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International EGOPS Maintenance Center (IEMC)  
Never seen occultations so bright — EGOPS



**IGAM/UG Technical Report for ESA/ESTEC No. 3/2002**

ESA study:

**End-to-end GNSS Occultation Performance Simulator (EGOPS) Enhancement**

[ESA/ESTEC contract no. 13327/98/NL/GD-CCN1, WP2.4: Preparation of updated Software User Manual (SUM)]

# **Atmospheric Sounding with GNSS Occultation / EGOPS Enhancement**

# **EGOPS4 S<sub>oftware</sub> U<sub>ser</sub> M<sub>anual</sub>**

## **Overview Manual**

**Software User Manual, Part 1 of 2, Doc. No. IGAMUG/ESA-EGOPS4/SUM-0V**  
[Document *EGOPS4\_SUM-0V*]

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# **Issue 2, March 2002**



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## **1 Introduction**

### **1.1 Scope**

This document (EGOPS4\_SUM-OV.pdf) is Part 1 of the Software User Manual for the End-to-end GNSS Occultation Performance Simulator, Version 4 [SUM], termed Software User Manual – Overview Manual [SUM-OV], and provides an overview description of the EGOPS4 simulator and its capabilities.

Part 2 of the Software User Manual for the End-to-end GNSS Occultation Performance Simulator, Version 4 ([EGOPS4\\_SUM-REF.pdf](#)) is the Software User Manual – Reference Manual [SUM-REF], which gives a detailed description of the various EGOPS functions, tasks and system operations. The operations are listed according to the EGOPS logical work-flow.

## **1.2 Abbreviations and Acronyms**

AD	Architectural Design
ADD	Architectural Design Document
ATPRO	Atmospheric Profiling
CIRA	COSPAR International Reference Atmosphere
COSPAR	Committee on Space Research
CRI	Computer Resources International A/S
DDD	Detailed Design Document
DMI	Danish Meteorological Institute
ECHAM(4)	Atmosphere/Climate model developed at MPI Hamburg (Version 4)
ECMWF	European Centre for Medium-Range Weather Forecasts
EGOPS <sup>®</sup>	End-to-end GNSS Occultation Performance Simulator (generic)
EGOPS2	End-to-end GNSS Occultation Performance Simulator, Version 2
EGOPS3	End-to-end GNSS Occultation Performance Simulator, Version 3
EGOPS4	End-to-end GNSS Occultation Performance Simulator, Version 4
ESA	European Space Agency
ESTEC	European Space Agency Technology Center
FoMod	Forward Modeling
GLONASS	(Russian) Global navigation satellite system
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRIB	Gridded Binary (file format for meteorological data)
HOOD	Hierarchical Object Oriented Design
IDL	Interactive Data Language
IEEE	Institute of Electrical and Electronics Engineer
IEMC	International EGOPS Maintenance Center
IGAM/UG (*)	Institute for Geophysics, Astrophysics, and Meteorology/University of Graz
IMG/UoG	Institute for Meteorology and Geophysics/University of Graz
InRet	Inversion/Retrieval
LEO	Low Earth Orbit
MAnPl	Mission Analysis/Planning
MPI	Max-Planck Institute (for Meteorology, Hamburg)
MPS	Multiple Phase Screen
MSISE90	Global atmospheric model MSISE90 ([HEDIN91])
MSIS90_DMI	MSISE90 variant (modifications by DMI)
NeUoG	Global ionospheric model NeUoG
OSMod	Observation System Modeling
ReFlexPortEx	Reliability, Flexibility, Portability, Extendibility
RO	Radio Occultation(s)
ROSAP	Radio Occultation Simulation for Atmospheric Profiling
SA	Selective Availability
SPD	Space Division
SRD	Software Requirements Document
TBD	To Be Defined
TEC	Total Electron Content

TERMA                      TERMA Elektronik AS  
URD                         User Requirements Document

(\*) Note: As of December 3, 1999, IGAM/UG is the legal successor of IMG/UoG.

### **1.3 Terms and Definitions**

Project	A group of simulation and visualization/validation activities whose output is separated from that of other projects. A project is identified by its user specified Project-id.
Task	A simulation activity within a project. Four Tasks are generically available in EGOPS. Mission Analysis/Planning, Forward Modeling, Observation System Modeling, and Occultation Data Inversion/Retrieval. A specific task is identified by its user-specified Task-id.
Toolkit	A group of software tools with related purposes.

## **1.4 Document Outline**

- [Chapter 2](#) provides a list of document references.
- [Chapter 3](#) contains information about the manual's intended readership, applicability and how to use the document, etc.
- [Chapter 4](#) presents a system overview, identifying the purpose and capabilities of the software.
- [Chapter 5](#) presents a instruction on installing, starting, running and exiting EGOPS.
- [Appendix A](#) contains a description of how error handling is treated within EGOPS and recommendations of what to do in case of unexpected run-time errors.
- [Appendix B](#) contains references to two comprehensive simulation examples, based on real planned GNSS RO missions. The simulation examples can be used as an instructual guide for new users.
- [Appendix C](#) contains information about the International EGOPS Maintenance Center.

## **2 Document References**

### **2.1 Applicable Documents**

The documents which are applicable for this document are:

- [EGOPSEXT] Kirchengast, G., Proposal for an “End-to-end GNSS Occultation Performance Simulator (EGOPS) Extension Study”; *IGAM/UG Doc.Id.: IGAMUG/ESA-EGOPSE/CCN2/1*, Proposal to ESA/ESTEC, March 27, 2000.
- [EGOPSECCN1] Kirchengast, G., Proposal for Contract Change Notice (CCN) to ESTEC Contract No. 13327/98/NL/GD “End-to-end GNSS Occultation Performance Simulator (EGOPS) Enhancement Study”; Initiator of Change: P. Silvestrin/ESTEC; *IGAM/UG Doc.Id.: IGAMUG/ESA-EGOPSE/CCN1/1*, Proposal to ESA/ESTEC, February 14, 2000.
- [EGOPSE] Kirchengast, G., J. Ramsauer, W. Muehlmann (now W. Poetzi), M. Gorbunov, G. Holler, M. Rieder, P. Hoeg, G.B. Larsen, and S. Syndergaard, End-to-end GNSS Occultation Performance Simulator (EGOPS) Enhancement, *IMG/UoG Proposal to ESA/ESTEC*, October 15, 1998; supplemented by Minutes of Kick-off meeting held at ESTEC on November 6, 1998.
- [SPV] Proposal 96-53 to ESTEC for GNSS Simulation and Performance Verification, CRI/SPD/PRO/96-53, July 1996.
- [ATMSOU] Proposal 95-52 for Atmospheric Sounding with GNSS Occultation, CRI/SPD/PRO/95-52, December 1995; supplemented by the draft contract annexed to the Minutes of Negotiation Meeting, CRI/15AS/MIN/96.
- [PSS-05] ESA Software Engineering Standards, Doc. PSS-05-0, Issue 1, February 1991.

## **2.2 Reference Documents**

The documents, except for the applicable documents, which are referenced in this document are:

- [URD/SRD] Poetzi, W., J. Fritzer, G. Kirchengast, Atmospheric Sounding with GNSS Occultation / EGOPS Enhancement, User Requirements Document/Software Requirements Document, *IGAM/UG Technical Report for ESA/ESTEC No. 3/2001*, Doc. No. IGAMUG/ESA-EGOPS4/URD-SRD, Issue 4, May 2001.
- [ADD/DDD] Poetzi, W., G. Kirchengast, J. Fritzer, J. Ramsauer, and M. Gorbunov, Atmospheric Sounding with GNSS Occultation / EGOPS Enhancement, Architectural Design Document/Detailed Design Document, *IGAM/UG Technical Report for ESA/ESTEC No. 4/2001*, Doc. No. IGAMUG/ESA-EGOPS4/ADD-DDD, Issue 3, May 2001.
- [SUM] Kirchengast, G., J. Fritzer, and J. Ramsauer, Atmospheric Sounding with GNSS Occultation / EGOPS Enhancement, EGOPS4 Software User Manual, *IGAM/UG Technical Report for ESA/ESTEC No. 5/2001*, Doc. No. IGAMUG/ESA-EGOPS4/SUM, Issue 1, September 2001.
- [SUM-OV] Kirchengast, G., J. Fritzer, and J. Ramsauer, Atmospheric Sounding with GNSS Occultation / EGOPS Enhancement, EGOPS4 Software User Manual – Overview Manual, *IGAM/UG Technical Report for ESA/ESTEC No. 5/2001*, Doc. No. IGAMUG/ESA-EGOPS4/SUM-OV, Issue 1, September 2001.
- [SUM-REF] Kirchengast, G., J. Fritzer, and J. Ramsauer, Atmospheric Sounding with GNSS Occultation / EGOPS Enhancement, EGOPS4 Software User Manual – Reference Manual, *IGAM/UG Technical Report for ESA/ESTEC No. 5/2001*, Doc. No. IGAMUG/ESA-EGOPS4/SUM-REF, Issue 1, September 2001.
- [IEEE-610.12] IEEE Standard Glossary of Software Engineering Terminology, Doc. ANSI/IEEE Std. 610.12-1990, 1990.

## **3 About the Manual**

### **3.1 Intended Readership**

The users of the software are expected to be scientists and engineers with the following potential expectations and reasons for using the software (note that in practice a „scientist“ and an „engineer“ may well reside in one physical person whatever its specific profession or job is; not uncommon in potential user organizations like ESTEC and research institutions):

- Scientists with specialist knowledge of the GNSS-based occultation technique who wish to have software which can serve as a technique-related research support tool and a data processing tool.
- Scientists with basic knowledge of the GNSS-based occultation technique who wish to have a software to learn about the technique by performing standard runs and with data processing capability to get auxiliary data for their own work or techniques where they are specialists.
- Engineers, who in general may have basic occultation knowledge and who wish to have a software for supporting mission/constellation planning and performance evaluation of the entire system with particular interest in technical/instrumental effects as involved in the GNSS radio occultation technique.

The reader of this manual is thus expected to come from the scientific/technical community, to have at least a small basic knowledge of the radio occultation technique, and to be familiar with the use of software in a UNIX environment.

### **3.2 Applicability Statement**

This manual covers version 4.0 of the EGOPS software.

For a detailed statement on the hardware and software requirements of EGOPS, please see the Section on “Installation Prerequisites” in [Chapter 5.1](#), “EGOPS Installation Guidelines”.



### **3.3 How to Use this Manual**

This is Part 1 of the Software User Manual [SUM], i.e. Software User Manual – Overview [SUM-OV], and contains five main chapters:

- The EGOPS overview description ([Chapter 4](#)) contains a detailed description of the purpose of the EGOPS system and the capabilities within the system. The overview gives a good introduction to both the RO technique and the different options within EGOPS. It is recommended reading for new users.
- The EGOPS installation guidelines and instructions on starting, running and exiting the EGOPS application are provided in [Chapter 5](#). It is mandatory reading for new users.
- The EGOPS error handling section ([Appendix A](#)) contains a descriptions of how EGOPS handles errors and the recommended actions to follow when an unexpected run-time error is encountered. The user should consult this appendix if a run-time error occur during the use of EGOPS. If an input parameter which the user has specified is rejected, use the reference manual to see the acceptable values for the parameter.
- The EGOPS example simulation part ([Appendix B](#)) contains two comprehensive example simulations with corresponding results based on real planned GNSS RO missions. The two examples is described in such detail that they can be reconstructed by new users, who wants to become familiar with the EGOPS system. After having read the EGOPS overview description (Chapter 4) the new user may switch to this appendix and use it in a learn-by-examples approach during the initial phase of building up his/her own practical working skills with EGOPS.
- The international EGOPS maintenance center (IEMC) information guide ([Appendix C](#)) contains the point of contact for all IEMC relevant matters, a list of all offered IEMC services, and the modalities and fees for using IEMC services.

The other part of the Software User Manual, the [Software User Manual – Reference Manual \[SUM-REF\]](#), contains information about all options within the EGOPS system including allowable ranges for input data, algorithms and techniques invoked when choosing different options, how to include user supplied data files etc. The reference manual is organized according to the logical work-flow when working with EGOPS. Each section corresponds to a main-level menu option. Each sub-section corresponds to one of the sub-options available.

### **3.4 Problem Reporting Instructions**

Comments on the EGOPS system and the reporting of errors encountered during the use of the software package can be directed to:

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## **4 EGOPS Overview**

### **4.1 EGOPS Background**

#### **4.1.1 Scientific-Technical Background and Potential of GNSS Occultations**

The Global Navigation Satellite System (GNSS, presently GPS/GLONASS) enables active limb sounding of the Earth's atmosphere and ionosphere by placing GNSS receivers into Low Earth Orbits (LEO) and employing the radio-occultation (RO) technique.

The RO method bears great utility for fields like operational meteorology, climate monitoring and modeling, and space weather, due to its potential to globally, and under practically all weather conditions, yield virtually bias-free profiles of fundamental atmospheric parameters, such as temperature and humidity, with quite unique vertical resolution (1 km or better) and accuracy (e.g., temperature < 1K).

The RO technique has been employed, from the mid-1960s onwards, with great success by planetary missions to measure vertical profiles of density and temperature for the atmospheres of Venus, Mars and the outer planets. With the advent of the GNSS satellites, which are high performance radio transmitters in high orbits (about 20000km) furnishing suitable L-band signals near 1.2GHz and 1.6GHz, along with GNSS receivers in LEO, it is now possible to make RO measurements of great utility, as noted above, also for the Earth's atmosphere.

The scientific basis of the RO technique is as follows. When radio waves pass through the atmosphere, they are refracted through an angle determined by the refractivity gradients along the path. These, in turn, depend on the gradients of density (and hence temperature), water vapor and electron density, and so a measurement of the refraction angle contains information on these atmospheric/ionospheric variables. These effects are most pronounced when the radiation traverses a long atmospheric limb path. Measurements for a series of such paths at different tangent heights, by exploiting the eigenmotions of orbiting GNSS and LEO satellite pairs in suitable geometry, contain information on the near-vertical profile of refractivity.

Though it is not possible at radio frequencies to measure the refracted angle directly, the refraction introduces an additional Doppler shift into the received signal, and this (or the related excess phase shift) can be measured very accurately and is directly related to the refraction angle.

An RO profile measurement by a receiver in LEO, which performs high-performance (millimetric precision), high-rate (50Hz or so) tracking of a GNSS signal occulted by the atmosphere near the Earth's limb, takes a period of about 1 minute, just before or after eclipse with respect to the transmitter. Scannings from top down (space to Earth's surface) are called "setting" occultations, those from bottom upwards (surface to space) are called "rising" occultations.

A receiver on a LEO can obtain up to 29 occultation profiles per day for each GNSS transmitter. Given the operational network of GPS and GLONASS transmitters (48 satellites) and typical antennae field-of-view of GNSS receiver antennae, this allows more than 1000 globally distributed soundings per day

for one receiver in LEO (with an average horizontal spacing of about 700 km). A constellation of successively more receivers reduces this horizontal spacing significantly (e.g., a 12-receiver constellation would reduce the average horizontal spacing to about 200 km per day).

In the stratosphere and upper troposphere, where the water vapor density is low, refraction variability is dominated by vertical temperature gradients, and the temperature profile can be retrieved accurately. In the lower troposphere, the water vapour effects are dominant, and the water vapor profile can be retrieved accurately (given temperature, but allowing for typical uncertainties in the prior knowledge of temperature). The height below which the information in the measurements is predominantly on water vapor varies with absolute humidity (and hence latitude); in the tropics it is typically around 7-8 km, whereas in the driest polar atmospheres, accurate temperature sounding is possible down into the planetary boundary layer (which extends up to about 1km above surface).

For both temperature and humidity sounding, it is necessary to account for the effects on the signals of refraction in the ionosphere. Correction for these effects can be made using RO signals at two radio frequencies available (about 1.2 GHz and 1.6 GHz), at which the effects of the ionosphere are substantially different. In addition, exploited in a complementary way, the presence of such effects provides accurate information on the ionosphere's electron density field.

Important features of the RO technique are its "all-weather" capability and the "long-term" stability (i.e., virtual absence of biases and drifts) of RO data. Most clouds have negligible effects on the measured signals. Even when a signal is attenuated a little (e.g., by rain), the measurement is not significantly degraded since the important measurement is of frequency shift (or excess phase), not of amplitude. For the same reason, the measurements have intrinsically high long-term stability, with no significant calibration problems. This feature is particularly important for climate monitoring and allows to directly combine data from different satellites and separated in time for many years.

EGOPS is a tool prepared to provide significant and effective help in addressing most of the open scientific and technical questions on the GNSS-based RO technique.

#### **4.1.2 Demonstration of the Potential of GNSS Occultation**

The potential of the GNSS-based RO technique has recently been demonstrated by early results from the GPS Meteorology (GPS/MET) experiment launched in April 1995 on the satellite Microlab 1. The results for temperature profile retrieval are already approaching the accuracies claimed for the technique. In the northern hemisphere extra-tropics, standard deviations of difference between GPS/MET retrievals and European Centre for Medium Range Weather Forecast (ECMWF) analyses are around 1-1.5K, with biases below 0.5 K. In the southern hemisphere, agreement is also good in general, but with clear evidence that the RO measurements can identify where the ECMWF temperature analysis is deficient through lack of observations. A particularly impressive result of the GPS/MET data has been the ability to resolve the detailed temperature structure around the tropopause, in good agreement with collocated radiosondes.

The hitherto results are consistent with expected errors for this technique, i.e., less than 1 K, at a vertical resolution of 0.5-1km in the upper troposphere and lower stratosphere, increasing to about 2 Kelvin near the stratopause (about 50 km). EGOPS will be a significant tool to study open questions regarding various components of the error budget.

The potential accuracy of RO measurements has also been assessed for water vapor. Better than 10% accuracy has been estimated for the lowest about 2 km throughout the tropics and mid-latitudes, and also, at low latitudes, for the mid-troposphere at pressures exceeding about 600hPa. EGOPS can also play a significant role in better quantifying the potential of GNSS occultation for retrieval of water vapor information.

Regarding electron density, the potential of the RO technique has long been demonstrated by studies of ionospheres of other planets, e.g., those of Mars and Venus. First results for the Earth, based on GPS/MET data, promise that the electron density can be gained throughout the ionosphere up to near the LEO orbit height at the 1% accuracy level. This, together with the global coverage potential of the technique, can open a new era for ionospheric remote sensing of unprecedented resolution and quality.

### **4.1.3 Potential of Using Ocean-Reflected GNSS Signals**

The Global Navigation Satellite System (GNSS, presently GPS/GLONASS) enables beside active limb sounding of the Earth's atmosphere and ionosphere by placing GNSS receivers into Low Earth Orbits (LEO) and employing the radio-occultation (RO) technique (as shown before) also the future potential of employing the radio-reflection (RR) technique. The RR method works by using ocean reflected GNSS radio waves as input signals for spaceborne LEO-GNSS receivers, a process which can be investigated within EGOPS. As a first development step in this direction EGOPS allows to study all geometrical aspects of RR and allow to investigate and optimize reflection event coverage and statistics.

The RR method bears great utility for fields like operational meteorology, climate monitoring and modeling, due to its potential to globally, and under practically all weather conditions, yield virtually bias-free information of ocean surface wind speed patterns and wave heights with quite good resolution (this could be already demonstrated with GNSS receivers on board of research aircraft). Nevertheless some major improvements of radio signal detectors are necessary for successful employment of GNSS RR signal receivers onboard LEO satellites (especially the sensitivity must be stretched to the technical limits because the received signal strengths are only a very small fraction compared to the GNSS signal strength available for the RO technique). Nevertheless enhancing EGOPS to such applications is a quite useful addition and will make the package even broader useful for future GNSS-related Earth Observation Missions.

### **4.1.4 References for Deepening the Understanding of GNSS Occultation**

The brief outline above can be considered drawn from a series of excellent references on GNSS occultation science and technology. For the convenience of further interested EGOPS User, a small expert's selection of these (which always reflects subjective judgement of course) of these is given below. References within the more recent of these references readily lead to further original work dealing in depth with specific aspects of the field.

- *Overviews for beginners in the field:*

Kursinski, E.R., Monitoring the Earth's Atmosphere with GPS, GPS World, Mar'94 issue, 50-54, 1994.

Kirchengast, G., and H.P. Ladreiter, The potential of the radio-occultation

technique based on GPS/GLONASS signals for determining fundamental atmospheric parameters (in German), Kleinheub. Ber., 39, 677-686, 1996.

Silvestrin, P., and P. Ingmann, Radio occultation observations using Global Navigation Satellite System signals – A new tool for exploring the atmosphere, *Earth Obs. Quarterly*, 54, 15-18, 1997. (Also WWW-online at <http://esapub.esrin.esa.it/eoq/eoq54.htm>)

- *A few "keynotes" of "historical" interest:*

Fjeldbo, G., and V.R. Eshleman, The bistatic radar-occultation method for the study of planetary atmospheres, *J. Geophys. Res.*, 70, 3217-3225, 1965.

Fjeldbo, G., A.J. Kliore, and V.R. Eshleman, The neutral atmosphere of Venus as studied with the Mariner V radio occultation experiments, *Astron. J.*, 76, 123-140, 1971.

Gurvich, A.S., and T.G. Krasilnikova, Navigation satellites for radio sensing of the Earth's atmosphere, *Sov. J. Rem. Sensing*, 7, 1124-1131, 1990 (Russian original published 1987).

- *A few works being both review-like and deeper-going:*

Hoeg, P., et al., Derivation of atmospheric properties using a radio-occultation technique, ESA Final Report (ESTEC Contr.No. 11024/94/NL/CN), also DMI Scientific Report 95-4 (ISBN 87-7478-331-9), 208p., 1995.

Kursinski, E.R., et al., Observing Earth's atmosphere with radio occultation measurements using the Global Positioning System, *J. Geophys. Res.*, 102, 23,429-23,465, 1997.

- *And a few recent works on performance demonstration/validation:*

Ware, R., et al., GPS sounding of the atmosphere from Low Earth Orbit: Preliminary results, *Bull. Amer. Met. Soc.*, 77, 19-40, 1996.

Kursinski, E.R., et al., Initial results of radio occultation of the Earth's atmosphere using the Global Positioning System, *Science*, 271 (Feb'96), 1107-1110, 1996.

Rocken, C., et al., Analysis and validation of GPS/MET data in the neutral atmosphere, *J. Geophys. Res.*, 102, 29849–29866, 1997.

Steiner, A.K., G. Kirchengast, and H.P. Ladreiter, Inversion, error analysis, and validation of GPS/MET occultation data, *Ann. Geophys.*, 17, 122-138, 1999.

- *Some European GNSS occultation mission planning documents:*

ESA (1996), Earth Explorer candidate mission report for assessment, Atmospheric Profiling mission, ESA Spec. Publ., SP-1196(7), 58p., ESA/ESTEC, Noordwijk, The Netherlands, 1996.

GRAS-SAG (1997), GNSS receiver for atmospheric sounding - Science advisory group report, The GRAS instrument on MetOp (Version 1), ESA/EUMETSAT publication, 38p., available, e.g., from ESA/ESTEC, Noordwijk, The Netherlands, 1997.

- *Finally, some books to browse for getting acquainted with GNSS:*

Hofmann-Wellenhof, B., H. Lichtenegger, and J. Collins, GPS – Theory and Practice, Springer-Verlag, Vienna, 1994.

Parkinson, B.W., and J.J. Spilker Jr. (Ed.), Global Positioning System: Theory and Applications (2 volumes), Progress in astronautics and aeronautics series (Vol.163, 763p., and Vol.164, 643p.), Am.Inst.Aeron.Astron. (AIAA) Publ., Washington, D.C., U.S.A., 1996.

## **4.2 What can EGOPS do for Me**

### **4.2.1 Main Objectives and Capabilities of EGOPS**

Having in view the scientific and technical background of GNSS occultation science (cf. the "EGOPS explained... EGOPS Background" Help text), the overall objective of EGOPS is effective treatment of as many as possible relevant aspects of GNSS occultation by an integrated, flexible, and user-friendly tool open for continuous improvements. In this spirit, EGOPS is capable of end-to-end simulation of the GNSS-based radio-occultation technique and of processing of real occultation data (e.g. from GPS/MET or CHAMP).

More specifically, the major aims and capabilities of EGOPS are

- 1) Mission analysis and planning for GNSS (GPS/GLONASS) receivers at LEO satellites (geometry/"shape" of events, coverage, statistics for given GNSS/LEO/ground-station constellations) for occultation or reflection events. [Consult the "Help on Task - Help on Mission Analysis/Planning" entry of the "Help" menu ([Chapter 4.4](#)) for more information.]
- 2) Simulation of occultation observations, i.e., forward modeling of GNSS signal propagation through the atmosphere/ionosphere system plus effects of the observing system, to obtain quasi-realistic observables (with excess phase and amplitude observables as the primary ones).[Consult the "Help on Task - Help on Forward Modeling, Help on Observation System Modeling" entries of the "Help" menu ([Chapter 4.5](#) and [4.6](#)) for more information.]
- 3) Processing of simulated or observed occultation data, i.e., inversion from excess phases and amplitudes, typically via dual frequency Doppler shift and bending angle data, to atmospheric/ionospheric profiles (EGOPS includes neutral atmospheric profiles of refractivity, density, pressure, temperature, water vapor [pressure], and specific humidity, and ionospheric profiles of total electron content, ionospheric refractivity, and electron density), as well as computation of various data product quality statistics. [Consult the "Help on Task - Help on Occ. Data Inv./Retrieval" entry of the "Help" menu ([Chapter 4.7](#)) for more information.]

For conveniently conveying to the User the results of EGOPS-based studies in the fields addressed by the above three objectives, EGOPS has integrated powerful visualization and validation functionality. It allows the User to effectively interpret any study-related processing results immediately in a user-friendly window-based working environment.



#### **4.2.2 Exemplary New General User I/F Functions of EGOPS4**

**Batch Processing Functionality of EGOPS.** EGOPS4 provides beside the usual interactive computing capabilities a versatile Batch Job Facility for time consuming computations, e.g., specific Forward Modeling (FoMod) or Inversion Retrieval (InRet) Tasks. EGOPS Batch Jobs can be scheduled to start immediately or at a User specified time instance by activating the "Batch ..." button, which is generally positioned besides the "Compute ..." or "Save and Compute ..." button. Clicking this button will pop up a dialogue window that allows the User to specify the desired start time & date of the EGOPS batch job. Furthermore, using the related button "Batch Jobs Info...", the User can check the status of previous EGOPS batch job requests, terminate running or pending jobs, remove a task from the Batch Processing Information window or remove all finished tasks from the Batch Processing Information window. EGOPS4 implicitly does not support "Batch Job Chain Processing" for stacking job requests. It is the responsibility of the User to properly specify the start times of inter-dependent jobs.

**EGOPS Project Archiving and Restore Facility.** In order to save disk space or to allow an easy transfer of whole projects (i.e., of all data of an EGOPS Project), EGOPS4 provides a project archiving facility. The project intended for archival will be put into a gzip'ed tar-archive file in the ../EGOPS/projshelf directory. Any shelved project file can be fully restored by using the EGOPS project restore facility at a later time and one may then proceeding working with it. Both shelving and restoring are accessible as new entries of the "Project" Menu at the main level of the EGOPS User I/F.

## **4.3 EGOPS Concept and Structure**

### **4.3.1 EGOPS Concept**

The EGOPS objectives lay down that EGOPS should be capable of quasi-realistic end-to-end simulation of the GNSS-based radio-occultation (GNSS-RO) technique including mission analysis/planning for GNSS receivers in Low Earth Orbit (LEO) or airborne receivers, simulation of GNSS-RO observables, and processing of such simulated, and observed RO data, towards atmospheric profiles. The EGOPS concept includes also geometry simulations of the GNSS-based radio-reflection (GNSS-RR) technique and offers as additional feature for RO data simulation and processing of ionospheric profiles. In addition, post-processing for different types of useful statistical information is required (e.g., occultation or reflection event coverage statistics or statistics for quantifying the quality of retrieval products), and powerful visualization/validation capability is integrated. [See the "EGOPS explained... EGOPS Background, What can EGOPS do for me?" entries of the "Help" menu for more information on the objectives and rationale of EGOPS.]

In order to be able to fully respond to these objectives, the fundamental conceptual idea behind EGOPS is to follow a most general layout: to mimic all components and processes relevant to the GNSS-RO technique in the "real world" as good as possible in the simulator's "model world".

In other words, in order to allow for quasi-realistic simulations of RO observables, all the GNSS-RO ingredients in the "real world" for arriving at the observables are mimicked in the "model world". In this spirit, the EGOPS concept includes as main components a "GNSS Signal Simulator" mimicking the GNSS signals, an "Atmosphere/Ionosphere System Simulator" mimicking the atmosphere/ionosphere system, a "Geometry Simulator" mimicking the GNSS occultation (reflection) system geometry, and a "Receiving System Simulator" mimicking the receiving system. The overall process involving all these systems is the propagation of the GNSS-transmitted signals through the atmosphere/ionosphere towards the GNSS receivers in LEO which is mimicked by a "Signal Propagation Simulator".

This "object-oriented" concept makes alternative options and upgrades of the various components/processes extremely flexible since the "system boundaries" are very generically chosen in the concept.

In the same spirit, the data processing concept for retrieving atmospheric/ionospheric data products from these observables, always a "model world" enterprise of course, includes a structured "Inversion/Retrieval Toolkit", naturally divided internally into generic processing steps (processes) and data pools (components). Again high flexibility exists for parallel alternative options as well as upgrades of various components/processes. The "Visualization/Validation System" concept, having integrated useful post-processing capability as well as capability for extracting "ground truth" information from the atmosphere/ionosphere system from internal or external sources, includes again a structured-toolkit layout of several flexible components for convenient interactive visual analysis and interpretation of EGOPS study results.

The modular structure of the EGOPS software as described in the section below directly reflects this generic concept in that the actual design and partitioning into program modules of software observes the generic natural boundaries prescribed by the concept. In this way a flexible software tool is obtained

which can well cope with the objectives outlined and which is truly open for continuous improvements. The EGOPS Concept is illustrated graphically in [Figure 4-1](#).

### **4.3.2 EGOPS Structure**

EGOPS is implemented following a modular structure which directly derives from the concept described above and which is compliant with the main objectives of the software. The latter is particularly important at the EGOPS User I/F level to make it straightforward for the User to address a topic within a specific objective (e.g., if you want to perform some specific mission planning with EGOPS – knowing that the tool involves such capability – you like to have a User I/F structure more or less immediately showing you how to address this objective with the tool).

The description of the EGOPS structure that follows is organized into the following subsections:

**--- Modular View of EGOPS**

**--- Main Design Guidelines**

**-- Fulfillment of the Main Objectives of EGOPS**

**-- ReFlexPortEx - Reliability, Flexibility, Portability, Extendability**

**-- Use of Two Programming Languages (IDL/FORTRAN)**

**--- File Structure Behind EGOPS**

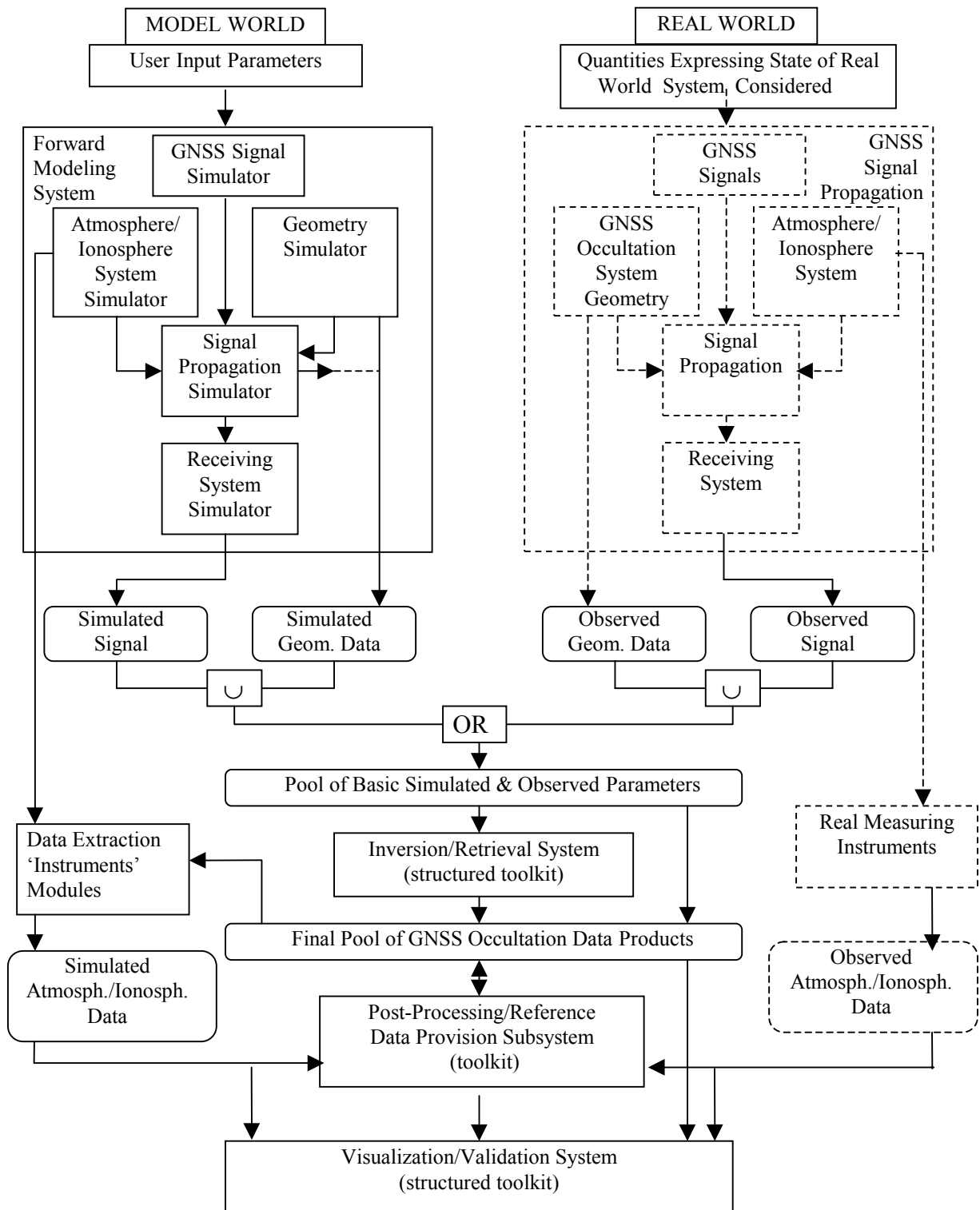
**--- Modular View of EGOPS**

The structural design of the EGOPS software can be best illustrated in terms of considering how the software is partitioned into high-level modules, i.e., in taking an implementation-oriented modular view of the entire tool. Such an implementation-oriented modular view is briefly described in this subsection, together with giving, where deemed appropriate, some rationale and explanation of different modular functions. The implementation-oriented modular view is illustrated in [Figure 4-2](#).

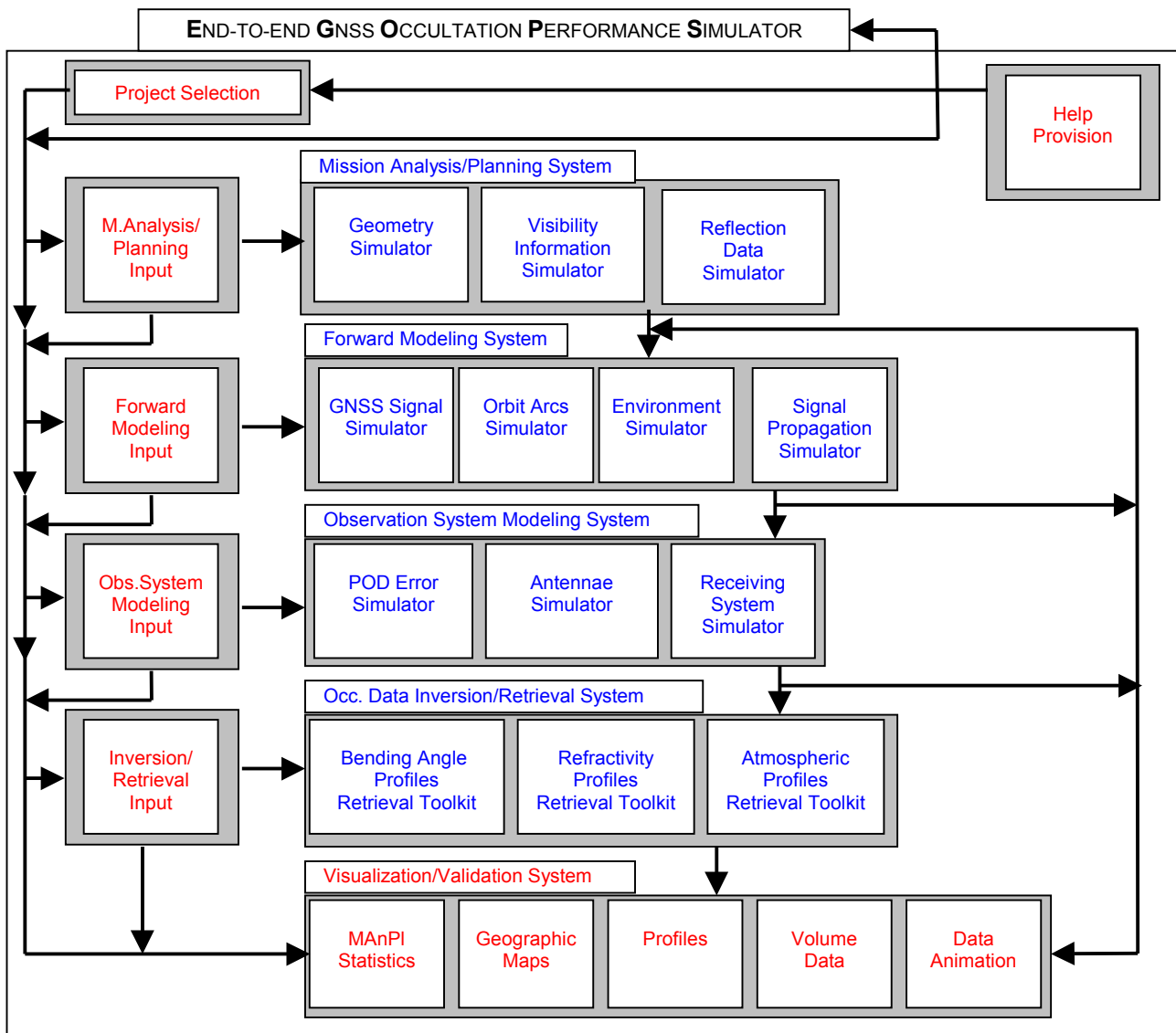
The entire software is can be understood to be composed of a series of high-level modules, which are partly integrated into so-called Systems, and their exist specific dataflow between the modules/systems.

The modular structure contains at highest level a "Project Selection" and a "Help Provision" module.

The rationale behind "Project Selection" is the following: EGOPS work and related data are organized in "projects" (handled at User I/F level via a "Project" menu), which provide the user with a convenient means to group the computations of a series of simulation scenarios, which for some logical reason belong to each other, into a common folder. A "Project" within EGOPS is thus a group of simulation and visualization/ validation activities whose data (input/output of simulation scenarios) is separated from that of other projects.



**Figure 4-1: Conceptual View of EGOPS**



**Figure 4-2: Modular View of EGOPS**

In fact the separation of the projects is physically reflected in the EGOPS file structure on disk, where each project's data are gathered below a /<project-id> subdirectory which is created as subdirectory of the root directory /EGOPS during project launch. (See the subsection on "File structure" below.)

The rationale behind on-line "Help Provision" for all EGOPS functions, both at main User I/F level and at sub-levels (window-based help within each pop-up User I/F window), is obvious: It is more convenient to work if one needs not necessarily refer to written documentation in course of using a software.

Furthermore, the modular structure contains a bulk of four modules named "...Input" and a bulk of five "Systems". Each of the first four "Systems" has an associated "Input" module. These first four "Systems", the "Mission Analysis/Planning System", the "Forward Modeling System", the "Observation

System Modeling System", and the "Inversion/Retrieval System", constitute the computational kernel of EGOPS in that these are actually performing the end-to-end occultation simulations whilst the last "System", the "Visualization/Validation System", is devoted to post-processing and validation processing and especially to conveying the results produced by the four computational "Systems" in convenient form to the User.

The possible dataflows among the modules/Systems reflect the natural hierarchy of the physics the software deals with (as further detailed below within the following subsections and also well seen in the graphical illustration of the modular view [Figure 4-2](#)).

### **--- Main Design Guidelines**

The rationale for implementing this specific modular design may be best understood if discussed with reference to the three main guidelines which have been baselined by the system developers as the main drivers of EGOPS development. These were

- 1) Fulfilment of the main objectives of EGOPS, as already noted above. (See the "EGOPS explained... What can EGOPS do for me?" entry of the "Help" menu for more information on these objectives.)
- 2) ReFlexPortEx, a convenient acronym for expressing the particular attention paid to Reliability, Flexibility, Portability, and Extendability.
- 3) The use of two programming languages (IDL/FORTRAN), mainly required to reach both the aim to include also already existing software (FORTRAN) and the aim to furnish a modern User I/F (IDL).

Each of these three main guidelines is discussed in the following subsections.

### **-- Fulfillment of the Main Objectives of EGOPS**

The appropriate fulfillment of the main objectives of EGOPS is certainly of utmost importance. Thus mission analysis/planning, RO (RR) observation simulations, and RO (RR) data processing need to form the computational core of EGOPS. Complementing this, integrated visualization/validation capability, including post-processing, is needed.

According to the EGOPS concept, a natural hierarchical partitioning to serve all these needs in an end-to-end framework, which was adopted for EGOPS, is to partition the computational core, at highest level, into mission analysis/planning, forward modeling, observation system modeling, and inversion/retrieval. Structured visualization and validation capability, with integrated post-processing functions, was added supporting the analysis and interpretation of studies performed with each of the computational parts.

In fact this partitioning just leads to what is called Systems (and Inputs to Systems for the computational parts) within the modular structure described above. The high-level structural components shall be briefly further explained below.

-> *Mission Analysis/Planning (MAnPl)*: This component comprises the analysis and planning of single LEO satellites and LEO constellations carrying GNSS occultation (reflection) receivers, including antennae field-of-view planning and analysis and visibility analysis w.r.t. ground stations, for assessing, investigating, and optimizing occultation event coverage and related relevant statistics. This will either be done "stand-alone" or as the first stage for planning and selection of useful occultation events then exploited for observation simulations.

Main modular parts for mission analysis and planning are simulation of occultation (reflection) geometries ("Geometry Simulator") and computation of the visibility of satellites from ground fiducial or tracking sites ("Visibility Information Generator"). (Cf. [Figure 4-2.](#))

[For more information on Mission Analysis/Planning, and the associated visualization capabilities within EGOPS, see [Chapter 4.4.](#)]

-> *Forward Modeling (FoMod)*: In case of interest in observation simulations, this is the natural stage following some planning for occultation events with desired properties (e.g., events occurring in a geographic region of interest, etc.).

Forward Modeling (FoMod), together with subsequent Observation System Modeling (OSMod), performs quasi-realistic simulation of observables, and related required variables, of the GNSS occultation technique. The main observables are time-tagged phase and amplitude measurements, obtained in real world by tracking occulted GNSS signals with a LEO platform-mounted GNSS receiver for atmospheric sounding (GRAS) during their set/rise through the atmosphere imposed by the relative orbital motion of the GNSS and LEO satellites.

Forward Modeling itself denotes the simulation of GNSS signal propagation through the atmosphere/ionosphere system given the orbital motions of the GNSS and LEO satellites. It results in "ideal" signals which contain the effects of the atmosphere/ionosphere media only. Thus FoMod results allow to inspect the environmental influence alone.

Main modular parts for forward modeling are GNSS signal simulation ("GNSS Signal Simulator"), orbit arcs simulation for GNSS and LEO for the period of the occultation events treated ("Orbit Arcs Simulator"), simulation of the atmosphere/ionosphere system ("Environment Simulator"), and propagation simulation (ray tracing) for the GNSS-LEO link ("Signal Propagation Simulator"). (Cf. [Figure 4-2.](#))

[For more information on Forward Modeling, and the associated visualization capabilities within EGOPS, see [Chapter 4.5.](#)]

-> *Observation System Modeling (OSMod)*: This next stage, following FoMod and using its "ideal" signal and orbit arcs output data, denotes the superposition of all sorts of relevant physical and technical influences of the observation system (antenna, receiver, platform, fiducial sites) on the "ideal" signal (phase and amplitude data) arriving at the receiving antenna, and on the "ideal" orbit data (GNSS and LEO positions and velocities). In fact these "ideal" data are the output of Forward Modeling, a necessary prerequisite to be performed before Observation System Modeling can be done.

The most relevant observation system effects to be modeled include precise orbit determination (POD) errors, the antennae gain pattern, receiver noise, local multipath (due to the platform structure in the vicinity of the antenna), and differencing treatment/clocks precision.

Main modular parts for observation system modeling are precise orbit determination (POD) error simulation ("POD Error Simulator"), antennae pattern simulation ("Antennae Simulator"), and receiving system simulation ("Receiving System Simulator"), the latter including modeling of receiver performance, local multipath, and differencing treatment/clocks. (Cf. [Figure 4-2.](#))

[For more information on Observation System Modeling, and the associated visualization capabilities within EGOPS, see [Chapter 4.6.](#)]

-> *Occ. Data Inversion/Retrieval (InRet)*: Inversion/Retrieval processing is the last computation stage of end-to-end simulations. In addition, besides processing of simulated data, it is applicable in an identical manner also to observed data (e.g. from the GPS/MET or CHAMP experiment). More specifically, the InRet function performs the processing of simulated or observed phase and amplitude data (supplemented by the necessary geometrical information) typically via Doppler shifts and bending angles down to quasi-vertical atmospheric profiles of refractivity, density, pressure, temperature, and humidity. EGOPS also allows to process ionosphere profiles of total electron content, Doppler shift, bending, refractivity, and electron density.

This processing chain typically requires, sequentially, tools for ionospheric correction and conversion of the "raw" excess phase observables to neutral-atmospheric bending angle profiles, for inversion of bending angle profiles into refractivity profiles ("Inverse Abel Transform"), and for finally retrieving the atmospheric variables (e.g., temperature) from refractivity. The air (in the troposphere) may be considered either dry or moist in the last stage of this processing chain.

Main modular parts for occultation data inversion/retrieval are, based on the processing chain outlined, an "Ionospheric Correction and Bending Angle Retrieval Toolkit", a "Refractivity Profiles Retrieval Toolkit", and an "Atmospheric Profiles Retrieval" Toolkit". (Cf. [Figure 4-2.](#))

-> *User I/F and post-processing, visualization and validation*: From the point of view of the EGOPS User I/F, there is a "Task" menu available at main level, which furnishes four generic Task options, i.e., menu entries. These correspond directly to the four main computational parts (MAnPI, FoMod, OSMoD, and InRet) outlined above. Thus the simulator fully reflects the natural hierarchy of the simulation problem and the results of one task the User performs (e.g., a MAnPI task) are typically part of the input of the next-stage task (e.g., a FoMod task). (Briefly on what EGOPS "tasks" are: these are the individual computational scenarios comprised by an EGOPS Project. A task corresponds to computing a specific scenario by employing one of the four generic Task options.)

The link between the "Task" menu entries and the computational parts is provided by the four modules "MAnPI Input", "FoMod Input", "OSMoD Input", and "InRet Input", which correspond to four User I/F window interfaces, each one accessed by a specific "Task" menu entry. These Input modules directly supply the User input data to their respective computational System. (Cf. [Figure 4-2.](#))

After any stage, post-processing and visualization/validation is possible for the results so far computed, by employing the EGOPS "Visualization/Validation System", which corresponds, at User I/F level, to



the "Visualize/Validate" menu. The modular parts of this System are "ManPI Profiles", "Geographic Maps", "Profiles", "Volume Data", and "Data Animation" (Note: The latter two modules compute and visualize atmosphere/ionosphere field variables rather than computational System results). These modules, in turn, correspond at User I/F level to five window interfaces, each one accessed by a specific "Visualize/Validate" menu entry. (Cf. [Figure 4-2.](#))

**-- ReFlexPortEx - Reliability, Flexibility, Portability, Extendability**

ReFlexPortEx is expressing, as a generic acronym, key quality requirements which an implementation design should try to fulfill well. These requirements were carefully observed for EGOPS as briefly detailed below.

-> *Reliability*: Reliability is taken care of by the strict modular design making EGOPS a "lean" sequential system robust in operation. The underlying file structure (cf. the subsection below) is strictly mirroring the modular implementation supporting reliable use and safety of already produced EGOPS data. Each computational routine within the modular structure takes a clearly defined role in a sequential control and data flow; thus in case of error (i.e., abnormal termination) only the results produced by a single routine currently running get lost, all other existing information is conserved and fully usable after EGOPS restart or resumption of operations (cf. the error handling information in [Appendix A.](#)).

-> *Flexibility*: Flexibility is provided to the User by the partitioning of EGOPS into four stages directly reflecting the natural parts of the GNSS-RO (RR) technique as described in the above subsection. The control and data flow is structured so that after any of these stages the User can, for the results already produced, post-process, visualize/validate, print and protocol the results. For instance, a specific EGOPS-based study may well be solved already at an intermediate stage so that the User wants to stop simulations with the data products so far obtained (e.g., doing mission analysis/planning only).

The User can furthermore, after any stage, temporarily or permanently: Change to another project to continue work there just at the point where it was stopped, suspend or stop work to resume it later (or let it be resumed by another User), etc.

For each of the four generic Task options, the User is furnished a specific single input window (e.g., MAnPI Input I/F window) providing for effective input of all necessary parameters for any desired individual computation scenario (task), and including the option of loading already existing tasks. (Note: within a project often scenarios are analyzed differing only in one or very few parameters in their input. In this case the respective individual task input data are very similar and loading of existing task input data can immediately provide a very good default for a next task.)

For more advanced Users, the transparent file structure (see subsection below) and file contents (formatted ASCII/80 character width format obeyed by all files) provides considerable interfacing flexibility in addition to the EGOPS User I/F (e.g., interfacing in parallel by a file manager or editor application or interfacing data files by User-produced non-EGOPS software for purposes like external post-processing or visualization). Furthermore, at various points the informed User (with source-code license) can, with modest effort, link his/her own routines to EGOPS, which are then directly accessible from within the EGOPS User I/F. (In EGOPS, such a "slot" is directly prepared for inclusion of User-

supplied atmospheric models. - The `usratm.SampleFile` in the `/prog/FORprog` directory of the EGOPS installation gives more information.)

-> *Portability*: EGOPS is an IDL/FORTRAN software product with the modules produced under IDL strictly partitioned from those under FORTRAN. All IDL routines strictly obey the IDL5.4 standard, all FORTRAN routines the F90 standard. This standardization secures independency from specific IDL/FORTRAN installations. All computational Systems (MAnPI System, FoMod System, OSMod System, and InRet System) are purely written in FORTRAN, the User I/F and the Visualization/Validation System are purely written in IDL (the latter with one exception, a "Reference data provider" program, which interfaces the atmospheric/ionospheric models of the computational Systems and is therefore written in FORTRAN). We note that besides portability this significantly eases software maintainability as this partitioning is coherent with the natural partitioning of the simulation problem as discussed above.

The data exchange of all data, from input data to result data, within the IDL and FORTRAN part of EGOPS is entirely performed via files (see the subsection below). This completely avoids any call of FORTRAN within IDL and vice versa and secures platform independency which would be lost with any other solution. With respect to the usage of operating system commands within EGOPS (changing/generating/naming directories, files, etc.), the generic Unix-standard is strictly obeyed so that any dependence on a specific Unix dialect, implementation or platform is avoided.

-> *Extendability*: The modular design of EGOPS with its "natural" interfaces makes the software an open system extendable both in its basic scope and its depth. The upgrading from EGOPS 2 to EGOPS 3 and to EGOPS 4 was an impressive confirmation of this extendability. A most important aspect here is that any module may be replaced or complemented by a "better" one (another GNSS system, another GNSS frequency, another atmospheric model, another signal propagation simulator, another bending angle inversion tool, etc.). A second aspect is that modules with entirely new functions can be added (e.g., an "... inversion" tool to the InRet System, an "Event Geometry" visualization tool to the Vis/Val System, etc.). A third aspect is that new computational Systems can be added (e.g., an Atmospheric Imaging (AtmIm) System, which would be placed as successor of the InRet system). Both the design of the User I/F and Visualization/Validation System (IDL) as well as the design of the computational Systems (FORTRAN) are structured with respect to their control and data flow in a way to ensure such extendability.

With respect limits to extendability harder to overcome, it should be noted that generally biggest upgrade efforts will occur for extensions by modules, which require input information currently not yet provided by the dataflow to the place the new module is supposed to fill (e.g., as an arbitrary example, extension by a novel improved ionospheric correction and bending angle retrieval module, which invokes auxiliary ionospheric occultation data acquired just before/after the setting/rising atmospheric occultation).

**-- Use of Two Programming Languages (IDL/FORTRAN)**

The use of two programming languages was constrained by the facts

(i) that the EGOPS User Interface and Visualization functionality should be user-friendly modern standard (window-driven, point-and-click, effective visualization), and

(ii) that several computational routines existed in FORTRAN-77, which were worth including in an adapted form within EGOPS.

Constraint (i) called for a powerful high-level language. IDL (Interactive Data Language) was selected, which is widely in use in the engineering/scientific world for interactive visual analysis applications as EGOPS can be considered to be one.

Constraint (ii) called for use of the FORTRAN standard for the computational modules. The FORTRAN-90 standard was selected, which is downward compatible to F77, which is widely in use in the engineering/scientific world for mathematical routines. The choice of F90, and adjustment of all existing F77 routines to this standard, ensures that newly developed EGOPS software can follow the state-of-the-art FORTRAN standard, while all existing F77 software is still readily included (generally needing minor adjustments only).

For the sake of a clear design and high ReFlexPortEx, the partitioning between the IDL and FORTRAN parts of EGOPS is strict. The four computational Systems are written in FORTRAN, the User Interface and the Visualization/Validation System are written in IDL (except the "Reference data provider" program, as mentioned above).

Control is exercised by IDL and the interfacing between IDL and FORTRAN is as follows.

An IDL Input module (e.g., the "MAnPI Input" User I/F after commanding "Save&Compute") generates a standardized input file for its respective computational System and then kicks off execution of this System. The System (FORTRAN), more precisely speaking its main program, reads the complete set of input data from the standardized input file and then performs the computations for the given scenario task according to the input. In parallel, it flags the status of the computations to a standardized information/error message file (to allow robust error handling).

Result files are then produced by specific modules of the System. (Note: In the "Modular View" [Figure 4-2](#) the result file dataflows are indicated by the vertical arrows from one computational System to the next and by the arrows, at the right part of the Figure, towards the Visualization/Validation System.) After completing its computations, the System passes a success information to the standardized message file.

Having resumed back control, the IDL interface reads the standardized message file and takes action as necessary (e.g., performs its error handling in case no successful completion is reported by the System). After this point, computations for the particular task are completed and the User can proceed further as desired with any other task, visualization, etc.

Each IDL/FORTRAN interfacing within EGOPS is strictly implemented as described, for ensuring high ReFlexPortEx.

### --- File Structure Behind EGOPS

The EGOPS file structure is illustrated in [Figure 4-3](#).

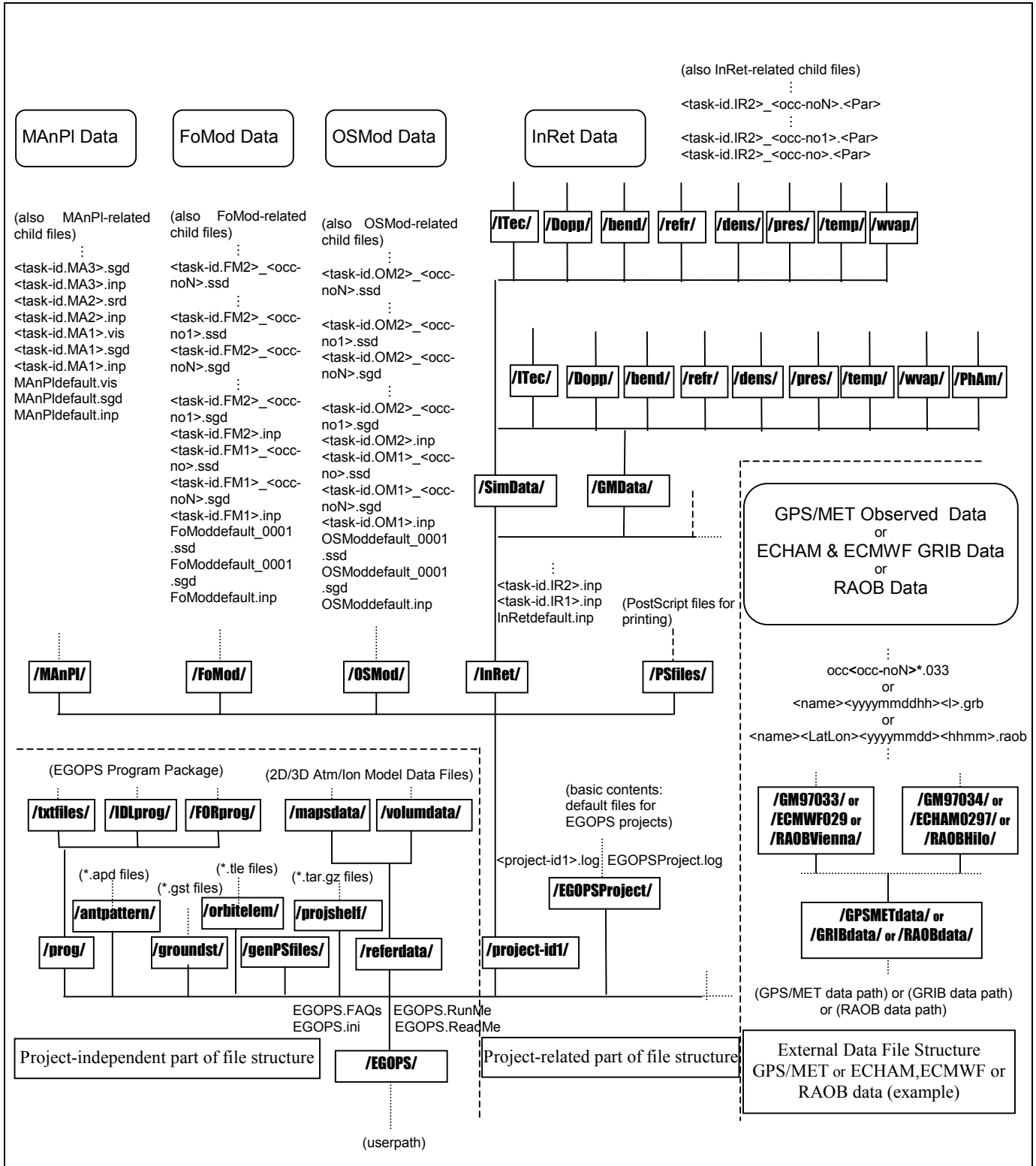
All EGOPS programs and data are placed under a root directory named /EGOPS during the installation process. EGOPS.RunMe is the root directory command file, also created during installation, which is executed to start EGOPS. The other EGOPS intrinsic files in the root directory are EGOPS.FAQs (accessed via the "EGOPS explained... EGOPS Users Corner FAQs" entry of the "Help" menu), EGOPS.ReadMe (accessed via the Help entry given in the note below), and EGOPS.ini (a file prepared to furnish miscellaneous external definitions to EGOPS). EGOPS.ReadMe and EGOPS.FAQs are files, which may be irregularly updated also between new EGOPS releases. (Note: The non-advanced user needs not know anything else about the EGOPS file structure but this fact that EGOPS is started by executing EGOPS.RunMe in the EGOPS root directory. – See [Chapter 5.1](#) for further information on installation-related questions.)

Below the root directory, the file structure consists of two main parts. One part holds the project-independent data of EGOPS (illustrated in the lower left part of the "EGOPS File Structure" Figure), the other part holds the project-related data, which are partitioned according to the four generic Task options available (MAnPl, FoMod, OSMod, InRet). Furthermore, a subdirectory /PSfiles appears, which holds all PostScript files the User prepares within the project for printer output.

There is one project which is integral to EGOPS, named "EGOPSProject", which is associated with the /EGOPSProject subdirectory in the file structure. It belongs to the basic installation package, and is the default project of EGOPS which contains the minimal default information necessary to operate the simulation and visualization/validation functionality. (Each time a new project is started, this minimal default information is carried over from the "EGOPSProject" to the new project's directories.)

-> *Project-independent part of the file structure:*

The file structure of the project-independent part consists of the four subdirectories: /prog (with an appropriate substructure), /groundst, /orbitelem, /genPsfiles, and /referdata (with an appropriate substructure). Under subdirectory /prog the EGOPS program package resides (/prog/txtfiles contains the Help texts, the exact contents of the /prog/IDLprog and /prog/FORprog subdirectories depending on the license type; cf. EGOPS.ReadMe). /groundst holds the ground-station coordinates/specs files (\*.gst files, see also the file gst.Help in this directory). /orbitelem holds the orbit element files for the GNSS/LEO satellites (\*.tle files, see also the file tle.Help in this directory). /genPsfiles holds the created PS files, which are not related to a specific project. Under /referdata reference "gridbox" data files of variables of atmosphere/ionosphere models reside (2D geographical datasets under /referdata/mapsdata and 3D volume datasets under /referdata/volumdata, respectively, available to be visualized with the "Volume Data" and "Data Animation" functions of EGOPS).



**Figure 4-3: EGOPS File Structure**

-> *Project-related part of the file structure:*

Concerning the project-related part, each User-specified project, as soon as launched via the EGOPS User I/F by assigning a Project-id (name), is allocated its own directory (directories `./<project-id1>/`, `./<project-id2>/`, etc.). (Note that the `/EGOPSProject` directory always exists.) A project directory contains all the information related to it in subdirectories named according to the four generic Task options available (subdirectories `/MANPl`, `/FoMod`, `/OSMod`, and `/InRet`). In any project directory a `<project-id>.log` file exists, which the User may utilize as "notebook" to protocol information on the project. (Note that `EGOPSProject.log` contains information on its own rationale which must not be touched.) A project can be closed, opened, and renamed at any stage of work without impairing the existing information conserved in its file structure.

The four "Task option" subdirectories contain the respective standardized input files for handling User I/F (IDL) information to the computational Systems (FORTRAN), one unique file for each specific scenario (task) computed by the User and thereby assigned a task-id. These files are the `<task-id>.inp` files, which exist in the "Task option"-subdirectories (`/MANPl/<task-id>.MA1.inp`, `/FoMod/<task-id>.FM1.inp`, etc.). (Note: For handling information from IDL to FORTRAN, the currently used `<task-id>.inp` file is always temporarily duplicated by IDL to a file in the EGOPS root directory with frozen filename (`MANPl.inp`, `FoMod.inp`, etc.) which is opened, read, and then deleted by the respective FORTRAN System.)

The "Task option" directories furthermore hold all result files produced by the respective computational Systems as explained below.

-> *MANPl directory:*

In case of `MANPl` these are, for each individual task performed, a "Simulated Geometry Data" file (`/MANPl/<task-id>.sgd`) and, optionally, a "Visibility Data" file (`/MANPl/<task-id>.vis`). The `/MANPl` directory will also contain all `MANPl` "child"-files derived during post-processing for visualization (e.g., histogram data).

-> *FoMod directory:*

In case of `FoMod` these are one or more "Simulated Geometry Data" file(s) (`/FoMod/<task-id>_<occ-no>.sgd`; containing the "ideal" `FoMod` geometry data) and one or more "Simulated Signal Data" file(s) (`/FoMod/<task-id>_<occ-no>.ssd`; containing the "ideal" `FoMod` phase and atmospheric power loss data). One file per simulated occ. event exists. The number of occ. events depends on the event sample size chosen by the User for the given task. The basic space/time information on the occurrence of the occultation events is taken from a `/MANPl/<task-id>.sgd` file prepared by an earlier `MANPl` task run (selected during `FoMod` input). The directory will also contain all `FoMod` "child"-files which may be derived in course of the visualization/validation processing from the "ideal" signal data.

-> *OSMod directory:*

In case of `OSMod` these are one or more "Simulated Geometry Data" file(s) (`/OSMod/<task-id>_<occ-no>.sgd`; containing the quasi-realistic geometry data) and one or more "Simulated Signal Data" file(s) (`/OSMod/<task-id>_<occ-no>.ssd`; containing the quasi-realistic excess phase and amplitude data). One

file per simulated occ. event per file. The number of occ. events depends on the event sample size chosen by the User for the given task. The basic event samples for superposition of observational effects, both \*.sgd and \*.ssd files, are taken from /FoMod/<task-id>\_<occ-no>.sgd(.ssd) file samples prepared by an earlier FoMod task run (selected during OSMoD input). The directory will also contain all OSMoD "child"-files which may be derived in course of the visualization/validation processing from the quasi-realistic signal data.

-> *InRet* directory:

In case of InRet there are subdirectories for simulated data products (/SimData) and for observed GPS/MET data products (/GMDData) both with identical substructure. (Note: Other observed data can be included in the file structure in full analogy to GPS/MET data, e.g., Oersted/GPS data would get a directory /OGData.) The substructure provides, for both simulated and observed RO data processing, directories tailored to the seven derived basic data products: Doppler shifts (/Dopp), bending angles (/bend), refractivities (/refr), densities (/dens), pressures (/pres), temperatures (/temp), water vapor (/wvap), total electron content (/Itec). These contain the respective result files, one file per occ. event, from the InRet computational system. The basic result profiles are contained in <task-id>\_<occ-no>.<Par> files, where <Par> denotes one of "Dopp", "IDop", "Bend", "IBen", "Refr", "IRef", "Dens", "IDen", "Pres", "Temp", "Wvap", "Humi", "Itec"; "Wvap" (water vapor pressure) and "Humi" (specific humidity) which are both contained in the /wvap directory. The respective directories contain as well all the "child"-files, which may be derived from the basic result profiles of the parameters in course of the visualization/validation process.

For observed data processing (EGOPS GPS/MET data processing), where the original data (profiles of RO observables) always reside in a file structure external to EGOPS as the "EGOPS File Structure" Figure indicates, an additional subdirectory /PhAm is furnished (for GPS/MET data an /InRet/GMDData/PhAm directory). This holds, as basic result files, the observed geometry and signal data (files /PhAm/<task-id>\_<occ-no>.ogd and /PhAm/<task-id>\_<occ-no>.osd, respectively) in the EGOPS-internal geometry and signal data format. Also, the "child"-files of the observed phases and amplitudes find their place here.

The basic data for computation are taken by the InRet system, in case of simulated data, from /OSMod/<task-id>\_<occ-no>.sgd(.ssd) file samples prepared by an earlier OSMoD task run (selected during InRet input). In case observed GPS/MET data are processed, the basic data (UCAR/POCC level-2 data) are taken from the respective GPS/MET data directory assigned by the User (during InRet input).

Comparing, the "EGOPS File Structure" Figure 4-3 with the "Modular View" Figure 4-2 indicates that the design of the directory and file structure was developed under strict guidance by the implementation design, i.e., the modular structure of the software, and its control and data flow. Thus the file structure can be considered to support well the efforts for high usefulness and ReFlexPortEx of the whole EGOPS software package.

## **4.4 Mission Analysis/Planning**

### **GENERAL DESCRIPTION**

Mission Analysis/Planning (MAnPI) is considered to include the analysis and planning of single LEO satellites and LEO constellations carrying GNSS occultation receivers, including antennae field-of-view planning and analysis and visibility analysis w.r.t. ground stations, for assessing, investigating, and optimizing occultation event coverage and related relevant statistics. EGOPS includes also reflection data calculation scenarios whereby the reflection geometry GNSS satellite - water surface (normally the ocean or several huge lakes) acts like a big mirror for reflecting the GNSS radio signals to the LEO - LEO satellite.

Such analysis requires a considerable number of "free input parameters" in a simulation tool in order to allow for a (realistic) MAnPI simulation of widely arbitrary GNSS occultation missions. (See the section "MAnPI INPUT PARAMETERS" below for an overview on the respective functionality furnished by EGOPS.)

Furthermore, it is necessary to have convenient tools for visualization of the simulation results available in order to carry out simulation studies efficiently and in order to effectively comprehend and interpret the results. (See the section "MAnPI VISUALIZATION" below for a crude overview on the respective functionality furnished by EGOPS.)

### **MAnPI INPUT PARAMETERS**

EGOPS allows to compute Mission Analysis/Planning tasks taking into account the set of "free input parameters" outlined below, which all together provide considerable flexibility and potential for Mission Analysis/Planning. Nomen est omen all these parameters can be - within their range of validity - freely set by the User just as desired for a specific MAnPI task. The "MAnPI Input" window, available via the "Mission Analysis/Planning" entry of the "Task" menu, is the convenient interface EGOPS provides for the supply of all of these parameters (including the supply of a few input file names, providing for access to some more lengthy parameter lists required, e.g., satellite orbit elements).

- Data type Selection: Occultation or Reflection data calculation can be selected, the User I/F change for the different data types. For Reflection data selection the specular points at the ocean surface are calculated at user selected time steps. For Occultation data selection the satellite occultations are calculated at the desired height levels.

- Simulation time:  
Start date and time, and the total time range for a simulation.

- Height levels of interest:  
For each of such height levels (and for each occultation in the time range) the corresponding occultation geometry is computed, interpreting the height levels as those tangent point heights of an occultation event for which the geometric information is sought just at the instant when the levels are crossed. The essential geometric information is the corresponding geographic coordinates of the tangent point



together with the corresponding positions of the GNSS and LEO satellites involved in the occultation event. Height levels are only used for calculation of occultation data.

- Time steps:

Choose an integer divide of the simulation time range for the reflection data time step. Time steps are only used for reflection data calculation. For each time step the coordinates of the specular point at the ocean surface are computed.

- Geographic area of interest:

Global, hemispheric, or any regional area for which the coverage by occultation or reflection events is sought.

- GNSS-LEO/Reflection ray treatment:

Straight-line approximation of rays, or rays with quasi-realistic bending caused by the neutral atmosphere.

- Earth Figure model:

Spherical (R=6371km) or Ellipsoidal (WGS-84) Earth.

- Occultation/Reflection antennae specifications:

Antennae pointing and characteristics, including boresight direction and field-of-view width and shape, for "anti-velocity" looking and forward-looking antenna.

- Spaceborne receiver segment (LEO satellites):

Number and orbit constellation (i.e., orbit elements) of receiver platforms in LEO, and information on the LEO's zenith-antenna field-of-view. This information is supplied by the leo\*.tle files in the /orbitelem directory, one of which is always selected within the "MAnPI Input" window. [Read the tle.Help file in the /orbitelem directory for more information on how to supply this information for LEOs.]

- LEO orbit propagator:

Spherical orbit approximation, Keplerian orbit, or "Simplified General Perturbation (SGP)" orbit (the latter including short and long period perturbations and parameterized atmospheric drag).

- Active space segment (GNSS):

Number and orbit constellation (i.e., orbit elements) of the GNSS transmitters. Either GPS or GLONASS or both these GNSS systems are available for selection. This information is supplied by the gps\*.tle and glo\*.tle files in the /orbitelem directory of EGOPS, which are selected within the "MAnPI Input" window. [Read the tle.Help file in the /orbitelem directory for more information on how to supply this information for the GNSS.]

- GNSS orbit propagator:

Spherical orbit approximation, Keplerian orbit, or "Simplified General Perturbation (SGP)" orbit (the latter including short and long period perturbations and parameterized radiation/star drag).

- Ground segment (Fiducial and Tracking sites):

The number, location, and antenna field-of-view of auxiliary GNSS receiver sites for aiding the usual single- or double-difference processing of occultation data (fiducial sites), and the number, location,

and antenna field-of-view of ground stations for telemetry/telecommand (tracking sites). This information is supplied by fid\*.gst and trk\*.gst files, respectively, in the /groundst directory of EGOPS, which are selected within the "MAnPI input" window. [Read the gst.Help file in the /groundst directory for more information on how to supply this information on the sites.] Satellite visibility information is then computed for the fiducial and tracking stations, as necessary for assessing the visibility conditions for single- and/or double-differencing and tracking for a given scenario.

## **MAnPI VISUALIZATION**

EGOPS provides for the visualization of results of Mission Analysis/Planning tasks by its "Visualize MAnPI Statistics" and "Visualize Geographic Maps" window interfaces, both available through the "Visualize/Validate" menu. The "MAnPI Statistics" interface allows to compute, visualize, and print-out 1D and 2D occultation (reflection) coverage statistics as function of variables like latitude, Local Time, Duration of occultation Events, etc. Furthermore, it allows to compute, visualize, and print-out visibility statistics for fiducial and tracking sites, e.g., no. of occultation events for which successful single- or double-differencing is possible by each of a given sample of fiducial sites, or no. of orbits seen for a certain time range per orbit by each of a couple of tracking sites. Additionally it is also possible to display a global statistics in latitude and longitude bands about number of events per area, mean distances and rms of mean distances, or time separations and rms of time separations between events.

The "Geographic Maps" interface allows to compute, visualize, and print-out latitude-longitude maps (different map projections available) of occultation and reflection event coverage for arbitrary geographic areas and including information such as on the geometrical shape and time of each event. Furthermore, it allows to compute, visualize (stand-alone or as overplot to occultation event coverage maps), and print-out geographic maps of a series of atmospheric/ionospheric variables (e.g., temperature and electron density) from all atmospheric/ionospheric models available within EGOPS. These may either slice the atmospheric/ionospheric field at a certain height or be vertically integrated quantities (e.g., total precipitable water).

## **4.5 Forward Modeling**

### **GENERAL DESCRIPTION**

Forward Modeling (FoMod), together with subsequent Observation System Modeling (OSMod), performs quasi-realistic simulation of observables, and related required variables, of the GNSS occultation technique. The main observables are time-tagged phase and amplitude measurements, obtained in real world by tracking occulted GNSS signals with a LEO or Airborne platform mounted GNSS receiver for atmospheric sounding (GRAS) during their set/rise through the atmosphere imposed by the relative orbital motion of the GNSS and LEO satellites or the tracks of airborne receivers.

Forward Modeling itself denotes the simulation of GNSS signal propagation through the atmosphere/ionosphere system given the orbital motions of the GNSS and LEO satellites or airborne GNSS receivers. It results in "ideal" signals which contain the effects of the atmosphere/ionosphere media only. - "Ideal" in the sense that it is the state of the signal right before it enters the receiving antenna and before any degradations by the receiving system are incurred. Thus FoMod results allow to inspect the environmental influence alone.

Furthermore, it is quite useful in terms of computational performance to separate FoMod, involving CPU-expensive propagation simulation (i.e., ray tracing) from OSMod, since the latter can be treated very efficiently as superposition of "observation system" effects on the "ideal" signal. Thus studies of different receiving system effects can be efficiently carried out using one and the same CPU-expensive FoMod results as baseline.

In case of interest in observation simulations, Forward Modeling is the natural stage in EGOPS following some planning and preparation of occultation events with desired properties within "Mission Analysis/Planning (MAnPI)" (e.g., events occurring in a geographic region of interest, etc.). In fact the geometric properties (i.e., LEO and GNSS orbital arcs) of an occultation event being "forward modeled" can be, in case simulations are desired for realistic geometry, directly taken from the results of a User-selected MAnPI task (typically prepared before). In contrast to the spaceborne case, the geometry analysis of airborne occultation simulations is prepared in a special FoMod-PopUp-Window directly. Such forward modeling requires a considerable number of "free input parameters" in a simulation tool in order to allow for a (realistic) FoMod simulation of widely arbitrary GNSS occultation missions. (See the section "FoMod INPUT PARAMETERS" below for an overview on the respective functionality furnished by EGOPS.)

Furthermore, it is necessary to have convenient tools for visualization and validation of the simulation results available in order to carry out simulation studies efficiently and in order to effectively comprehend and interpret the results. (See the section "FoMod VISUALIZATION" below for a crude overview on the respective functionality furnished by EGOPS.)

## **FoMod INPUT PARAMETERS**

EGOPS allows to compute Forward Modeling tasks taking into account the set of "free input parameters" outlined below, which altogether provide considerable flexibility and potential for Forward Modeling. Nomen est omen all these parameters can be - within their range of validity - freely set by the User just as desired for a specific FoMod task. The "FoMod Input" window, available via the "Forward Modeling" entry of the "Task" menu, is the convenient interface EGOPS provides for the supply of all of these parameters (including the supply of a "Reference MAnPI Task-id" in case simulations are desired for realistic geometry, providing for access to the input conditions and results of a prior MAnPI task).

- Type of occultation event to be simulated: A single event or a whole sample of events can be „forward modeled“, whereby single events (spaceborne or airborne) can be simulated either for an ideal geometry (assuming co-planar GNSS and LEO orbits or aircraft trajectories and, correspondingly, virtually-vertical tangent point trajectory) or for a realistic geometry (based on the geometry data obtained for a result event of a prior MAnPI task). Sample-of-event simulations (spaceborne only) always require event samples from a prior MAnPI task.
- Specifications for modeling a single event with ideal geometry: Tangent point location, azimuth of occultation plane (containing GNSS, LEO or aircraft, and the Earth's center), start date and time, GNSS and LEO orbital heights or aircraft flight altitudes, and height range over which the occultation event shall be „forward modeled“.
- Specifications for modeling with realistic geometry: Reference MAnPI Task-id (to be selected from the list of suitable MAnPI tasks existing within the current Project in case of a spaceborne occultation event), event number of desired event within the MAnPI results (if single event) or event number range within the MAnPI results (if sample of events), and height range over which the event(s) shall be „forward modeled“.
- Choice of atmospheric and ionospheric models:
  - Climatological atmospheric model: No atmosphere, or simple dry or moist (bi-)exponential atmosphere, or dry 3D atmosphere, or dry or moist 2D atmosphere, or the GSM 3D Atmosphere, or the HiVRes Atmosphere, or a user-supplied atmosphere (default for the latter: the bi-exponential atmosphere). [If you have a source-code version of EGOPS, please read the file `usratm.SampleFile` in the `/prog/FORprog` subdirectory of EGOPS in case you want to learn more about how to supply your own user-supplied atmosphere.]
  - Atmospheric disturbance model: No disturbance, or gravity wave superposed, or frontal system gradient superposed, or tropopause fold superposed, or atmospheric inversion superposed.
  - Climatological ionospheric model: No ionosphere, or simple double-Chapman ionosphere, or full 3D ionosphere.

- Ionospheric disturbance model: No disturbance, or traveling ionospheric disturbance (TID) superposed, or ionos. gradient superposed, or ionos. trough superposed, or ionos.storm effect superposed.

- Sampling rates for forward modeling: 500 Hz, 250 Hz, 100 Hz, 50Hz, or 25 Hz, or 10 Hz, or 5 Hz, or 1 Hz, or 0.1 Hz for the L1 frequency (in case of airborne simulations, only 5 Hz, 1 Hz or 0.1 Hz are allowed), and, for the L2 frequency, one rate of the above which is equally high or lower than the L1 rate. In case of modeling a sample of events including GPS and GLONASS events, the L2 rate for GLONASS can be set to a different rate than L2/GPS.

- Signal propagation simulator:

Quasi-3D ray tracing (considering, in terms of refractivity gradients, the radial gradient only), full-3D ray tracing (accounting for the full-3D refractivity gradient field), or wave optics propagator (for a more realistic computation dealing with diffraction and multipath effects). Accuracy of ray-tracing from GNSS to LEO can be set to be  $<\sim 1$  mm, or  $<\sim 1$  cm, or  $<\sim 10$  cm (less demanding accuracy allowing faster computations but yielding more inaccurate simulated phase observables) for the first two signal propagation simulators whereas the accuracy for the wave optics propagator can be set to be 'Basic', 'Advanced', or 'Highest'.

## **FoMod VISUALIZATION**

EGOPS provides for the visualization of results of Forward Modeling tasks by its "Visualize/Validate Profiles" window interface available via the "Visualize/Validate" menu.

The "Visualize/Validate Profiles" window interface allows, for FoMod tasks, to post-process, visualize, customize, compare, and print-out simulated phase and amplitude data (in terms of "atmospheric(/ionospheric) excess phase" and "atmospheric(/ionospheric) power loss") as function of occultation event time. The excess phase data at the L1 and L2 frequencies as well as the LC data (neutral atmosphere only after linear ionospheric combination of L1/L2 phases) and LI data (ionosphere only at L1) are all available for visualization and inspection, stand-alone or in combinations.

The post-processing includes functionality to compute absolute and relative difference profiles between profiles of different FoMod tasks or within a sample of events as well as profile statistics (mean and standard deviation profiles) for samples of events.

- Customization includes, among other features, functionality to fit an exponential or polynomial of user-specified order to a selected range of a profile or to compute the time average value over a selected range of a profile (and to visualize this information by overplot on the original profile).

## **4.6 Observation System Modeling**

### **GENERAL DESCRIPTION**

Observation System Modeling (OSMod), together with prior Forward Modeling (FoMod), performs quasi-realistic simulation of observables and related required variables of the GNSS occultation technique. The main observables are time-tagged phase and amplitude measurements, obtained in real world by tracking occulted GNSS signals with a LEO or airborne platform-mounted GNSS receiver for atmospheric sounding (GRAS) during their setting/rising events through the atmosphere imposed by the relative orbital motion of the GNSS and LEO satellites or airborne receivers.

Observation System Modeling itself denotes the superposition of all sorts of relevant physical and technical influences of the observation system (antenna, receiver, platform, fiducial sites) on the „ideal“ signal (phase and amplitude data) arriving at the receiving antenna, and on the „ideal“ orbit data (GNSS and LEO or aircraft positions and velocities). In fact these „ideal“ data are the output of Forward Modeling, a necessary prerequisite to be performed before Observation System Modeling can be done.

Many of the effects of the observation system correspond to the „classical“ sort of instrumental errors (e.g., receiver noise), others are intrinsic natural parts of the receiving system (e.g., effect of the antenna gain pattern on the signal amplitude finally available). The most relevant observation system effects to be modeled include precise orbit determination (POD) errors, the antennae gain pattern, receiver noise, local multipath (due to the platform structure in the vicinity of the antenna), and differencing treatment/clocks precision.

Such observation system modeling requires a considerable number of „free input parameters“ in a simulation tool in order to allow for a (realistic) OSMod simulation of widely arbitrary GNSS occultation missions. (See the section „OSMod INPUT PARAMETERS“ below for an overview on the respective functionality furnished by EGOPS.)

Furthermore, it is necessary to have convenient tools for visualization and validation of the simulation results available in order to carry out simulation studies efficiently and in order to effectively comprehend and interpret the results. (See the section „OSMod VISUALIZATION“ below for a crude overview on the respective functionality furnished by EGOPS.)

### **OSMod INPUT PARAMETERS**

EGOPS allows to compute Observation System Modeling tasks taking into account the set of „free input parameters“ outlined below, which altogether provide considerable flexibility and potential for Observation System Modeling. Nomen est omen all these parameters can be - within their range of validity - freely set by the User just as desired for a specific OSMod task. The „OSMod Input“ window, available via the „Observation System Modeling“ entry of the „Task“ menu, is the convenient interface EGOPS provides for the supply of all of these parameters (including the supply of a „Reference FoMod Task-id“, providing for access to the input conditions and results of a prior FoMod task).

- Forward modeling occultation event(s) selection: Reference FoMod Task-id (to be selected from the

list of suitable FoMod tasks existing within the current Project). Also, in case a sample of events is available for the selected Reference FoMod task, event number range (or individual event number) of desired event(s) within the available FoMod events.

- Receiver sampling rates: Default are the FoMod sampling rates for L1 and L2 frequency (one of 50 Hz, 25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.1 Hz; with L2 rate less equal L1 rate). Now, the receiver's L1 rate needs be less equal the FoMod L1 rate, and the receiver's L2 rate needs, in turn, be less equal the receiver's L1 rate.
- Transmitter signal powers: For GPS or GLONASS system L1-C/A and L2-P can be specified.
- POD error modeling: No POD errors, or use a „kinematic“ POD error model. (The latter model mimics POD position errors mainly by considering radial GNSS and LEO position errors, POD velocity errors by considering along-ray velocity bias and drift errors (superposed to the „ideal“ LEO velocity), and POD-induced excess phase errors by considering along-ray excess phase drift and acceleration errors incurred by along-ray velocity bias and drift errors.)
- Occultation antennae specifications: Antennae pointing and pattern characteristics, including boresight direction, field-of-view width and shape, and antenna gain at boresight (at GPS/L1 frequency), for „anti-velocity“ looking and forward-looking antenna. The availability of a specific one of the antennae or of both depends on the type of occultation event(s) baselined via the selection of the Reference FoMod task (e.g., if a single occultation event was baselined, only the „anti-velocity“ antenna will be available).
- Receiving system simulator type: Selection between Parameterized- or Realistic Receiving System Simulator has to be made.

For the Parameterized Receiving System Simulator, the following input parameters are available:

- Receiver performance/noise modeling specifications: No receiver noise, or Gaussian noise, or realistic performance/noise can be selected, with the following specifications of the latter two:
  - Gaussian noise model: RMS (root-mean-square) value of the Gaussian phase noise (thermal noise).
  - Realistic performance/noise model: Loop bandwidth (single-sided), LEO antennae noise temperature, and number of quantization levels in A/D conversion.
- Local multipath modeling specifications No local multipath, or sinusoidal local multipath, multiple sines multipath, or realistic local multipath can be selected, with the following specifications of the latter three:
  - Sinusoidal multipath model: Period of the phase error, amplitude of the phase error, and (initialization) amplitude of the phase error at the topmost height of the occultation event (a maximum of 4 sines can be superposed).
  - Multiple sines model: The same specifications as of the sinusoidal multipath model, but up to 4 individual sines can be chosen for calculation.

- Realistic multipath model: Ratio of multipath signal to direct signal, and source location (i.e., reflection point) of the multipath signal in (spherical) antenna coordinates.
- Differencing treatment and clocks modeling specifications: No differencing/perfect clocks, or no differencing/real clocks, or double differencing, or ground-based single differencing, or spacebased single differencing, with the following specifications of the latter four:
  - No differencing/real clocks: Relative stability of GNSS clock (assumed the worst clock in case of no differencing with real clocks involved).
  - Double differencing: Relative stability of ground clock (assumed the worst clock in case of double differencing), and atmospheric noise per ground-to-satellite link involved in the differencing (this noise considered as clock-like noise).
  - Ground-based single differencing: Relative stability of LEO clock (assumed the worst clock in case of ground-based single differencing), and atmospheric noise per ground- to-satellite link involved in the differencing.
  - Space-based single differencing: Relative stability of LEO clock (assumed the worst clock in case of space-based single differencing).

For the Realistic Receiving System Simulator, the following input parameters are available:

- GRAS Antenna Specifications – Antenna Pattern Files: It is possible to select between two different antenna pattern files or user-supplied ones if available. Also the random number seed can be specified.
- Technical Specifications: Selection of System Noise Temperature, Number of interfering GPS satellites, Implementation Loss, Antenna Internal Loss and Interference Misalign Loss can be set.
- Loop Specifications: Activation of Open Loop or Closed Loop Tracking (with Open Loop Tracking, two atmospheric models are available), Loop Period Values and Start Time of 2<sup>nd</sup> Value are required.
- Frequency Locked Loop Specifications: Stop Time and Filter Order can be set.
- Filter Specifications: The technical specifications for the L1 and CA Filter are to be selected (Filter Type and Filter Order, Bandwidth values and Start Time of 2<sup>nd</sup> Value).

### **OSMod VISUALIZATION:**

EGOPS provides for the visualization of results of Observation System Modeling tasks by its „Visualize/Validate Profiles“ window interface available via the „Visualize/Validate“ menu.

The „Visualize/Validate Profiles“ window interface allows, for OSMod tasks, to post-process, visualize, customize, compare, and print-out simulated phase and amplitude data (in terms of „observed excess phase“ and „observed power“, „observed“ here in the sense of end-to-end simulated observables) as function of occultation event time. The excess phase data at the L1 and L2 frequencies as well as the LC data (neutral atmosphere only after linear ionospheric combination of L1/L2 phases) and LI data



(ionosphere only at L1) are all available for visualization and inspection, stand-alone or in combinations.

The post-processing includes functionality to compute absolute and relative difference profiles between profiles of different OSMod tasks or within a sample of events as well as profile statistics (mean and standard deviation profiles) for samples of events.

Customization includes, among other features, functionality to fit an exponential or polynomial of user-specified order to a selected range of a profile or to compute the time average value over a selected range of a profile (and to visualize this information by overplot on the original profile).

## **4.7 Occultation Data Inversion/Retrieval**

### **GENERAL DESCRIPTION**

Inversion/Retrieval of occultation data denotes the processing of simulated or observed phase and amplitude data (supplemented by the necessary geometrical information) typically via Doppler shifts and bending angles down to quasi-vertical atmospheric profiles of refractivity, density, pressure, temperature, and humidity.

This processing chain typically requires, sequentially, tools for ionospheric correction and conversion of the „raw“ excess phase observables to neutral-atmospheric bending angle profiles, for inversion of bending angle profiles into refractivity profiles („Inverse Abel Transform“), and for finally retrieving the atmospheric variables (e.g., temperature) from refractivity. The air (in the troposphere) may be considered either dry or moist in the last stage of this processing chain.

Another route of inversion (possible within EGOPS), directly leading from the raw observables to refractivity, is „Inverse Fresnel Transform“: This method is CPU-expensive but exploits both phase and amplitude observables to resolve small-scale structures in the troposphere (down to the 100 m level), which are convolved in the observables due to atmospheric diffraction. For the „Inverse Abel Transform“, the resolution is "diffraction-limited" at the "Fresnel-scale" (being somewhat less than 1 km in the Earth's troposphere).

Necessary prerequisites for inversion/retrieval are either simulated observables, obtained by Observation System Modeling (OSMod) within EGOPS, or genuine observed phase and amplitude data (e.g. from the GPS/MET or CHAMP experiment).

Such occultation data inversion/retrieval requires a considerable number of „free input parameters“ in a simulation tool in order to allow for flexible data processing of widely arbitrary simulated GNSS occultation missions as well as for observed data. (See the section „InRet INPUT PARAMETERS“ below for an overview on the respective functionality furnished by EGOPS.)

Furthermore, it is necessary to have convenient tools for visualization and validation of the simulation results available in order to carry out simulation studies efficiently and in order to effectively comprehend and interpret the results. (See the section „InRet VISUALIZATION“ below for a crude overview on the respective functionality furnished by EGOPS.)

### **InRet INPUT PARAMETERS**

EGOPS allows to compute Occ. Data Inversion/Retrieval tasks taking into account the set of „free input parameters“ outlined below, which altogether provide considerable flexibility and potential for Occultation Data Inversion/Retrieval. Nomen est omen all these parameters can be - within their range of validity - freely set by the User just as desired for a specific InRet task. The „InRet Input“ window, available via the „Occ. Data Inv./Retrieval“ entry of the „Task“ menu, is the convenient interface EGOPS provides for the supply of all of these parameters (including either the supply of a „Reference OSMod Task-id“, providing for access to the input conditions and results of a prior OSMod task, or,

alternatively, including the supply of a „GPS/MET data path“, providing for access to User-prepared GPS/MET data files.)

- Type of occultation data to be processed: Simulated data (prepared by prior OSMod tasks run within EGOPS), or GPS/MET data (prepared by the User in a directory to which at least read-access exists from the EGOPS installation; mandatory file format: the „UCAR Level 2 data“ format).

- Occultation event(s) selection in case of simulated data: Reference OSMod Task-id (to be selected from the list of suitable OSMod tasks existing within the current Project). Also, in case a sample of events is available for the selected Reference OSMod task, event number range (or individual event number) of desired event(s) within the available OSMod events.

- Occultation event(s) selection in case of GPS/MET data: GPS/MET data path (full directory path of the directory where the desired GPS/MET data reside, e.g., /home/<usr>/gpsmet/level2/occ/95.294/). Also, in case a sample of events is available within the selected GPS/MET data directory, event number range (or individual event number) of desired event(s) within the available GPS/MET events.

- Choice of Retrieval Processing Specifications: "General Atmospheric Processing" (default) for General Phase/Power-to-Refractivity Processing, or "Atmospheric Inverse Fresnel Transform", or "Ionosphere Processing", where the first selection allows the following further choices:

- Choice of Bending Angle Retrieval Specifications: For bending angle retrieval, "IAP Differential Correction & Ionosphere Correction & Bending Angle Retrieval", "IGAM/UG Ionosphere Correction & Bending Angle Retrieval" (the latter being the default), "DMI Standard Ionosphere Correction & Bending Angle Retrieval", or "DMI Enhanced Ionosphere Correction & Bending Angle Retrieval". For IAP Diff. Corr. & Ion. Corr. & Bend. Angle Retrieval "No Diff. Correction", or "Diff. Correction" is possible for the Diff. Correction Type (in case of "Diff. Correction" the value of the Local Backpropagation Plane can be set). For IGAM/UG Ion. Corr. & Bend. Angle Retrieval and DMI Enhanced Ion. Corr. & Bend. Angle Retrieval the Ion. Correction Type can be varied between "Phase Correction" and "Bend. Angle Correction", whereas the Stat. Optimization Type can be chosen amongst "No Stat. Optimization", "Optimize invoking MSIS90\_DMI", "Optimize invoking CIRA86aQ\_UoG" in the first case and amongst "No Stat. Optimization", "Optimize using m+z BenA Search", and "Optimize using glob. BenA Search" in the latter case (for DMI Standard Ion. Corr. & Bend. Angle Retrieval both the Ion. Correction Type and the Stat. Optimization Type are insensitive).

- Refractivity Profiles Retrieval Specifications: For the Refractivity Profiles Retrieval/Inversion Tool, "No Atmospheric Refractivity Profiles Retrieval", or "DMI Abel Transform Atmos. Refractivity Profiles Retrieval" are possible.

- Retrieval tools in case of Atmospheric Inverse Fresnel Transform: For Atm. Inverse Fresnel Transform the Bending Angle Retrieval Tool is n/a and the Ion. Correction Type and the Stat. Optimization Type are also insensitive. The only allowed Refractivity Profiles Retrieval/Inversion Tool is "DMI Inverse Fresnel Refractivity Profiles Retrieval".

- Retrieval tools in case of Ionosphere Processing: For Ionosphere Processing the Bending Angle Retrieval Tool is constraint to "DMI Ionospheric Bending Angle Retrieval" and the Ion. Correction Type and the Stat. Optimization Type are insensitive. For the Refractivity Profiles Retrieval/Inversion

Tool "No Ionospheric Refractivity Profiles Retrieval" or "DMI Abel Transform Ionos. Refractivity Profiles Retrieval" is allowed.

- Choice of Atmospheric Profiles Retrieval Specifications:

- For the type of Atmospheric Profile Retrieval Tool: "No atmospheric profiles retrieval", or "DMI dry air profiles retrieval" (basic default), or "DMI/IGAM moist air profiles retrieval", where the latter selection allows the following further choices:

- For the type of moist air retrieval: "q, e, p, rho, T prescribed (It)", "q, e, p, rho, T prescribed (In)", "q, e, rho with p, T prescribed", "T, e, p, rho with q prescribed (In)", "T, e, rho with p, q prescribed" or "T, q, e, p, rho by Optimal Estimation Retrieval". The later has the following input parameters: Observation and Forward Modeling Error Covariance Matrix Specifications (with Refractivity RMS Uncertainty, Vertical Correlation Length of Refractivity Errors) and Background (T, q) Error Covariance Matrix Specifications (with Temperature and Humidity RMS Uncertainty, Vertical Correlation Length of Temperature and Humidity Errors).

- Atmospheric model used for prescribed parameters: "FoMod atmosphere" (default in case of simulated data, meaning the atmosphere used in the "forward modeling" of the simulated observables), or "Bi-Exponential atmosphere", or "HLat 2D Atmosphere (CIRA86aQ\_UoG)" (default in case of GPS/MET data), or the "(Moist) GCM 3D Atmosphere (GCM3DAtm)", or "(Moist) HiVRes Atmosphere (HiVResAtm)", or a "(Moist) User-supplied Atmosphere" (if moist air included in this atmosphere). [If you have a source-code version of EGOPS read the file `usratm.SampleFile` in the `/prog/FORprog` subdirectory of EGOPS in case you want to learn more about how to supply your own user-supplied atmosphere.]

- Choice of Ionospheric Profiles Retrieval Specifications (only possible in case of Ionosphere Processing):

- For the Ionospheric Profile Retrieval Tool: "No Ionosphere Profiles Retrieval", or "Electron Density Profiles Retrieval" are possible for selection.

## **InRet VISUALIZATION**

EGOPS provides for the visualization of results of Occ. Data Inversion/Retrieval tasks by its „Visualize/Validate Profiles“ window interface available via the „Visualize/Validate“ menu.

The „Visualize/Validate Profiles“ window interface allows, for InRet tasks, to post-process, validate against reference data, visualize, customize, compare, and print-out simulated or observed Doppler shift profiles (as function of occ. event time), bending angle profiles (as function of impact parameter), and refractivity, density, pressure, temperature, water vapor, and specific humidity profiles (as function of height). Also, in case of GPS/MET or CHAMP data, the original phase and amplitude data can be visualized (as function of occ. event time). The GPS/MET or CHAMP excess phase data at the L1 and L2 frequencies as well as the LC data (neutral atmosphere only after linear ionospheric combination of L1/L2 phases) and LI data (ionosphere only at L1) are all available for visualization and inspection, stand-alone or in combinations.

The post-processing includes functionality to compute absolute and relative difference profiles between profiles of different InRet tasks or within a sample of events as well as profile statistics (mean and standard deviation profiles) for samples of events. Furthermore, reference „ground-truth“ profiles of refractivity, density, pressure, temperature, water vapor, and specific humidity can be prepared with any available atmospheric model within EGOPS, at the tangent point locations of the retrievals. Absolute and relative difference profiles w.r.t. these reference profiles can then be computed, as well as difference profiles statistics (mean difference to „ground-truth“ and standard deviations compared to „ground-truth“) for samples of events.

Customization includes, among other features, functionality to fit an exponential or polynomial of user-specified order to a selected range of a profile or to compute the time average value over a selected range of a profile (and to visualize this information by overplot on the original profile).

## **4.8 Other EGOPS Documentation**

### **BACKGROUND DOCUMENTATION**

For learning about the functionality furnished by EGOPS and for getting an overview on its background, rationale, requirements, and implementation the following reports are useful (available via the International EGOPS Maintenance Center at IGAM/UG):

- Kirchengast, G.**, End-to-end GNSS Occultation Performance Simulator functionality definition, *Techn. Rep. for ESA/ESTEC No. 1/'96*, 25p., Inst. Meteorol. Geophys., Univ. of Graz, Austria, 1996.
- Kirchengast, G.**, End-to-end GNSS Occultation Performance Simulator overview and exemplary applications, *Wissenschaftl. Ber. No. 2/1998*, 138p. (Part I – III), Inst. Meteorol. Geophys., Univ. of Graz, Austria, 1998.

A detailed formal (development team internal) summary of all requirements on the EGOPS S/W is the EGOPS User & Software Requirements document (URD/SRD) which, in turn, formed the basis for the S/W design described in an Architectural & Detailed Design document (ADD/DDD).

The latter comprehensive technical document, held in form of a package of pdf files in an EGOPS4\_ADD-DDD.zip archive file, provides a rather detailed description of the EGOPS4 software. This is of interest to (expert) Users only needing to get very closely acquainted with technical details of the software. The EGOPS4 ADD/DDD is nominally not made available to Users but parts of it may be available in fulfilment of specific needs of qualified users (on a case by case basis).

## **5 EGOPS Setup and Use**

### **5.1 EGOPS Installation Guidelines**

#### **5.1.1 Installation Prerequisites**

Hardware:

- Minimum requirements: Unix-based workstation or Linux-based PC with at least 170MHz CPU clock rate, 128MB Ram, 1GB free hard disk space, disk access times of near 10msec, screen resolution of at least 1152x900 pixels, mouse device.
- Recommended hardware performance: 300MHz CPU clock rate or higher, 256MB Ram or higher, 4GB free hard disk space or more, disk access times < 10msec, screen resolution of 1280x1024 pixels or higher, 3-keys mouse device.

Software:

- Unix or Linux operating system; CDE (Common Desktop Environment), KDE (the CDE-like K Desktop Environment under Linux), GNOME (GNOME Desktop Environment under Linux), OpenWindows or Modif window-based interface; FORTRAN-95 compiler or FORTRAN-90 compiler (for PC/Linux: NAGWare F95 was confirmed to work fine); IDL (Interactive Data Language) license, version IDL 5.4 or higher (Developer's version for EGOPS4: IDL 5.4/Solaris and IDL 5.4/Linux). For EGOPS4.0/Rel#2 run-time versions IDL 5.4 is required, too.

Remarks:

- The baseline workstations (and development platforms) for EGOPS4.0 are SUNSparc workstations operated under Solaris 7 (Unix V5, Release 4 standard), using CDE (Common Desktop Environment) as interface, a Fujitsu FORTRAN-95 compiler or NAG FORTRAN-90 compiler (both worked fine) and IDL version IDL 5.4.
- The baseline PCs (and Linux-portability testbed platforms) for EGOPS4.0 are Pentium-II PCs (733 MHz and 350 MHz) operated under Linux Kernel 2.4.4 (product SuSE 7.2), using KDE 2.1.2, NAGWare FORTRAN-95 Linux compiler and IDL version IDL 5.4.
- In addition, the EGOPS4.0 software was installed, compiled and run on a Silicon Graphics workstation under Irix 6.5 operating system and employing an SGI F90 compiler and IDL 5.4. It was found to work fine on this platform as well.
- The previous-version software - EGOPS3.0 - was, furthermore, installed, compiled and run on a DEC/Alpha workstation under DEC Unix and employing a DEC FORTRAN-95 compiler and IDL 5.3.

It was found to work fine. There was not yet a chance to test the EGOPS4.0 software on this type of workstation but no major problems are expected if done so.

### **5.1.2 The EGOPS Software Package**

You should have received:

- A binary compressed archive file named EGOPS<version>-<yyyymmdd>.tar.gz; for the current version the name is EGOPsv40-20020301.tar.gz, or EGOPsv40rtsun-20020301.tar.gz, or EGOPsv40rtlin-20020301.tar.gz, or EGOPsv40rtsgi-20020301.tar.gz, respectively. (Version EGOPS V4.0, Release#2, March 1, 2002.) This archive file contains the entire EGOPS software package.
- A binary compressed archive file named EGOPS4\_SUM-Issue<n>.tar.gz; for the current version the name is EGOPS4\_SUM-Issue2.tar.gz. This archive file contains the EGOPS, Version 4, Software User Manual in form of a pdf file package comprising an overview and a reference manual part (EGOPS\_SUM-OV.pdf & EGOPS\_SUM-REF.pdf).
- An ASCII text file named EGOPS.ReadMe[\_v40-20020301].

Remarks:

The difference between "EGOPsv40...", "EGOPsv40rtsun...", "EGOPsv40rtlin...", and "EGOPsv40rtsgi..." is that "EGOPsv40..." contains the full IDL/FORTRAN(/C) source code, "EGOPsv40rtsun..." is a run-time version for SUNSparc/Solaris systems, "EGOPsv40rtlin..." is a run-time version for PC/Linux systems, and "EGOPsv40rtsgi..." is a run-time version for Silicon Graphics/Irix systems (all three run-time versions containing no IDL/FORTRAN(/C) source code). It depends on your license agreement and the system information you have supplied, which version you received.



### **5.1.3 Installation Procedure**

Proceed, step-by-step, as follows (slight alterations will work but be sure your expertise suffices for "extra trips"):

1) Select (or create) a directory below which you desire to install EGOPS. The EGOPS root directory /EGOPS, below which all the EGOPS software resides, will then be created as a subdirectory of this directory. (Example: Selecting the directory /home/usr/softw would lead to installation of EGOPS under the directory /home/usr/softw/EGOPS.)

2) Place the file EGOPS<version>-<yyyymmdd>.tar.gz into the selected directory. Place yourself, within your console window (shelltool), into the selected directory, too. (Example: Copy the file EGOPS<version>-<yyyymmdd>.tar.gz to the directory /home/usr/softw. Residing in /home/usr, the command "cd softw" places you into the directory /home/usr/softw.)

3) Unzip EGOPS<version>-<yyyymmdd>.tar.gz to recreate the file EGOPS<version>-<yyyymmdd>.tar (Example: The command "gzip -d EGOPS<version>-<yyyymmdd>.tar" will recreate the file EGOPS<version>-<yyyymmdd>.tar from EGOPS<version>-<yyyymmdd>.tar.gz.)

(Note#1: On Linux-based machines complete unpacking can be done directly by "tar xvfz EGOPS<version>-<yyyymmdd>.tar.gz" and step 4 can be skipped.)

(Note#2: If this EGOPS4 installation is to supersede an existing EGOPS3 installation, delete in advance of this step 3 the full contents of the EGOPS3 /EGOPS/prog directory, i.e., all 3 subdirectories plus contents. See the "EGOPS Upgrade Notes" section below for reasons.)

4) Expand EGOPS<version>-<yyyymmdd>.tar to get an installation of the entire software package under the subdirectory /EGOPS, which is created in the directory, where the EGOPS<version>-<yyyymmdd>.tar file is expanded. (Example: The command "tar xvf EGOPS<version>-<yyyymmdd>.tar" will install the entire software package.)

5) Change to the EGOPS root directory /EGOPS and confirm that you find there the files EGOPS.ReadMe, EGOPS.FAQs, EGOPS.RunMe and EGOPS.ini together with the subdirectories /prog, /EGOPSProject, /genPSfiles, /antpattern, /groundst, /orbitelem, /projshelf and /referdata.

/prog ... Contains EGOPS IDL programs (including source code or not) under /prog/IDLprog, EGOPS FORTRAN programs (including source code or not) under /prog/FORprog, and EGOPS Help text files under /prog/txtfiles.

/EGOPSProject ... Is the directory containing all information on the default project intrinsic to EGOPS (EGOPS work is organized in User-defined "Projects"; you will learn about this when starting work.) There is a fixed directory substructure below all such project directories of which you can learn by, e.g., inspecting the /EGOPSProject substructure.

/genPSfiles ... Contains PostScript files which will be generated during EGOPS work, which are not related to any "Project". (Note: This directory may be empty; if it even does not exist - can happen if you supersede an existing EGOPS2 installation - it will be automatically generated by EGOPS during the first run.)

/antpattern ... Contains files characterizing the antenna pattern of the so-called Realistic Receiving System Simulator.

- /groundst ... Contains files characterizing samples of ground stations (their location, etc.), which are available for EGOPS.
- /orbitelem ... Contains files holding orbital elements of samples of satellites, which are available for EGOPS.
- /projshelf ... Contains all archived and zipped EGOPS Projects.
- /referdata ... Contains geographic map data (under /referdata/mapsdata) and 3D "volume" data (under /referdata/volumdata) of atmospheric/ionospheric field variables, which are available for EGOPS.

6) Now start EGOPS. Change, in your console window, to the EGOPS root directory /EGOPS. This directory contains the EGOPS startup shellscript EGOPS.RunMe . Execute this script by entering './EGOPS.RunMe'. (For detailed guidelines on Starting and Exiting EGOPS, please see [Chapter 5](#) titled "EGOPS Setup and Use" .) Confirm that the following happens: The main-level window interface pops up containing at the top the main-level menu bar with its menus "Project", "Task", "Visualize/Validate", and "Help". The window itself shows the "EGOPS logo" (red letters over a blue/white image of the limb area of a cloud-covered Earth). A mini-animation of a satellite pass over the Earth in the image is seen during pop-up (Note: If the machine provides very fast graphics handling, it is possible that the mini-animation cannot be seen or just as one fast flicker.)

In case step 6 failed and you only got, instead of the EGOPS User I/F popping up, a message window as follows

<b>! EGOPS4 Authorization Failure !</b>
User: <user name> Host.Domain: <host.domain name> not authorized for EGOPS4 installation. If you hold a valid license this could be due to some installation problem, otherwise the reason is that you are not licensed for using EGOPS4. In either case please contact the International EGOPS Maintenance Center (IEMC) hosted by IGAM/UG Graz, Austria, for support and information. IEMC point of contact: Gottfried Kirchengast Director, International EGOPS Maintenance Center (IEMC) Institute for Geophysics, Astrophysics and Meteorology University of Graz Universitaetsplatz 5 A-8010 Graz, Austria Fax: +43-316-380-9825 E-Mail: <a href="mailto:gottfried.kirchengast@uni-graz.at">gottfried.kirchengast@uni-graz.at</a>

then your further actions should be clear from the contents of this message. In case you could proceed without problems down to this point your installation was basically successful. What is not yet tested is whether the FORTRAN executables work properly. You can test this following step 7 below.

- 7) a) Select the menu entry "Project - Open..." and give "Ok" in the pop-up window appearing. (Now the "EGOPSProject" is assigned as current project.)
- b) Select the menu entry "Task - Mission Analysis/Planning" and supply, in the pop-up window appearing, the Task-id "MAnPIConfirm" to the field "MAnPI/Task-id:" at the top line. Close this input by a <CR> (to finally deliver it to the system). Then press "Save&Compute" in the bottom line. (This starts FORTRAN computations.)
- c) Successful completion of the computations will be notified after a short time; confirm in the small pop-up window with "Ok" and then press "Quit" in the big pop-up window, which leads you back to the main-level. (The result data of these computations are now created.)
- d) Change (best with your file manager tool or within "xemacs" if you are lucky user of this highly recommended latter tool) to the subdirectory /EGOPSProject/MAnPI and confirm, by one-to-one comparison (e.g. in your text editor or, if you are lucky, conveniently within "xemacs"), that the files MAnPIdefault.sgd and MAnPIConfirm.sgd, as well as MAnPIdefault.vis and MAnPIConfirm.vis, are identical (except for rounding error in the last digit, maybe).
- e) Delete your test files MAnPIConfirm.sgd, MAnPIConfirm.vis, and MAnPIConfirm.inp in the subdirectory /EGOPSProject/MAnPI. (It is recommended that you start your own work with launching your own separate EGOPS Projects and not utilize "EGOPSProject".

In case you could complete also step 7 successfully it is virtually sure that your EGOPS installation will work smoothly in its entirety. You can skip the following item 8 in this case. In case you were successful down to item 6 but failed with item 7, follow item 8 below.

8) In case you have a run-time license (no FORTRAN source code) contact the IEMC at IGAM/UG at the address given in [Appendix C](#).

In case you have the FORTRAN source code included (being qualified Science-User Licensee), proceed as follows:

8a) Change, in your console window, to the FORTRAN program subdirectory /prog/FORprog.

8b) The default FORTRAN "Makefile" in this directory is "Makefile-NAG95Lin" (settings for the NAGware F95 Linux compiler). Note that alternatives included are "Makefile-LAYf95Lin" (settings for the Lahey LF95 Linux compiler), "Makefile-NAGf90Sun" (settings for NAG F90 compiler on Sun), "Makefile-FUJf95Sun" (settings for the Fujitsu F95 compiler on Sun), "Makefile-SGI f90" (settings for the SGI F90 compiler), and "Makefile-DECf95" (settings for the DEC F95 compiler), respectively.

If the default "Makefile" does not suit you, try to supersede the "Makefile" file with one of the alternative "Makefile-\*" files. (Example: with the command "cp Makefile-FUJ95Lin Makefile", you would select the EGOPS Makefile for the Fujitsu F95 Linux compiler.)

8c) Issue the command "make all" (wait until completion...) and close this with "make clean".

(Note: There are two C libraries linked during this procedure, which, if you find some linking process failing, may require recompilation with your cc compiler. In this case issue "make createclibs" before you again run "make all". Open and read the "Makefile" for details.)

8d) Issue the command "make allaux" (wait until completion...) and close this with "make clean".

8e) Repeat step 6 and the procedure of step 7, which should now work smoothly.

Should the procedure steps 8a) to 8e) pose any problem, contact the IEMC at IGAM/UG at the address given in Appendix C, titled "The International EGOPS Maintenance Center (IEMC)".

9) In case everything worked fine so far, but your User I/F does not show a blue background color (e.g., just gray), and help text has no yellow background color (try "Help - About EGOPS..." at the main level to confirm), or the terminal from which you started EGOPS shows a message like "Cannot allocate Color ..." then the following procedure is likely to solve this problem:

a) Change to the home directory of your EGOPS installation (e.g., by the command "cd" in the console window).

b) Open the ".Xdefaults" file in the home directory (by your favorite text editor). (Note: This file is hidden - 1st character "." – and maybe thus not visible by default if you want to open via your file manager; change the file manager to display hidden files in this case. If it does not exist create it or see your system administrator). Add the following lines to the ".Xdefaults" file by "Copy and Paste" (the block of lines starting with "Idl..."):

```
Idl.colors: -20
Idl*egops*background:#77a7ff
Idl*egops*item1*background:#6090e5
Idl*egops*error*background:#d07878
Idl*egops*information*background:#e0d090
Idl*egops*egops*background:#77a7ff
Idl*egops*egops*item1*background:#6090e5
Idl*egops*egops*error*background:#d07878
Idl*egops*egops*information*background:#e0d090
Idl*egops*egops*egops*background:#77a7ff
Idl*egops*egops*egops*item1*background:#6090e5
Idl*egops*egops*egops*error*background:#d07878
Idl*egops*egops*egops*information*background:#e0d090
```

c) Save and Close the modified ".Xdefaults" file and, in order to be sure that the new ".Xdefaults" settings take effect, restart your CDE (or KDE if on Linux), or other X-Windows environment.

d) Restart EGOPS and confirm whether background colors such as the blue background of all main-level pop-up windows are now appearing.

10) If the colors are basically displayed correctly, but the color table "jumps" between the EGOPS windows and the other applications (meaning that as soon as an EGOPS window is active all the background shows very odd coloring and vice versa) then the following action is likely to help:

-> Open the file /EGOPS/prog/IDLprog/r\_egops and change the first command  
"device, true\_color=24"

to:

device, pseudo\_color=8

Alternatively (but less likely) the following action may help:

-> Open the ".Xdefaults" file (as described under bullet 9b) and add "Copy and Paste" one of the following lines:

Idl.gr\_depth: 8

or

Idl.gr\_visual: PseudoColor

Note: This "jumping-color-table" problem may occur if you install on an older true color (Sun) machine or on an even older machine not yet capable of true color.

Should the actions 9a-d pose any problem, contact the IEMC at IGAM/UG at the address given in [Appendix C](#).

Having successfully worked through down to this point your EGOPS4 installation is now completed. Now you can make yourself acquainted with and start practical work with EGOPS, e.g., with the aid of the On-line Help ("Help" menu and Help within the EGOPS pop-up windows).

It will also be helpful for you to consult the EGOPS4 Software User Manual at this point, which is delivered with the software. Particularly recommended is, for novice Users, the overview part, which will rather quickly give you a good basic understanding of EGOPS and what it can do for you.

### **5.1.4 Installation Troubles**

In case of troubles you find difficult to solve, which look as they may depend on your specific Unix/Linux installation, IDL installation, or FORTRAN installation, contact your system administrator for either solution or most precise definition of the problem.

If necessary, notify the IEMC at IGAM/UG of your problem by sending a concise problem report to the address given in [Appendix C](#). The IEMC will try to help you in finding a solution quickly.

## **5.2 EGOPS Upgrade Notes**

### **5.2.1 Superseding an older EGOPS Version**

No problem. The simple installation procedure outlined above for an initial installation of EGOPS is baselined to apply identically for superseding an existing older installation by a new version/release. (Note: A one-to-one supersedence - using the same version/release as the "new" version/release - is of course also possible.)

User-created directory structures (project directories) and User-created files (in any EGOPS directory) generated with an older EGOPS version/release will still be fully available within a new version/release. It is only the files intrinsic to EGOPS which will be superseded.

### **5.2.2 EGOPS Upgrade History and Upgrade Notes**

Any exception to the above baseline from one version/release to another is notified below (in a cumulative list keeping the full history). Should some EGOPS-intrinsic files become obsolete with a newer version/release (no further supersedence) this is also notified along with directions for manual deletion of such obsolete files. The "upgrade notes" briefly inform about the changes applied from one Version/Release to the next.

Supersede V2.0, Release#1 (Dec 30, 1997) [initial official release] by...

1. EGOPS V2.0, Release#2 (Apr 15, 1998)
  - Baseline fully applies.
  - No new functionality added to Rel#1, but all bugs found during rigorous tests at IMG/UoG and TERMA cleared.

Supersede V2.0, Release#2, by...

2. EGOPS V2.0, Release#3 (Jun 30, 1998)
  - Baseline fully applies.
  - No new functionality added to Rel#2, but several remaining "cosmetic" bugs cleared and code header descriptions and documentation improved.

Supersede V2.0, Release#3, by...

3. EGOPS V2.1, Release#1 (Aug 31, 1998)
  - Baseline fully applies.
  - A major general upgrade effort was made to the IDL part: It was upgraded from IDL4 to IDL5 (most recent IDL version) and runs now smoothly in all respects under IDL5. (EGOPS2.0 users may positively note also some improvements in style, e.g., of buttons.)
  - IDL4 users: No new functionality was added so that users continuing to run EGOPS under IDL4 shall stay with EGOPS2.0 (EGOPS2.1 does no longer run under IDL4).

Supersede V2.1, Release#1, by...

4. EGOPS V2.2, Non-Official Release#1 (Feb 15, 1999)
  - Special Note: This is an internal, non-official release. It is only available to IMG/UoG and ESA/ESTEC (funding source of the release).
  - Baseline fully applies.
  - EGOPS now also runs on PCs under Linux, i.e., with EGOPS2.2 also the PC world is a hardware option now (see section INSTALLATION PREREQUISITES for more info). For achieving full Linux portability (and Linux application s/w compatibility), various minor upgrades have been made to the IDL and F90 parts. Also some minor adjustments necessitated by stepping from IDL 5.0 to IDL 5.1 have been performed.
  - The functionality itself remained the same as within EGOPS2.1; thus workstation users need not necessarily upgrade from EGOPS2.1 to EGOPS2.2.

Supersede V2.1, Release#1, by...

5. EGOPS V2.1, Release#2 (Oct 15, 1999)
  - Baseline fully applies.
  - No new functionality added to Rel#1, but a few User-reported bugs cleared in the "Mission Analysis/Planning" part of EGOPS (in IDL User I/F part).
  - This is foreseen to be the final official release of the EGOPS2 version. By the end of 1999 already the 1st release of EGOPS3 is scheduled to be available.

Supersede V2.1, Release#2, by...

6. EGOPS V3.0, Release#1 (Dec 15, 1999)
  - The baseline fully applies except that there will be several obsolete files in the program code subdirectories under the /prog directory if EGOPS2 is superseded by EGOPS3 without any measure (due to name and substructure changes, etc.). While this should not impair proper functioning but rather just leave "garbage", Users superseding EGOPS2 by EGOPS3 should delete the full contents of the EGOPS /prog directory before installing EGOPS3.
  - This 1st EGOPS3 release closes development cycle 3 of EGOPS, which was a major upgrade effort funded by ESA. Both the IDL part and the FORTRAN part were upgraded by a large number of new functionalities. (see the EGOPS3 documentation for details).

- A few highlights: A "GCM 3D Atmosphere" model was added allowing seamless access to GRIB formatted data as, e.g., ECMWF analyses fields. A "Wave Optics Propagator" was added accounting for diffraction in forward modeling. New high-quality bending angle retrieval tools were added including diffraction-correction capability and different advanced modes of statistical optimization. Full forward modeling and inversion/retrieval capability was added for ionospheric occultations. Mission Analysis and Planning functionality was added for ocean-reflected GNSS signals. Visualization and interactive visual analysis capabilities have been significantly extended and improved such as by mouse-driven zoom-in functionalities. (In order to get a full account of the many new features consult the EGOPS3 documentation.)
- EGOPS3 has a new security feature, which allows it to be used only by registered users. Practically, Users have to supply a specific username+host.domainname in advance, which can then be authorized for use.
- At least IDL 5.1 or higher is needed for EGOPS3 (see software requirements above); EGOPS3 may not start if the IDL version is < 5.1 (the current version is 5.2).

Supersede V3.0, Release#1, by...

7. EGOPS V3.0, Release#2 (Jan 15, 2000)

- Baseline as Valid for EGOPS3.0, Rel#1, fully applies.
- Given that as of 3 December 1999 IGAM/UG (Institute for Geophysics, Astrophysics, and Meteorology/University of Graz) is the legal successor of IMG/UoG (Institute for Meteorology and Geophysics/University of Graz), all reference to IMG/UoG in both the EGOPS3 software package and the EGOPS3 Software User Manual (SUM) was replaced by reference to IGAM/UG. Thus the organizational change of the EGOPS lead developer IMG/UoG into IGAM/UG is fully reflected in EGOPS3.0, Rel#2.
- The IDL/F90 functionality of EGOPS3.0, Rel#1 is unchanged

Supersede V3.0, Release#2, by...

8. EGOPS V3.0, Release#3 (Mar 15, 2000)

- Baseline as valid for EGOPS3.0, Rel#1, fully applies.
- Upgrade Notes: \* The EGOPS3 run-time versions were re-generated based on IDL version 5.3. Since IDL run-time code is not cross-version compatible, they run now under IDL 5.3 only (no longer under IDL 5.1). Tests of EGOPS3 when using IDL 5.3 have been performed under Sun/Solaris and code adjustments required in the "Visualize Data Animation" part and for correct on-screen positioning of pop-up windows under IDL 5.3 have been implemented. Otherwise the S/W was found to operate smoothly under IDL 5.3.
- The IDL functionality of EGOPS3.0, Rel#2, is unchanged by the minor IDL code adjustments.
- The F90 code of EGOPS3.0, Rel#2, is unchanged.



Supersede V3.0, Release#3, by...

9. EGOPS V4.0, Release#1 (Sep 30, 2001)

- The baseline fully applies except that there will be several obsolete files in the program code subdirectories under the /prog directory if EGOPS3 is superseded by EGOPS4 without any measure (due to name and substructure changes, etc.). While this will not impair proper functioning but rather just leave "garbage", Users superseding EGOPS3 by EGOPS4 are advised to delete the full contents of the EGOPS /prog directory before installing EGOPS4.
- This 1st EGOPS4 release closes development cycle 4 of EGOPS, which was a major upgrade effort funded by ESA. Both the IDL part and the FORTRAN part were upgraded by a large number of new functionalities. (see the EGOPS4 documentation for details).
- A few highlights: It is now possible to simulate also airborne radio occultations, where the GNSS receiver is mounted onto an airplane instead of a LEO satellite (this function is integrated as additional part of the FoMod . A high vertical resolution atmosphere model ("HiVRes Atmosphere") was added allowing seamless access to several different radiosonde (RAOB) formatted data as, e.g., FSL (NOAA Forecast System Labs) RAOB data files. A "Realistic Receiving System Simulator" was added (to the OSMod system), which realistically mimics L1 signal tracking including a loss-of-phase-lock detection feature and an initial open-loop tracking mode. A series of InRet system parts have been enhanced, i.p., a new moist air retrieval capability based on joint optimal estimation of temperature and humidity profiles has been added. An important improvement in general convenience is that EGOPS4 allows batch processing for all FORTRAN computations. This is especially valuable for all time consuming calculations (e.g., FoMod simulations with high sampling rate using the more sophisticated atmosphere/ionosphere models) since after starting a batch job the EGOPS user interface can be used immediately to proceed with other working tasks. Another new convenience is that projects can be automatically, via "Project" menu entries, shelved (into .tar.gz files) and restored, which eases maintenance and exchange of EGOPS projects. Also a big number of improvements was implemented in the data visualization/validation part of EGOPS. Several post-processing functions (e.g., computing difference profiles) are now much faster. One example of visualization enhancements is the new profiles data display window for interactively "slicing" volume data horizontally or vertically. Another one is that, under Visualize Data Animation, it is now possible to store the full animation window content as MPEG-Video file for use, e.g., electronic presentations (the IDL license needs to support the latter MPEG feature). New options to customize line styles and line thickness, to add text annotations to plots, etc., are also available.
- IDL 5.4 (the current version) or higher is needed for EGOPS4 (see software requirements above). EGOPS4 cannot run if the IDL version is < 5.4.

Supersede V4.0, Release#1, by...

10. EGOPS V4.0, Release#2 (March 1, 2002)

- This is a maintenance release implementing minor upgrades and corrections.
- The Batch Processing Information window now provides a button labeled "Remove finished Tasks" to remove all finished jobs from the Batch Processing Information list.
- The Observation System Modeling Input window for the Realistic Receiving System Simulator provides an additional button to select/deselect the creation of I/Q-Signal data files.

## **5.3 Use and Operating Notes**

### **5.3.1 Starting EGOPS**

The nominal way - and the only one officially supported - to start EGOPS is as follows:

- 1) Change, in your console window, to the EGOPS root directory /EGOPS. This directory contains the EGOPS startup shellscrip EGOPS.RunMe.
- 2) Start EGOPS by running EGOPS.RunMe, i.e., by executing the command "EGOPS.RunMe" in your console window. This nominally pops up the EGOPS main-level window. If you get a "EGOPS4 Authorization Failure" message instead act as advised in that message.

Remarks:

Should you observe the system saying "Command not found" after entering "EGOPS.RunMe", you should be successful with entering "./EGOPS.RunMe" instead. You can also consider to add the command "set lpath = ( . )" to the "set..." commands in the .cshrc file of the user account where EGOPS resides (in case a "set lpath..." command already exists just modify it accordingly; in case ".cshrc file" does not mean much to you consult your system administrator - it may also be a setup where ".cshrc" does not exist or exists under a different name such as ".kshrc", ".bashrc", or the like).

In case you directly double-click on the EGOPS.RunMe icon in your file manager application (which is also possible but not recommended) you will on some systems start up EGOPS as well (except if only "./EGOPS.RunMe" would work from within the console window; cf. 1st remark). In this case, however, you will usually have no console window available for reporting messages during the EGOPS session. Note that while it is not required for proper functioning to have a console window in parallel available it is quite inconvenient not to have it for both novice and advanced Users (cf. the section "Console Window Information during EGOPS Sessions"). Note that starting EGOPS by double-click is a way of starting not officially supported.

Within KDE (Linux) you can make a new application in kfm by clicking on the menu entry file > new > application. Chose a name for the application (e.g., EGOPS4.kdelink), and write the following into the execute field: `sh -c "cd <EGOPSPath>/EGOPS/prog/IDLprog ; idl < r_EGOPS"` Then you can drag-and-drop the file from kfm to the taskbar and you can then directly start EGOPS from the taskbar. Also this way is not officially supported.

There exist various other alternative ways to start EGOPS (e.g, in case of a source-code version, starting it directly within the IDL application with ".r EGOPS"). Since these are of interest to advanced Users only (which will be aware of them anyway) they are not detailed here.

All work of an EGOPS session, once EGOPS is started, is performed within and below the EGOPS main-level window. The main-level window is thus permanently open until exiting EGOPS. If desired, the window can be resized or iconized temporarily (by employing window manager functions external to EGOPS. Iconizing the main-level window will lead, on most systems, to iconizing all sub-level windows as well).

### **5.3.2 Exiting EGOPS**

The nominal way to exit EGOPS, which should always be followed, is as follows:

Select the menu entry "Exit EGOPS", which is the bottom entry of the EGOPS "Project" menu. This closes the EGOPS main-level window and leads the User back to the console window's system prompt from wherein EGOPS was started (assuming EGOPS has been started the nominal way).

Remarks:

Exit alternatives, such as using a window manager function "Quit" or "Close" to close EGOPS windows, should only be used in the unexpected case of abnormal termination when EGOPS windows get stalled and the User may fall back to the (IDL) system prompt (with an error message). Note that this can happen only to source-code Users who started EGOPS in a non-supported way from within IDL. In such a case the windows may be subsequently removed by "Quit", which provides an orderly way to keep the IDL system prompt level. The most rigorous way in such a case, which directly leads the User back to the Unix system prompt after immediately closing all stalled EGOPS windows, is to give straight the command "exit" at the IDL system prompt.

It need be emphasized that, whatever way of exiting EGOPS is taken (in the normal or unexpected termination case), there is no danger whatsoever that any data files get lost whose computation was completed before.

### **5.3.3 Console Window Information During EGOPS Sessions**

#### **General Remarks**

If EGOPS is started as nominally required (cf. the section "Starting EGOPS"), then always an EGOPS console window is available (while this is not the case if the start was done by EGOPS.RunMe icon-click).

This console window, which is the window within which EGOPS was started, is during EGOPS sessions permanently occupied (since EGOPS is a window-based IDL application) and issues miscellaneous console window messages. The system prompt becomes active again not before the EGOPS window interface is closed.

It is important to note that taking notice of the EGOPS console window messages is not necessary during smooth operation of EGOPS. Nevertheless, the more advanced User will like to follow the flow of messages in the console window mostly insofar as they provide brief information on the status of running FORTRAN computations.

Usually, it is only in the unexpected case of a run-time error that it is recommended to carefully observe the error information provided in the console window by the IDL or FORTRAN run-time error message function (cf. the Appendix A on "Error Handling within EGOPS ..." for more detailed information on this topic.)

#### **Miscellaneous Irrelevant Messages**

There exist a few other miscellaneous messages issued automatically by the Unix system, the IDL application, and the FORTRAN executables in course of a usual, smooth EGOPS session. All of these are practically irrelevant in that they do not impair at all the functioning and performance of EGOPS and the accuracy and reliability of EGOPS results produced. It is simply not appropriate (or not possible), from the system developer's point of view, to suppress some automatic messages.

However, especially the more recent User needs some explanation in order not to be confused by messages sounding perhaps alerting though being mostly harmless. These include, among others (but for providing an example of a more frequent message type sounding alerting), the following message type:

- "floating underflow" messages: These report the fact that some accuracy degradation occurs for floating numbers smaller than the "zero-limit" (about 1E-38) for floating point values. Underflows occur within EGOPS here and there mainly due to Exp() functions having asymptotically exponents near -100 or less. These underflows do not impair at all, however, the actual (double precision) accuracy of the computations, since there is no segment in any algorithm where it would be of any relevance whether numbers < 1E-38 take a 1E-39, or 1E-40, or 1E-50, or whatever quasi-zero value.

### **5.3.4 Useful Auxiliary On-Screen Applications During EGOPS Sessions**

#### **General Remarks**

During an EGOPS session it is very useful to have several other applications of the desktop environment (such as CDE) open in parallel to the EGOPS Window(s). A minimum baseline of these "assistants" is recommended below and their typical use concurrent with EGOPS outlined.

The recommended minimum baseline includes 2 console windows (shelltools), a file manager application, and a print tool. Advanced Users may find that additional windows (e.g., the powerful xemacs tool, a PostScript Viewer such as ghostview, a WWW browser, etc.) will significantly increase productivity.

Furthermore, in terms of on-screen window positions, it is recommended that EGOPS windows should be best used in their default pop-up positions using the upper left corner of the screen as reference. On the other hand, it is recommended that the auxiliary windows (and icons) are tentatively organized near the bottom and right edges of the screen. In this way even the large pop-up windows within EGOPS (e.g., the visualization windows) leave all of the "assistants" visible and immediately clickable in parallel. This is particularly helpful if your screen only furnishes the minimally required 1152x900 pixels.

#### **Typical Use of Auxiliary Windows**

Typical use of 1st console window: This will be the console window within which EGOPS is started, to which all console information of EGOPS is written during run-time, and to which the User is returned after exiting EGOPS.

Typical use of 2nd console window: This will be the "free" console window for issuing miscellaneous Unix commands during an EGOPS session. Such commands may include checking the status of computational EGOPS jobs at the system (priority, CPU time consumed, competitor jobs, memory load, etc.), terminating a job in case one decides it was not ideally prepared but would still last long, or any other system-related activity one may think of.

Typical use of the file manager: A good baseline directory setting for the file manager during an EGOPS session is the subdirectory /<Project-id>/PSfiles, which contains all print files one creates during (visualization) work on a current project "<Project-id>" (except project-independent print files which go to the /genPSfiles directory). In this way any print file generated within EGOPS could immediately be printed, simply by drag-and-drop of the file from the file manager to the print tool.

Advanced users may use this application, in addition, to navigate through the directory structure of EGOPS and, e.g., check the status and contents of various program and data files. (Note: An even better suited tool for the latter activities is the powerful xemacs tool.)

Typical use of the print tool: A good baseline is to have this tool available as iconized application, which is set to feed the desired printer and waiting to be dropped by some print file which shall be

conserved on paper or transparency.

Further "assistants", dependent on the type of projects to be addressed and on the User's computer experience, will certainly be found very valuable by advanced Users.

These will, just as arbitrary examples, help them to manipulate (view, edit, compare, print, compile, debug, etc.) program, data, and PS files, to include auxiliary external software or data, to exploit multi-machine availability, or to benefit from a teamwork approach to EGOPS projects.

### **5.3.5 Smoothly Terminating EGOPS FORTRAN Computations**

#### **General Remarks**

Different from undesired abnormal termination of FORTRAN programs due to unexpected run-time errors (cf. Appendix A on "Error Handling within EGOPS ...") there exists a form of desired abnormal termination useful in cases where a running FORTRAN job, started within an EGOPS User Interface window (IDL), is realized during run-time to be not a good choice. A typical reason, among others, is that the job would still take, say, hours until completion but one knows in the meantime that one better had supplied a little different input.

Two ways, which are outlined below, are useful and feasible to terminate such a job during run-time. Both perform the termination („kill“) of the Unix process associated with the running FORTRAN executable. The response of the EGOPS system to such deliberate termination is exactly the same as the response to termination due to a run-time error, which is described in Appendix A.1.3 „Run-time errors in FORTRAN modules“. The only difference is that here the message got in the console window is a brief „...terminated“ message instead of a run-time error message. Thus, as described there, EGOPS fully recovers this FORTRAN program termination without any impairment, and one can immediately proceed as usual.

#### **1<sup>st</sup> Method**

The 1st more convenient way requires the widely installed but non-standard Unix system tool „top“ to be installed on your system. In case „top“ is available (try it out or ask your system administrator), proceed as follows:

- (1) At the Unix system prompt of a „free“ console window (cf. „Hints on useful auxiliary on-screen applications...“ above) issue the command „top“, which provides you with a convenient list of general system status information and information on each specific process running, including the process-id (4 digits integer, „PID“ column), the username („USERNAME“ column), and the associated job name („COMMAND“ column).
- (2) Browse the lines showing your Username in the „USERNAME“ column (e.g., „usr“, if the home directory of the EGOPS installation is /home/usr) and find the process which shows one of the following job names in the „COMMAND“ column: MAnPISystem.x, FoModSystem.x, OSModSystem.x, InRetSystem.x, or RefDataProv.x. For sure (disregarding advanced Users which no longer need these hints), at least one and only one of these jobs actually runs (these are the FORTRAN core executables of EGOPS).
- (3) Read the process-id of the process found in the „PID“ column, press the „K“ key on your keyboard (which prompts the word „kill“ and places the cursor just to the right of it), and enter now the 4 digits process-id followed by a <CR> keystroke. The EGOPS console window will immediately display „...terminated“ message and the EGOPS system itself will respond exactly as in the case of run-time error (i.e., smoothly recover).



So all you do here is, keying in „top“, quickly orientating yourself in the process list, pressing „K“, and entering the process-id and <CR>.

Special note if you work under the KDE (Linux) environment:

Here it is even more convenient – just start the process manager (ktop), click with the mouse on the program you want to terminate (one of the five executables noted above) and then press the terminate button.

## **2<sup>nd</sup> Method**

The 2nd less convenient method available within any standard Unix is as follows:

- (1) At the Unix prompt of a „free“ console window issue the command „ps -ef | grep <username>“, (e.g., „ps -ef | grep usr“), or, alternatively, the command „ps -al | grep <username>“,. Try the latter command if the former fails, it is for older Unix versions. This commands gives you a list of all processes for <username>, with the 4 digits process-id following immediately the username (at the beginning of a line) and the job name shown at the end of a line.
- (2) Identify, as in item 2 of the „1st way“ above, the specific process associated with the name of one of the EGOPS FORTRAN executables.
- (3) Issue now, at the Unix prompt, the command „kill <process-id>“,, where you supply for <process-id> the 4 digits process-id of the process identified. This will lead to the termination of the process and the EGOPS system will respond exactly as in the case of run-time error (i.e., smoothly recover).

## **Appendix A**

### **A.1 Error Handling Within EGOPS and How to Act in Case of Errors**

#### **A.1.1 General Remarks**

Handling of errors within EGOPS means much less "dealing with errors after they have occurred" than rather "prevent errors at the very beginning" - at User Interface level - as rigorously as possible. As outlined in the subsection "User input errors" below, considerable efforts have been invested in the EGOPS software development for preventing User input errors.

Nevertheless, strict User input control can certainly not completely rule out run-time errors (abnormal terminations). Hidden program code errors which have gone unrecognized through the software test and validation procedures may be one reason (pointing to bugs which need to be fixed). Similarly, the User input control may not have correctly constrained a module's useful input parameter space (pointing to parameter range control bugs or processing module weaknesses which need to be fixed).

Another reason may be inappropriate input from file to processing modules. Such file input may be either erroneous (i) due to faulty assignments by the User (e.g., the User assigns an orbit element file or a ground station file which does not obey the specified format) or (ii) due to file contents of unexpected range (e.g., a "strange" Mission Analysis/Planning output file used as Forward Modeling input file leads to a run-time error during Forward Modeling computations).

(ii) is of no further concern (i.e., readily avoided by the User), (ii) needs reconsideration of the valid input parameter space for the module producing the "strange" file. The subsections "Run-time errors in IDL modules" and "Run-time errors in FORTRAN modules" describe the response of the EGOPS system to IDL and FORTRAN run-time errors and recommends actions of the User after such unexpected errors occurred.

#### **A.1.2 User Input Errors**

The most important part of EGOPS error handling is strict error prevention and control at User Interface level. This control is implemented in a threefold way.

- 1) Each individual User input parameter of whatever type (REAL, INTEGER, STRING, etc.) is checked for whether it matches all validity criteria applying to this parameter (match of foreseen numerical range, correct spelling of string input, etc.). In this way it is guaranteed that only parameters are accepted, which are considered valid and compatible with the computational modules of EGOPS.
- 2) Each logical group of User input values is checked for consistency and cross-value compatibility

as appropriate (e.g., all the input to a given module). This guarantees that only a consistent set of parameters, considered to represent a valid point in a logical group's parameter space, is accepted.

- 3) In case of input to computational modules (FORTRAN), where the input is handled via file to the programs, each input file is rigorously checked before computations can be started from within the IDL User Interface. This guarantees that the FORTRAN programs receive fully validated input even if some (advanced) User has (accidentally) brought in some error during direct manipulation of input files (<Task-id>.inp files) in the EGOPS file structure. (Note: If advanced Users directly use FORTRAN programs without invoking the IDL User I/F, this latter control is of course lost and all responsibility for correctness of input rests with the User.)

This strict control at User Interface level ensures that run-time errors due to incorrect inputs to processing modules are highly improbable (nominally impossible). This leads to the considerable advantage that the processing modules need no internal error checking at all since they nominally always get valid and consistent input so that no errors should occur. Consequently, the EGOPS processing modules are free of the burden of error checking and handling on their own. (Note: Some limited internal error checks of routine type such as checking validity of spelling of "string flags" have nevertheless been implemented in practice at many places in the F90 code. These can be helpful for the work of developers and advanced source-code Users.)

### **A.1.3 Run-Time Errors in IDL Modules**

In the unexpected case a run-time error occurs within an IDL module of EGOPS, the response of the system is - independent of the precise type of error – as follows:

- (i) The open EGOPS User I/F windows get immediately closed (stalled if EGOPS was started from within IDL).
- (ii) The User is returned to the system prompt in the console window, from where EGOPS was started.
- (iii) The console window reports the error information as delivered from the IDL run-time error function (e.g., "Error in module TMANPL, line xx, due to array subscripts out of range..."; the source-code version reports errors more informative than the run-time version).

(ii) and (iii) of course only apply if a console window is available (i.e., not if EGOPS startup was done by EGOPS.RunMe icon-click, where just every EGOPS-related window is immediately closed).

Open files left in an undefined state due to abnormal termination, an extremely unlikely situation due to the "instantaneous writing" generally performed by IDL write-out code, are logged in a temporary "Files-to-be-deleted" list file. The entries in this file, and then the file itself, are deleted immediately after EGOPS restart so that potentially corrupted files can never pose difficulties for subsequent sessions.

(Note: Only the information in a file just open during the occurrence of the run-time error can be lost, all other information from earlier processing is fully conserved in the EGOPS file structure.)

EGOPS can immediately be started again after such error (proceeding as noted in the section on "Starting EGOPS") and it will come up as usual.

Recommended actions by the User after an IDL run-time error:

- Check the error message in the console window and try to understand it. If run without console window, re-run from within such a window to be able to see and check the error message. (Advanced Users: In case of having IDL expertise you could try to explore the state of suspicious variables by interactive inspections at the IDL prompt.)
- Carefully check whether a relation of the error to some obvious misuse could exist (assignment of ill-formatted/deliberately manipulated files, deliberate modifications of EGOPS program files, file structure, or default data files as set up during EGOPS installation, etc.).
- Try to eliminate potential error sources.
- Re-start EGOPS and try to repeat the run-time error condition. If it no longer occurs, the (probably User-produced) problem is fixed. If the error repeats identically and repeated fixing efforts fail, evaluate whether the error can be avoided at first aid by an alternative approach to the simulation problem of interest.
- Bring, as appropriate and needed, the error to the attention of the IEMC at IGAM/UG (see address in [Appendix C](#)).

#### **A.1.4 Run-Time Errors in FORTRAN Modules**

In the unexpected case a run-time error occurs within a FORTRAN module of EGOPS, the response of the system is - independent of the precise type of error – as follows:

- (i) The FORTRAN program terminates execution and the FORTRAN run-time error function reports the respective FORTRAN error information to the console window (if a console window is available, i.e., no report if EGOPS startup was done by EGOPS.RunMe icon-click).
- (ii) The IDL User Interface immediately resumes control and reports to the User that an error has occurred in a specific FORTRAN program (e.g., such like "Error occurred during Forward Modeling computations...").

The User can close the Error Message window and proceed as usual. Open files, which may be left in an undefined state due to error, are generally logged via a temporary message file during FORTRAN computations and are, in case an error occurred, deleted immediately after IDL resumed back control.

The provisions made for handling information back to IDL about FORTRAN modules in which run-time errors occurred shall be briefly outlined. The main FORTRAN program always writes "markers" to a message file (<Task-id>.mes file), just before and after each call to a FORTRAN module (in generic terms, before call: "Starting computations...", after call: "...successfully completed."). Thus the message file always contains information on the FORTRAN processing done so far. As soon as IDL resumes back control (either after successful FORTRAN program completion or an abnormal termination) it checks the message file and briefs the User with information on the success of the FORTRAN computations. In addition, it deletes potentially corrupted files in case of abnormal termination as noted above.

Though the simulator thus fully recovers the FORTRAN run-time error situation so that you could proceed your work ignoring the error (as long as the precise task leading to the error is not critically relevant), it is recommended that you try to understand the error condition and act as noted in the paragraph below.

Recommended actions by the User after a FORTRAN run-time error:

- Check the error message in the console window and try to understand it. If run without console window, re-run from within such a window to be able to see and check the error message.
- Carefully check whether a relation of the error to some obvious misuse could exist (assignment of ill-formatted files such as ill-formatted ground station or orbit element files, deliberately manipulated files, deliberate modifications of EGOPS program files, file structure, or default data files as set up during EGOPS installation, etc.).
- Try to eliminate potential error sources.
- Re-start EGOPS and try to repeat the run-time error condition. If it no longer occurs, the (probably User-produced) problem is fixed. If the error repeats identically and repeated fixing efforts fail, evaluate whether the error can be avoided at first aid by an alternative approach to the simulation problem of interest.
- Bring, as appropriate and needed, the error to the attention of the IEMC at IGAM/UG (see address in [Appendix C](#) ).

### **A.1.5 Reporting Errors**

In case of errors you find unable to fix, and for which careful checks have shown erroneous use to be unlikely, notify the IEMC at IGAM/UG of your problem by sending a concise problem report to the address given in [Appendix C](#). The IEMC will try to help you in finding a solution quickly.

## **Appendix B**

### **B.1 Example Simulations and Results**

**Appendix B** of this EGOPS4 SUM-OV remains unchanged from **Appendix B** of the EGOPS2 SUM. Thus the reader is referred to sources from which Appendix B of the EGOPS2 SUM can be obtained. In essence, there exist **three alternative ways** to get it, which are listed below.

**Way #1 (printed version):**

Concerning a printed version of Appendix B of the EGOPS2 SUM, the best source, furnishing the many Tables and Figures of Appendix B printed in highest available quality, is to request the report

**Kirchengast, G.**, End-to-end GNSS Occultation Performance Simulator overview and exemplary applications, *Wissenschaftl. Ber. No. 2/1998*, 138p., Inst. Meteorol. Geophys., Univ. of Graz, Austria, 1998.

from IGAM/UG Graz, Austria (send e-mail to [iemc.igam@uni-graz.at](mailto:iemc.igam@uni-graz.at) or to [gottfried.kirchengast@uni-graz.at](mailto:gottfried.kirchengast@uni-graz.at), respectively).

**Way #2 (printed version):**

Alternatively, Appendix B of the EGOPS2 SUM is contained in the official EGOPS2 SUM report with Document No. CRI/ATMSOU/SUM/1.1, Issue 1, June 1998. This is available from ESTEC.

**Way #3 (electronic version):**

An on-line version of Appendix B of the EGOPS2 SUM is available via the CD-ROM No. TERMA/ATMSOU+OMC/CD-ROM/1 from/via ESTEC as well. In this electronic version the Tables and Figures are included in PDF file format in a rather moderate quality (since scanned from photocopies of printouts) and are located in separate directories named /tables and /figures, respectively.

## **Appendix C**

### **C.1 The International EGOPS Maintenance Center (IEMC)**

#### **C.1.1 What is the IEMC ?**

The IEMC is a Service Center set up at IGAM/UG as part of a trilateral "EGOPS Licensing Agreement" amongst the EGOPS2 developers IGAM/UG, DMI (Danish Meteorological Institute, Copenhagen, Denmark), and TERMA (TERMA Elektronik A/S, Birkerød, Denmark).

Its mission is to provide, at best effort within available resources, maintenance and user support services for the EGOPS2 user community.

The IEMC continues and enhances this mission with EGOPS3 and EGOPS4.

#### **C.1.2 IEMC Point of Contact**

The point of contact for all IEMC matters is:

Gottfried Kirchengast  
Director, International EGOPS Maintenance Center (IEMC)  
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Feel free to contact the IEMC with whatever relevant information need or EGOPS-related problem you have. The IEMC will try to help you with advice and in finding a solution.



### **C.1.3 IEMC Maintenance Work**

EGOPS Maintenance by the IEMC is to be understood in the broad sense of including both "classical" maintenance and improvement/upgrade work:

- *Secure archiving and maintenance* of master copies of all official EGOPS versions/releases (both source-code and run-time versions) and the related documentation (both source-text and read-only-text versions). Ensure permanent just-in-time availability of all versions/releases upon request. Maintain an always up-to-date database on all EGOPS Licensees and on the associated authorization specifications of EGOPS User machines.
- *Continuous and dedicated work on EGOPS improvements*. This includes - besides prompt clearance of any detected bug in the internal working copies of EGOPS - the outline of extension ideas, trade-off analyses and downselection to most desirable extensions, as well as work planning and design for upgrade development cycles. Based on available funding (so far generally from ESA study contracts), the IEMC then shares the lead with IGAM/UG's ARSCliSys Research Group in implementing development cycles together with international development partners.

### **C.1.4 IEMC Services**

The services provided by the IEMC include:

- *Distribution and Licensing Services.* Cover the distribution - against appropriate license agreements of which three different types exist - of run-time versions or source-code versions of EGOPS4 plus documentation. Predecessor EGOPS3 or EGOPS2 versions are also still provided upon specific request. The license types comprise ESA-User License (ESL), Science-User Licence (SCL), and Commercial-User Licence (COL), respectively. The IEMC provides upon request draft license letters for SCL and COL licenses, for detailed information, and properly refer to ESA points of contact in case an ESL license deems most suitable.
- *Support and Training Services for EGOPS Users.* HelpDesk Support, i.e., prompt help to Licensee's Users with any EGOPS problem received via e-mail/fax/phone, is offered either on annual-renewal or accumulated-hours basis. Support may also include automatic software upgrade. Training courses are offered in form of intensive 2-day courses at IGAM in Graz with EGOPS core team experts as trainers and each trainee having allocated a personal workstation (max. 4 trainees/course). Examples of major modules: EGOPS4 background and overview (setting the scene), interactive hands-on functionality introduction (incl. "tips and tricks"), trainee's example projects, demonstration and discussion of projects. The training contents can be customized to trainee's needs, e.g., dependent on their level of EGOPS experience. Each trainee receives a Certificate at the end indicating his/her training success.
- *Study and Consulting Services for EGOPS Users and Others.* These cover the full field of GNSS occultation science and applications in meteorology and geophysics as well as all aspects of the relevant atmospheric remote sensing methodology and data analysis. Furthermore, the services extend to the related fields of GNSS scatterometry and ground-based GNSS atmospheric sounding as well as stellar, solar, and LEO-to-LEO absorptive occultation methodology, science and applications. The services are offered in close cooperation with staff of IGAM/UG's ARSCliSys Research Group.

All these services are open to all EGOPS Licensees, whatever license type they have. For any further information on these services please contact the IEMC (see point of contact above). We will be happy to provide a license and service solution tailored to your needs.

### **C.1.5 Modalities and Fees for IEMC Services**

#### *Distribution and Licensing Services:*

- The modalities and fees vary over quite a range for these services, dependent on license type and number of licenses. For example licenses of type SCL can be obtained by qualified parties at no cost (except for a 99,- EUR handling fee), while baseline fees for EGOPS4 licenses of type COL range from 36.000,- EUR to 23.400,- EUR per authorized User (depending on the number of authorized Users). Contact the IEMC for details on license types and for which type you may qualify. Some further information on licensing policy can also be found on-line within EGOPS under "Help > EGOPS explained > About EGOPS...".

#### *Support and Training Services:*

- HelpDesk Support is provided either via firm-fixed priced annually-renewable Support and Upgrade Agreement (SUA) or based on hourly-rates in form of an Hours-based Support Agreement (HSA). These options hold for all types of Licensees (ESL, SCL, and COL Licensees).
- Upgrades are automatically provided to Licensees with a valid SUA. There are no Upgrades provided to Licensees with HSA only.
- If a Licensee decides on both no SUA and no HSA, a free-of-charge Free-will Support Agreement (FSA) is entered. IEMC still provides, also for Users of Licensees with FSA only, service in order to ensure successful installation as well as handles bug reports. Services are performed on a non-commitment level, however, and the IEMC reserves the right to freely offer or decline any specific service requested by Users of a Licensee with FSA.
- Support Fees: The current (year 2002) rate for an annual SUA is 2.300,- EUR (covering up to 40 hours of service per year). The current (year 2002) rate for an HSA is 64,- EUR/hour (invoiced quarterly for the hours of service accumulated during last quarter). FSA services are provided at no cost.
- Training is provided in form of intensive 2-day courses at IGAM in Graz for up to 4 trainees per course.
- Training Fees: The current (year 2002) rate for courses with one or two trainees is 710,- EUR/trainee, for courses with three to four trainees 530,- EUR/trainee, respectively. The rates cover all course-related expenses but travel, accommodation, and living costs associated with the course need to be borne by trainees.

#### *Study and Consulting Services:*

- The modalities and fees vary widely for these services. Contact the IEMC if you have interest in such services. Scope and specifics of services, which can be provided within any given time period, will depend on staff occupation. Basically, the IEMC and the ARSCLiSys Research Group will be happy to provide you with service in helping solve your most challenging problems.

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