Fusing LEO Hyperspectral Sounder Products at GEO Imager Spatial and Temporal Resolution

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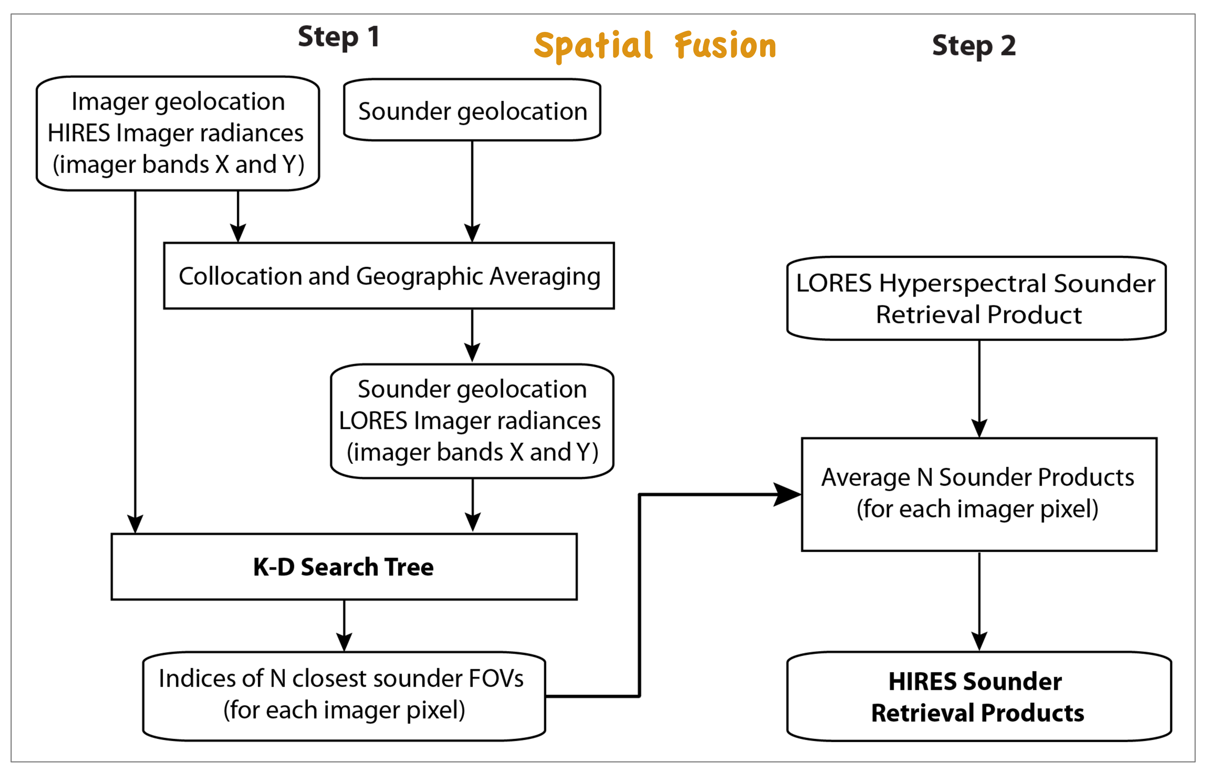
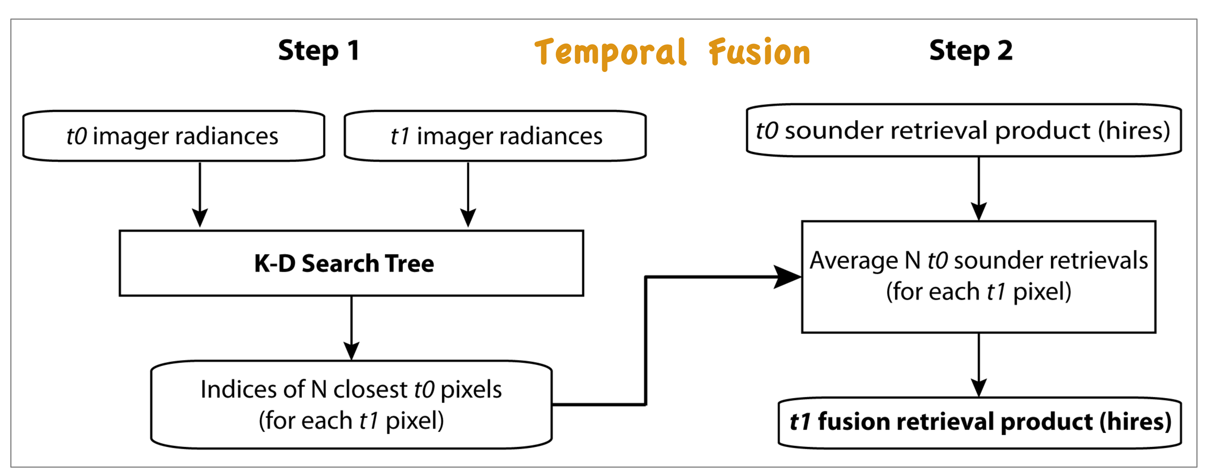
Introduction

Hyperspectral sounder measurements (e.g., from CrIS) on polar-orbiting satellites (Suomi NPP and NOAA-20) are sampled at relatively coarse spatial resolution (~14 km) but can be combined with imager (i.e., ABI) infrared (IR) band measurements to construct designated sounder products at imager spatial resolution (2 km). The imager and sounder (or imager/sounder) *radiance fusion*[1] starts with a nearest neighbor search (using the k-d tree search algorithm) on selected bands of imager radiances, given at original high and low spatial (i.e., sounder) resolution. The output are the indices for each imager pixel of the low spatial resolution FOVs (imager radiances averaged over the sounder FOV) that have radiance similarity and geographical proximity. Then the hyperspectral sounder radiances, convolved to the imager band to be constructed, associated with those indices are averaged to obtain new fusion radiances at high spatial resolution. In *product fusion*[2], sounder retrieval products (instead of convolved radiance data) are averaged. Promising results are found for all imager/sounder pairs, including LEO/LEO and GEO/LEO instrument pairings. In the latter, spatial radiance or product fusion can be extended to different times using *temporal fusion*[2,3] steps as presented here.





GEO/LEO Spatial and Temporal Product Fusion

For the GEO/LEO fusion, a k-d tree search is performed between ABI (Advanced Baseline Imager) radiances and latitude/longitude data low (LORES) and high (HIRES) spatial resolution at the time of the CrIS overpass. Currently eight ABI IR bands are used in the search (these are ABI bands 8 through 11, and 13 through 16, corresponding to 6.2, 7.0, 7.3, 8.5, 10.3, 11.2, 12.3, and 13.3 µm, respectively). Using an increased number of bands – not just window bands – in the k-d tree search improves the result, in particular mid-level moisture due to information gained from ABI's H_2O absorption bands[2]. The upper schematic on the left illustrates how the spatial fusion method transfers sounder products to the imager's high spatial resolution.

Working with a time sequence of GEO imager (ABI) measurements, the 'LORES to HIRES' spatial fusion with the GEO data at the LEO overpass time is denoted hereafter as *t0*. Then a temporal fusion approach is used to transfer the product fusion results at full imager spatial resolution from time *t0* to previous or subsequent times as illustrated in the lower schematic on the left. Thus, the temporal fusion k-d tree search is performed between ABI radiances at *t0* and *t1* to select the best matches for a *t1* pixel; the spatial fusion products from t0 are then averaged for the selected pixels to create spatial temporal fusion sounder products at *t1*. In the next time step radiances at *t1* are matched with those at *t2*, and so on.

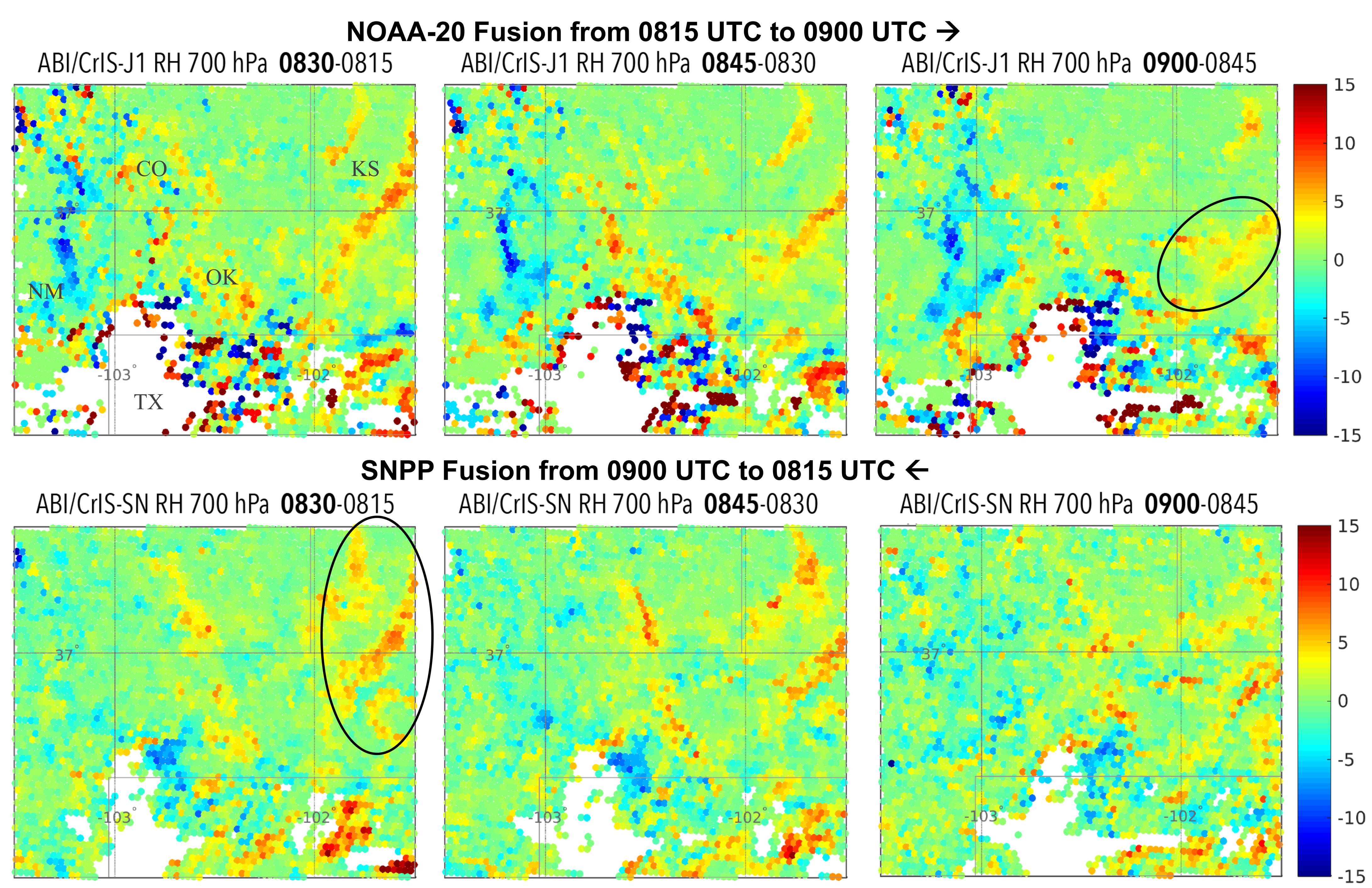


Figure 2. Same case as in Fig. 1, but here showing the change in RH [%] between the current time step (bold in the sub-panel titles) and the previous time step. Some of the NOAA-20 (top) moisture changes reshape correctly into the SNPP results (bottom) and vice versa; examples are marked by ovals in the upper right and lower left panels.

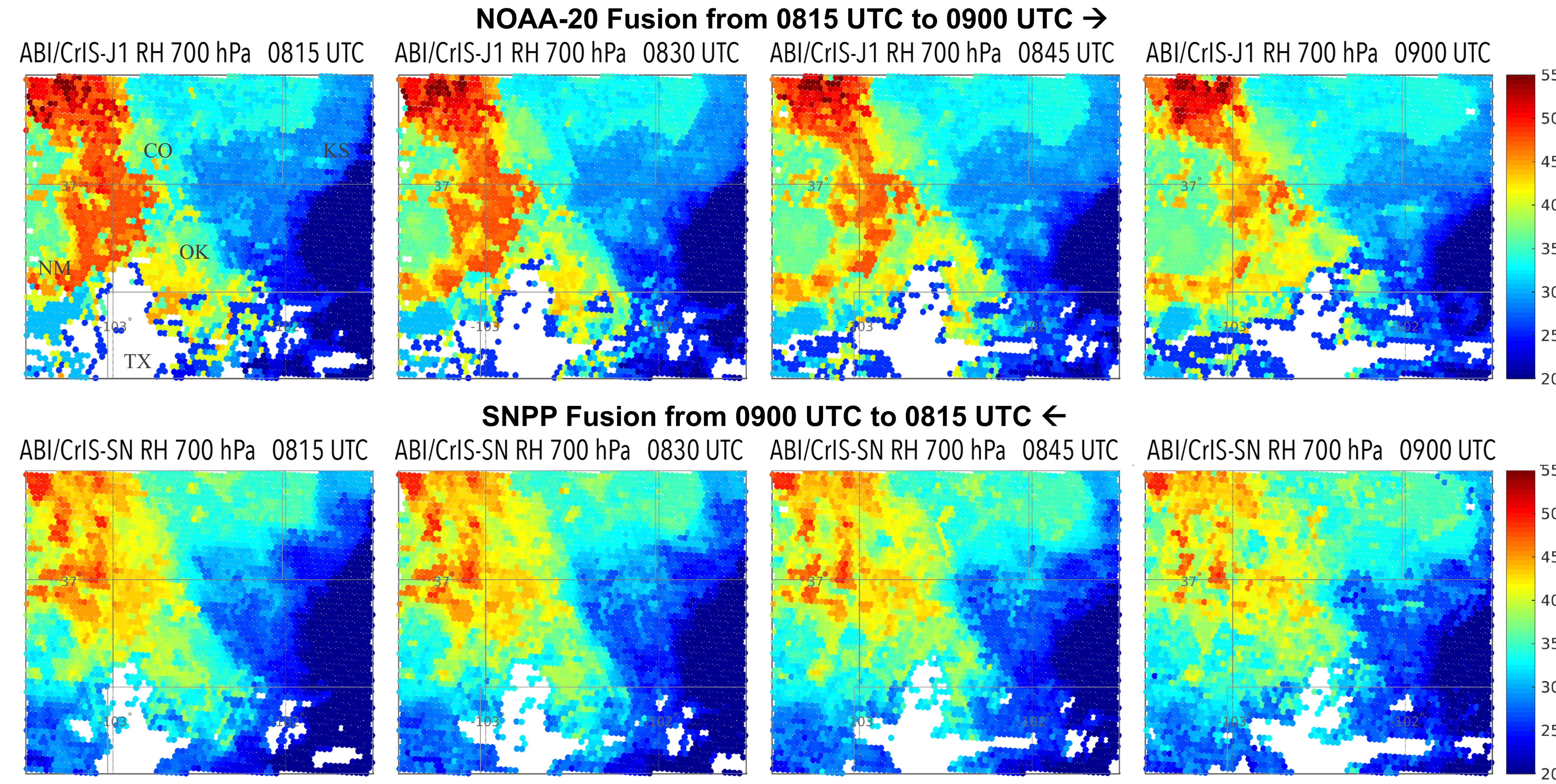


Figure 1. ABI/CrIS fusion results for DR RH [%] at 700 hPa using NOAA-20 (top) and SNPP (bottom) data together with ABI measurements in 15-min intervals. Note, the NOAA-20 fusion process starts at 815 UTC (and goes forward in time), whereas the SNPP fusion process starts at 900 UTC (and goes backward in time) on 28 Apr 2018.

Comparing Spatial/Temporal Fusion Forward vs Backward in Time

Application of the fusion process connecting LEO sounder products to time sequences of GEO imager radiances creates a GEO sounder-like perspective of atmospheric changes in time (through spatial/temporal fusion). We investigate moving forward in time as well as backward in time with spatial-temporal fusion of CrIS moisture soundings with GOES-16 ABI infrared radiances using the 50-minute time difference of CrIS overpasses on SNPP and NOAA-20. Figure 1 shows a comparison of 15-minute progressions of ABI/CrIS(NOAA-20) moving from 815 UTC (closest to the NOAA-20 overpass time) to 900 UTC (top panel of Fig. 1) and ABI/CrIS(SNPP) moving from 900 UTC (closest to the SNPP overpass time) to 815 UTC (bottom panel of Fig. 1) for Dual-Regression[4] retrieval determinations of relative humidity (RH) at 700 hPa over the western portion of the Oklahoma panhandle and surrounding US states. Of note is the transition zone from 40% to 30% RH; the spatial temporal fusion forward sequence from 815 UTC ABI/CrIS(NOAA-20) reshapes into the 900 UTC ABI/CrIS(SNPP) spatial fusion while in reverse the spatial temporal fusion sequence from 900 UTC ABI/CrIS(SNPP) reshapes into the 815 UTC ABI/CrIS(NOAA-20) spatial fusion. While the very moist values of CrIS(NOAA-20) are missing from the CrIS(SNPP) sounding, the gradient regions change in the representative fashion going forward as well as backward in time. Although values beyond the initial range cannot be created, gradients within the range of values still reshape in a realistic way. Figure 2 shows the actual RH changes that occurred between the 15-minute intervals. Several features seemed to have evolved correctly over time. For example, the oval in the lower left panel (i.e., SNPP fusion at 830 UTC) contains RH changes, which are similar to NOAA-20 shown in the upper left panel of Fig. 2, but these SNPP RH features did not yet show up at the SNPP fusion start time (at 900 UTC). This means that these RH properties were correctly created through the temporal fusion process. This demonstrates promising potential of the spatial-temporal fusion approach for a variety of applications. How far in time GEO/LEO fusion can reliably be continued depends on the synoptic situation, but good results have been demonstrated in several case studies for over two hours.

Summary

- The fusion method incorporates a k-d (multi-dimensional) tree search which finds all neighboring points from a training data set to a query data set. Here, training and query are represented by low and high spatial resolution imager radiances (in spatial fusion) and by imager radiances at the previous and current time step (in temporal fusion).
- Averaging the selected neighboring FOV hyperspectral sounder parameters (either radiances or Dual-Regression retrievals), new radiances or retrievals can be created. After applying spatial fusion these products are now at higher (imager) spatial resolution, providing more spatial detail in temperature, moisture and cloud features.
- Preliminary GEO/LEO spatial and temporal product fusion results are promising. Here the k-d tree search is applied to ABI radiances every 15 minutes, while connecting to the same CrIS retrieval product; the high spectral (which translates to high vertical) resolution retrieval products are then provided at high spatial as well as high temporal resolution.
- Spatial/temporal product fusion results forward in time from SNPP CrIS overpass do not entirely match spatial/temporal fusion results when going backward in time from NOAA20 CrIS overpass; however, gradient changes in time forward compare very well with those in time backward (and vice versa) in this case study. More case studies are planned. This work is supported through the NOAA ROSES Program.

[1] Weisz, E., B. Baum, and W. P. Menzel , 2017: Fusion of satellite-based imager and sounder data to construct supplementary high spatial resolution narrowband IR radiances, *J. of Appl. Remote Sens*, 11(3), 036022, doi: 10.1117/1.JRS.11.036022.

[2] Weisz, E., and W. P. Menzel, 2019: Imager and sounder data fusion to generate sounder retrieval products at an improved spatial and temporal resolution, *J. Appl. Remote Sens*. 13(3), 034506, doi: 10.1117/1.JRS.13.034506.

[3] Weisz, E., and W. P. Menzel, 2020: Approach to enhance trace gas determinations through multi-satellite data fusion, *J. Appl. Remote Sens*. 14(4), 044519, doi: 10.1117/1.JRS.14.044519.

[4] Dual-Regression is the underlying algorithm of the UW hyperspectral retrieval (HSRTV) software package, which is available through CSPP at http://cimss.ssec.wisc.edu/cspp.