Hyperspectral Sounder Derived Severe Weather Indices

Elisabeth Weisz, William L. Smith Sr., Kathy Strabala, Allen Huang and Nadia Smith*

Cooperative Institute for Meteorological Satellite Studies (CIMSS),
University of Wisconsin-Madison, Madison, WI, USA

*Science & Technology Corp. (STC), Columbia, MD, USA

Abstract

Advanced sounding instruments onboard polar-orbiting satellites provide high spectral resolution infrared measurements that can be turned into accurate and high vertical resolution temperature and humidity profiles. This information can be then used to evaluate the atmospheric stability in the pre-convective storm environment as described here with a case study of the May 2016 severe weather outbreak that occurred across parts of the US.

1. Introduction

Severe weather prediction requires detailed information about the three-dimensional atmospheric state at high spatial and temporal resolution and can therefore benefit from accurate and reliable atmospheric soundings derived from direct-broadcast (DB) high-spectral resolution radiance measurements. These radiance measurements come from hyperspectral infrared sounders, such as AIRS (Atmospheric Infrared Sounder) on EOS-Aqua, IASI (Infrared Atmospheric Sounding Interferometer) on MetOp-A and MetOp-B, and CrIS (Cross-track Infrared Sounder) on Suomi NPP (S-NPP), which measure the radiance emitted by the Earth system with very high spectral resolution using several thousand channels. These measurements can then be inverted into high-vertical resolution temperature and moisture profiles, from which severe weather indices such as the Lifted Index (LI) can be computed. In the following two hyperspectral retrieval algorithms, the NOAA Unique Combined Atmospheric Processing System (NUCAPS) [1] and the UW hyperspectral Dual-Regression (DR) algorithm [2, 3], are applied to S-NPP CrIS radiance measurements to investigate the atmospheric stability associated with a local convective storm event. Both algorithms are available through the UW/CIMSS Community Satellite Processing Package (CSPP).

2. Retrieval Methods

DR and NUCAPS retrievals differ due to differences in algorithm design and methodology. For example, NUCAPS provides more refined retrievals near the surface and more data below most clouds due to the incorporation of microwave data, while the DR allows for more horizontal detail in the products because it operates at single field-of-view resolution. An overview of the algorithms and their main differences are given in Ref. 4.

DR results below have been derived from the CSPP DR algorithm as well from a research version that includes a de-aliasing (DA) step to correct for the vertical resolution alias error [5]. In general, the vertical structure of retrieved profiles, limited by the vertical resolving power of the radiance measurements, will be aliased towards the training-set mean. The vertical alias is the difference between a model profile (e.g., Global Data Assimilation System or GDAS, Rapid Refresh or RAP) and the simulated profile retrieval, which is derived from simulated radiances. These simulated radiances have been calculated from the model profile using the Principal Component-based Radiative Transfer Model (PCRTM, [6]). The vertical alias is then removed from the DR profile retrieval, which has been obtained from the real measured radiance spectrum.

3. Severe Weather Case Study

Multiple days of severe weather (hail, damaging winds, heavy rainfall and tornadoes) were observed across the Midwest and Southern Plains in the week of 9 May 2016. Severe weather indices such as LI and CAPE derived from hyperspectral sounder measurements are used to describe atmospheric stability and probability of convective storm development [7]. Here we investigate atmospheric instability, derived by NUCAPS and DR, associated with the severe weather outbreak on 11 May 2016, where severe thunderstorms and MCSs (mesoscale convective systems) moved across the region as seen in Fig. 1a, which shows the NOAA SPC storm report as well as GOES images for different regions (e.g., Nebraska and Iowa, across the St. Louis, MO region, and northern Texas). These severe convection storm events are also revealed by means of the CrIS brightness temperature (BT) at a window channel and the corresponding cloud top pressure (CTOP), retrieved from CrIS measurements using the DR technique, in Fig. 1b. Shown are the S-NPP morning overpasses (~ 08:00 UTC/03:00 CDT) and the afternoon overpasses (~19:30 UTC/14:30 CDT) in the top and bottom panel, respectively.

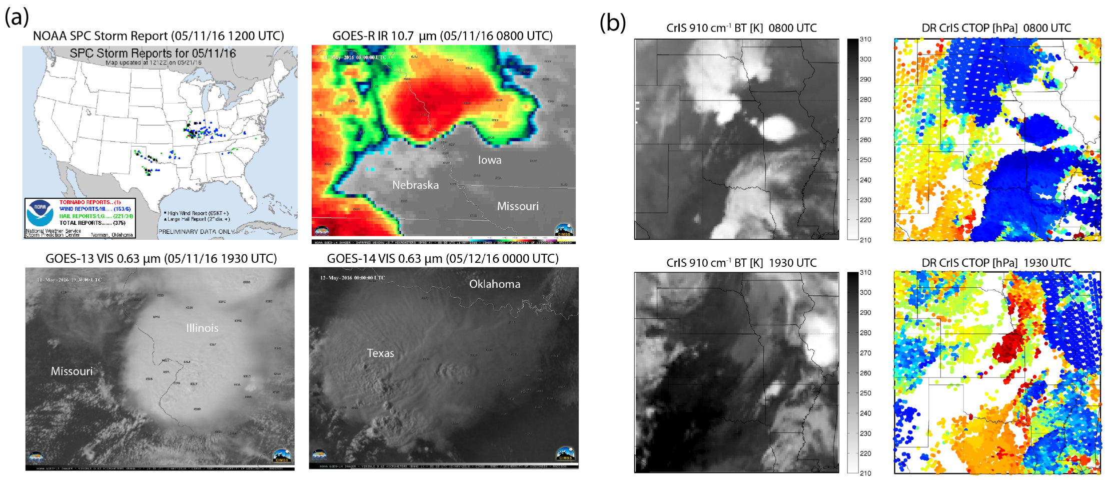

Figure 1. (a) NOAA Storm Prediction Center (SPC) storm report (from http://www.spc.noaa.gov/) and GOES infrared and visible images (from http://cimss.ssec.wisc.edu/goes/blog/) illustrating severe weather that occurred across the Midwest and Southern Plains on 11 May 2016 as part of a multi-day outbreak. (b) CrIS brightness temperatures (BT) at a window channel and DR retrieved cloud top pressures for the morning (top) and afternoon (bottom) S-NPP overpasses.

Figure 2 shows the lifted index (LI) as well as the 500-hPa dew point temperature. Negative LI and high dewpoint (high moisture) values indicate unstable conditions and severe thunderstorms are likely. As in Fig.1b, the results shown in the top panels and bottom panels are associated with the morning and afternoon overpasses on 11 May 2016, respectively. It can be seen that DR and NUCAPS retrievals offer different but complementary skills. NUCAPS provides more data under cloudy conditions (e.g., Fig. 2b), whereas DR has a lower retrieval yield below optically thick clouds but retains the instrument's spatial resolution to provide more detail in the products such as atmospheric stability (e.g., Fig. 2c). Overall, both methods are capable of identifying the regions of intense severe weather correctly.

Figure 3 shows retrieval, model and radiosonde observations temperature and dewpoint temperature profiles at four different weather stations (their locations are shown in Fig. 2d). Two panels are shown for each station; while the NUCAPS and the RAOB profile stay the same for the two panels the DR retrievals depend on the model used. The left panels show the GDAS model profile, and the GDAS profile is used within the DR and DR+DA retrieval run. The right panels show the RAP profile, which is also used by the DR and DR+DA method.

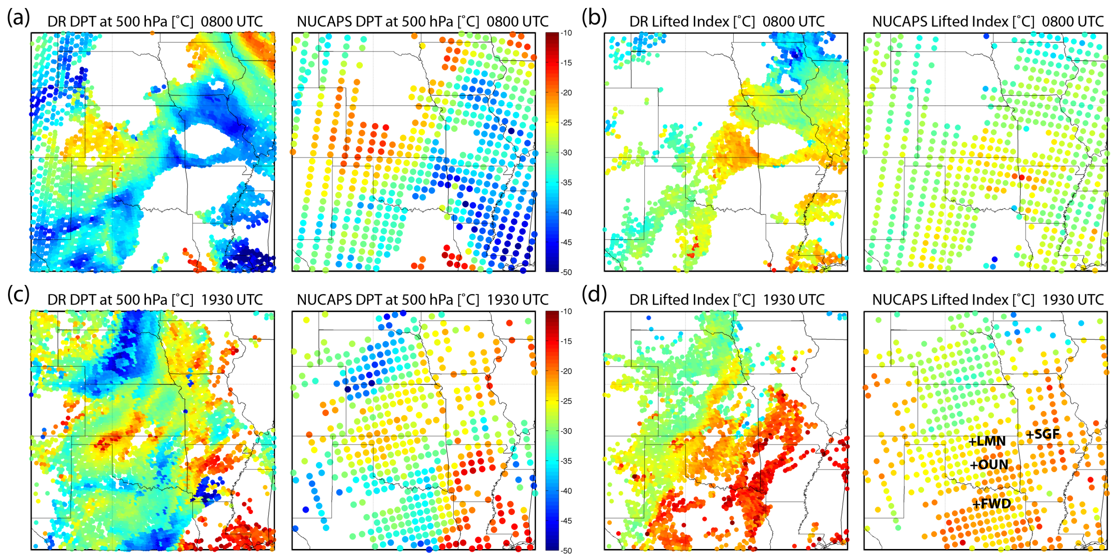

Figure 2. DR and NUCAPS retrievals of dewpoint temperature (DPT) at the 500-hPa pressure level (a) and of the lifted index (b) at approx. 08:00 UTC on 11 May 2016; DR and NUCAPS retrievals of dew point temperature (DPT) at the 500-hPa pressure level (c) and of the lifted index (d) at approx. 19:30 UTC on 11 May 2016.

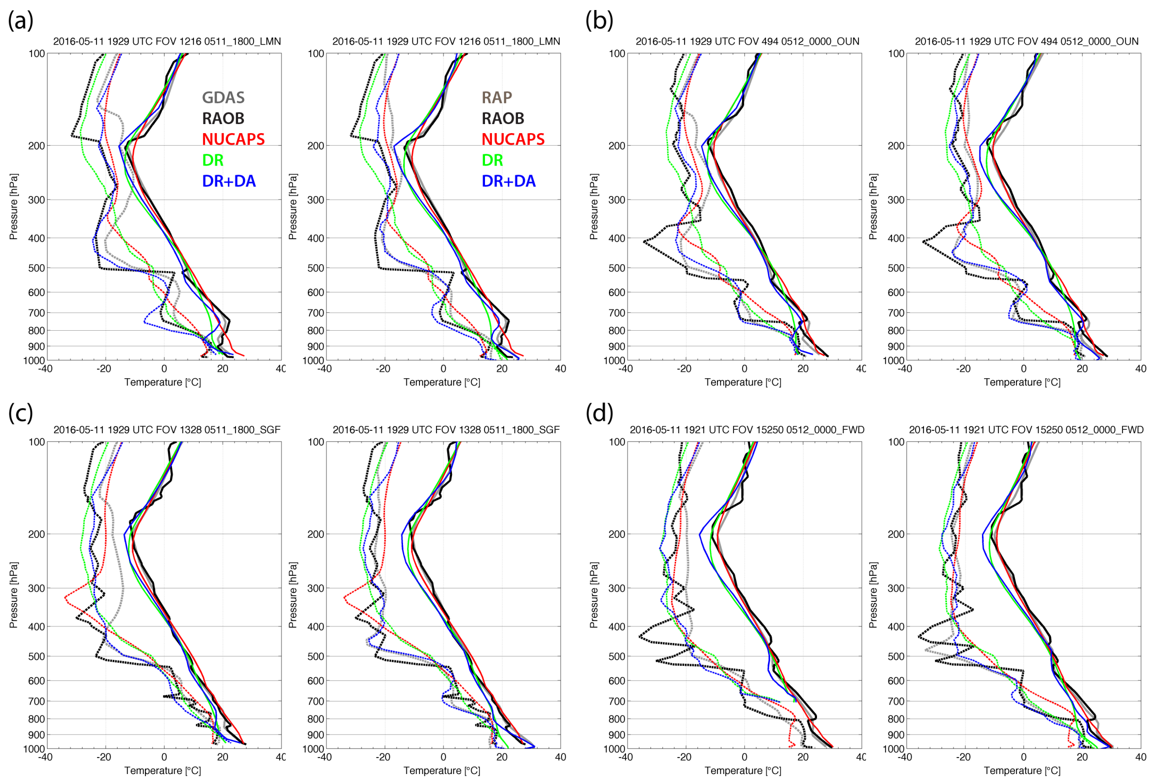

Figure 3. Co-located dewpoint (dashed) and temperature (solid) profiles for DR (green), DR+DA (blue) and NUCAPS (red) retrievals in comparison with either GDAS or RAP model profiles (gray) and radiosonde observations (black) at different weather stations: (a) Lamont, OK (LMN) on 05/11/16 at 18:00 UTC ; (b) Norman, OK (OUN) on 05/12/16 at 0000 UTC; (c) Springfield, MO (SGF) on 05/1/16 at 18:00 UTC; (d) Forth Worth, TX (FWD) on 05/12/16 at 00:00 UTC. See Fig. 2d (right) for locations of the stations.

The DR-only approach uses information from GDAS (or the higher resolution RAP) only to assist clear/cloudy differentiation and therefore the differences between the DR profiles on the left and right are very small. On the other hand, since the DR+DA algorithm uses the model profile to obtain simulated radiances and then simulated model retrievals the impact on the final results is more severe. Also, since RAP profiles provide more structure and vertical detail than GDAS profiles the associated DR+DA retrievals shown in the right panels of Fig. 3 for each station yield better results (than the profiles shown on the left). In other words, the de-aliased profiles, especially when using a local model instead of a global one, show fine-scale vertical temperature and water vapor features similar to the vertical structure of radiosonde observations. It should be noted, that the cold bias apparent for the DR (and DR+DA) retrievals can be eliminated with a radiometric bias correction (similar to what NUCAPS has already implemented); the reader is referred to Ref. 8 for bias-corrected DR+DA retrievals within a quasi-operational forecasting setting.

Table. 1. Lifted Index, computed from DR, DR+DA, NUCAPS and RAOB temperature profiles for different weather stations (as shown in Fig. 3)

Station	Lifted Index [°C]						
	GDAS **DR** RAP		GDAS **DR+DA** RAP		**NUCAPS**	1800 **RAOB** 0000	
LMN	-4.3	-5.7	-6.7	-10.8	-0.6	-1.7	-4.3
OUN	-1.4	-1.6	-5.5	-8.2	-4.1	--	-9.6
SGF	-7.2	-8.5	-12.6	-12.9	-3.4	-7.0	-8.6
FWD	--	--	--	-9.6	-2.8	--	-10.9

The LI values computed from the profiles shown in Fig. 3 are listed in Table 1. DR compares well to the RAOB except at Norman, OK (OUN) where DR+DA and NUCAPS provide better results. When taking temporal and spatial distances between the measurements into account and focusing on the overall ability to detect atmospheric instability instead on the absolute values of stability parameters these hyperspectral retrieval results render useful information towards critical improvements of monitoring, assimilation and forecasting capabilities.

4. Summary

Utilizing data from advanced sounding instruments, like CrIS on S-NPP, allows quantitative real-time monitoring of extreme weather events. The dual-regression (DR) and the NOAA Unique Combined Atmospheric Processing System (NUCAPS) offer different retrieval skills and when integrated together these methods could provide a more complete picture of the atmospheric state. While NUCAPS provides a higher retrieval yield below most clouds due to the incorporation of microwave data, the DR allows for more horizontal detail in the products due to its higher spatial resolution. Furthermore, profile retrievals derived from the DR+DA method, i.e., the DR approach is enhanced by a de-aliasing (DA) step, exhibits fine-scale vertical structure, which will benefit profile assimilation in numerical weather prediction (NWP) models. In summary, hyperspectral retrieval products prove valuable in the assessment of atmospheric conditions favorable to severe weather, and they have the potential to benefit weather monitoring and forecasting operations by complementing data from conventional surface and upper air data networks, satellite imagery and NWP models.

ACKNOWLEDGEMENTS

We gratefully acknowledge the funding received from the NOAA JPSS (Joint Polar Satellite System) PGRR (Proving Ground Risk Reduction) Program.

REFERENCES

[1] Gambacorta, A., et al. (2013), The NOAA Unique CrIS/ATMS Processing System (NUCAPS): Algorithm Theoretical Basis Documentation, Version 1.0, NOAA Center for Weather and Climate Prediction (NCWCP), 5830 University Research Court 2nd Floor, Office 2684 College Park, MD 20740-3818, USA.

[2] Smith, W. L., E. Weisz, S. Kirev, D. K. Zhou, Z. Li, and E. E. Borbas (2012), Dual-Regression Retrieval Algorithm for Real-Time Processing of Satellite Ultraspectral Radiances, *J. Appl. Meteor. Clim.,* vol. 51, no. 8, pp.1455-1476, doi: http://dx.doi.org/10.1175/JAMC-D-11-0173.1.

[3] Weisz, E., W. L. Smith Sr., and N. Smith (2013), Advances in simultaneous atmospheric profile and cloud parameter regression based retrieval from high-spectral resolution radiance measurements, *J. Geophys. Res. Atmos.*, vol. 118, pp. 6433-6443, doi: 10.1002/jgrd.50521.

[4] Weisz, E., W. L. Smith, and N. Smith, Assessing Hyperspectral Retrieval Algorithms and their Products for Use in Direct Broadcast Applications, 20th International TOVS Study Conference (ITSC-20) proceedings, 28 October - 3 November 2015, Lake Geneva, Wisconsin, USA; paper 3.03 available at https://cimss.ssec.wisc.edu/itwg/itsc/itsc20/papers/.

[5] Smith, W. L., and E. Weisz (2017), Dual-regression approach for high spatial resolution infrared soundings, Elsevier MRW Comprehensive Remote Sensing.

[6] Liu, X., W. L. Smith, D. K. Zhou, and A. M. Larar (2006), Principal Component-based Radiative Transfer Forward Model (PCRTM) For Hyperspectral Sensors, Part I: Theoretical Concept, *Applied Optics*, 201-209, 45.

[7] Weisz, E., W. L. Smith, R. Schultz, K. Strabala, A. Huang, and N. Smith, Leveraging Direct-Broadcast Hyperspectral Sounder Retrieval Data for Regional Weather Monitoring Applications (poster), Poster presented at the 2016 AGU Fall Meeting, 12-16 December 2016, San Francisco, California, USA.

[8] Smith, W. L, E. Weisz, J. McNabb, and M. Dutter, Hampton University Direct Broadcast Satellite Sounding Products, Poster presented at the 2017 NOAA Satellite Conference, City College New York, NY 17-20 July 2017.