1. Introduction

This document aims at describing the main features of the microphysics and dynamic product. Cloud wind and microphysical properties are retrieved using RASTA measurements (Reflectivity and Doppler measurements).

The RASTA radar includes 6 different viewing angles (3 downward and 3 upward). Three 45 cm diameter nadir pointing antenna, backward pointing antenna, transverse antenna (pointing toward the right side of the aircraft) are mounted on the bench. The three upward antennas, zenith, up backward, up transverse are slightly smaller (30 cm) in order to fit the size of the top window. The six-beam configuration of RASTA allows for the retrieval of selected microphysical ice-cloud properties and the 3D dynamics of clouds.

RASTA is capable to retrieve the 3D wind field by combining independent measurements of the Doppler wind velocity by the multi-beam antenna system. The 3D wind is retrieved using an optimal estimation approach, which consists in using an iterative process to adjust the state vector containing V_x (along track wind component), V_y (cross track) and V_z (vertical) to minimise the difference between the forward modelled Doppler velocity and the measured one on each antenna. After minimisation of the cost function the optimal state vector contains the retrieved 3D wind components.

Once the cross track, along track and vertical wind fields are retrieved above and below the aircraft, the vertical air velocity is used to quantify the level of turbulence at different height levels beyond the flight altitude, and to characterise the updraft /downdraft structures (intensity and size) associated with the convective cells.

The calibrated radar reflectivity and retrieved terminal fall speed are used to derive estimates of the IWC, mean volume diameter, and number concentration using the RadOnvar technique. RadOnvar algorithm is based on a variational approach (a combination of Delanoë et al 2007 and Delanoë and Hogan 2008). This technique corrects from ice attenuation.

Input:
Z, Vz = ($W+V_T$) from RASTA with (V_T : terminal fall speed, W: air motion)
Temperature

Output:
IWC, D_m, W

Then N0*, R_{eff}, extinction, N_T … are calculated

2. Miscellaneous

- **Convective index**

First we define the ice part and we keep only Vz (Vt+W) corresponding to ice.
n_vup = Sum of the pixels Vz > 2 (and Vz valid) updraft
n_vdown = Sum of the pixels Vz < -3 (and Vz valid) downdraft
Convective if n_vup or n_vdown > 8

- **Gaseous attenuation**

RH, T and P profiles are derived from in-situ and ECMWF reanalysis
The gaseous attenuation is computed using Liebe's model (O2 and H20). The variable saved is the cumulated attenuation for each radar gate as a function of the distance from the aircraft.

- **Melting layer/Phase discrimination**

Vertical gradients of Z and Vz are used
Horizontally averaged (running window), 10 radials

- Vz

  Melting zone dVz/dz > 3 and -4 < T < 10, variable set to 2

  The melting layer is determined using the mean values and standard deviation of the melting zone altitude

  The mean value is conserved only of the standard deviation is <= 0.2 km. Then the valid values are interpolated.

- Z

  Melting zone : dZ/dz < -8 and with 200m of the melting zone Vz
  Maximum altitude with this criterium
  mean_melting=averaged(altitude_melt_Z) 'single value'
  altitude_melt_Z is interpolated (only when difference between mean and melting line defined using Z is less than 500 m).
  Ice altitude >= altitude melting = 1
  Rain or liquid > altitude melting = 2

- **Rain rate (From Matrosov 2007)**

  Compute the reflectivity gradient below the melting layer: dZdr (most of the time below the aircraft but during take off or landing rain can be above the aircraft)
  Rain rate is computed 500m below the melting layer only
  rain_attenuation=0.5* dZdr - gaseous_attenuation
  K=1.1*rhoa**(-0.45), rhoa is the air density kg/m3
  RainRate = K*1.4*rain_attenuation

- **Attenuation**
  - how many pixels below the melting layer (npix)
  - can we detect the ground echo
  - quick check of the cloud/rain thickness (above 500m) (npix cloud)

Attenuation in ice part if npix < 20, ground echo not detected, roll < 20° and cloud thick enough (npix cloud > 25) => set to 1
Attenuation in ice part if aircraft below the melting layer => set to 1

attenuation_phase_flag:

- 0 no cloud
- 1 ice
- 2 rain (attenuated)
- 3 ice but likely attenuated
- 4 ground
- 5 ghost ground
- 6 interpolated

3. File content V5 (note, the netcdf file is self documented)

Variable	Dimension	unit	Comment
Dimensions			
time	time	h	Decimal hours UTC since midnight
range	range (250)	km	Range from the radar to the centre of each range gate
height	height (500)	km	Altitude above and below the aircraft have been concatenated
height_2D	time, height	km	Altitude above and below the aircraft have been concatenated as a function of time 0:249 below the aircraft toward the aircraft 250:499 above the aircraft toward the sky
Aircraft position and in-situ	from SAFIRE file (B. Piguet)		
latitude	time	degree	Latitude of the aircraft, from Global Positioning System (GPS)
longitude	time	degree	Longitude of the aircraft, from Global Positioning System (GPS)
altitude	time	km	Altitude of the aircraft above geoid, from Global Positioning System (GPS)
pitch	time	degree	Aircraft pitch angle, from Inertial Navigation System (INS): positive when the aircraft nose is up
roll	time	degree	Aircraft roll angle, from Inertial Navigation System (INS): positive when the starboard wing is down
drift	time	degree	Aircraft drift angle, from Inertial Navigation System (INS): positive if track is more clockwise than heading
heading	time	degree	Aircraft heading angle, from Inertial Navigation System (INS): relative to geographical North, positive clockwise
track	time	degree	Aircraft track angle, from Inertial Navigation System (INS): relative to geographical North, positive clockwise, track = heading + drift
aircraft_vh	time	m s-1	Aircraft horizontal speed
aircraft_vz	time	m s-1	Aircraft vertical speed
pressure	time	hPa	Pressure at flight level
temperature	time	degree C	Temperature at flight level
relative_humidity	time	%	Relative Humidity at flight level

Variable	Dimension	unit	Comment
eastward_wind	time	m s-1	In-situ Eastward Wind Component (positive when westerly)
northward_wind	time	m s-1	In-situ Northward Wind Component (positive when southerly)
u_wind	time	m s-1	Along track Wind Component
v_wind	time	m s-1	Cross track Wind Component
w_wind	time	m s-1	Vertical Wind Component (positive when upward)
u_wind_fuselage	time	m s-1	Along fuselage Wind Component
v_wind_fuselage	time	m s-1	Cross fuselage Wind Component
proj_insitu_wind_speed	time	m s-1	Projected in-situ wind speed along the nadir radial
land_water_flag	time	none	0 means Land, 1 means Water Derived from Very High Resolution land/sea tag map with distance from land, Naval Oceanographic Office (NAVOCEANO) 2007-06-28
RADAR measurements	Upward antennas are collocated with Zenith grid Downward antennas are collocated with Nadir grid Vertical: Nadir and Zenith Backward: Down and Up Transverse: Down and Up		
Z_vertical	time, height	dBZ	Radar reflectivity factor from Nadir and Zenith antennas
v_vertical	time, height	m s-1	Doppler velocity from Nadir and Zenith antennas (positive when target moves away from the radar)
R_vertical	time, height	m	Range from aircraft (Nadir and Zenith)
Z_L1_vertical	time, height	dBZ	L1 Radar reflectivity factor from Nadir and Zenith antennas
latitude_vertical	time, height	degree	Latitude of Nadir and Zenith data
longitude_vertical	time, height	degree	Longitude of Nadir and Zenith data
Z_backward	time, height	dBZ	Radar reflectivity factor from Down and Up Backward antennas
v_backward	time, height	m s-1	Doppler velocity from the Down and Up Backward antennas (positive when target moves away from the radar)
R_backward	time, height	m	Range from aircraft (Down and Up Backward)
Z_L1_backward	time, height	dBZ	L1 Radar reflectivity factor from Down and Up Backward antennas
latitude_backward	time, height	degree	Latitude of Down and Up Backward data

Variable	Dimension	unit	Comment
longitude_backward	time, height	degree	Longitude of Down and Up Backward data
distance_vertical_backward	time, height	km	Distance between vertical and backward gates
Z_transverse	time, height	dBZ	Radar reflectivity factor from Down and Up Transverse antennas
v_transverse	time, height	m s-1	Doppler velocity from Down and Up Transverse antennas (positive when target moves away from the radar)
R_transverse	time, height	m	Range from aircraft (Down and Up Transverse)
Z_L1_transverse	time, height	dBZ	L1 Radar reflectivity factor from Down and Up Transverse antennas
latitude_transverse	time, height	degree	Latitude of Down and Up Transverse data
longitude_transverse	time, height	degree	Longitude of Down and Up Transverse data
distance_vertical_transverse	time, height	km	Distance between vertical and transverse gates
azimuth_east_vertical	time, height	degree	Azimuth angle of Nadir and Zenith antenna beams with respect to the right wing (positive counterclockwise)
elevation_hor_vertical	time, height	degree	Elevation angle of Nadir and Zenith antenna beams with respect to the aircraft horizontal plane (positive when above aircraft)
azimuth_east_backward	time, height	degree	Azimuth angle of Down and Up Backward antenna beams with respect to the right wing (positive counterclockwise)
elevation_hor_backward	time, height	degree	Elevation angle of Down and Up Backward antenna beams with respect to the aircraft horizontal plane (positive when above aircraft)
azimuth_east_transverse	time, height	degree	Azimuth angle of Down and Up Transverse antenna beams with respect to the right wing (positive counterclockwise)
elevation_hor_transverse	time, height	degree	Elevation angle of Up and Down Transverse antenna beams with respect to the aircraft horizontal plane (positive when above aircraft)
Geophysical parameters WIND	WIND and masks 0:249 below the aircraft toward the aircraft 250:499 above the aircraft toward the sky		
Z	time, height	dBZ	Radar reflectivity (vertical, above and below the aircraft)
Vx	time, height	m s-1	Horizontal component of the retrieved 3D wind, along track

Variable	Dimension	unit	Comment
Vy	time, height	m s-1	Horizontal component of the retrieved 3D wind, cross track
Vz	time, height	m s-1	Vertical component of the retrieved 3D wind
VE	time, height	m s-1	Eastward Wind component of the retrieved 3D wind
VN	time, height	m s-1	Northward Wind component of the retrieved 3D wind
Mask_domain	time, height		This mask identifies the valid data above and below the aircraft (1:down/2:down and nadir only/3:up/4:up but zenith only)
altitude_melting	time, height	km	Altitude of the melting layer (derived from Z and V)
convective_index	time		Convective index (0:stratiform/1:convective)
Mask_wind	time, height		This mask identifies areas where wind retrieval is expected to be bad, good confidence when abs(roll) < 10 deg. (1: confident /2: less confident upper domain /3: less confident lower domain)
Mask_Vx	time, height		Mask for the Vx component of the wind 1: good confidence /2: should not be used
Mask_Vy	time, height		Mask for the Vy component of the wind 1: good confidence /2: should not be used
Mask_Vz	time, height		Mask for the Vz component of the wind 1: good confidence /2: should not be used /3: could be used but carefully
attenuation_phase_flag	time, height		Attenuation and Phase flag 0: no cloud / 1: ice / 2: rain / 3: ice but likely attenuated / 4: ground / 5: ghost ground / 6: interpolated
Gaseous_twowayatt	time, height	dBZ	Two way attenuation, From Liebe at 95GHz
Pressure_field	time, height	hPa	
Temperature_field	time, height	degree C	
Vx_error	time, height		Error in Vx, Horizontal component of the retrieved 3D wind
Vy_error	time, height		Error in Vy, Horizontal component of the retrieved 3D wind
Vz_error	time, height		Error in Vz, Horizontal component of the retrieved 3D wind
RainRate	time, height	mm/h	Similar to CloudSat basic retrieval using attenuation below the melting layer - Matrosov et al 2007

Variable	Dimension	unit	Comment
Inputs of the retrieval of the Geophysical parameters (Radonvar)	0:249 below the aircraft toward the aircraft 250:499 above the aircraft toward the sky		
T_in	time, height	degree C	Input temperature (used in the algorithm)
Z_in	time, height	dBZ	Input radar reflectivity
V_in	time, height	m s-1	Input vertical velocity
Geophysical parameters (Radonvar)	Microphysical and vertical air motion products 0:249 below the aircraft toward the aircraft 250:499 above the aircraft toward the sky		
w_ret	time, height	m s-1	Retrieved Vertical Wind Component (positive when upward)
iwc_ret	time, height	g m-3	Retrieved Ice water content
iwc_IWC_Z_T	time, height	g m-3	Retrieved Ice water content using IWC-Z-T relationship
Dm_ret	time, height	m	Retrieved Mean volume weighted diameter
N0_ret	time, height	m-4	Retrieved Intercept parameter of the normalised PSD
extinction_ret	time, height	m-1	Retrieved visible extinction
re_ret	time, height	m	Retrieved effective radius
Nt_ret	time, height	# m-3	Retrieved total number concentration
Z_fwd	time, height	mm6m-3	Forward modelled reflectivity
Z_noatt_fwd	time, height	mm6m-3	Forward modelled reflectivity corrected from attenuation
V_fwd	time, height	m s-1	Forward modelled vertical velocity
Z_Xband	time, height	dBZ	Simulated X band Radar reflectivity. Derived using microphysical parameterization and radonvar
Error and control parameters Geophysical parameters (Radonvar)	Microphysical and vertical air motion products 0:249 below the aircraft toward the aircraft 250:499 above the aircraft toward the sky		
error_v	time, height		
error_lnz	time, height		ln(z) error
lniwc_error	time, height		fractional error in IWC (lniwc error)
w_error	time, height		error in w

Variable	Dimension	unit	Comment
lniwc_apriori	time, height		ln(iwc) apriori from IWC-Z-T relationship
error_lniwc_apriori	time, height		ln(iwc) apriori error
Jd	time, niter		cost function below the aircraft
Ju	time, niter		cost function above the aircraft
iJd	time		index of the min cost function below the aircraft
iJu	time		index of the min cost function above the aircraft

Example of global attributes:
:Description = "95GHz Cloud Radar (RASTA) - Microphysics and Wind DATA" ;
:frequency = "95.04 GHz" ;
:peak_power = "1.8 kW" ;
:pulse_width = "0.4 us" ;
:ambiguous_distance = "15 km" ;
:pulse_repetition_frequency = "PRF=25kHz" ;
:beamwidth = "0.7 degrees" ;
:range_resolution = "60 m" ;
:reflectivity = "not corrected for attenuation, calibrated following Li & al (2005,J.Atmos.Oceanic.Tech.)" ;
:doppler_velocity = "corrected for aircraft motion and folding" ;
:real_time_processing = "Pulse Pair Technique" ;
:flight = "21" ;
:day = "DDMMYEAR" ;
:campaign = "XXX" ;
:year = "2014" ;
:experiment = "XXXX" ;
:airport_latitude = XX;
:airport_longitude = XX ;
:contact = "contact email: julien.delanoe@latmos.ipsl.fr" ;
:created = "YEAR-MM-DD" ;
:data_policy = "If you intend to use these data for any communication or publication please contact Julien Delanoe" ;

A few tips:

- If you want to display Z or iwc for instance you need to use “height_2D” for the altitude of each radar gate.
  - For instance (python example) : pcolor(time, height_2D.T,Z.T)
- When you wand to use the data don’t forget the mask information:
  - “attenuation_phase_flag” contains very useful information