Assessing snow and snowmelt runoff in remote mountain ranges

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Oregon State University, Valentines Day 2014
KABUL, 21 September 2011 (IRIN) – “The current dry spell sweeping across Afghanistan’s northern, northeastern and western provinces could lead to a large-scale food crisis and the humanitarian community should act quickly to ensure this does not degenerate into a disaster, government and aid officials warn.”

http://www.irinnews.org/Report/93781/
Analysis-Afghan-drought-conditions-could-spell-disaster
Accumulation season, passive microwave
The problem

- In mountains, no reliable real-time method to measure spatially distributed (or basinwide integrated) snow water equivalent
  - Passive microwave sensors have a large spatial footprint and tend to underestimate, which complicates interpretation of the results
  - Numerical weather models, driven by available data, have difficulty predicting precipitation, particularly snowfall and the rain-snow transition
- However, with optical data (MODIS, VIIRS) and energy balance models (driven by NLDAS or GLDAS) we can reconstruct the spatial distribution of snow water equivalent
- OK . . . Then what?
Snow Water Equivalent (fine resolution, accurate, timely)

Yes Analysis at US Army CRREL (Interactive Narrative) (Map Story) (Geoint)

Visualize & narrate historical bracket (automatic)

Concern?
No

Historical narratives (news, intelligence)

SSM/I, AMSR-E, AMSR2

MODIS

Snow Albedo

Snow-Covered Area

Model Snowmelt day-by-day

Downscale

Reconstructed Snow Water Equivalent (fine resolution, accurate, on/after peak, after snow gone)

Solar Radiation
Longwave Radiation
Air Temperature
Humidity
Wind (~)

Downscale

Snow Water Equivalent (coarse resolution, large uncertainty, dry snow only, timely)

Pattern Discovery

Solar Radiation
Longwave Radiation
Air Temperature
Humidity
Wind (~)
Water balance? 
Over a year so ? (Only for Reconstruction)
In the Sierra Nevada, where we can compare results to streamflow and surface measurements, passive microwave snow estimates see ~10% of the total volume.
MODIS
Afghan tile: wide swath (2300 km), 500 m pixels, daily coverage
Reconstructed
SWE
Spectra with 7 MODIS “land” bands
Fractional snow cover from MODIS

\[ R_\lambda = \epsilon_\lambda + \sum_{k=1}^{N} f_k R_{\lambda,k} \]
Viewable Snow?

\[ f_{SCA} = \frac{f_{SCA}^{(observed)}}{1 - \min(f_{\text{veg}})} \]
Seasonal Progression of $f_{\text{veg}}$, 2000-2006

National Land Cover Dataset, 2001
Vegetation Correction for $f_{SCA}$

$f_{SCA}$ viewable


$f_{SCA}$ corrected
Cloudy, 20%-80% depending on where/when
Snow covered area, clear day, notice the noise
Noise low-
(clouds) and high-
frequency (sensor)
Sensor viewing angles (larger angle = larger pixels)
Is peak microwave SWE the right number to compare with streamflow?

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No
Energy balance reconstruction

\[ SWE_n = SWE_0 \sum_{j=1}^{n} M_j \]

when \( SWE_n = 0 \), \( SWE_0 = \sum_{j=1}^{n} M_j \)

\[ M_j = M_{p_j} \ast f_{SCA_j} \]

\[ M_{p_j} = m_Q R_d + r T_D \]
Reconstruction on a grid cell

Daily potential melt $f_{SCA}$ Reconstructed SWE

(A. Kahl Homan et al., *Hyd Proc* 2011)
Downscaling incoming longwave radiation, Tuolumne-Merced River Basins

\[ L_A = \varepsilon_A \sigma T_A^4 \]

\[ \varepsilon_A = \frac{\sigma T_A^4}{L_A} \]
Energy balance components, Hindu Kush, 2011 April 01
Resulting melt for that day
Reconstructed SWE
Mar 2011
Reconstructed SWE
May 2011
AMSR-E
SWE
May 2011
Persistent sources of uncertainty in passive microwave retrieval of SWE: vegetation, deep snow, sub-grid heterogeneity

- For SWE < 150 mm:
  - RMSE = 32 mm
  - Bias = +8.5 mm
  - Correlation coefficient $r = 0.68$

- For all SWE:
  - RMSE = 43 mm
  - Bias = +1.1 mm
  - Correlation coefficient $r = 0.67$
Hindu Kush, AMSR-E & Reconstruction, basins sorted by Spearman

![Graphs showing reconstructed SWE vs AMSR-E SWE for different basins.]

- **Amu Darya**: $R^2=0.642$, $p=0.810$
- **Helmand**: $R^2=0.242$, $p=0.524$
- **Western**: $R^2=0.036$, $p=0.452$
- **Kunar**: $R^2=0.104$, $p=0.357$
- **Harinod-Murghab**: $R^2=0.002$, $p=0.333$
- **Upper Kabul**: $R^2=0.064$, $p=0.252$
- **Northern**: $R^2=0.117$, $p=-0.119$
- **Upper Helmand**: $R^2=0.008$, $p=-0.216$
Pixel-level comparison in drought years

Drought years in the Sierra and Amu Darya, Afghanistan

- Amu Darya, Afghanistan 2011 $y = 0.31x + 1.90$ ($R^2 = 0.84$)
- Sierra 2007 $y = 0.05x + 9.11$ ($R^2 = 0.25$)
Conclusions

• Reconstruction provides independent spatially distributed data for validation of measurements (e.g., passive microwave) or models (e.g., SNODAS, Central Asian Snow Model)
  • Driven by available data (MODIS or VIIRS, GLDAS or NLDAS)
  • But uncertainty in the starting date
• SWE retrieval from passive microwave data needs improvements to be reliable in the mountains
  • e.g., Tedesco’s neural network approach, but incorporating MODIS-derived snow-covered area