Interactive comment on "Improvement in cloud retrievals from VIIRS through the use of infrared absorption channels constructed from VIIRS-CrIS data fusion" by Yue Li et al.

Anonymous Referee #2
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General comments: Retrieval of cloud-top properties with the Visible Infrared Imaging Radiometer Suite (VIIRS) could be more challenging than its predecessor MODIS, because of the lack of water vapor and CO2 bands in thermal infrared region. This paper "Improvement in cloud retrievals from VIIRS through the use of infrared absorption channels constructed from VIIRS-CrIS data fusion" by Li et al. demonstrated that by leveraging fusion water vapor and CO2 bands from high-spectral resolution instrument CrIS, VIIRS cloud retrievals, including cloud mask, cloud thermodynamic phase, and cloud-top height are generally improved. This paper also shows that those fusion bands have a big boost in the accuracies of cloud mask/phase algorithm at high latitude. By including the extra fusion bands, cloud-top height retrieval is also improved with lower biases and uncertainties, in particular for those optically thin cirrus clouds with emissivity less than 0.8.

This paper is well organized and written. One of my major concerns is that the authors should give more details about the comparisons between VIIRS retrievals and CALIPSO/CALIOP. Furthermore, to highlight the importance of those absorptive fusion bands, it could be worth to check day/night samples separately.
Response: We appreciate your comments and address specific comments as noted below.

Please note that we studied day/night samples separately for cloud mask, phase and height. Results for cloud mask are presented in response to Comment 7. For cloud phase, the general conclusion is similar and the primary difference between day and night is detecting more water phase clouds during day because of an additional test by the VIIRS 1.6um channel, which also results in slightly larger increase in the percentage of correctly identified ice phase clouds compared to nighttime when fusion channels are used. For cloud height products, since only IR channels are used in ACHA and cloud phase is matched in the validation, no obvious differences are observed. Relevant discussions have been added to the manuscript.

Specific comments:
1. Line 10, Page 7: What the 13.3 channel is not used in the cloud mask detection?
Response: The cloud mask team led by one of the coauthors here, Dr. Andrew Heidinger, conducted cloud detection tests using various spectral channels. It was found that adding

the 13.3um channel did not help as much as the 6.7um channel. For the way our cloud mask is constructed, one doesn't need both channels.

2. Line 15 Page 7: Figures 7 and 8 in Wang et al. 2016 [doi.org/10.1002/2015JD024526] shows the importance of 13.3 and 6.7 channels for difference cases.
Response: We have revised the sentence "It is difficult to explain definitively the information content available in each of these IR bands so the approach is to test their impact on ice cloud height retrievals..." Now it reads "Previous studies explored spectral band information useful for cloud property retrievals by computing the Shannon information content (L'Ecuyer et al. 2006, Wang et al. 2016). The approach used here is to test their impact on ice cloud height retrievals through comparison with another cloud height product."

3. Line 3, Page 9: I think a 4 degree difference is too large for cloud comparisons. Do you mean 4 km?
Response: This has been addressed in response to Referee #1's comment.

4. Line 20, Page 9: How do you define pixel-level cloud fraction here, please clarify.
Response: We added discussion to clarify how we define pixel level cloud fraction: "When a cloud layer is detected by CALIPSO/CALIOP, the pixel is classified as cloudy. Neighboring pixels along the path are included and the cloud fraction is defined by computing the ratio between the number of cloudy pixels and the total number of pixels."

5. Line 2, Page 10: Could you please give the pixel fraction that CALIOP COTs are less than 0.03?

Response: A table is shown below of counts and fraction of CALIOP COTs less than 0.03. We added a sentence as follows: "The fraction of the sub-visible clouds is less than 4% from a global perspective and less than 3% in the polar regions."

		Sample Size COT < 0.3	**Sample Size All**	**Ratio**
S-NPP	**Global**	**217983**	**6091230**	**0.036**
	60°N to 60°S	**176734**	**4384193**	**0.040**
	Arctic	**16968**	**853006**	**0.020**
	Antarctic	**24281**	**854031**	**0.028**
NOAA-20	**Global**	**73869**	**2328596**	**0.032**
	60°N to 60°S	**58975**	**1645684**	**0.036**
	Arctic	**10374**	**329702**	**0.031**
	Antarctic	**4520**	**353210**	**0.013**

6. Line 3, Page 10: And it would be helpful if you can provide the cloudy and clear fractions in Table 2.

Response: We added the numbers of cloud fractions from both sensors to Table 2 and the following discussion: "In terms of total cloud fraction, as expected, VIIRS tends to report a lower cloud fraction than CALIOP. CALIOP has a better detection sensitivity to optically thin clouds, and global cloud fractions reported from the two sensors are in agreement when the minimum cloud optical thickness is set between 0.6 and 0.7. The global values do not necessarily become more closely aligned with CALIOP when a fusion channel is used. However, the use of a fusion channel results in a much larger impact in the polar regions, as will be shown in Figure 1."

7. Line 19, Page 10: This is true. However, the authors could apply the same comparison to nighttime pixels to highlight the importance of water vapor and CO2 channels.
Response: We are unsure if the reviewer is referring to this sentence "This is unsurprising since the cloud mask algorithm performs fairly well for a snow-free surface...". As noted, the cloud mask algorithm is not using the CO2 channels. We are computing the validation of cloud mask detection separating day and night as requested below. Note that we used a solar zenith angle threshold of 85 degrees to separate day and night, and discarded pixels that do not have a valid solar zenith angle.

Daytime Only

		Sample Size		Correct Detection	Missed Cloud	False Detection
S-NPP	Global	2899130	Fusion	82.9	13.1	3.9
			No Fusion	82.4	13.6	3.9
	60°N to 60°S	2154403	Fusion	84.3	12.5	3.1
			No Fusion	84.1	12.8	3.1
	Arctic	469177	Fusion	77.4	15.0	7.6
			No Fusion	75.5	16.7	7.8
	Antarctic	275550	Fusion	80.9	14.7	4.4
			No Fusion	80.7	15.2	4.1

NOAA-20	**Global**	**1098695**	**Fusion**	**84.4**	**12.5**	**3.1**
			No Fusion	**83.9**	**13.1**	**3.0**
	60°N to 60°S	**799995**	**Fusion**	**84.8**	**12.1**	**3.1**
			No Fusion	**84.6**	**12.4**	**3.1**
	Arctic	**14939**	**Fusion**	**84.9**	**10.0**	**5.1**
			No Fusion	**80.9**	**11.4**	**7.7**
	Antarctic	**283761**	**Fusion**	**83.3**	**13.8**	**2.8**
			No Fusion	**82.2**	**15.4**	**2.4**

Nighttime Only

		Sample Size		**Correct Detection**	**Missed Cloud**	**False Detection**
S-NPP	**Global**	**2974117**	**Fusion**	**83.6**	**11.9**	**4.5**
			No Fusion	**82.6**	**12.0**	**5.4**
	60°N to 60°S	**2053056**	**Fusion**	**87.2**	**8.8**	**4.0**
			No Fusion	**87.1**	**8.7**	**4.2**
	Arctic	**366861**	**Fusion**	**76.3**	**16.0**	**7.7**
			No Fusion	**73.7**	**17.0**	**9.3**
	Antarctic	**554200**	**Fusion**	**75.3**	**20.5**	**4.2**
			No Fusion	**71.8**	**21.0**	**7.2**

NOAA-20	**Global**	**1156032**	**Fusion**	**81.2**	**13.7**	**5.1**
			No Fusion	**79.6**	**13.4**	**7.0**
	60°N to 60°S	**786714**	**Fusion**	**86.2**	**9.4**	**4.4**
			No Fusion	**86.1**	**9.2**	**4.7**
	Arctic	**304389**	**Fusion**	**66.7**	**25.7**	**7.5**
			No Fusion	**60.9**	**25.0**	**14.0**
	Antarctic	**64929**	**Fusion**	**89.1**	**8.8**	**2.1**
			No Fusion	**88.2**	**10.0**	**1.8**

8. Table 2: What's the reason that the no fusion cloud mask retrievals are so different between NOAA-20 and SNPP in Arctic (e.g., 74.7% vs. 61.9%)?
Response: The data used for NOAA-20 and SNPP in this study are from different seasons, so this could be playing a part. The SNPP data are from April and October 2018, while NOAA-20 data are from January 2019. Given the limited amount of data processed for this study, we need to further investigate this difference more closely.

9. Section 3.2, Page 12: How do you deal with multi-level clouds and mixed-phase cloud? Did you use the uppermost cloud layer phases from CALIOP, in multiple cloudlayer cases? Please give more details.
Response: CLAVR-x does not retrieve mixed-phase cloud. There is some logic for discriminating the presence of multilayered clouds (primarily optically thin ice clouds overlying a lower-level liquid water cloud), and these are treated as ice phase in this study. We note that the uppermost cloud layer phase from CALIOP in multilayer cases is used.

10. Line 11, Page 16: In Figure 5, it is interesting that the fusion cloud-top heights (SNPP) are more negatively biased than no fusion heights in Antarctic. Do you have any speculation? I don't find the same feature in Figure 7 for NOAA-20.
Response: The bias is small in the Antarctic, and we are not sure what caused this behavior. We need to process much more data over seasons to determine whether this is caused by a relatively high surface elevation or some other factor.

11. Line 13, Page 22: Do you think it's due to artifacts of fusion bands? Since Figure 8c shows that near north pole, passive cloud-top height with fusion bands are higher than Lidar.

Response: There is an indication that the cloud heights improve further with the addition of the 6.7um fusion channel. What is interesting about this is that the 6.7-µm channel is not generally used for global operational cloud height retrievals; the 13.3-µm channel is more often used. The 6.7-µm channel is strongly impacted by the presence of water vapor, and obviously the amount of water vapor is quite small in the Antarctic. We need to do further study to determine the information content of this channel at high latitudes.