ATL09 Layer Parameters

The detection of layer heights will be performed on the atmospheric backscatter profiles of each of the 3 strong beams using the Density Dimension Algorithm (DDA) that is detailed in Part II of the Atmospheric ATBD. Please refer to that document for information pertaining to the algorithm. Here we define the parameters associated with the layers retrieved by the DDA and their related flags. Cloud detection is also performed using an estimate of the Apparent Surface Reflectivity (ASR) for each strong beam. This method does not retrieve the height of the layer. It only tells whether a cloud is present somewhere within the atmospheric column. It is assumed that the cloud detection for the strong beams represents the cloud condition for the weak beams at the same geophysical segment (ATL03 segment_id) since the tracks are separated by only 90 m and ½ second in time.

There will be a maximum of six layer heights (top and bottom) stored on the product for each of the 3 strong beams at 25 Hz resolution – ATL09 parameters *layer_top* and *layer_bot*. Associated with these will be a layer confidence flag (parameter *layer_conf*) and a layer attribute flag (parameter *layer_attr*). The confidence flag is calculated by averaging the bins within a layer and dividing it by the average molecular backscatter for the same vertical range. The integer value of this calculation will constitute the confidence flag (a value from 0 to approximately 100). The layer attribute flag is intended to discriminate between cloud and aerosol. If the layer bottom is above 6 km, then the layer is cloud (*layer_attr* = 1). If the layer top is below 6 km and the layer confidence is less than 10, then the layer is aerosol (*layer_attr* = 2).

ATL09 Cloud Flags

In addition to the layer parameters above, there are two cloud flags on ATL09: *Cloud_Flag_Atm* and *Cloud_Flag_ASR*. The first is a cloud flag which can be used to determine whether or not a layer was detected for a given atmospheric profile (ATL09 product parameter *Cloud_Flag_Atm*). This flag is set to a positive number corresponding to the number of layers found by the DDA algorithm. ATLAS atmospheric data will have a much higher signal to noise ratio at night as compared to day. Detection of thin clouds (optical depth < 1) will probably not be possible in daylight from the backscatter profiles at full resolution (25 Hz). The exact limit will depend on the solar zenith angle and surface albedo. Thicker clouds should be detected, but many of these will be so thick that no surface signal will be obtained. **While this flag can be used during the day, it might prove better to use the ATL09 product parameter *Cloud_Flag_ASR* which is based on Apparent Surface Reflectance and discussed below. But during night, *Cloud_Flag_Atm* is definitely the best cloud flag to use.** As an example of how to use the cloud flags derived from the backscatter profiles, suppose *Cloud_Flag_Atm* is equal to 2 (indicating the DDA found 2 layers). One would then look at the *layer_conf* parameter to see if any of those two layers had a confidence above say 50. The 50 would indicate a relatively high confidence that this was a cloud and a fairly optically thick cloud at that. The confidence level 50 used here is subject to change after we look at actual ATLAS data. If one wanted to screen all clouds from the data, then one would use a confidence level of 10.

The second cloud flag (*Cloud_Flag_ASR*) is obtained by using the ground surface return to compute the apparent surface reflectivity (ASR). The ASR is compared with an estimate of the true surface reflectance at the current location that is obtained from a monthly climatology data set compiled from GOME data and the NOAA daily snow and ice cover map. If the ratio of the computed ASR to the true (GOME/NOAA) surface reflectivity is less than a threshold value (T), then it is assumed cloudy (T is the product of the true surface reflectivity and the two-way molecular transmission to the surface). The cloud flag as determined from this method will be set to a value that is inversely proportional to the ratio of computed ASR to the true surface reflectivity as shown in Table 1. Note that over water, the true surface reflectivity is computed from the GMAO 10 m wind speed using the Cox-Munk relationship. Note also that a computed ASR of zero implies no surface return was found and thus a thick cloud is present. In this case, the cloud flag has its highest (most confident) value. **At present we believe this cloud flag to be more stable and accurate for daytime measurements than the above cloud flag derived from backscatter profiles**. The computation of ASR will require a calibration factor that will be obtained from passes over the high Antarctic plateau and periodically checked. We believe the calibration factor will be relatively stable. When considering cloud screening data for altimetry, it is recommended to consider any data with a cloud flag of 3 or greater to be cloud contaminated.

Each of the above methods will produce a cloud flag at full atmospheric data resolution which is 25 Hz or about 280 m along track.

Table 1. Cloud_Flag_ASR values and definition

P = (1 - ASR/T)*100	Product Flag	Flag Meaning
80 – 100%	5	Cloudy with high confidence
60 – 80%	4	Cloudy with medium confidence
40 – 60%	3	Cloudy with low confidence
20 – 40%	2	Clear with low confidence
0 – 20%	1	Clear with medium confidence
P < 0	0	Clear with high confidence

Blowing Snow Flag

Note also that there will be a blowing snow flag (*Bsnow_Con*) in addition to and independent from the cloud flags on the ATL09 product. The blowing snow detection algorithm will be invoked over any surface determined to be snow, ice sheet or sea ice. This determination is made by reading in the NOAA daily snow/ice cover map. Once a blowing snow layer is detected, the blowing snow confidence flag will be constructed from a combination of the signal strength within the layer and the wind speed. We will compute the average scattering ratio (attenuated total backscatter divided by the attenuated molecular) within the layer multiplied by the surface wind speed:

$$\chi = \frac{\overline{\beta}}{\beta_m} U_s$$

Where U is the surface wind speed. Table 2 shows the value of the blowing snow confidence flag as a function of χ. Note: the proposed limits may (will) change after launch.

Table 2. Blowing snow confidence flag

χ	Value	Confidence
< 5	1	None-little
5 - 10	2	Weak
>10 - 15	3	Moderate
>15 - 20	4	Moderate-high
>20 - 25	5	High
>25	6	Very high

The blowing snow detection algorithm will produce results at 25 Hz (full atmospheric resolution) and will work very well with nighttime data, but during daylight it will likely not perform well. Additional horizontal averaging may be employed to increase the signal to noise ratio during the day if needed.

It is recognized that scattering from the region 15 km above the surface that is folded into the near-surface scattering can produce a false positive blowing snow detection. This would only happen in the presence of polar stratospheric clouds that occur most frequently in late winter and early spring in high latitudes. There is a flag on the ATL09 product (*Bsnow_PSC*) which indicates the potential of PSCs to affect the blowing snow retrieval. The flag will be a function of month and hemisphere and will be applied only poleward of 60 north and south. If the blowing snow retrieval is outside of these latitudes, this flag will be zero regardless of month. Please see Table 3.

Table 3. Blowing Snow PSC interference flag for latitudes poleward of 60 N/S

Month	Southern Hemisphere	Northern Hemisphere
Jan	0	2
Feb	0	3
Mar	0	2
Apr	0	1
May	0	0
Jun	1	0
Jul	2	0
Aug	3	0
Sep	2	0
Oct	1	0
Nov	0	0
Dec	0	1

Multiple scattering warning flag

Atmospheric layers such as clouds and blowing snow can cause multiple scattering which will increase photon path length and make a surface appear to be lower than it actually is. The magnitude of multiple scattering is related to the height and optical depth of the scattering layer. The lower and denser the layer, the greater the multiple scattering. Hence, thick blowing snow or fog layers (which touch the ground) are of greatest concern. In theory it is possible to calculate the magnitude of photon delay if the height, thickness, optical depth and particle size are known. Unfortunately, we will not be able to measure these parameters from the ATLAS data itself accurately enough to compute a delay. Instead we use the height, thickness and estimated optical depth of the layer to produce a multiple scattering warning flag. **Note that these parameters are derived from the atmospheric backscatter profiles and are only viable for nighttime data. The multiple scattering warning flag will be present on the product both day and night, but the usefulness of the flag during day is questionable.**

The multiple scattering warning flag (ATL09 *msw_*parameter *flag*) has values from 0 to 5 where zero means no multiple scattering and 5 the greatest. If no layers were detected, then *msw_flag* = 0. If blowing snow is detected and its estimated optical depth is greater than or equal to 0.5, then *msw_flag* = 5. If the blowing snow optical depth is less than 0.5, then *msw_flag* = 4. If no blowing snow is detected but there are cloud or aerosol layers detected, the *msw_flag* assumes values of 1 to 3 based on the height of the bottom of the lowest layer: < 1 km, *msw_flag* = 3; 1-3 km, *msw_flag* = 2; > 3km, *msw_flag* = 1.

Conclusion

For nighttime data the use of the multiple scattering warning flag (*msw_flag*) is recommended as the best ATLAS derived indicator of clouds. For daytime the use of the *cloud_flag_ASR* flag is recommended as the best ATLAS derived indicator of clouds.