Changes, variability, and seasonality of sea ice energy budgets
Sunlight and Transmittance

- Sunlight (shortwave)
- Reflection
- Absorption
- Internal melting
- Transmission
- Turbulent fluxes
- Longwave incoming
- Longwave outgoing
- Surface melting
- Lateral melting
- Bottom melting & freezing
- Ocean heat flux
Snow Rules

- Physical properties
  - Thermal
  - Optical
- Surface characteristics
  - Melt ponds
  - Satellite signatures
- Mass balance
  - Snow depth
  - Snow density / mass
- Fresh water
Changes: The Ice Age Proxy

- Surface properties
- Physical properties: Drift and Dynamics
- Thickness distributions
- Habitat changes
Albedo Changes

- Decrease in surface albedo
- Increase of solar heat input (1-2 %/year)

=> Develop maps and trends for in- and under-ice fluxes

Fig. 2. The trend in total annual solar heat input to the ice within a gridcell, \( Q_t \). The units are \( \% \text{a}^{-1} \).

Perovich et al. (2011, AOG)
Seasonality

- Results from the drift of Tara
- At one drifting MYI site
- Great time series, no spatial variability

Nicolaus et al. (2010, JGR and CRST)
Seasonality at Tara

Nicolaus et al. (2010, JGR and CRST)
Under-Ice Investigations
View from Below: Level Ice
View from Below: Ridged Ice
Transmittance through Sea Ice

- 40% ponds on FYI: 11%
- 23% ponds on MYI: 4%

Nicolaus et al. (2012 & 2013, GRL)
Observed Changes in Summer

Transmission: + 200%
Albedo: - 50%
Absorption + 50%

Nicolaus et al. (2012 & 2013, GRL)
August 2011 – Upscaling

Nicolaus et al. (2012 & 2013, GRL)
August 2011 – Fluxes into the ocean

Sea ice only

Ice + Ocean

Nicolaus et al. (2012 & 2013, GRL)
Seasonality of Transmittance

New up-scaling method for calculation of under-ice radiation

Parameterization

Total transmittance of pond covered sea ice.

Arndt & Nicolaus (2014, TCD)
Seasonality of Transmitted Fluxes

- Add parameterization of transmittance for the entire year 2011

- **Surface flux** is same order of magnitude as ocean heat flux
- **96%** of the annual under-ice radiation are transmitted in only 4 months (May to August)
- Highest fluxes (= melt rate) in **June**

*Monthly mean of transmitted heat fluxes through Arctic sea ice in 2011.*

Arndt & Nicolaus (2014, TCD)

Monthly mean of $20 \times 10^5$ Jm$^{-2}$

$\cong 20$ cm sea-ice melt/month
Annual Trend (Sea Ice Only)

- Apply to all years 1979-2011

- Light transmission increases by 1.5% per year Arctic-wide since 1979
- Over 32 years: 1.6 times more warming and melt

Trend in annual total solar heat input through Arctic sea ice from 1979 to 2011.

Arndt & Nicolaus (2014, TCD)
Recent AUV mission

Photo: Christian Katlein
Optical Properties - Scattering

Irradiance
(180°)

Radiance
(7°)

Katlein et al. (2014, JGR)
Irradiance / Radiance

- Isotropy $C = \pi = 3.14$
- Mostly used, but overestimation of irradiance by >50%

- Anisotropy $C < 2.5$
- More realistic fluxes

Katlein et al. (2014, JGR)
Irradiance / Radiance

- Isotropy $C = \pi = 3.14$
  - Mostly used, but overestimation of irradiance by $>50$

- Anisotropy $C < 2.5$
  - More realistic fluxes

$C = \pi$

Katlein et al. (2014, JGR)
Parameterization of $C=\text{Irrad}/\text{Rad}$

- Best fit of anisotropy

$$C(\gamma)=2.5-2\gamma$$

- Error < 5%
- For isotropic case $C=2.5$
  - Boundary effect

- **Correct conversion** of radiance to irradiance is possible: anisotropy needed

Katlein et al. (2014, JGR)
Spectral Radiation Buoy

- Fully autonomous measurements

Wang et al. (2014, JGR)
Spectral Radiation Buoy

Wang et al. (2014, JGR)
Bio-Physical Observatory (drifting)

- Instrumentation
  - 1 Thermistor Buoy
  - 2 Spectral Radiation Buoy
  - 3-5 Data Transmission
  - 6 CTD
  - 7 ADCP
- Deployment 2014/15

Figure: H. Flores
Autonomous Stations (Buoys)

Sea-Ice Thickness

Snow Depth

Energy budgets
Summary

• Snow rules and we need better snow data sets

• Seasonality of light transmission
  • Highest fluxes in June
  • 96% in 4 summer months only (May-Aug)

• Trends in light transmission
  • Increase of 1.5% / year
  • Strongly related to the loss of multi-year sea ice

• Optical properties of sea ice
  • Scattering is anisotropic
  • Conversion of radiance to irradiance is possible (use C<2.5)

• Future directions
  • Similar studies for Antarctic sea ice
  • Towards AUV measurements
  • More connection to biological studies (primary production)
  • Applications in GCMs