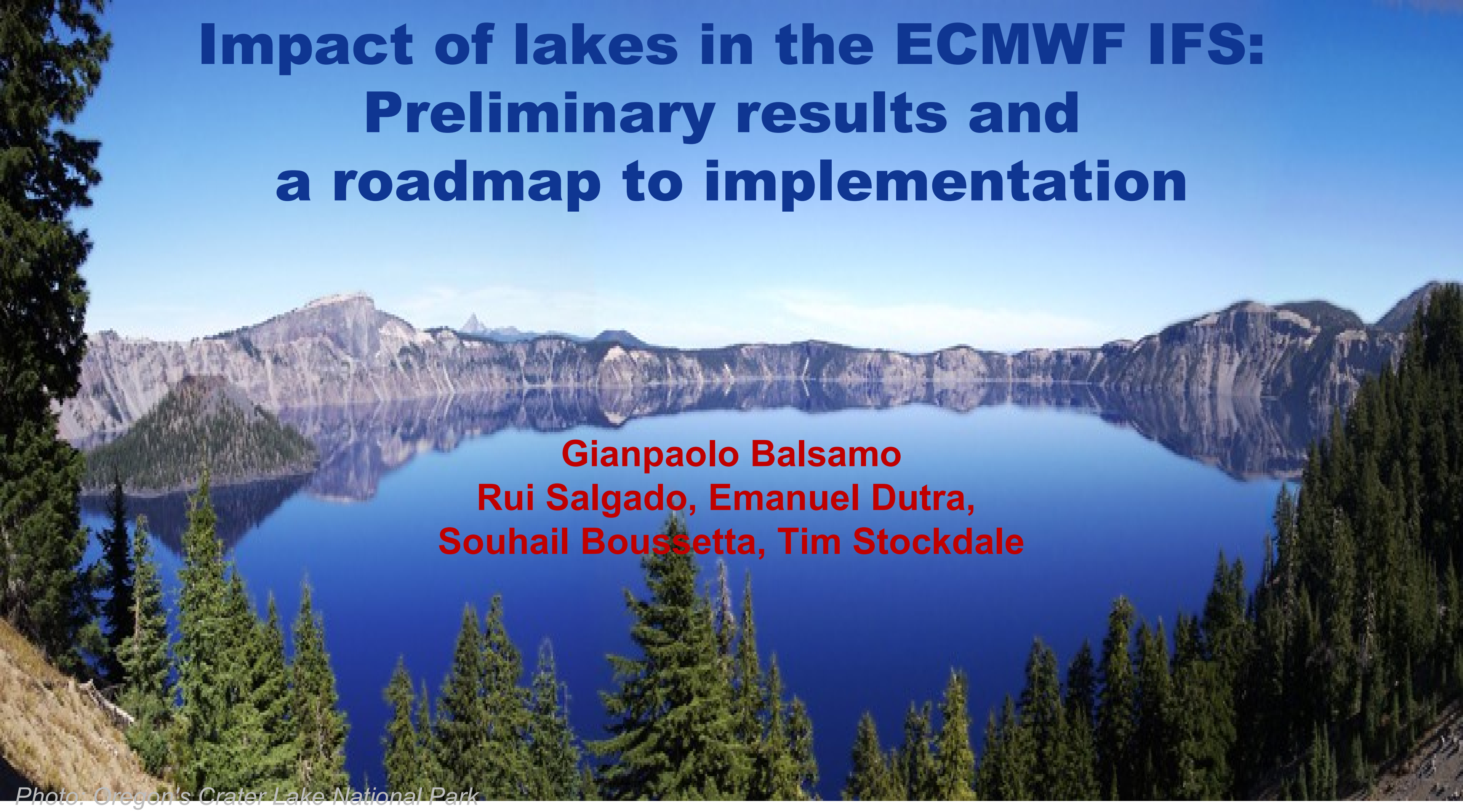
Impact of lakes in the ECMWF IFS: Preliminary results and a roadmap to implementation



Gianpaolo Balsamo
Rui Salgado, Emanuel Dutra,
Souhail Boussetta, Tim Stockdale

Photo: Oregon's Crater Lake National Park

ABSTRACT: A set of simulations performed with the ECMWF tiled land surface scheme (HTESSEL) including the Fresh water Lake model (FLake) treated as an extra surface tile and coupled with the ECMWF Numerical Weather Prediction (NWP) model is presented in order to show progress and current issues. In particular, the impact of fully resolved vs. subgrid (unresolved) lakes and the benefits of a more realistic treatment of lake bathymetry and lake state initial conditions as opposed to a fixed depth and a simplified initialization will be illustrated. A roadmap to a future operational implementation will be discussed.

ECMWF

Role of land surface at ECMWF

ECMWF model(s) and resolutions

	Length	Horizontal	Vertical	Remarks
- Deterministic	10 d	T1279 (16 km)	L91	00+12 UTC
- Monthly/VarEPS (N=51)	0-10d	T639(30 km)	L62	(SST tendency)
	11-32d	T399(60 km)	L62	(Ocean coupled)
- Seasonal forecast	6 m	T159 (125 km)	L62	(Ocean coupled)
- Assimilation physics inner	12 h	T255(80 km)/ T159(125 km)	L91	T95(200 km)
- ERA-40 Reanalysis	1958-2002	T159(125 km)	L60	3D-Var+surface OI
- ERA-Interim Reanalysis	1989-today	T255(80 km)	L91	4D-Var+surface

Land surface modelling (and LDAS systems) need flexibility & upscalability (conservation) properties to be used by at a wide range of spatial resolutions in spite of natural heterogeneity of land surfaces.

Errors in the treatment of land surface are likely to affect all forecasts products.

Land surface model evolution

2000/06	2007/11	2009/03	2009/09	2010

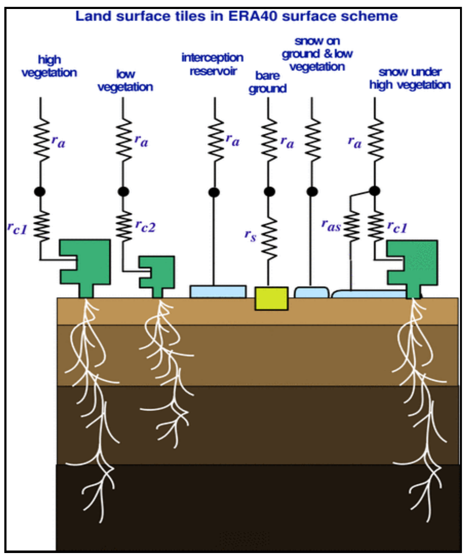
- TESSEL

Van den Hurk et al. (2000)
Viterbo and Beljaars (1995), Viterbo et al (1999)

Up to 8 tiles (binary Land-Sea mask)

GLCC veg. (BATS-like)

ERA-40 and ERA-I scheme



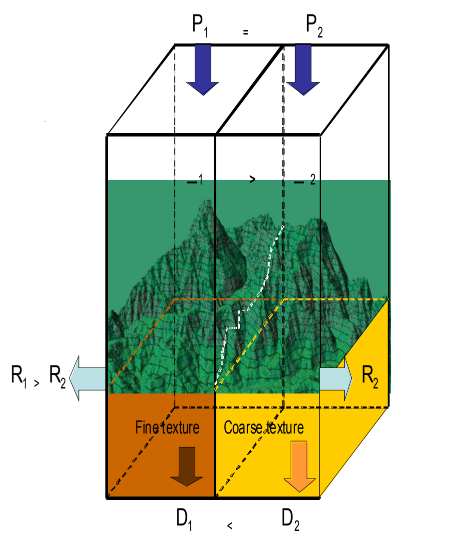
- Hydrology-TESSEL

Balsamo et al. (2009)
van den Hurk and Viterbo (2003)

Global Soil Texture (FAO)

New hydraulic properties

Variable Infiltration capacity & surface runoff revision



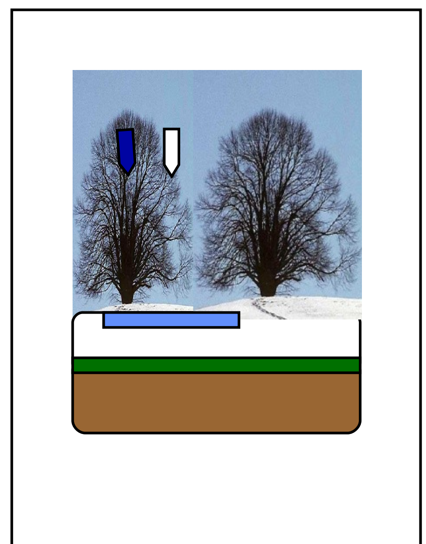
- NEW SNOW

Dutra et al. (2010)

Revised snow density

Liquid water reservoir

Revision of Albedo and sub-grid snow cover



- NEW LAI

Boussetta et al. (2010)

- FLAKE

Mironov et al (2010), Dutra et al. (2010), Balsamo et al. (2010)

Extra tile (9) to account for sub-grid lakes

Land surface data assimilation evolution

1999/07 | 2004/03 | 2008/09 | 2010

- **OI screen level analysis**

Douville et et al. (2000)

Mahfouf et al. (2000)

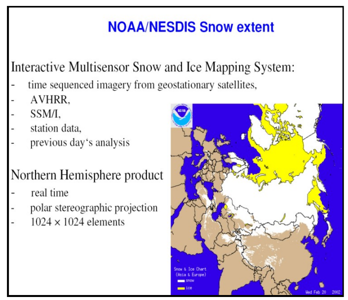
Soil moisture analysis based on Temperature and relative humidity analysis

- **Revised snow analysis**

Drusch et al. (2004)

Cressman snow depth analysis using SYNOP data

Improved by using NOAA / NSEDIS Snow cover extend data



- **NEW EKF Soil Moisture analysis**

Drusch et al. (2009) De Rosnay et al. (2010)

Extended Kalman Filter developed for soil moisture analysis

- **NEW OI Snow analysis**

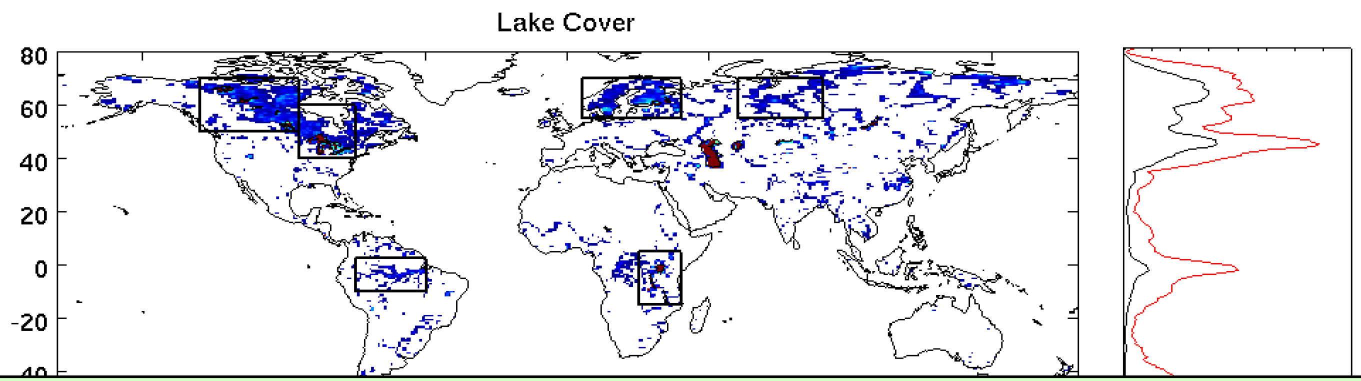
Drusch et al. (2009) De Rosnay et al. (2010) Extended Kalman Filter developed for soil moisture

- Potential for re-analysis to exploit land surface satellite data, such as long time series of soil moisture data (e.g. ASCAT).
- Potential to extend the surface analysis to use vegetation parameters from satellite data (e.g. AVHRR).
- Stand alone surface analysis: opens the possibility to run re-analysis at high resolution for land surfaces.

ECMWF

Lake modelling

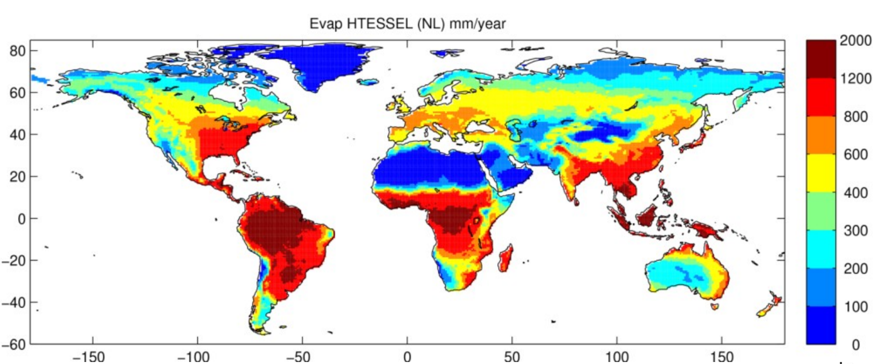
Dutra et al. (2009), Balsamo et al (2009), *Boreal Env. Res.*

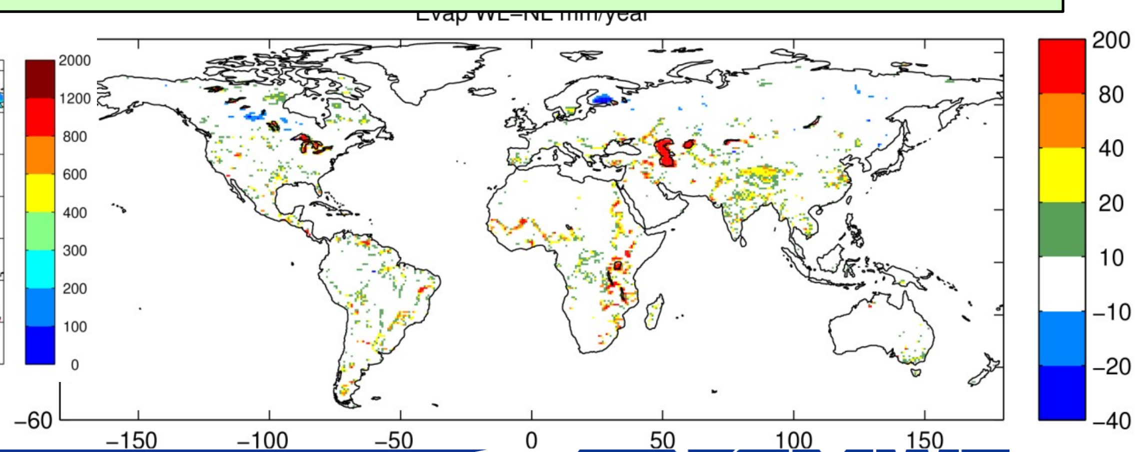


- FLAKE Lake model was tested in CY35R3.
- Evaporation rates were increased in temperate climate

This studies have been using ERA-Interim 1989-present as a 3-hourly forcing dataset to test the introduction of lakes in HTESSEL in offline mode (similarly to GSWP-type experiment).

This made possible to compare the and surface models output with recent satellite data in particular MODIS-based lake surface temperatures available from 2000. FLAKE-HTESSEL





A roadmap to implementation

- **In order to add the lake modelling component into the IFS, initialization is required for ancillary fields:**

  - lake cover (fraction of a given grid box of an atmospheric model covered by lake water), and
  - lake depth (mean depth of lakes present in a given grid box).

and for the prognostic variables:

- mixed-layer temperature,
- mixed-layer depth,
- bottom temperature (temperature at the water-bottom sediment interface),
- mean temperature of the water column,
- shape factor with respect to the temperature profile in the thermocline,
- temperature at the ice upper surface, and
- ice thickness

The lake depth

- Several authors have shown that lake depth is a crucial parameter.
- Balsamo et al. (2010) and Dutra et al. (2010) have shown that a lake depth tuning would be possible in absence of depth data but present the caveat of model dependency.

Table 1: Subset of European lake-depth dataset (developed by E. Kourzeneva) for all lak larger than 100 km2 and at least 80% coverage by MODIS data. Subset of European lake v1.0 by E. Kourzeneva

N	latitude	longitude	d_{mean}	d_{max}	Area*	Name of the lake (
1	63.12	25.67	6.50	66.20	502.00	Nimetön
2	62.80	29.72	11.80	58.60	279.70	Höytiäinen
3	66.16	28.73	4.60	42.00	240.20	Yli-Kitka
4	62.60	26.54	10.80	56.00	186.90	Konnevesi
5	62.97	30.79	10.80	47.40	169.60	Koitere
6	62.82	26.98	17.20	34.50	164.90	Iisvesi
7	63.09	25.16	8.40	45.00	156.20	Kivijärvi
8	60.99	22.32	5.50	26.20	154.00	Pyhäjärvi
9	65.03	29.11	21.50	43.00	152.70	Kiantajärvi (N43199.30)
10	62.72	29.30	6.00	58.30	135.40	Viinijärvi
11	64.13	29.19	14.50	29.00	102.00	Ontojärvi
12	63.30	25.74	8.70	66.00	101.30	Kolima
13	61.98	35.22	30.00	120.00	9690.00	Onega
14	58.12	38.67	5.60	30.40	4550.00	Rybinskoe
15	58.02	28.07	7.10	16.60	3512.00	Chudsko-Pskovskoe
16	63.60	34.60	7.40	20.50	1270.00	Vygozerskoe
17	58.35	31.63	2.70	4.50	1110.00	Ilmen
18	65.70	32.00	16.00	56.00	986.00	Topozero (Tuoppajärvi)
19	51.00	30.50	4.00	18.40	922.00	Kievskoe
20	67.93	32.97	12.80	67.00	876.00	Imandra
21	63.17	33.93	29.00	103.00	815.00	Segozerskoe
22	65.05	31.57	11.00	36.00	655.00	Yushkozerskoe
23	62.00	34.00	6.00	12.00	547.00	Vygozero
24	62.23	36.88	2.20	18.00	367.00	Vodlozerskoe
25	60.20	37.70	1.80	5.60	351.00	Lacha
26	67.55	34.33	57.50	115.00	313.00	Umbozero
27	61.88	33.32	6.50	24.00	266.00	Syanmozero
28	58.30	26.00	2.50	5.60	259.00	Vyrtsyarv
29	64.95	30.55	8.50	44.00	240.00	Verhneekujto
30	67.98	35.08	5.70	35.00	223.00	Lovozero
31	66.05	31.80	8.00	41.00	209.00	Tikshezero
32	61.00	31.00	46.9	230.00	17800.00	Ladoga
33	62.60	33.75	9.50	58.00	185.00	Sandalskoe
34	63.83	30.82	8.50	34.00	166.00	Leksozero
35	59.70	39.30	1.30	2.00	166.00	Kubenskoe
36	65.78	33.93	4.50	18.00	122.00	Engozero
37	62.52	33.67	18.50	74.00	109.00	Pale (Palzerskoe)
38	53.48	12.44	6.60	28.10	102.70	Fleesensee
39	53.37	-9.09	5.00	46.00	173.80	Corrib
40	52.92	-8.33	7.60	36.00	117.50	Derg
41	60.50	10.36	65.50	131.00	140.10	Randsfjorden
42	53.74	21.75	5.80	23.40	113.40	Sniardwy
43	58.90	13.25	27.00	106.00	5648.00	Vänern
44	58.32	14.56	39.90	128.00	1856.00	Vättern
45	59.52	17.03	11.90	61.00	1140.00	Mälaren
46	59.22	15.77	6.10	22.00	478.00	Hjäelmaren
47	54.60	-6.50	8.90	34.00	385.00	Neagh

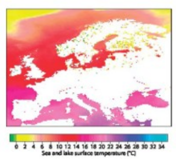


Figure 3 Example of LWST/SST of L3 MODIS product at 4-km resolution

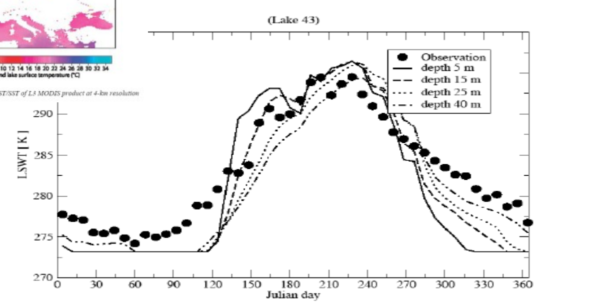


Figure 1 Mean annual cycle of LWST simulated by FLake on Lake Vanern (No. 43 in Table 1) for specified lake depths of 5, 15, 25 and 40 m.

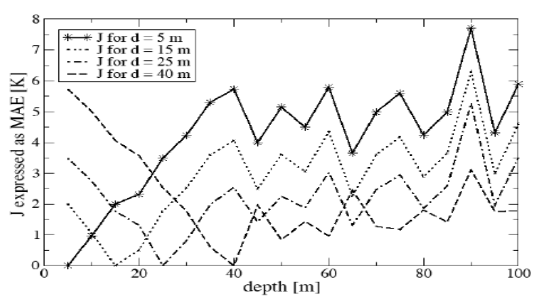


Figure 2 Cost function J expressed as Mean Absolute Error (MAE) between the model LWST and the simulated LWST observations for Lake Vanern (No. 43 in Table 1). Simulated LWST observations are generated assuming a 'true' lake depth of 5, 15, 25 and 40 m (consistently with Fig. 1). The existence of a single minimum of the cost function coincident with the 'true' lake depth is verified for all four depths

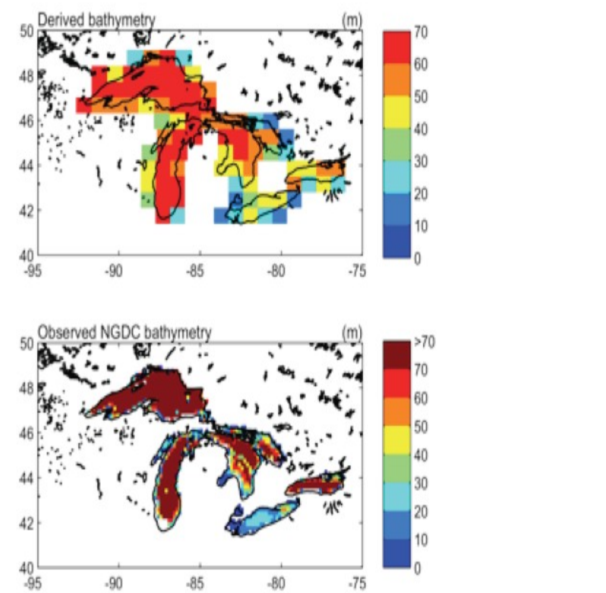
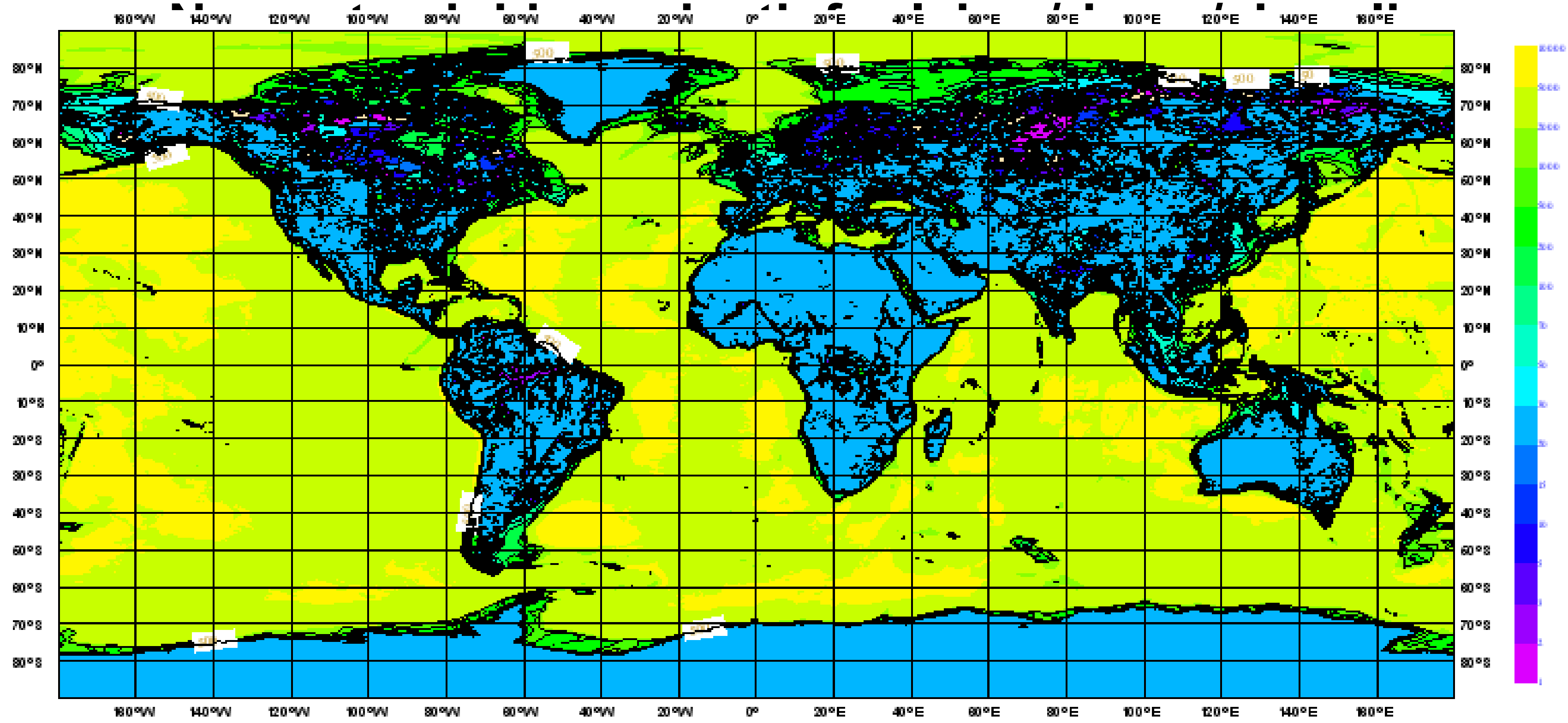


Figure 7: Derived bathymetry of the American Great Lakes at ERA-Interim model resolution (top panel) as compared to the NGDC observed bathymetry, limited to 70 m (bottom panel).

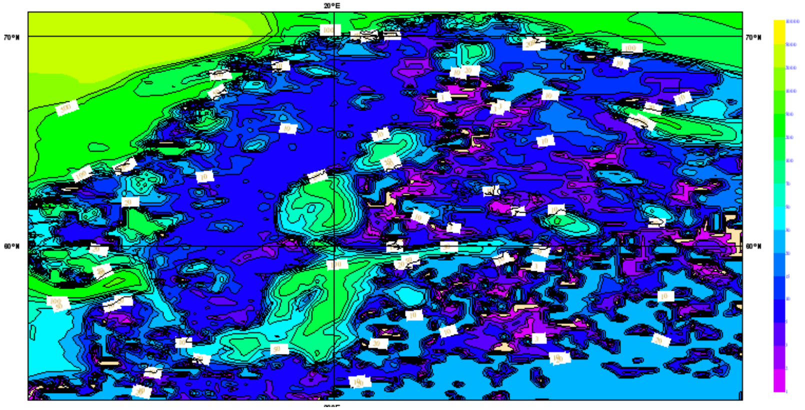
The lake depth (II)

- A new 1km dataset was produced (Kourzeneva, 2009)
- Combined with the ETOPO-5km bathymetry and with the a Caspian Sea bathymetry (Cavalieri, 2008)
  - background value of 25m

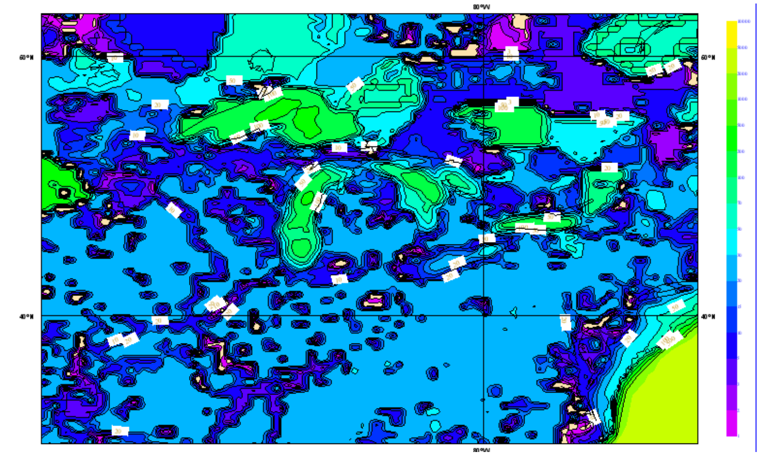


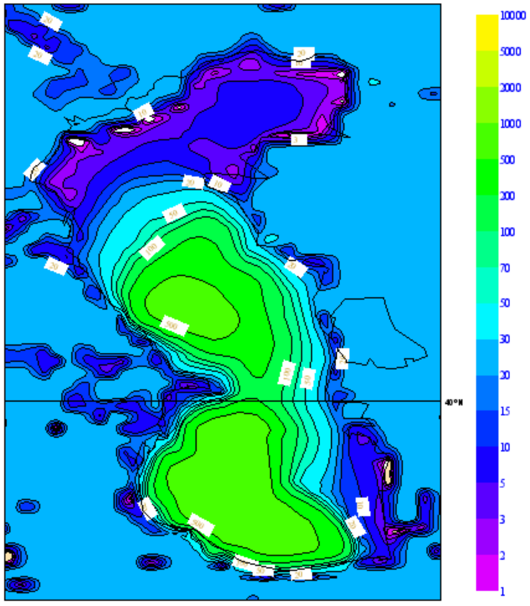
The lake depth (III)

Scandinavia&Baltic



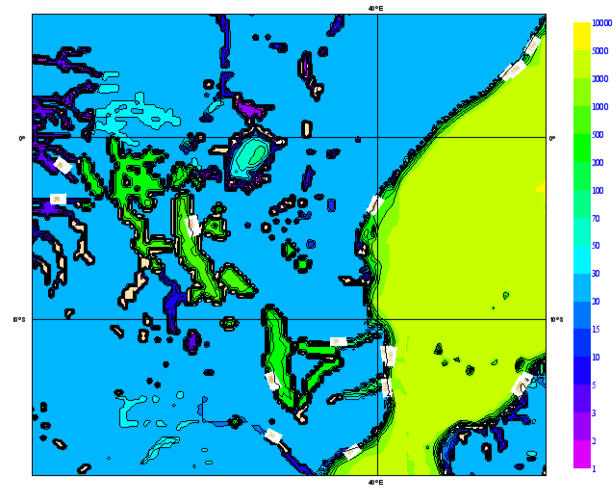
American Great Lakes





Caspian Sea

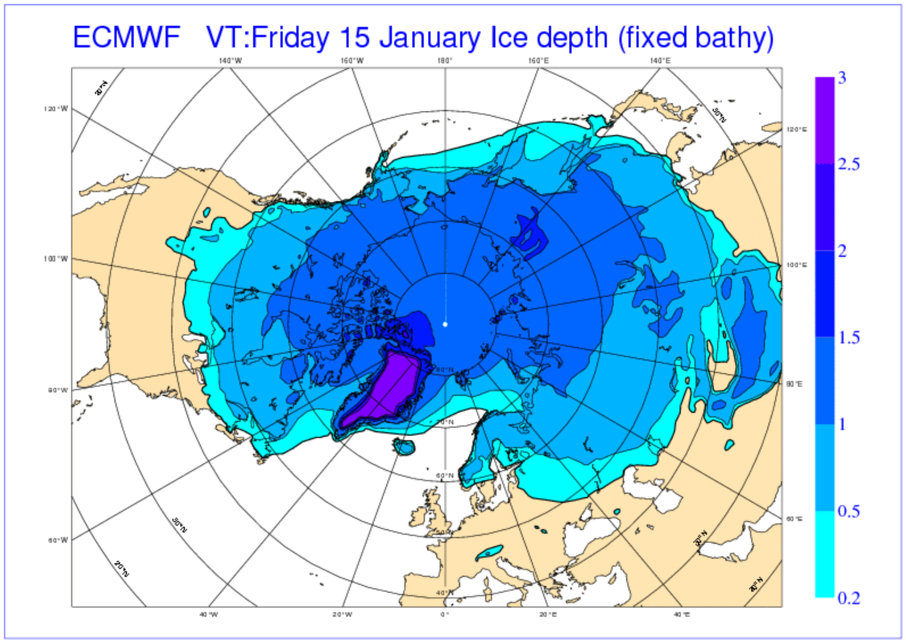
Lake Victoria

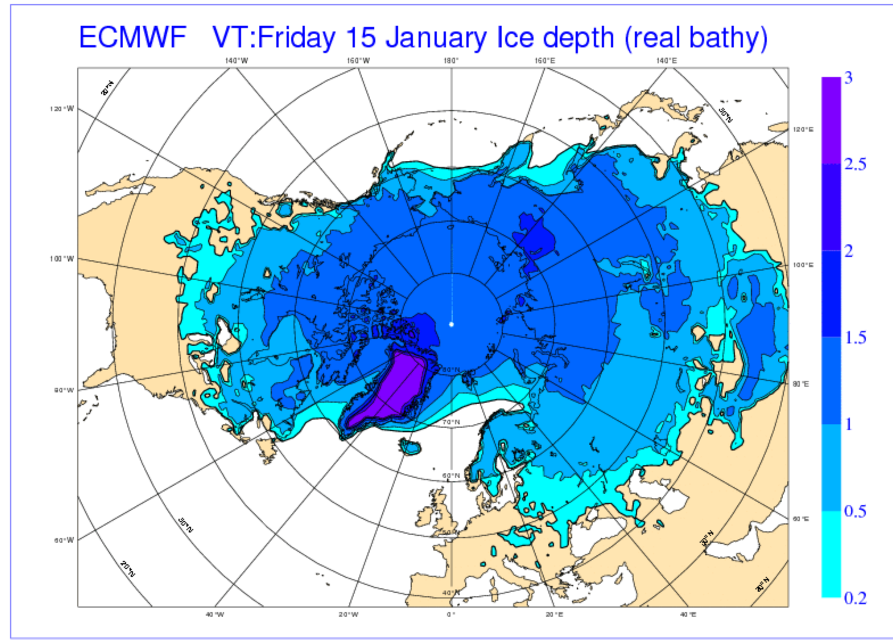


A 20-year long FLAKE-HTESSEL run

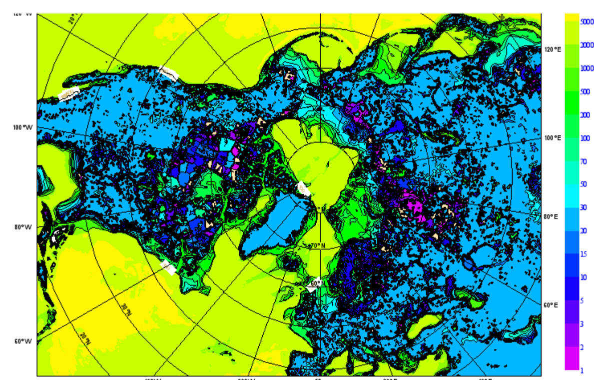
- In order to create initial conditions for the FLAKE-HTESSEL model for all points/resolutions, a long offline integration is performed
- Each grid-point on the globe is set to be a lake (strong test) LAKEPLANET experiment, using the lake/ocean depth previously obtained.
- The ERA-Interim 3-hourly forcing at T255 resolution (about 80 km) is used to drive FLAKE-HTESSEL
- The advantage of this model output is a set of spatially continuous lake model output which can be interpolated into higher resolution grid.
- The output is also resilient to changes of the land-sea mask or lake cover dataset.
- NOTE: see the presentation by Rui Salgado for indepth look

Impact of lake depth on offline mean lake ice depth





Fixed 25m depth



A roadmap to implementation

- In order to add the lake modelling component into the IFS, initialization is required for ancillary fields:

  - lake cover (fraction of a given grid box of an atmospheric model covered by lake water), and
  - lake depth (mean depth of lakes present in a given grid box).

and for the prognostic variables:

- mixed-layer temperature,
- mixed-layer depth,
- bottom temperature (temperature at the water-bottom sediment interface),
- mean temperature of the water column,
- shape factor with respect to the temperature profile in the thermocline,
- temperature at the ice upper surface, and
- ice thickness

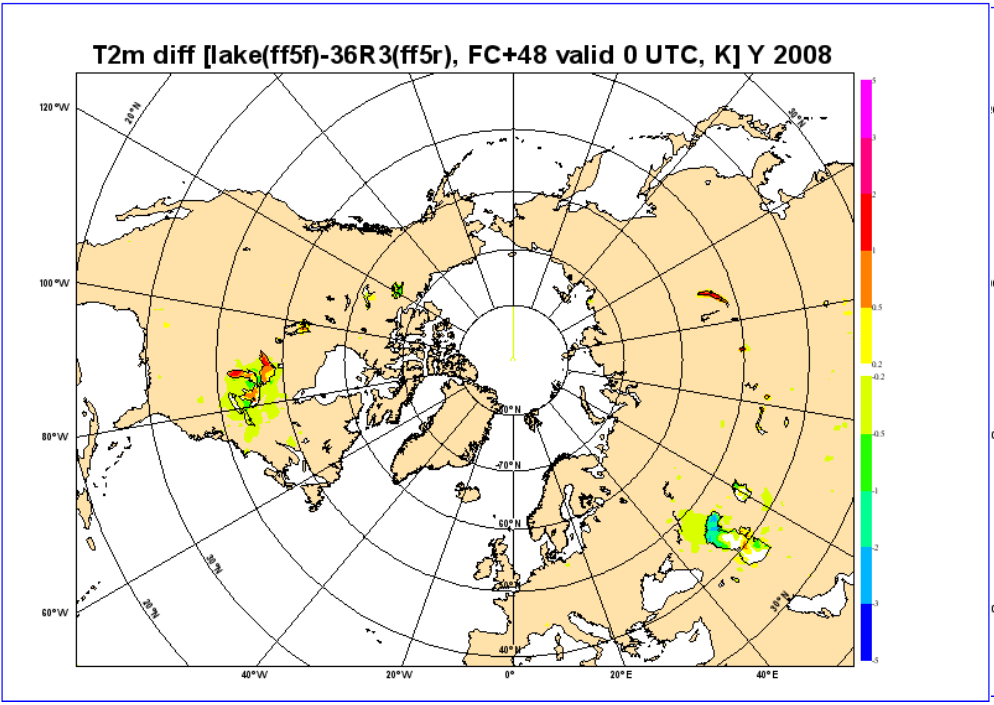
Due to the global continuity of the LAKEPLANET output the Initial conditions can be interpolated onto all resolution used by the IFS (from T21 to T2047).

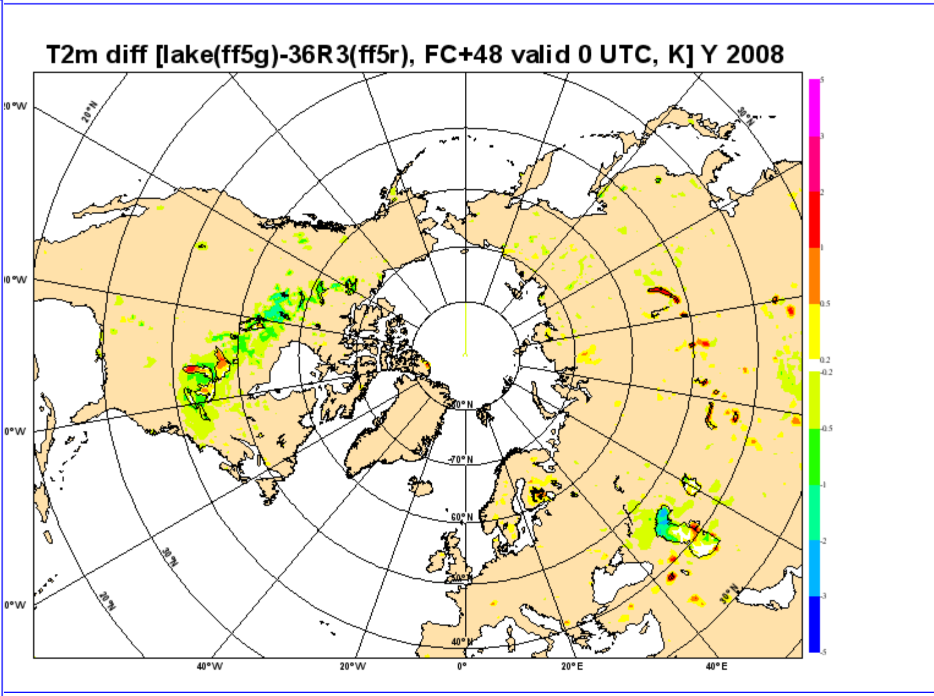
Coupled lake-land atmosphere experiments

- Forecast runs
  - 37 10-day forecasts spaced one every 10 days covering 2008 are run at resolution T399 (about 50km) initialized with the operational IFS analysis for all variables.
  - Lake initial conditions are provided by the LAKEPLANET simulations with “realistic” lake depth and forced by ERA-Interim near-surface meteorology at T255 (about 80 km) interpolated onto T399 target resolution
- Climate runs
  - 4 members AMIP-type experiment where the IFS model is integrated for 13-months (from August 2001) at T159 (about 125 km). Initial conditions are provided by ERA-Interim together with daily SSTs.
  - Lake initial conditions provided by the LAKEPLANET simulation

Forecasts experiments: Sensitivity (2008)

Resolved lakes only | **Resolved +Unresolved lakes**



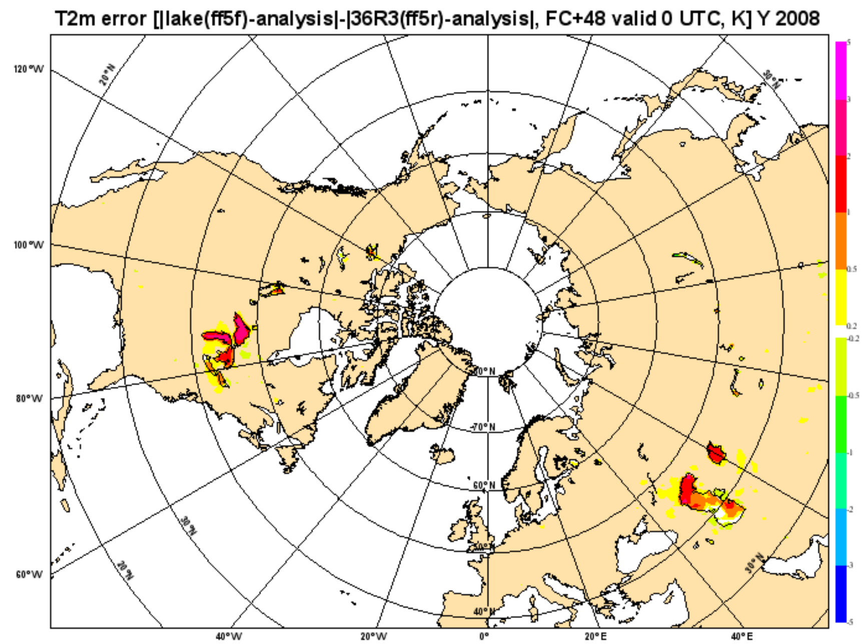


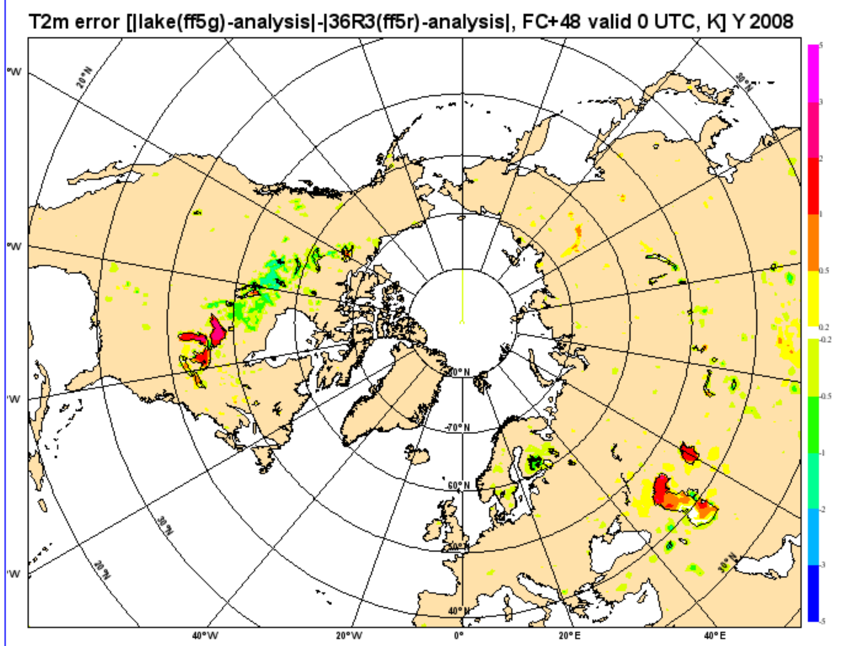
The sensitivity of 2m temperature forecasts (FC+48 shown here) see a co-located cooling over lakes (expect the Great Lakes). The addition of unresolved lakes extend the impact on large part of Northern Canada (where sub-grid lakes are vastly present).

Forecasts experiments: Impact (2008)

Resolved lakes only

Resolved +Unresolved lakes

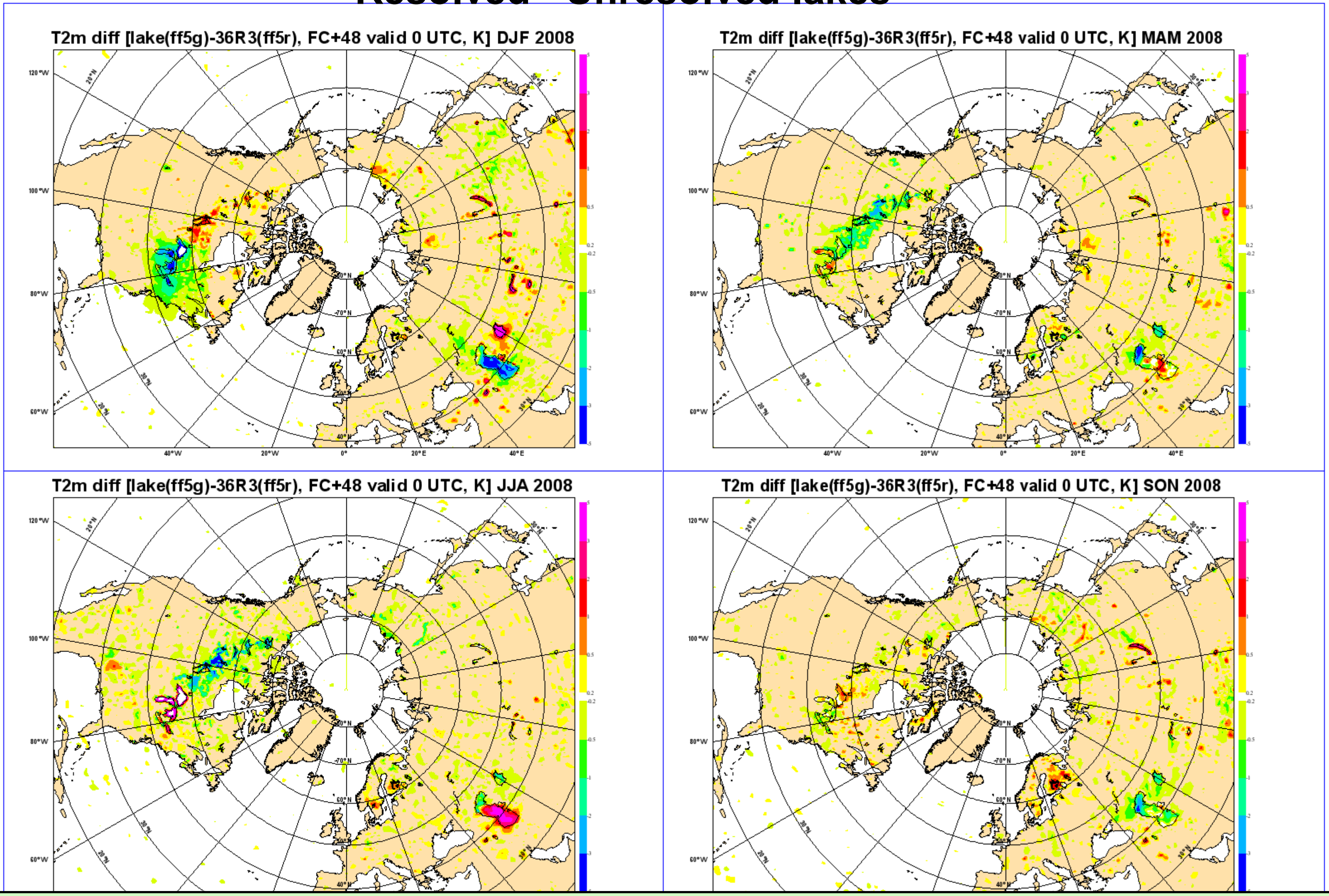




The impact evaluated against the operational 2m temperature analysis indicate an improvement (Mean Absolute Error reduction) over lakes (expect the Great Lakes and Caspian). The addition of unresolved lakes extend the positive impact on large part of Northern Canada and in the vicinity of Ladoga. Note: Green colour indicate 0.5-1.0K better

Forecasts experiments: sensitivity seasons

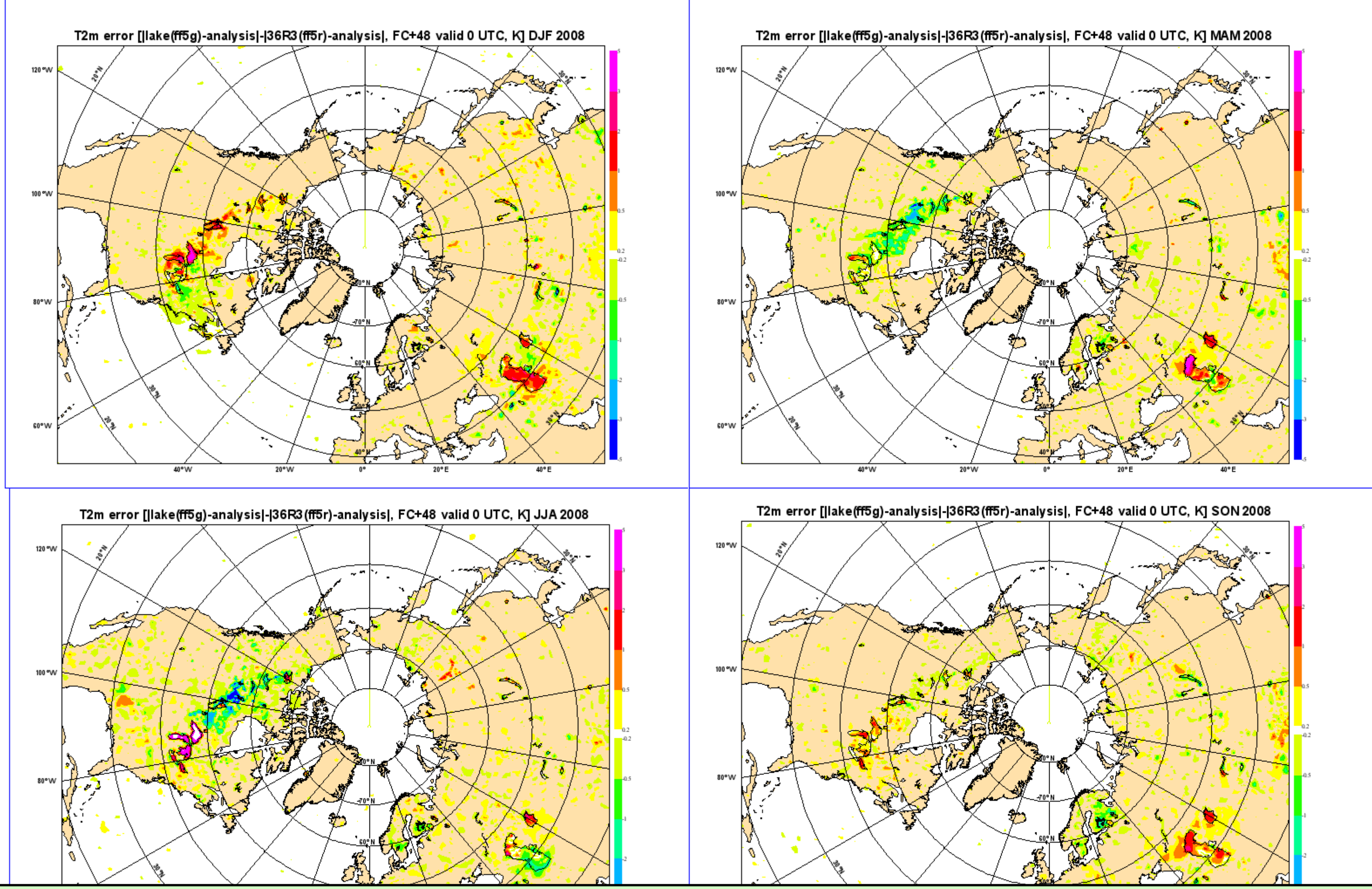
Resolved +Unresolved lakes



Mainly cooling in 2m temperature in Winter Spring and Summer over Canada. Warming Autumn effect over Scandinavia. Dipole in Winter between Central/Eastern Canada.

Forecasts experiments: Impact seasons

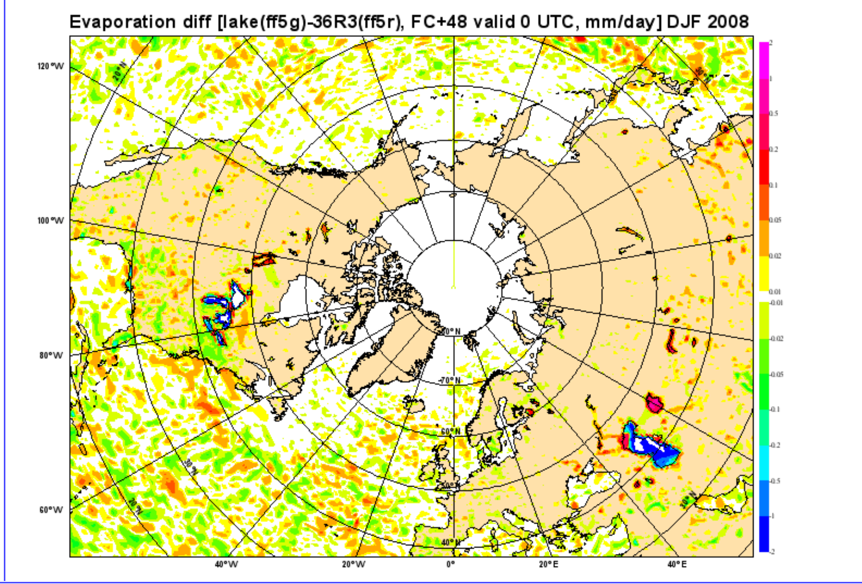
Resolved +Unresolved lakes

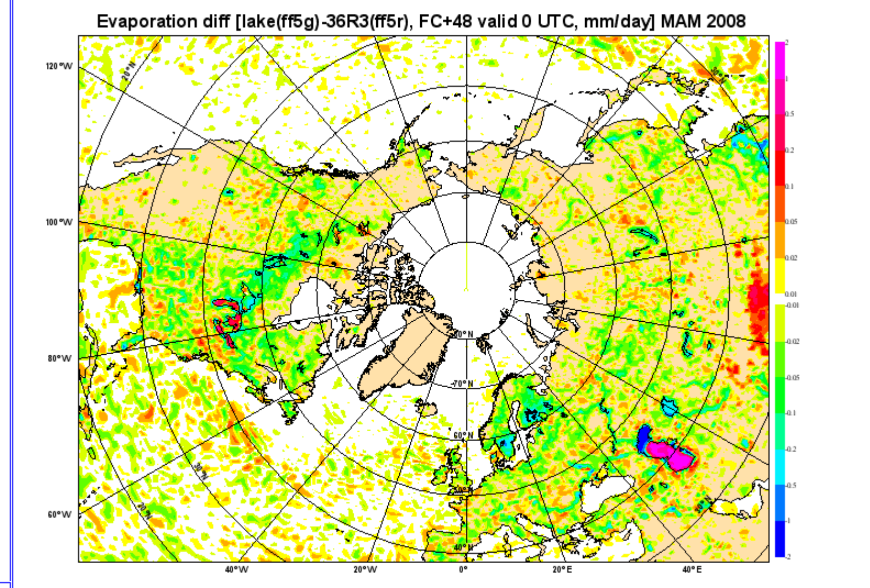


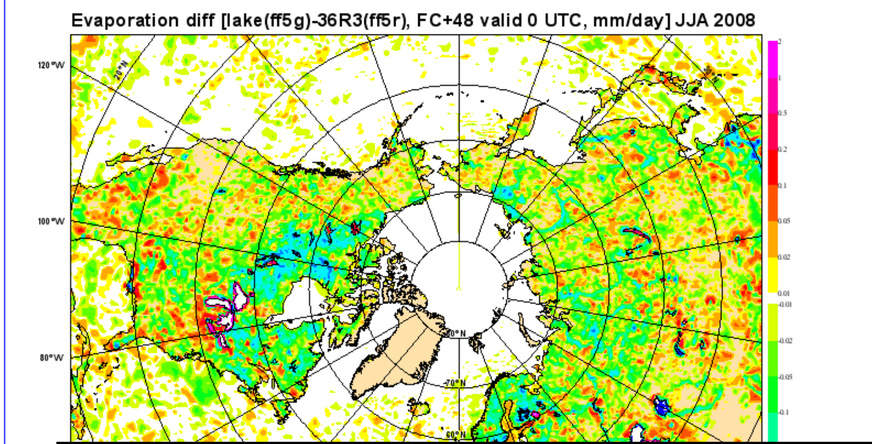
The largest positive impact is Spring over Canada and Autumn over Scandinavia. Small negative impact over central Canada in Winter (maybe related to lake ice initial conditions?). Positive winter impact east of the Great-Lakes (downwind lake effect?).

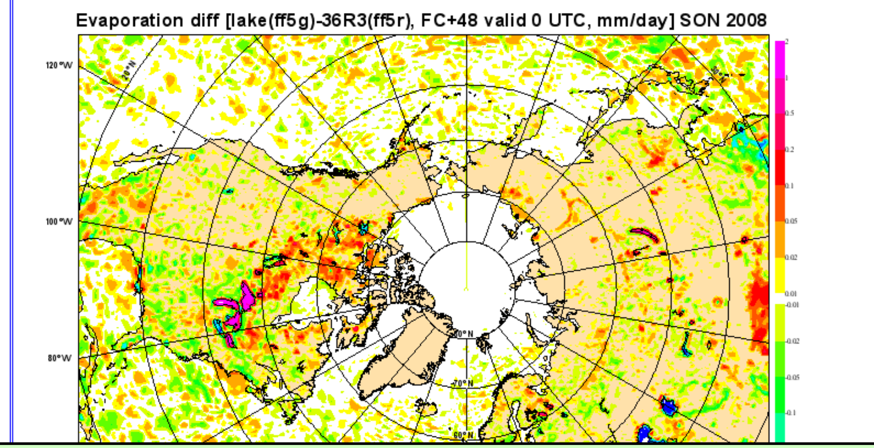
Forecasts experiments: Evaporation

Resolved +Unresolved lakes





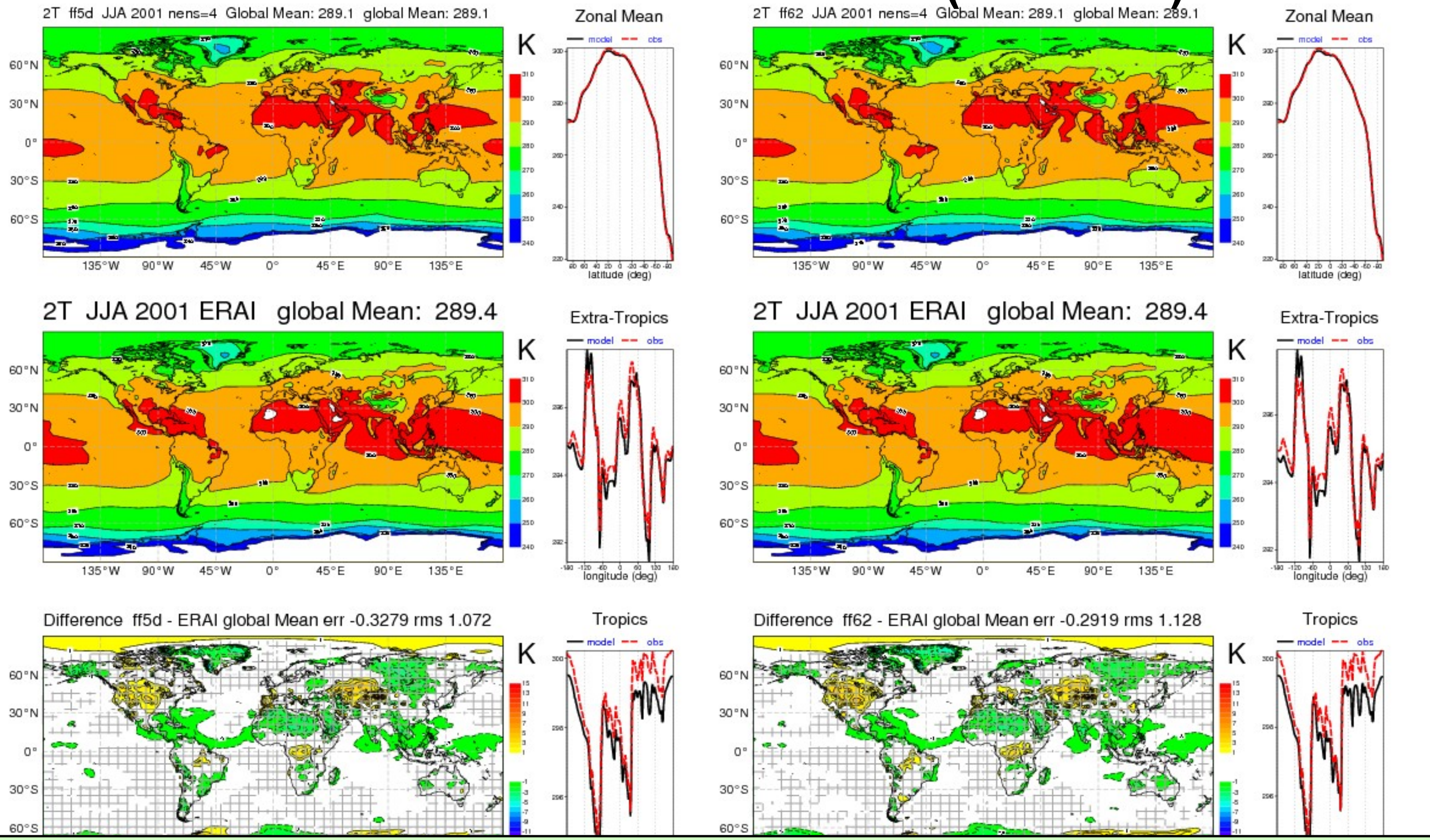




Evaporation is reduced in Spring/Summer and increased in Autumn. Overall it seems not an increased (unlike offline simulations possibly an unbalance in soil initial conditions?)

Climate (lake-coupled) experiments

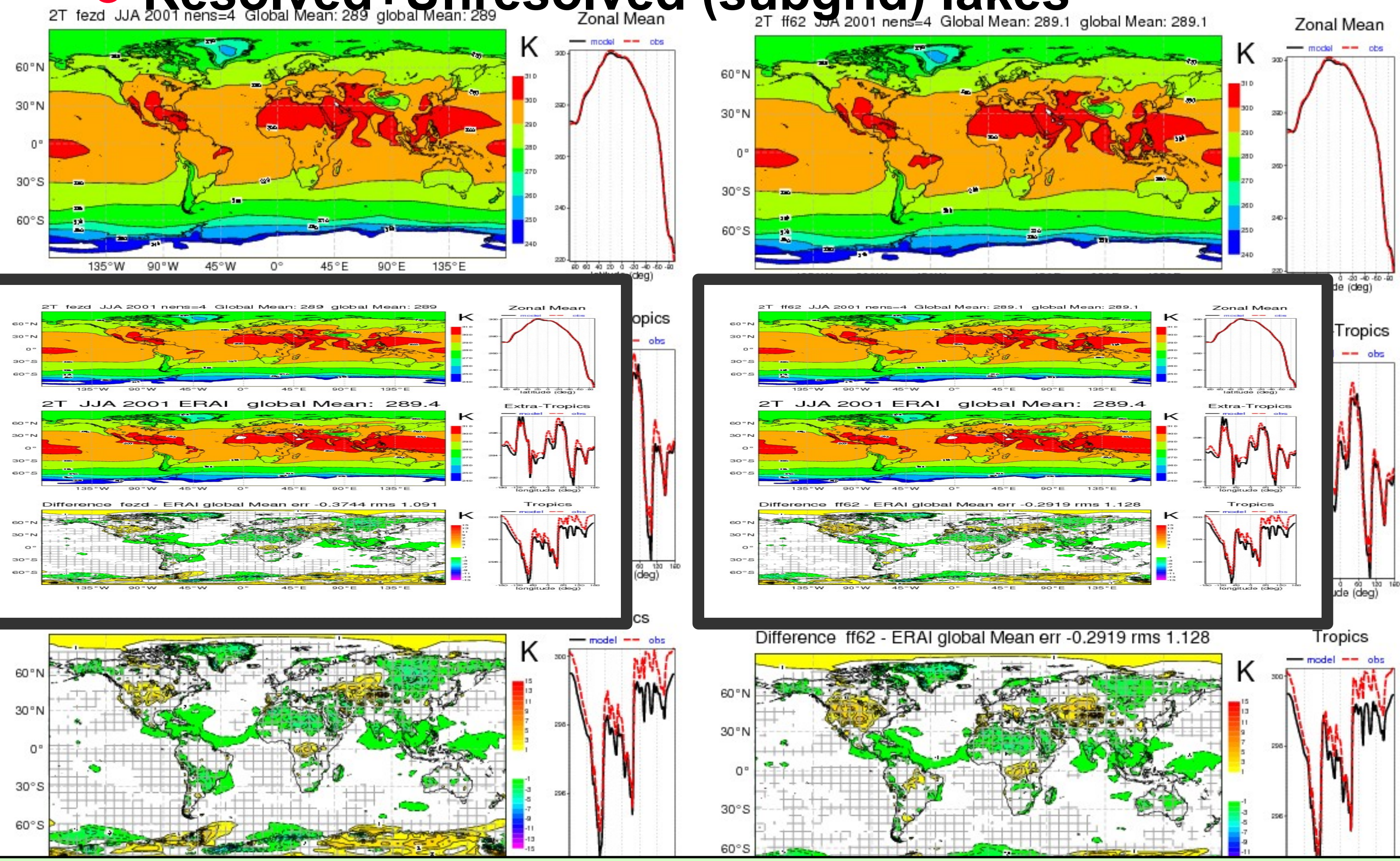
- **Resolved lakes vs. Control (no-lakes)**



Resolved lakes are expected to have very minor impact at T159 resolution as those concerns only 180 grid-points (Great-Lakes, Ladoga, Caspian, Aral, Victoria)

Climate (lake-coupled) experiments

- Resolved+Unresolved (subgrid) lakes



The summer North American impact on 2m temperature is confirmed in long coupled simulation although the signal is not passing the 95% significance (ensemble size of only 4-members)

Summary and Conclusions

- The land surface model at ECMWF successfully integrates FLAKE for both resolved and sub-grid lakes.
- A "cold-start" procedure (Lake-Planet) has been setup to initialize the lakes in any date between 1989 and present day and produce a monthly climatology
- Preliminary results from fully coupled atmospheric forecasts suggests that FLAKE can bring improvements on large portion of Canada and part of Scandinavia. Need to be confirmed by larger validation.
- The use of SSTs for Caspian and Great-Lakes is suggested for initializing the lake temperatures. Possible the extension to Baltic?
- Future tests will involve data assimilation cycles (autumn/winter 2010).
- The new surface analysis structure may allow for an assimilation of the 2m temperature analysis to correct for lake temperature errors.

THANK YOU FOR YOUR ATTENTION.