

Evaluation and Changes to CALIOP Cloud Ice and Water Phase Discrimination

I. Cloud Phase Algorithm Changes, Impacts



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Introduction: NASA's Cloud-aerosol Lidar Infrared Pathfinder Satellite Observations (CALIPSO) satellite carries both the Cloud and Aerosol Lidar with Orthogonal Polarization (CALIOP). CALIOP provides an unprecedented vertically-resolved global climatology of the distribution of ice and water clouds. CALIOP measures both parallel and perpendicular backscatter of linearly polarized 532 nm light from cloud particles in the atmosphere. The perpendicular component of the return signal allows differentiation between cloud layers consisting of spherical water droplets from those with non-spherical ice particles. A two-way distribution of layer-integrated 532 nm total backscatter and the layer-integrated 532 nm depolarization ratio further differentiates between water cloud layers with significant multiple scattering, horizontally-oriented ice particles that cause specular reflections, and randomly-oriented ice particles, as described in Hu et al., 2009. The cloud phase algorithm functions well for the majority of clouds, but there have been some recent changes and improvements that are described in this poster. The impact of the CALIOP viewing angle change from near-nadir (0.3 degrees) to slightly tilted (3.0 degrees) on the optical properties of the various CALIOP cloud particle phases is also shown. A major improvement to the phase algorithm is the limitation of a spatial coherence test for horizontally-oriented ice to cloud layers that have sufficient integrated attenuated backscatter to likely contain HOI. This change reduces a "striping" effect caused by noisiness in the spatial coherence test for thin cloud layers. Additional temperature tests are considered, and the regional and vertical distribution of cloud layers with the various CALIOP cloud phases is shown. Only one cloud particle phase is allowed for each 5 km portion of a cloud layer that is considered by the cloud phase algorithm, so we use *in situ* aircraft and CloudSat observations to determine how the CALIOP cloud phase algorithm is treating optically and thermally thick clouds, which may be mixed-phase.

CALIOP Cloud Phase Types*:

In parens are the decoded vfm bits – phase and confidence.

- 1 – High Confidence Water (2,3)
- 2 – Medium Confidence Water (2,2)
- 3 – Low Confidence Water (2,1)
- 4 – High Confidence Ice (1,3)
- 5 – Medium Confidence Ice (1,2)
- 7 – High Confidence Oriented Ice (3,3)
- 8 – 'Medium Confidence HOI' (3,2)
- 10 – Unknown (0,0)

Contains specular reflections, oriented horizontally, or perpendicular to the viewing angle, 'HOI'

Please see Sections I and II – may also be mixed water and ice or mixed 'ROI' and 'HOI'

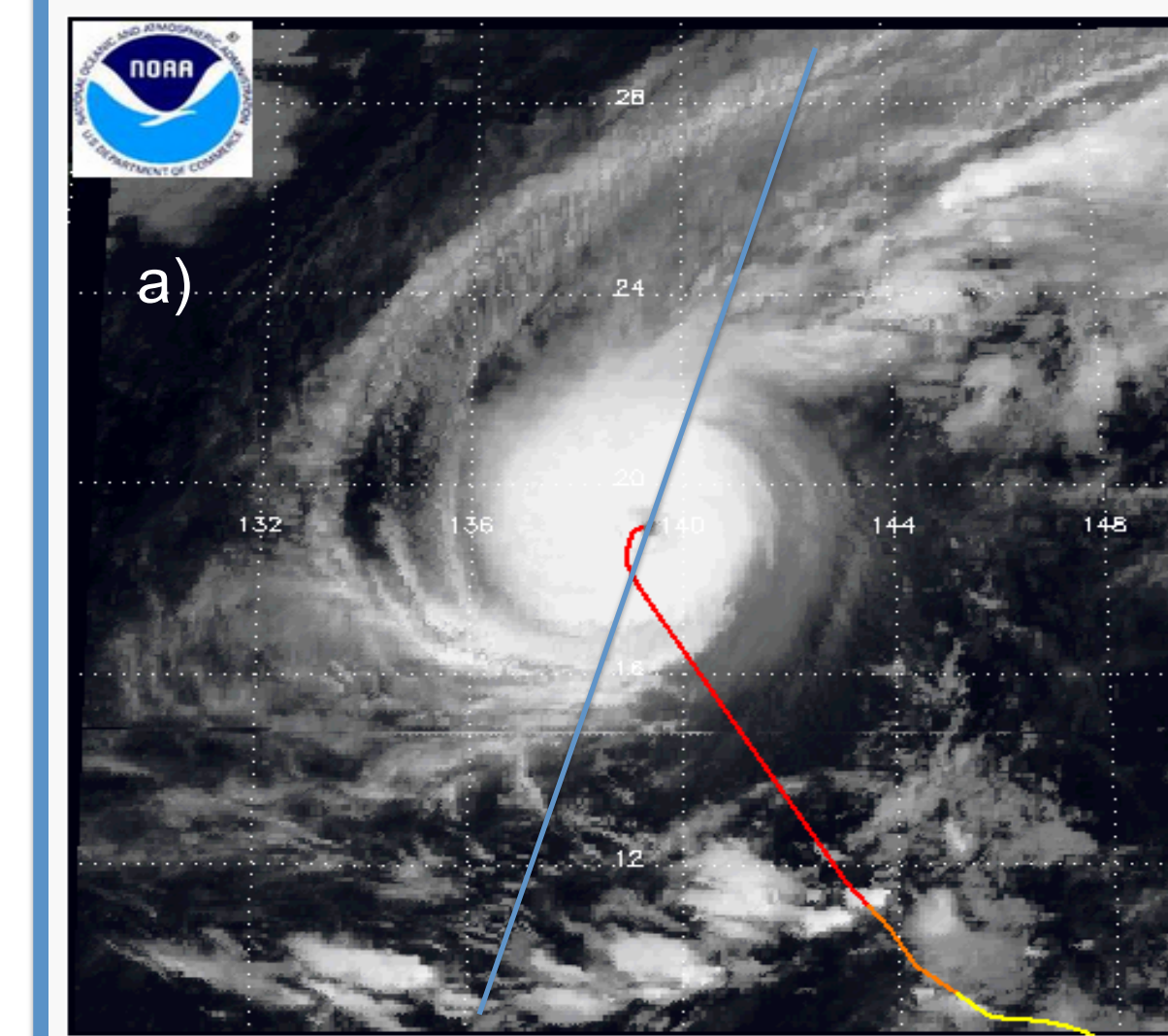
Most likely to be an aerosol (low CAD score) or might be a very optically thin layer with $0 > T > -40$ °C and low depolarization

* These cloud phase types can be found for each cloud layer or profile by decoding the vertical feature mask (layer files) or atmospheric volume descriptor (profile files). The individual bits are described in the CALIPSO User Guide or Data Products Catalogue. For clouds we always have feature type=2.

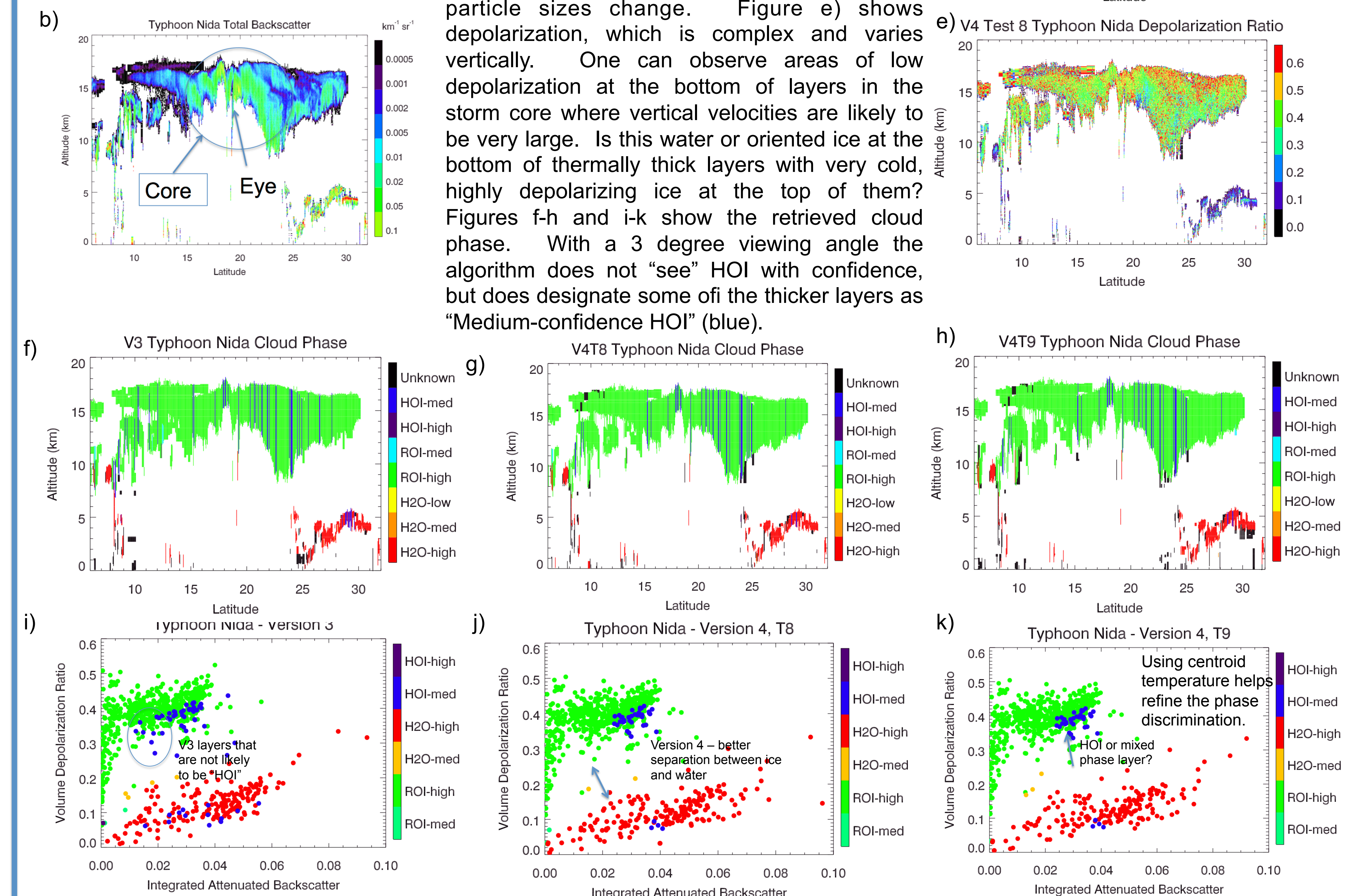
References:

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Hu, Y., et. al. (2009); *J. Atmos. Oceanic Technol.*, **26**, 2293-2309, doi:10.1175/2009JTECH1280.1.
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Winker et. al. (2009); *J. Atmos. Oceanic Tech.*, **26**, 2310-2323.
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Zhou, C. Z. et. al. (2012); *J. Appl. Met. Clim.*, **51**, 1426-1439, doi: 10.1175/JAMC-D-11-0265.1

II. Tilted View: Case Study of Typhoon Nida

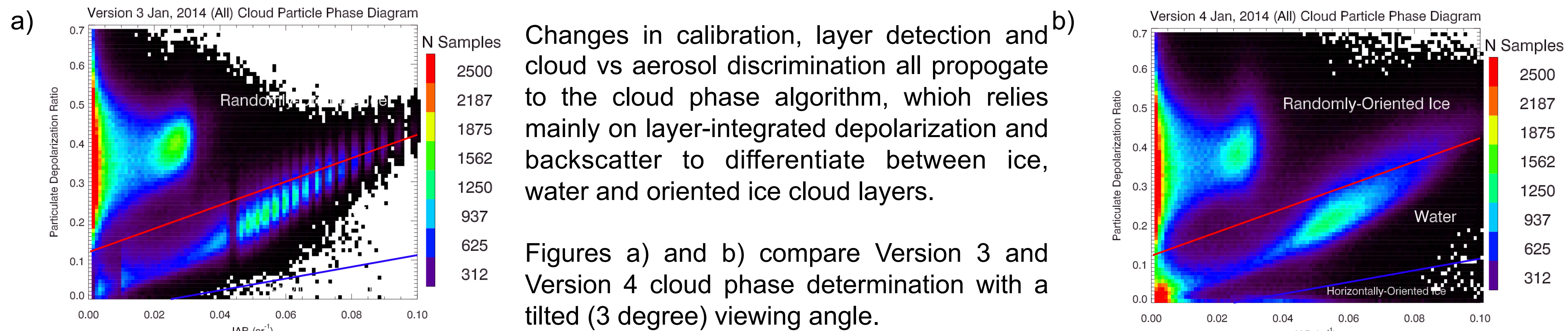
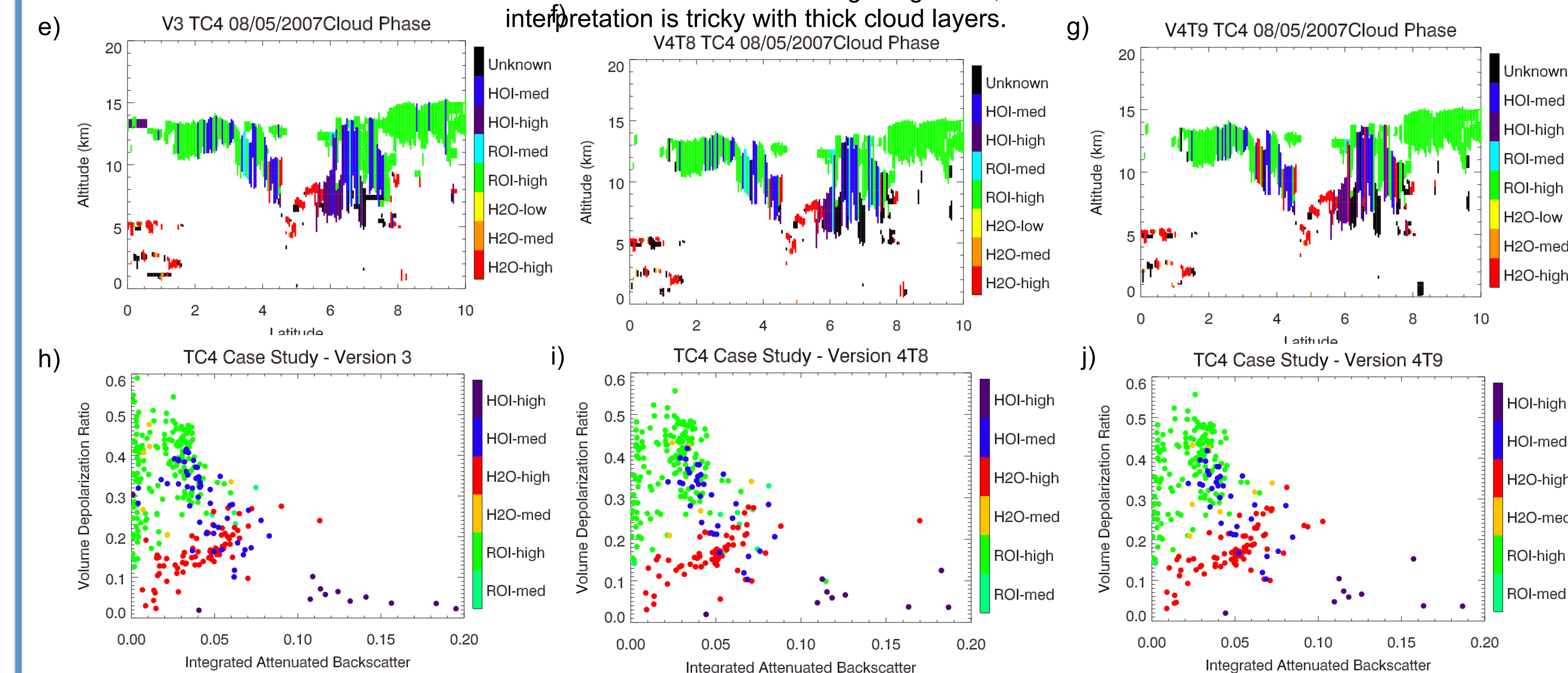


Tropical cyclones provide an ideal natural laboratory for testing the CALIOP cloud extinction and phase algorithms, as they consist of cloud layers with a large range of optical thickness within one storm system. Typhoon Nida was a Category 4 Typhoon that formed in the Western Pacific in November of 2009. This case study is a nighttime A-Train overpass that occurred on November 28, 2009, when the Typhoon was near Guam. Figure a) shows an IR ISCCP image of the Typhoon at 15Z. The warm-colored line is the hurricane track, with windspeeds of > 100 kt plotted beneath the image. Figure b) shows the CALIOP backscatter measured during the overpass, and c) is the GMAO GEOS temperature field. Figure d) illustrates 5 significant temperatures within a single cloud layer, and how these change relative to one another as the optical thickness and cloud particle sizes change. Figure e) shows depolarization, which is complex and varies vertically. One can observe areas of low depolarization at the bottom of layers in the storm core where vertical velocities are likely to be very large. Is this water or oriented ice at the bottom of thermally thick layers with very cold, highly depolarizing ice at the top of them? Figures f-h and i-k show the retrieved cloud phase. With a 3 degree viewing angle the algorithm does not "see" HOI with confidence, but does designate some of the thicker layers as "Medium-confidence HOI" (blue).



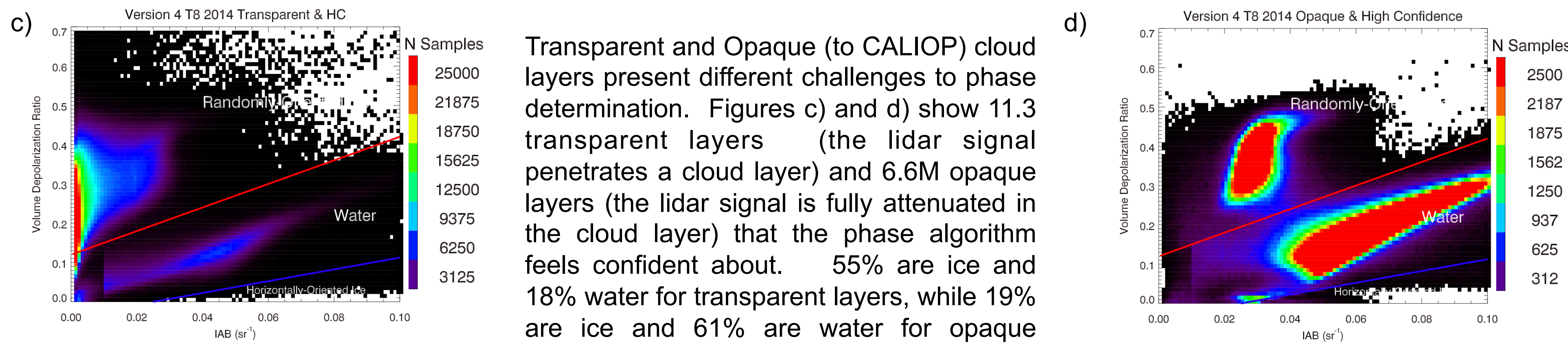
III. Nadir View: Case Study from TC4

This case study of an overpass during the TC4 mission is quite complex, and occurs during a nadir (0.3 degree) view by CALIOP. Figures a-c show the backscatter, temperature (from GMAO) and depolarization for a convective cloud near the ITCZ, of the coast of Costa Rica. Figure d shows aircraft observations of temperature and vertical velocity, as well as phase estimated from the CPI images (round water droplets vs shattered ice) and the corresponding radar reflectivity measured by CPR on CloudSat. The depolarization field from 5-8N is quite complex, corresponding to the large CPR reflectivity and observations of spherical water droplets. Profiles with near 0 depolarization occur interlaced with profiles that look more like water (increasing depolarization due to multiple scattering). Frequently the cloud tops are depolarizing more like randomly oriented ice. In figures e-f and h-j one can see the difficulty that the phase algorithm has with making a decision based on layer-integrated quantities. With a nadir view, the MC-HOI (blue) that occurs with high depolarization, similar to ROI, is more likely to be mixed ice and water, while that occurring with depolarization close to water is predicted by theory to be ROI mixed with HOI. This case points out that in a 5 km average, there may well be layers with ROI, water and HOI occurring together, so interpretation is tricky with thick cloud layers.

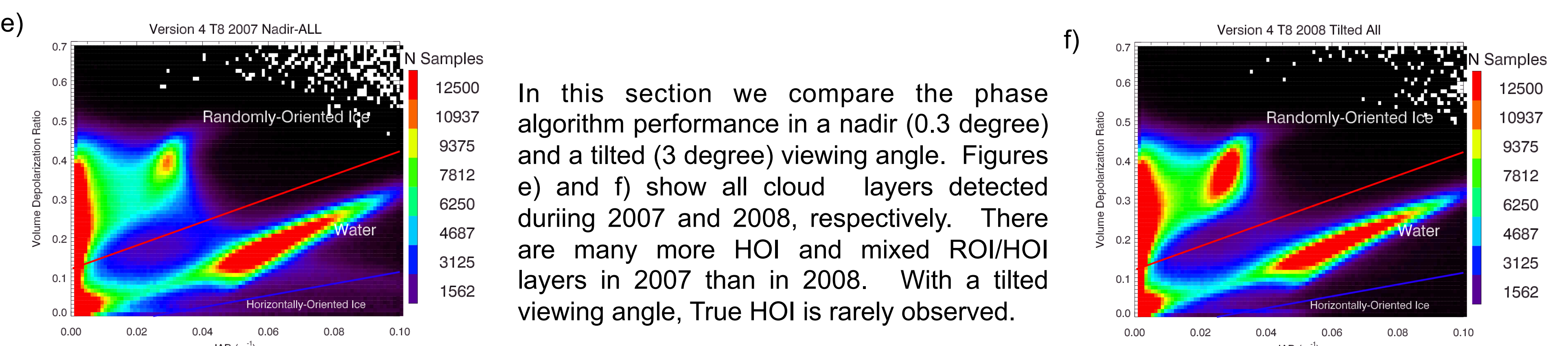


Changes in calibration, layer detection and cloud vs aerosol discrimination all propagate to the cloud phase algorithm, which relies mainly on layer-integrated depolarization and backscatter to differentiate between ice, water and oriented ice cloud layers.

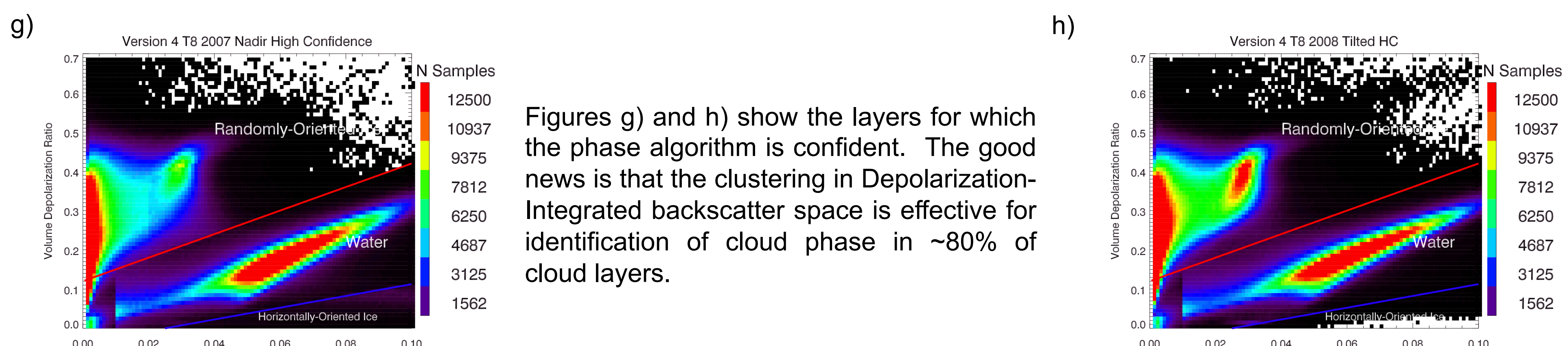
Figures a) and b) compare Version 3 and Version 4 cloud phase determination with a tilted (3 degree) viewing angle.



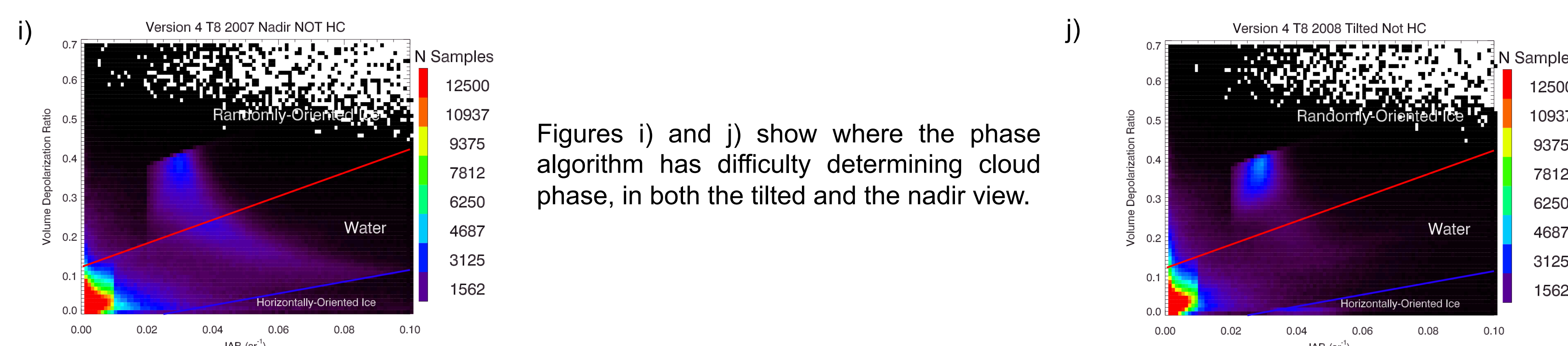
Transparent and Opaque (to CALIOP) cloud layers present different challenges to phase determination. Figures c) and d) show 11.3 transparent layers (the lidar signal penetrates a cloud layer) and 6.6M opaque layers (the lidar signal is fully attenuated in the cloud layer) that the phase algorithm feels confident about. 55% are ice and 18% water for transparent layers, while 19% are ice and 61% are water for opaque layers.



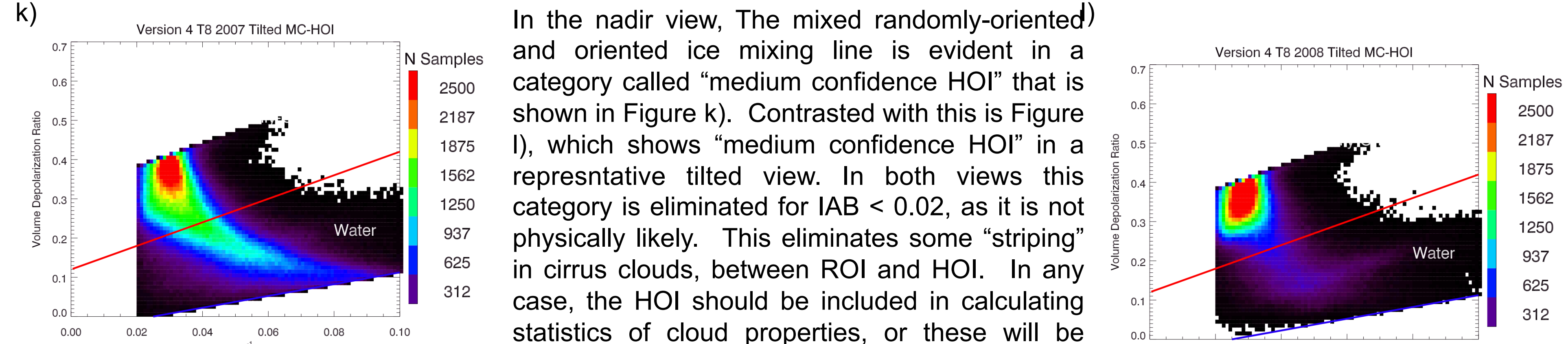
In this section we compare the phase algorithm performance in a nadir (0.3 degree) and a tilted (3 degree) viewing angle. Figures e) and f) show all cloud layers detected during 2007 and 2008, respectively. There are many more HOI and mixed ROI/HOI layers in 2007 than in 2008. With a tilted viewing angle, True HOI is rarely observed.



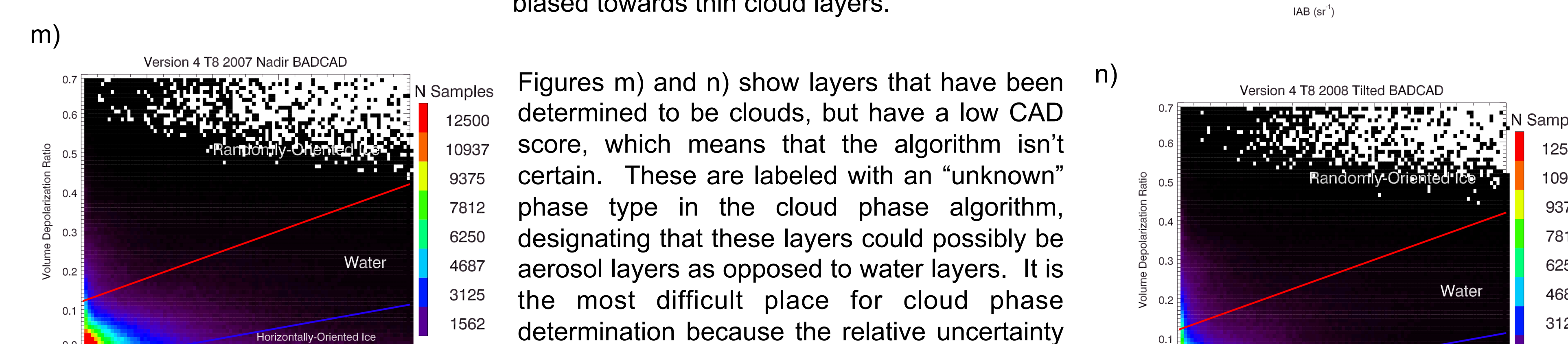
Figures g) and h) show the layers for which the phase algorithm is confident. The good news is that the clustering in Depolarization-Integrated backscatter space is effective for identification of cloud phase in ~80% of cloud layers.



Figures i) and j) show where the phase algorithm has difficulty determining cloud phase, in both the tilted and the nadir view.



In the nadir view, The mixed randomly-oriented and oriented ice mixing line is evident in a category called "medium confidence HOI" that is shown in Figure k). Contrasted with this is Figure l), which shows "medium confidence HOI" in a representative tilted view. In both views this category is eliminated for IAB < 0.02, as it is not physically likely. This eliminates some "striping" in cirrus clouds, between ROI and HOI. In any case, the HOI should be included in calculating statistics of cloud properties, or these will be biased towards thin cloud layers.



Figures m) and n) show layers that have been determined to be clouds, but have a low CAD score, which means that the algorithm isn't certain. These are labeled with an "unknown" phase type in the cloud phase algorithm, designating that these layers could possibly be aerosol layers as opposed to water layers. It is the most difficult place for cloud phase determination because the relative uncertainty in the cloud optical quantities tends to be large.

Opaque layer extinction retrievals in Version 4: a success story. See poster by Young et al. for details. Below, Figures o), p) and q) show a monthly time series of the mean (dashed) and median (solid) IAB, lidar ratio and optical depth for ice layers in 2007 and 2008. The viewing angle changed in November, 2007, which is month 11 in these plots. The lidar ratio compensates appropriately for HOI, so that in Version 4 the statistics of cloud optical depth do not change from the nadir to the tilted view.

