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Version 6.0

Department of the Interior
U.S. Geological Survey

Landsat
Atmospheric Auxiliary Data
Data Format Control Book (DFCB)

Version 6.0

October 2023

USGS
science for a changing world

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Executive Summary

This Data Format Control Book (DFCB) presents the format and contents of the atmospheric auxiliary data used during Level-2 product generation. The atmospheric auxiliary data are made available for distribution to the public.

This document is under Landsat Data Processing and Archive System (DPAS) Configuration Control Board (CCB) control. Please submit changes to this document, as well as supportive material justifying the proposed changes, via Change Request (CR) to the Configuration Management Tool.

Document History

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Contents

List of Tables

Section 1 Introduction

1.1 Background

Landsat is an Earth observation satellite program formulated, implemented, and operated by the National Aeronautics and Space Administration (NASA) and the Department of the Interior (DOI) U.S. Geological Survey (USGS). Landsat's ongoing record of data focuses on medium-resolution remote sensing of Earth's land surfaces.

The goal of Landsat is to continue the collection, archive, and distribution of multispectral imagery affording global, synoptic, and repetitive coverage of land surfaces at a scale where natural and human-induced changes can be detected, differentiated, characterized, and monitored over time. The mission's programmatic goals are stated in the United States Code, Title 15 Chapter 82 "Land Remote Sensing Policy" (derived from the Land Remote Sensing Policy Act of 1992). This policy requires the Landsat program to provide data into the future that are sufficiently consistent with previous Landsat data, allowing the detection and quantitative characterization of changes in or on the Earth's surface. The highly successful Landsat series of missions has provided satellite coverage since 1972. The data from these missions constitute the longest continuous record of Earth's surface as seen from space.

1.2 Purpose and Scope

This document provides descriptions of the format and content of the auxiliary atmospheric characterization data used in Level-2 product generation. The atmospheric auxiliary data are made available for distribution to the public in the case users want to create their own Level-2 products.

1.3 Document Organization

This document contains the following sections:

- Section 1 provides an introduction
- Section 2 provides data format definitions of the atmospheric auxiliary data files
- Appendix A describes the input data products that are used to construct the atmospheric auxiliary data files and organizations that provide them
- Appendix B provides a list of acronyms
- The References section provides a list of reference documents

1.4 Terminology

Level-1 – Level-1 processing refers to the generation of a radiometrically calibrated and orthorectified Level 1 Terrain Precision (L1TP) corrected, Level 1 Systematic Terrain (L1GT) corrected, or Level 1 Geometric Systematic (L1GS) product.

Level-2 – Level-2 processing refers to the generation of Surface Reflectance (SR) and Surface Temperature (ST). Sun angle and atmospheric corrections are applied to a Level 1 product to create a Level-2 product.

Section 2 Atmospheric Auxiliary Data

The USGS Image Assessment System (IAS) uses auxiliary atmospheric characterization data from multiple sources: Level-1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center (DAAC), Land Processes Distributed Active Archive Center (LP DAAC), National Centers for Environmental Prediction (NCEP), Goddard Earth Sciences Data and Information Services Center (GES DISC), and Goddard Space Flight Center (GSFC).

IAS extracts the data needed for processing. For some data types, IAS reformats the data.

This section provides an overview of each type of atmospheric auxiliary data that IAS uses, and documents the content and format of the repackaged files.

2.1 Level-2 Surface Reflectance Atmospheric Auxiliary Data Inputs

2.1.1 Earth Topography Five Minute Grid (ETOPO5)

ETOPO5 is a gridded global elevation data model derived from several sources at a resolution of 5 arcminutes and is used in surface reflectance algorithms for Landsat 4-9 data. This CMGDEM.hdf file is stored in Hierarchical Data Format Version 4 (HDF4) format. The “averaged elevation” Scientific Data Set (SDS) provides a 16-bit integer elevation value at each grid point.

2.1.2 Landsat 8-9 Ratio Map

This file of band ratio averages is used by the Land Surface Reflectance Code (LaSRC) algorithm for aerosol retrieval calculation in Landsat 8 surface reflectance processing. It is derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data and gives an estimate of Normalized Difference Water Index (NDWI). It is a 0.05 x 0.05 degree lat/long grid of 16-bit integers in HDF4 format. This file, named ratiomapndwiexp.hdf, is static.

2.1.3 Landsat Data Continuity Mission Look-Up Tables (LDCMLUT)

The four look-up tables contained in this file are used by the LaSRC algorithm in Landsat 8 surface reflectance processing. These files are static.

- ANGLE_NEW.hdf
    - This HDF4 file contains scattering, sensor viewing, and solar illumination angles.
- RES_LUT_V3.0-URBANCLEAN-V2.0.hdf
    - This HDF4 file contains intrinsic reflectance information.
- AERO_LUT_V3.0-URBANCLEAN-V2.0.ASCII
    - This American Standard Code for Information Interchange (ASCII) text file contains spherical albedo information.
- TRANS_LUT_V3.0-URBANCLEAN-V2.0.ASCII
    - This ASCII text file contains transmission information.

2.1.4 MODIS Fused Atmospheric Auxiliary Data

MODIS climate data is used in the SR algorithm for Landsat 8 and Landsat 9 data. MODIS Collection 6 data is used through February 16, 2023. MODIS Collection 6.1 data is used beginning February 17, 2023, through September 30, 2023.

The IAS extracts water vapor data from Terra and Aqua Aerosol Optical Thickness products (MOD09CMA and MYD09CMA) and ozone data from Terra and Aqua surface reflectance Climate Modeling Grid products (MOD09CMG and MYD09CMG). Each of these four MODIS products contains a daily global product in an HDF4 format, containing several SDSs. For each day, the IAS extracts the datasets needed from a set of four products and combines the data to create a single fused daily HDF4 file. The fused file has the same spatial resolution as the source products - geographic projection with 0.05 degree pixels. Terra data are used, if available, for both water vapor and ozone data. Where Terra data are not available, Aqua data (if available) are used to fill in missing values. If Terra data and Aqua data are both unavailable, fill values are generated by interpolation. For more information about the source MODIS products, see Appendix A.1.

The IAS-generated file contains the “Coarse Resolution Ozone” SDS (unsigned 8-bit integers), the “Coarse Resolution Water Vapor” SDS (unsigned 16-bit integers), and a "wherefrom" SDS (8-bit unsigned integers) to identify if the pixel is populated from Terra data, Aqua data, or “none” for interpolated values.

The IAS-generated file name is

L8ANC<yyyy><doy>.hdf_fused

where

yyyy = 4-digit year

doy = day of year

2.1.4.1 Sample File

This section includes HDF Dumper (hdp) output of a sample file for day 365 of year 2016:

Command: `hdp dumpsds -h L8ANC2016365.hdf_fused`

```
File attributes:
         Attr0: Name = command
                 Type = 8-bit signed char
                 Count= 335
                 Value =  combine_l8_aux_data --terra_cmg /tmp/lad
                         s/2016/MOD09CMG.A2016365.006.201700113214
                         5.hdf --terra_cma /tmp/lads/2016/MOD09CMA
                         .A2016365.006.2017001132153.hdf --aqua_cm
                         g /tmp/lads/2016/MYD09CMG.A2016365.006.20
                         17001134612.hdf --aqua_cma /tmp/lads/2016
                         /MYD09CMA.A2016365.006.2017001134621.hdf
                         --output_dir /usr/local/auxiliaries/L8/LA
                         DS/2016

Variable Name = Coarse Resolution Ozone
```

```
          Index = 0
          Type= 8-bit unsigned integer
          Ref. = 2
          Compression method = NONE
          Rank = 2
          Number of attributes = 0
          Dim0: Name=YDim_MOD09CMG
                  Size = 3600
                  Scale Type = number-type not set
                  Number of attributes = 0
          Dim1: Name=XDim_MOD09CMG
                  Size = 7200
                  Scale Type = number-type not set
                  Number of attributes = 0

Variable Name = Coarse Resolution Water Vapor
          Index = 2
          Type= 16-bit unsigned integer
          Ref. = 4
          Compression method = NONE
          Rank = 2
          Number of attributes = 0
          Dim0: Name=YDim_MOD09CMG
                  Size = 3600
                  Scale Type = number-type not set
                  Number of attributes = 0
          Dim1: Name=XDim_MOD09CMG
                  Size = 7200
                  Scale Type = number-type not set
                  Number of attributes = 0

Variable Name = wherefrom
          Index = 5
          Type= 8-bit signed integer
          Ref. = 7
          Compression method = NONE
          Rank = 2
          Number of attributes = 1
          Dim0: Name=YDim_MOD09CMG
                  Size = 3600
                  Scale Type = number-type not set
                  Number of attributes = 0
          Dim1: Name=XDim_MOD09CMG
                  Size = 7200
                  Scale Type = number-type not set
                  Number of attributes = 0
          Attr0: Name = key
                  Type = 8-bit signed char
                  Count= 23
                  Value = 0=none, 1=Terra, 2=Aqua
```

2.1.5 NCEP / NCAR Reanalysis 1

National Centers for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) Reanalysis 1 data are used in the SR algorithm for Landsat 4-7 data.

The IAS repackages information from three source Reanalysis product files into a daily HDF file that contains SDSs for surface pressure (“slp”), precipitable water (“pr_wtr”), and air temperature (“air”), stored as floating-point values. These global products are

2.5° x 2.5° lat/long grids from 90° N to 90° S, and 0° E to 357.5° E. Each grid position contains four daily values from 0Z, 6Z, 12Z, and 18Z. The repackaged file also contains “lat” and “lon” SDSs that contain the latitude and longitude value along each grid axis. See Appendix A.3 for a description of the source files provided by NCEP / NCAR.

The IAS-repackaged file name is

REANALYSIS_<yyyy><doy>.hdf

where

yyyy = 4-digit year

doy = day of year

2.1.5.1 Sample File

This section includes hdp output of a sample file for day 365 of year 2002.

Command: `hdp dumpsds -h REANALYSIS_2002365.hdf`

```
File attributes:
         Attr0: Name = Conventions
                 Type = 8-bit signed char
                 Count= 6
                 Value = COARDS
         Attr1: Name = title
                 Type = 8-bit signed char
                 Count= 30
                 Value = 4x daily NMC reanalysis (2002)
         Attr2: Name = description
                 Type = 8-bit signed char
                 Count= 143
                 Value = Data is from NMC initialized reanalysis\012
                         (4x/day). It consists of most variables
                         interpolated to\012pressure surfaces from
                          model (sigma) surfaces.
         Attr3: Name = platform
                 Type = 8-bit signed char
                 Count= 5
                 Value = Model
         Attr4: Name = history
                 Type = 8-bit signed char
                 Count= 94
                 Value = created 03/08/18 by Hoop (netCDF2.3)\012C
                         onverted to chunked, deflated non-packed
                         NetCDF4 2014/09
         Attr5: Name = References
                 Type = 8-bit signed char
                 Count= 67
                 Value = http://www.esrl.noaa.gov/psd/data/gridded
                         /data.ncep.reanalysis.html
         Attr6: Name = dataset_title
                 Type = 8-bit signed char
                 Count= 22
                 Value = NCEP-NCAR Reanalysis 1
         Attr7: Name = base_date
                 Type = 16-bit signed integer
                 Count= 3
                 Value = 2002 0 1
         Attr8: Name = Day Of Year
                 Type = 16-bit signed integer
```

```
                Count= 1
                Value = 365

Variable Name = lat
         Index = 0
         Type= 32-bit floating point
         Ref. = 2
         Compression method = NONE
         Rank = 1
         Number of attributes = 5
         Dim0: Name=lat
                Size = 73
                Scale Type = number-type not set
                Number of attributes = 0
         Attr0: Name = units
                Type = 8-bit signed char
                Count= 13
                Value = degrees_north
         Attr1: Name = actual_range
                Type = 32-bit floating point
                Count= 2
                Value = 90.000000 -90.000000
         Attr2: Name = long_name
                Type = 8-bit signed char
                Count= 8
                Value = Latitude
         Attr3: Name = standard_name
                Type = 8-bit signed char
                Count= 8
                Value = latitude
         Attr4: Name = axis
                Type = 8-bit signed char
                Count= 1
                Value = Y

Variable Name = lon
         Index = 1
         Type= 32-bit floating point
         Ref. = 4
         Compression method = NONE
         Rank = 1
         Number of attributes = 5
         Dim0: Name=lon
                Size = 144
                Scale Type = number-type not set
                Number of attributes = 0
         Attr0: Name = units
                Type = 8-bit signed char
                Count= 12
                Value = degrees_east
         Attr1: Name = long_name
                Type = 8-bit signed char
                Count= 9
                Value = Longitude
         Attr2: Name = actual_range
                Type = 32-bit floating point
                Count= 2
                Value = 0.000000 357.500000
         Attr3: Name = standard_name
                Type = 8-bit signed char
                Count= 9
                Value = longitude
         Attr4: Name = axis
```

```
                Type = 8-bit signed char
                Count= 1
                Value = X

Variable Name = slp
         Index = 2
         Type= 32-bit floating point
         Ref. = 6
         Compression method = NONE
         Rank = 3
         Number of attributes = 14
         Dim0: Name=time
                Size = 4
                Scale Type = number-type not set
                Number of attributes = 0
         Dim1: Name=lat
                Size = 73
                Scale Type = number-type not set
                Number of attributes = 0
         Dim2: Name=lon
                Size = 144
                Scale Type = number-type not set
                Number of attributes = 0
         Attr0: Name = long_name
                Type = 8-bit signed char
                Count= 26
                Value = 4xDaily Sea Level Pressure
         Attr1: Name = units
                Type = 8-bit signed char
                Count= 7
                Value = Pascals
         Attr2: Name = precision
                Type = 16-bit signed integer
                Count= 1
                Value = 0
         Attr3: Name = least_significant_digit
                Type = 16-bit signed integer
                Count= 1
                Value = -1
         Attr4: Name = GRIB_id
                Type = 16-bit signed integer
                Count= 1
                Value = 2
         Attr5: Name = GRIB_name
                Type = 8-bit signed char
                Count= 5
                Value = PRMSL
         Attr6: Name = var_desc
                Type = 8-bit signed char
                Count= 18
                Value = Sea Level Pressure
         Attr7: Name = level_desc
                Type = 8-bit signed char
                Count= 9
                Value = Sea Level
         Attr8: Name = statistic
                Type = 8-bit signed char
                Count= 14
                Value = Individual Obs
         Attr9: Name = parent_stat
                Type = 8-bit signed char
                Count= 5
                Value = Other
```

```
          Attr10: Name = missing_value
                  Type = 32-bit floating point
                  Count= 1
                  Value = -9969209968386869046778552952102584320.000000
          Attr11: Name = actual_range
                  Type = 32-bit floating point
                  Count= 2
                  Value = 93220.000000 110980.000000
          Attr12: Name = valid_range
                  Type = 32-bit floating point
                  Count= 2
                  Value = 87000.000000 115000.000000
          Attr13: Name = dataset
                  Type = 8-bit signed char
                  Count= 15
                  Value = NCEP Reanalysis

Variable Name = pr_wtr
          Index = 3
          Type= 32-bit floating point
          Ref. = 57
          Compression method = NONE
          Rank = 3
          Number of attributes = 14
          Dim0: Name=time
                  Size = 4
                  Scale Type = number-type not set
                  Number of attributes = 0
          Dim1: Name=lat
                  Size = 73
                  Scale Type = number-type not set
                  Number of attributes = 0
          Dim2: Name=lon
                  Size = 144
                  Scale Type = number-type not set
                  Number of attributes = 0
          Attr0: Name = long_name
                  Type = 8-bit signed char
                  Count= 48
                  Value = 4xDaily Precipitable Water for entire atm
                          osphere
          Attr1: Name = units
                  Type = 8-bit signed char
                  Count= 6
                  Value = kg/m^2
          Attr2: Name = precision
                  Type = 16-bit signed integer
                  Count= 1
                  Value = 2
          Attr3: Name = least_significant_digit
                  Type = 16-bit signed integer
                  Count= 1
                  Value = -1
          Attr4: Name = GRIB_id
                  Type = 16-bit signed integer
                  Count= 1
                  Value = 54
          Attr5: Name = GRIB_name
                  Type = 8-bit signed char
                  Count= 4
                  Value = PWAT
          Attr6: Name = var_desc
                  Type = 8-bit signed char
```

```
                Count= 26
                Value = Precipitable Water Content
        Attr7: Name = level_desc
                Type = 8-bit signed char
                Count= 46
                Value = Entire Atmosphere Considered As a Single
                        Layer
        Attr8: Name = statistic
                Type = 8-bit signed char
                Count= 14
                Value = Individual Obs
        Attr9: Name = parent_stat
                Type = 8-bit signed char
                Count= 5
                Value = Other
        Attr10: Name = missing_value
                Type = 32-bit floating point
                Count= 1
                Value = -9969209968386869046778552952102584320.000000
        Attr11: Name = actual_range
                Type = 32-bit floating point
                Count= 2
                Value = -6.700012 88.300003
        Attr12: Name = valid_range
                Type = 32-bit floating point
                Count= 2
                Value = -50.000000 150.000000
        Attr13: Name = dataset
                Type = 8-bit signed char
                Count= 15
                Value = NCEP Reanalysis

Variable Name = air
        Index = 4
        Type= 32-bit floating point
        Ref. = 125
        Compression method = NONE
        Rank = 3
        Number of attributes = 14
        Dim0: Name=time
                Size = 4
                Scale Type = number-type not set
                Number of attributes = 0
        Dim1: Name=lat
                Size = 73
                Scale Type = number-type not set
                Number of attributes = 0
        Dim2: Name=lon
                Size = 144
                Scale Type = number-type not set
                Number of attributes = 0
        Attr0: Name = long_name
                Type = 8-bit signed char
                Count= 42
                Value = 4xDaily Air temperature at sigma level 99
                        5
        Attr1: Name = units
                Type = 8-bit signed char
                Count= 4
                Value = degK
        Attr2: Name = precision
                Type = 16-bit signed integer
                Count= 1
```

```
        Value = 2
Attr3: Name = least_significant_digit
        Type = 16-bit signed integer
        Count= 1
        Value = 1
Attr4: Name = GRIB_id
        Type = 16-bit signed integer
        Count= 1
        Value = 11
Attr5: Name = GRIB_name
        Type = 8-bit signed char
        Count= 3
        Value = TMP
Attr6: Name = var_desc
        Type = 8-bit signed char
        Count= 15
        Value = Air temperature
Attr7: Name = level_desc
        Type = 8-bit signed char
        Count= 7
        Value = Surface
Attr8: Name = statistic
        Type = 8-bit signed char
        Count= 14
        Value = Individual Obs
Attr9: Name = parent_stat
        Type = 8-bit signed char
        Count= 5
        Value = Other
Attr10: Name = missing_value
        Type = 32-bit floating point
        Count= 1
        Value = -9969209968386869046778552952102584320.000000
Attr11: Name = actual_range
        Type = 32-bit floating point
        Count= 2
        Value = 193.200012 322.500000
Attr12: Name = valid_range
        Type = 32-bit floating point
        Count= 2
        Value = 185.160004 331.160004
Attr13: Name = dataset
        Type = 8-bit signed char
        Count= 15
        Value = NCEP Reanalysis
```

2.1.6 TOMS / OMI Ozone Data

Total Ozone Mapping Spectrometer (TOMS) / Ozone Monitoring Instrument (OMI) Ozone data are used in the SR algorithm for Landsat 4-7 data.

The IAS repackages the TOMS and OMI ozone product text files and creates daily HDF files that contain an “ozone” SDS, stored as 16-bit integers. The daily file is a global dataset with 1.25° x 1° lat/long grids or 1° x 1° lat/long grids, depending on the source of the data, which is denoted in the “Platform” attribute. The repackaged file also contains “lat” and “lon” SDSs that contain the latitude and longitude value along each grid axis. See Appendix A.5 for a description of the source files provided by GSFC.

The output files are named

TOMS_<yyyy><doy>.hdf.

where

yyyy = 4-digit year

doy = day of year

2.1.6.1 Sample File

This section includes hdp output of a sample file for day 365 of year 2002.

Command: `hdp dumpsds -h TOMS_2002365.hdf`

```
File name: TOMS_2002365.hdf

File attributes:
         Attr0: Name = base_date
                 Type = 16-bit signed integer
                 Count= 3
                 Value = 2002 1 1
         Attr1: Name = Day Of Year
                 Type = 16-bit signed integer
                 Count= 1
                 Value = 365
         Attr2: Name = Platform
                 Type = 8-bit signed char
                 Count= 11
                 Value = EARTHPROBE\000

Variable Name = lat
         Index = 0
         Type= 32-bit floating point
         Ref. = 2
         Compression method = NONE
         Rank = 1
         Number of attributes = 0
         Dim0: Name=lat
                 Size = 180
                 Scale Type = number-type not set
                 Number of attributes = 0

Variable Name = lon
         Index = 1
         Type= 32-bit floating point
         Ref. = 4
         Compression method = NONE
         Rank = 1
         Number of attributes = 0
         Dim0: Name=lon
                 Size = 288
                 Scale Type = number-type not set
                 Number of attributes = 0

Variable Name = ozone
         Index = 2
         Type= 16-bit signed integer
         Ref. = 6
         Compression method = NONE
         Rank = 2
         Number of attributes = 3
         Dim0: Name=lat
```

```
        Size = 180
        Scale Type = number-type not set
        Number of attributes = 0
Dim1: Name=lon
        Size = 288
        Scale Type = number-type not set
        Number of attributes = 0
Attr0: Name = scale_factor
        Type = 32-bit floating point
        Count= 1
        Value = 1.000000
Attr1: Name = add_offset
        Type = 32-bit floating point
        Count= 1
        Value = 0.000000
Attr2: Name = units
        Type = 8-bit signed char
        Count= 7
        Value = Dobson\000
```

2.1.7 VIIRS Atmospheric Auxiliary Data

Visible Infrared Imaging Radiometer Suite (VIIRS) Aerosol Daily L3 Global 0.05-degree Climate Modeling Grid (CMG) products are used in the SR algorithm for Landsat 8 and Landsat 9 data. VIIRS CMG data serves as a replacement for MODIS Fused Atmospheric Auxiliary Data as both Terra and Aqua entered a phase of orbital drift with changing Mean Local Time (MLT) equatorial crossing. For the Landsat 8 and Landsat 9 data acquired October 1, 2023 and onward, the surface reflectance data are processed utilizing ozone and water vapor datasets retrieved from VIIRS CMG.

The IAS extracts the raw water vapor and ozone datasets from VIIRS datasets. Currently, three sources of VIIRS CMG data are considered. The NOAA-21 (designated as Joint Polar Satellite System (JPSS)-2 prior to launch) (VJ204ANC) is the highest priority. If data is unavailable for a specific day, the NOAA-20 (designated as JPSS-1 prior to launch) (VJ104ANC) or Suomi National Polar-orbiting Partnership (Suomi-NPP) (VNP04ANC) data (in that order) will instead be used.

The source ozone and water vapor datasets contain gaps of missing data that have been filled with zero values. These gaps are filled by a gap filling process (named “gapfill”). To do this, gapfill uses precalculated full resolution monthly averages of these source VIIRS datasets for the previous month, the current month of the previous year, and the next month of the previous year. The weight that each monthly average contributes to the final fill value is dependent on the day of the month and whether the corresponding pixel in the monthly average files contain fill.

The gap-filled ozone and water vapor datasets are compressed and archived in daily HDF5 files. These IAS-generated files contain the “Coarse Resolution Ozone” SDS (unsigned 8-bit integers) and the “Coarse Resolution Water Vapor” SDS (unsigned 16-bit integers). The LocalGranuleID (e.g., ‘VJ104ANC.A2018005.002.2022256072652.h5’) and PlatformShortName (e.g., ‘JPSS-1’) of the source product are also carried over to the IAS-generated file for data provenance.

The IAS-generated file name is

VIIRS<yyyy><doy>.h5

where

yyyy = 4-digit year

doy = day of year

2.1.7.1 Sample File

This section includes HDF5 Dumper (h5dump) output of a sample file for day 005 of year 2018:

Command: `h5dump -Hp VIIRS2018005.h5`

```
HDF5 "VIIRS2018005.h5" {
GROUP "/" {
   ATTRIBUTE "LocalGranuleID" {
      DATATYPE  H5T_STRING {
         STRSIZE 39;
         STRPAD H5T_STR_NULLTERM;
         CSET H5T_CSET_ASCII;
         CTYPE H5T_C_S1;
      }
      DATASPACE  SCALAR
   }
   ATTRIBUTE "PlatformShortName" {
      DATATYPE  H5T_STRING {
         STRSIZE 7;
         STRPAD H5T_STR_NULLTERM;
         CSET H5T_CSET_ASCII;
         CTYPE H5T_C_S1;
      }
      DATASPACE  SCALAR
   }
   DATASET "Coarse Resolution Ozone" {
      DATATYPE  H5T_STD_U8LE
      DATASPACE  SIMPLE { ( 3600, 7200 ) / ( 3600, 7200 ) }
      STORAGE_LAYOUT {
         CHUNKED ( 600, 1200 )
         SIZE 1728441 (14.996:1 COMPRESSION)
      }
      FILTERS {
         COMPRESSION DEFLATE { LEVEL 5 }
      }
      FILLVALUE {
         FILL_TIME H5D_FILL_TIME_IFSET
         VALUE  H5D_FILL_VALUE_DEFAULT
      }
      ALLOCATION_TIME {
         H5D_ALLOC_TIME_INCR
      }
   }
   DATASET "Coarse Resolution Water Vapor" {
      DATATYPE  H5T_STD_U16LE
      DATASPACE  SIMPLE { ( 3600, 7200 ) / ( 3600, 7200 ) }
      STORAGE_LAYOUT {
         CHUNKED ( 600, 1200 )
         SIZE 7928181 (6.539:1 COMPRESSION)
      }
      FILTERS {
         COMPRESSION DEFLATE { LEVEL 5 }
```

```
      }
      FILLVALUE {
         FILL_TIME H5D_FILL_TIME_IFSET
         VALUE  H5D_FILL_VALUE_DEFAULT
      }
      ALLOCATION_TIME {
         H5D_ALLOC_TIME_INCR
      }
   }
}
}
```

2.2 Level-2 Surface Temperature Atmospheric Auxiliary Data Inputs

2.2.1 ASTER GED

Emissivity data from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Emissivity Dataset (GED) bands 13, 14, and Normalized Difference Vegetation Index (NDVI) are used in the ST algorithm for Landsat 4-9 data.

The ASTER GED is divided into a separate file for each 1º×1º area of all major non-frozen land masses of the Earth's land surface. Antarctica and some small islands are not covered. The IAS extracts Emissivity, NDVI, and geolocation information from each ASTER GED file and stores them in a new Hierarchical Data Format Version 5 (HDF5) file. Within a file, the Emissivity and NDVI data are recorded in 100m grids. The Emissivity "Mean" and "SDev" datasets contain a value for ASTER bands 10, 11, 12, 13, and 14, although only bands 13 and 14 are used in the ST algorithm. The latitude and longitude values at each grid point are also stored. The new files are in the same format and spatial resolution as the source files; refer to Appendix A.2 for content and format information.

The new files are named

AG100.v003.<NWlat>.<NWlong>.0001.subset.h5

where

NWlat = northwest corner latitude
NWlong = northwest corner longitude

IAS includes the following datasets in the new file:

/Emissivity/Mean
/Emissivity/SDev
/Geolocation/Latitude
/Geolocation/Longitude
/NDVI/Mean

2.2.1.1 Sample File

This section includes an h5dump output of a sample file.

Command: `h5dump -H AG100.v003.48.-117.0001.subset.h5`

```
HDF5 "AG100.v003.48.-117.0001.subset.h5" {
GROUP "/" {
```

```
GROUP "Emissivity" {
   DATASET "Mean" {
      DATATYPE  H5T_STD_I16LE
      DATASPACE  SIMPLE { ( 5, 1000, 1000 ) / ( 5, 1000, 1000 ) }
      ATTRIBUTE "Description" {
         DATATYPE  H5T_STRING {
            STRSIZE 79;
            STRPAD H5T_STR_NULLTERM;
            CSET H5T_CSET_ASCII;
            CTYPE H5T_C_S1;
         }
         DATASPACE  SIMPLE { ( 1 ) / ( 1 ) }
      }
   }
   DATASET "SDev" {
      DATATYPE  H5T_STD_I16LE
      DATASPACE  SIMPLE { ( 5, 1000, 1000 ) / ( 5, 1000, 1000 ) }
      ATTRIBUTE "Description" {
         DATATYPE  H5T_STRING {
            STRSIZE 93;
            STRPAD H5T_STR_NULLTERM;
            CSET H5T_CSET_ASCII;
            CTYPE H5T_C_S1;
         }
         DATASPACE  SIMPLE { ( 1 ) / ( 1 ) }
      }
   }
}
GROUP "Geolocation" {
   DATASET "Latitude" {
      DATATYPE  H5T_IEEE_F32LE
      DATASPACE  SIMPLE { ( 1000, 1000 ) / ( 1000, 1000 ) }
      ATTRIBUTE "Description" {
         DATATYPE  H5T_STRING {
            STRSIZE 9;
            STRPAD H5T_STR_NULLTERM;
            CSET H5T_CSET_ASCII;
            CTYPE H5T_C_S1;
         }
         DATASPACE  SIMPLE { ( 1 ) / ( 1 ) }
      }
   }
   DATASET "Longitude" {
      DATATYPE  H5T_IEEE_F32LE
      DATASPACE  SIMPLE { ( 1000, 1000 ) / ( 1000, 1000 ) }
      ATTRIBUTE "Description" {
         DATATYPE  H5T_STRING {
            STRSIZE 10;
            STRPAD H5T_STR_NULLTERM;
            CSET H5T_CSET_ASCII;
            CTYPE H5T_C_S1;
         }
         DATASPACE  SIMPLE { ( 1 ) / ( 1 ) }
      }
   }
}
GROUP "NDVI" {
   DATASET "Mean" {
      DATATYPE  H5T_STD_I16LE
      DATASPACE  SIMPLE { ( 1000, 1000 ) / ( 1000, 1000 ) }
      ATTRIBUTE "Description" {
         DATATYPE  H5T_STRING {
            STRSIZE 73;
```

```
               STRPAD H5T_STR_NULLTERM;
               CSET H5T_CSET_ASCII;
               CTYPE H5T_C_S1;
            }
            DATASPACE  SIMPLE { ( 1 ) / ( 1 ) }
         }
      }
   }
}
}
```

2.2.2 GEOS-5 FP-IT

Goddard Earth Observing System Model, Version 5 (GEOS-5) Forward Processing for Instrument Teams (FP-IT) data are used in the ST algorithm for Landsat 7 data starting in 2000 as well as Landsat 8-9 data for global products. The files are the same format and content as Modern Era Retrospective analysis for Research and Applications Version 2 (MERRA-2), except for the GEOS-5 files being one file per 3-hour period containing one-time observation (8 files per day) whereas the MERRA-2 file is one file per day, containing 8 separate time observations.

The IAS writes Network Common Data Form Version 4 (NetCDF4) files that contain the subset of GEOS-5 FP-IT datasets used in ST processing. Each 3-hour global file contains "H" height, "QV" specific humidity, and "T" air temperature values on a grid of 576 longitude, 361 latitude, and 42 pressure levels, for a single 3-hour period. The axis values are recorded in the "lat", "lon", "lev", and "time" datasets, respectively. The new files are in the same format as the input files; refer to Appendix A.4 for content and format information.

The new files are named

fpit_<YYYY><MM><DD>.<HHMM>.nc4

where

YYYY = 4-digit year
MM = 2-digit month
DD = 2-digit day of month
HHMM = hour and minute of the period

IAS includes the following datasets in the new file:

H
QV
T
lat
lev
lon
time

2.2.2.1 Sample File

This section includes ncdump output of a sample file for July 01, 2018.

Command: `ncdump -h fpit_20180701.0000.nc4`

```
netcdf fpit_20180701.0000 {
dimensions:
       lon = 576 ;
       lat = 361 ;
       lev = 42 ;
       time = UNLIMITED ; // (1 currently)
variables:
       double lon(lon) ;
              lon:long_name = "longitude" ;
              lon:units = "degrees_east" ;
              lon:vmax = 1.e+15f ;
              lon:vmin = -1.e+15f ;
              lon:valid_range = -1.e+15f, 1.e+15f ;
       double lat(lat) ;
              lat:long_name = "latitude" ;
              lat:units = "degrees_north" ;
              lat:vmax = 1.e+15f ;
              lat:vmin = -1.e+15f ;
              lat:valid_range = -1.e+15f, 1.e+15f ;
       double lev(lev) ;
              lev:long_name = "vertical level" ;
              lev:units = "hPa" ;
              lev:positive = "down" ;
              lev:coordinate = "PLE" ;
              lev:standard_name = "PLE_level" ;
              lev:vmax = 1.e+15f ;
              lev:vmin = -1.e+15f ;
              lev:valid_range = -1.e+15f, 1.e+15f ;
       int time(time) ;
              time:long_name = "time" ;
              time:units = "minutes since 2018-07-01 00:00:00" ;
              time:time_increment = 30000 ;
              time:begin_date = 20180701 ;
              time:begin_time = 0 ;
              time:vmax = 1.e+15f ;
              time:vmin = -1.e+15f ;
              time:valid_range = -1.e+15f, 1.e+15f ;
       float H(time, lev, lat, lon) ;
              H:long_name = "edge_heights" ;
              H:units = "m" ;
              H:_FillValue = 1.e+15f ;
              H:missing_value = 1.e+15f ;
              H:fmissing_value = 1.e+15f ;
              H:scale_factor = 1.f ;
              H:add_offset = 0.f ;
              H:standard_name = "edge_heights" ;
              H:vmax = 1.e+15f ;
              H:vmin = -1.e+15f ;
              H:valid_range = -1.e+15f, 1.e+15f ;
       float QV(time, lev, lat, lon) ;
              QV:long_name = "specific_humidity" ;
              QV:units = "kg kg-1" ;
              QV:_FillValue = 1.e+15f ;
              QV:missing_value = 1.e+15f ;
              QV:fmissing_value = 1.e+15f ;
              QV:scale_factor = 1.f ;
              QV:add_offset = 0.f ;
              QV:standard_name = "specific_humidity" ;
              QV:vmax = 1.e+15f ;
              QV:vmin = -1.e+15f ;
              QV:valid_range = -1.e+15f, 1.e+15f ;
       float T(time, lev, lat, lon) ;
```

```
                T:long_name = "air_temperature" ;
                T:units = "K" ;
                T:_FillValue = 1.e+15f ;
                T:missing_value = 1.e+15f ;
                T:fmissing_value = 1.e+15f ;
                T:scale_factor = 1.f ;
                T:add_offset = 0.f ;
                T:standard_name = "air_temperature" ;
                T:vmax = 1.e+15f ;
                T:vmin = -1.e+15f ;
                T:valid_range = -1.e+15f, 1.e+15f ;

// global attributes:
                :NCO = "0.2.0" ;
                :Contact = "http://gmao.gsfc.nasa.gov" ;
                :History = "Original file generated: Sun Jul  1 07:00:51 2018 GMT" ;
                :Filename =
"GEOS.fpit.asm.inst3_3d_asm_Np.GEOS5124.20180701_0000.V01.nc4" ;
                :Comment = "GMAO filename:
d5124_rpit_jan12.inst3_3d_asm_Np.20180701_0000z.nc4" ;
                :Source = "GEOSadas-5_12_5_p7_OPS\000 experiment_id: d5124_rpit_jan12" ;
                :Conventions = "CF-1" ;
                :Title = "GEOS-5.12.4 FP-IT " ;
                :Institution = "NASA Global Modeling and Assimilation Office" ;
                :References = "http://gmao.gsfc.nasa.gov" ;
                :Format = "NetCDF-4/HDF-5" ;
                :SpatialCoverage = "global" ;
                :VersionID = "5.12.4" ;
                :TemporalRange = "2000-01-01 - ongoing" ;
                :ShortName = "DFPITI3NPASM" ;
                :RangeBeginningDate = "2018-07-01" ;
                :RangeBeginningTime = "00:00:00.000000" ;
                :RangeEndingDate = "2018-07-01" ;
                :RangeEndingTime = "00:00:00.000000" ;
                :GranuleID =
"GEOS.fpit.asm.inst3_3d_asm_Np.GEOS5124.20180701_0000.V01.nc4" ;
                :ProductionDateTime = "Original file generated: Sun Jul  1 07:00:51 2018
GMT" ;
                :LongName = "GEOS5124 FP-IT 3d assimilated state on pressure levels" ;
                :SouthernmostLatitude = "-90.0" ;
                :NorthernmostLatitude = "90.0" ;
                :WesternmostLongitude = "-180.0" ;
                :EasternmostLongitude = "179.375" ;
                :LatitudeResolution = "0.5" ;
                :LongitudeResolution = "0.625" ;
                :DataResolution = "0.5 x 0.625 (42 pressure levels)" ;
}
```

2.2.3 GEOS-5 IT

Goddard Earth Observing System Model, Version 5 (GEOS-5) IT data will be used in the ST algorithm for Landsat 7-9 data starting in 2023 or 2024 for global products. The files serve as a replacement for GEOS-5 FP-IT data and are the same format and include the same content.

The IAS writes Network Common Data Form Version 4 (NetCDF4) files that contain the subset of the source GEOS-5 IT datasets that are used in ST processing. Each 3-hour global file contains "H" height, "QV" specific humidity, "T" air temperature on a grid of 361 latitude and 576 longitude, and 42 pressure levels, and “PS” surface pressure values on a 361 latitude by 576 longitude grid, for a single 3-hour period. The axis

values are recorded in the "lat", "lon", "lev", and "time" datasets, respectively. The new files are in the same format as the input files; refer to Appendix A.4 for content and format information.

The IAS generated files are named

it_<YYYY><MM><DD>.<HHMM>.nc4

where

YYYY = 4-digit year
MM = 2-digit month
DD = 2-digit day of month
HHMM = hour and minute of the period

IAS includes the following datasets in the IAS archived file:

- H
- PS
- QV
- T
- lat
- lev
- lon
- time

2.2.3.1 Sample File

This section includes ncdump output of a sample file for April 19, 2018.

Command: `ncdump -h it_20180419.1800.nc4`

```
netcdf it_20180419.1800 {
dimensions:
       lon = 576 ;
       lat = 361 ;
       lev = 42 ;
       time = UNLIMITED ; // (1 currently)
variables:
       double lon(lon) ;
              lon:long_name = "longitude" ;
              lon:units = "degrees_east" ;
       double lat(lat) ;
              lat:long_name = "latitude" ;
              lat:units = "degrees_north" ;
       double lev(lev) ;
              lev:long_name = "vertical level" ;
              lev:units = "hPa" ;
              lev:positive = "down" ;
              lev:coordinate = "PLE" ;
              lev:standard_name = "PLE_level" ;
       int time(time) ;
              time:long_name = "time" ;
              time:units = "minutes since 2018-04-19 18:00:00" ;
              time:time_increment = 30000 ;
              time:begin_date = 20180419 ;
              time:begin_time = 180000 ;
       float H(time, lev, lat, lon) ;
              H:long_name = "edge_heights" ;
```

```
            H:units = "m" ;
            H:_FillValue = 1.e+15f ;
            H:missing_value = 1.e+15f ;
            H:fmissing_value = 1.e+15f ;
            H:scale_factor = 1.f ;
            H:add_offset = 0.f ;
            H:standard_name = "edge_heights" ;
            H:vmin = -1.e+15f ;
            H:vmax = 1.e+15f ;
            H:valid_range = -1.e+15f, 1.e+15f ;
      float PS(time, lat, lon) ;
            PS: long_name = "surface_pressure" ;
            PS:units = "Pa" ;
            PS:_FillValue = 1.e+15f ;
            PS:missing_value = 1.e+15f ;
            PS:fmissing_value = 1.e+15f ;
            PS:scale_factor = 1.f ;
            PS:add_offset = 0.f ;
            PS:standard_name = "surface_pressure" ;
            PS:vmin = -1.e+15f ;
            PS:vmax = 1.e+15f ;
            PS:valid_range = -1.e+15f, 1.e+15f ;
      float QV(time, lev, lat, lon) ;
            QV:long_name = "specific_humidity" ;
            QV:units = "kg kg-1" ;
            QV:_FillValue = 1.e+15f ;
            QV:missing_value = 1.e+15f ;
            QV:fmissing_value = 1.e+15f ;
            QV:scale_factor = 1.f ;
            QV:add_offset = 0.f ;
            QV:standard_name = "specific_humidity" ;
            QV:vmin = -1.e+15f ;
            QV:vmax = 1.e+15f ;
            QV:valid_range = -1.e+15f, 1.e+15f ;
      float T(time, lev, lat, lon) ;
            T:long_name = "air_temperature" ;
            T:units = "K" ;
            T:_FillValue = 1.e+15f ;
            T:missing_value = 1.e+15f ;
            T:fmissing_value = 1.e+15f ;
            T:scale_factor = 1.f ;
            T:add_offset = 0.f ;
            T:standard_name = "air_temperature" ;
            T:vmin = -1.e+15f ;
            T:vmax = 1.e+15f ;
            T:valid_range = -1.e+15f, 1.e+15f ;

// global attributes:
            :Contact = "http://gmao.gsfc.nasa.gov" ;
            :_NCProperties = "version=2,netcdf=4.7.3,hdf5=1.10.6," ;
            :History = "Original file generated: Mon Aug  2 06:43:36 2021 GMT" ;
            :Comment = "GMAO filename:
d5271_it_sample.asm_inst_3hr_glo_L576x361_p42.2018-04-19T1800Z.nc4" ;
            :Filename = "GEOS.it.asm.asm_inst_3hr_glo_L576x361_p42.GEOS5271.2018-04-
19T1800.V01.nc4" ;
            :Source = "GEOSadas-5_27_1 experiment_id: d5271_it_sample" ;
            :Conventions = "CF-1" ;
            :Title = "GEOS-5.27.1 GEOS-IT" ;
            :Institution = "NASA Global Modeling and Assimilation Office" ;
            :References = "http://gmao.gsfc.nasa.gov" ;
            :Format = "NetCDF-4" ;
            :SpatialCoverage = "global" ;
            :VersionID = "5.27.1" ;
```

```
            :TemporalRange = "1998-01-01 - ongoing" ;
            :ShortName = "GEOSIT_ASM_I3_L_P42" ;
            :GranuleID = "GEOS.it.asm.asm_inst_3hr_glo_L576x361_p42.GEOS5271.2018-04-
19T1800.V01.nc4" ;
            :ProductionDateTime = "Original file generated: Mon Aug  2 06:43:36 2021
GMT" ;
            :LongName = "GEOS5271 GEOS-IT 3d assimilated state on pressure levels" ;
            :SouthernmostLatitude = "-90.0" ;
            :NorthernmostLatitude = "90.0" ;
            :WesternmostLongitude = "-180.0" ;
            :EasternmostLongitude = "179.375" ;
            :LatitudeResolution = "0.5" ;
            :LongitudeResolution = "0.625" ;
            :DataResolution = "0.5 x 0.625 (42 pressure levels)" ;
            :RangeBeginningDate = "2018-04-19" ;
            :RangeBeginningTime = "18:00:00.000000" ;
            :RangeEndingDate = "2018-04-19" ;
            :RangeEndingTime = "18:00:00.000000" ;
}
```

2.2.4 MERRA-2

IAS uses either MERRA-2, GEOS-5 FP-IT, or GEOS-5 IT data for Surface Temperature processing. MERRA-2 data are used in the ST algorithm for Landsat 4-7 data for global products when GEOS-5 FP-IT data is not available (prior to 2000).

The IAS writes NetCDF files that contain the subset of the MERRA-2 datasets used in ST processing. Each daily global file contains "H" height, "QV" specific humidity, and "T" air temperature values on a grid of 576 longitude, 361 latitude, and 42 pressure levels, for 8 times within the day (every 3 hours). The axis values are recorded in the "lat", "lon", "lev", and "time" datasets, respectively. The new files are in the same format and spatio-temporal resolution as the input files; refer to Appendix A.4 for content and format information.

The new files are named

merra2_<YYYY><MM><DD>.nc4

where

YYYY = 4-digit year
MM = 2-digit month
DD = 2-digit day of month

IAS includes the following datasets in the new file:

- H
- QV
- T
- lat
- lev
- lon
- time

2.2.4.1 Sample File

This section includes ncdump output of a sample file for December 22, 2009.

Command: `ncdump -h merra2_20091222.nc4`

```
netcdf merra2_20091222 {
dimensions:
        lon = 576 ;
        lat = 361 ;
        lev = 42 ;
        time = UNLIMITED ; // (8 currently)
variables:
        double lon(lon) ;
                lon:long_name = "longitude" ;
                lon:units = "degrees_east" ;
                lon:vmax = 1.e+15f ;
                lon:vmin = -1.e+15f ;
                lon:valid_range = -1.e+15f, 1.e+15f ;
        double lat(lat) ;
                lat:long_name = "latitude" ;
                lat:units = "degrees_north" ;
                lat:vmax = 1.e+15f ;
                lat:vmin = -1.e+15f ;
                lat:valid_range = -1.e+15f, 1.e+15f ;
        double lev(lev) ;
                lev:long_name = "vertical level" ;
                lev:units = "hPa" ;
                lev:positive = "down" ;
                lev:coordinate = "PLE" ;
                lev:standard_name = "PLE_level" ;
                lev:vmax = 1.e+15f ;
                lev:vmin = -1.e+15f ;
                lev:valid_range = -1.e+15f, 1.e+15f ;
        int time(time) ;
                time:long_name = "time" ;
                time:units = "minutes since 2009-12-22 00:00:00" ;
                time:time_increment = 30000 ;
                time:begin_date = 20091222 ;
                time:begin_time = 0 ;
                time:vmax = 1.e+15f ;
                time:vmin = -1.e+15f ;
                time:valid_range = -1.e+15f, 1.e+15f ;
        float H(time, lev, lat, lon) ;
                H:long_name = "edge_heights" ;
                H:units = "m" ;
                H:_FillValue = 1.e+15f ;
                H:missing_value = 1.e+15f ;
                H:fmissing_value = 1.e+15f ;
                H:scale_factor = 1.f ;
                H:add_offset = 0.f ;
                H:standard_name = "edge_heights" ;
                H:vmax = 1.e+15f ;
                H:vmin = -1.e+15f ;
                H:valid_range = -1.e+15f, 1.e+15f ;
        float QV(time, lev, lat, lon) ;
                QV:long_name = "specific_humidity" ;
                QV:units = "kg kg-1" ;
                QV:_FillValue = 1.e+15f ;
                QV:missing_value = 1.e+15f ;
                QV:fmissing_value = 1.e+15f ;
                QV:scale_factor = 1.f ;
                QV:add_offset = 0.f ;
                QV:standard_name = "specific_humidity" ;
                QV:vmax = 1.e+15f ;
```

```
                QV:vmin = -1.e+15f ;
                QV:valid_range = -1.e+15f, 1.e+15f ;
        float T(time, lev, lat, lon) ;
                T:long_name = "air_temperature" ;
                T:units = "K" ;
                T:_FillValue = 1.e+15f ;
                T:missing_value = 1.e+15f ;
                T:fmissing_value = 1.e+15f ;
                T:scale_factor = 1.f ;
                T:add_offset = 0.f ;
                T:standard_name = "air_temperature" ;
                T:vmax = 1.e+15f ;
                T:vmin = -1.e+15f ;
                T:valid_range = -1.e+15f, 1.e+15f ;

// global attributes:
                :History = "Original file generated: Sun Mar 22 09:07:25 2015 GMT" ;
                :Comment = "GMAO filename:
d5124_m2_jan00.inst3_3d_asm_Np.20091222.nc4" ;
                :Filename = "MERRA2_300.inst3_3d_asm_Np.20091222.nc4" ;
                :Conventions = "CF-1" ;
                :Institution = "NASA Global Modeling and Assimilation Office" ;
                :References = "http://gmao.gsfc.nasa.gov" ;
                :Format = "NetCDF-4/HDF-5" ;
                :SpatialCoverage = "global" ;
                :VersionID = "5.12.4" ;
                :TemporalRange = "1980-01-01 -> 2016-12-31" ;
                :identifier_product_doi_authority = "http://dx.doi.org/" ;
                :ShortName = "M2I3NPASM" ;
                :GranuleID = "MERRA2_300.inst3_3d_asm_Np.20091222.nc4" ;
                :ProductionDateTime = "Original file generated: Sun Mar 22 09:07:25
2015 GMT" ;
                :LongName = "MERRA2 inst3_3d_asm_Np: 3d,3-
Hourly,Instantaneous,Pressure-Level,Assimilation,Assimilated Meteorological Fields" ;
                :Title = "MERRA2 inst3_3d_asm_Np: 3d,3-Hourly,Instantaneous,Pressure-
Level,Assimilation,Assimilated Meteorological Fields" ;
                :SouthernmostLatitude = "-90.0" ;
                :NorthernmostLatitude = "90.0" ;
                :WesternmostLongitude = "-180.0" ;
                :EasternmostLongitude = "179.375" ;
                :LatitudeResolution = "0.5" ;
                :LongitudeResolution = "0.625" ;
                :DataResolution = "0.5 x 0.625 (42 pressure levels)" ;
                :Source = "CVS tag: GEOSadas-5_12_4" ;
                :Contact = "http://gmao.gsfc.nasa.gov" ;
                :identifier_product_doi = "10.5067/QBZ6MG944HW0" ;
                :RangeBeginningDate = "2009-12-22" ;
                :RangeBeginningTime = "00:00:00.000000" ;
                :RangeEndingDate = "2009-12-22" ;
                :RangeEndingTime = "21:00:00.000000" ;
}
```

Appendix A Data Sources

A.1 LAADS DAAC

The LAADS DAAC distributes atmosphere science products produced by the Moderate Resolution Imaging Spectroradiometer (MODIS) Adaptive Processing System (MODAPS) as well as by the Visible Infrared Imaging Radiometer Suite (VIIRS).

Instrument	Date Range	Source
MODIS C6	3/18/2013 – 2/16/2023	https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/6
MODIS C6.1	2/17/2023 – 9/30/2023	https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/61
VIIRS	10/1/2023 – present	https://ladsweb.modaps.eosdis.nasa.gov/archive/allData/5200/

Table A-1. LAADS DAAC CMG Data Products

A.1.1 Moderate Resolution Imaging Spectroradiometer (MODIS)

The SR suite of products includes Climate Modeling Grid (CMG) and Climate Modeling Grid - Aerosol (CMA) products for both Terra data and Aqua data.

The MODIS SR CMG products (MOD09CMG and MYD09CMG) are global products, generated daily. Pixels with cloud cover, high solar zenith angle (86 degrees or more), and high blue reflectance are excluded. These products are in geographic projection with a 0.05 degree spatial resolution.

For more information, refer to the following:

- https://lpdaac.usgs.gov/products/mod09cmgv061/
- https://lpdaac.usgs.gov/products/myd09cmgv061/
- MODIS Surface Reflectance User's Guides
    - https://lpdaac.usgs.gov/documents/306/MOD09_User_Guide_V6.pdf
    - https://lpdaac.usgs.gov/documents/925/MOD09_User_Guide_V61.pdf

The MODIS Aerosol Optical Thickness products (MOD09CMA and MYD09CMA) are global products, generated daily. Pixels with cloud cover or high solar zenith angles (86 degrees or more) are excluded. These products are in geographic projection with a 0.05 degree spatial resolution.

For more information, refer to the following:

- https://modaps.modaps.eosdis.nasa.gov/services/about/products/c61-nrt/MOD09CMA.html
- https://modaps.modaps.eosdis.nasa.gov/services/about/products/c61-nrt/MYD09CMA.html

A.1.2 Visible Infrared Imaging Radiometer Suite (VIIRS)

The Suomi National Polar-orbiting Partnership (Suomi-NPP) and Joint Polar Satellite System (JPSS) satellites extend the measurement series initiated with Aqua and Terra with the Aerosol Daily L3 Global 0.05 Degree CMG products.

For more information refer to the following:

- https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/viirs/
- https://eospso.nasa.gov/missions/suomi-national-polar-orbiting-partnership
- https://www.nesdis.noaa.gov/current-satellite-missions/currently-flying/joint-polar-satellite-system
- https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/VNP04ANC
- https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/VJ104ANC

A.2 LP DAAC

The LP DAAC provides the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Emissivity Dataset (GED). ASTER is an instrument on the Terra satellite. ASTER GED is a global, ~100 meter (m) spatial resolution emissivity map of the Earth's non-frozen land surfaces at different wavelengths in the thermal infrared spectrum. The ASTER GED is available from https://e4ftl01.cr.usgs.gov/ASTT/AG100.003/2000.01.01/. Refer to https://lpdaac.usgs.gov/documents/120/ASTERGED_User_Guide_V3.pdf for additional information about the ASTER GED files.

A.3 NCEP / NCAR

The NCEP / NCAR Reanalysis 1 products are annual Network Common Data Form (netCDF) files, which contain the daily values for each surface pressure, precipitable water, and air temperature. The NCEP data are pulled from ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis/surface. (Surface pressure products use filename format slp.{year}.nc; precipitable water files use filename format pr_wtr.eatm.{year}.nc; air temperature files use filename format air.sig995.{year}.nc.) These global products are 2.5° x 2.5° lat/long grids from 90° N to 90° S, and 0° E to 357.5° E. Each grid position contains four daily values from 0Z, 6Z, 12Z, and 18Z.

Refer to file ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis/surface/README for a description of the NCEP Reanalysis data.

A.4 GES DISC

MERRA-2, GEOS-5 FP-IT, and GEOS-5 IT data are available from the GES DISC https://disc.gsfc.nasa.gov/.

MERRA-2 is a NASA atmospheric reanalysis that begins in 1980. Information about the MERRA-2 Project may be found at https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/.

The content and format are described in the MERRA-2 File Specification document located at https://gmao.gsfc.nasa.gov/pubs/docs/Bosilovich785.pdf (March 2016).

MERRA-2 data are updated every three hours. MERRA-2 is one file per day, containing 8 separate time observations. MERRA-2 is not available until four to six weeks after acquisition.

The specific MERRA-2 data collection used is “M2I3NPASM v5.12.4”. The full name of this data collection is “MERRA-2 inst3_3d_asm_Np: 3d,3-Hourly,Instantaneous,Pressure-Level,Assimilation,Assimilated Meteorological Fields V5.12.4”.

GEOS-5 FP-IT is a system of models integrated using the Earth System Modeling Framework that begins in 2000. Information about the GEOS-5 FP-IT project may be found at https://gmao.gsfc.nasa.gov/GEOS_systems/ and https://gmao.gsfc.nasa.gov/weather_prediction/. The content and format are described in the File Specification document located at https://gmao.gsfc.nasa.gov/pubs/docs/Lucchesi865.pdf (October 2015).

The specific FP-IT data collection used is “DFPITI3NPASM v5.12.4”. The full name of this data collection is “GEOS5124 FPIT 3d assimilated state on pressure levels v5.12.4”.

GEOS-5 IT system replaces the GEOS FP-IT system to provide improved products. The GEOS-5 IT system includes model enhancements that lead to more realistic moisture, temperature, and land surface analysis. The specific GEOS-5 IT version is GEOS-5.29.4. The content and format are described in the File Specification document located under https://gmao.gsfc.nasa.gov/GMAO_products/.

A.5 GSFC

Ozone data products are available from GSFC for the Total Ozone Mapping Spectrometer (TOMS) instruments and for the Ozone Monitoring Instrument (OMI). Different platforms / instruments provide data for the following date ranges:

Platform	Instrument	Date Range	Source
Nimbus7	TOMS	10/24/1978 – 5/6/1993	https://acd-ext.gsfc.nasa.gov/anonftp/toms/nimbus7/data/ozone/
Meteor3	TOMS	8/22/1991 – 11/24/1994	https://acd-ext.gsfc.nasa.gov/anonftp/toms/meteor3/data/ozone/
Earth Probe	TOMS	7/2/1996 – 12/14/2005	https://acd-ext.gsfc.nasa.gov/anonftp/toms/eptoms/data/ozone/
Aura	OMI	7/15/2004 – present	https://acd-ext.gsfc.nasa.gov/anonftp/toms/omi/data/ozone

Table A-2. GSFC Ozone Data Products

The source filenames are of the form L3_ozone_XXX_YYYMMDD.txt, where XXX is ‘n7t’ for Nimbus, ‘m3t’ for Meteor3, ‘epc’ for Earth Probe (EP), and ‘omi’ for OMI. The TOMS global products are 1.25° x 1° lat/long grids from 90° S to 90° N, and 180° W to 180° E. The OMI products are 1° x 1° lat/long grids.

For more information, refer to the following web pages:

- https://ozoneaq.gsfc.nasa.gov/
- https://ozoneaq.gsfc.nasa.gov/missions (Source of dates listed in Table A-2)
- http://ozoneaq.gsfc.nasa.gov/data/toms
- ftp://toms.gsfc.nasa.gov/1README

Appendix B Acronyms

ASCII	American Standard Code for Information Interchange
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CCB	Configuration Control Board
CMA	Climate Modeling Grid - Aerosol
CMG	Climate Modeling Grid
CR	Change Request
DAAC	Distributed Active Archive Center
DEM	Digital Elevation Model
DFCB	Data Format Control Book
DOI	Department of the Interior
DPAS	Data Processing and Archive System
EP	Earth Probe (TOMS)
EROS	Earth Resources Observation and Science
ETOPO5	Earth Topography Five Minute Grid
FP-IT	Forward Processing for Instrument Teams
GED	Global Emissivity Dataset
GEOS-5	Goddard Earth Observing System Model, Version 5
GES DISC	Goddard Earth Sciences Data and Information Services Center
GRIB	Gridded Binary, a format of the WMO/CBS
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
HDF4	Hierarchical Data Format Version 4
HDF5	Hierarchical Data Format Version 5
HDP	HDF Dumper
IAS	Image Assessment System
ISD	Interface Specification Document
JPSS	Joint Polar Satellite System
L1GS	Level 1 Geometric Systematic
L1GT	Level 1 Systematic Terrain (Corrected)
L1TP	Level 1 Terrain Precision (Corrected)
L8	Landsat 8
LAADS	Level 1 and Atmosphere Archive & Distribution System
LaSRC	Land Surface Reflectance Code
LDCM	Landsat Data Continuity Mission
LP DAAC	Land Processes Distributed Active Archive Center
LSDS	Land Satellites Data System
LUT	Look-Up Table
m	Meter
MERRA-2	Modern Era Retrospective analysis for Research and Applications Version 2
MODAPS	MODIS Adaptive Processing System

MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
OMI	Ozone Monitoring Instrument
SDS	Scientific Data Set
SR	Surface Reflectance
ST	Surface Temperature
Suomi-NPP	Suomi National Polar-orbiting Partnership
TOMS	Total Ozone Mapping Spectrometer
USGS	U.S. Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite
WMO/CBS	World Meteorological Organization/Commission for Basic Systems

References

Please see https://www.usgs.gov/landsat-missions/landsat-acronyms for a list of acronyms.

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