Tim Stöven [1], T. Tanhua[1], M. Hoppema[2] and W.-J. von Appen[2]

[1] GEOMAR Helmholtz Centre For Ocean Research Kiel

[2] Alfred-Wegener-Institut Helmholtz Zentrum für Polar- und Meeresforschung

Transient tracers in the Fram Strait – Excess SF_6 and anthropogenic carbon transport

13th ASOF-ISSG Meeting
March 2016, Lerici, Italy

GEOMAR

Transient tracers

General

- CFCs, SF_6, Ar^{39}
- inert trace gases
- enter ocean via gas-exchange only
- provide time information (atmospheric history / input function)

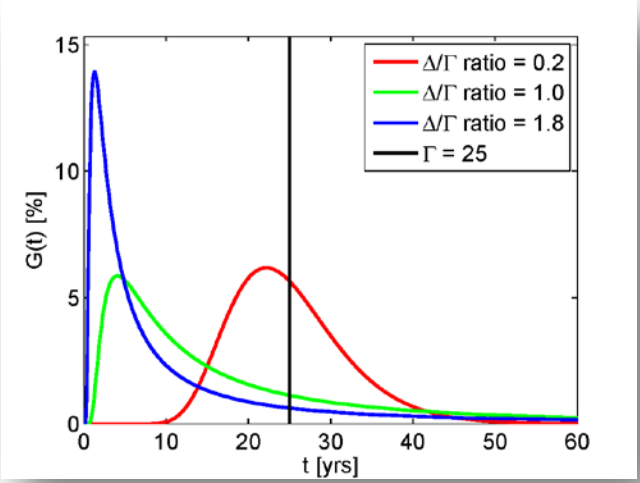
OUTPUT

- mean age
- changes in ventilation
- ventilation pattern
- anthropogenic carbon
- AOUR

The Inverse Gaussian – Transit Time Distribution

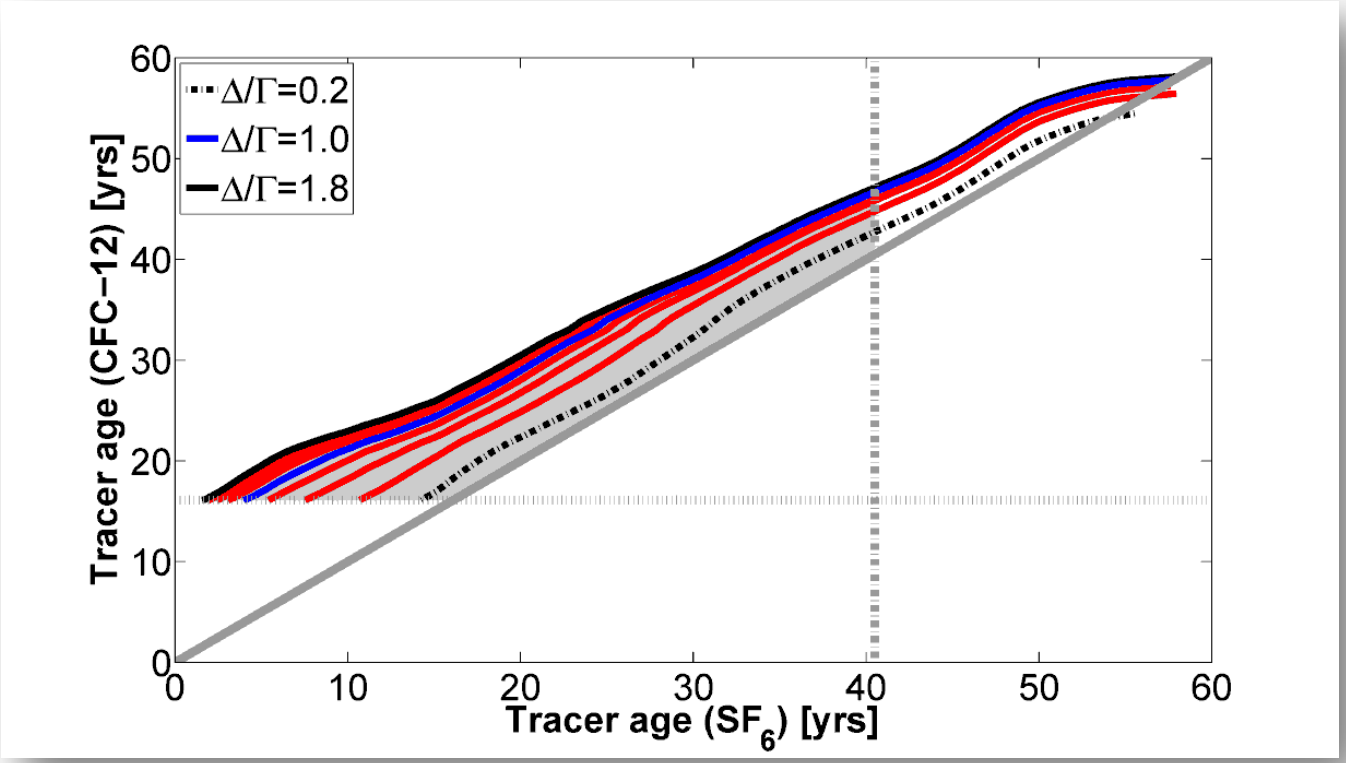
$$C(t_s) = \int_0^{\infty} C_0(t_s - t)\, e^{-\lambda t} \cdot G(t)dt$$

$$G(t) = \sqrt{\frac{\Gamma^3}{4\pi\Delta^2 t^3}} \cdot \exp\left(\frac{-\Gamma(t-\Gamma)^2}{4\Delta^2 t}\right)$$



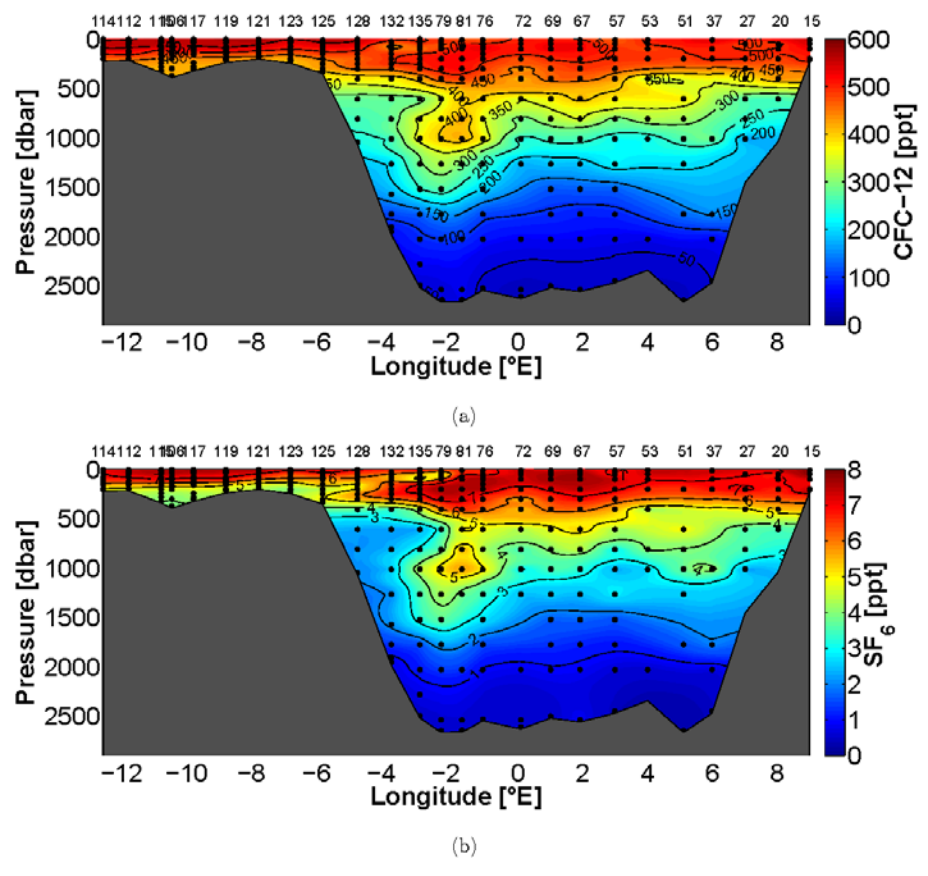
- IG-TTD is based on constant adv./dif. along flow pathway
- parameters to constrain: Γ = mean age / Δ = width of the IG-TTD
- transient tracer couples → sufficiently different input functions

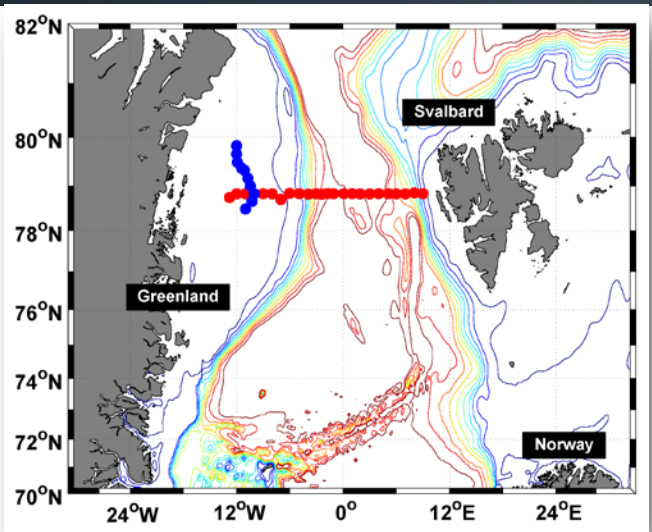
The tracer age relationship



- tracer age / apparent age is based on a purely advective flow
- tracer age used as tracer unit instead of concentrations

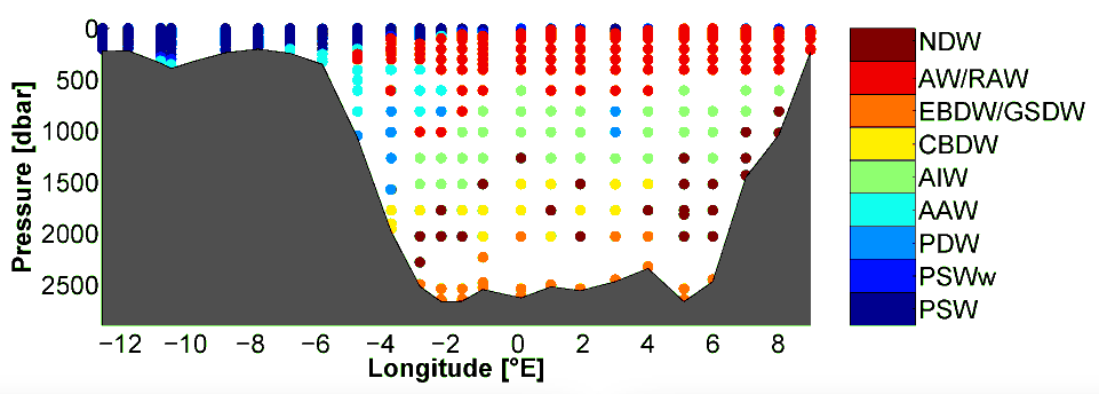
Transient tracers at 79°N

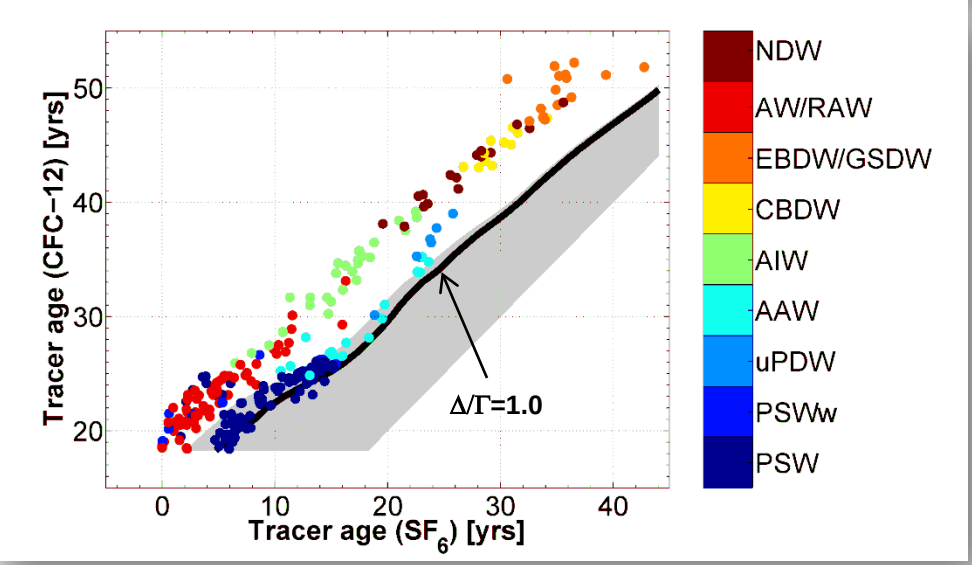


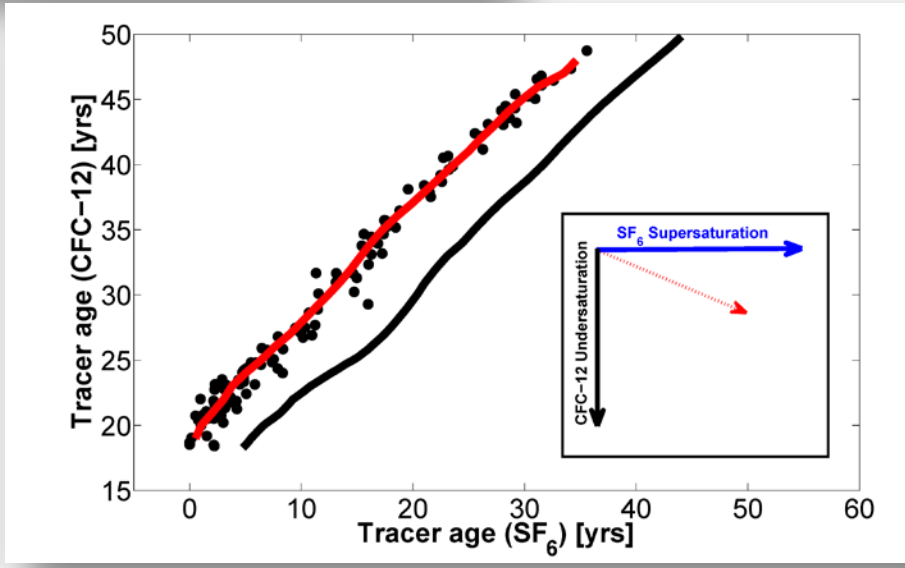


- ARK-XXVII/1 expedition in 2012
- measurments of CFC-12 and SF_6 along 78°50‘N (red) and along the fast ice edge (blue)
- data publically available at CDIAC (CLIVAR Repeat Section 75°N)

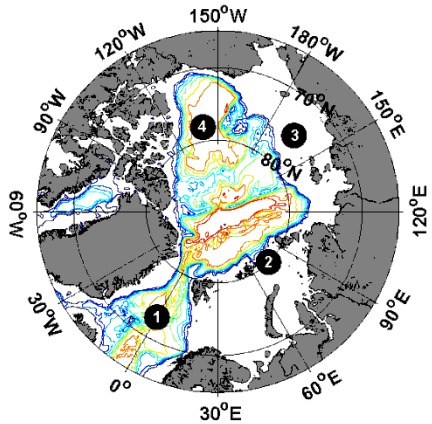
Transient tracers at 79°N



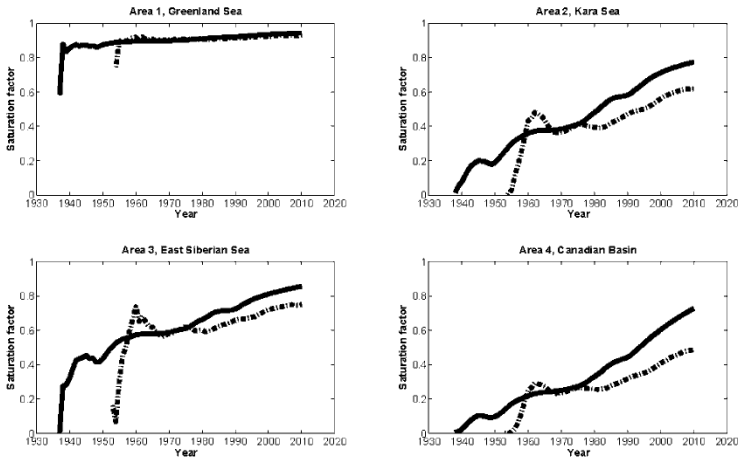




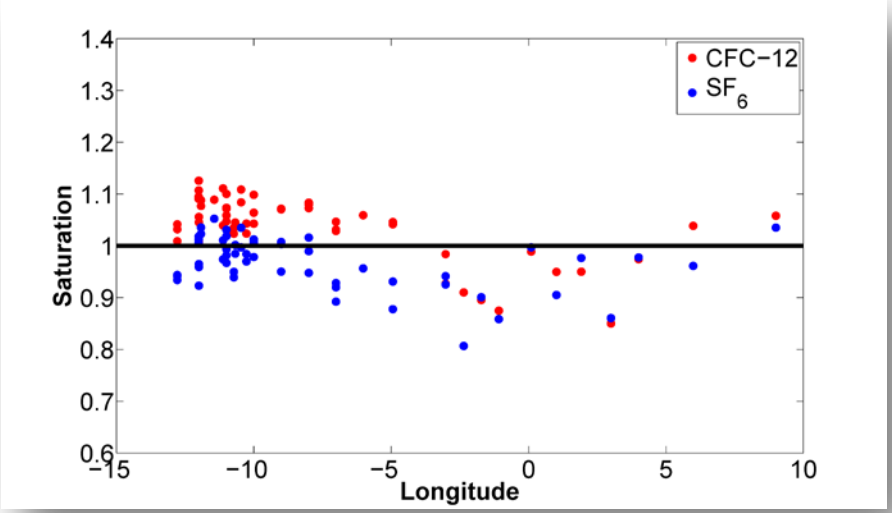
Saturation models



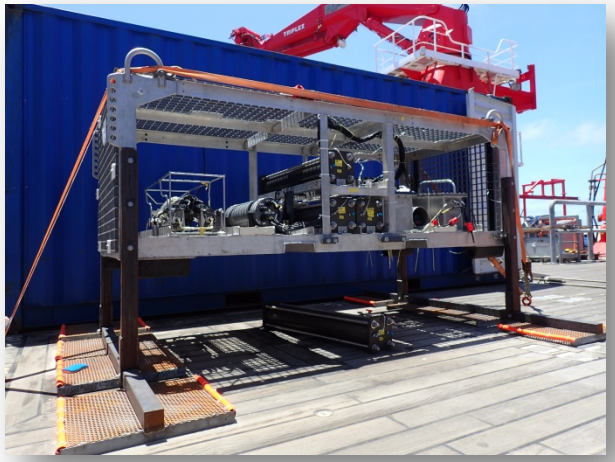
- saturation model extremely biased at high latitudes
- good agreement in tropical / subtropical regions
- saturation in the Greenland Sea as proxy for the water masses in the Fram Strait



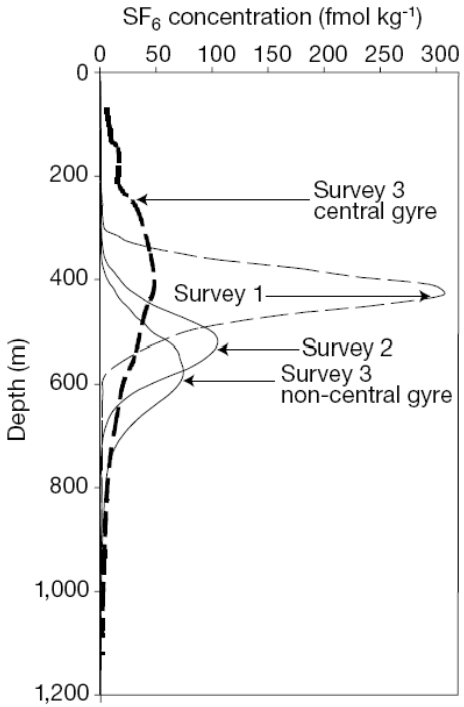
Model output by A.Shao et al., JGR 2013

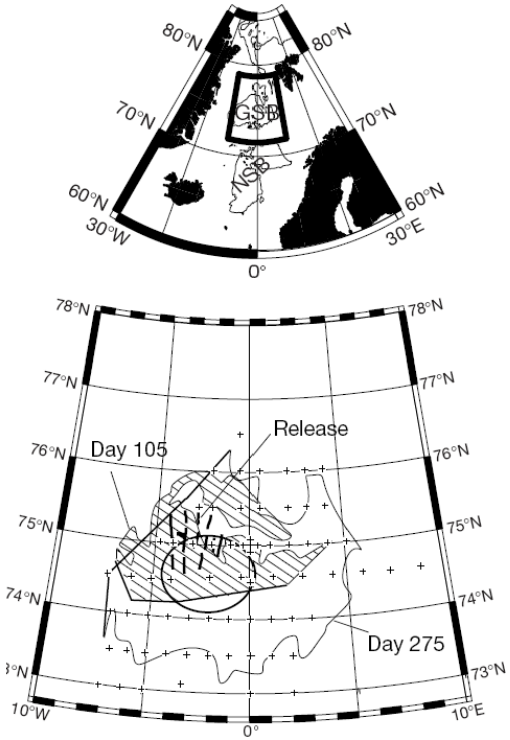


Tracer release experiment



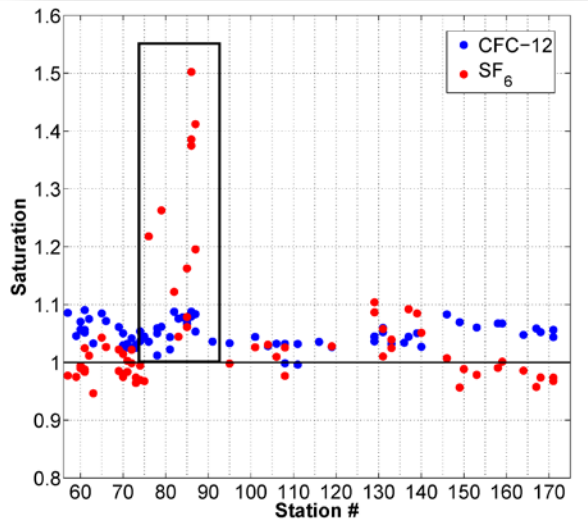
- tracer release experiment in the central Greenland Sea in 1996
- 300 kg of SF_6
- distribution pattern in 2012?

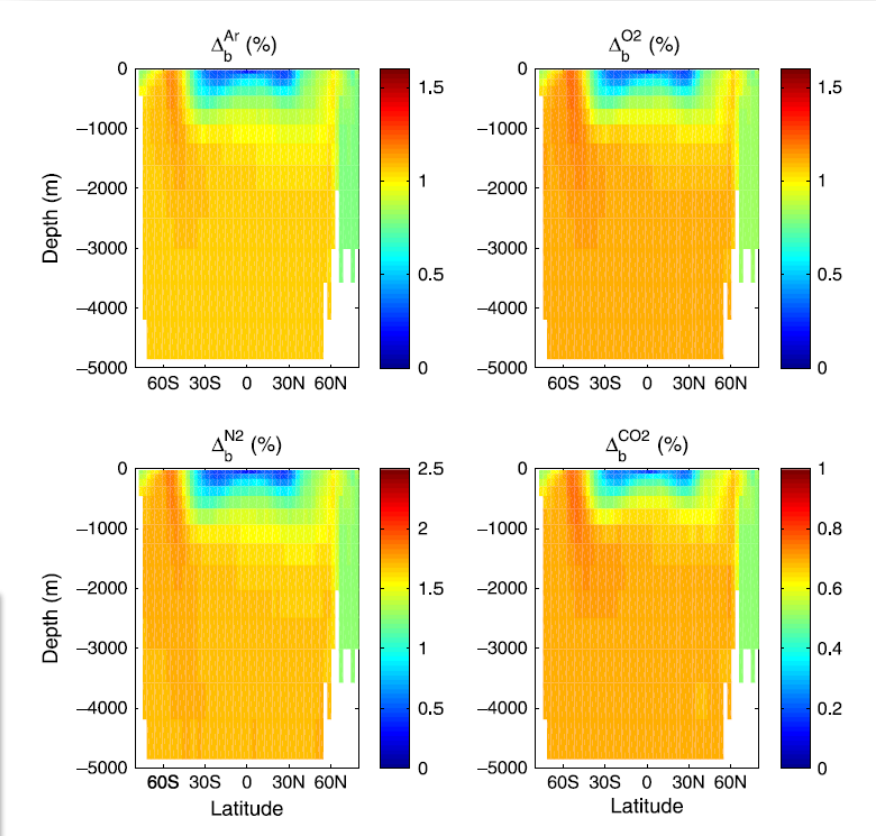




A.J. Watson et al., Letters to nature 1999

Supersaturation by bubble effects





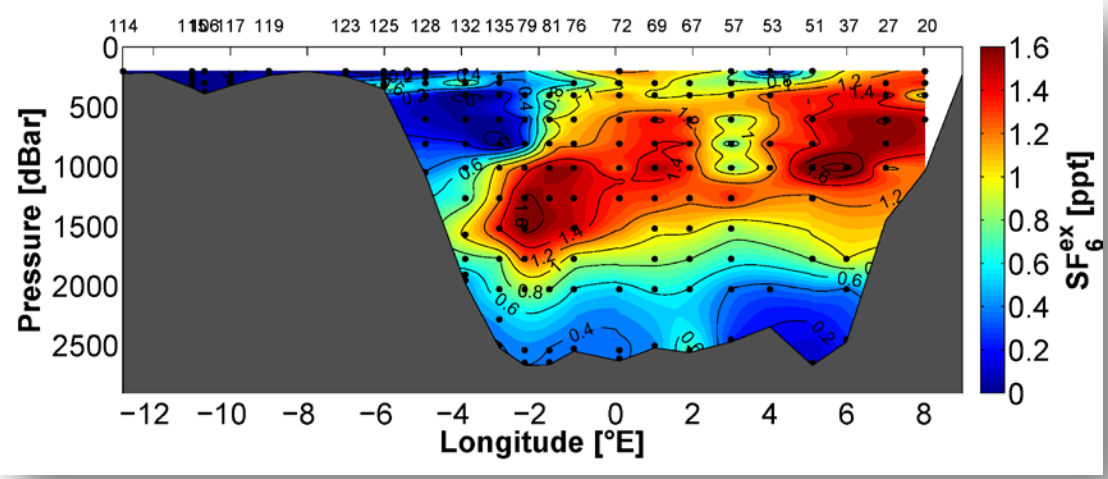
- less soluble gases like SF_6 are much more affected by bubble effects
- data observations during heavy wind conditions are relatively rare
- high uncertainties of the models

J.-H. Liang et al., Global Biogeochem. Cycles 2013

Excess SF_6

Assumptions

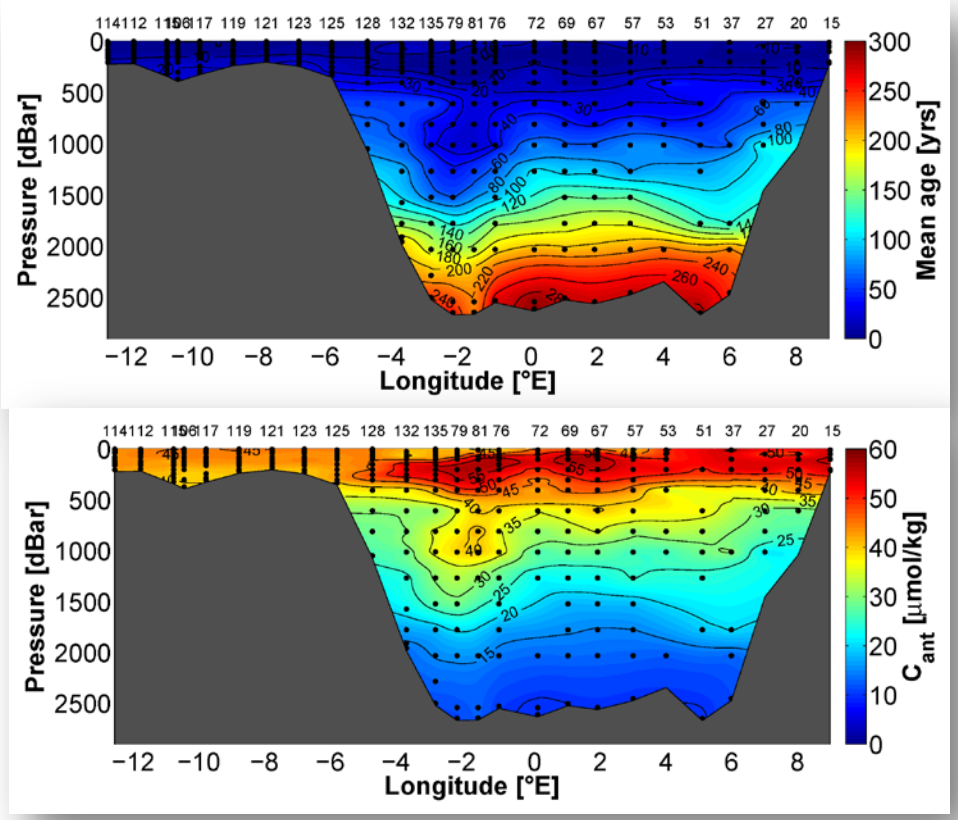
- IG-TTD valid with Δ/Γ=1.0
- CFC-12 time dependent undersaturation
  (Shao et al., JGR 2013; Tanhua et al., JGR 2008)



CFC-12 (corrected) → Γ → SF_6 (theoretical)

SF_6 (excess) = SF_6 (measured) – SF_6 (theoretical)

Mean age and anthropogenic carbon



- C_{ant} as inert tracer / „transient tracer“
- Boundary condition:

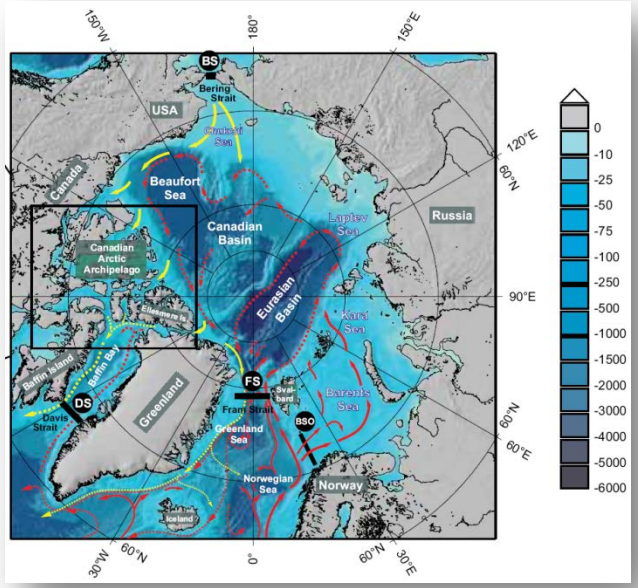
$$pCO_{2,preind} + TA_{pref} \rightarrow DIC_{preind}$$

$$pCO_{2,hist} + TA_{pref} \rightarrow DIC_{hist}$$

$$DIC_{hist} - DIC_{preind} = C_{ant}(0)$$

- $C_{ant}(0)$ + IG-TTD → **interior $C_{ant}(t)$ + Γ**

Arctic Ocean mass balance

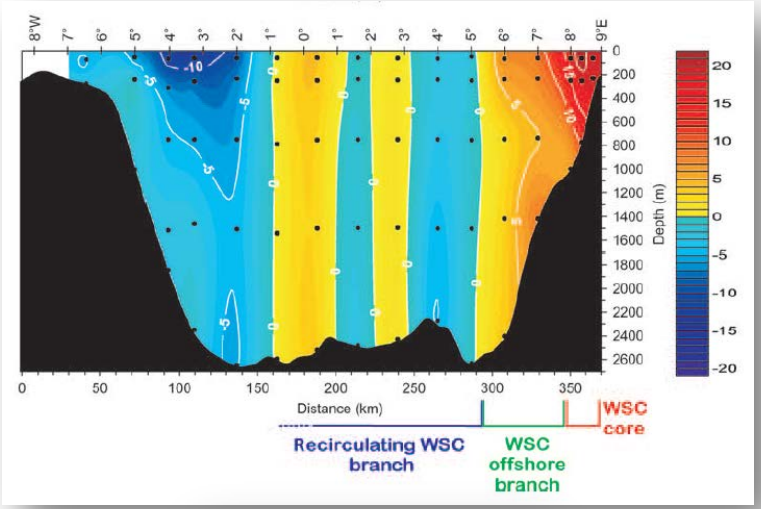


Beszczynska-Möller et al., Oceanography, 2012

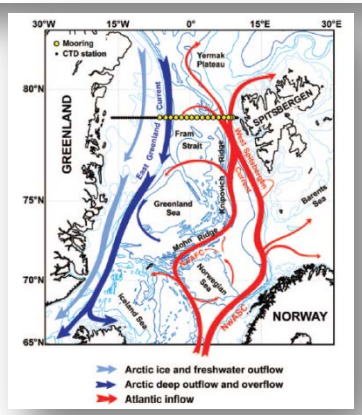
Water mass	C_{ant} ($\mu mol\,kg^{-1}$)	Mean age (years)
AW/RAW	50 (±6)	9 (±10)
PSWw	46 (±5)	9 (±10)
PSW	43 (±2)	7 (±6)
AAW	38 (±5)	32 (±15)
AIW	31 (±5)	54 (±20)
uPDW	28 (±4)	69 (±19)
NDW	18 (±4)	143 (±44)
CBDW	15 (±2)	173 (±23)
EBDW/GSDW	11 (±1)	254 (±32)

- C_{ant} concentrations are highest in poleward flowing water masses in the Fram Strait, Bering Strait and Barent Sea Opening
- C_{ant} concentrations in poleward flowing WM increase twice as fast as in equatorward flowing WM (~2 μmol/kg yr between 2002 and 2012)
- Canadian Archipelago **?**

Transport through Fram Strait



- mean velocity field from 2002-2010
- separated into Polar Water, Atlantic Water and Recirculating / Return Atlantic Water
- flux data in the Fram Strait has high uncertainties



	Volume (Sv)	Transport (Tg C yr^{-1})	
		DIC	Anthropogenic carbon
AW	4.4 (±3.2)	3592 (±2612)	78 (±57)
RAW/AAW	−3.5 (±1.9)	−2852 (±1549)	−67 (±36)
PW	−1.4 (±0.8)	−1118 (±639)	−23 (±13)
Σ	−0.5	−378	−12

Beszczynska-Möller et al., J. Mar. Sci., 2012

Outlook

- **Saturation at high latitudes**

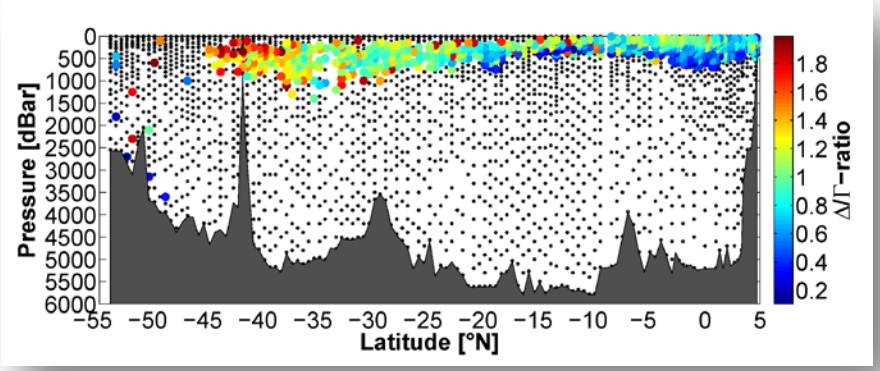
  → bubble mediated gas transfer of transient tracers

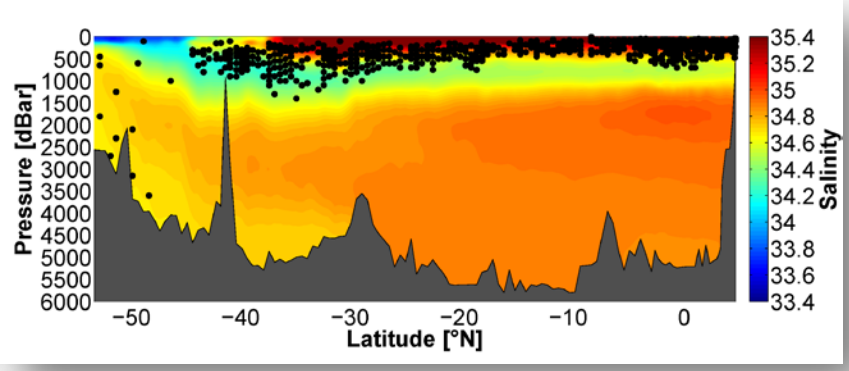
  → comparison with existing models (Ne, Ar, He)

  → possible relationship between chem. / phys. parameters?

  → influence of ice cover / gas exchange

- **More refined ventilation models for high latitudes?**





Thank you!