The remote sensed status and trend of ecosystem Services over Three-River Headwaters, Qing-Tibet Plateau, China, in 2000-2012

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Sofia, 6-8 February 2017
Outlines

- Background
- Methods and data
  - GLOPEM-CEVSA
  - Data
- TRH NPP and climate effect
- Summary
Background

- The Three-River Headwater (TRH) region is located in the core of the Tibet Plateau, China.
- Known as China’s, and even Asia’s water tower, this region provides 25% of the water volume of the Yangtze River, 49% of the Yellow River, and 15% of the Lantsang River (Qin et al. 2008).
- The TRH is of key importance to the ecological security of China and Southeast Asia for its most sensitive and fragile ecosystems (Wang et al., 2010).

Vulnerability in TRH (Xiao et al., 2010)
Background

- Monitoring and evaluating the ecosystem service function and its changes in the TRH region could support decision-making for regional ecological protection and restoration programs (Zhu et al., 2015).

- Grasslands are the principal ecosystems of the region and the utilization of the forage they produce for animal production is the leading industry (Fan et al., 2009).

(Xu et al., 2008)
The 26%–46% of the total grassland area is significantly degraded (Chen et al. 2006; Yang et al. 2006; Liu 2007). The degradation has taken place since the 1970s and continued (Liu Jiyuan et al., 2008).

Meanwhile, climate changes are suggested to be the main cause of increased grassland production (Fan et al., 2009; Liu et al., 2013; Wu et al., 2016).

**Tab. 1 Areas and proportion of vegetation NDVI change in the Three-River Headwater Region**

<table>
<thead>
<tr>
<th>变化类型</th>
<th>像元数</th>
<th>面积(km²)</th>
<th>百分比(%)</th>
<th>累计百分比(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>极显著增加</td>
<td>162756</td>
<td>10172.25</td>
<td>2.90</td>
<td>2.90</td>
</tr>
<tr>
<td>增加</td>
<td>2765663</td>
<td>172853.94</td>
<td>49.29</td>
<td>64.06</td>
</tr>
<tr>
<td>极显著减少</td>
<td>24119</td>
<td>1507.44</td>
<td>0.43</td>
<td>64.49</td>
</tr>
<tr>
<td>减少</td>
<td>1832409</td>
<td>114525.56</td>
<td>32.65</td>
<td>100</td>
</tr>
</tbody>
</table>

(Liu et al., 2013)
In an effort to keep the ecosystem and social sustainability, The Chinese government implemented “The project of ecological protection and construction for TRH nature reserve” since 2005.

In the first stage of 2005 to 2009, allocated 7.5 billion Chinese Yuan (1.1 billion US$) for the ecological restoration and degradation control.

Since 2013, the second stage started.

As China's first national park, it will be invested 1 billion RMB source in infrastructure before the end of 2017 to protect its ecosystems, especially water.
The changes of ecosystems were attributed as follows:

- Climate changes (Mao, 2015; Wang, 2015);
- The project of ecological protection and construction (Zhang, 2016; Zhao, 2016; Zhang 2014; Ding 2005);
- The both climate changes and the projects (Zhao 2016);
- Climate and grazing in early and middle stage, while improved by the projects in recent period (Shao et al., 2010).

Changes of livestock units since 1800 to 2005.

(Fan et al., 2009)
The objectives of this study were to measure the dynamics of change of grassland production and to examine how recent climate change are affecting the net primary production of TRH.

Our aim was to gain understanding of natural driven mechanisms causing changes to the grassland ecosystems of TRH.

Findings from the study will be applied to develop scientific strategies and programs for grassland restoration, management and utilization, and to assess the effectiveness of the TRH nature reserve project.
Methods: GLOPEM-CEVSA model

- Synthesizing of observation and modeling
  - System integration and scaling with model
  - A new-generation model that couples the “top-down” and “bottom-up” methods is required, as suggested by Cao et al. (2005).
A new model was developed to couple a production efficiency model based on remote sensing with an ecosystem mechanic model, named as GLOPEM-CEVSA.
Model developments: GLOPEM-CEVSA

**Soil Respiration**

- Model simulate carbon transformation and decomposition based on the CENTURY model (Parton et al. 1987, 1988, 1993)

- Model divides soil organic matter into surface litter, root litter, microbes, and slow and passive carbon pools (Cao & Woodward, 1998b)

\[
\text{Decomp} = \sum_{i=1,2} K_i L_c A C_i
\]

\[
\text{Decomp} = \sum_{i=3} K_i A T_m C_i
\]

\[
\text{Decomp} = \sum_{i=4,\ldots,8} K_i L_c A C_i
\]

- $K$: the potential decay rate (fraction month\(^{-1}\))
- $L_c$: the effect of soil lignin content on the decomposition
- $A$: the influence of soil moisture and temperature on decomposition
- $C$: the size of the 8 different carbon pools (gCm\(^{-2}\))
- $T_m$: the influence of soil texture on SOM turnover rate
Litter fall

- CEVSA calculates the carbon allocation among leaves, stems, and roots.
- Given a mean residence time with a statistical distribution that varies with plant function type.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Component</th>
<th>Unit</th>
<th>Default</th>
<th>ENF</th>
<th>DNF</th>
<th>MF</th>
<th>EBF</th>
<th>DBF</th>
<th>Grass</th>
<th>Shrub</th>
<th>Desert</th>
<th>Crop</th>
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</thead>
<tbody>
<tr>
<td>carbon allocation</td>
<td>Leaf</td>
<td>-</td>
<td>0.3</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.2</td>
<td>0.6</td>
<td>0.2</td>
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</tr>
<tr>
<td></td>
<td>Stem</td>
<td>-</td>
<td>0.2</td>
<td>0.90</td>
<td>0.90</td>
<td>0.93</td>
<td>0.90</td>
<td>0.93</td>
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<td>0.2</td>
<td>0.2</td>
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</tr>
<tr>
<td></td>
<td>Root</td>
<td>-</td>
<td>0.5</td>
<td>0.09</td>
<td>0.08</td>
<td>0.06</td>
<td>0.09</td>
<td>0.06</td>
<td>0.6</td>
<td>0.2</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>litter C turnover</td>
<td>Leaf</td>
<td>a</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td></td>
<td>Stem</td>
<td>a</td>
<td>1</td>
<td>90</td>
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<td>90</td>
<td>90</td>
<td>100</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Root</td>
<td>a</td>
<td>1</td>
<td>45</td>
<td>30</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

ENF - evergreen needle-leaf forest; DNF - Deciduous needle-leaf forest; MF - mixed forest; EWF - evergreen broadleaf forest; DWF - deciduous broadleaf forest.
Soil water

- Soil water balance is estimated on the basis of the soil “bucket” model, which includes the calculations of rainfall input, snowmelt, canopy interception, evapotranspiration, and overflow (Liu et al. 1997).

\[
SWC_t = \begin{cases} 
  SWC_{t-1} - (PET_t - PPT_t)RDR & PPT_t < PET_t \\
  SWC_{t-1} + (PPT_t - PET_t) & PPT_t \geq PET_t 
\end{cases}
\]

\[
PET = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}
\]

\[
AET_t = \begin{cases} 
  PET_t & PPT_t \geq PET_t \\
  \min(PPT_t + (PET_t - PPT_t)RDR_t, PPT_t + SWC_{t-1} - WP) & PPT_t < PET_t 
\end{cases}
\]
## GLOPEM-CEVSA Model: Data Needed

<table>
<thead>
<tr>
<th>Data source</th>
<th>Variables</th>
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</thead>
<tbody>
<tr>
<td>Remote sensing</td>
<td>FPAR</td>
</tr>
<tr>
<td></td>
<td>Vegetation classification</td>
</tr>
<tr>
<td>Interpolated with observed data on Meteorological station</td>
<td>Air temperature</td>
</tr>
<tr>
<td></td>
<td>Precipitation</td>
</tr>
<tr>
<td></td>
<td>Wind speed</td>
</tr>
<tr>
<td></td>
<td>Sunlit time</td>
</tr>
<tr>
<td></td>
<td>Relative humid</td>
</tr>
<tr>
<td>Surveyed data</td>
<td>Soil texture (sand, clay percent)</td>
</tr>
<tr>
<td></td>
<td>Soil organic carbon</td>
</tr>
<tr>
<td></td>
<td>Vegetation carbon</td>
</tr>
</tbody>
</table>
Methods and data: GLOPEM-CEVSA model

- Its developments:
  - Sites validations (Wang et al., 2009)
  - Assessments and application on region
    - Spatial-temporal variation of NPP in Indian (Wang Meng et al. 2015)
  - Gross Primary Productivity in Southeast Asia (Wang et al., 2014)
  - Net primary productivity in Jiangxi Province (Ding Qingfu et al., 2013)
  - vegetation precipitation use efficiency on the Qinghai-Xizang Plateau (Ye H. et al., 2012)
  - TRH (Fan J. et al., 2009, 2010, 2011; Xiao T. et al., 2010; Wang J.B. et al., 2009)
FPAR is Land Product (MOD15A2) of the Moderate-resolution Imaging Spectroradiometer (MODIS)

Climate data interpolated with observation of 750 stations from China Meteorological Administration

Methods and data: Data in 2000-2012
The averaged NPP was 149 gC m\(^{-2}\) a\(^{-1}\) for the whole region in 2000-2012. Higher NPP in headwater region of Yellow River and Lantsang River, while lower in Yangtze River.

- Headwater region of Yangtze River: 123 gCm\(^{-2}\)a\(^{-1}\)
- Headwater region of Yellow River: 200 gCm\(^{-2}\)a\(^{-1}\)
- Lantsang (Mekong) River: 203 gCm\(^{-2}\)a\(^{-1}\)
- No significant trend over the whole region: slope = $13.7 \text{gC/m}^2/10\text{a}$, $R^2=0.18$, $p=0.14$
- Yellow River: quickly increasing trend: $17.4 \text{gC/m}^2/10\text{a}$, $R^2=0.161$, $P=0.085$
- Then Yangtze River: $12.9 \text{gC/m}^2/10\text{a}$, $R^2=0.173$, $P=0.158$
- No trend over Lantsang River: $12.2 \text{gC/m}^2/10\text{a}$,
Results: NPP and climate effect

- In 2000-2012, the NPP of the almost whole region showed an increasing trend of 40~80 gCm\(^{-2}\) per 10 years, while the NPP of some local region showed a decreasing trend in a rate of ~40 gCm\(^{-2}\) per 10 years.

NPP trend in 2000-2012 (This study)

NPP trend in 1988-2004 (Wang J.B. et al., 2009)
**Wetting 48 to 100 mm/10a**

- **Grass**
  - NPP: -3.4 to 21.5 gC/m²/10a
  - Equation: $y = 0.2622x - 377.35$
  - $R^2 = 0.0127$

- **Desert**
  - NPP: 2.4 to 15.2 gC/m²/10a
  - Equation: $y = 0.7711x - 1454.5$
  - $R^2 = 0.2429$

**Warming 0.1 to 0.7 °C/10a**

- **Grass**
  - NPP: 3.4 to 21.5 gC/m²/10a
  - Equation: $y = 0.0326x - 3.476$
  - $R^2 = 0.173$, $p = 0.05$
  - $y = 0.0677x - 138.70$
  - $R^2 = 0.309$, $p = 0.05$

- **Desert**
  - NPP: 2.4 to 15.2 gC/m²/10a
  - Equation: $y = 6.2131x - 11979.71$
  - $R^2 = 0.630$, $p < 0.001$
  - $y = 4.8273x - 9211.26$
  - $R^2 = 0.380$, $p = 0.044$
  - $y = 9.9935x - 19567.45$
  - $R^2 = 0.535$, $p = 0.004$
ENF -20.2 to 11.6 gC/m²/10a

Grass -23.7 to 24.6 gC/m²/10a

Crop -10.2 to 24.1 gC/m²/10a

Shrub -22.0 to 25.9 gC/m²/10a
### Linear regression coefficients (NPP = $b_0 + b_1 \times \text{Precipitation} + b_2 \times \text{Temperature}$)

**IN 2000-2012 in this study**

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Standardized regression coefficients</th>
<th>$R^2$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Precipitation</td>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>Crop</td>
<td>0.26</td>
<td>0.55</td>
<td>0.49</td>
</tr>
<tr>
<td>Forest</td>
<td>-0.61</td>
<td>1.01</td>
<td>0.77</td>
</tr>
<tr>
<td>Grass</td>
<td>-0.39</td>
<td>0.94</td>
<td>0.82</td>
</tr>
<tr>
<td>All</td>
<td>-0.41</td>
<td>0.96</td>
<td>0.83</td>
</tr>
</tbody>
</table>

**Linear regression coefficients (NPP = $b_0 + b_1 \times \text{Precipitation} + b_2 \times \text{Temperature}$)

**IN 1988-2004 (Wang et al., 2009)**

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Unstandardized coefficients</th>
<th>Standardized coefficients</th>
<th>$R^2$</th>
<th>显著性 Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$b_0$</td>
<td>$b_1$</td>
<td>$b_2$</td>
<td>$B_1$</td>
</tr>
<tr>
<td>农田 Crop</td>
<td>-101.341</td>
<td>0.697</td>
<td>26.551</td>
<td>0.761</td>
</tr>
<tr>
<td>森林 Forest</td>
<td>60.106</td>
<td>0.383</td>
<td>10.168</td>
<td>0.546</td>
</tr>
<tr>
<td>草地 Grass</td>
<td>146.243</td>
<td>0.138</td>
<td>14.536</td>
<td>0.327</td>
</tr>
<tr>
<td>荒漠 Desert</td>
<td>115.901</td>
<td>0.030</td>
<td>11.084</td>
<td>0.121</td>
</tr>
<tr>
<td>湿地 Wet land</td>
<td>178.501</td>
<td>0.000</td>
<td>14.937</td>
<td>0.001</td>
</tr>
<tr>
<td>全区 Whole area</td>
<td>105.817</td>
<td>0.067</td>
<td>10.476</td>
<td>0.253</td>
</tr>
</tbody>
</table>
The trend of NPP can be explained by temperature and precipitation for whole region: $R^2 = 0.83$

- Yangtze River: $R^2 = 0.80$
- Lantsang River: $R^2 = 0.77$
- Yellow River: $R^2 = 0.73$

For the grass of the whole region: $R^2 = 0.83$

- Higher coverage fraction of grass: $R^2 = 0.76$
- Median coverage fraction of grass: $R^2 = 0.78$
- Lower coverage fraction of grass: $R^2 = 0.84$
<table>
<thead>
<tr>
<th>Region</th>
<th>Vegetation</th>
<th>Standardized regression coefficients</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Precipitation</td>
<td>Temperature</td>
<td>$R^2$</td>
</tr>
<tr>
<td>Yangtze</td>
<td>Whole basin</td>
<td>-0.33</td>
<td>3.25</td>
<td>0.80</td>
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<tr>
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<td>-0.12</td>
<td>0.70</td>
<td>0.74</td>
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<td>0.86</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Grass</td>
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<td>0.90</td>
<td>0.81</td>
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<td>Yellow</td>
<td>Whole basin</td>
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<td>0.73</td>
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<tr>
<td></td>
<td>Crop</td>
<td>0.29</td>
<td>0.50</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>-0.62</td>
<td>1.00</td>
<td>0.73</td>
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<tr>
<td></td>
<td>Grass</td>
<td>-0.38</td>
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<td>0.73</td>
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<tr>
<td>Lantsang</td>
<td>Whole basin</td>
<td>0.04</td>
<td>4.27</td>
<td>0.77</td>
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<tr>
<td></td>
<td>Crop</td>
<td>-0.10</td>
<td>0.64</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>-0.34</td>
<td>0.74</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>Grass</td>
<td>-0.48</td>
<td>0.77</td>
<td>0.77</td>
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<tr>
<td>Whole</td>
<td>Crop</td>
<td>0.26</td>
<td>0.55</td>
<td>0.49</td>
</tr>
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<td></td>
<td>Forest</td>
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<td>1.01</td>
<td>0.77</td>
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<td>Grass</td>
<td>-0.39</td>
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<td>0.82</td>
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<tr>
<td></td>
<td>All</td>
<td>-0.41</td>
<td>0.96</td>
<td>0.83</td>
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</table>

Linear regression coefficients between NPP and climate factors of precipitation and temperature ($NPP = b_0 + b_1 \times \text{Precipitation} + b_2 \times \text{Temperature}$)
<table>
<thead>
<tr>
<th>Region</th>
<th>Vegetation</th>
<th>Standardized regression coefficients</th>
<th></th>
<th></th>
<th>$R^2$</th>
<th>p</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Precipitation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temperature</td>
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</tr>
<tr>
<td>Yangtze</td>
<td>All Grass</td>
<td>-0.33</td>
<td>3.25</td>
<td>0.80</td>
<td>0.000</td>
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</tr>
<tr>
<td></td>
<td>Higher cover</td>
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<td>0.86</td>
<td>0.63</td>
<td>0.007</td>
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<tr>
<td></td>
<td>Median cover</td>
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<td>5.24</td>
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<tr>
<td></td>
<td>Lower cover</td>
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<td>2.99</td>
<td>0.83</td>
<td>0.000</td>
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<tr>
<td></td>
<td>Higher cover</td>
<td>-0.43</td>
<td>0.95</td>
<td>0.73</td>
<td>0.001</td>
<td></td>
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<tr>
<td></td>
<td>Median cover</td>
<td>-0.40</td>
<td>0.93</td>
<td>0.73</td>
<td>0.001</td>
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<tr>
<td></td>
<td>Lower cover</td>
<td>-0.33</td>
<td>0.92</td>
<td>0.73</td>
<td>0.002</td>
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<tr>
<td></td>
<td>All Grass</td>
<td>0.04</td>
<td>4.27</td>
<td>0.77</td>
<td>0.001</td>
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<tr>
<td></td>
<td>Higher cover</td>
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<td>0.72</td>
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<tr>
<td></td>
<td>Median cover</td>
<td>-0.43</td>
<td>0.74</td>
<td>0.73</td>
<td>0.001</td>
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<tr>
<td></td>
<td>Lower cover</td>
<td>-0.49</td>
<td>0.77</td>
<td>0.79</td>
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<tr>
<td></td>
<td>Higher cover</td>
<td>-0.59</td>
<td>1.02</td>
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<tr>
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<td>0.95</td>
<td>0.78</td>
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<tr>
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<td>0.93</td>
<td>0.84</td>
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<tr>
<td></td>
<td>All Grass</td>
<td>-0.41</td>
<td>0.96</td>
<td>0.83</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>
Summary

- The increasing trend of NPP mainly may be affected by the increasing temperature and precipitation in this region.
- Some local region at center and eastern region may be mainly affected by the impact of human activities.
- And it is suggested that the NPP over TRH benefited from the warmer and dryer climate change.
Summary

- However, the **grazing pressure should be quantified in future researches, which is great challenge.**

- These findings **indicate** the importance of understanding the effect of climate change on them especially for a region sensitive to climate changes.

- This research, more important, **provided a methodological reference** to map ecosystem service, such as production, regulation services of ecosystems, through applying remote sensing.
Summary

- **Future developments**
  - There are more great challenges in this field, including parameterization, potential scaling errors at the regional scale, and systematic validation of model-based flux estimates.
  - Ecosystem service not only includes matter production, but also water conservation, soil and fertility maintenance, prevents windstorms and fastens sand.
  - So a new model will be developed recently.
Climate, Atmospheric CO2, vegetation, Soil

1. Climate controlled LAI
   \[ \text{LAI}_n = \text{LAI}_{n-1} + m \times \text{SLA} \]

2. Remotely sensed LAI

3. Observed LAI on ground

Drivers

- ET
- prcp
- interception

LAI

N input

Leaf N

N allocation

N uptake

Soil N

C allocation

Soil C

Litter fall

Soil respiration

GPP

Autotrophic respiration

NPP

NEP

Soil water

outflow

Water conservation

Soil conservation

Phenology

Photo.
Acknowledgements

This work was supported yet by grants from:
- The National Natural Science Foundation of China (No. 31270520).
- National Key Technologies R&D Program (2016YFC0500203)
- The CAS Science and Technology Service Network Initiative (KFJ-SW-STS-167)

Thanks very much!