

High-resolution polarimetric X-band weather radar observations at the Cabauw Experimental Site for Atmospheric Research

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In 2007, the horizontally scanning polarimetric X-band radar IDRA (IRCTR Drizzle Radar) was installed on top of the 213 m high mast at the Dutch meteorological observatory Cabauw Experimental Site for Atmospheric Research (CESAR) at Netherlands. This radar complements a large variety of measurement instruments at CESAR by providing information on the horizontally spatial distribution and the temporal evolution of precipitation around the site. IDRA is a frequency-modulated continuous-wave radar developed at TU Delft's International Research Centre for Telecommunications and Radar (IRCTR). IDRA is designed to provide a high spatial resolution (down to 3 m in range) at a temporal resolution of 1 min. Its central frequency of 9.475 GHz, sensitive receivers with a large dynamic range, and the possibility to adjust the power of the transmitted signal permit IDRA to measure the whole spectrum of meteorological echoes from low-level clouds and drizzle to heavy convective rain. Similarly to most data collected at CESAR, also the data collected by IDRA are freely available for scientific purposes. IDRA data are stored at the Dutch 3TU.Datacentrum in order to make it easily accessible for everyone. In this article, we outline the IDRA dataset, including details on the data acquisition, processing, and possible applications.

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Dataset

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Creator: T. Otto, H. W. J. Russchenberg, R. R. Reinoso Rondinel, C. M. H. Unal

Title: IDRA weather radar measurements – all data

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Introduction

Compact X-band weather radars are a popular choice for the observation of precipitation up to a range of <60 km. Often they are deployed as gap-filling radars in complex terrain (Kabeche *et al.*, 2012), or as high-resolution precipitation mapping devices in densely populated urban areas (Kato & Maki, 2009). The maximum observation range at X-band is limited due to the significantly higher attenuation of the radar signals in rain compared to lower frequencies in the S- or C-band. Nevertheless, good results in quantitative precipitation estimation can be expected when polarimetry is employed (Wang & Chandrasekar, 2010).

All details of polarimetric X-band radar signal and data processing, and also quantitative precipitation estimation can be studied with the freely accessible, long-term dataset of TU Delft's polarimetric X-band

radar IDRA (IRCTR Drizzle Radar) which is introduced in this contribution. IDRA is one of the latest additions to the Dutch meteorological observatory Cabauw Experimental Site for Atmospheric Research (CESAR) (<http://www.cesar-observatory.nl>; Leijnse *et al.*, 2010). This compact radar is placed on top of the 213 m high meteorological measurement mast at Cabauw which is the second highest location in the surroundings. For IDRA a centre frequency of 9.475 GHz (X-band) was chosen as it provides a smart compromise to not only monitor precipitation but it is also sensitive enough to measure weak meteorological echoes from low-level clouds and drizzle.

IDRA is the first instrument at CESAR that extends the vertical column remote sensing observations by measurements in the horizontal domain. The radar scans at a fixed low-elevation angle of 0.5° with a rotation speed of one round per minute to be able to

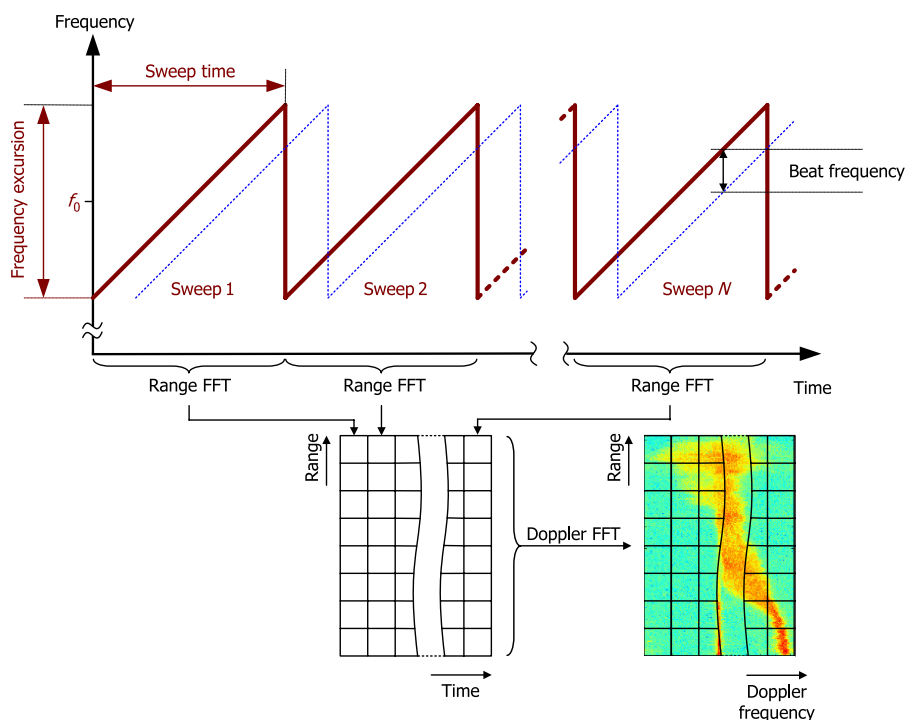


Figure 1. Measurement principle and basic data processing of an FM-CW radar like IDRA. Displayed in red is the saw tooth modulated transmitted signal around the centre frequency f_0 of 9.475 GHz for IDRA. The backscattered and received signal is delayed in time and therefore shifted in frequency with respect to the transmitted signal. The backscattered signal of one single, non-moving point target is shown exemplarily (dotted blue line). The beat frequency as a result of mixing the transmitted and the received signal is linearly related to the range of the targets. The signal processing includes a range fast Fourier transform (FFT) to resolve the targets in range, followed by a Doppler FFT to compute the Doppler spectrum. As an example, a power spectrogram of atmospheric targets measured by IDRA is shown.

observe the spatial characteristics of precipitation. Furthermore, due to its polarimetric capabilities, the microphysical composition of moderate to heavy precipitation can be studied.

One of the prime objectives of CESAR is the collection of long-term observations to monitor trends in atmospheric changes. Therefore, a solid data preservation strategy is required not only for the data storage, but also for making the data easily accessible to a wide scientific community.

IDRA data are stored at the Dutch 3TU.Datacentrum in NetCDF format compliant with the climate and forecast convention (CF 1.4). Its metadata are self-explanatory and conform to the Dutch profile of ISO-19115:2003 Geographic information metadata standard.

The IDRA measurement set-up is introduced next, followed by a description of the dataset format, location, and accessibility. Possible applications and uses for the IDRA measurements will conclude this article.

1. Data production methods

1.1. Data acquisition

IDRA is a frequency-modulated continuous-wave (FM-CW) radar designed and built at Delft University of Technology (Figueras i Ventura, 2009). An FM-CW radar transmits and receives simultaneously. The

transmitted signal of IDRA is linearly modulated (saw tooth) typically over a bandwidth of 5 MHz around its centre frequency of 9.475 GHz, see Figure 1. The backscattered and received echo is delayed in time and therefore shifted in frequency with respect to the transmitted signal. This frequency shift, called beat frequency, is linearly 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.

IDRA is a polarimetric radar transmitting alternately sweeps at linear horizontal and at linear vertical polarization. The two-channel receiver measures simultaneously the co- and cross-polarized echoes.

IDRA's colocated antennas (one for transmit and one for receive) mounted on top of the 213 m high meteorological mast at Cabauw, The Netherlands, rotate continuously at a fixed low-elevation angle of 0.5° at a rate of one round per minute. Important specifications of IDRA are summarized in Table 1.

1.2. Data processing

A range and Doppler fast Fourier transform is applied to the sampled beat frequency to compute the power spectrograms for all polarizations, see Figure 1. A polarimetric spectral clutter filter (Unal, 2009) is applied to preserve only the atmospheric

Table 1. Specifications of IDRA.

| Parameter | Value |
|-----------------------------------|---|
| Position | Latitude: 51°58'11.92" North Longitude: 04°55'37.16" East Height: 213 m above ground-level |
| Transmitter | Solid-state amplifiers, modulation achieved by a direct digital synthesizer |
| Polarization on transmit | Alternately linear horizontal and linear vertical |
| Modulation on transmit | Saw tooth, linear frequency-modulated upchirp |
| Centre frequency | 9.475 GHz (X-band) |
| Sweep time | 102.4, 204.8, 409.6, 819.2, 1683.4, or 3276.8 μ s |
| Frequency excursion | 5, 10, 25, or 50 MHz which corresponds to range resolutions of 30, 15, 6, and 3, respectively |
| Transmit power | 0, 1, 2, 5, 10, or 20 W |
| Receiver | Superheterodyne architecture, quadrature demodulation, two-channel architecture for the simultaneous measurement of the co- and the cross-polarized component (linear horizontal and vertical polarization) |
| Receiver dynamic range | 69 dB |
| Antennas | Two equal parabolic antennas of 1.3 m diameter with dual-polarized feeds |
| Antenna gains | 38.65 dB |
| Antenna half-power beam widths | 1.8° |
| Elevation angle | 0.5° (fixed) |
| Scanning speed | One round per minute (fixed) |
| Cross-polarization isolation | < -30 dB |

echoes. Subsequently, the power spectrograms are integrated over the Doppler domain, and the radar equation for distributed targets is applied to calculate the reflectivities. Also other polarimetric weather radar observables, i.e. differential reflectivity, linear depolarization ratio, and differential phase, and the Doppler moments, i.e. Doppler velocity and Doppler spectrum width are computed (Figueras i Ventura, 2009). Figure 3 shows an example of the IDRA weather radar observables available in the processed and raw data files.

1.3. Data storage

IDRA data are processed in real-time and stored in binary format on hard disks placed in the basement of the Cabauw mast. Regularly, the hard disks are brought to Delft where the data are converted to NetCDF format. Also a daily quick-look is created, Figure 2, and the data are uploaded to the 3TU.Datacentrum. Raw data are usually stored parallel to processed data during interesting meteorological events. Table 2 summarizes IDRA processed, raw, and quick-look data available at the 3TU.Datacentrum (Russchenberg *et al.*, 2010). Note that processed data are only uploaded if they were taken with the indicated standard measurement specifications.

2. Dataset location and format

The IDRA dataset is stored at the Dutch 3TU.Datacentrum (Russchenberg *et al.*, 2010). The data are in NetCDF format compliant with the Climate and Forecast convention (CF 1.4). The self-explanatory meta-data conform to the Dutch profile of ISO-19115:2003 Geographic information metadata standard. A comprehensive dataset description document describes the dataset in all its details.

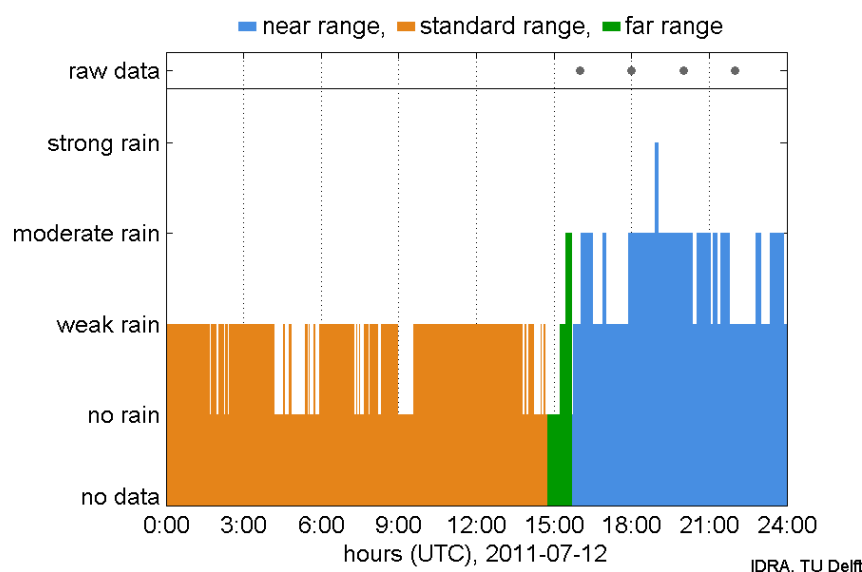


Figure 2. Example of a daily quick-look of IDRA data. The quick-look indicates at which times during a day IDRA provided raw and processed data, and whether significant precipitation was measured within the IDRA domain.

Table 2. IDRA datasets available at the 3TU. Datacenter and their content ('yyyy_mm_dd' stands for the year month and date, 'HH-MM' for the hour and minute).

| Name | Measurement specifications | Primary variables |
|--------------------------------|---|--|
| <i>IDRA processed data</i> | | |
| IDRA_YYYY_MM_DD_standard_range | Sweep time: 409.6 μ s frequency excursion: 5 MHz range resolution: 30 m maximum range: 15.36 km time extend: full day | Reflectivity, differential reflectivity, and linear depolarization ratio not corrected for attenuation, differential phase, Doppler velocity, Doppler spectrum width |
| IDRA_YYYY_MM_DD_near_range | sweep time: 409.6 μ s frequency excursion: 50 MHz range resolution: 3 m maximum range: 1.536 km time extend: full day | |
| IDRA_YYYY_MM_DD_far_range | Sweep time: 819.2 μ s frequency excursion: 5 MHz range resolution: 30 m maximum range: 61.44 km time extend: full day | |
| <i>IDRA raw data</i> | | |
| IDRA_YYYY_MM_DD_raw_data | Arbitrary, see dataset metadata for details time extend: 1 min of data which corresponds to one plan position indicator | Complex received voltages of the beat frequency for the two co-polarized (horizontal and vertical polarization) and one cross-polarized measurements processed weather radar observables noise power for the horizontal and vertical polarized receiver channel measured by switching off transmission |
| <i>IDRA quick-look data</i> | | |
| IDRA_YYYY_MM_DD_quicklook | Time extend: full day | Information displayed on the daily quicklook |

For details please refer to the dataset description document available at the 3TU. Datacenter alongside the dataset.

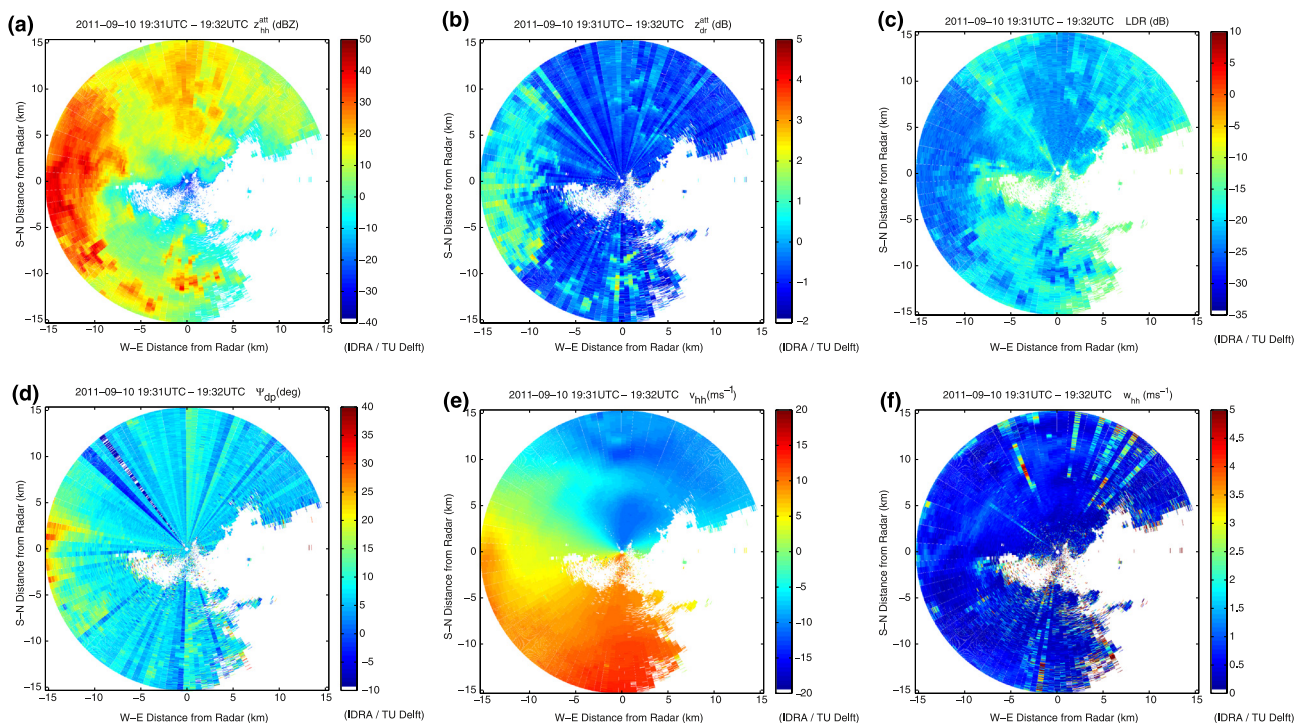


Figure 3. Example of 1 min of processed data (i.e. one plan position indicator) of IDRA data. Shown are all the primary variables stored in the IDRA_2011_09_10_standard_range.nc for 19:31 UTC – 19:32 UTC. Shown are the (a) co-polarized reflectivity at horizontal polarization not corrected for differential attenuation, (b) differential reflectivity not corrected for differential attenuation, (c) linear depolarization ratio not corrected for differential attenuation, (d) differential phase, (e) Doppler velocity, and (f) Doppler spectrum width.

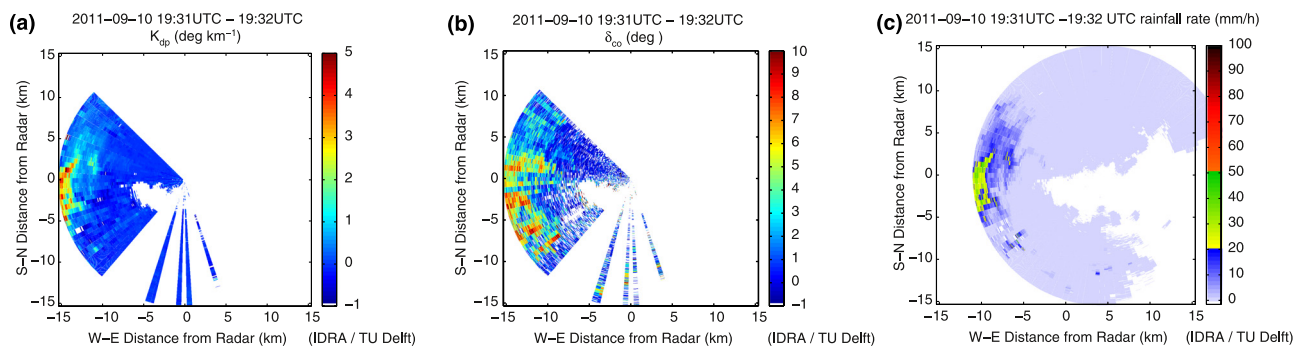


Figure 4. Example of secondary products derived from the data shown in Figure 3. The differential phase of Figure 3(d) is decomposed into its forward- and backward-scattering component: (a) the specific differential phase and (b) the differential backscatter phase, respectively. Note that the differential phase is only processed in sectors with a significant differential phase accumulation. (c) The estimated instantaneous rainfall rate based when available on the specific differential phase else on the reflectivity corrected for gaseous and rain attenuation.

IDRA data are accessible online without registration and restrictions. The data can be used freely for scientific studies according to the CESAR data policy (<http://www.cesar-database.nl>).

A MATLAB[®] toolbox is also made freely available at the 3TU.Datacentrum to automatically download, read, and plot the data.

3. Dataset use and reuse

IDRA data were used so far mainly to study possible improvements of weather radar signal and data processing, e.g. spectral polarimetric clutter filtering (Unal, 2009), differential phase processing (Otto & Russchenberg, 2011). The IDRA dataset is also used in the frame of remote sensing education at Delft University of Technology, The Netherlands, and also at Politecnico di Bari, Italy.

Due to a number of requests for ready-to-use rainfall rate estimates based on IDRA data, a post-processing was set-up to estimate rainfall rates based on IDRA standard range data.

The rainfall rate estimates are based whenever possible on the differential phase measurements such that they are independent of radar calibration and signal attenuation. As an example, the rainfall rate estimated from the data shown in Figure 3 is shown in Figure 4(c). The estimated rainfall rate based on IDRA data will be used for a large variety of studies, e.g. catchment hydrology, for the validation and the refinement of precipitation schemes of large-eddy simulations (Schalkwijk *et al.*, 2012), and for studies of the small-scale space and time structure of precipitation. To make also these post-processed data easily available, they are stored at the CESAR database (<http://www.cesar-database.nl>) together with data from other meteorological measurement instruments at the site.

The post-processed IDRA data not only include the reflectivity corrected for gaseous and rain attenuation and estimated rainfall rate but also the estimated specific differential phase and the differential backscatter phase as a result of the (Otto & Russchenberg, 2011)

processing, shown in Figure 4(a,b), respectively, for the data of Figure 3. Because the estimate of the differential backscatter phase, Figure 3(b), is quite noisy, a mean filter in range and azimuth with a 3×3 cross-shaped kernel was applied. The differential backscatter phase, an indicator of Mie scattering, is usually neglected by the weather radar community. However, its independence of radar calibration, signal attenuation makes it an interesting weather radar observable in moderate to strong rain at X-band, (Otto *et al.*, 2012), with promising applications in the future.

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