A literature review of Snow DA

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Outlines:

- Inroduction
- Snow physics …
- Snow models / snow parameterisations
- Observations
  in situ
  space-born: raw data, products
- Snow analysis algorithms
- Snow analysis in different forecasting systems: IFS, HIRLAM, COSMO
- Plans, projects

Introduction

Snow cover … for meteorology:

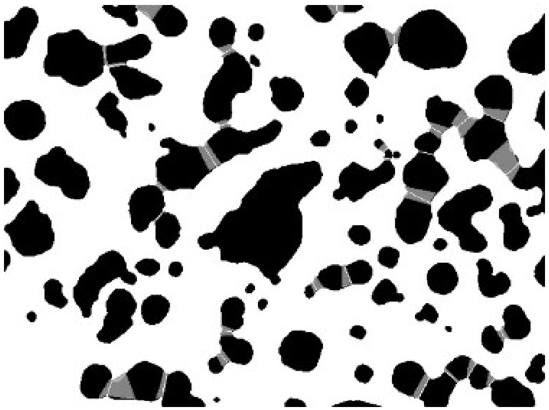
- Snow Water Equivalent (SWE) and Snow Extent are key parameters for earth's energy balance
- Snow cover affects the surface albedo
- Snow cover affects the heat flux between the ground and the atmosphere
- Snow cover has a strong effects on the lower part of the atmosphere

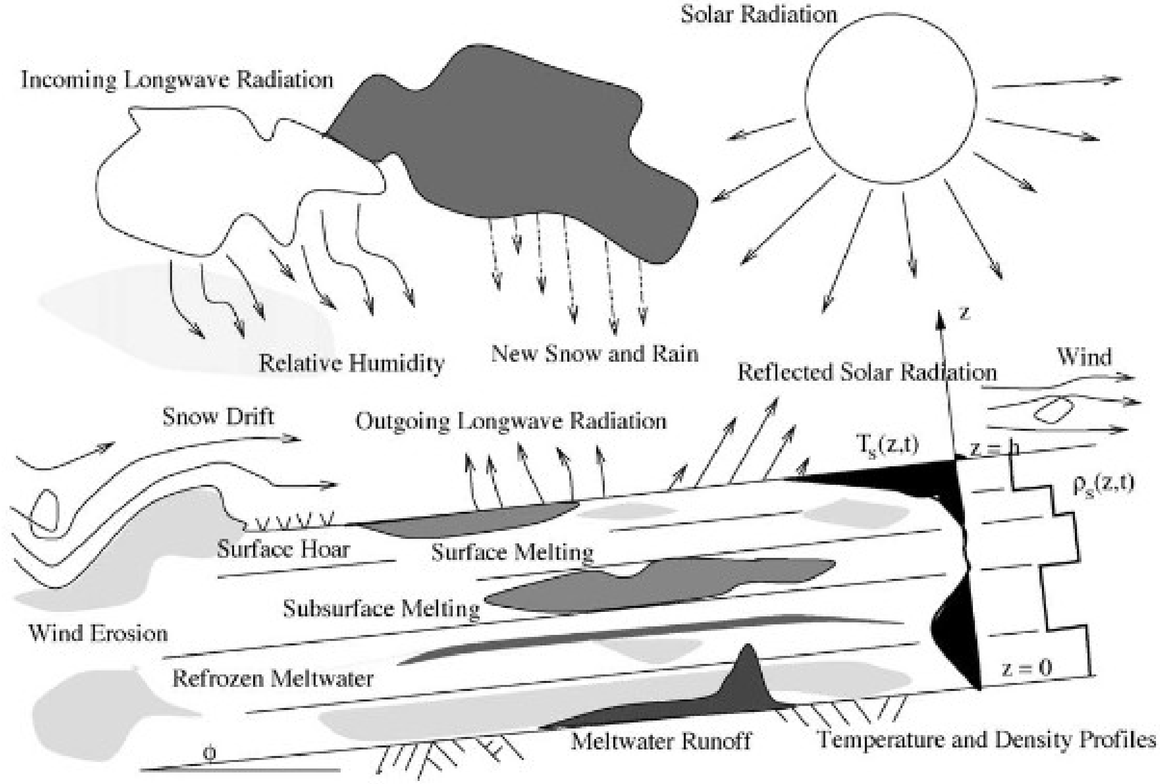
Snow cover … for hydrology:

- Maximum SWE is typically the most important characteristic for operational run-off and **flooding** forecasts in spring snowmelt.
- Snow is the main source for spring water supply important **for agriculture**, especially for semi-arid regions
- In mountains**:** **avalanche** warnings
- In some regions the run-off from mountain snow is the **only source of water**

Snow cover parameters are crucial for performance of environmental applications

Snow physics …





Ref: Perry Bartelt, Michael Lehning. A physical SNOWPACK model for the Swiss avalanche warning. Cold Regions Science and Technology 35 (2002) 123–145

Snow models / snow parameterisations

- SWE
- Snow Depth (SD)

- Temperature
- Liquid water content

- Snow density
- Albedo
- Grain size

- Snow Extent (SE)

Model	Affiliation
2LM	Tohoku University and IORGC/JAMSTEC, Japan
ACA	University of California Davis, USA
CLASS	Environment Canada, Canada
CLM2-TOP	University of Texas at Austin, USA
CLM3	Colorado State University, USA
COLA-SSiB	Center for Ocean-Land-Atmosphere (COLA), USA
CoupModel	Royal Institute of Technology KTH, Sweden
CRHM	University of Saskatchewan, Canada
ESCIMO	University of Munich, Germany
ISBA-D95	Météo-France, France
ISBA-ES	Météo-France, France
JULES	University of Durham, UK
MAPS	NOAA/ESRL/GSD, USA
MATSIRO	JAMSTEC/FRCGC, Japan
MOSES	University of Wales Aberystwyth, UK
NOH	NOAA/NWS/OHD & NCEP, USA

Model	Affiliation
RCA-LSS	Swedish Meteorological and Hydrological Institute (SMHI), Sweden
S17	NOAA/NWS/OHD, USA
SAST	National Climate Center, Beijng, China
SiB 2.5	Colorado State University, USA
SiB 3.0	Colorado State University, USA
SiBUC	Kyoto University, Japan
SNOWCAN	University of Reading, UK
SNOWPACK	Swiss Federal Institute for Snow and Avalanche Research, Switzerland
SPONSOR	Russian Academy of Sciences, Russia
SRGM	Water Problem Institute of Russian Academy of Sciences, Russia
SSiB3	UCLA, USA
SWAP	Russian Academy of Sciences
TESSEL	ECMWF and Instituto de Meteorologia, Portugal
UEBMOD	Bridgewater State College, MA, USA
Updated UEB	USDA, USA
VEG3D	Karlsruhe Research Centre, Germany
VIC	University of Washington, USA

Ref: http://xweb.geos.ed.ac.uk/~ressery/SnowMIP2.html

Observations: in situ

- Operational
  SYNOP: snow depth

- Non-operational
  snow courses: snow depth, SWE => snow density

+) reliability

-) low coverage
  no information about gaps in data
  the absence of report about snow depth does not mean that there is actually no snow!
  no plans to develop this type of measurements in future

Observations:
space-born. Raw data

Visible and near-infrared channels – AVHRR, etc.

Resolution: 500 m (highest), no data at night and under cloudy conditions

High reflectivity in 0.54– 0.56 micrometers and high absorption in 1.63 – 1.65 micrometers.

Microvawe radiometry– SSM/I, AMSR-E

Resolution: (after preliminary processing) gridded - 0.25 degree, data present at night time and do not depend of cloudiness

Satellites

Geostationary: GOES, Meteosat

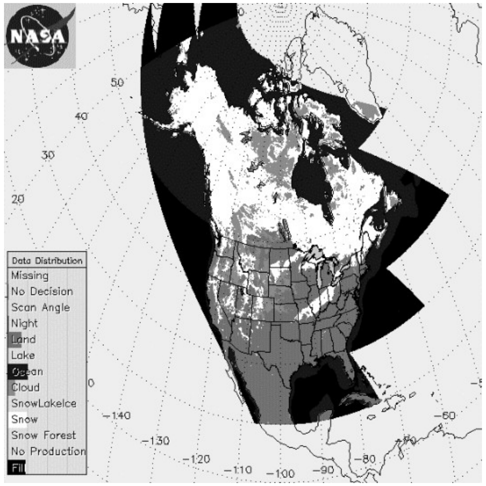
Polar-orbiting satellites: POES, Aqua, Terra

+) high coverage
high resolution
methods are developing intensively!

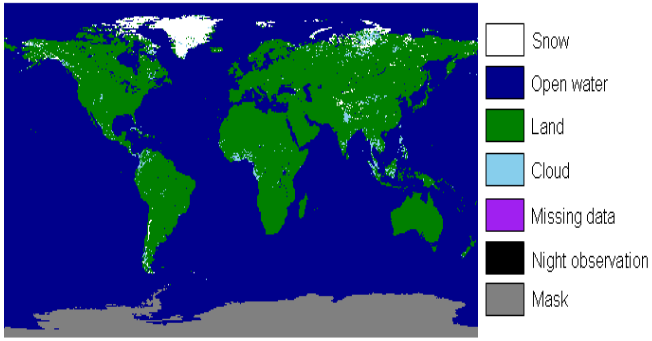
-) reliability is lower in comparison with in-situ measurements

Observations:

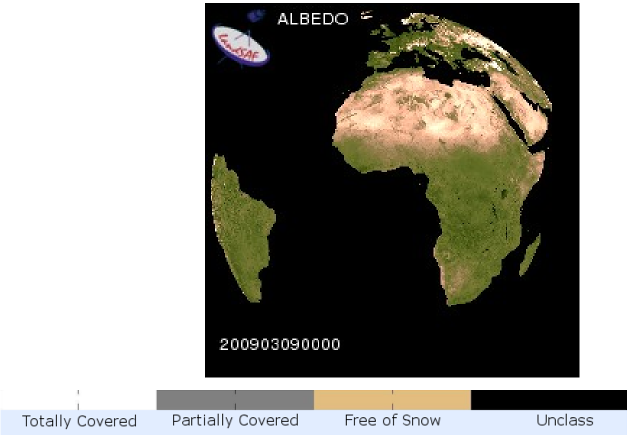
space-born. Main products.



- IMS (NOAA)
  Intractive Multisensor Snow and Ice Mapping System
  uses many types of data, combine data from various sensor sources
  daily snow and ice information
  currently 2 resolutions: 25 km (1024x1024 grid) and 4 km (6144x6144)
  algorithm: subjectively analysis!
  output: SE, each pixel is classified as snow, snow-free land, clouds, water



- MODIS
  (receiving apparatus with fully automatic system)
  Moderate Resolution Imaging Spectroradiometer
  working with signals from Terra and Aqua
  daily observation
  up to 250 m resolution
  snow-mapping algorithm: Hall D., et al 1995
  output: raw data and calculated Normalized Difference Snow Index (NDSI)
  to classify each pixel as snow, snow-free land, clouds, water



- SAF (EUMETSAT)
  Satellite Application Facilities
  uses Meteosat (MSG) and EUMETSAT Polar System
  daily snow cover map
  resolution depends on region (from 1 up to 7 km)
  algorithm based on cloud-mask: Derrien, M. et al, 2005
  output: snow presence product, which classifies every land pixel as snow covered,
  partially covered or snow free if the clouds conditions allow the classification

Ref:

- Hall D. and G. Riggs, 1995 Accuracy assessement of the MODIS snow-cover products. Hydrological processess, 21 (14), 1534-1547
- http://modis.gsfc.nasa.gov/about/specifications.php
- Derrien M., and H. LeGléau, 2005: MSG/SEVERI cloud mask and type from SAFNWC. International Journal of Remote Sensing, 26 (21), 4707-4732.

Snow analysis algorithms

- Successive corrections
- Optimum Interpolation
- Kalman Fiter – in hydrology

Quality control:

• Inhomogenious field =>use ancillary information: precipitation, screen level temperature

• Observations are more often give larger values (not smaller) than analysis (Brasnett B., 1999)

Ref:
•Slater A. G. and M. P. Clark, 2006: Snow Data Assimilation via an Ensemble Kalman Filter. *J. Hydrol*., Vol. 7, 478-493
•Brasnett B., 1999: A Global Analysis of Snow Depth for Numerical Weather Prediction. J. Appl. Meteorol., 38, 726-740.

SA in different systems:
IFS (ECMWF)

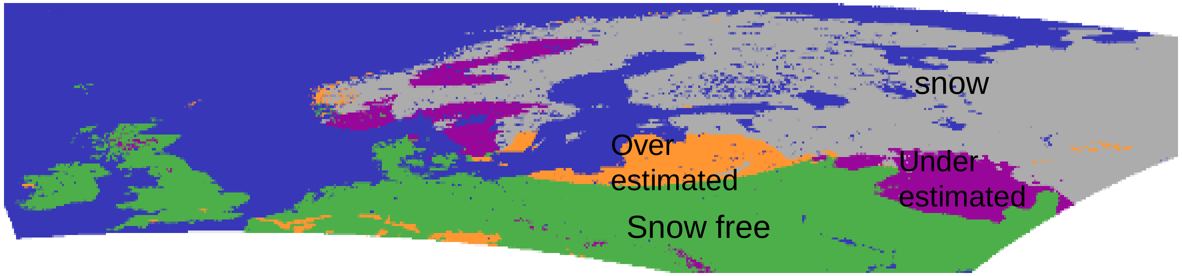
- obs – SYNOP
- F.g. field: 6-hour forecast
- Main prognostic variable: SWE
- Assimilation algorithm: successive corrections
- IMS products used to correct snow boundary
  no snow in f.g., but snow in IMS: SD=10cm
  pseudo-observations of 0 cm of SD

Ref:

- Drusch M., D. Vasilevic, and P. Viterbo, 2004: ECMWF's Global Analysis: Assessment and Revision Based on Satellite Observations. *J. Appl. Meteorol.,* Vol. 43, 1282-1294
- Hyvärinen O., K. Eerola, N. Siljamo and J. Koskinen, 2009: Comparison of snow cover from satellite and numerical weather predicition models in Northerm Hemisphere and northern Europe. Journal of Applied Meteorology and Climatology, in print

In different systems:

HIRLAM



- obs – SYNOP
- F.g. field: 6-hour forecast
- Prognostic variable: SWE (SD)
- Assimilation algorithm: OI
- No space-born products are used at the moment

Ref:

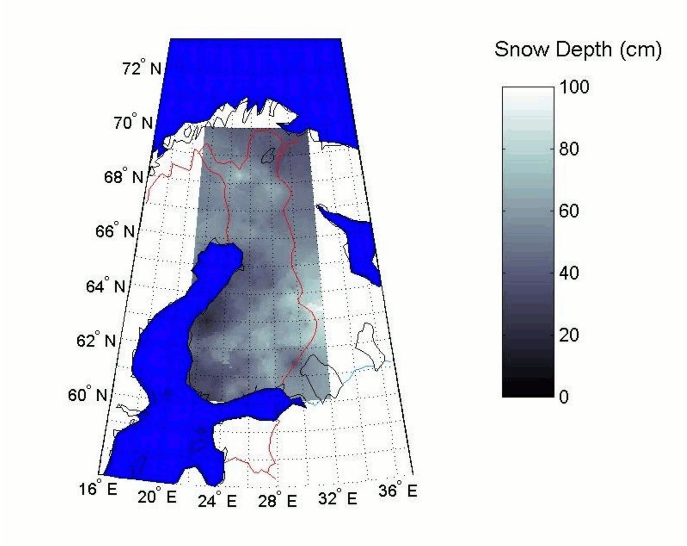
- Cansado A. and B. Navacués, 2004: Optimum interpolation analysis method for snow depth. *Hirlam Newletters,* N45, 58-64.
- Hyvärinen O., K. Eerola, N. Siljamo and J. Koskinen, 2009: Comparison of snow cover from satellite and numerical weather predicition models in Northerm Hemisphere and northern Europe. *Journal of Applied Meteorology and Climatology*, in print

In different systems:
COSMO

- obs – SYNOP
- F.g. field: snow analysis form IFS and DWD
- Prognostic variable: SWE (SD)
- Assimilation algorithm: Cressmann analysis
- Snow Mapping Using Multi-Temporal METEOSAT-8 Data

Ref: **Philippe A.J. Steiner1 , Francis Schubiger1, 2007, Numerical Weather Prediction at MeteoSwiss,**

Plans, projects:



- GlobSnow
  start at 2009
  funding by European Space Agency (ESA)
  coordination by FMI
- Planned products:
  SE, SWE
- SWE:
  method: the inversion of brightness temperatures in different channels from semi-empirical snow emission model (Helsinki University of Technology, HUT) (Pulliainen J., 2006)
- SYNOP observations will be used for calibration the HUT model.
- The intended spatial resolution for SWE: 10 km
- http://snow.fmi.fi

Ref:

- Pulliainen J., 2006: Mapping of snow water equivalent and snow depth in boreal and sub-arctic zones by assimilating space-born microwave radiometer data and ground-based obsrvations. Remote Sensing of Environment, 101 (2006), 257-269.

Plans and possible problems:

- Plans: to assimilate SWE products into HIRLAM

  But:

- Methods applicable for dry snow only
- Double-counting of SYNOP observations

- Probably others …?

Thank you for attention!