Titan General Circulation Model

Laboratoire de Météorologie Dynamique
Service d'Aéronomie

Institut Pierre-Simon Laplace

TITAN ATMOSPHERE DATABASE
User's Guide

Database: Version 1.0

GUI: Version 1.0

Pascal Rannou
Sébastien Lebonnois
Frédéric Hourdin
David Luz
Jean-Baptiste Madeleine

January 17, 2006

Contents

1 Introduction

We have developed in the last decade a two dimensional version of the LMD Titan General Circulation Model (Hourdin et al., 1995). This model accounts for multiple coupling occuring on Titan between dynamics, haze, chemistry and radiative transfer. It was successful at explaining many observed features related to atmosphere state (wind, temperature), haze structure and chemical species distributions (Rannou et al., 2002, 2004; Lebonnois et al., 2001; Hourdin et al., 2004). An important step in our knowledge about Titan has now been taken with the Cassini mission and Huygens descent on Titan. In this context, we want to make the results of our model available for the scientific community which is involved in the study of Titan. Such a tool should also be useful for interpreting ground based telescope observations.

2 Atmospheric model

2.1 Characteristics

The characteristics of the GCM configuration used for the building of the version 1.0 of the database are described here (see also Rannou et al. (2005)).

The model grid is based on 49 latitude points regularly spread from north pole to south pole (3.75 degrees intervals), with 55 vertical layers (Table 1), of which the last three serve as a sponge layer to dump down the wind and prevent spurious reflexion of waves. Level 52 is approximately 480 km above the surface. The vertical resolution is about 3 km in the troposphere, 5 km at the tropopause and 10-15 km in the stratosphere, which correspond to one half to one third of a scale height. The surface pressure is set to 1.429 bar.

The dynamical equations are integrated with a time step of 3 minutes. While our model is a two dimensional circulation model, some three dimensional features must be accounted for. Hourdin et al. (1995) have shown that interaction between barotropic eddies and the mean circulation contributes to transport momentum (which contributes to maintain supperrotation) and other physical quantities. Luz and Hourdin (2003), Luz et al. (2003) have carefully studied transport by these eddies with a shallow water model and have proposed simple parameterizations for the two dimensional version which significantly improves the results.

Physical parameterizations (radiative transfer, haze microphysics) are computed ten times per Titan day. Gaseous infrared cooling rates are still computed from prescribed uniform descriptions of CH_4, H_2, C_2H_2 and C_2H_6, as described in Hourdin et al. (1995).

Haze is also not yet coupled with the photochemistry (source function of haze, condensation), and is treated as described in Rannou et al. (2004).

Chemistry includes 44 species with 343 reactions, and is computed once per Titan day, with diurnal mean used for photodissociation rates.

Hydrogen recombination at the surface of haze particles (Lebonnois et al., 2003) is

Table 1: Sigma (pressure/surface pressure) levels at the bottom of the 55 layers of the GCM

1 = 1.	21 = 3.8504500E-02	41 = 1.1447493E-04
2 = 0.9914345	22 = 2.9118838E-02	42 = 8.5298823E-05
3 = 0.9747803	23 = 2.1956168E-02	43 = 6.3561754E-05
4 = 0.9457894	24 = 1.6515372E-02	44 = 4.7366539E-05
5 = 0.9020025	25 = 1.2398265E-02	45 = 3.5299545E-05
6 = 0.8431745	26 = 9.2925178E-03	46 = 2.6307378E-05
7 = 0.7712567	27 = 6.9556511E-03	47 = 1.9604786E-05
8 = 0.6899117	28 = 5.2009565E-03	48 = 1.4605718E-05
9 = 0.6037201	29 = 3.8856156E-03	49 = 1.0871382E-05
10 = 0.5173233	30 = 2.9009616E-03	50 = 8.0704231E-06
11 = 0.4347296	31 = 2.1646656E-03	51 = 5.9471772E-06
12 = 0.3589053	32 = 1.6145692E-03	52 = 4.2948582E-06
13 = 0.2916572	33 = 1.2038737E-03	53 = 2.9343585E-06
14 = 0.2337385	34 = 8.9742360E-04	54 = 1.7186045E-06
15 = 0.1850762	35 = 6.6885859E-04	55 = 6.3567296E-07
16 = 0.1450357	36 = 4.9844151E-04	
17 = 0.1126611	37 = 3.7141205E-04	
18 = 8.6864494E-02	38 = 2.7674198E-04	
19 = 6.6557929E-02	39 = 2.0619774E-04	
20 = 5.0733529E-02	40 = 1.5363596E-04	

taken into account. Haze production parameterization (Lebonnois et al., 2002) is not yet included.

At the upper boundary, the exchange flux between the upper atmosphere and the upper layer of the GCM is fixed for chemical species. These fluxes are calculated using a 1-dimensional model of Titan's atmosphere in equatorial conditions (Lebonnois et al., 2002, 2003). As a first approximation, these fluxes are fixed, both in time and as a function of latitude. At the lower boundary, methane mole fraction is fixed at the surface and at the tropopause. To simulate condensation, chemical species are removed from the atmosphere when their partial pressure exceeds their vapor pressure, which is computed with a fixed vertical temperature profile (Lellouch et al., 1989).

2.2 Available fields

The fields available in the database are presented in Table 2. Other fields of interest may be added in the future if desired.

For information, the aerosols bins are detailed in Table 3.

Table 2: Fields available in the database

Field	Units
Temperature	K
Density	m^{-3}
Zonal winds	m s^{-1}
Meridional winds	m s^{-1}
Vertical winds	m s^{-1}
Geopotential	m^2 s^{-2}
Stream function	kg s^{-1}
Aerosol bins (#1 to #10)	particle/m^3
Haze extinction at 0.575μm	m^{-1}
Haze opacity at 0.575μm	m^{-1}
CH_4, H_2	mole fraction
C_2H_2, C_2H_4, C_2H_6	mole fraction
C_3H_4, C_3H_8, C_4H_2	mole fraction
Benzene, HCN, HC_3N	mole fraction
C_2N_2, CH_3CN	mole fraction

Table 3: Aerosol bins and corresponding radii

Bin #	Bulk Radius(m)	Spherical	Aggregate
1	1.638×10^{-09}	X	
2	4.127×10^{-09}	X	
3	1.040×10^{-08}	X	
4	2.621×10^{-08}	X	
5	6.604×10^{-08}	X	N=1 (= monomer)
6	1.664×10^{-07}		N=16
7	4.193×10^{-07}		N=256
8	1.057×10^{-06}		N=4096
9	2.662×10^{-06}		N=65536
10	6.709×10^{-06}		N=1.0486×10^6

3 Installation

3.1 Files needed

All files are available on the database website

http://www.lmd.jussieu.fr/titanDbase

The atmospheric data is stored in the ASCII file database-1.0.wrk (28 Mo). To use it, two methods are proposed:

- Use the Fortran routines ready to read the database.
- Get and install the Graphical User Interface (GUI) package corresponding to your machine. If you have MATLAB (at least 7.0), you can use the MATLAB routines directly. Otherwise, choose the application package ready for your operating system:

MATLAB, any OS	titandbase-1.0-gui-matlab.tar.gz
Linux	titandbase-1.0-gui.tar.gz (108 Mo)
Solaris	Not yet ready. To be done soon...
Windows	Not yet ready. To be done soon...
Mac OS X	Not yet ready. To be done soon...

For each archive files.tar.gz, you will need to unpack it. For Unix, Linux and Mac OS X users, you can use the command:

```
tar -zxvf files.tar.gz
```

For Windows, use... I don't know. Please anyone tell me.

3.2 Fortran routines

You can get and unpack the archive that includes all provided Fortran routines: fortran-routines.tar.gz

You should get the routines which read and interpolate inside the database (askDbase.f, callDbase.f, readDbase.f), and two examples of calling routines (interface.f, interface3.f). These routines are provided as examples, to help you build your own applications. interface3.f is especially built to compute haze properties, at any wavelengths, from the aerosols distribution obtained from the database (qa01, qa02,...qa10). It needs to work with routines for scattering properties of aerosols (cmie.f, cfffv11.f included in the "package" annexeN7.f). Khare et al. (1984) refractive index are assumed (subroutine tholin() in annexeN7.f). The average haze phase function can also be computed in this routine, but the 'write' statement is commented since it generates a large amount of data.

Example of compilation lines:

```
f77 interface.f askDbase.f callDbase.f readDbase.f -o interface.e
f77 interface3.f askDbase.f callDbase.f readDbase.f annexeN7.f -o interface3.e
```

These routines are - in principle - simple enough to be used with any compilator on any machine.

3.3 Installing the GUI

The archive and the database file should be installed in the same directory, which will further be called "interface directory". You will need to copy the database file to database.wrk.

3.3.1 If you have MATLAB

Unpack the archive. You should get:

- titandbase-1.0.m : the main MATLAB routine, version 1.0.
- askDbase-1.0.mexglx (for Linux)
- askDbase-1.0.mexsol (for Solaris)
- askDbase-1.0.f (fortran to be compiled with `MEX`)

Copy the version-labeled files to unlabeled files (askDbase.mexglx, titandbase.m, etc. . .)

To use the GUI in MATLAB, go into you interface directory. You need the main routine (titandbase.m) and the mex file (askDbase.mex**) corresponding to your platform. If it is not present, and if you have the `mex` command, you can build it by executing

```
mex askDbase.f
```

If you succeed, please send us the corresponding askDbase.mex** file, so that we can add it to the archive for other users that do not have the `mex` command.

Launch MATLAB. Typing `titandbase` within MATLAB launches the GUI.

3.3.2 Linux

Unpack the archive. You should get:

- run_tdb
- titandbase
- titandbase.ctf
- MCR/MCRinstaller.zip

MCRinstaller.zip

In the interface directory, go into the MCR directory and unzip the file MCRinstaller.zip, which creates a whole architecture in a v72 directory.

```
cd MCR
unzip MCRinstaller.zip
```

run_tdb

You have to edit this file to put the right path for the interface directory:

```
INTERFACE="(path to interface directory)"
```

then move it into your $HOME/bin directory, so that you can launch the command from any directory (though any saved files will be stored into your interface directory):

```
mv run_tdb $HOME/bin
```

When you execute the command run_tdb, it initializes needed environnement variables ($MCRROOT, $LD_LIBRARY_PATH, and $XAPPLRESDIR), goes into your interface directory, and launches the GUI titandbase.

Once you have done these two steps, you should not have to do them again when upgrading the database with further versions.

3.3.3 Other systems: Windows, Solaris, Mac OS X

We can adapt the GUI for other systems, such as Solaris, Windows or Mac OS X. It is not yet done, but it is possible. If you are interested in such versions, please contact us. This will tease us to hurry up on this question...

4 Using the Graphical User Interface

4.1 Presentation of the interface

This GUI has been built using MATLAB, and then compiled into a stand-alone application depending on operating system. Launching the application opens the main window (see Fig. 1).

Description of the main features

(When not precised, a click is a left click)

1. **Mode:**

   Choose the number of dimensions for your plot.

2. **Values for the fixed dimensions:**

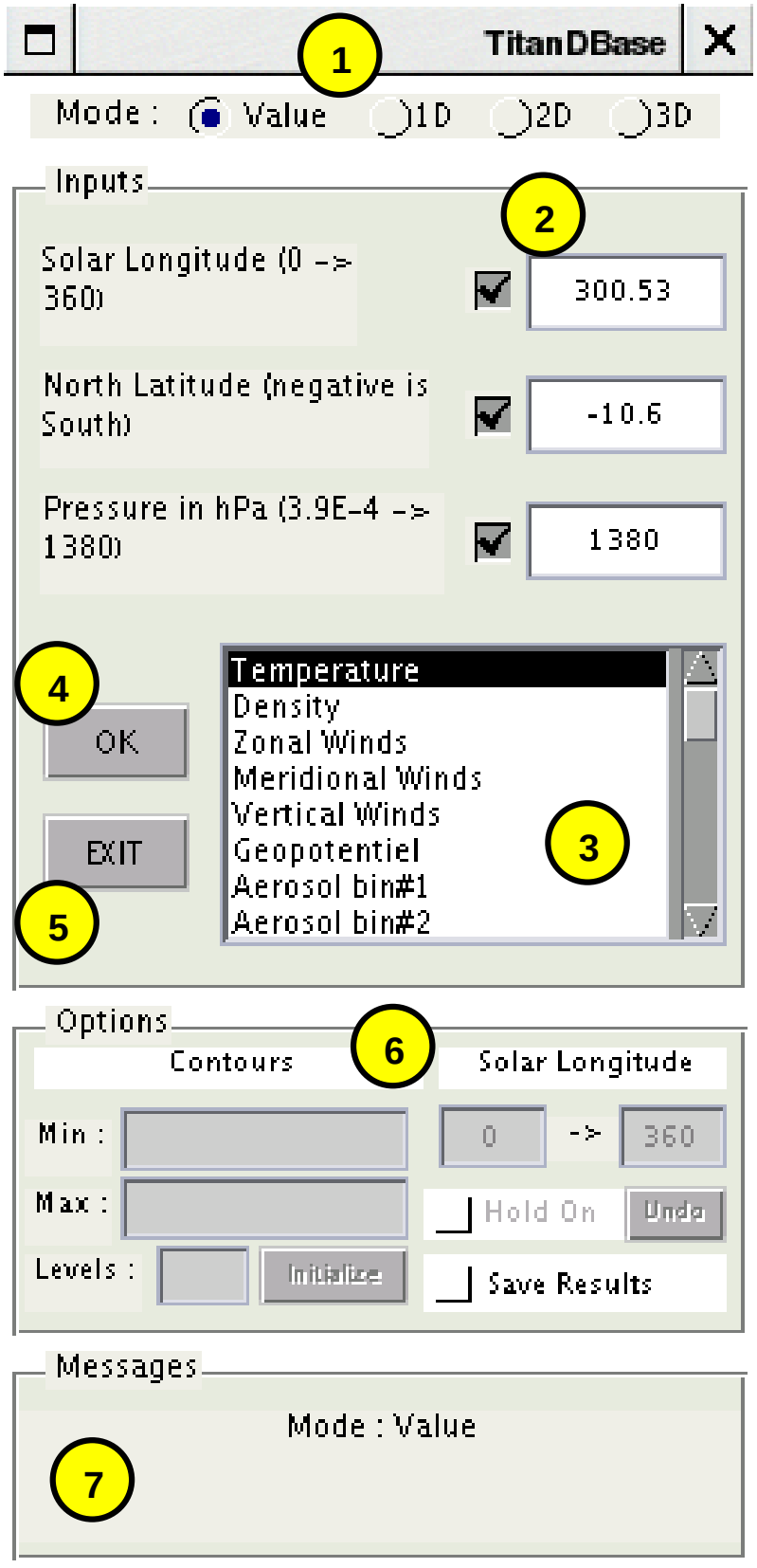

Figure 1: Main window of the GUI

Check the dimensions that will be fixed, and define their values. When unchecked, the value for a varying dimension is appearing as -99, in a grey box.

3. **Variable:**

   Select the variable you want to plot

4. **"OK" button:**

   Each time you click on "OK", a new graphical window is opened, except for the "Value" mode, for which the value of the chosen variable at the defined location appears in the "Messages" window.

5. **"Exit" button:**

   Terminates the application.

6. **Options:**

   (a) Contours (option for 2D and 3D plots)

   After selecting a variable, you can define the minimum and maximum values used for the contours. You can also define the number of contours you want. Clicking on "Initialize" returns to the default values for the chosen variable.

   (b) Solar longitude range (option for 3D plots)

   For 3D plots (i.e. stacks of 2D plots), you have to define here the solar longitude interval you need. The program will make one 2D plot for each database point within this interval.

   (c) "Hold on" and "Undo" (option for 1D plots)

   If you want to overplot different variables (1D plots), you must first check the "Hold on" box. This opens a graphic window with only two axes displayed. Choose a variable and click on "OK" to add it. If you want to suppress the last variable you added, press the "Undo" button. When all the variables you want are displayed, save your graph (see below), then uncheck the "Hold on" box. This will close the graphic window.

   (d) Save results:

   When you want to save the results in files, you need to check this box before plotting the graph.

7. **Messages:**

   Messages appearing here may be important for the correct use of the GUI. Take the time to read them.

   When all three dimensions are fixed ("Value" mode), the resulting value for the chosen inputs is displayed here.

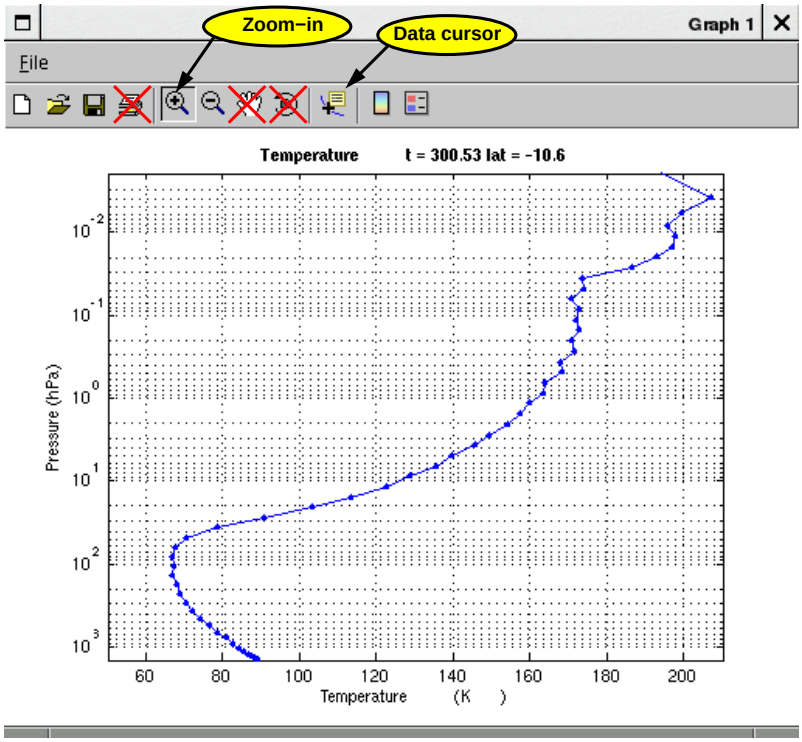

Figure 2: Example of a 1D plot. Avoid the buttons with the red crosses...

4.2 Plotting graphs

4.2.1 1-dimensional plots

Once you clicked "OK", your graph is displayed either in a new window (see Fig. 2), or in the same window if you checked the "Hold on" box (1D plots).

You can zoom on a specific region with the "Zoom in" button: you click on this button, then click and drag the mouse on the region of interest. The axes will adapt automatically. Click on this button again to exit the "zoom in" mode.

You can add datatips by clicking the "Data cursor" button. Once placed, you can drag a datatip when the arrows cross appears as a cursor. Options are reached with a right click. Click on this button again to exit the "data cursor" mode.

You can save your plot in any of the different available formats (eps, jpg, pcx, pbm, pdf, pgm, ai, fig, png, ppm, pkm, tif).

Careful: clicking on the "Pan" button (the hand), or other buttons, terminates the application abruptly...

4.2.2 2-dimensional maps

When clicking on "OK", a 2D map of the chosen variable is displayed with shaded colors and contours (Fig. 3).

Careful ! First thing you should do is putting your mouse on the plot, and either

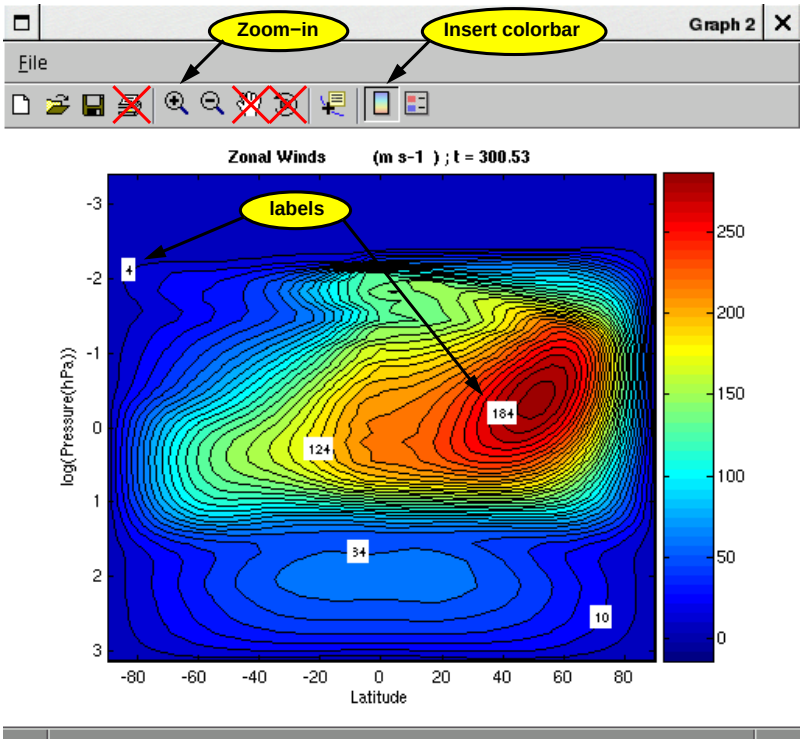

Figure 3: Example of a 2D plot. Avoid the buttons with the red crosses...

click on contours to add labels, or press enter to exit this "labelling" mode.

Once you're done with labels, you can use the "Zoom in" mode, as for 1D plots. You have also the option to choose to show the color bar, or not ("Insert colorbar" button).

Careful: As for the 1D plots, the other buttons terminate the application abruptly...

4.2.3 3-dimensional movies

When all three dimensions are varying, one 2D plot is calculated for each database point in the solar longitude interval chosen (32 points per year, i.e. one point every 11.25° of L_s). The 2D maps are stored, then the full movie is displayed again.

To save the movie, see below.

4.3 Saving values for further use

In order to save your results, you need to check the "Save results" box before plotting the graph. The results are saved in three files, which names have the following construction:
<variable>_<axis1/axis2/field>_<dimensions>.txt
axis1 gives the values of the horizontal grid, axis2 the values of the vertical grid, and field gives the matrix of the variable values, saved in the following way: each line corresponds to one fixed value along axis1.

For a 1D plot, the varying dimension is stored in the axis1 file. The axis2 contains only 1 dummy value, and is not useful.

For 3D movies, you can also check the "Save results" box before displaying the movie. It is then saved in a file <variable>_movie_<Ls range>.avi, in avi format.

Any saved file is stored in your interface directory.

5 Contacts

For questions, comments, suggestions or report for bugs, please contact:

Pascal RANNOU Service d'Aéronomie du CNRS
Université Versailles-St-Quentin
BP3 - 91371 Verrières le Buisson - FRANCE
Tel:(+33/0) 1 64 47 42 16
Fax:(+33/0) 1 69 20 29 99
pra@aero.jussieu.fr

or

Sébastien LEBONNOIS Laboratoire de Météorologie Dynamique
4 Place Jussieu, Box 99
75252 Paris cedex 05 - FRANCE
Tel:(+33/0) 1 44 27 23 14
Fax:(+33/0) 1 44 27 62 72
sllmd@lmd.jussieu.fr

References

Hourdin, F., Lebonnois, S., Luz, D., Rannou, P., 2004. Titan's stratospheric composition driven by condensation and dynamics. J. Geophys. Res. 109 (E12).

Hourdin, F., Talagrand, O., Sadourny, R., Courtin, R., Gautier, D., McKay, C. P., 1995. Numerical simulation of the general circulation of the atmosphere of Titan. Icarus 117, 358–374.

Khare, B. N., Sagan, C., Arakawa, E. T., Suits, F., Callcott, T. A., Williams, M. W., 1984. Optical constants of organic tholins produced in a simulated titanian atmosphere: from soft X-rays to microwaves frequencies. Icarus 60, 127–137.

Lebonnois, S., Bakes, E., McKay, C. P., 2002. Transition from gaseous compounds to aerosols in Titan's atmosphere. Icarus 159, 505–517.

Lebonnois, S., Bakes, E., McKay, C. P., 2003. Atomic and molecular hydrogen budget in Titan's atmosphere. Icarus 161, 474–485.

Lebonnois, S., Toublanc, D., Hourdin, F., Rannou, P., 2001. Seasonal variations in Titan's atmospheric composition. Icarus 152, 384–406.

Lellouch, E., Coustenis, A., Gautier, D., Raulin, F., Dubouloz, N., Frère, C., 1989. Titan's atmosphere and hypothesized ocean: A reanalysis of the Voyager 1 radio-occultation and IRIS 7.7μm data. Icarus 79, 328–349.

Luz, D., Hourdin, F., 2003. Latitudinal transport by barotropic waves in Titan's stratosphere. I. General properties from a horizontal shallow-water model. Icarus 166, 328–342.

Luz, D., Hourdin, F., Rannou, P., Lebonnois, S., 2003. Latitudinal transport by barotropic waves in Titan's stratosphere. II. Results from a coupled dynamics-microphysics-photochemistry GCM. Icarus 166, 343–358.

Rannou, P., Hourdin, F., McKay, C. P., 2002. A wind origin for Titan's haze structure. Nature 418, 853–856.

Rannou, P., Hourdin, F., McKay, C. P., Luz, D., 2004. A coupled dymamics-microphysics model of titan's atmosphere. Icarus 170, 443–462.

Rannou, P., Lebonnois, S., Hourdin, F., Luz, D., 2005. Titan atmosphere database. Adv. Space Res. 36, 2194–2198.