Application of the Snowmelt Runoff Model in the Kuban River Basin by using MODIS satellite images

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State Hydrological Institute, Russia
Study area: Kuban River Basin
Catastrophic Flood in the Kuban River Basin, 20-22 June 2002

107 people died
More than 170000 people suffered
Catastrophic Flood in the Kuban River Basin, 20-22 June 2002

More than 1100 km$^2$ flooded
Scheme of the Kuban River Basin Flood (20-22 June, 2002)

- 1.0 discharge gauging stations where peak discharge in June 2002 was the highest during all observation period with frequency of occurrence within the limits of 0.03 – 4.2 %
- 0.5 discharge gauging stations where peak discharge in June 2002 was the 2nd-5th during all observation period with frequency of occurrence within the limits of 2 – 30 %
- 0.0 discharge gauging stations where peak discharge in June 2002 wasn’t observed
In 2006, the Government of the Russian Federation announced a tender for implementation of the following scientific project:

Investigation of modern conditions and scientific justification of new methods and tools for providing stable functioning of multipurpose water-resources scheme of the Kuban River as well as decreasing of risks of water deleterious effect in the basin.

- **Budget:** 58 million rubles
- **Duration:** 3 years

**Executive organization:**

<table>
<thead>
<tr>
<th>Russian State Hydrological Institute</th>
<th>73</th>
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<tr>
<td>Subcontractors:</td>
<td></td>
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<tr>
<td>Public institution “Hydrochemical Institute”</td>
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<tr>
<td>State Moscow University, Faculty of Geography</td>
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<tr>
<td>North-Caucasian interregional territorial office of ROSGIDROMET</td>
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<tr>
<td>Institute of design and survey “Kuban’vodproekt”</td>
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<tr>
<td>North-Caucasian Institute of designing of hydroeconomic and reclamation building</td>
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</table>
One of the main issue of the project

Development a decision support system based on GIS for managing multipurpose water-resources scheme of the Kuban River Basin under different water-resources conditions

Our part of the issue

Development of forecasting schemes of river inflow to the Krasnodar reservoir
Request from the leaders of SHI

Try to integrate the application of remote sensing data in developing forecasting methods of river inflow to the Krasnodar reservoir
Presentation Outline

1. Database of MODIS snow satellite images
2. Application of the Snowmelt Runoff Model in the Kuban River Basin
3. Conclusions
4. Development of long-term forecasting method of river inflow to the Krasnodar reservoir
### LIST OF EXISTING SNOW MODIS PRODUCTS

<table>
<thead>
<tr>
<th>Data Product Name</th>
<th>MODIS Snow and Ice Data Products</th>
<th>ESDT*</th>
<th>Spatial Resolution</th>
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<td><strong>8-day composite snow-cover</strong>&lt;br&gt;MODIS/Terra Snow Cover 8-day L3 Global 500m Grid</td>
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*Earth Science Data Type,
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<tr>
<th>MODIS/Aqua</th>
<th>Version 3 (V003)</th>
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<tr>
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**Differences in Algorithms**

The MODIS snow mapping algorithm is based on a Normalized Difference Snow Index (NDSI). The NDSI is a measure of the difference between the infrared reflectance of snow in visible and shortwave wavelengths. For Terra data, the algorithm uses MODIS bands 4 (0.55 µm) and 6 (1.6 µm) to calculate the NDSI. MODIS band 6 detectors failed on Aqua shortly after launch, so band 7 (2.1 µm) is used to calculate the NDSI for Aqua. Also with Aqua data, the NDSI/NDVI test for snow in vegetated areas was disabled, because the use of band 7 resulted in too much false snow detection.
MODIS MOD10A2 v04 vs. MODIS MOD10A2 v05

Legend
- boundary of Kuban River Basin
- ground
- inland water
- cloud
- snow cover
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*Earth Science Data Type,
Percentage of SCA and Cloud obtained from MOD10A1 snow product (daily tile snow cover) during snow accumulation period of 2000.
Description of Created Database of snow MODIS satellite images of the Kuban River Basin

Name of MODIS snow product used for creating database

**MOD10A2 8-day composite snow-cover**
MODIS/Terra Snow Cover 8-day L3 Global 500m v05

**Time period:** 2000-02-24 - at present

**Repeat period:** 8 day

**Horizontal resolution:** ~ 450 meters

**Number of images:** 376

**Spatial coverage:**

Lat 46.0 - Lat 43.0
Lon 37.2 - Lon 42.7
Flowchart of creating MODIS snow satellite images of the Kuban River Basin

1. Downloading HDF-files from NSIDC

2. Using MODIS Reprojection Tool (MRT) for merging and reprojection of two MODA2-hdf files

3. Converting the HDF-file produced by MRT to ASCII-file
How to use the database? What kind of advantage can we get?

There is good visual agreement between daily discharge and snow covered area (SCA) in the Kuban River Basin.

Revealed that snow cover extent in the Kuban River Basin before the destructive flood of 2002 (second decade of June) was the highest (from 5 up to 20 %) in comparison with the same periods during 2000-2008.

Unfortunately, Snow Covered Area obtained from MODIS satellite images can't be used itself in river inflow forecast since we couldn't reveal any good relationship between amount of SCA and snowmelt runoff in the Basin.
The method of automated drainage network extraction from grid DEM developed by Ao T. (2002)
Distribution of Snow Cover Extent over the Kuban River Basin (second decade of June)

Confirm the assumption that the flood of 2002 was caused by snow washed down by intensive precipitation.
Interannual distribution of SCA over the Kuban River Basin during the second decade of 2002 (red line) and the same period averaged during 2000-2008 (blue line)
Landsat satellite images

Before the flood

After the flood
Application of the Snowmelt Runoff Model (SRM) in the Kuban River Basin

SRM:
- developed by Martinec (1975)
- has been applied in about 80 basins situated in 25 different countries
- successfully underwent tests by the World Meteorological Organization with regard to runoff simulations (WMO, 1986) and simulated conditions of real time runoff forecast (WMO, 1992)

WHY SRM?
- designed to simulate and forecast daily streamflow in mountain basins where snowmelt is a major runoff factor
- uses air temperature, precipitation and snow covered area as data inputs
- can be applied in mountain basins of almost any size and any elevation range
Application of the Snowmelt Runoff Model in the Kuban River Basin

Our goals:

- to analyse the applicability of the SRM based on using MODIS snow satellite images in the Kuban River Basin
- to examine the possibility of using the SRM for short-range forecast
\[ Q_{n+1} = \left[ c_{SN} \cdot a_n \left( T_n + \Delta T_n \right) S_n + c_{RN} P_n \right] \frac{A \cdot 1000}{86400} \left( 1 - k_{n=1} \right) + Q_n \cdot k_{n+1} \cdot T_{CRIT} \]

Where:
- \( Q \) average daily discharge [m\(^3\)s\(^{-1}\)]
- \( C \) runoff coefficient with \( C_S \) referring to snowmelt and \( C_R \) to rain
- \( a \) degree-day factor [cm\(\cdot^\circ C\cdot d\(^{-1}\)] indicating the snowmelt depth resulting from 1 degree-day
- \( T \) number of degree-days [\(^\circ C\cdot d\)]
- \( \Delta T \) temperature lapse rate [\(^\circ C\cdot d\)]
- \( S \) ratio of the snow covered area to the total area
- \( P \) precipitation [cm]. A preselected threshold temperature, \( T_{CRIT} \), determines whether precipitation is rainfall or new snow.
- \( A \) area of the basin or zone [km\(^2\)]
- \( k \) recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall:
- \( n \) sequence of days during the discharge computation period
- \( \frac{1000}{86400} \) conversion from cm\(\cdot\)km\(^2\)\cdot d\(^{-1}\) to m\(^3\)s\(^{-1}\)
1 – r. Teberda – Teberda
2 – r. Ullu-Kam – Hurzuk
3 – r. Kuban – Kosta Hetagurova
4 – r. Aksaut – Hasaut-Grecheskoe
5 – r. Maruha – Maruha
6 – r. Bolshoy Zelenchuk – Zelenchukskay
7 – r. Bolshaya Laba – Aziatskiy Most
8 – r. Malaya Laba – Burnoe

- weather stations
- discharge gauging stations
- boundary of Krasnodar reservoir basin
Application of the SRM in the Teberda River Basin

Data used

Period: 2000 - 2005

Daily
- discharge
- air temperature
- precipitation
- snow covered area

Interannual distribution of snow covered area during the period of 2001-2007 at three elevation zones of the Teberda River Basin
Results: R. Teberda - v. Teberda 01/10/2000 - 30/09/2001

Runoff (Measured vs Computed)

- Measured Runoff
- Computed Runoff

Measured Runoff Volume (10$^6$ m$^3$): 655.163
Average Measured Runoff (m$^3$/s): 26.775
Computed Runoff Volume (10$^6$ m$^3$): 646.912
Average Computed Q (m$^3$/s): 26.177
Volume Difference (%): 0.9541
Coefficient of Determination ($R^2$): 0.8935

Runoff (Measured vs Computed)

- Measured Runoff Volume (10^6 m^3): 673.754
- Average Measured Runoff (m^3/s): 21.365
- Computed Runoff Volume (10^6 m^3): 640.318
- Avg Computed Q (m^3/s): 20.304
- Volume Difference (%): 4.9527
- Coefficient of Determination (R^2): 0.9918
Conclusions

- SRM shows good performance for the mountain part of the basin

**Statistical evaluation: Coefficient of determination**

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- SRM has a good perspective to be used for short-term forecast of daily discharge in the basin

- Work is in process and further research is needed
Method of long-term forecast of river inflow to the Krasnodar reservoir

Proposed equation:

$$Q_{AMJ} = f(SWE_{31\text{mar}} + \bar{P}_{AMJ})$$

- $SWE_{31\text{mar}}$ - snow water equivalent on 31 March (date before starting melting)
- $P_{AMJ}$ - norm AMJ precipitation counted during a period of data availability (fixed value)
Scheme of long-term forecast of river inflow to the Krasnodar reservoir

1. Snowmelt Runoff Model  (using remote sensing as data input)
   - Parameters transfer
     - Degree-day factor
     - Temperature lapse rate
     - Threshold temperature

2. Distributed Snowmelt Model
   - Model output
     - Computed snow water equivalent

3. Proposed forecasting equation
Distributed snowmelt model of the Krasnodar reservoir

**Data used**

**DEM GTOPO30**

precipitation, air temperature \( \{ \) 17 stations, 1975 - 2006 \( \} \)

**Model Outputs**

Snowmelt

Snow water equivalent

Snow covered area

Solid and liquid precipitation

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**Basic equation (Degree-day method)**

\[
M = M_f (T_a - T_{base})
\]

where \( M \) is the melt (mm day-1); \( M_f \) (mm °C-1 d-1) is a degree-day factor and \( T_{base} \) (°C) is a threshold parameter that represents the temperature above which melt occurs.

**Model parameters**

transferred from SRM

same as in SRM
Computed snow water equivalent

Simulated SWE (mm)

Snow accumulation and ablation period
Simulated SWE (mm) for the period 1977-1978. The graph shows a significant peak on 31 March with a value of 48 mm.
Relationship between observed $Q_{AMJ}$ and $SWE_{31Mar}$ (calculated by the distributed model) + norm $P_{AMJ}$ (counted based on ground observation over 1975-2006)

\[ y = 2.3735x - 418.25 \]

$R^2 = 0.6643$

Correlation coefficient: 0.82
Thank you