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# Sea-ice in the snow microwave radiative transfer model

Slides (mostly) courtesy Ghislain Picard

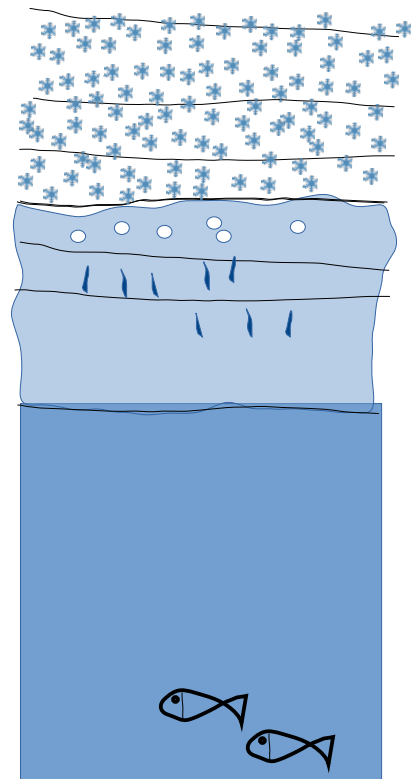
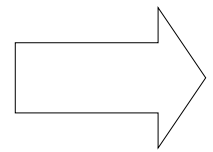
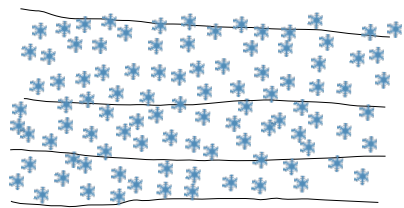


# Goal:

Before

After

Snow



Saline snow

Ice, brine, bubbles, ...

Saline water

Picard et al., 2018

Lake Ice: Murfitt et al., 2022

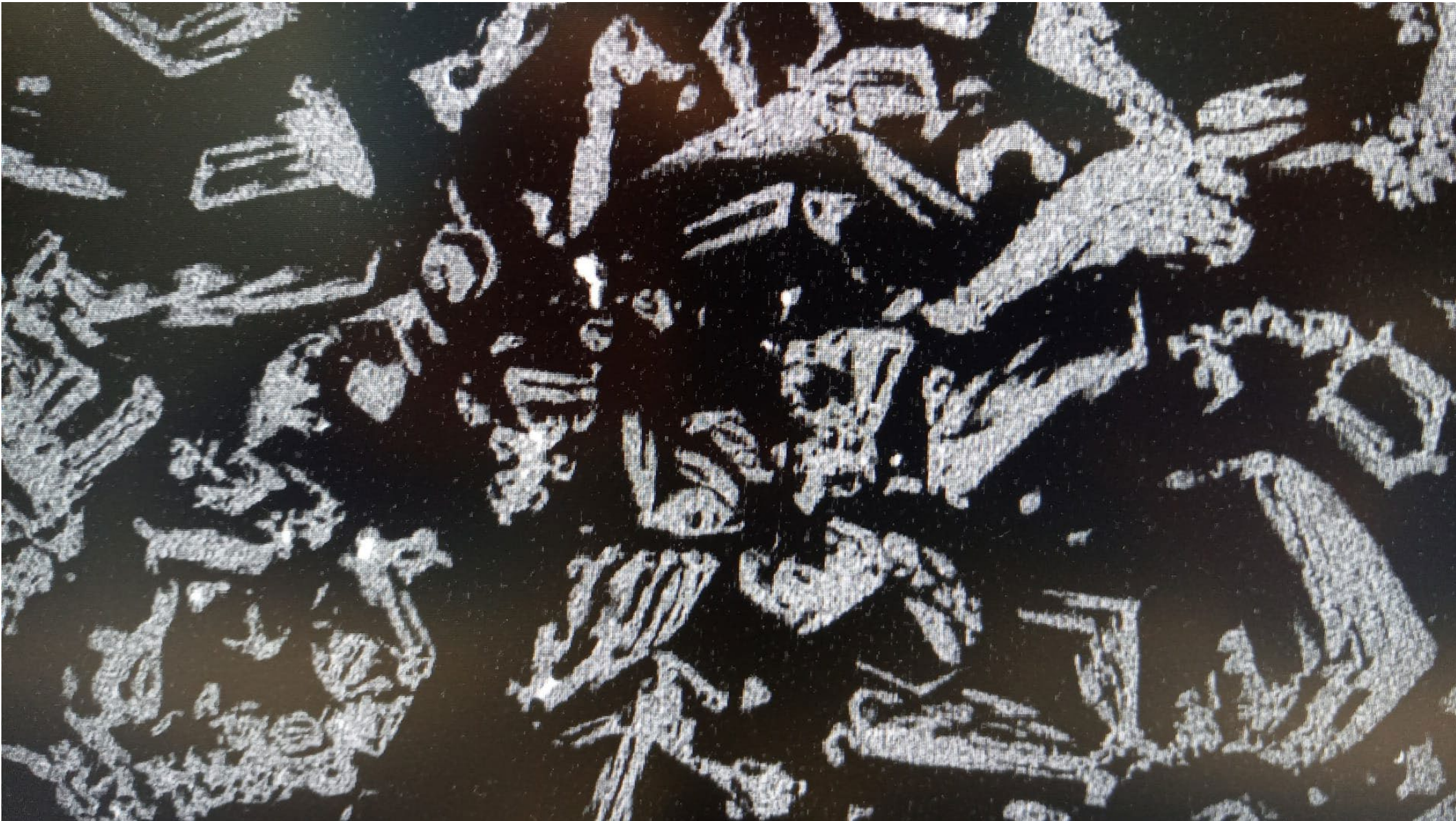
Sea Ice: Soriot et al., 2022



## A note on snow salinity:

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Brine inclusions within snow matrix as viewed by x-ray tomography:



In SMRT => change permittivity (see practical)

# Snow Microwave Radiative Transfer (SMRT)

## Sea water:

It is a homogeneous medium

→ implement saline water permittivity formulation proposed in the literature

## Sea-ice:

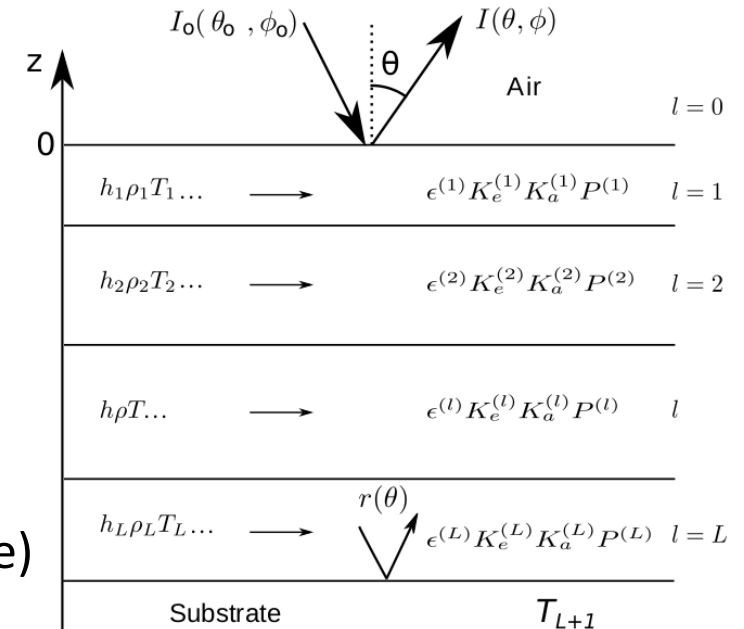
It is a multi-phase random medium

→ implement effective permittivity + random scatterers

Electromagnetic theories in SMRT are versatile, but are limited to bi-phase media.

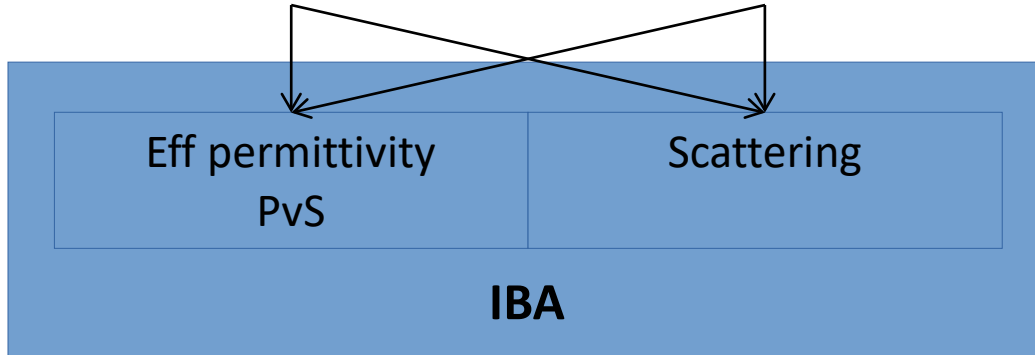
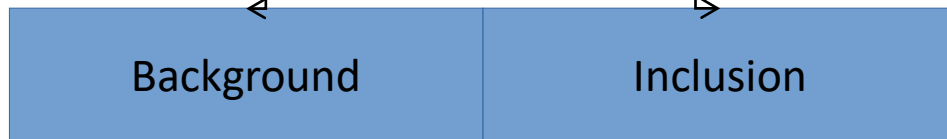
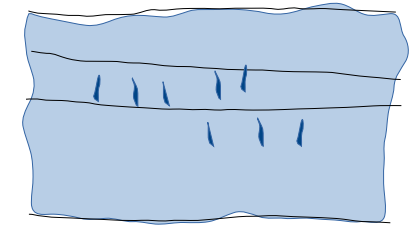
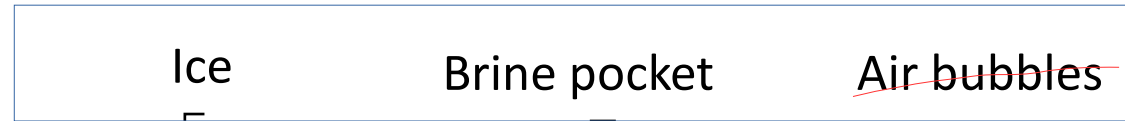
Our approach:

- three-phase random media have not been considered
- neglect one phase when possible (e.g. first year sea-ice)
- merge phases intelligently (e.g. multi-year sea ice)



# Modeling sea-ice

## First year sea-ice

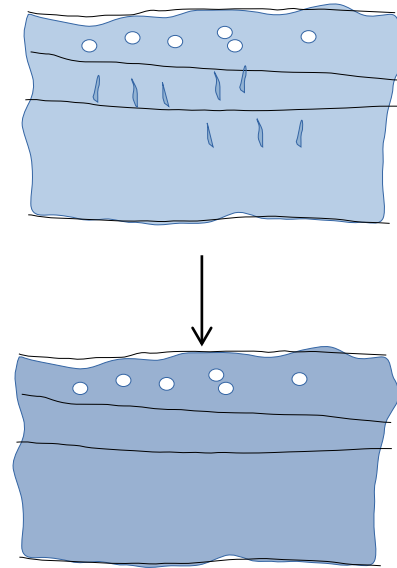
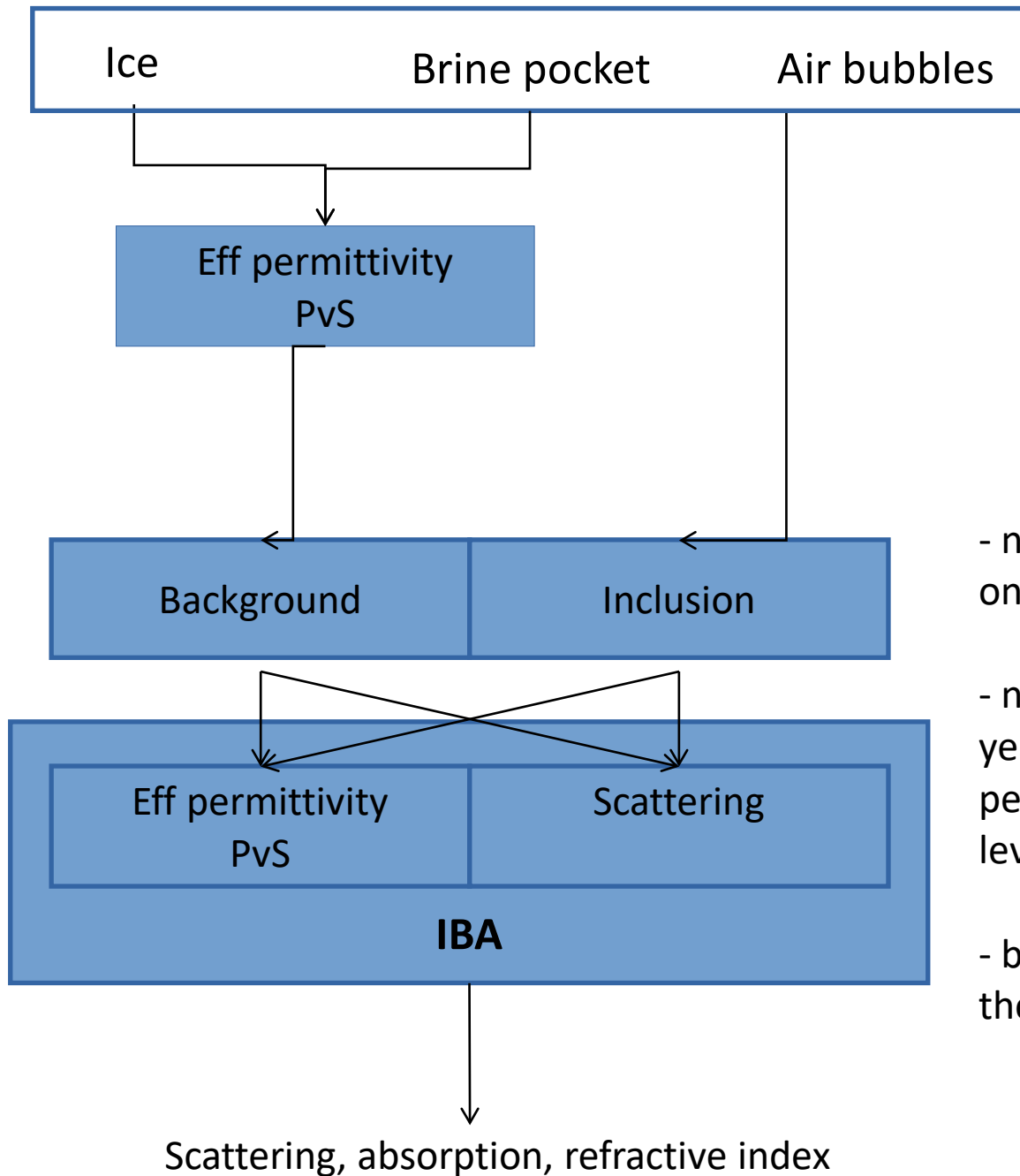


Scattering, absorption, refractive index



# Modeling sea-ice

## Multi year sea-ice



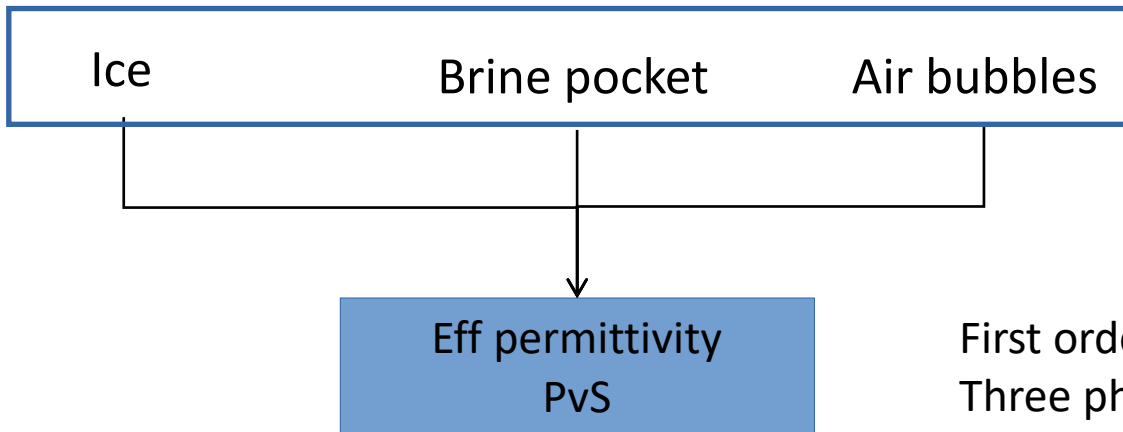
- no scattering by brine pockets, but their effect on the absorption is taken into account

- no 'continuity' between first year and multi year sea-ice, **except for low frequencies?** (if Eff permittivity uses the same formula at both levels)

- but no better solution has been proposed in the past (to our knowledge)

# Modeling sea-ice

## 3 phase?



First order scattering only

Three phases need to be random and symmetrical

FYI may be ok. Not wet snow.

`polder_van_santen_three_spherical_components(f1, f2, eps0, eps1, eps2)`

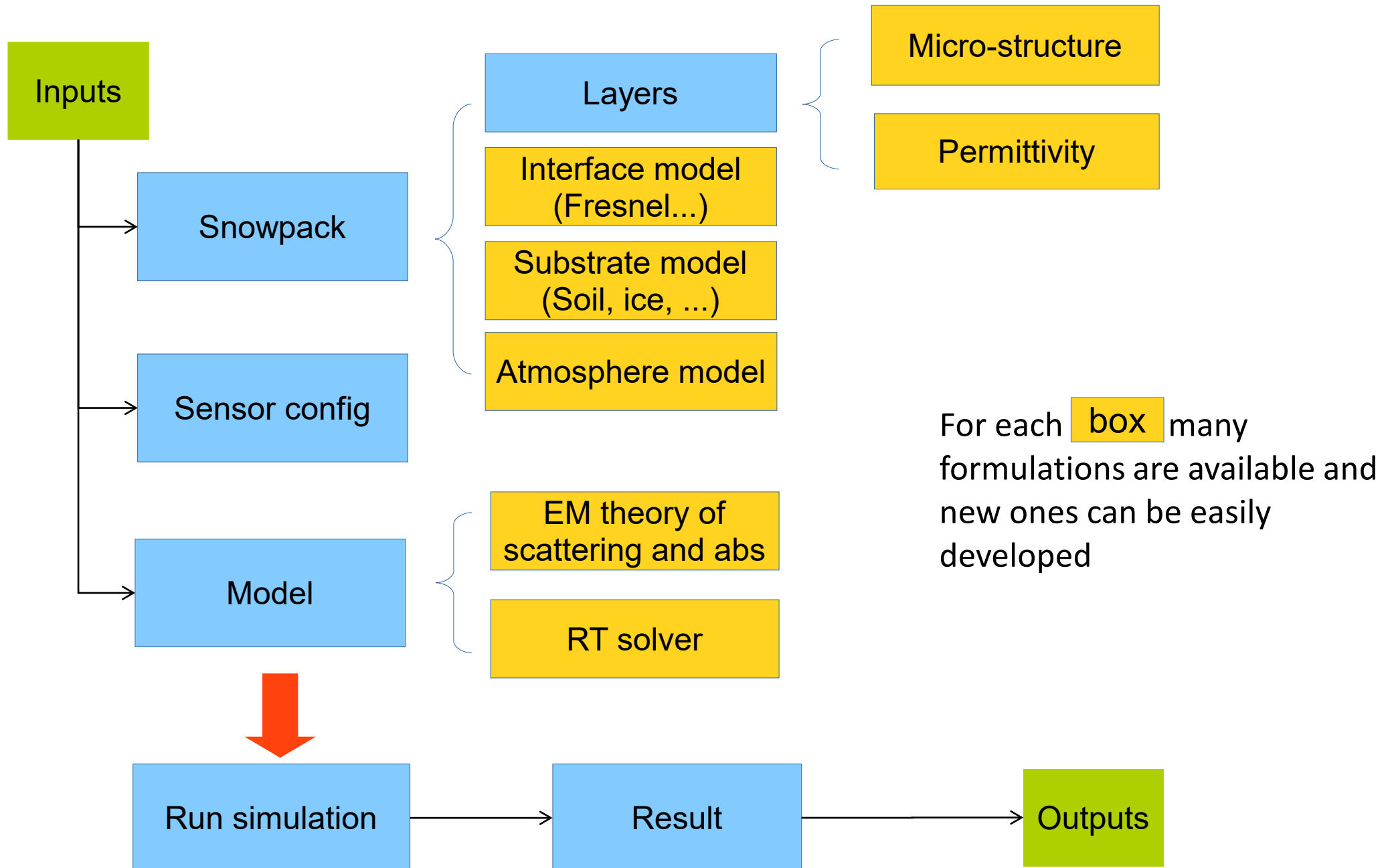
Calculates effective permittivity using Polder and van Santen with three components assuming spherical inclusions

### Parameters:

- **f1** – fractional volume of component 1
- **f2** – fractional volume of component 2
- **eps0** – permittivity of material 0
- **eps1** – permittivity of material 1
- **eps2** – permittivity of material 2

# Implementation

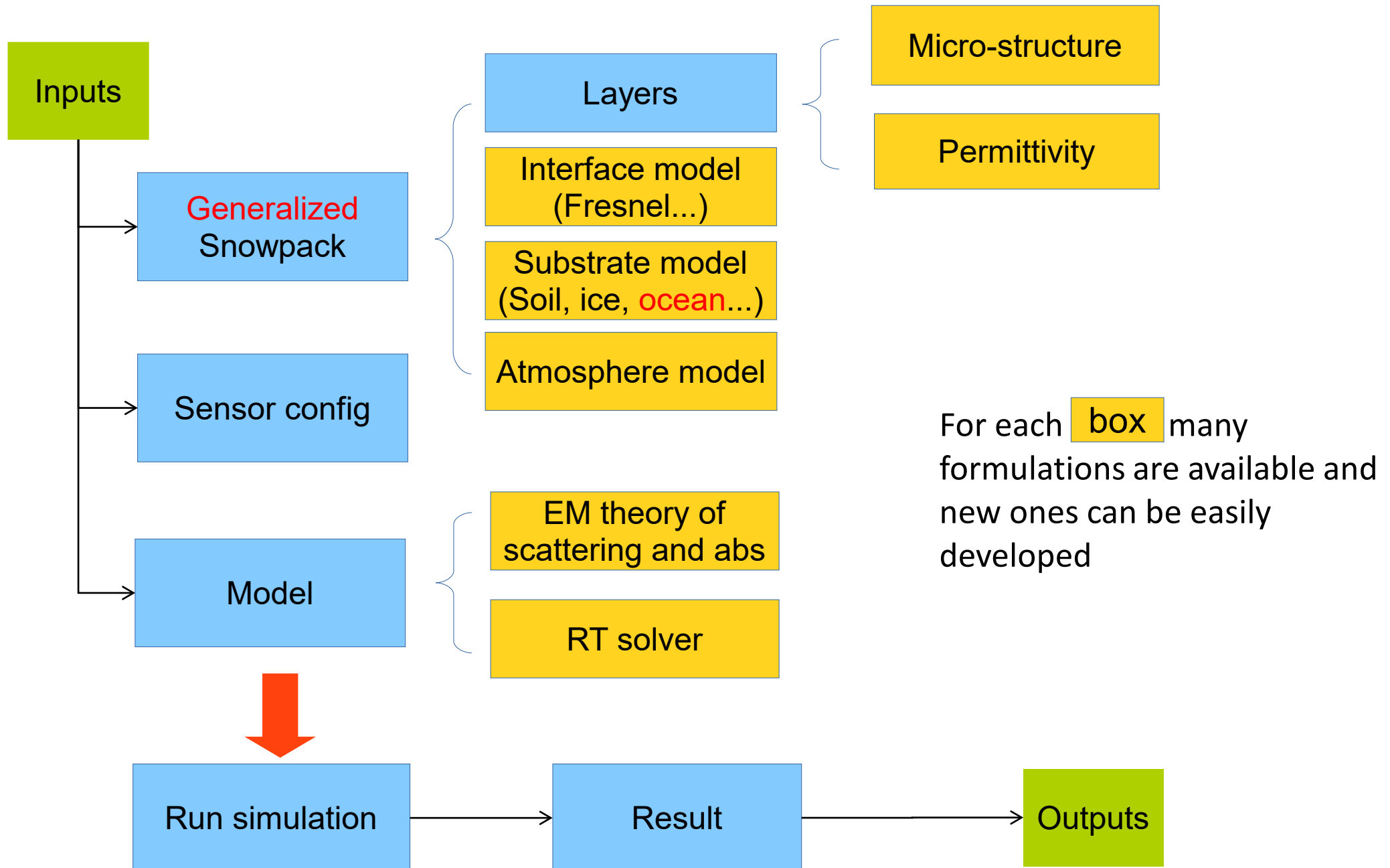
Structure of SMRT **before sea-ice**:





# Implementation

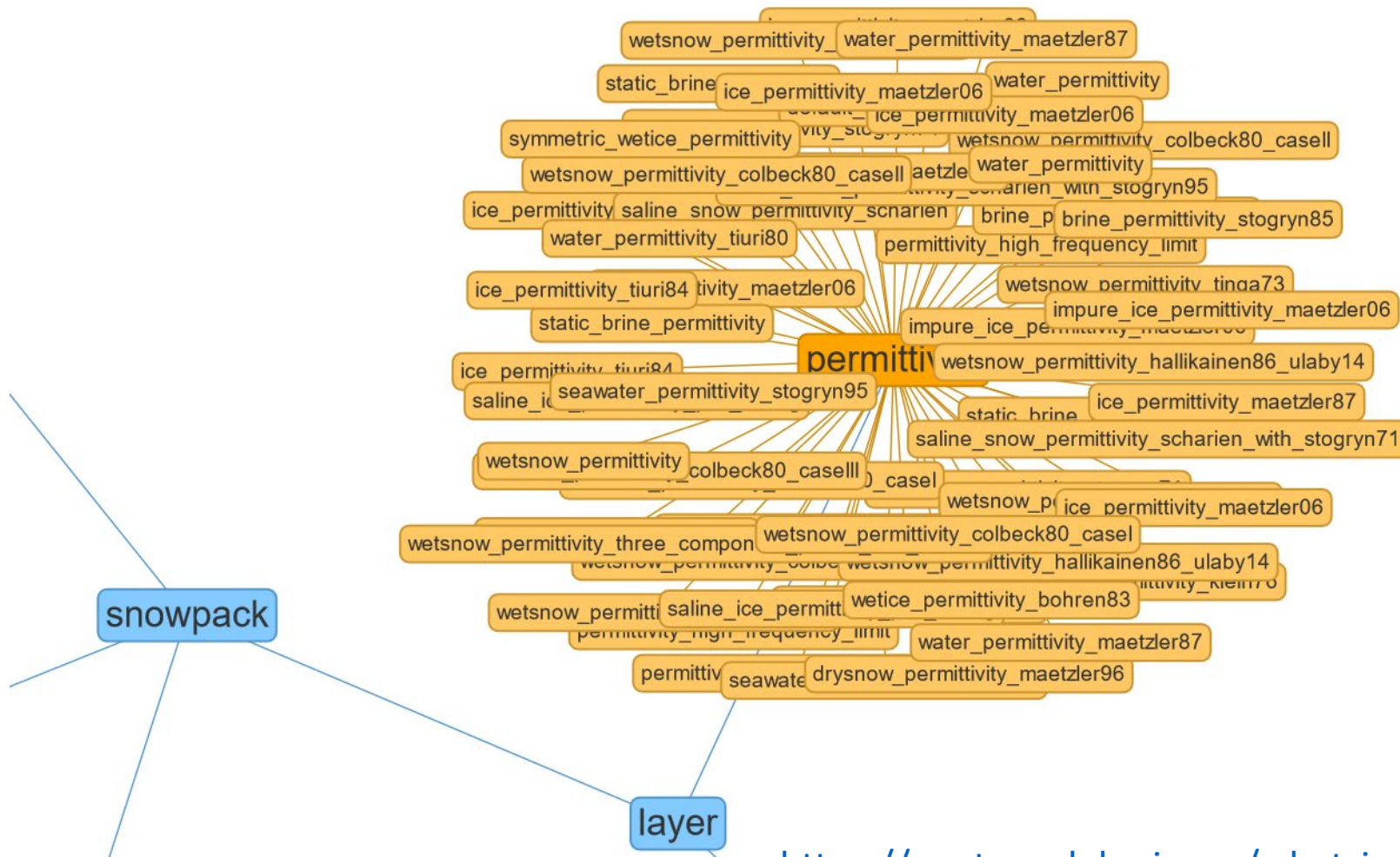
Structure of SMRT after sea-ice:



# Implementation

**1<sup>st</sup> step:** Many new permittivity formulation in SMRT contributed by: Ludovic Brucker, Nina Maass, Mai Winstrup

- saline snow, saline ice and sea-water with documentation, references, etc...



**2<sup>nd</sup> step:** `make_ice_column` function, contributed by: Nina Maass, Mai Winstrup

```
make_ice_column(ice_type, thickness, temperature, microstructure_model, brine_inclusion_shape='spheres', salinity=0.0,
brine_volume_fraction=None, brine_permittivity_model=None, ice_permittivity_model=None, saline_ice_permittivity_model=None,
porosity=0, density=None, add_water_substrate=True, surface=None, interface=None, substrate=None, atmosphere=None,
**kwargs)
```

Build a multi-layered ice column. Each parameter can be an array, list or a constant value.

`ice_type` variable determines the type of ice, which has a big impact on how the medium is modelled and the parameters: - First year ice is modelled as scattering brines embedded in a pure ice background - Multi year ice is modelled as scattering air bubbles in a saline ice background (but brines are non-scattering in this case). - Fresh ice is modelled as scattering air bubbles in a pure ice background (but brines are non-scattering in this case).

First-year and multi-year ice is equivalent only if scattering and porosity are nulls. It is important to understand that in multi-year ice scattering by brine pockets is neglected because scattering is due to air bubbles and the emmodel implemented up to now are not able to deal with three-phase media.

- Parameters:**
- `ice_type` – Ice type. Options are “firstyear”, “multiyear”, “fresh”
  - `thickness` – thicknesses of the layers in meter (from top to bottom). The last layer thickness can be “numpy.inf” for a semi-infinite layer.
  - `temperature` – temperature of ice/water in K

A lot of effort and common discussion to :

- make the names of the function and arguments as clear and unambiguous as possible
- choose the most adequate default for beginners
- allow fine tuning of many aspects for experts

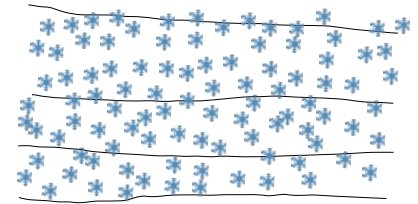
# Implementation

3<sup>rd</sup> step: The « plus » operator

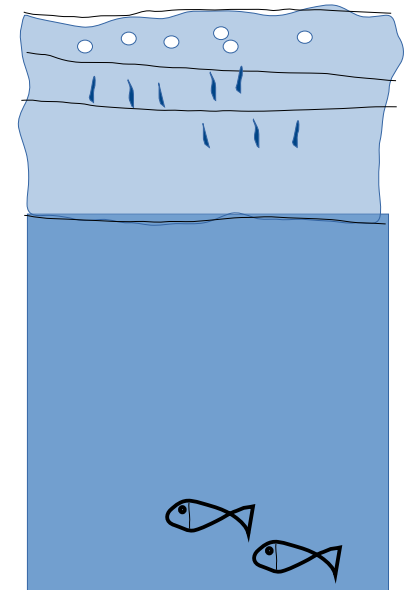
```
# create the snowpack
snowpack = make_snowpack(thickness=thickness_s,
                        microstructure_model="exponential",
                        density=density_s,
                        temperature=temperature_s,
                        corr_length=p_ex_s)

# create the sea-ice
ice_column = make_ice_column(ice_type=ice_type, thickness=thickness,
                             temperature=temperature,
                             microstructure_model="exponential",
                             brine_inclusion_shape="spheres",
                             salinity=salinity,
                             porosity=porosity,
                             corr_length=p_ex,
                             add_water_substrate="ocean"
                             )

# add snowpack on top of ice column:
medium = snowpack + ice_column
```



+



= sea-ice

# Summary

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**First year sea ice:** brine scatterers in pure ice background

**Multi year sea ice:** air bubble scatterers in slightly saline background

**Additive layers.** If you want:

medium = atmosphere + make\_snowpack + make\_ice\_column + make\_water\_body

**Many permittivity formulations:** choice may matter!

**Read the documentation:** [smrt.readthedocs.io](http://smrt.readthedocs.io)

In tutorials:

- Make and compare FYI / MYI sea ice layers
- Change sea ice permittivity
- Add snow salinity

