Glacier lakes and snow cover dynamics in Tibetan Plateau using field and remote sensing data

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The Third Pole
The "water tower" of Asia

Mean elevation 4000m (13,123 ft)
Highest 8,840m (29,002 ft)
The temperature rise: $0.3^\circ$C/decade, $1.8^\circ$C over the past 50 years

Winter temperature: $2.9-4.2^\circ$C from 1995 to 2005 (Wu et al., 2008)
Glaciers in Tibetan Plateau (TP) recreating/melting at accelerated rate under global warming

Total 36,800 glaciers

Total 1500 lakes
Total 1500 lakes in Tibetan Plateau

Zhang et al., 2011a
Ice, Cloud, and Land Elevation Satellite (ICESat)

Instrument: Geoscience Laser Altimeter System (GLAS)
Orbit Height: 600 km
Inclination: 94°
Laser Wavelengths: 1064 nm and 532 nm
Orbit Repeat: 8 day and 91 day
Transmitted Pulse FWHM: 5 ns
Laser Footprint Diameter on the ground: 70 m
Sample interval on the ground: 170 m
Sample Rate: 40 laser shots per second.

Animation
The only lake level 4725.41m, GPSed on Nov 18, 2009.

4725.43m from ICESat, Oct 9, 2009.
Fig. 3. Spatial distribution of the 74 lakes with lake level changes (m/year) and the largest rivers in the Plateau. Named lakes are discussed in the text. I, II, III, and IV are subareas.

Table 2
The number (percentage %) and change trend (m/year, i.e., increasing (+) or decreasing (-)), of salt (S), fresh (F), or S+F lakes and within different subareas I, II, III and IV.

<table>
<thead>
<tr>
<th></th>
<th>Salt</th>
<th>Fresh</th>
<th>S+F (all)</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>50 (89), 0.27</td>
<td>12 (67), 0.24</td>
<td>62 (84), 0.26</td>
<td>5 (100), 0.12</td>
<td>37 (95), 0.28</td>
<td>19 (73), 0.27</td>
<td>1 (25), 0.02</td>
</tr>
<tr>
<td>Decreasing</td>
<td>6 (11), -0.10</td>
<td>6 (33), -0.03</td>
<td>12 (16), -0.06</td>
<td>0</td>
<td>2 (5), -0.04</td>
<td>7 (27), -0.03</td>
<td>3 (75), -0.16</td>
</tr>
<tr>
<td>I+D (all)</td>
<td>56, 0.23</td>
<td>18, 0.15</td>
<td>74, 0.21</td>
<td>5, 0.12</td>
<td>39, 0.26</td>
<td>26, 0.19</td>
<td>4, -0.11</td>
</tr>
</tbody>
</table>
Lake Qinghai

Location of Lake Qinghai, and rivers, hydrological and meteorological station sites
The 47 ICESat tracks through Lake Qinghai.
Lake level change from gauge station Xiashe during 1959-2009
Lake level change

Zhang et al., 2011b
Lake level from in-situ station vs. ICESat data

Absolute average difference = 0.06 m
RMSD = 0.08 m

$Y = 0.92 \times X + 274.82$
R-squared = 0.90
Annual mean runoff at stations Buha from 1956-2009
Annual mean runoff at stations 1956-2009

Runoff in Buha
Runoff in Gangcha
5-year moving average

Linear trend (-0.004 10^6 m^3/yr)
Linear trend (0.015 10^8 m^3/yr)
Linear trend (0.03 °C/yr)
Linear trend (1.39 mm/yr)
Linear trend (-1.80 mm/yr)
Precipitation-Evaporation

1967 1989 2005
The lake level increase from 2004 to 2009 could mainly due to accelerated glaciers/perennial snow cover melting.
MODIS & Terra/Aqua satellites

- Terra satellite launched on 12/18/1999
- Aqua launched on 5/22/2002

Moderate Resolution Imaging Spectroradiometer - MODIS

Spectrum coverage (36 bands)
- Visible
- Near Infrared
- Thermal Infrared

Spectral resolution
- 10-500 nm

Spatial resolution (m)
- 250, 500, 1000

Spatial coverage
- 2400 km (swath), global

Radiometric resolution and CVG
- 12 bits, 0 - 4095

http://terra.nasa.gov/About/MODIS/modis_swath.html
MODIS snow cover products

MOD10_L2
(Swath 2330 by 2030 km, 500m)

MODL2G
(sinu, 1200 by 1200 km, 500m)

MOD10A1
(sinu, daily, 1200 km, 500m)

MOD10A2
(sinu, 8-day, 1200 km, 500m)

MOD10C1
(CMG, daily, 180° by 360°, 0.05°)

MOD10C2
(CMG, 8-day, 180° by 360°, 0.05°)

MOD10CM
(CMG, Monthly, 180° by 360°, 0.05°)

MODIS Terra snow cover products begin with MOD
MODIS Aqua snow cover products begin with MYD

Hall et al., 2002, 2007; Riggs et al. 2006
Daily snow cover map: cloud contamination

8-day snow cover map: a kind of too long and overestimation
Flexible multiday combination,
Xie et al. 2010
Wang et al. 2009
Gao et al. 2010
Fig. 4. A workflow chart of flexible multi-day combination algorithm. $P$ and $N$ are user-defined thresholds and are predefined as 10% and 4 days or 8 days respectively in this study.
Application in TP lake basins

Zhang et al., submitted
Work flow chart for data processing

Terra MODIS Daily Snow cover product (MOD10A1) -> HDF -> Geotiff (Mosaic and resample) -> Extract by mask -> Watershed snow cover product (MOD10A1)

SRTM 90 m DEM -> Delineated Watershed (WMS 8.3) -> Raster -> ASCII
- Filling gaps
- Computer flow data
- Create outlet points
- Delineate basins

Aqua MODIS Daily Snow cover product (MYD10A1) -> HDF -> Geotiff (Mosaic and resample) -> Extract by mask -> Watershed snow cover product (MYD10A1)

Unifying Codes
- 200 (snow) -> 6 (snow)
- 100 (lake ice) -> 5 (lake ice)
- 37 (lake), 39 (ocean) -> 4 (water)
- 25 (land) -> 3 (land)
- 50 (cloud) -> 2 (cloud)
- 11 (polar) -> 1 (polar)
- 0, 1,254, 255 -> 0 (no data)

Daily MOD10A1 and MYD10A1 combined snow cover product

Multi-day combination with maximum cloud percentage of 10% and snow composite days of 8

Snow cover duration (SCD)
Snow cover index (SCI)
Nam Co

Time series snow cover change

Seasonal snow cover change
Spatial distribution of snow cover duration
11 year mean SCD and elevation relationship
11 year mean SCD and elevation relationship
Normalized SCI (\(\text{km}^2 \cdot \text{day}/\text{km}^2\))

Zhang et al., submitted
Take home messages

- ICESat data are used to examine 111 lakes in Tibetan Plateau (TP) for lake level changes
- MODIS data are used to examine 4 lake basins for snow cover and glacier area changes
- ICESat elevation match well with gauge measurements ($r^2=0.90$, RMSE 0.08 m) at Lake Qinghai
- 84% of all lakes and 89% of the salt lakes show tendency of lake level increase; the largest lake level increase (0.80 m/year) is the lake Ceda Caka.
- Increase in lake level is consistent with the accelerated glacier and perennial snow cover melting in summer season
Thank you!

Emperor Penguins

Photo: Blake Weissling