Water-Energy-Plant Interactions over Tibetan Plateau: a STEMMUS perspective and Progress

RUNNING WILD
The Plateau of Tibet is the source of most of Asia’s major rivers. Changes in the environment of the plateau caused by climate change and human activity could affect billions of people whose livelihood depends on the river flow.

Yijian Zeng, Lianyu Yu, Yunfei Wang, Bob Su
Department of Water Resources, ITC Faculty
WHY TIBETAN PLATEAU?

Outlines:
1) Observations
2) Scientific Challenges
3) Current Progress

- Asian Water Tower
- >1.4 Billion People
- Grassland & lake
- infrastructures
- Agriculture
- GLOFs
- Glacial debris flow
1) Observations (Current States)
DECADAL CHANGES IN CLIMATE

- **e) Solar Radiation**
  - Positive ▲ Negative ▼
  - 1 W m\(^{-2}\) a\(^{-1}\)

(Yang et al. 2014, GPC)

(1984-2006)
DECADAL CHANGES IN HYDROLOGIC REGIMES

(Yang et al. 2014, GPC) (1984-2006)

(a) Precipitation
- Positive △
- Negative ▲
- 6 mm a⁻¹

(b) Evaporation
- Positive △
- Negative ▲
- 4 mm a⁻¹

(c) Runoff
- Positive △
- Negative ▲
- 4 mm a⁻¹

(d) Surface soil water content
- Positive △
- Negative ▲
- 0.001 m³ m⁻³ a⁻¹
DECADAL CHANGES IN WATER BODIES

(Yao et al. 2015, JGS)

Figure 2  Decadal variation amplitude of wetland (a) and swamp (b) within different regions of the Tibetan Plateau from 1950s to 2000s

(Zhao et al. 2015, JGS)
DECADAL CHANGES IN PERMAFROST

(Wu & Zhang, 2010, JGR)
DECADAL CHANGES OVER TP

- Humidity
- Precipitation
- Wind
- Air Temp.

Atmosphere

- Solar Radiation

- Permafrost
- Glacier Mass
- Lakes
- Wetlands

- Act. Evaporation
- Pan Evaporation

- Runoff

- Surface SM

River discharge and Groundwater

EGU HS6.2 28-4-2020
2) Scientific Challenges
PROBLEMS AND CHALLENGES IN LAND-ATMOSPHERE INTERACTIONS ON TIBETAN PLATEAU

- **General problems**
  1) Extreme thermal dynamic processes
  2) Unknown soil physical and hydraulic properties
  3) Little known vegetation processes

- **Particular problems**
  1) Most LSM models developed for homogeneous terrain at low elevation
  2) Lack of quantitative understanding of the complete land-atmosphere interactions – energy/heat, water/mass
  3) Lack of dedicated and validated parameterizations of the above processes (i.e. ‘typical models’)

28-4-2020
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.
NEED AN INTEGRATED MODELLING SYSTEM

Carbon Cycle

Atmosphere

Water energy

Land processes
Snow, Permafrost and Seasonal frozen soil

Glacier mass & energy balance

Lake mass & energy balance

Wetland mass & energy balance

Runoff

River discharge and Groundwater balance
NEED AN INTEGRATED MODELLING SYSTEM

Atmosphere

Biogeochemical Cycles

Active Layer
Soil Hydrothermal Coupling Processes
Permafrost
Perennially Unfrozen Soil
Groundwater

Water Flow → Heat Transport

a) Physical processes

- Water Flow
- Heat Transport

b) Coupling processes

- Q* – Downward Radiation
- H – Sensible Heat Flux
- LE – Latent Heat Flux
- G – Ground Heat Flux
- P – Precipitation
- E – Evaporation
- R – Surface Runoff

Dynamic Vegetation Model

LAI High Veg.
LAI Low Veg.
Leaf & Wood
Mic
Slow SOC
Root Lit
Mic
Subsurface
Passive SOC
Lit – Litter pool
Mic – Microbial biomass
SOC – Soil organic content

UNIVERSITY OF TWENTE.
WATER-ENERGY-PLANT INTERACTIONS IN COLD REGIONS

H-TESSL (Freezing/Thawing)

Simultaneous Transfer of Energy, Momentum and Mass in Unsaturated Soil

VEGETATION DYNAMICS

CARBON CYCLE

NUTRIENT CYCLE

Soil-Canopy-Observation of Photosynthesis and Energy fluxes: SCOPE

STEMMUS

A Model for Saturated-Unsaturated Variable-Density Ground-Water Flow with Solute or Energy Transport
3) Current Progress
Tibetan Plateau observatory of plateau scale soil moisture and soil temperature (Tibet-Obs)

Project:
ESA Dragon programme
EU FP7 CEOP-AEGIS project
EU FP7 CORE-CLIMAX
NWO SMAP-Freeze/Thaw

Su, Z., et al. 2011, HESS
Su, Z., de Rosnay, P., et al., 2013 JGR
Tibetan Plateau observatory of plateau scale soil moisture and soil temperature (Tibet-Obs)

- Research Focus:
  Measuring, remote sensing and modeling the land surface states (soil moisture, temperature, vegetation) and heat fluxes (latent, sensible);

- SMAP Products to Validate:
  L2_SM radar/radiometer, L3/L4

- Site Characteristics:
  - Method of Data Transmission
    Data can be downloaded through FTP site maintained by ITC-WRS.
  - Expected Latency:
    For the Tibet-Obs sites, we expect to provide data before and after the monsoon seasons each year. This is related to the remoteness of the sites and the harsh environmental conditions. For the Twente site, monthly data can be provided.
  - Status:
    All four SM/ST observation networks are operational.

### Site Characteristics Table

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<tr>
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<th>Twente</th>
<th>Naqu</th>
<th>Maqu</th>
<th>Ngari</th>
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<td>2</td>
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<td>Nr. Points</td>
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### Data Download Table

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<td>Per 3 Mons.</td>
<td>Per Year</td>
<td>Per 3/6 Mons</td>
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<td>Calibration</td>
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### Measurement Type Table

<table>
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<tr>
<th>Measurement Type</th>
<th>Method</th>
<th>Depths</th>
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<tbody>
<tr>
<td>Soil Moisture</td>
<td>ECH2O (Capacitance probe)</td>
<td>Naqu Station -2.5, -7.5, -15, -30, -60 cm, Maqu &amp; Twente Station -5, -10, -20, -40, -80 cm, Ngari Station -5, -10, -20, -40, -60, -80 cm</td>
</tr>
<tr>
<td>Soil Temperature</td>
<td>EC-10 &amp; EC-TM</td>
<td></td>
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<tr>
<td>Micrometeorological</td>
<td>AWS, PBL Tower</td>
<td>1.5, 2, 5, 6.5, 10, 14.0 m</td>
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</table>
Simultaneous **Transfer of Energy, Momentum and Mass in Unsaturated Soil**

Three driving forces:
- Temperature Gradient,
- Matric Potential Gradient, and
- Soil Air Pressure Gradient.

Fully coupled transport in the soil of
- water,
- vapor,
- air, and
- heat
With Soil Ice Content (SIC), one can see exactly how the active layer is freezing back. (Ming-ko Woo, 2012, Permafrost Hydrology)
**STEMMUS Freeze-Thaw**

$q_{VT}$ - Thermal vapor flow, due to temperature gradient;

$q_{VH}$ - Isothermal vapor flow, due to soil matric potential gradient;

$q_{LT}$ - Thermal liquid flow, due to temperature gradient;

$q_{LH}$ - Isothermal liquid flow, due to soil matric potential gradient;

$q_{LA}$ - Liquid flow due to air pressure gradient;

$q_{VA}$ - Vapor flow due to air pressure gradient;

(Yu, Zeng & Su, 2018, JGR)
STEMMUS + TeC: If the enhanced soil water and heat transfer process have effects on ecosystem functioning? – L. Yu
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).

(YU, Zeng & Su, 2018, unpublished)
STEMMUS + TeC: If the enhanced soil water and heat transfer process have effects on ecosystem functioning? – L. Yu

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, 2018, unpublished)
STEMMUS + TeC: If the enhanced soil water and heat transfer process have effects on ecosystem functioning? – L. Yu
STEMMUS + SCOPE: If the enhanced soil water and heat transfer process have effects on ecosystem functioning? – Y. Wang

- Integrated model of soil-canopy spectral radiances, photosynthesis, fluorescence, temperature and energy balance

- It considers the radiative transfer and energy balance at leaf level.

- Currently one of selected algorithms for ESA’s FLEX mission (Earth Explorer, Fluorescence Explorer - FLEX).
STEMMUS + SCOPE: If the enhanced soil water and heat transfer process have effects on ecosystem functioning? – Y. Wang
STEMMUS + SCOPE: If the enhanced soil water and heat transfer process have effects on ecosystem functioning? – Y. Wang

Comparison of observed and modeled half-hourly Net radiation (Rn), Latent heat (LE), Sensible heat (H) and soil heat flux (G).
STEMMUS + SCOPE: If the enhanced soil water and heat transfer process have effects on ecosystem functioning? – Y. Wang
STEMMUS + SCOPE: If the enhanced soil water and heat transfer process have effects on ecosystem functioning? – Y. Wang
CONCLUSIONS

- Over Tibetan Plateau, the freezing-thawing processes link closely to hydrological processes, requiring an integrated approach;

- STEMMUS-FT is capable to capture the subtle land flux changes during winter period, which is often ignored;

- STEMMUS + TeC show that the enhanced soil water and heat transfer can revive vegetation about 2 weeks earlier;

- STEMMUS + SCOPE show that the enhanced soil water and heat transfer can improve the Net Ecosystem Exchange of CO2.
THANK YOU FOR YOUR ATTENTIONS

Yijian Zeng, y.zeng@utwente.nl