Airborne retrievals of snow properties

Felix Seidel,
Thomas Painter

Jet Propulsion Laboratory /
California Institute of Technology

JPL Postdoc Seminar Series

Pasadena, July 25. 2013

Jet Propulsion Laboratory
California Institute of Technology

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Caltech

Introduction: Airborne Snow Observatory

Relevance / Impacts / Objectives

Society:

- Water resources and Hydropower
- Natural disasters
- Tourism

Science:

- Climate: Energy balance, precipitation, validation of models, etc.
- Hydrology: improvement of run off models
- Remote sensing: improvement and validation of algorithms, towards orbital appl.

Agency:

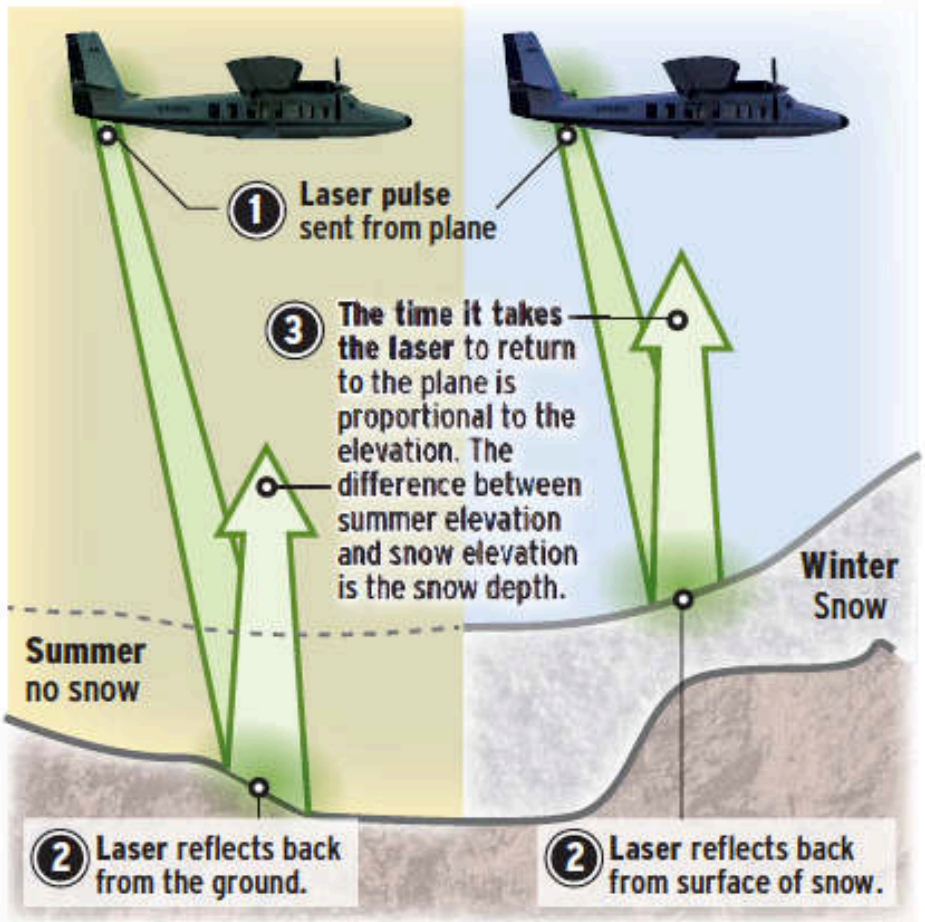
- Programs: cryospheric science, terrestrial hydrology, climate change/variability, and applied sciences
- Missions: decadal survey mission HyspIRI, other (to-be) proposed missions

AS
Western Water Assessment
NASA
JPL
NSIDC
AIG

Airborne Observations

How much snow?

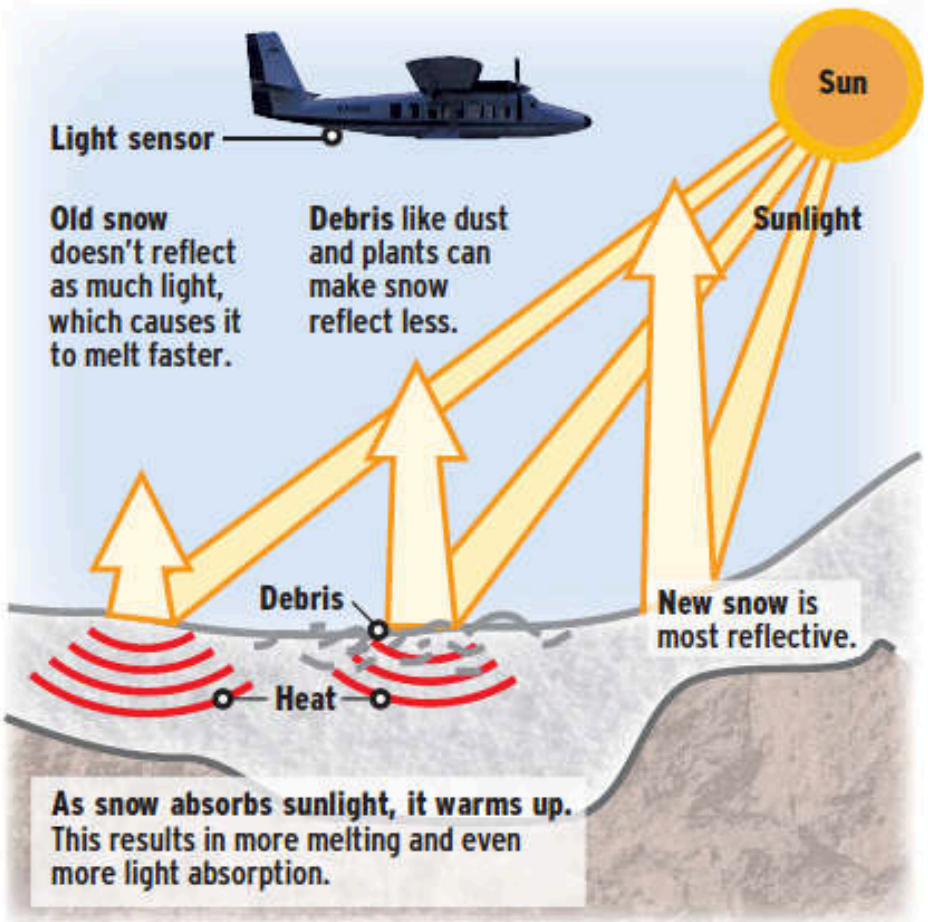
Using laser radar, known as Lidar, researchers measure the depth of snowpack in California.



Sources: Thomas Painter, Frank Gehrke, Optech Inc.

How will it melt?

With an advanced light sensor, scientists measure snow's reflectivity – an indicator of how it will melt.



Maxwell Henderson / The Register

From: Orange County Register, May 31 2013

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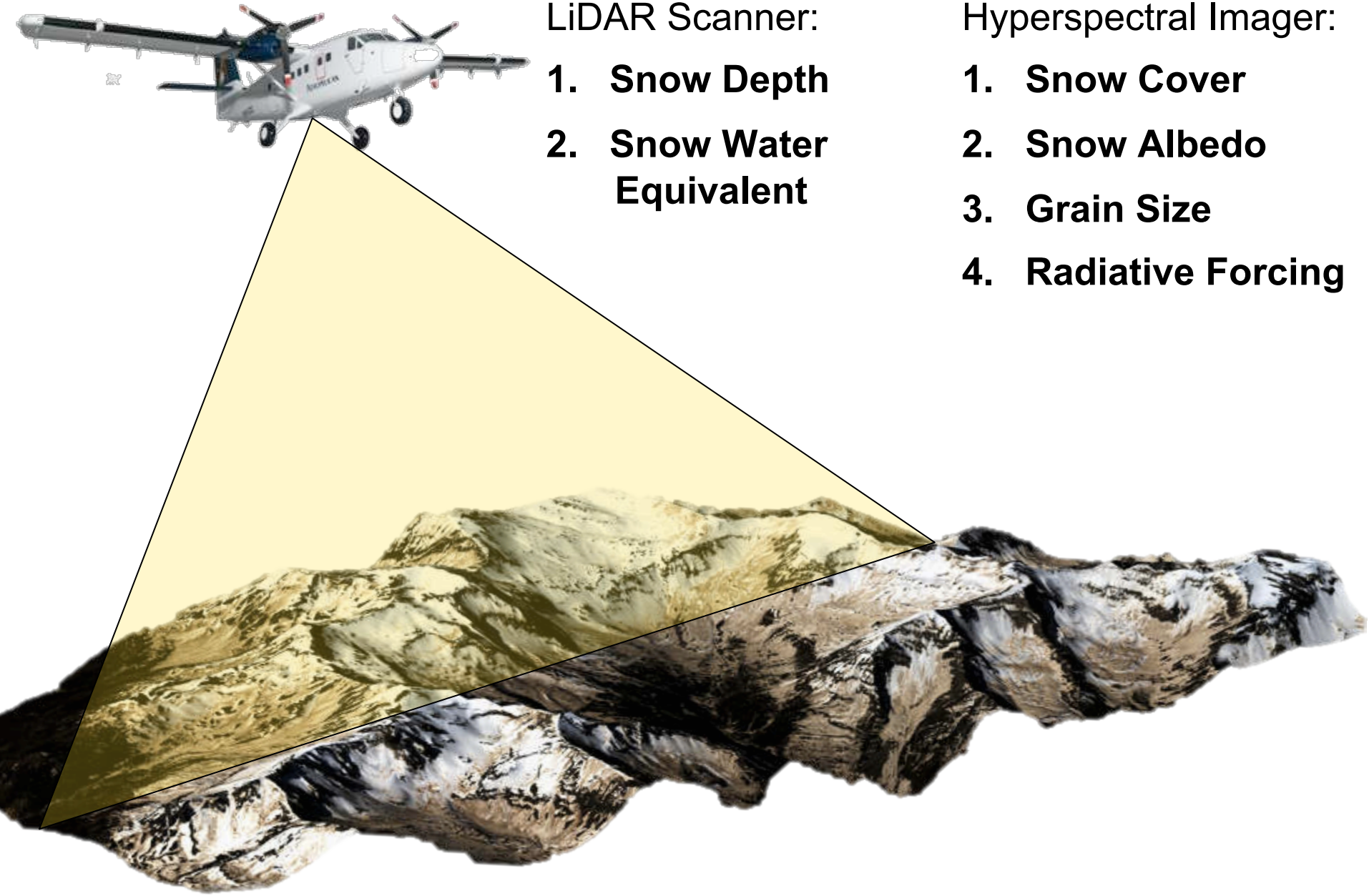
Airborne Observations



LiDAR Scanner:

1. **Snow Depth**
2. **Snow Water Equivalent**

Hyperspectral Imager:

1. **Snow Cover**
2. **Snow Albedo**
3. **Grain Size**
4. **Radiative Forcing**

Study Site: Tuolumne River Basin, CA

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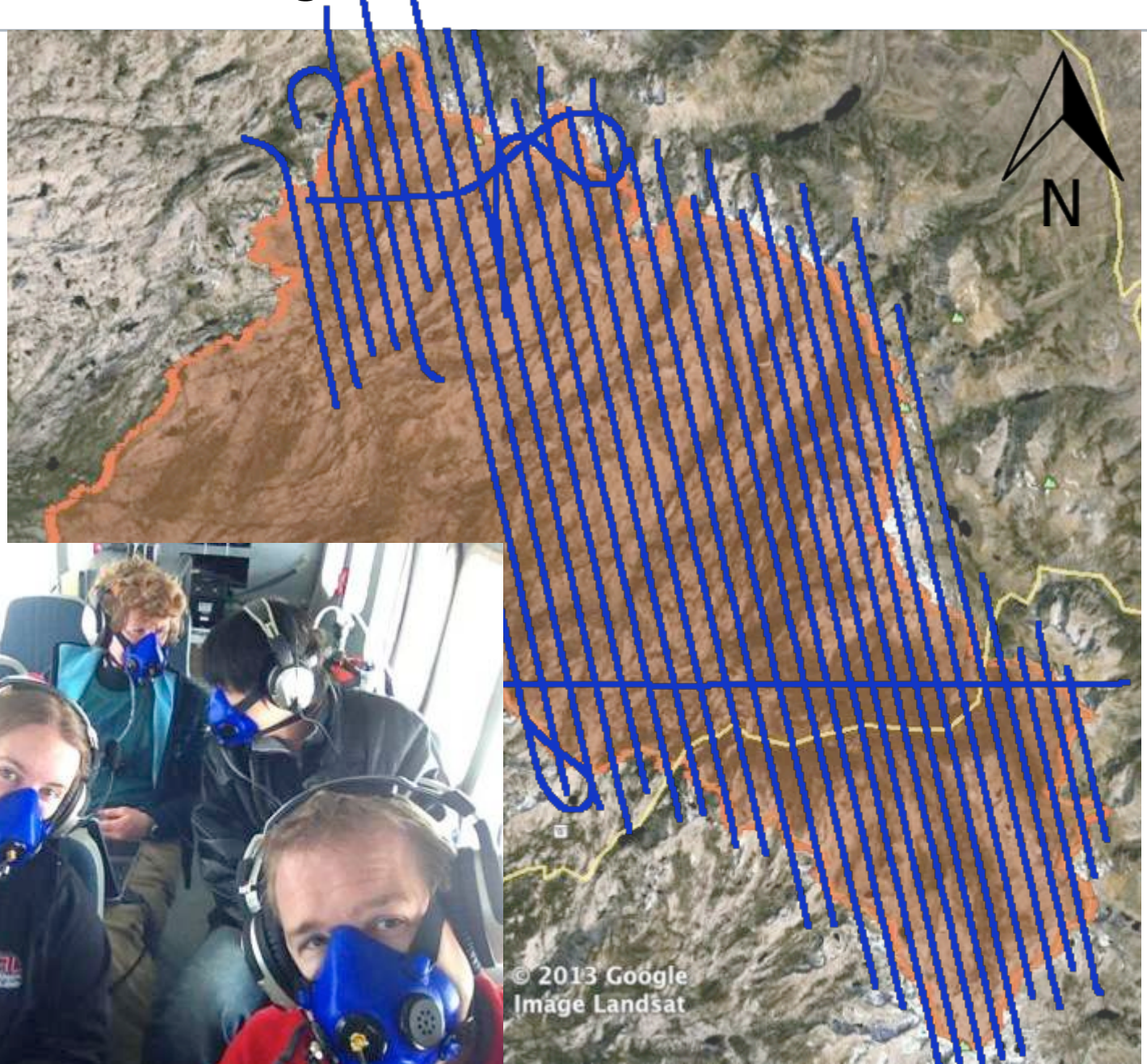
California Institute of Technology

Flight Team



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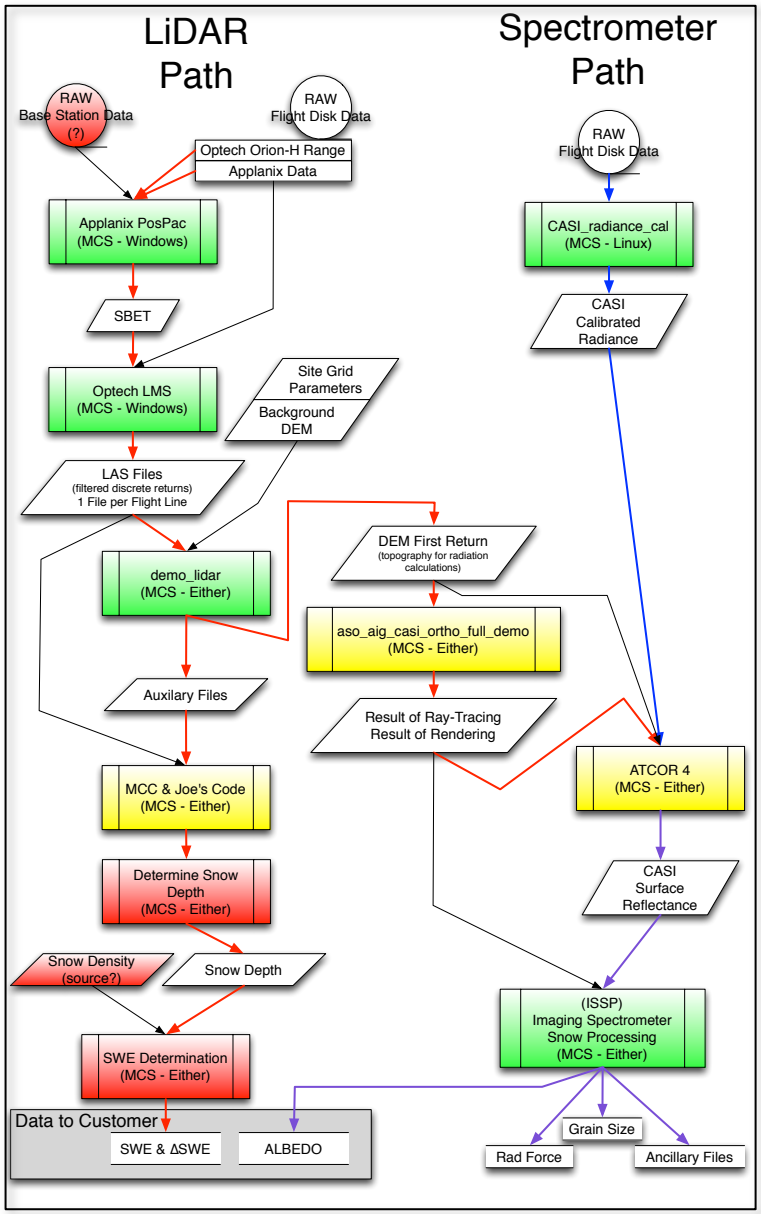
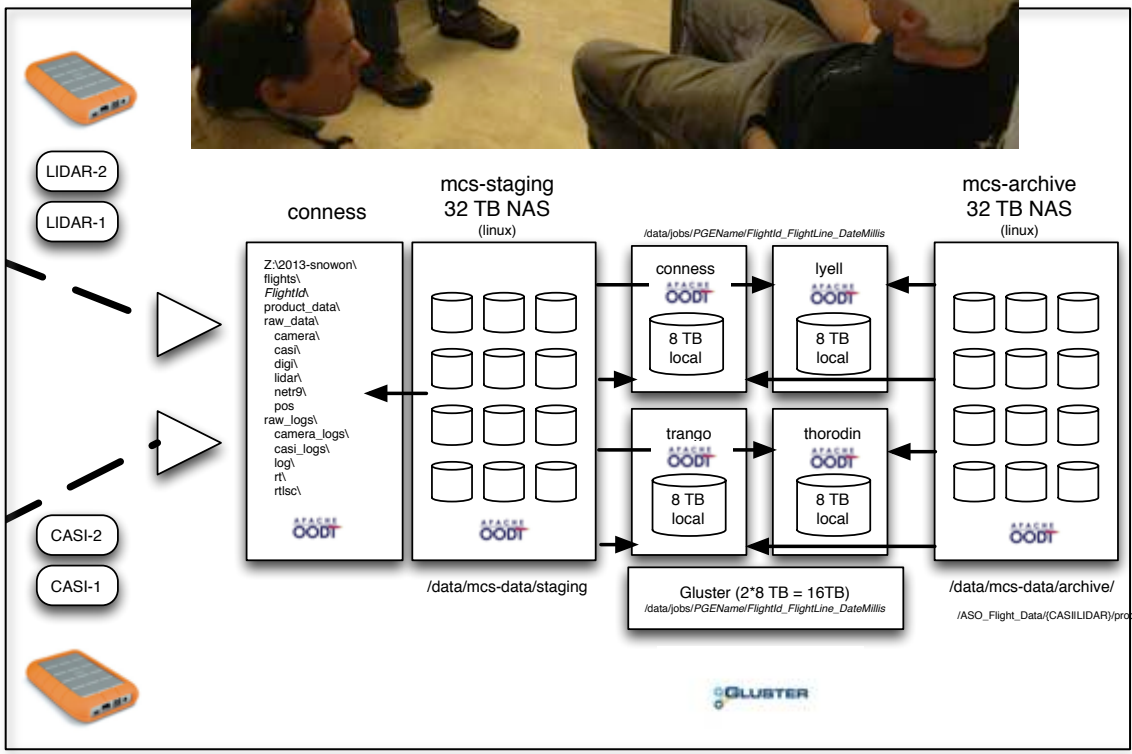
Algorithm & Compute Team





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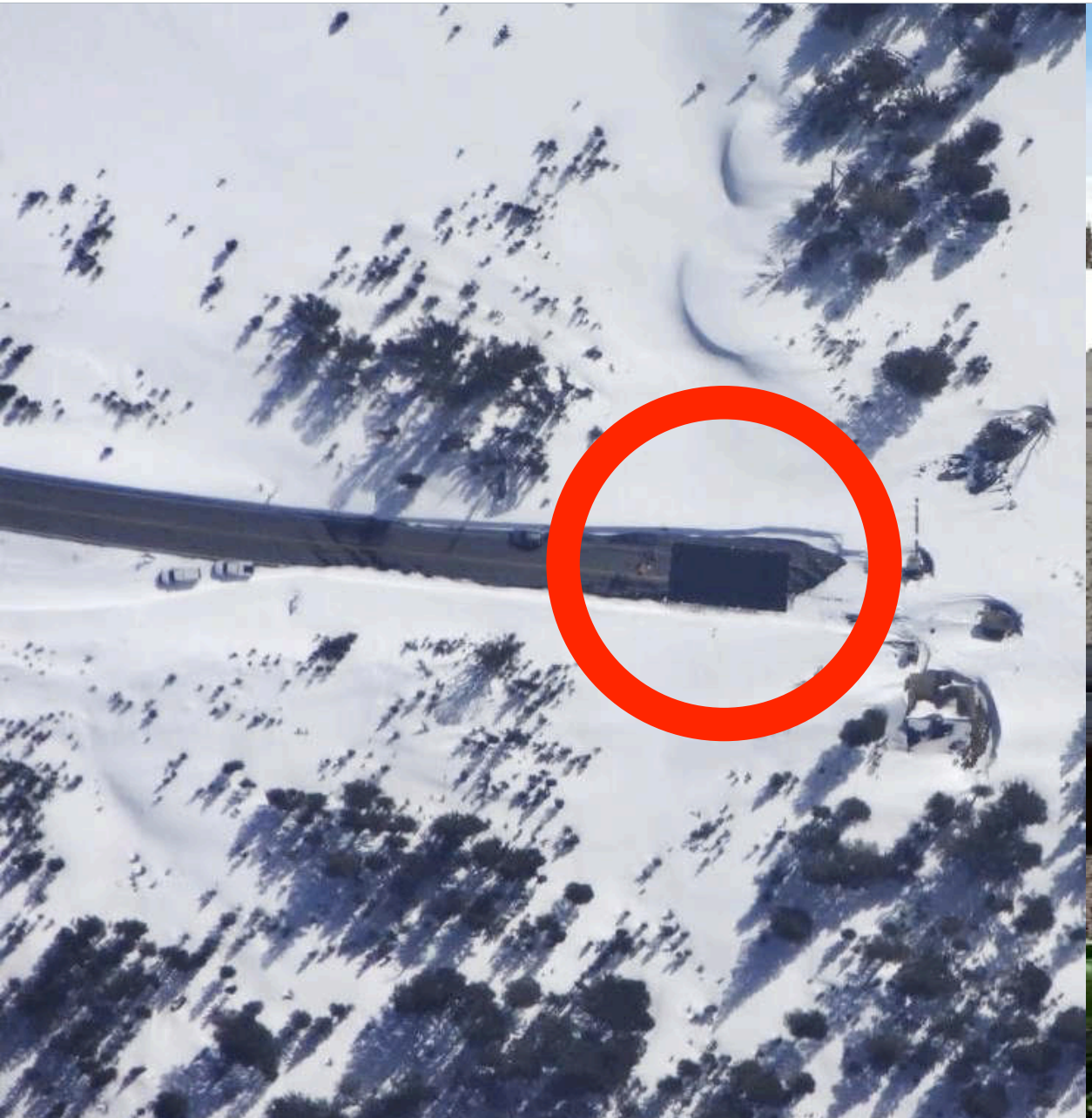
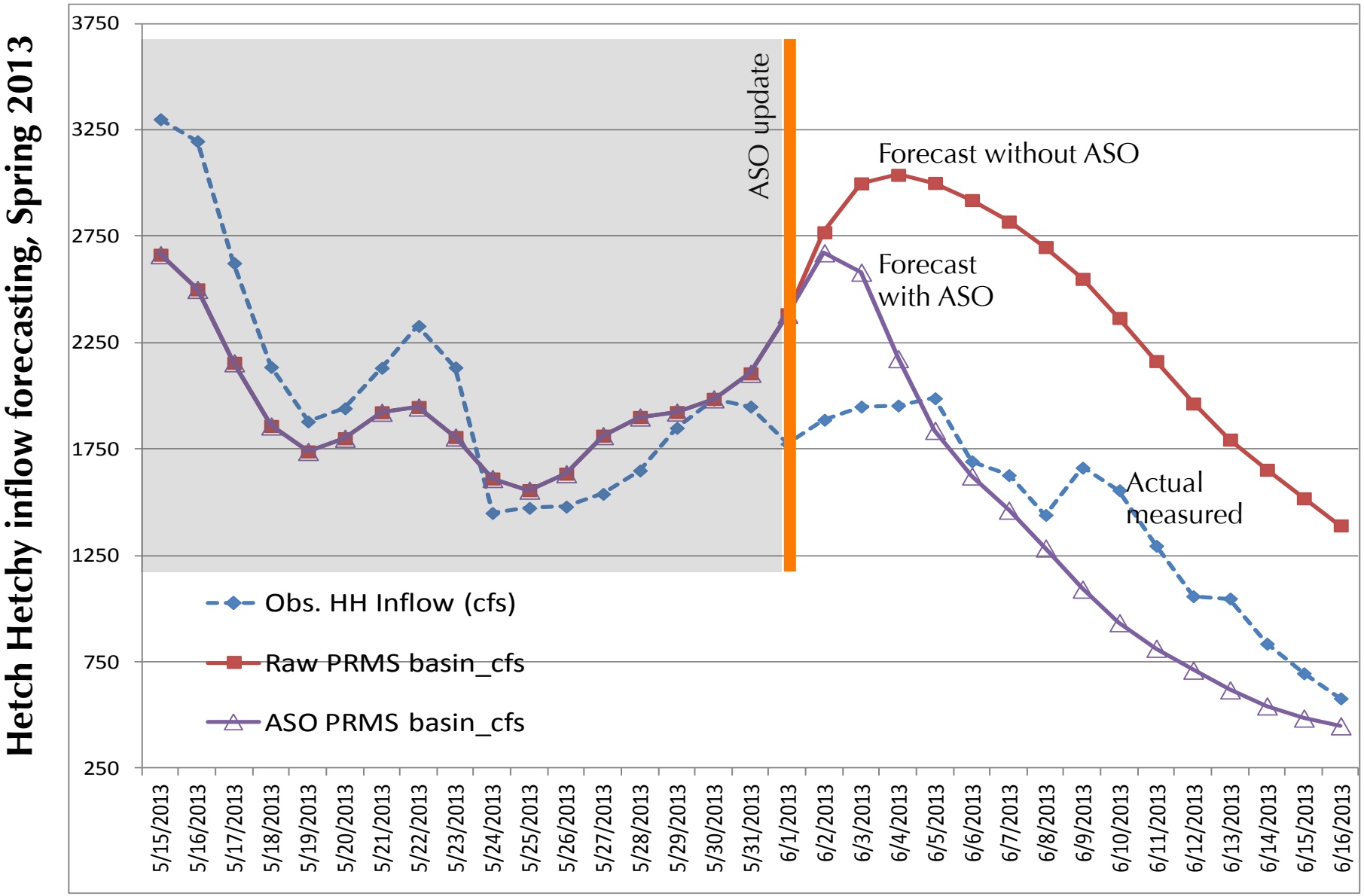
Ground Team (Calibration/Validation)



Impact on Water Resources Management



Adapted from: Tom Painter, et al.

Main Part: Overview

Snow Cover Area

- Product

Albedo

- Method & Theory
- Product
- Analysis

Snow Grain Size

- Method & Theory
- Product
- Analysis

Radiative Forcing

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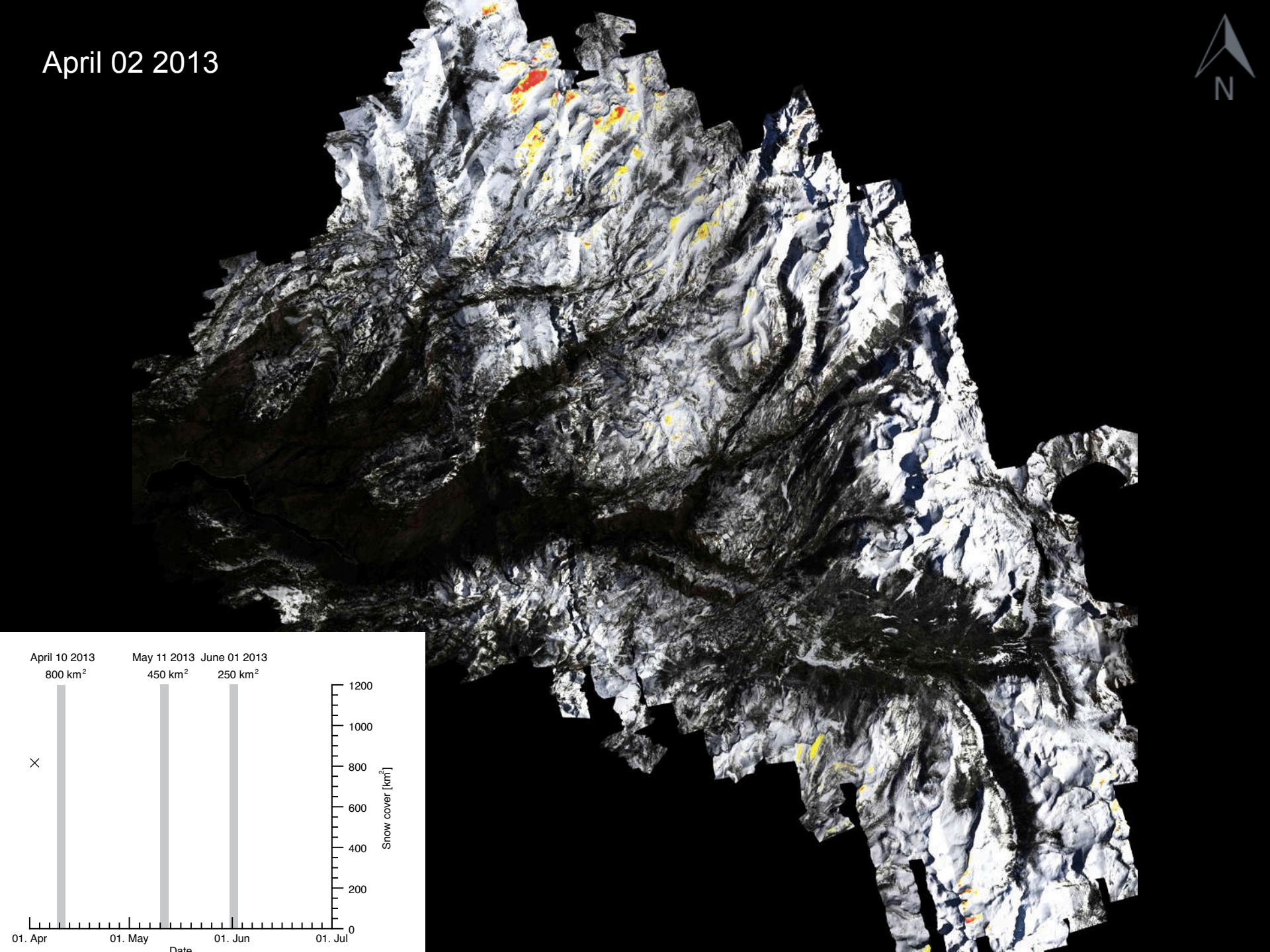
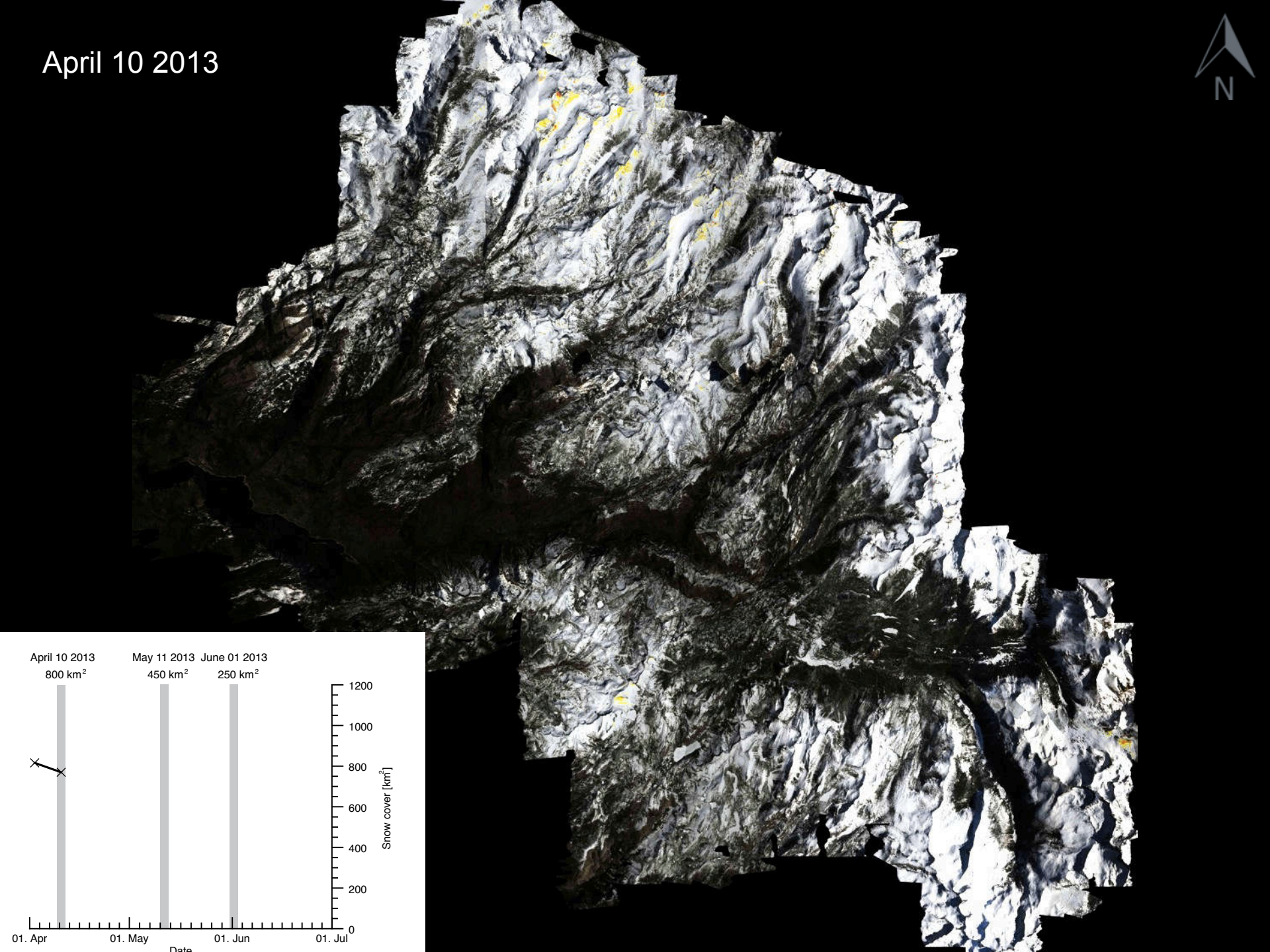
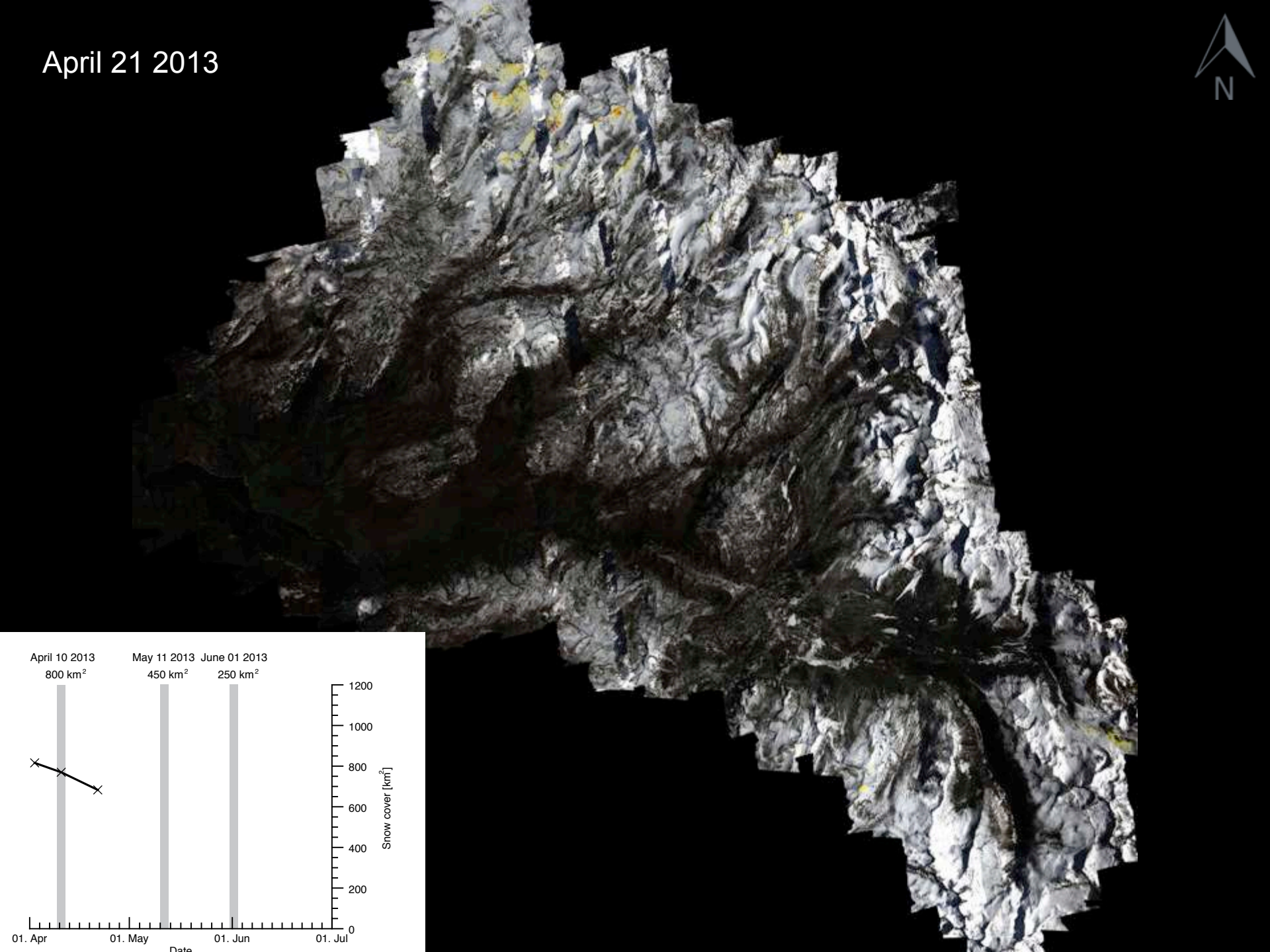
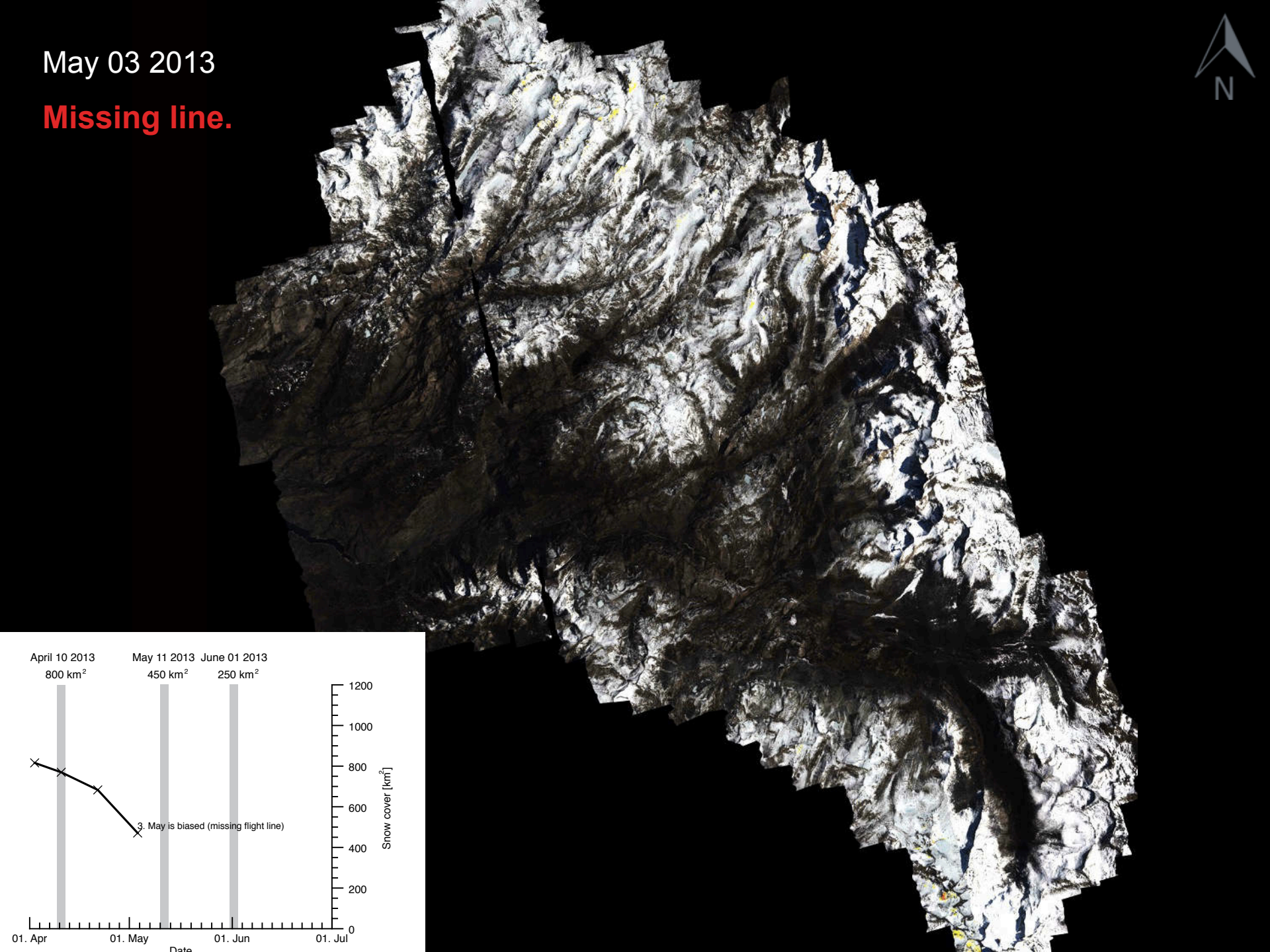

April 02 2013
N
April 10 2013
800 km²
May 11 2013
450 km²
June 01 2013
250 km²
1200
1000
800
600
400
200
0
Snow cover [km²]
01. Apr
01. May
01. Jun
01. Jul
Date

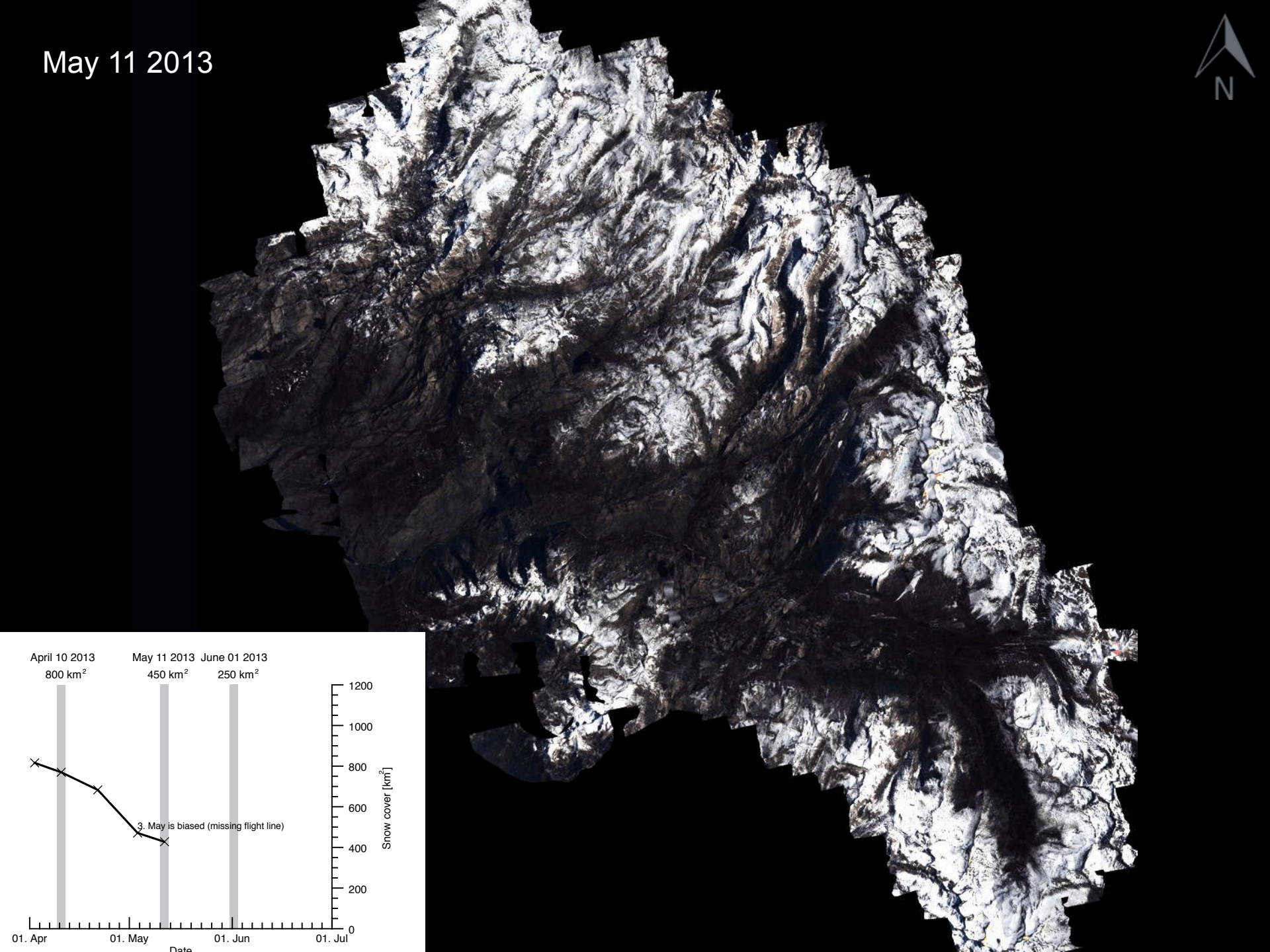

April 10 2013
N
April 10 2013
800 km²
May 11 2013
450 km²
June 01 2013
250 km²
1200
1000
800
600
400
200
0
Snow cover [km²]
01. Apr
01. May
01. Jun
01. Jul
Date

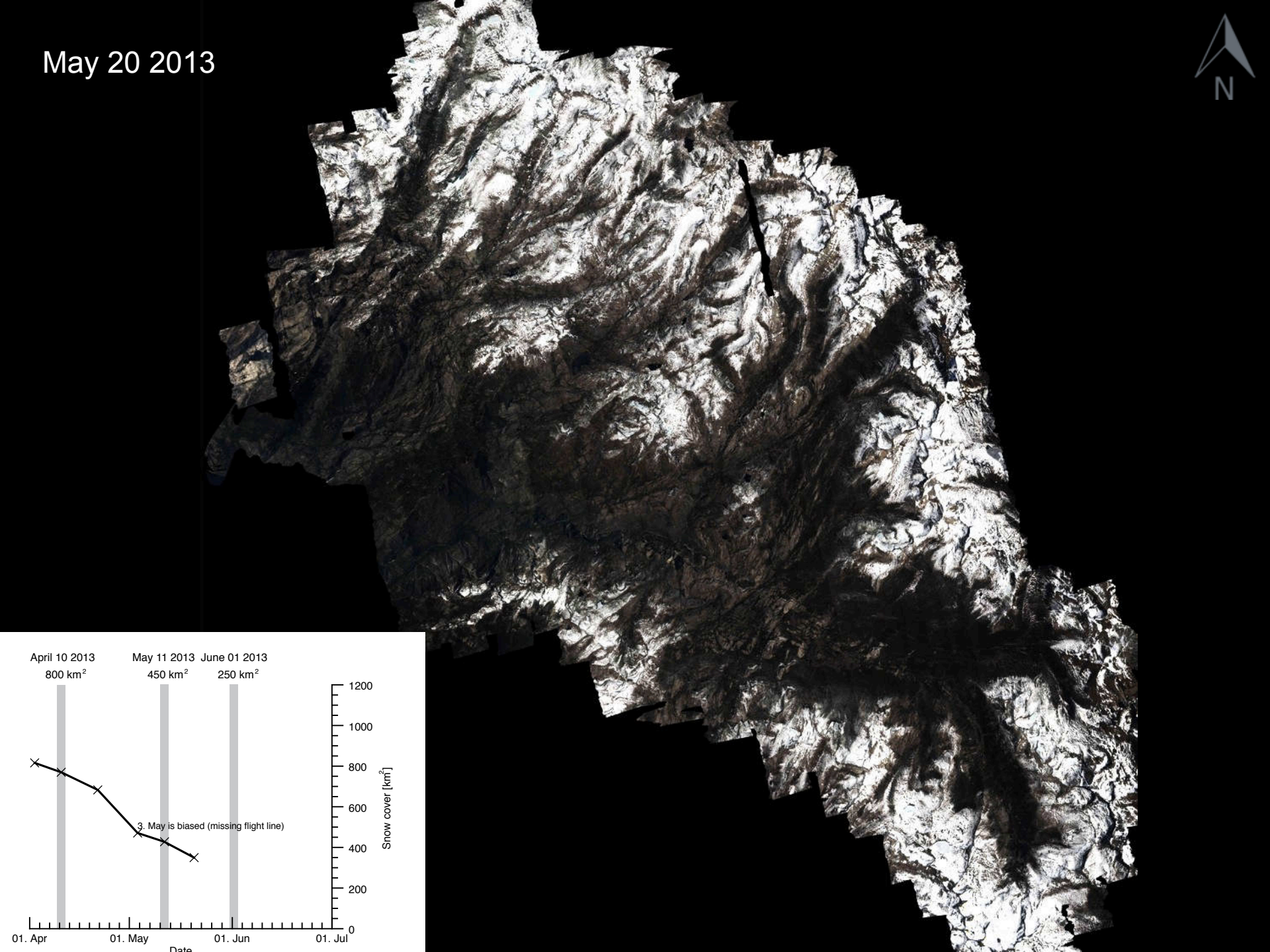

April 21 2013
N
April 10 2013
800 km²
May 11 2013
450 km²
June 01 2013
250 km²
1200
1000
800
600
400
200
0
Snow cover [km²]
01. Apr
01. May
01. Jun
01. Jul
Date

May 03 2013

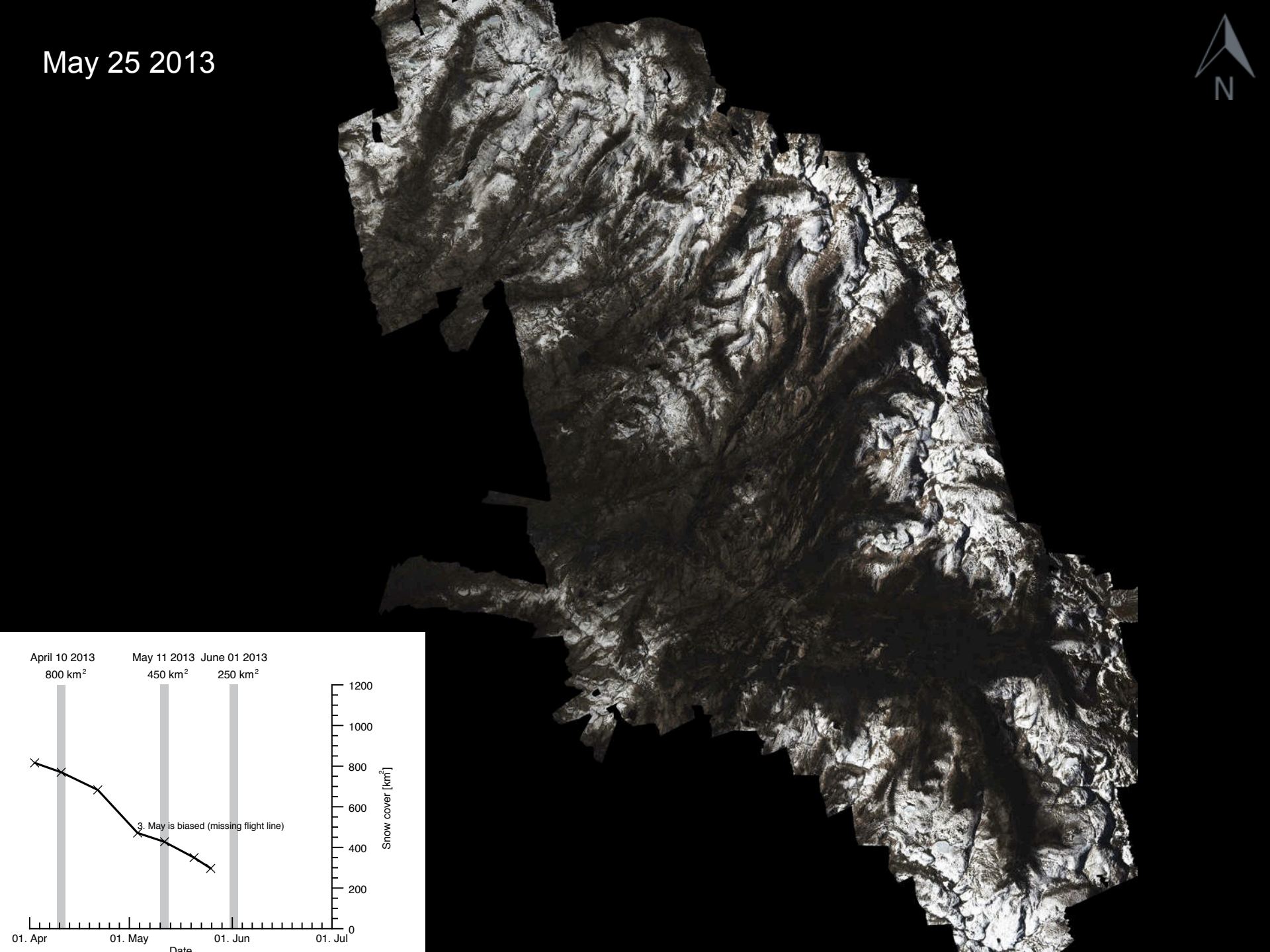
Missing line.




May 11 2013
N
April 10 2013
800 km²
May 11 2013
450 km²
June 01 2013
250 km²
3. May is biased (missing flight line)
Snow cover [km²]
1200
1000
800
600
400
200
0
01. Apr
01. May
01. Jun
01. Jul
Date


May 20 2013
N
April 10 2013
800 km²
May 11 2013
450 km²
June 01 2013
250 km²
3. May is biased (missing flight line)
Snow cover [km²]
1200
1000
800
600
400
200
0
01. Apr
01. May
01. Jun
01. Jul
Date

May 25 2013


N
April 10 2013
800 km²
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1200
1000
800
600
400
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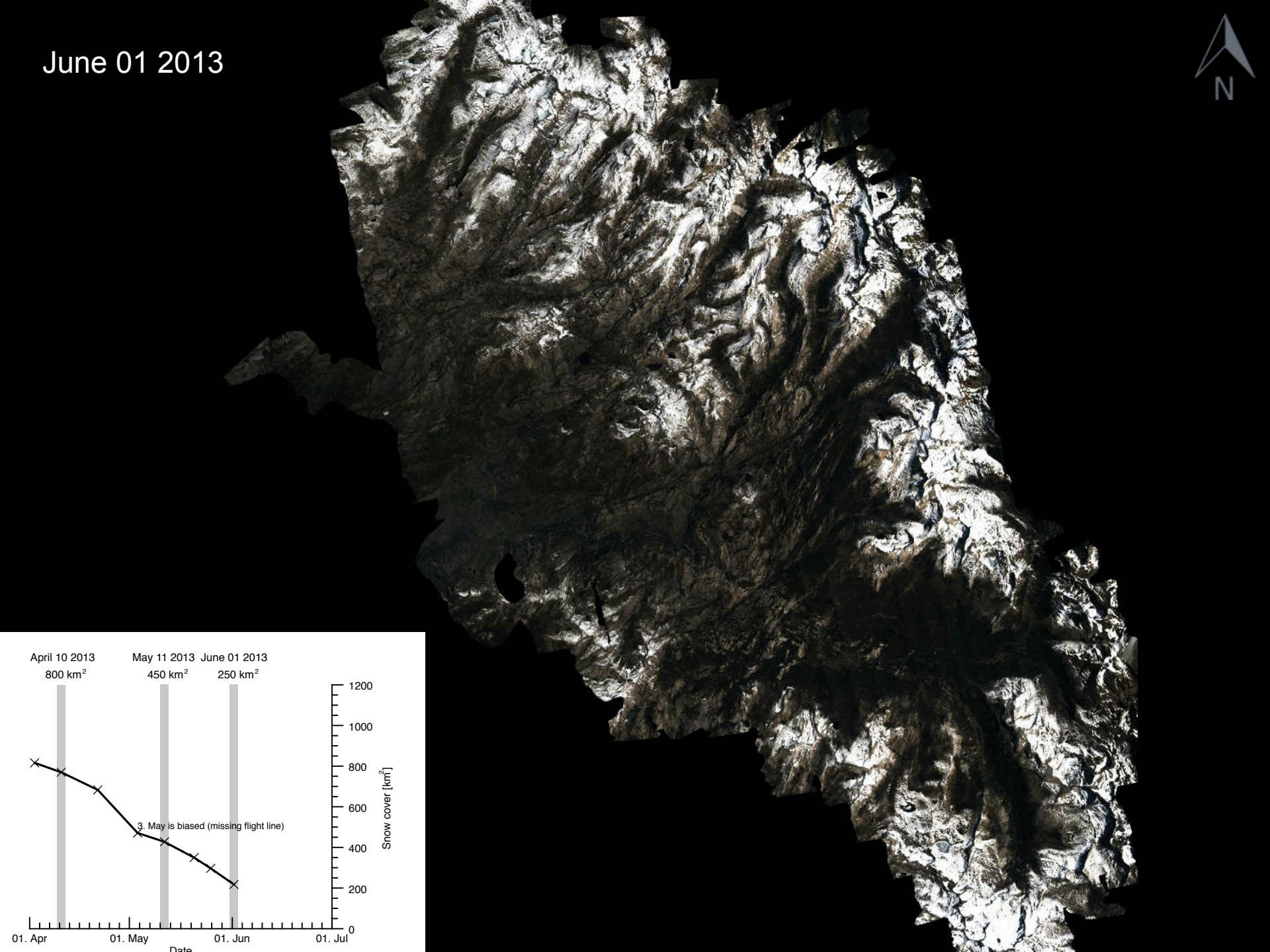
0
01. Apr
01. May
01. Jun
01. Jul
Date


June 01 2013
N
April 10 2013
800 km²
May 11 2013
450 km²
June 01 2013
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1200
1000
800
600
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0
01. Apr
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01. Jul
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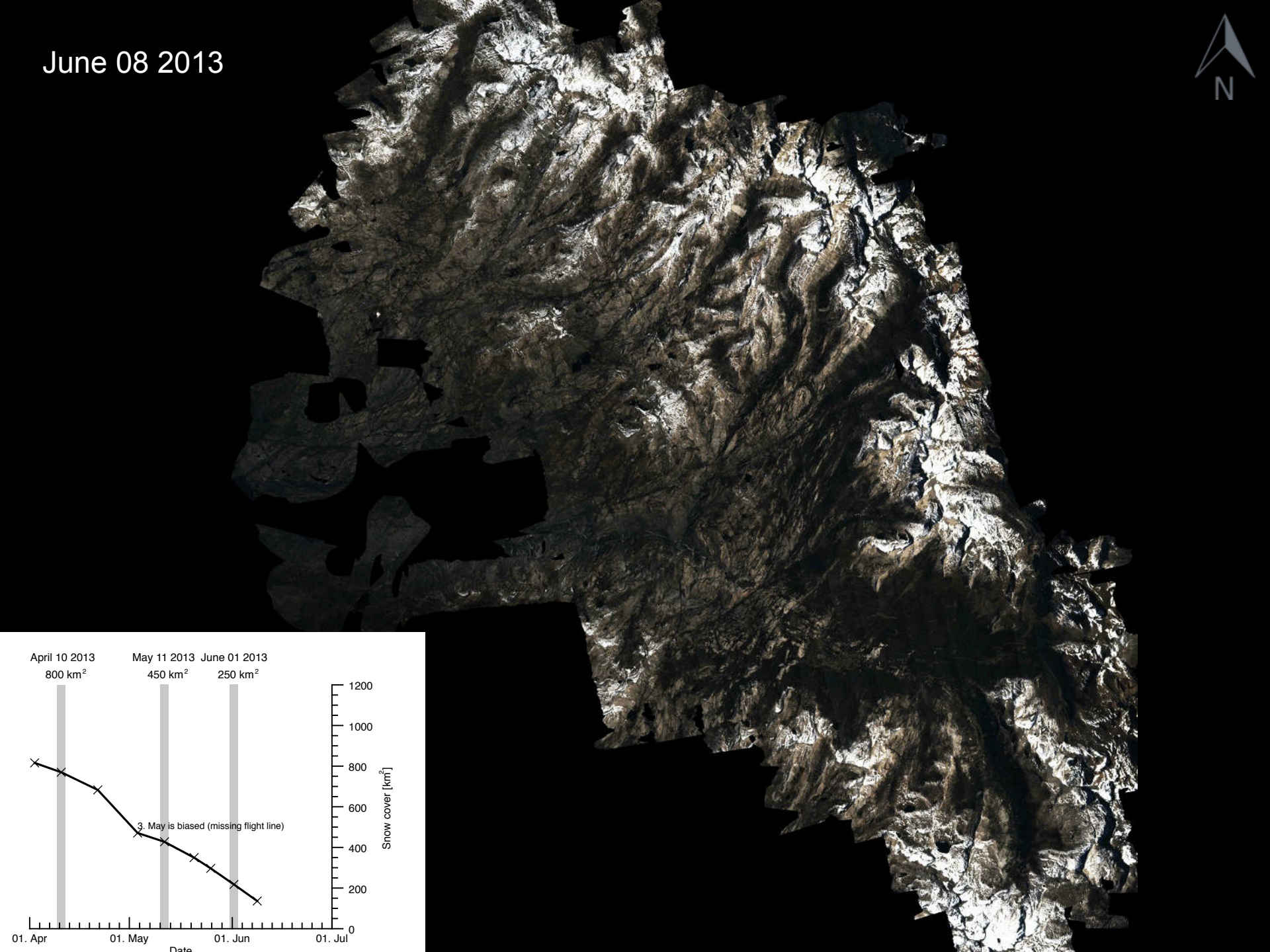
June 08 2013
N
April 10 2013
800 km²
May 11 2013
450 km²
June 01 2013
250 km²
3. May is biased (missing flight line)
Snow cover [km²]
0
200
400
600
800
1000
1200
01. Apr
01. May
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Date

Main Part: Albedo

Snow Cover Area

- Product

Albedo

- Method & Theory
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Snow Grain Size

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Radiative Forcing

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Journal of Geophysical Research: Atmospheres,
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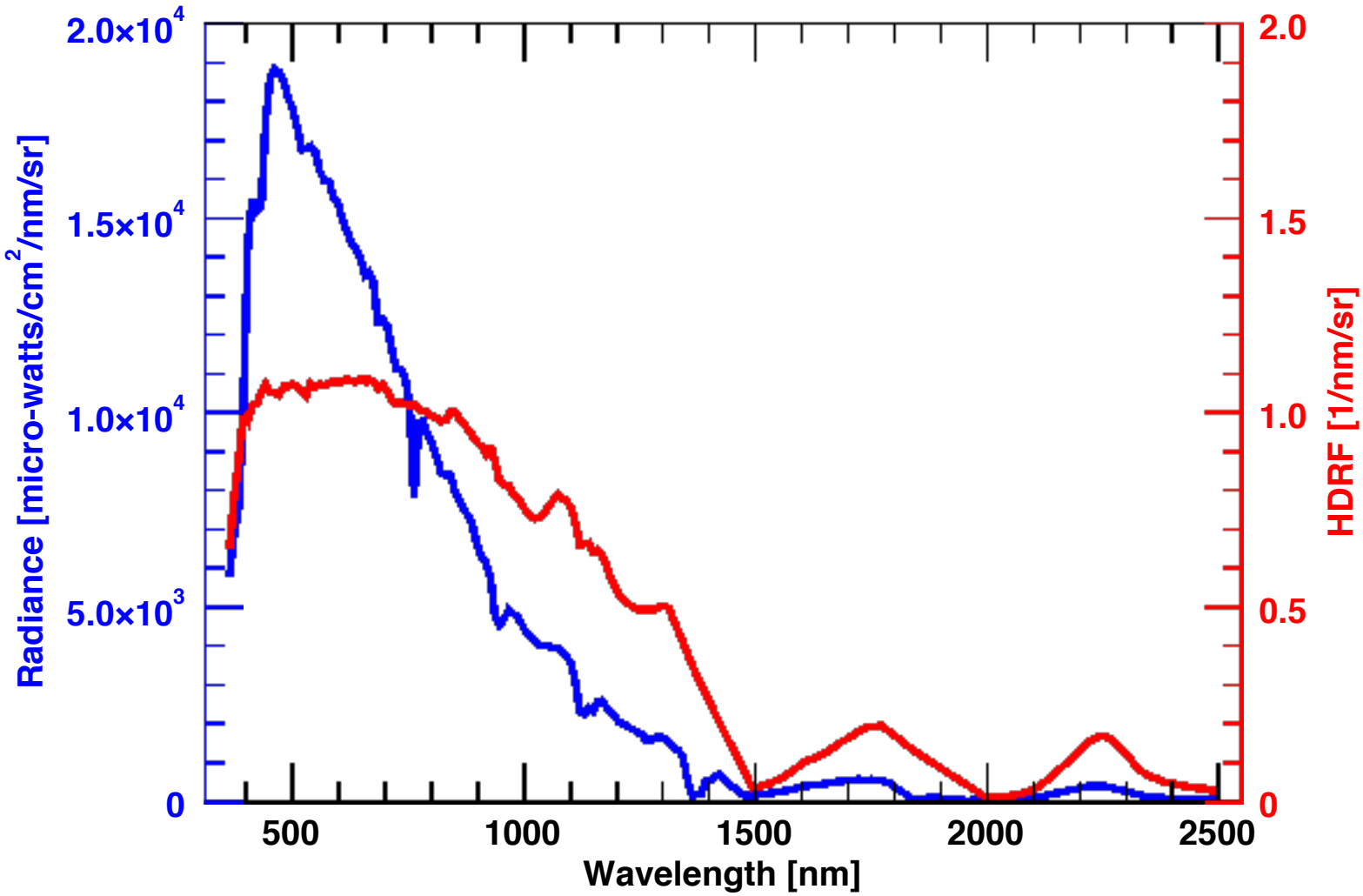
Radiance vs. Directional Reflectance

HDRF = Hemispherical Directional Reflectance Function



Data: AVIRIS June 2011, Rocky Mountains.

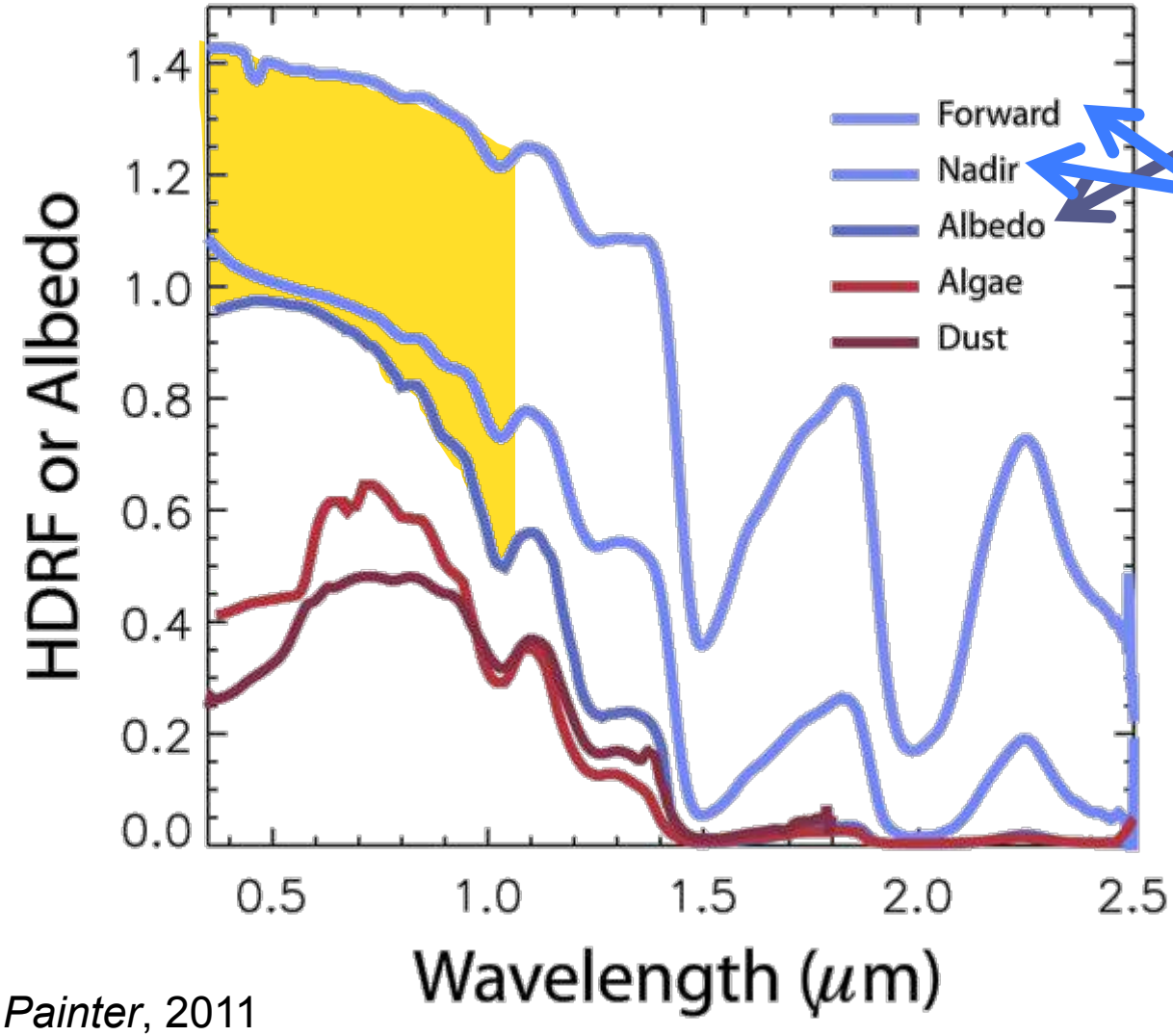
Radiance => Directional Surface Reflectance

Atmospheric Correction using ATCOR4 (MODTRAN5)
=> Hemispheric Directional Reflectance Factor

$$HDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T^{\updownarrow,mdl} + S_{sfc}^{mdl}\left(R_{sensor}^{obs} - R_{atm}^{mdl}\right)}$$

Directional R. vs. Albedo (Anisotropy Factor)

HDRF = Hemispherical Directional Reflectance Function



$$\underbrace{\frac{A^{mdl}_{snow}(r,\lambda)}{HDRF^{mdl}_{snow}(\ldots)}}_{\text{anisotropy factor}}$$

Difference between reflectance in fwd. vs. nadir direction for the spectral range of the CASI1500 instrument.

Painter, 2011

Directional Reflectance & Atmospheric Scattering

Directional Reflectance

Reflectance => Spectral Albedo

Atmos Corr. using ATCOR4 (MODTRAN5)

$$HDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T^{\updownarrow,mdl} + S_{sfc}^{mdl}\left(R_{sensor}^{obs} - R_{atm}^{mdl}\right)}$$

Correction for dir. Effects => Spectral Albedo

DISORT – RT model

$$A_{snow}^{obs}(r,\lambda) = HDRF_{snow}^{obs}(\theta_0, \theta_v, \phi_0 - \phi_v; r; \lambda) \cdot \underbrace{\frac{A_{snow}^{mdl}(r,\lambda)}{HDRF_{snow}^{mdl}(\ldots)}}_{\text{anisotropy factor}}$$

Spectral Albedo => (Broadband) Albedo

Atmos Corr. using ATCOR4 (MODTRAN5)

$$HDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T^{\updownarrow,mdl} + S_{sfc}^{mdl}\left(R_{sensor}^{obs} - R_{atm}^{mdl}\right)}$$

Correction for dir. effects

DISORT – RT model

$$A_{snow}^{obs}(r,\lambda) = HDRF_{snow}^{obs}(\theta_0, \theta_v, \phi_0 - \phi_v; r; \lambda) \cdot \underbrace{\frac{A_{snow}^{mdl}(r,\lambda)}{HDRF_{snow}^{mdl}(\ldots)}}_{\text{anisotropy factor}}$$

Irradiance at each terrain cell

$$E_{sfc}^{mdl}(\lambda,\theta_0) = \int_{\lambda=0.36\,\mu m}^{1.05\,\mu m} \left(E_{sfc}^{mdl,dir}(\lambda,\theta_0) + E_{sfc}^{mdl,dif}(\lambda,\theta_0)\right)\Delta\lambda$$

Broadband Albedo

$$A_{snow}^{obs}(r) = \frac{\int_{\lambda=0.36\,\mu m}^{1.05\,\mu m} E_{sfc}^{mdl}(\lambda,\theta_0) \cdot A_{snow}^{obs}(r,\lambda)\,\Delta\lambda}{\int_{\lambda=0.36\,\mu m}^{1.05\,\mu m} E_{0}^{mdl}(\lambda,\theta_0)\,\Delta\lambda}$$

Main Part: Albedo

Snow Cover Area

- Product

Albedo

- Method & Theory
- Product
- Analysis

Snow Grain Size

- Method & Theory
- Product
- Analysis

Radiative Forcing

- Method & Theory
- Product

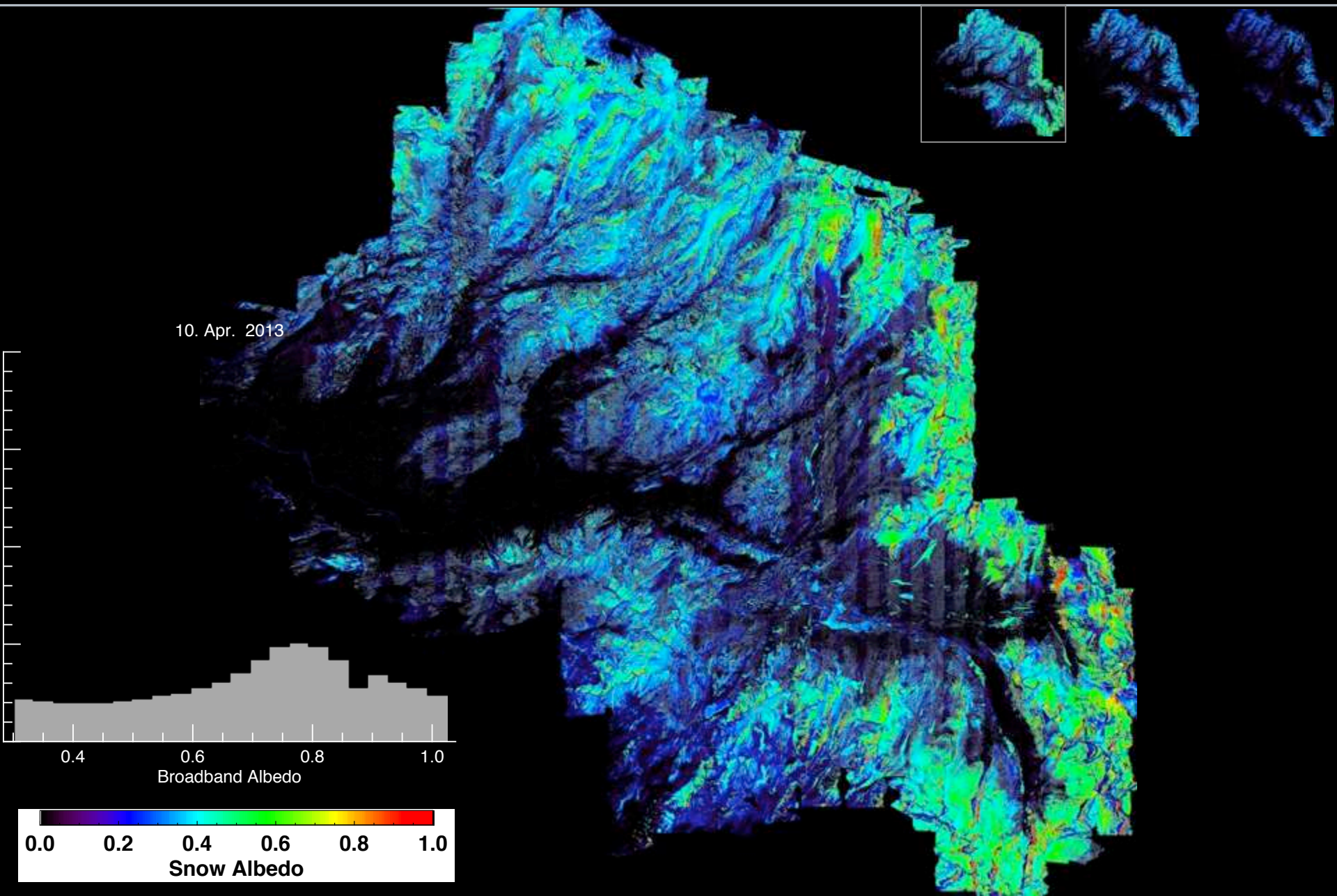
Snow Depth

- Product

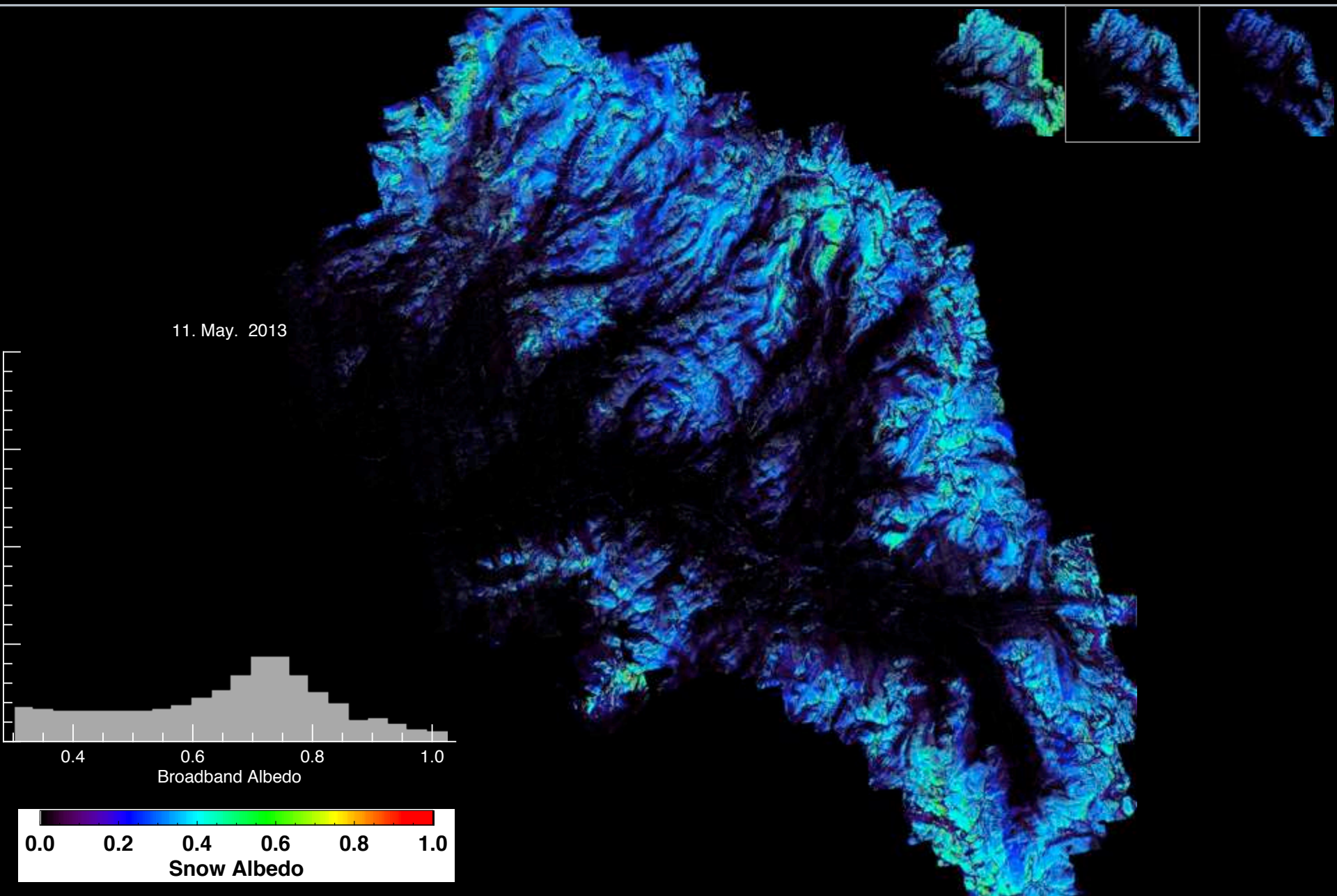
Snow Water Equivalent

- Product

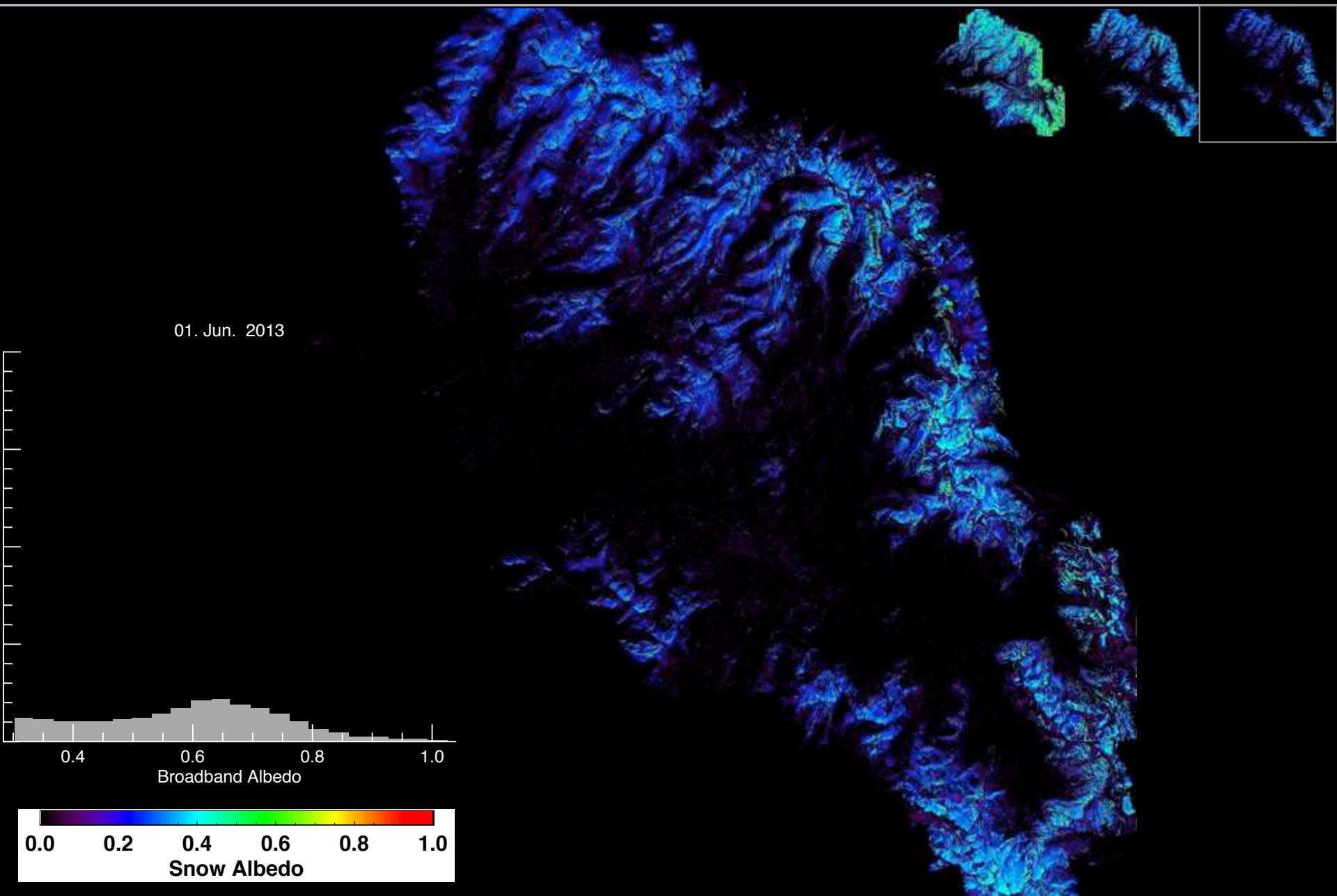
Albedo: April 10 2013



Albedo: May 11 2013



Albedo: June 01 2013



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Snow Depth

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Snow Water Equivalent

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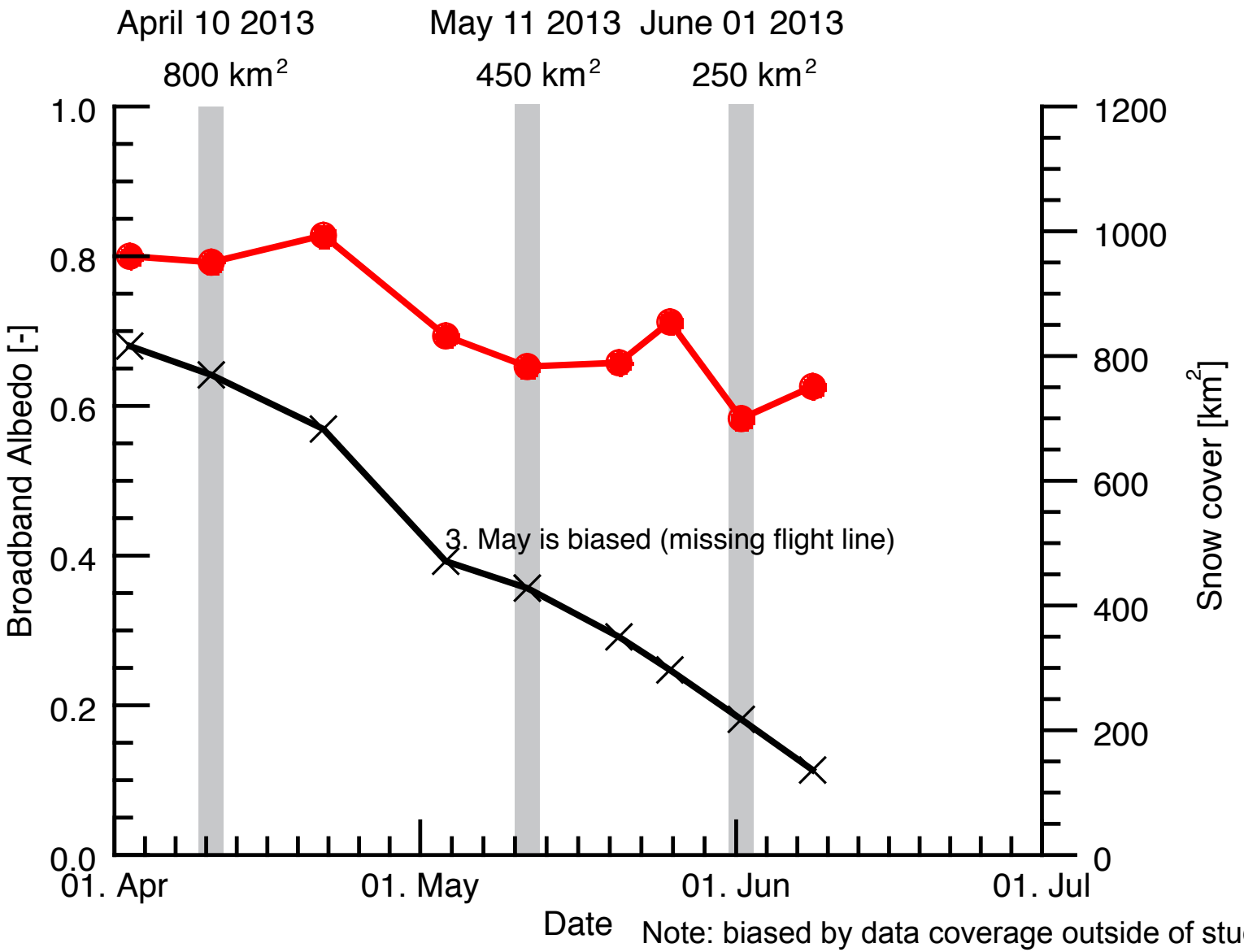
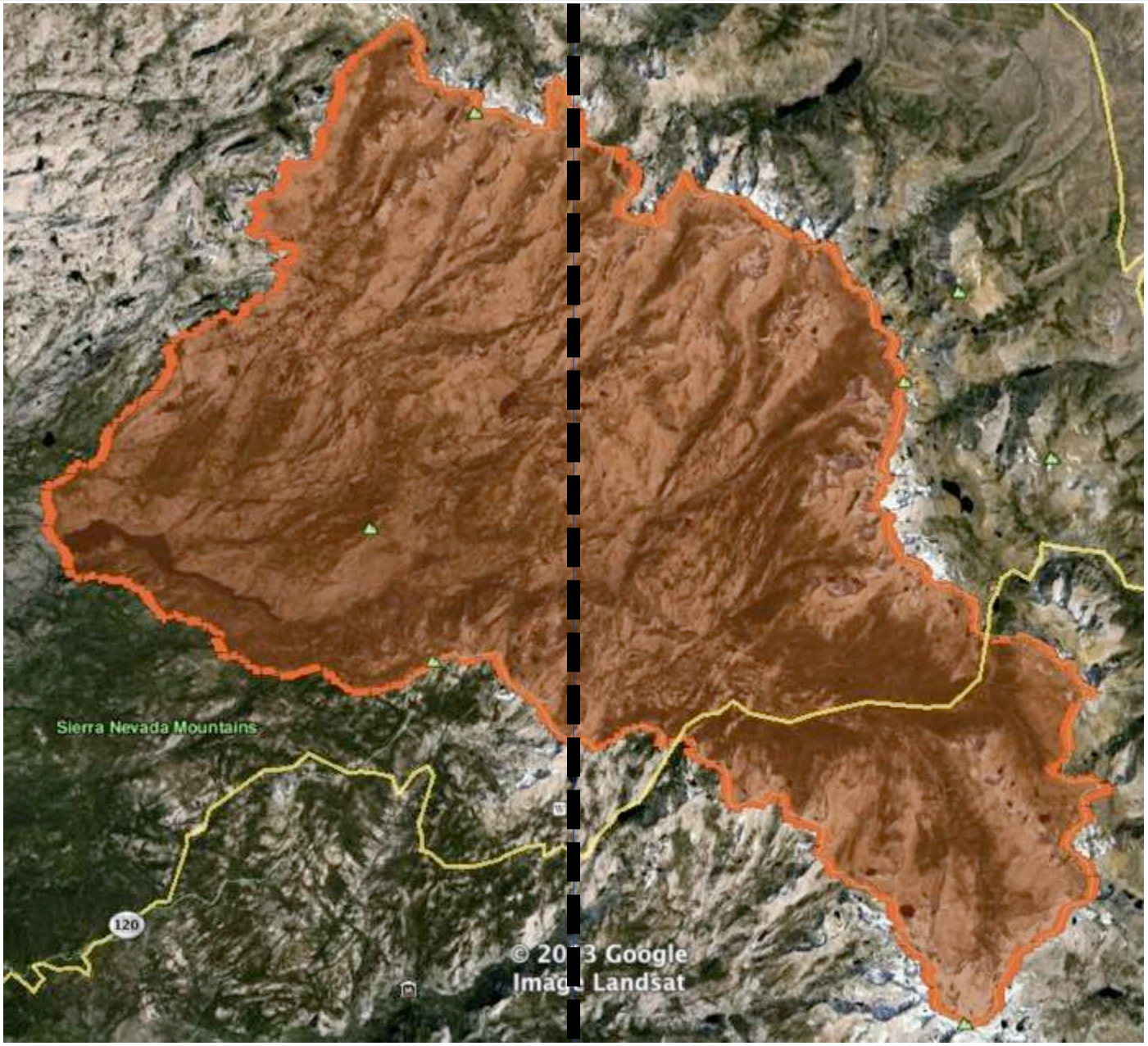
Time Series (preliminary results)



Note: biased by data coverage outside of study area.

Albedo Profile



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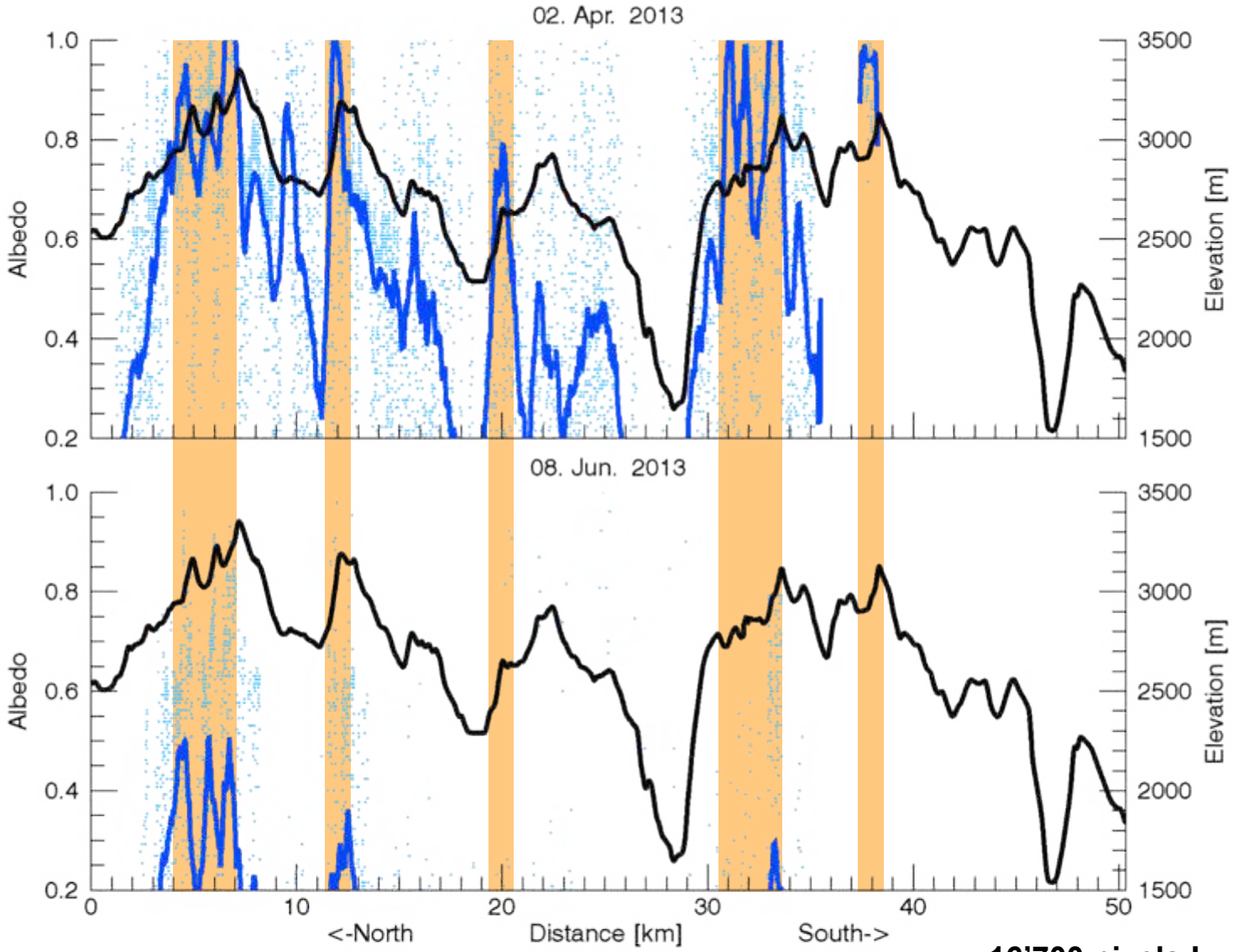
Albedo Profile



16’700 pixels !

Main Part: Snow Grain Size

Snow Cover Area

- Product

Albedo

- Method & Theory
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Snow Grain Size

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Radiative Forcing

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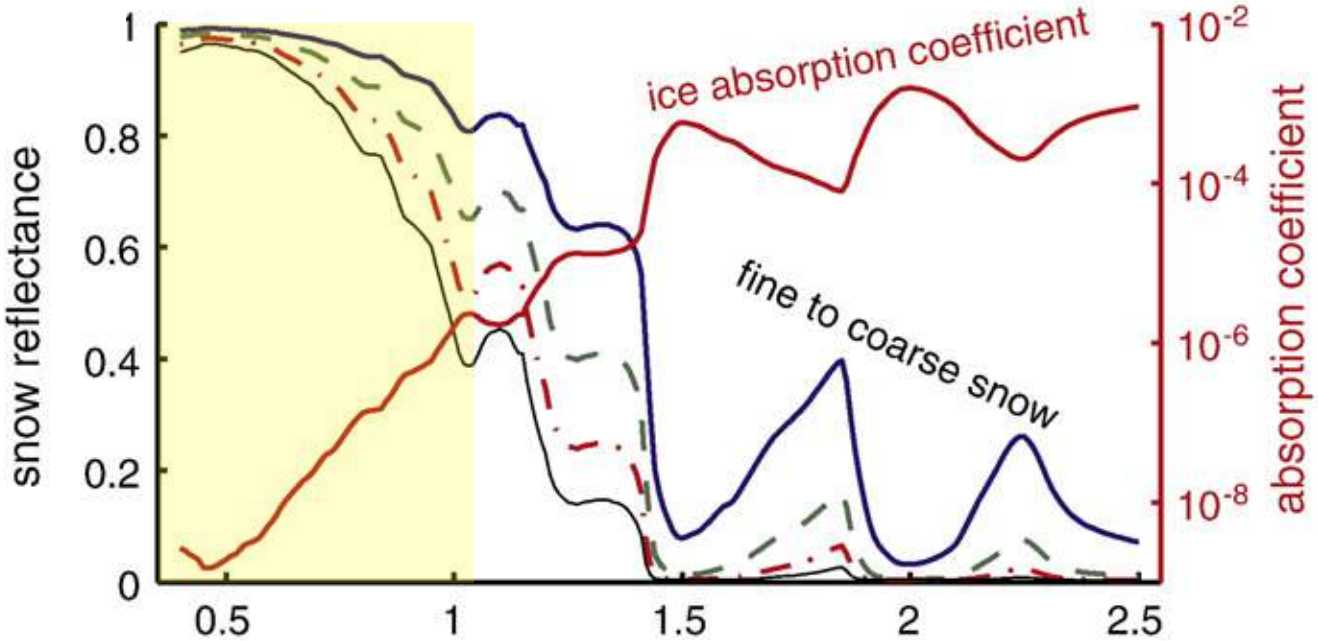
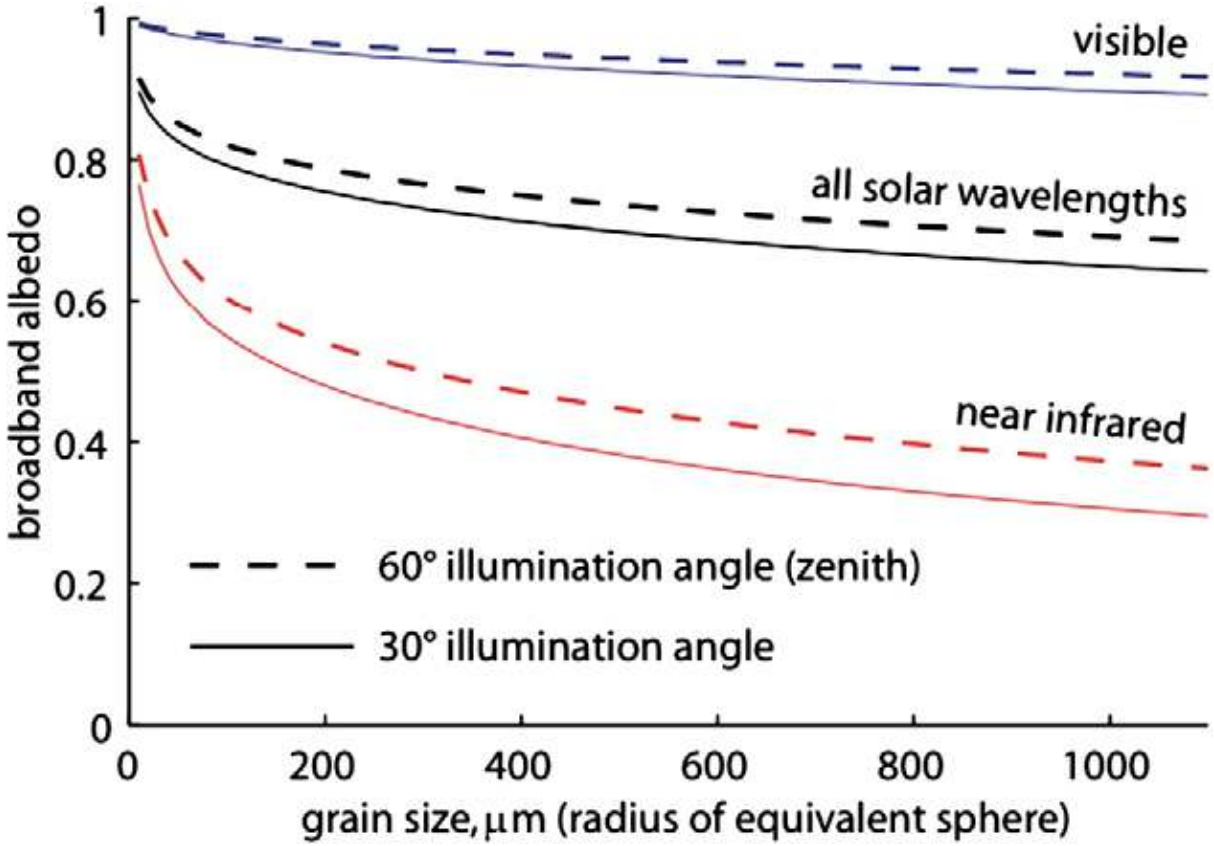
Snow Grain Size



CASI1500
spectral range

Dozier, 2009

Snow Grain Size



Painter, 2009

Snow Grain Size

$$HDRF_{sfc}^{obs} = \frac{R_{sensor}^{obs} - R_{atm}^{mdl}}{T^{\updownarrow,mdl} + S_{sfc}^{mdl}\left(R_{sensor}^{obs} - R_{atm}^{mdl}\right)}$$

Inverse Procedure with Least Absolute Deviation (cost funct. to find best fit)

$$r : \left(\min \left| \sum_{i=1.02\,\mu m}^{1.04\,\mu m} HDRF_{snow}^{mdl}\left(\theta_0, \theta_v, \phi_0 - \phi_v; r; \lambda_i\right) - HDRF_{snow}^{obs}\left(\theta_0, \theta_v, \phi_0 - \phi_v; r; \lambda_i\right) \right| \right)$$

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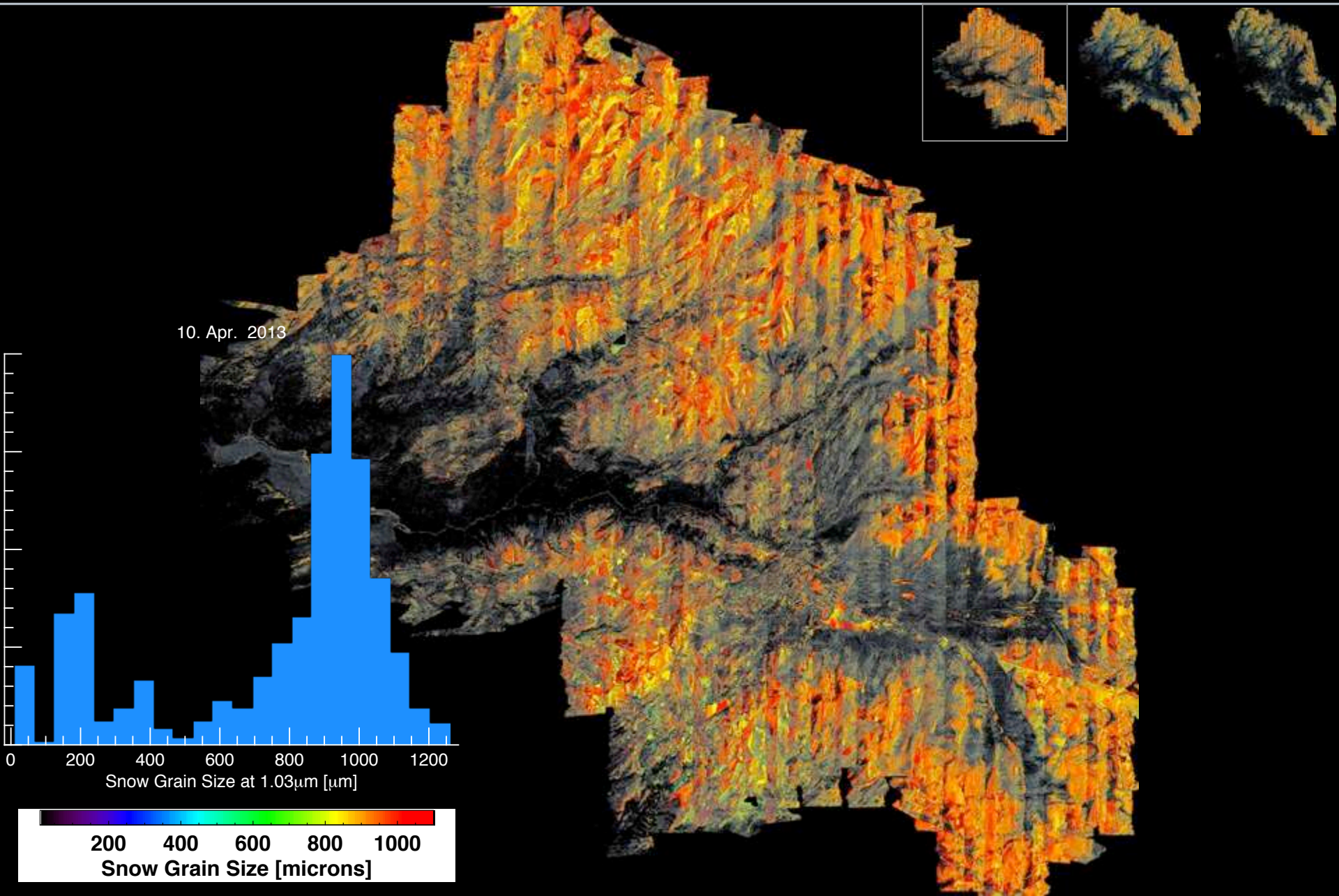
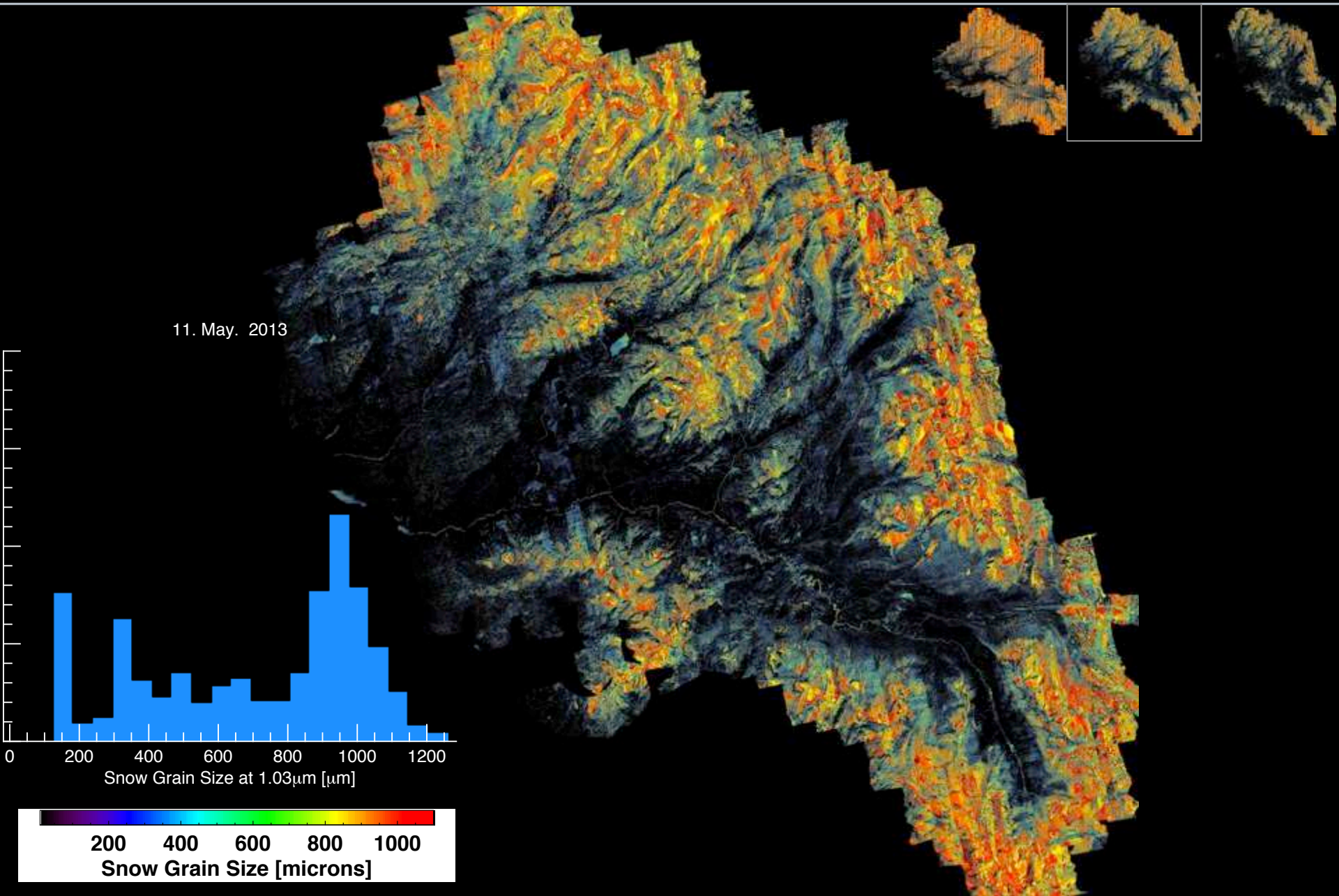
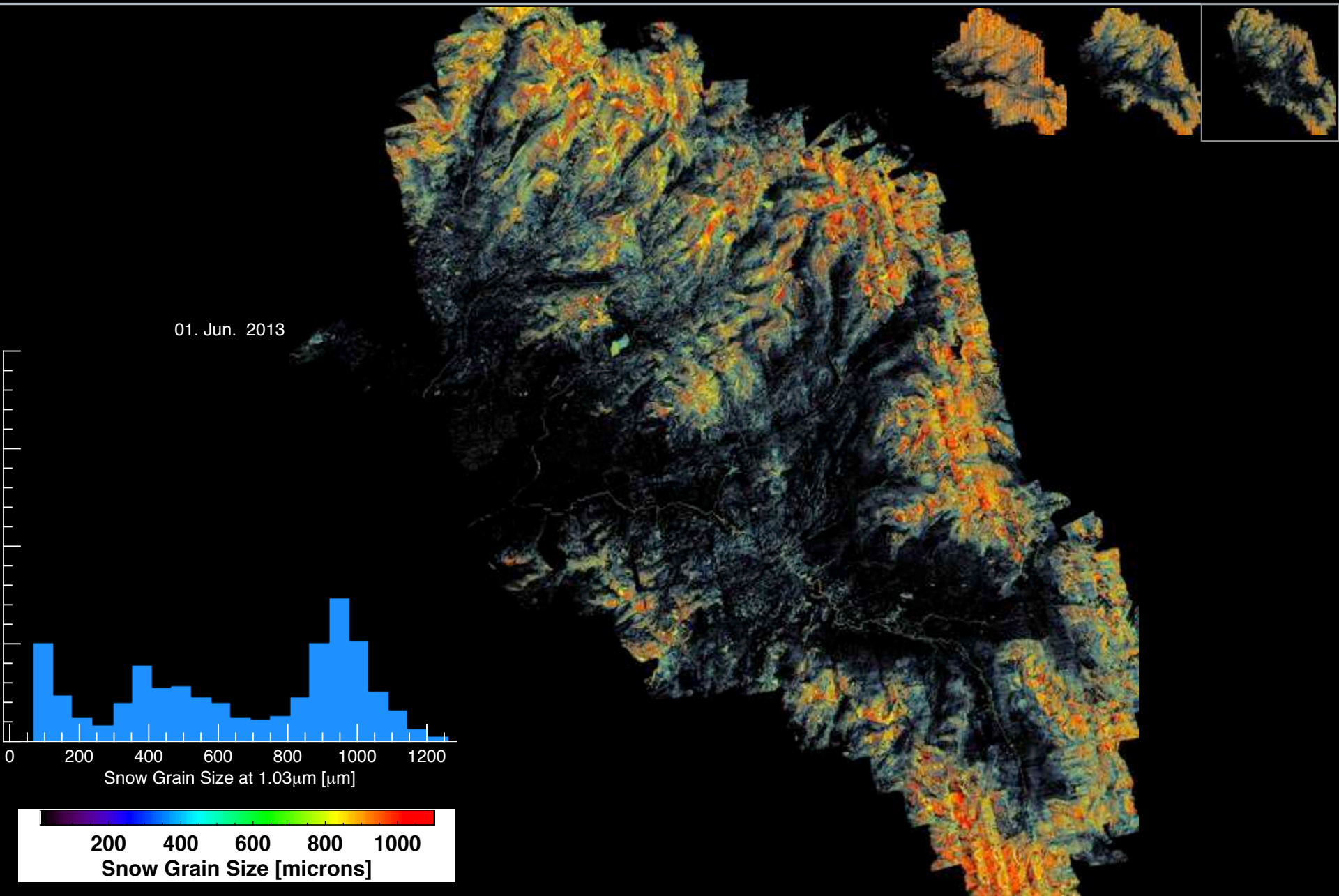
Snow Grain Size: April 10 2013



Snow Grain Size: May 11 2013



Snow Grain Size: June 01 2013



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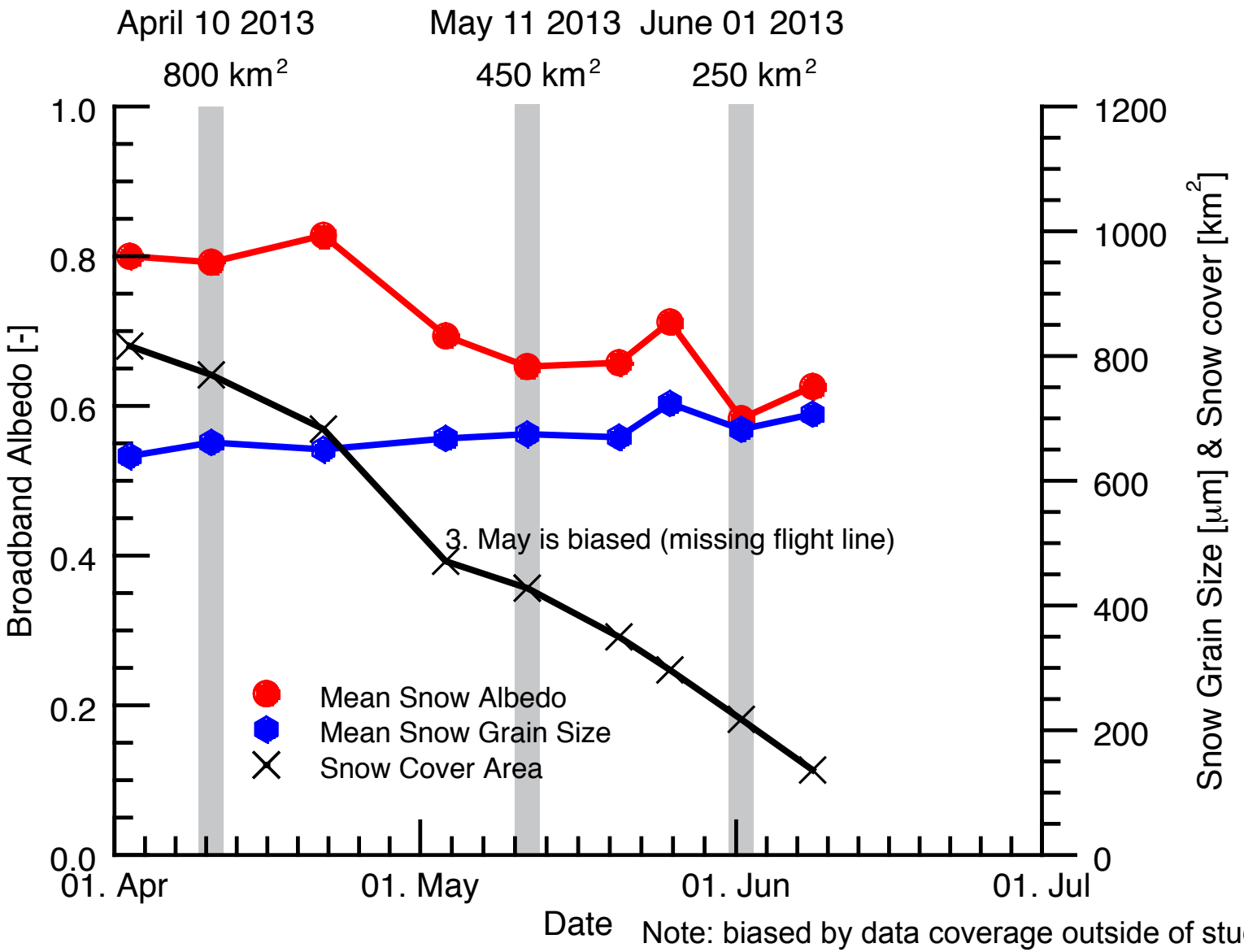

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Radiative Forcing

Irradiance at each terrain cell

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Broadband Albedo

$$A_{snow}^{obs}(r) = \frac{\int_{\lambda=0.36\,\mu m}^{1.05\,\mu m} E_{sfc}^{mdl}(\lambda,\theta_0) \cdot A_{snow}^{obs}(r,\lambda)\,\Delta\lambda}{\int_{\lambda=0.36\,\mu m}^{1.05\,\mu m} E_{0}^{mdl}(\lambda,\theta_0)\,\Delta\lambda}$$

Radiative Forcing of Snow Impurities

$$RF_{snow} = \int_{\lambda=0.36\,\mu m}^{1.05\,\mu m} E_{sfc}^{mdl}(\lambda,\theta_0) \cdot \left(A_{snow}^{mdl}(r,\lambda) - A_{snow}^{obs}(r,\lambda) \underbrace{\frac{A_{snow}^{mdl}(r,1.05\,\mu m)}{A_{snow}^{obs}(r,1.05\,\mu m)}}_{\text{correction factor}} \right) \Delta\lambda$$

Main Part: Radiative Forcing

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Radiative Forcing

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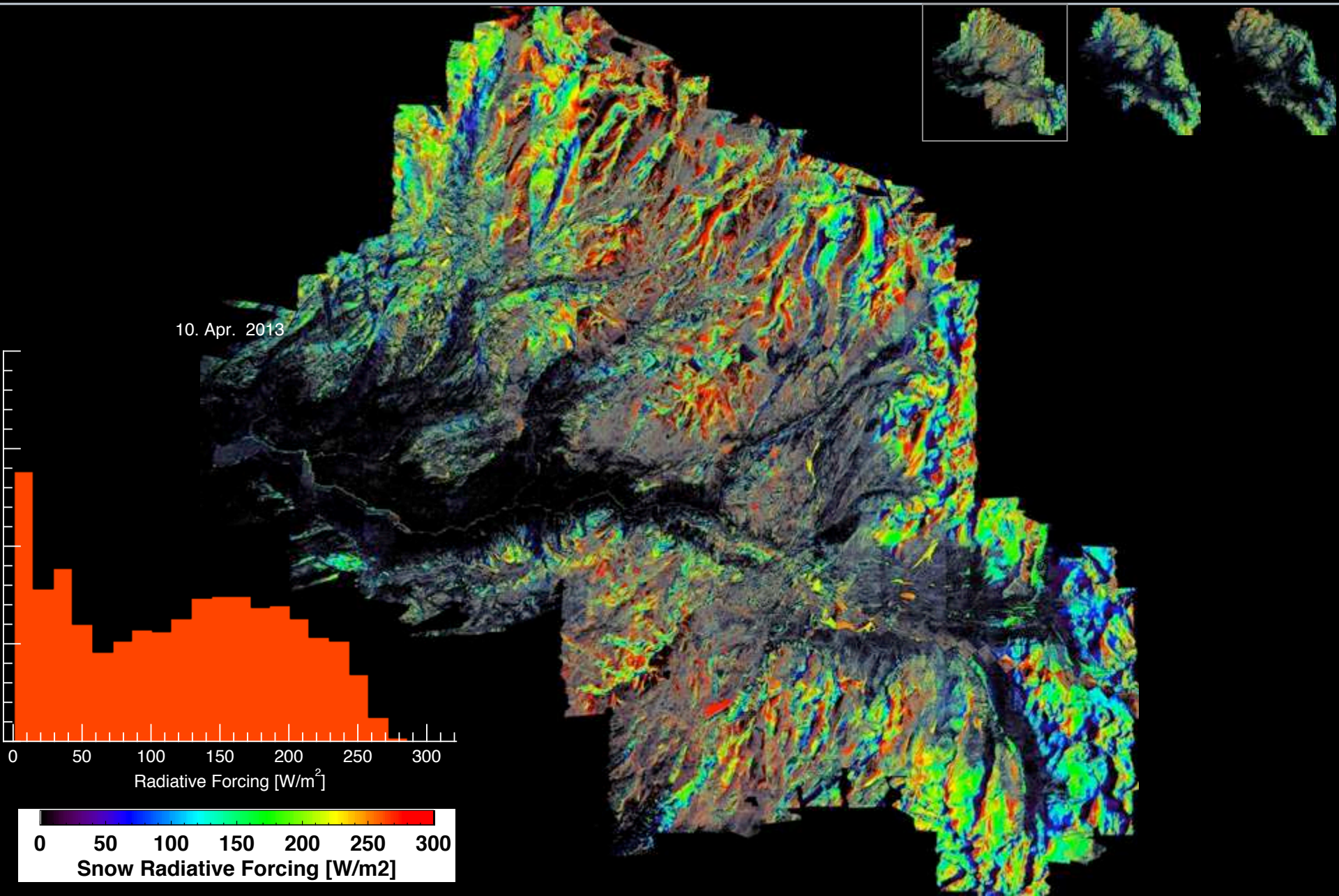
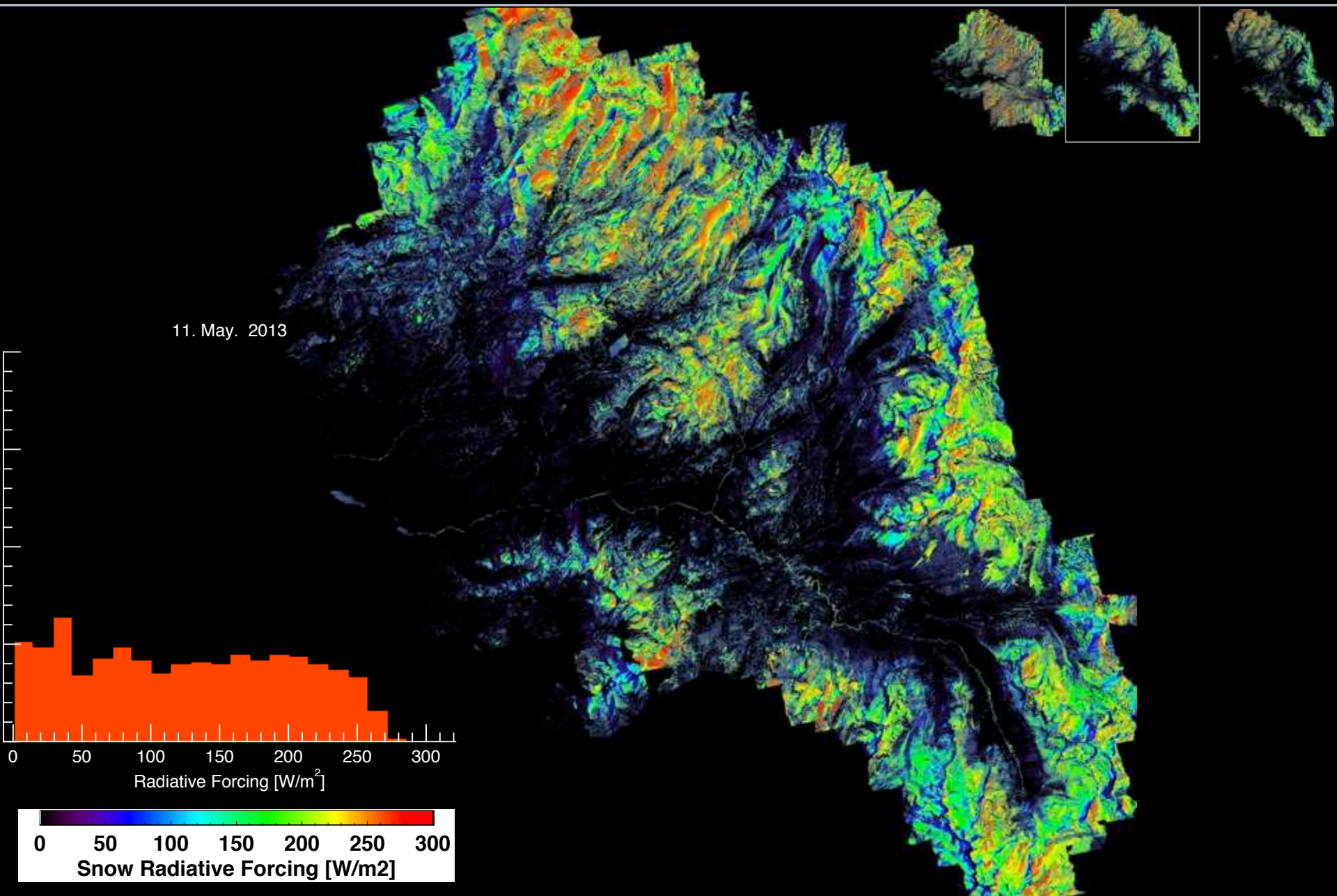
- Product

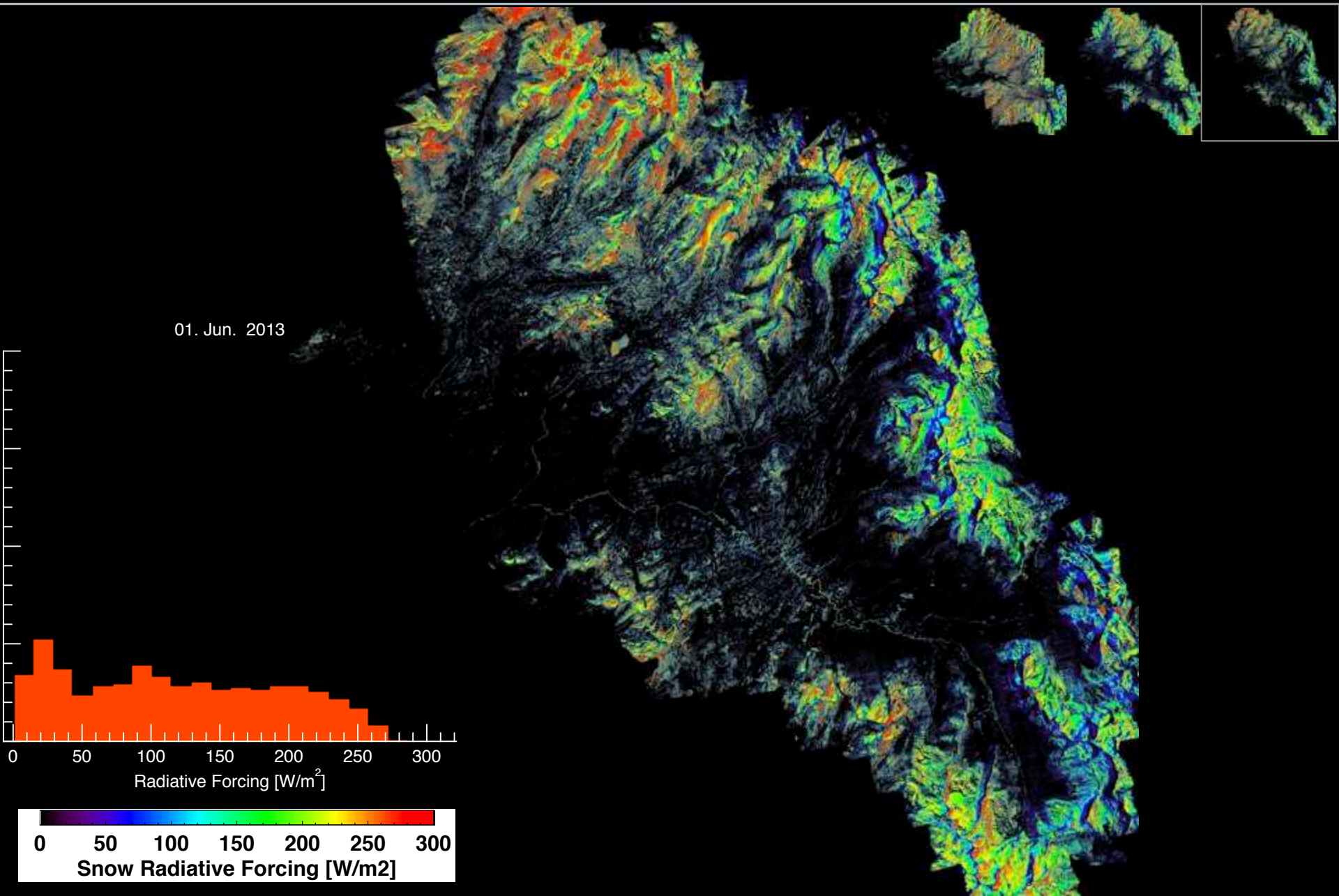
Radiative Forcing: April 10 2013



Radiative Forcing: May 11 2013



Radiative Forcing: June 01 2013



Main Part: Snow Depth

Snow Cover Area

- Product

Albedo

- Method & Theory
- Product
- Analysis

Snow Grain Size

- Method & Theory
- Product
- Analysis

Radiative Forcing

- Method & Theory
- Product

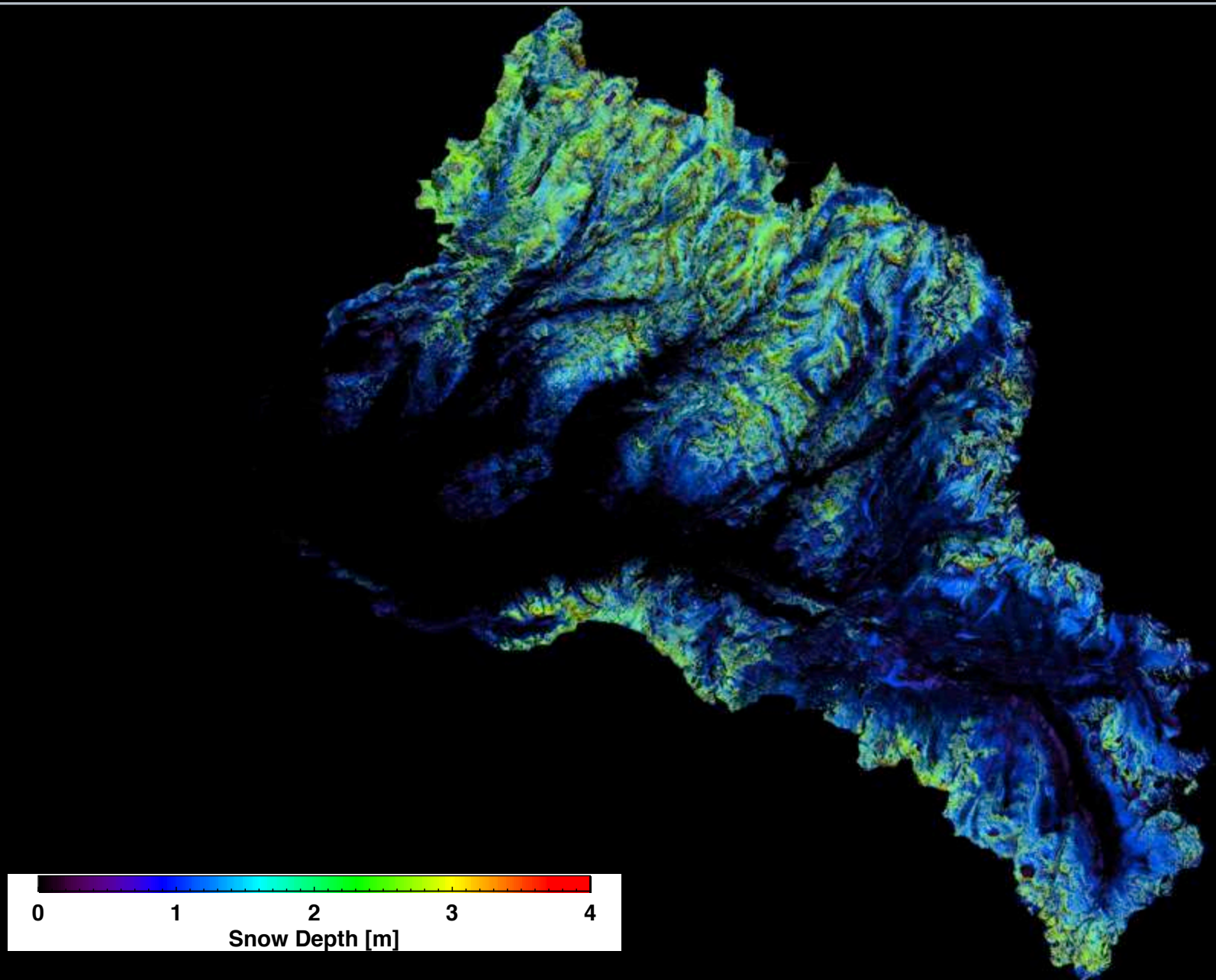
Snow Depth

- Product

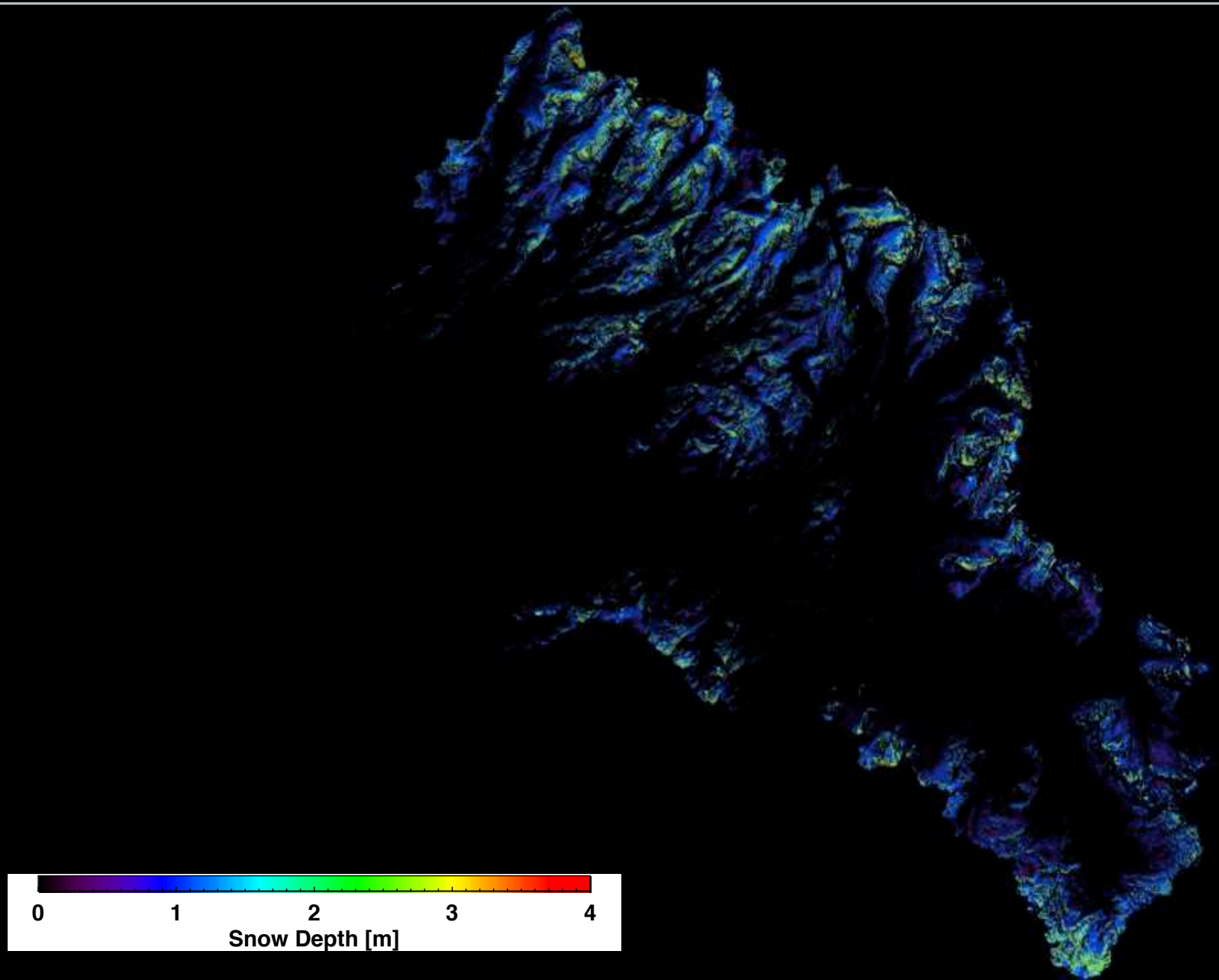
Snow Water Equivalent

- Product

Snow Depth: April 02 2013



Snow Depth: May 05 2013



Main Part: Snow Water Equivalent

Snow Cover Area

- Product

Albedo

- Method & Theory
- Product
- Analysis

Snow Grain Size

- Method & Theory
- Product
- Analysis

Radiative Forcing

- Method & Theory
- Product

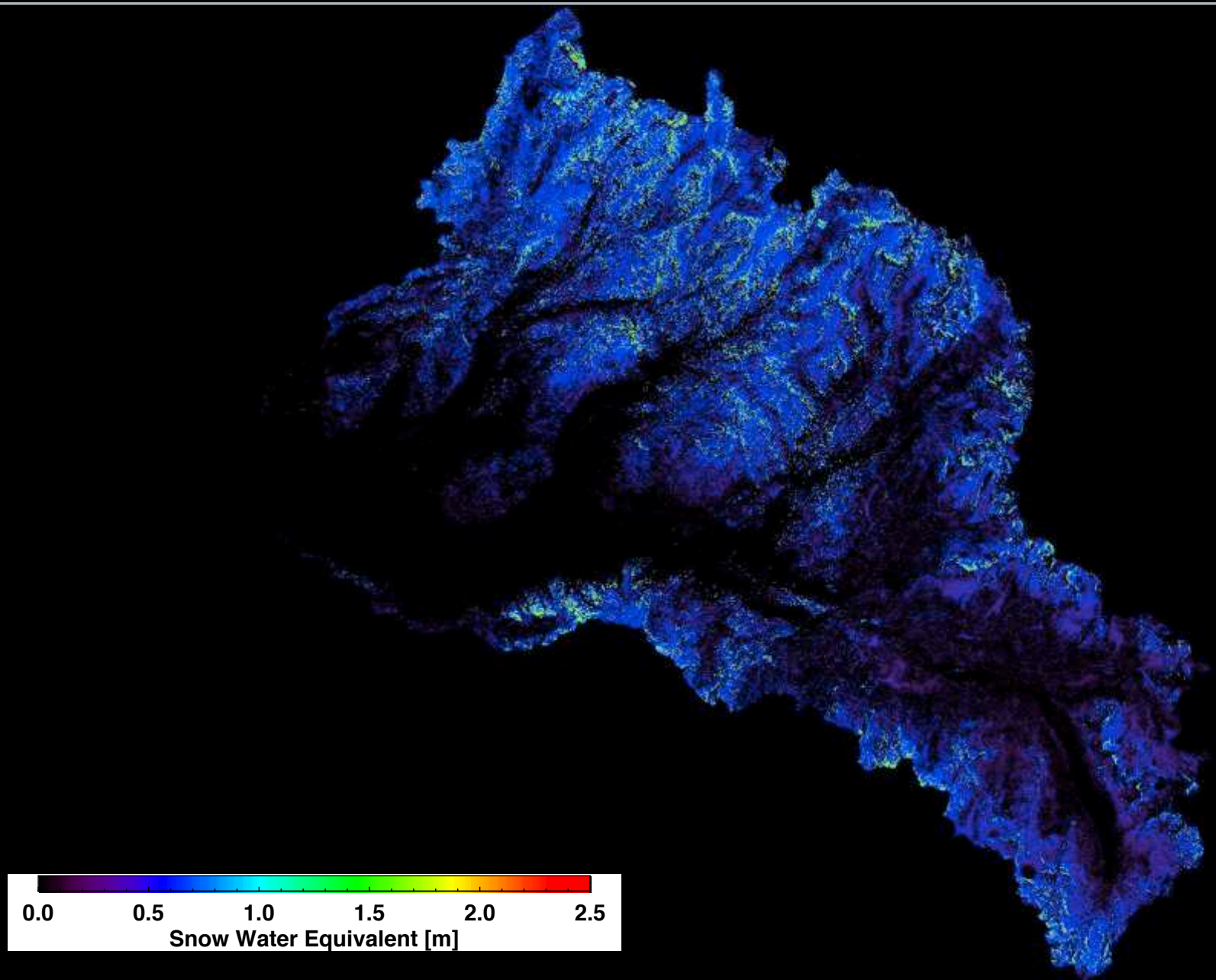
Snow Depth

- Product

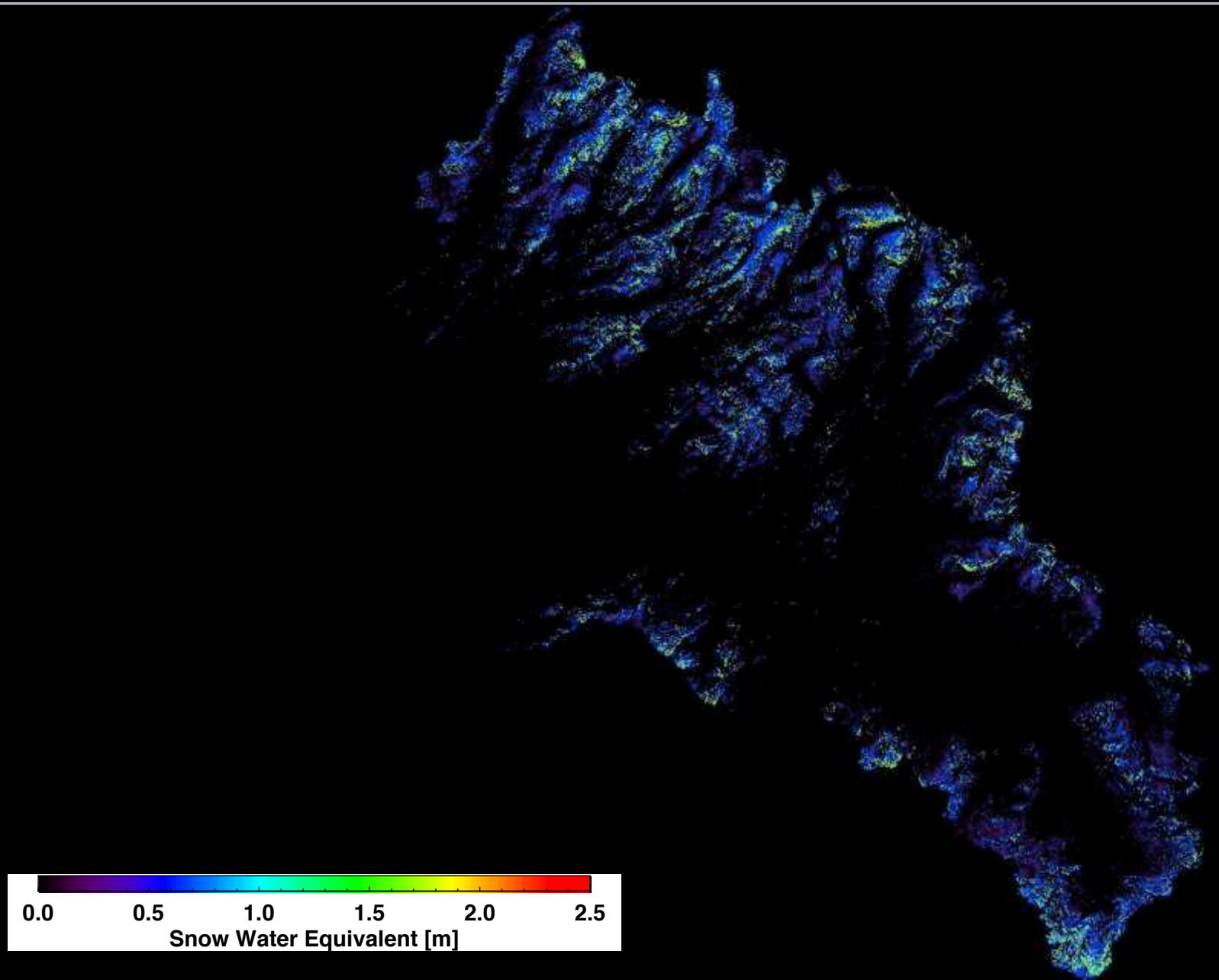
Snow Water Equivalent

- Product

Snow Water Equivalent: April 02 2013

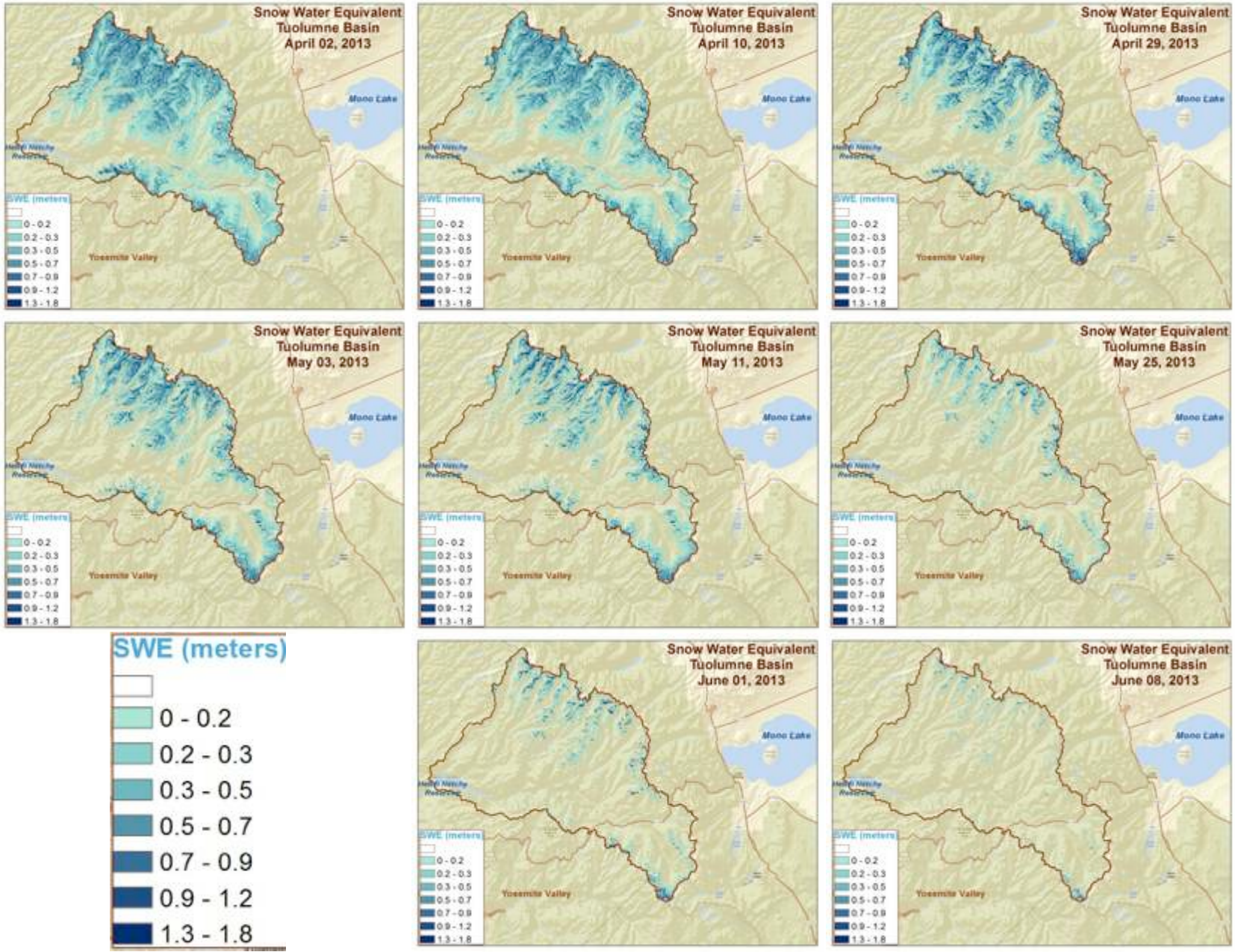


Snow Water Equivalent: May 05 2013



Jet Propulsion Laboratory
California Institute of Technology

Snow Water Equivalent



Outreach

Outlook

To Do

2013

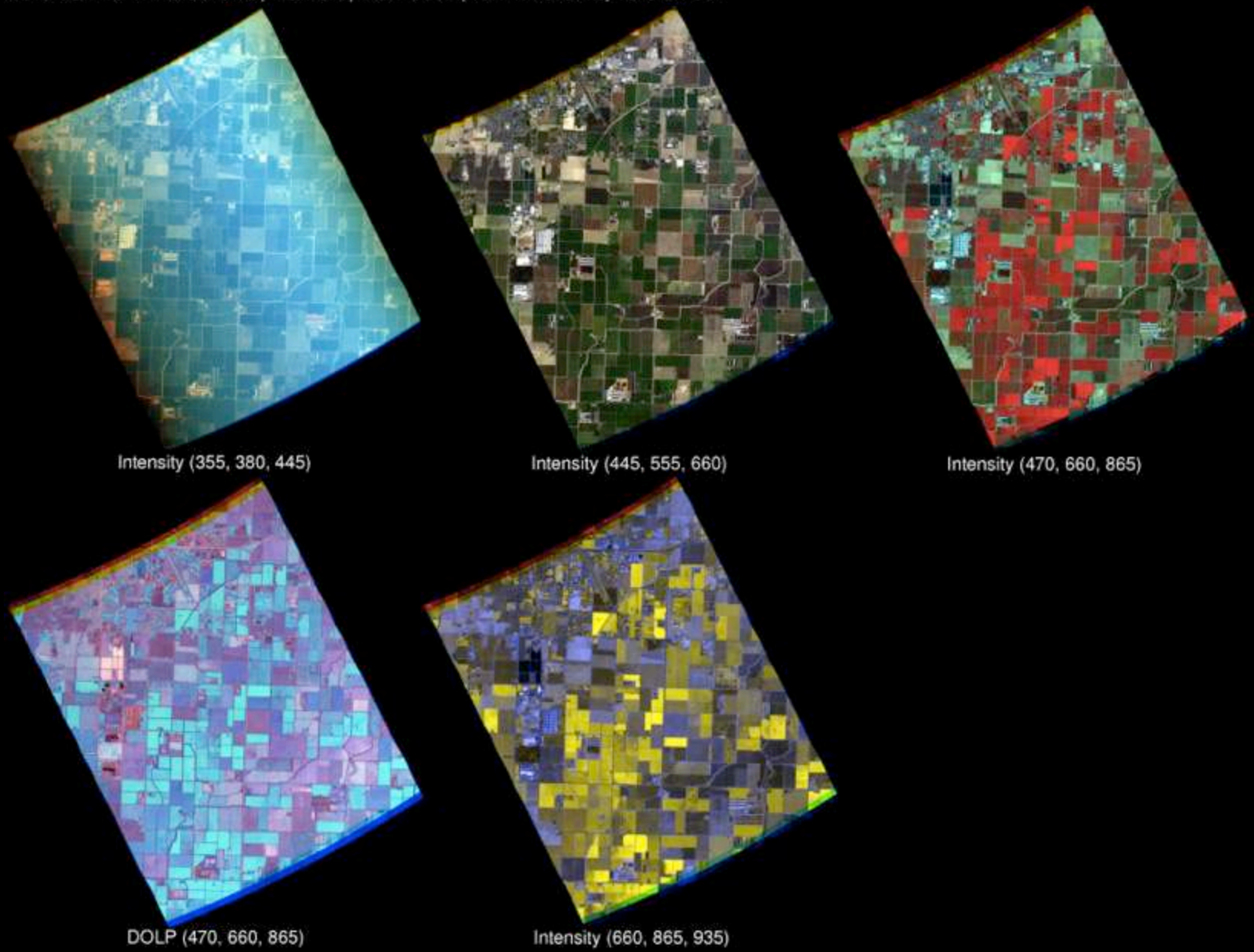
- Masking
- Validation against in-situ data
- Re-calibration of CASI NIR radiances
- Updating products

2014+

- Improve atmospheric correction and retrievals
- Upscale to much larger areas worldwide
- New instruments
- Add observations for atmospheric retrievals (aerosols)

First Public AirMSPI data

2013-Jan-18 17:49:53 UTC, Hanford, view 000N, run 174510-12, version 001



Thank you for your attention!

Felix Seidel,

Thomas Painter,

ASO Team

Felix.Seidel@jpl.nasa.gov

More in:

Painter, T. H., Seidel, F. C., Bryant, A. C., Skiles, S. M., and Rittger, K.: Imaging spectroscopy of albedo and radiative forcing by light absorbing impurities in mountain snow, *Journal of Geophysical Research: Atmospheres*, doi: 10.1002/jgrd.50520, 2013.