Methodology to Validate AIRS Ozone Observations

Evan Fishbein[1]
F. William Irion[1]

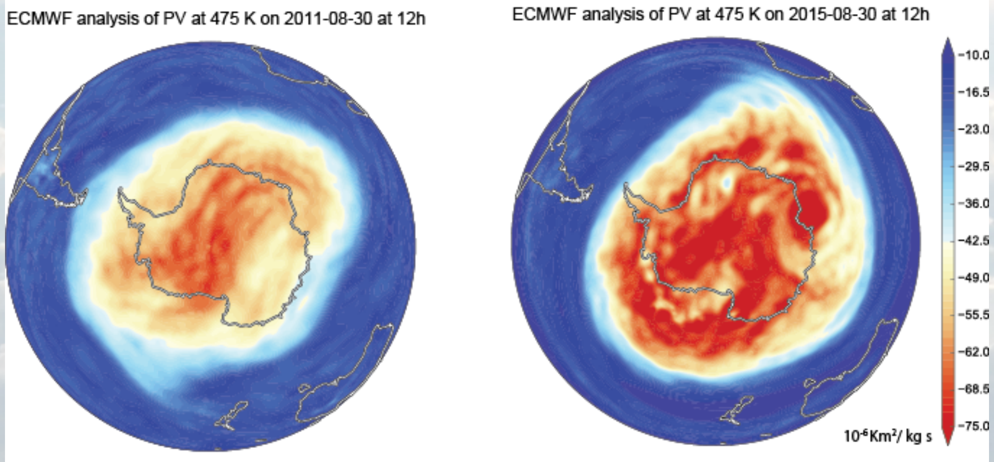
Affiliation: Jet Propulsion Laboratory, California Institute of Technology

MOTIVATION

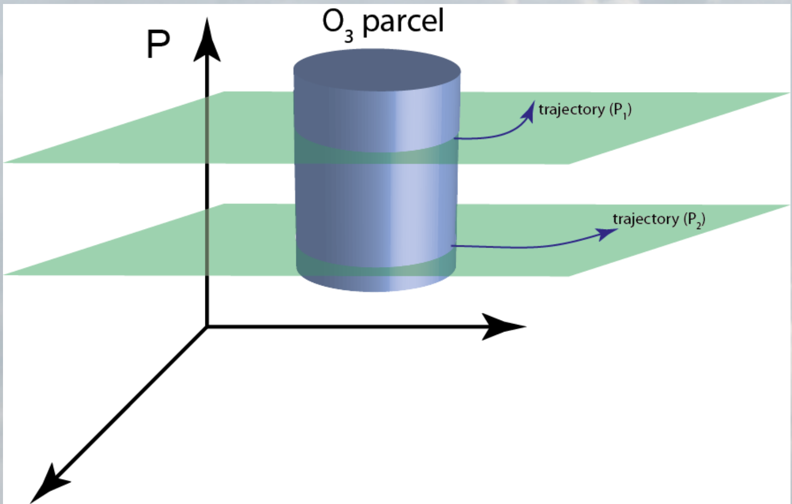
Motivation – Polar Vortex Mixing

- There are many ozone data sets, What does AIRS/CrIS/IASI add?
  - Profiles: MLS, TES, OMI, SBUV
  - Total: OMI, SBUV, TOMS, GOME
- AIRS/CrIS/IASI provide dense coverage, but with coarser vertical resolution than MLS or TES
- Potential vorticity (PV) shows complex mixing within polar vortex (see right).
- PV and O_3 provide information about transport out of the vortex
  - PV is conserved along a trajectory for adiabatic flow
  - O_3 away from PSCs is also conserved.
- The accuracy of tracing O_3 flow involves trade-off between shear, vertical resolution and horizontal resolution (see figure left)
- This talk focuses on characterizing AIRS O_3 vertical resolution and it importance in validation

Maps of potential vorticity at the 475K isentropic

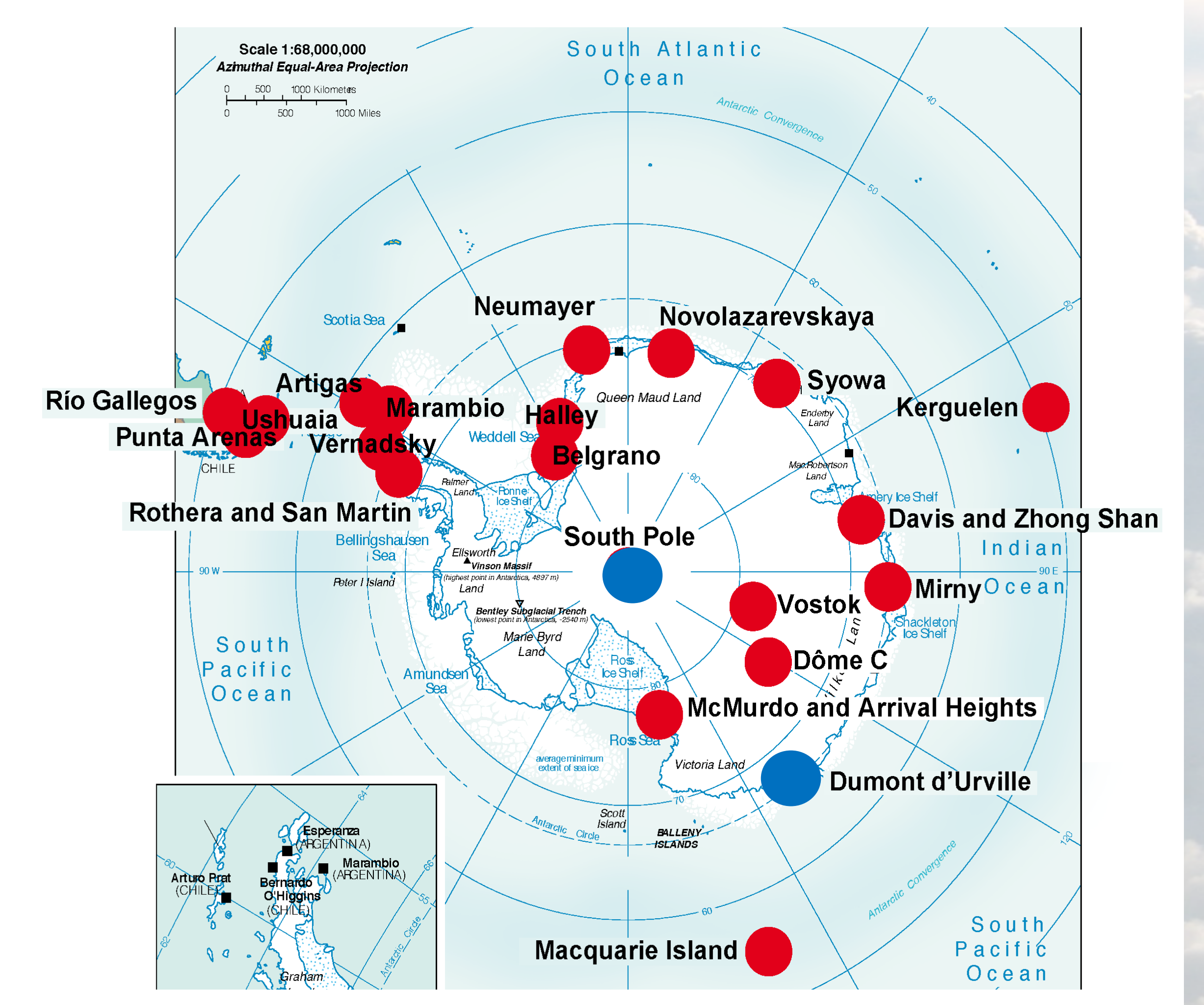


Maps of potential vorticity at the 475K isentropic level on 30 August 2011, 2015. The data originates from the European Centre for Medium Range Weather Forecasts (ECMWF) and were made available by the Norwegian Institute for Air Research (NILU) through a project funded by the European Space Agency (ESA). The plotes are produced at WMO.



Motivation - Error from Complex Ozone Initial Quess

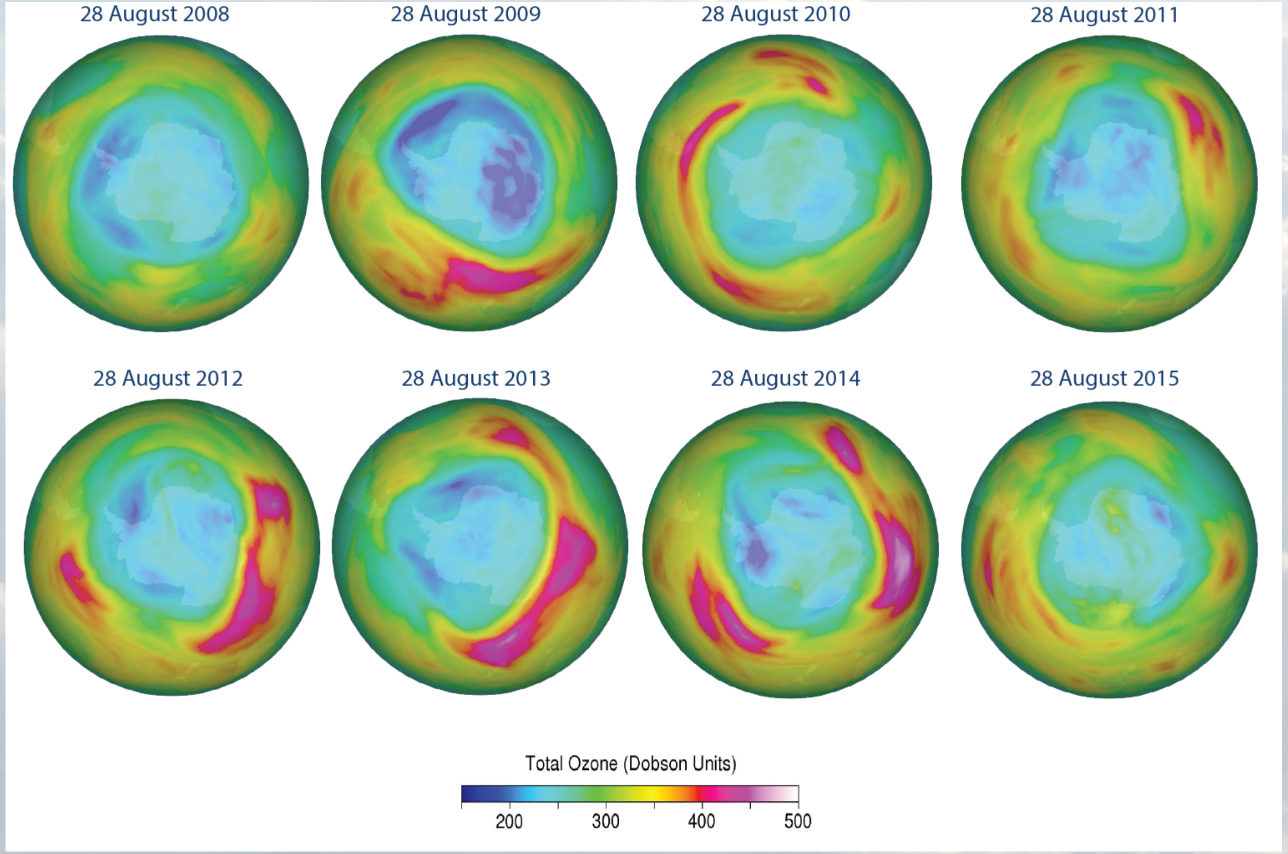
- Version 7 prototype includes more complicated O_3 initial guess.
  - Low O_3 climatology is averaged with nominal O_3 climatology when lower stratosphere temperature falls below PSC-I threshold ~ 188K.
- However, rate of heterogeneous O_3 destruction is tied to amount of PSC and light, not amount
- Does adding a seasonal, temperature-dependent ozone initial guess introduce features which are not supported by either the AIRS radiances or correlative observations
- Analysis compares Antarctic ozonesonde profiles with matched AIRS profiles
- Data is from WMO Antarctic Ozone Bulletin
  - 5 reports per year
  - 20 stations (not all report profiles)
  - ECMWF trajectory



DATA SELECTION

Inter-Annual Ozone Hole Variability

- August polar stratosphere is characterized by descent of O_3 rich mid-stratosphere air into the polar vortex (Brewer-Dobson circulation)
- O_3 is destroyed where PSCs and sunlight are present.
- Diabatic processes, e.g. wave breaking, mixes air across the polar jet
- August 2015 is characterized high mixing and lower O_3 along periphery of polar



August total O_3 zone maps from GOME-2 on MetOp-A and SCIAMACHY

Total Ozone Comparison
South Pole versus Dumont d'Urville

- South Pole
  - Station is below center of polar vortex
  - Interannual variability is smaller
  - Ozone decrease occurs end of Aug
- Dumont d'Urville
  - Stations on Antartic coast lis below edge of vortex
  - Interannual variability is large,
  - Ozone begins decreasing in Jun
  - 2015 is anomalous
    - Ozone decrease through end of Sep and doesn't start recovering until Nov
- PSC begin forming in early May
- Ozone at Dumont d'Urville is a good ozone validation site because of its large interannual variability
- 18 ozonesondes

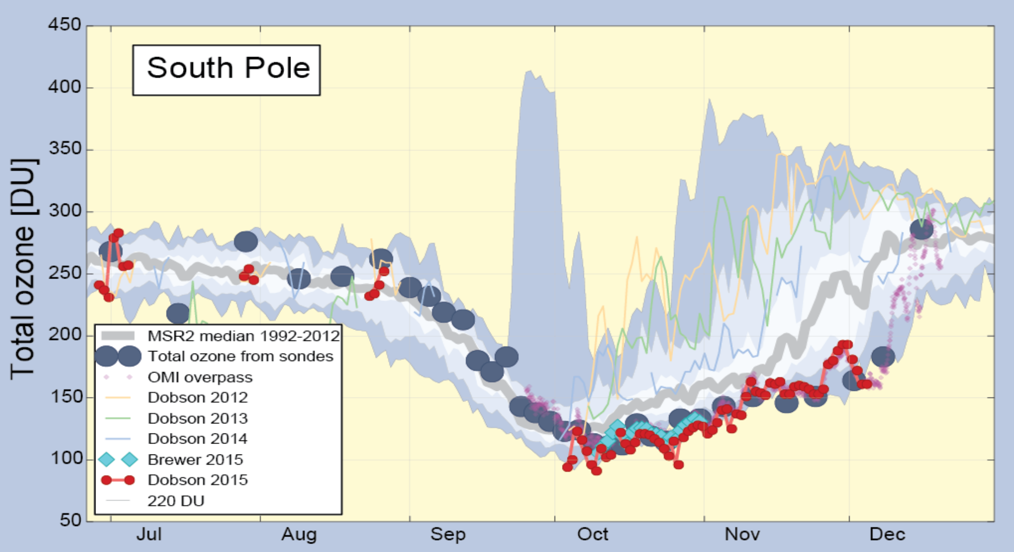
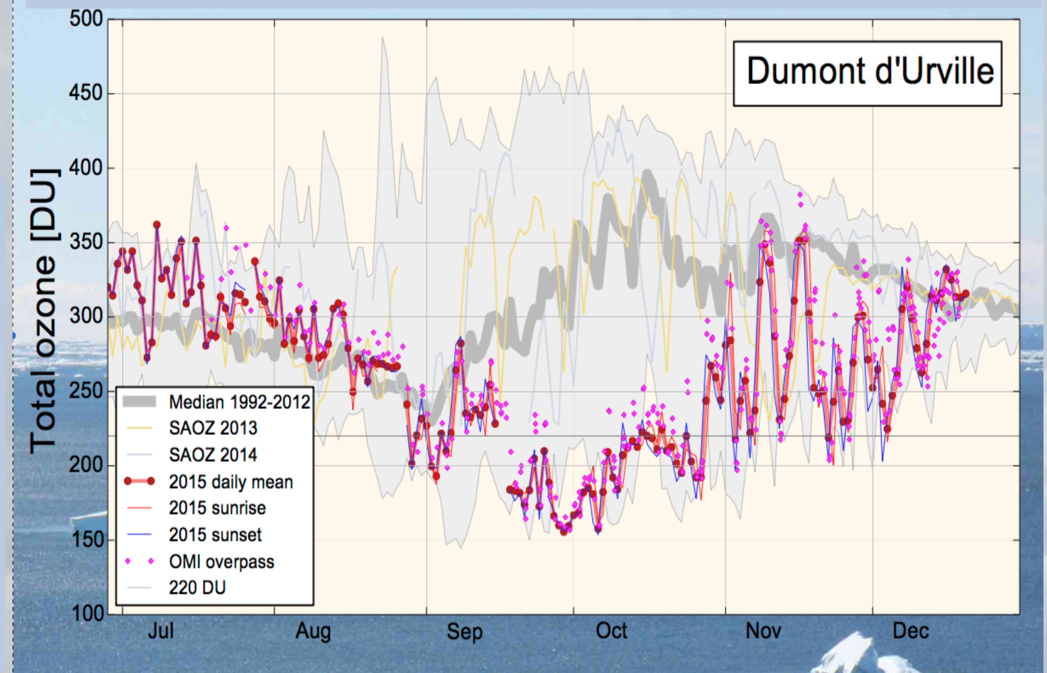
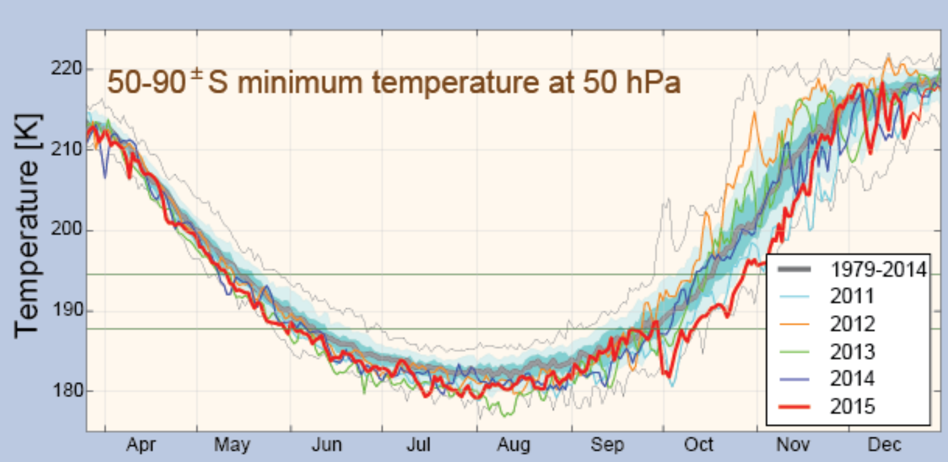


Figure 41. Total ozone measured at the South Pole from late June until early December 2015. Both Dobson and Brewer data are shown together with total ozone calculated from ozonesondes. Satellite overpass data are also shown.



Type 1 PSC form ~ -78°C
Type 2 PSC form ~ -85°C

Rate of O_3 destruction is tied to PSC surface area and mass of NO_x sequestered in PSC



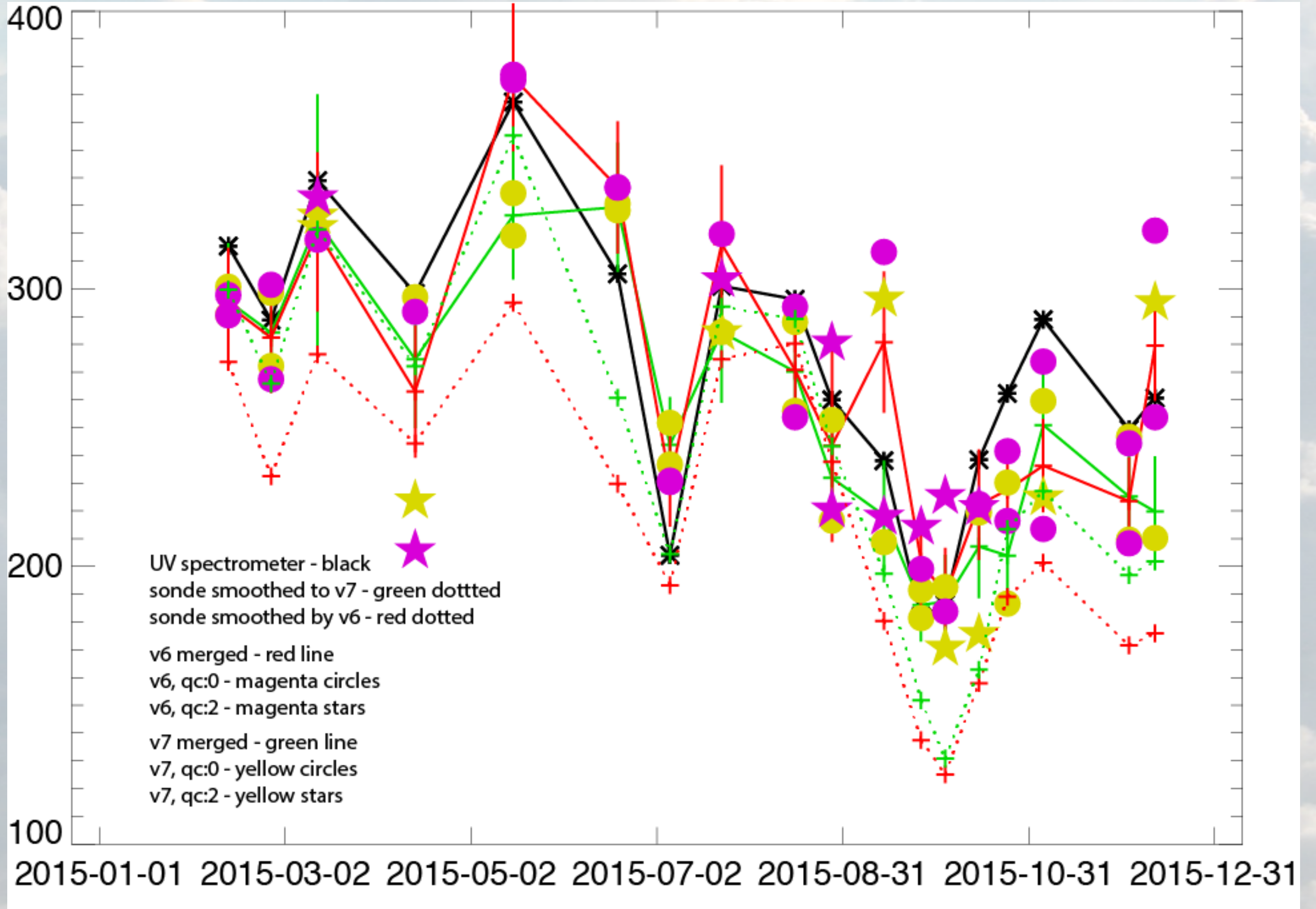
TOTAL OZONE TIME SERIES

AIRS RETRIEVALS, OZONESONDES AND UPLOOKING UV SPECTROMETER

Total Ozone Time Series
Version 6 versus Version 6.4.6

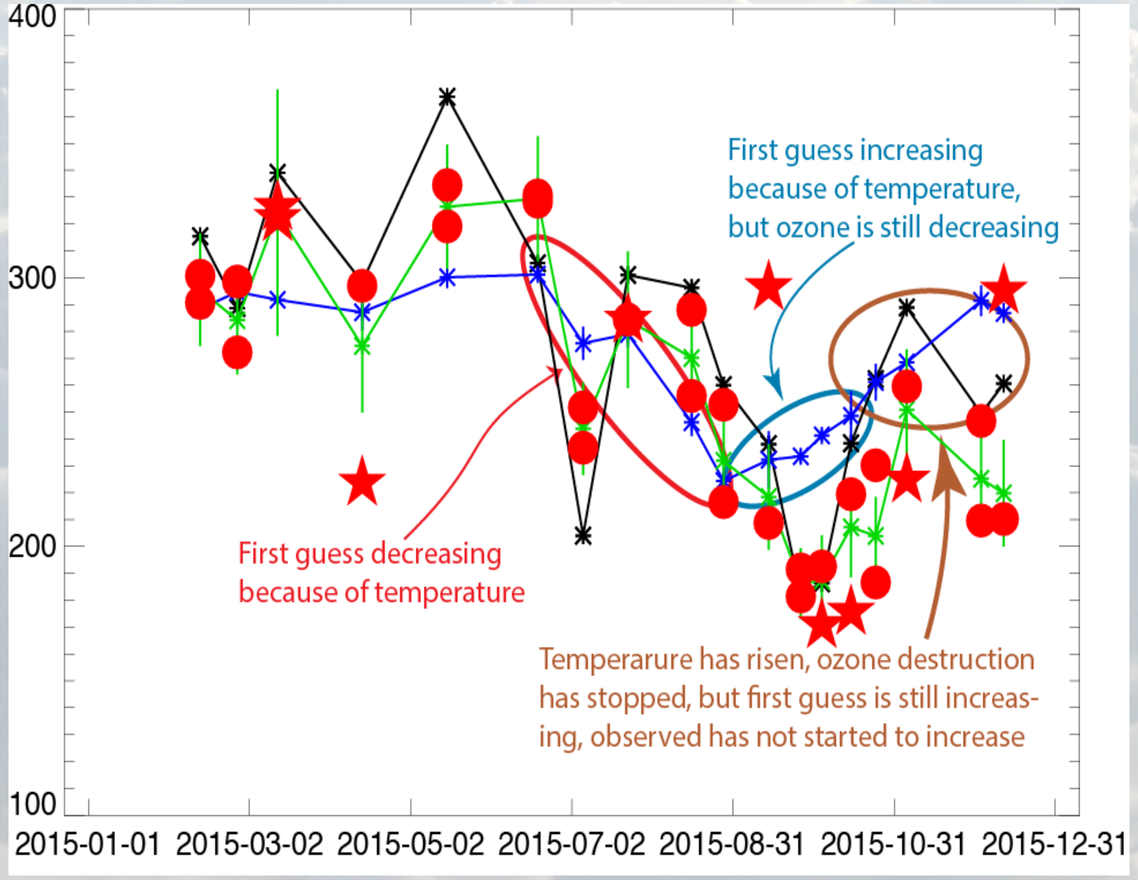
- Retrieved time series curves are of optimal averages of closest footprints in two nearest AIRS granules
- Southern Fall, increasing ozone from descent
  - When v6 and v6.4.6 differ, v6 is better
- Late Fall, Winter, ozone is destroyed
  - V6.4.6 is usually lower than V6 and generally worse
  - Except 06 July, but v6 is closer to UV spectrometer
- Spring
  - Both products about the same, sometimes v6 is closes to sonde while other times v6.4.6

- Observations
  - Both products capture seasonal cycle
  - V6.4.6 sticks closer to climatology
  - Smoothed sonde is always biased low because smoothing is done in log mixing ratio.



Total Ozone Time Series
V4.4.6 Compared to First Guess

- Ozone move from first guess to ozonesonde, but only partially, neither biased high or low
  - Retrieval first guess follows temperature
- Green curve is error weighted estimate from closest retrieval from two closest granules
  - Optimally merged estimate is closest to sonde when both products have Q/C=0
    - Error estimates indicate relative quality of individual products
    - χ^2 test not performed, but errors seem low.
- Early winter is biased low – cold temperature, but little ozone destruction
- Early fall biased high – warm temperatures, but ozone has not recovered.
- Q/C test throws out good and bad data

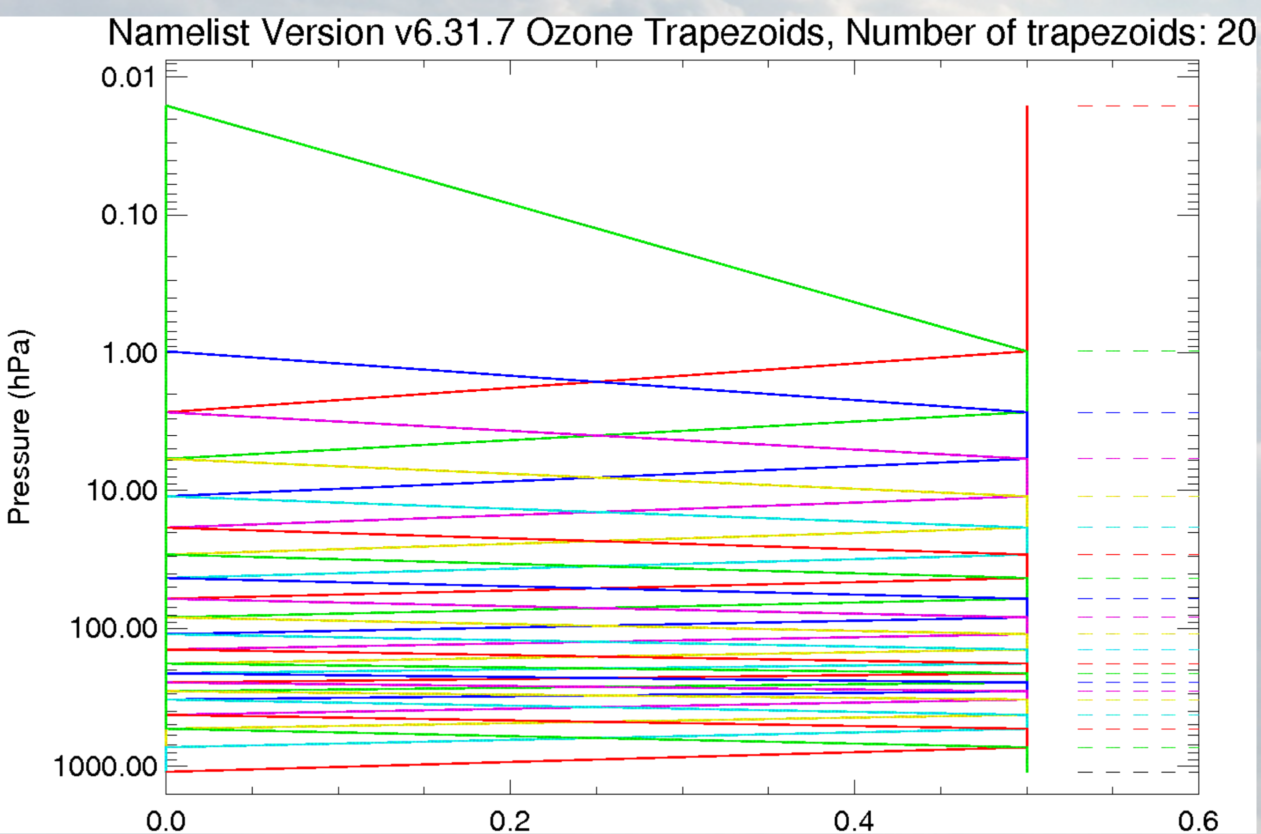


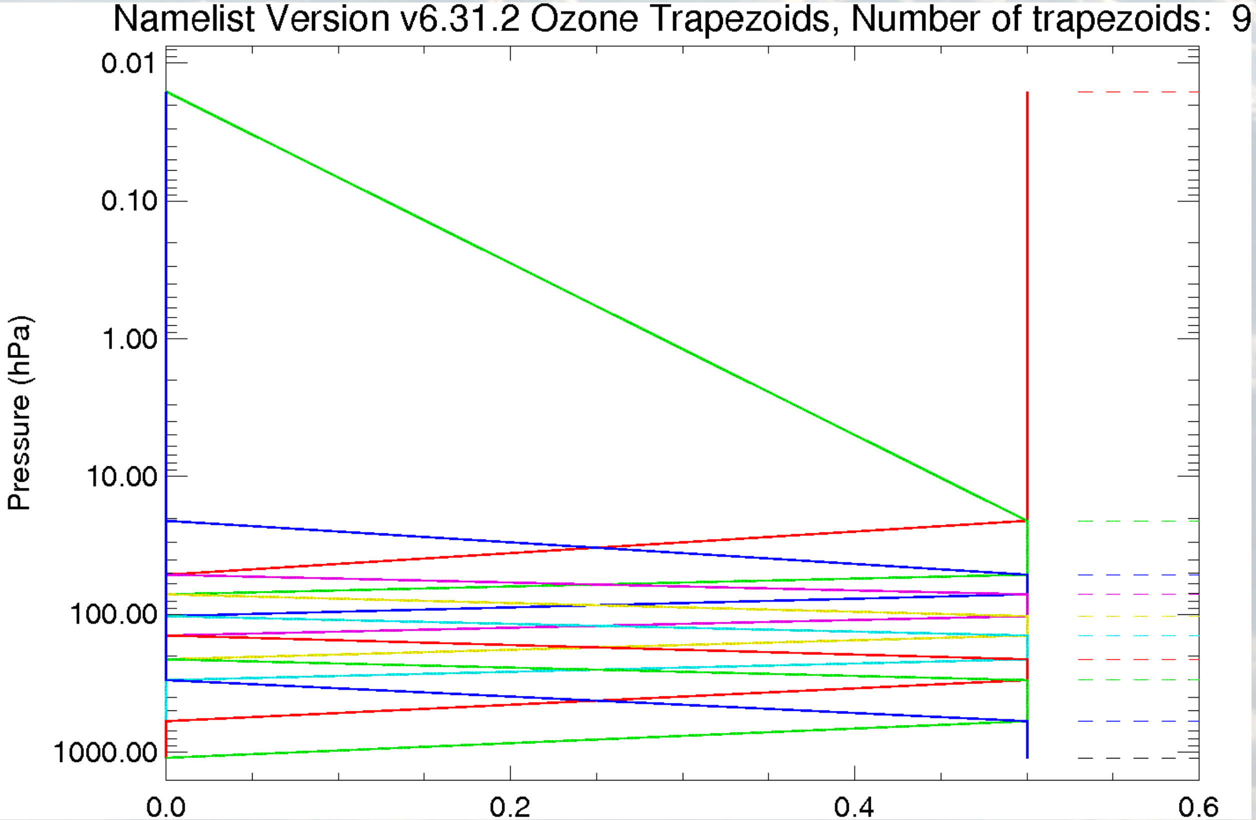
VERTICAL RESOLUTION

Trapezoids

$$\ln O_3[p] = \sum_{i=0}^{N} a_i\, t_i[\ln(P)]$$

t_i are the trapezoid basis functions shown below

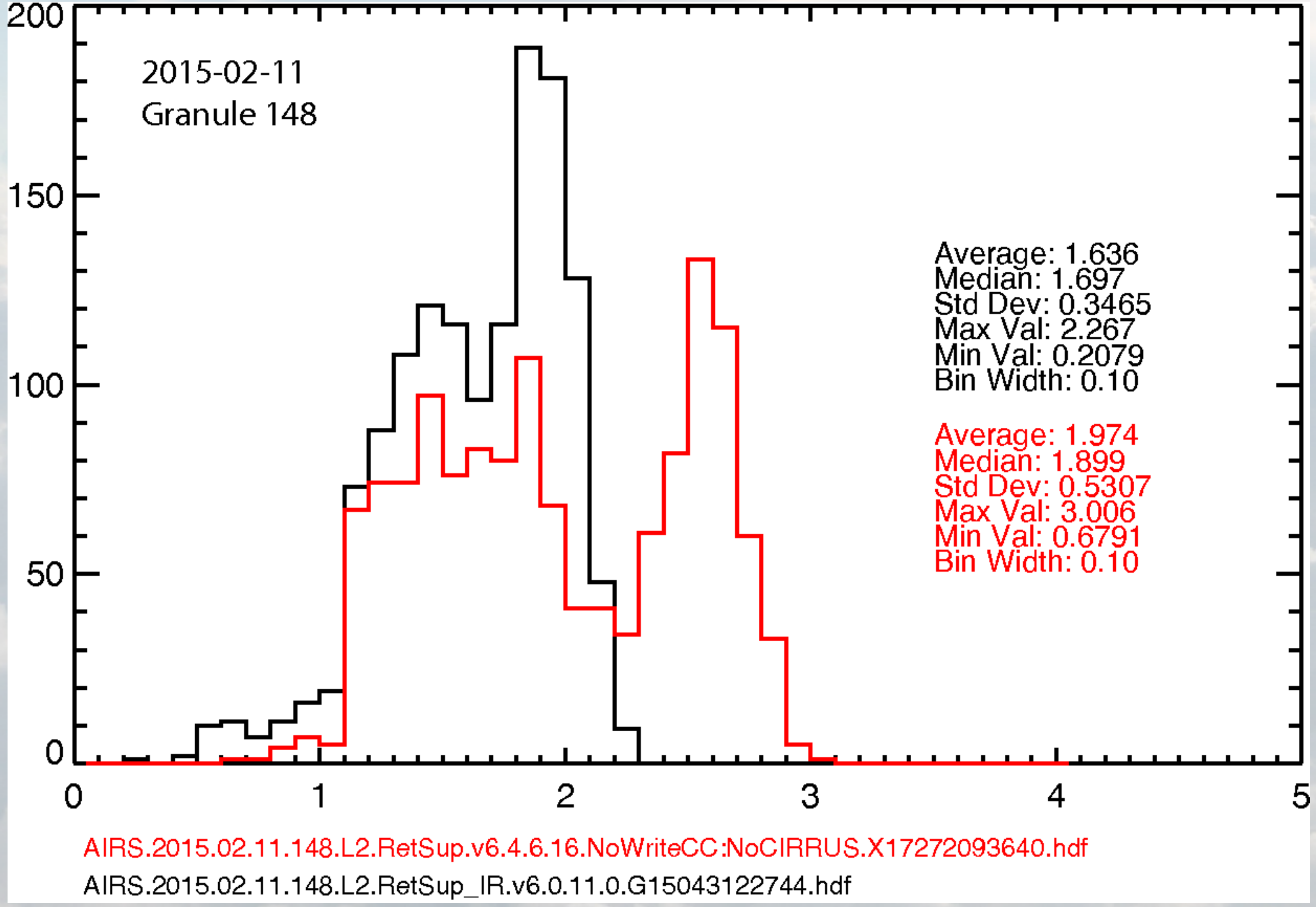




Degrees of Freedom

- Comparison of degrees of freedom (trace of averaging kernel matrix) for one Antarctic granule,

- New representation has added 0.34 degrees of freedom, but has added a second mode with 2.6 DOF



Vertical Resolution

- Use the averaging kernel squared as a weighting function to infer for each averaging kernel, a height (pressure) of maximum sensitivity

$$c(z) = \int z' A^2(z, z')\, dz' / \int A^2(z, z')\, dz' \qquad (3.24)$$

- and a width

$$s(z) = 12 \int (z - z')^2 A^2(z, z')\, dz' / (\int A(z, z')\, dz')^2. \qquad (3.23)$$

- The factor 12 arises for boxcar smoothing, but for Gaussian smoothing

$$s(z) = \int (z' - c)^2 A^2(z, z') dz' / \int A^2(z, z') dz'$$

- These expressions are relevant when $< A >^2 = \int \mathbf{A}^2(z, z')dz$ is near 1

Rodgers, C, *Inverse Methods for Atmospheric Sounding*, World Scientific, 2000, pg. 55

Vertical Resolution
Regions with Low Sensitivity

- In the absence of a rigorous formalism for how an initial guess folds into a final solution for maximum likelihood retrieval, we use in this analysis:

$$c_c(z) = \bar{A}\, c(z) + (1 - \bar{A}) c_i(z)$$

$$s_c(z) = \bar{A}\, s(z) + (1 - \bar{A})\, s_i(z)$$

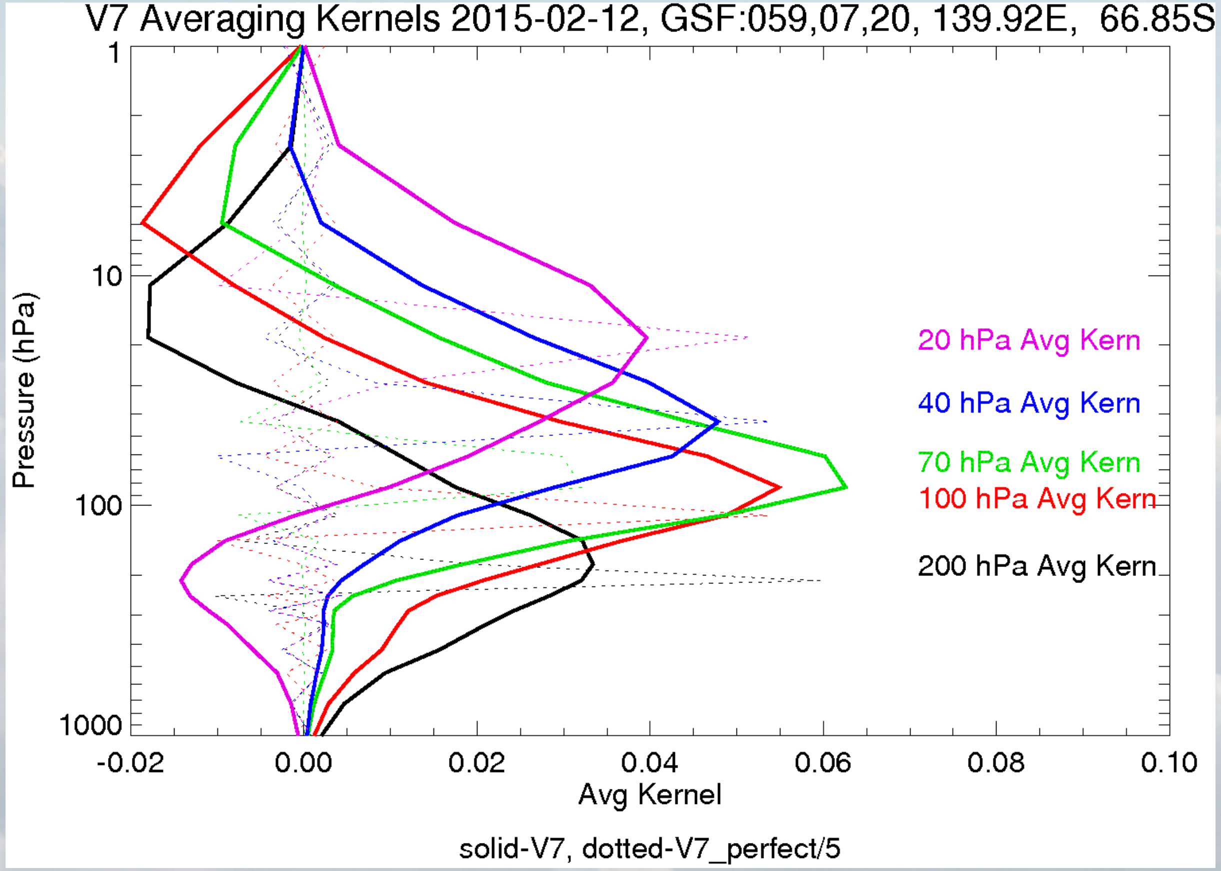
where:

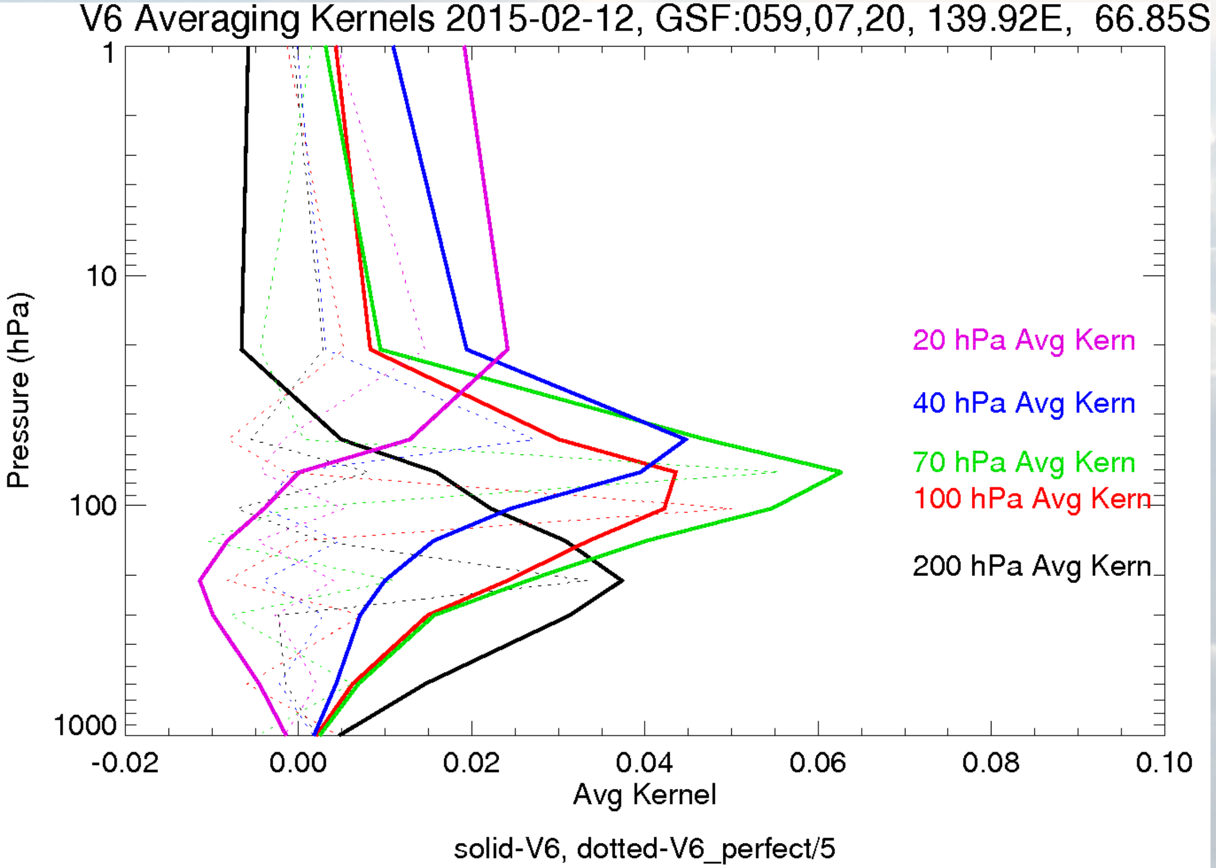
$$\bar{A}(z) = \int \mathbf{A}(z, z')dz, \text{ bounded within } [0,1]$$

  - $\bar{A}$ is the row sum of the averaging kernels

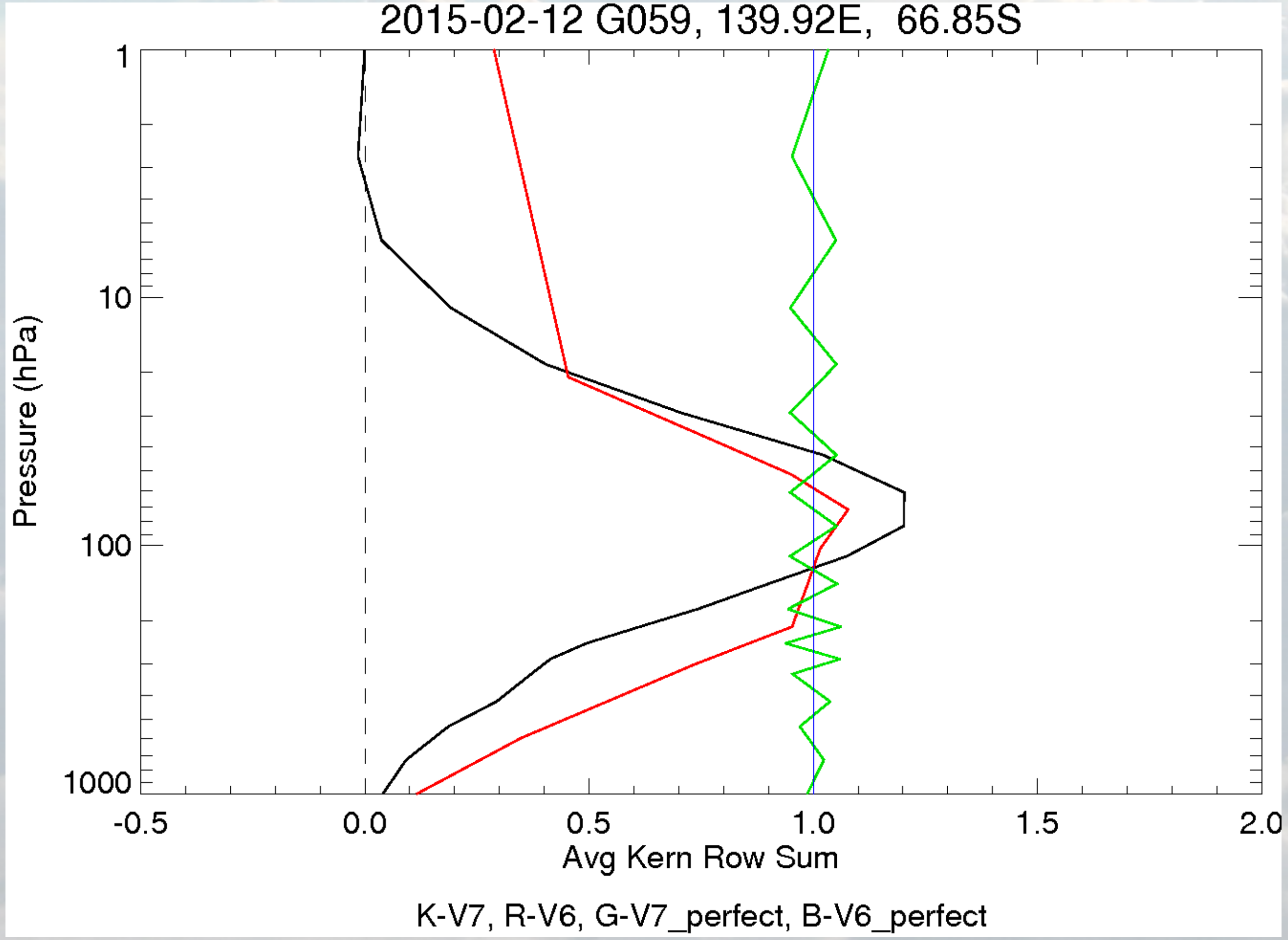
- This is more consistent with definition of averaging kernel and leads to less reliance on the background than <A>

Averaging Kernels



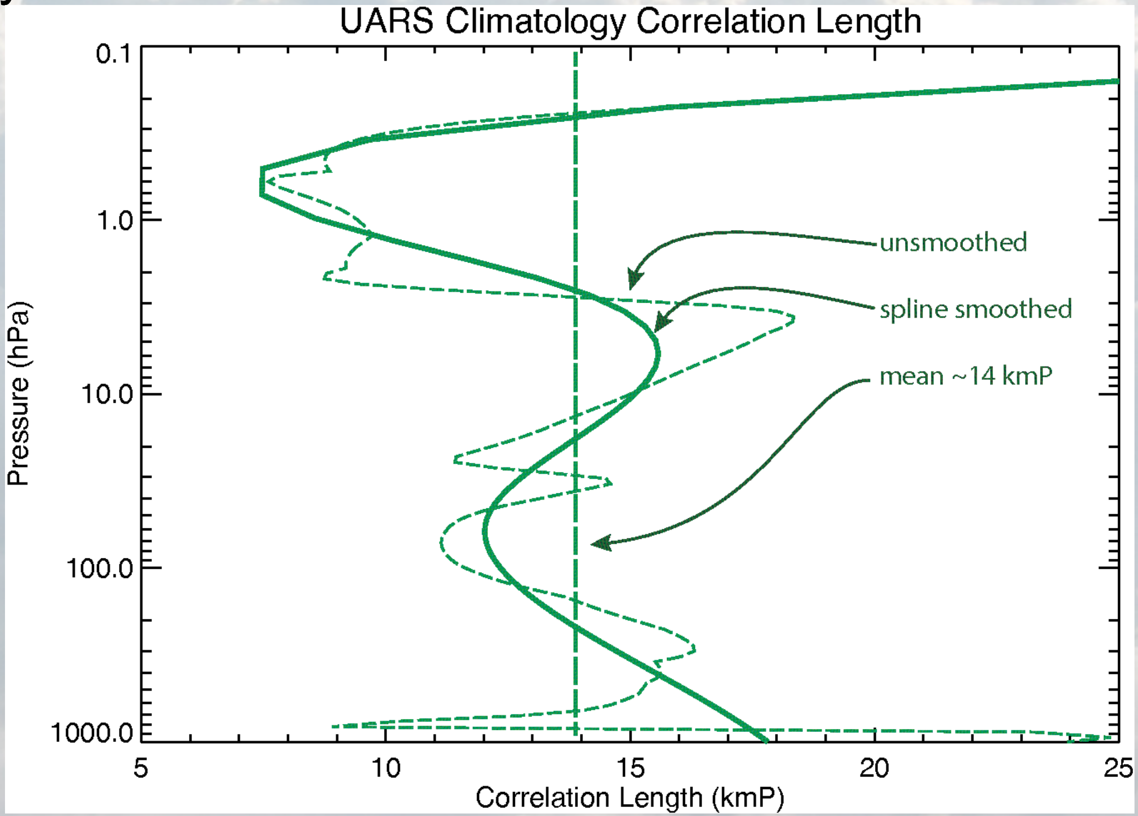


Averaging Kernel Row Sum



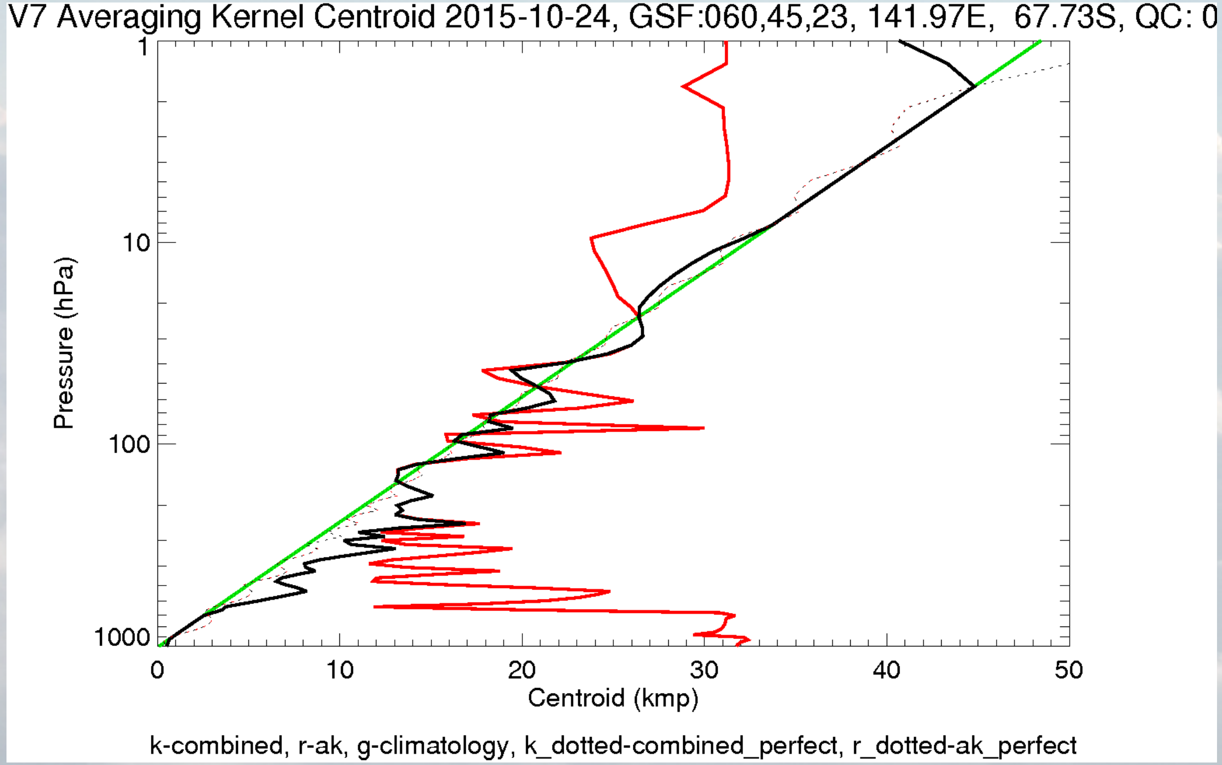
Climatological Vertical Resolution

- What is the vertical resolution of the initial guess?
  - The correlation length is not the vertical resolution, but the convolution of the vertical resolution with the atmospheric correlation length.
  - We use the correlation length
    - it is a worse case estimate
    - It isnot important where the measurement system is sensitive, e.g. $\overline{A}$ is close to one.
- Global, all-seasons UARS O_3 climatology

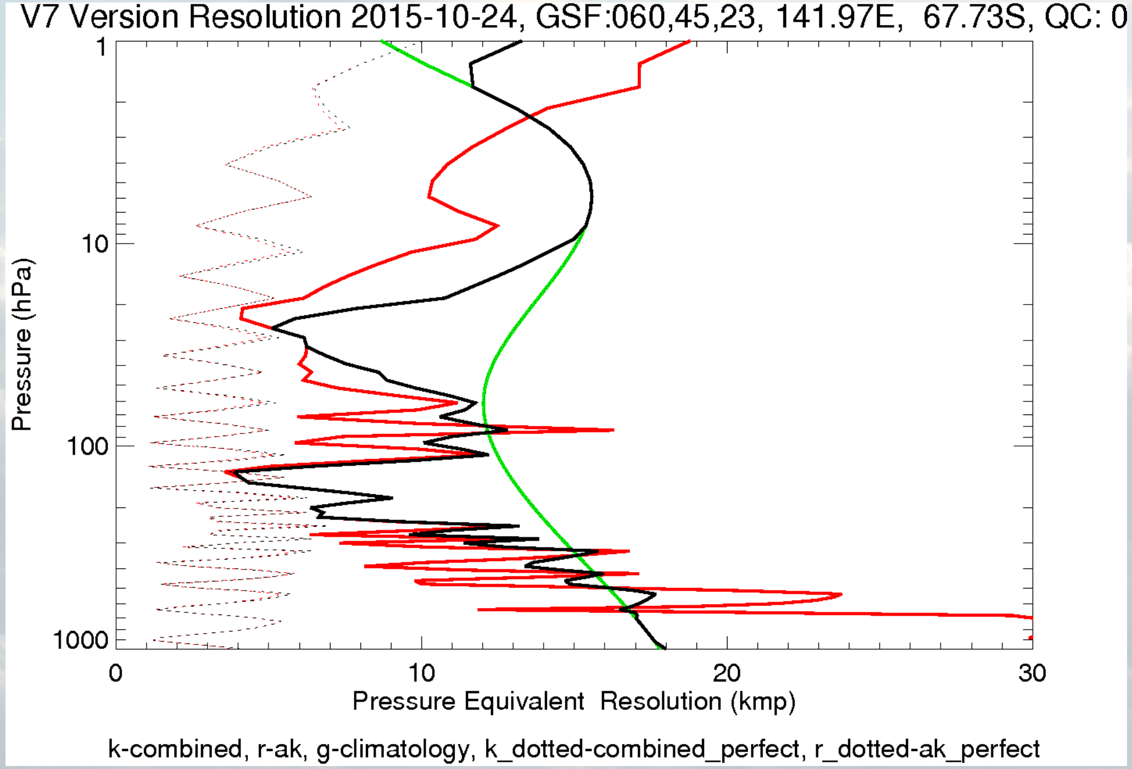


Vertical Resolution
Single Footprint: 2015-10-24, GSF: 060, 45, 23

- Centroid



- Vertical resolution



- Units are pressure-equivalent height, e.g. H log pressure
- Black is combined retrieval + 1st guess climatology
- 1st guess is green
- Averaging kernel only is red.

Dotted lines are results for perfect (identity matrix) averaging kernels

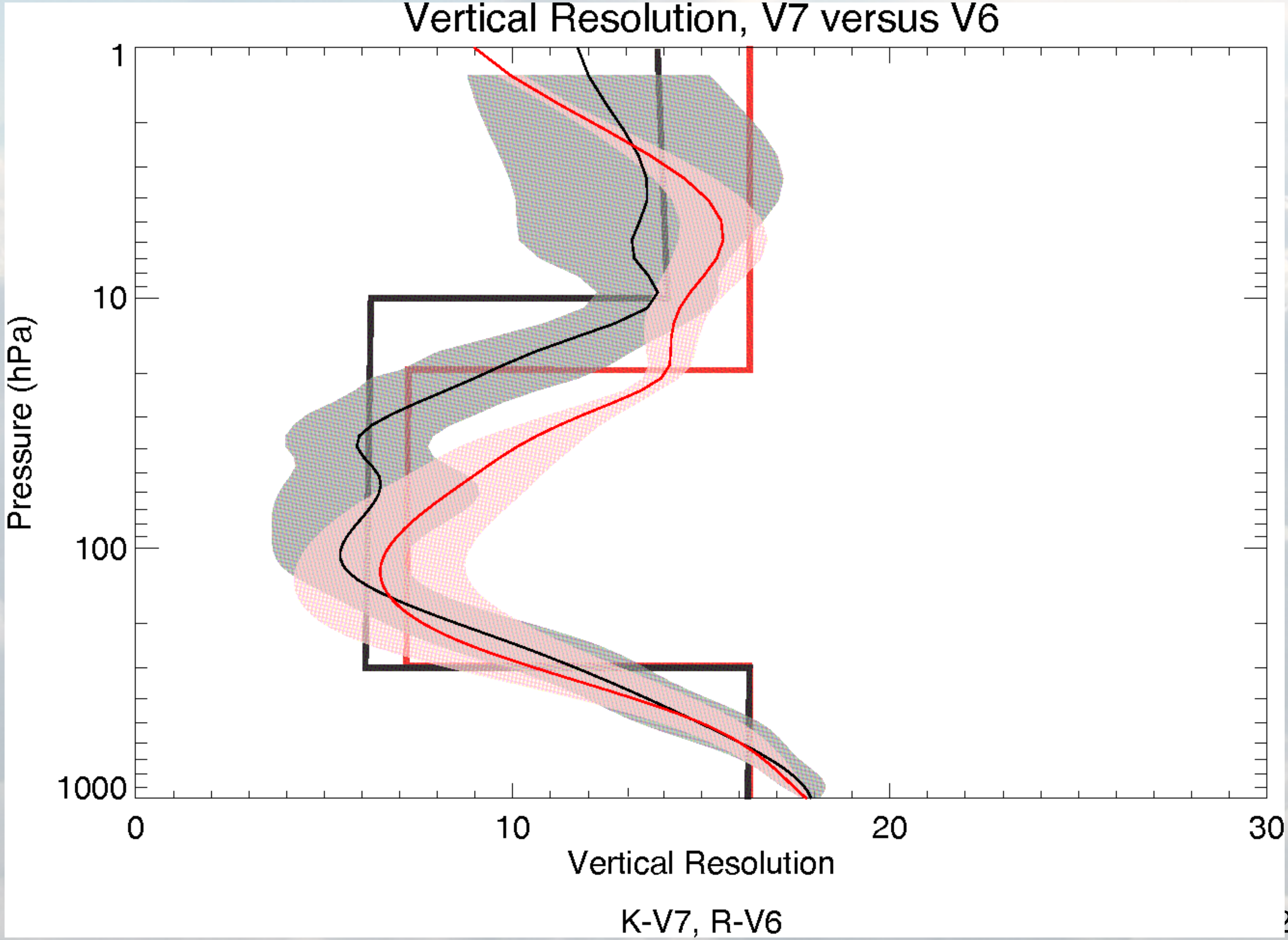
Vertical Resolution Summary

Mean vertical resolution with error bars (standard deviation) derived from for all footprints examined in this study

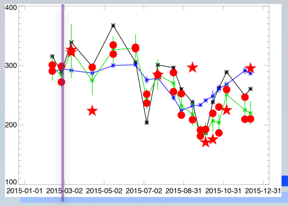
- Black is version 6.4.6
- Red is version 6.0

Simple ozone smoothing model

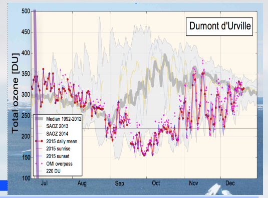
- Version 6.4.6
    - 16-kmp, surface to 300 hPa
    - 6-kmp, 300 to 10 hPa
    - 14-kmp above 10 hPa
- Version 6.0
    - 16-kmp, surface to 300 hPa
    - 7-kmp, 300 to 20 hPa
    - 16-kmp, above 10 hPa



OZONESONDE - AIRS RETRIEVAL VERTICAL PROFILE COMPARISON

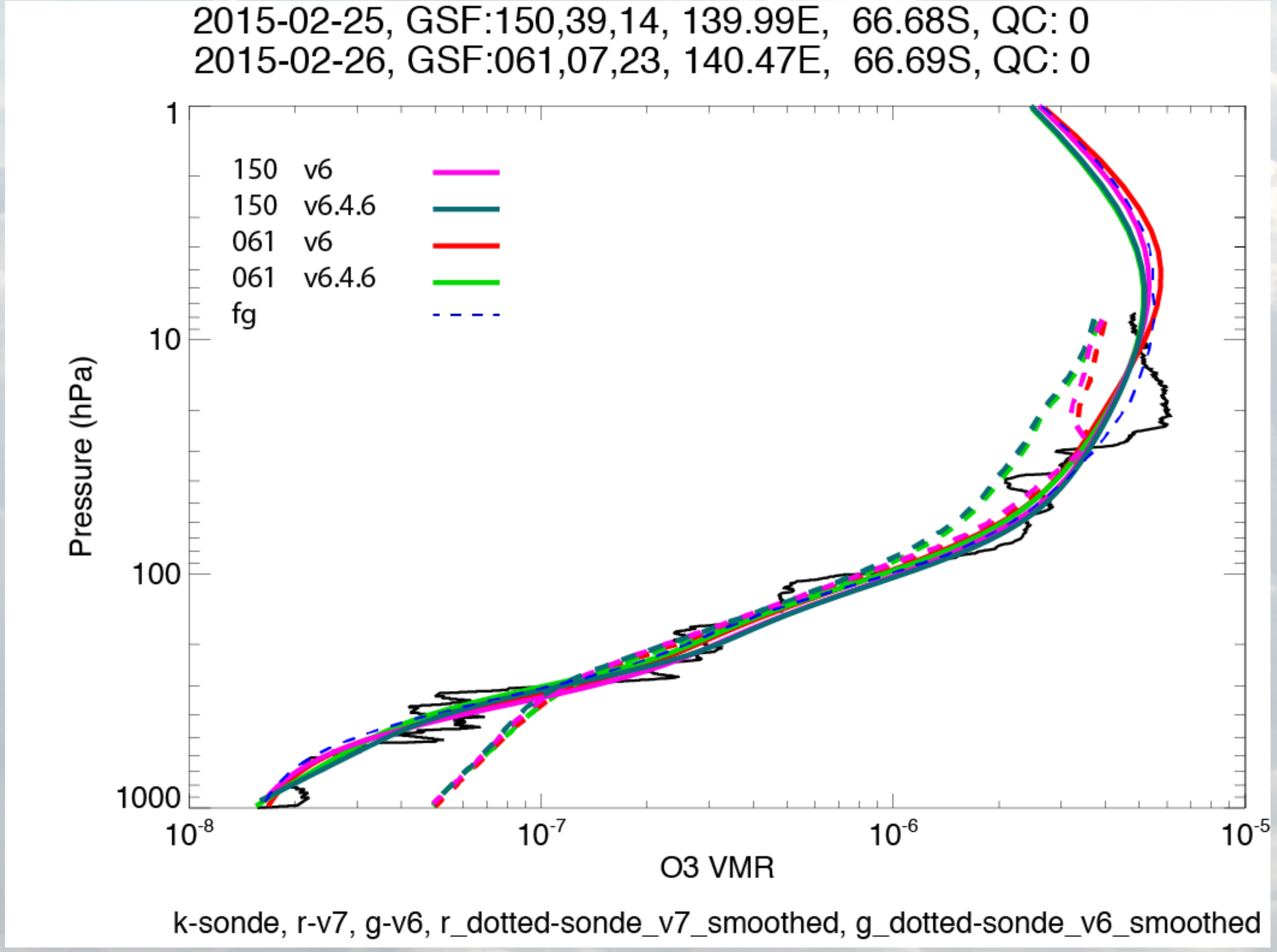


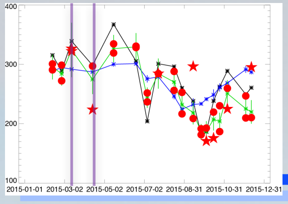
Profile Comparison
26 Feb 2015



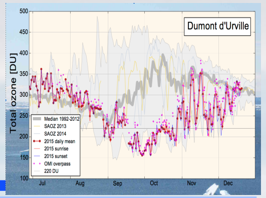
Date / GSF	V6.0	V6.4.6
25-Feb 150,39,14	301.4	298.5
26-Feb 061,07,23	267.5	272.2

- UV Spectrometer: 288.7 Dobson
- First guess and solution are similar
- Largest Differences occurs in
  - mid stratosphere
  - Lower troposphere (small contribution to total)

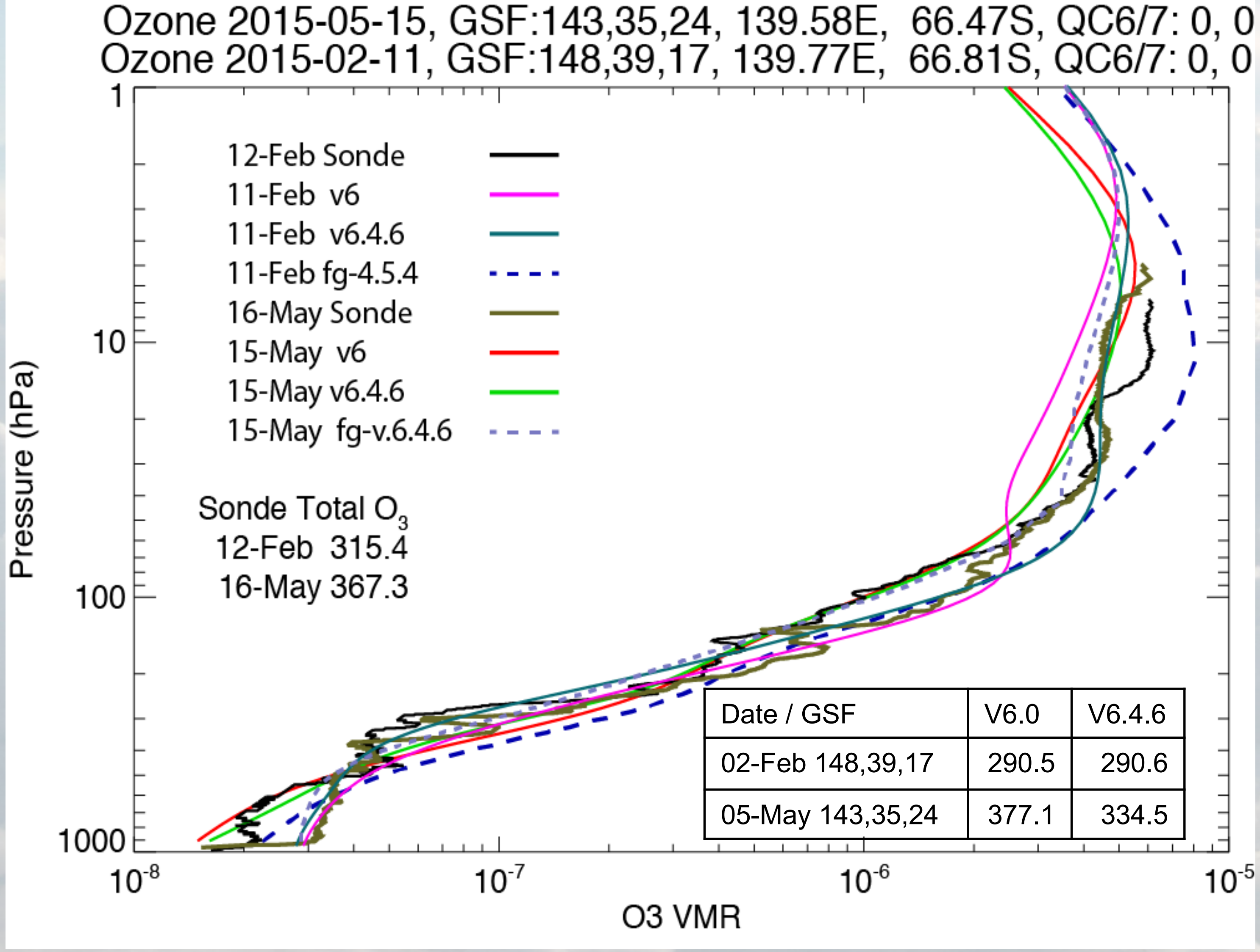


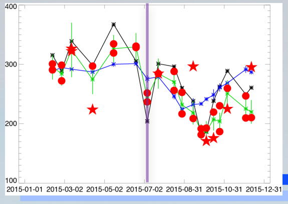


Profile Comparison
Ozonesondes Launch 12 Feb 2015 and 16 May 2015

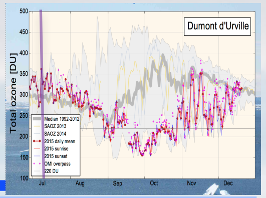


- Total Ozone increases by 17%, because
  - Tropopause descends
  - Ozone rich mid stratospheric air descends into lower stratosphere
  - Percentage increase
    - V6.4.6 15%
    - V6.0 30%
- 06-May first-guess have the descent, but
  - Actual descent smaller than climatology and closer to solution
- Both profiles relax from first-guess to ozonesonde around 80 hPa.
- Improvement agreement in v6.4.6 at 20 hPa related to added trapezoids.





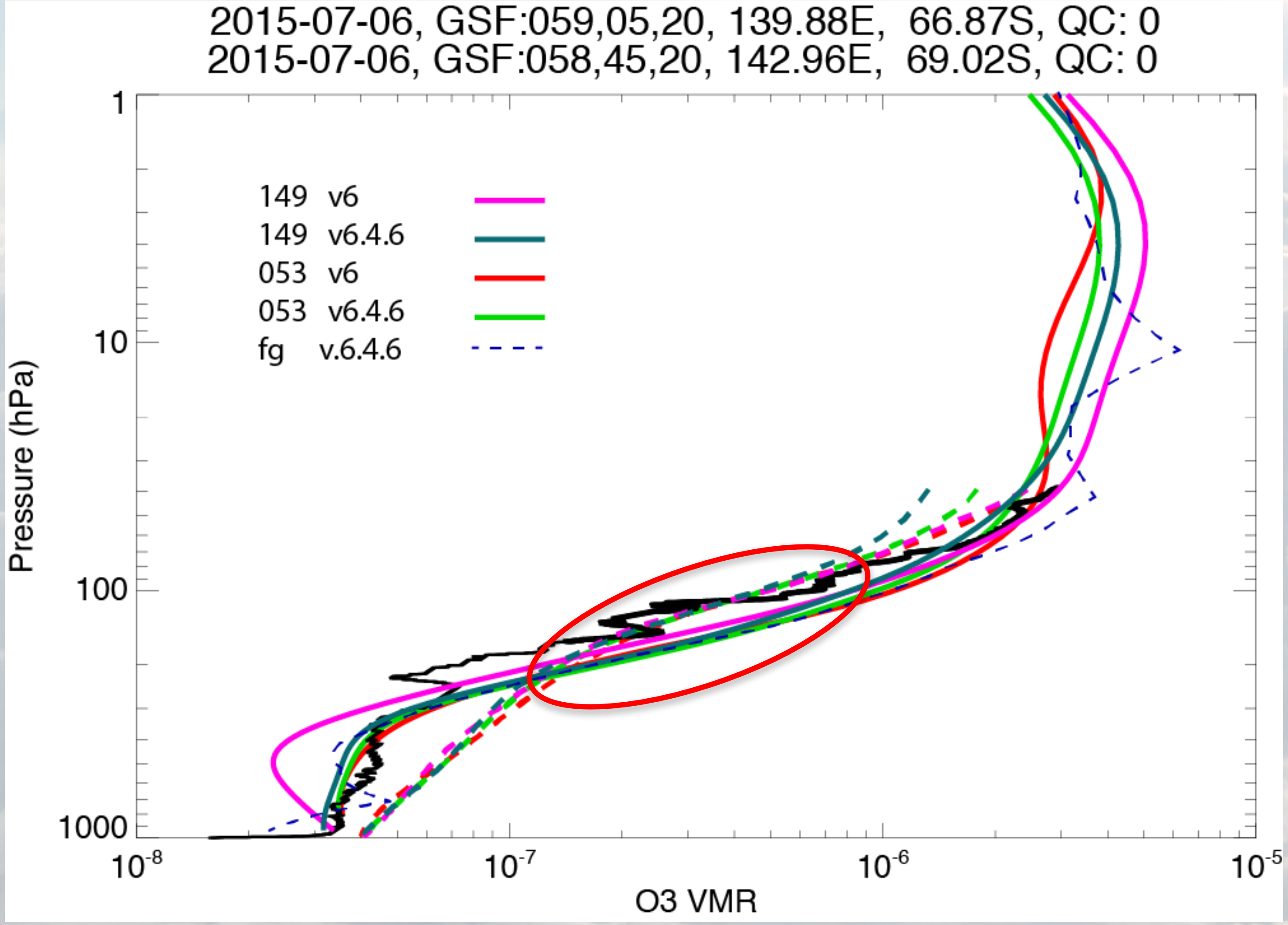
Profile Comparison
06 July 2015- Beginning of Ozone Hole

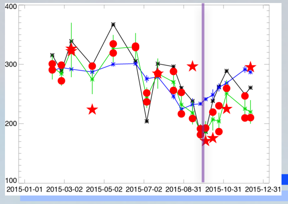


- Ozonesonde total O_3: 204

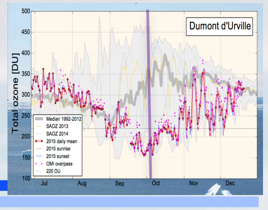
Date / GSF	V6.0	V6.4.6
06-Jul 059,05,20	230.9	251.7
06-Jul 058,45,20	230.4	236.7

- Differences in retrieved profiles
  - mid-stratosphere
  - mid-lower troposphere
- Profiles don't capture O_3 loss in lower stratosphere
- Coldest temperatures, but not most depleted O_3
- First-guess does not have an obvious O_3 minimum





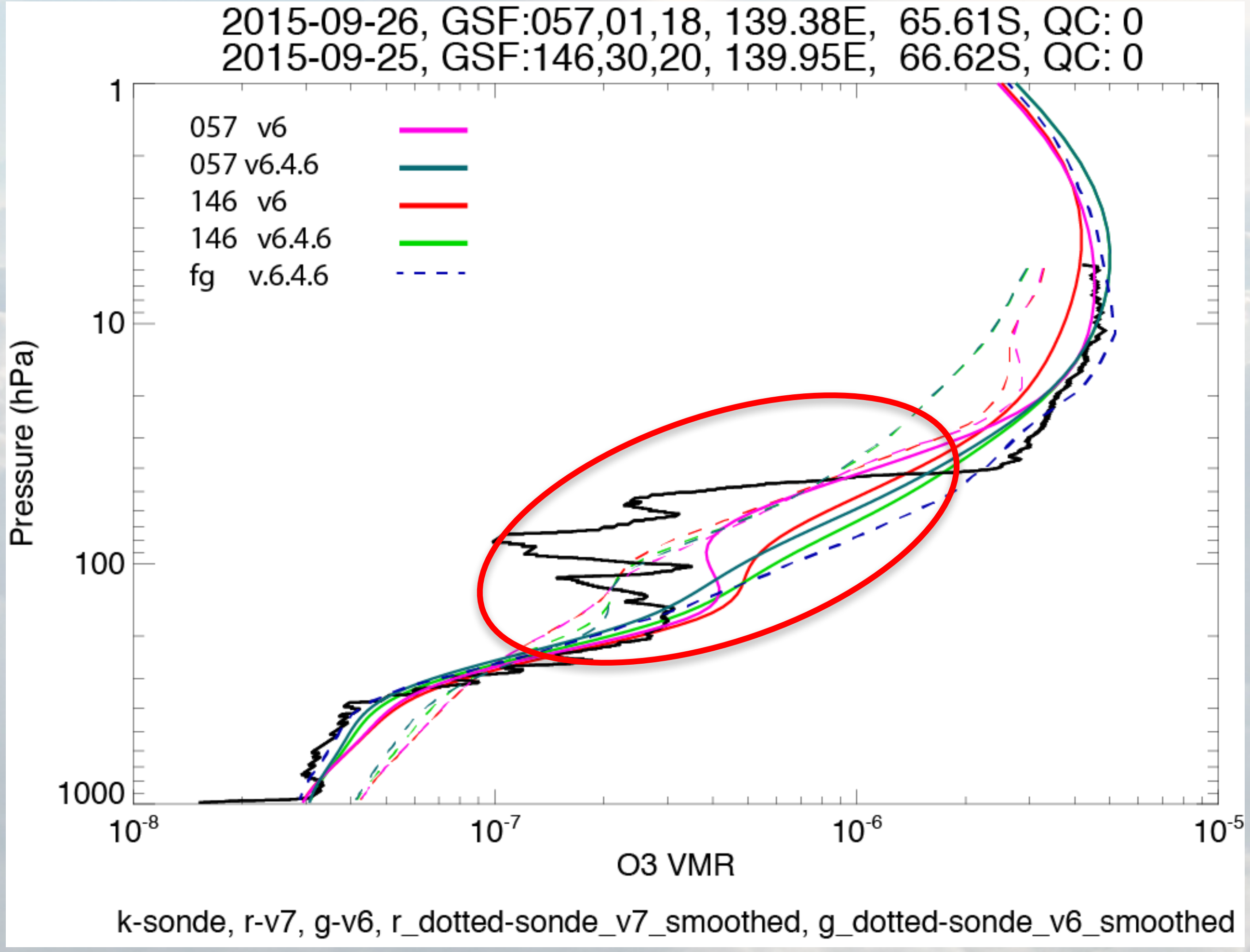
Profile Comparison
26 Sep 2015

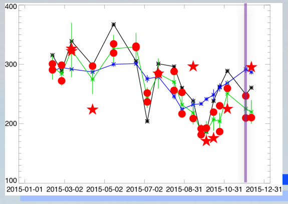


- Ozonesonde total O_3: 182

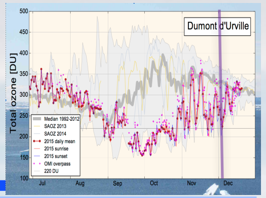
Date / GSF	V6.0	V6.4.6
26 Sep 057,01,18	199	181
25 Sep 146,30,20	214	191

- V6.4.6 profiles don't capture minimum (v6.0 does somewhat)
- O3 reduced in lower stratosphere, but profile is very smooth
- Smoothed ozonesonde profiles show stronger minimum than retrievals
  - Averaging kernel-implied vertical resolution is not realized





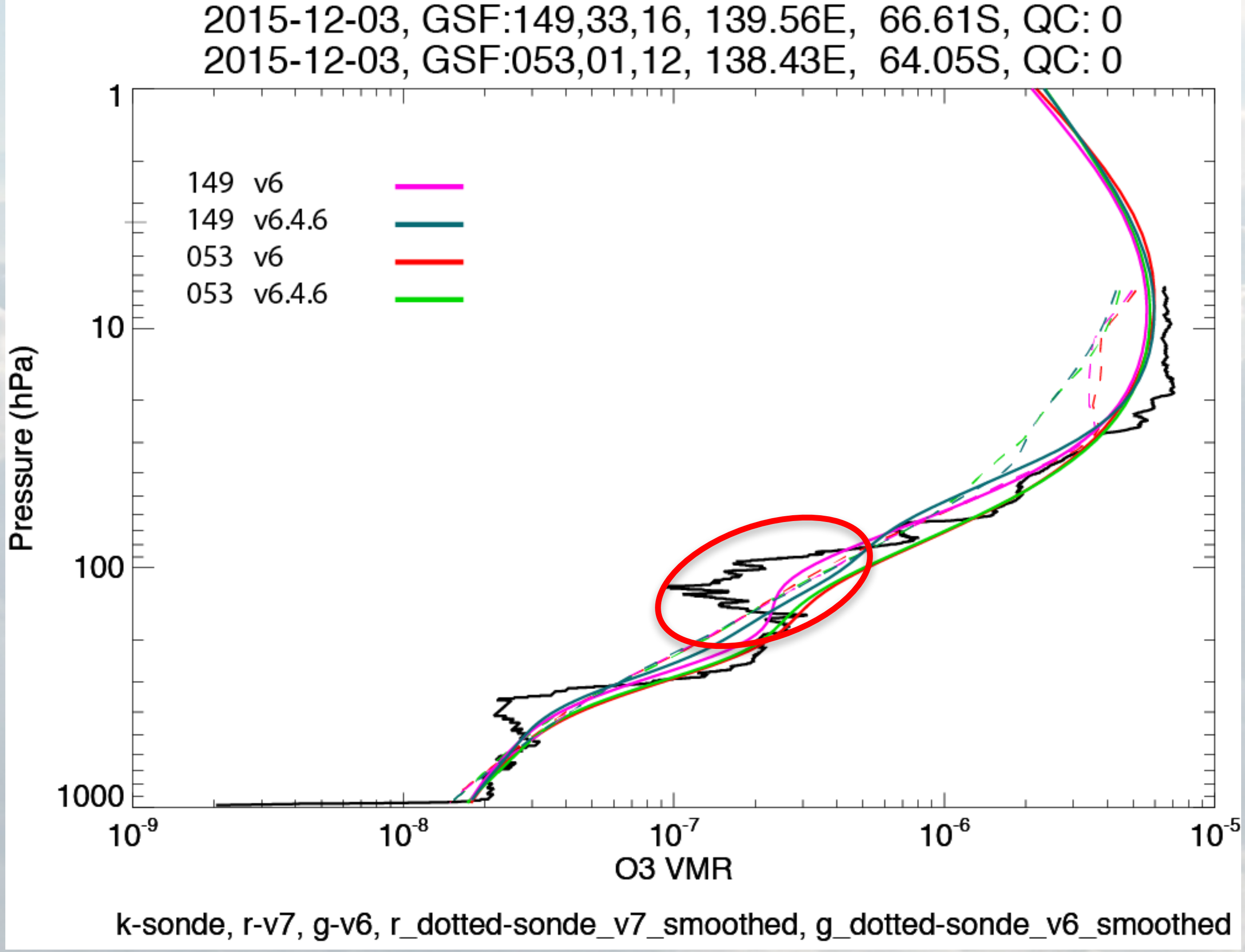
Profile Comparison
03 Dec 2015



- Ozonesonde total O_3: 249.4

Date / GSF	V6.0	V6.4.6
03 Dec 053,01,12	244.4	246.7
03 Dec 149,33,16	208.5	209.6

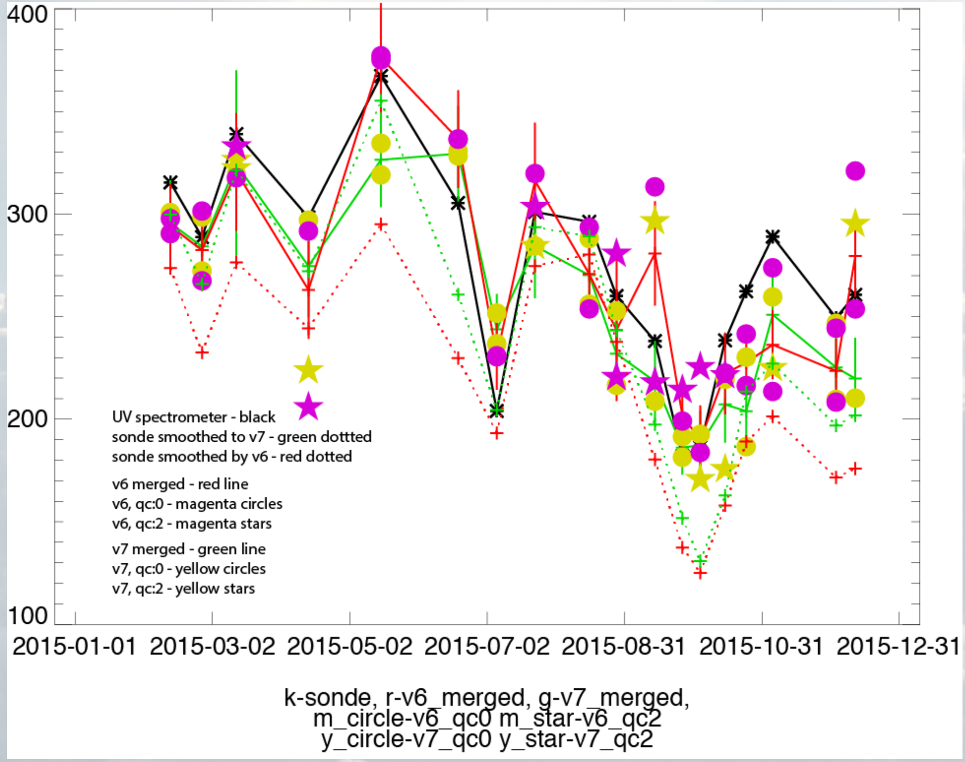
- Matchup conditions (closest is worse)
  - 149 is 20 km away, but 13 hours later
  - 053 is 300 km away, but 4 hours later
    - (probably should have used granule 52)
- O_3 reduced in lower stratosphere, but profile is very smooth
- Smoothed ozonesonde profiles show stronger minimum than retrievals, but v6.4.6 shows a weaker minimum
  - Averaging kernel-implied vertical resolution is realized in v6.4.6



CONCLUSIONS

Conclusions
Total Ozone Time Series

- O_3 is a blend of first-guess and “AIRS sensitivity”
  - Solution lies between first-guess and UV spectrometer
- Impact of first-guess having O_3 hole
  - No significant improvement in time series
  - Bias of O_3 during non-climatological regimes is small compared to other errors
- Additional trapezoids have increased degrees of freedom
  - Possibly reducing dependence on first guess, but no consistent improvement
- Averaging kernel smoothing add low bias to ozonesonde total O_3,
  - Smoothing has not been applied correctly
  - Averaging kernels are not indicative of information,



Conclusions
Ozone Mixing Ratio Profiles

- Vertical profiles have less vertical resolution than implied by averaging kernels
- What is appropriate way to apply averaging kernels? obvious
  - Averaging kernel are defined in terms of trapezoids of log mixing ratio, not mass preserving
    - Mixing ratio versus pressure, or
    - Density versus altitude
  - Are a linearized approximation of mixing of a priori and AIRS inforamation
- V6.4.6 profiles show less O_3 depletion
  - Added trapezoids has reduced sensitivity in lower stratosphere
- Profiles are mixture of first-guess and AIRS information, but
  - New first-guess has not significantly changed final product
- Increased number of trapezoids has improved profiles in mid-stratosphere
- Differences between profiles and ozonesonde track across versions