Approvals

The purpose of this review and approval is to evaluate this Standard Operating Procedure (SOP) for adequacy prior to issuance. The signatories below are stating that the approach defined within this document is acceptable and that the affected company interests have been represented.

Author Signature:

Program: QA Manager – Emily Vanden Hoek

Approval Signature:

Program: Field Operations Manager – Mark Tigges

REVISION HISTORY

Review date:	Changes made:	Changes made by:
October 2019	Initial version	J. Adlhoch

ANNUAL REVIEW

The undersigned attests that this standard operating procedure has undergone annual review for adherence to current practices and the latest QA/QC protocols:

Signature	Title	Date
Signature	Title	Date
Signature	Title	Date
Signature	Title	Date

1.0 PURPOSE

This Standard Operating Procedure (SOP) describes the steps of nephelometer data reduction and validation, to assure quality data and ensure that data are placed in a format consistent with IMPROVE Protocol.

The Optec NGN-2 nephelometer measures the scattering coefficient due to particles in the atmosphere (b_{sp}). The raw nephelometer output is converted to b_{sp} using instrument- and time-specific calibration information.

2.0 SUMMARY OF METHOD

This SOP is a guide to the reduction and validation of Optec NGN-2 nephelometer and collocated ambient temperature and relative humidity data. Data reduction and validation begin with the hourly interrogation of the on-site datalogger and end with Level-1 validated nephelometer and meteorological data. Nephelometer and meteorological data undergo the following reduction and validation steps:

- Processing data daily to convert the raw data to Level-A validation format.
- Reviewing data visually for details on monitoring system performance.
- Processing data through Level-0 validation to verify quality assurance validation codes, calibration parameters, and estimate precision; and ensure completeness of files.
- Determining zero calibration validation parameters.
- Processing data through Level-1 validation to compute hourly averages, perform overrange/underrange checks, and identify data affected by meteorological interference.
- Verify the integrity of parameters and ensure completeness of files.

Because most stations are remote, daily data review is critical to the identification and resolution of problems.

3.0 SCOPE

Activities described in this document are performed by ARS program/project managers, data analysts and field technicians. ARS staff have been appropriately trained in data validation and reduction and possess the required technical knowledge and abilities to perform the activities described below.

4.0 ROLES AND RESPONSIBILITIES

Program Manager

- Review Level-1 validated data with the project manager to ensure quality and accurate data validation.
- Coordinate with the Contracting Officer's Representative (COR) for desired method of data reduction required of the IMPROVE Program.

Project Manager

- Review and verify calibration results for each instrument.
- Review Level-1 validated data with the program manager, data analysts, and field specialists.

Data Analyst

- Perform data validation procedures described in this technical instruction.
- Resolve data validation problems with the project manager and field specialists.

- Identify instrument or data collection and validation problems and initiate corrective actions.
- Review data with the project manager and field specialists.

Field Specialist

- Review data with the project manager and data analysts.
- Provide input as to the cause of instrument problems and specific siting characteristics.

5.0 REQUIRED EQUIPMENT AND MATERIALS

All data reduction and validation occurs on PC computer systems. The required computer system components include:

- Microsoft Windows operating system
- Software for processing raw nephelometer data:
  - NGN_pull.exe and NGN_plot.exe
  - NGN_seas.exe and NGN_QA.exe
  - NGN_nsum.exe
  - NGN_Neph_Data_Check.exe
- ASCII text editor such as UltraEdit.32
- File viewing utility
- Completed operator log sheets

6.0 PROCEDURES

Data reduction and validation begin with the hourly interrogation of the on-site datalogger and end with Level-1 validated nephelometer and associated meteorological data.

This section includes three subsections:

6.1 Data Collection Procedures
6.2 Daily Reduction and Validation Procedures
6.3 Quarterly Reduction and Validation Procedures

Figure 6-1 is a flowchart of the data reduction and validation procedures for nephelometer and collocated meteorological data. These procedures are described in the following subsections.

6.1 DATA COLLECTION PROCEDURES

On-site dataloggers are interrogated hourly via IP or satellite modem for all raw nephelometer and meteorological data available since the last download. During periods when communications are not functioning, data are collected via storage module at regular intervals. Raw data collected are saved in daily site-specific ASCII files. Refer to the following documentation for detailed data collection procedures:

- SOP 4300 — *Collection of Optical Monitoring Data (IMPROVE Protocol)*
- TI 4300-4002 — *Nephelometer Data Collection via IP Modem or Satellite Modem (IMPROVE Protocol)*
- TI 4300-4006 — *Nephelometer Data Collection via Campbell Scientific Data Storage Module (IMPROVE Protocol)*

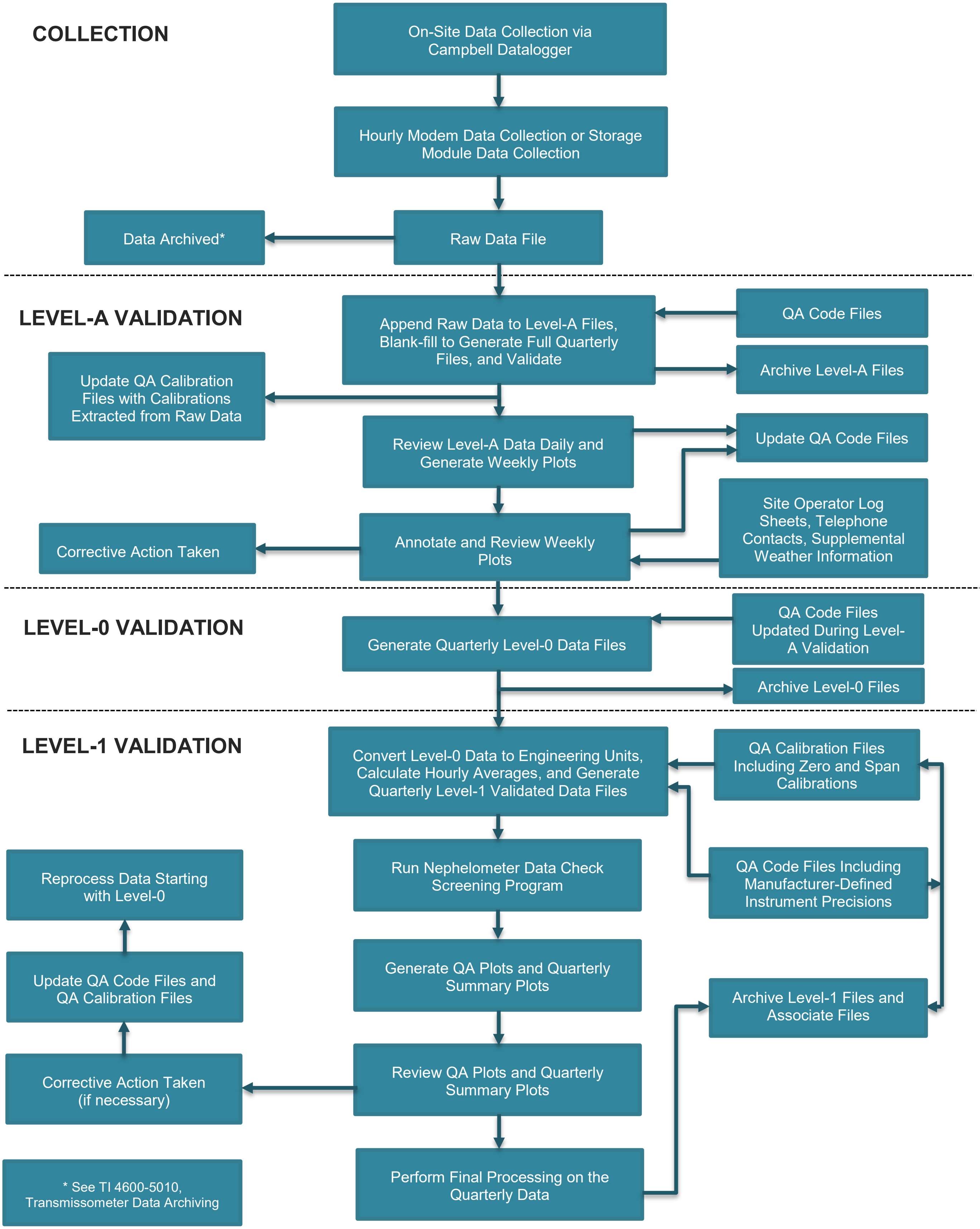

Figure 6-1. Nephelometer Data Processing Flowchart.

Figure 6-2 presents the file format of raw data collected via IP modem or Campbell Scientific storage module. The data analyst verifies that all data were collected. Any data collection problems are immediately reported to the project manager. Ongoing data collection problems are resolved according to TI 4100-3100, *Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems – Type 1 (IMPROVE Protocol)* and TI 4100-3105, *Routine Site Operator Maintenance Procedures for Optec NGN-2 Nephelometer Systems – Type 2 (IMPROVE Protocol).*

6.2 DAILY REDUCTION AND VALIDATION PROCEDURES

Validation begins with the raw nephelometer files (*xxxxxyyc.jjj*) where *xxxxx* is the five-character site code, *yy* is the year, *c* is the form of data collection (D or a number 1 to 9), and *jjj* is the Julian date. Validation consists of three levels: Level-A, Level-0, and Level-1. Level-A validation is performed daily. Level-0 and Level-1 are performed quarterly. Processing at each level is presented in Figure 6-1, Nephelometer Data Processing Flowchart, and described in the following subsections.

6.2.1 Level-A Validation

Level-A validation of raw nephelometer and meteorological data is performed daily using NGN_pull.exe software. Validation tasks the software performs are:

- The parameters listed below are extracted from the raw data file and are appended to site-specific quarterly data files:
  - Serial nephelometer raw scattered light (counts)
  - Serial nephelometer direct light (counts)
  - Serial nephelometer chamber temperature (°C)
  - Serial nephelometer status code (1-9)
  - Analog nephelometer normalized scattered light (1 mVDC = 1 count)
  - Analog status code (1 VDC = code 1)
  - Ambient temperature (°C)
  - Relative humidity (%)
  - AC and DC power failure information

- Automatic clean air zero calibrations and operator-initiated clean air zero and span calibrations recorded by the datalogger are extracted from the raw data file and appended to instrument-specific QA calibration files. Figure 6-3 shows an example QA calibration file.

- Three Level-A validity codes are assigned to the nephelometer data:
  - The *Power Code*, generated by the datalogger, is an hourly summary of any AC or DC power problems that occurred during the previous hour.
  - The *Nephelometer Status Code,* generated by the nephelometer, indicates the type of measurement (ambient, clean air zero, or span calibration), or problem (rain or lamp out).
  - The *Data Type Code* indicates the source of the nephelometer data (serial or analog).

- Meteorological data are not assigned Level-A validity codes. Meteorological parameter values that exceed the field sizes of the Level-A file are set to -99.

5-Minute Analog Data

```
01+0163.  02+2019.  03+0059.  04+0755.  05+582.6  06+0999.  07+2.234  08+097.1
```

Element #	Description
01	Datalogger program array identifier
02	Year
03	Julian date
04	Time (HHMM) at the end of the data period
05	Nephelometer A1 channel (mV x 2.0)
06	Nephelometer A2 channel (mV x 2.0)
07	Ambient air temperature (°C)
08	Ambient relative humidity (%)

5-Minute Serial Data

```
01+0119.  02+2019.  03+0059.  04+0757.  05+1.000  06+0891.  07+3493.  08+510.0
09+2.000  10+3.510  11+2.000  12+0755.  13+509.3  14+0999.  15+2.456  16+097.1
```

Element #	Description
01	Datalogger program array identifier
02	Year
03	Julian date
04	Time (HHMM) the serial stream was received by the datalogger
05	Nephelometer status code
06	Nephelometer raw scattered light reading (counts)
07	Nephelometer direct light reading (counts)
08	Nephelometer normalized scattered light reading (counts)
09	Nephelometer integration time (minutes)
10	Nephelometer chamber temperature (°C)
11	Not used
12	Nephelometer time (HHMM)
13	Nephelometer A1 channel (mV x 2.0)
14	Nephelometer A2 channel (mV x 2.0)
15	Ambient air temperature(°C)
16	Ambient relative humidity (%)

Hourly Code Summary

```
01+0104.  02+2019.  03+0059.  04+0800.  05+50.00  06+0.000
```

Element #	Description
01	Datalogger program array identifier
02	Year
03	Julian date
04	Time (HHMM) at the end of the data period
05	Nephelometer code summary for the past hour
06	Support system code summary for the past hour

The nephelometer code summary is the sum of any or all of the following:

Code	Description
50	Ambient reading
100	Clean air calibration
300	Span calibration
500	Lamp burned out
1000	Precipitation event detected

The support system code summary is the sum of any or all of the following:

Code	Description
300	Datalogger power low (CR10, 21X, or 23X)
500	DC power supply voltage low
1000	AC power outage
2000	Blue Earth serial data buffer restarted

Figure 6-2. Raw Modem or Storage Module Data File Format.

- Data at this point are at Level-A validation. Level-A files are located in the O:/neph/daily directory of the ARS computer network. Figure 6-4 shows an example Level-A validated data file and the associated validity codes.

```
MACA2
NGN-2-089 (LED)
Number 8
  63.94
 160.25
----------
----------
----------
09-24-2019 12:07:20
YR    JD HHMM ZERO    SPAN    AT      CT      RH      M A      F         COMMENT
2017,250,1355,-099.00,0160.25,020.33,022.14,047.77,1,1,F 12/22/2017,
2017,250,1401,-099.00,0160.20,020.25,-99.00,047.39,A, ,F 12/22/2017,
2017,250,1406,-099.00,0159.50,020.25,-99.00,047.75,A, ,F 12/22/2017,
2017,250,1411,-099.00,0159.50,020.73,-99.00,047.20,A, ,F 12/22/2017,
```

<u>Field (separated by commas)</u>
Year
Julian Date
Time (HHMM)
Clean Air Calibration or -99 (counts)
Span Calibration or -99 (counts)
Ambient Temperature (°C)
Nephelometer Chamber Temperature (°C)
Relative Humidity (%)
Manual Validity Code (1=Valid serial, A=Analog, Other=Invalid)
Automatic Validity Code (1=Valid serial, Other=Invalid)
Final Processing has been conducted if this field contains an F
Comment (no commas allowed in comment)

Figure 6-3. Example Nephelometer QA Calibration File.

```
ARSDATA 2016-04-29 07-01-2019 06:01:40-------------------------------------------------------
---------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------
GRBA2 20190401 091 0000  21   88.50   88.50 -99.00 -99.00 -99.000 -99.00   0.44  62.77    -99
GRBA2 20190401 091 0005  10   88.37   88.50 -99.00 -99.00 -99.000   0.26  -0.01  65.78   2150
GRBA2 20190401 091 0010  10   88.45   88.50 -99.00 -99.00 -99.000   0.26   0.13  64.16   2148
GRBA2 20190401 091 0015  10   87.69   88.50 -99.00 -99.00 -99.000   0.26   0.26  64.02   2144
GRBA2 20190401 091 0020  10   88.62   88.50 -99.00 -99.00 -99.000   0.23   0.19  64.16   2144
GRBA2 20190401 091 0025  10   85.82   85.80 -99.00 -99.00 -99.000   0.29   0.33  63.41   2144

                                         Column Number
         1         2         3         4         5         6         7         8         9
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
```

Columns	Description
1-5	Site abbreviation (five characters)
7-10	Year
11-12	Month
13-14	Day
16-18	Julian Date
20-21	Hour
22-23	Minute
24	Power Code (Space = No power failure)
25	Nephelometer status code (1-9)
26	Nephelometer Data Type Code (0=Serial 1=Analog)
28-33	Nephelometer Serial Calculated Normalized Reading (Counts)
35-40	Nephelometer Analog Reading (1 mVDC = 1 Count)
42-47	Not used
49-54	Not used
56-62	Not used
64-69	Nephelometer Chamber Temperature (°C)
71-75	Ambient Temperature (°C)
77-81	Relative Humidity (%)
83-86	Nephelometer Direct Light Intensity (Counts); -99 when analog reading

Figure 6-4. Level-A Validated Nephelometer Data File Format.

6.2.2 <u>Review of Data</u>

After Level-A validation, the data analyst visually reviews the raw and Level-A data file listings and operator log sheets received from the monitoring locations to identify operational problems and initiate corrective procedures. Level-A validated data are plotted weekly using the NGN_plot.exe software. The plots are posted and visually reviewed by the data analyst, field specialist, and project manager. Comments regarding the operation of the nephelometer are noted on the plots. An example weekly plot is shown in Figure 6-5. If a new problem is identified beyond those discovered in the daily data review, corrective actions are initiated.

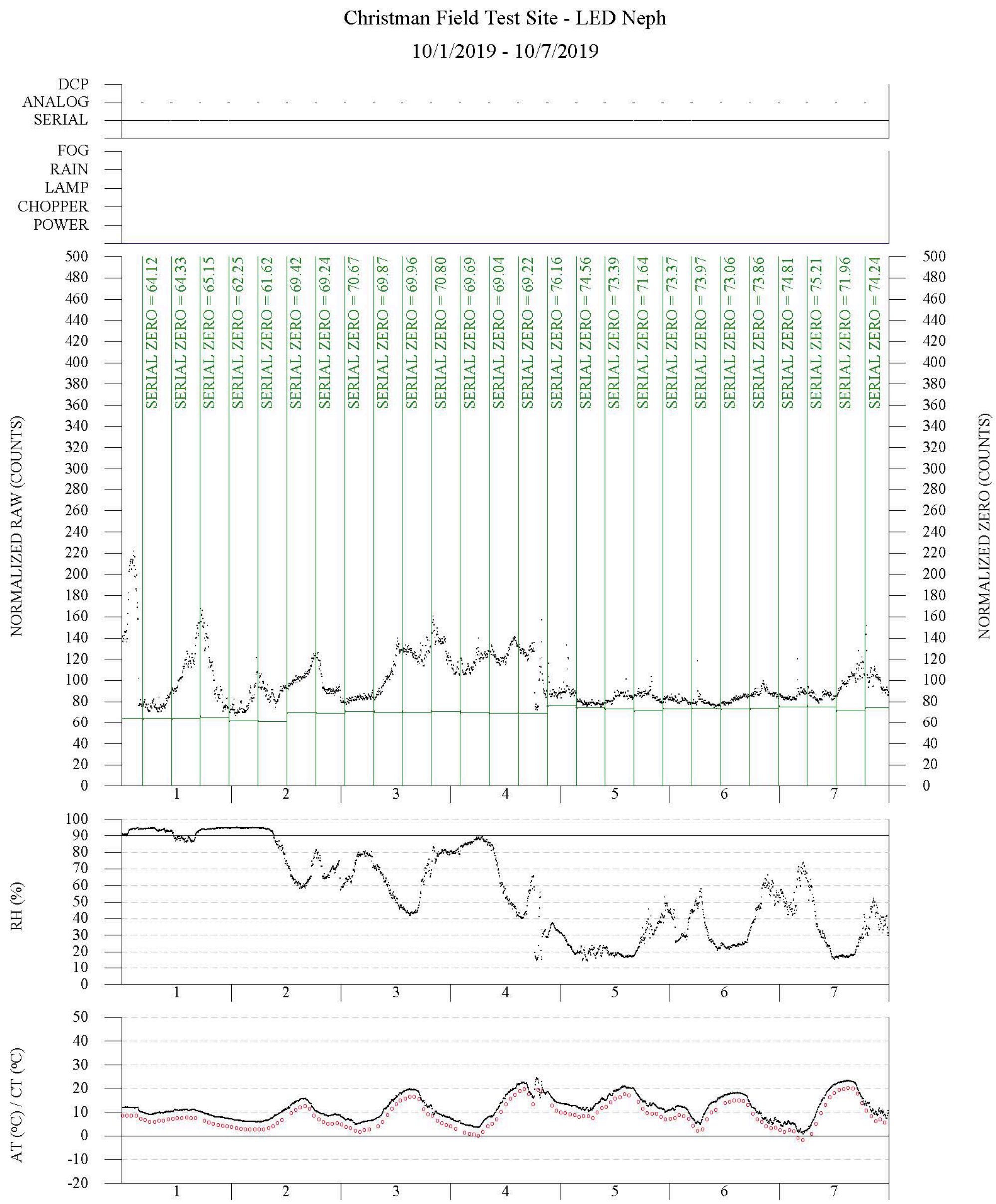

Figure 6-5. Example Weekly Plot of Level-A Validated Nephelometer and Meteorological Data.

6.3 QUARTERLY REDUCTION AND VALIDATION PROCEDURES

During daily Level-A validation, data are appended to calendar quarter data files for each site. Calendar quarters are defined as:

1st Quarter	(January, February, and March)
2nd Quarter	(April, May, and June)
3rd Quarter	(July, August, and September)
4th Quarter	(October, November, and December)

The file structure at this point in validation is *xxxxx*_N.*yyq*, where *xxxxx* is the five-character site code, N indicates nephelometer data, *yy* is the year, and *q* is the quarter (1, 2, 3, or 4). Quarterly reduction and validation includes blank-filling of files to ensure they represent full calendar quarters, updating code files and calibration files, and processing through Level-0 and Level-1 validation. Processing at each level is outlined in Figure 6-1, Nephelometer Data Processing Flowchart, and described in the following subsections.

6.3.1 <u>Blank-Fill Level-A Files</u>

All Level-A nephelometer files must be blank-filled to ensure they represent full calendar quarters, as defined above. Final blank-filling of Level-A files is performed using NGN_Neph_Data_Check.exe software. This action should be performed prior to quarterly reduction and validation procedures.

BLANK-FILL LEVEL-A FILES

Blank-fill Level-A nephelometer files as follows (refer to Figure 6-6):

- Select the directory where the files reside.
- Select **Level-A Check (_N)** under *Processing Choice*.
- Select one or more files to blank-fill, then click on the double arrow (>>) button.
- Click **GO**.
- Information related to the progress of individual files will be displayed at the top of the program screen.

Figure 6-6. NGN_Neph_Data_Check.exe Screen Display for Level-A Checks.

CREATE ENTIRE BLANK-FILLED LEVEL-A FILES

Create an entire blank-filled Level-A quarterly file as follows (refer to Figure 6-6):

- Select the directory where the files reside.
- Select **Level-A Check (_N)** under *Processing Choice*.
- Click **Add Blank Quarter** (_N).

- At the prompt, fill in the site abbreviation, year, and quarter for the desired blank-filled file.

CHECK RESULTS

Any dates that required blank-filling will be documented in the file PreProcess.txt. This file should be reviewed for consistency and to be sure that no unexpected or incorrect blank-filling was performed.

6.3.2 Update Code Files

The QA code files are site-specific files (*xxxxx*_C, where *xxxxx* is the 5-character site abbreviation) containing the time-tagged operational history of each site. Specifically, each file includes:

- QA codes entered manually during Level-A validation, that identify periods as invalid
- Precision estimates for nephelometer and meteorological instrumentation.
- QA calibration file names.
- The factor to convert Rayleigh scattering from 550 nm to 530 nm (if using an LED nephelometer), which is 1.1597.
- The angstrom exponent used to convert particle scattering from 530 nm to 550 nm (if using an LED nephelometer); the default is 1.0.
- The Rayleigh coefficient for 550 nm expressed in km^{-1}.

Editing the QA code files is the only method of manually invalidating data. Quarterly updating of the QA code files includes:

- Filing log sheets.
- Entering Level-A plot review information in the QA code files.
- Editing the Rayleigh coefficient
- Specifying if the nephelometer used had an LED light source. (See Appendix C for a discussion of how LED nephelometer scattering is converted to the equivalent scattering when using the older style incandescent lamps.)

Hardcopy log sheets are chronologically filed by site. Periods identified in the review of Level-A data as invalid are recorded in the site-specific QA code files. The following codes are used in the QA code files:

1: Valid
x: Invalid (*x* = any other character)

Figure 6-7 shows an example QA code file.

```
Grand Teton National Park
Nephelometer Calibration File
8/14/19

1.1597
1.0
0.009453085
----------------------------------------------------------------------------------------------------
-
YEAR  JUL TIME  LAMP NCODE N-PR CT-CODE  CT-PR AT-CODE AT-PR RH-CODE RH-PR    QA File,  Comment
----------------------------------------------------------------------------------------------------
-
2011,   182, 0000, 1,   M,   0.05,   1,     1.0,   1,     1.0,    1,    2.0,   159_1.QA, #LED# dummy
line for beginning of quarter - instrument not yet installed - JCB!
2011,   242, 1510, 1,   1,   0.05,   1,     1.0,   1,     1.0,    1,    2.0,   159_1.QA, #LED# ARS on
site - instrument installed and power on - JCB!
2011,   311, 1530, 1,   1,   0.07,   1,     1.0,   1,     1.0,    1,    2.0,   159_2.QA, #LED# ARS on
site - SUVA leak detected - started a new QA file - JCB!
2011,   341, 1840, 1,   2,   0.07,   1,     1.0,   1,     1.0,    1,    2.0,   159_2.QA, #LED# lamp
out code (false - LED) - JCB!
2011,   342,  945, 1,   1,   0.07,   1,     1.0,   1,     1.0,    1,    2.0,   159_2.QA, #LED# neph
power reset via IP - valid readings resume - lamp not out - JCB!
```

Field	Description
YR	Year
JUL	Julian Date
TIME	Time (HHMM)
LAMP	Lamp number
NCODE	Nephelometer validity code (1 = valid, Other = invalid)
N-PR	Nephelometer factory-defined precision (%, 0.20 = 20%)
CCODE	Chamber temperature validity code (1 = valid, Other = invalid)
CT-PR	Chamber temperature factory-defined precision (°C)
ACODE	Ambient temperature validity code (1 = valid, Other = invalid)
AT-PR	Ambient temperature factory-defined precision (°C)
RCODE	Relative humidity validity code (1 = valid, Other = invalid)
RH-PR	Relative humidity factory-defined precision (%)
QA FILE	Name of the QA calibration file in use
COMMENT	Comment – No commas allowed; Specify LED nephelometers with #LED# at the beginning of each applicable comment line

Figure 6-7. Example Nephelometer QA Code File.

6.3.3 Update Calibration Files

The QA calibration files are nephelometer-specific files containing all zero and span calibrations performed on a nephelometer during a specific time period, including the initial zero and span performed during installation. The calibration information in the QA calibration files are used during data reduction to calculate the scattering coefficient based on the nephelometer raw data and to estimate the precision of that data. The files also include parameters used by software to help identify invalid calibrations.

The QA calibration file names are defined in the QA code files. The file structure is *xxx*_N.qa, where *xxx* is the instrument number, N is the number of QA file for the instrument (1, 2, 3, etc.), and qa indicates this is a QA file. A new QA calibration file must be defined for the following reasons:

- A new nephelometer was installed at the site.
- A significant change in the nephelometer's operation was indicated by the raw data.

There may be several QA calibration files defined in each QA code file. This usually indicates that the nephelometer (or another nephelometer) has been installed more than once.

The quarterly update of QA calibration files includes the following:

- Update of the QA file header information.
- Generation of preliminary QA calibration plots and uncertainty estimates
- Review and manual validation of QA file entries
- Generation of final QA calibration plots and uncertainty estimates

Each QA calibration file header must be updated manually to include correct information for the parameters detailed in Figure 6-3, including:

- Site and instrument number
- Nephelometer operational cycle number
- Initial zero and span calibration

The QA calibration file header can be edited using the NGN_seas.exe software (described below) or using any ASCII text editor.

The data analyst uses NGN_QA.exe software to generate QA calibration plots showing nephelometer zero and span calibrations recorded in the instrument-specific QA calibration files, and an estimate of the precision of the nephelometer data based on those calibrations.

GENERATE PRELIMINARY PLOTS AND UNCERTAINTY ANALYSIS

Execute the NGN_QA.exe software. The display will appear as shown in Figure 6-8.

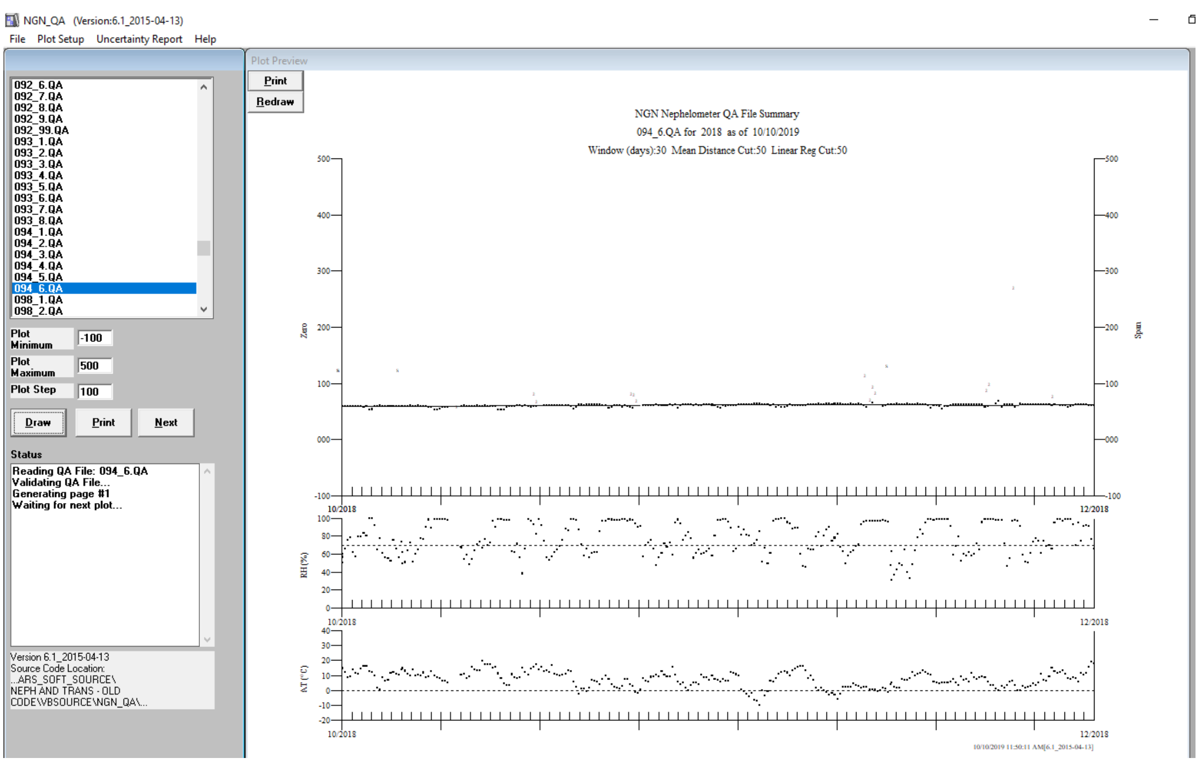

Figure 6-8. NGN_QA Software Display.

Highlight the QA calibration files to plot. The files will be plotted with at most, one year of information per plot.

The highlighted plots can be plotted to the screen or printer. An example plot is shown in Figure 6-9 and an example uncertainty analyses is shown in Figure 6-10. The following procedures are used to generate the plots and uncertainty analysis:

- Highlight the file(s) to plot. Click **Draw** (refer to Figure 6-8) and the plot will appear on screen, or **Print**, and the plot will go to printer. Click **Next** to view the next plot.
- Highlight the file desired for an uncertainty analysis report. Click **Uncertainty Report** from the top toolbar (refer to Figure 6-8). Choose **Display Uncertainty Report,** for the plot to appear on the screen, or **Print Uncertainty Report** for the plot to go to the printer.

The NGN_QA.exe software does not change the calibration data in the QA file – it simply identifies which calibrations will be identified as invalid during Level-0 and Level-1 data validation.

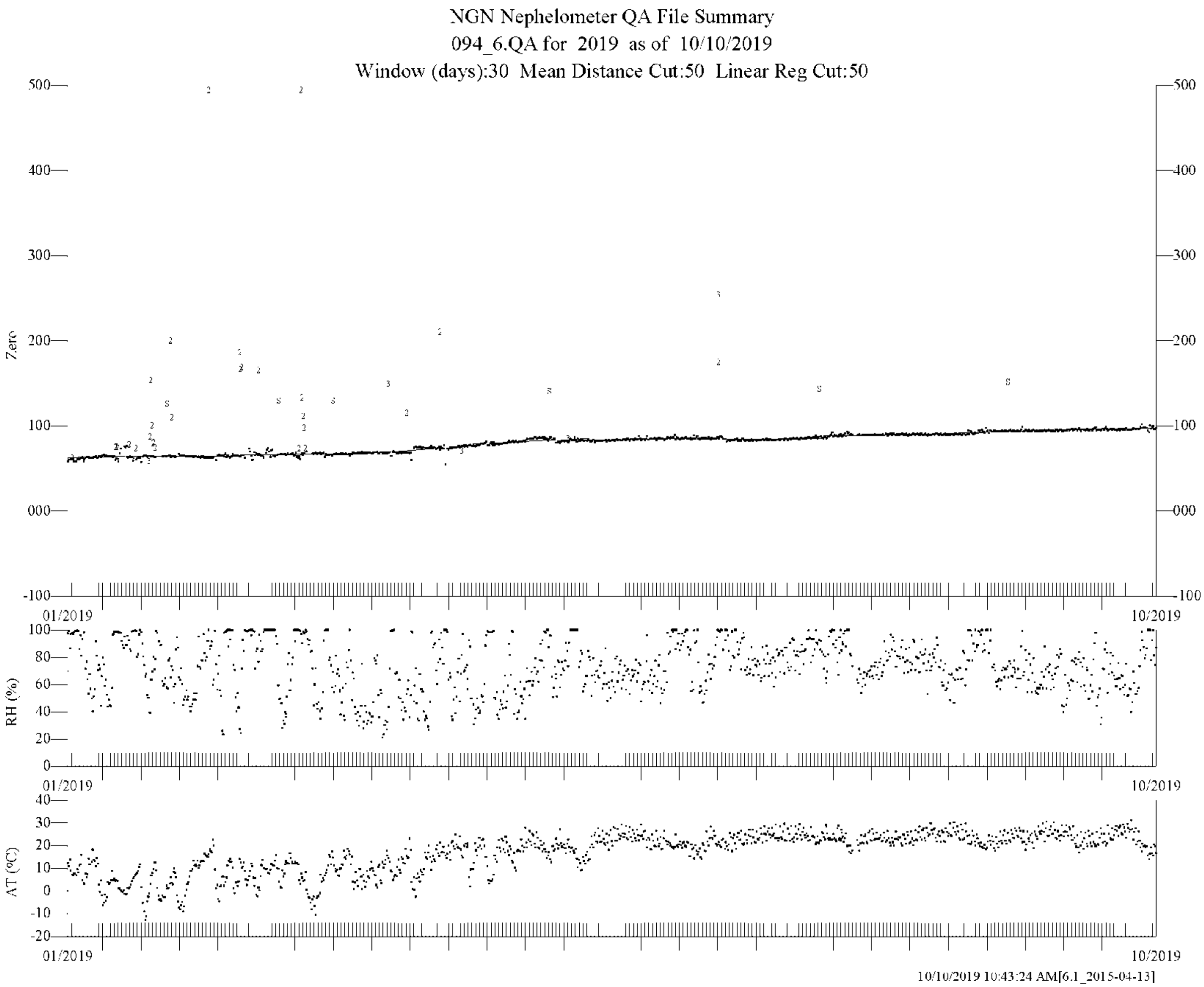

Figure 6-9. Example QA Calibration File Plot.

```
Nephelometer QA File Uncertainty Analysis - 10/10/2019

File:094_6.QA


---------------------------------------------------------
Rayleigh (1/Mm)  (b,spo): 10.636
Span (1/Mm) (b,spf):      75.515590
---------------------------------------------------------

The following calibration checks were made:

YEAR/MM/DD  JD TIME ZERO        YEAR/MM/DD  JD TIME SPAN      DIFF     SLOPE m(t)
----------------------------------------------------------------------------
2018/10/17 290 1340 0059.900    2018/10/17 290 1325 0125.600  0065.700 0000.987513
2018/10/17 290 1430 0059.700    2018/10/17 290 1410 0125.230  0065.530 0000.990075
2018/10/23 296 1340 0059.630    2018/10/23 296 1325 0125.460  0065.830 0000.985563
2018/12/11 345 1225 0062.890    2018/12/11 345 1210 0133.010  0070.120 0000.925265
2019/01/28 028 1320 0064.140    2019/01/28 028 1305 0131.690  0067.550 0000.960468
2019/02/26 057 1320 0065.820    2019/02/26 057 1300 0135.100  0069.280 0000.936484
2019/03/12 071 1200 0066.880    2019/03/12 071 1140 0135.140  0068.260 0000.950478
2019/05/07 127 1310 0079.940    2019/05/07 127 1255 0145.860  0065.920 0000.984217
2019/07/16 197 1345 0085.260    2019/07/16 197 1325 0148.680  0063.420 0001.023015
2019/09/03 246 1320 0093.790    2019/09/03 246 1305 0156.790  0063.000 0001.029835

---------------------------------------------------------
Mean Span-Zero Difference:      66.461
Std. Dev. Span-Zero Difference: 2.336
---------------------------------------------------------

Mean of the slopes:      0.977291
Std. Dev. of the slopes: 0.034335
Number of samples:       10
Degrees of freedom:      9
T value:                 2.262
Uncertainty: 0.0786  (7.8647%)
```

Figure 6-10. Example Uncertainty Analysis.

REVIEW PLOTS

The data analyst reviews the preliminary QA calibration plots to identify invalid zero and span calibrations caused by incorrect nephelometer operation. The plots show the following:

- Zero calibrations that pass all software validation tests [**.**]
- Span calibrations coded as valid [**s**]
- Zero calibrations that fail at least one software validation test [**m, r, >, <**]
- Manually invalidated zero or span calibrations [**I, 2**, or **3**]
- Ambient temperature and relative humidity [**.**]

Zero calibrations are identified as invalid (code r, m, >,<) for the following reasons:

- Mean Test (**m**) - In a given window of time (30 days), the zero calibration exceeds the mean of all valid zeros in the window by a defined number of counts (50).
- Linear Regression (**r**) - In a given window of time (30 days) the zero calibration exceeds the linear best fit value through the valid zeros in the Test window by a defined number of counts (50).
- Absolute Minimum (<) or Maximum (>) - The zero calibration raw counts are less than the defined absolute minimum (0) or greater than the defined absolute maximum (500).

Invalid calibrations *not identified by the software* must be invalidated manually by the data analyst. The NGN_seas.exe software or any ASCII text editor can be used to edit the QA calibration files. The following codes are used in the QA calibration file:

1:	Valid serial zero or span
A:	Valid analog zero or span
I, 2, or 3:	Invalid zero or span (invalid zero = I or 2, invalid span = I or 3)

Any code other than 1 is considered invalid by the NGN_seas.exe software during Level-0 and Level-1 data reduction. Analog calibrations are recorded in the QA calibration files for backup purposes only – they are not used for data reduction. If serial datalogging fails, analog calibrations can be coded with a 1 and used in place of serial data.

GENERATE FINAL PLOTS AND UNCERTAINTY ESTIMATES

Final QA calibration plots are generated after validating the zero and span calibrations based on the preliminary plots. Any invalid calibrations shown on the final plots as valid must be edited manually as described above. Uncertainty estimates generated during QA calibration plot review are entered manually in the QA code files. The uncertainty estimates appear in the Level-1 data file for reference.

6.3.4 Level-0 Validation

Level-0 validation of nephelometer and meteorological data is performed quarterly and serves as an intermediate data reduction step. Level-0 data validation includes:

- Reviewing Level-A data
- Updating the Nprocess.con constants file
- Level-0 validation processing procedures

The data analyst and project manager further review the Level-A nephelometer data and plots to identify periods of invalid nephelometer data caused by a burned out lamp, power failures, water contamination, or other problems. Level-A meteorological data are also reviewed to identify invalid periods caused by sensor failures. Corrective actions are initiated if required.

The nephelometer data validation constants file (Nprocess.con) is verified for correct information and contains the following:

Level-0 Validation Constants	Level-1 Validation Constants
Raw nephelometer underrange and overrange	Nephelometer raw standard deviation / mean filter
Raw nephelometer rate-of-change	Nephelometer b_{sp} rate-of-change filter
Ambient temperature underrange and overrange	Nephelometer b_{sp} RH filter
Relative humidity underrange and overrange	Nephelometer b_{sp} maximum filter

The Nprocess.con file must be updated as described in the following text with the correct data validation constants before Level-0 and Level-1 data validation can proceed. Figure 6-11 is an example nephelometer constants file.

```
NPROCESS.CON
Optec NGN-2 Nephelometer Data Processing Constants File
Last Update by: Carter B.
------------------------------------------------------------------------------------------------------------
     |   Min    |   Max    | Delta   |SD/MEAN|Delta |Max     |  RH   |   AT (C)           |    RH (%)      |  CT (C)        |
     |   raw    |   raw    |  raw    | bscat | bsp  |bscat   | bscat| Range Limits       | Range Limits | Range Limits |
Site | (counts)| (counts)|(counts)|  (%)  |(1/Mm)|(1/Mm)|  (%)  | Min Max  Delta| Min Max Delta| Min Max Delta|
------------------------------------------------------------------------------------------------------------
ACAD1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
ACAD2,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
BIBE1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
BOWA1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
CORI1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
DOSO1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
EBFO1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
GICL1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
GLAC2,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
GRGU1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
GRBA2,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
HANC1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
GRSM1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
JARB1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
LOPE1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
LYBR1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
MACA1,    0,      9999.0,    -99,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
MACA2,    0,      9999.0,    -99,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
MORA1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
MOZI1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
MOZI2,    0,      9999.0,    -99,      10,  50.0,   1000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
NACA1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
OKEF1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
ROMO3,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
SHEN1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
SHRO1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
SNPA1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
THSI1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
UPBU1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
VIIS1,    0,      9999.0,    100,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
QUAK1,    0,      5000.0,    200,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
CADZ1,    0,      5000.0,    200,      10,  50.0,   5000.0,   90,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
AFTC1,    0,      9999.0,    100,      10,  50.0,   5000.0,  -99,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
DALA1,    0,      9999.0,    100,      10,  50.0,   5000.0,   95,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
DALA2,    0,      9999.0,    100,      10,  50.0,   5000.0,   95,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
LTBV1,    0,      9999.0,    100,      10,  50.0,   5000.0,   95,  -30, 60,   5,   1,  110,   5,  -50, 50,   5
```

Figure 6-11. Nephelometer Constants (Nprocess.con) File.

Level-0 validated nephelometer data are generated from Level-A data by the NGN_seas.exe software using the following validation criteria:

- Nephelometer data with a Level-A nephelometer status code not equal to 1 are invalid at Level-0.
- Meteorological data with parameter values of -99 are invalid at Level-0.
- Nephelometer and meteorological data identified as invalid in the site-specific QA code files are considered invalid at Level-0.
- Out-of-range data and data whose rate-of-change between 5-minute values exceeds the specified criteria specified in the nephelometer constants file is invalid at Level-0. Table 6-1 lists the range and rate-of-change criteria for IMPROVE nephelometer and meteorological data.

Table 6-1

Nephelometer and Meteorological Level-0 Validation Range Criteria

Parameter	Underrange	Overrange	Rate-of-Change (per 5 minutes)
Nephelometer raw reading (counts)	0	9999	100
Ambient temperature (°C)	-30	60	5
Relative humidity (%)	1	110	5
Nephelometer chamber temperature (°C)	-50	50	5

Nephelometer data can be of any type (serial or analog) to be valid at Level-0 validation. The file naming structure for Level-0 data is *xxxxx*_N0.*yyq*, where *xxxxx* is the five-character site code, N indicates nephelometer data, 0 indicates Level-0, *yy* indicates year and *q* indicates quarter (1, 2, 3, or 4). The Level-0 data file format and validity code summary is shown in Figure 6-12.

GLAC2_N0.192

```
ARSDATA 2016-04-29 07-01-2019 06:01:10------------------------------------------------------------------------------------------
LEVEL-0: 09-24-2019 11:41:22 NGN_SEAS v7.20041104 EXE DATE:04/13/2015 16:07----------------------------------------------------
LEVEL-0: INPUT FILE: O:\neph\IMPROVE\2019\GLAC2_N.192 07/01/2019 06:01--------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------
 SITE YEARMMDD  JD HHMM    NORM PNTMV     CT 12     AT 12     RH 12 RMIN RMAX RDEL AMIN AMAX ADEL CMIN CMAX CDEL HMIN HMAX HDEL
GLAC2 20190401  91 0000   77.65 21011   3.04 11   3.03 11  84.00 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0005   79.55  1011   2.93 11   2.76 11  86.60 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0010   78.26  1011   2.93 11   2.83 11  86.00 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0015   82.04  1011   2.90 11   2.69 11  87.80 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0020   79.52  1011   2.84 11   2.76 11  86.50 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0025   77.63  1011   2.84 11   2.69 11  86.70 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0030   76.36  1011   2.81 11   2.76 11  86.30 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0035   75.73  1011   2.78 11   2.76 11  86.30 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0040   77.00  1011   2.81 11   2.76 11  86.50 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0045   76.36  1011   2.84 11   2.83 11  86.30 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0050   78.89  1011   2.81 11   2.76 11  86.50 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0055   77.60  1011   2.81 11   2.83 11  86.30 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0100   77.60 21011   2.78 11   2.83 11  86.40 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0105   79.50  1011   2.78 11   2.83 11  87.70 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0110   78.23  1011   2.75 11   2.83 11  86.60 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0115   78.86  1011   2.75 11   2.83 11  86.30 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0120   78.86  1011   2.72 11   2.76 11  87.00 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0125   78.86  1011   2.69 11   2.76 11  86.80 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0130   80.13  1011   2.75 11   2.76 11  87.50 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0135   80.13  1011   2.69 11   2.76 11  87.30 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0140   79.47  1011   2.60 11   2.69 11  87.70 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0145   79.47  1011   2.60 11   2.69 11  87.50 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0150   78.21  1011   2.55 11   2.70 11  87.10 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0155   77.58  1011   2.58 11   2.70 11  86.50 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0200   78.84 21011   2.55 11   2.70 11  85.70 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0205   79.47  1011   2.60 11   2.76 11  86.30 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0210   78.84  1011   2.58 11   2.69 11  86.20 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0215   80.10  1011   2.60 11   2.63 11  87.70 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0220   80.73  1011   2.52 11   2.56 11  87.50 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0225   78.21  1011   2.49 11   2.56 11  86.90 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0230   80.08  1011   2.49 11   2.63 11  86.70 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0235   79.47  1011   2.46 11   2.63 11  86.50 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0240   81.36  1011   2.46 11   2.35 11  88.80 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
GLAC2 20190401  91 0245   81.34  1011   2.37 11   2.35 11  88.80 11    0 9999  100  -30   60    5  -50   50    5    1  110    5
```

For Help, press F1 | Ln 94, Col. 60, C0 | DOS

Figure 6-12. Level-0 Validated Nephelometer Data File Format.

The following are the Level-0 data validation procedures:

EXECUTE PROCESSING SOFTWARE

Execute the NGN_seas.exe software. The display will appear as shown in Figure 6-13.

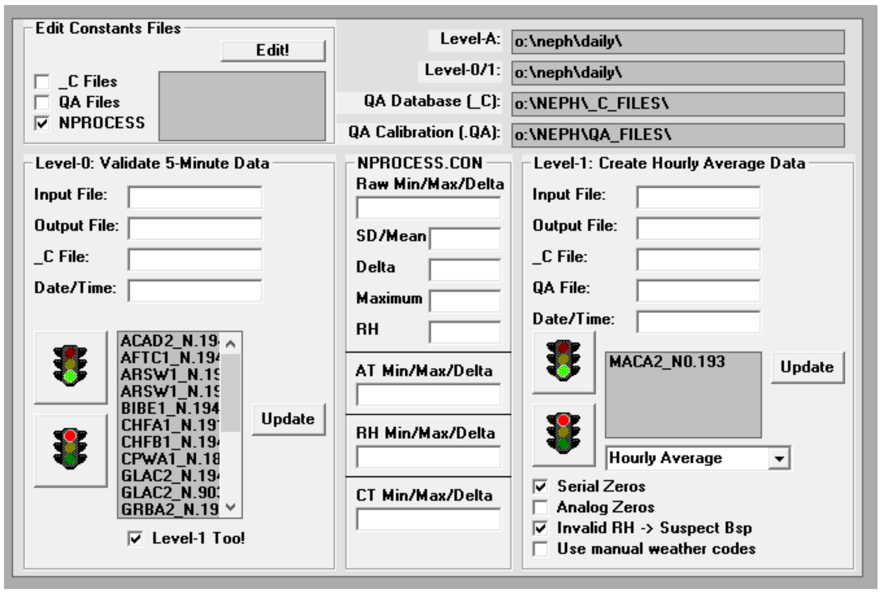

Figure 6-13. NGN_seas Software Display.

SET DATA DIRECTORIES

The directories for all files used by NGN_seas.exe area shown on the display. Set the Level-A directory to the location where the Level-A data files exist by clicking the Level-A directory box. A dialog box will appear which allows the user to change the directory. Set the correct directory for the Level-0/1, QA code, and QA calibration files the same way.

CHECK QA CODE FILES

Verify that the QA code (*xxxxx*_C) files have been updated correctly as follows:

- Click the **_C Files** box in the Edit Constants Files frame.
- Highlight the *file* to edit in the File to Edit box.
- Click the **EDIT!** button to load the file into the Windows Notepad editor.
- Verify that the file is correct. Save any changes and exit Notepad.
- Select all the files that require Level-0 validation.

CHECK QA CALIBRATION FILES

Verify that the QA calibration (xxx_N.qa) files have been updated correctly as follows:

- Click the **QA Files** box in the Edit Constants Files frame.
- Highlight the *file* to edit in the File to Edit box.
- Click the **EDIT!** button to load the file into the Windows Notepad editor.

The following validity codes are used to manually edit the QA calibration files:

1:	Valid serial calibration
I, 2, or 3:	Invalid
A	Valid analog calibration

- Verify that the file is correct. Save any changes and exit Notepad.
- Check all the files that will be required for Level-1 validation.

CHECK CONSTANTS FILE

Verify the Level-0 and Level-1 data validation constants are correct as follows:

- Click the **Nprocess.con** box in the Edit Constants Files frame.
- Highlight the *file* to edit in the File to Edit box.
- Click the **EDIT!** button to load the file into the Windows Notepad editor.
- Edit the constants as required in the file.
- Verify that the file is correct. Save any changes and exit Notepad.
- Check all the files that will be required for Level-1 validation.

START LEVEL-0 VALIDATION

Start Level-0 validation as follows:

- Click the **Update** button to update the list of available Level-A validated files to process.
- Highlight the Level-A validated file(s) to process.
- Click the **green light** icon to start Level-0 validation.
- Click the **red light** icon to stop any processing in progress.
- Each highlighted Level-A file will be processed in order. The Level-0 validated data will b output to the file shown in the Output File box.
- The Status box will show the current processing status. When all the highlighted files have been processed the status box will show DONE.

The input, output, QA code, and QA calibration file names being used for processing are updated on the NGN_seas.exe display.

CHECK ERRORS

Any errors encountered by NGN_seas.exe during data validation are recorded in the file NGN_seas.err. The number of errors will be displayed at the bottom of the display.

To check the errors click on **Errors** at the bottom of the display. The Notepad program will be invoked to view the error file. Correct any errors by updating the following files:

- QA code files
- QA calibration files
- Nephelometer constants file

6.3.5 Level-1 Validation

Level-1 validation of nephelometer and meteorological data is performed quarterly following Level-0 validation, and is typically the final validation level for IMPROVE nephelometer data. Level-1 validation of nephelometer and meteorological data is handled by the NGN_seas.exe software, which handles the following tasks:

- Computation of hourly averages from Level-0 data
- Automatic validation of QA calibration file entries
- Conversion of hourly average data to engineering units
- Overrange/underrange checks
- Identification of nephelometer b_{sp} data affected by meteorological interference
- Estimation of precision

Level-1 data files are checked for completeness and parameter integrity once all other validation steps have been completed. This file integrity check is performed using the NGN_Neph_Data_Check.exe software. The software checks for the following:

- The site abbreviation is consistent throughout the file.
- The date, Julian date, and time sequences are correct.
- The b_{sp} is between -2 and 5000 Mm^{-1} for a nephelometer validity code of 0.
- The Precision is not 0.
- The Validity Code is 0, 1, 2, or 9.
- The Weather/Interference Code is A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, or Z.
- The AT is -99 or between -30°C and +60°C.
  (An additional check is made to alert the user if AT is between -30°C and -20°C).
- The AT # value is 0 if AT = -99, or 1-12 if AT $\neq$ -99.
- The CT is -99 or between -50°C and +50°C.
- The CT # value is 0 if CT = -99, or 1-2 if CT $\neq$ -99.
- The RH is -99, or between 1% and 110%.
- The RH # value is 0 if RH = -99, or 1-12 if RH $\neq$ -99.

COMPUTE HOURLY AVERAGES

Level-1 hourly averages are computed from Level-0 validated data for nephelometer and meteorological parameters. The data in an hourly average period includes the data following the hour. For example, the hourly average for 1100 includes data from 1100 through 1159.

VALIDATE QA CALIBRATION FILE ENTRIES

The zero calibration information in the QA calibration files is used to calculate a calibration line for each nephelometer data point. Validation of QA zeros is detailed in Section 6.3.2.

CONVERT DATA TO ENGINEERING UNITS

Meteorological data (ambient and chamber temperatures and relative humidity) are already in engineering units. The nephelometer particle scattering coefficient (b_{sp}) is calculated by determining a calibration line for each raw nephelometer scattering data point as follows:

- The zero is determined by interpolating (in time) between the valid clean air calibrations prior to, and following the data point.
- The *initial span* is determined from the initial calibration of the instrument upon installation.

Initial Span = Initial upscale span gas calibration – Initial clean air calibration

- The Rayleigh coefficient is the site-specific altitude-dependent scattering of particle-free air.
- The *designated span* is determined by the span gas used during the initial calibration, and the Rayleigh coefficient. The span gas SUVA (HFC-134a) (Dupont) has been shown to scatter 7.25 times that of particle-free (Rayleigh) air.

Designated Span = 7.25 x Rayleigh

- The slope and intercept of the calibration line are:

Slope = (Designated Span – Rayleigh) / Initial Span
Intercept = – (Slope x Zero)

- Nephelometer data and calibrations are in unitless counts. If the units for the Rayleigh coefficient are Mm^{-1}, the units for b_{sp} will also be Mm^{-1}. Nephelometer scattering (b_{sp}) is calculated from the calibration line as follows:

$$b_{sp} = (Slope \times raw\ nephelometer\ value) + Intercept$$

OVERRANGE/UNDERRANGE CHECKS

The following additional validation checks are performed to complete Level-1 validation:

- Data invalid at Level-0 is invalid at Level-1
- Calculated b_{sp} data less than 80% of Rayleigh scattering is invalid
- Meteorological data is not validated beyond Level-1

The file naming structure for Level-1 data is xxxxx_N1p.yyq, where xxxxx is the five-character site code, N indicates nephelometer data, 1 indicates Level-1 data, p is the averaging period in hours (default = 1), yy is the year, and q is the quarter (1, 2, 3, or 4). The file format for Level-1 validated data is provided in Figure 6-14.

IDENTIFY DATA AFFECTED BY METEOROLOGICAL INTERFERENCE

Nephelometer data is filtered to identify periods likely affected by meteorological interference. See Appendix A for detailed filter criteria.

Nephelometer data identified as affected by meteorological interference is still considered valid. An additional validity code is assigned to the hourly average data point in the Level 1 file as shown in Figure 6-14.

```
ARSDATA 2016-04-29 07-01-2019 06:00:40----------------------------------------------------------------------------------------------------------------
LEVEL-0: 09-24-2019 11:36:54 NGN_SEAS v7.20041104 EXE DATE:04/13/2015 16:07-------------------------------------------------------------------------
LEVEL-0: INPUT FILE: O:\neph\IMPROVE\2019\BIBE1_N.192 07/01/2019 06:00----------------------------------------------------------------------------
LEVEL-1: 09-24-2019 11:40:58 NGN_SEAS v7.20041104 EXE DATE:04/13/2015 16:07-------------------------------------------------------------------------
LEVEL-1: Rayleigh= 10.45 Span Mult= 7.25 QA Search Flags:1 1-----------------------------------------------------------------------------------------
LEVEL-1: NEPHCOMMON LIBRARY VERSION:-----------------------------------------------------------------------------------------------------------------
LEVEL-1: INPUT FILE: O:\neph\IMPROVE\2019\BIBE1_N0.192 09/24/2019 11:40----------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------------------------
 SITE YEARMMDD  JD HHMM INS  BSP    PREC V A   RAW-M  RAW-SD  #   N/A  SD/M   DEL    MAX  RH 0123456789mPMOT  YINTER   SLOPE     AT  AT-SD  #  AT-PR    CT  CT-SD  #  CT-PR     RH  RH-SD  #  RH-PR N/A
BIBE1 20190401  91 0000 071    6   0.140 0     76.08    0.92 12 -99.0  10.0    50   5000  90 0C000000000000   -54.8    0.94   8.32   0.26 12   1.00   8.07   0.26 12   1.00  37.79   0.81 12   2.00XXXX
BIBE1 20190401  91 0100 071    6   0.140 0     75.66    0.75 12 -99.0  10.0    50   5000  90 0C000000000000   -54.8    0.94   8.07   0.20 12   1.00   7.70   0.13 12   1.00  39.02   0.80 12   2.00XXXX
BIBE1 20190401  91 0200 071    6   0.140 0     75.86    0.72 12 -99.0  10.0    50   5000  90 0C000000000000   -54.8    0.94   7.80   0.22 12   1.00   7.39   0.12 12   1.00  41.15   1.15 12   2.00XXXX
BIBE1 20190401  91 0300 071    7   0.140 0     76.43    0.58 12 -99.0  10.0    50   5000  90 0C000000000000   -54.8    0.94   7.00   0.13 12   1.00   6.68   0.17 12   1.00  44.96   0.63 12   2.00XXXX
BIBE1 20190401  91 0400 071    8   0.140 1 D   78.17    9.12 10 -99.0  10.0    50   5000  90 0A200000000023   -54.8    0.94   7.02   0.18 12   1.00   6.68   0.13  9   1.00  45.70   0.30 12   2.00XXXX
BIBE1 20190401  91 0500 071    7   0.140 0     77.05    1.72 12 -99.0  10.0    50   5000  90 0C000000000000   -54.7    0.94   5.74   0.30 12   1.00   5.60   0.37 12   1.00  47.91   1.30 12   2.00XXXX
BIBE1 20190401  91 0600 071    8   0.140 0     77.00    1.01 12 -99.0  10.0    50   5000  90 0C000000000000   -54.6    0.94   5.30   0.12 12   1.00   4.95   0.09 12   1.00  51.38   0.87 12   2.00XXXX
BIBE1 20190401  91 0700 071    8   0.140 0     77.79    0.67 12 -99.0  10.0    50   5000  90 0C000000000000   -54.4    0.94   5.62   0.35 12   1.00   5.37   0.40 12   1.00  51.14   0.92 12   2.00XXXX
BIBE1 20190401  91 0800 071    8   0.140 0     77.36    0.51 12 -99.0  10.0    50   5000  90 0C000000000000   -54.3    0.94   7.50   0.88 12   1.00   7.34   0.83 12   1.00  47.45   1.53 12   2.00XXXX
BIBE1 20190401  91 0900 071    7   0.140 0     76.09    0.85 12 -99.0  10.0    50   5000  90 0C000000000000   -54.1    0.94  10.40   0.58 12   1.00  10.36   0.58 12   1.00  42.53   1.43 12   2.00XXXX
```

<u>Field</u>	**<u>Description</u>**
SITE	Site Abbreviation
YYYYMMDD	Date (4-digit year/month/day)
JD	Julian Date
HHMM	Time using a 24-hour clock in hour/minute format
INS	Nephelometer Serial Number
BSP	b_{sp} (Mm^{-1})
PREC	b_{sp} Estimated Precision (%/100)
V	b_{sp} Validity Code (0 = valid, 1 = interference, 2 = invalid, 9 = suspect)
A	b_{sp} Interference Code[1]
RAW-M	Raw Nephelometer Hourly Average (Counts)
RAW-SD	Standard Deviation of Raw Nephelometer Average (Counts)
#	Number of Data Points in Hourly Nephelometer Average
N/A	(Not Used)
SD/M	Standard Deviation/Mean Interference Threshold
DEL	b_{sp} Rate of Change Interference Threshold
MAX	Maximum b_{sp} Interference Threshold
RH	Relative Humidity Interference Threshold
0123456789mPMOT	Composite Nephelometer Code Summary[2]
YINTER	Y-intercept of Calibration Line Used to Calculate b_{sp}
SLOPE	Slope of Calibration Line Used to Calculate b_{sp}
AT	Average Ambient Temperature (°C)
AT-SD	Standard Deviation of Hourly AT Average
#	Number of Data Points in Hourly AT Average
AT-PR	Estimated Precision of Ambient Temperature
CT	Average Nephelometer Chamber Temperature (°C)
CD-SD	Standard Deviation of Hourly CT Average
#	Number of Data Points in Hourly CT Average
CT-PR	Estimated Precision of Chamber Temperature
RH	Average Relative Humidity (%)
RH-SD	Standard Deviation of Hourly RH Average
#	Number of Data Points in Hourly RH Average
RH-PR	Estimated Precision of Relative Humidity
N/A	(Not Used)

[1] b_{sp} Interference Code:

Condition	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
RH > RH threshold	x		x		x		x		x		x		x		x
b_{sp} > maximum b_{sp} threshold		x	x			x	x			x	x			x	x
SD/M > uncertainty threshold				x	x	x	x					x	x	x	x
$\triangle b_{sp}$ > delta threshold								x	x	x	x	x	x	x	x

(Column heading over the letters: Letter Code)

Z Weather observation between two other weather observations.

Threshold values may be different for each site.

[2] Composite Nephelometer Code Summary:

0123456789	Nephelometer diagnostic code (internal use)
m	Number of missing data points
P	Number of power failure codes
M	Number of manual QA invalidation codes
O	Number of Level-0 invalidated data points
T	Number of times non-serial data were used

Figure 6-14. Level-1 Validated Nephelometer Date File Format.

ESTIMATE PRECISION

The following methods are used to estimate the precision of Level-1 validated data. Specific calculations for these estimates are presented in Appendix B.

- The precision of meteorological data are defined by the factory specified precision for the sensors. These precisions are recorded in the site-specific QA code files.

- The estimated precision of nephelometer data for a given time period is based on calibrations performed during that time period. The precision estimates are recorded in the site-specific QA code files and are automatically placed in the Level-1 data files.

6.3.5.1 Level-1 Validation Processing Procedures

Level-1 validation of nephelometer data, detailed above, is handled by the NGN_seas.exe software. The procedures for validating data to Level-1 are as follows:

EXECUTE PROCESSING SOFTWARE

Execute the NGN_seas.exe software. The display will appear as shown in Figure 6-13.

CHECK QA CALIBRATION FILES

The QA calibration files are nephelometer-specific files containing the automatic and manual clean air zero and span calibrations performed on the instrument. The clean air calibrations are used to calculate the calibration line for each nephelometer data point. Invalid calibrations must be coded as invalid in the QA calibration files, as described in the Level-0 validation section of this SOP.

CHECK NPROCESS FILE

The nephelometer constants (Nprocess.con) file contains the data validation constants used for Level-0 and Level-1 validation. Verify the constants in the file as described in the Level-0 validation section of this SOP.

START LEVEL-1 VALIDATION

Start Level-1 validation as follows:

- Click the **Update** button to update the list of available Level-0 validated files.
- Highlight the Level-0 validated file(s) to process.
- Click the **green light** icon to start Level-1 validation.
- Click the **red light** icon to stop any processing in progress.
- Each highlighted Level-0 file will be processed in order. The Level-1 validated data will be output to the file shown in the Output File box.
- The Status box will show the current processing status. When all the highlighted files have been processed the status box will show DONE.

The input, output, QA code, and QA calibration file names being used for processing are updated on the NGN_seas display.

CHECK ERRORS

Any errors encountered by NGN_seas during data validation are recorded in the file NGN_seas.err. The number of errors will be displayed at the bottom of the NGN_seas display.

To check the errors click on **Errors** at the bottom of the display. The Notepad program will be invoked to view the error file. Correct any errors by updating the following files:

- QA code files
- QA calibration files
- Nephelometer constants file

After updated the above files, start Level-0 and Level-1 validation again.

6.3.5.2 Level-1 File Check

The Level-1 file check (see section 6.3.5) is performed using NGN_Neph_Data_Check.exe software (refer to Figure 6-15).

PERFORM LEVEL-1 FILE CHECK

The procedures for running a Level-1 file check include:

- Select the directory where the files reside.
- Select **Level-1 Check (_N11)** under *Processing Choice*.
- Select one or more files to check, then click the double arrow (>>) button.
- Click **GO**.
- Information related to individual file progress will be displayed at the top of the program screen.

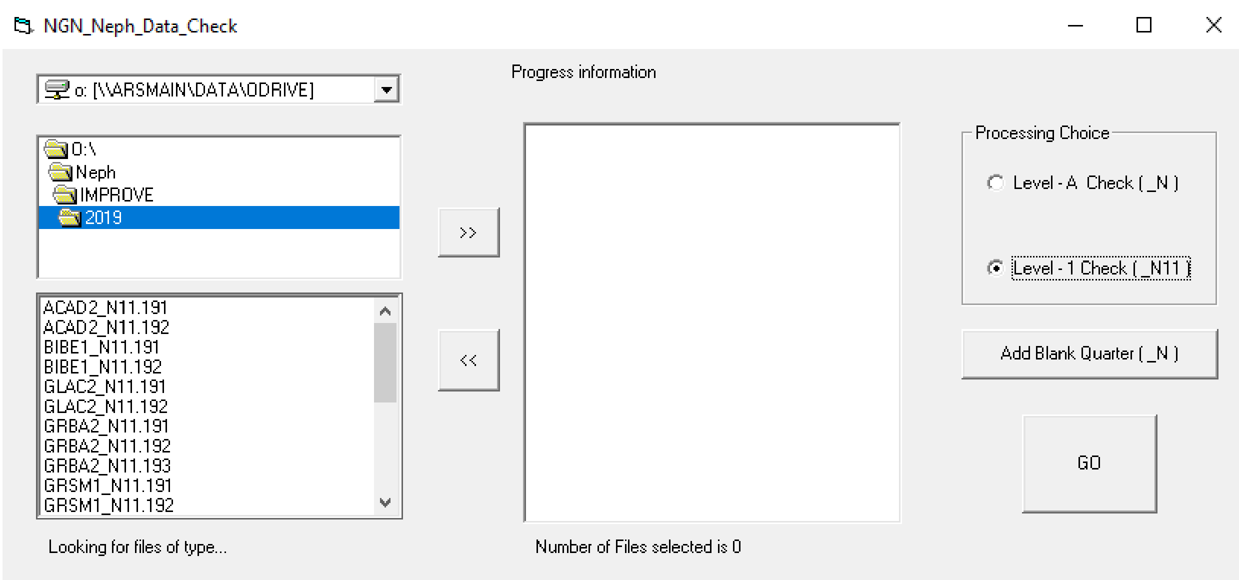

Figure 6-15. NGN_Neph_Data_Check.exe Screen Display for Level-1 Checks.

CHECK ERRORS

An error file called PostProcess.txt will be created. This file contains a summary of all problems encountered in each of the selected Level-1 files.

Any errors encountered by NGN_Neph_Data_Check.exe will be recorded in the file PostProcess.txt. This file can be opened in any text editor. All errors must be corrected prior to the data being considered final validated. The specific steps required to correct problems will vary according to the nature of the problems.

6.3.5.3 Quarterly Summary Plots

Quarterly summary plots are generated using the NGN_nsum.exe software. The following procedures describe the operation of the software:

EXECUTE PROCESSING SOFTWARE

Execute the NGN_nsum.exe software. The display will appear as shown in Figure 6-17.

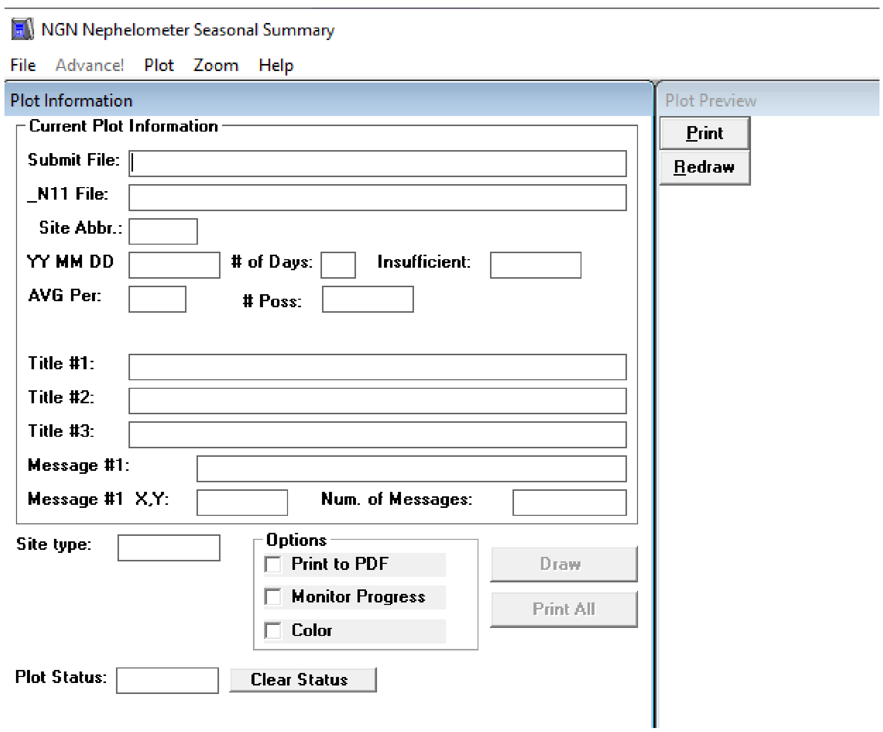

Figure 6-17. NGN_nsum Software Display.

EDIT THE SUBMIT FILE

The submit file defines the Level-1 validated data files and associated parameters used to generate the plots. Figure 6-18 details the format of the submit file. The following procedures are used to edit the submit file:

- Click on **File**. Click on **Edit Submit File**. The Windows Notepad program will be launched.
- Open an existing submit file or create a new one in Notepad.
- Save the submit file and exit Notepad.

GENERATE THE PLOTS

The plots defined in the submit file can be plotted to the screen or to any printer attached to the network. The following procedures are used to generate the plots:

- Choose the submit file to use by clicking **File** and then **Choose Submit File**. Select the submit file to use from the file selection box.
- Generate the plots defined in the submit file by clicking **Plot** and then **Plot All Plots** (printer) or **Plot To Screen** (screen).

The plots defined in the submit file will be sent to the printer selected by the user after clicking Plot All Plots.

nsum192.sbm

```
ACAD2_N11.192
ACAD2
2019,4,1
91
0
1
-99
4
0
ACADIA NATIONAL PARK, MAINE
IMPROVE Nephelometer Data Summary
Second Quarter: April 1, 2019 - June 30, 2019


-99
12

-99,-99
BIBE1_N11.192
BIBE1
2019,4,1
91
0
1
-99
4
0
BIG BEND NATIONAL PARK, TEXAS
IMPROVE Nephelometer Data Summary
Second Quarter: April 1, 2019 - June 30, 2019


-99
12

-99,-99
GLAC2_N11.192
GLAC2
2019,4,1
91
0
1
-99
4
```

Figure 6-18. NGN_nsum Software Submit File Format.

Quarterly summary plots of Level-1 validated data are reviewed by the data analyst, project manager, and program manager to identify the following:

- Data reduction and validation errors
- Instrument operational problems
- Calibration problems

Problems identified in the Level-1 quarterly summary plot review are resolved by editing the QA code and/or calibration files to identify additional data as valid or invalid and performing the Level-0 and Level-1 validation procedures again. Once all changes have been made the data analyst processes the Level-1 files again using the **Final Processing** command (see upper left-hand commands in Figure 6-13) in the NGN_seas.exe program. Final processing will "lock down" the QA files used for the season by placing an F code in the comments field in each row of the QA files.

When the Level-1 quarterly summary plots have passed the review process, the raw through Level-1 validated data and associated QA files are archived as described in TI 4600-5000, *Nephelometer Data Archives (IMPROVE Protocol)*.

Level-1 validated nephelometer and relative humidity data are summarized in quarterly summary plots. Figure 6-16 shows an example quarterly summary plot. The plots are described in detail below:

- **4-Hour Average Variation in Visual Air Quality (Filtered Data)**
  Timeline of 4-hour average scattering data filtered to remove data affected by meteorological interference. The data are plotted as b_{sp} (Mm^{-1}).

- **Relative Humidity**
  Timeline of hourly relative humidity. Note that periods of high scattering are often associated with periods of high relative humidity.

- **Frequency of Occurrence and Cumulative Frequency Summary**
  Frequency of occurrence distribution of hourly scattering data, both unfiltered and filtered for meteorological interference. The 10% to 90% values are plotted in 10% increments and are summarized in the table next to the plot. The 50% values represents the median of the valid hourly averages.

- **Visibility Metric**
  Visibility statistics for data filtered for meteorological interference, including:
  - Mean of the cleanest 20% of valid data
  - Mean of all valid data
  - Mean of the dirtiest 20% of valid data

- **Nephelometer Data Recovery**
  Data collection statistics, including
  - Total number of hourly averages possible in the period
  - Number of valid hourly averages including filtered and unfiltered data
  - Number of valid hourly averages including filtered data only
  - Filtered data as percent of unfiltered and filtered data

ROCKY MOUNTAIN NATIONAL PARK, COLORADO
IMPROVE Nephelometer Data Summary
Second Quarter: April 1, 2019 - June 30, 2019

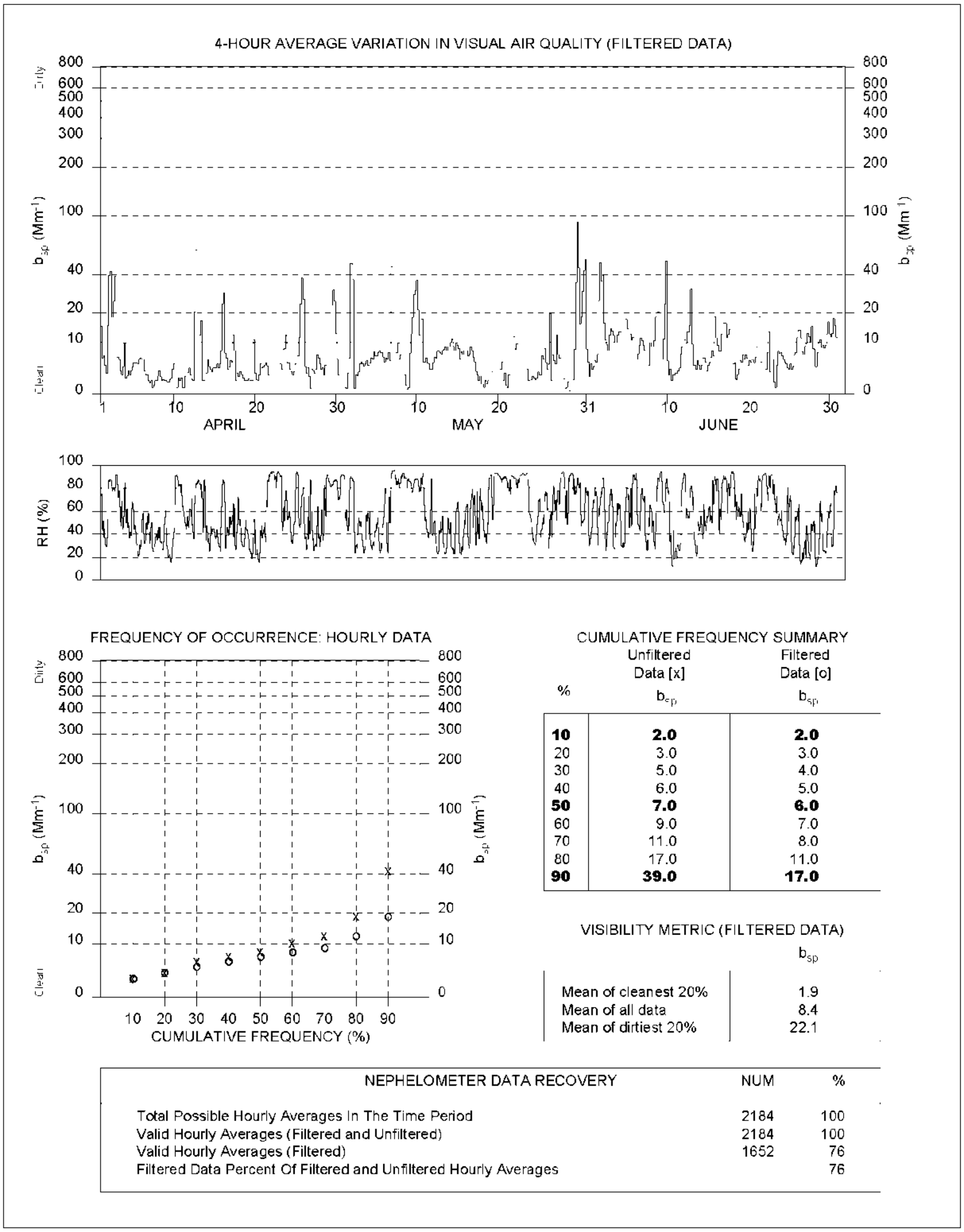

Figure 6-16. Example Level-1 Quarterly Summary Plot.

7.0 REFERENCES

Optec, Inc., 2000, Model NGN-2 Open-Air Integrating Nephelometer Technical Manual for Theory of Operation and Operating Procedures (August 2000).

8.0 DEFINITIONS AND ACRONYMS

ARS	Air Resource Specialists, Inc.
AT	Ambient Temperature
b_{ext}	Total atmospheric light extinction
b_{scat}	Total atmospheric light scattering
b_{sp}	Atmospheric light scattering due to particles
IMPROVE	Interagency Monitoring of Protected Visual Environments
LED	Light emitting diode
NGN	New Generation Nephelometer
QA	Quality assurance
RH	Relative humidity
SOP	Standard Operating Procedure
TI	Technical Instruction
VDC	Volts-direct current

APPENDIX A

IDENTIFICATION OF DATA AFFECTED BY METEOROLOGICAL INTERFERENCE

Nephelometer data are filtered to identify periods likely affected by meteorological interference. The following filter criteria (defined in the nephelometer constants file, Nprocess.con) are used to identify these periods:

- **Rate of Change** - If the rate of change between nephelometer hourly b_{sp} data exceeds the following threshold, the b_{sp} value is coded as filtered:
  Nephelometer b_{sp} rate-of-change threshold: 50 Mm^{-1}

- **Maximum** - If the nephelometer b_{sp} data exceeds the following threshold, the b_{sp} value is coded as filtered:
  Nephelometer b_{sp} maximum threshold: 5000 Mm^{-1}

- **Relative Humidity** - If the relative humidity corresponding to the nephelometer b_{sp} value exceeds the following threshold, the b_{sp} value is coded as filtered:
  Nephelometer b_{sp} RH threshold: 90%

- **σ/μ** - If the standard deviation of the hourly raw nephelometer data divided by the mean of the hourly raw nephelometer data exceeds the following threshold, the value is coded as filtered:
  Raw nephelometer σ/μ threshold: 10%

Nephelometer data identified as affected by meteorological interference is still considered valid. An additional validity code is assigned to the hourly average data point in the Level-1 file as shown in Figure 6-14.

APPENDIX B

ESTIMATING PRECISION IN NEPHELOMETER DATA VALIDATION AND PROCESSING

The following methods are used to estimate the precision of Level-1 validated data.

- The precision of meteorological data are defined by the factory specified precision for the sensors. These precision are recorded in the site-specific QA code files. Typical precisions of meteorological sensors are detailed in Table B-1.

Table B-1

Typical Factory-Defined Precisions of Meteorological Sensors

Sensor	Precision
Rotronics Ambient Temperature	± 0.5 °C
Rotronics Relative Humidity	± 2%
Optec NGN-2 Nephelometer Chamber Temperature	± 2°C

- The estimated precision of nephelometer data for a given time period is based on calibrations performed during that time period. The precision estimates for are recorded in the site-specific QA code files and are automatically placed in the Level-1 data files. The relative error (uncertainty) in scattering due to drift of the slope of the calibration line is evaluated based on the instrument-specific zero and span checks performed. The following statistical analysis was applied to calculate potential uncertainty:

$V(t)$ =	Normalized nephelometer reading at time t
$V_o(t)$ =	Normalized clean air reading at time t
$V_s(t)$ =	Normalized SUVA 134a reading at time t
$b_{scat,o}$ =	Scattering coefficient for clean air
$b_{scat,s}$ =	Scattering coefficient for SUVA 134a
V_o =	Average normalized clean air reading
V_f =	Average normalized SUVA 134a reading
b_{sp} (t) =	Theoretical scattering coefficient at time t
m =	Slope of the calibration line used to calculate the theoretical scattering coefficient bsp(t)

$$m = \frac{(b_{scat,s} - b_{scat,o})}{(V_s(t) - V_o(t))}$$

Given a normalized nephelometer reading $V(t)$, the theoretical b_{sp} at time t is:

$$b_{scat}(t) = b_{scat,o} + m\,(V(t) - V_o(t))$$

Assuming that $V_o(t)$ and $V(t)$ are known without error.

The slope of the calibration line is not constant as defined above, but changes (drifts) with time. Figure B-1 illustrates the drift in the clean air and span values with time. Figure B-2 illustrates how these drifting values cause the slope of the calibration line to drift.

The actual slope of the calibration line at time t is:

$$m(t) = (b_{scat,s} - b_{scat,o}) / (V_s(t) - V_o(t))$$

The actual b_{scat} (denoted b'_{scat}), given a nephelometer reading $V(t)$, is:

$$b'_{scat}(t) = b_{scat,o} + m(t)\ (V(t) - V_o(t))$$

The relative error between the theoretical b_{scat} and actual b'_{scat} is:

$$-\ ((m - m(t))\ (V(t) - V_o(t)))\ /\ (b_{scat,o} + m\ (V(t) - V_o(t)))$$

$$relative\ error = (b_{scat}(t) - b'_{scat}(t))\ /\ b_{scat}(t)$$

$$= (m - m(t))\ /\ (b_{scat,}o\ /\ (V(t) - V_o(t)) + m)$$

$$= |\ (m\text{-}m(t))\ /\ (b_{scat,o}\ /\ (V(t) - V_o(t)) + m)\ |$$

The magnitude of the relative error is:

$$|\ relative\ error\ | = |\ (b_{scat}(t) = b'_{scat}(t))\ /\ b_{scat}(t)\ |$$

The magnitude of the relative error is bounded by the slopes such that:

$$|\ relative\ error\ | \leq |\ (m - m(t))\ /\ m\ |$$

Assuming that the calculated slopes, $m(t)$, of the calibration lines are normally distributed about the average slope m with a standard deviation s, then for a probability (confidence level) of 95%:

$$|\ m - m(t)\ \backslash \leq 2s$$

so that

$$|\ (b_{scat}(t)) - b'_{scat}(t))\ /\ b_{scat}(t)\ | \leq |\ 2s\ /\ m|$$

Assuming that s is estimated by s_m with k degrees of freedom, based on k+1 sample values of $m(t)$, and using the two-tailed t distribution, the relative error at a 95% confidence level (which for a two-tailed t distribution is read from the 97.5 column of the t table) is:

$$|\ relative\ error\ | \leq t_{k,0.025} * s_m\ /\ m$$

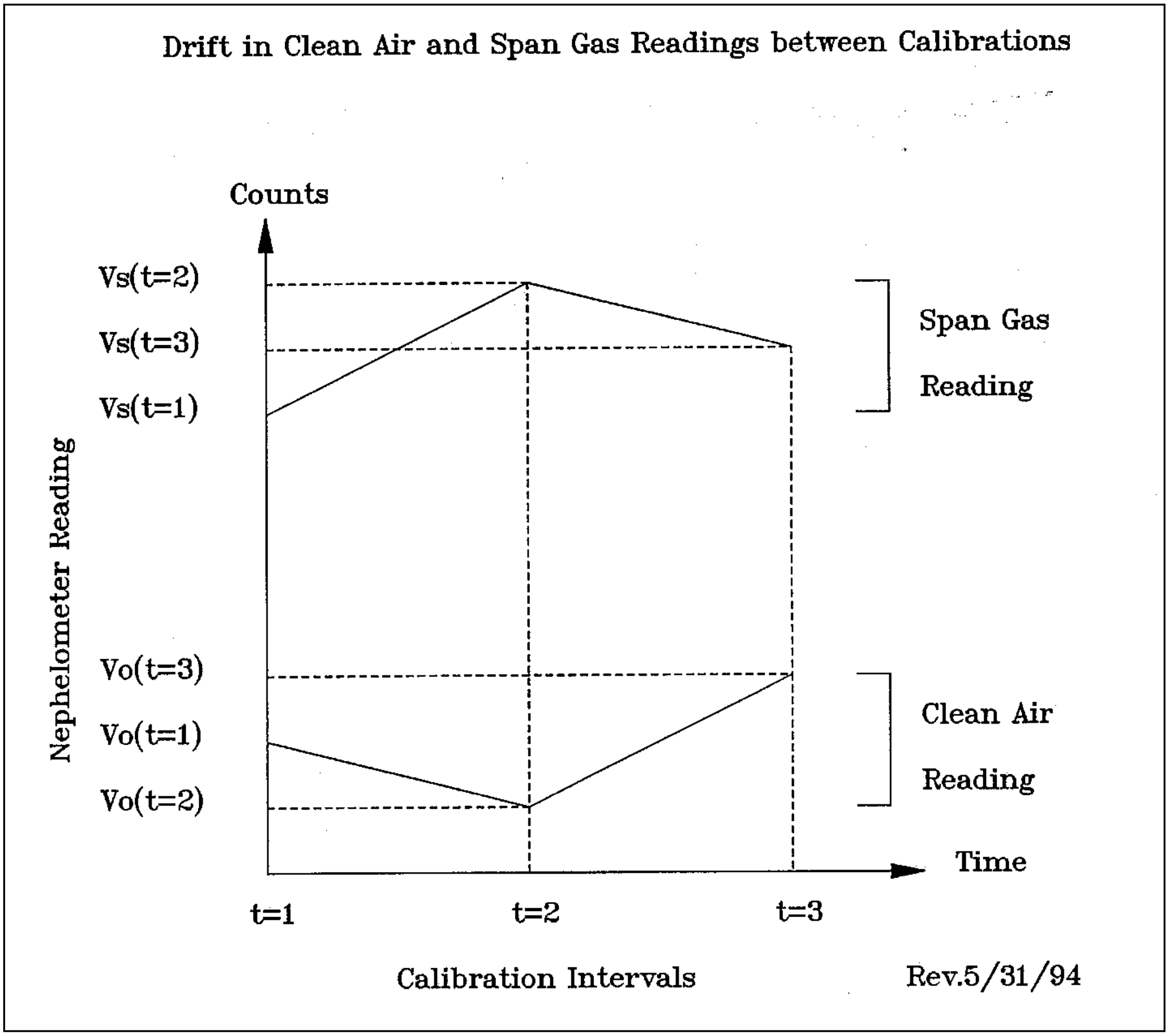

Figure B-1. Drift in the Clean Air and SUVA 134a Values With Time.

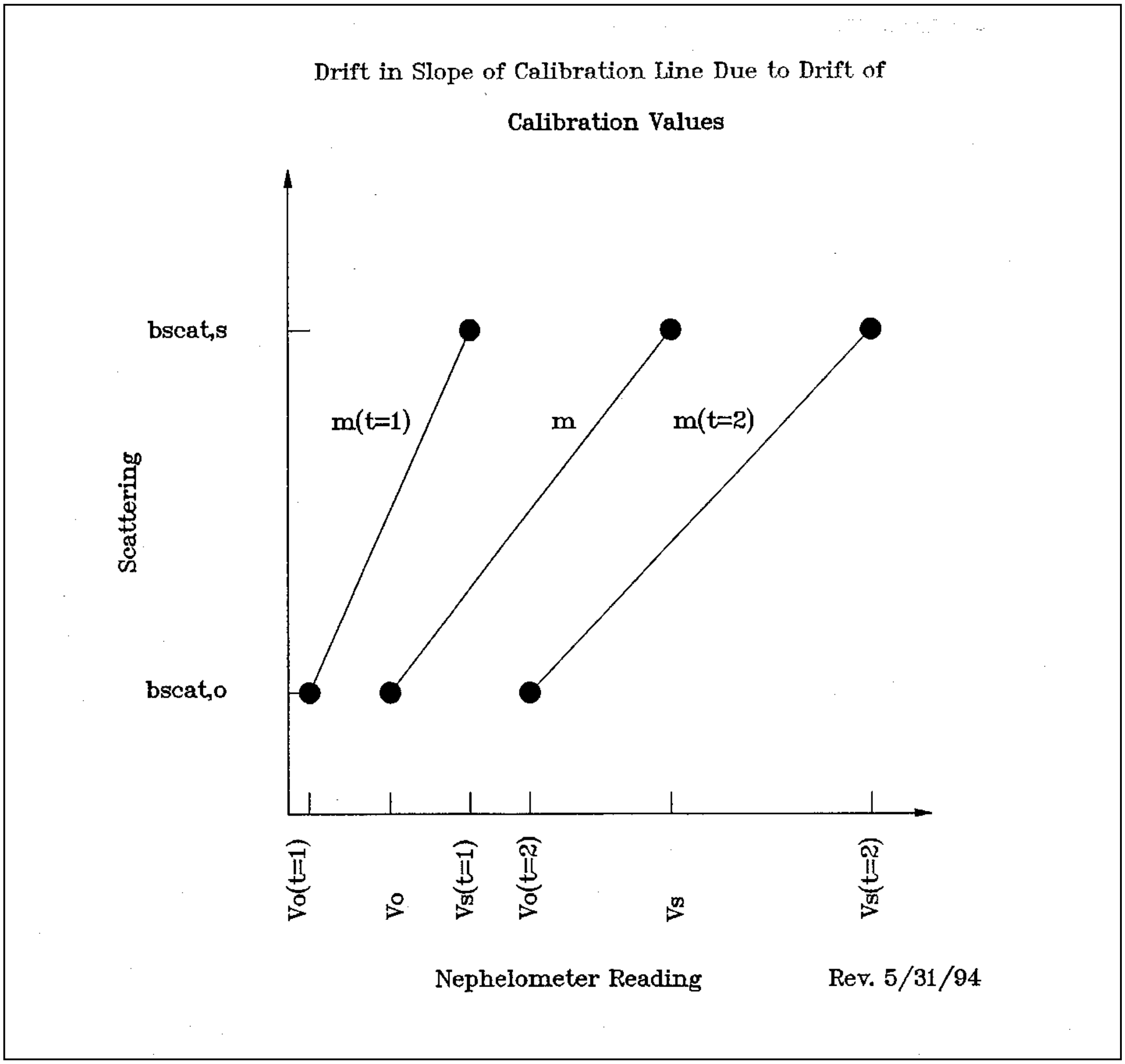

Figure B-2. Drift in Slope of Calibration Line Due to Drift of Calibration Values.

APPENDIX C

DATA PROCESSING FOR NEPHELOMETERS WITH LED LIGHT SOURCES

Optec NGN-2 ambient nephelometers can be configured to operate with either incandescent or LED light sources. In 2007, ARS began replacing incandescent NGN-2 models with an LED version. The incandescent (550 nm) and LED (530 nm) light sources output different effective wavelengths which have different light scattering characteristics.

Mie theory can be used to calculate the scattering coefficient of spherical particles at any wavelength of light. This relationship of aerosol scattering (b_{sp}) with the wavelength of incident light (λ) can be approximated using the Aerosol Angstrom Coefficient α as follows:

$$\frac{b_{sp}(\lambda_1)}{b_{sp}(\lambda_2)} = \left(\frac{\lambda_2}{\lambda_1}\right)^{\alpha}$$

where: α is the Angstrom exponent

λ = wavelength of incident radiation

$b_{sp}(\lambda_1)$ = aerosol scattering coefficient at λ_1

$b_{sp}(\lambda_2)$ = aerosol scattering coefficient at λ_2

For Rayleigh scattering, where the diameter of gas molecules is much less than the incident wavelength, α is exactly equal to 4. For incandescent nephelometers replaced with LED nephelometers, wavelength specific Rayleigh values must be applied to convert nephelometer output to b_{sp} values as follows:

$$b_{sp} = \left(\frac{6.25 \times Rayleigh(\lambda)}{Span_i - Zero_i}\right) \times \left(RawNephValue - Zero\right)$$

For comparisons to historic nephelometer data, and for comparisons to aerosol scattering, scattering from LED nephelometers can be converted from 530 nm to 550 nm. For aerosols, α varies between 0 and 3, depending on the size of the aerosol. Large aerosols have $\alpha = 0$, with no wavelength dependence of aerosol scattering (this is why fogs and clouds are white). For very small aerosols, α approaches 3. Thus the wavelength dependence of ambient aerosols is a function of the mix between fine and coarse aerosols and their respective size distributions. Figure C-1 shows the wavelength dependence of Rayleigh and aerosol scattering (relative to 550nm) modeled by Mie theory for lognormal aerosol size distributions of various mass mean diameters (mmd) and various Angstrom coefficients (α).

As an approximation of the aerosol scattering conversion from b_{sp}(530nm) to b_{sp}(550nm), ARS nephelometer data processing uses α=1 as follows:

$$b_{sp}(550) = \left(\frac{530}{550}\right)^{1} b_{sp}(530)$$

$$\Rightarrow b_{sp}(550) = 0.96 \times b_{sp}(530)$$

Figure C-2 presents results from a 2-week collocated study comparing and LED nephelometer (NGN-LED) and an incandescent nephelometer (NGN-2). The comparison indicates that the central data tendency was consistent with α values between 1 and 2. This sample is representative of only a short period of time in one location. Actual angstrom coefficients will be dependent upon the mix between fine and coarse aerosols and their respective size distributions.

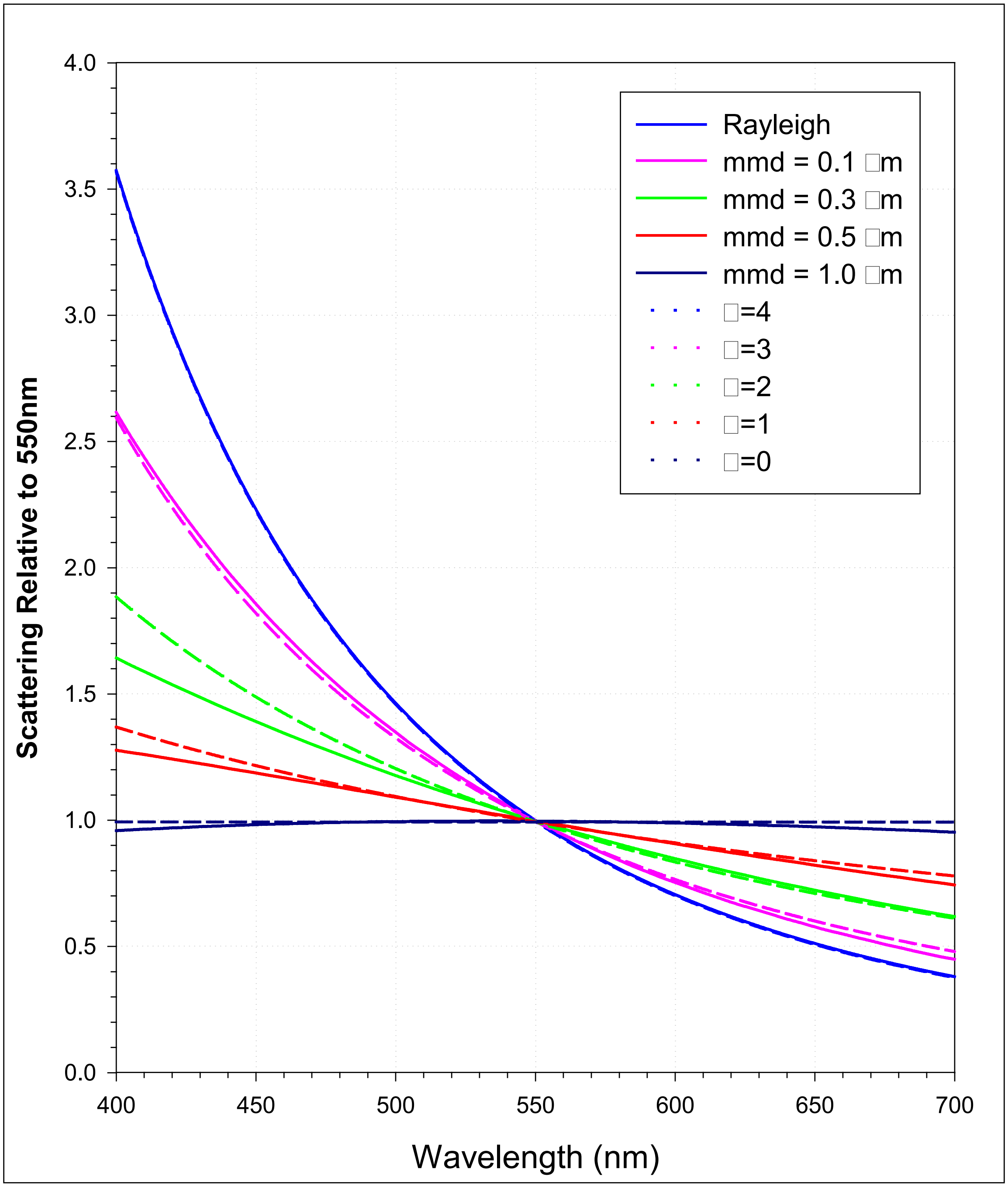

Figure C-1: Wavelength dependence of Rayleigh and aerosol scattering (relative to 550nm) modeled by: (1) MIE theory with lognormal aerosol size distributions of various mass mean diameters (mmd), geometric sigma = 1.75, and index of refraction = 1.52 $\pm$ 0.006*i* and (2) various Angstrom coefficients (α).

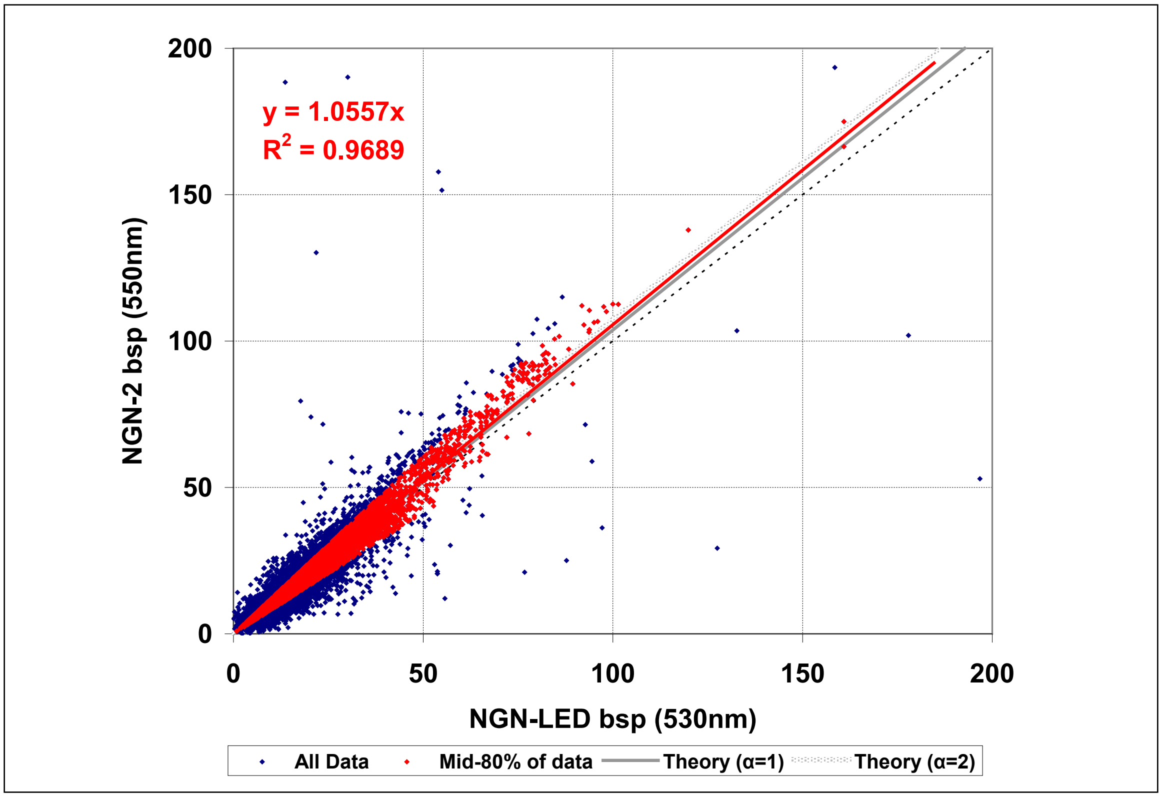

Figure C-2: Comparison between NGN-2 (incandescent light source) and NGN-LED (LED light source) for 5-minute data collected between June 9 and July 12, 2011 at ARS headquarters in Fort Collins, Colorado. Red data excludes the largest and smallest 10% of differences between the nephelometers. Gray lines indicate expected relationships for α = 1 and α = 2.