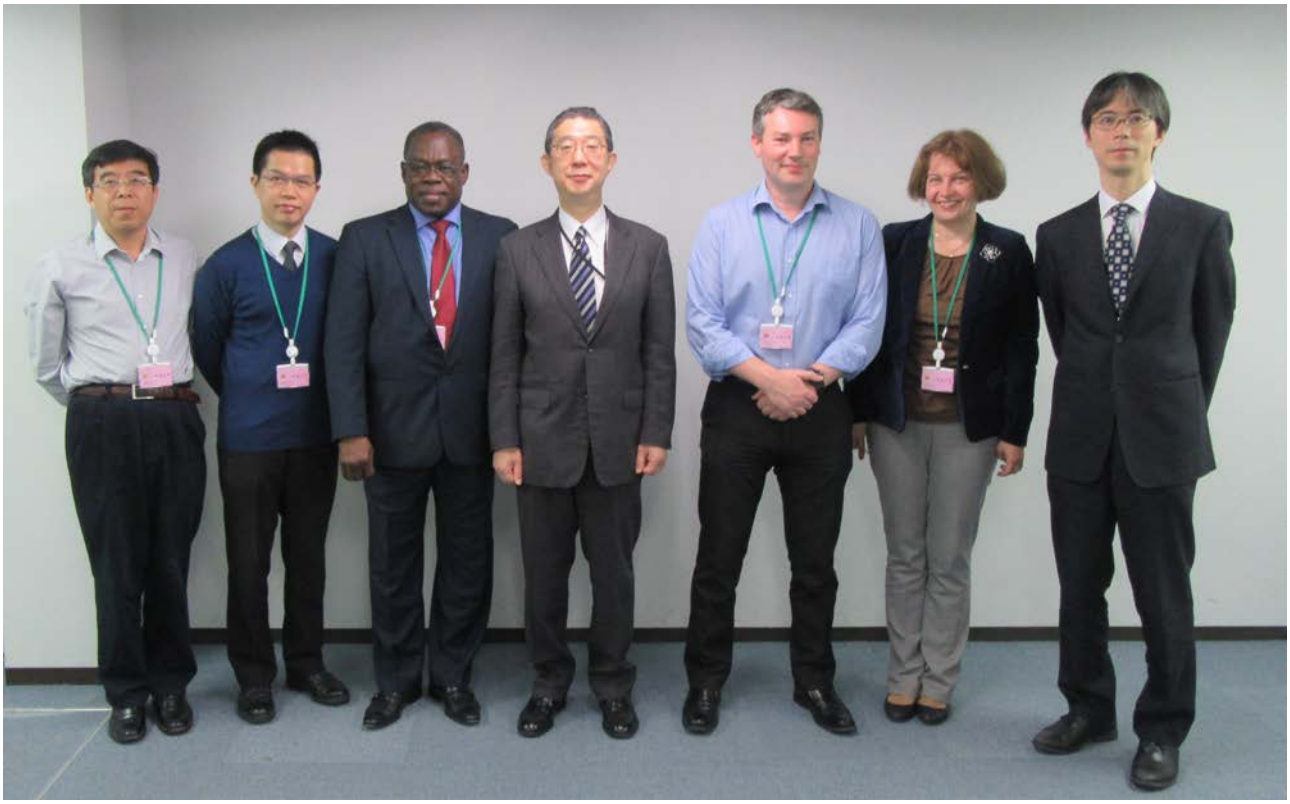
WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS

TASK TEAM ON THE DEVELOPMENT OF GUIDELINES ON HIGH-RESOLUTION NWP

Tokyo, Japan, 6-8 April 2016

DRAFT REPORT



Yuejian Zhu, Wai Kin Wang, Abdoulaye Harou, xx, Douglas Boyd, Inna Rozinkina, Yuki Honda

EXECUTIVE SUMMARY

The meeting of the CBS Task Team on the Development of Guidelines on High-Resolution NWP (TT-LAM)) was held from 6 to 8 April 2016, in Tokyo, Japan. The TT reviewed the ToRs and the outlines of the guidelines and provided more detailed elements to be covered.

GENERAL SUMMARY OF THE WORK OF THE SESSION

1. OPENING

1.1 The meeting of the CBS Task Team on the Development of Guidelines on High-Resolution NWP (TT-LAM) opened at 9:30 AM on 06 April 2016, at Japan Meteorological Agency Headquarters.. After a tour de table of participants to introduce themselves, the Chair, Mr Yuki Honda, invited Mr Mr Sekita, the new Director General of Forecast Department, representing Dr Hashida, Director general of Japan Meteorological Agency to provide his opening his opening remarks. Following Mr Sekita's remarks, Mr Abdoulaye Harou, Chief Data-Processing and Forecasting System was invited to provide also his opening remarks on behalf of the WMO Secretary General, Mr Petteri Taalas.

1.2 Mr Yasuo Sekita welcomed the participants and highlighted the importance of the work of the Task Team and the commitment of JMA to fully contribute. He explained that technical progress in numerical weather prediction is significant over the past few decades and the short-range to seasonal forecasting and warning services absolutely rely on outputs of the NWP systems. This is also facilitated with the availability of high-performance computers and community NWP models**.** He noted that it may not be easy for all Members to take full advantage of such advanced science and technology, thus, the importance of the development of guidance to assist Members in harnessing the use of high-resolution NWP.

1.3 Mr Sekita also highlighted the expertise of JMA in the use of NWP suites since 1959. JMA is one of advanced NWP centers. He also recalled the role of JMA in supporting Members in Regional Association II for many years as RSMC for geographical specialization, through the provision of NWP products and participating in SWFDP as global center. He concluded by he expressed his sincere appreciation to the WMO Secreatariat and its Data-Processing and Forecasting Division (DPFS) for the great support provided to this Task Team activities.

1.4 Mr Harou also welcomed the participants to the meeting and expressed Mr Taalas's appreciation to the Government of Japan for agreeing to host this event in the beautiful City of Tokyo. He recalled, that, noting the accuracy and usefulness of NWP depend critically on the quality and reliability of all observational data and other information for both NWP data-assimilation and for verification of forecast products, the World Meteorological Congress in 2011 (Cg-16) requested the Secretary-General and CBS to develop a strategy to assist Members in the implementation of improved high-resolution regional NWP including data assimilation. The Task Team on the development of guidelines on high-resolution NWP was created to address this Cg-16 request. He pointed out that the work of this TT is important in many ways: It will assist with nowcasting forecasting as well as building one of the bridges to Seamless Data-Processing and forecasting which Cg-17 (2015) asked CBS to work on. Mr Harou noted that the outlines of the guidelines was developed and that the task on hand is to populate the various sections of the guides and recalled that Cg-17 was eager to see the guidelines completed as soon as possible and published for the benefit of Members. He concluded by thanking the participants for their commitment to this work.

2. ORGANIZATION OF THE MEETING

2.1 Adoption of the agenda

2.1.1 The meeting adopted the provisional agenda (see Annex I) without change. The list of participants is available in Annex II.

2.2 Working arrangements

2.2.1 All documents submitted for the meeting are referenced and hyperlinked in the Documentation Plan (INF. 1), which had been posted on the WMO website at:

http://www.wmo.int/pages/prog/www/DPFS/Meetings/TT-LAM_Tokyo2016/DocPlan.html

2.2.2 The Task Team agreed on its hours of work and other practical arrangements for the meeting. It was agreed that the meeting will start at 9:00 am and finish at 5:30pm with two 30 minutes coffee breaks (in the Morning and Afternoon) and a lunch around noon for 1h30.

3. INTRODUCTION

3.1 Outcome of WMO Constituent Body Session related to High-resolution NWP Aspects

3.1.1 Mr Harou presented the organigram (Annex IV) of the Outcome Programme Area Group on Data-Processing and Forecasting System (OPAhG-DPFS) and highlighted where the TT-LAM fit. The Team noted that the organigram was the result of discussion at the February 2016 meeting of the CBS Management Group (CBS-MG) which also decided to add to the OPAG on DPFS, the Inter-Programme Team on Space Weather Information System and Service (IPT-SWISS). Four Expert Teams (ETs) compose the OPAG-DPFS with a number of Task Team. This ETs are ET-Operational Weather Forecast Process and System (ET-OWFPS); ET-Operational Prediction from Sub-seasonal to Longer time Scale (ET-OPSLS), ET-Emergency Response Activities (ET-ERA) and the the above IPT-SWISS.

3.1.2 Mr Harou then summarized the various decisions of the Constituent Bodies and of the ET-OWFPS related to the work of this Task Team. The Team noted that it was the request of Cg-16 as described in para 1.3 which triggered the creation of this TT-LAM. It also noted that the ET-OWFPS meeting in 2014 has also identified the following additional Experts to address the following aspects of the guidelines: André Methot (Canada) as a core member for all aspects; Yuejian Zhu (USA) for global post-processing, Pierre Eckert (Switzerland) for the use and interpretation and, Paul Davie (UK) for application on Impact. He underlined the requirement of Cg-17 (2015) to complete the guidelines and distribute to Member as soon as possible. In addition he highlighted the requirement of Cg-17 for the Secretary General and CBS to explore possibilities for setting up Regional Limited Area Model (LAM) Consortium to facilitate access to high-resolution NWP while building capacity of participating member through training and development assignments.

3.2 Terms of reference of the Task Team

3.2.1 The Team discussed the ToRs in light of the directives from Congress. It also considered that the targets audience is the Mangers and technical staff of NMHSs working in the modelling area. Based on these considerations, it has reviewed the ToR as per the Annex IV

4. GENERAL DISCUSSION ON THE GUIDELINES ON HIGH-RESOLUTION NWP

4.1 Review of the outline

4.1.1 The team decided to proceed first with defining the elements of the strategy for the implementation of high-resolution NWP to guide the review of the outline of the guide. The result of the work on the strategy is provided in a table in Annex V.

4.2 Contribution by participants

4.2.1 Dr Hamza Kabelwa presented on their NWP system. He informed the team that they have acquire an IBM cluster in 2013 and they are able to use WRF, at high resolution, operationally, over Lake Victoria. They have also acquire acquired COSMO model in the effort to increase the number of operational models in TMA. The objective is to run COSMO operationally after a successful connection to their national optical fibre. The team learned that they have 10 people working in the NWP area and they are aiming at being able to perform Data Assimilation.

4.2.2 Dr Inna presented on the Consortium for Small-scale Modeling (COSMO) whose goal is to develop, improve and maintain a non-hydrostatic limited-area atmospheric model for both operational and for research applications by the members of the consortium. The Consortium is responsible for the development and maintenance of the NWP application. The team noted that the COSMO model allows for three different applications, namely: a) a convection permitting NWP; b) Aerosols and Reactive Trace gases (ART) and c) Regional, high resolution climate simulation. It also noted that training and support are part of the package and that Dutcher Wether Dienst (DWD) provides boundary conditions. It also noted that the fee for full Membership is in the range of 20,000 Eu per year.

4.2.3 Dr YueJian Zhu (USA) presented on the North America Ensemble Forecasting (NAEFS) Statistical Post Processing. The team learned that Canada, US and Mexico signed the agreement in 2004 to exchange global ensemble system on a real time (Canada and US Systems). The system entered into initial operating capability (IOC) in 2006. In February 2006, forecast products were generated based on the joint ensemble. Before combining the forecasts from the two centers, each set of forecast will undergo a statistical post-processing procedure, reducing their systematic errors. Finally, the NAEFS generates enhanced weather forecast products. Probability forecasts are now produced at 5 km resolution. Decay methods versus reforecast showed that the decay method is weaker during the change of season as it accumulates wrong information.

4.2.4 Dr Zhu indicated that the NAEFS system will accelerate research and development by sharing the research and development tasks among the participating countries allowing more new methods to be tested. He ensured that this system will increase the rate of improvements both in the area of ensemble forecasting, and the generation and use of weather forecast products resulting in the improvement of forecast skills by increasing ensemble members when applying post-processing techniques such as: a) Bias Correction (Statistic) done for each variable, each lead-time and each forecast cycle on point wise basis; b) Dual-resolution (hybrid) Ensemble combining the bias corrected GEFS products with the bias corrected forecast from NCEP's high resolution deterministic integration (GFS, currently TL1534L64) with forecast lead-time dependent weights; c) statistical Downscaling to provide forecast guidance at local scale. Real Time Mesoscale Analysis (RTMA, Pondeca and et al, 2011), which generates real time hourly analysis at NDFD (5km for CONUS, 2.5km later on) resolution, is used as the reference for downscaling; d) Frequency Matching Calibration use for precipitation calibration. An adaptive (Kalman Filter type) algorithm has been used to accumulate past information for calibration; e) 2nd moment justification using Ensemble Kernel Density MOS (EKDMOS)

method to improve second moment calibration by using spread-skill relationship; g) Improvement of Statistical Post-Processing (SPP) using GEFS reforecast to enhance exist GEFS bias corrected forecast.

4.2.5 Mr Wa Kin Wong (Hong Kong Observatory) provided and overview of their high performance computing (HPC) systems in supporting NWP applications and mesoscale modelling. He indicated that the Hong Kong Observatory (HKO) has been operating several forecasting systems on high performance computing (HPC) clusters to support public weather forecasts and warning services. Currently, there are two main Linux based HPC clusters with peak performance of 18.7 and 12 TFLOPS respectively used for running the operational mesoscale NWP model system with 3-dimensional data assimilation system based on the Non-Hydrostatic Model (NHM) adapted from the Japan Meteorological Agency; and the fine-resolution Aviation Model (AVM) based on the Weather Research and Forecasting (WRF) model. The HPC cluster of the mesoscale NWP model system also provides an integrated computing environment for model pre-processing, model product generation, post-processing application and verification, as well as to support the research development of NWP modelling. The team noted that to maintain a stable operating environment, high availability features in various hardware, internal network interconnect between the computing nodes and software components are implemented, and maintained by a team of in-house staff with technical support from the HPC supplier.

4.2.6 Mr Wong also reported that to supporting various forecast applications, a multi-model approach is used by combining available NWP model data to generate a seamless integration of forecasts up to 10 days ahead. In particular, a system called the Objective Consensus Forecast (OCF) following Engel and Ebert (2007)[1] has been developed. The hourly forecast time-series of temperature, wind speed and wind direction, dew point and relative humidity, and daily minimum and maximum temperatures up to 240 hours ahead are generated based on an ensemble of post-processed outputs from NHM, global deterministic model forecasts from ECMWF, JMA, NCEP and CMA, as well as EPS from ECMWF. Probabilistic rainfall forecasts and time series of weather icons are developed using ECMWF EPS and the deterministic models above. Moreover, based on OCF, the "Automatic Regional Weather Forecast" (ARWF) service (http://maps.weather.gov.hk/ocf/) has been made available for the public since late 2013 with continuing improvement.

5. DEVELOPMENT OF AN EXPANDED OUTLINE OF THE GUIDELINES

5.1 Following the development of the strategy for the implementation of high-resolution NWP, the team reviewed the outline of the guidelines and identified elements to consider under each section. It has also identified the Lead Expert who will develop the section. The team agrees that, if necessary, the Lead Expert could request some support from other team members or other experts who may have expertise in the area of concern. The revised outline with lead Experts of the sections is provided in Annex VI.

[1] Engel C. and E. Ebert, 2007: Performance of hourly operational consensus forecasts (OCF) in the Australian region. Wea. Forecasting, 20, 101-111.

Annex I

AGENDA

1. OPENING OF THE MEETING

2. ORGANIZATION OF THE MEETING
- 2.1 Adoption of the agenda
- 2.2 Working arrangements

3. INTRODUCTION
- 3.1 Outcomes of WMO Constituent Body sessions related high-resolution NWP aspects
- 3.2 Terms of Reference of the Task Team

4. GENERAL DISCUSSION ON THE GUIDELINES ON HIGH-RESOLUTION NWP
- 4.1 Review the outline
- 4.2 Contribution by participants

5. DEVELOPMENT OF AN EXPANDED OUTLINE OF THE GUIDELINES

6. ASSIGNMENT OF RESPONSABILITIES AND TIMELINE FOR FURTHER DEVELOPMENT OF THE GUIDELINES

7. ANY OTHER BUSINESS (AOB)

8. CLOSURE OF THE MEETING

Annex II

LIST OF PARTICIPANTS

Name	City & Country	E-mail address	Remarks
PARTICIPANTS			
Mr André **METHOT**	Montréal, Canada	andre.methot@ec.gc.ca	**Absent**
Mr Wai Kin **WONG**	Hong Kong, China	wkwong@hko.gov.hk	
Mr Yuki **HONDA**	Tokyo, Japan	honda.yuuki@met.kishou.go.jp	
Ms Inna **ROZINKINA**	Moscow, Russian Fed.	inna.rozinkina@mail.ru	
Mr Pierre **ECKERT**	Zurich, Switzerland	pierre.eckert@meteoswiss.ch	**Absent**
Mr Hamza **KABELWA**	Dar es Salaam, Tanzania	hamza.kabelwa@meteo.go.tz	**Absent- presented remotely**
Dr Douglas **BOYD**	Exeter, UK	douglas.boyd@metoffice.gov.uk	
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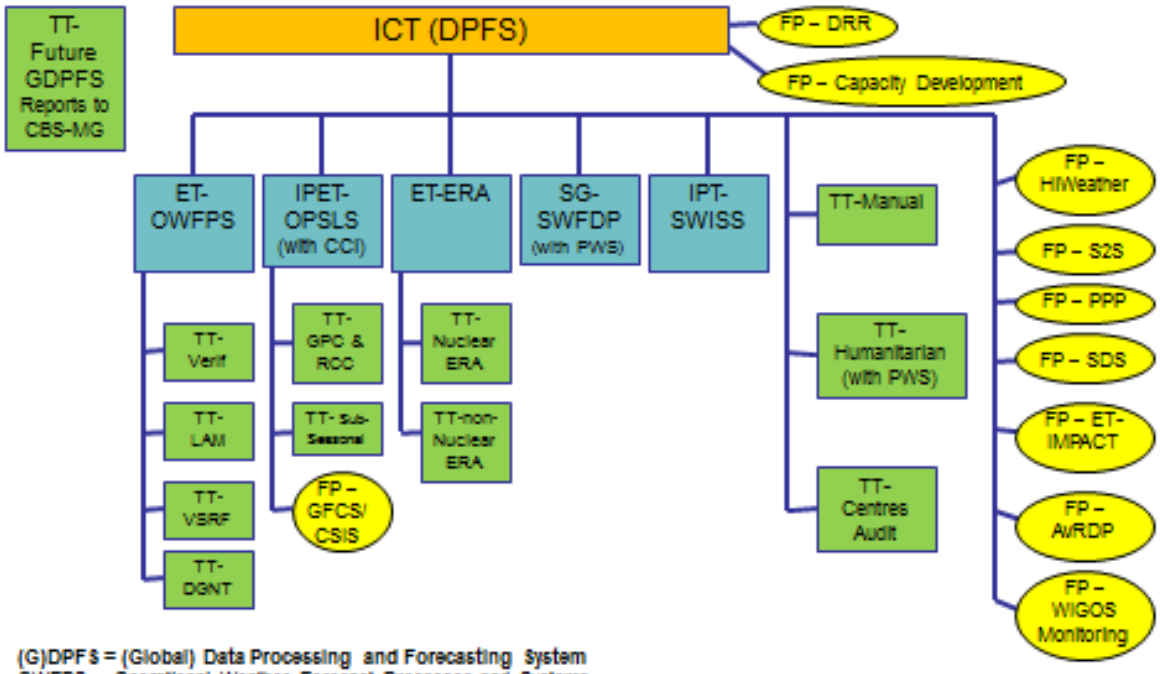
STAFF			
Mr Abdoulaye **HAROU**	Geneva, Switzerland	aharou@wmo.int	

Annex III

OPAG-DPFS Structure



(G)DPFS = (Global) Data Processing and Forecasting System
OWFPS = Operational Weather Forecast Processes and Systems
OPSLS = Operational Prediction from Sub-Seasonal to Longer Timescales
ERA = Emergency Response Activities
SWFDP = Severe Weather Forecasting Development Project
SWISS = Space Weather Information Systems and Services
DRR = Disaster Risk Reduction
VSRF = Very Short Range Forecast (including Nowcasting)
DGNT = Development of Guidelines for Nowcasting Techniques

Annex IV

Terms of Reference

The Task Team shall:

- Develop a strategy for improving access to high-resolution NWP and implementing limited-area models in order to improve high-impact weather forecasting and service delivery;
- develop guidelines to assist Members with improved access to high-resolution NWP products and implementation of high-resolution regional NWP and publicize them as WMO publication;
- summarize information on high-resolution global and regional NWP that is available to Members ;
- Coordinate with other TTs under ET-OWFPS to ensure synergies and consistency in developing guidelines.
- consolidate information on current modelling and data assimilation techniques of high-resolution regional NWP models, and their research developments.

Annex V

Strategy for the Implementation of High-Resolution NWP based on the capacity of NMCs

- Level 1 – Best use of NWP products from global/regional NWP centres
  - The purpose is to get the benefit of the advanced science and technology.
  - This is in consideration of global NWP systems going into finer resolution such as 10km…
  - Use of pictorial products as well as raw digital data
  - Statistical downscaling
- Level 2 – Downscaling regional model implementation
  - The purpose is to add benefit beyond the performance of global NWP products.
  - dynamical downscaling
- Level 3 – Regional NWP including Data Assimilation
  - The purpose is to improve the initial fields.
  - Key observations: surface data, radar data, ground-based GNSS, aircraft data…
  - Regular steps
    - 1. Adopt and setup appropriate assimilation system
    - 2. Monitor quality of observation
    - 3. Evaluate the impact of observation
- Level 4 – Regional EPS
  - The purpose is to capture the uncertainty.

Resources	Level 1	Level 2	Level 3	Level 4
Minimum Human Resource	(NWP, Soft Engineer) 1-2 FTEs (IT) 1-2 FTEs	(NWP) 3-5 FTEs (SE) 1-2 FTEs (IT) 2-3 FTEs	(NWP) 5-7 FTEs (Remark: additional 2FTEs for DA and QC) (SE) 2-3 FTEs (IT) 2-3FTEs	(NWP) 7-9 FTEs (Remark: additional 2FTEs for ENS system and Applications) (SE) 2-3 FTEs (IT) 2-3 FTEs
Computer Resource	Workstations	HPC Cluster with performance to produce T+36 hour forecasts within two hours.	HPC Cluster with performance to produce T+36 forecasts within two hours.	HPC Cluster with performance to produce T+36 hour ensemble forecasts within two hours.
Communication Network	Broad enough to obtain pictorial products and global NWP data sufficient for post-processing.	Broad enough to obtain NWP grid data for initial and boundary conditions within one hour.	Additional capability to obtain local observation data (which are not available on WIS/GTS reliably.)	Possible additional capability to obtain grid data of ensemble members for boundary conditions.
Storage Resource				
Modelling System				
Data Assimilation	None	None	Nudging, 3/4DVar Land surface analysis	None(Downscale), 3/4DVar, EnKF, Hybrid DA
Forecast Model	None	Convection-permitting Model - Optimal nesting configuration – Direct nesting from global model or through intermediate model. - Note) The resolution of grid data of available global model tends to be	Convection-permitting Model	Convection-permitting Model

		finer (-0.25degree) - Note) Relationship with a Member provision global NWP data to obtain highest resolution grid data. - Note) Communication infrastructure should accommodate the transfer of grid data within appropriate time period. Option) 10km Limited-area model - May need to be implemented because the time interval and space resolution of available global NWP data is not sufficient to drive Convection permitting model - Difficult to obtain benefit rather than global NWP data.		

Applications				
Post Processing	Diagnostic variables Site-specific BC	In addition… Grid-point BC	In addition… - Downscale based on high-density observation - Downscale based on high-resolution analysis - Blending with nowcasting to produce VSRF	Calibration of probabilistic forecasts to improve the reliability.
Verification				
Service & Products	Fundamental meteorological information to support forecasting operations and to provide guidance of severe weather.	- Enhanced support to forecasting operations and services to users. - Specialized customer products	- Further enhanced support in terms of severe weather forecasting and warnings. - Enhanced support to forecasting operations and services to users. - Specialized customer products with more local feature.	- Impact-based forecast and Risk-based warning - Probabilistic information representing forecast uncertainties (EFI and anomaly forecasts)
Notes				

Annex VI

Guidelines Sections development and Lead Experts
Expected # of pages 15-20pp

Sections	Lead Experts
1. Introduction - Background - Scope - Target Audience	**Yuki**
2. Concept of high-resolution NWP - 10km scale global NWP products - Convection permitting model (1-5km)	**Yuki/Andre**
a) Components of NWP (a) Resources ① Human resources 1. NWP – Scientists – Develop NWP system and Applications 2. Software Engineer – Install and Maintain NWP systems and Applications 3. IT – Setup and Maintain HPC and Communication Network ② Computer resources ③ Communication network ④ Storage resources (Data Archiving) (b) Modelling System ① Data Assimilation 1. Collection of Observation Data What is element to be considered? 2. Quality Control of Observation Data 3. Data Assimilation (Analysis) ② Forecast Model (c) Applications ① Post Processing ② Verification	**(a) Douglas** **(b)(DA) Yuki;** **(Fcst) Wai Kin** **c) Yuejin**
4. Use and interpretation of high-resolution NWP model (a) General aspects (and difference in techniques) as compared to using global NWP output (b) Best practices on usage of high-resolution NWP model products	Pierre/Inna

(c) Post-processing techniques (d) Online training materials - COMET MetEd, eumetcal, COSMO tutorial, GSI & WRF tutorial, DTC (UCAR) (e) Verification and usability of the NWP models (f) (f) Deal with Uncertainty (EPS)	
5. Application of high-resolution NWP in forecast of severe weather (and warning services?) (a) Integration with forecasts from global NWP and EPS (b) Blending with nowcasting system (c) Involve another partner in application (d) Integration with decision-making process	**(a)(b) Wai Kin** **(c)(d) Paul/Haleh**
6. Strategy See "Strategy.docx" - limited computer resources (focus on use and interpretation, post-processing techniques and verification; Running regional NWP in off-line / R&D basis for benefits of understanding of weather processes and improving the forecast techniques) - with small size computer (need to define in terms of number of processing cores ?) and limited number of staff - with middle size computer (HPC cluster?) [strategies for the above two types of NHMSs may include recommended approach or common method/practices in setting up the model and data assimilation system (DAS), sensitivity tests and tuning, etc]	**Douglas**
7. Implementation of (high-resolution) regional NWP model and DAS (a) Identify the goals and purpose (b) Required Resources (Computer / Human / Financial / Training) (c) Technical considerations • Choice of model, DAS and EPS. • Data assimilation techniques • Verification • Maintenance for operational (24/7) • Boundary and initial conditions (coordination with global NWP centres if necessary)	**Hamza**
Annex to Ch6 : Where to find further information on regional	

NWP model and data assimilation system (DAS)	
How to collect information? What information should be collected? Information related to the High-Resolution NWP below will be available through links to home sites of these NWP: (a) ALADIN / AROME (b) LACE (c) COSMO Consortium (d) CMC RDPS (e) CMA GRAPES (f) HIRLAM / HARMONIE (g) JMA NHM (h) NRL COAMPS (i) UKMO UM (j) WRF-ARW and WRF-NMM (k) Other regional NWP models with model developers'/community support and applied for severe weather forecasts (e.g. CreSS ?)	

Annex VII

Recommended Considerations for access to high-resolution and implementation of NWP

- Global NWP centres to provide a standard (to be defined) set of forecast products via an accessible web portal (must be useful to Members on low bandwidth) and possibly satellite dissemination, e.g. Eumetcast.
    - Review the additional products in the new Manual (e.x. product list of SWFDP)
- Global centres to take efforts to make native Global resolution available to members (rather than downgraded to lower resolution).
    - This is for post-processing at centers.
- Members to make efforts to put high-quality sustainable local obs onto WIS/GTS so that Global centres can assimilate these to improve Global forecasts.
- Members to keep number of regional NWP models run to a minimum to focus resource.
- Members to avoid running regional NWP at resolutions coarser than Global driving model resolution. Focus on adding benefit relative to Global forecasts.
- Consult modelling capability guidelines (criteria to be defined) to check whether funding/resource/sustainability criteria for running NWP are met.
- In cases where Global centre is providing driving data, Members to ensure that their network infrastructure is capable of timely data transfers.
- Recognise effort required for adoption of a new NWP system, e.g. minimum ~5 FTE required over 2 years, with additional effort and infrastructure required for data assimilation and ensembles.
- Recognise additional resource (staff and obs infrastructure) required for beneficial data assimilation – must demonstrate improvement over downscaler and local in-region obs gathering/ingestion.
- Recognise additional resource (staff & HPC) required for running a scientifically robust regional ensemble locally and developing probabilistic products that are useful to forecasters/public.
- Local post-processing specific to the region may be applied/required to add value to raw model output.
- Build relationships with civil authorities and emergency responders to improve severe weather alerts and response to severe weather.
- Members to employ CBS standard verification methods to measure forecast skill.
- Apply verification methods appropriate to the model resolution and availability of obs (to be consulted with TT-Verification) .
- Suggest minimum level of trialling for model upgrades? E.g. 1 month at different times of year, e.g. Summer, Winter
- Recommend upgrading modelling systems regularly, e.g. at least every 5 years?
- Strengths and weaknesses of regional model forecasts to be fed back by Member to the model owning Member.
- Ensure regular backups of system are made. Operational resilience by having 2 physically separate clusters. Archive minimum set of model parameters (set to be defined, e.g. u,v winds, temp, RH) for defined length of time to build up local database.
- Members to ensure their NWP staff are trained in running the chosen model (by model owner?) and their forecasters are trained in interpretation of model output, e.g. via SWFDP.
- A HPC is supposed to have capability of conducting R&D.

Annex VI

Annex VII

Timelines for the completion of the Guidelines

- **Manual of GDPFS …recommend information to ET for additional list of products Global deterministic NWP products to be made available on the WIS….(discussion on the strategy)…to ET-OWFPS for CBS agreement.**
- **Global centres to make efforts to make native Global resolution available to members (rather than downgraded to lower resolution)**
- **Member to avoid running regional NWP…(CBS)**
- **In order to avoid Duplication of requests for information from WGNE (for their Blue book) and DPFS requests. Suggest to point to DPFS information for common information and for WGNE to request only the missing information they are interested in.**
- **Collection of GDPFS information to be based on CPDP.. (CBS)**
- **Consideration is for completion of running NWP within 3 hrs for 72 hrs**
-