FMI

Modelling snow and ice thickness for lake Vanajavesi, Finland

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- Geometry condition of lake Vanajavesi
- HIGHTSI model
- Modelling ice and snow thickness for ice season (2008/2009)
- Sensitivity studies

  - thermal conductivity of snow/ice

  - albedo

  - ice-water heat flux

  - longwave radiation, shortwave radiation
- Conclusions

Study Motivation

1. There are so many lakes in Finland, 187,888 lakes larger than 500 m^2. Most are small, but 309 lakes or reservoirs larger than 10 km^2. And in Finland, ice season is a long period up to 4-6 months. So Lake ice is very important.
2. For the Finish lakes, there is few ice model to simulate the ice thickness and snow thickness.
3. HIGHTSI (Launiainen and Cheng, 1998) is originally applied for sea ice and snow (e.g. Baltic Sea, Arctic and Antarctic sea ice and snow).

Lake Vanajavesi

Location: 61° 05′- 61 ° 12′N

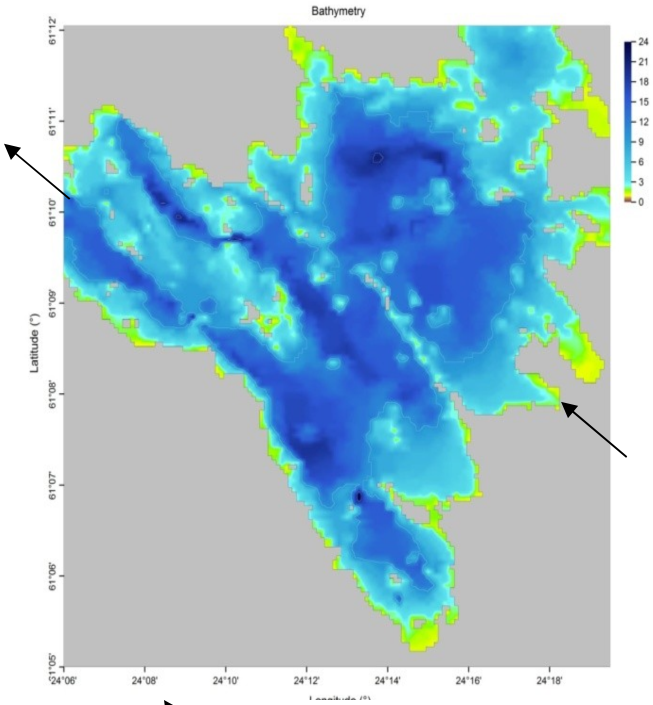
24 ° 03′- 24 ° 23′E

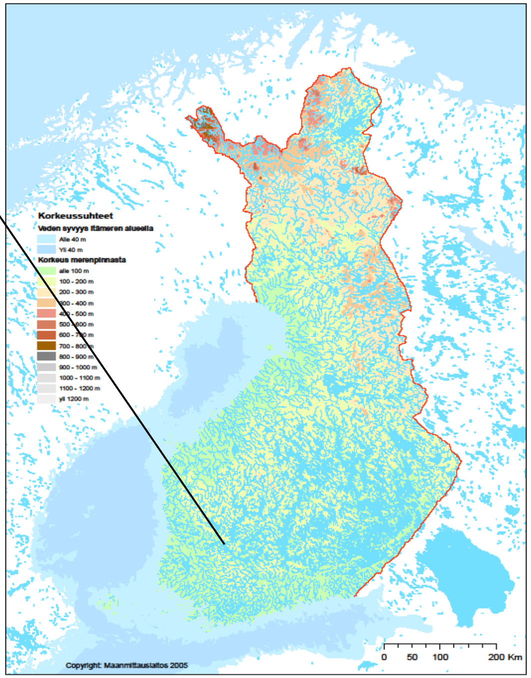
Lake area: 113 km^2

Shore length: 457 km

Mean & max. depth: 7 & 24 m

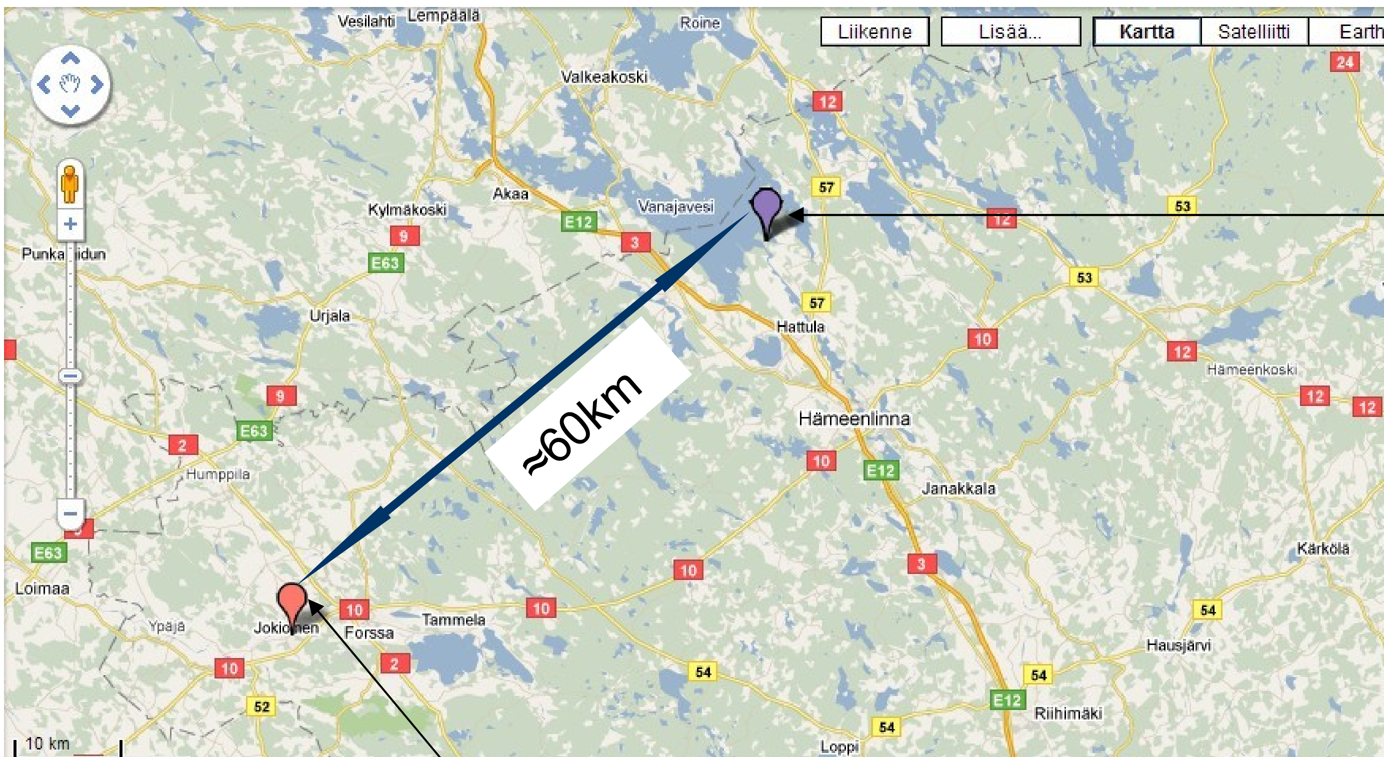
Water Volume: 0.952 km^3





Weather station of FMI

Jokioinen Meteorological Observatory (60° 48′N, 23° 30′E) was found in 1957-01-01.



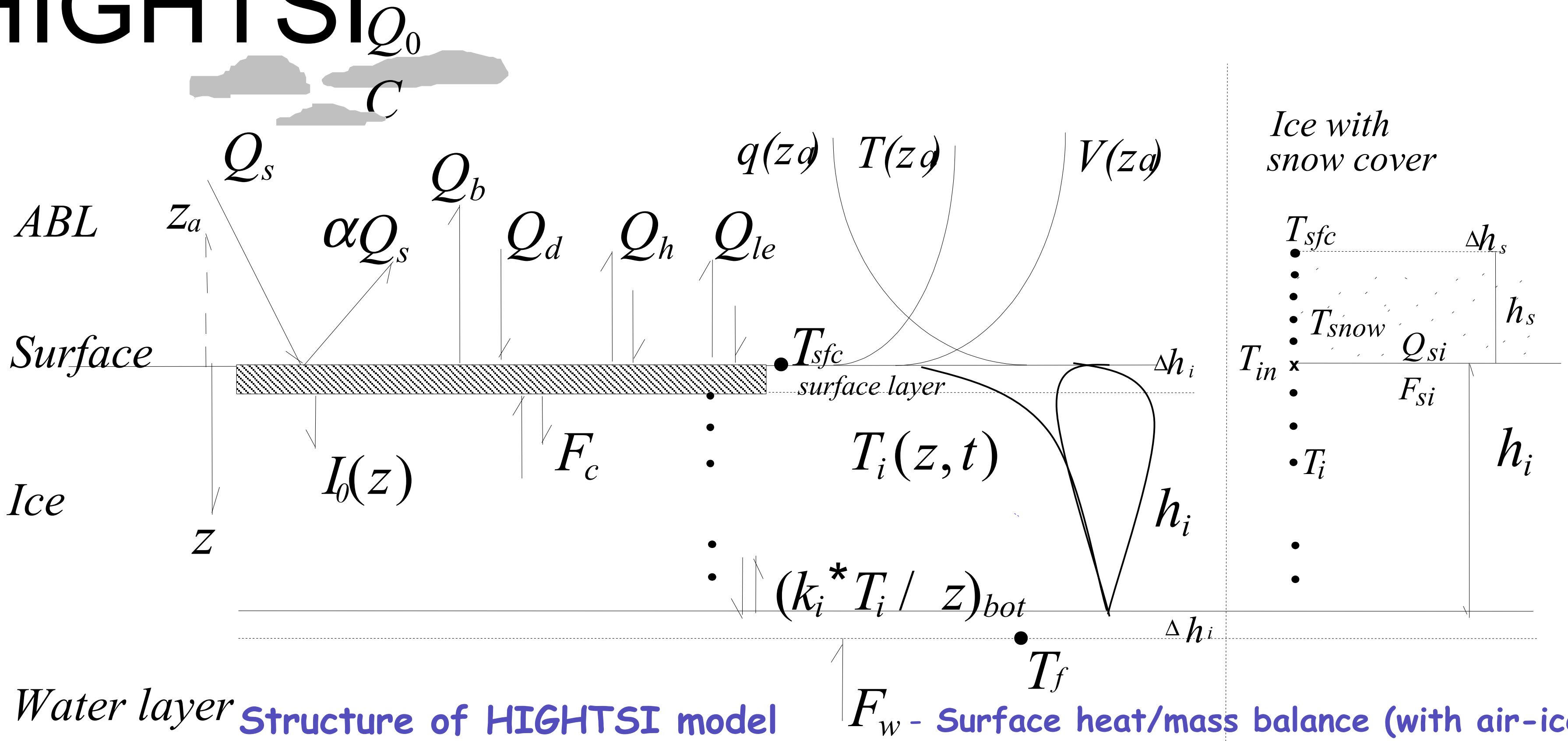
Vanajavesi

Jokioinen

- Annual mean air temperature is 3.9 °C.
- Lake Vanajavesi is fully ice covered every winter, freezes over annually for 4-6 months (normally from December to April).
- 1981-2009

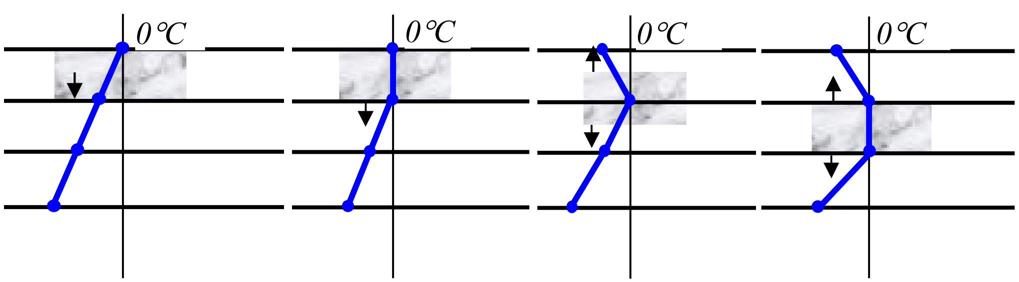
	Freezing	**Break-up**	**Duration (days)**
Average	Dec. 10	Apr. 30	141
Standard deviation	18	8	21
Maximum	Jan. 25(2008)	May 13(2003)	171(1993-1994)
Minimum	Nov. 20(1983)	Apr.8(1990)	86(2006-2007,2007-2008)

HIGHTSI



Structure of HIGHTSI model

- Surface heat/mass balance (with air-ice interactions)
  - Parameterization of snow properties, surface albedo
- Penetrating solar radiation in snow/ice
- Heat conduction equations in snow/ice
- Sub-surface melting
  - Snow to ice transformation (snow-ice and superimposed ice formation)



Launianinan and Cheng (1998)

Heat/mass balance at ice–water

- Heat conduction equation

$$(\rho c)_{s,i}\frac{\partial T_{s,i}(z,t)}{\partial t}=\frac{\partial}{\partial z}\left(k_{s,i}\frac{\partial T_{s,i}(z,t)}{\partial z}\right)-\frac{\partial q_{s,i}(z,t)}{\partial z}$$

- The surface temperature (T_{sfc}) is solved from a detailed surface heat/mass balance:

$$(1-\alpha_{i,s})Q_s-I_0+\varepsilon Q_d-Q_b(T_{sfc})+Q_h(T_{sfc})+Q_{le}(T_{sfc})+F_c(T_{sfc})-F_m=0$$

$\left(\alpha_{i,s}\quad Q_h;\quad Q_d\quad Q_{le}\right)$ ABL stability has been taken into account in the calculation

- Heat and mass balance at the ice bottom

$$-\rho_i L_f\frac{dh_i}{dt}=-k_i\left.\frac{\partial T_i}{\partial z}\right|_{bottom}+F_w$$

- Slush layer

$$-\rho_{sui} L_f\frac{dH_{si}}{dt}=k_s\left.\frac{\partial T_s}{\partial z}\right|_{z=h_s}-k_i\left.\frac{\partial T_i}{\partial z}\right|_{z=h_i}$$

Model parameters

Parameter	Value	Source
Extinction coefficient of ice (κ_i)	1.5 - 17 m^{-1}	adapted from Grenfell and Maykut(1977)
Extinction coefficient of snow (κ_s)	15 - 25 m^{-1}	adapted from Perovich (1996)
Freezing point (T_f)	0°C	
Heat capacity of ice (c_i)	2093 J kg^{-1} K^{-1}	Literature value
Latent heat of freezing (L_i)	0.33×106 J kg^{-1}	Literature value
Lake ice density (ρ_i)	1000kg m^{-3}	Literature value
Snow density (ρ_s)	320 kg m^{-3}	Literature value
Surface emissivity (ε)	0.97	Assumed
Thermal conductivity of ice (k_i)	2.03 W m^{-1} K^{-1}	Maykut and Untersteiner (1971)
Thermal conductivity of snow (k_s)	Function of ρ_s	Sturm, et al, (1997), Huwald et al (2005b)

- Case study:

  winter season 2008-2009: January to April, 2009

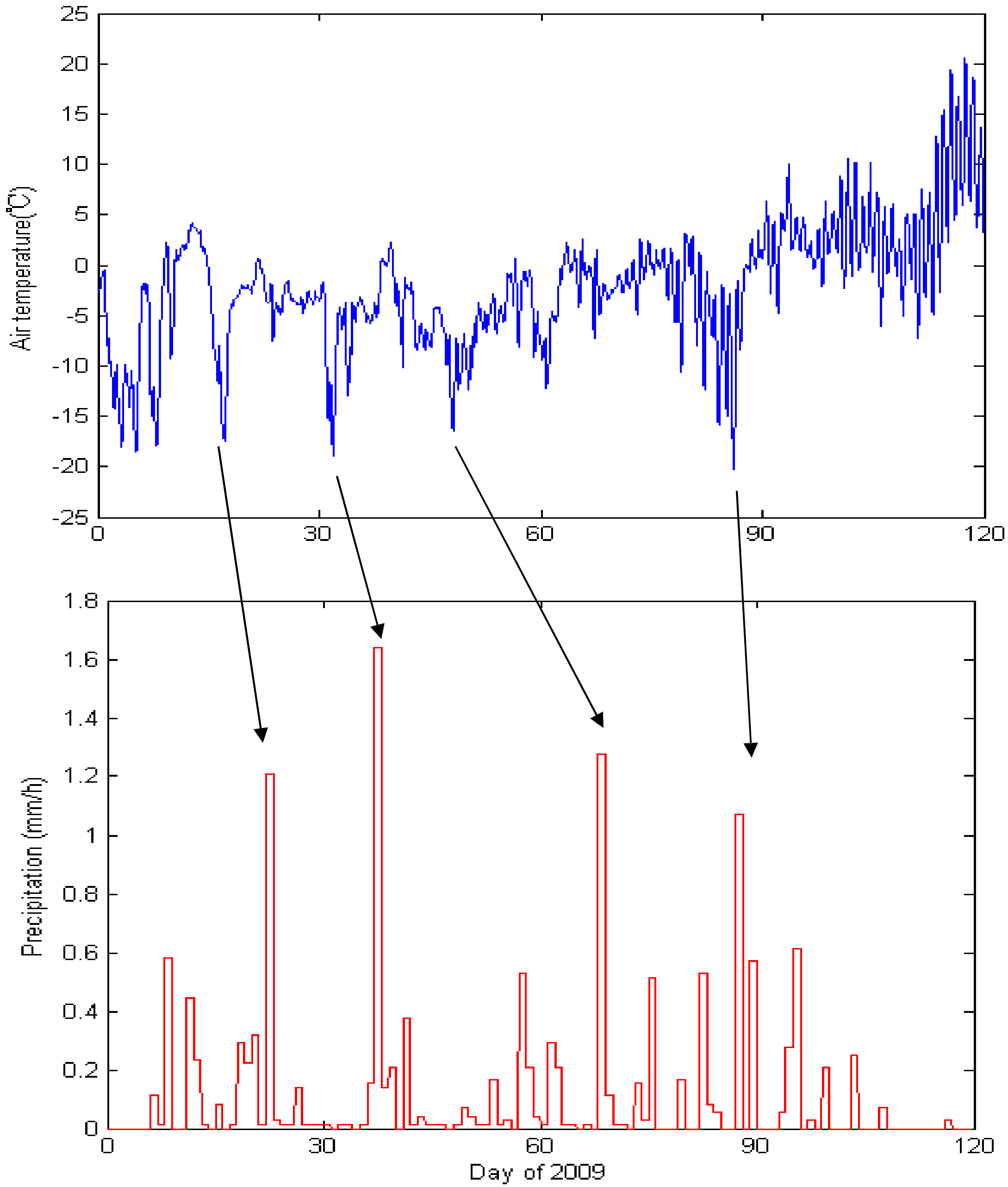
- Other index:

  Time step: 1 hour

  Spatial resolution: 20 layers in ice and 10 layers in snow

- External forcing data:

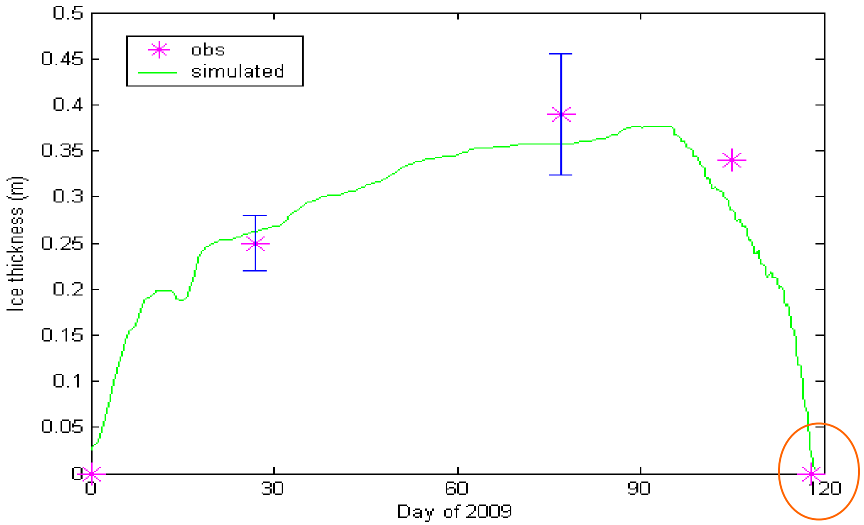
  basic variables: V_a (m/s), T_a(°C), Rh(%), CN(0-1), *Precipitation* (mm/h),Q_s

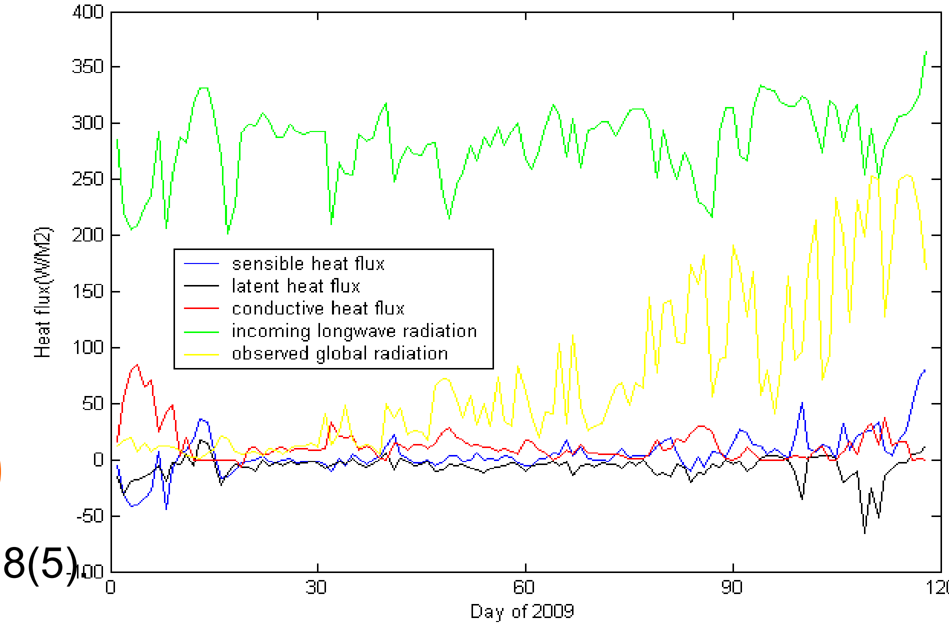


minimum air temperature	**-20.2 °C (2009-03-27)**
maximum air temperature	**20.5 °C (2009-04-27)**

total precipitation	**102.70 mm**
January	**27.40 mm/month**
February	**27.30 mm/month**
March	**37.00 mm/month**
April	**11.00 mm/month**

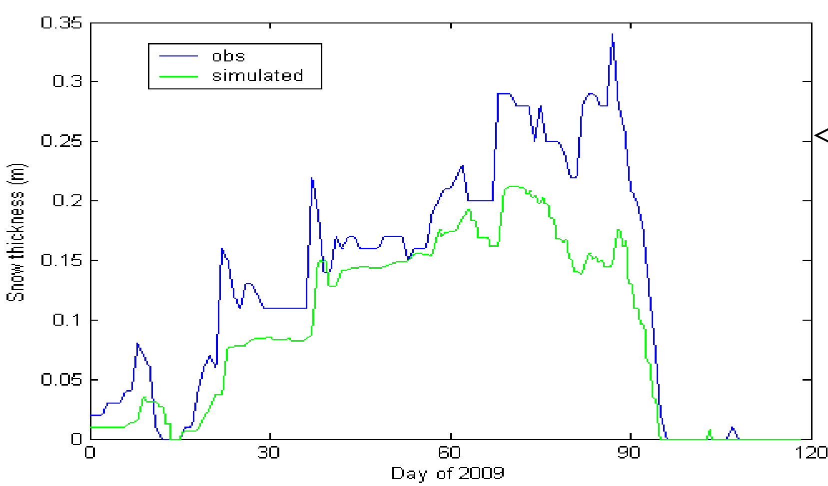
Results





Observed ice thickness: January 26(14), March 18(5)
Freezing date: Januanry 1, 2009
Break-up date: April 27, 2009
Model initial ice thickness: 3cm; snow depth:1cm

Daily mean surface heat balance flux

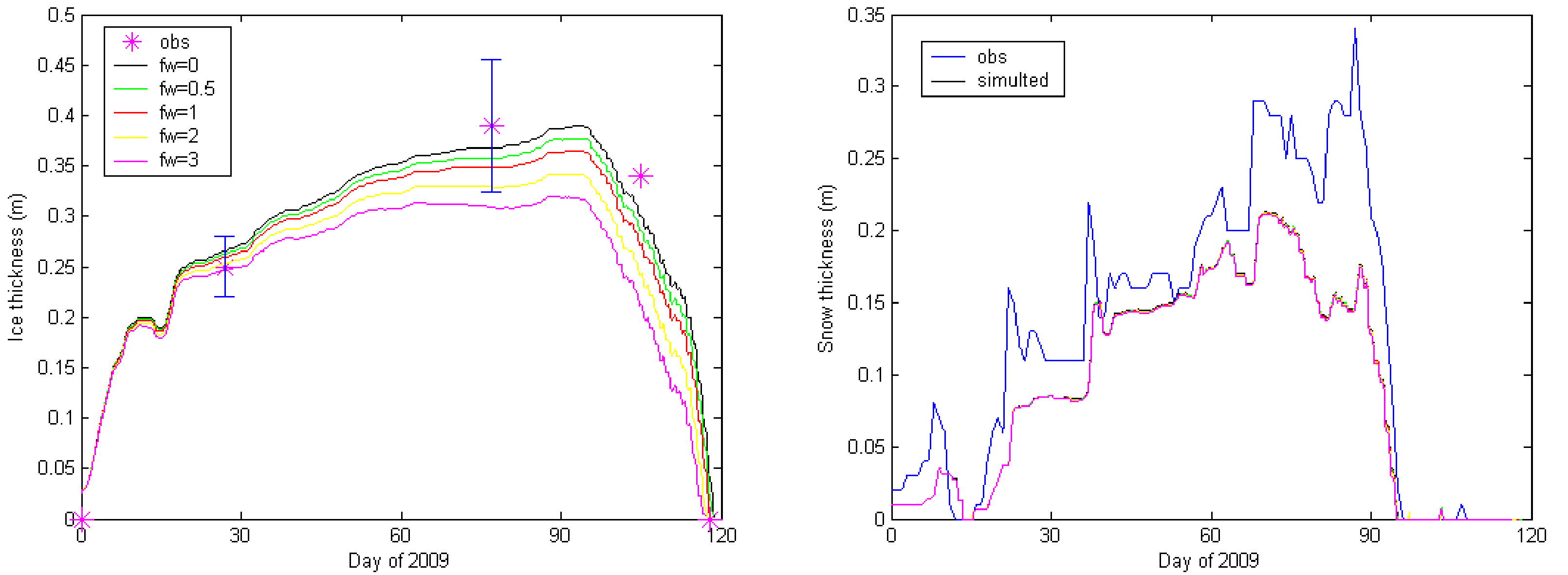


The time series of observed and simulated ice and snow thickness (the observed snow depth got from FMI, so these data were the snow depth on ground)

Sensitivity studies

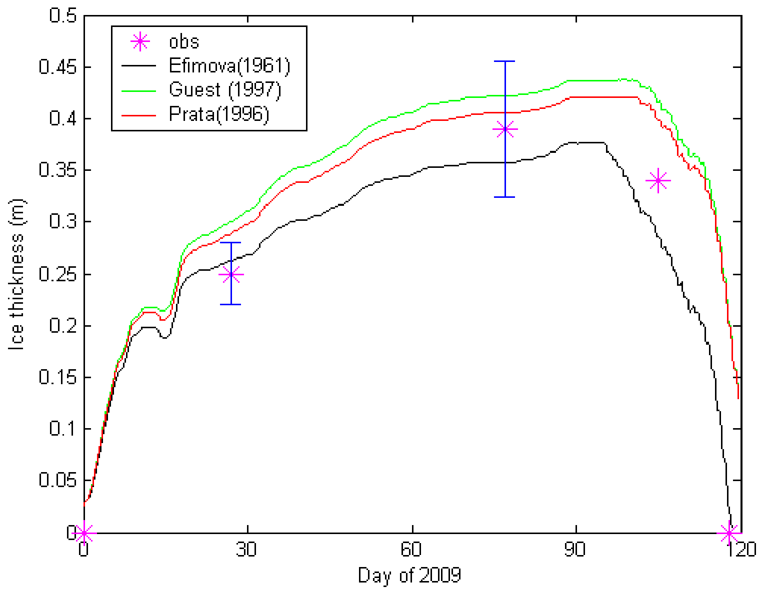
Parameter	Parameterization		Model Experiment
Thermal conductivity of snow	0.18	A	(A,B,C)+E+H+L+O+R=**a**
(W/mk)	0.3	B	
	0.7	C	
Thermal conductivity of ice	1.8	D	B+(D,E,F)+ H+L+O+R =**b**
(W/mk)	2.03	E	
	2.1	F	
Albedo	Perovich (1996)	G	B+E+(G,H,I,J)+L+O+R =**c**
	Modified Perovich	H	
	CCSM3	I	
	Roberta (2006)	J	
Heat flux at ice bottom	0	K	B+E+H+(K,L,M,N)+O+R =**d**
(W/m^2)	0.5	L	
	1	M	
	2	N	
Longwave radiation	Efimova (1961)	O	B+E+H+L+(O,P,Q)+R =**e**
	Guest(1997)	P	
	Prata(1996)	Q	
Global radiation	Observed value (from FMI)	R	B+E+H+L+O+ (R,S) =**f**
	Shine (1984)	S	

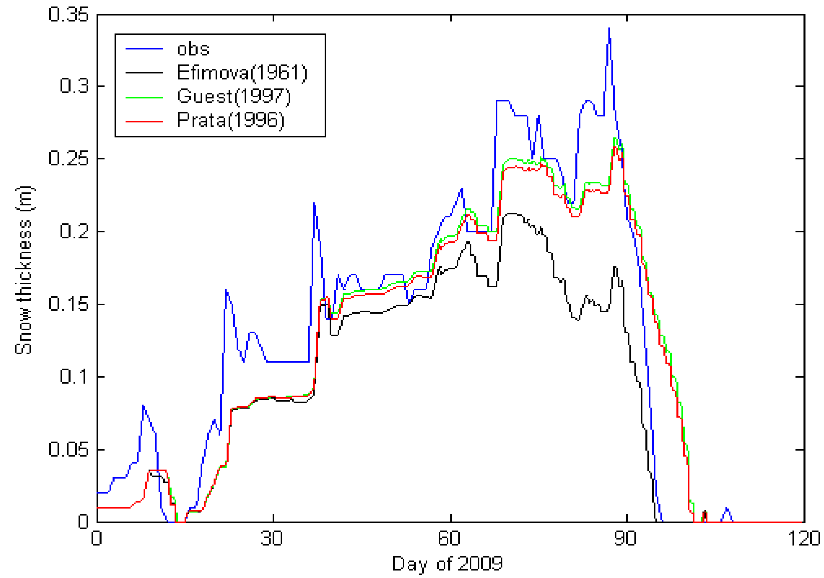
Results of sensitivity studies



d: Different heat flux at ice bottom

- d : During the middle of ice season, the heat flux at ice bottom increasing 0.5 W/m^2 will cause simulated ice thickness decrease 1cm.





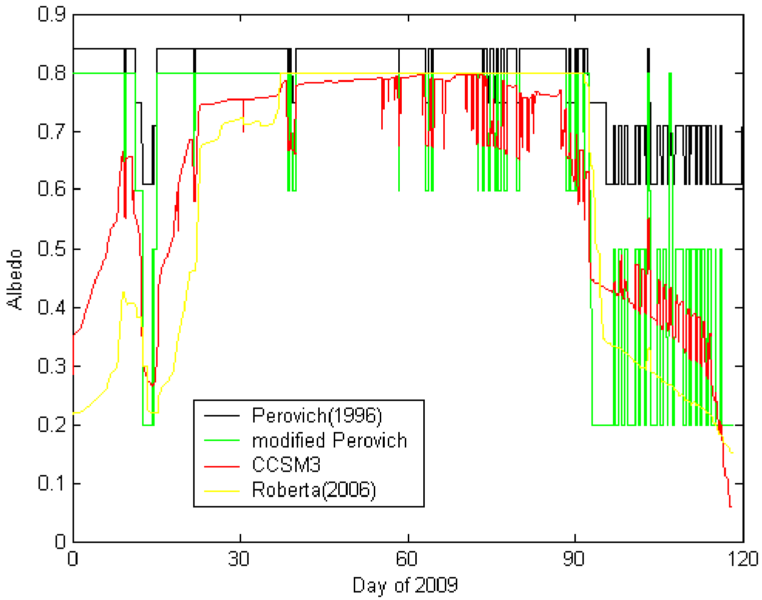
e: Different longwave radiation parameterizations

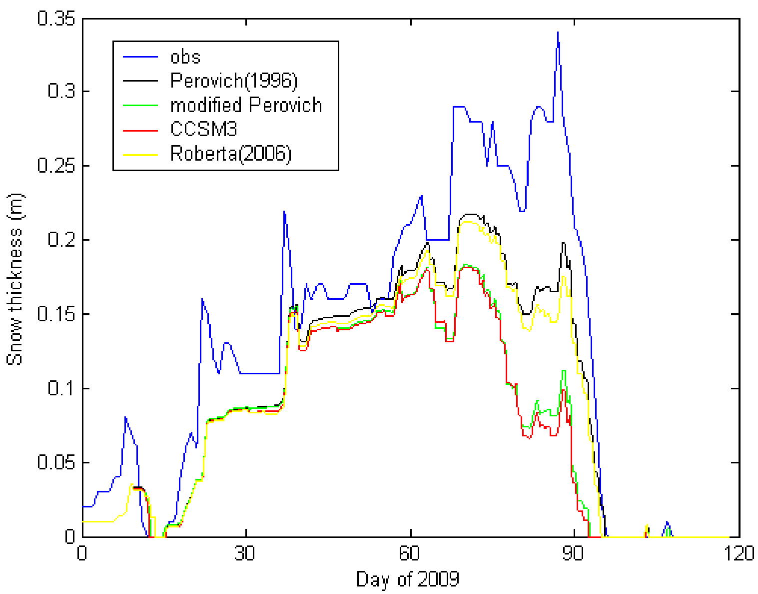
There are totally 12 longwave schemes considered in HIGHTSI. The sensitivity studies have been given for different condition (Launianinan and Cheng, 1998).

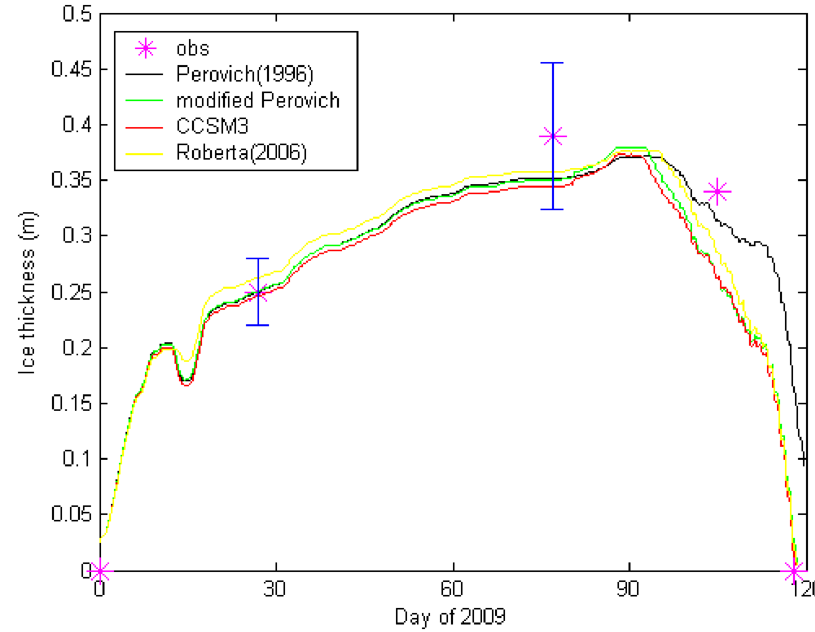
$$\mathrm{Efimova(1961)} = (0.746 + 0.0066 \cdot e) \cdot \sigma_a \cdot T_a^4 \cdot (1 + 0.26 \cdot C)$$

$$\mathrm{Guest(1997)} = (\sigma_a \cdot T_a^4 - 85.6) \cdot (1 + 0.26 \cdot C)$$

$$\mathrm{Prata(1996)} = \left[1 - (1 + 46.5 \cdot \frac{e}{T_a}) \cdot \exp(-\sqrt{1.2 + 3 \cdot 46.5 \cdot \frac{e}{T_a}}) \right] \cdot \sigma_a \cdot T_a^4 \cdot (1 + 0.26 \cdot C)$$







c: Different albedo parameterizations

The sensitivity studies of different albedo schemes to snow and ice mass balance for the Arctic Ocean have been made (Cheng et al, 2008).

Conclusion and future work

- HIGHTSI model is capable to simulate lake ice after a proper adapation.
- The most sensitivity factors that affect the lake ice simulation are:
  - Ice bottom heat flux
  - Longwave radiation
  - Albedo
- Further modelling of lake ice are underway (for different lakes and different ice seasons).
- HIGHTSI maybe used as a separate module in numerical weather prediction model for the lake ice simulation.


Thank you for your attention!