One-Dimensional Sea Ice-Ocean Model Applied to SHEBA Experiment in 1997-1998t

by

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INTRODUCTION

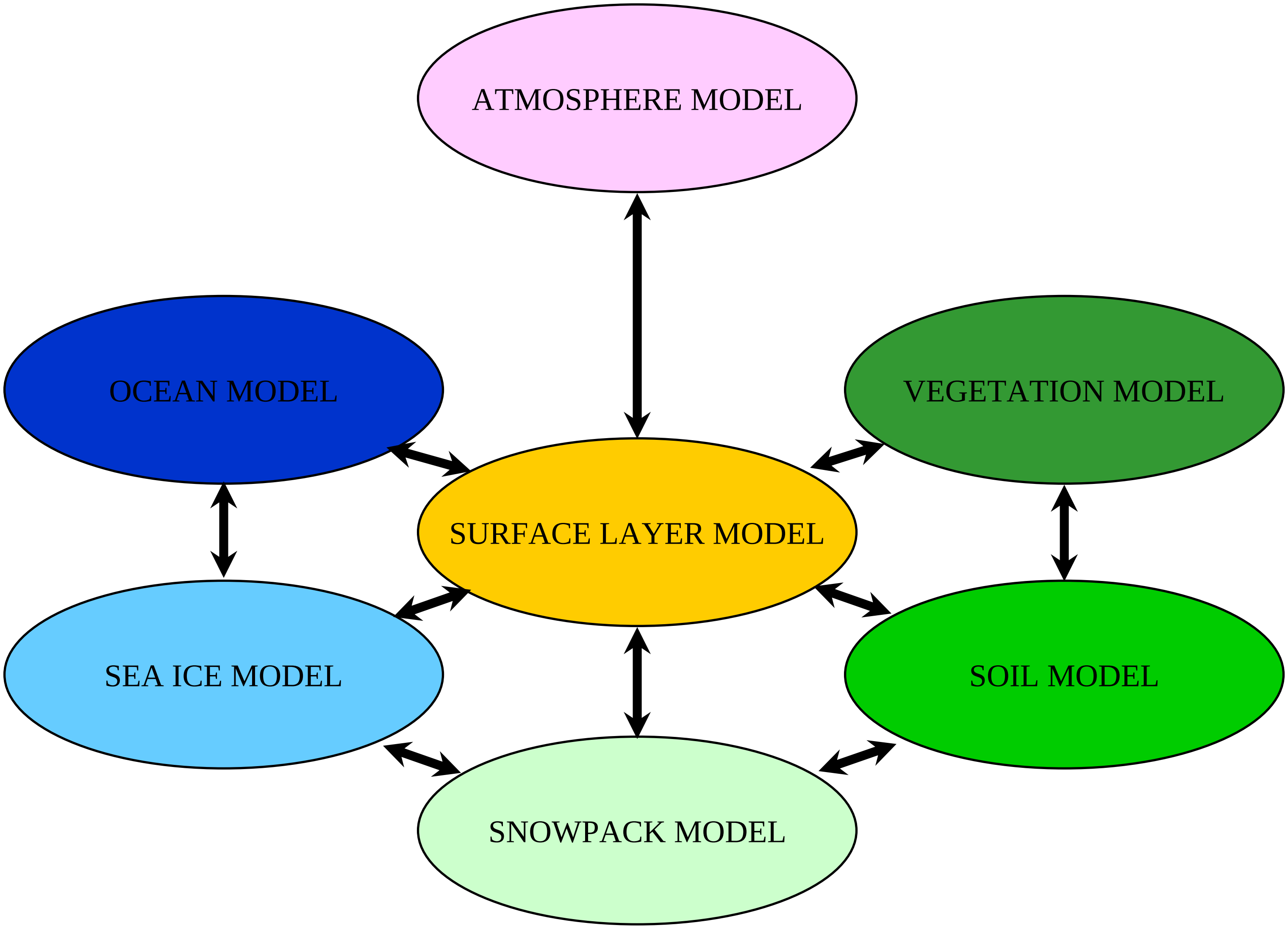
(1) MOTIVATIONS:

- **Variation of sea ice distribution and thickness is one of the strongest signals in climate changes.**
- **Current sea ice models in the GCMs are too simple and ignore some important physical processes.**

(2) OBJECTIVES:

- **Develop a comprehensive and physically-based surface model for the Regional Model.**
- **Develop a flexible surface model for studying different scale phenomena in the Polar region.**
- **Use SHEBA data to validate and improve the model.**
- **Integrate observations and model for better understanding the interactions among atmosphere, snowpack, sea ice, and ocean.**

PURDUE SURFACE MODEL



SNOWPACK MODEL

(1) Multi-layer one dimensional snow model based on conservation of mass, momentum and energy.

(2) Thickness of each model layer can change with time.

(3) Number of model layer can change with time.

(4) Key physical processes:

- **snow compaction (mechanical and metamorphism);**
- **liquid water infiltration;**
- **snow ventilation;**
- **penetration of solar radiation;**
- **albedo is function of spectral, cloudiness, grain size, age, and zenith angle;**
- **snow grain growth;**
- **diffusion and transport of heat;**
- **melting and freezing processes;**
- **snow accumulation/ablation.**

SEA ICE MODEL

(1) Multi-layer one dimensional thermodynamic model based on conservation of mass and energy.
(2) Thickness of each model layer can change with time.
(3) Number of model layer can change with time.
(4) Model includes melt pond on the top of the ice.
(5) Key physical processes:

- penetration of solar radiation;
- albedo is function of spectral, cloudiness, and zenith angle;
- diffusion and transport of heat;
- melting and freezing processes;
- melt water and sea water infiltration;
- salinity and brine volume.

OCEAN MODEL

(1) One-dimensional mixed-layer ocean model based on conservation of mass and energy.

(2) Thickness of the top layer can change with time.

(3) Key prognostic variables are:

- velocity;
- temperature;
- salinity;
- turbulent kinetic energy.

(4) Density is a function of temperature and salinity.

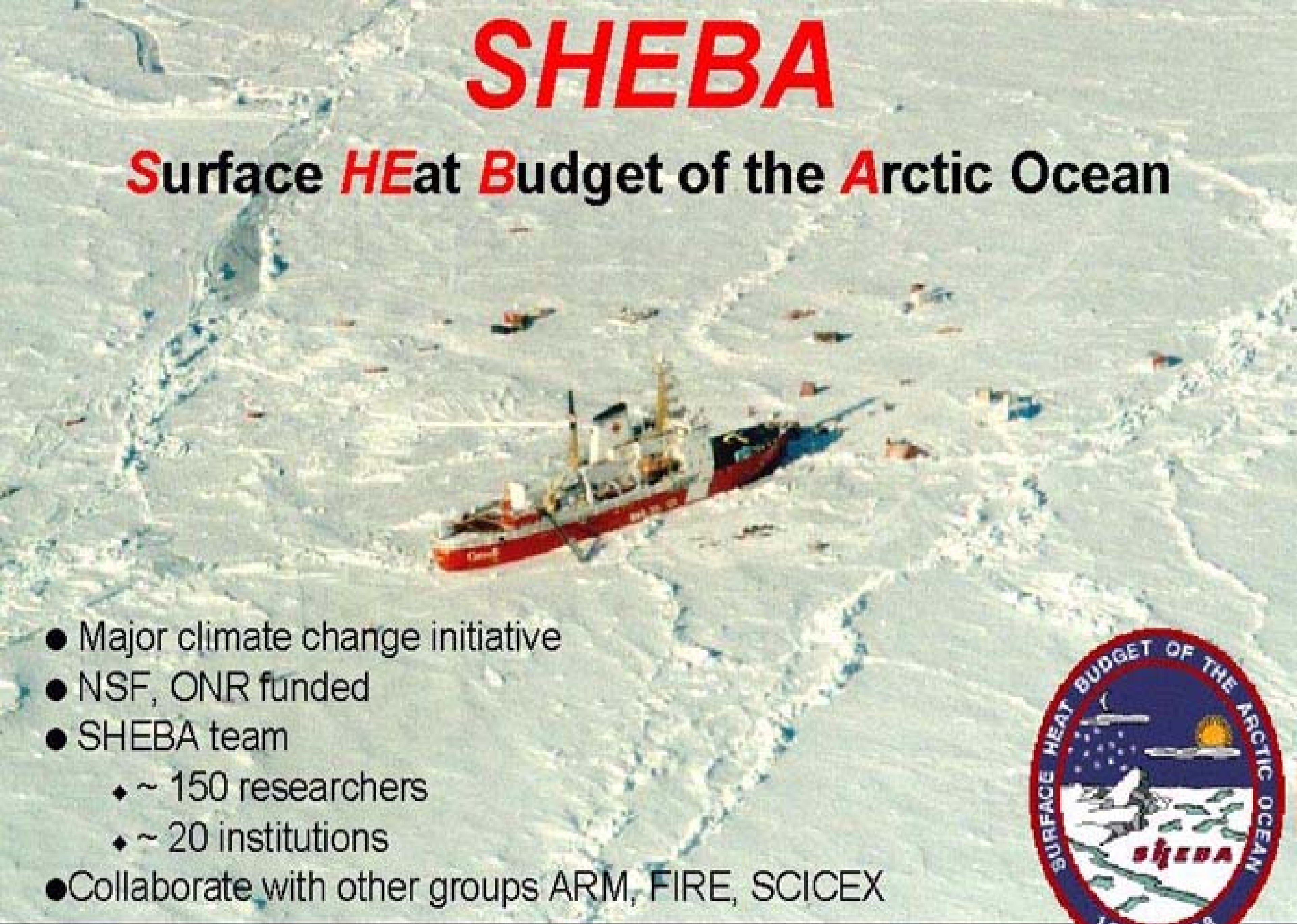
(5) Freezing point of sea water is a function of salinity.

(6) Key physical processes:

- penetration of solar radiation;
- albedo is function of spectral, cloudiness, and zenith angle;
- turbulent mixing in the mixed layer;
- melting and freezing processes;
- release of salinity during freezing.

SHEBA

Surface HEat Budget of the Arctic Ocean



- Major climate change initiative
- NSF, ONR funded
- SHEBA team
  - ~ 150 researchers
  - ~ 20 institutions
- Collaborate with other groups ARM, FIRE, SCICEX

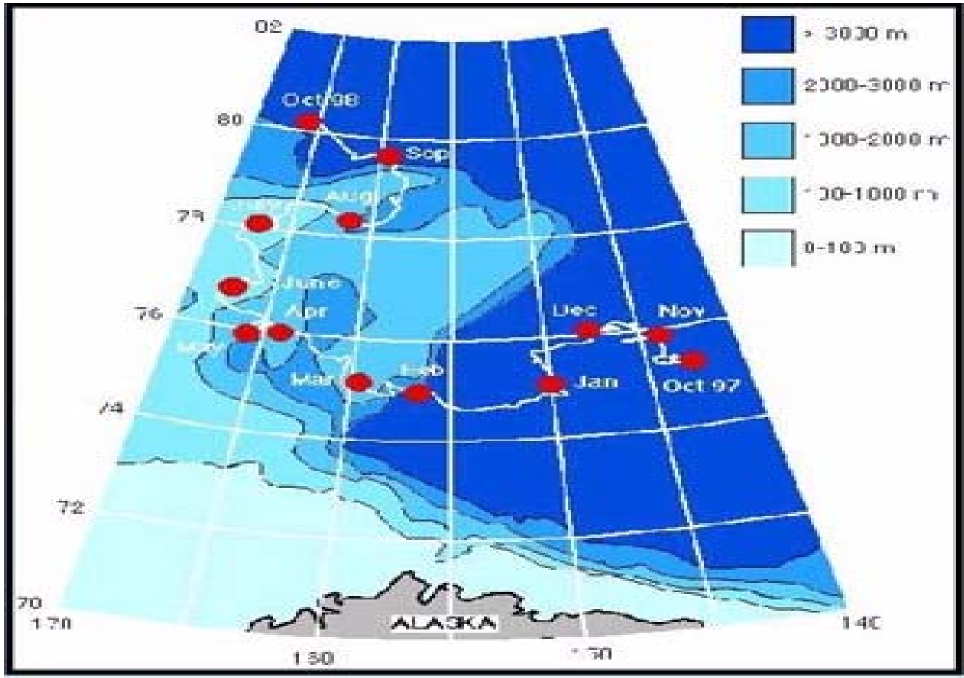
SHEBA: Goals

- Determine ice-ocean-atmosphere processes that control
  - ice-albedo feedback mechanism
  - cloud radiation feedback mechanism
- Develop models that improve
  - simulations of present day Arctic climate
  - simulation of "future" Arctic climate using GCM's

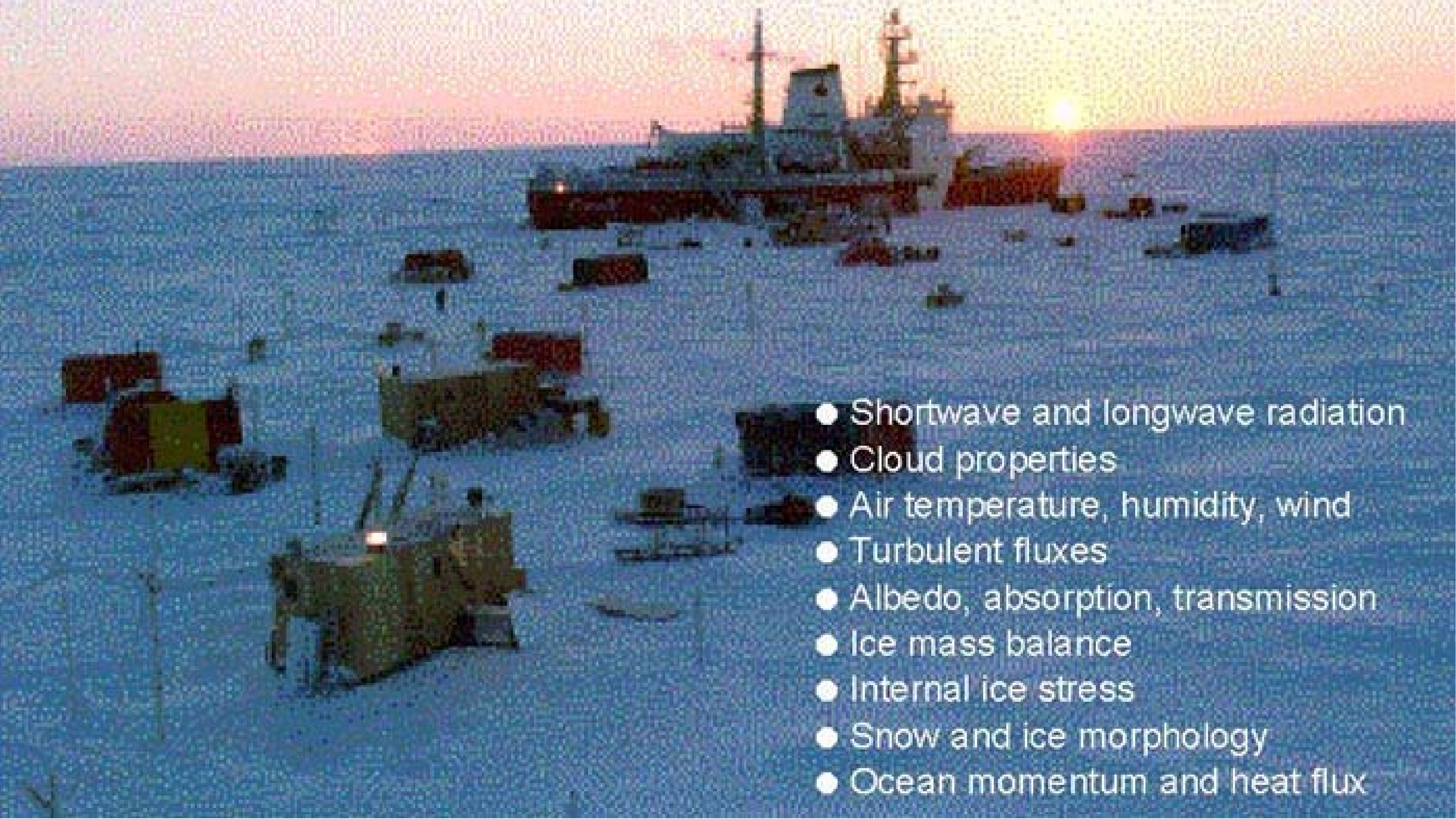
SHEBA LOCATION

Ice Station was installed on a multi-year ice floe

- **about 1.6 meter in thickness;**
- **at 75 N, 142 W on October 2, 1997;**
- **at 80 N, 166 W on October 2, 1998;**
- **total drift was ~ 2800 km;**
- **one-year displacement was 770 km.**

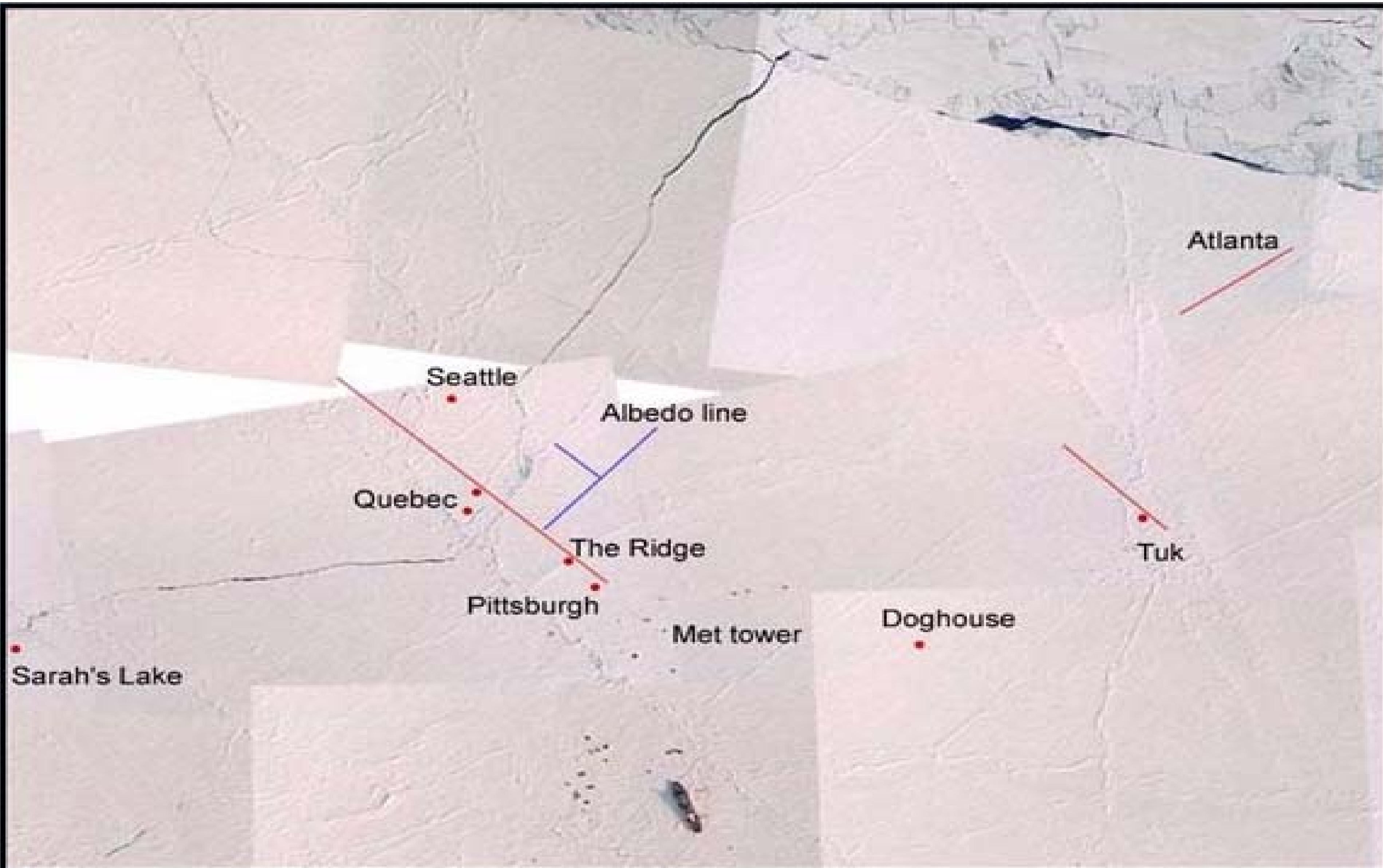


SHEBA: Time series measurements



- Shortwave and longwave radiation
- Cloud properties
- Air temperature, humidity, wind
- Turbulent fluxes
- Albedo, absorption, transmission
- Ice mass balance
- Internal ice stress
- Snow and ice morphology
- Ocean momentum and heat flux

LOCATION OF OBSERVED STATIONS



ATMOSPHERE DATA

(1) Hourly forcing data:

- Air temperature at 2.5 m;
- Mixing ratio at 2.5 m;
- Wind at 2.5 m;
- Precipitation;
- Incoming solar radiation;
- Incoming longwave radiation.

(2) Hourly validation data

- Reflected solar radiation;
- Surface sensible heat flux;
- Surface latent heat flux;
- Upward longwave radiation;
- Surface temperature.

SNOW/ICE DATA

Initial condition & validation:

(1) Snow, sea ice & melt pond thickness;

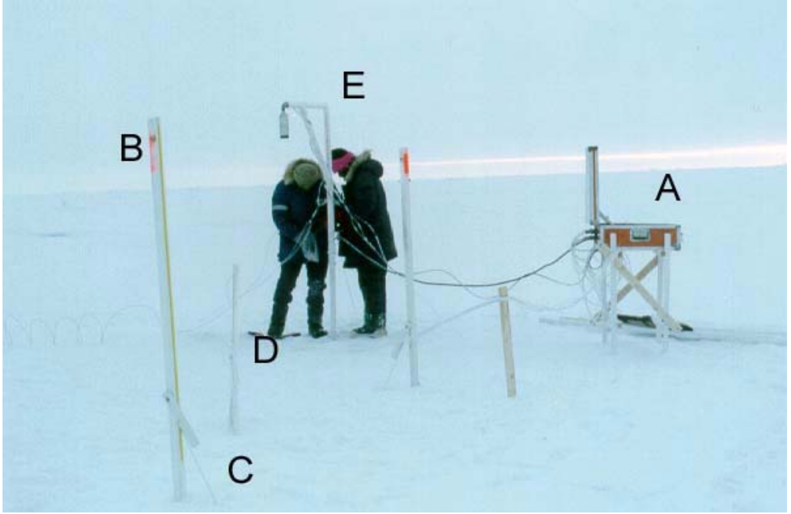
(2) Snow and sea ice temperature;

(3) Snow and ice optical properties:

- albedo & transmittance, through the ice,
- in-ice irradiance profiles.

(4) Snow and ice physical properties:

- density,
- permeability,
- porosity,
- salinity,
- brine and air volumes.

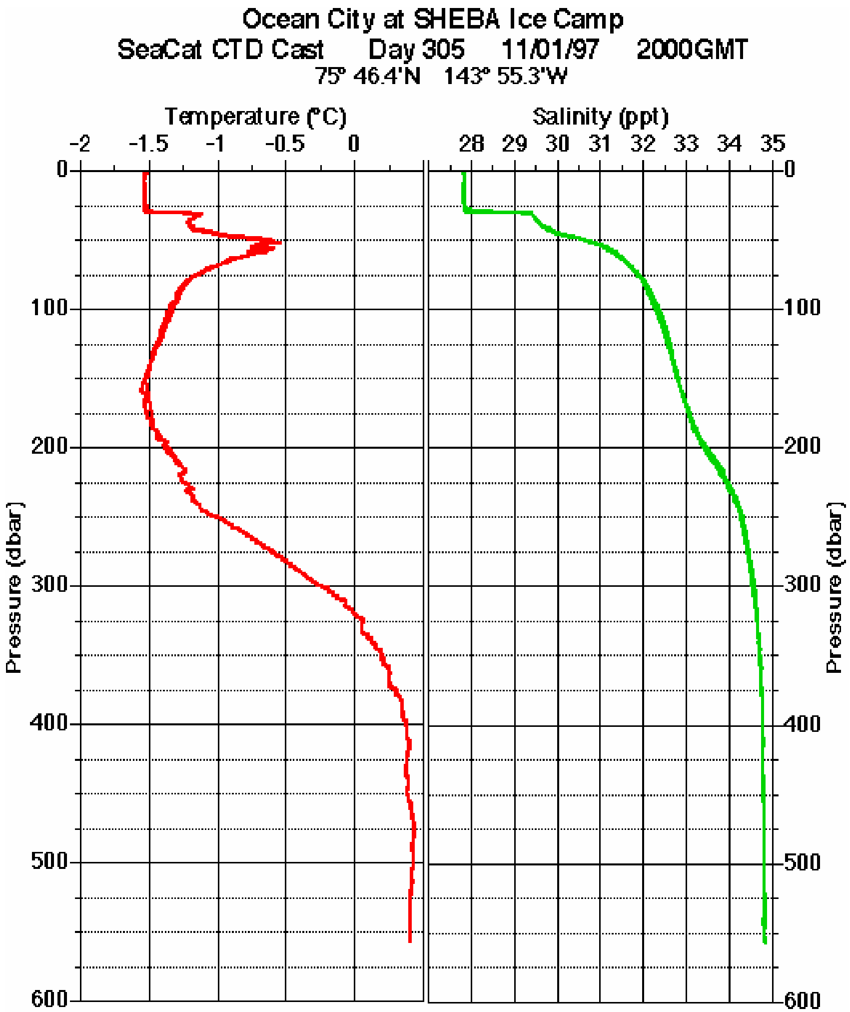


A) datalogger, B)ablation stake, C)thickness gauge D)thermister probe, and E) acoustic sounder

OCEAN DATA

Data for initial condition and Validation:

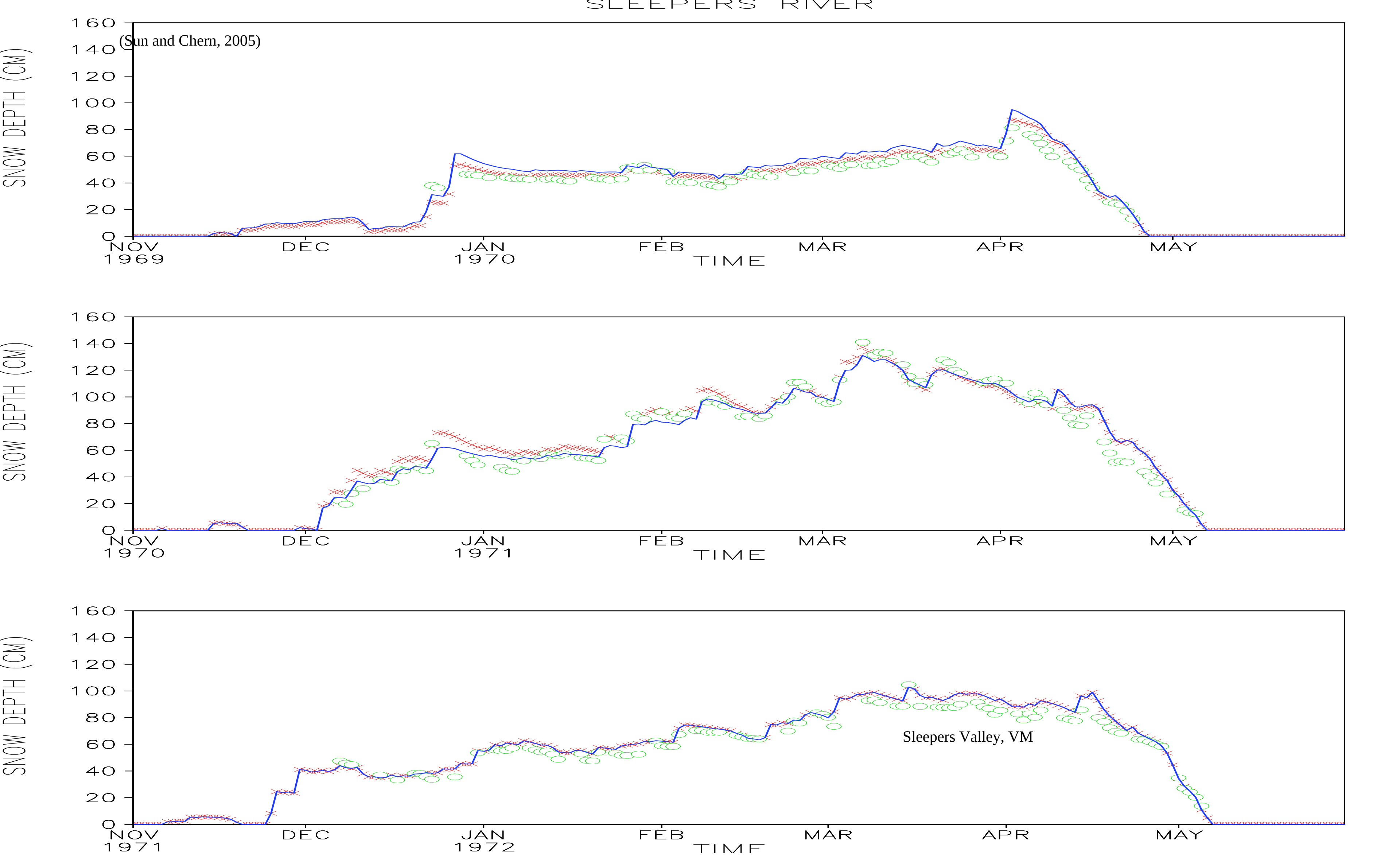
- Vertical profile of sea temperature;
- Vertical profile of salinity;
- Vertical profile of density;
- Vertical profile of velocity.



EXPERIMENTAL DESIGN

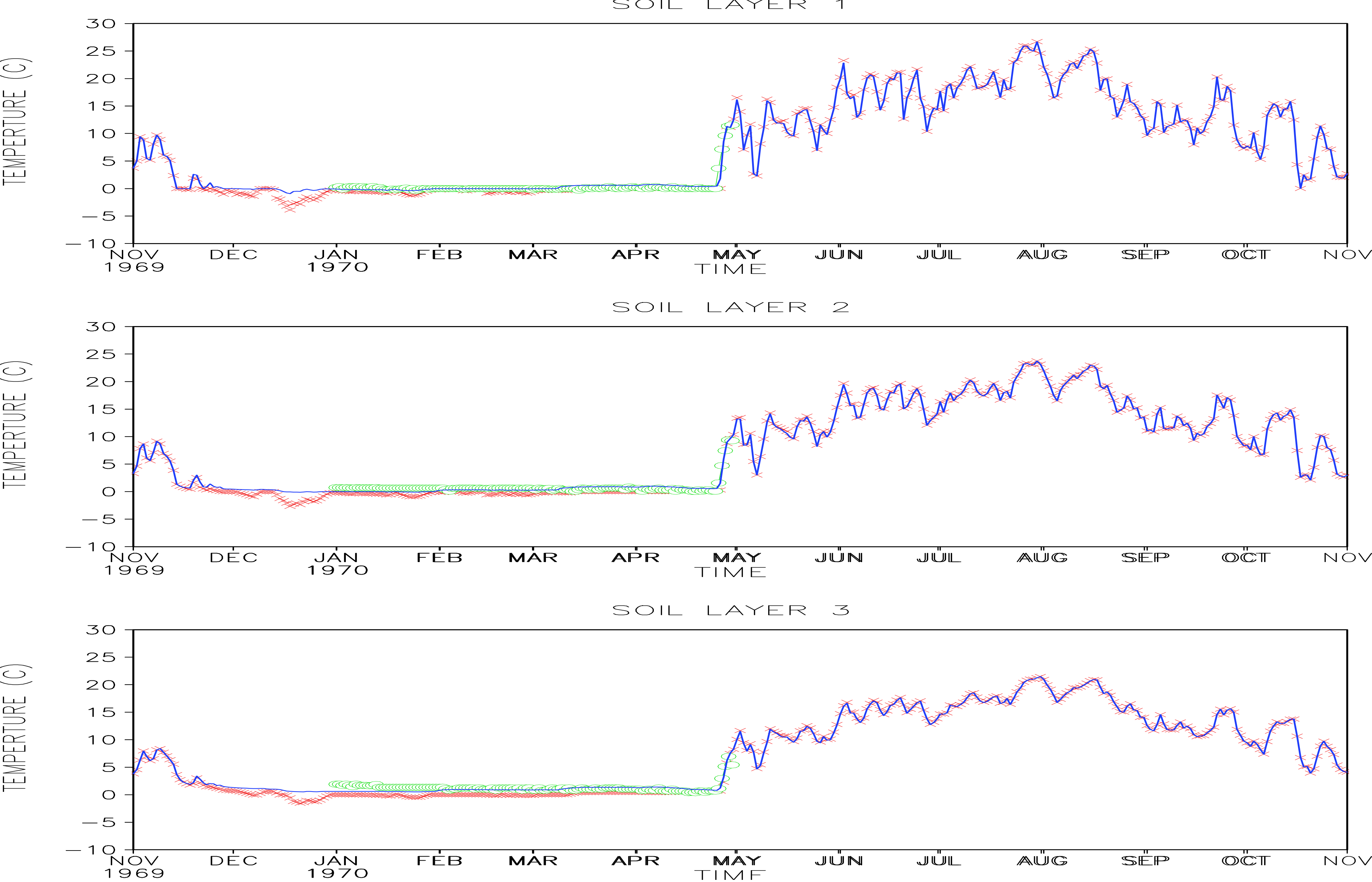
(1) Stand-alone model is used;
(2) Hourly atmospheric forcings from the tower are used to drive the model;
(3) Model is initialized at 0000 GMT, Oct. 31 , 1997 and integrated for two months;
(4) There are 2-4 layers in snow, 2-4 layers in sea-ice (total 6 layers); 20 layers in ocean model to -95m deep;
(5) Model time step is 5 minutes;
(6) The snow model is initialized with the mean snow thickness from the 500 meter MAIN LINE;
(7) The sea ice is initialized with the data from Baltimore mass balance site (first-year ice) and Seattle (multiyear Ice);
(8) The initial thickness of snow and sea ice is 15.1 cm and 53.0 cm, respectively (Baltimore) and 14.2 and 145.5cm (Seattle)

The soil-snow-ice model has been verified against 5-year Observational data at Sleeper Water Shed in VM during 1969-1974
(Sun and Chern 2005)

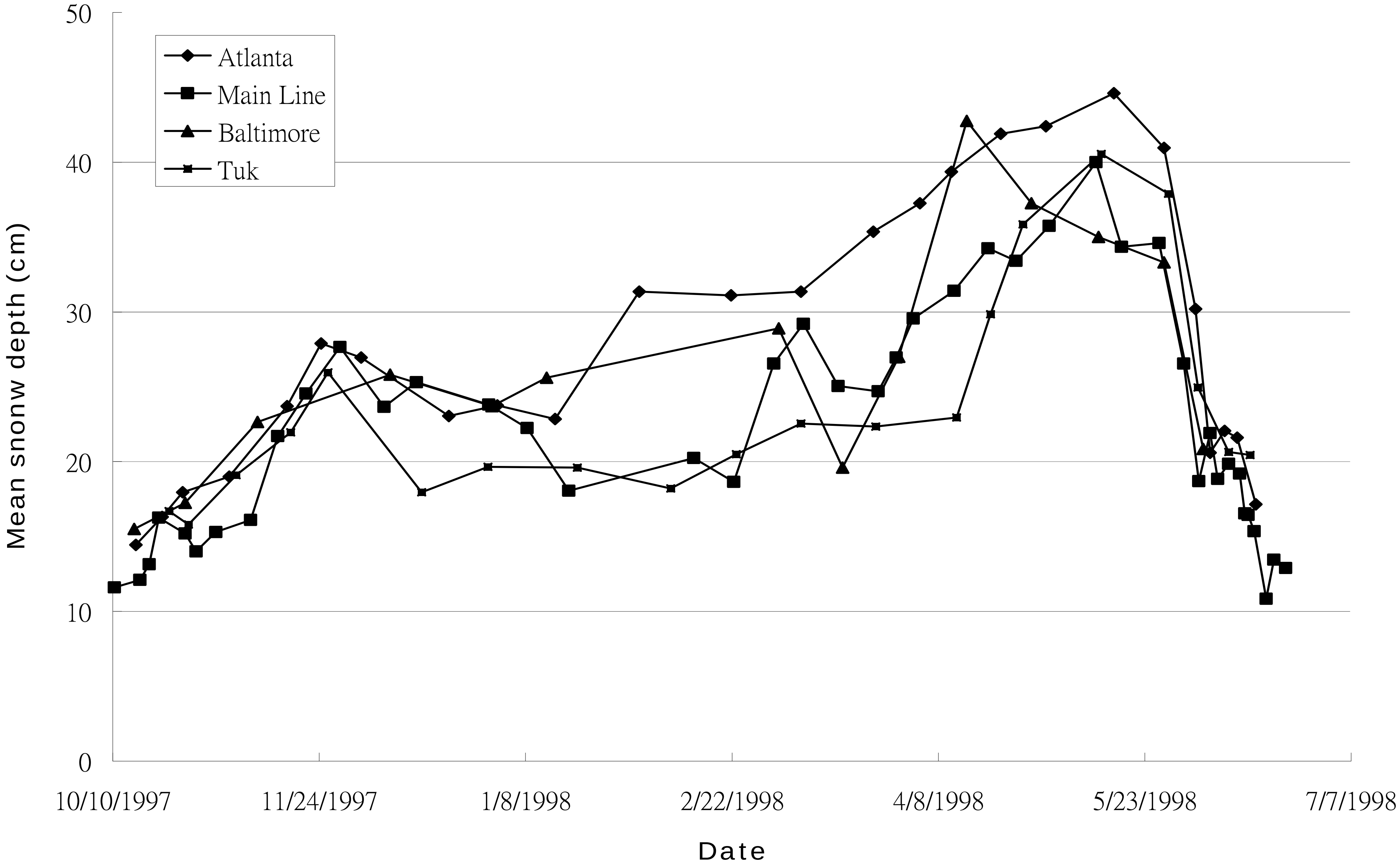


Observed (green circle) and simulated (red x for Case A, blue line for Case B) of snow depth during 1 Nov. 1969 and 31 May 1972

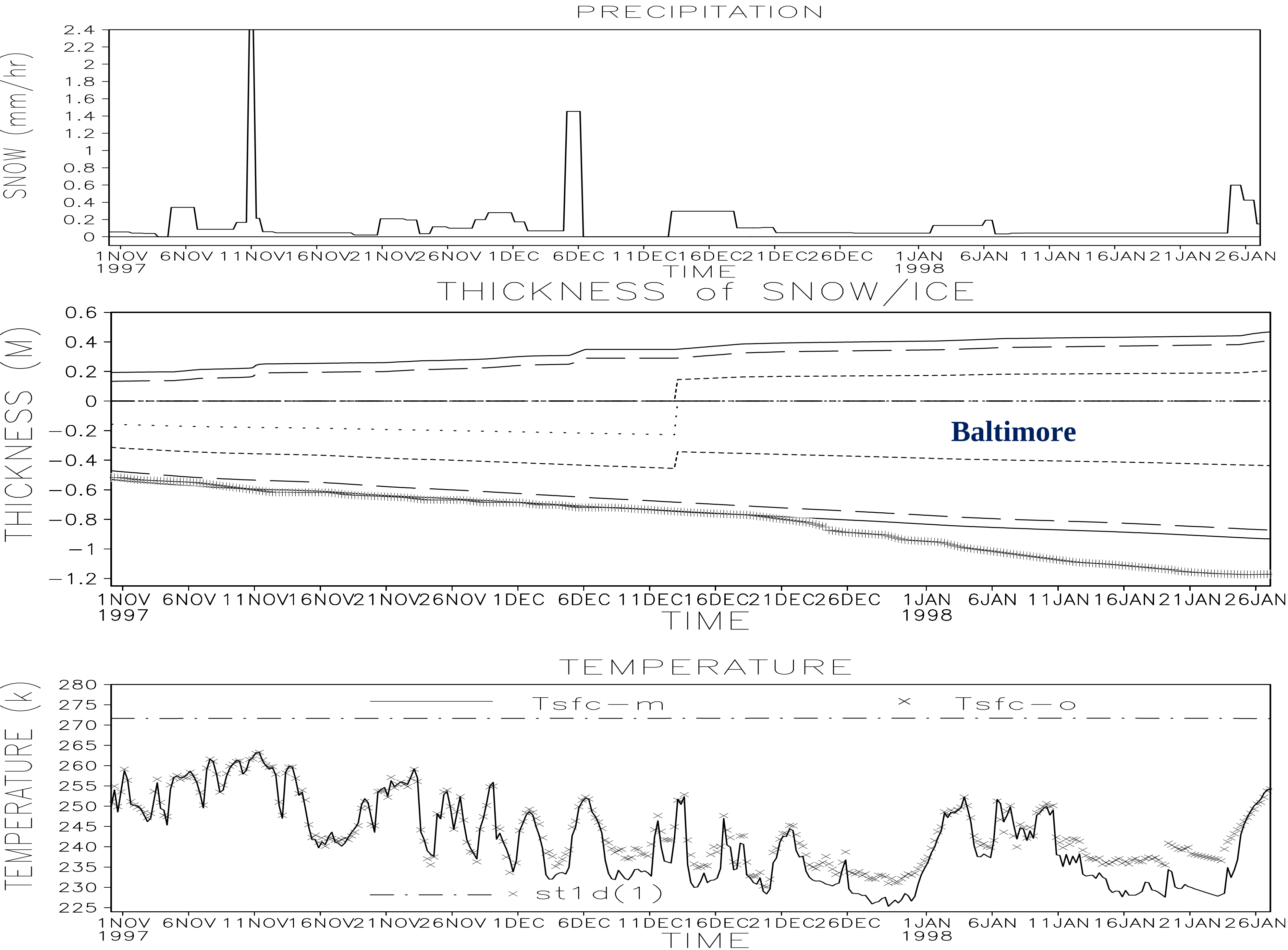
Snowpack temperatures at 6, 12, and 24 inches above ground between November 1969 and May 1970.

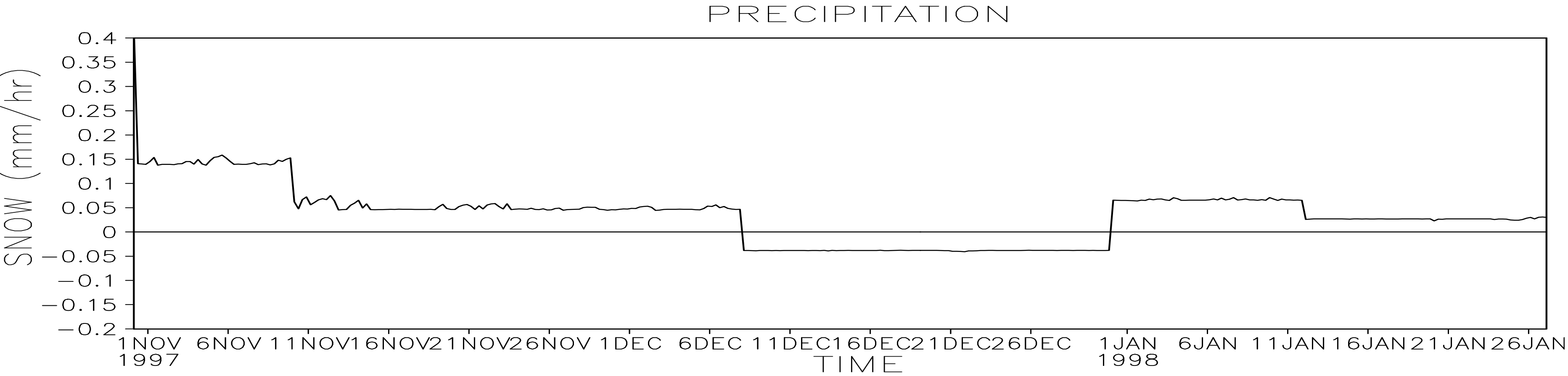


Observed and simulated ground temperatures at layer 1-5 during 1 November 1969 and 1 November 1970 (Sun & Chern 2005)
)

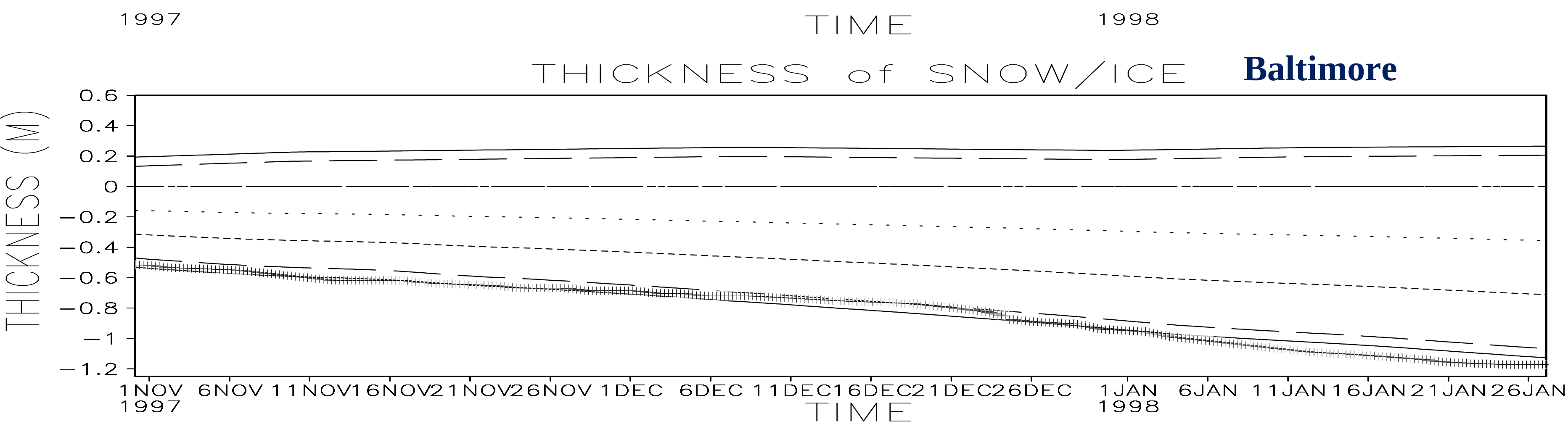


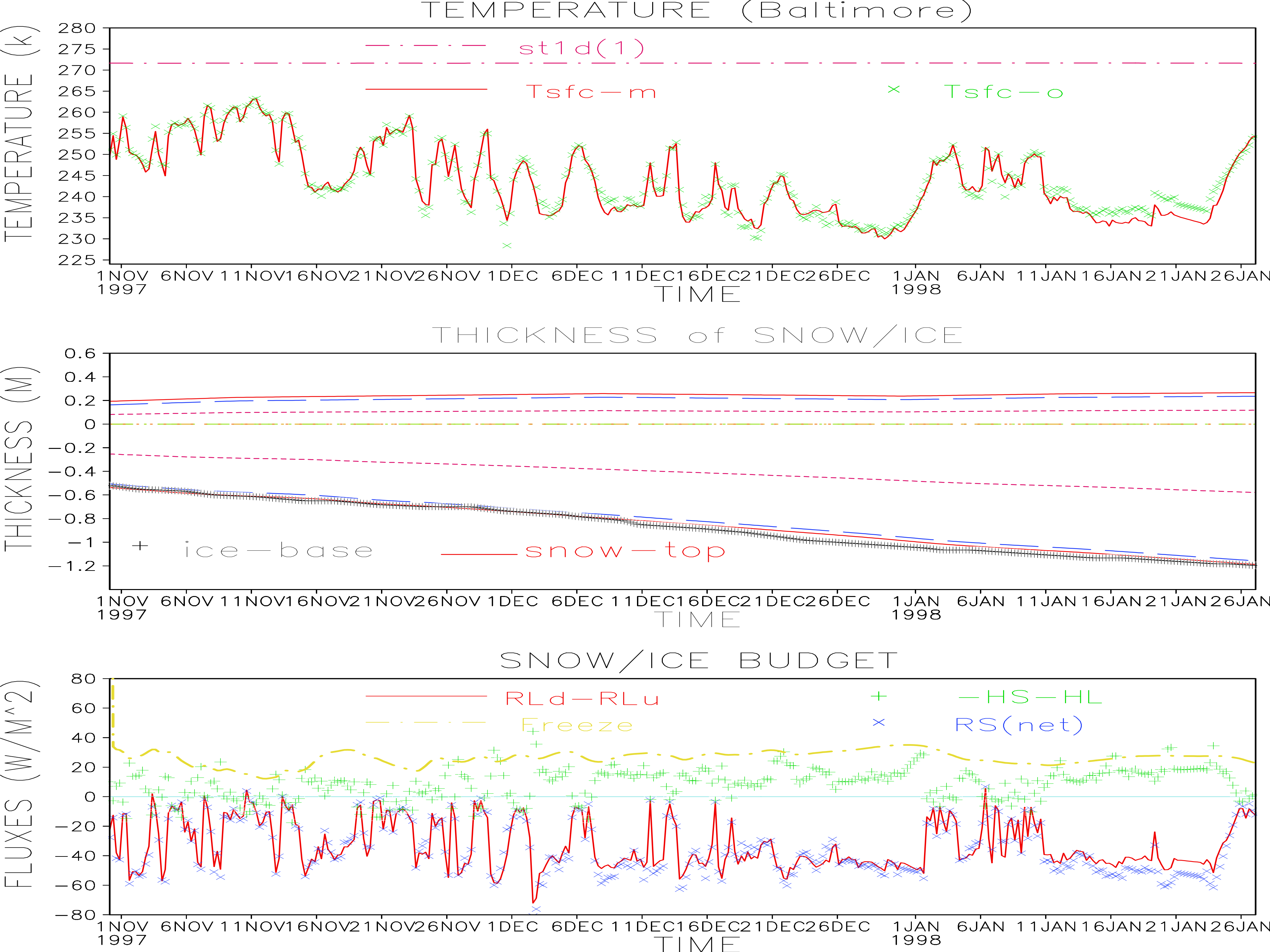
Mean snow depth of four snow survey lines at SHEBA


PRECIPITATION
SNOW (mm/hr)
TIME
THICKNESS of SNOW/ICE
THICKNESS (M)
Baltimore
TIME
TEMPERATURE
TEMPERATURE (k)
Tsfc−m
Tsfc−o
st1d(1)
TIME
1NOV 1997
1JAN 1998

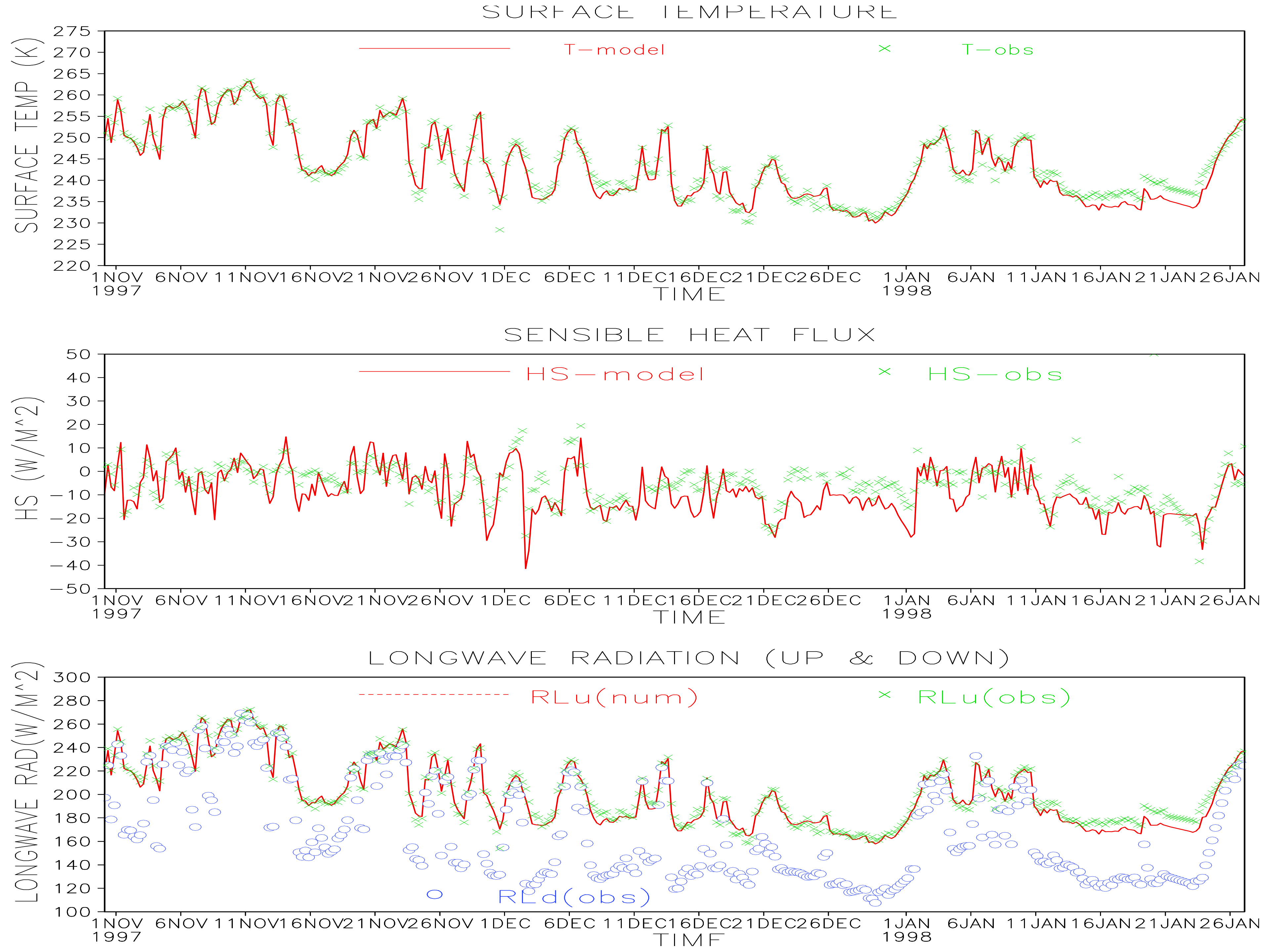


Effective precipitation rate at Baltimore site derived from Fig. 2.

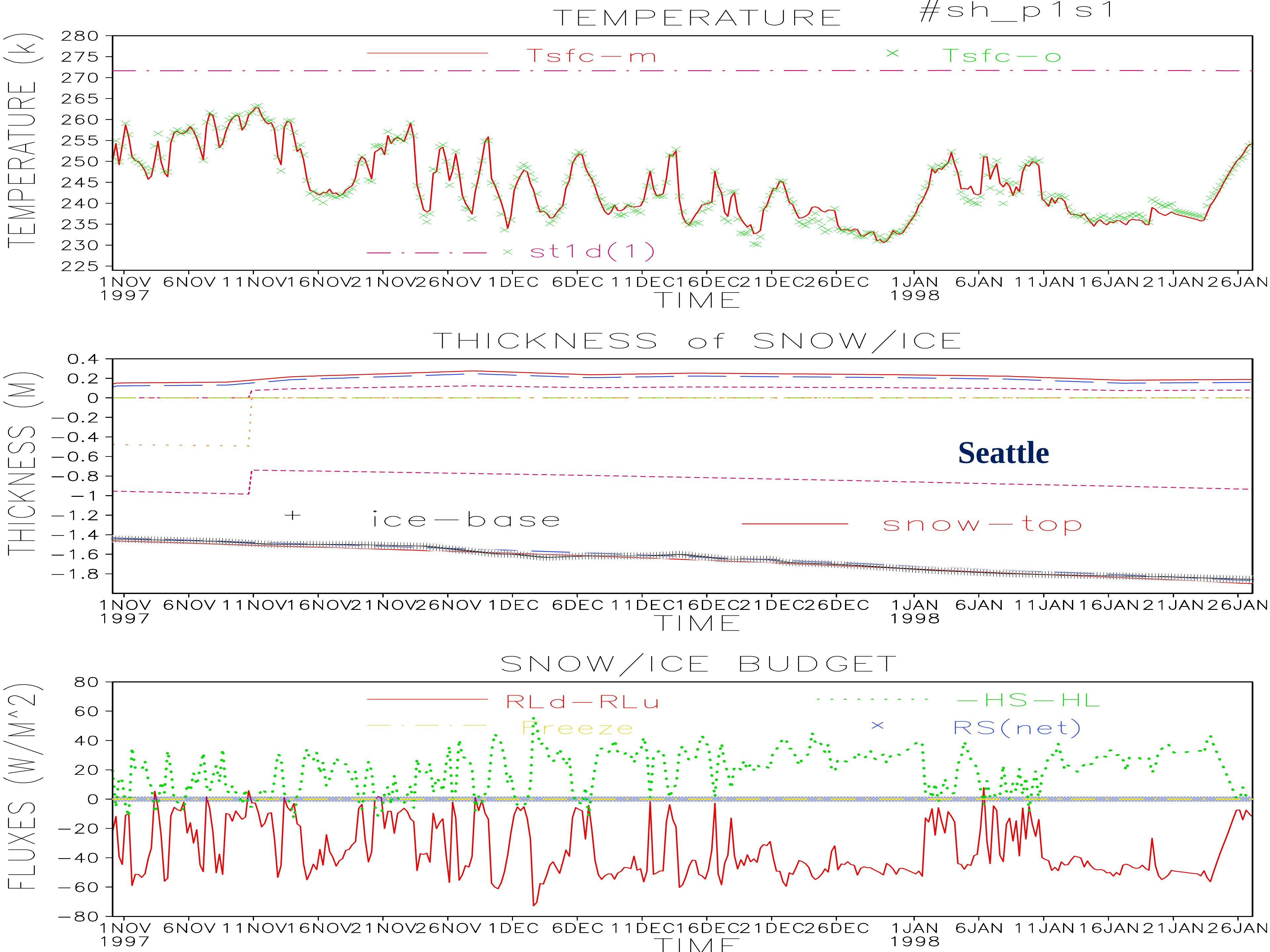




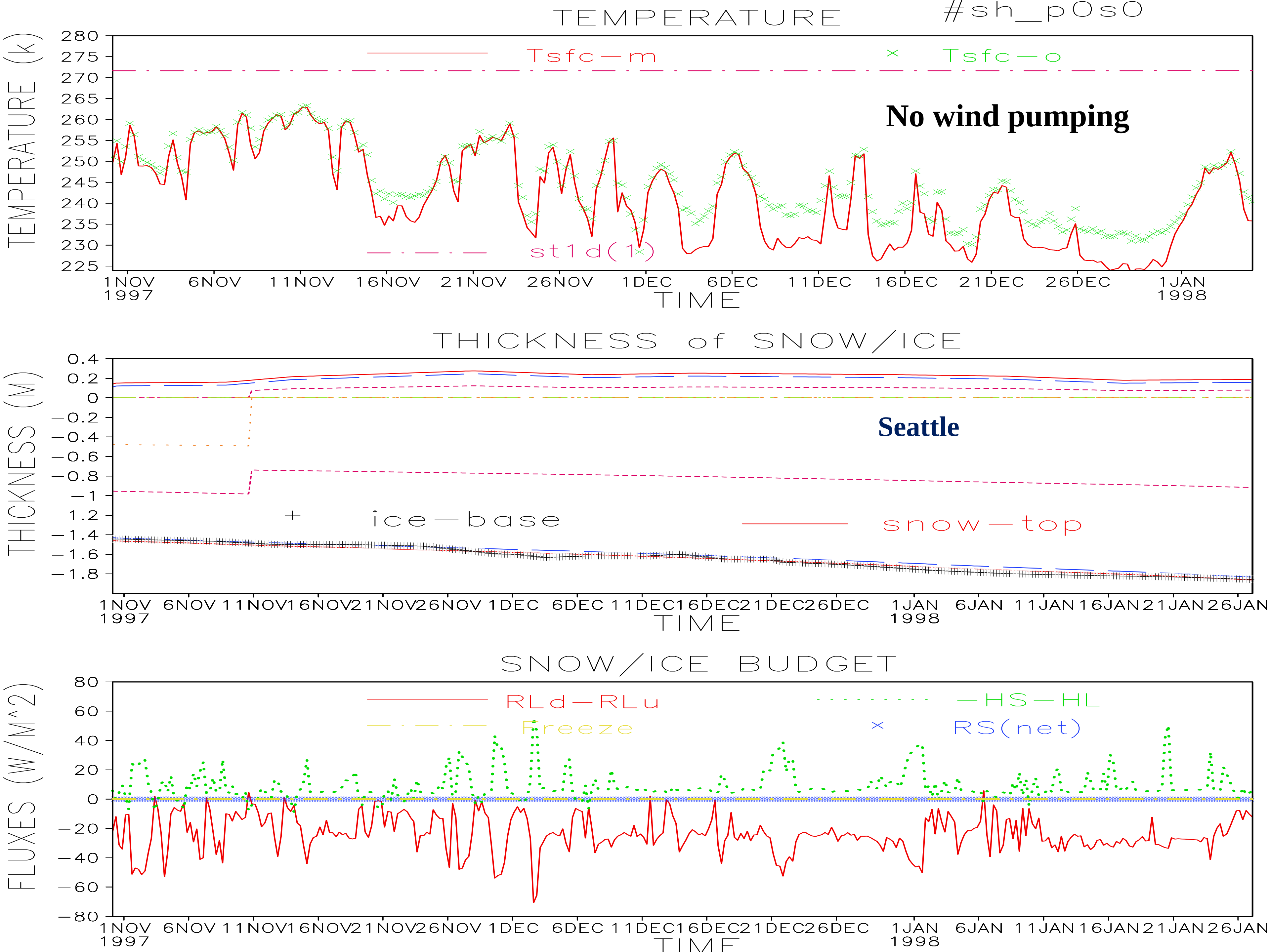
TEMPERATURE (Baltimore)
TEMPERATURE (k)
st1d(1)
Tsfc−m
Tsfc−o
TIME
THICKNESS of SNOW/ICE
THICKNESS (M)
ice−base
snow−top
TIME
SNOW/ICE BUDGET
FLUXES (W/M^2)
RLd−RLu
−HS−HL
Freeze
RS(net)
TIME
1NOV 1997
6NOV
11NOV
16NOV
21NOV
26NOV
1DEC
6DEC
11DEC
16DEC
21DEC
26DEC
1JAN 1998
6JAN
11JAN
16JAN
21JAN
26JAN

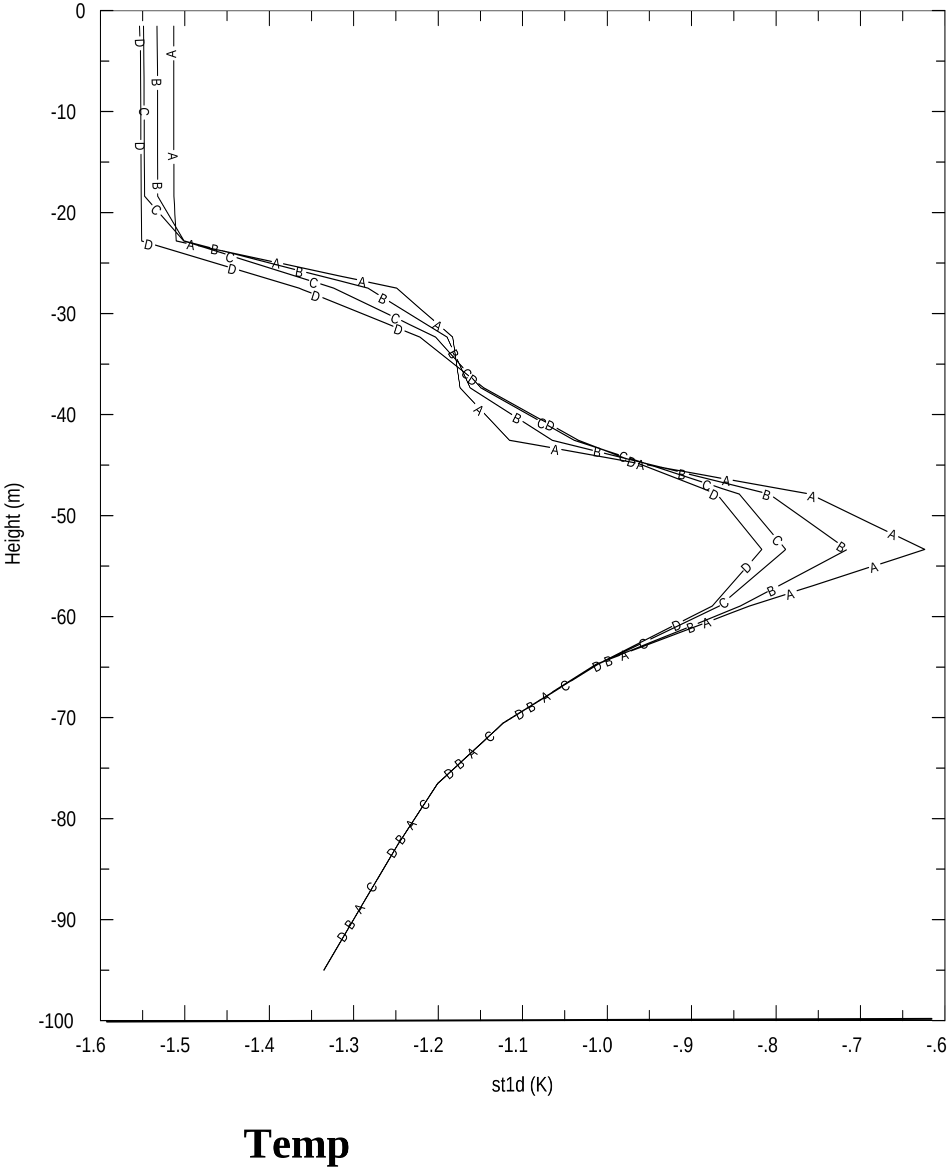


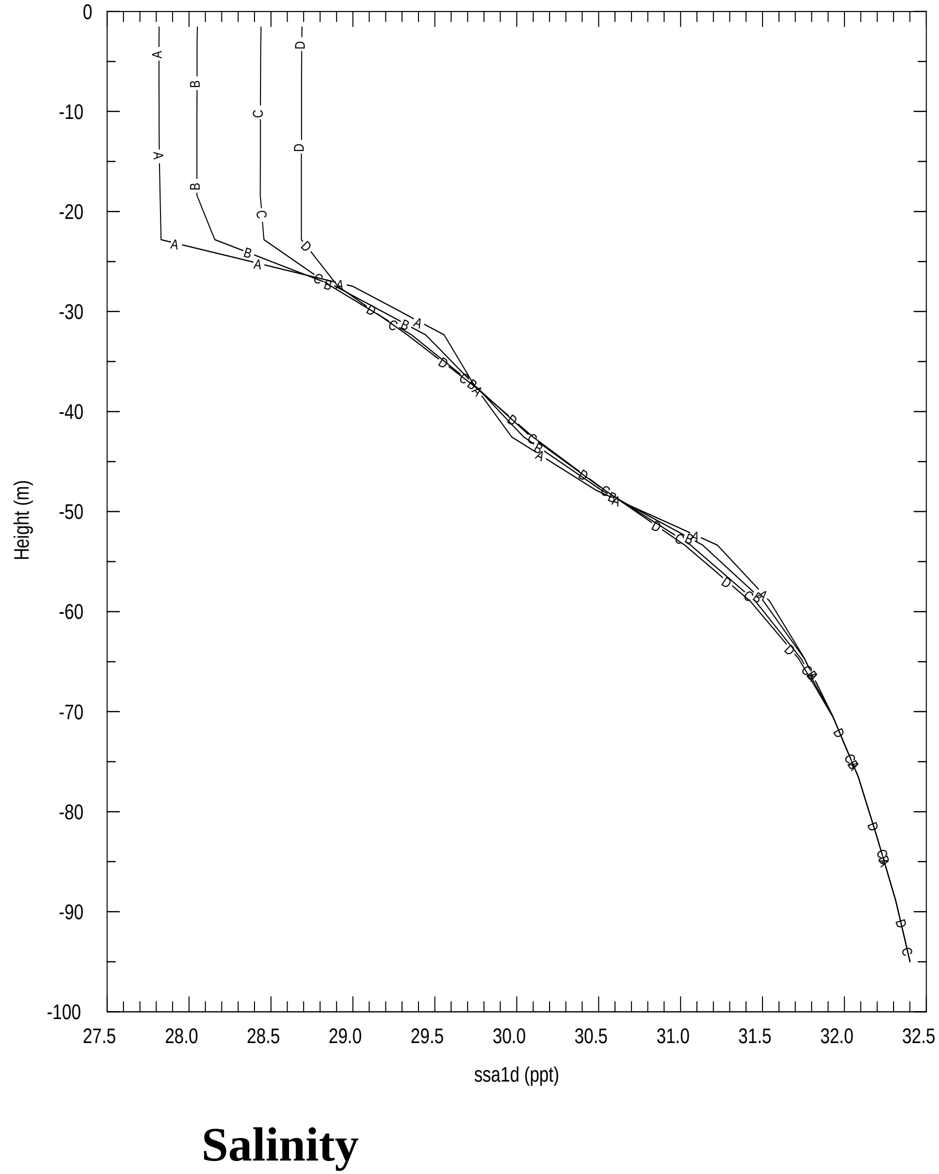
SURFACE TEMPERATURE
SURFACE TEMP (K)
T-model
T-obs
SENSIBLE HEAT FLUX
HS (W/M^2)
HS-model
HS-obs
LONGWAVE RADIATION (UP & DOWN)
LONGWAVE RAD(W/M^2)
RLu(num)
RLu(obs)
RLd(obs)
1NOV 1997
6NOV
11NOV
16NOV
21NOV
26NOV
1DEC
6DEC
11DEC
16DEC
21DEC
26DEC
1JAN 1998
6JAN
11JAN
16JAN
21JAN
26JAN
TIME



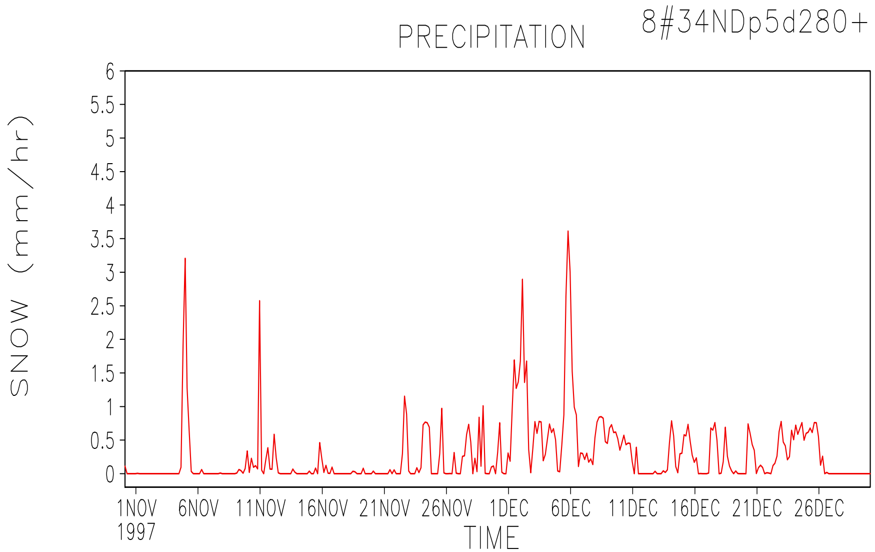
TEMPERATURE
#sh_p1s1
TEMPERATURE (k)
Tsfc−m
Tsfc−o
st1d(1)
TIME
THICKNESS of SNOW/ICE
THICKNESS (M)
Seattle
ice−base
snow−top
TIME
SNOW/ICE BUDGET
FLUXES (W/M^2)
RLd−RLu
−HS−HL
Freeze
RS(net)
1NOV 1997
6NOV
11NOV
16NOV
21NOV
26NOV
1DEC
6DEC
11DEC
16DEC
21DEC
26DEC
1JAN 1998
6JAN
11JAN
16JAN
21JAN
26JAN
TIME

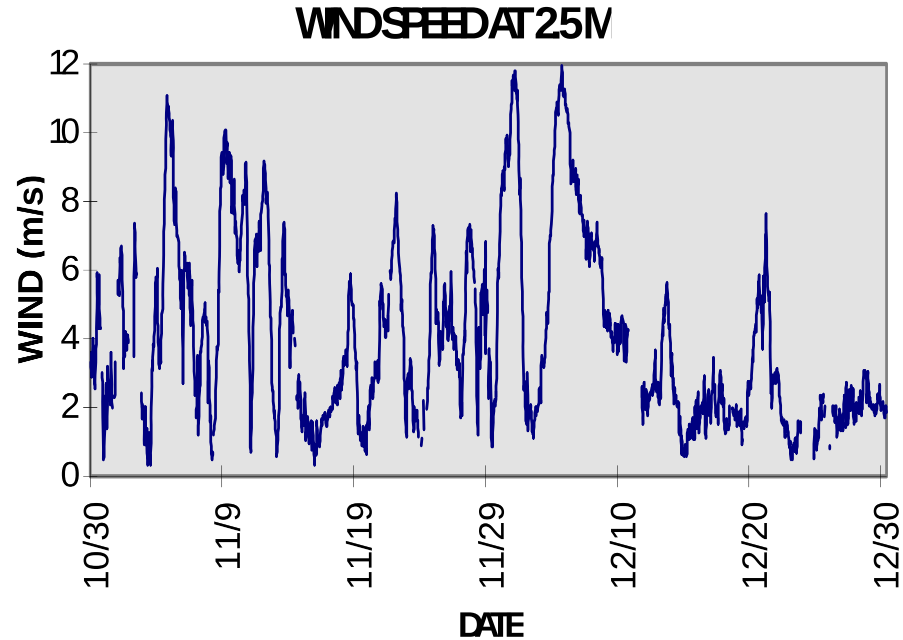

TEMPERATURE
#sh_p0s0
TEMPERATURE (k)
Tsfc−m
Tsfc−o
st1d(1)
No wind pumping
280
275
270
265
260
255
250
245
240
235
230
225
1NOV 1997
6NOV
11NOV
16NOV
21NOV
26NOV
1DEC
6DEC
11DEC
16DEC
21DEC
26DEC
1JAN 1998
TIME
THICKNESS of SNOW/ICE
THICKNESS (M)
Seattle
ice−base
snow−top
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
−1.6
−1.8
1NOV 1997
6NOV
11NOV
16NOV
21NOV
26NOV
1DEC
6DEC
11DEC
16DEC
21DEC
26DEC
1JAN 1998
6JAN
11JAN
16JAN
21JAN
26JAN
TIME
SNOW/ICE BUDGET
FLUXES (W/M^2)
RLd−RLu
−HS−HL
Freeze
RS(net)
80
60
40
20
0
−20
−40
−60
−80
1NOV 1997
6NOV
11NOV
16NOV
21NOV
26NOV
1DEC
6DEC
11DEC
16DEC
21DEC
26DEC
1JAN 1998
6JAN
11JAN
16JAN
21JAN
26JAN
TIME

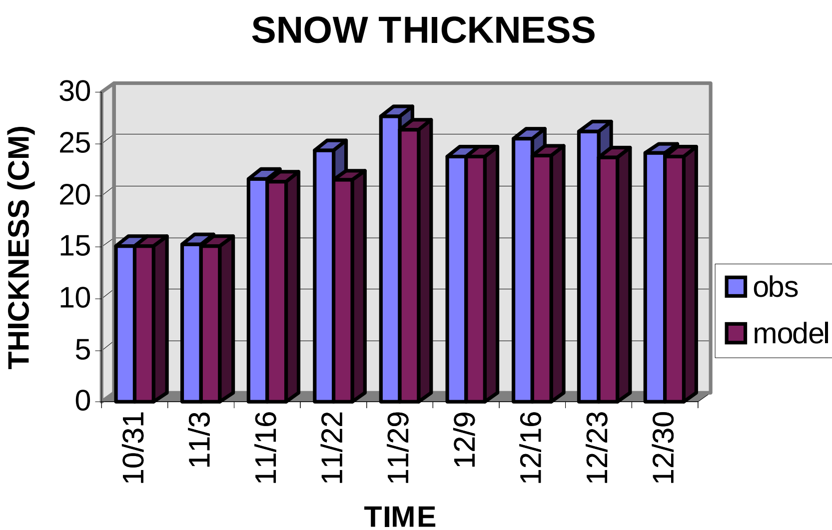


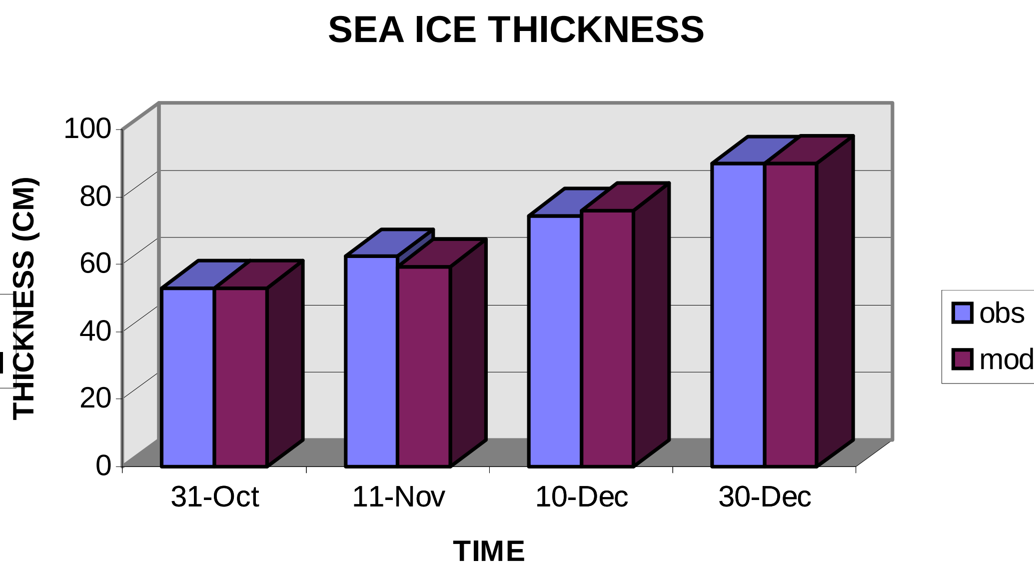


Simulated sea water temperature and salinity at different times


PRECIPITATION
8#34NDp5d280+
SNOW (mm/hr)
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6
1NOV 1997
6NOV 11NOV 16NOV 21NOV 26NOV 1DEC 6DEC 11DEC 16DEC 21DEC 26DEC
TIME


WINDSPEED AT 2.5M
WIND (m/s)
0 2 4 6 8 10 12
10/30 11/9 11/19 11/29 12/10 12/20 12/30
DATE


SNOW THICKNESS
THICKNESS (CM)
0 5 10 15 20 25 30
10/31 11/3 11/16 11/22 11/29 12/9 12/16 12/23 12/30
TIME
obs
model

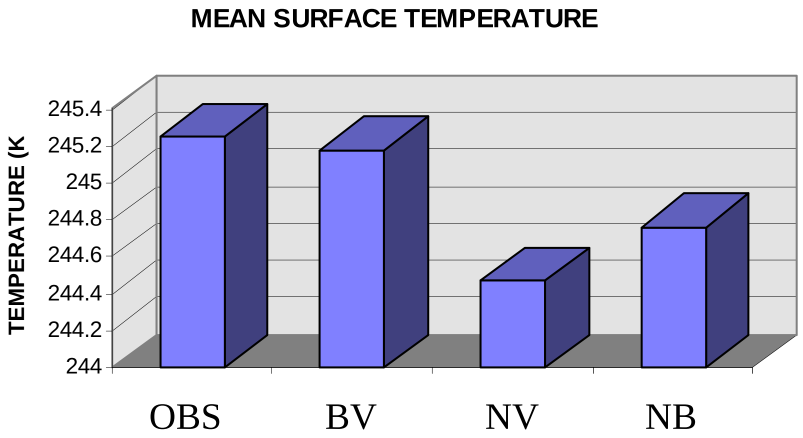

SEA ICE THICKNESS
THICKNESS (CM)
0 20 40 60 80 100
31-Oct 11-Nov 10-Dec 30-Dec
TIME
obs
mod

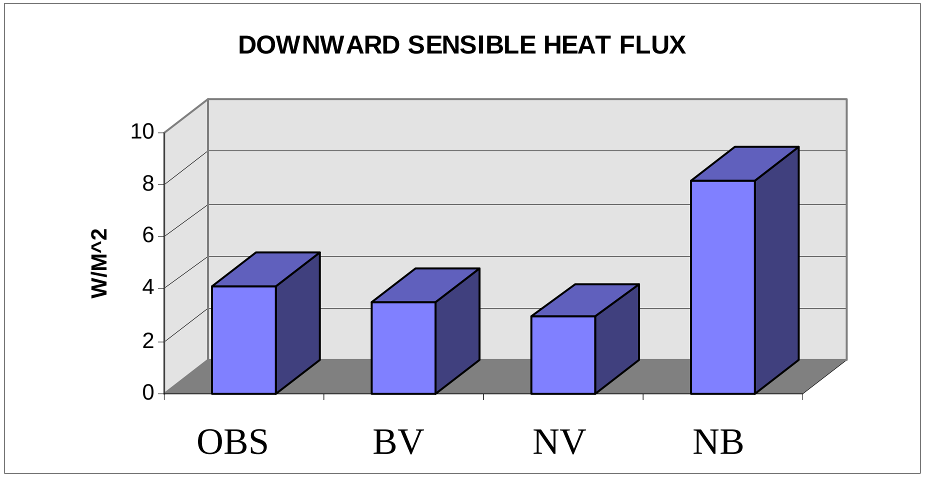
SENSITIVITY TESTS

Experiment Design

Experiment	blowing snow	snow ventilation
BV	yes	yes
NV	yes	no
NB	no	yes

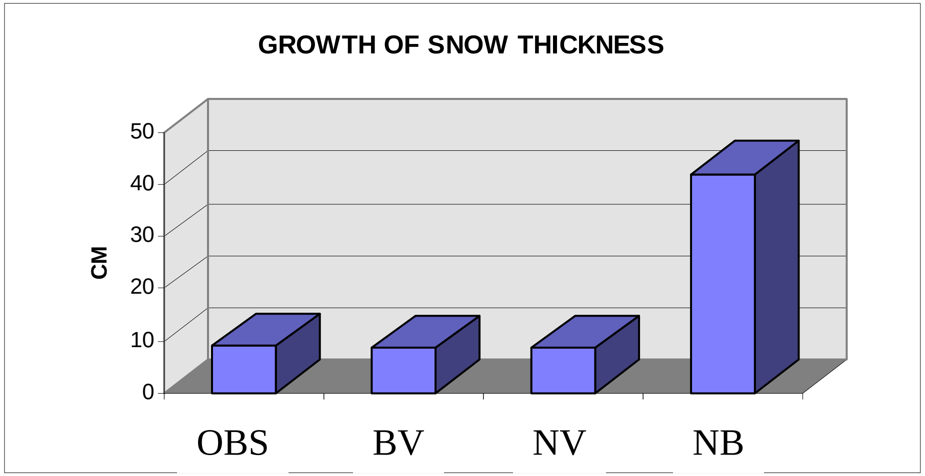
Numerical Results

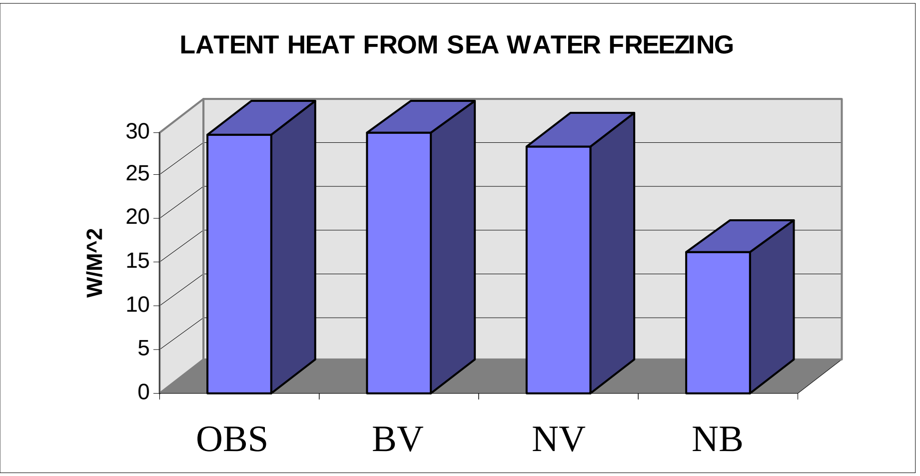


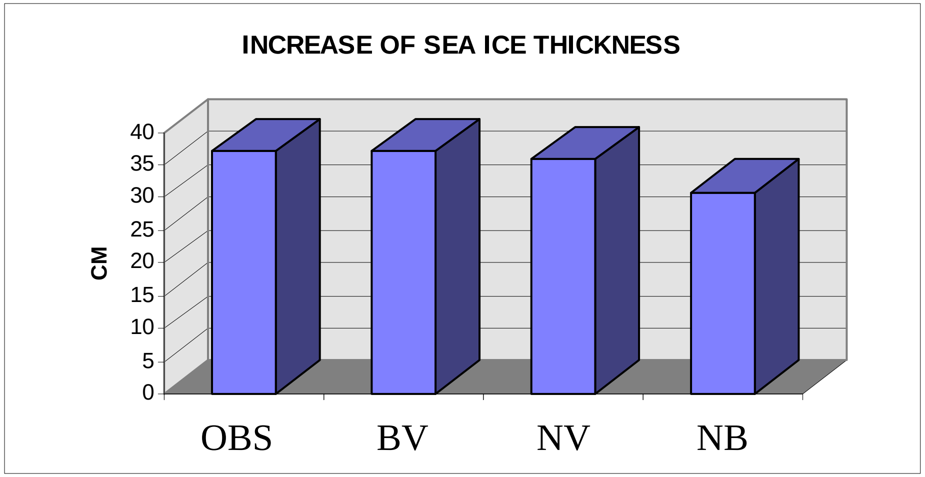


(1) Snow ventilation increases surface temperature, downward sensible heat flux, and the thickness of sea ice.

(2) Without blowing snow, snow thickness increases; surface temperature, latent heat of freezing, and sea ice thickness decrease.







SUMMARY

(1) Growths of snow & ice are in good agreement with observations.
(2) Sensible heat flux, upward longwave radiation, and snow surface temperature are well reproduced by the model.
(3) Net longwave radiation lost at snow surface and latent heat release due to freezing at ice-ocean interface are the major terms in energy budget during winter.
(4) Snow ventilation increases the surface temperature, downward sensible heat flux, and the thickness of sea ice.
(5) Increase snow thickness decreases the surface temperature, latent heat of freezing at ice-ocean interface, and sea ice thickness.
(6) To better simulate the temperature and salinity profiles in the ocean, it need to consider the effects of advection and the drift of ice floe.

Thanks