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Presentation and poster abstracts:

Impact Based Agromet Advisory Services in India

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The challenges facing agriculture in India are ever increasing. First, agriculture is highly dependent on weather and subject to its variability. Second, the possible impacts of climatic variability and climate change leading to extreme weather events pose major challenges. Finally, the sustainability of agriculture is being questioned within the context of the global climate change debate. India being mainly a agrarian country, the economy and further its growth purely depends on the vagaries of the weather and in particular the extreme weather/ climatic events. Failure of rains and occurrence of natural disasters such as floods and droughts could lead to crop failures, food insecurity, loss of property and life, mass migration, and negative national economic growth. In recent years, aberrant weather conditions like delayed arrival of monsoon, prolonged dry spell and hailstorm and unusual rains hampering crop growth and development show significant impact. These lead to loss of crops to various extents.

In order to decrease the vulnerability of agriculture to increasing climatic variability and ultimately to increase the crop production, India Meteorological Department (IMD) runs an operational Agromet Advisory Services (AAS) under Gramin Krishi Mausam Sewa (GKMS) scheme with the help of 130 Agromet Field Units (AMFUs) located at State Agricultural Universities, Indian Council of Agricultural Research (ICAR) institutes and Indian Institute of Technology. The major aims of GKMS scheme are minimizing impacts of malevolent weather & climate and harnessing benevolent weather & climate in agriculture. AAS rendered by IMD is a step towards weather-based crop and livestock management strategies and operations dedicated to enhancing crop production and food security besides reducing crop damage and loss due to extreme weather events.

Under this project, IMD is generating and issuing quantitative district level weather forecast upto 5 days exclusively for agriculture. The products comprise of quantitative forecasts for major weather parameters *viz.*, rainfall, maximum and minimum temperatures, wind speed and direction, relative humidity and cloudiness. These products are translated by the AMFUs for the preparation of district level agromet advisories twice a week, i.e. on every Tuesday and Friday and dissemination to the farming community to help them in taking appropriate decisions for day-to-day farm operations. They use quantified crop/ pest & disease weather impact relationship derived under network project of All India Corodinated Research Programme on Agrometerology of ICAR-CRIDA and Intramural project of Agriculture University.

Weather forecast has wider applications in agriculture in areas like resource management (soil, water and other inputs like seeds, fertilizers and pesticides), pest management (insect, disease and weeds) and in sustaining / enhancing production (yield, quality of produce and post-harvest), market of agricultural commodity. Specifically, weather forecast has vital applications before and after sowing of crops. Late or early arrival of monsoon rains followed by dry spells hamper sowing decisions. Besides, quantity of rainfall as per the forecast, land preparation and sowing of crops can be planned with adequate availability of soil moisture in the seed zone which requires ample rainfall. Temperature forecast in advance during *rabi* season is important for taking decision on sowing of crops. Soil temperature also impacts seed germination.

Even after sowing of crops, weather forecast has the role in deciding intercultural operations, scheduling of irrigation, pest and diseases management and harvesting. Rains that contribute to root zone soil moisture is essential for active growth of crops. Similarly, forecast of dry periods after wet weeks is crucial for planning intercultural operations and application of fertilizers and spraying of chemicals for pest and diseases control. Weather forecast has also potential application in pests and disease forewarning in many crops as per the stage. Forecast on weather anomalies has also impact on crops during the growth stages. Forecast on duration and intensity of various extreme weather events like cyclone, thunderstorm, heavy rainfall, prolonged dry spell, hail storm, occurrence of frost and fog etc. with adequate lead time and related Agromet advisories help the farmers to reduce the impact on crops up to a considerable limit.

There is a need to understand farmers' requirement in terms of weather and proper interpretation of weather information in crop management. Impact of weather on crops varies with respect to stage. In view of understanding the condition of crop health as well as identify the probable reasons, IMD uses number of Agromet products, like spatial distribution of weather parameters, soil temperature, observed and forecast soil moisture and satellite products like Vegetation Condition Index (VCI), Temperature Condition Index (TCI), Normalized Difference Vegetation Index (NDVI) etc. Thresholds for various weather parameters for the crops during growth stages are the basis for generating Impact Based Forecast (IBF) for its application in various regions for aiding the farmers in taking timely decisions on agricultural operations. In poultry sector, thresholds are better defined and impact based advisory are being issued to farmers. For other sectors *viz.* livestock, horticulture, fishery etc., such thresholds are being worked out in collaboration with AMFUs.

There is also need to develop methodologies for climate risk management in Agriculture, estimation of soil moisture within root zone depth, irrigation mapping etc. to prepare more effective Agromet advisories. Categorical and probabilistic rainfall forecasts are also vital for crop planning and management in various parts of the country.

Keeping the need for Agromet Advisory Services (AAS) to be more crop and location-specific to address wide variations in weather within the district into consideration, IMD is in the process of implementing block level AAS by establishing 530 District Agromet Units (DAMUs) in the premise of Krishi Vigyan Kendras (KVK) in collaboration with Indian Council of Agricultural Research (ICAR). Implementation of block level AAS will be beneficial to more no. of farmers due to high resolution forecast with appropriate agromet advisories for the farmers of specific blocks.

Impact based Forecast of Heavy rainfall Events in India: Status and Future Prospective

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In recent years, occurrence of non cyclonic storm related high monsoonal precipitation event over a much localized area in very short time span has been major cause of damage to lives and properties in India. In terms of severity of the event and impact, followings are very high impact rainfall events those affected India during last 15-years of 2005-2019:

- **Mumbai 26-27 July 2005**-One of the worst ever observed unusual localized extreme rainstorm at Mumbai when a maxima of 94.6cm in 24-h with almost 60% of it observed during 1430-2030ISTof 26 July. The event was so localized that it was restricted to areas around Santcurze Airport, due to which 400 people lost their lives, and city was without phone, transport and electricity for a week, damage 5000 crores with closure of Mumbai airport was for almost a week.
- **The sudden Leh cloud burst on 6 August, 2010** leading to flash flood and mud slides leading to over 200 deaths and huge loss to normal life, civic amenities and infrastructure.
- **Uttarakhand severe rainstorm 15-18 June 2013-**The devastating flash flood and series of landslides triggered by Uttarakhand severe rainstorm 15-18 June 2013, killed around 6000 people. Made 100,000 people stranded latter were rescued by Govt.
- **On 30 July 2014**, Malin was hit by mud flow/land slide early in the morning while residents were asleep and it was caused by a burst of heavy rainfall and killed at least 134 people.
- **During 3-7 Sept of monsoon 2014**, Jammu and Kashmiri, the northern most state of India, had rainfall up to 30 to 61cm in 3 to 4 days with worst effect at capital town of Srinagar. Around 250 lives lost and affected whole city for 15 days. Country's another biggest rescue operation by Govt for 250,000 people who were stranded.
- **16-17 Nov and 1-2 Dec 2015 Chennai Flood:** It was hard-hit with more than 500 people were killed and damages and losses ranging from nearly 15000 crore. This is the most severe urban flooding in Modern times.
- **Kerala Extreme rains and Floods of Aug 2018**- 14-16 Aug 2018 was the worst rain episode by which 483 people died, and 14 are missing. Property lost is ₹40,000 crore. Highest rain touched/number of stations reported>7cm and the respective numbers are 11cm/7, 27cm/50, 35cm/50, 19cm/30 and 11cm/3 for 12-13, 14-15, 15-16, 16-17 and 17-18 Aug, respectively with most extreme part of rainfall spell occurred in 14-16 Aug 2018.
- **Extreme rain spells of Aug 2019 at west coast of India:** a) **Kokan and Madhya Maharashtra including Mumbai City during 3-7 Aug 2019** causing 40-80cm of cumulative rainfall due to which around 50 lives. The ever highest 24- hours rainfall for the period for the state was reported from Pen with value of 49.3cm with Mumbai airport closing partially. b) **Kerala during 8-10 Aug 2019-** Kerala received extreme rainfall(>20.4cm) spell during 7-10 Aug with cumulative 20-60cm. The ever highest reported was 33 cm in Ottapalam on 8-9th August. This cause landslides and around 102 lives lost. Cochin airport was also closed for a day.

IMD classification of rain events based upon reporting of 1-hour rainfall and accumulated 24-h rains at a place are available at http://imd.gov.in/section/nhac/wxfaq.pdf. As per the IMD, cloudburst phenomenon though explicitly still have not been mentioned in hourly rainfall classification, but an amount of 5-10cm in an hours if recorded by any station, called as Very Intense Spell to Extremely intense Spell. In the present study, we have briefly analyzed all these major extreme rain episodes including their types of impact using high resolution rainfall as well as impact data for identification of types of different rainfall realized range against the damage reported from various sectors. IMD till 2017 was issuing heavy rainfall warning up to 5-days for different category in textual form and then from 2018 has started color code warning(Red, orange, Yellow, Green) in multi-hazard warning map form, at both district and Met sub-division wise where extreme rainfall defined at >20.4cm in 24-h, if forecasted, then the area has to mark as red(take action), heavy(>6.4cm) to very heavy(>12.4 cm) at scattered places over an area if, for 3rd day consecutively, has red color warning etc. Recently, since 5th Sept 2019, IMD has implemented Experimental Impact forecast based on heavy rainfall warning with following impact component added and by considering topography of likely occurrence areas (e.g. hilly region or plains or coastal areas).

Expected impact corresponding to “Red color” warning (for plain region)
• Localized Flooding of roads and water logging in low lying areas, closure of underpasses. • Occasional reduction in visibility due to heavy rainfall. • Disruption of traffic flow in major cities due to water logging in roads leading to increased travel time. • Closure of under passes. • Minor damage to kutcha roads. • Possibilities of damage to vulnerable structure • Localized Mudslides, rock falls & land slide in hilly region. • Damage to horticulture crops

IMD IBF work components related to heavy rainfall events, have been classified into following 4 stages starting from developmental phase to implementation phase of each stage in order to achieve its goal:

- **Stage I:** Most generic form-In form of Multi-hazards map/Textual form- only inclusion and color cod based as per severity of a particular series /type of whether event affecting for day from a season/month
- **Stage II:** Color cod warning of IBF by classifying vulnerability of different areas under impact in terms of generalized impact and assigning Red color warning for the worst impact type in the order.
- **Stage III:** Impact Data collection from past severe weather damage (IMD, NDMA, Ministry of Information& Technology (MeITy) and district’s NIC websites etc.)
- **Stage IV:** Development, customization and implementation of dynamic system of IBF (IBF Models)

For heavy rainfall events, IMD has already implemented IBF since start of summer 2018 and 5 Sept 2019 respectively as stage I, in which IMD has only implemented IBF in terms of identifying various components of potential impact to various sectors in most generic form in the context of vulnerability of the respective areas as impact to respective severe weather event type. In the present paper, the progress so far in heavy rainfall event has been discussed including action plan of 2019-2021. The collaboration works those IMD has implemented with UKMO under WCSSP Project 2018-2021 and with NCCR in order achieve its objective of IBF from heavy rainfall events have also been discussed.

Fog across Indo-Gangetic Plains: IBF for different sector using Event and Impact Characteristics of 2008-2019

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During each winter, Indo-Gangetic Plain(IGP) suffers severely from frequent spells of occurrences of high duration dense fog and smog events at both moso-scale as well as large-scale. Study of fog layer across IGP using satellite shows complexities of such fog events lies with its sudden development and its fast spreading to cover most parts of this great plain and hence a challenge to forecast. Studies also show both temporally and spatially, such fog events may be the fastest in formation, largest in areas and longest in duration, if compared to any other fog areas of the world and, so also in terms of magnitude of its severe impact as it spreads over such world's mostly densely populated region. Impact of dense fog most severely felt in Aviation, Railway and Highway, Ferry services in rivers and power sector (tripping of its high power cable lines). Fog cover for longer period of the day disrupt sunlight causing low day temperature or cold day and also impacts AQI and Pollutions. It also impact agriculture in terms of Crop growth stage, flowering stage and at seed formation stage. It is utmost dangerous and disturbing for all mode of transports especially aviation and Railway. In some winters when such large-scale fog layer is in peak form in terms of both in spatial coverage and intensity across this great plains, study of impact data finds 100s of trains cancelled and 1000s of passengers are held up. Such impact further aggravates, due to their regular occurrences night after night consecutively 10-15 days across this great IGP in the absence of any significant winds. It also blinds most of major airports across this IGP resulting complete closure of airports from any aviation operation across it, as encompasses a number of large urban areas with Lahore at west, then Amritsar, Ludhiana, Jaipur, Chandigarh, Delhi, Lucknow, Allahabad, Varanasi, Patna, Gaya, Kolkata, Dhaka, Guwhati etc. The common people have to face severe impact as it impaired their visibility. Though no define study of its impact available, but data from multiple sources alone for just two winters of 2016-17(2017-18) find around 120(159) human lives lost in Dec-Jan across north India out of which there were some of the terrible accidents.

The classification of fog intensity has been defined based upon user's criteria of operations minima in various sectors and also its impact on impairing visibility for common man road travels. **The present study aims at identification of major severe spells season-wise during 2008-2019 using surface data and Satellite fog coverage on day to day and hour to hour from IMD and then analyzed event features in terms of onset, lifting, lowest surface visibility reached, duration remains, areas covers with their impacts on each of above sectors and on lives of common human being.** Some of the impact has been illustrated in the present study using real time data from railway and aviation sectors. Also, fog impact in terms of road accident cases has been discussed. It also discuses IMD implementation of stage-1 of Fog IBF at real time in color code fog warning at district and state wise as Multi-hazards map based color code warning with Red as highest warning based upon likely lowest Vis range over those areas from likely fog intensity.

Table 1. Impact table for common people Fog based on Vis

Very Low Impact VIS BET 1000-500	Low Impact VIS BET 500-200	Medium Impact VIS BET 200-50	High Impact Vis<50m
• Limited travel disruption with difficult travel conditions mostly confined to a few prone routes. • A few road traffic collisions.	• Difficult driving conditions with slower journey times. • Some road traffic collisions • Passengers delayed with short-term closure of airports.	• Difficult driving conditions with long journey times. • Road traffic collisions • Passengers delayed and/or stranded at airports and/or ferry terminals.	Closure of rail routes, high ways and Airports

Table 2 Fog intensity defined for different users communities-An IBF

General Visibility Range Common (Road ways, Ferry services, and Railways, Airport)	Specific to Airport and aircraft operation minima (RVR Range as per DGCA CAR) (in meters)	CAT-Types as per ICAO	General Visibility Range valid for IGIA (in meters)
Shallow	1000-500	1200-800	Safeguarding procedure to start
Moderate	500-300	800-550	CAT-1
	350-200	550-275	CAT-II
Dense	200-50	270-175	Cat IIIA
		175-50	Cat IIIB
Very Dense	< 50	175-50	Cat IIIB
		<50	Cat-IIIC

Impact based forecasting for Thunderstorm and associated phenomena

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Thunderstorms over the Indian region range are pre-dominantly in the meso-beta and meso-gamma scale and have lifetimes ranging from a few minutes to a few hours. The associated weather also affects a mesoscale domain. In the absence of a dense network of observatories, this creates constraints in true reporting of events and their impacts. However, as various government statistics indicate, these phenomena have emerged as one of the major sources of destruction of both lives and resources. The various phenomena associated with the occurrence of thunderstorms over the Indian region may be separated into four categories:

a. Rainfall
b. High winds
c. Hail
d. Lightning

Associated with these primary phenomena there are secondary phenomena such as flash floods due to heavy rainfall, uprooting of trees, electric transmission lines etc due to high winds, forest fires in association with lightning. All these phenomena do not affect the entire Indian region uniformly and throughout the year. While rainfall is the most significant phenomenon during the monsoon season over most parts of the country, the other phenomena have distinct spatial and temporal maxima. Figure 1 a indicates the annual spatial frequency of thunderstorms over the Indian region, while figure 1 b displays the intra-annual total frequency of thunderstorms over the Indian region during two consecutive years in 2016 and 2017. It may be noted from the figures that although the thunderstorm frequency is high along the foothills of the Himalayas, the highest frequency values are over the region of Bangladesh and adjoining east India and over South west peninsula (Kerala). The frequency is highest in May and June, and is generally high during the period of April to October. However, the spatial distribution of severe weather associated with thunderstorms has a different pattern. If the entire Indian region is divided into five zones as indicated in figure 2, it may be noted that during the period when, their frequency is highest –March to June, the frequency of hail and wind squall events are not uniform throughout the region (figure 3 a to f). While frequency of thunder squalls is highest over the east Indian region, frequency of hailstorms are highest over the east Indian region. Also while hail events are most frequent during the noon to evening hours (12 IST to 20 IST), the squall events are frequent in the afternoon to late night hours (12 IST to 04 IST). Also, while Hailstorms are more frequent in March to May period, squall events are more frequent during the April to June period. Earlier studies (Saha et al, 2017) indicate that lightning is most frequent over east India during the March to May period and over the West Himalayan region and adjoining plains during June to September period.

Figure 4 indicates the population density over the Indian region in 2018. It may be noted that the population density is highest in the fertile Ganges Delta in North India as well as well extreme south west peninsular India. These are also the regions where annually, thunderstorms are most frequent. Associated phenomena such as lightning and high winds are most frequent over east India. Hence, it is expected that related damages will be highest over these regions.

However, an analysis of the regions of maximum impact from thunderstorms indicates that they don't necessarily match the regions of high frequency of occurrence. The difference in their occurrence will be discussed in detail in the presentation. This pattern is reflected in previous studies too with various data sources (Singh et al, 2015, Selvi et al, 2016).

Further analysis also indicates that spatially, damaging thunderstorm events may be categorized into two types,- (a) Regions with frequent low impact events and (b) Regions with infrequent high impact events. This has ramifications in the warning strategy for each region. For the former regions, since awareness is greater, the public and civic authorities are likely to be more receptive and cooperative to permanent lifestyle changes, and investments to infrastructure for damage control. Nowcast warnings are also more effective in triggering appropriate action. For the latter, more detailed meteorological analysis is necessary to provide necessary warnings well in advance for such events to take adequate action for saving lives and property. Also, in the absence of awareness, in the latter case, pre-season disaster management exercises need to be undertaken more thoroughly, to raise awareness among the public about such events.

The last mile connectivity regarding dissemination of thunderstorm warning and mitigation of its impact is a major step. In this regard, the National Disaster Management Authority of India, have stepped in to bring various ongoing such endeavours –at national as well as state level, under a common umbrella and coordinating their future course of action. The organization has brought out a document, that lists the various actions to be taken, and the agencies responsible for the same.

Since monitoring the intra-annual change of seasons, as well as intensity and spatial extant of weather events is under the purview of the India Meteorlogical Department, the organization has a leading role in these endeavours. India Meteorological Department follows a multipronged approach to warning about thunderstorms and associated phenomena. The action regarding the warnings is issued in three phases:

(i) Pre season preparedness meeting: As a part of this initiative, at the national and state level, pre-season meetings are organized with various stakeholders, to alert them of the significant weather of a season and its impact. The stakeholders are not only a part of the Government machinery such as the District Collectors and other State level disaster management functionaries but also media people, who provide a huge help in disseminating correct information about the weather and also report back about associated damages.

(ii) 24-48 hour Severe weather advisory: This advisory delineates the regions likely to be affected by significant weather within the subsequent 24-48 hours.

(iii) 3 hourly Nowcast Bulletin: This bulletin is issued at district or sub-district level, as well as significant towns and cities. The warning contains information for the severe weather in as much quantitative form as possible as well as likely associated impacts.

Standard Operating Procedures are in place for Step (ii) and Step (iii). Periodic training programs are organized for weather forecasters to educate them about the new products that become available as well as provide a two-way feedback mechanism for issuing of weather warnings. All these steps have significantly improved thunderstorm forecasts over the Indian region. However, on account of the inter-annual variability of weather over the Indian region, it is too early to gauge its effect in terms of amelioration of the disastrous weather events over the Indian region.

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Impact Based Forecasting in North East India

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In recent years, phenomenal improvement has been observed in weather forecasting and prediction skills with great benefit from the introduction of Early Warning Systems (EWSs). Despite significant advances and continuous quest for innovation from the scientific and user communities towards EWSs, still it was mostly confined to the meteorological/hydro-meteorological hazard forecast and the information on probable consequences and potential impacts was generally missing till recent past. There are evidences that people have a tendency to under-react to the weather warnings generally because of improper understanding of the potential impacts of the severe weather event and accordingly fail to demonstrate the appropriate response behavior to a large extent. Introduction of Conceptual Multi-Hazard Impact Based Forecasting and Warning services by WMO resolution with the aim to bridge the gap between scientific community, different stakeholders and end user has brought an exemplary progress towards the last mile connectivity in most appropriate & understandable format by connecting & increasing synergies between four (04) fundamental components of effective EWSs *viz.* Risk Knowledge, Monitoring & Warning, Dissemination & Communication and Response Capability with inception of cross cutting component in the form of Community Centric Bottom-up Approach. Out of these four fundamental components, the first component *viz.* Risk Knowledge is one of the most sensitive & challenging aspect to quantify in terms of Hazard, Exposure & Vulnerability; which ultimately translates into Impact/Risk and demands maximum attention having multifold sensitivity to various natural, socio-economic and physical issues due to complex mutual interaction mechanism. Impact Based Forecasting has brought a paradigm shift in the forecasting jargon by switching from Static system (Seamless Forecasting) to Dynamic system (Multi Hazard Impact Based Forecasting), which has proven to be a great initiative towards '*TRANSLATING HAZARD INFORMATION INTO IMPACT SCENARIOS*'.

India Meteorological Department is the national nodal agency under the aegis of World Meteorological Organisation to issue different meteorological forecasts & warnings and to extend all possible support to other nodal agencies dealing with different type of Hydro-meteorological, Geological & Environmental Hazards including most important Agriculture & Aviation sectors and many more. Regional Meteorological Centre Guwahati is the nodal Agency in this domain for the North Eastern Region of India consisting of 07 states broadly classified under three meteorological subdivisions, *viz.* Arunachal Pradesh, Assam & Meghalaya (A&M) and Nagaland, Manipur, Mizoram & Tripura (NMMT). Each of these region have different climatic zones/features owing to its complex physiographical characteristics due to which this region is one of the most vulnerable part of the Indian subcontinent pertaining to various severe/disastrous natural hazards like floods, cloud burst, flash floods, landslides, intense & severe convective storms and seldom Fog events; often resulting into high socio-economic impacts due to its peculiar geophysical settings in the vast flood plain of two major river systems forming the Brahmaputra–Barak basins (BBB).

This region is very often prone to furry of monsoon and the floods in Assam are most acute and unique so far its extent, duration and magnitude are concerned with 40% of its land surface susceptible to flood damage (Rastriya Barh Ayog). Though heavy rainfall events are very common over this region during monsoon season, but a prolonged & extensive spell of intense rainfall (heavy or more) is a not a regular phenomenon. This year North-Eastern Region experienced a prolonged and extensive spell of intense rainfall activity during July, 07-16; which resulted into one of the worst floods over Assam in the recent past affecting 31 (out of total 34) districts of the state during July-2019. This continuous Widespread rainfall activity & Active monsoon conditions over NER, which lasted for more than a week, resulted into 'LARGE-EXCESS' rainfall in all three meteorological subdivisions of the region *viz.* Arunachal Pradesh (159%), Assam & Meghalaya (106%) and NMMT (70%) in excess to the NORMAL and due to which the seasonal rainfall deficiency, following the late arrival of monsoon, has been brought down to NORMAL (8% as on 16th July 2019) category from the DEFICIENT (38% as on 06th July 2019) category over the East & North East Homogeneous Region.

In this study, a methodology for qualitative real-time impact assessment for this extensive and prolonged spell of Heavy Rainfall is presented. This paper discusses about the potential challenges and opportunities offered by this approach in the decision-making workflow in an operational context. The methodology may be classified into three principal aspects. The first & foremost input comes from the Analysis of all available observations in the form of diagnosis & prognosis through thorough evaluation of different broad scale synoptic systems, meso-scale geophysical (dynamical and thermodynamical) characteristics & microphysical (Radar & Satellite) characteristics. It also configures a proper set of initial condition for the numerical model integration with different sensitivities. The second part comes in the form of quantitative assessment of different forecast/warning elements and identification of hazard type through subjective consensus after thorough evaluation of objective analysis of different numerical models and different single/multi-model ensemble guidance products with different sensitivities through proper value addition. Final, but most vital part is the translation of this scientific information into impact scenarios to include exposure & vulnerability factors qualitatively and to quantify the uncertainties in the first two parts for proper Risk Assessment and Decisive Action.

The present approach goes one step further and comes up with a Provisional Nine (09) Point Proposal towards qualitative Impact Based Warning products on experimental basis with specified colour codes depending upon the scale of exposure & vulnerability pertaining to the specific type of hazard/multi-hazard in the North Eastern Regions of the country, which may ultimately result in better contingency planning with community centric bottom-up approach. This approach would also improve the objective evaluation of responsibilities of forecasters and decision makers in the EWS context. Additionally, Impact Based Forecast/Warning elements can further contribute towards Community Based Disaster Risk Reductions, Resilience & Response (CBDRRRR) mechanism through common situational awareness & behavioral recommendations (BRs) in order to achieve the prescribed seven (07) Global Targets of Sendai Framework (2015-2030) with four (04) well defined Priorities for action towards Disaster Risk Reduction.

Overall, this study aims to offer a first insight into the impact-based forecasting and warning services with various sectoral applications in North-East India to trigger further research and project developments with empirical justification for the added expense and time associated with the more detailed hazard warnings.

Key Words: EWS, Seamless, Impact, Hazard, Risk, Response, Resilience, Sendai Framework etc.

Prediction & impact-based forecast for Heat Waves issued by India Meteorological Department

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As per annual climate summary report published by India Meteorological Department (IMD) in year 2011, the mean maximum temperature over India has increased by about 1.1° C since the beginning of the twentieth century. In general, studies indicate increasing trends in heat wave over most parts of the India particularly along west coast of India. Worldwide, there is no uniform definition of heat wave, generally it is defined as a prolonged period of excessive heat over some particular area or region. As per the World Meteorological Organization (WMO), when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5°C, it is defined as heat wave.

In India, heat wave is considered when actual maximum temperatures reach at least 40°C for plains and at least 30°C for Hilly regions

a. Based on Departure from Normal

Heat Wave: Departure from normal is 4.5°C to 6.4°C

Severe Heat Wave: Departure from normal is >6.4°C or more

b. Based on Actual Maximum Temperature

Heat Wave: When actual maximum temperature ≥ 45°C

Severe Heat Wave: When actual maximum temperature ≥47°C

c. Criteria for describing Heat Wave for coastal stations

When maximum temperature departure is 4.5°C or more from normal, Heat Wave may be described provided actual maximum temperature is 37°C or more.

In India, Heat wave occurs mostly over an interior plain area when dry and warmer air is transported in a region with clear skies and hence maximum insulation during the summer season. Bay islands, Lakshadweep, Tamil Nadu, Kerala, Coastal and South Interior Karnataka are not affected by heat waves due to the occurrence of maritime air over these regions. It is generally develop over Northwest India and spread gradually eastwards & southwards but not westwards (since the prevailing winds during the season are westerly to northwesterly). But on some occasions, heat wave may also develop over any region in situ under the favorable conditions. Heat wave is predicted by IMD in short, medium, extended & seasonal range in meteorological sub-divisional scale. During March to June, Forecasting Demonstration Project (FDP) is carried out by IMD to issue special heat wave bulletin in graphic format everyday at

4:00 PM for all the 36 sub-divisions of India to various stakeholders including health and power sector and disaster managers. IMD issued impact based warning during summer months (March to June) 2019 as per the criterion given below:

Colour Code	Alert	Warning	Impact	Suggested Actions
Green (No action)	Normal Day	Maximum temperatures are near normal	Comfortable temperature. No cautionary action required.	Nil
Yellow Alert (Be updated)	Heat Alert	Heat wave conditions at isolated pockets persists on 2 days	Moderate temperature. Heat is tolerable for general public but moderate health concern for vulnerable people e.g. infants, elderly, people with chronic diseases	(a) Avoid heat exposure. (b) Wear lightweight, light-coloured, loose, cotton clothes. (c) Cover your head: Use a cloth, hat or umbrella
Orange Alert (Be prepared)	Severe Heat Alert for the day	(i) Severe heat wave conditions persists for 2 days (ii) Through not severe, but heat wave persists for 4 days or more	High temperature. Increased likelihood of heat illness symptoms in people who are either exposed to sun for a prolonged period or doing heavy work. High health concern for vulnerable people e.g. infants, elderly, people with chronic diseases.	(b) Avoid heat exposure– keep cool. Avoid dehydration. (b) Drink sufficient water- even if not thirsty. (c) Use ORS, homemade drinks like lassi, torani (rice water), lemon water, buttermilk, etc. to keep yourself hydrated
Red Alert (Take Action)	Extreme Heat Alert for the day	(i) Severe heat wave persists for more than 2 days. (ii) Total number of heat/severe heat wave days exceeding 6 days.	Very high likelihood of developing heat illness and heat stroke in all ages.	Extreme care needed for vulnerable people.

During 2019, all major heat wave epochs over Central parts of India was during 29 May-12 June, 2019 over central & northwest India and during 12-17 June, 2018 over East & adjoining south India. The warning for the same was given 3 to 5 days in advance. The different verification scores are given in following figure, there is significant improvement in the scores in this year as compare to the previous years.

All India	**FAR**			**MR**			**CSI**			**POD**		
	D1	**D2**	**D3**	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**
2017	.07	.06	.02	.33	.51	.77	.40	.32	.19	.67	.49	.23
2018	.03	.04	.02	.09	.28	.52	.54	.40	.32	.91	.72	.48
2019	**.11**	**.10**	**.08**	**.08**	**.15**	**.38**	**.49**	**.47**	**.38**	**.92**	**.85**	**.62**

South Asia Flash Flood Guidance System – A Brief

Ashok Raja
IMD Delhi

World Meteorological Organization (WMO), in partnership with the U.S. Agency for International Development/ Office of the U.S. Foreign Disaster Assistance (USAID/OFDA), the National Weather Service (NWS) of the U.S. National Oceanic and Atmospheric Administration (NOAA), and the Hydrologic Research Center (HRC) started a Global Flash Flood Guidance System project to cater services for hydro meteorological events occurring in short duration time. Global Flash Flood Guidance System (FFGS) is recognized as one of the **Impact Based Forecast and Warning Service (IBFWS)** tool.

The use of this tool in IBFWS has the ability to improve the synergy between NMHSs, NDMAs and citizens that play a role in hazard mitigation (e.g. flash floods), by bridging the gaps between the four components for effective early warning systems: 'risk knowledge', 'monitoring and warning service', 'dissemination and communication' and 'response capability'.
The adoption of such a robust approach is identified as a high priority in the WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services (2015, WMO-No 1150) as well as in the Multi-hazard Early Warning Systems: A Checklist (2018). These support the Sendai Framework for Disaster Risk Reduction 2015-2030 (United Nations, 2015).
The aim of the FFGS is to provide a diagnostic value (known as flash flood guidance) that estimates the amount of rainfall of a given duration within a watershed that is required to produce flooding at the outlet of the catchment. The FFGS is designed to update its values in time and space and to "remember" rainfall that has already occurred in the catchment. In this way, the FFGS takes account of antecedent catchment conditions and can calculate the amount of additional rainfall that is needed in order to produce flooding. When these values are used in real time with nowcasts or in a forecasting capacity, they provide an objective basis to generate flash flood warnings.

The FFGS provides global coverage to 3 billion people or 40% of the world's population. The countries using the FFGS have a combined land surface area of around 25 million square Kilometers, which is equivalent to 18% of the total land surface area of the world. Specifically, the South Asia Flash Flood Guidance System (SAsiaFFGS) provides coverage for nearly 51% of the world's population.

Presently, ***SAsiaFFGS is in experimental operation catering services to India, Nepal, Bhutan, Srilanka and Bangladesh this 2019*** and it is active through two servers (Computational & Dissemination) hosted at **India Meteorological Department (IMD), India, as Regional Centre of SAsiaFFGS**. Upon verification of cases and validation on different temporal and spatial scales, the same is likely to put on full operation mode from **May 2020**.
The inherent nature of social media platforms allow for rapid dissemination and amplification of information among the key players both within the country and outside. WhatsApp in particular has emerged as a widely used tool for such communications between weather forecasters, emergency managers and communities. Tapping in on the potential of the social networking platforms This is a powerful tool for gathering information for verification studies of FFGS products and flash flood warnings as it allows for the in-formation to be transmitted instantly and in real-time from the field.

Further ***to improve the system with better forecasting abilities, the following South Asia Flash Flood Guidance System (SAsiaFFGS) project activities is planned by 2021***:

- Steering Committee Meeting;
- Upgrade High Resolution Multi-model Numerical Weather Prediction (NWP) Quantitative Precipitation Forecasts (QPF) into the SAsiaFFGS;
- Initial Collaboration Visit for Radar Data Ingestion into the System;
- Conditional re-delineation of basins accounting for previous adjustments;
- Re-calibration of the land surface model for the new basins;
- Radar Quality Control and Ingest of Radar Precipitation Estimates into the SAsiaFFGS;
- On-line Radar Hydrology Course;
- Training at HRC For Radar QA/QC, Radar Hydrology (All Countries With Radar);
- Regional QA/QC and Radar Hydrology Workshop (1 Week);
- Step 5 Training.

Heat Wave Episodes over India during MAM 2019: Bias Correcting the Probabilistic Forecasting and their Verification

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In spite of many significant improvements in NWP models including major improvements in the model physics and resolution, these models still suffer from systematic biases. There are several methods available to remove these systematic errors from a model, for example by applying statistical post processing algorithms. In the current study we have made an attempt to correct the bias in the maximum temperature (*Tmax*) forecasts obtained from the NCMRWF's Ensemble Prediction System (NEPS) by applying Decaying Average Bias Correction (BCDA). This statistical post-processing method applies an adaptive [Kalman filter type (KF)] algorithm to accumulate the decaying averaging bias. To mimic the operational environment and maximize the benefit from a bias correction, this method is applied to ensemble mean for maximum temperatures (*Tmax*) initially at each forecast lead time. Later on the bias-corrected members are also created. Thus bias correction significantly improves the probabilistic forecasts for Tmax**.**

The probabilistic verification of NEPS bias-corrected *Tmax* forecast along with IMD's observed *Tmax* valid for 30 May 2019. For *Tmax* ≥ 43°C, in observed Rajasthan, Punjab, Haryana, Delhi, Uttar Pradesh, Madhya Pradesh, Jharkhand, Odisha, and Maharashtra regions are covered *Tmax* exceeding 43°C which was very well forecasted by NEPS more than 95% of probability for all the states for all lead times. For *Tmax* ≥ 46°C north Rajasthan, NW MP and SW UP is having probability within the range of 65-95% for all lead times. For Vidharbha there is over forecasting probability of 5-35%.

Keywords: Extreme Events, bias correction, decaying average, Brier Score, Probabilistic forecasts

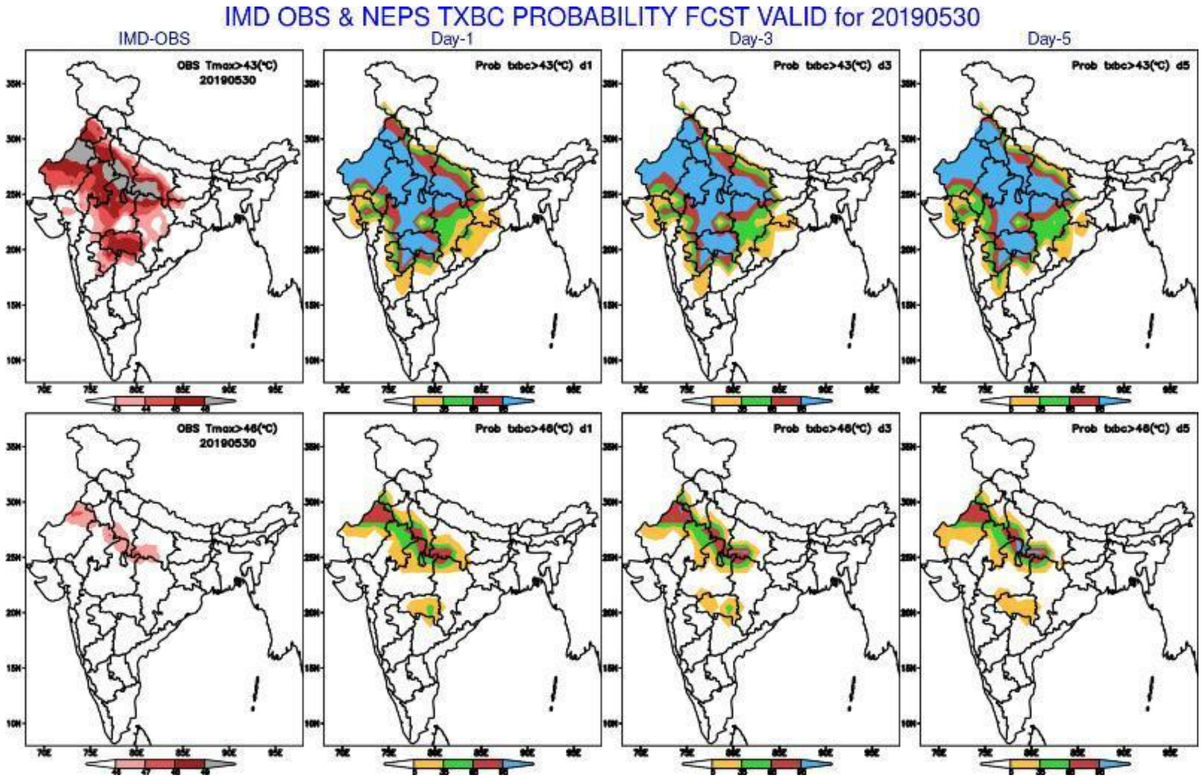

Figure: The probabilistic verification of NEPS bias-corrected *Tmax* forecast along with IMD's observed *Tmax* valid for 30 May 2019.

Probabilistic Forecasting of extreme weather events by NCMRWF ensemble forecasting systems

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The global ensemble prediction system of NCMRWF (NEPS-G) is based on Met Office Global and Regional Ensemble Prediction System (MOGREPS) operational at Met Office, UK. The horizontal resolution of NEPS-G is 12 km and it consists of 23 ensemble members (1 control +22 perturbed). The initial condition perturbations are generated by Ensemble Transform Kalman Filter Method and the uncertainty in model physics is taken into account by Stochastic Kinetic Energy Backscattering (SKEB) and Random Parameter (RP) schemes. In order to address the problem of lack of spread in near surface variables the perturbations of sea surface temperature, deep soil temperature and soil moisture content have been included. A set of eleven members run from initial conditions of 00 UTC of current day and another set of eleven members run from 12 UTC of previous day to give forecasts up to next 10 days.

NCMRWF has also implemented a 12 member (1 control+11 perturbed) regional ensemble prediction system (NEPS-R) based on regional version of MOGREPS. The horizontal resolution of NEPS-R is 4 km and it has 80 vertical levels extending up to a height 38.5 km.Initial and boundary conditions of NEPS –R are provided by NEPS-G. The horizontal domain of NEPS-R extends from 7^0 to 38^0 E and from 67^0 to 98^0N which includes entire India. NEPS-R runs from 00 UTC every day and gives 75 hours forecast.

A tropical cyclone and a heavy rainfall event have been considered in the present study to investigate the performances of NEPS-R and NEPS-G. The categorical probabilistic forecasting of 24 hourly accumulated precipitations from both the forecasting systems has been studied for both the events. The probabilistic forecasting of track and intensity of the tropical cyclone from these two forecasting systemshasbeen presented. The need for generating more impact based probabilistic forecasting products has also been highlighted

Impact based forecast for drought and flood monitoring and management and also for health sector

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India is a large developing country and almost all the people of country living in rural or urban areas directly depend on climate-sensitive sectors like water, health, energy, agriculture etc. Water sector has direct influence with other sectors like agriculture, health, food security, disasters etc. Rainfall/Precipitation the only input to the hydrological cycle is having high spatial and temporal variability. Both real time monitoring and forecast of rainfall are crucial and also very useful for flood and drought, agriculture and other sector managements. However demands or requirements of information on spatial scales are different for different sectors. Also since both flood and drought are basically impact based hazards it is necessary to monitor the events not only with rainfall but the effective indices defining the impact based hydrological hazards. The primary cause of drought or flood is though precipitation but both the hazards are purely defined based on impact on the society. Generally based on impact on different sectors drought is categorized as meteorological drought, agricultural drought, hydrological drought and Socioeconomic Drought. Instead of simple precipitation, there are various indices to monitor different types of drought. Standardized Precipitation Index(SPI) and Standardized Precipitation Evapotranspiration Index are the most well accepted index for monitoring meteorological, agricultural as well as hydrological drought. Weekly monitoring of these indices as well as generation drought outlook from one week to four week using SPI along with the performances of the outlook generated during the Southwest monsoon 2019 will be presented. In flood monitoring and prediction, weekly rainfall and volume of water in the 101 river sub basins of India and also weekly outlook of expected rainfall and volume of water using IMD-IITM ERF output during the southwest monsoon rainfall is discussed. To analyse the important of impact based river basin forecast in view of recent flood events of Maharashtra during July-August 2019, the performances of river basin forecast is also highlighted. Also using ERF activities of IMD on generating weekly climate outlook for health and also verification of outlook for Malaria and Dengue will be presented.

Satellite based indicators of IBF

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Extreme weather events such as heavy downpours, heat wave, flood, thunderstorm, etc. have become a major concern over several regions of globe in the warming climate scenario. In recent past, extreme weather events have led to large calamity over different parts India and hence it is a major concern to be addressed. For example, meteorological parameters such as the Convective Available Potential Energy (CAPE), the Hot Weather Outlook and concentration/distribution of $PM_{2.5}$ have a major bearing on the societal impacts and need to be timely assessed towards welfare of living beings, which includes vegetation and livestock besides human beings.

National Information System for Climate and Environment Studies (NICES) has been addressing different issues related to climate, including extreme weather events, by integrating satellite and ground based measurements along with model simulations.

One of the important parameters which can be used to predict heavy rainfall events and thunderstorm activities is CAPE, which is a measure of positive buoyancy available for the rise of air parcel and, hence, the parameter indicates the instability in lower troposphere. CAPE plays a dominant role in convective precipitation and provides a deeper insight into genesis and intensity of atmospheric convection. As part of NICES activities, estimation of CAPE has been carried out (from 2014 onwards) using vertical profiles of atmospheric temperature and humidity from Indian Geostationary satellite INSAT-3D sounder and foreign polar satellite JPSS1-CrIS. Validation of satellite retrieved CAPE has been carried out by using ground based atmospheric profiling with Hyperspectral Microwave radiometer.

In order to address the issue of heat waves, NRSC has developed a Hot Weather Outlook (HWO) through which day-ahead alerts are being hosted on Bhuvan web-portal, for the entire country since 2017. The HWO is generated using satellite measurements of Outgoing Longwave Radiation and Vegetation Index (which indicate the spatial pattern of heating at the land surface and the inertia of the surface to temperature changes respectively), ground based measurements of meteorological parameters from ISRO AWS network and forecasts of air temperatures from atmospheric models. Using these inputs from different sources, heat alert levels are estimated over the area of interest at 5km grid level in the form of spatial map. The HWO product for entire India during pre-monsoon season (March – May) is being disseminated to public through Bhuvan web-portal.

Outdoor air pollution is a major contributor to global environmental burden of diseases. Particles suspended in the atmosphere with diameter less than 2.5μm ($PM_{2.5}$) one of the major air pollutants. Alarming concentrations of $PM_{2.5}$ is a major concern in many of the cities in several countries including India. Traditionally, ground based measurements are used for monitoring $PM_{2.5}$ concentration. But, large spatial variability of $PM_{2.5}$ concentration makes, surface based measurements over limited number of locations insufficient to provide realistic information needed for the impact assessment on air quality and human health. Satellite based retrieval of $PM_{2.5}$ is a possible solution to address this major issue. Aerosol optical depth (AOD), retrieved by satellites can be used as a primary parameter for estimating $PM_{2.5}$ concentration. Under NICES, estimation of $PM_{2.5}$ is carried out from satellite measurements of AOD. The conversion factors used for estimating $PM_{2.5}$ from AOD is established for the entire India using multi-satellite observations and ground based measurements.

Developing an Impact Based Ocean State Forecasting and Warning System: for Saving Life and Property

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Prior knowledge of ocean state is important for an informed and proper planning of marine operations, safe navigation, saving life and livelihood at sea, and even it is so crucial for national security. Here lies the importance of impact-based operational ocean state forecasting and dissemination to various categories of users through various dissemination modes. ESSO-Indian National Centre for Ocean Information Services (INCOIS) is the Indian nodal agency to provide operational ocean information, forecast and advisory services. The users include offshore industries, coastal population, fisher folks, navy, coastguard, port and harbors, maritime boards etc. At present, we provide daily updated user-customised general forecasts of Wave height, direction and period (of wind waves and swells), Sea surface currents, SST, MLD, D_{20}, Astronomical tides,Wind speed and direction and Oil-spill trajectory. Joint INCOIS-IMD bulletins consisting the meteorological and oceanic information and forecasts, along with separate high sea state warnings, are issued during extreme weather conditions. High wave, high period swell, perigion spring tide and rough sea conditions are warned/alerted with a lead time of minimum three days with remarkable operational accuracy and without any miss/false alarms.

User-required customised products such as 'Search and Rescue Aid Tool' (SARAT), 'Ocean state forecast along ship routes', 'Sea state forecast for port and harbours', 'OSF-Web map services', were developed, and made operational, and which was highly demanded and used as evidenced from the drastic increase in the users. These products are found to be used by offshore industries, in turn, it caused to positively affect the Indian Blue economy. Consultancy projects and data delivery are carried out in a user-demanded fashion and payment-basis to various maritime or offshore industries. ESSO-INCOIS already extended the Ocean State Forecast services to neighboring countries like Maldives, Sri Lanka, Seychelles, Comoros, Madagaskar and Mozambique in collaboration with The Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES, which is an international and intergovernmental institution, owned and managed by its Member States, for the generation and application of early warning information), especially through a dedicated webpage designed for them.

Statistical bias correction to the forecasts are applied to the direct ocean model forecasts using real-time observations from different parts of the Indian ocean. The Ocean State Forecasting operations and services's Quality Management System is conferred with ISO 9001:2008 certification in 2014. User feedbacks and delayed mode evaluation/auditing suggest not only that the forecasts are > 80% accurate, but also that the forecasts/information reach the maximum end users on time, which is also equally crucial for saving life and property.

Modern trends of Information and Communication Technology are used right from the forecast generation, evaluation & fine-tuning until the forecast dissemination to the end users. The dissemination modes include Public Addressing Systems, Fax, Telephone, Radio, TV, E-mail,Web site, Social media and Mobile phones (both SMSs and audio messages) individually or in combination.

According to the World Meteorological Organisation (WMO, 2015), it is no longer enough to provide a good and timely weather forecast or warning, but there is presently an increased demand for the information regarding the safeguard of the lives and property of common man. In simple terms, while there is a realization of what the weather might be, there is frequently a lack or at least ambiguity of understanding of what the weather or high sea state might do. Accordingly, as per WMO (No. 1150 in 2015) manual, they urge all weather forecasting centres of its member countries to convert/upgrade their weather forecast and warning services to a multi-hazard impact-based one, rather than a general one. The latest update of WMO manual (No. 558 in 2018) states and put forward a guideline that "Warning should be provided for the following phenomena, (a) Unusual and hazardous sea-ice conditions and (b) Dangerous sea states". Being a tropical region, Indian Ocean Forecast System at INCOIS tries to focus on the second phenomenon, viz., 'identifying dangerous seas', and also captures upcoming high sea conditions through short term forecasts and specialised warnings/alerts, which effects the coastal population and seafarers. In this context, we are in an effort to transforming the general forecasts to an impact-based multi-hazard forecast and warning services. As an initial effort towards achieving it and a consequential implementation, the warnings/alerts on rough sea conditions because of the high period swell waves are warned along with the type of people affected and even with how it would be affected, and what kind of pre-cautions to be taken care of. Also, We are on the verge of operationalising a Small Vessel Advisory and Forecast System, where in the possible regions of boat capsizing are alerted/warned along with the type and category of boats based on a newly coined index, namely, Boat Safety Index (BSI). Categorisation of users such as coastal population, artisanal fishermen, large-scale fishing etc., whom a warning is applicable or not is also so crucial and sensible. In such a way, we are on the process of transforming and updating our forecasts, warnings, advisories and alerts in to a multi-hazard impact-based ones. Development of such a system can only be achieved by a sustained and close interaction with the end users and feedback collection, and the incorporation of the same to update and to additionally incorporate, if any, the thresholds and yardsticks used in this system.

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Ocean response to Tropical Cyclone Vayu

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A very severe cyclonic storm Vayu which is unique in many aspects originated near the southeast Arabian sea with multiple curvatures on 10-June-2019 and made landfall on 17-June-2019. We have simulated the storm using a coupled ocean-atmosphere model. The coupled system has its ocean component as Indian Ocean HYCOM setup at INCOIS and WRF-NMM core as the atmospheric part. Cyclone induced cooling was prominent along the westward recurved path and a maximum cooling of 3.5 °C was observed. Spatial extent and magnitude of model-simulated SST cooling agreed well with satellite observations. During the initial northward movement of the storm, it closely followed the shelf break till it made the first curvature. During this period, warm water (>28 °C) was present along the west coast of India for the entire depth of water column. Thus, warm water on the right side of the cyclone track suppressed the SST cooling before the first curvature. A right-ward bias in maximum mixed layer depth (MLD) is evident in the model simulation, which confirms that wind mixing of the whole water column near the coast. However, the lack of a vertical thermal gradient caused poor surface cooling expected due to entrainment. A shallow mixed layer (MLD<40m) and a low TCHP (<60 kJ/cm^2) might have contributed to the weakening of the storm after the first curvature.

Forecasting high-impact weather using weather pattern forecasts – Examples from the UK

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The Met Office uses output from a probabilistic weather pattern forecasting tool within its medium- to long-range forecast guidance for the UK. This forecasting tool, called Decider, is based on a set of 30 objectively-derived daily weather patterns centred on the UK and covering a wider European area. Decider assigns forecast scenarios from several global ensemble prediction systems to the closest matching pattern definition allowing probabilistic weather pattern forecasts to be produced. These forecasts help summarise key aspects from the large volumes of data which ensembles provide, such as highlighting the most likely large-scale circulation changes. Certain meteorologically induced hazards (such as coastal flooding, fluvial flooding, heat waves and landslides) and resulting impacts are more likely to occur during the occurrence and persistence of a few specific weather patterns. Once a relationship has been established, forecasts for these high-impact weather patterns can be used to highlight an increased likelihood of particular impacts at relatively long forecast lead times. This relationship can be used to develop bespoke forecasting applications, with UK examples for coastal and fluvial flooding shown in this presentation.

Sector-focused, seasonal impact-based forecasting for UK transport

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Over recent years, a bespoke seasonal forecast product for the UK transport sector has been developed and trialled with stakeholders, supported by funding from the EU and from UK Government. The product consists of risk-based forecasts of particular transport impacts over a given winter season and is built using relationships between the observed winter (DJF) North Atlantic Oscillation (NAO) index and stakeholder-supplied historical data for winter impacts on transport. Using stakeholder-supplied data enhances the relevance of the forecasts as they can be presented in terms of impacts rather than in meteorological terms – though this requires multiple years' worth of impacts data to be available. NAO forecasts from the Met Office's Global Seasonal forecasting system version 5 (GloSea5) are then used in conjunction with the derived NAO/impact relationships, to create the risk-based forecasts of these impacts. Care is taken to ensure the forecast messaging is consistent with other Met Office seasonal forecasting information received by the stakeholders. Different presentations of the forecast have been trialled with stakeholders over several winters, and feedback has been sought to gauge how useful the forecasts are when used as part of the winter preparedness community's wider set of forecasting tools.

Impact Based Forecasting – An Operational Perspective

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The Met Office is responsible for the National Severe Weather Warning Service (NSWWS) in the UK, which warns of impacts caused by severe weather. This service provides warnings up to seven days ahead for impacts from rain, thunderstorms, wind, snow, lightning, ice and fog. The NSWWS has continually developed since its inception in 1988; a key milestone was the transition to an impact-based service in 2011 with a renewed focus on communicating what is expected to happen as a result of severe weather rather than forecasting against a set of meteorological thresholds. The warnings are multi-layered in design to cater for a varied audience; namely the public, Government and Emergency Responders such as the Police, Fire Service and Local Authorities. At its basic level the warning service provides a colour-coded 'traffic light' overview, however these colours are determined by a risk matrix which assesses the combination of likelihood and impact level and helps guide suitable mitigating actions.

Impact assessments for this operational warning service are made in a live environment every day of the year, with decisions and communication often required at short notice. To do this the Met Office have a number of sub-teams who combine their expertise to produce a single source of output; this includes communicating with Emergency Responders, developing impact forecast models, and working with external partners such as hydrological agencies who model the downstream impacts of severe weather.

Developing common approaches for understanding disaster risk

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The Natural Hazards Partnership (NHP) was established in 2011 as a collaboration of government departments and bodies from across the UK, with the aim of providing authoritative and consistent information, research and analysis on natural hazards for the development of more effective policies, communications and services for civil contingencies, governments and the responder community across the UK. Its membership includes a diverse set of partners with different priorities and responsibilities relating to natural hazards and their impacts. The Hazard Impacts Framework (HIF) is a key output of the NHP. The HIF was developed as a framework for understanding and modelling natural hazards. It sets out approaches for impact modelling, including terminology and the concepts of risk, and addresses issues for partnership working on natural hazards and their impacts. The HIF also provides a workflow for developing hazard impact models, with a focus on taking scientific knowledge and moving it into operational services to assist disaster preparedness, forecasting, and response.

A Surface Water Flooding Hazard Impact Model (SWF HIM) for England & Wales

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Following major summer floods in 2007 across England, there has been an accelerated effort in developing improved Surface Water Flooding (SWF) forecasting and warning services. This has been led by the Flood Forecasting Centre for England & Wales (FFC) – a partnership between the Environment Agency and Met Office – and the development of a novel SWF Hazard Impact Model (SWF HIM) that forecasts both the flood hazard footprint and its potential impact.

This SWF HIM development has been undertaken by the UK's Natural Hazards Partnership and exploits existing national-scale hydrometeorological ensembles to produce forecasts of the SWF hazard footprint. The potential impact on people, buildings and transport is automatically assessed for each ensemble member using a pre-calculated Hazard Impact Library. A Flood Risk Matrix approach is then used to combine the ensemble of impact information into a category of risk severity to inform the national Flood Guidance Statement issued to emergency responders. Currently the SWF HIM is in the final stages of operational implementation following real-time trials so it is a timely opportunity to provide an overview of the developments to date.

Asia Regional Resilience to a Changing Climate (ARRCC): Programme Overview

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The South Asian region is highly vulnerable to weather and climate impacts such as flooding, droughts and cyclones. In the past two decades, over 50 % of South Asians, more than 750 million people have been affected by at least one natural disaster. Vulnerability to both extreme weather events, such as flooding and slow-onset hazards, such as drought, is expected to increase due to, both growing populations in vulnerable areas and climate change. The Met Office is working in partnership with the World Bank and the UK's Department for International Development (DFID) to reduce this vulnerability and build resilience, through the four-year ARRCC programme which started in 2018. The ARRCC programme will strengthen weather forecasting systems across the region and deliver new technologies and innovative approaches to help vulnerable communities, primarily in Bangladesh, Pakistan, Nepal and Afghanistan, to use weather warnings and forecasts, to better prepare for climate-related shocks. This poster will provide an overview of the ARRCC programme to inform synergies and opportunities.

Semi-automated impact-based evaluation of the Global Hazard Map

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The Met Office Global Hazard Map (GHM) summarises the likelihood of high-impact weather across the globe over the coming week using global ensemble forecast data. In addition to gridded daily probability forecasts, a symbol and polygon-based summary layer in the web map service gives an at-a-glance view of likely high-impact weather for the week ahead. To evaluate the performance of the GHM, a semi-automated evaluation approach is presented that assesses the ability of the GHM to highlight events that cause community impacts. The impact-based evaluation method involved collating a global heavy-rainfall impacts database, using a range of media sources, and comparing entries with summary symbol polygons produced from multi-model ensemble forecasts. The results indicate that: (1) the GHM approach of identifying climatological extreme forecasts can successfully identify observed socio-economic impact events around the globe; and (2) the impact-based evaluation approach is a feasible mechanism for evaluation, which could be used to evaluate other similar warnings systems.

A seamless approach to disaster risk management drawing on our seamless weather and climate science and modelling capability

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The Met Office has scientific and modelling capabilities across a range of meteorological timeframes from hours to days, seasons to decades. We refer to this as "seamless weather and climate modelling capability". In the dedicated Met Office Applied Science team, we work on making this excellent science accessible and useful to stakeholders and end users who could utilise weather and climate information in their decision-making. As a way of demonstrating the value of this seamless weather and climate modelling to decision-making across a range of timescales, we use the disaster risk management cycle. This requires weather and climate information for: extreme event prediction, planning and preparation, post event emergency response, impacts assessment and recovery, reconstruction and for building resilience through adaptation, mitigation and preparedness. We also acknowledge that disaster risk management is not only reliant on hazard information that we can readily obtain, but also on exposure and vulnerability information, which requires working with external partners who have complimentary skills in obtaining this key risk assessment information. These strong partnerships help us to pull through excellent meteorological science, enabling the development of useful weather and climate services.

Developing a hazard impact model to support impact-based forecasts and warnings: The Vehicle Overturning (VOT) Model

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The Vehicle OverTurning (VOT) model is a prototype hazard impact model developed to provide an objective and consistent assessment of the potential risk of disruption to road users during high wind events. It aims to support the production of National Severe Weather Warning Service (NSWWS) wind warnings by highlighting areas of the road network that are at risk of disruption due to vehicle overturning. The model combines probabilistic hazard information with vulnerability and exposure data to produce a risk of vehicle overturning forecast. The model is being demonstrated with operational meteorologists at the Met Office and initial feedback has indicate that: (1) the scientific methodology used in the prototype can identify routes with a higher risk of vehicle overturning, associated with strong wind events, and (2) the risk modelling approach is useful to operational meteorologists when issuing warnings.