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Technological evolution of communication and dissemination of meteorological data and information

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1. Introduction

150th year of the foundation of India Meteorological Department ushers in a universal acclaim for the new World Meteorological Organization (WMO) Information System 2.0 (WIS 2.0), which is the framework for Earth Systems (meteorological, hydrological, climate and ocean) data sharing in the 21st century. WIS 2.0 is a collective response by WMO member countries facing challenges to handle the 5 Vs (Volume, Variety, Velocity, Value and Veracity) of big data which, for example, for an advanced numerical weather prediction center such as ECMWF could be 1 peta (10**15) bytes daily for European Union's Destine project which will simulate a Digital Twin (DT) of the earth to visualize high impact weather and climate changes at sub-kilometer resolution [ECMWF (2023)]. Similarly, NOAA is collaborating with Microsoft, Amazon, Google and IBM to host earth system data for any user including commercial users to generate products needed for the specific business needs [NOAA (2023)]. Also, the UK Met Office "Next Generation Modelling Systems Program" has been launched to reformulate and redesign the Met Office's complete weather and climate research and operational/production systems, including oceans and the environment, to allow the Met Office and its partners to fully exploit future generations of exascale supercomputers for the benefits of society [UKMO (2023)]. But these are still way below in comparison to business analytics data volumes of 64 Zetta (10 ** 21) bytes with a daily addition of 2.5 quintillion (10 ** 18) bytes [Bartley (2022)]. 90 percent of the world's data was added (created or replicated) [Djuraskovic (2023)] in the last two years, largely, a gift of the MAGI (Microsoft, Amazon, Google and IBM) allowing 66% of world's population to participate in some form through social media or any other application of the internet to become creator of this data. Also, every two years, the volume of data across the world doubles in size. The continuous expansion of satellite data, mobile data, cloud computing, machine learning, Internet of Things powers the surge in big data including a large amount of unstructured data from social media. Structured earth system data is the core asset of IMD which is unique and to derive maximum value out of it we need to transform the information system from its present framework of Global Telecommunication System (GTS) based WMO Information System (WIS 1.0) to a cloud based new framework of WIS 2.0 so that users of WIS 2.0 will be able to discover data using commercial search engines such as Google or Bing and access data in real-time by subscribing to a Global Broker and receiving notifications when new data are available for download from a Global Cache or from the data provider directly. In this paper we try to examine from a historical perspective how the exchange of data evolved over the past many years in IMD with special reference to innovations and contributions made by IMD scientists and also on the design options as to how IMD can plan transition to WIS 2.0 so that users of WIS 2.0 will be able to access data in real-time using cloud Infrastructure As A Service (IAAS) and latest web technology (WEB 2.0/WEB 3.0).

2. Telegraphy (1878-1975)

Telegraphy was largely responsible for the advancement of operational meteorology in India during the 19th century augmented by wireless transmission in early 20th century. Very detailed account of the early years of telecommunication has been communicated by Roy (1954). Major milestones of this evolution are described under Table 1.

TABLE 1

Major milestones during first 100 years of meteorological telecommunication

Year	Technology
1878	Data collection and forecast transmission through XXW Telegram
1912	Weather bulletin transmission started to ships through Coastal Radio
1920	Met ship observation collection started through Coastal Radio
1929	Karachi short wave radio station installed to support met civil aviation
1935	Coastal met broadcast started from Mumbai and Kolkata
1936	All India Radio started broadcasting in India and included weather news to citizens as part of regular news bulletin.
1937	Aeronautical broadcast started from Kolkata and Karachi
1939	Met broadcast started from aeronautical transmitting station at New Delhi and P&T transmitter at Pune. Pune radio broadcast covered whole country while other stations worked as regional collection and transmission centers.
1944	All India Meteorological Broadcast Center (AIMBC) at Nagpur started operating from Nagpur after installation of two high power W/T (Wireless Telegraphy) transmitters to support operation of allied air command during second world war. Regional W/T broadcast centers started functioning from Calcutta, Madras, Bombay, Poona, New Delhi, Karachi and Rawalpindi. The Calcutta center took over the responsibilities of collection and broadcast of data from Burma, Thailand, Malayan Peninsula and Indo China.
1945	Meteorological Communication Center (MCC) started functioning from Bombay Telephone Exchange Building. “Met Teletype System” started with the establishment of T/P links between Bombay – Nagpur and Bombay – Poona. Other important centers were given access to Defense Teleprinter Network (DTN).
1946	Exclusive teleprinter circuits could be arranged between MCC and Regional Centers to support southeast air command.
1947	Following commonwealth meteorological director’s conference recommendation in London, an expanded schedule of broadcast covering African and Far Eastern countries was started from New Delhi in 1947 and Regional broadcast centers at Madras and Calcutta were handed over to Civil Aviation Authorities.
1948	AIMBC from Nagpur was closed down and Poona and Bombay broadcasts were discontinued and New Delhi became AIMBC and was broadcasting all India data in addition to extra-Indian data. The first session of the Regional Association (Asia) of the International Meteorological Organization (IMO) held in New Delhi recommended New Delhi as Sub Regional Broadcast Center and was entrusted with the collection of meteorological data from all over South Asia, the contiguous African Countries and Australia and also the contiguous sea and ocean areas. These broadcasts were redesignated as Sub Regional Broadcast by WMO whereas the broadcast with Indian data only used to be called as Territorial Broadcast.
1950	MCC shifted to its own building at Colaba from Bombay telephone exchange building. Later it was shifted to New Delhi to support both national and international data exchange.
1960	New Delhi - Moscow direct radio circuit was established.
1961	New Delhi – Tokyo circuit was established. WMO developed integrated exchange system covering the two hemispheres. Five centers, namely, Washington, Offenbach (Frankfurt), Moscow, New Delhi and Tokyo were designated as international meteorological data exchange centers in the northern hemisphere for this purpose.
1963	To cover the areas of southern hemisphere New Delhi was linked to Melbourne via Singapore as a relay station to collect Australian region data, Offenbach was connected to Nairobi to collect African region data and Washington was connected to Brasilia for Latin American data. New Delhi was called as Northern Hemispheric Exchange and Analysis Centre (NHEAC). The Plan for the WWW (World Weather Watch) with three components [Global Observation System (GOS), Global Telecommunication System (GTS) and Global Data Processing System (GDPS)], was agreed in principle.
1965	Door Darshan started its broadcast including weather bulletins as part of regular newscast.
1966	Thus, global coverage for exchange of meteorological data was completed.
1967	WWW was formally adopted as Resolution 16 (Cg-V) by the fifth Congress of WMO.
1969	So long the telecommunication activities were part of the forecasting division at the headquarters of New Delhi but with the increase of national and international responsibilities a new Directorate of Telecommunications was constituted
1971	To implement complex national and international data exchange requirements in Regional Telecommunication Hub (RTH), New Delhi WMO offered through its Voluntary Cooperation Program (VCP) through Netherlands to install DS714 computer system to automate the operation of RTH New Delhi. Two more important assistance came under VCP, firstly one from USA in the form of multi-channel VFT (Voice Frequency Transmission) equipment to support setting up New Delhi - Moscow circuit and later LUCH equipment to upgrade the circuit for two-way transmission and reception of both data and facsimile charts. A number of experienced engineers came from the then Overseas Communication Service (OCS) to carry out reorganization and execution of various telecommunication projects including training of 11 officers on the maintenance of hardware and software of the new DS714 message switching system in the factory premises of Philips, Netherlands. DS714 was first of its kind to be installed in South Asia.

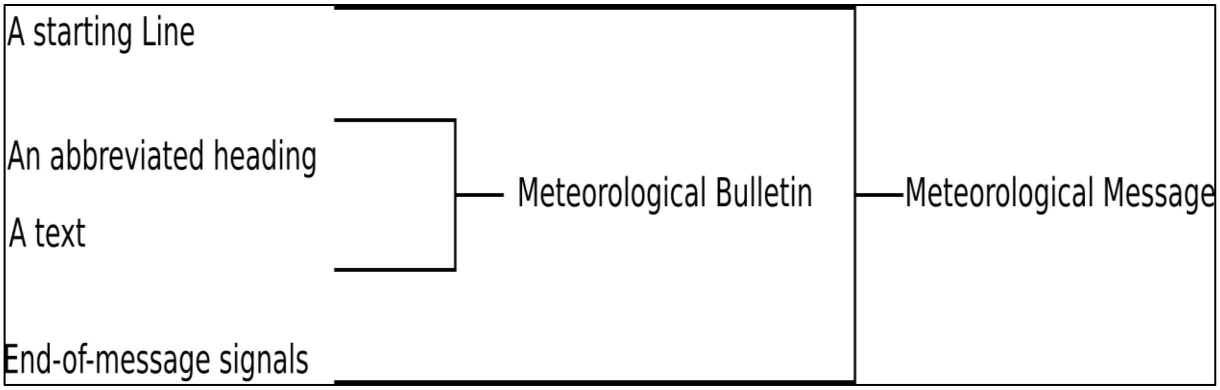

Fig. 1. Meteorological bulletin and message format

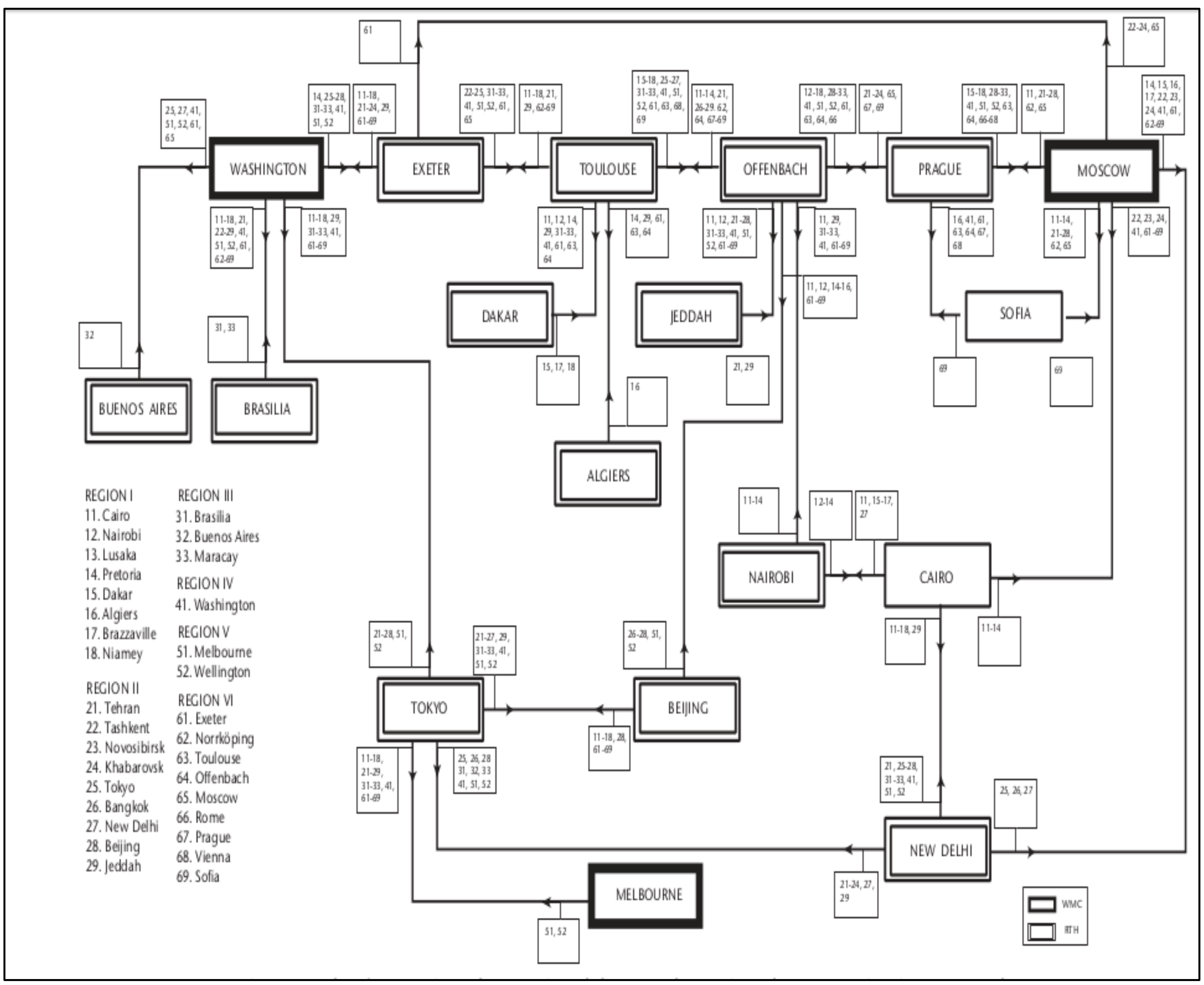

Fig. 1. Routing in Main Trunk Network

3. Pre-internet automatic message switching (1975-2000)

WWW required exchange of observational data from 78 observatories in India to be available throughout the GTS within 30 minutes of the hour of observation. For this purpose, the IMD telecom network was designed so that in case of failure of the main link there always existed a backup channel so that operational exchange continues uninterrupted. The network as described in 100 years of

IMD report (1975) consisted of T/P circuits linking forecasting offices and other circuits linking important observatories. Trunk teleprinter circuits between principal aviation offices were set up to serve as backup channels for Meteorological Network for (aviation) Information (METNI). Normal activities are carried out using the Aeronautical Fixed Telecommunication Network (AFTN) while METNI acted as backup along with Telex connectivity. Around 1 million characters used to be exchanged daily. The structure of a GTS message as described in Fig. 1 has remained the same throughout the evolution of GTS (WMO No.386 2015). Automatic Message Switching Computers use the abbreviated heading information to route messages using a routing table which contains the destination queues for the switching center. In the case of RTH New Delhi the responsibility of international exchange is shown in Fig. 2. While the content structure of a GTS message remained same over the years there has been phenomenal progress in the exchange infrastructure in each generation of computer and communication technology. Store and forward is the core principle of automatic message switching. DS714 used dedicated hardware and assembly language for programming and supported two medium speed circuits with Moscow and Tokyo at 2.4 Kilo Bits Per Second (KBPS) using WMO Software Checked Protocol (WMOSCP) and its data throughput was 7 million characters daily.

3.1. *PDP-11 (Airport AMSS systems)*

In 1985 CMC (Computer Maintenance Corporation) after its success in railway passenger reservation system was dealing with almost all government IT projects. It had set up its R&D center at Hyderabad and was developing AMSS software for automatic switching of AFTN (Aeronautical Fixed Telecommunication Network) messages for the then International Airport Authority of India (IAAI) under the modernization program of Delhi, Mumbai and Kolkata airports. The Department of Electronics ordered for 3 AMSS systems for IMD for exchange of OPMET messages along with IAAI systems for switching of AFTN messages as part of Airport Modernization in India. These message switches were based on PDP-11 minicomputers and the software was developed using RSX-11 real time multiuser operating system and Pascal and C programming languages. All the three airport message switches were connected to RTH New Delhi through teleprinter channels.

3.2. *Vax-11/750 (1988-2000)*

Global Weather Dynamics Inc., Monterey, USA in partnership with Hinditron of India offered to replace DS714 with Vax 11/750 mini computer system in 1988. Automatic Message Switching technology thus evolved from dedicated hardware to general purpose computer with 8 MB memory and 450 MB hard disk. It used multitasking feature of VMS (Virtual Memory System) to run similar software like DS714 on Vax machine. It partnered with Applied Electro Magnetics Private Ltd. (AEM) providing 16-channel multiplexers for interfacing T/P lines to asynchronous ports of Vax machines in redundant configuration. With Vax system several new technological developments were introduced in IMD. VT 220 terminals were used for software development and monitoring of message switch operation and maintenance. A Local Area Network (LAN) using 10 mbps ethernet cable between the two Vax machines was installed. This came in very handy for computer-to-computer communication after NCMRWF (National Center for Medium Range Weather Forecasting) came into being with Cray XMP/24 as the supercomputing machine and Vax/VMS as its frontend in the INSAT building of IMD. A fiber optic LAN cable and DecHubs at the two ends connected Vax systems in the two buildings. Observation data files for model analysis used to be transferred automatically through this LAN. This file transfer procedure was subsequently extended to RSMC New Delhi Control Data Corporation (CDC) computer system. Another important development was the launching of INSAT satellite and its integration with RTH New Delhi AMSS system. Internet connectivity using a dial-up modem in the form of a ERNET node was established in 1994. Two Silicon Graphics O2 machines using Irix operating system and Netscape web servers hosted experimental website of IMD. Also in 1999, IMD started providing full Global Maritime Distress and Safety System (GMDSS) service to the ships on the high seas under Met area VIII (N) with routine bulletins at 0900 and 1800 UTC daily and additional bulletins during cyclone period. New communication software was developed inhouse and medium speed connectivity was established using HDLC protocol (x.25 frame level) with PDP-11 systems at Palam, Santacruz and Dumdum airports. During this period exchange of point observations in binary code form BUFR and forecast fields in Gridded Binary (GRIB) codes were introduced. Around 100 million characters used to be exchanged daily.

3.3. *Sun E250 (2000-2011)*

In 1999 AMSS system at RTH New Delhi was replaced by “Weatherman” message switch from NetSys, South Africa. In 2003 PDP-11 systems at 3 airports were replaced by NetSys systems and a new NetSys system was installed at Chennai airport using Sun Fire280R and Sun Blade2000 and Weatherman and Flightman message switching software. Consequently, all these systems formed TCP/IP mesh network and provided zero loss of data in case of link failures and could be monitored and

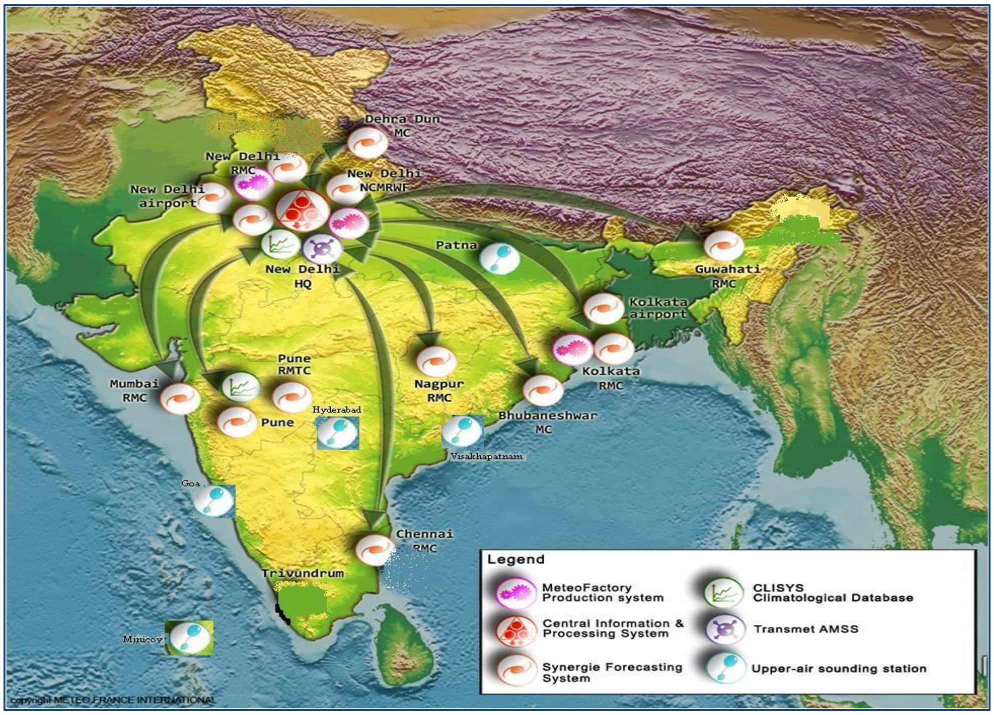

Fig. 3. Deployment of Information Systems at 14 IMD centers under VARSAMANA

administered from RTH New Delhi. The most important development in the NetSys systems was the connectivity to World Area Forecast Centers through SADIS (Secure Aviation Data Information Service) receiving terminal at HQ New Delhi to receive OPMET messages, WINTEM forecast in GRIB messages and SIGWX charts in BUFR. Secondly the web portal of IMD started getting dynamically updated from the end user departments like Satellite, Radar and NWP. In Guwahati a Vax/VMS-3400 machine was installed by CMC in the late 1990's. Guwahati system was replaced by Messir-Corrobor AMSS ssystem and a new Messir-Corrobor AMSS was installed at Nagpur in 2012. The airports at Delhi and Chennai also offered On Line Briefing Systems (OLBS) for commercial airlines operators. In the year 2006 a new ministry called Ministry of Earth Sciences (MOES) was formed and IMD was moved from Ministry of Science and Technology to MOES. MOES formed several expert committees to examine and recommend requirements for modernization of IMD to become at par with the national meteorological services of the developed nations in the world like Japan, Australia, UK, France, Germany and USA. As per the recommendation of these committees Government of India approved proposal to automate observation, communication, modelling, forecasting, visualization, climate system, public weather services and training of personnel to transform the quality of operational services from a largely manual subjective analytic framework to an objective digital framework in the form of 10 sub projects which provided a major thrust for improving weather forecasts to all stakeholders in India.

4. Internet (2011-2023)

IMD modernization and restructuring under an overarching project named 'Varsamana' put IMD on the track for becoming the Global Information System Center (GISC) of WMO for South-Asia (2011). A description of this system was communicated by Singh *et al*. (2017) and Yadav (2020). For the first time integration and project management, consultancy and assistance to transition and training of 400 officers of IMD both in India and abroad led to drastic increase of weather & climate production capacities and revaluation of the role of IMD's different specialized activities of National Weather Forecasting Center (HQ), Regional Specialized Meteorological centers, National Climatology Center at Pune which was also upgraded to a GISC (DR) Disaster Recovery Center, 6 Regional Met Centers and specialized centers such as airports, cyclone warning centers, agrometeorology centers, Meteorological Training Institute *etc*. (Fig. 3)

4.1. *WMO Information System (WIS 1.0)*

A new generation of meteorologists emerged with digital data experience and objective analysis. Under the modernization program RTH New Delhi system has been,

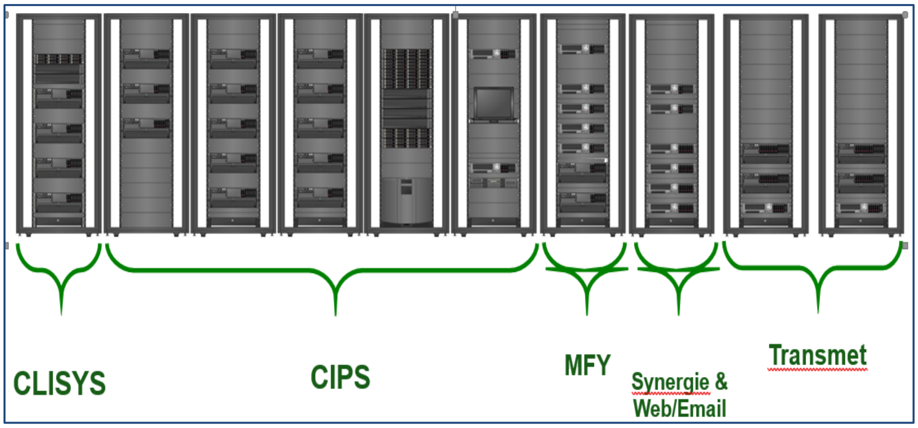

Fig. 4. Contral Information Processing System (CIPS)

replaced by a new Central Information Processing System (CIPS) Architecture (Fig. 4) comprising message switches super-computing back-end and climatological system. These three systems together conform to GISC (Global Information Processing System) specifications of WMO.

Fig. 5. Automatic Message Switching System 'TRANSMET'

4.2. *TRANSMET*

The whole new RTH system called 'TRANSMET' (Fig. 5) designed by Meteo France is configured as two separate Message switching systems (National MSS and International MSS System) and Database cum portal server. This system is configured for high availability cluster. The database system decodes and store data pool as well as metadata in the metadata pool and provide web delivery on the front-end. Storage is low latency and high volume. Mobile, WAN, MPLS VPN, VSAT, DTH TV and Internet are connected to Server through firewall. The system is able to generate WEB pages of all types of products and images. Facility for storage of all metadata in the form of WMO no. 9 vol. A, C & D, routing tables, WMO monitoring, various code table are available. Metadata pool is designed based on WMO core metadata standard version 0.2 which is XML based. 'TRANSMET' is capable of exchanging 1 Tera Byte (1000 GB) of weather data and processed information every day.

4.3. *CIPS*

Critical in the ongoing realization of the WMO information system Central Information and Processing System (CIPS) installed in IMD gave a paradigm shift in its core activities from observation and network management towards integrated and connected information systems to provide effective services to the user community. CIPS is able to manage, store, process and archive all data from national and international observation networks, NWP models including the ones running on IMD HPC, products from INSAT and other satellites, and Doppler Weather Radar (DWR) products.

4.4. *CLISYS*

Clisys systms enabled IMD to systematically gather 150 years of weather observations, quality control, manage and organize in digital form. These climatological data along with properly managed metadata allowed scientists to evaluate climate change in the long term and precisely define the nature of climatic fluctuations at time scales up to a century with facilities for developing climatological products and monitoring through web interface.

4.5. *SYNERGIE*

This forecaster workstation based on man machine mix and interaction with huge amount of data has become an indispensable tool for IMD forecasters. A major feature of Synergie (Fig. 6) is the integration of all meteorological data in WMO format in the same system to speed up the

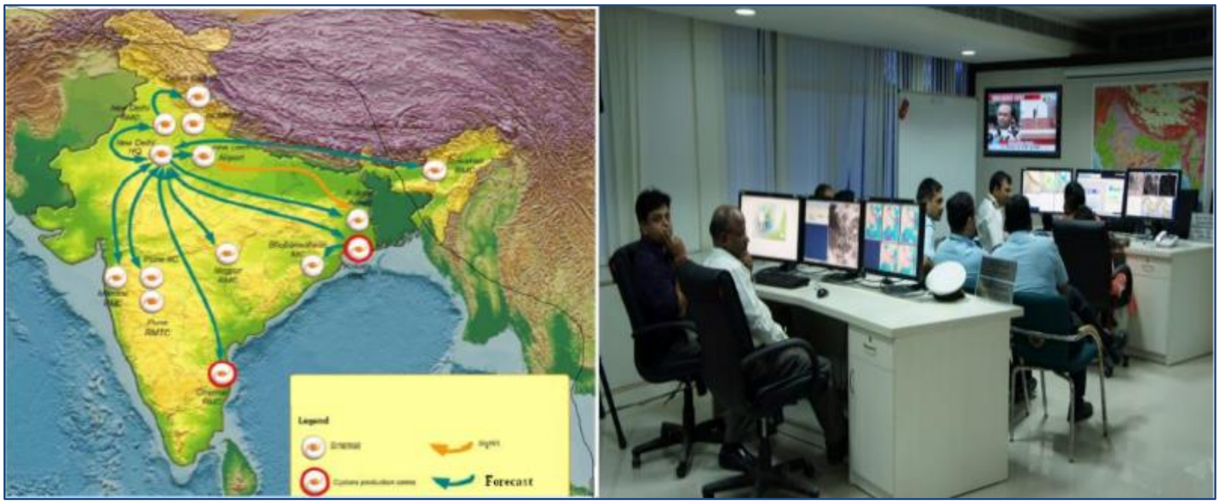

Fig. 6. Synergie & Meteofactory workflow & Deployment at Mausam Bhawan, New Delhi

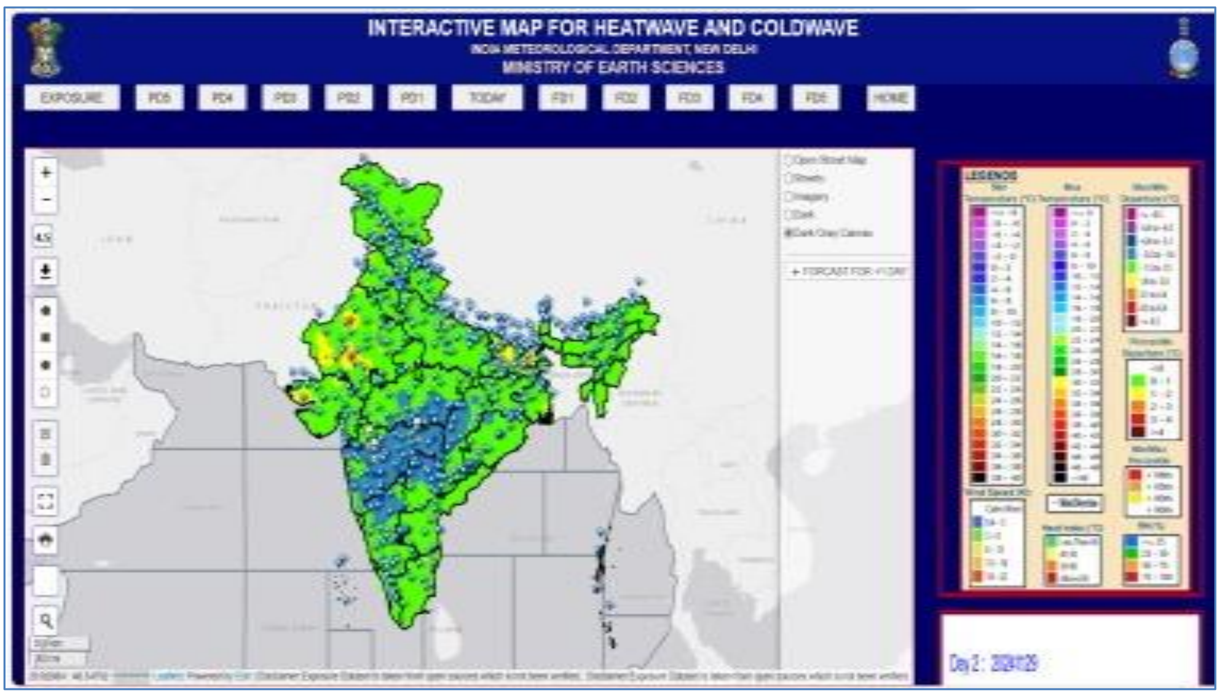

Fig. 7. Geospatial Services System

extraction of information and allow the forecasters to use and or combine any type of data at any step of his work: understanding, analysis and forecasting with various modules like cyclone track forecasting.

4.6. *METEOFACTORY*

A new Public Weather Service (PWS) System called "Meteofactory" enabled the forecaster to generate in custom required presentation form the automatic delivery of products to the newspaper, TV, commercial airlines, farmers, shipping etc. It was also capable of generating Common Alerting Protocol (CAP) format early warning system products as per WMO guidelines. However, at present this system has been replaced with more advanced (Fig. 7) Geospatial Services System.

4.7. *WEB and SOCIAL MEDIA*

The positive effect of IMD Modernization (VARSAMANA) program could be seen in the form of a new generation of IMD scientists who are enabled for

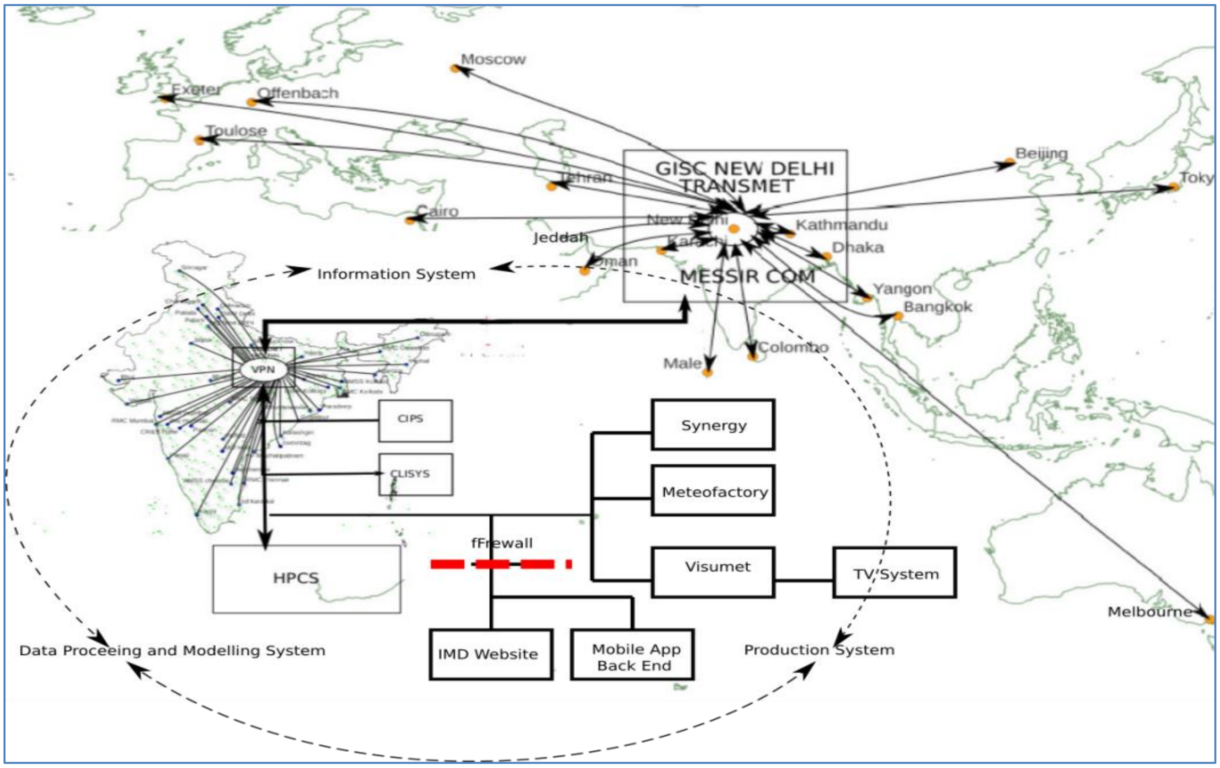

Fig. 8. IMD Information System 2023

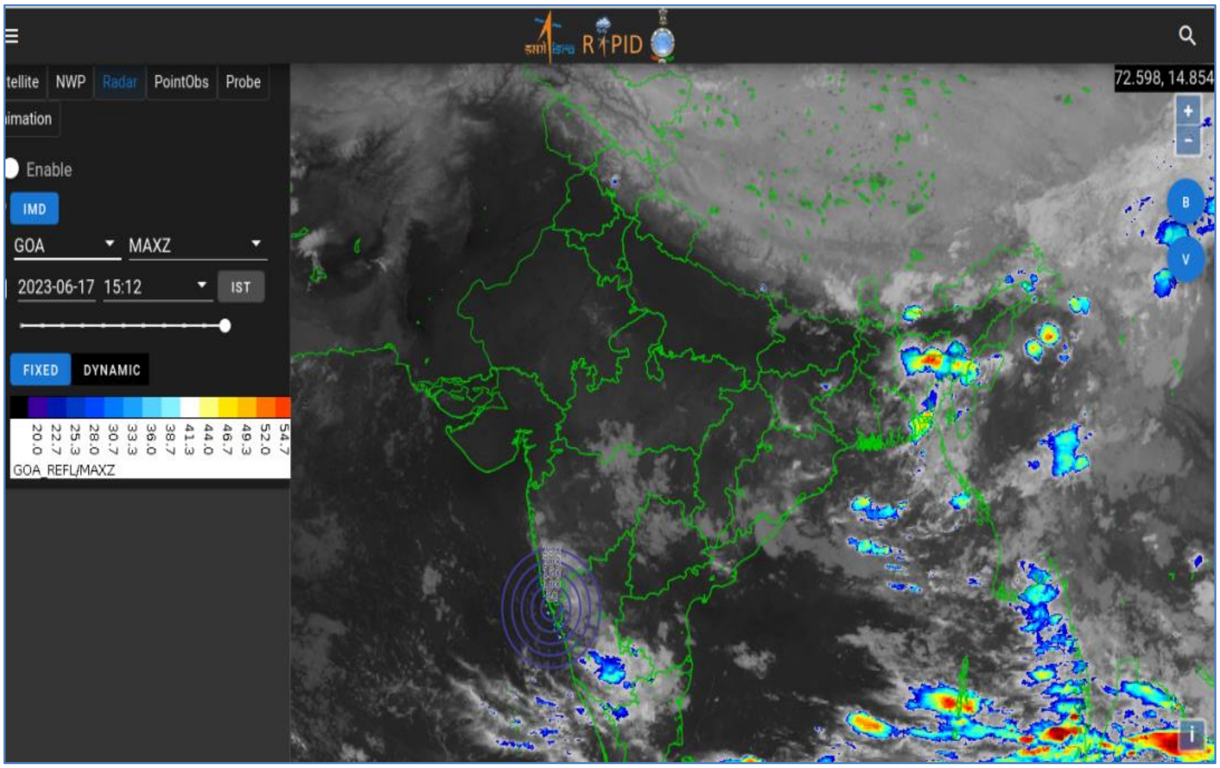

Fig. 9. RAPID Web Workstation

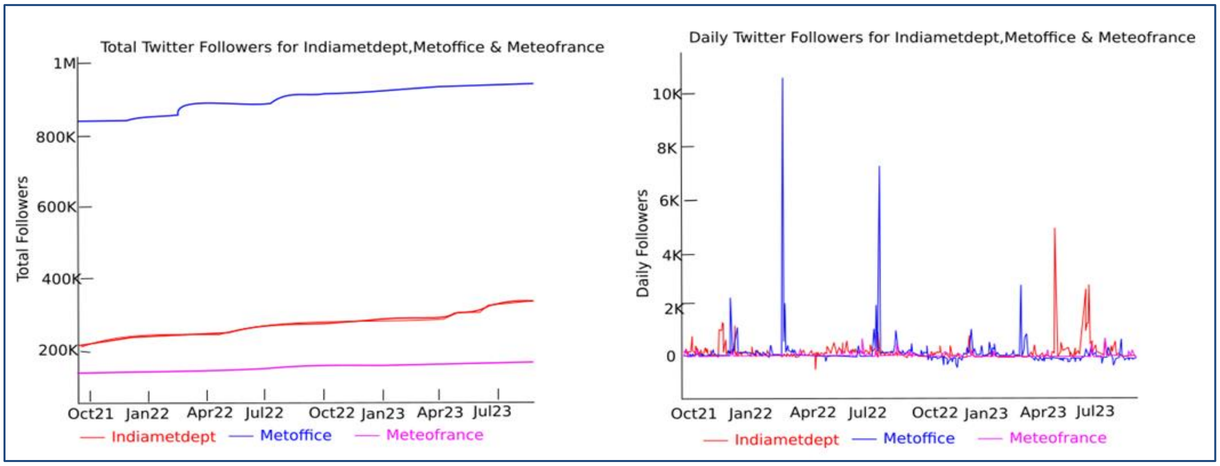

Fig. 10. Total and Daily Twitter Followers of IMD, UKMO & Meteofrance

digital frameworks as could be seen through generation of new digital products and web dissemination using web technologies version 2.0 and use of social media for product dissemination as shown Fig. 8.

A detailed study of the VPN (Virtual Private Network) which interconnects IMD offices for collection of observational data as well as exchange of forecast products was communicated by Birbaj *et al*. (2018) and its implementation was reported by Chug *et al*. (2021). IMD has 14 websites of domain specific centers, 6 regional websites and 22 websites of meteorological centers covering 28 states and 8 union territories totaling 42 and more. The contents of these websites are managed dynamically and capable of generating more than 1 million products using ZEND web servers with Oracle10g and Postgres relational databases at the backend. Special mention may also be made of 'Real-time Analysis of Product and Information Dissemination 'version 2.0 of IMD (Fig. 9) which enables forecasters to use Web Map Service (WMS) to analyze satellite, NWP, radar and also to perform simple analysis such as time series generation, transection, area statistical calculations *etc*. IMD also posts its products in the social media such as YouTube, X, Meta and Instagram. With the advent of WhatsApp community feature by Meta it will be possible to use WhatsApp for both weather data collection and dissemination of early warnings with rich audio-visual contents. A comparative example of X posts by IMD, UK Met Office and Meteo France can be seen under Fig. 10 from one of many analytics site "socialblade.com".

Smartphone users in India total about 467 million and IMD is providing services through mobile apps for users since 2022. These mobile apps (Mausam, Meghdoot, Public Observation IMD *etc*.) along with backend web services have been developed using open source Dot NET Xamarin and PHP- JSON frameworks communicating with back-end servers using Representational State Transfer (REST) for building web services.

9. Big data (2023 – ?)

GTS "store and forward" served the meteorological community well till the advent of Big Data, namely, the requirement for adaptability to climate change and manyfold increase in the disruptive impacts of weather events around the world justifying the need of a system of "meteorological real-time" alerting, where the time to transmit data is of the order of a few seconds. WIS 2.0 framework of WMO proposes to implement such a system in a phased manner replacing the GTS by 2030. We shall discuss the implementation of WIS 2.0 by IMD keeping in view of the 'cloud computing' and 'web technology' as the two core technologies of this framework. IMD is quite in an advantageous position because as a GISC node it maintains a global cache of data and has a metadata store conforming to WMO core metadata profile 1.3 and OAI-PMH (Open Archives Initiative Protocol for Metadata Harvesting) for Discovery, Access and Retrieval of messages and after the installation of WIS2 in a box it is able to operate as a global broker using Message Queuing Protocol (MQP) for pub/sub messaging framework. IMD is also using web services in GISC New Delhi for product development and dissemination. So, some changes could be needed for GISC New Delhi framework to become full-fledged WIS 2.0 node -

(*i*) Cloud hosting of WIS 2 in a box - Government of India encourages cloud hosting by Government Departments through 20 empaneled CSPs (Cloud Service

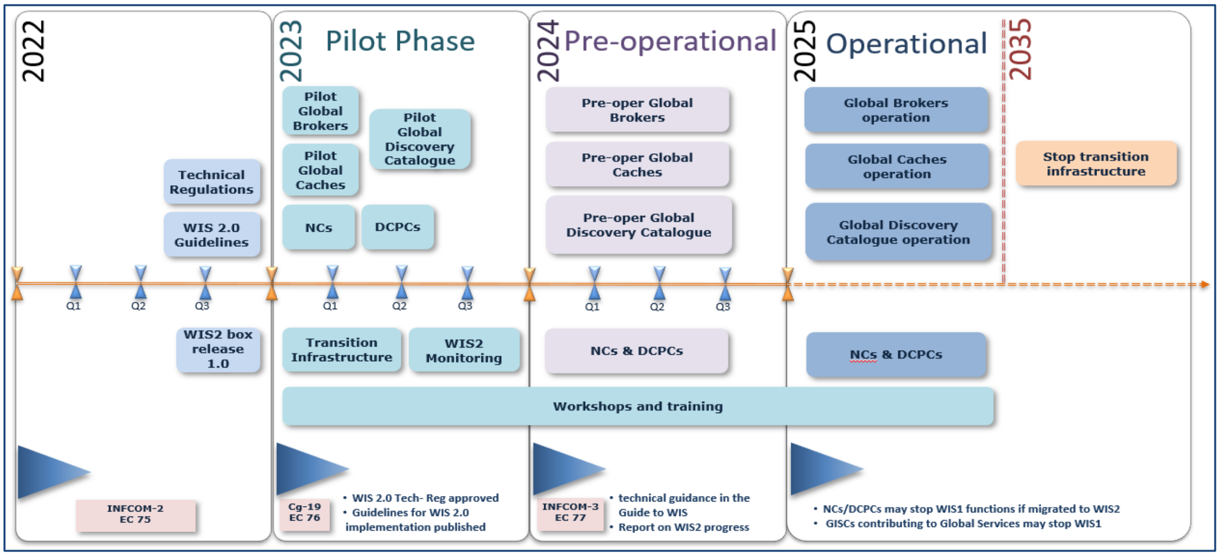

Fig. 11. WIS 2.0 timeline.

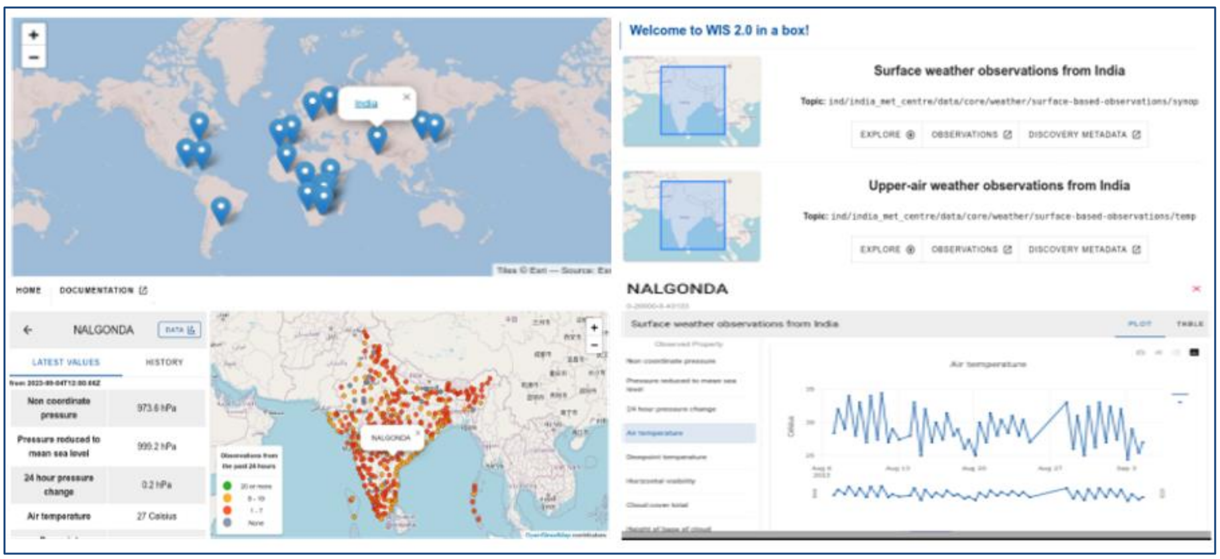

Fig. 12. WIS 2.0 implementation demonstration by IMD.

Providers) including MAGI (Microsoft, Amazon, Google and IBM) with detailed guidelines for hiring Cloud services, under all the categories listed on the Government e-Marketplace (GeM) platform. The procurement of Cloud Services can easily be done through the GeM platform. A step-wise guide on how to procure the MeitY empaneled Cloud Services from GeM is also provided in the MeitY website. This will enable GISC New Delhi to upgrade to act as Global Broker and Global Cache providing pub/sub MQP framework.

(*ii*) Metadata Cataloguing - Transform format of GISC New Delhi metadata store elements from XML to JSON/YML format and adding hyperlinks to API specification. This will enable GISC New Delhi to become a Global Catalogue Server.

(*iii*) Commercial search engine - Data discovery is possible through commercial search engines like google, Bing, yahoo *etc*. Fig. 11. depicts the WIS 2.0 implementation timeline of WMO.

A demonstrative WIS 2.0 node of IMD hosted by WMO for surface and upper air data is shown in Fig. 12.

It may be noted that WIS2.0 is an automated computer to computer information exchange framework where Earth System Scientists will focus on scientific research, analysis, visualization and production of inferences as

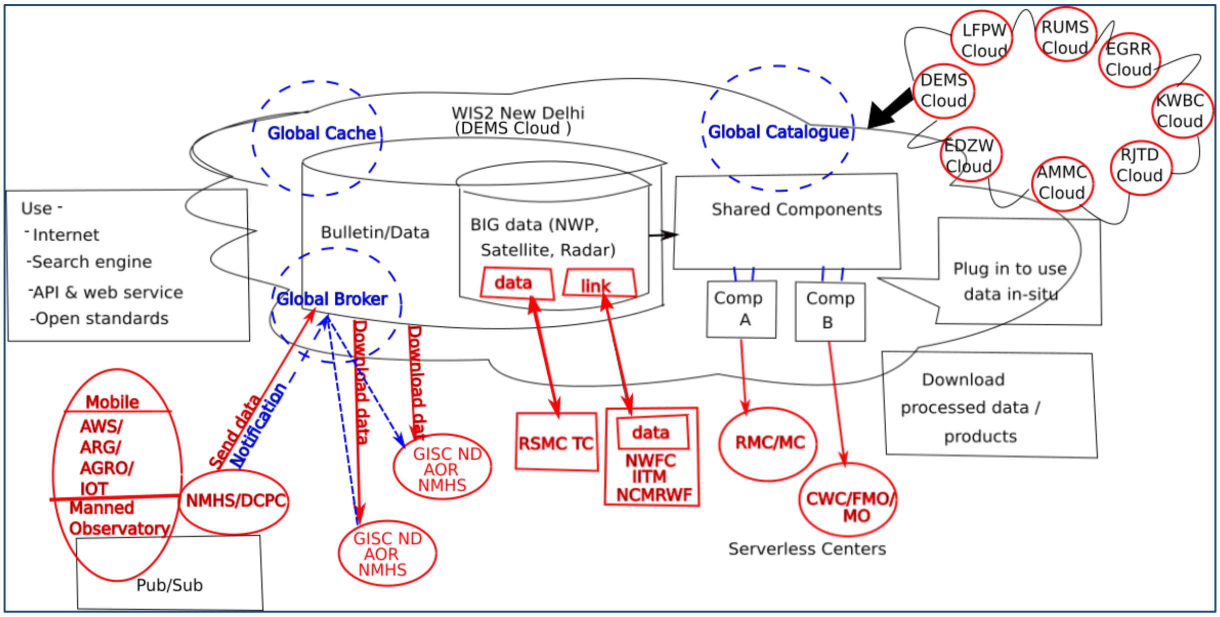

Fig. 12. Schematic cloud implementation of WIS2 New Delhi (DEMS Cloud).

specified by the end user requirements. A design schematic of possible implementation of the WIS2 New Delhi (DEMS cloud) is shown in Fig. 13.

WIS2 New Delhi can act as Global Broker, Global Cache as well as Global Catalogue Server. Observational data can be published directly by mobile devices, automatic weather stations including rain gauges and agro-sensor based stations or manned observers directly using web interfaces. For downloading observational data from other centers one can use message filtering using wild cards using topic filtering. For example, if one needs India's Synoptic data one can subscribe following topic ("+" means all) : WIS/+/+/+/DEMS/+/+/Synoptic/+.

10. Conclusion

Ever since the days of World Weather Watch GTS served the member countries throughout pre-internet era and up to the 1990s using WMO No.9 Vol. C of Catalogue of Meteorological Bulletins and WMO No.386 Manual on GTS. In 2007 WMO Information System (WIS 1.0) put metadata and catalogue atop GTS. Today WIS 2.0 proposes to use Simple data exchange, Open Standards, APIs, Pub/Sub and Cloud for Earth System Monitoring and Prediction so that all users such as an NWP center operator can find/bind/analyze/integrate/publish, a Forecaster can find/analyze and file his inference, a start-up can find his business risks due to weather, a developer can find/bind his development project and a casual user can also find information. Benefits of such an arrangement will be broad interoperability, a simple format like JSON will work with any JSON tooling, GeoJSON will work with any GIS (Geographic Information System) tooling and interoperability with Google and mass market search using JSON-LD/schema.org.

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Disclaimer:

The contents and views expressed in this article are the views of the authors and do not necessarily reflect the views of the organizations they belong to

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