Science Framework Program of the Leibniz Institute of Atmospheric Physics in Kühlungsborn (IAP)

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1 Foreword

After the reunification of Germany the Institute of Atmospheric Physics (IAP)was founded in Kühlungsborn on 1. January 1992 based on a former institute which existed at this location. The institute was later named „Leibniz Institute of Atmospheric Physics at the Rostock University e. V.“. The science plan and the research quality of IAP is supervised by a scientific advisory board and regularly reviewed by an external evaluation, the latest one took place in May 2008. The external reviews of these evaluations were very positive and triggered an increase of permanent positions at IAP. The last science framework was issued in June 2007. It is the purpose of this document to update the science framework for IAP based on actual scientific questions and taking into account the scientific and technological progress being achieved in recent years.

As a member of the Leibniz society IAP is dedicated to excellent research of supra-regional interest with relevance for the community. In contrast to university institutes this imposes constraints on the freedom of research for scientists working at IAP. According to the constitution of IAP, it is the responsibility of the director to develop a science plan. During preparation of this science plan intensive discussions were initiated in the departments and a preliminary list of topics was presented at the advisory board meeting in October 2012. Some final adjustments were made after several planning meetings of the department heads who submitted major contributions to this document.

Twenty years after its foundation the consolidation phase of IAP has terminated and IAP has become an established and well respected member of the international research community dealing with the terrestrial middle atmosphere. We can expect that the main boundary conditions at IAP in terms of number of employees, available infrastructure, and funding will not change significantly in the next years.

This framework program has been discussed and endorsed by the scientific advisory board of IAP and has been approved by the board of trustees in October 2013. We expect that the program shall be effective for a period of 6 to 8 years.

2 Disciplinary importance and unique characteristics of IAP

The middle atmosphere, and in particular the mesosphere/lower thermosphere (MLT), is a unique region in the Earth's system with some fundamentally specific physical concepts because it covers the interface between the terrestrial atmosphere and space. To study this region requires special experimental and theoretical expertise which can only be developed and maintained at a competitive level with highly qualified personnel and sophisticated instrumentation. This in turn requires long-term planning and sufficient funding. As has become increasingly evident in recent years the MLT is an integrative part of the entire terrestrial atmosphere. The MLT is modified by other layers, by the Sun, and by anthropogenic activities, but also influences other regions and even the Earth's surface. At IAP physical processes relevant for the MLT are studied including coupling mechanisms and trends. We intend to communicate our results for application in other context, e. g., in global climate models. In summary, the science strategy of IAP can be summarized as:

„Atmospheric physics: understand and apply“

2.1 Disciplinary importance, supra-regional interest, relevance for the society

The main research topic at IAP is the mesosphere/lower thermosphere (MLT) and its coupling to other regions in the terrestrial atmosphere, especially the stratosphere. The MLT is an important part of the Earth's system where major physical processes are not fully understood. The MLT is special since it is located at the transition region between the atmosphere and space where some physical concepts change fundamentally. Various peculiarities exist, for example, 1) radiation is no longer in local thermodynamic equilibrium with matter, 2) the summer mesopause at polar latitudes is the coldest place on Earth despite permanent sunshine, 3) gravity waves originating in the troposphere break in the MLT, 4) winds frequently reach speeds typical for a tornado, 5) molecular demixing overwhelms turbulent mixing so that mixing ratios of inert trace gases change with altitude.

The MLT is relevant for the entire atmosphere because it is strongly coupled to other regions. This implies that it is modified from the outside but also influences other layers down to the Earth's surface. For example, the high-energy part of the solar radiation is absorbed in the MLT which causes photochemical and dynamical patterns progressing downward. Gravity waves generated in the troposphere propagate upward and indirectly drive the thermal state away from radiative equilibrium by more than one hundred degrees. Climate change in the MLT reaches values of up to –2 Kelvin/decade (cooling) which is an order of magnitude larger (and of opposite sign) compared to the troposphere. The MLT is a substantial part of the system Earth. The IAP provides important contributions to a better understanding of this part of our atmosphere by investigating basic physical processes. The relevance of the MLT for climate is realized by funding agencies which promote dedicated research activities in this area, for example ROMIC (see section 5.3).

Germany needs an institute which is competent in the field of middle atmosphere research. This concerns, for example, the question if the large changes observed in the MLT are man-made, if these changes affect us, or if the Sun contributes to climate change. These questions can only be addressed adequately if the physical processes involved are sufficiently understood. It is the strategy of IAP to improve our understanding of the main physical mechanisms in the atmosphere and to apply the results wherever appropriate, e. g., in global climate models.

Research in the MLT requires special expertise regarding experimental techniques and models. This is true because mean densities in the MLT are orders of magnitude smaller than in the lower atmosphere but, on the other hand, orders of magnitude larger than in space. This transition region can only be explored by special and sophisticated instrumentation and modeling, as is available at IAP. In order to achieve such expertise, long-term experience and sufficient funding is required which can only be guaranteed in a research organization like the Leibniz society.

The IAP contributes significantly to the education of physics students at various levels (bachelor, master, PhD) and thereby provides qualified experts for the society in a field of growing relevance, namely atmospheric and climate physics. The number of students working at IAP has increased tremendously in the last years which has various reasons, e. g., the increasing number of students at the University in Rostock and the appointment of all IAP department heads as professors. These activities are in close reconcilement with the Physics Department and are in agreement with the cooperative treaty between the IAP and the University of Rostock.

2.2 Unique characteristics of IAP

The aim of experimental and theoretical investigations at IAP is to better understand the MLT and its importance for the rest of the atmosphere. Specific instrumental and model expertise has been developed at IAP in the past and we plan to continue in this direction.

IAP operates several lidars with unique capabilities. This concerns resonance and Rayleigh/Mie/Raman (RMR) lidars which can operate even under full daylight conditions. For example, the ALOMAR[1] RMR lidar measures noctilucent clouds (NLC) with a time resolution of seconds and is the only lidar worldwide to measure winds in the entire middle atmosphere. The iron lidars of IAP measure temperatures in the MLT region with a distinctive accuracy of a few Kelvin and high temporal and spatial resolution.

Regarding radars, IAP operates state of the art phased and modular array instruments at several frequencies which are used to continuously observe mesospheric neutral winds. The new radar called MAARSY[2] is the most flexible and versatile VHF[3] radar worldwide and allows for the detection of, for example, 3D structures in mesospheric ice layers.

[1] Arctic Lidar Observatory for Middle Atmosphere Research
[2] Middle Atmosphere Alomar Radar System
[3] Very High Frequency

Special experimental techniques have been developed at IAP for in-situ measurements on sounding rockets and balloons. This concerns in particular sensors with extremely high time resolution (milli-seconds) for turbulence detection as well as aerosol measurements.

In order to interpret phenomena related to the MLT in a global context, IAP has developed circulation and chemistry-transport models. These describe vertical coupling from the surface to the thermosphere and the interaction across scales from planetary waves to turbulence. Some of these models are unique with regard to their numerical schemes and parametrization characteristics. Theoretical and experimental studies at IAP also take advantage of reanalysis data, satellite observations, and community models.

Some of the techniques described above are unique at IAP. The combination of expertise at IAP is nowhere else available worldwide. We intend to develop and maintain these expertise which can only be successful if IAP is able to employ highly qualified scientific and technical personnel.

2.3 Strategic aims at IAP and its realization

The science plan at IAP aims at a better understanding of important physical processes in the middle atmosphere and their application in other areas, such as global climate models. It is our goal to continue to belonging to the leading institutes worldwide in the area of MLT research. The expertise available at IAP shall be further developed and updated. New science areas shall be explored if adequate and feasible. Cooperation is crucial for IAP. This concerns, for example, collaborations with universities, international research institutes, and science organizations such as SCOSTEP[4]. IAP provides optimal infrastructure to attract scientists and students from the main science institutes in our field. Within the institute it is important to establish mechanisms which stimulate the interaction between experimental and theoretical groups, for example, by forming matrix groups (see section 5.4.)

3 Scientific topics

The main scientific topics at IAP are:

- Exploration of the mesosphere and lower thermosphere
- Coupling of atmospheric layers
- Long-term changes in the middle atmosphere

3.1 Exploration of the mesosphere and lower thermosphere

3.1.1 General aspects

The MLT region is scientifically interesting because of various fluid dynamical and other physical curiosities which do not exist in the troposphere. In recent years the MLT has become to be recognized as the missing piece in understanding the connection of weather and climate to processes occurring in the upper atmosphere and space. At the same time a physical explanation of the MLT region is particularly challenging and requires the combination of different physical disciplines. The most important open questions are related to the large-scale momentum and energy budgets and corresponding contributions from all kind of motions such as thermal tides, planetary waves, mesoscale gravity waves, and turbulence. These motions show very strong interactions such that, for example, turbulent dissipation becomes a first-order effect in the large-scale energy budget. Further issues arise from interactions with radiation and photo-chemically active trace gases. Moreover, radiative transfer in the MLT strongly deviates from local thermodynamic equilibrium and the gray limit. Trace gases are demixed in the thermosphere as a result of the exponential increase

[4] Scientific Committee on Solar Terrestrial Physics

of molecular diffusion. The most spectacular feature resulting from these crucial processes is the polar summer mesopause region where temperatures are as low as 120 K and deviate from radiative equilibrium by more than 100 degrees.

We plan to focus more on the thermosphere, particularly the lower part (90-120 km) by applying existing lidar and sounding rocket expertise and by extending the radar wind measuring capabilities to those altitudes. New expertise in experimental and theoretical methods will have to be developed. The lower thermosphere influences the mesosphere and even the upper stratosphere. Some physical processes of general relevance appear specifically pronounced here, e. g., wave mixing and generation of secondary gravity waves. This region is dynamically coupled to the mesosphere and lower atmospheric regions by gravity waves, tides, and planetary waves which propagate upward from below and often dissipate in the 80 to 150-km region. It is difficult to represent neutral dynamics in this region adequately in a model because of uncertainties in representing wave forcing from below and magnetospheric forcing from above. This increase of research activity is a natural evolution of IAP's latest advances. Lidars and sounding rockets are already making measurements in this region. Coherent and incoherent scattering from existing and improved radars can be used to diagnose this region. Some models already extend into the lower thermosphere but some further development shall be considered to better represent magneto-hydrodynamic and ionospheric effects.

3.1.2 Thermal and dynamical structure

The morphology of basic parameters in the MLT (temperatures, winds) has been studied intensively by ground-based and satellite instruments in recent years. Still, there are significant gaps, in particular in the summer MLT and in the lower mesosphere. For example, a direct coupling of high latitude mesopause temperatures to the polar vortex has only recently been demonstrated at Antarctic latitudes and is not yet fully explained. Unexpected large temperature tides in the summer mesosphere have been measured and need to be studied. The first technique to measure winds continuously in the upper stratosphere/lower mesosphere has only recently been developed (our DORIS[5] lidar technique). A comparison of winds measured by lidars and radars with winds deduced from satellite temperature allows to detect ageostrophic wind components and provides an indirect experimental bench mark test of gravity wave drag in models. We want to study the latitudinal and longitudinal variation of winds which can be measured by, for example, by a chain of meteor radars and perhaps lidars in combination with satellites.

3.1.3 Layers in the mesosphere and lower thermosphere: NLC, (P)MSE and PMWE

Significant progress in our basic understanding of ice layers (NLC) and related phenomena (PMSE[6]) has been achieved in the last decade. However, there are still some important open questions, for example, regarding the importance of freeze-drying for the water vapor budget in the MLT or the creation of tidal signals in NLC. The physical processes involved to create PMSE have been explored in recent years but several important details need to be explained, for example, the role of charged aerosols or background electron and aerosol number densities in creating these echoes. We will continue to study PMSE by a combination of ground based (radar, lidar) and in-situ measurements and, for the first time, derive electron density profiles continuously by a combination of radars.

With our new and more sensitive MAARSY radar we detect radar echoes in the lower mesosphere, called PMWE[7], much more frequently. How are these echoes created and what is the importance of turbulence and charged aerosols? We plan to study the temporal and altitudinal morphology of PMWE with MAARSY to characterize them and understand their existence. Preliminary results show that both PMSE and PMWE exhibit features that appear to be modulated by the background neutral dynamics, e.g., by gravity waves. We plan to investigate horizontal structuring in scales ranging from few hundreds of meters to tenths of kilometers. The radar cross-section

[5]Doppler Rayleigh Iodine System
[6]Polar Mesosphere Summer Echoes
[7]Polar Mesospheric Winter Echoes

of PMSE as function of latitude and longitude is not well understood. In conjunction with other research groups and using IAP portable radar systems, we plan to study this dependence. If PMSE strength depends on low background temperatures, why do they appear to be weaker at Resolute Bay (75°N) compared to ALOMAR (69°N) bearing in mind that mesospheric temperatures decrease towards the pole in summer. Is there any significant longitude dependence, and if so why? In both PMSE/PMWE, we plan to exploit their spectral widths with different scattering volumes to study the turbulent energy dissipation rates associated to these echoes. These studies will be complemented by numerical modeling as well as in-situ measurements on board rockets. Waves generated in the lower atmosphere are expected to be amplified in mesospheric regions and to continue propagating upwards into the lower thermosphere, where they will eventually dissipate. We plan to study the neutral dynamics and electrodynamics of the lower thermosphere by observing middle and high latitude sporadic E layers and meteors with existing and improved IAP instruments. As a byproduct we expect to contribute to the understanding of this region and the plasma physics associated to the radar echoes.

We note that microphysics of ice particle and aerosol formation and charging is not yet understood. We plan to continue our efforts in this direction and, for example, derive aerosol parameters from multi-frequency detection of PMSE at Poker Flat, Alaska (with PFISR[8]) and our 'mobile' VHF radar. In-situ measurements of aerosols will be performed in cooperation with Prof. Markus Rapp who was recently appointed as director of DLR/IPA, Oberpfaffenhoven. He plans to continue his research on aerosols in the MLT.

The formation of ice layers is obviously influenced by gravity waves and turbulence, similarly to formation of clouds in the troposphere. A qualitative and quantitative understanding of these influences is still missing. We plan to study these processes by a combination of models at IAP (e. g., KMCM[9] plus ice model and CARMA[10]) and with high resolution direct numerical simulations (DNS) available at other institutes (Prof. Dave Fritts, GATS[11] Inc., Boulder). Model results shall be compared with high resolution measurements from lidars, radars, satellites, and from ground based cameras operated by IAP.

The large signals received from NLC (lidars) or PMSE (radars) allow to detect structures created by gravity waves and turbulence which cannot be studied otherwise. For example, single laser shot detection of NLC by lidar and high resolution PMSE detection by MAARSY have revealed periodic structures at temporal scales down to few minutes. Three-dimensional structures in PMSE can now be measured by MAARSY and are planned to be available from lidar oblique scanning.

Mesospheric ice layers are also important for trend studies since they constitute the longest measurement record in the MLT and are very sensitive to background temperatures. We will continue to compare our lidar climatology of NLC with historic records and perform model studies with LIMA(see section 4.2). Since lidar measurements of NLC are now available for more than a decade we intend to systematically study solar cycle influence and in particular the potential impact of the current unusual solar cycle (one of the lowest maxima).

3.1.4 Transport and mixing of trace gases

The closure problem in geophysical fluid dynamics results from the fact that only certain scales can be resolved in numerical models while the effects of unresolved scales must be parameterized. This problem is particularly relevant for minor constituents (trace gases in the atmosphere) which are not well mixed. Trace gases are not just transported according to the mean Lagrangian motion, but are in addition *mixed* due to the combined action of resolved transient motions and subgrid-scale diffusion. Well-known examples are the meridional mixing by planetary Rossby waves in the stratosphere or the downward mixing of atomic oxygen in the lower thermosphere. Mixing by gravity waves has recently been addressed at IAP using a chemistry-transport model of the MLT, yielding

[8] Poker Flat Incoherent Scatter Radar
[9] Kühlungsborn Mechanistic General Circulation Model
[10] Community Aerosol and Radiation Model for Atmospheres
[11] Global Atmospheric Technologies and Science

surprisingly strong effects for all relevant trace gases and corresponding consequences for chemistry and radiation. The same process is presumably responsible for the transport of chemically active trace gases from the thermosphere all the way down to the stratosphere in wintertime during solar particle precipitation events. Furthermore, mixing by orographic gravity waves is presumably also relevant in the troposphere and stratosphere. Notwithstanding these examples, mixing by gravity waves is either neglected or insufficiently represented in current chemistry climate models.

At IAP we plan to investigate mixing by gravity waves for the whole altitude range up to the MLT. In addition, meridional mixing by thermal tides and transient planetary waves shall be quantified for the MLT. These goals are ideally reached by combing IAP's experimental facilities to measure gravity waves and turbulence in the upper troposphere/lower stratosphere by radars and balloons, as well as in the MLT by rockets, radars, and lidars, with corresponding computational results from ICON-IAP and KMCM in combination with MECTM (see section 4.2). High resolution insitu measurements of trace gases with sounding rockets will be used to check theoretical predictions. We will investigate whether ground-based measurements of trace gases in the MLT region can be achieved at sufficient resolution. For example, the resonance-lidar measurements of iron densities may be analyzed with the help of an iron-chemistry model in order to estimate mixing in the mesopause region. Results of our mixing studies shall be applied to global climate models. Global transport ways in the middle atmosphere will be studied by combining the newly developed 3D residual circulation concept (including mixing) with satellite retrievals of trace gases and temperatures. Last not least, the role of mixing for the temporal evolution of ice clouds shall be addressed with the help of measurements and by running the microphysical community model CARMA with high-resolution dynamical fields.

The ground based facilities available at IAP contribute to this topic by characterizing the temporal and spatial evolution of waves around the turbopause at various scales. Turbulence is measured by rocket borne sensors and by radars. Regarding measurement of trace gases the FIPEX sensor of the Stuttgart University will be applied for the first time on a sounding rocket during the WADIS [12] campaigns in 2013 and 2014. If successful, we plan to perform in-situ measurements of trace gases with this instrument more frequently in the future. The IAP microwave instrument MISI[13] observes water vapor profiles up to approximately 85 km which allows to characterize transport phenomena to a certain extent. Lidars measure number densities of metals (K, Fe etc.) with high temporal and vertical resolution in the turbopause region. However, these gases are not passive tracers and subject to photochemistry which complicates the comparison of measurements with transport models as outlined above.

3.2 Coupling of atmospheric layers

3.2.1 Dynamical coupling between tropo- strato-, meso- and lower thermosphere

The crucial importance of the MLT for the entire atmosphere, including weather and climate close to the surface, originates from vertical coupling due to dynamical processes. This coupling is twofold. Upward coupling is mainly due to Rossby waves and gravity waves which are generated at lower altitudes and propagate upward. So-called 'wave mean-flow interactions´ lead to a strong dynamical control of the winter stratosphere and the MLT on a global scale. Subtle changes in tropospheric wave generation (e.g., storm intensities) can yield strongly amplified signals in the MLT that can be detected by accurate measurements. The upward coupling is, however, complicated for various reasons: 1) Wave-wave interactions among Rossby waves, gravity waves, thermal tides, and tropical waves, 2) in situ generation of planetary waves in the MLT due to dynamical instability, 3) in situ generation of secondary gravity waves, and 4) the close relationship between wave breaking and small-scale turbulence (as is manifested in the non-acceleration theorem). Downward coupling is basically a far-reaching consequence of upward coupling: Wave breaking causes alterations of

[12] Wave propagation and dissipation in the middle Atmosphere: Energy budget and distribution of trace gases

[13] MIcrowave Spectrometer at IAP. A similar instrument called WASPAM belongs to MPS-Lindau and is located at ALOMAR.

the mean flow and thereby of wave-propagation conditions. As a result, the breaking region progresses downward synchronously with the mean-flow alteration. The time scale of this downward progression can be years, as is well known for QBO[14].

Nonlinear interactions also play a dominant role for the large-scale natural variability in the extratropics, known as Annular Modes (AMs). Prominent features of the Northern AM (NAM) are the North-Atlantic Oscillation and sudden stratospheric warmings. By virtue of the NAM, even large-scale weather patterns close to the surface are preceded by stratospheric circulation changes with a time lag of up to several weeks. At IAP we have shown that the AMs affect the MLT on a global scale with a particularly strong signal even in the vicinity of the polar summer mesopause. This global variability pattern has been confirmed by several observational and modeling studies and is known as interhemispheric coupling. In the summer hemisphere, it is superposed by intra-hemispheric coupling which means that the large-scale flow in the Upper Troposphere and Lower Stratosphere (UTLS) controls the onset of summer conditions in the MLT prior to summer solstice. This mechanism is particularly relevant to the southern hemisphere since year-to-year variations in the ozone hole have crucial effects on temperatures, PMSE, and ice clouds in the MLT. The relative importance and especially the mutual coupling of different variability patterns is only poorly known, which is also true for the role of nonlinear interactions and in situ generation of gravity waves, Rossby waves, and thermal tides in the MLT.

IAP is dedicated to further explore the generation, propagation, interactions, and breaking of all relevant atmospheric waves in order to achieve an improved understanding of the dynamical control of the MLT. This includes an attribution of long-term variations in the MLT to changes in the troposphere and stratosphere. Likewise, by considering the extensions of AMs into the MLT, we will aim at improving our knowledge of circulation changes in the middle atmosphere and their impact on the troposphere. Some specific topics in this context are the role of the QBO and solar variability, sudden stratospheric warmings, gravity-wave-tidal interactions, the dynamics of planetary waves in the summer and winter MLT (vertical propagation versus in situ generation versus interaction with gravity waves), the role of non-hydrostatic gravity waves in the MLT, the generation of gravity waves in the troposphere, Rossby-wave breaking, secondary gravity waves, the estimation of momentum fluxes resulting from dissipating gravity waves, the morphology of thermal tides at high latitudes, north-south asymmetries, and the interaction of large-amplitude waves and thermal radiation. Of course, this list is not complete and only indicates the general direction of research at IAP with regard to vertical coupling and includes the consideration of radiative and photochemical processes. In this context the two main stations of IAP, namely Kühlungsborn and ALOMAR, are well suited for experimental studies since in winter they are located outside and inside the polar vortex, respectively.

3.2.2 Turbulence

Atmospheric turbulence is of fundamental importance in atmospheric dynamics and climate physics for the following reasons: i) Turbulence is closely linked to wave breaking and hence vertical coupling (section 3.2.1), ii) turbulent motions strongly determine mixing of trace gases by atmospheric waves (section 3.1.4), iii) several phenomena in the MLT (radar echoes, ice clouds) can only be understood along with turbulence generated by gravity-wave breaking, iv) turbulence connects the energetics of the general circulation to the viscous scale. The latter point is important even for climate dynamics since turbulent dissipation is an essential part of the global energy budget and therefore relevant for the radiation budget at the top of the atmosphere. Nonetheless, our understanding of processes by which energy cascades from planetary scales to small-scale turbulence is only rudimentary. The MLT is an ideal field to study the physics of wave breaking and the transition to turbulence because waves have much higher amplitudes, and turbulence acts on much larger scales than in the troposphere or stratosphere.

Since experimental facilities and modeling capabilities at IAP have strongly improved in recent

[14]Quasi-Biennial Oscillation

years we plan to further evolve our understanding of the role of turbulence in the atmosphere, with particular emphasis on the MLT. We shall focus on GW breakdown and small-scale turbulence by combining high resolution measurements of vertical and horizontal structures and turbulence with results from corresponding sophisticated models. In addition, we shall further elaborate the concept of macroturbulence, which means that, in a statistical sense, the high-wavenumber range of the gravity-wave field can also be considered as turbulence. Recent studies have shown that the -3 spectral slope with regard to vertical wavenumber (typically observed for gravity waves) is consistent with a horizontal energy inertial range. This concept, known as *stratified turbulence*, is quite promising since it provides guidance to further advance our theoretical framework and resulting parameterizations of unresolved waves and turbulence in models, a topic that is traditionally addressed at IAP (see section 4.2).

Experimental investigations of turbulence in the MLT are challenging. The smallest scales involved can only be detected by in-insitu sensors on board sounding rockets. IAP has a long record of turbulence measurements on rockets which shall be continued and further improved in the future. Apart from applying our standard sensor CONE[15] we are currently developing a multi-probe instrument ('mother/daughter') to characterize for the first time the three-dimensional structure of turbulence in the MLT (TURB3D project). In a recent memorandum of understand IAP has indicated its interest to cooperate with the University of Oslo (Prof. Joran Moen) to study plasma turbulence in the MLT by sounding rockets. Combining existing technologies and expertise will allow us to investigate neutral and plasma phenomena leading to turbulence. Cooperation on theoretical studies is also foreseen.

Direct detection of turbulent structures by lidar or radar is still beyond existing technologies, although spatial and temporal resolution has been improved in recent years and may be further optimized for this purpose. However turbulence can be detected indirectly, for example, by spectral broadening of radar signals or by measuring PMSE and PMWE which rely on turbulence. MAARSY allows to monitor the 3D structure of PMSE and PMWE. We plan to perform multi-instrument campaigns with rockets, radars, and lidars together with modeling efforts to investigate turbulence including its impact on radar scattering and mixing.

In recent years we have developed turbulence measurements with very high resolution (millimeters) on balloons flying up into the stratosphere. These observations are important to study turbulent mixing and the dissipation of gravity waves in the stratosphere. Some exciting and unexpected results were obtained in the flights we have performed so far. For example, turbulent layers may only be some tens of meters thick and turbulence dissipation rates occasionally reach up to 0.1–1 W/kg which corresponds to heating rates of 9–90 K/d). We plan to continue these activities and aim at developing sensors which can routinely be flown on standard radiosondes.

3.3 Long-term changes in the middle atmosphere

3.3.1 Trends

The MLT is very sensitive to long-term changes in greenhouse gases (in particular CO_2) and gravity waves. Unfortunately, long-term measurements of temperatures or winds are not available in the MLT region. However, some indirect measurements exist since several decades, concretely the morphology of NLC (since 1890) and radio wave reflection heights (since 1956). From the reflection heights large (negative) temperature trends in the mesosphere are deduced, much larger compared to the troposphere. On the other hand, NLC altitudes are practically constant since 130 years which comprises a major constraint on our understanding of trends in the MLT region. We plan to continue our studies on trends of NLC and reflection heights, as well as the interpretation in terms of greenhouse gas increase with the LIMA model[16]. We will also continue our analysis of trends in the ionosphere, i. e., E and F region electron density peaks and altitudes, using measurements from our ionosonde in Juliusruh which is the oldest still active ionosonde in Europe. Regarding modeling

[15] COmbined Neutral and Electron density sensor
[16] Leibniz-Institute Middle Atmosphere

of trends with LIMA, we will expand our studies even further into the past (19th century) and also employ future scenarios from climate models. Radar measurements of mean winds, gravity waves, and PMSE since early 1990 are also being used for trend analysis at IAP.

In a climatological sense, the dynamical control of the MLT is closely linked to the troposphere and its variability. In particular, subtle changes in the troposphere can have significant effects in the MLT in terms of gravity-wave activity and drag, as well as turbulence. It is currently debated if orographic gravity waves play a central role in long-term changes of the stratospheric residual circulation. Much stronger effects are expected in the MLT due to non-orographic gravity waves. The reason is that the generation of non-orographic tropospheric gravity waves falls into the regime of stratified (macro)turbulence (see section 3.2.2) and that tropospheric climate variability affects this regime through energy cascades and the hydrological cycle. Some trend in gravity-wave activity in the MLT has already been detected by IAP radars and mechanisms based on idealized high-resolution simulations have been proposed at IAP. This preliminary work shall be extended by advanced measurements and detailed high-resolution model simulations. The overall goal is to consistently interpret the strong climate signal in the MLT in terms of the combined changes in radiation and dynamics. We expect that measurements and comprehensive simulations of trends in the MLT will also improve our understanding of tropospheric climate change, in particular regarding the importance of coupling processes mentioned in section 3.2.

3.3.2 Solar cycle impact

Some unique data records at IAP are available since more than a decade which allows to study the impact of solar cycle on the MLT (e. g., radar winds, NLC, PMSE, radio wave reflection heights). Solar activity is expected to directly impact temperatures and winds in the upper mesosphere and thermosphere and therefore modulate NLC. The influence on PMSE is more complicated since solar radiation also affects electron densities. The current solar cycle is unusual which offers a unique chance to study its impact in the MLT. We plan to investigate the footprint of the actual solar cycle in the MLT. These activities are closely related to studies on global variability modes and the QBO. They are imbedded in an international context since SCOSTEP has initiated a world wide observation program related to the current solar cycle.

3.4 Other scientific topics, mostly in combination with other institutes

We plan to expand our studies of meteor echos. Until recently, we have used radars mainly to observe background horizontal winds in the upper mesosphere. However, given that meteors are the major source of metals in the MLT, we plan to explore different aspects of the three different types of radar meteor echoes (specular, non-specular, and head echoes) that contribute directly or indirectly to the MLT composition and layering phenomena. We have already started to study the seasonal variability of neutral densities from specular meteor echoes. We plan to use meteor-head echoes to study neutral densities in the region where they are observed, usually at higher altitudes than specular echoes. From the meteor trajectory we will be able to study the astronomical origin of these meteors. This is primarily of astronomical relevance, but indirectly, contributes to the chemistry of metals that are deposited in the MLT region. This is because meteors coming from specific sources (e.g., showers) have characteristic composition. In addition, our studies will contribute to determine the meteoric mass input and a better understanding of metal layers as detected by IAP lidars.

The non-specular echoes (echoes that come from angles close to perpendicular to the magnetic field), have not been studied in detail at mid and high latitudes. We plan to explore the possibility of using such echoes to measure MLT wind profiles and therefore extend our current altitudinal coverage of winds to higher altitudes. This technique has recently been developed at equatorial latitudes. Some of the topics mentioned above shall be investigated in close cooperation with other institute, for example, with Prof. John Plane (Leeds University) on metal chemistry.

IAP scientists are involved in the preparation of future thermospheric satellite missions, namely

SWARM[17] and QB50[18]. For SWARM, we intend to characterize the MLT region which is known to transfer signals from the troposphere to the upper thermosphere. For QB50 we plan to be involved in the scientific interpretation of the measurements which will include a unique data-set in the lower thermosphere.

Finally, some atmospheric parameters are measured at IAP as a byproduct and are not studied intensively at our institute. This concerns, for example, aerosol layers in the stratosphere (from lidars) or winds and turbulence in the troposphere (from radars). We plan to seek cooperation with other national and international research institutes working in relevant areas to scientifically explore these observations.

4 Scientific methods

4.1 Experimental methods

4.1.1 Lidars

Some unique lidar capabilities have been developed at IAP for application in the MLT. The combination of lidars available at IAP are able to measure temperatures from the troposphere up to the lower thermosphere with high spatial/temporal resolution and high accuracy. Mean state conditions, gravity waves, and tides are derived from these observations. Lidars are still the only reliable technique to measure temperatures in the MLT quasi-continuously covering a unique range of scales. We want to continue using this technique in the future, at the same time developing new capabilities and applications. Daylight capability for RMR lidars is available since few years and allows to study tides in temperatures and NLC. Large tides in temperatures, NLC, and in metal layers have been measured but have not yet been explained. NLC studies by lidar shall be continued and analyzed in terms of trends, mean morphology, and small-scale structures caused by gravity waves etc. Again, new capabilities are developed. For example, RMR lidar detection of NLC at ALOMAR has recently been performed with single laser shot data acquisition and showed spectacular periodic structures at very small-scales (as small as one minute). We plan to perform three-dimensional imaging of NLC with lidars and compare with PMSE.

Lidars are increasingly applied for wind measurements. In the last years we have developed a new technique (DORIS)[19] to measure the small Doppler shift of the Rayleigh signal caused by winds. This technique is employed in combination with the two telescopes of the RMR lidars at ALOMAR which are steerable and can be tilted off-vertical. We plan to optimize DORIS for quasi-continuous wind measurements in the stratosphere and mesosphere. Such measurements are important for our understanding of gravity wave propagation and are unique worldwide. This technique perfectly complements the capabilities of radars measuring winds in the mesosphere. Our resonance lidars are currently operated in vertical alignment only, thereby measuring vertical winds. We plan to redesign the laser alignment and the general mechanical design to be able to tilt the telescopes to measure horizontal winds in the metal layer.

Since a few years IAP cooperates with the Fraunhofer Institute of Laser Technology (ILT) in Aachen to develop specific lasers for our purpose. This promises to improve the laser performance giving access to even smaller scale phenomena. At the same time the instrument is designed for an easier operation which reduces man power requirements.

In summary, lidars at IAP will continue to play a crucial role for the science plan at IAP. This concerns the lidars in Kühlungsborn and ALOMAR, but also the mobile system which has been (and will be) located at various remote places, like Spitsbergen and Antarctica.

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[17]ESA's Magnetic field mission

[18]An ESA project with a network of 50 very small satellites for multi-point, in-situ measurements in the lower thermosphere

[19]Doppler Rayleigh Iodine System

4.1.2 Radars

IAP radars operate in the MF[20], HF[21], VHF[22] frequency bands under any weather conditions, allowing continuous measurements of neutral dynamics and inferred atmospheric parameters. In the near future, we plan to exploit the unique fast steering and modular features of MAARSY to study: (a) Turbulence at scales ranging from few hundreds of meters to few kilometers, using nested beams (wide and narrow), synthetic aperture radar techniques, and frequency domain interferometry; and (b) the horizontal structure of PMSE/PMWE and its relation to background neutral dynamics. In addition we plan to fine-tune the existing MAARSY system to be able to: (a) observe different regions at the same time, therefore increasing the observing time of a given region/phenomena (more dynamic range and more data throughput); (b) improve the radar cross-section (RCS) measurements of PMSE by measuring simultaneously the F region Incoherent scatter power with MAARSY, including for the first time the actual transmitted power and antenna gain in the normalization process; (c) synchronize with close-by radar systems (e.g., Saura, KAIRA[23], MORRO[24]...) to allow bistatic as well as common volume observations of the MLT region, including a feasibility study to obtain electron density measurements from Faraday rotation of signals coming from the D and E region. D-region electron density measurements will also be explored with passive radio measurements with existing systems in collaboration with scientists from the Sodankyla Geophysical Observatory. We have started the evaluation of relocating existing radars as well as the need of new radars to contribute to the understanding of the latitudinal and/or longitudinal features of the neutral dynamics, particularly during winter months. For example, to improve the latitudinal coverage around Kühlungsborn/Andøya longitudes, we could move one of the existing meteor systems to Munich, allowing latitudinal coverage from Munich up to Svalbard. Another request by our experimental and modeling scientists is to fill existing longitudinal gaps, e.g., performing observations in Russia and Iceland. Given that some of the science topics cannot be studied from existing IAP locations, we also plan to acquire portable radars (or convert existing ones). Some of the topics that will be explored with these systems are: (a) Multi-frequency observations of PMSE to study aerosol parameters (technique recently developed at IAP) in conjunction with the Poker Flat Incoherent Scatter radar (PFISR) in Alaska that operates continuously at UHF, (b) PMSE RCS at different latitudes and longitudes, by having the same type of system performing observations at different sites; and (c) E region coherent echoes from both auroral electrojet and sporadic E, as well as non-specular meteor trails. For the latter, we plan to explore this possibility with existing equipment. Finally we plan to upgrade existing radar systems with the main objectives of (a) improving data quality and operations (e.g., standarizing hardware/software components across the different radars), and (b) getting more information out of the systems (e.g., measuring different targets at the same type, UTLS, PMSE, meteors, ...).

4.1.3 Sounding rockets

Sounding rockets are used at IAP primarily for measurements of small-scale structures in the MLT, both in the neutral atmosphere and in plasma. We plan to continue using our standard sensor CONE for example for PMWE studies, but at the same time develop a new class of sensors for simultaneously deploying several sensors ('mother/daughter'). Corresponding studies are performed in the industry. We expect to make the first flights in 2-3 years. These measurements will be used for 3D studies of turbulent layers and PMSE, in combination with MAARSY. Note that CONE also measures plasma irregularities. We plan to combine these capabilities with expertise available at the University of Oslo for studies of plasma phenomena in the lower thermosphere.

Trace gas measurements in the turbopause region have been performed in the past (not at

[20]Medium Frequency
[21]High Frequency
[22]Very High Frequency
[23]Kilpisjärvi Atmospheric Imaging Receiver Array
[24]MST Mobile Rocket and Radar Observatory in Tromsø

IAP) with rather complicated instruments. Provided that the new electrolyte sensors FIPEX and PHLUX (developed by the University Stuttgart) perform as scheduled we plan to fly these sensors more frequently in the future to measure trace gases such as carbon dioxide and atomic oxygen and to study gravity wave mixing effects (see section 3.1.4).

Sounding rockets are also important for reliable measurements of atmospheric background parameters, for example, neutral densities, temperatures, winds, and electron densities. Such measurements are used to characterize the scientific conditions during flight, but also for validating ground based instruments. In cooperation with a company in Rostock we currently develop a simple and cost-effective active falling sphere to measure neutral densities and winds in the MLT as a replacement of the outdated passive falling sphere. The new sensor can be flown on meteorological rockets or as piggyback on instrumented rockets. In the near future the Faraday rotation technique to measure absolute electron densities will be transferred from the Graz University (Dr. Martin Friedrich) to IAP. This is the only technique to reliably measure absolute electron number densities on sounding rockets.

After the WADIS campaigns in 2013 and 2014 we plan to launch several sounding rockets in 2015 - 2016 at the Andoya Rocket Range to study PMWE. Neutral and plasma dynamics will be detected by CONE, and aerosols will be measured by the ECOMA[25] sensor in cooperation with the DLR/IPA in Oberpfaffenhofen. This will be the first time that sophisticated insitu-measurements are performed in the vicinity of PMWE. It is important to understand the physics of PMWE since these echoes indicate turbulence and perhaps also the presence of charged dust particles. Further launches with new capabilities are in the pipeline, for example using TURB3D (see above).

4.1.4 Balloons

In recent years we have engineered temperature and wind sensors[26] for very high resolution measurements on balloons flying up to middle stratosphere. The high spatial resolution of millimeters is required to reliably deduce turbulent parameters. We plan to perform several flights in the future and to compare with radar measurements in the troposphere as well as with model results from ICON/IAP in regional mode. Special attention will be payed to potential sources of turbulence by gravity wave breaking which impacts coupling from the lower to the middle atmosphere. Furthermore, the potential role of turbulent mixing in the stratosphere will be studied. We intend to continue these activities and aim at developing sensors which can routinely be flown on standard radiosondes.

4.2 Modeling and theoretical methods

The experimental and theoretical/modeling expertise at IAP is dedicated to reach synergetic results whenever possible. In order to address the specific questions associated with research focusing on the MLT as well as vertical coupling, a variety of modeling approaches is required. IAP basically develops its own models for process-oriented investigations. As a result, IAP-models differ from comprehensive community models: They are idealized in some respects, but are specific and sophisticated otherwise, for example by including some novel modules developed for a specific purpose. Ultimately, one has to use global or large-scale regional models to interpret local phenomena within a global context. Corresponding numerical simulations will therefore span a wide range of scales and require High Performance Computing (HPC) facilities, as they available at IAP. IAP models are permanently subject to further developments and improvements, partly based on new theoretical insight. The same is true for the development of theory-based model diagnostics. Some examples for future developments are given below.

Evidently, comprehensive community models are valuable tools for research at IAP. Likewise, IAP takes advantage of highly specialized models of external groups by collaborations. Last not

[25] Existence and Charge state Of meteoric dust particles in the Middle Atmosphere

[26] Constant temperature anemometers (CTA) for winds and constant current anemometers (CCA) for temperatures

least, we use reanalysis data sets provided by the leading weather forecast and climate research centers.

4.2.1 Global circulation models

IAP maintains two specific general circulation models (GCMs): The Kühlungsborn Mechanistic general Circulation Model (KMCM) and the Icosahedral Nonhydrostatic model at IAP (ICON-IAP). KMCM is a hydrostatic model based on the standard spectral dynamical core. It is presently used in two versions: A mechanistic version with high resolution for GW resolving global simulations and an idealized climate-model version with conventional resolution. The latter includes newly developed parameterizations for radiation and gravity waves, the full surface energy budget by means of a swamp ocean with prescribed lateral heat fluxes, as well as a new transport scheme and the tropospheric moisture cycle. Though the formulation of differential heating is idealized in both model versions, the resulting thermal forcing, large-scale wave activity, and intensity of the energy cycle are are consistent with comprehensive models. Both versions include an advanced turbulence model based on the anisotropic formulation of Smagorinsky.

KMCM will continue to be used to study a variety of questions associated with mixing of trace gases, vertical coupling, turbulence, trends in gravity waves, and climate feedbacks. In addition, KMCM will be further developed by improving its parameterizations. For example, the turbulence model shall be based on the dynamic Smagorinsky model. Also a nudged version using reanalysis data sets will be developed to allow for real-date comparisons with measurements. The climate model version shall furthermore be run in gravity-wave resolving mode and coupled with MECTM (see below).

ICON-IAP is a mechanistic version of the ICON model that is currently developed at the 'Deutscher Wetterdienst' (DWD) and the Max-Planck Institute for Meteorology in Hamburg. ICON-IAP is based on a distinct hexagonal grid and employs a novel discretization that allows for precise numerical representation of conservation laws and the correct simulation of high-frequency gravity waves. In addition, ICON-IAP includes the anistropic Smagorinsky scheme (like KMCM) and a consistent transport of trace gases. ICON-IAP shall be further developed by adapting the radiation scheme from KMCM. The GCM version of ICON-IAP can already be run up to 120 km height and will be used in the future to study, for example, the importance of non-hydrostatic gravity waves for the general circulation in the MLT, turbulence, mixing of tracers, etc. The ICON-IAP code can also be run with very high resolution in regional geometry (see section 3.2.2).

Currently, there exist three comprehensive GCMs that resolve the mesopause region: The Whole Atmosphere Community Climate Model (WACCM), the extended Canadian Middle Atmosphere Model (CMAM), and the HAMburg MOdel of the Neutral and Ionized Atmosphere (HAMMONIA). WACCM and HAMMONIA include online computation of atmospheric chemistry. These models will continue to be used at IAP, partly in cooperation with the corresponding institutes who maintain these community models. Typical topics are related to thermal tides, planetary Rossby waves and breakdown of tropospheric Rossby waves, 3D-residual circulation, and trace gases in the middle atmosphere. Also other comprehensive climate models may be used if required.

4.2.2 Models of specific physical processes

We will continue to use LIMA for studying ice layers (NLC, PMSE) as well as trends in the MLT region. There are several open topics regarding these layers, for example the importance of freeze drying for the water vapor budget in the summer mesopause region or the generation of tides in NLC layers. We will elaborate our trend studies on temperature trends in the MLT with LIMA performing sensitivity tests with respect to water vapor and ozone climatologies to be taken from GCM models such as WACCM. For the first time, we will extend our trend studies into the 19th century but also into the future employing climate change scenarios. We expect that this will significantly contribute to some outstanding questions regarding the role of the MLT and NLC as climate change indicators.

IAP maintains two further models for specific physical processes: ICON-IAP in regional mode and the Mesospheric Chemistry Transport Model (MECTM). Using ICON-IAP with regional geometry allows studies with a very high spatial resolution. This feature shall be used to perform gravity-wave resolving simulations from the surface to the lower thermosphere in order to allow for direct comparison with the scales resolved by IAP lidars and radars as well as rocket and balloon borne instruments. We will aim at quantitative comparisons with vertical and horizontal structures of wave breaking and thereby gain further insight in the nature of gravity wave dynamics, stratified turbulence, and the transition to small-scale turbulence. These investigations will guide the development of parameterizations of unresolved waves and turbulence in GCMs. In addition to ICON-IAP, community circulation models with regional geometry such as WRF[27] are used at IAP to study gravity-wave dynamics in the troposphere and stratosphere.

MECTM has been used at IAP for various studies on the photochemistry in the MLT. In recent years, it has been driven by gravity-resolving dynamical fields, offering some new insights into the mixing of trace gases by gravity waves and consequences for chemical and radiative effects. In the future we aim at a detailed understanding of mixing processes in the atmosphere and corresponding consequences for photo-chemistry. MECTM will be coupled to KMCM such that MECTM employs the new tracer transport scheme and the turbulence model of KMCM. We also plan to feed back relevant trace concentrations and chemical heating rates (as calculated by MECTM) to the radiation scheme and dynamical core of KMCM. In addition, MECTM will be further developed to allow for online calculations of photolysis rates.

IAP also takes advantage of other specialized models that are developed by other groups. For example, a Boussineq model of the University of Frankfurt is used to perform direct numerical simulations of GW breaking and the generation of turbulence. Furthermore the Gravity-wave Regional Or Global RAy Tracer (GROGRAT) is employed to compute GWs propagation in realistic large-dynamical field. CARMA has already been used at IAP in the past to study NLC. We plan to further use CARMA for dedicated studies on, for example, the role of GWs and turbulence in forming ice particles.

Finally, the development of various diagnostics tools to evaluate IAP models, IAP measurements, community models, satellite retrievals, as well as reanalysis data sets is an ongoing task. This includes, in particular, to continue the development of corresponding theoretical concepts.

5 Realisation

5.1 Cooperation with other research groups

This framework program can only be successfully implemented in cooperation with other research institutes. IAP has established many cooperations with national and international institutes, for example with Universities in Frankfurt, Stuttgart, Munich, Hamburg, Oslo, Stockholm, Toronto, Fairbanks, Boulder, Paris etc., and with several groups within the Max-Planck, Helmholtz and Fraunhofer associations and other organisations at international levels (GATS, NCAR, AAD, etc.)[28]. These cooperations concentrate on synergy effects on techniques existing at IAP (lidars, radars, models) but also in merging expertise, in particular with the satellite community. IAP cooperates with basically all relevant satellite communities (TIMED, AIM, ODIN, Envisat, MLS, SWARM, QB50 etc.). In 2013 a ‘memorandum of understanding´ on future cooperation on sounding rocket science has been signed by IPA/DLR, the Universities in Oslo and Tromsø, and IAP. This will further strengthen our commitment for research at polar latitudes.

Scientists at IAP frequently visit other institutes to exchange and discuss recent results and to plan future cooperations. Many visiting scientists and PhD students from various countries have visited IAP in the past. We plan to continue and strengthen such exchange activities.

[27] Weather Research and Forecasting model, provided by NCAR
[28] A complete list of cooperations is listed in IAP’s biennial report

5.2 Cooperation with the Rostock University

Cooperation with the Rostock University is particularly important for IAP and is regulated by a formal agreement. Department heads at IAP lecture within one of the four priority topics called 'Atmosphere and Ocean' as part of the master program in physics. The ILWAO[29] graduate school was initiated by IAP and involves the University Rostock[30] and the Leibniz Institute for Baltic Sea Research, Warnemünde (IOW). In general, the number of physics students in Rostock has increased by almost an order of magnitude in 20 years which also brings many more bachelor, master, and PhD students to IAP. IAP intends to continue and strengthen its cooperation with the University Rostock.

Apart from the University of Rostock, IAP also cooperates with other close-by universities, namely in Wismar and Greifswald. Attracting students is crucial for IAP, for example when recruiting next generation scientists. Teaching at a university is also taken as a chance for qualification for young IAP scientists planning a university teacher career.

5.3 Relation to national and international programs

IAP scientists are members of several national and international science advisory boards and are thereby closely related to larger programs. On a national level, BMBF has started a new research initiative called 'Role Of the Middle atmosphere In Climate' (ROMIC) which includes IAP related science topics such as trends in the mesosphere and coupling through gravity waves. ROMIC starts in 2013 and runs for (at least) 3 years. Several international programs are relevant for IAP, such as SPARC and SCOSTEP. In November 2013 SCOSTEP will announce its new science program for the next couple of years. In a recent planning meeting ROMIC was accepted as one of four major themes. This implies that the German solar/terrestrial community as well as IAP is well represented in international programs which will facilitate communication and cooperation with other research groups worldwide.

5.4 Matrix structure

IAP has established a 'matrix structure', i. e., apart from departments a dedicated group of experimental and theoretical scientists from IAP work closely together on a dedicated subject, for example on turbulence. These matrix groups have been very successful in the past and have stimulated the discussion between experimental and model activities. Furthermore, it offers the opportunity for young scientists to get experience in autonomously leading a small group of scientists. We plan to continue the matrix structure, which also implies that groups can be terminated and new groups can be formed according to actual needs.

5.5 Quality control

It is basically impossible to judge the quality of scientific research per se. Still, IAP is requested to define measures for prosperous research in order to be successful at the next external evaluation. We mainly follow the guidelines given by the evaluation procedure of the Leibniz society. The most important criteria are 1) publication in international peer-reviewed journals, 2) procurement of research grants, 3) being invited to present scientific results on international science symposia. The information required to monitor these criteria is frequently collected at IAP and is used to compliment and stimulate scientists.

The scientific advisory board plays a prominent role in controlling the research output of IAP and adjusting its near term goals. Since the members of this group are experts in atmospheric physics they give valuable advice on the results achieved at IAP and on future strategic planning.

[29] International Leibniz Graduate School for Gravity waves and Turbulence in the Atmosphere and Ocean

[30] LSM = Labor für Strömungsmechanik

6 Concluding remarks

It is the aim of this framework program to coordinate actual and mid term research activities at IAP with special focus on the main topics mentioned above. Despite the guidance given by this program, open discussions on potentially new directions at IAP are stimulated. It is very helpful in this context to invite competent colleagues from outside the IAP for critical feedback.

As an institute mainly funded by the local and federal government as well as by publicly funded science foundations, IAP will continue to communicate its research to the open public. This is done by launching press articles, performing guided tours through the institute, and offering various opportunities for pupils and students to visit IAP. An 'open house´ is performed regularly since the year 2000 and has demonstrated to be very attractive for community members.

The success of this framework program primarily relies on the technical and scientific personnel working at IAP. It can only be implemented successfully if it is accepted by the employees and realized with motivation. We hope that we can generate enthusiasm for this program and for the IAP as a member of the Leibniz society.

Kühlungsborn, 14 October 2013

Prof. Franz-Josef Lübken

Prof. Jorge Chau

Prof. Erich Becker