TRANSPORTABLE ATMOSPHERIC RADAR

- TARA -

DATASET DESCRIPTION DOCUMENT
FOR THE CDS DATASET

<cesar_tara_measurements_la1_t00_v1.0>

Table of Contents

Document Status

*status)**	*name*	*organisation*	*date*	*signature*
prepared	T. Otto	TUD	2012-07-20	
checked v1.0	Y. Dufournet	TUD	2012-07-24	

) prepared, checked, approved, authorized, accepted.*

document title : DDS for the CDS dataset <cesar_tara_measurements_la1_t00_v1.0>			
document reference id: cesar_tara_measurements_la1_t00_v1.0.pdf			
version	*author*	*date*	*reason for change*
0.1	T. Otto	2012-07-10	draft
0.2	T. Otto	2012-07-15	completion of the document
0.3	T. Otto	2012-07-20	minor changes and corrections
1.0	Y.Dufournet	2012-07-24	minor changes and corrections

General Overview

This dataset description document provides information for the CDS dataset
cesar_tara_measurements_la1_t00_v1.0.

TARA is the TU Delft transportable atmospheric radar that is located at the remote sensing site of the Cabauw Experimental Site for Atmospheric Research (CESAR). TARA is a polarimetric S-band (3.298 GHz, horizontal/vertical polarisations) FMCW radar developed at Delft University of Technology. Beside the main beam with polarimetric measurement capabilities, TARA has two offset beams at vertical polarisation pointing with an offset of 15deg with respect to the main beam. Its antennas are pointing at a fixed elevation of usually 45deg or 75deg (main beam) providing time-height indicators with an observation range of 15 km at a range resolution of usually 30 m. The radar transmits linear frequency modulated sweeps alternately at horizontal and vertical polarisation for the main beam, and linear frequency modulated sweeps at vertical polarisation for the two offset beams. The backscattered signal is received by a one-channel receiver either from the main beam (horizontal or vertical polarisation) or by one of the two offset beams.

Figure 1: TARA (right) at the remote sensing site at Cabauw next to the KNMI 35GHz vertically pointing cloud radar (left).

The central frequency of 3.298 GHz combined with sensitive receivers with a good dynamic range and the possibility to adjust the power of the transmitted signal, permit TARA to monitor echoes from refractive index variations (due to atmospheric changes in temperature and humidity), ice particles within ice and mixed-phase clouds, and rain. Thanks to Doppler measurements of the three beams, the horizontal wind speed and direction, and the vertical Doppler velocity can be estimated at high temporal and spatial resolution.

This dataset contains the *time-height indicators of the main beam reflectivity* (dBZ), the estimated *horizontal wind speed and direction*, and the *vertical Doppler velocity*.

Contacts

Principle Investigator

Name: Yann Dufournet
Herman Russchenberg

Address: TU Delft Climate Institute
Department of Geoscience and Remote Sensing
Stevinweg 1
2628 CN Delft
The Netherlands

Tel.: +31 (0)15 27 89526

E-Mail: y.dufournet@tudelft.nl

Instrument Developer

Name: TU Delft IRCTR
Fred van der Zwan (Technical staff)
Paul Hakkaart (Technical staff)
Johan Zijderveld (Technical staff)

Address: International Research Centre for Telecommunications and Radar - IRCTR
Delft University of Technology
Mekelweg 4
2628 CD Delft
The Netherlands

Deployment Locations and History

TARA is a transportable radar system usually located at the CESAR remote sensing site (as depicted on Figure 1).

April 2000	TARA is operational
Summer 2007	TARA at COPS measurement campaign (black forest, Germany)
2011	Upgrade of TARA's control and processing unit
January 2012	TARA is operational again with state-of-the-art real-time data processing and real-time estimation of the 3D wind field
Aug-Nov 2012	TARA at HyMEX campaign (near Montpellier, France)
November 2012	TARA back at CESAR

Near-Real-Time Data Plots

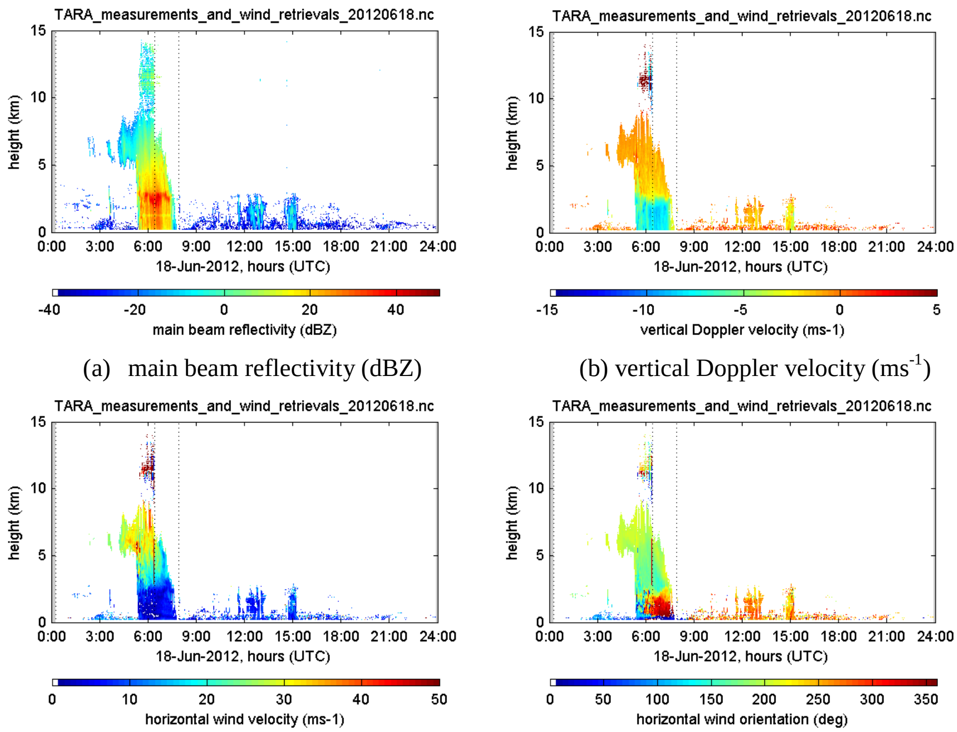
Near-real-time data plots of TARA measurements can be found online at:

http://ftp.tudelft.nl/TUDelft/irctr-rse/tara/

TARA's near-real-time plots are updated every minute.

Data Description and Examples

Figure 2 shows time-height indicators for one day (2012, June 18) of TARA measurements. Shown are all the parameters that are stored in the CESAR database, i.e. the main beam reflectivity (Figure 2a), and the estimated 3D winds (Figure 2b-d). The main beam reflectivity in linear units ($mm^6 \cdot m^{-3}$) is proportional to the backscattered and received power. Using empirically derived Z-R relations, the rain rate might be directly inferred from the reflectivity.



(a) main beam reflectivity (dBZ)

(b) vertical Doppler velocity (ms^{-1})

(c) horizontal wind velocity (ms^{-1})

(d) horizontal wind direction (ms^{-1})

Figure 2: Example of a TARA measurement (time-height indicators).

The dataset contains the time-height indicators usually with a time resolution of about 3s and a height resolution of approximately 30m. In irregular intervals, data might be missing which usually indicates that TARA was not measuring.

Data File Contents

Table 1 summarises the dimensions, global attributes, and variables contained in the dataset. Additional information about the dimensions and variables can also be found directly in the dataset within the corresponding *units* and *comment* attributes.

Table 1: Data file contents.

Dimensions	**Description**
scalar	dimension used for scalar variables
time	time dimension
range_bin	range bin dimension (count)
measurement interval	indicates how often a TARA measurement was stopped and restarted, possibly with a change in the measurement specifications (resolution, sensitivity, elevation etc.)
range_#_interval	main beam slant range (m) per measurement interval
height_#_interval	height axis (m) per measurement interval

Attributes	**Description**
global attributes	as specified by [2]

Primary variables	**Description**
equivalent_reflectivity_factor	the main beam equivalent reflectivity factor at horizontal polarisation Z_{hh} (dBZ)
vertical velocity	estimated vertical mean Doppler velocity (m s^{-1})
horizontal_wind_speed	estimated horizontal wind speed (m s^{-1})
horizontal_wind_direction	estimated horizontal wind direction (degree measured clockwise from the Geographic North Pole)

Secondary variables	**Description**
iso_dataset	contains a copy of the dataset metadata, for more information refer to [2]
product	contains a copy of the product metadata, for more information refer to [2]
station_details	contains metadata describing station details, for more information refer to [2]
radar_sensitivity *tx_attenuation*	At 100% sensitivity, the radar is able to detect echoes due to atmospheric refractive index variations, ice and mixed-phase clouds and precipitation. Sensitivity values below 100% are a result of the optimisation of the radar dynamic range for the measurement of precipitation and strong cloud echoes. The radar sensitivity is directly related to <tx_attenuation>.
measurement_intervals	indicating which range / height dimension is to be used at a specific acquisition time
range_resolution	the resolution along slant range (m)
height_resolution	height resolution (m)
radiation_wavelength	TARA's wavelength (m)
frequency_excursion	frequency excursion of the transmitted linear chirp (Hz)
sweep_time	sweep time of the transmitted linear chirp (ms)
NDop	number of sweeps that are averaged for the calculation of the Doppler spectra
elevation_main_beam	elevation of TARA's main beam (degree from ground)
longitude, latitude, altitude	TARA's position

Primary Variables and Expected Uncertainty

The main beam equivalent reflectivity factor at horizontal polarisation *equivalent_reflectivity_factor* in the logarithmic unit *dBZ*, i.e. normalised with respect to 1 $mm^6 \cdot m^{-3}$. To illustrate this, one spherical raindrop with a diameter of 1 mm per cubic metre would produce a reflectivity of 0 dBZ.

The expected measurement uncertainty of the reflectivity is ±1 dB over the receiver dynamic range. In this context, the uncertainty displays the probable maximum deviation of the measured value from the true value within a 95% confidence interval. It must be stressed that further aspects may deteriorate the quality of the reflectivity measurements. Those are outlined in the chapter “Data Quality”.

The estimated 3D winds rely on the homogeneity of the medium sensed by TARA’s three beams. Therefore, in case of a fast evolving meteorological event (convective situations), especially the estimated horizontal wind velocity might show some non-physical variations. In those situations, the horizontal wind should be averaged with a time window of about 10min.

In case of small horizontal wind velocities (< 1 m s^{-1}), the estimation of the horizontal wind direction can be erroneous.

Quicklook

The CESAR database quicklook shows the main beam reflectivity as a time-height indicator for the full day. An example is shown in Figure 3.

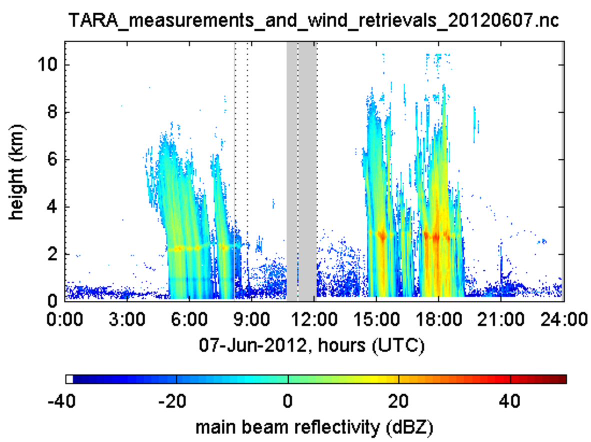


Figure 3: Example of a quicklook.

Time intervals where TARA is not measuring are greyed out. Vertical dotted black lines indicate when TARA was stopped and restarted, i.e. when the measurement interval changed and possibly also the measurement specifications (sensitivity, range/height resolutions, antenna elevation etc.).

Data Quality

The raw data streams of TARA are processed in real-time by the radar control computer. Clutter is suppressed as good as possible and only meteorological echoes are retained in the data. Data quality flags are at the moment not provided by this data processing. Thus, users of this dataset must be aware of the following issues that might deteriorate the measurements.

Receiver Saturation

When the received echo exceeds the dynamic range of the radar receiver, saturation occurs. TARA is equipped with an attenuator to reduce the transmitted power in these cases. However, this attenuator is controlled manually. Thus, the data might include receiver saturation effects that due to the nature of a FMCW radar results in a smearing effect in range. The 3D wind retrievals might be affected by strong receiver saturation.

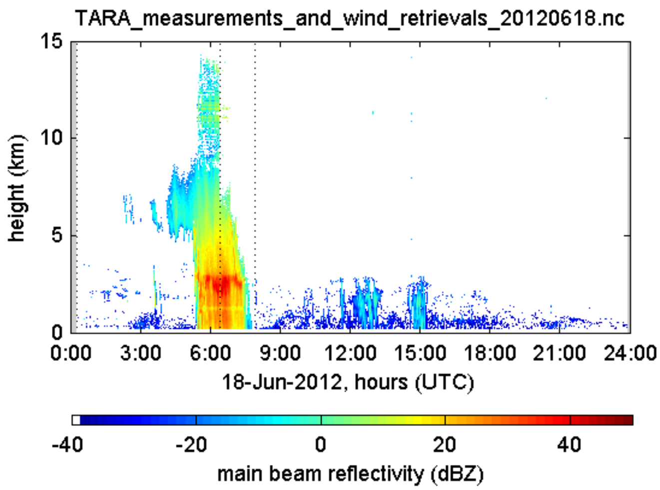


Figure 4: The effect of receiver saturation on reflectivity measurements from 5:00-7:00UTC.

Figure 4 shows receiver saturation from 5:00-7:00UTC, visible by the weak echoes at heights above 10km, whereas the precipitation and the cloud extends only up to 9km. At around 7:00UTC, the radar was stopped and restarted with a dynamic range optimised for the measurement of precipitation (lower transmit power and therefore lower sensitivity). The echoes due to saturation at heights above 10km disappear. But due to the lower sensitivity, also parts of the cloud are no longer detectable by TARA.

Instrument Details

Detailed Description

For a detailed description of TARA, the reader is referred to [i] and [ii].

The synchronisation of the system is provided by a GPS timing unit. This GPS timing unit is also used to provide an accurate time stamp (UTC) for the processed data.

Specifications

Table 2: Specifications of TARA.

<table>
<tr><th>Parameter</th><th colspan="2">Value</th></tr>
<tr><td>latitude</td><td colspan="2">51.96794 deg North</td></tr>
<tr><td>longitude</td><td colspan="2">4.92935 deg East</td></tr>
<tr><td>height above sea-level</td><td colspan="2">0 m asl.</td></tr>
<tr><td>transmitter</td><td colspan="2">solid-state amplifiers, modulation achieved by a direct digital synthesiser</td></tr>
<tr><td>polarisation on transmit</td><td colspan="2">linear horizontal, linear vertical for the main beam, linear vertical for the offset beams</td></tr>
<tr><td>frequency modulation on transmit</td><td colspan="2">sawtooth</td></tr>
<tr><td>receiver</td><td colspan="2">one channel receiver</td></tr>
<tr><td>maximum range</td><td colspan="2">15 km in standard mode (depending on the measurement specifications)</td></tr>
<tr><td>cross-polarisation isolation</td><td colspan="2">< -30 dB</td></tr>
<tr><th>Parameter</th><th>Symbol</th><th>Value</th></tr>
<tr><td>central frequency</td><td>f_c</td><td>3.298 GHz</td></tr>
<tr><td>frequency excursion, the corresponding range resolution is c/(2·Δf)</td><td>Δf</td><td>arbitrary, usually 5 MHz</td></tr>
<tr><td>sweep time</td><td>ΔT</td><td>arbitrary, usually 0.5ms</td></tr>
<tr><td>transmitted power</td><td>P_t</td><td>maximum 36W</td></tr>
<tr><td>antenna half-power beamwidth, Tx</td><td>θ_t</td><td>2.1°</td></tr>
<tr><td>antenna half-power beamwidth, Rx</td><td>θ_r</td><td>2.1°</td></tr>
</table>

Theory of Operation

TARA employs the frequency-modulated continuous wave radar principle, i.e. the radars is transmitting and receiving at the same time. The frequency of transmitted signal is sawtooth modulated. The backscattered and received echo is shifted in frequency with respect to the transmitted signal. This frequency shift, called the beat frequency, is directly related to the range of the echo.

The beat frequency is evaluated by mixing the transmitted signal with the received signal. Subsequently, a Fourier analysis is performed to separate the contributions from different range bins. The radar equation for distributed targets is then applied to calculate the reflectivity of each range bin.

Calibration

Before each measurement, a noise measurement is taken (transmitter switched off), and the received noise power is compared to the theoretically expected noise power. The radar constant is adjusted each time such that received noise power and expected noise power are the same.

Operation and Maintenance

More information about the operation and the maintenance of TARA are available as internal documentation at TU Delft.

Glossary and Acronyms

CDS	CESAR database system
CESAR	Cabauw experimental site for atmospheric research
DDD	dataset description document
DDS	direct digital synthesizer
FMCW	frequency-modulated continuous-wave
GPS	global positioning system
IRCTR	International Research Centre for Telecommunications and Radar of the Delft University of Technology
MDD	metadata description document
S-band	electromagnetic frequency band from 2 GHz to 4 GHz
TARA	transportable atmospheric radar

Citable References

[i] S.H. Heijnen, L.P. Ligthart, H.W.J. Russchenberg, 2000: First measurements with TARA: An S-band Transportable Atmospheric Radar, *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere*, **25**, 995-998.

[ii] L.P. Ligthart, S.H. Heijnen, 2002: Transportable multi-beam Doppler polarimetric radar, *Proceedings of Microwaves, Radar and Wireless Communications, MIKON-2002*, **2**, 334-340.

References

[1] R. J. Doviak and D. S. Zrnić: “Doppler Radar and Weather Observations: Second Edition”, *Dover Publications*, 2006.

[2] H. Klein Baltink: “Cesar Database System – Metadata Description Document”, v0.7, KNMI, October 2007.

[2] H. Klein Baltink: “Cesar Database System – Interface Control Document”, v1.4, KNMI, August 2009.