Sea Ice, Climate Change and Remote Sensing

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www.umanitoba.ca/ceos
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?
Global mean surface temperature anomalies relative to the 1951-1980 climatology (2\(\sigma\) error bars in blue)

Hansen et al. 2006
Global mean surface temperature anomalies relative to the 1951-1980 climatology

Hansen et al. 2006
The Warming Arctic
Growth and Decay of Sea Ice

Rate of Change $\delta\%$ (P<0.01)
Reduction in the sea ice minimum

We are losing 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?

March

G. Flato, CCMA

The Future?

September
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
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)
Cyclone Forcing

Cyclone frequency and trajectory (CASES’04)

What is the effect of wind forcing on the surface?

Fisico and Hanesiak, 2006
Changes in Atlantic water (depth and temperature)

Dmitrenko et al. 2006

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.
Ocean-sea ice-atmosphere coupling at the shelf break

Carmack and Chapman 2003
The ice-albedo feedback mechanism (thermodynamic)

Positive feedback as more ocean absorbs shortwave radiation.

Complications with longwave flux
Physical-Biological Coupling

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

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

RS measures the $E_R(\lambda)$
Extraction of Information

- Geophysical Inversion

\[ Q^* = K^* + L^* \]
\[ TSS = \alpha + \beta K^* + \varepsilon_i \]

\[ \text{DN} = \text{W} \cdot \text{m}^{-2} \cdot \text{st}^{-1} \]

\[ \text{DN} = °K_r \]

\[ °K_k = \sigma \varepsilon °K_r \]

\[ L^* = \varepsilon °K_r \downarrow - \varepsilon °K_r \uparrow \]
Data Characteristics

• Surface Scattering

\[ \sigma < \frac{\lambda}{32 \cos \theta} \]

RMS height
Correlation length
Data Characteristics

- Volume Scattering

Number density
Volume fraction
Scattering physics
Complex Dielectric
\( \varepsilon^* = \varepsilon' + j\varepsilon'' \)

**Radiative transfer model**

**Forward Approach**
- Ice Type
- Ice Thickness
- Ice Salinity
- Ice Temperature
- Snow Depth
- Freeze onset date

**Inverse Approach**

- Multi-frequency & polarized EM Signatures
- Radiative transfer model
Applications
Snow/Sea Ice Geophysics
Ocean/Atmosphere
Biology
Process Studies

Processes of Interest
Energy cycle
Water cycle
Freshwater-marine coupling

Combine *in situ*, RS data and modelling
Sea ice concentration anomalies (1978-2006)

$$W_{kij} - \sum \frac{W_{kij}}{n}$$

Deviation

-100 %  0%  +100%

What drives the coherence?

1979-2001 weekly animation at www.umanitoba.ca/ceos
Periodicities and trends in the Anomalies?

$y = -0.012x + 7.68$

$P < 0.01$

1978 2000
Slopes in $\partial_{ij}$ (1978-2001)

Pos

Neg

P<0.01
Temporal autocorrelation functions and e-folding times

\[ R(\tau) = \langle (\phi(t) - \langle \phi \rangle)(\phi(t + \tau) - \langle \phi \rangle) \rangle \]

\[ (\phi(t) - \langle \phi \rangle)^2 \]

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

\[ R(\tau) = \langle (\phi(t) - \langle \phi \rangle)(\phi(t + \tau) - \langle \phi \rangle) \rangle \]

\[ (\phi(t) - \langle \phi \rangle)^2 \]

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

Lukovich and Barber, GRL 2005
The Beaufort Gyre and Transpolar Drift (dynamic)

Average SLP
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 $\sigma^\circ$

Phenomenological summary of the seasonal evolution of $\sigma^\circ$ 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
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
Ice sampling
Monitoring met. parameters
Optical measurements
Passive and active microwave measurements
Radiative Transfer Studies
CTD casts
Ehn et al. 2006
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
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

Gas permeability
The International Polar Year
SBI: Shelf-Basin Interactions
CFL: Circumpolar Flaw Lead system study

Laptev Sea
Kara Sea
Barents Sea
NEW Polynya
NOW Polynya

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

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