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SAHF Numerical Weather Prediction Working Paper

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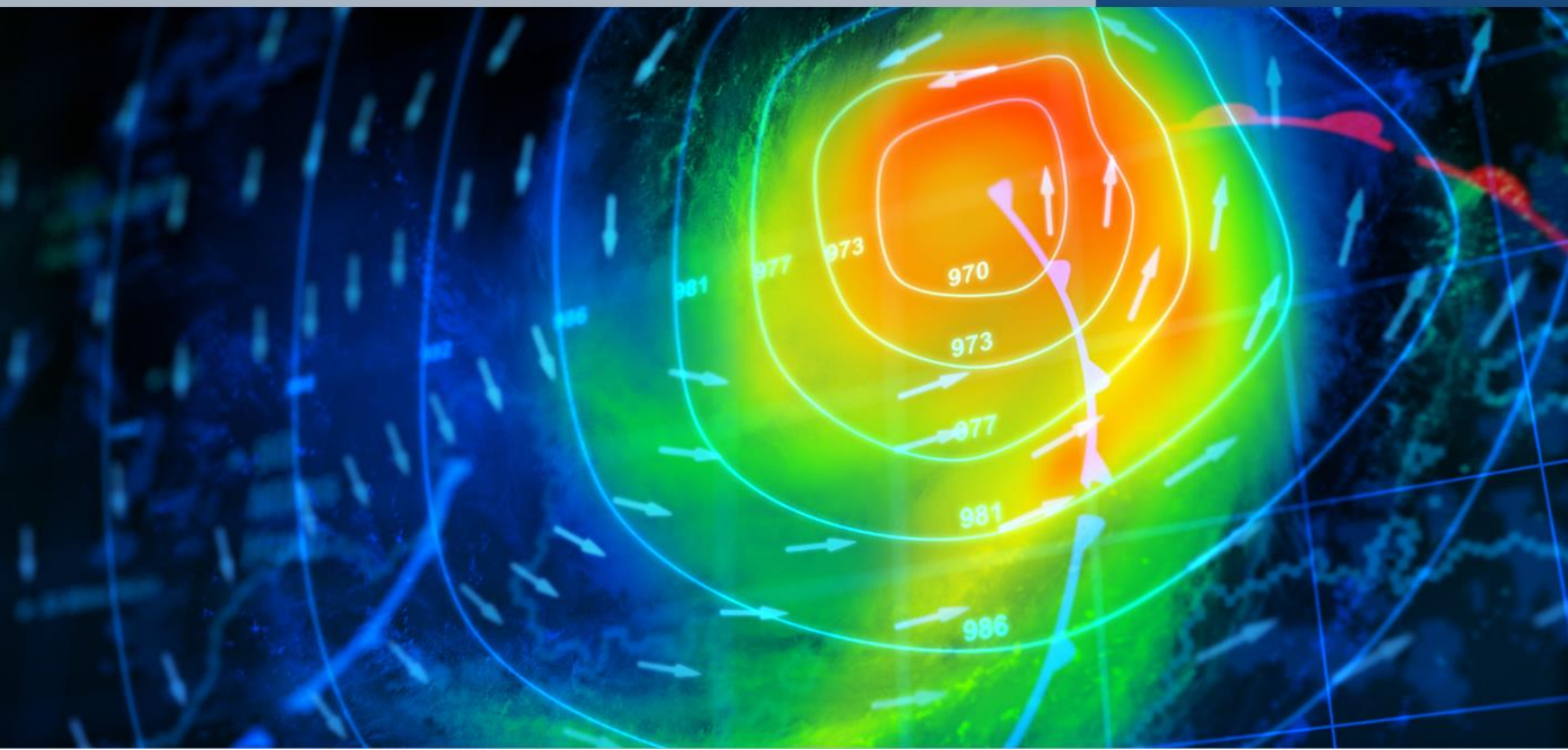

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The information regarding Afghanistan, including analysis and data, reflect the situation in the period before July 2021.

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CONTENTS

LIST OF TABLES AND FIGURES

ACRONYMS

ADCIRC	Advanced Circulation Model
AI	Artificial Intelligence
AIRS	Atmospheric Infrared Sounder
AMD	Afghanistan Meteorological Department
ARRCC	Asia Regional Resilience to a Changing Climate
AWLS	All Weather Landing System
AWS	Automatic Weather Station
BANCCA	Bangladesh National Center for Climate Applications
BMD	Bangladesh Meteorological Department
CE	Capacity Enhancement
DATAEX	Data Exchange Platform by RIMES
DIANA	Digital Analysis
DMH	Department of Meteorology and Hydrology
DSS	Decision Support Systems
ICON	Icosahedral Nonhydrostatic
DWR	Doppler Weather Radar
ECMWF	European Centre for Medium-Range Weather Forecasts
EMSWRF	Environmental Modeling System Weather Research and Forecasting
EPS	Ensemble Prediction System
EWA	Early Warning Advisory
FFGS	Flash Flood Guidance System with Global Coverage
FMI	Finnish Meteorological Institute
FTP	File Transfer Protocol
GEFS	Global Ensemble Forecast System
GFS	Global Forecast System
GIS	Geographic Information System

GLOF	Glacial Lake Outburst Flood
GTS	Global Telecommunication System
HPC	High Performance Computing
HRRR	High-Resolution Rapid Refresh
IITM	Indian Institute of Tropical Meteorology
IMD	India Meteorological Department
INCOIS	Indian National Centre for Ocean Information Services
JMA	Japan Meteorological Agency
KMA	Korea Meteorological Administration
LAM	Local Area Model
METCAP	Meteorological Communication and Application Package
ML	Machine Language
MME	Multi-model Ensemble
MMS	Maldives Meteorological Services
MOS	Model Output Statistics
NCEP	National Centers for Environmental Prediction
NCHM	National Center for Hydrology and Meteorology
NCMRWF	National Centre for Medium Range Weather Forecasting
NMHS	National Meteorological and Hydrological Services
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
NWP	Numerical Weather Prediction
PMD	Pakistan Meteorological Department
RADAR	Radio Detection and Ranging System.
RTC	Regional Training Center
SA	South Asia
SAHF	South Asia Hydromet Forum
SCOPE	South Asia Consortium for data and weather Predictions
SMARTMET	Software Tool for Visualizing and Editing Meteorological Data

SNCCA	Sri Lanka National Center for Climate Applications
SOP	Standard Operating Procedure
SWAN	Simulating Waves Nearshore
SWFP	Severe Weather Forecasting Programme
TAF	Terminal Aerodrome Forecast
TOR	Terms of Reference
WARF	Weather Research and Forecasting Model
WB	World Bank Group
WBG	World Bank Group
WG	Working Group
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting

Executive Summary

The high-impact weather events such as extreme temperature days and heavy rainfall are increasing all over South Asia and yearly their probability of occurrence is on rise. Timely and accurate forecasts when contextualized with localized sector wise risk knowledge delivered appropriately to responders can not only save lives, but also guide emergency management and mitigation of impacts and prevent economic losses.

Therefore, skillful operational Numerical Weather Prediction systems are one of the most relevant components of routine and severe weather forecasting and warnings at National Meteorological and Hydrological Services (NMHSs). However, the capability among NMHSs in weather forecasting varies enormously and more so in the South Asian region. Except India Meteorological Department and Pakistan Meteorological Department, most SAHF NMHSs, do not have dedicated NWP teams represented by at least five or more well trained operational NWP personnel. Adequate induction level and mid-level training is lacking in most countries, as a result capacities to interpret and use a range of global and regional NWP products is very limited. Use of NWP for operational forecast generation is generally limited to rainfall and temperature graphics. No Standard Operation Procedures(SOPs) or standardized guidance manuals are in place for forecasters to enable best practices and maximal utilization of available NWP products in a national context for the different critical seasons. DIANA (developed and promoted by Met Norway), METCAP+, SMARTMet and SYNERGY systems are all being used as graphical interfaces in different NMHSs of the region. However, lack of basic and mid-level NWP training seems to be a barrier in maximization of the range of model diagnostics made available by these platforms.

SAHF, under the guidance of the Executive Council, brings together nine Asian countries: Afghanistan, Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Pakistan and Sri Lanka. It has the overarching objective to reinforce national activities leading to a more sustainable program of building state-of-the-art meteorological and hydrological services across the region through a structured and staggered approach. This is achieved through the guidance of the SAHF Executive Council and its thematic Working Groups to strengthen the key elements of the hydro-meteorological services by leveraging regional collaboration while enhancing national capacities to fully meeting user requirements. Among the most

immediate and specific priorities are the improved forecasts of extreme events, both in terms of intensity and lead time anticipation, using ensemble prediction systems, impact-based forecasting, and user-specific advisory services. Thus, the main purpose of this working paper is to present the existing capacities and needs of NMHSs with regard to NWP and contextualize them within the domain of global and regional resources and advances in NWP and prioritize regional activities that will complement and reinforce national capacities in NWP.

Moving ahead, efforts of SAHF will focus on the following:

- Training and development of SAHF Knowledge Hub to allow training, access, and use of global and regional NWP products.
- Initiating ensemble prediction system (EPS) based probabilistic forecasts for the region.
- Support for sectorial impact-based forecasting and decision support tools.
- Capacity building and training of NMHS personnel.
- Region research and development in NWP and climate extremes.

1. Introduction

The probability of occurrence of high-impact weather events such as extreme temperature days and heavy rainfall are increasing all over South Asia on a regional scale. Timely and accurate forecasts when contextualized with localized sector wise risk knowledge delivered appropriately to responders can not only save lives, but also guide emergency management and mitigation of impacts and prevent economic losses. Progress in tropical cyclones monitoring, prediction and early warnings developed with close involvement of stakeholders like disaster management authorities have demonstrated beyond doubt the substantial benefits, that far outweigh the costs of investing in the targeted scientific research, super-computing facilities, satellite and other modern observing systems that are essential to produce high-quality forecasts at regional level.

Globally, the emphasis is on implementing increasingly sophisticated and diverse numerical models interfaced with application tools for local scale impact assessment with risk informed warning to serve the ever-increasing variety of demands of different user sectors. Over the past 4-decades, international NWP centers periodically increased computer power to enable the improvement of their overall forecast skill by:

- capturing details through high spatial resolution (horizontal and vertical)
- issuing short-range predictions more frequently (4-cycles; 00/06/12/18 UTC runs) with non-hydrostatic meso-scale horizontal resolution of less than 5Km grid scale,
- improving data assimilation (directly measured radiance assimilation)
- instituting ensemble forecasting
- increasing the sophistication of parameterized physical processes (e.g., clouds - precipitation processes and turbulences); higher order planetary boundary layer scheme; land surface/snow/vegetation treatment
- extending forecasts to sub-seasonal or seasonal (from 2 weeks to 9 months), and
- reforecasting to allow more accurate statistical post-processing.

For example, at NCEP, USA a hybrid isentropic–sigma vertical coordinate that minimizes cross coordinate vertical transport and related numerical diffusion has been applied on an experimental basis resulting in demonstrable improvements in tropical processes. Physical parameterizations to capture sub grid-scale features has become more sophisticated enabling higher horizontal resolution up to 1–3 km, currently being tested. Increased vertical resolution of the models has enabled better representation of boundary later processes, explicit cloud variables and frontal zones r leading to an overall improved NWP accuracy due to more realistic control fluxes of heat, moisture, and momentum between Earth's/ocean surface and atmosphere.

NWP centers like the Indian National Centre for Medium-Range Weather Forecasting and India Meteorological Department (IMD) have also dedicated resources towards shorter-range

regional models with higher resolution with more sophisticated parameterizations of sub-grid scale processes. Regional models of have upgraded to much finer horizontal resolution regional models, driven by global model data across the lateral boundaries, in the recent years providing improved precipitation fields, orographic and coastal effects, and explicit representation of clouds and near-surface details. As of 2018, many NWP centers including IMD have started running these non-hydrostatic models over regional domains at horizontal resolution below 5 km, defined as convection-allowing models (CAMs). Operational NWP systems have added assimilation of available radar reflectivity and cloud ceilometer and satellite-based retrievals of cloud layers.

Observations of air chemistry and the ocean and coastal environments are facilitating development of Numerical Environmental Weather Prediction (NEWP) systems. New satellite instruments [e.g., high spectral-resolution sounders such as AIRS and the infrared atmospheric sounding interferometer (IASI); also, Earth-observing system instruments] have provided a wealth of information on the chemical state of the atmosphere as it relates to regional and urban air quality.

SAHF brings together nine countries: Afghanistan, Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Pakistan, and Sri Lanka, with the overarching objective to reinforce national activities through a regional approach leading to a more sustainable program of building state-of-the-art meteorological and hydrological services. This is achieved through the guidance of the SAHF Executive Council and its thematic Working Groups, SAHF endeavors to strengthen the key elements of the hydro-meteorological services by leveraging regional collaboration while enhancing national capacities to fully meeting user requirements. Among the most immediate and specific priorities are the improved forecasts of extreme events, both in terms of intensity and lead time anticipation, using ensemble prediction systems, impact-based forecasting, and user-specific advisory services.

Skillful operational NWP systems are therefore, one of the most relevant components of routine and severe weather forecasting and warnings at National Meteorological and Hydrological Services (NMHSs). However, the capability among NMHSs in weather forecasting varies enormously and more so in the South Asian region. The more advanced NMHSs are making use of the progress in NWP, but those in the developing and least developed countries have seen little advancement due to limited infrastructures and skilled human resources. SAHF's scope is to expand encompassing all systems operated by SAHF Member states to collectively leverage regional capacities to improve Hydro met services delivery focused on managing risks due to weather and climate hazards. It needs to enable SAHF Members to make use of the advances in NWP by providing a framework for sharing data related to operational meteorology, hydrology, ocean state, climate, and multi-hazards. In addition, it shall be aimed at mitigating the growing technological gap in weather forecasting by building and operating a sustained regional cooperative mechanism for knowledge transfer, skill development, service delivery enhancement and user specific product customization. All necessary common support systems integration for accomplishing all envisaged targets under SAHF shall be built by RIMES under the guidance of the SAHF Executive Council (EC) and its thematic WGs.

2. Objective

This working paper on NWP has the following objectives:

- To present the existing capacities and needs of NMHSs with regards to NWP and contextualize them within the domain of global and regional resources and advances in NWP.
- Prioritize regional activities that will complement and reinforce national capacities in NWP.

3. Approach and process

As a first step, the Working Groups (WG) for four thematic areas (Numerical Weather Prediction (NWP), Impact Based Forecasting (IBF), Observational Networks (ON), Capacity Enhancement (CE)) of SAHF were established by the SAHF Executive Council. The first WG meeting for the thematic area NWP was held on 28 June 2021, where a preliminary stocktaking of existing capacities and needs of NMHSs took place (see Annex 1 for the meeting report). A review of all existing reports that document operational prediction process and capabilities of SAHF countries was also carried out. This included the recent assessments conducted in 2017 by the World Bank Group experts (Kootval & Soares, 2021).

Following this, individual consultations with WG members of each NMHS of SAHF member countries was carried out to have an in-depth understanding of the status in four thematic areas concerning: existing capacities, available operational systems, gaps in current operational procedures, access to various datasets, challenges faced in sustaining operations, priorities for improvements and availability of human and technical resources (see Annex I and III). Additionally, an online survey was conducted from September to October 2021, which covered not only the WG members but also the staff from the NMHSs working at various levels (see Annex IV for the survey results). The survey collected information on existing capacities, gaps and needs in the four SAHF thematic areas.

In November 2021, SAHF III was organized that brought together the NMHSs of SAHF member countries, regional partners and experts, international partners and experts, and users in the region. The forum identified several needs to improve the capacities of SAHF NMHSs in operational services delivery and recognized capacity development as the backbone for improving services. The needs that were identified and recommended during SAHF III were considered in the stocktaking process. The summary of needs ensued from the SAHF III is given as Annex V.

4. Present scenario of NWP

Afghanistan: AMD issues public weather forecasts based on data accessed via METCAP+, which includes the GFS (22 km resolution) model freely available from the Internet and a cloud model from ECMWF. No operational NWP systems in place.

Bangladesh: WRF is run on multiple servers forced by Global Forecast System (GFS) model, NCEP, NOAA, at 9 and 18 km resolutions for operational NWP products. Finer resolutions like 1 km and 3 km are also being tried for specific locations. One of the WRF systems is directly connected to the DIANA visualization interface to assist operational forecasters.

Bhutan: Local Area Model, the Environmental Modeling System Weather Research and Forecasting (EMSWRF) version 3.4 installed by Finnish Meteorological Institute (FMI in 2015) is being used as the operational NWP for the daily weather forecast generation at 3 km horizontal resolution with lead time of 3 days. GFS, NCEP, NOAA is the driving global model for the LAM. The operational model is run 4 times every 6 hours at 00, 06, 12 and 18 UTC every day to generate high resolution forecasts at 3 km spatial scale. No systematic verifications with standard metrics.

India: Is the only country in the region running two operational global modelling systems for NWP products. IMD Global Forecast System (GFS), adopted from National Centre for Environmental Prediction (NCEP) at T1534 (~ 12 km horizontal resolution over the tropics) with global data assimilation generates forecasts up to 10 days, twice daily at 00 UTC and 12 UTC. The National Centre for Medium Range Weather Forecasting (NCMRWF) Unified Model (NCUM) from the UKMet Office is the other global modelling system generating ~12 km forecast products from 00UTC and 12UTC initial conditions for next 10 days. Besides these both centers also run LAMs at 9 and 3 km resolutions over the South Asian domain. Hurricane WRF is operationally run at IMD whenever a tropical cyclone is anticipated in the region. For ocean state and marine forecasts, the INCOIS has implemented Ocean Models (POM)/Hybrid co-ordinate ocean model (HYCOM) with real time data of SST over Indian Seas.

Maldives: At MMS, the operational WRF model runs at 27 km, once a day, on a large domain covering East to West of the Indian Ocean and 35S and 30 N. The model simulation is done once initialized with 12 UTC NCEP GFS 0.5 data. There is another version of the model that runs 9km as well. Both are currently used to support the operational forecast. MMS intends to expand computing resources further for generating higher-resolution products and services. With the support from the Italian government, access to operational wave model data is also available.

Myanmar: Since Jan 2021, DMH has a full access to ECMWF outputs at the highest resolution and JMA NWP products. Currently running 30 km WRF with 3-day lead time run once day.

Nepal: WRF version 4.1.2 run at 9 km and 3 km resolutions. No systematic verifications exist at national or subnational levels.

Pakistan: Mainly use China Meteorological Agency's GSM-CMA (30 km) Global Spectral Model, GFS-NOAA/NCEP (22 km) and Deutscher Wetterdienst DWD ICON (Icosahedral Nonhydrostatic) model at 13 km resolutions.

Sri Lanka: Operationally the WRF model is run for a domain over Sri Lanka at 9 km horizontal resolution with GFS (0.25 km) 3 hourly data, twice a day using 00 & 12 UTC initial conditions to produce 5-day forecasts. In addition, DoM has licensed access to high resolution ECMWF forecast datasets.

4.1 Critical Assessment and Issues:

Most operational NWP product generation in NMHSs of the region is through Limited Area Models (LAM)s (or meso-scale) systems, excepting India, where two global modelling systems are operational. Despite the diversity of freely available LAM systems, the Weather Research and Forecasting (WRF) developed by National Centre for Atmospheric Research (NCAR), USA is the operational system for most NMHSs in the region. Ease of access, installation, training and documentation support have contributed to popular adoption of WRF as preferred work-horse for operational NWP in the region. Driven by the requirement for providing forecasts at relevant sub-national scales, most MNHSs run a single cycle of WRF at ~9 km resolution to produce deterministic NWP products without any local data assimilation. Future needs are generally to increasing spatial resolutions to about 1 km, running additional operational forecast cycles (already being done in some countries), running storm surge models and marine forecasting models for waves watch, local data assimilation, in particular radar data and access to digital data from global centers like ECMWF. Plans also include regular generation of standard verification stats and evaluation of WRF over the country domain, but lack of human resources and better computational facilities seem to the main barriers. Operational NWP systems need systematic archival and retrieval of the generated data and clear protocols for which variables at what frequencies need to be archived for future verification and evaluation requirements, but no such plans exist in any of the NMHSs, including IMD or NCMRWF.

Most SAHF NMHSs, except IMD and PMD, do not have dedicated NWP teams represented by at least five or more well training operational NWP personnel. Adequate induction level and mid-level training is lacking in most countries, as a result capacities to interpret and use a range of global and regional NWP products is very limited. Use of NWP for operational forecast generation is generally limited to rainfall and temperature graphics. No SOPs or standardized guidance manuals are in place for forecasters to enable best practices and maximal utilization of available NWP products in a national context for the different critical seasons. DIANA (developed and promoted by Met Norway), METCAP+, SMARTMet and SYNERGY systems are all being used as graphical interfaces in different NMHSs of the region. However, lack of basic and mid-level NWP training seems to be a barrier in maximization of the range of model diagnostics made available by these platforms. Also, it may be beneficial for NMHSs in the region to adopt a unified graphical interface platform so that future development and customization for region and country specific needs can be undertaken in a cost-effective manner. This will also help porting of a wider range of global NWP and

Satellite products besides regional relevant data set such as radar mosaic, merged rainfall and regional re-analyses etc.

There is an awareness and expressed need for ensemble forecasts. Deterministic forecasts have been shown to have limited skill beyond three days, particularly the sought-after quantitative rainfall forecasts, perceived as the most useful variable by user sectors.

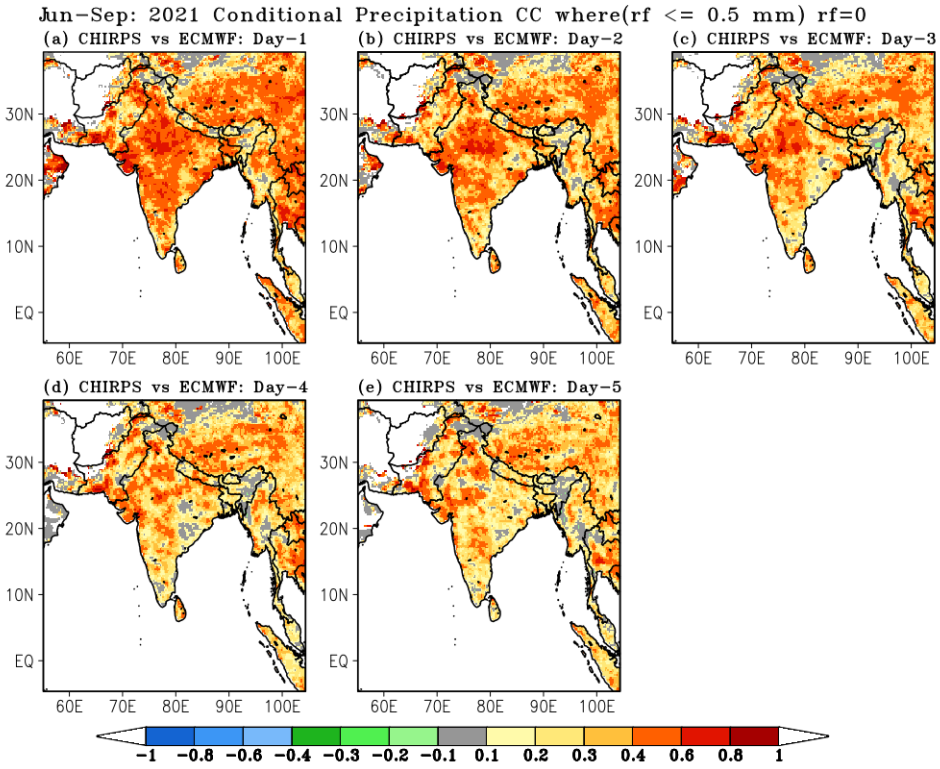

Figure 1: Correlation Coefficients (CC) of seasonal precipitation over South Asia based on the CHIRPS and ECMWF day-1 to day-5 Forecast data sets of JJAS 2021

The precent area of the region above 0.6 CC falls rapidly beyond three days. As seen from the efforts of NMHSs in the region, they have strived to implement high resolution deterministic forecasts in their operational NWP systems. Such an approach has however severe limitation when forecast information is to be used in user sector contexts for decisions to manage risks. To overcome this limitation, there has been a shift towards “probabilistic forecasts” that account for imperfections in the initial conditions leading to uncertainty of NWP products. Therefore, there is an immediate need for introducing operational probabilistic forecasts based on Ensemble Prediction Systems (EPS) within all the SAHF countries to strengthen the hydro-met services delivery value chain. Implementing such a system will require capacity enhancement of NMHSs personal, besides access to computational platforms and voluminous data pooled from global, regional, and national centers to be processed with analytic tools for national customized requirements. Taking a regional approach to EPS will therefore be significantly beneficial for SAHF.

4.2 Severe weather requirements

The value of the SAHF initiatives is not limited to severe weather forecasting but also supporting strongly towards day-to-day routine weather forecasting. Moreover, it plays an important role in harmonizing the day-to-day forecasts of the NMHSs for SAHF regional partners. Participating NMHSs must increase their lead-time for alerting users up to 15-days as well as improving their ability to anticipate and forecast all severe weather events.

All the efforts will reinforce forecasters' confidence in issuing warnings with due element of advocacy and communication skills to users. All efforts will focus on enhancing recognition of NMHSs value added services from the disaster management and civil protection agencies with whom they keep interacting from now on even more closely. Also ensure NMHSs are benefitted from an anticipated better public image, and the status and enhanced visibility they will gain shall surely support and enhance national investment in Early Warning Systems. It is through SAHF that the RIMES intend to strongly assist NMHSs in building effective relationships with users, including emergency preparedness and emergency response authorities.

5. Way Forward

Sustenance NWP development issues of concern to be addressed are:

Computational affordability will continue to be a constraint, given that a sizeable proportion of the cost of producing a forecast is associated with data assimilation and finer and finer horizontal and vertical resolution.

Future assimilation systems need to include atmospheric composition (aerosols, trace gases) as well as ocean, land surfaces and sea-ice. Each Earth-system component has process characteristics and space–time scales and dealing with those in a fully unified data assimilation framework will be extremely challenging.

Enhancing capacities in the region to produce global ensemble forecasts using all operationally accessible ensemble datasets and providing South Asia NMHSs with access to all this resources. This can be achieved through a SAHF-Cloud that is gradually built by scaling-up a network of computational platforms. Such a SAHF system shall endeavor to prepare the region to meet the challenges associated with access and customization of EPS to specific country needs and bring together in-country expertise to focus on their extreme weather early warning requirements.

SAHF will be also required to undertake synergizing all the available academic strengths within the region to address specific R & D requirements. At country level, research foci could be developed to specific issues of national and regional importance such as severe storms, Tropical cyclones, marine and coastal hazards etc.

5.1 SAHF Knowledge-Hub

SAHF can build an integrated regional platform to make all agreed products available to support national services through applications related to weather, climate, water and multi-hazards. Further, enabling scientific and technological advances made in meteorology and related fields to be shared as efficiently and effectively as possible among the SAHF member states shall be the focus of SAHF activities. Hence, under SAHF umbrella, all service delivery needs of digital forecast product access and exchange of information shall be served through operating Knowledge Hub and SAHF Knowledge-Hub platform.

The activities, organizational structure and operations of the RIMES SAHF Knowledge Hub platform shall be designed in accordance with the needs of NMHSs and their ability to contribute to, and benefit from, the system. The envisaged platform shall have a three-level system with various functions carried out interfacing: 1) medium range and Ensemble Prediction product access from ECMWF and IMD, 2) regional scale multi-hazard warning from Regional Specialized Meteorological Centres (RSMCs), and Regional Climate Centres (RCCs) and short-range forecasts from NMHS levels. The 3) Data EX component of the Knowledge Hub will facilitate cooperation and exchange of information, thereby also contributing to building capacity amongst all SAHF countries.

The accuracy of forecast products at all the 3-levels shall have to be monitored by objective verification procedures (figure below). The goal is to provide consistent standardized verification of the forecast products from very short range (from 6-hrs) to extended range (15-days) so that sub-national scale users and stakeholders of SAHF member states can make best use of products and NMHSs can identify opportunities for improvement. The non-real-time functions of the SAHF platform include long-term storage of observations, products and verification of results for operational and research use.

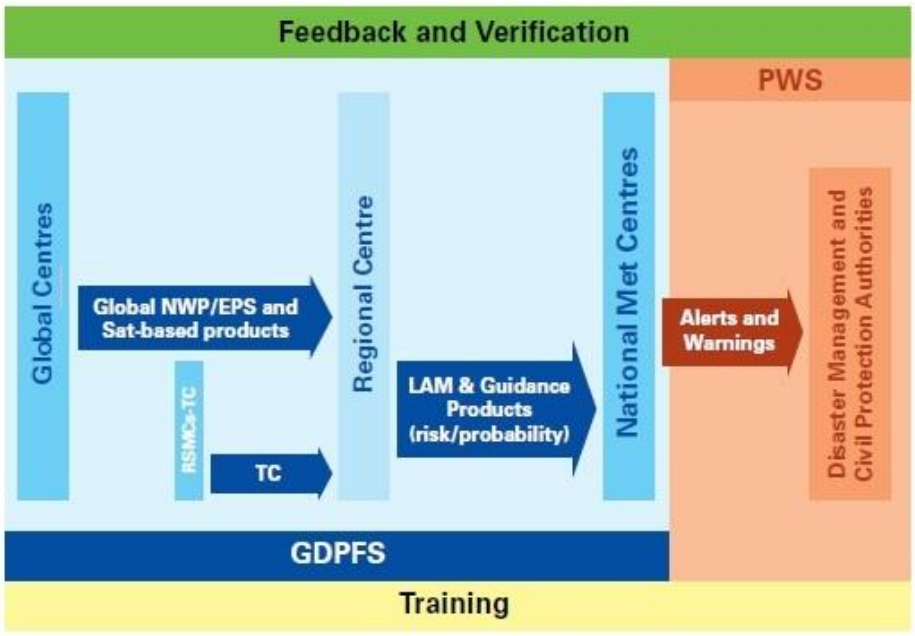

Figure 2: The Cascading Forecasting Process (Source: WMO Bulletin Vol 62 (2) - 2013)

5.2 Initiating EPS based probabilistic forecasts for the region

It is planned to generate and host multi-model probabilistic prediction products associated with the severe weather development for the SAHF region from the ensemble prediction products from India to provide access through SAHF Knowledge-Hub platform. Priority efforts will be made to build a framework of MME so as to support generation of probabilistic forecast of extreme precipitation and temperature (maximum and minimum) by utilizing 21 member GEFS forecast being generated at IITM/IMD and 23 member NEPS-G forecast being generated at NCMRWF. In addition, efforts also include development of value-added products to support sectorial IBFs.

5.3 Support for sectorial IBF & Decision support tools

The effective use of NWP and ensemble systems also requires the application of complex model-output post-processing systems to generate forecast products to support severe weather forecasting. Efforts to be made to provide all necessary sophisticated products (maps of potential instability, convection indices, etc.) to forecasters.

All activities under SAHF shall leverage and consolidate gains made under the Severe Weather Forecasting Program (SWFP) initiated by WMO.

The SWFP was initiated to make the NWP, including EPS, products of the most advanced GDPFS Centres available to all WMO Members. Using a Cascading Forecasting Process, the SWFP makes global-scale products available to Regional Specialized Meteorological Centres (RSMC) that integrate and synthesize them to provide daily guidance for short-range and medium-range forecasts of hazardous weather conditions and weather-related hazards to NMHSs in their geographical region.

SAHF approach endeavours strengthening such Cascading Forecasting Process further, by integrating and synthesizing global-scale products of ECMWF, IMD and NCMRWF available to SAHF regional use to provide daily guidance for short-range and medium-range forecasts of hazardous weather conditions and weather-related hazards to NMHSs in their geographical region.

The current effort under SAHF umbrella contributes to capacity building by helping SAHF member states to access and make use of all necessary NWP products for improving hazardous weather warnings. It encourages operational forecasters to use relevant standard or newly developed products and procedures to render IBF along with appropriate service delivery enhancements. The primary aim is to demonstrate how best to advance cooperative work program among operational meteorological centres of SAHF. The focus will be to enhance the forecasting and service delivery processes of several types of severe weather phenomena, which in turn improve the warning services provided by the NMHSs. The expected outcomes from the planned and combined efforts of other thematic areas now include:

- Enhanced capability for NMHSs to forecast severe weather and issue warnings with improved accuracy with longer lead-times at sub-national level (very short range to monthly and seasonal prediction products).

- Establishment of warning mechanisms as per the needs of national disaster management and civil protection authorities, along with effective responses for protection of lives, life line infrastructure and property by making anticipated impacts understandable for action through risk loading of extreme event forecasts.

Building of sectoral application services with Quality Management Systems (QMS), and strengthened forecast capabilities in support of critical and weather sensitive user sectors in society (agriculture and food security, aviation, marine safety and transportation, water resources, public health, air quality, environment etc.) at the sub-national level by the sectoral agencies for risk management and reduction involving Decision Support Systems(DSSs).

6. Capacity building and training

The SAHF activities shall be implemented in close collaboration with various WMO activities such as Public Weather Services (PWS) Programme to improve severe weather forecasting and warning services to extend the range of applications and broaden the benefits to other user sectors in society.

Near real-time verification and evaluation, based on observations of meteorological parameters collected at local meteorological stations and information gathered on the impacts of the severe weather phenomena will be supported by the SAHF Knowledge-Hub platform. The comprehensive performance evaluation of the cascading process, including the quality of the NWP/ EPS and guidance products, are provided as feedback to ECMWF, IMD and NCMRWF to further fine-tune the systems and products.

Training and capacity development of NMHSs personnel is a critical component of the SAHF initiative and is carried out on scheduled activity basis as depicted in the CE working paper. Forecasters need to know how to make optimal use of the various products coming from the SAHF regional platform. Training is also carried out in service delivery principles and practices including user focus, communication skills and user satisfaction assessment.

7. Regional Research & Development

Research and Development in NWP should focus on specific extreme weather events such tropical cyclone, coastal flooding, mountain meteorology, etc. involving academic and R&D institutes of South Asia. Equal priority also to be accorded for public-private engagement for co-development of service delivery application tools involving efficient science and technology advancements for the accelerated capacity enhancement of NMHSs and associated user agencies.

The Indian Institute of Tropical Meteorology (IITM), Pune, India is a leading research centre with dedicated research groups on various aspects of NWP. Substantial R & D capacities in universities and academic institutions exist in India in institutions such as Andhra University, the Indian Institute of Technology, Delhi and the Cochin University. Nepal's Tribhuvan University has a research group in its Meteorology Department, while in Bangladesh academic centres have been recently established in the Dhaka University.

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Annex I – Country-Level Assessment of NWP Capacities

Table 1: Gaps and needs in NWP in the SAHF member countries

Country	Gaps	Flagged immediate Needs	Priorities for implementation
Afghanistan/ AMD	• No WRF • Lack of skills for NWP • Lack of computing systems • Open Web GFS product resolution is coarse.	• High resolution modelling • MME and High-Resolution models required. • No operational WRF/LAM models being run at AMD • Support for synoptic forecasting; Aviation services; GIS tools	• Data Ex to provide digital Web-GIS product access to medium, extended, monthly and seasonal forecast products of ECMWF • 3 km scale short range Meso-scale products from IMD shared through SAHF Knowledge-Hub • Customization of DSS tools for Drought and Agriculture Advisory services (through interfacing Dept of Agriculture and Animal Husbandry) • MME products of Extended range anomalies will be generated and shared through SAHF Knowledge-Hub • Expand the use of FFGS products for Flood Forecasting • Augmentation of Aviation Met Service tools
Bangladesh/ BMD	• Robust NWP system – currently a clutter of WRF versions, approach for effective use of global forecast data & LAM runs made at BMD • Marine meteorological products for vulnerable coastal areas • Coastal inundation models and better surge prediction models	• Missing components of BMD WRF system assimilation of local observations (particularly radar data) • Ensemble prediction for probabilistic forecasts, and • Systematic verification, model bias correction for location-specific forecasts. • Dedicated NWP Group and skilled manpower to improve NWP • Archival for operational NWP data • Ocean state forecasts and other allied applied systems	• Residual needs of NWP beyond World Bank funded activities will be taken up • 3 km scale short range Meso-scale products from IMD shared through SAHF Knowledge-Hub Web-GIS integration • DWR and AWS data assimilation and support for operating High Resolution Rapid Refresh (HRRR) WRF at 1 km resolution • Augmentation of Marine Meteorological Services involving coupled model products; Coastal hazards and inundation forecast services - Through development of analysis and visualization tools using Ocean State Forecast and coastal hazard products of INCOIS

Country	Gaps	Flagged immediate Needs	Priorities for implementation
			• Multi-model Ensemble products access and utilization for improved operational severe weather prediction services • Tropical cyclone surge models coupled with coastal inundation models
Bhutan /NCHM	• Lack of data assimilation • Limited skill to run WRF model	• Medium Range Forecasting & Extended Range Forecasting System (ERFS) access to NCMRWF in addition to IMD products • Nowcasting for Aviation Forecasting	• Data Ex to provide digital product access to medium, extended, monthly and seasonal forecast products of ECMWF • 3Km scale short range Meso-scale products from IMD shared through SAHF Knowledge-Hub Web-GIS integration • Multi-model Ensemble products access and utilization for improved operational severe weather prediction services • AWS data and simulated reflectivity assimilation and support for operating HRRR WRF at 1Km resolution • Augmentation of Aviation Met Service tools
India/IMD	• State level User sector application tools for anticipation of local impacts - Public Health; transport; river basin water resource management; multi-hazard risk management • Limited use of IBFS • Limited Urban Flood EWSs • Improved Nowcast tools	• Modelling of hydro-meteorological hazards within an integrated framework • Grand Global Ensemble or Multi-model ensemble from various deterministic and probabilistic forecast • Use of NWP in IBFS	• Sectorial application tools of RIMES will be customized using IMDs forecasts for various states of India as prioritized by IMD • Hierarchical physical, socio-economic and infrastructure/attribute data will be interfaced with geospatial analytics as per the hazard specific IBF tools • Urban watershed scale hydrological frameworks will be customized for various cities

Country	Gaps	Flagged immediate Needs	Priorities for implementation
Maldives/ MMS	• Limited access to High Performance Computing Capacity • Limited skills for NWP	• Capacity to support HPCs in long term • High resolution run in WRF with data assimilation • (NWP training needs included)	• Augmentation of Marine Meteorological Services involving coupled model products; Coastal hazards and inundation forecast services - Through development of analysis and visualization tools using Ocean State Forecast and coastal hazard products of INCOIS & ECMWF • DWR and AWS data assimilation and support for operating HRRR WRF at 1Km resolution
Myanmar/ DMH	• Limited IT knowledge • Lack of modelers	• Nowcast • Wave Model- Sea condition forecast and Marine Forecast • 3 days forecast at district level • Utilization of ECMWF and other global data for NWP models	• Residual needs of NWP beyond World Bank funded activities will be implemented • Data Ex to provide digital product access to medium, extended, monthly and seasonal forecast products of ECMWF • DWR and AWS data assimilation and support for operating HRRR WRF at 1Km resolution • Augmentation of Marine Meteorological Services involving coupled model products; Coastal hazards and inundation forecast services - Through development of analysis and visualization tools using Ocean State Forecast and coastal hazard products of INCOIS • Multi-model Ensemble products access and utilization for improved operational severe weather prediction services • Tropical cyclone surge models coupled with coastal inundation models

Country	Gaps	Flagged immediate Needs	Priorities for implementation
Nepal/DHM	• Lack of data assimilation • Limited skill for NWP	• Forecast Verification System • Data Assimilation • Optimization and customization of NWP Model • Products for Aviation and Transportation • Nowcasting • Medium Range Forecast (Demand for Agriculture Sector) • Planning for Ensemble Prediction System [Meso Scale] • Single Platform for all products to facilitate forecasters • on the job training in NWP specialized centers	• Residual needs of NWP beyond World Bank funded activities will be implemented • Data Ex to provide digital product access to medium, extended, monthly and seasonal forecast products of ECMWF • DWR and AWS data assimilation and support for operating HRRR WRF at 1Km resolution • Augmentation of Aviation Met Service tools • Customization of DSS tools for Drought and Agriculture Advisory services (through interfacing Dept of Agriculture and Animal Husbandry)
Pakistan/PMD	• Limited skill for NWP pertaining to new recruits	• General processing of numerical models • Assimilating various available data for forecasts • Validation of NWP models	• DWR and AWS data assimilation and support for operating HRRR WRF at 1Km resolution • Tools for Bias correction and performance evaluation of NWP products will be customized
Sri Lanka/ DoM	• Lack of data assimilation • Limited skill for NWP	• Customization requirements • Verification for ocean products • Verification of upper air temperatures and temperature data. • Verification of ocean model data	• Residual needs of NWP beyond World Bank funded activities will be implemented • Data Ex to provide digital product access to medium, extended, monthly and seasonal forecast products of ECMWF • DWR and AWS data assimilation and support for operating HRRR WRF at 1Km resolution • Augmentation of Marine Meteorological Services involving coupled model products; Coastal hazards and inundation forecast services - Through development of analysis and visualization tools using Ocean State Forecast and coastal hazard products of INCOIS • Multi-model Ensemble products access and utilization for

Country	Gaps	Flagged immediate Needs	Priorities for implementation
			improved operational severe weather prediction services • Tropical cyclone surge models coupled with coastal inundation models

Annex II- NWP Working Group Meeting Summary

Overview

The meeting of the Working Group (WG) II- Numerical Weather Prediction (NWP) was held on 28 June 2021, from 3:00 to 4:30 PM Bangkok time (UTC+7) through virtual mode. The agenda and list of participants are provided in Appendix-1 and Appendix-2. The meeting has the following objectives:
To understand and carry out an initial assessment of country-wise existing capacities, gaps and priority requirements in NWP

- To appoint Co-Chairs of WG
- To acquaint WG members on the requirements of WG

Opening session

On behalf of RIMES and the World Bank, Mr. Tshencho Dorji, Project Officer, RIMES and chair of the session opened the session of the first meeting of Working Group II-Numerical Weather Prediction at 3:00 pm Bangkok time (UTC+7) on Monday, 28 June 2021. He welcomed the members of the working group and other participants to the meeting. Dr. K.J. Ramesh, Chief Scientist, RIMES welcomed the participants on behalf of the Director, RIMES and he thanked the members of the working group for showing enthusiasm in this regional endeavors. He highlighted that Numerical Weather Prediction is at the core of forecasting services in the region. It is of utmost importance to ensure availability of high-quality forecasts of all temporal ranges. The SA region could benefit from more data generation that is representative at country level.

Introduction of participants

Mr. Tshencho Dorji moderated the introduction of participants. He highlighted the importance of continued communication and interaction within the WG members to know each other well and taking the works of the WG forward.

Appointment of Co-Chairs

To lead the WG and liaise with the project team of the RIMES, the need for co-chairs of the WG was noted. The delegates from the NMHSs of the SAHF partner countries and members to this WG elected the following delegates as the co-chairs for the WG II- Numerical Weather Prediction:

- Mr. Ahmed Rasheed, Director Meteorology, Maldives Meteorological Services, Maldives (Co-Chair)
- Dr. Tin Mar Htay, Assistant Director Department of Meteorology and Hydrology, Myanmar (Co-Chair)

Presentation by each WG member

The members of the working group presented their reflections on the TOR of the WG, and the existing capacities, gaps and priorities needs of their countries in numerical weather prediction. The summary of priority requirements of numerical weather prediction in South Asia (SA) are highlighted below:

- Need to interface numerical weather prediction and impact-based forecasting and risk-based warning services for the benefit of various stakeholders
- Need to develop customized sector specific NWP product analytics for nowcasting, short, medium range forecast services
- Need to develop automated standard verification system along with bias correction

- Capacity building of NHMSs staff in numerical weather prediction (short term and long-term training required)
- Utilization of ensemble prediction models, climate models (both statistical and dynamical) and wave and ocean state forecasting models for marine and coastal hazard services

Table 2: A summary of country-wise priority requirements is tabulated below. More information on country-wise requirements is provided in their respective presentations provided in Appendix-3.

Country	Priority requirement for NWP
Afghanistan	Utilization of short and medium range forecasts (WRF; ECMWF) utilization; Support for synoptic forecasting; Aviation services; GIS tools
Bangladesh	Integration of IBF and NWP Utilization of ensemble prediction Wave modelling; storm surge and coastal inundation (SWAN+ ADCIRC models); Coupled Hurricane WRF forecast products access and utilization SW/HW, Network, data exchange framework support with SAHF countries
Bhutan	Capacity building for running climate models Data assimilation and bias correction of WRF outputs NWP utilization for IBF Services support for Aviation and nowcasting Dynamical downscaling of climate change scenario products Skill development of operational service manpower
India	Development of nowcasting applications using observations and NWP products through utilization of AI/ML tools Assessment of rapid intensity changes for cyclones over the open seas Anticipation of multi-hazard impact scenarios viz. Heavy rainfall; heat waves; thunderstorms & lightening Evaluation of ensemble products for probabilistic heavy rainfall prediction Development of multi-model ensemble forecast products for extreme weather events
Maldives	Staff attachment and familiarization to working environment of regional NWP centers or GPC. Increase model resolution with data assimilation for mesoscale weather systems Access to regional HPC systems to host and run local NWP models up to 1Km scale models. Ocean state forecast products utilization for waves and ocean current predictions
Myanmar	Establishment of data assimilation system and nowcasting Improved computing facilities to support NWP Capacity building through human resource skill enhancement (training of IT specialists, programmers and modelers) Ocean state forecast products utilization for waves and ocean current predictions FFGS customization Support services for river management activities
Nepal	Forecast processing suite, integrated knowledge hub and long-term plan for developing tools for bias correction Additional products, pattern recognition and cognizant algorithms for AI/machine learning and risk assessment as per the requirement for operational forecasters. Need to develop specialized NWP products for aviation, tourism, transportation, and nowcasting. Medium range forecast products

Pakistan	Developing NWP for weather prediction in the country Proposed for development of SA NWP Consortium for weather and climate services and IBF systems Development of convection permitting 1-Km local scale models Assessment of stake holder needs for improved services Road map for using ECMWF forecast products and utilization of AI/ML tools for weather and climate services
Sri Lanka	Capacity building in NWP through knowledge sharing Skilled manpower development programs Ocean state forecasting and coastal hazards Utilization of standard verification and bias correction tools

Discussion and way forward

Dr. Ramesh, RIMES moderated the discussion session. The following recommendations ensued from discussions for taking the work in NWP forward.

- Target to get assimilated data in FTP format
- Development of standard verification and bias correction mechanisms at knowledge hub level that will form a dynamic verification platform
- Collaborative efforts with ECMWF for procuring high resolution data
- Evolve systematic NWP training mechanism in SA region
- Improvement of NWP products using Machine language and AI techniques
- Development of the SAHF Knowledge Hub to discuss advancements and requirements in NWP and integrate forecasting products.

Appendix-1: Agenda

SAHF Working Group Meetings, Online session, 28-29 June 2021

Table 3: Agenda of Working Group meetings held on 28-29 June 2021

Program	Time (minutes)
Remarks (Moderator)	5
Introduction	5
Appointment of Chair and Co-chair of the Working Group	10
Presentation by each WG member (5 minutes each) *Reflections on WG TOR* *Priority needs of each country based on respective Thematic Areas*	45
Discussion and way forward	25

Table 4: Schedule of Working Group meetings held on 28-29 June 2021

Monday, 28 June 2021	
1:00 pm-2:30 pm (Bangkok Time)	Working Group 1- Impact Based Forecasting
3:00pm-4:30 pm (Bangkok Time)	Working Group 2- Numerical Weather Prediction
Tuesday, 29 June 2021	
1:00 pm-2:30 pm (Bangkok Time)	Working Group 3- Observational Networks
3:00pm-4:30 pm (Bangkok Time)	Working Group 4- Capacity Building

Appendix -2: Participants List

Table 5: Participant list of the NWP Working Group Consultation held on 28 June 2021

WG-2	Mr. Humayoun	Afghanistan	Humayoun_akbary@hotmail.com
	Ms. Kubra	Afghanistan	Kubramahmoodi100@gmail.com
	Dr. Md. Abdul Mannan	Bangladesh	mannan_u2003@yahoo.co.in
	Ms. Monju Subba	Bhutan	msubba@nchm.gov.bt
	Dr. Ananda Kumar Das	India	akuda.imd@gmail.com
	Mr. Ahmed Rasheed	Maldives	ahmed.rasheed@met.gov.mv
	Dr. Tin Mar Htay	Myanmar	tmarhtay@gmail.com
	Mr. Rajudhar Pradhananga	Nepal	raj.prd@gmail.com
	Dr. Jehangir Ashraf Awan	Pakistan	jehangirawan@gmail.com
	Mr. T.P.N. Peries	Sri Lanka	nandalalpeiris@yahoo.com
RIMES Team	Dr. G. Srinivasan		srini@rimes.int
	Dr. K.J. Ramesh		kjramesh2607@gmail.com
	Dr. Anshul Agarwal		anshul@rimes.int
	Dr. Itesh Dash		itesh@rimes.int
	Mr. Tshencho Dorji		tshencho@rimes.int
	Ms. Kousalya V Kumar		kousalya@rimes.int
World Bank	Ms. Dechen Tshering		dtshering@worldbank.org
Other Representatives	Mr. Nasim Muradi	Afghanistan	Nasim.muradi786@gmail.com

Annex III- Country Consultations

Background

South Asia Hydromet Forum (SAHF) is constituted with the vision to strengthen the key elements of the hydro meteorological services at national and regional scale. The forums are dedicated towards evolving collaborative regional strategies to increase the use of ensemble predictions, impact-based forecasting systems and user oriented advisory services. Capacity enhancement shall align to these requirements by adopting a demand and context driven approach that leverages regional actions while meeting the differential needs of the various NMHSs.

It is a unique institutional mechanism involving shared vision, participatory process, openness to innovation, open data sharing and engagement with research institutes and communities for innovation. SAHF is envisioned to be a demonstrable institutional mechanism of the WMO's Hydromet value chain and a best practice to replicate in all other regions globally.

An overarching objective of the **SAHF** is to reinforce national activities leading to a more sustainable program of development of meteorological and hydrological services throughout the region. An important aspect of the forum is **"learning from each other";** which involves developing solutions to the meteorological and hydrological challenges that are unique to the region. SAHF aims to leverage hydromet capacities within the region to strengthen each other through collaborative regional strategies. SAHF also aims to identify specific fit-for-purpose investments to build technical and intellectual capacity of NMHSs in South Asia to respond to the main users' needs using skills that exist in the region and globally.

Process and Preparation of Consultation

With the overarching objectives and purpose SAHF in place, meetings of the Working Groups (WG) in the four thematic areas were conducted during 28-29 June 2021 from all nine South Asian countries to familiarize WG members with SAHF process, seek initial understanding of each NMHSs' capacities and needs. This consultation with WG members of each NMHS of SAHF countries was carried out to get in-depth understanding of the status in four thematic areas with respect to: existing capacities, available operational systems, current operational procedures, access to various datasets, challenges faced in operations, priorities for improvements and human and availability of technical resources. Also, this consultation aimed to identify the strengths of individual NMHSs which could be a resource for the region.

Table 6: Schedule for consultation meeting with WG members of SAHF countries

Date	Time (Bangkok Time: UTC+7hrs)	Country
10 August 2021	11:00 am- 1:00 pm	Bhutan
	3:00 pm -5:00 pm	Afghanistan
11 August 2021	11:00 am- 1:00 pm	Maldives
	3:00 pm -5:00 pm	Bangladesh
13 August 2021	3:00 pm -5:00 pm	Myanmar
16 August 2021	3:00 pm -5:00 pm	Pakistan
18 August 2021	11:00 am- 1:00 pm	India
19 August 2021	3:00 pm -5:00 pm	Nepal
20 August 2021	11:30 am -1:30 pm	Sri Lanka

The consultation meeting was coordinated and led by the RIMES and the World Bank team involved in SAHF implementation (Table 2). The consultation meeting was attended by the WG members of SAHF four thematic areas from the SAHF member countries.

Table 7: Composition of RIMES and World Bank for the consultation meetings

RIMES	Dr. G Srinivasan, Team leader Dr. K.J. Ramesh, Sr. Advisor Dr. Anshul Agarwal, Technical Expert Dr. Itesh Dash, Technical Expert Mr. Tshencho Dorji, Technical Expert Ms. Kousalya V Kumar, Program Coordinator
World Bank	Ms. Dechen Tshering, WB Expert

Summary of Consultation

The following sections provide a summary of discussions with individual SAHF countries.

Afghanistan

The consultation meeting with Afghanistan Meteorological Department (AMD) was held on 10 August 2021 between03:30 pm -05:00 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from Afghanistan Meteorological Department attended the meeting:

- Mr. Nasim Muradi
- Mrs. Tahmina Askari
- Mrs. Kubra Mahmoodi

Table 8: Outlines of consultation meeting between WG from SAHF and Afghanistan

Impact Based Forecasting	**Existing Capacities** Flash Flood Warning provided through AMD website Warnings issued before 24 hours through media platforms like Facebook and WhatsApp 3-day weather forecast issued in AMD website
	Gaps and Needs GEFS forecasts not skillful over Afghanistan FFGS warnings not consistent, reported to have some uncovered areas where flood events were reported during 2021 monsoon season (JJA) No Media Center or broadcasting of weather information on television High altitude areas need to be focused on as they experience heavy snowfalls and avalanches
Numerical Weather Prediction	**Existing Capacities** 3 days forecast through AMD website in 3 languages Aviation Briefing Department Upper Air Station-1(Kabul Airport) METCAP+ connected to GFS model
	Gaps and Needs High resolution modelling MME and High-Resolution models required. GFS resolution is weak No operational WRF/LAM models being run at AMD
Observational Networks	**Existing Capacities** 25 synoptic stations (6 stations connected in GTS); 6 AWS stations Observations are shared between stakeholder on request Work on data sharing policy ongoing Weather stations in high elevation

	Gaps and Needs Generation of TAF reports and other aviation met forecasts Lack of stations in all provinces Other agencies and govt departments may have observational networks that need to be assessed, mapped and included in a future strategy for observational networks.
Capacity Building	**Existing Capacities** Online Trainings
	Gaps and Needs **Trainings in** Synoptic Division Basic synoptic training to carry out interpretations Communication Systems

Others Matters

- Online trainings are hardly possible because of limited resources a laptops/computers and poor internet connectivity. In addition, current civil the ongoing situation makes the situation worst for attending online trainings.
- Prefer to receive face to face trainings at regional training center in India or other similar venues.

Bangladesh

The consultation meeting with Bangladesh Meteorological Department (BMD) was held on 11 August 2021 between 03:00 pm -05:00 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from BMD attended the meeting.

- Dr. Muhammad Abul Kalam Mallik
- Dr. Md. Abdul Mannan
- Mr. Md. Abdul Matin
- Mr. S. M. Quamrul Hassan

Table 9: Outlines of consultation meeting between WG from SAHF and Bangladesh

Impact Based Forecasting	**Existing Capacities** Thunderstorm, Cyclonic Storm, Storm Surge and Fog Forecasting Access to risk information as static data Heat Wave Forecast Pilot IBF project on Fog being conducted under ARRCC Work Package 1
	Gaps and Needs Event wise assessment of impact Lack of impact data Assessment of IBF Improve forecast accuracy Linking risk information with early warning and forecasting Access to risk information as meta data Increase lead time Listing of different indicators for vulnerability, exposure, examples of how the data intensive IBF process can be simplified using satellite-based analysis, gridded regional, global data. [This may help scaling up pilot initiatives]
Numerical Weather Prediction	**Existing Capacities** WRF model GFS Model JMA Model [Storm Surge]
	Gaps and Needs Advanced Storm Surge Model Test run for boundary forcing Probabilistic forecasts Institutional bias correction of models
Observational Networks	**Existing Capacities** 57 synoptic observations 5 RADAR system [conditions not good; 2 RADARS non-functional, 3 partially functioning, JAICA replacing 2 RADARS] AWS/AWLS [Lack of maintenance and communication concerns] Rain Gauge 8 lighting sensors Satellite data reception – HIMAWARI-CMA FY and KMA Under World Bank projects – 35 AWS, 65 Agromet stations and 125 automatic rain gauges being added
	Gaps and Needs Lack of manpower in synoptic stations Satellite observation system [to be received from JMA] Common lighting observation system BMD has been conducting induction trainings at both senior and Class 2 levels. For the last 2-3 years such trainings have not been conducted as no new recruitments are being done at BMD.

Capacity Building	**Existing Capacities** New Recruits: WMO affiliated 1 year training [Administrative problems in new recruitment] All staff has basic knowledge in Linux operating system Refresher courses [Not conducted for past 5 years] WB Supported Project-Trainings in Marine meteorology, climatology, disaster management and ICT In house trainings IMD training in association with UK Met Office

Other Matters

- Frequent trainings are necessary to keep update of evolving science in weather and climate.
- Integration of all RADARs in South Asia under one system is required

Bhutan

The consultation meeting with National Center for Hydrology and Meteorology (NCHM) was held on 10 August 2021 between 11:00 am -01:00 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from NCHM attended the meeting.

- Mr. Saroj Acharya
- Ms. Monju Subba
- Mr. Jangchup Choephyel Dorji
- Ms. Ugyen Tshomo

Table 10: Outlines of consultation meeting between WG from SAHF and Bhutan

Impact Based Forecasting	**Existing Capacities** IBF system not operational. Still in pilot phase (details required to be furnished) [IBF system- not sector specific. Covers air culture, roads, and transport services.] Dissemination of alerts through website, email, social media platforms Regular monitoring of glacier lakes (15) Water level monitoring in river basins Drought Monitoring Platform [Not Operational] ICIMOD Flash Flood Guidance system (SAFFG)
	Gaps and Needs Lack of knowledge about IBF Stakeholders' coordination Data on impacts and vulnerabilities Gaps in communication and utilization of warnings Web based applications for IBF There has been loss of lives due to extreme weather events

Numerical Weather Prediction	**Existing Capacities** WRF models
	Gaps and Needs Data Assimilation Medium Range Forecasting & Extended Range Forecasting System (ERFS) access to NCMRWF in addition to IMD Nowcasting-Aviation Forecasting Verification /Hydrological models being used for IB
Observational Networks	**Existing Capacities** Automatic weather station Water level stations **Normal Forecasting-** WRF Model Output+ Guidance from IMD + Thai Surface Charts Satex software for Satellite data – with analysis for RBG channels
	Gaps and Needs Network covering northern part of the region Training of new staffs in AWS/AWLS; as senior staff have left Calibration setup – (lab for pressure, temp and RH) Upper air observations and RADAR station Internships in instrumentation (3 months basic) GTS Data: To be able to represent at least 1 region and utilize 5-6 weather stations Dense observational network required
Capacity Building	**Existing Capacities** Virtual Training from WMO, IMD and RIMES on Seasonal Operational Services and Nowcasting
	Gaps and Needs **Trainings in** Nowcasting/Aviation Data Assimilation Short/Long Range Forecast Introductory training on IBF Hydrological IBF Introductory Training on Flood Forecasting Introductory Training in Glacio-Hydrological Modelling & glacier and mass-balance studies, snow mapping Upper Air Observations RADAR Installation Calibration and Instrumentation Network Design Satellite Image Processing Finance, Human Resource and Procurement ICT Short-term trainings; secondment training for six months and one-year (attachment) **Academic long term – degree courses:** Aeronautical Meteorology Electronics and Communication Glaciology Instrumentation

Other Matters

Past Trainings:

- 3 months training for new recruits including two months of theory sessions and 1 month of respective department technical training.

Existing Trainings:

- New recruits: 2 days orientation programme and 1 week of technical orientation

Requirements and Preferences:

- Short Term Trainings and Knowledge Sharing Culture [With monitoring and evaluation]
- Secondment/ Internship [3 months or more]
- Institutionalization of mandatory training for freshers

NMHS Strength:

- Accurate Data Dissemination in GLOF as a result of past experience and importance given to the aspect.
- Glaciology
- Training structure for consideration:
- Basic Modules – for induction level forecasters and instruments/communication
- Short-term (face-to-face) & Follow-up and pre-training online modules
- Specialized modules – face-to-face short-term – example Satellite data analysis
- Secondment and advanced training modules – 3 months/six-months/one-year
- Academic programs- masters and PhD in climate science

India

The consultation meeting with India Meteorological Department (IMD) was held on 18 August 2021 between 11:00 am -01:00 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from IMD attended the meeting.

- Dr Udhay Kumar Shende
- Dr. Somenath Dutta

Table 11: Outlines of consultation meeting between WG from SAHF and India

Observational Networks	**Existing Capacities** Calibration of AWS units, now being done at regional level after trainings 50 doppler RADARS data is being used to generate a high-resolution mosaic Can extend training support in various aspects
	Gaps and Needs Integration of observational networks from different agencies – not complete – at present some State Govt data is being received, private sector entities Upper air system – needs improvements
Capacity Building	**Existing Capacities** Several WMO compliant training courses are being organized and announced through WMO Global Campus platform for meteorological training.
	Gaps and Needs **Trainings in** India can extend support through RTC IMD, Pune Only limited numbers of participants/trainees from South Asia NMHSs

Maldives

The consultation meeting with Maldives Meteorological Department (MMS) was held on 11 August 2021 between 11:00 am -01:00 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from IMD attended the meeting.

- Mr. Ali Shareef
- Mr. Ahmed Rasheed
- Mr. Ibrahim Humaid
- Ms. Shaheema Ibrahim

Table 12: Outlines of consultation meeting between WG from SAHF and Maldives

Impact Based Forecasting	**Existing Capacities** Refined CAP system SWFP guidelines
	Gaps and Needs Coastal hazards
Numerical Weather Prediction	**Existing Capacities** WRF models Operational HPC- Wave Watch 3
	Gaps and Needs Capacity to support HPCs in long term High resolution run in WRF with data assimilation
Observational Networks	**Existing Capacities** INCOIS model Integration of all existing MMS system [AWS systems and NWP products] Mobile application improvement Rainfall data and ocean state data for fisheries Marine weather forecast for sea transportation Utilization of products from ECMWF, WMO and IMD
	Gaps and Needs Ocean observations Ocean current data Ocean current forecast for save and rescue Costal Hazards Datasets for visualization
Capacity Building	**Existing Capacities** Local trainings Basic and advanced courses in IMD Forecasters-Foreign Trainings Basic instruction package
	Gaps and Needs Introductory and middle level training in observational networks Introductory and middle level training in IBF and for forecasters Certification [required for eligibility for promotion] Refresher course in marine observations Improve manpower

Other Matter

Training Priorities:

- Virtual trainings are sufficient and necessary to maintain learning culture among the NMHS professionals.
- List of training in the last 3-5 years to be provide by MMS.

Country Priorities:

- Marine Observations
- Ongoing Projects
- WMO-Hydromet Diagnostic Project
- GCF Project

Myanmar

The consultation meeting with Department of Meteorology and Hydrology (DMH) was held on 13 August 2021 between 03:00 pm -05:00 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from DMH attended the meeting.

- Ms. Chaw Su Hlaing,
- Dr. Tin Mar Htay,
- Ms. Waitoe Aung,
- Ms. Han Swe,

Table 13: Outlines of consultation meeting between WG from SAHF and Myanmar

Impact Based Forecasting	**Existing Capacities** IBF in initial stage Water Level Forecast Flood Hazard Map-Hydrology Department Seismic Hazard Map- Hydrology Department Meteo LAN- EWA 2 threshold value
	Gaps and Needs Utilizing hazard data for issuing warning Hazard map for extreme rainfall, heat hazard and others
Numerical Weather Prediction	**Existing Capacities** WARF model Marine Forecasting- INCOIS Model, IITM Model Storm Surge- IITM Model, JMA Model Daily weather Forecast AgroMet Forecast Aviation Forecast Agricultural Forecasting Seasonal Forecast
	Gaps and Needs Nowcast Wave Model- Sea condition forecast and Marine Forecast 3 days forecast at district level Utilization of ECMWF and other global data for NWP models
Observational Networks	**Existing Capacities** WMO Projects-AWS Stations RADAR Stations 3 Doppler Weather Station 121 Synoptic Stations 40 Water Level Stations DIANA System- Himawari Data Two JICA Projects- Calibration
	Gaps and Needs Integration of Observational Networks- Common Integration platform

Capacity Building	**Existing Capacities** **Past Training:** Storm Surge Training **Planned Trainings:** COMET Training for forecasting, ON Marine Training UK Met- Aviation Training Climatology Training Meteo LAN system
	Gaps and Needs **Training on** Induction Training Threshold Value Calculation Issuance Of Warning Doppler Weather Training Aviation Forecasting Training Hydrological Forecasting Trainings **General** Barometer Calibration Phasing out plan for old systems Limited Human Resource Strengthening institutional capacities

Nepal

The consultation meeting with Department of Hydrology and Meteorology (DHM) was held on 13 August 2021 between 03:00 pm -05:00 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from DHM attended the meeting.

- Ms. Shanti Kandel,
- Mr. Rajudhar Pradhananga,
- Mr. Suman Kumar Regmi
- Mr. Shiva Nepal,

Table 14: Outlines of consultation meeting between WG from SAHF and Nepal

Impact Based Forecasting	**Existing Capacities** Piloting IBF in 16 municipalities of 4 districts in June 2021 under ARRCC UKMet support [Landslide as an impact of heavy rainfall along with other impacts of rainfall – more details requested from DHM WG Member on IBF] Flash Flood Guidance System (Utilizing high resolution products)
	Gaps and Needs IBF Research- Historical data & Analysis – thresholds Improving Reliability of NWP System- Hourly and Weekly Verified products of NWP system Rainfall, Wind and Temperature

Numerical Weather Prediction	**Existing Capacities** FMI- Older version of WRF WRF- 4.1.2: 4 times a day (Resolution 9 km) ECMWF products (ECMWF products better than GFS)
	Gaps and Needs Forecast Verification System Data Assimilation Optimization and customization of NWP Model Products for Aviation and Transportation Nowcasting Medium Range Forecast (Demand for Agriculture Sector) Ensemble Forecast Products Planning for Ensemble Prediction System [Meso Scale] Single Platform for all products to facilitate forecasters
Observational Networks	**Existing Capacities** 1 RADAR (2 under installation) 100 AWS (90 working)-PPCR Work on scanning strategy and data sharing Glacier Monitoring System – 6 AWS att high altitude other stations for Glacier mass-balance in collaboration with ICIMOD 2 upper air stations are being planned with Govt Nepal funds
	Gaps and Needs Glacier and Snow Monitoring Section
Capacity Building	**Existing Capacities** Refresher trainings for forecasters [1-2 years one] On the job training
	Gaps and Needs **Trainings on** Forecast Verification Modification and learning in IBF Manpower: Increase number of forecasters No induction trainings at present, only on job attachment – plans to restart this year.

Pakistan

The consultation meeting with Pakistan Meteorological Department (PMD) was held on 16 August 2021 between 03:00 pm -05:00 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from PMD attended the meeting.

- Mr. Sarfaraz
- Dr. Zaheer Ahmed Babar
- Mr. Nadeem Faisal
- Dr. Jehangir Ashraf Awan

Table 15: Outlines of consultation meeting between WG from SAHF and Pakistan

Impact Based Forecasting	**Existing Capacities** Ties with National disaster management authority, province disaster management authority and district DMA Weather Advisory-Information on identified impacts Flood Forecasting Division-Lahore Robust system for riverine flooding Flood Forecasting updated through website, fax, emails, and WhatsApp messages Weather Forecast Guidance System- Responsive and Robust [Ongoing]
	Gaps and Needs Impact Assessment Integration of forecast with severe weather events
Numerical Weather Prediction	**Existing Capacities** Two new Doppler Radars 90+ Weather Stations METCAP+ COSMO Model and ICON Model GFS Model downscaling JMA Model
	Gaps and Needs Numerical Modelling General processing of numerical models Assimilating various available data for forecasts Validation of NWP models
Observational Networks	**Existing Capacities** Access to ECMWF data Surface Observations GLOF project- 2nd phase
	Gaps and Needs Dense Network Better Ground Observations Better Radiosonde Observations Upper Air Observations
Capacity Building	**Existing Capacities** **Trainings in** Initial Meteorology Courses and other introductory courses Product Interpretation-JMA
	Gaps and Needs Trainings in IBF and NWP Trainings in data modelling, climate modelling, model validation and data assimilation Mechanism for refresher courses Improved computational capacities [ICT Infrastructure] Human resources lacking

Other Matter

NMHS Strength:

- Training Capacity, Regional Training Institute

Sri Lanka

The consultation meeting with Department of Meteorological (PMD) was held on 20 August 2021 between 11:30 am -01:30 pm (Bangkok time: UTC+7hrs). Following WG members of SAHF WG from DM attended the meeting.

- Dr. I.M.S.P. Jayawardane,
- Mr. Chana Rodrigo,
- Mr. Meril Mendis,
- Mr.A.G.M.M. Wimalasuriya,
- Mr.A.L.K. Wijemanna,
- Mr.T.P.N. Peries,

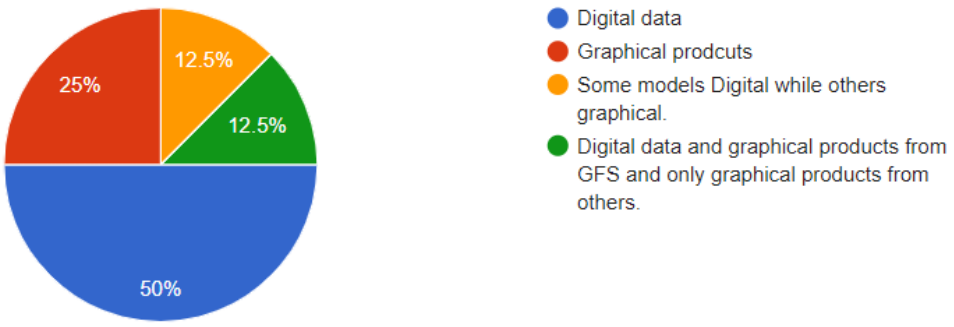
Impact Based Forecasting	**Existing Capacities** Flash Flood Guidance Warning depended on thresholds
	Gaps and Needs Early warning for costal inundation Knowledge about impact from equatorial waves Automatic Rain Gauge System linked to FFG Single weather threshold for entire country. Specific thresholds for different areas.
Numerical Weather Prediction	**Existing Capacities** Utilizing ECMWF Forecasts Data from INCOIS ECMWF ecCharts Standard Verification for 24 hours
	Gaps and Needs Customization requirements Verification for ocean products Verification of upper air temperatures and temperature data. Verification of ocean model data
Observational Networks	**Existing Capacities** Two new Doppler Radars[Yet to be installed] One radiosonde observation station Pilot balloons- 4 stations Lighting detection system- Chinese Government [Experimental State]
	Gaps and Needs Weather Buoys

	Real time data for thunderstorm and lighting forecast [Automatic Rain Gauges-Expansion of real time data network] Integration of Automatic Rain Gauges
Capacity Building	**Existing Capacities** **Trainings in** Basic Meteorology [New Recruits] On the job training [New Recruits]
	Gaps and Needs **Trainings in** Marine Meteorology [Introductory] NWP [In three levels]- Verification, Data Processing, and Data Model Processing. RADAR Meteorology Maintenance of Observational Network [On the job training] Equatorial and Tropical Meteorology Data Analysis and Programming Support for Marine Products

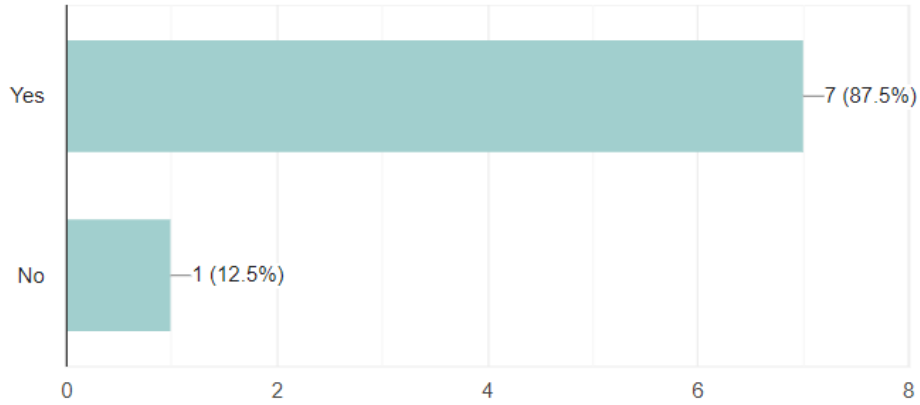
Annex IV- Survey NWP Questionnaire

1. **Please provide details of the Global Models Forecasts that you access regularly.**
   - ECMWF high resolution products, rain, QPE, winds, stability indices, location specific Meteograms are most often used parameters, RIMES graphical NWP products received via email on daily basis, Ocean Wave Model (WAVE4M), 3-1 km resolution, digital data set, BoM, Australian NWP model, digital data set, NWP model products from IMD website, NWP mode products facilitated under WMO program of SWFP-Asia.
   - Global forecasting System (GFS)_28km, all parameters downscaled to 15 km and 3 km in WRF.
   - ECMWF 0.1 degree, GFS 0.25 degree
   - IMD-GFS, NCEP-GFS, NCUM-G, ECMWF, JMA
   - Yes
   - ECMWF (HRES), GFS (27 Km, downscaled to 9 Km & 3 Km using WRF), NCMRWF (4 Km), IMD (12 Km), RIMES (9 Km)
   - Variables accessed are rainfall, temperature, wind speed and direction at different levels, relative humidity, geopotential heights, CAPE, total precipitable water, meteograms, forecast soundings etc.
   - ICON, GFS, ECMWF

2. **Access to Global Forecasts**



3. **Do you also access Ensemble predictions?**



4. **If Ensemble predictions used, are they used for probabilistic forecasts in daily weather bulletins and how?**
   - They are used as forecast guidance material among other products.
   - No probabilistic forecasting
   - Yes
   - The likelihood of weather extremes are included in the bulletin based on a criteria over the values of meteorological parameters in the ensemble forecasts.
   - 10 days weather forecast
   - Probability is used for precipitation forecasts for 12 major cities only.
   - Not Applicable

5. **State briefly challenges faced in access and use of Global NWP forecast products.**
   - Limited access to Digital data set,
   - Limited Training and experts on NWP data post processing techniques.
   - only graphics are available
   - High resolution model products using internet and license cost of some products.
   - Timeliness and quick apprehension of all NWP forecasts is a challenge for a better consensus forecast. An automated decision support system to integrate all kinds of forecasts for weather extremes is a necessary part of effective forecast system.
   - yes. because model forecast cant not catch topogräphy and monsoon
   - Inconvenient to analyze weather systems as all forecast models products are available in different platforms, difficult to download data sets due to huge file size, expensive datasets, lack of operational meteorologists in DHM, Nepal
   - Data Sharing

- Currently only freely available products are being used. The major challenge is cost for paid products.

6. **State briefly challenges faced in access and use of Global NWP forecast products.**
    - Limited access to Digital data set,
    - Limited Training and experts on NWP data post processing techniques.
    - only graphics are available
    - High resolution model products using internet and license cost of some products.
    - Timeliness and quick apprehension of all NWP forecasts is a challenge for a better consensus forecast. An automated decision support system to integrate all kinds of forecasts for weather extremes is a necessary part of effective forecast system.
    - yes. because model forecast cant not catch topogräphy and monsoon
    - Inconvenient to analyze weather systems as all forecast models products are available in different platforms, difficult to download data sets due to huge file size, expensive datasets, lack of operational meteorologists in DHM, Nepal
    - Data Sharing
    - Currently only freely available products are being used. The major challenge is cost for paid products.

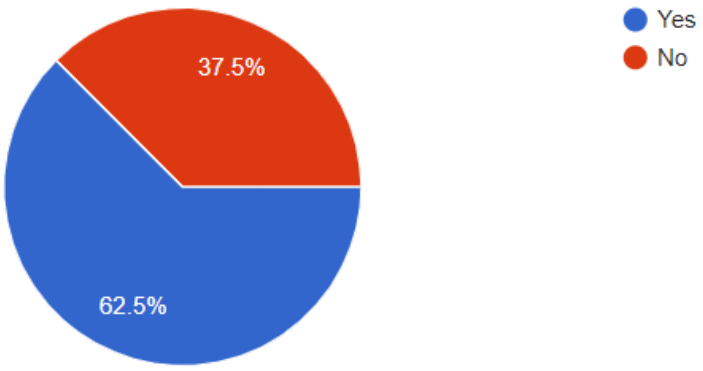
National NWP system

7. **Provide details of the Limited Area Model used for operational NWP**
    - WRF model
    - WRF, 4 Run/day, 15km and 3 km, boundary condition:GFS
    - WRF model with 9km horizontal resolution.
    - WRF, NCUM-R, HWRF for cyclones
    - We can not use.
    - WRF version 4.1.2 (27 km datasets used to downscale to 9 km and 3 km) & WRFDA (3DVAR)
    - WRF Model
    - WRF

8. **Is the local data assimilated, if yes provide details?**
    - No data assimilation
    - no
    - Yes. Satellite radiance and conventional data from from NCEP.

- Yes, Local data are assimilated using regional GSi data assimilation system.
- not yet
- Yes. The data assimilated are AWS, GTS (Upper and Surface) and Radar
- Not yet
- Not yet. We are planning to ingest local data in future.

9. Is the operational NWP system digital data systematically archived and accessible?



10. If yes, state the year since the archival started and remains accessible.

- 2016- Till date.
- 2015
- Only time series data for about 88 stations are archived since 2021 Jan 24. The grib2 data are auto deleted every 3 months due to huge file size due to lack of sufficient space in server.
- During last few years
- Operation NWP produce data in bulk volume. At present the data upto a year is retained that is also because we don't have a demand for past NWP data.

11. How many NWP forecast cycles are being run operationally currently? [Also add the cycle in which assimilation is done.]

- daily once , with 1200UTC initial condition.
- 4 runs/day
- 2 cycles per day (0000UTC and 12000UTC with DA)
- 2 forecast cycles for GEFS & NCUM; 4 cycles for GFS, WRF, NCUM-G and NCUM-R; In each cycle data assimilation is carried out.
- Only one.

- 4 NWP forecast cycles are being run operationally. Data assimilation is done for all 4 cycles (00Z, 06Z, 12Z, 18Z).
- Four
- 04 times a days.

Long term NWP strategy

12. Please provide your views on current challenges and how to plans for future NWP system

- Limited access to High Performance Computing Capacity.
- Training on NWP and data assimilation
- The model has bias. We have to do Data Assimilation.
- Localized convective system still challenge to resolve by current system and increase resolution to 3km will resolve convection more accurately.
- Better data assimilation system preferably coupled land-ocean-atmospheric data assimilation; Improved dynamics and physics for the prediction of weather extremes; Modelling of hydro-meteorological hazards within an integrated framework; Bias correction in NWP model forecasts; Grand Global Ensemble or Multi-model Ensemble from various deterministic and ensemble forecasts.
- We need IT knowledge and modellers
- Generating 7 days forecasts products to fulfill demands of stakeholders especially farmers, developing specialized forecasts products for aviation, tourism, transportation, generating nowcasting products, experimental studies to customize model to improve the reliability and accuracy of the model forecasts etc. are the challenges being faced currently.
- DHM plans to collaborate with international agencies to improve NWP capabilities, updating hardware, establishing standard verification system, and installing ensemble prediction system.
- Data Assimilation and Ensemble Prediction
- Regional NWP effort in South Asia is very limited. Models are operating with limited observations particularly upper air data, on small different domains by different countries at coarse resolutions. It is important to explore existing technical skills and computational facility available in the region and mobilize resources to strengthen that capacity to enable a launch of regional NWP system for South Asia region. Two to three countries with established NWP systems and better computational facilities could be focused to host the regional NWP system operations with customized products and access to all the member states.

13. How can regional initiatives contribute to improve NWP capacities in the region?

- Provide access to NWP digital data sets for post processing at local level to produce customized products.
- Establish a central High Performance Computing facility that regional countries can get shared access to and use to run high resolution local area models.
- Assist in DA of WRF MODEL.
- Regional model such as IMD GFS is highly contribute.
- Division of development works amongst partners; Working groups for various development works; Sharing of resources (data and computing) through remote access and distributed man-power over the region do not limit the simultaneous development by various groups.
- Cooperate each other.
- By sharing data with regional members and by providing capacity development training programs to the NWP staffs.
- Capacity Building and collaborative research
- It is indeed essential to build South Asia NWP consortium and strengthen the regional capacity in numerical modelling. It will not only reduce redundant efforts by each country but will also provide an improved fine resolution NWP system customized to the needs of member states.

14. Can ensemble forecasts and probabilistic inference help meeting user expectations and requirements for Impact-Based Forecasts (IBFs)?

- Yes
- Yes.
- Yes, it will help as guiding products and increase the confidence of the forecasters on the provision of IBF.
- YES.
- The ensemble forecasts and their inferences facilitate IBFs. But, still reliability of hazard forecasts is an issue to be tackled. Moreover, a lot more quality data on exposure, vulnerability and geophysical & socio-economic conditions are required for improved IBFs.
- Probabilistic forecast is important to provide the stake-holders the forecast with inherent uncertainty that is inevitable for their better decision making.

IT infrastructure

15. What is the current installed computing capacity and planned upgrades in future?

8 responses

- Dell PowerEdge R520, 8 CPUs @ 2.40GHz, 23 GB RAM
    - Inte(R) Xeon(R), 4 CPUs @ 3.2GHz, 31 GB RAM
- Unable to upgrade due to financial constraints.
- CentOS 6, no plans as of now.
- current 64-core system will be upgraded to 128-256 cores future.
- 10 PFLOPS within Ministry of Earth Sciences, govt. of India; Proposed upgradation up to 40 PFLOPS within one year.
- We need to upgrade our current computing system and current system is very small server and poor resolution. So we need fine resolution also.
- The computing capacity used has the following specifications:
    - 1. Cluster Node: 23 nodes with 32 cores, 2x AMD EPYC 7351 2.4/2.9 GHz, 128GB RDIMM, IPMI Management, 480GB solid state drive SATA.
    - 2. Frontend Node: 2 Nodes with 32 cores, 2x AMD EPYC 7351 2.4/2.9 GHz, 128GB RDIMM, IPMI remote management, SAS RAID1, RedHat Enterprise Linux
    - 3. Storage: 80TB, SAS 6Gbps, 7200 RPM
    - 4. FDR infinity band Switch
    - 5. HPC software Pack with scientific libraries.
    - 6. Batch system.
- Future planned upgrades are purchasing of one additional HPC system and further improvement and upgrading of the data assimilation system.
- BMD has been using HPC for NWP Modelling, Through WB supported it is planned to be optimum to WRF model, Ocean and storm surge model, climate model and HIWAT system.
- PMD acquired 22 TFLOPS in recent past years and is planning to upgrade it to 5 PetaFLOPS soon.

16. Details of the visualization interface for NWP, observational, remotely-sensed and satellite datasets

- Multi-Monitors installed at forecasters work station for viewing multiple products at the same time.
- Currently ongoing project for integration of products (NWP, Satellite, AWS etc.)under a common platform and installation of display panels in duty forecast room for visualization of these products.

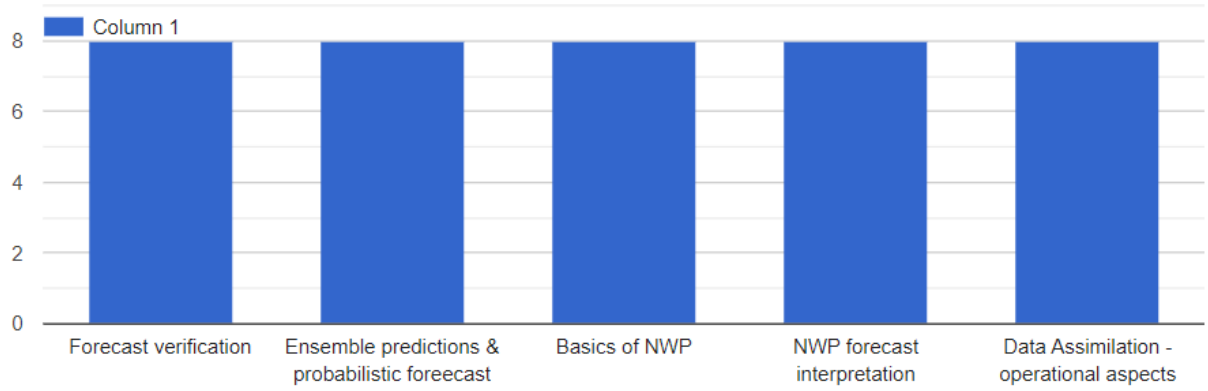
- SMARTMET
- Separate display systems area used.
- GIS based visualization and static web interface.
- Currently we can use GrADS tool for visualization.
- Internal webpage is designed for visualization of NWP forecasts.
- Data management system is designed for observational data and Himawari cast system is used for viewing satellite imageries.
- Synergie web software is used to visualized NWP, observational and remotely sensed and satellite datasets.
- NWP data has been visualized using GrADS and other relevant software, all other data have been visualized using data supported software.
- IBL Visual Weather and Meteorological Information Comprehensive Analysis Process System (MICAPS)

17. Details of the Climate Data Base Management Systems

- Now data is managed in MS Excel spread sheets.
- Currently ongoing project for development of Data base system for archive of climate data.
- no going
- Traditional Database system available.
- National Data Centre, IMD, Pune has an established Climate Data Base Management System.
- DHM has been using the FNEP database along with an old gw basic program for data management which has a lot of limitations. With the implementation of new DMS under PPCR/BRCH, DHM is able to get following benefits:
    - - integrated database for managing meteorological as well as hydrological data
    - - web-based data entry platform for manually operated hydro-met stations which
    - supports in quick update of observations in DMS
    - - feature of auto quality control with handy HQC system
    - - better visualization platform for observation assisting in QC procedure
    - - feature to control permission in accessing different modules in DMS for various users
- BMD have no systematic Climate Data Base Management System, data has been stored and retrieve using Fortran Programme

Training requirements

18. List areas where NWP training is required



19. Any other specific requirements for operational NWP work?

- NWP post processing techniques and training
- Hands on training and short-term staff Attachment program at regional NWP centers.
- Customization of model physics if possible.
- Use of NWP in IBFs.
- We need a lot of training program and IT knowledge for NWP.
- on the job training in nwp specialized centers.
- Knowledge sharing
- Nowcasting

Annex V- SAHF Outcome

OUTCOMES

SAHF participants unanimously acknowledged SAHF as a vital & ongoing process in the South Asia region that would remain relevant in the future as well so as to strengthen and support the hydromet service delivery capacities of SAHF countries.

The forum agreed that:

1. **The changing landscape of real time observing system networks and forecast data acquisition** for monitoring, detection, and early warning of multi-hazards requires efforts to enhance actionable weather and climate services to protect lives & yield economic benefits.
2. **Collaborative efforts and resources are necessary** to tailor forecasts for key user sectors as per country's needs by generating a suite of useful indices to assist forecasters as well as for value addition towards sectoral applications. Enhancing observing systems- both terrestrial and upper air- in critical gap areas such as mountainous regions and oceans along with innovative mechanisms for their establishment and operation is a key need along with public-private sector engagement centred around NMHSs.

The Forum agreed on several tangible priorities to be undertaken in a time-bound manner as part of an Action Plan with measurable targets. The key outcomes of the Forum are listed below;

Driving the early-warning information value-chain with impact-based Forecasts:

1. Pool collaborative efforts and resources to post-process and tailor forecasts for different sectors and country requirements
2. Generate a range of useful indices that both assist forecasters as well as add value to users' situations within sectors
3. **IBFs offer opportunities for an integrative approach** towards better delivery of hydromet services. Such context oriented forecast information would lead to suitable decision support tools co-developed with sector/ line departments such as agriculture, water resources and fisheries, public health which would benefit them.
4. All SAHF countries would establish an institutional framework to connect NMHS and sector institutions for co-production of IBF services integrating geospatial and socio-economic data with real-time weather data and its exchange for improved IBF, development of Decision Support Systems (DSSs) for risk informed development.

Improving weather and climate forecasts:

5. To synergize efforts and to leverage global and regional strengths, **set up a South Asia Consortium for data and weather Predictions (SCOPE),** a regional collaborative mechanism blending both cutting-edge technological advances and conventional techniques potentially enabled by SAHF regional cloud computing, storage, and

networking services infrastructure with investment by pooling of resources. All efforts in this endeavor would leverage significant commitment from institutions and partners collaborating with countries in the region. SCOPE would focus on post-processing data blending conventional MOS techniques, ensemble probabilistic forecasts, high-resolution regional domains for specific country clusters within the region and modern approaches like AI/ML to exploit all the forecast data and observational data to bring best science approaches for the generation of relevant forecast products and derived indices tailored to a range of users.

6. Focus on forecasting weather and climate extremes - tropical cyclones, severe thunderstorms & lightning, heavy rainfall events and heatwaves
7. Prioritize specific national requirements that are also common to sub-regions like marine & coastal services focusing on coastal hazards, shoreline management, mountain meteorology and similar requirements
8. Create knowledge repositories to support high-quality operational weather and climate forecasts

Observational Networks (OBN):

9. Improve observations in critical gap areas such as mountainous areas, upper-air networks and oceans along with innovative mechanisms to establish and maintain OBN.

10. **Establish a robust Regional Data Exchange mechanism** for rapid exchange of observational data and forecast products and significantly strengthen South Asia's overall extreme weather and climate services through a systematic increase in expansion of critical observing system networks.

11. Setup mechanism to lead to utilization of the additional data in forecasting systems, post-processing, and above-all value-addition for better hydromet services.

12. Enhance assimilation, leading to improved high-resolution forecasts and also better verification, evaluation, and downscaling.

Capacity Enhancement:

13. **Capacity development is the backbone for improved services,** and SAHF III sought to design and implement a capacity development calendar across all components of the information value-chain.

Agreed Action Plan & Targets

The forum identified and agreed on several tangible priorities to be undertaken in a time-bound manner as a part of an action plan with measurable targets. The table below outlines the priorities and action plans that were agreed upon. Feasibility, resources required, and a phased approach will be initiated to implement the agreed action plans within the current phase of the SAHF project and beyond.

Priority	Targets	Time Frame	Considerations for implementation
14. Enhance observations & integration into forecasting	1. NHMS-ECMWF and RIMES - Data Exchange Platform to be scaled up.	6- 9 months	Mechanism of feedback for improving medium range skill (3–5-day lead) of extreme weather prediction will be established using country level data for performance evaluation.
	1.2 Real-time data exchanged within the region: 15% improvement		RIMES data exchange platform is already operational. Countries will be pursued to meet the targets.
	1.3 Historical observation data: 20% improvement.		Historical data of extreme events for past 5-years will be used - to evaluate global severe weather forecasts - show value of additional data improving past country level severe weather predictions
15. Address user needs through tailor-made products leveraging collective strengths	2.1: Forecast Accuracy: 10% improvement -		By using real time data from countries for continuous assimilation at 3Km grid scale for SAHF countries NWP needs
	2.2: Establish SAHF Regional Cloud computing, storage, and networking services infrastructure with investment by pooling of resources Through scaling up existing DATAEX Platform to acquire, host and share new and additional global and regional digital ensemble prediction products		Under SAHF implementation knowledge platform will be operational within 1 year. This can be further enhanced based on a feasibility study to implement 2.2

16. IBF- An integrating approach for better service delivery	3.1: National institutional mechanisms involving User Sector institutions established on lines of BANCCA (Bangladesh), IRU (India) & SNCCA (Sri Lanka) for co-production of Services in all other 6 SAHF countries	1 Year	Initial steps to be taken to interface with relevant sectoral partners. Other follow up activities to be pursued beyond the current SAHF implementation
	3.2 IBF/DSS implemented for at least 3 sectors – Agri, DRM and Water	2 Years	Initial steps to be taken to interface with relevant sectoral partners. Other follow up activities to be pursued beyond the current SAHF implementation
17. Capacity development is the backbone	4.1 At least 30% of the NMHS operational staff trained	2-3 Years	All necessary efforts to be taken in working group activities and continue beyond current SAHF implementation
	4.2 At least 20% Staff of user sector institutions trained	2-3 Years	All necessary efforts to be taken in working group activities and continue beyond current SAHF implementation