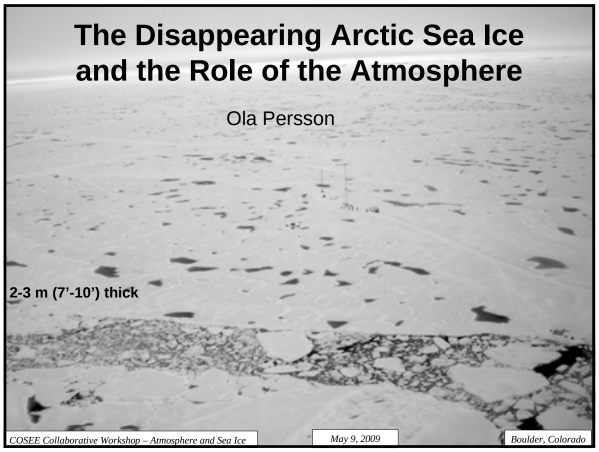
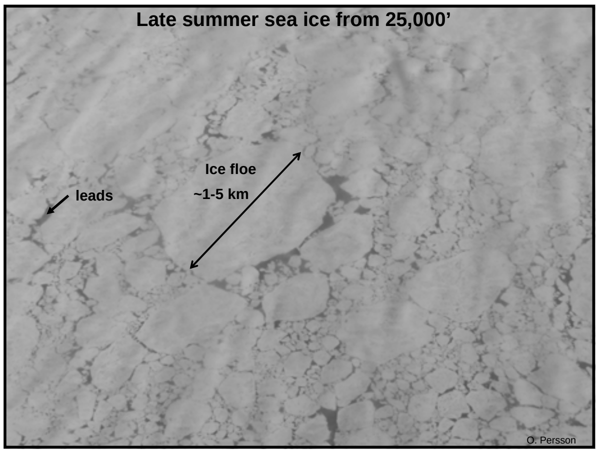
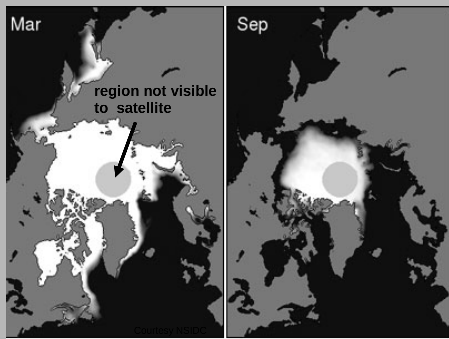




OUTLINE

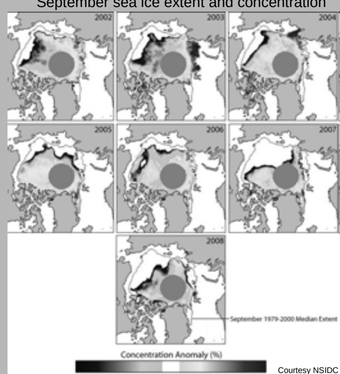
- **1) What is happening to the Arctic Sea ice?**
- **2) Possible mechanisms for changing sea ice**
  - oceanographic, ice circulation, atmospheric thermodynamic processes
- **3) Review basic laws of radiation**
- **4) Atmospheric thermodynamic effects on sea ice**
  - Arctic energy balance
  - surface energy fluxes
  - direct radiative effects from "greenhouse" gases (GHG)
  - ice albedo (reflectivity) feedback
  - cloud radiative forcing
  - role of cloud properties
- **5) Manned scientific Arctic expeditions, 1893-2008**
  - science issues being addressed by each
  - instrumentation
  - life on an Arctic research field campaign

Typical Sea Ice Extent

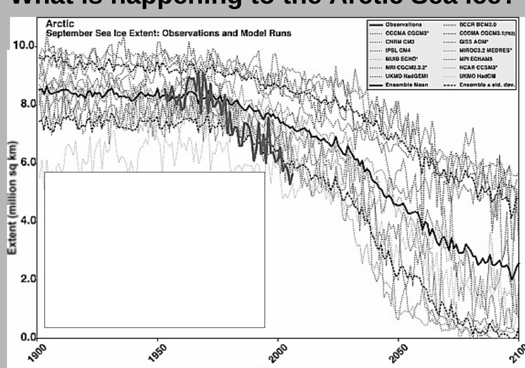


What is happening to the Arctic Sea ice?

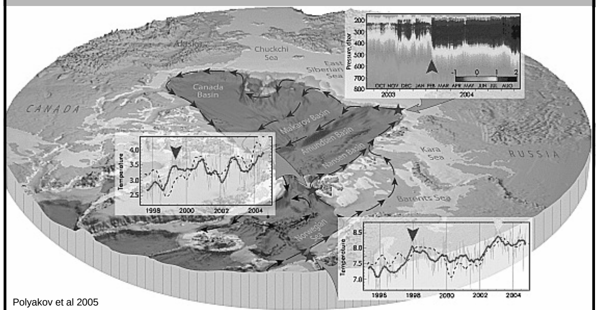
September sea ice extent and concentration



What is happening to the Arctic Sea ice?

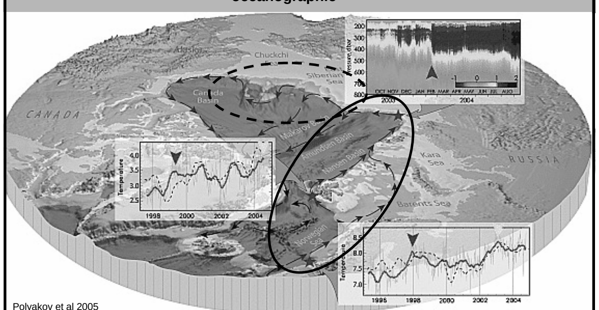


Possible mechanisms-1
- oceanographic



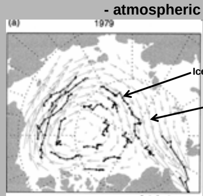
Polyakov et al 2005

Possible mechanisms-1
- oceanographic



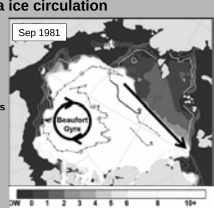
Polyakov et al 2005

Possible mechanisms-2
- atmospheric winds/ sea ice circulation



Ice buoy tracks

Sea ice motion vectors

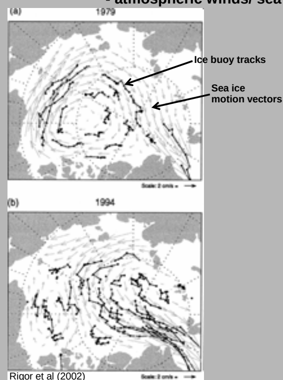


Rigor et al (2002)

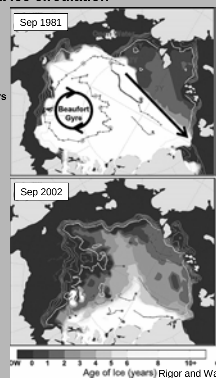
Rigor and Wallace (2004)

Possible mechanisms-2

- atmospheric winds/ sea ice circulation



Rigor et al (2002)



Rigor and Wallace (2004)

Possible mechanisms-3

- atmospheric thermodynamic forcing

Review of Basic Laws of Radiation

1) All objects emit radiant energy

2) Hot objects emit more energy than cold objects.
Stefan Boltzmann Law: **$F = \sigma T^4$ (Blackbody radiation)**
F = flux of energy (W/m^2)
T = temperature (K)
$\sigma = 5.67 \times 10^{-8}$ W/m^2K^4 (a constant)

3) Hotter objects emit at shorter wavelengths than colder objects
sun ~ 6000 K – emits in the visible light portion of spectrum (shortwave radiation)
earth ~ 300 K – emits in the infrared (heat) portion of spectrum (longwave radiation)

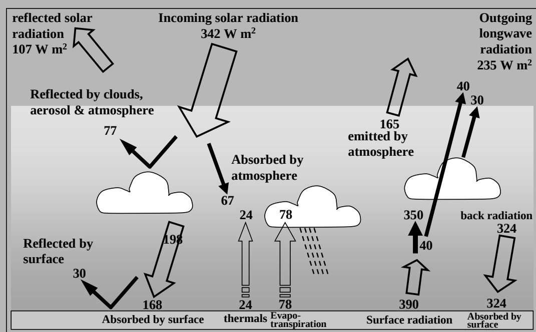
4) Emissivity, ε, measure of how closely an object approximates a blackbody:
blackbody $\varepsilon = 1$;
greybody $\varepsilon < 1$ and $F = \varepsilon \sigma T^4$

5) Albedo, a, is a measure of an object's reflectivity (0-1)

Possible mechanisms

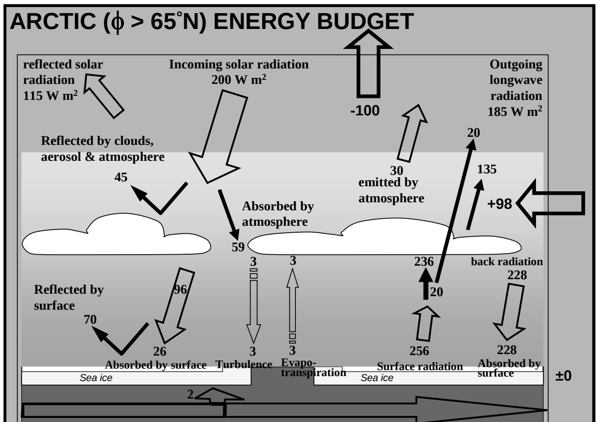
- atmospheric thermodynamic forcing

GLOBAL ATMOSPHERIC ENERGY BUDGET



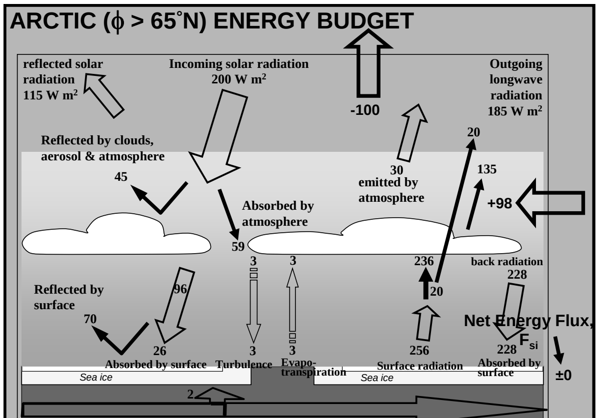
COSEE Collaborative Workshop - Atmosphere and Sea Ice — May 9, 2009 — Boulder, Colorado

ARCTIC (ϕ > 65˚N) ENERGY BUDGET



COSEE Collaborative Workshop - Atmosphere and Sea Ice — May 9, 2009 — Boulder, Colorado — 14

ARCTIC (ϕ > 65˚N) ENERGY BUDGET



COSEE Collaborative Workshop - Atmosphere and Sea Ice — May 9, 2009 — Boulder, Colorado — 15

F_{si} Magnitude Significance

Annual Energy Flux Required to Melt 1 Meter (~ 3 feet) of Ice:

$F_{si} = L_f \, \rho_{ice} \, \Delta Z / t$

$= (3.34 \times 10^5 \text{ J kg}^{-1})\,(0.917 \text{ X } 10^3 \text{ kg m}^{-3})\,(1 \text{ m}) / (3.154 \times 10^7 \text{ s})$

$\approx$ 10 W m^{-2}

F_{si} – net sea-ice energy flux

t = 1 year = 3.154 x 10^7 s – time over which energy flux change applied

L_f = 3.34 x 10^5 J kg^{-1} – latent heat of fusion of ice

ρ_{ice} = 0.917 X 10^3 kg m^{-3} – density of ice at 0° C

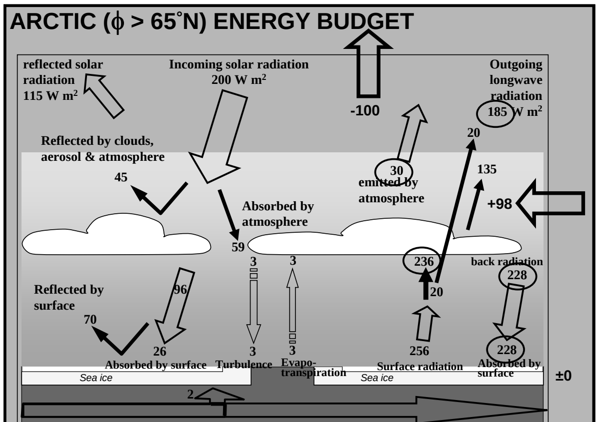
ΔZ = 1 m - thickness of ice melted

Current Sea Ice Thickness ~ 2 - 3 meters

F_{si} = 10 W m^{-2} ⇒ Sea ice melts in 2 – 3 years

F_{si} = 1 W m^{-2} ⇒ Sea ice melts in 20 – 30 years

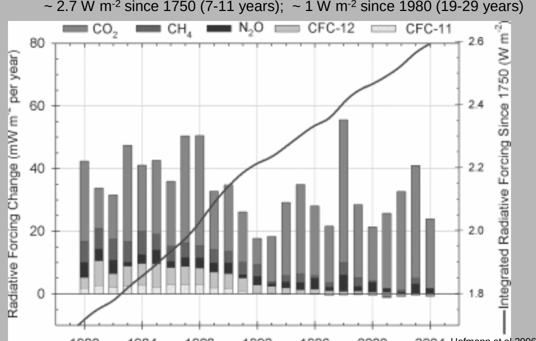
ARCTIC (ϕ > 65°N) ENERGY BUDGET



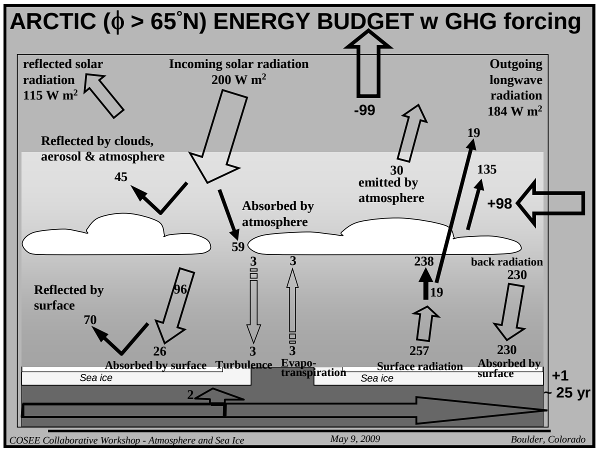
DIRECT RADIATIVE FORCING BY GREENHOUSE GASES

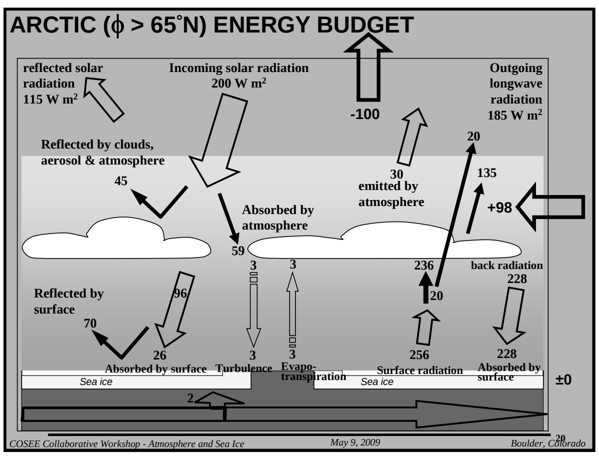
Global direct radiative forcing by greenhouse gases

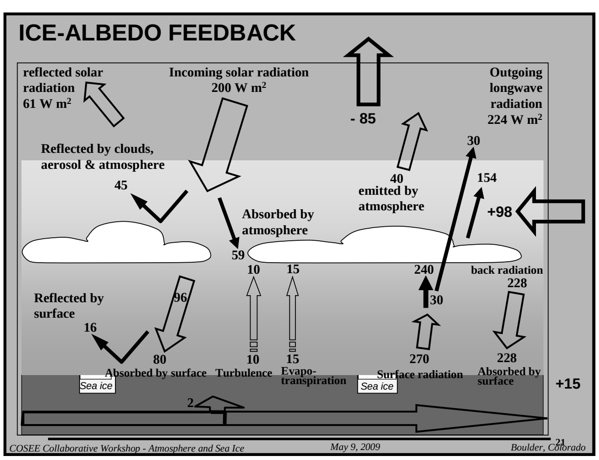
~ 2.7 W m^{-2} since 1750 (7-11 years); ~ 1 W m^{-2} since 1980 (19-29 years)

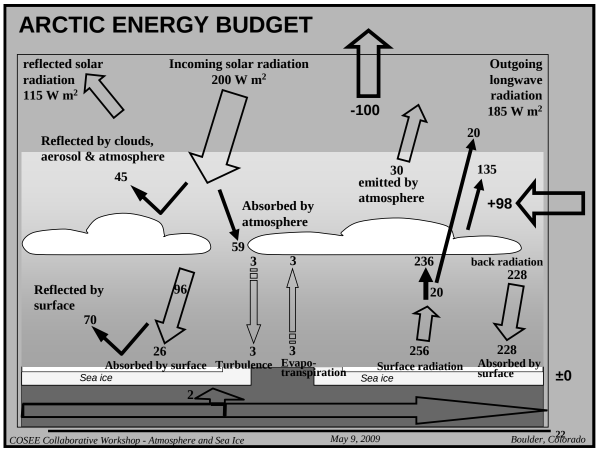


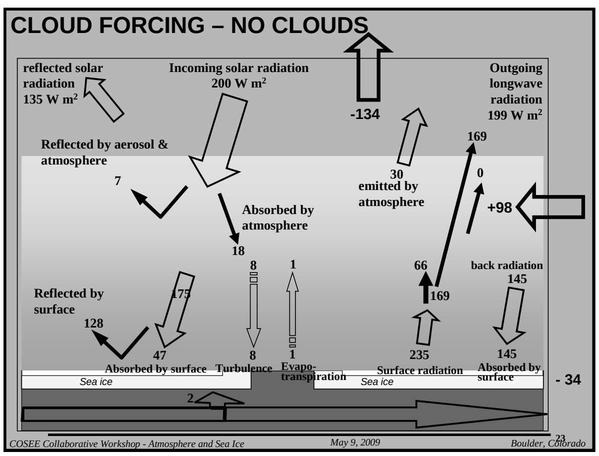
Hofmann et al 2006

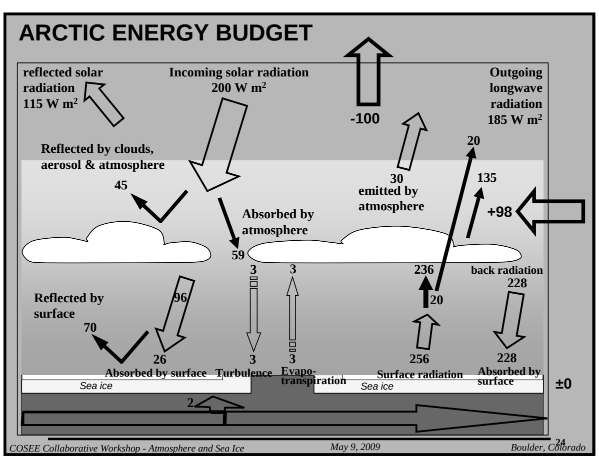

ARCTIC (ϕ > 65˚N) ENERGY BUDGET w GHG forcing
reflected solar radiation 115 W m2
Incoming solar radiation 200 W m2
Outgoing longwave radiation 184 W m2
-99
Reflected by clouds, aerosol & atmosphere
45
Absorbed by atmosphere
59
30
emitted by atmosphere
19
135
+98
3
3
238
19
back radiation
230
Reflected by surface
70
96
26
Absorbed by surface
3
Turbulence
3
Evapo-transpiration
257
Surface radiation
230
Absorbed by surface
Sea ice
Sea ice
2
+1
~ 25 yr
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado


ARCTIC (ϕ > 65˚N) ENERGY BUDGET
reflected solar radiation 115 W m2
Incoming solar radiation 200 W m2
Outgoing longwave radiation 185 W m2
-100
Reflected by clouds, aerosol & atmosphere
45
Absorbed by atmosphere
59
30
emitted by atmosphere
20
135
+98
3
3
236
20
back radiation
228
Reflected by surface
70
96
26
Absorbed by surface
3
Turbulence
3
Evapo-transpiration
256
Surface radiation
228
Absorbed by surface
Sea ice
Sea ice
2
±0
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado
20


ICE-ALBEDO FEEDBACK
reflected solar radiation 61 W m2
Incoming solar radiation 200 W m2
Outgoing longwave radiation 224 W m2
- 85
Reflected by clouds, aerosol & atmosphere
45
Absorbed by atmosphere
59
40
emitted by atmosphere
30
154
+98
10
15
240
30
back radiation
228
Reflected by surface
16
96
80
Absorbed by surface
10
Turbulence
15
Evapo-transpiration
270
Surface radiation
228
Absorbed by surface
Sea ice
Sea ice
2
+15
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado
21


ARCTIC ENERGY BUDGET
reflected solar radiation 115 W m2
Incoming solar radiation 200 W m2
-100
Outgoing longwave radiation 185 W m2
Reflected by clouds, aerosol & atmosphere
45
20
30 emitted by atmosphere
135
+98
Absorbed by atmosphere
59
3
3
236
20
back radiation 228
Reflected by surface
96
70
26
3
3
256
228
Absorbed by surface
Turbulence
Evapo-transpiration
Surface radiation
Absorbed by surface
±0
Sea ice
Sea ice
2
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado
22


CLOUD FORCING – NO CLOUDS
reflected solar radiation 135 W m2
Incoming solar radiation 200 W m2
-134
Outgoing longwave radiation 199 W m2
Reflected by aerosol & atmosphere
7
169
30 emitted by atmosphere
0
+98
Absorbed by atmosphere
18
8
1
66
169
back radiation 145
Reflected by surface
175
128
47
8
1
235
145
Absorbed by surface
Turbulence
Evapo-transpiration
Surface radiation
Absorbed by surface
- 34
Sea ice
Sea ice
2
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado
23


ARCTIC ENERGY BUDGET
reflected solar radiation 115 W m2
Incoming solar radiation 200 W m2
-100
Outgoing longwave radiation 185 W m2
Reflected by clouds, aerosol & atmosphere
45
20
30 emitted by atmosphere
135
+98
Absorbed by atmosphere
59
3
3
236
20
back radiation 228
Reflected by surface
96
70
26
3
3
256
228
Absorbed by surface
Turbulence
Evapo-transpiration
Surface radiation
Absorbed by surface
±0
Sea ice
Sea ice
2
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado
24

Possible mechanisms-3

- atmospheric thermodynamic forcing

We have seen that Arctic system is sensitive to

1) Albedo of sea ice
2) Longwave and shortwave radiative characteristics of the clouds
3) Turbulent heat transfer

A possible atmospheric cause of decreasing sea ice:

Characteristics of the atmosphere or clouds are changing to increase the longwave radiative forcing of the surface, decreasing sea-ice. Ice-albedo feedback then accelerates the sea-ice decrease.

Possible mechanisms-3

- atmospheric thermodynamic forcing

We have seen that Arctic system is sensitive to

1) Albedo of sea ice
2) Longwave and shortwave radiative characteristics of the clouds
3) Turbulent heat transfer

A possible atmospheric cause of decreasing sea ice:

Characteristics of the atmosphere or clouds are changing to increase the longwave radiative forcing of the surface, decreasing sea-ice. Ice-albedo feedback then accelerates the sea-ice decrease.

Current research address key elements of the Arctic energy system

1) processes affecting albedo of sea ice (melt ponds, snow cover, soot)
2) processes affecting cloud formation and cloud radiative characteristics (cloud phase, cloud emissivity, cloud condensation nuclei)
3) turbulent energy transfer processes

Possible mechanisms-3

- atmospheric thermodynamic forcing

We have seen that Arctic system is sensitive to

1) Albedo of sea ice
2) Longwave and shortwave radiative characteristics of the clouds
3) Turbulent heat transfer

A possible atmospheric cause of decreasing sea ice:

Characteristics of the atmosphere or clouds are changing to increase the longwave radiative forcing of the surface, decreasing sea-ice. Ice-albedo feedback then accelerates the sea-ice decrease.

Current research address key elements of the Arctic energy system

1) processes affecting albedo of sea ice (melt ponds, snow cover, soot)
2) processes affecting cloud formation and cloud radiative characteristics (cloud phase, cloud emissivity, cloud condensation nuclei)
3) turbulent energy transfer processes

Possible mechanisms-3
- atmospheric thermodynamic forcing

We have seen that Arctic system is sensitive to
1) Albedo of sea ice
2) Longwave and shortwave radiative characteristics of the clouds
3) Turbulent heat transfer

A possible atmospheric cause of decreasing sea ice:
Characteristics of the atmosphere or clouds are changing to increase the longwave radiative forcing of the surface, decreasing sea-ice. Ice-albedo feedback then accelerates the sea-ice decrease.

Current research address key elements of the Arctic energy system
1) processes affecting albedo of sea ice (melt ponds, snow cover, soot)
2) processes affecting cloud formation and cloud radiative characteristics (cloud phase, cloud emissivity, cloud condensation nuclei)
3) turbulent energy transfer processes

Impact of cloud phase, emissivity

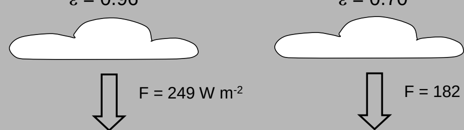
Stefan-Boltzmann Law for a greybody

$F = \varepsilon \sigma T^4$

both at T = -13°C (260 K)

water cloud $\varepsilon = 0.96$

ice cloud $\varepsilon = 0.70$



$F = 249\ W\ m^{-2}$

$F = 182\ W\ m^{-2}$

Impact of cloud phase, emissivity, and temperature

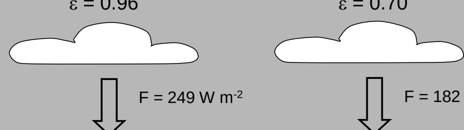
Stefan-Boltzmann Law for a greybody

$F = \varepsilon \sigma T^4$

both at T = -13°C (260 K)

water cloud $\varepsilon = 0.96$

ice cloud $\varepsilon = 0.70$



$F = 249\ W\ m^{-2}$

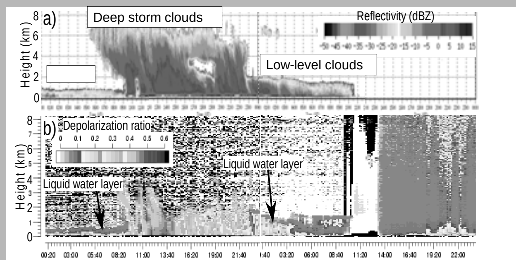
$F = 182\ W\ m^{-2}$

both at T = -14°C (259 K)

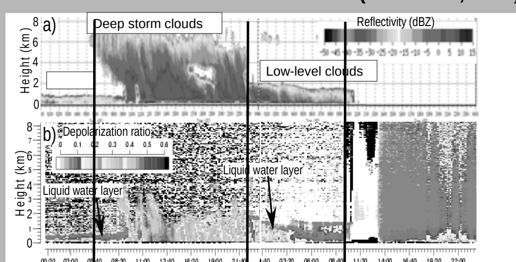
$F = 245\ W\ m^{-2}$ $-4\ W\ m^{-2}$

$F = 179\ W\ m^{-2}$ $-3\ W\ m^{-2}$

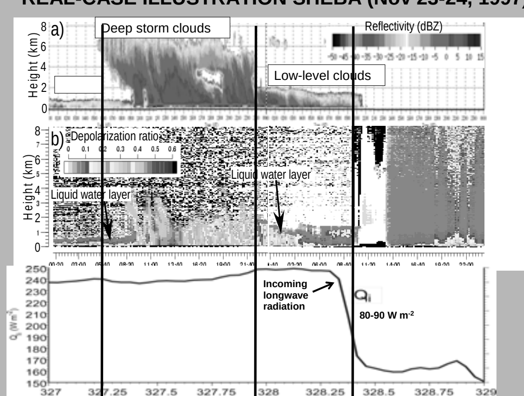
REAL-CASE ILLUSTRATION SHEBA (Nov 23-24, 1997)



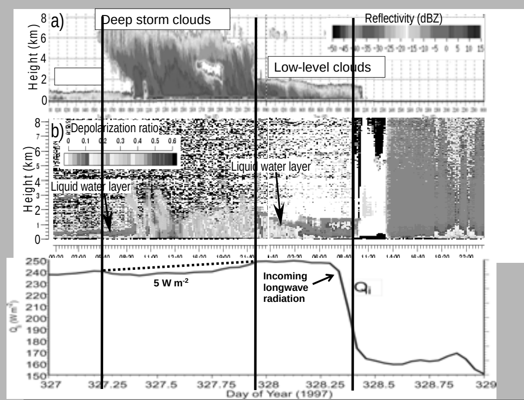
REAL-CASE ILLUSTRATION SHEBA (Nov 23-24, 1997)



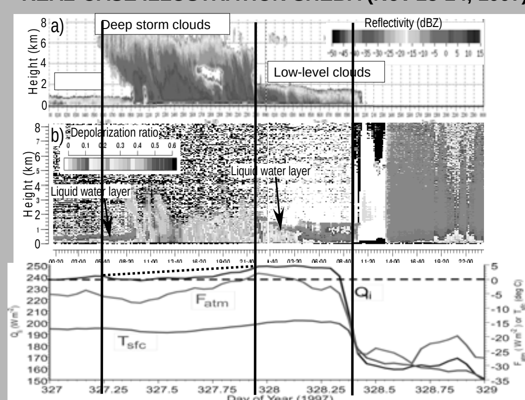
REAL-CASE ILLUSTRATION SHEBA (Nov 23-24, 1997)



REAL-CASE ILLUSTRATION SHEBA (Nov 23-24, 1997)



REAL-CASE ILLUSTRATION SHEBA (Nov 23-24, 1997)



Arctic Ocean Atmospheric Research Expeditions (1893-2008)

Norwegian Arctic Expedition (1893-1896) oceanographer Fridtjof Nansen, wooden ship Fram; first true scientific investigation of Arctic pack-ice environment

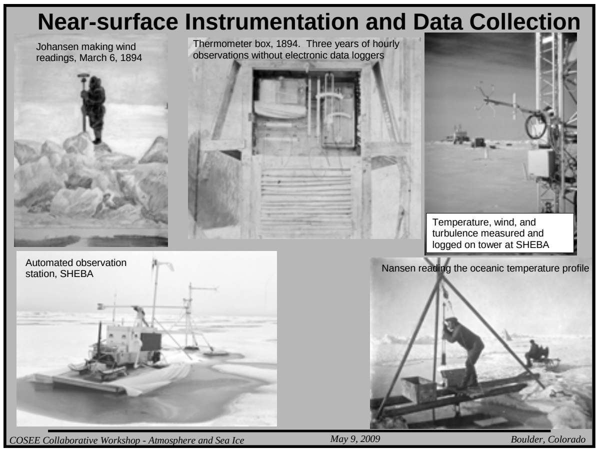
Soviet/Russian Drifting Ice Islands (1937-1991; 2003-2008) – 35 stations on drifting ice floes; observational data used extensively

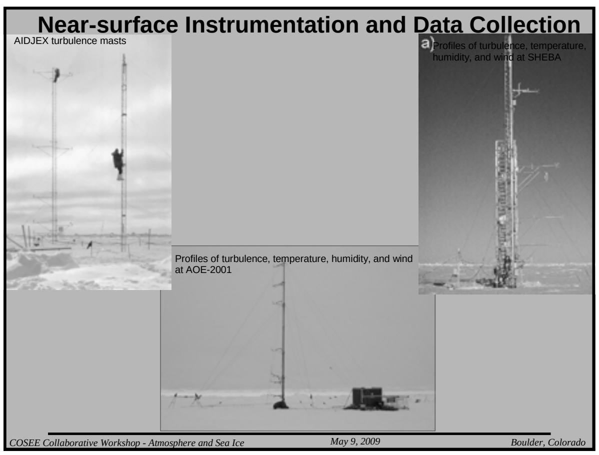
AIDJEX (3/1975 – 5/1976) – American-Canadian project, 4 drifting ice camps in Beaufort Sea; focused on ice dynamics, but also collected atmospheric turbulence data

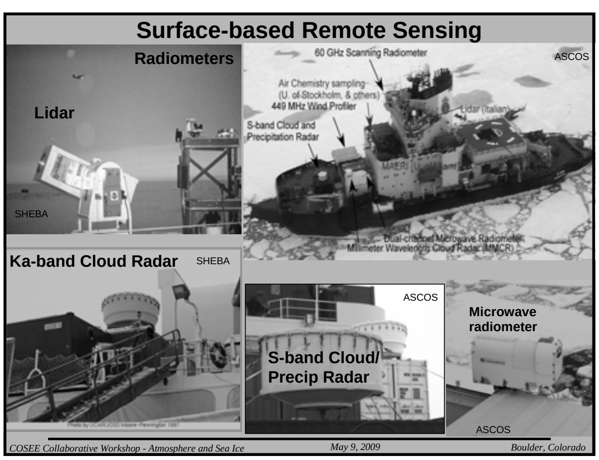
LEADEX (3-4/1992) - U. S. led ice camps on floe in Beaufort Sea; focused on impacts of leads

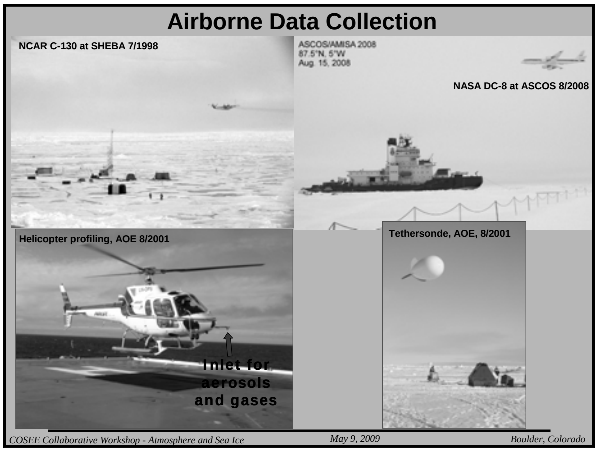
SHEBA (10/1997 - 10/1998) - U.S. led, Beaufort and Chuckchi Seas, on drifting ice floe with icebreaker; year-long data of clouds, surface energy budget, sea-ice characteristics, ocean energy fluxes; data set used extensively for model development and validation

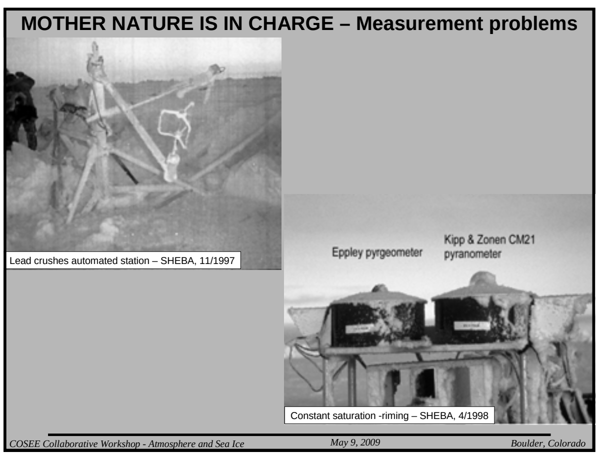
AOE, ASCOS (1991, 1996, 2001, 2008) – Swedish-led international 1-2 month campaigns using icebreaker Oden and on drifting floes; initially focused on air chemistry and aerosol measurements, but later included extensive atmospheric boundary-layer and cloud measurements

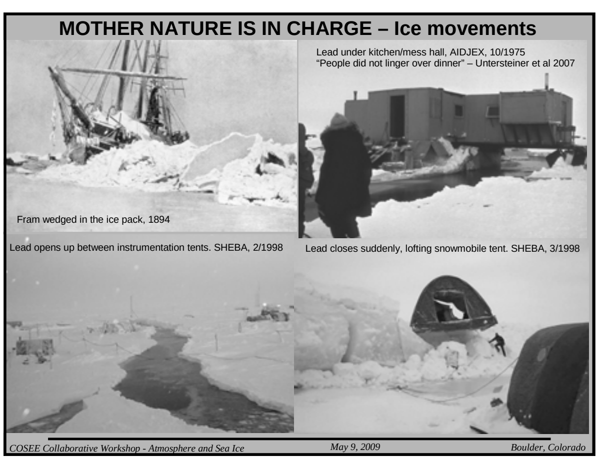

Near-surface Instrumentation and Data Collection
Johansen making wind readings, March 6, 1894
Thermometer box, 1894. Three years of hourly observations without electronic data loggers
Temperature, wind, and turbulence measured and logged on tower at SHEBA
Automated observation station, SHEBA
Nansen reading the oceanic temperature profile
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado


Near-surface Instrumentation and Data Collection
AIDJEX turbulence masts
Profiles of turbulence, temperature, humidity, and wind at SHEBA
Profiles of turbulence, temperature, humidity, and wind at AOE-2001
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado


Surface-based Remote Sensing
Radiometers
Lidar
SHEBA
60 GHz Scanning Radiometer
ASCOS
Air Chemistry sampling (U. of Stockholm, & others)
449 MHz Wind Profiler
S-band Cloud and Precipitation Radar
Lidar (Italian)
Dual-channel Microwave Radiometer
Millimeter Wavelength Cloud Radar (MMCR)
Ka-band Cloud Radar
SHEBA
ASCOS
S-band Cloud/ Precip Radar
Microwave radiometer
ASCOS
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado


Airborne Data Collection
NCAR C-130 at SHEBA 7/1998
ASCOS/AMISA 2008
87.5°N, 5°W
Aug. 15, 2008
NASA DC-8 at ASCOS 8/2008
Helicopter profiling, AOE 8/2001
Tethersonde, AOE, 8/2001
Inlet for
aerosols
and gases
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado


MOTHER NATURE IS IN CHARGE – Measurement problems
Lead crushes automated station – SHEBA, 11/1997
Eppley pyrgeometer
Kipp & Zonen CM21
pyranometer
Constant saturation -riming – SHEBA, 4/1998
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado


MOTHER NATURE IS IN CHARGE – Ice movements
Lead under kitchen/mess hall, AIDJEX, 10/1975
"People did not linger over dinner" – Untersteiner et al 2007
Fram wedged in the ice pack, 1894
Lead opens up between instrumentation tents. SHEBA, 2/1998
Lead closes suddenly, lofting snowmobile tent. SHEBA, 3/1998
COSEE Collaborative Workshop - Atmosphere and Sea Ice
May 9, 2009
Boulder, Colorado

Beauty and Surprises

Azure blue meltponds – D. Perovich at SHEBA
O.Persson

Logistical Concerns - dark, visibility, cold, bears

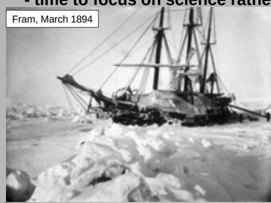
Bears interrupted and hindered on-ice work – AOE-2001

Lack of visibility sometimes mandated special safety regulations AOE-2001

Bears mandated firearm training and special safety regulations – O. Persson at SHEBA

SHIP AS HOTEL AND RESTAURANT

- time to focus on science rather than personal needs and safety



Fram, March 1894

Desgrossiellier, 1998

French-Canadian cuisine, Desgrossiellier, 1998

Oden, 2001