Sea Ice, Climate Change and Remote Sensing

Prof. David Barber
Canada Research Chair in Arctic System Science
Director, Centre for Earth Observation Science
University of Manitoba
Winnipeg, MB. Canada

www.umanitoba.ca/ceos

ESA Summer School, August, 2006

Lecture outline

1) Arctic Climate Change and Remote Sensing

2) Geophysics, dielectrics and thermodynamics

3) Scattering and emission modeling

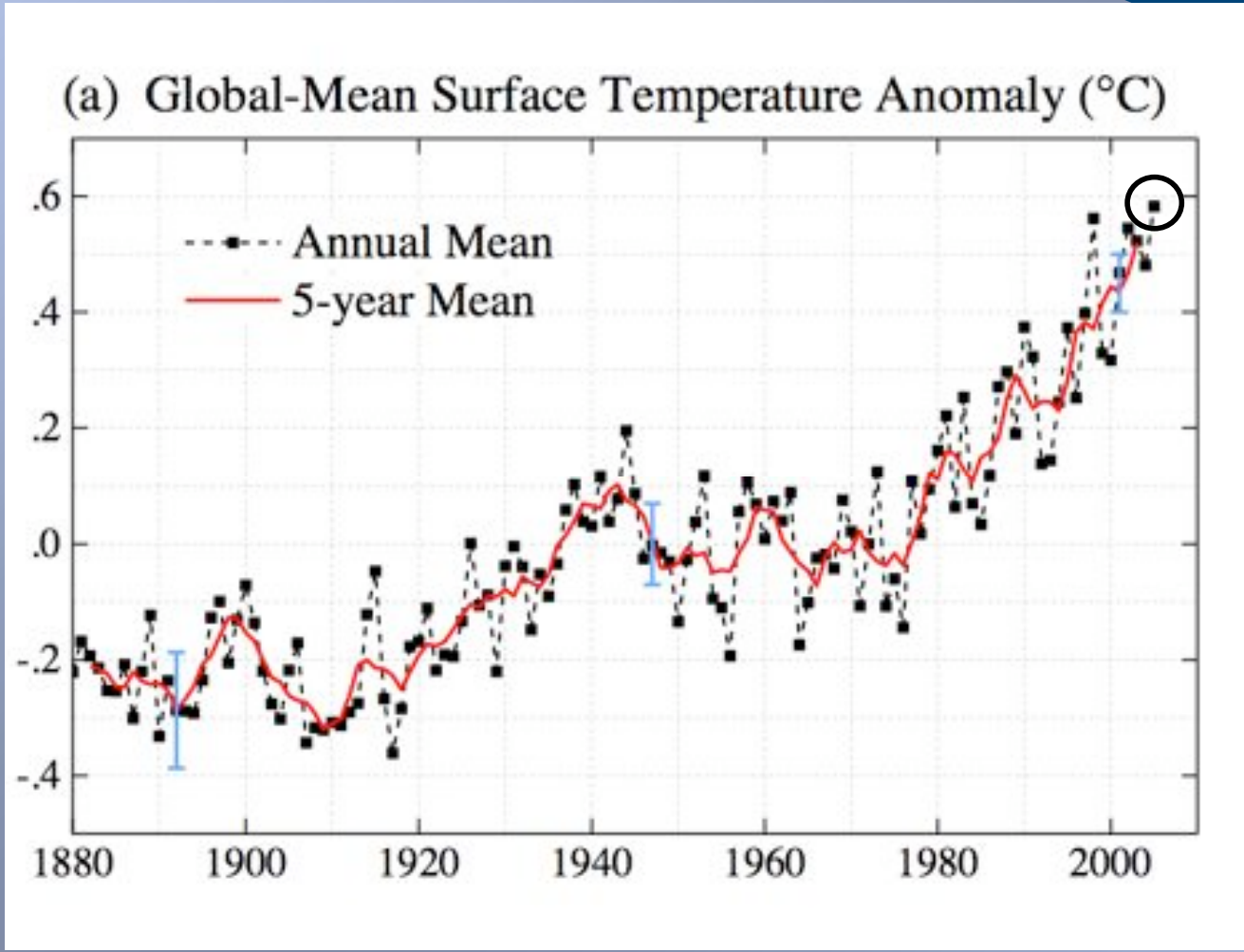
Outline of this talk

- Sea ice
- Climate Change
- Overview of remote sensing applications
- Conclusions

A survey

- Do you believe climate change is real?
- Have you heard about the changes going on in the Arctic?
- Have you ever been to either pole of our planet?

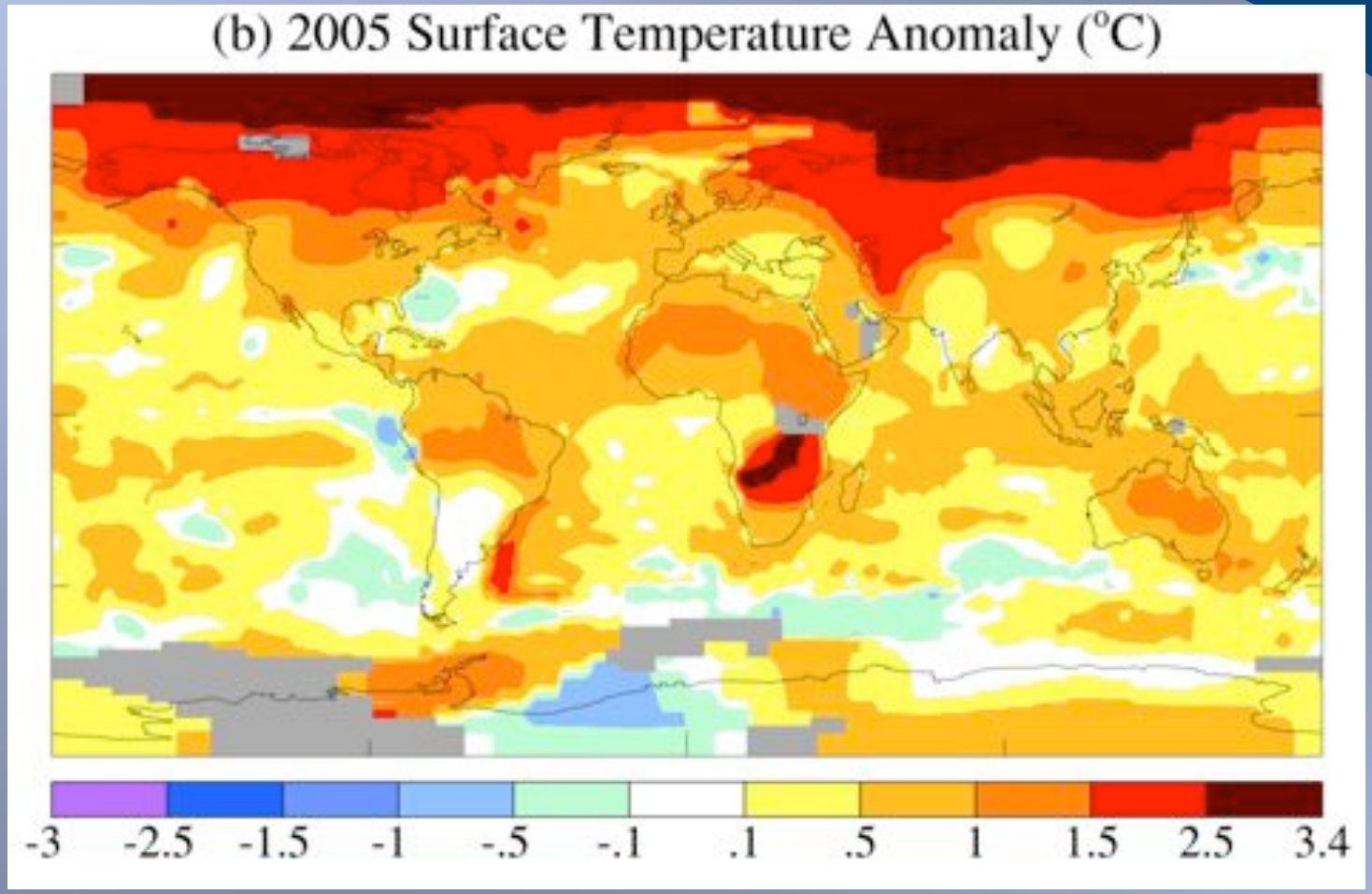
CANADIAN EDITION
SEPTEMBER 4, 2000 $4.50
TIME
This polar bear's in danger, and so are you. Here's how global warming is already threatening Canada—and the whole planet
ARCTIC
ELTDOWN
SPECIAL REPORT GLOBAL WARMING
TIME
BE WORRIED. BE VERY WORRIED.
Climate change isn't some vague future problem—it's already damaging the planet at an alarming pace. Here's how it affects you, your kids and their kids as well
EARTH AT THE TIPPING POINT
HOW IT THREATENS YOUR HEALTH
HOW CHINA & INDIA CAN HELP SAVE THE WORLD—OR DESTROY IT
THE CLIMATE CRUSADERS
2ND-QTR SIZZLE PROFITS AT 900 COMPANIES (P. 74)
PAYING FOR COLLEGE BEWARE OF THOSE HIGH 529 FEES (P. 96)
TERRORISM WHAT COMPANIES STILL NEED TO DO (P. 26)
The McGraw-Hill Companies
BusinessWeek
GLOBAL WARMING
Why Business Is Taking It So Seriously
BY JOHN CAREY (P. 60)
FROM THE DIRECTOR OF INDEPENDENCE DAY
THE DAY AFTER TOMORROW
WHERE WILL YOU BE?
MAY 28



Global mean surface temperature anomalies
relative to the 1951-1980 climatology
(2σ error bars in blue)

Hansen et al. 2006

CEOS

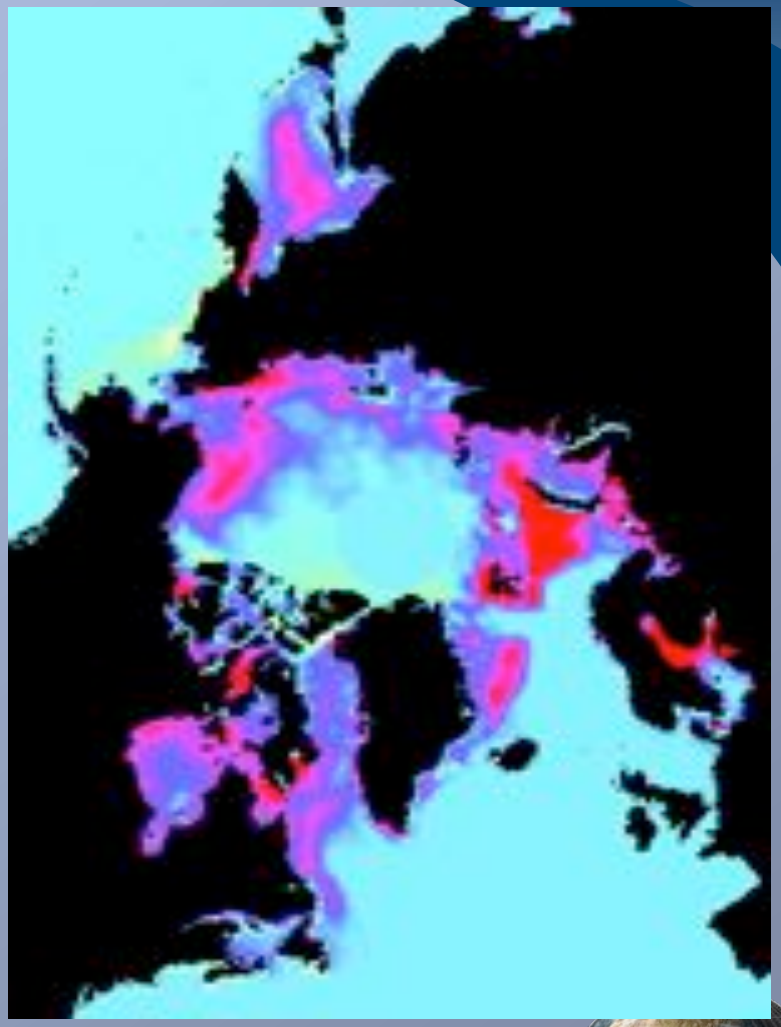


Global mean surface temperature anomalies relative to the 1951-1980 climatology

Hansen et al. 2006

CEOS

The Warming Arctic

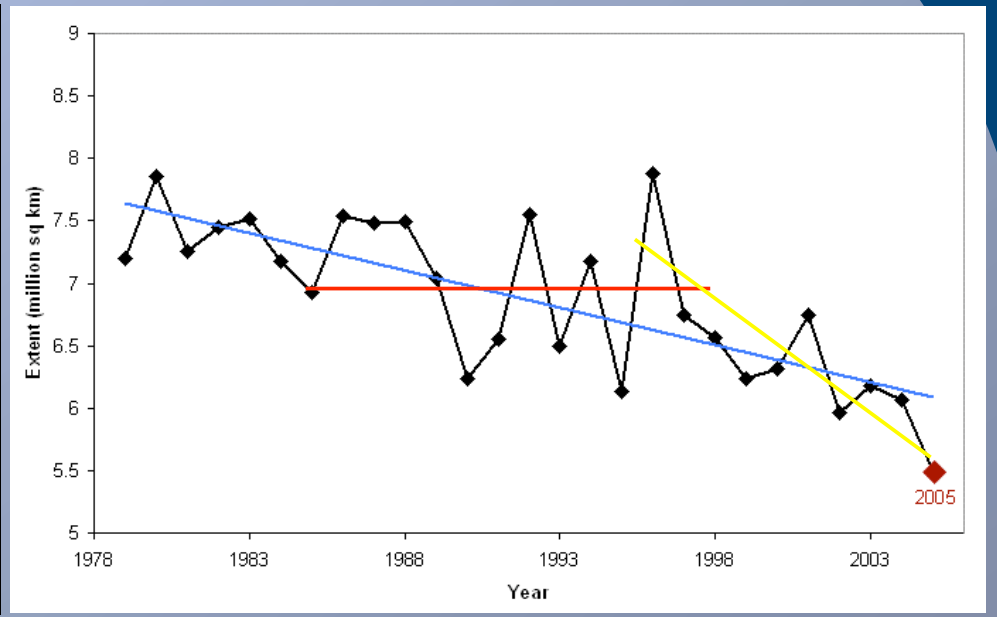


Rate of Change δ% (P<0/01)

Growth and Decay of Sea Ice

CEOS

Reduction in the sea ice minimum

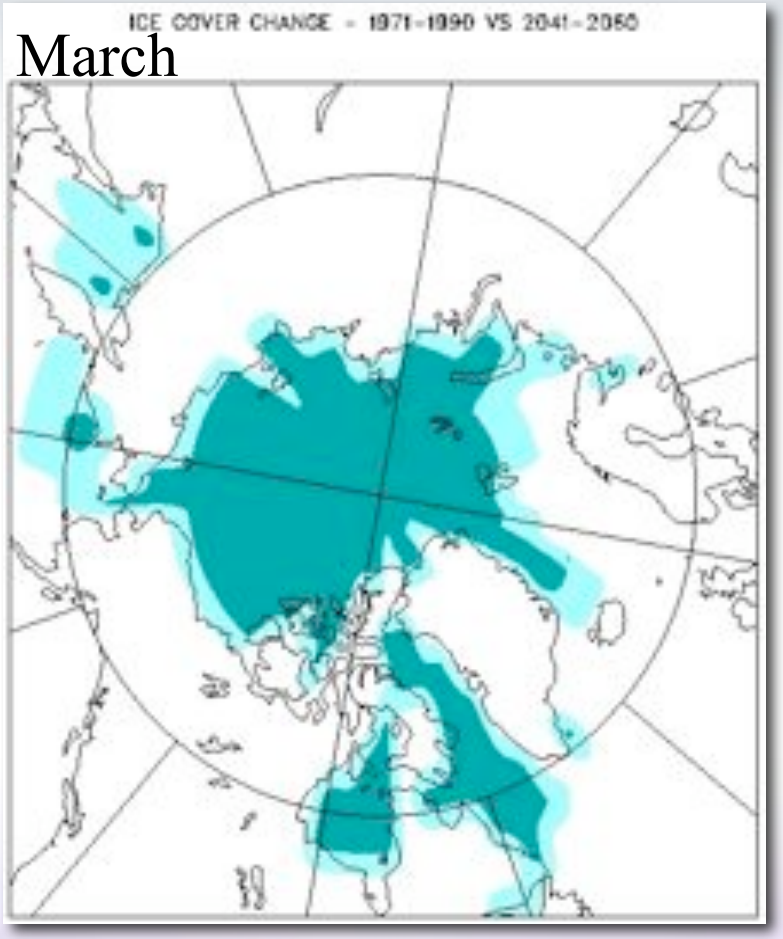


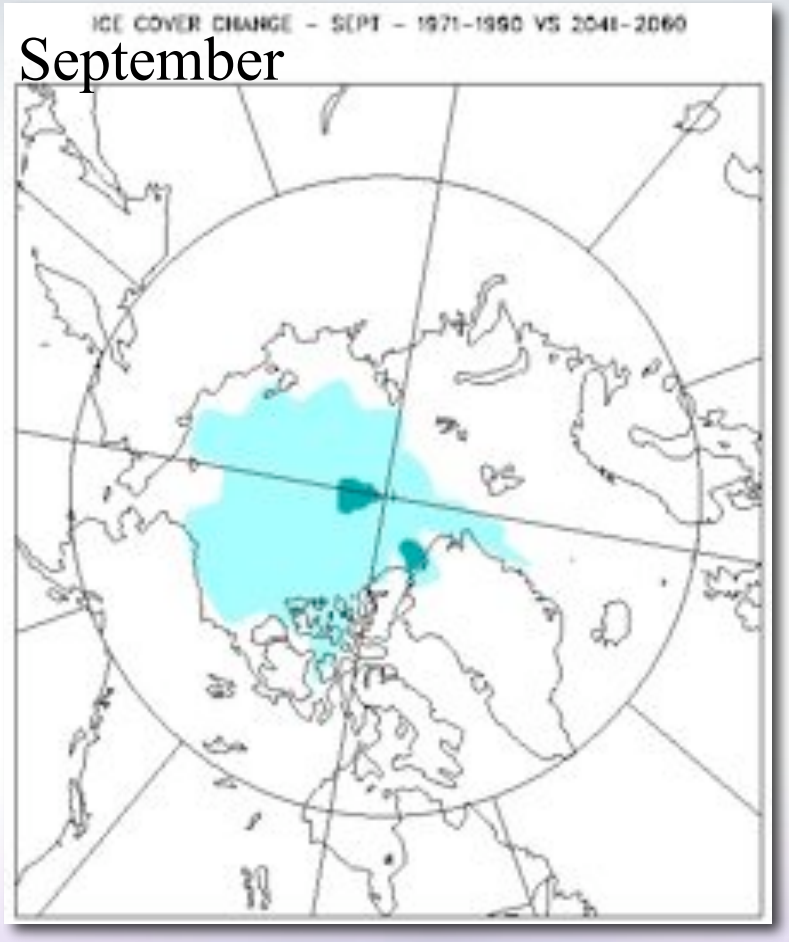
We are loosing a lot of sea ice

70,000 km^{-2} per year or 2.2M km^{-2} over 30 years

Seasonally ice free around 2050!!

The Future?





G. Flato,CCMA

Geopolitical Response?

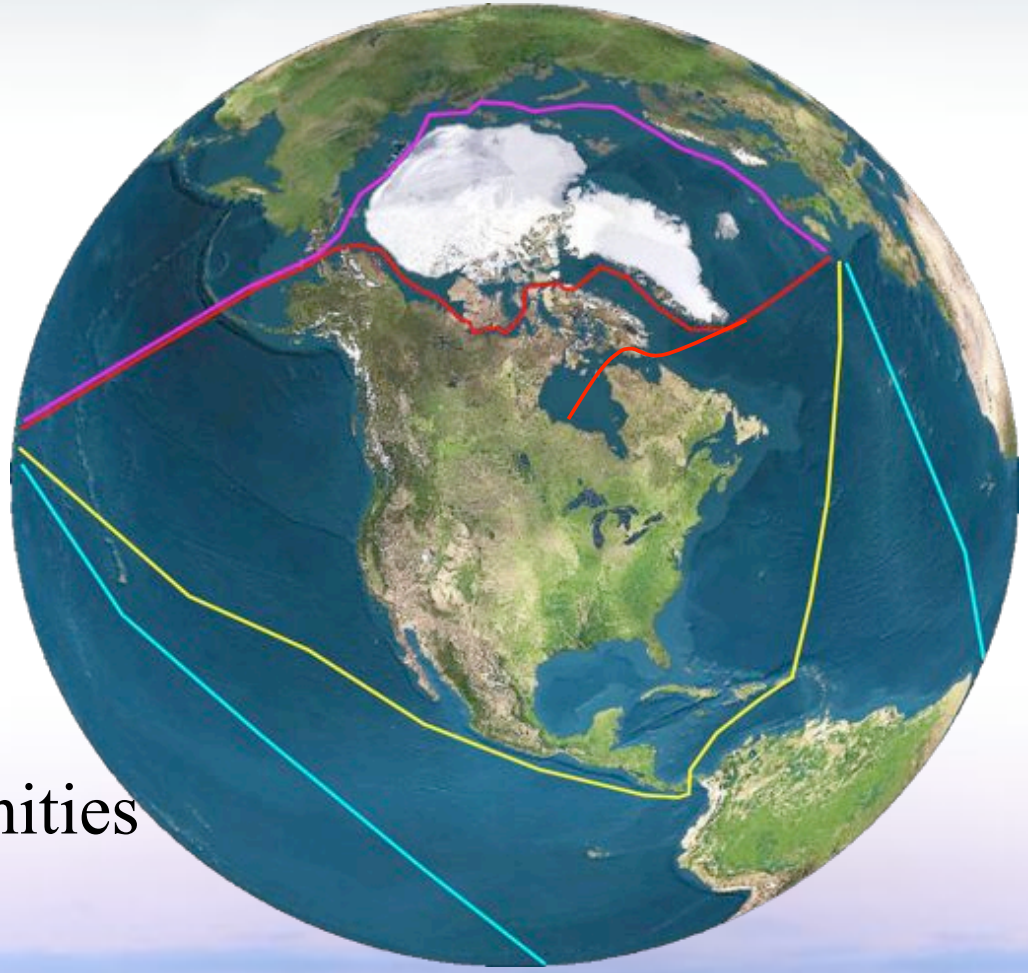
A new ocean to navigate, exploit and preserve

NW Passage

NE Passage

Panama
(+ 11 000 km)

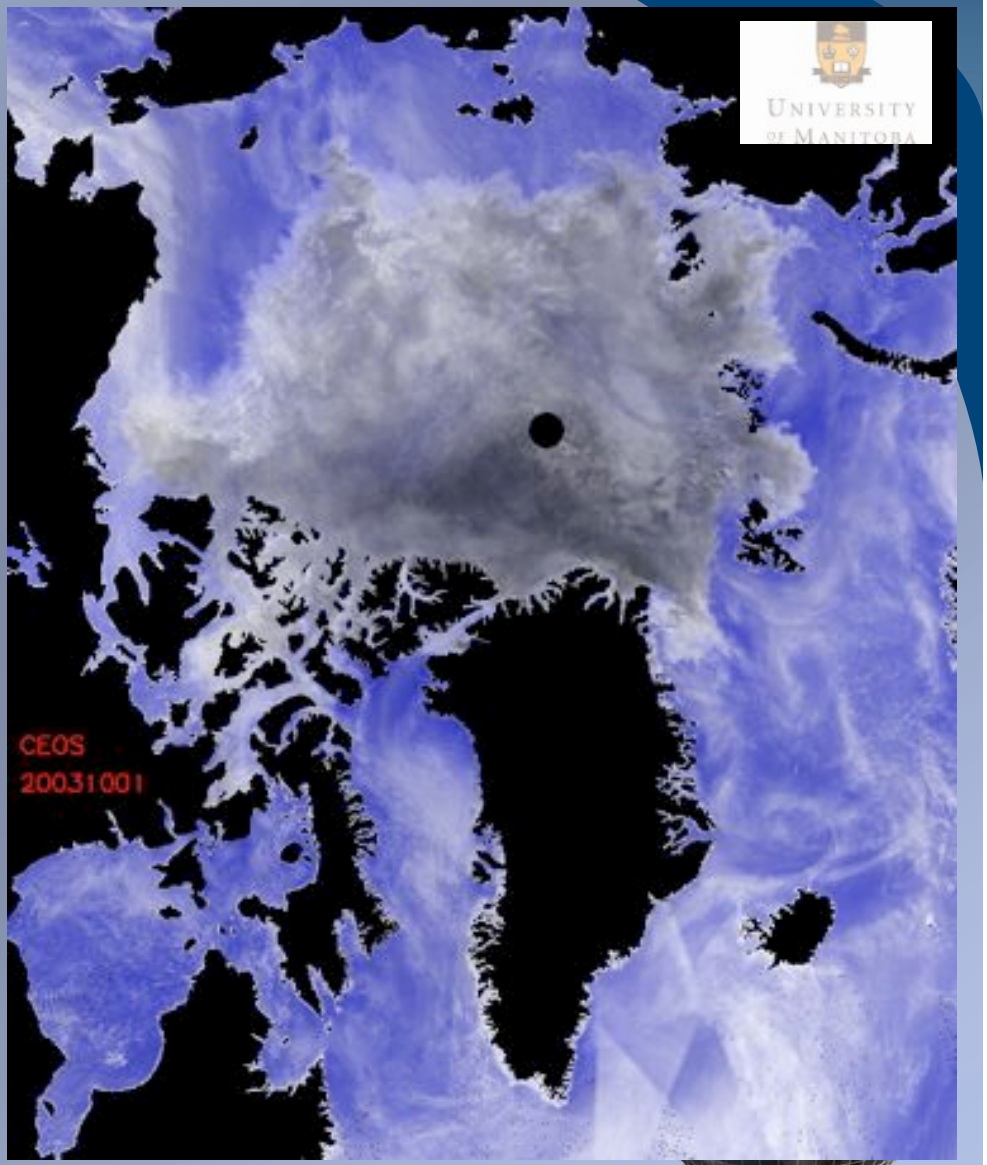
Cape Horn
(+ 19 000 km)



Challenges and Opportunities

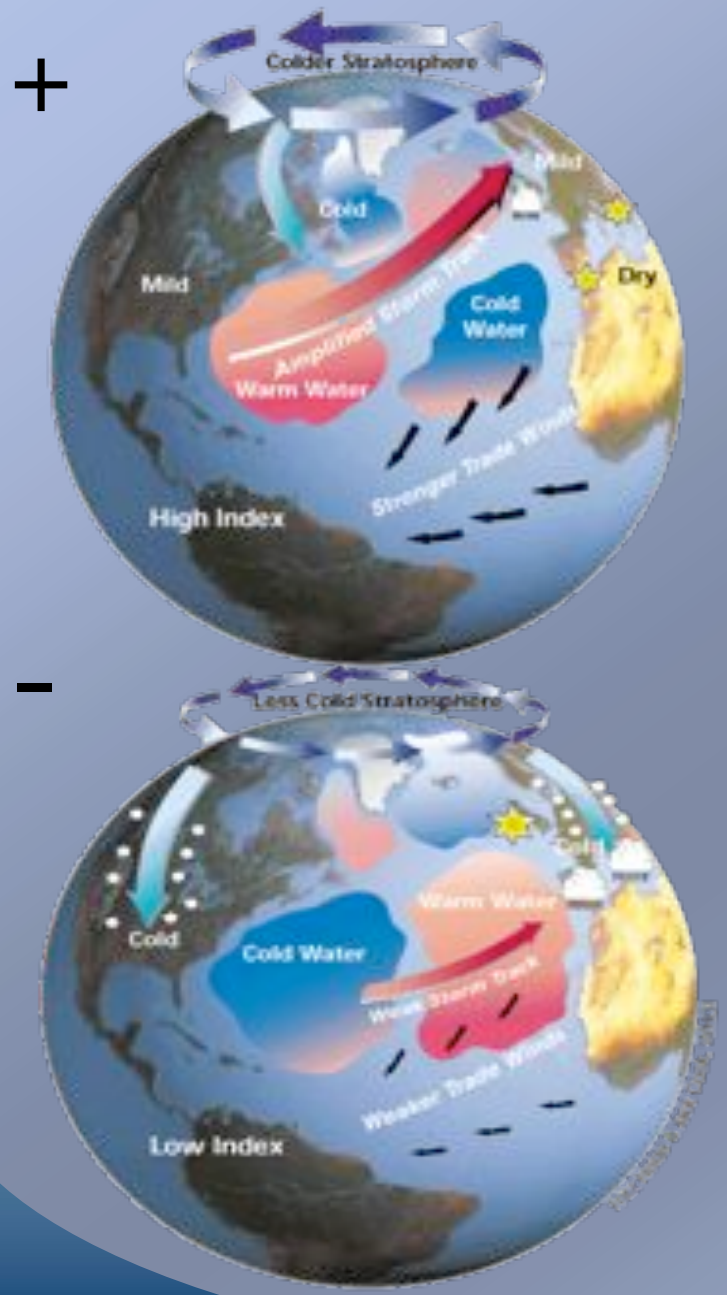
Drivers

Yearly Mean
S O N D J F M A M J J A


UNIVERSITY
OF MANITOBA
CEOS
20031001

CEOS

The Arctic Oscillation (AO)



+ low press over the pole
+ high press mid lat
- high press over the pole
- low press mid lat

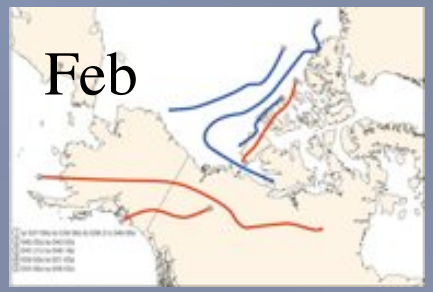
controls storm tracks, moisture, etc

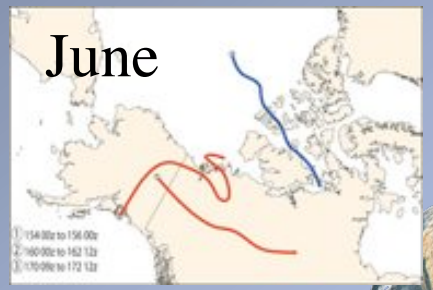
Connection between the stratosphere-troposphere and surface

(Lukovich and Barber, 2005)

CEOS

Cyclone Forcing





Cyclone frequency and trajectory (CASES'04)

What is the effect of wind forcing on the surface?

Fisico and Hanesiak, 2006

CEOS

Changes in Atlantic water (depth and temperature)

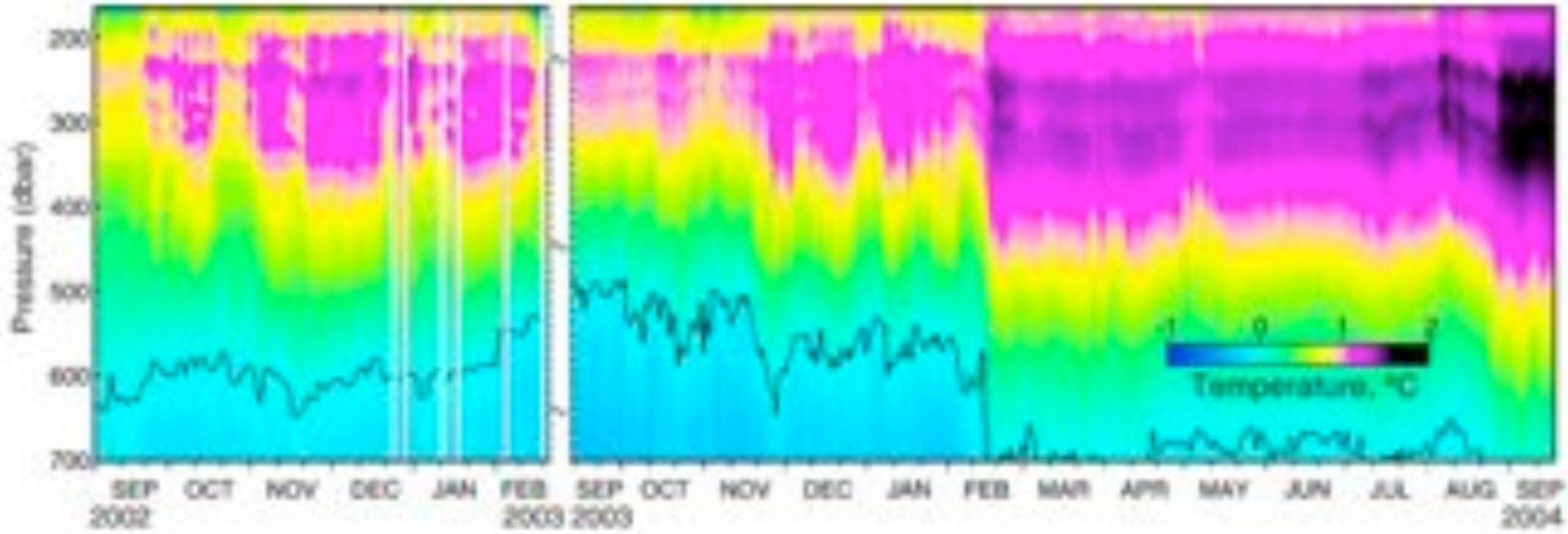
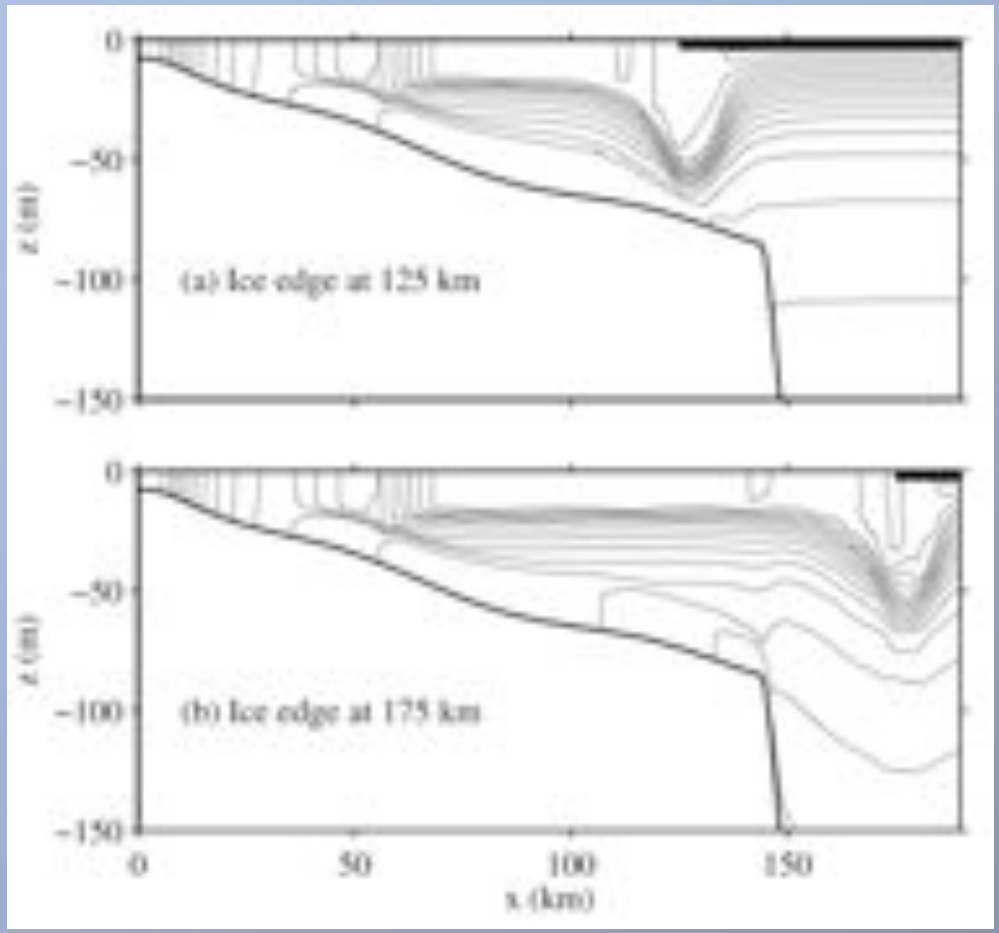
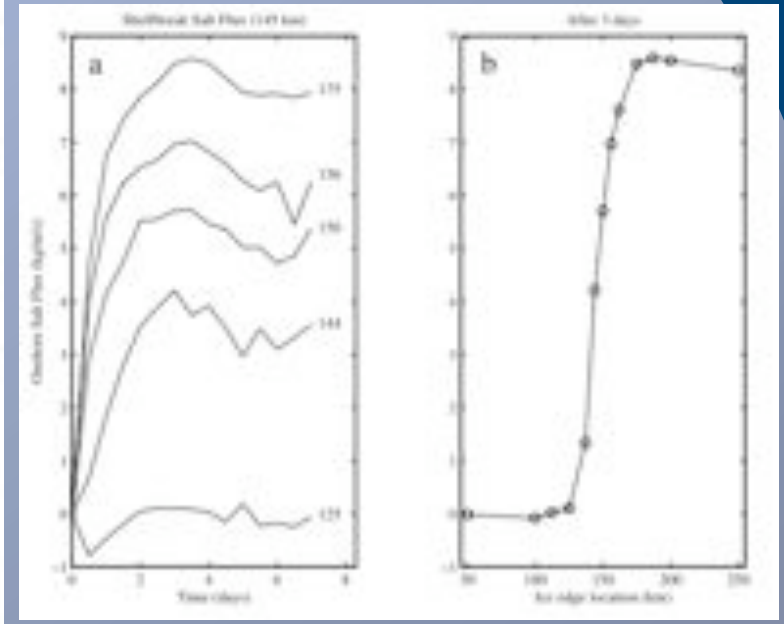


Fig. 3. Water temperature from the MMP profiler. The 0 °C isotherm (black line) traces the lower boundary of the AW layer. Blank areas represent missing data. 10-m vertical binning is used.

Dmitrenko et al. 2006

Ocean-sea ice-atmosphere coupling at the shelf break

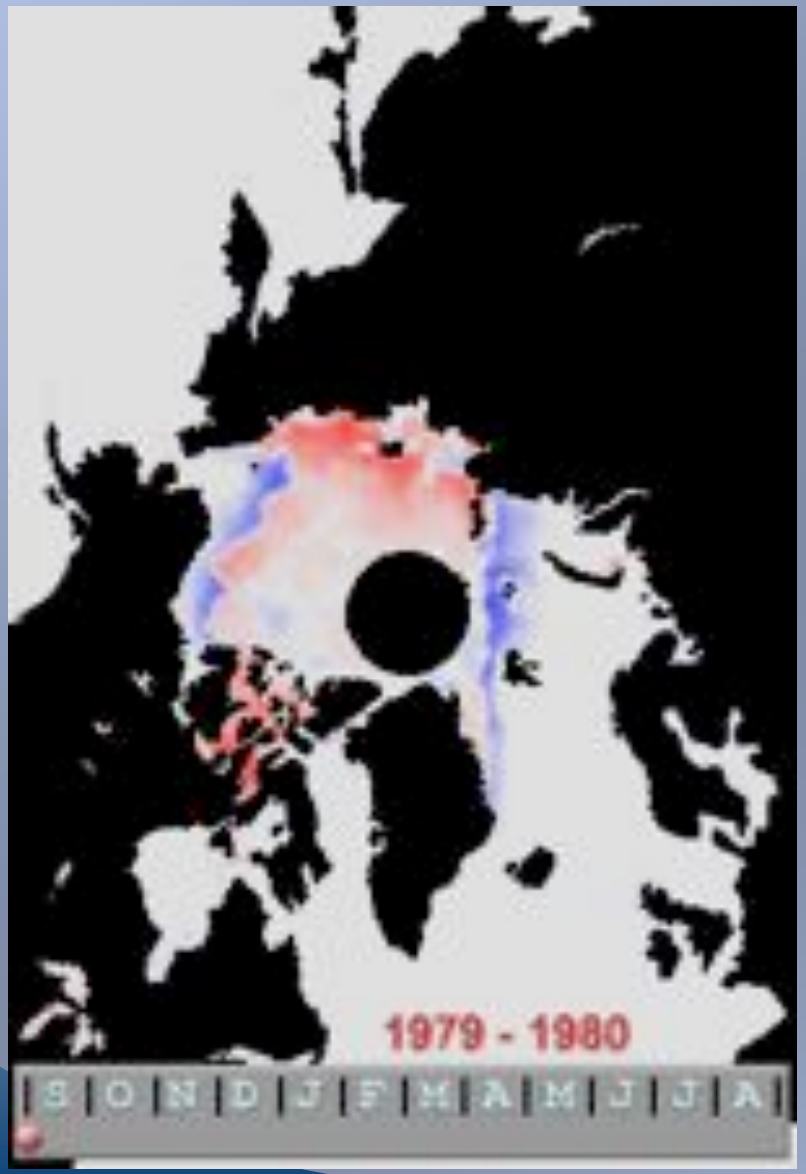




Carmack and Chapman 2003

CEOS

The ice-albedo feedback mechanism (thermodynamic)

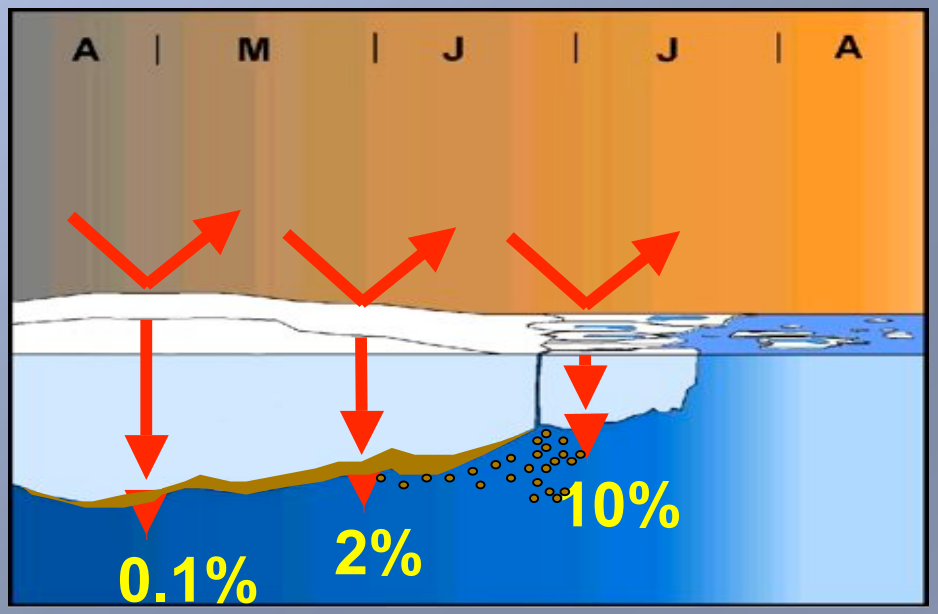


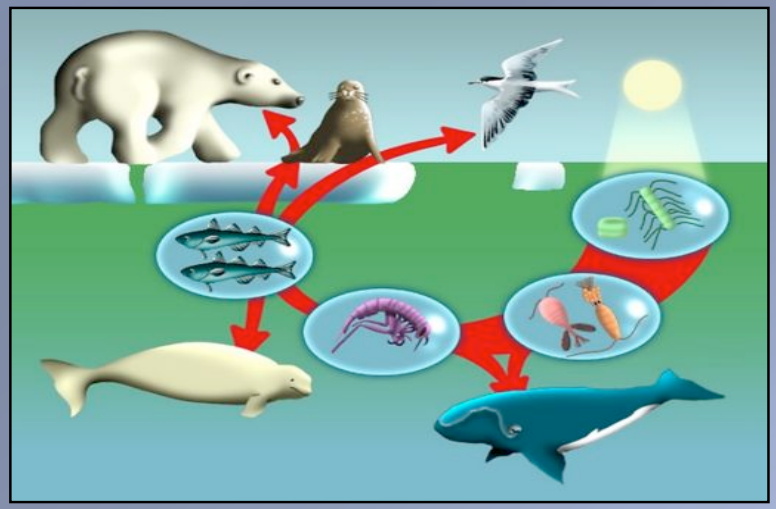
Positive feedback as more ocean absorbs shortwave radiation.

Complications with longwave flux

CEOS

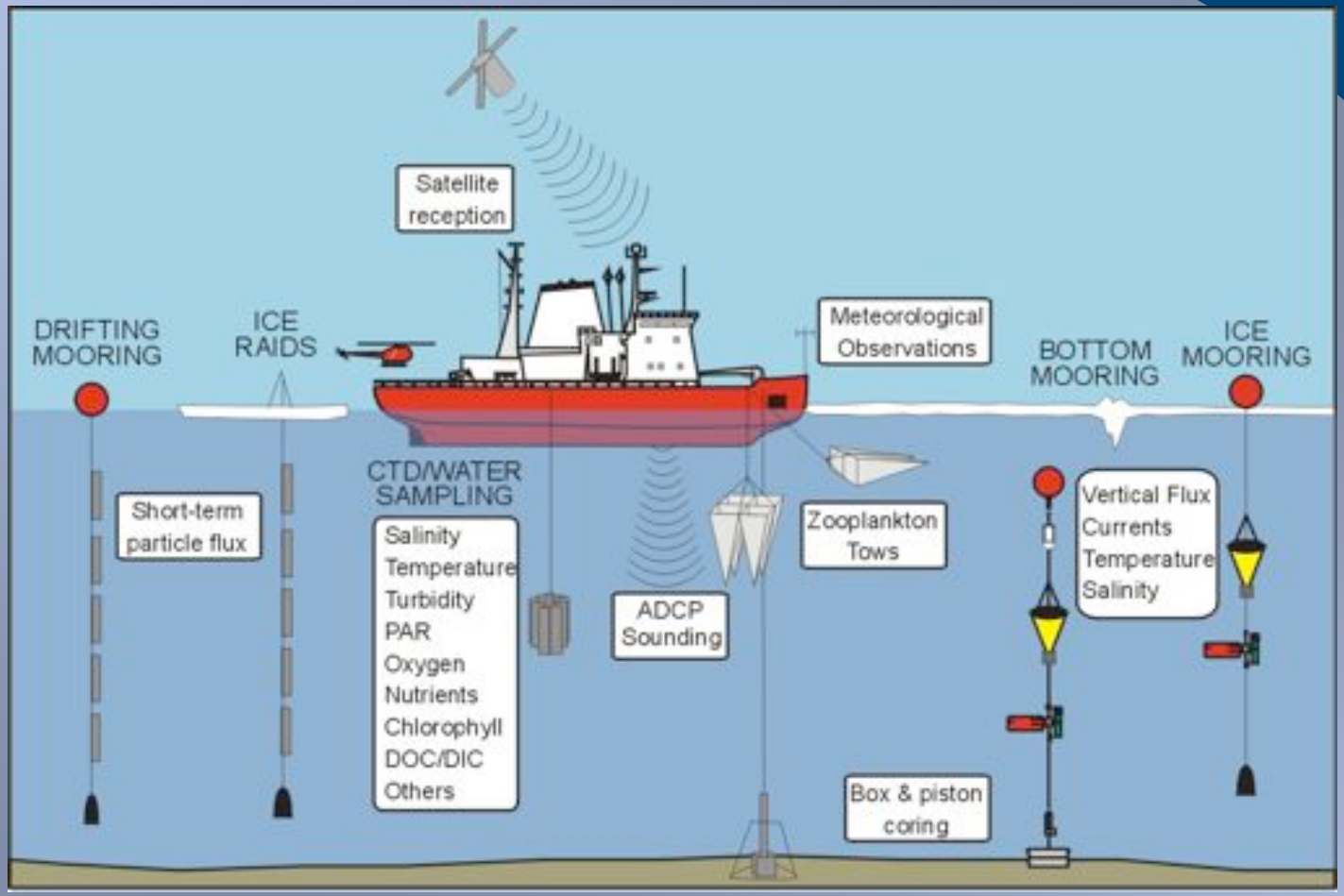
Physical-Biological Coupling





- Process Studies
- Modelling Studies
- Scaling Studies
- Ocean-sea ice-atmosphere
- Bio-physical
- Contaminants

CEOS



How we conduct Arctic Science

CEOS

How we conduct Arctic Science

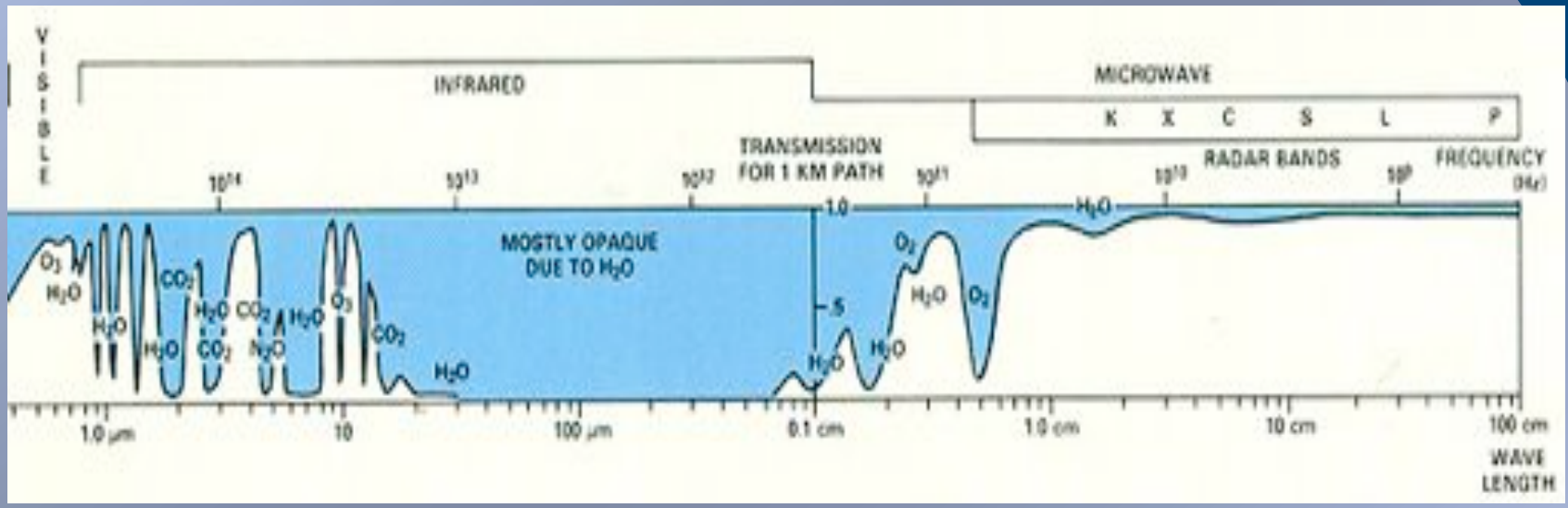
Remote Sensing

Shuttle window (ideal case)

Shuttle window (summer)

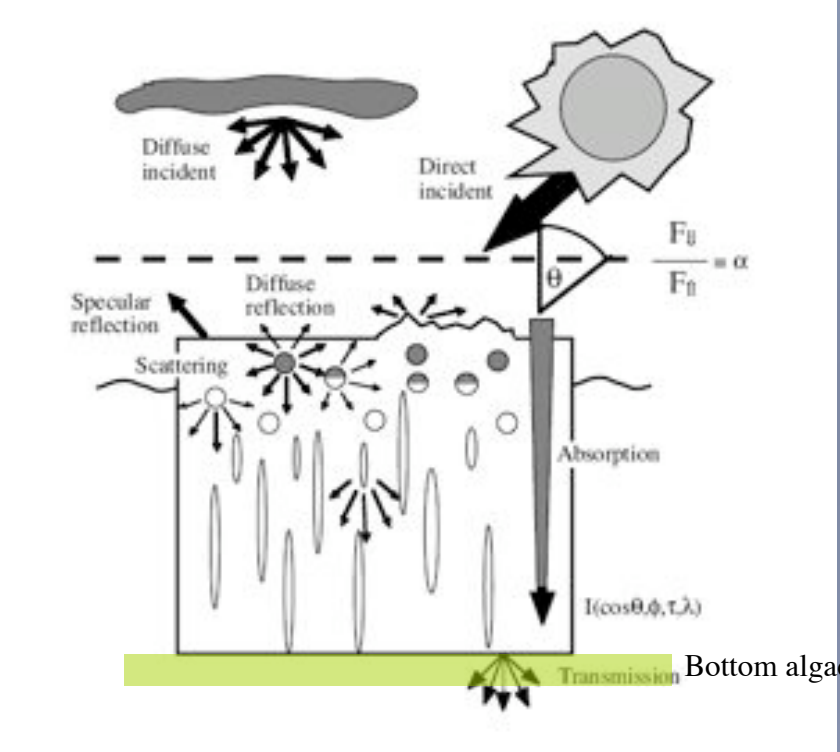
Shuttle window (winter)

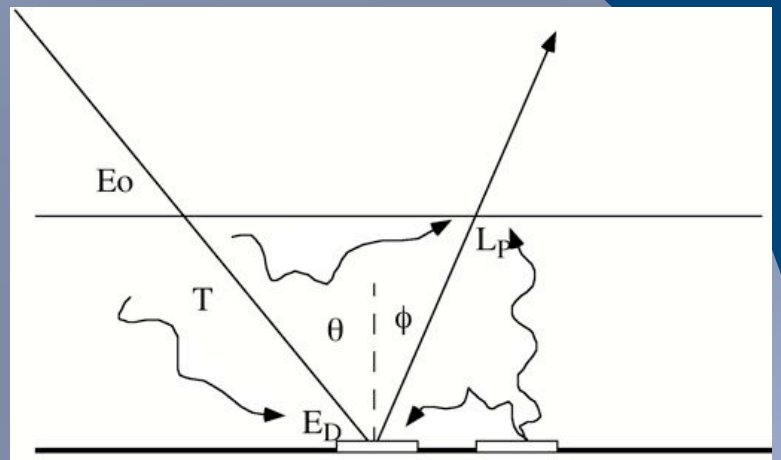
Atmospheric Transmission and EMI



$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda)$$

EM interactions and Sea ice





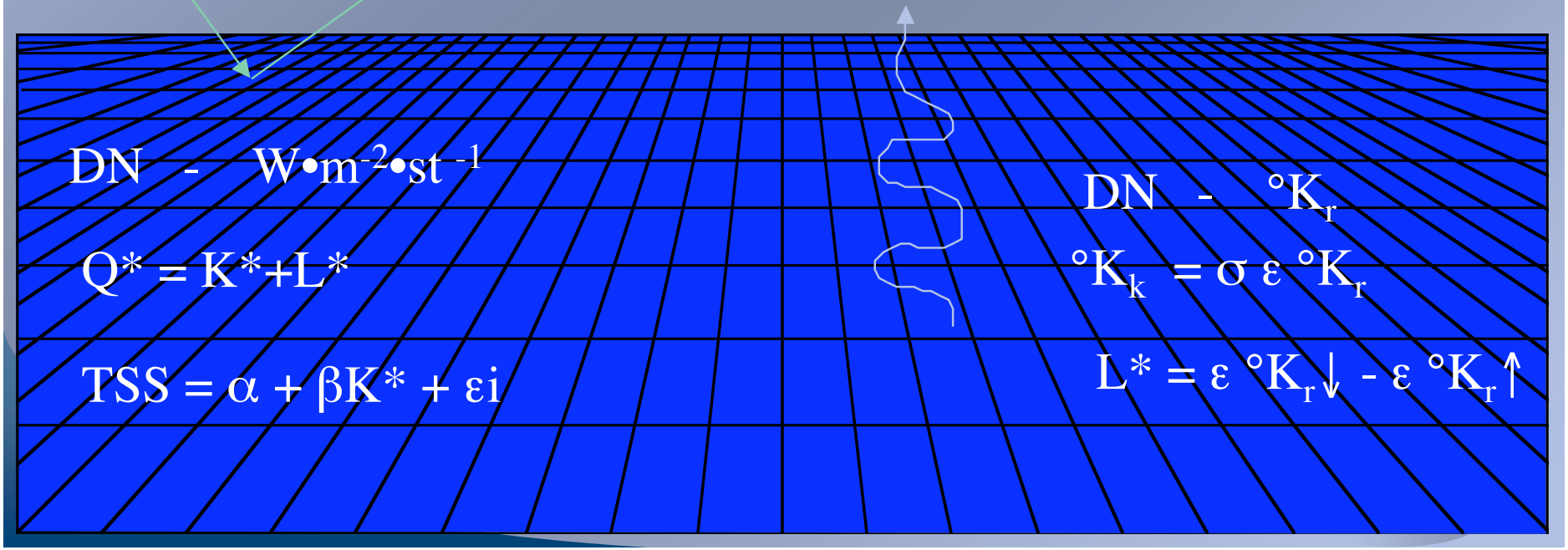
Eo	Irradiance at the T.O.A.
L_P	Average Path Radiance at the T.O.A.
E_D	Average Path Irradiance at the pixel
T	Transmission path length
θ	Incidence angle of irradiance
ϕ	Reflection angle of radiance

$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda)$$

RS measures the $E_R(\lambda)$

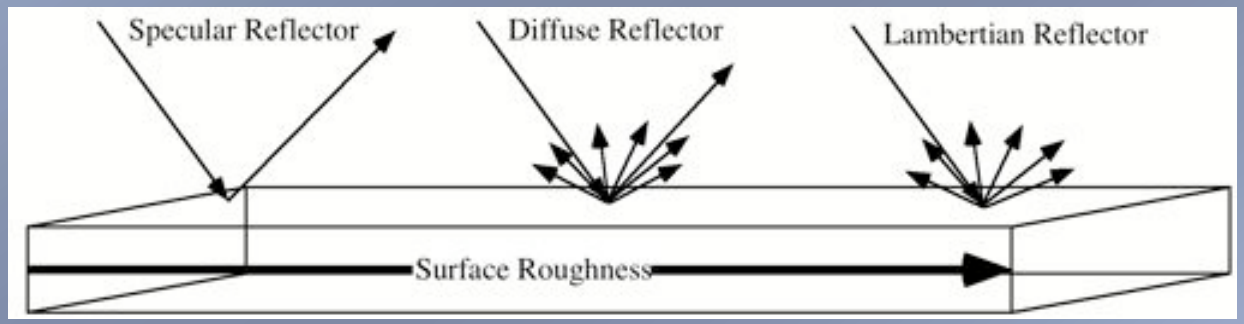
Extraction of Information

- Geophysical Inversion



Data Characteristics

- Surface Scattering



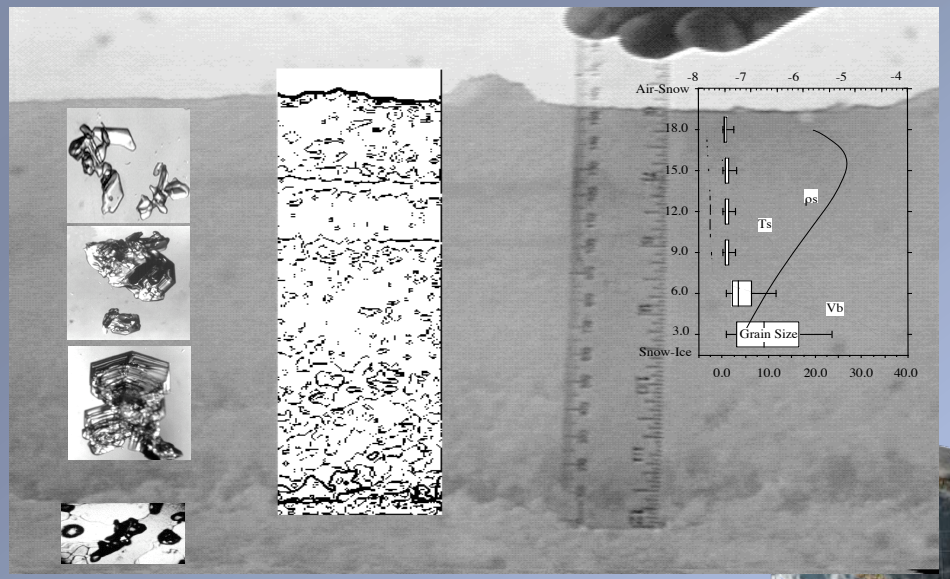
$$\sigma < \frac{\lambda}{32\cos\theta}$$

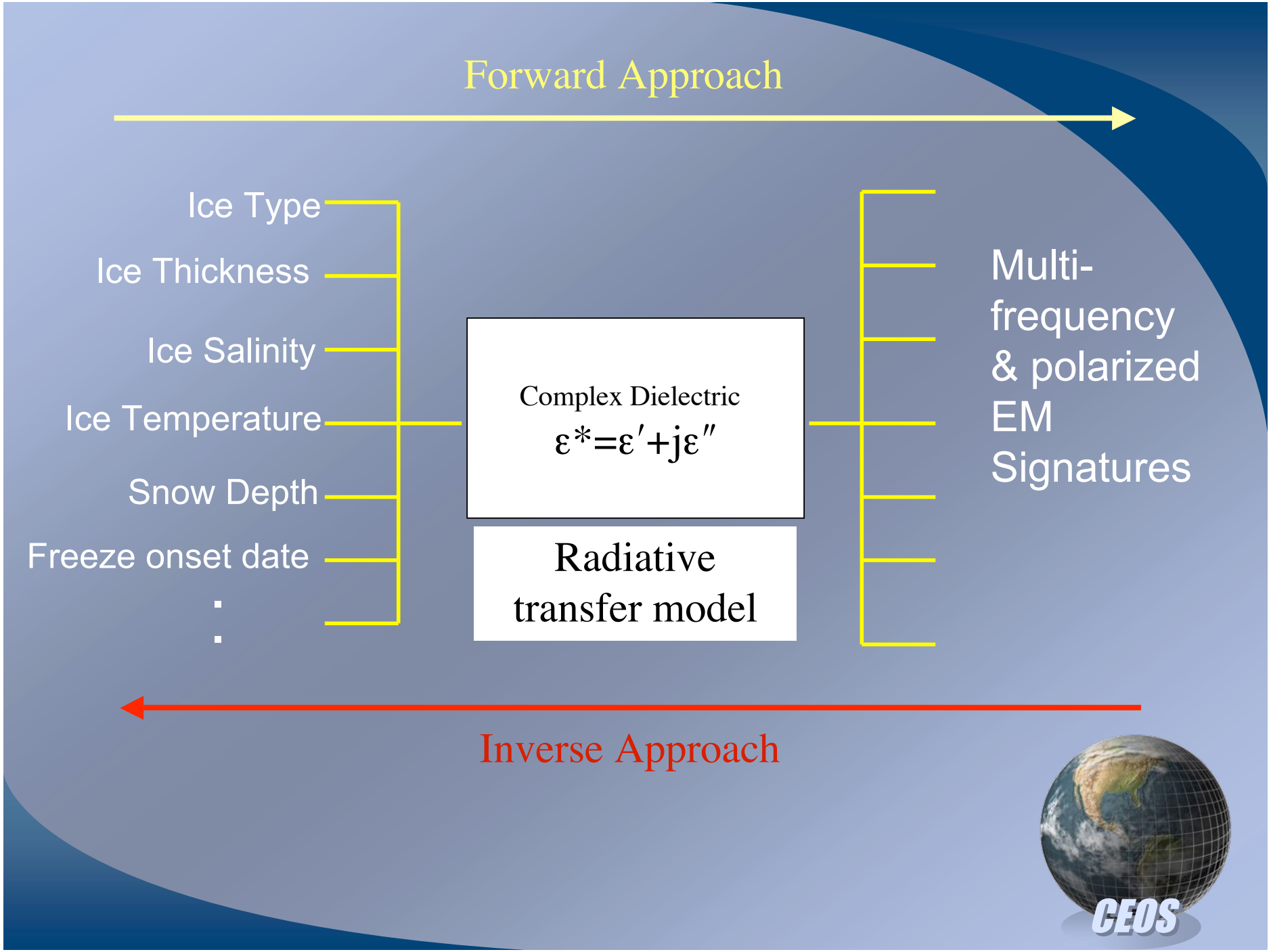
RMS height
Correlation length

Data Characteristics

- Volume Scattering

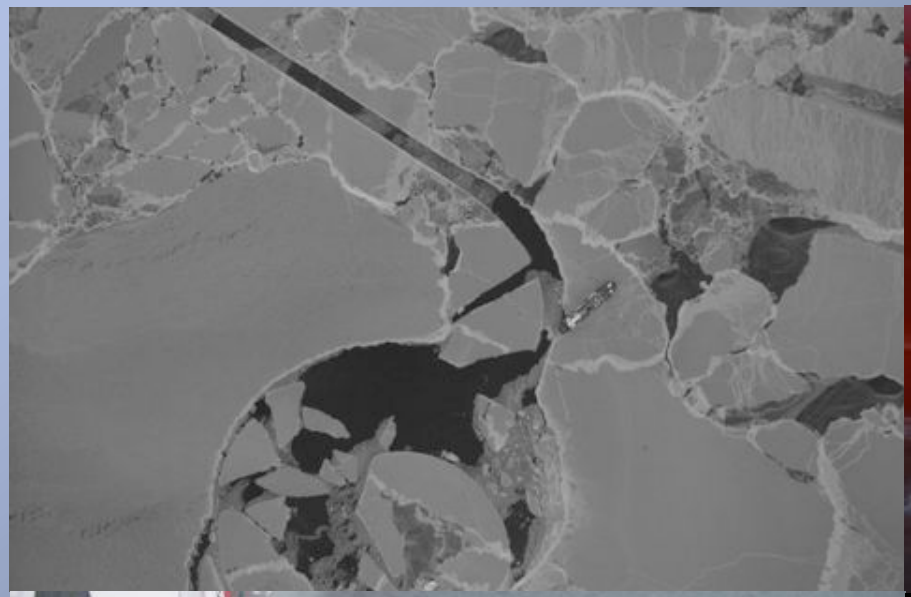
Number density
Volume fraction
Scattering physics




Forward Approach
Ice Type
Ice Thickness
Ice Salinity
Ice Temperature
Snow Depth
Freeze onset date
Complex Dielectric
ε*=ε′+jε″
Radiative transfer model
Multi-frequency & polarized EM Signatures
Inverse Approach
CEOS

Applications

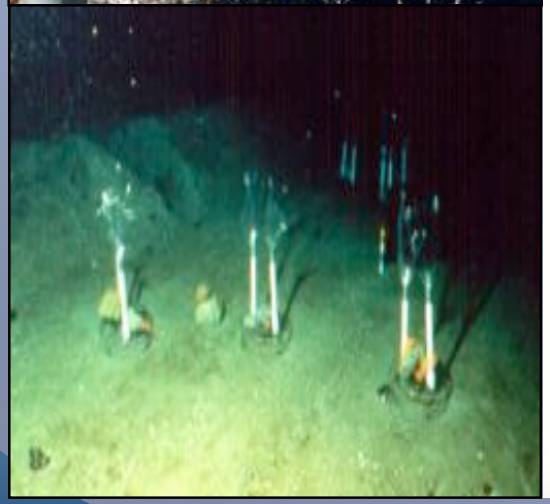
Snow/Sea Ice Geophysics



Ocean/Atmosphere

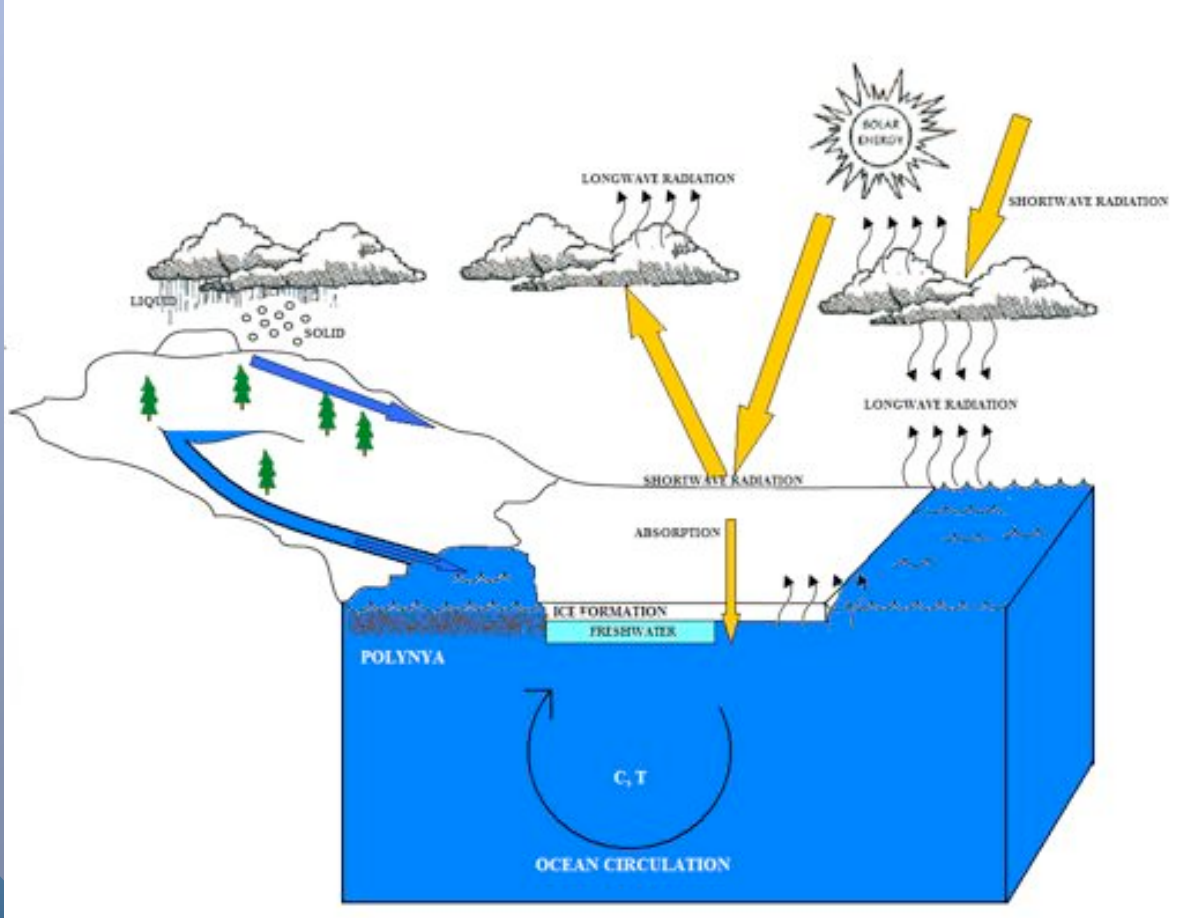
CEOS

Biology



CEOS

Process Studies



Processes of Interest

Energy cycle
Water cycle
Freshwater-marine coupling

Combine *in situ*, RS data and modelling

CEOS

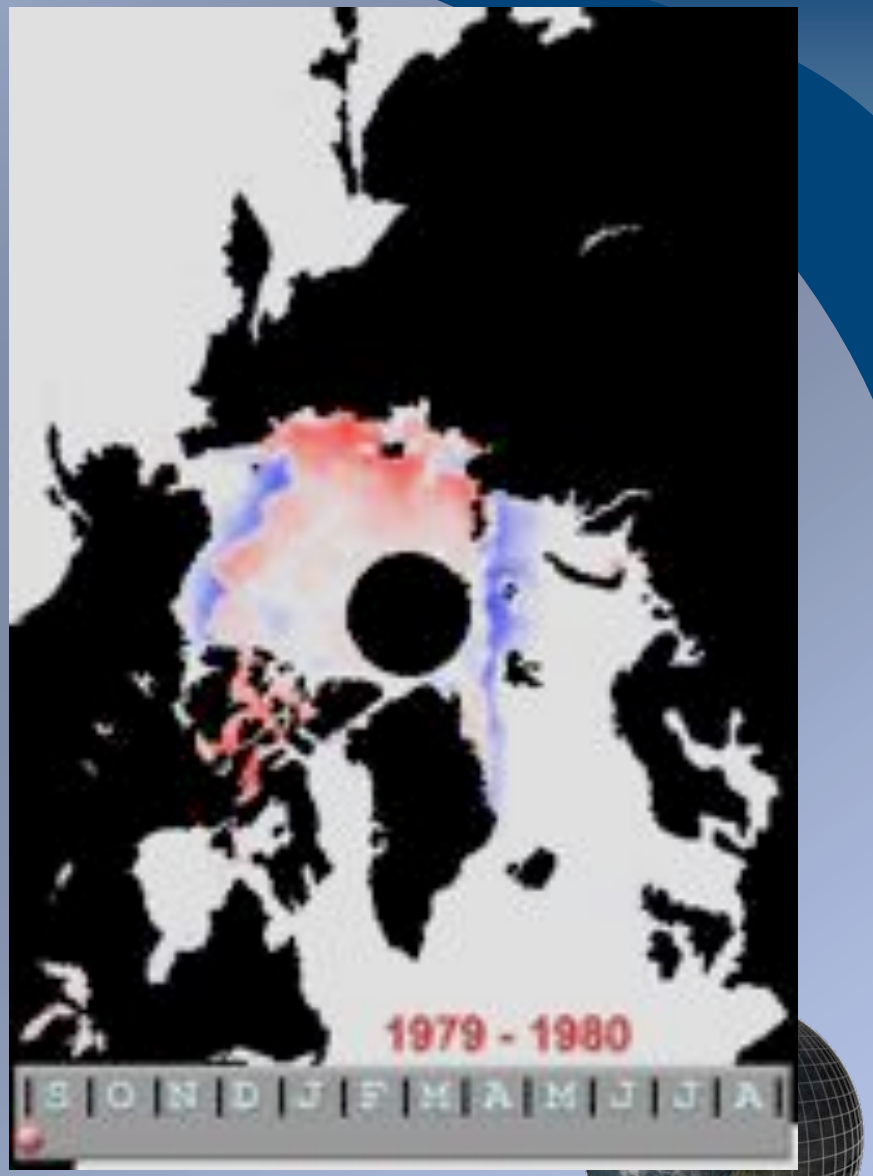
Sea ice concentration anomalies (1978-2006)

$$Wkij - \sum \frac{Wkij}{n}$$

Deviation

-100 % 0% +100%

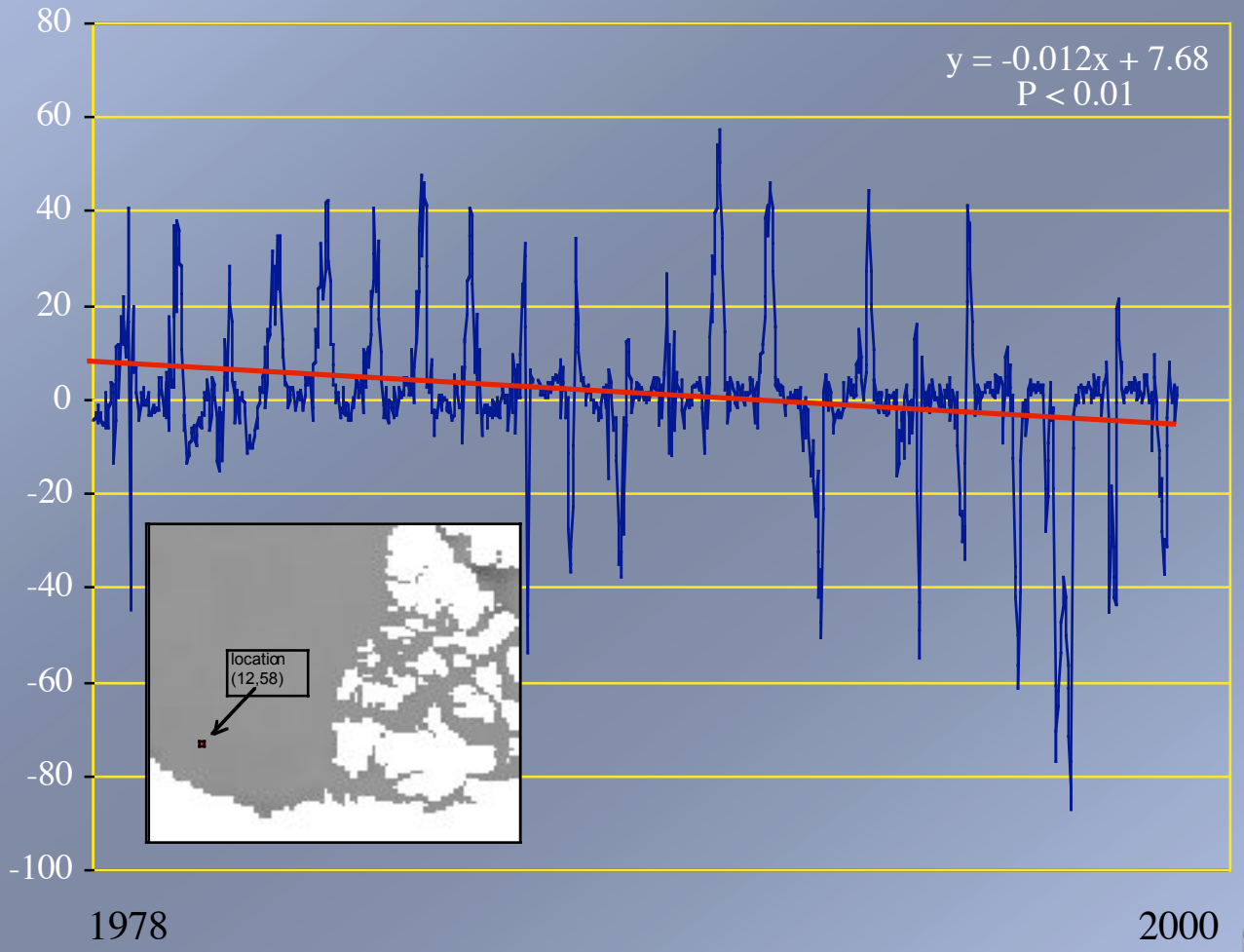
What drives the coherence?



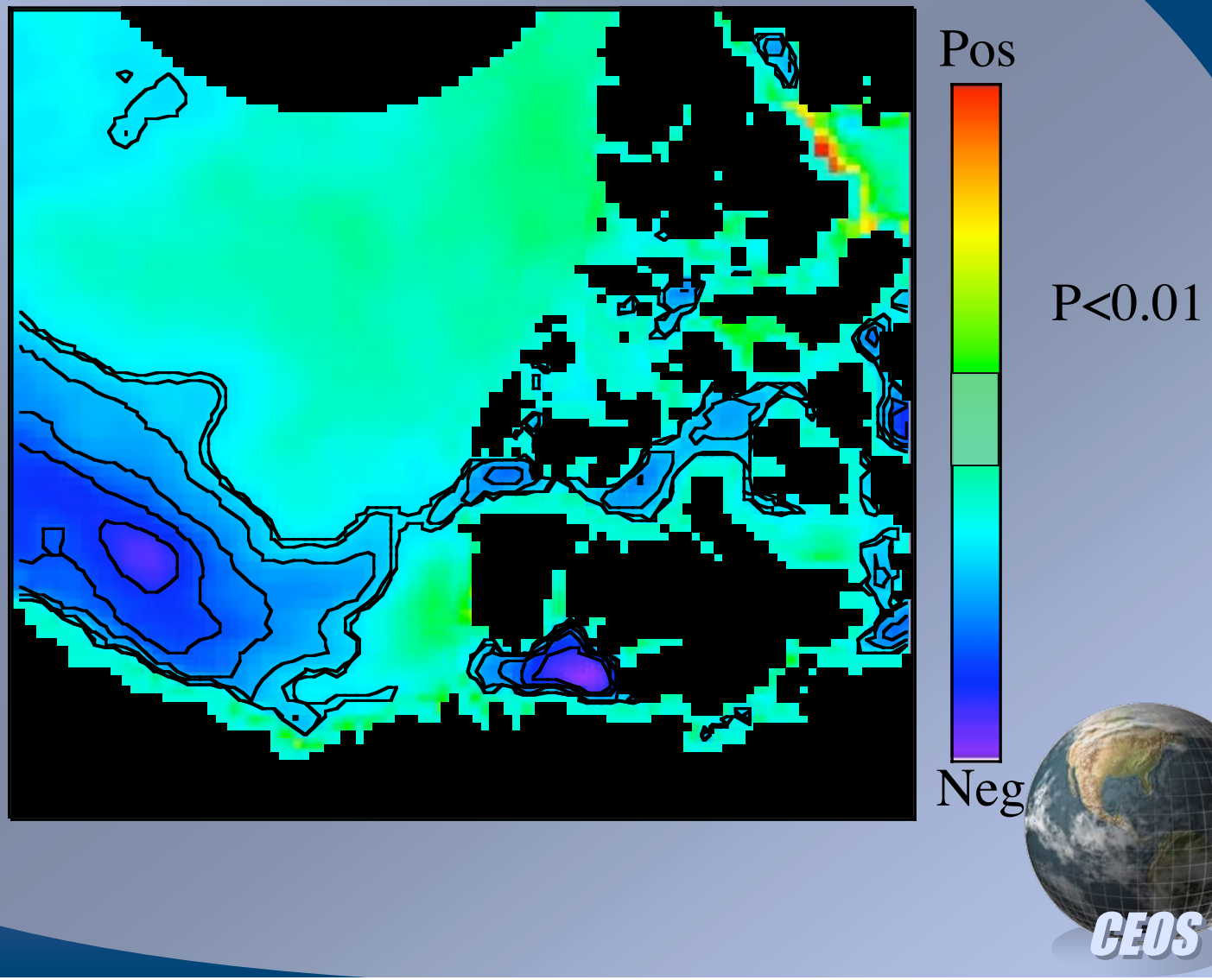
1979-2001 weekly animation at www.umanitoba.ca/ceos

CEOS

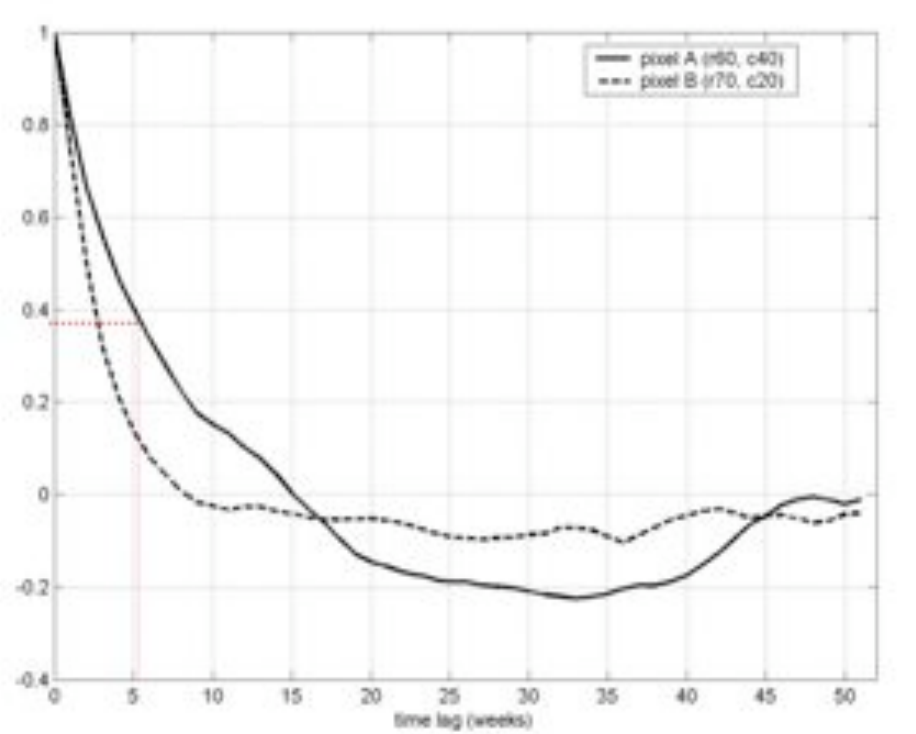
Periodicities and trends in the Anomalies?



Slopes in ∂ ij (1978-2001)



Temporal autocorrelation functions and e-folding times



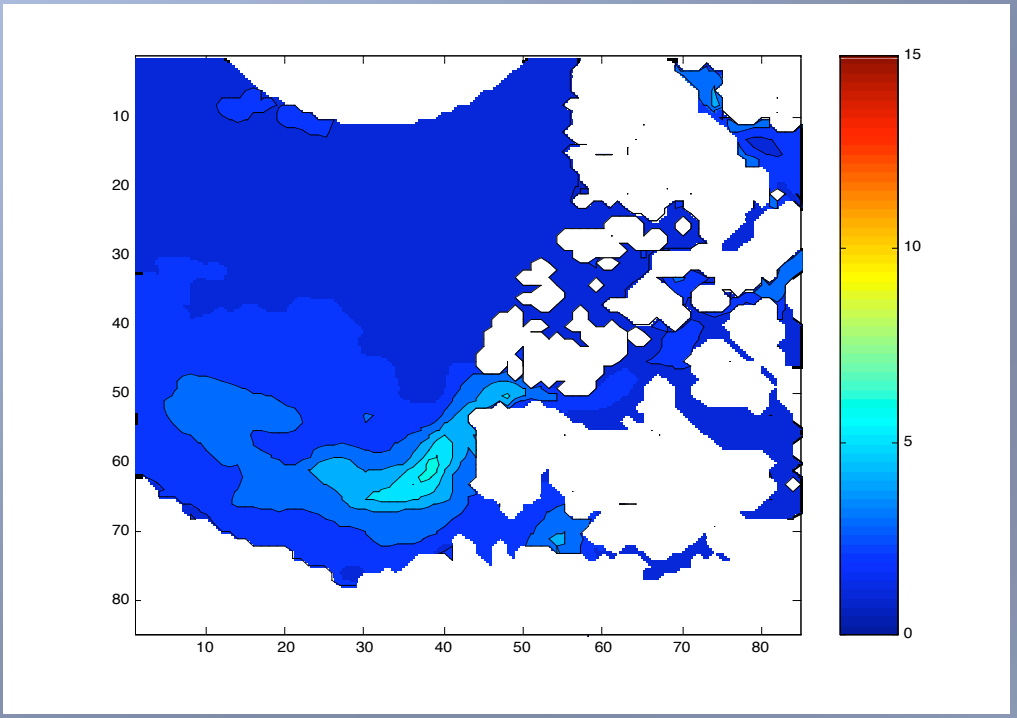
$$R(\tau) = \frac{\langle (\phi(\tau) - \langle\phi\rangle)(\phi(t+\tau) - \langle\phi\rangle) \rangle}{(\phi(t) - \langle\phi\rangle)^2}$$

e-folding times ($R(\tau)=1/e$)

- Autocorrelation functions vary as a function of ice dynamics and thermodynamics
- e-folding times provide a statistical measure of persistence
- e-folding time spatial distribution (efsd) shows pattern?

Lukovich and Barber, GRL 2005

Temporal autocorrelation functions and e-folding times



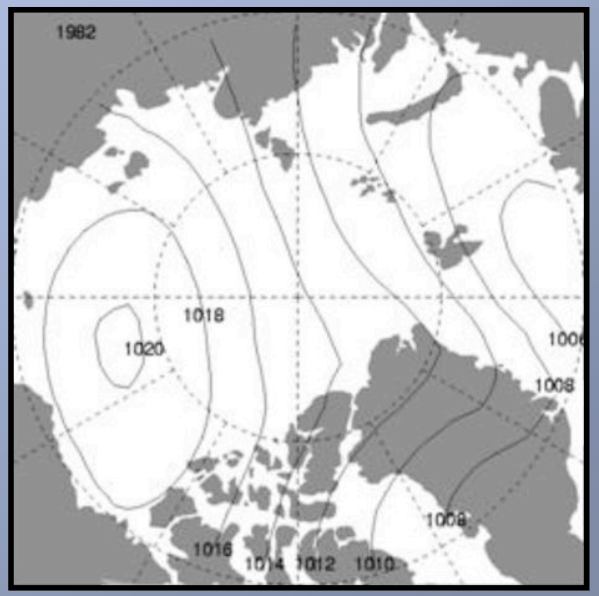
- Distinct coherent pattern exists
- Occurs in all years with stronger patterns in some than others
- Avg over 22 years presented

$$R(\tau) = \frac{\langle (\phi(\tau) - \langle\phi\rangle)(\phi(t+\tau) - \langle\phi\rangle) \rangle}{(\phi(t) - \langle\phi\rangle)^2}$$

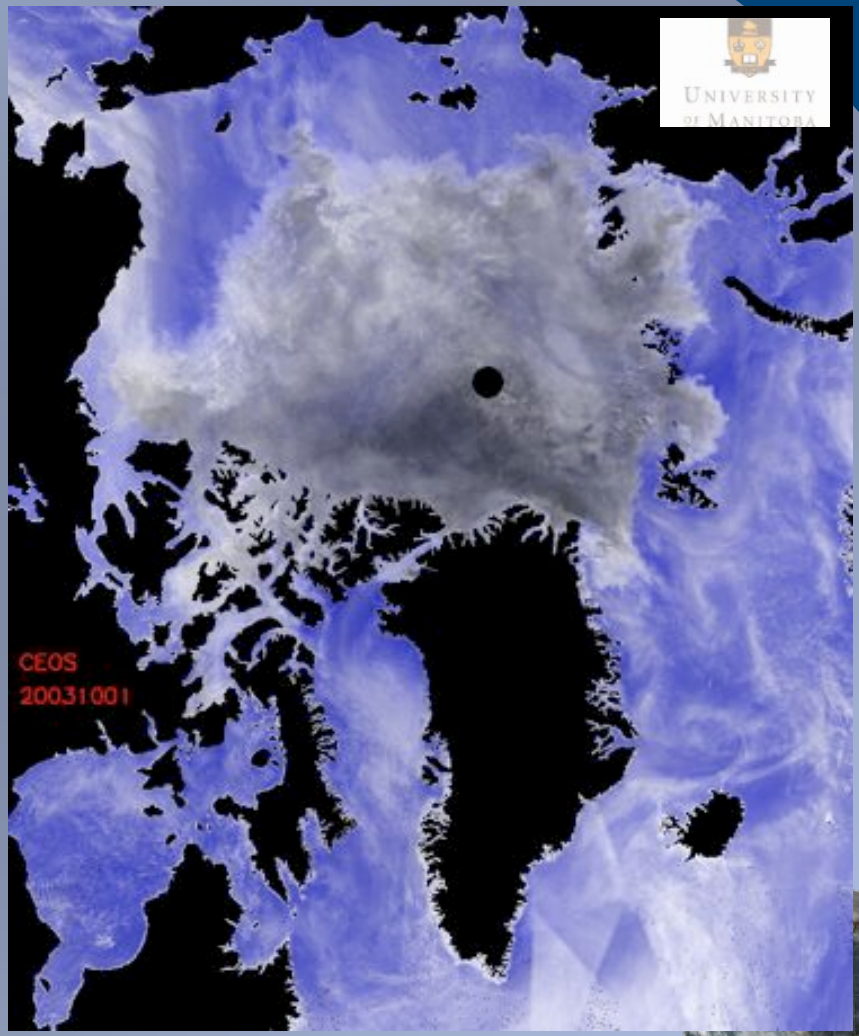
e-folding times ($R(\tau)=1/e$)

Lukovich and Barber, GRL 2005

The Beaufort Gyre and Transpolar Drift (dynamic)

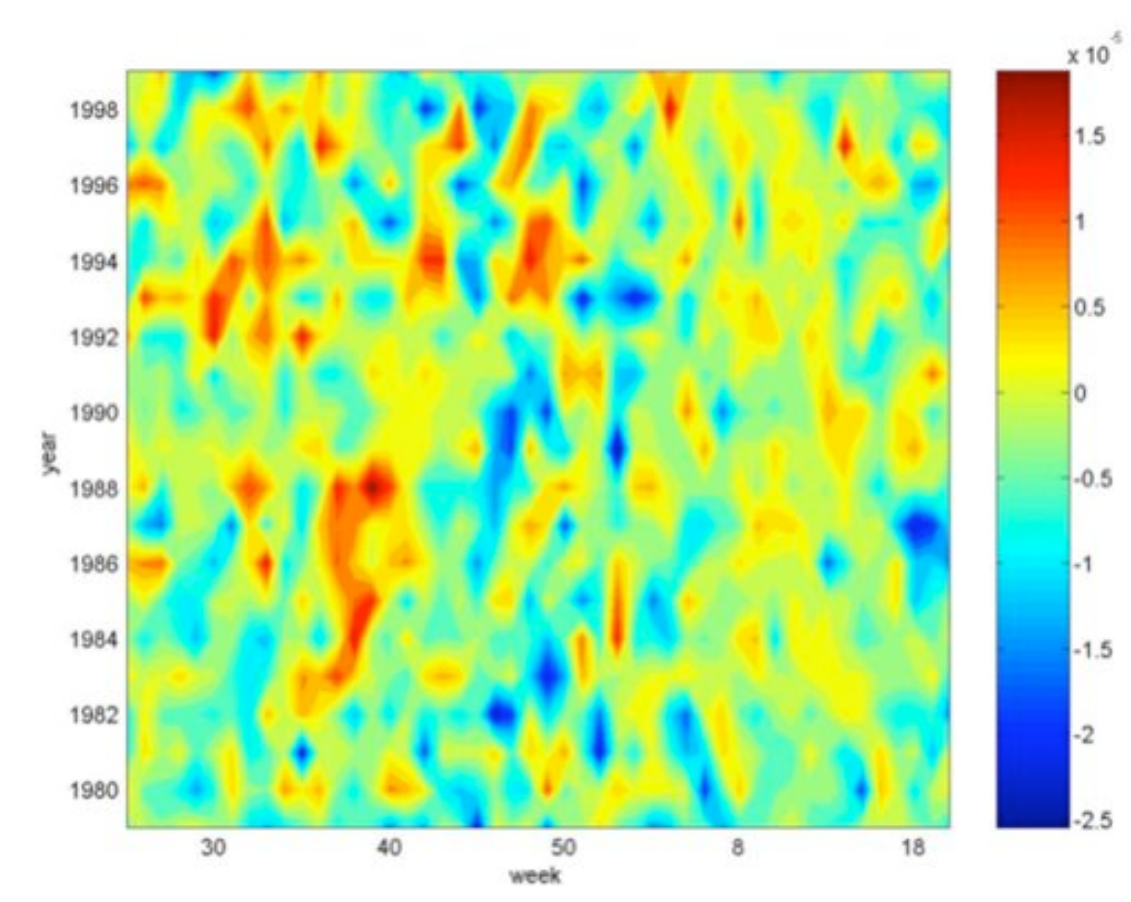


Average SLP



CEOS

The Beaufort Gyre and Transpolar Drift (dynamic)



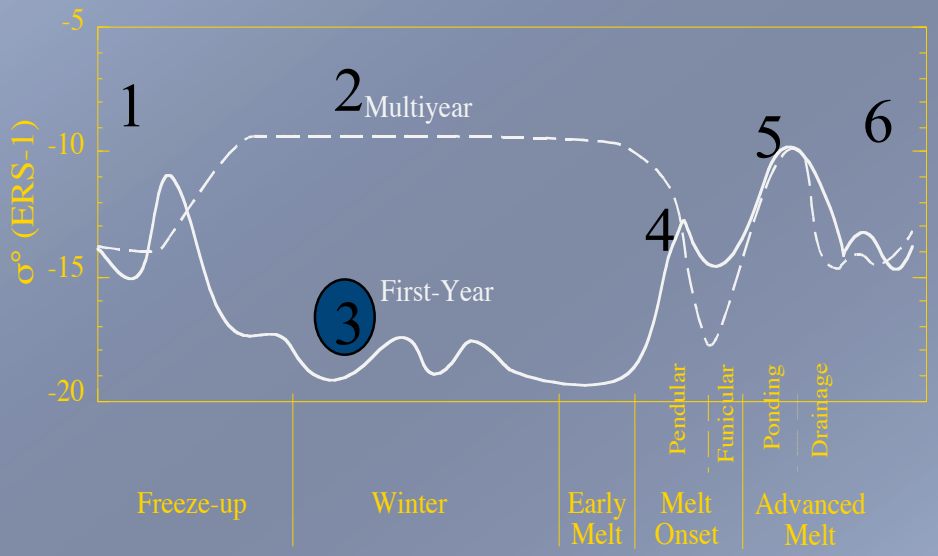
Mean relative vorticity

-Red (Blue) shades denote cyclonic (anticyclonic) activity

Reversal of the Beaufort Gyre

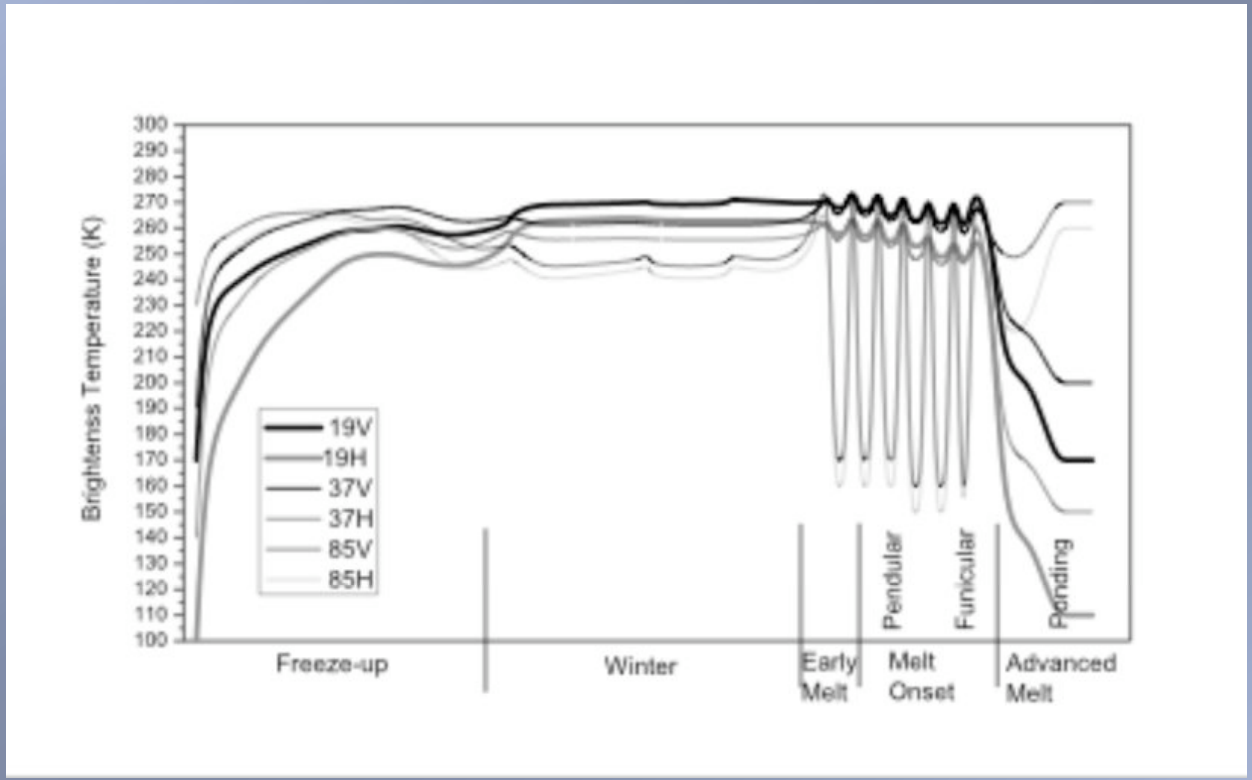
Lukovich and Barber, 2005

Temporal Evolution in σ°



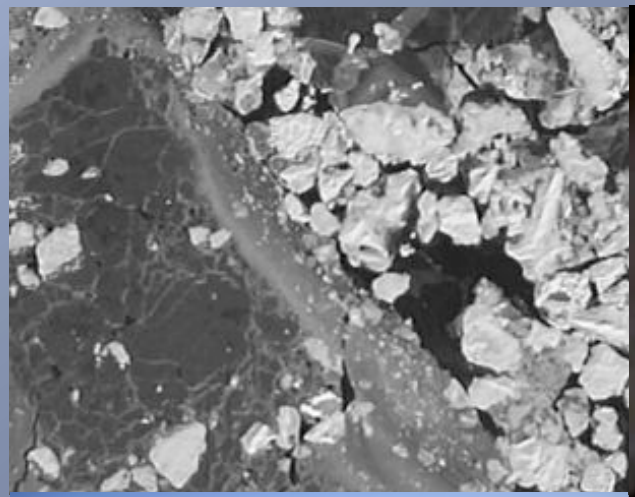
Phenomenological summary of the seasonal evolution of σ° for thick first year and multi-year sea ice from ERS data.

The Temporal Evolution of T_b



Evaluation of SAR sea ice concentration, type, thermodynamic State

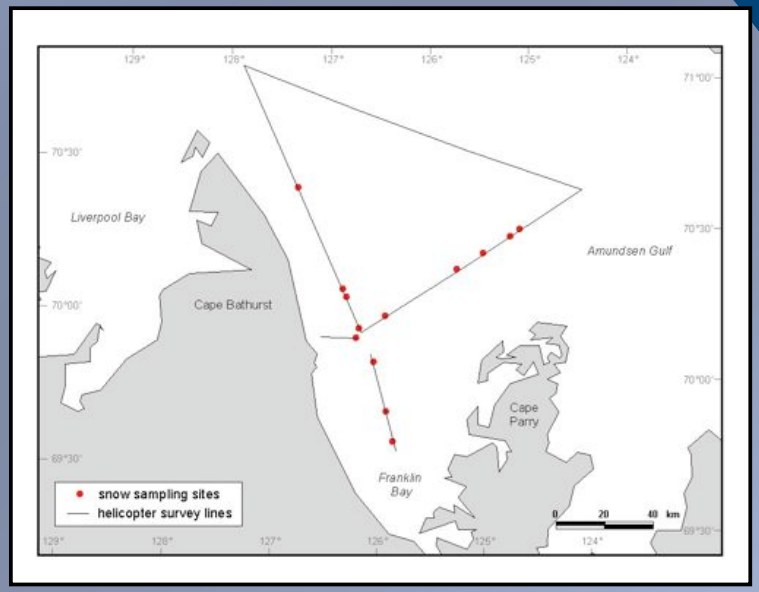
- MYI
- FYI
- Rubble
- Pond fraction
- Time series
- (type)
- SWE



CEOS

Linking snow distribution and ice roughness over first-year sea ice

- Objectives:
  - (i) characterizing and statistically modeling the relationship between ice roughness and snow distribution and
  - (ii) using this relationship to recreate the snow distribution using a snow distribution model and ice roughness information.
- Methods: helicopter EM (Ice Pic) and in situ snow sampling



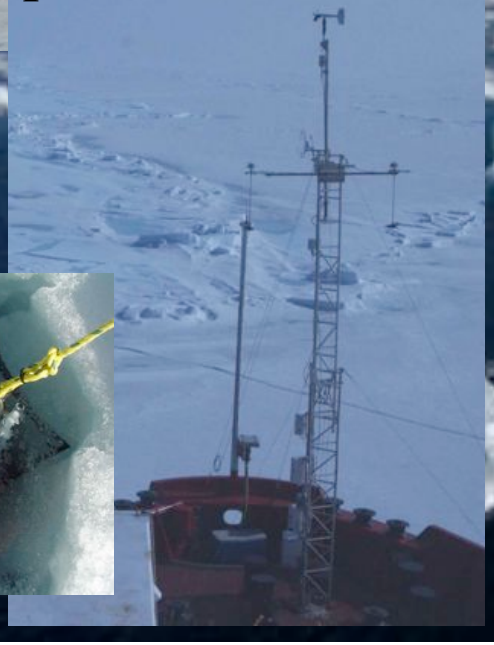
CEOS

Radiative Transfer Studies

Optical measurements

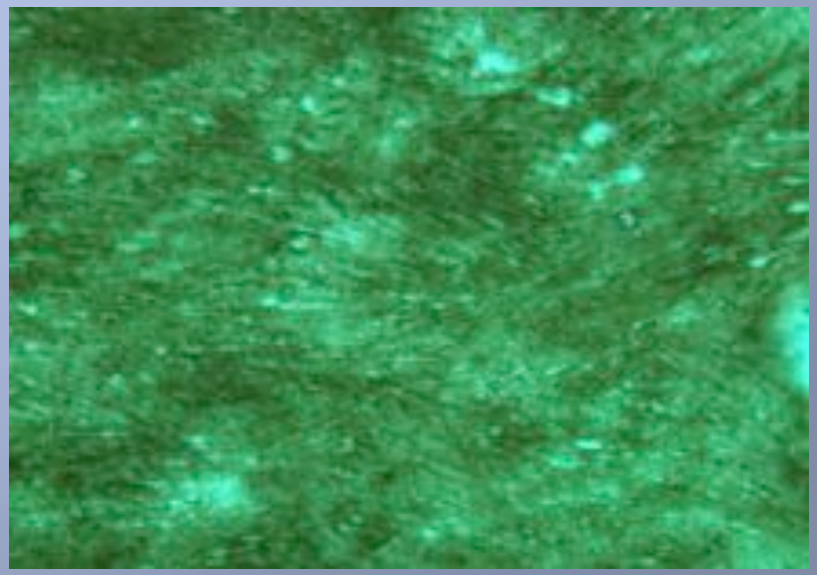
Ice sampling

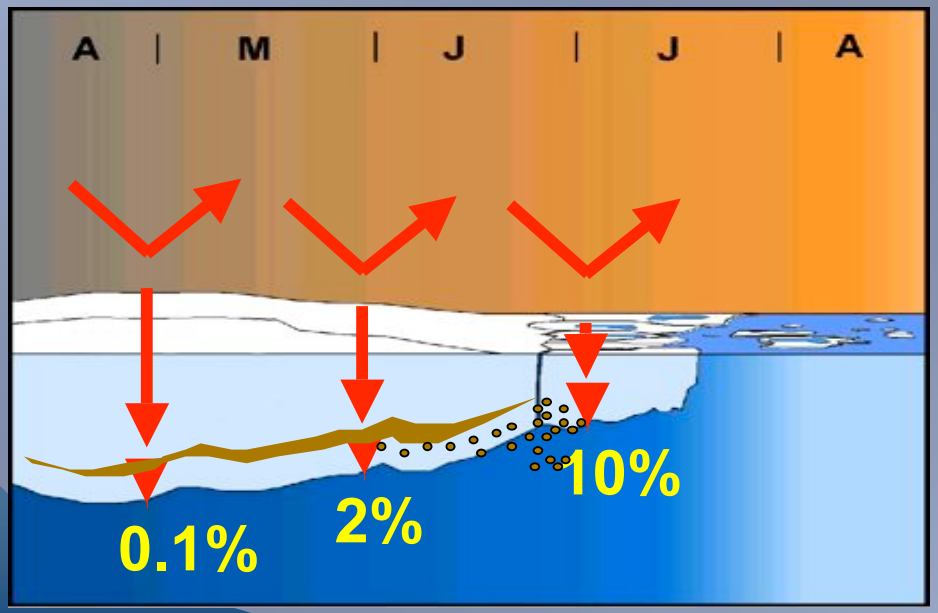
Monitoring met. parameters

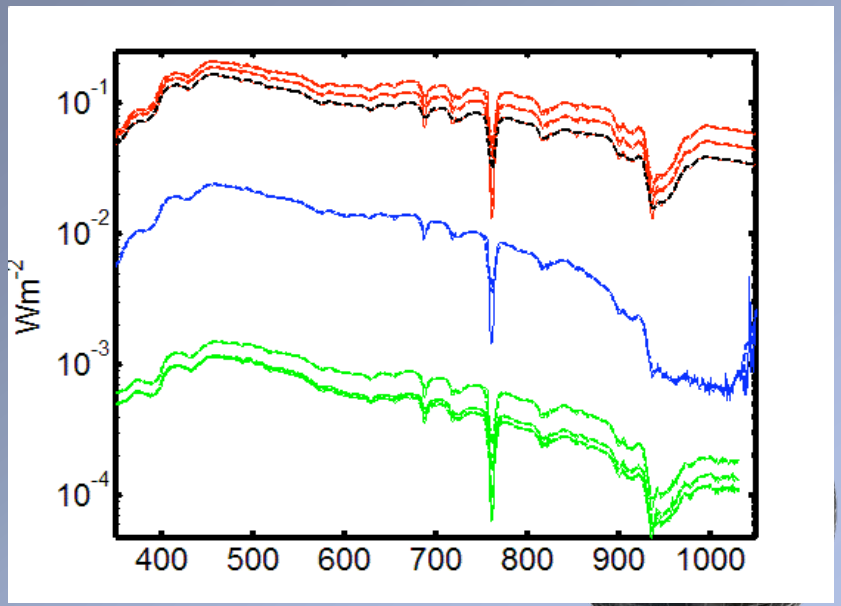


Passive and active microwave measurements

CTD casts





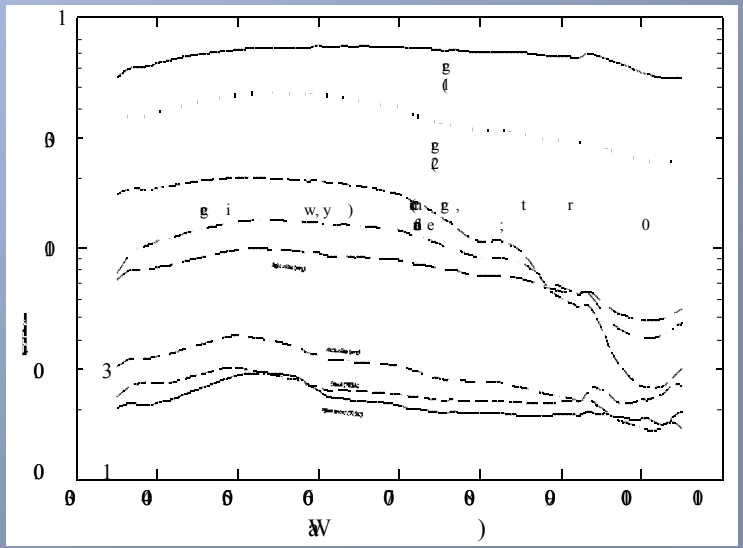


Ehn et al. 2006

CEOS

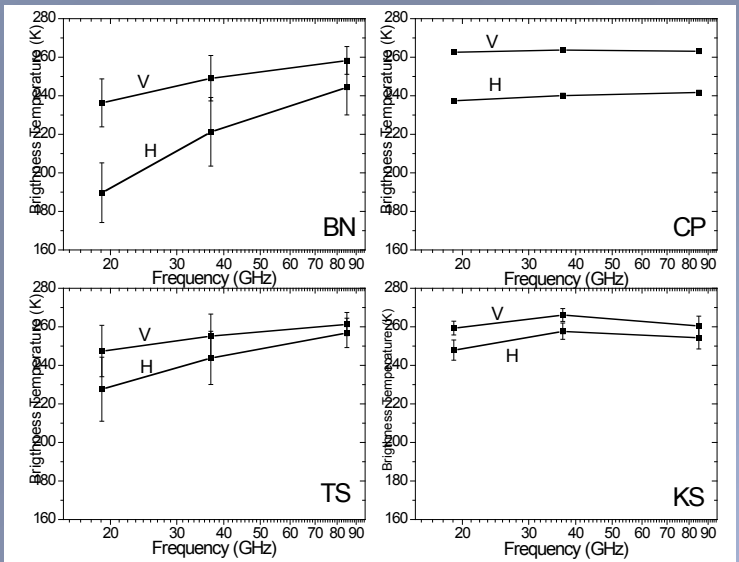
Spectral reflectance and brightness temperature (*In situ* measurements)

Spectral reflectance



**Ice and snow thickness is shown in the parenthesis with station name. The 'avg' refer to an average albedo of all observed spectra of the specific ice type*

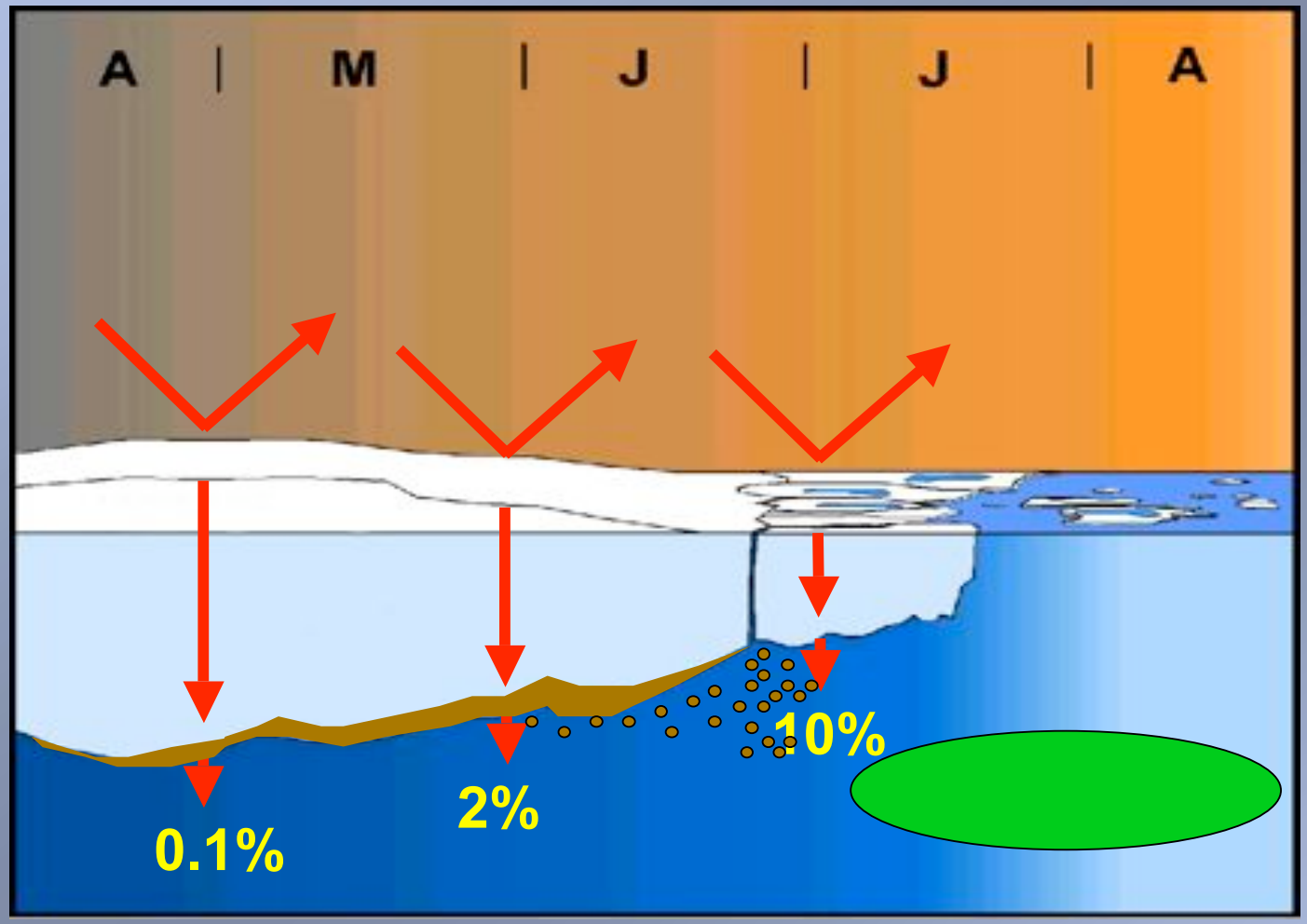
Spectral brightness temperature



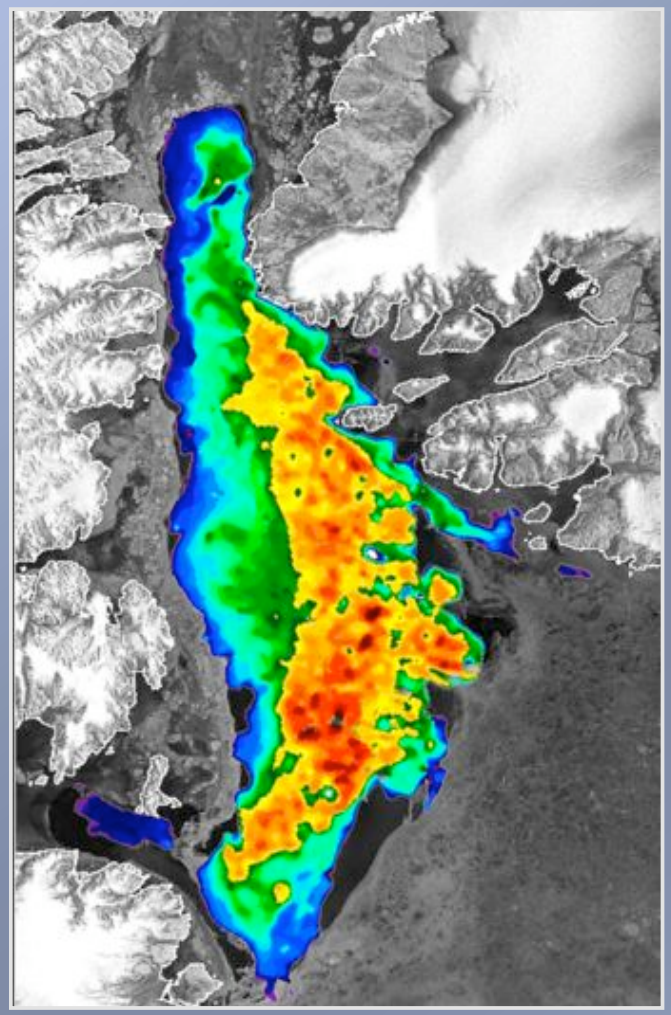
**BN, CP, TS and KS denotes bare ice, consolidated pancake ice, thin snow-covered, and thick snow-covered ice, respectively. 'V' are for vertical and 'H' for horizontal polarization.*

Ehn et al. 2006
Hwang et al. 2006

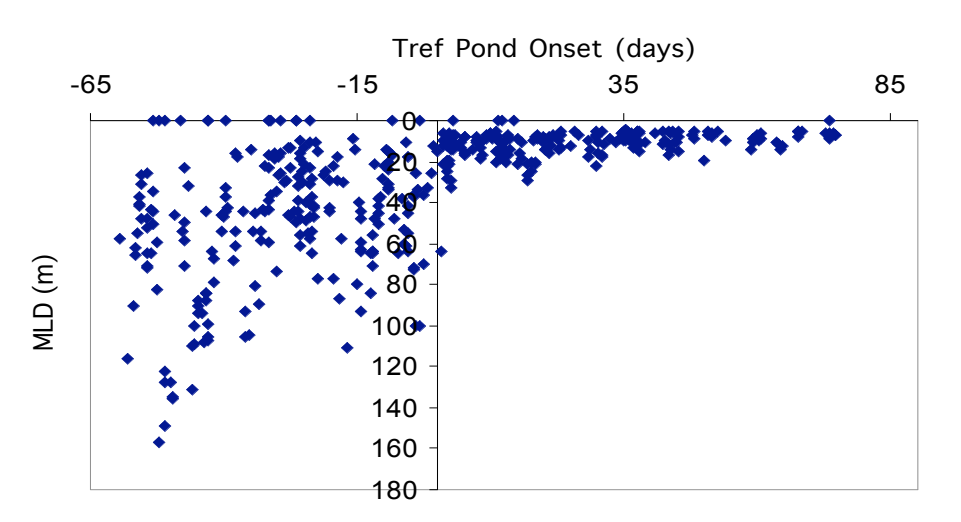
PAR transmission



Phytoplankton and sea ice



Radarsat derived pond onset
CTD computed mixed layer depths



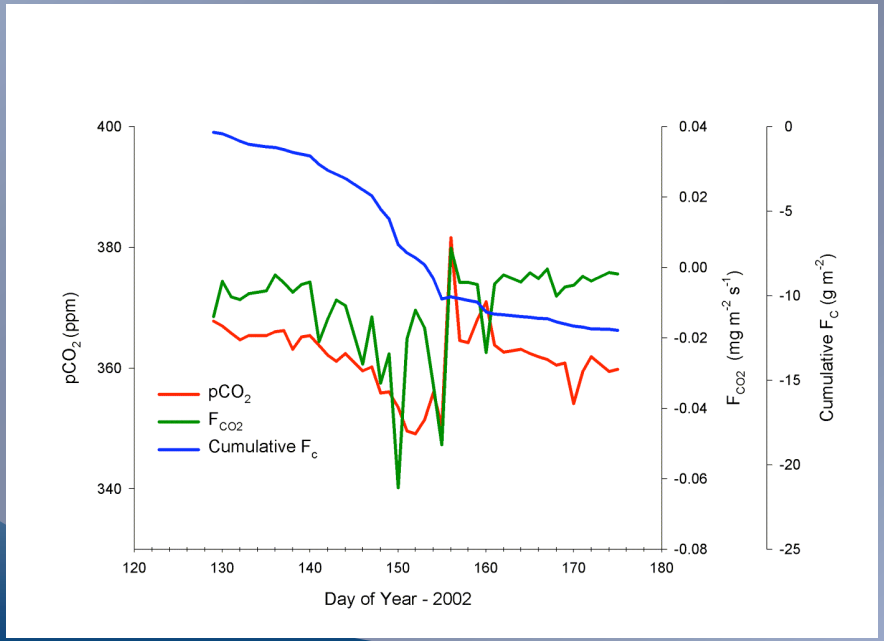
Ocean Colour

SeaWifs

Galley and Barber, 2004

CEOS

Gas permeability



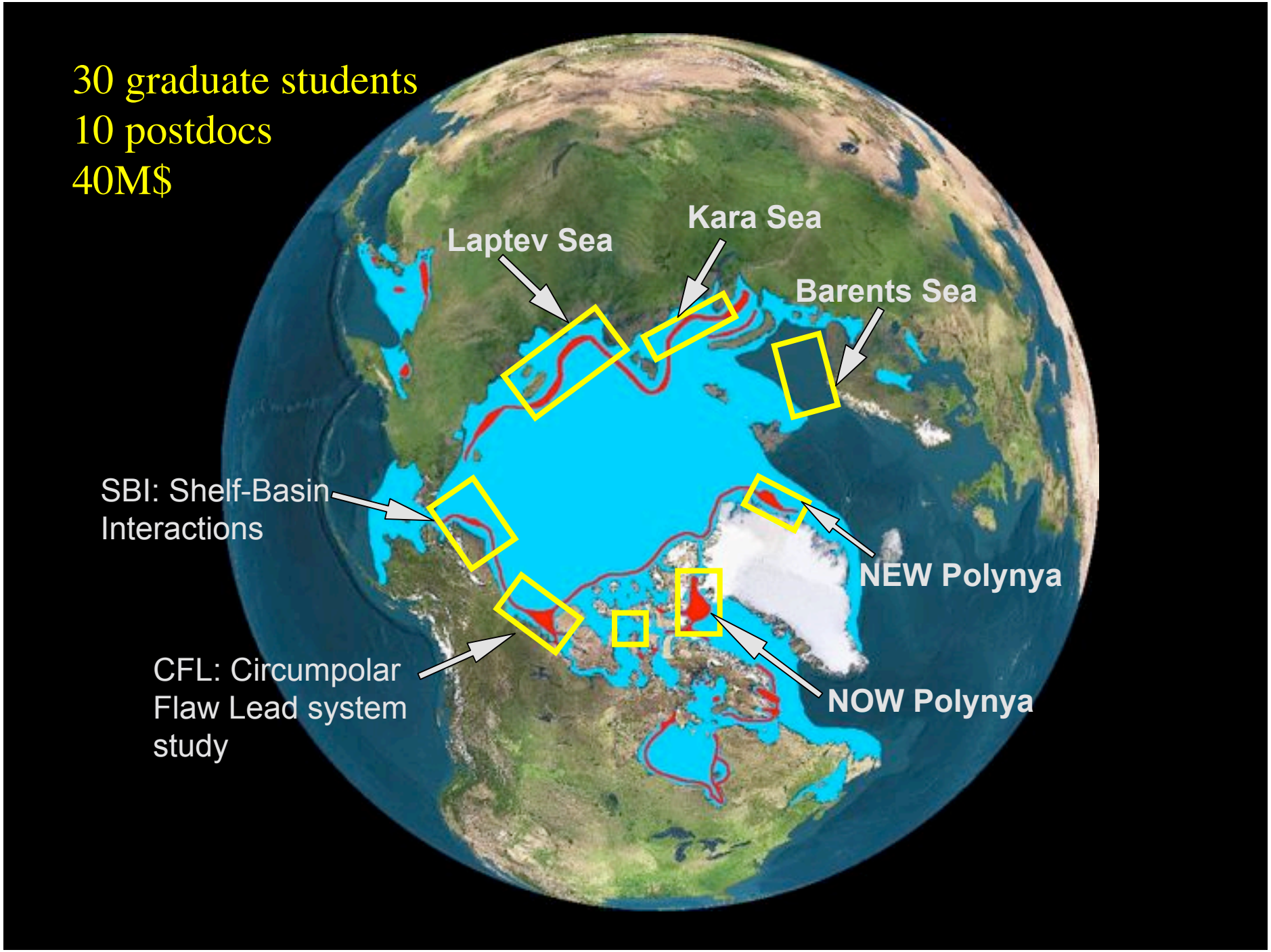
- Evidence of strong air-surface exchange of CO2.
- Flux is associated with brine chemistry thus link to dielectrics
- How is the carbon used in the cryosphere/biosphere?
- Flux is about the same magnitude as a wetland!

Papakyriakou, 2004

The International Polar Year

CEOS

30 graduate students
10 postdocs
40M$



Conclusions

- First and strongest impacts of global scale climate change are being felt now in the Arctic.
- Remote Sensing is a key observation technique when combined with in situ and modelling approaches
- Measurement vs Modelling

Next Lecture

1) Arctic Climate Change and Remote Sensing

2) Geophysics, dielectrics and thermodynamics

3) Scattering and emission modeling