Investigating the Utility of Hyperspectral Sounders in the 9.6 μm Band to Improve Ozone Analyses

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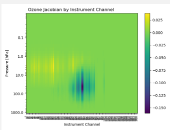
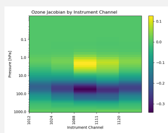
1. Introduction

Currently, hyperspectral sounder brightness temperatures assimilated in the Goddard Earth Observing System Atmospheric Data Assimilation System (GEOS-ADAS) are limited to assimilating temperature and moisture. The ozone sensitive 9.6 um region is sensed by several hyperspectral sounders including AIRS (Atmospheric InfraRed Sounder), IASI (Infrared Atmospheric Sounding Interferometer), and CrIS (Cross-track Infrared Sounder). Direct assimilation of brightness temperatures in the 9.6 μm region have been used previously to improve ozone analyses. This has recently been achieved by ECMWF (Dragani and McNally, 2013; Eresmaa et al., 2017), and while every system presents its challenges, it should be possible to take advantage of this spectral region using the GEOS-ADAS. For this study, channels were selected from available operational subsets evaluating information content, and minimizing inter-channel correlation. Additionally, information such as channel selections made by other studies, and vertical sensitivities of ozone and temperature were considered in developing the study. The analyses produced show improvements verified against ozonesondes taken from SHADOZ (Southern Hemisphere Additional Ozonesondes), and WOUDC (World Ozone and Ultraviolet Data Center). The addition of ozone channels does degrade forecast skill in the Tropics, on the border of statistical significance. Overall, the addition of these channels in some form could improve ozone analyses in the GEOS-ADAS.

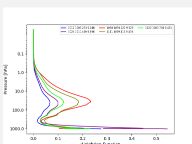
2. Channel Sensitivities - Example AIRS



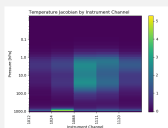
- Ozone Jacobians to the left are for channels currently assimilated
- In the GSI, a flag is typically turned on "qc_noirjaco3"
- The Jacobians to the left are usually "zeroed out", but in one experiment are turned on



- Ozone Jacobians in the 9.6 um band typically have the structure to the left (selected channels for experiments)
- Contributions in the stratosphere an troposphere



- Weighting functions to the left show strong peak in the stratosphere extending into upper troposphere
- Second strong peak towards the surface → for these experiments chose to assimilate over ocean only as a first step.



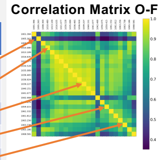
- Temperature Jacobians to the left show a double peak as well with strong sensitivity to the surface

3. Channel Selection

AIRS Channel Selection

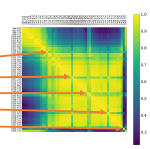
Channel	Wavenumber [cm-1]	Error (K)	Limit
1012	1005.263	1.7	1.7
1024	1010.480	1.0	1.0
1088	1039.227	1.0	1.25
1111	1059.415	1.4	1.5
1120	1063.738	1.4	1.5

Correlation Matrix O-F July 2018



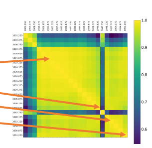
CrIS NSR Channel Selection

Channel	Wavenumber [cm-1]	Error	Limit
577	1010.0	0.9	0.75
607	1028.75	1.4	1.0
626	1040.625	1.3	1.0
650	1055.625	1.5	1.0
667	1066.25	1.0	0.75



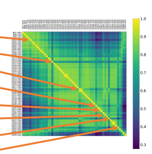
CrIS FSR Channel Selection

Channel	Wavenumber [cm-1]	Error (K)	Limit
596	1021.875	1.3	1.0
626	1040.625	1.3	1.0
646	1053.125	1.3	1.0
659	1061.25	1.3	1.0



IASI Channel Selection

Channel	Wavenumber [cm-1]	Error (K)	Limit
1427	1001.5	1.6	1.25
1479	1014.5	1.4	1.25
1536	1028.75	1.6	1.5
1579	1039.5	1.5	1.4
1585	1041.0	1.4	1.4
1626	1051.25	1.4	1.4
1643	1055.5	1.7	1.5
1671	1062.5	1.6	1.5



Strategy for Channel selection

- Generate Correlation matrices using observations – background for 1 month
- Use PCA to evaluate information content
- Select channels with smaller inter channel correlation

Strategy for Observation Errors

- Look at Jo/n (penalty) for Water Vapor channels
- Tune observation error for ozone channels to give that penalty close
- AIRS ~ 0.15, CrIS ~ 0.07, IASI ~ 0.1

Strategy for QC limits

- Again, looking towards water vapor channel assimilation strategy for guidance
- Tight limits to improve temperature solution on first outer loop (lots of points thrown out initially)
- improved temperature solution on second outer loop
- more observations get through QC (not as many point thrown out in the final analysis)

4. Observing System Experiments

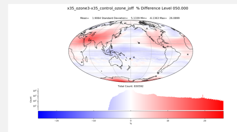
Experiment	Correlated Error	Ozone Jacobian	9.6 um channels
X35_control_ozone_joff	Off	Enabled	Disabled
x35_ozone3	Off	Enabled	Enabled
x35_ozone3_new_flag	Off	Enabled Only from 996 to 1170 cm^{-1}	Enabled

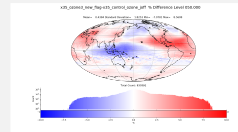
Observing System Experiments conducted

- For all experiments correlated error capability has been turned off – will be added in the near future
- One experiment (x35_ozone3) uses the GSI without any modification and uses all Jacobians (even channels outside the 9.6 um band)
- Second experiment (x35_ozone3_new_flag) preserves what the GSI typically does – zeroes out ozone Jacobians, but only outside the 9.6 um band

5. Changes in Ozone Monthly Means (July 2018)

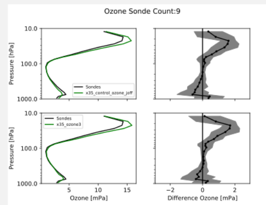
- Percent difference ozone concentration at 50 mbars for x35_ozone3 (left), and x35_ozone3_new_flag (right).
- Note large increase over South Pole for x35_ozone3 case.
- Which represents reality? Fortunately, ozonesondes over this period….

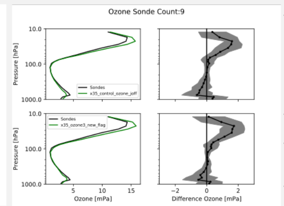




6. Verification Against Ozonesondes

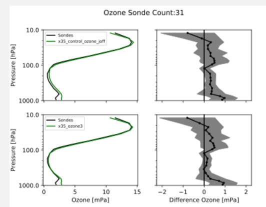
SHADOZ Tropical Atlantic - Ascension Island (Jul-Sept 2018)

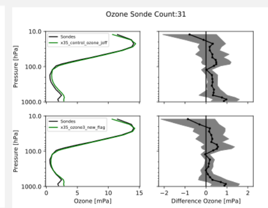




- Both experiments show improvements near the surface with x35_ozone3 (lower left panel) showing a slightly better improvement that x35_ozone3_new_flag (lower right panel)
- Left panels represent means of analysis and sondes
- Right panels represent differences in the mean between sondes and analysis
- Gray shading represents RMSE

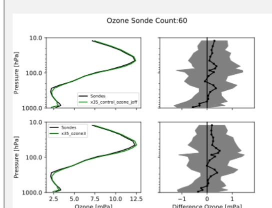
SHADOZ Tropical Pacific (Jul-Sept 2018)

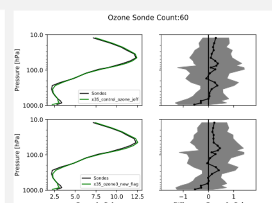




- Both experiments show similar improvements in the troposphere

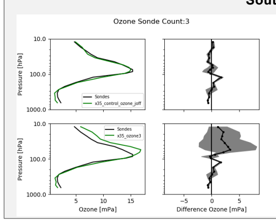
WOUDC Extratropics (Jul-Sept 2018)

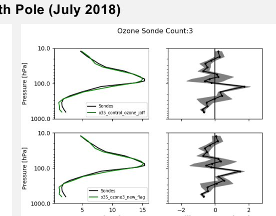




- Both experiments show a slight degradation in the stratosphere
- Slight improvement near surface (more so for x35_ozone3)

South Pole (July 2018)

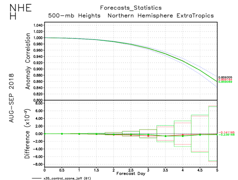


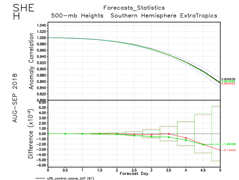


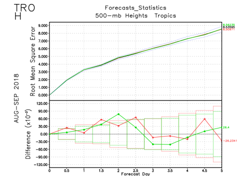
- Large increase in stratospheric ozone near the South Pole for x35_ozone3 in July doesn't verify
- X35_ozone3_new_flag appears to verify as well as control

6. Forecast Statistics (2018 Aug- Sept)

Forecast statistics show no significant change in anomaly correlation in extratropics (NHE, SHE), but a slight degradation in RMSE height error in the tropics (just outside boxes of significance).







6. Summary

Both experiments have some improvement in ozone analysis when verified against ozonesondes. Currently, it appears x35_ozone3_new_flag would be selected as x35_ozone3 seems to add a large amount of ozone (which doesn't verify against ozonesondes) over Antarctica during July 2018. There appears to be a slight degradation in the forecast skill in the tropics in the troposphere. Additional work is being conducted to evaluate the effects upon the forecast in the stratosphere.

References

Dragani, R., & Mcnally, A. P. (2013). Operational assimilation of ozone-sensitive infrared radiances at ECMWF. *Quarterly Journal of the Royal Meteorological Society, 139*(677), 2068–2080. https://doi.org/10.1002/qj.2106

Eresmaa, R., Letertre-Danczak, J., Lupu, C., Bormann, N., & McNally, A. P. (2017). The assimilation of Cross-track Infrared Sounder radiances at ECMWF. *Quarterly Journal of the Royal Meteorological Society, 143*(709), 3177–3188. https://doi.org/10.1002/qj.3171

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