Modeling in aquatic environment

Lecture 10

Data assimilation and data fusion in models

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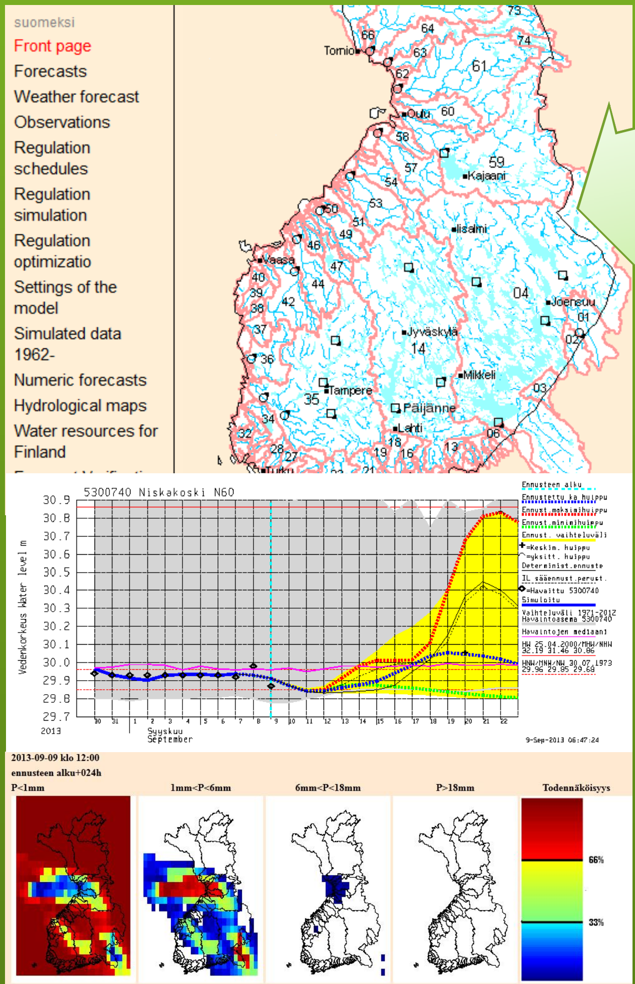
http://www.ymparisto.fi/syke/jyvaskyla

User and operator interface (mobile)

http://wsfs.vyh.fi



Full system control

HYDROLOGICAL MODELING AND FORECASTING SYSTEM

All products and system information

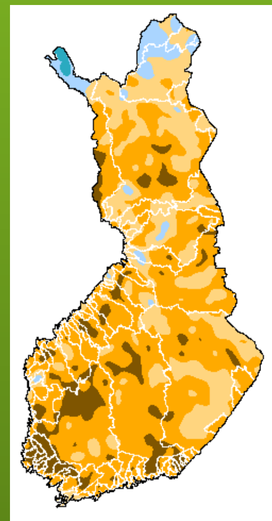
Automatic forecasts and maps

Water situation description

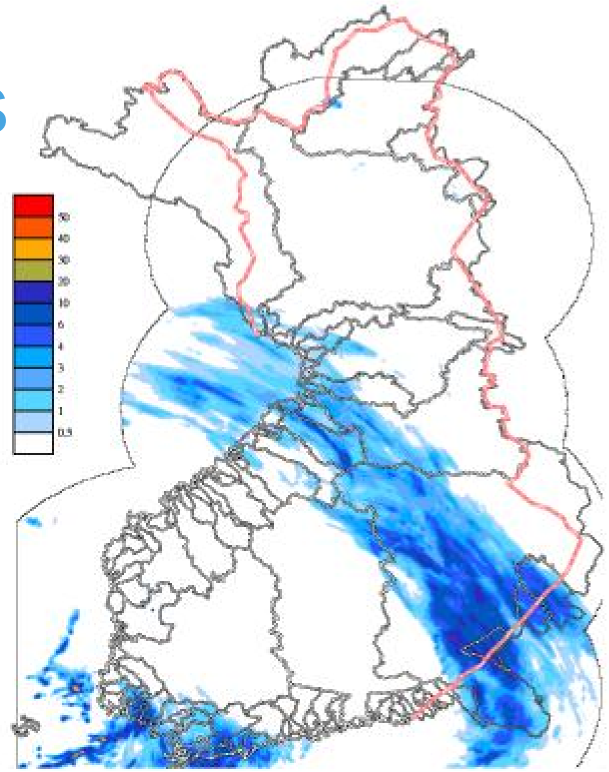
Public www

River discharges are low throughout the country

River discharges have decreased during sunny and dry period. Only light rains are forecasted so discharges will stay low…



Weather radar and LAPS in WSFS



Cumulative precipitation sum (mm) UTC 201309020000-201309020800.

Weather radar

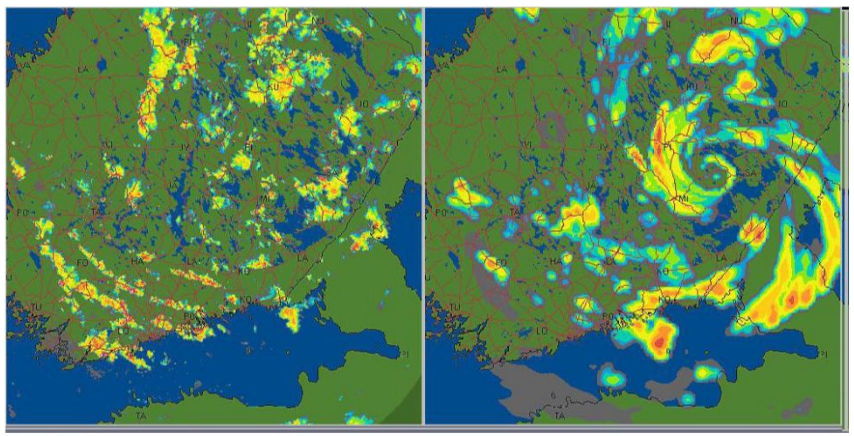
- Hourly radar data in 2x2km grid
- Used for 2 days in model
- Underestimates large rainfalls
  - Corrected manually against rain gauges

Radar nowcasting

- 3hrs in Southern Finland
- Ensamble of 50 members

LAPS

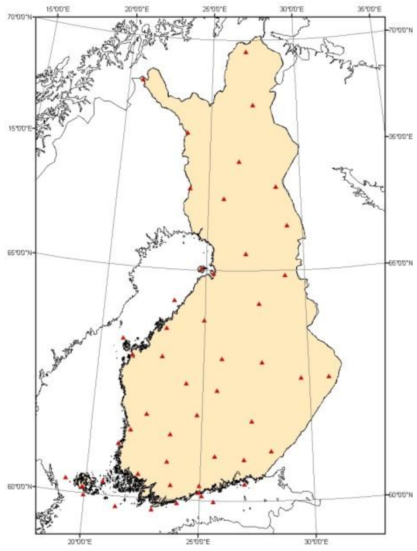
- Combines information from weather radar, automatic real-time rain gauges, road weather measurements, …
- Will probably be used in WSFS as a weather radar replacement in near future



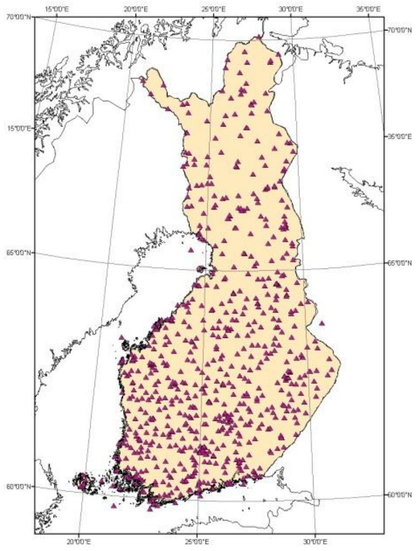
Realtime and historical hydrometeorological and nutrients observations (1/4)

Observation networks

- Automatic realtime precipitation 1-hour measurements from 100 stations
- 380 discharge stations
  - 220 with daily measurements
  - 160 external stations with usually daily measurements
- 660 water level stations
  - 400 with daily measurements
  - 260 external stations with usually daily measurements
- Snow courses
  - 140 montly measurements
- Water quality measurements



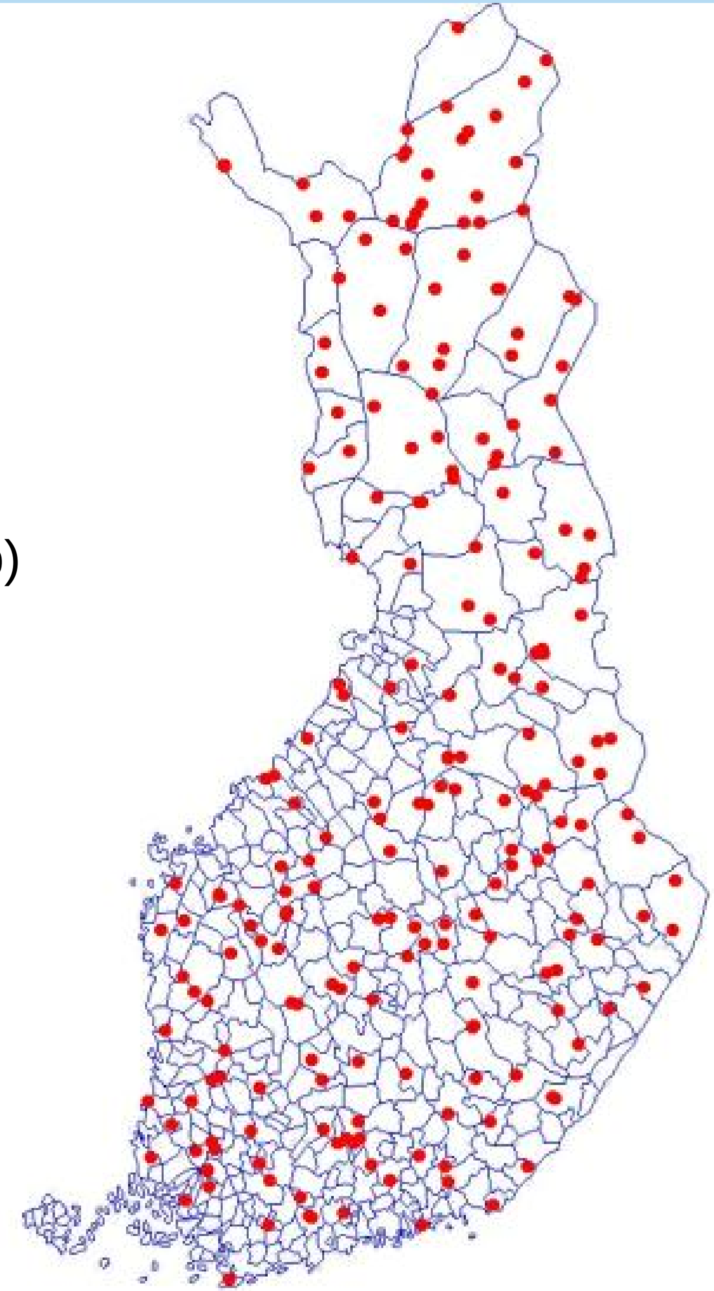
Synoptic weather stations, 50 daily measurements



Other weather stations, 200 daily measurements

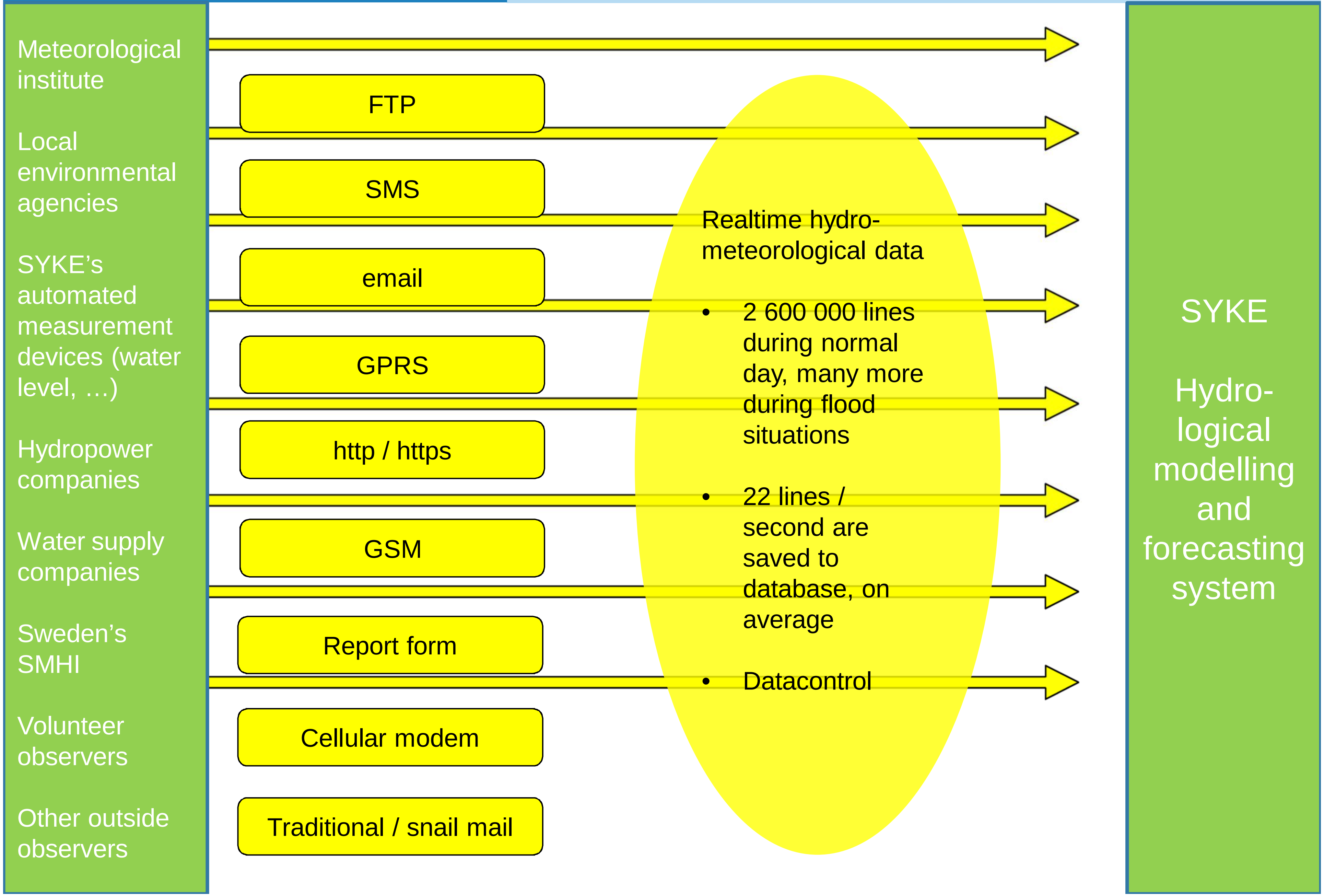
Measuring the snow water equivalent

- Snow water equivalent is measured by snow course measurements
  - About 140 snow courses in Finland (less than what is shown at the map)
- Areal snow water equivalents are calculated for approximately 110 areas
- Snow courses are 2-4 km long routes through various terrains
  - 80 depth measurements
  - 8 manual weightings
- Measurements are made once or twice a month



Measuring the snow water equivalent

Realtime and historical hydrometeorological and nutrients observations (4/4)



Data assimilation and control (1/6)

Manual measurements

- Manual river discharge measurement
- Manual precipitation observations
- Snow line measurements

Automatic observations

- Automatic river water level observation
- Automatic precipitation observations
- Snow depth from automatic stations

Derived results / algorithmic data

- Weather radar precipitation
- Wind corrected precipitation observations
- ”Near-by-complemented” precipitation observations
- Satellite value for snow water equivalent
- Interpolated snow water equivalent

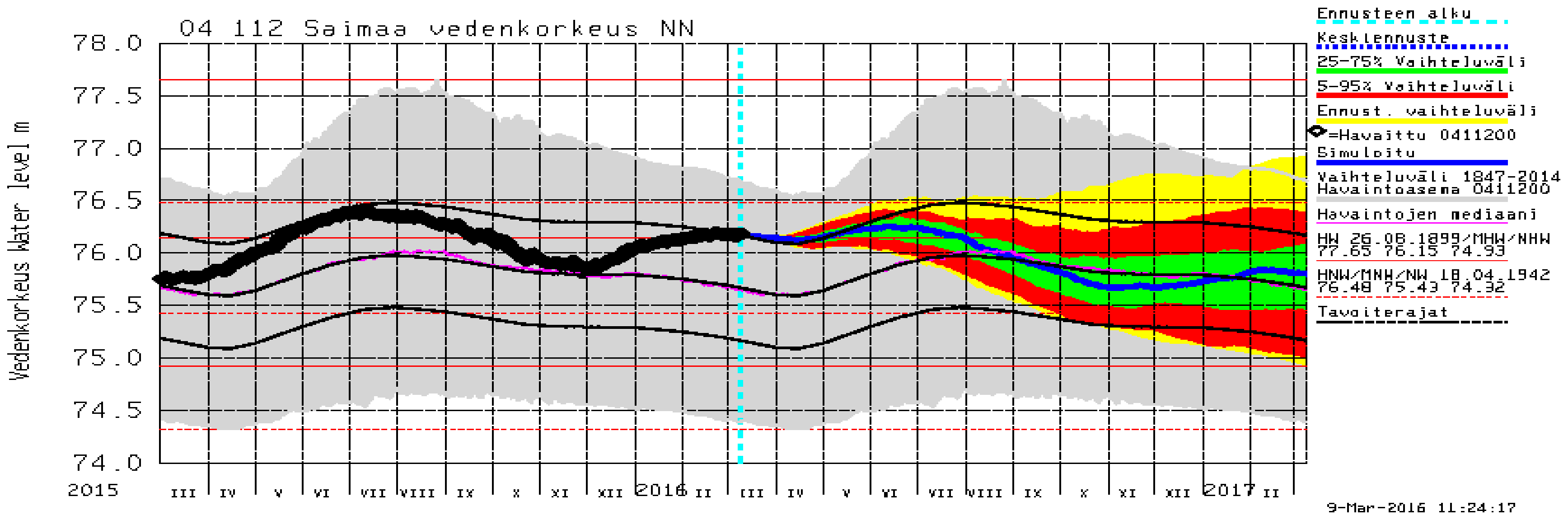
Simulations

- Areal precipitation
- Runoff, discharge, water level, soil moisture, …
- Areal precipitation corrected to match water balance
- Snow water equivalent, snow depth, ground frost depth
- Ice thickness

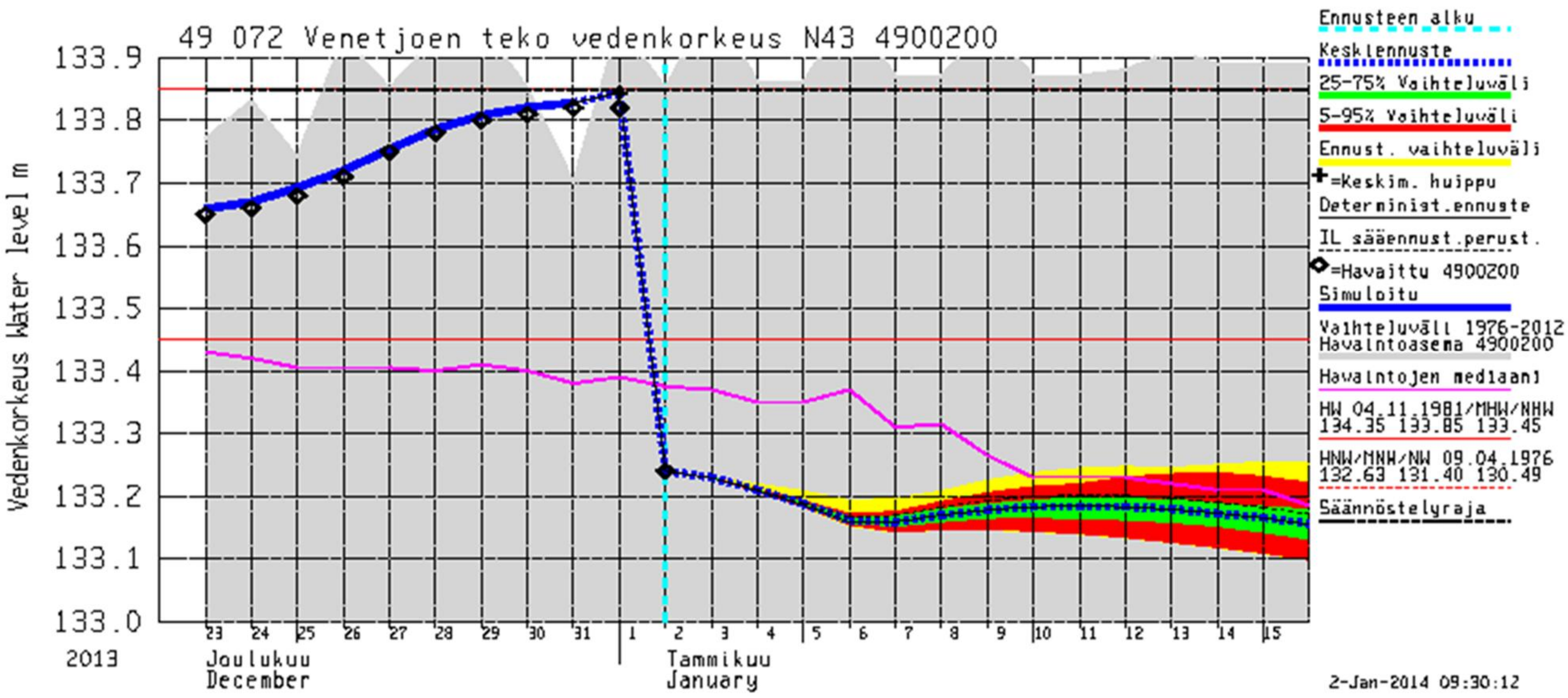
Observed data — Calculated data

Data assimilation algorithm

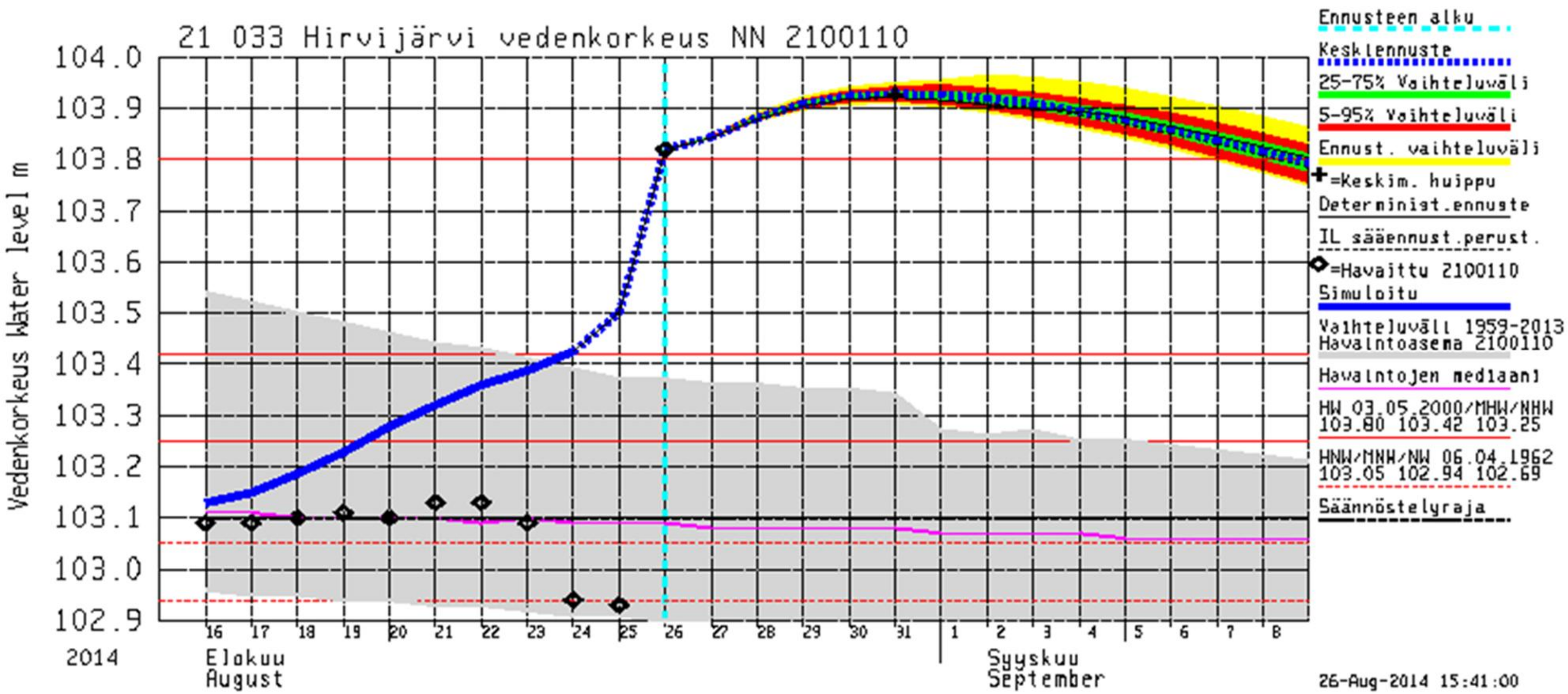
- To estimate the state of the hydrological system today
- Assimilation observations of:
  - discharge and water levels (over 400 stations)
  - snow water equivalent (over 150 stations)
  - SnowCoverArea satellite data
  - flood cover area (experimental)
- Corrects inputs of the model (daily precipitation and temperature)
- Simulation is corrected to agree with observations on a 1-2 year long period backward



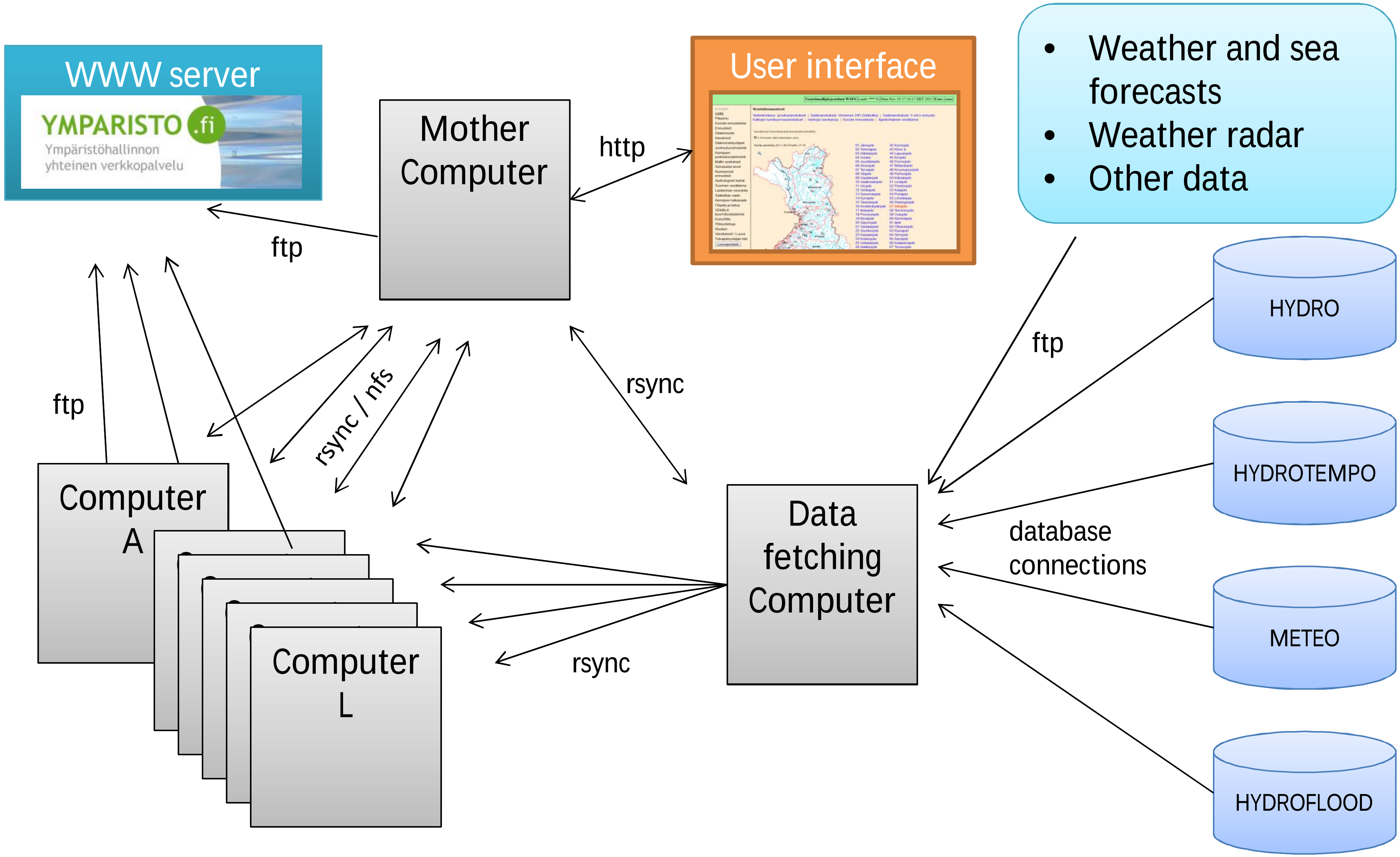
Example: forecast gone wrong when data is not filtered



Example: forecast gone wrong when data is not filtered



Data transfers in Watershed Simulation and Forecasting System



Data Control State Machine

State: UNKNOWN (at the beginning)

U_AO (accept observ.)
→ U_FO

U_FO (fetch observ.)
→ U_RF

U_RF (read flag)
- ACCEPTABL. → U_AO
- REVISED → O_AO
- SUSPICIOUS → U_AO
- NULL → O_AO

State: OK

O_AO (accept observ.)
→ O_FO

O_FO (fetch observ.)
→ O_RF

O_RF (read flag)
- ACCEPTABLE → O_AO
- REVISED → O_AO
- SUSPICIOUS → O_TR
- NULL → O_TR

O_TR (test rejection)
- PASS → O_TS
- FAIL → D_FO

O_TS (test suspicion)
- PASS → O_AO
- FAIL → S_AO

State: DISCARD

D_AO (accept observ.)
→ D_FO

D_FO (fetch observ.)
→ D_RF

D_RF (read flag)
- ACCEPTABLE → D_AO
- REVISED → O_AO
- SUSPICIOUS → D_TR
- NULL → D_TR

D_TR (test rejection)
- PASS → D_TS
- FAIL → D_FO

D_TS (test suspicion)
- PASS → O_AO
- FAIL → S_AO

State: SUSPICION

S_AO (accept observ.)
→ S_FO

S_FO (fetch observ.)
→ S_RF

S_RF (read flag)
- ACCEPTABLE → S_AO
- REVISED → O_AO
- SUSPICIOUS → S_TR
- NULL → S_TR

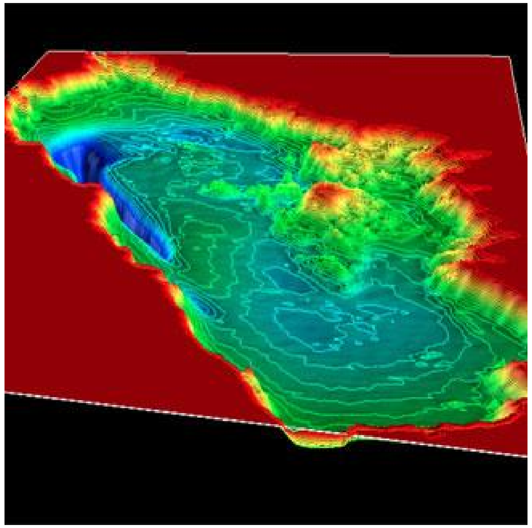
S_TR (test rejection)
- PASS → S_TS
- FAIL → D_FO

S_TS (test suspicion)
- PASS → O_AO
- FAIL → S_AO

Wind data assimilation to Coherens (Shuku&Suito)

Local wind fields strongly impact on water current fields (Suito et al., 2014)

Coupled simulations between air flow and water flow are recommended



(http://www.ems.okayama-u.ac.jp/suito/)

- Time consuming
- Complex (Confusing)

How should we deal with the dilemma?

Water Science & Technology

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Assimilation of satellite data to 3D hydrodynamic model of Lake Säkylän Pyhäjärvi

Akiko Mano, Olli Malve, Sampsa Koponen, Kari Kallio, Antti Taskinen, Janne Ropponen, Janne Juntunen, Ninni Liukko

Published April 2015, 71 (7) 1033-1039; **DOI: 10.2166/wst.2015.042**

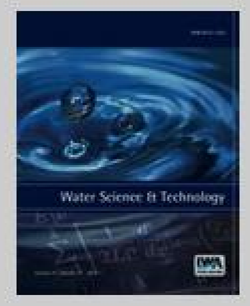
Article | Info & Metrics | Data | PDF

Abstract

To analyze the applicability of direct insertion of total suspended matter (TSM) concentration field based on turbidity derived from satellite data to numerical simulation, dispersion studies of suspended matter in Lake Säkylän Pyhäjärvi (lake area 154 km^2; mean depth 5.4 m) were conducted using the 3D COHERENS simulation model. To evaluate the practicality of direct insertion, five cases with different initialization frequencies were conducted: (1) every time, when satellite data were available; (2) every 10 days; (3) 20 days; (4) 30 days; and (5) control run without repeated initialization. To determine the effectiveness of initialization frequency, three methods of comparison were used: simple spatial differences of TSM concentration without biomass in the lake surface layer; averaged spatial differences between initialization data and the forecasts; and time series of TSM concentration and observation data at 1 m depth at the deepest point of the lake. Results showed that direct insertion improves the forecast significantly, even if it is applied less often.

First received 14 March 2014.

SELECTED ISSUE



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FRESHWATER CENTRE

Data and methods

- Models
  - COHERENS V2(Luyten, 2011)
- Open boundary conditions at 3 river mouths:
  - River discharge (observation extracted from Hertta data base of the Finnish Environmental Administration)
  - Temperature (model results provided by VEMALA*)
  - Total suspended sediment (observation interpolated by linear function)
- Surface data
  - Meteorological data such as wind speed and direction, air temperature, humidity, cloud coverage and air pressure. (observation provided by Finnish Meteorological Institute)

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*VEMALA: the water quality component of the Watershed Simulation and Forecasting System (Vehviläinen B et al., 2005) of the Finnish Environment Institute. This system simulates variables such as the transport of total phosphorus and nitrogen and suspended solids in land area, rivers and lakes. (Huttunen I. et al., 2008).

Huttunen I, Huttunen M, Tattari S, Vehviläinen B. 2008. Large scale phosphorus load modelling in Finland. In Northern Hydrology and its Global Role, Volume 2, Sveinsson ÓGB, Garðarsson SM, Gunnlaugsdóttir S (eds). XXV Nordic Hydrological Conference 2008. NHP Report No. 50. Icelandic Hydrological Committee: Reykjavik; 548-556.

Vehviläinen B, Huttunen M, Huttunen I. 2005. Hydrological forecasting and real time monitoring in Finland: The watershed simulation and forecasting system (WSFS). In Innovation, Advances and Implementation of Flood Forecasting Technology, Conference Papers, Tromsø, Norway, 17–19 October 2005.

S Y K E

FRESHWATER CENTRE
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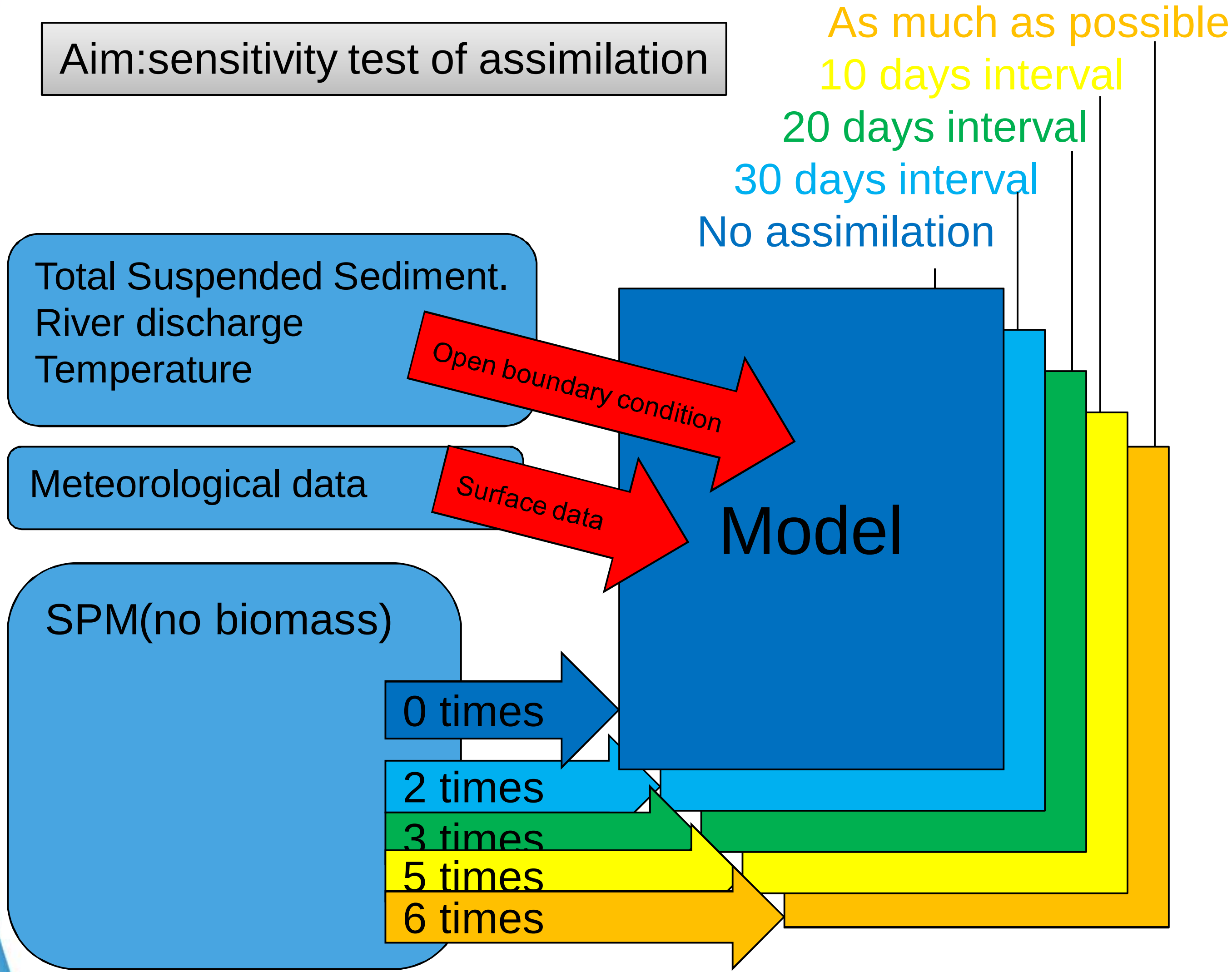
Objective

Aim:sensitivity test of assimilation



SYKE

Tested cases and initialization timing

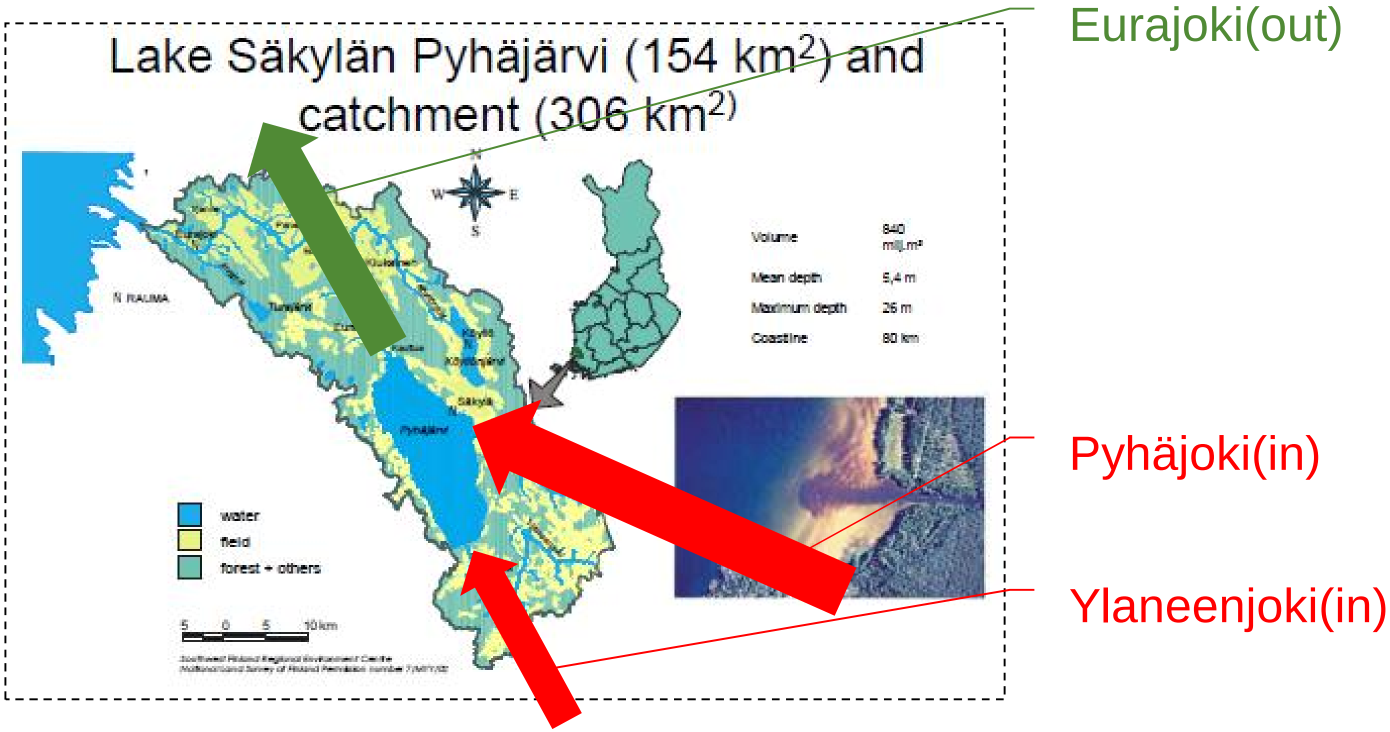
To evaluate the practicality of the assimilation (direct insertion) of the model, five model runs (1–5) were performed using different initialization frequencies: (1) every time, when satellite data were available; (2) every 10 days; (3) 20 days; (4) 30 days; and (5) the control run without repeated initialization (except for the initialization on 16 May 2009). The initialization timings were at noon on: (1) June 1, 8, 18, 21 and 26 and July 6; (2) June 1, 8, 18 and 26 and July 6; (3) June 1 and 21 and July 6; and (4) June 1 and July 6.

FRESHWATER CENTRE

Taneli Duunari-Työntekijäinen, SYKE

Target area

- Study area



(Reports of Finnish Environment Institute, 2008)

Reports of Finnish Environment Institute 15/2008, 73 p. URN:ISBN: 987-952-11-3125-7 ISBN: 987-952-11-3125-7 (PDF).Vehviläinen B, Huttunen M, Huttunen I. 2005. Hydrological forecasting and real time monitoring in Finland: The watershed simulation and forecasting system (WSFS). In Innovation, Advances and Implementation of Flood Forecasting Technology, Conference Papers, Tromsø, Norway, 17–19 October 2005.

SYKE

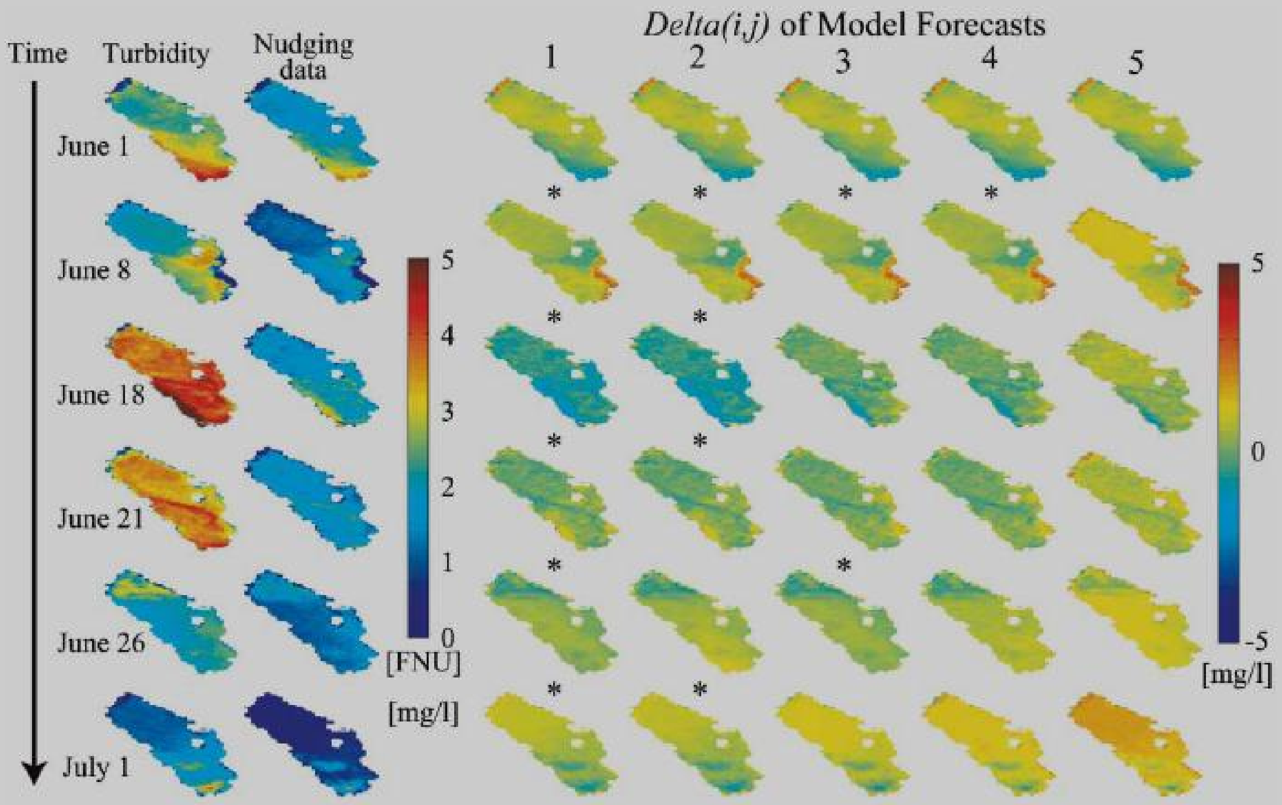
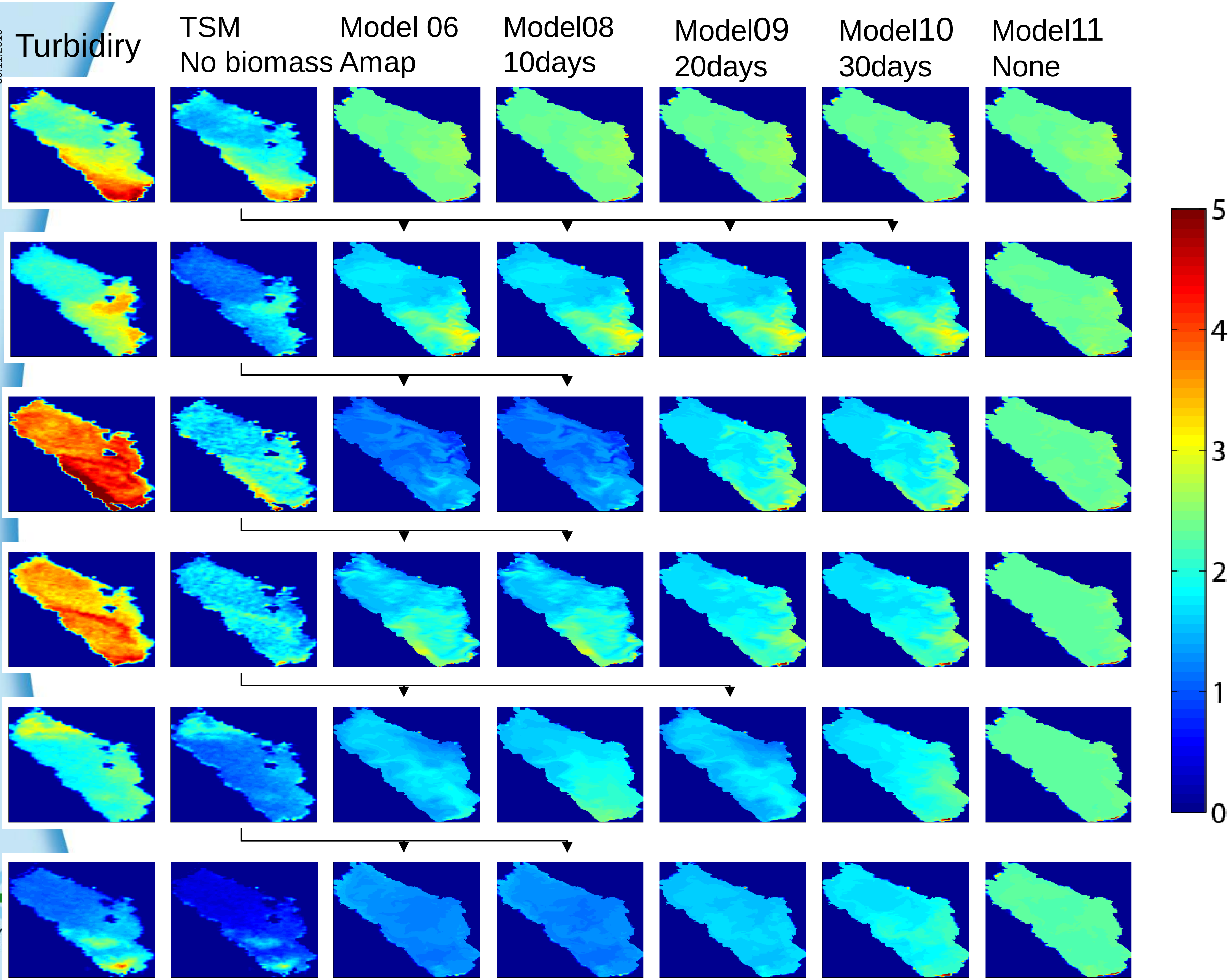


Figure 2 | Comparison of turbidity from satellite data [FNU], TSM concentration without biomass (nudging data regarded as 'true' value) [mg/l] and *delta(i,j)* of model forecasts at the lake surface. The six rows represent dates from June 1 to July 6. The columns are turbidity derived from satellite data [FNU], converted TSM concentration without biomass [mg/l] (nudging data), and five cases of *delta(i,j)* taken with Equation (3) from left to right: every time that satellite data were available (1); every 10 days (2); 20 days (3); 30 days (4); and control run without repeated initialization (5). The initialization timings are shown with asterisk (*) symbols below each figure of *delta(i,j)*.



Turbidiry
TSM
No biomass
Model 06
Amap
Model08
10days
Model09
20days
Model10
30days
Model11
None
6/1
6/8
6/18
6/21
6/26
7/6
5
4
3
2
1
0

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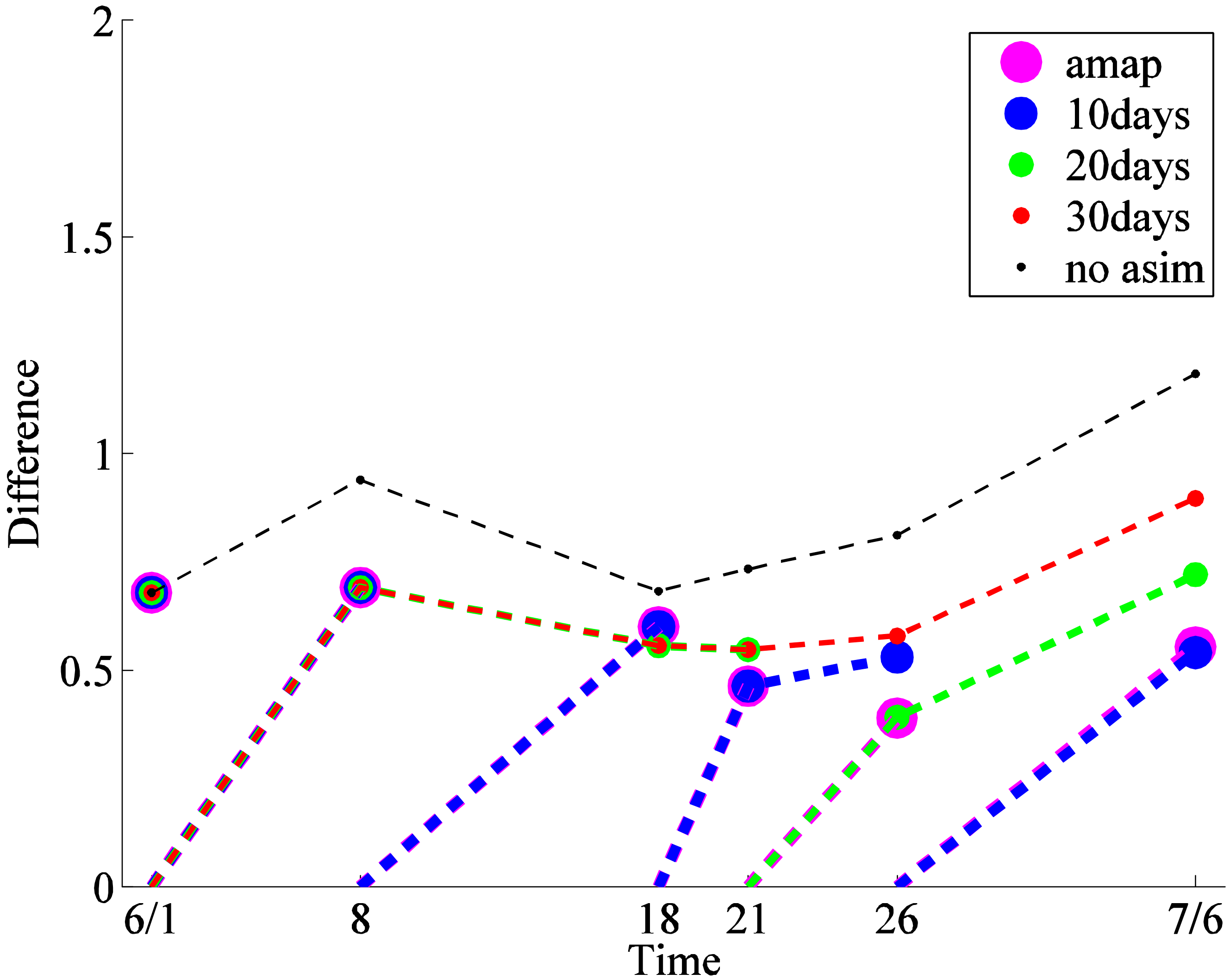
Results



S Y K E

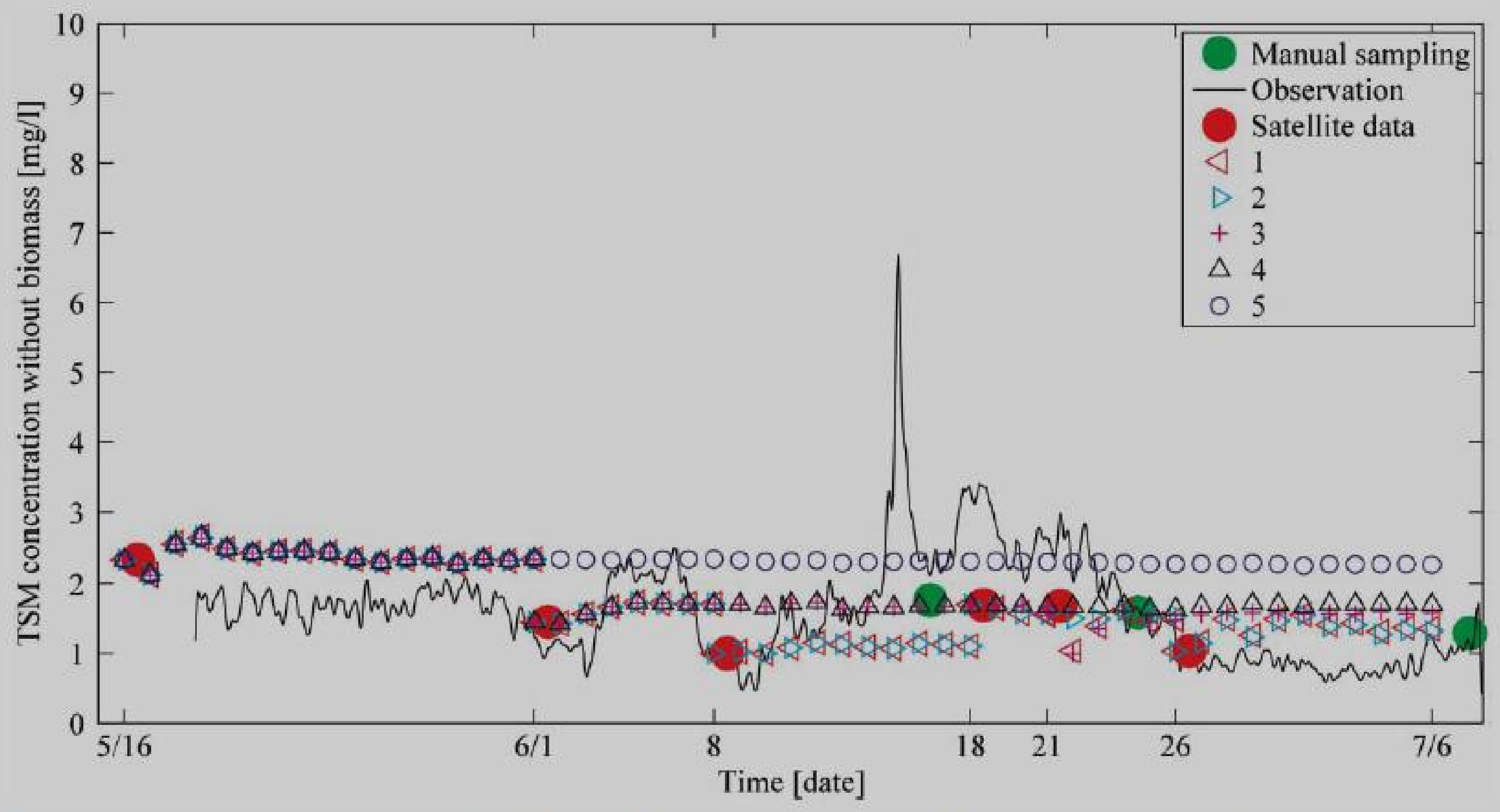


Figure 4 | Time series of TSM concentration without biomass at 1.0 m depth at the deepest point comparing the forecasts with observations measured by automatic station and by manual sampling. Values were averaged from nine grids around the point. Green dots represent manual sampling converted from turbidity. The black line represents the automatic station converted from monitored turbidity using Equation (1), the same equation used to obtain the nudging data. Red dots are from satellite data (nudging data). The full colour version of this figure is available online at http://www.iwaponline.com/wst/toc.htm.

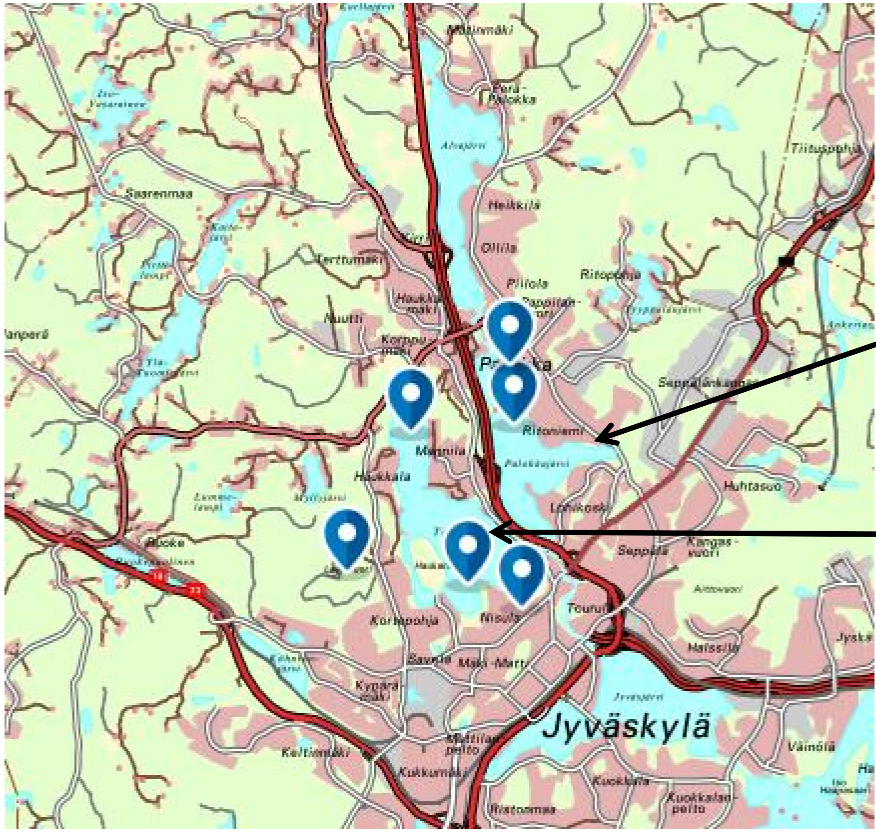
This paper demonstrates that the predictive performance of a coupled circulation-sediment model can be notably improved by incorporating satellite data, even if the used sediment model and assimilation method are simple and its parameterization of sediment transport is not exhaustively calibrated, as only the sinking velocity is calibrated at a single observation point. This is also true when direct insertion is applied less often, such as the interval of 30 days. In particular, the 10-day period shows values of Forecast RMSE increases that are smaller when compared to situations where no simulation is used at all.

For usability, until the necessary modules are implemented and until the demanding calibrations have been done, direct insertion can obtain more realistic forecasts of lake water quality. Future studies should be performed carefully to examine considerations of the possibilities of using satellite-based bathymetrical data and detailed sedimentation processes. Such studies can enrich our experience in using more sophisticated data assimilation methods.

Observation Station

Meteorological data

→ wind direction, wind speed, temperature, humidity



Palokkajärvi

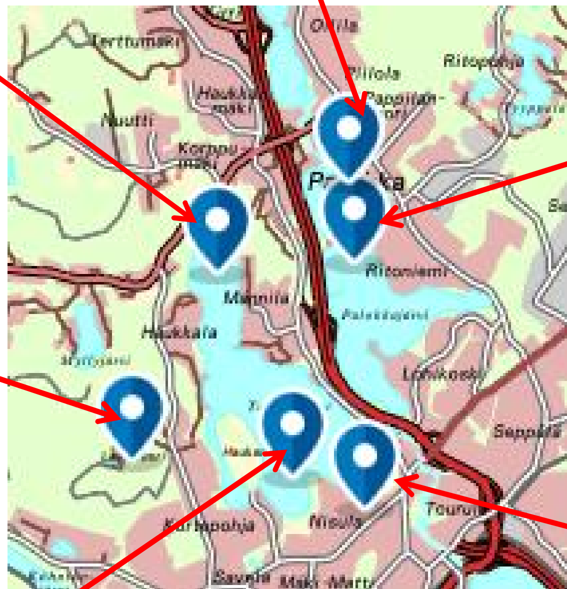
Tuomiojärvi

Observation Station

Palokka

Ranta-Niemela

Kaijala



Laajavuori

JEnergia

Lehtisaari

Temporal Modeling

- Auto-Regressive (AR) Model

$$y_n = \sum_{i=1}^{m} a_i y_{n-i} + v_n$$

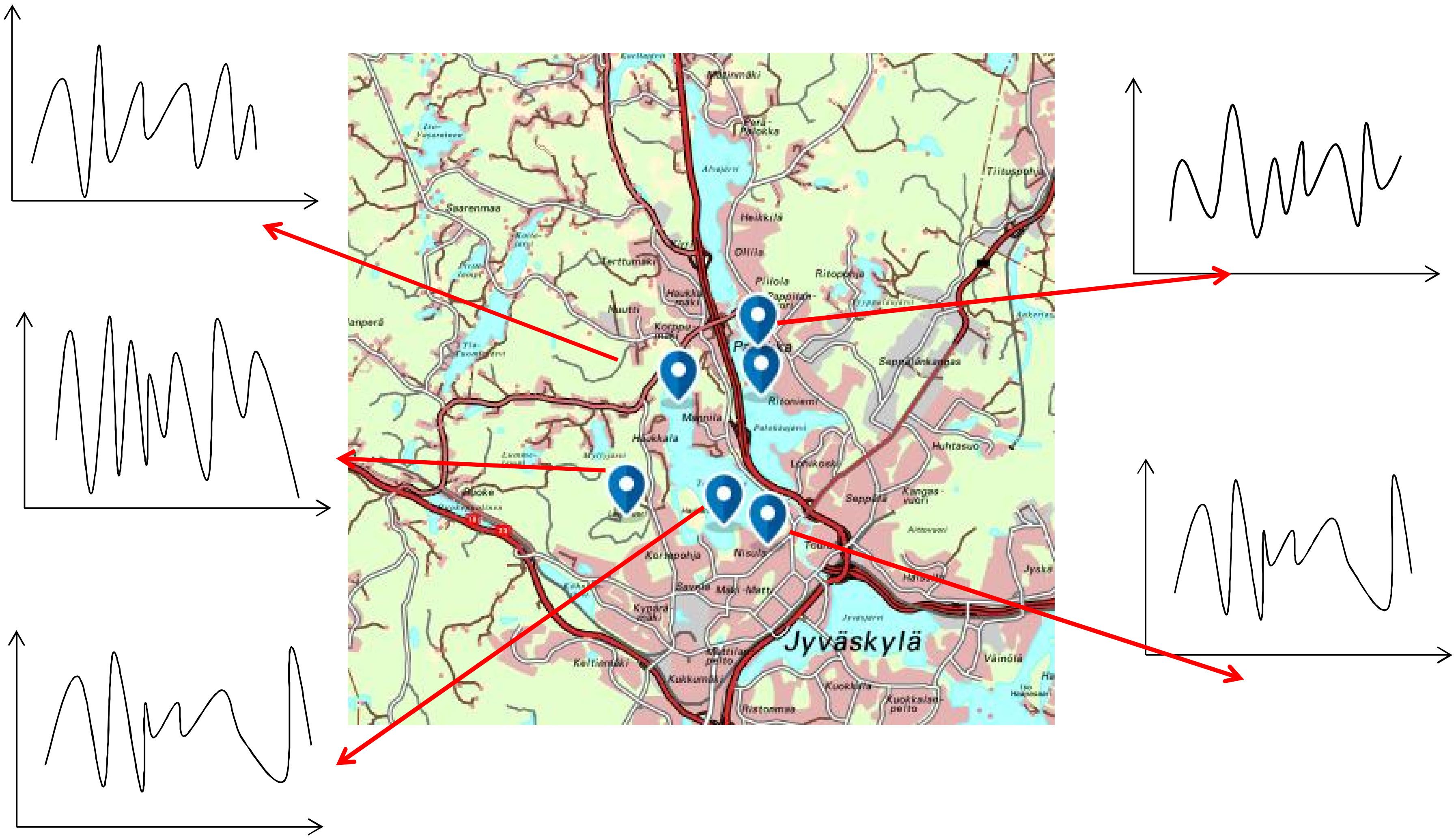
- y_n : n^{th} time-series data
- a_i : i^{th} AR coefficient
- v_n : white noise
- m : autoregressive order

<Yule-Walker method>

$$\begin{bmatrix} \hat{C}_0 & \hat{C}_1 & \cdots & \hat{C}_{m-1} \\ \hat{C}_1 & \hat{C}_0 & \cdots & \hat{C}_{m-2} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{C}_{m-1} & \hat{C}_{m-2} & \cdots & \hat{C}_0 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{bmatrix} = \begin{bmatrix} \hat{C}_1 \\ \hat{C}_2 \\ \vdots \\ \hat{C}_m \end{bmatrix}$$

- $\hat{C}_i$: auto-correlation function
- a_i : AR coefficient

Spatial Modeling



Ordinary Kriging

- System equation

$$\begin{bmatrix} \gamma(y_1 - y_1) & \gamma(y_1 - y_2) & \cdots & \gamma(y_1 - y_n) & 1 \\ \gamma(y_2 - y_1) & \gamma(y_2 - y_2) & \cdots & \gamma(y_2 - y_n) & 1 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \gamma(y_n - y_1) & \gamma(y_n - y_2) & \cdots & \gamma(y_n - y_n) & 1 \\ 1 & 1 & 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \\ \mu \end{bmatrix} = \begin{bmatrix} \gamma(y_1 - y_0) \\ \gamma(y_2 - y_0) \\ \vdots \\ \gamma(y_n - y_0) \\ 1 \end{bmatrix}$$

γ : Variogram (auto correlation function)

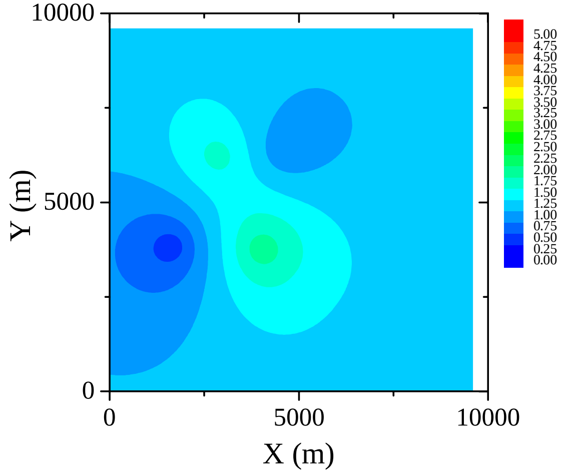
y_0 : Unknown value (wind speed and wind direction)

$y_{i(1\sim n)}$: Known value (wind speed and wind direction)

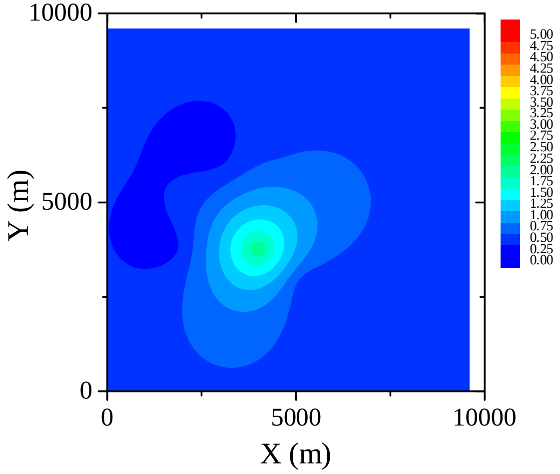
μ : Mean value

w_i : Weight

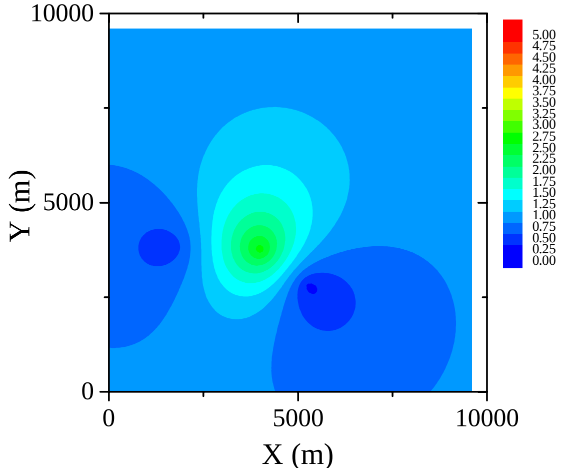
Interpolated data



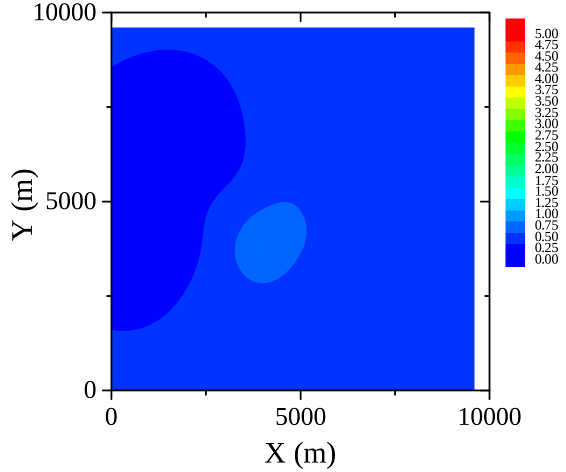
1st August



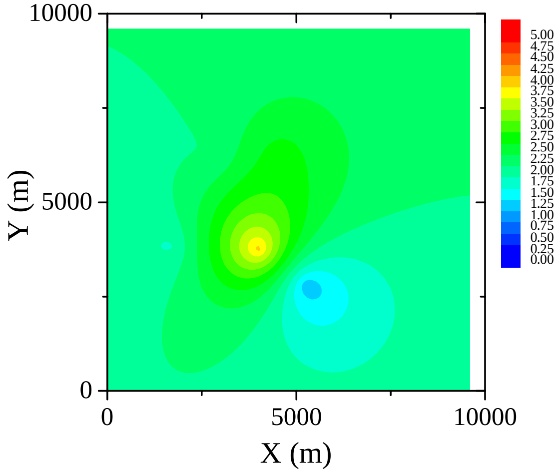
20th August



30th August



10th September



20th September

Estimated local wind field