海洋生態系モデリング研究集会＠東大大気海洋研

Mar. 5, 2015

Arctic sea ice algae modeling

~ collaborating work with sediment trap observation ~

北極海アイスアルジーモデリング
～セディメントトラップ観測との融合研究～

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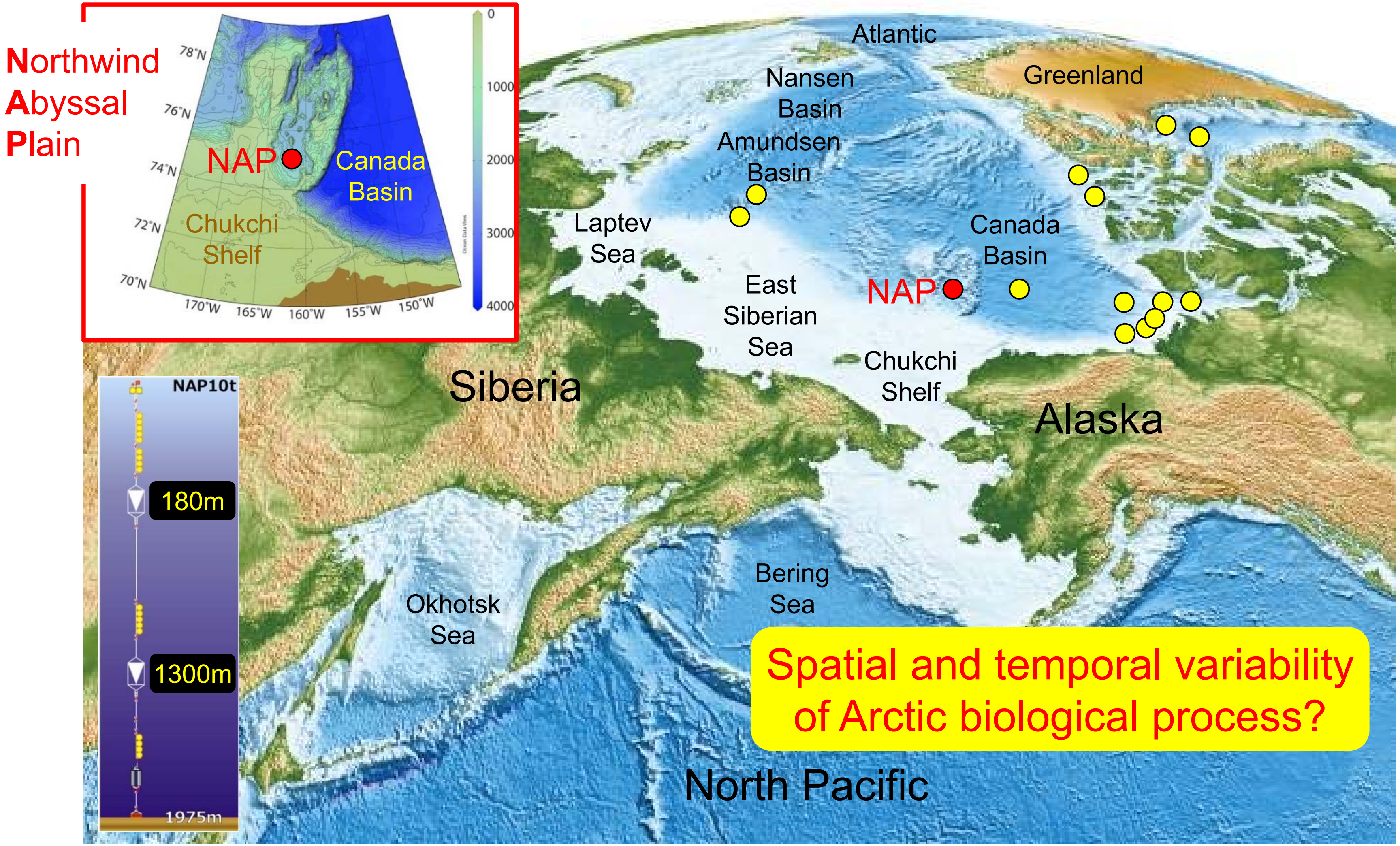
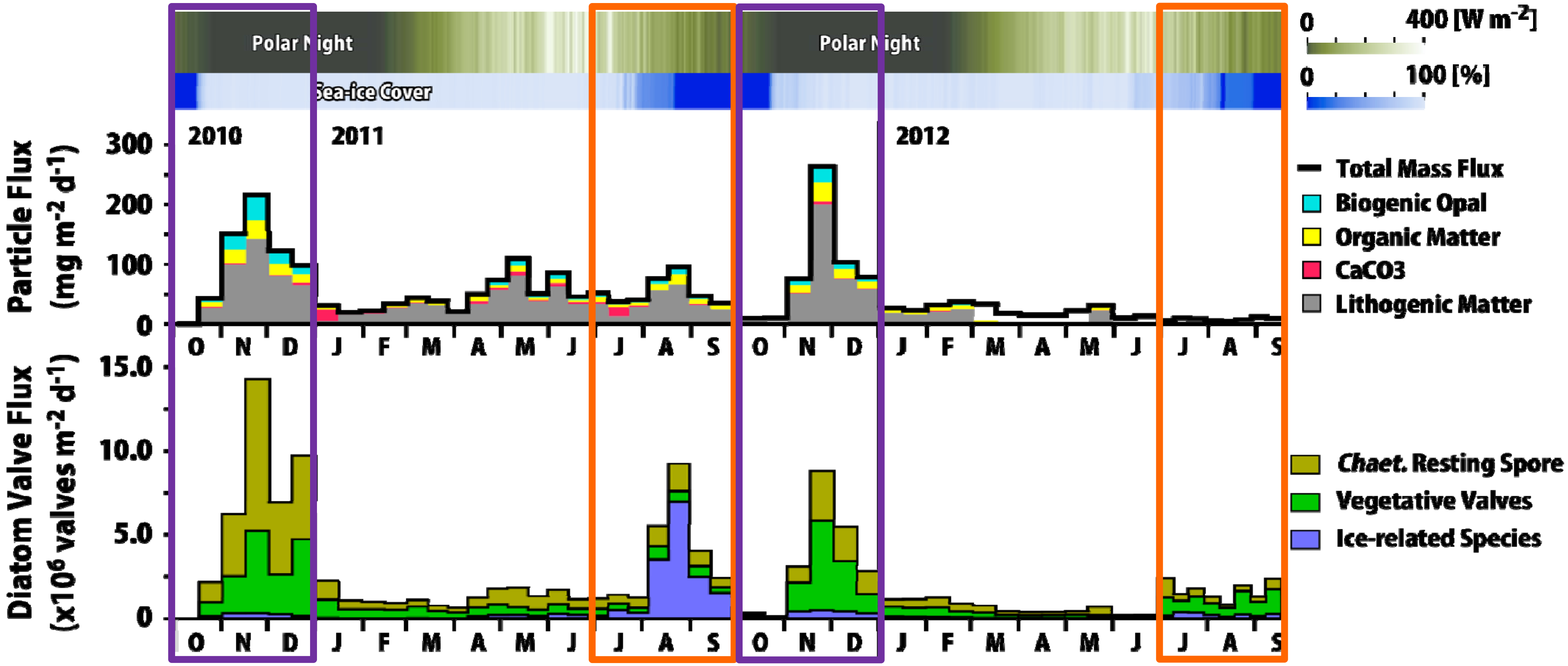
Sediment Trap in Chukchi Borderland



○ Previous stations of bottom-tethered sediment trap

Unique Seasonality of Biogenic Flux



Onodera et al. [2015]

Early-winter peaks of particle flux with fresh organic materials

→ Eddy-induced shelf-water transport [Watanabe et al., 2014]

Summer particle flux had remarkable interannual variability

→ Oligotrophic basin-water transport [Onodera et al., 2015]

Previous Ice Algae Observation

Reference	Region	Period	Keyword
Cota et al. [1991]	Hudson Bay etc.	1985 etc.	Review paper
Michel et al. [1993]	Hudson Bay	1986	Sinking rate
Michel et al. [1996]	Resolute	1992	Carbon budget
Michel et al. [2006]	CAA	historical	Algal sedimentation
Gosselin et al. [1997]	Trans-Arctic	1994	Meridional change
Mundy et al. [2007]	Resolute	2003	Light property
Mundy et al. [2011]	Darnley Bay	2011	High-light acclimation
Lee et al. [2008]	Point Barrow	2003	Landfast ice
Gradinger et al.[1999]	Greenland Sea	1991, 1994	Vertical structure
Gradinger et al. [2009]	Chukchi shelf	2002	SBI project
Boetius et al. [2013]	Eurasian Basin	2012	Massive deposition

Previous Ice Algae Modeling

Reference	Region	Period	Keyword
Arrigo et al. [1993]	Antarctic (1D)	1989 etc.	Landfast ice
Nishi & Tabeta [2005]	Lake Saroma (1D)	1992	Food source
Lavoie et al. [2005]	Resolute (1D)	2002	Landfast ice
Lavoie et al. [2009]	Mackenzie shelf (1D)	1987	Export flux
Lavoie et al. [2010]	Mackenzie shelf (1D)	1975 ~ 2100	Future projection
Pogson et al. [2011]	Resolute (1D)	2002	Multi-ice layers
Tedesco et al. [2012]	Greenland (1D)	2006	Biological active layer
Jin et al. [2006]	Point Barrow (1D)	2002	Landfast ice
Deal et al. [2011]	Global (3D)	1992	Slab ocean
Jin et al. [2012]	Global (3D)	1992 ~ 2007	Ice-ocean model
Dupont [2012]	Pan-Arctic (3D)	1950 ~ 2006	Decadal variability

Method

Pan-Arctic Ice-Ocean Model COCO

Center for Climate System Research Ocean Component Model version 4.9

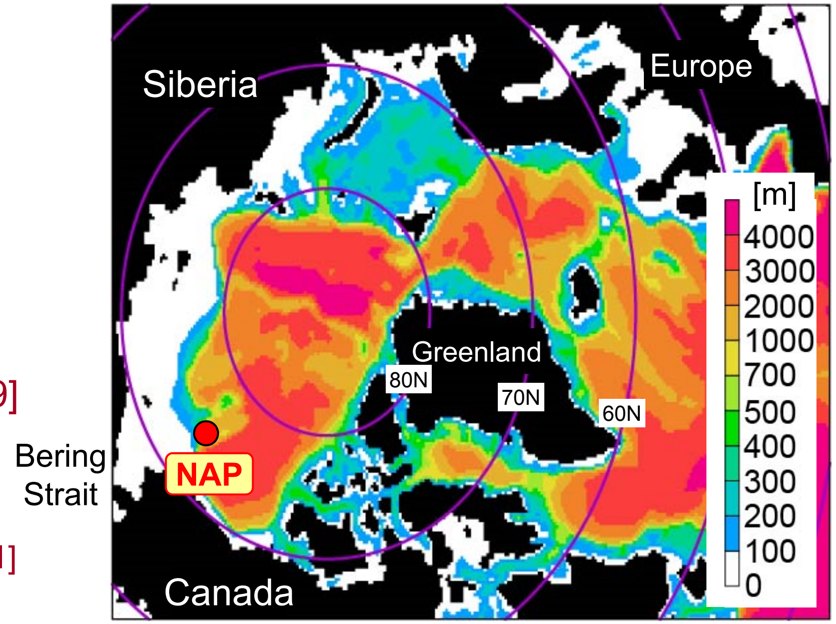
Sea Ice Part
- 1 layer thermodynamics [Lipscomb et al., 2001]
- EVP rheology [Hunke and Duckwicz, 1997]
- 7 thickness category [Bitz et al., 2001]

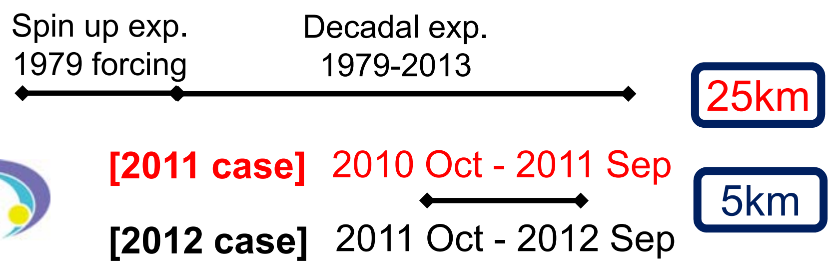
Ocean Part
- free surface general circulation model
- UTOPIA/QUICKEST advection scheme
- turbulence closure scheme [Noh and Kim, 1999]

(for eddy-resolving configuration)
- Smagorinsky harmonic viscosity [Griffies, 2000]
- Enstrophy preserving scheme [Ishizaki and Motoi, 2001]

Experimental Design
- NCEP/CFSR atmospheric daily forcing
- AOMIP river water discharge
- Pacific water inflow at Bering Strait
- Sponge layer in Atlantic side
- Shelf-break water tracer

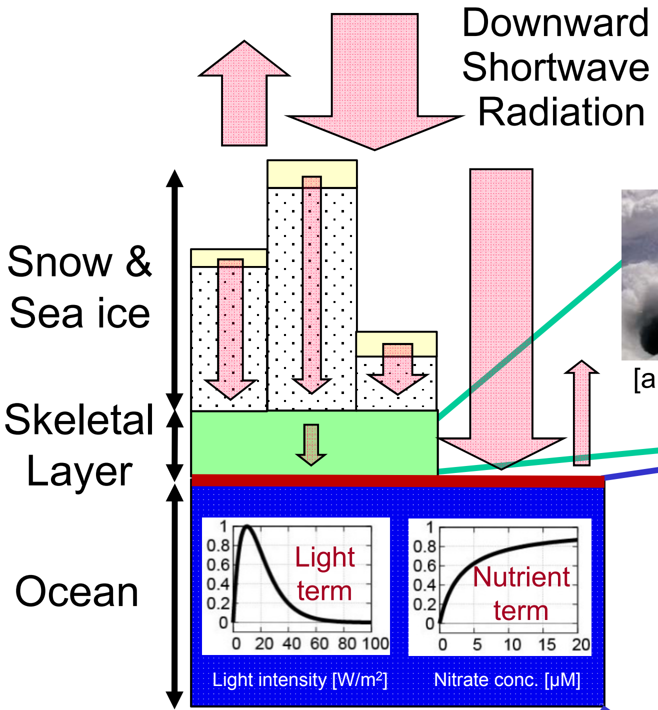
Model bathymetry



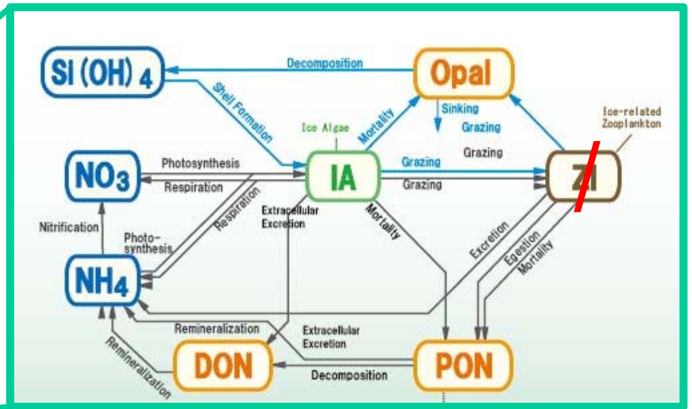


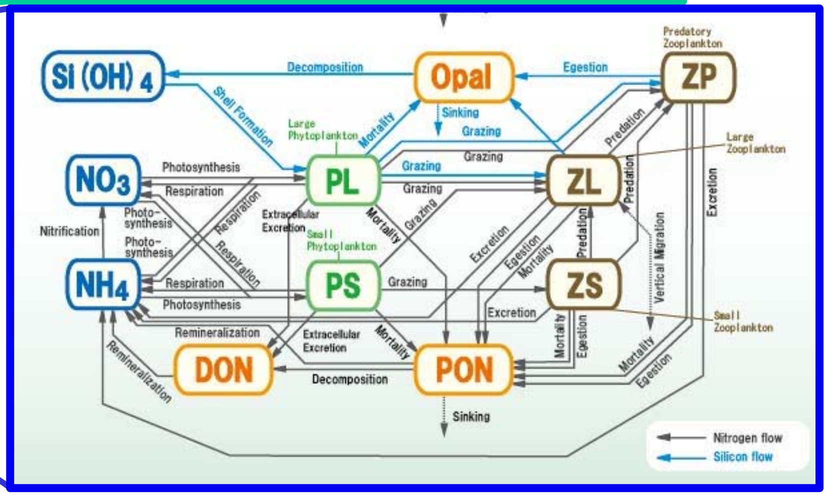
Method

Sea Ice-Ocean Ecosystem Model



[arctic.noaa.gov]





dB/dt [増加率] = αB [成長] – βB [呼吸] – γB^2 [枯死]
– [捕食] – [海氷融解]

$\alpha = \alpha_{max}$ x [光条件] x [栄養塩条件] x [水温条件]

海氷海洋間の物質交換を
海氷生成・融解速度に応じて計算

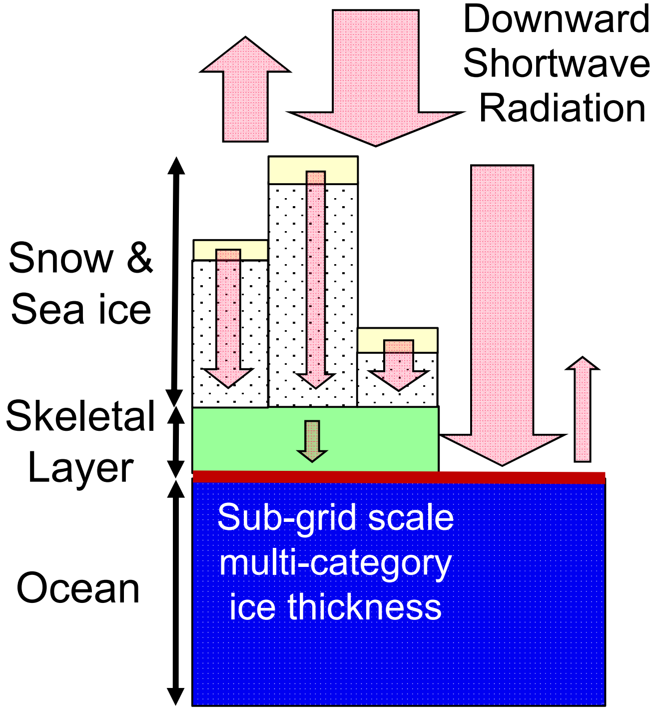
[Arctic NEMURO]

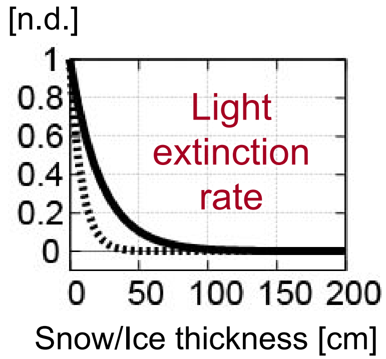
Light Availability

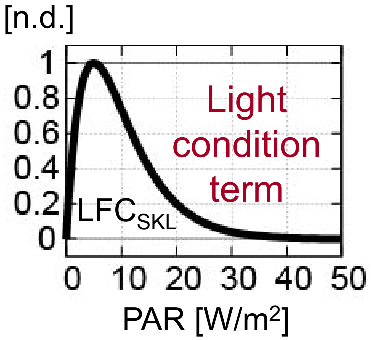
【光条件の検討】 ※光制限が全くなければ極夜時に成長してしまう

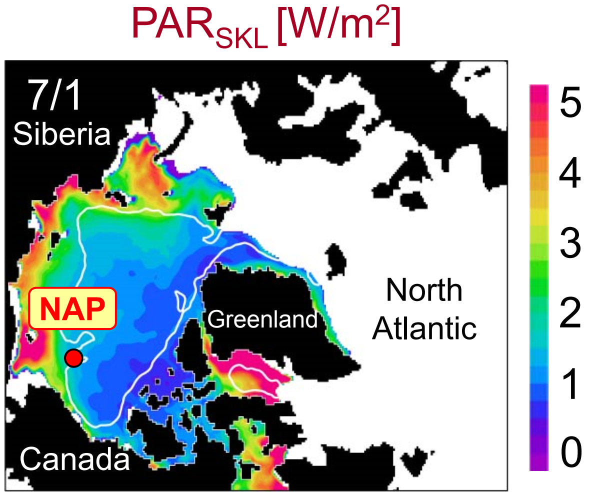
◎海氷底面まで透過した光を利用 （COCOでは海氷内透過を無視）

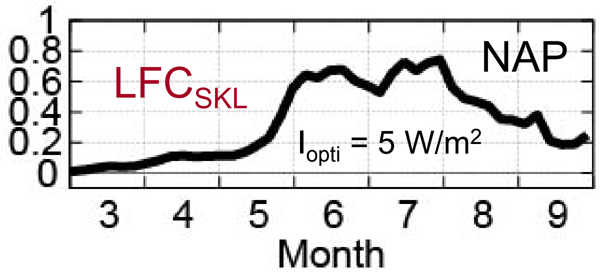
- 下向き短波放射，表面アルベド，積雪深，海氷厚，PAR_{frac}の関数として計算
- 積雪＆海氷による光の減衰は Dupont [2012], Aota and Ishii [1982] を採用
- 氷厚カテゴリー毎に光減衰を計算してから透過光をグリッド平均





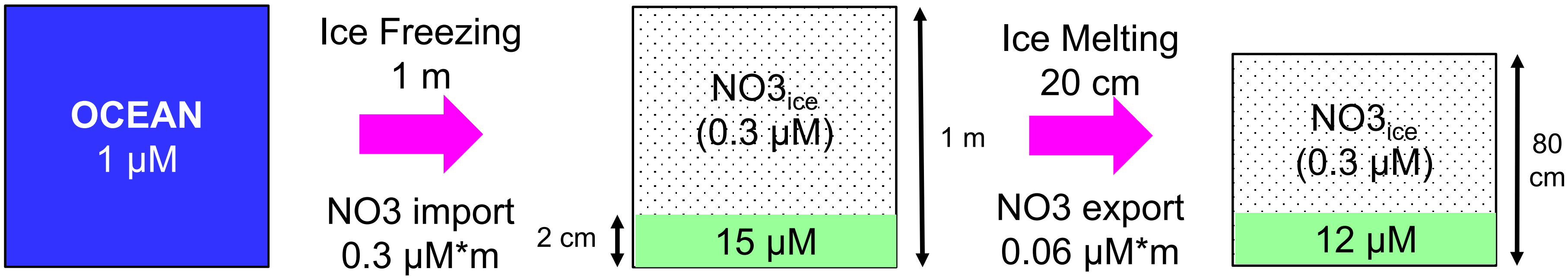






Method

Sea Ice-Ocean Nutrient Exchange



【海氷生成期の栄養塩取込】 ※海氷に取り込んだ栄養塩はすべてSkeletal Layerに濃縮

$d(NO3_{SKL})/dt$ [μM/s] = $\underline{CDH}_{NO3}$ x $\underline{DH}$ [cm/s] x $NO3_{OCN}$ [μM] / $\underline{DZ}_{SKL}$ [cm]

Coefficient　Ice freezing rate　Skeletal layer thickness

- 海氷塩分(5 ~ 10 psu)は海洋塩分(~ 30 psu)の約15 ~ 30 %
- NO3/NH4/SIL/DON(溶存態)は同様に扱う. P/Z/PON/OPL(粒子状)は交換なし

【海氷融解期の栄養塩排出】 ※表面・底面・側面融解が混在した中間的な状況

$d(NO3_{SKL})/dt$ [μM/s] = DH [cm/s] x $NO3_{SKL}$ [μM] x DZ_{SKL} [cm] / $\underline{HI}$ [cm]

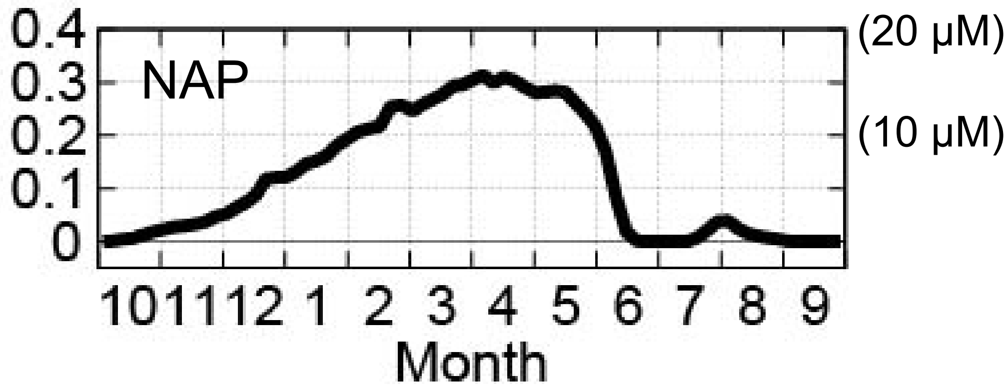
Ice thickness

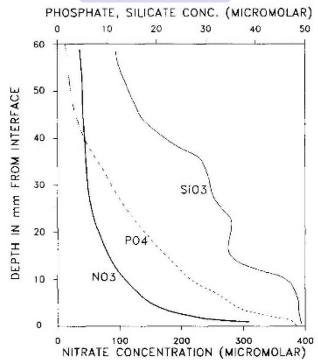
- すべての海氷生態系変数(IA/ZI/NO3/NH4/SIL/DON/PON/OPL)を同様に扱う
- 海氷が融け切るタイミングで海氷生態系変数の値がゼロになる
- ブルーム途中でも海氷融解によりバイオマス減少(海氷由来PONとして沈降)

Result

Hybrid-type Nutrient Uptake

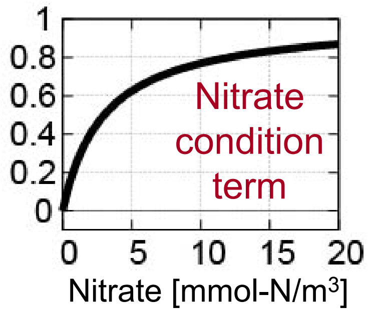
Ice nitrate content [mmol-N/m²]



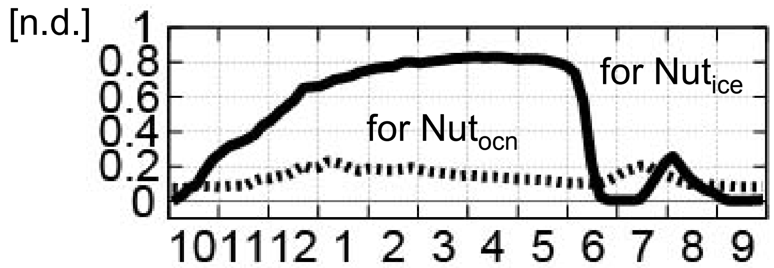


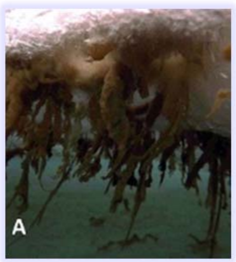
cf. $NO3_{SKL}$ ~ 300 μM in Resolute, CAA [Cota & Smith, 1991]

K_{NO3i} = 3 μM

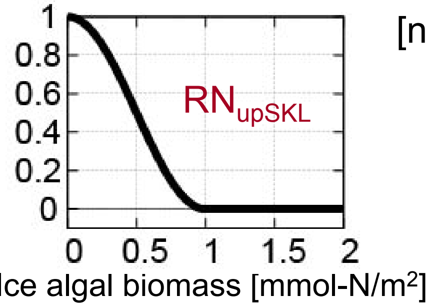


Nitrate condition term

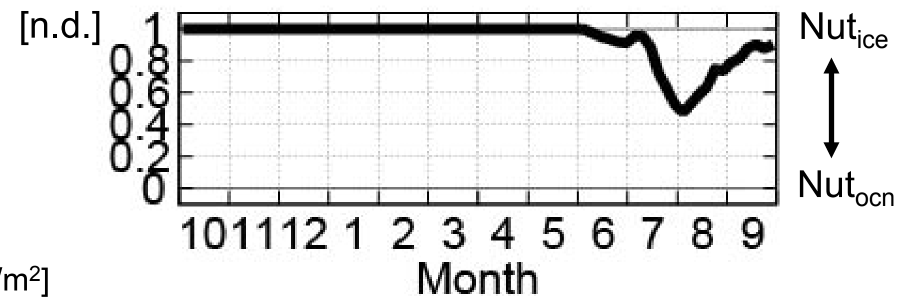




Boetius et al. [2013]



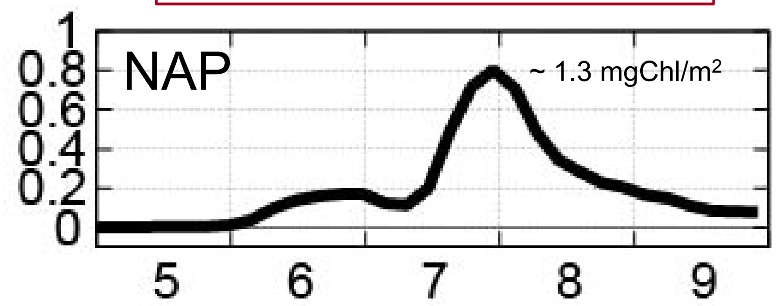
Ice nutrient uptake ratio



Result

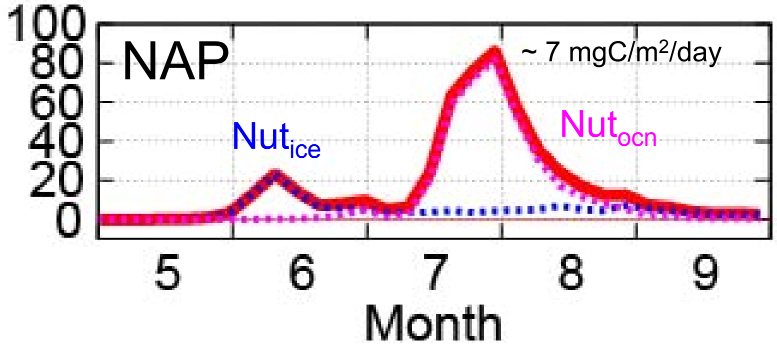
Ice Algal Productivity

Ice algal biomass [mmol-N/m²]



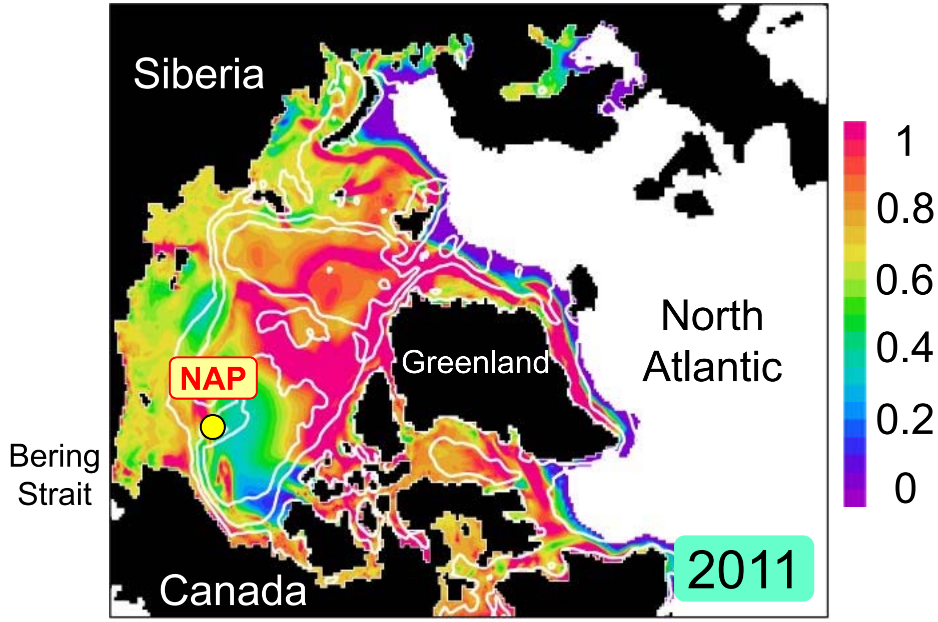
cf. ice algal biomass in arctic coastal waters
10 ~ 300 mgChl/m² [Cota et al., 1991]

Primary production rate [μmol-N/m²/day]



cf. ice algal productivity across trans-Arctic section
0.5 ~ 310 mgC/m²/day [Gosselin et al., 1997]

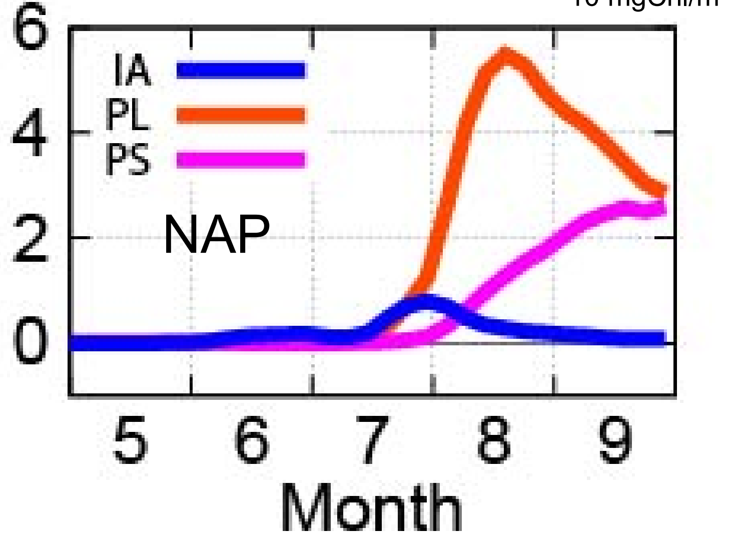
Annual primary production
of ice algae [mmol-N/m²]



✓ 初期ブルーム時は海氷内部の栄養塩利用
✓ ある程度成長後は海洋表層の栄養塩利用
✓ 基礎生産は多年氷で高く，カナダ海盆で低い

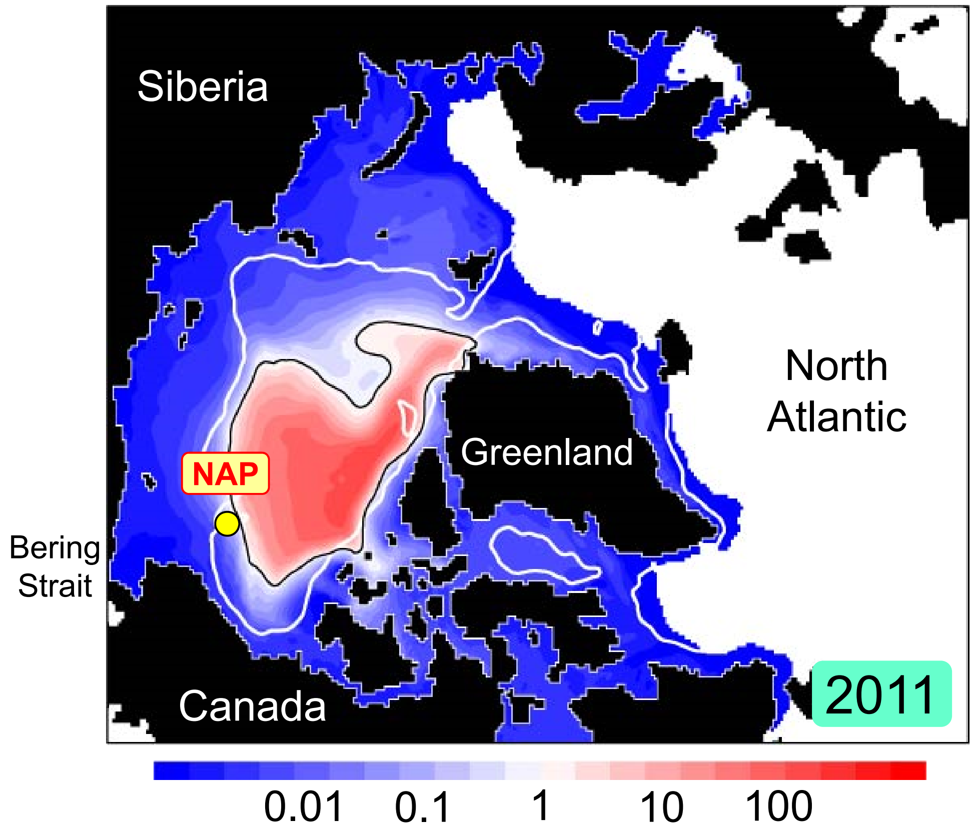
Result

Ice Algal Productivity



cf. total biomass in Canada Basin
1 ~ 27 mgChl/m^2 [Gosselin et al., 1997]

IA ratio to annual primary production

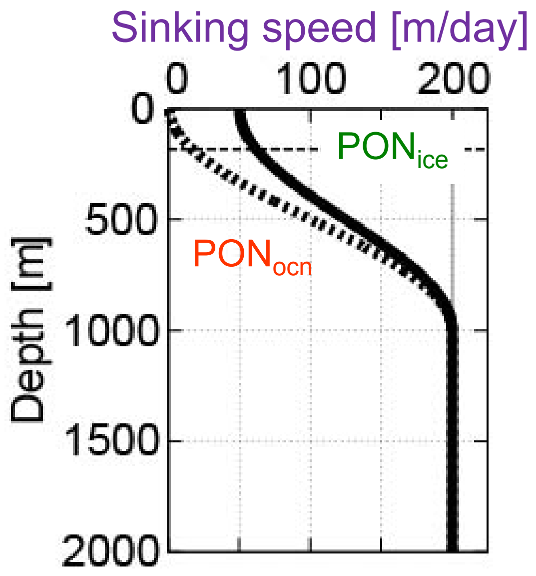


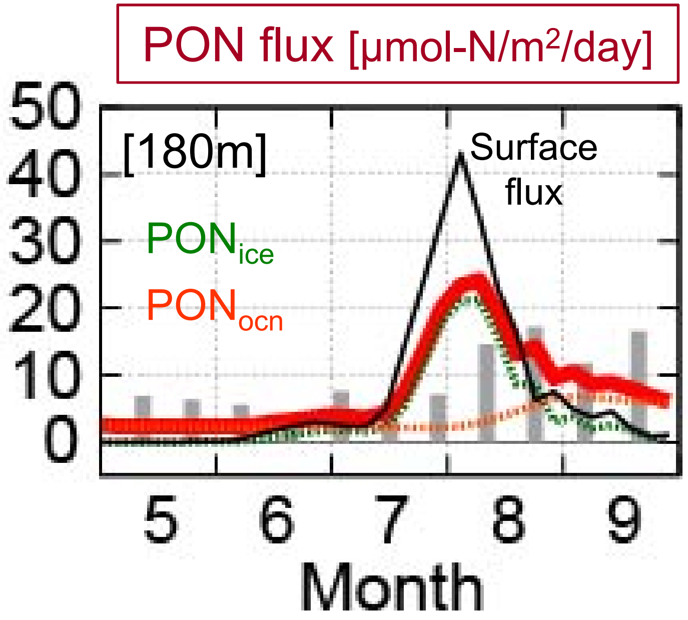
年間基礎生産量に対するアイスアルジーの寄与は
海盆外縁域で浮遊性植物プランクトンと同じオーダー

Particle Sinking Process

Result

生物由来粒子の沈降はPON Fluxで評価
- モデルでは PON [μM] x SinkVP [m/day] として計算
- PONを海氷由来(PON_{ice}) と海洋由来(PON_{ocn}) に分類
- 海氷由来PON_{ice}は沈降前の凝集を想定し，速く沈降させる





春季極大なし

陸棚水輸送の寄与？

夏季増加早い

海氷融解速度大？