

## **Chairman's Report**

### **With Chief Scientist's response**

#### **Preamble**

The 21<sup>st</sup> meeting of MOSAC took place concurrently with the annual meeting of the Hadley Centre's Scientific Review Group (SRG). Approximately 70% of the MOSAC meeting time was dedicated to joint plenary sessions with the SRG.

The Chief Executive opened the meeting and welcomed both Committees. This was the last MOSAC meeting for Professor Julia Slingo as Chief Scientist. The Committee expressed its appreciation for her admirable foresight and visionary leadership that has strikingly enhanced the status, scope and quality of MO science. It congratulated Stephen Belcher on his appointment as her successor.

Following the retirement of some individuals, MOSAC welcomed three new members – Eugenia Kalnay (formerly Director of Environmental Modeling Center at NCEP and now Distinguished Professor at the University of Maryland), Gilbert Brunet (Director of the Meteorological Research Division of Environment Canada and erstwhile Head of Weather Science at the Met Office), and Janet Barlow (Professor of Environmental Physics at the University of Reading). A non-Executive Member of the Met Office Board and the Chairman of the PWSCG attended as observers.

At the meeting the Chief Scientist overviewed the Office's research accomplishments, and the four Deputy Directors summarized both recent developments and the on-going activities in their specific domains. In addition there were contributions by the Chief Meteorologist and the Head of Government Services, and one session was devoted to a BEIS-orientated discussion on its future Climate Programme and the Programme's link to Met Office science. A further 17 presentations covered specific aspects of the Office's research portfolio.

#### **1. Overview.**

Here we set out briefly some of the major achievements and highlights of the Met Office's activities over the last twelve months and note some key MOSAC concerns. More detailed comments are deferred to subsequent sections.

Notable advances in the suite of weather forecast and climate models have resulted in identifiable improvements in the Office's forecast capabilities. For the global model a more effective assimilation of satellite-derived radiance data into the initial state for NWP, bringing the Met Office inline with other major global forecasting systems, yielded a strikingly significant improvement in the forecast performance. For the updating of the regional suite of models the added-value of the UK ensemble system was shown to have increased relative to that of the UK deterministic model. These changes have enabled the Office to retain its second position (- to the ECMWF) in the ranking for global model predictions based upon a comparison of deterministic scores, and to deliver state-of-the-art, high quality and timely regional deterministic and ensemble forecasts. In effect the Office remains one of the world's leading operational weather forecasting centres. There remains a pressing need to develop more refined verification metrics. The strength

and range of the Office's activities together with its publications and communications in the realm of Weather and Climate Science places it at the international forefront of research in these fields.

- We note MOSAC's comments on the pressing need for more refined verification metrics, which are discussed in more detail below

Significant advances were achieved in *longer-term research activities* involving the complex task of developing techniques for the dynamic core of the next generation of computers, but MOSAC noted that some major challenges lie ahead. The HPC upgrade proceeded on-schedule but did entail an unplanned change in processors. The latter switch resulted in a modest decrease in the net HPC capacity, but has yielded the more homogeneous distribution of processors as advocated by MOSAC in last year's report, and hence has resulted in a more flexible HPC configuration. Notable progress has also been recorded in the development and consolidation of *more recently established projects* such as 'Regional Reanalysis' and 'UK Environmental Prediction'. In addition MOSAC warmly commended an exciting *new methodology* related to the 'National Flood Resilience Review'. This methodology grew out of the Office's rapid and innovative response to a recent flooding event that entailed using hindcast seasonal forecasts as a base for a revised risk assessment. The Committee encourages an active pursuit of the methodology itself. It embodies a novel scientific approach, a trans-disciplinary format and a harmonized multi-agency organizational structure.

- We welcome the committee's positive comments on this approach. We are using it in some other projects (e.g. as part of Climate Sciences to Services Partnership in China) and believe that it has the potential to be used much more widely in evaluating environmental risk.

Other highlights presented to MOSAC included brief accounts related to:- radar wave-ducting; acquisition and processing of a novel global land surface temperature data set; contribution to a major field campaign on the monsoon; assimilation of Chinese satellite data; and the first exploitation of a novel (- CubeSat) satellite data. These creative and high quality studies illustrate the range and application-orientated character of the Office's research.

Further MOSAC noted that the impressive number of high quality Met Office publications co-authored with researchers from other national and international institutions. It affirmed that this, together with the accompanying updated bibliographic statistics and citation records, places the Office in a favourable light when compared with other similar organizations.

*For the technical component of the Science Programme* a notable achievement was the on-schedule completion of Phase (1c) of the major HPC upgrade. This task included an agile response to the non-availability of the planned Skylake chip whilst maintaining the overall performance of the new system. MOSAC was also impressed with the progress being made in the challenging Gung-Ho and LFRic projects for the atmospheric model component. This progress has benefited from adopting a rigorous approach to addressing the technical issues, from innovative developments, from effective collaboration with specialized UK Research Council and University Institutions, and it could not have been achieved without the dedication of highly skilled IT staff.

- We are delighted that Phase 1C of our HPC upgrade has been accepted more than 3 months ahead of schedule and maximizing exploitation of this asset to deliver the promised HPC benefits is a key focus for Met Office. At the same time, we need to keep pushing forward with the next generation model, and welcome MOSAC's positive comments about the progress being made there.

Finally MOSAC urges the Office to re-examine, in consultation with the relevant parties, the relative roles of the Scientific Advisory Committee (MOSAC) of the Met Office and the Scientific Review Group (SRG) of the Hadley Centre with a view to establishing a more transparent, effective and unified structure for overseeing its science.

- We note these comments about the structure of the meeting and we are working with relevant stakeholders to review how our science is reviewed and the structure of the MOSAC and SRG meetings.

## 2. Foundation Science.

The Foundation Science Directorate is to be commended for continuing to successfully underpin and advance the Met Office's understanding of and ability to model weather and climate across all time-scales.

However MOSAC also cautions that within the constellation formed by Gung-Ho, LFRic and the emerging EXASCALE Projects there remain major challenges. The Office noted the challenge associated with physical parameterization schemes, but the challenges associated with the scalability of data assimilation, shared numerical codes (such as NEMO), and the choice of a coupling softwares (e.g. ESMF, and the UKEP link to OASIS) might well require the investment of significant manpower over an extended time. In light of this it would be beneficial to identify issues that could better be tackled in the framework of an international consortium. Likewise, given the present inevitably amorphous state-of-knowledge on the model framework for the 2020s, MOSAC urges the Office to assess carefully the relative priority it assigns to proceeding as rapidly as possible toward the development of these three projects relative to the benefits that could accrue from more fully exploiting the current (- yet new) EndGame configuration.

- We agree with MOSAC that the Exascale challenge is large. We are assessing, under the umbrella of an exascale programme, how to ensure that all elements of our modelling systems are prepared for future HPC architecture. We would be happy to report on progress next year. As noted by MOSAC, it is clear that the resource implications are significant and we will continue to actively seek UK and international partnership opportunities. Finally, ENDGame has good scalability, which means that our current modelling systems should be adequate on the next HPC.

The Committee also encouraged the Office to assess the effectiveness of the evolving and complex numerical codes not only in terms of 'Time-to-Solution' but also in terms of 'Energy Efficiency'. In this context MOSAC noted that for some computational purpose the Office does operate with reduced precision, and it speculated that much 'Earth System Complexity' could be coded in reduced precision. The Committee noted that some of the alleged counter arguments for adopting this procedure were invalid, but that the use of reduced precision might need to be assessed on a fit-for-purpose case-by-case basis. There may well be opportunities to exploit the fact that chip manufacturers are now bringing out mixed precision chips which allow 16-bit arithmetic to be performed efficiently as well as more conventional 32- and 64-bit.

- We agree that there is potential here, and have increased the amount of effort we put to this (specifically at the moment looking at single precision physics).

At present a significant and appropriate amount of the new HPC time is being devoted to research linked to initial runs of the next generation of models and to detailed scaling exercises for EndGame and Gung-Ho etc. It is to be expected that the associated Research / Operations ratio will

decrease somewhat when the planned model upgrades (including increased resolutions) are implemented operationally in 2017. However MOSAC emphasizes the need to maintain an effective R/O ratio, and strongly supports the aspiration to operate with a ratio in the [4:1 - 3:1] range.

- We welcome MOSAC's strong support to maintain an R:O ratio of order 4:1 integrated over the lifetime of the HPC. We have built this aspiration into our NWP plans, implying a concerted effort in Weather and Foundation Science to maximize throughput of research trials on the HPC over the coming year while the actual R:O ratio is actually much higher than 4:1.

*For the global modelling and atmospheric processes components of the Directorate* there have been several notable advances. These include :- better cloud representation; reduction of the warm bias in the southern oceans; pinpointing shortcomings in the representation of the diurnal cycle, conservation properties in the LAM, and limitations of the semi-Lagrangian technique when operating on convection-permitting scales. MOSAC welcomed the Office's collaborative effort with the academic community to improve the representation of cloud and aerosol interactions in the Unified Model, and in particular appreciated the rigorous yet realistic approach being adopted. In addition the Office has identified and seeks to further assess and address sensitivities detected in the global model such as wave-drag and the influence of land surface processes upon the stability properties of the overlaying layer. For the former MOSAC noted that such a feature was not confined to the MO model (e.g. it was even evident in early versions of the ECMWF model), and emphasized the need for scale-dependent drag formulations. For the latter the Committee noted that comprehensive validation of the parameterization schemes would require testing against data from many stations and not only Cardington.

- We welcome the committee's comments on these advances. We are embarking on a new I collaboration (jointly led by ECMWF and the MO) to reduce uncertainty in model drag. And data from Cardington has been important in much of our land-surface and boundary layer work in recent years – although we of course agree with the committee on the need to continue to also use data from other sites in different topographic and climatic regimes. Involvement in major international field campaigns, often involving the FAAM and other aircraft (see below), has also proved valuable.

*For the observation-based research component of the Directorate* a particularly commendable aspect was the prominence being accorded to major field campaigns. These campaigns can lead to enhanced scientific understanding and form the bedrock for model improvements with an accompanying knock-on effect upon both weather prediction and climate projections. For example the recent participation in NAWDEX could help identify the key observational data required for day-to-day NWP in the extra-tropics, and the MONSOON project will provide a firm data base for tackling model deficiencies in representing the drivers of this globally significant climate phenomenon. It is noteworthy that substantial added-value accrues from participation in major international field campaigns and that an integral feature of such campaigns are carefully choreographed flight missions by instrumented aircrafts. In this context MOSAC wishes to stress that the FAAM aircraft facility constitutes an important component of the Office's purpose-driven weather and climate research and it can concomitantly serve to lever additional resources on the national and international stage for key Met Office research aims.

- We thank the committee for these comments

### **3. Weather Science.**

The Weather Science Directorate has during the past twelve months continued to advance its core mission of developing, optimizing, monitoring, refining and providing the operational capability of the Office for weather, oceanic, and atmospheric dispersion and air quality forecasting. Here we comment in turn upon:- the evolution of the Office's suite of operational models, the updates provided on specific aspects of the Office's regional forecast models, and the issue of verification metrics.

FIRST the composition and configuration of the operational models is evolving rapidly. For the global model a particularly striking improvement in forecast performance (- promised to MOSAC last year) followed the implementation in March 2016 of a variational bias correction (VarBC) scheme for satellite radiance assimilation bringing the Met Office system in line with most major global NWP systems. MOSAC applauds this development recognizing that the improvement can be justifiably regarded as significant when compared to other advances achieved during the last decade. The Committee awaits with interest the assessment of the model's performance for the 2016/17 Winter.

- We welcome MOSAC's comments on the impact of our March 2016 global NWP upgrade. We also note that although VarBC was the major contributor, the inclusion of a range of new instruments (including those on the Indian/French MeghaTropiques, Chinese FY-3C, and US/DoD SSMIS satellites) also provided significant benefit. We will report on the performance over the past winter at the next MOSAC meeting.

For the regional scale a major development (- operational in early November 2016) is the reconfiguration of the UKV to a larger domain with an accompanying extension of the forecast range and ensemble MOGREPS runs. Pre-operational tests and the commendable step of incorporating assessment by bench-forecasters point to the new configuration's potential. The Office anticipates forecast benefits to accrue from a more effective spin-up and the better development of flow systems advancing toward the UK. However improvement could also occur in situations of weak incident flow and a greater contribution of in-situ generated systems. Extended assessment of the performance will establish whether the output in the 3-to-5 day range will in general amount to more than a conventional downscaling of the global model. Also maintaining the ensemble approach together with rapid forecast (regional and global) cycling will pose DA challenges along with being computationally and observationally demanding. Further changes scheduled from Spring 2017 onward are indicative on the one hand of the Directorate's challenging and ambitious strategy and on the other hand of the benefits that could accrue from the new HPC.

- We have worked hard in recent years to strengthen the links between the Science Programme and the Operational Meteorologists and are pleased that MOSAC recognizes the value of this. Indeed with the ambitious programme of planned upgrades (including hourly cycling), it will be even more crucial in the coming years, to ensure that (i) the science of the modelling systems is optimized, (ii) the impact of any changes to the UK observing network is understood, and (iii) that the outputs are exploited by meteorologists as effectively as possible.

SECOND updates were provided on specific aspects of the Office's current and planned regional forecast models. Data assimilation and ensemble generation are key components of high-resolution regional models and these issues are being addressed vigorously. Ambitious plans are also in place for an En4DVar system (replacing the current ETKF), and for hourly cycling DA system for global NWP – the system that provides the lateral boundary conditions for the regional model. Updates were provided on the 'Regional Reanalysis Project' and the 'UK Environmental Prediction Project' (UKEP). Progress is satisfactory with a series of notable achievements that will

enhance the Office's future activities in climate and weather science. The UKEP project benefits considerably from strong national collaboration with NERC institutes, and MOSAC applauds the success achieved for assessing short-term small-scale air-wave-sea interactions and strongly endorses plans to extend the capability to improving storm surge predictions and the hydro-meteorological modeling of large catchment areas.

- We welcome the committee's comments on these successes. In particular the UK Environmental Prediction project is an important vehicle for our collaboration with the UK academic community and we are currently actively seeking mechanisms to continue to fund this joint work.

THIRD the issue of designing and testing suitable verification metrics remains a most pressing issue. Last year MOSAC commended the Office's distinctively novel contribution to this and the related field of post-processing. Information provided this year demonstrated that the Office's verification strategy is in a state of flux:

- the standard (deterministic-based) metric(s) for assessing and comparing global model forecasts is viewed as being outmoded (- inappropriate level for verification, and deterministic as opposed to ensemble-based), but there has yet to emerge a well-founded and fully tested alternative,
- the new HiRA framework has been adopted for assessing and comparing the performance of the deterministic UKV and ensemble regional MOGREPS systems, but it does not appear to capture the (subjectively assessed) observed improvement of the UKV model, and
- the customer-orientated PWSCG metrics are suitably functional, and yet in the recent past not all selected forecast variables display an improved performance.

In light of the foregoing MOSAC not only concurs with Office that there is an *"ongoing need to review top-level forecast accuracy metrics"*, but furthermore strongly urges the Office to address and alleviate the issues highlighted above. It recognizes the enormity of the task of developing a theoretically well-founded, scale-sensitive, operationally viable, preferably probabilistically-based, and customer-orientated set of metrics. It also recognizes that the adoption of refined verification metrics for comparison of global forecasts models would be facilitated by international agreement. Notwithstanding MOSAC asserts that

- global model inter-comparison metrics should be more sensitive to 'weather-related features' and should incorporate consideration of ensemble (as well as deterministic) forecasts, and urges the Office to prepare for and work toward realizing this goal. (- the Office already operates its own 'ensemble versus deterministic' assessment for regional models),
- attention needs to be directed to clarifying the apparent misrepresentation of the UKV's performance based upon the current HiRA metrics with a view to refining the metrics, and
- an evaluation of the forecast performance achieved with the customer-orientated metrics is required to establish model or metric shortcomings.

- We agree with MOSAC that the issues of verification and forecast accuracy metrics require further work. Ongoing efforts, briefly summarized at MOSAC, will be described in more detail at the next MOSAC
- We are glad that MOSAC supports our proposal to revise the global model inter-comparison metrics to include additional 'weather' parameters, and are proactively encouraging other centres to provide the necessary additional data (weather parameters, increased resolution) consistent with recent WMO CBS recommendations. The draft ensemble dashboard presented at MOSAC will be implemented internally this year to assess research trial performance. We will continue to push through WMO to accelerate



sharing of ensemble data (including weather parameters) to permit a Met Office metric based on international inter-comparison of global EPS skill.

- We agree that there is further work to do to reconcile UKV performance with results from the new HiRA system, likely including additional metrics to capture features that HiRA does not capture, as well as working with end users, such as the Environment Agency, to understand how improved performance translates into customer decision-making.

Finally MOSAC welcomed the systematic exploration of some on-going issues related to the configuration of forecasting suites (c.f. the questions posed annually in the Appendix). In particular insightful studies were undertaken of the sensitivity to domain size, the number of ensemble members and vertical resolution. The Committee notes the null-result achieved in tests assessing the impact of increased vertical resolution, but remains of the opinion that such tests will need to be carefully evaluated given the complexity of physics-dynamics interaction and the resolution-dependency of some physical parameterization schemes.

- As the committee noted, we have not found sufficient improvement from increased vertical resolution to prioritize operationalisation of this development (c.f. other advances which more clearly will deliver benefits in the short-medium on the enhanced HPC). We do however agree with MOSAC that it is worthy of further investigation, and will continue to look at this in research mode.

#### 4. Climate Science

*The Climate Science Directorate* continues to develop and refine its state-of-the-art research capabilities. MOSAC noted that its research is patently at the cutting-edge of the discipline and provides a wealth of impressive information on a range of international and national issues for both government and business customers. It is also commendable that significant aspects of the research are being conducted in collaboration with other international institutions.

The evolving international framework for Climate Science now places an increasing emphasis upon the development of 'Climate Services' (c.f. the extant concept of 'Weather Services'). MOSAC recognizes the desirability of such a development but it also wishes to assert strongly that sustaining and further fostering high quality fundamental climate science research is essential for the effective future development and use of Climate Services.

- We agree with MOSAC that the foundation of credible climate services is a strong programme in fundamental climate science. We are currently designing the next 3-year climate science programme and will ensure that this point is respected

Plans are well-advanced for the Office's contribution to the next Coupled Model Inter-comparison Project (CMIP6) with a model that has significant improvements compared with the previous one and with characteristics that deviate from the mean of other models scheduled to participate in CMIP6. The latter feature reflects the Office's commendable trust in its model development and testing programme.

The Committee appreciated the effort being devoted to and underscored the need for updated climate projections for the United Kingdom (*sic*. UKCP18). It noted that it constitutes integral contribution to 'Climate Services' and that will consume substantial computer time. The project also links neatly with the Regional Reanalysis project of the Weather Science Directorate referred to earlier. Other issues related to Climate Science, but relevant to MOSAC, were discussed separately by the SRG.

- We thank MOSAC for these comments on CMIP6 and UKCP18, and for pointing out the connection to the regional re-analysis work

MOSAC reflected upon the respective roles of MOSAC and the SRG and noted both the overlap and the limitations of the current 'two-committee' structure for reviewing MO science. For example:

- (i) Advances in 'Climate Science' has resulted in an ever closer alignment of the Climate Science Directorate with the Office's other Science Directorates.  
*(Climate Science is highly dependent upon the research being undertaken in 'Foundation Science' for the development and deployment of future state-of-the-art models and for the acquisition of the observational data base necessary to undergird refinement of parameterization schemes. It is closely aligned to, and in part dependent upon 'Weather Science' for both the conduct of seamless modeling that extends across the range of spatial scales and involves multi-disciplinary environmental aspects, and for the construction of weather-sensitive climate scenarios. Likewise some of the Directorate's objectives parallel, complement and feed into those of Applied Science.)*
- (ii) There is a critical overlap in the ToR of the MOSAC and SRG.  
*(It can be argued that this renders the present two-committee arrangement ineffective and manifestly untenable for the Chief Scientist and decidedly unsatisfactory for MOSAC.)*
- (iii) Streamlining the present structure would lighten the Office's administrative load, and restructuring could deliver for the Office a more effective oversight capability that would be in line with both recent developments of the underlying science and the evolving need(s) of customers.

In light of the foregoing MOSAC urges the Met Office Leadership to:-

*"conduct, in consultation with the MO Board, pertinent Governmental Departments and the PWSCG, a re-examination of the current two-committee structure for reviewing MO science with a view to establishing a 'Committee / Review' structure that reflects the evolving nature of the science and is appropriate to the relevant parties."*

- We agree with MOSAC that the current mechanisms for review and quality assurance of Met Office science is in need of review. There are conflicting demands from different review panels and we shall need to balance Met Office, MOSAC and sponsor requirements. We shall report on progress at the next meeting.

## 5. Applied Science & Scientific Consultancy.

This young Directorate has continued to consolidate and extend its effort to link and exploit the Office's research with client needs to the benefit of both parties. The progress to date is particularly commendable because the Directorate has experienced a rapid succession of major organizational changes involving administrative restructuring, partial redirection and resource reduction. Whilst recognizing that some adjustment might well have been necessary, MOSAC is of the opinion that

- for the young Directorate to flourish a period of relative stability is now most desirable, and
- further radical reorganization would call into question the rationale underlying the original foundation of the Directorate.

Noting that mutual benefit was expected from closer 'Office-Client' links forged by the Directorate, MOSAC had sought and was provided at the meeting with a catalogue of the positive



impacts of its activities upon the Office's basic research activity. The range and number of items in the catalogue is a testament to the growing effectiveness of this aspect of the Directorate's activities. MOSAC was unclear as to the nature of the linkage and the level of coordination between projects in the Applied Science and International projects.

- We thank MOSAC for the question on the linkage between international projects done by Applied Science and those done by other areas of Science. The coordination is done broadly by a choice of priority regions in the world, so that we can ensure the modelling and observations skills are in place. We are currently reviewing the scope of work being undertaken by Applied Science and will keep this point in mind during the review.

MOSAC reiterated that it would be desirable for the Directorate to interact with and help shape the programmes of academic institutions to meet its own longer-term staffing needs. On the operational level MOSAC stressed that the advice given to customers was often best expressed in probability terms, and sought assurances that this was indeed common practice.

- We agree that one of the threads running through Applied Science projects is the use of risk language, and taking a risk based approach. We recognize that some customer areas prefer deterministic forecasts and we are trying to work with them to use ensemble products.

## **6. Collaborative Activities and Partnerships**

The scope of the Office's international activities was illustrated in a presentation by the Head of Government Services and then amplified in a subsequent panel discussion. MOSAC commends both the Office's participation in international collaborative efforts and the range and breadth of these activities. Such activities can foster scientific interaction and be mutually beneficial to the participating nations and institutions, and can be geared to specific needs (for example HMG Resilience Agenda). The Committee explored the extent to which these activities were aligned to the Office's overarching goals as opposed to being merely pragmatic and opportunistic, and emphasized that there was scope for further international collaboration on fundamental research issues (- such as Exascale computing).

- We thank MOSAC for probing us in the way during the meeting! We agree that there are other areas of science that might benefit from partnership working.

In the same vein MOSAC noted that the positive impact of international 'UM Partnerships' is reflected in the improved forecast performance of partner institutions. Steps taken by the Office in recent years has facilitated the undertaking of collaborative research with these Institutes, and MOSAC would welcome an update on these activities.

- We greatly value our collaborations across the UM partnerships (and more widely) and would be happy to provide an update on these activities at the next meeting.

Likewise the influence of the Office's UK links with Academic Partners (MOAP) is attested by the increase in the number of papers co-published with authors from these partner institutions. MOSAC also commends the Office's collaboration with other non-MOAP UK institutions, and notes that one of these institutions indeed featured in the 2015 'top-ten' list of Met Office co-publications.

## 7. Further Remarks

In accord with its duties, MOSAC reviewed the Office's response to the requests, comments and queries that it had raised in last year's report. It concluded that the combination of written responses and subsequent actions addressed directly and appropriately the vast majority of points raised by the Committee, and it fully expects that the remaining points will feature on the agenda of future MOSAC meetings. MOSAC also believes that changes to the annual meeting's format would be beneficial. These could include:- more comprehensive presentations and extended discussion of the overviews provided by the Deputy Directors plus extended consideration of some key themes, breakthroughs and pressing challenges. It welcomed this year's poster session that provided an opportunity for less formal and highly informative interaction with members of staff, but both the time-slot for and the setting of this session needs to be more congenial.

- Alongside the review of our scientific committees, we will consider the format of the meeting, taking the committee's comments into account.

An institution's success in research depends vitally upon the calibre and enthusiasm of its research personnel, and the advances recorded by the Met Office in the last twelve months is a testament to the high quality of its researchers and their esprit de corps. In this context MOSAC emphasizes that continued success at the highest level depends upon the Office attracting and hiring the most highly motivated and able young researchers drawn from across the spectrum of academic disciplines. For example it was noted that some extant code optimization tasks might be attractive and suited to pure mathematics graduates.

- We appreciate the committee's comments on the importance of having the right staff in place, and are reviewing our science recruitment to ensure that we have the best staff in place to achieve our plans.

Finally MOSAC wishes to thank the speakers for the time and care they invested in the preparation of their papers and presentations, and furthermore appreciates the willingness of participants to engage in open, lively and constructive discussion on the challenges currently confronting the Office's research. As always the Committee is grateful to the administrative staff for ensuring the smooth conduct of the meeting.

## APPENDIX

### ***Key Issues for Ensemble Forecasting.***

An operational weather service is confronted with a range of enduring scientific challenges that can serve as a prompter for research and as a helpful benchmark for monitoring progress. A partial list of such challenges that relate predominantly to regional ensemble forecasting has featured in previous MOSAC reports and is reproduced, rephrased and supplemented below.

- *What should be the balance between resolution, domain size and ensemble size?*
- *How should the different ensemble members be generated?*
- *What is the relative importance of the observation-based initial state uncertainty and model representation error?*
- *How should the nesting in the larger-scale model be performed?*

- *How should the results be diagnosed for use by forecasters and is extensive hindcasting required to calibrate the system?*
- *How should the very high resolution probabilistic forecasts be evaluated?*
- *How should probabilistic forecasts be communicated to the general populace?*