Challenges and opportunities in the use of hydrological modelling to provide status and outlook information – Examples from Sweden, Europe, Niger River, Arctic, India, and WorldWide-HYPE

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Swedish Meteorological and Hydrological Institute (SMHI)

National agency with Operational, Research and Business departments

Mission: To provide decision-support for a safe and sustainable society.

Cover:
- Meteorology, Hydrology, Oceanography and Climatology.
- National monitoring networks and computational systems.
- Operational Forecast, Warning services, Climate projections, Consultancy …

National hub for international cooperation (e.g. IPCC, WMO, UNESCO-IHP, EUMETSAT, ECMWF)

www.smhi.se

Challenges for global hydrological modelling

Accuracy of global information at regional & local scales

Some reasons

- Hydrological processes
  - Natural and human (e.g. reservoirs, water transfers)
  - Many different processes active simultaneously
  - Varies in space and time
  - → Represent dominant processes in ‘sufficient’ detail
- Data
  - Availability, quality, resolution, delay, homogeneity etc.
  - Large data volume → intelligent information extraction / synthesis necessary
- Ungauged basins → model necessary, conventional model calibration insufficient
- Trade-off of global consistency vs. local accuracy
- Insufficient collaboration / lack of critical mass & funding

Suggestions for HydroSOS

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Use multiple hydrological models

- Distributed production
- Data delivery to HydroSOS using standardised data format / API
- HydroSOS: synthesize, visualize and distribute data & information to users (also low data size info.).
- Benefits: Improved accuracy, Clarified uncertainty, Operational redundancy, Resource efficiency, Quick start of production, Easier to use, Critical mass, Open for new participants

Integrate observations and model data operationally

- Tailored operational meteorological inputs (e.g. GFD, daily meteo. data)
- Data assimilation of hydrological variables (e.g. discharge, soil moisture.)
- In each case, use multiple data types (in situ, earth observations etc.)

Evaluate participating models

- Accuracy: performance vs. hydrological observations, multiple variables
- Operational reliability: delay, missing data, data format
- Openness of code/model: transparency, better development, easier for new groups to contribute
- Evaluate global models at regional & local scales, standardised protocols
- Communicate skill

Community

- Critical mass of developers, producers and users at global, regional and local scales
- Each NMS/NHS test global information in their country & provide feedback (e.g. evaluation results, suggested improvements, implemented improvements)

Versions

SMHI's approach to provide hydrological status and outlooks for large domains

- Open code, open data, open science → transparency, collaboration and quality
- Large scale: countries, continents, global
- Hydrological model development and applications
  - Historical dynamics
  - Current status
  - Outlooks: days, weeks, months, season, decades, century
- Tailoring meteorological data for hydrological use
- Data assimilation: integrating modelled & observed data
- Water services to provide information:
  - Open data: vattenwebb.smhi.se, hypeweb.smhi.se, swicca.climate.copernicus.eu
  - Custom deliveries: hypedata.smhi.se

The hydrological model HYPE

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Aims

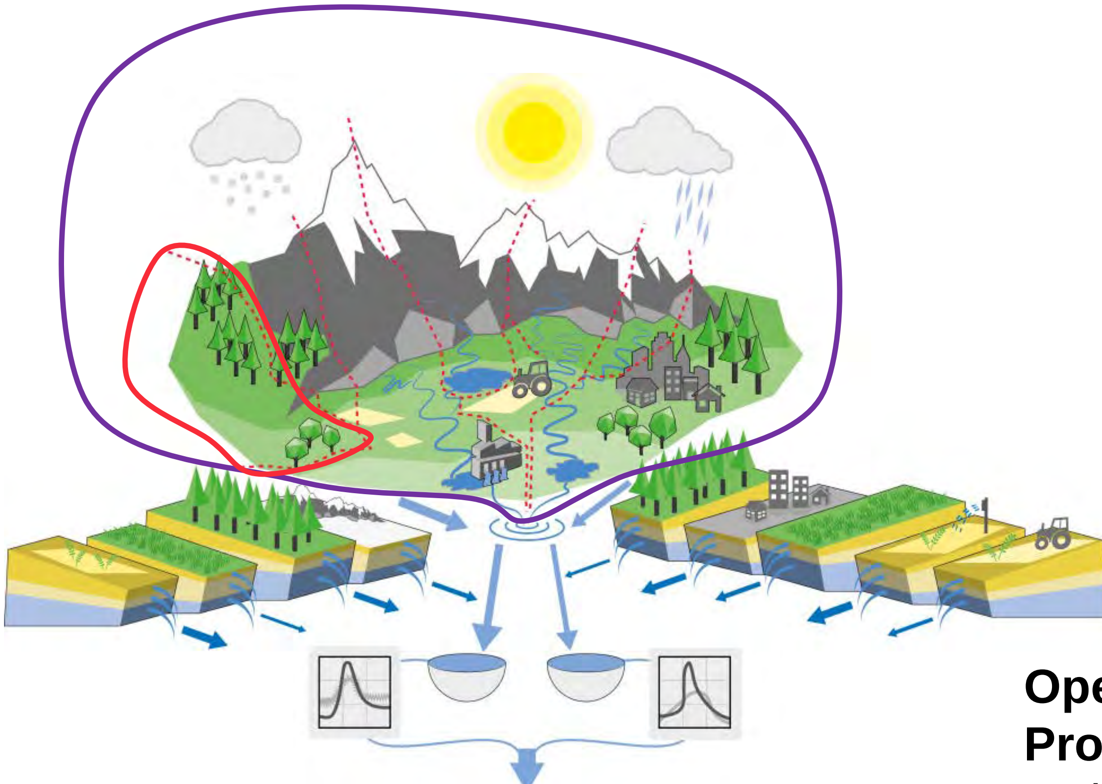
- Simulate the land phase of the water cyle
- Capture dynamics of water flow and water storage (and WQ)

Semi-distributed

- River basins
- Catchments
- Hydrologic Response Units (HRUs)

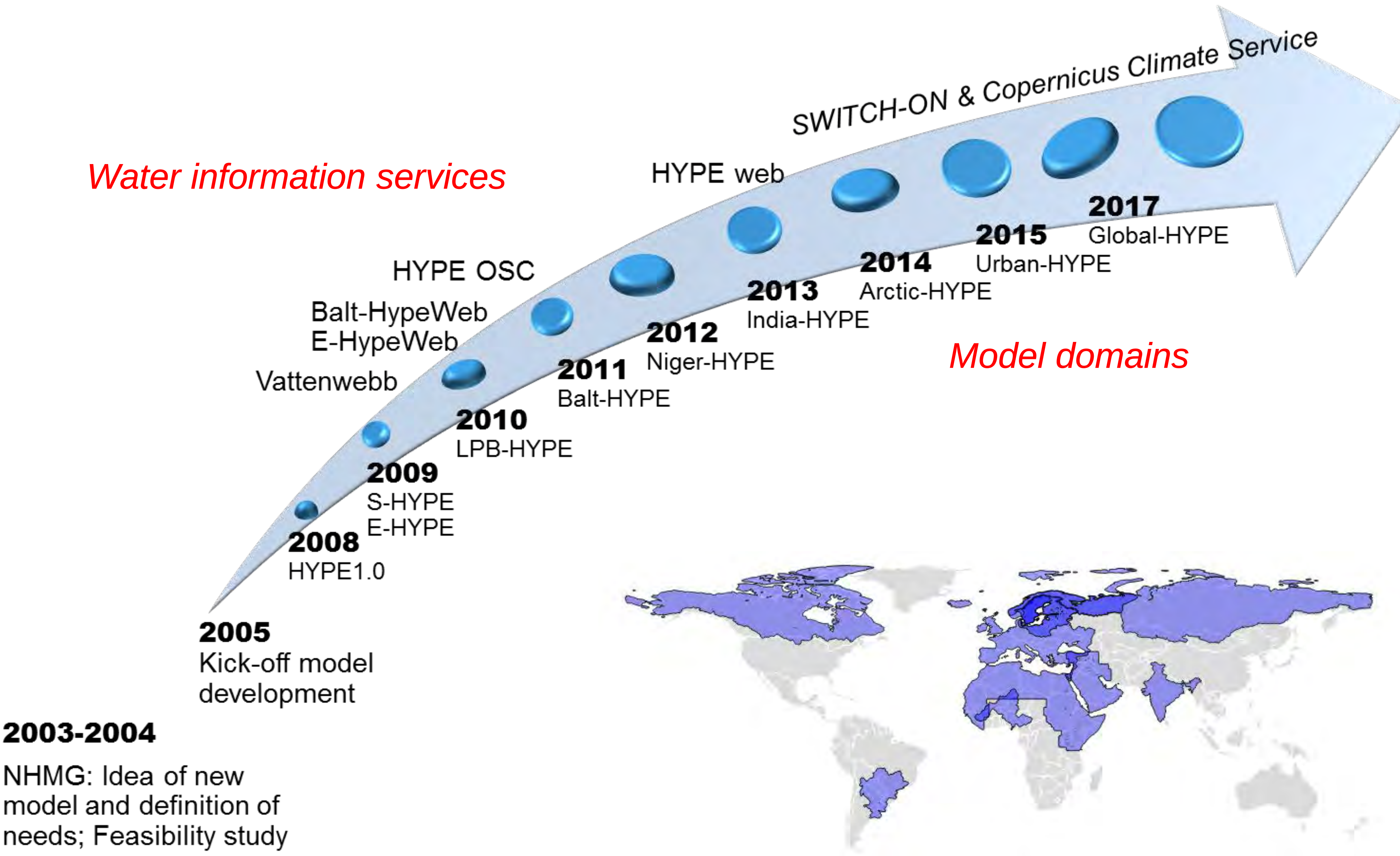
Hydrological fluxes & stores

- *Streamflow (discharge)*
- Precipitation
- Snow and glaciers
- Infiltration
- Soil moisture
- Evapotranspiration
- Runoff (surface & sub-surface)
- Routing
- Lakes
- Floodplains
- Reservoirs
- Irrigation
- …

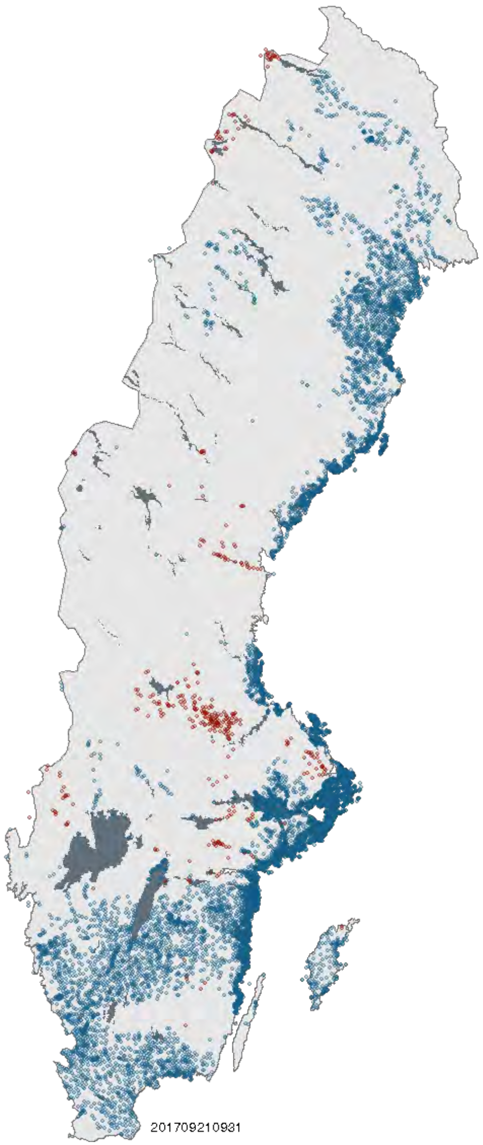


Open-source: http://hypecode.smhi.se
Process detail: keep it simple, capture major dynamics, balanced complexity

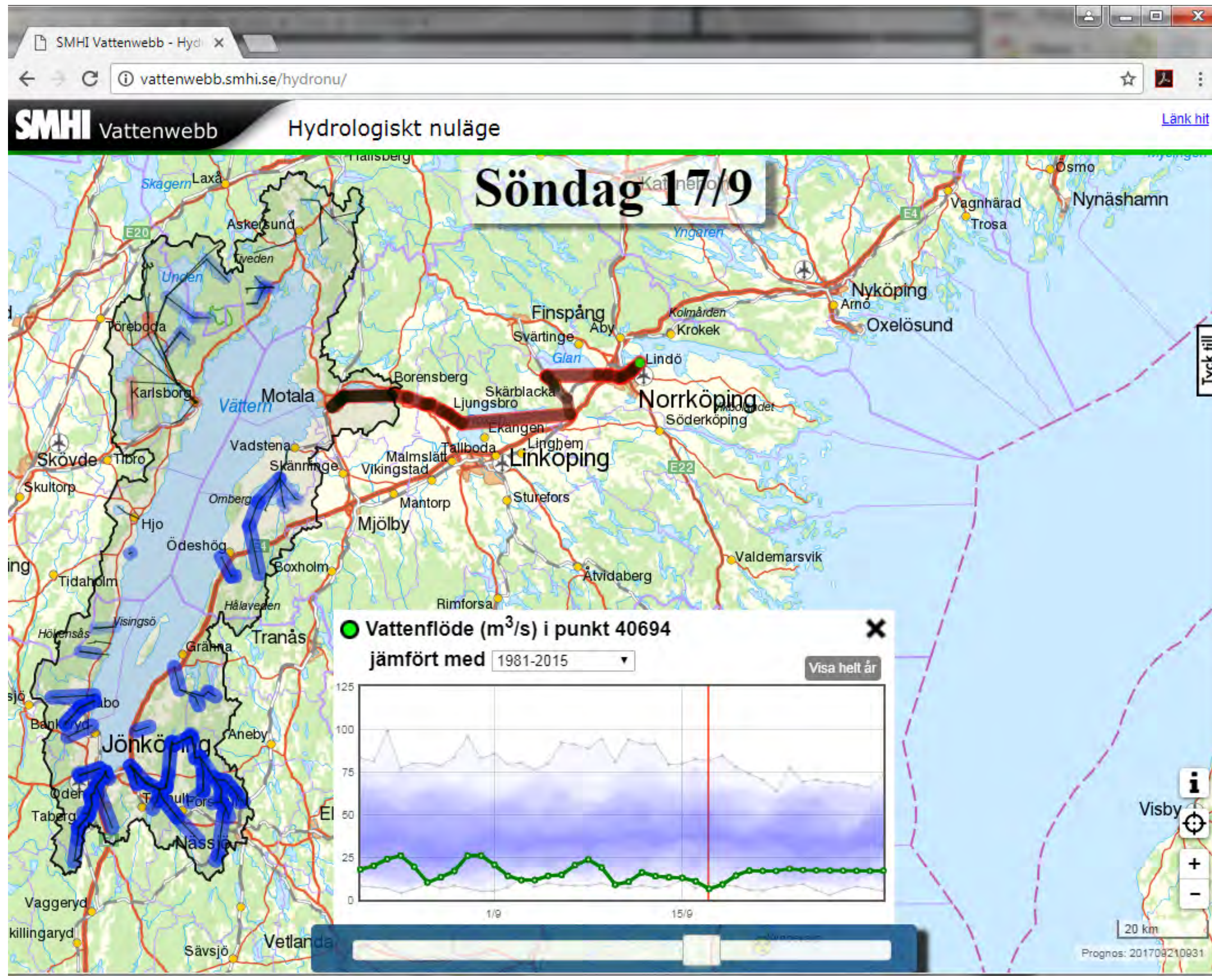
A brief history of HYPE



Quick overview

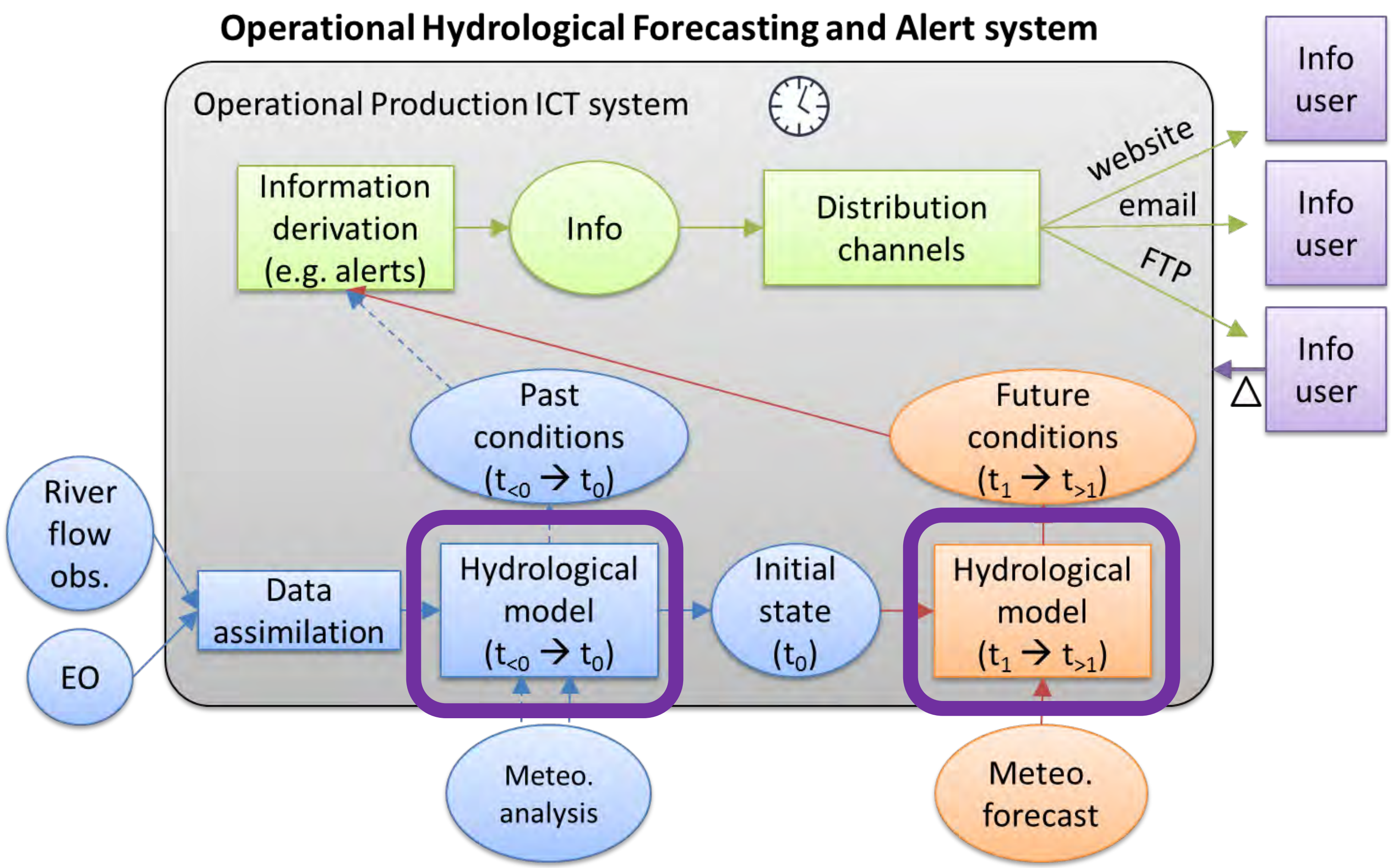


Interactive details for each catchment



Source: http://vattenwebb.smhi.se/

Production system to provide hydrological status & outlooks



Every component counts & has to be continuously improved

Collaboration to refine process descriptions: example of floodplain dynamics in Niger River, West Africa

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Inner Niger Delta

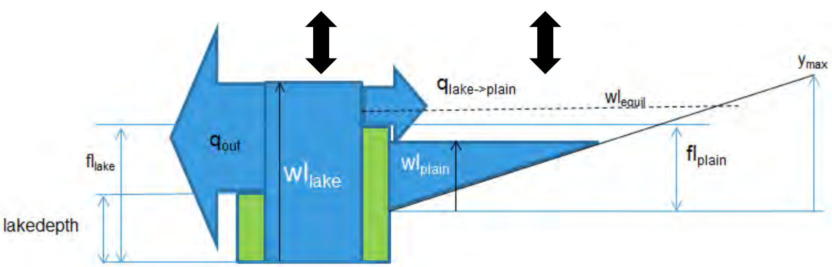
- >30000 km^2 in Mali
- Annual flooding processes: floodplain with dynamic area, river area & atmospheric exchange, post-flood evaporation

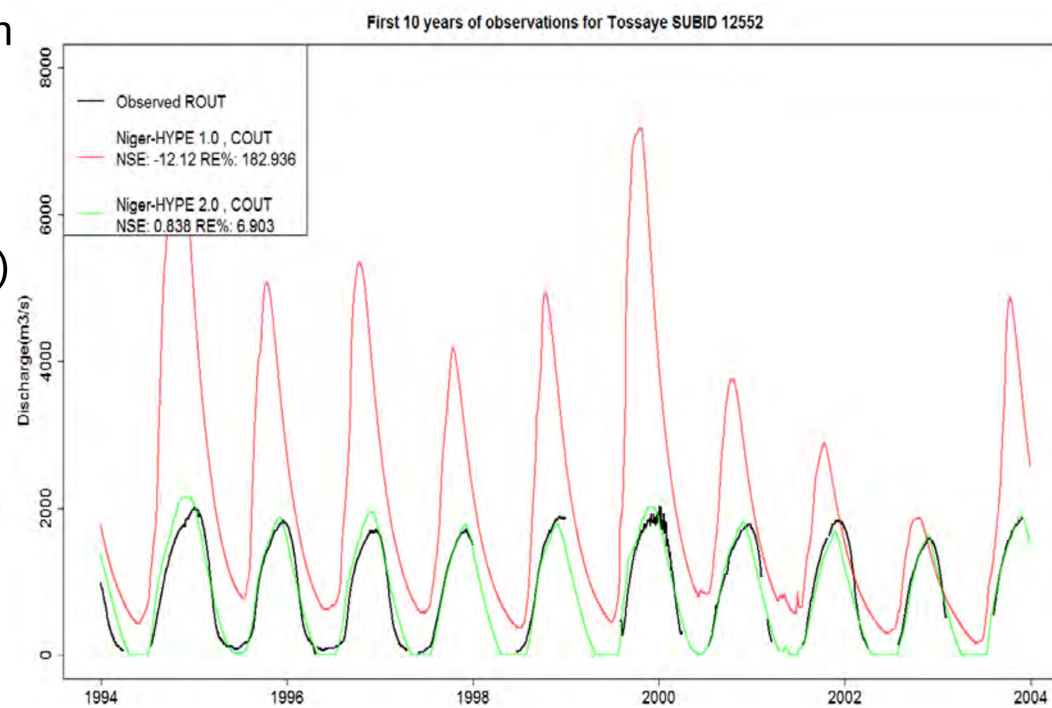
Regional collaboration

- AGRHYMET: process understanding
- SMHI: process conceptualization and programming of open-source solution

Results

- Increased model performance
- Increases local understanding and confidence in model (status/outlooks)

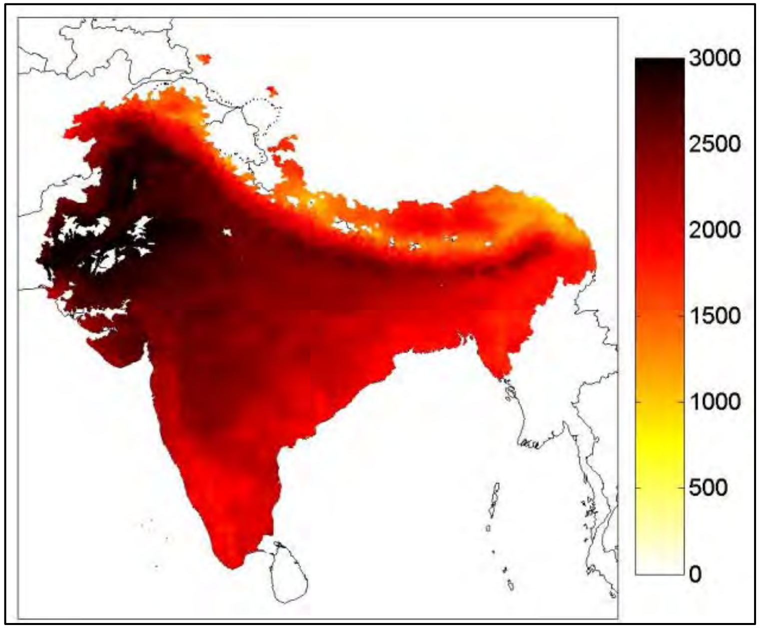




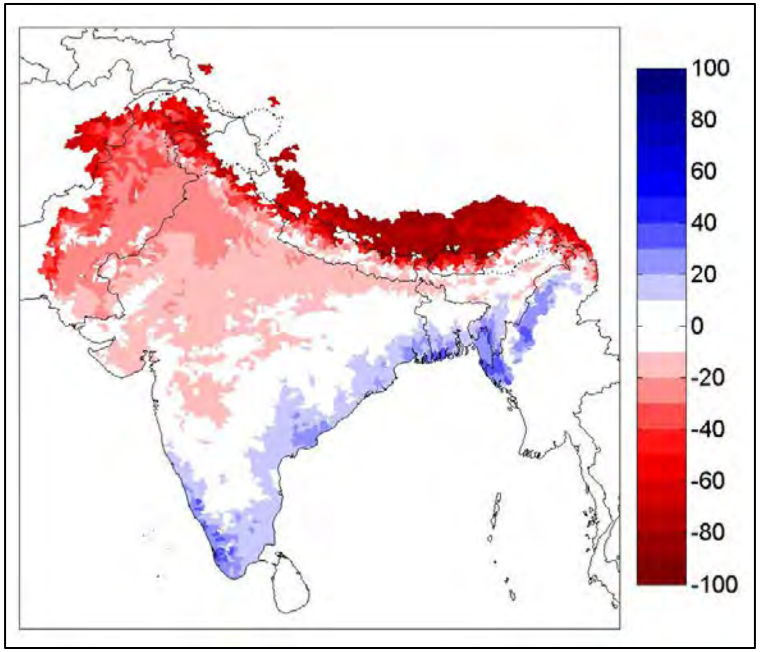
Andersson et al. (2017)
http://dx.doi.org/10.1016/j.pce.2017.02.010

Model improvement using Earth Observations: example of PET parameters & India-HYPE

Mean annual PET from MODIS (mm)

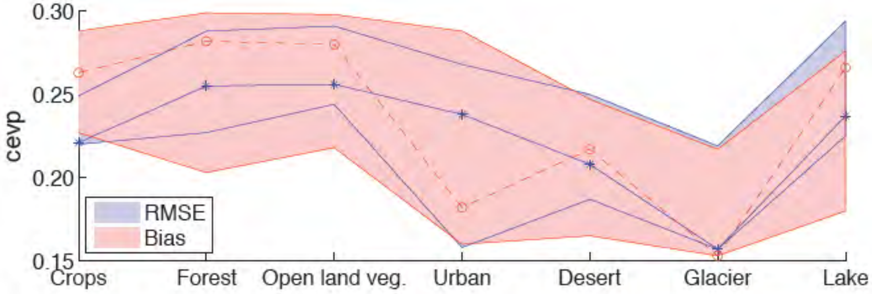


MODIS – India-HYPE (% difference)



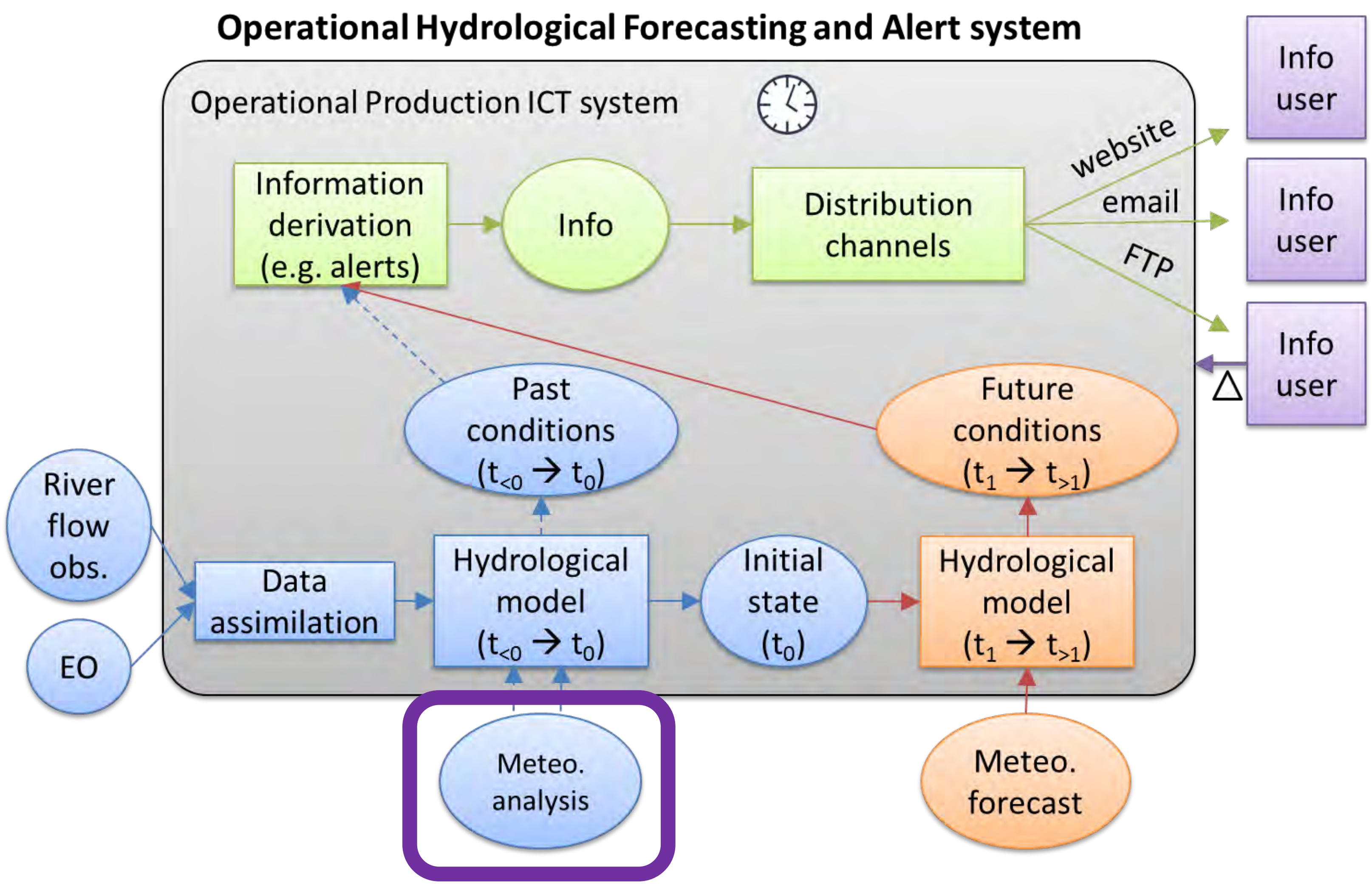
Risk if only using discharge: compensatory process parameterisation
Our approach: Constrain PET parameters directly against MODIS

Resulting parameter ranges & optima



Pechlivanidis & Arheimer (2015)
https://www.hydrol-earth-syst-sci.net/19/4559/2015/

Production system to provide hydrological status & outlooks



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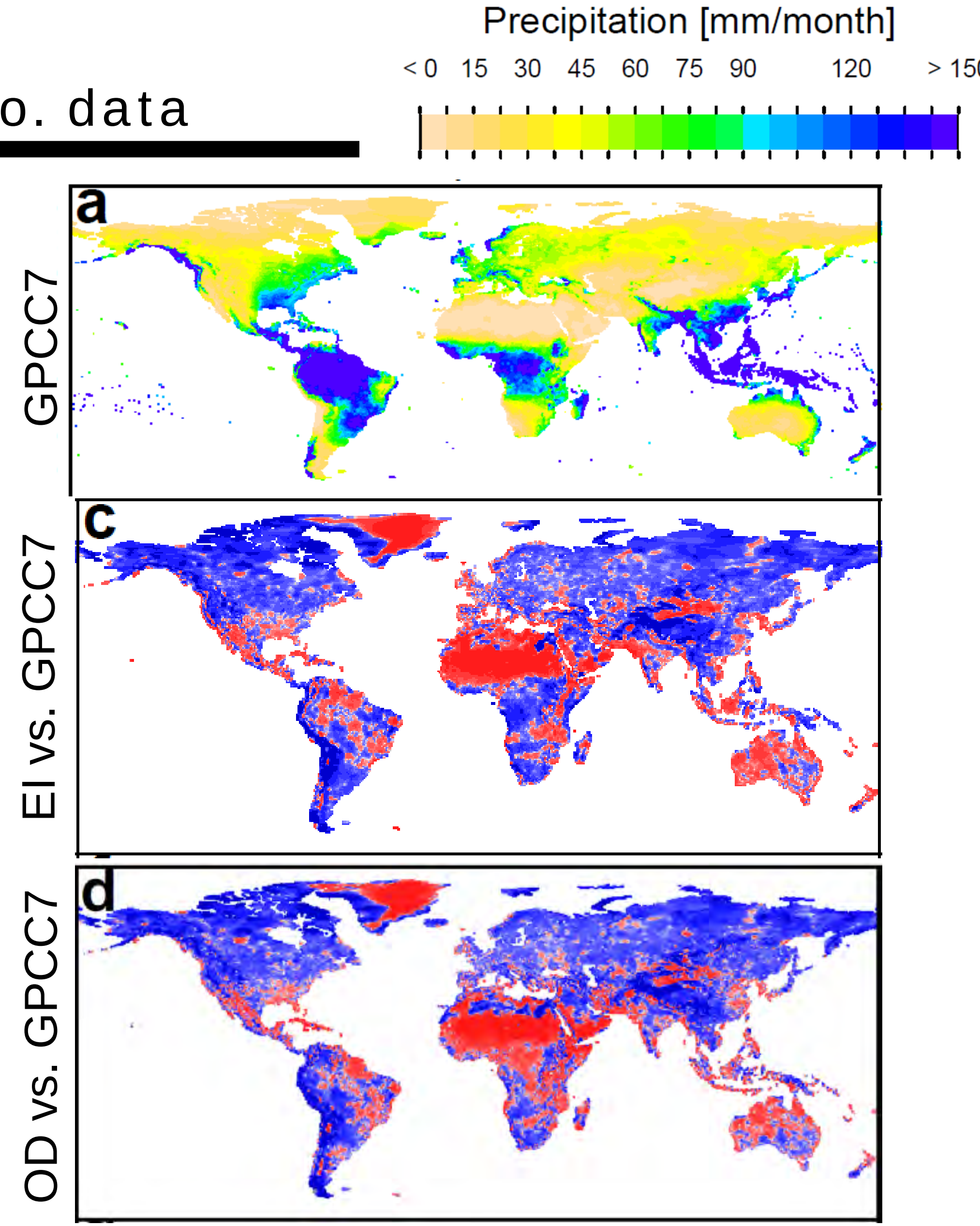
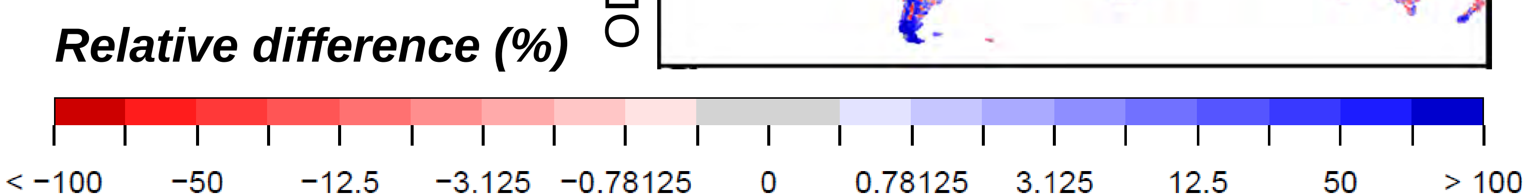
Problems with global meteo. data

- Meteorological re-analyses (e.g. ERA-Interim) and forecasts (e.g. ECMWF) are key data sources for large-scale operational hydrology
- Problem in meteo. data: significant precipitation bias & incorrect no. wet days → erroneous hydrological simulations
- Approach: bias adjustment toward obseved P (e.g. WFDEI). However, long delay of adjusted datasets → **not available for operational hydrological initialisation**

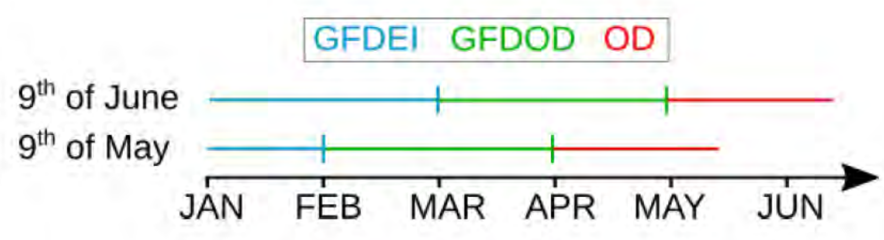
Berg et al. 2017, http://dx.doi.org/10.5194/hess-2017-326





SMHI solution: Global Forcing Data (GFD)

- Adjusting bias & no. wet days relative to best available observations
- Up to date: utilising best available adjustment dataset for each period until present (t)
- Global coverage
- Daily temporal resolution
- Currently extended with satellite data



Period	Name	Atm. model	Precip.	Wet days	Temp.
1979-2013	GFDCL	ERA-Interim	GPCC7	CRU ts3.22	CRU ts3.22
2013 to [t–3m]	GFDEI	ERA-Interim	GPCC Monitor	GPCC-FG daily	GHCN-CAMS
[t–3m] to [t–1m]	GFDOD	ECMWF-OD	GPCC-FG monthly	GPCC-FG daily	GHCN-CAMS
[t–1m] to today	OD	ECMWF-OD	NA	NA	NA

Berg et al. 2017, http://dx.doi.org/10.5194/hess-2017-326

GFD: improves model initialisation

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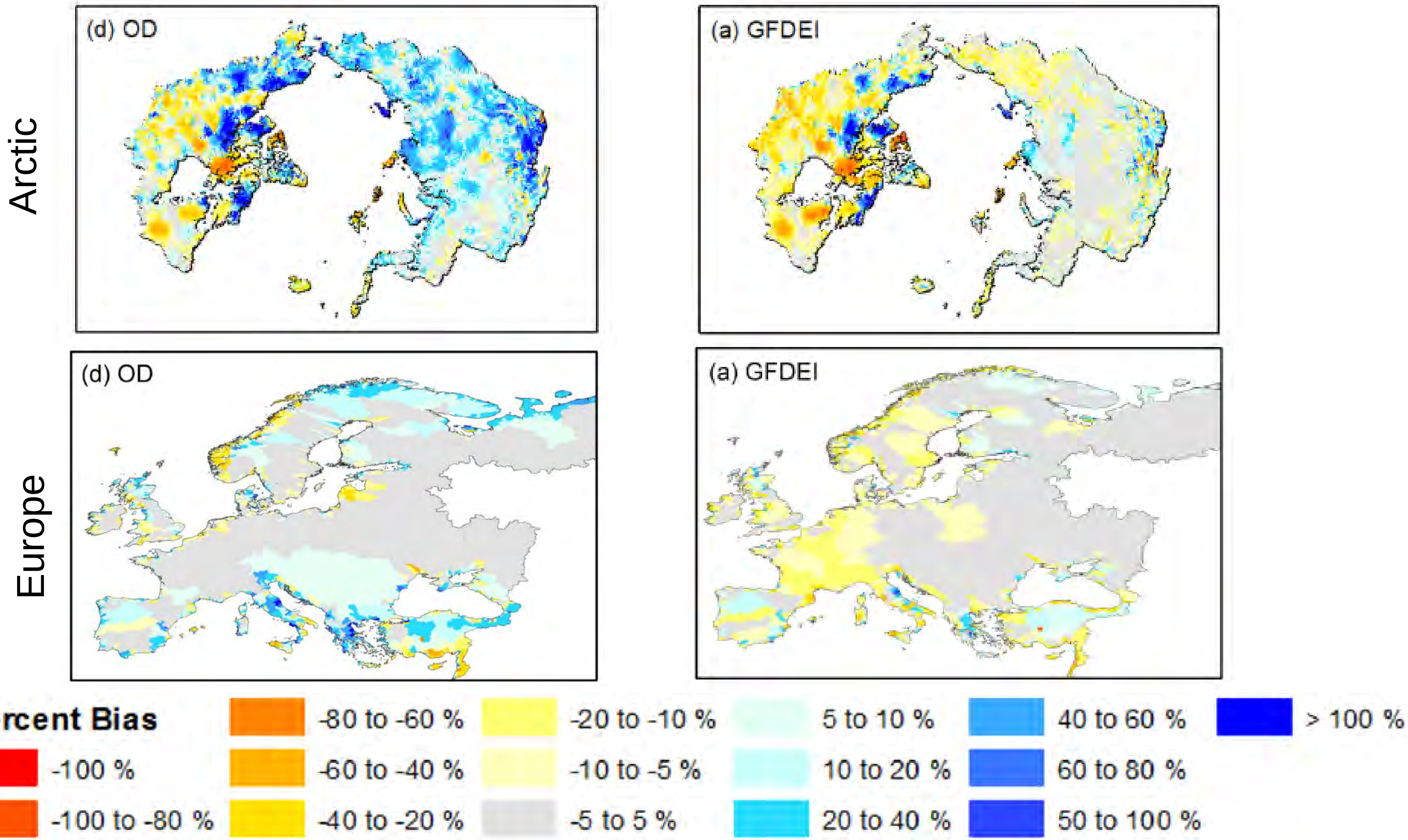
Comparison: Percent bias in specific runoff vs. GFDCL (reference climate)

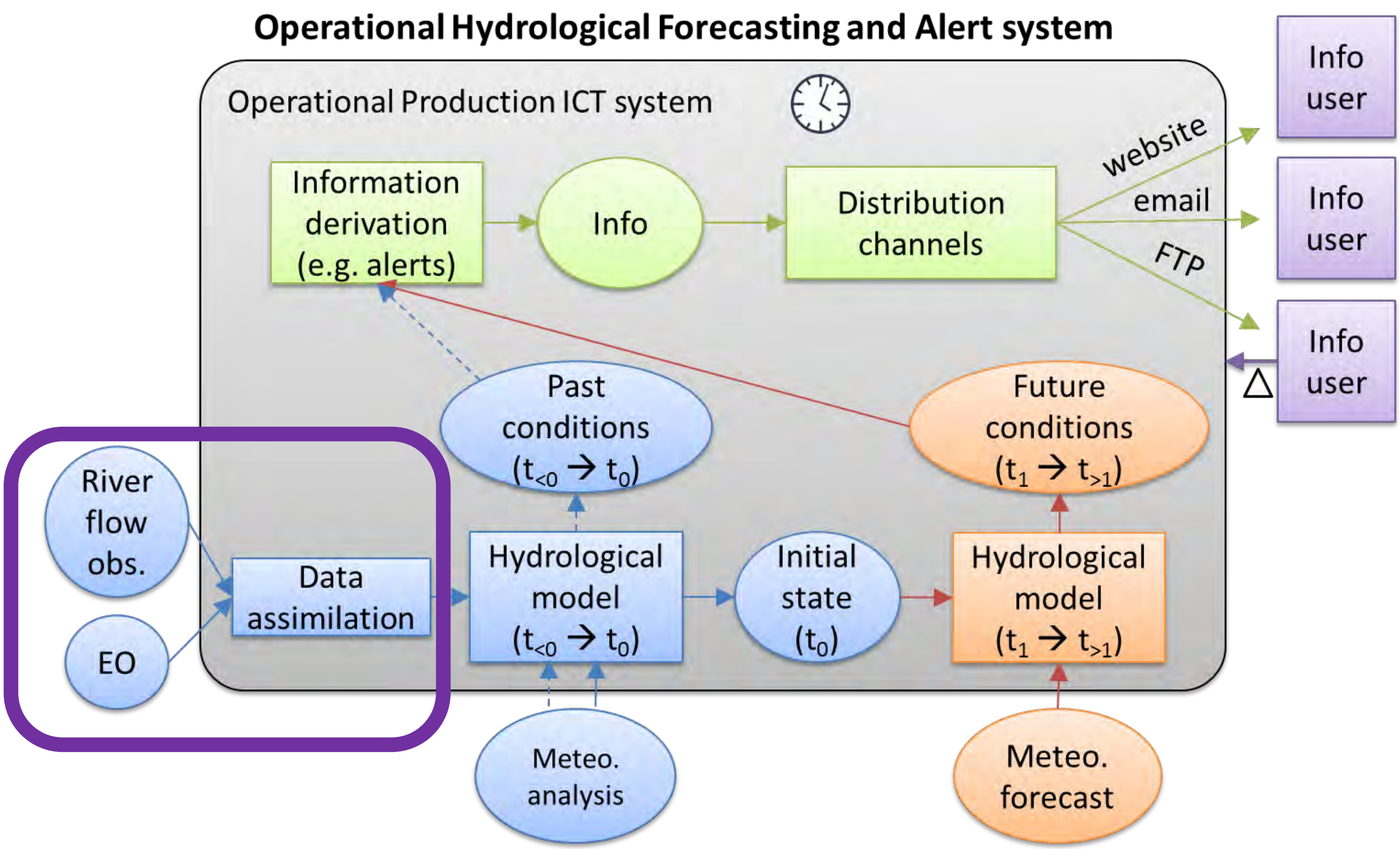
Conventional operational (ECMWF-OD no adjustment)

GFDEI (adjusted, month t-3)



Berg et al. 2017, http://dx.doi.org/10.5194/hess-2017-326

Production system to provide hydrological status & outlooks



Every component counts & has to be continuously improved

Improving status & outlooks by integrating modelled & observed data (Sweden)

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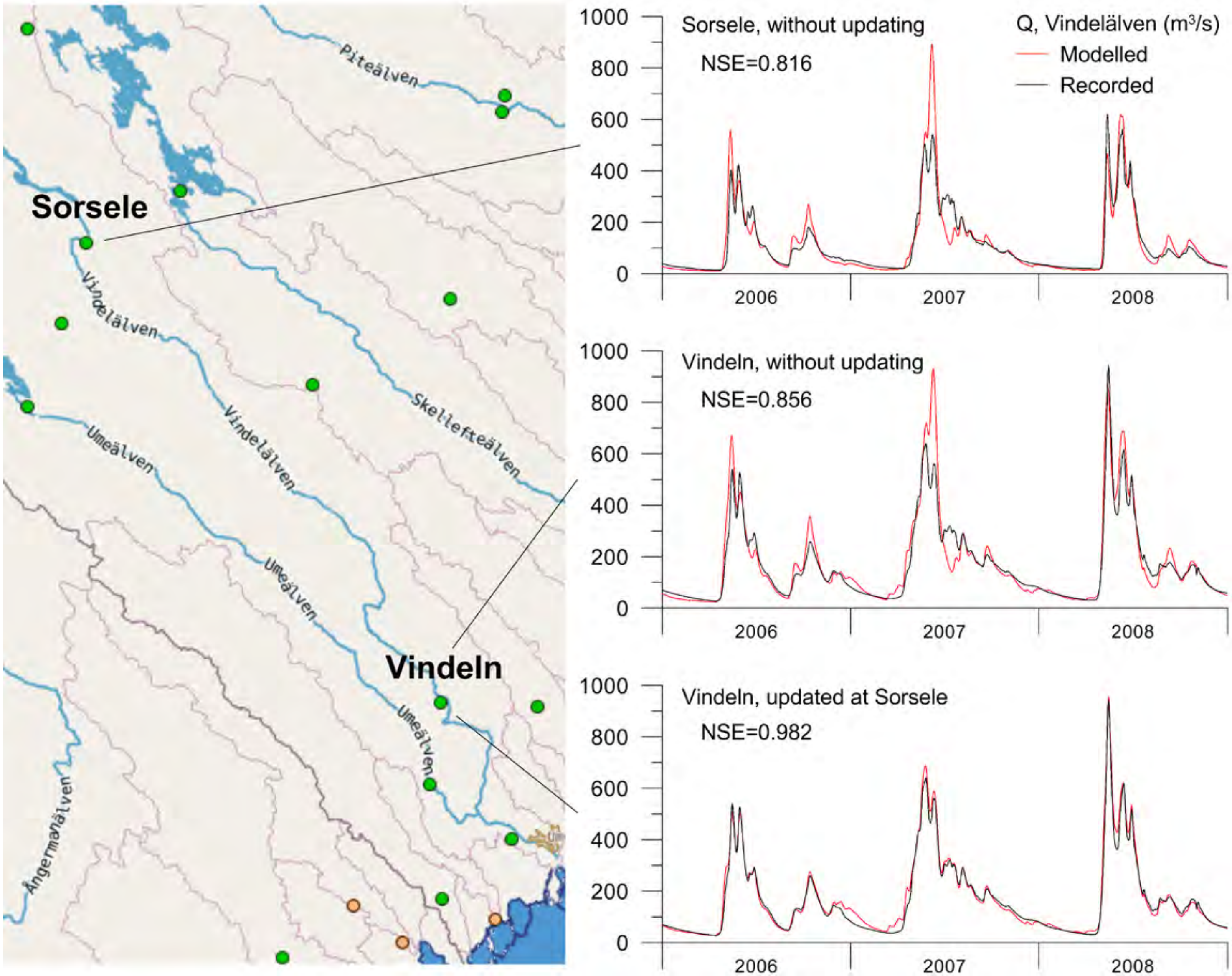

Lindström et al. The power of simple downstream updating, submittted

Improving status & outlooks by integrating modelled & observed data (Sweden)

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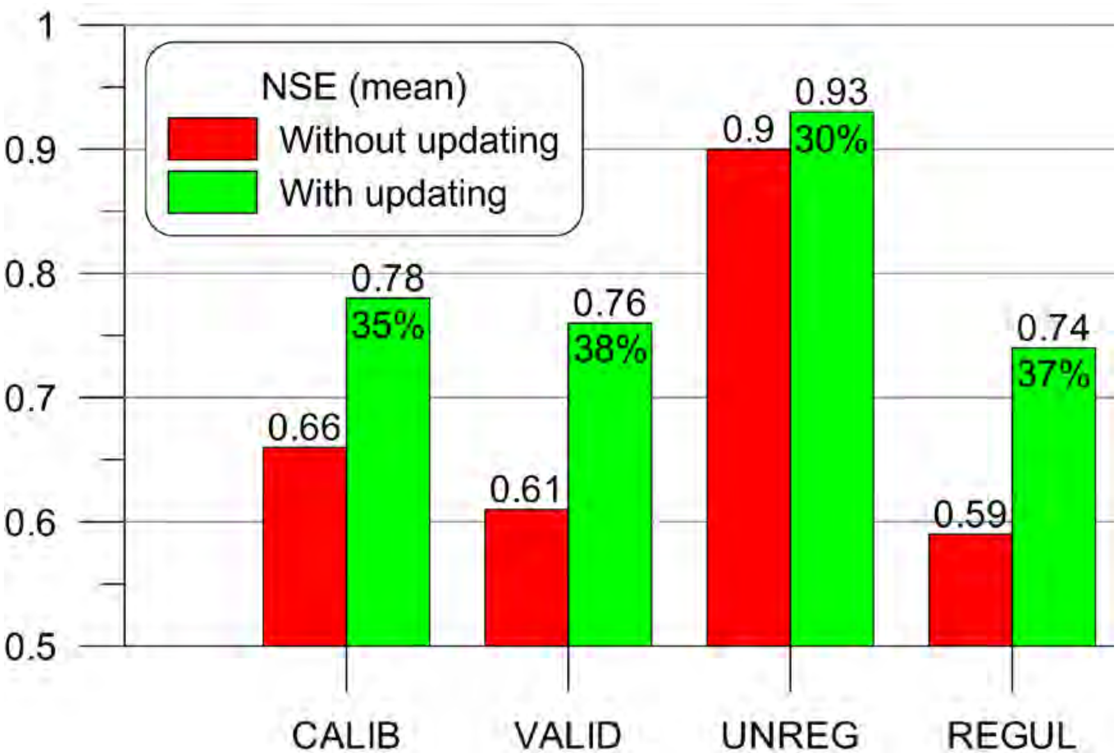
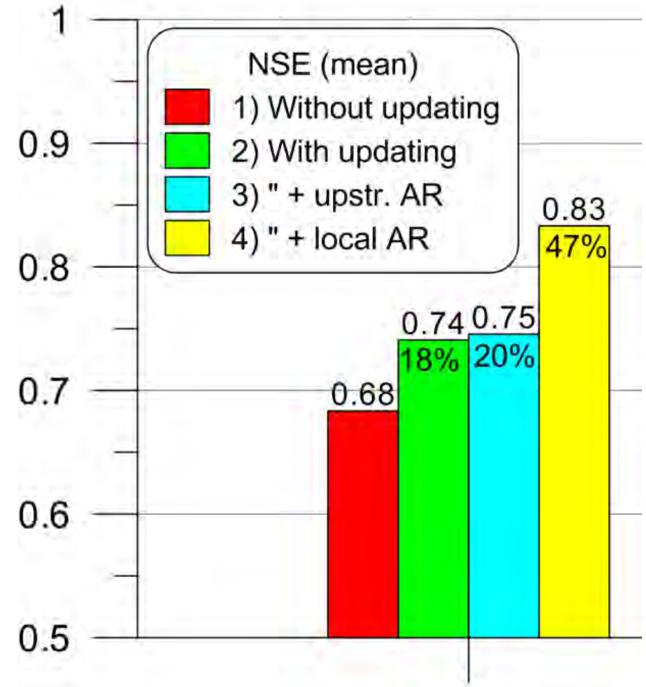
Summary for historical period



- Correcting for e.g. erroneous representation of regulation
- Number of gauges:159 for calibration & validation, 34 unregulated, 125 regulated

Summary for 4-day forecast



- Observations still important for forecasts due to hydrological memory
- Requires low latency of observation data delivery
- Smoothing beneficial

Lindström et al. The power of simple downstream updating, submittted

Production system to provide hydrological status & outlooks

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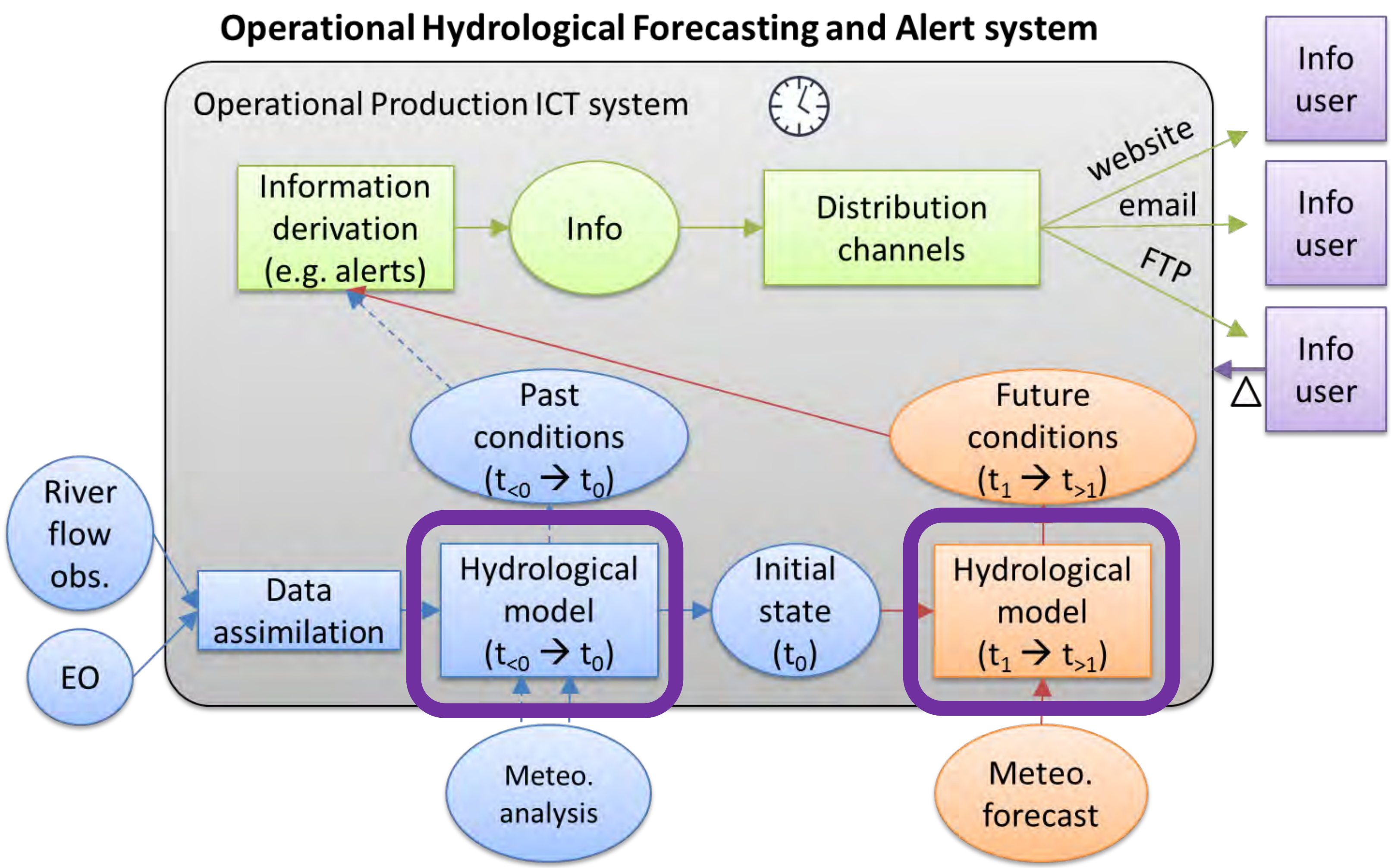

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Improving status & outlooks by using multiple hydrological models

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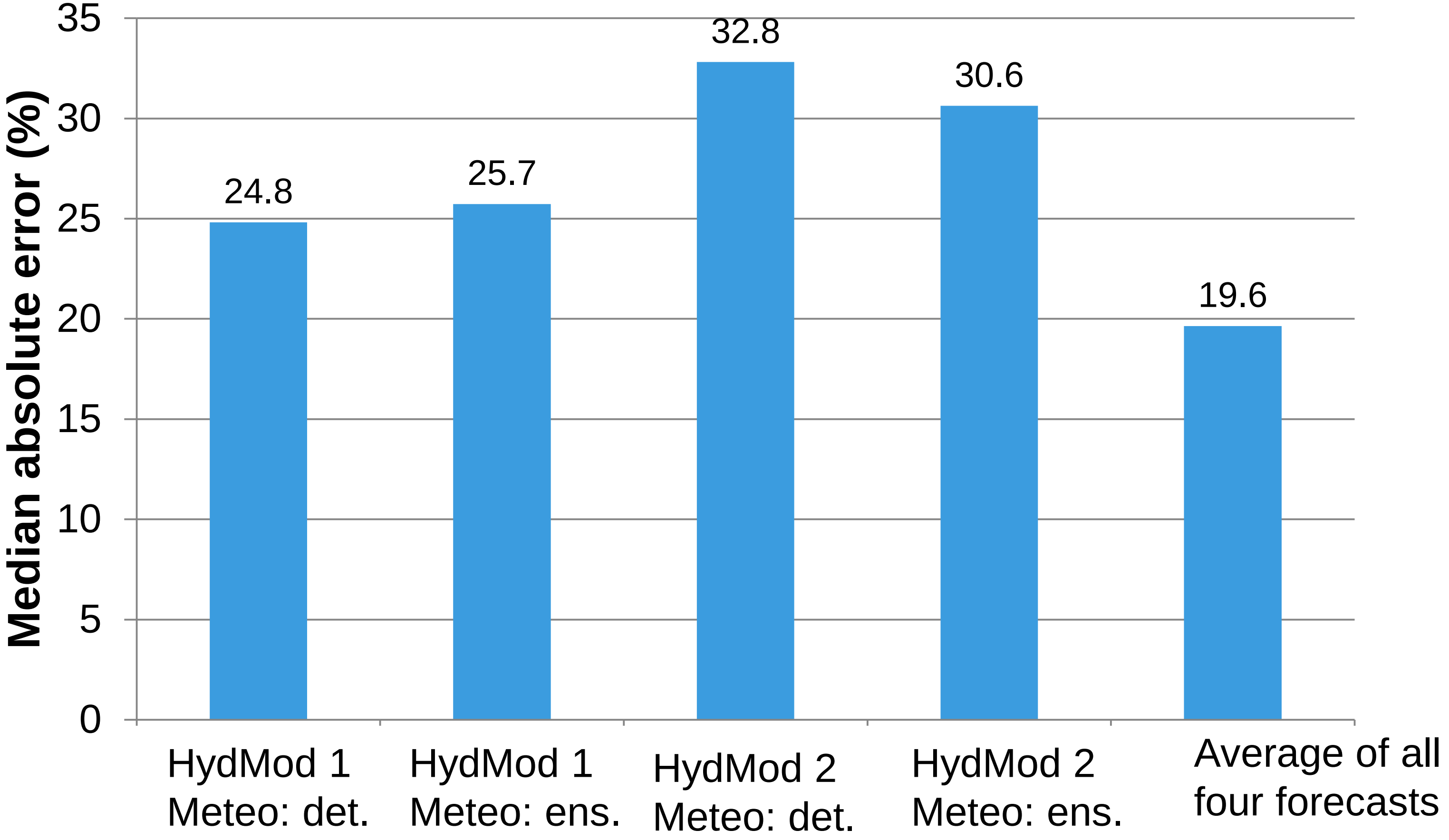
Forecasting performance using 2 hydro. models and 2 meteo. forecasts



Forecasting example details

Period: Apr 2014 - Okt 2014, 106 events, Forecasting horizon: 2-9 days ahead

HydModels: S-HYPE & HBV

Meteo forecasts: SMHI PMP & ECMWF ensemble

Improving status & outlooks by using multiple hydrological models

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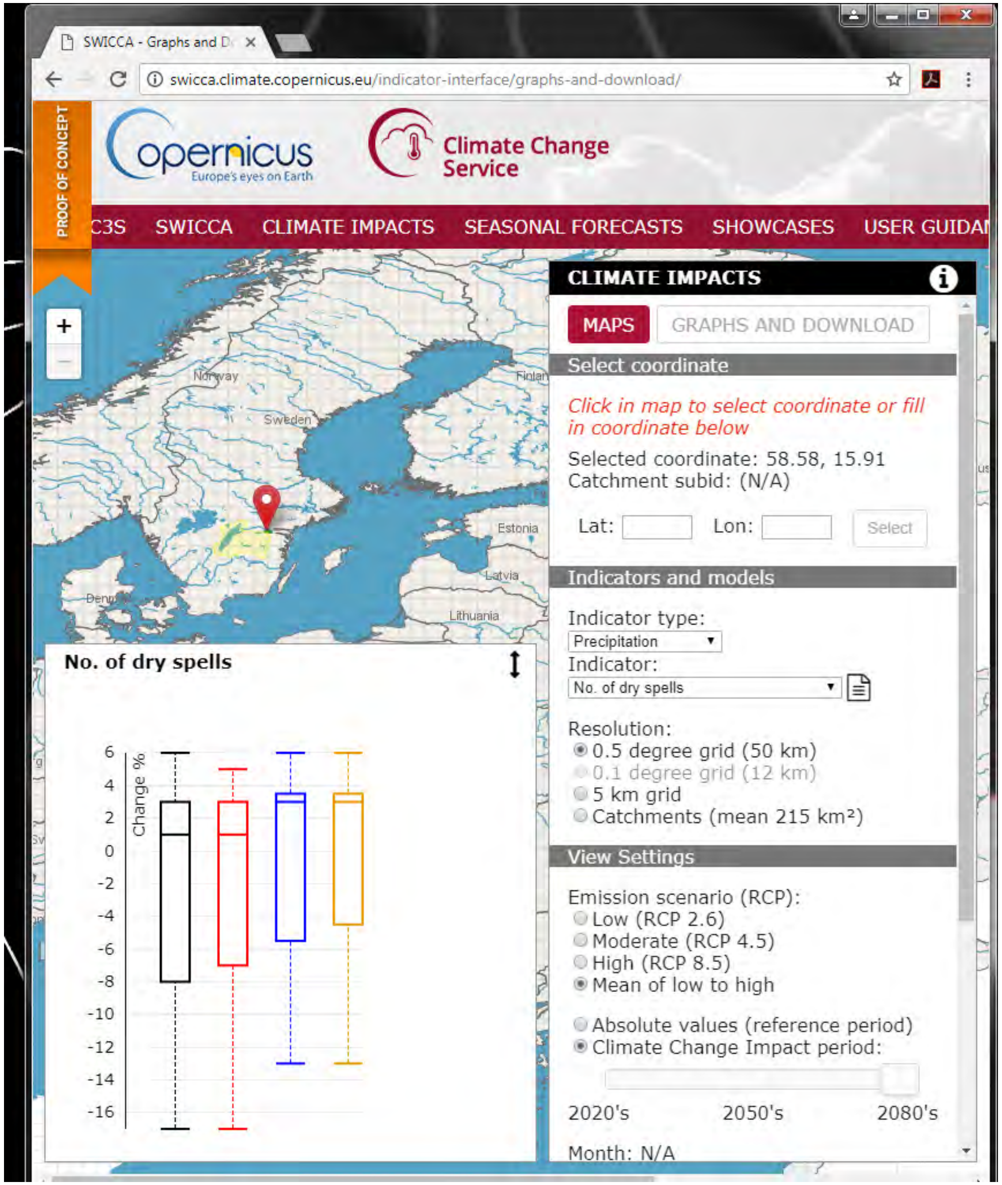


Source: http://swicca.climate.copernicus.eu/

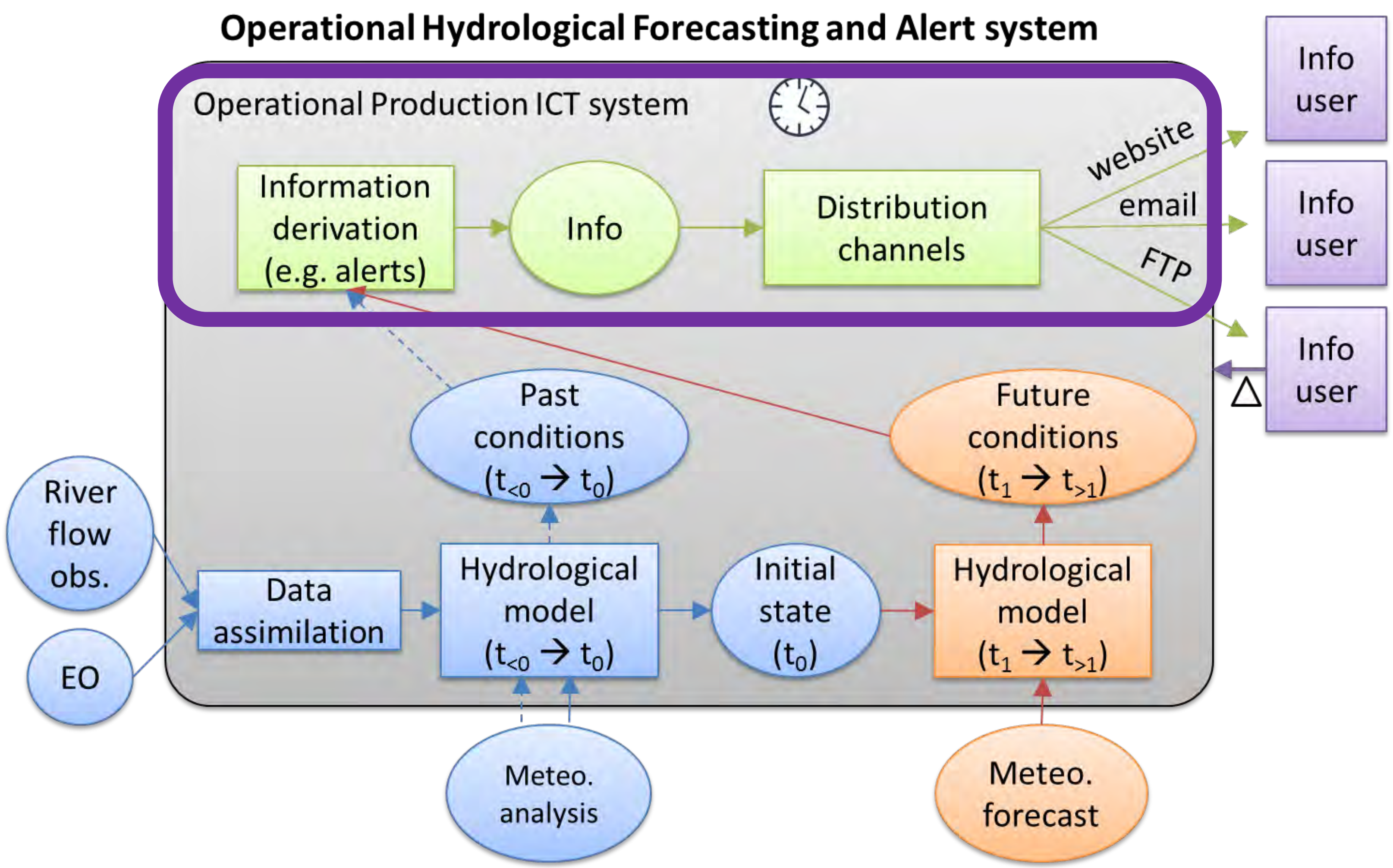
- Multiple hydrological models helps to understand and convey uncertainty

Example details

- Four hydrological models over Europe
- Climate change impacts on no. dry spells in southern Sweden

Production system to provide hydrological status & outlooks

SMHI



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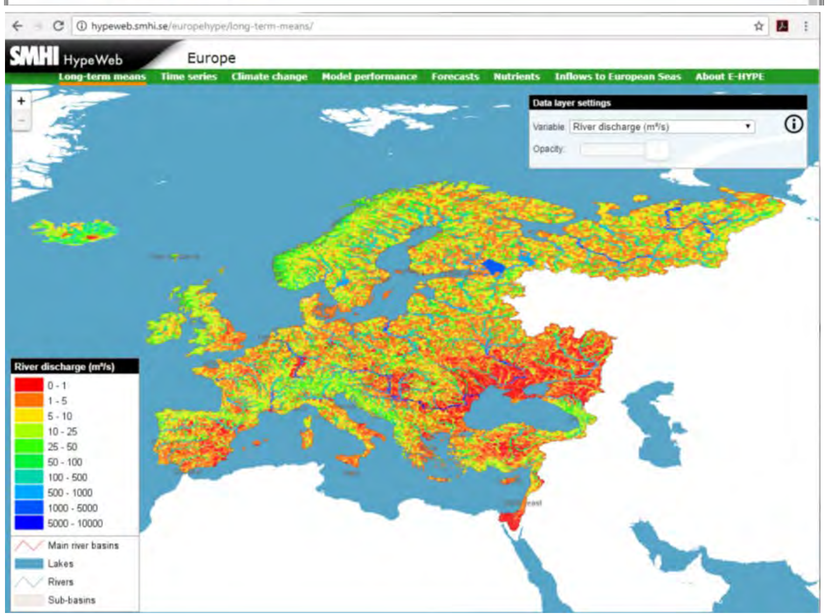
Information distribution / communication



Sweden: http://vattenwebb.smhi.se/

- Status & outlooks
- Model performance / skill
- Scenario tools (WQ, regulations)
- Climate change impacts
- Data download: **observations** & model output, lakes&reservoirs, waterfalls, wetlands …
- Multiple users: authorities, business, public etc.

Global: http://hypeweb.smhi.se/

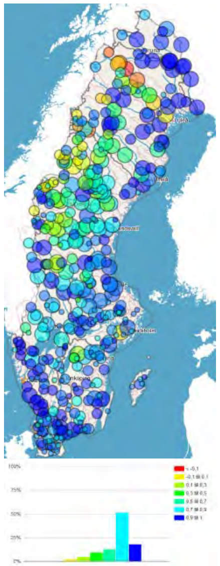
- Water resources
- Historical dynamics
- Model performance / skill
- Forecasts
- Climate change impacts
- Data download

Customized for clients:

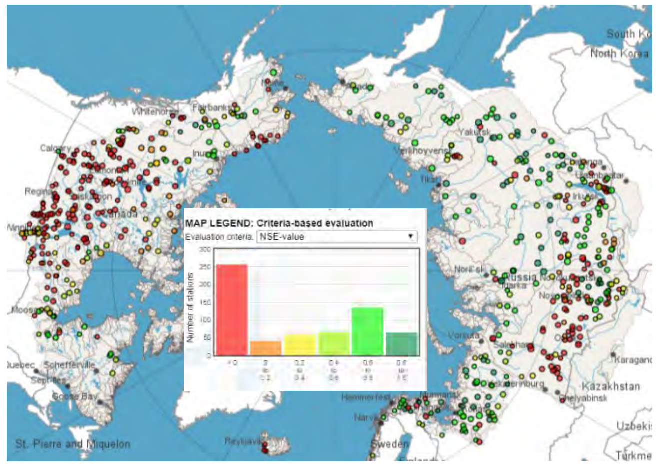
- Copernicus: http://swicca.climate.copernicus.eu/ WMO / HydroSOS?

Performance communication: examples for simulation of historical dynamics

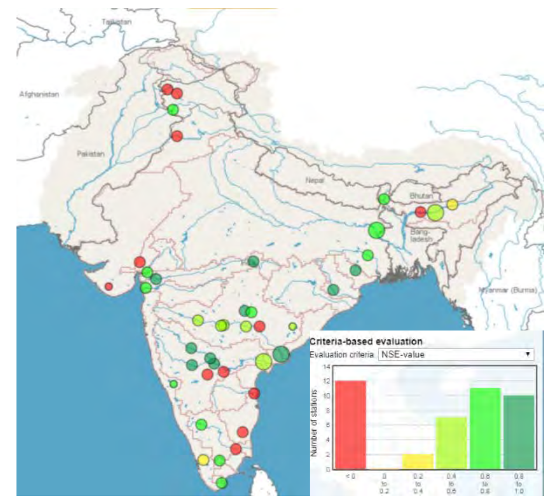
Sweden



Arctic

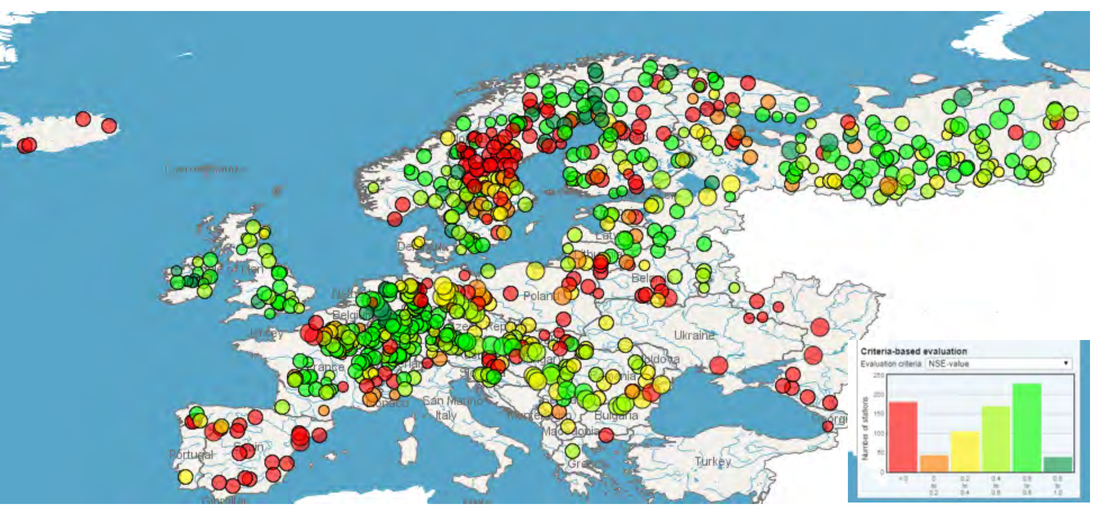


Indian subcontinent

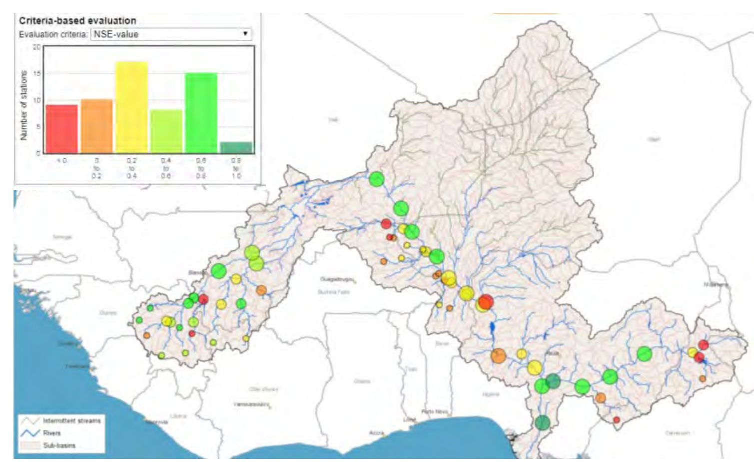


http://hypeweb.smhi.se

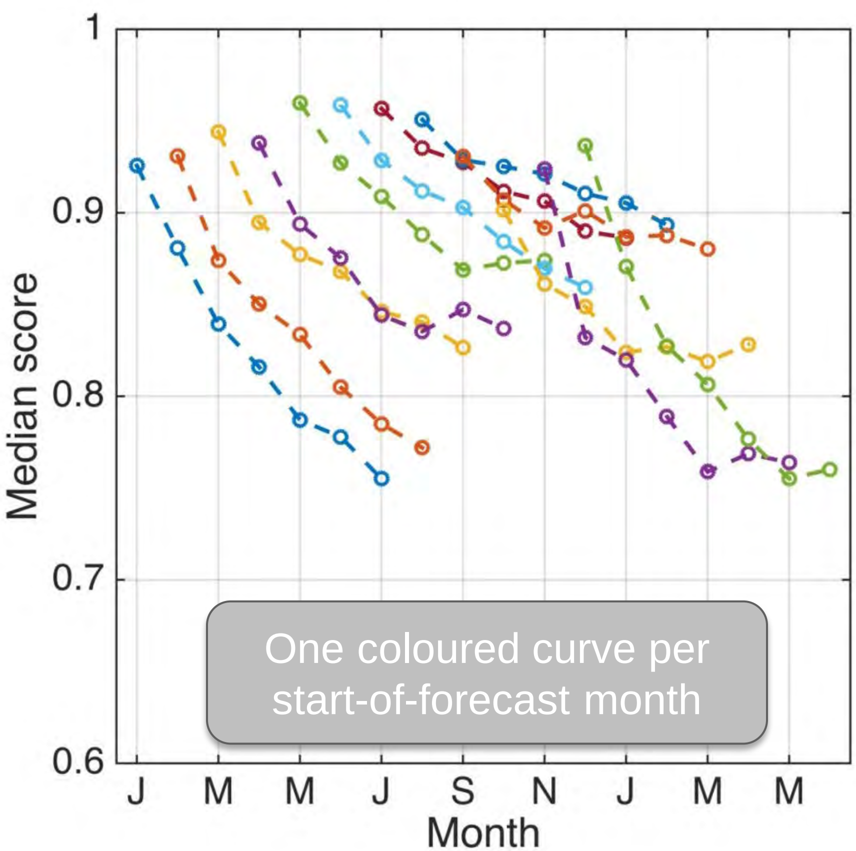
Europe



Niger River basin



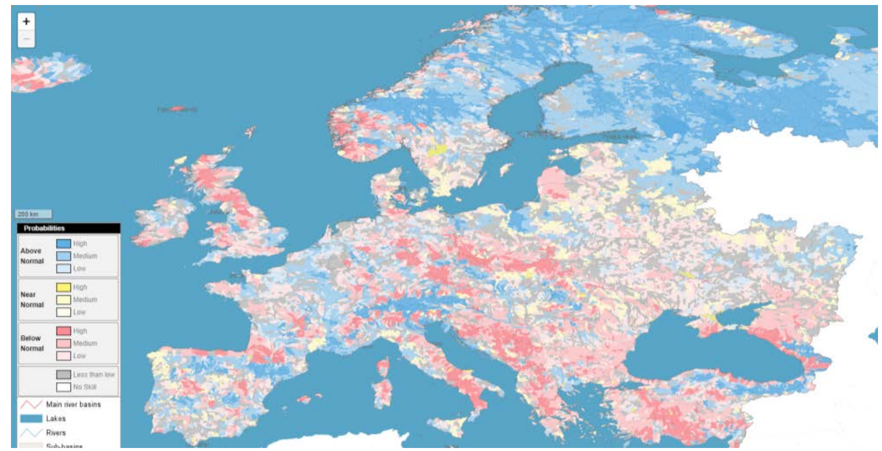
Performance communication: example of seasonal hydrological forecasting skill in Europe



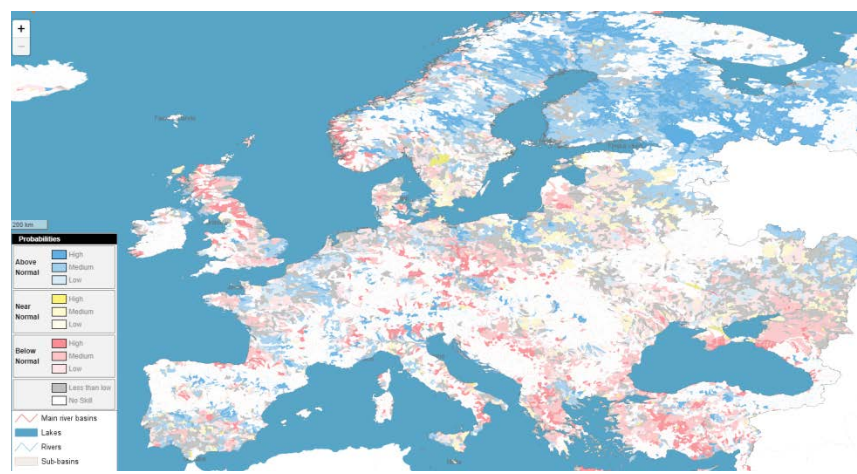
Skill variability: season, lead time, location, regime…

Pechlivanidis et al., 2017, Seasonal hydrological forecasting in Europe: Analysis of skill and its key driving factors, CEST 2017, https://cest.gnest.org/

All catchments



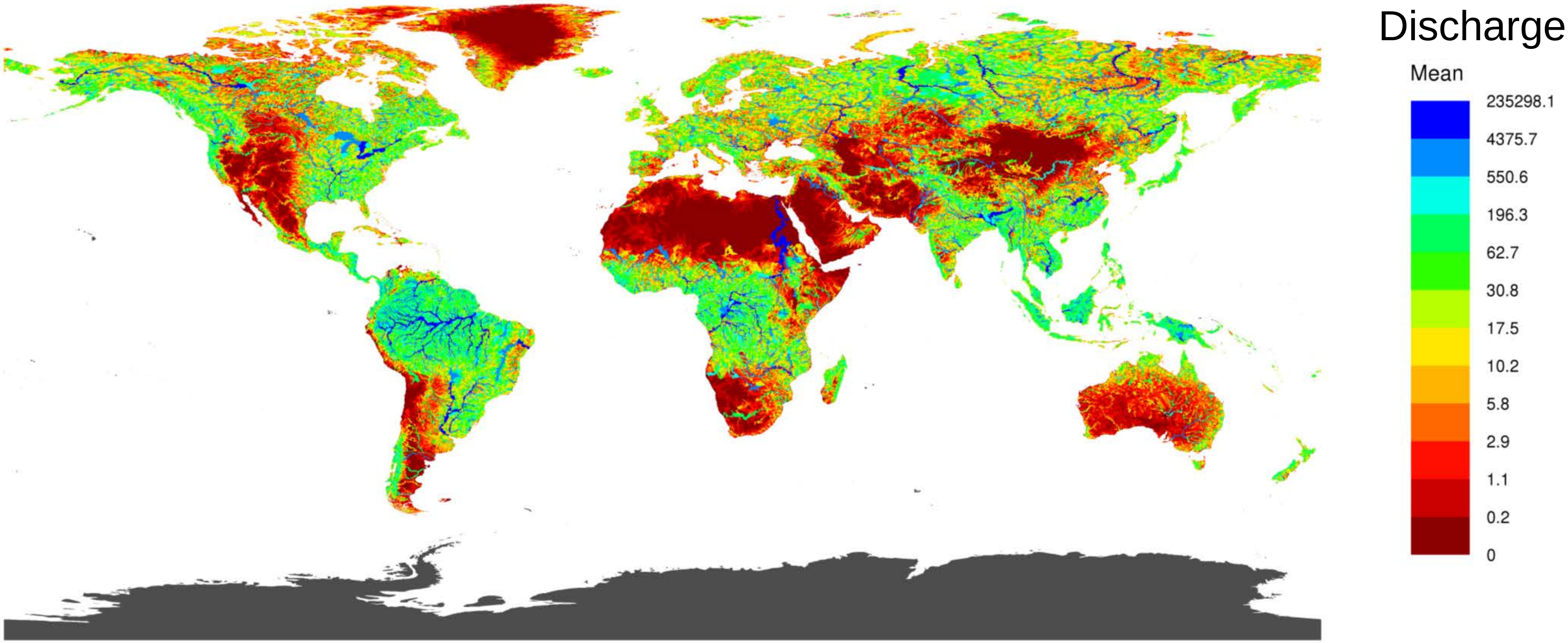
ONLY catchments with skill



http://swicca.climate.copernicus.eu/

World-Wide HYPE (WWH)

- Global hydrological model (all land areas except Antartica)
- Spatial resolution: 130 000 catchments (average size 1000 km^2)
- Temporal resolution: daily
- Continuously developed into refined versions
- Producing information since April 2016
- Operational forecast production: spring 2018
- Co-development regionally/locally



Global hydro. model needs a lot of data!

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Databases for catchment delineation in WWH

TYPE	DATA SET	Provider/References
Topography (Flow accumulation, flow direction, digital elevation, river width)	GWD-LR (3 arcsec) GIMP-DEM (3 arcsec) HYDRO1K (30 arcsec) SRTM (3 arcsec)	Yamazaki et al., 2014 Howat et al., 2015 USGS USGS
Non contributing areas in Canada *	Areas of Non-Contributing Drainage (AAFC Watersheds Project – 2013)	Government Canada
Watershed delineation (Iceland) **	IMO subbasins and main river basins	Icelandic Met Office (IMO)
*Carst ****	*World Map of Carbonate Rock Outcrops v3.0*	*Williams & Ford (2006)*
*Global Flood Risk *****	*Global estimated risk index for flood hazard*	*UNEP/GRID-Europe*
*Floodplains ******	Global Lake and Wetland Database (GLWD)	Lehner and Döll, 2004
*Desert areas *******	*World Land-Based Polygon Features*	*Kelso, et al., 2012*

** original dataset imported and tailored to WWH subbasins*
*** original subbasins merged and adjusted into larger units for WWH*
**** sinks within carst area were relinked into the subbasin routings*
***** used to find larger cities within areas with high flood risk*
****** used to find floodplains and merge subbasins within these to larger units (for later use of flooddata.txt)*
******* used to select and amerge subbasins into larger units within desert areas*

Global hydro. model needs a lot of data!

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Databases for land cover, lakes & reservoirs in WWH

TYPE	DATA SET	Provider/References
Land cover characteristics	ESA CCI Landcover v 1.6.1 epoch 2010 (300 m)	ESA Climate Change Initiative - Land Cover project
Glaciers*	Randolph Glacier Inventory (RGI) v 5.0	Arendt et al., 2015
Lakes**	ESA CCI-LC Waterbodies 150 m 2000 v 4.0	ESA Climate Change Initiative - Land Cover project
Lakes**	Global Lake and Wetland Database 1.1 (GLWD)	Lehner and Döll, 2004
Lake depths	Global Lake Database v2(GLDB)	Kourzeneva, 2010, 2012, Oulga, 2014
Reservoirs and dams**	Global Reservoir and Dam database v 1.1 (GRanD)	Lehner et al., 2011
Irrigation***	GMIA v5.0	Siebert et al., 2013

* Added as a land cover class in the land cover grid
** Combination of databases resulting in: *A new world lakes database for global hydrological modelling*, Piementel et al., EGU 2017.
*** Irrigated/nonirrigated cropland has been updated with information from GMIA v5.0

Global hydro. model needs a lot of data!

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Databases: meteorological inputs in WWH

TYPE	DATA SET	Provider/References
Precipitation	MSWEP v1.1* (Multi-Source Weighted-Ensamble Precipitation)	Beck, H.E et al. (2016)
Temperature	GFD (Global Forcing Data)	Berg et al., in review 2017
Climate classification*	Köppen-Geiger Climate classification, 1976-2000, v June 2006	Institute for Veterinary Public Health, Vienna

- *Used for linking subbasins to optimal PET (Potential EvapoTranspiration) model option in HYPE.*

Global hydro. model needs a lot of data!

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Databases: river flow gauges in WWH (20k time series)

Characteristic/Data type	Info/Name	Coverage	Provider/References
Discharge + metadata	**GRDC**	Global	GRDC
" "	**EWA**	Europe	GRDC
" "	**ds553.2 Russian River data by Bodo**	Former Soviet Union	Byron Bodo. 2000
" "	**R-ArcticNet v 4.0**	Arctic region	UNH
" "	**RIVDIS v 1.1**	Global	Vörösmarty et al., 1998
" "	**USGS**	USA	U.S. Geological Survey
" "	**HYDAT**	Canada	Water Survey of Canada (WSC)
" "	**Chinese Hydrology Data Project**	China	Henck et al., 2011
" "	**National data**	Spain	Spanish authorities
" "	**WISKI**	Sweden	SMHI
Metadata	**CLARIS-project**	La Plata Basin	CLARIS project
"	**CWC handbook**	India	Central Water commission (CWC)
"	**SIEREM**	Africa	Boyer et al., 2006
"	**Regional data**	Congo Basin	International Commission for Congo-Ubangui-Sangha Basin
"	**National data**	Australia	BOM (Bureau of Meteorology)
"	**Red Hidrometrica SNHN 2013**	Bolivia	Servicio Nacional de Hidrgrafía Naval
"	**Estacoes Fluviometrica**	Brazil	ANA (Agencia Nacional de Aguas)
"	**Red Hidrometrica**	Chile	DGA (Direccion General de Aguas)
"	**Catalogo Nacional de Estaciones de Monitoreo Ambiental**	Colombia	IDEAM (Instituto de Hidrologia, Meteorologia y Estudios Ambientales)
"	**Estaciones_Hidrologicas**	Ecuador	Instituto Nacional de Meteorologia e Hidrologia
"	**National data**	Peru	SENAMHI (Servicio Nacional de Meteorologia e Hidologia del Peru)
"	**National data**	Venezuela	IGVSB (Instituto Geográfico de Venezuela Simon Bolivar)
"	**Conabio 2008**	Mexico	Instituto Mexicano de Tecnología del Agua/CONABIO
"	**Niger HYCOS**	Niger river	ABN / AGRHYMET
"	**National data**	South Africa	Department Water & Sanitation, Republic of South Africa
"	**National data**	Mauritius	Mauritisus Ministry of Energy and Public Utilities

Suggestions for HydroSOS

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Use multiple hydrological models

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- Accuracy: performance vs. hydrological observations, multiple variables
- Operational reliability: delay, missing data, data format
- Openness of code/model: transparency, better development, easier for new groups to contribute
- Evaluate global models at regional & local scales, standardised protocols

Community

- Critical mass of developers, producers and users at global, regional and local scales
- Each NMS/NHS test global information in their country & provide feedback (e.g. evaluation results, suggested improvements, implemented improvements)
- SMHI wants to participate with our experience, operational production system, and communication platforms

Versions

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