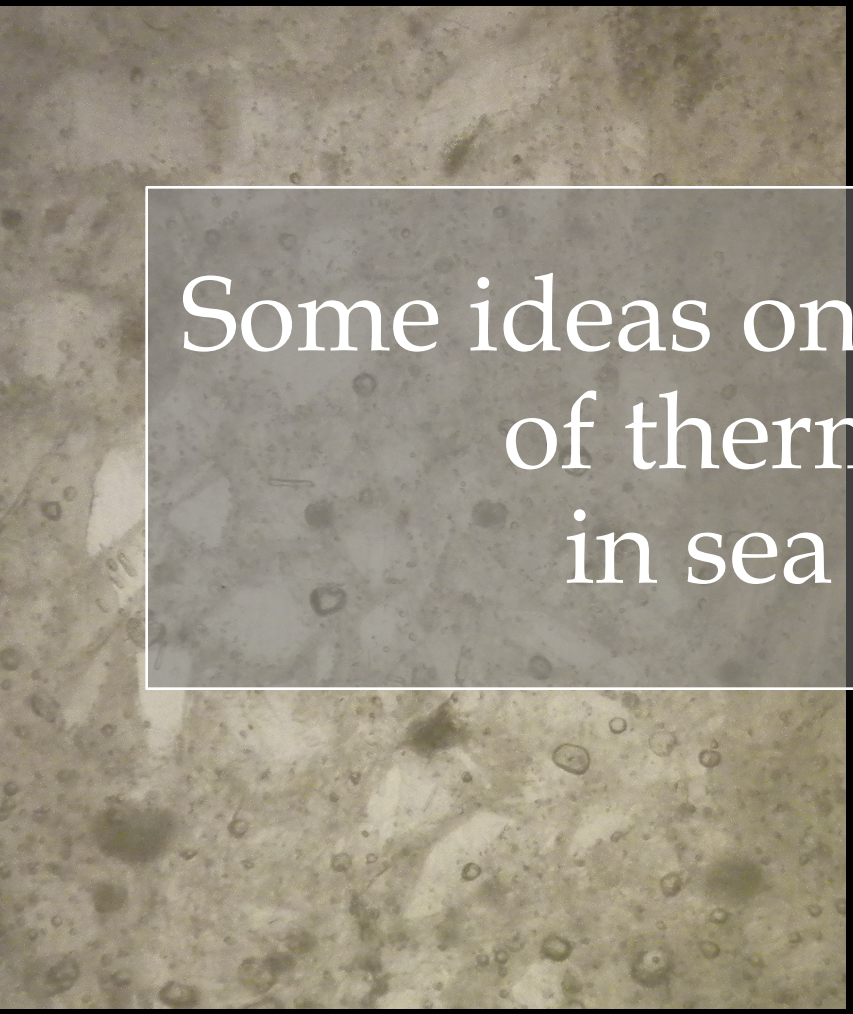


# Some ideas on the representation of thermodynamics in sea ice models

Martin Vancoppenolle

LOCEAN-IPSL, Paris France

# New framework for sea ice phase composition

TEOS-10 COMPLIANT !

NOW INCLUDING MINERALS

$$\phi_{br}(S,T) = [1 - f_{sm}(T)] \cdot \frac{S}{S_{br}(T)}$$

NEW !!!

CHEAP! EASY!

JGR Oceans

RESEARCH ARTICLE

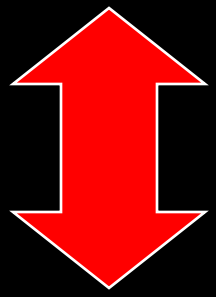
10.1029/2018JC014611

## Thermodynamics of Sea Ice Phase Composition Revisited

Martin Vancoppenolle[1], Gurvan Madec[1], Max Thomas[2], and Trevor J. McDougall[3]

Classical motivation

- Climate model have issues in the sea ice zone
- Sea ice thermodynamics are inadequate in other models than mine
- Need to improve physics to reduce uncertainties



?

- Climate models are insensitive to uncertainties in sea ice thermodynamics

# Overarching issues

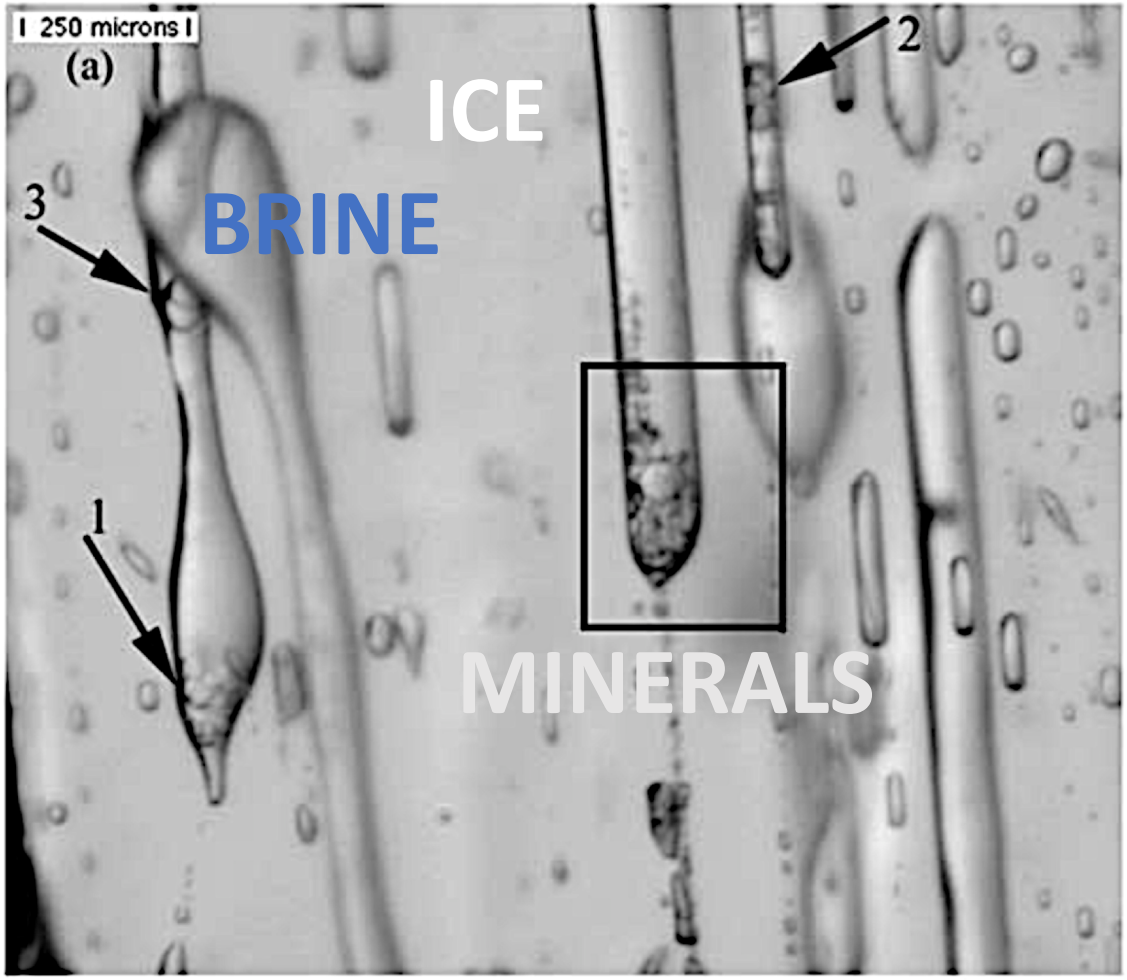
- How well do we know sea ice phase composition?
- For which purposes do we need thermodynamic sea ice model complexity ?
- How should we treat this contradiction in terms of model development ?

# Sea ice thermo in CMIP5 models

- SST = Tf
- Albedo
- Conservation of mass and (latent+sensible) heat
- Ice thickness distribution

Pure ice
Static salinity

# Sea ice = ice + brine + minerals




-15°C, natural sea ice thin section (Light et al., 2003)

# Key issue : salt

*The chief difference between sea ice and freshwater ice is the presence of salt in the former (Malmgren, 1927)*

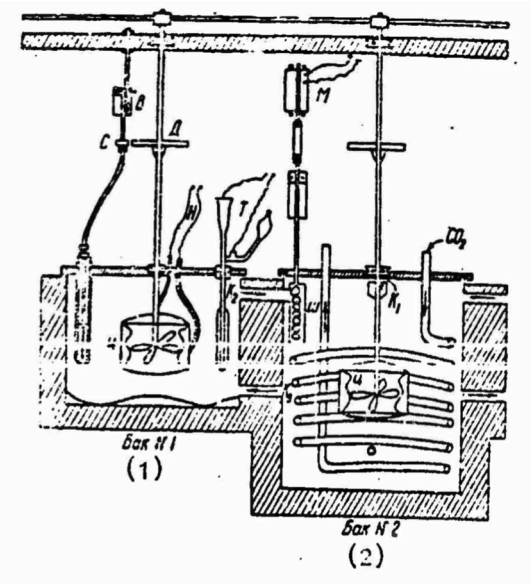
- Composition of sea ice function of T and S
  - H2O crystals does not like salt
  - Tfr = Tfr(S)

# More realistic representation of salt in sea ice thermodynamics ?

- **o** Conservation of mass and (latent+sensible) heat
- **o** Phase composition (ice, brine, minerals)
- **o** Enthalpy — $q(S,T)$
- **o** Thermal conductivity — $k(S,T)$
- **o** Salt dynamics — $dS/dt$

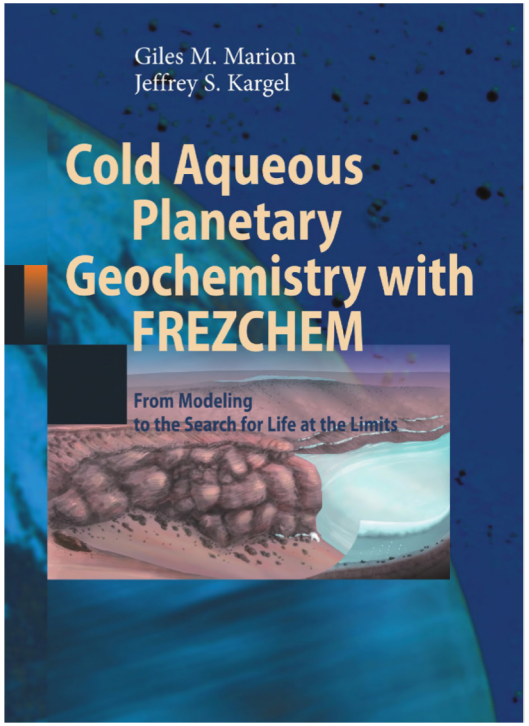
# On which base can we develop more realistic sea ice thermodynamics ?

**Experimental** works




*Gitterman 1936*

Gibbs-Pitzer **theory**
for electrolyte solutions



# Proposed revised Framework

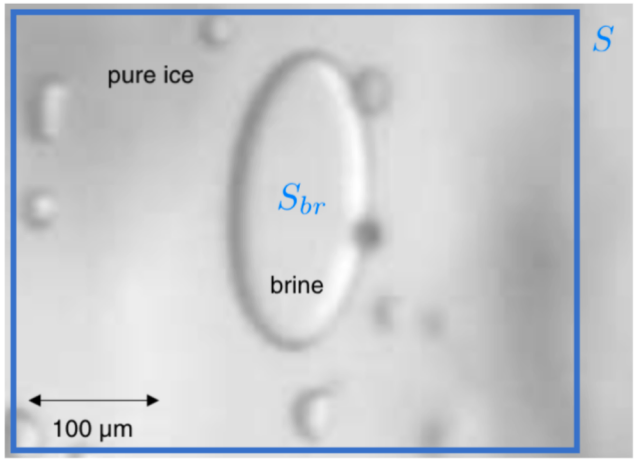
Thermal equilibrium
Standard seawater

$$\phi_{br}(S,T) = [1 - f_{sm}(T)] \cdot \frac{S}{S_{br}(T)}$$

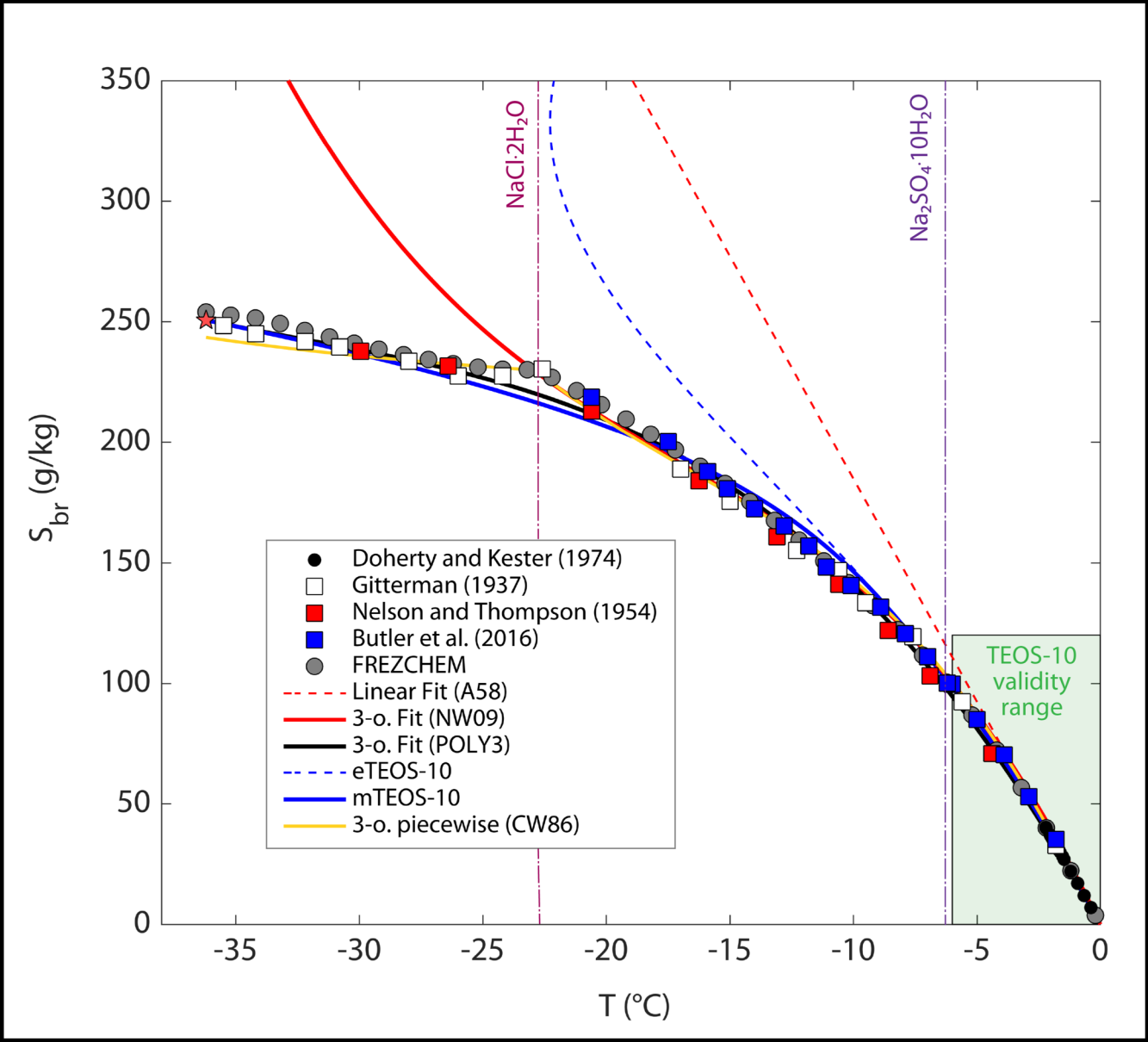
$\phi_{br}$ Brine mass fraction

$f_{sm}$ Mass fraction of solid salt in minerals (specified)

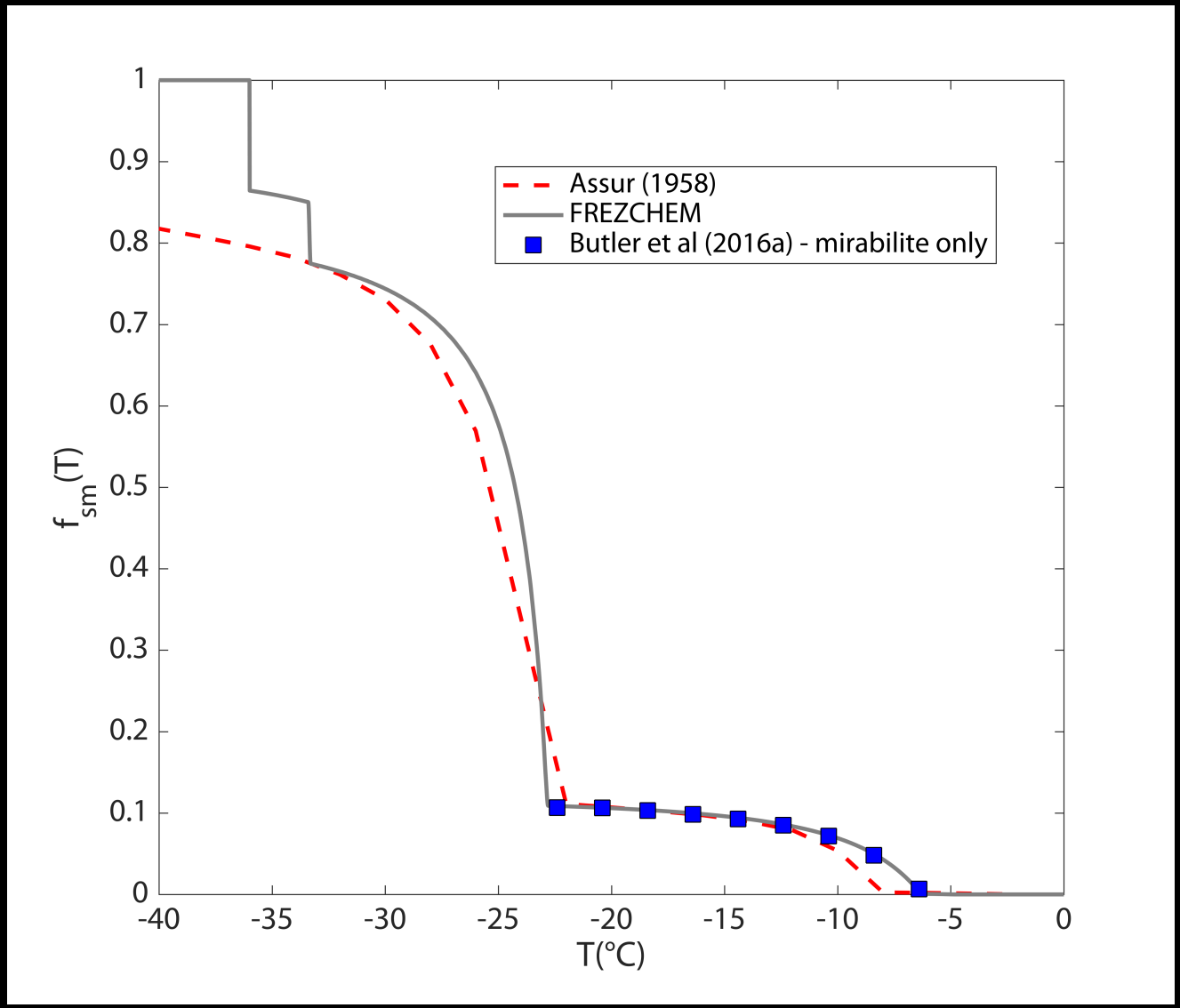
$S_{br}$ Brine salinity (specify)



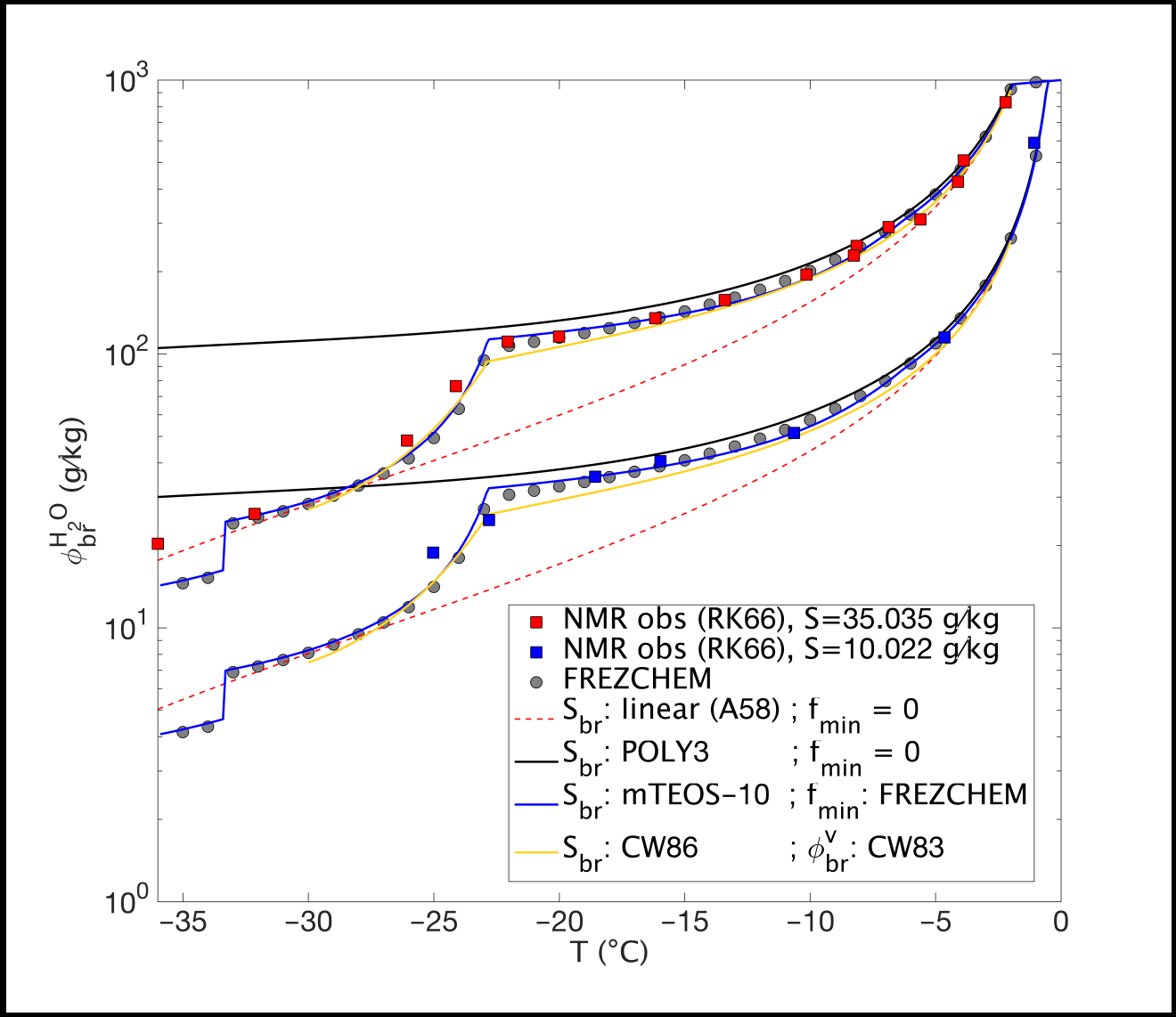
# Brine salinity



# Minerals


Assur (1958)
FREZCHEM
Butler et al (2016a) - mirabilite only
$f_{sm}(T)$
T(°C)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-40
-35
-30
-25
-20
-15
-10
-5
0

# Liquid fraction

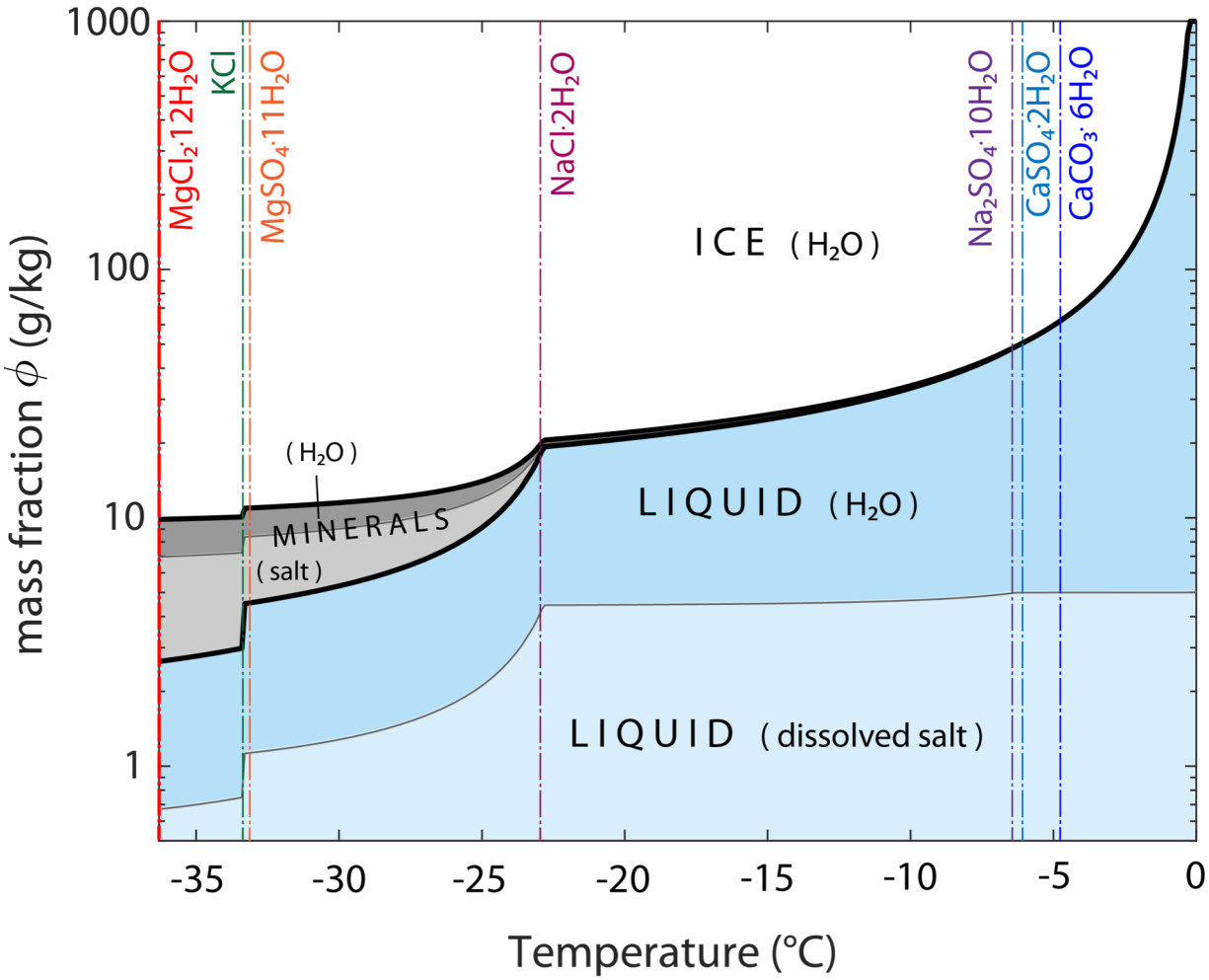


# Framework… is appropriate

$$\phi_{br}(S,T) = [1 - f_{sm}(T)] \cdot \frac{S}{S_{br}(T)}$$

- FREZCHEM is the most precise source for all diagnostics
- Uncertainties are reasonable (5-10%)
- One option compatible with TEOS-10

$$\phi_{br}(S,T) = [1 - f_{sm}(T)] \cdot \frac{S}{S_{br}(T)}$$



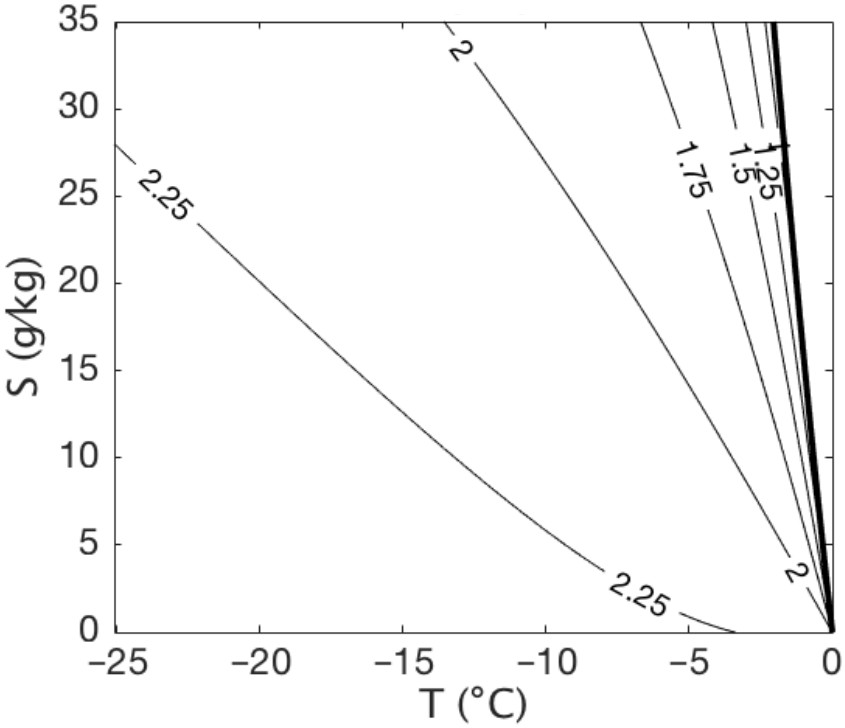
# More realistic sea ice thermo ?

- **o** Conservation of mass and (latent+sensible) heat
- **o** Phase composition (ice, brine, minerals)
- **o** Enthalpy — $q(S,T)$
- **o** Thermal conductivity — $k(S,T)$
- **o** Salt dynamics — $dS/dt$

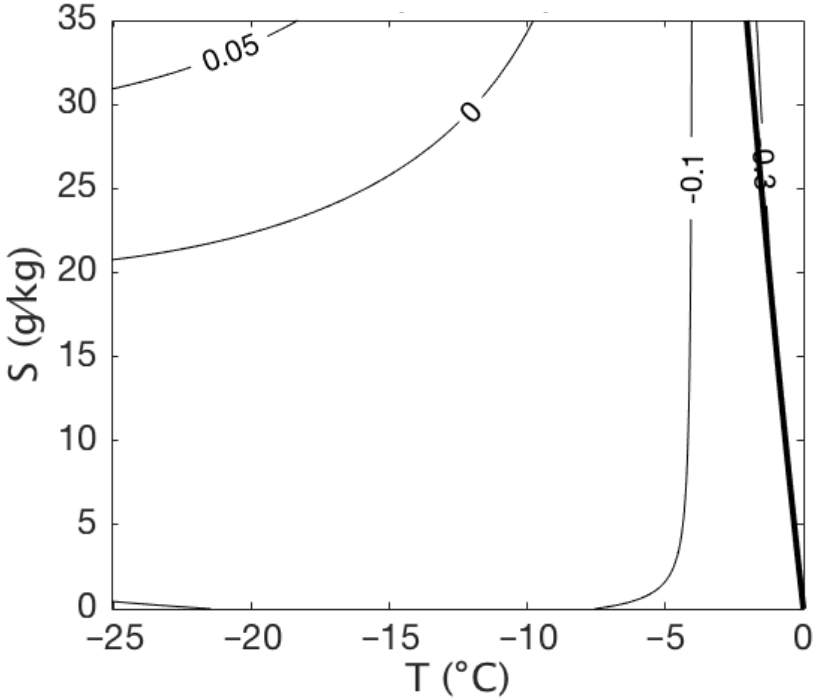
# Thermal conductivity

$$k(S,T) = \phi(S,T) \cdot k_{br}[S_{br}(T)] + [1 - \phi(S,T)] \cdot k_i(T)$$

New Theoretical Framework



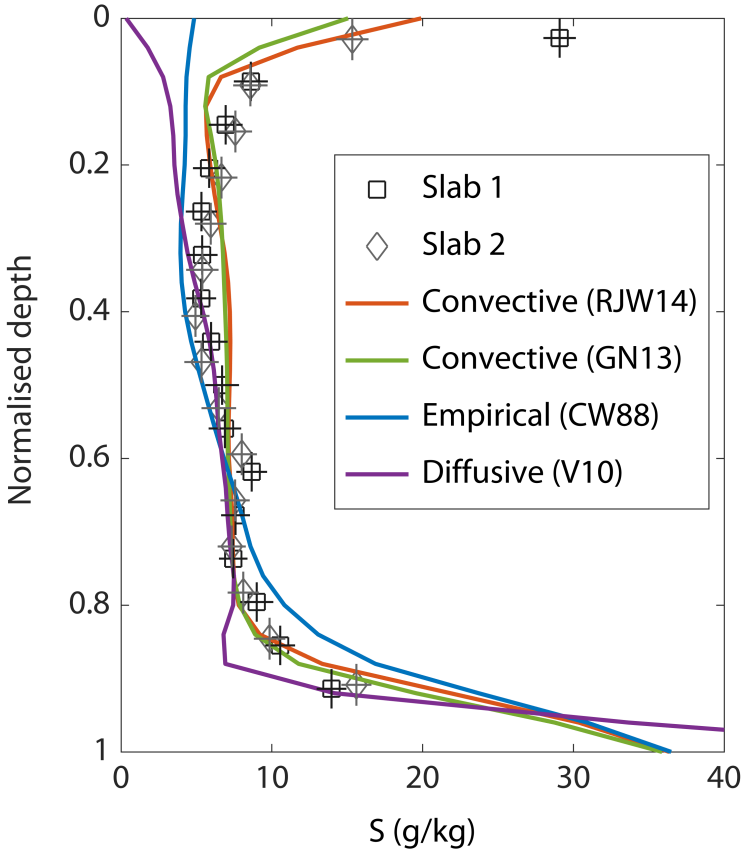

Empirical obs based - theory

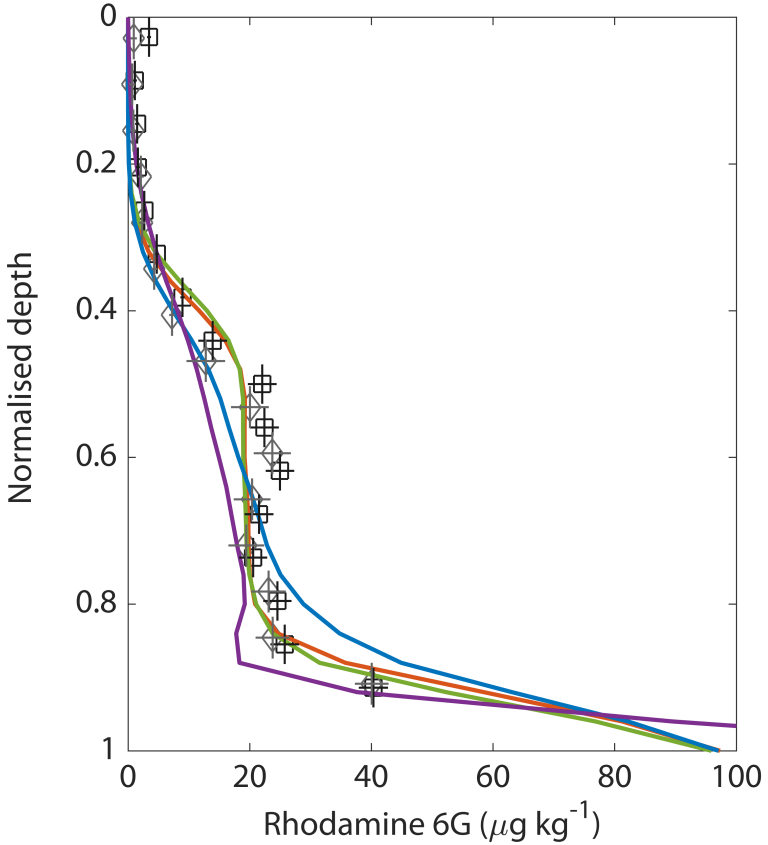



Obs-based = *Pringle et al (2007)*

# Salt dynamics tested in the lab

# Salt dynamics tested in the lab




Courtesy Max Thomas

- **How well do we know about sea ice thermodynamics ?**

- When and for which purposes do we need thermodynamic sea ice model complexity ?

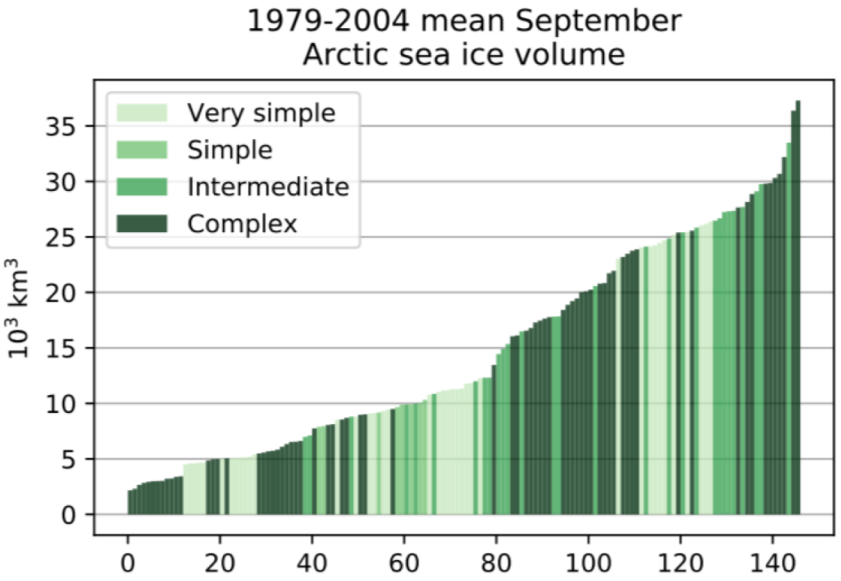
- How should we treat this contradiction in terms of model development ?

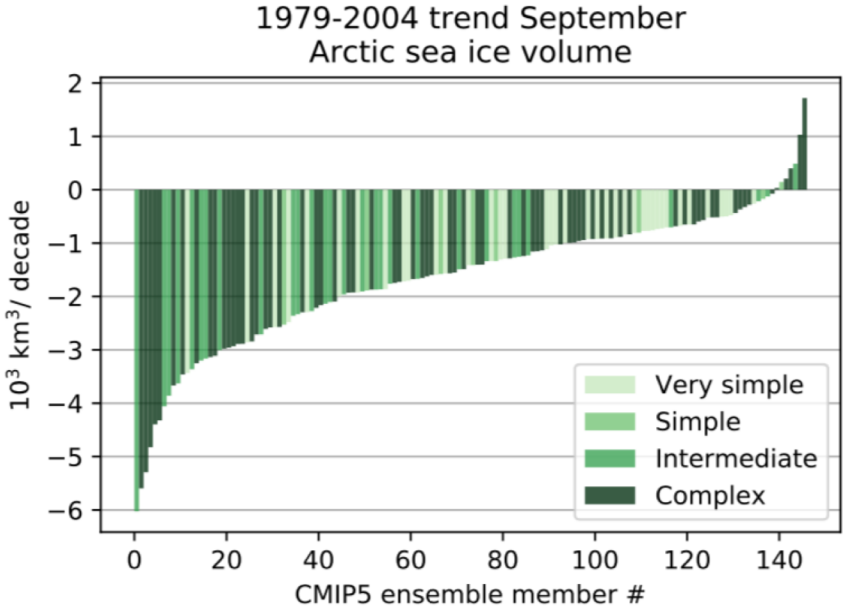
# How well do we know about sea ice thermodynamics ?

- **o** Conservation of mass and (latent+sensible) heat
- **o** Phase composition (ice, brine, minerals)
- **o** Enthalpy — *q(S,T)*
- **o** Thermal conductivity — *k(S,T)*
- **o** Salt dynamics — *dS/dt*

- How well do we know sea ice phase composition?
- **When and for which purposes do we need thermodynamic sea ice model complexity ?**
- How should we treat this contradiction in terms of model development ?

# Yet climate models seem insensitive to thermodynamic complexity




Courtesy François Massonnet, from Notz et al (in revision)

# So what ?

- No need for complicated ice thermo to understand the basics of climate problem
- Benefits from refined thermodynamic representation of sea ice — in terms of impacts
- Modular models are a way to go to choose required complexity
- Remaining uncertainties: ice volume, interactions with atmosphere, and ocean