



A refinement of MODIS snow cover algorithm for Himalayan region

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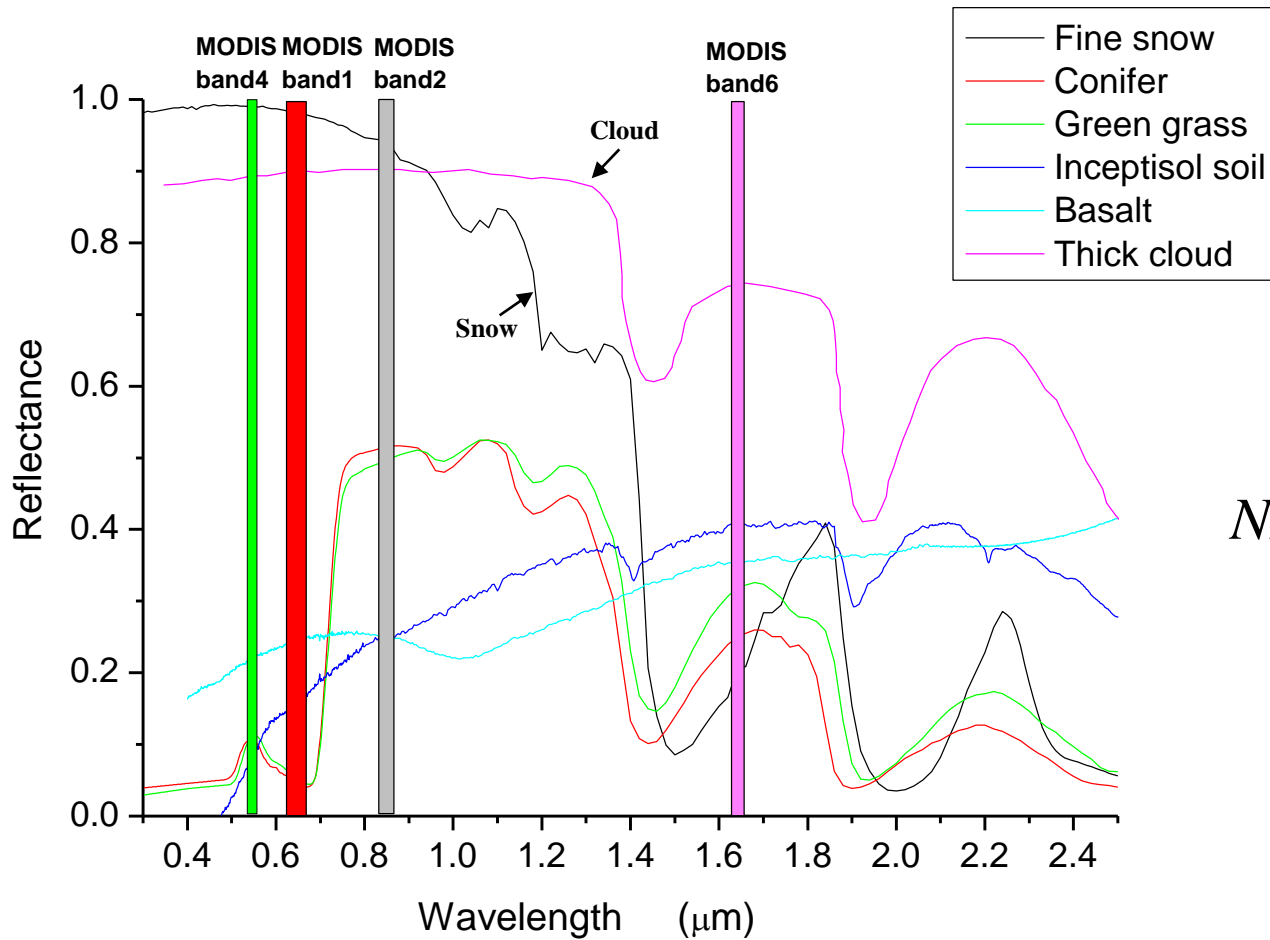
Oct. 4, 2010

Outline

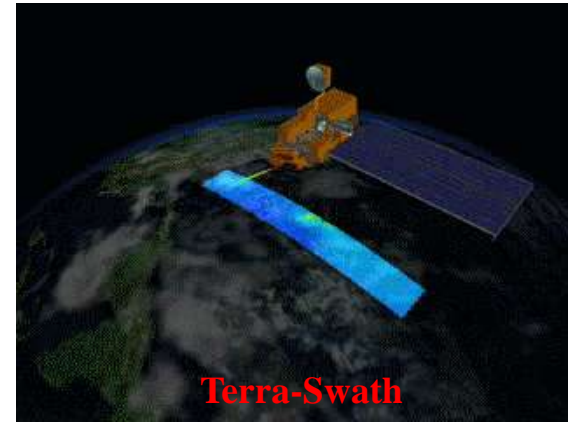
- **Introduction**
- **Methodology**
- **Result**
- **Validation**
- **conclusion**



Introduction



Spectral curves for different land covers (data from ASTER spectral database)



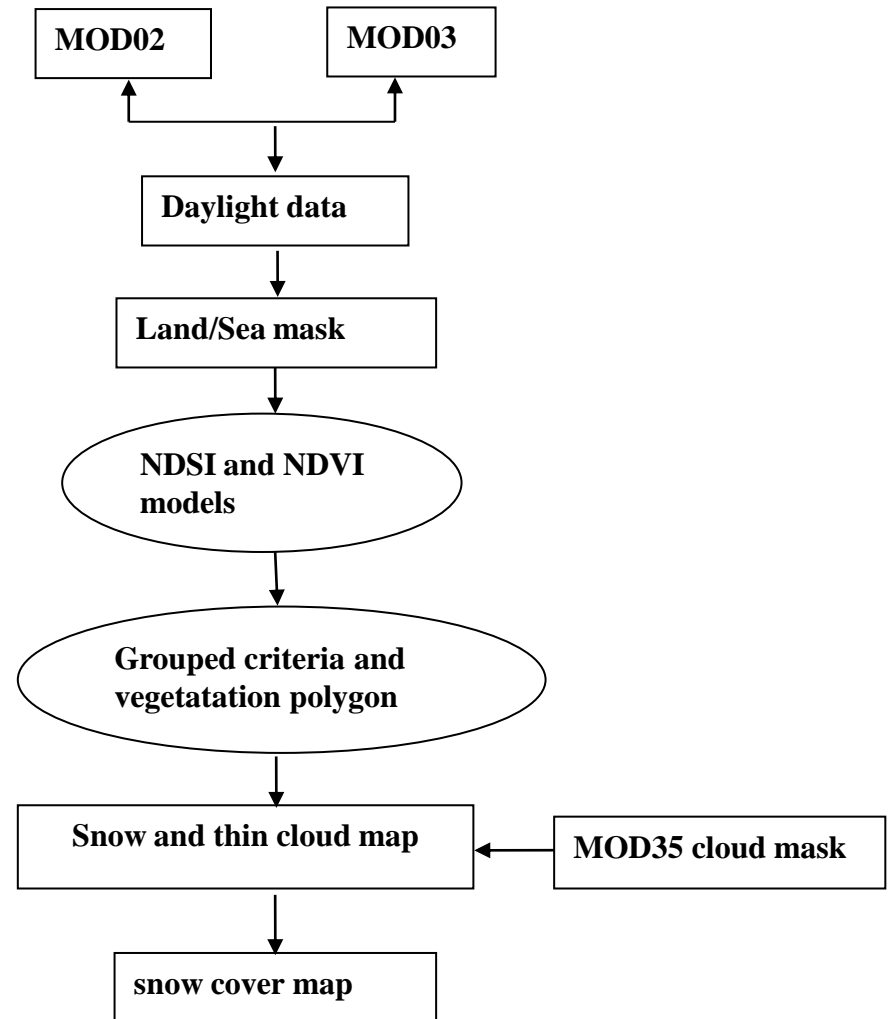
$$NDSI = \frac{\rho_{MODIS4} - \rho_{MODIS6}}{\rho_{MODIS4} + \rho_{MODIS6}}$$

Based on **the difference** of the high reflectance in **the visible** and low reflectance in **the near infrared**, it can easily distinguish snow from other objects

Introduction

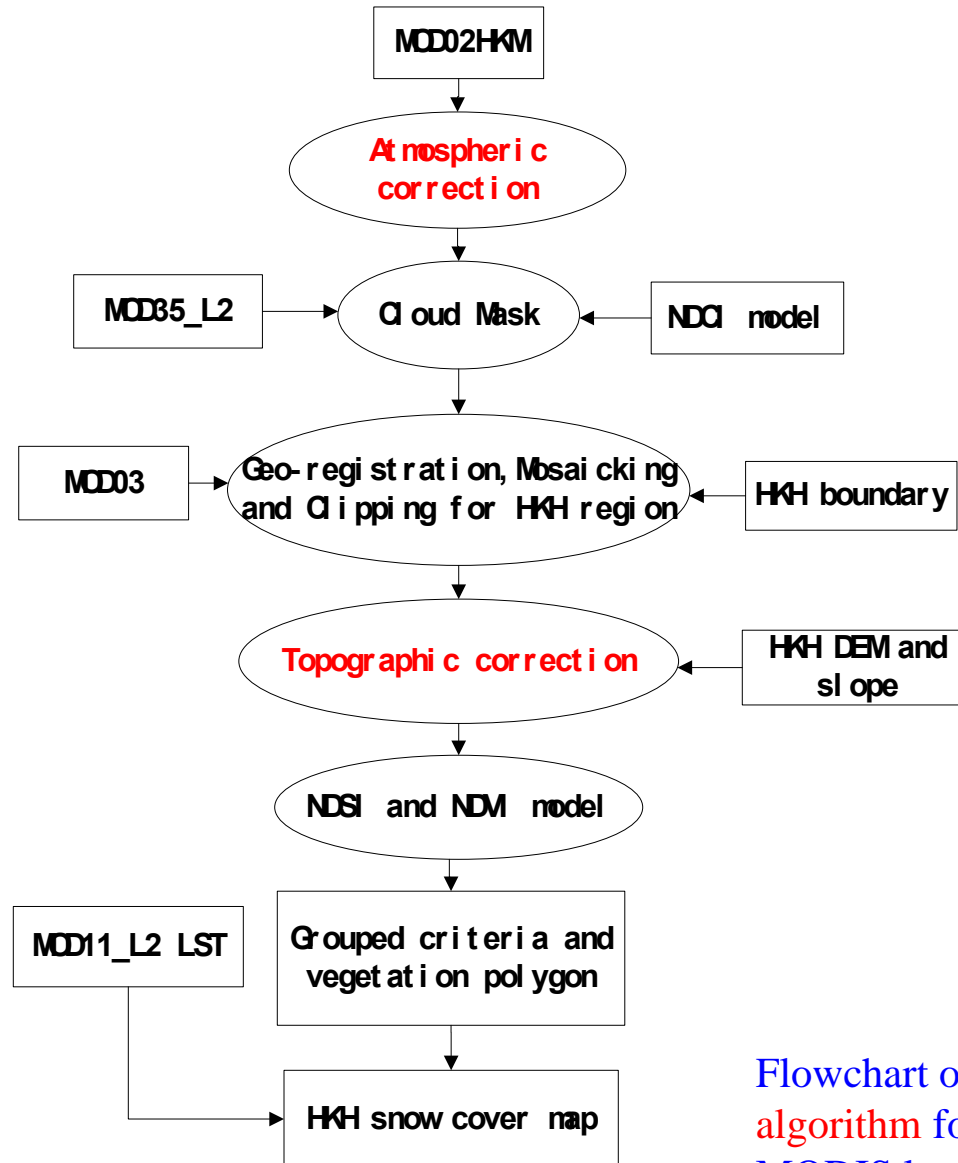
Drawback:

- Without considering **atmospheric** effect
- Without performing **topographic** correction
- Without eliminating the effects of **illumination and Viewing geometry** on the values of the used reflectance.



Flowchart of **NSIDC**'s snow cover algorithm

Methodology

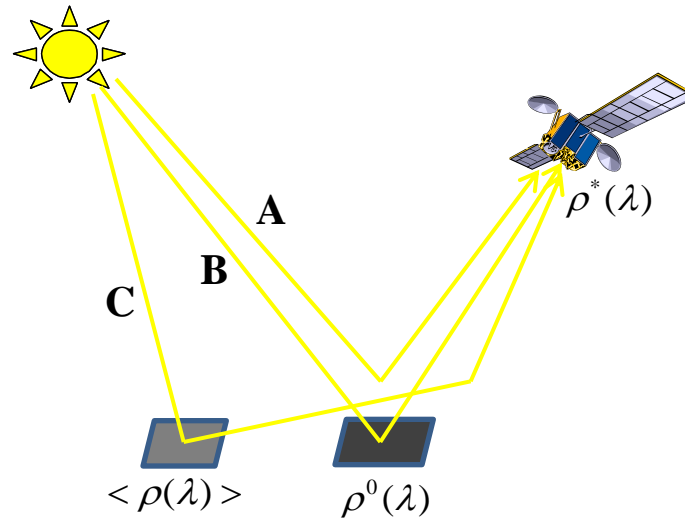


Flowchart of proposed snow cover algorithm for HKH region using MODIS level_1B data

Methodology

Atmospheric correction

QUAC model
was used in this
work



A, B and C describe the
transmission and scattering
of the atmosphere

$$\rho^*(\lambda) = A(\lambda) + \frac{B(\lambda)}{1 - S(\lambda) \langle \rho(\lambda) \rangle} \rho^0(\lambda) + \frac{C(\lambda)}{1 - S(\lambda) \langle \rho(\lambda) \rangle} \langle \rho(\lambda) \rangle$$

the spectral reflectance at the satellite level

the spectral surface reflectance of the target

the atmospheric spherical albedo

the spatially averaged surface reflectance

Methodology

Topographic correction (Hapke model)

the effect or apparent
reflectance

the true reflectance

$$r_R(\Omega_s, \Omega_v) = r(\Omega_{se}, \Omega_{ve}) S(\Omega_s, \Omega)$$

the shadowing function

When $\theta_s < \theta_v$

$$S(\mu_s, \mu_v, \xi) = \frac{\mu_e(\xi)}{\mu_e(0)} \cdot \frac{\mu_s}{\mu_{se}(0)} \cdot \frac{\chi(\bar{\theta})}{1 - f(\xi) + f(\xi)\chi(\bar{\theta})[\mu_s / \mu_{se}(0)]}$$

With

$$\mu_{se}(\xi) = \chi(\bar{\theta}) \left[\mu_s + \sqrt{1 - \mu_s^2} \tan(\bar{\theta}) \frac{\cos(\xi)E_2(\theta_v) + \sin^2(\xi/2)E_2(\theta_s)}{2 - E_1(\theta_v) - (\xi/\pi)E_1(\theta_s)} \right]$$

$$\mu_e(\xi) = \chi(\bar{\theta}) \left[\mu_v + \sqrt{1 - \mu_v^2} \tan(\bar{\theta}) \frac{E_2(\theta_v) + \sin^2(\xi/2)E_2(\theta_s)}{2 - E_1(\theta_v) - (\xi/\pi)E_1(\theta_s)} \right]$$

Methodology

Topographic correction

When $\theta_s \geq \theta_v$

$$S(\mu_s, \mu_v, \xi) = \frac{\mu_e(\xi)}{\mu_e(0)} \cdot \frac{\mu_s}{\mu_{se}(0)} \cdot \frac{\chi(\bar{\theta})}{1 - f(\xi) + f(\xi)\chi(\bar{\theta})[\mu_v / \mu_e(0)]}$$

With

$$\mu_e(\xi) = \chi(\bar{\theta}) \left[\mu_v + \sqrt{1 - \mu_v^2} \tan(\bar{\theta}) \frac{\cos(\xi)E_2(\theta_s) + \sin^2(\xi/2)E_2(\theta_v)}{2 - E_1(\theta_s) - (\xi/\pi)E_1(\theta_v)} \right]$$

Where

$$\chi(\bar{\theta}) = \frac{1}{\sqrt{1 + \pi \tan^2(\bar{\theta})}}$$

$$E_1(x) = \exp\left(-\frac{2}{\pi} \cot(\bar{\theta}) \cot(x)\right)$$

$$f(\xi) = \exp\left(-2 \tan\left(\frac{\xi}{2}\right)\right)$$

$$E_2(x) = \exp\left(-\frac{1}{\pi} \cot^2(\bar{\theta}) \cot^2(x)\right)$$

Methodology

Determination of snow cover

Three normalized indexes

$$\text{NDSI} = \frac{\rho_{\text{MODIS4}} - \rho_{\text{MODIS6}}}{\rho_{\text{MODIS4}} + \rho_{\text{MODIS6}}}$$

$$\text{NDCI} = \frac{\rho_{\text{MODIS1}} - \rho_{\text{MODIS6}}}{\rho_{\text{MODIS1}} + \rho_{\text{MODIS6}}}$$

$$\text{NDVI} = \frac{\rho_{\text{MODIS2}} - \rho_{\text{MODIS1}}}{\rho_{\text{MODIS2}} + \rho_{\text{MODIS1}}}$$

In non-forested area

$$\text{NDCI} > 0.5 \text{ and } \text{cld_msk} \neq 0 \text{ and } \text{LST} \leq 283\text{K}$$

$$\text{NDSI} \geq 0.3 \text{ and } \rho_{\text{MODIS2}} \geq 0.09 \text{ and } \rho_{\text{MODIS4}} \geq 0.09$$

In forested area

$$\text{NDCI} > 0.5 \text{ and } \text{cld_msk} \neq 0 \text{ and } \text{LST} \leq 283\text{K}$$

$$\text{NDSI} < 0.3 \text{ and } \rho_{\text{MODIS2}} \geq 0.09 \text{ and } \rho_{\text{MODIS4}} \geq 0.09$$

$$-0.5\text{NDSI} + 0.3 \leq \text{NDVI} \leq 2.5\text{NDSI}$$

Methodology

Comparison with NSIDC's snow cover algorithm

Type	NSIDC's snow cover algorithm	Proposed snow cover algorithm
Input data	MOD02_L1B, MOD03, MOD35	MOD02_L1B, MOD03, MOD35, MOD11_L2, DEM
Atmospheric correction	No	Yes
Topographic correction	No	Yes
models	NDSI, NDVI	NDSI, NDVI, NDCI
Constraints of threshold	<p>For nonforest area:</p> <p>and $NDSI \geq 0.4$</p> <p>and $\rho_{band2}^* \geq 0.11$</p> <p>and $\rho_{band4}^* \geq 0.10$</p> <p>For forest area:</p> <p>a defined polygon and</p> <p>and $NDSI < 0.4$</p> <p>and $\rho_{band2}^* \geq 0.11$</p> <p>and $\rho_{band4}^* \geq 0.10$</p>	<p>For nonforest area:</p> <p>$NDCI > 0.5$ and $cld_msk \neq 0$ and $LST \leq 283\text{ K}$</p> <p>and $NDSI \geq 0.3$ and $\rho_{band2} \geq 0.09$ and $\rho_{band4} \geq 0.09$</p> <p>For forest area:</p> <p>$NDCI > 0.5$ and $cld_msk \neq 0$ and $LST \leq 283\text{ K}$</p> <p>and $NDSI < 0.3$ and $\rho_{band2} \geq 0.09$ and $\rho_{band4} \geq 0.09$ and</p> <p>$-0.5NDSI + 0.3 \leq NDVI \leq 2.5NDSI$</p>

Result

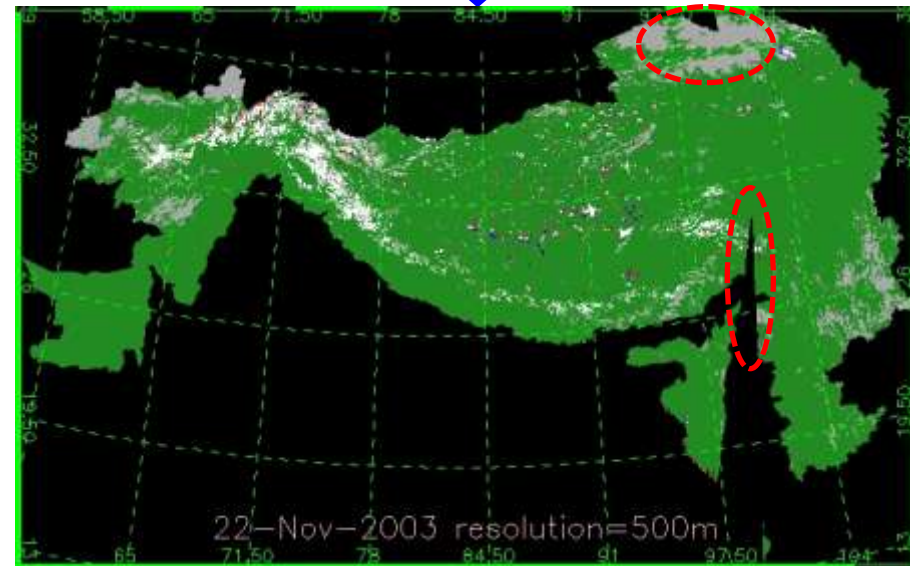


← Study area

Snow cover map estimated with the proposed method

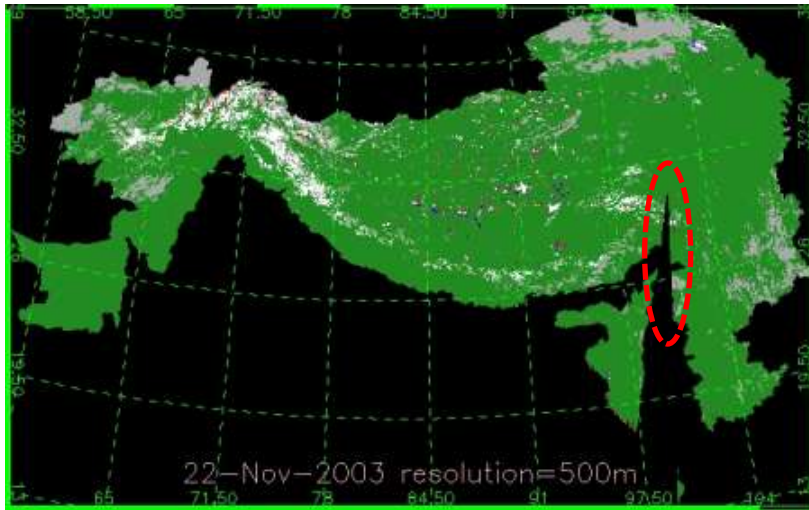


- cloud contamination
 - Existing gap area
- ←



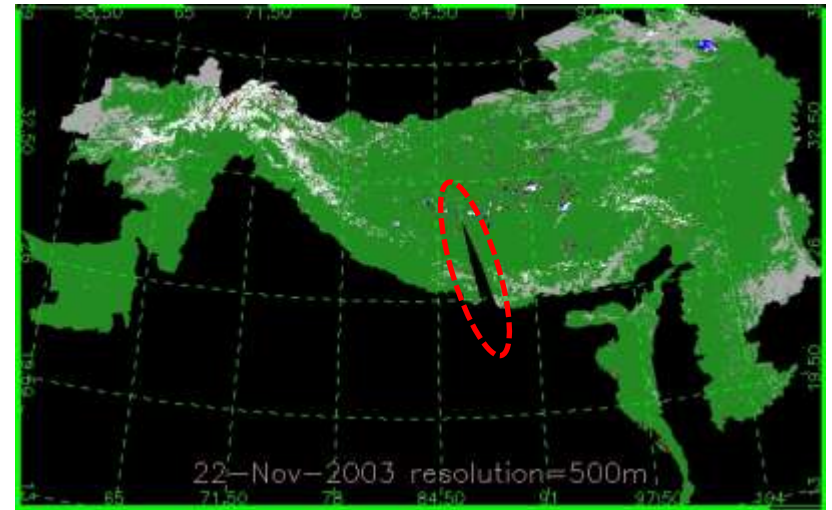
Result

Composition of MODIS-Terra and MODIS-Aqua snow cover maps



Terra Snow Cover

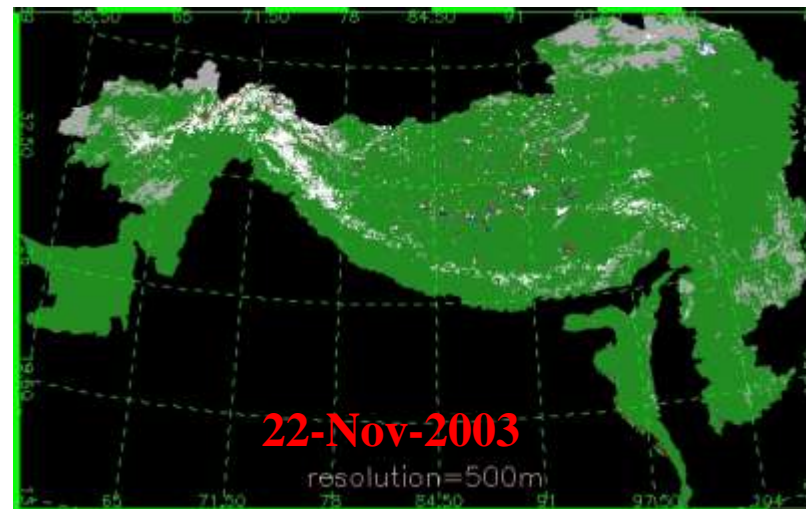
+



Aqua Snow Cover

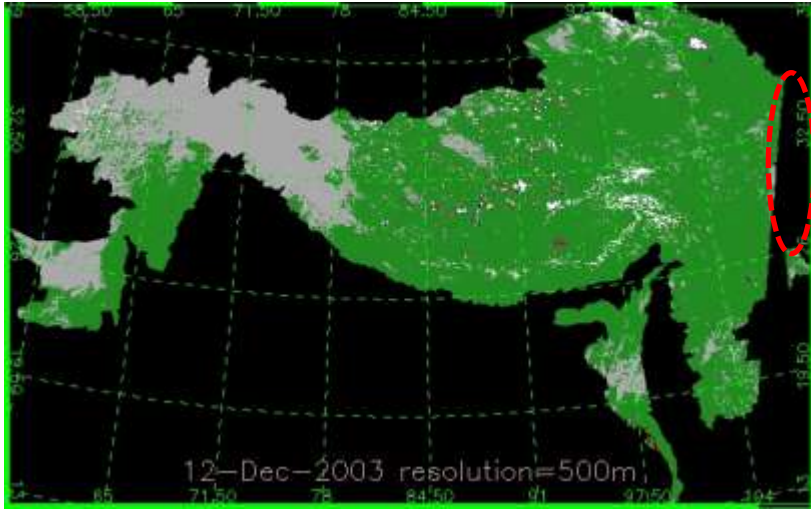


- Maximize the snow
- Reduce cloud contamination
- Fill the gap area



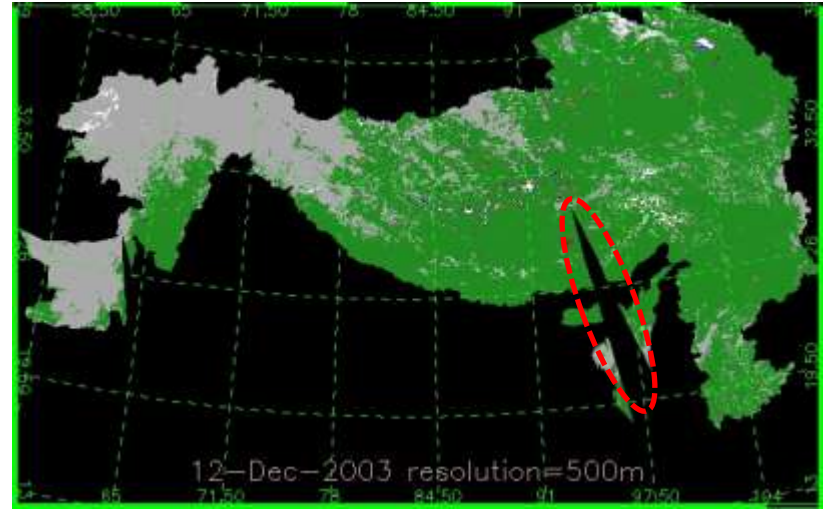
Composition of Snow Cover

Result

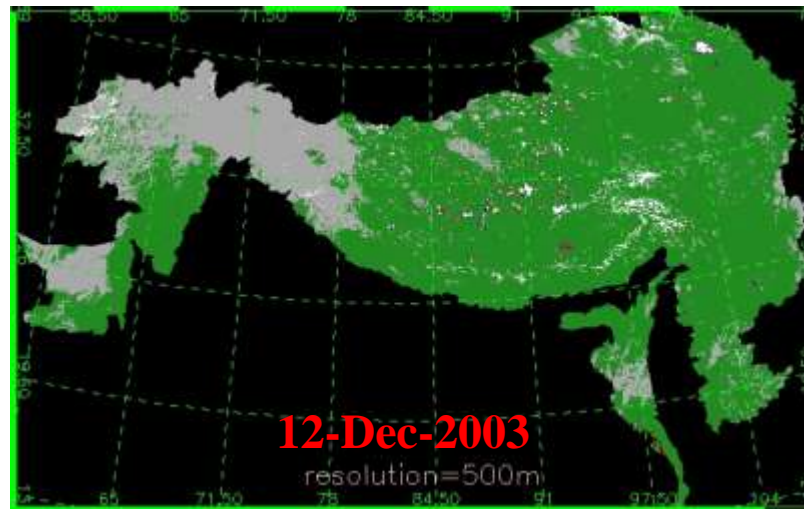


Terra Snow Cover

+



Aqua Snow Cover



**Composition of
Snow Cover**

Validation

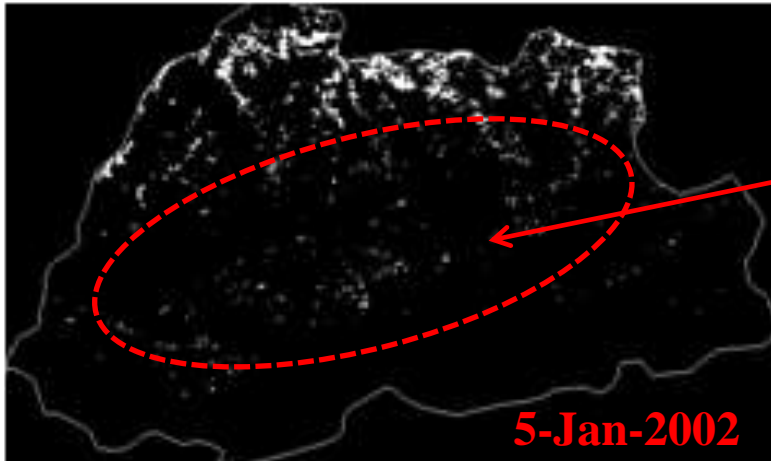
Comparison with MODIS snow cover product



Composited image by MODIS bands 1, 4, 3



snow cover map estimated using the **proposed algorithm**



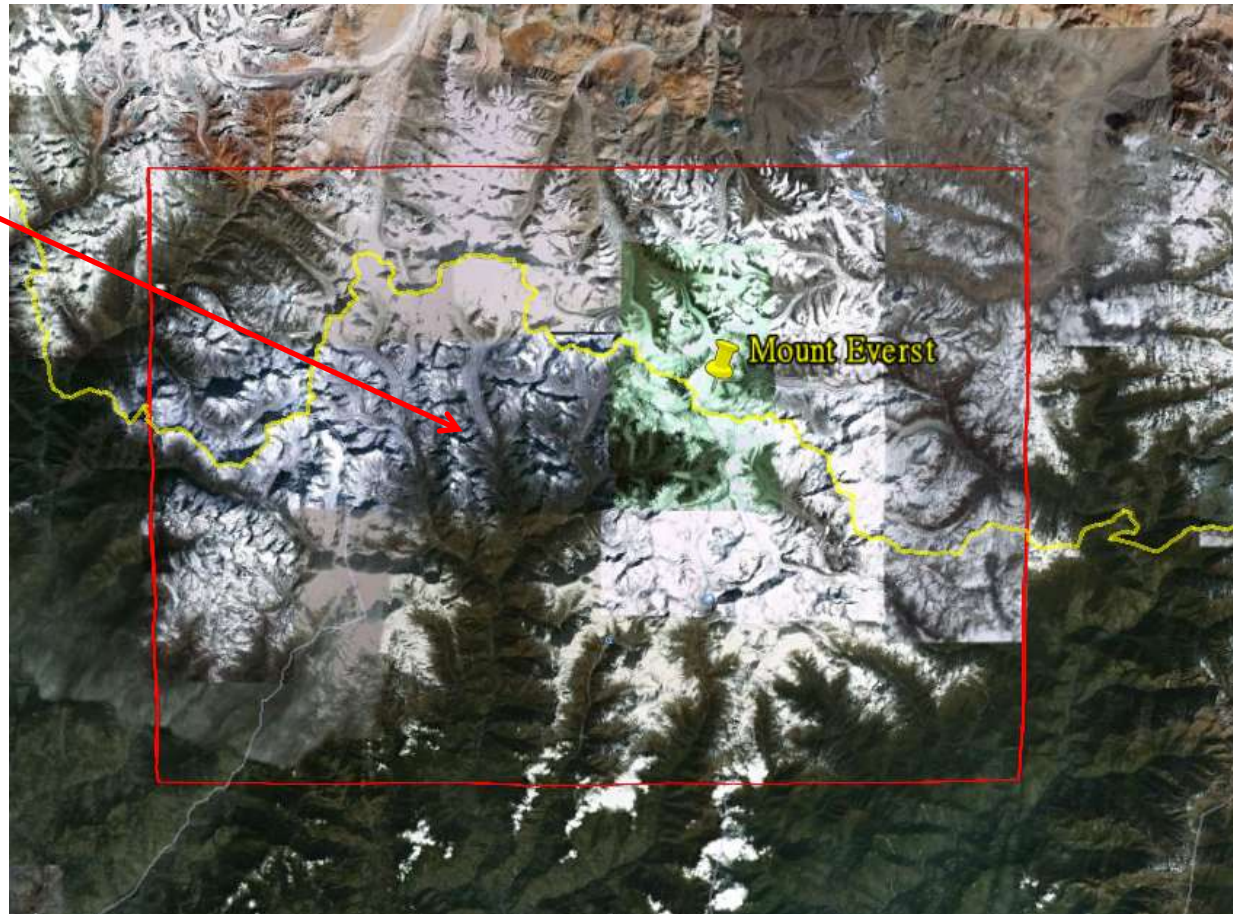
snow cover map obtained from **MOD10_L2** product

NSIDC's algorithm **mistakes** many pixels as snow covers in southern Bhutan which **does not exist** snow cover in the true color composited image

Validation

Validation with high resolution data

Test area



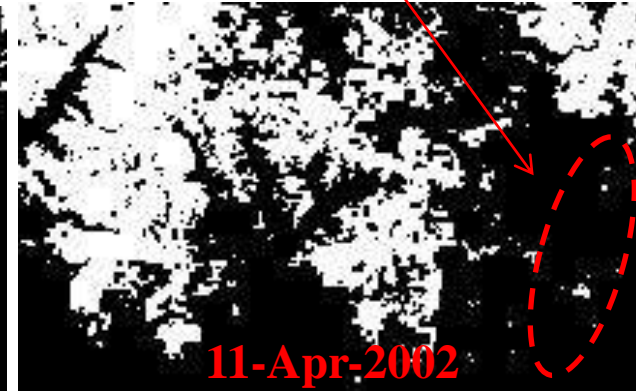
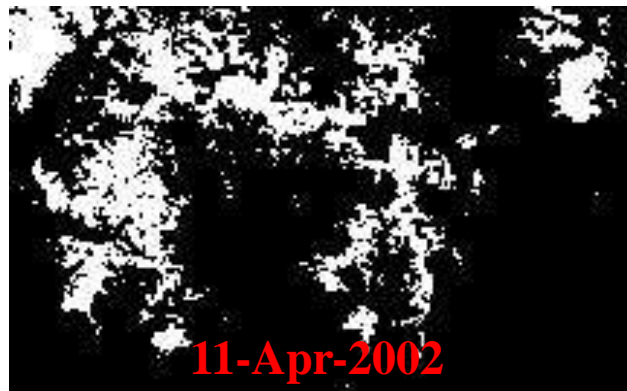
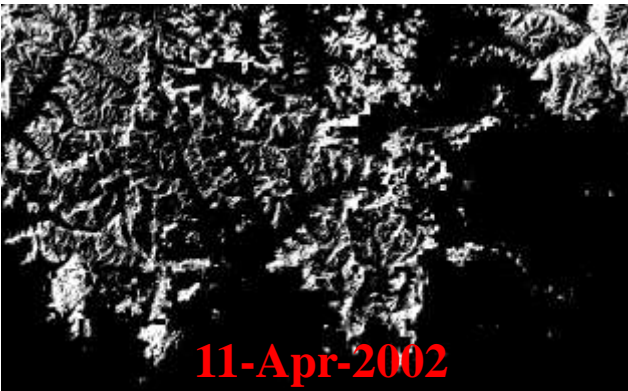
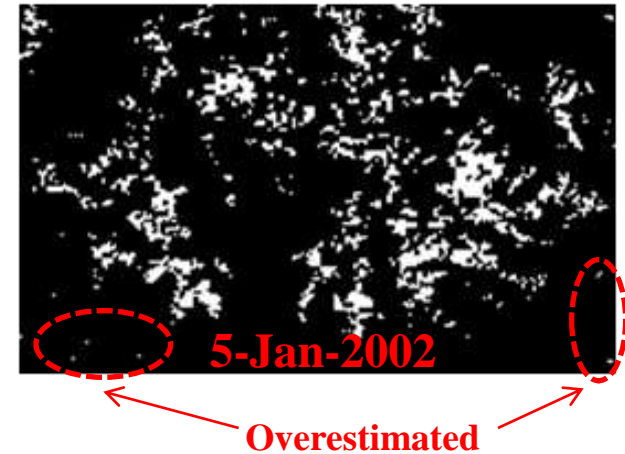
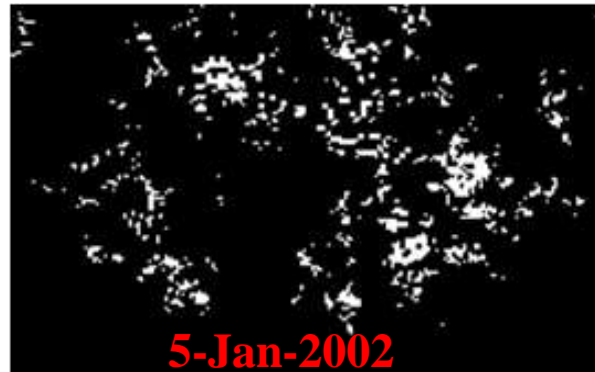
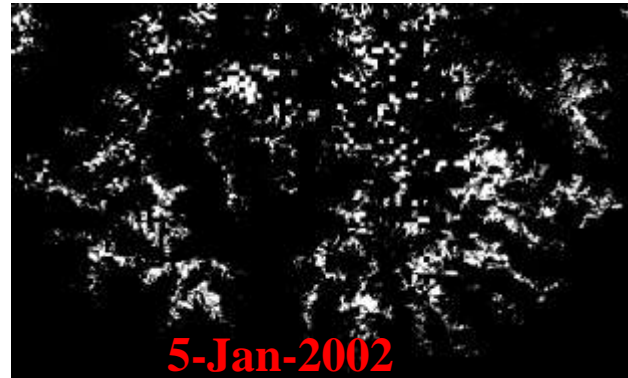
Validation

Validation with high resolution data

ETM+ snow cover

Estimated MODIS snow cover

MOD10_L2 snow cover



Validation

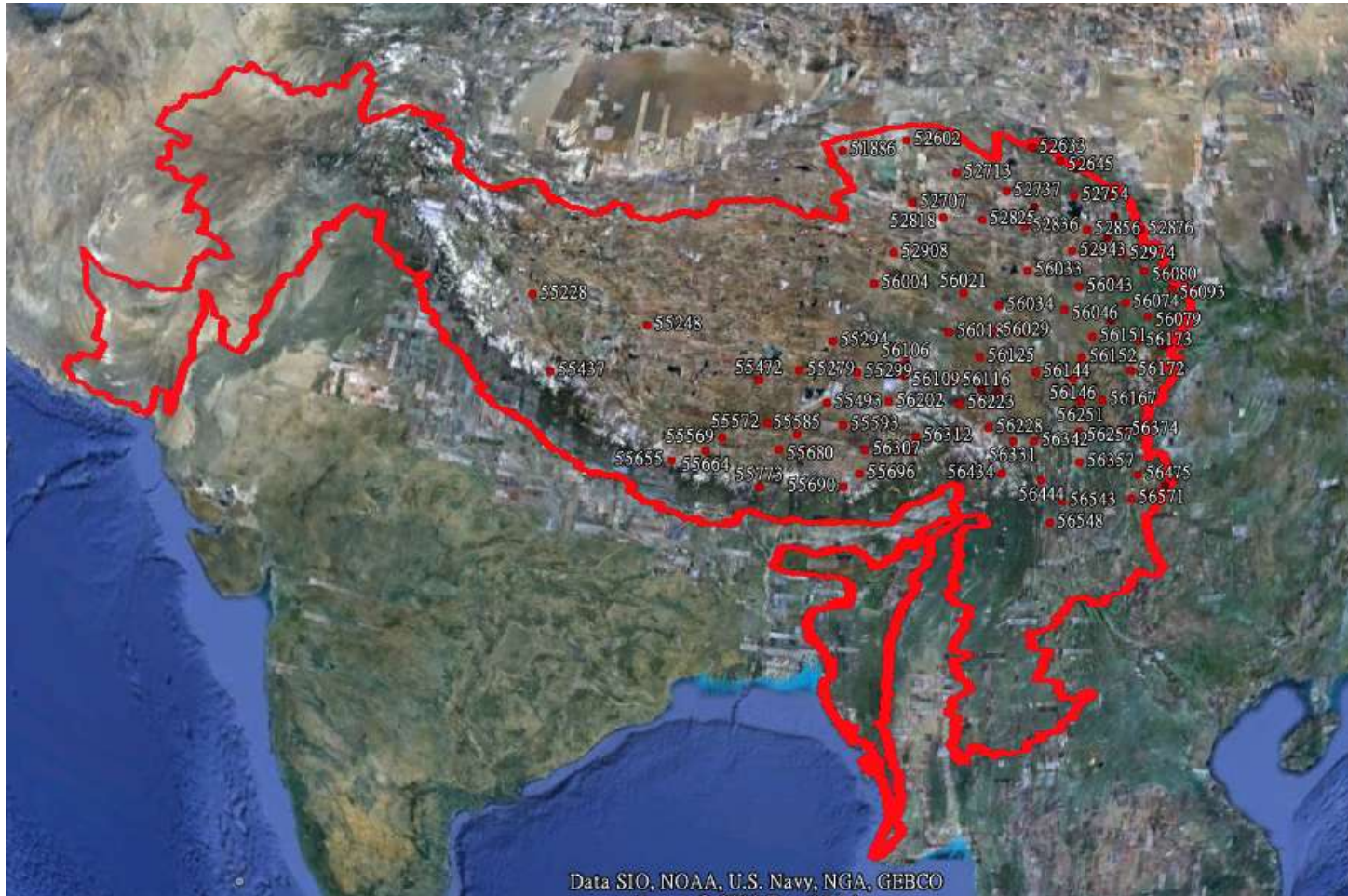
Validation with high resolution data

Statistics of snow cover area obtained from different methods for Mount Everest region for different seasons in 2002

Date	ETM+ (km ²)	Estimated (km ²)	Absolute error (%)	MOD10_L2 (km ²)	Absolute error (%)
Jan. 5	596.62	543.00	8.9	760.00	27.4
Apr. 11	1201.70	1310.75	9.1	1871.25	55.7
May 13	1464.62	1307.50	10.7	1758.75	20.1
Oct. 04	1480.97	1329.50	10.2	1807.75	22.1

Validation

Validation with in-situ data



95 stations located in the HKH region

Validation

Validation with in-situ data

Validation of the proposed classification method with in-situ data of the 95 stations in the HKH region

Date	Corrected classification (%)	Uncorrected classification (%)
Jan. 10, 2003	95.79	4.21
Jan. 22, 2003	94.74	5.26
Apr. 14, 2003	91.58	8.42
Oct. 16, 2003	91.58	8.42
Nov. 22, 2003	95.78	2.11
Dec. 12, 2003	93.68	3.16

Conclusion

- **NSIDC's MODIS snow cover products overestimate the snow cover in the Himalayan region**
- **Our proposed algorithm can estimate the snow cover for the Himalayan region more feasible with accuracy better than 90%**
- **Estimating of the snow cover over heavy mountain regions needs to do atmospheric and topographic corrections**

Thanks !

