FDR4LDYN
Fundamental Data Record for Land Dynamic

ESA RFP/3-18440/24/I-DT-I

Product Description Document (PDD)

DT2-2

Revision History

Revision	Date	Author(s)	Description
1.0	1 October 2025	TU Wien	FDR4LDYN data record v0.1 release
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1 Executive summary

The FDR4LDYN products are derived from C-band backscatter observations collected by the scatterometers (ESCAT) onboard the European Remote Sensing satellites ERS-1 and ERS-2. The core variables provided in the main FDR4LDYN data record are normalized backscatter, slope, and curvature, together with noise estimates and relevant flags indicating their quality. This dataset is complemented by separate FDR4LDYN products containing ancillary parameters such as yearly azimuthal correction terms, uncertainty estimates, and advisory flags. Moreover, different variants of the slope and curvature time series will be included in future FDR4LDYN data products to address different application requirements. The data records are designed to ensure optimal interoperability with the corresponding current Metop ASCAT and future Metop-SG SCA backscatter observables, supporting the creation of a consistent long-term record of land surface backscatter. The FDR4LDYN products enable the monitoring of land surface dynamics and support diverse scientific and operational applications in domains such as soil moisture estimation, vegetation dynamics, flood monitoring, cryospheric research, and climate studies.

2 Introduction

2.1 Purpose of the document

The Product Description Document (PDD) provides a comprehensive overview of the FDR4LDYN data records, describing their key characteristics, parameters, data formats, and modes of availability. Although designed to be reasonably self-standing, the PDD is part of a broader documentation suite and relies on companion documents for in-depth technical detail:

- Quality Assessment, Quality Control, and Interoperability Report (QA/QC/IO) [1], providing a detailed analysis of the quality characteristics, applied quality control measures, and interoperability of ERS ESCAT data with MetOp ASCAT.
- Algorithm Theoretical Basis Document (ATBD) [2], describing in detail the algorithms, processing steps, and corrections applied to derive the backscatter observables.

Together, these documents form a coherent framework, with the PDD serving as the entry point for users interested in the content and practical use of the FDR4LDYN data records.

2.2 Targeted audience

This document mainly targets:

- Users of FDR4LDYN backscatter, slope, and curvature data sets and related azimuth and error model parameters

3 Product description

The FDR4LDYN ESCAT land backscatter data records provide harmonized ERS scatterometer observables on a fixed Fibonacci Earth grid at 12.5 km sampling. The records focus on land surfaces and are distributed as a set of complementary files, comprising the main data record with calibrated backscatter observables, accompanied by ancillary datasets providing azimuthal correction coefficients, uncertainty characterizations, and quality information. All files in the set refer to the same 12.5 km target grid and are co-registered.

3.1 Product lineage

The FDR4LDYN ESCAT data records are derived from ERS wind scatterometer level 2.0 data inputs and produced through the following steps [2]:

1. **Pre-processing and gridding.** Valid triplet backscatter observations (fore/mid/aft) are filtered using node-confidence flags, then mapped to a 12.5 km Fibonacci grid (nearest-neighbor to preserve native values and flags). ERS-1 and ERS-2 streams are merged.

2. **Quality control and inter-calibration.** Outliers are filtered with robust, incidence-angle-aware statistics; recommended flags are applied. Inter-calibration with static coefficients yields optimal alignment of ERS-1/2 to MetOp-A ASCAT data for future combined use.

3. **Azimuthal correction.** A dual-reference scheme, right-ascending and right-descending, is used to minimize azimuthal noise while retaining diurnal backscatter effects and long-term land-cover changes.

4. **Uncertainty estimation.** Measurement noise is quantified via the estimated standard deviation (ESD) of backscatter. ESD is provided on a yearly basis, and is used for uncertainty propagation in the incidence-angle interpolation to $\sigma^0(40^\circ)$ and for downstream quality screening.

5. **Slope and curvature.** Backscatter triplets (fore/mid/aft beam) are used as input to the computation of slope and curvature of the incidence angle–backscatter behavior at 40° in two variants: (i) climatologies and (ii) dynamic time-series estimates based on a kernel smoother approach. Per-variable noise estimates are generated for downstream use.

6. **Normalization.** Backscatter is normalized to 40° using dynamic slope and curvature.

3.2 Spatial resolution, sampling and coverage

The FDR4LDYN backscatter observations are resampled to a fixed Earth Fibonacci grid with a spatial sampling of about 12.5 km, named after the Fibonacci ratio [3]. The Fibonacci grid differs from other spiral constructed grids on the sphere in that the longitudinal turn between consecutive points along the generative spiral is the golden angle ($360^\circ \cdot (1 - \phi^{-1}) \simeq 137.5^\circ$) or its complement ($360^\circ \cdot \phi^{-1} \simeq 222.5^\circ$). The spatial sampling distance is defined by the number of points used to generate the grid ($N = 1,650,000$). Since the grid point locations are computed on a spherical Earth, latitude and longitude coordinates are converted to WGS84 ellipsoidal coordinates (EPSG:4326). This transformation introduces deviations of the sampling regularity on a larger scale. However, due to the fact that the Fibonacci grid can only be computed in a closed form on a sphere and deviations are minor considering only the near vicinity of grid points (< 20 km), these irregularities in sampling are deemed acceptable. To visualize this, a small patch on the surface of both the sphere and the ellipsoid can be used as an example. If the patch is small enough, it looks flat, and the distances within this patch are nearly the same for both shapes. But for points across the entire surface, the sphere's uniformity contrasts with the ellipsoid's varied stretching, making the distances diverge more.

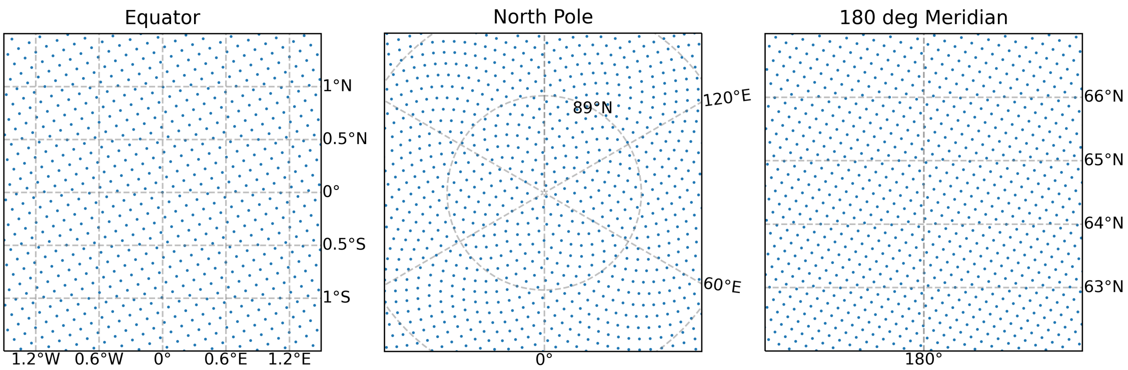

Figure 3.1: Fibonacci grid (12.5 km) at the equator (left), North Pole (middle) and 180° meridian (right).

The spatial resolution of the FDR4LDYN products is 25 km × 25 km. All FDR4LDYN products have a global coverage, i.e. 65°S 180°W and 80°N 180°E.

3.3 Temporal resolution, sampling and coverage

The temporal resolution of the FDR4LDYN products is represented by instantaneous observations. The temporal sampling depends on the number of ERS satellites and latitude. Additional factors include the operational modes of ERS-1 and ERS-2, the impact of gyroscope failures, and the regionally varying mission coverage [4]. A comprehensive discussion of how these mission characteristics influenced temporal sampling is provided in [1]. Figures 3.2 and 3.3 show the number of valid backscatter triplet observations for ERS-1 and ERS-2, respectively.

3.4 Application, limitation and caveats

The FDR4LDYN data records provide consistent, calibrated backscatter, slope, and curvature observations over global land surfaces. However, the backscatter signal is inherently influenced by a range of geophysical and observational factors, particularly in complex environments such as dense forests, snow-covered or frozen soils, open water bodies, wetlands, and urban areas. In these cases, the signal may exhibit behaviors that differ from typical land surface scattering and may require careful interpretation. While these effects do not compromise the integrity of the backscatter observations themselves, they can affect the stability and interpretability of derived downstream variables. Users are therefore encouraged to consider ancillary datasets when analyzing time series in such regions. Additionally, the dynamic nature of azimuthal anisotropy, subsurface scattering, and seasonal transitions should be taken into account when assessing temporal changes. These considerations are particularly relevant for applications that

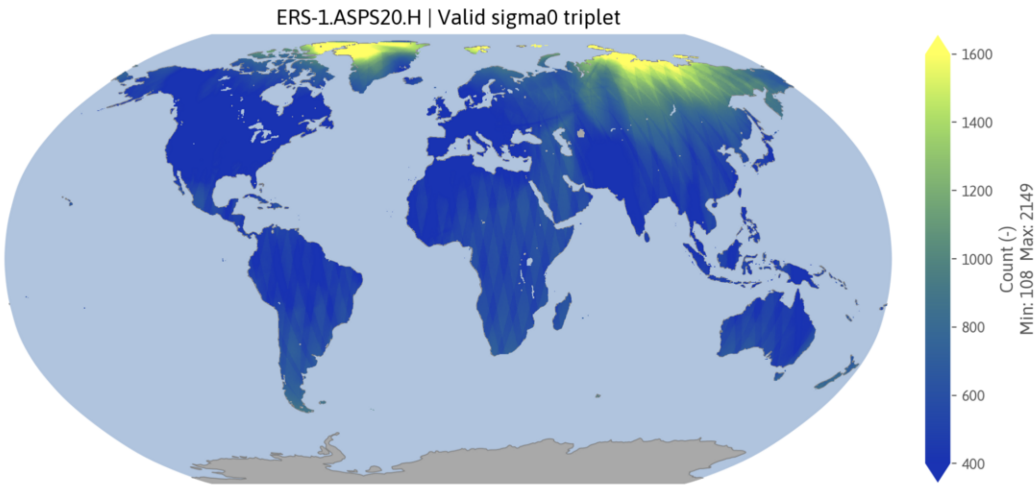

Figure 3.2: Number of valid backscatter triplet observations for ERS-1.

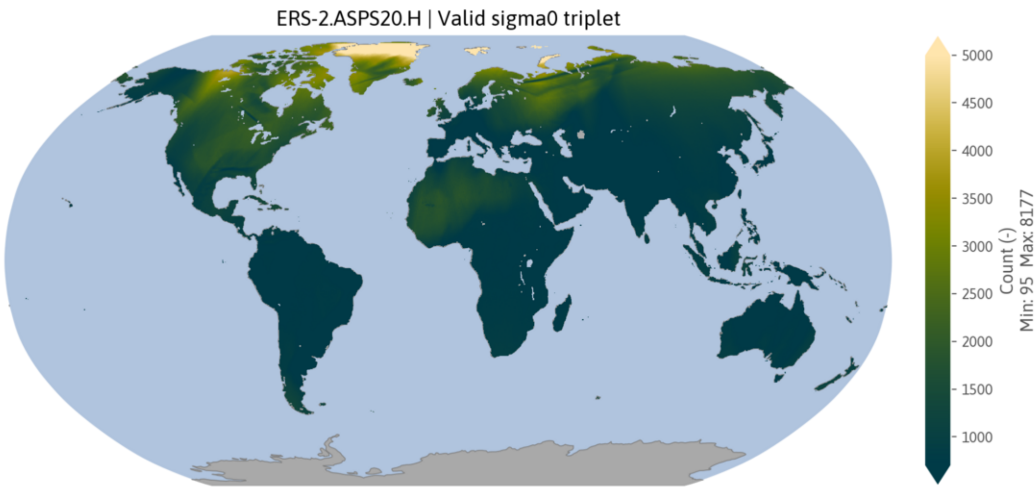

Figure 3.3: Number of valid backscatter triplet observations for ERS-2.

use FDR4LDYN products as input to further retrieval algorithms, including soil moisture estimation or vegetation dynamics monitoring. To support informed data use, the FDR4LDYN data records provide a comprehensive set of advisory flags that guide users in identifying observations of suitable reliability for their applications. More details and the influence of the different error sources are discussed in the Algorithm Theoretical Basis Document (ATBD) [2].

4 Product format

The main FDR4LDYN products and advisory flags are provided in NetCDF4 (Network Common Data Form, version 4) format following the Climate and Forecast (CF) Metadata Conventions [5]. Ancillary azimuthal correction parameters and uncertainty estimates are currently distributed as Generic IO files.

The Generic IO format was developed internally at TU Wien to avoid hard-coded binary templates within the processing software. Instead, file definitions are outsourced to reusable templates that may also contain default values, improving flexibility and maintainability. In a future iteration of the FDR4LDYN product suite, all outputs will be harmonized to NetCDF4 to ensure consistency across products, align with widely adopted community standards, and facilitate uniform reading and handling of the data.

The time series representation of both NetCDF4 and Generic IO products is organized in cells. A cell contains a number of grid points stored as a dedicated file (`<cell_nr>.nc` or `<cell_nr>.dat`). This way, the two extreme cases will be avoided: (i) one file per grid point and (ii) one file for all grid points. A cell is defined as $5^\circ \times 5^\circ$ and contains up to 2000 grid points. The cell number and the number of grid points per cell are shown in Figure 4.1.

Figure 4.1: $5^\circ \times 5^\circ$ cell partitioning of the grid points. The upper number in each cell represents the cell number, and the lower number represents the number of grid points in this cell.

The time series are stored in the contiguous ragged array representation defined by the NetCDF Climate and Forecast (CF) Metadata Conventions [5]. The time series parameters (like `backscatter40`) are associated with the coordinate values `time(obs)`, `lat(i)`, and `lon(i)`, where i indicates the grid point time series. The time series i comprises the following data elements:

$$\texttt{row\_start}(i) \text{ to } \texttt{row\_start}(i) + \texttt{row\_size}(i) - 1$$

where

$$\texttt{row\_start}(i) = 0 \quad \text{if } i = 0$$

$$\texttt{row\_start}(i) = \texttt{row\_start}(i-1) + \texttt{row\_size}(i-1) \quad \text{if } i > 0$$

The variable `row_size` is the count variable containing the length of each time series feature along with an attribute named `sample_dimension` which holds the name of the sample dimension (`obs` in this case). The auxiliary location parameters `lat` and `lon` are GPI variables.

This section provides an overview of the general data structure of the FDR4LDYN products. A complete list of attributes, dimensions, and variables is given in Sections 4.4 and 4.5.

4.1 Spatial and temporal coordinates

Spatial information is provided as longitude and latitude coordinates (EPSG:4326). Each pair of coordinates is described by a unique location identifier. Observation timestamps are stored as a fraction of days since 1970-01-01 00:00:00 UTC (e.g., 13679.52083 represents 2007-06-15 12:30:00.000). In addition, the satellite identifier (ERS-1/ERS-2) and orbit direction (ascending/descending) are provided for each location.

4.2 Backscatter at 40 degrees incidence angle

Fore, mid, and aft backscatter observations are interpolated to the reference incidence angle at 40° and averaged. The computation is based on the slope and curvature parameters, which are coefficients in a second-order Taylor polynomial describing the incidence angle dependency of backscatter (see ATBD [2] for more information).

4.3 Advisory flags

Advisory flags provide support in assessing the validity and quality of backscatter observations. These flags include information about soil surface conditions, land cover/features, and soil scattering characteristics. In addition, specific flags report on corrections or errors recognized in the backscatter retrieval algorithm. A number of flags use bit field notation, which allows the flags to describe independent Boolean conditions (i.e., 0, 1). However, these flags are stored as a decimal number and need to be converted into their binary representation (e.g., 100 = 0110 0100, most significant bit (MSB) furthest to the left). Not a valid Number (NaN) is indicated when all bits are set. This means that for the datatype used, NaN is represented by the highest possible number. For example, in the case of an 8-bit flag, NaN would be represented by 1111 1111, which is the decimal number 255. This representation ensures that NaN stands out as a unique value, indicating invalid or missing data.

4.3.1 Soil surface conditions

Snow cover and frozen soil probability flags are included, ranging between 0 and 100%. These flags were computed based on a historic analysis of ERA5 temperature and snow cover information (1980–2020) on a day-of-year (DOY) basis. For example, if on December 31 (DOY=366) for a specific location, half of all years have had snow cover, the snow cover probability flag is set to 50%. In a future update, dynamic snow cover and frozen soil flags based on the actual ERA5-Land snow depth and temperature history will be employed as part of the FDR4LDYN product suite.

4.3.2 Land cover/features

Open water surfaces dominant in the ASCAT footprint can be a problem in several applications, such as soil moisture retrieval. The penetration depth of C-band microwaves into water is less than about 2 mm, and backscatter depends on the roughness of the surface. When water is calm, specular reflection occurs, and backscatter at off-nadir angles is very low. Moreover, water waves generated by wind increase scattering into the backward direction. The signal return is highest when the radar looks into the upwind or downwind direction, and is smallest when it looks normal to the wind vector. In this context, wetlands are a special case because, in addition to open water, inundated vegetation further increases the complexity of the radar scattering characteristics. In order to indicate possible interference from wetlands, a wetland fraction flag is added to the product. The flag is defined as the fractional coverage of inundated and wetland areas ranging between 0 and 100%. These areas are derived from the Global Lakes and Wetlands Database (GLWD) level 3 product, which includes several wetland and inundation types [6].

Mountainous regions are another sensitive land surface prone to backscatter signal distortions. Rough terrain, the influence of permanent snow and ice cover, reduced sensitivity due to forest and rock cover, as well as highly variable surface conditions can affect results in these regions. For this reason, the topographic complexity flag has been added to the product. The flag is derived from the Copernicus DEM - Global and European Digital Elevation Model (COP-DEM) 90 m resolution and computed as the standard deviation of elevation normalized to a value between 0% and 100% [7].

It is important to note that these flags are static and intended to showcase areas where the quality of the FDR4LDYN products could potentially suffer. Hence, they could be used as static masks, but it is recommended to utilize them in a verification process, depending on the product application.

4.3.3 Soil scattering characteristics

Backscatter usually increases with higher soil water content present in the soil, due to its sensitivity to dielectric properties. However, under dry soil conditions, it is possible that radar waves can travel into deeper soil layers, interacting with near-subsurface features (e.g., rocks, stones) and potentially counteracting the overall signal coming from the soil surface. Thus, leading to an increase in backscatter signal strength when the surface starts to dry out [8]. These anomalous subsurface scattering characteristics break the generally assumed positive relationship between backscatter and soil moisture. This phenomenon has been observed in distinct regions worldwide. While such misinterpretations are not relevant for the FDR4LDYN product series itself, they should be considered when using the dataset as input for downstream applications. To support this, affected areas are indicated by a subsurface scattering probability (0–100%) flag.

4.3.4 Backscatter observables

An active monitoring of ESCAT input data, model parameters, intermediate results, and output data takes place throughout the computation of the FDR4LDYN products. Several specific flags are part of this monitoring procedure, recording errors and corrections in the course of the SSM retrieval using a bit field notation. The backscatter40 flag indicates which ASCAT beam (fore, mid, aft) is based on usable or slightly degraded backscatter observations. A processing flag is provided to indicate whether a slope and/or curvature estimate has been masked and, if applicable, the reason for masking. Masking is applied when the local slope fit is insufficiently constrained, either because too few local slope estimates are available within the Epanechnikov kernel window or because the available local slopes cover an incidence angle range that is too narrow for a robust fit. The NetCDF flag descriptions are defined in the Tables 4.5 and 4.6.

4.4 NetCDF4 format of main backscatter observables product and advisory flags products

Attribute Name	Description	Type	Unit	Range or Value
product_name	Product name	NC_STRING	NA	FDR4LDYN ERS ESCAT Backscatter, Slope, Curvature Record 12.5 km Sampling
cdm_data_type	Structural type of the dataset	NC_STRING	NA	“Time Series”
platform	Satellite identifier	NC_STRING	NA	“ERS-1, ERS-2”
source	Source of input data	NC_STRING	NA	“ERS-1, ERS-2 SCATTEROMETER Ocean Wind field and Sea Ice probability, ASPS20.H, Version ASPS v10.04.”
project	Project reference	NC_STRING	NA	“FDR4LDYN”
contact	Contact email address	NC_STRING	NA	“remote.sensing@geo.tuwien.ac.at”
geospatial_lon_resolution	Spatial resolution in longitude	NC_STRING	NA	“25 km”
geospatial_lon_sampling	Spatial sampling in longitude	NC_STRING	NA	“12.5 km”
geospatial_lat_resolution	Spatial resolution in latitude	NC_STRING	NA	“25 km”
geospatial_lat_sampling	Spatial sampling in latitude	NC_STRING	NA	“12.5 km”
created_with_software	Software provenance	NC_STRING	NA	“Python [major.minor.build] and NetCDF [major.minor.build]”
software	Level 2 processing software version	NC_STRING	NA	“[major.minor.build]”
git_hash	Processing software git commit version	NC_STRING	NA	“[GGGGGGG]”
date_created_utc	UTC time of file creation	NC_STRING	NA	“yyyy-mm-dd HH:MM:SS.ddd”
institution	Name of the originating organization	NC_STRING	NA	“ESA”
creator_name	Dataset creator	NC_STRING	NA	“TU Wien”
creator_url	Dataset creator	NC_STRING	NA	“https://www.tuwien.at/mg/geo/rs”
creator_email	Dataset creator	NC_STRING	NA	“remote.sensing@geo.tuwien.ac.at”

Table 4.1: Global attributes defined in the FDR4LDYN 12.5 km product.

Dimension Name	Description	Range or Value
obs	Number of observations sampled on the fixed Earth grid.	N is the number related to the time period over which the observations are collected

Table 4.2: Dimensions defined in the FDR4LDYN 12.5 km product.

Attribute Name		Description	Type	Range or Value	Dimension
location_id		Location identifier	NC_DOUBLE		obs
	long_name	Location identifier (Grid Point ID)	NC_STRING	"location id"	
	valid_min	valid minimum	NC_INT	0	
	valid_max	valid maximum	NC_INT	3,300,000 (12.5 km)	
	missing_value	missing value	NC_INT	-2^{31}	
	_FillValue	fill value	NC_INT	-2^{31}	
time		Measurement time	NC_DOUBLE		obs
	long_name	description of the variable	NC_STRING	"measurement time"	
	calender	calender type	NC_STRING	"standard"	
	units	unit type	NC_STRING	"days since 1970-01-01 00:00:00"	
	_FillValue	fill value	NC_DOUBLE	0	
latitude		Latitude coordinate	NC_INT		obs
	long_name	description of the variable	NC_STRING	"latitude"	
	units	unit type	NC_STRING	"degrees_north"	
	scale_factor	scale factor applied	NC_DOUBLE	1e-6	
	add_offset	offset applied	NC_DOUBLE	0e0	
	valid_min	valid minimum	NC_INT	-90000000	
	valid_max	valid maximum	NC_INT	89999999	
	missing_value	missing value	NC_INT	-2^{31}	
	_FillValue	fill value	NC_INT	-2^{31}	
longitude		Longitude coordinate	NC_INT		obs
	long_name	description of the variable	NC_STRING	"longitude"	
	units	unit type	NC_STRING	"degrees_east"	
	scale_factor	scale factor applied	NC_DOUBLE	1e-6	
	add_offset	offset applied	NC_DOUBLE	0e0	
	valid_min	valid minimum	NC_INT	-180000000	

	valid_max	valid maximum	NC_INT	179999999	
	missing_value	missing value	NC_INT	-2^{31}	
	_FillValue	fill value	NC_INT	-2^{31}	
as_des_pass		Orbit overpass direction	NC_BYTE		obs
	long_name	description of the variable	NC_STRING	"orbit overpass direction (ascending, descending)"	
	flag_values	flag values	NC_STRING	"0, 1"	
	flag_meanings	flag meanings	NC_STRING	"ascending descending"	
	valid_min	valid minimum	NC_BYTE	0	
	valid_max	valid maximum	NC_BYTE	1	
	missing_value	missing value	NC_BYTE	-2^{7}	
	_FillValue	fill value	NC_BYTE	-2^{7}	
swath_indicator		Swath indicator	NC_BYTE		obs
	long_name	description of the variable	NC_STRING	"swath indicator (left, right)"	
	flag_values	flag values	NC_STRING	"0, 1"	
	flag_meanings	flag meanings	NC_STRING	"left right"	
	valid_min	valid minimum	NC_BYTE	0	
	valid_max	valid maximum	NC_BYTE	1	
	missing_value	missing value	NC_BYTE	-2^{7}	
	_FillValue	fill value	NC_BYTE	-2^{7}	
backscatter40		Backscatter at 40°	NC_INT		obs
	long_name	description of the variable	NC_STRING	"backscatter at 40 degree incidence angle"	
	units	unit type	NC_STRING	"dB"	
	scale_factor	scale factor applied	NC_DOUBLE	1e-7	
	add_offset	offset applied	NC_DOUBLE	0e0	
	valid_min	valid minimum	NC_INT	-3e8	
	valid_max	valid maximum	NC_INT	3e8	
	missing_value	missing value	NC_INT	-2^{31}	
	_FillValue	fill value	NC_INT	-2^{31}	

slope40	Slope at 40°	NC_INT		obs
long_name	description of the variable	NC_STRING	“slope at 40 degree incidence angle”	
units	unit type	NC_STRING	“dB/deg”	
scale_factor	scale factor applied	NC_DOUBLE	1e-7	
add_offset	offset applied	NC_DOUBLE	0e0	
missing_value	missing value	NC_INT	-2^{31}	
_FillValue	fill value	NC_INT	-2^{31}	
curvature40	Curvature at 40°	NC_INT		obs
long_name	description of the variable	NC_STRING	“curvature at 40 degree incidence angle”	
units	unit type	NC_STRING	“dB/deg^2”	
scale_factor	scale factor applied	NC_DOUBLE	1e-7	
add_offset	offset applied	NC_DOUBLE	0e0	
missing_value	missing value	NC_INT	-2^{31}	
_FillValue	fill value	NC_INT	-2^{31}	
slope40_clim	Slope climatology at 40°	NC_INT		obs
long_name	description of the variable	NC_STRING	“slope climatology at 40 degree incidence angle”	
units	unit type	NC_STRING	“dB/deg”	
scale_factor	scale factor applied	NC_DOUBLE	1e-7	
add_offset	offset applied	NC_DOUBLE	0e0	
missing_value	missing value	NC_INT	-2^{31}	
_FillValue	fill value	NC_INT	-2^{31}	
curvature40_clim	Curvature climatology at 40°	NC_INT		obs
long_name	description of the variable	NC_STRING	“curvature climatology at 40 degree incidence angle”	
units	unit type	NC_STRING	“dB/deg^2”	
scale_factor	scale factor applied	NC_DOUBLE	1e-7	
add_offset	offset applied	NC_DOUBLE	0e0	
missing_value	missing value	NC_INT	-2^{31}	

	_FillValue	fill value	NC_INT	-2^{31}	
backscatter40_flag		Backscatter40 flag	NC_UBYTE		obs
	long_name	description of the variable	NC_STRING	"backscatter40 flag"	
	flag_masks	flag values	NC_UBYTE	1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384	
	flag_meanings	flag meanings	NC_STRING	"sigma0_usable sigma0_slightly_degraded sigma0_noise_out_of_limits reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use"	
	valid_min	valid minimum	NC_UBYTE	0	
	valid_max	valid maximum	NC_UBYTE	2^{15}-1	
	_FillValue	fill value	NC_UBYTE	2^{16}-1	
processing_flag		Processing flag	NC_UBYTE		obs
	long_name	description of the variable	NC_STRING	"processing flag"	
	flag_masks	flag values	NC_UBYTE	1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384	

flag_meanings	flag meanings	NC_STRING	"slope40_not_usable curvature40_not_usable number_of_local_slopes_too_low incidence_angle_range_of_local_slopes_too_low reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use reserved_for_future_use"
valid_min	valid minimum	NC_UBYTE	0
valid_max	valid maximum	NC_UBYTE	2^{15}-1
_FillValue	fill value	NC_UBYTE	2^{16}-1

Table 4.3: Variables defined in the FDR4LDYN 12.5 km backscatter observables product.

Attribute Name	Description	Type	Range or Value	Dimension
snow_cover_probability	Snow cover probability	NC_BYTE		obs
long_name	description of the variable	NC_STRING	"snow cover probability"	
units	unit type	NC_STRING	"percent"	
valid_min	valid minimum	NC_BYTE	0	
valid_max	valid maximum	NC_BYTE	100	
missing_value	missing value	NC_BYTE	-2^7	
_FillValue	fill value	NC_BYTE	-2^7	
frozen_soil_probability	Frozen soil probability	NC_BYTE		obs
long_name	description of the variable	NC_STRING	"frozen soil probability"	
units	unit type	NC_STRING	"percent"	
valid_min	valid minimum	NC_BYTE	0	
valid_max	valid maximum	NC_BYTE	100	
missing_value	missing value	NC_BYTE	-2^7	
_FillValue	fill value	NC_BYTE	-2^7	
wetland_fraction	Wetland fraction	NC_BYTE		obs
long_name	description of the variable	NC_STRING	"wetland fraction"	
units	unit type	NC_STRING	"percent"	
valid_min	valid minimum	NC_BYTE	0	
valid_max	valid maximum	NC_BYTE	100	
missing_value	missing value	NC_BYTE	-2^7	
_FillValue	fill value	NC_BYTE	-2^7	
topographic_complexity	Topographic complexity	NC_BYTE		obs
long_name	description of the variable	NC_STRING	"topographic complexity"	
units	unit type	NC_STRING	"percent"	
valid_min	valid minimum	NC_BYTE	0	
valid_max	valid maximum	NC_BYTE	100	

missing_value	missing value	NC_BYTE	-2^7	
_FillValue	fill value	NC_BYTE	-2^7	
subsurface_scattering_probability	Subsurface scatter probability	NC_BYTE		obs
long_name	description of the variable	NC_STRING	“subsurface scattering probability”	
units	unit type	NC_STRING	“percent”	
valid_min	valid minimum	NC_BYTE	0	
valid_max	valid maximum	NC_BYTE	100	
missing_value	missing value	NC_BYTE	-2^7	
_FillValue	fill value	NC_BYTE	-2^7	

Table 4.4: Variables defined in the FDR4LDYN 12.5 km advisory flag product.

Table 4.5: Code table backscatter40 flag (bit position 1 = least significant bit).

Bit position	**Decimal value**	**Description**
1	1	sigma0 usable
2	2	sigma0 slightly degraded
3	4	sigma0 noise out of limits
4	8	Reserved for future
5	16	Reserved for future
6	32	Reserved for future
7	64	Reserved for future
8	128	Reserved for future
9	256	Reserved for future
10	512	Reserved for future
11	1024	Reserved for future
12	2048	Reserved for future
13	4096	Reserved for future
14	8192	Reserved for future
15	16384	Reserved for future
16	32768	Spare

Table 4.6: Code table processing flag (bit position 1 = least significant bit).

Bit position	Decimal value	Description
1	1	slope40 not usable
2	2	curvature40 not usable
3	4	Number of local slopes too low
4	8	Incidence angle range of local slopes too low
5	16	Reserved for future
6	32	Reserved for future
7	64	Reserved for future
8	128	Reserved for future
9	256	Reserved for future
10	512	Reserved for future
11	1024	Reserved for future
12	2048	Reserved for future
13	4096	Reserved for future
14	8192	Reserved for future
15	16384	Reserved for future
16	32768	Spare

4.5 Generic IO format of azimuth and uncertainty products

Attribute Name		Description	Type	Range or Value	Dimension
gpi		Grid point identifier	`int32`		1
	long_name	variable description	`string`	"grid point identifier"	
	units	unit type	`string`	"–"	
	missing_value	missing value	`int32`	–2 147 483 648	
	_FillValue	fill value	`int32`	–2 147 483 648	
fitcoeff		Quadratic fit coefficients per geometry and year	`float32`		year × config × coeff
	long_name	variable description	`string`	"yearly azimuth fit coefficients"	
	units	unit type	`string`	"mixed [dB, dB deg^{-1}, dB deg^{-2}]"	
	missing_value	missing value	`float32`	–999999.0	
	_FillValue	fill value	`float32`	–999999.0	
fitvar		Variances of residual and coefficients	`float32`		year × config × 4
	long_name	variable description	`string`	"variance of fit (residual and coefficients)"	
	units	unit type	`string`	"mixed [dB^2, dB^2, dB^2 deg^{-2}, dB^2 deg^{-4}]"	
	missing_value	missing value	`float32`	–999999.0	
	_FillValue	fill value	`float32`	–999999.0	
n_obs		Number of observations used	`int32`		year × config
	long_name	variable description	`string`	"number of valid observations"	
	units	unit type	`string`	"count"	
	missing_value	missing value	`int32`	–2 147 483 648	
	_FillValue	fill value	`int32`	–2 147 483 648	
inc_limits		Incidence-angle limits used in fit	`float32`		year × config × 2

	long_name	variable description	`string`	“incidence-angle fit limits”	
	units	unit type	`string`	“degree”	
	missing_value	missing value	`float32`	–999999.0	
	_FillValue	fill value	`float32`	–999999.0	
year		Year of estimate	`int16`		year
	long_name	variable description	`string`	“year of estimation”	
	units	unit type	`string`	“year”	
	missing_value	missing value	`int16`	–32 768	
	_FillValue	fill value	`int16`	–32 768	
flag_nobs		Observation-count flag (yearly)	`uint32`		year
	long_name	variable description	`string`	“observation-count quality flag”	
	units	unit type	`string`	“–”	
	missing_value	missing value	`uint32`	4 294 967 295	
	_FillValue	fill value	`uint32`	4 294 967 295	
flag_irng		Incidence angle-range flag (yearly)	`uint32`		year
	long_name	variable description	`string`	“incidence angle-range quality flag”	
	units	unit type	`string`	“–”	
	missing_value	missing value	`uint32`	4 294 967 295	
	_FillValue	fill value	`uint32`	4 294 967 295	

Table 4.7: Variables defined in the FDR4LDYN Generic IO azimuth parameter files.

Attribute Name	Description	Type	Range or Value	Dimension
gpi	Grid point identifier	`int32`		1
long_name	variable description	`string`	"grid point identifier"	
units	unit type	`string`	"–"	
missing_value	missing value	`int32`	–2 147 483 648	
_FillValue	fill value	`int32`	–2 147 483 648	
esd_sig_bef	Estimated standard deviation of σ^0 (before azimuth correction)	`float32`		year
long_name	variable description	`string`	"ESD of backscatter before azimuth correction"	
units	unit type	`string`	"dB"	
missing_value	missing value	`float32`	–999999.0	
_FillValue	fill value	`float32`	–999999.0	
esd_sig_aft	Estimated standard deviation of σ^0 (after azimuth correction)	`float32`		year
long_name	variable description	`string`	"ESD of backscatter after azimuth correction"	
units	unit type	`string`	"dB"	
missing_value	missing value	`float32`	–999999.0	
_FillValue	fill value	`float32`	–999999.0	
esd_inc	Estimated standard deviation of incidence angle	`float32`		year
long_name	variable description	`string`	"ESD of incidence angle"	
units	unit type	`string`	"degree"	
missing_value	missing value	`float32`	–999999.0	
_FillValue	fill value	`float32`	–999999.0	

fitcoeff_corr		Yearly quadratic fit coefficients (after azimuth correction)	`float32`		year × config × coeff
	long_name	variable description	`string`	"yearly azimuth fit coefficients (corrected)"	
	units	unit type	`string`	"mixed [dB, dB deg^{-1}, dB deg^{-2}]"	
	missing_value	missing value	`float32`	–999999.0	
	_FillValue	fill value	`float32`	–999999.0	
fitvar_corr		Variances of residual and coefficients (after azimuth correction)	`float32`		year × config × 4
	long_name	variable description	`string`	"variance of fit (residual and coefficients), corrected"	
	units	unit type	`string`	"mixed [dB^2, dB^2, dB^2 deg^{-2}, dB^2 deg^{-4}]"	
	missing_value	missing value	`float32`	–999999.0	
	_FillValue	fill value	`float32`	–999999.0	
inc_limits		Incidence-angle limits used in the corrected fits	`float32`		year × config × 2
	long_name	variable description	`string`	"incidence-angle fit limits (corrected)"	
	units	unit type	`string`	"degree"	
	missing_value	missing value	`float32`	–999999.0	
	_FillValue	fill value	`float32`	–999999.0	
year		Year of estimate	`int16`		year
	long_name	variable description	`string`	"year of estimation"	
	units	unit type	`string`	"year"	
	missing_value	missing value	`int16`	–32 768	
	_FillValue	fill value	`int16`	–32 768	

Table 4.8: Variables defined in the FDR4LDYN Generic IO yearly ESD files.

Table 4.9: Code table `flag_nobs` (bit position 1 = least significant bit).

Bit position	**Decimal value**	**description**
1	1	number of observations flag for left-ascending-fore
2	2	number of observations flag for left-ascending-mid
3	4	number of observations flag for left-ascending-aft
4	8	number of observations flag for left-descending-fore
5	16	number of observations flag for left-descending-mid
6	32	number of observations flag for left-descending-aft
7	64	number of observations flag for right-ascending-fore
8	128	number of observations flag for right-ascending-mid
9	256	number of observations flag for right-ascending-aft
10	512	number of observations flag for right-descending-fore
11	1 024	number of observations flag for right-descending-mid
12	2 048	number of observations flag for right-descending-aft
13	4 096	number of observations flag for all geometries
14	8 192	number of observations flag for right-ascending
15	16 384	number of observations flag for right-descending
16	32 768	number of observations flag for right-all
17	65 536	number of observations flag for left-ascending
18	131 072	number of observations flag for left-descending
19	262 144	number of observations flag for left-all
20	524 288	number of observations flag for ascending-all
21	1 048 576	number of observations flag for descending-all

Table 4.10: Code table `flag_irng` (bit position 1 = least significant bit).

Bit position	**Decimal value**	**Description**
1	1	incidence angle range flag for left-ascending-fore
2	2	incidence angle range flag for left-ascending-mid
3	4	incidence angle range flag for left-ascending-aft
4	8	incidence angle range flag for left-descending-fore
5	16	incidence angle range flag for left-descending-mid
6	32	incidence angle range flag for left-descending-aft
7	64	incidence angle range flag for right-ascending-fore
8	128	incidence angle range flag for right-ascending-mid
9	256	incidence angle range flag for right-ascending-aft
10	512	incidence angle range flag for right-descending-fore
11	1 024	incidence angle range flag for right-descending-mid
12	2 048	incidence angle range flag for right-descending-aft
13	4 096	incidence angle range flag for all geometries
14	8 192	incidence angle range flag for right-ascending
15	16 384	incidence angle range flag for right-descending
16	32 768	incidence angle range flag for right-all
17	65 536	incidence angle range flag for left-ascending
18	131 072	incidence angle range flag for left-descending
19	262 144	incidence angle range flag for left-all
20	524 288	incidence angle range flag for ascending-all
21	1 048 576	incidence angle range flag for descending-all

5 Data download, terms and conditions

5.1 Data access

The FDR4LDYN products are available via TU Wien's FAIR Research Data repository: https://doi.org/10.48436/yanjk-b7t43.

All FDR4LDYN products are owned by ESA, and the ESA Earth Observation Data Policy applies[1]. The products are available for all users free of charge, and users should recognize the respective roles of ESA, TU Wien, and TU Delft when publishing results that are based on FDR4LDYN products. ESA's ownership and intellectual property rights in the FDR4LDYN data and products are best safeguarded by simply displaying the words "© ESA" under each of the FDR4LDYN data and products shown in a publication or website.

5.2 Citation

ESA, TU Wien, TU Delft (2026): ERS ESCAT Fundamental Data Record for Land Dynamics (FDR4LDYN) 12.5 km sampling.

```
@misc{FDR4LDYN_v0.1,
  author = {{ESA}, {TU Wien}, {TU Delft}},
  title = {{ERS ESCAT Fundamental Data Record
  for Land Dynamics 12.5~km sampling)}},
  year = 2025,
}
```

5.3 User feedback and support

User feedback is welcome and encouraged. All questions and remarks concerning the product can be addressed to fdr4ldyn_user_support@geo.tuwien.ac.at.

[1] https://earth.esa.int/eogateway/documents/d/earth-online/esa-eo-data-policy

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List of Acronyms

AMI Active Microwave Instrument

ASCAT Advanced Scatterometer

ATBD Algorithm Theoretical Basis Document

DoY Day of Year

ECMWF European Centre for Medium-Range Weather Forecasts

ERA5-Land ERA5-Land Surface Reanalysis from ECMWF

ERS European Remote-sensing Satellite (1 and 2)

ESA European Space Agency

ESCAT ERS-1 and ERS-2 Scatterometer

ESD Estimated Standard Deviation

FDR4LDYN Fundamental Data Record for Land Dynamics

KS Kernel Smoother

MetOp Meteorological Operational Platform

RFI Radio Frequency Interference

SAR Synthetic Aperture Radar

SCA Scatterometer on Metop-SG-B

SNR Signal-to-Noise Ratio

TU Delft Technische Universiteit Delft (Delft University of Technology)

TU Wien Technische Universität Wien (Vienna University of Technology)

VV Vertical Transmit and Vertical Receive Polarisation