Do we need to account for lakes in climate and NWP modelling?

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Deutscher Wetterdienst

Why we did this work

From experience we know that lakes are important enough to be considered separately in climate and NWP models, although we haven't quantified their effect before.

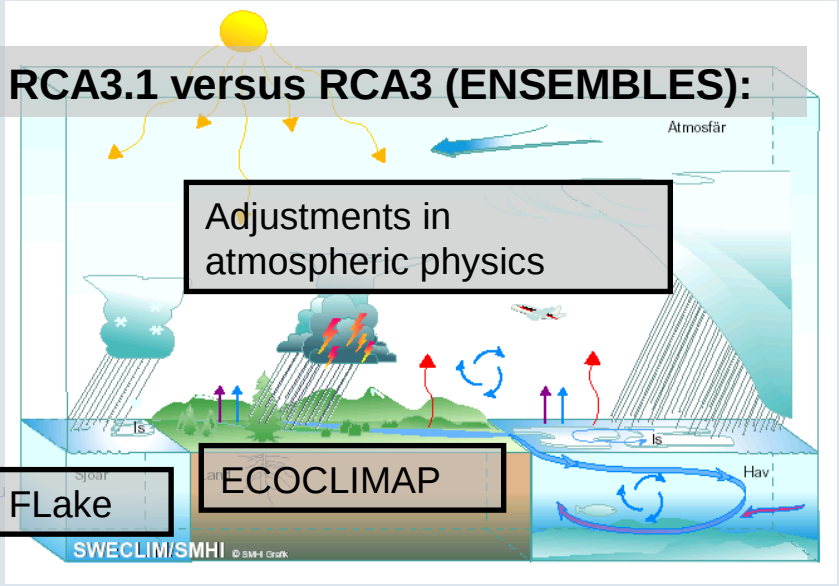
Surface temperature from i.e. ERA40 is not enough as a forcing because lakes do not exist in the surface temperature analysis.

In principal we are not interested in the lake interior as long as we can describe its surface temperature well enough. Thus, a model as simple as possible fulfilling that criteria is the best.

Do we need to account for lakes in climate and NWP modelling?

To answer that question two sets of RCM simulations have been done:

- **RCM:**
  the Rossby Centre Regional Climate Model (RCA3.1)
- **Time period:**
  1961-1990
- **Lateral BC and SST:**
  from ERA40 (ECMWF Reanalysis)



102x111 grid points ~50 km resolution

Lake model FLake used for all inland water

All inland water replaced by land

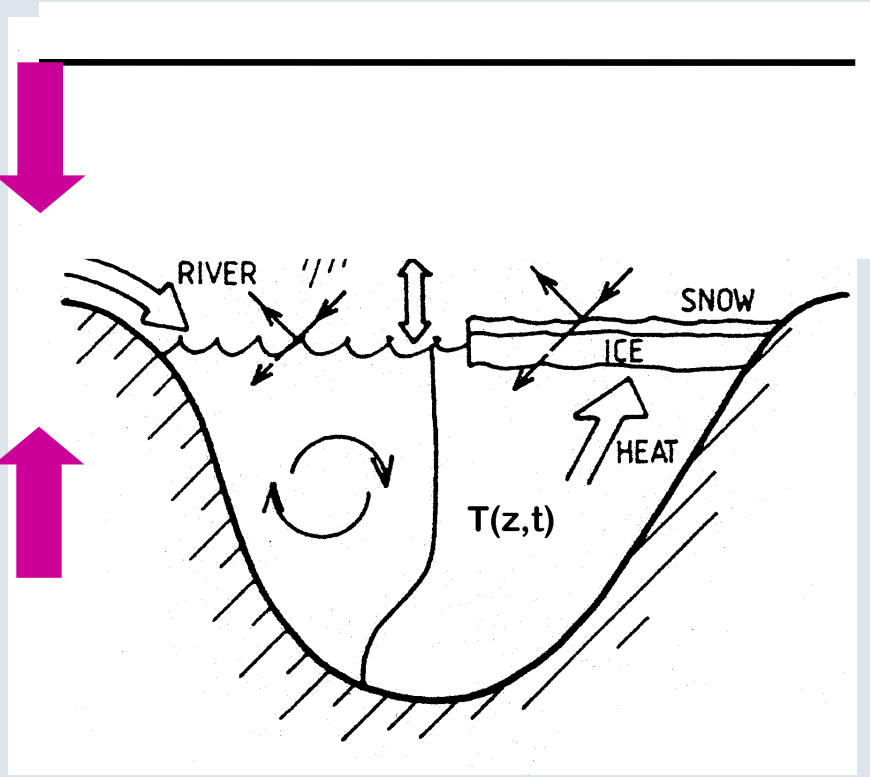
FLake – http://lakemodel.net

Coupling to RCA3.1

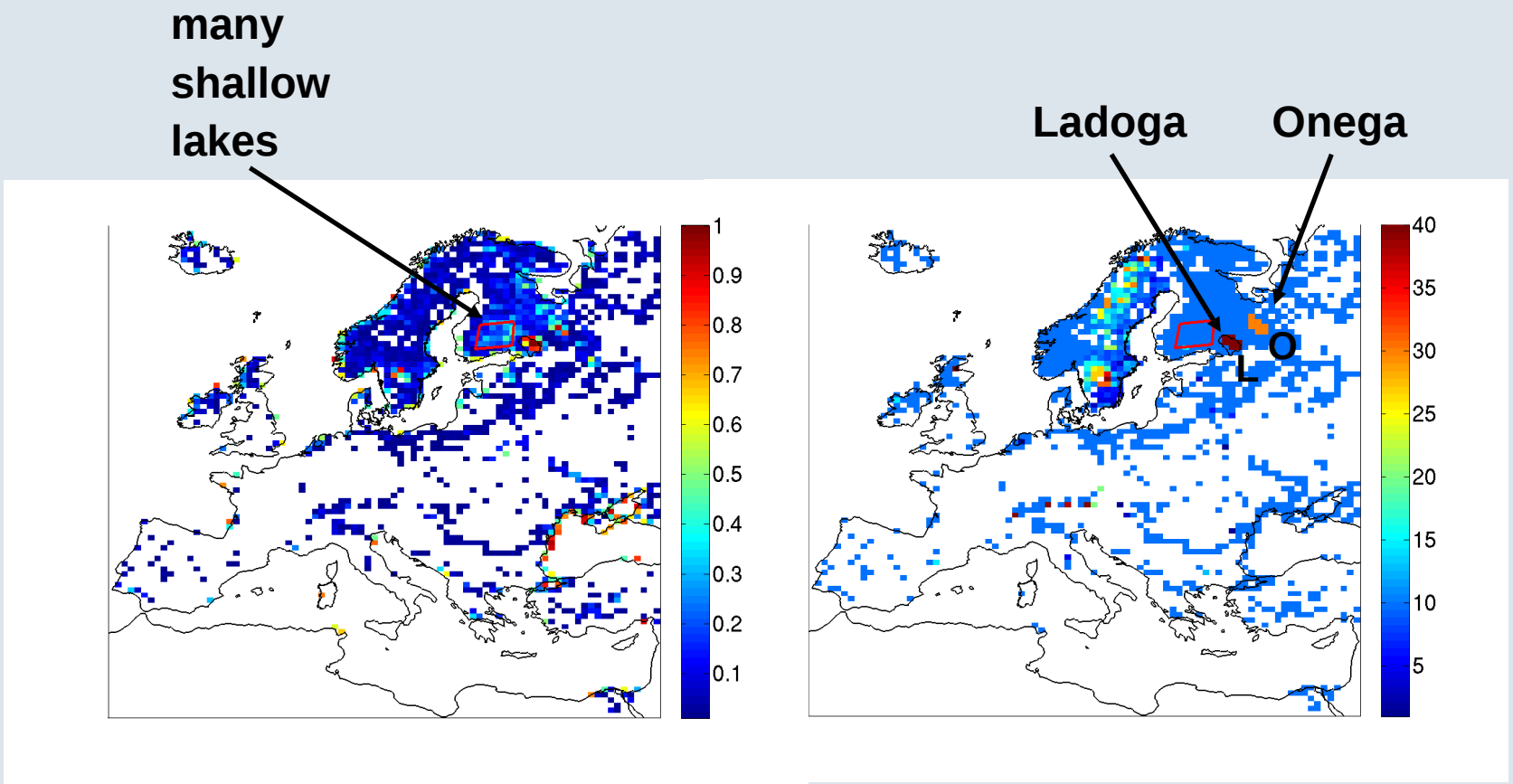
FLake is fully coupled to RCA3.1
(at each time step, 30 min):

RCA3.1 provides:
u,v,q,T,SW↓,LW↓, psurf, precipitation

FLake provides:
turbulent fluxes, albedo
prognostic & diagnostic variables



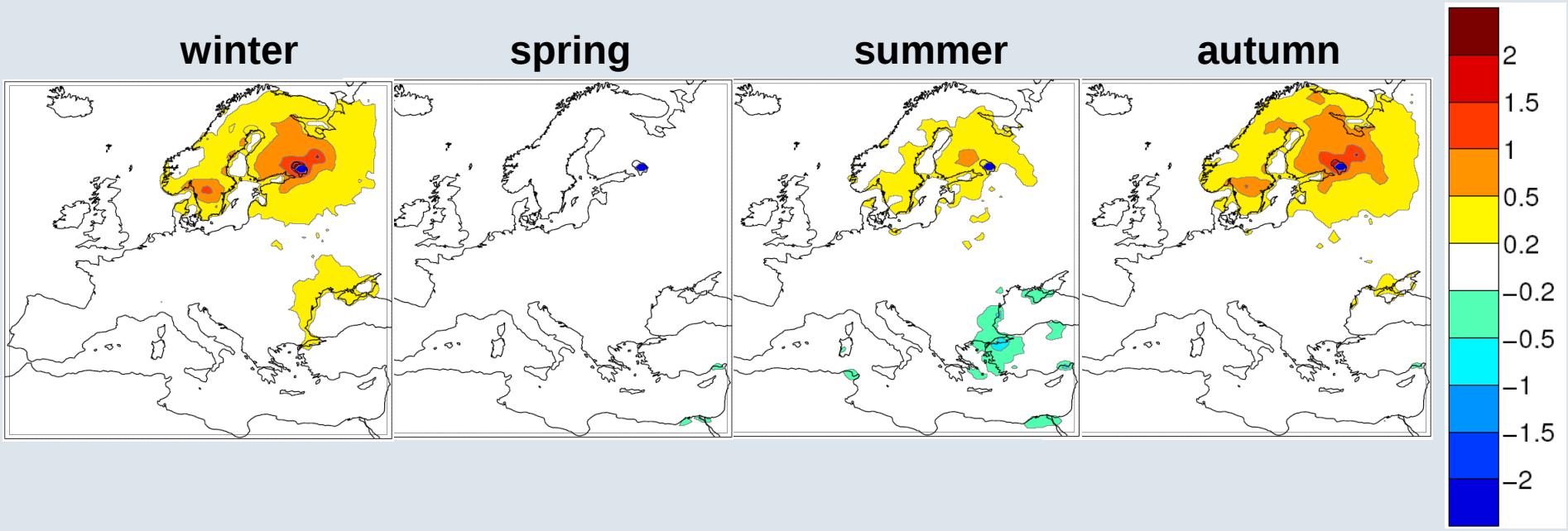
Fraction and depth of lakes in Europe



The coupling allows up to three different categories of lakes in each grid square (shallow, medium and deep lakes).
Now only used for Sweden.
Outside Sweden most lakes are set to 10 m depth.

Lake influence on 2m-temperature

Open land 2m-air-temperature for (lake version) – (no lake version):

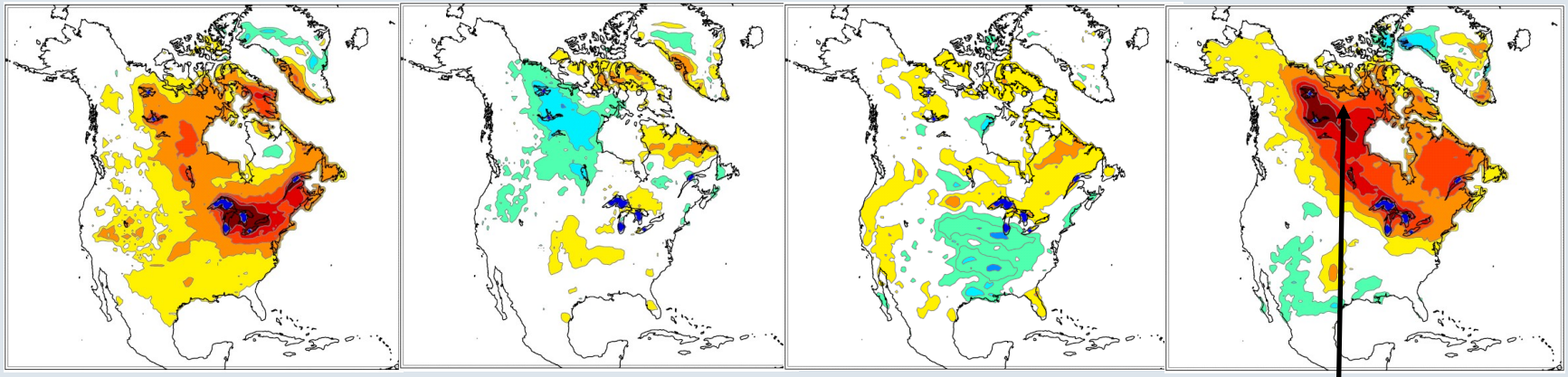


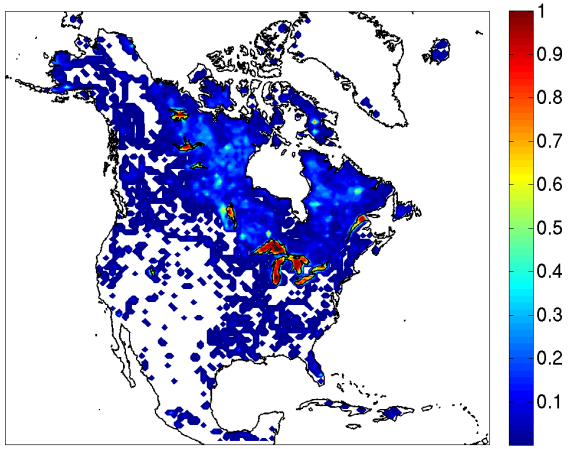
Lake influence on 2m-temperature

North America 1985-1989

Open land 2m-air-temperature for (lake version) – (no lake version):

winter **spring** **summer** **autumn**

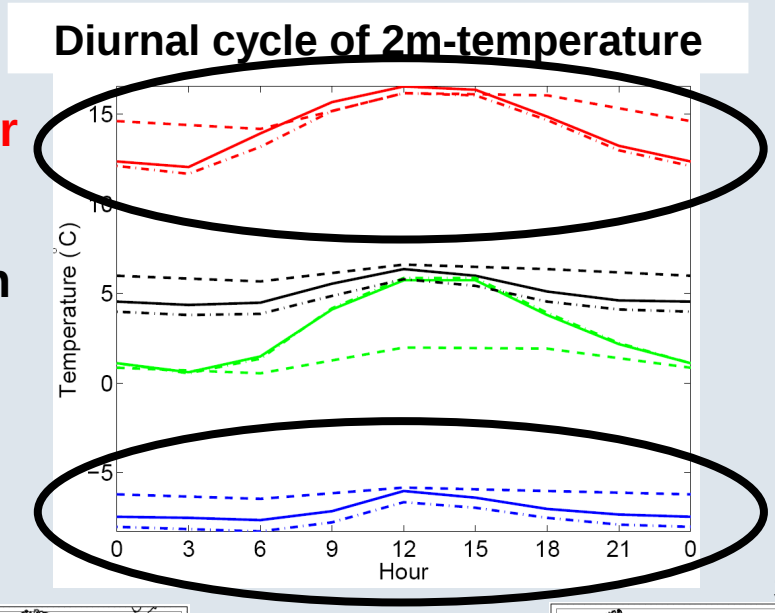


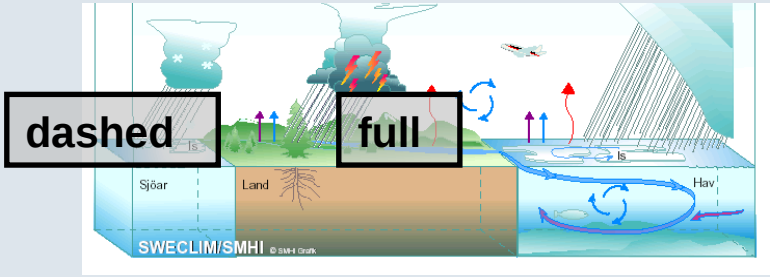


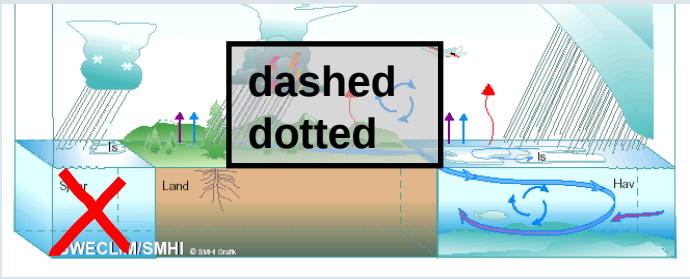
Lake fraction

Too deep lakes in this area can contribute to a warm bias we experience (also the case in Siberia).

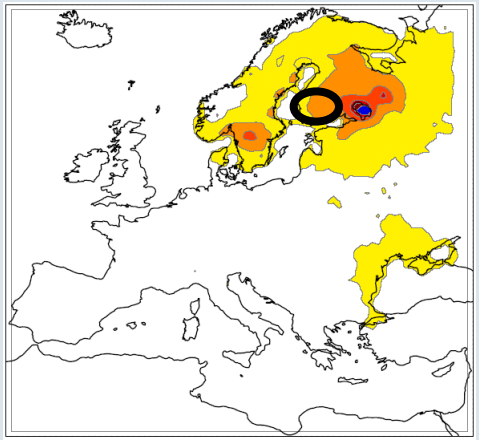
Lake influence on 2m-temperature



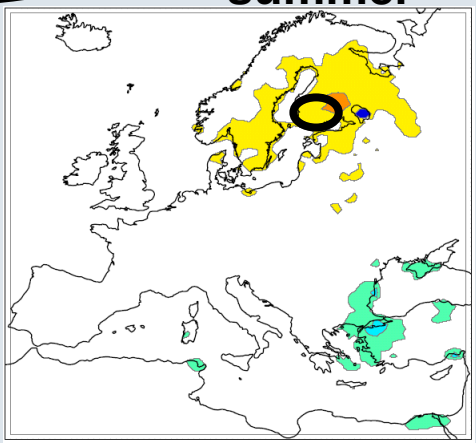




winter



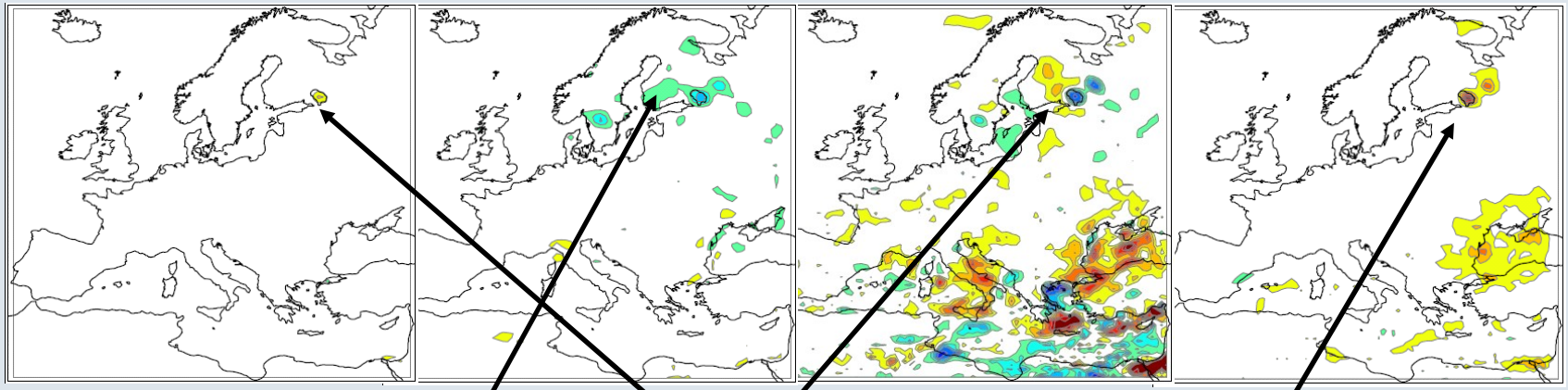
summer



Lake influence on precipitation

winter spring summer autumn

Total precipitation for ((lake version) – (no lake version))/(no lake):



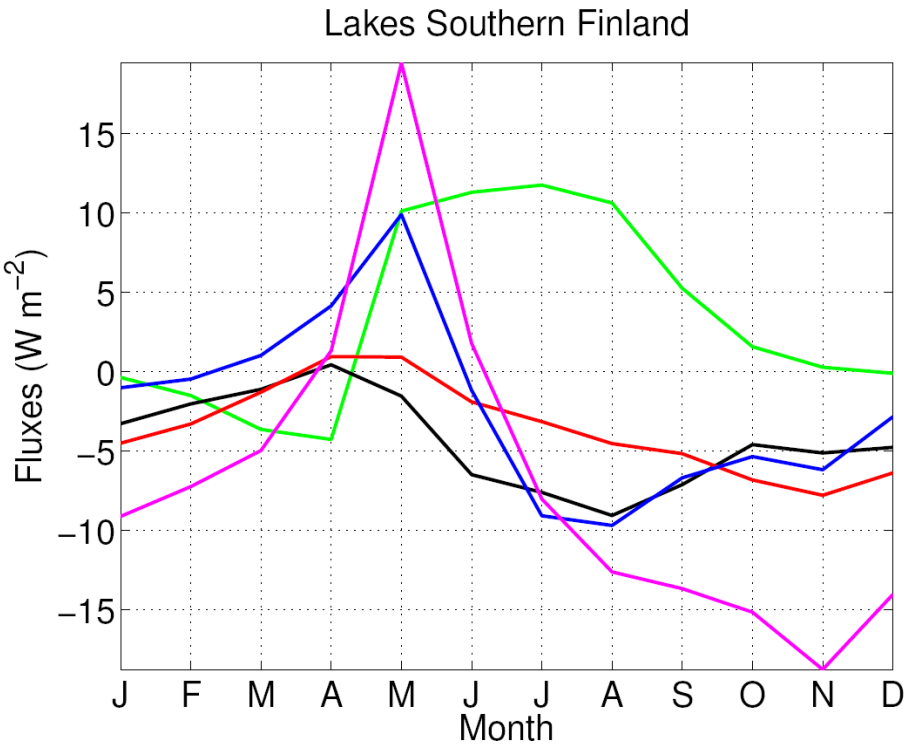
Less prec over lakes in spring

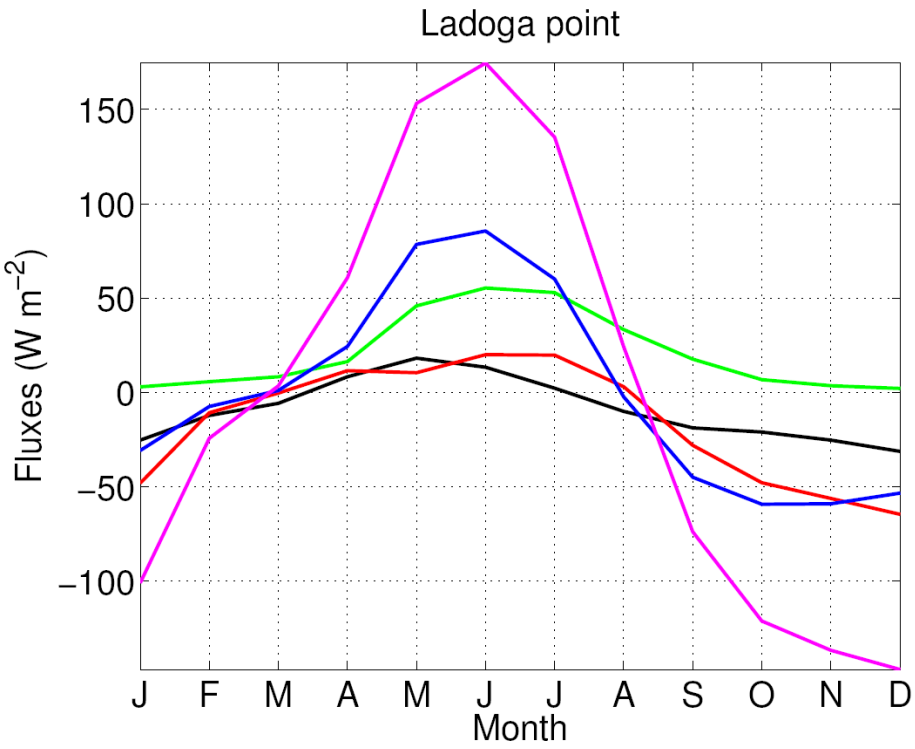
More prec over big/deep lakes in autumn-winter

More prec over small/shallow lakes

Lake influence on energy fluxes

(lake version) – (no lake version)



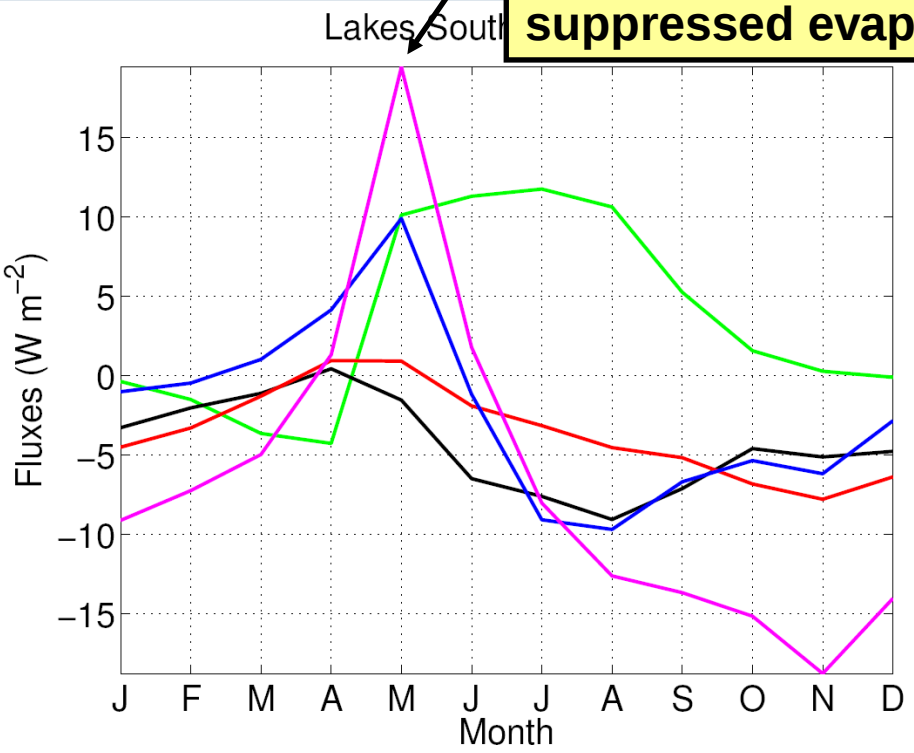


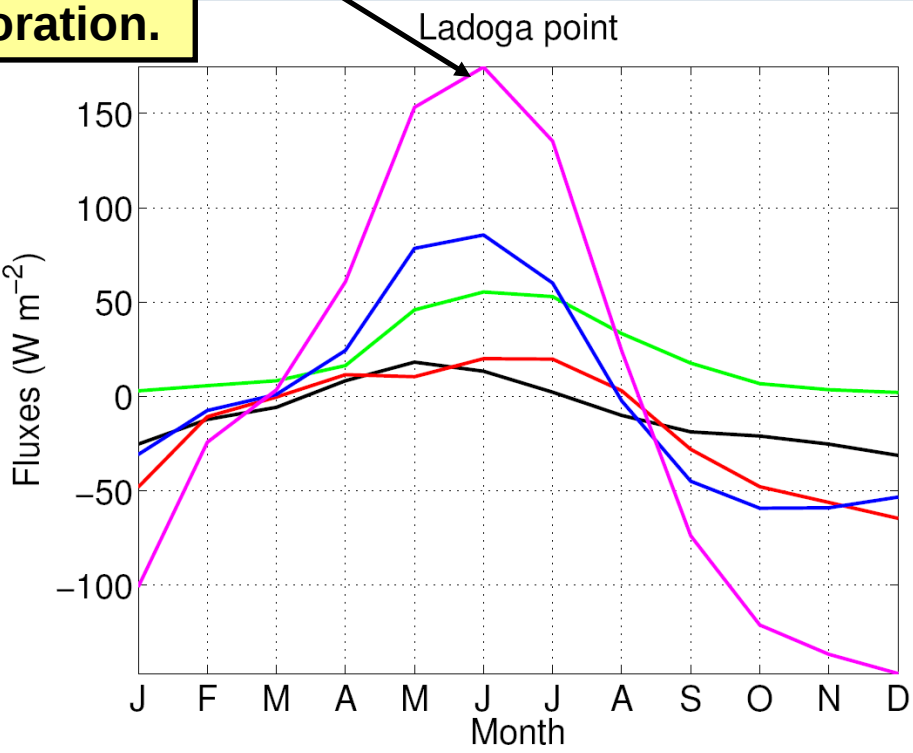
SWnet radiation
LWnet radiation
Sensible heat flux

Latent heat flux
SWnet+LWnet+H+LE

Lake influence on energy fluxes

Input of energy to lakes peaks in May and June resp. Main contribution is from SWnet and suppressed evaporation.



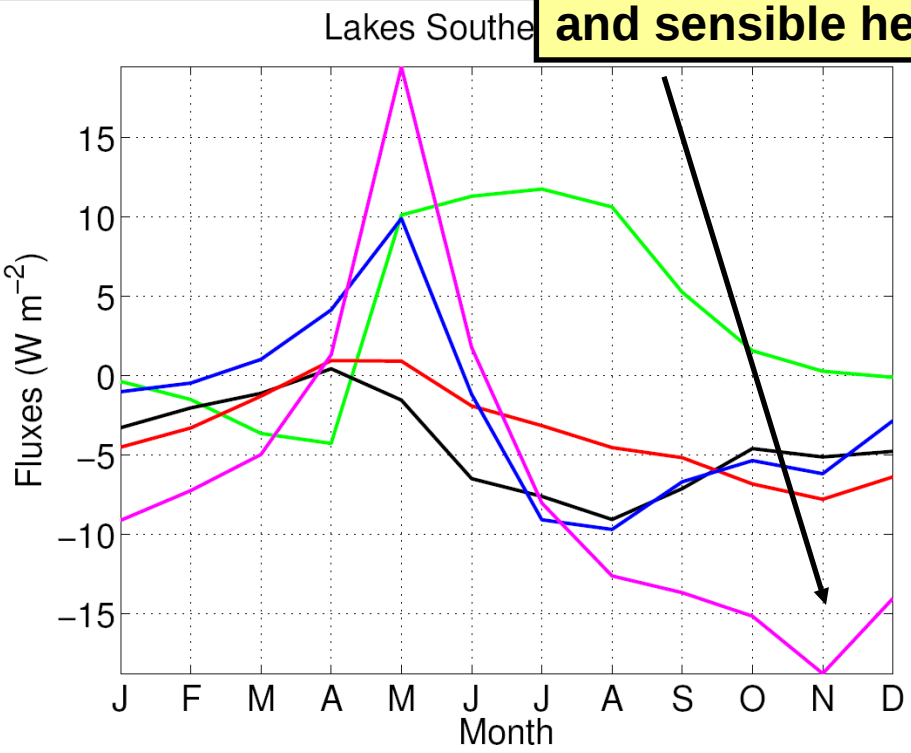


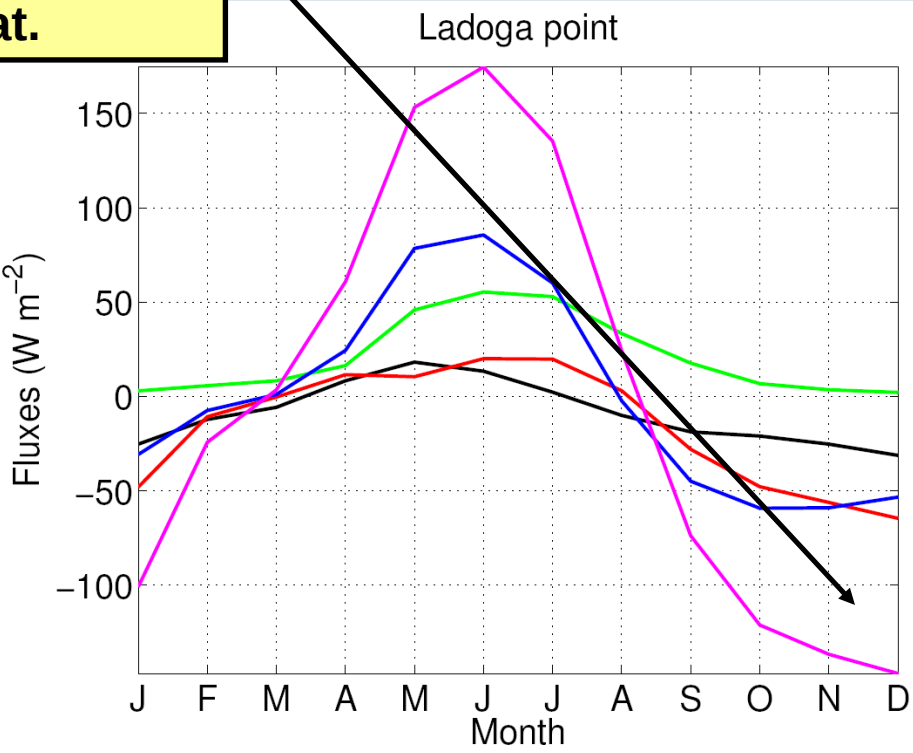
SWnet radiation
LWnet radiation
Sensible heat flux

Latent heat flux
SWnet+LWnet+H+LE

Lake influence on energy fluxes

Loss of energy from lakes peaks in Nov and Dec resp. Contributions from LWnet, evaporation and sensible heat.





SWnet radiation

LWnet radiation

Sensible heat flux

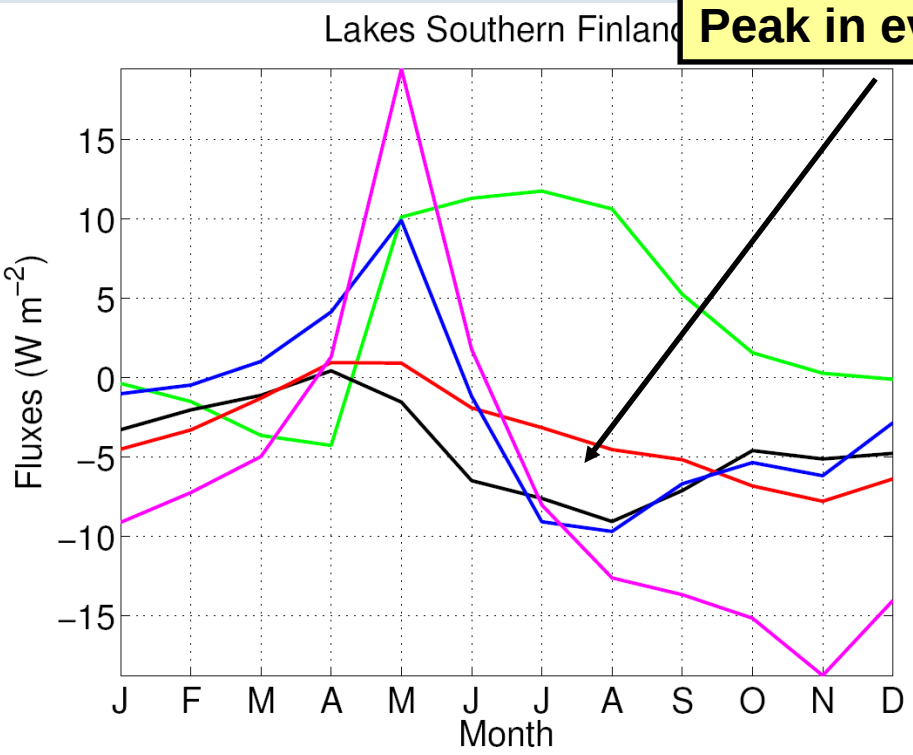
Latent heat flux

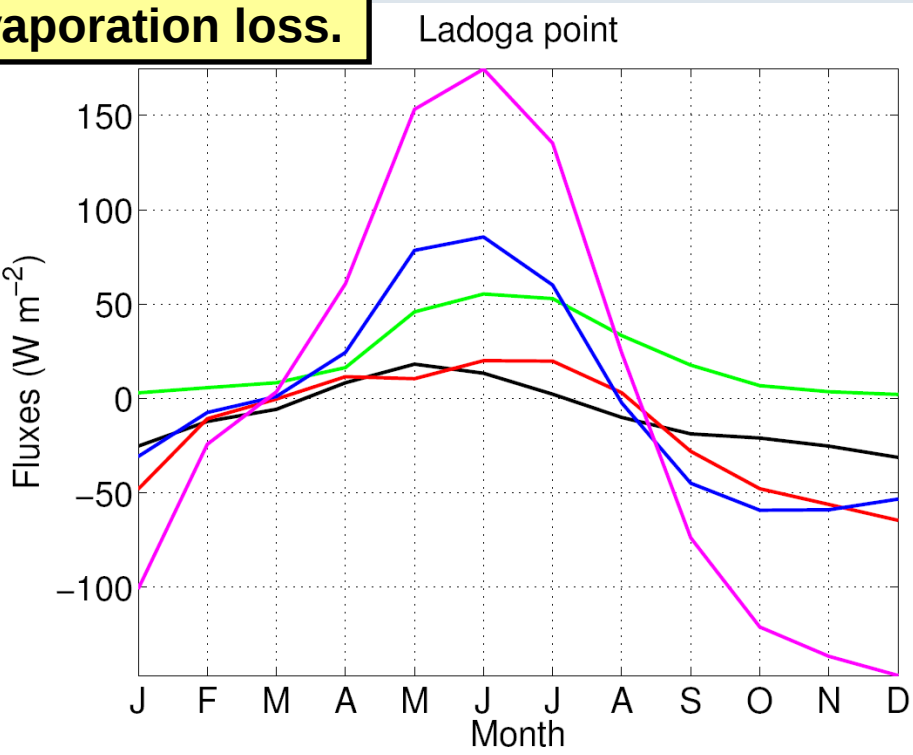
SWnet+LWnet+H+LE

Lake influence on energy fluxes

LWnet heat loss due to high night-time temperature.

Peak in evaporation loss.





SWnet radiation

LWnet radiation

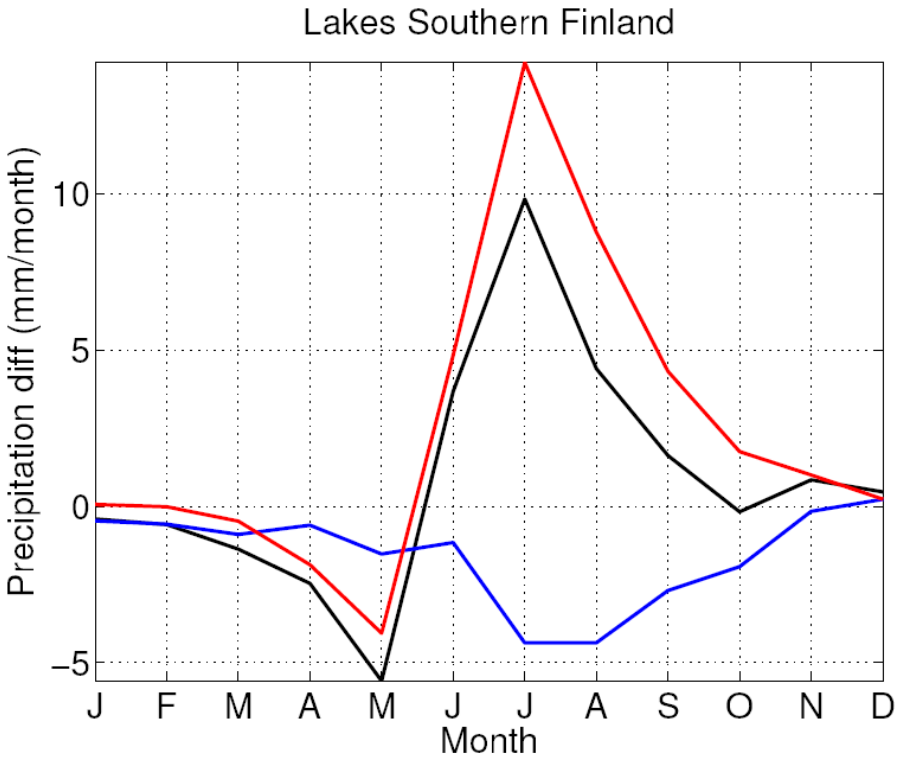
Sensible heat flux

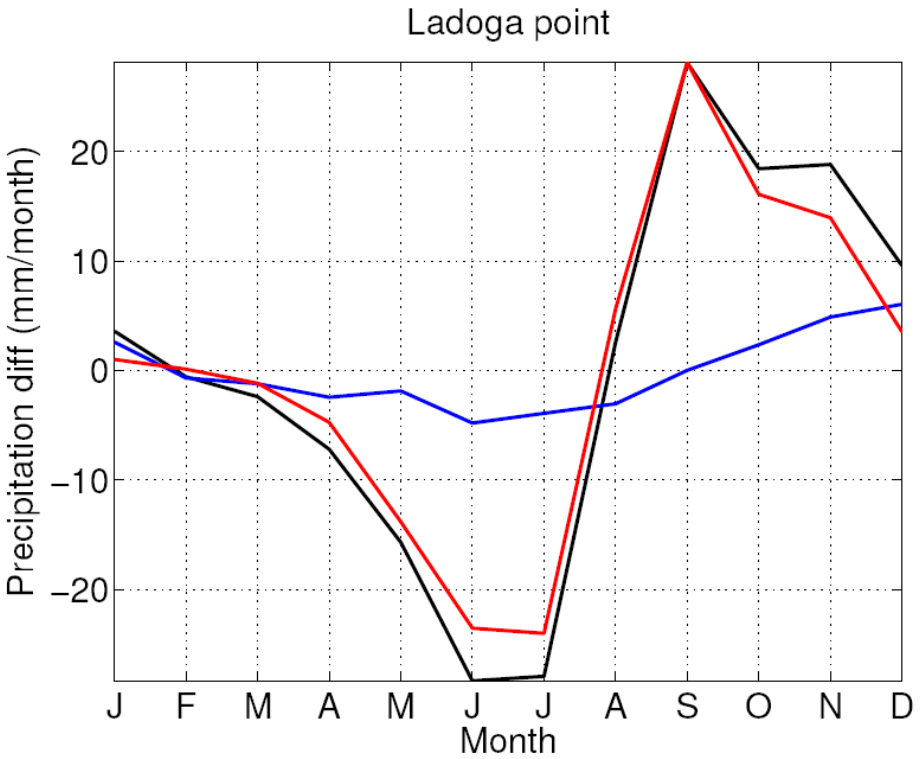
Latent heat flux

SWnet+LWnet+H+LE

Lake influence on precipitation

(lake version) – (no lake version)





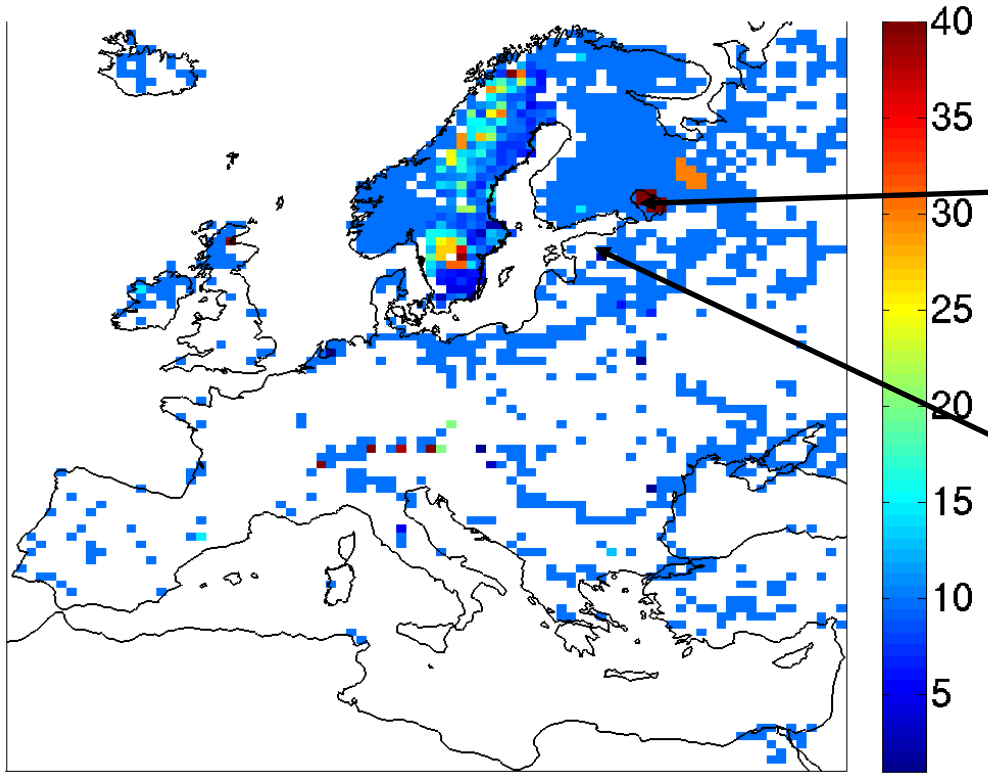
Total precipitation

Large scale component

Convective component

FLake – http://lakemodel.net

Does it work? Let's check the annual temperature cycle



Lake Ladoga, Russia
51 m deep
(40 m in the model)

Lake Võrtsjärv, Estonia
3 m deep

FLake – http://lakemodel.net

Does it work? Let's check the annual temperature cycle

RCA/FLake results:

Lake Surf Temp –

Mixed layer temp - -

Lake T2m -

Open land T2m - -

Ice depth*10 -

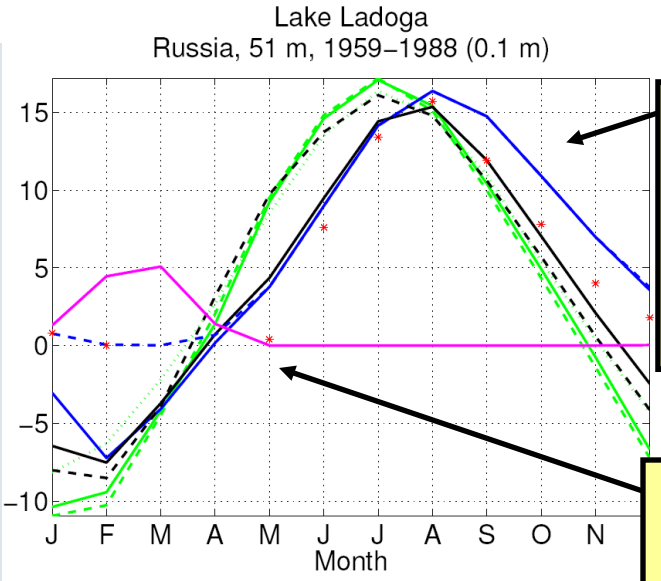
Observations:

Observed LST *

(http://www.ilec.or.jp/database/)

Observed opl T2m

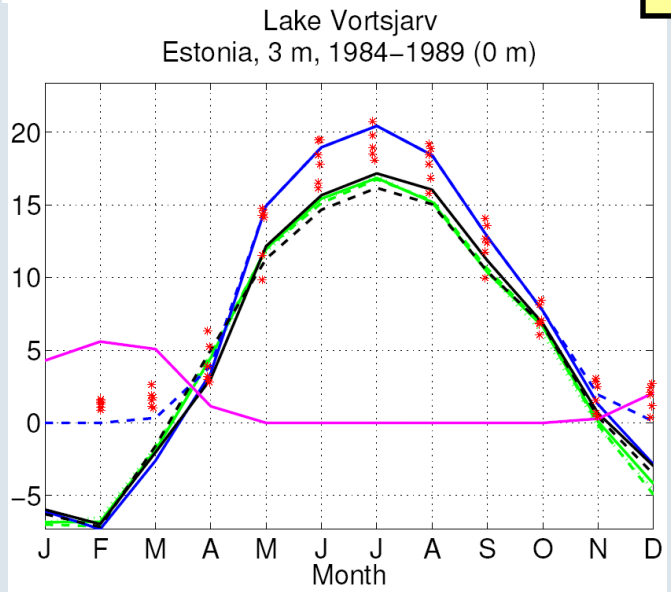
(ERA40, CRU, Willmott)



Lag between Lake T2m (-) and land T2m (- -)

Note that lakes are not seen in ERA40.

Too early ice break up due to warm winter bias



Conclusions

Do we need to account for lakes in climate and NWP modelling?

Yes, at least in Northern Europe, where they make the surrounding mean temperature climate warmer for most seasons.

A few big/deep lakes contra many small/shallow lakes

Less precipitation over big/deep lakes in summer BUT more precipitation over small/shallow lakes

FLake – http://lakemodel.net

Successfully implemented in RCA3.1

FLake – http://lakemodel.net Does it work?

FLake gives satisfactory results which makes it a good candidate to be the next official lake model in RCA.

Further work

Snow is not yet allowed on lake ice which may cause an unrealistic heat transfer through the ice.

Ekatherina is working on a lake data base for Europe and beyond (depth and area) that will be implemented.

ECOCLIMAP software gives 20% lake and 80% nature for wetland areas....(?)

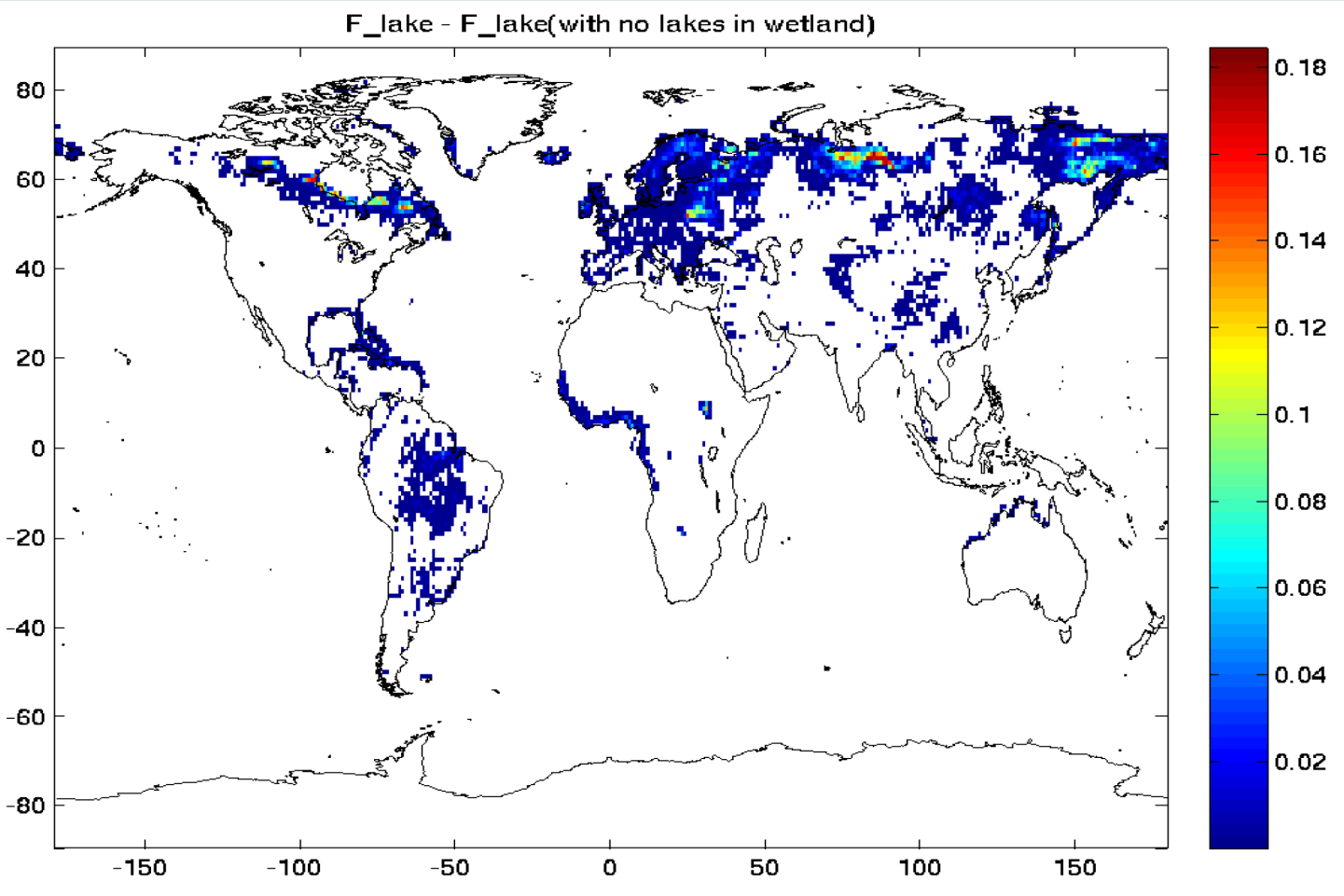
More lake surface temperatures will be used for evaluation.

Lake dynamics (changing area of lakes) may be important to consider in some areas as a consequence of climate change (collapsing of permafrost in Siberia).

Lake Pääjärvi, Finland, winter 2003 by *Matti Leppäranta*

Discussion points

In ECOCLIMAP wetlands are assumed to consist of 20% lakes. Difference in lake fraction when no lakes are assumed for wetlands:



Discussion points

There is no snow on ice in FLake in these simulations

RCA/FLake results:

Lake Surf Temp –

Mixed layer temp - -

Lake T2m -

Open land T2m - -

Ice depth*10 -

Observations:

Observed LST *

(http://www.ilec.or.jp/database/)

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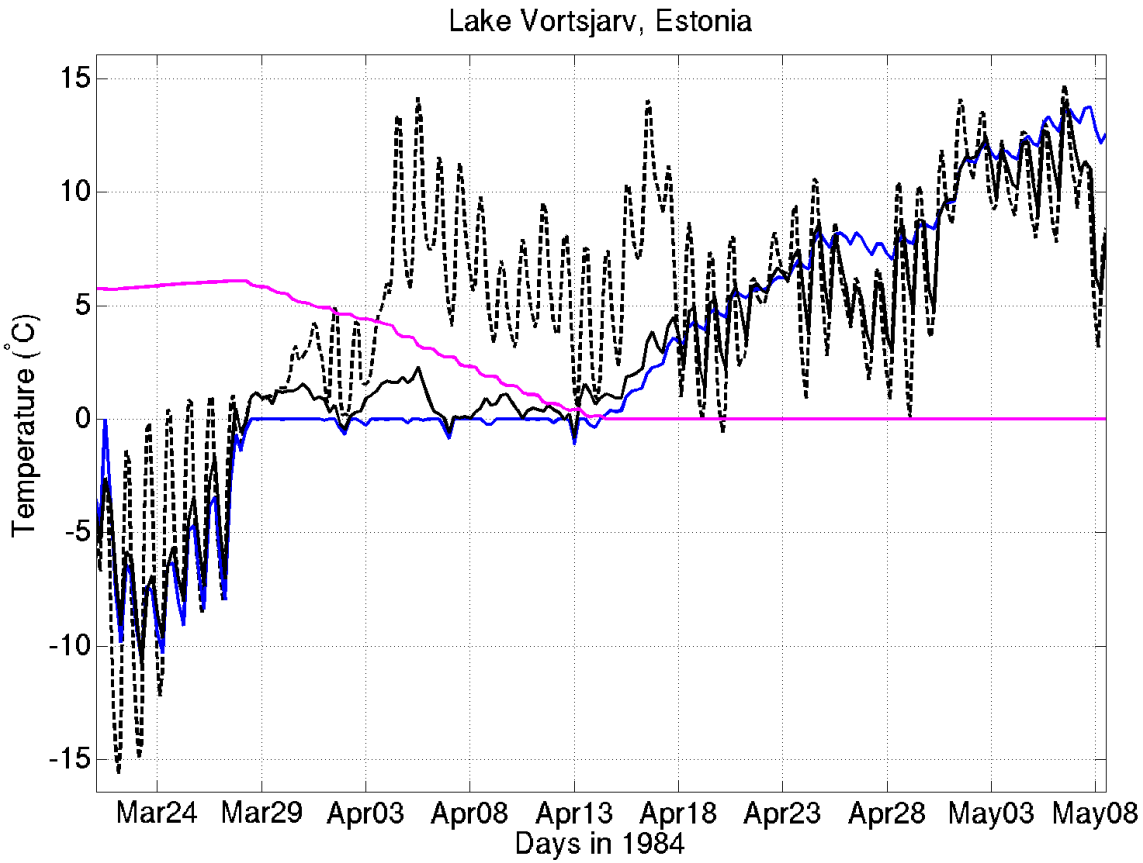
(ERA40, CRU, Willmott)

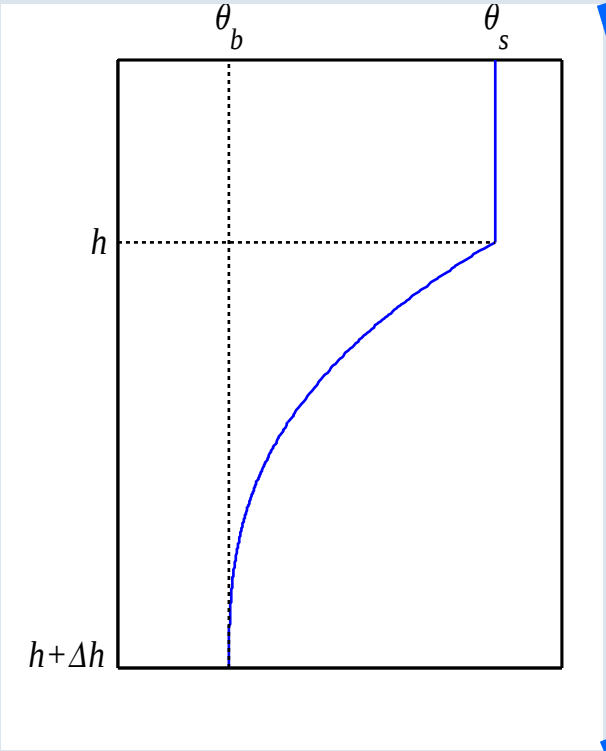


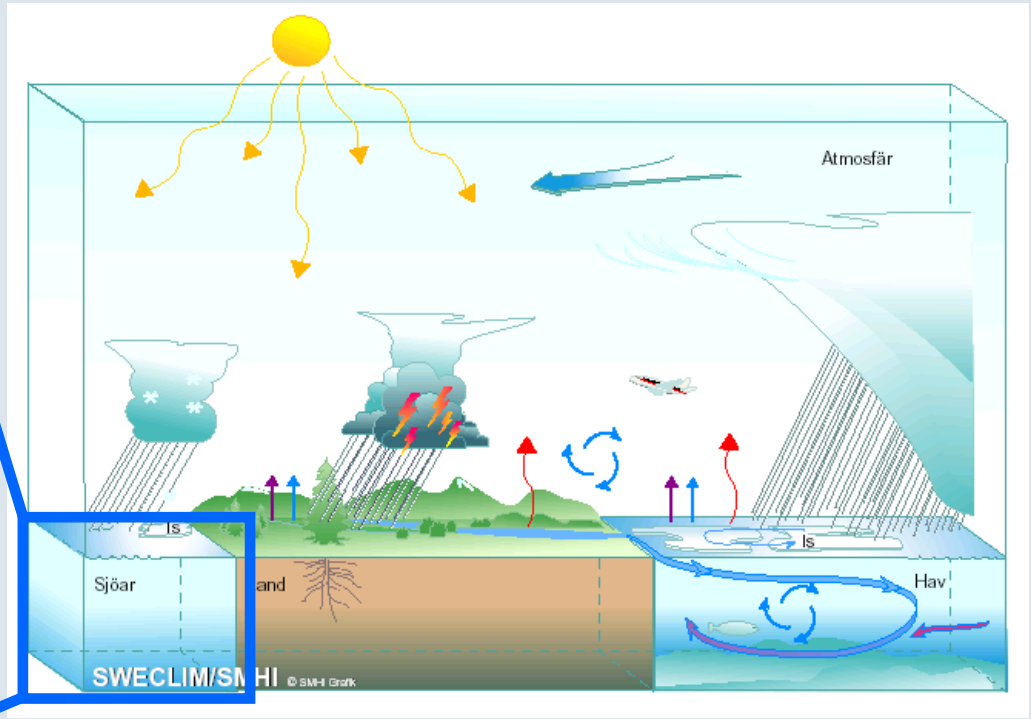
FLake – http://lakemodel.net

Concept

FLake – a new lake model in RCA3.1 (a package of 21 f90-files)

FLake is based on a two-layer representation of the temperature profile and self-similarity concept. Thus, it is not a multi-layer model, which makes it numerically efficient.



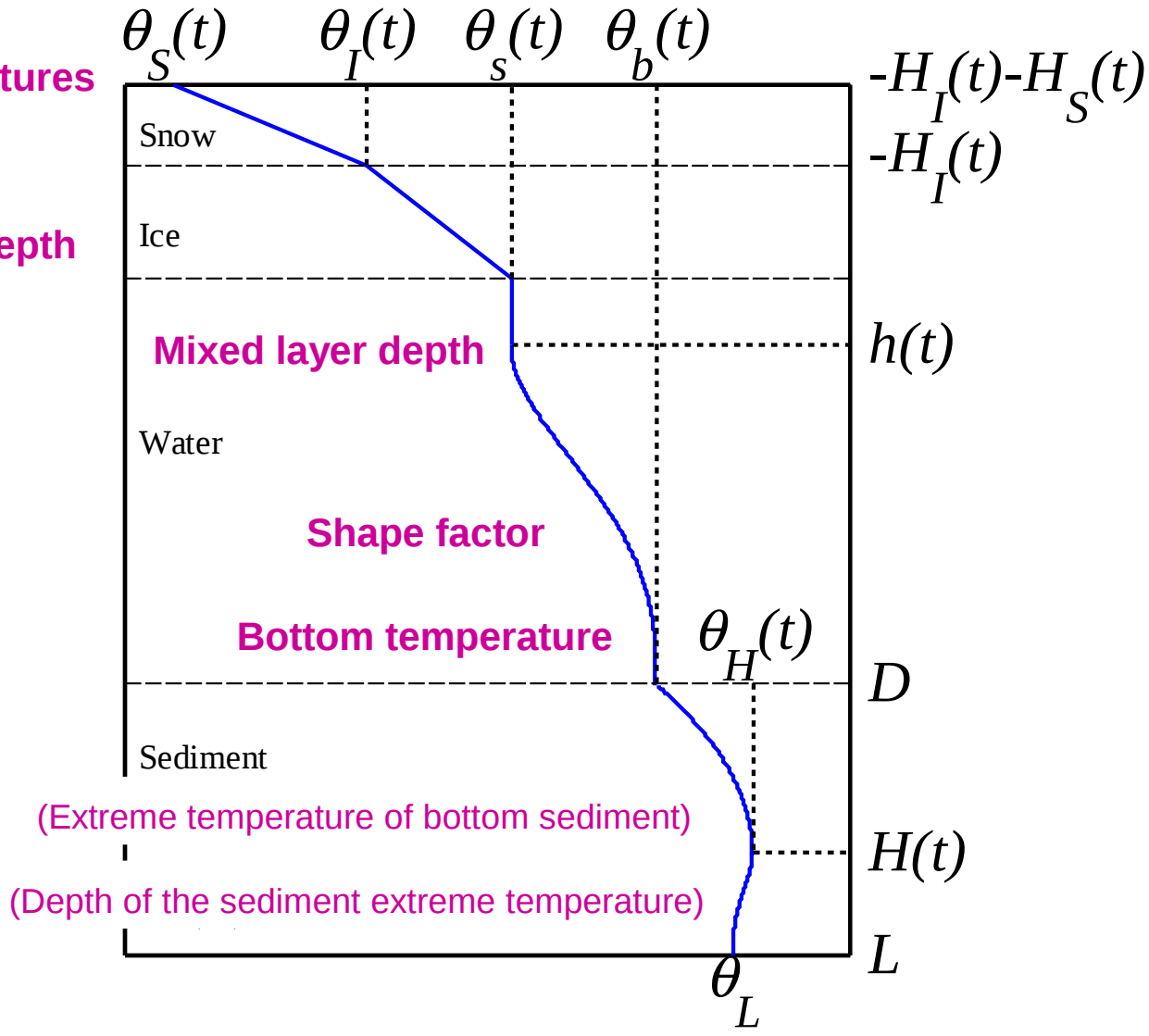


FLake – http://lakemodel.net

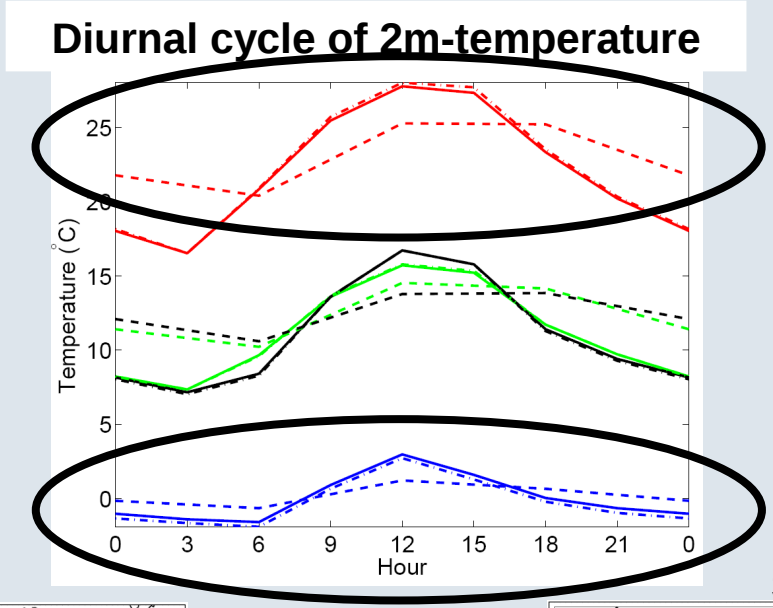
Prognostic variables in FLake

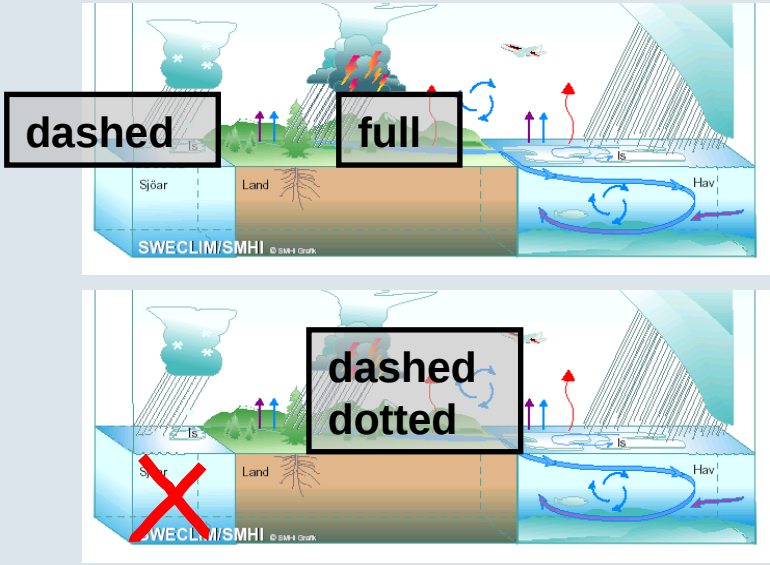
Surface temperatures (water, ice, snow**)**

Ice (and snow) **depth**

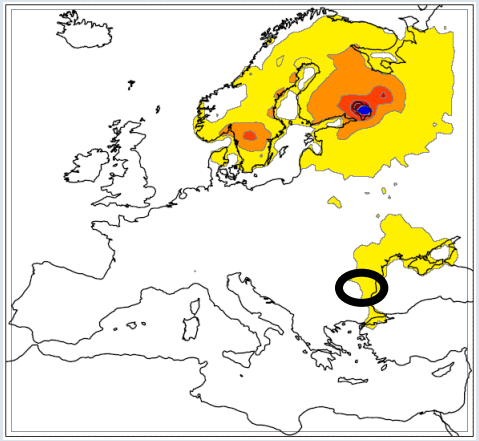


Do we need to take lakes into account in climate and NWP modelling?

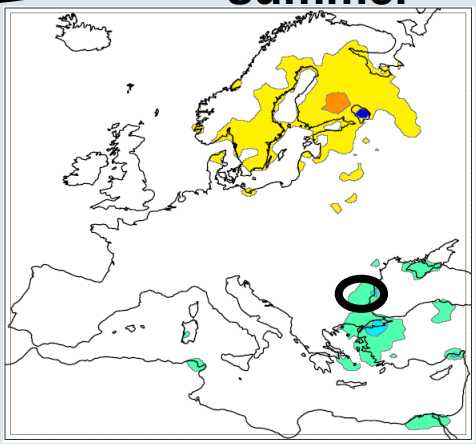




winter



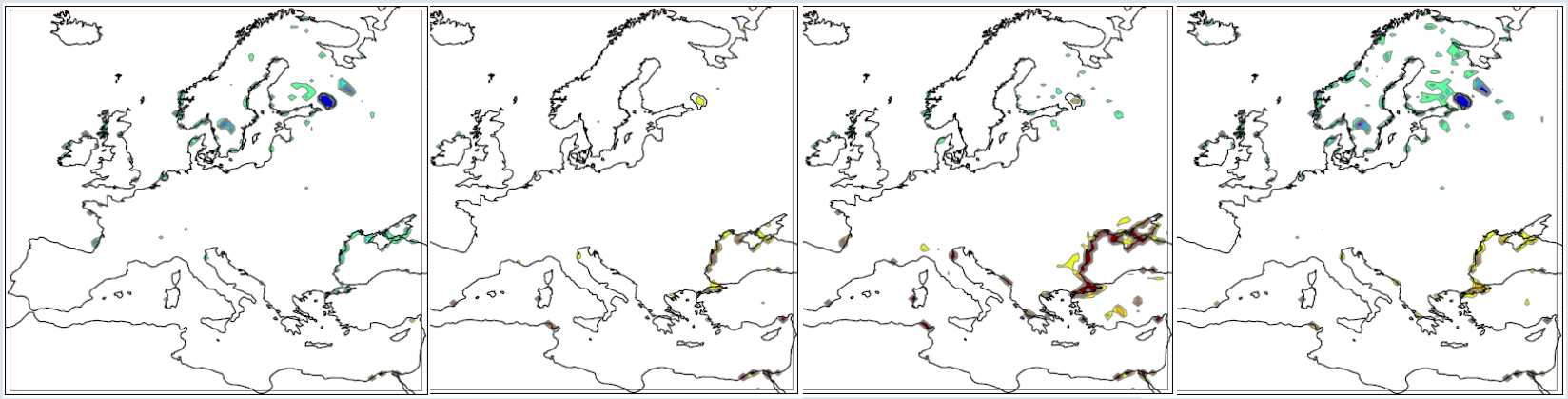
summer



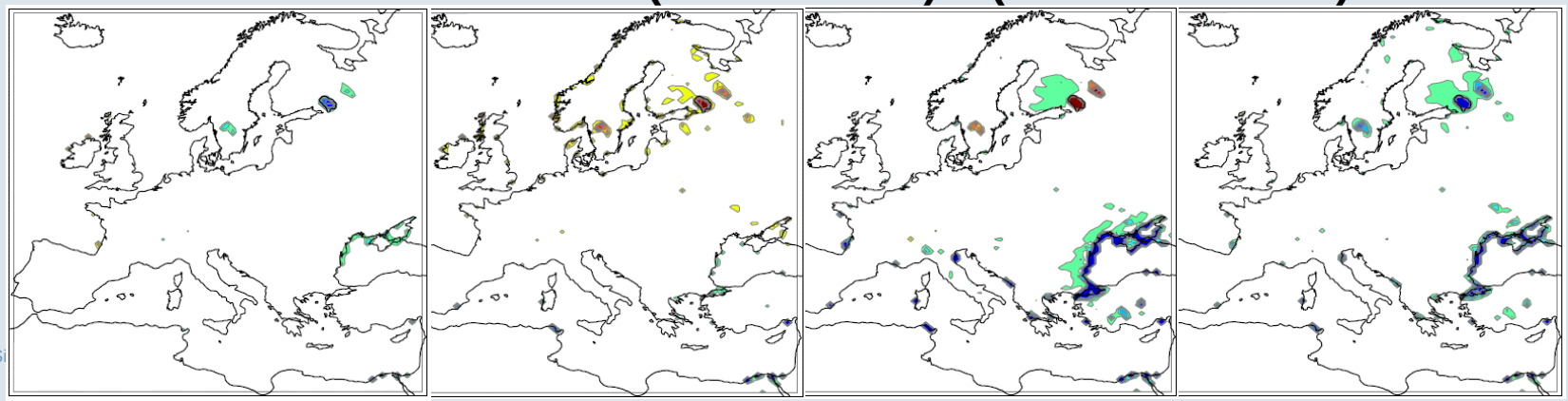
Lake influence on sensible and latent heat fluxes

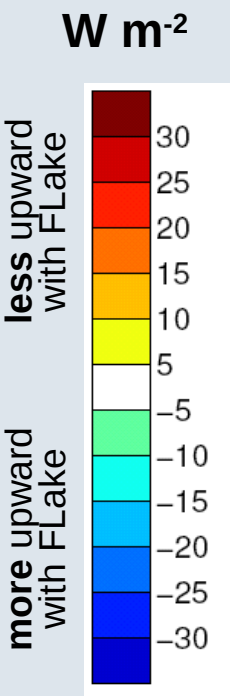
winter spring summer autumn

Sensible heat flux for (lake version) – (no lake version):



Latent heat flux for (lake version) – (no lake version):





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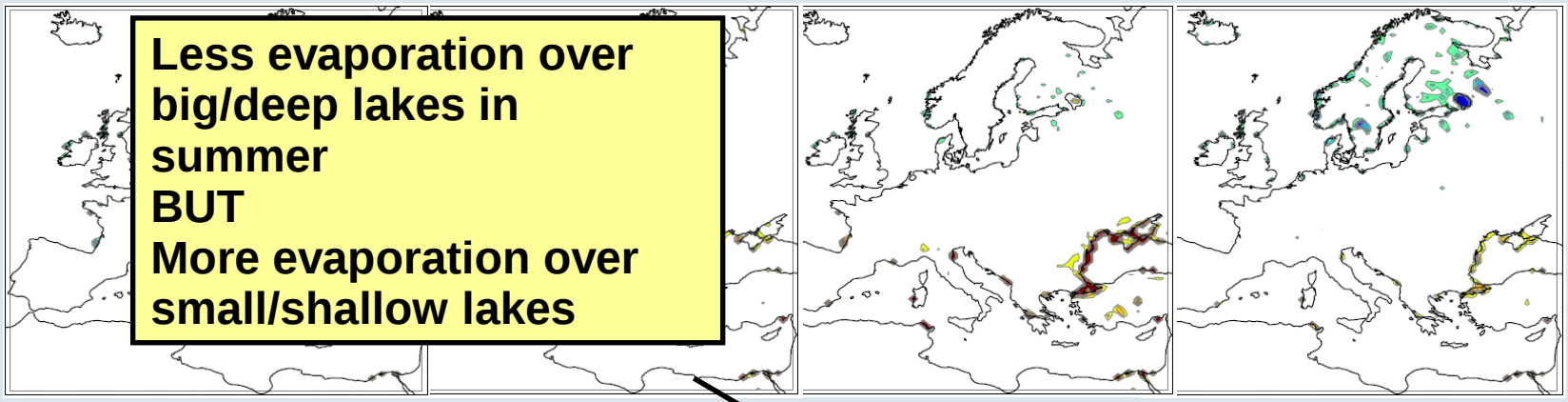
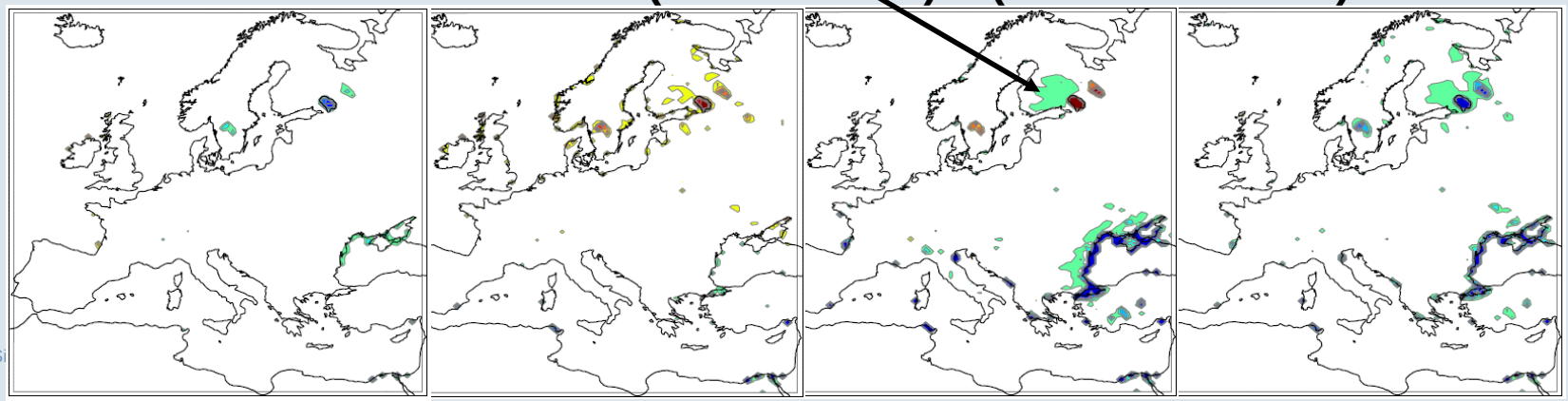
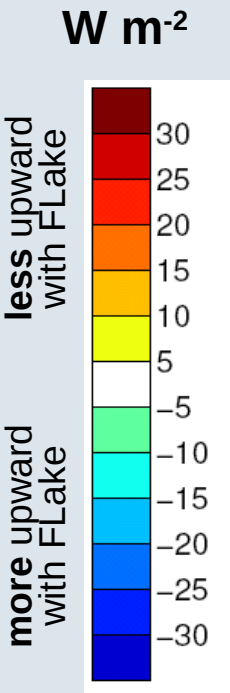


Less evaporation over big/deep lakes in summer
BUT
More evaporation over small/shallow lakes

Latent heat flux for (lake version) – (no lake version):

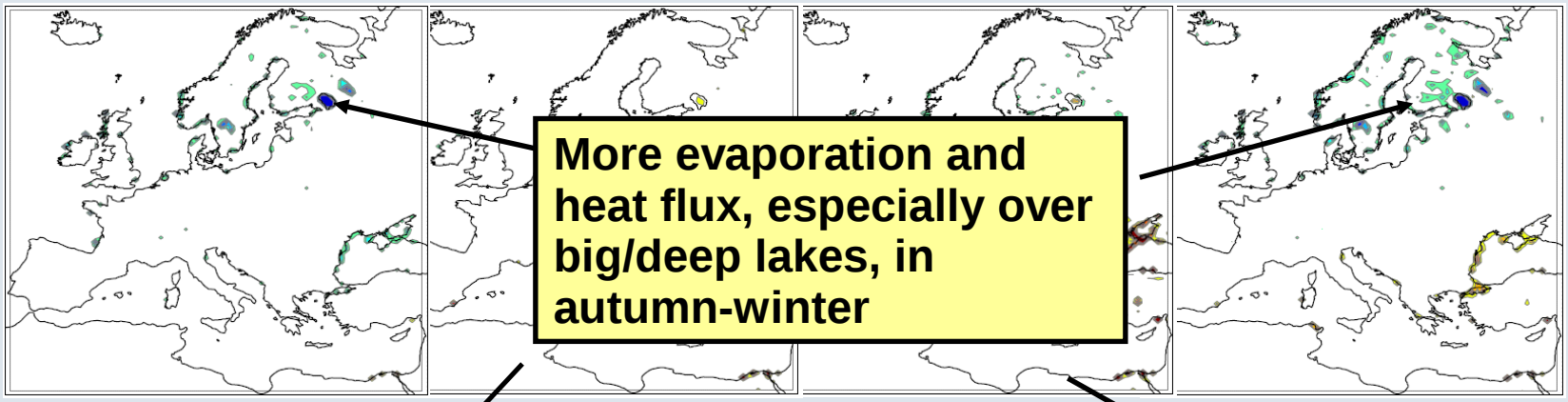




Lake influence on sensible and latent heat fluxes

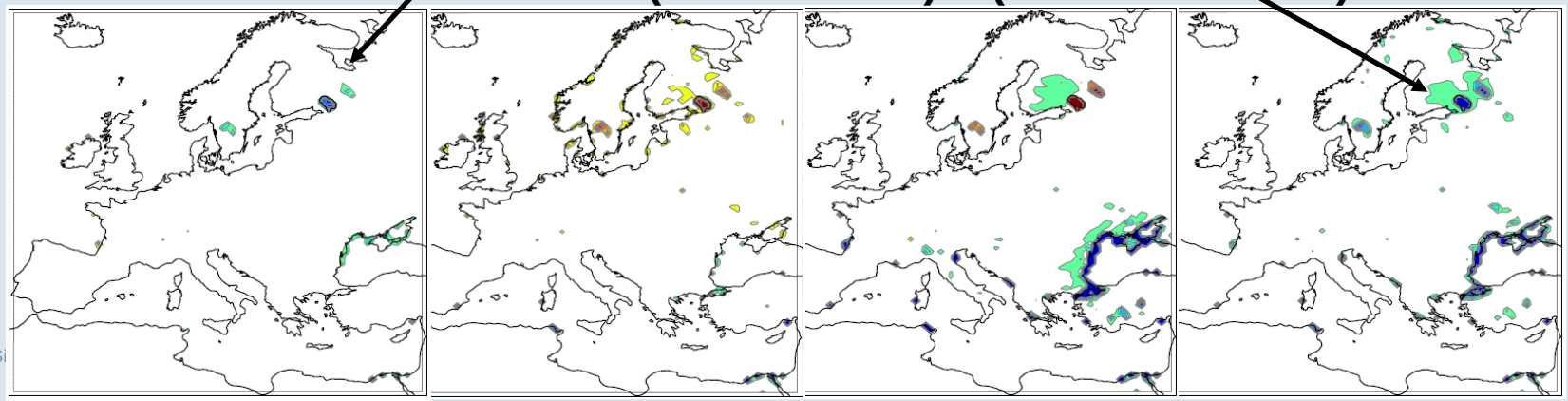
winter spring summer autumn

Sensible heat flux for (lake version) – (no lake version):



More evaporation and heat flux, especially over big/deep lakes, in autumn-winter

Latent heat flux for (lake version) – (no lake version):



W m^{-2}

less upward with FLake

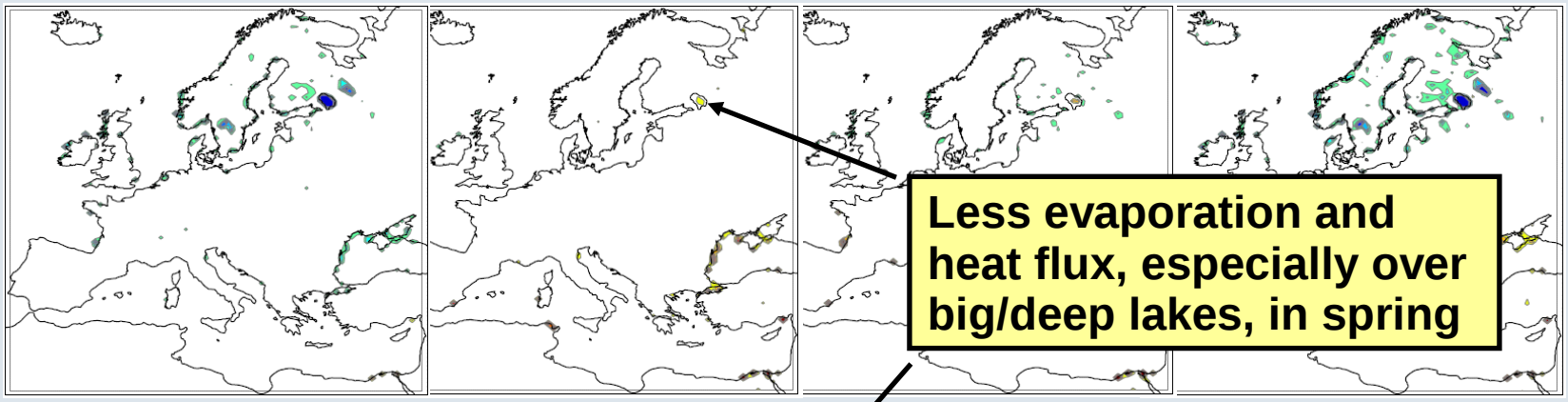
more upward with FLake

30
25
20
15
10
5
−5
−10
−15
−20
−25
−30

Lake influence on sensible and latent heat fluxes

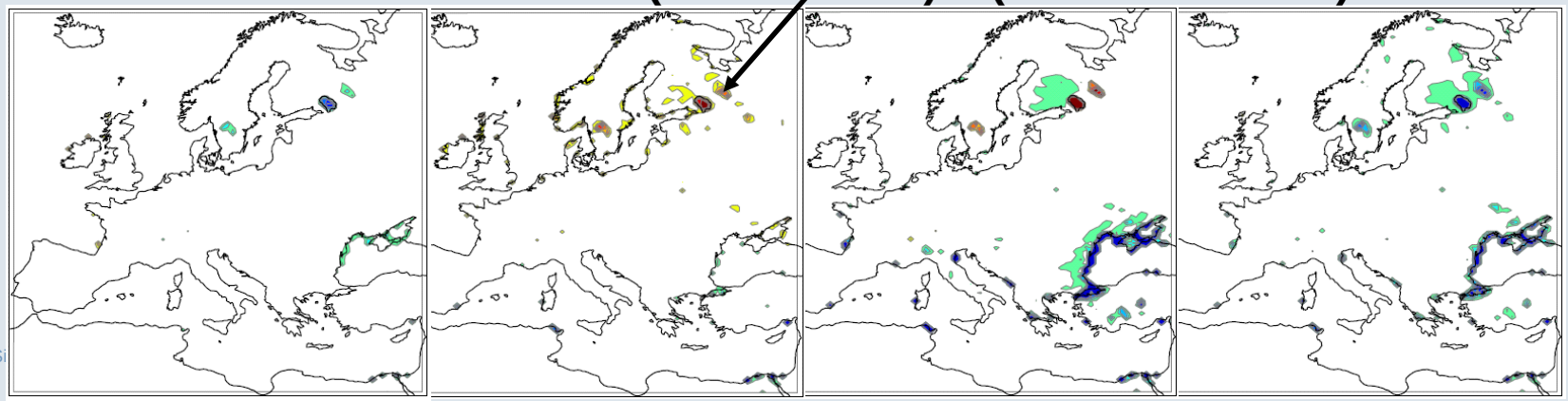
winter spring summer autumn

Sensible heat flux for (lake version) – (no lake version):



Less evaporation and heat flux, especially over big/deep lakes, in spring

Latent heat flux for (lake version) – (no lake version):



W m^{-2}

less upward with FLake

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30
25
20
15
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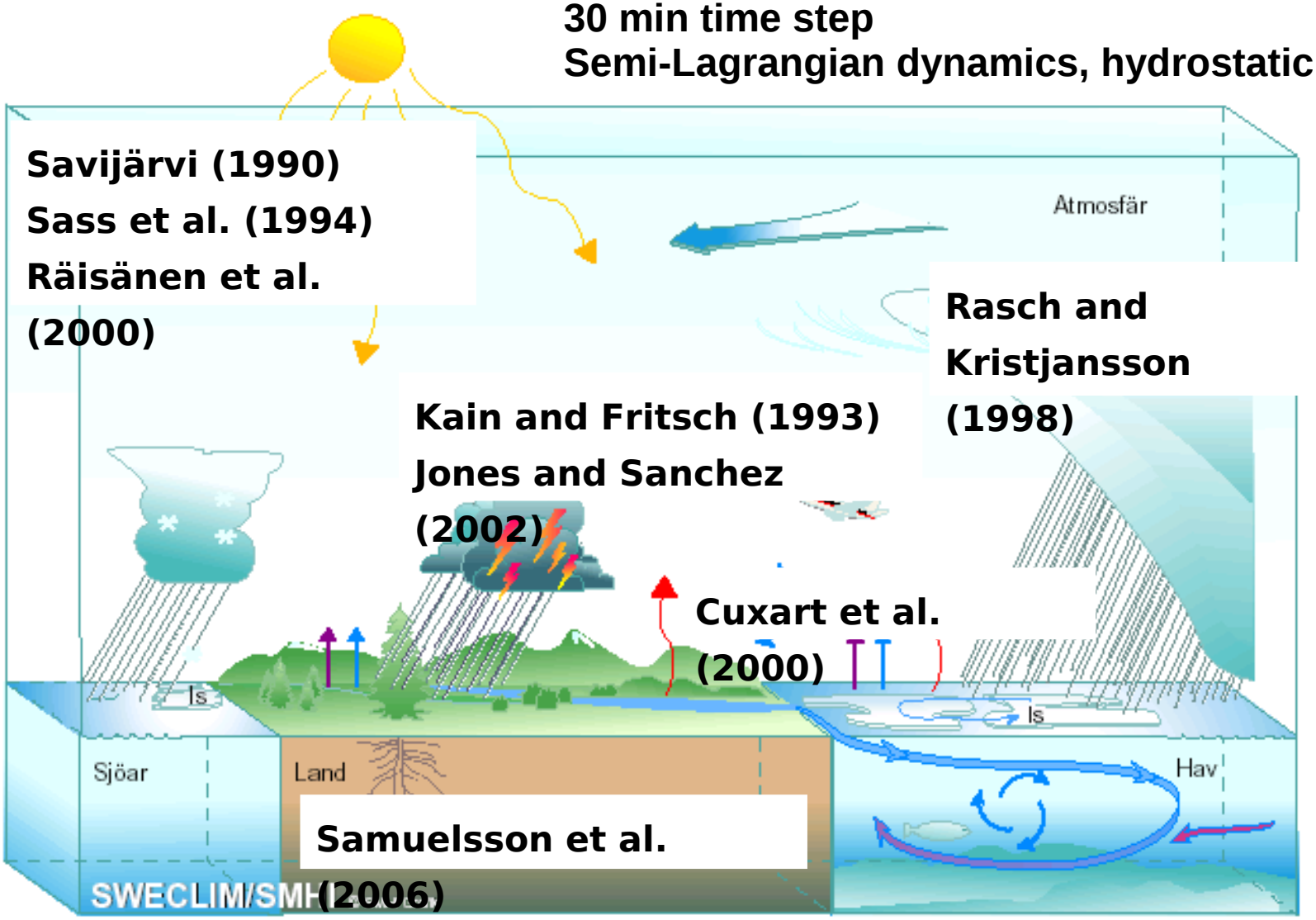
−5
−10
−15
−20
−25
−30

RCA3 Kjellström et al. (2005)

102x111 grid points (0.4deg~50km)
24 vertical levels
30 min time step
Semi-Lagrangian dynamics, hydrostatic

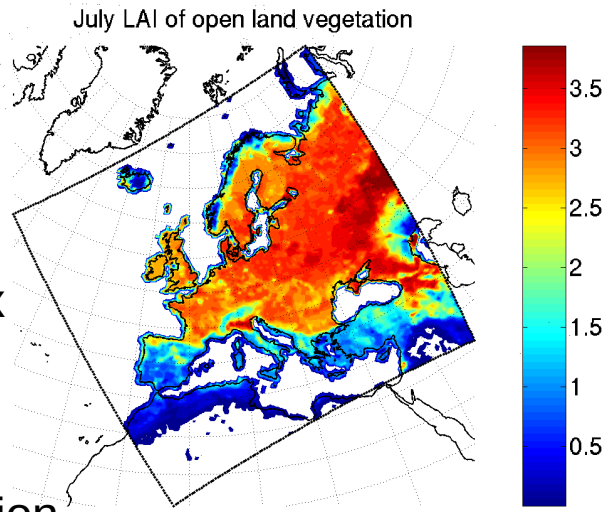


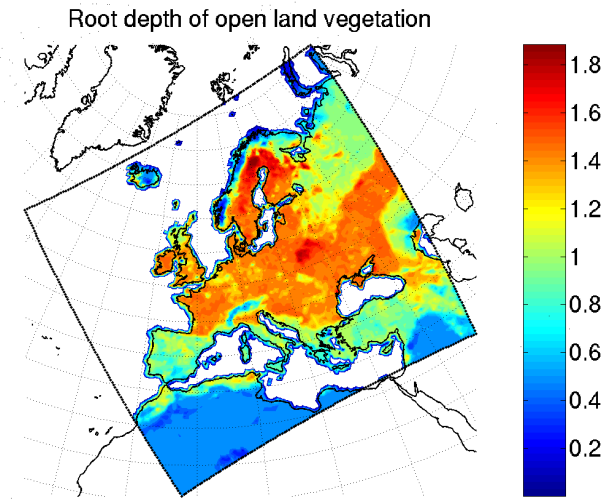
Physiography information of tiles ECOCLIMAP (Masson et al. 2001)

Global data base with 1 km resolution

- fraction of sea
- fraction of inland water
- bare soil
- rocks
- permanent snow
- deciduous broadleaf trees
- coniferous trees
- evergreen broadleaf trees
- C3 crops
- C4 crops
- irrigated crops
- natural herbaceous not irrigated (temperate and polar)
- natural herbaceous not irrigated (tropical and equatorial)
- swamp herbaceous and gardens
- clay
- sand

Leaf Area Index
root depth
albedo
emissivity
vegetation fraction
roughness
…

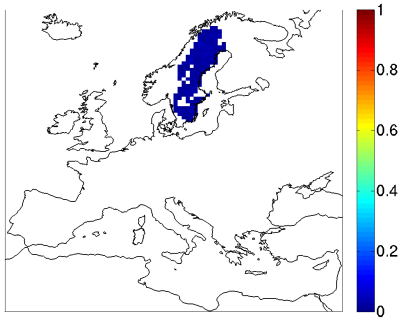




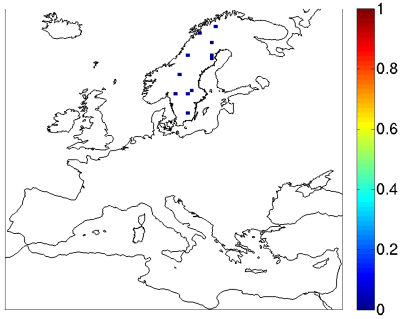
Fraction and depth of lakes

fraction of lakes

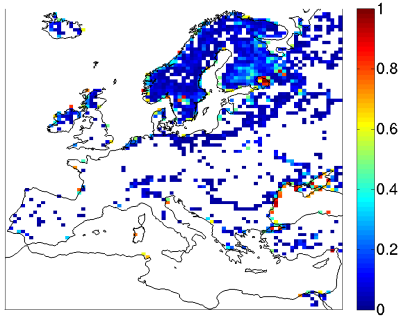
shallow
3.5 m



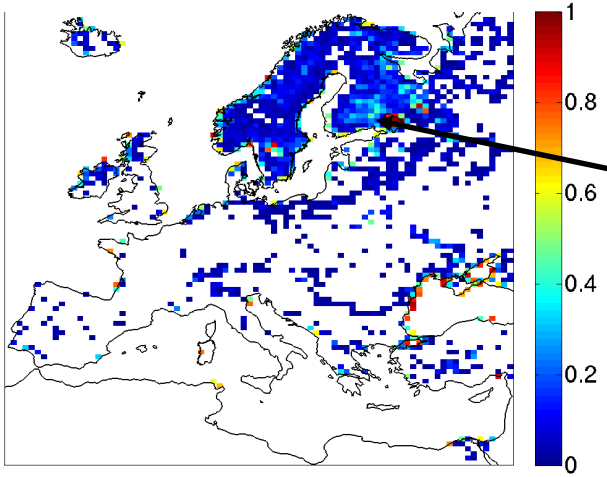
medium
7.4 m



deep
≥10 m

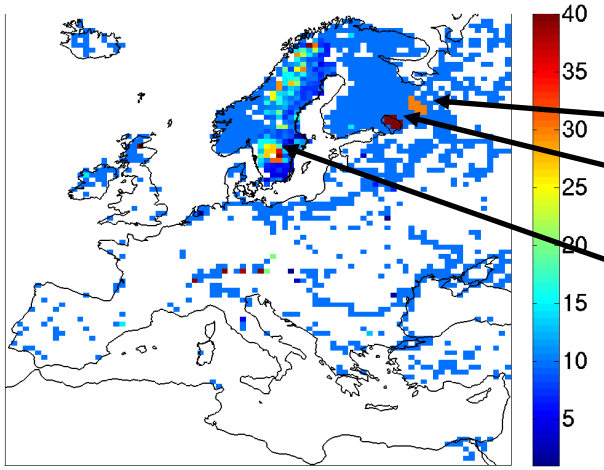


total fraction of lakes



many
shallow
lakes

depth of deep lakes



Onega
Ladoga
Vänern
Vättern

FLake – http://lakemodel.net

Sensitivity tests

Sensitivity tests have shown

- In summer the mixed layer depth tends to be underestimated. Adjustments in shape-factor may be needed.
- The sensitivity of the model to fetch and optical parameters is not high.
- The sensitivity to bottom sediments block on/off appears only for long periods of simulation.
- Depth of the lake is the main parameter to which model is sensitive. A maximum lake depth of 40 m works best.