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Is Soil Ice Content Detectable from Remote Sensing?
Is Soil Ice Content Detectable? – A Case at Tibetan Plateau

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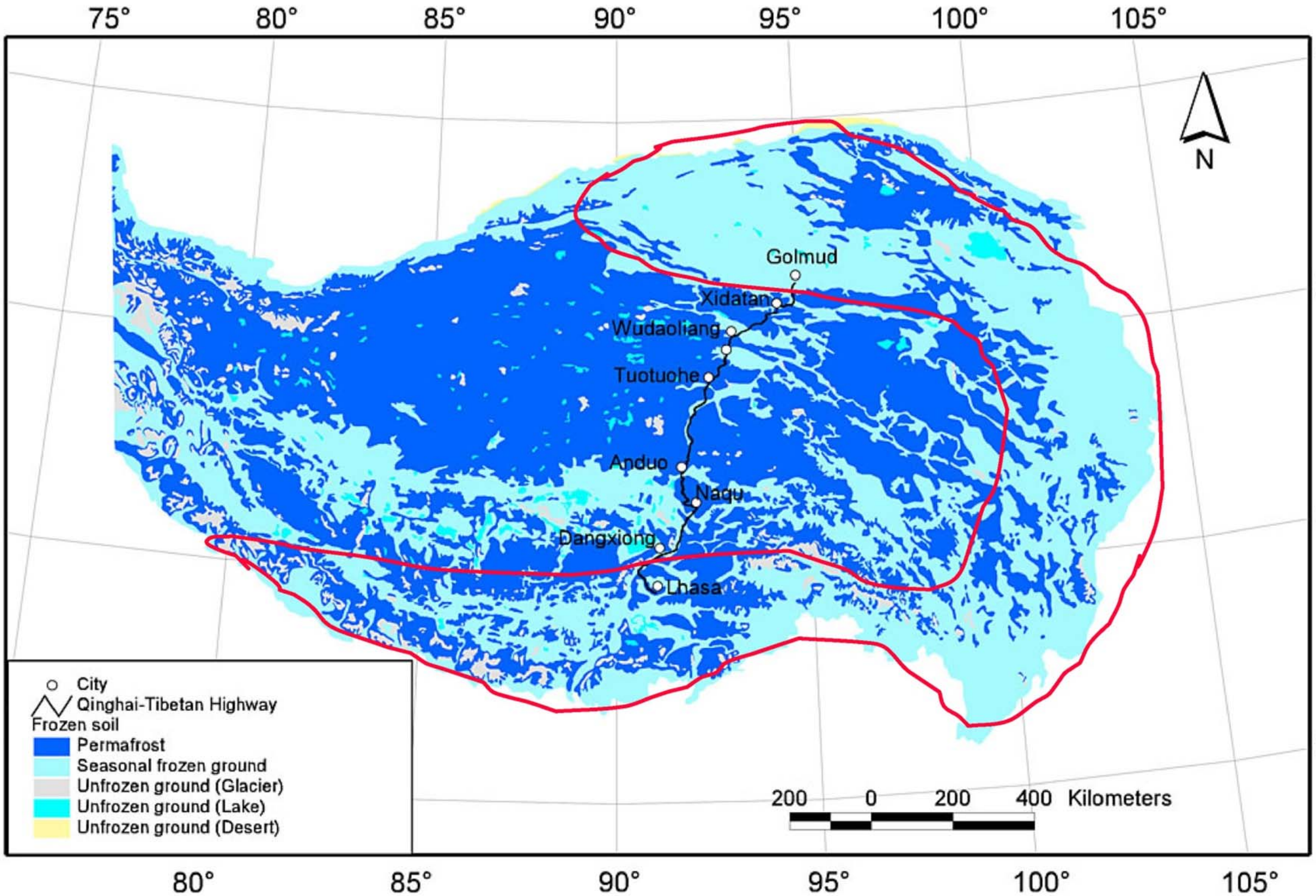
OUTLINES

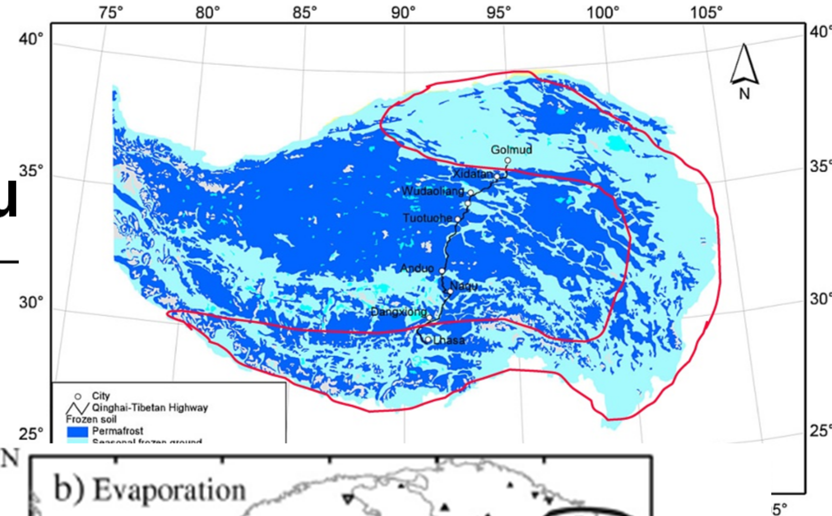
- **Permafrost over Tibetan Plateau and its Implications;**
- **Why Soil Ice Content? – The Need for Integrated Approach**
- **Current progress: (how to detect SIC)**
  - **Laboratory;**
  - **Field;**
  - **Remote Sensing;**

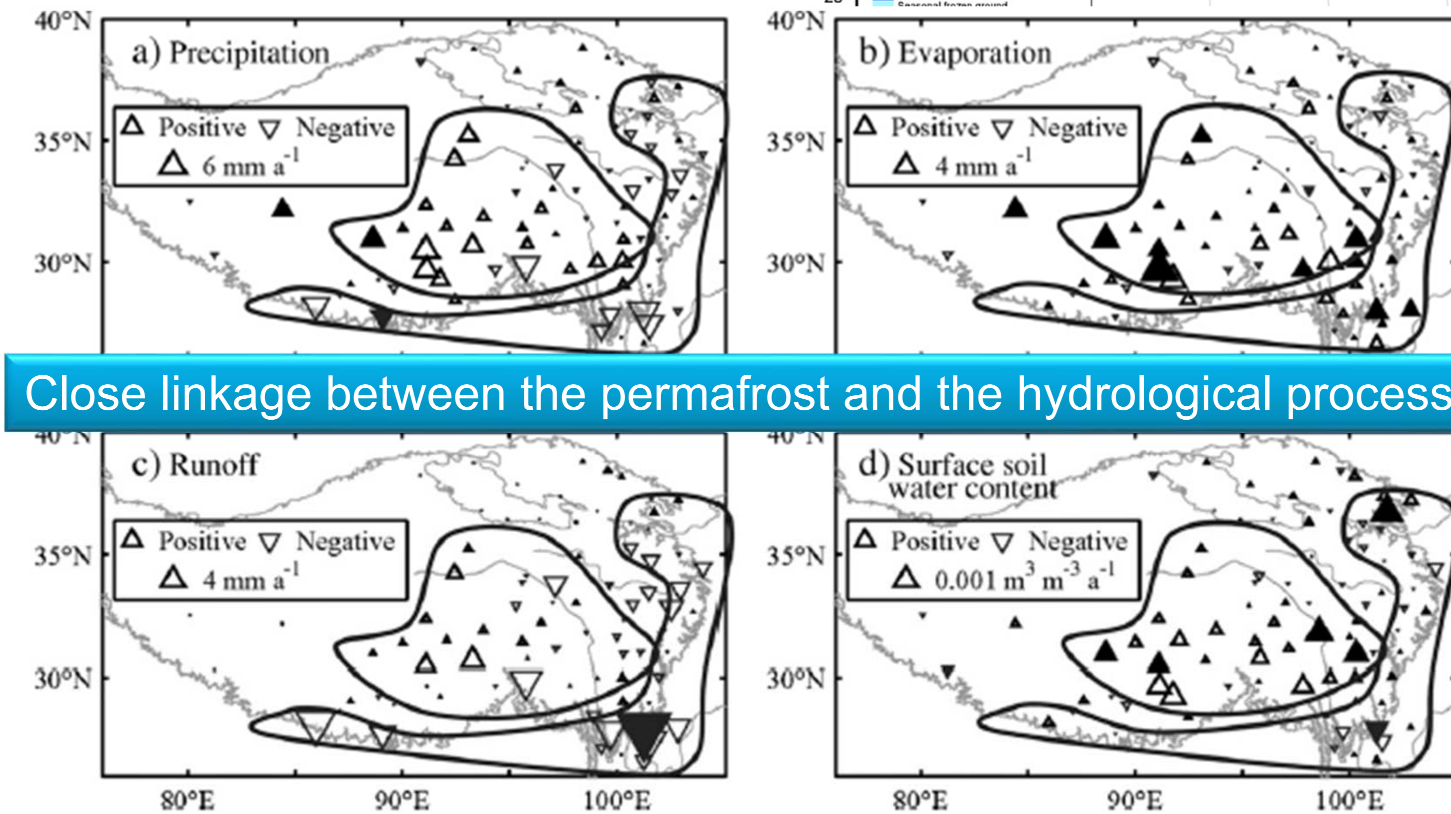
Permafrost over Tibetan Plateau



Permafrost over Tibetan Plateau

(K. Yang et al. 2014, GPC)

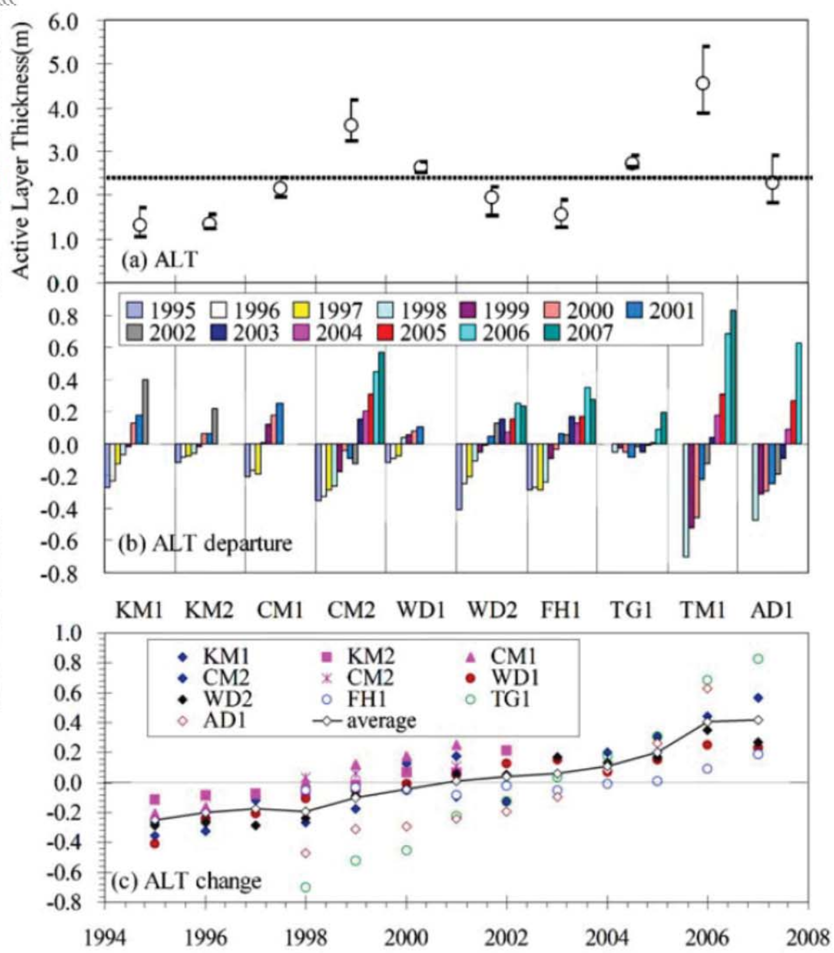




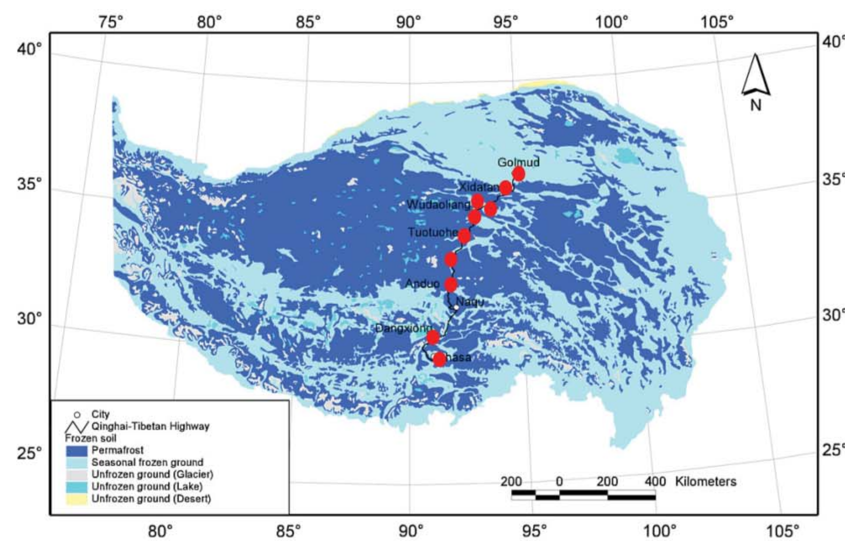
Close linkage between the permafrost and the hydrological processes!

Fig. 9. Trend slope in annual mean values of observed precipitation, simulated evaporation, runoff and soil moisture at the Plateau CMA stations over 1984–2006 (modified from Fig. 4 in Yang et al., 2011c). The solid triangle symbol indicates a trend passing the t-test ($p < 0.05$) and its size indicates the magnitude of the trend.

Decadal changes of permafrost degradation

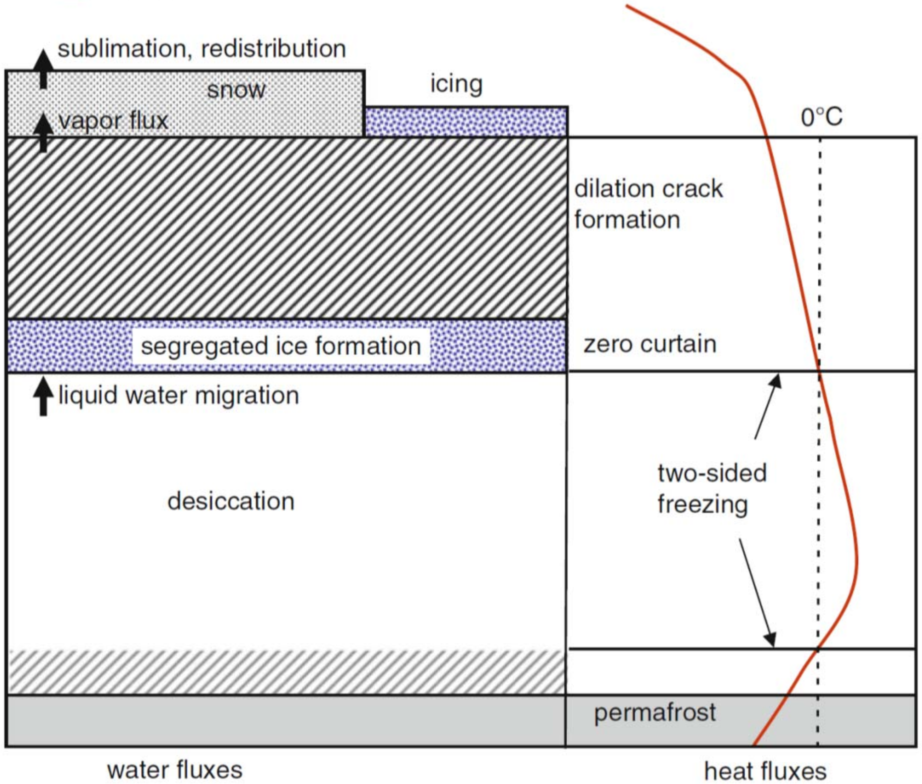


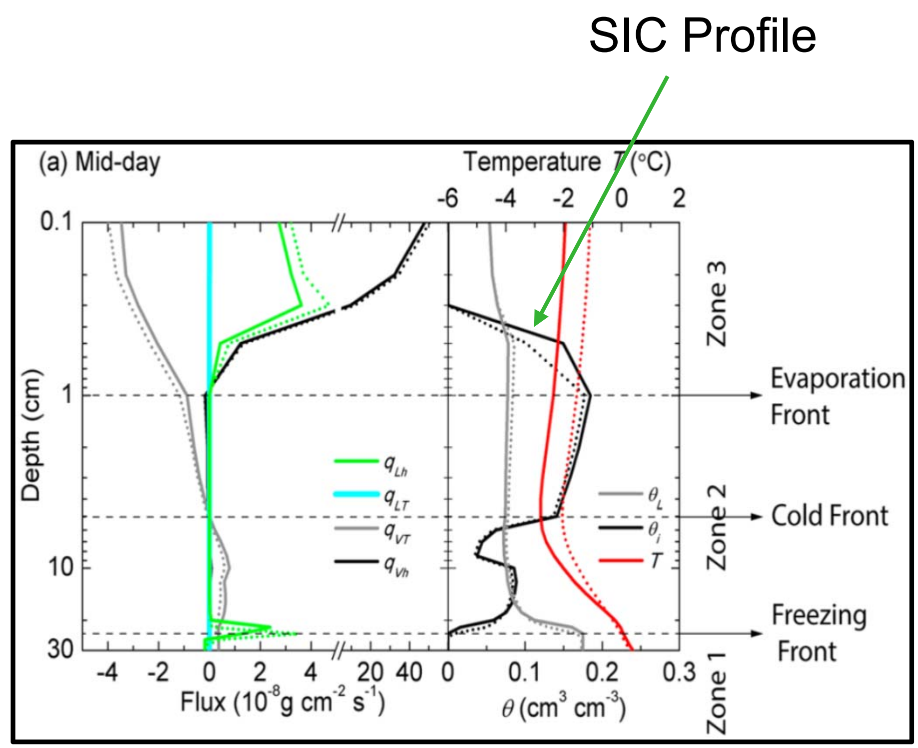
The annual change of Active Layer Thickness is at mm - cm scale.



(Wu & Zhang, 2010, JGR)

Soil ice content enables tracking ALT changes at mm-cm scale





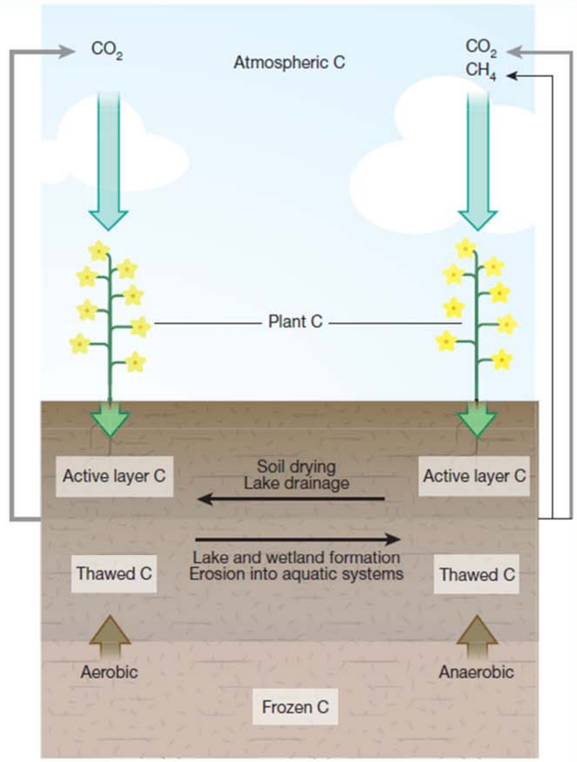
Hydrologic and thermal conditions of the active layer during freeze-back and winter periods

(Ming-ko Woo, 2012, Permafrost Hydrology)

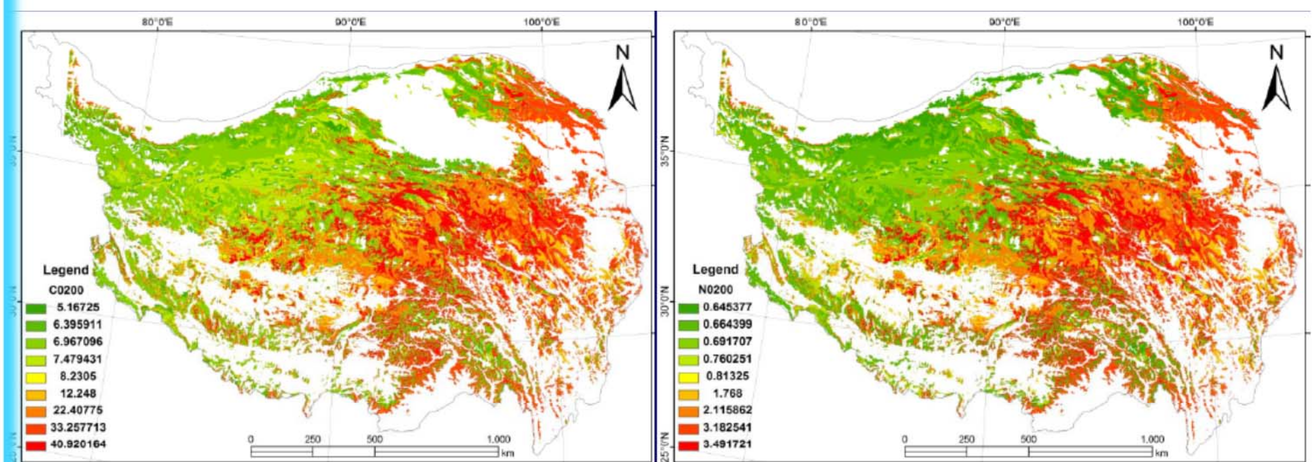
With Soil Ice Content (SIC), one can see exactly how the active layer is freezing back.

STEMMUS-FT Model (YU, Zeng & Su, 2018, JGR)

Potential permafrost carbon feedback over Tibetan Plateau



Box 1 Figure | Key features regulating the permafrost carbon feedback to climate from new, synthesized observations.

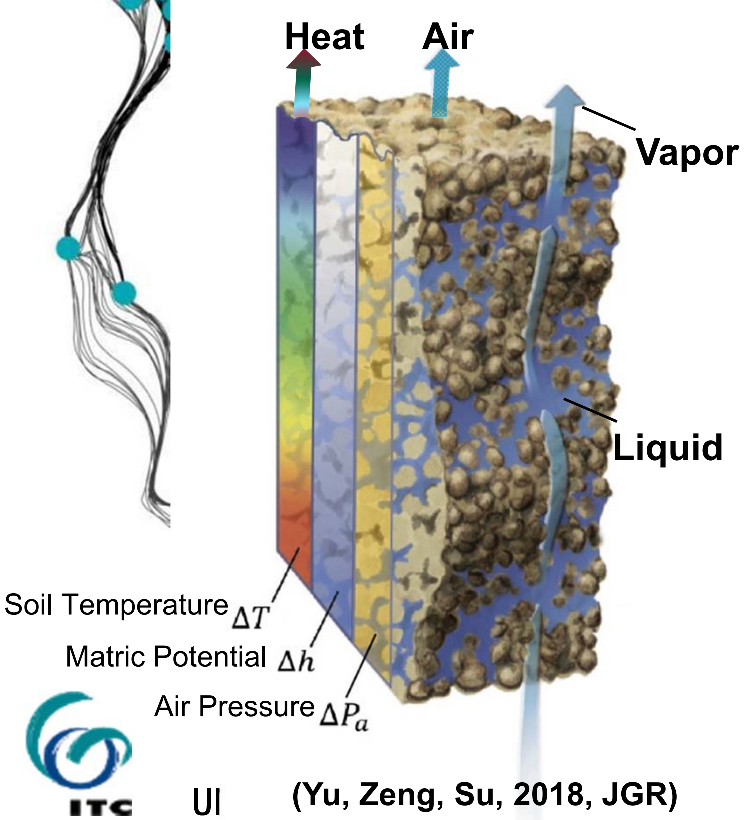


Total carbon : 25.4-26.5 Pg   Total nitrogen : 2.0-2.4 Pg

With Soil Ice Content, the ALT change can be tracked at mm-cm scale, which is expected to improve the estimate of permafrost carbon feedback.

Do we need to detect soil ice content with such details?

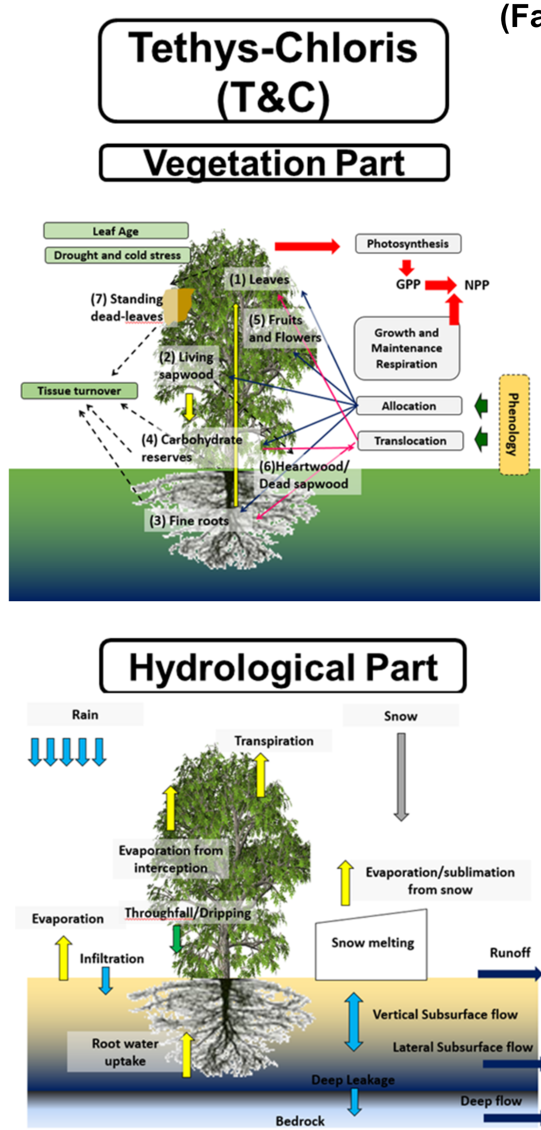
STEMMUS - FT



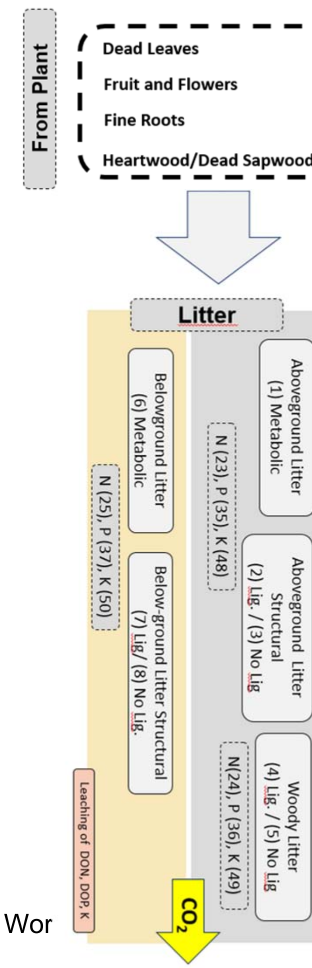
(Yu, Zeng, Su, 2018, JGR)

+

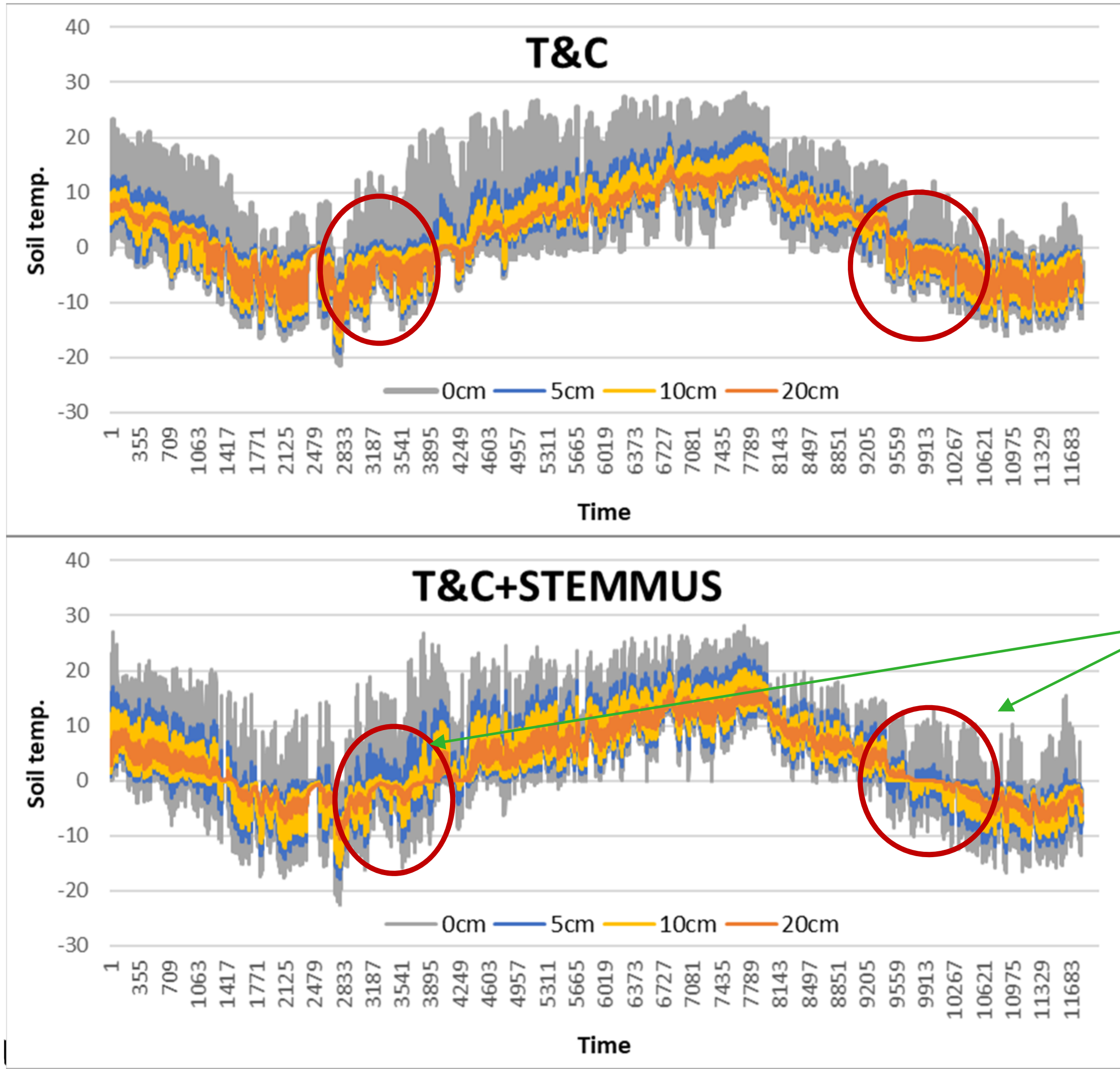
(Fatichi, et al. 2012, ETH)



55 prognostic pools



Do we need to detect soil ice content with such details?



The seasonal soil temperature variations can be clearly observed in both simulations.

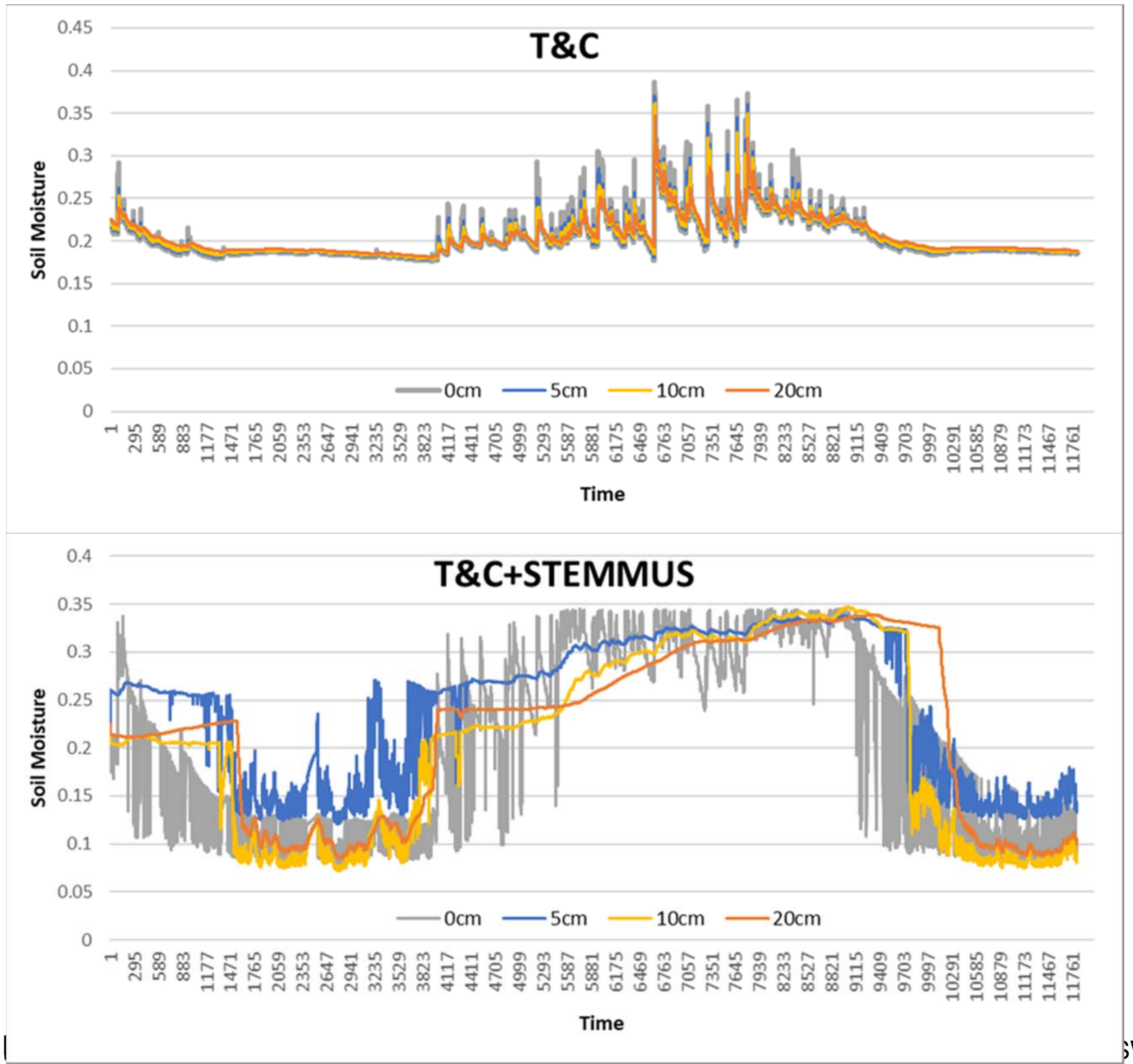
Although the amplitude of surface temperature variation is the same for the two runs, as temperature propagates downwards, the fluctuation of soil temperature start to differ at deeper soil.

(YU, Zeng & Su, 2019, unpublished)

Zero Curtain

Zero-curtain effect is that the phase transition rate is slowed down due to latent heat release/absorption, resulting a relative flat variation of soil temperature near the freezing point temperature (i.e., zero or subzero degree).

Do we need to detect soil ice content with such details?

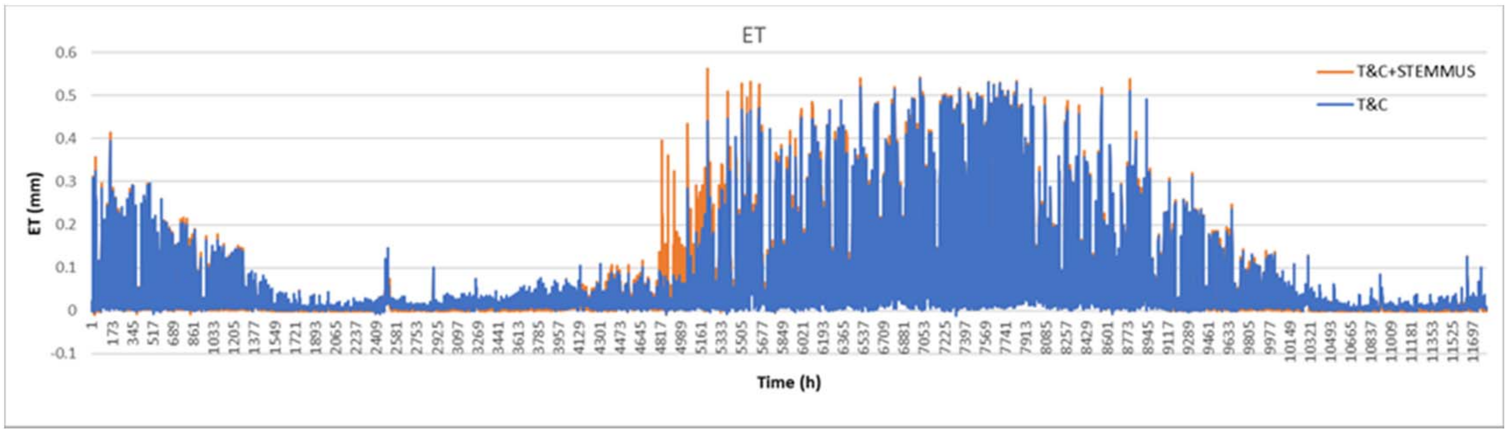


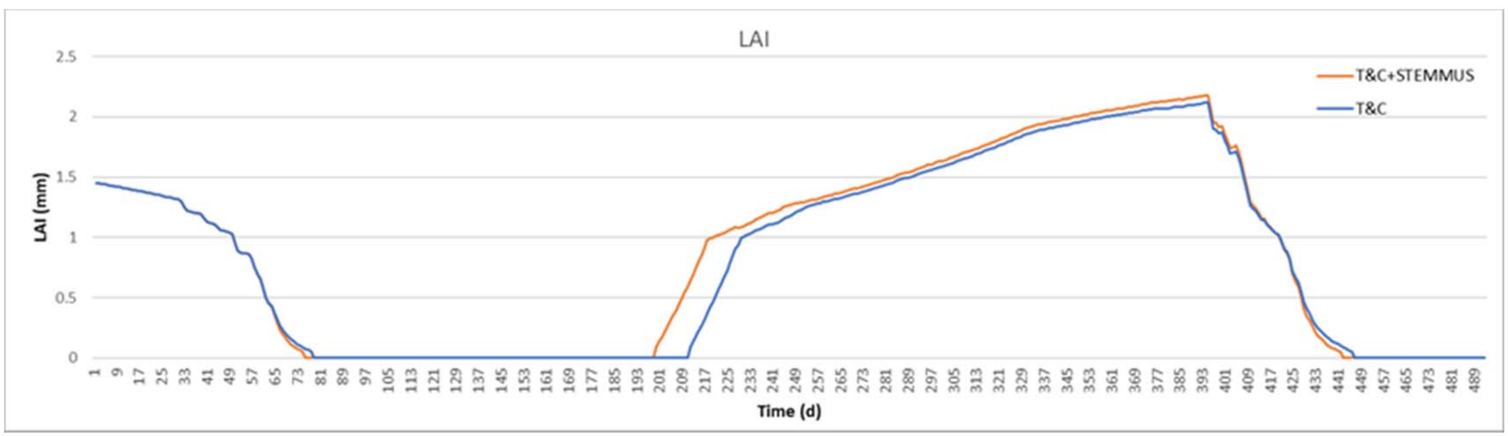
Soil moisture at different soil layers looks similar, and no significant drop at subzero temperature.

Soil moisture reduction due to ice content can be seen below the freezing temperature.

(Yu, Zeng & Su, 2019, unpublished)

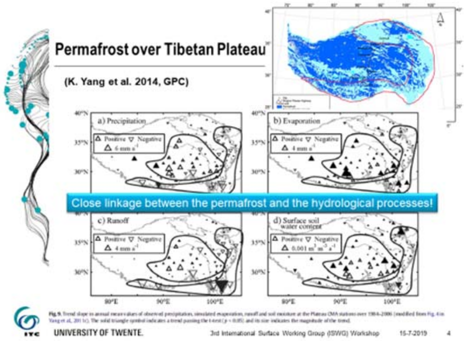
Do we need to detect soil ice content with such details?

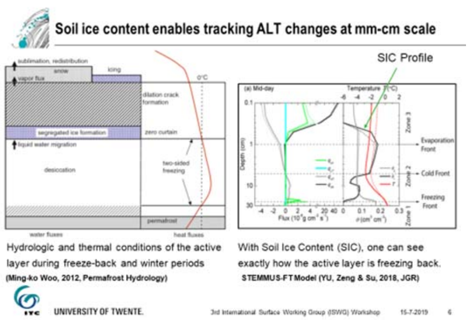


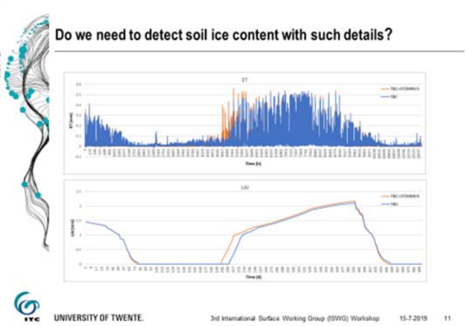


(Yu, Zeng & Su, 2019, unpublished)

Interim Conclusion/Recommendation







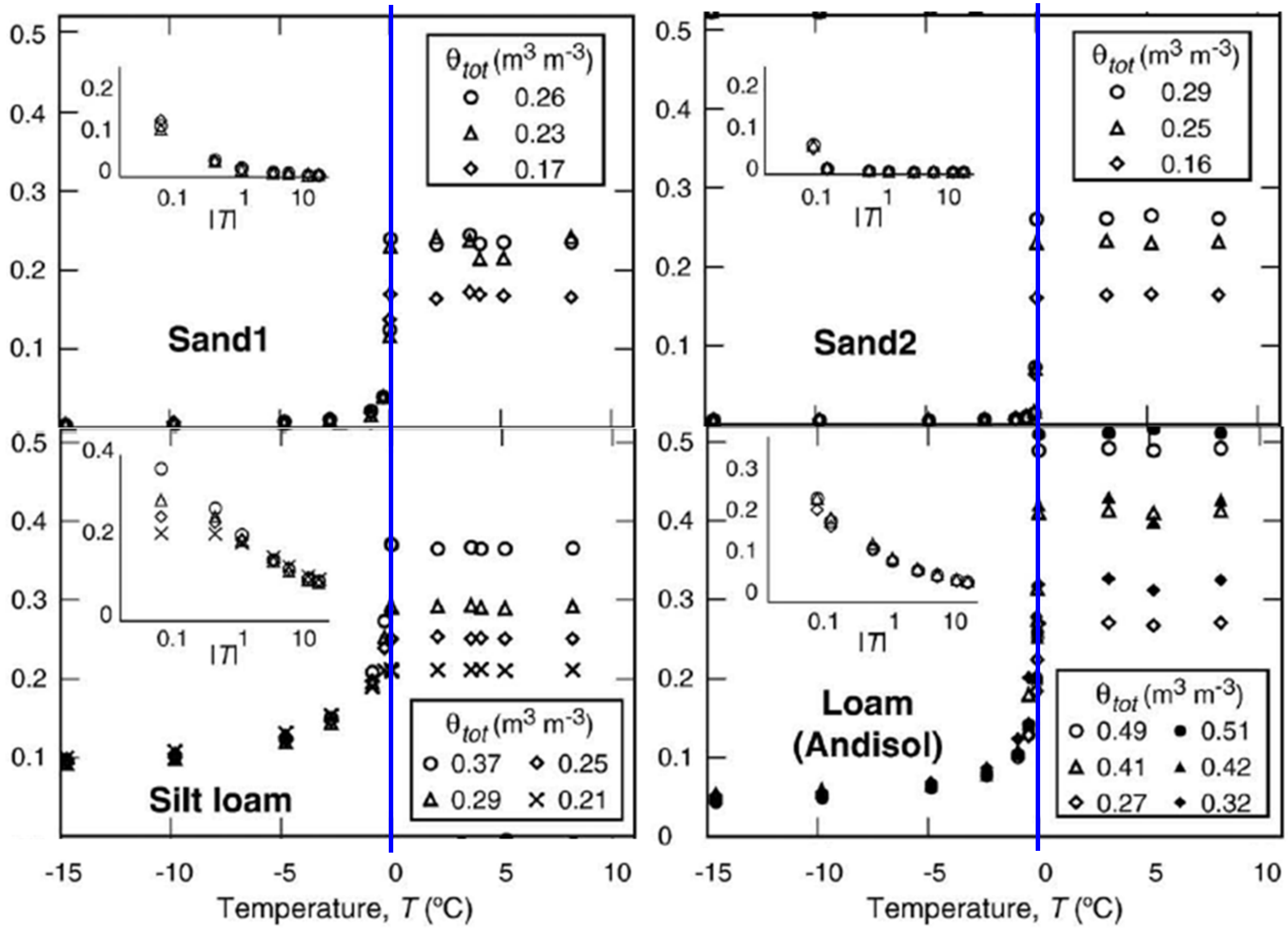
- Permafrost plays an important role in hydrological and biogeochemical processes over Tibetan Plateau;
- To track permafrost degradation (ALT changes) at mm-cm scale, we need to detect Soil Ice Content (and to understand the freeze-thaw dynamics: two-sided freezing, zero curtain effect …);
- The presence of SIC (therefore, freezing-thawing processes) affect hydro-thermal states of soil, which will subsequently influence the land surface fluxes, vegetation dynamics and relevant carbon cycles.

SIC is important to understand PCF, BUT ...

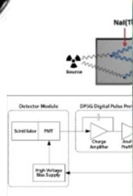
- Permafrost over Tibetan Plateau and its Implications;
- Why Soil Ice Content? – The Need for Integrated Approach
- **Current progress: (how to detect SIC)**
  - **Laboratory (NMR, Gamma Ray Attenuation, Dielectric Constant Model);**
  - **Field (Cosmic Ray Neutron Probe);**
  - **Remote Sensing (via Data Assimilation);**

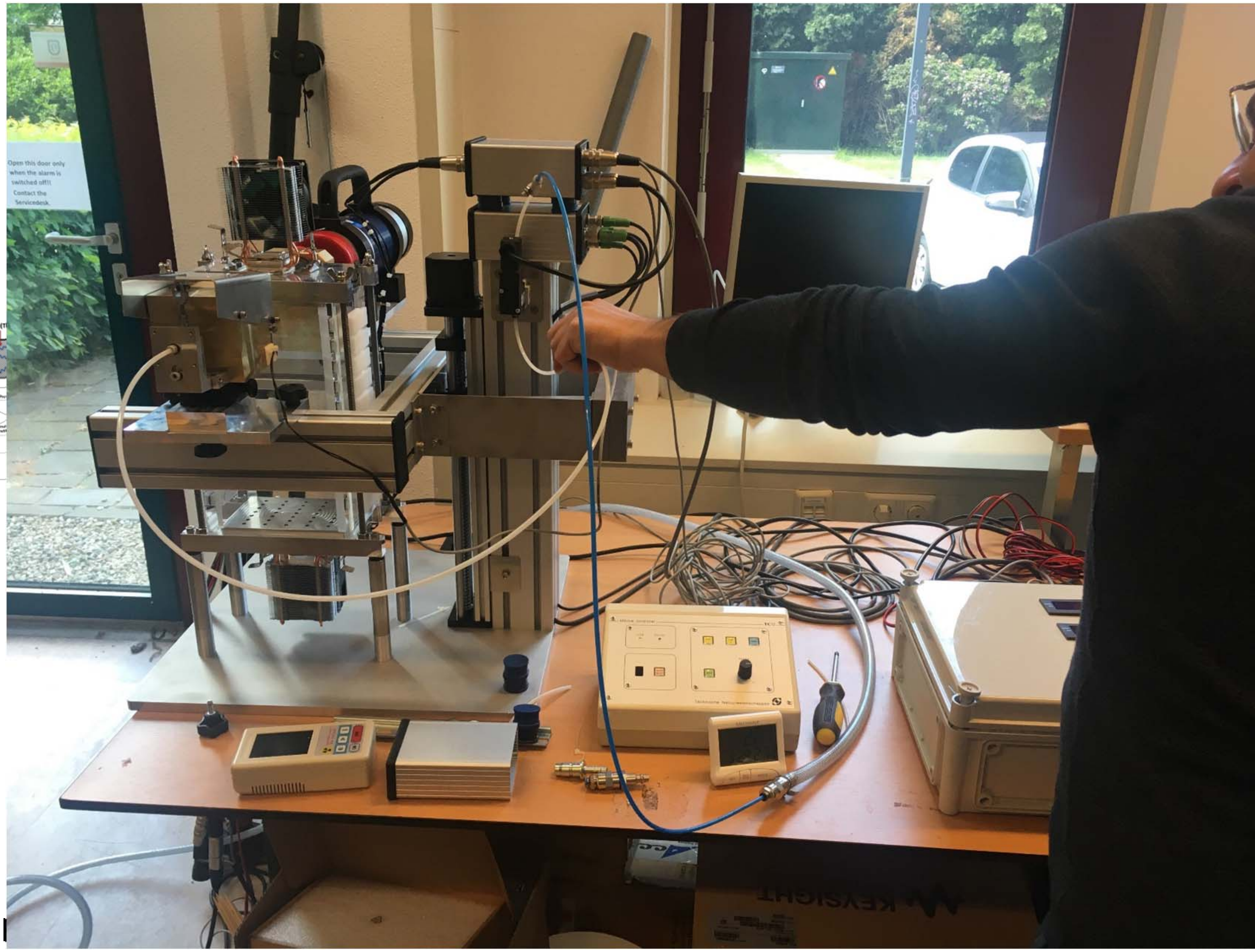
Difficult to detect soil water content (/SIC) in frozen soil (NMR – Nuclear Magnetic Resonance Method)

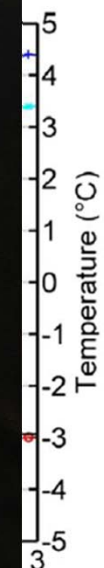
(*Watanabe et al.* 2009)



Laboratory (Gamma Ray Attenuation)







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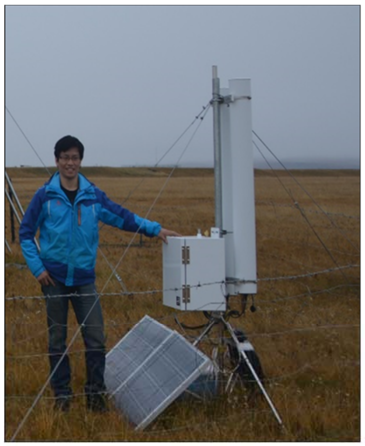
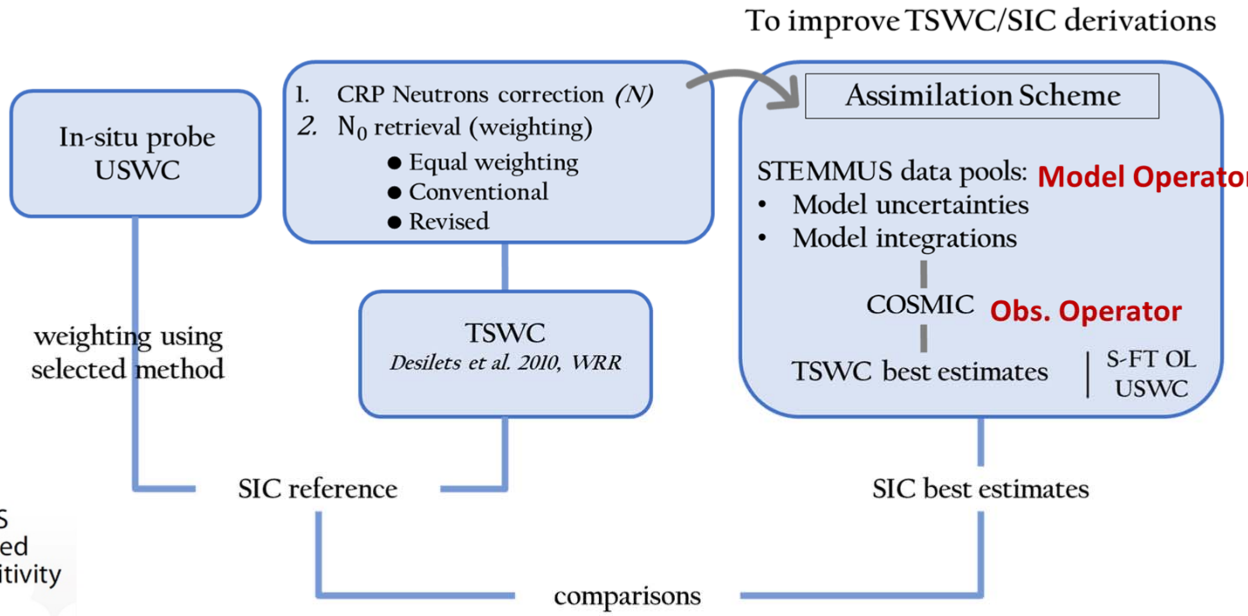
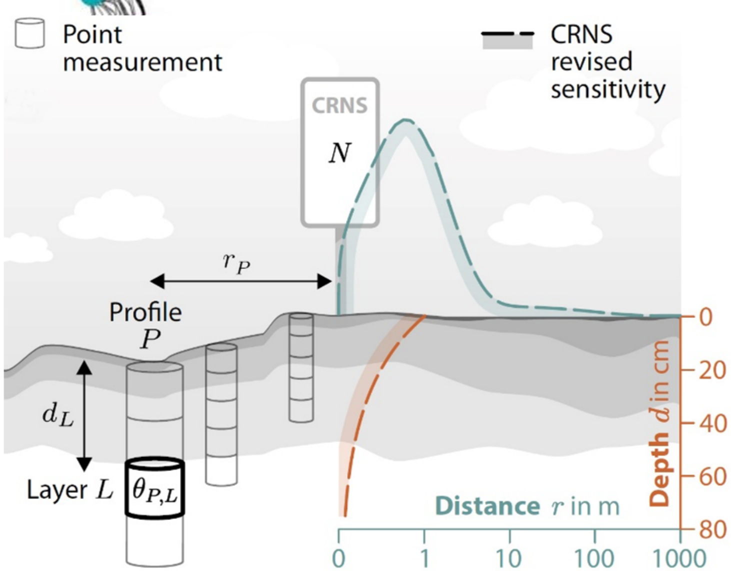
Assimilating cosmic ray neutron counts for SIC detection







(Schrön *et al.* 2017)

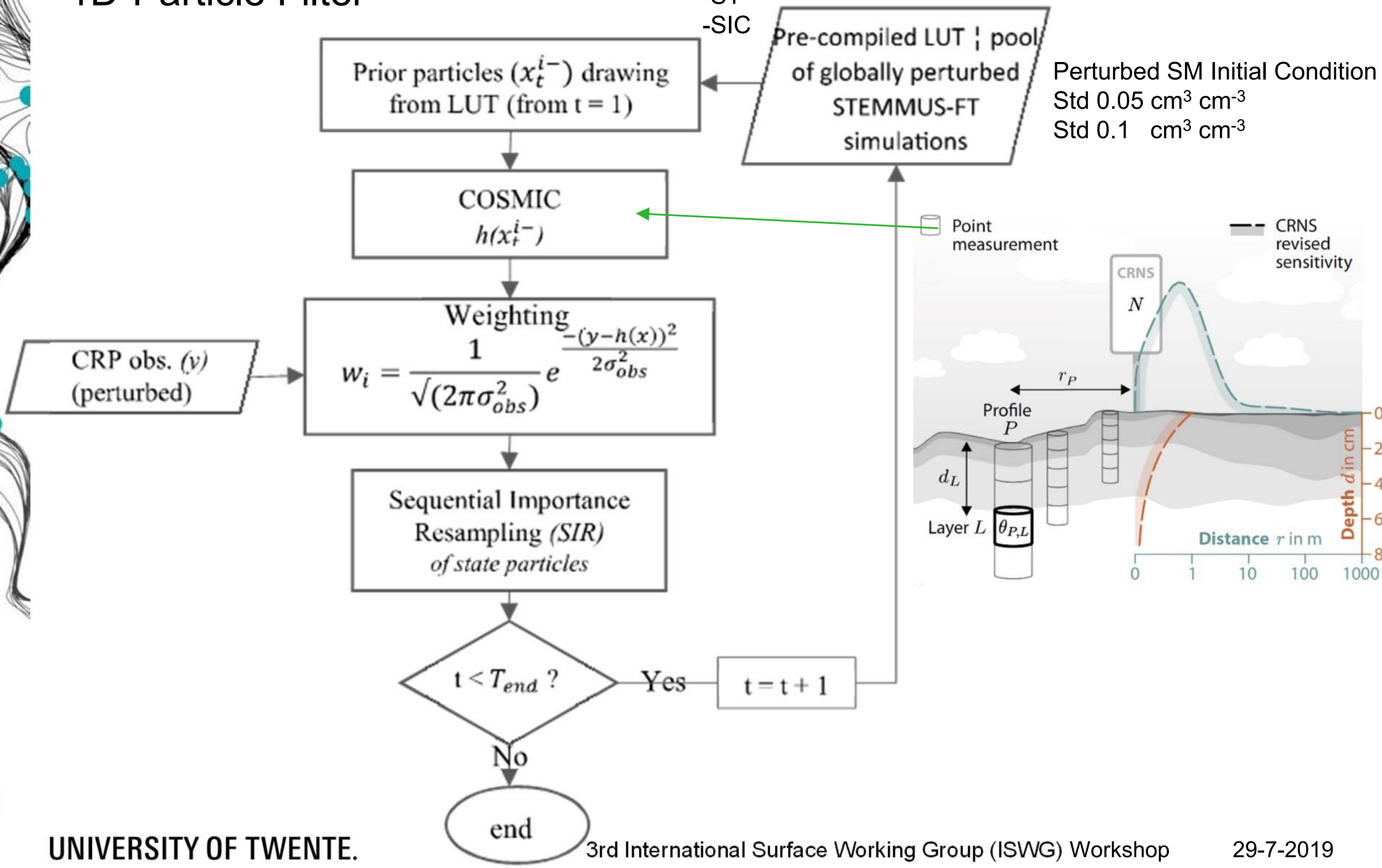
Important to know what were measured, before assimilating the neutron counts.

Assimilating cosmic ray neutron counts for SIC detection

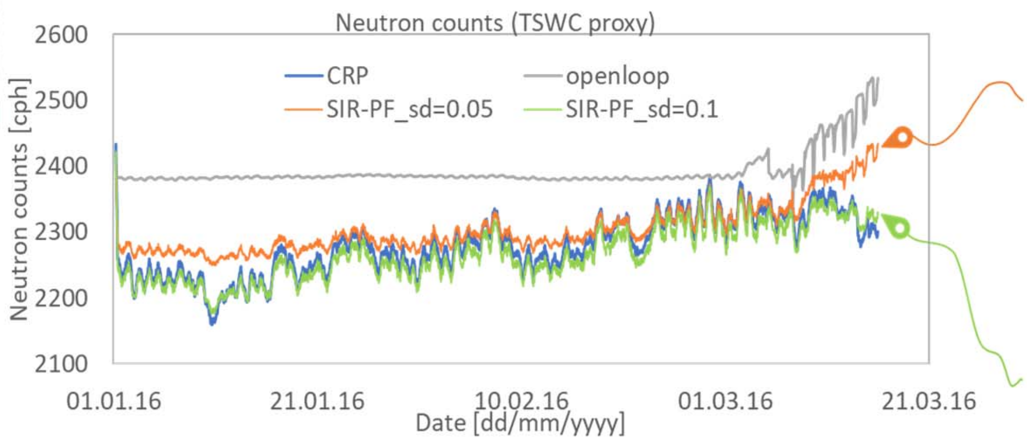
1D-Particle Filter

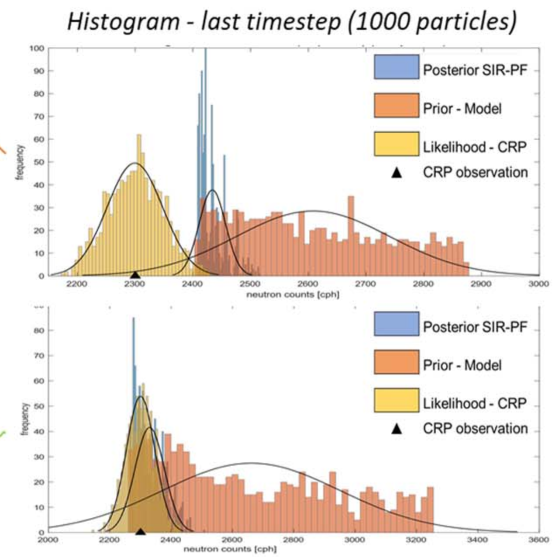
-TSWC
-ST
-SIC

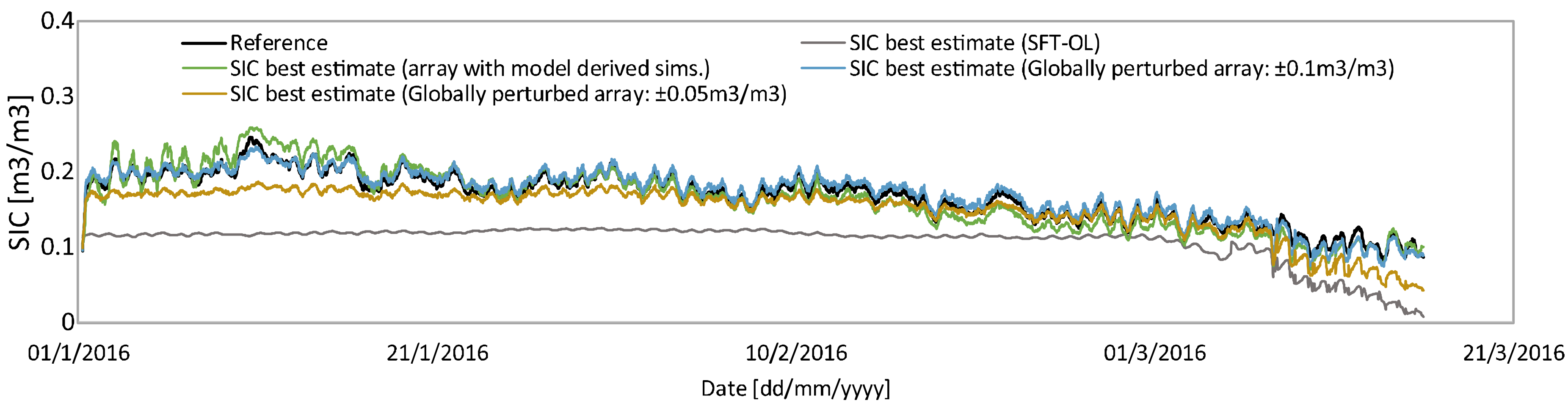
Perturbed SM Initial Condition
Std 0.05 $cm^3\ cm^{-3}$
Std 0.1 $cm^3\ cm^{-3}$



Assimilating cosmic ray neutron counts for SIC detection







Remote Sensing

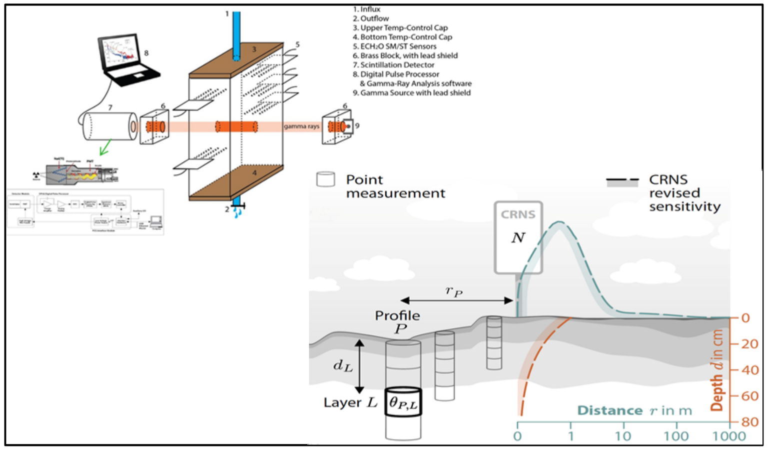
Extend it to satellite remote sensing?

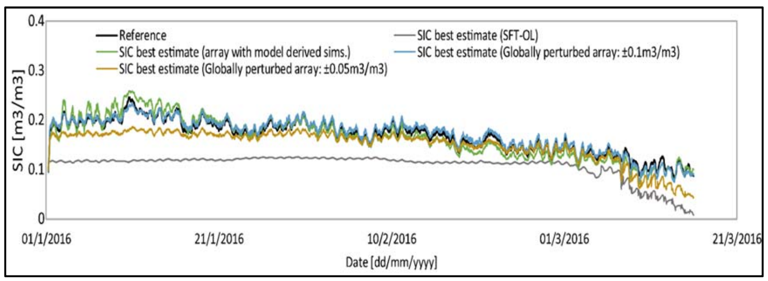
Data Assimilation (ongoing)

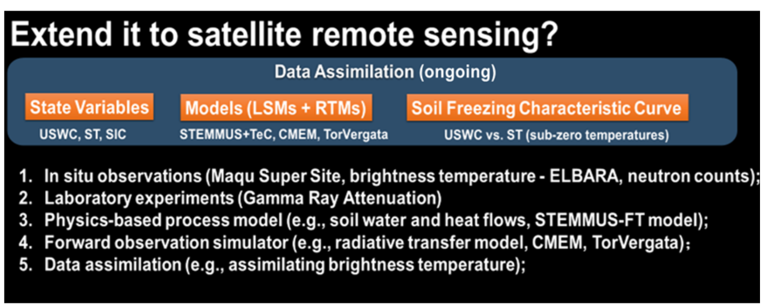
State Variables	Models (LSMs + RTMs)	Soil Freezing Characteristic Curve
USWC, ST, SIC	STEMMUS+TeC, CMEM, TorVergata	USWC vs. ST (sub-zero temperatures)

1. In situ observations (Maqu Super Site, brightness temperature - ELBARA, neutron counts);
2. Laboratory experiments (Gamma Ray Attenuation)
3. Physics-based process model (e.g., soil water and heat flows, STEMMUS-FT model);
4. Forward observation simulator (e.g., radiative transfer model, CMEM, TorVergata);
5. Data assimilation (e.g., assimilating brightness temperature);

Conclusions







- Soil Ice Content (SIC) can be indirectly detect with lab and field experiments, via determining Total Soil Water Content (TSWC), Unfrozen Soil Water Content;
- Assimilating cosmic ray neutron counts can update TSWC for the better detection of SIC;
- EO for SIC detection need to deploy the OSSE approach, while putting also efforts into laboratory/field experiments to understand the fundamental physics.

Challenges

Special Interest Group of Land Ice and Snow

European Association of
Remote Sensing Laboratories

9th EARSeL workshop on Land Ice and Snow

Remote Sensing of the Cryosphere: Monitor what is vanishing

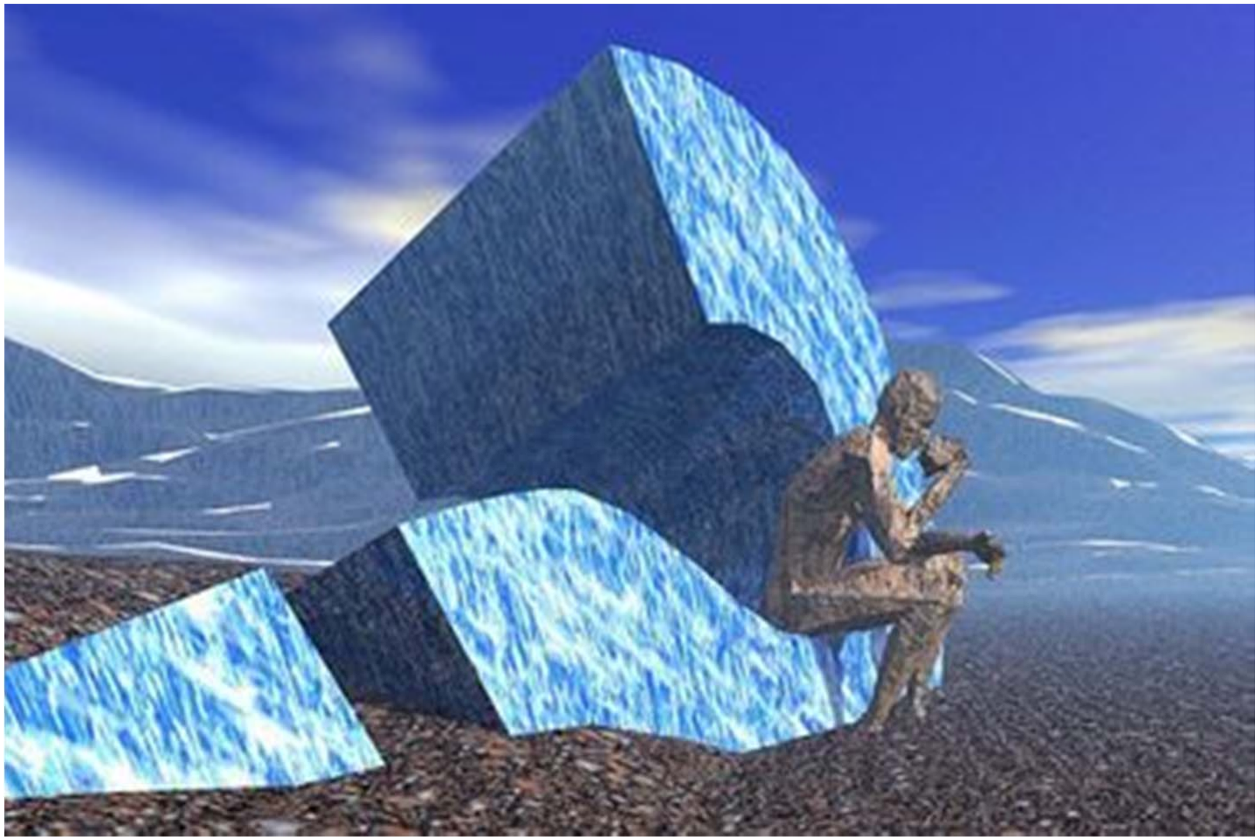
03 - 05 February 2020, Bern, Switzerland

Preliminary session topics

- Glaciers and Ice Caps
- Snow cover (regional to global scale)
- Snow hydrology
- Snow on sea ice and glaciers
- Albedo of the cryosphere
- Cryosphere and climate
- Cryospheric modelling and data assimilation
- New technologies (sensors/methods)
- ESA CCI+ snow
- EUMETSAT operational services

Is soil ice content detectable from remote sensing?

THANK YOU FOR YOUR ATTENTIONS



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BACK UP SLIDES

GAMMA-RAY-ATTENUATION MEASUREMENT

$$N = N_0 e^{-(\mu_{fm}\rho_{fm}x_{fm}+\mu_{cl}\rho_{cl}x_{cl}+\mu_s\rho_s d+\mu_w\rho_w\theta_w d+\mu_i\rho_i\theta_i d)}$$

$$N_{t0} = N_0 e^{-(\mu_{fm}\rho_{fm}x_{fm}+\mu_{cl}\rho_{cl}x_{cl}+\mu_s\rho_s d+\mu_w\rho_w\theta_{w\_t0} d+\mu_i\rho_i\theta_{i\_t0} d)}$$

$$N_t = N_0 e^{-(\mu_{fm}\rho_{fm}x_{fm}+\mu_{cl}\rho_{cl}x_{cl}+\mu_s\rho_s d+\mu_w\rho_w\theta_{w\_t} d+\mu_i\rho_i\theta_{i\_t} d)}$$

$$\ln(N_t/N_{t0}) = \mu_w\rho_w d[\theta_{w\_t0} - \theta_{w\_t} + \frac{\rho_i}{\rho_w}(\theta_{i\_t0} - \theta_{i\_t})]$$

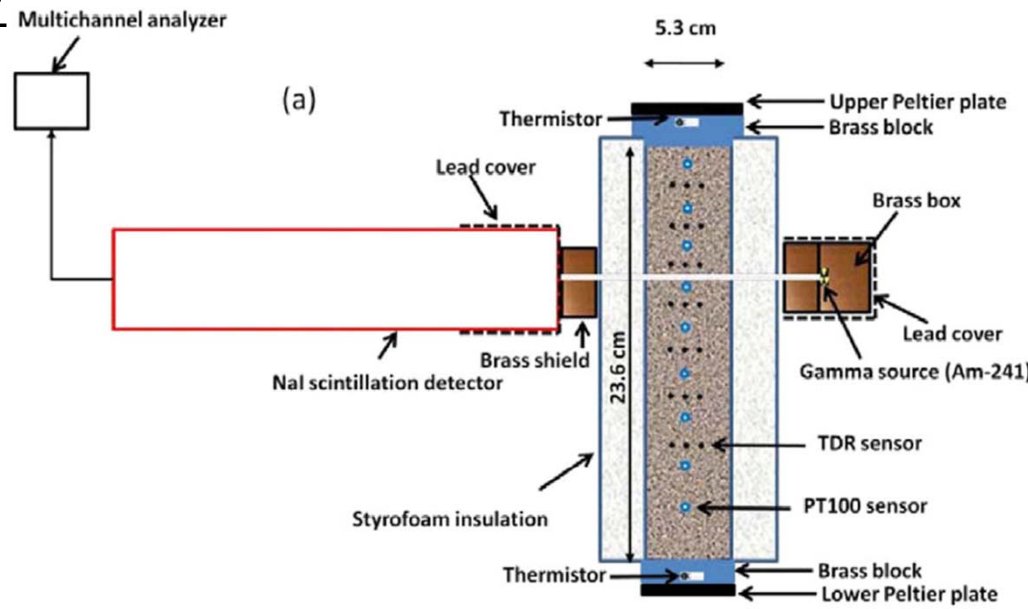
(Zhou et al. 2014, WRR)

$$\theta_{total\_t} = \theta_{total\_t0} - \frac{\ln(N_t/N_{t0})}{\mu_w\rho_w d}$$

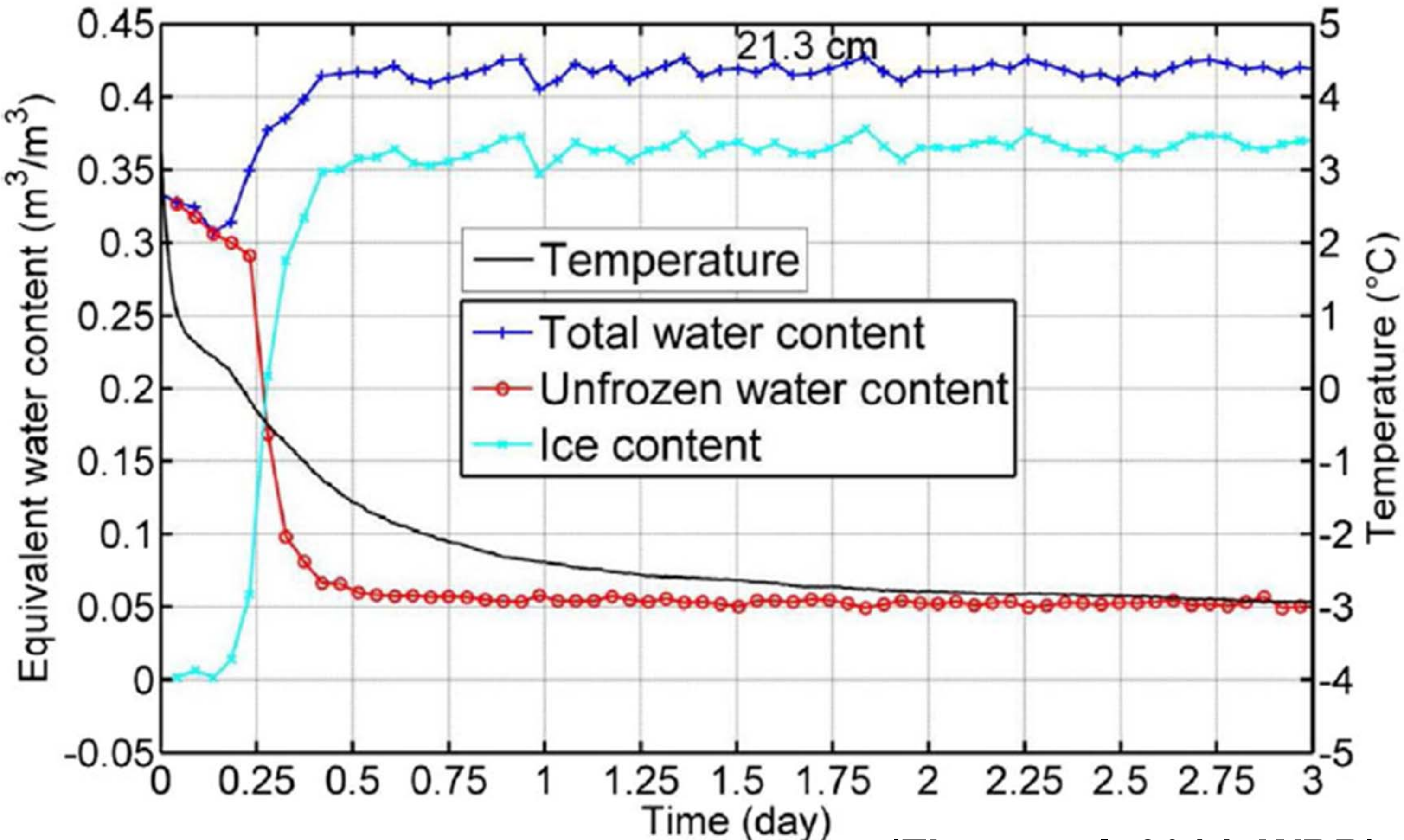
$$\frac{\rho_i}{\rho_w}\theta_i = (\theta_{total} - \theta_w)$$

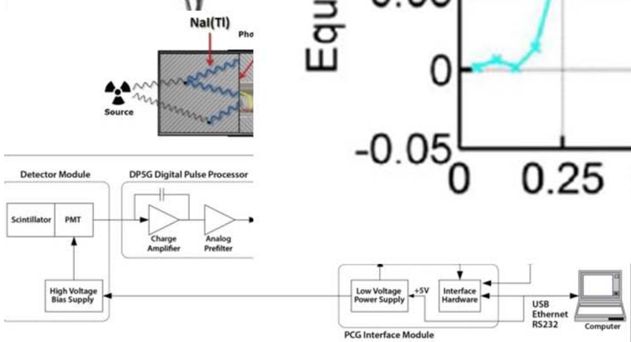
$$\theta_w = (\theta_{total}, \varepsilon_{soil})$$

(Dielectric Mixing Model)



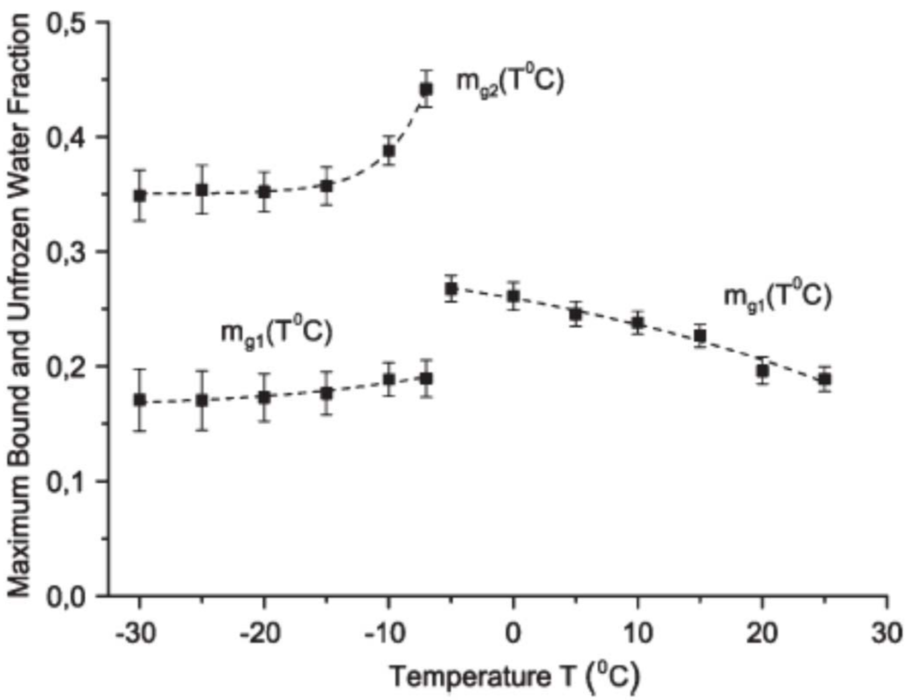
GAMMA-RAY-ATTENUATION MEASUREMENT

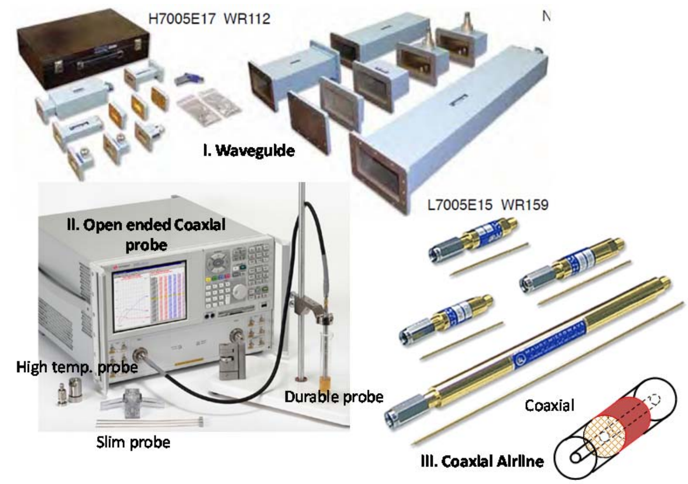




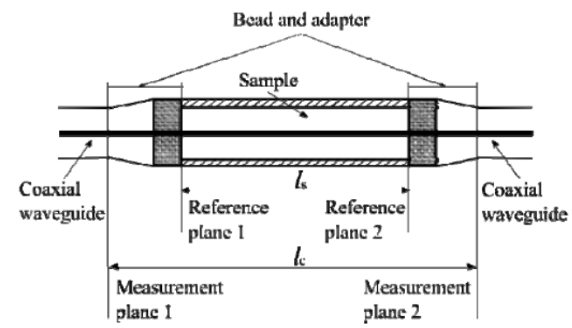
(Zhou et al. 2014, WRR)

MIRONOV'S APPROACH





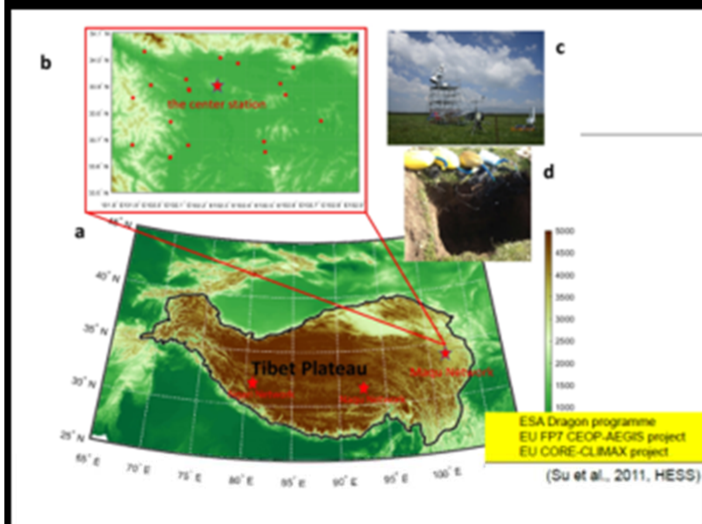
Vector network analyzer and calibration kit.



The schematic of coaxial waveguide used in Mironov's works [*Mironov et al.* 2010]

IN-SITU

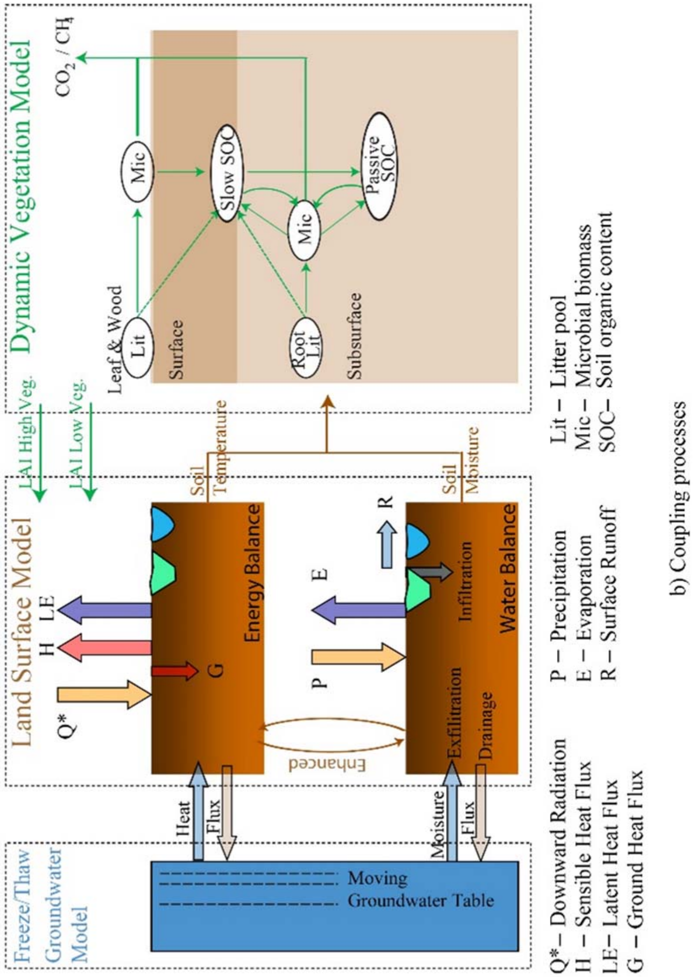
1. In situ observations (Maqu Super Site, brightness temeprature, neutron counts);



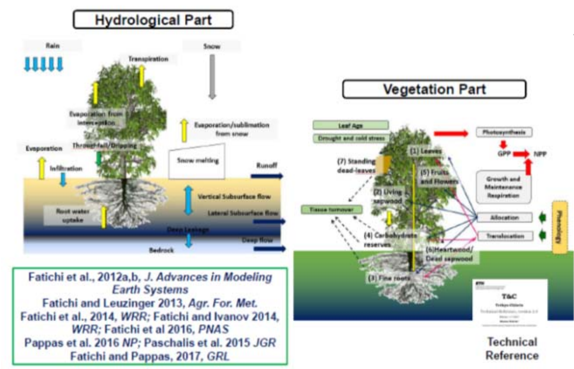
ELBARA III:
Zheng, 2019, RSE;
Zheng, 2017, IEEE TGRS;
Tabalia, 2016, MSc thesis;

Neutron Counts:
Peng, 2017, MSc thesis;
Mwangi, 2019, MSc thesis;

Physically-based process model



Tethys-Chloris (T&C) MODEL

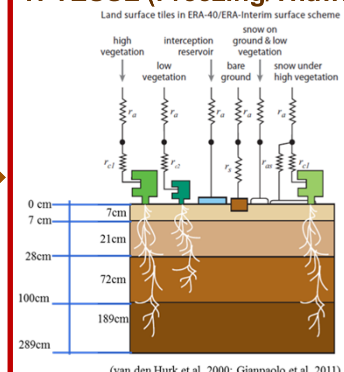


Vegetation Dynamics

Carbon Cycle

Nutrient Cycle

H-TESSL (Freezing/Thawing)

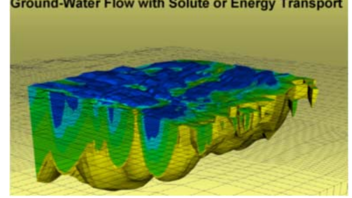


STEMMUS

Simultaneous Transfer of Energy, Momentum and Mass in Unsaturated Soil

SUTRA

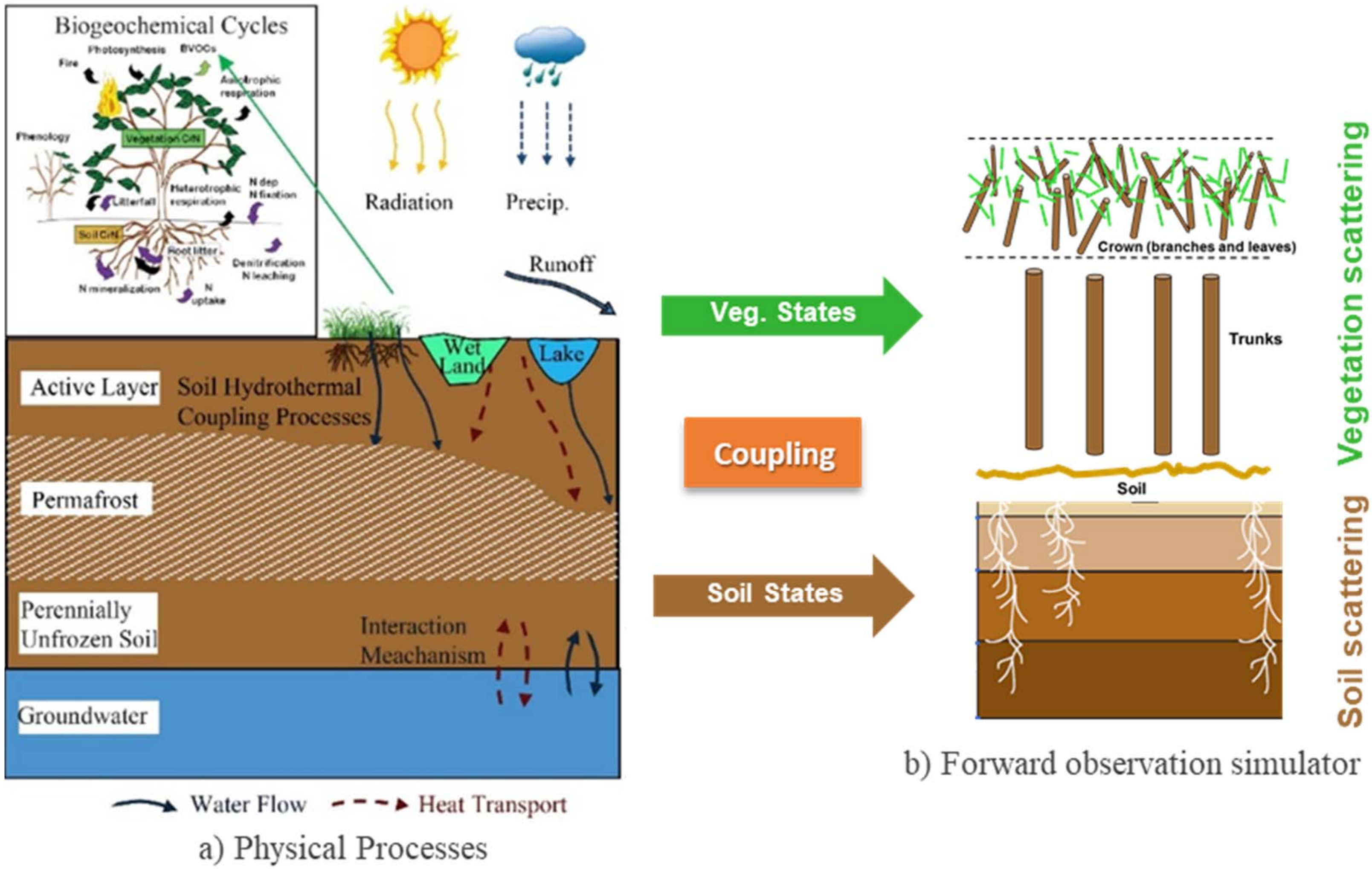
A Model for Saturated-Unsaturated Variable-Density Ground-Water Flow with Solute or Energy Transport



PFLOTRAN

A Massively Parallel Reactive Flow and Transport Model for describing Surface and Subsurface Processes

Forward Observation Simulator



Forward Observation Simulator (CMEM)

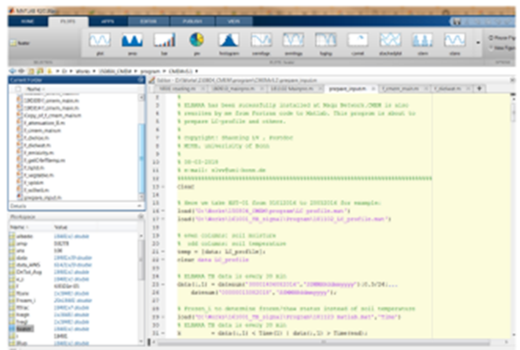
CMEM: from Fortran to Matlab

Table 1.1 The frame for a passive microwave transfer model. The brackets form a possible option in current CMEM.

ATMOSPHERE	**Atmospheric radiative transfer model** *(None/Pellarin/Liebe/Ulaby)*
VEGETATION	**Vegetation opacity model** *(None/Kirdyashev/Wegmuller/Wigneron)*
SOIL	**Smooth surface emissivity model** *(Fresnel/Wilheit)*
	Soil roughness model *(None=Smooth/Choudhury/Wegmuller/Wigneron)*
	Soil dielectric mixing model *(Wang & Schmugge/Dobson/Mironov)*
	Effective temperature model *(Choudhury/Wigneron/Holmes)*

WRF-ARW/NWP

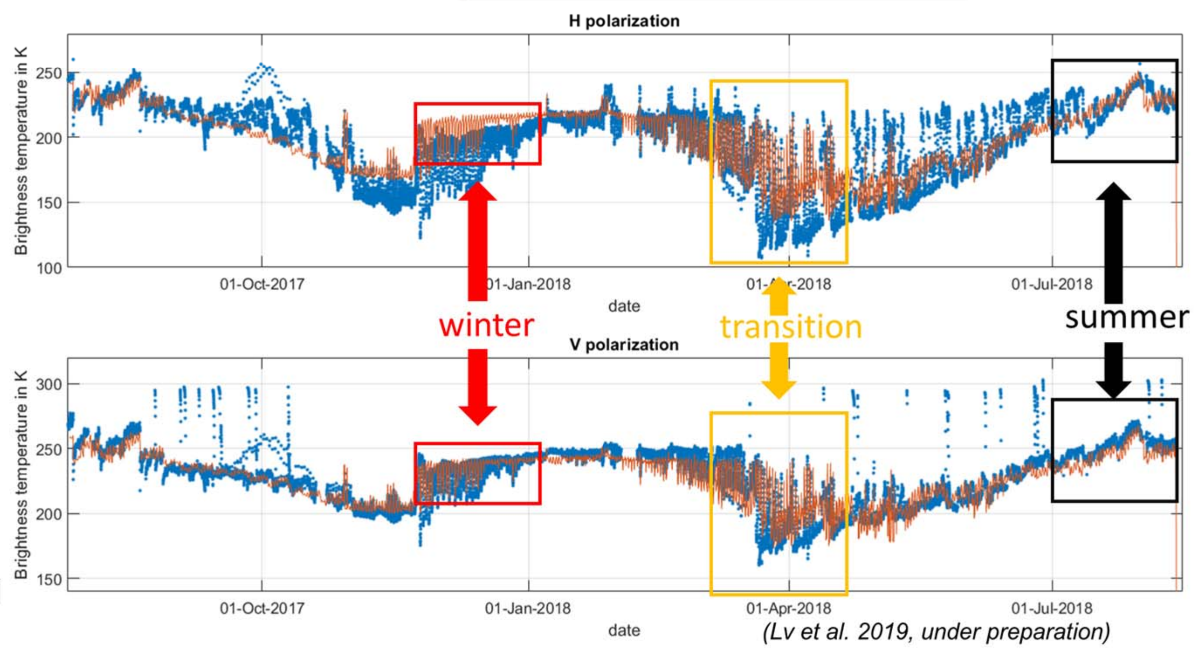
Most of CMEM functions are avail in Matlab now for In-site study.



1) The ELABRA brightness temperature observation is reliable;

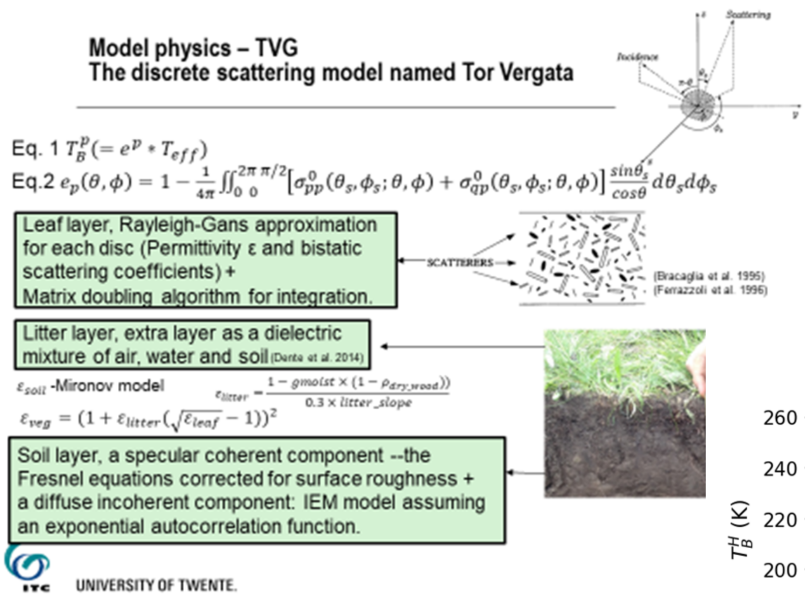
2) LAI inside/outside of the ELBARA's footprint can explain most TB difference between SMAP and ELBARA; Also the difference as seen here.

3) Skin freezing/thaw status cannot be ignored.

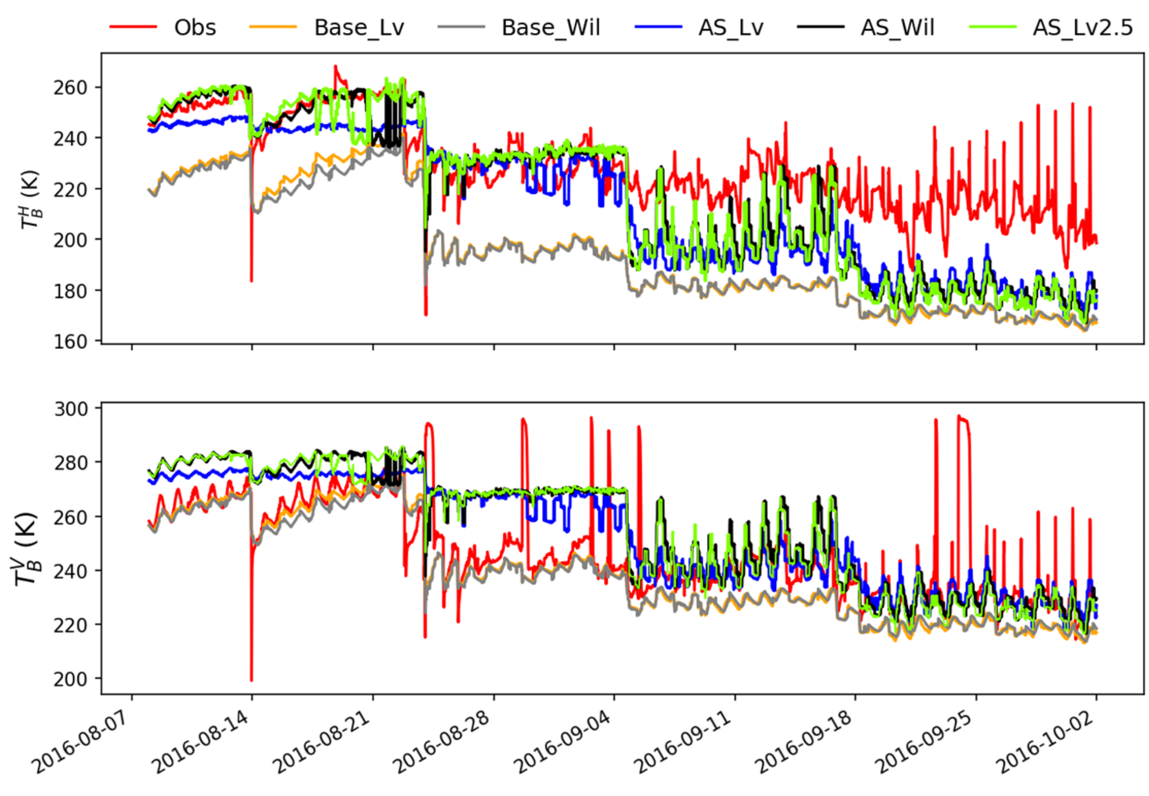


(Lv et al. 2019, under preparation)

Forward Observation Simulator (TorVergata)



Aided by in situ soil moisture (SM) and soil temperature profile measurement, this preliminary study demonstrated a necessity of an air-to-soil transition model (AS) for understanding seasonal L-band radiometry.



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