# Proposal for Extension to ESA Contract 11369/95/NL/JG. Martian Environment Models.

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## 1 Introduction

This proposal requests new funding to support an extension to the European Space Agency Contract No. 11369/95/NL/JG, Martian Environment Models, which has been undertaken jointly by Laboratoire de Météorologie Dynamique of CNRS, Paris, France (hereafter LMD), the Atmospheric, Oceanic and Planetary Physics, Department of Physics, University of Oxford, United Kingdom (hereafter AOPP), and the Instituto de Astrofisica de Andalucia (IAA), CISC, Granada, Spain. Under the original contract and its previous extensions, an advanced general circulation model of the Martian atmosphere from 0 to 120 km was developed taking into account preliminary input from the Mars Global Surveyor mission (e.g. accurate topography). and sets of multi-annual simulations were conducted in order to compile a database of climate statistics (version 3.0) for use in future engineering studies.

This proposal seeks further support in order to test, improve and extend the products of the contract so far. The current database will be improved in important respects relating to the extension of the model into the thermosphere up to at least 200 km, the use of new data (mostly coming from the Mars Global Surveyor Spacecraft) to improve and validate the model, plus various other improvements in the software.

The following work packages, in two deliverable stages, are proposed to be added to the existing ESA Contract, No. 11369/95/NL/JG. The packages are proposed to improve and to extend the General Circulation Model and Climate Database developed under that contract. The General Conditions (Part II) of the original contract will continue to apply without further changes.

# 2 Deliverables

## 2.1 Extension of the General Circulation Model into the thermosphere up to at least 200 km

In its current version, the General circulation model is reliable up to about 120 km. Above this level (the homopause) the atmosphere is not well mixed anymore. Lighter species tend to have larger scale heights. In addition, the thermal structure and thus the circulation is controlled by other sources of heat, loss processes and transport mechanisms specific of the highest part of a planetary atmosphere. The largest heat source is the UV and Extreme UV solar radiation absorption (with photodissociation, partial ionization and subsequent reactions that liberate heat). The main direct heat loss in the Martian upper atmospheric layers is radiation to space by non-thermal emission in the 15 microns $CO_2$ band. Radiation transfer is very important in this spectral region, and together with this molecule's near infrared solar absorptions they dominate the energy balance of the upper mesosphere and lower thermosphere of Mars. Transport processes are also known to play relevant roles in the thermosphere. Among these, molecular diffusion is increasingly effective with height, and was mentioned above. Molecular conduction is also very important, and it possibly dominates over eddy mixing at all layers above the homopause. Large scale winds and the wave-mean flow interaction are also expected to be very important.

On this basis, we propose to extend the GCM into the thermosphere with the following steps :

- **Inclusion of hybrid coordinates.**

In the current version, the model vertical coordinate is based on the terrain following sigma-coordinate ($\sigma = p/p_s$). In the upper atmosphere, and especially in the thermosphere, the surface topography may creates artificial gradients. To improve this aspect of the model, we propose to use "hybrid" coordinates ($\sigma$ layers near the

surface merged with pressure levels higher in the atmosphere) as in state-of-the-art Earth General Circulation models. The principal effort will be directed towards modifying the LMD model, though AOPP will also investigate the feasibility of adapting the spectral dynamical code for use with similar hybrid coordinates.

*[LMD to take primary responsibility, with input from AOPP]*

• **New physical parameterization**

We need to develop new parameterizations including:

- UV/EUV absorption and photodissociation, including solar variability,
- Non-LTE emission in the 15 microns $CO_2$ band, including improvements to the parameterization developed in the previous phase of the project for the Martian mesosphere,
- molecular conduction and molecular diffusion
- A simple photochemical model to simulate the evolution of the major species of the neutral atmosphere ($CO_2$, $N_2$, O and if necessary other species to be determined etc.)

In practice, a one dimensional complete model including all radiative transfer processes and chemistry mentioned above will be developed in parallel with the GCM to be used as a reference and to develop computer-efficient parameterizations.

Further studies will also be performed to estimate the impact of some poorly known processes like the energy input from the solar wind or the momentum input from the ionospheric circulation.

*[IAA to take primary responsibility for the development of the reference 1-D energetics-chemistry code ]*

*[LMD and IAA jointly developing the radiative transfer and chemical model parameterization suitable for the GCM ]*

*[LMD to take primary responsibility for other processes and the parameterisation of all processes for the GCM ]*

• **New Atmosphere-Thermosphere General Circulation model and database**

The new physical parameterizations will then be included in a hierarchy of models: 1D and 3D "simple" model, 1D and 3D state-of-the-art model.

The output of the model will be compared with the available observations (analysis of UV airglow and IR emissions available)

The output from the atmosphere-thermosphere general circulation model for various period of the solar 11 year cycle will then be included in a new version of the database

*[LMD to take primary responsibility for the thermosphere model and the database simulations]*

*[IAA to take primary responsibility for the validation tool for the comparison with the available data]*

*[AOPP to take primary responsibility for the update of the database software ]*

## 2.2 Improvement of the database using Mars Global Surveyor and other new observations

Although we have done our best to improve the models' performance from a theoretical point of view in the past years, we are only starting to be able to compare the results with actual observations. Indeed, the large-scale release of Mars Global Surveyor atmospheric data (Thermal infrared sounding and radio occultation) has only started recently. These are the first data from which we can start to really validate our model. In comparison, data from the previous missions, Viking and Mariner 9, were very sparse in both space and time. Obviously, validating and developing our model to reproduce and understand the observed features of the meteorology of Mars should greatly improved it, and allow us to produce a much more accurate and representative database.

• **Model improvements**

Our better understanding of the Martian climate system in the light of the new data will lead us to improve the following parts of the model: 1) radiative transfer parametrizations and dust properties; 2) dust distribution scenarios; 3) inclusion of water ice aerosol (see below); 4) $CO_2$ condensation and sublimation in the polar

caps; 5) wave-mean flow interaction (crucial for Mars' middle atmosphere).

*[LMD to take primary responsibility, with contributions from AOPP]*

**• Reproducing Mars as observed by Mars Global Surveyor using data assimilation**

In terrestrial meteorology and numerical weather prediction (and most recently, in oceanography), observations are regularly analysed by direct *assimilation* into a large-scale circulation model of the atmosphere (or oceans). By this means, an accurate, dynamically self-consistent and continuously updated estimate of the evolving state of the entire global atmosphere is obtained, during which a model prediction is perturbed at regular intervals by the introduction of measurements in order to reduce the model misfit to the data. The atmospheric state recovered is thus optimally consistent (in a statistical sense) with both the available observations (typically noisy and incomplete both parametrically and in space and time) and the physical constraints represented by the dynamical model. This sophisticated technique is widely used on Earth both to initialise daily operational weather prediction systems, and to compile weather/climate databases over periods from days to decades.

A form of this technique has recently been applied by AOPP to the analysis of MGS/TES observations of atmospheric temperature and dust. This approach will continue to be used during the period of this phase of the contract to analyse a substantial portion of the MGS/TES observations during the current mapping phase of the mission. It is anticipated that this will result in a virtually complete record of the synoptic evolution of Mars' atmosphere (from the surface to 40km altitude) for almost a complete Mars year. This record will be used in the present context to define a new climate scenario which will form the baseline scenario for Mars' current atmospheric state and its seasonal evolution and diurnal variability. The definition of this scenario (in terms of atmospheric variables and an evolving distribution of dust loading) will be used by LMD to run the definitive simulations (with the new troposphere/thermosphere model) which will form the basis of v4.0 of the database.

*[AOPP to take primary responsibility]*

• **Inclusion of aerosol statistics in the database**

The knowledge of the characteristic of the aerosol (concentration, size distribution, composition) at a given time and place in the Martian atmosphere can be very useful for mission design scientific studies. To provide such data in the future database, we propose to continue the development of a GCM-dust cycle model. The available Mars Global Surveyor data (TES observations and MOC images) now allow us to constrain such models much more rigorously; model calibration for dust was found to be difficult during the previous phase of the contract because of the lack of observations. This model could also be complemented by a water cycle model which would be used to predict the formation of water ice clouds and haze in the atmosphere. Such models will be calibrated and validated as closely as possible using the relevant Mars Global Surveyor data (TES observations and MOC images).

*[LMD to take primary responsibility with contributions from AOPP]*

## 2.3 Software improvements

• **New GCM and database file format**

The previous versions of the Database files, as well as the General circulation model input-output files, were all written using the Data Retrieval and Storage (DRS) library developed for the Program for (Terrestrial) Climate Model Diagnosis and Intercomparison (PCMDI). In future versions, it seems desirable to adopt a new, more universal format such as NetCDF (network Common Data Form), recently developed by the University Corporation for Atmospheric Research and Unidata. Whereas DRS seems to have been less and less used by other institutions in recent years, the latter format is evidently becoming the new standard for the Earth climate science community. Adoption of this format would allow us to take advantage of the most recent developments in atmospheric science data analysis software. In particular, NetCDF is readily portable to most of the currently available computer systems. This would allow us to run the model on new powerful super-computers (e.g. NEC) which are incompatible with DRS. Above all, this new format would allow us to make the database run on IBM-compatible PCs, which is not currently possible with DRS.

*[LMD to take primary responsibility for the GCM]*

*[AOPP to take primary responsibility for the database software]*

• **High resolution pressure maps**

For re-entry studies and the selection of landing sites, space agencies need high resolution, accurate maps of the atmospheric pressure at the surface of Mars. In its current version, however, the database is still difficult to use for this purpose because of its relatively low spatial resolution. Furthermore, the use of a high resolution topography map to estimate surface pressure from the Viking Lander measurements simply using the hydrostatic equation, as most engineering teams do now, is not sufficiently accurate because pressure can vary horizontally due to various ”meteorological” effects (including diurnal and semi-diurnal tides), and because the correct scale height to use for this interpolation is difficult to estimate. We propose, therefore, to provide some simple software, based on a high resolution accurate topography map (as provided by the MGS MOLA team), to estimate accurately the surface pressure everywhere on the planet. The software would use the database to estimate the horizontal ”meteorological” correction and scale height, in order to provide the best possible pressure estimation at any given place on Mars [consistent with(?) the Viking Lander pressure records?]. [- can we really achieve this?]

*[LMD to take primary responsibility ]*

• **World Wide Web**

The interactive World Wide Web site (http://www.lmd.jussieu.fr/mars.html), which gives access to the Martian database, will be improved to reflect the latest database improvements and (where possible) user recommendations. In particular, data will be supplied in various vertical coordinate systems (pressure level, altitude) in addition to sigma coordinates.

*[LMD to take primary responsibility ]*

## 2.4 Comparison with Mars GRAM

The database will be compared to the latest version of the Mars GRAM software (the main other tool use for Mars mission design) The purpose of this comparison is to document and possibly understand the differences that may arise between the two products.

*[AOPP to take primary responsibility ]*

# 3 Work Package Description

## WP8.1

Contractor : CNRS (LMD)
Start : 1 April 2001
end : 30 September 2002

**Major tasks:**

- Inclusion of hybrid coordinates in the GCM
- New NetCDF input-output format to be implemented into the GCM
- Parameterization of thermospheric physical processes; First implementation and GCM test runs
- Improvement of the atmospheric GCM using new observations
- GCM-aerosol transport model to be improved and validated in the light of new data.
- Development of the high resolution surface pressure software
- Improvement of the World Wide Web interactive site Database

**Deliverables**

- technical report on ”Extension of the Mars GCM into the thermosphere” (preliminary version)
- technical report on ”Improvement of the Mars GCM with new spacecraft data” (preliminary version)
- high resolution surface pressure software to be supplied with appropriate documentation to be included in the database UM and DDD.
- Interactive Web site software to be improved.

## WP8.2

Contractor : Oxford University (Subcontractor)
Start : 1 April 2001
end : 30 September 2002

**Major tasks:**

- Assimilation of MGS temperature observations and design of a corresponding ”MGS year” scenario, for use in model validation and the production of the database
- Contribution to GCM improvements and aerosol models
- New NetCDF input-output format to be implemented into v3.1 of the database

**Deliverables**

- Technical report : Assimilation of MGS data and application to the Mars climate database.
- Technical report : Comparison of the Mars Climate database (v.3.1) with MarsGram (preliminary version).
- Contribution to technical report on ”Improvement of the Mars GCM with new spacecraft data” (Preliminary version)

## WP8.3

Contractor : Instituto de Astrofisica de Andalucia
Start : 1 April 2001
end : 30 September 2002

**Major tasks:**

- Modeling of thermospheric physics processes for the 1-D reference model.

- Contribution to the development of corresponding parameterizations for the GCM. First implementation and GCM test runs.
- Validation tool: Review of and first comparison with available thermospheric data of relevance (airglow) for the new physical package.

**Deliverables**

- Technical report on ”Energetics and chemistry of the neutral upper atmosphere of Mars” (preliminary version)
- Contribution to technical report ”Extension of the Mars GCM into the thermosphere” (preliminary version)

## WP9.1

Contractor : CNRS (LMD)
Start : 1 October 2002
end : 31 March 2003

**Major tasks:**

- Final implementation of the parameterization and full GCM runs.
- Atmosphere – Thermosphere model to be tested and finalized.
- Version 4 of the Mars Climate database simulations to be performed
- Model documentation to be updated

**Deliverables**

- Latest version of Mars GCM to be installed
- GCM user manual to be updated for changes
- Web site to be updated for access to Mars Climate version 4.0

- technical report on ”Extension of the Mars GCM into the thermosphere” (final version)
- technical report on ”Improvement of the Mars GCM with new spacecraft data” (final version)

### WP9.2

Contractor : Oxford University (Subcontractor)
Start : 1 October 2002
end : 31 March 2003

**Major tasks:**

- Comparison of Mars Climate database with Mars Gram
- Continued assimilation of MGS temperature observations for model and database evaluation
- Version 4 Mars Climate database to be generated from simulations performed at LMD
- Update of the database software and documentation for version 4

**Deliverables**

- Mars Climate Database version 4 to be installed.
- Architectural Design document, User manual and programming guides for the database to be updated
- Contribution to technical report on ”Improvement of the Mars GCM with new spacecraft data” (Final version)
- Technical report : Comparison of the Mars Climate database (inc. v4.0) with Mars Gram (Final version).

**WP9.3**

Contractor : Instituto de Astrofisica de Andalucia
Start : 1 October 2002
end : 31 March 2003

**Major tasks:**

- Development of 1-D energetic-chemistry reference code for the neutral thermosphere of Mars.
- Parameterization of thermospheric physical processes: Final implementation into GCM.
- Development of validation tool: algorithm to simulate available observations (airglow) using the GCM output fields.

**Deliverables**

- Technical report on ”Energetics and chemistry of the neutral upper atmosphere of Mars” (final version)
- Contribution to technical report ”Extension of the Mars GCM into the thermosphere” (final version)
- Technical report on “Validation of thermospheric GCM results”.
- Validation tool: Simulation of Martian airglow emissions using GCM results.

# 4 Travel Plan

Progress meetings will be held approximately every three months, Meetings will be held in rotation at Paris, Oxford and Granada, with the final meeting to be held at ESTEC. At least one person from each centre will attend each meeting. At other times, the contractors will communicate primarily through e-mail and the World Wide Web sites established under the contract.

# 5 Resources

The work described above will require significant researcher time. In addition to the current permanent staff, each group will hire at least one scientist/engineer for the project. In addition to salaries, resources will also be required to cover consumables necessary for preparation of the deliverables, management and maintenance of the computing facilities for the model experiments, the compilation and dissemination of the new database and a travel budget sufficient to cover attendance at project meetings.

The work in the contract extension will be conducted for a firm fixed price of 200Keuro. LMD will contribute to the project mostly using separate ressources. The ressources will be shared as follow : LMD: 30 Keuro, AOPP: 95 Keuro, IAA: 75 Keuro