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Small-Scale Modelling

COSMO Standards

for

Source Code Development

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Ulrich Schättler

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Some Abbreviations and Explanations

STC	Steering Committee The STC is the main governing and steering body of COSMO. It is responsible for and approves the changes to the official versions of the COSMO Software.
SMC	Scientific Management Committee The SMC defines the changes to the COSMO Software and is responsible for their implementation.
TAG	Technical Advisory Group The TAG defines the technical rules for implementing COSMO Software.
SCA	Source Code Administrator Every COSMO Software has a main SCA, who is responsible for the maintenance.
VCS	Version Control System A system to manage changes to source code and documentation which allows to track modifications and retains the history of all previous versions of a software.

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1 Introduction

This document specifies standards for source code development within the *Consortium for Small Scale Modeling*, COSMO. The CLM Community, which uses the COSMO-Model, also follows these standards. They are valid for all versions of the COSMO Software and will also be applied to software provided by other institutions or communities that is intended to be incorporated into COSMO Software. At the date of writing the COSMO Software is composed of

- the COSMO-Model,
- the interpolation program INT2LM,
- the postprocessing tool `fieldextra`,
- the verification package `VERSUS`.

The COSMO Standards for Source Code Development are based on the *European Standards for Writing and Documenting Exchangeable Fortran 90 Code* [1] and should complement and adapt these for the needs of COSMO where necessary. The *European Standards* have been defined in the 90ies to facilitate the exchange of code between meteorological centres. They provide a framework for the use of Fortran 90, in which some details have to be elaborated.

The exchange of code surely has not become common practice up to now, but following the *European Standards* facilitated the development and documentation of the COSMO-Model. This, in turn, lead to the dissemination of the model system to a wide community. The further development of the COSMO-Model within this bigger community now requires an even stronger emphasis on a clear and structured development and a detailed documentation. This also holds for the other components of the COSMO Software.

The aim of this document is to provide some guidelines for several aspects of the development and programming process and should serve the following goals:

- encourage well structured programming
- increase readability and useability of source code
- standardize the look and usage of source code units
- create machine independent portable source code
- simplify maintenance tasks
- facilitate quality management and control

The main chapters of the COSMO Standards are:

- *Mandatory Aspects*

Throughout all sections of this paper, some mandatory aspects of source code development are specified. This section just summarizes the most important ones at a glance and can be used as a step-by-step instruction.

- *Software Design*
Software design is the process of problem solving and planning a software solution. It thus includes the construction of the underlying physical model as well as the definition of the major components of the software needed to provide a robust and efficient solution.
- *Coding Rules*
The coding rules specify a common programming style that has to be adhered to by all COSMO Software. This enhances the readability and exchangeability of source code.
- *Documentation*
The term *Documentation* refers to both kinds of documentation, i.e. the process documentation, which can be defined separately for every project, and the product documentation. The product documentation is split into the internal code documentation and the external documentation outside of the code.
- *Software Maintenance and Quality Control*
An essential part of the software development process is the maintenance of the software and the quality control of each version. Also, clear rules have to be defined how to go from one version to another in operational production.
- *Implementation Issues*
In addition to the Coding Rules, we will give some recommendations for the practical implementations. Issues like memory management, parallelization, optimization and vectorization will be discussed briefly.

The preferred language for model development still is Standard Fortran. But as new computer architectures evolve, it might be necessary to use other languages or language extensions. Especially for non-numeric applications (like VERSUS) Fortran surely is not the first choice for the computer language to use. But no matter which language is used, a *portable*, i.e. a *standard* source code is absolutely necessary. Therefore we intend to transfer these standards *logically* also to non-Fortran applications.

We are aware of the fact that the existing COSMO Software does not fulfill all of these standards, and sometimes not even the most necessary ones. But the development team is working on that and tries to make the COSMO-Model better with every new version. Not only regarding the meteorology, but also regarding the software engineering aspects.

Some rules stated in this document do not apply to all of the COSMO Software. This will be explicitly stated when this is the case. If additional rules or clarifications are necessary, they are stated in appendices to that document or a link is given to accompanying documentation.

Note that additional and / or slightly different and adjusted rules might be valid for the source code development at partner institutions and communities for source code not to be incorporated into COSMO Software.

This document has been enacted in summer 2011, and is now in a process of continuous improvement based on the experiences made. The users are invited to give their feedback.

2 The Development Process - Some Mandatory Aspects

This section sketches the process of software development, i.e. the steps that modifications or new contributions to COSMO Software have to pass, before they are part of official COSMO Software. It summarizes the general rules that have to be fulfilled by the developers and can be taken as step-by-step instructions, how COSMO Software can be developed. Links to more detailed explanations in the following chapters are given.

For a better understanding some terms are defined first.

- **The Software:**
The code under consideration.
- **The Developer:**
Everybody contributing to the Software by implementing changes and / or new components.
- **The Management:**
The group that has to decide on changes to the Software. For COSMO this is the Scientific Management Committee (SMC) on the basic working level and the Steering Committee (STC) on the final level. For this document, *The Management* addresses the role of SMC while the role of the STC is described explicitly. For the CLM Community it is the CLM Coordination group (CLM_CO).
- **The Source Code Administrator:**
Every COSMO Software has a main Source Code Administrator (SCA), who is responsible for the maintenance.
- **Private versions and official versions:**
The Software is maintained using a version control system (VCS). Every version available by such a VCS is an official version, while all other versions, that exist only in a private framework, are private versions. SCA defines a status of the official version which can be development, test or released version.
- **Reference Version:**
Reference version is an official released software version approved by the Steering Committee. It must be at least every unified version of the software.

According to the Agreement establishing the COSMO Consortium, the Steering Committee is responsible for approval of the valid reference version of the Software. The STC approves the COSMO resources if they are used for the development of the Software. And the STC also approves this document and therefore the whole development process.

For the COSMO-Model the STC defined some extra rules to coordinate the Software development between the NWP, COSMO-CLM and COSMO-ART communities:

The STC confirms the importance of these three COSMO applications and the fruitful cooperation between the respective communities. For accomplishing this goal it stresses in particular the key role of the common reference COSMO code and its long-term stability. Consequently, the ART and CLM communities take part in the source code management process via scientific cooperation with the respective Working Groups and via their representatives in the

Scientific Management Committee. The STC will thoroughly consider their opinions while making the final decisions on the reference software. For functions which are mission critical for CLM or ART, it will be open for implementing them with `ifdefs`.

In the following, the steps are specified that changes to the Software have to pass. At the same time, it shows the management decisions that have to be taken when adopting developments to the official COSMO Software.

1. **The idea:**

In the beginning there has to be an idea about what can be developed for the Software. The Developer implements all necessary changes into a private version based on the latest official version of the Software and performs appropriate tests. He / she presents the results as a report and / or a presentation to the Management and proves the usefulness of the changes.

Note:

In this state it is not necessary to fulfill the rules of the COSMO-Standard, but it will be very helpful for the further steps.

2. **The first decision:**

The Management decides whether the idea and the corresponding change to the Software is in-line with the scientific and / or the technical planning. If it is of interest and usefulness has been proved, it is included into the *Planning for Future Developments*. (see Chap. 6.4, Release Planning, for details).

The Developer is asked to design and implement the changes according to the COSMO-Standards. Depending on the complexity of the changes the Management decides on minimum range of necessary tests.

For developments on the CLM side, the developer should start using the *development report template*, which is available on the CLM-Webpage. This document keeps track of the steps of code development for the CLM-Community model versions.

Notes:

- Ideas can be initiated (among others) by individuals, the Working Groups, and the Management itself.
- If COSMO resources are to be used for the Software development the approval of the Steering Committee is needed.

3. **The development:**

The Developer now has to prepare the changes and do the tests according to the COSMO Standards. This is still done with a private version. The following issues have to be met:

- **The source code provided is properly designed:**
Some guidelines for software design (especially for the COSMO-Model) are outlined in Chap. 3, Software Design. The Developer should design the changes and the assembly into the official Software in collaboration with the SCA and the code responsible persons of the corresponding software components.

- **The source code provided conforms to the coding rules:**

The decision, whether the coding rules are fulfilled, is taken by the SCA of the corresponding software. In case of conflict, the case is taken to the *Technical Advisory Group* (TAG).

For CLM versions, the CLM-Community has its own working group *Support and Technical Issues* (CLM-SUPTECH), which is responsible in this case.

(See Chap. 4, Coding Rules, for details)

- **All source code modifications are documented:**

This means that for all modifications (extensions, changes, bug fixes) the product documentation (scientific, user guide) has been written or updated and a contribution to the process documentation (short description of the changes for the version log-file) is available.

(See Chap. 5, Documentation, for details).

- **All changes have been tested. The results are published appropriately:**

To ensure continuing high quality of the COSMO Software, tests have to be performed for all new or modified Software. Depending on the scope of the changes, more or less extensive tests are required. The results have to be published to inform the community (e.g. as a COSMO Technical Report, a contribution to the COSMO-Newsletter, a presentation at the General Meeting or the COSMO User Seminar, and are linked to the appropriate entries of the code management web pages).

(See Chap. 6, Software Maintenance and Quality Control, for details)

- **A Code Responsible Person is available in the future:**

In order to assure a good quality code and support in the future, there is the need that all components of the code do have a responsible person, who can be contacted in case of questions or problems.

(See Chap. 6, Software Maintenance and Quality Control, for details)

4. **The second decision:**

The Management checks the results of the tests and whether the above conditions are fulfilled. If all issues are satisfied, the change is included into the *Release Planning*, which defines the intended version number and date for an official release. The code is given to the SCA for implementation into an official version.

5. **The official implementation:**

The SCA implements the changes into an official version. The official implementation may have a status of development, test or released version. As there might be several contributions, which should not be implemented all in one, there might be several consecutive versions, which are not released officially (called Development Versions, see 6.1, Version and Release Management, for more details). The SCA provides the officially implemented code to the Developer again for cross-checking.

6. **The STC approval:**

The STC approves the Reference version of the software after it was approved by the Management via its second decision and after it was implemented by the SCA and positively tested by the COSMO test users to become a release version. The STC approval concerns especially software versions which are unified for all COSMO communities.

3 Software Design

Before the software can be designed, the physical model has to be constructed. For non-physical (or non-numerical) projects an abstract specification has to be developed that specifies the tasks of the software and the services it should provide. Also the constraints under which it has to operate have to be defined. A *Top-Down* design, starting by the main task and splitting this into smaller units (modular design), is most promising for an efficient software development. Depending on the complexity of the model, the system can be split into sub-systems, which themselves consist of components. The components then have to be mapped to programming language components such as procedures, functions or modules¹.

Fig. 1 gives a sketch of the top-down design for the software of the COSMO-Model. This rather coarse but generic breakdown could also be used for other software projects.

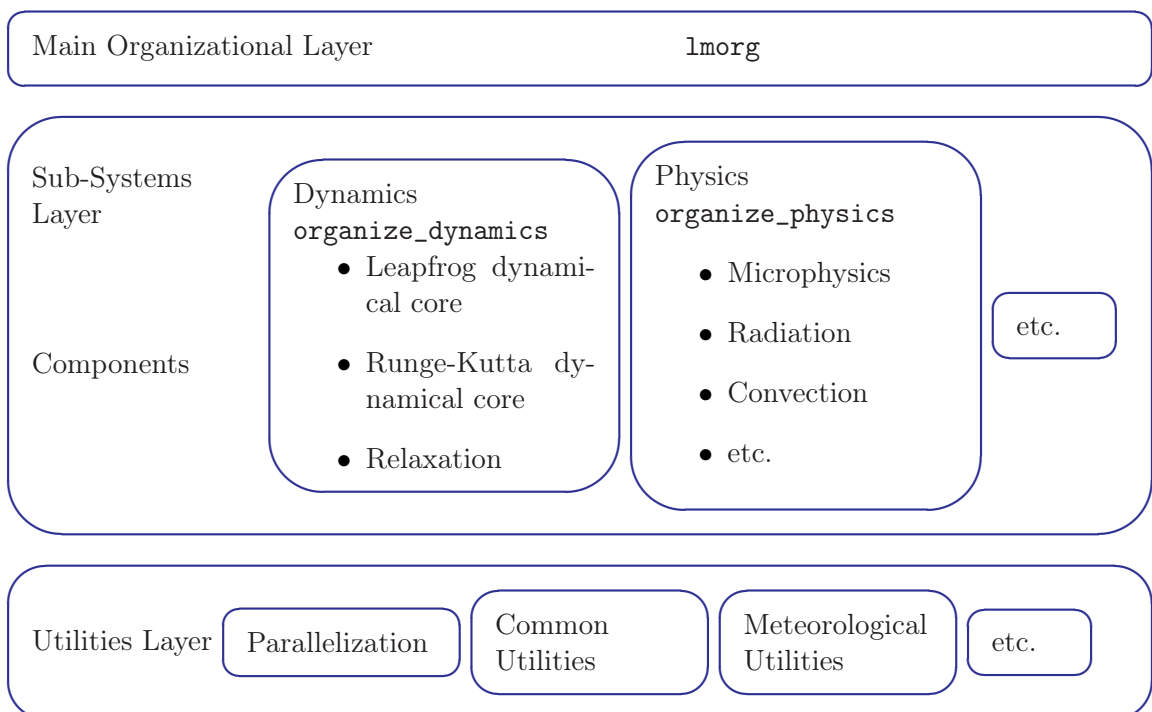


Figure 1: Schematic view of a Software Design

In the following we will give some common rules for the design and implementation of individual software components, especially for the use in meteorological models. Some of them are derived from the *European Standards* [1], which in turn are based on the plug-compatibility rules of Kalnay [2]. She defines a *package* as a set of Fortran subroutines to parameterize atmospheric subgrid-scale physical processes. To exchange packages between different centres it is necessary to use a standard programming style that facilitates the interchange.

¹In the *European Standards* the term *package* is used, but not clearly defined. As they refer to the *plug compatibility* rules of Kalnay et al. [2], it is likely that e.g. the physics packages are meant. More commonly we will speak of software components (or just components).

“The goal of these rules is to make the “physics” routines easily transferable between models with only a few hours of work, and at the same time minimize the degradation in model efficiency.”

Common rules for the design and implementation

- A package / component shall provide different set-up and running procedures (if necessary), each with a single entry point. All initialization of static data must be done in the set-up procedure and these data must not be altered by the running procedures.
- A package / component shall refer only to
 - its own modules and subprograms,
 - to programmer-defined utility procedures such as error-handling, parallelization or basic algorithms,
 - to external libraries,
 - to the intrinsic routines included in the Fortran standard.
- The package / component shall not terminate program execution. If any error occurs within the package it should gracefully exit, externally reporting the error via an integer variable in its argument list (with the possibility to indicate fatal errors). Packages should also write a diagnostic message describing the problem, using Fortran I/O, to an ‘error stream’ unit number selectable via the package’s set up routine.
- The package / component should be written as general as possible (e.g. independent of resolution, time step, etc.) The resolution, for example, must be adjustable via the set up routine for the package.
- The package / component should be written in such a form that it can easily be extended in the future, if e.g. the requirements change.
- The routines of a package / component shall be grouped together in bigger program units of reasonable size. In principle it would be good to have them all in one file (or compilation unit), but this might not be possible due to computer resources (available memory during compilation) or also human resources (one file of several thousand lines of code will be hard to manage by a programmer).
- The interface(s) with other packages / components must be clearly defined and documented. The interface specification must be unambiguous as it allows the package / component to be used without deeper knowledge of the internal operations.
- The data structures used in the system implementation must be defined and documented in detail. This also includes the memory management of the software.
- The algorithms used to provide the services have to be designed and documented.

System Installation

Once the software has been designed and implemented, some means should be provided for the installation of the system. This also has to be documented clearly.

4 Coding Rules

The general ethos is to write portable code that is easily readable and maintainable. Code should be written in as general a way as possible to allow for modifications. In practice this means that coding will take a little longer. This extra effort is well spent, however, as maintenance costs will be reduced over the lifetime of the software.

The SCA of the corresponding code will supervise the programmers and check all developments. If changes are not in line with the coding rules (or more general: with the COSMO-Standards), the code can be rejected and / or be given back to the developers for improvement. In case of conflict, a *Technical Advisory Group* (TAG) will decide on the issue. Since the rules specified in the following do not cover all aspects, the SCA and / or the responsible TAG (either COSMO or CLM-SUPTECH) can be contacted in case of further questions.

The rules presented in this chapter are mainly applicable for Standard Fortran, but some of them can surely be transferred to other programming languages. We give some style and typing rules and for Fortran we distinguish between mandatory features and banned features from former Fortran standards (Fortran77 and older).

The Fortran Standard is evolving with the years but compilers do not always comply with the full standard. In August 2015 it can be expected that all compilers support Fortran 2003. Therefore compliance to this standard is required. Please contact the TAG before using elements from a newer standard.

In autumn 2015 the first parametrization from the COSMO-Model could run on GPUs. Some more schemes have been added then. These parametrizations are still written in Fortran and are augmented with OpenACC directives to produce code for the GPUs. Subsection 4.4 gives some rules, how the OpenACC directives should be used in the COSMO-Model.

These rules are primarily intended for the COSMO-Model and the INT2LM. Other COSMO Software might define additional or modified rules and conventions for development. See the following appendices or additional documents:

- For `fieldextra`: Appendix B.
- For Versus: Appendix C.
- For CLM: Appendix D.
- For the C++ version of the dynamical core, see the additional document *OPCODEC++StyleGuide_20130513.docx*.

4.1 Style and Typing Rules

The general objective behind a style guide is to write portable code that is easily readable and can be maintained by different people. Many rules follow common sense and should be obvious. Although it is always tempting for scientists to restrict coding efforts to their specific application, we strongly urge you to try and write the code in a more general form. This will make it much easier to make modifications or couple your routine to others.

The following coding rules can be split into

1. *Rules* that should be applied and will be checked by the source code administrators before implementing changes to the official version. Some of these rules are strict (which is indicated below) and their application is mandatory!
2. *Conventions* that are not checked but are highly recommended to follow.

1. Rules

- (strict) Only use standard language elements to ensure a portable code.
- (strict) Use free format syntax.
- Text style
 - (strict) Fortran statements (keywords) must be written in upper case only.
 - (strict) Names of variables, parameters, subroutines, etc., must be written in lower case.
 - (strict) Never use a Fortran keyword as variable name!
 - (strict) Owing to the international user community, all naming of variables, modules, functions and subroutines as well as all comments must be written in English.
- Code indentation
 - (strict) To improve the readability of the code indent the lines within `DO`; `DO WHILE`; block `IF`; `CASE`; `INTERFACE`; etc. Indentation of 2 characters seems to be appropriate in most cases.
 - (strict) Where they occur on separate lines indent also internal comments like the code they refer to for reflecting the structure of the code.
 - (strict) Indent continuation lines to ensure that e.g. parts of a multi line equation or function / procedure call line up in a readable manner.
 - (strict) Do not use tab characters in your code. This will ensure that the code looks as intended when ported or printed.
 - (strict) Use blank space in the horizontal and vertical, to improve readability. In particular leave blank space between variables and operators, and try to line up related code into columns. Similarly, try to make equations recognizable and readable as equations.
- Variables and constants
 - (strict) `IMPLICIT NONE` must be used in all program units. This ensures that all variables must be explicitly declared, and hence documented. It also allows the compiler to detect typographical errors in variable names. One `IMPLICIT NONE` per program unit is enough.

- Try to use meaningful variable names, or at least avoid use of cryptic names. A variable name in Fortran can have up to 31 characters (Fortran 90/95) and even up to 63 characters in Fortran 2003. Nevertheless we think that it is still useful to name the temperature as `t` and not as `temperature`. This notation is also closer to the formulas in the documentation.
- Do not use the `DIMENSION` statement or attribute: declare the shape and size of arrays inside brackets after the variable name on the declaration statement. Use the saved space for documenting.
- Always use the `::` notation, even if there are no attributes.
- Declare the length of a character variable using the `(LEN =)` syntax.
- There still is no default `REAL` datatype across all compilers. Most compilers implement the `REAL` datatype in 32 bit decision, but there can be exceptions. To improve portability between all compilers it is extremely useful to make use of `KINDs` to obtain the required numerical precision and range. A module should be written to define parameters corresponding to each required `KIND`. This module can then be `USED` in every routine allowing all variables to be declared with an appropriate precision. See Sect. 7.2 (Working Precision) for more details
- Program Units and Interface Blocks
 - (strict) Always name program units and always use the `END PROGRAM; END MODULE; END SUBROUTINE; END INTERFACE;` etc. constructs, again specifying the name of the program unit.
 - Always use only one `MODULE` per file, where the file name matches the name of the `MODULE`.
 - Always use `USE modulename, ONLY:` to specify which of
 - For variables in argument lists: Always use the attribute `INTENT (IN|OUT|INOUT)` to indicate usage of the variables.
- Miscellaneous:
 - Checking of return codes (e.g. from `ALLOCATE, DEALLOCATE, OPEN, READ` statements) helps in avoiding unexpected program behaviour and should be used wherever possible.
 - I/O: Separate the information to be output from the formatting information on how to output it on I/O statements. That is, do not put text inside the brackets of the I/O statement.
 - Use `>, >=, ==, <, <=, /=` instead of `.gt., .ge., .eq., .lt., .le., .ne.` in logical comparisons. The new syntax, being closer to standard mathematical notation, should be clearer.
 - If array notation is used, show the array's shape in brackets to improve the readability, e.g.

```

array_1d(:) = array_1d_b(:) + array_1d_c(:),

array_2d(:, :) = scalar * another_array_2d(:, :).

```

2. Conventions

- All new code should be based on the templates given for different programming units (see A). Unused header lines should be removed.
- We recommend the following conventions for variable names:
 - INTEGER variables start with the letters `i`, `j`, `k`, `m`, `n`
 - Local INTEGER variables start with `iz`, `jz`, `kz`, `mz`, `nz` (loop indices `i`, `j`, `k`, etc. are an exception to this rule!)
 - LOGICAL variables start with the letter `l`
 - Local LOGICAL variables start with the letter `lz`
 - CHARACTER variables start with the letter `y`
 - Local CHARACTER variables start with the letter `yz`
 - All other variables can start with any other letter except the above ones.
 - Local REAL variables start with the letter `z`
- Do not put multiple statements on one line: this will reduce code readability.
- If necessary, introduce continuation lines by `&` at the end of the line to be continued. Do not use empty lines between continued lines, because some compilers cannot handle them and will abort. For viewing on terminals and for printers, about 90 characters per line should not be exceeded.
- CPP (the C Pre-Processor) keys are only used for
 - Differentiating codes in relation to computer architecture and compiler properties;
 - Controlling the access to external libraries.
 - Controlling the access to non-COSMO software packages as e.g. COSMO-ART.

4.2 Mandatory Features

The newer Fortran Standards offer some means to write code faster and much more portable than e.g. Fortran 77. Among them are

- Dynamic memory allocation
- The KIND concept to specify the working precision

The use of these features is mandatory. For a more detailed explanation see Chapter 7.

4.3 Banned Features

Some of the following sections detail features deprecated in or made redundant from Fortran 90 onwards. Others ban features whose use is deemed to be bad programming practice as they can degrade the maintainability of the code.

- **COMMON** blocks - use the declaration part of **MODULEs** instead.
- **EQUIVALENCE** - use **POINTERS** or derived data types instead to form data structures.
- Assigned and computed **GOTOs** - use the **CASE** construct instead.
- Arithmetic **IF** statements - use the block **IF**, **ELSE**, **ELSEIF** **ENDIF** construct instead.
- Labels
 - Labelled **DO** constructs - use (named) **ENDDO** instead.
 - I/O routine's **END** and **ERR** - use **IOSTAT** instead.
 - **FORMAT** statements: use **CHARACTER** parameters or explicit format specifiers inside the **READ** or **WRITE** statement instead.
 - Avoid any unused statement like a labeled **CONTINUE** not being jumped to.
- **GOTO**: Avoid **GOTO** by making use of **IF**, **CASE**, **DO WHILE**, **EXIT** or **CYCLE** statements.
- **PAUSE**
- **ENTRY** statements – a subprogram may only have one entry point.
- Fixed source form
- Avoid **FUNCTIONs** with side effects, i.e. functions that alter variables in their argument list or in modules used, or functions which perform I/O operations. Although this is common practice in C, there are good reasons to avoid side effects. First, the code is easier to understand, if you can rely on the rule that functions do not change their arguments, second, some compilers generate more efficient code for *pure* functions, because they can store the arguments in different places (from Fortran 95 on there are the attributes **PURE** and **ELEMENTAL**).
- Avoid changing the shape of an array implicitly when passing it into a subroutine. Although actually forbidden in the Fortran 77 standard it was very common practice to pass n dimensional arrays into a subroutine where they would, say, be treated as a 1 dimensional array. This practice, though banned in Fortran 90, is still possible with external routines for which no **INTERFACE** block has been supplied. This only works because of assumptions made about how the data is stored.
(Note: When using external libraries like **BLAS** or **LAPACK**, this is still common practice. The performance improvement here is worth these 'dirty tricks' and well marked by the **BLAS** and **LAPACK** usage.)
- Try to avoid the use of **DATA** and **BLOCKDATA**. This functionality is now given by initializers.

4.4 OpenACC Style Guide

This subsection provides information on the preferred style for the OpenACC directives in the COSMO-Model.

General

The OpenACC directives and clauses should be in lower case:

```
!$acc parallel
```

Structured Data Regions

For subroutines which fully run on the GPU, structured data regions should begin after the header in a new section (e.g. "Declaration of GPU arrays"). The `end data` directive shall be placed right before the `END SUBROUTINE/FUNCTION`.

```
!Declarations of GPU arrays
!$acc data present(t,qv,qc)
... subroutine body ...
!$acc end data
END SUBROUTINE name
```

Multi-Line Directives

A line continuation symbol (&) at the end of an incomplete line is sufficient. A leading & in the beginning of the continued line is not required. The & symbols should be aligned. A space should separate the clause from the arguments in parenthesis.

Recommended:

```
!$acc data           &
!$acc present (foo) &
!$acc create  (bar)
```

Discouraged:

```
!$acc data &
!$acc present (foo) &
!$acc create (bar)
```

If a list is stretched over multiple lines, every line should contain a leading keyword (`present`, `update host`, etc).

Recommended:

```
!$acc data
!$acc present (lorem,ipsum,dolor,sit,amet)      &
!$acc present (consectetur,adipiscing,elit)    &
!$acc present (sed,sagittis,purus,molestie)    &
!$acc create (aliquam,enim,in,lacinia,erat)    &
!$acc create (duis,fringilla,feugiat,feugiat)  &
!$acc create (aliquam,eget,gravida,felis)
```

Discouraged:

```
!$acc data
!$acc present (lorem,ipsum,dolor,sit,amet,      &
!$acc      consectetur,adipiscing,elit,        &
!$acc      sed,sagittis,purus,molestie)      &
!$acc create (aliquam,enim,in,lacinia,erat,    &
!$acc      duis,fringilla,feugiat,feugiat,    &
!$acc      aliquam,eget,gravida,felis)
```

Indentation

The directives should be indented with the code, not put to the left border like preprocessor directives.

Recommended:

```
IF (lsomething) THEN
  !$acc parallel
  DO k=1,ke
    !$acc loop gang
    DO j=1,je
      !$acc loop vector
      DO i=1,ie
        foo(i,j,k) = bar(i,j,k)**2
      ENDDO
    ENDDO
  ENDDO
!$acc end parallel
ENDIF
```

Discouraged:

```
IF (lsomething) THEN
!$acc parallel
  DO k=1,ke
!$acc loop gang
  DO j=1,je
!$acc loop vector
  DO i=1,ie
    foo(i,j,k) = bar(i,j,k)**2
  ENDDO
  ENDDO
  ENDDO
!$acc end parallel
ENDIF
```

Comments

Directives used to declare the parallel execution (`!$acc parallel`, `!$acc loop`, etc.) do not necessarily require comment. Directives related to data creation and movement need comments. This is particularly true for `!$acc update` in order to keep track of the data flow.

Example:

```
!t is used on CPU in the next section
!$acc update host(t)
```

5 Documentation

All large software systems have an enormous amount of associated documentation. Some remarkable part of the software process costs should be used to produce this documentation. Therefore, developer and management should pay as much attention to the documentation and its associated costs as to the development of the software itself.

The documentation associated with a system falls into two classes:

- **Process Documentation**
These documents record the process of development and maintenance. Plans, schedules and project standards for example are process documentation.
- **Product Documentation**
This documentation describes the product which is developed. System documentation describes the product from the point of view from the engineers developing and maintaining the system; user documentation provides a product description oriented towards system users.

5.1 Process Documentation

Process Documentation contains the following (important) features:

- Standards for coding rules, documentation, quality control, testing and verification.
This document.
- For subsequent changes to the code: A version history and a changes log-file.
The SCA distributes that with every version of the Software.
- Plans for future developments, milestones and deliverables.
The Management maintains lists for these purposes.
- A list of known / reported bugs (Bug Tracker).
This is maintained by the SCA.
- Regular reporting on the work done.
The SCA of the COSMO Software are reporting to the SMC. This is done in the framework of the COSMO Priority Task *Support Activities*.

All process documentation will be available on the COSMO web page in the near future.

5.2 Product Documentation

Product Documentation may be split into two categories: external documentation (outside the code) and internal documentation (inside the code). In order for the documentation to be useful it needs to be both up to date and readable at centres other than that at which the code was originally produced. Since these other centres may wish or need to modify the imported code we specify that all documentation, both internal and external, must be available in English.

External Documentation

In most cases this will be provided at the package level, rather than for each individual routine. It must include the following:

- *Scientific Documentation*
This sets out the problem being solved by the package and the scientific rationale for the solution method adopted. This documentation should be independent of (i.e. not refer to) the code itself.
- *Implementation Documentation*
This documents a particular implementation of the solution method described in the scientific documentation and / or describes the structure of the code (for more technical oriented software). All public procedures (subroutines, functions, modules, etc.) in the package should be listed by name together with a brief description of what they do. A calling tree for routines within the package must be included. The main data structures must be described.
- *User Guide*
This describes all things that are necessary to know for to use the software in an educated way. In particular, this describes in detail all inputs into the package. This includes both subroutine arguments to the package and any switches or ‘tuneable’ variables within the package. Where appropriate default values; sensible value ranges; etc should be given. Any files or namelists read should be described in detail.

The external documentation for the COSMO-Model and the INT2LM is written in LaTeX. Other COSMO Software might define different formats.

Internal Documentation

This is to be applied at the individual routine level. There are four types of internal documentation, all of which must be present.

- *Procedure headers*
Every subroutine, function, module, etc. must have a header. The purpose of the header is to describe the function of the routine, probably by referring to external documentation, and to document the variables used within the routine. All variables used within a routine must be declared in the header and commented as to their purpose including physical units if applicable. It is a requirement of this standard that the headers listed in Appendix A (or similar headers for different COSMO Software) be used and

completed fully. Centres are allowed to add extra sections to these headers if they so wish.

- *Section comments*

These divide the code into numbered logical sections and may refer to the external documentation. These comments must be placed on their own lines at the start of the section they are defining. The recommended format for section comments is:

```
!-----  
! <Section number> <Section title>  
!-----
```

where the text in <> is to be replaced appropriately.

- *Other comments*

These are aimed at a programmer reading the code and are intended to simplify the task of understanding what is going on. These comments must be placed either immediately before or on the same line as the code they are commenting.

- *Meaningful names*

Code is much more readable if meaningful words are used to construct variable and subprogram names.

All internal documentation has to be written in English.

5.3 Delivering New or Modified Code

If new or modified code is delivered, the programmer has also to provide the corresponding (external) documentation to the Editor of the Documentation System:

- **Internal product documentation:**

The code has to be structured in meaningful units / sections, which are documented within the source code.

- **External product documentation:**

For new code an external scientific (and implementation) documentation as well as an extension to the User Guide has to be provided. For modified code, the existing external documentation has to be updated. If new scientifically oriented components are added to the COSMO-Model, external scientific documentation can be provided by a COSMO Technical Report or by a COSMO-Newsletter article.

- **Process documentation:**

The programmer has to produce a (short) documentation of the changes to the existing software version that can be included to the version history and the changes log-file.

- **All documentation has to be written in such a way that it can be taken over to the existing official documentation without substantial modifications or technical adjustments. It is planned to distribute the LaTeX source files of the documentation together with the Source Code Repository.**

6 Software Maintenance and Quality Control

The purpose of this section is to define a clear and transparent release management. This should ensure a proper implementation of new versions and a smooth updating of the operational systems. A necessary condition for that purpose is to give clear rules how the software can be updated.

6.1 Version and Release Management

The purpose of maintenance is that the product continues to meet the needs of the end-user. Over the lifetime of a system, its original requirements can be modified to reflect changing needs, the system's environment can change, and errors may show up. Therefore we can identify three categories of maintenance.

A Further developments:

If the requirements to the software are changing, the software must be extended to meet the new requirements. This means either that new components have to be developed or that existing components must be changed significantly in contents.

B Perfective maintenance (technical changes):

Perfective maintenance improves the system but does not change the functionality. These can be changes in parallelization, data I/O or also modifications to the general architecture of the software.

C Corrective maintenance (bug fixes):

This is needed to correct detected bugs and coding errors. Usually they are easy to correct but less easy to find sometimes.

Maintenance can be considered as an iteration of the development process and therefore the same standards and procedures should be applied. This means among other things:

- If necessary, new requirements must be formulated and validated.
(E.g. the need for a new parameterization or a new dynamical core.)
- New components must be designed and implemented.
- If existing components of the system must be changed, there has to be a clear redesign before the implementation phase.
- Parts or all of the system must be tested and validated (Quality Control).

In short: there have to be similar rules to update the software and implement changes as there are for the initial development. For COSMO Software, Table 6.1 in Sect. 6.2 specifies these rules.

To keep track of all the changes, a version control system (VCS) must be used. With a VCS, the source code is stored at a central repository and the history of all files can be

recorded. Thus it is able to distinguish between the different versions of the software. The COSMO-Model and the INT2LM are maintained at DWD using a VCS, which is an in-house development, based on publicly available tools. `fieldextra` is maintained by MeteoSwiss using Subversion.

Every version which is not part of a VCS is called a private version and is available only for the developer. Only if code is provided to the SCA and checked into the VCS, it is part of an official version. For every official version the SCA defines a certain status to identify its availability for the users:

- Development Versions:

These versions are intermediate versions that are only given to the developers for further work and testing (private versions).

Such versions are necessary, if several changes by different developers have to be incorporated into an official version. With different development versions the SCA has the possibility to check in the different developments one by one.

- Test Versions:

These versions can combine several contributions by different developers and are defined by the SMC (see 6.4). They are given to special test persons, who are conducting more extensive common tests.

The individual changes have been tested separately by the developers. To check that the changes also work well in combination, further tests have to be performed. Also, different configurations have to be tested here.

- Released Versions (or Releases):

If a test version passes the common tests successfully, it can be released to all users.

- Recommended CLM-Community Versions:

The released versions need an intensive evaluation in the climate mode including the provision of an optimum configuration for regional climate simulations. In the case the model proves to provide better results in the climate mode the version can be recommended to the CLM-Community users.

For the COSMO-Model there are some flavors of releases, Depending on the different communities:

- NWP release: A version that passed the NWP tests (see 3.3, 3.4 in Table 6.1) and verification and is released to the NWP community.
- CLM release: A version that passed the COSMO-CLM tests (see 3.5, 3.6 in Table 6.1) and standard evaluation and is released to the CLM-Community.
NOTE: COSMO-CLM subversions are maintained within the CLM-Community. Therefore, COSMO-CLM releases may differ from any NWP versions of the code.
- Unified release: A model version which is a NWP and a COSMO-CLM release.

STC approves a special released version to be the Reference Version and that concerns especially software versions which are unified for all COSMO communities.

For the COSMO-Model it is planned that each main model version (Version x.0) is a unified release for numerical weather prediction, regional climate modelling and environmental modelling.

The following sections are mainly written for the COSMO-Model and the INT2LM. Nevertheless, some of the rules are also applicable to other COSMO Software, but specific guidelines (e.g. for `fieldextra`) are given in the Appendices.

6.2 Rules for Implementation of Changes

All updates for the COSMO Software should follow two guidelines:

- **Scientific**
The COSMO Software is further developed according to the COSMO Science Plan, which describes the COSMO goal and the strategy to attain the goal in the near future. Of course this does not mean, that developments can only find their way into the model, if they are reflected in the Science Plan. COSMO is still open for developments that do not (fully) adhere to this plan, if they are valuable for the community. Similar, but less extensive, plans do also exist for other COSMO Software.
- **Technical:**
Implementation and documentation of all changes have to follow the *COSMO Standards for Source Code Development* (this document). This holds for all developments, whether they come from inside or outside of COSMO.

Depending on the categories of changes given in Sect. 6.1 and on the type of the code, the standards for updating software are different. For the COSMO-Model, changes of Category A (further developments) surely have to fulfill more requirements than technical changes. Table 6.1 below lists a set of rules, that have to be followed. Bug fixes and technical changes can skip some of these rules. The last columns indicate, which rules have to be obeyed.

Note that these rules apply to the COSMO-Model and the INT2LM. For other COSMO Software, similar rules may be specified.

The CLM-Community also compiled a lists with *Steps of Code Development for CLM-Community Model Versions*, wich is given in Appendix D.

Table 6.1: Rules for Implementation of Changes

No.	Description	Further Developments	Bug Fixes	Technical Changes
1	Information of Working Group Coordinators and discussion within the Management on planned changes / new developments. The Management maintains a list of actions for planned / ongoing developments, the <i>Planning for Future Developments</i> .	✓		✓

No.	Description	Further Developments	Bug Fixes	Technical Changes
2.1	Design, development, implementation and documentation of the changes within COSMO or by external partners.	✓		✓
2.2	The <i>COSMO-Standards for Source Code Development</i> (this document) have to be followed. This is monitored by the TAG.	✓	✓	✓
3	Testing of the changes according to the Quality Control System of the COSMO partner or of the external partner that implements them. For NWP users this system must include at least the steps 3.1-3.4. For CLM users steps 3.1, 3.2, 3.5 and 3.6 apply.			
3.1 (all)	Pass the technical standard test suite (see Sect. 6.5). This is monitored by the SCA/TAG.	✓	✓	✓
3.2 (all)	4-eyes-assurance: All changes must be checked by a second person. This is monitored by the SCA/TAG.	✓	✓	✓
3.3 (NWP)	Testing of single cases with verification against observations.	✓	✓	✓
3.4 (NWP)	<p>If significant changes of results are expected, more intensive tests have to be performed, e.g.</p> <ul style="list-style-type: none"> - Longer experiments, also for different seasons / domains / climates, with verification against observations. - Experiments to check interdependencies between data assimilation and forecast and also possible impacts on a fine-grid nest. (7 km → 2-3 km) - Additional experiments to check dependencies of results on the mesh-size (7 km as well as 2-3 km). - Verification results should be positive or neutral regarding the latest official release. (Note: The term "should" is chosen on purpose. Sometimes a change leads to a more physical formulation, although the results do not improve). 	✓	✓	✓
3.5 (CLM)	Individual tests exhibiting the effects of the modifications.	✓	✓	✓
3.6 (CLM)	Standard evaluation of climate simulations.	✓		

No.	Description	Further Developments	Bug Fixes	Technical Changes
4	Presentation of the results: The results should be presented to the corresponding COSMO and / or CLM Working Group, if possible during the COSMO General Meeting, the COSMO User Seminar or the CLM Assembly, where appropriate.	✓		
5	Provide extensions / modifications for the Documentation System. Provide a test case and associated results, if appropriate.	✓	✓	✓
6	For new components a code responsible person has to be nominated by the developer(s).	✓		
7	Discussion within the Management about the implementation into the VCS and updating of the <i>Release Planning</i> . For COSMO, a final approval has to be done by the STC.	✓		✓
8	Submission of the changes to the SCA, who does a final check, whether the technical requirements (Coding Rules, Documentation) are met. He checks the modifications into the VCS and in collaboration with SMC assigns a status (development, test, release) to the new version. If it is going to be a released version, the NWP and / or COSMO-CLM test suite have to run with this version (see 6.6).	✓	✓	✓

Some comments on these rules

- 1: Before the discussion in the SMC, new developments / changes can also be discussed in other groups (development teams, Working Groups, teams at universities, etc.), which want to contribute to the development of the COSMO Software. The SMC will then discuss and decide on the acceptance of changes and propose a Priority Project, a Priority Task or a Working Group Task to the STC.
- 2a: For major developments it is recommended to split up the design and implementation process in several steps to make sure early that scientific / technical requirements are met. This can be done by discussing the design with other scientists and / or the TAG.
- 2b: If developers are not sure about meeting technical requirements, the TAG should be contacted in an early phase of the development.
- 3a: Testing the changes:
Which tests have to be performed depends on the type of change. In the *list of actions*, the SMC should also specify for all developments, which tests are required.

3b: Bug fixes:

Bug fixes have to be implemented into an official version without much delay, but it has to be clear that it is a bug. This can be discussed with the Code Developer / Responsible and / or the Working Group Coordinator. The bug, the solution and the expected effects on the results have to be documented.

3c: Technical changes:

For technical changes no or only slight differences in the results are expected. Slight differences due to numerical reasons (e.g. changing order of computations for optimization) are acceptable, but must be clearly documented.

3d: Verification:

Sometimes physically more consistent implementations can lead to worse verification scores (for what reasons ever). Changes can be taken over in such cases also.

3e: Timings:

For operational reasons, increasing run times are not desired. On the other hand it is obvious that more accurate / better algorithms can take more time to run.

6: In order to assure a good quality code and support in the future, there is the need that all components of the code do have a responsible contact person. This responsible person has to be affiliated at a COSMO member or a COSMO partner institution (institutions which are allowed to use the COSMO-Model). Preferably this should be the developer him- or herself, but alternatively, an institution responsibility can be accepted.

8: Before checking code into the VCS, the SCA will give the changes back to the developers for a last cross-check of the implementation.

Sharing of code with other software and incorporation of code from other communities

If code from the CLM- or the ART-communities should be incorporated into the COSMO-Model, the same rules do apply (e.g. the Unified Releases). The only exception is for code, which is only incorporated with `ifdef`, as is the case for e.g. COSMO-ART. Code that is belonging to the sources of the COSMO-Model (also the code between `ifdef` and `endif`) has to obey to the rules. Additional code, that is only linked afterwards (e.g. the sources from COSMO-ART), does not have to fulfill these rules.

There is also the necessity to incorporate code from other centres like e.g. the convection code from IFS. Such code is taken as it is to have it comparable to the IFS versions and to keep track of the changes there.

6.3 Rationale for Changes

All modifications of the COSMO-Model should follow the *Rationale for Changes*:

In the past we often had the situation that new features have been implemented into an official version as *optional*, even if they were not fully developed and tested yet. This approach ensures that the results of the operational applications are not affected, but leads to a rapid growth of the number of Namelist variables, with which the COSMO-Model can be controlled. Adding new features with this procedure more or less as a "technical change" must be avoided in

the future. The Management not only has to decide about adding new features or variants of algorithms, but also needs to decide on which components can eventually be removed.

On the other hand there is a demand from the CLM community, that results should be reproducible between subsequent versions. Therefore we give the following recommendations when introducing changes:

- Bug fixes: Can be introduced without backwards compatibility.
- Technical changes: These should change the results only because of numerical reasons. If it can be shown by long term simulations that the changes are neutral, they can be introduced without backwards compatibility. If this cannot be shown, then these changes should be treated as the next item.
- Modifications which change the results, but should be adopted by everybody: Use a clearly documented internal switch in the source code. Once the change is commonly accepted, this switch can be removed again.
- Adding of new components: In this case a (new) namelist switch may be used.

6.4 Release Planning

In addition to the list of actions (*Planning for Future Developments*), the SMC will maintain a roadmap for every COSMO Software (including priorities) for the upcoming changes (the *Release Planning*). STC, who eventually has to approve resources for the work required, will continuously be informed about these lists, which will be published on the COSMO web site.

The planning should aim at having at most 2-3 major releases for the software every year. There might be more development and test versions. Especially bug fixes can be implemented in interim versions.

In the following we want to describe the (perhaps iterative) process, how accepted contributions to the COSMO-Model (also INT2LM) are incorporated into official versions and how new releases are defined:

1. Every contribution has to be accepted by SMC before it can be put to an official version (according to No. 7 from Table 6.1). The SMC includes accepted contributions to the Release Planning. So all accepted contributions are assigned to a special future release. The SCA updates the lists on the COSMO web site accordingly.
2. Accepted contributions are implemented by the SCA into official versions. Depending on the scope of the contributions, several contributions can be put to a single or to several new Development Versions.
3. After implementing some or all of the accepted contributions, the SCA in collaboration with the SMC defines a certain version to be a Test Version.
4. The Test Version is tested by designated COSMO colleagues. See also Sect. 6.7 for more details on testing.

5. If the tests were successful,
 - either other contributions are implemented on top of this Test Version to get another Test Version
 - or this Test Version is defined to be a Release Version (if all the contributions for a special release are implemented) and will be distributed.

Every released version contains concluded developments and is capable of performing proper forecasts. But not every released version is necessarily a Reference Version. Reference Versions are defined and approved by the STC based on general planning in line with the COSMO Science Plan. But on the way between two Reference Versions, several (working) released versions might occur.

Rationale, how new releases are defined:

Assume there are 5 new accepted contributions (A, B, C, D, E) that have to be implemented into official versions. The SMC puts up the following list for Release Planning:

- Release I contains contributions: A, C, D
- Release II (based on Release I) contains contributions: B, E

The SCA implements the contributions:

- development version x.n: contains contribution A
- development version x.n+1: contains contribution C

The SCA declares version x.n+1 to be a Test Version, because contributions A and C have to be tested together. After successful testing, contribution D is implemented.

- development version x.n+2: contains contribution D

The SCA again declares version x.n+2 to be a Test Version. This is now also a release candidate for Release I. If the testing is successful, version x.n+2 will be declared as a Release Version. If the testing indicates problems, these have to be investigated again, which might lead to additional development work and additional model versions.

After successful testing, a consolidated model version x.m will become Release I and implementation of the other developments can start.

- development version x.m+1: contains contribution B
- development version x.m+2: contains contribution E

The SCA declares version x.m+2 to be a Test Version, and if all tests are successful, a (if necessary consolidated version x.y) will become Release II.

6.5 Standard Test Suite for the COSMO-Model

Depending on the category of changes, all contributions to the software have to go through the steps specified in Section 6.2 before they are submitted to the SCA. One aspect is to test pure technical issues like the independence of the processor configurations and similar things. Issues to be checked are for example:

- Independence of processor configurations (MPI and OpenMP - for parallel code)
- Reproducibility of results with older versions (if applicable)
- Restart functionality
- I/O with Grib/NetCDF
- Tests with array bound checking
- Possibility to run with input data from different models (GME, IFS, ERA, etc.)
- Timings / efficiency / scalability
- Portability

For testing most of these issues, a standard technical test suite has been developed at MeteoSwiss, which can easily be installed and applied at every center. The user can then adapt and use already existing tests or can define additional tests of his own. The test suite together with a User Guide are distributed with the COSMO-Model.

6.6 Meteorological Test Suite

NWP Test Suite:

In addition to the developers tests on individual implementations, the NWP test suite has to be performed for each completed new version of the COSMO-Model before acquiring the status of a *released version* by the SMC.

A COSMO Priority Task was defined in the year 2013-14 with the goal to develop a platform using ECMWF resources, on which new test versions of the COSMO-Model will be tested for their forecasting performance against the previous version, within a common statistical framework. A detailed manual that describes the use of the NWP test suite is available on the COSMO web site.

For the purposes of the NWP test suite, each COSMO-Model test version will be installed and executed in a hardware environment that is accessible and available to COSMO scientists (assigned by STC), who will be responsible for the maintenance and the operation of the suite on an annual basis. ECMWF computer resources are used for the aim of this task for simulation and archiving purposes as well as for the performance of the verification analysis, by using billing units of the members provided through a special project SPITRASP. The

model domain, horizontal and vertical resolution, duration of simulation, number of simulations that are applied within this NWP test suite, are following the guidelines provided by an assigned group of COSMO coordinators.

The model domain covers the main area of interest from a meteorological point of view that surrounds the territory of the participating COSMO countries. The forecast period of each daily run is 72 hours, on one daily cycle based on the 00UTC initializing data. The simulation period for each test was decided to include one month for the summer (July 2013) and one month for the winter season (January 2013), in total 4 months (two for each model version). The initial and boundary data are provided by the ECMWF IFS system. As a first approach, the 7km version of the COSMO-Model is used for these tests, following the operational resolution in most meteorological services. If the implemented changes in the model code are especially designed to influence the performance of a higher resolution model version, then the NWP test suite can be expanded to include additional experiments to check the dependencies of results on the mesh size.

The VERSUS verification software is installed on a virtual machine (based on ECGATE linux system) at ECMWF, in order to facilitate the verification process. For the needs of the NWP tests, the verification analysis includes grid-to-point comparisons utilized to compare gridded surface and upper-air model data to point observations. A list of selected stations (around 3500 stations) situated in various places of interest in the domain of simulation, are utilized for each test. Verification forms include the current standard verification statistics widely used by the NWP community, in particular for:

- surface continuous parameters (2mT, Dew Point T, WindSp, TCC, MSLP): BIAS, RMSE;
- 6h, 12h, 24h accumulated precipitation: ETS, FBI, Performance diagrams;
- upper air verification (T, RH, WindSp for selected pressure levels [250., 500., 700., 850., 925., 1000.mb]): BIAS, MAE, RMSE.

After the completion of each meteorological test, a report will have to be prepared by the responsible person for this task that will include the main comparisons (graphs) and will highlight the main findings extracted from the comparison of the two model versions (test and last released) performed using the NWP test suite. This report will summarize the main verification results and will include the evaluation based on the statistical outcome of the test model version. A new version of the model will in principle be validated if the set of verification results show a positive impact on the common domain or if the results are neutral but the scientific bases of the code are sounder.

COSMO-CLM Test Suite:

In addition to the developers' tests on individual implementations, the COSMO-CLM test suite has to be performed for each completed new version of the COSMO-CLM-Model before acquiring the status of a released COSMO-CLM version by the SMC.

The latest version of the COSMO-CLM test suite is available on RedC.

The COSMO-CLM test suite consists of two parts: The first part encompasses technical tests which are based on the meteorological test suite of MeteoSwiss with additional checks for the

climate mode (netCDF files, restarts, SAMOA). The second part comprises climatological tests. These tests are based on five years simulations which are compared to observations (presently: mean sea level pressure, 2 m air temperature (mean, minimum, and maximum) and total precipitation from the latest version of EOBS). From these results standard plots are provided using the CLM-Community standard evaluation tool ETOOL available on RedC.

6.7 Testing the official versions in the VCS

If a contribution to the COSMO Software has fulfilled all steps specified above (especially: all the prescribed tests) and is accepted by the Management for a future official version, the code is given together with all documentation to the SCA. He incorporates them into the VCS according to the *Release Planning*. In accordance with the guiding authority (SMC for COSMO, CLM_CO and CLM-SUPTECH, for CLM) he assigns a status to each version: development, test, release. See Sect. 6.1 for the definition of these terms. The following tests will be done with the official versions:

- Development Versions:

If several changes by different developers have to be incorporated into an official version, the SCA can build different development versions for that. The SCA checks the standard technical test suite for these versions.

- Test Versions:

While the individual changes have been tested separately by the developers, the test versions (which summarize different contributions) are given to special test persons within the Consortium, who are conducting more extensive common tests. For the COSMO-Model, for example, DWD will test such versions in its "Parallelsuite".

- Released Versions (or Releases):

If a test version passes these tests successfully, it can be released to all users.

6.8 Coordination between COSMO and ICON

The global model ICON is developed and maintained in a collaboration between DWD and the *Max-Planck-Institut für Meteorologie* in Hamburg. These partners are responsible for the development, maintenance and quality control of the ICON system.

The developments at DWD foresee a replacement of the current COSMO-Model in the medium term by a regional mode of the ICON modelling system. It is planned that other COSMO partners can adopt the regional mode of ICON and participate in the future development of the code. In this context the sharing of responsibilities for code development and maintenance between the original ICON and the COSMO partners needs to be discussed.

Right now there is a point of contact between ICON and COSMO, which is the common COSMO-ICON physics. The development, maintenance and quality control of contributions to this COSMO-ICON physics therefore needs coordination between the two groups.

- Development:

The development for special packages shall be coordinated by the *Responsible Code Owner* of the package.

- **Quality Control:**

Contributions that shall enter the official code have to be tested in both systems, ICON and COSMO, and have to pass all corresponding tests.

By the time of writing these standards not all COSMO developers (from the Consortium or the CLM group) have access to the ICON model and therefore cannot test their developments. Because of that, contributions might be accepted with special configuration switches or `ifdef`. It is stressed, however, that all these developments have to be closely coordinated with the *Current Code Owner*!

- **Conflicts:**

Conflicting contributions can be implemented with namelist switches and `/` or `ifdefs`. It is recommended to keep such implementations to a minimum.

An ICON representative is invited to the COSMO SMC Meetings, if appropriate, to discuss and coordinate the development of the COSMO-ICON physics. A representative of COSMO shall also take part in ICON development meetings.

The ICON representative in the SMC is responsible to regularly check the new developments in the COSMO physics and to initiate the corresponding insertion procedure into ICON. He reports on the status of the insertion requests to the SMC.

7 Implementation Issues

This chapter should give some hints for efficient programming. All that follows is a draft and will be further developed in the near future.

NOTE:

This chapter is work in progress. The TAG still has to complete it.

7.1 Memory Management

Allocation of Memory

The use of dynamic memory is highly desirable as it allows one set of compiled code to work for any specified resolution and allows the efficient reuse of work space memory. Care must be taken, however, as there is potential for inefficient memory usage, particularly in parallelized code. For example heap fragmentation can occur if space is allocated by a lower level routine and then not freed before control is passed back up the calling tree. There are three ways of obtaining dynamic memory in Fortran 90:

1. *Automatic arrays*

These are arrays initially declared within a subprogram whose extents depend upon variables known at runtime e.g. variables passed into the subprogram via its argument list. Automatic arrays will not be retained once the subprogram ends.

2. *Pointer arrays*

Array variables declared with the `POINTER` attribute may be allocated at run time by using the `ALLOCATE` command.

3. *Allocatable arrays*

Array variables declared with the `ALLOCATABLE` attribute may be allocated at run time by using the `ALLOCATE` command. However, unlike pointers, allocatables were not allowed inside derived data types before Fortran2003 and some compilers might still not recognize it.

Space allocated using 2. and 3. above must be explicitly freed using the `DEALLOCATE` statement. In a given program unit do not repeatedly `ALLOCATE` space, `DEALLOCATE` it and then `ALLOCATE` a larger block of space. This will almost certainly generate large amounts of unusable memory and can degrade performance (depending on the platform). Using `ALLOCATE`s in every time step (or even more often) should therefore be avoided unless there is no other way to implement a special feature.

Always test the success of a dynamic memory allocation and deallocation. The `ALLOCATE` and `DEALLOCATE` statements have an optional argument to let you do this.

Passing arrays through argument lists

- Call-by-reference vs. Call-by-value
- Assume-shaped vs. explicit-shaped arrays

7.2 Working Precision

Use of the KIND-type concept

Fortran 90 provides representation methods for the intrinsic data types (`INTEGER`, `REAL`, `COMPLEX`, `CHARACTER`, `LOGICAL`). Each method can be specified by a value called *kind type parameter*, which is a scalar integer initialization expression that indicates

- the decimal exponent range for the integer type,
- the decimal precision and exponent range for the real and complex types
- and the representation methods for the character and logical types.

Each intrinsic type supports a specific set of kind type parameters. For `REAL`-types for example, every compiler must support the former types `single precision` and `double precision`. To specify the representation method, the kind type parameter can be given for some type specifiers (`INTEGER`, `REAL`, `COMPLEX`):

`REAL(KIND=method1)` or `REAL(KIND=method2)`.

Here, *method_x* are the kind type parameters. Intrinsic functions are provided to specify the kind parameter for a specified precision and variable range:

`method1 = SELECTED_REAL_KIND (12,200)`.

specifies the representation method that has a working precision of at least 12 significant digits and an exponent range of at least 200. This is the `double precision` data type.

For `CHARACTER` data types, the *length type parameter* `LEN` specifies the number of characters in such an entity.

7.3 Parallelization

7.4 Optimization

7.5 Vectorization

7.6 I/O

7.7 Error Handling / Debug Messages

Just a comment:

"Error messages should be meaningful and easily understandable for the user and it should be possible to find them in the source code. It is not sufficient just to give an error code

number; especially it should be avoided to compose this number as a sum of an index with some basis number (which makes it too difficult to locate the error with a `grep` or similar)."

References

- [1] Andrews, Philip (UKMO), Gerard Cats (KNMI/HIRLAM), David Dent (ECMWF), Michael Gertz (DWD), and Jean Louis Ricard (MeteoFrance), European Standards For Writing and Documenting Exchangeable Fortran 90 Code, Version 1.1, 1995.
- [2] E. Kalnay, et al., Rules for Interchange of Physical Parametrizations, *Bull. A.M.S.* 70, No. 6, p. 620, 1989.
- [3] Sommerville Ian, Software Engineering, Fourth Edition, Addison-Wesley, 1992.

A Standard Headers for the COSMO-Model and INT2LM

The standard headers are presented in this appendix. They are written as templates. Text inside < > brackets must be replaced with appropriate text by the user.

Program Header

```

!+ <A one line description of this program>
!-----

PROGRAM <NameOfProgram>

!-----
! Description:
!   <Say what this program does>
!
! Method:
!   <Say how it does it: include references to external documentation>
!   <If this routine is divided into sections, be brief here,
!       and put Method comments at the start of each section>
!-----
!
! Input files: <Describe these, and say in which routine they are read>
! Output files: <Describe these, and say in which routine they are written>
!
! Current Code Owner: <Name of person responsible for this code>
!
! History:
! Version   Date       Comment
! -----   ----       -
! <version> <date>    Original code. <Your name>
!
! Code Description:
! Language:           Fortran 90.
! Software Standards: COSMO Standards for Source Code Development
!-----

! Modules used:

USE, ONLY : &
! Imported Type Definitions:
! Imported Parameters:
! Imported Scalar Variables with intent (in / out):
! Imported Array Variables with intent (in / out):
! Imported Routines:
!
! <Repeat from USE for each module...>
!-----

IMPLICIT NONE

!-----
!
! Declarations must be of the form:
! <type>   <VariableName>      ! Description/ purpose of variable
!
! Local parameters / scalars / arrays:
!
!- End of header -----

!-----
! Program Body
!-----

END PROGRAM <ProgramName>

```

Subroutine header

```

!+ <A one line description of this subroutine>
!-----
SUBROUTINE <SubroutineName> (<InputArguments, inoutArguments, OutputArguments>)

!-----
! Description:
!   <Say what this routine does>
!
! Method:
!   <Say how it does it: include references to external documentation>
!   <If this routine is divided into sections, be brief here,
!       and put Method comments at the start of each section>
!-----
!
! Current Code Owner: <Name of person responsible for this code>
!
! History:
! Version   Date       Comment
! -----   ----       -
! <version> <date>    Original code. <Your name>
!
! Code Description:
! Language:          Fortran 90.
! Software Standards: COSMO Standards for Source Code Development
!-----

! Declarations:
! Modules used:

USE, ONLY : &
! Imported Type Definitions:
! Imported Parameters:
! Imported Scalar Variables with intent (in / out):
! Imported Array Variables with intent (in / out):
! Imported Routines:
!
! <Repeat from USE for each module...>
!-----

IMPLICIT NONE

!-----
!
! Declarations must be of the form:
! <type>   <VariableName>      ! Description/ purpose of variable
!
! Subroutine arguments
! Scalar arguments with intent(in):
! Array arguments with intent(in):
! Scalar arguments with intent(inout):
! Array arguments with intent(inout):
! Scalar arguments with intent(out):
! Array arguments with intent(out):
! Local parameters:
! Local scalars:
! Local arrays:
!
!- End of header -----

!-----
! Subroutine Body
!-----

END SUBROUTINE <SubroutineName>

```


Function header

```

!+ <A one line description of this function>
!-----
<Type> FUNCTION <FunctionName> (<InputArguments>)

!-----
! Description:
!   <Say what this function does>
!
! Method:
!   <Say how it does it: include references to external documentation>
!   <If this routine is divided into sections, be brief here,
!       and put Method comments at the start of each section>
!-----
!
! Current Code Owner: <Name of person responsible for this code>
!
! History:
! Version   Date       Comment
! -----   -
! <version> <date>    Original code. <Your name>
!
! Code Description:
! Language:           Fortran 90.
! Software Standards: COSMO Standards for Source Code Development
!-----
!
! Declarations:
! Modules used:
!
! USE, ONLY : &
! Imported Type Definitions:
! Imported Parameters:
! Imported Scalar Variables with intent (in):
! Imported Scalar Variables with intent (out):
! Imported Array Variables with intent (in):
! Imported Array Variables with intent (out):
! Imported Routines:
!
! <Repeat from USE for each module...>
!-----

IMPLICIT NONE

!-----
! Declarations must be of the form:
! <type>   <VariableName>      ! Description/ purpose of variable
!
! Function arguments
! Scalar arguments with intent(in):
! Array arguments with intent(in):
! Local parameters:
! Local scalars:
! Local arrays:
!
!- End of header -----

!-----
! Function Body
!-----

END FUNCTION <FunctionName>

```

Module header

```

!+ <A one line description of this module>
!-----

MODULE <ModuleName>

!-----
! Description:
!   <Say what this module is for>
!-----
!
! Current Code Owner: <Name of person responsible for this code>
!
! History:
!
! Version   Date       Comment
! -----   -
! <version> <date>   Original code. <Your name>
!
! Code Description:
! Language:           Fortran 90.
! Software Standards: COSMO Standards for Source Code Development
!-----
!
! Modules used:
!
USE, ONLY : &
! Imported Type Definitions:
! Imported Parameters:
! Imported Scalar Variables with intent (in):
! Imported Scalar Variables with intent (out):
! Imported Array Variables with intent (in):
! Imported Array Variables with intent (out):
! Imported Routines:
!
! <Repeat from USE for each module...>
!
! Declarations must be of the form:
! <type>   <VariableName>           ! Description/ purpose of variable
!-----

IMPLICIT NONE

!-----
! Global (i.e. public) Declarations:
! Global Type Definitions:
! Global Parameters:
! Global Scalars:
! Global Arrays:
!
! Local (i.e. private) Declarations:
! Local Type Definitions:
! Local Parameters:
! Local Scalars:
! Local Arrays:
!
! Operator definitions:
!   Define new operators or overload existing ones.
!-----

CONTAINS

!-----
! Define procedures contained in this module.
!-----

END MODULE <ModuleName>

```

B Amendments for `fieldextra`

Style and Typing Rules

A set of additional coding rules and conventions are defined in the file `README.developer` distributed with the `fieldextra` package. At the time of the writing, this document is a work in progress based on the release 10.4 of `fieldextra`.

Note that most of the rules defined in Chap. 4 of this document apply. The most notable exceptions are:

- **DIMENSION:**
Use of `DIMENSION` statement is recommended.
- **USE `modulename`, ONLY:**
Is not required for general purpose modules, such as modules used for definition of program entities (`fxtr_definition`) or modules used to manage program diagnostic (`support_information`).
- **GOTO:**
Usage is accepted when dealing with error conditions to jump to the error processing part of the procedure.
- **Variable names:**
Do not use the naming conventions associated with the variable type (e.g. `LOGICAL` starts with `l` and similar).
- **Multiple statements on the same line:**
Is allowed for short statements logically related (e.g. exception handling, initialization of some local variables).

Documentation

The documentation for `fieldextra` is written in plain ASCII.

The following documents are available within the `fieldextra` package or on the COSMO web site:

- **CREDITS:** list of contributors;
- **HISTORY:** version history and change log files, list of known bugs;
- **ROADMAP:** plans, milestones and deliverables;
- **README.install:** installation guide;
- **FirstContact.pdf**, **README.user**, **README.user.locale** and **FAQ:** user guide;
- **README.developer** and **README.cosmo_api:** implementation guide.

Software Maintenance and Quality Control

`fieldextra` is maintained by MeteoSwiss using Subversion.

The code design is described in the documentation of `fieldextra`.

A test case with its associated results should be provided with any new development.

All changes to the code have to be tested using the standard set of examples provided within the `fieldextra` package.

C Amendments for VERSUS

Style and Typing Rules

A set of coding rules and conventions are defined in the file `CodingRules.pdf` that will be distributed with the Software.

Note that most of the rules are defined on following modules:

1. RDBMS (MySQL) hosting:
 - forecasts to be verified (time series and grib format)
 - observation (Synop and Temp data)
 - configuration data to perform verification (models, station lists and so on)
 - manager of the verification results (Numeric scores and plots)
2. Loader Front end for data loading into DB. This module is written using php code and follows the object oriented paradigm.
3. Scores Front End for:
 - scores computation, by means of R language scripting
 - graphical production, by means of jgraph-php libray
4. A Web-GUI for users written by into php code

Documentation

The **VERSUS** documentation is written using openOffice. The available documents are:

1. User Manual that describes the **VERSUS** functionalities (downloadable through GUI of the system).
2. Technical Manual describes the system architectural design (downloadable through GUI of the system).
3. Coding Rule document that describes the convention adopted that will be available on <ftp.meteoam.it> in the next future
4. Performance Test that describes the test cases to follow for system testing, available on <ftp.meteoam.it>

N.B. User and Technical manuals are updated every time a new version of system is delivered.

Other used tools are:

1. MySQL workbench for database design
2. Doxygen for automatic PHP documentation.

Software Maintenance and Quality Control

VERSUS is maintained by CNMCA using Patching versioning. A complete installation package will be release a the end of the Project development (with no Patches in addition).

All changes to the code are tested extensively before the official release.

Performance test dataset, available on <ftp.meteoam.it> and the test cases to follow described on PerformanceTest.doc documentation, should be used by the user to check system performance after any update.

D Steps of Code Development for CLM-Community Model Versions

(Version from 02.10.2015)

Contact the **CLM-Community WG SUPTECH** in case of further questions (mail to: clm_suptech@listserv.dfn.de).

	Steps	What to do	CSCD Chap.	Tab. 6.1
A	Inform the CLM-Community coordination group about your plans			
		Contact a member of the CLM coordination group (CLM-CO) (mail to: clm_co@listserv.dfn.de). Add information about the intended development to the CLM topic browser and to the COSMO webpage. Start using the development report template ²	2.2, 6.1	1
	Get a released version			
		Download a COSMO-CLM version available from the CLM-Community home page (RedC) and contact the CLM-SUPTECH (mail to: clm_suptech@listserv.dfn.de) if another COSMO version is needed.		
	Implement your changes			
		Right from the implementation of the first changes the released version becomes a <i>development version</i> (1st private version) (see COSMO-Standards for Source Code Development (CSCD), Section 6.1). Although a development version is not subject to the conditions of the CSCD it is good practice to follow them right from the beginning. For new program units (FUNCTIONs , MODULEs, PROGRAMs, SUBROUTINEs,) use the available templates.	2.3, 4, 7, A	2.1
	Perform development specific tests and simulations			
		Define and apply some development specific tests and simulations exhibiting the effect of the code development on your development version. The tests and simulations should be applicable also to the released version in which the final implementation of the development will be included.	2.3	3.5
B	Write a short report			
		Summarize the development and the results from the development specific tests in a short report and provide it to CLM-CO.		2.1
	<i>CLM-CO discusses the report and recommends the implementation in a released version (or not).</i>			
	Port the development into the last released version			
		If necessary, port the implemented and tested development in the last released version (2nd private version). The CSCD are mandatory now.	4, 7, A	2.1 2.2
	Technical test suite			

²<http://www.clm-community.eu/index.php?menuid=216>.

		Apply the technical test suite ³ to the 2nd private version. Contact the source code administrator (SCA) in order to know how to do that.	4, 7, A	3.1
C	Repeat the development specific tests and simulations			
		Discuss with the coordinator of the respective working group which development specific simulations need to be repeated with the 2nd private version, conduct the simulations, compare the effect with that of the original implementation and update the short report.		3.5
	<i>CLM-CO discusses the updated report and recommends the implementation in a released version (or not).</i>			
D	CSCD check			
		Provide the development to the SCA together with the test results and the internal and process documentation.	4, 5.3	3.2 8
	<i>SCA checks if the coding rules of CSCD are respected. In case the check is negative, the code has to be revised and the revised version has to be sent to the SCA again.</i>			
E	Climatological test suite⁴			
		Pass on the new development to the coordinator of the evaluation group.		3.6
	<i>The evaluation group applies the standard test suite⁵, discusses the results and recommends the implementation in a released version (or not).</i>			
	Presentation of results			
		Present the development to the corresponding CLM Working Group, if possible during the COSMO/CLM/ART User Seminar or the CLM-Community Assembly.	6.2	4
G	Extend/Modify the official COSMO-Documentation			
		Revise the parts of the source document of the COSMO documentation that need to be extended or/and modified. Write the scientific documentation and the necessary extension for the user's guide and provide it to CLM-Community coordinator (mail to: clm.coordination[at]dwd.de).	5.2	

³still under development⁴still under development⁵still under development