# Documentation for LMDZ, Planets version

## Venus and Titan post-processing tools

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# 1 Context

## 1.1 Why these tools ?

Once you run the Venus or Titan LMDZ GCM, you'll get some variables in the output files that you may want to transform. These tools are meant to do some of this post-processing, to get angular momentum budget, meridional stream function, or to make an FFT analysis of $U$, $V$ or $T$, for example.
Here, we present these tools and how to compile and use them.
The computation of the mass in each cell is part of these tools. In the case of Titan, $g$ is considered as constant with altitude. When this changes in the GCM, we will need to adapt the tools.

## 1.2 Compiling

The script you can use is compile_pgf. You need to adapt it so that it will find the netcdf libraries. It uses pgf95, but you can adapt it by changing the compiler. The first argument is the tool you want to compile, the second argument is the planet you're working on:
compile_pgf <tool> <planet>
where <tool> may be angmom, psi, etc, and <planet> may be venus or titan.
For the FFT decomposition, you need the fftw3 library. I leave it to you to find it (em http://www.fftw.org/; some linux packages can also be found on the web) and install it if you don't have it already. The script to use is then compilefft_pgf and you need to adapt it so that it finds the fftw3 library.
The executable is named <tool>-<planet>.e.

# 2 Tools

When zonal averages are done, it is better to regrid the GCM outputs on a fixed pressure grid with zrecast.F90, so that averages are really done on pressure levels. The altitude above the aeroid $z_a$ is computed by zrecast.F90 and may be used for Titan to get $g(r)$. For the moment, this is commented in all tools, so that $z_a$ is not in the required input files.

## 2.1 zrecast.F90

This tool was adapted from a version initially developed for the Martian GCM. It now takes as input the Venus and Titan LMDZ GCM output files.
This program reads 4D (lon-lat-alt-time) fields from GCM output files (e.g. histmth.nc time series) and, by integrating the hydrostatic equation, recasts data along the vertical direction.
The vertical coordinate can be either "pressure", "above areoid altitudes" or "above surface altitudes". Some interpolation along the vertical direction is also done, following instructions given by user.
The dataset must include the following data:

- surface pressure
- atmospheric temperature

- hybrid coordinates aps() and bps(), or sigma levels
- ground geopotential
- When integration the hydrostatic equation, we assume that $R$, the molecular Gas Constant, may not be constant, so it is computed as $R = P/(\rho \times T)$ ($P$=Pressure, $\rho$=density, $T$=temperature). If $\rho$ is not available, then we use a constant $R$.

The output file is labeled with _P (just before .nc) when recast on fixed pressure levels, _A when recast on fixed "above areoid" altitudes, or _S when recast on fixed "above surface" altitudes. In _P files, you'll find the variable zareoid while in _A and _S files, you'll find the variable pressure.
In the Titan file, the solar longitude (Ls) is also present in the output file, as a 1D (time only) variable.
You may find here some examples of zrecast.input that can be used (after changing the file name in the first line !) as direct input for zrecast.e:
zrecast.e < zrecast.input

## 2.2 angmom.F90

This program reads 4D (lon-lat-alt-time) fields directly from LMD outputs histmth.nc (and dynzon.nc if this file is present), but also from files recast in $\log P$ coordinates (histmth_P.nc).
It computes:

- dmass – 4D – mass of each cell (kg)
- osam – 4D – specific angular momentum (omega term)
- rsam – 4D – specific angular momentum (zonal wind term)
- oaam – 1D – integrated angular momentum (omega term)
- raam – 1D – integrated angular momentum (zonal wind term)
- tmou – 1D – Mountain torque
- tbls – 1D – Surface friction torque if duvdf is present
- tdyn – 1D – Dynamics torque if dudyn is present
- tgwo – 1D – Orographic GW torque if dugwo is present
- tgwno – 1D – Non-Orographic GW torque if dugwno is present

Specific angular momentum is in $10^{25}$ m$^2$s$^{-1}$, integrated angular momentum is in $10^{25}$ kg m$^2$s$^{-1}$, torques are in $10^{18}$ kg m$^2$s$^{-2}$.
If dynzon.nc is present, it also computes

- tdyndz – 1D – Dynamics torque
- tdisdz – 1D – Horizontal dissipation torque
- tspgdz – 1D – Sponge layer torque
- tphydz – 1D – Total physics torque

The dataset must include the following data:

- surface pressure and surface geopotential
- zonal wind
- Optional: dudyn, duvdf, dugwo, dugwno (acceleration terms from dycore and physiq parametrisations)
- Optional, in dynzon.nc: dmcdyn, dmcdis, dmcspg, dmcphy (angular momentum tendency terms from dycore, horizontal dissipation, sponge layer and physiq parametrisations)

The output file is labeled with _GAM (just before .nc).
The details about how these variables are computed can be found in *Lebonnois et al.* (2010, 2013).

## 2.3 psi.F90

This program reads 4D (lon-lat-alt-time) fields directly from LMD outputs histmth.nc, but also from files recast in $\log P$ coordinates (histmth_P.nc).
It computes:

- dmass – 4D – mass of each cell (kg)
- psi – 3D – Stream function (kg/s)

The dataset must include the following data:

- surface pressure
- meridional wind

The output file is labeled with _PSI (just before .nc).

**Computation of $\psi$** The meridional mass flux is computed in each cell

$$v_m = v \times \Delta m/(r\Delta lat)$$

then integrated over longitude, then downwards to compute $\psi$. Given the longitudinal integration, it should be better to use the recast _P files.

## 2.4 energy.F90

This program reads 4D (lon-lat-alt-time) fields directly from LMD outputs histmth.nc, but also from files recast in $\log P$ coordinates (histmth_P.nc).
It computes:

- dmass – 4D – mass of each cell (kg)
- sek – 4D – Specific kinetic energy (note that vertical component of wind is neglected)
- sep – 4D – Specific potential energy
- ek – 1D – Integrated kinetic energy (note that vertical component of wind is neglected)
- ep – 1D – Integrated potential energy

Specific energies are in J/kg, integrated energies are in J.
The dataset must include the following data:

- surface pressure
- atmospheric temperature
- zonal and meridional winds

The output file is labeled with _NRG (just before .nc).

## 2.5 stability.F90

This program reads 4D (lon-lat-alt-time) fields from LMD files recast in $\log P$ coordinates (histmth_P.nc).
It computes:

- stab – 4D – stability (K/km)
- Ri – 4D – Richardson number
- deqc – 3D – distance to cyclostrophic equilibrium (%)

The dataset must include the following data:

- surface pressure
- meridional wind

The output file is labeled with _STA (just before .nc).

## 2.6 tem.F90

This program reads 4D (lon-lat-alt-time) fields from LMD files recast in log $P$ coordinates (histmth_P.nc).
Developed from the tool built by Audrey Crespin during her PhD.
It computes TransEulerianMean variables:

- vtem – 3D – Residual meridional speed (m s$^{-1}$)
- wtem – 3D – Residual vertical speed (Pa s$^{-1}$)
- psitem – 3D – Residual stream function (kg s$^{-1}$)
- epfy – 3D – meridional component of Eliassen-Palm flux
- epfz – 3D – vertical component of Eliassen-Palm flux
- divepf – 3D – Divergence of Eliassen-Palm flux
- ammctem – 3D – Acc due to residual MMC

The dataset must include the following data:

- surface pressure
- atmospheric temperature
- zonal, meridional and vertical (Pa/s) winds

The computation is mostly done in the epflux.F90 routine (I need to put additional details here... TBD...).
The output file is labeled with _TEM (just before .nc).

## 2.7 tmc.F90

This program reads 4D (lon-lat-alt-time) fields from LMD files recast in log $P$ coordinates (histmth_P.nc).
It computes angular momentum transport from high-frequency outputs:

- totvang – 2D – Meridional transport of angular momentum, total (m$^3$ s$^{-2}$)
- totwang – 2D – Vertical transport of angular momentum, total (m$^3$ s$^{-2}$)
- mmcvang – 2D – Meridional transport of angular momentum, by MMC (m$^3$ s$^{-2}$)
- mmcwang – 2D – Vertical transport of angular momentum, by MMC (m$^3$ s$^{-2}$)
- trsvang – 2D – Meridional transport of angular momentum, transients (m$^3$ s$^{-2}$)
- trswang – 2D – Vertical transport of angular momentum, transients (m$^3$ s$^{-2}$)
- stnvang – 2D – Meridional transport of angular momentum, stationaries (m$^3$ s$^{-2}$)
- stnwang – 2D – Vertical transport of angular momentum, stationaries (m$^3$ s$^{-2}$)
- dmass – 2D – Averaged mass in each cell

These variables in the meridional plane (latitude-pressure).
The dataset must include the following data:

- surface pressure
- zonal, meridional and vertical (Pa/s) winds

Notations:

- $\overline{u}$: zonal average of $u$
- $u^* = u - \overline{u}$

- $< u >$: time average of $u$
- $u' = u - < u >$
- $m$: specific angular momentum

Computations (here with meridional wind $v$, same with vertical wind $w$):

- Total angular momentum transport: $\overline{< mv >}$
- MMC angular momentum transport: $\overline{< m >}\,\overline{< v >}$
- Transients angular momentum transport: $< m'v' >$
- Stationaries angular momentum transport: $< m^* >< v^* >$

The output file is labeled with _TMC (just before .nc).

## 2.8 fft.F90

This program reads 4D (lon-lat-alt-time) fields from LMD files recast in log $P$ coordinates (histmth_P.nc). It computes the FFT (on the time axis) of temperature, zonal and merid winds from high-frequency outputs, and it separates the variable in three different bands. You choose the frequencies for the filters and their bandwidth in the file filter.h before compiling. You can also choose what variables you want to analyse by tuning the *ok_out* parameter.
Choosing *ok_out(1)=.true.*, you'll get in _UFFT (see below) :

- fftau – 4D – FFT in amplitude of zonal wind (m s$^{-1}$)
- ulf – 4D – low freq part of zonal wind perturbation uprim (m s$^{-1}$)
- ubf – 4D – band freq part of zonal wind perturbation uprim (m s$^{-1}$)
- uhf – 4D – high freq part of zonal wind perturbation uprim (m s$^{-1}$)

Same for the other elements of *ok_out*, for the meridional wind $v$ (m s$^{-1}$), the vertical wind $w$ (Pa s$^{-1}$), and the temperature $T$ (K).
The dataset must include the following data:

- atmospheric temperature
- zonal, meridional and vertical (Pa/s) winds

We use a triangle window to improve spectral analysis. Once the FFT is done, we filter to get three different regions of the spectrum, then we use the reverse FFT to get the filtered variables (e.g. for $u$: $ulf$ for the frequencies below *fcoup1*, $uhf$ for the frequencies above *fcoup2* and $ubf$ for the frequencies in between).
The output files are labeled with _[U,V,W,F]FFT (just before .nc). You get one file for each variable that you chose to analyse in filter.h (U,V,W and/or T).

# References


Lebonnois, S., F. Hourdin, V. Eymet, A. Crespin, R. Fournier, and F. Forget (2010), Superrotation of Venus' atmosphere analysed with a full General Circulation Model, *J. Geophys. Res.*, *115*, E06006, doi:10.1029/2009JE003458.

Lebonnois, S., C. Covey, A. Grossman, H. Parish, G. Schubert, R. Walterscheid, P. Lauritzen, and C. Jablonowski (2013), Angular Momentum Budget in General Circulation Models of Superrotating Atmospheres: A Critical Diagnostic, *J. Geophys. Res.*, Submitted.