NOAA ROSES Semi-Annual Report

Reporting Period: September 2021 – February 2022 (3rd report)

PI: Elisabeth Weisz
Co-PI: Paul Menzel

Project Title: Realizing LEO Sounder Products at GEO Imager Spatial and Temporal Resolution

Executive Summary

The knowledge gained from this LEO-GEO fusion work should suggest improved approaches for weather watch and warning operations through an improved fusion of LEO and GEO assets. One focus is to study nowcasting enhancement with ABI/CrIS spatial/temporal fusion. Algorithm adjustment (e.g., spectral bands used in k-d tree search, number of neighbors/matches used in the sounder product averaging, refinement of the cloud mask, investigation of useful extent of temporal fusion) is a significant part of this activity. Initially LEO sounder products will be fused into GEO imager space and time resolutions. Subsequently spatial/temporal fusion enhanced depiction of low-level moisture using on-line off-line rotational water vapor differences in the LEO sounder infrared windows will be attempted. A second focus is to enhance TROPOMI detection of trace gases from natural and anthropogenic sources using VIIRS, ABI, and AHI as imager companions in a spatial (and spatial/temporal with GEO) fusion. Case studies of trace gas intrusions from volcanoes, fires, and industrial activities are planned.

Progress toward FY21 Milestones and Relevant Findings

1. Convective Case Study (5 May 2021)

Convective destabilization and subsequent tornadic activity in the US Midwest were investigated with a combination of LEO sounder and GEO imager data in a fusion process. Specifically, GOES-16 ABI infrared radiances with 2-km spatial resolution are fused with SNPP and NOAA-20 (or JPSS-1) CrIS single field-of-view (~14 km) humidity retrievals from one LEO overpass and then transferred to 10-minute temporal resolution to realistically capture the vertical detail from the hyperspectral sounder humidity profiles at subsequent (or earlier) ABI measurement times. Several tornadoes were reported on 5 May 2021 in Nebraska including tornadoes that hit Meadow Grove (NE) at 2110 UTC and Clay Center (NE) at 2130 UTC (https://www.spc.noaa.gov/climo/reports/210505_rpts.html). To validate the spatial and temporal fusion process we investigated the changes of relative humidity (RH) between two consecutive ABI timesteps from ABI/CrIS-SNPP fusion forward in time (starting at 1900 UTC) and compare them with those from ABI/CrIS-NOAA20 backward in time (starting at 1950 UTC) over the fifty minutes between their overpasses (Fig. 1). Some changes evident in SNPP going forward are also found in NOAA-20 going backward and vice versa, indicating that space-time fusion agrees for the two ABI/CrIS fusion streams. Figure 2 shows the humidity information available from ABI/CrIS-NOAA-20 fusion at 500 and 800 hPa in comparison with 2-hr forecast RAP (Rapid Refresh) fields at 13-km spatial resolution at 2000, 2100 and 2200 UTC. The scale of the moisture features resolved by the RAP model at 850 and 500 hPa is too coarse to resolve the convective development at Meadow Grove or Clay Center. The area of upper-level moistening and lower- level drying is broadly suggested but not resolved. In addition, the RAP availability at only hourly intervals limits the ability to detect more rapid changes.

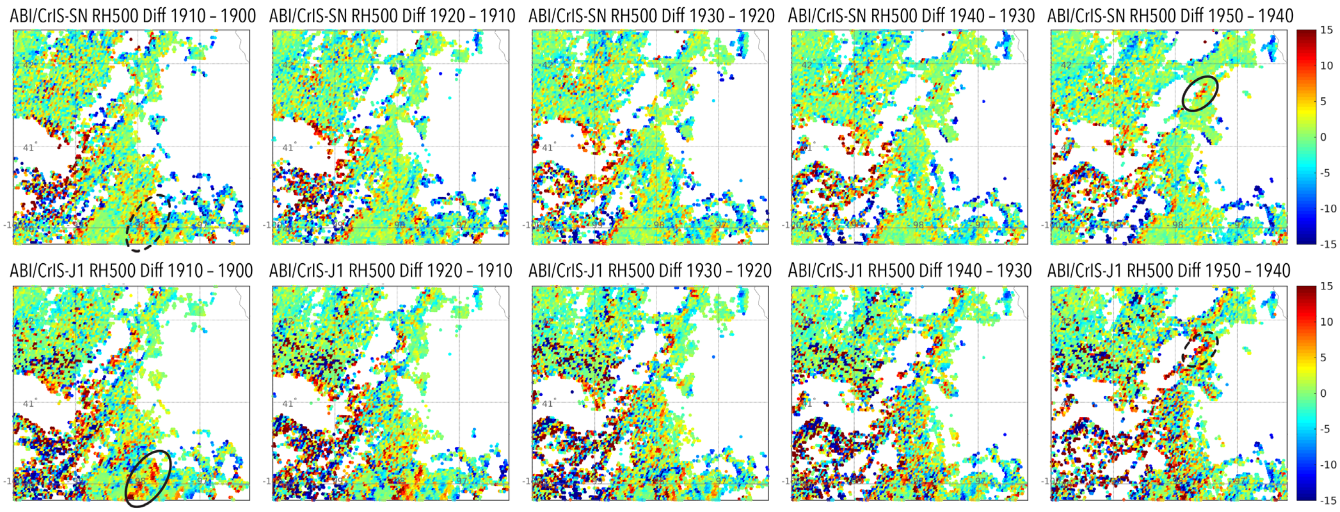

Figure 1. 10-minute time differences in ABI/CrIS-SNPP (top row) and ABI/CrIS-NOAA20 (bottom row) relative humidity fusion results in [%] from 1900 to 1950 UTC over Nebraska. The SNPP fusion process starts at 1900 UTC (and goes forward in time), whereas the NOAA-20 fusion process starts at 1950 UTC (and goes backward in time) on 5 May 2021. Examples of moisture changes that correctly reshape into the other instrument's results are marked by ovals (dashed and solid lines refer to initial and created features, respectively).

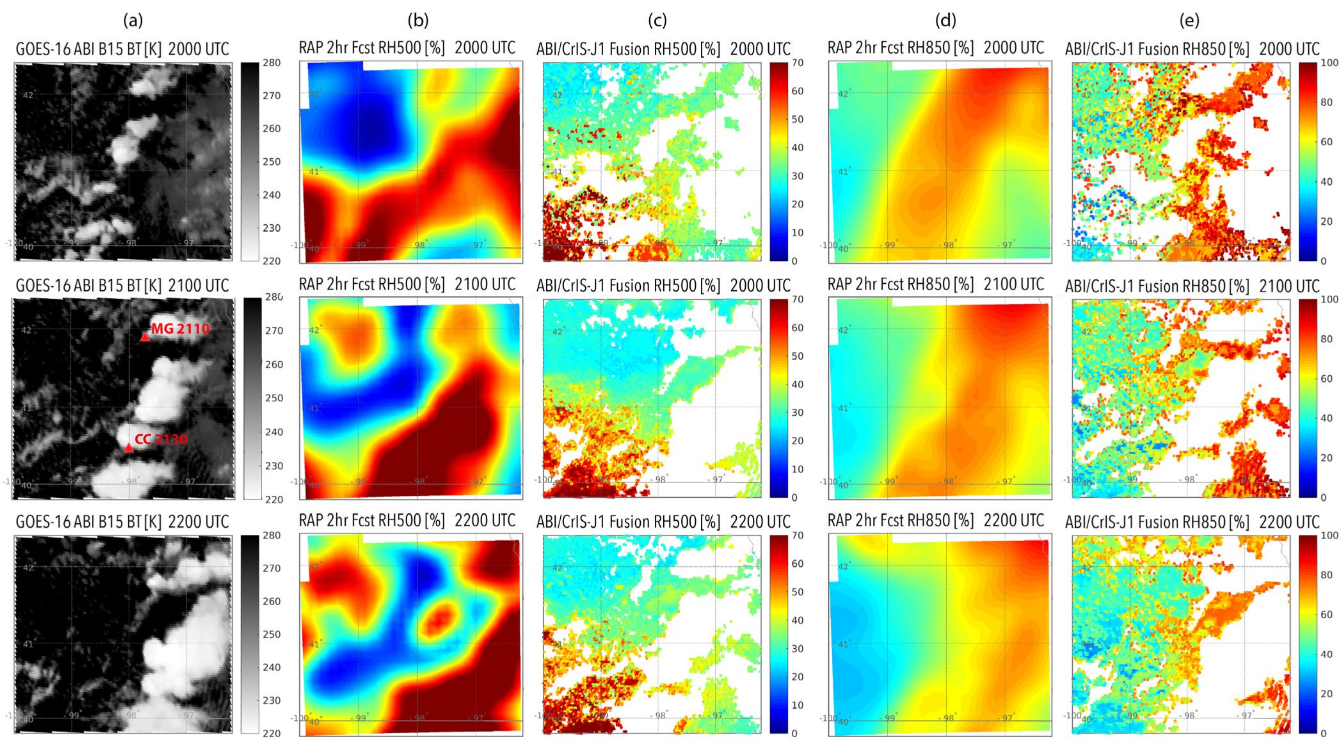

Figure 2. ABI Band 15 (12.3 μm) brightness temperatures (a), RAP RH at 500 hPa (b), ABI/CrIS fusion RH at 500 hPa (c), RAP RH at 850 hPa (d), and ABI/CrIS fusion RH at 850 hPa (e); for 2000 UTC (top row), 2100 UTC (middle row) and 2200 UTC (bottom row) on 5 May 2021. Locations of Meadow Grove (NE), denoted by MG 2110, and Clay Center (NE), denoted by CC 2130, are shown in middle panel of column (a).

To further illustrate the type of atmospheric detail fusion can provide, ABI/CrIS fusion results at the 500 and 850 hPa pressure levels are shown superimposed on the ABI B15 (12.3 μm) cloud background every hour from 20 UTC to 22 UTC in Fig. 3. Signs of convective instability (i.e., dry mid-level air over warm and moist low-level air) are already evident at 20 UTC, especially within and east of the line of convective clouds (i.e., eastern half of the plots); these instabilities intensify quickly indicating an increasing possibility of severe thunderstorms and tornadoes. A convective boundary layer, possibly capped by a temperature inversion, is also apparent from the lower panels, where cold dry air moves in from the west towards Clay Center, whereas the moisture content at the higher-level stays relatively large (one example is marked by an oval in the 2100 UTC panel).

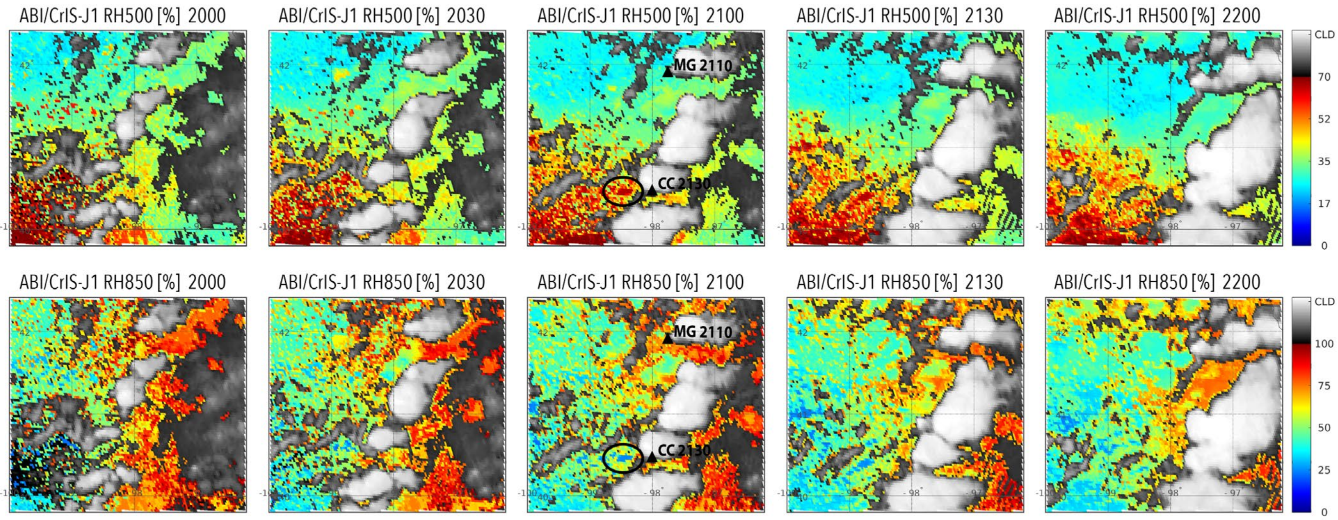

Figure 3. ABI/CRIS(NOAA-20) fusion results for relative humidity (RH) in [%] at the 500 hPa (top row) and 850 hPa (bottom row) pressure levels from 2000 UTC to 2200 UTC on 5 May 2021 in Nebraska. The NOAA-20 (or JPSS-1) overpass occurred at approx. 1950 UTC. ABI Band 15 (12.3 μm) brightness temperatures are shown in the background. Tornado touchdown locations (MG and CC) as well as an example of a low-level dry air pocket are highlighted, respectively, as black triangles and ovals in the 2100 UTC panels.

Next, we applied the ABI/CrIS fusion approach to all tropospheric levels; the resulting fusion humidity profiles for one specific location (about 45 km west of Clay Center), shown in Fig. 4, also corroborate the existence of low-level cold dry air advection over a moistening boundary layer, which is most pronounced at 2100 UTC – just 30 minutes before the tornado touched down in Clay Center. Also shown in Fig. 4 are the RAP hourly profiles, which, however, show only slight changes from one hour to the next, whereas the ABI/CrIS fusion profiles successfully capture the changes in the vertical distribution of moisture from one ABI measurement time to the next.

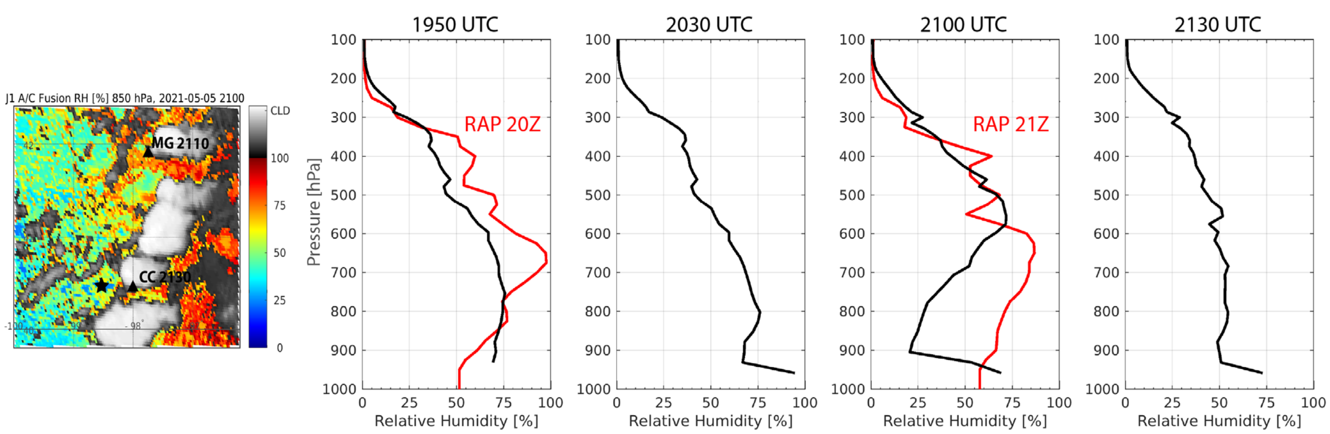

Figure 4. ABI/CrIS-NOAA20 RH fusion profiles at 1950 (NOAA-20 overpass time), 2030, 2100 and 2130 UTC at one selected location (40.48º N and 98.74º W, approx. 45 km west of Clay Center, is marked by a black star symbol in the left plot) are shown in black. The 2000 and 2100 UTC RAP RH profiles are shown in red.

This case study, which has been presented in detail at the 2022 Annual AMS Meeting (Talk 14B.2), shows that fusion of the CrIS high vertical resolution profiles with the high frequency of ABI radiance measurements allows for a fast detection of the rapid atmospheric changes that can cause tornadoes. These results would not have been possible with either the ABI data (which lacks the vertical resolution) or the CrIS data (which lacks the temporal and horizontal resolution) alone.

It is also important to note that the minima and maxima created in the fusion process are those available within the granule from the initial CrIS overpass data. If more extremal values in temperature or moisture occur at the previous or subsequent times of the LEO overpass, fusion cannot create them. In clear skies this limits the depiction of extreme drying or moistening, and in cloudy skies (not shown) the cloud top pressure of the deep overshooting domes is placed too low in the atmosphere. In addition, the ABI k-d tree search for 2 km gradients in an area of interest involves averaging of the 13.5 km field-of-view (FOV) measurements (or derived parameters) made by CrIS. We investigated adjustments to the cloud mask that increase the clear sky coverage as well as decreasing the number of similar CrIS FOVs used in the averaging process can increase the small-scale gradients but also the scatter. We also turned off the cloud mask and processed all FOVs in the k-d tree search; this resulted in unrealistic warm temperatures in the clouds and diminished the narrative of string updrafts within and near the clouds.

2. Methane (CH_4) Release in the Frozen Tundra

Methane changes occurring over Victoria Island in northern Canada during the transition from winter to summer and back again to winter are being studied using TROPOMI level 2 CH_4 determinations in clear skies. Changes as the snow cover evaporates and the frozen waters melt have been collected using VIIRS/TROPOMI fusion. Figure 5 shows the observations over the sun-light portion of a full year (1 April, 21 July, 21 August 2021, and 31 March 2022).

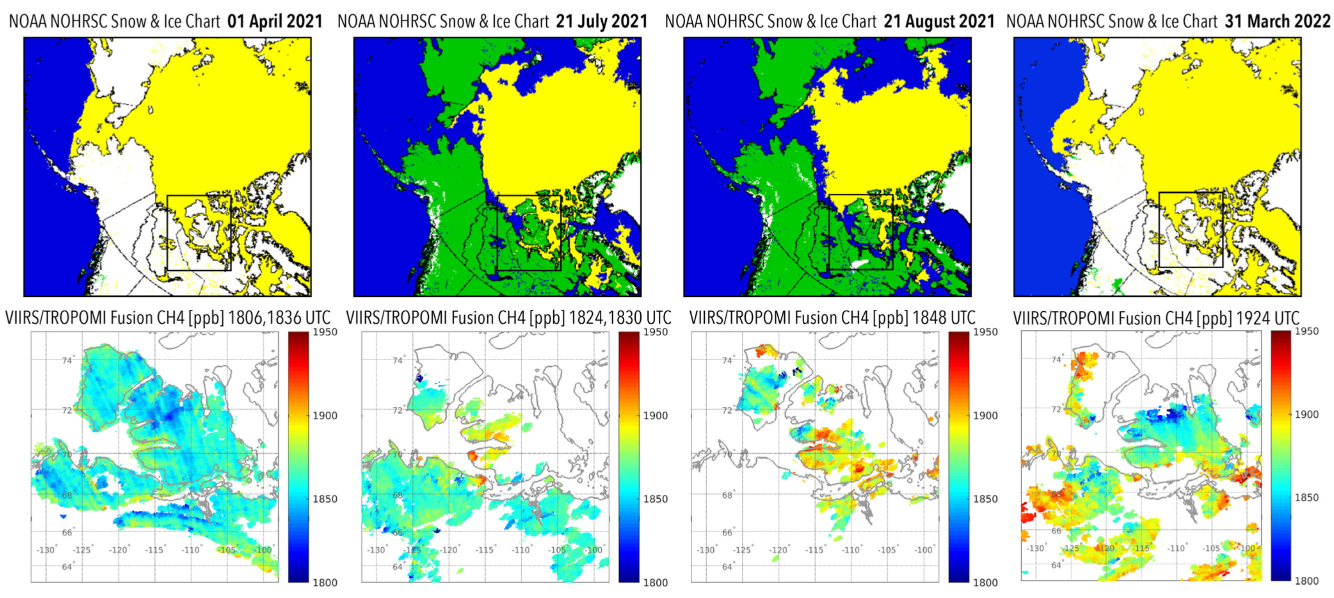

Figure 5. Top: NOAA NOHRSC snow & ice charts (adapted from https://www.nohrsc.noaa.gov/nh_snowcover/), where yellow and white refer to ice and snow, respectively, for 1 April 2021, 21 Jul 2021, 21 Aug 2021 and 31 March 2022. The area of interest - Victoria Island and surrounding regions - is marked by black frames. Bottom: SNPP-VIIRS/TROPOMI fusion methane results for the same days as the NOHRSC maps. The times in the subtitle of the bottom row figures refer to the VIIRS granule measurement start times.

As the snow and ice melts there is a hint of a more pronounced presence of methane in the surrounding area; perhaps in the southern shoreline after the thaw. The return of sunlight in late March 2022 shows more methane detection after the equinox than the previous year, but the difficulty in obtaining clear sky measurements renders any conclusion from this limited data set to be premature. A longer record that is beyond the scope of our efforts is required.

3. Conference Attendance

- Paul Menzel and E. Weisz, "Investigating a Tornado Outbreak by Creating LEO Sounder Products at GEO Imager Spatial and Temporal Resolution", poster presentation at the Asia Oceania Meteorological Satellite Users Conference (virtual), 1 – 3 November 2021, Beijing, China.
- Weisz, E., W. P. Menzel and E. Borbas, "Creating LEO Sounder Products at GEO Imager Spatial and Temporal Resolution – Atmospheric Moisture Changes in the Pre-convective Environment of a Tornado", talk 14B.2 in session: Special Session on the GOES Series Satellite System, Part II. 102nd AMS Annual Meeting (virtual), 23-27 January 2022.

Both presentations summarized the GEO/LEO fusion approach and highlighted results from a case study of ABI/CrIS mapping moisture gradients forward and backward in time on 5 May 2021 during a frontal passage in the Midwest.

Plans for Next Reporting Period

(1) Continue to apply GEO/LEO fusion to severe weather events; we plan to add another day of convective storm and tornadic activity to the current 5 May 2021 case before summarizing our findings in a peer-reviewed paper.

(2) Investigate the emission and dispersion of volcanic sulfur dioxide (SO_2) and ash from the Cumbre Vieja volcano (Canary Islands, Spain) eruptions in October 2021. This will be accomplished with TROPOMI, ABI, and CrIS measurements. As part of a publication the SO_2 and ash fusion products will be evaluated by comparison to operational GOES-16 ABI products, and differences of plume growth and extension along with implications for improved aircraft safety will be discussed.