

NOAA / AVHRR Sub-pixel Snow Cover Data Set

Theoretical Basis and Data Set Description

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Contents

Contents	II
List of Acronyms	III
1 Dataset Overview	1
2 Investigator(s)	4
3 Theory of Sub-pixel estimation	5
4 Equipment	6
5 Data Acquisition Methods	10
6 Data Description	11
7 Data Organization	14
8 Data Manipulations	15
9 Errors	19
10 Notes	21
11 Application of the Dataset	22
12 Dataset Plans	23

<i>CONTENTS</i>	III
13 Related Software	24
14 Data Access	25
15 Output Products and Availability	26
16 References	27
17 Documentation Information	30

List of Acronyms

AVHRR	Advanced Very High-Resolution Radiometer
BRDF	Bidirectional Reflectance Distribution Function
CASPR	The Cloud and Surface Parameter Retrieval
FTP	File Transfer Protocol
IFOV	Instantaneous Field-Of-View
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction Model
PCA	Principal Component Analysis
RMS	Root Mean Squared
RSGB	Remote Sensing Research Group
SSA	Sub-pixel Snow Cover Algorithm
TOA	Top of Atmosphere

Chapter 1

Dataset Overview

Dataset Identification

This user guide includes information on the Remote Sensing Research Group Sub-pixel Snow Algorithm (SSA) which produces snow cover fraction data from NOAA AVHRR.

Dataset Introduction

Snow measurements from satellite are acquired by optical, passive and active microwave sensors. For operational snow monitoring, data from the NOAA AVHRR sensors provide a favourable cost/benefit trade-off. This data set uses observations from the AVHRR/2 and AVHRR/3 instrument on the operational polar satellites. These satellites are in sun-synchronous orbits, with nominal ascending equatorial crossing at 7:30 AM and 2:00 PM. The instruments measure emitted and reflected radiances in five spectral bands (see Table 1.1). The solar reflectance channels of the AVHRR/3 instruments on board NOAA K(15), L(16) and M(17) differ from the earlier version in two respects: First, channel 3 is intended to alternate between 1.6 microns during daylight hours and 3.7 microns during the night. The 1.6 micron channel is known as 'channel 3A' while the 3.7 micron channel is called 'channel 3B'. Important for the Sub-pixel Snow Algorithm, is the new channel 3A on board of NOAA-17, which provides snow, ice and cloud discrimination. After 1 May 2003, there is no AVHRR channel 3A/3B switching and channel 3B is on permanently on NOAA-16. For NOAA-15 channel 3B is still maintained as the operational AVHRR channel 3. Therefore the reflective part of channel 3B on NOAA-12, -14, -15 and -16 is calculated

based on Baum and Trepte (1999). NOAA-17 and NOAA-16 are classified as the NOAA Polar operational satellites.

Table 1.1: AVHRR Spectral Channel Characteristics

Channel	Wavelength (microns)
1	0.58 - 0.68
2	0.725 - 1.10
3A	1.58 - 1.64
3(or 3B)	3.55 - 3.93
4	10.30 - 11.30
5	11.50 - 12.50

The instrument has an IFOV of 1.3 milliradians providing a nominal spatial resolution of 1.1 km (0.69 mi) at nadir. Each pass of the satellite provides a 2399 km wide swath. The satellite orbits the earth 14 times each day from 833 km above its surface. The 1.1 km 'HRPT' data are broadcast to any ground receiver in the field of view transmitting antenna.

The Sub-pixel Snow Algorithm Version 1.0 has been implemented by N. Foppa and the members of the Remote Sensing Research Group at the University of Bern. The algorithm is based mainly on Adams and others (1989) and Roberts and others (1998).

Objective and Purpose

The mandate of the snow cover task is to produce operational AVHRR snow cover maps for the European Alps to use in different ways, such as improving of snow depth maps and for hydrological runoff modeling.

Summary of Parameters

Snow Cover Fraction

Discussion

Since many years remote sensing data has been used to provide information on distribution and properties of snow. Snow cover analysis in mountainous regions are needed for various purposes such as snow mapping, meteorological modeling, climate studies, estimation of stored water equivalent or snowmelt runoff prediction. Some of these applications even require reliable information of the snow covered area in near real-time. Conventional classification algorithms or hierarchical threshold approaches applied to snow cover estimation generate binary maps containing snow or not snow information. Due to the medium spatial resolution of the AVHRR sensor of 1.1 km at nadir, each pixel potentially represents a mixture of snow, cloud, forest, rock etc.. Classification of such mixed pixels can lead to errors which renders the area estimation inaccurate. These errors are caused by the premise of classification that all pixels are pure, i.e. consists of a single ground cover type or clouds, while in fact they are not. There are many studies dealing with the development of methods to map snow cover at sub-pixel scale (Nolin and others, 1993; Painter and others, 1998; Metsämäki and others, 2002; Simpson and others, 1998; Vikhamar and Solberg, 2002; Solberg and Andersen, 1994). The linear spectral mixture algorithm is a widely used technique for the decomposition of mixed pixels. It has the advantage to be a straightforward approach, which provides physically meaningful measure of abundance that is portable across sensors and through time. Although mixture analysis is originally developed for sensors with a great number of bands, it has been adapted to AVHRR data successfully for various fields of application. The algorithm has been proved to be well suited for snow cover analysis using AVHRR data (Daly and others, 2000; Simpson and others, 1998). Recent studies contribute to an improvement in sub-pixel analysis for snow cover estimation and are focused on a specific subject of snow cover fraction retrieval e.g. varying snow grain size or snow cover detection in forested area. Several studies mapping montane snow cover at sub-pixel scale have generally yielded acceptable results (Rosenthal and Dozier, 1996). Accordingly, the linear mixing assumption is appropriate for mapping alpine snow cover at sub-pixel resolution. Most of the approaches including the linear spectral mixture modeling are supervised techniques and do not underlie the requirement of being a procedure without any human intervention.

Chapter 2

Investigator(s)

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Has implemented the operational Sub-pixel Snow Cover processing scheme for the European Alps using NOAA AVHRR data.

Chapter 3

Theory of Sub-pixel estimation

Linear mixture modeling (Adams and others, 1989) is based on the assumption that the signal received at the sensor is composed of a linear mixture of pure-element reflections called endmembers. The weights of these endmembers represent the percentage of the pixel area occupied by each surface cover type. The weighting coefficients (fractions) are constrained to be non-negative and sum to one. The system can be solved by a least square solution which minimizes the unmodeled sum of squares of errors.

Chapter 4

Equipment

Sensor/Instrument Description

Collection Environment

NOAA-Series Satellites

Source/Platform

All active NOAA AVHRR polar-orbiting satellites

Source/Platform Mission Objectives

Each of the NOAA polar-orbiting satellites have carried an AVHRR as one of three sensors aboard the spacecraft. AVHRR was designed for multispectral investigations of meteorological, oceanographic, and hydrologic parameters, measuring emitted and reflected radiance in four or five spectral bands, spanning the visible portion of the spectrum to the thermal infrared.

Key Variables

The sensor measures emitted and reflected radiation from Earth in two visible channels and three infrared channels.

Principles of Operation

Each AVHRR scan views Earth for 51.282 milliseconds, during which time each channel of the analog data output is digitized. Scans occur at the rate of 6 per second, and the sampling rate of the AVHRR sensors is 39,936 samples per second per channel. During a scan, the detectors view an internal target, cold space, and the external scene. The temperature of the internal target is monitored, and space is assumed to have a black-body temperature of 3K. Calibration is done according to Goddard and others (1999) and EPO (1992).

Sensor/Instrument Measurement Geometry

The AVHRR has a cross-track scanning system which use an elliptical beryllium mirror rotating at 360 RPM about an axis parallel to the Earth. The 110.8 degrees cross-track scan equates to a swath width of about 2700 km. This swath width is greater than the 25.3 degrees separation between successive orbital tracks and provides overlapping coverage. Coverage is global, twice daily, at an IFOV of 1.4 milliradians, giving a ground field of view of 1.1 km at nadir for a nominal altitude of 833 km.

Manufacturer of Sensor/Instrument

ITT Aerospace

Calibration

Specifications

Channels 1 and 2 are observed to degrade in orbit because of the outgassing and launch associated contamination. Continued exposure to the harsh space environment is also a contributing factor. In addition, the instrument's components age in the years that elapse between the pre-launch tests and actual launch. Furthermore, this aging process continues during the two or more years that the instrument is typically operational. The calibration coefficients are incrementally updated on a monthly basis by NOAA/NESDIS.

The calibration coefficients for the visible channels for AVHRR/2 are provided by the Commonwealth Scientific Industrial Research Organisation (CSIRO) of Australia (<http://www.dar.csiro.au/rs/CalWatch/calwatch.html>). From NOAA-15 on the calibration coefficients (published by NOAA) are operationally extracted from the Level1B-format image. This leads to a possibility of using a time dependent correction which accounts for sensor degradation and intercalibrates among the satellites. The pre-launch calibration coefficients are taken from the NOAA Polar Orbiter Data User's Guide (<http://www2.ncdc.noaa.gov/docs/podug/html/c3/sec3-3.htm>) and the NOAA KLM User's Guide (<http://www2.ncdc.noaa.gov/docs/klm/html/d/app-d3.htm>). Channels 4 and 5 are calibrated using a non-linear function based on the internal calibration targets, baseplate temperatures, instrument dependent response curves, and NOAA-provided gains and offsets. Channel 3B can be computed to TOA reflectance using the formula presented by Baum and Trepte (1999). The measured radiance of channel 3B is decomposed into its emissive and reflective fractions. The reflective part in this channel carries essential information for the differentiation of snow and cloud. This decomposition is achieved by estimating the emissive part and subtracting it from the measured radiance. This is done by using the purely thermal channels 4 and 5 and the assumption that the earth's emission can be approximated through the Planck law.

Tolerance

The instrument is designed to maintain a constant operating temperature for the IR detectors and provide a signal-to-noise ratio (SNR) of 3:1 at 0.5% albedo.

Frequency of Calibration

The thermal infrared channels are calibrated in-flight using a view of a stable blackbody and space as a reference. Channels 1 and 2 have no in-flight calibration capabilities, however, they are calibrated before launch.

Other Calibration Information

The solar reflectance channels on the NOAA AVHRR instrument have no on-board calibration source and are known to drift in sensitivity following launch. Various methods have been developed for the post-launch calibration of these channels. The basis of the calibration of the visible channels is the compilation by CSIRO of Australia (<http://www.dar.csiro.au/rs/CalWatch/calwatch.html>). This document brings together the results of this work in a form suited to the operational calibration of AVHRR data sets from both historical and currently operational sensors.

Chapter 5

Data Acquisition Methods

Full resolution AVHRR data are read out in High Resolution Picture Transmission (HRPT) format at University of Bern, Bern Switzerland. These data are the starting point for the AVHRR RSGB sub-pixel snow processing. The Level-1B data are defined as radiometrically-corrected and calibrated data in physical units at full instrument resolution as acquired. Data is calibrated, atmospherically corrected and orthorectified.

Chapter 6

Data Description

Spatial Characteristics

The Sub-pixel Snow Cover data are distributed in full resolution. The product is produced as data set of each ascending (daytime) satellite pass. Descending (nighttime) images are not used.

Spatial Coverage

Full resolution subset: 0 degree E - 17 degree E; 40.5 degree N - 50 degree N

Spatial Resolution

Full resolution subset: 1.1 km

Projection

Full resolution subset: Geographic, WGS84

Grid Description

Full resolution subset: The AVHRR RSGB sub-pixel snow cover data is processed in a geographic grid. The pixel size in x-dimension is $\text{pixx}=0.007$ degrees

in the y-dimension $\text{pixy}=0.01$ degrees. The data sets have the dimension of 1700 x 1357 pixels.

Temporal Characteristics

Temporal Coverage

Varies on the reception schedule of the RSGB groundstation, typical is around 8 data sets within 24h. Archive data goes back to the mid eighties.

Temporal Coverage Map

Temporal Resolution

Up to 8 passes a day

Data Characteristics

Parameter/Variable

Snow cover fraction

Variable Description/Definition

Sub-pixel snow cover

Unit of Measurement

Full resolution data set: Percent snow cover (0-100%)

Data Source

AVHRR

Data Range

The data range is greater equal 0% and smaller equal than 100%.

Sample Data Record

Not available

Related Datasets

RSGB AVHRR calibrated, atmospherically corrected and orthorectified.

RSGB AVHRR cloud cover according to CASPR.

Chapter 7

Data Organization

Data Granularity

Full resolution data set: The basic granule is every 11b pass data set, which is subset to 0 degree E - 17 degree E; 40.5 degree N - 50 degree N. The data volume is about 2.5 MB.

Data Format

Full resolution data set: The data are stored in the ER Mapper data format, 8 bit unsigned, 1700 pixels, 1357 lines.

Sample Data Record

Not available

Chapter 8

Data Manipulations

Formulae

Derivation Technique and Algorithm

According to Adams and others (1989) a general equation for linear spectral unmixing is:

$$DN_c = \sum_{n=1}^N F_n DN_{n,c} + E_c \quad (8.1)$$

where

$$\sum_{i=1}^n x_i = 1 \quad (8.2)$$

and

$$x_i \geq 0 \quad (8.3)$$

with

- DN_c = reflectance in channel c
- N = number of endmembers
- F_n = fraction of endmember n
- $DN_{n,c}$ = reflectance of endmember n in channel c
- E_c = error in channel c of the fit of N spectral endmembers.

Equations (8.2) and (8.3) introduce the constraints that fractions sum to one and are non negative. The system of linear equation can be solved by a least square solution which minimizes the unmodeled sum of squares of errors.

Data Processing Sequence

Processing Steps

Level-1B data are first ingested from HRPT data, then converted from to a standard image format. Data is calibrated georeferenced, orthorectified, etc.. For improving the georeferencing, a feature matching algorithm is used to geocode the satellite imagery at sub-pixel accuracy. First, the image is approximately rectified using a control point grid which was generated at the data unpacking phase. Secondly, two images, a map and the image to be rectified are used to find automatically control points based on sub-window correlation between the two images. Afterwards the original image is rectified again. An orthorectification of the imagery is essential in an alpine region to overcome the displacement errors introduced by the topography. An automated procedure, which uses a terrain model based on the GTOPO30, was developed and implemented. Atmospheric correction is done using an updated SMAC version based on the newer 6S code instead of the previous 5S code (Rahman and Dedieu, 1994). The input for SMAC is ozone, air pressure as a measure for the atmospheric depth, water vapor and aerosol. Surface pressure and ozone concentration data result from the NWP model by the MeteoSwiss (alpine Local Model, aLMo). The total ozone concentration is derived from NCEP data. The atmospheric aerosol content is extracted from the same AVHRR data set processed. The calculated reflectance of the normalized imagery is based on the assumption of a lambertian surface. The local topography with varying slope and aspect is taken into account computing the BRDF based on the method presented by Wu and others (1995). There is no BRDF computation for snow covered surface performed. Cloud detection and masking is done using the CASPR package (Key, 2002). An accurate cloud mask is essential for the alpine region, because with it's

topography and location in the mid latitudes, blocking situations of air masses occur, causing a wide variety of cloud types.

Next the Sub-pixel Snow Algorithm is used to compute the snow cover fraction:

Estimating data dimensionality including AVHRR channels 1 and 2 and additionally channel 3A respectively the reflective part of channel 3B. Some studies, particularly for vegetation, include AVHRR thermal channels 4 and 5 in the unmixing process although thermal emission is converted to temperature by the non-linear Planck function. This does not accomplish the assumption of linearity, on which the unmixing model used in this study is based on. In this sense, only the reflective channels of the AVHRR sensor are integrated in the linear mixing algorithm. PCA is used to compress the data set, to remove spectral redundancy and to improve the spectral separability. The PCA transformation enables a graphical extraction of pixels representing the outer lines of the polygon surrounding the data space of the first two principal component. The concept of convex geometry, introduced by Settle and Drake (1993), assumes that these points have the most pure pixel spectra whereas mixed pixel lie within the data cloud. Some of these pixel signatures clearly represent snow and differ substantially from other pure spectra. An arbitrarily selected range of value is defined to determine which of the potential image endmembers correspond to a snow reflectance and represent a snow image endmember. A mean average of all potential snow spectra is calculated to take into account different reflectances of snow which result from variations in elevation and exposition of snow surfaces in alpine terrain. Sets of image endmember pairs are build consisting of the calculated snow endmember and another unknown image endmember which is not further analysed. The number of endmembers and the snow image endmember are fixed whereas one endmember type is allowed to vary. These endmember combinations are used to describe the various mixed pixels in the data set. The output of each mixing model is a fraction image of the unknown endmember and the snow endmember. In addition, a RMS error image is representing the modeling error for each pixel. The fraction of snow in a specific pixel corresponds to the model with the lowest RMS for this pixel. The RMS error explains how well the individually predicted pixel spectra match the data.

Calculations

Special Corrections/Adjustments

If no image snow endmember is detected from the convex hull a reference snow spectra will be take.

Calculated Variables

Sub-pixel snow cover is calculated from a linear mixing model (see above).

Graphs and Plots

Not available

Chapter 9

Errors

Sources of Error

One of the greatest limitations is the obstruction by clouds in the field of view. In addition, the sub-pixel method overestimates snow fractions at lowest elevations zones, where no snow is actually expected (i.e. model noise). This effect results from the two-endmember model 'snow' and 'snow free', which forces the pixel spectrum to be unmixed with only two endmembers, whereof one corresponds to snow, which might not even exist in the pixel. The modeling accuracy correlates to areas representing a specific ground cover type (e.g. forested areas), which has not been detected from the feature space of the PCA transformation using the concept of convex geometry. The modeling accuracy is further influenced by the anisotropic behaviour of snow.

Quality Assessment

For every pixel an information will be available on which test mentioned pixels will not pass, especially to define a snow fraction threshold corresponding to the model noise. A separated information image file is produced including five channels:

channel 1: RMS error image with the minimal RMS of all multiple combinations for each single pixel. A visual investigation reveals the spatial patterns of the RMS error and highlights where the model has not been constructed correctly.

channel 2: Model number of which the minimal RMS and the fraction of snow in the specific pixel corresponds.

channel 3: Reflectance from the AVHRR channel 1 used as the snow free endmember in the corresponding endmember combination model (refers to background fraction of the specific pixel).

channel 4: Reflectance from the AVHRR channel 2 used as the snow free endmember in the corresponding endmember combination model (refers to background fraction of the specific pixel).

channel 5: Reflectance from the AVHRR channel 3A used as the snow free endmember in the corresponding endmember combination model (refers to background fraction of the specific pixel).

In addition, basic statistics are calculated and reported in a log-file output.

Chapter 10

Notes

Limitations of the Data

None

Known Problems with the Data

Cloud cover

Usage Guidance

For more detailed information, contact N. Foppa at foppa@giub.unibe.ch

Any Other Relevant Information about the Study

None

Chapter 11

Application of the Dataset

Improvement of snow depth maps, operational hydrological runoff modeling for alpine and sub-alpine areas, estimation of snow water equivalent-distribution, assimilation in NWP models, local and regional climate studies.

Chapter 12

Dataset Plans

Description of Future Plans

Processing efforts and extensive validation of the product are ongoing.

Chapter 13

Related Software

Software Description

The RSGB is supplying IDL routines to read and ER Mapper data on request.

Chapter 14

Data Access

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Chapter 15

Output Products and Availability

FTP

Products are available by ftp pull.

WWW

Quicklooks of products are available by WWW.

Chapter 16

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Chapter 17

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