CloudSat Project

A NASA Earth System Science Pathfinder Mission

CloudSat ECMWF-AUX Auxiliary Data Product Process Description and Interface Control Document

Product Version: P1_R05
Document Revision: 0
Date: 7 October 2022

Questions concerning the document and proposed changes shall be addressed to

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Document Revision History

Date	Revision	Description	Section(s) Affected
October 2022	0	Initial Release	All

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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-TAU, 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.

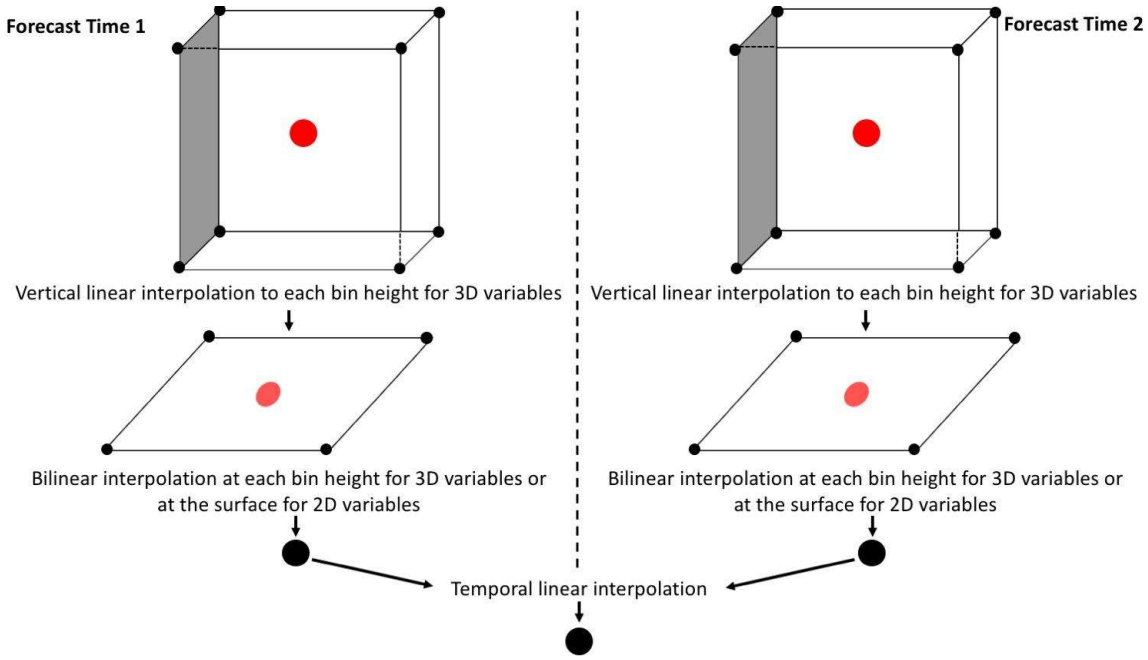


Figure 1. Interpolation procedure to calculate a single spatially and temporally interpolated AN-ECMWF data value for each CloudSat CPR ray and radar bin height.

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
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) 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
Missing value operator: ==
Factor: 1
Offset: 0

Spacecraft Geodetic Latitude.

(4) 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
Missing value operator: ==
Factor: 1
Offset: 0

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

(8) V component of wind
Name in file: V 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

(9) Sea surface temperature
Name in file: Sea surface 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

(10) Ten-meter U component of wind
Name in file: 10 metre U wind component
Source: AN-ECMWF
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nlon,nlat
Units: m/s
Missing value: N/A
Missing value operator: N/A
Factor: 1
Offset: 0

(11) Ten-meter V component of wind
Name in file: 10 metre V wind component
Source: AN-ECMWF
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Dimensions: nlon,nlat
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.

$$p_k = \frac{\left(A_{k-\frac{1}{2}} + B_{k-\frac{1}{2}} p_{sfc}\right) + \left(A_{k+\frac{1}{2}} + B_{k+\frac{1}{2}} p_{sfc}\right)}{2} \qquad (1)$$

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 P1_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
Missing value operator: ==
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
Missing value operator: ==
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
Missing value operator: ==
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
Missing value operator: ==
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
Source: ECMWF-AUX P1_R05
Field type (in file): INT(1)
Field type (in algorithm): INT(1)
Dimensions: nbin,nray
Units: N/A
Range: N/A
Missing value: N/A
Missing value operator: N/A
Factor: 1
Offset: 0

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 P1_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 P1_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 P1_R05
Field type (in file): REAL(4)
Field type (in algorithm): REAL(4)
Missing value: -999
Missing value operator: ==
Factor: 1

Dimensions: nbin,nray **Offset:** 0
Units: kg/kg

(13) Ozone mass mixing ratio
Name in file: Ozone
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1
Dimensions: nbin,nray **Offset:** 0
Units: kg/kg

(14) Surface pressure
Name in file: Surface_pressure
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1
Dimensions: nray **Offset:** 0
Units: Pa

(15) Skin temperature
Name in file: Skin_temperature
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1
Dimensions: nray **Offset:** 0
Units: K

(16) Two-meter temperature
Name in file: Temperature_2m
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1
Dimensions: nray **Offset:** 0
Units: K

(17) U component of wind
Name in file: U_velocity
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1

Dimensions: nbin,nray **Offset:** 0
Units: m/s

(18) V component of wind
Name in file: V_velocity
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1
Dimensions: nbin,nray **Offset:** 0
Units: m/s

(19) Sea surface temperature
Name in file: Sea_surface_temperature
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1
Dimensions: nray **Offset:** 0
Units: K

(20) Ten-meter U component of wind
Name in file: U10_velocity
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1
Dimensions: nray **Offset:** 0
Units: m/s

(21) Ten-meter V component of wind
Name in file: V10_velocity
Source: ECMWF-AUX P1_R05 **Missing value:** -999
Field type (in file): REAL(4) **Missing value operator:** ==
Field type (in algorithm): REAL(4) **Factor:** 1
Dimensions: nray **Offset:** 0
Units: m/s

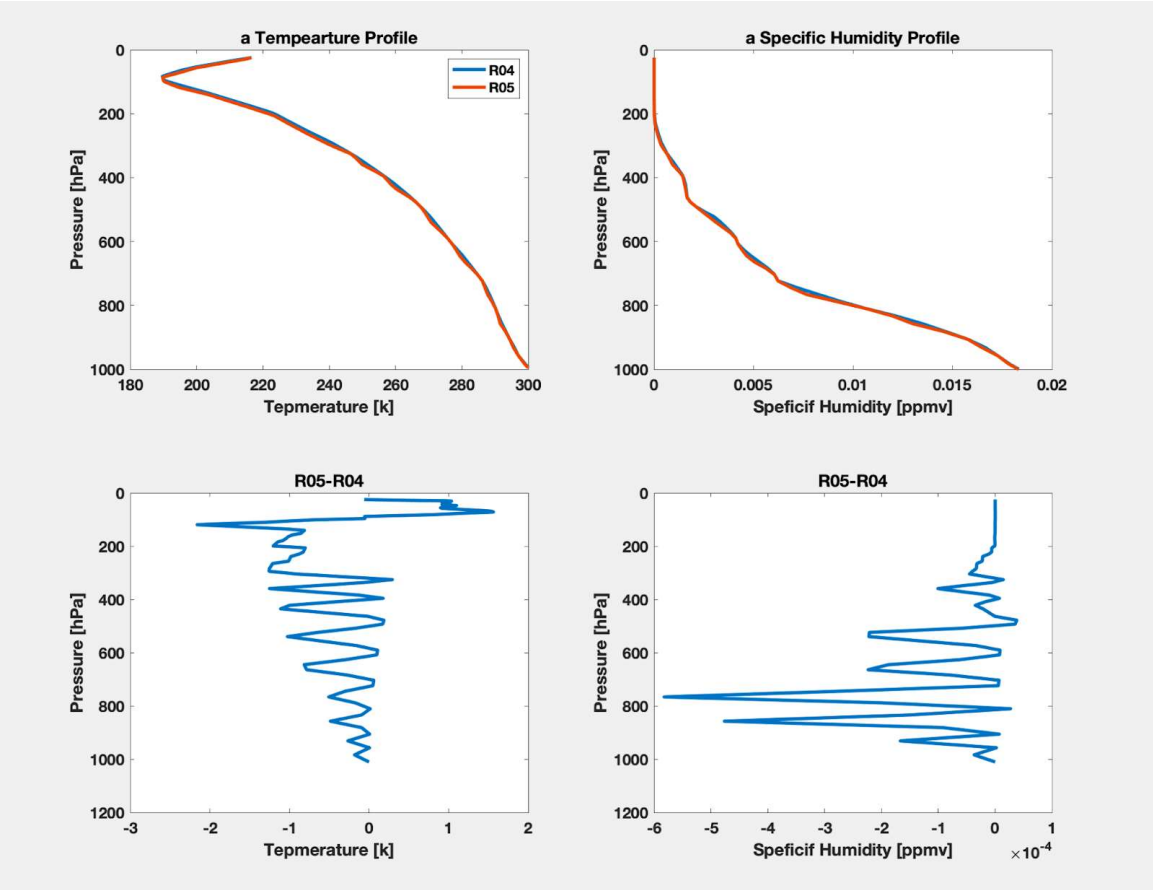
5 Caveats for Users

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_R05

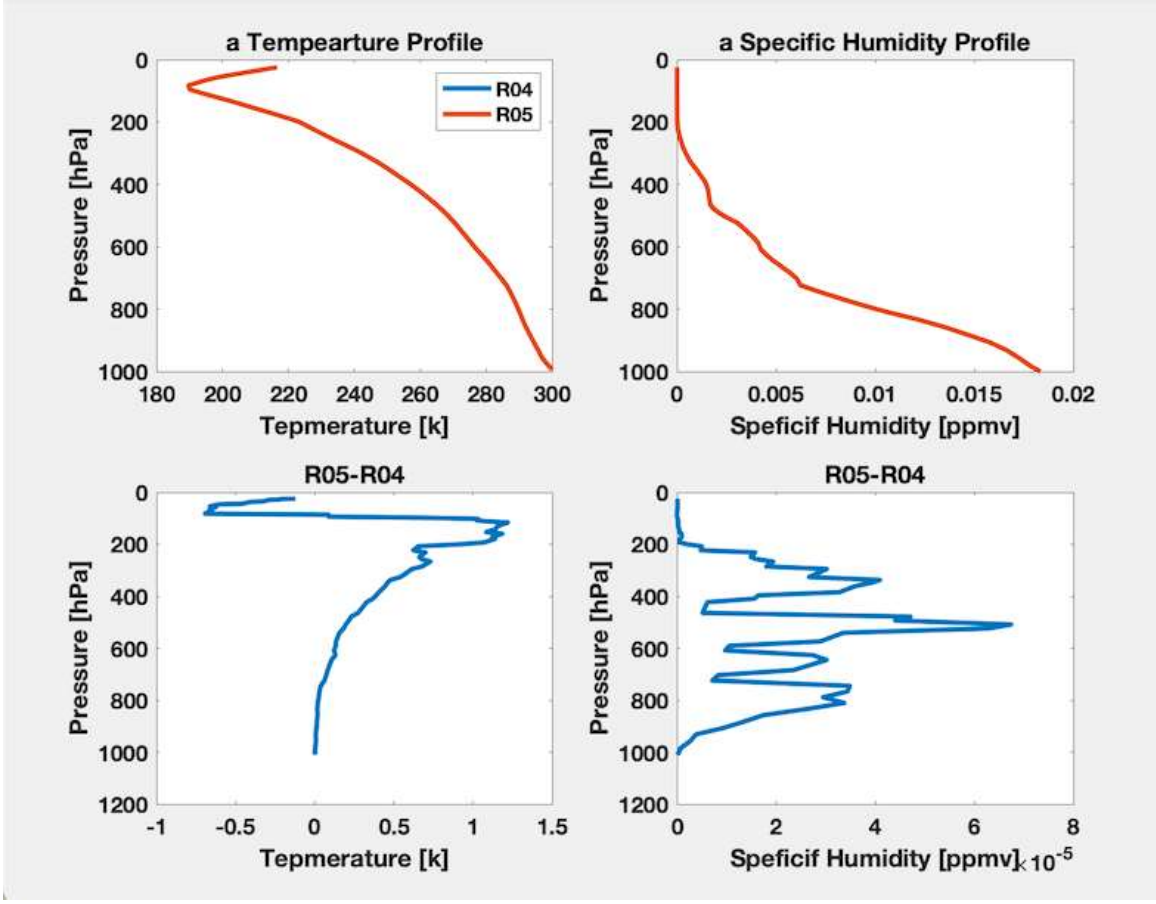
The calculation of the ECMWF pressure profile was corrected to fix a bug in the P_R05 code that caused small errors during the interpolation to the CloudSat bin heights when compared to P_R04 results. This resulted in "wobbles" affecting the vertical profile of every variable when plotted against pressure (see Figure 2).



Courtesy Hanii Takahashi (JPL)

Figure 2. Comparison of P_R04 and P_R05 vertical profiles of Temperature and Specific Humidity showing the impact of the pressure interpolation error.

Fixing the error results in values shown in Figure 3 (note the scale change in the difference plots, particularly for Specific Humidity).



Courtesy Hanii Takahashi (JPL)

Figure 3. Comparison of P_R04 and P_R05 vertical profiles of Temperature and Specific Humidity after correcting the pressure interpolation.

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