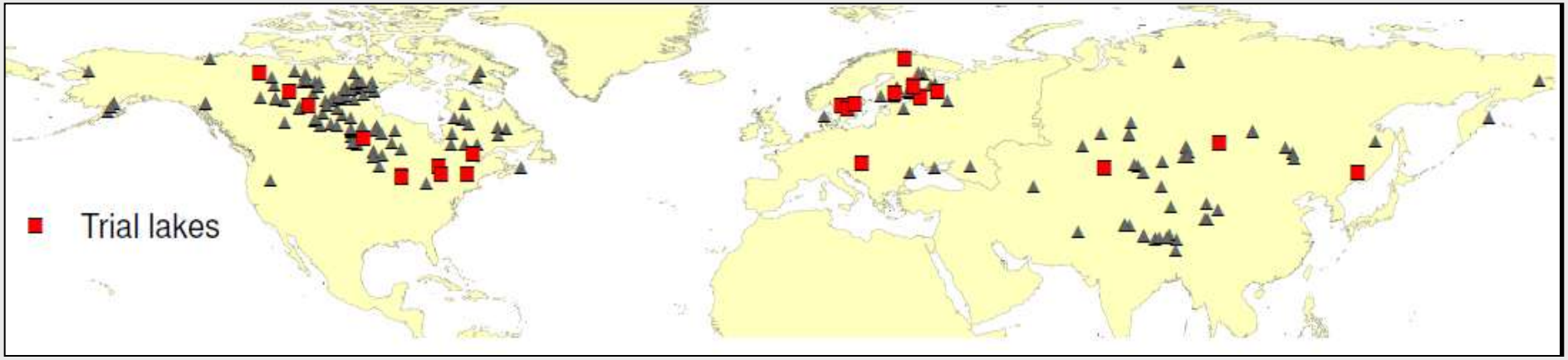
Tuning of *FLake* model using ARC lake observational data to determine LSWTs of 159 large temperate lakes



29º to 69º N

mean lake depths (< 1 to 680 m)

surface areas 100 - 32,000 km^2)

lake altitudes from -12 to >5000 m a.s.l.

salinity values up to 155 g/l

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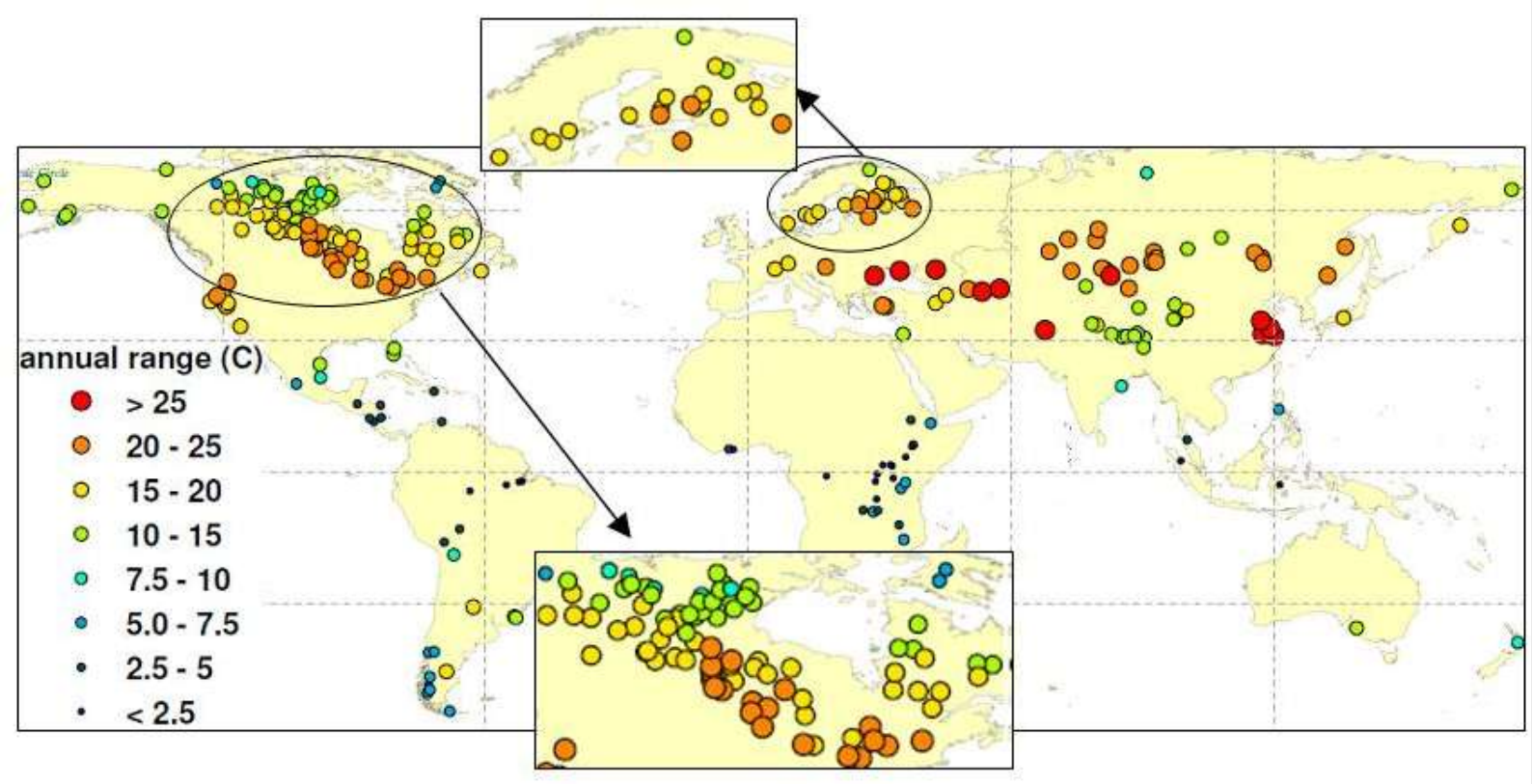
Observational data – ARC lake

- LSWTs of 247 globally distributed large lakes
- surface area > 500 km^2
- Along-Track Scanning Radiometers (ATSR)
- the period 1991 to 2011
- observations are made at ~1 km resolution and averaged to 5 km resolution



Why tune LSWT model?

- FIXED period of observational data (15-20 years)
- need for reliable and CONTINUOUS LSWTs
- Uses;
  - better representation of lakes in NWP models
  - Assess affect of meteorological changes on LSWTs
    - Climate studies
    - Ecological studies
  - LSWT trends and climatology evaluation

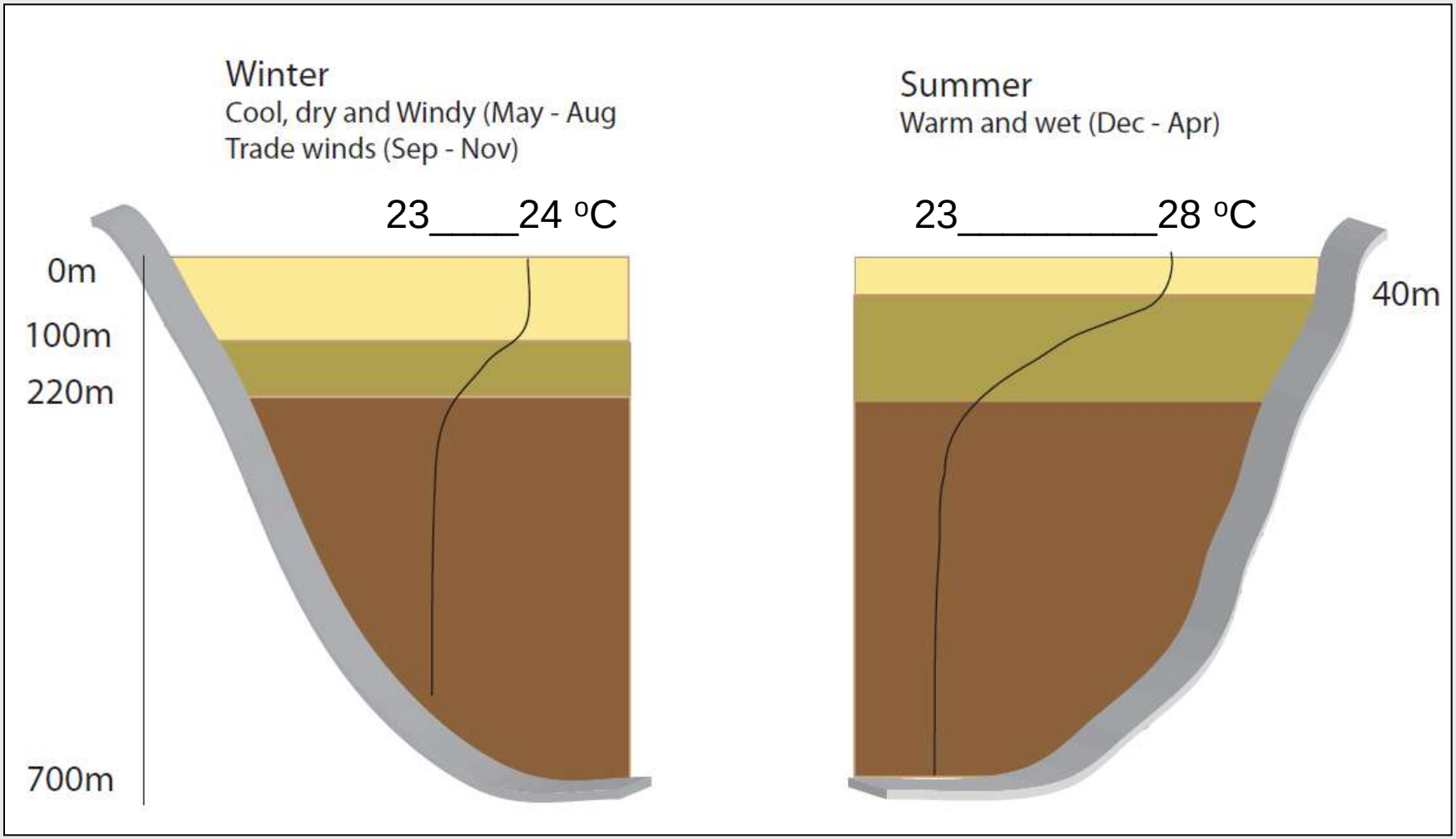
The model - *FLake*

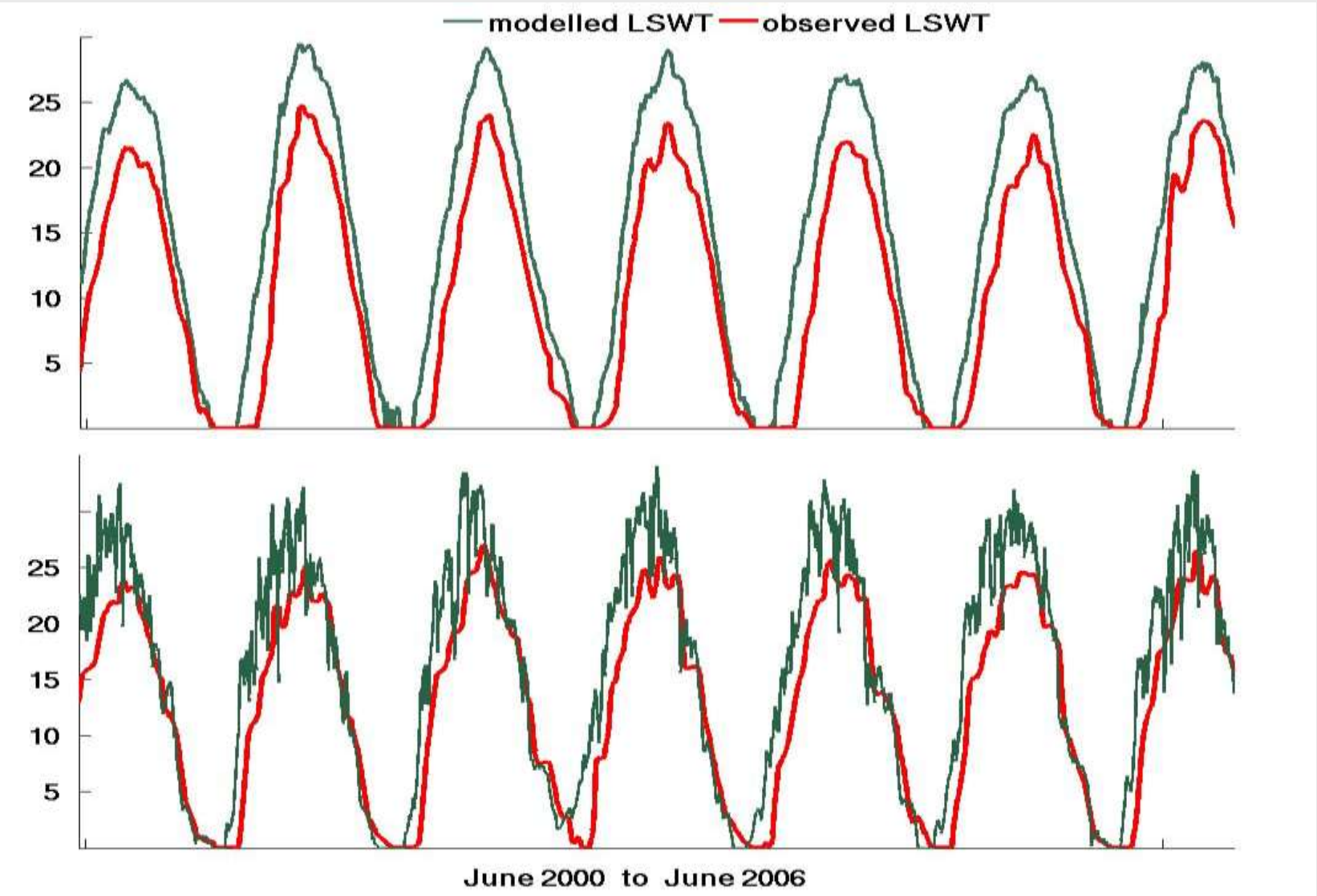
- 1d model predicts the vertical temperature structure and mixing

- forced with ECMWF ERA-Interim (>33 yrs)
  - **wind**, air temp, solar, cloud and vapour pressure

- lake-specific input parameters
  - ***Light extinction, depth, snow and ice albedo***

- outputs determined by the budgets of heat and kinetic energy


Winter
Cool, dry and Windy (May - Aug
Trade winds (Sep - Nov)
23____24 ºC
0m
100m
220m
700m
Summer
Warm and wet (Dec - Apr)
23_____28 ºC
40m

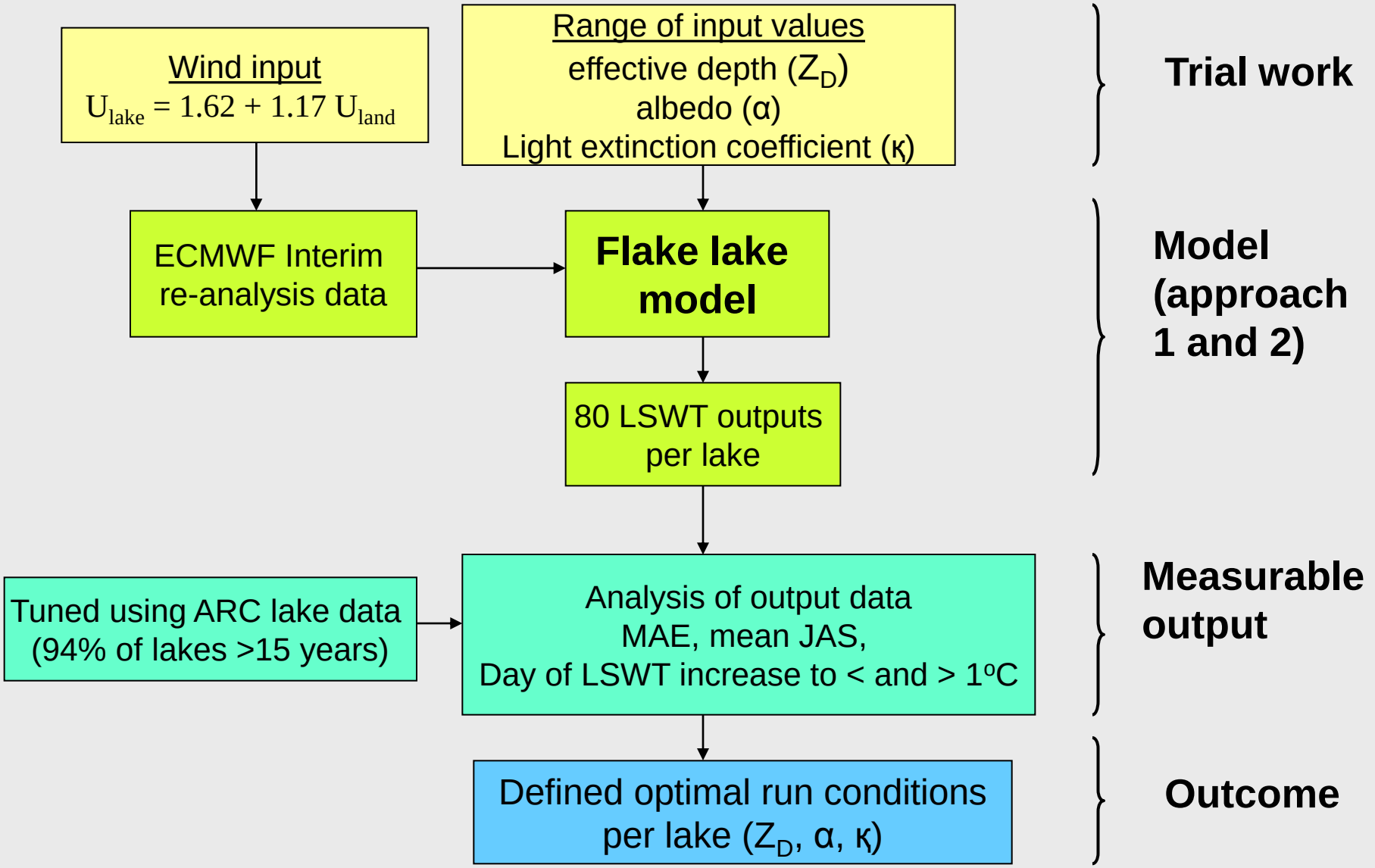


Lake Simcoe

Lake Balaton

	MAE (°C)	JAS (°C)	1 °C warming (day)
Simcoe	3.85	+4.97	-34
Balaton	3.59	+2.96	-30

Overview


Wind input
$U_{lake} = 1.62 + 1.17\ U_{land}$
Range of input values
effective depth (Z_D)
albedo (α)
Light extinction coefficient (ϰ)
Trial work
ECMWF Interim re-analysis data
Flake lake model
80 LSWT outputs per lake
Model (approach 1 and 2)
Tuned using ARC lake data (94% of lakes >15 years)
Analysis of output data
MAE, mean JAS,
Day of LSWT increase to < and > 1°C
Measurable output
Defined optimal run conditions per lake (Z_D, α, ϰ)
Outcome

Wind Trials

Trial	Light extinction coefficient κ	Albedo			Lake depth Z_D
		α	Snow & white ice	Melting snow and blue ice	
1-3	derived from secchi disk	α1	0.60	0.10	Z_D1 (mean depth)

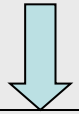
Wind input	**No wind adjustment**	**wind x 1.2**	**1.62 + 1.17 U_{land}**
Daily MAE (°C)	3.07 +/-2.25	2.66 +/-1.93	2.02 +/-1.30
Mean JAS (°C)	+3.71 +/-3.51	+3.07 +/-3.41	+1.87 +/-2.93
1°C cooling (days)	+12.0 +/-39.6	+7.9 +/-33.3	+1 +/-30.5
1°C warming (days)	- 27.1 +/-29.7	- 23.6 +/-22.7	- 20.3 +/-18.4

Optimization approach 1

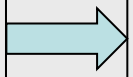
Light extinction coefficient **κ**				Albedo			Effective depth Z_D
				α	Snow & white ice	Melting snow and blue ice	
κ	375nm	475nm	700nm				
κ1	0.038	0.018	0.56	α1	0.60	0.10	Z_D1
κ2	0.052	0.025	0.57	α2	0.80	0.60	Z_D2 (Z_D1*0.75)
κ3	0.066	0.033	0.58	α3	0.80	0.40	Z_D3 (Z_D1*0.50)
κ4	0.122	0.062	0.61	α4	0.60	0.30	Z_D4 (Z_D1*1.50)
κ5	0.22	0.116	0.66				

134 lakes – good results

25 lakes – poor results



- 1°C cooling day > 15 days early
- JAS LSWT cooler by > 2 °C



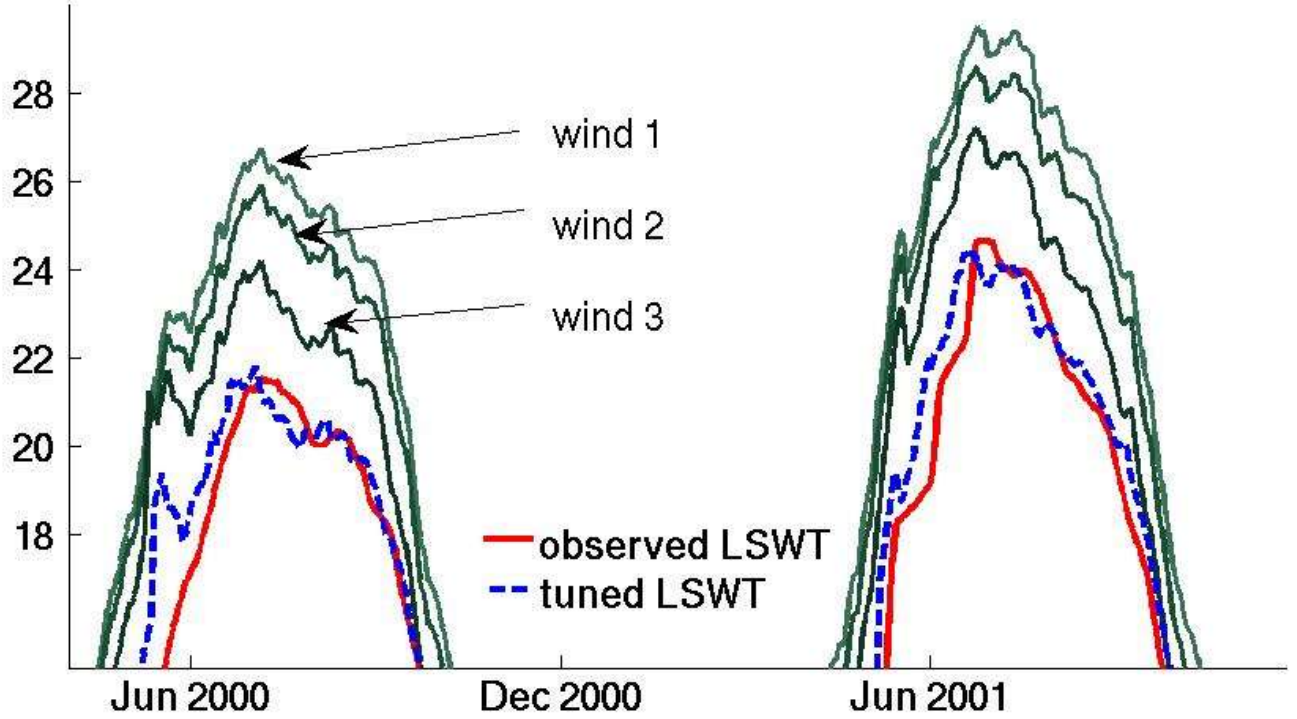
Optimization approach 2

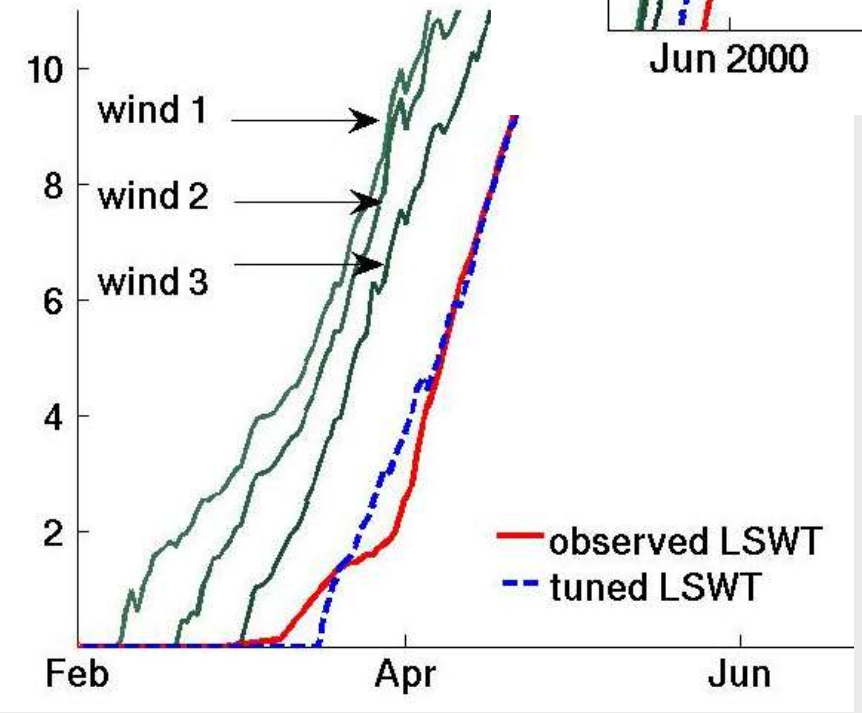
Z_D x 1.5 to Z_D x 4
2 **coastal** ocean

Tuned model - results

Measured output	21 lakes	Approach 1 (134 lakes)	Approach 2 (25 lakes)
Daily MAE (°C)	0.84 +/- 0.51	0.74 +/-0.48	1.11 +/-0.56
Mean JAS (°C)	+0.12 +/- 1.09	-0.01 +/-1.11	- 0.33 +/-1.22
1°C cooling (day)	+1.6 +/- 12.8	-1 +/-8.7	-1.3 +/-6.9
1°C warming (day)	+0.2 +/- 10.65	+1 +/-12.7	- 1 +/-10.2

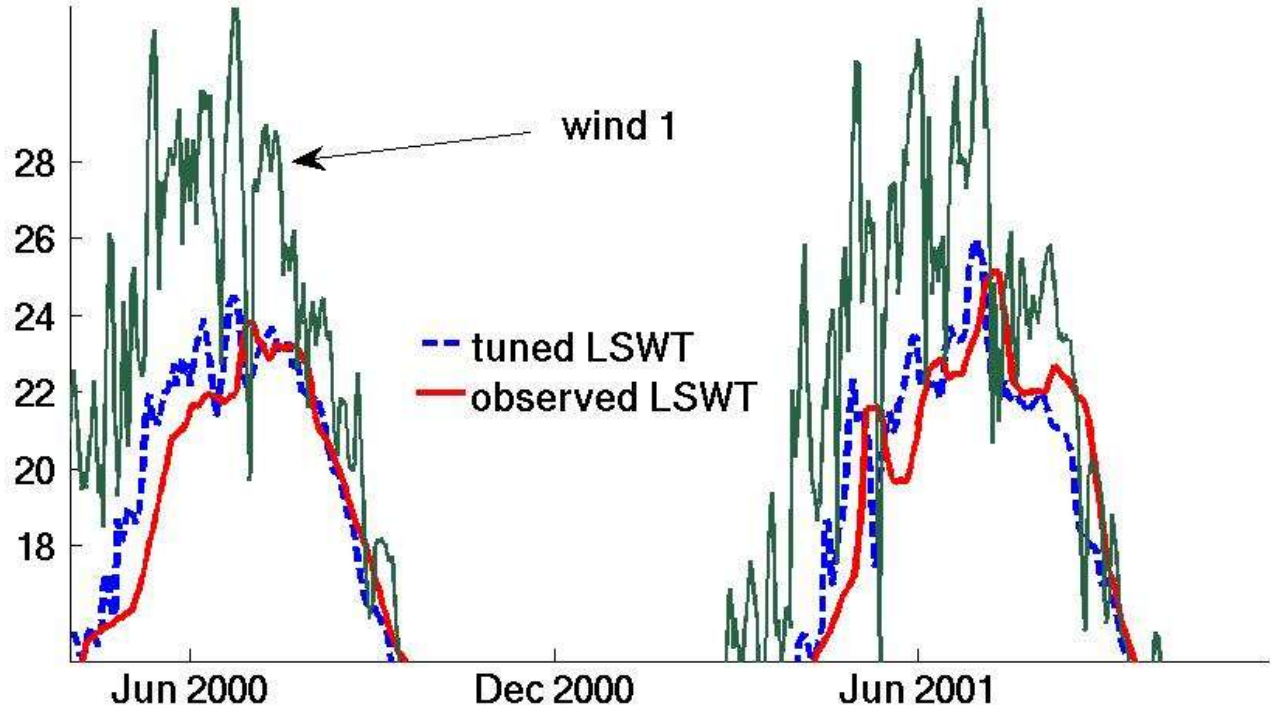
Lake Simcoe

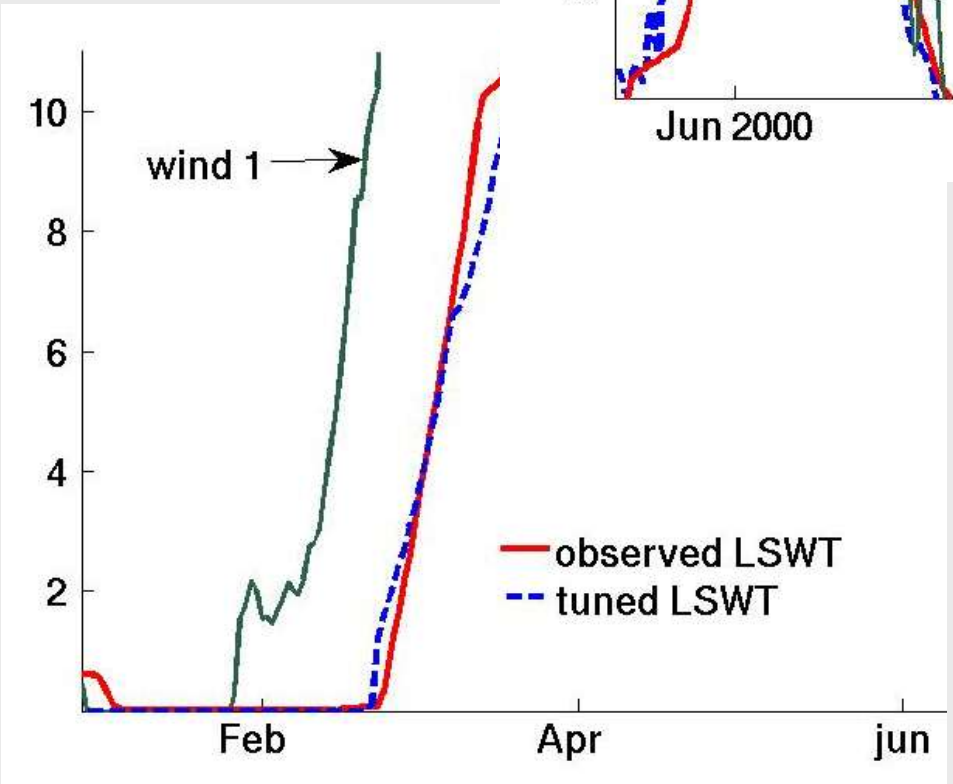




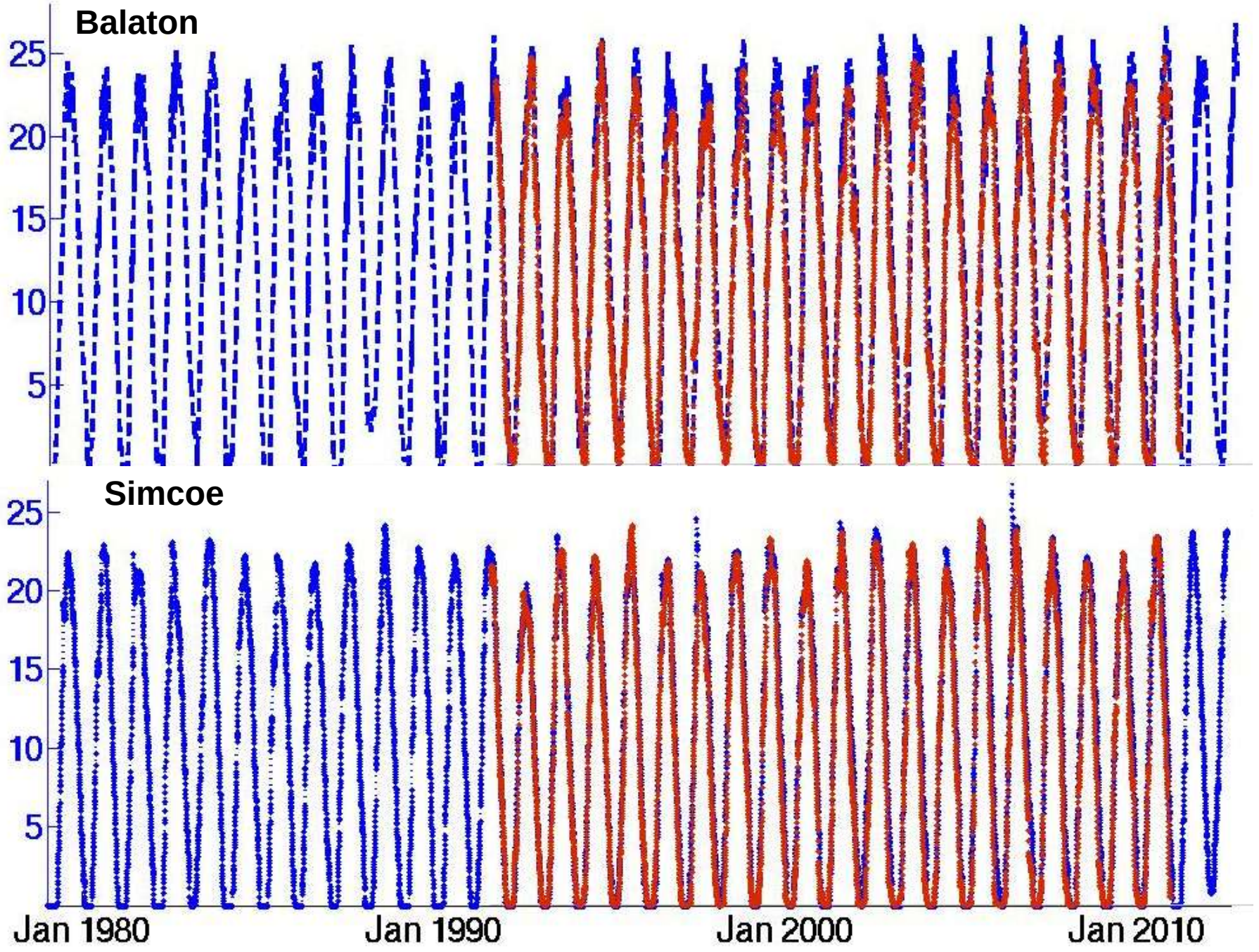
	Wind 1	**tuned**
MAE (^{o}C)	3.85	1.08
Mean JAS (^{o}C)	+4.97	+0.25
1 ^{O}C warming (day)	- 34	-4

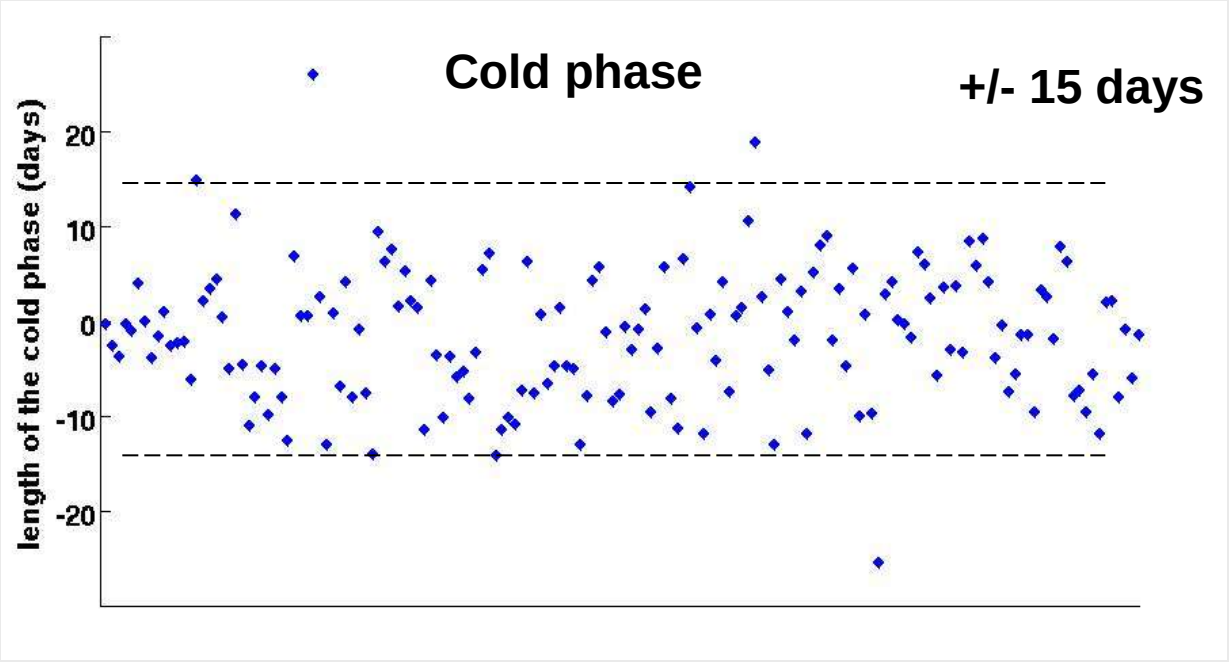
Lake Balaton



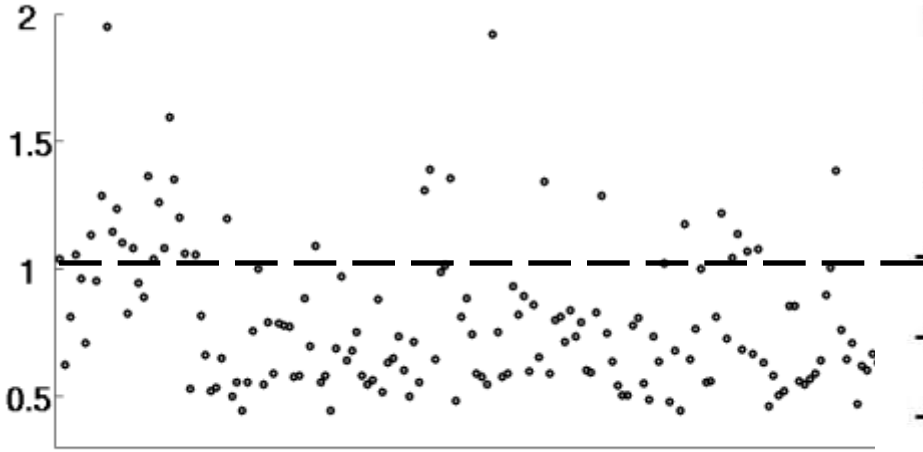


	Wind 1	**tuned**
MAE (^{o}C)	3.59	1.04
Mean JAS (^{o}C)	+2.96	+0.18
1 ^{O}C warming (day)	- 30	-4

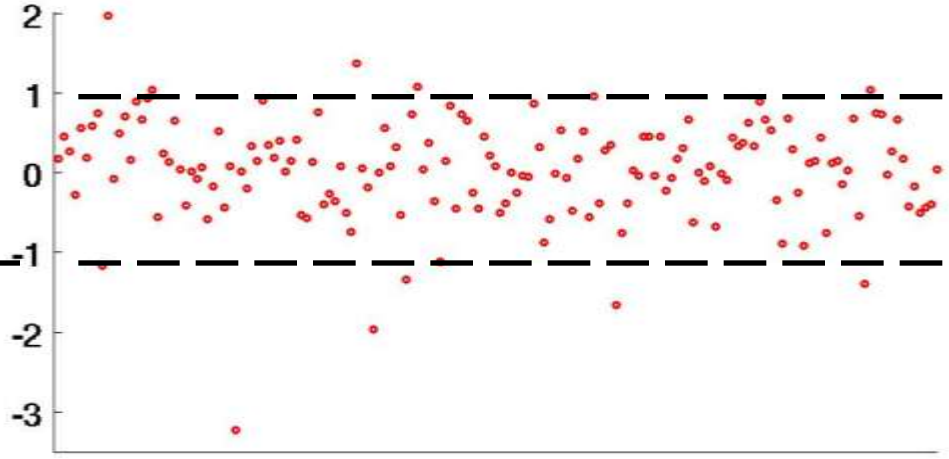

Balaton
25
20
15
10
5
Simcoe
25
20
15
10
5
Jan 1980
Jan 1990
Jan 2000
Jan 2010



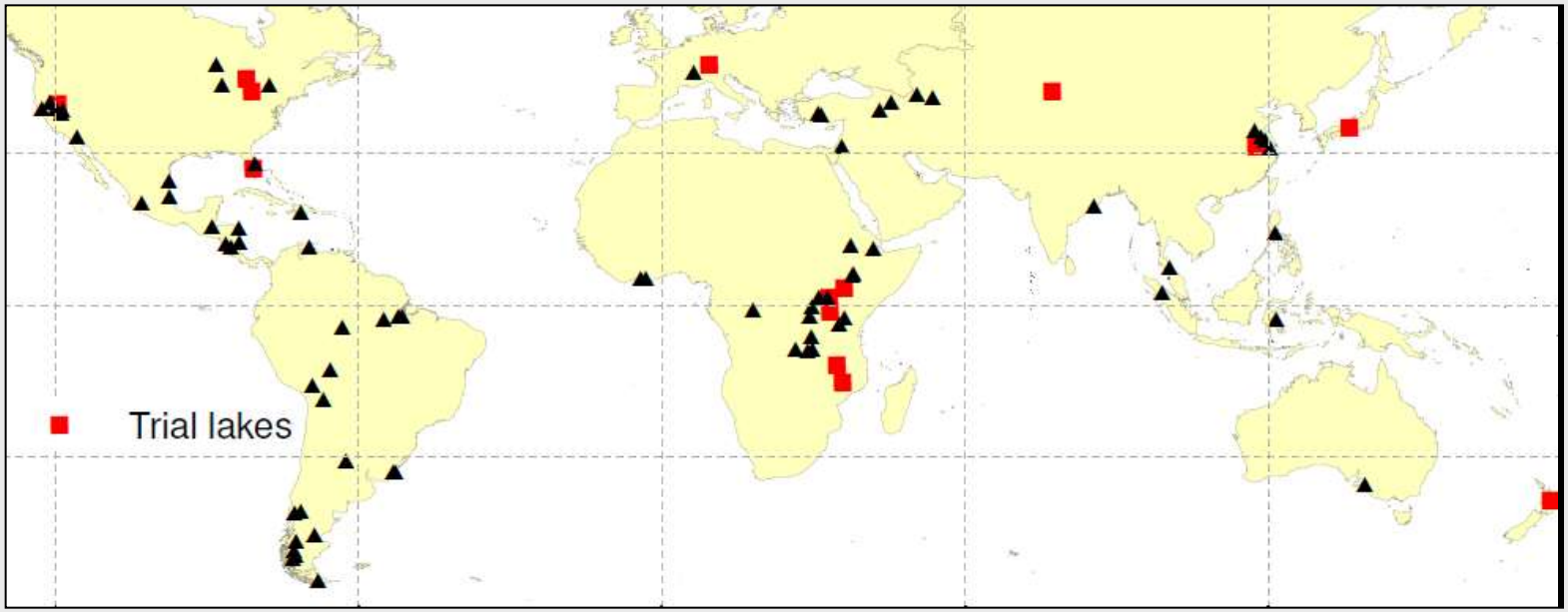
Daily MAE (ºC)



Mean JAS (ºC)



Non-freezing lakes



-55º to 47º N

mean lake depths (< 1 to 572 m)

surface areas 100 - 82,000 km^2)

lake altitudes from -404 to 3800 m a.s.l.

salinity values up to 149 g/l

Tuning approach works;

- daily MAE from **3.07 ºC +/- 2.25** to **0.80 ºC +/- 0.56**
- cold phase difference from **39 days +/- 59** to **1.5 days +/- 14**
- expect similar improvements from non-freezing lakes

Next

- complete tuning for non freezing lakes
- Assess LSWT global trends over 33 year period

Thank you

Questions?

References

Resio, D. T., S. M. Bratos, et al. (2008). Meteorology and Wave climate. Coastal Engineering Manual, U.S. Army Corps of Engineers. **II**.

Jerlov, N. G. (1976). Marine Optics, Elsevier Scientific Publishing Company.

Hsu, S.A. (1988). *Coastal Meteorology*. Academic Press Inc., San Diego, USA.

Benson, B. and J. Magnuson, 2000. Global lake and river ice phenology database, updated 2007. Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.

Calibration

	Approach 1			Approach 2		
Year	2011 Untuned	1996 Tuned (atsr2)	2010 Tuned (aatsr)	2011 Untuned	1996 Tuned (aatsr2)	2010 Tuned (aatsr)
Daily MAE (^{o}C)	0.86 +/-0.68	0.75 +/-0.74	0.87 +/-0.71	1.59 +/-1.04	1.33 +/-0.79	1.66 +/-0.95
JAS_diff (^{o}C)	+0.18 +/-1.50	-0.33 +/-1.79	+0.30 +/-1.51	+0.12 +/-1.71	+0.17 +/-1.19	+0.28 +/-1.81
cp_diff (days)	-3.9 +/-28.3	+7.16 +/-36.1	-2.0 28.8	-1.5 +/-30.7	+16.4 +/-43.2	-10.8 +/-48.4