MODIS Snow and Ice Cover

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Acknowledgement:
Most of this material is from **Dorothy Hall**, NASA, who is responsible for the MODIS snow and ice products

Overview

We will cover:

- Normalized Snow Difference Index (NDSI)
- Snow albedo (briefly)
- Sea ice surface temperature (IST)
- Sea ice motion: covered in lab but not lecture

Why do we need these derived parameters?

- Navigation (ice)
- Agriculture and energy use (snow)
- Weather and climate models
- Trends in snow and ice cover

Who finds them useful?

- Climate researchers
- Forecasters
- Modelers

Standard MODIS Snow and Ice Products

MODIS Snow and Ice Data Products			
Data Product Name	**ESDT***	**Spatial Resolution**	**Availability**
Swath snow-cover	MOD10_L2 MYD10_L2	500 m	NSIDC
Daily tile snow-cover	MOD10A1 MYD10A1	500 m	NSIDC
8-day composite snow-cover	MOD10A2 MYD10A2	500 m	NSIDC
Daily snow-cover CMG¯	MOD10C1 MYD10C1	0.05° (or ~5.6km)	NSIDC
* New Product * Daily snow-cover CMG¯	N / A	0.25°	Email dorothy.k.hall AT nasa.gov for further information.
8-day composite snow-cover CMG¯	MOD10C2 MYD10C2	0.05°	NSIDC
Monthly snow-cover CMG¯	MOD10CM MYD10CM	0.05°	NSIDC
Swath sea ice extent and IST**	MOD29 MYD29	1 km	NSIDC
Daily sea ice extent and IST**, daytime	MOD29P1D MYD29P1D	1 km	NSIDC
Daily sea ice extent and IST**, nighttime	MOD29P1N MYD29P1N	1 km	NSIDC
Daily sea ice extent and IST CMG**,¯	MOD29E1D MYD29E1D	0.05°	NSIDC
*Earth Science Data Type, **Ice surface temperature, ¯ Climate-modeling grid			

From http://modis-snow-ice.gsfc.nasa.gov/intro.html

Snow Products

MODIS data-product sequence

Input MODIS Level 1B bands 1, 2, 4, 6 (MOD02_HKM), 31 & 32 (MOD02_1km)

Input MODIS 1-km resolution geolocation, cloud mask MOD35 and land/water mask MOD03

Input data is L2G product in which all swaths for the day have been mapped onto the projection.

A scoring algorithm based on solar zenith angle, distance from nadir and observation coverage in a cell selects the most favorable observation for the day.

Calculate NDSI, NDVI, grouped-criteria tests, vegetation polygon

Apply surface temperature screen (≥ 283K)

Swath snow 500-m product MOD10_L2 (includes FSC)

Daily snow tile product 500-m resolution MOD10A1 (includes daily snow albedo)

8-day composite snow tile product 500-m resolution MOD10A2

8-day composite snow CMG 0.05° resolution MOD10C2

Daily snow CMG 0.05° resolution MOD10C1

Monthly snow CMG 0.05° resolution MOD10CM

Algorithm Heritage:

Kyle et al., 1978

Bunting and d'Entremont, 1982

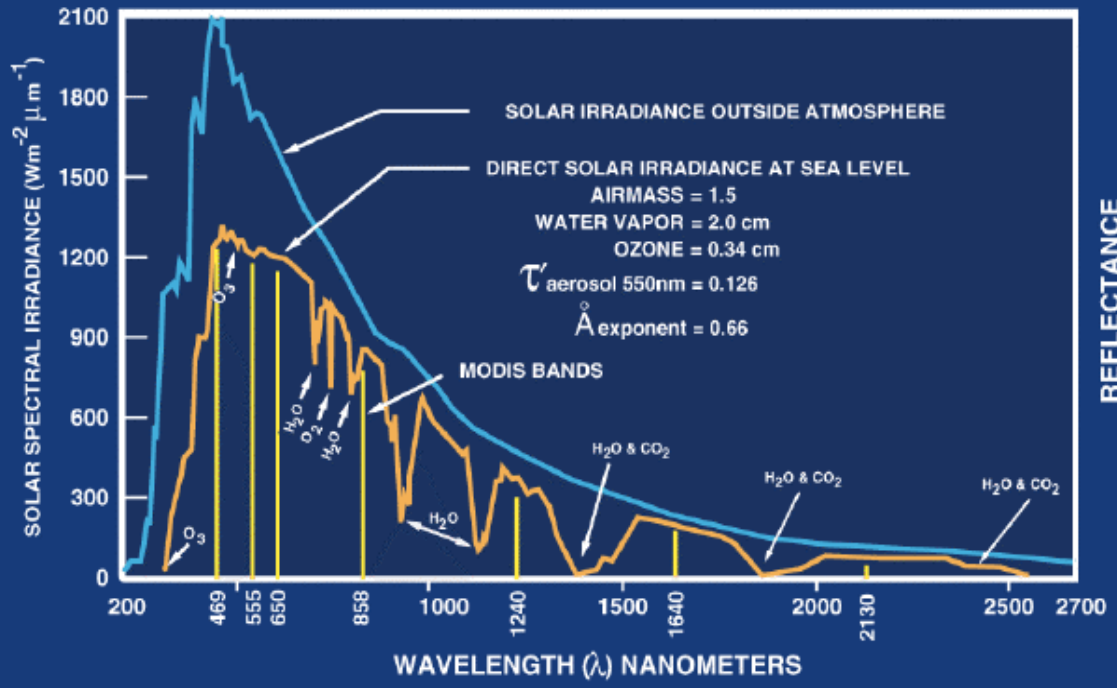
Crane and Anderson, 1984

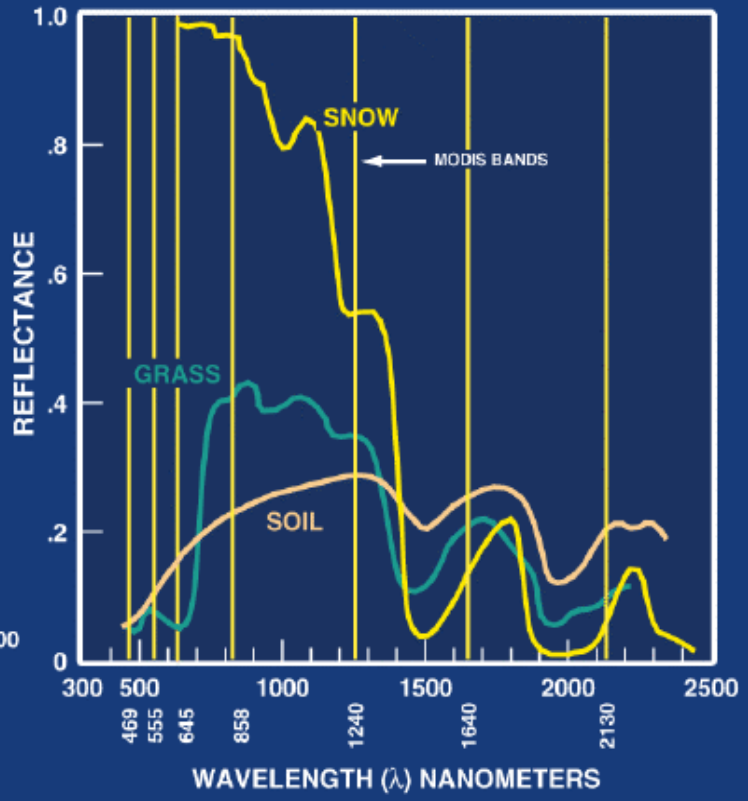
Tucker et al., 1985

Dozier, 1989

Romanov et al., 2000

LAND-SOLAR RADIATION





NDSI

The Normalized Difference Snow Index (NDSI) is analogous to the normalized-difference vegetation index (NDVI).

Snow has strong visible reflectance but absorbs strongly in the short-wave IR.

NDSI is an effective way to distinguish snow from many other surface features.

- Quick and easy to use
- Relatively insensitive to a wide range of illumination conditions, is partially normalized for atmospheric effects, and does not depend on reflectance in a single band.
- One draw back is that it is only useful during daylight hours.
- Both sunlit and some shadowed snow is mapped effectively.
- Some snow/cloud discrimination is accomplished using the NDSI.

NDSI Algorithm

At-satellite reflectances in MODIS bands 4 (0.545-0.565 μm) and 6 (1.628-1.652 μm) are used to calculate the normalized difference snow index (NDSI):

$$NDSI = \frac{\text{band 4} - \text{band 6}}{\text{band 4} + \text{band 6}}$$

Because Aqua's channel 6 detectors are damage, channel 7 (2.105 – 2.155 μm) is used instead.

$$NDSI = \frac{\text{band 4} - \text{band 7}}{\text{band 4} + \text{band 7}}$$

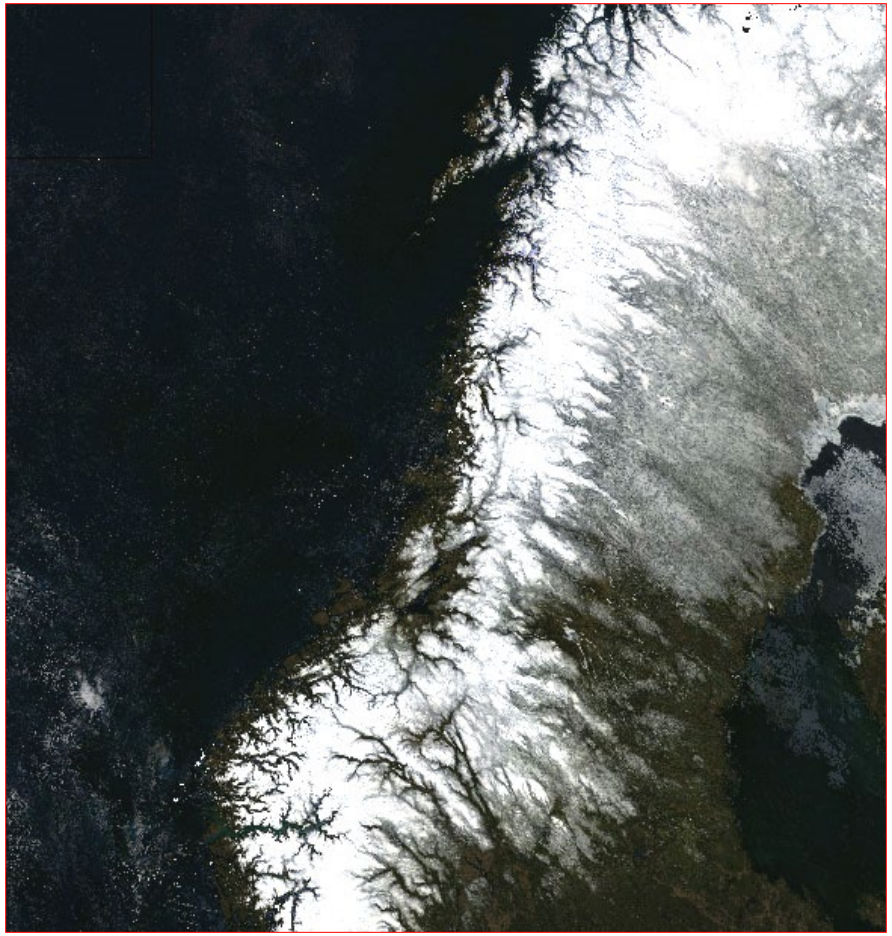
A pixel will be mapped as snow if the NDSI is ≥ 0.4 and reflectance in MODIS band 2 (0.841-0.876 μm) is > 11%. However, if the MODIS band 4 reflectance is < 10%, then the pixel will not be mapped as snow even if the other criteria are met, thus eliminating water bodies that have an NDSI > 0.4.

A "thermal mask" using a split-window technique (bands 31 and 32) is used to remove spurious snow cover, for at-satellite temperatures > 277 K (283 K for Collection 4).

An "impossible snow mask" is also used.

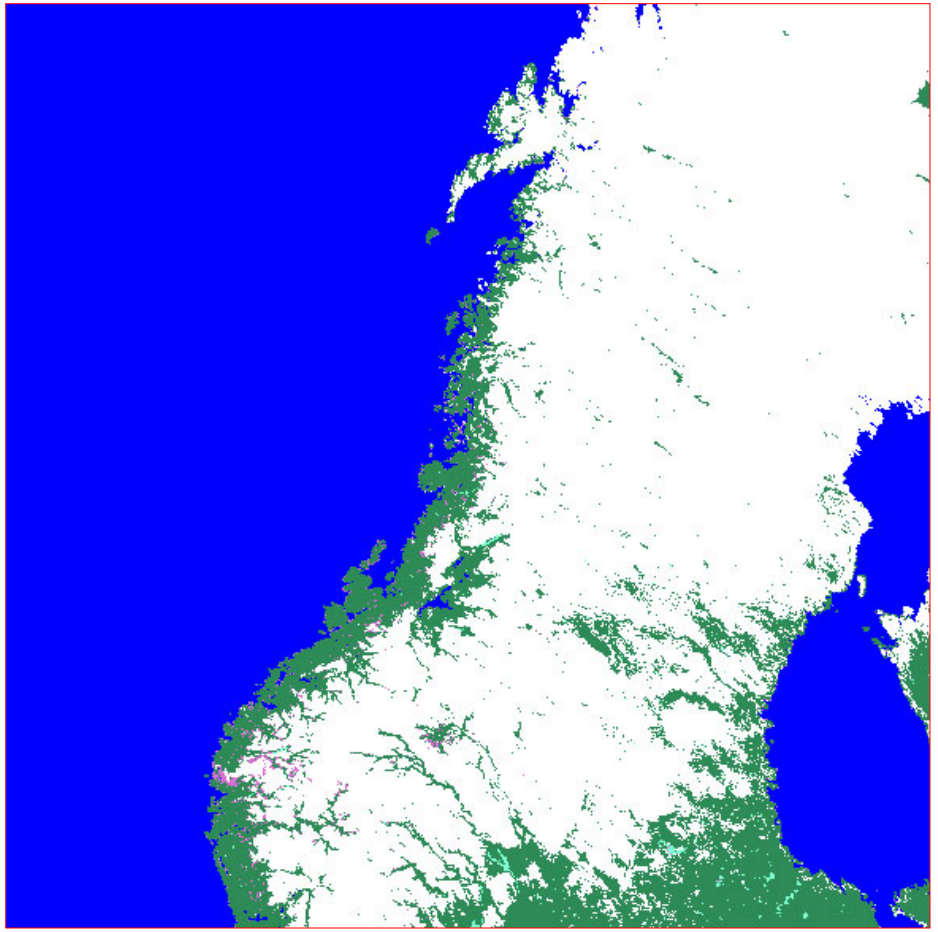
Snow in Norway and Sweden

April 15, 2002



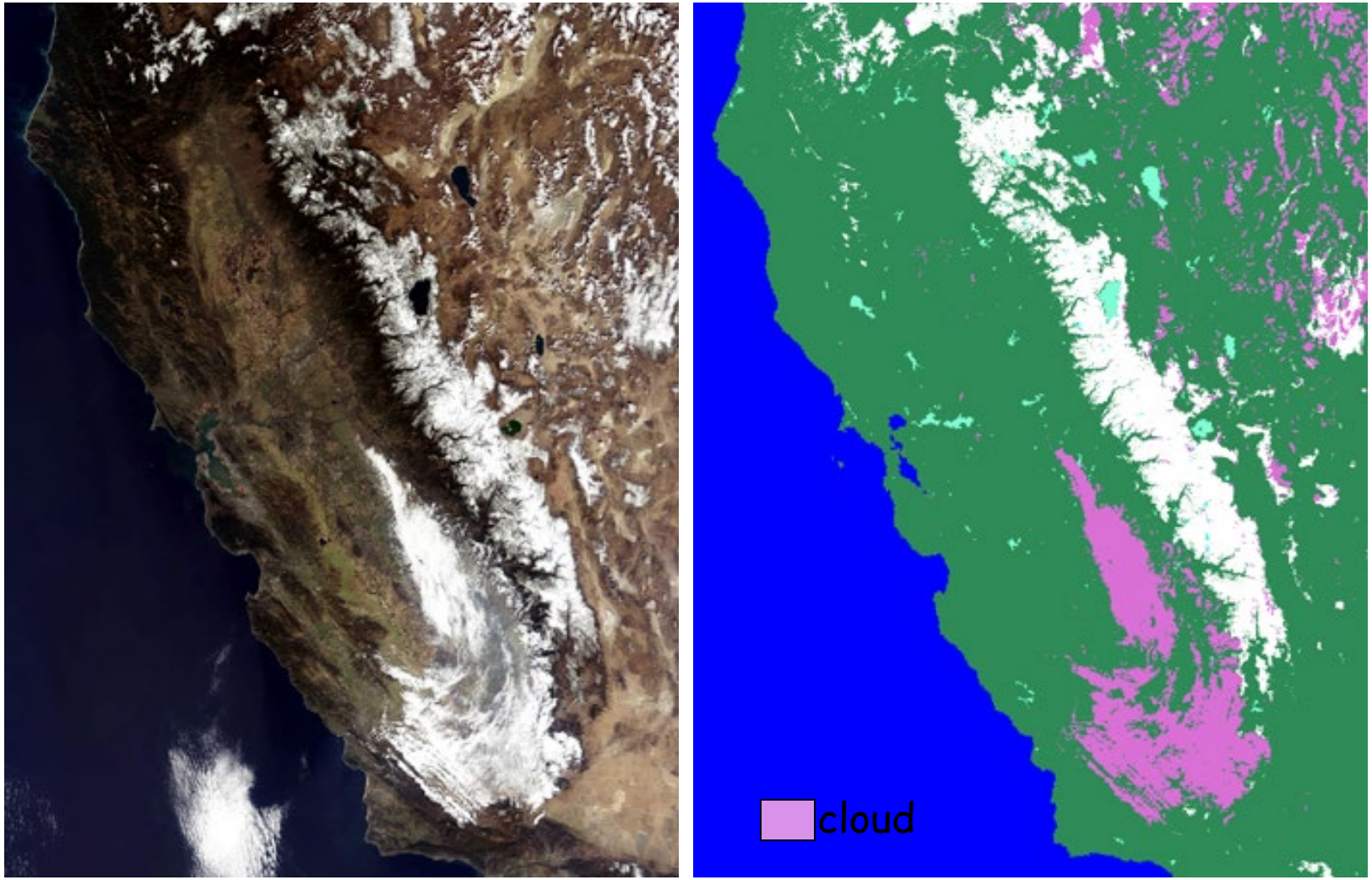
MOD09 bands 1,4,3 (0.65, 0.46, 0.55 um) -

8 Day Surface Reflectance Product



MOD10_A2 - 8 Day Maximum Snow Tile Product

MOD10_L2: 500-m swath product of California and the western U.S., October 31, 2004

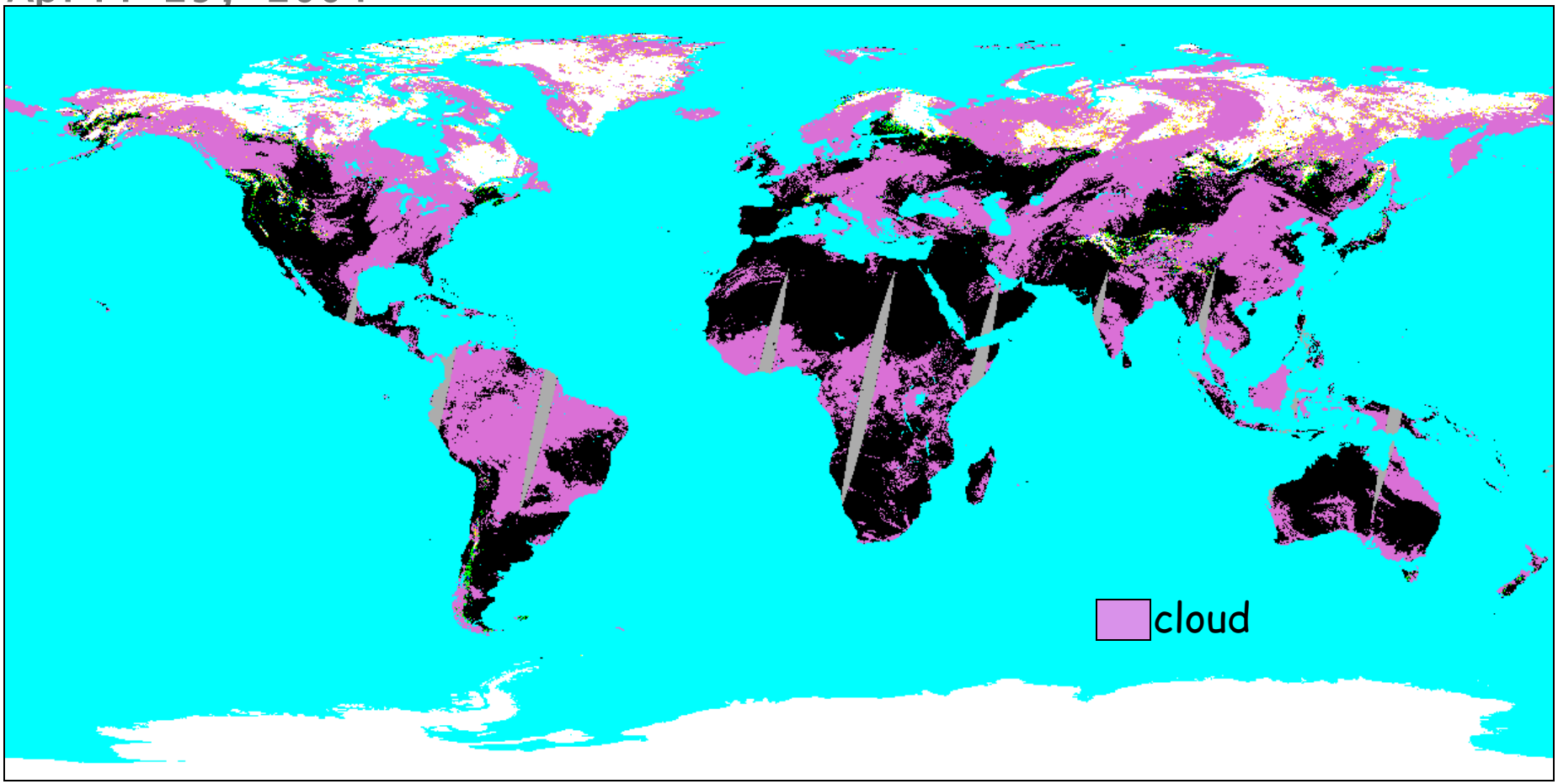


MODIS true-color image (left - bands 1, 4, 3) and snow map (right)

MOD10C1: Daily CMG snow map

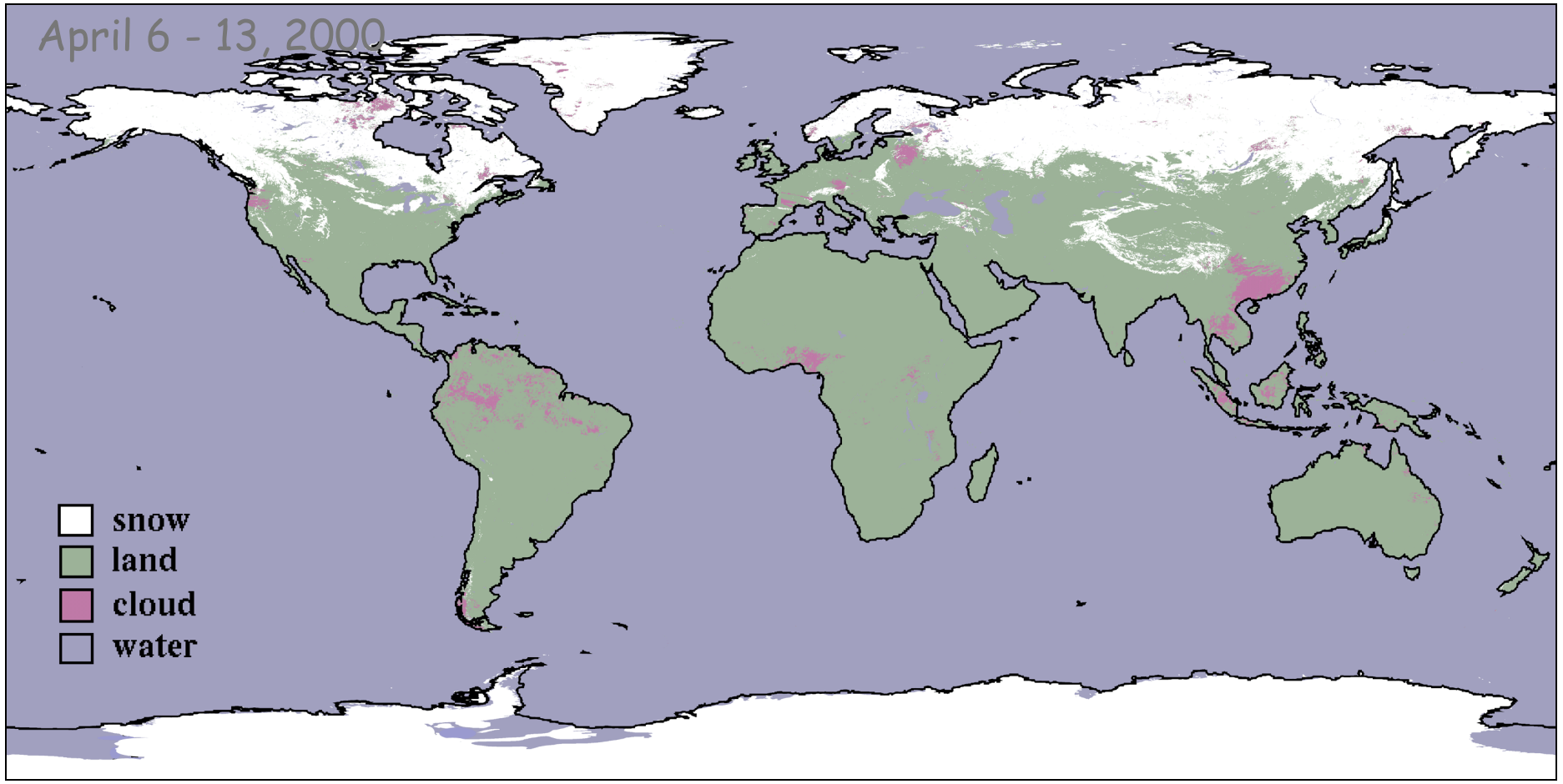
(0.05° resolution)

April 25, 2004



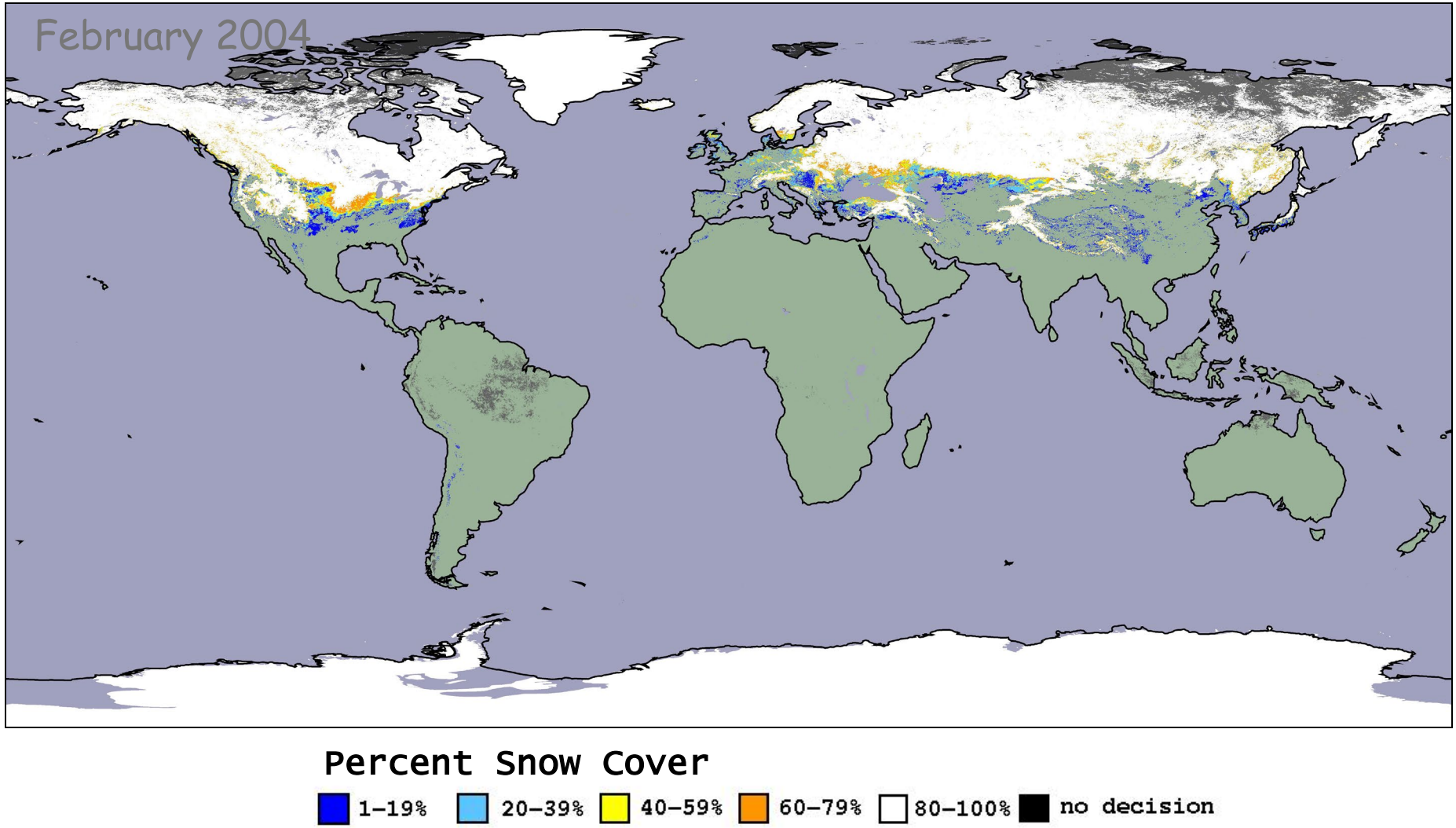
MOD10C2: 8-Day Composite CMG snow map

fractional snow cover from 1 - 100% not shown



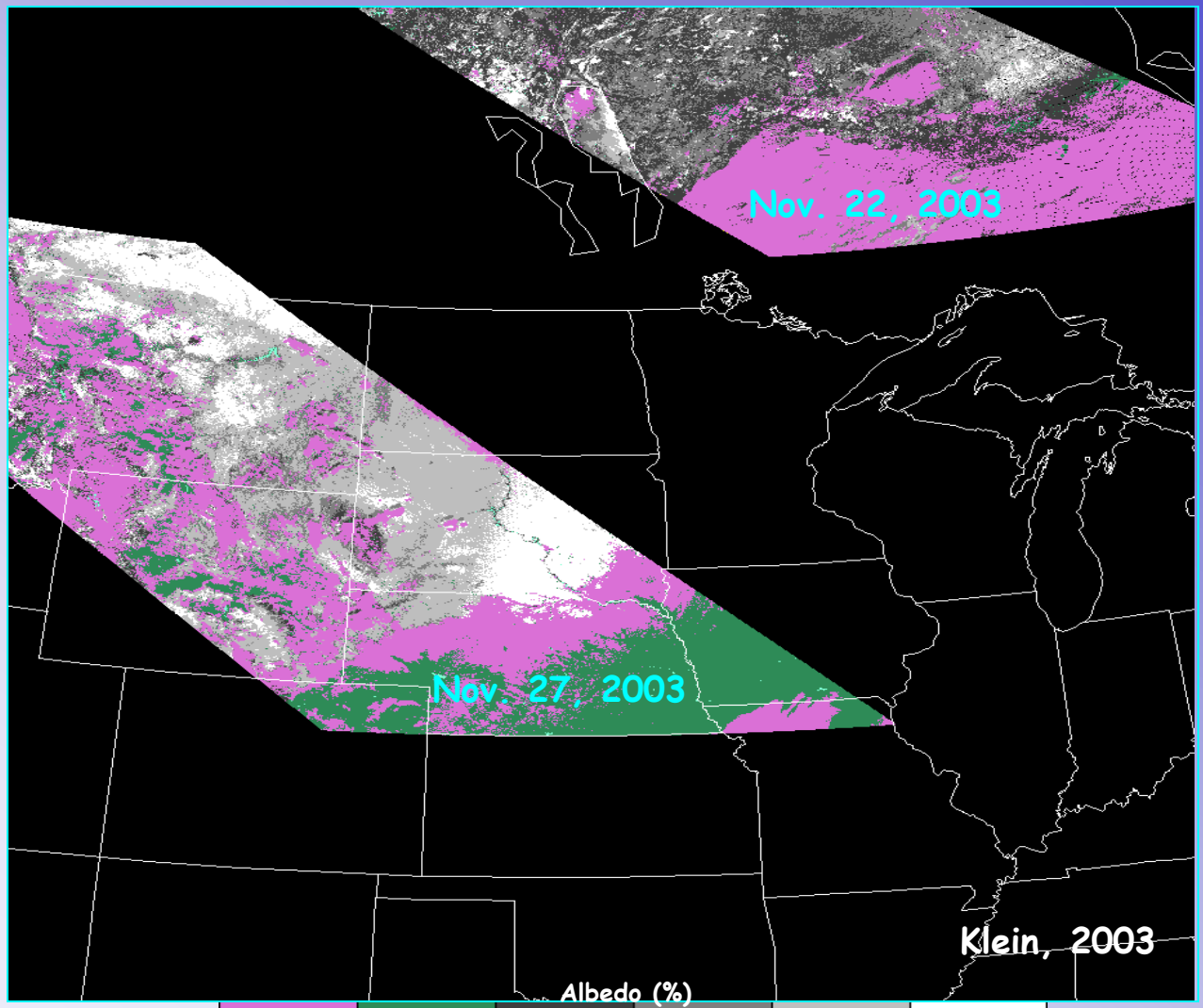
The 8-day composite CMG maps maximize snow cover and minimize cloud cover for the compositing period

MOD10CM: 0.05° Monthly Climate-Modeling Grid (CMG) Snow Maps



Daily snow albedo product (MOD10A1) 500-m resolution

Snow albedo swaths - North America



Snow Product Validation Status

MOD10_L2 validated to "stage 2" (including fractional-snow cover in Collection 5)

MOD10A1 & MOD10A2 validated to "stage 2" (except snow albedo which is "beta")

MOD10C1 & MOD10C2 validated to "stage 2"

MOD10CM "provisional" (in Collection 5)

Beta: early release product to allow users to gain familiarity with data formats and parameters. Products are minimally validated and may still contain significant errors; they are not appropriate as the basis for quantitative scientific publications.

Provisional: partially validated; incremental improvements are still occurring. Quality may not be optimal since validation and quality assurance are ongoing. Users are urged to review product quality summaries before publication of results.

Stage 1 validation: product accuracy has been estimated using a small number of independent measurements from selected locations and time periods. A paper is in the process of being published in the peer-reviewed literature.

Stage 2 validation: product accuracy has been assessed by a number of independent measurements, at a number of locations or times representative of the range of conditions portrayed by the product. Accuracy assessment is described in a paper in the peer-reviewed literature.

Sea Ice Product

Sea Ice Detection and Ice Surface Temperature

• Snow-covered sea ice has albedo characteristics similar to snow (duh!), so NDSI can be used to identify snow-covered sea ice.

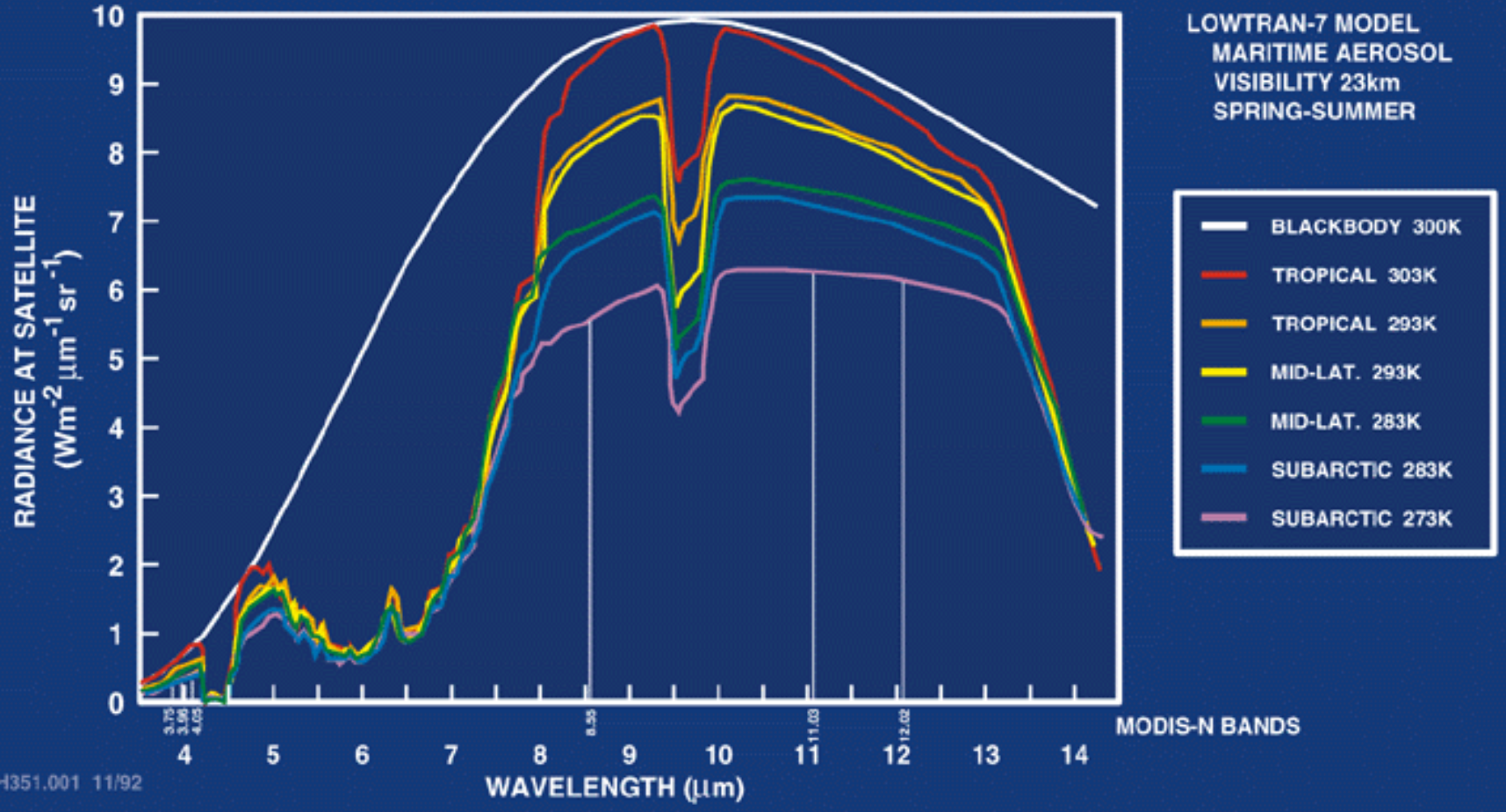
• The MODIS sea ice algorithm identifies sea ice by its reflectance characteristics in the visible and near IR and its sharp contrast to open water. If NDSI > 0.4 and band 1 > 0.11, then the pixel contains snow covered sea ice.

• The algorithm also estimates the ice surface temperature (IST), which is used as an additional discriminatory variable for the identification of sea ice cover.

• Some types of sea ice, such as grease ice, however, may be difficult to identify with such criteria tests because they lack sharp contrast with open ocean.

• In addition to presence/absence of ice and its temperature, other characteristics are also important, including the areal extent, albedo, thickness, concentration, and motion.
    - Albedo can be calculated in the same manner as for snow.
    - Concentration (percent of ice in a given area) is most commonly calculated with passive microwave data, e.g., SSM/I or AMSR-E.
    - Motion can be calculated with MODIS (clear areas) and/or passive microwave.
    - Thickness is very difficult to estimate from satellite with any reasonable degree of accuracy, but knowing IST and albedo can help.
    - Ice type (first-year, multi-year) can be determined with passive microwave data.

MODIS SEA SURFACE TEMPERATURE



H351.001 11/92

Ice Surface Temperature

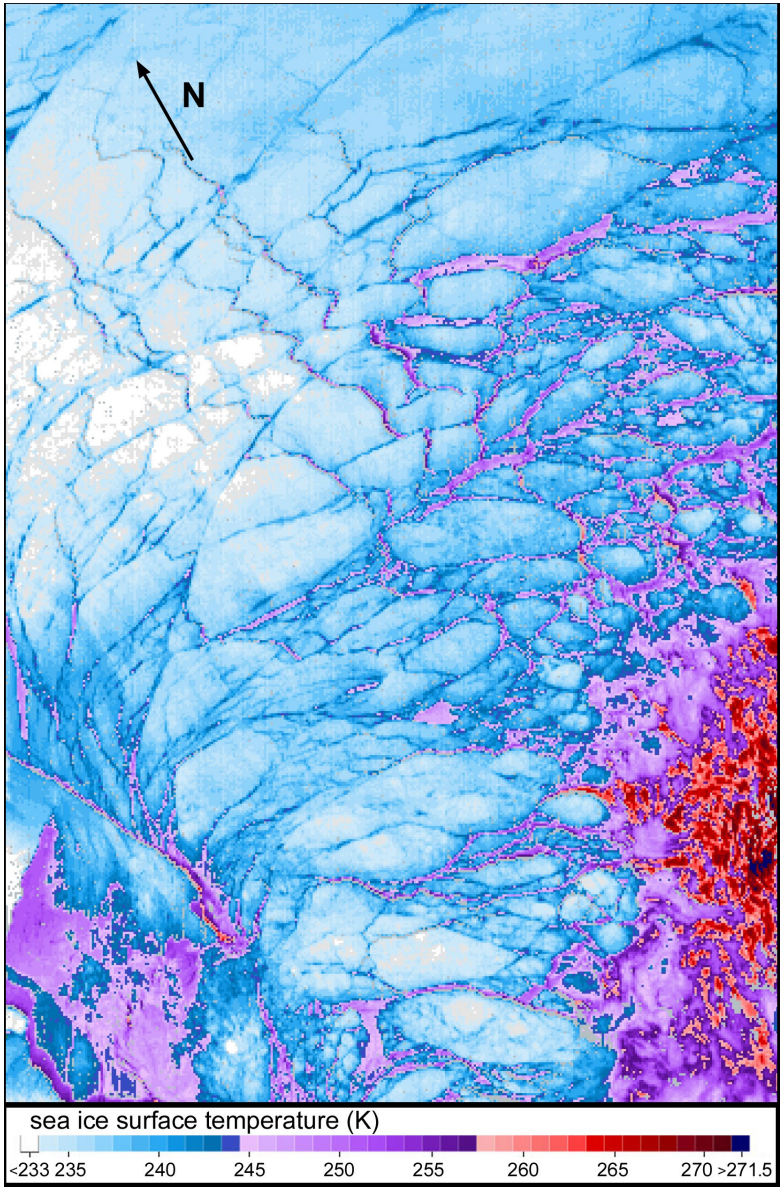
• MODIS thermal IR window bands (31 and 32) are used for mapping sea ice surface temperature. IST is used with the NDSI for estimating sea ice extent.

• The surface temperature of open water is assumed to be > 271.4 K while the surface temperature of saline ice is ≤ 271.4 K.

• The MODIS IST algorithm is similar to SST algorithms, using the 11 and 12 μm brightness temperatures and the satellite scan angle:

$$IST = a + b*T_{11} + c*(T_{11} - T_{12}) + d*(T_{11} - T_{12)}*(\sec(\theta)-1)$$

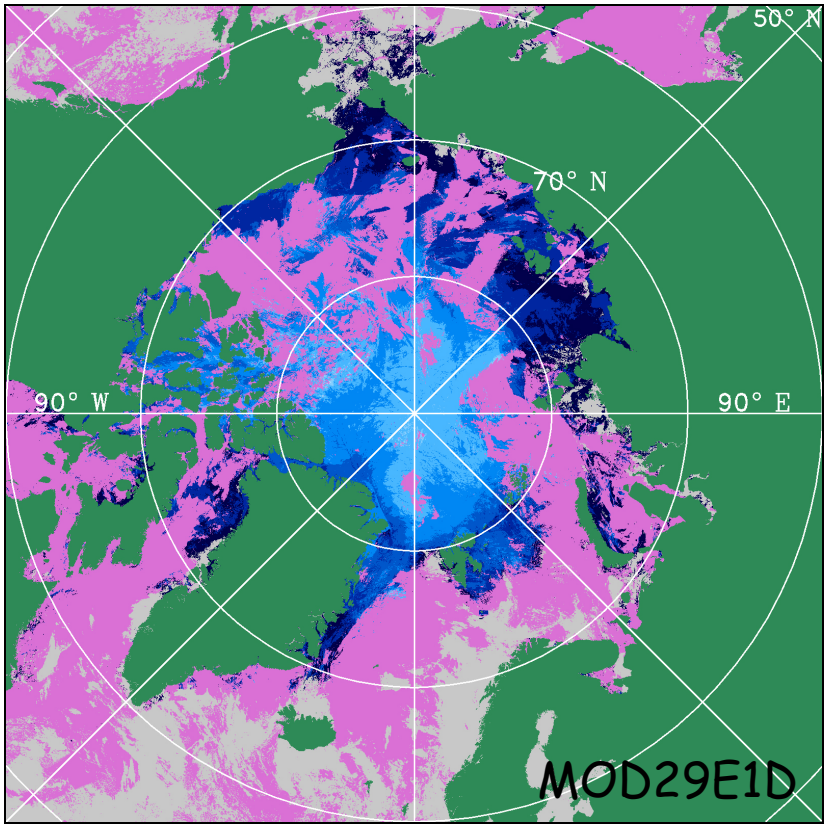
• The algorithm is only applicable in clear-sky conditions, so errors in the cloud mask may result in significant error in estimating the IST.



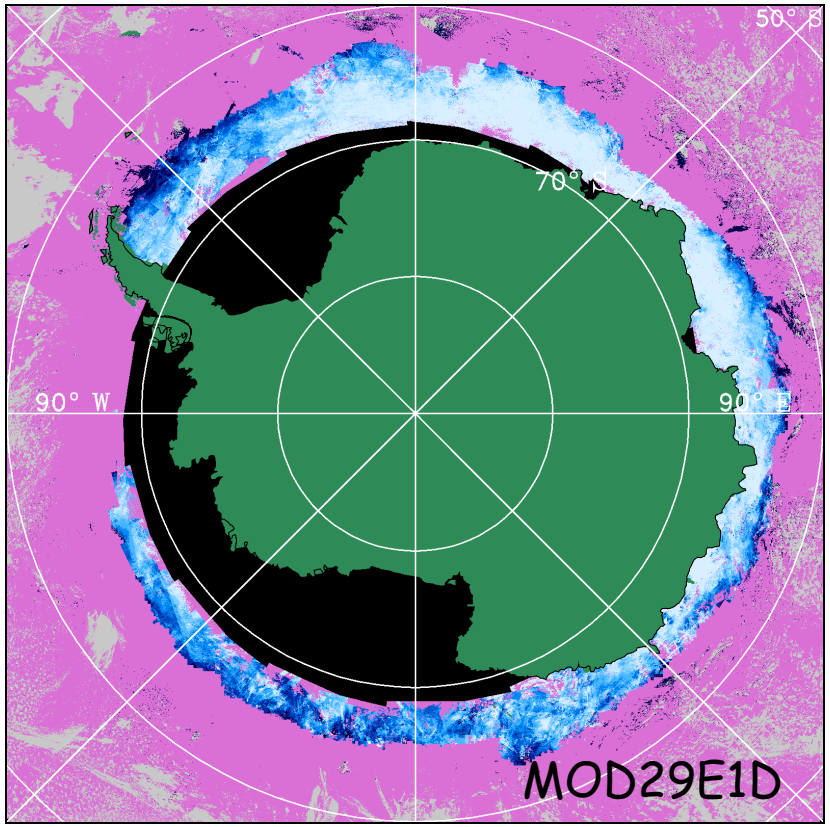
Hall et al. (2004)

Daily global 4-km resolution ice extent & IST products - composites from May 15-19, 2000

North Polar View



South Polar View

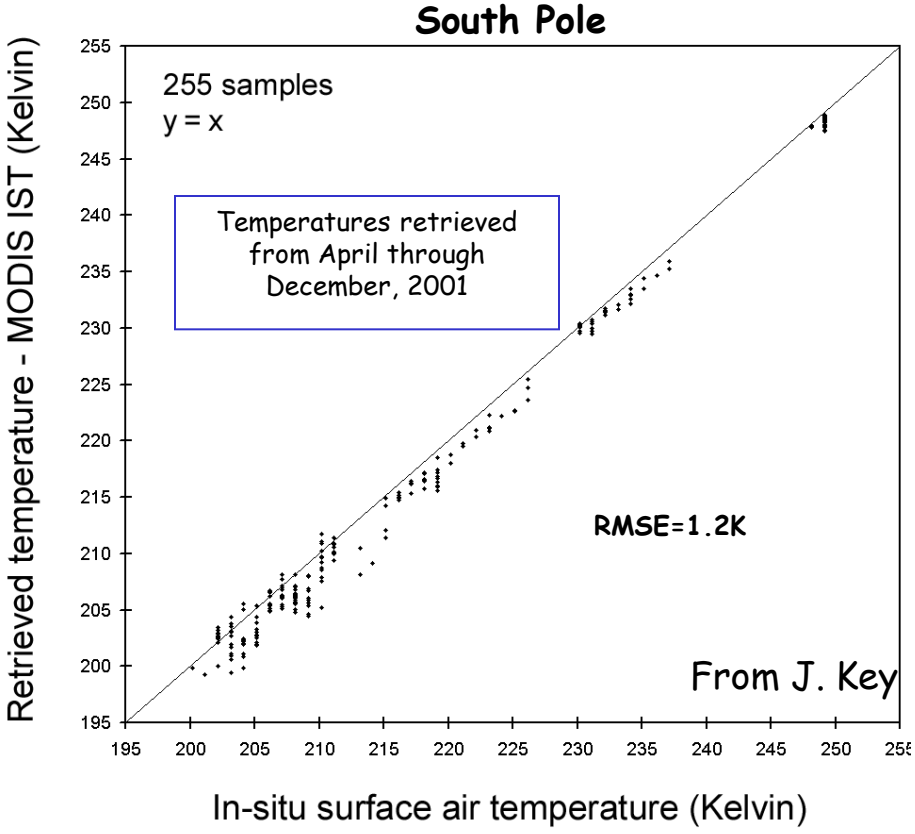


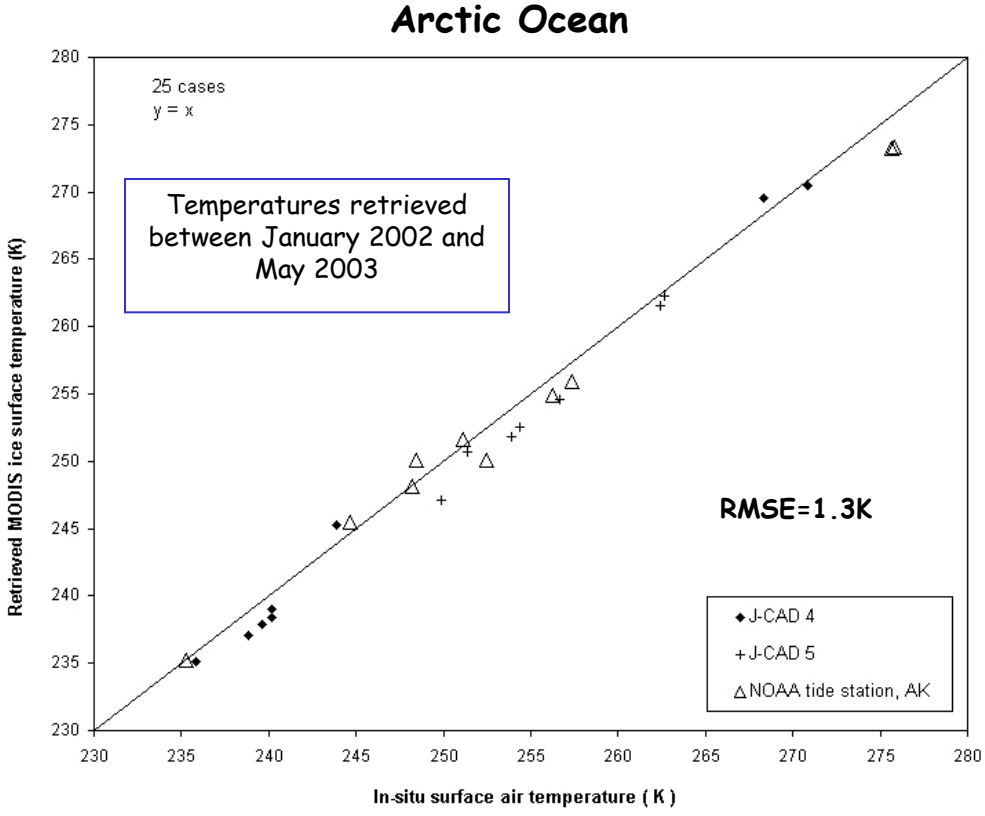
cloud

>230 - <250	>250 - <253	>253 - <256	>256 - <259	>259 - <262	>262 - <265	>265 - <268	>268 - <271	>271

Hall et al. (2004)

MODIS IST-retrieved skin temperatures and measured surface temperatures at the South Pole & from buoy temperatures in the Arctic Ocean





Hall et al. (2004)

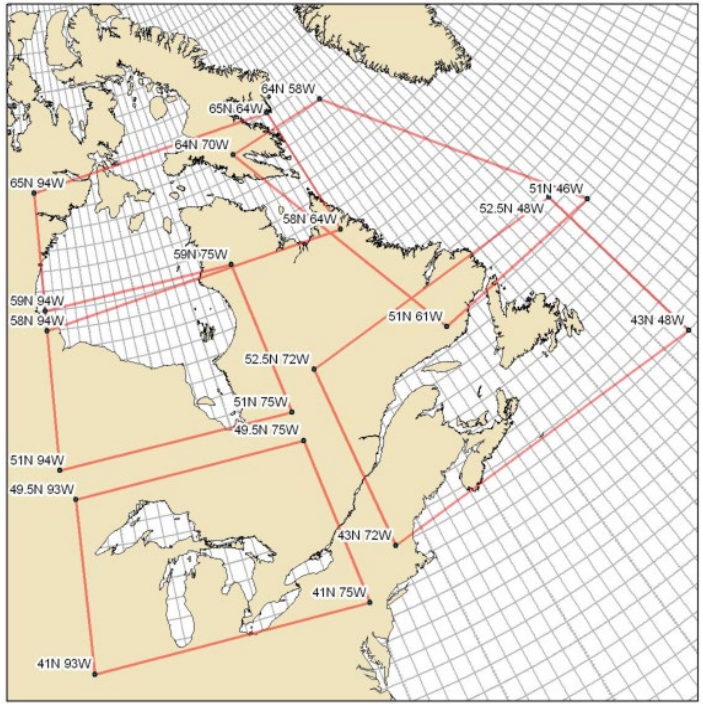
Other Products

Realtime GeoTIFF products for Ice Monitoring

Terra and Aqua MODIS 250 meter true color images are produced daily at SSEC for the Great Lakes and Northeast Canada.

GeoTIFF format in UTM projection (GIS compatible).

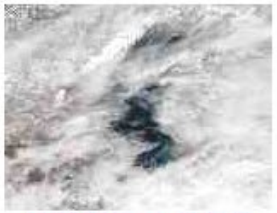
NOAA Coastwatch, National Ice Center, and Canadian Ice Service download the images in realtime.



NOAA CoastWatch - Great Lakes Region

Lake Michigan MODIS Imagery - True Color, 250 m Resolution

Current time: 03/24/2005 14:17:55 GMT


03/23/2005 18:17 GMT


03/23/2005 16:38 GMT

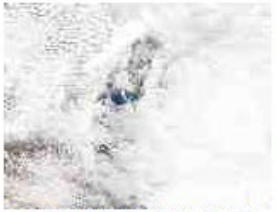

03/22/2005 19:12 GMT


03/22/2005 17:33 GMT


03/22/2005 15:56 GMT


03/21/2005 18:29 GMT


03/21/2005 16:50 GMT

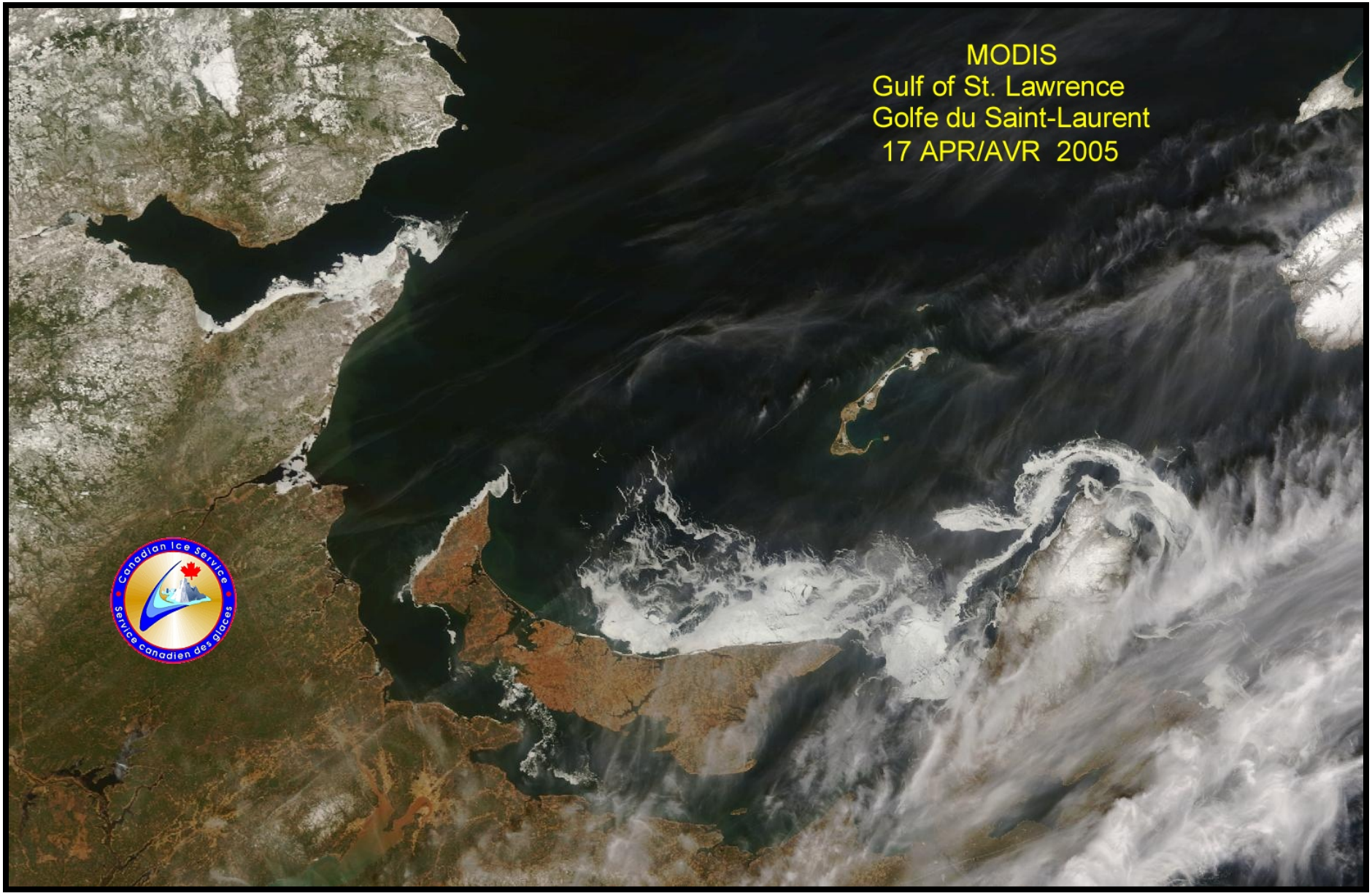

03/20/2005 19:24 GMT


03/20/2005 16:08 GMT

MODIS data acquired by direct broadcast and processed at the Space Science and Engineeering Center, University of Wisconsin-Madison

Canadian Ice Service Example

http://ice-glaces.ec.gc.ca/

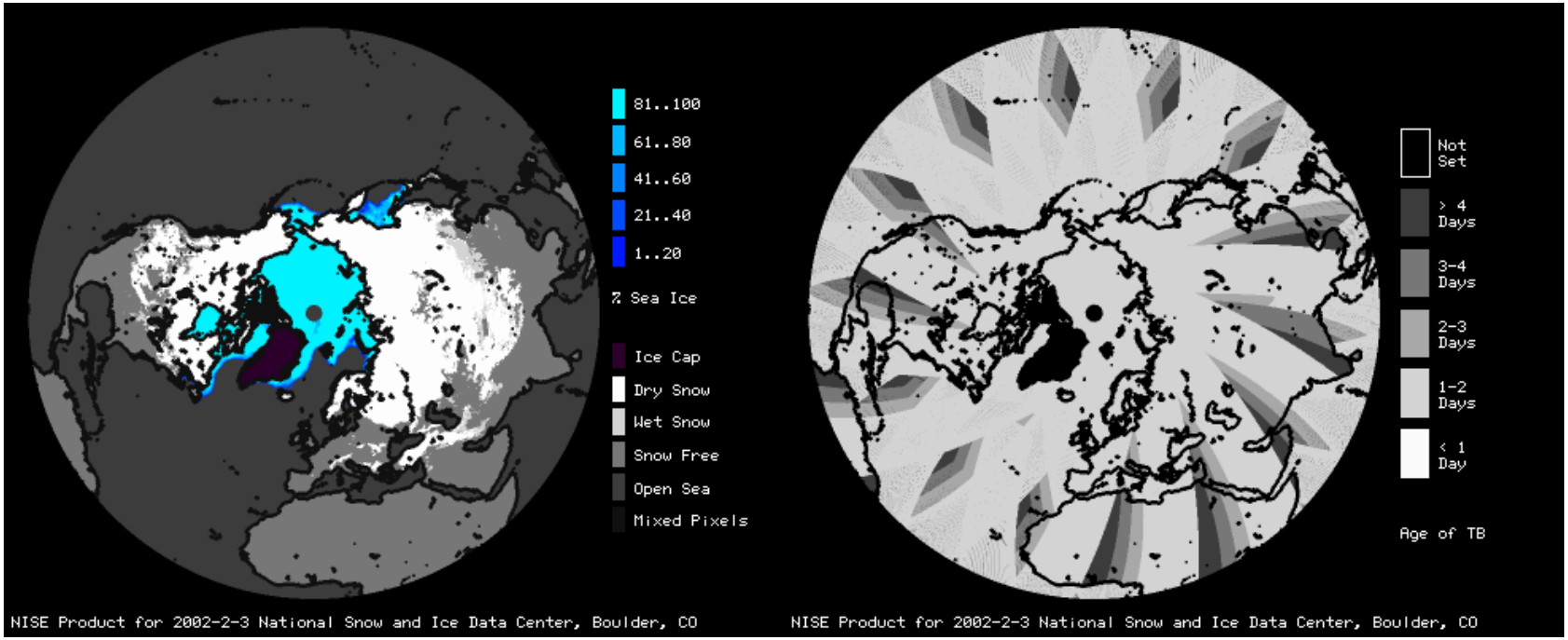


Near Real-Time SSM/I EASE-Grid Daily Global Ice Concentration and Snow Extent (NISE)

Global, near real-time maps of snow cover and sea ice concentration from the National Snow and Ice Data Center (NSIDS, http://nsidc.org).

Based on SSM/I passive microwave satellite data. NOT MODIS!

25 km EASE grid, HDF format, updated daily.



Snow Wetness and Depth

Snow wetness can be estimated with SAR data, because the backscatter decreases as snow wetness increases. Example: EnviSnow from NORUT IT and NR (see Hans Koren for more information). Passive microwave data can also be used.

Snow depth can be estimated with passive microwave satellite instruments, but are currently considered to be relatively low quality.

Variability of Snow Cover and Sea-Ice Surface Temperature as Determined from MODIS Snow and Sea Ice Products, 0.05° resolution, Winter 2002-03

(external animation)

MODIS Snow and Ice Project & GSFC Scientific Visualization Studio (SVS)

MODIS Reflected Solar Bands

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

MODIS Thermal Emissive Bands

Primary Atmospheric Application	Band	Bandwidth[1]	$T_{typical}$ (K)	Radiance[2] at $T_{typical}$	NEΔT (K) Specification	NEΔT (K) Predicted
Surface Temperature	20	3.660-3.840	300	0.45	0.05	0.05
	22	3.929-3.989	300	0.67	0.07	0.05
	23	4.020-4.080	300	0.79	0.07	0.05
Temperature profile	24	4.433-4.498	250	0.17	0.25	0.15
	25	4.482-4.549	275	0.59	0.25	0.10
Moisture profile	27	6.535-6.895	240	1.16	0.25	0.05
	28	7.175-7.475	250	2.18	0.25	0.05
	29	8.400-8.700	300	9.58	0.05	0.05
Ozone	30	9.580-9.880	250	3.69	0.25	0.05
Surface Temperature	31	10.780-11.280	300	9.55	0.05	0.05
	32	11.770-12.270	300	8.94	0.05	0.05
Temperature profile	33	13.185-13.485	260	4.52	0.25	0.15
	34	13.485-13.785	250	3.76	0.25	0.20
	35	13.785-14.085	240	3.11	0.25	0.25
	36	14.085-14.385	220	2.08	0.35	0.35