LMDZ outputs

LMDZ Training, january 2026

Outline

- Introduction
- «history» files
- «restart» files
- «control printing and error messages» file / specific output files

Abderrahmane IDELKADI

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Introduction

LMDZ outputs include

- «**history**» files : they gather instantaneous or averaged diagnostic variables
- «**restart**» files : used to extend or to restart a simulation
- «**control printing**» file : collects all control and error messages

Netcdf / IOIPSL / XIOS libraries

- LMDZ «history» and «restart» files are in **NetCDF** format and written using either :
  - directly the **NetCDF** library or
  - **IOIPSL**/**XIOS** libraries : developed at *IPSL* for model I/Os using the NetCDF library
- **« restart »** files of dynamics and phisics modules are **written using directly NetCDF**
- «**history**» output files
  - are written by using **IOIPSL**/**XIOS** libraries
  - For « history » files, the output of variables consists in 2 steps:
    - **definition of the variables to output** (during initialisation of the run)
    - **computation and writing of the variables** (during the simulation)

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Introduction

IOIPSL / XIOS libraries

LMDZ «history» output files are written by using **IOIPSL/XIOS** libraries

- **IOIPSL** library :
  - older and easy to use (outputs controlled in def files)
  - not parallelized ⇒ with IOIPSL : each process writes its own history files in its domain. Then, global file is reconstructed from these various files by using the ***rebuild*** utility distributed with the IOIPSL library.
  - limited in the mathematical operations on the output variables, canot output variables with more than 3D, …

- **XIOS**: XML–IO–SERVER
  - Based on **client–server principle** ⇒ IO server manages the outputs so that the climate code does not waste time on its outputs, it just sends them to the IO server ⇒ code not slowed down by outputs
  - All aspects of the outputs (name, units, post-processing frequencies, operations, …) are **controlled by external xml files** ⇒ no recompilation of code necessary when changing IO definitions
  - Don’t need rebuilding the global file in parallel mode
  - Lots of functionalities with more mathematical transformations : reading files, filters and transformations, on-the-fly interpolation to a particular grid, on-the-fly timeseries output
  - But to use XIOS, needs to install additional libraries (mpi, boost, blitz)

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«history» outputs of the physics module

Generalities

- **10 « history » output files :**
  managed according to a scheme witch allows to control individually the output of the variables in **10 files**

  - **5 basic files that are used most often** :
    monthly/daily/high frequency - averege/instantanous

  - **5 output files with particular uses** :
    - *histstn.nc* ⇒ *fields for a number of grid points (*data sites was requested by CMIP)
    - 3 files : *histmthNMC.nc, histdayNMC.nc, histhfNMC.nc (was requested by CMIP)* ⇒ *outputs interpolated on 17 standard levels pressures (in hPa):*
      1000., 925., 850., 700., .600., 500., 400., 300., 250., 200., 150., 100., 70., 50., 30., 20., 10.
    - *histstrataer.nc* ⇒ Outputs of stratospheric aerosols

- Output variables :
  - **2D** fields are written on the **horizontal grid** of the model (longitude, latitude)
  - **3D** fields are written on a the **horizontal** and **verticale grid** :
    - 2D (longitude,latitude)
    - vertical level : the **hybrid coordinate system is used for the verticale in LMDZ**
      ⇒ **More detail in « Dynamics » presentation (Ehouarn)**

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Control of output files and variables

- types of keys
  - **- Flags to control the activation of the output of files / change the name of files and variables**
  - **- Flags controlling how many and which variables are written to each output file**
  - **- Flags controlling time frequencie/mathematical operation used to write in output file**
  - **- Flags to activate and define the output on a limited domain**

- Keys controlled
  - - with **IOIPSL** in **def** files (**config.def** or **output.def)**
  - - with **XIOS** in **xml** files (**field_lmdz.xml, file_hist*_lmdz.xml**)

➔ Sample def and xml files are in DefLists directory :

../modipsl/modeles/LMDZ/**DefLists**

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Control of activation of output of files / change the name of output files and variables

- 3 flags :
  - flag used to activate or not the output of files
  - flag used to change the name for each of output files
  - flag used to change the name of the output variable in each output file

- In practice, how to control these keys ?
  - With IOIPSL in **config.def or output.def:**

```
phys_out_filekeys  =   y        y        n       y        n
phys_out_filenames =  histmth   histday  histhf  histins  histLES
name_tsol          =  ts_mth    ts_day   ts_hf   ts_ins   tsol
```

  - With XIOS in file_histhf_lmdz.xml

```
<file_definition>
  <file_group id="defile">
    <file id="histhf" name="histhf" output_freq="3h" output_level="2" enabled="TRUE">
        <field_group operation="average" …
                <field field_ref="tsol" name="ts_hf" level="1" />
                        …
```

- Default values in the code (.../LMDZ/libf//phylmd/**phys_output_mod.F90**) :
  - *File names : histmth histday histhf6h histhf3h histhf3hm histstn histmthNMC histdayNMC histhfNMC histstrataer*
  - *Activate/not : y n n n n n n n n n*
  - Default names of variables are defined in **:** .../LMDZ/libf//phylmd/**phys_output_mod.F90**

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Controlling of how many and which variables to write in the output files

- **Principle :**
  - For each output file **fileN.nc** (N from 1 to 10) ⇒ an output level **file_level(N)**, which is an integer :

    phys_out_filelevels = file_level(1) … **file_level(N)** … file_level(10)

  - For each output variable **Var** ⇒ an output level **flag_Var(N)** associated with **fileN.nc**, which is an integer :

    flag_Var = flag_Var(N) … **flag_Var(N)** … flag_Var(10)

    ⇒ If **flag_Var(N) ≤ file_level(N)** then variable **Var will be defined and written** to the file **fileN.nc**

- In practice, how to control these keys ?
  - With IOIPSL in **config.def or output.def:**

phys_out_filekeys =	y	y	n	y	n
phys_out_filenames =	histmth	histday	histhf	histins	histLES
phys_out_filelevels =	**5**	**1**	**1**	**1**	**1**
flag_tsol =	**1**	**2**	**3**	**4**	**5**

  - With XIOS in **file_histday_lmdz.xml** :

```
<file_definition>
  …
    <file id="histday" ... output_freq="1d" output_level="2">
        <field field_ref="tsol" level="2" />
```

- Default values in the code (.../LMDZ/libf//phylmd/**phys_output_mod.F90**) :
  - ***file_level(1:10)*** **:** ***2 1 1 1 1 1 5 5 5 5***
  - ***tsol_levels(1:10)*** **:** ***1 1 1 5 10 10 11 11 11 11***

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Control of time frequencie and mathematical operation used to write in output files

- 2 flags :
  - Flag controlling the **time frequencies** of output files : (mounthly, daily, hourly, physical time step)
  - Flag to control **mathematical operations** used to archive variables : (instantaneous, average , min, max)

- In practice, how to control these keys ?
  - With IOIPSL in **config.def or output.def:**

```
phys_out_filekeys       =   y        y        n        y        n
phys_out_filenames      =   histmth  histday  histhf   histins  histLES
phys_out_filetimesteps  =   1mth     1day     6h       3h       1TS
phys_out_filetypes      =   ave(X)   ave(X)   ave(X)   inst(X)  inst(X)
```

  - With XIOS in file_histmth_lmdz.xml :

```
<file_definition>
   <file_group id="defile">
     <file id="histmth" output_freq="1m" output_level="2" …
       <field_group operation="average" ...
```

- Default values in the code (.../LMDZ/libf/phylmd/**phys_output_mod.F90**) :
  - ***output time frequency :*** *1month 1day 3hours 30mn 3hours 30mn 1month 1day 6hours 1month*
  - ***archive operation :*** *ave(X) ave(X) inst(X) inst(X) ave(X) inst(X) inst(X) inst(X) inst(X) ave(X)*

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«history» outputs of the physics module

Control of output on a limited domain

- Flags : { - Flag to activate or note the output on limited domain for each file
  - Flage Flags to define the limited horizontal domain for each file
  - Flag to define the limited vertical axis for each file

- In practice, how to control these keys ?
  - **With IOIPSL in config.def/outputs.def:**

phys_out_filekeys	=	y	y	y	y	n
phys_out_filenames	=	histmth	histday	histhf	histins	histLES

    - to activate or note the output on limited domain for each file :

phys_out_regfkey	**=**	**n**	**n**	**y**	**n**	**n**

    - to define the limited horizontal domain for each file :

phys_out_lonmin	**=**	**-180**	**-180**	**0**	**-180**	**-180**
phys_out_lonmax	**=**	**+180**	**+180**	**90**	**+180**	**+180**
phys_out_latmin	**=**	**-90**	**-90**	**-30**	**-90**	**-90**
phys_out_latmax	**=**	**+90**	**+90**	**+40**	**+90**	**+90**

    - to define the limited vertical axis for each file :

phys_out_levmin	**=**	**1**	**1**	**1**	**1**	**1**
phys_out_levmax	**=**	**39**	**39**	**3**	**39**	**39**

  - **With XIOS in context_lmdz.xml**

```
<domain_definition>
  <domain id="dom_glo" data_dim="2" />
  <domain id="dom_MyRegion"  domain_ref="dom_glo">
    <zoom_domain id="dom_MyRegion" ibegin="12" jbegin="14" ni="8" nj="10" />
  </domain>
</domain_definition>
```

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«history» outputs of the physics module :

In practice, with IOIPSL:

In **config.def** file :

 # Activate or not the output of the file ⇒ y (yes), n (no)

phys_out_filekeys = y y n y n

 # Name of files :

phys_out_filenames = histmth histday histhf6h histhf histins

Q1 : Which files will be written here?

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«history» outputs of the physics module :

In practice, with IOIPSL:

In **config.def** :

 # Activate or not the output of the file ⇒ y (yes), n (no)

phys_out_filekeys = y y n y n

 # Name of files :

phys_out_filenames = histmth histday histhf6h histhf histins

 # *Time frequency* ⇒ *mth/mo/mois/..* (month), *day/jour/j/..* (day), *hour/heure/h/..* (hour), *TS/ts* (time step of physics), ...

phys_out_filetimesteps = 1mth 1day 6hr 3hr 1TS

 # Archive operation ⇒ *inst(X)* (instantaneous), *ave(X)* (average), *t_min(X)* (min), *t_max(X)* (max)

phys_out_filetypes = ave(X) ave(X) ave(X) inst(X) inst(X)

Q2 : For each file to be written, can you give me the time frequency and the mathematical operation used to output the variables?

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«history» outputs of the physics module :

In practice, with IOIPSL:

In **config.def** or **output.def**, file ⇒ we can change the control keys of output files :

 # Activate or not the output of the file ⇒ y (yes), n (no)

phys_out_filekeys = y y n y n

 # Name of files :

phys_out_filenames = histmth histday histhf6h histhf histins

 # Output level of files ⇒ *0*, *1*, … (integer)

phys_out_filelevels = 5 2 2 1 1

 # writing of variable in output files : *0*, *1*, … (integer)

flag_tsol = 2 3 7 10 10

Q3 : In wich output files tsol will be written here ?

Q4 : If you want to output tsol in histday.nc file how to do it ?

«history» outputs of the physics module:

In practice with IOIPSL:

Control the output of variables on a limited domain :

```
phys_out_filekeys    =    n          y          n          n
phys_out_filenames   =  histmth    histday    histhf     histins
```

```
# Activate or note the output on a limited domain
phys_out_regfkey =        n          y          y          n
```

```
# Longitude min and max of domain
phys_out_lonmin =      -180         -5        -180       -180
phys_out_lonmax =      +180        +10        +180       +180
# Latitude min and max of domain
phys_out_latmin =       -90        +40         -90        -90
phys_out_latmax =       +90        +53         +90        +90
```

```
#   Vertical level min and max
phys_out_levmin  =        1          1          1          1
phys_out_levmax =        39          5         39         39
```

Q1 : In this case, for which output file will we activate the outputs on a limited domain ?
On which horizontal and vertical grids?

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«history» outputs of the physics module

In practice with XIOS

- Need to
  - Download XIOS from : http://forge.ipsl.jussieu.fr/ioserver/XIOS
  - Compile LMDZ with XIOS : ***makelmdz*** / ***makelmdz_fcm*** with options : **-io xios** (only XIOS), **-io mix** (both IOIPSL and XIOS), **-io ioipsl** : only IOIP)
  - To put : **ok_all_xml = y** in run.def / config.def file to get xml to control everything
- **Xml file :** one file, at least must be present (model will crash if this file is absent) ⇒ **iodef.xml**

```
<simulation>
        <context  id="xios">
            <variable_definition>
            <variable_group id="buffer">
            buffer_size = 85000000
            buffer_server_factor_size = 2
            </variable_group>
            <variable_group id="parameters" >
                <variable id="using_server" type="bool">true</variable>
                <variable id="info_level" type="int">0</variable>
            </variable_group>
            </variable_definition>
        </context>
        <context id="LMDZ" src="./context_lmdz.xml"/>
</simulation>
```

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In practice With XIOS

- **XML files ⇒ context_lmdz.xml :**

```
<context id="LMDZ">
    <!-- Define available variables -->
     <field_definition src="./field_def_lmdz.xml"/>

    <!-- Define output files. Each file contains the list of variables and their output levels -->
    <file_definition src="./file_def_histday_lmdz.xml"/>

    <!-- Define domains and groups of domains -->
    <domain_definition>
        <domain id="dom_regular" ni_glo="144" nj_glo="143" type="rectilinear"  >
                <generate_rectilinear_domain lat_start="-90" lat_end="90" lon_start="0"/>
                <interpolate_domain order="1"/>
        </domain>
          ...
    </domain_definition>

    <!-- Define groups of vertical axes -->
    <axis_definition>
          <axis id="time_month" n_glo="12" value="(0,11) [1 2 3 4 5 6 7 8 9 10 11 12]"/>
          …
    </axis_definition>

    <grid_definition>
          <grid id="grid_glo">
                <domain domain_ref="dom_glo" />
          </grid>
          …
    </grid_definition>
</context>
```

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In practice with XIOS

- **Xml files ⇒ field_def_lmdz.xml**

```
<definitionfield_definition level="1" prec="4" operation="average" freq_op="1ts" enabled=".true."
default_value="9.96921e+36">

   <field_group id="fields_2D" domain_ref="dom_glo">
      <field id="phis"    long_name="Surface geop.height"     unit="m2/s2" />
      <field id="ffonte"    long_name="Thermal flux for snow melting"    unit="W/m2" />
      ...
   </field_group>
   <field_group id="fields_3D" domain_ref="dom_glo" axis_ref="presnivs">
      <field id="tke"    long_name="TKE"    unit="m2/s2" />
      ...
   </field_group>

   <field_group  id="fields_NMC" domain_ref="dom_glo" axis_ref="plev">
     <field id="ta" long_name="Air temperature" unit="K" />
     ...
   </field_group>
     ...
   <field_group id="fields_COSP_CALIPSO" domain_ref="dom_glo" freq_op="3h">
     <field id="cllcalipso"    long_name="Lidar Lowlevel Cloud Fraction"   unit="1" />
     ...
   </field_group>
</field_definition>
```

«history» outputs of the physics module

In practice with XIOS

- **XML files** ⇒ file_def_**histday_lmdz.xml** :

```
<file_definition>
   <file_group id="defile">
      <file id="histday" name="histday" output_freq="1d" output_level="2" enabled="TRUE">
         <! VARS 2D >
         <field_group operation="average" freq_op="1ts">
            <field field_ref="phis" level="1" />
            ...
            <field field_ref="ffonte" level="10" />
            ...
            <field_group operation="average" freq_op="1ts" detect_missing_value=".true.">
               <field field_ref="u850" level="7" />
               ...
            </field_group>
         </field_group>
         <! VARS 3D >
         <field_group operation="average" freq_op="1ts" axis_ref="presnivs">
            <field field_ref="cldtau" level="5" />
         </field_group>
      </file>
   </file_group>
</file_definition>
```

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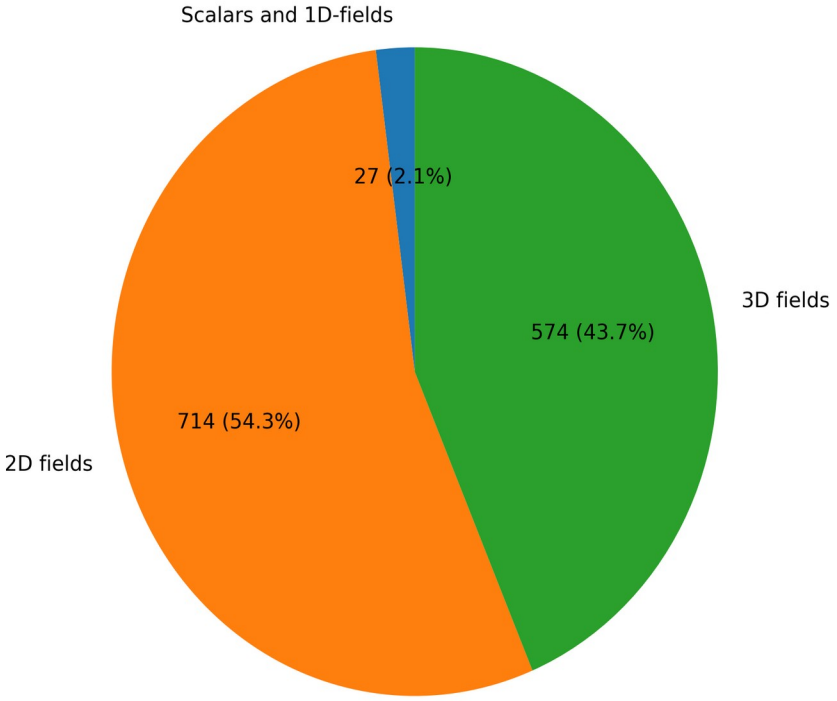
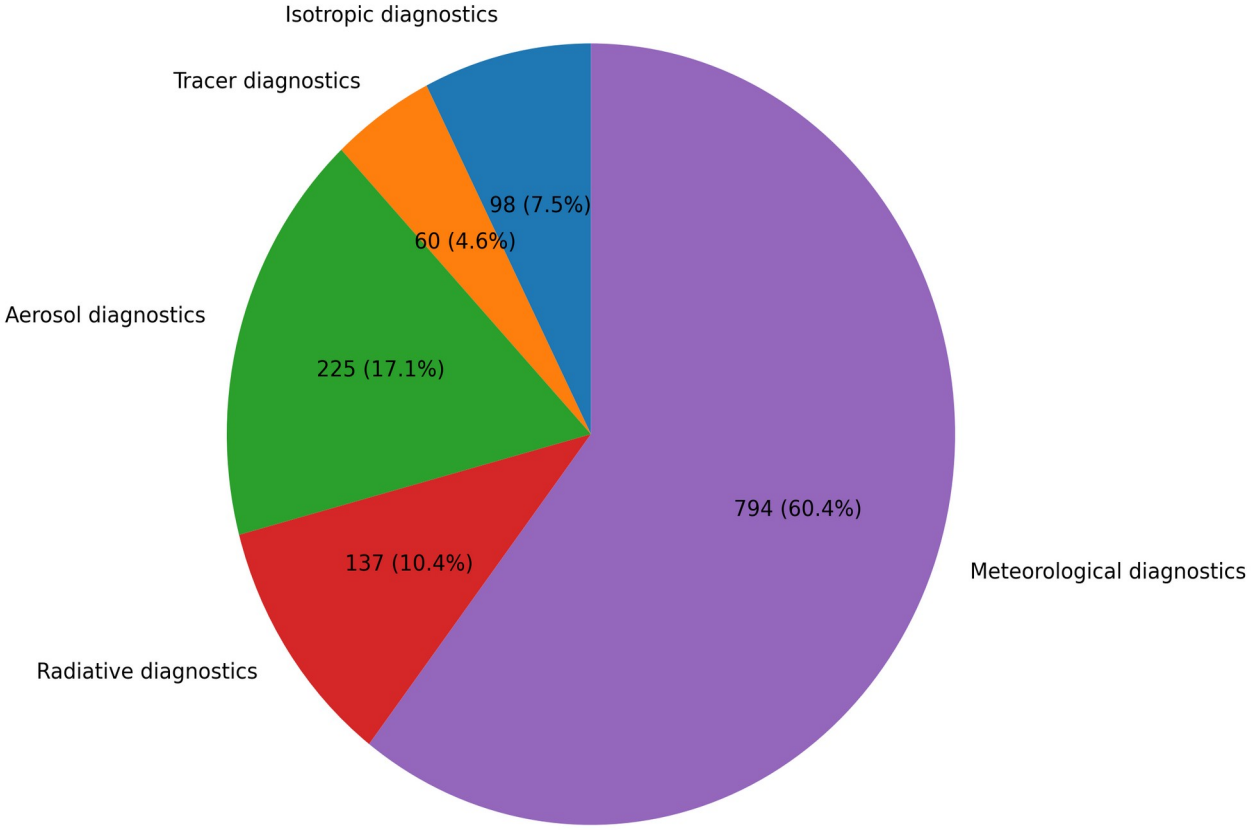
«history» outputs of the physics module:

Approximate number of output variables (LMDZ svn5855) ~ 1314 fields





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«history» outputs of the physics module:

How to add a new output variable ?

- 2 routines need to be modified
  - **libf/phylmd/phys_output_ctrlout.F90 :** declaration of output level, name, description, unit, archiving operation of variable
  - **libf/phylmd/phys_output_write.F90 :** write the new variable in each file

- Example for «**my_newvar**» variable :
  - Declaration of variable in **…LMDZ//libf/phylmd/phys_output_ctrlout.F90**

```
type(ctrl_out), save :: o_my_newvar   =   ctrl_out((/ 1,1,1,5,10,11,11,11,11,11/), &
                                           'my_newvar','My New field', 'K',  &
                                           (/ 'ave(X)', 'ave(X)', 'ave(X)', ave(X), inst(X), &
                                           'inst(X)','inst(X)','inst(X)','inst(X)','ave(X)' /))
```

  - Write a new variable in **…/LMDZ/libf/phylmd/phys_output_write.F90**

```
call histwrite_phy(o_t2m_min, znewvar)
```

znwvar : variable calculated in the code that corresponds to my_new_var

  - To add variable to the XIOS output files ⇒ **you also need to add them to the xml files** (necessarily in field_lmdz.xml)

«Restart» files :

- "restarts" files contain the final state of the simulation ⇒
  used **to extend this simulation or to restart an other new one**

- The dynamical and physical modules each write their own restart file (**restart.nc** and **restartphy.nc**).
  These files save the state variables that the model needs at each time step so that :
  the model can be restarted without losing continuity (in practical terms this is known as «**1+1=2**»)

- Routines involved in this process are :
  - for the dynamical module :
    - **…/LMDZ//libf/dyn3d/dynredem.F90** / **…/LMDZ/libf/dyn3dmem/dynredem_mod.F90**
    - **…/LMDZ//libf/dyn3d/dynetat0.F90** / **…/LMDZ/libf/dyn3dmem/dynetat0_loc.F90**

  - for the physics module :
    - **…/LMDZ//libf/phylmd/phyredem.F90** / **…/LMDZ/libf/phylmd/phyredem.F90**
    - **…/LMDZ//libf/phylmd/phyetat0.F90** /**…/LMDZ//libf/phylmd/phyetat0_mod.F90**

- These routines do not use the **IOIPSL** library and are interfaced directly with the **NetCDF** library.

files of control printing and error messages:

- **Controlling output messages :**

  - Most of control outputs and messages are written to standard output (the screen) by the use of commands such as:

    print*, or **write(*,*) 'ma variable =', ...**

  - A cleaner mechanism exists to output these messages to a file rather than the screen :

    - to **include in any new routine**, the iniprint.h file ⇒ **#include iniprint.h**

      in iniprint.h are defined 2 parameters
      - **- lunout :** a unit number corresponding to the output file
        (if lunout ≠ 6 ⇒ lmdz.out file is created and assigned to this number)
      - **- prt_level :** an output level

      The **value of these two parameters can then be modified in the run.def** file

    - to use them in the routine you then **just need to add** lines such as :
      IF (prt_level>9) WRITE(lunout,*) 'pas de convection'
      While keeping small values of prt_level for really important messages

Output file of control printing and error messages:

- **What use are they ?**

If the model crashes or does not seem to run properly, these output messages should give you an indication of what's going on.

- The first thing to do is : **grep 'Houston, we have a problem ' output_file**
  As the model will output this string with an indication of the problem it encountered, when the problem has been anticipated by the developers (might be a configuration problem, a temperature that's suddenly out of range, …)

- If the string is not found and no obvious error (**segmentation fault, memory violation, floating point exception**) can be found in the output messages ⇒
  - to recompile the model with the **-debug** option
  - and run it again.
    ⇒ It should now give you an indication of :
    - the line
    - the routine that is causing the crash.
      ⇒ Once found, you can :
      - start debugging the routine or
      - call for help with some vital information.

Output specific files :

- **«history» file for the dynamics module :**
  only consists of the variables of state (U, V, T, Q, Ps) at two frequencies : instantaneous and averaged.

- **«history» output files of COSP** (CFMIP Observation Simulator Package) :
  3 output files (monthly, daily and HF) with a lot of cloud diagnostics

- **Output files with variables in the GrADS format :**
  to help with the debugging of the code, there is also a mechanism which writes the variables in the GrADS format by using directly NetCDF library

- **Files with all the control parameters used for the simulation :**
  a mechanism to write files with all the control parameters effectivly read and used for the simulation : used_run.def, used_config.def, used_physiq.def, ...

- **CMIP6 IPSL workflow :**
  with XIOS, LMDZ outputs files containing single timeseries of requested variables of CMIP

- **Alert messages in output of control printing file or in file ALERTES.txt :**
  We have introduced a routine called prt_alerte_mod.F90 to print informative alert messages ⇒ see for information: https://lmdz-forge.lmd.jussieu.fr/mediawiki/LMDZPedia/index.php/HowTo:_Print_alert_messages

Output specific files :

« history » output files of COSP

- COSP : CFMIP Observation Simulator Package
  - simulator : a diagnostic code that computes pseudosatellite observations from model variables in order to compare them to real satellite observations
  - Cosp implemented in LMDZ to evaluate the representation of cloud process in the models **(https://lmdz.lmd.jussieu.fr/Members/aidelkadi/cosp)**

  - COSP has simulators for these satellite cloud products:
    ISCCP, CALIPSO, CLOUDSAT, PARASOL, MISR, MODIS

- 2 versions of COSP implemented in LMDZ model :
  - ***cospv1*** (used for CMIP6 exercise)
  - ***cospv2*** (new version of cosp with more diagnostics)

  - Cosp routines in directory :
    - **Cospv1** : .../LMDZ/libf/***phylmd/cosp***
    - **Cospv2** : ***.../LMDZ/libf/phylmd/cospv2***

      Cosp output routines :

      cospv1: cosp_output_mod.F90 and cosp_output_write_mod.F90
      cospv2: lmdz_cosp_output_mod.F90 and lmdz_cosp_output_write_mod.F90

- To run LMDZ simulation with COSP simulator :
  - Compile LMDZ model with option : makelmdz/makelmdz_fcm **-cosp none/v1/v2** ….
  - Activate COSP in LMDZ simulation : **ok_cosp=y** in config.def file
  - ***cosp_input.txt*** and ***cosp_output.txt*** : Cosp namelist files to control input and output of simulators

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Output specific files :

« history » output files of COSP

The same philosophy, as described before for *LMDZ history files,* is used with IOIPSL and XIOS:

- 3 outputs files for COSP: ***histmthCOSP.nc, histdayCOSP.nc, histhfCOSP.nc***
  Lot of cloud diagnostics : low, mid, hight level, total, vertical distribution of cloud fraction, …

- The control keys of files and variables :
  - **With IOIPSL library:**

cosp_outfilenames =	***histmthCOSP.nc***	***histdayCOSP.nc***	***histhfCOSP.nc***
cosp_outfilekeys =	**y**	**y**	**n**
cosp_ecritfiles =	**1mth**	**1day**	**3h**
cosp_outfiletypes =	**ave(X)**	**ave(X)**	**inst(X)**
cles_cllcalipso =	**y**	**y**	**n**
name_cllcalipso =	**LowCldMth**	**LowCldDay**	**LowCldHf**

  - **With XIOS library:**
    Variables defined in XML file: **field_def_cosp1.xml / field_def_cospv2.xml**
    Output files defined in XML files:
    file_def_histmthCOSP_lmdz.xml / file_def_histmthCOSPv2_lmdz.xml
    file_def_histdayCOSP_lmdz.xml / file_def_histmthCOSPv2_lmdz.xml
    file_def_histhfCOSP_lmdz.xml / file_def_histhfCOSPv2_lmdz.xml

- **Number of Cosp output variables (approx.) : +70(cospv1) +110(cospv2)**