TITLE: General comments plus important updates, changes and fixes to the ORACLES 2C-RAIN data product (now WCOD product)

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INSTRUMENTS: APR-3 (W-band radar), RSP

NOTE: This document outlines all changes made to the new W-band plus cloud optical depth (WCOD) retrieval product (i.e. the original 2C-RAIN data product). The author would like to acknowledge all data users for their valuable feedback, which improved the quality of this data product. The WCOD files are in NetCDF, and every variable has been documented extensively to make their intended use clear.

REFERENCE: Dzambo, A.M., T. L'Ecuyer, O.O. Sy, and S. Tanelli, 2019: The Observed Structure and Precipitation Characteristics of Southeast Atlantic Stratocumulus from Airborne Radar during ORACLES 2016–17. *J. Appl. Meteor. Climatol.,* **58**, 2197–2215, doi:10.1175/JAMC-D-19-0032.1

General comments, as well as changes and updates made to the WCOD product (formerly 2C-RAIN):

1. Inclusion of a **cloud optical depth** constraint.
    a. Cloud optical depth data are provided by the **Research Scanning Polarimeter (RSP)** via their **wcld_v1** product.
    b. Cloud optical depth in the updated algorithm is assumed to be the sum of both **cloud water path (CWP)** and **rainwater path (RWP)**. The algorithm uses a Newtonian iteration scheme such that, if the solution converges, the modeled optical depth from clouds + drizzle/rain will closely match the input cloud optical depth (to within the measurement uncertainty).
    c. The cloud effective radius (863 nm) is also used in the calculation of cloud water path.
    d. The details of this new algorithm will be the topic of a new manuscript, to be submitted to the ORACLES ACP/AMT special issue. Until this manuscript is submitted, please reach out to Andrew if you have any questions.

2. When RSP data are not present, cloud water content is parameterized according to the equations found in Lebsock & L'Ecuyer (2011).

3. Cloud water content is distributed from cloud top down to the altitude of max reflectivity, with exceptions:
    a. If the max reflectivity is near cloud top, all CWC is distributed down through the next 5 bins (6 total bins), unless the cloud is thinner than this.
    b. Multi-layer clouds are not accounted for, and occasionally happen near the ITCZ.

4. An adiabatic cloud water model following Merk et al. (2016) is used to initialize the CWP:
    a. Variance is set to 500 g/m^2 if the maximum cloud top height is in the MBL.
    b. Given that the adiabatic cloud water model can result in large liquid water contents, the total CWP is based off the integration of adiabatic "CWC" from the top $1/5^{th}$ of all bins in the radar profile.
    c. If a cloud has a cloud top height above 2.0 km (i.e. likely trade cumulus), a priori guess is set to 500 g/m2 with a 1000 g/m2 variance.

5. A nearest-neighbor interpolation approach is used to find the clear-sky PIA.
    a. New algorithm will revert to the PIA lookup table if no (or very few) clear sky profiles exist in a given scene (details in Dzambo et al., 2019).
    b. The uncertainty is set to 1 dB, i.e. the measurement uncertainty of the APR-3 radar.

6. The evaporation model now includes a near-surface bias correction according to Kalmus and Lebsock (2017). Given that the radar can detect unambiguous returns to ~200 meters, the changes are not overly dramatic.

7. To clarify the terminology found in the Dzambo et al. (2019) study as well as upcoming studies, there are now **FOUR** primary rainfall variables included in the final dataset:
    a. Profile of rain rate (variable ID: `rainfallProfile_rainProfile`)
    b. Surface rain rate (variable ID: `rrSurface_rainProfile`)
    c. Near surface rain rate (variable ID: `rrNearSurface_rainProfile`)
    d. Column maximum rain rate (variable ID: `rrMaxColumn_rainProfile`)
    e. The column maximum rain rate corresponds to our "best guess" cloud base. The near surface rain rate will contain non-zero data if the radar profile extends to the last bin unaffected by ground clutter. The near surface rain rate variable will be zero if the radar profile is (1) fully attenuated, (2) a virga profile, or (3) a clear sky profile.

   f. The `rrNearSurface_rainProfile` variable can be interpreted as `rrSurface_rainProfile` but *without the Kalmus and Lebsock (2017) & Comstock et al. (2004) evaporation model applied*.
   g. The `rrNearSurface_rainProfile` variable in WCOD is exactly the same as `rainRate_rainProfile` in the version 1.0 2C-RAIN files.

8. The `modelRWP_rainProfile` variable includes both the integrated rainwater content and the rainwater path between the surface and lowest radar echo (this is computed following Comstock et al., 2004). Integrating RWC in the 2C-RAIN files will always result in a RWP that is less than the reported RWP for this reason. If a user wants to find the sub-cloud RWP, subtract [integrate(RWC*radar_bin_space)] from [modelRWP_rainProfile].

9. Fixes were made in the adapted 2C-PRECIP-COLUMN algorithm to pre-classify any and all shallow StCu, including near the surface, as a valid cloud. Some of these clouds were inadvertently screened out in the original 2C-RAIN product.

10. The new data product now includes the full uncertainty profile corresponding to the retrieved rainfall rates.

11. A new variable, dubbed the contribution matrix (C-matrix, or contribution fraction), i.e. the contribution of an independent variable or the a priori estimate to the retrieved quantity (rain rate or CWP) has been made available for users.
    a. The contribution ranges from 0 (no effect) to 1 (full effect).
    b. The contribution fraction can be interpreted as the fractional uncertainty contribution to the final retrieved quantity.
    c. The rain rates and CWP contain contributions from:
        i. Reflectivity
        ii. Optical depth
        iii. Path integrated attenuation
        iv. A priori constraint
    d. For example, if the CWP has a contribution fraction of 1 from the cloud optical depth, the optical depth constraint (e.g. RSP) fully determined the final CWP retrieval. As another example, if the CWP retrieval has contribution fractions of 0.5 from the reflectivity and optical depth fields, their uncertainties contributed equally to the final retrieved CWP uncertainty.
    e. This data will be VERY useful for assessing profiles heavily influenced by the a priori constraint, which intentionally has a very large uncertainty. The end user can use the C-matrix data to ensure their data are constrained to the observations (reflectivity, COD, PIA).