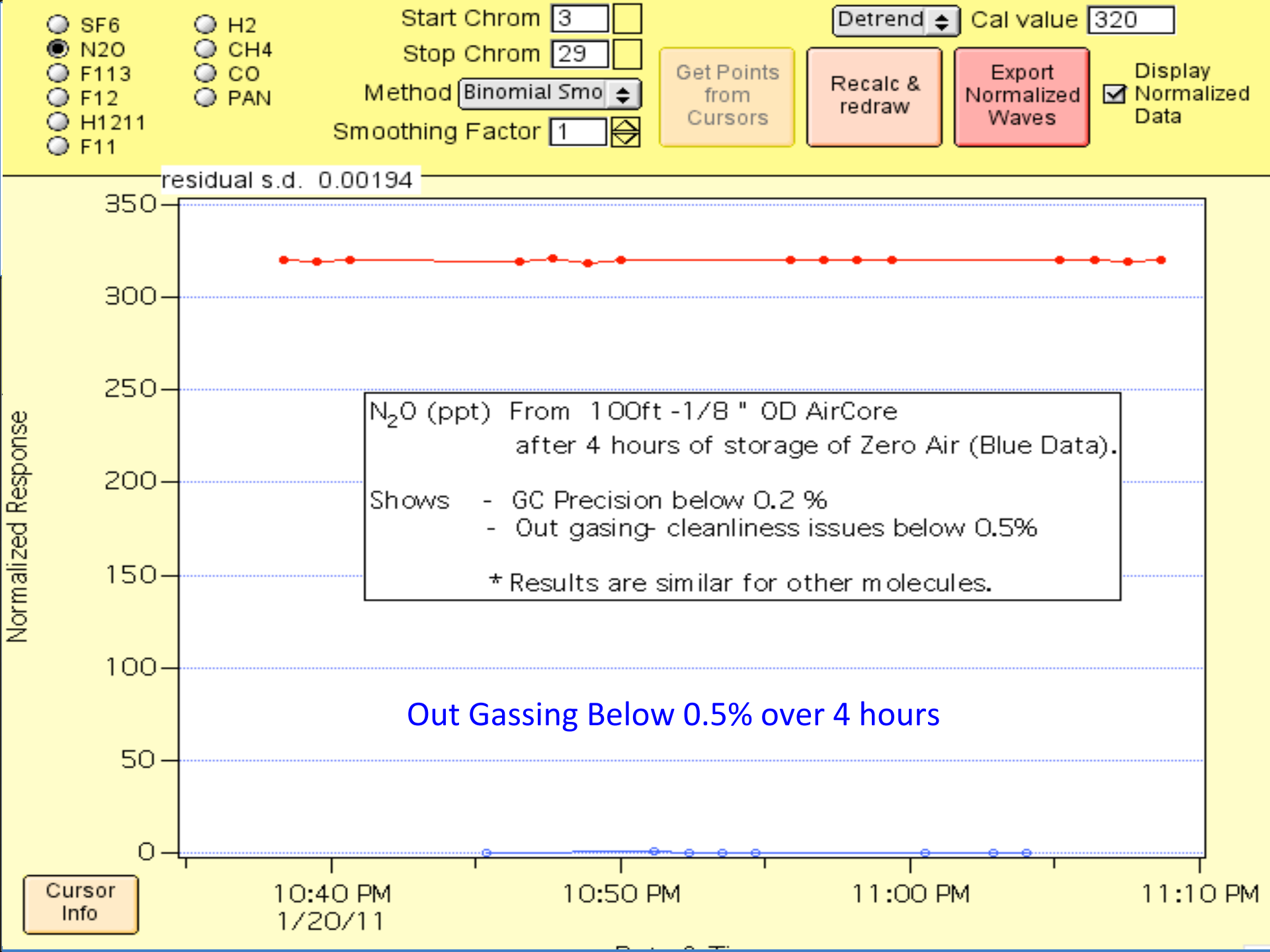
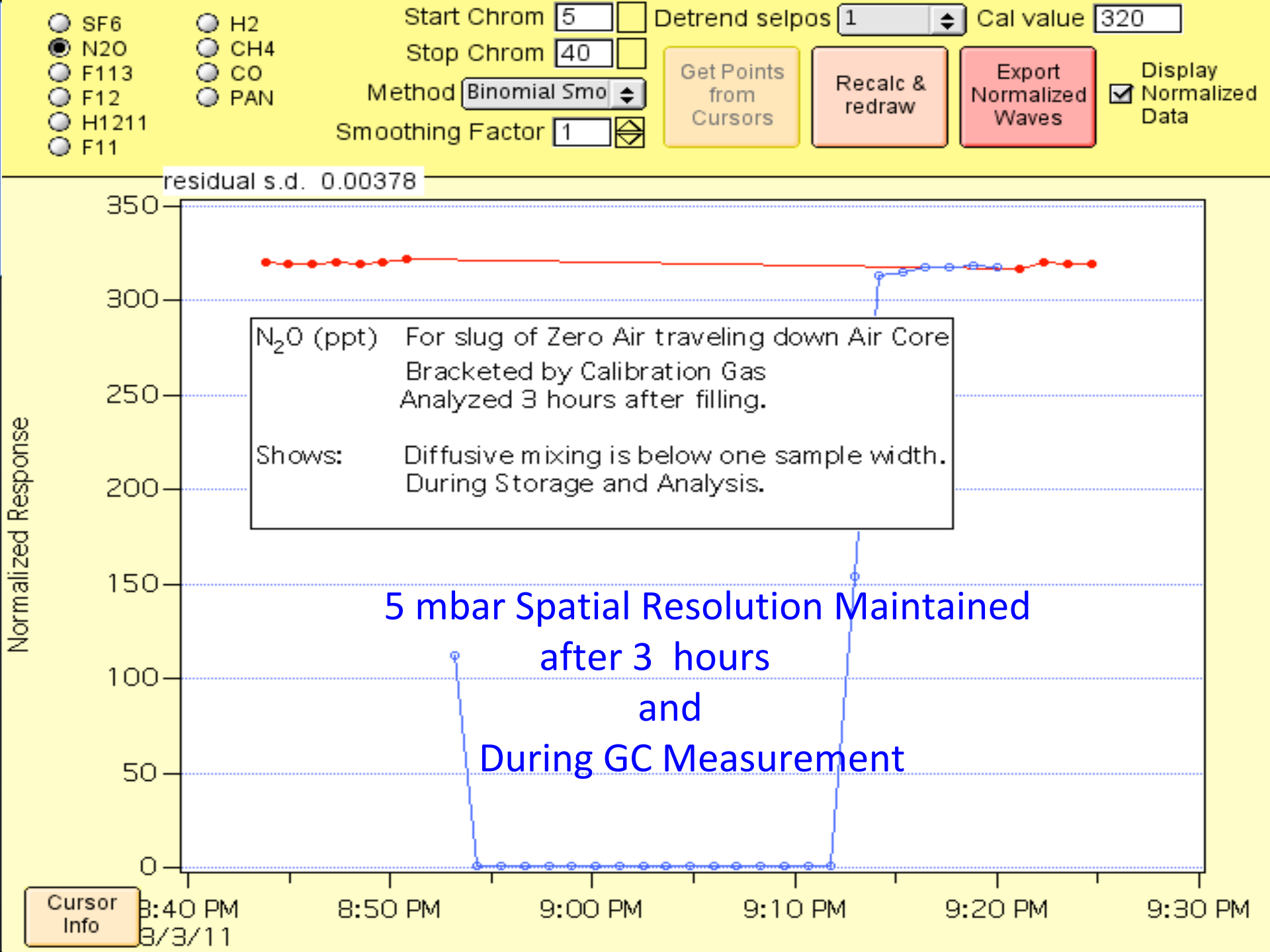

SF6
N2O
F113
F12
H1211
F11
H2
CH4
CO
PAN
Start Chrom 3
Stop Chrom 29
Method Binomial Smo
Smoothing Factor 1
Get Points from Cursors
Detrend
Cal value 320
Recalc & redraw
Export Normalized Waves
Display Normalized Data
residual s.d. 0.00194
Normalized Response
350
300
250
200
150
100
50
0
N2O (ppt) From 100ft -1/8 " OD AirCore
after 4 hours of storage of Zero Air (Blue Data).
Shows - GC Precision below 0.2 %
- Out gasing- cleanliness issues below 0.5%
* Results are similar for other molecules.
Out Gassing Below 0.5% over 4 hours
Cursor Info
10:40 PM
1/20/11
10:50 PM
11:00 PM
11:10 PM


SF6
N2O
F113
F12
H1211
F11
H2
CH4
CO
PAN
Start Chrom 5
Stop Chrom 40
Method Binomial Smo
Smoothing Factor 1
Detrend selpos 1
Cal value 320
Get Points from Cursors
Recalc & redraw
Export Normalized Waves
Display Normalized Data
residual s.d. 0.00378
Normalized Response
350
300
250
200
150
100
50
0
N2O (ppt) For slug of Zero Air traveling down Air Core
Bracketed by Calibration Gas
Analyzed 3 hours after filling.
Shows: Diffusive mixing is below one sample width.
During Storage and Analysis.
5 mbar Spatial Resolution Maintained
after 3 hours
and
During GC Measurement
Cursor Info
8:40 PM
8/3/11
8:50 PM
9:00 PM
9:10 PM
9:20 PM
9:30 PM

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

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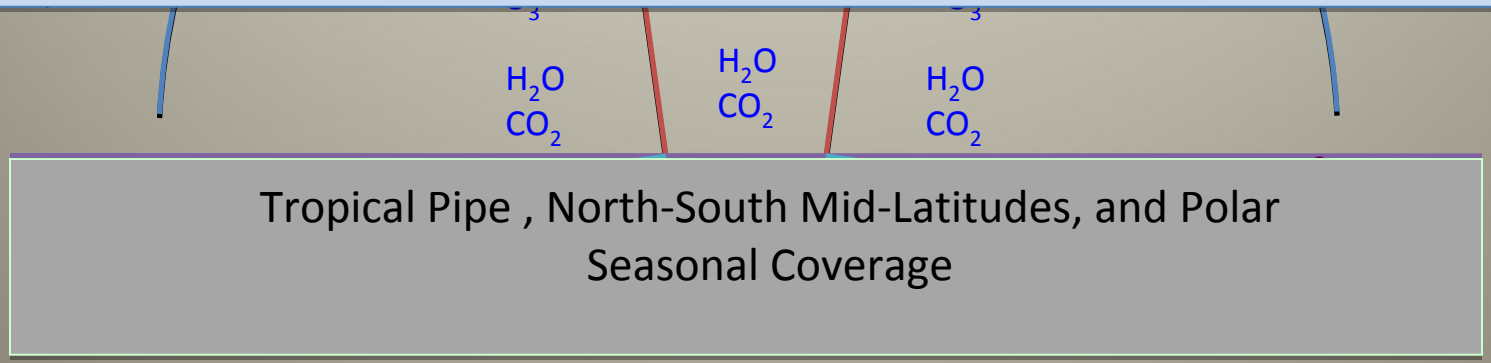
Targeted Trace Gases are at the ppt level were as CO2 , CH4 are above the ppm level.

Bottom Line: Air Core 100 ft 1/8 inch SS tube, fed by a 100 feet of 1/4 inch SS tube
Gives Data from 32 km to the troppause with 5 mbar sample resolution.

Translates to: A Package that is below the FAA 6 lb regulations,
>> reducing cost and increasing versatility.



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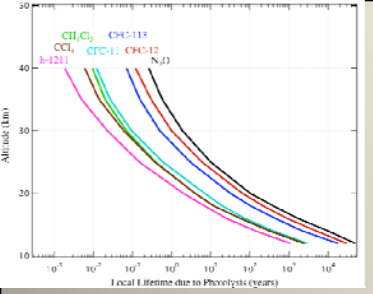
Recently received Funds from the NOAA UAS program.

>> GC front end Development.
>> A couple Balloon Flights out of Boulder.
>> Sky Wisp UAS flight.

Stratospheric Circulation Data Set



Mesosphere

O_3 SF_6 H_2 CO CO_2

Tropical Pipe

CO_2
CO
H_2
SF_6
N_2O
CFC-12
O_3
.
.

Mid Latitude Surf Zone

SF_6
N_2O
CFC-12
CFC-113
CFC-11
Halon-1211
O_3

SF_6
N_2O
CFC-12
CFC-113
CFC-11
Halon-1211
O_3

Mid Latitude Surf Zone

CO_2
CO
H_2
SF_6
N_2O
CFC-12
O_3
.
.

halon-1211 cutoff

H_2O
CO_2

H_2O
CO_2

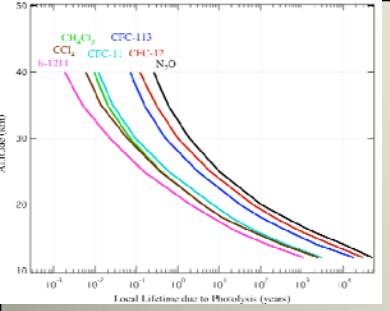
H_2O
CO_2

θ = 380 K

Tropopause

Troposphere

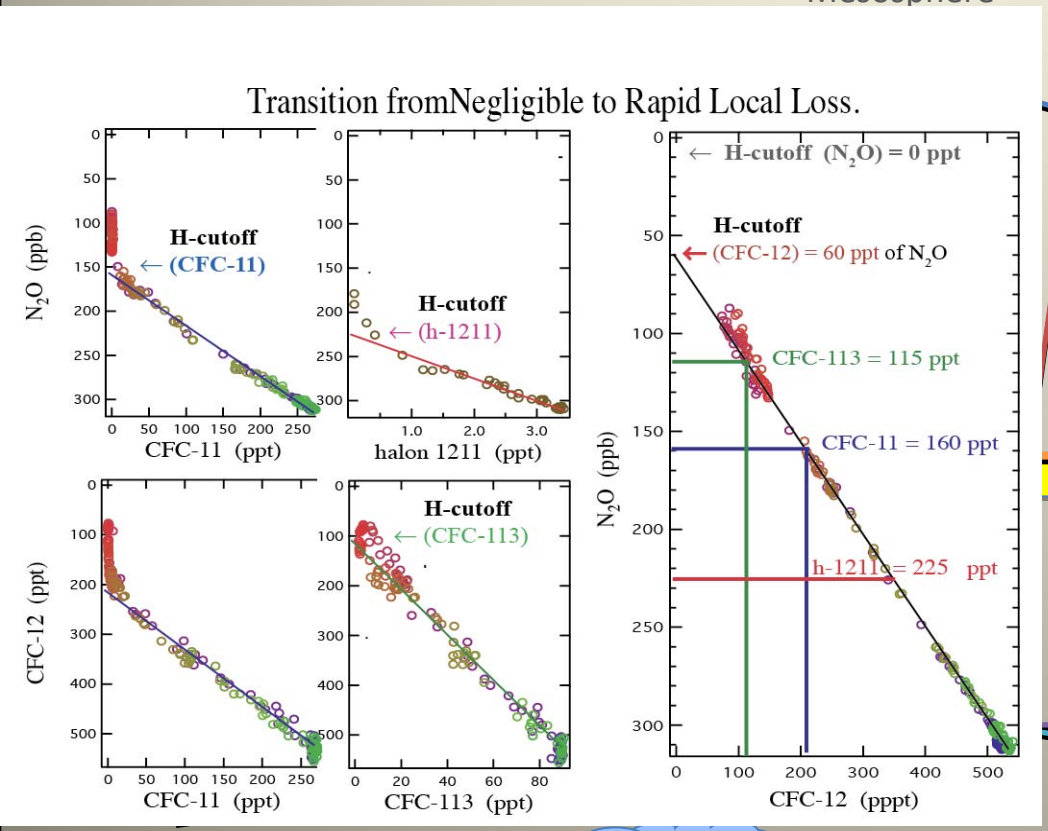
Surface

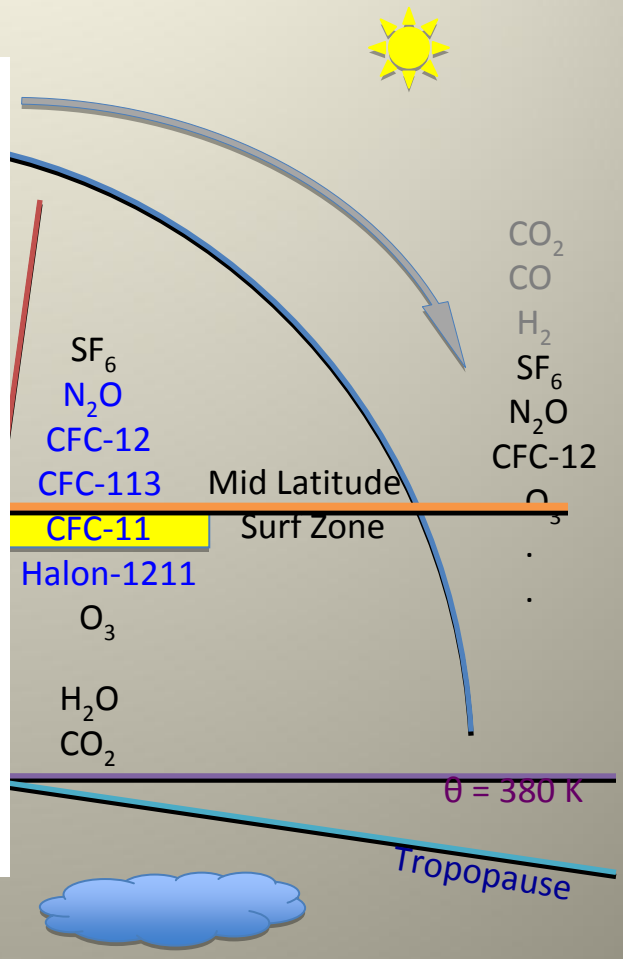


Stratospheric Circulation Data Set

Transport Time Scales from Age Tracers SF_6 or CO_2

Path and Mass Flux from Photolytic Tracers halon-1211, CFC's and N2O .

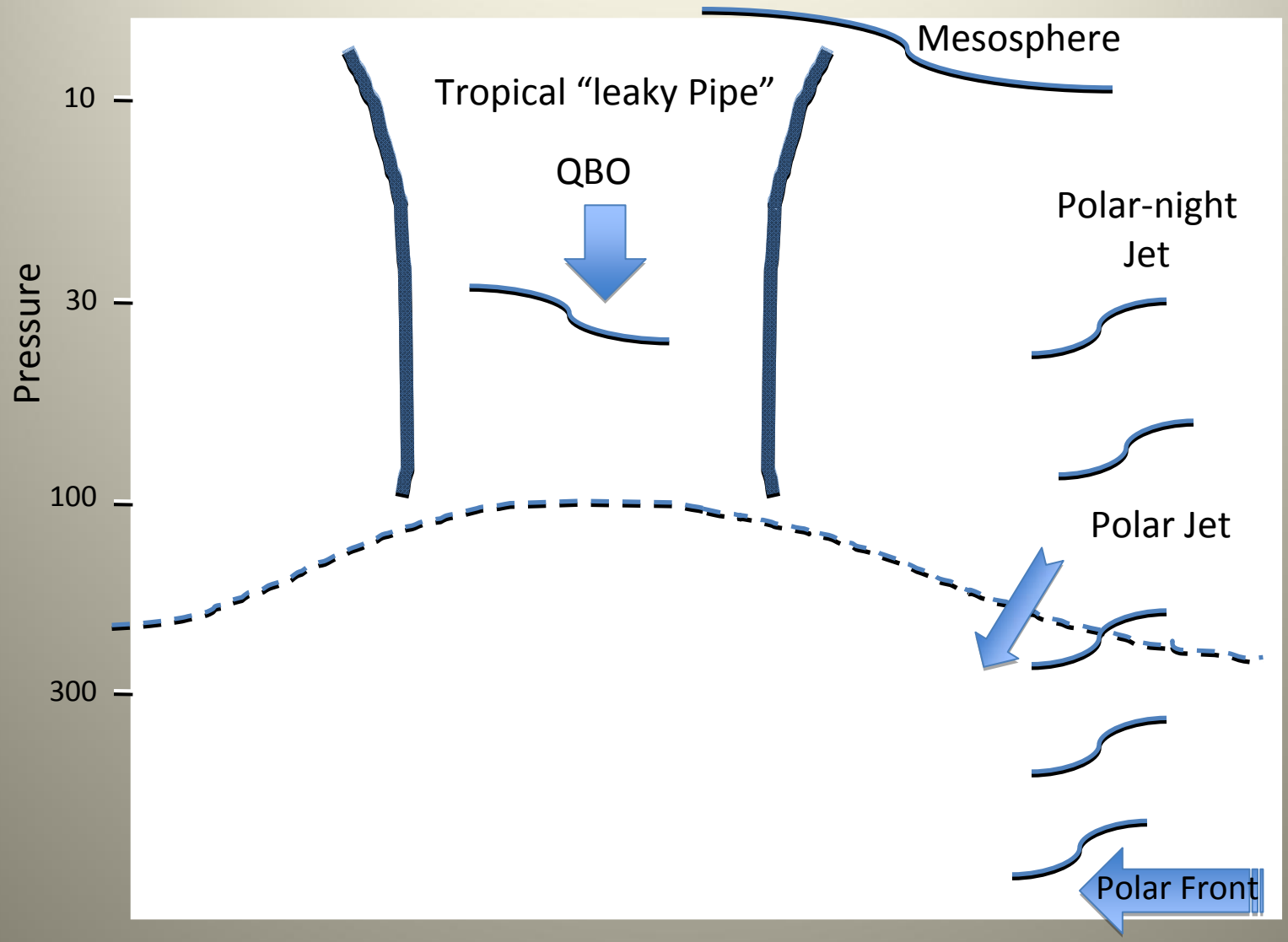




CLIMATE CHANGE

*drives change in weather in the troposphere. >> Induces change in wave generation

Much more complicated, especially when we include Zonal winds.



What is Different from Current AirCore CO_2/CH_4/CO measurements?

Target Stratosphere:

Our stratospheric signals are large.

CFC-11 changes by 100% going from its troposphere value to zero at altitude, while CO_2 changes by only 6%.

Translates to: Our targeted accuracy of 1.0% to obtain science objectives.
Compared to 0.1% to 0.05 % for CO_2 measurements.

Analyze air from the AirCore with a gas chromatograph (GC).

Sample volume of < 1 sccm for each channel (minimum 2 channels.)

> Substantially smaller that that of the Picarro optical cell .

Concentration:

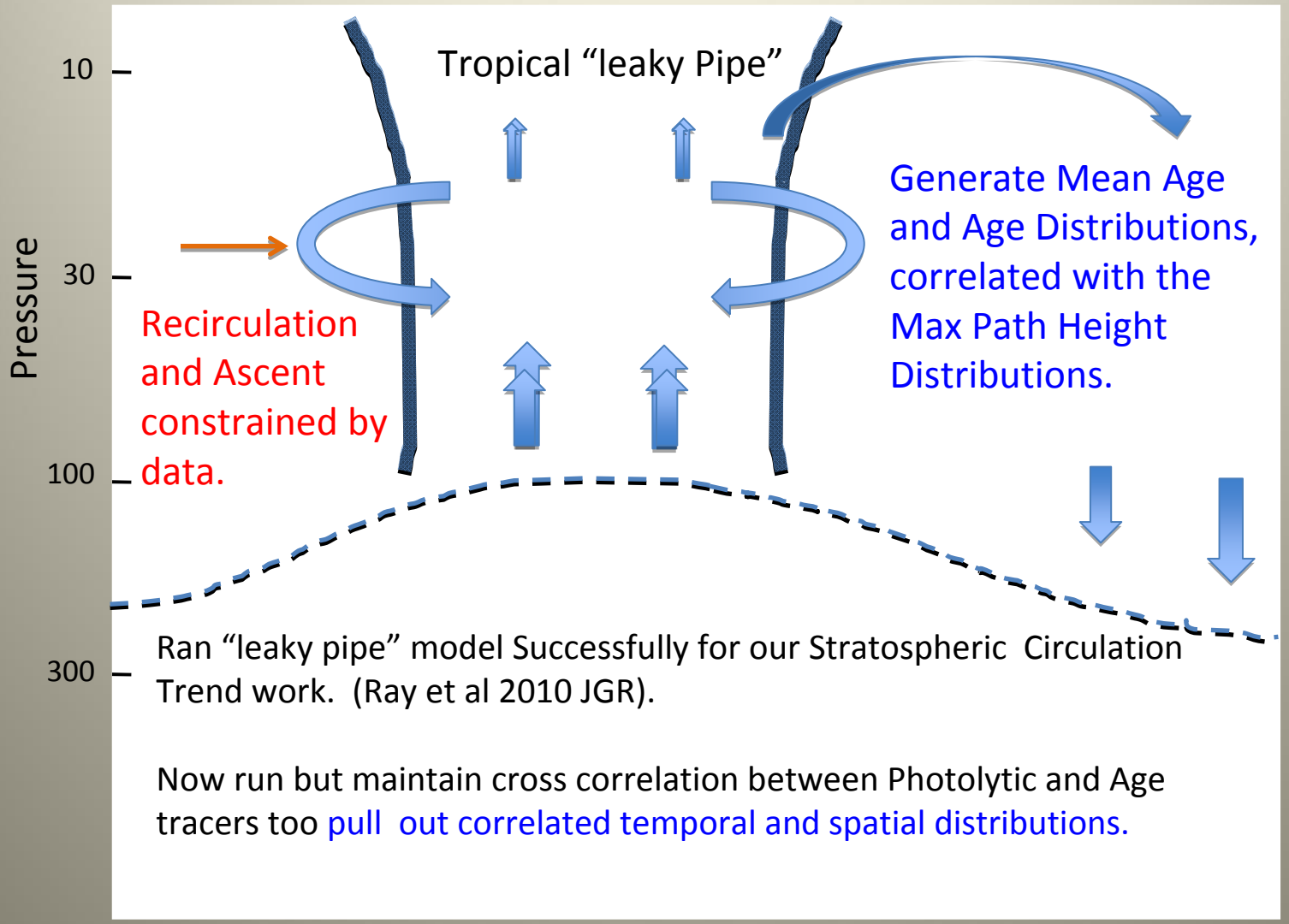
Targeted Trace Gases at the ppt level were as CO_2 , CH_4 are above the ppm level.

Bottom Line: AirCore 100 ft 1/8 inch SS tube, fed by a 100 feet of 1/4 inch SS tube will acquire data with 10 mbar resolution from below the tropopause up to 32km in the stratosphere.

Translates to: a Package that is below the FAA 6 lb regulations.

Track Stratospheric Circulation Change due to Climate Change

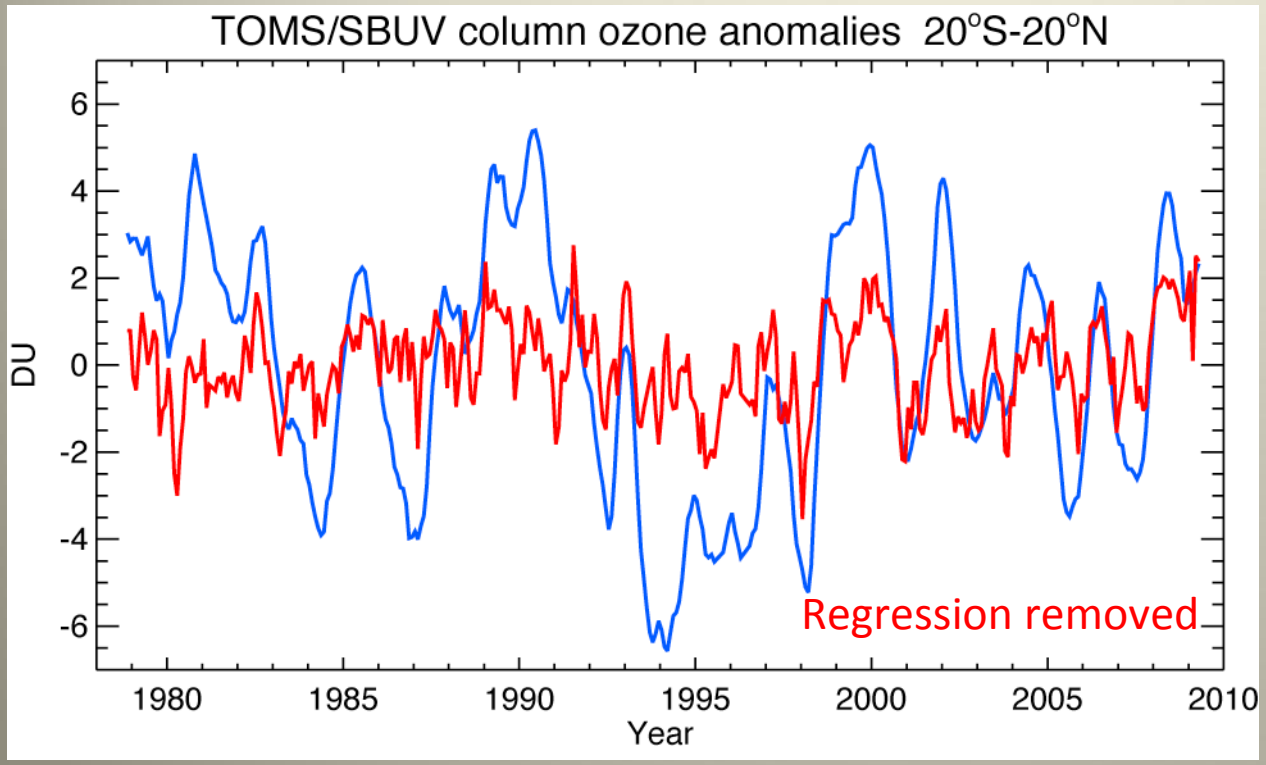
Using Age and Photolytic Traces: SF_6, N_2O, CFC-12, CFC-113, CFC-11, halon-1211



Ran "leaky pipe" model Successfully for our Stratospheric Circulation Trend work. (Ray et al 2010 JGR).

Now run but maintain cross correlation between Photolytic and Age tracers too pull out correlated temporal and spatial distributions.

Total Ozone "Residual" Trends



Identify the "residual" total ozone trends due to circulation and mixing changes by using multiple linear regression to remove:

- QBO (NCEP Rean 5S-5N, 10 and 50 hPa)
- ENSO (NOAA multivariate ENSO index lagged 6 months (Marsh and Garcia, 2007))
- EESC (2yr age in tropics, 5yr in midlats (Newman et al., 2007))
- Solar cycle (10.7 micron radio flux).
- Volcanic aerosol (Deshler et al., 2006).