Deltares
Enabling Delta Life

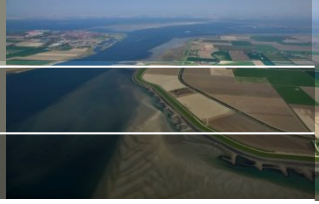
Improving Hydrologic Prediction at the Basin Scale through State Updating

Albrecht Weerts

21 juni 2016

WAGENINGEN UR
For quality of life

Acknowledgements



J. Schellekens, Deltares
E. Bos, Deltares / SNOW
A. Kockx, Deltares
S. Hummel, Deltares
R. Molenaar, WUR
D. Tretjalova, WUR
J. Ren, UNESCO-IHE
Albert van Dijk, ANU
Bulut Akkol, Anadolu University
Aynur Sensoy Sorman, Anadolu University
N. Drost, eScience Centre

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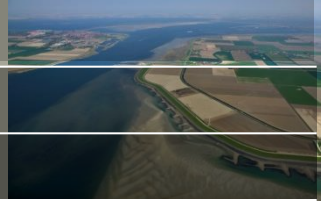
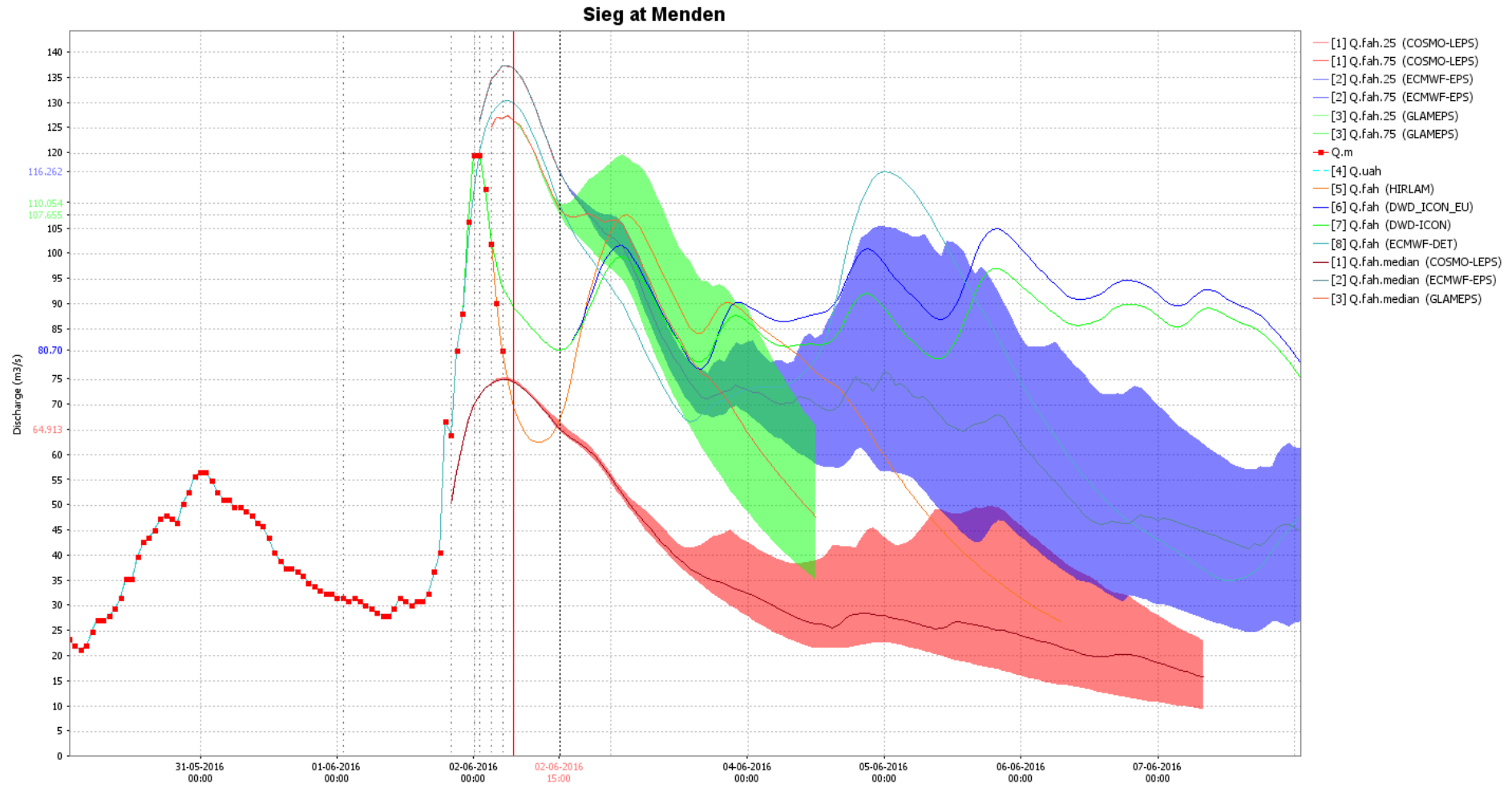
Initial state does matter…





Rijn_Forecast_COSMO-LEPS: [1] Forecast Rhine COSMO... 01-06-2016 20:00:00 GMT+1 Current
Rijn_Forecast_ECMWF-EPS: [2] Forecast Rhine ECMWF... 02-06-2016 01:00:00 GMT+1 Current
Rijn_Forecast_GLAMEPS: [3] Forecast Rhine GLAME... 02-06-2016 03:00:00 GMT+1 Current
Rijn_Update_SBK3: [4] Pilot Historical Sim... 01-06-2016 01:00:00 GMT+1 Current
Rijn_Forecast_HIRLAM: [5] Forecast Rhine HiRLA... 02-06-2016 07:00:00 GMT+1 Current
Rijn_SBK3_Forecast_DWD_ICON_EU: [6] Pilot Forecast Rhine... 02-06-2016 05:00:00 GMT+1 Current
Rijn_Forecast_DWD-ICON: [7] Forecast Rhine ICON 02-06-2016 05:00:00 GMT+1 Current
Rijn_SBK3_Forecast_ECMWF-DET: [8] Pilot Forecast Rhine... 02-06-2016 00:00:00 GMT+1 Current

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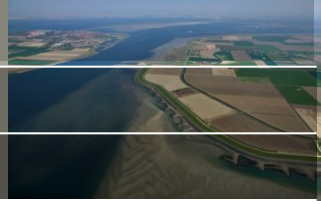
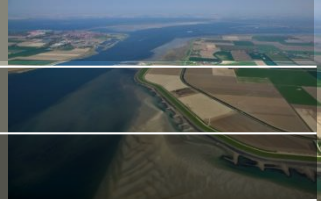
Introduction



- Improving the accuracy of flood forecasting is challenging
- Automated DA is hardly used within operational hydrology (See Liu et al., 2012)
- Streamflow data assimilation with a distributed hydrological model can improve the accuracy of flood forecasting (Rakovec et al., 2012, 2015)
- Discharge measurements are the most widely available hydrological observations for real-time model updating

Outline



OpenDA - WFLOW

Example:

- Discharge assimilation using EnKF
  - DA in continental/global scale scale flood forecasting system (GLOFFIS)

(
- daily discharge assimilation using EnKF
  - discharge & snow data assimilation Turkey (Karasu basin)
  - discharge Murrumbegee
- hourly discharge assimilation using EnKF
  - discharge Ourthe, Jadar, Kolubra. Raba

)

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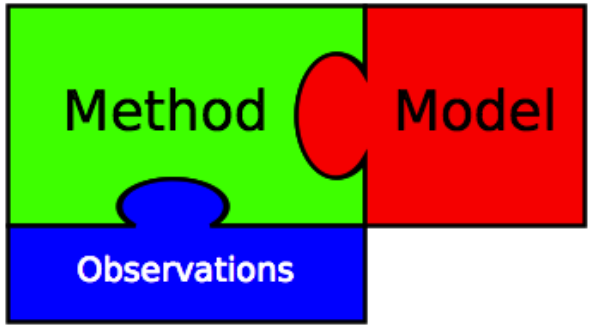
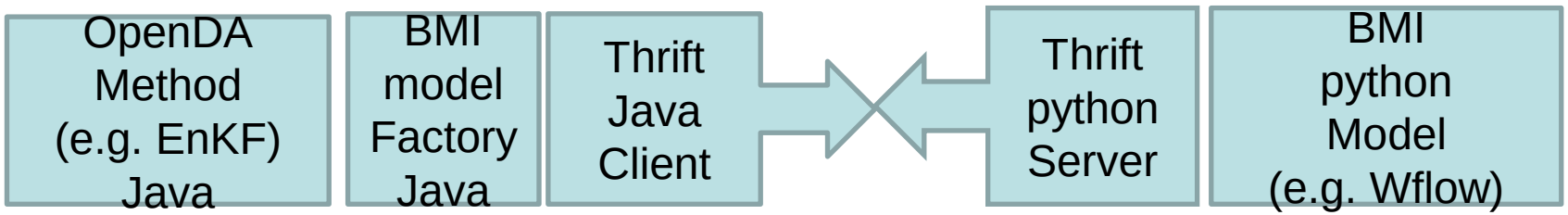
OpenDA-WFLOW

OpenDA is an open source toolbox for data assimilation and parameter calibration in a generic modeling context.





Drost et al., (2015)

Weerts et al., (in prep., 2016)

https://github.com/openstreams/wflow

BMI=> http://csdms.colorado.edu/wiki/BMI_Description

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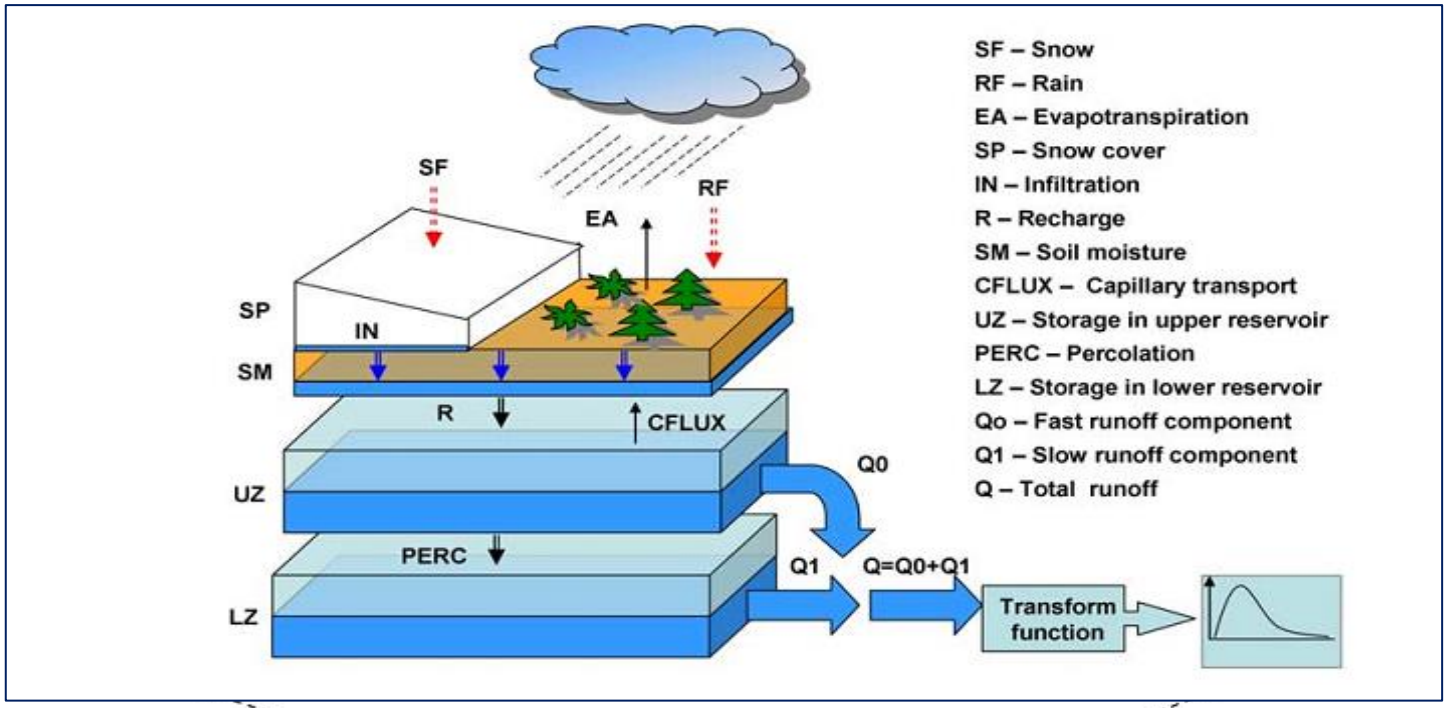
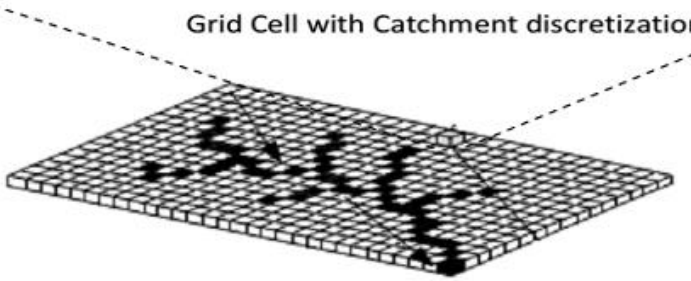
For example Python WFLOW/OpenStreams HBV-96 distributed hydrological model



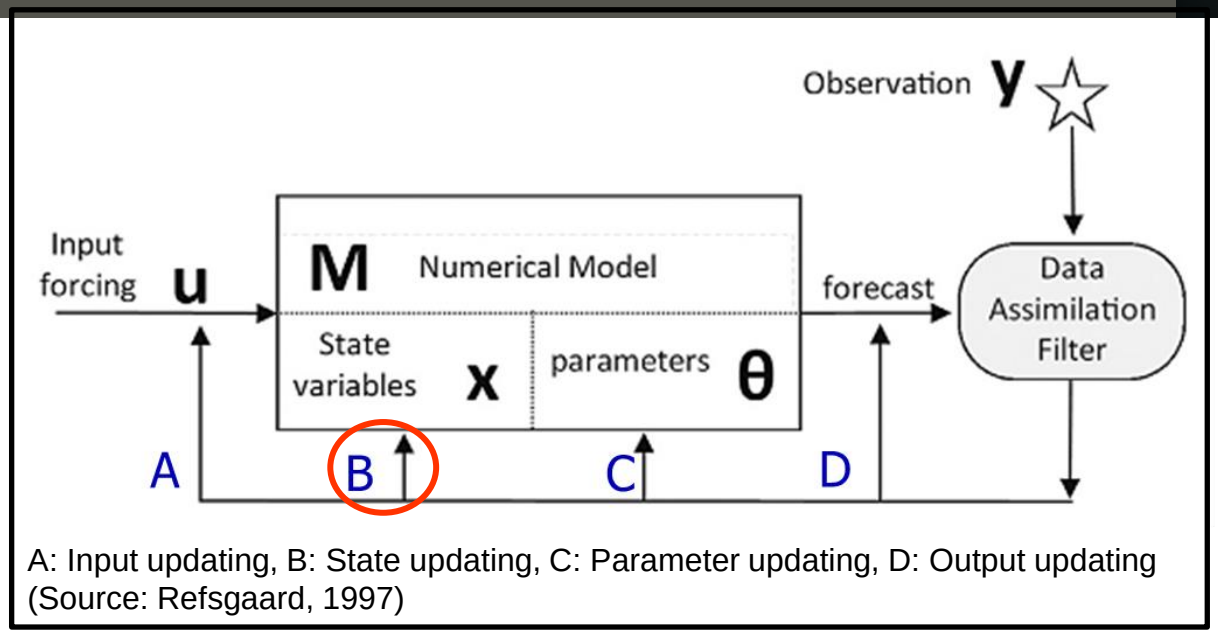


Resolution	1km*1km
Grid cell	95*90
Model Input	SF,RF,T, EA
Model State	SN, SM, UZ, LZ, WL, Q, IC
Discharge Routing	Kinematic Wave model

HBV-96 model (Lindström et al. 1997)

Source: modified after Solomatine and Shrestha 2009 & Rakovec et al. 2012

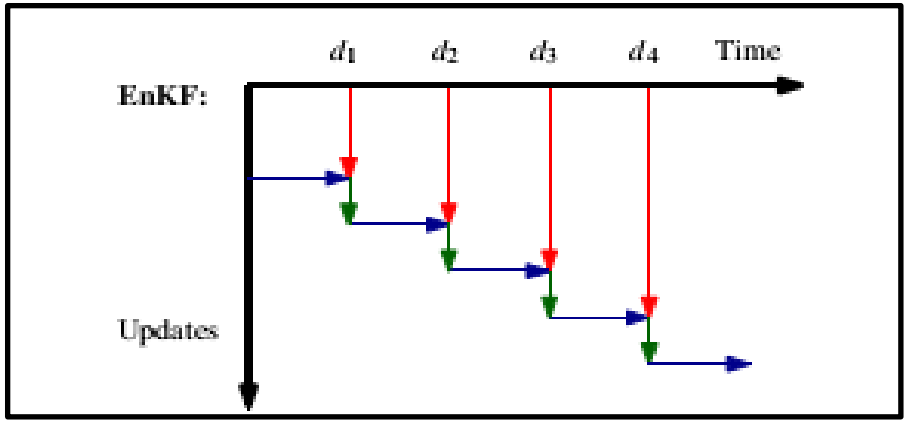
Literature Review

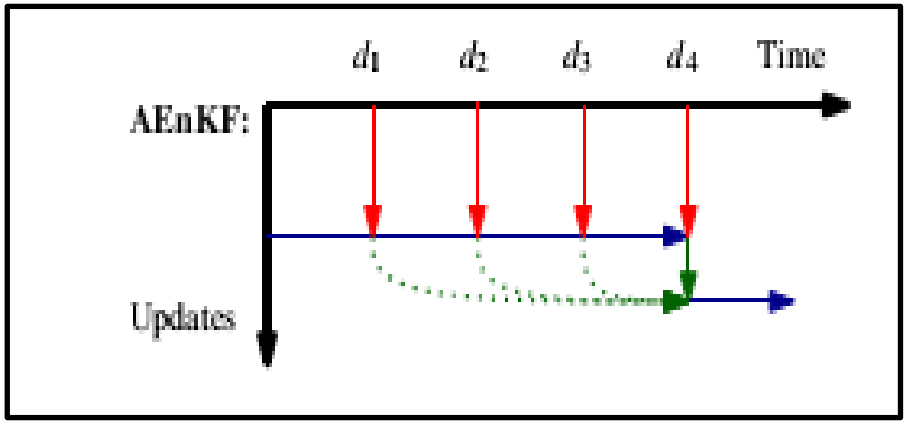


A: Input updating, B: State updating, C: Parameter updating, D: Output updating
(Source: Refsgaard, 1997)

$$\mathbf{X}_i^a = \mathbf{X}_i^f + \mathbf{K}(\mathbf{d} + \mathbf{D}_i - \mathbf{H}\mathbf{X}_i^f),$$

X^a_i is analyzed model state
X^f_i is forecasted model state
d is the observation
D_i is the measurement noise
H is the measurement operator
K is the Kalman Gain





Blue arrow: on-going model prediction. **Red arrow:** introduction of observations. **Green arrow:** model update. **Green dotted arrows :** the past observation being assimilated using AEnkF

(Source: Evensen et al. 2009 & Rakovec et al. 2015)

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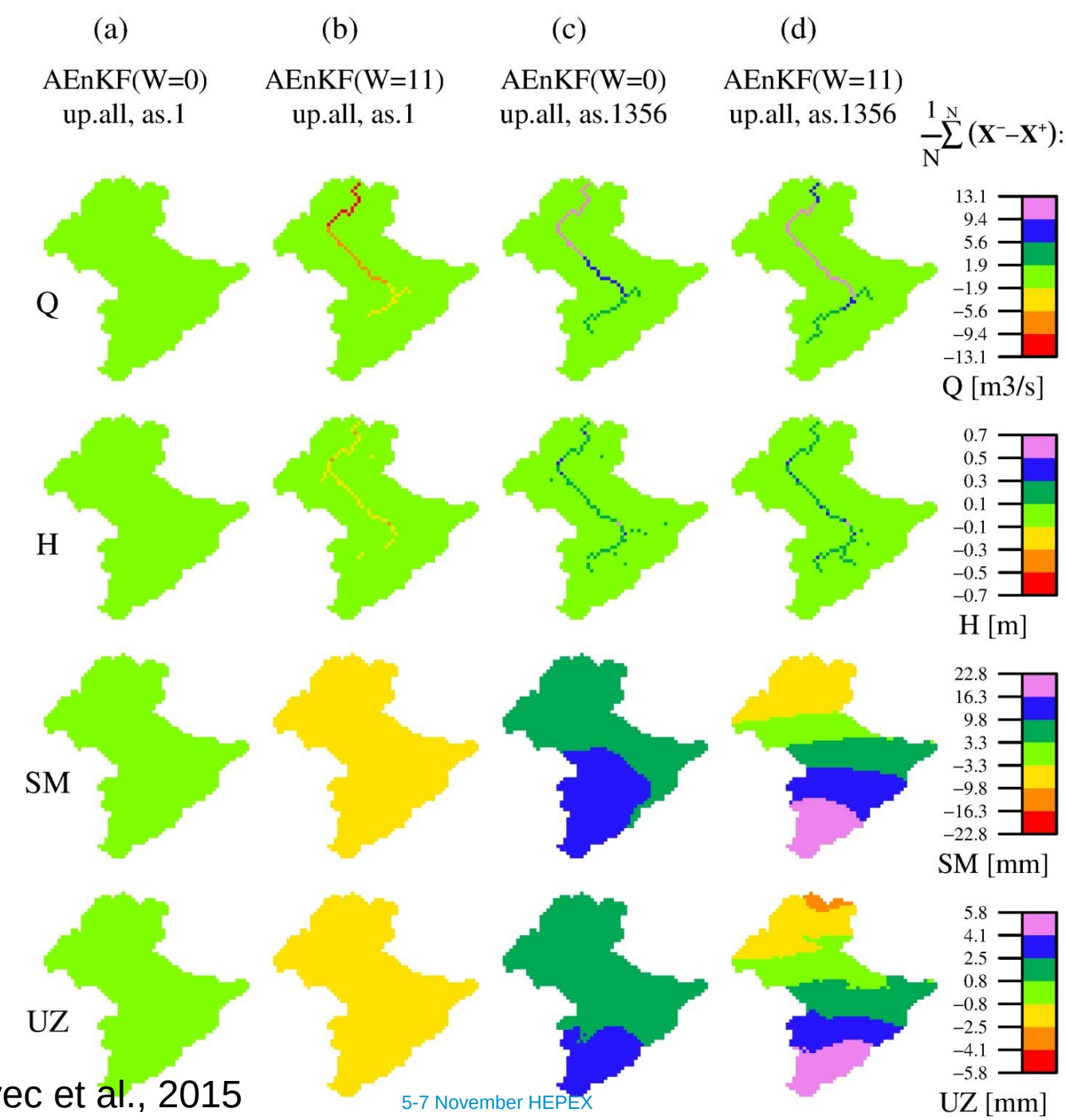

Rakovec et al., 2015

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GLOFFIS Flood Forecasting Information System

Global Hydrologic Models:

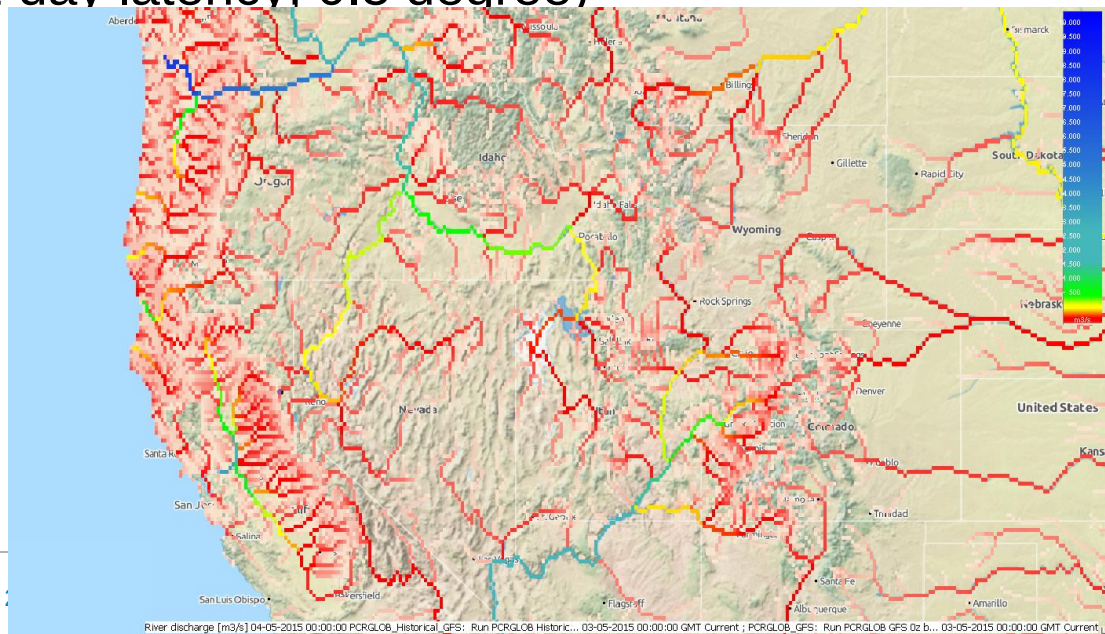
- PCRGLOB-WB (0.1 degree)
- W3RA (0.5 degree => 0.05 degree in progress)
- wflow_routing

Meteo:

-GFS (4x day)

-GEFS ensembles (4x day) 80 members (time-lagged)

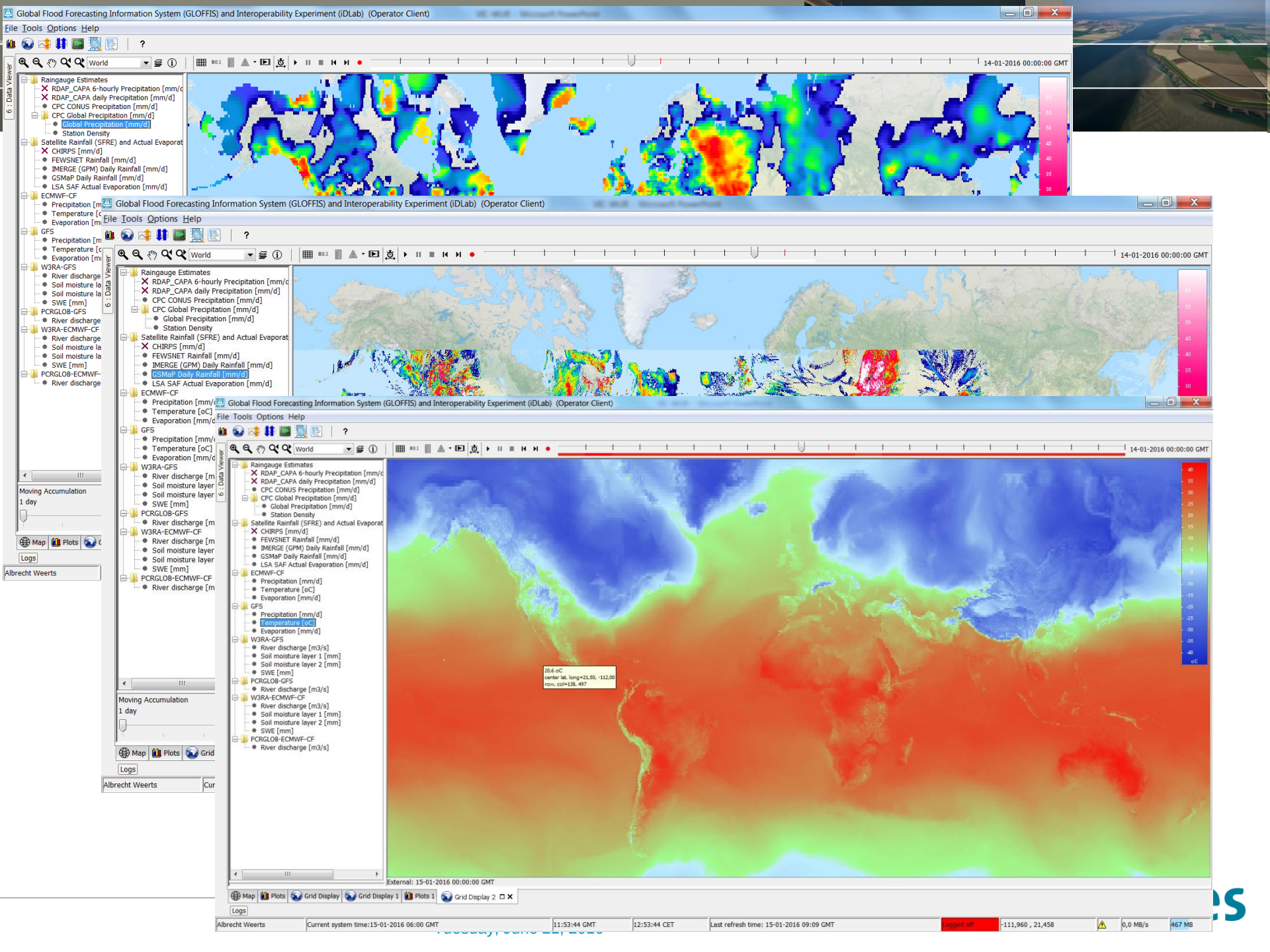
-ECMWF ensembles (TIGGE ~2 day latency, 0.5 degree)

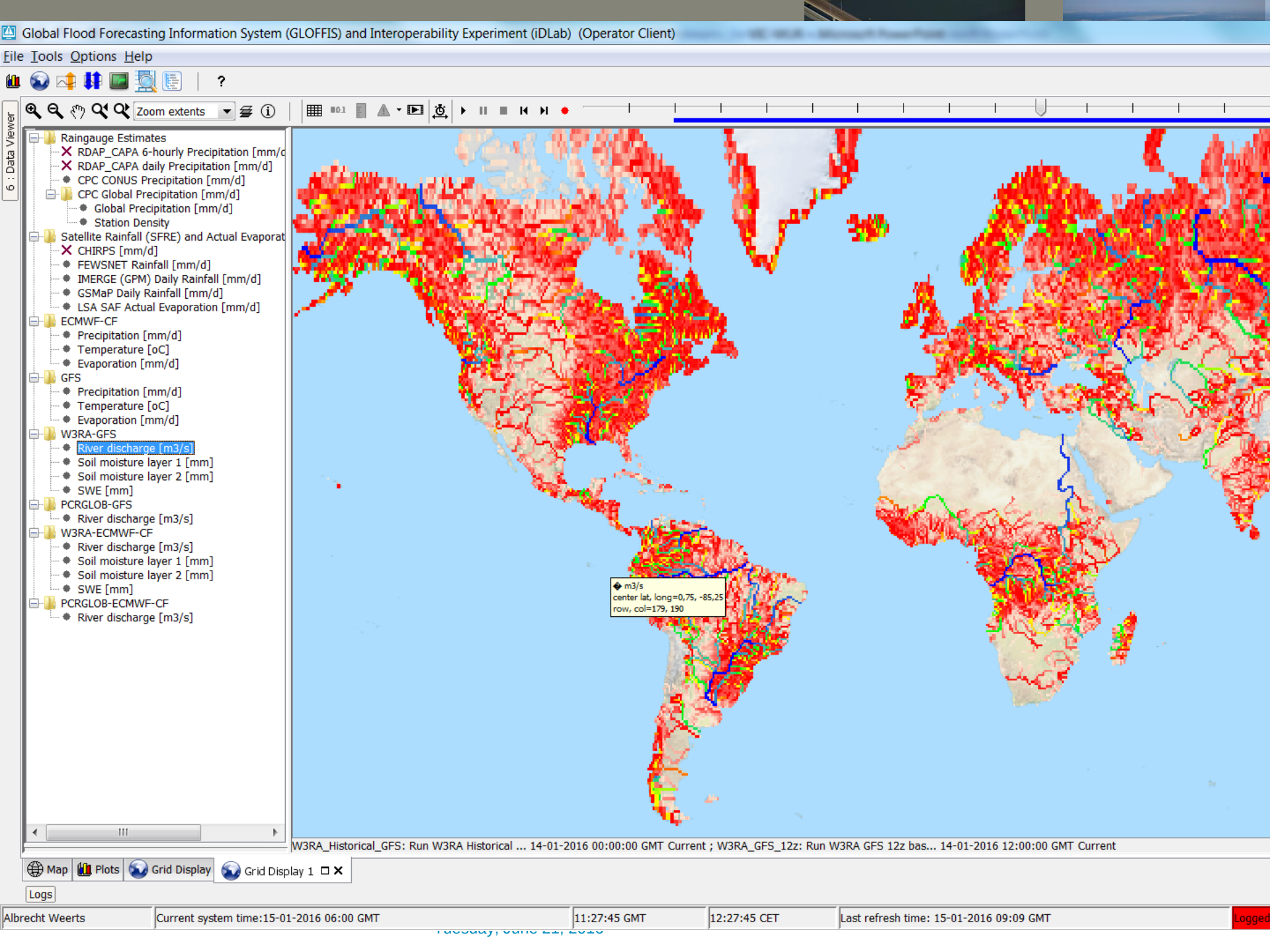


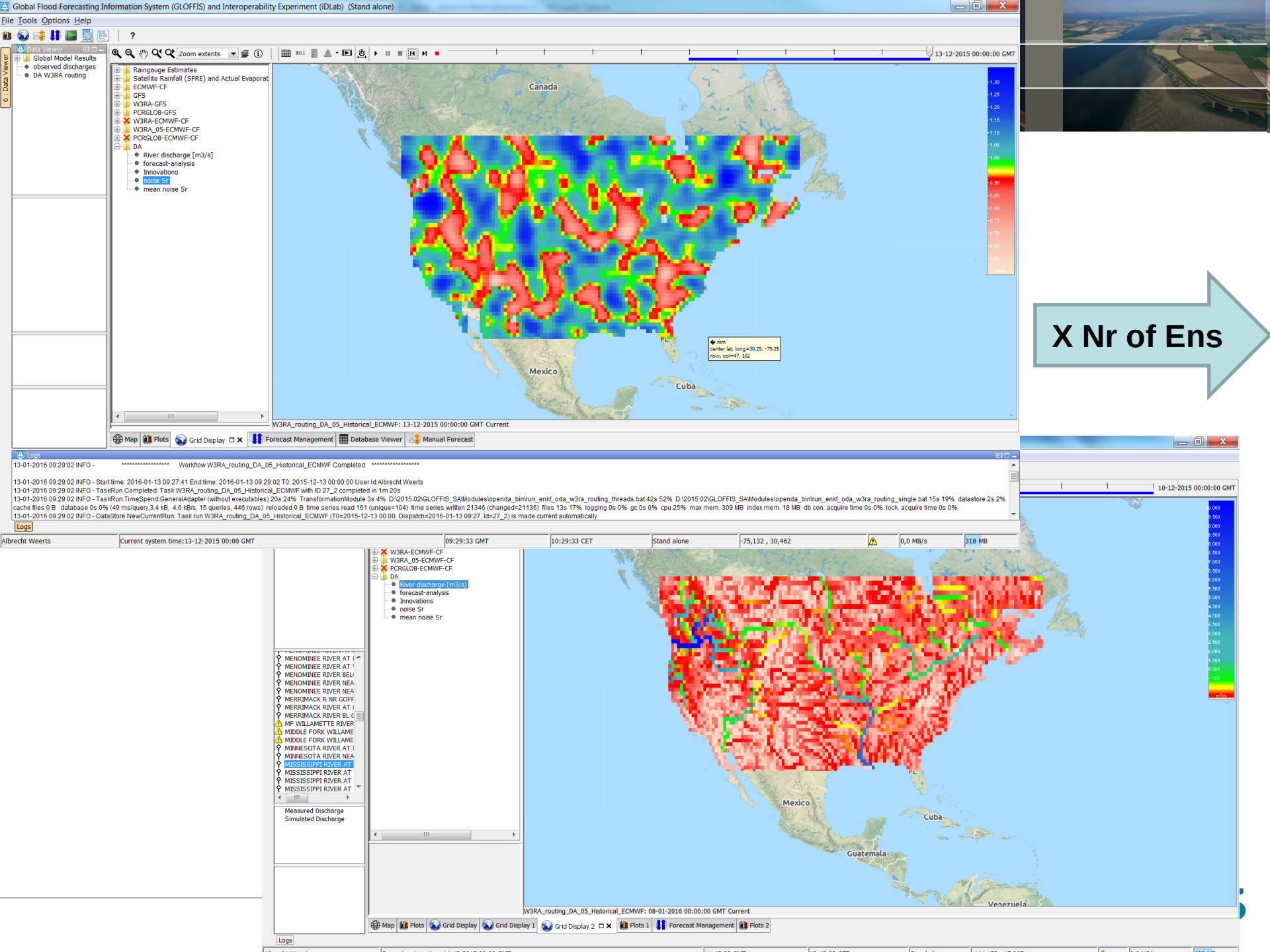
See also

Emmerton et al. 2016

Beck et al 2016 HESSD


Global Flood Forecasting Information System (GLOFFIS) and Interoperability Experiment (iDLab) (Operator Client)
File Tools Options Help
World
14-01-2016 00:00:00 GMT
Raingauge Estimates
RDAP_CAPA 6-hourly Precipitation [mm/d]
RDAP_CAPA daily Precipitation [mm/d]
CPC CONUS Precipitation [mm/d]
CPC Global Precipitation [mm/d]
Global Precipitation [mm/d]
Station Density
Satellite Rainfall (SFRE) and Actual Evaporat
CHIRPS [mm/d]
FEWSNET Rainfall [mm/d]
IMERGE (GPM) Daily Rainfall [mm/d]
GSMaP Daily Rainfall [mm/d]
LSA SAF Actual Evaporation [mm/d]
ECMWF-CF
Precipitation [mm/d]
Temperature [oC]
Evaporation [mm/d]
GFS
Precipitation [mm/d]
Temperature [oC]
Evaporation [mm/d]
W3RA-GFS
River discharge [m3/s]
Soil moisture layer 1 [mm]
Soil moisture layer 2 [mm]
SWE [mm]
PCRGLOB-GFS
River discharge [m3/s]
W3RA-ECMWF-CF
River discharge [m3/s]
Soil moisture layer 1 [mm]
Soil moisture layer 2 [mm]
SWE [mm]
PCRGLOB-ECMWF-CF
River discharge [m3/s]
6 : Data Viewer
Moving Accumulation
1 day
Map
Plots
Grid Display
Grid Display 1
Plots 1
Grid Display 2
Logs
Albrecht Weerts
20.6 oC
center lat, long=21,50, -112,00
row, col=138, 497
External: 15-01-2016 00:00:00 GMT
Current system time:15-01-2016 06:00 GMT
11:53:44 GMT
12:53:44 CET
Last refresh time: 15-01-2016 09:09 GMT
-111,960 , 21,458
0,0 MB/s
467 MB

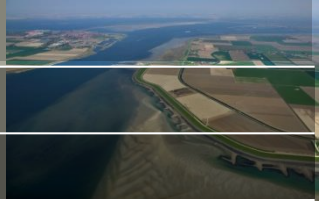

Global Flood Forecasting Information System (GLOFFIS) and Interoperability Experiment (iDLab) (Operator Client)
File Tools Options Help
Zoom extents
6 : Data Viewer
Raingauge Estimates
RDAP_CAPA 6-hourly Precipitation [mm/d
RDAP_CAPA daily Precipitation [mm/d]
CPC CONUS Precipitation [mm/d]
CPC Global Precipitation [mm/d]
Global Precipitation [mm/d]
Station Density
Satellite Rainfall (SFRE) and Actual Evaporat
CHIRPS [mm/d]
FEWSNET Rainfall [mm/d]
IMERGE (GPM) Daily Rainfall [mm/d]
GSMaP Daily Rainfall [mm/d]
LSA SAF Actual Evaporation [mm/d]
ECMWF-CF
Precipitation [mm/d]
Temperature [oC]
Evaporation [mm/d]
GFS
Precipitation [mm/d]
Temperature [oC]
Evaporation [mm/d]
W3RA-GFS
River discharge [m3/s]
Soil moisture layer 1 [mm]
Soil moisture layer 2 [mm]
SWE [mm]
PCRGLOB-GFS
River discharge [m3/s]
W3RA-ECMWF-CF
River discharge [m3/s]
Soil moisture layer 1 [mm]
Soil moisture layer 2 [mm]
SWE [mm]
PCRGLOB-ECMWF-CF
River discharge [m3/s]
m3/s
center lat, long=0,75, -85,25
row, col=179, 190
W3RA_Historical_GFS: Run W3RA Historical ... 14-01-2016 00:00:00 GMT Current ; W3RA_GFS_12z: Run W3RA GFS 12z bas... 14-01-2016 12:00:00 GMT Current
Map
Plots
Grid Display
Grid Display 1
Logs
Albrecht Weerts
Current system time:15-01-2016 06:00 GMT
11:27:45 GMT
12:27:45 CET
Last refresh time: 15-01-2016 09:09 GMT
Logged

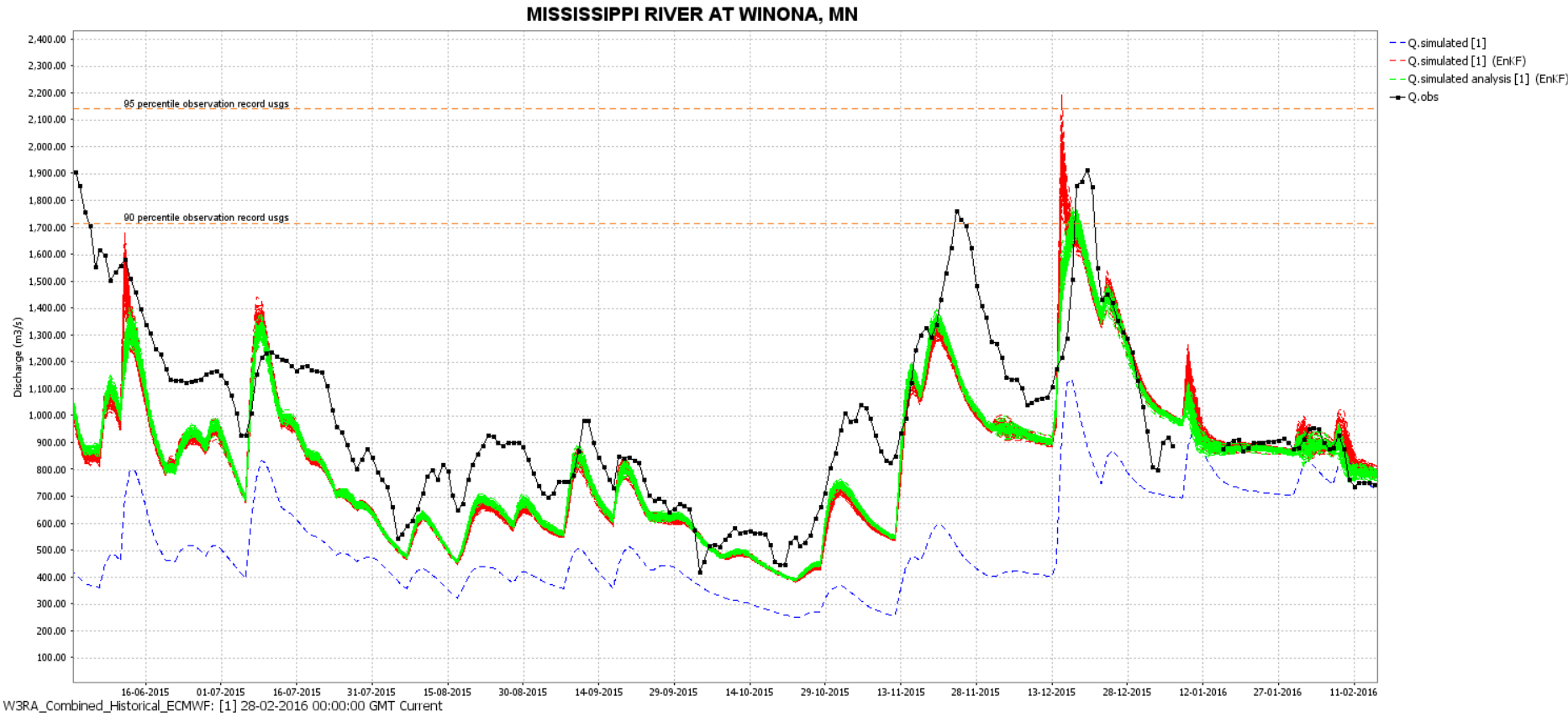

Global Flood Forecasting Information System (GLOFFIS) and Interoperability Experiment (iDLab) (Stand alone)
File Tools Options Help
Data Viewer
Global Model Results
observed discharges
DA W3RA routing
Zoom extents
13-12-2015 00:00:00 GMT
Raingauge Estimates
Satellite Rainfall (SFRE) and Actual Evaporat
ECMWF-CF
GFS
W3RA-GFS
PCRGLOB-GFS
W3RA-ECMWF-CF
W3RA_05-ECMWF-CF
PCRGLOB-ECMWF-CF
DA
River discharge [m3/s]
forecast-analysis
Innovations
noise Sr
mean noise Sr
Canada
Mexico
Cuba
W3RA_routing_DA_05_Historical_ECMWF: 13-12-2015 00:00:00 GMT Current
Map
Plots
Grid Display
Forecast Management
Database Viewer
Manual Forecast
Logs
13-01-2016 09:29:02 INFO - ********** Workflow W3RA_routing_DA_05_Historical_ECMWF Completed **********
Albrecht Weerts
Current system time:13-12-2015 00:00 GMT
09:29:33 GMT
10:29:33 CET
Stand alone
-75,132 , 30,462
0,0 MB/s
318 MB
Measured Discharge
Simulated Discharge
Guatemala
Venezuela
W3RA_routing_DA_05_Historical_ECMWF: 08-01-2016 00:00:00 GMT Current
Grid Display 1
Grid Display 2
Plots 1
Plots 2

X Nr of Ens


N
Temiskaming Shores
Fargo
Duluth
Minnesota
Marquette
Elliot Lake
North Bay
Escanaba
Saint Cloud
ST. CROIX RIVER AT ST. CROIX FALLS, WI
Minneapolis
Wisconsin
Michigan
MINNESOTA RIVER NEAR JORDAN, MN
CHIPPEWA RIVER AT DURAND, WI
Green Bay
Rochester
MISSISSIPPI RIVER AT WINONA, MN
Oshkosh
Toronto
Milwaukee
Flint
Sarnia
Buffalo
Lansing
Waterloo
Detroit
Erie
Iowa
Chicago
Mississippi River at Clinton, IA
Toledo
Davenport
Cleveland
KANKAKEE RIVER NEAR WILMINGTON, IL
Omaha
PLATTE R AT LOUISVILLE NE
km
100
200
300
400
500

Winona, Mississippi





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wflow_w3ra
wflow_routing
online/timestep
based coupled

ECMWF control forecast
1 day ahead as forcing

Noise on precip. &
temp.

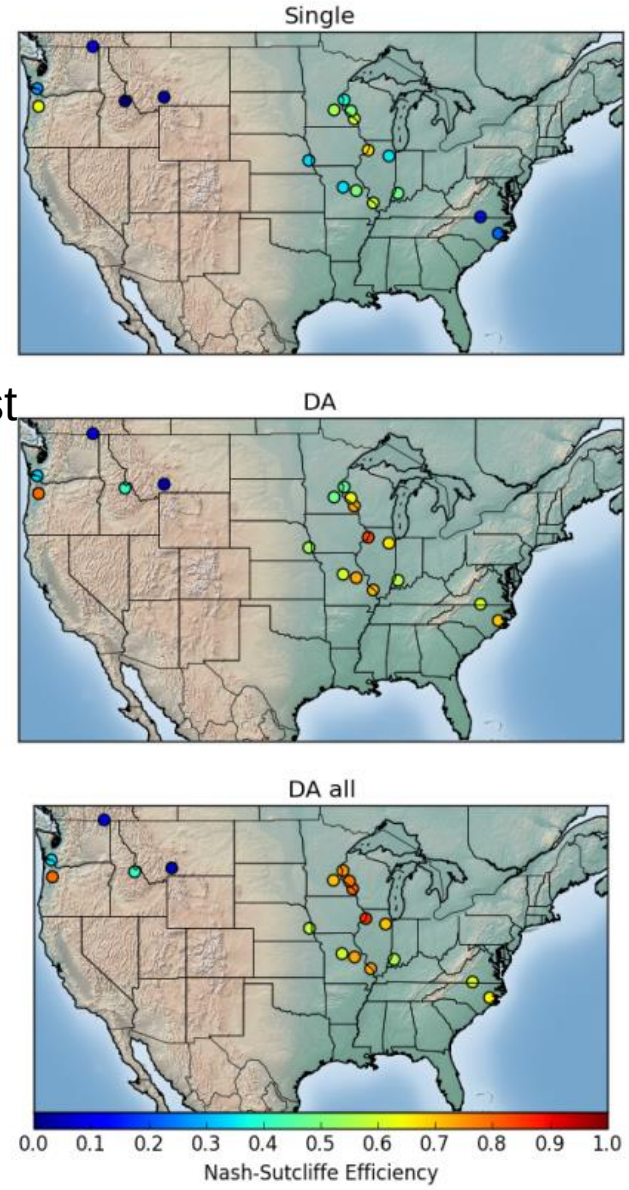
DEnKF

Localization
(autozhang)

64 ens. members

SWE not updated

reservoirs not modelled



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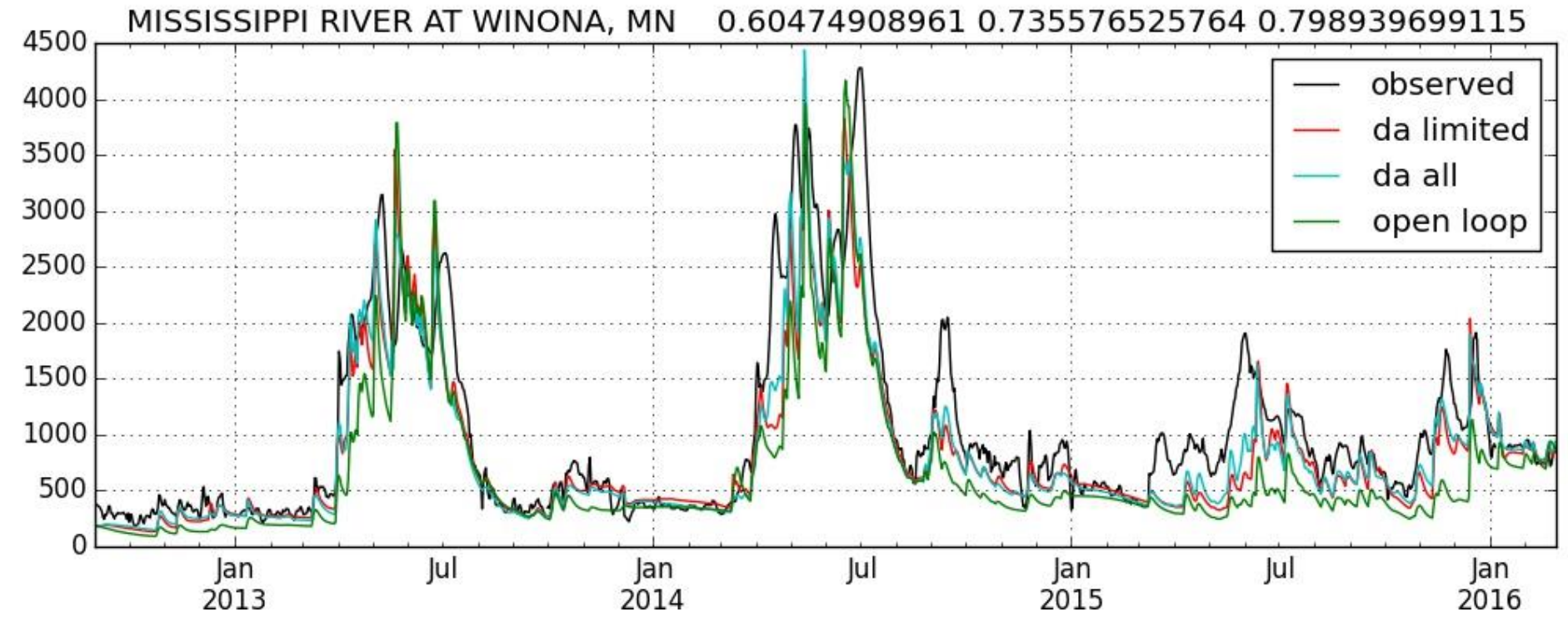
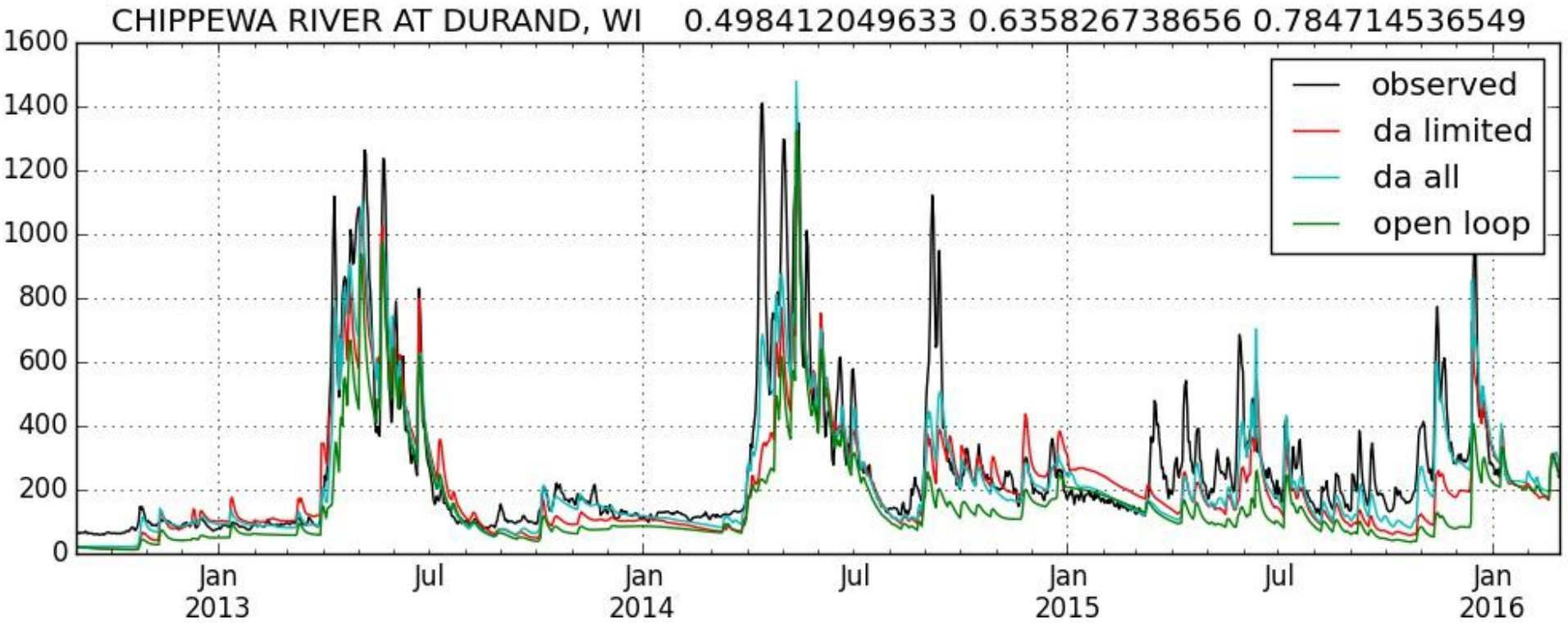
Winona, Mississippi



Chippewa river, Upstream WINONA



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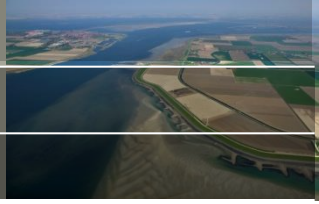
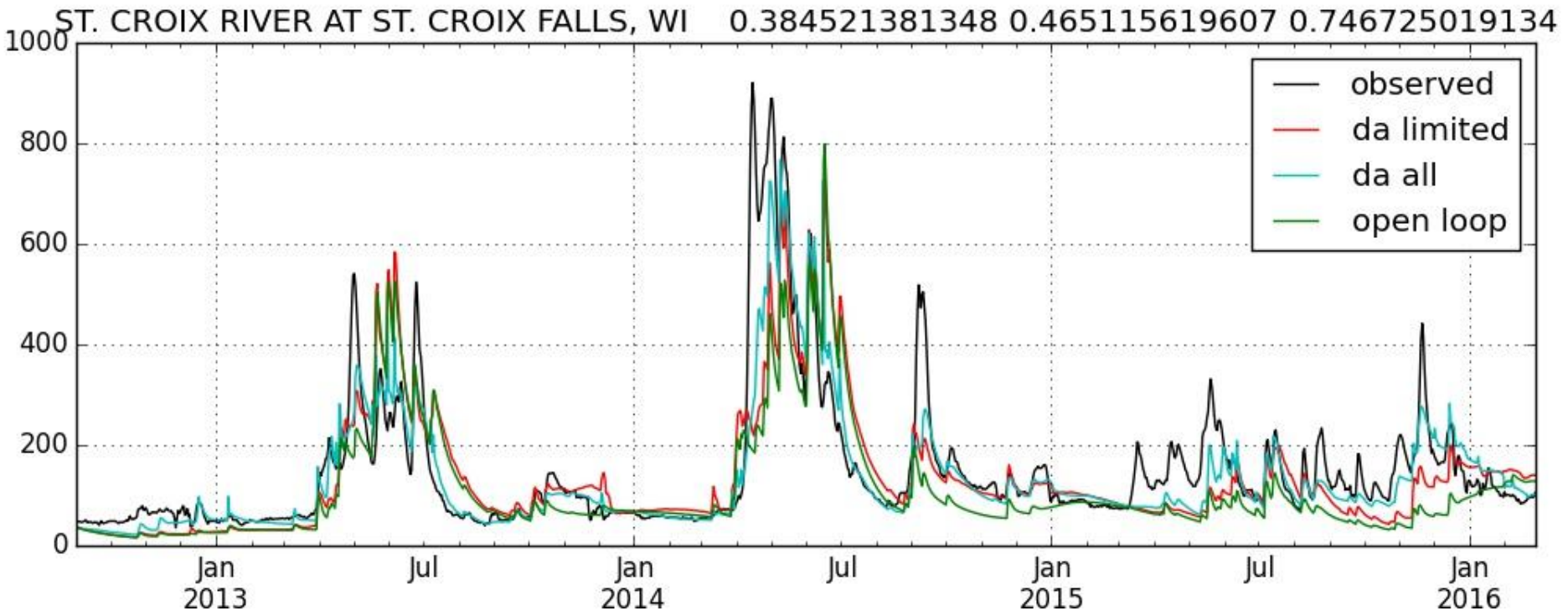
St Croix upstream Winona





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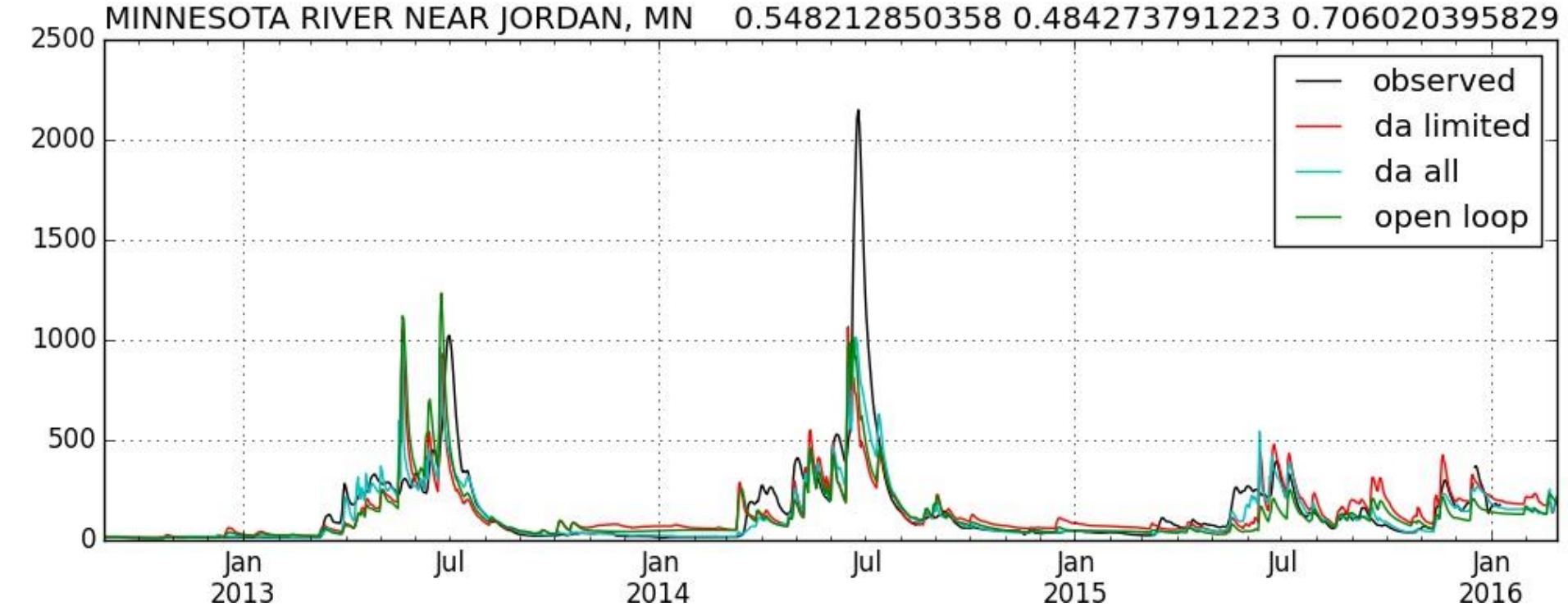
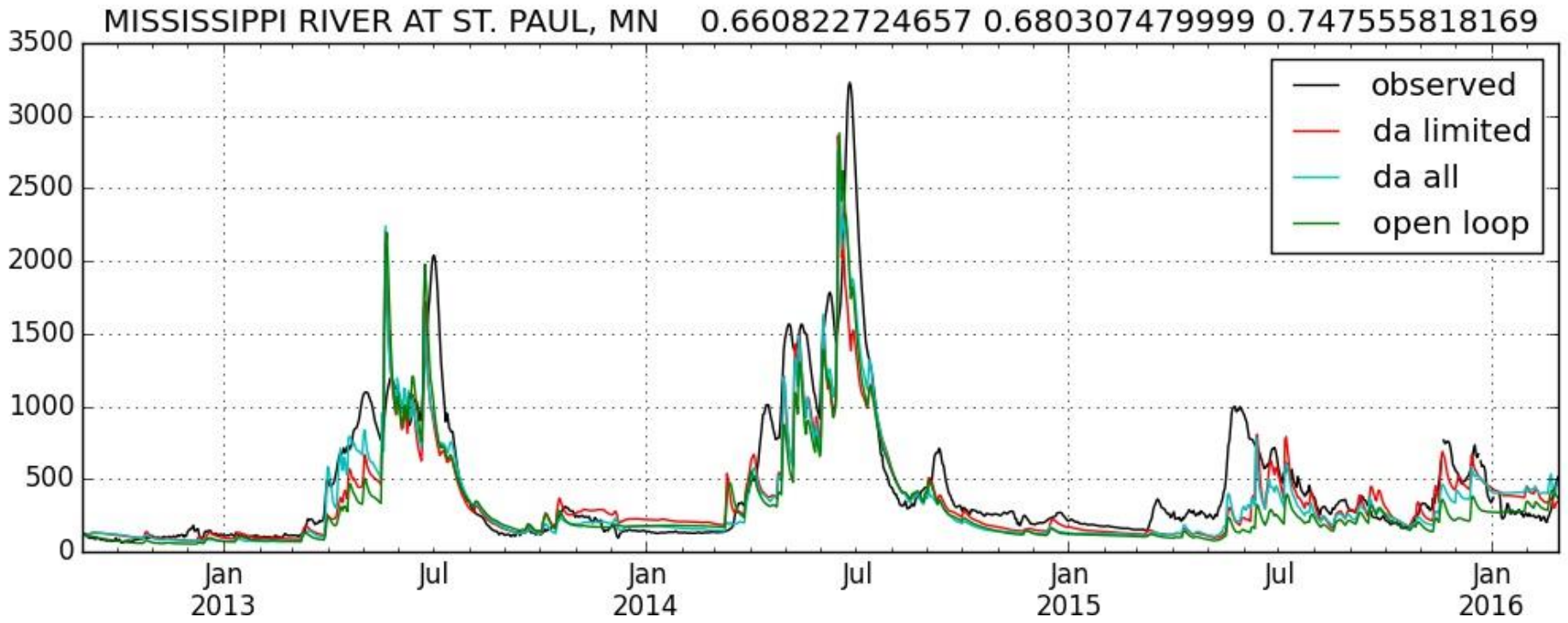
Minnesota river, Upstream Winona



St Paul, Mississipi upstream Winona and tributaries



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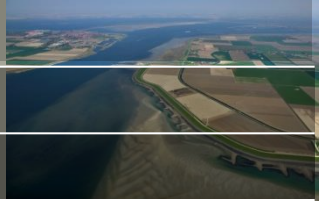
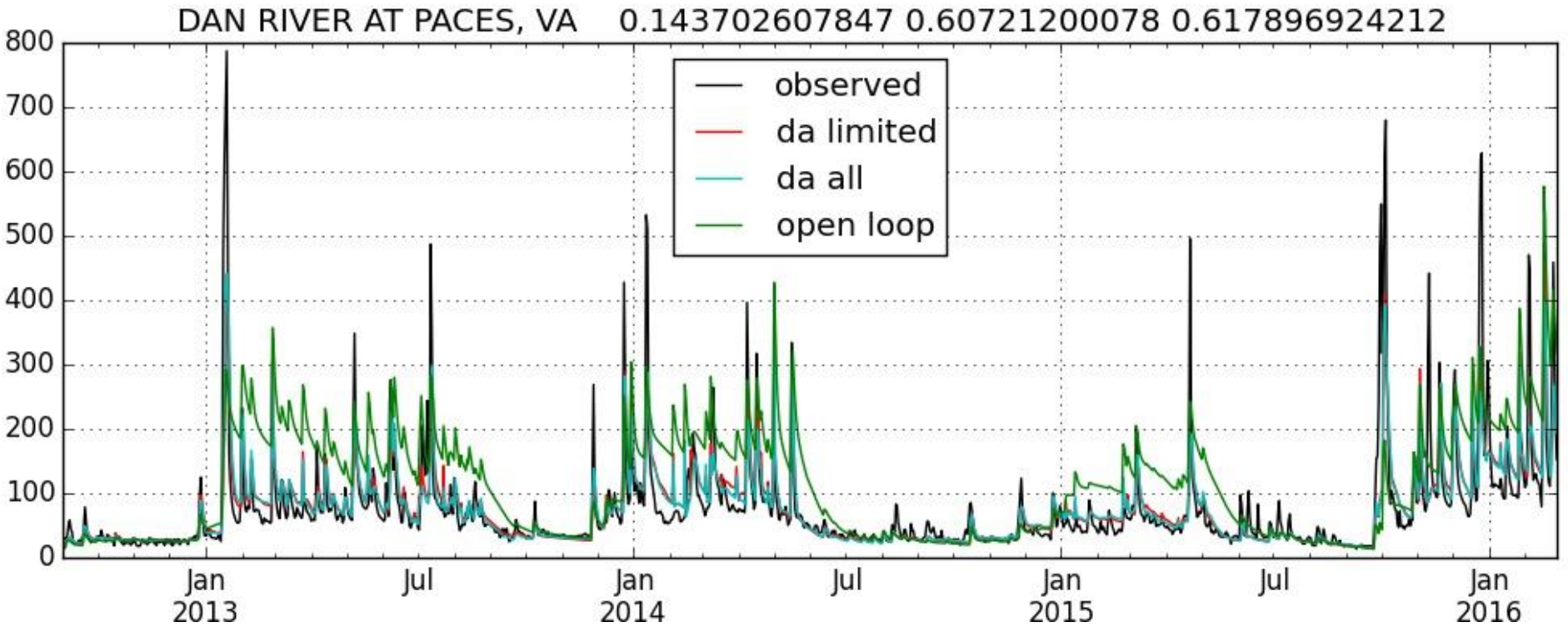
Dan River





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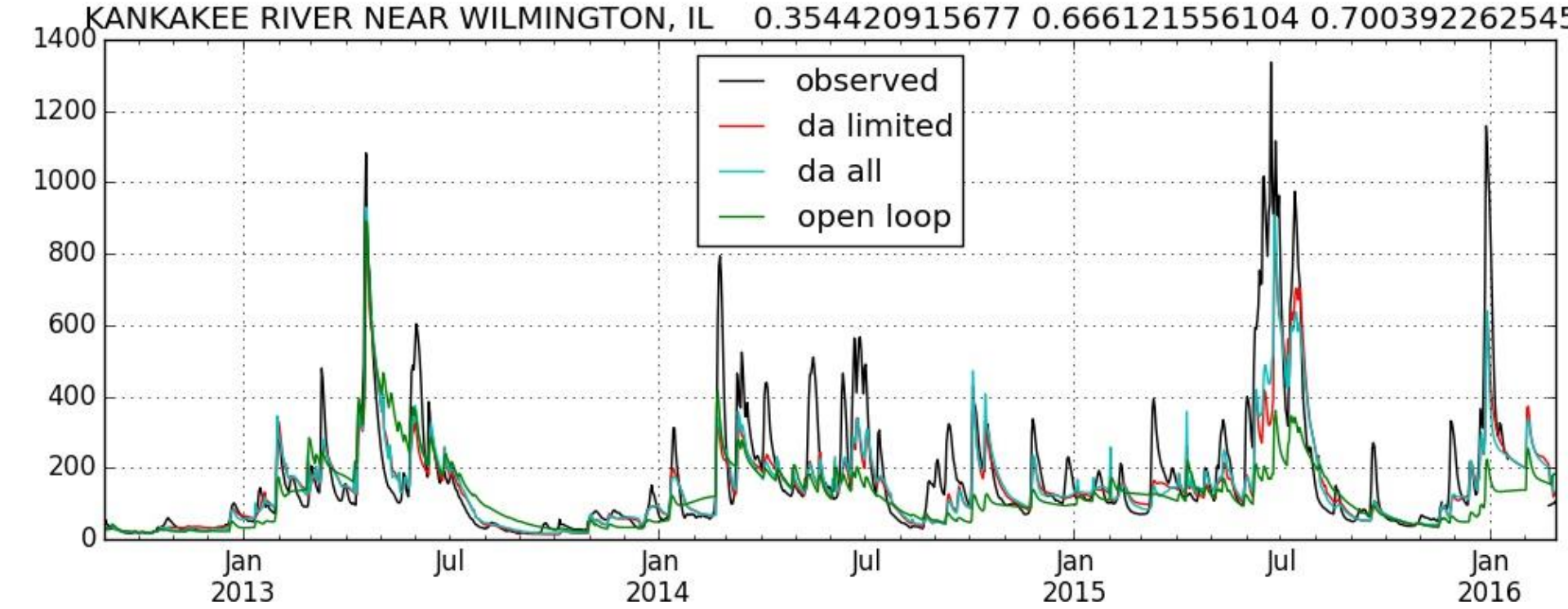
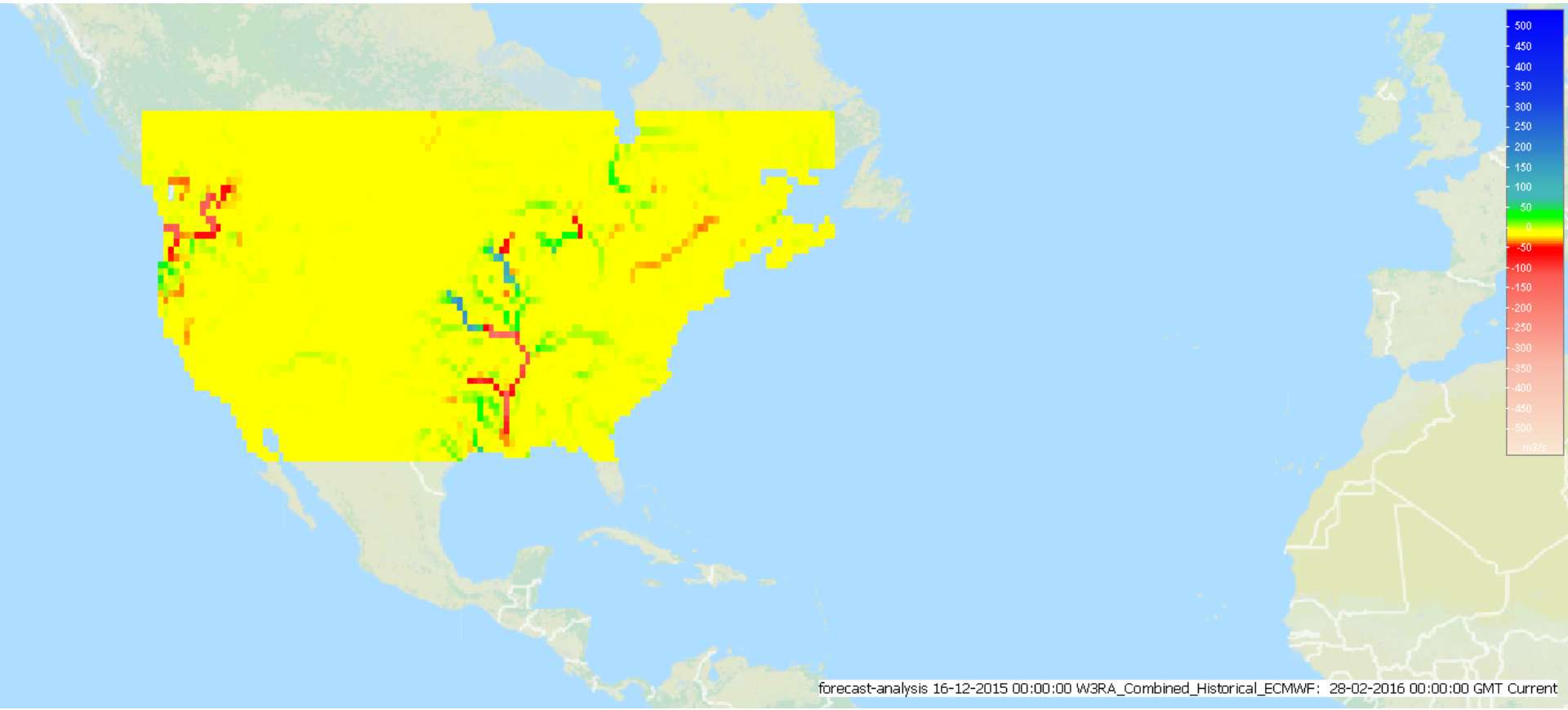
KANKAKEE


KANKAKEE RIVER NEAR WILMINGTON, IL 0.354420915677 0.666121556104 0.700392262545
observed
da limited
da all
open loop
1400
1200
1000
800
600
400
200
0
Jan
2013
Jul
Jan
2014
Jul
Jan
2015
Jul
Jan
2016

forecast-analysis



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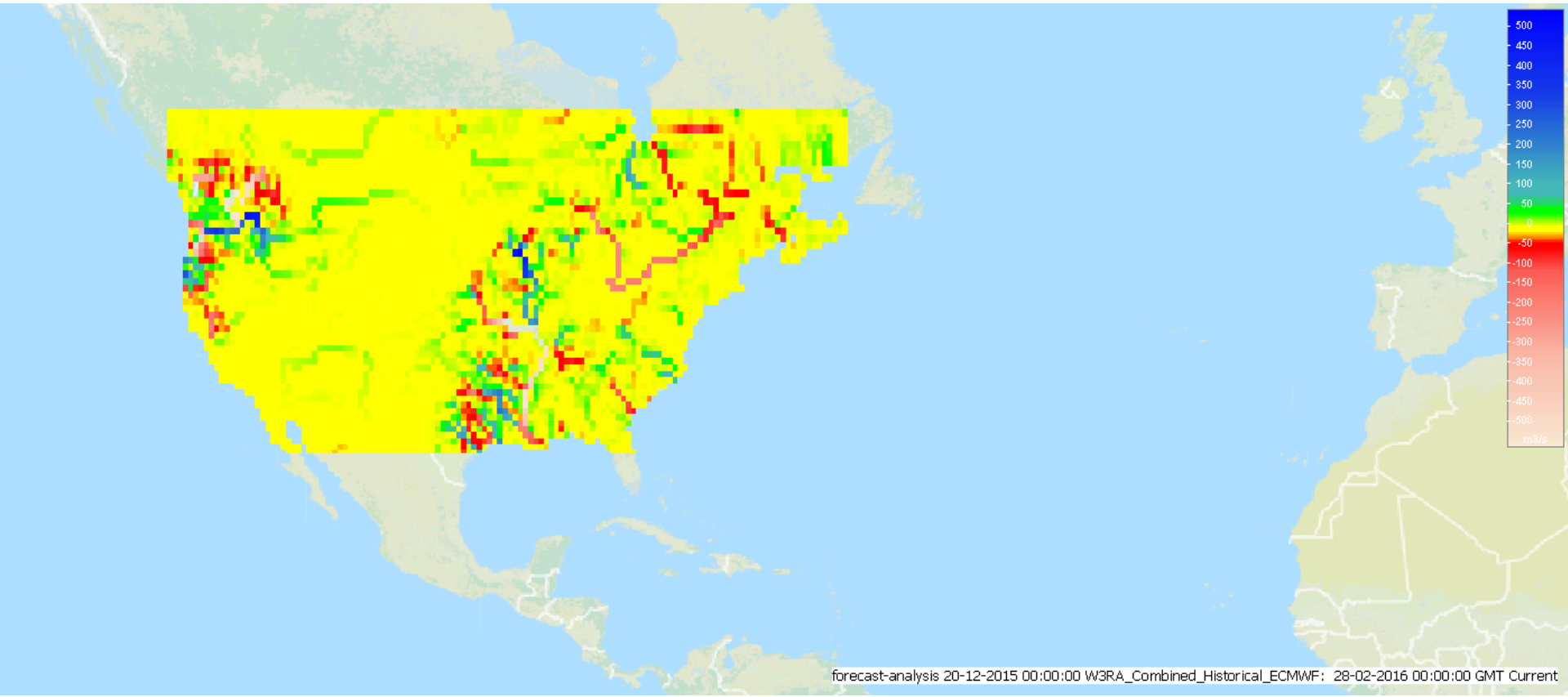
forecast-analysis (summed over 10 days)



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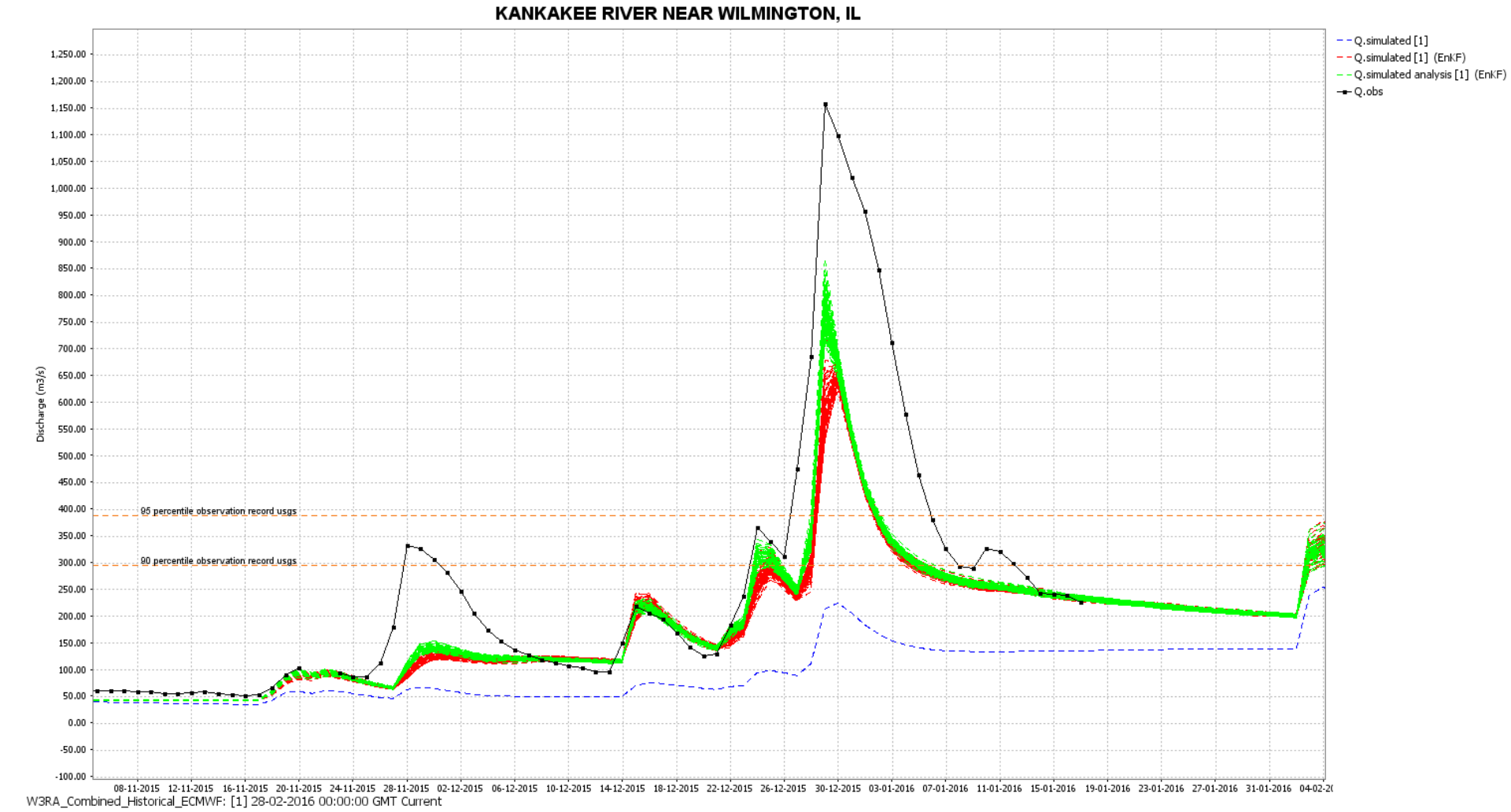
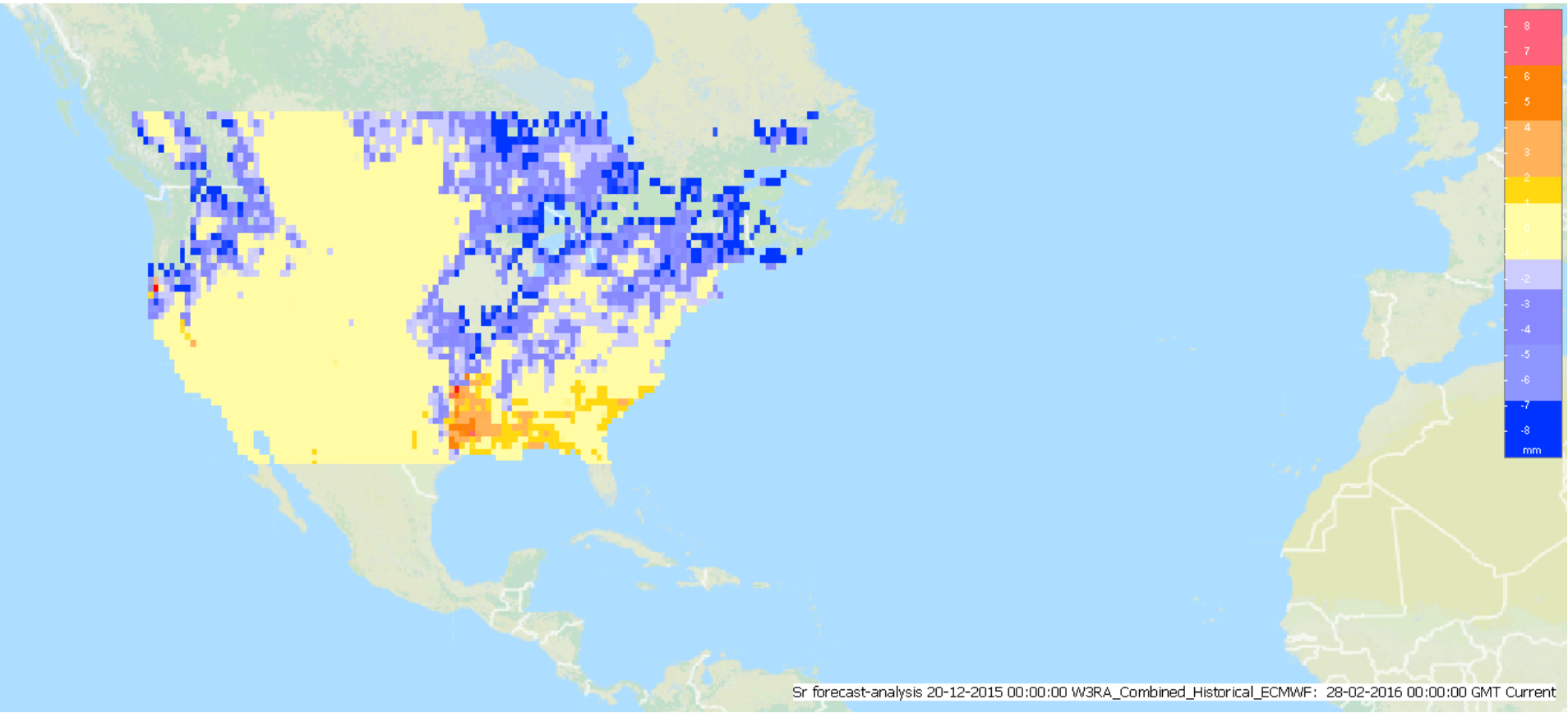
Major flood peak December 2015 (and subsequent state update)



forecast-analysis (Sr=surface runoff store)



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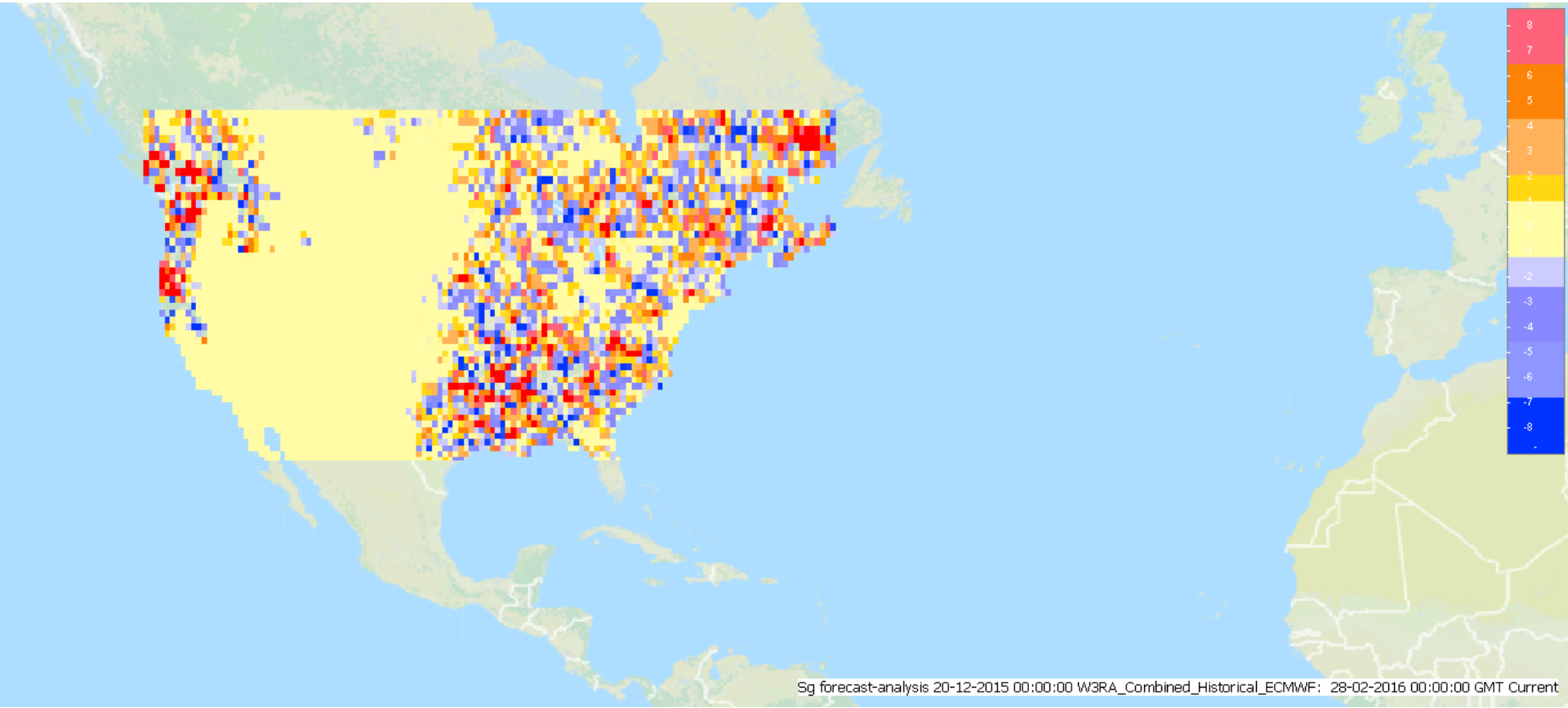
forecast-analysis (Sg = groundwater store)



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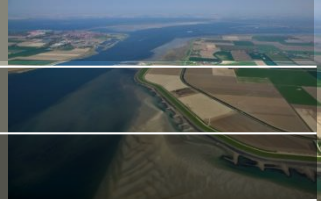
Conclusions



- OpenDA-OpenStreams/wflow is a power full (open source) tool for hydrological modelling, forecasting and DA
- Simultaneous streamflow DA is possible also over multiple catchments and at continental scale
- Localization is needed to avoid spurious correlations
- Without using measured forcing results show improved prediction of streamflows (correcting errors in both forcing and model)
- Inclusion of reservoirs in model will further improve results and add new possibilities for updating (water level reservoirs)
- For this case snow measurements may be needed to constrain build up of unrealistic snow packs

- AEnKF to be tested
- Model to be upgraded to 0.05 degree

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