Questions concerning the document and proposed changes shall be addressed to

Heather Cronk
heather.cronk@colostate.edu
(970) 491-8575

or

Philip Partain
philip.partain@colostate.edu
(970) 491-7835
## Document Revision History

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1 Introduction

The ECMWF-AUX data set is an intermediate product that contains the set of ancillary ECMWF atmospheric state variable data interpolated to each CloudSat cloud profiling radar (CPR) bin. These data are required for input to the LIDAR-AUX, 2B-GEOPROF, 2B-CLDCLASS, 2B-CLDCLASS-LIDAR, 2B-CWC-RO, 2B-CWC-RVOD, 2B-RO, 2B-FLXHR, 2B-FLXHR-LIDAR, 2C-PRECIP-COLUMN, 2C-RAIN-PROFILE, 2C-SNOW-PROFILE, and 2C-ICE algorithms. The ECMWF-AUX product is created using a spatial (vertical and horizontal) and temporal interpolation scheme. The input data are obtained from the AN-ECMWF dataset provided by the European Center for Medium-Range Weather Forecasts. This document describes the interpolation scheme and the format of the ECMWF-AUX product.

2 Description of the Interpolation Process

The AN-ECMWF dataset provided by the European Center for Medium-Range Weather Forecasts contains 3-hourly forecast atmospheric state variable data on a half-degree Cartesian latitude and longitude grid. Operating one CloudSat ray at a time, using geolocation data from the CloudSat 1B-CPR product as the reference, the interpolation algorithm first finds the four bounding AN-ECMWF grid points around the CloudSat ray. For three-dimensional atmospheric state variables, the height of each 1B-CPR radar bin is used to find the two adjacent AN-ECMWF vertical levels and a linear interpolation is performed to get a single data value for the given radar bin height at each of the bounding grid points. Then, a bilinear interpolation is used on the resulting four values to calculate a single value of each data field at the location of the CPR ray at each bin height. Note that for two-dimensional variables, the bilinear interpolation is performed only once at the surface. This procedure is replicated for each of the two forecast times that bound the profile time of the CPR ray. Finally, a temporal linear interpolation is performed on the values obtained at each forecast time, resulting in a single spatially and temporally interpolated value for each CPR ray location and radar bin height. A visual depiction of this procedure is shown in Figure 1.
Figure 1. Interpolation procedure to calculate a single spatially and temporally interpolated AN-ECMWF data value for each CloudSat CPR ray and radar bin height.

When a CloudSat bin occurs below the lowest vertical bin of one or more of the surrounding AN-ECMWF grid points, the AN-ECMWF data at those grid points are extrapolated to the level of the CloudSat bin with a data field-dependent methodology. Ozone, wind data, and specific humidity are kept constant at their lowest ECMWF bin value, temperature is increased at a lapse rate of 6.5 K/km, and pressure is increased using the hypsometric equation.

3 Algorithm Inputs

Input data for the ECMWF-AUX algorithm includes CloudSat 1B-CPR and AN-ECMWF data sets. Each 1B-CPR data file contains data for one orbit of the CloudSat spacecraft. The AN-ECMWF data arrives via ftp at the DPC and is stored in GRIB format. The files contain the atmospheric state variable data on a half-degree Cartesian grid covering the globe for three hour forecast times.
3.1 1B-CPR Specifications

Fields available in the 1B-CPR P_R05 data set used by this algorithm include

(1) Seconds since the start of the granule.
   Name in file: Profile_time
   Range: 0 to 6000
   Source: 1B-CPR P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: nray
   Units: seconds

   Seconds since the start of the granule for each profile. The first profile is 0.

(2) UTC seconds since 00:00 Z of the first profile.
   Name in file: UTC_start
   Range: 0 to 86400
   Source: 1B-CPR P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: <scalar>
   Units: seconds

   The UTC seconds since 00:00 Z of the first profile in the data file.

(3) Spacecraft Latitude
   Name in file: Latitude
   Range: -90 to 90
   Source: 1B-CPR P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: nray
   Units: degrees

   Spacecraft Geodetic Latitude.

(4) Spacecraft Longitude
   Name in file: Longitude
   Range: -180 to 180
   Source: 1B-CPR P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: nray
   Units: degrees

   Spacecraft geodetic longitude.
(5) Ray status range bin size

Name in file: RayHeader_RangeBinSize  Range: 239.8 to 239.8
Source: 1B-CPR P_R05  Missing value: -9999
Field type (in file): REAL(4)  Missing value operator: ==
Field type (in algorithm): REAL(4)  Factor: 1
Dimensions: <scalar>  Offset: 0
Units: meters

Spacing between samples in range in meters.

(6) Digital Elevation Map

Name in file: DEM_elevation  Range: -9999 to 8850
Source: 1B-CPR P_R05  Missing value: 9999
Field type (in file): INT(2)  Missing value operator: ==
Field type (in algorithm): INT(2)  Factor: 1
Dimensions: nray  Offset: 0
Units: meters

Elevation in meters above Mean Sea Level. A value of -9999 indicates ocean. A value of 9999 indicates an error in calculation of the elevation.

3.2 AN-ECMWF Specifications

The AN-ECMWF data set provided by ECMWF is derived from the GOPER high-resolution forecast (atmosphere) model. The GRIB format files contain the following fields for creation of the ECMWF-AUX product and use by the Level 2 algorithms:

(1) Temperature

Name in file: Temperature
Source: AN-ECMWF  Missing value: N/A
Field type (in file): REAL(4)  Missing value operator: N/A
Field type (in algorithm): REAL(4)  Factor: 1
Dimensions: nlon,nlat,nlev  Offset: 0
Units: K

(2) Specific humidity

Name in file: Specific humidity
Source: AN-ECMWF  Missing value: N/A
Field type (in file): REAL(4)  Missing value operator: N/A
Field type (in algorithm): REAL(4)  Factor: 1
Dimensions: nlon,nlat,nlev  Offset: 0
Units: kg/kg
(3) Ozone mass mixing ratio
Name in file: Ozone mass mixing ratio
Source: AN-ECMWF
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nlon,nlat,nlev
Units: kg/kg
Missing value: N/A
Missing value operator: N/A
Factor: 1
Offset: 0

(4) Surface pressure
Name in file: Surface pressure
Source: AN-ECMWF
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nlon,nlat
Units: Pa
Missing value: N/A
Missing value operator: N/A
Factor: 1
Offset: 0

(5) Skin temperature
Name in file: Skin temperature
Source: AN-ECMWF
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nlon,nlat
Units: K
Missing value: N/A
Missing value operator: N/A
Factor: 1
Offset: 0

(6) Two-meter temperature
Name in file: 2 metre temperature
Source: AN-ECMWF
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nlon,nlat
Units: K
Missing value: N/A
Missing value operator: N/A
Factor: 1
Offset: 0

(7) U component of wind
Name in file: U component of wind
Source: AN-ECMWF
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nlon,nlat,nlev
Units: m/s
Missing value: N/A
Missing value operator: N/A
Factor: 1
Offset: 0
The three-dimensional pressure data are constructed for each model level using Equation 1.

$$ p_k = \frac{A_{k-\frac{1}{2}} + B_{k-\frac{1}{2}} p_{sfc} + A_{k+\frac{1}{2}} + B_{k+\frac{1}{2}} p_{sfc}}{2} $$

(1)

where $k$ is the model level, $A_{k\pm\frac{1}{2}}$ and $B_{k\pm\frac{1}{2}}$ are constants stored in the GRIB header that define the vertical coordinate of the “half levels” above and below each model level, and $p_{sfc}$ is the surface pressure.
4 Data Product Output Specifications

Each HDF-EOS 4 product file is built for the orbit specified by the input 1B-CPR data. Within each file, the Geolocation Fields contain the CloudSat ray geolocation, time, and surface elevation from the 1B-CPR file along with the idealized height of the ECMWF data bins. The two-dimensional Data Fields contain top-down profiles of the ECMWF atmospheric state variables for each CPR ray and the one-dimensional Data Fields similarly contain the state variables for the surface. The specifications for the ECMWF-AUX P_R05 file contents are as follows:

(1) Seconds since the start of the granule.
   - **Name in file:** Profile_time
   - **Source:** 1B-CPR P_R05
   - **Field type (in file):** REAL(4)
   - **Field type (in algorithm):** REAL(4)
   - **Dimensions:** nray
   - **Units:** seconds
   - **Range:** 0 to 6000
   - **Missing value:** N/A
   - **Missing value operator:** N/A
   - **Factor:** 1
   - **Offset:** 0

   Seconds since the start of the granule for each profile. The first profile is 0.

(2) UTC seconds since 00:00 Z of the first profile
   - **Name in file:** UTC_start
   - **Source:** 1B-CPR P_R05
   - **Field type (in file):** REAL(4)
   - **Field type (in algorithm):** REAL(4)
   - **Dimensions:** <scalar>
   - **Units:** seconds
   - **Range:** 0 to 86400
   - **Missing value:** N/A
   - **Missing value operator:** N/A
   - **Factor:** 1
   - **Offset:** 0

   The UTC seconds since 00:00 Z of the first profile in the data file.

(3) TAI time for the first profile.
   - **Name in file:** TAI_start
   - **Source:** 1B-CPR P_R05
   - **Field type (in file):** REAL(8)
   - **Field type (in algorithm):** REAL(8)
   - **Dimensions:** <scalar>
   - **Units:** seconds
   - **Range:** 0 to 6e+008
   - **Missing value:** N/A
   - **Missing value operator:** N/A
   - **Factor:** 1
   - **Offset:** 0

   The TAI timestamp for the first profile in the data file. TAI is International Atomic Time: seconds since 00:00:00 Jan 1 1993.
(4) **Spacecraft Latitude**  
Name in file: Latitude  
Source: 1B-CPR P_R05  
Field type (in file): REAL(4)  
Field type (in algorithm): REAL(4)  
Dimensions: nray  
Units: degrees  
Range: -90 to 90  
Missing value: -999  
Factor: 1  
Offset: 0  

Spacecraft geodetic latitude.

(5) **Spacecraft Longitude**  
Name in file: Longitude  
Source: 1B-CPR P_R05  
Field type (in file): REAL(4)  
Field type (in algorithm): REAL(4)  
Dimensions: nray  
Units: degrees  
Range: -180 to 180  
Missing value: -999  
Factor: 1  
Offset: 0  

Spacecraft geodetic longitude.

(6) **Height of the ECMWF data bins**  
Name in file: EC_height  
Source: ECMWF-AUX P_R05  
Field type (in file): INT(2)  
Field type (in algorithm): INT(2)  
Dimensions: nbin  
Units: m  
Range: -5000 to 30000  
Missing value: -9999  
Factor: 1  
Offset: 0  

Idealized height of the ECMWF data bins where bin 105 is at 0 m MSL. Each profile uses the same height information.

(8) **Digital Elevation Map**  
Name in file: DEM_elevation  
Source: 1B-CPR P_R05  
Field type (in file): INT(2)  
Field type (in algorithm): INT(2)  
Dimensions: nray  
Units: m  
Range: -9999 to 8850  
Missing value: 9999  
Factor: 1  
Offset: 0  

Elevation in meters above Mean Sea Level. A value of -9999 indicates ocean. A value of 9999 indicates an error in calculation of the elevation.
(9) ECMWF data extrapolation flag

| Name in file:  | Extrapolation_flag | Range: N/A |
| Source:       | ECMWF-AUX P_R05   | Missing value: N/A |
| Field type (in file): | INT(1) | Missing value operator: N/A |
| Field type (in algorithm): | INT(1) | Factor: 1 |
| Dimensions:   | nbin,nray        | Offset: 0 |
| Units:        | N/A             |

The extrapolation flag is a bit field that indicates areas where ECMWF data are extrapolated to fill in CPR bins that occur below the lowest ECMWF layers between grid points.

Bit 0: CPR bin below ground
Bit 1: Data from Northeast grid point missing
Bit 2: Data from Northwest grid point missing
Bit 3: Data from Southwest grid point missing
Bit 4: Data from Southeast grid point missing

(10) Atmospheric pressure

| Name in file:  | Pressure |
| Source:       | ECMWF-AUX P_R05 |
| Field type (in file): | REAL(4) |
| Field type (in algorithm): | REAL(4) |
| Dimensions:   | nbin,nray |
| Units:        | Pa        |

Missing value: -999
Missing value operator: ==
Factor: 1
Offset: 0

(11) Temperature

| Name in file:  | Temperature |
| Source:       | ECMWF-AUX P_R05 |
| Field type (in file): | REAL(4) |
| Field type (in algorithm): | REAL(4) |
| Dimensions:   | nbin,nray |
| Units:        | K         |

Missing value: -999
Missing value operator: ==
Factor: 1
Offset: 0

(12) Specific humidity

| Name in file:  | Specific_humidity |
| Source:       | ECMWF-AUX P_R05 |
| Field type (in file): | REAL(4) |
| Field type (in algorithm): | REAL(4) |
| Dimensions:   | nbin,nray |
| Units:        | kg/kg      |

Missing value: -999
Missing value operator: ==
Factor: 1
Offset: 0
(13) Ozone mass mixing ratio
   Name in file: Ozone
   Source: ECMWF-AUX P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: nbin,nray
   Units: kg/kg
   Missing value: -999
   Missing value operator: ==
   Factor: 1
   Offset: 0

(14) Surface pressure
   Name in file: Surface_pressure
   Source: ECMWF-AUX P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: nray
   Units: Pa
   Missing value: -999
   Missing value operator: ==
   Factor: 1
   Offset: 0

(15) Skin temperature
   Name in file: Skin_temperature
   Source: ECMWF-AUX P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: nray
   Units: K
   Missing value: -999
   Missing value operator: ==
   Factor: 1
   Offset: 0

(16) Two-meter temperature
   Name in file: Temperature_2m
   Source: ECMWF-AUX P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: nray
   Units: K
   Missing value: -999
   Missing value operator: ==
   Factor: 1
   Offset: 0

(17) U component of wind
   Name in file: U_velocity
   Source: ECMWF-AUX P_R05
   Field type (in file): REAL(4)
   Field type (in algorithm): REAL(4)
   Dimensions: nbin,nray
   Units: m/s
   Missing value: -999
   Missing value operator: ==
   Factor: 1
   Offset: 0
(18) V component of wind
Name in file: V_velocity
Source: ECMWF-AUX P_R05
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nbins,nrays
Units: m/s

(19) Sea surface temperature
Name in file: Sea_surface_temperature
Source: ECMWF-AUX P_R05
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nrays
Units: K

(20) Ten-meter U component of wind
Name in file: U10_velocity
Source: ECMWF-AUX P_R05
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nrays
Units: m/s

(21) Ten-meter V component of wind
Name in file: V10_velocity
Source: ECMWF-AUX P_R05
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nrays
Units: m/s

5 Caveats for Users

The ECMWF-AUX team has identified the following caveats that users should be aware of:

- The sea surface temperature (SST) field is not suitable for scientific analysis near coastlines. Non-existent ECMWF SST values on land prevent spatial bilinear interpolation near the coast and therefore the ECMWF-AUX product contains missing values (-999.0) in this area.
6 Changes Since Algorithm Version P_R04

- The source code was re-written in Python for improved accessibility and flexibility.

- The calculation of the ECMWF pressure profile was corrected which will affect the vertical profile of every variable when compared to P_R04.

- Additional AN-ECMWF data fields were added to the ECMWF-AUX product, including
  
  o U and V wind components
  o Sea surface temperature
  o 10 meter U and V wind components

  See Section 3.2 and Section 4 for more details.

7 Acronym List

AGL    Above Ground Level
CPR    Cloud Profiling Radar
DPC    Data Processing Center
ECMWF  European Center for Medium-Range Weather Forecasts
EOS    Earth Observing System
GRIB   Gridded Binary Data Format
HDF    Hierarchical Data Format
MSL    Mean Sea Level