High impact environmental events
The role of Earth System modelling

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With contributions from
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The Norwegian Academy of Science and Letters

Norwegian Meteorological Institute

WORLD METEOROLOGICAL ORGANIZATION

Why fully integrated hydro-meteorological observing and prediction systems?

1. Integration with the atmosphere to ensure consistency in evapo-transpiration across the land-atmosphere interface
2. Representation of the space/time heterogeneity of precipitation - fundamentally important for surface water/flash flooding and the functioning of terrestrial water cycle.
3. Integration with the coastal ocean to represent river outflows (including nutrients), estuaries and the effects of tides and storm surges.
4. Integration of the water cycle with other key terrestrial cycles to ensure consistency between water, heat, carbon and nitrogen cycles - critical for understanding and predicting the Earth system.
5. Internally consistent assessments of climate change impacts on hydro-meteorological hazards and water availability.

Julia Slingo, Cg-18, WMO 2019

Way forward: National/Nordic (regional) ambition for seamless earth system modelling and interoperable observations

- MET with support of academia and in collaboration with agencies like NVE, HI and the Environment Directorate should move current model and observations systems for forecasting in the seamless regional ES direction, driven by service needs and science capabilities
- Weather forecasting and climate projection research experience are the basis for the growth in societal services and ensuing risk reduction in numerous societal sectors
- When regional ES forecasting succeeds, the expectations are lower risks in:
  - High impact weather;
  - Floods,
  - Droughts and fire danger,
  - Runoff to coastal regions incl estuaries;
  - Marine conditions (waves, currents);
  - Environmental pollution in the atmosphere, freshwater, land surface and at sea. High impact events affecting health and national security. Reactive nitrogen, phosphate, radioactivity etc

Outline

1. Observations of some recent water-related high impact events
2. Systematic changes in the distribution of environmental events
3. How do we observe and forecast?
4. Global observations, data distribution and forecasting through WMO, past, present, future
5. How to proceed nationally with Earth System forecasting

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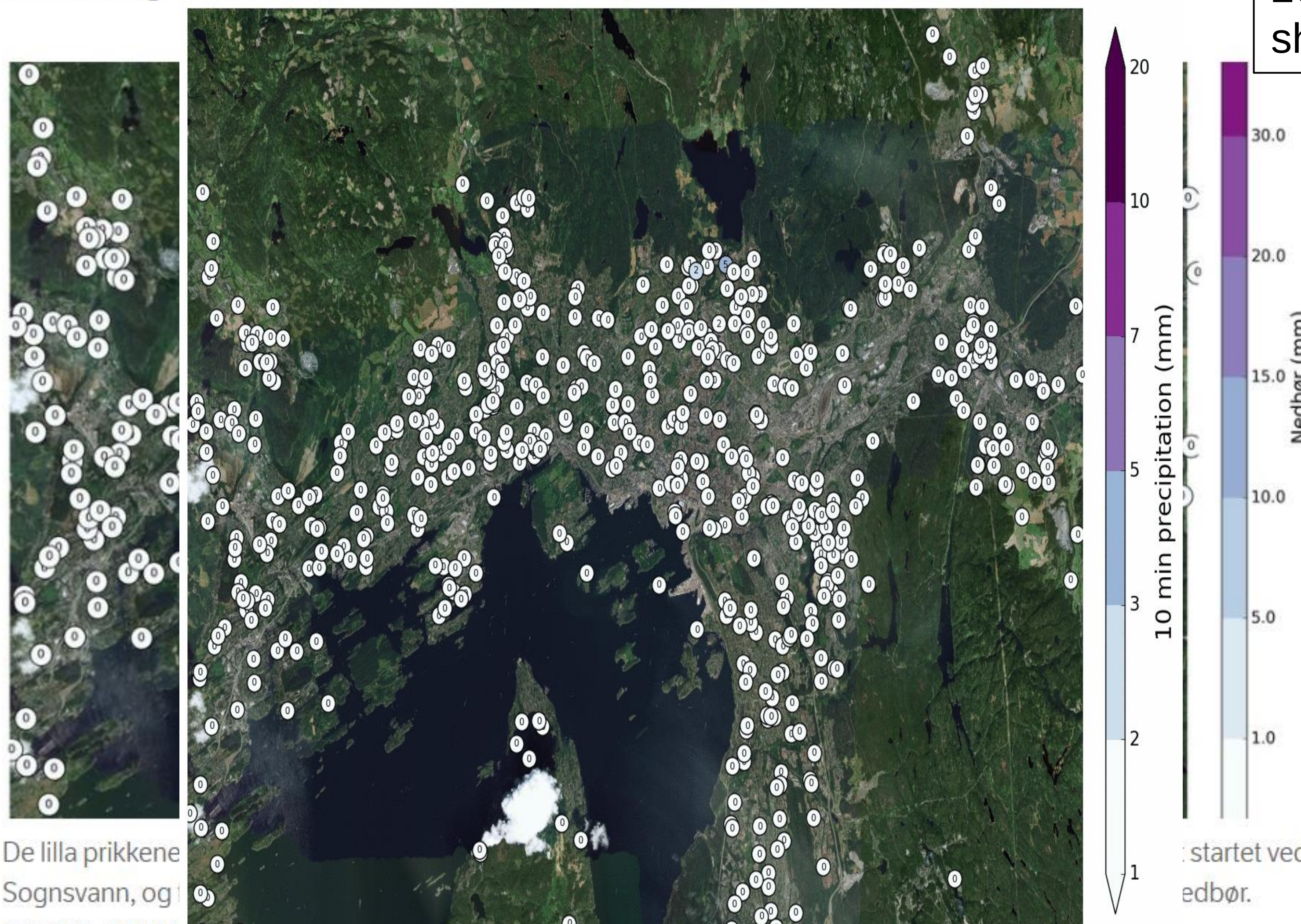
Se hvordan styrtregnet splittet Oslo

Langt nok vest eller øst regnet det lite eller ingenting i Oslo natt til søndag. Bygen kom nordfra, og fosset bokstavelig talt gjennom byen før den bar mot Østfold og Sverige.

The night into
Sunday 4 August
2019,
short time scale!



De lilla prikkene … startet ved
Sognsvann, og … edbør.
GRAFIKK: NETATM…

Kristine Hirsti
@NRKKristine
Journalist

Publisert 5. aug. kl. 22:08

Fredrikstad 1.9.2019

«Styrtregnet på Østlandet den siste uka har ført til vannskader for over 250 millioner kroner. Nå krever forsikringsselskap at det opprettes en klimatilpasningsminister.»

https://www.nrk.no/ostfold/en-uke-ekstremvaer-har-kostet-en-kvart-milliard-kroner-1.14687989 published 5.9.2019

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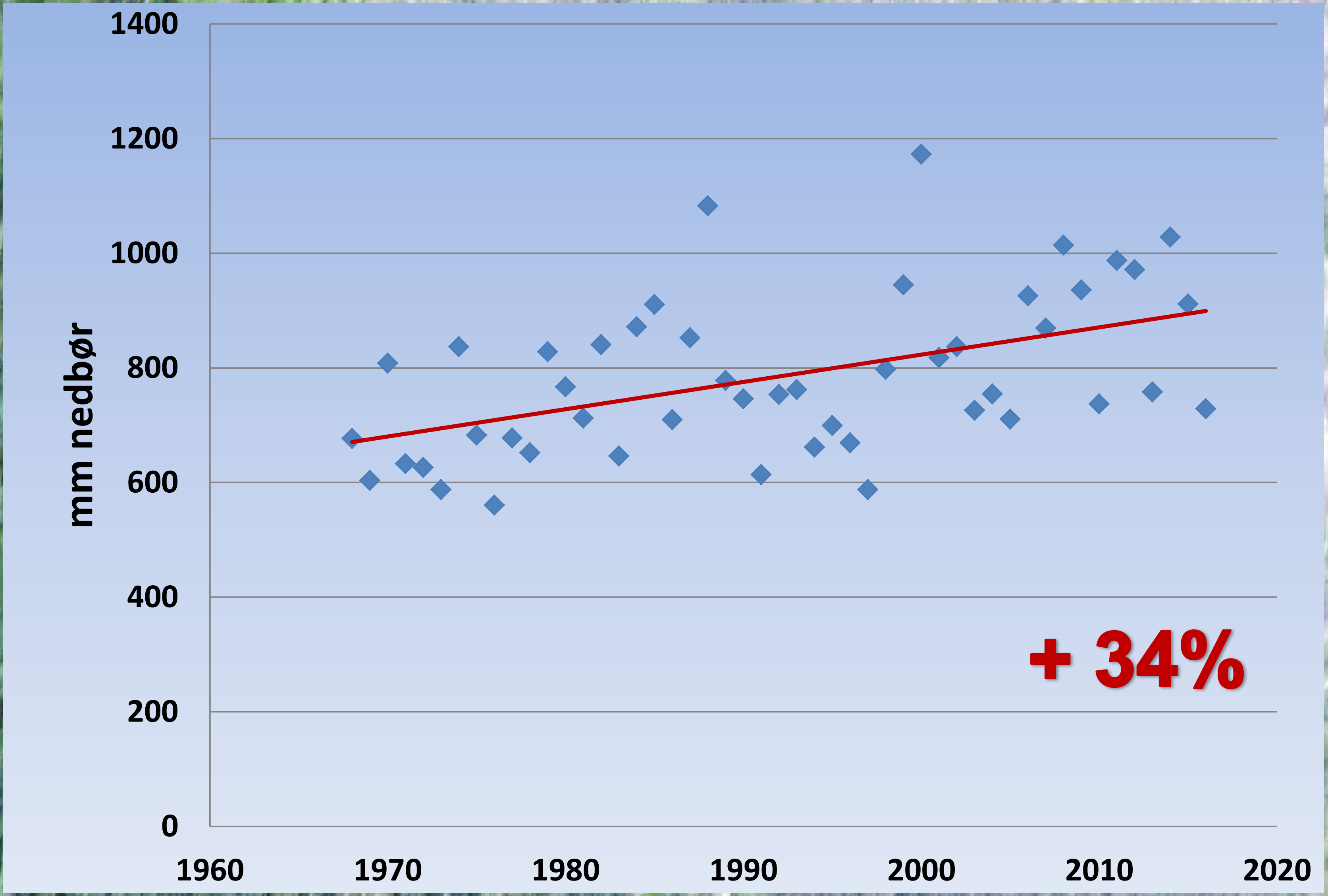
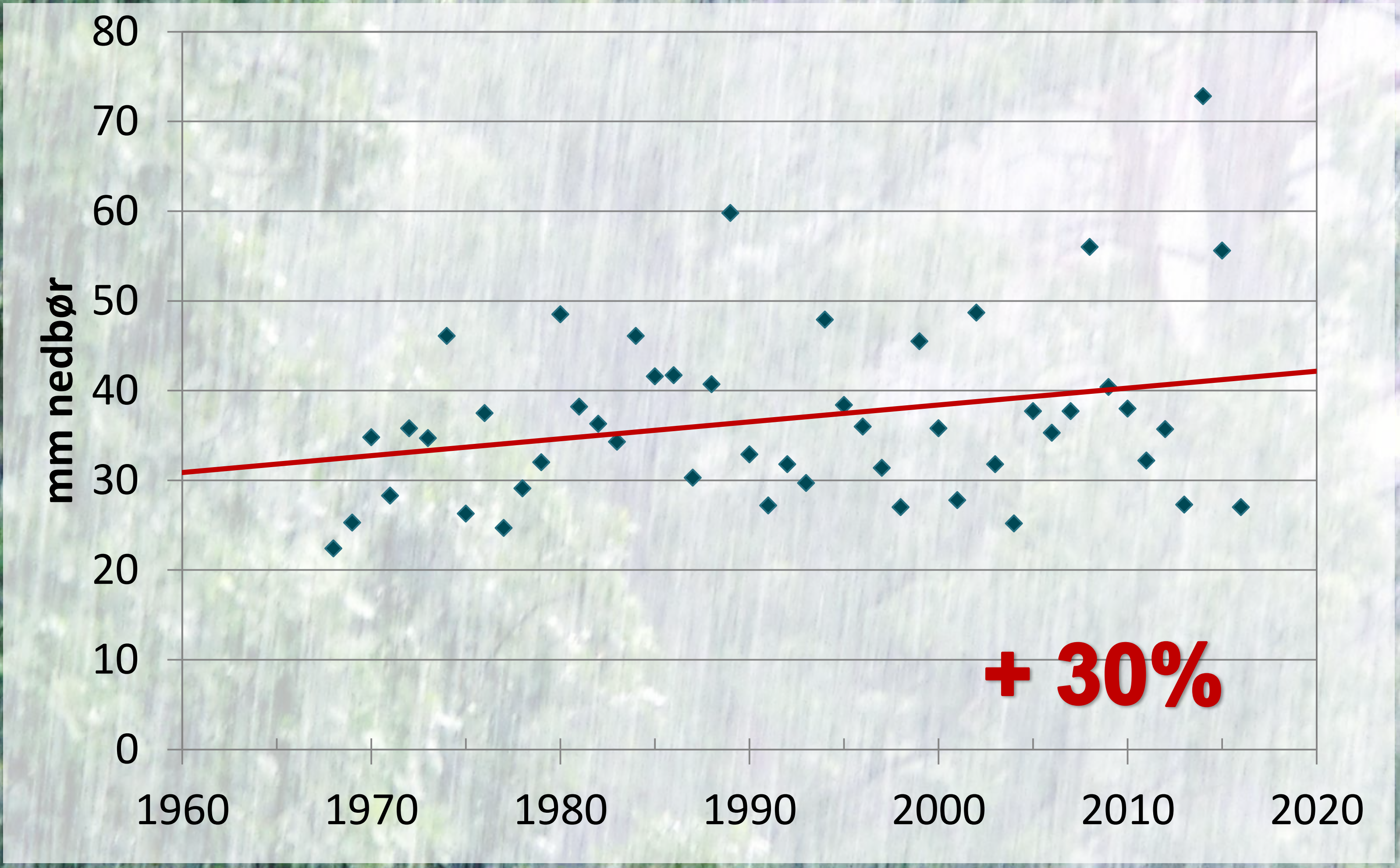
Oslo: Annual precipitation



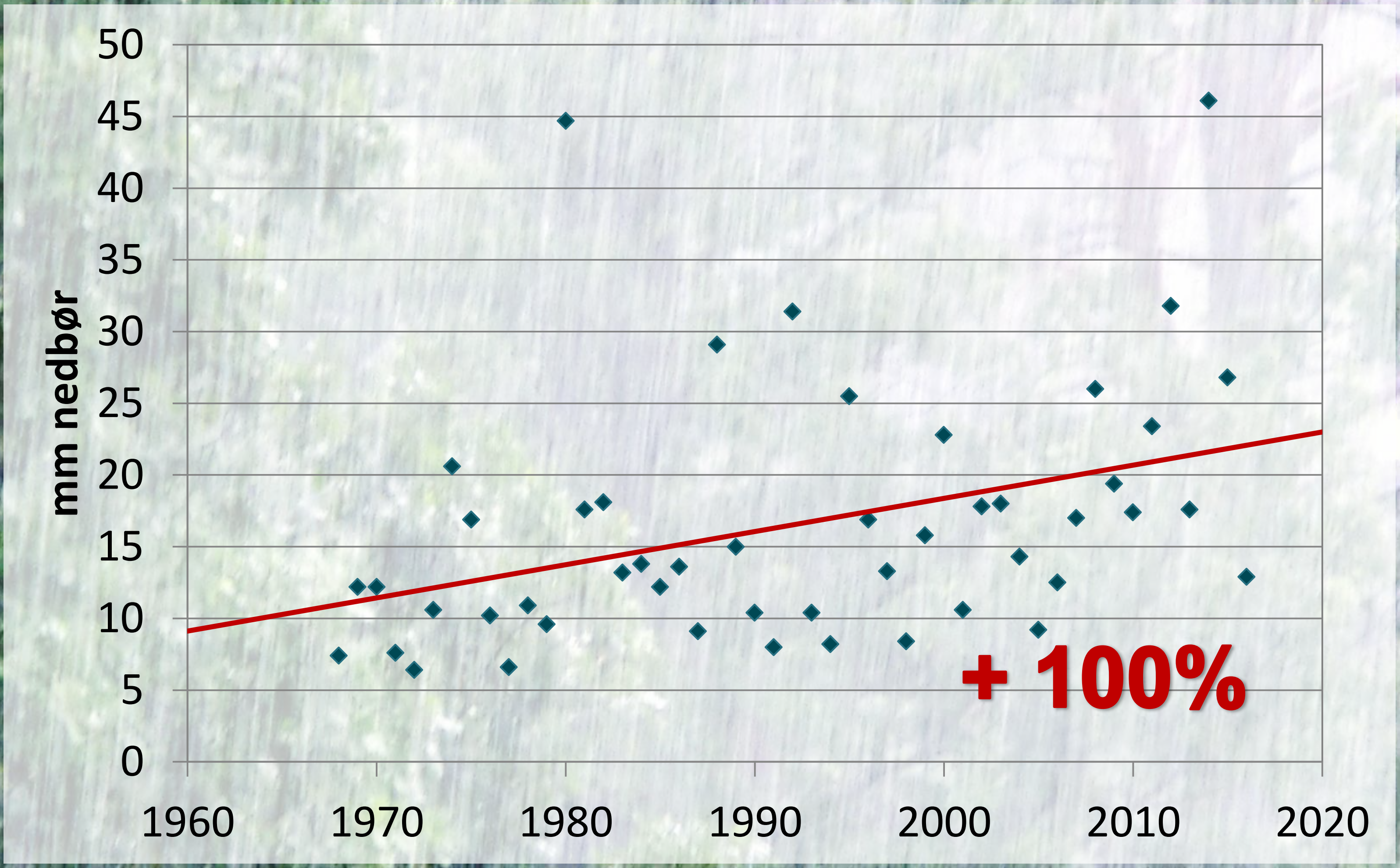
MET KSS, Eirik Førland, 2019

Oslo: Daily precipitation maximum



MET KSS, Eirik Førland, 2019

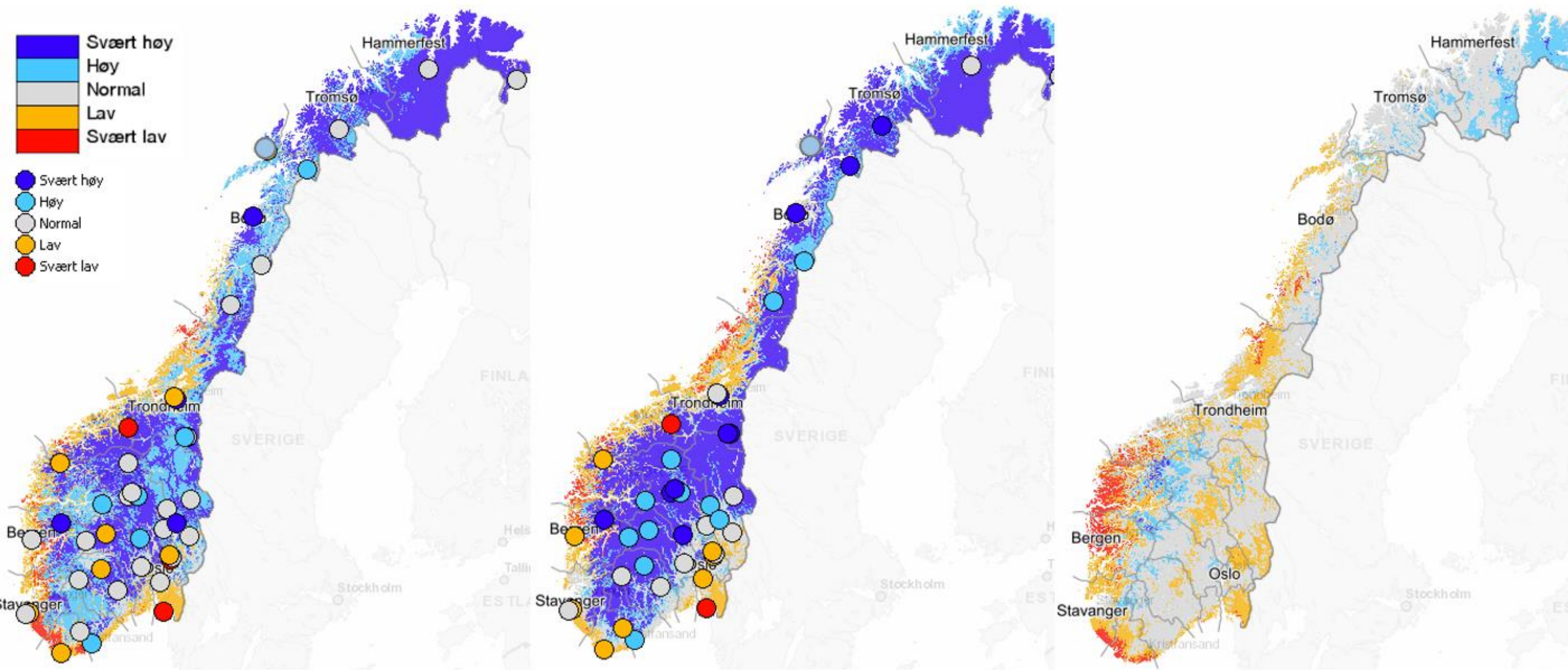
Oslo: Maximum hourly precipitation



MET KSS, Eirik Førland, 2019

Ground water table 2019

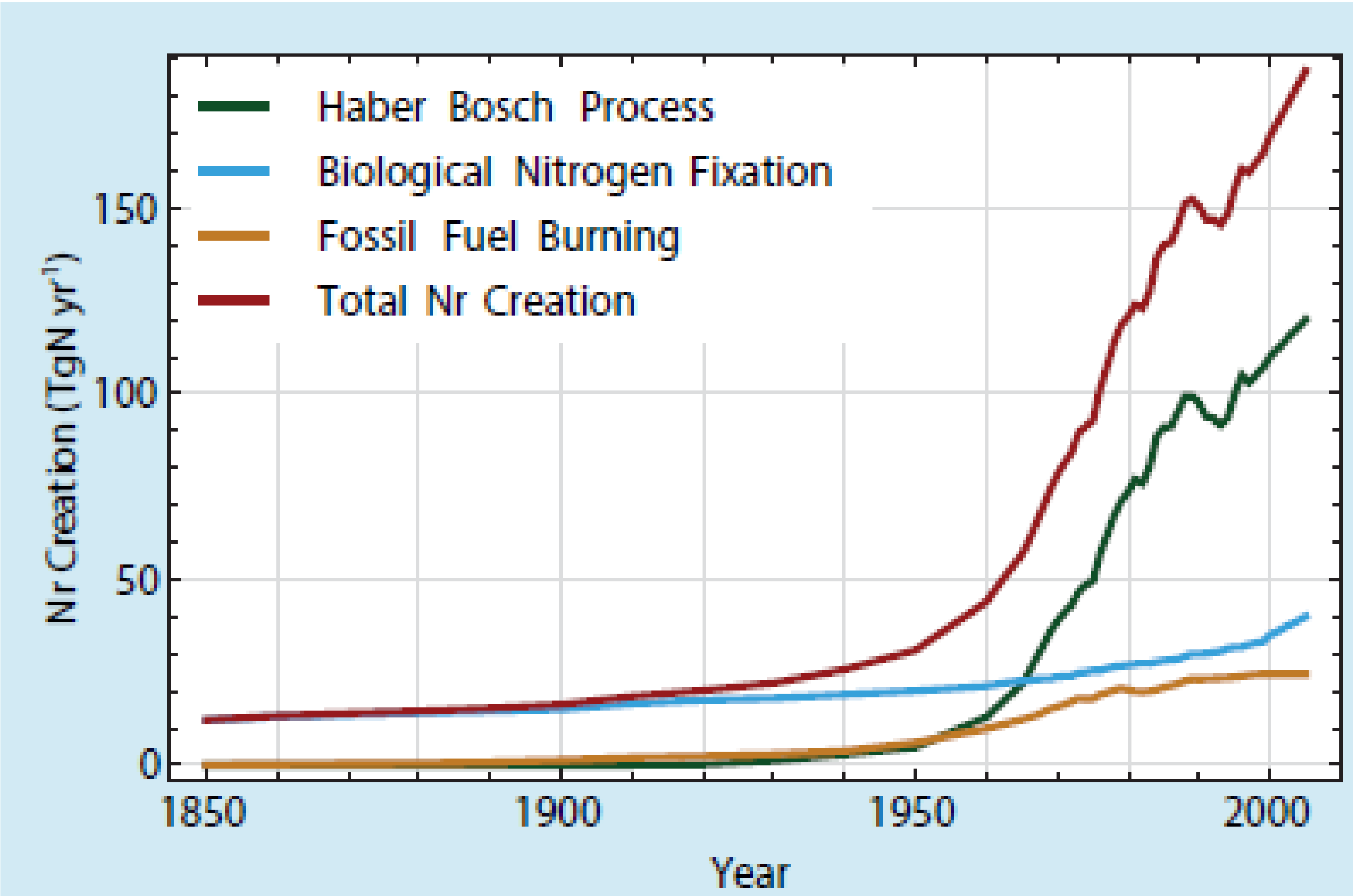
Grunnvanntilstand 21. april 28. april 10. mai 2019



seNorge.no (NVE, MET, SK)

Reactive nitrogen N_r – carried by water in the atmosphere, in soil, rivers and lakes, and in the ocean

Air quality, water quality, ecosystem services, climate, ocean acidification



Nr half life in air: <1month, ocean: 10-100 yrs, soil: 10-50 yrs

Total global Nr fixation 413 TgN/a, of that man-made 210 TgN/a

IPCC AR5 WGI Ch 6 Box 6.2 Figure 1 Ciais et al., 2013

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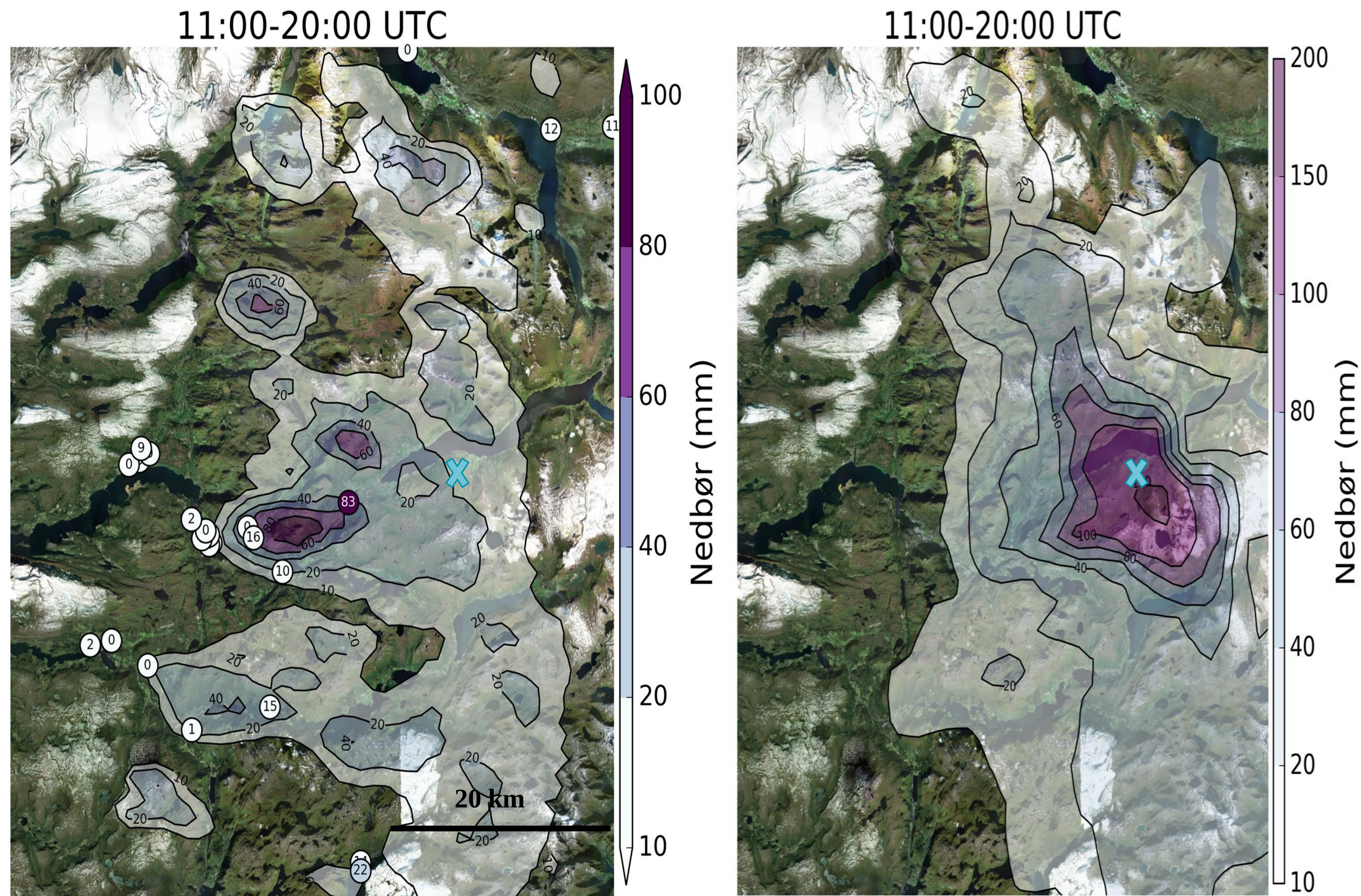
Estimated observed precipitation

citizen obs, (blocked) radar and best analysis NWP+obs (Vassenden 30 July 2019)



Global weather in WMO

- **Mandate:**
  - Protect life and property,
  - safeguard the environment,
  - contribute to sustainable development,
  - promote long-term observation of
    - meteorological,
    - hydrological,
    - climatological data,
    - related environmental data,
  - promote capacity-building,
  - meet international commitments
- **Core WMO programme since 1963: World Weather Watch WWW**
  - Global Observing System (GOS),
  - Global Telecommunication System (GTS) (with radio frequency coordination – RFC)
  - Global Processing and Forecasting System GPFS
  - World, Regional Specialized, and National Meteorological Centres serve forecasting everywhere
  - provide processed data, analyses, and forecast products on a wide range of temporal and spatial scales.
- **"NWP and atmosphere". In practise a weak value cycle (gap between development and operations)**

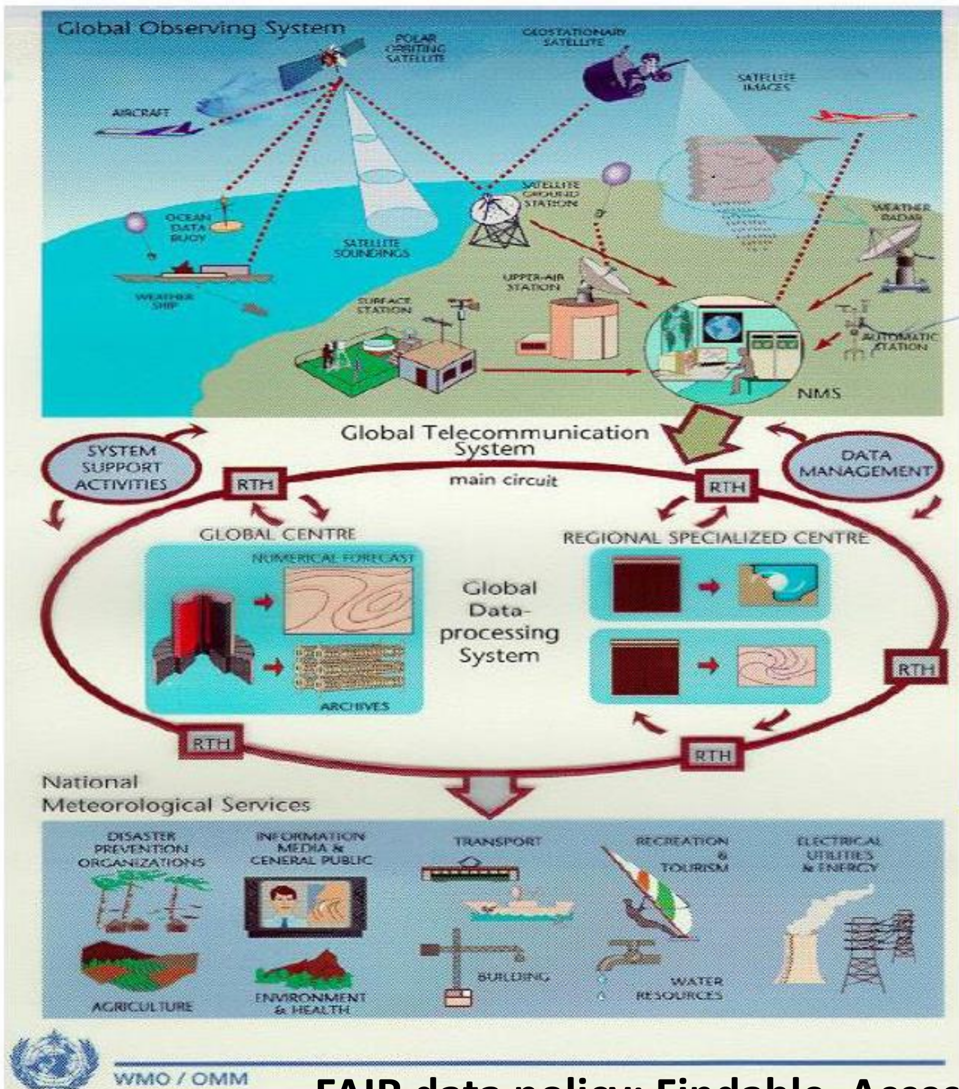
In recent years:
WMO moving from «closed loop» GDPS, GOS and GTS to «open» S-GDPFS, WIGOS and WIS, the new backbone for Earth System Forecasting

WIGOS

WIS

GDPFS

Service delivery



191 NMHSs: satellites, land, ships, buoys, and aircraft contribute to Global Observing every day

Global Telecom with Regional Hubs – becoming the WMO Information System

The GDPFS: Global, Regional Specialized Met. Centres (RSMC, RCC), and National Centres

NMHSs deliver analyses, forecast and early warning services

FAIR data policy: Findable, Accessible, Interoperable, Reusable

WWW built on the value chain in weather forecasting - the legacy of the Bergen school: «Science for service»

Quality, relevance, impact
Value chain weakened over time?

Research topics

Vilhelm Bjerknes 1904:
Weather prediction – an initial value problem in physics
- Diagnose (analyse)
- Prognose
Developed empirical forecasting methods
The Circulation Theorem

Synoptic forecasts, operational (365/12/24)

Users:
Fishermen
Coastal population
agriculture

Near real time observations

The telegraph

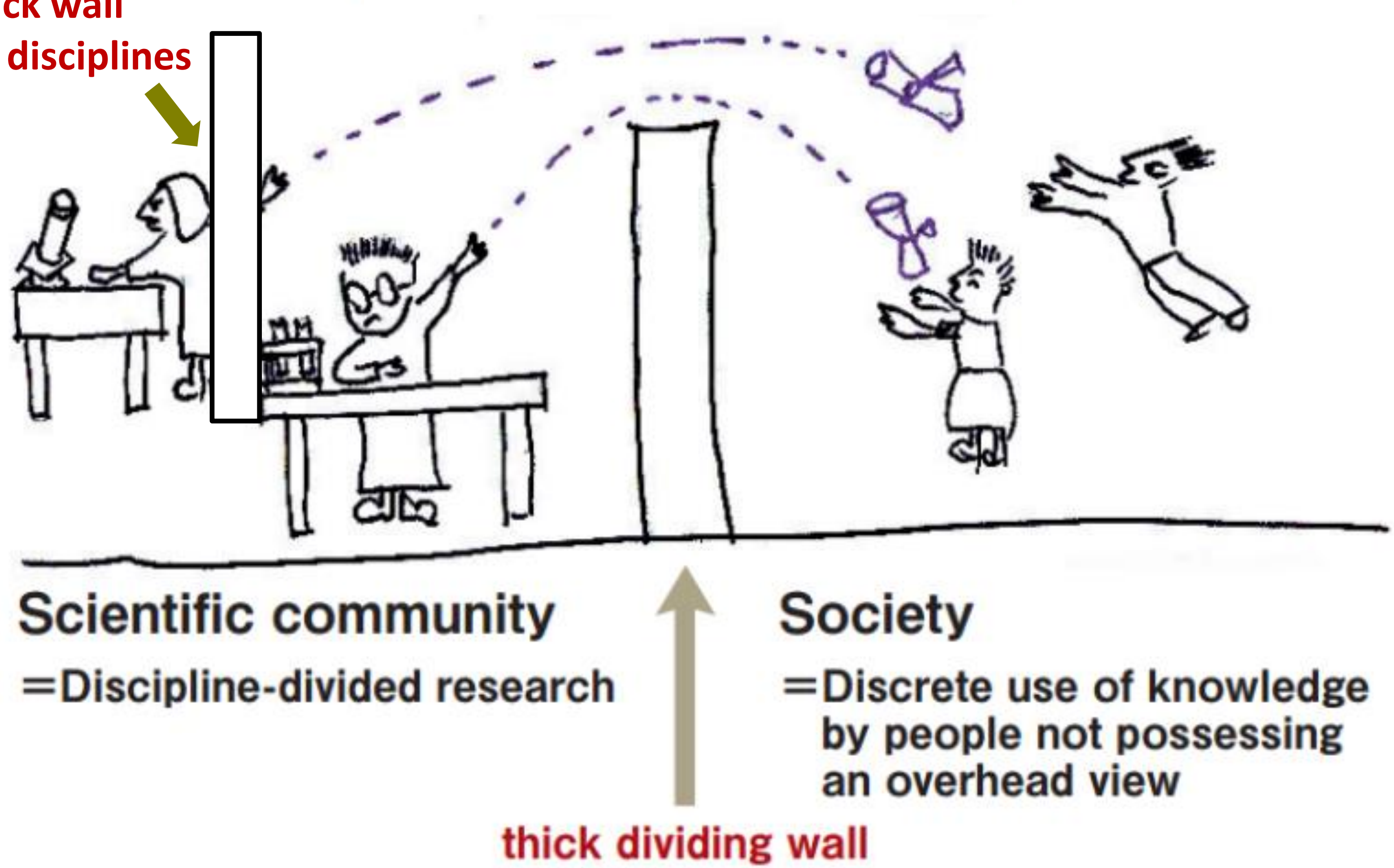
Projects
Network
funding

3-4 assistants/a 1905-1940 from Carnegie foundation

Academic research

Weakened value chain?
Traditional relation between science and society (One way and separated)

Other thick wall
between disciplines

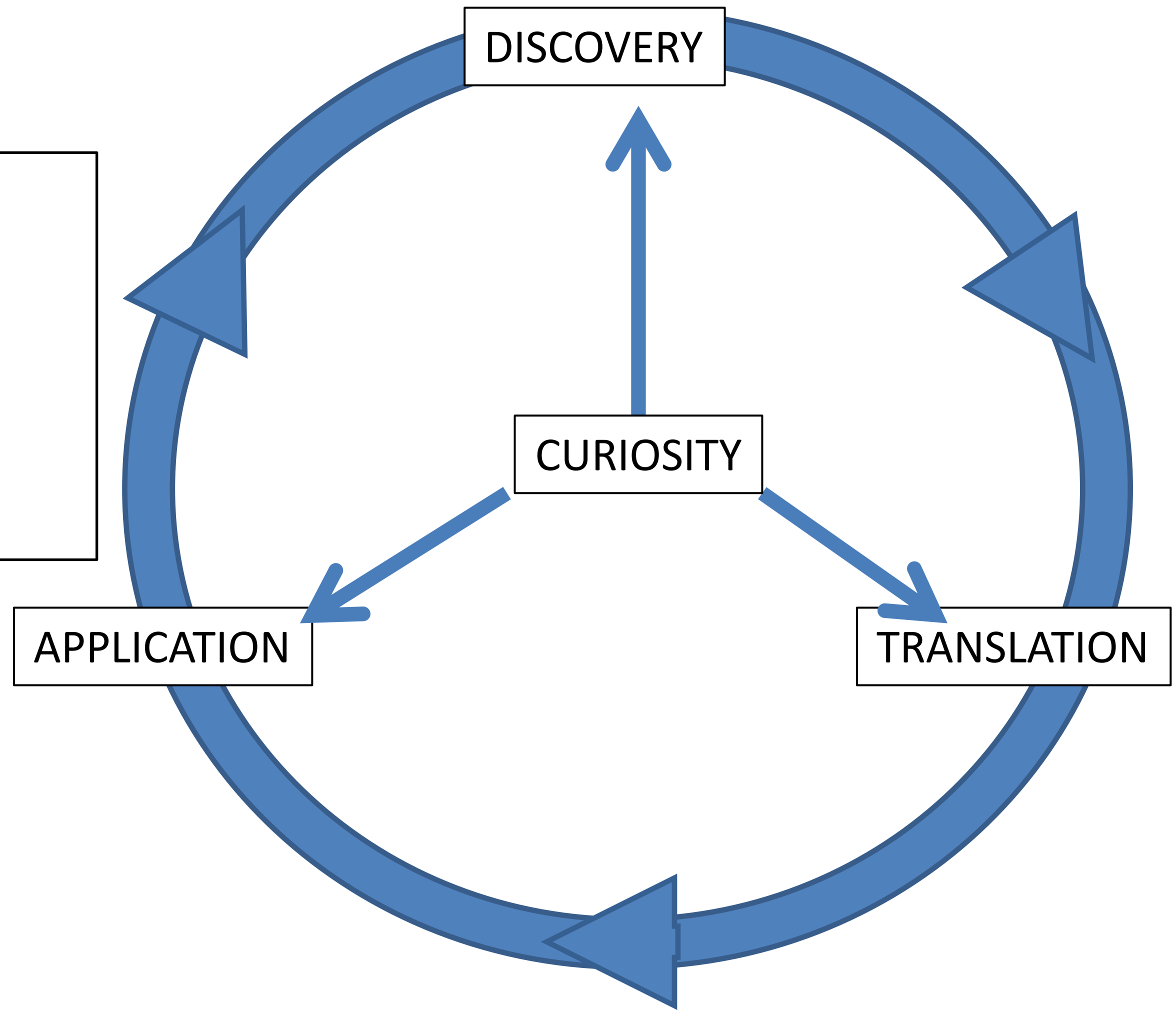


«Weakened value chain?»

- Operational centres push for the best skill scores while scientists seek fundamental understanding.
- The best answers for the wrong reasons (compensating errors in unreliable parametrizations), and the wrong answers for the right reasons (good physics with insufficient calibration)

What is needed is **Science for service** in thematic research: A value cycle, or continuum, around discovery-translation-application. Judged by quality – relevance - impact

Enabling technologies and enabling cultures are required

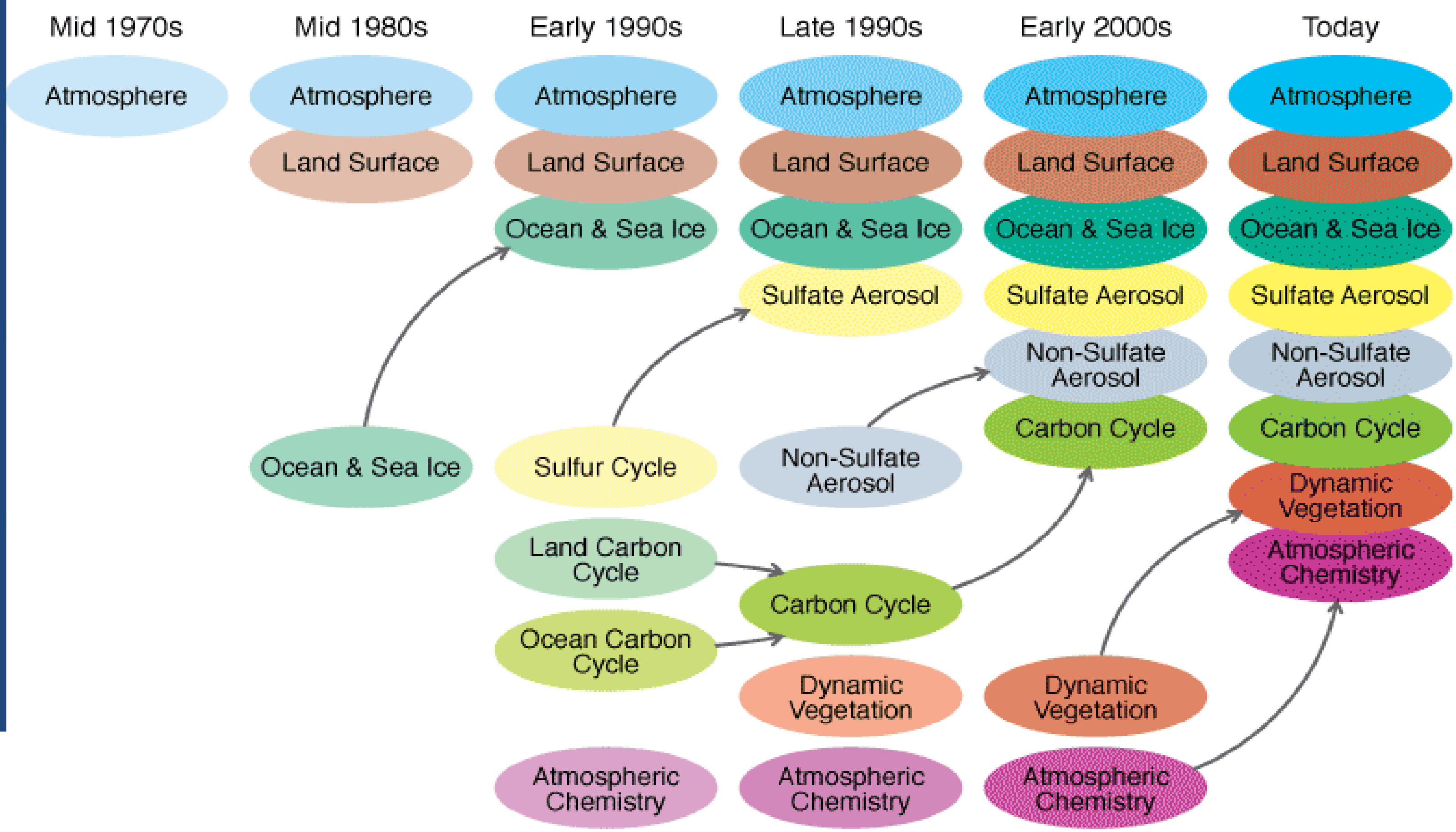


Cultural enablement. Why did Bjerknes succeed? Tor Bergeron (1962) tells about Vilhelm Bjerknes:

- understood that a dense network of observations within Norway could enable them to trace and follow the weather features.
- wanted to increase the number of reporting stations, and not only the assistants, but Bjerknes himself went on navy patrol boats along the coast to establish stations.
- convinced Theodor Hesselberg, the director of NMI to put two young scientists as leaders of the weather forecasting divisions in Bergen and Oslo (Jack Bjerknes and Halvor Solberg).
- was anxious to give credit to the young collaborators for the fundamental discoveries and their applications
- supported and defended his young meteorologists when established Central European authorities argued against them
- both theoretician and empiricist, accepting that the real advances in science are achieved by an intimate combination of the two
- no fixed office hours at the small Bergen Weather Service
- observations came in by cable telegrams, and their significance was pondered over and discussed. Bjerknes would turn up in the map-room, with his eyes gleaming of expectations: “Are there any new discoveries tonight?”
- Bergeron portrays Bjerknes as a humoristic person with a dignified face “often with a shy, tolerant or humoristic smile on it”.

LEARNING FROM EARTH SYSTEM MODELLING developed primarily through WCRP. Boundary value problem. Earth system forecasts require initial as well as boundary values

Evolution of Climate Models to Earth System Models



The water cycle is a key factor in extreme weather

- Increased intensity and longer dry spells are two features of the same response
- Smaller scale, more intense and less predictable precipitation systems
- Large consequences for
  - value of 30-year average climate data
  - how do we make sense of anomalies
  - estimation of return values
  - long-term urban, agricultural, energy, planning

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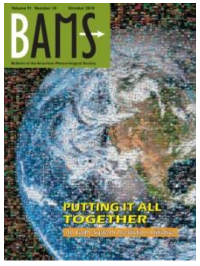
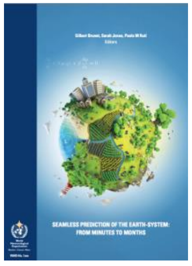
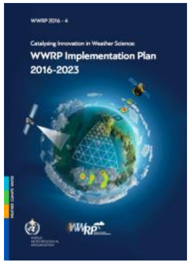
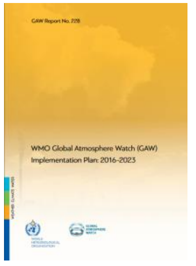
From 2010: A Seamless Science Road Map

- Putting it all together (BAMS, 2010)
- World Weather Open Science Conference (2014)
- Seamless prediction of the Earth System: from minutes to months (WMO, 2015)
- Resolution 11 Cg-17 (2015) - Move to seamless, integrated Data Processing and Forecasting System
- Catalysing Innovation in Weather Science: WWRP Implementation plan (2016-2023)
- GAW Implementation Plan (2016-2023)
- Making it work seamlessly: Global Data Processing and Forecasting System Implementation Plan (2018-)









A seamless approach

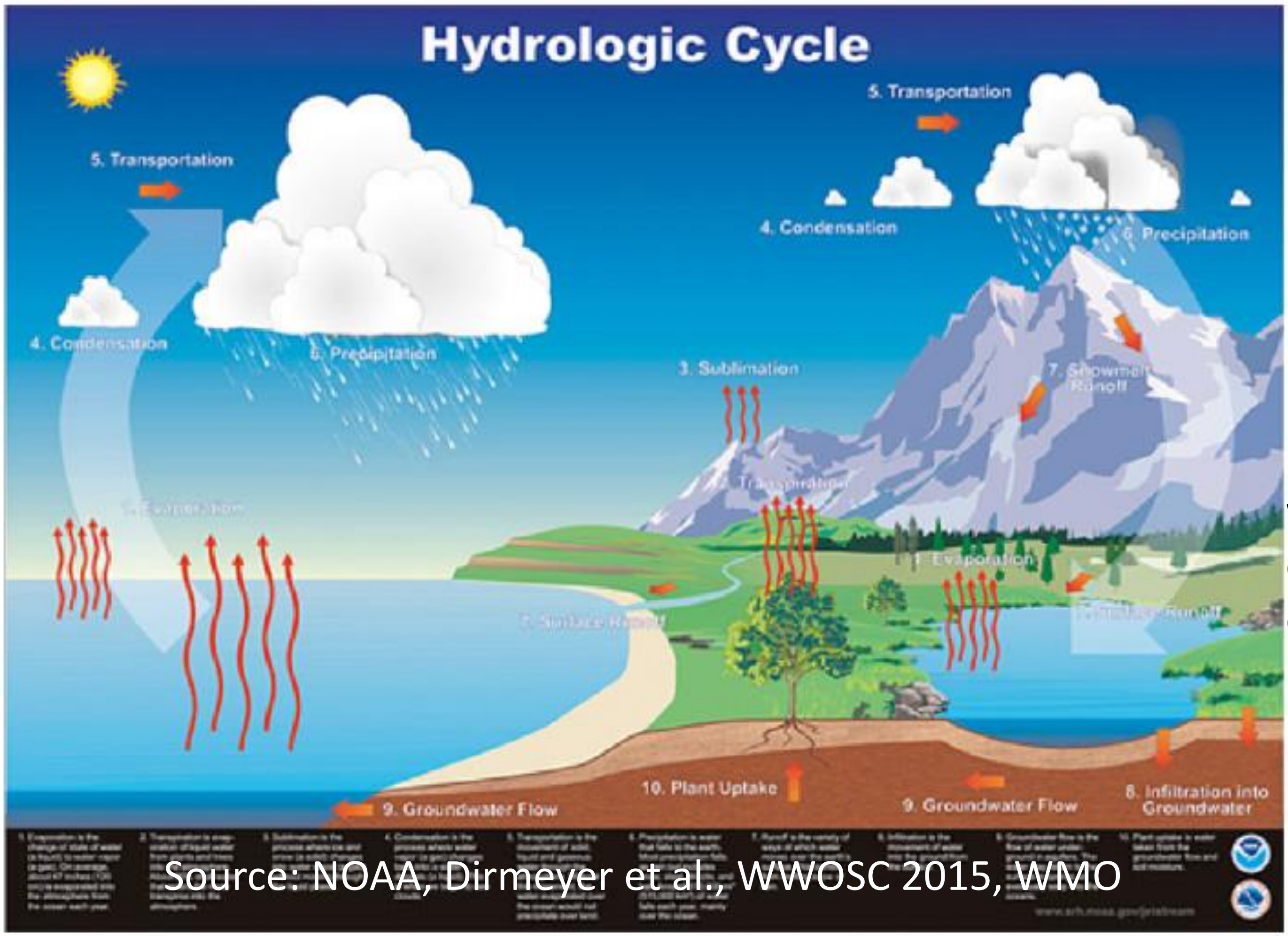
WMO's mechanism to foster and progress cooperative research for improved weather and environmental prediction services from minutes to months

Seamless Definition

In the context of WMO, seamless prediction considers not only all compartments of the Earth system, but also all disciplines of the weather–climate–water–environment value chain (monitoring and observation, models, forecasting, dissemination and communication, perception and interpretation, decision-making, end-user products) to deliver tailor-made weather, climate, water and environmental information covering minutes to centuries and local to global scales.

First priority: Land-atmosphere links through water via precipitation and evaporation; and via energetic, thermodynamic, hydrological and biogeochemical processes

Upward branch of land-atmosphere feedback loop important for weather and subseasonal to seasonal time scales



Source: NOAA, Dirmeyer et al., WWOSC 2015, WMO

Downward branch relevant for weather, climate, environment

Surface states vary more slowly than the atmospheric states => enhanced weather and climate predictability

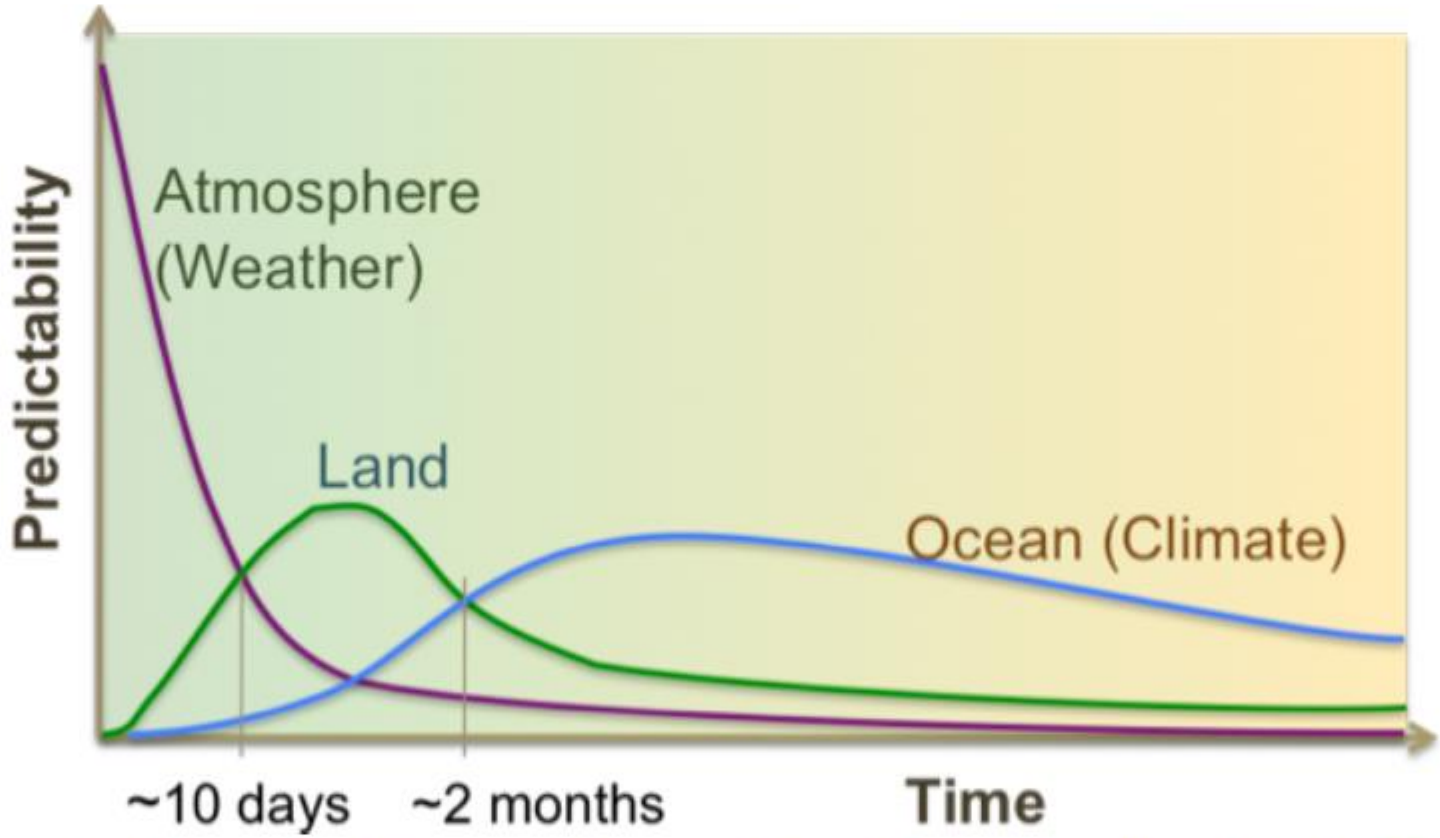


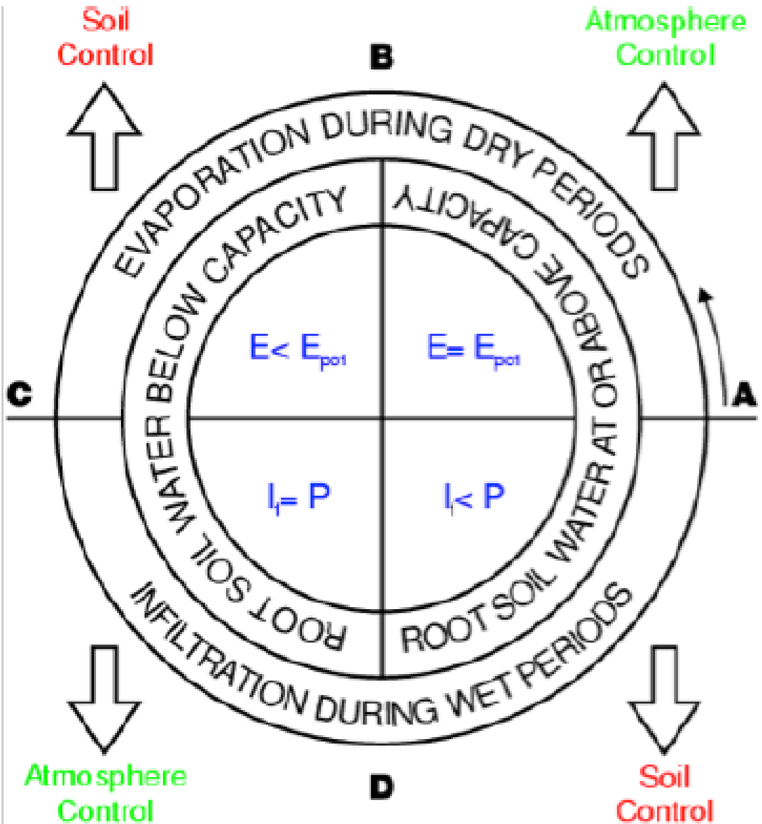
Figure 2. Schematic of the time scales associated with predictability originating from the initial states of atmosphere, land and ocean

Dirmeyer et al., WWOSC 2015, WMO

Land surface state time scales peak at 1-2 weeks, between the weather forecasting time scales and seasonal time scales where (tropical) ocean time scales can impact globally

Do statistical approaches outperform physically-based models?

- For prediction, physically-based models may identify extreme events. A statistical model is calibrated on only «unexceptional past data», and cannot encompass unprecedented occurrences



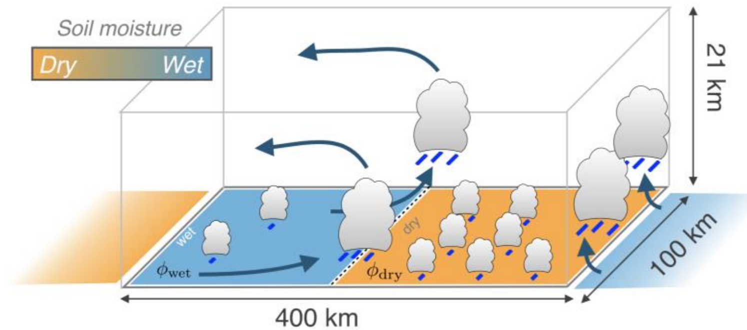
Dooge, 1992;
Dirmeyer et al.,
WWOSC 2015, WMO

Figure 3. Schematic representation of soil and atmosphere control, P, precipitation; E, evapotranspiration; Epot, potential evapotranspiration and I_t rate of downward infiltration of water.

Hydrology in the Earth System approach

Moving towards high-resolution systems makes land-surface atmosphere feedbacks more relevant to weather and climate prediction

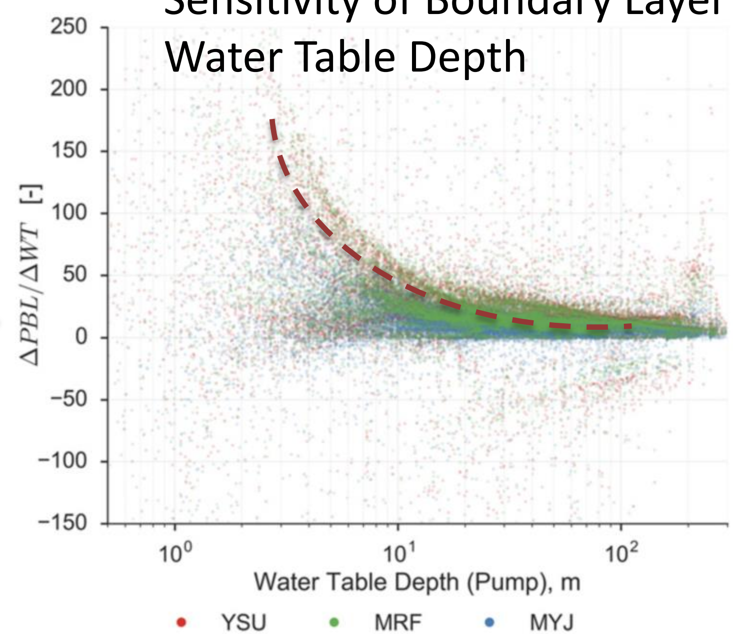
Interactions between soil moisture, convection and precipitation.
Cioni 2018 MPI Report



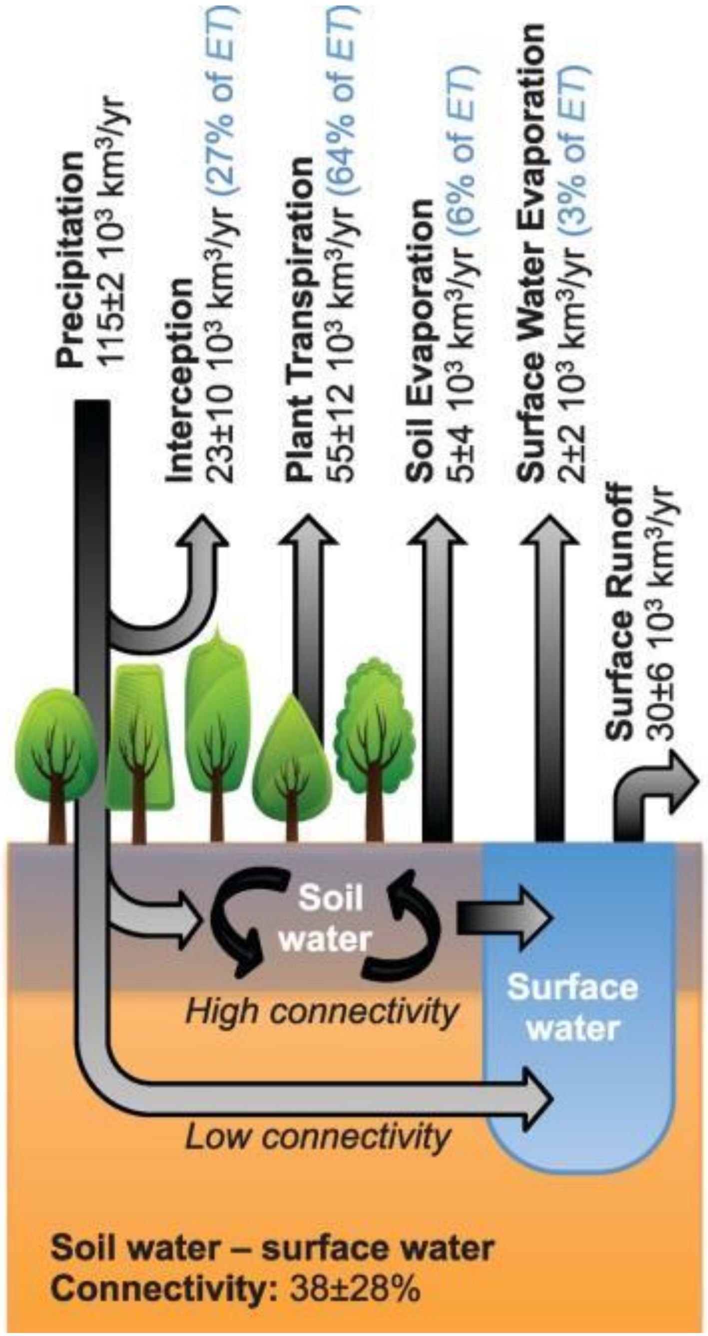
High-Resolution coupled hydrology-atmosphere systems show feedbacks

Effects of Water-Table Configuration on the Planetary Boundary Layer. Gilbert et al., Journal of Hydrometeorology 2017

Sensitivity of Boundary Layer to Water Table Depth



WMO OMM



Good et al. 2015

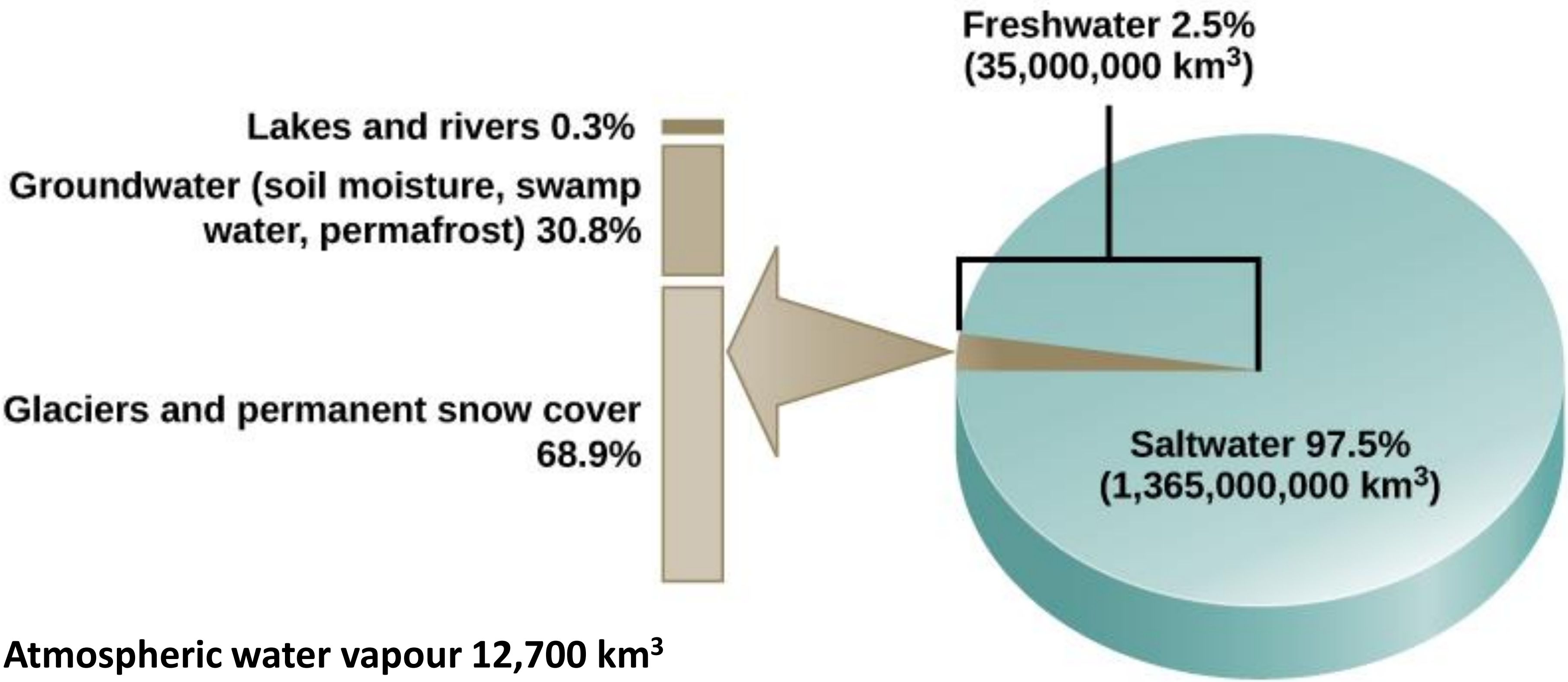
Where does all the water go?

Land-Atmosphere Interactions are fundamental to Terrestrial Hydrology

- How much precipitation is intercepted by vegetation?
- How much precipitation is lost through surface run-off?
- How much water is returned to the atmosphere by evaporation and transpiration?

Depends on surface winds, radiation balance (cloudiness), precipitation characteristics (frequency, intensity)

Global water distribution



Atmospheric water vapour 12,700 km^3

http://cnx.org/contents/24nI-KJ8@24.18:D-ygu4Ty@13/Biogeochemical-Cycles

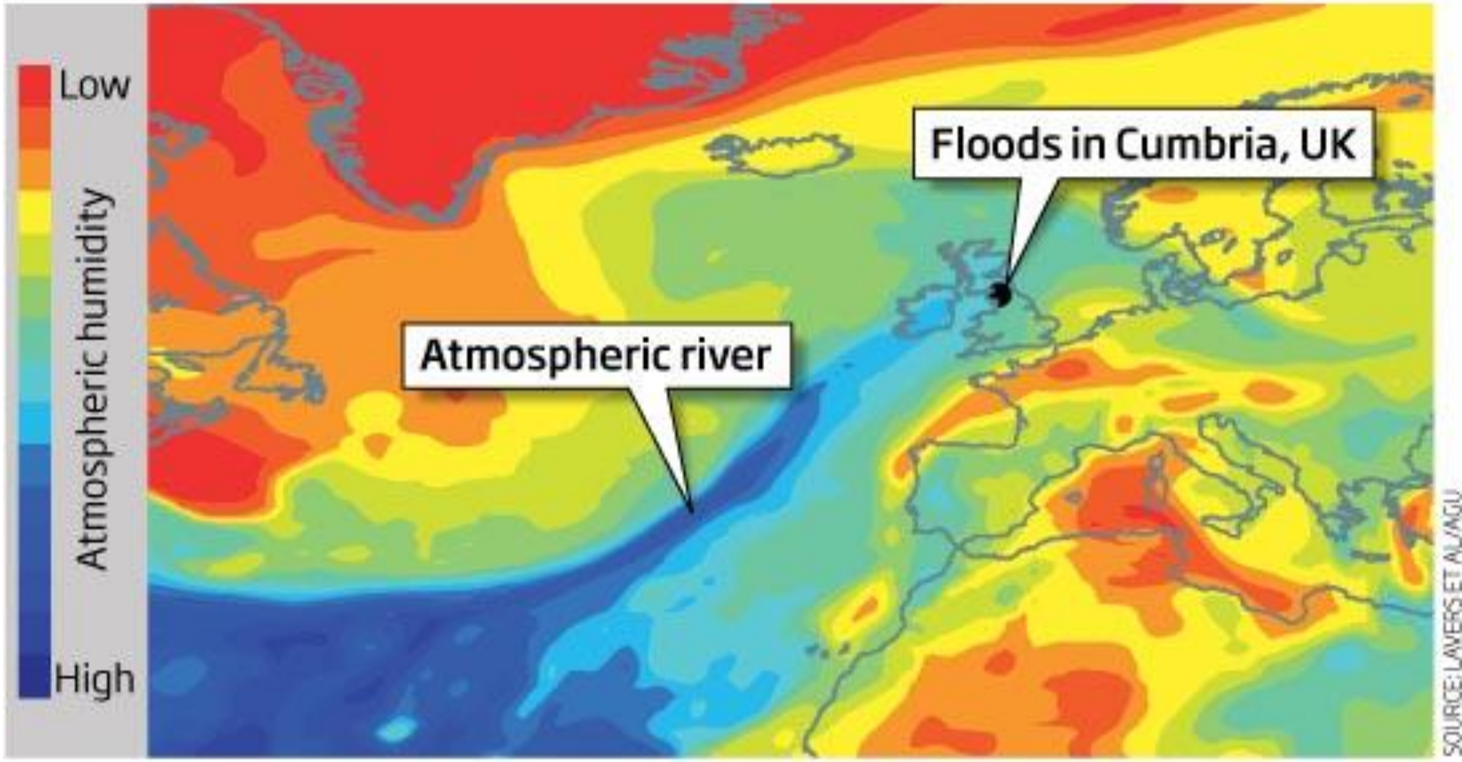
Atmospheric rivers

Can carry as much water as the Amazonas

Rivers up high

©NewScientist

Air flows called atmospheric rivers carry moisture across the Atlantic and can trigger floods in the UK, as happened on 19 November 2009



The resulting flooding in the river Derwent in Cumbria =>

Four or five ARs carry nearly 90 per cent of the moisture that is moving towards the poles.

The water cycle, the land surface coupling to the atmosphere

- Couplings impacting precipitation important for weather to seasonal climate time scales .
- Atmospheric vertical stability and the partitioning between latent and sensible heat flux, determine cloud formation
- Land surface - cloud base linkage depends on the land surface (soil moisture controls stomatal resistance), or the atmosphere (turbulent exchanges of heat and moisture at the top of a growing PBL), or a product of both land and atmosphere (rates of latent and sensible heat flux).
- Errors depend on the weakest link in the chain - if one component is accurate but others are flawed, the overall simulation of the LA feedback will be poor (e.g. Dirmeyer 2001).
- Near surface atmospheric humidity may depend strongly on the land surface state. Cloud formulations can impact near-surface temperature as much as land surface parameters.
- **Earth system modelling rests on the assumption that there is more accountability for maintaining parameters in a realistic physics space.**

Dirmeyer et al., WWOSC 2015, WMO

Observations of near surface fluxes and other properties

- More observations now of high resolution near surface fluxes and parameters (ICOS, Fluxnet, lidars), needs remain for observational data to inform model developments at fine scales
- Poor representation of temporal variability in land states and fluxes in coupled land-atmosphere models is often due to poor variability in downward fluxes of energy and water from clouds and aerosols in the atmospheric model

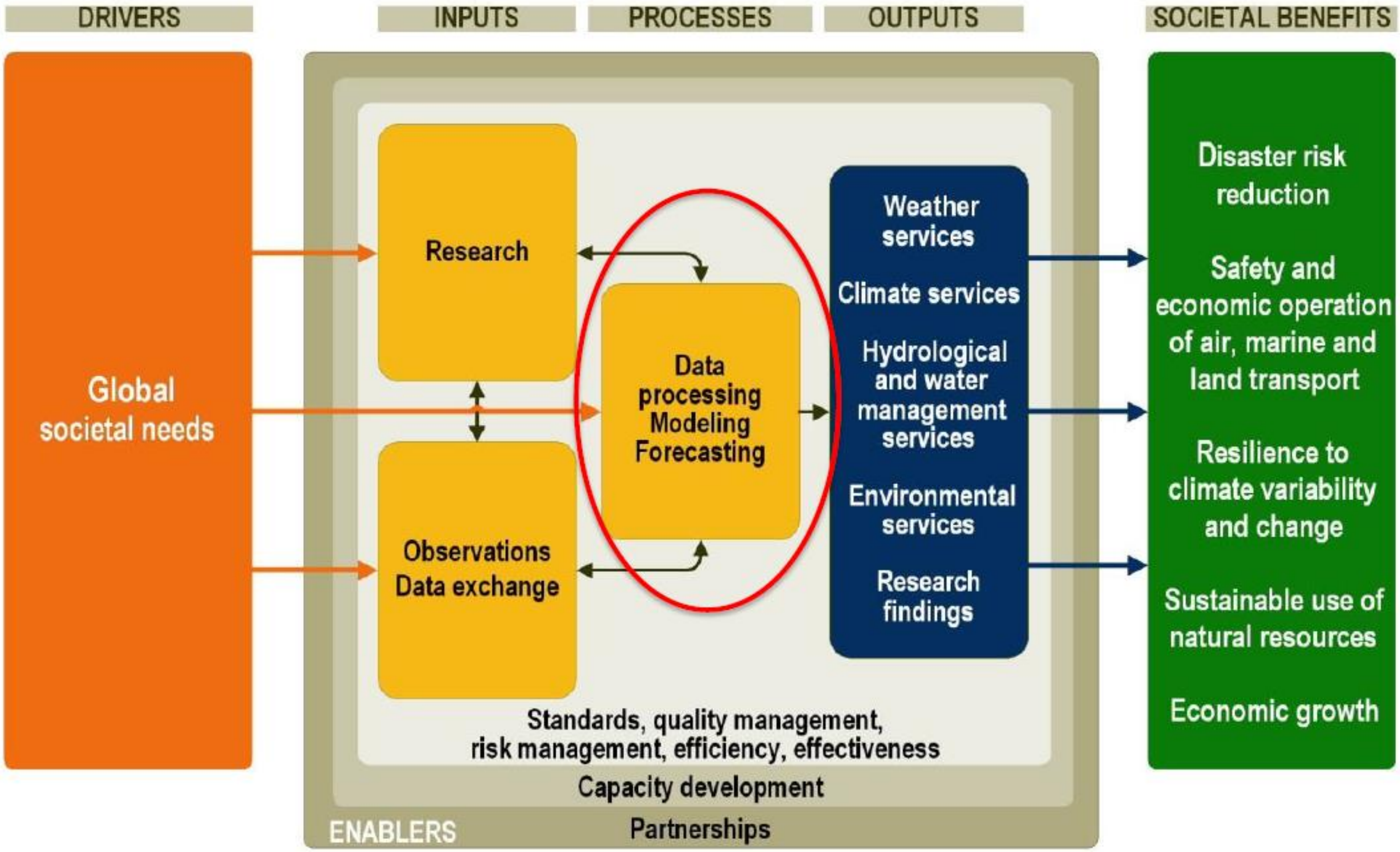
Dirmeyer et al., WWOSC 2015, WMO

Land surface memory effects

- Memory in soil moisture anomalies may be dormant until the surface fluxes become sensitive to the land surface state
- The rebound in predictability can come weeks after intialization
- Delayed realization of predictability can e.g. occur when winter snow anomalies become spring and summer soil moisture anomalies
- Positive feedbacks between land and atmosphere can exacerbate or prolong climate anomalies (droughts), providing a coupled memory
- Understand and quantify land surface memory is important for the forecast of extremes and for improvement of sub-seasonal prediction skill

Dirmeyer et al., WWOSC 2015, WMO

At the heart (engine room) of the WMO operational system



From WMO 2016-2019 Strategic Plan

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Julia Slingo, Cg-18, WMO 2019

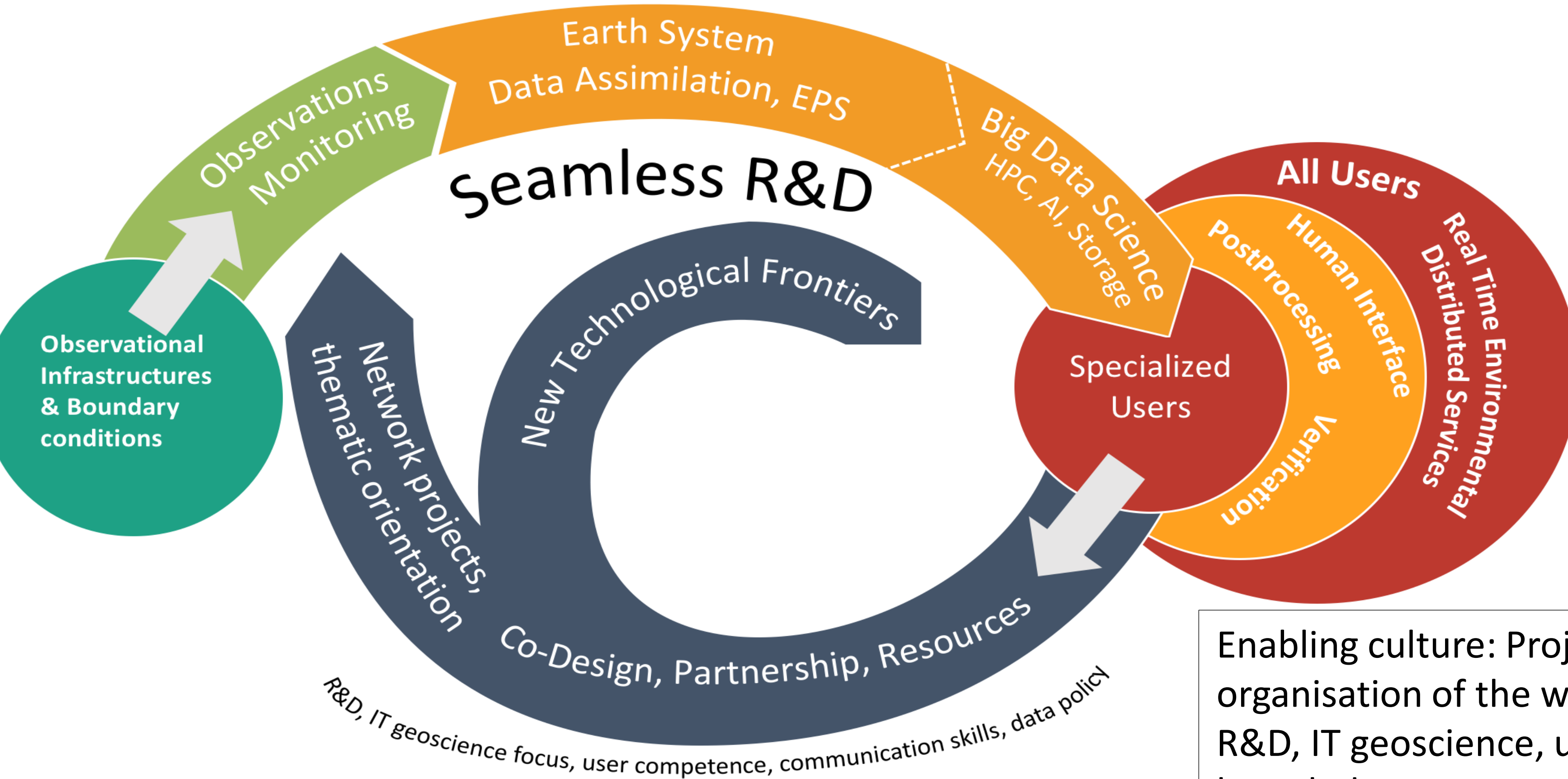
WMO Seamless Global Data Processing and Forecasting System (S/GDPFS) - Vision for WWW

- Weather, water, climate, environment, ice and ocean
- The GDPFS will be an effective and adaptable monitoring and prediction system enabling Members and partners to make better-informed decisions;
- The GDPFS will facilitate the provision of impact-based forecasts and risk-based warnings through partnership and collaboration;
- The GDPFS will share weather, water, climate and related environmental data, products and services in a cost effective, timely and agile way, benefitting all WMO Members, and reduce the gaps between developed and developing Members.

WMO OMM

SCIENCE FOR SERVICES JOURNEY
during the century following the Bergen school 1918

- Quality, Relevance and Impact:
- User Interactions forces exploration of "What works"
- Seamless Earth system modelling across weather, water, environment, ocean, climate; interoperable observation systems of ES components



Enabling culture: Project organisation of the work - R&D, IT geoscience, user knowledge, communication

Julia Kelly et al., BAMS 2019

S/GDPFS Implementation Plan

- Concrete Activities -

WMO OMM

Concrete Activities




Implementation is a 2 stage process:
1) Conduct Benchmarks and Pilot projects
2) Transfer into operational system

Current focus is to identify, prioritise and plan benchmarks and pilot projects to kick-start the implementation process

Some key criteria for setting priorities:
- Information needed in decision making
- Ensuring relevance for WMO and its Members
- Geographical Dimension
- Building on existing and emerging data platforms

WMO OMM

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Coupling of Earth System components on a limited domain

- Atmosphere-water
- Atmosphere-ice
- Atmosphere-coastal areas
- Atmosphere-ocean

Weather, water, climate, environment, ice, ocean

National/Nordic (regional) ambition for seamless earth system modelling and interoperable observations

- MET with support of academia and in collaboration with agencies like NVE, HI and the Environment Directorate should move current model and observations systems for forecasting in the seamless regional ES direction, driven by service needs and science capabilities
- Weather forecasting and climate projection research experience are the basis for the growth in societal services and ensuing risk reduction in numerous societal sectors
- **Move from a weak value chain to a strong value cycle**
- When regional ES forecasting succeeds, the expectations are lower risks in:
  - High impact weather;
  - Floods,
  - Droughts and fire danger,
  - Runoff to coastal regions incl estuaries;
  - Marine conditions (waves, currents);
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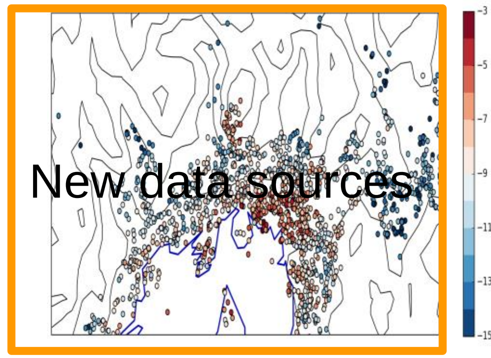
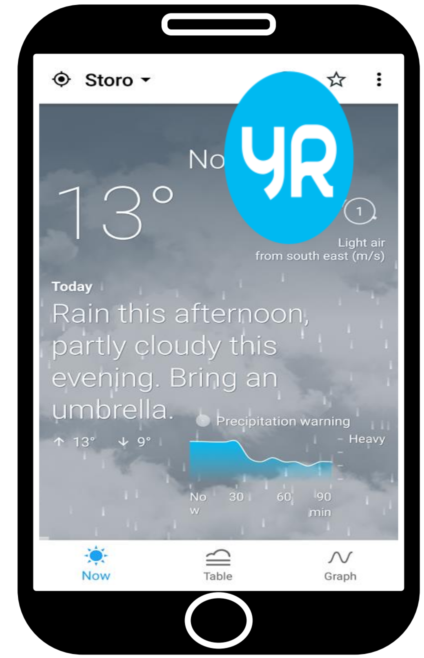
WMO OMM

Numerical weather prediction

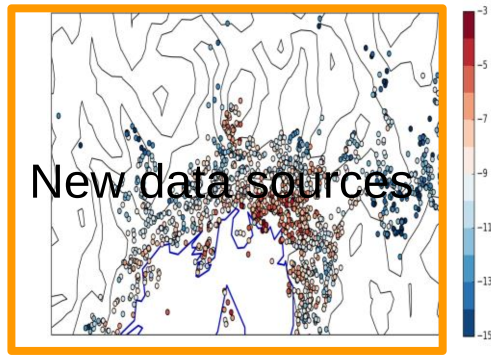


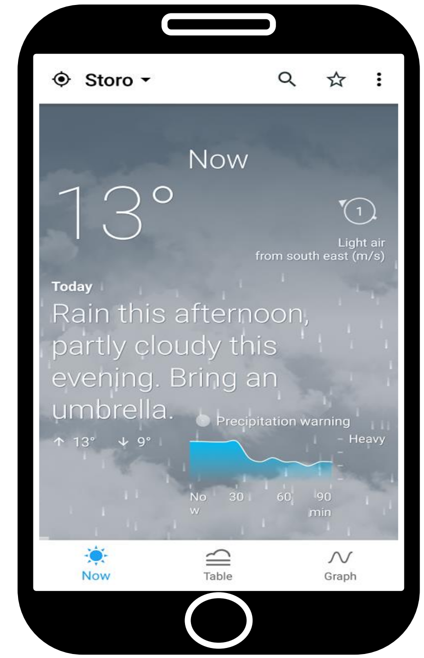


Data assimilation → NWP model → Post-processing → End users

Müller, M., M. Homleid, K. Ivarsson, M.A. Køltzow, M. Lindskog, K.H. Midtbø, U. Andrae, T. Aspelien, L. Berggren, D. Bjørge, P. Dahlgren, J. Kristiansen, R. Randriamampianina, M. Ridal, and O. Vignes, 2017: AROME-MetCoOp: A Nordic Convective-Scale Operational Weather Prediction Model. *Wea. Forecasting,* **32**, 609–627, https://doi.org/10.1175/WAF-D-16-0099.1

Numerical land-atmosphere prediction





Data assimilation

Land-atmosphere model

Post-processing

End users

Thank you for your attention