Improvements to Ozone Analyses using Hyperspectral Sounders in the 9.6 μm Band

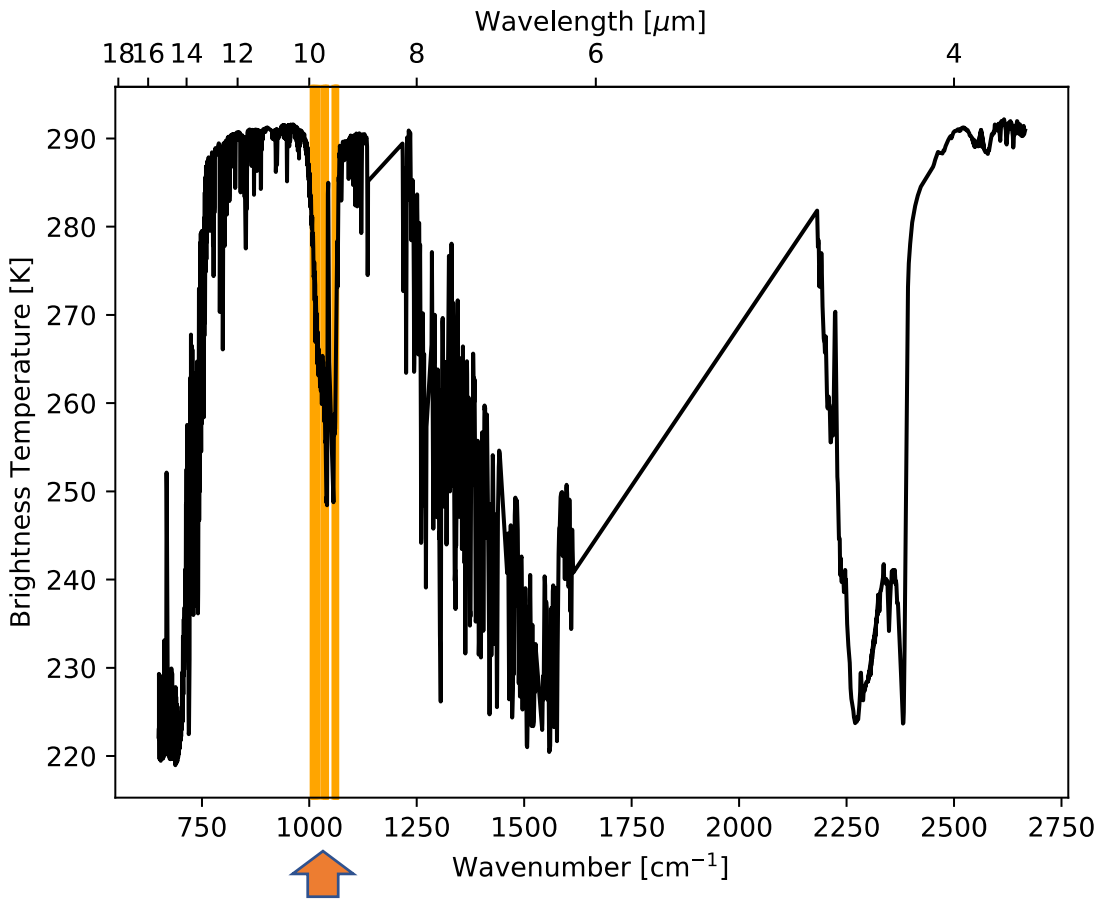
Bryan M. Karpowicz[1,2,3], Will McCarty[1], Krzysztof Wargan[1,4]

1. NASA Global Modeling and Assimilation Office (GMAO)
2. Goddard Earth Sciences Technology and Research (GESTAR)
3. Universities Space Research Association
4. Science Systems and Applications, Inc (SSAI)

November 4, 2019

Outline

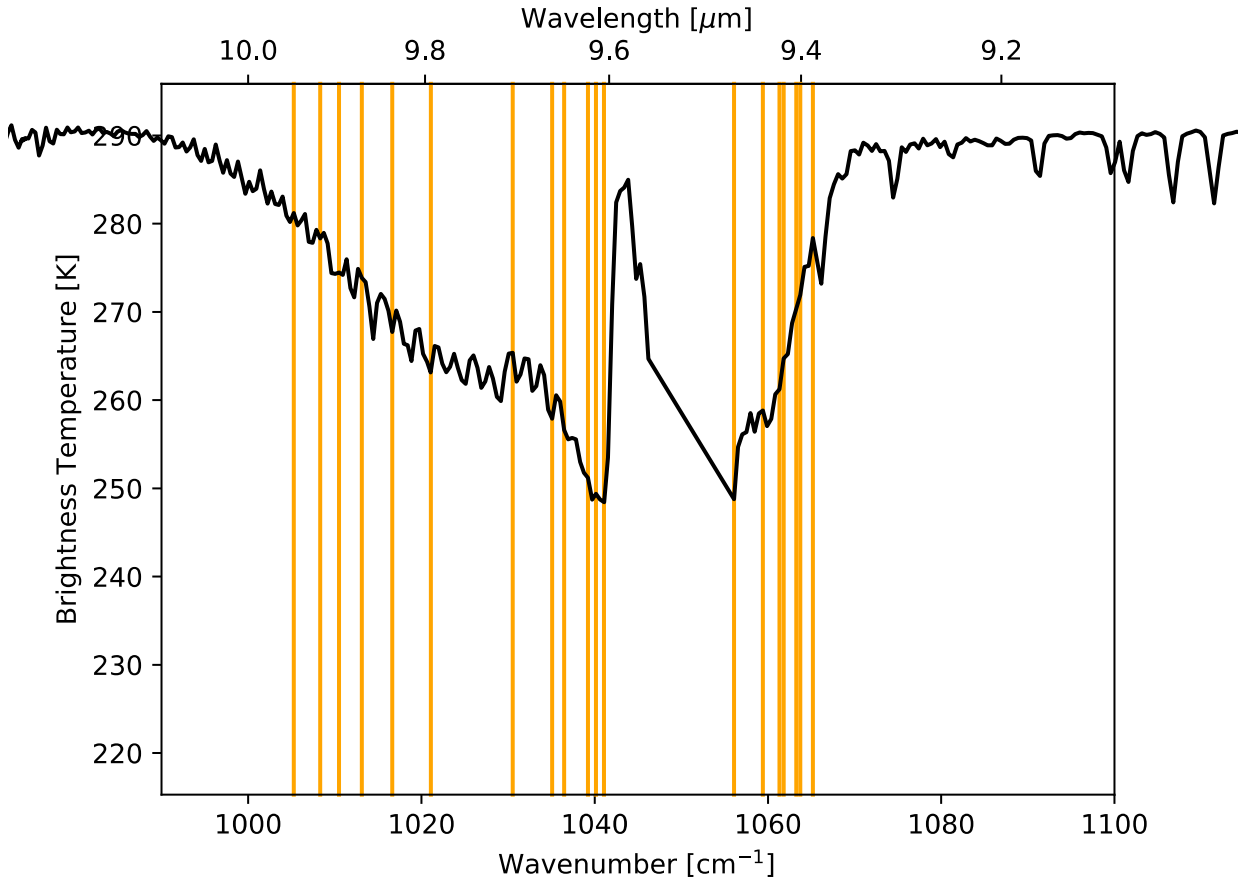
- Motivation
- Approach
- Does it break things? Forecast Statistics
- Does it improve fit to Ozonesondes?
- Next Steps



Ozone Sensitive Channels

Outline

- Motivation
- Approach
- Does it break things? Forecast Statistics
- Does it improve fit to Ozonesondes?
- Next Steps

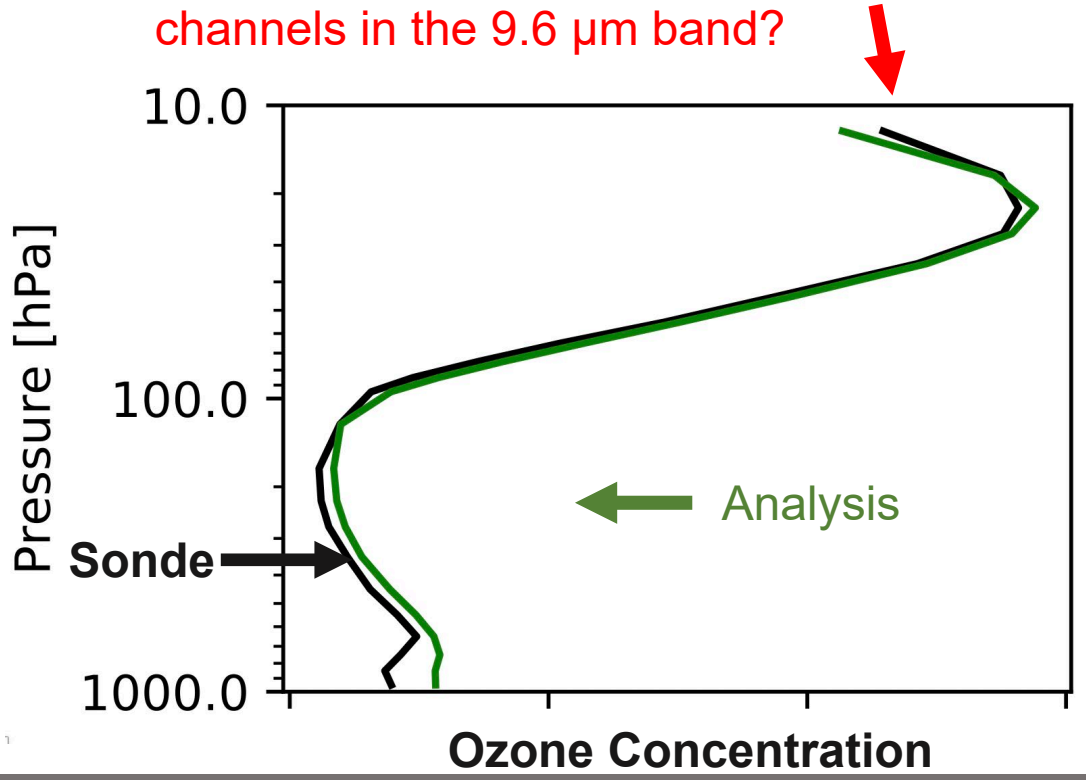


Ozone Sensitive Channels
(ECMWF Subset)

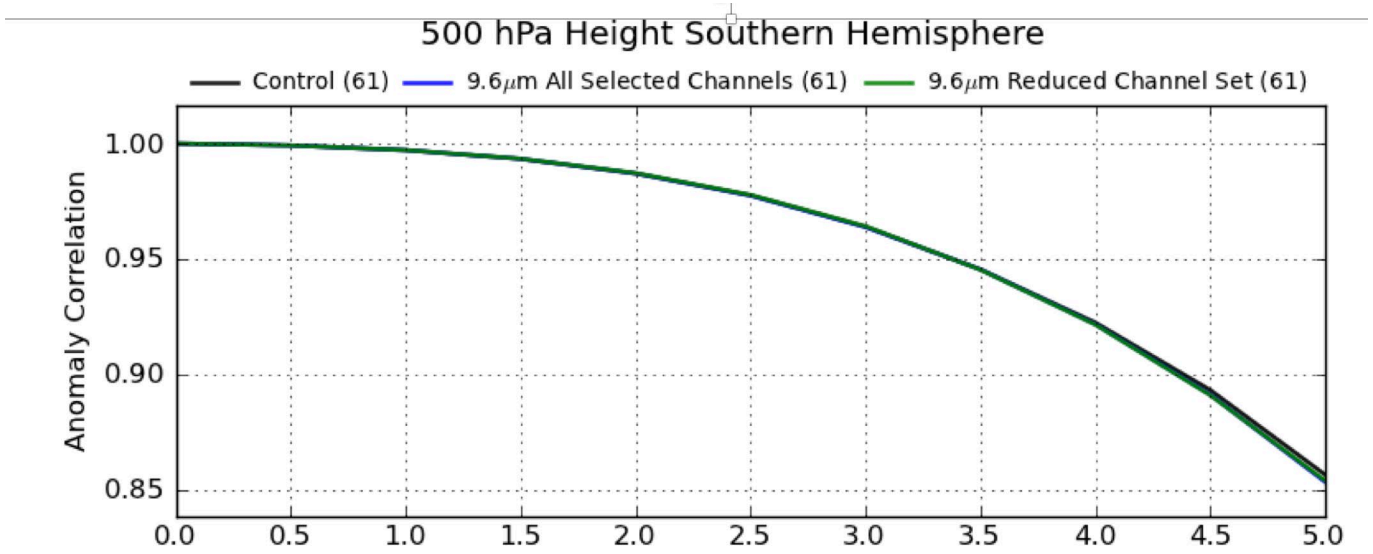
Motivation

- ECMWF has shown improvements assimilating ozone sensitive channels using AIRS, IASI and HIRS (Dragani and McNally, 2013), later added CrIS (Eresmaa et al., 2017)
- Improve ozone analysis is the upper troposphere/lower stratosphere
- Data source to improve ozone analysis to mitigate loss of sensors such as MLS, OMI, …
- Potential to improve ozone analysis in future reanalysis products

Can this picture be improved by assimilating channels in the 9.6 μm band?



Without changing this picture?



Approach (Overview)

Channel Selection (using AIRS, CrIS, IASI):
- Correlation → Look at O, O-F channels correlations
- Information Content → PCA, and Jacobians

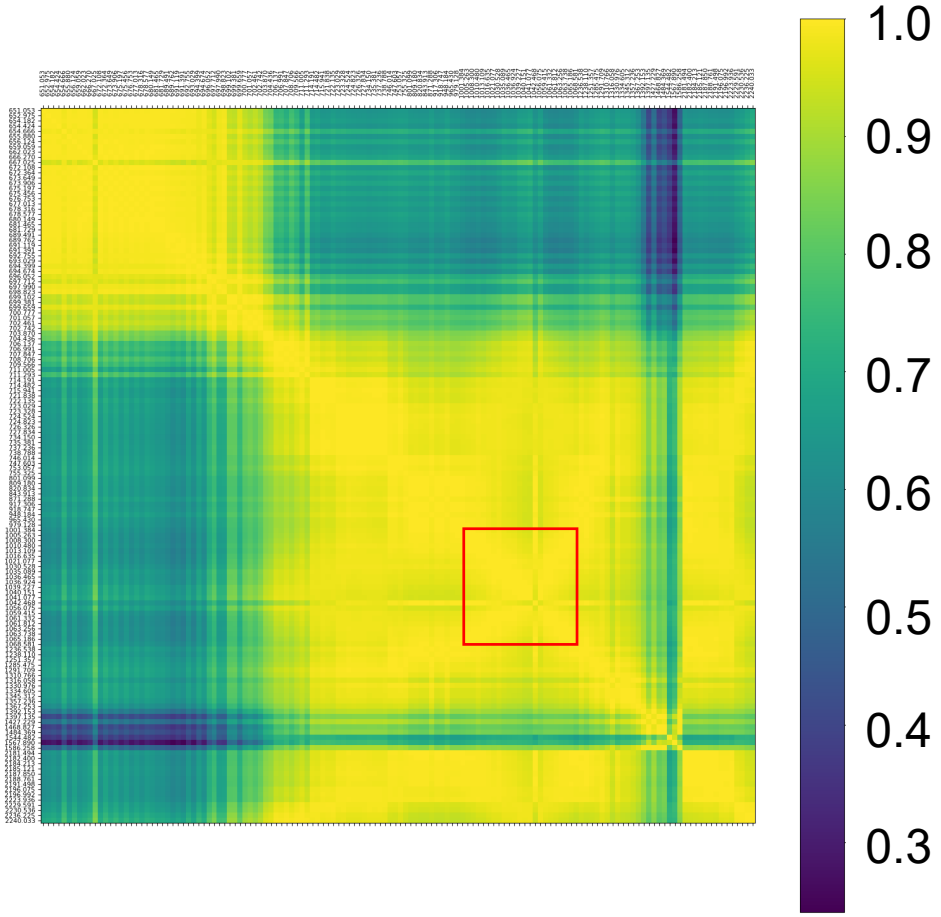
Observation Error Specification:
- Run a few DA cycles, tune observation error such that Jo/n to roughly matches water vapor channels
- Set tight QC limits based on histograms of O-F → use outer loop to improve temperature solution (same philosophy as for water vapor channels)

Observation System Experiment (OSE):
- Run control(s) (nominally system w/o IR channels turned on)
- Run case w/ selected channels turned on

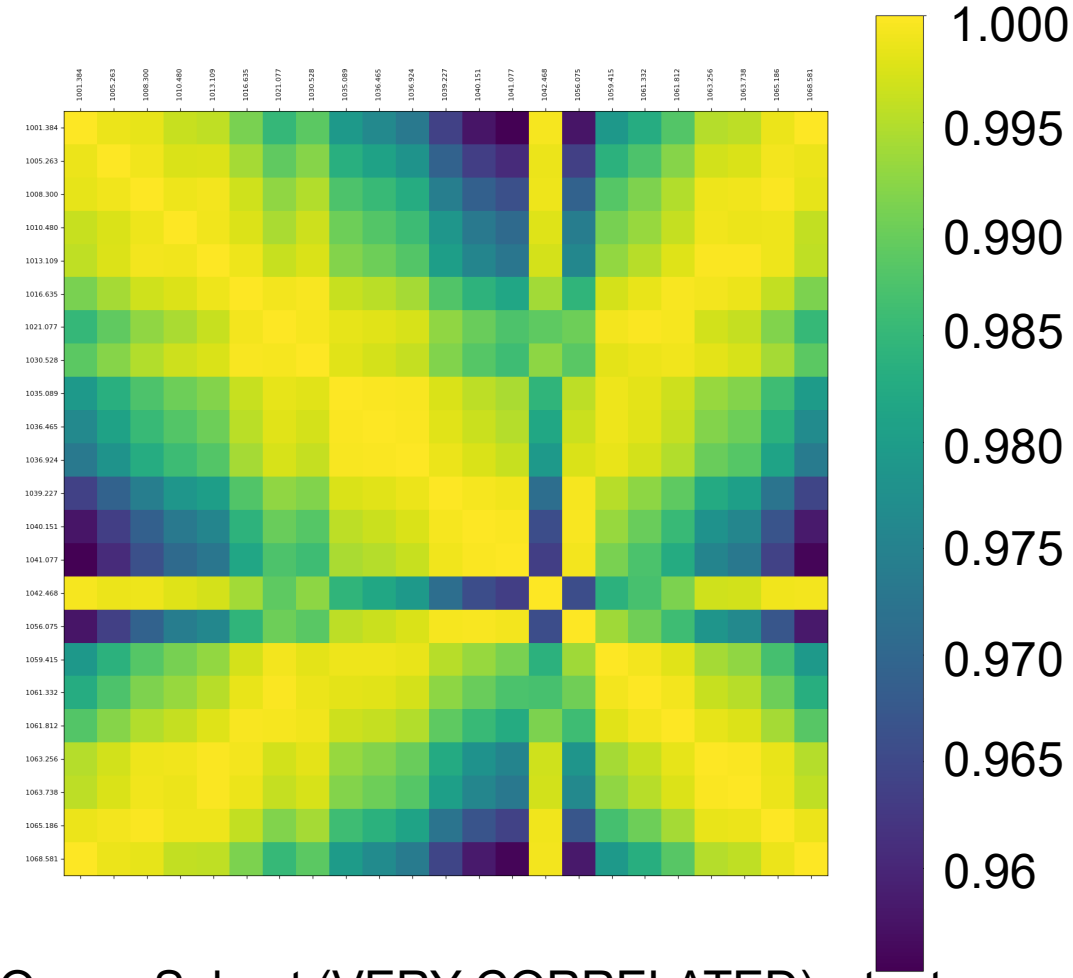
Evaluation/Verification:
- Look at fit to available ozonesondes
- Look to see if adding ozone channels degrades the forecast, or temperature analysis in any way

Example Channel Selection: AIRS Observation Correlation

(Inter-channel correlation for Month of Ocean only QC'd)

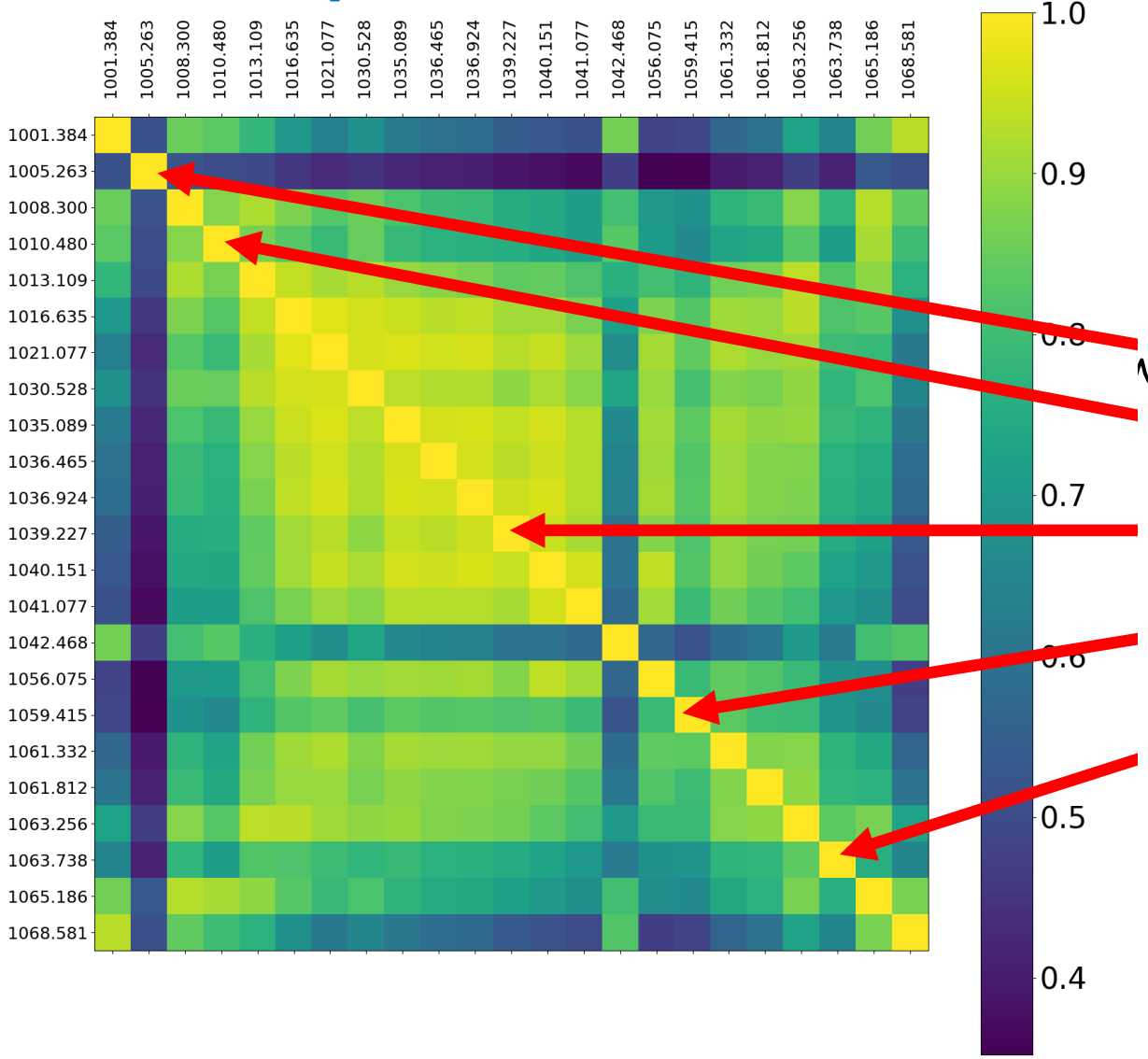


All Channels Currently Assimilated
+ All available Ozone sensitive channels

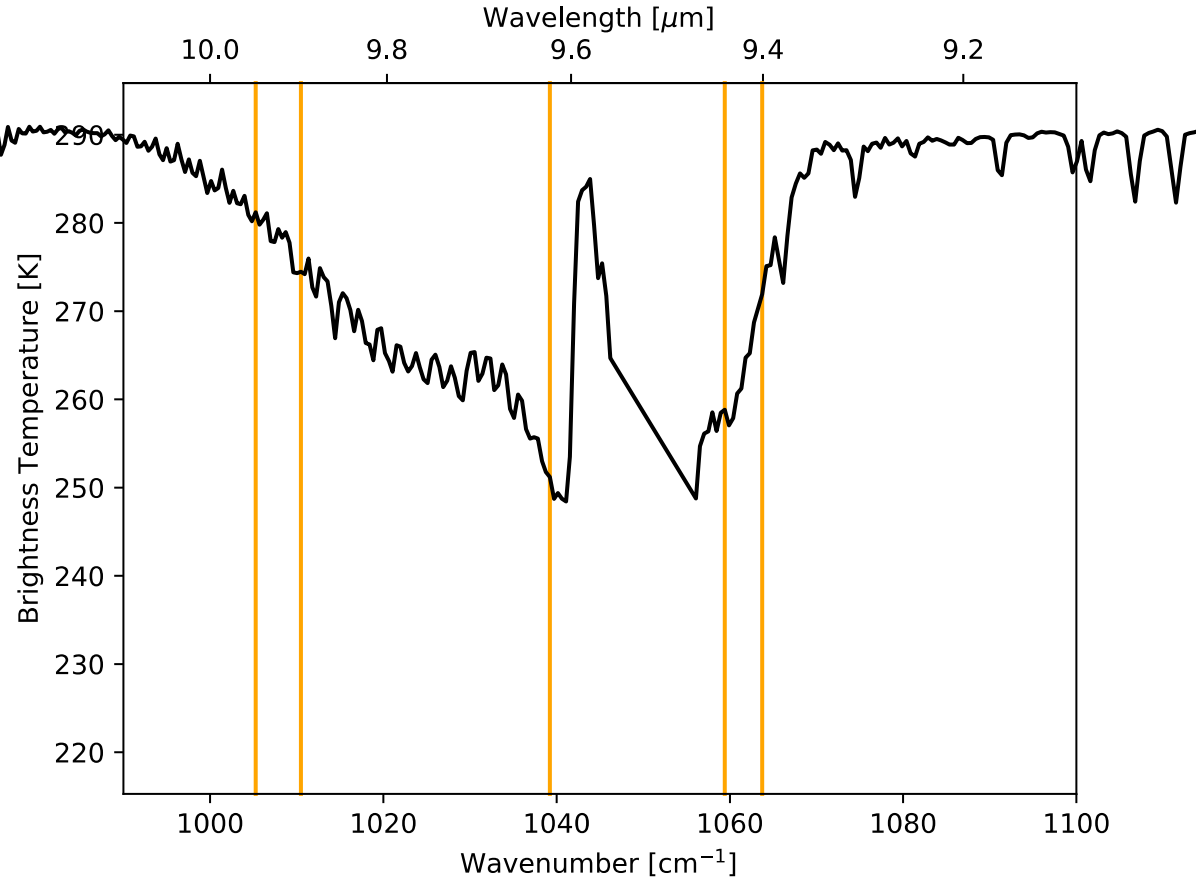


Ozone Subset (VERY CORRELATED)…try to use O-F to make selection easier (correlation reduced)?

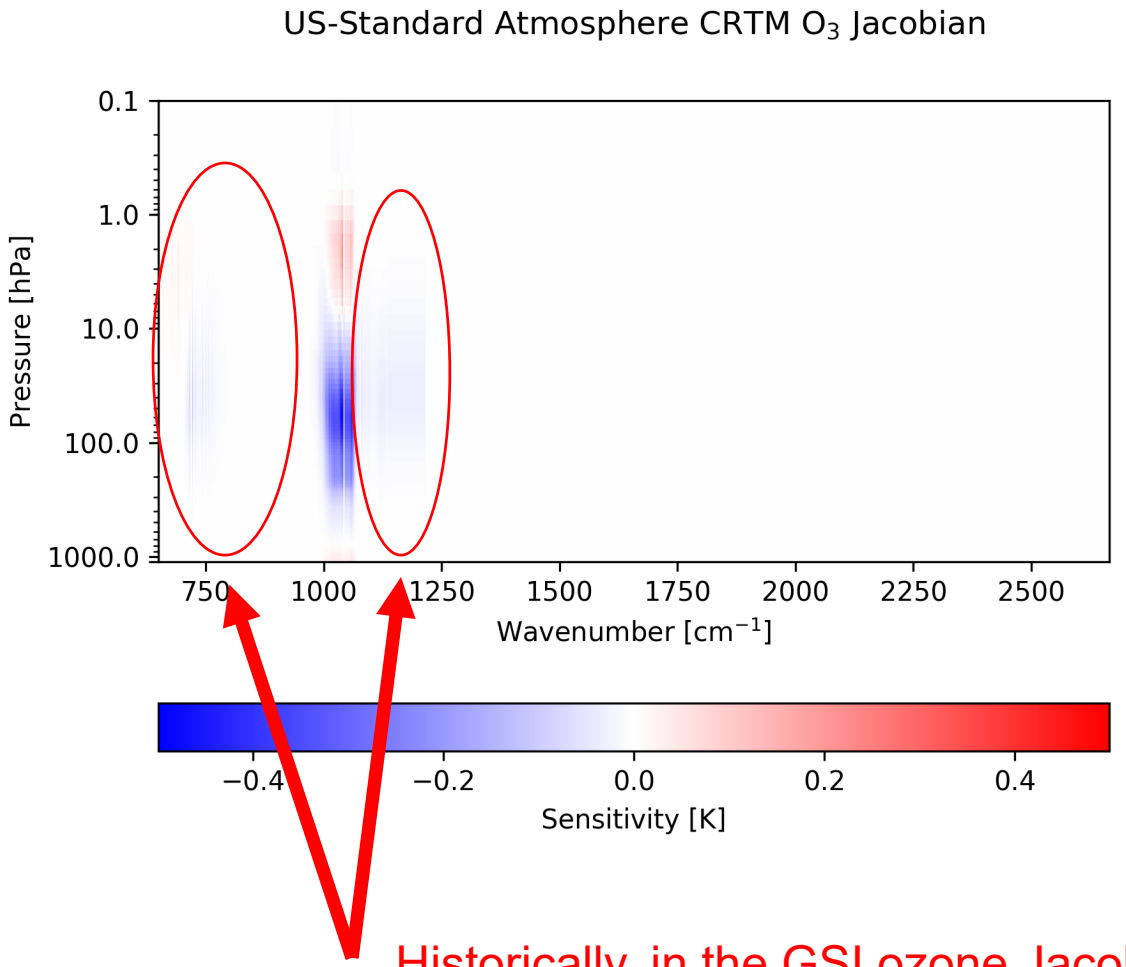
Example Channel Selection: AIRS Observation - Forecast

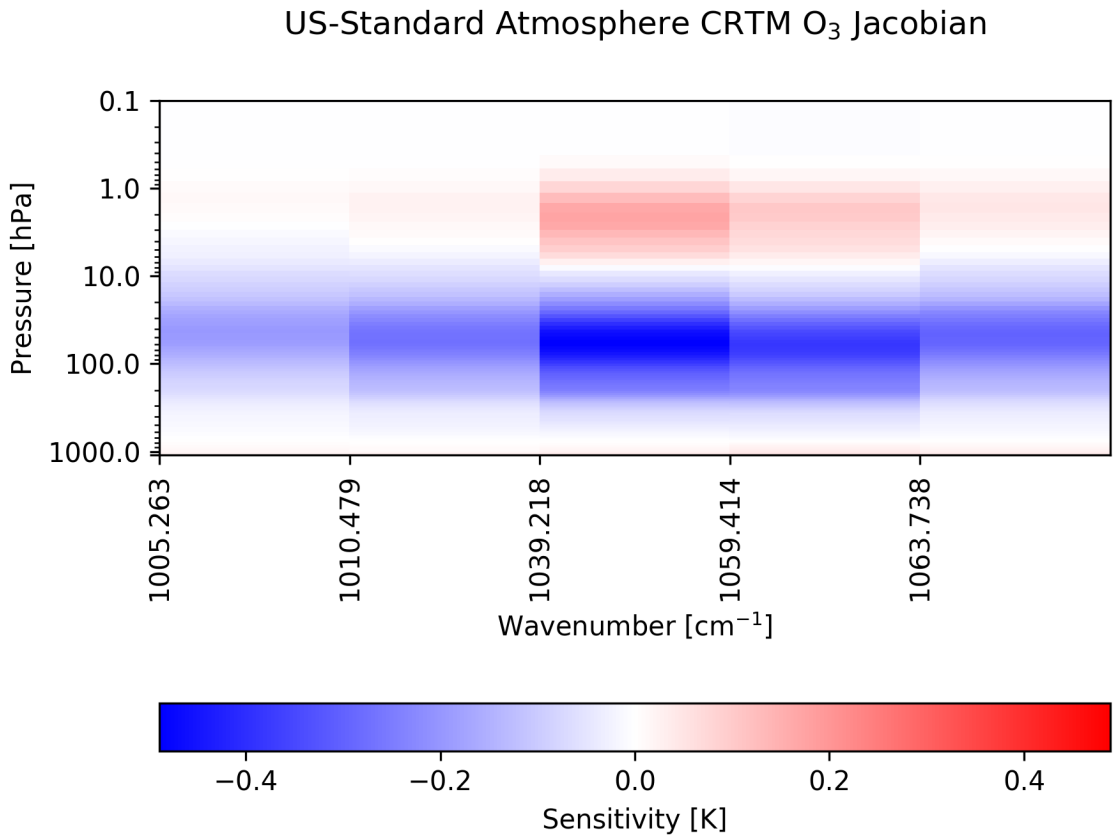


- A bit easier to select channels that are less correlated
- To further simplify use PCA to



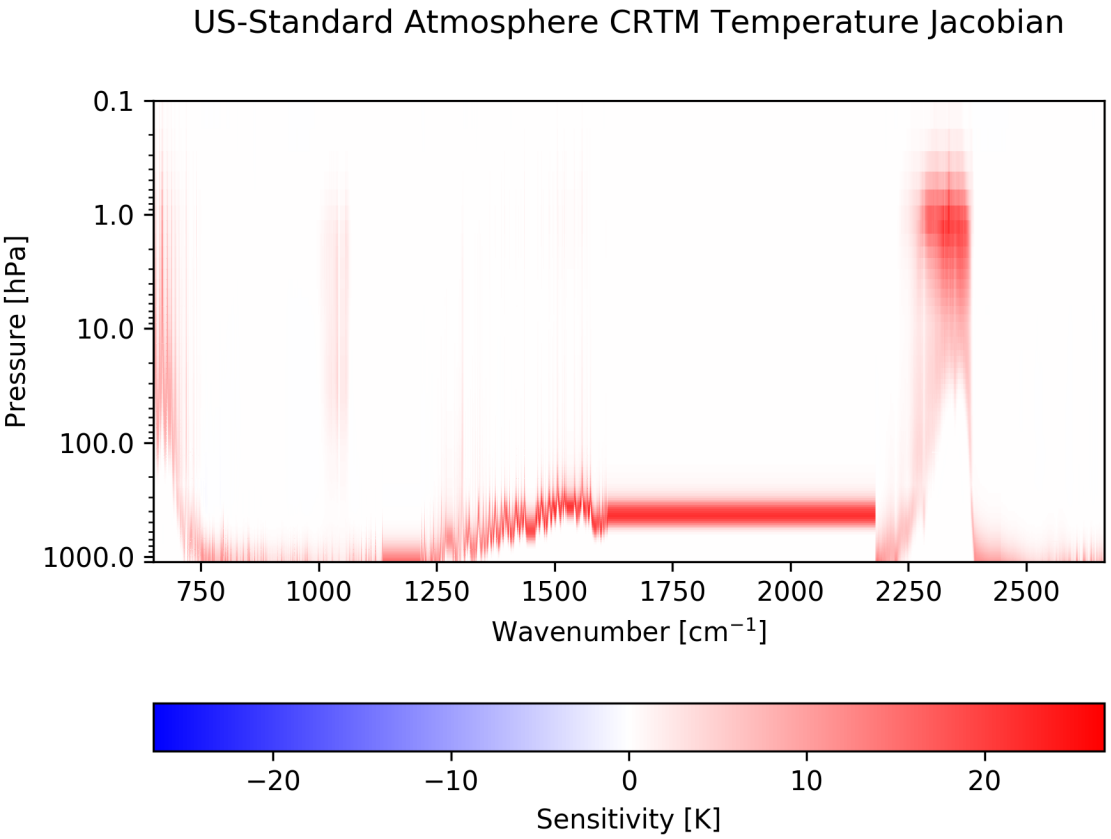
Example Channel Selection: AIRS Ozone Jacobians

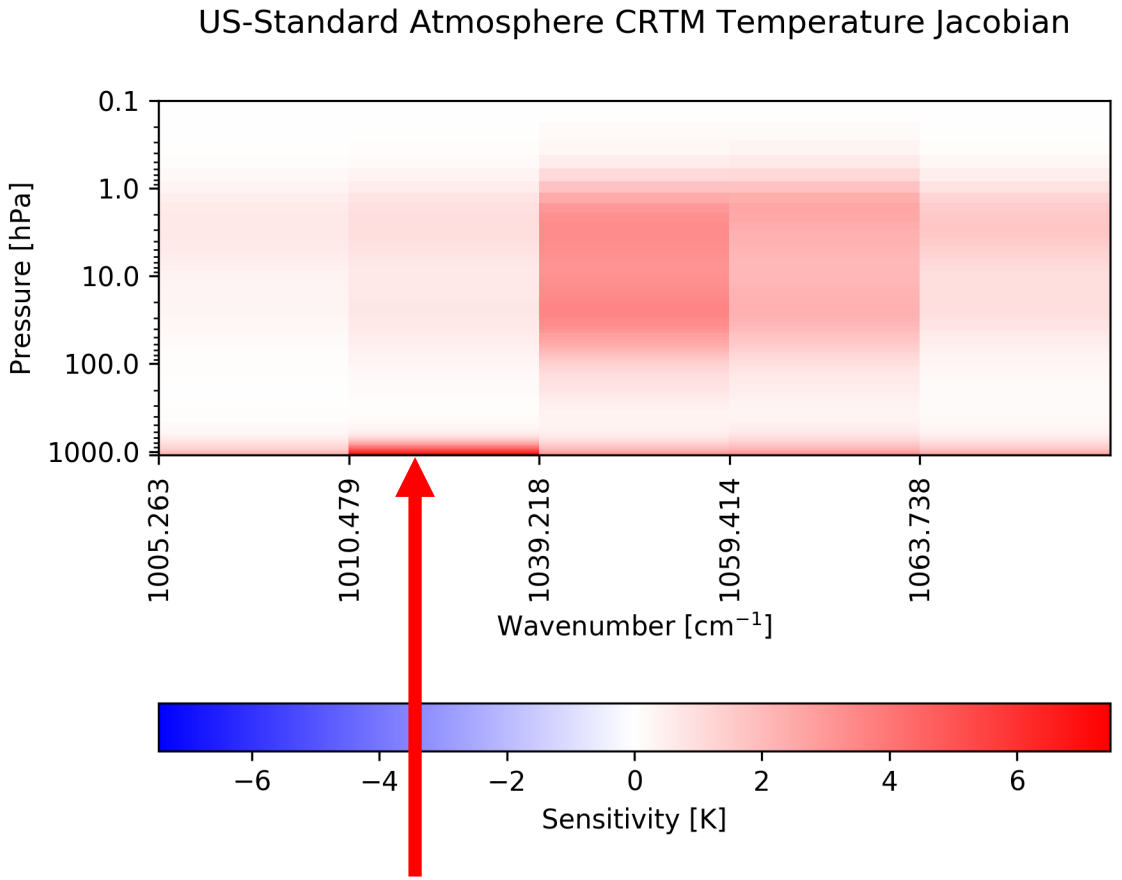




Historically, in the GSI ozone Jacobians are set to zero, potential problem aliasing of ozone/temperature signal

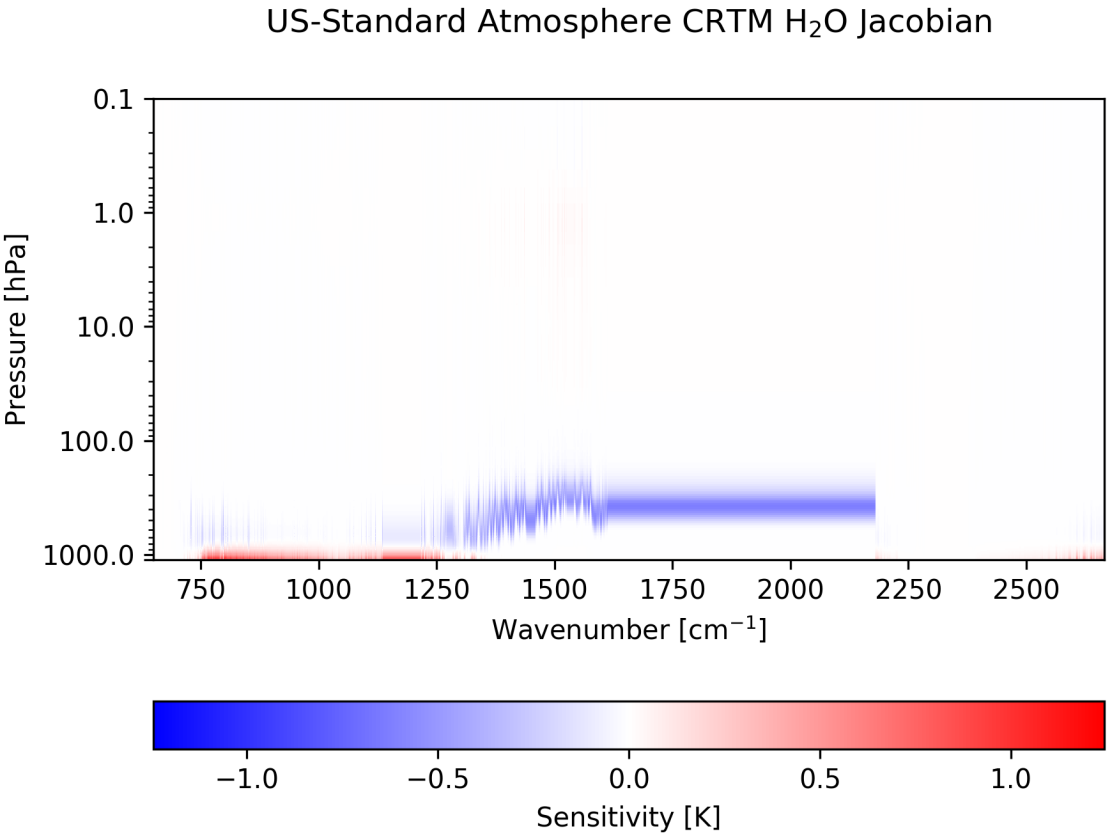
Example Channel Selection: AIRS Temperature Jacobians

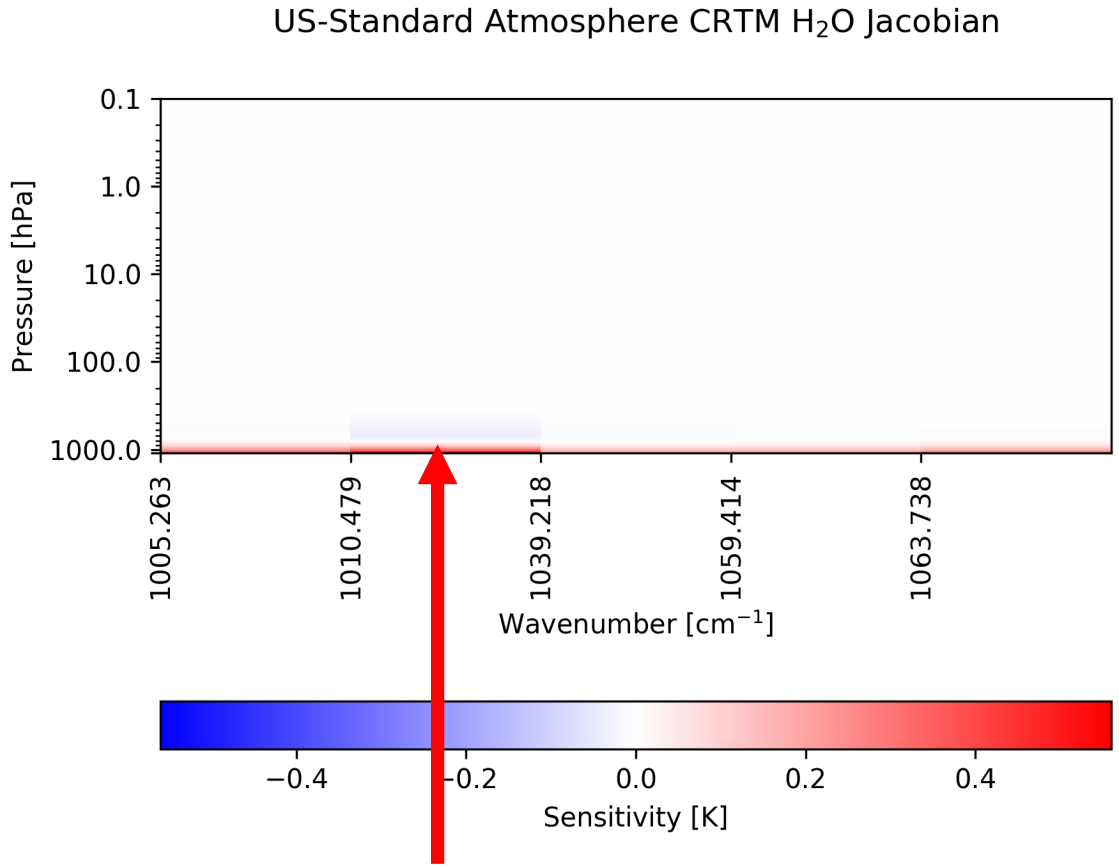




Relatively large surface temperature sensitivity, potential problem aliasing ozone/temperature signal

Example Channel Selection: AIRS Water Vapor Jacobians



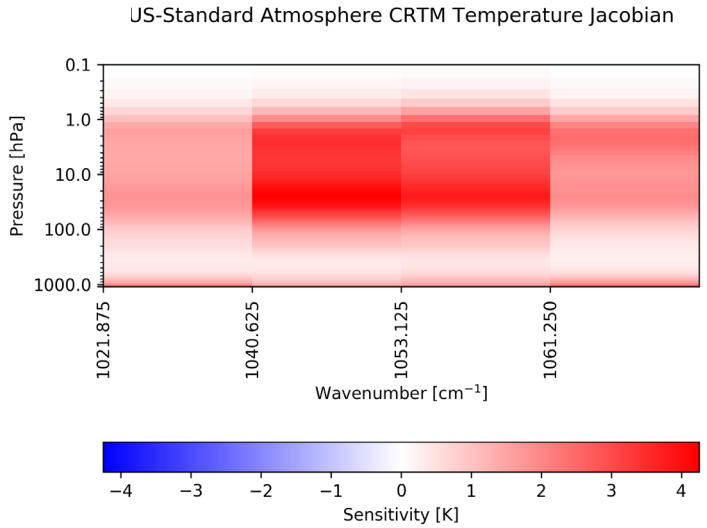


***Shameless Plug* Originally looked at RTTOV Jacobians, but a new CRTM Python interface has been developed →**
https://github.com/karpob/pycrtm/

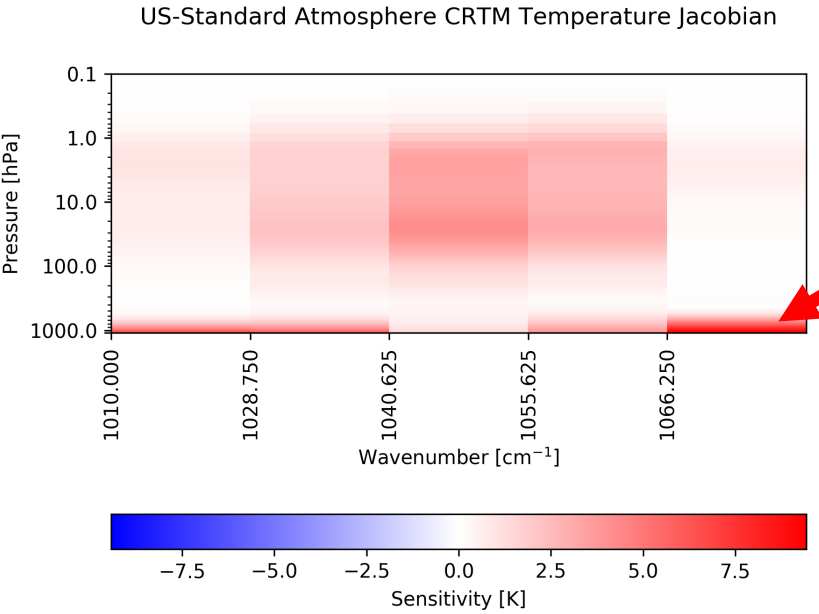
Relatively large water vapor sensitivity, potential problem aliasing water/ozone signal.

CrIS and IASI Channel Selections (Temperature Sensitivities)

CrIS FSR 431 Subset Selection

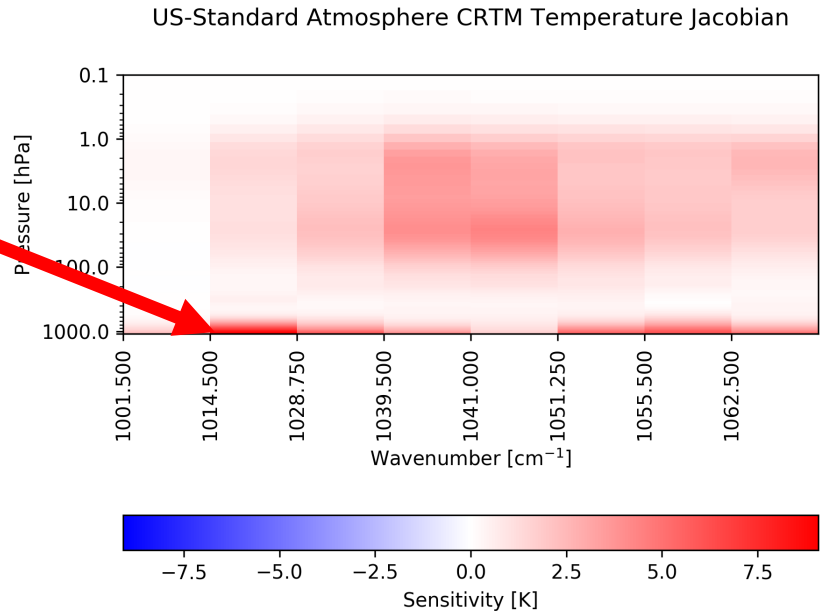


CrIS NSR 399 Subset selection



Consider Dropping?

IASI 616 Subset Selection



Observing System Experiments using AIRS, CrIS and IASI

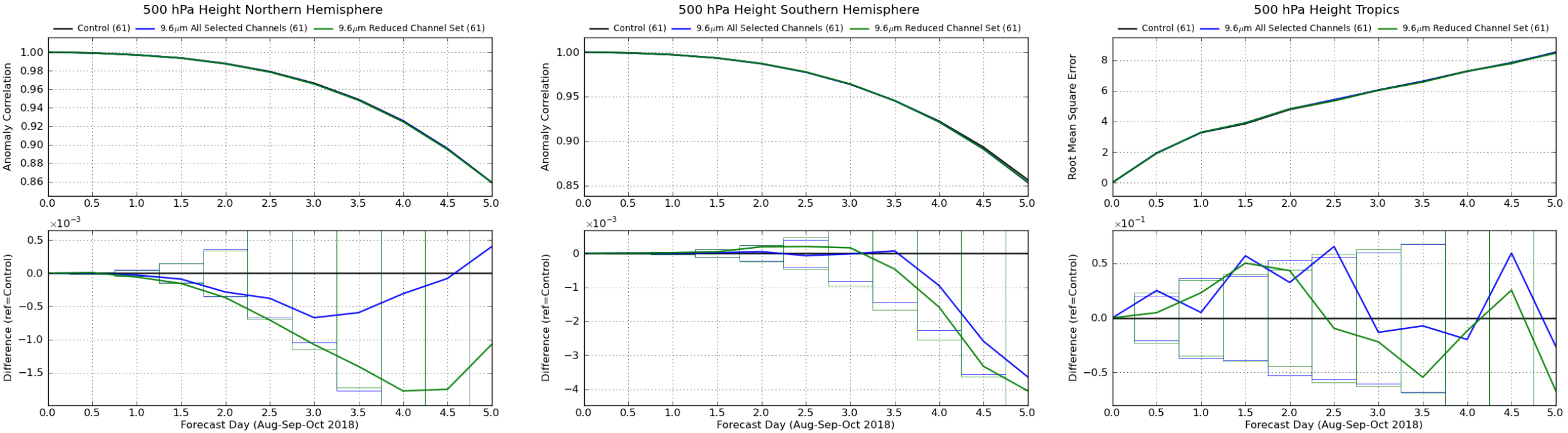
OSE Design

- Conduct several OSEs using channels in the 9.6 μm absorption region for AIRS, CrIS and IASI (currently CrIS/NPP →NSR, CrIS /N20 → FSR)
- IASI and AIRS are configured to run with correlated error operationally, CrIS NPP/N20 are not
- Keep things simple initially and run control and experiments **without** correlated error
- Assimilate these channels over water leaving radiances only (no sea ice, etc.)
- ”Zero-out” Jacobians outside 9.6 μm region →initial tests w/ unmodified Jacobians produced excessive ozone over the South Pole

Experiments for Today:

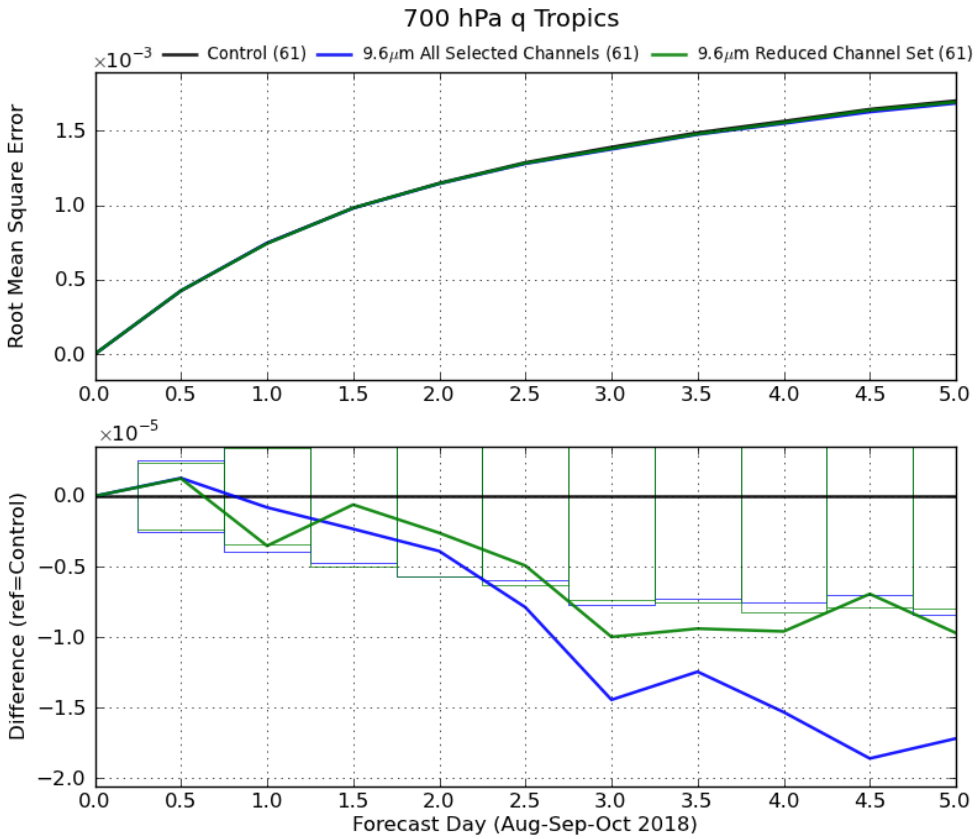
- Control → System without correlated error (along with 2 experiments)
- All Channels → More aggressive channel selection going off of PCA selection
- Reduced Channel Set → Less aggressive channel selection dropping channels w/ strong near surface sensitivity

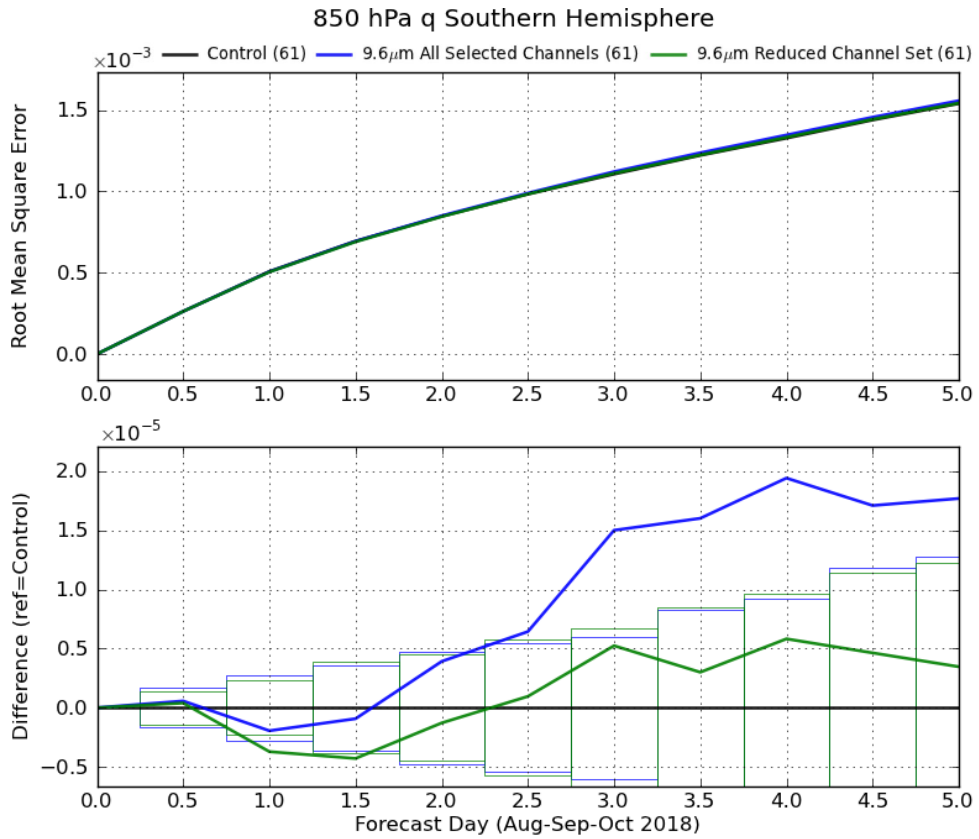
Forecast Statistics – Does it break things? (1st Order)



- Left - Northern Hemisphere extratropics 500 mb Height Anomaly Correlation
- Middle - Southern Hemisphere extratropics 500 mb Height Anomaly Correlation
- Right - RMSE 500 mb height
- Reduced set slightly worse for Northern/Southern hemisphere (inside statistical significance)
- RMSE worse (barely outside significance bars) in tropics for “All Selected Channels” case

Forecast Statistics – Water Vapor (Mixed results)



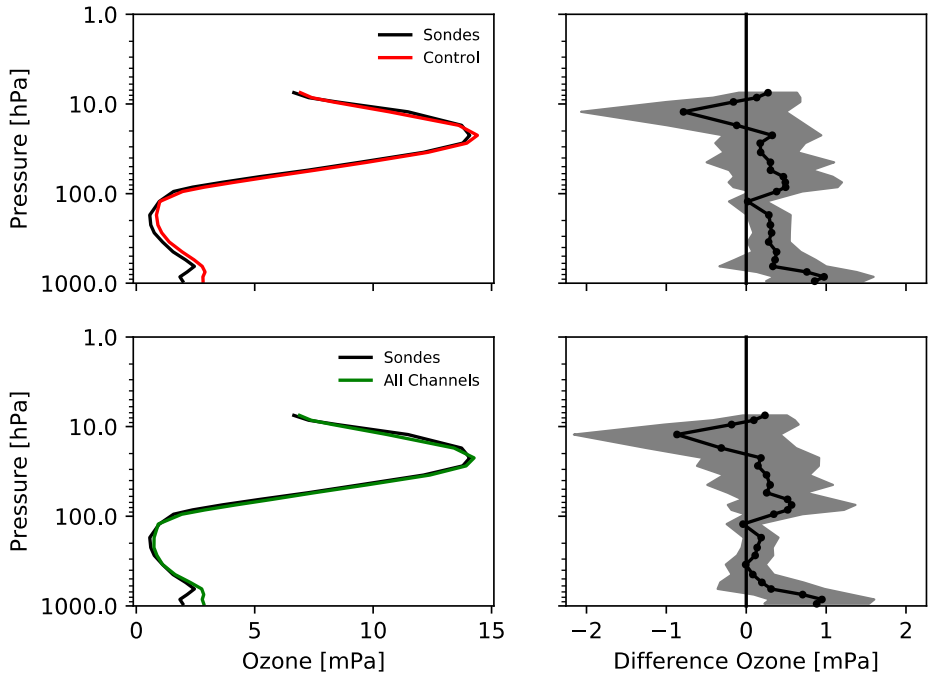


- Both cases have decreased RMSE @700 mb in the tropics (“All Selected Channels” well outside significance)
- Increased RMSE in the Southern Hemisphere with “All Selected Channels” case well outside significance boxes
- To keep things forecast neutral it appears the “Reduced Channel Set” may be the best option

Verification Against Ozonesondes (All Channels)

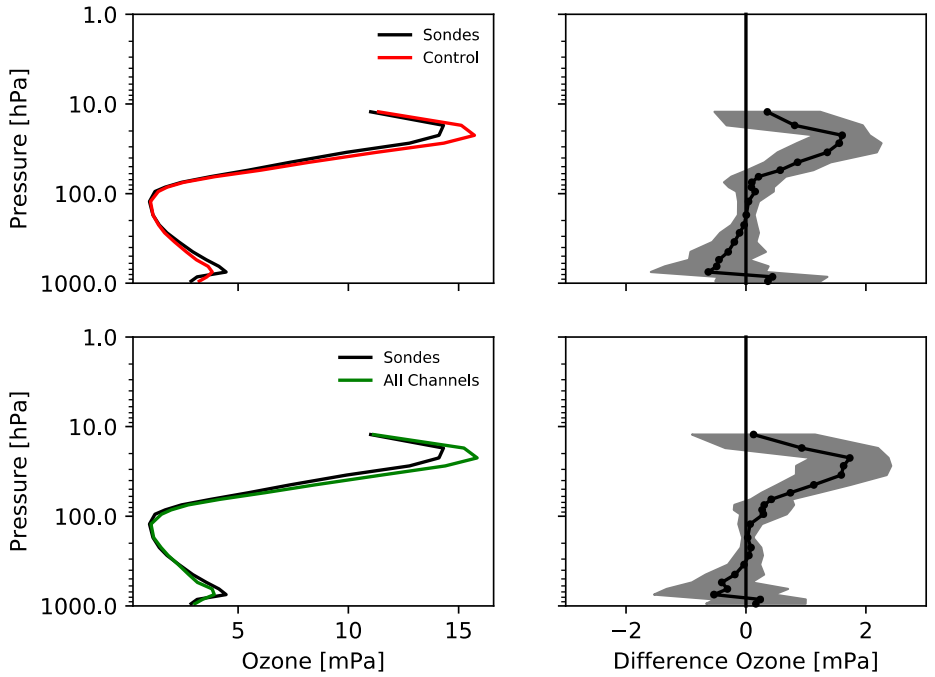
SHADOZ Tropical Pacific (Jul-Sept 2018)

Ozone Sonde Count:31



SHADOZ Tropical Atlantic (Jul-Sept 2018)

Ozone Sonde Count:9

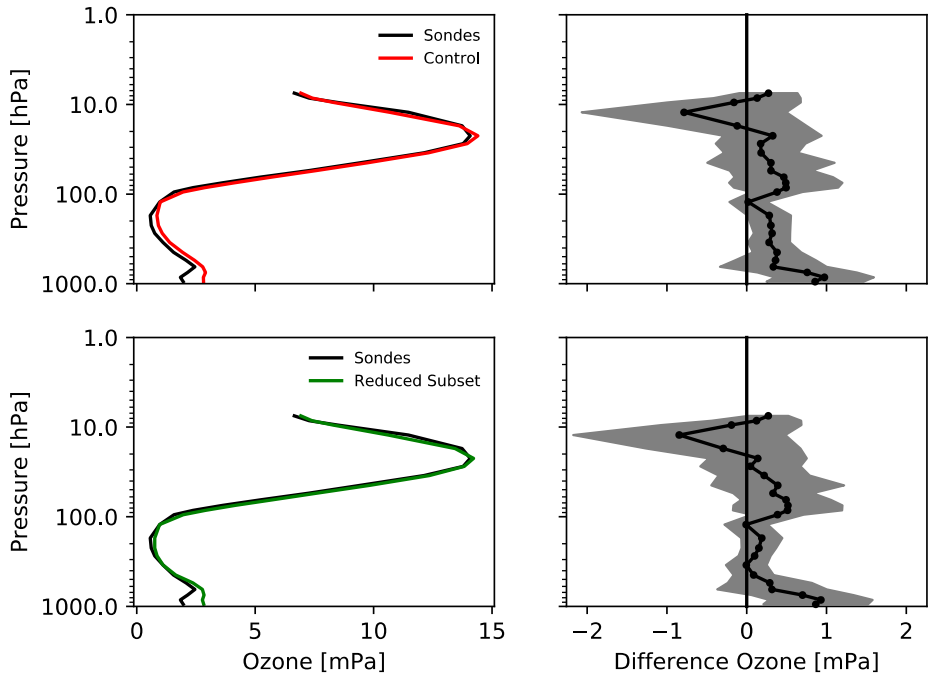


- Ozonesonde measurement, Control Analysis, Experiment Analysis
- Better Agreement in Upper troposphere lower stratosphere
  (Means on left closer/ differences on right panels closer to zero)
- RMSE (grey shading) improved at some vertical levels

Verification Against Ozonesondes (Reduced Channel Set)

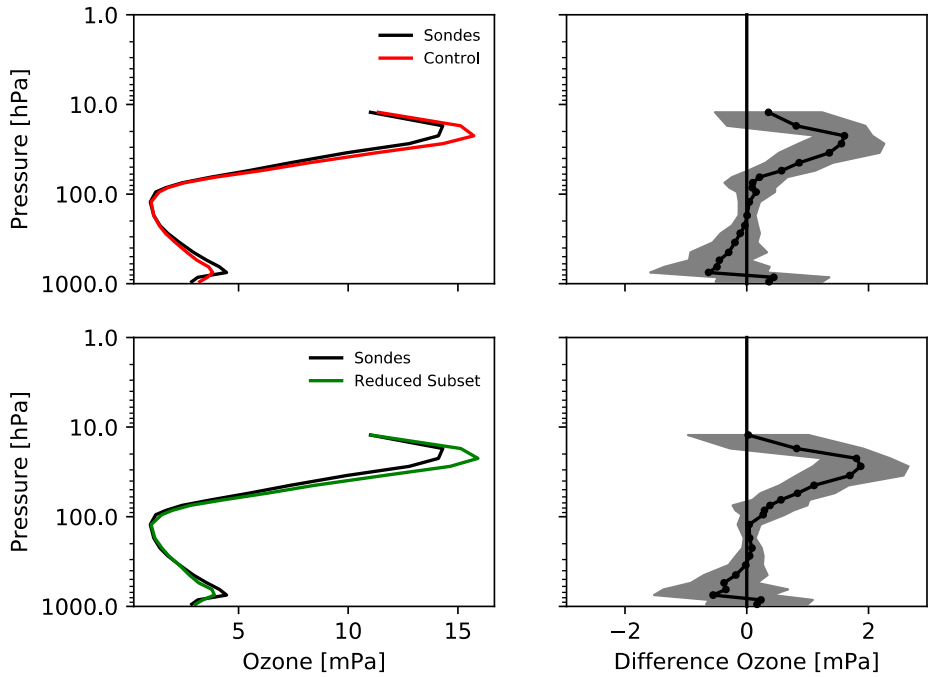
SHADOZ Tropical Pacific (Jul-Sept 2018)

Ozone Sonde Count:31



SHADOZ Tropical Atlantic (Jul-Sept 2018)

Ozone Sonde Count:9



- Ozonesonde, Control Analysis, Experiment Analysis
- Similar to All Channels- Better Agreement in Upper troposphere lower stratosphere
- Under a configuration without correlated error, it would appear the “Reduced Channel Set” would be preferable – forecast neutral, and similar improvements against ozonesondes

Conclusions

- Under a system **without** correlated error, it appears that the “Reduced Channel Set” will provide the least forecast impact, and equivalent improvements in ozone analysis
- Turn on correlated error and include error correlations for channels in 9.6 μm band
  - Will having more channels improve ozone analysis?
  - Will it further reduce impact on the forecast skill?
- Will the same improvements be observed with a different ozone observing system?
  - Can you get the same UT/LS improvements without MLS, or replacing it with OMPS-LP, SBUV, or without any additional ozone observations?

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