GOES-R Advanced Baseline Imager (ABI) Aerosol Detection Product (ADP) Users' Guide

Version 1, August 2024

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1. Purpose of this Guide

This GOES-R ABI Aerosol Detection Product (ADP) User's Guide is intended for users of the Level 2 (L2) ADP data files generated from the Advanced Baseline Imager (ABI) on board the Geostationary Operational Environmental Satellites R-Series (GOES-R) satellites. It provides a general introduction to the ABI sensor, the aerosol detection product (including smoke/dust detection), and the format and contents of the ABI ADP L2 data files.

On April 17, 2024, the ABI ADP algorithm was updated to the Enterprise Processing System (EPS) version. Prior to this date, operational ABI ADP L2 data were generated using the Baseline algorithm. This guide serves as an introduction to the more technical ABI Enterprise ADP Algorithm Theoretical Basis Document (ATBD) and ABI Baseline ADP Algorithm Theoretical Basis Document (ATBD).

2. Points of Contact

For questions or comments regarding this document, please contact Shobha Kondragunta, Pubu Ciren, or Amy Huff.

3. Document Definitions

The aerosol detection product (ADP), also called the smoke/dust mask, is a qualitative indicator of the presence of smoke and dust aerosols in the atmosphere. Table 1 lists additional acronyms and abbreviations used in this document.

Table 1. List of acronyms and abbreviations used in this document.

Acronym/Abbreviation	Definition
ADP	Aerosol Detection Product
ATBD	Algorithm Theoretical Basis Document
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CLASS	Comprehensive Large Array-Data Stewardship System
CONUS	Continental United States
ECM	Enterprise Cloud Mask
EPS	Enterprise Processing System
GOES	Geostationary Operational Environmental Satellites
L2	Level 2+
NUC	None/Unknown/Clear Sky
POCD	Probability of Correct Detection
RGB	True Color Imagery (Red-Green-Blue)
SNPP	Suomi National Polar-orbiting Partnership
SZA	Solar Zenith Angle
VIIRS	Visible Infrared Imaging Radiometer Suite
VZA	(Satellite) View Zenith Angle

4. ABI Overview

ABI is the primary instrument on the GOES-R Series satellites for imaging Earth's weather, oceans and environment. It is an imaging radiometer with 16 spectral bands: 2 visible bands, 4 near-infrared bands, and 10 infrared bands. The current operational GOES-R satellites are GOES-16 (GOES-East), centered at 75.2° W longitude, and GOES-18 (GOES-West), centered at 137.0° W longitude. ABI ADP is generated at 2 km spatial resolution (at nadir) for all three of the ABI scan sectors: the full hemispheric disk, the CONUS/PACUS domain (3000 km x 5000 km), and two mesoscale domains (1000 km x 1000 km).

5. ABI ADP Algorithms

The theoretical basis – the physics – of the Baseline and Enterprise ADP algorithms are the same. The ADP algorithms use spectral and spatial threshold tests to identify pixels with smoke or dust aerosols. The algorithms treat detection differently over water and over land.

The ABI spectral bands used as inputs to both ADP algorithms are listed in Table 2. In addition, both algorithms input the upstream (external to the ADP algorithm) Enterprise Cloud Mask (ECM) and snow/ice mask products. The Enterprise ADP algorithm handles cloud clearing slightly differently, however, which allows it to retrieve more correct dust detections than the Baseline ADP algorithm, especially over water. Details about the inputs to the ABI ADP algorithms are given in the Enterprise ATBD and the Baseline ATBD.

Although the Baseline and Enterprise ADP algorithms generate the same information, the contents of the ADP output data files are slightly different, including different variable names and flag values. Section 8 describes the key differences for working with Baseline and Enterprise ADP L2 data files.

Table 2. ABI bands used as inputs to the ADP algorithms.

ABI Band	Nominal Central Wavelength (μm)	Use in Algorithm
1	0.47	Dust and Smoke
2	0.64	Dust and Smoke
3	0.865	Dust and Smoke
4	1.378	Dust
5	1.61	Dust and Smoke
6	2.25	Smoke
7	3.9	Dust and Smoke
13	10.35	Dust
14	11.2	Dust and Smoke
15	12.3	Dust

6. ABI ADP Smoke/Dust Detection Accuracy

The required accuracy of ABI ADP retrievals is 80% probability of correct detection (POCD) for dust over water and land, 80% POCD for smoke over land, and 70% POCD for smoke over water. Based on quantitative comparisons with ground-based AERONET Ångström Exponent-based smoke/dust classifications and the CALIPSO/CALIOP satellite vertical feature mask, Baseline ADP met the POCD requirements. Accuracy is highest for thick smoke and dust plumes over dark surfaces. Smoke detection over semi-arid and arid regions is less accurate due to the lower contrast with the relatively bright surface.

A minimum of approximately one year of observations is needed for verification of ADP POCD requirements. Because the Enterprise ADP algorithm became operational for ABI on April 17, 2024, there is not yet sufficient data to evaluate its performance. However, the Enterprise ADP algorithm has been validated for the VIIRS sensor on the SNPP, NOAA-20, and NOAA-21 satellites. Results show that VIIRS Enterprise ADP from all three satellites meets the POCD requirements. Although VIIRS ADP has higher spatial resolution (750 m at nadir) and lower temporal resolution (~1 day) compared to ABI ADP, the accuracy of ABI Enterprise ADP is expected to be comparable.

7. ABI ADP Level 2 Data Files

ABI ADP L2 data files are available for all three ABI scan sectors (Full Disk, CONUS, and mesoscale) and are distributed in NetCDF4 format (.nc). Variables in ABI ADP L2 data files have 2 km resolution at nadir and are contained in 5424 x 5424 arrays for Full Disk sector files, 1500 x 2500 arrays for CONUS sector files, and 500 x 500 arrays for mesoscale sector files.

Figure 1 breaks down the file naming convention for ABI ADP L2 data files. The convention is the same for files generated by the Baseline and Enterprise ADP algorithms. The “Satellite” is abbreviated “G16” for GOES-16 (GOES-East), and “G18” for GOES-18 (GOES-West). A full explanation of ABI L2 filenames is available on the STAR Atmospheric Composition Training website.

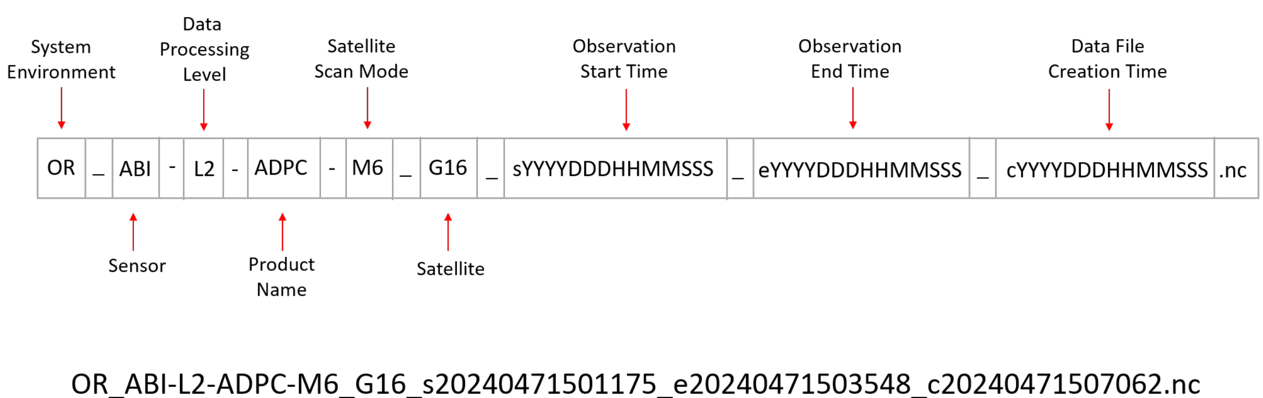

Figure 1. Example of an ABI ADP Level 2 filename and breakdown of the naming convention.

8. Working with ABI ADP Level 2 Data Files

ABI ADP L2 files contain many variables. The GOES-R Series Product Definition and Users' Guide (PUG) includes the full list of variables, including the variables common to all ABI L2 files. The variables of interest to most users include:

- Dust
- Smoke
- DQF
- PQI1 (Enterprise algorithm files only)
- PQI2 (Enterprise algorithm files only)
- goes_imager_projection
- x
- y

The "Dust" and "Smoke" variables are binary flags that indicate the presence (yes/no) of dust or smoke aerosols. ADP smoke/dust is not retrieved at night or over regions covered by clouds, snow, or ice. ADP is retrieved over regions of sun glint on water, but only smoke detections should be used because a high incidence of false dust detections occurs over glint regions. In addition, only smoke/dust retrievals within the valid range of solar zenith angle (SZA) and satellite view zenith angle (VZA) are recommended, i.e., 0° ≤ SZA ≤ 60°, 0° ≤ VZA ≤ 60°.

Table 3 summarizes the recommended settings for processing smoke and dust detections from ABI ADP Level 2 files generated by the Baseline and Enterprise algorithms. **Note the differences in variable names and flag values for each setting in the two types of files!**

In general, users should process smoke and/or dust detections using the settings in Table 3 as follows:

- Select smoke pixels using the "Smoke" variable (same for Baseline & Enterprise)
- Select dust pixels using the "Dust" variable (same for Baseline & Enterprise)
  - For dust only: select dust pixels outside of sun glint regions using
    - "DQF" variable bit 6 (Baseline)
    - "PQI2" variable bit 1 (Enterprise)
- Select smoke/dust pixels in valid SZA range using
  - "DQF" variable bit 7 (Baseline)
  - "PQI1" variable bits 2-3 (Enterprise)
- Select smoke/dust pixels in valid VZA range using
  - "DQF" variable bit 7 (Baseline)
  - "PQI1" variable bits 4-5 (Enterprise)
- Calculate latitude and longitude of smoke/dust pixels in the 2 km resolution ABI fixed grid using the "x", "y", and "goes_imager_projection" variables (e.g., using Python) or download netCDF (.nc) files containing latitude and longitude for the Full Disk or CONUS sectors
  - Note that the locations of the ABI mesoscale sectors change based on current hazards, so latitude and longitude will always need to be calculated for ADP mesoscale ("ADPM1" or "ADPM2") files.

ABI ADP L2 files also include confidence flags, which allow users to select smoke/dust retrieved with high, medium, or low confidence. For **qualitative** applications, all qualities ADP (high + medium + low confidence) may be used; this is the default setting. For **quantitative** applications, "Top 2" qualities ADP (high + medium confidence) is recommended. Process smoke/dust confidence flags using the settings in Table 3 as follows:

- For smoke pixels, use the "DQF" variable bits 2-3:
    - High quality = 12, medium quality = 4, low quality = 0 (Baseline)
    - High quality = 0, medium quality = 4, low quality = 8 (Enterprise)
- For dust pixels, use the "DQF" variable bits 4-5:
    - High quality = 48, medium quality = 16, low quality = 0 (Baseline)
    - High quality = 0, medium quality = 16, low quality = 32 (Enterprise)

Example plots of ABI ADP smoke/dust detection are shown in Figure 2. Examples of IDL and Python code for processing ABI ADP L2 data files are given in the Appendix.

Table 3. Settings for processing smoke/dust detections from ABI ADP Level 2 files generated by the Baseline and Enterprise algorithms.

<table>
<tr><th rowspan="2">Setting</th><th colspan="2">Baseline Algorithm
(prior to April 17, 2024)</th><th colspan="2">Enterprise Algorithm
(April 17, 2024 and later)</th></tr>
<tr><th>Variable</th><th>Flag Values</th><th>Variable</th><th>Flag Values</th></tr>
<tr><td>Smoke detection</td><td>Smoke</td><td>smoke absent == 0
smoke present == 1</td><td>Smoke</td><td>smoke absent == 0
smoke present == 1</td></tr>
<tr><td>Dust detection</td><td>Dust</td><td>dust absent == 0
dust present == 1</td><td>Dust</td><td>dust absent == 0
dust present == 1</td></tr>
<tr><td>Valid solar zenith angle (SZA)</td><td rowspan="2">DQF, bit 7</td><td rowspan="2">valid SZA/VZA == 0
invalid SZA/VZA == 128</td><td>PQI1, bits 2-3</td><td>valid SZA == 0
out of range SZA == 12</td></tr>
<tr><td>Valid satellite view zenith angle (VZA)</td><td>PQI1, bits 4-5</td><td>valid VZA == 0
out of range VZA == 48</td></tr>
<tr><td>Outside sun glint regions (Dust only)</td><td>DQF, bit 6</td><td>outside sun glint == 0
within sun glint == 64</td><td>PQI2, bit 1</td><td>outside sun glint == 0
within sun glint == 2</td></tr>
<tr><td>Smoke detection confidence</td><td>DQF, bits 2-3</td><td>high == 12
medium == 4
low == 0</td><td>DQF, bits 2-3</td><td>high == 0
medium == 4
low == 8</td></tr>
<tr><td>Dust detection confidence</td><td>DQF, bits 4-5</td><td>high == 48
medium == 16
low == 0</td><td>DQF, bits 4-5</td><td>high == 0
medium == 16
low == 32</td></tr>
</table>

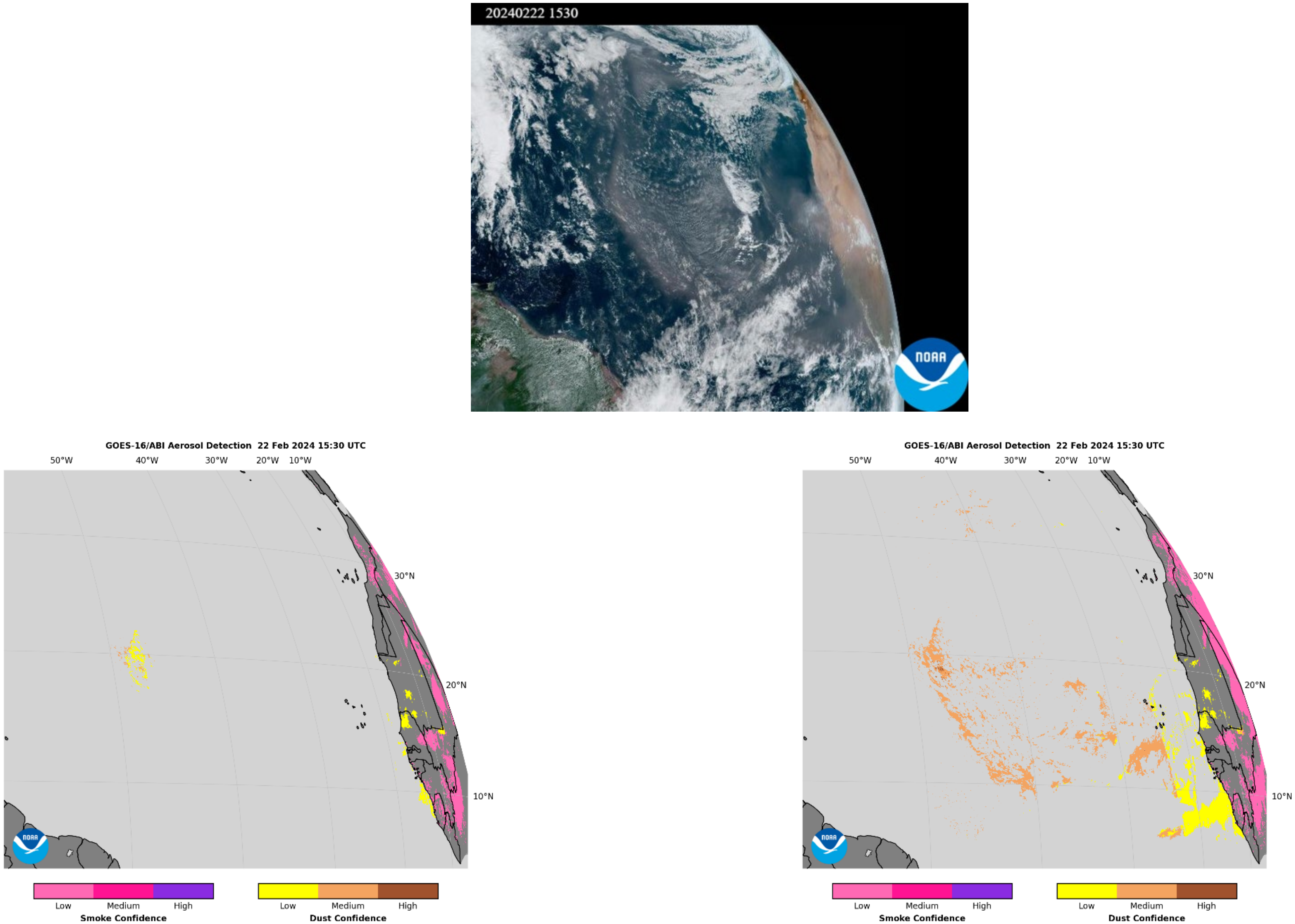

Figure 2. ABI ADP for a Saharan dust transport event over the Atlantic Ocean on February 22, 2024: (a) GOES-16 ABI GeoColor image showing blowing dust and GOES-16 ABI smoke/dust confidence from the (b) Baseline and (c) Enterprise algorithms. Note that Enterprise dust ADP has greater coverage due to a difference in handling cloud clearing as described in Section 5.

9. Known Issues to Date

The ABI Aerosol team has identified the following APD data quality problems that the users should be aware of:

- False smoke detections over thin clouds over land at large SZA & VZA (>60°);
- Occasional false low confidence dust detections over bright surfaces at large SZA & VZA (>60°), such as over the Andes Mountains.

10. Data Access

10.1. NODD

The NOAA Open Data Dissemination (NODD) Program is the newest and easiest way to access ABI Level 1b & Level 2 data files. Through public-private partnerships, the NODD provides public access to NOAA's open data on commercial cloud platforms, including Amazon Web Services (AWS). Access to NOAA data on AWS Simple Storage Service (S3) buckets is free, and an AWS cloud computing account is not required.

The main page for the GOES-R program NODD on AWS includes general information and links to the S3 buckets for the current GOES-R satellites, including GOES-16 (GOES-East) and GOES-18 (GOES-West). ABI ADP L2 data files on the NODD are updated in near real-time, with a full data archive for each GOES-R satellite. More information and links to the individual data files on the NODD GOES-R S3 buckets are provided on the STAR Atmospheric Composition Training website.

10.2. CLASS

The historical data archive for all ABI data is NOAA's Comprehensive Large Array-data Stewardship System (CLASS) (www.class.noaa.gov). ABI ADP L2 files are available in CLASS for the GOES-R satellites.

Instructions on how to order and download ABI data from CLASS are available as a slide file or a video. The steps required to order ABI ADP files are summarized here, for reference:

A. If you have not already done so, register to become a user of CLASS.
B. Login with your username and password.
C. From the drop-down product search list on the home page, select "GOES-R Series ABI Products (GRABIPRD)" and click the ">>GO" button on the right.
D. Once on the "Search – GRABIPRD" page, in the "Temporal" section, select the date and time period of interest by changing the "Start/End Date/Time".
E. In the "Advanced Search" section (you may need to expand the list by clicking the + button), under "Datatype" select "ABI L2+ Product Data" and under "Product Type" select "Aerosol Detection".
F. Select the "Satellite": "G16" (GOES-16) or "G18" (GOES-18).
G. Select the "ABI Scan Sector": "Full Disk", "CONUS", "Mesoscale scene 1", or "Mesoscale scene 2".
H. Click "Quick Search & Order" or "Search" button to order the data.

The “Search” option is useful if you would like to view the inventory listing of the data available within your search parameters and select a small number of specific files. If you are confident in your search parameters, use the “Quick Search and Order” button, which will skip the inventory list.

Once the ordered data are ready, you will receive an email instructing you how to download the data via anonymous FTP. For larger order sizes, you can request Block Orders through the CLASS helpdesk (class.help@noaa.gov). Since these data requests must be manually pulled from the tape library, CLASS handles the bulk orders on a best effort basis. Finally, subscriptions are also available to users who require regular data access. Daily TAR files of the products for the most recent 90 days are also available via anonymous FTP download at ftp://ftp-npp.bou.class.noaa.gov/.

Appendix: Helpful Tools for Working with ABI ADP Files

A. NetCDF Data Model

For users unaccustomed to working with NetCDF4 formatted files, please visit the website https://docs.unidata.ucar.edu/netcdf-c/current/netcdf_data_model.html for information.

B. Panoply Data Viewer

The Panoply NetCDF, HDF and GRIB Data Viewer developed by NASS GISS is a convenient tool for visualization of the EPS ADP outputs. Please visit the website https://www.giss.nasa.gov/tools/panoply/ for more information about this software.

C. IDL Tools

IDL has a built-in library of commands for NetCDF4 files. Documentation can be found online at https://www.harrisgeospatial.com/docs/NCDF_Overview.html or using IDL Help.

Michael Galloy has written a particularly helpful IDL program to read HDF5 (also works for NetCDF4) arrays into IDL, available at http://docs.idldev.com/idllib/hdf5/mg_h5_getdata-code.html.

D. Example Code

a. Example of IDL Code for Processing ABI Enterprise ADP L2 Files (written by Pubu Ciren)

```
; read EPS ADP
; flags: smoke, dust, cld (clouds), snowice (snow ice)

         smoke=mg_h5_getdata(filename,'Smoke')
          dust=mg_h5_getdata(filename,'Dust')
          cld = mg_h5_getdata(filename,'Cloud')
         snowice=mg_h5_getdata(filename,'SnowIce')
         Qual_B1=mg_h5_getdata(filename,'DQF')
         Qual_B2=mg_h5_getdata(filename,'PQI1')
         Qual_B3=mg_h5_getdata(filename,'PQI2')

; Ancillary information
; 1. Out of valid angle (SZA/VZA)- and_inv (0: valid, 1: invalid)
```

```
; 2. Sun glint mask – sugln (0: outside sun glint, 1: inside sun glint)
; 3. Land water mask – lndwat (0: water, 1: land)

sugln=smoke
sugln(*,*)=0
lndwat=smoke
lndwat(*,*)=0
ang_inv=smoke
ang_inv(*,*)=0

; read from quality flag

; Out of valid angle (SZA/VZA) for GOES-R

; Byte 2 bit 2,3 and bit 4,5

tmp_mask=Qual_B2

   idx = WHERE(((ishft(tmp_mask,-2) AND 3) EQ 3), COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN ang_inv[idx] = 1

   idx = WHERE(((ishft(tmp_mask,-4) AND 3) EQ 3), COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN ang_inv[idx] = 1


; Byte 3 bit 2 (sun glint)
tmp_mask=Qual_B3
   idx = WHERE((tmp_mask AND 2) EQ 2, COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN sugln[idx] = 1

; Byte 3 bit 3 (land/water)
tmp_mask=Qual_B3
   idx = WHERE((tmp_mask AND 4) EQ 4, COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN lndwat[idx] = 1

; Recommended best quality control
; 1. Remove detected dust from sun glint region over ocean
```

```
; 2. Remove detected smoke/dust outside valid sza/vza range

   idx = WHERE(dust eq 1 and lndwat eq 0 and sugln eq 1, COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN dust[idx] = 0

   idx = WHERE(smoke eq 1 and ang_inv eq 1, COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN smoke[idx] = 0

   idx = WHERE(dust eq 1 and ang_inv eq 1, COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN dust[idx] = 0


; Confidence (or quality) level for smoke and dust flag- Smoke_qual and dust_qual
; Smoke_qual (4: missing, 1: low, 2: medium, 3: High)
; dust_qual (4: missing, 1: low, 2: medium, 3: High)

smoke_qual=smoke
smoke_qual(*,*)=0
dust_qual=dust
dust_qual(*,*)=0

; smoke quality
  idx=where(smoke eq 1, n)
   if (n gt 0) then smoke_qual(idx)=3
; dust quality
  idx=where(dust eq 1, n)
   if (n gt 0) then dust_qual(idx)=3


; byte1 bit 3-4 (smoke quality)
tmp_mask=Qual_B1
   idx = WHERE(((ishft(tmp_mask,-2) AND 3) EQ 1) and (smoke eq 1), COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN smoke_qual[idx] = 2

; bytet1, bit5-6 (dust quality)
tmp_mask=Qual_B1
   idx = WHERE(((ishft(tmp_mask,-4) AND 3) EQ 1) and (dust eq 1), COMPLEMENT=cidx, nc)
```

```
   IF nc GT 0 THEN dust_qual[idx] = 2


; byte1 bit 3-4 (smoke quality)
tmp_mask=Qual_B1
   idx = WHERE(((ishft(tmp_mask,-2) AND 3) EQ 2) and (smoke eq 1), COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN smoke_qual[idx] = 1

; byte1, bit5-6 (dust quality)
tmp_mask=Qual_B1
   idx = WHERE(((ishft(tmp_mask,-4) AND 3) EQ 2) and (dust eq 1), COMPLEMENT=cidx, nc)
   IF nc GT 0 THEN dust_qual[idx] = 1

; byte1 bit 3-4 (smoke quality): MISSING
tmp_mask=Qual_B1
   idx = WHERE(((ishft(tmp_mask,-2) AND 3) EQ 3) and (smoke eq 1) , COMPLEMENT=cidx, nc)
;  IF nc GT 0 THEN smoke_qual[idx] = 4

; byte1, bit5-6 (dust quality): missing
tmp_mask=Qual_B1
   idx = WHERE(((ishft(tmp_mask,-4) AND 3) EQ 3) and (dust eq 1) , COMPLEMENT=cidx, nc)
;  IF nc GT 0 THEN dust_qual[idx] = 4
```

b. Example of Python Code for Processing ABI Enterprise ADP L2 Files using xarray & NumPy (written by Amy Huff)

Python configuration:
python=3.9
 - numpy=1.23.4
 - netcdf4=1.6.2
 - dask=2022.7.0
 - xarray=2022.11.0

```
# Module to set filesystem paths for user's operating system
```

```
from pathlib import Path

# Library to work with labeled multi-dimensional arrays
import xarray as xr

# Library to perform array operations
import numpy as np

# User: enter directory & file name of ADP data file
file_path = Path('D://Data/2024/20240324')  # Directory where .nc file is located
file_name = 'OR_ABI-L2-ADPC-M6_G16_s20241001431172_e20241001433545_c20241001435001.nc'

# Process ABI ADP smoke/dust detection
def process_abi_adp_detection(ds):

    # Convert xarray Data Arrays to NumPy masked arrays w/correct data type
    # Select "smoke present" (Smoke = 1) and "dust present" (Dust = 1) pixels
    smoke_detection = ds.Smoke.where(ds.Smoke == 1).to_masked_array().astype('int8')
    dust_detection = ds.Dust.where(ds.Dust == 1).to_masked_array().astype('int8')
    pqi1 = ds.PQI1.to_masked_array().astype('uint16')
    pqi2 = ds.PQI2.to_masked_array().astype('uint16')

    # Mask dust pixels within sun-glint regions using "PQI2" bit 1
    # outside sun-glint (0): 0, within sun-glint (1): 2
    dust_detection = np.ma.masked_where(pqi2 & 2 == 2, dust_detection)

    # Mask smoke & dust pixels out of valid SZA range using "PQI1" bits 2-3
    # out of range SZA (11): 4 + 8 = 12
    sza_mask = ((pqi1 & 4 == 4) & (pqi1 & 8 == 8))
    smoke_detection = np.ma.masked_where(sza_mask, smoke_detection)
    dust_detection = np.ma.masked_where(sza_mask, dust_detection)
```

```
    # Mask smoke & dust pixels out of valid VZA range using "PQI1" bits 4-5
    # out of range VZA (11): 16 + 32 = 48
    vza_mask = ((pqi1 & 16 == 16) & (pqi1 & 32 == 32))
    smoke_detection = np.ma.masked_where(vza_mask, smoke_detection)
    dust_detection = np.ma.masked_where(vza_mask, dust_detection)

    return smoke_detection, dust_detection


# Main function
if __name__ == "__main__":

    # Set full path for ADP data file
    file_id = file_path / file_name

    # Open file using xarray (automatically closes file when done)
        with xr.open_dataset(file_id, engine='netcdf4') as ds:
            # Process VIIRS ADP smoke/dust detection
            smoke, dust = process_abi_adp_detection(ds)
```