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Subject: Full proposal for a new COST Action:
Basic Concepts for Convection Parameterization in Weather Forecast and Climate Models

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[*] Will be completed by the COST Office

DRAFT
MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action
designated as

COST Action

Basic Concepts for Convection Parameterization in Weather Forecast and Climate Models

The signatories to this "Memorandum of Understanding", declaring their common intention to participate in the concerted Action referred to above and described in the "Technical Annex to the Memorandum", have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 299/06 "Rules and Procedures for Implementing COST Actions", or in any new document amending or replacing it, the contents of which the Signatories are fully aware of.

2. The main objective of the Action is [*]

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at [*] Euro [*] million in [*] prices.

4. The Memorandum of Understanding will take effect on being signed by at least five Signatories.

5. The Memorandum of Understanding will remain in force for a period of years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter V of the document referred to in Point 1 above.

[*] Will be completed by the COST Office

A. ABSTRACT & KEYWORDS

A.1 ABSTRACT

The main objective of the Action is to provide clear theoretical guidance on convection parameterizations for climate and numerical weather prediction models. Both global and regional atmospheric models are concerned. The Action achieves this objective by creating a core theoretical group to addressi the fundamental issues of convection parameterization. Modellers and theoreticians join together under this framework. The Action proposes a clear pathway for more coherent and effective parameterizations by integrating existing operational schemes and new theoretical ideas. Proposed alternative approaches intend to replace conventional tuning-based approaches. The Action complements extensive inter-comparison based validations performed by operational modellers.

The Action responds particularly to urgent need which has arisen from increasing the resolutions of forecast models. In these new-generation models not only the traditional approximations break down, but associated physical processes become increasingly complex. Thus, the parameterization must be extensively re-formulated with more sophisticated physics under new constraints.

The Action contributes to reduce uncertainties in weather forecasts and climate projection by overcoming the often weak physical basis of the current parameterizations. Particular benefits will be in prediction of highly unusual extreme weather events, such as local heavy precipitation, tropical cyclone trajectories etc. The IPCC will be a particular international agent that will be benefited from the present Action.

A.2 Keywords

Climate, Clouds, Convection, Parameterization, Uncertainties

B. BACKGROUND

B.1 General background

research topic and wider relevance:

The extent of the social and economical dimensions that are affected by climate change and weather forecasts (especially by extreme events) is beyond measure. Atmospheric circulation models, both for numerical weather prediction (NWP) and climate projection, have become increasingly important, both socially and economically, in recent years. Most seriously, political decisions of how to deal with climate change heavily rely on climate projection studies provided by these global climate models. At the same time, weather forecast centres extensively invest into development of high-resolution regional models in order to improve the reliability of extreme event predictions.

However, those numerical models suffer from an inherent problem: they can run only with limited spatial resolutions. Based on partial differential equations, they can perform horizontal differentiations only by numerical approximations based on, for example, finite differences or spectral methods. As a result, any variability at scales smaller than the grid spacing of a model cannot be calculated explicitly. Prime examples of such variability are precipitation and vertical mass and energy transport associated with atmospheric convection.

Convection is a key process within the Earth system. Deep convection in the tropics is a main driver of the atmospheric general circulation. It vertically transports an enormous amount of latent and sensible heat, and generates the bulk of the precipitation reaching the Earth surface. For successful applications of the numerical models, thus, it is crucial that unresolved variability, most notably the variability associated with convection, have to be properly accounted for. Methods for accounting these subgrid-scale processes are called parameterizations. Unfortunately, the current numerical models suffer from various deficiencies in this respect. Models produce too early an onset of afternoon convection; the rainfall maximum tends to be underestimated; and they fail to represent the 20-60 day planetary-scale tropical oscillation (the Madden-Julian oscillation).

These deficiencies are often responsible for failed warnings of heavy rainfall (extreme events) and consequential major floods, common in the Mediterranean area, for example, even in short term weather forecasts. For longer time scales, the deficiencies become major factors limiting the usability of climate model results for policy makers and stakeholders. For this reason, the most recent IPCC report singles out convection and cloud parameterization as the key issues to be resolved in order to reduce uncertainties in the future climate projections.

Current operational parameterizations use various technical assumptions. The parameters in parameterizations are often simply "tuned" ,f or example, to achieve a good radiation balance at the top of the atmosphere. The most notorious example of such assumptions is the "closure" that is required to define the total intensity of parameterized convection. Another example is the assumptions around the rate of entrainment and detrainment which characterise the lateral exchange of air between a convective plume (convective cloud) and the environment..

Though it may sound very technical, these choices critically influence the overall performance of the models. Change of closure hypothesis can qualitatively change even the global climatological distribution of precipitation. The entrainment and detrainment rates are critical in defining the vertical extent of convection. Clearly, a more robust methodology for defining these parameters are required.

More fundamentally, current parameterizations are designed to separately represent particular elements of the model physics (e.g., deep convection, boundary layer turbulence, radiation). ,As a result, tuning is also performed separately in such manner that overall errors compensate each other. A better methodology for coupling these physics are clearly in need.

why COST?:

The convection parameterization problem is one of the key issues, in spite of its critical importance, left to be properly addressed. The goal of the present Action is to address this problem from a more fundamental level. The Action seeks theoretical principles for convection parameterization that lead to significant improvement of its the performance. For this goal, the Action establishes a link between operational and climate research centres with the theoretical physics and applied mathematics community. The Action is built upon existing corporate efforts in a bottom-up manner (cf. Sec. B.4). The goal is achieved by extensive networking that encourages exchange and corporation between researchers across Europe. The Action also strengthens and supports the current extensive inter-comparison and validation efforts by weather-service consortia and international projects (cf., Sec. B.4).

advantages and benefits:

The present Action has arisen from many informal conversations and e-mail communications that have gradually recognized the urgent need for well-organized meetings and multi-lateral collaboration to consolidate, promulgate and inspire intensive theoretically-oriented research at the European level. Due to their "bottom-up" nature, these needs are best met through a COST Action. A well-funded network is necessary to bring the existing grass-root efforts to recognition and make them more efficient in a joint effort of the involved scientists from very different organizations (universities, research centres, and weather services) to work towards a common goal. A COST Action is best suited as it mainly aims at European networking.

The Action facilitates, boosts and enhances existing research and inspires future research by providing a strong theoretical impetus through mutual interactions. For this purpose, the Action particularly establishes a strong link between academic research at universities and application-oriented research both at operational and climate centres. As a result, the Action also complements, supports, and enhances currently existing model inter-comparison projects as well as model verification and validation against observations by establishing more physically-based and process-oriented approaches.

B.2 Current state of knowledge

The current standard formulation of convection parameterization, based on mass fluxes, was first introduced more than thirty years ago. The basic approach has hardly changed since then, although substantial elaborations have been introduced. The main unresolved issues of the problem have not changed since then either: convective-triggering conditions, closure, and the specification of entrainment and detrainment rates. The progress in the fundamental issues has been slow.

Moreover, the past emphasis has been on testing parameterizations' overall performance rather than examining them more from a theoretical, process oriented perspective. The issue is more than often reduced to that of "tuning" with compensating balance of errors of various sources in order to obtain best possible predictions, but not necessarily for the right reason. As a result, it can easily miss the correct response during the process of climate change.

At the most fundamental level, the problem of convection parameterization has long been identified as that of constructing a statistical theory for ensembles of cumulus convective elements, or moist convective plumes. However, so far only exploratory work has been performed towards this goal, mostly in Europe. The present Action puts these efforts into a coherent, organized activity.

Since the early 1990s a new methodology has emerged that compares outputs of convection parameterizations against those of cloud-resolving models (CRMs) and large-eddy simulations (LESs). These more explicit models, first of all, greatly contribute to improved phenomenological understanding of atmospheric convection. More importantly, these models provide a fully time-evolving three-dimensional data-set in high spatial resolution to an extent that is hardly obtained by field measurements. Such efforts have certainly contributed significantly to improvements in the performance of convection parameterizations. However, verification methodologies of such detailed results aiming at improved parameterizations are still to be fully developed.

Recent satellite missions, most notably the A-Train, have begun to provide unprecedented amount of information on detailed cloud properties at the global scale. For example, the CloudSat radar images provide a global three-dimensional distribution of precipitating water (both liquid and ice) and the CALIPSO lidar measures backscatter of much smaller non-precipitating condensed-water particles within clouds.The proposed COST Activity, in turn, provides a clear theoretical framework translating increasing availability of high-quality data sets into model improvements.

At the European level, the EUROCS (European Cloud Systems) project (2000-2003) greatly contributed to convection parameterization studies. One of the major conclusions from this project was a critical importance of more fundamental research to understand elementary processes associated with convection. For example, for the understanding of the diurnal cycle of continental convection, the trigger condition of convection was identified as a major unknown process. The present Action exactly focuses on examining these elementary processes.

Major European operational centres are currently moving towards an operational mode of high-resolution regional numerical forecasts with horizontal resolutions of 1-5 km. Increasing horizontal resolution makes the subgrid-scale problem even more acute than before. The better resolution of convective dynamics means that additional physical processes (e.g., ice microphysics) must be parameterized at higher accuracy. Moreover, some current parameterizations (e.g., auto-conversion of warm rain, which in nature depends on the highly variable cloud depth) work well at certain horizontal resolutions but not at others. Such resolution-dependence of physics parameterization has to be addressed. The Action addresses these fundamental issues in order to provide a clearer strategy for the future parameterization development.

B.3 Reasons for the Action

Reasons for launching the Action:

Atmospheric sciences consist of three major components: theory, detailed modelling at ever-increasing resolution, and observations. The present Action is going to contribute from the theoretical aspects by augmenting the existing research and projects. With increasing capabilities of computing and satellite technologies, the last two components have advanced dramatically during the last decades. The Action exploits these gains by coordinating the theoretical studies of subgrid-scale physical parameterization.

A main question asked by the Action is: what is a general formulation of the mathematical description of the subgrid-scale physical processes in atmospheric models? A clear and general theoretical formulation is required in order to better guide model developments with ever-increasing resolutions and more complex physics. A well-defined theoretical guideline is also required for better exploiting ever-increasing possibilities for model verification by observations. The present Action initiates strong, theoretically-based, coordinated efforts for this purpose.

Over the last years, initiatives for fundamental theoretical investigations of convection parameterization have been launched across Europe. Interest in fundamental research is also gradually growing at both operational and climate research centres. Interest by theoretical physicists has also been identified. The present Action puts these efforts and interests together into a coherent activity creating a core activity of concerted theoretical synthesis by cross-fertilizing ideas. The activity will re-examine the above mentioned fundamental issues in convection parameterization. The overarching methodology of the Action is the critical analysis of the problem from a perspective of fundamental theoretical physics. Classical and statistical mechanics, turbulence theories and dynamic system theories provide a basis for the systematic investigation of the convection-parameterization problem. The Action potentially leads to radically new scale-independent parameterizations that have a more solid physical basis than current parameterizations, and could produce step changes in both climate research and operational forecasting.

Maximum productive outcomes:

The present Action builds upon existing attempts by organizing a network for the subgrid-scale parameterization problem focused on fundamental theoretical aspects. The required financial investment is minimum to support this Action, and expected outcomes are extensive considering both the importance and urgency of the issue as discussed above. The present Action chiefly aims at scientific and technological advance, but it is also clearly beneficial for European economic and social needs by providing improved weather forecasts and climate projection. The Action will further foster Europe-wide collaboration between scientific communities that normally do not find common grounds easily.

B.4 Complementarity with other research programmes

This COST Action is unique in addressing the subgrid-scale parameterization problem in atmospheric modelling from a perspective of fundamental theoretical physics and applied mathematics. Statistical cumulus dynamics is a main focus of the Action and requires intensive investigations.

Currently, massive validation efforts based on model verifications and inter-comparisons already exist aiming at improving subgrid-scale parameterizations in atmospheric models. Efforts are underway at NWP centres. Furthermore, there are collaborations coordinated by various NWP consortia such as ALADIN (Aire Limitee Adaption dynamique Developpement InterNational), COSMO (Consortium for Small-scale Modeling), HIRLAM (High Resolution Limited Area Model), LACE (Limited Area modeling in Central Europe) together with the UK Met Office within the framework of EWGLAM/SRNWP. International activities such as GCSS [GEWEX (Global Energy and Water Cycle Experiment) Cloud System Studies] also focus on convective and cloud processes. Extensive efforts are also being undertaken through numerical calculations based either on "super-parameterization" or on global cloud-system resolving modelling, as currently performed in the USA and Japan, respectively.

The present Action is a clear outgrowth of these current efforts, and the results from this Action will be fed back to these projects through the strong links of the Management Committee (MC) members and other Action participants. Notably, fundamental research has already been underway for many years with a leading role of GCSS. An important new step of the present Action is to make it a stand-alone activity under strong links with operational research as well as with the afore-mentioned on-going consortia and project activities.

In summary, the Action defines theoretical fundamental physics as it's main guiding principle. For this reason, the present Action will play a unique role among the existing projects on subgrid-scale parameterizations for atmospheric modelling. These existing efforts are more focused on testing, validation, inter-comparison and improvement of subgrid-scale parameterizations. By taking a new and distinctive approach, this COST Action will complement well these current modelling-oriented activities. Where appropriate, the Action will seek close collaboration with the existing activities, notably with GCSS, but also with various other consortia of

European weather services. Especially, by actively participating in GCSS model comparison projects, the Action will propose new methods, as well as a new theoretical basis for model comparisons. In order to establish close links with operational consortia, the Action Working Group meetings will be primarily held in conjunction with these consortia meetings (cf. Secs. E.3, F). The Action will also contribute to IPCC by assessing the physical origins of the uncertainties in climate projections that are due to the convection and cloud parameterization.

C. OBJECTIVES AND BENEFITS

C.1 Main/primary objectives

The main objective of the Action is to provide clear theoretical guidance on convection parameterizations for climate and numerical weather prediction models. The Action coordinates an in-depth analysis of state-of-the-art parameterizations and introduces new concepts from theoretical physics and applied mathematics. As a result of the analysis, the Action proposes more suitable convection parameterizations for climate and numerical weather prediction models. The goal is achieved through a coherent and coordinated effort from members of various institutions scattered across Europe.

C.2 Secondary objectives

The Action creates a core theoretical group that supplements current weather and climate research focused on detailed modelling and observations. The Action performs fundamental theoretical investigations addressing conceptual issues in convection parameterization.

The specific scientific objectives of the Action are:

1. Critical analysis of the strengths and weaknesses of the state-of-the-art convection parameterizations
2. Development of conceptual models of atmospheric convection by exploiting methodologies from theoretical physics and applied mathematics
3. Proposal of a generalized parameterization scheme applicable to all conceivable states of the atmosphere
4. Defining suitable validation methods for convection parameterizations against explicit modeling (CRM and LES) as well as against observations, especially satellite data.

These objectives define the tasks of the proposed working groups.

C.3 How will the objectives be achieved?

The above objectives are achieved by the following means:

1. Documentation of the basic formulations of the existing convection parameterizations, along with their specific assumptions, defining their range of validity and the extent of (or lack of) their theoretical and

empirical support

2. Theoretical, systematic, fundamental investigations of the convection parameterization problem by introducing concepts of theoretical physics and applied mathematics

3. Development of more general and clearer formulations of the convection parameterization, of new conceptual models for convective processes, and of new validation methods utilizing both, explicit models (CRM and LES) and observations based on these new theoretical ideas

The present COST activity is based on various observational data sets and numerical models already widely available in the community. The Action, in turn, provides infusions of theoretical ideas and principles with which to interpret the huge data sets of observations and model output. Hence, the Action develops new conceptual models and perspectives. By this activity, the Action stimulates the application of new ideas to the operational weather and climate research community. These efforts lead to model improvements and, potentially, to completely new parameterizations. The present Action is to be expected to bring a long-lasting catalytic effect to the field.

The Action members are expected, in great part, to be recruited from operational (notably Regional Co-operation for LACE), and climate research centres, where there are very strong demands for improvements to weather forecast and climate models (ALADIN, ARPEGE, COSMO, ECHAM/ICON, HIRLAM, IFS, Unified Model). The Action is expected to extensively produce results with strong potential applications supported by strong awareness of these participants that direct applications are in urgent need. A strong motivation for achieving the main goal of the Action is provided by the direct links of participants with parameterization development and implementation: new, improved, solidly-based parameterizations.

C.4 Benefits of the Action

Most serious uncertainties in current weather and climate models are attributed to convection and cloud parameterizations. The Action is going to reduce these uncertainties by providing a robust physical basis in convection and cloud parameterizations. A stronger physical basis of the parameterization makes global and regional weather forecasts more accurate and reliable. Especially highly unusual extreme weather events (e.g. local heavy precipitation, tropical cyclone trajectory) become easier to predict by placing these parameterizations on a more solid physics. Moreover, climate projection becomes more trustful by constructing convection and cloud parameterizations from first physical principles as much as possible. For all the above purposes, hypothesis behind parameterizations must be clearly pin-downed. As a result uncertainty of climate projections is better estimated.

For these reasons, the network focusing on fundamental theoretical aspects of the subgrid-scale parameterization problem greatly benefits both the scientific community and the wider society. Considering importance and urgency of the issues, expected benefits are extensive.

The benefits of the Action are derived by fostering the collaboration between theoretical physicists and operational numerical weather and climate forecasters. The lack of strong theoretical underpinning ultimately blocks progress in any scientific discipline (Secs. B.2 and B.3). The Action replaces the traditional problematic "tuning" approach, often based on ad-hoc assumptions, by theoretically based approaches that ultimately lead to more robust operational results.

It is very unlikely, in spite of increasing horizontal resolutions, that within the next few decades a full-fledged

Earth system model will have sufficient computational capability to be able to resolve all relevant convective processes. Instead, improved subgrid-scale physical parameterizations must be introduced by catching up with increasing resolutions. Most importantly, there will always be some dynamical processes (e.g., shallow convection, boundary-layer turbulence) that need to be parameterized as subgrid-scale processes.

Sometimes, marginally-resolved processes can be most problematic. For example, the current typical regional forecast models with 1-5 km resolutions do marginally resolve deep convection. However, strangely enough, deep convection is often not triggered in a timely manner, presumably due to a lack of coupling with boundary-layer processes. When it is triggered, then it often turns into a singularly strong vertical motion confined to a single grid column.

Even when millions of processors are used for parallel-processing of extremely high-resolution climate models, this situation does not change. Thus, the parameterization problem becomes more and more critical in coming years. The present Action guides the parameterization development and verification by placing the issues under wider theoretical perspectives based on concepts of theoretical physics and applied mathematics. Especially a general theoretical formulation can guide various operational developments. For example, in this manner a list of possible options can more easily be provided for inclusion of particular physical process into an operational model.

A non-exhaustive list of benefits of the Action is as follows:

- A core activity of concerted theoretical efforts by cross-fertilising ideas, providing catalytic impetus on both NWP and climate research both at the European and international levels
- A channel for efficient delivery of theoretical ideas to operational centres, consortia, and international programs
- A platform for inter-disciplinary collaboration, exchange of information and coordination, and for strengthening the NWP and climate projection research in Europe; establishment of a stronger link between the universities and operational research centres
- A better exploitation of meteorological data sets, especially those from satellite missions; a potential contribution to an improved assimilation of satellite data
- Stimulation of research on related climate and environment issues, such as cloud-radiation feedbacks, cloud physics, turbulence, extreme events, downscaling, and hydrology
- Enhanced recognition of a European platform for excellence in NWP and climate projections
- A closer collaboration with international partners on the basis of mutual benefits.
- Incorporation of the vast experience available in theoretical physics and applied mathematics into the further development of weather and climate prediction models.

The proposed effort is also expected to ultimately contribute to improvements of the security, safety and quality of life of European citizens. This will be achieved through a higher quality of NWP and climate projections that are essential, among other things, for warnings of extreme weather events, projections of possible climate scenarios, and mitigation of their potential impacts.

C.5 Target groups/end users

The present Action is targeted at intensified interaction of four principal groups

1. Operational weather forecast and climate research centres as the main users of the results
2. Those involved with "explicit" numerical modeling of convective processes in the atmosphere, through cloud-resolving models (CRMs) and large-eddy simulations (LESs) providing highly specialized techniques for the development and evaluation of parameterizations
3. Those taking and working with observations, especially from satellite missions and dedicated field campaigns
4. The theoretical physics community as a source of new ideas and techniques

For these groups, the Action will provide

1. suggestions, recommendations, and guidelines for development and improvements of subgrid-scale physical parameterizations from theoretical perspectives.
2. analysis methods (diagnostics) to effectively exploit explicit modelling results for development and improvements of subgrid-scale physical parameterizations
3. new validation methods of subgrid-scale parameterization employing most advanced observations; theoretical principles are required in order to analyze massive satellite data sets and to organize well-prepared and focused field campaigns
4. a platform and links between the subgrid-scale parameterization problem and theoretical physicists by posing theoretical problems that are of interest of its own right for "pure science"

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

The most important research task to be coordinated by the Action concerns fundamental theoretical and conceptual issues of convection parameterizations. This includes a statistical theory for convective ensembles, which can be constructed in the spirit of statistical physics by analogy with a thermodynamic equilibrium state in statistical physics. The analogy with statistical physics also provides links with other disciplines, e.g. Hamiltonian dynamics and chaos, mathematical theories for statistics and probability, and asymptotic expansion. All these elements will be brought into the context of convection and cloud parameterization under the present Action.

D.1.1 Work Plan

The basic strategy of the Action proceeds from critical examinations of the state of the art of the problem at the conceptual level. The present state of knowledge will be critically synthesized from theoretical physics perspectives and a general formulation and new conceptual models will be sought.

The work is divided into the following three steps in order to achieve the four specific scientific objectives presented in Sec. C.2.

1) Careful analysis of existing parameterizations

i) The formulation of current convective parameterizations is critically reviewed and examined. The current knowledge of subgrid-scale parameterization for global and regional atmospheric models is summarized with a focus on convection parameterizations.

ii) These reviews are further developed and exploited with a focus on the assumptions made within convective parameterizations. A clear distinction is made between ad hoc assumptions and those that can be deductively derived from either basic physical principles or well-established empirical relationships.

A careful distinction is also made between those assumptions that are essential for the formulation of a parameterization and those that are introduced only for convenience and simplifications. The latter will also be further divided into assumptions made for scientific reasons or purely for technical and practical reasons.

2) Development of conceptual models

i) The issues in convection parameterization are explored and examined from the more fundamental perspectives of theoretical physics. Such perspectives will be provided by, but are not limited to, classical and statistical mechanics, turbulence theories and dynamic system theories. For this purpose, various concepts that are under-explored by the majority of the climate-dynamics community will be considered. For those concepts that are unfamiliar to most climate scientists, but which provide new insights into parameterization issues, the Action will initiate and support pedagogic activities.

ii) New conceptual models will also be proposed in order to advance the theoretical understanding of the problem. Such considerations are expected to lead to ideas for new types of convection parameterization. As well as driving a work plan that will energize such ideas, the Action will also encourage the exploration of such new methods. In particular, through the mechanism of Short-Term Scientific Missions (STSMs), the Action will support short test-of-concept studies.

3) Development of revised and new operational schemes

On the solid theoretical basis of the results from the above, more general formulations of the convection parameterization problem will be sought and proposed to the community. Methodologies for exploiting observational data as well as new validation methods will also be carefully considered.

The Action is focused on deep convection, which is characterized by complex microphysics. At the same time, it seeks idealizations and simplifications to facilitate theoretical progress. There is a strong tension between the complexity of reality and theoretical idealizations. This tension is a main driving force within the Action.

D.1.2 Human and Technical Means

In order to achieve the objectives of the Action, i.e., performing theoretical and conceptual developments of the parameterization problem, the human contributions are paramount, especially contributions from early-stage researchers with fresh ideas. Any gender-biases implicit in previous studies must be amended by encouraging talented female scientists to take part in the Action.

Moreover, especially for performing theoretical investigations, well established links between operational and theoretical groups must be developed so that new ideas can be shared efficiently and further developed by discussions and collaboration. The Working Groups (WGs) provide basic units for coordinating these collaborations. COST's STSM provides an optimal scheme for promoting the required spontaneous collaboration. These theoretical developments are assimilated back into Working Group discussions (cf., Sec. E.1).

Annual workshops of the Action are designed to function as a core European network of scientists of all stages of their professional development. The tasks and results are equally distributed (including tutorials for early-stage researchers) so that mutual confidence between the participants of the Action can be developed.

As technologies and instruments in developing and testing convection parameterizations, the use of explicit CRM or LES modelling is critical. The present Action continues to exploit this methodology based on existing approaches, but also by seeking more advanced, process-oriented analysis methods. Notably, a formal link between explicit modelling and parameterization at a level of theoretical formulations will be emphasized (cf., Sec. D.2, item 3)). Furthermore, observations, especially those by satellites, will be used extensively to infer constraints on parameterizations and to evaluate results from simulations.

D.2 Scientific work plan methods and means

The Action focuses on four major tasks:

1) Assumptions inevitably introduced in constructing subgrid-scale parameterizations

The Action focuses on two technical, but highly-critical issues in mass-flux based convection parameterization: Critical analysis of ad hoc assumptions used within existing convection parameterizations, a.o. closure hypotheses and entrainment-detrainment.

i) Closure

In order to "close" a mass-flux based convection parameterization, an assumption must be introduced in order to determine an overall amplitude for subgrid-scale convective processes, given the model-resolved large-scale processes. The problem is called the "closure". A closure condition is traditionally imposed on a vertically-integrated quantity, such as the convectively-available potential energy (CAPE), under a framework of "convective quasi-equilibrium". Hence, it naturally follows that the equilibrium concepts must also be closely examined. Various possibilities for properly defining equilibrium and testing its stability will be explored both from modelling and data-analysis points-of-view. The exploration of the stability of a convective equilibrium is innovative and actually a key question to ask. Should the convective equilibrium state turn out to be inherently unstable under a fixed large-scale state, it would imply that the convective system is at self-organized criticality. An equivalent state is realized at critical points in thermodynamic systems, where well-defined macroscopic thermodynamic variables are no longer available. In the vocabulary of dynamic systems, it means that the system has no stable steady solution (fixed point) under a constant forcing, but remains on a strange attractor, or "chaos".

Issues to be addressed include:

- Can a general unified formulation of convection parameterization be constructed on the basis of mass fluxes?
- Is it feasible to re-formulate the closure problem as that of the lower boundary condition of the system? Is it desirable to do so?
- How can the convective quasi-equilibrium principle be generalized to a system subject to time-dependent forcing? How can a memory effect (e.g., from a convection event the day before) possibly be incorporated into quasi-equilibrium principle?
- Are there theoretical formulations available that could be used to directly test convective quasi-equilibrium (e.g., based on population dynamics)?
- How strong and how robust is the observational evidence for self-organized criticality of atmospheric convection?

- How does the fundamentally chaotic and turbulent nature of atmospheric flows affect the closure of parameterizations? Can the quasi-equilibrium still be applied for these flows?

ii) entrainment-detrainment

Entrainment and detrainment refer to processes of exchanges of air between convective "plumes" and the surrounding environment. The process is called entrainment when the air enters into convection, and it is called detrainment when the air exits from convection. "Efficiencies" of these processes are currently treated as major tunable parameters in convection parameterizations. The determination of such parameters is a key issue for example in properly representing the transition from shallow (non- or weakly precipitating) to deep (precipitating) convection. The parameters appear to depend on the large-scale environment as well as on the type of convection.

Arguably, explicit modelling with cloud-resolving models (CRMs) and large-eddy simulations (LESs) can provide the estimates of the entrainment and detrainment rates. However, there is no well-defined method at the present time to determine the rates from the simulation data. A few methods have been proposed, but each of them appears to suffer various defects.

In order to determine the entrainment and detrainment rates in a more consistent manner, their physical meanings must be systematically explored by tracing back their historical origin to classical plume dynamics theories. Most notably, there appears to be confusion between the lateral mixing process and a net contribution to the cloud mass.

Issues to be addressed include:

- What is the precise physical meaning of entrainment and detrainment?
- If they provide nothing other than artificial tuning parameters, how could they be replaced with more physically-based quantities?
- From a critical review of existing methods for estimating entrainment and detrainment rates from CRM and LES, what are the advantages and disadvantages of the various approaches?

iii) New theoretical ideas

In order to critically analyze these fundamental issues, various new theoretical concepts will be introduced. A particular approach that appears to be highly promising is statistical cumulus dynamics.

The essence of closure in a mass-flux framework is to define the spectrum of an ensemble of convective plumes. Thus, the most solid approach for solving the closure issue would be to develop the statistical dynamics for ensembles of plumes in the same sense as statistical mechanics provides the ultimate basis for macroscopic thermodynamics.

Classical statistical mechanics appears to provide a powerful guiding principle. The approach has already been extensively applied to turbulent flows and exploratory investigations are already under way for atmospheric convective systems. The approach is expected to work better for ensembles of convective plumes because they are naturally described as discrete elements, unlike continuous-medium turbulent flows. A main challenge under this approach would be to cast an ensemble plume system into a discrete Hamiltonian system under a framework of classical mechanics, since the general framework of classical statistical mechanics would then

become readily applicable.
Issues to be addressed include:

- How can a standard, "non-interacting", statistical description of plumes be generalized to account for plume interactions?
- How can plume-plume interactions and their role in convective organization be determined?
- How can the transient, life-cycle behaviour of plumes be taken into account for the statistical plume dynamics?
- How can a statistical description be formulated for the two-way feedbacks between convective elements and their "large-scale" environment?
- How can statistical plume dynamics best be described within a Hamiltonian framework?
- Does the Hamiltonian framework help to develop a general theory for statistical cumulus dynamics?

2) Development of more consistent formulations by unifying existing approaches (mass flux, similarity theory, probability density) and by incorporating new theoretical ideas
In current numerical models, subgrid-scale parameterizations are constructed for individual physical processes (e.g., deep moist convection, boundary-layer turbulence, clouds) separately by taking different approaches (mass flux, similarity theory, probability density), and the interactions between different processes are only considered a posteriori at the best.
The second task of the Action is to develop a consistent formulation for these independent approaches. For this goal, the two major alternative approaches (similarity theory, probability density) are also critically reviewed as was the mass-flux approach in the first task. These two approaches are underexploited in the context of deep-convection parameterization, thus potential for their application to deep convection is also investigated.
i) similarity theory
The similarity theory has been extensively employed in boundary turbulence theory. The method can equally be extended for describing the statistical dynamics of deep convective plumes. A key issue for this extension is the choice of non-dimensional parameters, especially for those characterizing cloud physics. A major challenge in developing a similarity theory for precipitating deep convection is that the system is not closed in terms of conserved quantities, but that the precipitating-water mixing ratio directly enters the budget equations for both the turbulent kinetic energy and the potential energy. In other words, the coupling between the dynamics and the microphysics must be explicitly considered.
Issues to be addressed include:

- What are the key non-dimensional parameters that characterize the microphysical processes?
- How can the correlations be determined between the microphysical (e.g., precipitation rate) and dynamical variables (e.g., plume vertical velocity)?
- How should a fully consistent energy budget be formulated in the presence of precipitating processes?

ii) probability density

The use of probability density functions may provide a more systematic statistical description of cloud systems, not only for deep convection but also for stratiform and cirrus clouds. The approach has already proved successful in representing non-convective clouds, but the incorporation of convective processes remains a major open challenge. A more formal mathematical way of describing a stochastic system is through a more sophisticated stochastic modelling approach based on the Fokker-Planck equation. This possibility will also be seriously considered under the Action.
Issues to be addressed include:

- How can current probability-density based approaches be generalized?
- How can convective processes be incorporated into probability-based cloud parameterizations? Can suitable extensions of the approach be made consistently?
- Is the moment expansion a good approximation for determining the time-evolution of the probability density? What is the limit of this approach?
- Could the Fokker-Planck equation provide a useful general framework?
- How can microphysics be included properly into the probability-density description?

3) Development of more general and flexible parameterizations applicable at higher resolutions of host atmospheric models with more elaborated physics

An increasingly urgent issue is defining a solid strategy for developing a new generation of parameterizations for regional models with fine resolution. Major European operational centres are rapidly moving towards regional numerical forecasts with deep moist convection processes marginally resolved. In order to exploit the full power of the enhanced resolution it is essential to address fundamental conceptual issues in parameterization. Some of the basic assumptions in convection parameterization (e.g., quasi-equilibrium, scale separation) begin to break down and more sophisticated physics, notably microphysics, must be introduced into the parameterizations.
Issues to be addressed include:

- Which scales of motion should be parameterized and under which circumstances?
- How can convection parameterizations be made resolution-independent in order to avoid double-counting of energy-containing scales of motion or loss of particular scales?
- What is the degree of complexity of physics required at a given horizontal resolution?

Such investigations are likely to lead to intermediate models that establish a better link between conventional parameterizations and explicit models. At the mesoscale (i.e., the scale of regional modelling), it may no longer be sufficient to rely upon the leading-order expansion in the fractional convective area that leads to the standard mass flux formulation. The formal and systematic expansion to higher orders needs to be addressed. A mathematical theory of asymptotic expansion is likely to become a powerful tool for this purpose.

4) Development of a unified framework that couples parameterizations of different physical processes in a more consistent way

This task goes beyond Task 2) by asking a question not only of consistency among the subgrid-scale parameterizations (mass flux, similarity theory, probability density, etc) in a given model, but asking of bringing them all together into a unified formulation. Here, a unified formulation first means that a whole parameterization package is derived from basic principles of physics by introducing various elements of approximations consistently. Moreover, rules must be introduced in order to define where to introduce which approximations under this unified approach.

Treatments of microphysics become a major issue in this context. Recent field campaigns, such as the RICO (Rain In Cumulus over the Ocean) experiment, increasingly point to the critical importance of precipitation processes and associated cloud microphysics, even for shallow cumulus clouds where precipitation rates are relatively weak.

Some recent satellite missions, most notably the A-Train, have begun to provide detailed information on cloud microphysics from space at a global scale. On the other hand, the implementation of extensive cloud microphysics into convection parameterizations has been slow, partially due to a formulational difficulty of implementing them into current standard mass flux parameterizations. A systematic and consistent methodology for implementing detailed microphysics into a convection parameterization is still to be fully developed.

One important first step is to try to relate the subgrid-scale variability of vertical velocity to that of the in-cloud supersaturation, which controls the clouds' phase and the microphysical nucleation and growth processes. Supersaturation is the fundamental linkage between cloud dynamics and microphysics. Those aspects of the microphysics which are required for accurate convection parameterization must be carefully established by considering an ever increasing complexity of microphysical schemes.

Issues to be addressed include:

- How can a microphysical formulation (which is itself a parameterization) be made resolution dependent?
- Can detailed microphysics with its essential sensitivity to environmental aerosols be incorporated into a mass-flux convection parameterization? Are the current approaches self-consistent or not? If not, how can it be achieved?

E. ORGANISATION

E.1 Coordination and organisation

The Action provides an open environment for developing collaborations on the theoretical issues of convection parameterization. The organization of the Action will be structured in order to achieve a delicate balance between its openness and a clear focus. Openness is critical for the vivid scientific discussions to initiate and organize as the Action is explicitly designed for. At the same time, a clear focus is required in order to maintain effective investigation on well-defined theoretical issues.

The Management Committee (MC) will supervise and coordinate the implementation of the activities based on a Memorandum of Understanding, as defined in detail by Sec. VII of "Rules and Procedures for implementing COST Actions". It will monitor the advances performed within Working Groups (WGs), and it will integrate the results. At the kick-off meeting the MC will assign the tasks to WGs according to the work plan (Sec. D.2). Particularly, MC will pay careful attention to safeguarding the original spirit of the theoretically-oriented critical analysis of the problem, so that the character and uniqueness of the Action is effectively maintained.

The core activity of the Action is an annual workshop meeting over several days for intensive discussion of a pre-defined core conceptual issue in convection parameterization. Each workshop will be hosted at an established operational or research centre and will be open to all in accordance with the general spirit of the openness of the Action. In particular, participants from host institutions will be strongly encouraged. The location will change each year. An annual MC meeting will be held in conjunction with the workshop.

More focused scientific activities will be performed within the framework of the four WGs. The coordinator of the Action, supported by the WG leaders, will ensure that all participants have their tasks allocated. The results will be reported at the next meeting. WGs will deliver pre-assigned tasks listed in Sec. E.2. The WGs meetings will be held as part of major European meetings (e.g., EGU, RMS) and of meetings of NWP consortia (ALADIN, COSMO, HIRLAM, LACE, SRNWP).

The Action will also contribute in organizing sessions at these major European meetings by inviting speakers. Furthermore, the Action activities will be coordinated with the activities of various international programmes such as GCSS (cf., Sec.E.3).

The most important function of these formal organization structures is that new ideas are fertilized into the convection parameterization problem. By actively assigning the tasks, WGs encourage collaborations between WG members. Sub-WGs may be organized as required for this purpose. The WGs will also actively monitor the development of these collaborations, and absorb them as official agendas of WGs. MC should function in a similar manner so that new visions emerging from the COST member collaborations are also reflected in the management of the whole Action. Short-Term Scientific Missions (STSMs) actively support these collaborations within the COST framework. In this manner, the present Action continues to be actively driven by these bottom-up initiatives. The COST Action organization is seen as the best means to formalize these bottom-up driven activities.

E.2 Working Groups

The four Working Groups (WGs) are organized by the following four major tasks of the Action as defined in Sec. D.2. Each WG is assigned to deliver the following deliverables (tasks):

WG1: Mass-Flux Parameterization

T1.1: Review of current state of art of closure hypothesis

T1.2: Critical review of the concept of convective quasi-equilibrium

T1.3: Proposal for a general framework of parameterization closure

T1.4: Review on current state of art of entrainment-detrainment formulations

T1.5: Critical review of existing methods for estimating entrainment and detrainment rates from CRM and LES

T1.6: Proposal and recommendations for the entrainment-detrainment problem

WG2: Non Mass-Flux Parameterizations

T2.1: Review of similarity theory

T2.2: Review of probability-density based approaches

T2.3. Assessments of possibilities for the statistical cumulus dynamics
T2.4: Proposal for a consistent subgrid-scale convection formulation
WG3: High-Resolution Limit
T3.1: Review of state of art of high-resolution model parameterizations
T3.2: Analysis based on asymptotic expansion approach
T3.3: Proposal and recommendations for high-resolution model parameterization
WG4: Physics and Observations
T4.1: Review of subgrid-scale microphysics parameterizations
T4.2: Proposal and recommendations on observational validations
T4.3: Proposal and recommendations for a parameterization with unified physics
The assigned tasks will be performed and delivered following the time table defined in Sec. F.

E.3 Liaison and interaction with other research programmes

GCSS and IPCC are two major international programmes with natural, strong links to the Action. In order to provide highly efficient liaison with these two programmes and to seek possible collaborations, the Action has already asked for the participation of representatives from both programmes. The majority of the expected Action participants is already actively involved in the activities of various weather services and weather service consortia (e.g., ALADIN, COSMO, HIRLAM, LACE). For these reasons, various joint meetings are also expected to be organized for various occasions.
Particularly, the Action is expected to provide extensive suggestions to GCSS for parameterization modifications, new testing methods and new validation statistics. It is hoped that the Action will also be able to provide useful suggestions to IPCC on the uncertainty estimates for climate projections.
The Action will also be actively involved with session organization at EGU through the pre-existing involvement of Action members. The Action will also seek to organize special sessions at EMS, EWGLAM/SRNWP and RMS, as appropriate.

E.4 Gender balance and involvement of early-stage researchers

This COST Action will respect an appropriate gender balance in all its activities and the Management Committee will place this as a standard item on all its MC agendas. The Action will also be committed to considerably involve early-stage researchers. This item will also be placed as a standard item on all MC agendas.
Conscious efforts will be made in order to maintain the gender balance. For example, the majority of early-stage researchers identified and contacted as expected Action participants are female (see also Sec. D.1, Human and technical needs to achieve the objectives).
The involvement of early-stage researchers in this Action is a desirable and natural consequence of its basic character: the theoretical thinking of many scientists is at its sharpest and most innovative when youngest. In seeking strong, new theoretical perspectives, the Action will ask for the active involvement of early-stage researchers as a substantial fraction of members of its Management Committee as well as of the Working

Groups. The Action will also encourage them to initiate extensive collaborations under STSMs. The Action will further inspire early-stage researchers by organizing a summer school towards the end of the Action.
In this context, the Action will note and implement the "Commission Recommendation on the European Charter for Researchers and on a Code of Conduct for the Recruitment of Researchers".

F. TIMETABLE

The duration of the present Action will be four years.
A workshop will be organized annually, and the MC will also meet in its conjunction. Additional MC meetings may be organized as and when they are deemed necessary by the MC members.
Each WG will be required to meet at least once per year, with the normal expectation being for two meetings. A WG meeting will normally be organized in conjunction either with European conferences or operational consortia meetings.
The Action activity will begin with an initial kick-off meeting to be held in Brussels. The Action activities will be concluded with a final training school and the publication of a monograph.
The WGs will perform the assigned tasks (cf., Sec. E.2) by following the time schedule given below with a final report for each task delivered at the end of each period.
The schedule below also provides an overview of the whole COST Action activity.

Year 1	Year 2	Year 3	Year 4
Review T1.1 T1.2 T1.4 WG1 WG3 WG4	**Review** T1.5 T3.1 T4.1 WG1 WG3 WG4		
	New concepts T1.6 T2.1 T2.2 WG1 WG2 WG3	**New concepts** T2.3 T3.2 WG1 WG2 WG3	
		Validation methods T4.2 WG4	**Validation methods** T4.2 WG4
			Coordinated proposal T1.3 T1.6 T2.4 T3.3 T4.3 All working groups
Kick-Off Meeting 1st Workshop	2nd Workshop	3rd Workshop	4th Workshop Training school Monograph

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT,BE,HR,CZ,FI,FR,DE,IT,NL,PL,RO,UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at four (4) Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

The estimate is also based on the assumption that four scientists will participate in average per country. Any departure from this will also change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

Dissemination of the results is targeted at several different levels. First of all, all the reports and papers generated through the activities of WGs as well as STSMs are targeted to wider scientific communities that include not only those in atmospheric sciences, but also those in fluid mechanics as well as in theoretical physics in general. These reports shall be published in the Action's webpage and an alert function will be used to inform those who potentially may have an interest about the updates.

An important mission of the Action at the most general level is to establish the subgrid-scale parameterization problem as one of theoretical physics. This will be achieved by active participation of members of the Action in conferences dedicated to theoretical physics. In targeting wider communities, special attention is also paid to inducing interest of early-stage researchers. The final training school will particularly serve for this purpose.

At the second level, the Action will deliver various highly specialized recommendations and suggestions to international organizations, notably at GCSS, but also at IPCC. These deliverables will also serve for the purpose of bringing the theoretical agendas considered under the Action activities to an international level.

Moreover, the Action will communicate with participating members of various operational consortia on more specific and concrete technical issues. For this purpose, MC strongly encourages the Action members to actively participate in the consortia meetings so that the Action can put substantial input to these consortia activities.

At the most direct level, the findings of the Action should be immediately available for modifications of parameterization schemes both at operational and climate research centres. At this end of the spectrum, the theoretical findings from the Action must be well translated into operational contexts.

H.2 What?

Dissemination will be performed first of all by extensive documentations produced by the Action activities. At the same time, various means of more direct communication will also be taken.

An initial version of the reports of the WG tasks will be placed at the publicly-available Action web site. These reports will then be submitted to major scientific journals for wider access by the community. A final dissemination of the Action outcomes will be delivered through a publication of a monograph.

A monograph is chosen as a medium of a final deliverable in order to serve various pedagogical purposes: providing a good introduction of the subgrid-scale problem in atmospheric modelling to wider scientific communities, and also for introducing new methodologies based on theoretical physics and applied mathematics to the operational community. The monograph is expected to become a major milestone for the Action that would not only serve as a standard reference for operational researchers but, more importantly, it would continue to provide inspiration for theoretical work in the future. A preliminary agreement with Imperial Publishing, U.K., is already achieved for the publication of a monograph in the "Science of Climate" series.

The Action will also communicate more directly with the community for dissemination of the results. First of all, the annual workshop will be open to wider communities. Furthermore, a workshop report will be published in a peer-reviewed journal in order to induce further attention to the Action activities.

The final training school will be designed for dissemination at a more pedagogical level. Strong participation of early-stage researchers (notably Ph. D. students) is anticipated for this final event. The training school would be the best and direct medium for transmitting the acquired knowledge from the Action to early-stage researchers, as well as to other researchers interested in conceptual parameterization issues especially with non-traditional backgrounds.

Communications among the Action members will be organized by setting up a forum page at the Action web site (with password protection).

Furthermore, various recommendations and suggestions will be made by the Action members for interaction with various interested groups in an informal but also in a more direct manner.

To summarize, the Action will disseminate the outcomes to various end users by the following methods:

1) For scientists already involved in parameterization research, the main dissemination routes are: direct communication both at personal level as well as various consortia meetings; the reports; the articles in the open literature; the monograph; the encouragement to participate in all aspects of the Action, especially the annual workshop.

2) For scientists involved with explicit modelling or observations, the main dissemination routes are: direct communication both at personal level as well as through various international projects (notably GCSS); appropriate reports available from the website; appropriate articles in the open literature; the monograph; the final training school; encouragement to participate in selected aspects of the Action.

3) For theoretical physicists, the main dissemination routes are: appropriate reports available from the website; the monograph; the final training school; encouragement to participate in selected aspects of the Action, especially in specially-organized focused discussions organized by particular WGs.

H.3 How?

It is emphasized that the Action is attempting an extremely challenging goal of establishing a strong link between theoretical physics and operational research of subgrid-scale physical parameterization. The goal will be first of all achieved by inviting a wide spectrum of people to the Action ranging from operational researchers to theoretical physicists. However, due to its challenging role, the actual dissemination process is expected to go well beyond the defined period of the Action activities. The most important aspect to take care from this aspect is to prepare deliverables that remain valuable resources to the communities on longer terms.

A main outcome of the Action will be the dissemination of current knowledge of subgrid-scale parameterizations for global and regional atmospheric models, with a focus on convection parameterization.

Clear exposition of the basic structure of the problem will be one of the most important outcomes from the Action. Such exposition is essential, both as an end in itself, but also in order to provide a clear context for the effective dissemination of investigations that seek to generalize the formulation of convection parameterization, and draw from the fresh perspectives of theoretical physics. These expositions will be prepared in such way that they will serve as standard references for many years to come.

Dissemination of knowledge from the Action will provide a solid, broader basis for subgrid-scale parameterization research. Review articles will work as the best primary medium for this purpose, which is furthermore supplemented by a final publication of the monograph.

The Action will also examine parameterization issues from the more fundamental perspectives of theoretical physics and applied mathematics. As noted in Sec. D.2, various concepts will be introduced that are new for many climate scientists, drawn from classical and statistical mechanics, turbulence theory, dynamical system theory, and asymptotic expansion. To particularly be noted are aspects of Hamiltonian dynamics, canonical ensemble statistics, the Fokker-Planck equation, bifurcations and chaos. Pedagogical introduction of relevant concepts to the climate community will be an important function of the Action, whenever the concepts are found to be particularly useful. The final training school and the monograph are expected to be the best mechanisms for such pedagogic aims.

The Action further seeks to provide a solid physical basis for subgrid-scale convection parameterizations and to contribute to substantial improvements for both weather forecasts and climate projections. Thus, an implicit, but nonetheless highly significant mode of dissemination will arise from the exploration of new parameterization approaches by the Action participants. Presentations of the novel parameterization methods to model developers and model users (through talks, reports, papers and even informal conversations) will also help to disseminate the theoretical ideas underpinning the new methods. The ultimate goal of the Action is to contribute to a better theoretical understanding of the extreme complexities of the climate system so that a solid physical basis for improvements of climate models can be provided.

Part II - Additional Information (This part will not be element of the MoU)

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Part II-B. ADDITIONAL INFORMATION

Historical background of the Action:

The mass-flux formulation, originally proposed by Arakawa and Schubert (1974), is currently adopted by the majority of operational convection parameterizations in various different forms. For this reason, the present Action focuses on the mass-flux based convection parameterization, but with a good attention on alternative possibilities. We refer to Kasahara (2000) as a balanced historical review of the convection parameterization problem. Emanuel and Raymond (1993) provide a comprehensive review on current existing operational convection parameterizations. Extensive discussions on limits of current convection and cloud parameterizations in global climate modelling are found in IPCC report (Randall et al., 2007).

As explicitly stated in Arakawa and Schubert (1974), the convection parameterization problem can ultimately be considered as that of constructing a statistical theory for ensemble of moist convective elements, or convective thermal plumes. Arakawa and Schubert more explicitly state that it would be an ultimate approach for fundamentally resolving the closure problem, the issue of defining an overall intensity of parameterized convection. Emanuel et al. (1994), Emanuel (2000), for example, emphasize an analogy of the convection parameterization problem with the statistical mechanics.

However, not much attention was paid on such a fundamental issue of convection parameterization until

George Craig's group at University of Reading begun explorative research on statistical cumulus dynamics (Cohen and Craig 2004, 2006, Craig and Cohen 2006, Plant and Craig 2008, Plant 2009). Without exaggeration, the present Action is an outgrowth from their pioneering research.

Thus, the Action intends to organize fundamental theoretical research on convection parameterization in full fledge by building it up on the previous efforts of Reading group. For this reason, Bob Plant, who took over the group of George Craig since 2004, constitutes a core member of the Action.

Importance of fundamental theoretical investigations going to be performed under the present Action is emphasized notably by Arakawa (2004).

Team structure of the Action:

At European level, further initiatives for fundamental theoretical investigations on the convection parameterization are under way. Interest in this fundamental research is also gradually growing at both operational and climate research centres. However, currently, there is no European network that coordinates these efforts together: that is exactly the reason for creating the present Action.

Hans Graf's group at University of Cambridge developed a new type of convection parameterization based on a population dynamics (Nober and Graf 2005, Graf and Yang 2007, see also Yano 2006). More recently, Till Wagner, Hans Graf's Ph.D. student, found by analyzing a link between the population-dynamics model and the mass-flux parameterization, the former provides a self-contained system for describing a time evolution of a spectrum of moist convective plumes (Wagner 2008, 2009, Wagner and Graf 2007, 2008, Wagner et al. 2009). The standard convective quasi-equilibrium, a basic concept introduced by Arakawa and Schubert (1974), can be defined as a steady-state solution to this system. As a result, under this framework, it becomes possible to numerically evaluate characteristics of the convective quasi-equilibrium state more quantitatively than hitherto possible under a framework of a dynamic system theory.

Laura Davies (2008), a recent Ph.D graduate from Bob Plant (Reading), on the other hand, systematically investigated the validity of convective quasi-equilibrium under periodic forcing. It was demonstrated by her CRM modelling that the concept loses its validity below a certain threshold period (Davies et al., 2009). The approach opens another way of more systematically investigating the concept of convective quasi-equilibrium.

On the other hand, Ole Peters (Peters and Neelin 2006, Peters et al. 2002) suggested from an observational data analysis that the quasi-equilibrium state of the tropical atmosphere may be viewed as the stationary state of a self-organized critical system. If this interpretation is correct, it offers a new approach to closures of convection parameterizations. Thus, we are facing extremely challenging issues that make the present Action an urgent need.

Along with the issue of convective quasi-equilibrium and closure, we are also going to pay special attention to the question of entrainment and detrainment. Alan Blyth (Leeds), who has performed extensive field measurements of this process, is going to contribute to the Action from perspectives of an observational specialist.

Pier Siebesma (KNMI and Delft), Harm Jonker (Delft), Wim de Rooy (KNMI) have in recent years extensively contributed to the issue by analyzing the large-eddy simulations (LES) systematically for this goal (e.g., Siebesma and Cuijpers 1995, Jonker et al. 2008, de Rooy and Siebesma 2008). Notably, they have developed a rigorous approach for evaluating the entrainment-detrainment rate from LESs. Their methodology will provide a basis for a more systematic investigation on the issues of entrainment and detrainment under the Action.

These theoretically-oriented contributions are augmented by efforts for improving parameterizations in operational contexts.

Peter Bechtold (ECMWF) played a major role in revising the physics for preparing the current version of ECMWF forecast model (IFM: Bechtold et al., 2004, 2008). Introduction of a variable convective adjustment time-scale, a convective entrainment rate proportional to the environmental relative humidity into convection parameterization at ECMWF has greatly improved the forecasts of tropical-cyclone geneses, Madden-Julian oscillations, among others.

Jean-Francois Gueremy (Météo France) is likewise involved with improvements of deep-convection parameterization for the ARPEGE model. Johannes Quaas and Swati Gehlot (MPI, Hamburg) are working on verifications and improvements of cloud parameterization for ECHAM global model (Gehlot and Quaas 2007, 2008a, b, 2009).

Dimitrii Mironov (DWD) and Ekaterina Machuslskya (HCRF) are actively involved with improvements of unified turbulence-shallow convection parameterization (Mironov 2001, Mironov et al. 1999), and Axel Seifert (DWD) is actively involved in improvements of microphysics (Seifert and Beheng 2006a, b).

For regional weather forecasts, Sami Niemela (FMI) is taking a major responsibility in implementing a high-resolution NWP model AROME into operation. Explicit modelling and parameterization of convection, as well as microphysics, are major considerations here. Jean-Francois Geleyn (CHMI), Jean-Marcel Piriou (Meteo France), and Luc Gerard (RMIB) are working together on a new generation of prognostic convection parameterization (Gerard and Geleyn 2005, Gerard 2007, Piriou et al., 2007, Gerard et al. 2009). Jun-Ichi Yano (Météo France) is developing a new type of convection representation based on an intermediate approach between a traditional parameterization and CRM.

These more direct efforts on parameterizations are complemented by studies of convective processes both by CRM and LES. Jean-Pierre Chabereau (LA), Alison Sterling (Met Office), and Jon Petch (Met Office) are examining deep convective processes by CRM studies, whereas Steve Derbyshere (Met Office), Elisabetta Fiori (CIMA), and Szymon Malinowski (Warsaw) examine shallow convection by LES, notably for investigations of entrainment-detrainment processes (Fiori 2008, Firori et al., 2009a, b; Kurowski, Malinowski, and Grabowski 2009).

As an alternative approach for convection parameterization, Antonio Parodi (CIMA) pursues a similarity theory for deep moist convection (Parodi and Emanuel 2009). Sandra Turner (Météo France) is developing a subgrid-scale parameterization of cloud microphysics that is to be coupled with convection parameterization (Turner et al. 2008a, b).

Jun-Ichi Yano proposes a unified approach for subgrid-scale parameterization based on mode decomposition (Yano et al., 2005). Pier Siebesma has already prepared an overview on mass-flux convection parameterization (Siebesma 1998), whereas Dmitrii Mironov has prepared an overview of subgrid-scale convective boundary-layer parameterization (Mironov 2009).

These efforts focused on the convective processes are complemented by efforts by Zeljka Fuchs (Split) understanding the Madden-Julian oscillations (MJO) from a theoretical point of view (Fuchs and Raymond 2005, 2007). As emphasized in the background section (Section B), the current operational global models have great deal of difficulties in successfully simulating the MJO, an important phenomenon driven by deep moist convection in the tropics.

Vaughan Phillips (Hawaii) will contribute to the Action as a world leading specialist of ice microphysics (Phlipps et al., 2005, 2008, 2009). Daniela Rezacova and Zbynek Sokol (Czech Academy), both with strong geophysical-fluid dynamics backgrounds, guide a direction of the Action from a perspective of regional risk managements (Rezácová et al. 2007, Sokol 2009, Sokol and Rezácová 2006, 2009).

All these contributions from atmospheric sciences are further augmented by contributions of theoretical physicists: Alexander Bihlo (Vienna) contributes to the Action as a specialist of Hamiltonian dynamics, and considers its applicability to the problem of the statistical cumulus dynamics. Florin Spineanu and Madalina Vlad (Bucharest) will contribute to the problem of the statistical cumulus dynamics from perspectives of the field theory (Spineau and Vlad 2009, Vlad and Spineau 2009). Ole Peters (Imperial College) contributes to the question of convective self-organized criticality from perspectives of statistical physics.

Many of the expected participants from atmospheric side also have strong backgrounds in theoretical physics as well as applied mathematics. Without intending a complete list, among the younger participants, Zeljka Fuchs has a background in theoretical physics, especially strong in classical mechanics, Till Wager is trained as a mathematician, whereas Bob Plant obtained his Ph.D. degree in quantum field theory, and Pier Siebesma his Ph.D. degree in theoretical turbulence studies.

Financial needs for further organizing the existing activities:

Recognizing needs for creating a community for theoretical studies of convection parameterization, a core member of the expected participants to the Action has already been organizing a workshop series during the last two years. The first one was organized under a title "Core Concepts for Convective Parameterizations in Large-Scale Models" at MPI for Meteorology, Hamburg in February 2008 with a focus on convective quasi-equilibrium and statistical convective dynamics (Yano et al., 2008). The second was held at CHMI, Prague in March 2009 with a focus on entrainment and detrainment processes (Yano and Bechtold 2009). The third workshop is planned to be organized in Warsaw in March 2010 with a focus on issues arising from increasing resolutions of regional forecast models.

However, the group is already facing difficulties in continuously organizing "informal" workshops annually. Most critically, the travel budgets at operational weather centres are relatively limited with priorities on supporting more operationally-oriented meetings. Even this year (2009), we had an extreme difficulty in finding a funding for the participation of one of the invited speakers. Furthermore, a couple of potential participants finally declined to come by raising an issue of limits in travel budget. For organizing a workshop for next year, we are already facing the same problem even with inviting only few speakers. In short, this informal workshop series is already at risk of drying out unless we could find a robust financial support. Thus, the finance under a COST Action is indispensable even for this reason.

There is no doubt that a financial support under COST will make it possible for many more researchers to participate in the workshops. For potential participants from the Eastern side of Europe, the possibility even for coming to workshops has so far simply remained out of question in spite of their strong interests. The situation will be totally changed by the COST Action support.

A demand for a financial support for ESF was considered as an alternative possibility. However, we decided not to pursue this possibility for couple of critical reasons. First of all, the ESF scheme is designed for a single explorative workshop. It is against our desire for organizing a series of workshops in a continuous basis. More importantly, we are wishing to do something more than simply meeting once a year. The current informal workshop series is our best effort for generating and sustaining a community for theoretical studies of convection parameterization. However, we are blocked at this minimum level due to a lack of a proper financial support. For this reason, clearly the COST framework provides far a more desirable feature than any other alternatives.

The most important advantage of the COST framework for the present activity is that actual mutual collaborations become financially feasible. In this respect, the Working Group activities will better articulate both existing and potential collaborations and furthermore they will spontaneously generate more mutual collaborations.

The collaborations are gradually taking shape among the core member of current informal theoretical group. First of all, the collaborative project between CHMI (Jean-Francois Geleyn), IRMB (Luc Gerard), and Météo France (Jean-Marcel Piriou) will be much facilitated under the COST Action. Furthermore, Bob Plant (Reading), Georg Craig (Munich), and Antonio Parodi (CIMA) are pursuing a common project on convective quasi-equilibrium. Johannes Quaas, Swati Gehlot (MPI, Hamburg), and Jun-Ichi Yano (Meteo France) are pursing collaborations on cloud-convection parameterization in ECHAM model.

Alan Blyth (Leeds) is finding needs to communicating with wider community in organizing a next generation field campaign for renewed measurements of entrainment-detrainment processes. His invited participation to the last workshop in Prague (2009) has indeed provided him such a starting point. He is currently planning to launch a UK proposal in collaborations with Bob Plant (Reading) and Alison Stirling (Met Office). The present COST Action is expected to induce similar research initiatives more extensively both at national and European levels.

Early-stage researchers are also looking for new opportunities. Ole Peters (Imperial College) is actively looking to extend his collaborative network for pursuing his new convection parameterization project in Europe. Elisabetta Fiori (CIMA), just finished her Ph. D., is looking for new collaborative possibilities. Till Wagner (Cambridge), who is expected to finish his Ph. D. shortly, also finds needs to changing his research directions with new collaborations. Zeljka Fuchs (Split), just returned from an extended post-doc in U.S.A., is trying to re-integrate herself into an European community. The COST Action will clearly facilitate their efforts. No doubt, COST's STSS scheme provides an ideal framework for making these collaborations to realize, especially for early-stage researchers.

Core members are already organizing sessions at European Geophysical Union (J. I. Yano, a session on the "Dynamics and Chemistry of Atmospheric Convection"; J. Quaas, a session on "Clouds, Aerosols and Radiation") The Action will partially sponsor both sessions as a mechanism for promoting theoretical approaches to the atmospheric convective parameterization problem. In this capacity, the MC of the Action will suggest invited speakers for the sessions, under the financial support of COST. Such efforts will clearly further boost interests on theoretical studies of the convection parameterization problem.

Some additional details of the organization:

Provisionally-proposed Management Committee (MC) members are:

A. Bhlio (Austria), L. Davies (Australia), E. Fiori (Italy), Z. Fuchs (Croatia), J.-F. Geleyn (Czech), L. Gerard (Belgium), H.-F. Graf (UK, COST Co-Chair), E. Machulskaya (Russia), S. Malinowski (Poland), D. Mironov (Germany), V. Phillipes (USA), R. S. Plant (UK), J. Quaas (Germany, COST Co-Chair), P. Siebesma (Netherlands), M. Vlad (Romania), J.-I. Yano (France, COST Chair).

The Working Groups are expected to be co-chaired by

E. Fiori, T. Wagner (WG1)

O. Peters, A. Parodi (WG2)

D. Mironov, J.F. Geleyn (WG3)

J. Quaas, S. Turner (WG4)

A search for potential interest has been made widely across Europe, as detailed in Part II-A List of Experts. A participant from a near-neighbor country (Russia) and another from a country with a reciprocal arrangement (Australia) are expected.

Action will be organized in close links with GCSS and IPCC. Pier Siebesma (GCSS chair) and Jon Petch (chair of a GCSS deep-convection working group) will be in charge of liaison with GCSS, whereas Hans F. Graf will be in charge of liaison with IPCC. They will also monitor the Action activities from perspectives of these two programmes.

A major effort will be required for the preparation of a final training school, to take place in the fourth (and last) year of the Action. R. S. Plant has provisionally agreed to take charge of its organization. Many of expected participants have already served as lecturers in training schools as well as taken responsibility is organizing training schools. For example, Peter Bechtold annually takes a charge of training courses at ECMWF. All these experiences will be applied to the final training school of the present Action.

The Grant Holder of the Action will be the MPI for Meteorology in Hamburg, because of its well-established efficiency in administration. A preliminary web site is already available at http://convection.zmaw.de, which will turn into an official web site of the Action as soon as it is officially accepted.

Some additional details on the involvement of early-stage researchers and on gender balance:

Among the provisionally-identified participating members, three are currently Ph.D. students and four are currently postdocs. Three of these members have been provisionally asked to join the Management Committee (MC) and all seven are expected to join Working Groups. All already have excellent records of scientific work. Additionally, we have one junior female faculty member, who will also join as a MC member. Among these eight participating early-stage researchers, five are female.

We have three additional pre-confirmed female participants. Conscious efforts were made for maintaining the gender balance both in MC and WGs as indicated in the lists above.

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Note that a full publication list for the proposer is available at:
ftp://cnrm-ftp.meteo.fr/pub-moana/yano/list/list.html