EUFAR FP7

N6SP - Standards and Protocols

EGADS Algorithm Handbook

Version 0.2.0

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Contents

Chapter 1

Introduction

This document contains descriptions of algorithms contained in the EGADS toolbox. Within each algorithm description is the following:

- **Algorithm Name** – name of algorithm as implemented in EGADS .
- **Category** – general category of algorithm. Algorithm can be found in this subdirectory in EGADS .
- **Summary** – short description of what the algorithm does.
- **Inputs** – expected inputs to algorithm. This field includes expected units, and data type of input.
- **Outputs** – outputs produced by algorithm.
- **Formula** – description of formulas or methods behind the algorithm.
- **Source** – person, institution or entity who provided the algorithm.
- **References** – any references to literature, journals or documents with more information on the current algorithm

To aid in algorithm usage, there is a general naming scheme for EGADS algorithms. Generally, algorithm names are composed as follows: `{general calculation}_{specific calculation}_{` So, for example, an algorithm provided by CNRM to calculate the density of dry air would be named `density_dry_air_cnrm`.

Chapter 2

Thermodynamics

2.1 Pressure altitude

Algorithm name: altitude_pressure_cnrm

Category: Thermodynamics

Summary: Calculates pressure altitude using virtual temperature.

Inputs:

T_v	Vector	Virtual temperature [K or °C]
P_s	Vector	Static pressure [hPa]
$P_{surface}$	Coeff	Surface pressure [hPa]
R_a/g	Coeff	Gas constant of air over acceleration of gravity

Outputs:

Alt_p	Vector	Pressure altitude [m]

Formula:

$$Alt_p = \frac{R_a}{g} T_v \log\left(\frac{P_{surface}}{P_s}\right)$$

Source: CNRM/GMEI/TRAMM

References:

2.2 Density of dry air

Algorithm name: density_dry_air_cnrm

Category: Thermodynamics

Summary: Calculates density of dry air given static temperature and pressure.

Inputs:

P_s	Vector	Static pressure [hPa]
T_s	Vector	Static temperature [K or °C]

Outputs:

ρ	Vector	Density of dry air [kg/m^3]

Formula:

$$\rho = \frac{100 P_s}{R_a T_s}$$

with $R_a = 287.05$ J kg$^-1$ K$^-1$

Density of humid air can be calculated using this same algorithm by using virtual temperature instead of static temperature.

Source: CNRM/GMEI/TRAMM

References: Equation d'état d'un gaz parfait, Triplet-Roche [?], page 34.

2.3 Relative humidity from capacitive probe

Algorithm name: hum_rel_capacitive_cnrm

Category: Thermodynamics

Summary: Calculates relative humidity using the measured frequency from a capacitive probe.

Inputs:

$Ucapf$	Vector	Output frequency of the capacitive probe [Hz]
T_s	Vector	Static temperature [K]
P_s	Vector	Static pressure [hPa]
ΔP	Vector	Dynamic pressure [hPa]
C_t	Coeff.	Temperature correction coefficient [%°C]
F_{min}	Coeff.	Minimal acceptable frequency [Hz]
C_0	Coeff.	0th degree calibration coefficient
C_1	Coeff.	1st degree calibration coefficient
C_2	Coeff.	2nd degree calibration coefficient

Outputs:

H_u	Vector	Relative humidity [%]

Formula: If $Ucapf \leq F_{min}$ then $Ucapf = F_{min}$

$$H_u = \frac{P_s}{P_s + \Delta P}\left[C_0 + C_1 Ucapf + C_2 Ucapf^2 + C_t(T_s - 20)\right]$$

with T_s in $°C$.

Source: CNRM/GMEI/TRAMM

References: H. Bellec and G. Duverneuil. Appareils de mesure de l'hygrométrie sur le Merlin IV. Note de Centre 9, Météo-France CNRM/CAM, July 1996.

2.4 Pressure and angle of incidence

Algorithm name: pressure_angle_incidence_cnrm

Category: Thermodynamics

Summary: Calculates static pressure and dynamic pressure by correction of static error. Angle of attack and sideslip are calculated from the horizontal and vertical differential pressures.

Inputs:

P_{sr}	Vector	Raw static pressure [hPa]
ΔP_r	Vector	Raw dynamic pressure [hPa]
ΔP_h	Vector	Horizontal differential pressure [hPa]
ΔP_v	Vector	Vertical differential pressure [hPa]
C_α	Coeff.[2]	Angle of attack calibration coefficients
C_β	Coeff.[2]	Slip calibration coefficients
$C_{errstat}$	Coeff.[4]	Static error coefficients

Outputs:

P_s	Vector	Static Pressure [hPa]
ΔP	Vector	Dynamic pressure corrected with static error [hPa]
α	Vector	Angle of attack [rad]
β	Vector	Sideslip [rad]

Formula: If $\Delta P_r > 25\text{hPa}$:

$$Errstat = C_{errstat}[0] + C_{errstat}[1]\Delta P_r + C_{errstat}[2]\Delta P_r^2 + C_{errstat}[3]\Delta P_r^3$$

otherwise:

$$\begin{aligned} Errstat &= \frac{\Delta P_r}{25}\,\text{Errstat @ 25 hPa} \\ P_s &= P_{sr} - Errstat \\ \Delta P &= \Delta P_r + Errstat \\ \alpha &= C_\alpha[0] + C_\alpha[1]\frac{\Delta P_v}{\Delta P} \\ \beta &= C_\beta[0] + C_\beta[1]\frac{\Delta P_h}{\Delta P} \end{aligned} \tag{2.1}$$

Source: CNRM/GMEI/TRAMM

References:

2.5 Potential Temperature

Algorithm name: temp_potential_cnrm

Category: Thermodynamics

Summary: Calculates potential temperature.

Inputs:

T_s	Vector	Static temperature [K or ◦C]
P_s	Vector	Static pressure [hPa]
R_a/c_{pa}	Coeff.	Gas constant of air divided by specific heat of air at constant pressure

Outputs:

θ	Vector	Potential temperature [same unit as T_s]

Formula:

$$\theta = T_s \left(\frac{1000}{P_s} \right)^{R_a/c_{pa}}$$

Source: CNRM/GMEI/TRAMM

References: Triplet-Roche [**?**].

2.6 Equivalent Potential Temperature

Algorithm name: temp_potential_equiv_cnrm

Category: Thermodynamics

Summary: Calculates equivalent potential temperature of air. The equivalent potential temperature is the temperature a parcel of air would reach if all water vapor in the parcel condensed, and the parcel was brought adiabatially to 1000 hPa.

Inputs:

T_s	Vector	Static temperature [K or ◦C]
θ	Vector	Potential temperature [K or ◦C]
r	Vector	Vater vapor mixing ratio [g/kg]
c_{pa}	Coeff.	Specific heat of dry air at constant pressure

Outputs:

θ_e	Vector	Equivalent potential temperature [same units as T_s]

Formula:

$$\theta_e = \theta \left(1 + r \frac{L}{c_{pa} T_s} \right)$$

where $L = 3136.17 - 2.34 T_s$ (for T_s in K)

Source: CNRM/GMEI/TRAMM

References: From the CAM routine which is identical to the algorithm P. Durand cited in the formula book created for PYREX.

2.7 Static Temperature

Algorithm name: temp_static_cnrm

Category: Thermodynamics

Summary: Calculates static temperature of the air from total temperature. This method applies to probe types such as the Rosemount.

Inputs:

T_t	Vector	Measured total temperature [K]
ΔP	Vector	Dynamic pressure [hPa]
P_s	Vector	Static pressure [hPa]
r_f	Coeff.	Probe recovery coefficient
R_a/c_{pa}	Coeff.	Gas constant of air divided by specific heat of air at constant pressure

Outputs:

T_s	Vector	Static temperature [K]

Formula:

$$T_s = \frac{T_t}{1 + r_f\left(\left(1 + \frac{\Delta P}{P_s}\right)^{R_a/c_{pa}} - 1\right)}$$

Source: CNRM/GMEI/TRAMM

References:

2.8 Virtual Temperature

Algorithm name: temp_virtual_cnrm

Category: Thermodynamics

Summary: Calculates the virtual temperature of air.

Inputs:

T_s	Vector	Static temperature [K or ∘C]
r	Vector	Water vapor mixing ratio [g/kg]

Outputs:

T_v	Vector	Virtual temperature [same units as T_s]

Formula:

$$T_v = T_s \frac{1 + (R_v/R_a)r}{1 + r}$$

where $R_v/R_a = 1.608$

Source: CNRM/GMEI/TRAMM

References: Triplet-Roche [?], page 56.

2.9 True air speed

Algorithm name: velocity_tas_cnrm

Category: Thermodynamics

Summary: Calculates true air speed based on static pressure, static temperature and dynamic pressure using the Barré-St Venant formula.

Inputs:

T_s	Vector	Static temperature [K]
ΔP	Vector	Dynamic pressure [hPa]
P_s	Vector	Static pressure [hPa]
c_{pa}	Coeff.	Specific heat of air at constant pressure (for dry air 1004 J K^{-1} kg^{-1})
R_a/c_{pa}	Coeff.	Gas constant of air divided by specific heat of air at constant pressure

Outputs:

V_t	Vector	True air speed [m/s]

Formula:

$$V_p^2 = 2c_{pa}T_s\left[\left(1+\frac{\Delta P}{P_s}\right)^{R_a/c_{pa}} - 1\right]$$

Source: CNRM/GMEI/TRAMM

References: NCAR-RAF Bulletin #23 [?], *Méchanique des fluides*, Candel [?]

2.10 Longitudinal true airspeed

Algorithm name: velocity_tas_longitudinal_cnrm

Category: Thermodynamics

Summary: Calculates the true air speed along the longitudinal axis of the aircraft.

Inputs:

V_t	Vector	True air speed [m/s]
α	Vector	Angle of attack [rad]
β	Vector	Sideslip angle [rad]

Outputs:

V_{tx}	Vector	Longitudinal true air speed [m/s]

Formula:

$$V_{tx} = \frac{V_t}{\sqrt{1 + \tan^2 \alpha + \tan^2 \beta}}$$

Source: CNRM/GMEI/TRAMM

References: NCAR-RAF Bulletin #23 [?]

Chapter 3

Microphysics

3.1 Mean diameter

Algorithm name: diameter_mean_raf

Category: Microphysics

Summary: Calculates the arithmetic average of all particle diameters given in a particle size distribution.

Inputs:

n_i	Array[time, bins]	Number of particles in each channel i
d_i	Vector[bins]	Channel i size [μm]

Outputs:

$\bar{D}$	Vector[time]	Mean diameter [μm]

Formula:

$$\bar{D} = \frac{\sum_i n_i d_i}{N_t}$$

where N_t is the total number of particles.

Source: NCAR-RAF

References: NCAR-RAF Bulletin No. 24 – http://www.eol.ucar.edu/raf/Bulletins/bulletin24.html

3.2 Total Number Concentration

Algorithm name: number_conc_total_raf

Category: Microphysics

Summary: Calculation of total number concentration for a particle probe.

Inputs:

n_i	Array	Number of particles in each channel i
SV	Array	Sample volume [m^3]

Outputs:

N_t	Vector	Total number concentration [m^{-3}]

Formula:

$$N_t = \frac{\sum_i n_i}{SV}$$

Source: NCAR-RAF

References: NCAR-RAF Bulletin No. 24 – http://www.eol.ucar.edu/raf/Bulletins/bulletin24.html

3.3 Sample area for imaging probes

Algorithm name: sample_area_oap_all_in_raf

Category: Microphysics

Summary: Calculation of 'all in' sample area size for OAP probes such as the 2DC, 2DP, CIP, etc. This sample area varies by number of shadowed diodes. This routine calculates a sample area per bin.

Inputs:

λ	Coeff.	Laser wavelength [nm]
D_{arms}	Coeff.	Distance between probe arm tips [mm]
dD	Coeff.	Diode diameter [μm]
M	Coeff.	Probe magnification factor
N	Coeff.	Number of diodes in array

Outputs:

SA	Vector	Sample area [m^2]

Formula:

$$\begin{aligned} DOF_i &= \frac{6R_i^2}{\lambda} \\ R_i &= i\frac{dD}{2} \\ X &= 1...N \end{aligned} \tag{3.1}$$

where DOF must be less than D_{arms}. The parameter i ranges from 1 to N.

$$ESW_i = \frac{dD(N - X_i - 1)}{M}$$

A value for ESW_i (effective sample width) is calculated for each X.

$$SA_i = (DOF_i)(ESW_i)$$

Source: NCAR-RAF

References: NCAR-RAF Bulletin No. 24 – http://www.eol.ucar.edu/raf/Bulletins/bulletin24.html

3.4 Sample area for imaging probes

Algorithm name: sample_area_oap_center_in_raf

Category: Microphysics

Summary: Calculation of 'center in' sample area size for OAP probes such as the 2DC, 2DP, CIP, etc. This sample area varies by number of shadowed diodes. This routine is intended to calculate a sample area per bin.

Inputs:

λ	Coeff.	Laser wavelength [nm]
D_{arms}	Coeff.	Distance between probe arm tips [mm]
dD	Coeff.	Diode diameter [μm]
M	Coeff.	Probe magnification factor
N	Coeff.	Number of diodes in array

Outputs:

SA	Vector	Sample area [m^2]

Formula:

$$DOF_i = \frac{6R_i^2}{\lambda} \tag{3.2}$$
$$R_i = X\frac{dD}{2}$$
$$X = 1...N$$

where DOF must be less than D_{arms}. The parameter i ranges from 1 to N.

$$ESW = NdD$$

$$SA_i = (DOF_i)(ESW)$$

Source: NCAR-RAF

References: NCAR-RAF Bulletin No. 24 – http://www.eol.ucar.edu/raf/Bulletins/bulletin24.html

3.5 Sample area for scattering probes

Algorithm name: sample_area_scattering_raf

Category: Microphysics

Summary: Calculation of sample area for scattering probes such as the FSSP, CAS, etc.

Inputs:

DOF	Coeff.	Depth of field [m]
BD	Coeff.	Beam diameter [m]

Outputs:

SA	Coeff.	Sample area [m^2]

Formula:

$$SA = (DOF)(BD)$$

Source: NCAR-RAF

References: NCAR-RAF Bulletin No. 24 – http://www.eol.ucar.edu/raf/Bulletins/bulletin24.html

3.6 Sample Volume

Algorithm name: sample_volume_general_raf

Category: Microphysics

Summary: Calculates sample volume for microphysics probes (1D, 2D, FSSP, etc).

Inputs:

V_t	Vector	True air speed [m/s]
SA	Coeff.	Sample area of probe [m^2]
t_s	Coeff.	Sample rate [s]

Outputs:

SV	Vector	Sample volume [m^3]

Formula:

$$SV = V_t t_s SA$$

Source: NCAR-RAF

References: NCAR-RAF Bulletin No. 24 – http://www.eol.ucar.edu/raf/Bulletins/bulletin24.html

Chapter 4

Biophysics

4.1 NDVI

Algorithm name: biophys_indices (NDVI is one index calculated within the overall program)

Category: Biophysics - broad band VIS

Summary: Calculation of Normalised Difference Vegetation index (NDVI)

Inputs: Multi- or hyperspectral imagery (ENVI standard image data) including channels close to the wavelengths of 671nm and 864nm.

Outputs: Single band with NDVI values

Formula:

$$\frac{R_{864} - R_{671}}{R_{864} + R_{671}}$$

Source: DLR-DFD

References: Rouse, J. W., Haas, R. H., Schell, J. A. and Deering, J. A. (1973). Monitoring vegetation systems in the great plains with erts. In: Proceedings of the Third Symposium on Significant Results Obtained with ERTS Vol. 1, p. 309317

4.2 RVI

Algorithm name: biophys_indices (RVI is one index calculated within the overall program)

Category: Biophysics - broad band VIS

Summary: Calculation of Ratio Vegetation index (RVI)

Inputs: Multi- or hyperspectral imagery (ENVI standard image data) including channels close to the wavelengths of 671nm and 864nm.

Outputs: Single band with RVI values

Formula:

$$\frac{R_{864}}{R_{671}}$$

Source: DLR-DFD

References: Pearson, R. L., and L. D. Miller, 1972, Remote mapping of standing crop biomass for estimation of the productivity of the short-grass Prairie, Pawnee National Grassland, Colorado: 8th international symposium on remote sensing of environment, p. 1357-1381

4.3 MCARI

Algorithm name: biophys_indices (MCARI is one index calculated within the overall program)

Category: Biophysics - narrow band chlorophyll indices

Summary: Calculation of Modified Chlorophyll absorption in Reflectance Index (MCARI)

Inputs: Narrow band multi- or hyperspectral imagery (ENVI standard image data) including channels close to the wavelengths of 550nm, 670nm and 701nm.

Outputs: Single band with MCARI values

Formula:

$$MCARI = ((R_{701} - R_{670}) - 0.2 * (R_{701} - R_{550})) * \frac{R_{701}}{R_{670}}$$

Source: DLR-DFD

References: Daughtry, C.S.T., Walthall, C.L., Kim, M.S., Brown de Colstoun, E., McMurtrey, J.E. III (2000): Estimating corn leaf chlorophyll concentration from leaf and canopy reflectance. In: Remote Sensing of Environment, 74, p.229-239.

4.4 CAI

Algorithm name: biophys_indices (CAI is one index calculated within the overall program)

Category: Biophysics - dry vegetation (stress) indices

Summary: Calculation of Cellulose Absorption Index (CAI)

Inputs: Narrow band multi- or hyperspectral imagery (ENVI standard image data) including channels close to the wavelengths of 2000nm, 2100nm and 2200nm.

Outputs: Single band with CAI values

Formula:

$$CAI = 0.5 * (\rho_{2000} + \rho_{2200}) - \rho_{2100}$$

Source: DLR-DFD

References: Nagler, P.L., Daughtry, C.S.T., Goward, S.N. (2000): Plant Litter and Soil Reflectance. In: Remote Sensing of Environment, 71, P.207-215.

4.5 PRI

Algorithm name: biophys_indices (PRI is one index calculated within the overall program)

Category: Biophysics - narrow band chlorophyll indices

Summary: Calculation of Photochemical Reflectance Index (PRI), also Carotenoid/chlorophyll

Inputs: Narrow band multi- or hyperspectral imagery (ENVI standard image data) including channels close to the wavelengths of 529nm and 569nm.

Outputs: Single band with PRI values

Formula:

$$PRI = \frac{\rho_{529} - \rho_{569}}{\rho_{529} + \rho_{569}}$$

Source: DLR-DFD

References: Sims, D.A., Gamon, J.A. (2002): Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. In: Remote Sensing of Environment, 81, p.337-354.

4.6 mND705

Algorithm name: biophys_indices (PRI is one index calculated within the overall program)

Category: Biophysics - narrow band chlorophyll indices

Summary: Calculation of Chlorophyll-Index mND705 // hyperbolic regression

Inputs: Narrow band multi- or hyperspectral imagery (ENVI standard image data) including channels close to the wavelengths of 445nm, 705nm and 750nm.

Outputs: Single band with PRI values

Formula:

$$mND705 = \frac{\rho_{750} - \rho_{705}}{\rho_{750} + \rho_{705} - 2 * \rho_{445}}$$

Source: DLR-DFD

References: Sims, D.A., Gamon, J.A. (2002): Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. In: Remote Sensing of Environment, 81, p.337-354.

4.7 DGVI1

Algorithm name: biophys_indices (DGVI1 is one index calculated within the overall program)

Category: Biophysics - red edge parametrisation

Summary: Calculation of Derivative-based Green Vegetation Index (DGVI). Surface under curve of first derivative between 680nm and 760nm.

Inputs: Narrow band multi- or hyperspectral imagery (ENVI standard image data) including channels close to the wavelengths of 627nm and 793nm.

Outputs: Single band with PRI values

Formula:

$$DGVI1 = \int_{\lambda_1=627nm}^{\lambda_2=793nm} \frac{d\rho}{d\lambda}$$

Source: DLR-DFD

References: Elvidge, C.D., Chen, Z.(1995): Comparison of Broad-Band and Narrow-Band Red and Near-Infrared Vegetation indices. In: Remote Sensing of Environment, 54, p.38-48.

Chapter 5

Quality Control

5.1 Check navigation data for inconsistencies

Algorithm name: nav_chk

Category: Quality Control

Summary: Tests navigation file (position and attitude) for inconsistencies and corrects them. The code is based on a HyMap *gps File.

Inputs: *.gps file plus the number of image lines according to the ENVI header of the related image data. The *.gps file is a multi-column ASCII file derived by HyVista Corp. proprietary software, which synchronises times and generates an output which is indexed by scan line number. The table below shows the list of parameters.

Parameters	Example	Description
Line	1	Scan line number
UTC Time	48835.0462/20/5/2004	Time of day in seconds/day/month/year
VME Time	929386852.0	Internal computer tick time in microseconds
IMU Time	2048825953.1	Internal IMU time in microseconds
Latitude	48.03321015	Decimal degrees (positive = north, negative = south)
Longitude	11.28140200	Decimal degrees (positive = east, negative = west)
Altitude	2970.79892155	Meters above MSL
Pitch	0.22235917	Decimal degrees (positive = nose up)
Roll	0.54269902	Decimal degrees (positive = right wing up)
Heading	0.37774316	Decimal degrees (positive = N-E-S direction, negative = N-W-S direction)
True Track	1.00507651	Decimal degrees (0 to 360)
Ground Speed	72.90907700	Meters / second
Sat	5	Number of satellites being received
DGPS	1	DGPS status: 1 = DGPS being received 0 = no DGPS received

Outputs: status file → template+'_status'
If applicable: corrected gps file
backup of original .gps → filename.gps_original

Formula: test & correct the following

- point or colon - separator in .gps =¿ error catched in hymap_read_gps.pro corrected when re-writing the .gps-file anyway

- #lines in image = #lines in gps
  if too many gps-lines: truncate lines at beginning (like Hyvista does)
  if too few gps-lines: adding extrapolated lines at end
- invalid start / end time: calculating average timestep & using last relieable line
- data gaps (indicated by identical time): interpolate info

Source: DLR-DFD

References: EUFAR FP7 - DJ2.2.2 - Quality Layers for VITO, DLR, INTA and PML

5.2 Additional consistency check & QA for navigation data (no correction!)

Algorithm name: nav_const

Category: Quality Control

Summary: Tests navigation file (position and attitude) for consistency. The code is based on a HyMap *gps File.
This check can be performed after nav_chk.pro.

Inputs: *.gps file. The *.gps file is a multi-column ASCII file derived by HyVista Corp. proprietary software, which synchronises times and generates an output which is indexed by scan line number. The table below shows the list of parameters.

Parameters	Example	Description
Line	1	Scan line number
UTC Time	48835.0462/20/5/2004	Time of day in seconds/day/month/year
VME Time	929386852.0	Internal computer tick time in microseconds
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Altitude	2970.79892155	Meters above MSL
Pitch	0.22235917	Decimal degrees (positive = nose up)
Roll	0.54269902	Decimal degrees (positive = right wing up)
Heading	0.37774316	Decimal degrees (positive = N-E-S direction, negative = N-W-S direction)
True Track	1.00507651	Decimal degrees (0 to 360)
Ground Speed	72.90907700	Meters / second
Sat	5	Number of satellites being received
DGPS	1	DGPS status: 1 = DGPS being received 0 = no DGPS received

Outputs: if (KEYWORD_SET(gps_err_array)) → QC array
otime, lat, lon, alt, pit, rol, heading, track, speed, sat, dgps
Values: 0:OK 1:minor problem 2:major problem
if (KEYWORD_SET(gps_data)) → gps data as array
otime, lat, lon, alt, pit, rol, heading, track, speed, sat, dgps

Formula: test & report the following

- if data range is not plausible

- if change between steps > threshold:
  latlon, alt, pit, rol, heading, track, speed
- uncorrectable errors in:
  time, latlon, alt, pit, rol, heading, track, speed, sat, dgps

Source: DLR-DFD

References: EUFAR FP7 - DJ2.2.2 - Quality Layers for VITO, DLR, INTA and PML

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