Difficulties in Determining Ocean Surface Fluxes in the Polar Regions

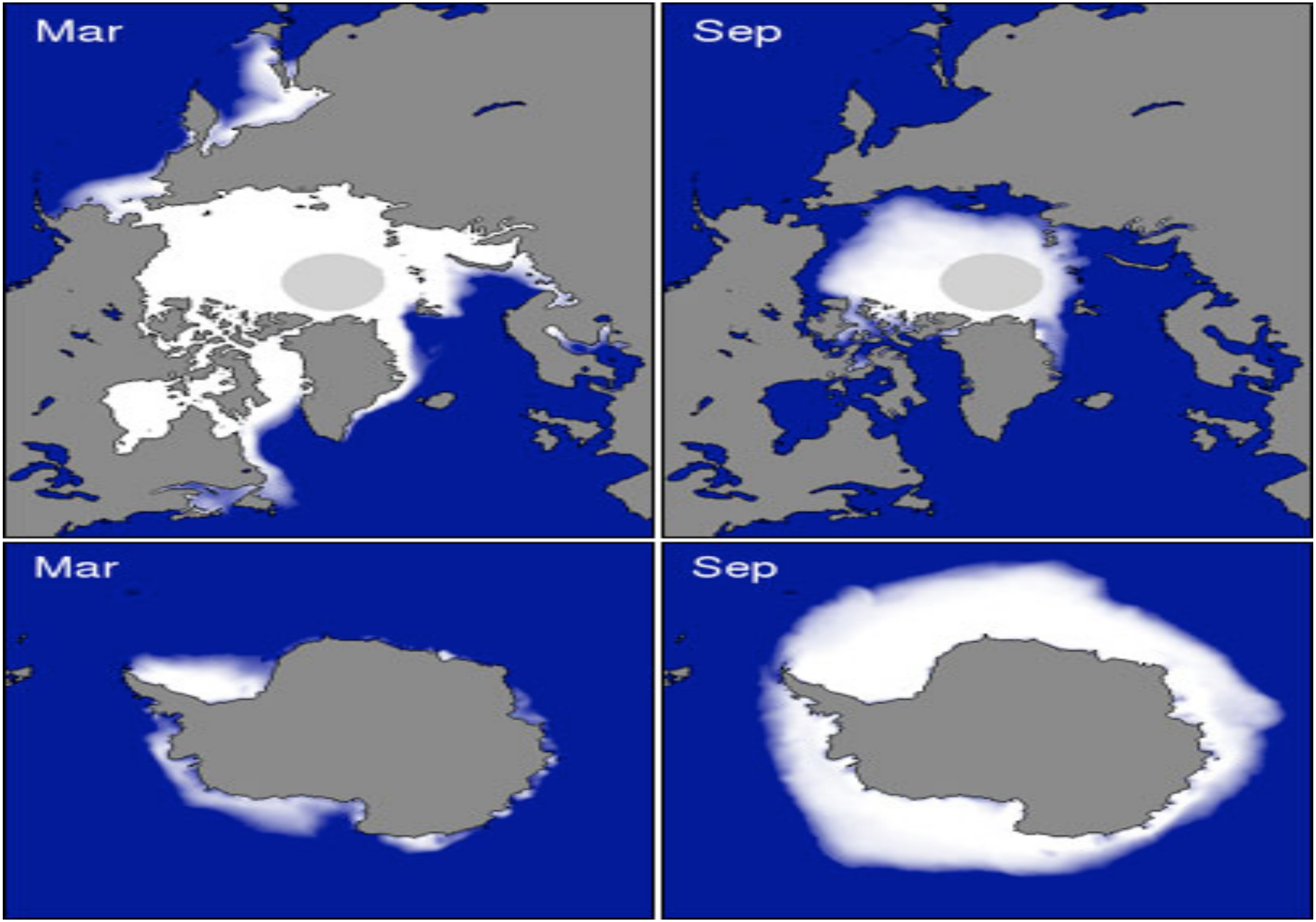
William B. Rossow

CREST at City College of New York

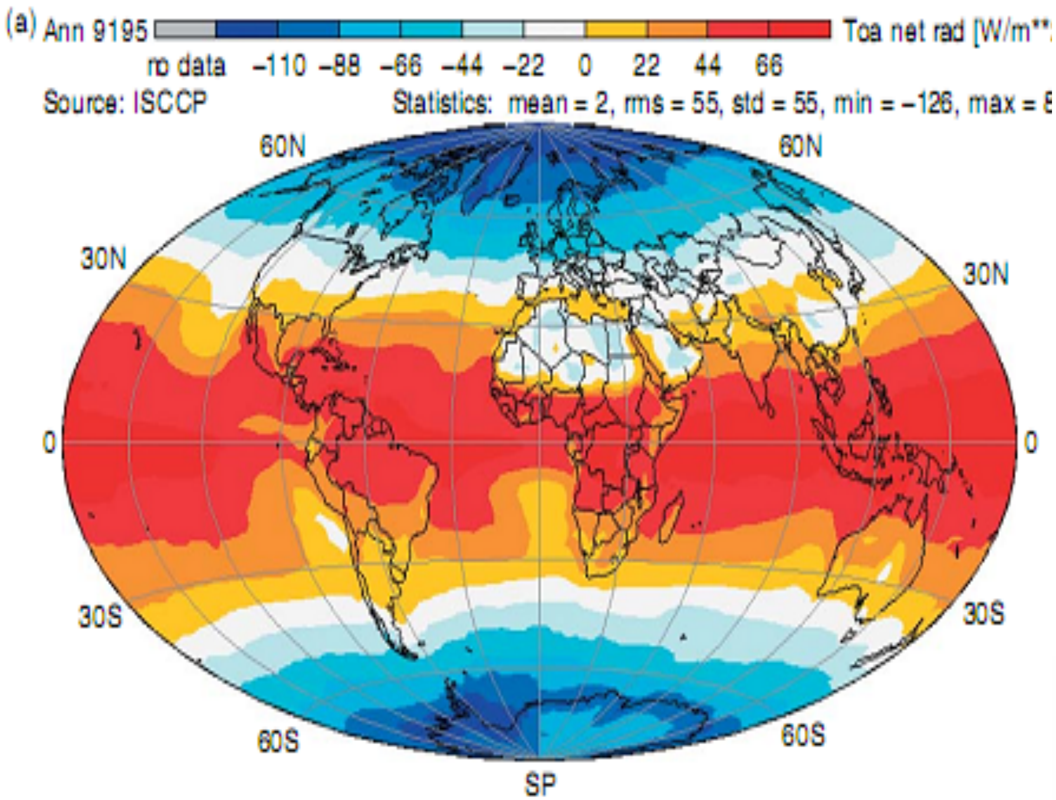
17-19 March 2010

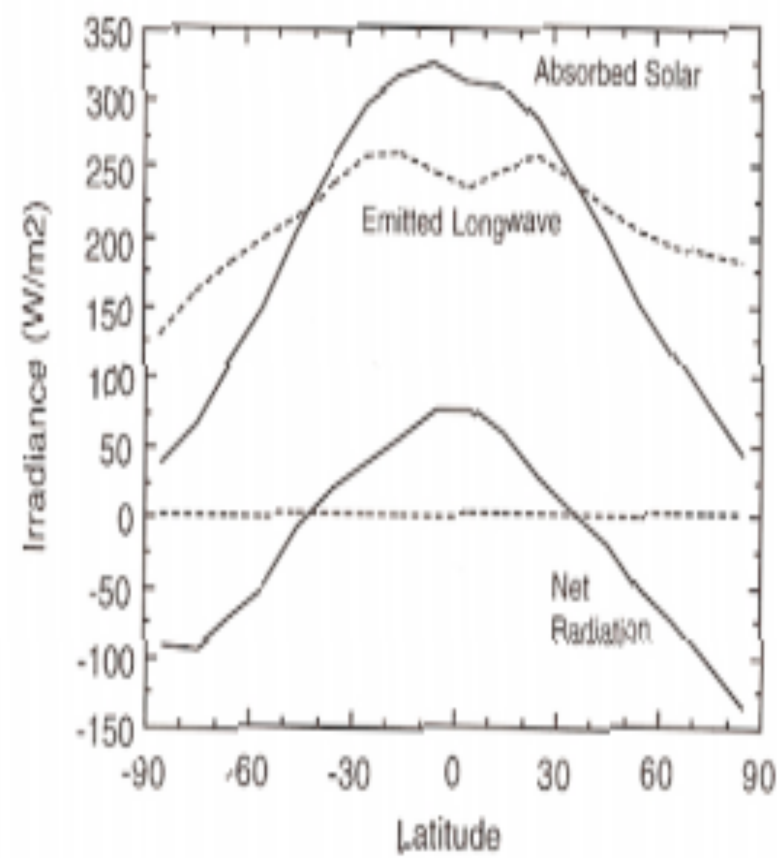
STAGE SETTING

POLAR CHARACTERISTICS

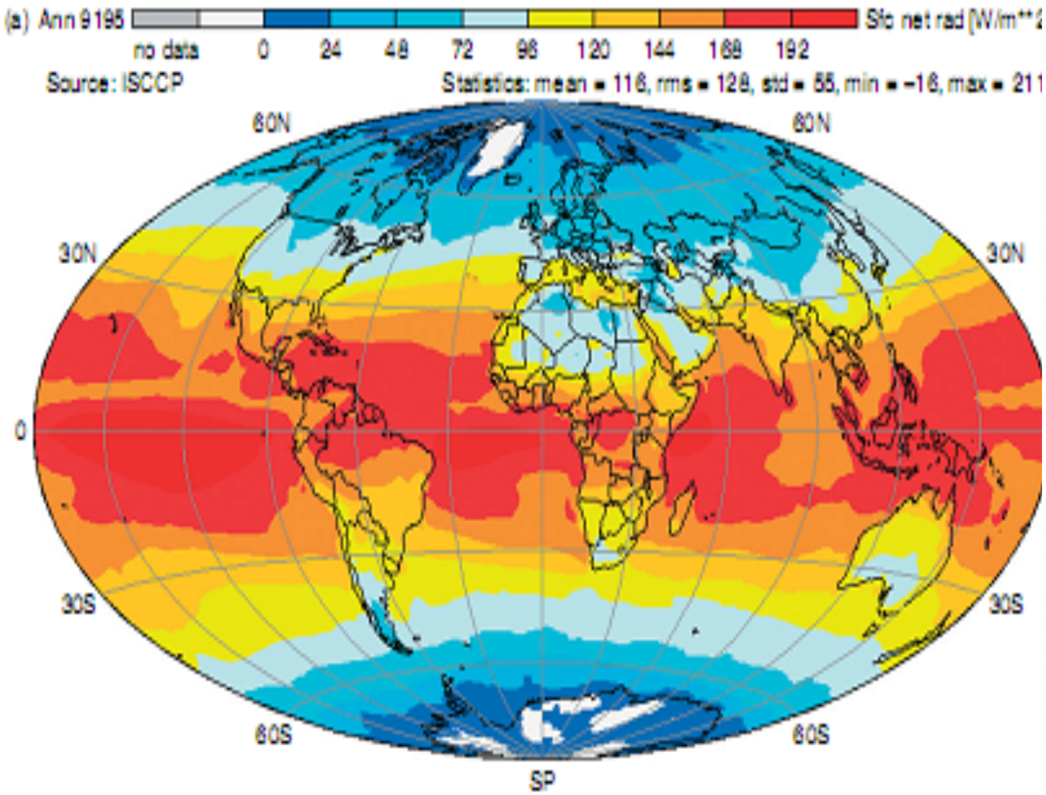


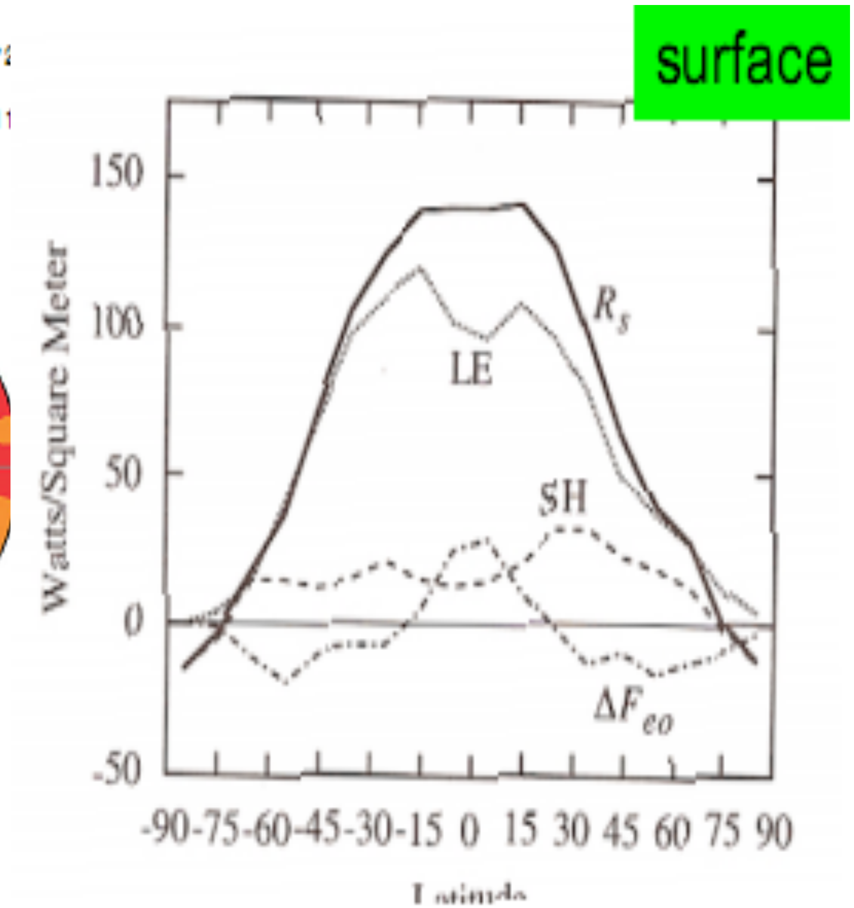
ANNUAL MEAN TOP OF ATMOSPHERE RADIATION





ANNUAL MEAN SURFACE ENERGY BALANCE





HEAT TRANSPORT IMPLIED BY RADIATIVE IMBALANCE

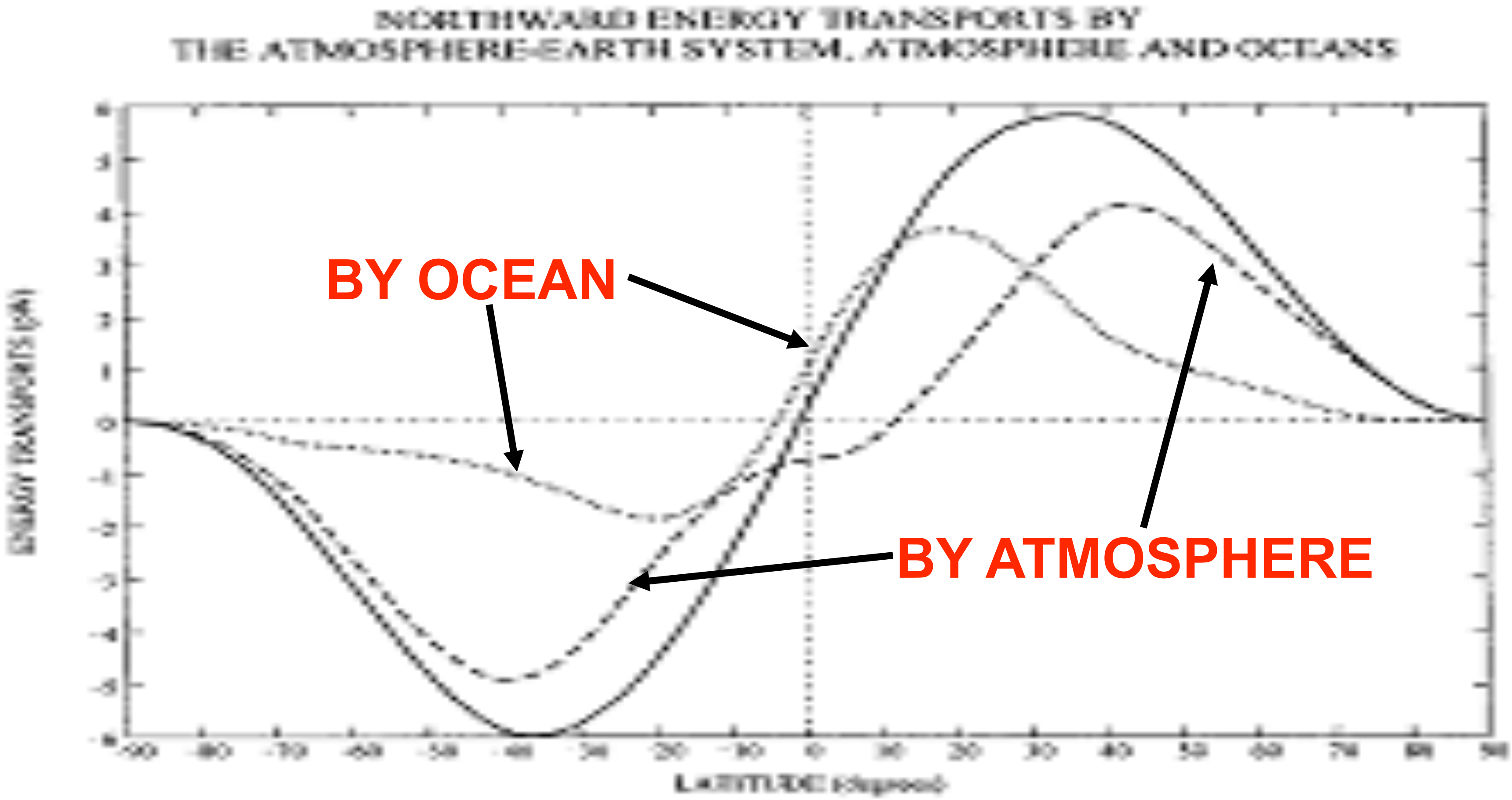
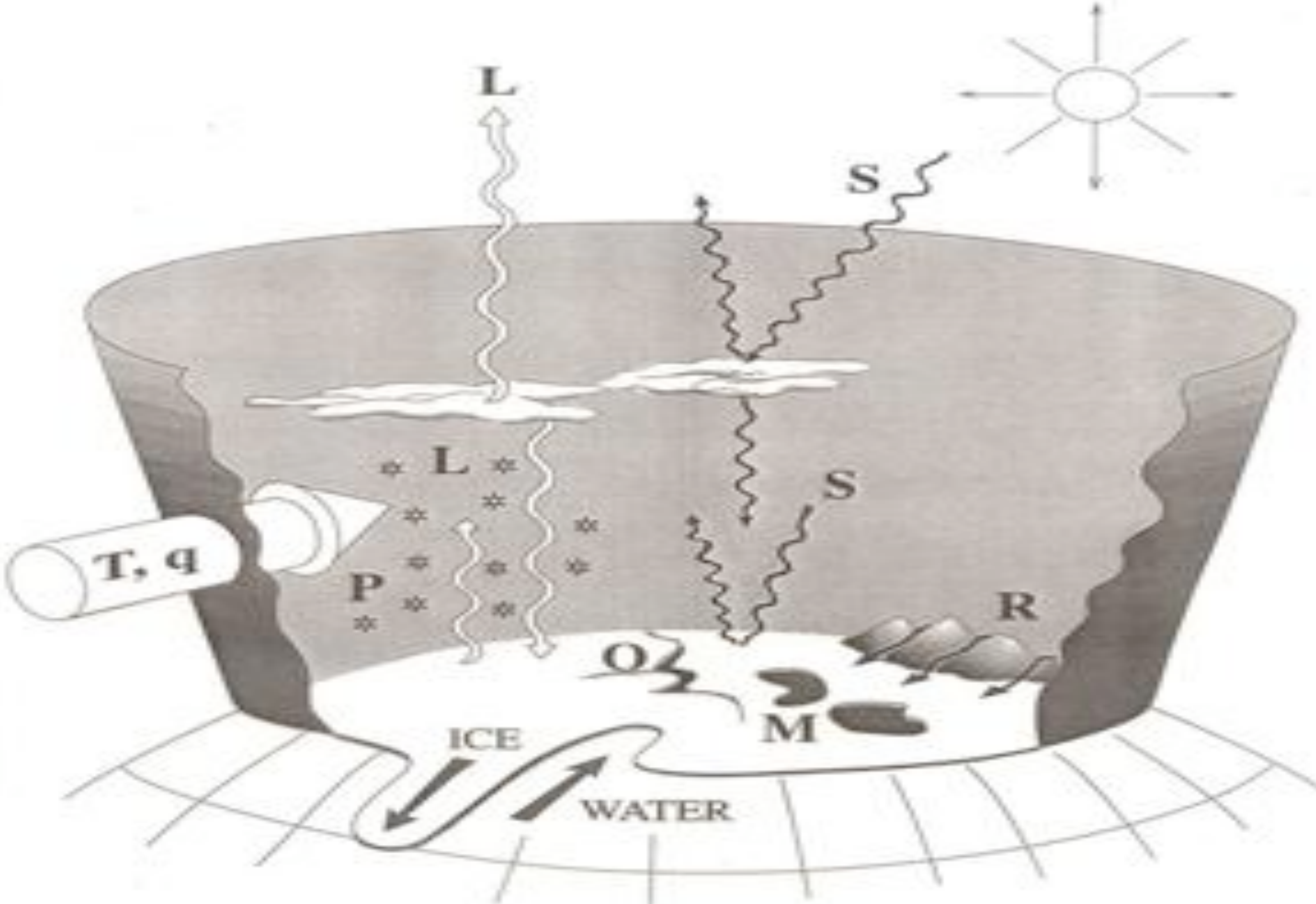
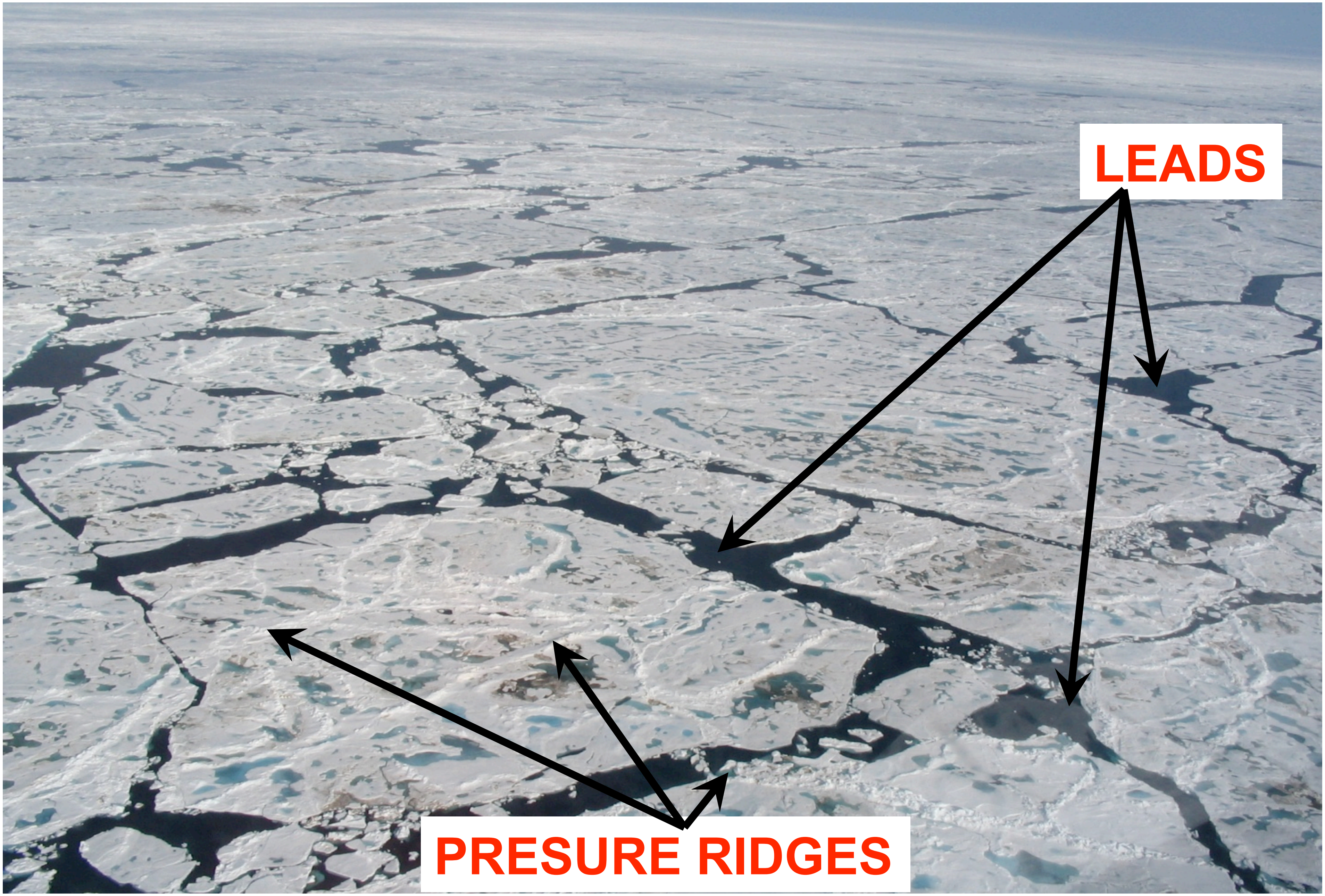


FIG. 15. Zonal annual mean northward total energy transports (PW = 10^{15} W) in the atmosphere–ocean system as required by the top-of-atmosphere radiation budget (solid line), by the atmosphere (dashed line), and by the ocean (dotted line) from this work (FC + Sellers data).

POLAR ENERGY BUDGET

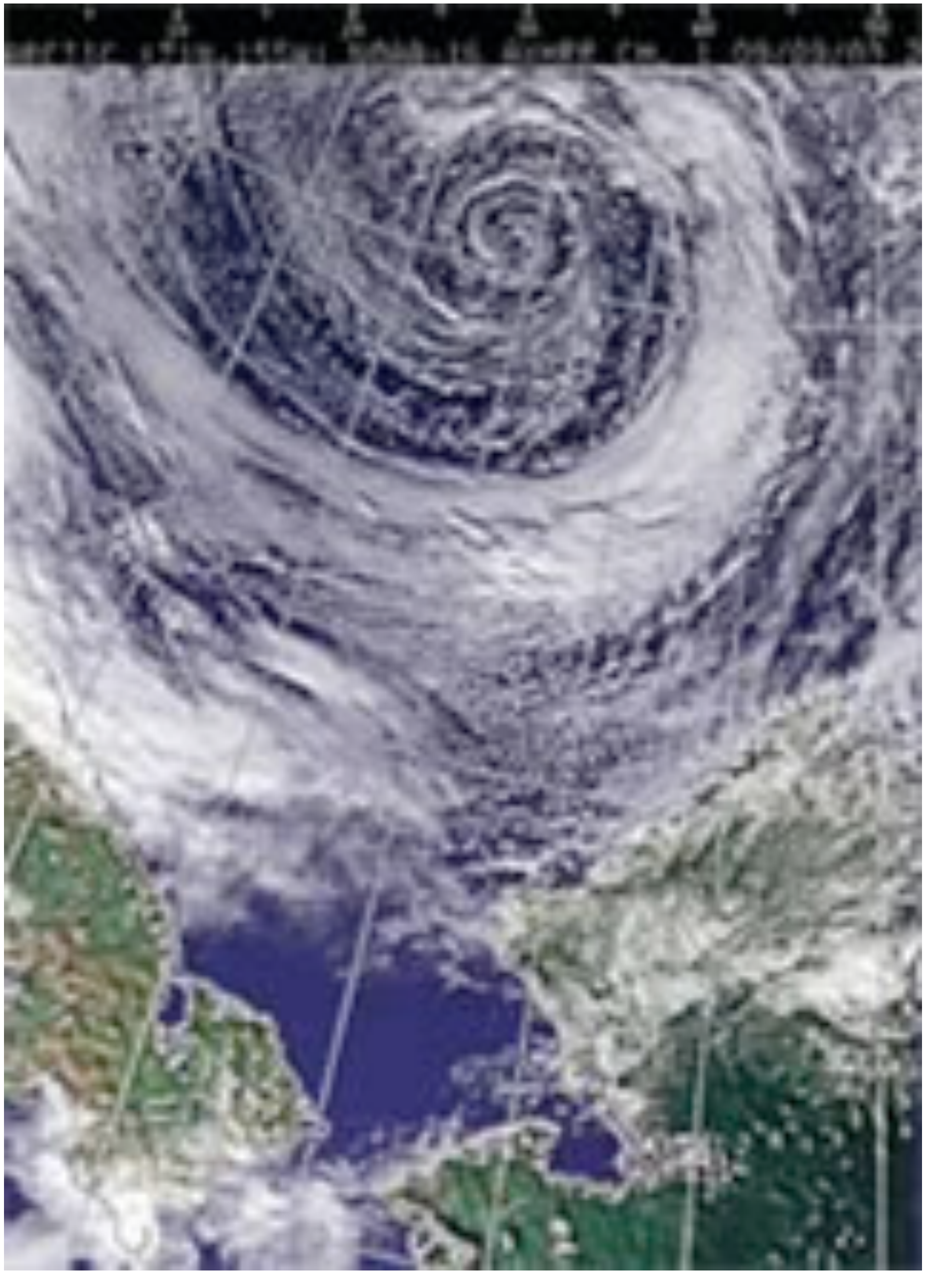


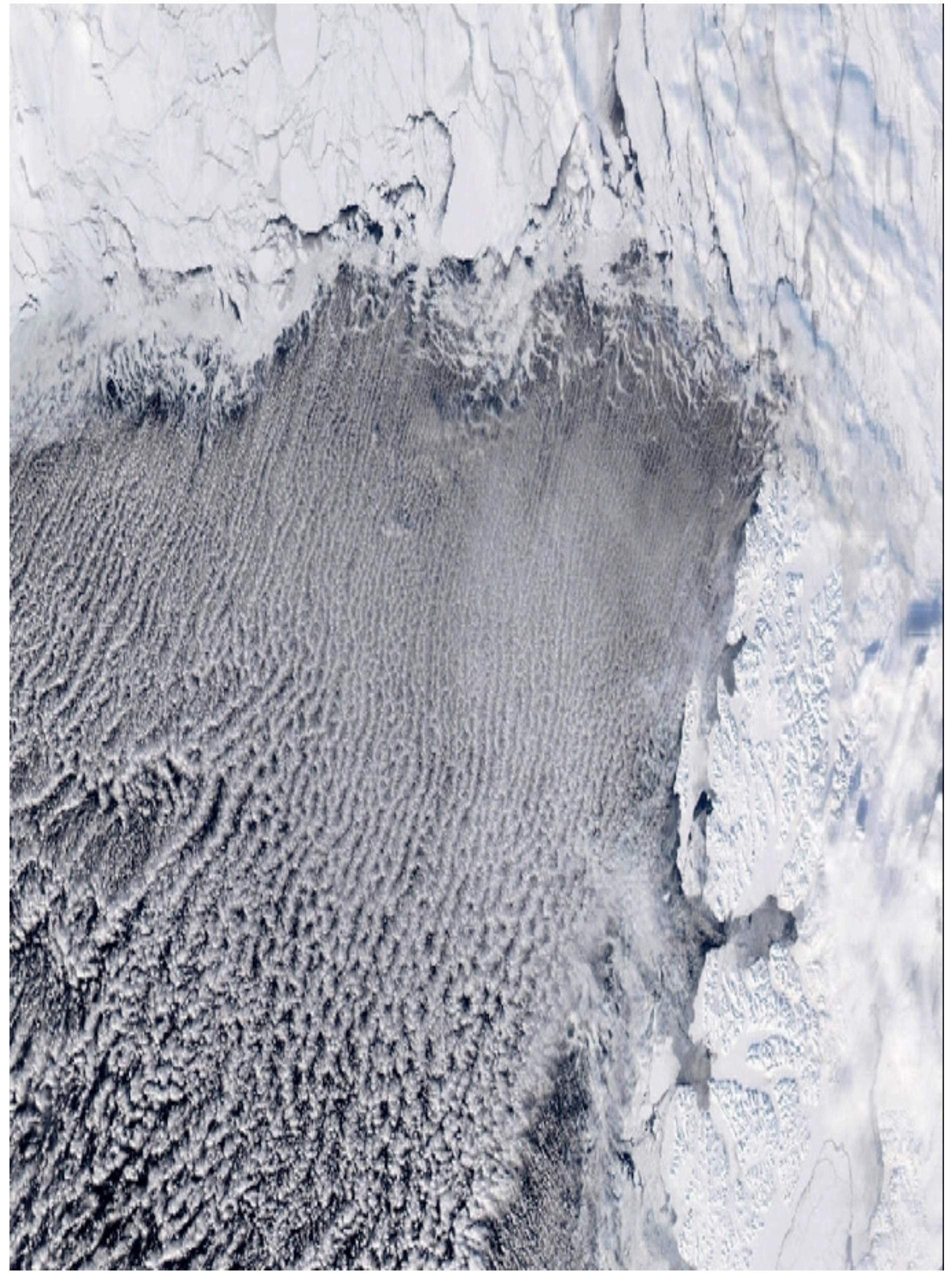
SEA ICE SURFACE FEATURES



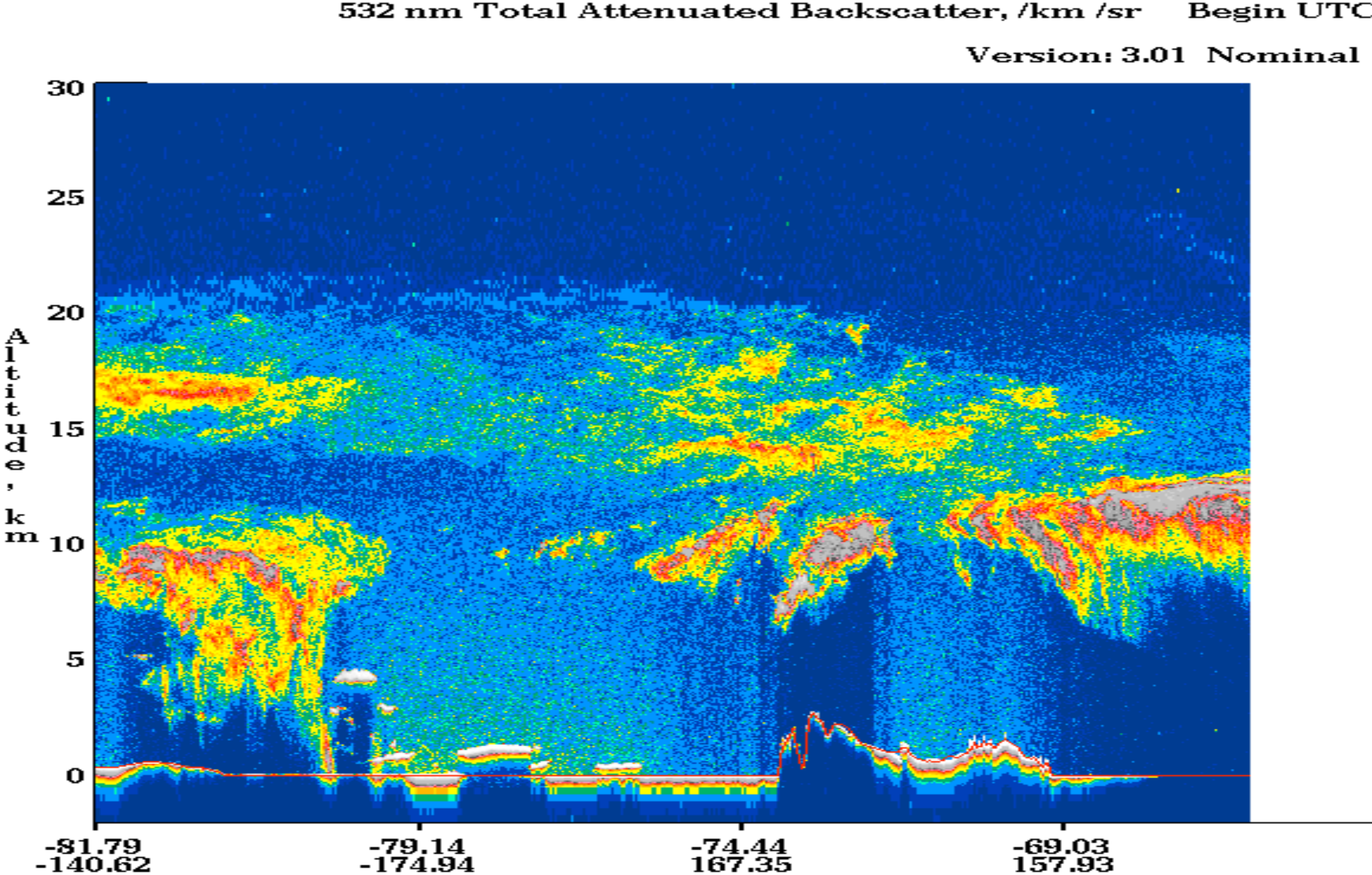
SEA ICE SURFACE FEATURES

STORM-SURFACE INTERACTIONS

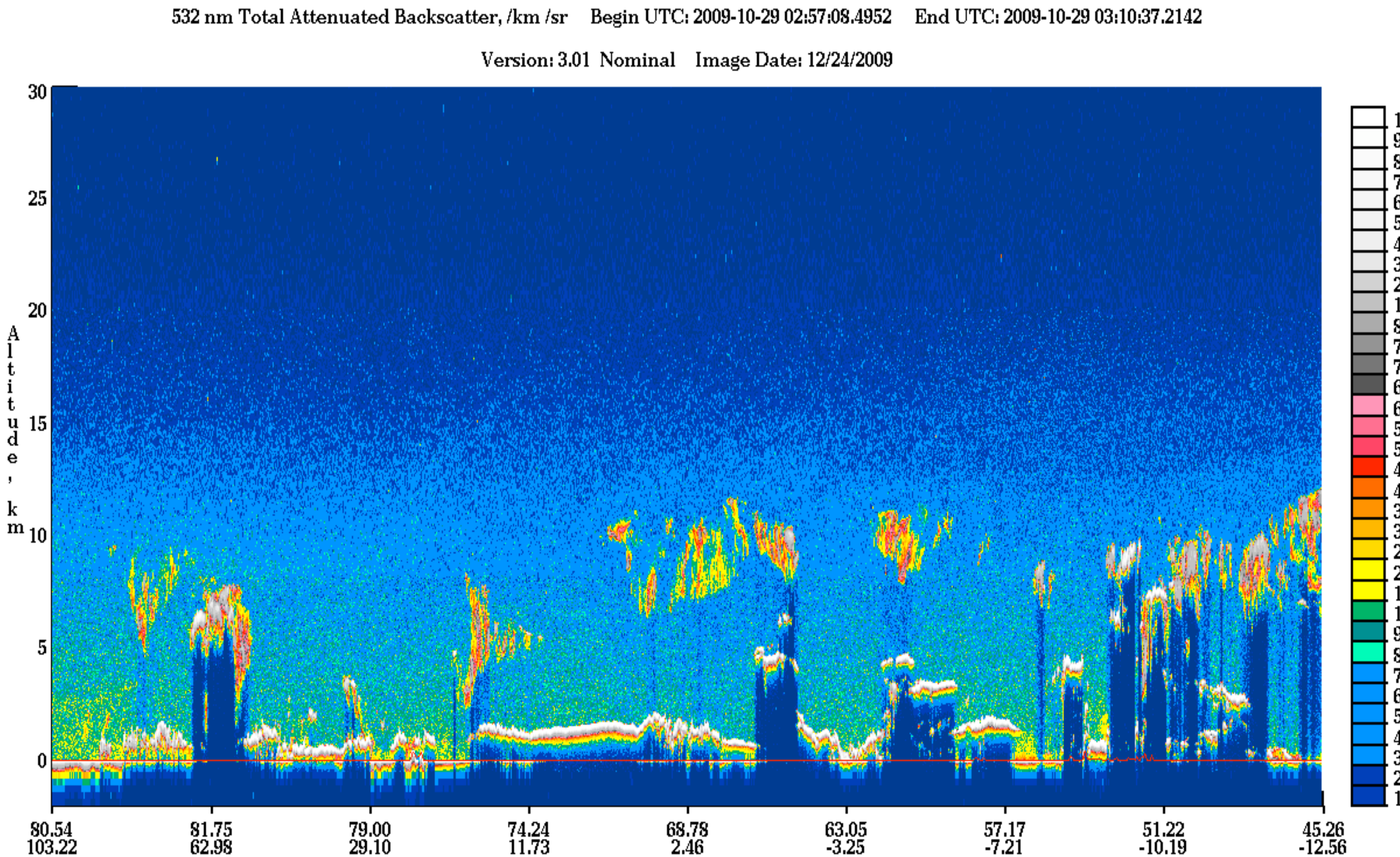




CALIPSO VIEW OF WINTER ANTARCTIC CLOUDS



CALIPSO VIEW OF AUTUMN ARCTIC CLOUDS



Polar Characteristics

Emphasis has been on disparate spatial scales

BUT

Main problem is disparate time scales of coupling

To understand processes, we need to evaluate time derivatives – fluxes are exchange **rates**

SATELLITE REMOTE SENSING

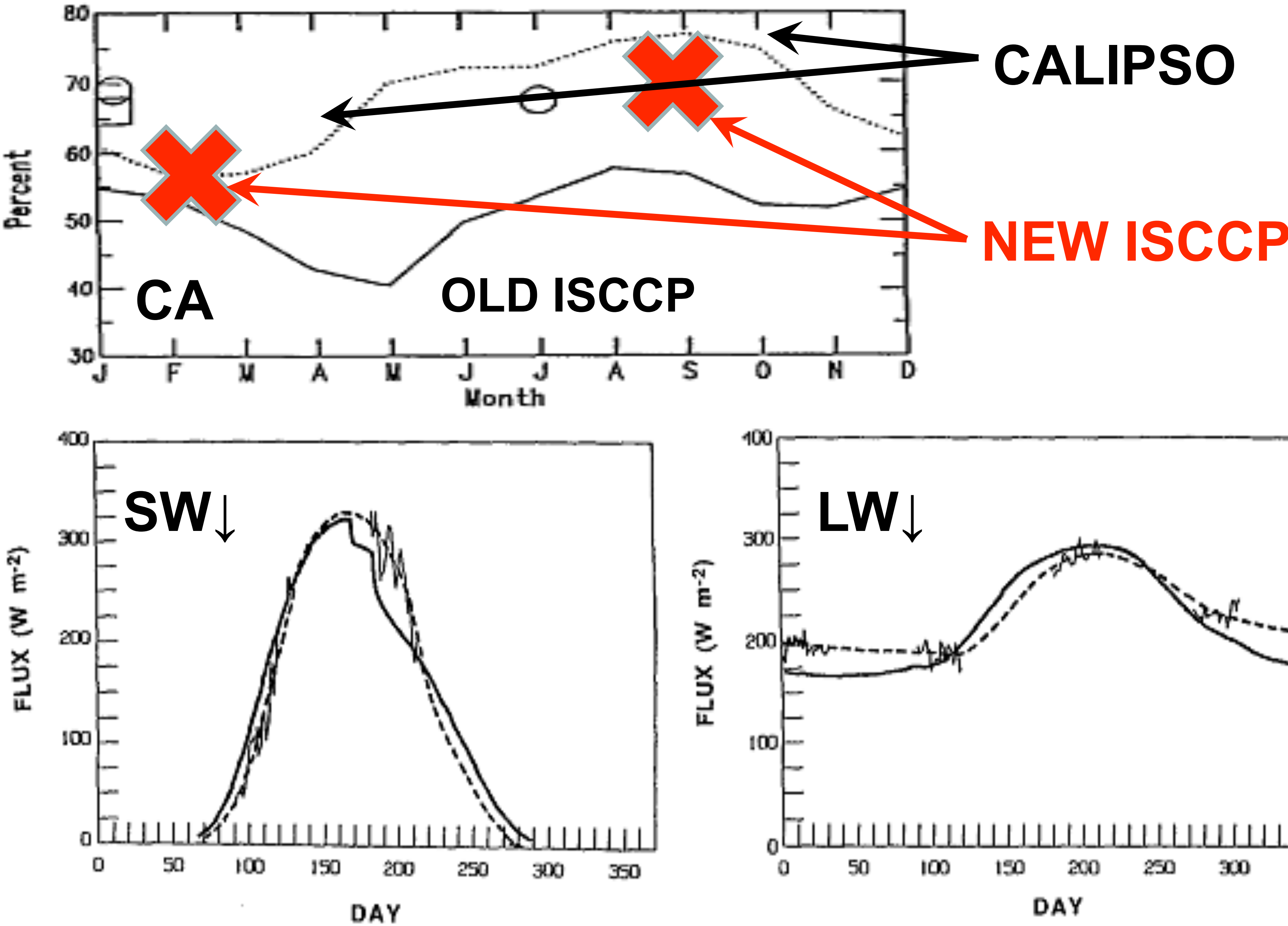
Remote sensing necessary because of multiple space-time scales of variation and interaction

Difficult because

Surface--cloud contrasts small, water vapor and precipitation rates small and

●●●Surface Variations are nearly as rapid as Atmospheric Variations making separation much more difficult

Clouds & Radiative Fluxes from RS

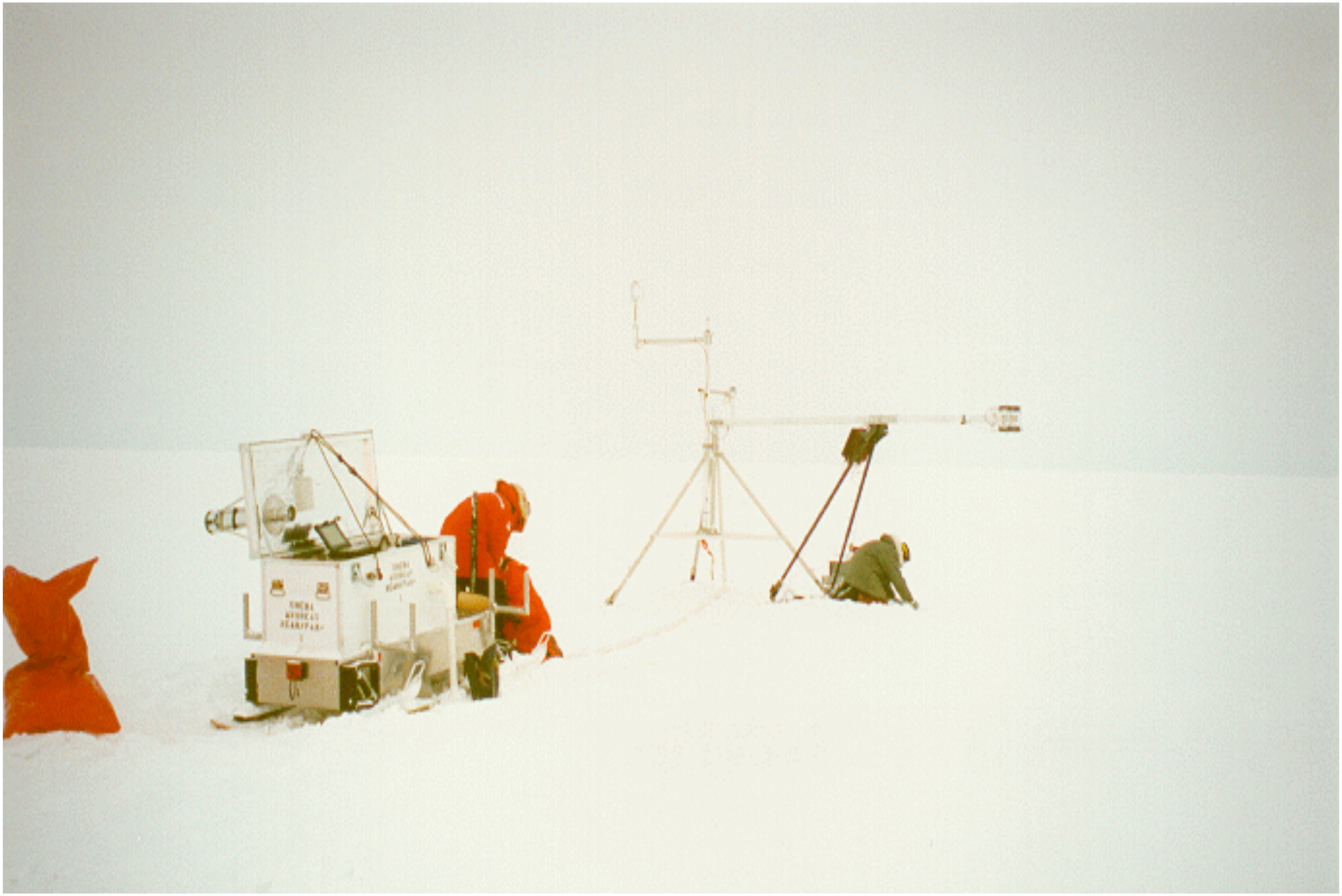


SHEBA CASE STUDY

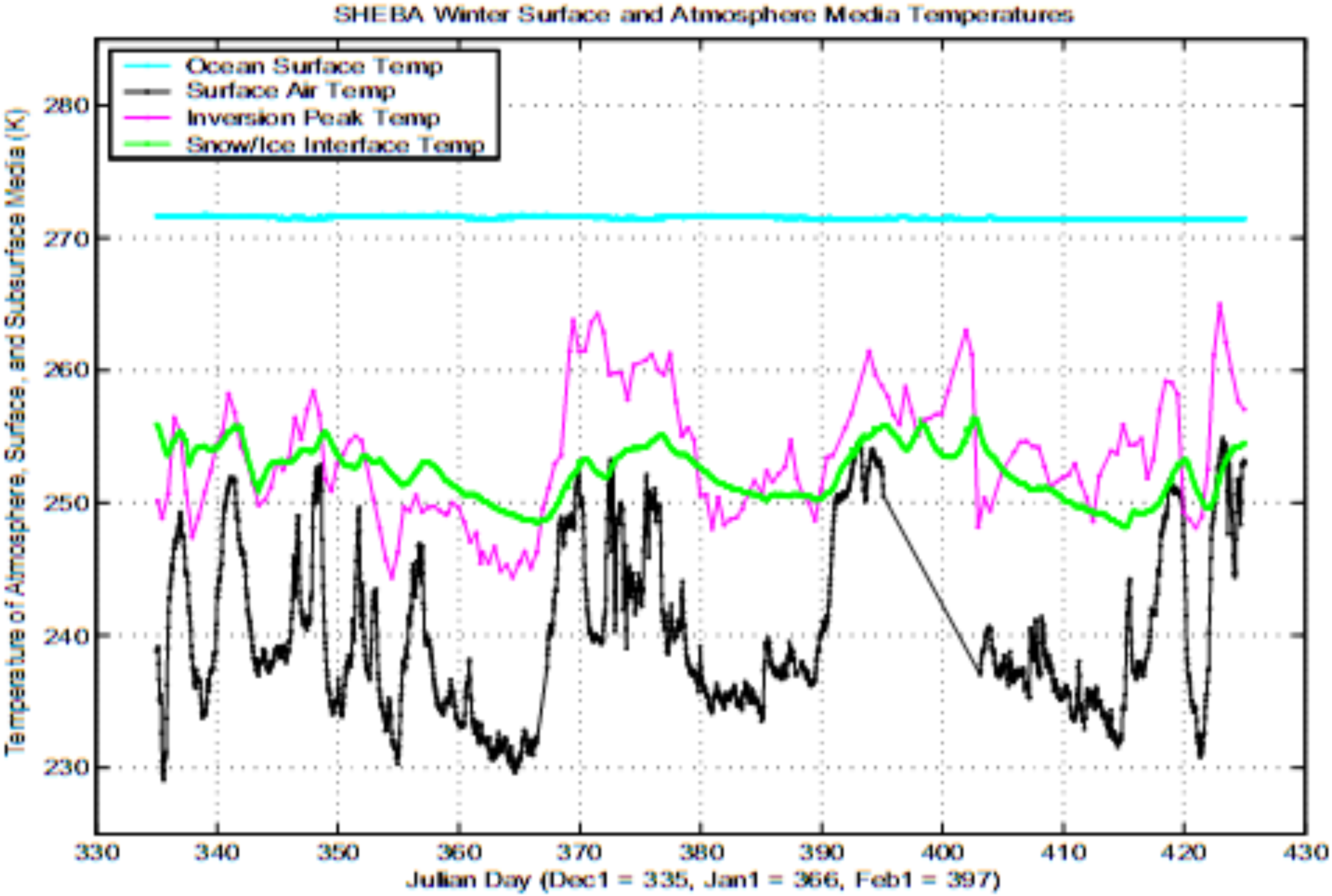
Winter Surface Energy Exchanges

Just One Story

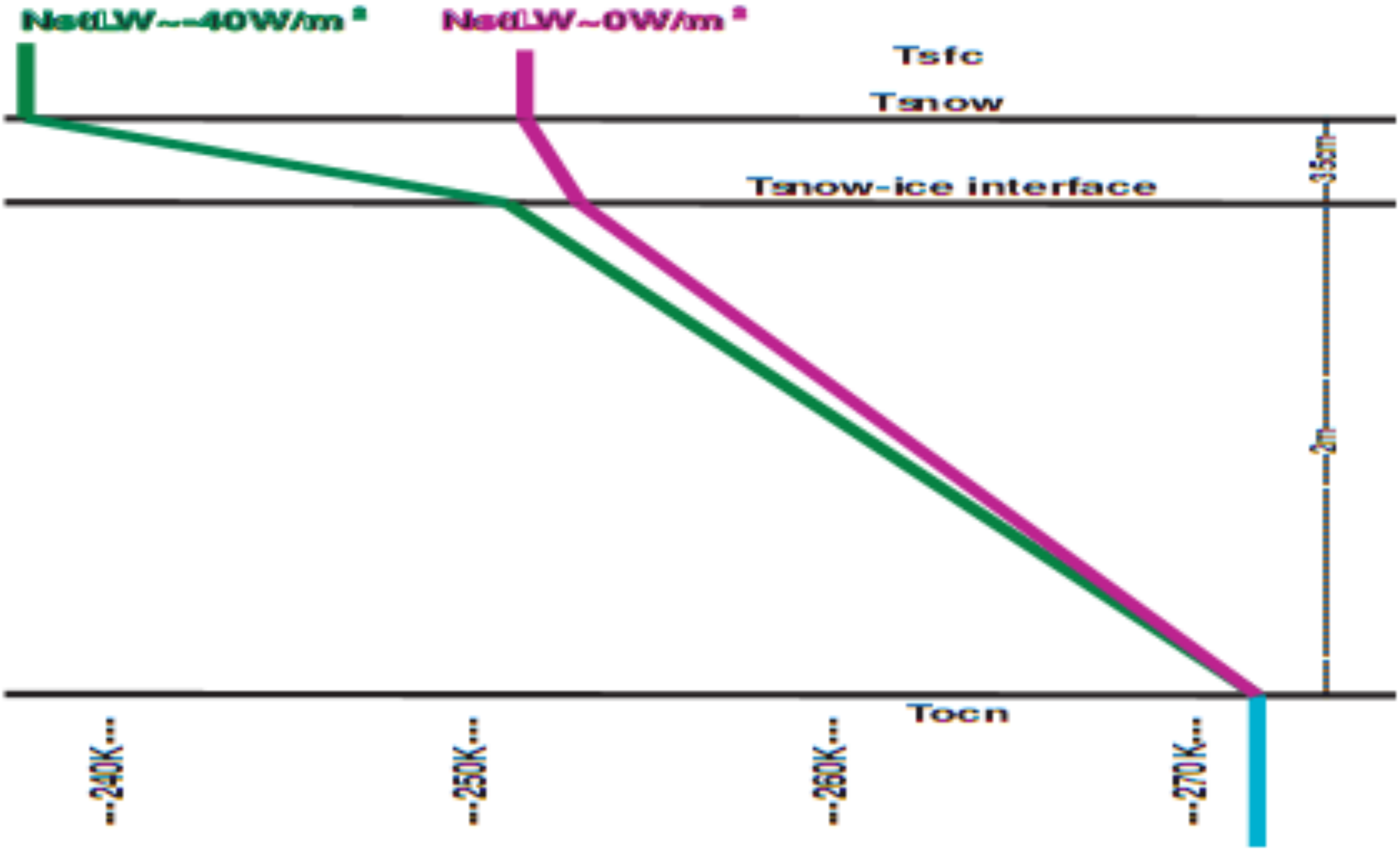
SHEBA FLUX MEASUREMENTS



WINTER TEMPERATURE RECORDS



Sea Ice Regulation of Heat Loss



WHAT CAN WE DO?

Better Temperatures: merged infrared – microwave from multiple platforms for better time resolution, better treatment of temperature inversions in cloudy & clear conditions

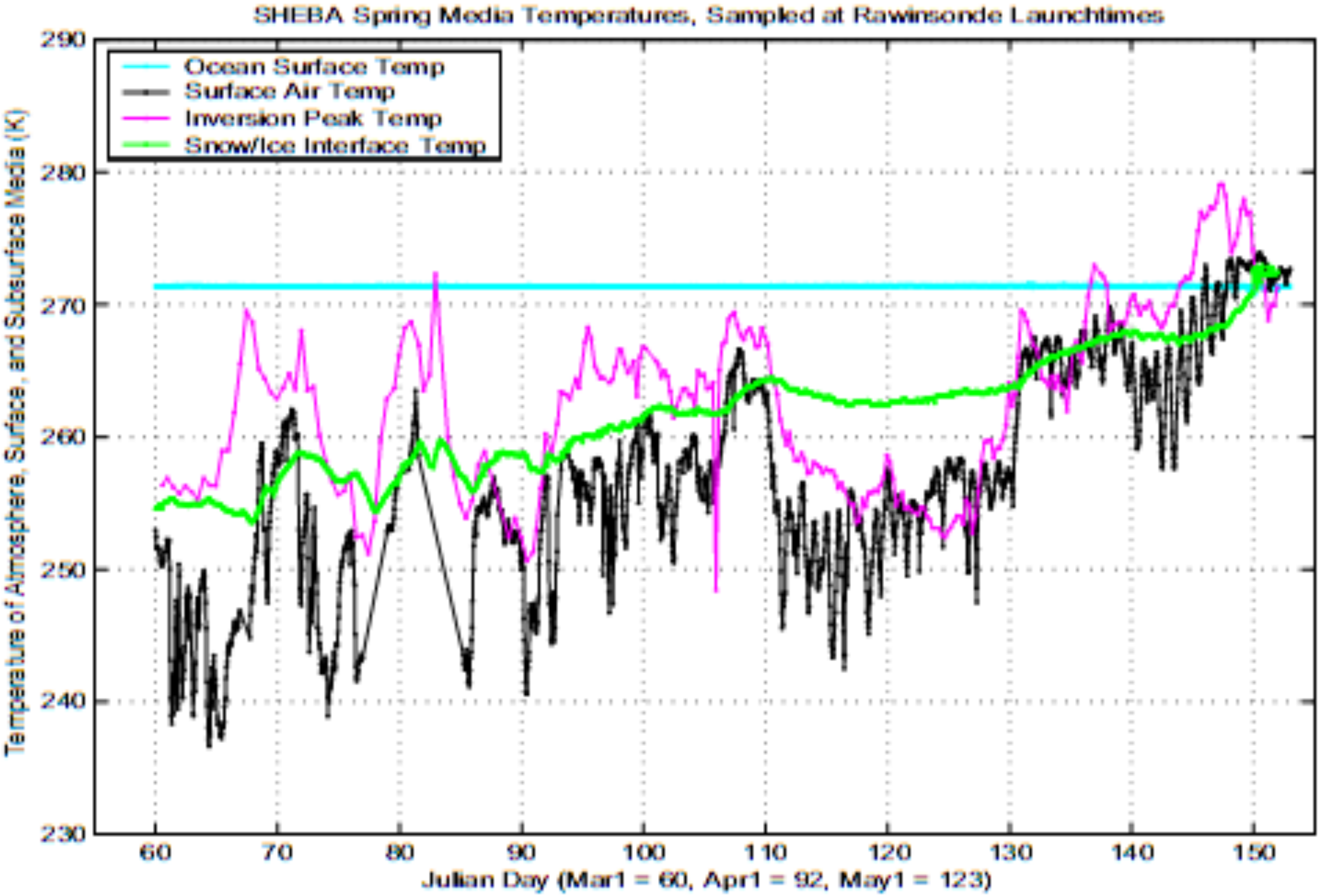
Multi-instrument Cloud-Water Vapor-Precipitation Analysis

More Attention to Polar Atmospheric & Oceanic Dynamics

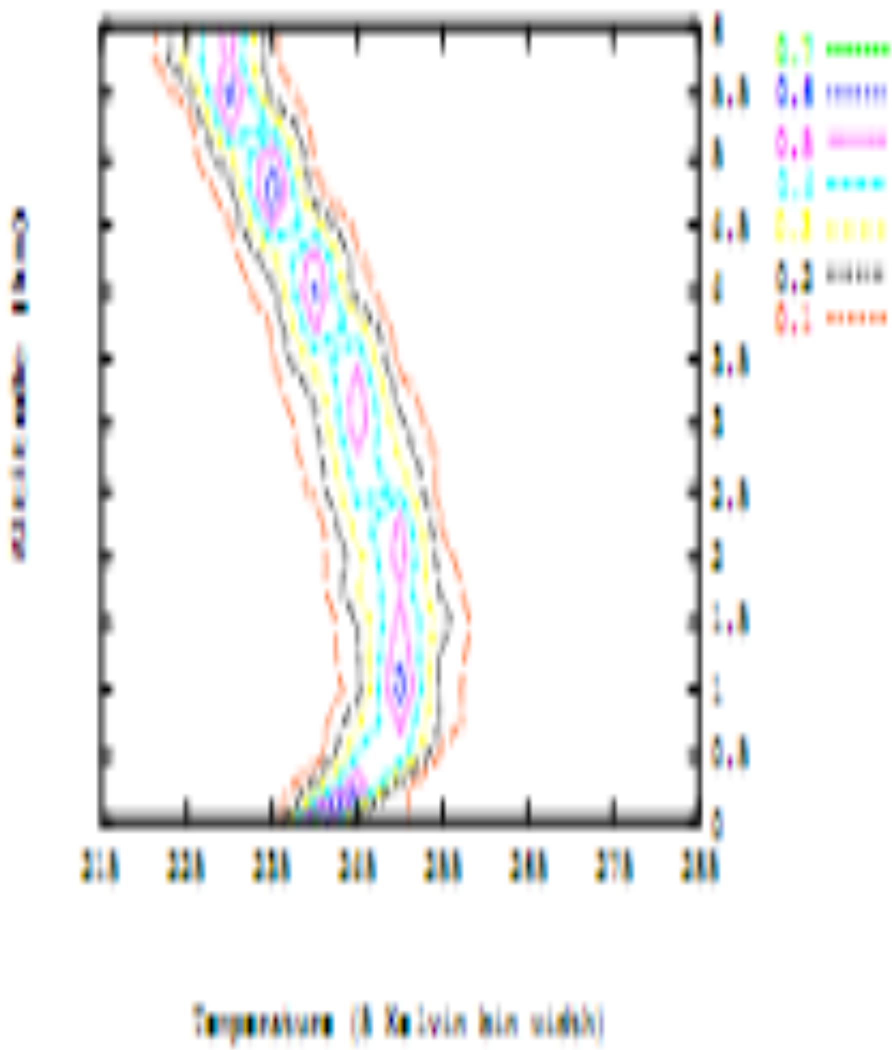
SOME STATISTICS

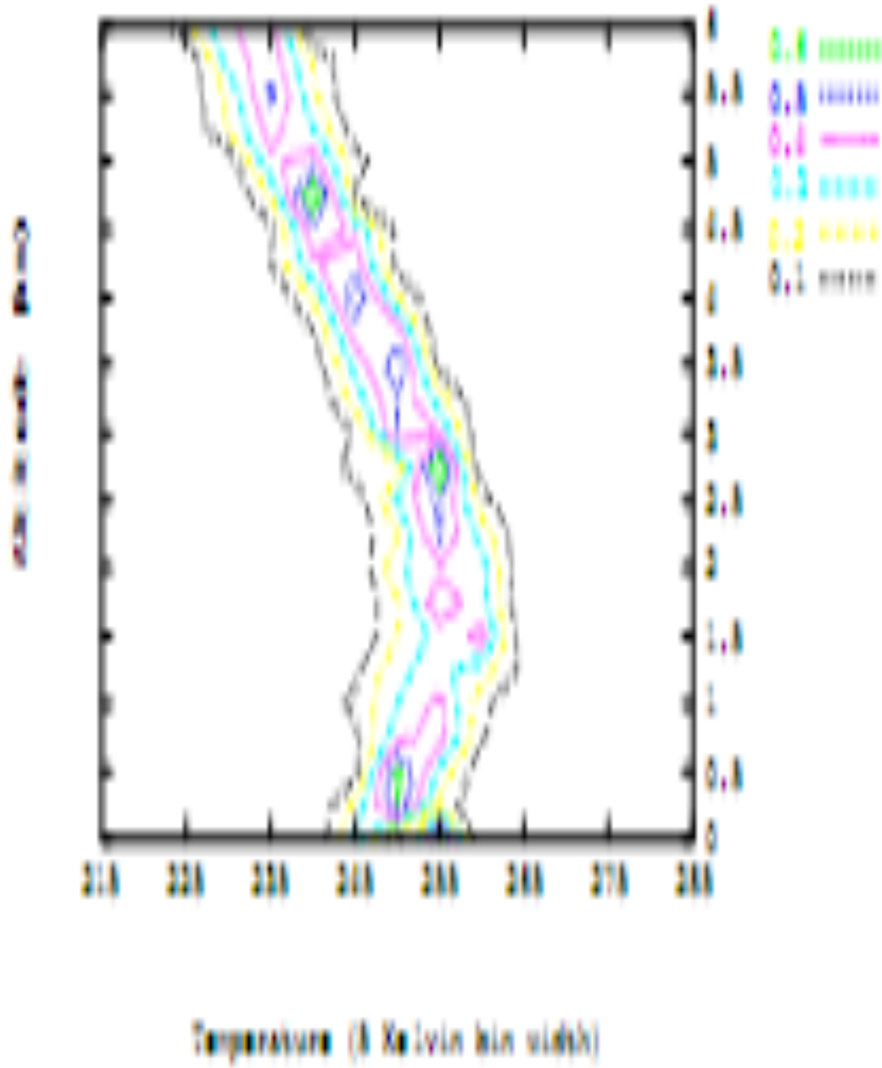
Parameter	Radiatively Clear Sky Avg.	Opaquely Cloudy Sky Avg.
Mode Occurrence	67% of winter obs	22% of winter obs
T_{ocn}	271.5K	271.5K
$T_{snow-ice}$	251.5K	253.2K
T_{snow}	238.3K	249.5K
T_{sfc}	236.5K	250.4K
$T_{inv,peak}$	250.9K	257.3K
NetLW	-40 W/m^2	0 W/m^2
SH	11 W/m^2	-1 W/m^2
≈OHC	11 W/m^2	3 W/m^2
≈SEB	-18 W/m^2	2 W/m^2

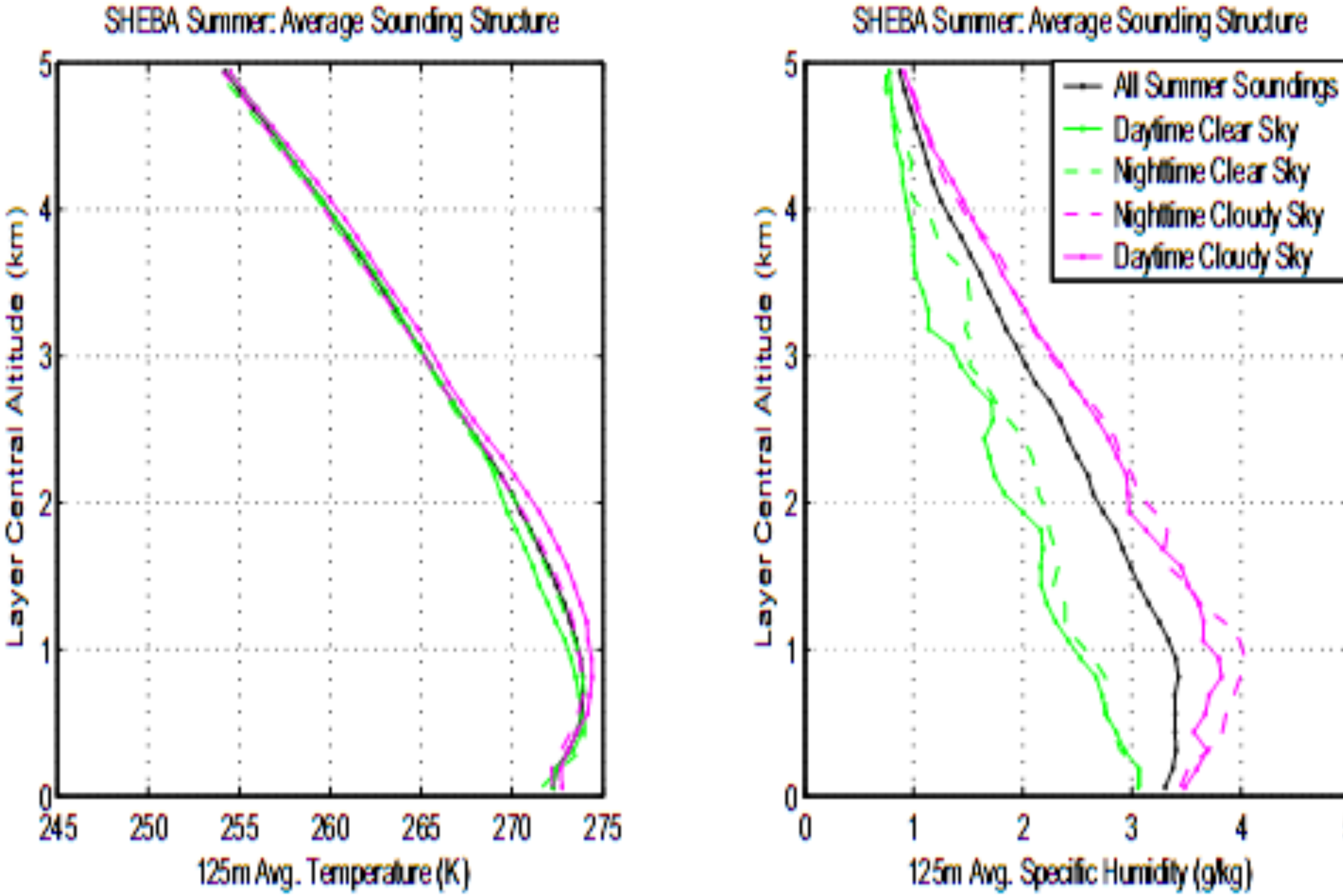
SPRING TEMPERATURE RECORDS

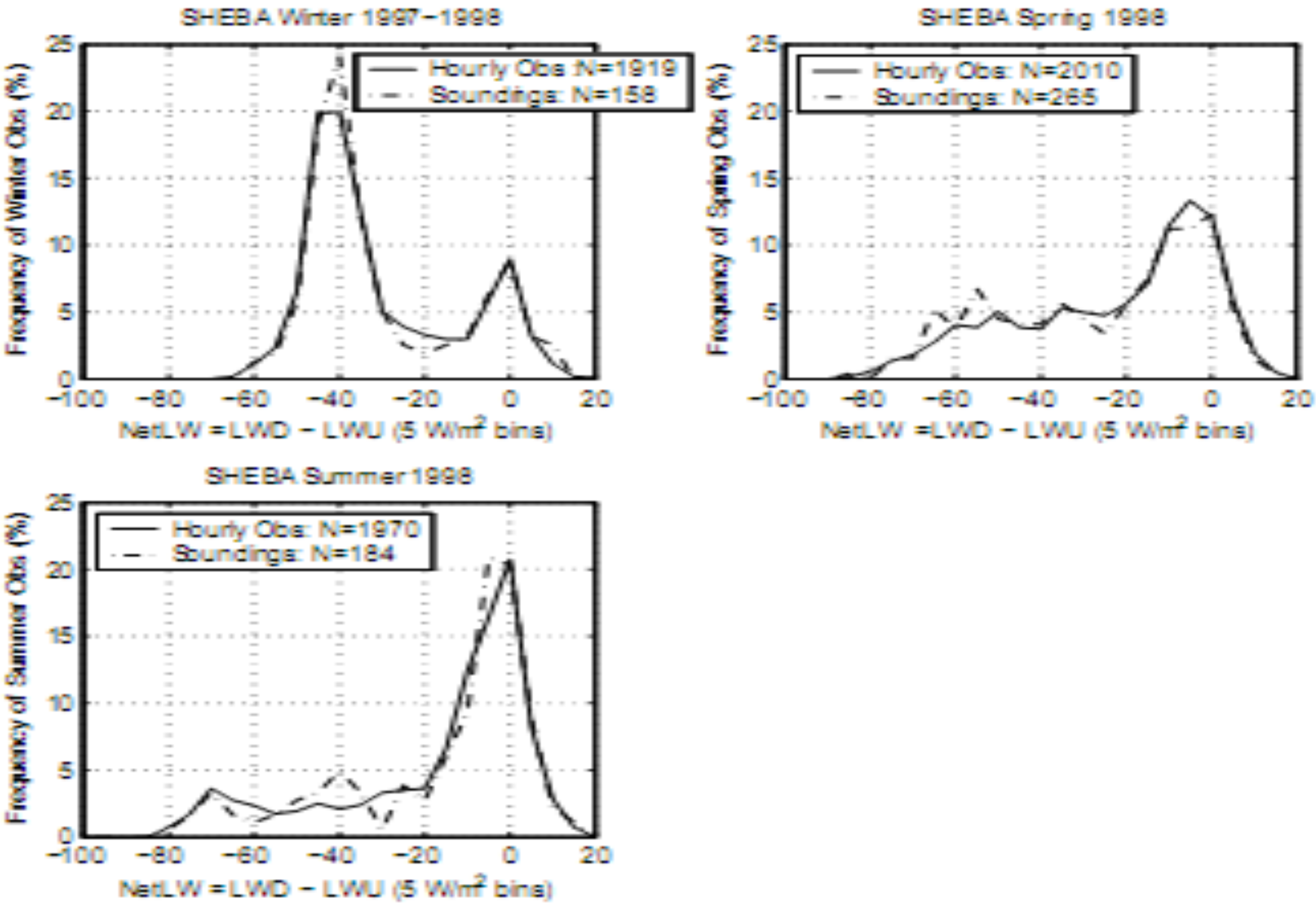


WINTER ATMOSPHERIC PROFILES

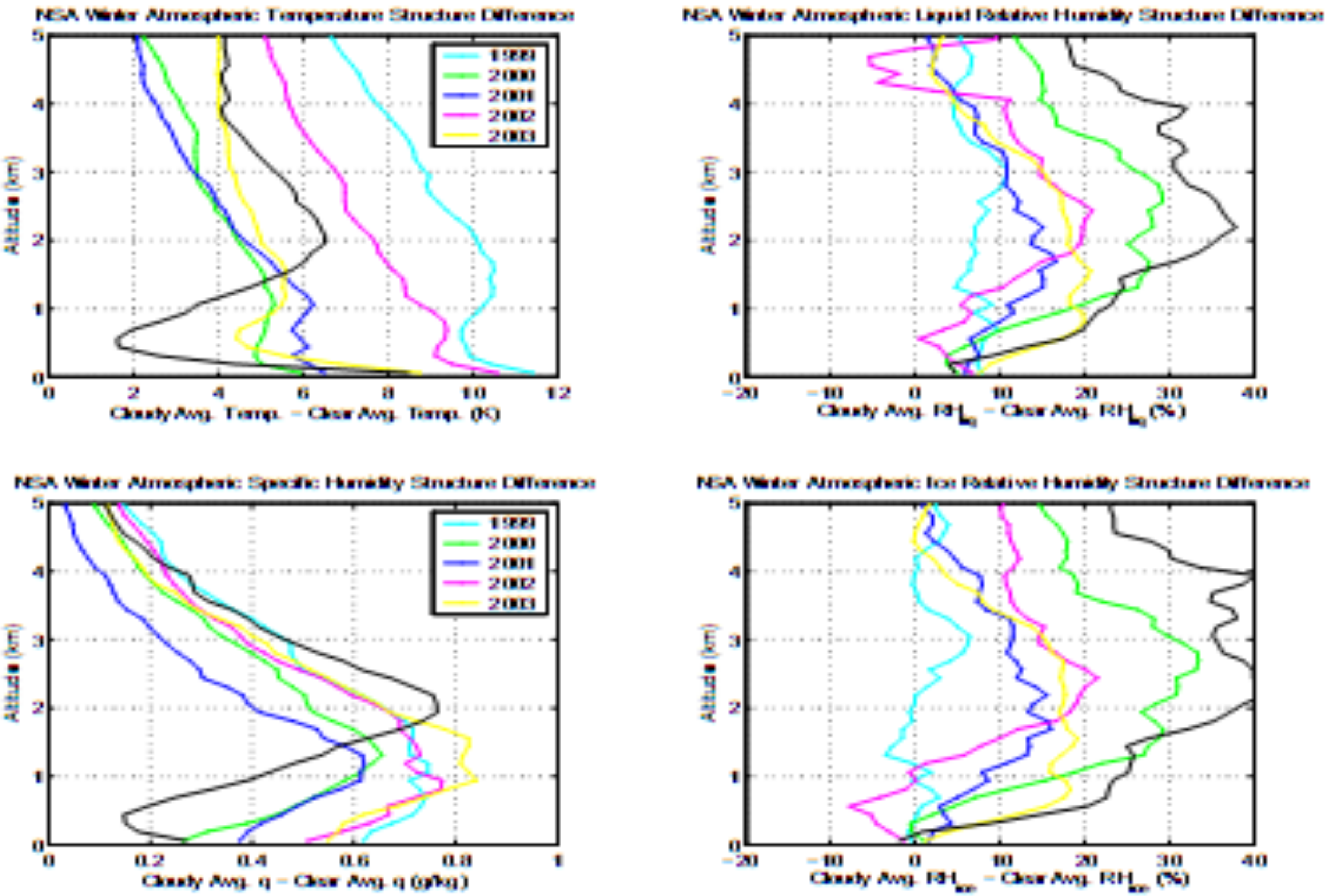


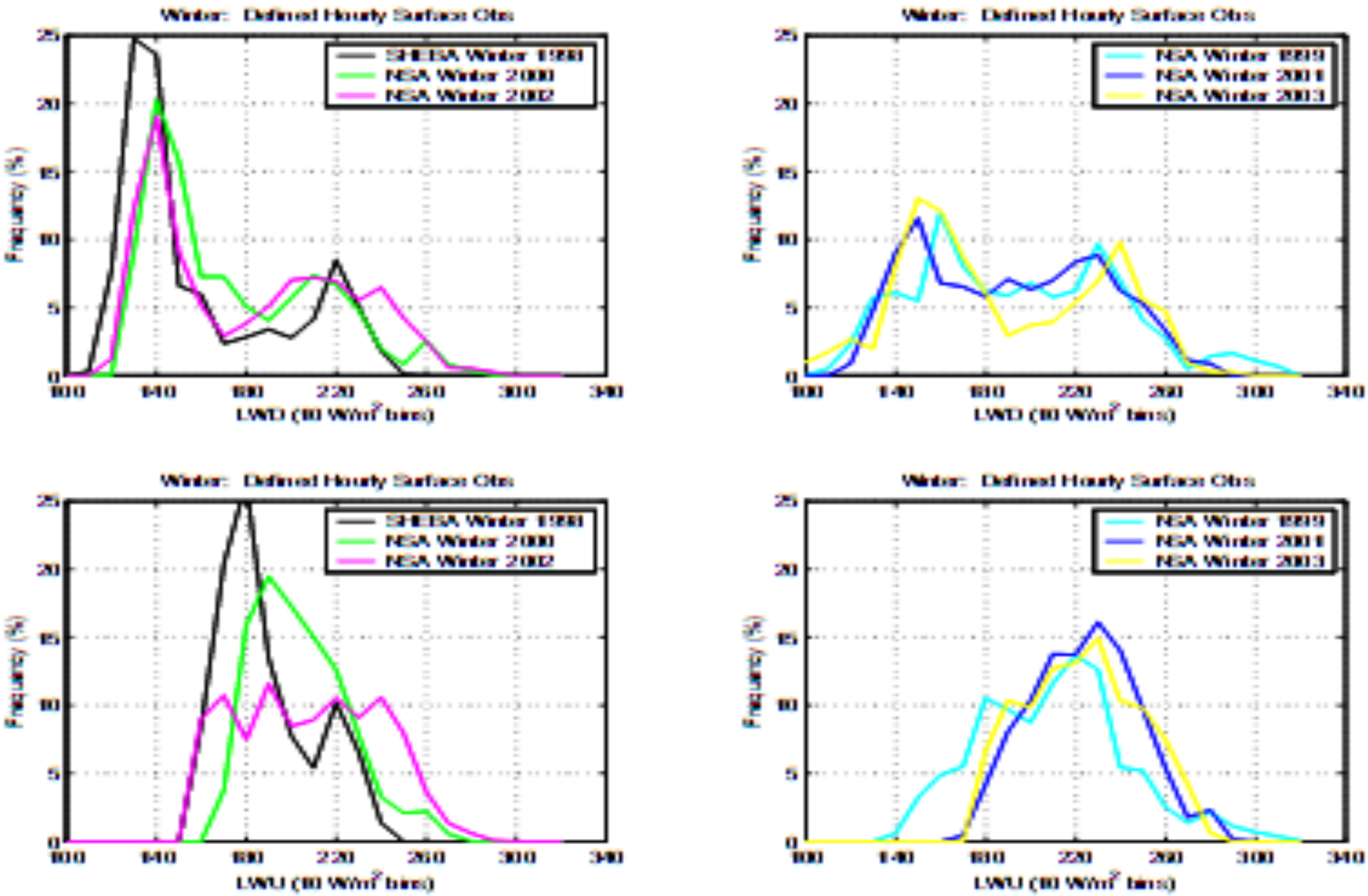



SHEBA Summer: Average Sounding Structure
Layer Central Altitude (km)
125m Avg. Temperature (K)
SHEBA Summer: Average Sounding Structure
Layer Central Altitude (km)
125m Avg. Specific Humidity (g/kg)
All Summer Soundings
Daytime Clear Sky
Nighttime Clear Sky
Nighttime Cloudy Sky
Daytime Cloudy Sky



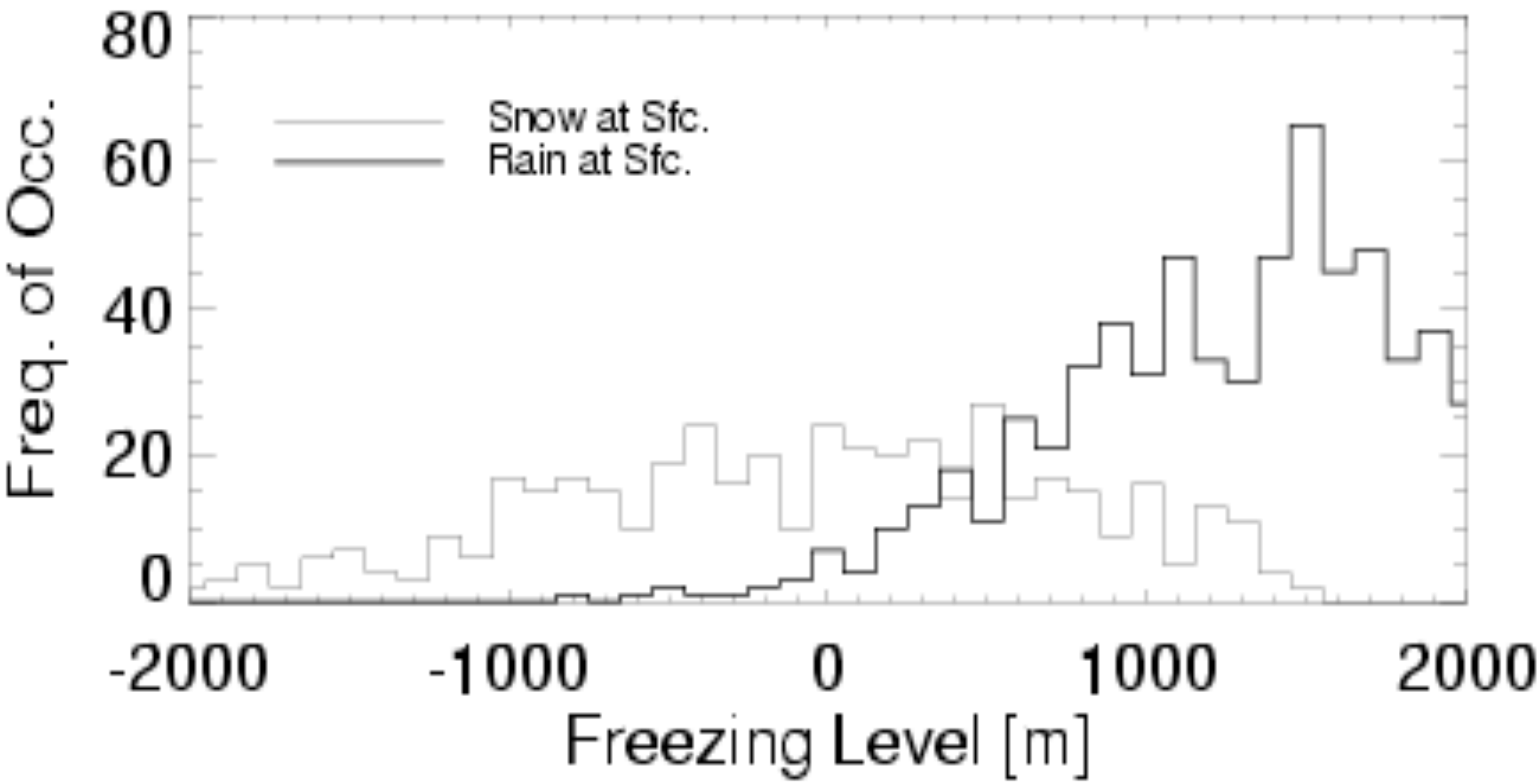
SHEBA Winter 1997−1998
Hourly Obs :N=1919
Soundings: N=158
Frequency of Winter Obs (%)
NetLW =LWD − LWU (5 W/m² bins)
SHEBA Spring 1998
Hourly Obs: N=2010
Soundings: N=265
Frequency of Spring Obs (%)
NetLW =LWD − LWU (5 W/m² bins)
SHEBA Summer 1998
Hourly Obs: N=1970
Soundings: N=184
Frequency of Summer Obs (%)
NetLW =LWD − LWU (5 W/m² bins)


NSA Winter Atmospheric Temperature Structure Difference
1999
2000
2001
2002
2003
Altitude (km)
Cloudy Avg. Temp. − Clear Avg. Temp. (K)
NSA Winter Atmospheric Liquid Relative Humidity Structure Difference
Altitude (km)
Cloudy Avg. RH$_{liq}$ − Clear Avg. RH$_{liq}$ (%)
NSA Winter Atmospheric Specific Humidity Structure Difference
1999
2000
2001
2002
2003
Altitude (km)
Cloudy Avg. q − Clear Avg. q (g/kg)
NSA Winter Atmospheric Ice Relative Humidity Structure Difference
Altitude (km)
Cloudy Avg. RH$_{ice}$ − Clear Avg. RH$_{ice}$ (%)

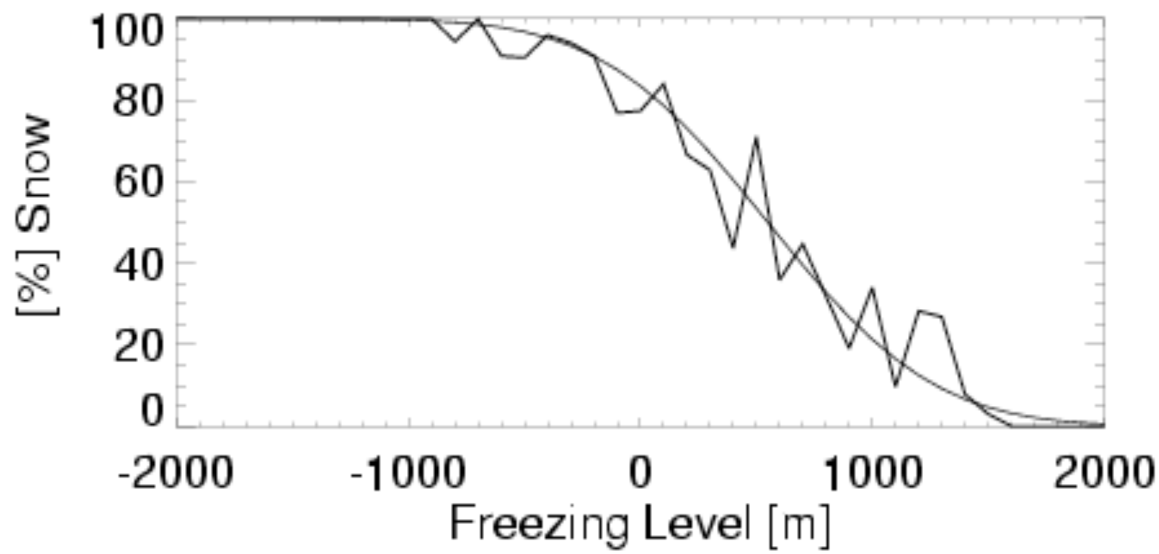


Winter: Defined Hourly Surface Obs
SHEBA Winter 1998
NSA Winter 2000
NSA Winter 2002
Frequency (%)
LWD (10 W/m² bins)
Winter: Defined Hourly Surface Obs
NSA Winter 1999
NSA Winter 2001
NSA Winter 2003
Frequency (%)
LWD (10 W/m² bins)
Winter: Defined Hourly Surface Obs
SHEBA Winter 1998
NSA Winter 2000
NSA Winter 2002
Frequency (%)
LWU (10 W/m² bins)
Winter: Defined Hourly Surface Obs
NSA Winter 1999
NSA Winter 2001
NSA Winter 2003
Frequency (%)
LWU (10 W/m² bins)

Likelihood of snowfall and rainfall at the surface as function of freezing level from AMSR-E

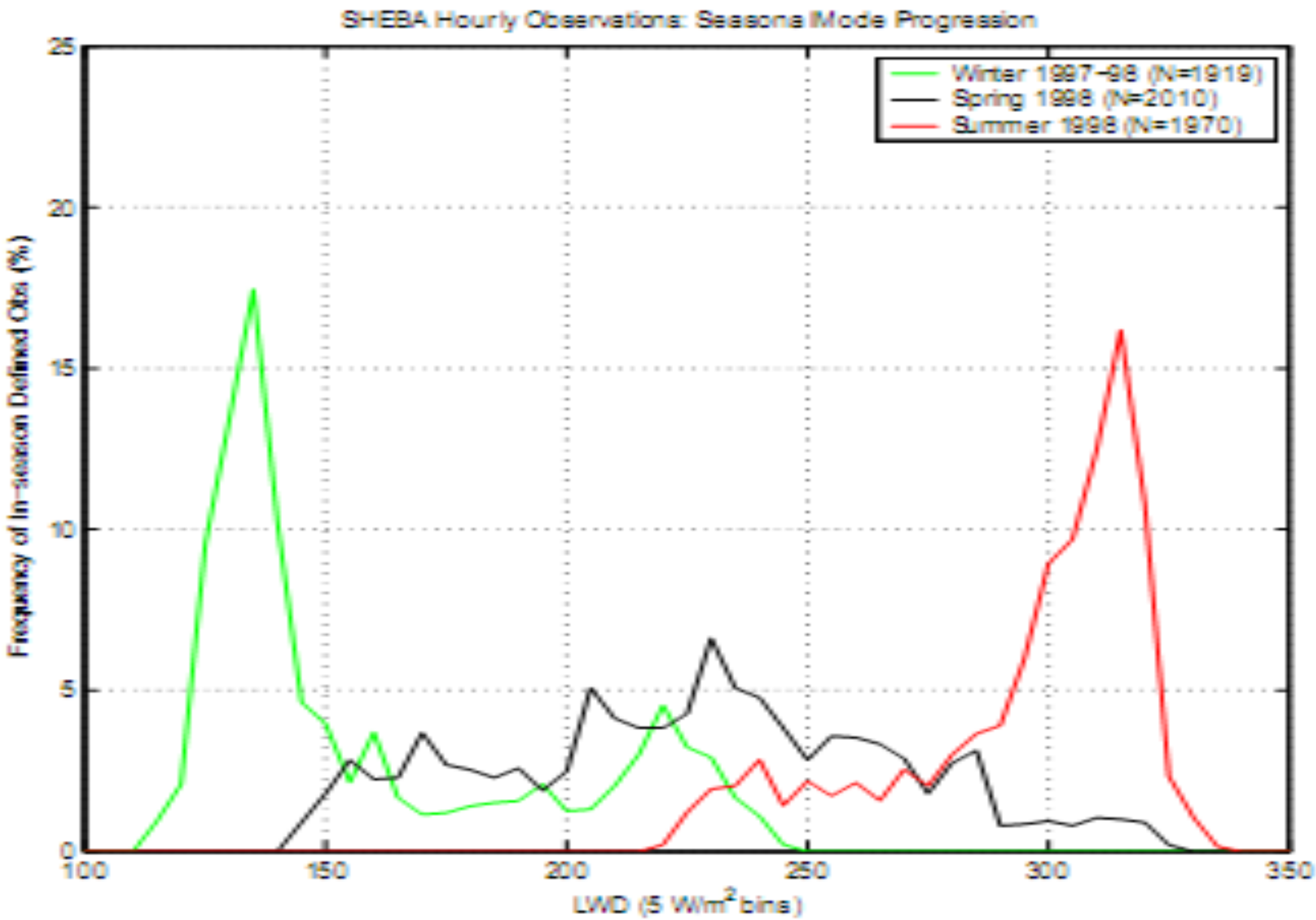


Cumulative likelihood of snowfall at the surface as function of freezing level

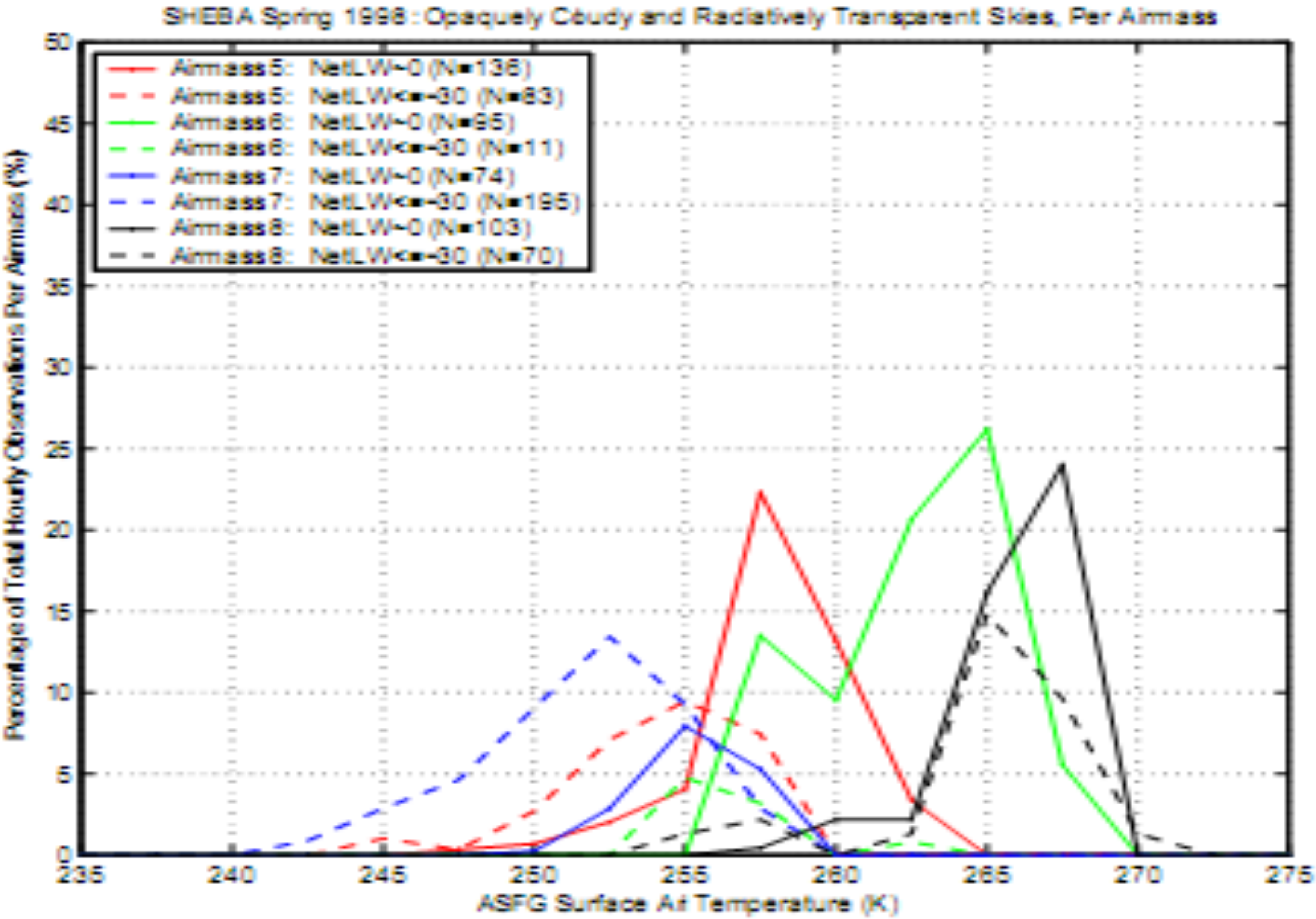


Zigzag line

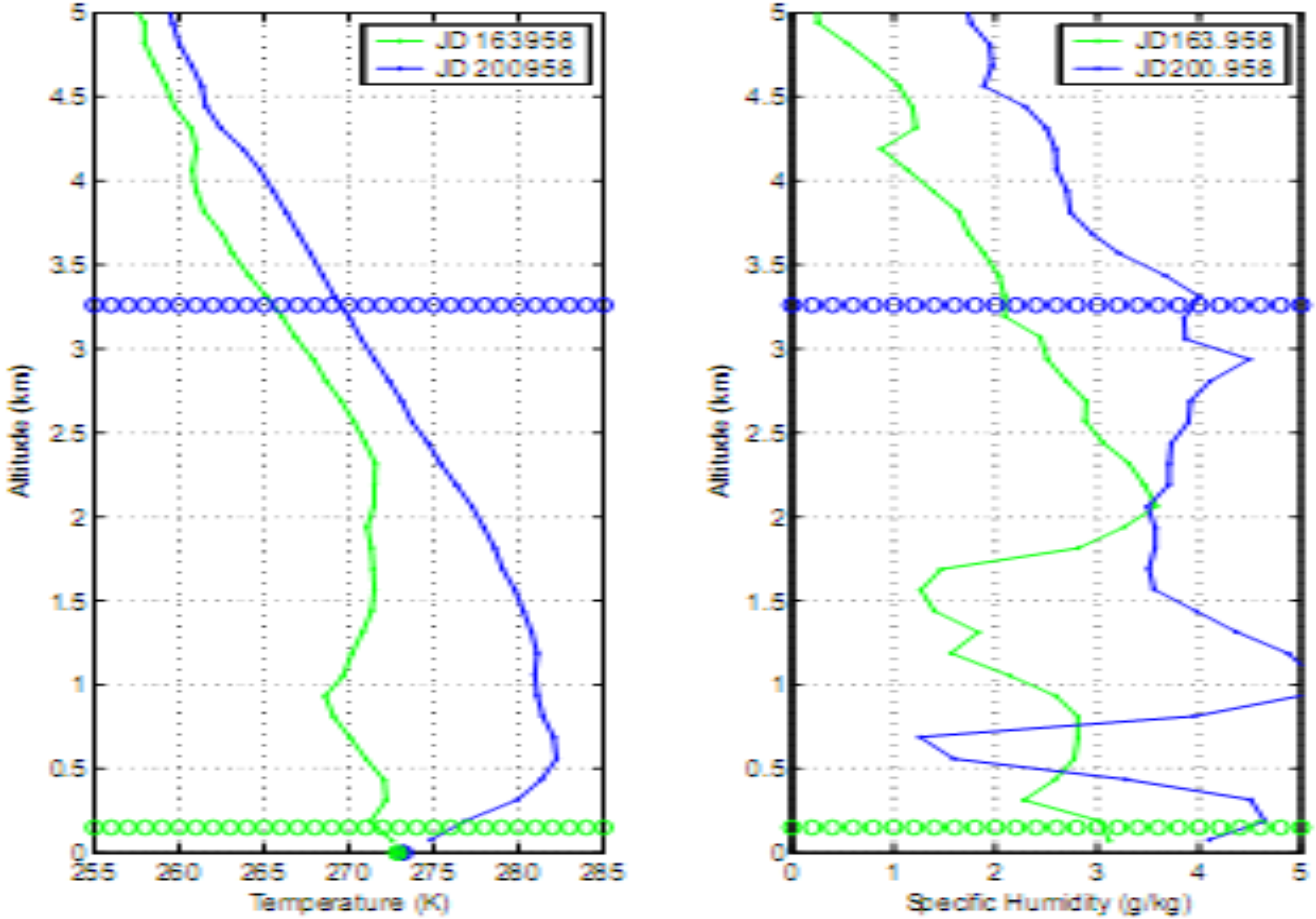
Smooth line



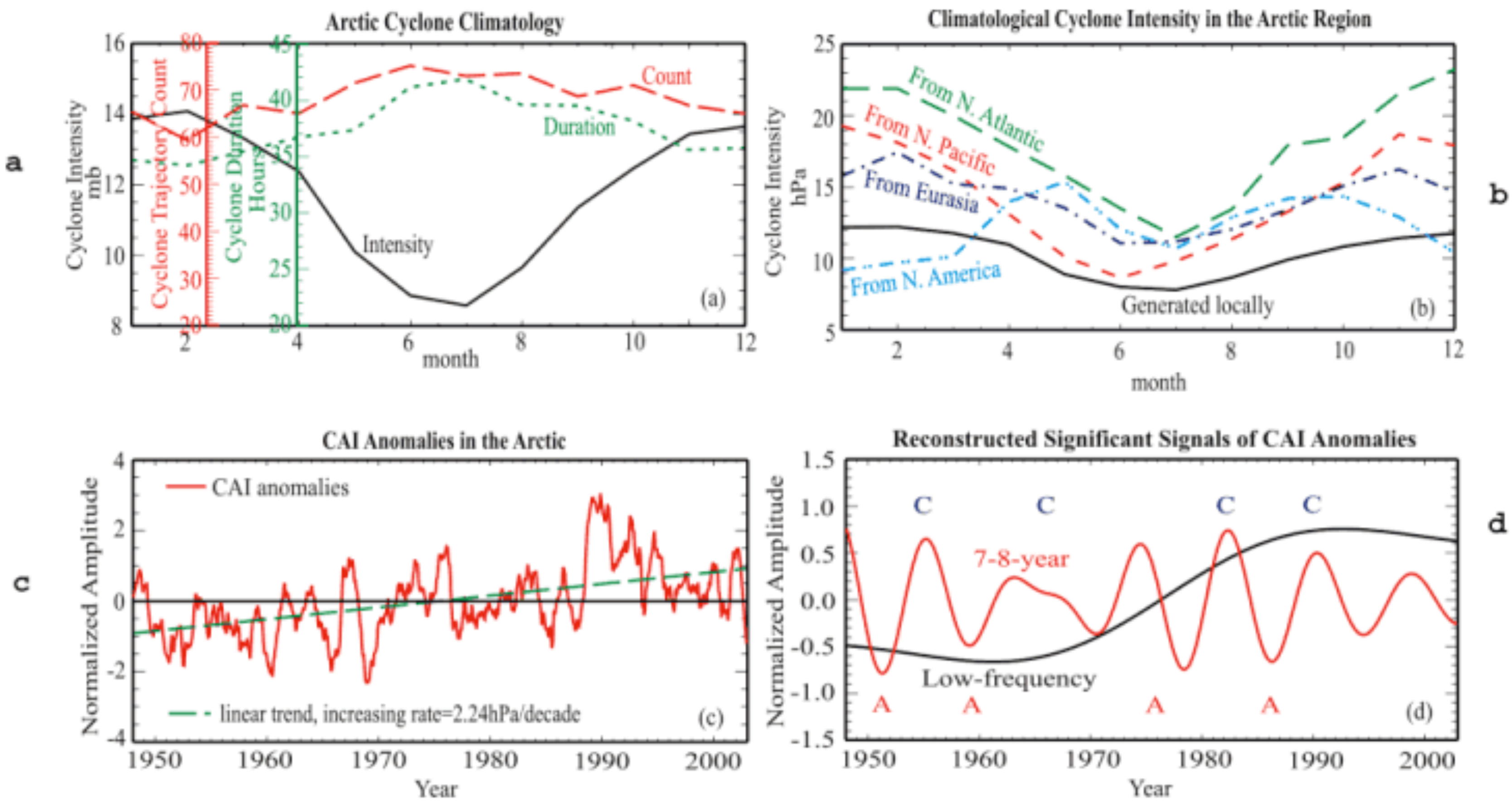
SHEBA Hourly Observations: Seasonal Mode Progression
Winter 1997-98 (N=1919)
Spring 1998 (N=2010)
Summer 1998 (N=1970)
Frequency of In-season Defined Obs (%)
LWD (5 W/m^2 bins)
0
5
10
15
20
25
100
150
200
250
300
350

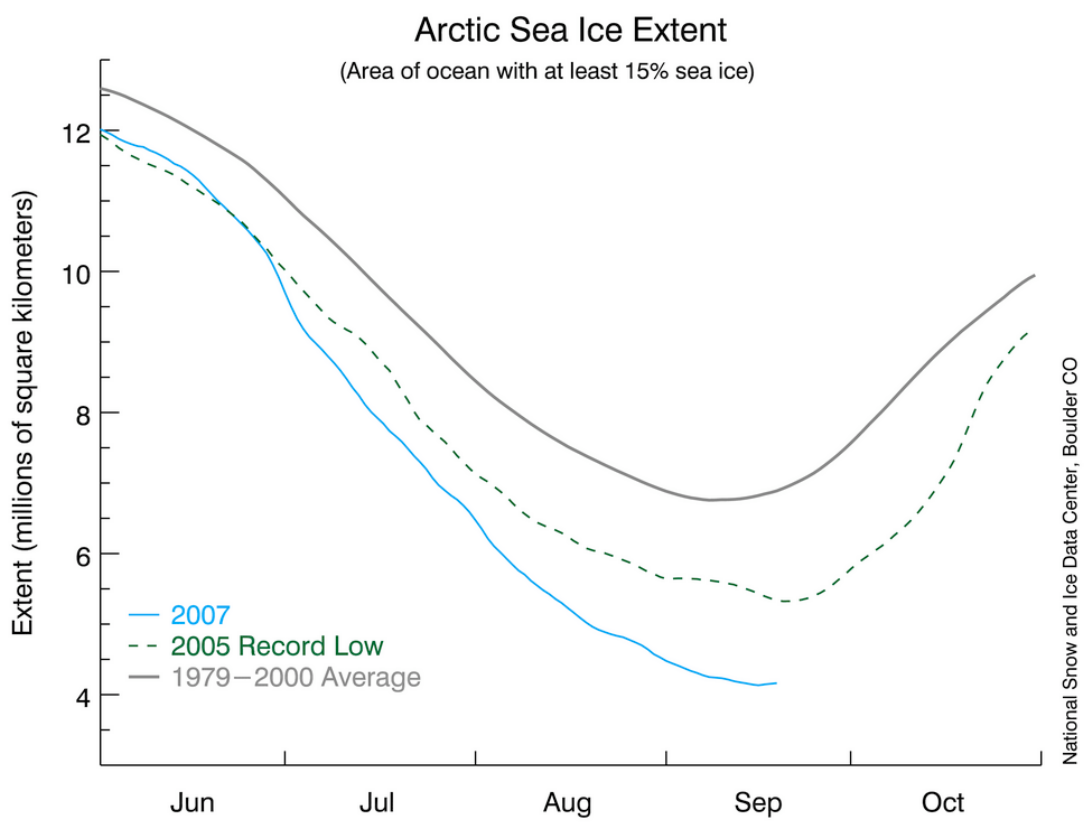


SHEBA Spring 1998: Opaquely Cloudy and Radiatively Transparent Skies, Per Airmass
Airmass 5: NetLW~0 (N=136)
Airmass 5: NetLW<=-30 (N=83)
Airmass 6: NetLW~0 (N=95)
Airmass 6: NetLW<=-30 (N=11)
Airmass 7: NetLW~0 (N=74)
Airmass 7: NetLW<=-30 (N=195)
Airmass 8: NetLW~0 (N=103)
Airmass 8: NetLW<=-30 (N=70)
Percentage of Total Hourly Observations Per Airmass (%)
ASFG Surface Air Temperature (K)
0
5
10
15
20
25
30
35
40
45
50
235
240
245
250
255
260
265
270
275

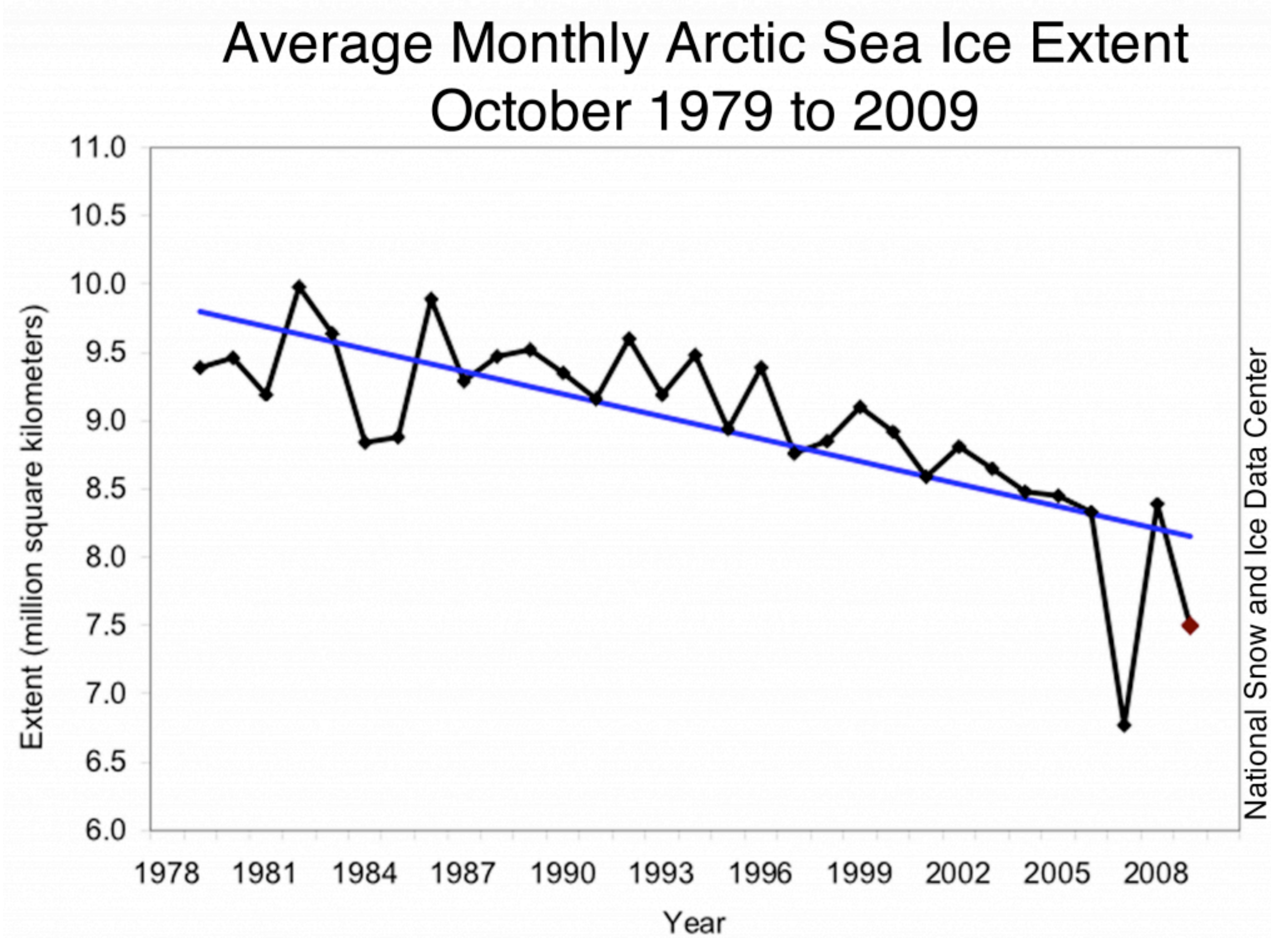


JD 163958
JD 200958
Altitude (km)
Temperature (K)
255
260
265
270
275
280
285
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
JD163.958
JD200.958
Specific Humidity (g/kg)

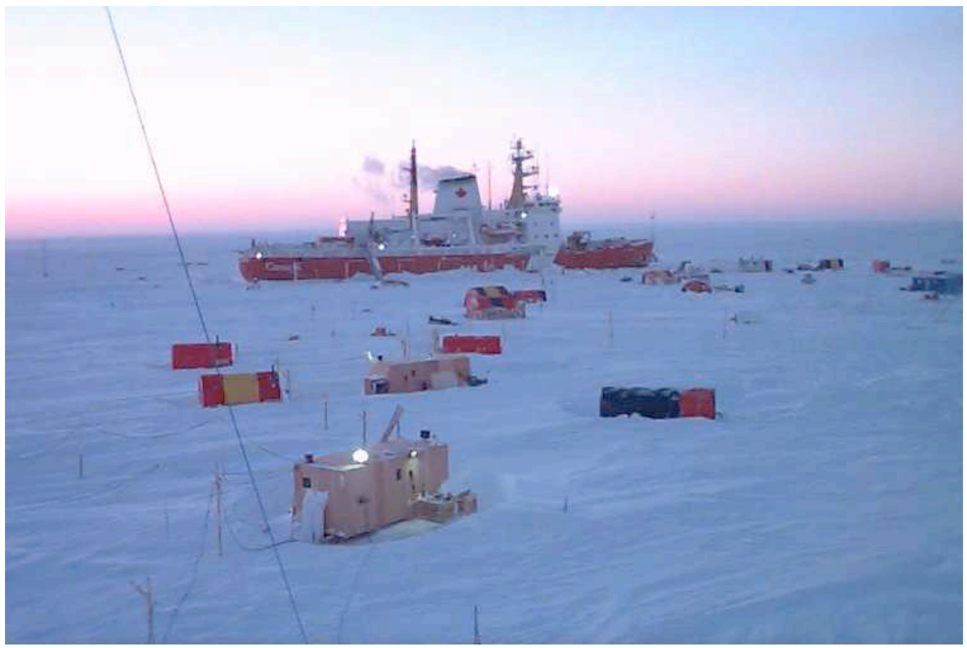

a
Arctic Cyclone Climatology
Cyclone Intensity mb
Cyclone Trajectory Count
Cyclone Duration Hours
Count
Duration
Intensity
(a)
month
b
Climatological Cyclone Intensity in the Arctic Region
Cyclone Intensity hPa
From N. Atlantic
From N. Pacific
From Eurasia
From N. America
Generated locally
(b)
month
c
CAI Anomalies in the Arctic
Normalized Amplitude
CAI anomalies
linear trend, increasing rate=2.24hPa/decade
(c)
Year
d
Reconstructed Significant Signals of CAI Anomalies
Normalized Amplitude
C
C
C
C
7-8-year
Low-frequency
A
A
A
A
(d)
Year



Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Extent (millions of square kilometers)
12
10
8
6
4
Jun
Jul
Aug
Sep
Oct
2007
2005 Record Low
1979−2000 Average
National Snow and Ice Data Center, Boulder CO

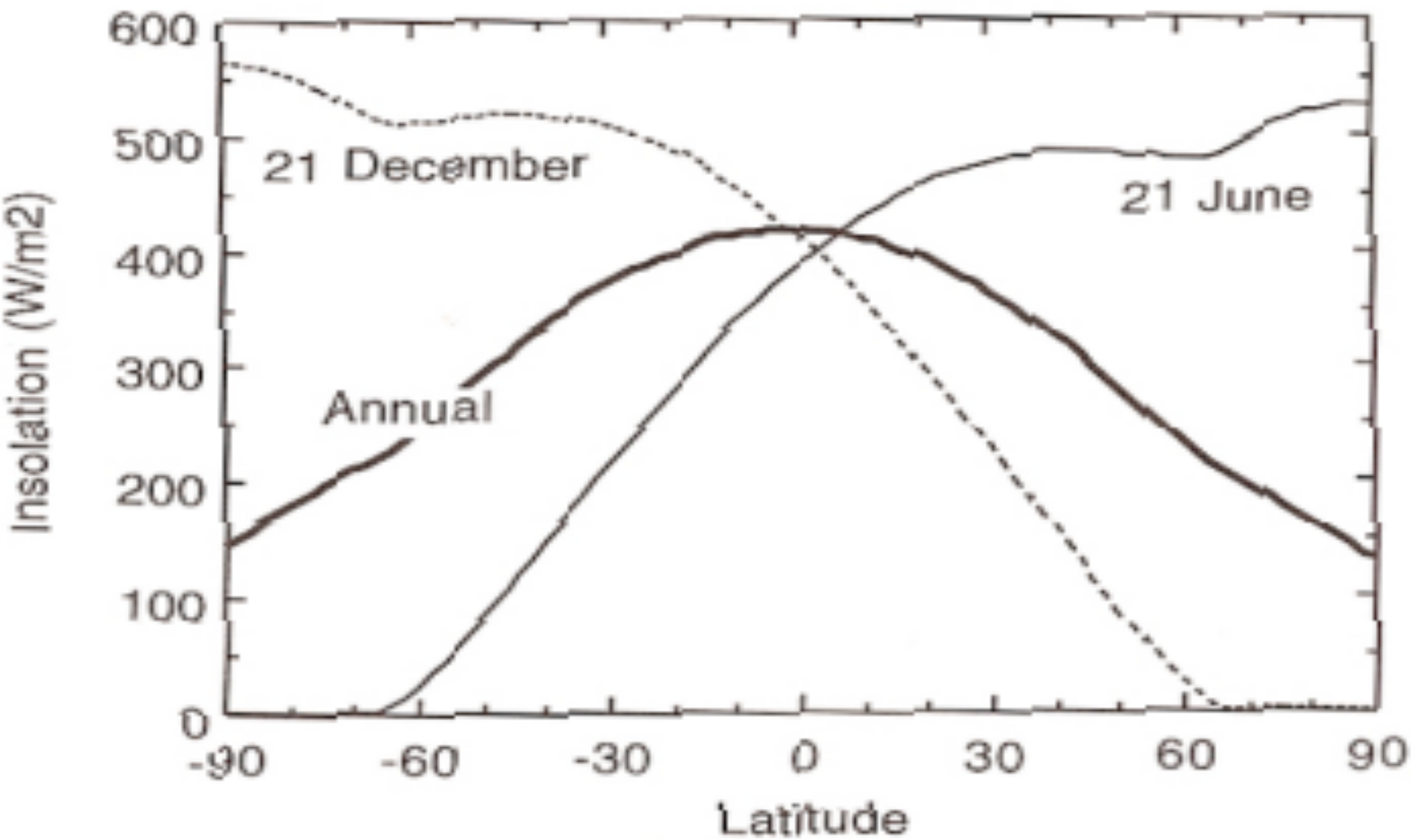


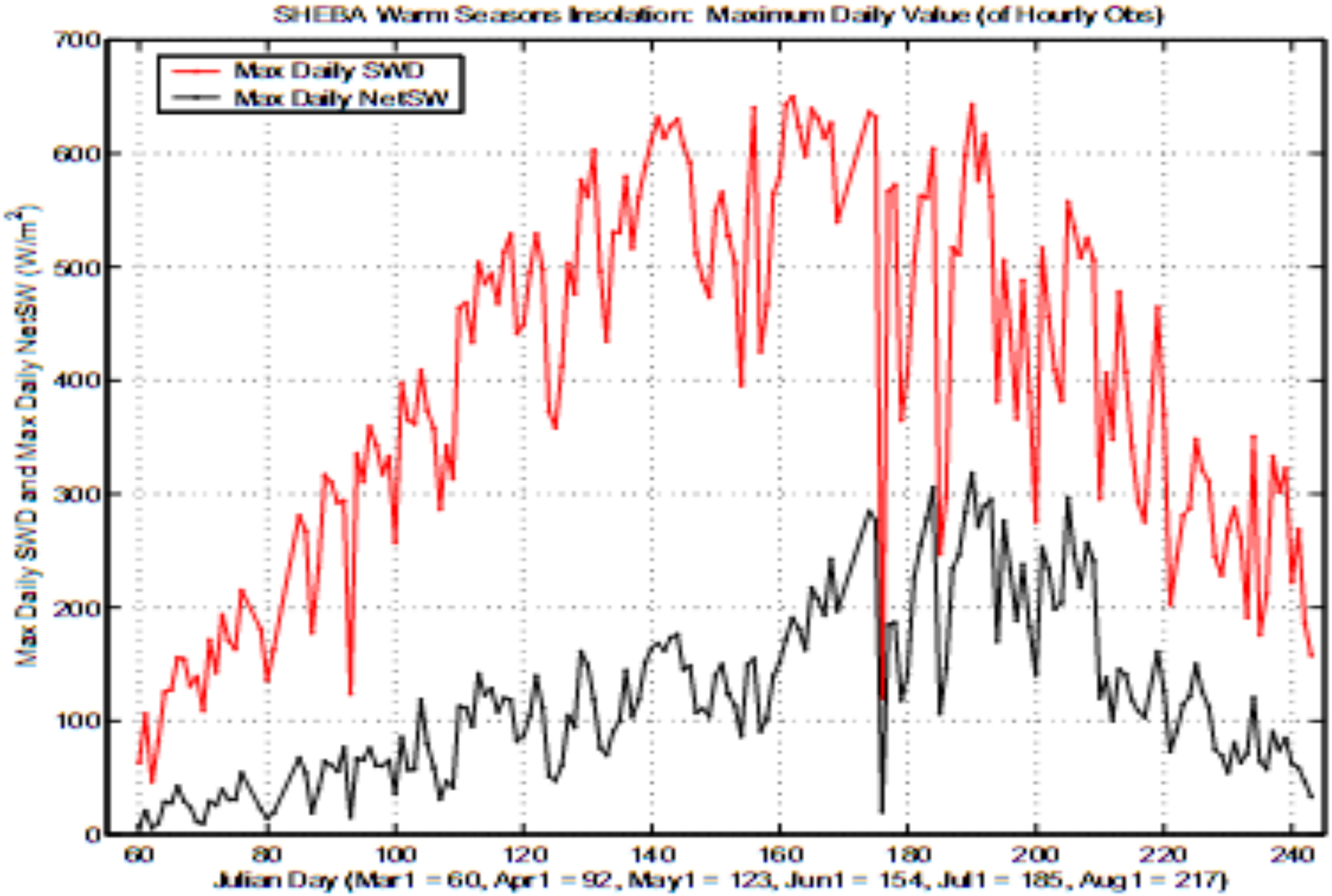
Average Monthly Arctic Sea Ice Extent
October 1979 to 2009
Extent (million square kilometers)
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
Year
National Snow and Ice Data Center



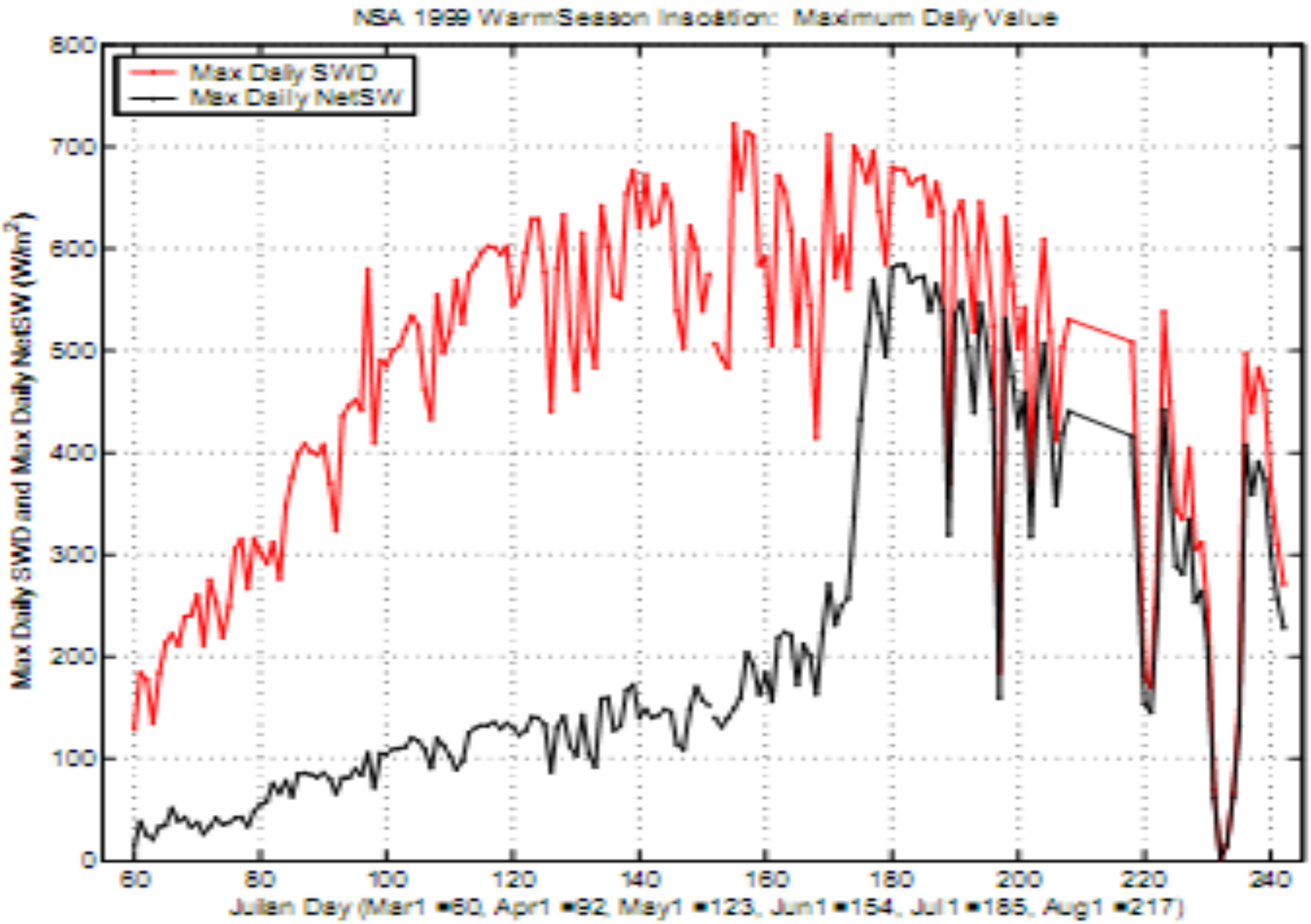
Annual and Solstice Insolation

AREA RATIO & ROTATION
REDUCE INSOLATION TO 341.5 Wm^{-2}



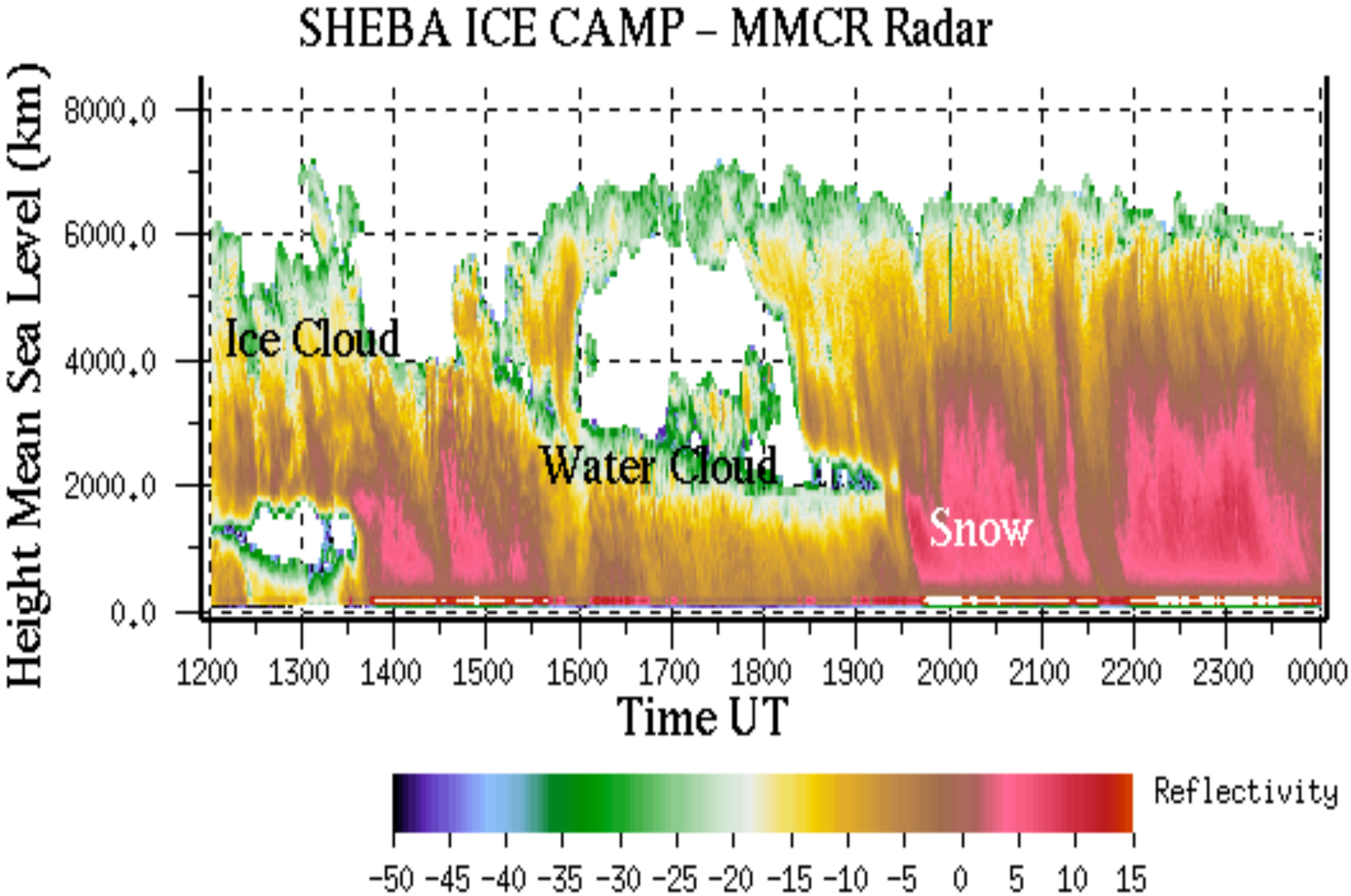


SHEBA Warm Seasons Insolation: Maximum Daily Value (of Hourly Obs)
Max Daily SWD
Max Daily NetSW
Max Daily SWD and Max Daily NetSW (W/m^2)
Julian Day (Mar1 = 60, Apr1 = 92, May1 = 123, Jun1 = 154, Jul1 = 185, Aug1 = 217)
0
100
200
300
400
500
600
700
60
80
100
120
140
160
180
200
220
240



NSA 1999 WarmSeason Insolation: Maximum Daily Value
Max Daily SWD
Max Daily NetSW
Max Daily SWD and Max Daily NetSW (W/m^2)
Julian Day (Mar1 =60, Apr1 =92, May1 =123, Jun1 =154, Jul1 =185, Aug1 =217)
0
100
200
300
400
500
600
700
800
60
80
100
120
140
160
180
200
220
240

Cloud and Precipitation



LIST OF ISSUES

Surface Properties: albedo, emissivity, **temperature**, “wetness”, “roughness”

Near-surface atmosphere: **temperature & humidity inversions**, windspeed, cloud properties, precipitation

Diurnal and Weather-scale Variations of these properties and their **correlations**

Difficulties of remote sensing: lack of contrast, reversed contrast,
rapid time variations of surface

Surface temperature and fluxes much more sensitive to changes in cloudiness
But water phase changes mediate time variations of the surface temperature