P2.37

SIMULATION OF AND COMPARISON BETWEEN GIFTS, ABI, AND GOES I-M SOUNDER OZONE ESTIMATES AND APPLICATIONS TO HES

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1. INTRODUCTION

The next generation of meteorological infrared (IR) sensors promise to improve the estimation and retrieval of ozone profile and total column values. The Sounder on the current Geostationary Operational Environmental Satellite (GOES) series is capable of total column ozone accuracy on the order of 5-7% when compared to the Total Ozone Mapping Spectrometer (Li et al 2001; Schmidt 2000). Simulation has shown that hyperspectral IR sensors such as the proposed Geostationary Interferometer Fourier Transform Spectrometer (GIFTS) and the Hyperspectral Environmental Suite (HES) can reduce the error by as much as a factor of two when the optimal set of bands is used (for the purposes of this research, GIFTS and HES are essentially interchangable (Li et al 2004a,b)). GOES, GIFTS/HES, and the proposed Advanced Baseline Imager (ABI) have been compared in simulation using the linear ozone regression algorithm currently used for the GOES Sounder (Li et al 2001). The simulations illustrate that the accuracy of the regression-based ozone profile and total column estimates is primarily impacted by spectral coverage. Instrument noise plays a role in ozone estimate accuracy for GIFTS/HES but has a negligible impact for the GOES Sounder and ABI.

2. SIMULATION METHOD

The radiances from each satellite are simulated using a forward model applied to the NOAA88b profile dataset, which includes 7,547 collocated temperature, moisture, and ozone profiles. 90% of these profiles are used to generate the regression coefficients, and the remaining 10% are used to determine the accuracy of the coefficients.

The ozone regression algorithm used in the simulations is very similar to that used for the GOES Sounder (Li et al 2001). In both versions the brightness temperatures from several channels and their squares are used in conjunction with the latitude, month, and surface pressure as predictors in the regression equation. In these simulations the secant of the viewing angle has been substituted with the surface temperature and moisture.

Hyperspectral radiances are handled differently than radiances from traditional sensors such as the GOES Sounder. The simulated hyperspectral radiances are processed using principle component analysis, which reduces the data volume by using eigenvectors and eigenvalues to find the dominant subspace of the data (Huang and Antonelli 2001; Li et al 2004a,b). In other words, the data volume is reduced from as many as 2048 channels to approximately 200 or so values that represent over 95% of the original data set. Those representative values are then used in the regression, thus maintaining the accuracy of the procedure while improving the speed.

For the GOES Sounder and ABI, all IR bands with wavelengths greater than 4 μm are used in the ozone regression. While each instrument has only one band that is sensitive to ozone (at approximately 9.7 μm), the other bands have been shown to improve the ozone estimates by virtue of the correlation between stratospheric temperature and ozone (Li et al 2001). For GIFTS/HES, different combinations of bands have been explored, with bands in the long-wave (8.3 μm to 15.3 μm, in wavenumbers ~650 cm^{-1} to ~1200 cm^{-1}) providing the best results (Fig. 1). It should be noted that HES coverage outside of the long-wave has yet to be determined. The spectral coverage proposed for GIFTS was used in the simulations. The percent root mean square error (%RMSE) peaks dramatically in the lower atmosphere as a result of the low density of ozone in that region and the inability of infrared measurements to deect ozone at those levels. The overall impact of lower-atmosphere ozone on the total column value is relatively small. Table 1 outlines the bands used in simulation for GOES, ABI, and GIFTS. For GIFTS and ABI the specified instrument noise was used. For GOES, the actual values for GOES-12 were used.

3. SIMULATION RESULTS

Fig. 2 contains the profile %RMSE for GIFTS/HES, GOES, and ABI in this simulation. The results assume that the radiances are single field of view, which means the spatial resolution varies.

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Satellite	Bands used in ozone regression
GOES Sounder	4.45, 4.53, 4.58, 6.5, 7.0, 7.5, **9.7**, 11.0, 12.1, 12.7, 13.4, 13.7, 14.1, 14.4, 14.7 µm
ABI	3.9, 6.15, 7.0, 7.4, 8.5, **9.7**, 10.35, 11.2, 12.3, 13.3 µm
GIFTS/HES	8.3 µm to 15.3 µm (~685 cm^{-1} to ~1150 cm^{-1}) (hyperspectral)

Table 1: Bands used for ozone regression in this study. Bold indicates the "ozone band".

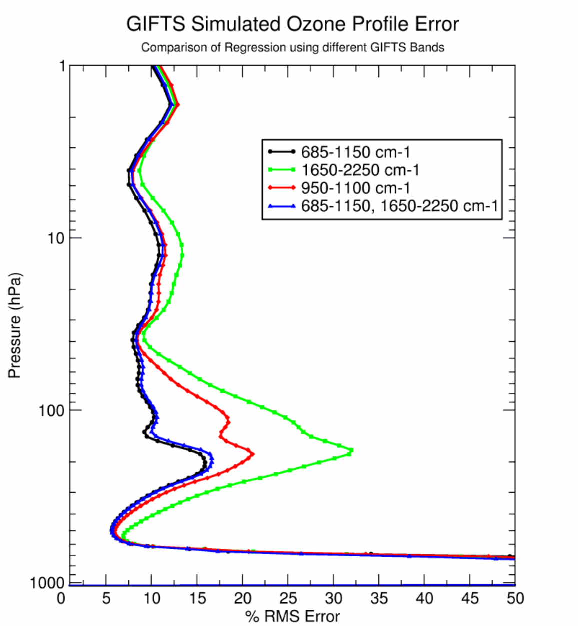

Figure 1: GIFTS/HES simulated ozone profile error for different combinations of hyperspectral radiances. Longwave radiances covering the ozone absorption band (~685 cm^{-1} to ~1150 cm^{-1}) produce the smallest error.

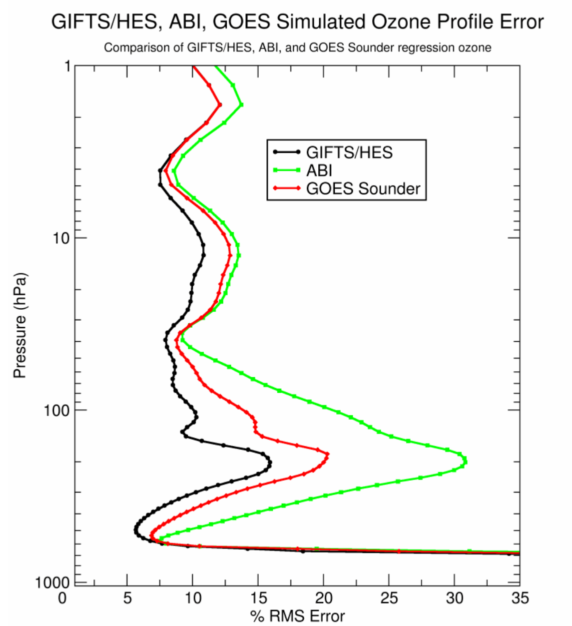

Figure 2: Intercomparison of percent root mean squared error profiles for GIFTS/HES, ABI, and GOES. All platforms show notable error maxima at the level of maximum ozone variability (~200 hPa) and below 700 hPa, where all IR ozone estimates lose accuracy (though ozone density is very small close to the surface, minimizing impact on total column values). All platforms simulated at single field of view, nadir view.

GOES is 8 km, ABI is 2 km, and GIFTS/HES is assumed to be 4 km. All profiles show similar trends with the highest spectral resolution coverage achieving the best results. GOES outperforms ABI as GOES has better spectral coverage. ABI will have a temporal advantage over the current GOES Sounder (5 minute vs 60 minute resolution) and will be used in conjunction with data from the HES (15 minute resolution) to produce higher temporal and spatial resolution ozone data than is currently available from the GOES Sounder. GIFTS and HES will achieve the best results of the current and planned IR platforms using their bands in the 8.3 µm to 15.3 µm region.

Table 2 compares the accuracy of the total column ozone values as calculated from simulation. Various noise multipliers were also simulated to estimate the impact of spatial averaging (for example, a multiplier of ½ implies a 2x2 field of view spatial average). The instrument noise was also zeroed out to estimate the error due to the regression itself. ABI and GOES are not notably impacted by spatial averaging, indicating that even at single field of view (SFOV) the regression is utilizing most of the available spectral information. GIFTS/HES, on the other hand, show marked improvement with spatial averaging. The no-noise case shows remarkable accuracy, thereby strengthening the case for ozone estimates made using hyperspectral IR measurements.

4. CONCLUSION AND FUTURE WORK

Hyperspectral sensors such as GIFTS and HES are superior to traditional IR broadband sensors such as GOES and ABI. ABI will have a temporal and spatial resolution advantage over GIFTS and HES, and a synergistic ozone estimation algorithm that utilizes the data from the HES and ABI would combine the advantages of both instruments (Li et al 2004a), potentially allowing close to HES accuracy

Multiplier	GIFTS/HES		ABI		GOES Sounder	
	RMSE (DU)	%RMSE	RMSE (DU)	%RMSE	RMSE (DU)	%RMSE
0	6.3 DU	1.8%	23.5 DU	6.8%	16.0 DU	4.9%
1/5 (5x5)	10.3 DU	2.9%	25.1 DU	7.2%	16.1 DU	4.9%
1/3 (3x3)	12.0 DU	3.5%	25.7 DU	7.4%	16.1 DU	5.0%
1 (1x1)	15.7 DU	4.6%	26.9 DU	7.7%	17.0 DU	5.2%

Table 2: Total column ozone error for GIFTS/HES, ABI, and GOES Sounder for different simulated noise levels. 3x3 field of view (FOV) reduces the instrument noise by 1/3, 5x5 FOV reduces the instrument noise by 1/5, and 0 simulates the error produced by the regression itself.

every 5 minutes at 2 km resolution, a level of detail that is currently unrivaled.

Ozone regression simulations do not account for sources of error outside of instrument error, such as uncertainty in parameters such as surface emissivity. Experience with the GOES Sounder has shown that a lack of treatment of surface emissivity is the largest source of error in IR total column ozone estimates. Future ozone algorithms should be able to treat the emissivity problem more directly than the algorithm simulated here as the spectral coverage of instruments like GIFTS and HES will allow for better characterization of surface emissivity than is currently available from GOES and polar orbiting platforms (Li et al 2004b).

5. REFERENCES

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