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REPORT OF THE TWENTY-FOURTH SESSION OF THE WORKING GROUP ON NUMERICAL EXPERIMENTATION (WGNE)

(Montreal, Canada, 3-7 November 2008)

SUPPORTING NUMERICAL EXPERIMENTATION RESEARCH ACTIVITIES OF THE:

WMO/IOC/ICSU WORLD CLIMATE RESEARCH PROGRAMME

WMO WORLD WEATHER RESEARCH PROGRAMME

WMO GLOBAL ATMOSPHERE WATCH PROGRAMME

AND RESEARCH LINKS TO

OPERATIONAL WEATHER AND CLIMATE PREDICTION

CAS/JSC-WCRP
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WGNE-24 Session report

The 24th session of the joint World Climate Research Programme/Commission for Atmospheric Sciences (WCRP/CAS) Working Group on Numerical Experimentation (WGNE) took place from 3-7 November 2008 in Montreal, Canada. The meeting was hosted at the Biosphere Museum by Environment Canada, to whom the co-chairs of WGNE, Dr. Martin Miller and Prof. Christian Jakob and the participants express their sincere gratitude for the excellent hospitality the group experienced in Montreal.

This report provides a short summary highlighting the main discussions and resulting actions and decisions of the meeting. The report is structured by the main areas of discussion, which were issues related to parametrization, operational Numerical Weather Prediction (NWP), climate modelling, verification and the interaction with other WCRP and CAS activities, such as the Global Energy and Water Cycle Experiment (GEWEX), the World Weather Research Program (WWRP) including WWRP-THORPEX, and the Year of Tropical Convection (YOTC). **A fuller annotated list of decisions and actions can be found in Appendix A.**

a. Parametrization

Following an initiative at WGNE-23 by the then WGNE and GMPP chairs, WGNE was tasked by both the WCRP and CAS to expand its portfolio to better meet the needs of WCRP and the programmes of CAS by providing expert advice and acting as a catalyst for the development of numerical experimentation aimed at advancing **physical parametrizations** in the numerical models used by the climate and weather prediction communities. As a result the position of a new co-chair of WGNE with specific responsibility for this area was created. Christian Jakob was appointed as co-chair. In addition, the chairs of the GEWEX parametrization studies became members of WGNE. As a consequence of that decision WGNE-24 addressed a large number of parametrization-related issues. The meeting discussed at length the perception that some parametrizations, most notably that of deep convection, will soon be obsolete due to the emergence of convection-permitting global models. It is the firm opinion of WGNE that the use of such models in global operational NWP is at least a decade away. Furthermore, its use in operational seasonal and climate prediction is not likely to occur for an additional decade after that. WGNE therefore strongly urges a reinvigoration and increase in activities related to parametrization research.

The meeting received reports from all three GEWEX parametrization efforts, namely the GEWEX Cloud System Study (GCSS), the GEWEX Land-Atmosphere System Study (GLASS) and the GEWEX Atmospheric Boundary Layer Study (GABLS). WGNE congratulated the studies on their achievements in 2008 and encouraged all of them to continue along the plans they presented. In particular, WGNE encouraged GABLS to maintain its major efforts to improve the representation of the stable boundary layer in models and to withstand the temptation to move on to potentially easier problems.

A specific topic of the discussion was how to best progress work on the representation of microphysics. It is recognized that the importance of this representation is increasing in all areas of modelling especially in convection-permitting models as well as models that include cloud-aerosol interactions. It was decided to focus research efforts through the recently created GCSS working group on microphysics. WGNE encourages its members and the wider research community to make best use of this effort by participating in existing activities of the group and by suggesting new projects aimed at testing and improving parameterizations for climate and weather. In particular WGNE suggests building on the existing efforts in GCSS and expanding to include the increasing number of operational and research convection-permitting models in the GEWEX model evaluation and development activities. In particular WGNE encourages the modelling groups involved in the WWRP Working Group on Mesoscale Weather Forecasting Research and the limited area modelling component of TIGGE (TIGGE-LAM) to participate in the GCSS model evaluation efforts.

The new co-chair presented a number of proposals to enhance the parametrization effort and to engage a broader community in its activities. Three initiatives in particular were discussed and supported by WGNE. First the co-chair has been tasked to conduct an audit i) on existing parametrization activities in the broader WMO community and ii) on the problems ascribed to parametrization issues throughout the application communities including NWP and data assimilation, seasonal prediction and climate simulation and projection. Results of an initial survey are encouraging in its response. A second initiative, led by Dr Joao Teixeira (JPL), is to organize a conference/workshop on the representation of physical processes in Climate System Models. WGNE agreed to support such a meeting subject to a more detailed plan being submitted to members and discussed by email. It is likely that the conference, rather than focussing on model components, will discuss parametrization issues in various applications and geographic regions, including issues of coupling. WGNE also supported a proposal to write a white paper on parametrization issues. It was decided to tie the publication of the paper to the conference and to request the conference organizers to seek broad community input and support for the conclusions of the paper.

b. Progress and challenges in NWP

Every WGNE meeting reviews the new developments, plans and progress made by **the main NWP Centres**. As in recent years the drive to higher resolutions (both in the horizontal and now in the vertical also) for both global and regional systems continues, and several operational global models are running with grids of 20-40kms. Furthermore, several Centres are now generating short-range forecasts from non-hydrostatic models with 1-2km gridlengths. These are increasing the focus on boundary layer and land surface parametrizations and also cloud microphysics. There are substantial challenges emerging as to the choice of algorithms for data assimilation at convective scale resolutions. There is also increasing activity in the application of much higher resolution models for local (e.g. urban) forecasts. The overall improvements in forecast system performance are discussed in Section d). A comprehensive set of Tables summarizing global NWP Centres forecast systems and plans are contained in Appendix E.

c. Climate modelling issues

Several **climate modelling issues** were discussed at the meeting. Serious concerns were voiced with the timelines set by the IPCC AR5 effort and reflected in the CMIP5 effort. These concerns mainly relate to the fact that due to the pressures of performing the CMIP5 experiments and the related need to add additional model components, many climate modelling groups will not have the resources to continue the much required research on improving the atmospheric models; perceived as a significant impediment to progress.

A proposal to submit high resolution AMIP simulations under the CMIP5 protocol was well-supported with several NWP Centres indicating that they would try and do this, and this would be communicated to chairs of WGCM and the CMIP panel for their final approval.

As well as this addition to CMIP5, WGNE discussed and strongly supported a suggestion from WOAP to include the transpose AMIP simulation protocol originally instigated by WGNE in the CMIP set of experiments. The co-chairs were tasked to approach WGCM and CMIP in this matter. If the CMIP panel agreed then Keith Williams offered to lead the development of an experiment protocol.

For a number of years, WGNE has discussed the issues and potential pitfalls of Regional Climate Modelling. These discussions have led to investigations by RCM groups, notably by the group led by René Laprise, who presented a concise summary of the results of these studies, and a set of recommendations. WGNE thanked Dr Laprise for his continued leadership in the ongoing discussion and endorsed his recommendations (See Appendix D).

The formation of the new WCRP task force on regional climate modelling was noted and possible interactions of WGNE with this group were considered. Collaboration with the group through WGNE representation on the task force was an obvious possibility. However WGNE recommends that the task force first focuses on the research required for the effective use of RCMs rather than the hasty delivery of “predictions” for AR5.

Finally, WGNE once again reiterated its overall support for reanalysis efforts, such as the activities of the WRCP’s Observation and Assimilation Panel (WOAP). WGNE encourages these reanalysis efforts as they are important for advancing the goals of climate research, and also for research on issues associated with weather and seasonal variations - as evidenced by the large number and breadth of users of the major reanalysis products. The funding agencies need to be made aware that the generation of reanalyses are costly in terms of human and computing resources and such efforts are all too often essentially unfunded mandates given to operational centres.

d. Forecast verification and model evaluation

There are several WGNE-related projects involving **verification of forecasts** especially of less-standard quantities such as weather parameters and severe weather events. The meeting discussed a number of issues related to verification and reviewed the progress made in the multi-centre forecasts of tropical cyclone tracks and intensities, precipitation for various regions of the world, and verification and comparison of MJO forecasts. It also reviewed the encouraging improvements made in more traditional forecast performance in terms of objective scores such as the 500hPa height fields, MSLP and wind. WGNE members were encouraged to ensure that their model developers were kept up-to-date with all these results, especially the less conventional ones.

Specific initiatives to establish cloud prediction verification using a range of techniques were reported on by the Joint (WWRP-WGNE) Working Group on Forecast Verification Research (JWGV), and their report will form the basis for future developments in this area. The JWGV also reported on a new effort to apply a common verification approach to operational and research predictions of seasonal forecasts of tropical cyclone activity, with scores made available through a password protected web site. WGNE encourages reporting on these results in the future.

The SURFA project was running routinely now with just two NWP Centres (ECMWF and DWD) contributing flux data currently. Both the Met Office and Météo-France plan to participate in the near future. The role of WGSF was queried and also links to SEAFLUX are needed.

The group reiterated its support of WOAP's recommendations regarding data standards and the verification of the reanalysis products

e. WGNE Recommendations on CAS activities

WGNE-24 made several recommendations related to the **interaction with CAS activities.** A presentation was made on the activities of the THORPEX Working Group on Data Assimilation and Observing Systems (DAOS). WGNE supports efforts by the THORPEX DAOS to quantify the impacts of targeting in recent field and numerical experiments. Specifically the group supported the conclusions of the working group that there is little evidence that the current approach for targeted observations in data assimilation leads to improvements in the average forecast skill in the extratropics, acknowledging that isolated, individual forecasts may well improve by using the technique.

On the request for closer interaction with the THORPEX PDP working group, WGNE supports the THORPEX suggestion to give a WGNE-focused presentation at the THORPEX symposium in May 2009. THORPEX also recommended that an appropriate representative from WGNE with expertise in parameterization attend the annual meetings of the PDP Working Group as that group within THORPEX is tasked with identifying barriers to improving predictive skill, which include parameterization and other model errors. The WGNE co-chair with responsibility for parametrization, currently Christian Jakob, has agreed to be the WGNE representative on this group. Appropriate reciprocal representation of the PDP group at WGNE meetings is under discussion.

WGNE discussed the plans for the the joint WCRP-WWRP programme called the Year of Tropical Convection (YOTC) and encouraged YOTC to continue its very exciting activities. A concern was raised that most of the YOTC modelling activities are focussed on high-resolution modelling and that plans do not sufficiently include strategies for applying YOTC data and science to the improvement of parametrizations. WGNE offered help in this area and charged the co-chairs, who are members of the YOTC Science Team, to initiate further discussions with YOTC and to participate in the discussions on the YOTC implementation plan.

WGNE received a request to support HEPEX. The discussion of this request concluded that WGNE needed clarification on the relationship of CAS activities to hydrological research including the activities of the Commission on Hydrology. This relationship will be clarified as part of the WWRP strategic planning process.

It was recognized that the prediction of atmospheric composition and hence pollution is becoming a more and more integrated part of NWP systems and that WGNE through both its connection to operational centres and its new parametrization effort has a strong connection to such efforts. It is however unclear at this stage to what extent WGNE ought to become involved in these efforts. It is suggested to have an in-depth discussion of this issue at WGNE-25 and to invite an expert presentation to guide the discussion.

f. Additional Issues

The discussion on TIGGE noted that the archive produced data volumes of such a size that they cannot be easily downloaded due to limitations in data transfer capabilities, especially in developing countries, but also in the university sector. The point was made that other model related activities (e.g., CMIP, YOTC, CEOP) also face the same problem, which can effectively exclude a sizeable fraction of the research community from the above activities. WGNE urged all data systems groups to consider alternatives to the “download and process at home” paradigm currently in place. One suggestion was to consider coordinating discussions through the existing GO-ESSP (Global Organization for Earth System Science Portal) effort.

In similar vein to the IPCC AR5 deadlines discussed earlier, WGNE identified the substantial and growing demands on computing and people resources of the regular hindcast efforts in seasonal prediction as a negative impact on model development. While appreciating the scientific rationale for this, the group would like to see more research into possible ways of reducing hindcast needs to the minimum necessary, rather than persisting with the all-encompassing approach currently in use.

WGNE-24 Actions and decisions

Parametrization Issues

1) **Statement: The use of convection-permitting models in global operational NWP is at least one decade away and the use in operational seasonal and climate prediction is unlikely for some considerable time after that. WGNE therefore strongly urges a reinvigoration and increase in activities related to parametrization research for global models.**

The meeting discussed the role of convection-permitting models on several occasions. While it is evident that such models are now very close to becoming the tool of choice for regional operational weather prediction as well as for many research efforts, the group felt obliged to highlight that such models will not be used for some time to come (decades most likely) in global operational applications. It is therefore imperative that the emergence of these models does not distract both attention and resources from the important research yet to be carried out on the representation of convection in particular in lower-resolution models.

2) **WGNE supported the plans of all GEWEX parametrization efforts.**
3) **WGNE urged GABLS to withstand pressures to divert research away from that on the stable boundary layer. It is recognized that this is a difficult but very important problem on which to make progress.**
4) **WGNE encouraged its members to make good use of the GCSS microphysics effort in developing better schemes, in particular for convection permitting models**
5) **WGNE encouraged the GEWEX activities, and GCSS in particular, to include the convection-permitting models now increasingly used at operational centres for regional/local prediction in its model evaluation and improvement activities.**

The inclusion of the GEWEX parametrization activities in WGNE was seen as a major success to further enhance the very good collaboration between the groups. WGNE was very impressed with all the existing efforts and once again encouraged members to engage as much as possible with these activities and to take advantage of them in their model development efforts.

6) **WGNE supported the audit of parametrization issues and existing efforts proposed by the co-chair.**
7) **WGNE supported the proposal for a conference on the physics of Climate-System Models subject to further refinement of the concept and an email consultation of the WGNE members in the near future**
8) **WGNE supported the writing of a white paper on parametrization tied to the parametrization conference. The GEWEX study group chairs, the WGNE co-chairs and Andy Brown were charged with progressing this in consultation with Joao Teixeira, who is likely to chair the conference organizing committee.**

The above suggestions by the new co-chair have been well supported by the group, and WGNE expects a status report on these initiatives at its next meeting.

Climate-Modelling Issues

9) **WGNE expressed its unease with the precipitousness of the AR5 timelines and is once again extremely concerned with their impact on model development.**
10) **WGNE members proposed to participate in CMIP5 through the submission of high-resolution (25-50 km) AMIP runs with global NWP models. A strong connection to the CMIP panel is sought on this matter.**
11) **WGNE supported the WOAP proposal to include transpose AMIP simulations in the CMIP protocol. Keith Williams will coordinate an initiative in this area with Peter Gleckler as a liaison to the CMIP panels. The WGNE co-chairs will approach the WGCM co-chairs immediately to get the ball rolling (DONE).**
12) **Regional Climate Modelling: WGNE endorsed several recommendations made by R. Laprise for the proper configuration of RCMs (see Appendix B)**
13) **WGNE urged the new RCM task team to focus on the research required (see previous item) rather than "product delivery" for AR5. WGNE would like to have a strong link to the task force, possibly by adding a WGNE representative to the task force.**

Verification Issues

14) **WGNE was pleased with the proposed metrics panel meeting and nominated Beth Ebert to serve as the JWGV member on that panel.**

WGNE has been involved for a long time in developing standard model diagnostics and metrics. NWP has successfully benefited from using metrics for many years and following discussions over several WGNE meetings it has been agreed (with support from the JSC of WCRP and PCMDI) to form an ad-hoc panel to define an agreed initial set of metrics for climate models with a view to applying them in the CMIP5/AR5 process.

15) **WGNE decided to await the JWGV report on cloud verification before proceeding further on this issue.**
16) **Following a proposal for joint precipitation verification activities by the International Precipitation Working Group (IPWG), it was agreed that Beth Ebert would clarify the current situation vis-à-vis operational Centres precipitation data to help properly define a formal data request**
17) **WGNE noted the lack of WGSF activity in the SURFA project and Ghassem Asrar offered to follow this up.**

In view of the range of verification activities, WGNE should consider at some point the writing of a journal paper summarizing these efforts.

18) **It was agreed that Chiasi Muroi (JMA) will check on what is needed to reinvigorate the uptake of the multi-centre EPS verification efforts carried out by JMA.**
19) **WGNE nominated Tom Hamill as their liaison with the CBS expert team on EPS and the Joint WWRP/WGNE Working Group on Forecast Verification.**

Although the standards for EPS verification should be set through the CBS, WGNE was concerned that in practice comparisons of ensemble forecast systems were difficult due to clear differences in methods and their applications.
More generally, the verification activities of CBS, WGNE and the JWGV are in part complementary, but it is important that good liaison is maintained between these parties to

avoid duplication and to ensure that state-of-the-art techniques and agreed standards are used whenever possible.

20) **WGNE reiterated its strong support for reanalysis efforts noting the concerns expressed by WOAP regarding standardization of the data products and the need for thorough evaluation and comparison of the results from the various efforts.**

Interaction with CAS activities

21) **WGNE supported the conclusions of the THORPEX DAOS WG on targeting.**
22) **WGNE agreed with the suggestions of the THORPEX PDP WG for closer collaboration and an invited WGNE presentation will be offered at the THORPEX Symposium in May. The WGNE co-chair with responsibility for parametrization will follow an invitation to participate in PDP meetings and activities.**
23) **WGNE encouraged the YOTC team jointly supported by WCRP and WWRP-THORPEX to continue to develop their activities and offered help in the area of parametrization.**
24) **On the request to support HEPEX, WGNE suggested that a closer connection between CAS and CHy is needed first before any further action.**

Miscellaneous

25) **WGNE to take a position on involvement in the modelling of atmospheric composition. Action: Invite an expert talk at next year’s meeting**
26) **WGNE expressed concern that the large data volumes involved in many current efforts (CMIP, TIGGE, YOTC, CEOP, ...) exclude a sizeable fraction of the research community from activities related to them due to limitations in the ability to transfer the data. WGNE urged all data systems groups to consider alternatives to the download and “process at home” paradigm currently in place.**

One possible course of action was for these groups to liaise with the GO-ESSP effort and include them in discussions on possible solutions.

27) **WGNE expressed its concern that the computational demands of the hindcasts used by seasonal forecasting systems are threatening to retard model development, and WGNE would like to see more research aimed at investigating ways to reduce the volume of hindcasts currently being used.**

Meeting agenda

Monday 3 November

Agenda Item	Subject	Responsibility/ Introductory speaker
0900-1040		
1.1	Opening welcome, local arrangements, agenda etc	M. Miller P. Gauthier
1.2	Relevant activities under CAS auspices	M. Béland
1.3	WCRP and the last JSC meeting	G. Asrar
1.4	Outcome of the World Modelling Summit for Climate Prediction	M. Miller
1.5	Report from the GEWEX Scientific Steering Group and GEWEX Executive meeting	P. Van Oevelen
1040-1100	**Coffee**	
1100-1230		
1.6	Report on the WCRP observations and assimilation Panel (WOAP)	P. Gauthier
1.7	Data assimilation activity, workshops etc Observing systems and results of OSEs, also CBS work.	P. Gauthier
1.8	Weather and environmental prediction in Canada (30min)	P. Pellerin
1.9	Recent developments at operational forecasting centres (not on extended range, see Item 3.8)	Participants (max 20min each)
1230-1345	**Lunch**	
1345-1530		
	Recent developments at operational forecasting Centres (continued)	Participants
1530-1550	**Coffee**	
1550-1730		
	Recent developments at operational forecasting Centres (continued)	Participants
1830-2000	Ice-breaker at the Hôtel des Gouverneurs	All

Tuesday 4 November

Agenda Item	Subject	Responsibility/ Introductory speaker
0900-1040		
2.1	Plans or results from national climate or global change modelling activities, reports on programmes such as that of the Earth Simulator, progress towards a unified weather prediction and climate modelling framework	C. Muroi, J. Hack K. Puri, A. Brown, V. Balaji, F. Rabier
2.2	Report on the WGCM meeting	C. Jakob
1040-1100	**Coffee**	
1100-1230		
2.3	Tenets and issues in regional climate modelling (30min)	R. Laprise
2.4	Activities in regional climate modelling	R. Laprise
2.5	Progress with Stretched-Grid Model Intercomparison Project (SGMIP)	J. Côté
1230-1345	**Lunch**	
1345-1530		
2.6	Progress in reanalysis activities at NCEP, GMAO ECMWF, JMA and CPTEC	M. Iredell, M. Miller C. Muroi, P. Silva Dias
2.7	AMIP, CMIP and progress with Metrics for climate models (40 mins)	P. Gleckler
2.8	“Transpose” AMIP: status of project	J. Hack
2.9	Report on the APE (Aqua-planet Experiment)	J. Hack
1530-1550	**Coffee**	
1550-1730		
2.10	Cloud verification talk (30 mins)	K. Williams
2.11	Cloud verification from the JWGV perspective (15)	B. Ebert
2.12	Cloud verification at operational centres	Participants

Wednesday 5 November

Agenda Item	Subject	Responsibility/ Introductory speaker
0900-1040		
3.1	General report on WWRP	G. Brunet
3.2	THORPEX including TIGGE, IPY and recent meetings	D. Parsons
3.3	THORPEX Pacific-Asia Regional Campaign	D. Parsons/P. Gauthier
1040-1100	**Coffee**	
1100-1230		
3.4	Report from the THORPEX DAOS WG	F. Rabier
3.5	Year of Tropical Convection (YOTC) and progress with the MJO verification activity	WGNE Co-chairs
3.6	WGNE and WWRP/THORPEX	C. Jakob/D. Parsons
1230-1345	**Lunch (followed by short tour of the Biosphere)**	
1345-1530		
3.7	Towards seamless prediction	G. Brunet
3..8	Recent developments/activities in monthly and seasonal forecasting	Participants
3.9	Ensemble forecasting: progress and issues (30 mins)	T. Hamill
	- Possible WGNE activities??	T. Hamill to lead
1530-1550	**Coffee**	
1550-1730		
3.10	LAM Modelling in support of the 2010 Vancouver Winter Olympics	J. Mailhot
	Progress and plans with convection-permitting models in limited-area and global NWP	Participants
3.11	New numerical developments and test cases including non-hydrostatic systems, and a report on the NCAR ASP workshop on numerical techniques for global atmospheric models	D. Majewski X. Shen, F. Rabier Participants

Thursday 6 November

Agenda Item	Subject	Responsibility/ Introductory speaker
0900-1040		
4.1	Status of the new WGNE parametrization effort and plans for future developments (30 mins)	C. Jakob
4.2	GMPP: Progress and future activities (10 mins)	C. Jakob
4.3	GABLS: progress reports and ideas for a joint case study (50 mins)	G. Svensson
1040-1100	**Coffee**	
1100-1230		
4.4	GCSS: Progress reports including the interaction with CFMIP (60 mins)	P. Siebesma
4.5	Land-surface and the key issues (30 mins)	B. van den Hurk
1230-1345	**Lunch**	
1345-1530		
4.6	GLASS : Progress reports (60 mins)	B. van den Hurk
4.7	Progress with SURFA (15 mins)	D. Majewski
4.8	Microphysics talk (30 mins)	P. Yau
1530-1550	**Coffee**	
1550-1730		
4.9	Modelling activities in CEOP (30 mins)	M. Bosilovich
4.10	Microphysics in the WGNE parametrization effort – Where to and how important is it? (20 mins)	C. Jakob to lead
4.11	Possible conference on ’The Physics of Earth-System Models’ (20 mins)	C. Jakob
4.12	Discussion on future activities (30 mins)	C. Jakob to lead
1900	Cocktails and dinner at the ‘Restaurant Le Wilson’ (dinner is offered by Environment Canada)	All

Friday 7 November

Agenda Item	Subject	Responsibility/ Introductory speaker
0900-1040		
5.1	Report on the activities of the Joint Working Group on Forecast Verification Research including new ideas etc	B. Ebert
5.2	Inter-comparison of typhoon track forecasts	C. Muroi
5.3	Trends in performances of the models of the main operational forecasting centres	M. Miller
5.4	Verification and comparison of precipitation forecasts at various centres	D. Majewski, F. Rabier, M. Iredell, K. Puri, C. Muroi, A. Brown M. Miller
5.5	Proposal for joint precipitation intercomparison activities with the International Precipitation Working Group (IPWG)	B. Ebert
1040-1100	**Coffee**	
1100-1230		
5.6	Report from the CBS coordination group on verification	M. Miller
5.7	Outstanding items and actions	Chairs/D. Parsons
	Arrangements for publication of the 2008 edition of “Research Activities in Atmospheric and Oceanic Modelling”	P. Gauthier
	WGNE’s web page	
	Venue for WGNE 2009 and close of session	M. Miller
1230	**(Lunch)**	

Appendix C

Meeting participants

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Appendix D

Conclusions on Regional Climate Modelling – courtesy René Laprise

This appendix summarizes some general conclusions on Regional Climate Modelling with limited-area nested models, based on work summarised in Laprise (2008), Laprise et al. (2008) and references therein and elsewhere.

A pragmatic approach to reduce the computing cost of high-resolution global climate models is to apply the high resolution over only a subset of the globe, a technique known as nested Regional Climate Modelling. Lower resolution data, either simulated by Coupled Global Climate Models (CGCM) or from reanalyses of observations, are interpolated in time and in space on the high-resolution grid of a limited-area Regional Climate Model (RCM) and serve to define the lateral (and often the ocean surface) boundary conditions (LBC). Like all models, RCM are subject to a variety of sources of errors and uncertainty; but in addition to these common problems, there are specific issues that arise with RCM relating to their limited computational domain, the nesting technique, the resolution jump between the RCM and the driving data, the update frequency of the LBC, and the imperfections in LBC data.

The ansatz behind the technique, which is also referred to as “dynamical downscaling”, is that, driven by large-scale fields at LBC, an RCM generates fine scales that are dynamically consistent with these. Hence RCM are expected to act as a kind of “magnifying glass” that reveals details that cannot be resolved on a coarse mesh. It is now well documented that fine-scale structures do develop in high-resolution RCM even when they initialised with and driven at their LBC by lower resolution data. These small scales represent the potential added value of high-resolution RCM. The spin-up of fine scales proceeds fairly rapidly (within a day) in the atmosphere, but possibly on much longer time scales for surface fields. The hypothesised development mechanisms include fine-scale surface forcing, hydrodynamic instabilities, mesoscale processes, and nonlinear interactions cascading information from the large to the small scales.

The size of the domain is a central issue. Due to the continuous transport of low-resolution information from the lateral boundary, some distance is required for the spin-up process to proceed. The spin-up distance on the inflow side of domain is larger for stronger ventilation flow through the domain. For mid-latitude domains, this distance is thus larger in winter and at upper levels due to stronger winds. The physically meaningful portion of the limited-area domain must exclude the spin-up distance, in addition to any sponge or buffer zone used as part of the lateral boundary nesting. The downscaling skill has been documented through a set of idealised “perfect prog” tests. Over very small domains (e.g. 70 linear grid points), the small-scale transient eddies are amplitude deficient, especially at upper levels. With large enough domain (e.g. of the order of 200 linear grid points), small-scale transient eddies are simulated with the correct amplitude, but with very little time correlation with the reference; this is unimportant for climate applications, but must be taken into consideration for process studies.

By their nature, nested RCM require externally provided data to drive them. Over mid-latitude domain, the application of LBC is usually sufficient to control the large-scale circulation through the RCM domain. There are however occasional episodes in RCM simulations when the circulation within the regional domain (the inner solution) decouples substantially from that of the driving data (the outer solution). This phenomenon is referred to as “Intermittent Divergence in Phase Space”; it is particularly frequent with large computational domain and under conditions of weak ventilation flow through the domain. These episodes result in unphysical flow near the outflow boundary. The application of the alternative nesting technique called large-scale (spectral) nudging, that forces the large-scale flow throughout the entire regional domain, is effective in suppressing this occurrence.

The impact of errors in the driving data is an issue when low-resolution CGCM-simulated or global model forecasts data are used to drive an RCM. According to a strict interpretation of dynamical downscaling, RCM are expected to simply reproduce the large-scale errors supplied as LBC. Some forecast experiments carried over very large domains have shown some promises at correcting part of the large-scale forecast errors over the regional domain, due to reduced numerical truncation and improved treatment of some mesoscale forcings. On the other hand, it has been argued that planetary-scale circulation may be poorly handled over limited-area domain, and there are indications of some attenuation in the amplitude of the largest scales in RCM simulations. Idealised experiments with a perfect-prog approach over intermediate domain sizes (e.g. 100 linear grid points) indicate that the large scales that are supplied at the LBC are essentially replicated within the regional domain, without reduction or amplification of their errors. As ought to be expected, the fine scales that are generated suffer degradation in proportion to the large-scale errors (this is referred to as “garbage-in, garbage-out”).

In ensembles of RCM runs driven by identical LBC but initialised from slightly different initial states, differences develop in time between instantaneous values simulated by the various members. Hence the fine-scale structures that develop in RCM are not uniquely defined, but they are subject to some internal variability (IV), defined as inter-member spread. Different variables exhibit different degree of IV compared to natural variability: relative IV of precipitation rate for example is much larger than that of mid-tropospheric geopotential. IV is rather episodic, staying around small background values for extended periods of time, with episodes of rapid growth and decay. IV varies with domain size, location, season, and weather regime. The intensity of IV is negligible on small domains (e.g. less than 70 linear grid points), and it increases with domain size, reflecting the reduced control exerted by LBC with larger domains. With large domains (e.g. 200 linear grid points), IV occasionally and locally approaches natural variability. For climate applications, the RMS IV of time-averaged variables is inversely proportional, on average, to the square root of the averaging period. For process studies or testing model sensitivity to changing parameters, it is important to acknowledge the presence of IV in the interpretation of the results. It is noteworthy that the application of large-scale (spectral) nudging greatly reduces IV.

With respect to the resolution jump between the RCM mesh and the driving data, successful simulations have been achieved with very large jumps, with changes in resolution by factors as large as 25 (e.g. from 250-km mesh driving data to 10-km RCM mesh) without using a cascade with intermediate-resolution meshes. There is some empirical evidence that it is not so much the ratio of resolution that matters, but that the RCM domain should span several (e.g. 10 or more linear) grid points of the driving data in both horizontal directions. With respect to the update frequency of LBC, it appears that six-hourly data are sufficient for 45-km mesh RCM; it can be expected that the acceptable time interval scales with the RCM mesh size.

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Appendix E

WGNE List of Operational Global Numerical Weather Prediction Systems (as of January 2009)

Forecast Centre (Country)	Computer (Sustained in TFlop/s)	High resolution Model (FC Range in days)	Ensemble Model (FC Range in days)	Type of Data Assimilation
ECMWF (Europe)	IBM p575, 2x155 nodes (2x2)	T_L799 L91 (10)	T_L399 L62; (10) T_L255 L62 (+5)	4D-Var (T_L255)
Met Office (UK)	NEC SX6, 34 nodes NEC SX8 25 nodes (5)	~40 km L50 (6)	~90km L38; M24 (3)	4D-Var (~120km)
Météo France (France)	NEC SX8R (2x1)	T_L538(C2.4) L60 (4)	T_L358(C2.4) L55; M11 (4)	4D-Var (T_L224)
DWD (Germany)	NEC SX9; 2x14 nodes (2x4.5)	40 km L40 (7)	No global EPS	3D-Var
HMC (Russia)	SGI Altix4700; SGI ICE8200 (1.8; 1.3)	T85 L31 (10); 0.72°x0.9° L28 (10)	No global EPS	3D-OI
NCEP (USA)	IBM p655 (Cluster 1600) (2x1.9)	T382 L64 (7.5) T190 L64 (16)	T126 L28; M45 (16)	3D-Var (T382)
Navy/FNMOC/NRL (USA)	SGI and IBM (800 proc) (3.2)	T239 L30 (7.5)	T119 L30; M16 (10.5)	3D-Var
CMC (Canada)	IBM p575, 2X40 nodes (1.0)	~35 km L58 (10)	GEM (0.9°) L28; M20 (16)	Det: 4D-Var (1,5°) EPS: EnKF M96 (0.9°)
CPTEC/INPE (Brazil)	NEC SX6, 12 nodes (0.8) NEC/SUN 1100 Opteron Cluster (5.7)	T299 L64 (7); T126 L28 Coupled (30)	T126 L28; M15 (15)	3D-Var
JMA (Japan)	Hitachi SR11000-K1, 2*80 nodes (2x0.7)	T_L959 L60 (9)	T_L319 L60; M51 (9)	4D-Var (T159)
CMA (China)	IBM p655/p690 120 nodes (2.1)	T_L639 L60 (10)	T213 L31; M15 (10)	3D-Var
KMA (Korea)	Cray X1E-8/1024-L (2x0.7)	T426 L40 (10)	T213 L40; M32 (17/cycle) (10)	3D-Var
NCMRWF (India)	Cray X1E-64 processor (1.1) IBM P6 - 1280 processor (2.4)	T254 L64 (7)	T80 L18; M8 (7)	3D-Var (T254)
BoM (Australia)	NEC SX6, 23 nodes (0.4)	T_L239 L60 (10)	T_L119 L19; M33 (10)	3D-OI

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WGNE Overview of Plans at the NWP Centres with Global Forecasting Systems

Part I: Computer (Sustained Performance in TFlop/s based on main deterministic model)

Forecast Centre (Country)	2009	2010	2011	2012	2013	2014
ECMWF (Europe)	2x15	2x15	2x30	2x30	tbd	tbd
Met Office (UK)	0.15 on 1/8 of system	1.2 (on 1/8)	1.2 (on 1/8)	4 (on 1/8)	4 (on 1/8)	tbd
Météo France (France)	2x2	2x3	2x3	tbd	tbd	tbd
DWD (Germany)	2x4.5	2x15	2x15	2x15	tbd	tbd
HMC (Russia)	1.8+1.3	1.8+1.3	1.8+1.3	1.8+1.3	tbd	tbd
NCEP (USA)	2x1.9	2x9.3	2x9.3	2x27	2x27	2x90
Navy/FNMOC/NRL (USA)	3	3	3	tbd	tbd	tbd
CMC (Canada)	2.5	3.2	3.2	tbd	tbd	tbd
CPTEC/INPE (Brazil)	15	15	15	tbd	tbd	tbd
JMA (Japan)	2x0.7	2x0.7	2x0.7	tbd	tbd	tbd
CMA (China)	2.1	2.1(IBM) 5.0(SW2)	2.1(IBM) 5..0(SW2)	tbd	tbd	tbd
KMA (Korea)	2x0.7 2x0.7	1.4 2x7	2x7	2x7	2x7	tbd
NCMRWF (India)	2.5	2.5	tbd	tbd	tbd	tbd
BoM (Australia)	1.5	1.5	3	3	tbd	tbd

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WGNE Overview of Plans at NWP Centres with Global Forecasting Systems

Part II: Global Modelling

a) Deterministic Model (Resolution and number of layers)

Forecast Centre (Country)	2009	2010	2011	2012	2013	2014
ECMWF (Europe)	T_L799 L91	T_L1279 L91	T_L1279 L140	T_L1279 L140	tbd	tbd
Met Office (UK)	25 km L70	25 km L70	20 km L90	tbd	tbd	tbd
Météo France (France)	T799c2.4 L70	T799c2.4 L70	T1240c2.4 L90	tbd	tbd	tbd
DWD (Germany)	30 km L60	30 km L60	15 km L70	15 km L70	tbd	tbd
HMC (Russia)	T169 L31; 0.72°x0.9° L50	T169 L31; 0.37°x0.45° L50	T339 L63; 0.19˚x0.225˚L60	tbd	tbd	tbd
NCEP (USA)	T382 L64 (7.5) T190 L64 (16)	T878 L91 (7.5) T574 L91 (16)	25 km L90	25 km L90	25 km L90	25 km L90
Navy/FNMOC/NRL (USA)	T319 L36	T319 L36	T319 L36	T479 L60	T479 L60	T511 L64
CMC (Canada)	(0.45°x0.3o°) L80	(0.45°x0.3o°) L80	(0.45ox0.3o°) L80	(0.45°x0.3o°) L80	(0.3°x0.2°) L90	(0.3°x0.3°) L90
CPTEC/INPE (Brazil)	20 km L96	20 km L96	20 km L96	10 km L96	10 km L128	tbd
JMA (Japan)	T_L959 L60	T_L959 L60	T_L959 L60	tbd	tbd	tbd
CMA (China)	T_L639 L60 GRAPES 50 km L31	T_L639 L60 GRAPES 50 km L31	T_L639 L60 GRAPES 50 km L31	GRAPES 25 km L31	GRAPES 26 km L31	tbd
KMA (Korea)	T426 L40	40 km L50	25 km L70	25 km L70	25 km L90	tbd
NCMRWF (India)	T382 L64	T382 L64	tbd	tbd	tbd	tbd
BoM (Australia)	ACCESS ~80 km L50	~40 km L50	25 km L70	25 km L90	tbd	tbd

WGNE Overview of Plans at NWP Centres with Global Forecasting Systems

Part II: Global Modelling

b) Global Ensemble Prediction System (Resolution, number of layers, number of members, forecast range in days)

Forecast Centre (Country)	2009	2010	2011	2012	2013	2014
ECMWF **(Europe)**	T399/T255 L62; M 51; 15; change of res. at day 10	T639?? Resolutions to be determined	T639 Resolutions to be determined	T639 Resolutions to be determined	tbd	tbd
Met Office (UK)	~60 km L70; M24; 3	~60 km L70; M24; 3	~60 km L90; M24; 3	tbd	tbd	tbd
Météo France (France)	T358c2.4 L65; M30 4 days	T538c2.4 L65; M30; 4 days	T538c2.4 L65; M30; 4 days	tbd	tbd	tbd
DWD (Germany)	No EPS	~40 km L40; M20; 1	~40 km L40; M20; 1	~40 km L40; M20; 1	tbd	tbd
HMC **(Russia)**	T85 L31; M30; 10	(T85L31+ 0.72°x0.9°L28); M60; 10	(T85L31+ 0.72°x0.9°L28); M60; 10	tbd	tbd	tbd
NCEP **(USA)**	T190 L28; M88; 20/cycle; 16 days	T270 L42; M88; 20/cycle; 16 days	50 km L45; M88; 16	50 km L45; M88; 16	50 km L45; M88; 16	tbd
Navy/FNMOC/NRL (USA)	T119 L30; M20; 10.5	T239L30; M20; 16	T239L30; M20; 15	T319L40; M20; 16	T319L40; M20; 16	T319L40; M20; 30
CMC (Canada)	GEM (0.9°x0.9°) L58 M20 16	GEM (0.9°x0,9°) L58-80 M20 16	GEM (0.7°x0.5°) L58-80 M20 16	GEM (0.7°x0.5°) L58-80 M20 16	GEM (0.6°x0.4°) L58-80 M20 16	GEM (0.6°x0.4°) L58-80 M20 16
CPTEC/INPE (Brazil)	50 km, L42, M40; 15	50 km, L42, M50; 15	50 km, L42, M50; 15	40 km, L64, M60; 15	40 km, L64, M60; 15	tbd
JMA (Japan)	T_L319 L60; M51; 9	T_L319 L60; M51; 9	T_L319 L60; M51; 9	tbd	tbd	tbd
CMA **(China)**	T213 L31; M30 (BGM, 10)	T213 L31; M30 (BGM, 10) GRAPES 100 km L31; M15;10	T213L31; M30 (BGM,10) GRAPES 100 km L31; M15;10	GRAPES 50 km M15, 10	tbd	tbd
KMA (Korea)	T213 L40; M34; 17/cycle; 10	40 km L50; M25; 10	40 km L50; M25; 10	40 km L70; M25; 10	40 km L70; M25; 10	tbd
NCMRWF (India)	T126 L64; 8; 7	T126 L64; 16; 7	tbd	tbd	tbd	tbd
BoM **(Australia)**	T_L119 L9; M33	MOGREPS, ~80 km L50; M24	MOGREPS, ~60 km L70; M24	MOGREPS, ~60 km L90; M24	tbd	tbd

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Part II: Global Modelling

c) Global Data Assimilation Scheme (Type, resolution, number of layers)

Forecast Centre (Country)	2009	2010	2011	2012	2013	2014
ECMWF **(Europe)**	4D-Var; T_L799 with T255 final inner loop; L91	4D-Var; T_L1279 with T_L399 final inner loop; L91	4D-Var; T_L1279 with T_L399 final inner loop; L140?	4D-Var; T_L1279 with T_L399 final inner loop; L140?		
Met Office **(UK)**	4D-Var; 75 km; L70	4D-Var; 75 km; L70	4D-Var; 60 km; L90	tbd	tbd	tbd
Météo France **(France)**	4D-Var+ensemble; T350: L70	4D-Var+ensemble; T350; L70	4D-Var+ensemble; T350; L90	tbd	tbd	tbd
DWD **(Germany)**	3D-Var; 30 km; L60	3D-Var+ensemble; 30 km; L60	3D-Var+ensemble; 15 km; L60	3D-Var+ensemble; 15 km; L60	tbd	tbd
HMC **(Russia)**	T85 L31; M30; 10	(T85L31+ 0.72°x0.9°L28); M60; 10	(T85L31+ 0.72°x0.9°L28); M60;	tbd	tbd	tbd
NCEP **(USA)**	Advanced-Var; T382; L64	Advanced-Var; T878; L91	4D-Var; 22 Km	4D-Var; 22 km	4D-Var; 22 km	tbd
Navy/FNMOC/NRL **(USA)**	4D-Var T319L36 outer lp T119L60 inner lp	4D-Var tdb outer lp T119L60 inner lp	4D-Var tbd outer lp T159L60 inner lp	tbd	tbd	tbd
CMC **(Canada)**	Det: 4D-Var (1.5ox1.5o), (0.45ox0.3o) L80 EPS: EnKF M96(0.9°x0.9°)	Det: 4D-Var (0.9ox0.9o), (0.45ox0.3o) L80 EPS: EnKF M96 (0.9°x0.9°)	Det: 4D-Var (0.9ox0.9o), (0.45ox0.3o) L80 EPS: EnKF M96 (0.7°x0.5°)	Det: 4D-Var (0.9ox0.9o), (0.45ox0.3o) L80 EPS: EnKF M96 (0.7°x0.5°)	Det: 4D-Var (0.6°x0.45°), (0.3°x0.2°) L80 EPS: EnKF M96 (0.6°x0.4°)	Det?: 4D-Var (0.6°x0.45°), (0.3°x0.2°) L80 EPS?: EnKF M96 (0.6°x0.4°)
CPTEC/INPE **(Brazil)**	LETKF; 40 km	LETKF; 40 km	LETKF; 40 km	LETKF; 20 km	LETKF; 21 km	tbd
JMA **(Japan)**	4D-Var; T159; L60	4D-Var; T_L319; L60	4D-Var; T_L319; L60	tbd	tbd	tbd
CMA **(China)**	SSI GRAPES_3DVar 100 km; L31	SSI GRAPES_3DVar 50 km; L31	SSI GRAPES_3DVAR 50 km; L31	GRAPES_4DVAR 100 km;L61	tbd	tbd
KMA **(Korea)**	3D-Var; T106; L40	4D-Var; 75km; L70	4D-Var; 75km; L70	4D-Var; 75km; L71	tbd	tbd
NCMRWF **(India)**	3D-Var; T382; L64	3D-Var; T382; L64	tbd	tbd	tbd	tbd
BoM **(Australia)**	ACCESS; 4DVAR; 100 km; L50	4DVAR; 75 km L50	4DVAR; 75 km L70	4DVAR; 75 km L90	tbd	tbd

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Part III: Regional Modelling

a) Regional deterministic model (number of gridpoints, resolution, number of layers)

Forecast Centre (Country)	2009	2010	2011	2012	2013	2014
ECMWF (Europe)	-	-	-	-	-	
Met Office (UK)	600*360; 12 km; L70 768*960; 1.5 km; L70	600*360; 12 km; L70 768*960; 1.5 km; L70	600*360; 12 km; L90 768*960; 1.5 km; L70	tbd	tbd	tbd
Météo France (France)	600x512; 2.5 km; L60	800x800; 2.5 km; L60	800x800; 2.5 km; L60	tbd	tbd	tbd
DWD (Germany)	665x657; 7 km; L40 421x461; 2.8 km; L50	665x657; 7 km; L40 421x461; 2.8 km; L50	local zooming 421x461; 2.8 km; L50	local zooming 421x461; 2.8 km; L50	tbd	tbd
HMC (Russia)	168x300; 14 km; L40	680x640; 7 km; L40 500x500; 2.8 km; L50	680x640; 7km; L40 500x500; 2.8km; L50	tbd	tbd	tbd
NCEP (USA)	669x1165; 12km; L60 720x1011; 4 km; L50	943x823; 12km; L75 985x845; 4.5 km; L75 515x401 6 km;L75 3 km; L60	943x823; 12km; L75 985x845; 4.5 km; L75 515x401; 6 km;L75 3 km; L60	943x823; 12 km; L91 985x845; 4.5 km; L91 515x401; 6 km;L91 3 km; L75	1131x988; 10 km; L91 1182x1014; 3.5 km; L91 618x481; 5 km;L91 2 km; L75	1131x988; 10 km; L91 1182x1014; 3.5 km; L91 618x481; 5 km;L91 2 km; L75
Navy/FNMOC/NRL (USA)	27/9/3 km; L40	27/9/3 km; L50	9/3/1 km; L50	9/3/1 km; L60	9/3/1 km; L60	tbd
CMC (Canada)	15 km; L80 4 LAMs at 2.5km; L58	15 km; L80 4 LAMs at 2.5km; L58	10 km; L58 LAMs at 2.5km; L58	10 km; L58 LAMs at 2.5km; L58	10 km; L58 LAMs at 2.5km; L58	8km; L80 LAMs at 2.5km; L58
CPTEC/INPE (Brazil)	601x1201, 10 km; L50	601x1201, 10 km; L50	601x1201, 10 km; L50	1001x2101, 5 km; L80	1001x2101, 5 km; L80	tbd
JMA (Japan)	721x577; 5 km; L50	721x577; 5 km; L50	721x577; 5 km; L50	tbd	tbd	tbd
CMA (China)	550x330, GRAPES-15kmL31	550x330, GRAPES-15kmL60	1650x990, GRAPES-5kmL60	1650x990, GRAPES-5kmL60	tbd	tbd
KMA (Korea)	513x573; 10 km; L40	574x514 10 km; L38	574x514 10 km; L38	tbd	tbd	tbd
NCMRWF (India	27km, L38 9km, L38	27km, L38 9km, L38	tbd	tbd	tbd	tbd
BoM (Australia)	320x220; 37.5km L50 680x544; 12km L50	320x220; 37.5km L70 680x544; 12km L70	960x660; 12km L70 6 LAMs 600x600; 2km L70	960x660; 12km L90 6 LAMs 600x600; 2km L90	tbd	tbd
	6 LAMs 240x240; 5km L50	6 LAMs 240x240; 5km L70				

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Part III: Regional Modelling

b) Regional Ensemble Prediction System (Resolution, number of members, forecast range in days)

Forecast Centre (Country)	2009	2010	2011	2012	2013	2014
ECMWF (Europe)	-	-	-	-	-	
Met Office (UK)	16 km; M24; 2	16 km; M24; 2	16 km; M24; 2 1.5 km; M6; 1	tbd	tbd	tbd
Météo France (France)	25 km; M30; 4	15 km; M30; 4	15 km; M30; 4	tbd	tbd	tbd
DWD (Germany)	2.8 km; M20; 1	2.8 km; M20; 1	2.8 km; M40; 1	2.8 km; M40; 1	tbd	tbd
HMC (Russia)	No regional EPS	No regional EPS	tbd	tbd	tbd	tbd
NCEP (USA)	32 km; M21; 3.625	26 km; M25; 3.625	26 km; M25; 3.625	20 km; M25; 4	20 km; M25; 4	tbd
Navy/FNMOC/NRL (USA)	45/15 km; M10; 2	45/15 km; M20; 3	45/15 km; M30; 3	27/9 km; M30; 3	27/9 km; M30; 3	tbd
CMC (Canada)	No regional EPS	33 km L60 M20 48h	33 km L60 M20 72h	33 km L60 M20 72h	22 km L70 M20 72h	22 km L80 M20 72h
CPTEC/INPE (Brazil)	20 km; M21; 10	20 km; M21; 10	20 km; M21; 10	10 km, M21, 10	10 km, M21, 10	tbd
JMA (Japan)	T_L319 L60; M11; 4times/day; 5	T_L319 L60; M11; 4times/day; 5	T_L319 L60; M11; 4times/day; 5	tbd	tbd	tbd
CMA (China)	GRAPES 30 km; M15	GRAPES 30 km; M15	GRAPES 15 km;M30	GRAPES 15 km; M30	tbd	tbd
KMA (Korea)	No regional EPS	10 km; M20; 3	10 km; M20; 3	10 km; M20; 3	10 km; M20; 3	tbd
NCMRWF (India	No regional EPS	No regional EPS	No regional EPS	No regional EPS	tbd	tbd
BoM (Australia)	No regional EPS	MOGREPS; 24 km; M24; 3	MOGREPS; 24 km; M24; 3	tbd	tbd	tbd

WGNE Overview of Plans at NWP Centres with Global Forecasting Systems

Part III: Regional Modelling

c) Regional Data Assimilation Scheme (Type and resolution)

Forecast Centre (Country)	2009	2010	2011	2012	2013	2014
ECMWF (Europe)	-	-	-	-	-	-
Met Office (UK)	4D-Var, 24 km 3D-Var + LH nudging, 1.5 km	4D-Var, 24 km 3D-Var + LH nudging, 1.5 km	4D-Var, 24 km 4D-Var, 4 km?	tbd	tbd	tbd
Météo France (France)	3D-Var; 2.5 km	3D/4D-Var; 2.5 km	3D/4D-Var; 2.5 km	tbd	tbd	tbd
DWD (Germany)	nudging; 7 km nudging; 2.8 km	3D-Var + LETKF	3D-Var + LETKF	3D-Var + LETKF	3D-Var + LETKF	tbd
HMC (Russia)		nudging; 7km	nudging; 7km nudging; 2.8 km	tbd	tbd	tbd
NCEP (USA)	Advanced-Var; 12 km	Advanced-Var; 12/4.5 km	4D-Var; 12/6/4.5 km	4D-Var; 12/6/4.5 km	4D-Var; 10/5/3.5 km	4D-Var; 10/5/3.5 km
Navy/FNMOC/NRL (USA)	3D-Var; 27/9/3 km	3D-Var; 27/9/3 km	3D-Var / EnKF 9/3/1 L60	4D-Var / EnKF TBD	Hybrid 4D-Var / EnKF TBD	Hybrid 4D-Var / EnKF TBD
CMC (Canada)	Continental: 3D-Var 55 km L80	Continental: 3D-Var 55 km L80	Continental: 4D-Var 55 km L80 Local: 3D-Var 10 km L58	Continental: 4D-Var 55 km L80 Local: 3D-Var 10 km L58	Continental: 4D-Var 55 km L80 Local: 3D-Var 10 km L58	Continental: 4D-Var 25 km L80 Local: 3D-Var 8 km L80
CPTEC/INPE (Brazil)	LETKF; 20 km	LETKF; 20 km	LETKF; 20 km	LETKF; 10 km	LETKF; 10 km	tbd tbd
JMA (Japan)	4D-Var, 15 km	4D-Var, 15 km	4D-Var, 15 km	tbd	tbd	tbd
CMA (China)	GRAPES-3DVAR, 15 km	GRAPES-4DVAR, 15 km	GRAPES-4DVAR, 15 km	GRAPES-4DVAR, 15 km	tbd	tbd
KMA (Korea)	3D-Var 10 km	4D-Var 30 km	4D-Var 30 km	4D-Var 30 km	4D-Var 30 km	tbd
NCMRWF (India	3D-Var	3D-Var	tbd	tbd	tbd	tbd
BoM (Australia)	ACCESS; 4DVAR; 75km; ACCESS; 4DVAR; 36 km; L50	4DVAR; 75 km; L70 4DVAR; 36 km; L70	4DVAR; 36 km; L70	4DVAR; 36 km; L90 3DVAR; 6 km; L90	tbd	tbd