World Meteorological Organization

Weather • Climate • Water

Minimizing risks from weather, climate, hydrological and related environmental events

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The quiet revolution of numerical weather prediction

Peter Bauer[1], Alan Thorpe[1] & Gilbert Brunet[2]

Advances in numerical weather prediction represent a quiet revolution because they have resulted from a steady accumulation of scientific knowledge and technological advances over many years that, with only a few exceptions, have not been associated with the aura of fundamental physics breakthroughs. Nonetheless, the impact of numerical weather prediction is among the greatest of any area of physical science. As a computational problem, global weather prediction is comparable to the simulation of the human brain and of the evolution of the early Universe, and it is performed every day at major operational centres across the world.

At the turn of the twentieth century, Abbe[1] and Bjerknes[2] proposed that the laws of physics could be used to forecast the weather; they recognized that predicting the state of the atmosphere could be treated as an initial value problem of mathematical physics, wherein future weather is determined by integrating the governing partial differential equations, starting from the observed current weather. This proposition, even with the most optimistic interpretation of Newtonian determinism, is all the more audacious given that, at that time, there were few routine observations of the state of the atmosphere, no computers, and little understanding of whether the weather possesses any significant degree of predictability. But today, more than 100 years later, this paradigm translates into solving daily a system of nonlinear differential equations at about half a billion points per time step between the initial time and weeks to months ahead, and accounting for dynamic, thermodynamic, radiative and chemical processes working on scales from hundreds of metres to thousands of kilometres and from seconds to weeks.

A touchstone of scientific knowledge and understanding is the ability to predict accurately the outcome of an experiment. In meteorology, this translates into the accuracy of the weather forecast. In addition, today's numerical weather predictions also enable the forecaster to assess quantitatively the degree of confidence users should have in any particular forecast. This is a story of profound and fundamental scientific success built upon the application of the classical laws of physics. Clearly the success has required technological acumen as well as scientific advances and vision.

Accurate forecasts save lives, support emergency management and mitigation of impacts and prevent economic losses from high-impact weather, and they create substantial financial revenue—for example, in energy, agriculture, transport and recreational sectors. Their substantial benefits far outweigh the costs of investing in the essential scientific research, super-computing facilities and satellite and other observational programmes that are needed to produce such forecasts[3].

These scientific and technological developments have led to increasing weather forecast skill over the past 40 years. Importantly, this skill can be objectively and quantitatively assessed, as every day we compare the forecast with what actually occurs. For example, forecast skill in the range from 3 to 10 days ahead has been increasing by about one day per decade: today's 6-day forecast is as accurate as the 5-day forecast ten years ago, as shown in Fig. 1. Predictive skill in the Northern and Southern hemispheres is almost equal today, thanks to the effective use of observational information from satellite data providing global coverage.

More visible to society, however, are extreme events. The unusual path and intensification of hurricane Sandy in October 2012 was predicted 8 days ahead, the 2010 Russian heat-wave and the 2013 US cold spell were forecast with 1–2 weeks lead time, and tropical sea surface temperature variability following the El Niño/Southern Oscillation phenomenon can be predicted 3–4 months ahead. Weather and climate prediction skill are intimately linked, because accurate climate prediction needs a good representation of weather phenomena and their statistics, as the underlying physical laws apply to all prediction time ranges.

This Review explains the fundamental scientific basis of numerical weather prediction (NWP) before highlighting three areas from which the largest benefit in predictive skill has been obtained in the past—physical process representation, ensemble forecasting and model initialization. These are also the areas that present the most challenging science questions in the next decade, but the vision of running

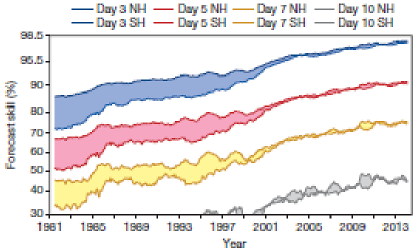

Figure 1 | A measure of forecast skill at three-, five-, seven- and ten-day ranges, computed over the extra-tropical northern and southern hemispheres. Forecast skill is the correlation between the forecasts and the verifying analysis of the height of the 500-hPa level, expressed as the anomaly with respect to the climatological height. Values greater than 60% indicate useful forecasts, while those greater than 80% represent a high degree of accuracy. The convergence of the curves for Northern Hemisphere (NH) and Southern Hemisphere (SH) after 1999 indicates the breakthrough in exploiting satellite data through the use of variational data[100].

[1]European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading RG2 9AX, UK. [2]Environment Canada, Trans-Canada Highway Dorval, Québec H9P 1J3, Canada.

Seamless Prediction of the Earth System:

From Minutes to Months

http://library.wmo.int/pmb_ged/wmo_1156_en.pdf

Recent Extreme Events

World Meteorological Organization
Weather • Climate • Water

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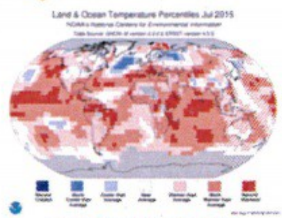
January – July 2015 Warmest on Record

News

25 August 2015



July 2015 Blended Land and Sea Surface Temperature Percentiles

The combined globally averaged temperature over land and ocean surfaces for January to July 2015, and for the month of July, was the highest on record for the period, driven by continuing high sea surface temperatures, according to the U.S. National Oceanic and Atmospheric Administration.

NOAA said the January-July 2015 global average temperature was 0.85°C (1.53°F) above the 20th century average. The July 2015 temperature was 0.81°C (1.46°C) above the 20th century average for July. As July is climatologically the warmest month for the year, this was also the all-time highest monthly temperature in the 1880-2015 record, at 16.61°C (61.86°F).

The average temperature for Africa was the **second highest for July on record**, behind only 2002, with regional record warmth across much of eastern Africa into central areas of the continent. Record warmth was also observed across much of northern South America and central Asia, and the far western United States. Large parts of central and southern Europe were gripped by a heatwave.

A wide swath stretching from eastern Scandinavia into western Siberia was cooler than average, with part of western Russia much cooler than average. Cooler than average temperatures were also observed across parts of eastern and southern Asia and scattered areas in central and northern North America.

For the oceans, the July global sea surface temperature was 0.75°C (1.35°F) above the 20th century average of 16.4°C (61.5°F), the highest departure not only for July, but for any month on record. The **10 highest monthly departures from average for the oceans** have all occurred in the past 16 months (since April 2014).

World Meteorological Organization

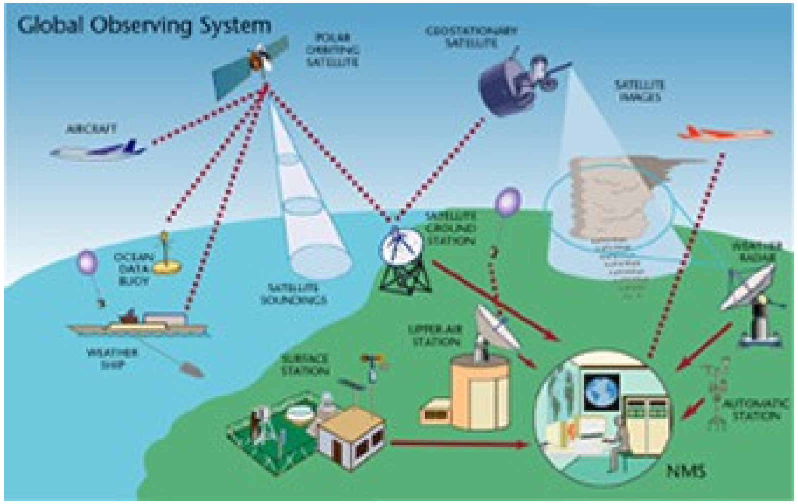
It originated from the International Meteorological Organization (IMO), which was founded in 1873. **Established in 1950,** WMO became the specialized agency of the United Nations in 1951 for meteorology (weather and climate), operational hydrology and related geophysical sciences.

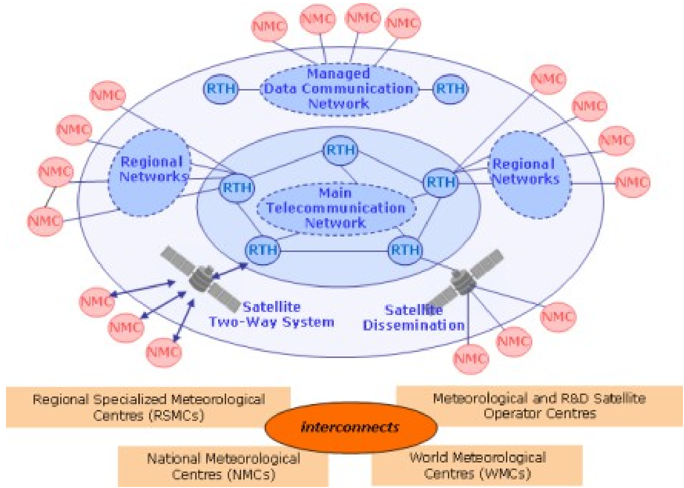
Meteorologists, Climatologists and Hydrologists from 185 Member States & 6 Territories WORKING for YOU

World Meteorological Organization

WHAT WMO DOES

Takes the Pulse of the Earth System

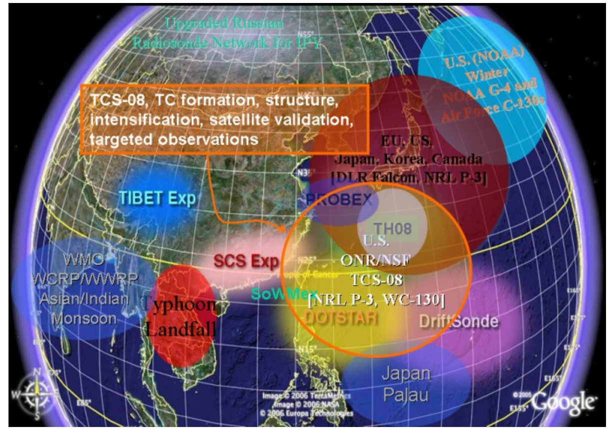




Works for the Universal Availability of Data and Products

World Meteorological Organization

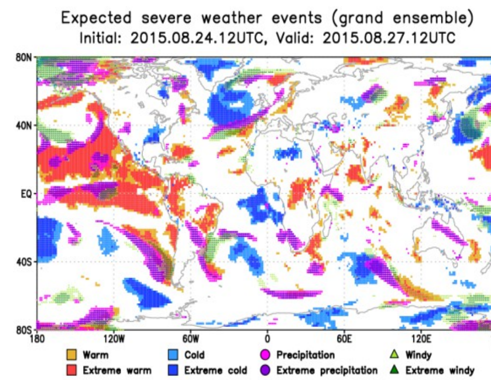
RESEARCH



Coordinates & Organizes Research programmes

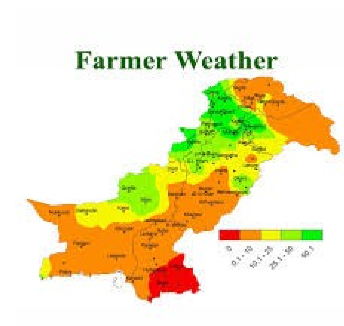
Improved Understanding of the Earth System

Improved Quality & Accuracy of NWP



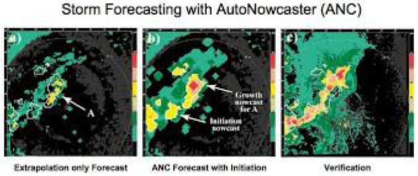
Enhanced Accuracy & Usefulness of Forecasts/Warnings

Transforming Data into Useful Products



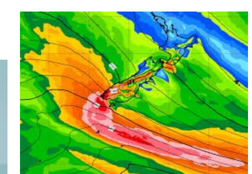
Forecasts 6 hrs ahead

Storm Forecasting with AutoNowcaster (ANC)

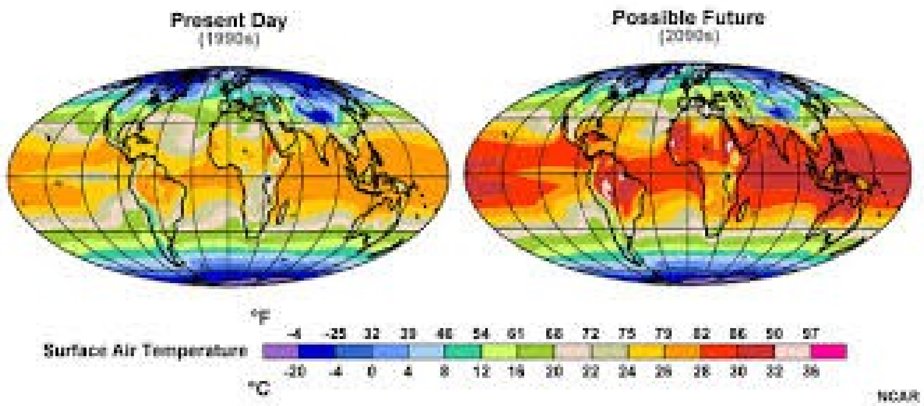


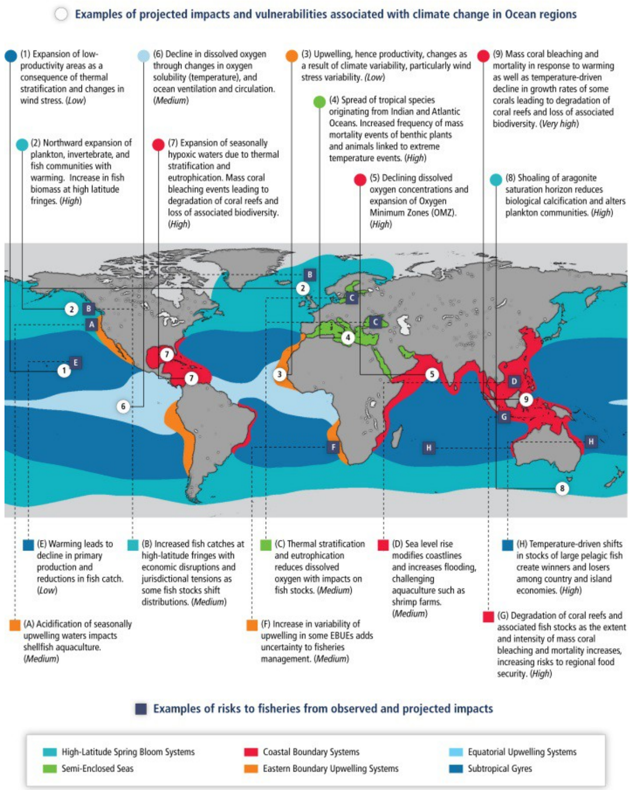
…to a week ahead

…to a year ahead



Knowing our Future Climate





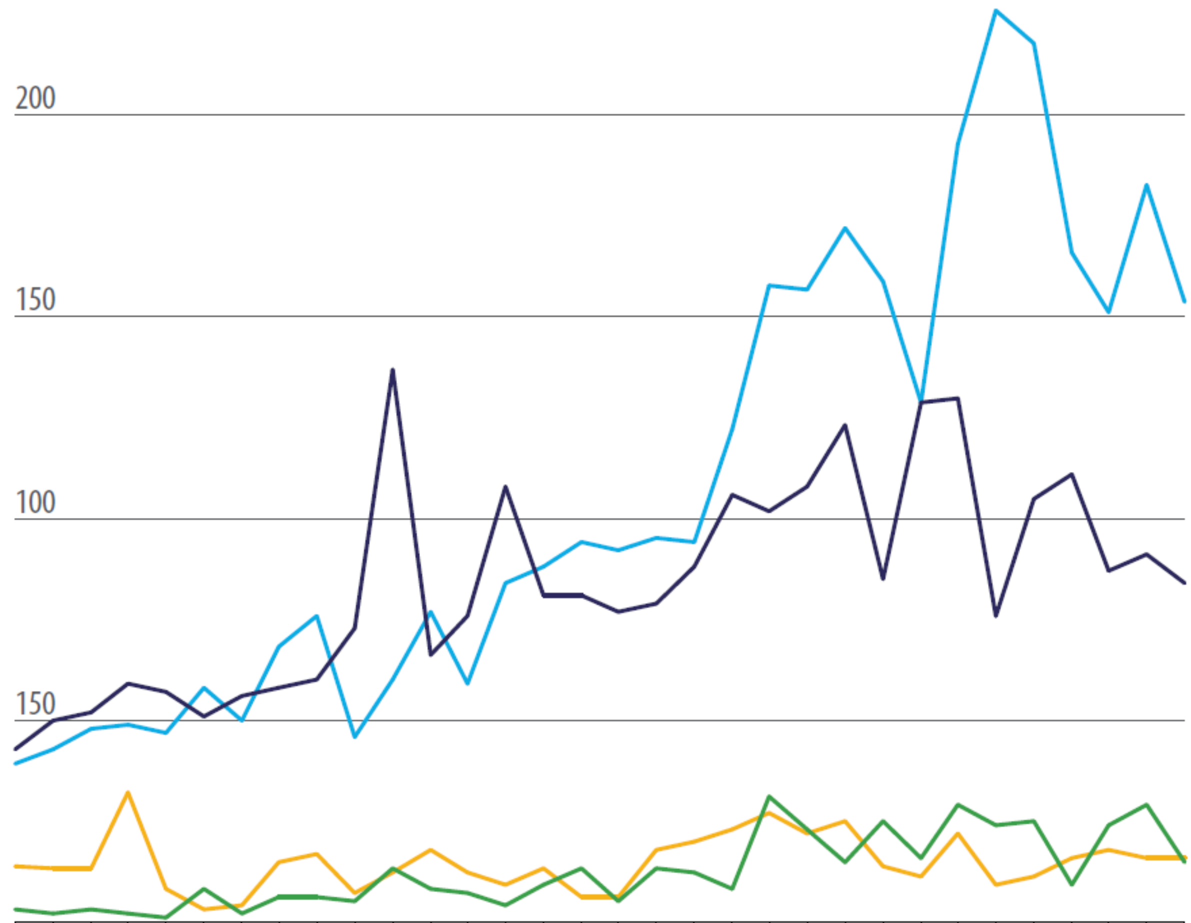
Number of Climate-related Disasters Around the World (1980-2011)

3455 FLOODS

2689 STORMS

470 DROUGHTS

395 EXTREME TEMPS



	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
FLOOD	39	43	48	49	47	58	50	68	76	46	60	77	59	84	88	94
STORM	43	50	52	59	57	51	56	58	60	73	137	66	76	108	81	81
DROUGHT	14	13	13	32	8	3	4	15	17	7	12	18	12	9	13	6
EXTREME TEMPERATURE	3	2	3	2	1	8	2	6	6	5	13	8	7	4	9	13

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
FLOOD	92	95	94	122	158	157	172	159	129	193	226	218	166	151	183	154
STORM	77	79	88	106	102	108	123	85	129	130	76	105	111	87	91	84
DROUGHT	6	18	20	23	27	22	25	14	11	22	9	11	16	18	16	16
EXTREME TEMPERATURE	5	13	12	8	31	23	15	25	16	29	24	25	9	24	29	15

UNISDR

The United Nations Office for Disaster Risk Reduction
http://www.unisdr.org

Created on 13 June 2012

DATA SOURCES

EM-DAT - http://www.emdat.be/ - The OFDA/CRED International Disaster Database; Data version: 13 June 2012 - v12.07

Humanitarian Symbol Set (2008):
http://www.ungiwg.org/map/guideline.php

Weather and Climate-related Disasters/Impacts

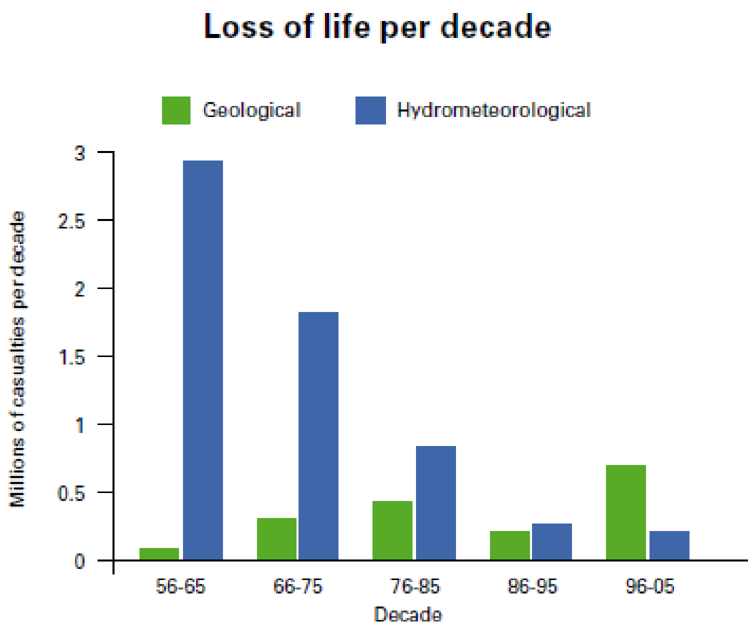


Figure 1a

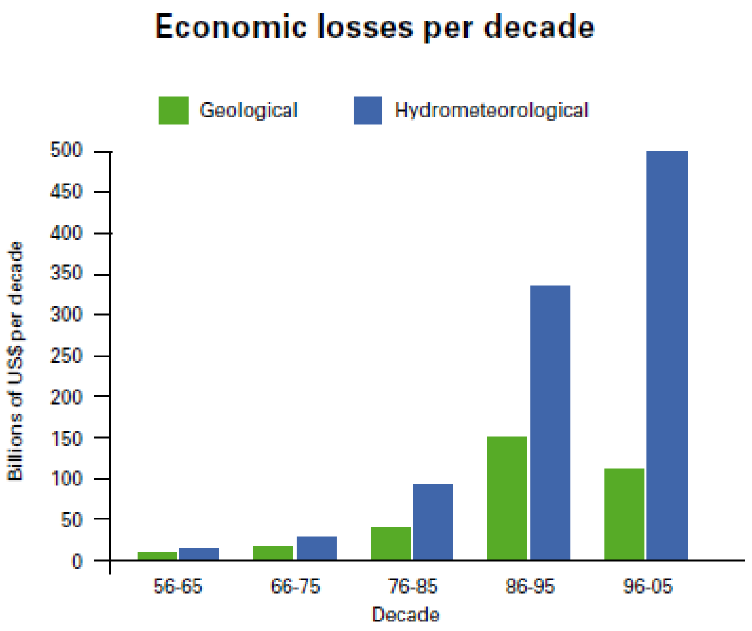


Figure 1b

Decadal trends in natural hazard impacts over the last five decades associated with hydrometeorological hazards


WHAT IS RISK

Risk is combination of the probability of an event and its negative consequences - UNISDR

To best mimimize RISKS:

Be Proactive

STEP 1

Identify RISKs & Assess their Significance

STEP 2

Develop ways to minimize/avoid RISKs

STEP 3

Develop strategies to manage RISKs

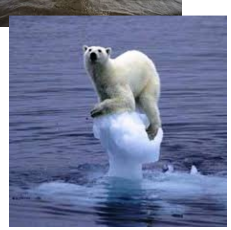
STEP **1**

Identify RISKs & Assess their Significance

Weather RISKs

Climate RISKs

Hydrological RISKs



and Others

STEP **2**

Develop ways to minimize/avoid RISKs

- **Multi-Hazard Early Warning Systems** & Standards for Meteorological, Hydrological and Climate Services
- Application of **Weather, Air Quality and Climate Models** in **Improved Decision Support Systems**
- Advances in **Hydrologic Forecast and Flood Warning Services**

STEP 2

Develop ways to minimize/avoid RISKs

- Multi-Hazard Early Warning Systems & Standards for Meteorological, Hydrological and Climate Services

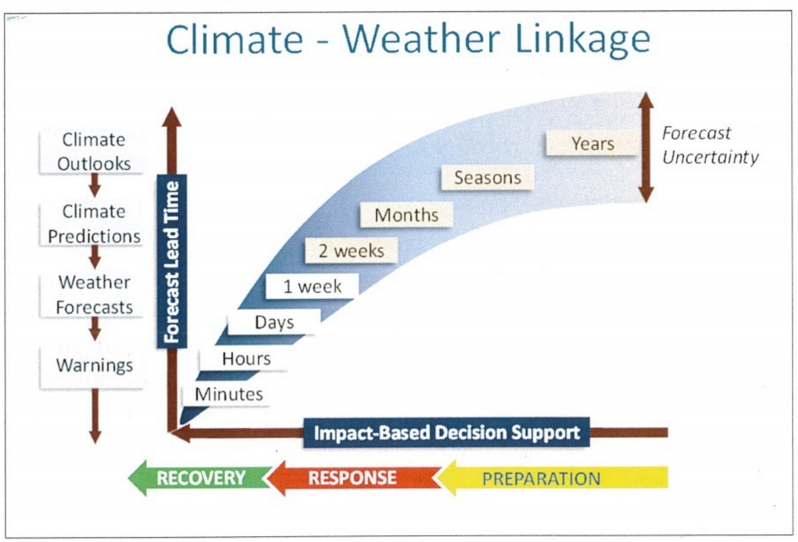
WMO

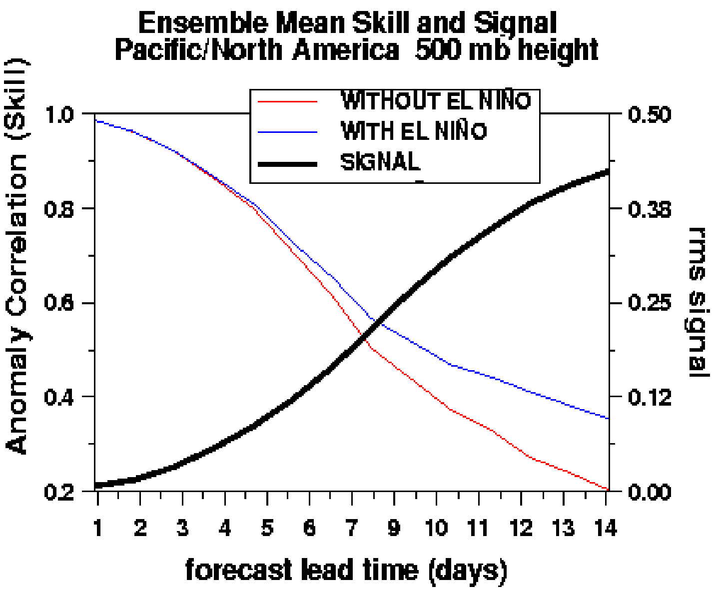
WMO's strategic goals in Disaster Risk Reduction are derived from the **Hyogo Framework for Action**, pertaining to those high priority areas that fall under the mandate of WMO and National Meteorological and Hydrological Services.

STEP **2**

Develop ways to minimize/avoid RISKs

- **Application of Weather and Climate Models in Improved Decision Support Systems**

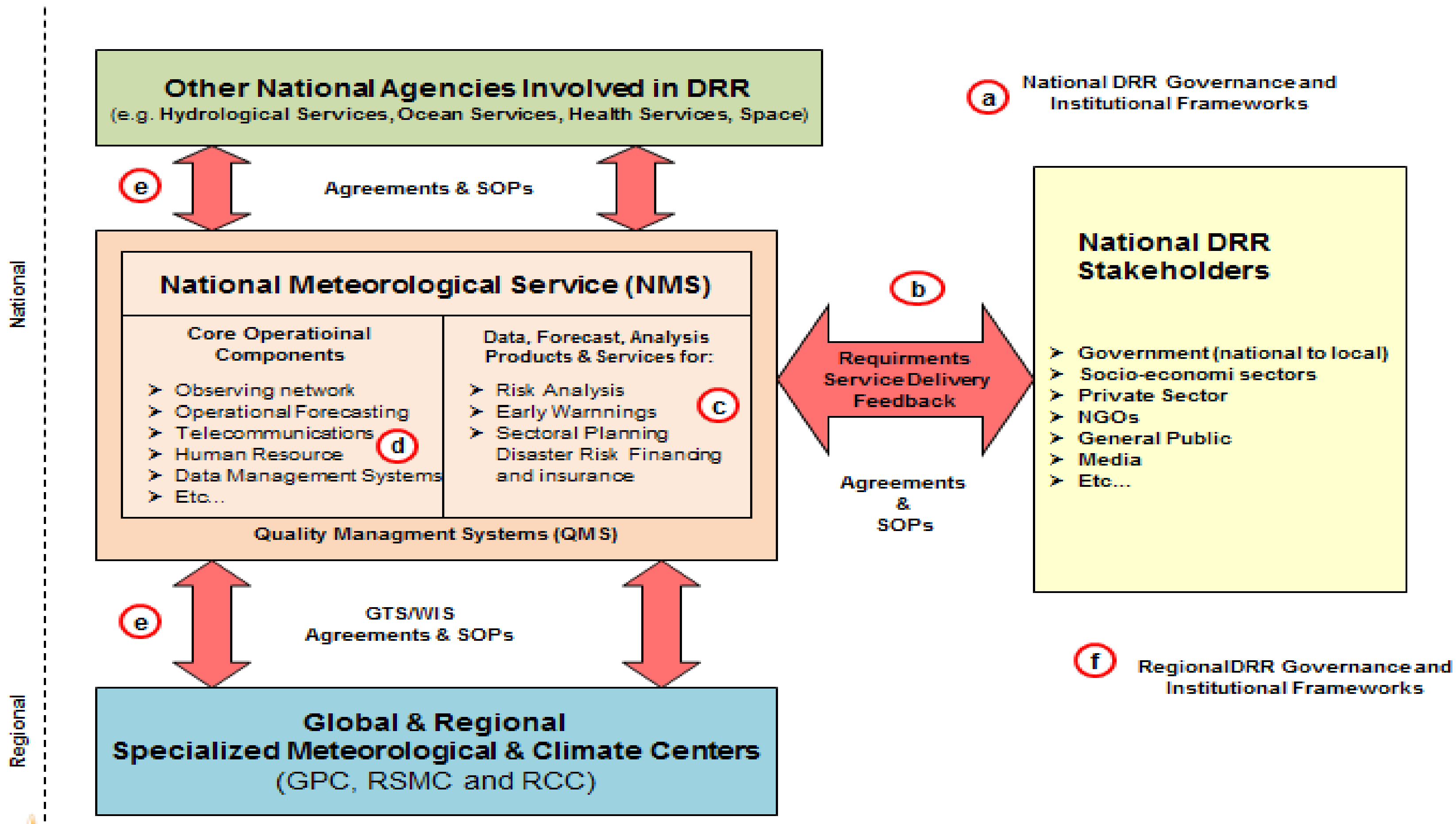




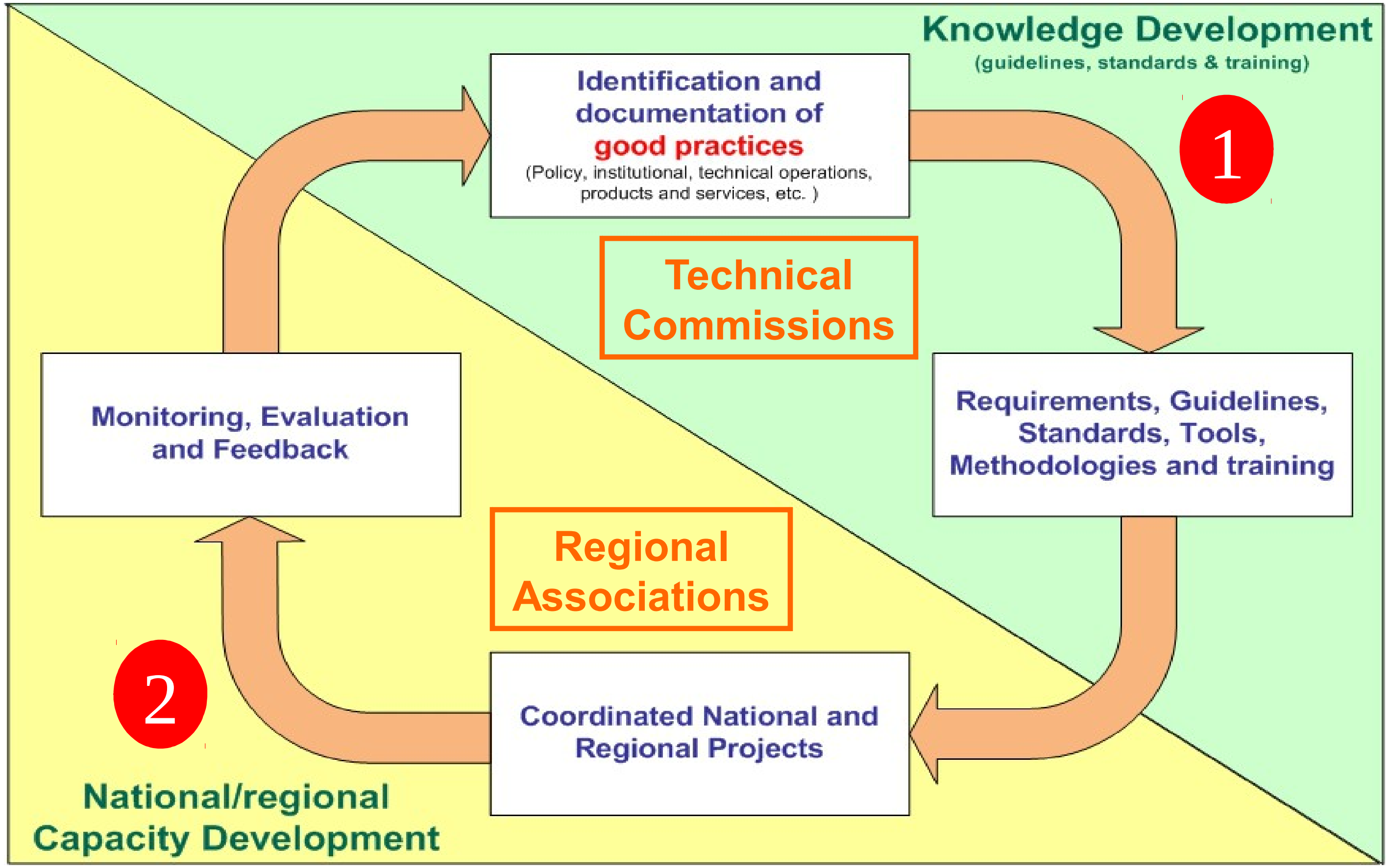
STEP **2**

Develop ways to minimize/avoid RISKs

Weather, Climate and Hydrological Services to support Disaster Risk Reduction Decision-Making



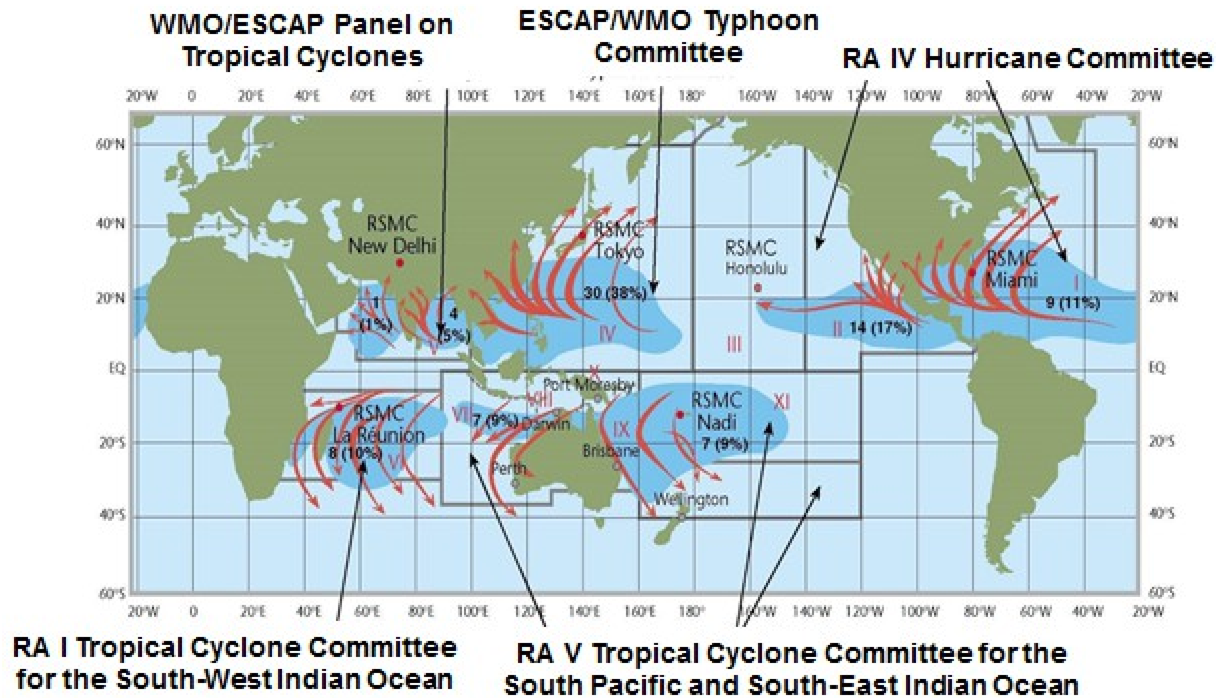
WMO Disaster Risk Reduction Two-Tier Work Plan



STEP **2**

Develop ways to minimize/avoid RISKs

- **Multi-Hazard Early Warning Systems & Standards for Meteorological, Hydrological and Climate Services**

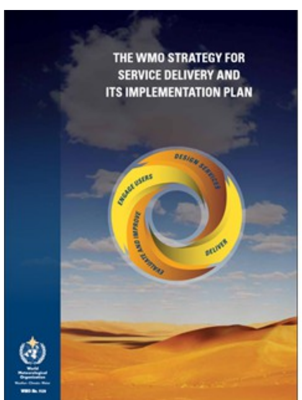


Global Tropical Cyclone Early Warning System

STEP **2**

Develop ways to minimize/avoid RISKs

- **Multi-Hazard Early Warning Systems & Standards for Meteorological, Hydrological and Climate Services**

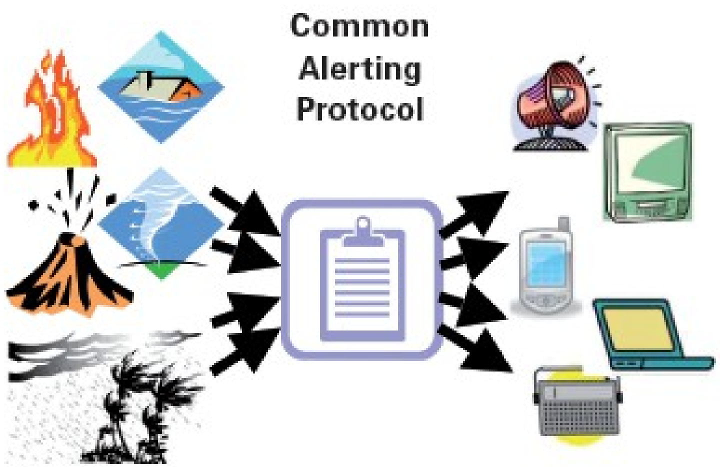


WMO Public Weather Services Programme

STEP **2**

Develop ways to minimize/avoid RISKs

- **Multi-Hazard Early Warning Systems & Standards for Meteorological, Hydrological and Climate Services**



CAP serves as a “universal adaptor” for alert messages

- International standard format for emergency alerting and public warning
- Designed for “all-hazards
- Also designed for “all-media”
- Benefits of the CAP format

WMO is offering expert assistance to NMHSs or other official alerting authority on how to implement the CAP standard

COMMON ALERTING PROTOCOL

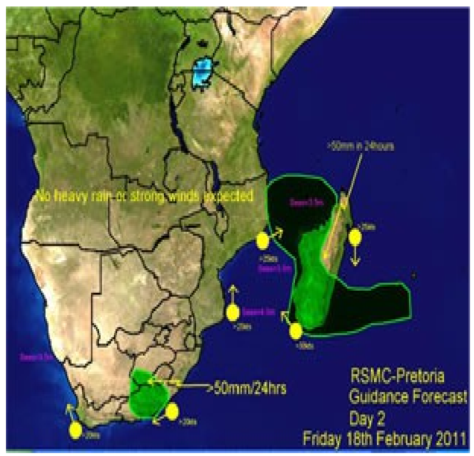
STEP **2**

Develop ways to minimize/avoid RISKs

- **Multi-Hazard Early Warning Systems & Standards for Meteorological, Hydrological and Climate Services**

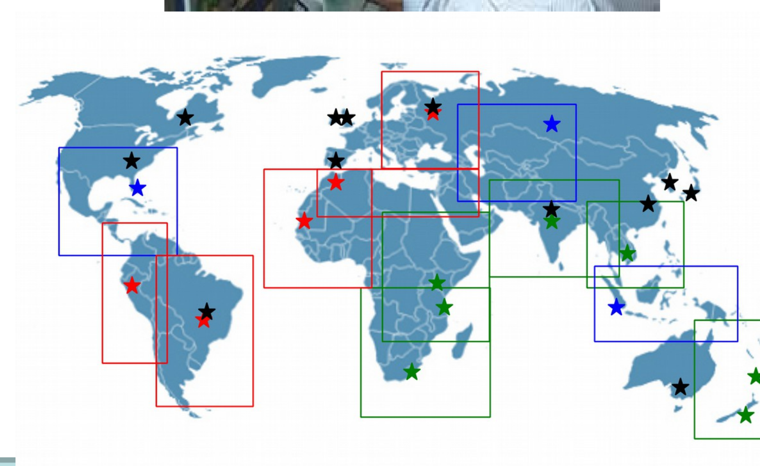
Regional implementation

- **Southern Africa**
- **Eastern Africa**
- **South Pacific Islands**
- **Bay of Bengal region**
- **Southeast Asia**



Future projects

- **Western Africa**
- **Northern Africa**
- **Southern of South America**
- **Asia-Pacific region**
- **Others…**

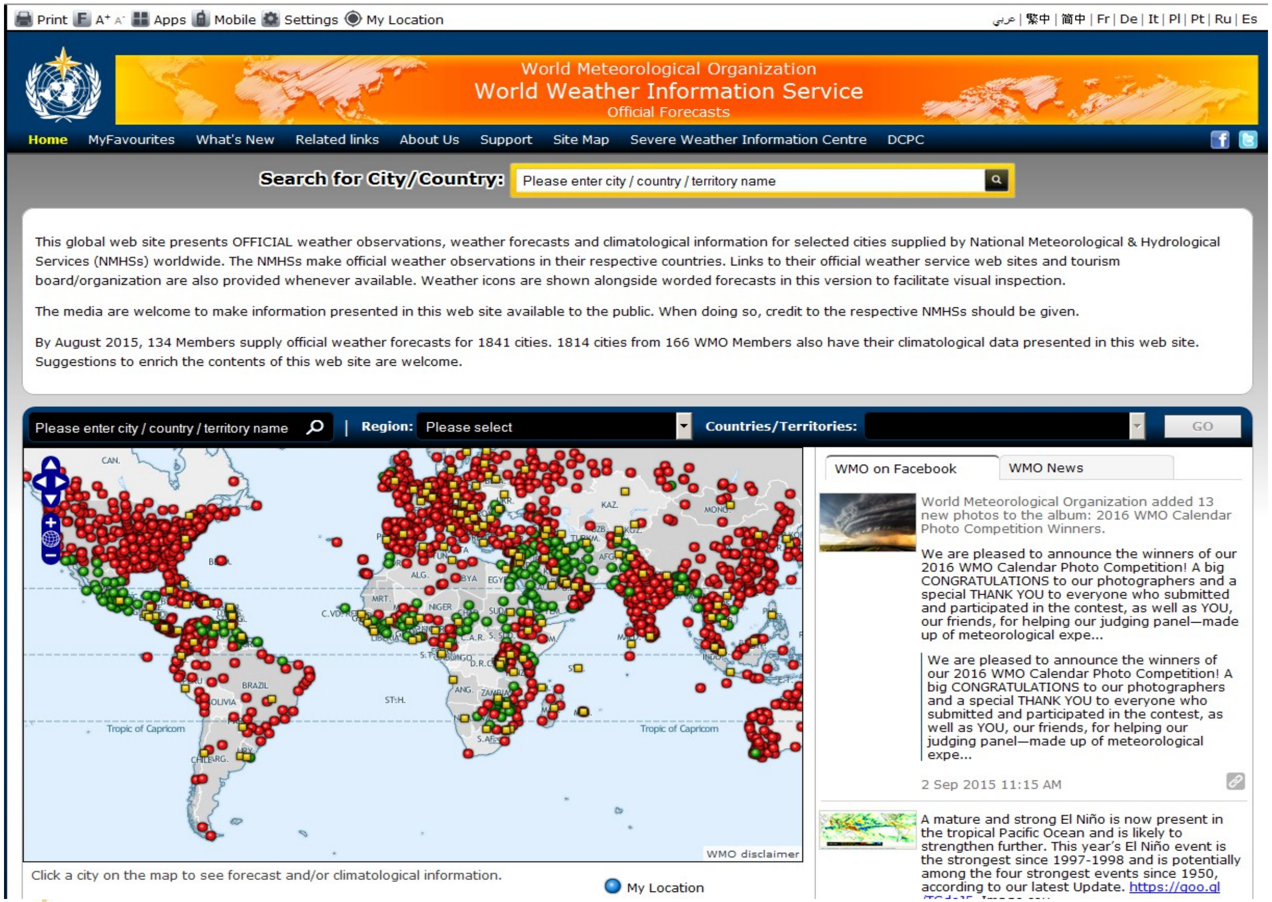


Severe Weather Forecast Demonstration Project

STEP **2**

Develop ways to minimize/avoid RISKs

- **Multi-Hazard Early Warning Systems & Standards for Meteorological, Hydrological and Climate Services**



World Weather Information Service

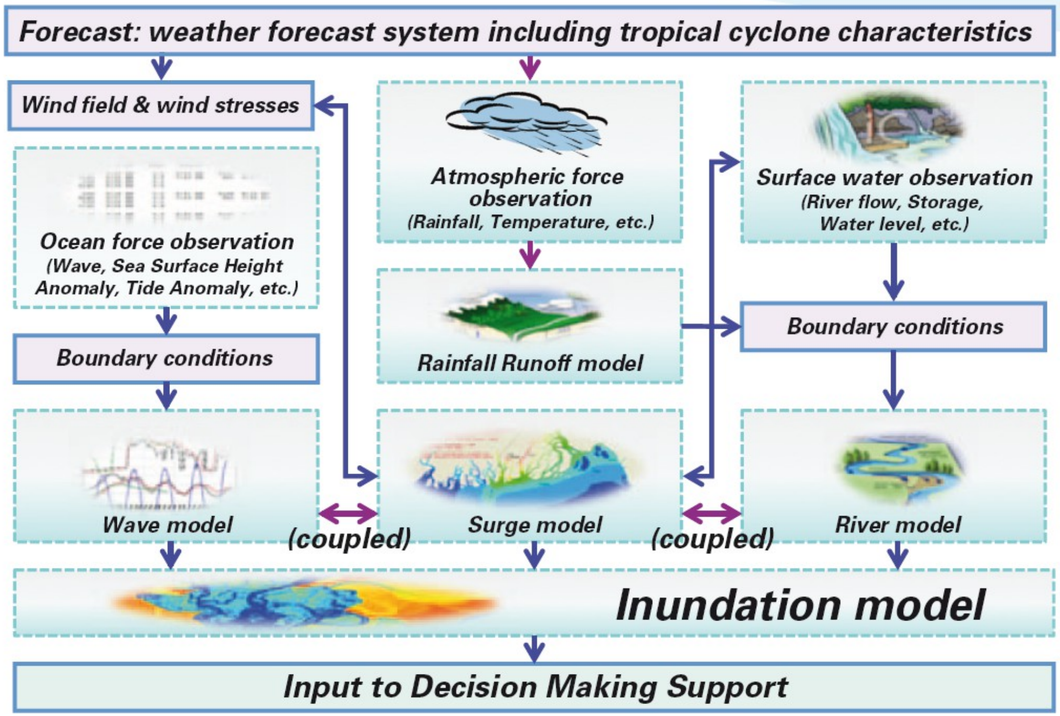
Maritime Safety Information (MSI) Service

LIMITS OF METAREAS

* The GMDSS is under implementation for the Arctic METAREAs and is expected to be fully operational by 2010/11

WMO METAREAs are aligned with IMO NAVAREAs

COASTAL INUNDATION FORECASTING



- **Use of NMHSs capabilities to produce and provide coastal inundation forecasting and warning services**
- **Improving interactions between NMHSs and end-users**
- **Demonstration project in Dominican Republic**

A regional approach to coastal inundation forecasting in the Caribbean:

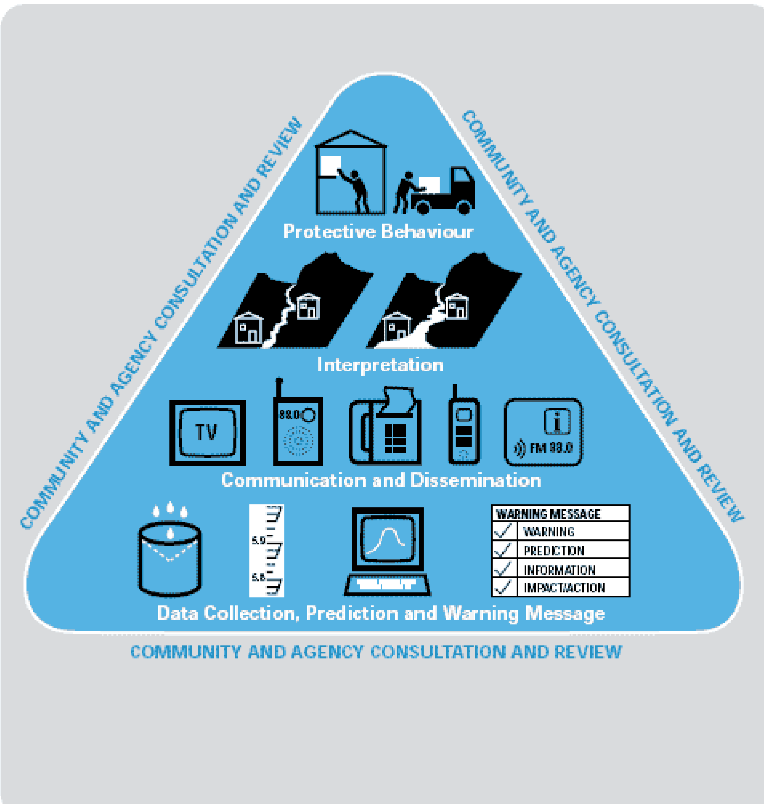
- **Issues: availability of marine meteorology products, requirements of models, accessibility of observations and gaps analysis**
- ***Strengthening of observation and monitoring capacities***
- ***Strengthening of forecasting capacities***

STEP **2**

Develop ways to minimize/avoid RISKs

- **Advances in Hydrologic Forecast and Flood Warning Services**

WMO Flood Forecasting Initiative



- Promotes **cooperation** between Meteorology and Hydrology in order to improve **flood forecasting**

Major activities

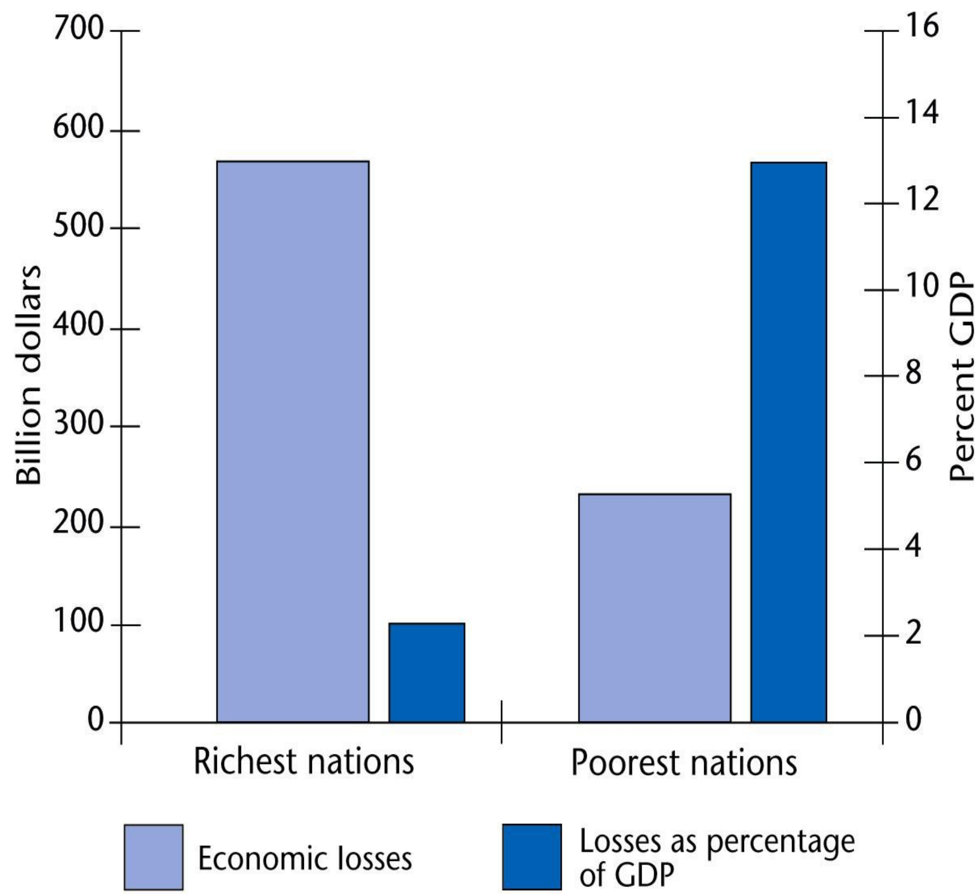
- Conferences and Workshops
- Establishment of regional networks of experts
- Implementation of projects with extrabudgetary funds on **Flash Flood Guidance**

STEP **2**

Develop ways to minimize/avoid RISKs

- **Advances in Hydrologic Forecast and Flood Warning Services**

Developing Countries are hit the hardest



STEP **3**

Develop Strategies to Manage RISKs

WMO's Key Priorities (2016-2019)


Disaster Risk Reduction


WMO Integrated Global Observing System


Aviation


Polar/High Mountain Regions

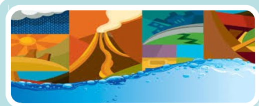

Capacity Development

WMO Governance

STEP **3**

Develop Strategies to Manage RISKs

Disaster Risk Reduction



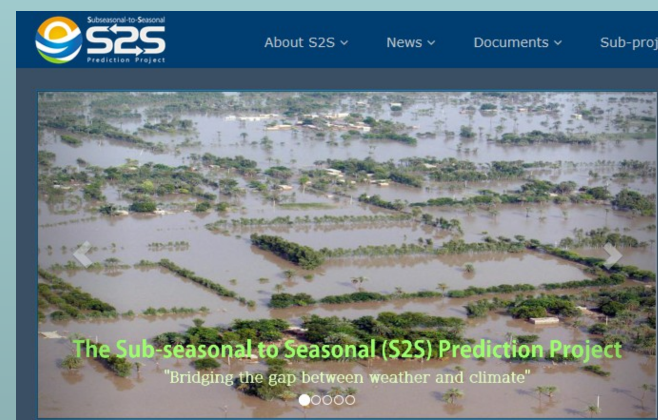
WMO's Key Priorities (2016-2019)

STEP **3**

Develop Strategies to Manage RISKs

nework for Climate Services

WMO's Key Priorities (2016-2019)

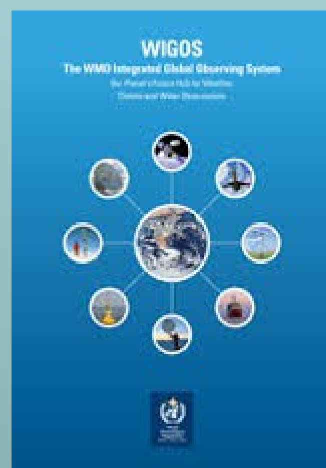


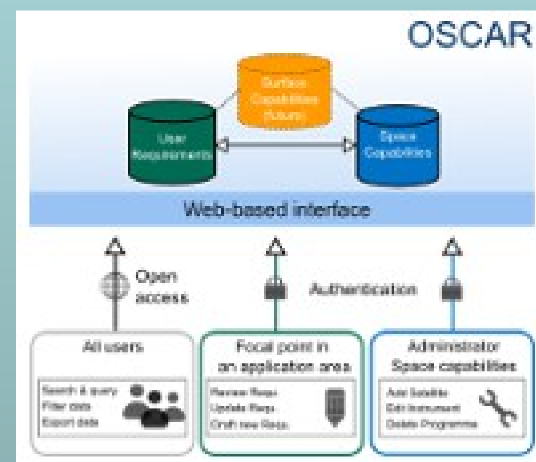
STEP **3**

Develop Strategies to Manage RISKs

WMO's Key Priorities (2016-2019)

O Integrated Global Observing System



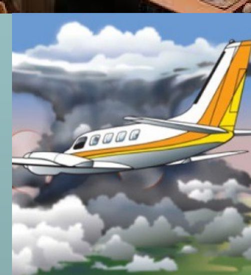


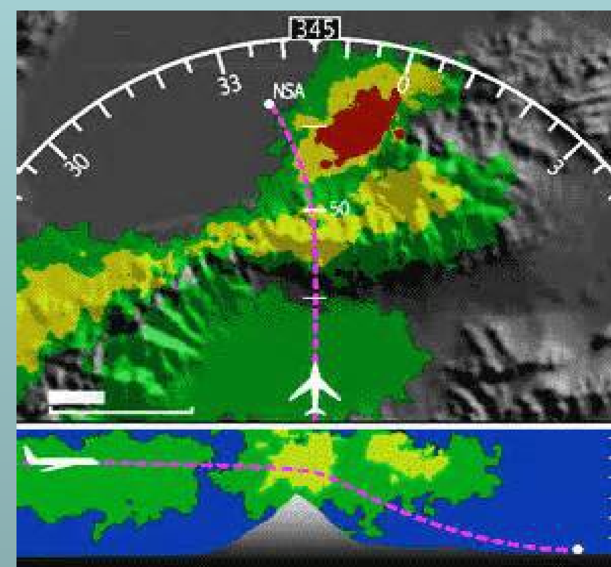
STEP **3**

Develop Strategies to Manage RISKs

Aviation

WMO's Key Priorities (2016-2019)





STEP **3**

Develop Strategies to Manage RISKs

WMO's Key Priorities (2016-2019)

igh Mountain Regions

Polar Prediction Project

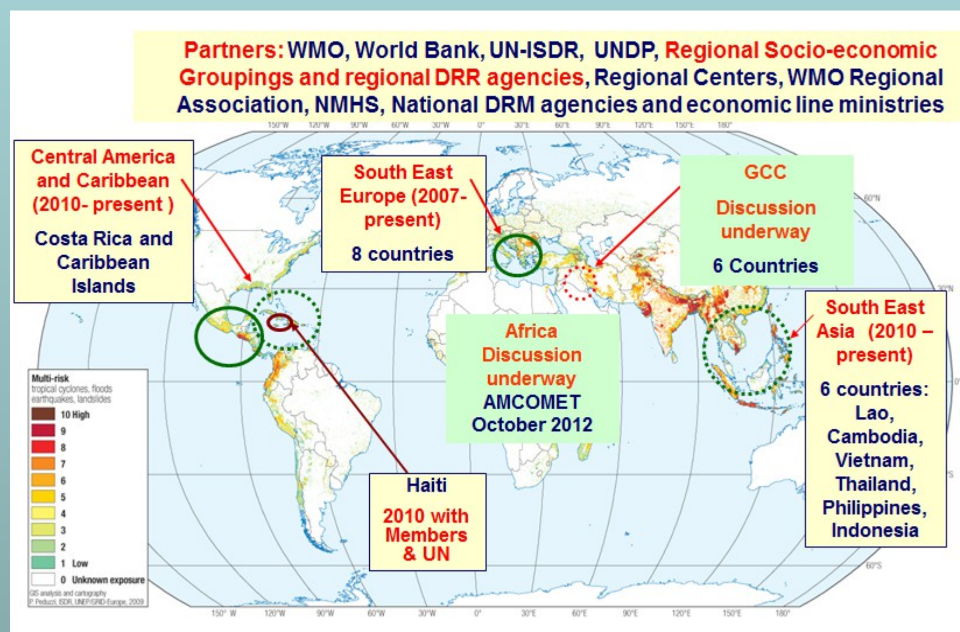
YOPP YEAR OF POLAR PREDICTION

STEP **3**

Develop Strategies to Manage RISKs

ity Development

WMO's Key Priorities (2016-2019)



STEP **3**

Develop Strategies to Manage RISKs

WMO Governance

WMO's Key Priorities (2016-2019)

STEP **3**

Develop Strategies to Manage RISKs

WWW
GAW
WWRP
HWRP
WCP
WCRP
Space Programme
PWS
AMP
TCP
MMOP
IPA
VCP
ETP
LDC
RP
DRR
AeMP

WMO's Strategic Plan

remains committed to research and the development of technologies related to observing, monitoring, modeling, forecasting and warning of hydrometeorological hazards, as well as making them available to all its 191 Members.

STEP **3**

Develop Strategies to Manage RISKs

WMO's Strategic Plan

Disaster Risk Reduction Programme

WMO will continue to strengthen its support to NMHSs in enhancing and optimizing their **Early Warning Services** and strive to respond efficiently and effectively to urgent requests of its Members.

World Meteorological Organization

Weather • Climate • Water

Thank you for your attention

DTerblanche@wmo.int