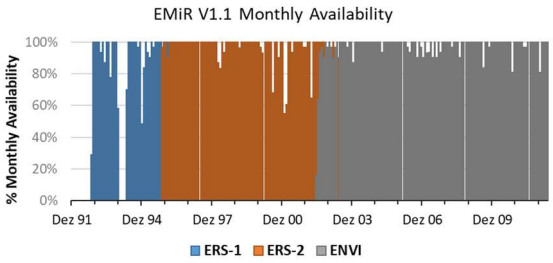

Percentage of EMiR V1.1 L2 data monthly availability.

ESA contract

4000109537/13/I-AM

ERS/Envisat MWR Recalibration and Water Vapour TDR Generation (EMiR)

EMiR Data Record Version 1.1

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Product Description

(Combined Deliverable DLV-CCN2-01 and DLV-CCN2-02)

Berlin, 5. November 2018

Document control sheet

Project	ERS/Envisat MWR Recalibration and Water Vapour TDR Generation (EMiR)	
Client	European Space Agency, ESRIN Via Galileo Galilei, Casella Postale 64 00044 Frascati, Italy http://www.esa.int	
Main contractor	Informus GmbH Brehmestr. 50 13187 Berlin, Germany http://www.informus.de	
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1 Introduction

1.1 Overview on EMiR

The project "*ERS/Envisat MWR Recalibration and Water Vapour Thematic Data Record Generation*" (EMiR) is being funded by the European Space Agency (ESA) as part of its Long-Term Data Preservation (LTDP) activities (https://earth.esa.int/web/gscb/ltdp).

LTDP EMiR has the following objectives:

- To generate a fundamental data record (FDR) of top-of-atmosphere (TOA) brightness temperatures from the Microwave Radiometer (MWR) series of instruments flown onboard the platforms ERS-1, ERS-2, and Envisat.
- To generate a thematic data record (TDR) of the total column water vapour (TCWV) above the world's ice-free oceans from MWR observations.
- To compare the newly derived TDR on TCWV with other long-term TCWV data records through the GEWEX water vapour assessment (GVAP, see http://gewex-vap.org/).
- To assess the impact of improved TCWV information obtained from MWR on the accuracy of concomitant ocean altimetry observations from ERS-1, ERS-2, and Envisat.
- To provide guidance for the next generation of MWR instruments flown onboard the Sentinel- 3 series of satellites.

Further information about the EMiR project can be found under http://esa-mwr.org.

1.2 Purpose and structure of this document

The purpose of this document is to comprehensively describe data format, content and coverage of the EMiR dataset V1.1, established in July 2018.

Compared to the initial release (EMiR V1.0, October 2016), EMiR V1.1 Level-2 (L2) data contain a number of additional geophysical fields, such as the prior TCWV and error estimates as well as further ancillary data to support user-specific quality assurance procedures. The contents of EMiR V1.1 L2 data are described in detail in section 2.

EMiR V1.1 Level-3 (L3) data files contain temporal and spatial averages. These are unchanged as compared to the previous version V1.0. Their generation process and structure are described in section 3.

The EMiR data set is affected by a number of data gaps, especially during the early ERS-1 years. This document lists the temporal gaps in the EMiR V1.1 data record and informs about their causes in section 4, while ways towards their reduction are suggested in section 5.

1.3 Acronyms and abbreviations

Acronym	Description
CLS	Collecte Localisation Satellites
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
EMiR	ERS/Envisat MWR Recalibration and Water Vapour TDR Generation
Envisat	Environmental Satellite
ERS	European Remote Sensing satellite
ESA	European Space Agency
FDR	Fundamental data record
GDR	Geophysical data record
GEWEX	Global Energy and Water Exchanges project
GVAP	GEWEX water vapour assessment
HSM	High-speed multiplexer
ICU	Instrument control unit
L1	Level-1 processing
L2	Level-2 processing
L3	Level-3 processing
LBR	Low bit rate
LTDP	Long-term data preservation
LWP	Liquid water path
MWR	Microwave Radiometer
NetCDF/CF	Network Common Data Form / Climate and Forecast
OBDH	On-board data handling
OPR	Ocean product
RA	Radar Altimeter
RA-2	Radar Altimeter 2
RBI	Remote bus interface
REAPER	Reprocessing of Altimeter Products for ERS
SAR	Synthetic Aperture Radar
SM	Service module
TB	Brightness temperature
TCWV	Total column water vapour
TDR	Thematic data record
TOA	Top-of-Atmosphere
WTC	Wet tropospheric correction

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2 EMiR Level-2 data

2.1 Level-2 file structure

The revised EMiR V1.1 L2 data record provides swath-based global information on a daily basis. The individual data files contain TCWV retrievals, the background equivalent, and the corresponding retrieval error. Additional data, as for example the underlying brightness temperatures as well as a quality flag, are also part of the EMiR L2 product (see Table 1).

In addition to these data fields already present in the previous version V1.0, the revised dataset contains the following additional information for each observation:

- Satellite cycle and pass number,
- Solar zenith angle,
- Day/night/twilight flag,
- TCWV prior used in the retrieval,
- *A posteriori* retrieval uncertainty of TCWV, liquid water path (LWP) and wet tropospheric correction (WTC).

The EMiR V1.1 L2 files are organised on a per-day basis, i.e. one file contains all EMiR L2 products for one specific calendar day. The files are provided in netCDF / CF-1.6 format and typically have a size of 4 MB.

Table 1: Contents of EMiR V1.1 Level-2 netCDF files. Variables shown in green background have been newly added to V1.1.

Variable	Name	Units	Description
Cycle number	cycle_number	unitless	Satellite orbit cycle for each observation
Pass number	pass_number	unitless	Satellite pass number in current orbit cycle for each observation
Time	time	days	Days since 1950-01-01 00:00:00.0
Latitude	lat	degrees N	Geographical latitude (WGS 1984), North positive
Longitude	lon	degrees E	Geographical longitude (WGS 1984), Range 0°-360°, East: 90°
Solar zenith angle	SZEN	degrees	Solar zenith angle at point of observation
Day/night/twilight flag	DNTFLAG	unitless	0: day (SZEN < 90°) 1: night (SZEN > 102°) 2: twilight (SZEN 90°-102°, definition of nautical twilight)
Prior for total column water vapour	TCWV_PRIOR	kg/m^2	*A priori* value used for TCWV in RTTOV retrieval
Total column water vapour	TCWV	kg/m^2	Instantaneous retrieved value
Uncertainty of TCWV	TCWV_UNC	kg/m^2	*A posteriori* uncertainty of instantaneous retrieved value

Variable	Name	Units	Description
Liquid water path	LWP	kg/m^2	Instantaneous retrieved value
Uncertainty of LWP	LWP_UNC	kg/m^2	*A posteriori* uncertainty of instantaneous retrieved value
Wet tropospheric correction	WTC	m	Instantaneous retrieved value
Uncertainty of WTC	WTC_UNC	m	*A posteriori* uncertainty of instantaneous retrieved value
Cost function	cost	unitless	Value of cost function for retrieval. *Recommended threshold to identify valid retrievals: cost < 5.*
Retrieval quality flag	flag	unitless	– 1: Retrieval performed – 2: ERS-2 after gain drop. Retrieval performed, gain drift in 23.8 GHz channel likely – 3: ENVISAT initial heating period, retrieval performed – 98: Retrieved values out of range – 99: No retrieval (above sea ice or land)
23 GHz brightness temperature	Tb23	K	Inter-calibrated instantaneous Tb
36 GHz brightness temperature	Tb36	K	Inter-calibrated instantaneous Tb

2.2 Fill values

In a number of cases, gaps in the Level-1 brightness temperatures have been filled with constant values. These are instrument dependent and amount to 323.5 K (23 GHz) and 320.5 K (36 GHz) for ERS-1, 325.2 K (23 GHz) and 324.0 K (36 GHz) for ERS-2, as well as 324.8 K (23 GHz) and 322.1 K (36 GHz) for Envisat (all values rounded to one digit).

These fill values are kept in the EMiR dataset to remain consist with the MWR Level 1 data obtained from CLS and used for product generation (see section 4.1 for more details). Obviously, Level-2 retrievals are not applied to these data and the corresponding retrievals are set to fill values of -999.

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3 EMiR Level-3 data

The EMiR L2 data files are used to calculate global fields of monthly averages of TCWV, LWP, and brightness temperatures at 23 and 36 GHz on a 2°×2° as well as a 3°×3° latitude-longitude grid.

3.1 Level-2 pre-screening

Before calculating monthly means, filters are applied. A Level-2 data pixel is used for L3 product generation if and only if the following conditions are met:

TCWV retrieval >0.0 kg/m² **AND** LWP retrieval > -1.0 kg/m² **AND** cost function value < 5.

The condition on the cost function effectively removes heavily precipitation-contaminated pixels as well as observations with remaining sea ice or land contribution.

3.2 Level-3 product generation

EMiR V1.1 L3 products are generated as follows.

(1) First, a global grid is set up according to the considered spatial resolution. Here, datasets of 2°×2° and 3°×3° latitude / longitude resolution have been established, where the 2°×2° resolution has been created to meet the specific requirements of the GEWEX Water Vapour (GVAP) intercomparison exercise (see www.gewex-vap.org). The 3°×3° resolution offers better temporal coverage and reduced noise and is thus better suited for the analysis of climatic trends.

(2) For each MWR footprint, the corresponding grid cell is determined from the latitude/longitude information. If the pre-screening conditions are met (see section 3.1 above), retrievals and auxiliary values are added to the grid box. The daily averages are then calculated as the arithmetic mean of all observations within that grid box within one day.

(3) If for a given month more than 20 daily averages exist, the arithmetic mean of those is assigned to be the monthly mean value. This way, it is ensured that the calculated monthly mean is representative of the true conditions.

3.3 Level-3 file structure

The Level-3 output files contain the parameters listed in Table 2. The files are provided in netCDF/CF format and have a size of 57.6 MB for 2°×2°, and of 25.6 MB for the 3°×3° resolution product.

Table 2: Contents of EMiR V1.1 Level-3 netCDF files. Coordinates refer to the grid-box centre.

Variable	Name	Units	Description
Time	time	days	Days since 1950-01-01, 00:00:00.0.
Latitude	lat	degrees N	Geographical latitude (WGS 1984)
Longitude	lon	degrees E	Geographical longitude (WGS 1984)

Variable	Name	Units	Description
Total column water vapour	TCWV	kg/m^2	Monthly mean of daily means for 2°×2° or 3°×3° grid cells
Liquid water path	LWP	kg/m^2	Monthly mean of daily means for 2°×2° or 3°×3° grid cells
23 GHz brightness temperature	Tb23	K	Monthly mean of daily means for 2°×2° or 3°×3° grid cells
36 GHz brightness temperature	Tb36	K	Monthly mean of daily means for 2°×2° or 3°×3° grid cells

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4 Gaps in the EMiR data record

The EMiR V1.1 data record does not cover the entire duration of the operational phases of the ERS-1/2 and Envisat missions. Especially during the early ERS-1 years between the launch and the beginning of the Geodetic Mission in April 1994 (Table 3), there are two large gaps each lasting several months. Data availability is better afterwards, but there are still a number of episodes of EMiR unavailability lasting from several hours to more than a week. The reasons for gaps in the EMiR data record are outlined and analysed in more detail below.

4.1 Design decisions

The EMiR data record aims at providing consolidated observations useful for climatological and altimetry applications, more specifically brightness temperatures, total column water vapour, and wet tropospheric correction.

In order to facilitate the application of EMiR for global mean sea level rise studies, it was decided in the early project stages to use the so-called 1 Hz altimeter time tag from ESA's operational altimetry products *"Ocean Product"* (OPR, ERS-1/2) and *"Geophysical Data Record"* (GDR, Envisat) as chronological basis for EMiR. In consequence, L1B MWR observations have to be interpolated onto the altimeter time tag. Thus, the application of the EMiR retrieval scheme as it is now requires the existence altimeter observations concomitant to MWR observations.

For practicality and efficiency reasons, it was further decided to use the altimeter time tag from the L2 altimeter database readily available at project partner CLS, which also allowed for the direct application of pre-existing processing software.

These initial decisions result in the following scenarios resulting in gaps within the EMiR V1.1 data record:

(1) MWR or altimeter observations are not available, *e.g.* due to individual instrument failure or general platform unavailability.

(2) Both MWR and altimeter observations have been concomitantly acquired at satellite level, but the derived altimeter L2 data are not contained in the CLS database, hence no altimeter time tag is available.

As shown below in sections 4.4 and 4.5, both scenarios contribute to gaps in the EMiR V1.1 data record.

4.2 Mission phases

For a better understanding of the factors affecting EMiR data availability, we provide here a summary of the mission phases for the three concerned satellites, i.e. ERS-1, ERS-2, and Envisat. Each phase represents a period during which the main parameters and characteristics are left unchanged, particularly the orbital characteristics and the priorities for sensor operations.

Table 3: Mission phases of ERS-1, ERS-2, and Envisat, based on information obtained from https://earth.esa.int/ers/eeo/ERS1.1.7.html.

Mission phases	Start	Cycle	Mission objectives
ERS-1			
Launch	17-Jul-91		
Payload switch-on and verification	17-Jul-91		
A Commissioning	25-Jul-91	3 days	Engineering calibration and geophysical validation; until 10-Dec-91
B Ice	28-Dec-91	3 days	Arctic ice experiments, pollution monitoring
R Roll-tilt (experimental)	04-Apr-92	35 days	Testing SAR imaging at an incidence angle of 35°
C Multi-disciplinary	14-Apr-92	35 days	Mean sea level, ocean variability, land surfaces.
D 2nd ice	01-Jan-94	3 days	See phase **B**
E Geodetic	10-Apr-94	168 days	Improve the determination of the geoid with the Radar Altimeter
F Shifted geodetic	28-Sep-94	168 days	Same as phase **E**, but with an 8 km shift for a denser grid
G 2nd Multi-disciplinary	21-Mar-95	35 days	See phase **C**
G Tandem	17-Aug-95	35 days	Interferometry and mapping using parallel ERS-1/2 observations
G Back-up	2-Jun-96	35 days	ERS-1 on stand-by
Mission end	10-Mar-00		Failure in the on-board attitude control system
ERS-2			
Launch	21-Apr-1995		
Payload switch-on and verification	21-Apr-95	35 days	
A Commissioning	02-May-95	35 days	Engineering calibration and geophysical validation
B Tandem	17-Aug-95	35 days	see ERS-1 tandem phase **G**
B Multi-disciplinary	3-Jun-96	35 days	see ERS-1 phase **C**
C Ice	10-Mar-11	3 days	See ERS-1 phase **B**, document changes in ice balance
Mission end	05-Sep-11		
Envisat			
Launch	01-Mar-2002		
A Commissioning	05-Mar-2002	35 days	Engineering calibration and geophysical validation
B Routine operations	01-Jan-2003	35 days	Multi-discipline scientific data acquisition
C 2nd Routine operations	02-Nov-2010	30 days	Extend mission lifetime to create a bridge to the Sentinel missions
Mission end	08-Apr-2012		Loss of contact

4.3 Overview on EMiR temporal coverage

The EMiR V1.1 data record covers most of, but not the entire, MWR observation period. Table 4 lists the main events of the ERS-1/2 and Envisat missions affecting EMiR coverage.

Table 4: Main events of the ERS-1/2 and Envisat missions and the resulting EMiR V1.1 temporal coverage.

Time	ERS-1	ERS-2	Envisat
1991-07-17	ERS-1 launched		
1991-12-28	Routine operations begin		
1992-10-23	First ERS-1 EMiR V1.1 file		
1995-04-21		ERS-2 launched	
1995-08-17		Routine operations begin	
1995-10-02		First ERS-2 EMiR V1.1 file	
1996-06-02	Last ERS-1 EMiR V1.1 file		
1996-06-02	ERS-1 in stand-by mode		
1996-06-26		23.8 GHz gain drop	
2000-03-10	ERS-1 mission end		
2002-03-01			Envisat launched
2002-03-15			MWR in measurement mode
2002-05-14			First ENVI EMiR V1.1 file
2003-01-01			Routine operations begin
2003-06-22		Last ERS-2 EMiR V1.1 file	
2003-06-22		Tape recorder failure	
2011-07-06		ERS-2 mission end	
2012-04-08			Last ENVI EMiR V1.1 file
2012-04-08			Envisat mission end

The EMiR data record for each satellite mission starts ca. 15 months, 6 months, and 2 months respectively after the corresponding ERS-1, ERS-2, and Envisat launch dates. The instrument-specific end dates for the EMiR data record correspond to the official end-of-life dates for ERS-1 and Envisat. For ERS-2, the date of the last available EMiR L2 file (22. June 2003) corresponds to the failure of the internal tape recorder[1]. Since Envisat was already fully operational at that time, global MWR coverage is uninterrupted.

[1] As a consequence of the failure of the low bit rate (LBR) tape recorders, no onboard recordings could be made, and observations could only be performed within direct receiving station coverage. Therefore, from July 2003, the ERS-2 LBR mission continued as a regional mission with an initial global coverage of just 8%. Within a few weeks the LBR mission scenario was modified to take maximum advantage of the existing ERS LBR station network, which was gradually extended over the years to cover 45% of Earth's surface. Special efforts were made by ESA to ensure full coverage of the North Atlantic, since this has strong influence on European weather. More ERS-2 data are thus available which could in principle be used to extend the EMiR ERS-2 time series. However, since these data are not contained in the CLS data base, EMiR data from ERS-2 are not available after 22 June 2003.

4.4 Gaps in the EMiR data record

As outlined above in section 4.1, a number of reasons can lead to gaps in the EMiR data record. The resulting (un-)availability of EMiR V1.1 L2 data files is shown in Figure 1. Since EMiR L2 data files are organised on a daily basis, we refer here to gaps in units of calendar days. The dates corresponding to the gaps graphically shown in Figure 1 are listed in Table 5. The potential EMiR V1.1 full temporal coverage is assumed here to stretch from 1991-12-28 (ERS-1 starting routine operations) to 2012-04-08 (contact to Envisat lost).

Please note that the availability of an EMiR V1.1 L2 data file does not indicate that data coverage is complete for that day. It rather indicates that at least one valid acquisition has been made and processed that day.

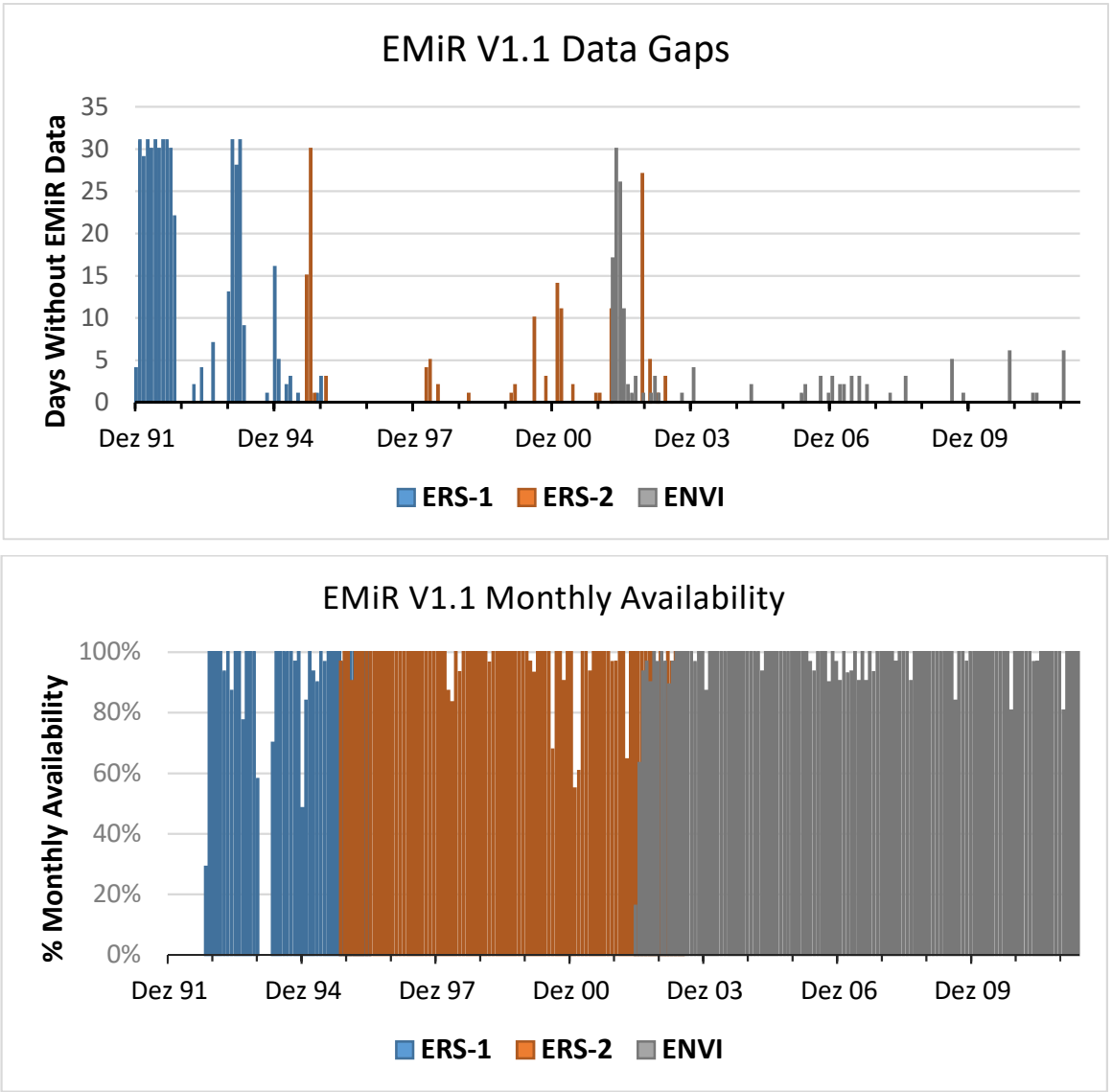

Figure 1. Top: Number of days per calendar month without EMiR V1.1 coverage. Bottom: Percentage of EMiR V1.1 L2 data monthly availability.

As can be seen from Figure 1, data availability is generally best for the ENVISAT and worst for the ERS- 1 time series, the latter showing significant data gaps, not only at the beginning of the ERS-1 mission between July 1991 and October 1992, but also between December 1993 and April 1994. This last and by far biggest gap within the ERS-1 EMiR time series coincides with the ERS-1 second ice mission (Table 3). While not part of the CLS database, data can likely be obtained from ESA in the context of a potential reprocessing to significantly improve data coverage for ERS-1 (section 5.1).

The total number of missing full calendar days within the data record amounts to 157 for ERS-1, 108 for ERS-2, and 89 for Envisat. In general, all EMiR data in temporal vicinity to data gaps should be treated cautiously, as gaps are often related to technical failures at satellite level (section 4.5).

Table 5: Gaps between first (1992-10-23) and last day (2012-04-08) of EMiR L2 V1.1 product availability, ordered by instrument and year. The brackets "[]" indicate calendar days for which EMiR L2 files are available, but do not contain any valid observations. The star "*" designates the ERS-1 second ice phase for which no data are available in the CLS database. The superscript (1) designates gaps for which the cause is known (see Table 6, Table 7, and Table 8 for ERS-1, ERS-2, and Envisat, respectively); in all other cases, the causes of data gaps could not be identified.

Mission	Year	Data gaps	Days missing
ERS-1	*1991*	*1991-12-28: Begin of scientific program*	
ERS-1	*1992*	*1992-10-23: First EMiR V1.1 ERS-1 L2 file*	
ERS-1	1992	No ERS-1 gaps after 1992-10-23	0
ERS-1	1993	[03/10], 03/22, 05/03-04, 05/07, 05/10, 08/07, 08/10, 08/15, 08/17, [08/19], 08/23, 08/26, [12/14-15], 12/21-31	26
ERS-1	1994	01/01-04/09*, [10/06], [12/16-31]	116
ERS-1	1995	[01/01-05], 03/22-23, [04/22], [04/25], [04/28], 06/19(1), 11/29, 12/06, 12/14, 12/17	15
ERS-1	*1996*	*1996-06-02: Last EMiR V1.1 ERS-1 L2 file*	
ERS-2	*1995*	*1995-08-17: Begin of scientific program*	
ERS-2	*1995*	*1995-10-02: First EMiR V1.1 ERS-2 L2 file*	
ERS-2	1995	[10/02]	1
ERS-2	1996	01/25(1), [01/26-27](1)	3
ERS-2	1997	No ERS-2 gaps in 1997	0
ERS-2	1998	[03/28-04/05], 06/04-05	11
ERS-2	1999	02/06	1
ERS-2	2000	01/01, 02/08-09(1), 07/01-10(1), 10/08-09(1), [10/10](1)	16
ERS-2	2001	01/18-02/08(1), [02/18-20], 05/22-23(1), 11/18(1), [12/12]	29
ERS-2	2002	03/09-19, 11/04-30	38
ERS-2	2003	[01/02-06], [03/23], 05/17-18(1), [05/19](1)	9
ERS-2	*2003*	*2003-06-22: Last EMiR V1.1 ERS-2 L2 file*	

Mission	Year	Data gaps	Days missing
Envisat	*2002*	*2002-05-14: First EMiR V1.1 Envisat L2 file*	
Envisat	2002	[05/14-15](1), 05/18-23(1), 05/27, 05/28-29(1), 05/30-06/05, 06/06-10(1), 06/25(1), [07/07-08](1), [08/08](1), 09/09(1), [09/10](1), [09/16](1), [11/19](1)	31
Envisat	2003	*2003-01-01: Begin of scientific program*	
Envisat	2003	01/26, 02/21(1), [02/22-23](1), 03/16(1), 09/05(1), 12/04(1), 12/07-09(1)	10
Envisat	2004	No Envisat gaps in 2004	0
Envisat	2005	[03/30-31]	2
Envisat	2006	04/07(1), 05/27-28(1), 09/08-09(1), [09/10](1), [11/29](1), 12/13-14(1), 12/15	10
Envisat	2007	02/17, 02/18(1), 03/10-11(1), [05/27-29](1), 07/01(1), [07/29-30](1), 09/25-26(1)	12
Envisat	2008	[03/21], [07/29-31]	4
Envisat	2009	[07/27-31], [10/31]	6
Envisat	2010	[10/20-22](1), 10/23-25(1)	6
Envisat	2011	[04/04](1), [05/22](1), [12/21-26]	8
Envisat	*2011*	*2012-04-08: Last EMiR V1.1 Envisat L2 file*	

4.5 Reasons for the EMiR data gaps

4.5.1 Data gaps in the ERS-1/2 time series

Since information from publicly accessible sources on the events affecting data availability from the ERS-1 and ERS-2 platforms is limited, lists of mission events have been directly obtained from ESA *[S. Casadio and S. Pinori, pers. communication]*. Many of the events listed therein are of short duration and do not significantly affect EMiR data availability. However, several incidents result in data loss for full calendar days or longer, either for individual instruments or the whole payload (Table 6, Table 7).

Table 6: Unavailability of the MWR and RA instruments onboard ERS-1. Only unavailability periods covering one or more full calendar days are listed.

Year	Month	Day	MWR	RA	Description
1991	12	28	Begin of scientific program		
1992	02	18		X	RA history file filling with type 3 entries
1992	06	05		X	RA ICU stack overflow
1992	06	26		X	PL-Sol during AMI recovery
1992	06	26	X		PL-Sol during AMI recovery
1992	07	20-22	X	X	PL-Sol due to OBC error
1992	10	23	First EMiR V1.1 ERS-1 L2 file		
1995	06	19		X	RA emergency switch-down due to memory check violation
1996	06	02	Last EMiR V1.1 ERS-1 L2 file		

Table 7: Unavailability of the MWR and RA instruments onboard ERS-2. Only unavailability periods covering one or more full calendar days are listed.

Year	Month	Day	MWR	RA	Description
1995	05	04-24	X		Instrument in commissioning phase
1995	08	17			Begin of scientific program
1995	09	29		X	RA emergency switch-down due to a software anomaly
1995	10	02			First EMiR V1.1 ERS-2 L2 file
1996	01	25	X	X	Payload off due to PL-SOL
1996	01	26-27	X		Payload off due to PL-SOL
2000	02	08-09	X	X	RA picks up MPS
2000	07	01-08	X	X	
2000	10	08-09	X	X	
2000	10	10	X		
2001	01	18-31	X	X	Major spacecraft anomaly day 017 / 1953 Z and subs. recovery
2001	02	01-04	X	X	Major spacecraft anomaly day 017 / 1953 Z and subs. Recovery; RA had IDHT anomaly due to external clock
2001	02	05-06	X		Major spacecraft anomaly day 017 / 1953 Z and subs. recovery
2001	05	22-23	X	X	IT1 Memory protection error: NO NVDS
2001	11	18	X	X	Reconfiguration Times after LEONIDS
2003	05	17-18	X	X	
2003	05	19	X		
2003	06	22			Last EMiR V1.1 ERS-2 L2 file
2003	06	26-30	X		
2004	12	28	X		Due to an on-board anomaly, instruments switched to standby mode
2005	05	23		X	RA emergency switch-down
2008	10	22		X	RA switch-down to WUP1+SPSA on / MCMD refused
2009	05	13		X	RA switch-down to WUP1+SPSA on / MCMD refused
2009	06	01		X	RA switch-down to WUP1+SPSA on / MCMD refused
2009	08	05-06		X	RA planned unavailable due to power cycle
2010	01	31		X	RA emergency switch-down
2010	07	04		X	RA switch-down to WUP1+SPSA on / MCMD refused

4.5.2 Data gaps in the Envisat time series

Availability of information on instrumental and platform conditions is better for Envisat. Event registers providing start and stop dates of unavailability periods for all instruments as well as their causes have

been published online[2]. Table 8 lists unavailability periods of one or more calendar days for both the MWR and/or RA-2 instruments. The events listed in Table 8 explain most of the EMiR unavailability for the Envisat time series. There are further periods where EMiR V1.1 L2 files are either not available or entirely filled with VOID values. The reasons for these latter gaps are not clear yet at this moment.

Table 8 can also be used to identify the gaps caused solely by the lack of RA-2 data (remember that EMiR L2 data are currently not produced if the altimeter time tag is missing). Would EMiR become independent of the altimeter time tag, those gaps could be filled. For Envisat, the corresponding gaps amount to 10 calendar days in total.

Table 8: Unavailability of the MWR and RA-2 instruments on Envisat. Only unavailability periods covering full calendar days are listed.

Year	Month	Day	MWR	RA-2	Description
2002	03	30-31	X		DORIS/MWR instrument control unit (ICU) spurious wait state
2002	04	01-09	X		DORIS/MWR ICU spurious wait state
2002	04	02-07		X	RA2 ICU in suspended mode
2002	05	02	X		DORIS/MWR ICU in reset/wait mode
2002	05	12-13	X	X	Payload switch-off
2002	05	14	First EMiR V1.1 ERS-2 L2 file		
2002	05	14-15	X		Payload switch-off
2002	05	18-23		X	RA-2 switched to heater0 / refuse mode
2002	05	28	X	X	Payload switch-off
2002	05	29		X	Payload switch-off
2002	06	06-09	X	X	Payload switch-off
2002	06	10	X		Payload switch-off
2002	06	25		X	RA2 in standby mode
2002	07	07-08	X		DORIS/MWR ICU switched down
2002	08	08		X	RA-2 in reset/wait mode. ICU locked
2002	09	09	X	X	Planned service module (SM) switch-off; RA2 in standby/refuse mode
2002	09	10	X		Planned service module (SM) switch-off
2002	09	16	X		DORIS/MWR ICU restarted
2002	11	19	X		Switch-off due to Leonid shower preparation
2003	01	01	Begin of scientific program		
2003	02	21	X	X	Unplanned payload switch-off

[2] MWR: https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mwr/mission-operations-overview

RA2: https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/ra2/mission-operations-overview

Year	Month	Day	MWR	RA-2	Description
2003	02	22-23	X		Unplanned payload switch-off
2003	03	16	X		Autonomous MWR) / unplanned (RA-2) payload switch-off
2003	09	05	X	X	Payload switch-off
2003	09	06-07	X		Payload switch-off
2003	12	04		X	Unplanned payload switch-off
2003	12	07-09		X	RA2 ICU in reset/wait mode
2005	01	07-16	X		Housekeeping data products can't be generated
2006	04	07	X	X	On-Board Data Handling (OBDH) anomaly
2006	05	27-28		X	RA2 commanded in heater-1
2006	09	08-09	X	X	Payload off due to SM anomaly
2006	09	10	X		Payload off due to SM anomaly
2006	11	29	X		Correction SM memory maintenance
2006	12	13-14	X	X	High-speed multiplexer (HSM) protocol error (MWR); unplanned payload switch-off (RA-2)
2007	02	18		X	RA2 in heater0/refuse mode
2007	03	10-11		X	RA2 in heater0/refuse mode
2007	05	27-29	X		MWR in standby and refuse mode
2007	07	01		X	RA2 in heater1/refuse mode
2007	07	29-30	X		DORIS/MWR in reset mode anomaly
2007	09	25-26	X	X	Payload switch-off due to SM anomaly
2010	10	20-24	X		MWR data not generated correctly
2011	04	04	X		Payload switch-off due to SM anomaly
2011	05	22	X		Remote bus interface (RBI) status check error
2012	04	08	Last EMiR V1.1 ERS-2 L2 file		

4.6 Analysis of instrument unavailability

The total number of gaps of the EMiR data record, defined as the number of calendar days without (or completely empty) daily L2 files between the dates of the first and last EMiR L2 data file, amounts to 157 to ERS-1, 108 for ERS-2, and 89 for Envisat respectively (see section 4.4).

The following conclusions can be drawn from the information on mission phases and instrument unavailability for the different platforms:

ERS-1: Of the 157 calendar days without EMiR data,

- 99 days are related to the 2nd ice phase, and
- 58 days are without further information on the reasons for missing data.

ERS-2: Of the 108 calendar days without EMiR data,

- 42 days are caused by missing MWR data, and
- 66 days are without further information on the reasons for missing data.

Envisat: Of the 89 calendar days without EMiR data

- 24 days are part of the Envisat commissioning phase. Of these,
  - 14 days are caused by missing MWR data;
  - 10 days are caused by missing RA-2 data.
- 48 days are part of the Envisat scientific program. Of these,
  - 38 days are caused by missing MWR data;
  - 10 days are caused by missing RA-2 data.
- 17 days are without further information on the reasons for missing data.

The gap analysis can be summarised as follows:

- The total number of days without data within the temporal coverage of the EMiR data record (1992-10-23 to 2012-04-08) amounts to 354 days (157 + 108 + 89).
- The reasons for data gaps are known for 213 (99 + 42 + 24 + 48) of the total 354 days without data.
  - In 94 (42 + 14 + 38) of the 213 known cases, the gaps can be directly attributed to missing MWR data. These gaps cannot be covered.
  - For another 20 days, the gaps are caused by missing RA-2 data. If EMiR products were derived from MWR observations only, these gaps could be filled.
- There are no data gaps for either MWR or RA during ERS-1's entire 2nd ice phase (1994-01-01 to 1994-04-10). The corresponding data gap (99 days) can probably also be closed using MWR L0 data from the official ESA sources.

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5 Recommendations

5.1 Improving EMiR data coverage

In case of a potential EMiR V2.0 reprocessing, a number of measures should be envisaged to increase data coverage.

- **ERS-1**: The EMiR gaps in the early stages of the ERS-1 time series should be filled as much as possible.
  - This mainly concerns the period (1991-12-28 to 1992-10-22) prior to the start of the EMiR V1.1 data record. Except for a limited number of days, concomitant MWR and RA data are available for this period such that EMiR data products can be derived.
  - Also, the second ice phase (1.1.1994 to 9.4.1994) is currently not covered by the EMiR V1.1 data record. Here again, both MWR and RA observations are available for most of the time.
  - In order to fill the gaps in the EMiR ERS-1 time series, it will be required to switch from the MWR L0 data hosted at CLS (which e.g. does not contain the ice missions) to the latest official LTDP ESA MWR L0 dataset as a basis for Level-2 product generation.
- **ERS-2**: The EMiR ERS-2 Level-2 time series could be significantly extended in time by considering the data acquired from the network of mobile receiving stations set up after the failure of the on-board tape recorder which took place on 2003-06-22.
  - As this period is already fully covered by Envisat, this approach would not fill many temporal gaps in the overall EMiR Level-2 time series.
  - However, it would increase the density of EMiR observations, which in turn should lead to a better coverage in the EMiR Level-3 products.
  - It would also allow to study the temporal evolution of drifts or biases in the overlapping period with Envisat.
- **Envisat**: The EMiR Envisat Level-2 time series contains relatively few gaps such that no specific measures are required to enhance data coverage.
  - Most of these gaps are caused by the actual lack of MWR data at platform level, e.g. due to instrument malfunction, orbital manoeuvres, etc. (Table 5). These gaps cannot be filled.
  - Relatively few gaps are caused by the lack of concomitant RA-2 observations. Such gaps could in principle be filled if the EMiR processing would be solely based on MWR observations, but we deem this not necessary (see section 5.3).

5.2 Regenerating EMiR Level-1 brightness temperatures

The following procedure is suggested for a future EMiR V2.0 reprocessing of the EMiR Level-1 brightness temperatures:

- MWR: Acquire the consolidated LTDP ESA MWR Level 0 data, process these L0 data with the latest available processor to Level 1.
- Altimeter: Apply the Level 2 altimeter time tag and sigma-0 from REAPER for ERS-1/2 and Envisat V3, respectively.
- Interpolate the MWR brightness temperatures to the altimeter time tag to create the EMiR V2.0 Level 1 dataset serving as input for the TCWV and WTC retrieval schemes.

5.3 Removing the dependence on the altimeter time tag

For the reasons outlined in section 4.1, EMiR V1.1 L2 products have only been generated if concomitant altimeter observations were available. This approach inevitably reduces EMiR V1.1 product availability. It was therefore discussed whether a dual approach would be appropriate to overcome this issue, with one EMiR data record generated solely from MWR observations (= less gaps, less accurate), whereas another one would combine MWR and RA/RA-2 observations (= more gaps, more accurate).

Considering the relative limited number of data gaps caused by the lack of RA/RA-2 observations obtained concomitantly to MWR observations (see section 4.5), we do not consider the slightly improved temporal coverage of an MWR-only data record as sufficient to outweigh the drawbacks of having to generate and manage two different EMiR records in parallel.

We therefore recommend producing only one EMiR V2.0 data record by implementing the strategy sketched in section 5.2 above.

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