National Aeronautics and Space Administration

OPERA

Observational Products for End-Users from Remote Sensing Analysis

Product Specification Document for Troposphere Zenith Radar Delays

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Observational Products for End-users from Remote sensing Analysis (OPERA) Project

OPERA Level-4 Troposphere Zenith Radar Delays Product Specification

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Section	Description	Due Date
1	Add JPL D- Number	
1.1	Confirm DAAC for TROPO products	

Table of Contents

1 INTRODUCTION

1.1 Purpose

This document provides a specification of the OPERA (Observational Products for End-users from Remote-sensing Analysis) Level-4 Troposphere Zenith Radar Delays product from ECMWF HRES weather model data. This product, referred to by the short name TROPO, is to be generated by the OPERA Data System and openly distributed by NASA's Alaska Space Facility Distributed Active Archive Center (ASF-DAAC, TBC).

1.2 Document Organization

The rest of this document is organized as follows. Section 2 provides an overview of the product including its purpose. Section 3 outlines the structure of the product, including tile definition, file organization, spatial resolution, temporal and spatial organization of the content, the size and data volume. Section 4 provides a detailed description of TROPO product layers and corresponding metadata. Appendix A includes a list of the acronyms used in this document.

1.3 Applicable and Reference Documents

The product described in this document responds to requirements imposed by applicable documents indicated below. In case of conflict between the applicable documents and this one, the OPERA Project shall review the conflict to find the most effective resolution.

Applicable Documents (TBD)

[AD1] OPERA Level-2 Project Requirements, JPL D-107391, Revision A, 2021-12-16.

[AD2] OPERA Level-3 Algorithm Requirements Documents, JPL D-107406, Revision- (Initial Release), 2022-01-31.

Reference Documents

[RD1] ECMWF Atmospheric Model high resolution 10-day forecast (Set I - HRES) Documentation, https://www.ecmwf.int/en/forecasts/datasets/set-i [Accessed 05 Feb 2025]

[RD2] Network Common Data Form, Format 4, version 1.7.2., https://unidata.github.io/netcdf4-python/#version-172 [Accessed 05 Feb 2025]

[RD3] NetCDF Climate and Forecast (CF) Metadata Conventions CF-1.8, https://cfconventions.org/Data/cf-conventions/cf-conventions-1.8/cf-conventions.html . [Accessed 05 Feb 2025]

As noted on the cover of this document, the latest official versions of OPERA documents should be obtained from [TBD]. This document is a working version for the OPERA Algorithm Development Team's (ADT) Interface (IF) delivery to OPERA Science Data System (SDS).

2 Product Overview

2.1 Product Background

The OPERA Level 4 Troposphere Zenith Radar Delays (L4_TROPO-ZENITH) product is derived from the high-resolution 10-day forecast (HRES) model of the European Centre for Medium-Range Weather Forecasts (ECMWF). The OPERA project is creating a radar sensor-agnostic, one-way troposphere zenith-integrated delays, including both wet and hydrostatic components, at various height levels.

Tropospheric delay in satellite radar measurements is primarily influenced by atmospheric temperature, water vapor, and pressure, which are correlated with topography. It is characterized as the integral of air refractivity from the surface up to top of the atmosphere at approximately 80 km altitude (*Eq.1*).

$$ZTD = 10^{-6} \int_{z}^{Zmax} N(x, y, z)\, ds \tag{1}$$

Refractivity consists of wet and hydrostatic components that vary in space and time, driven by atmospheric pressure, temperature, and water vapor partial pressure. While hydrostatic delay (*Eq. 3*) is mainly governed by atmospheric pressure (p) and temperature (t), wet delay (*Eq. 3)* is predominantly affected by water vapor content, i.e water pressure (e) normalized by the temperature (t).

$$N = hydrostatic_{refractivity} + wet_{refractivity} \tag{2}$$

$$hydrostatic_{refractivity} = k_1 * \frac{p}{t}$$
$$wet_{refractivity} = k_2 * \frac{e}{t} + k_3 * \frac{e}{t^2} \tag{3}$$

$$where\ k_1 = 0.776\ K/Pa,\quad k_2 = 0.716\ K/Pa,\quad k_3 = 3.75e^3\ K^2/Pa\ are\ constants.$$

Global estimates of these atmospheric parameters are available from Numerical Weather Prediction (NWP) models, such as ECMWF's high-resolution forecast model (HRES), which provides the data used to compute the L4_TROPO-ZENITH product. Note that this product contains one-way zenith-integrated tropospheric delays, which must be intersected with topography elevation, projected to an imaging path and scaled to the radar wavelength to apply the two-way tropospheric correction for radar propagation (*Eq. 4*).

$$tropo_{corr.} = \frac{-4\pi}{\lambda} * \frac{ZTD}{cos(radar_{incidence\ angle})} \quad (4)$$

The theoretical basis and processing sequence used to generate TROPO will be fully described in the Algorithm Theoretical Basis Document, JPL-TBD. Figure 2-1 summarizes the workflow interface used to generate a TROPO product.

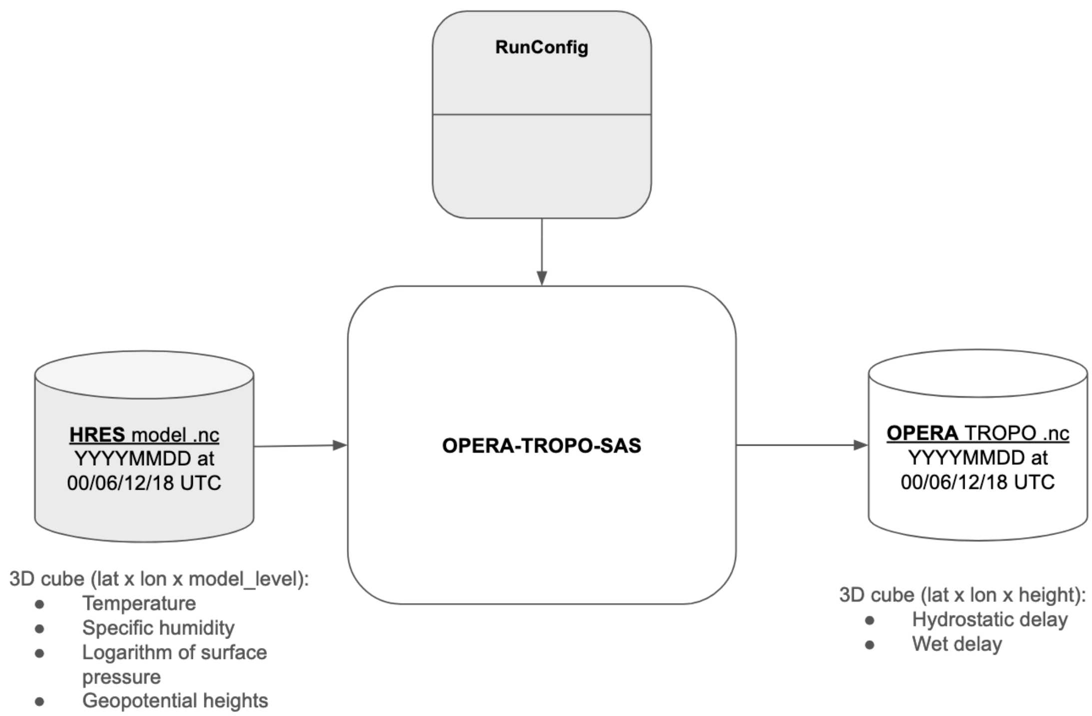

Figure 2-1 OPERA TROPO workflow interface.

The primary input datasets of the workflow are a set of HRES model products for specific data and time. Input HRES products are distributed on geographical map coordinates (latitude, longitude) in the World Geodetic System 1984 (WGS84) reference system. The input HRES weather model forecast data cover the globe at a 0.1° × 0.1° latitude/longitude grid for each date at 0, 6, 12, and 18 UTC. The HRES model parameters used for the 3D tropospheric radar delay calculations include geopotential heights, the logarithm of surface pressure, specific humidity, and temperature at 137 model levels [RD1].

The workflow is controlled by a YAML configuration file ("RunConfig" in Figure 2-1), which contains the input files, output files, and configuration options for processing worker settings, output compression, and height levels.

Product	Posting in Latitude (degree_north)	Posting in Longitude (degrees_east)	Spatial Reference System	Description
HRES	~0.07	~0.07	WGS84	Level 3 HRES product produced by ECMWF, and packaged by SDS

Table 2-1. Input products for generating TROPO products.

2.2 TROPO Overview

Each TROPO product is distributed as a Network Common Data Form version 4 (NETCDF4) file following the Climate and Forecast (CF)-1.8 conventions [RD3]. The file format is compatible with Network Common Data Form version 4 (netCDF4) software. It contains both data raster layers (e.g. hydrostatic and wet delay) at 145 globally consistent height levels, and product metadata. The pixel spacings of the TROPO product in Longitude and Latitude directions are 0.07 and 0.07 degrees (approx. 8km), in the WGS84 reference system (Table 2-2).

The TROPO products are global products distributed for specific date and time. OPERA TROPO products use a "pixel is area" convention. This convention uses latitude and longitude coordinates with (0,0) denoting the upper-left corner of the image and increasing longitude to the east (-180 to 180 degrees), decreasing latitude to the south (90 to -90 degrees). The first pixel value fills the grid cell with the top-left position (0,0) and bottom-right position (1,1).

Product	Posting in Latitude (degree_north)	Posting in Longitude (degrees_east)	Spatial Reference System	Description
TROPO	~0.07	~0.07	WGS84	One-way Zenith-integrated Troposphere radar delays

Table 2-2. Spatial organization for TROPO product.

3 Product Organization

3.1 File Format - Network Common Data Form version 4

NETCDF4 is a binary file format optimized for storing large scientific datasets, particularly in Earth and environmental sciences. NetCDF4 is built on top of Hierarchical Data Format version 5 (HDF5), inheriting its hierarchical structure and efficient data storage features while adding a structured data model tailored for climate, ocean, atmospheric geospatial applications, designed for flexible and efficient I/O, for high volume, and it supports complex data allocation. NetCDF was developed and is maintained at the National Science Foundation (NSF) Unidata Program center. NetCDF4 files follow a structured model with four main components: dimensions -size and shape of data arrays (e.g., time, height, latitude, longitude), variables - multi-dimensional arrays storing actual data, associated with specific dimensions, attributes - Metadata describing variables, datasets, and global properties, and groups – hierarchical containers (similar to directories) for organizing datasets. NETCDF files are equally accessible in Fortran, C/C++, and other high-level computation packages such as IDL, MATLAB or Python. The NETCDF4 file format enables the storage of compressed images with associated metadata that can be easily read by Geographic Information System (GIS) software including Geospatial Data Abstraction Library (GDAL) and Quantum Geographic Information System (QGIS) if following the CF-1.8 convention. The NETCDF4 Group website at https://unidata.github.io/netcdf4-python/#version-172 to download NETCDF software and documentation [RD2/RD3] .

3.2 File Organization

The OPERA TROPO products have the primary hydrostatic and wet delay rasters located in the root group ("/") for user convenience. See Section 4 for full product outline.

Global metadata in the root group level are currently given as Global Attributes in Table 3-1.

Attribute	Format	Description
Conventions	string	NetCDF-4 conventions adopted in this product. This attribute should be set to "CF-1.8" to indicate that the group is compliant with the CF NetCDF conventions.
title	string	"OPERA_L4_TROPO-ZENITH"
institution	string	Name of producing agency (e.g. "NASA JPL").
contact	string	Contact information for the producer of the product. (e.g., "opera-sds-ops@jpl.nasa.gov").
source	string	Source provider (e.g. ECMWF)
platform	string	Numerical Weather Model input. (e.g. Model High Resolution 15-day Forecast (HRES))
spatial_resolution	string	Spatial resolution of source and product (e.g. 0.07deg)
temporal_resolution	string	Temporal resolution of source and product (e.g. 6 hours)
source_url	string	Source url documentation, (e.g. https://www.ecmwf.int/en/forecasts/datasets/set-i for HRES)
references	string	Url documentation for software (e.g. "https://raider.readthedocs.io/en/latest/" for RAiDER)

mission_name	string	"OPERA"
description	string	OPERA One-way Tropospheric Zenith-integrated Delay for Synthetic Aperture Radar
comment	string	Intersect/interpolate with DEM, project to slant-range and multiply with -4pi/wavelength (2way) to get SAR correction
software	string	RAiDER
software_version	string	0.5.3
reference_document	string	Name and version of Product Description Document to use as reference for product. (TBD)
history	string	Created on processing datetime, e.g. 2025-02-06 01:14:14.265581+00:00 (UTC)

Table 3-1 Global Attributes of TROPO product.

3.3 File Naming Convention

OPERA TROPO granule names are designed to ensure unique names for the OPERA TROPO products. The file name convention for TROPO follows the standard:

OPERA_L4_TROPO-ZENITH_*WeatherModelDateTime_ProductGenerationDateTime_NWPName_ProductVersion*.nc

where:

- WeatherModelDateTime: The weather model (e.g. HRES) base date and time in the format YYYYMMDDTHHMMSSZ . Note. MMSS are always 0000
- ProductGenerationDateTime: The date and time at which the product was generated by OPERA with the format of YYYYMMDDTHHMMSSZ
- NWPName: Numerical Weather Prediction (NWP) model name, e.g. HRES
- ProductVersion: OPERA TROPO product version number with four characters, including the letter “v” and two digits indicating the major and minor versions, which are delimited by a period

An example of a TROPO product file name:

OPERA_L4_TROPO-ZENITH_20190101T060000Z_20250201T232711Z_HRES_v1.0.nc

4 Product Specification

4.1 Dimensions and Shapes of Data

To simplify the description of the layout of data within the NETCDF4 file, we will use a table of dimensions and shapes to represent the relationship between similarly sized datasets. The entries in this table do not present actual datasets in the NETCDF4. This table is meant to be a guide to interpreting the shapes of the datasets in subsequent subsections.

Name	Description
tropo_width	Width (number of columns) of the troposphere product
tropo_length	Length (number of rows) of the troposphere product
tropo_depth	Depth (number of levels) of the troposphere product
tropo_time	Time of the troposphere product

4.2 Product Imagery Layers

Product Imagery Variables		
Name: hydrostatic_delay		
Type: float32	Shape: (tropo_time, tropo_depth, tropo_length, tropo_width)	Units: meters
Description: One-way Zenith-integrated Hydrostatic Delay.		
Name: wet_delay		
Type: float32	Shape: (tropo_time, tropo_depth, tropo_length, tropo_width)	Units: meters
Description: One-way Zenith-integrated Wet Delay.		
Name: longitude		
Type: float64	Shape: (tropo_width,)	Units: degrees_east
Description: Angular distance of a point east or west of the Prime Meridian.		
Name: latitude		

Type: float64	Shape: (tropo_length,)	Units: degrees_north
Description: Angular distance of a point north or south of the equator.		
Name: height		
Type: float64	Shape: (tropo_depth.)	Units: meters
Description: Ellipsoidal_height levels above WGS84 ellipsoid		
Name: time		
Type: datetime	Shape: (tropo_time,)	Units: hours since 1900-01-01
Description: Numerical Weather Model base time		

Table 4-2 TROPO variables.

5 TROPO Sample Product

Figure 5-1 shows an example of the TROPO product processed for June. 13, 2019, base time 06 UTC.

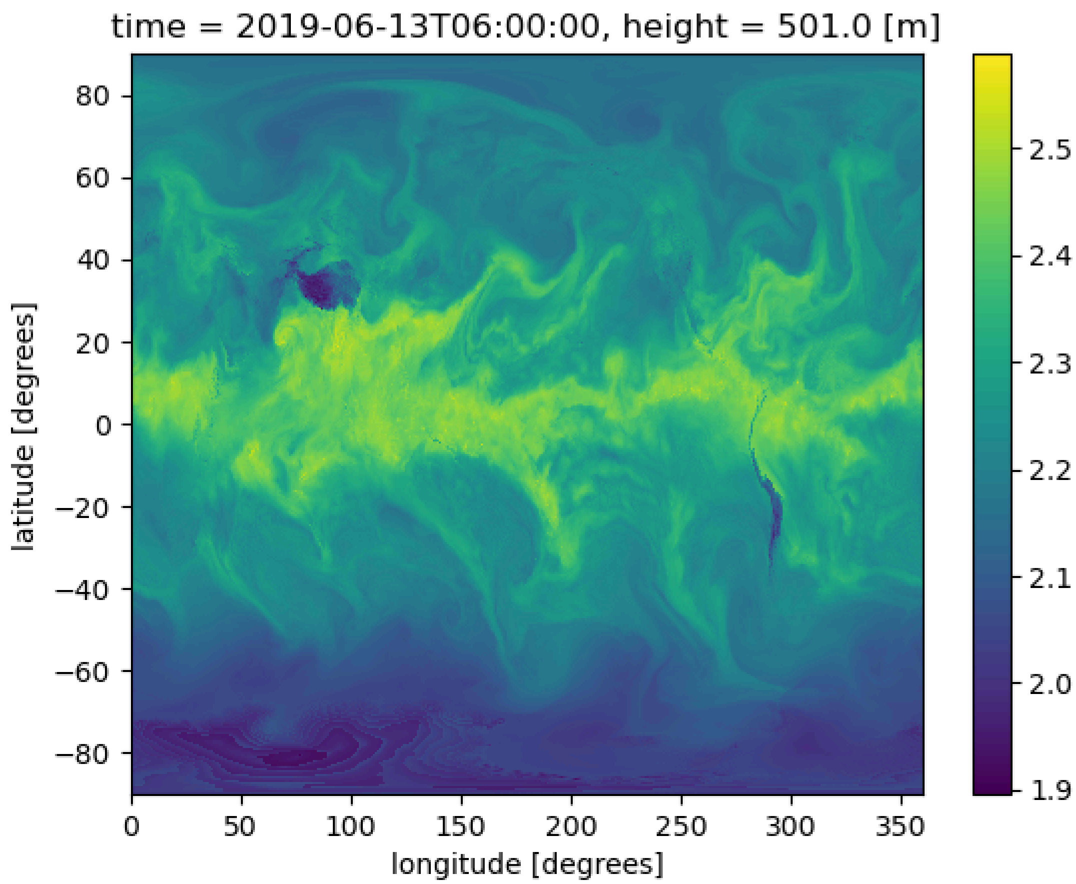

Figure 5-1 TROPO total (hydrostatic plus wet) zenith delay in meters at 501m altitude

Appendix A: Acronyms

ADT	Algorithm Development Team
ASF-DAAC	NASA's Alaska Space Facility Distributed Active Archive Center
CF	Climate and Forecast
ECMWF	European Centre for Medium-Range Weather Forecasts
DAAC	Distributed Active Archive Center
DOI	Digital Object Identifier
GIS	Geographic Information System
HDF5	Hierarchical Data Format version 5
HRES	High-Resolution Forecast (HRES) model
IF	Interface (delivery)
L4	Level-4
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
NCSA	National Center for Supercomputing Applications
NETCDF	Network Common Data Form
OPERA	Observational Products for End-users from Remote-sensing Analysis
PGE	Product Generation Executable
RADAR	Radio Detection and Ranging
SDS	Science Data System
UTC	Coordinated Universal Time
WGS84	World Geodetic System 1984
YAML	YAML Ain't Markup Language