# Long data series – climate related data for global change trend analysis


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# Outline of this talk

- Snow patch analysis in the Swedish sub-arctic
- Changes of glacier front in Svalbard/Spitsbergen
- Fog dynamics in Namibia
- Rainy season dynamics 2010/2011 in Namibia

# 40 years of satellite based late summer snow patch distribution in the Abisko mountains/N-Sweden


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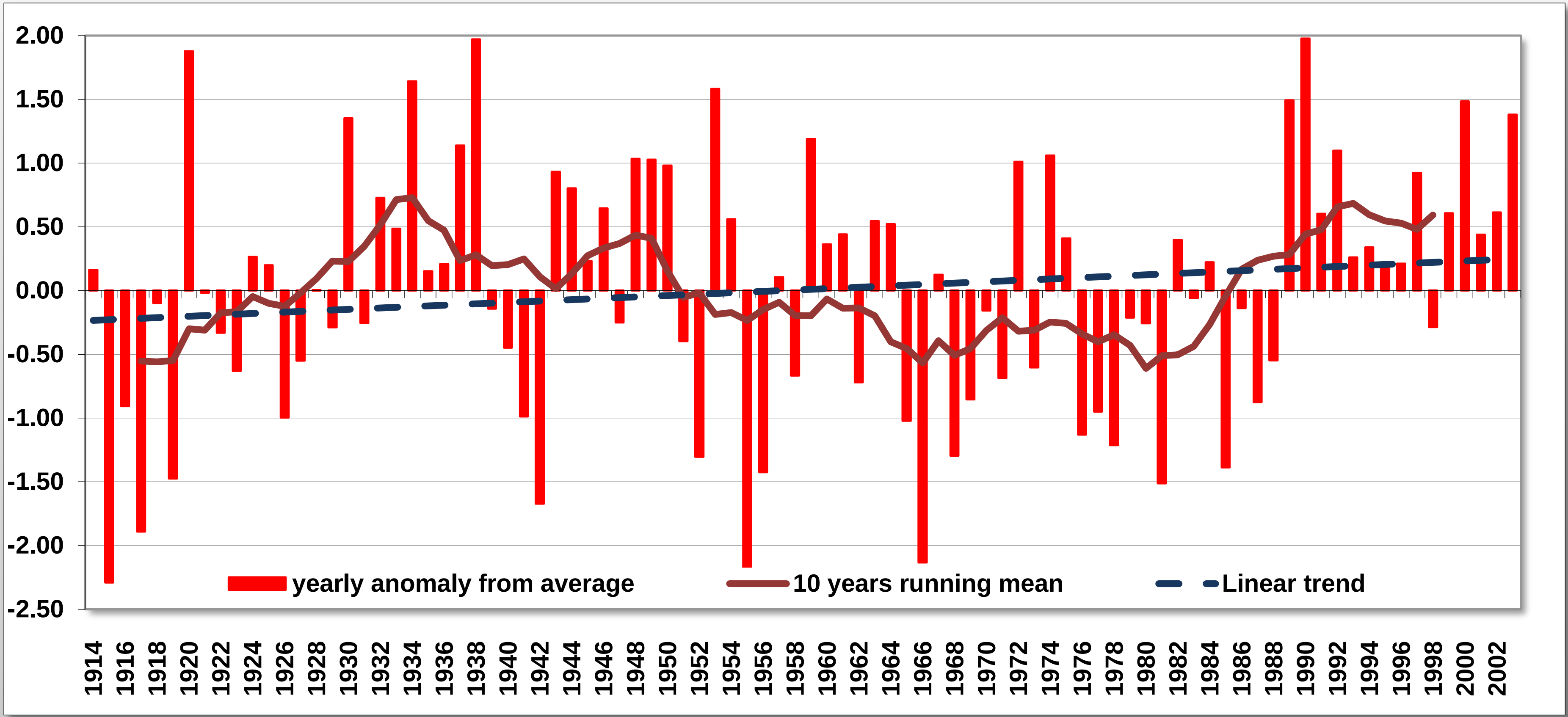
# Late summer snow patches as indicator for climate trends ?

## Why snow patches as a research target ?

- GCMs predict a rapid warming in polar/subpolar latitudes until 2100.
- In contrast to glaciers snow patches are responding very rapidly from year to year on weather and climate conditions.
- Influence of annual changes of  temperature and precipitation, especially winter precipitation, has to be considered.
- Validation with measurements of temperature, precipitation and snow cover/depth from Abisko Research Station (data since 1913 available !!).
- Landsat, Spot, Aster, IRS, Sentinel and other satellite sensors covering the years 1973 – 2014/16 are unique as data source for climate change studies
- High spectral contrasts of snow compared to clouds and all other land surface types in satellite imagery in different spectral bands
- Can be classified even in shadow areas of mountains or clouds
- Pixel resolution compatible with snow patch size
- Spatial analysis over large and remote areas possible.
- Spatially distributed information covering all terrain influences.
- High repetition cycle in sub-polar regions due to orbit side overlap of 65-70%

# Annual temperature deviations from mean value (-0.59°C)

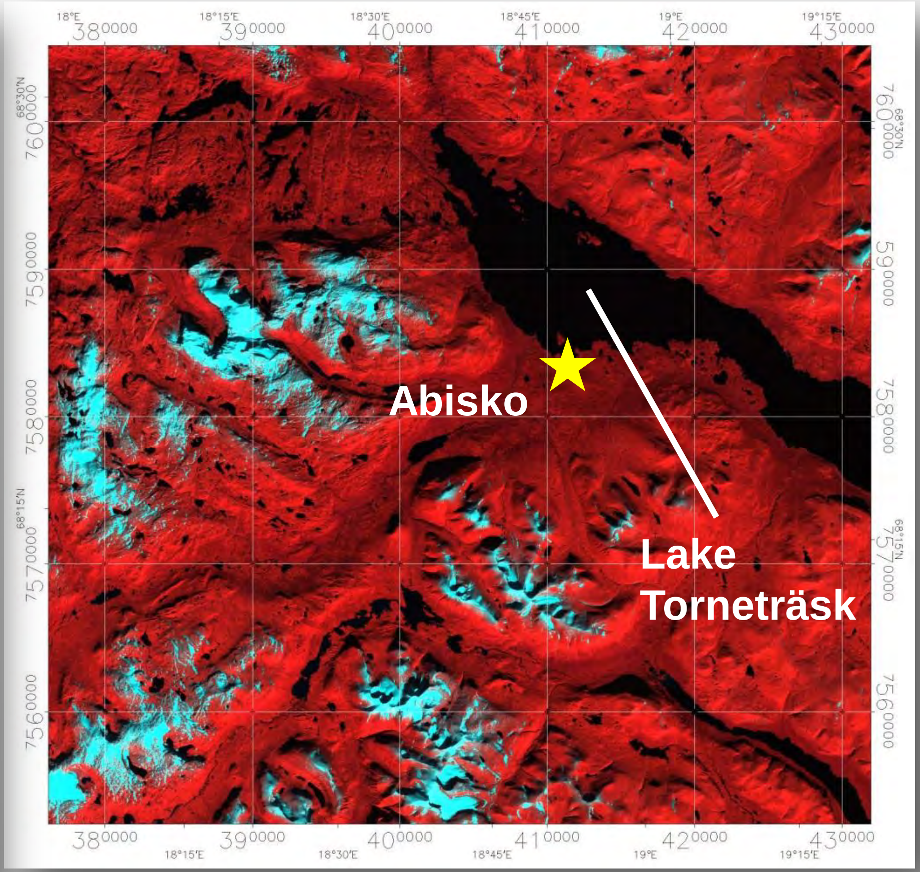
## Data Abisko ANS 1913 – 2003




Also at this high latitude there is a significant temperature increase but long station measurements are rare at this part of the world.

Abisko: World's longest temperature record in the Arctic (since 1913)

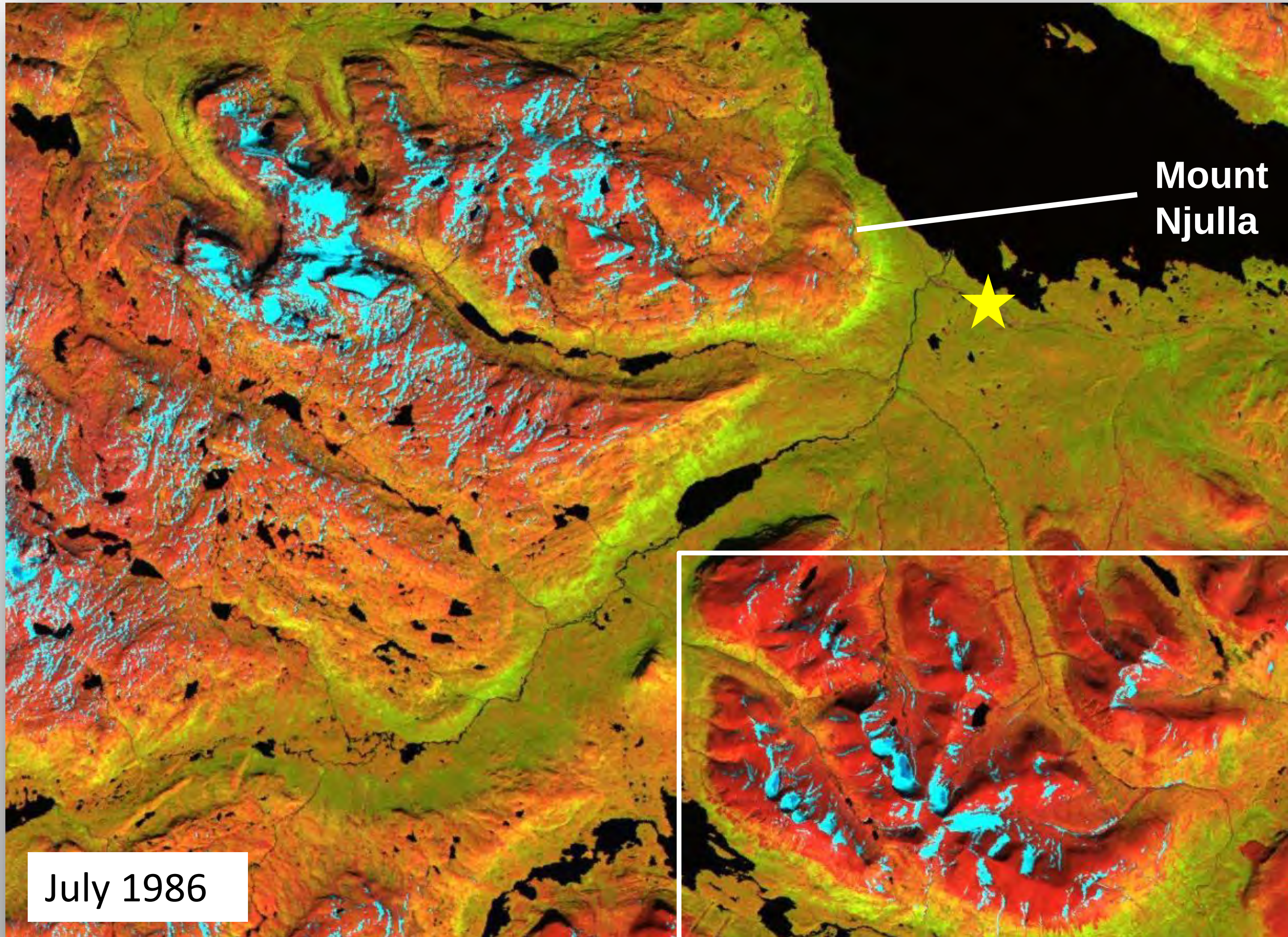
# Study area Abisko (N-Sweden)


68.5° N / 19° E

340 – 2200 m NN

# … some years ago I was smoking my pipe at Abisko Research Station looking to Mount Njulla ….



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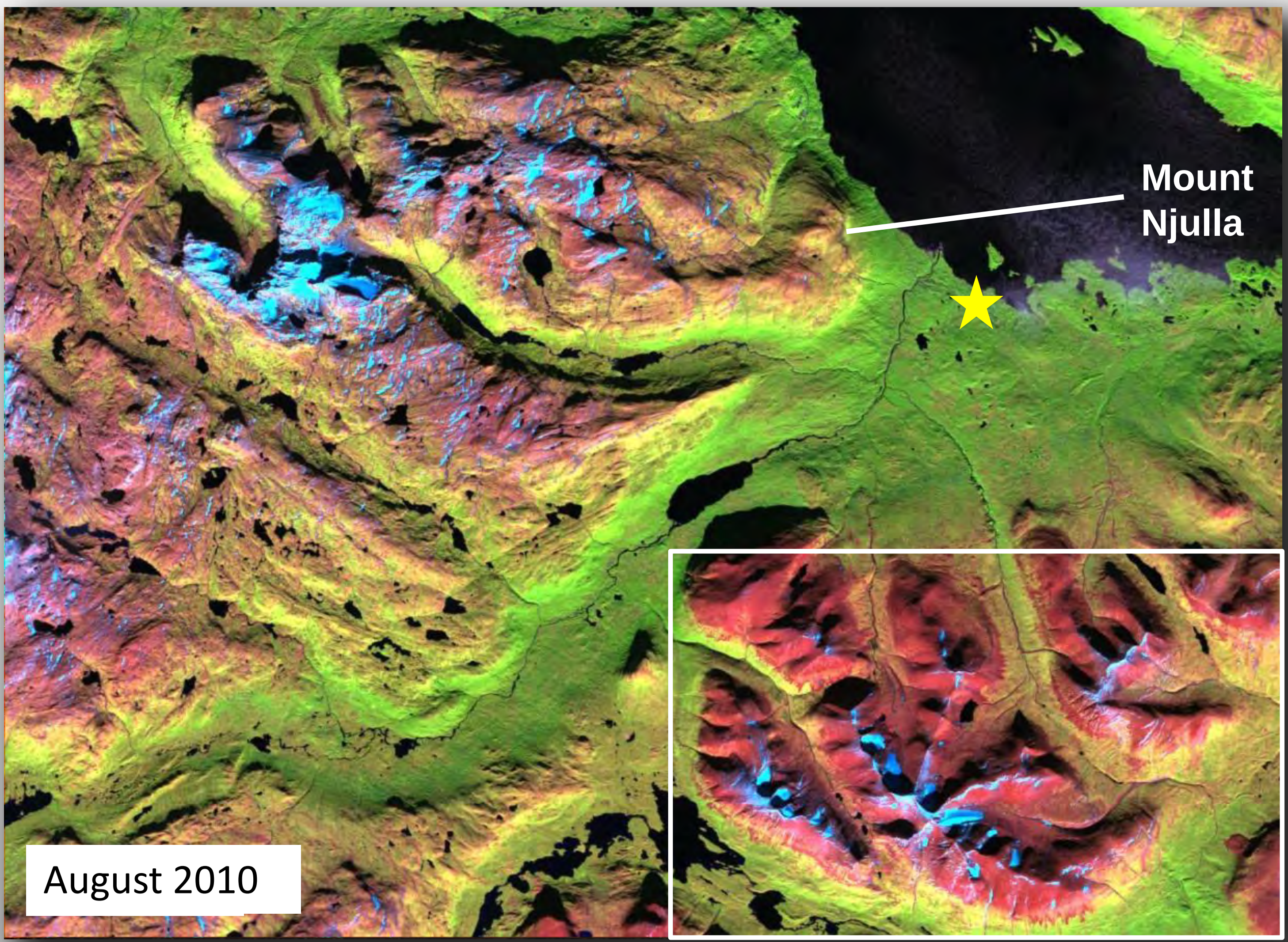
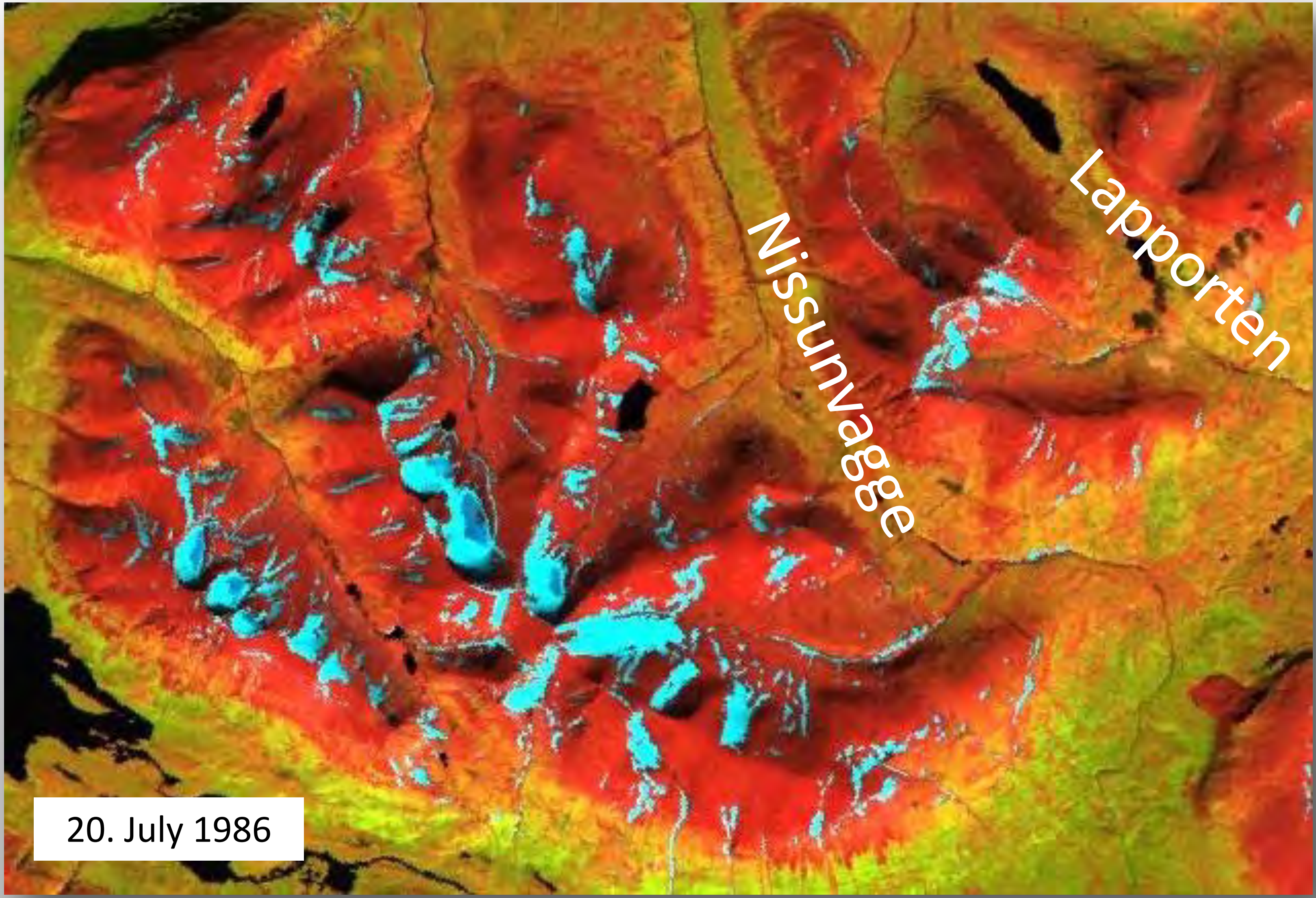
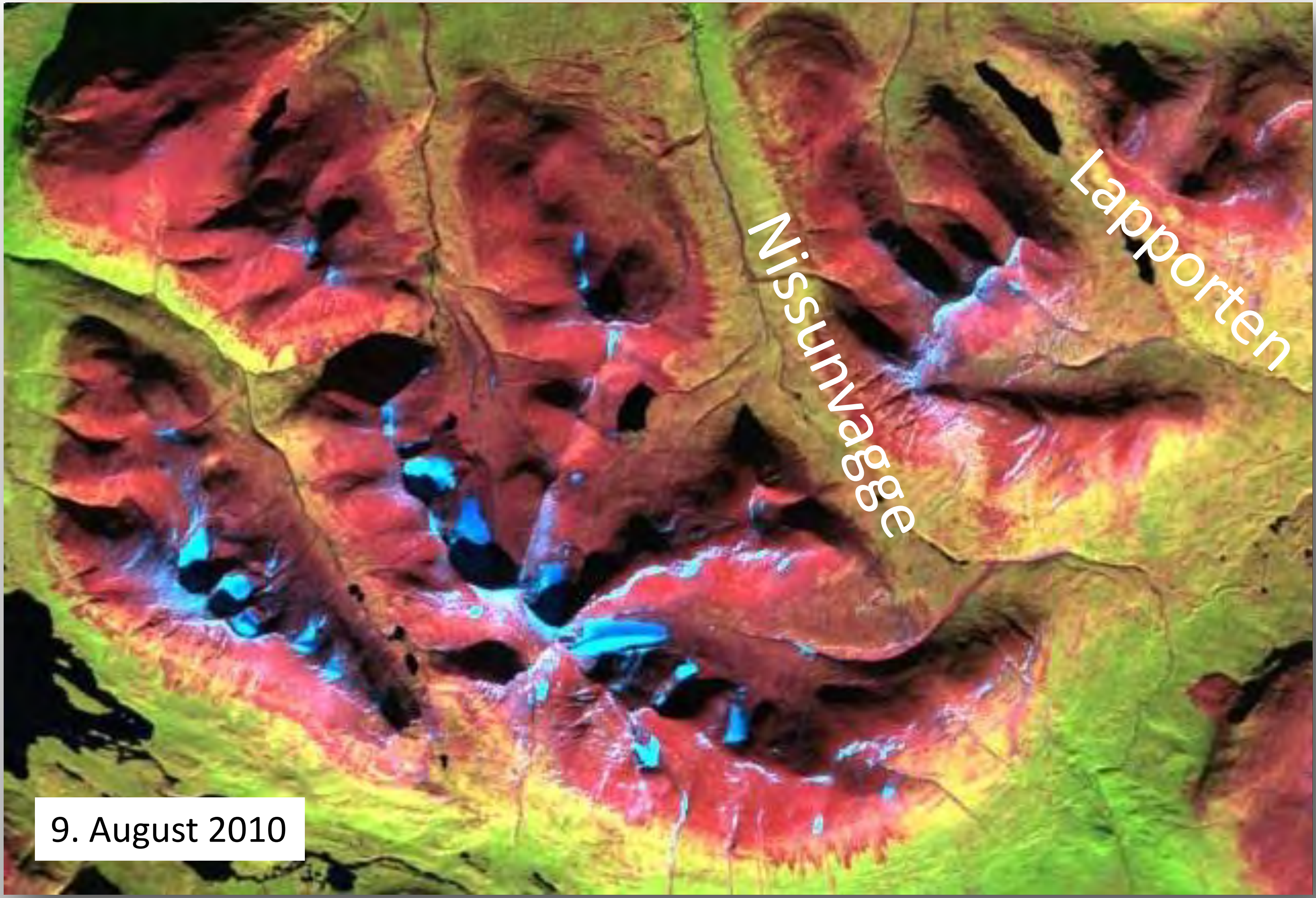


# Changes of snow patches and glaciers



# Changes of snow patches and glaciers



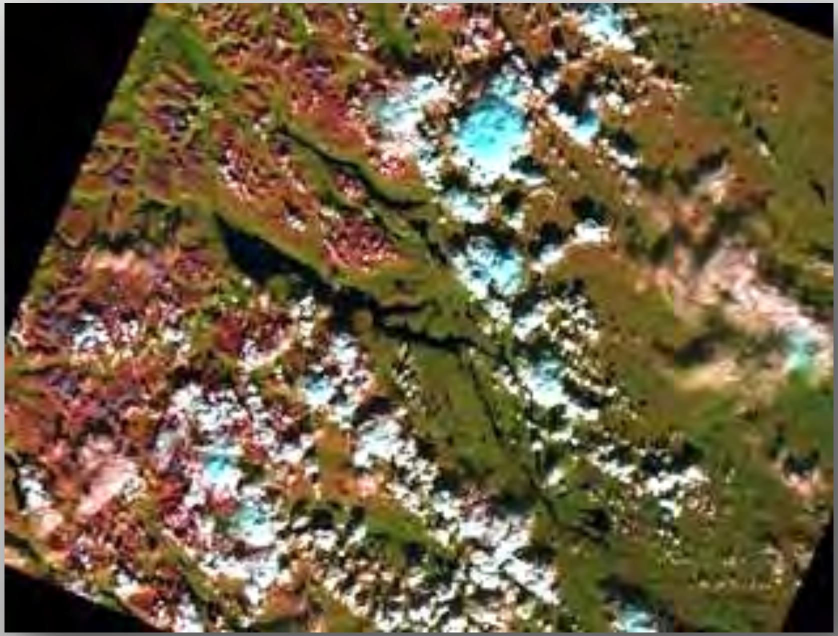
# Satellite data from Landsat, Aster and IRS

## Selection criteria

– Summer months (July, especially August and early September)
– If possible cloud free scenes
– 3 Landsat orbits cover study area :
  196/12; 197/12; 198/12, enables high repetition rate due to side overlap of orbits

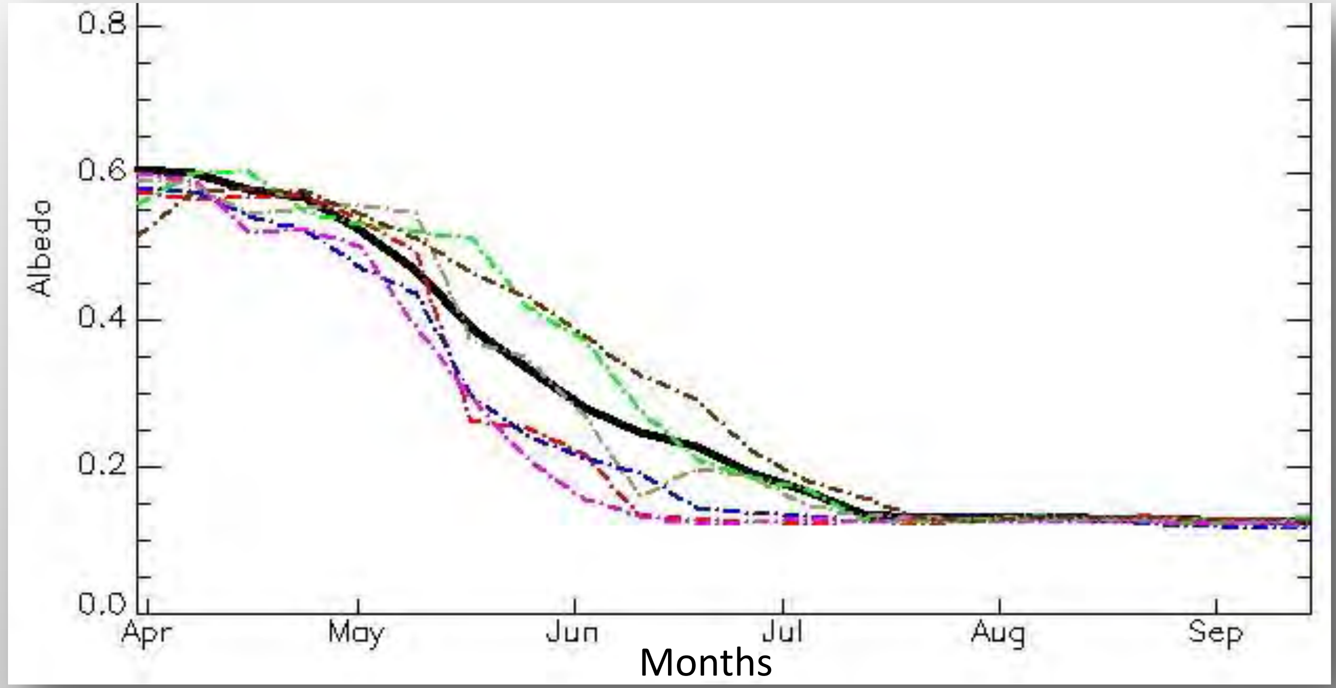
27.07.2006 cloud cover: 0%

28.08.2006 cloud cover: 10%



# Mean annual course of albedo in study area

(MODIS albedo product (MCD43A3) : 2010 - 2015)




Since data are from different periods of the snow season a correction coefficient for the mean annual snow melt period has to be considered for final analysis. Albedo values show that at the second half of July there is no significant albedo change ! That means that snow melt period has ended and snow patches remain quite stable until next winter (Source : Joel Franceschi (BSc-thesis 2016/Uni Basel)

# 41 years of satellite data from 1973 – 2014

19730708_L1_p213r012
19810518_L2_p213r012
19810519_L2_p214r012
19840603_L5_p197r012
19840626_L5_p198r012
19840626_L5-MSS_p198r012
19841002_L5-MSS_p196r012
19850724_L5-MSS_p197r012
19850816_L5_p198r012
19860625_L5_p196r012
19860704_L5_p196r012
19860720_L5_p196r012
19860720_L5_p196r012
19860828_L5_p197r012
19860913_L5_p197r012
19870409_L5_p197r012
19870714_L5_p197r012
19870815_L5_p197r012
19880707_L5_p198r012
19890710_L5_p198r012
19890901_IRS
19891007_L5_p197r012
19900715_L5_p196r012
19900924_L5_p197r012
19920602_L5_p196r012
19920602_L5_p196r013
19920609_L5_p197r012
19920718_L5_p198r012
19920809_L5_p197r012
19940818_L5_p197r012
19940903_L5_p197r012
19950526_L5_p196r012
19960823_L5_p197r012
19970830_SPOT
19980829_L5_p197r012
19980930_L5_p197r012
19990630_L7_p196r012
19990714_L7_p198r012
19990815_L7_p198r012
19990918_L7_p196r012
20000823_SPOT
20000927_L7_p197r012
20010820_Aster
20010820_L7_p198r012
20010911_Aster
20020120_Aster
20020528_Aster
20020604_L7_p198r012
20020825_L7_p196r012
20020908_L7_p198r012
20030524_L7_p196r012
20030618_Aster
20030810_L7_p198r012
20040410_Aster
20040729_L7_p196r012
20041001_L7_p196r012
20050410_L5_p197r012
20050612_L7_p198r012
20050630_L7_p196r012
20050706_L5_p198r012
20060507_L7_p197r012
20060702_L5_p197r012
20060720_L5_p196r012
20060727_L5_p196r012
20060804_L7_p196r012
20060810_L5_p198r012
20060812_L5_p196r012
20060819_L5_p197r012
20060820_L7_p196r012
20060826_L5_p198r012
20060827_L7_p197r012
20060828_L5_p196r012
20060927_L5_p198r012
20070518_L5_p197r012
20070603_L5_p197r012
20070604_L7_p196r012
20070705_L5_p197r012
20070813_L5_p198r012
20080708_L7_p196r012
20080910_L7_p196r012
20090624_L5_p197r012
20090703_L5_p196r012
20090726_L5_p197r012
20090804_L5_p196r012
20090826_L7_p198r012
20090904_L7_p197r012
20100611_L5_p197r012
20100907_L7_p197r012
20100908_L5_p196r012
20110614_L5_p197r012
20110918_L5_p197r012
20110919_L7_p196r012
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20120820_L7_p196r012
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20130824_L8_p195r012
20130831_L8_p196r012
20130908_L7_p196r012
20130916_L8_p196r012
20130930_L8_p198r012
20140318_L8_p197r012
20140320_L8_p195r012
20140410_L8_p198r012
20140505_L8_p197r012 tbc

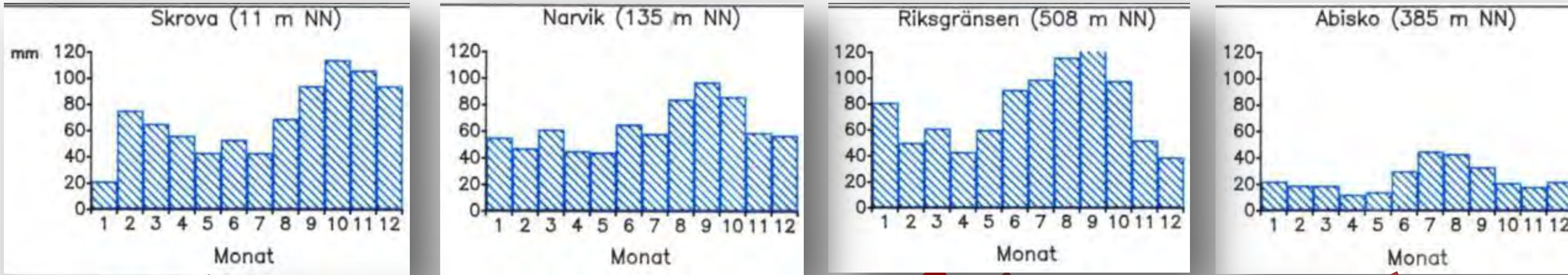
Since the Landsat archives of NASA and ESA are being merged together the number of available and pre-processed scenes has grown rapidly – still going on !!

# One year of snow cover dynamics in Abisko

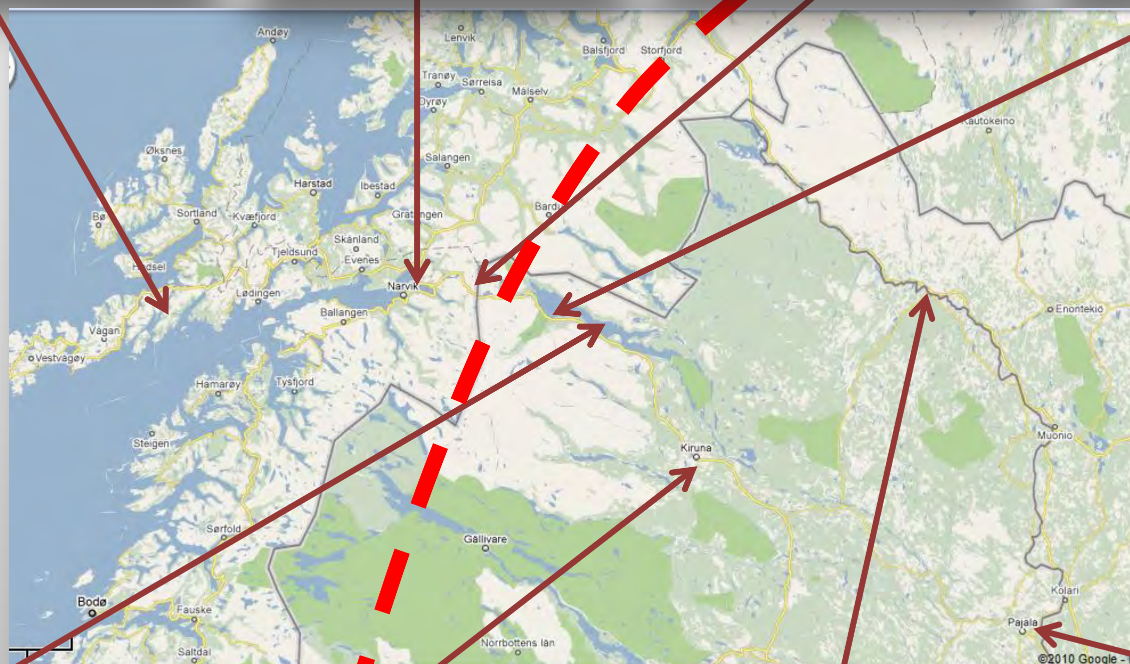
19.1.2004 – 18.3.2005


The various images from different camera apertures and locations are super-imposed very coarsely and therefore show up some artificial geometrical shifts.

# Precipitation gradient Lofot islands – Finn. border

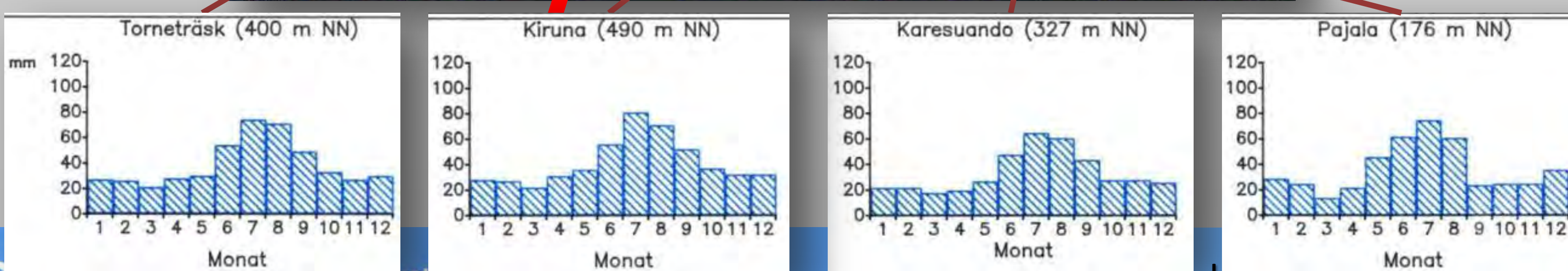


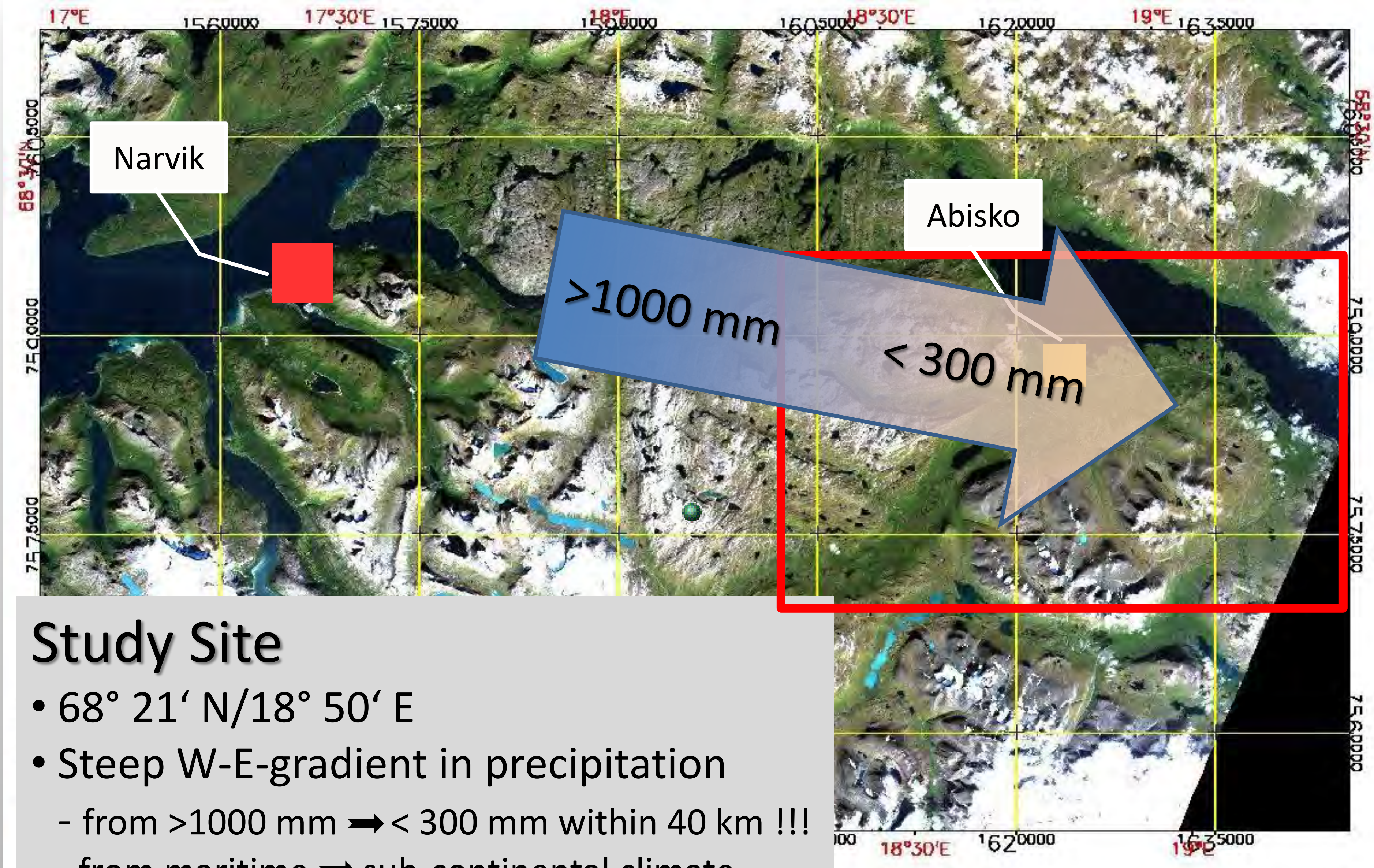

W
Maritime climate with precipitation peak in autumn/winter




E
Sub-continental climate with precipitation peak in summer

Parlow 1988

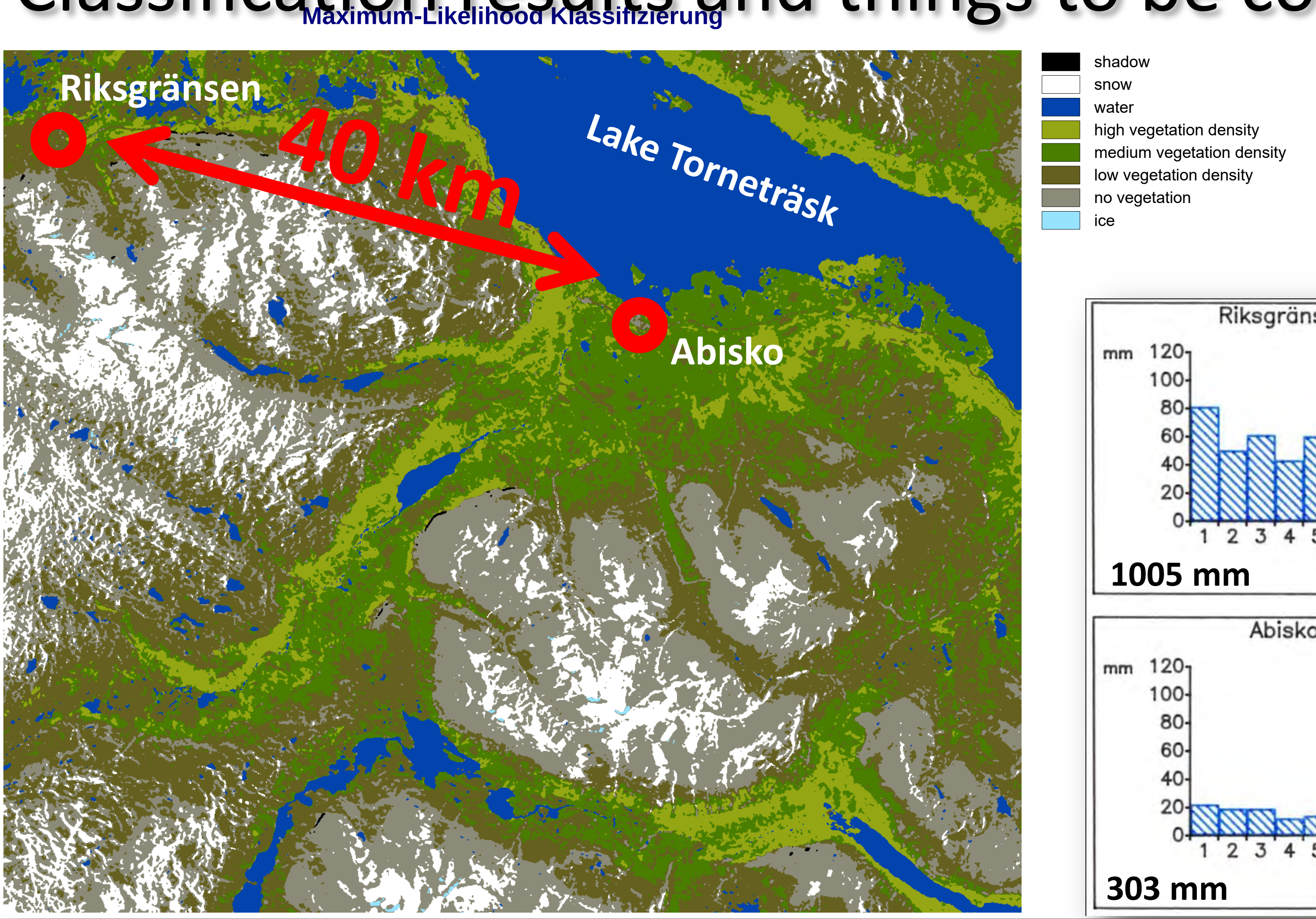


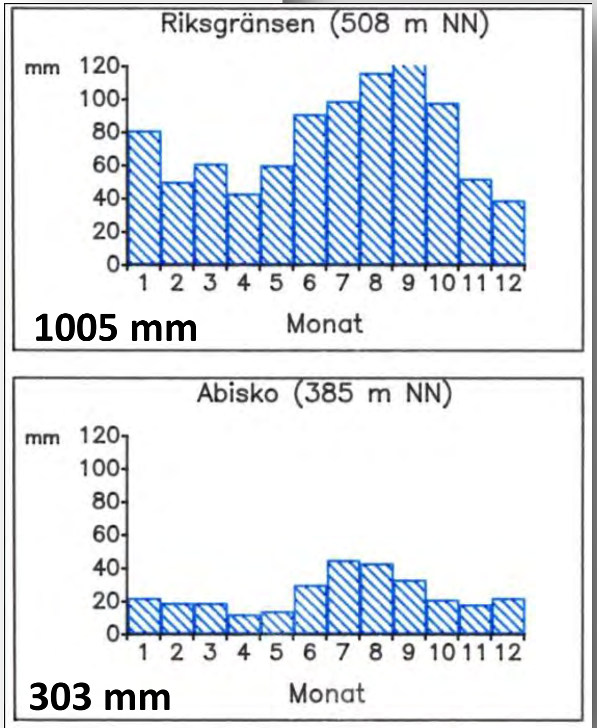



# Study Site

- 68° 21‘ N/18° 50‘ E
- Steep W-E-gradient in precipitation
  - from >1000 mm ➡ < 300 mm within 40 km !!!
  - from maritime ➡ sub-continental climate
  - from fall/winter rain ➡ summer rain type

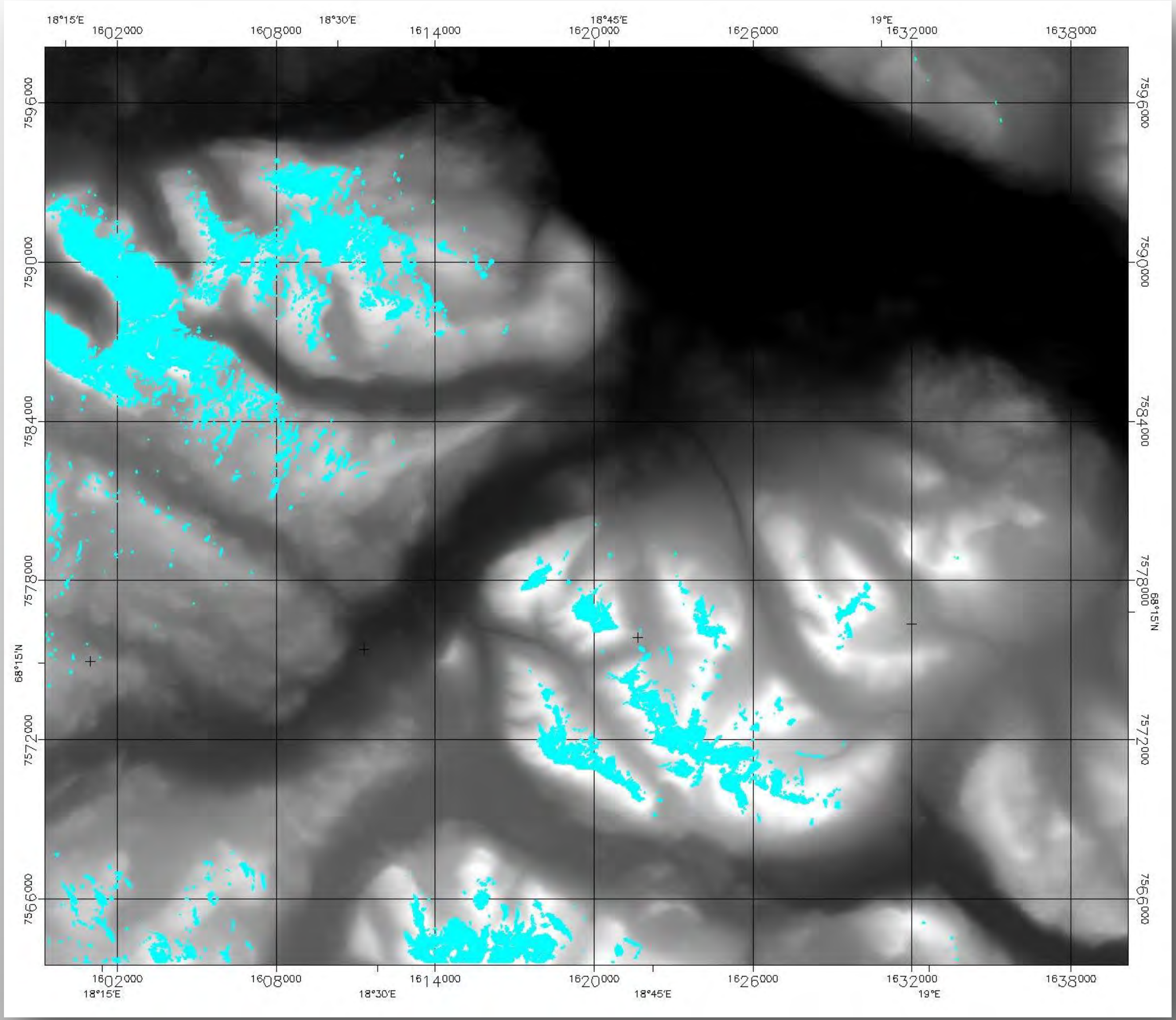
# Classification results and things to be considered

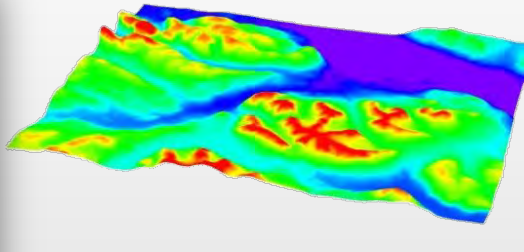


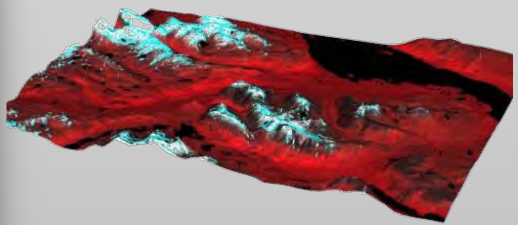

Due to a steep precipitation gradient from W-E (Riksgränsen – Abisko) and different annual precipitation schemes snow precipitation dynamics varies in time and space.

# Binary snow-/ice mask for each scene

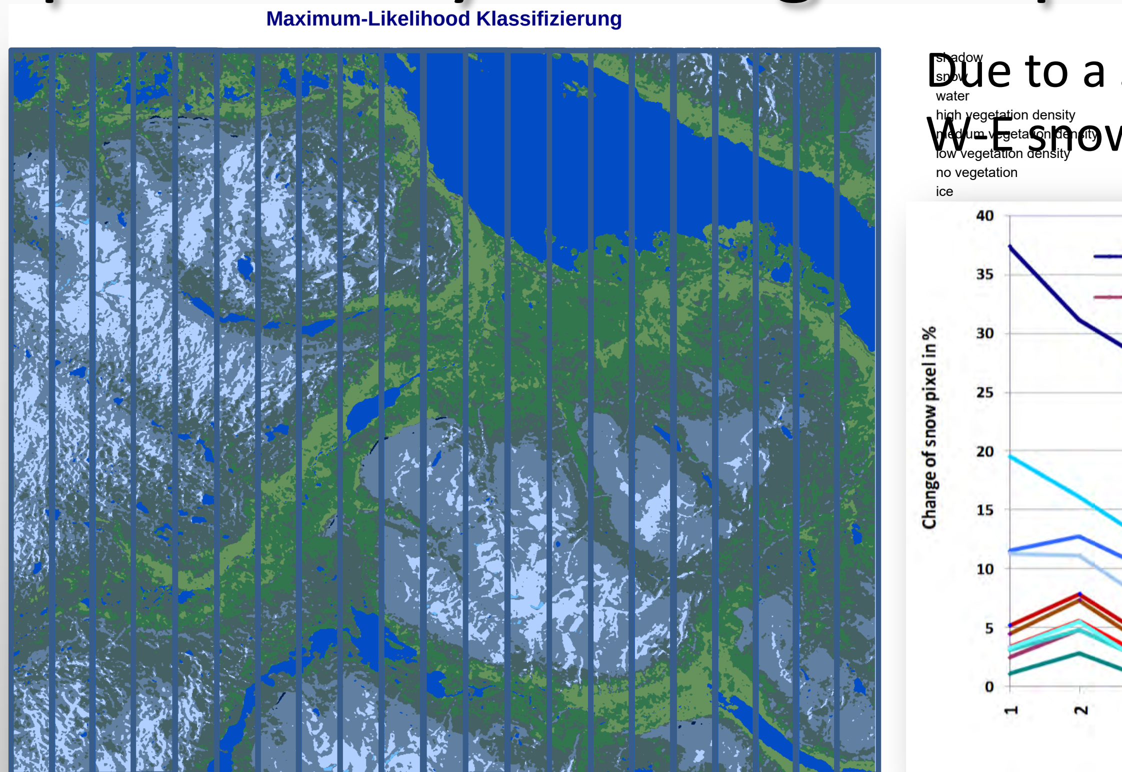


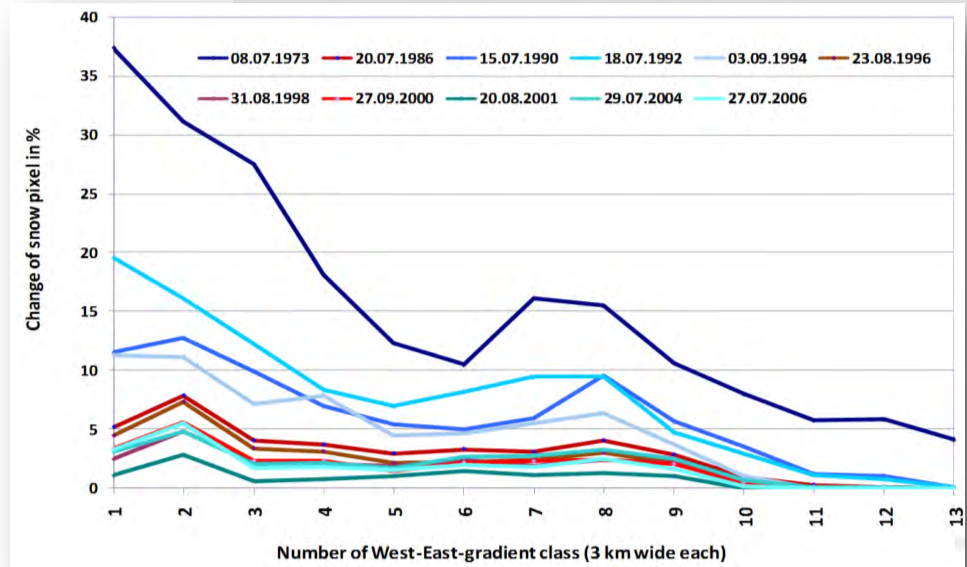
ASTER-DEM enables terrain analysis of snow patch distribution



# Spatial analysis along W-E-precipitation gradient



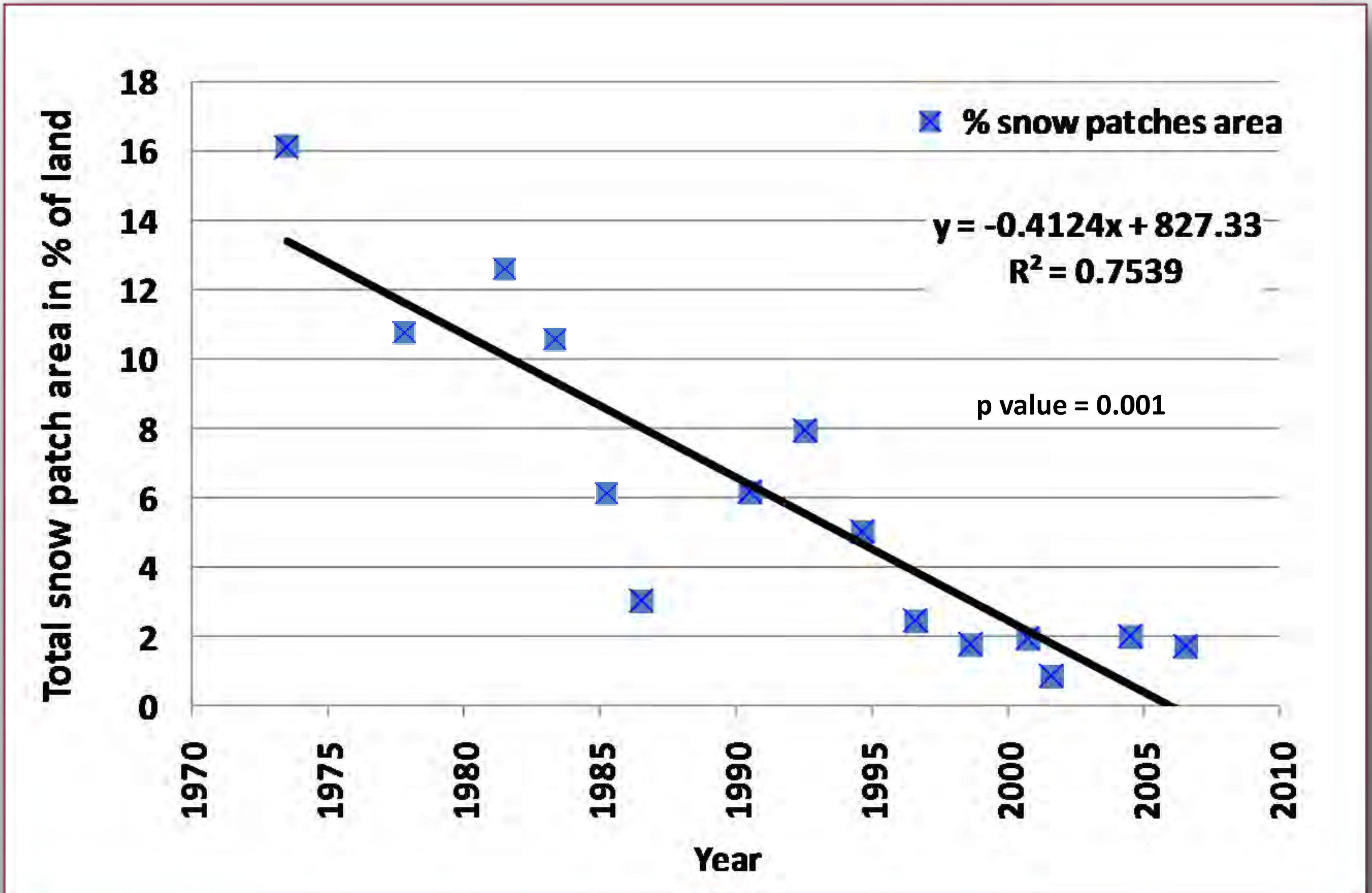

Due to a steep precipitation gradient from W-E snow fall varies in time and space.




A first and trivial approach to consider the W-E- gradient is to create W-E-stripes of equal width and compute statistics. But this is too static and does not include N-S variations and mountains. There is a drastic reduction in snow cover from W-E due to the climatic gradient and over the years a reduction of snow pixels especially in western and central part of the region.

# Total area of late summer snow patches in %

(water surfaces excluded – not all available data included)



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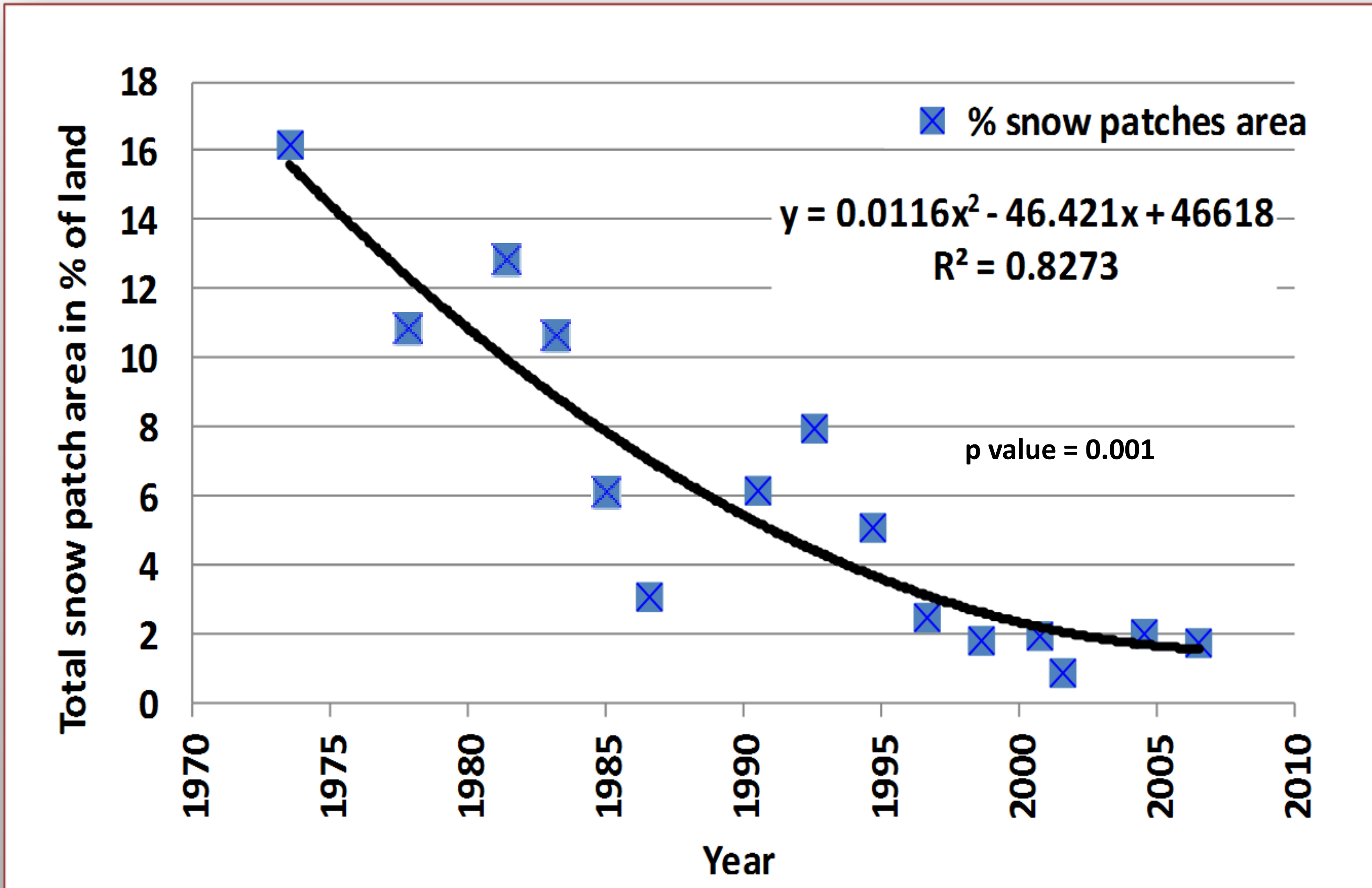
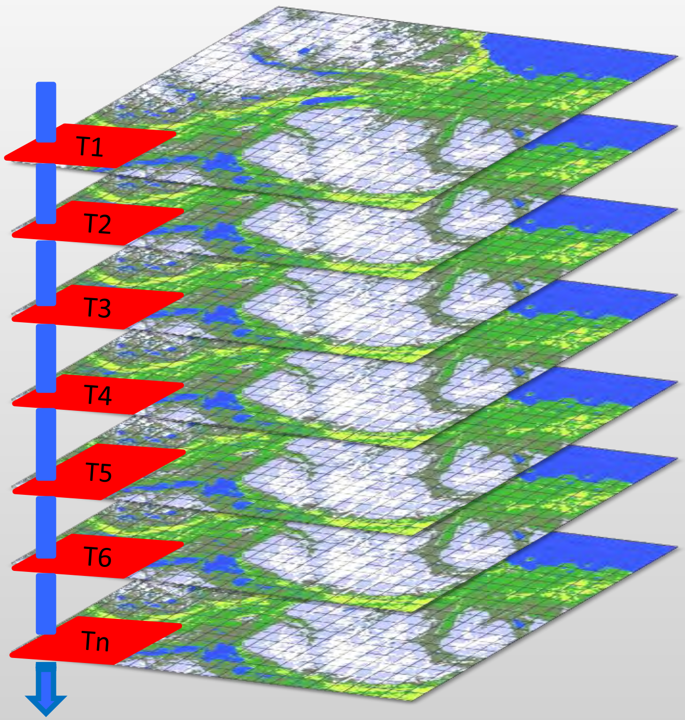
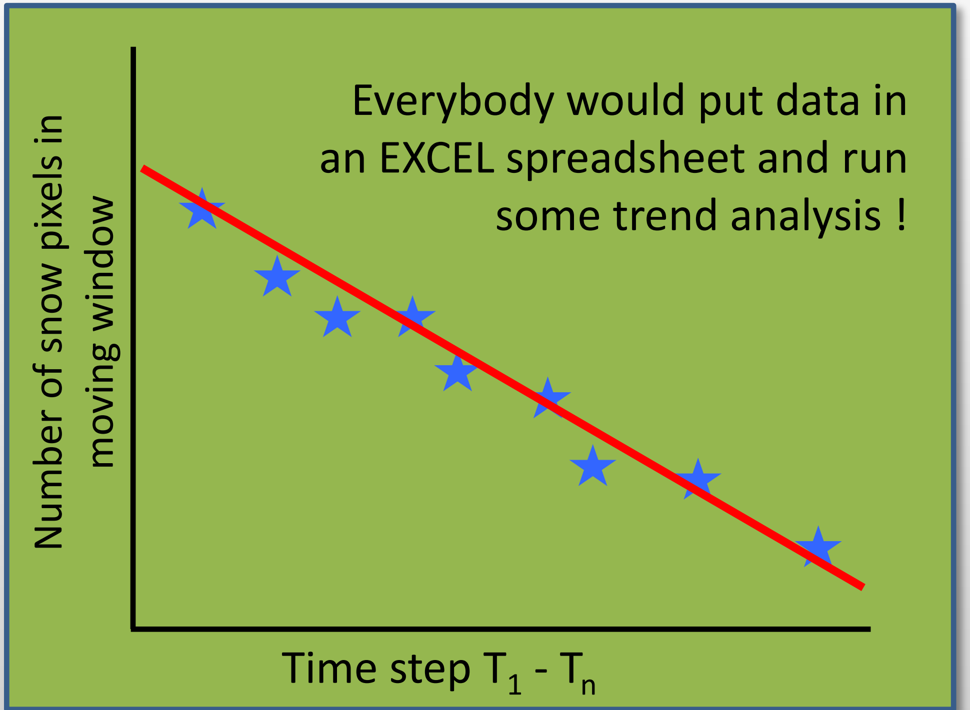


# Spatio-temporal dynamics of snow patch change

## 1973 – 2006/2015




Linear regression in moving window over all time steps $T_1$ – $T_n$ (1973 – 2006/13)

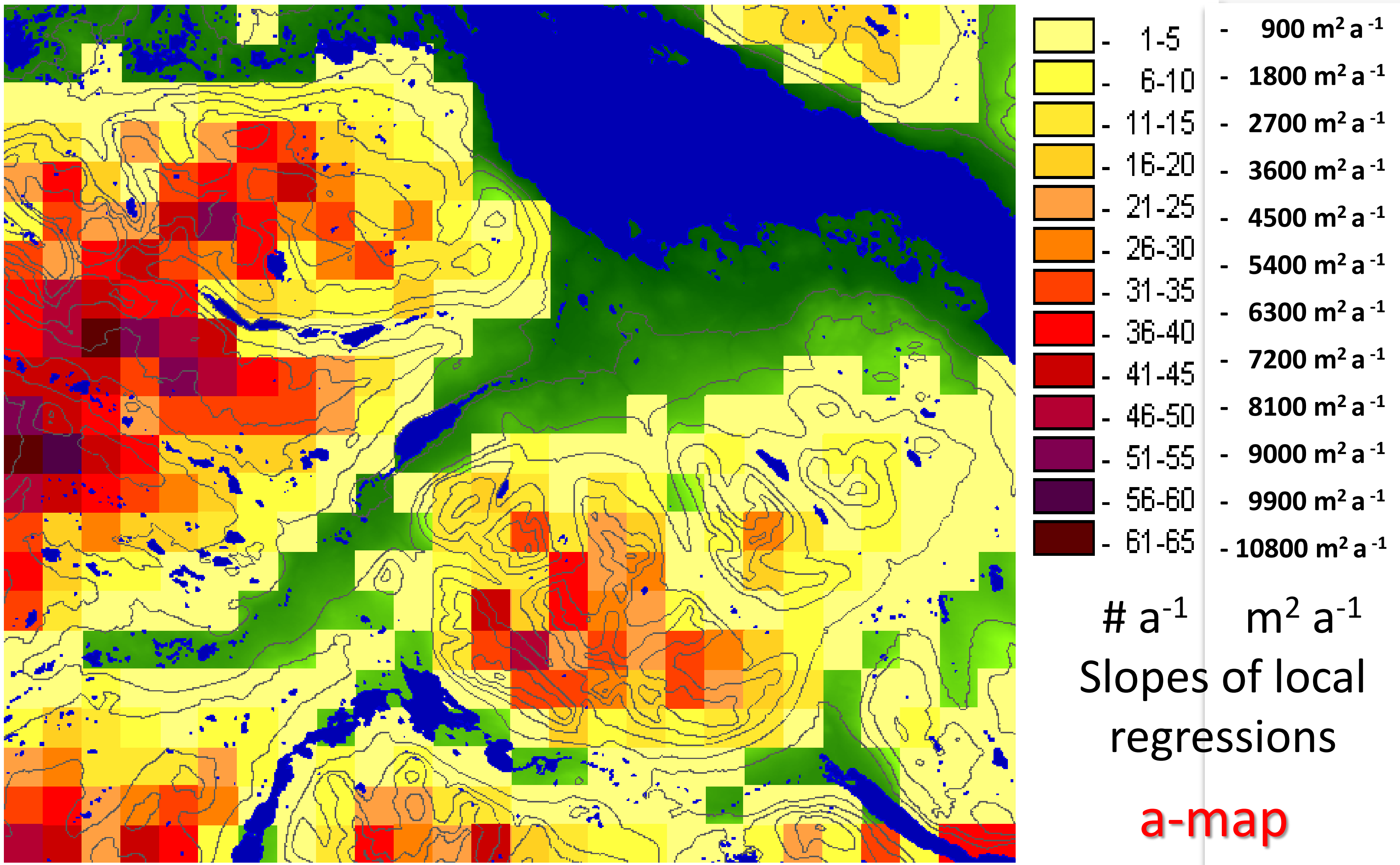
For each window position : $F_{(Ti)} = a\, T_i + c$ (slope) → a-map

and $R^2$ (correl. coeff) → $R^2$-map

A regression of higher order would be better but the trends cannot be displayed in a single map. One would need one map for the quadratic and the linear part each.

# Spatio-temporal dynamics of snow patch change

1973-2006 : Mean decrease of # of snow pixels (size 900 $m^2$) per annum



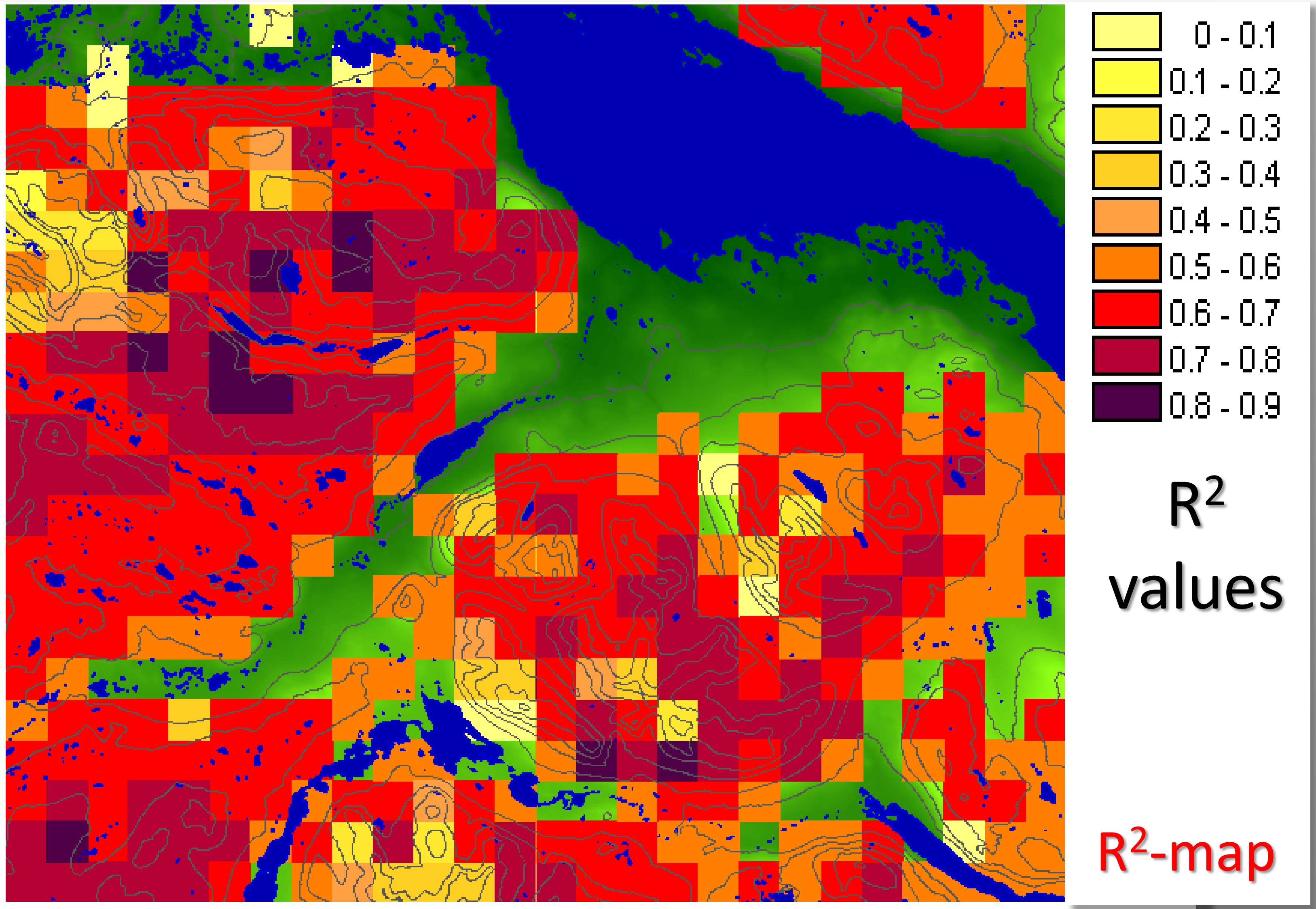

# $a^{-1}$ $m^2 a^{-1}$

Slopes of local regressions

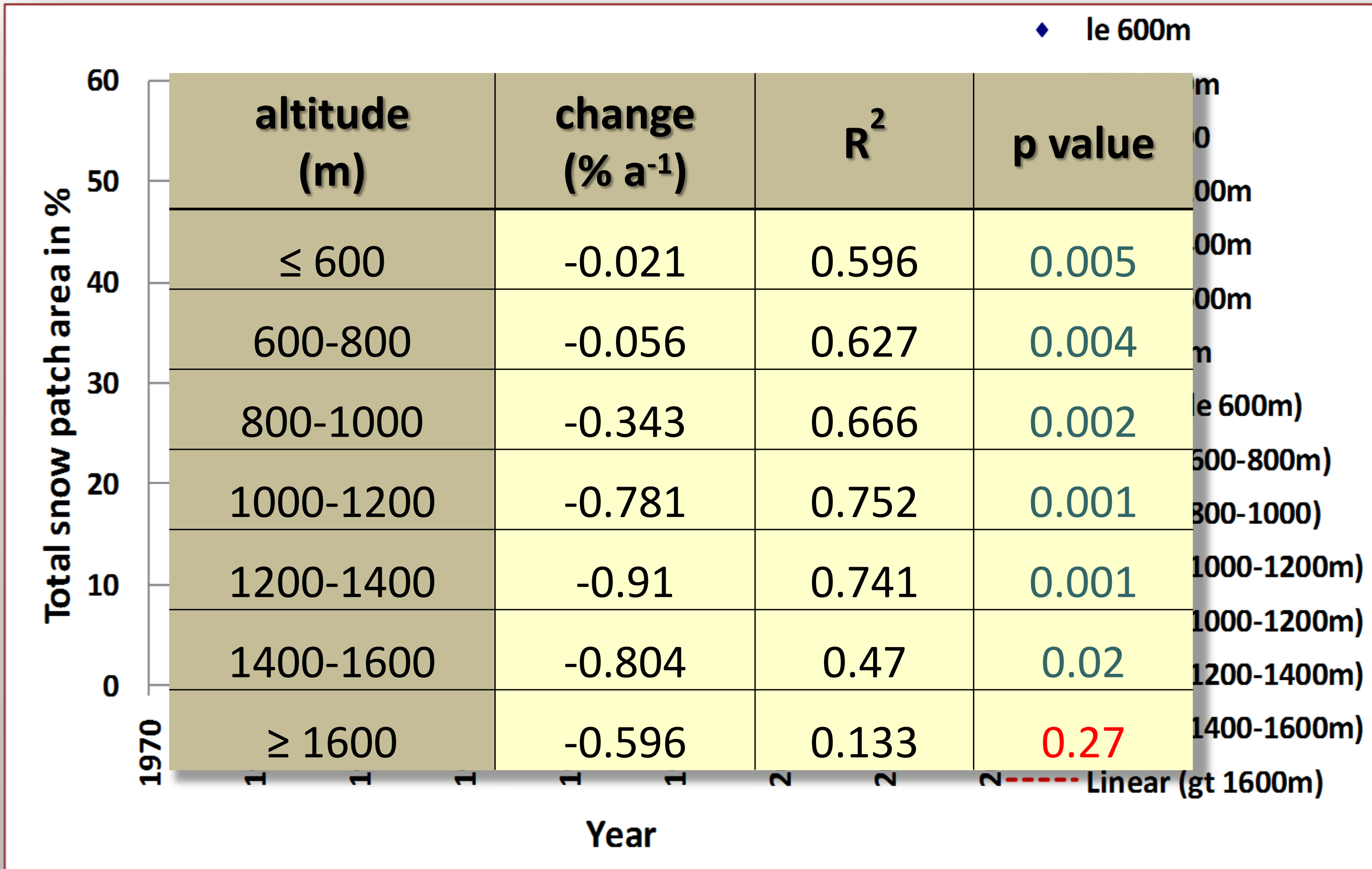
a-map

# Spatio-temporal dynamics of snow patch change

1973-2006 : Spatially distributed $R^2$ values for moving window position



# Total area of snow patches in % as $f_{(altitude)}$

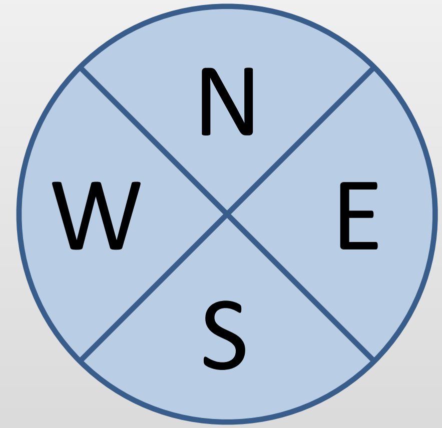



| altitude (m) | change (% $a^{-1}$) | $R^2$ | p value |
|---|---|---|---|
| ≤ 600 | -0.021 | 0.596 | 0.005 |
| 600-800 | -0.056 | 0.627 | 0.004 |
| 800-1000 | -0.343 | 0.666 | 0.002 |
| 1000-1200 | -0.781 | 0.752 | 0.001 |
| 1200-1400 | -0.91 | 0.741 | 0.001 |
| 1400-1600 | -0.804 | 0.47 | 0.02 |
| ≥ 1600 | -0.596 | 0.133 | 0.27 |

In nearly all altitudinal belts a decrease of snow patch area is indicated. The lowest altitudinal belt (≤ 600 m) normally has a few snow patches  and the area ≥ 1600 m has not the amount of pixel needed for proper statistics (less than 0.7 % of all pixels).

# Total area of snow patches in % as $f_{(aspect)}$

| aspect | change (% $a^{-1}$) | $R^2$ | p value |
|---|---|---|---|
| N | -0.354 | 0.74 | 0.001 |
| E | -0.674 | 0.764 | 0.000 |
| S | -0.431 | 0.764 | 0.000 |
| W | -0.191 | 0.583 | 0.006 |




All aspects indicate a significant decrease of snow patch area. Western slopes never had high snow patch coverage due to the special micro-meteorological situation with much solar irradiance in the afternoon, but in the eastern slopes we can demonstrate a severe reduction of snow patch area over the years which can only be explained by climate change effects.

# Intermediate results

- Satellite data archives of long time series (e.g. Landsat series: 40 years) are  a treasure of information for many environmental processes to be monitored in a reasonable spatial resolution .
- Environmental changes due to global warming are mostly slowly developing and not easy to be investigated with satellite imagery.
- In contrast to vegetation or glacier changes snow patch fluctuations are reacting very fast on all weather and climate impacts on an annual scale.
- Moving window linear regression analysis is an interesting tool for analysing spatially distributed landscape processes.
- This local analysis enables to consider the normal spatial variability of the study target and its boundary conditions (e.g. climatic gradients like precipitation).
- The reduction of snow patch area in the Abisko mountains of N-Sweden over the last 4 decades could be well documented.

View from the best sauna of the world at ANS field station
in Kärkevagge (68°23'N/ 18°19'E) at midnight sun
and thanks to Abisko Naturvetenskapliga Station (ANS)
for 30 years of fruitful co-operation
and the provision of data

# Glacier Dynamics in NW-Spitsbergen Using Landsat Time Series Data (1976 – 2014)

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Department of Environmental Sciences
University Basel, Switzerland
* now University Zurich

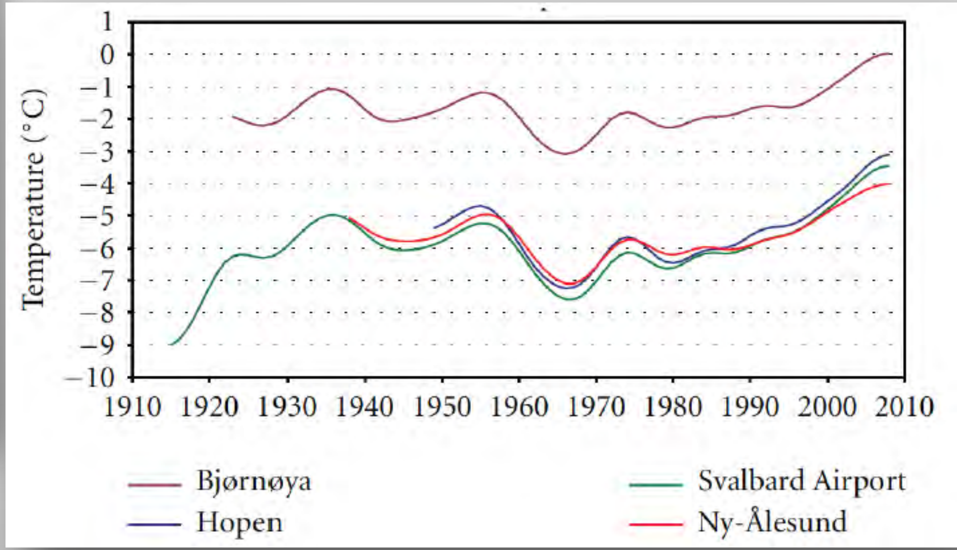
Photography: E. Parlow

# Objectives

- Time series analysis of Landsat-data from 1976 – 2014 of a surge glacier in NW-Svalbard (79.5 ° n.lat.) (Monacobreen)
- Fine tuning of image geometry to guarantee accurate pixel location. In the USGS-data archive there are many scenes with "horrible = wrong" geo-locations
- Gap-filling of SLC-off Landsat-7-data
- Classification of glacier area and changes of annual frontal positions of Monacobreen/Liefdefjord area
- Quantification of length changes of glacier fluctuations (km)
- Quantification of spatial changes of glacier fluctuations (gains and losses in $km^2$)
- Analysis of altitudinal glacier dynamics using DEM
- Mapping of frontal positions in the time domain

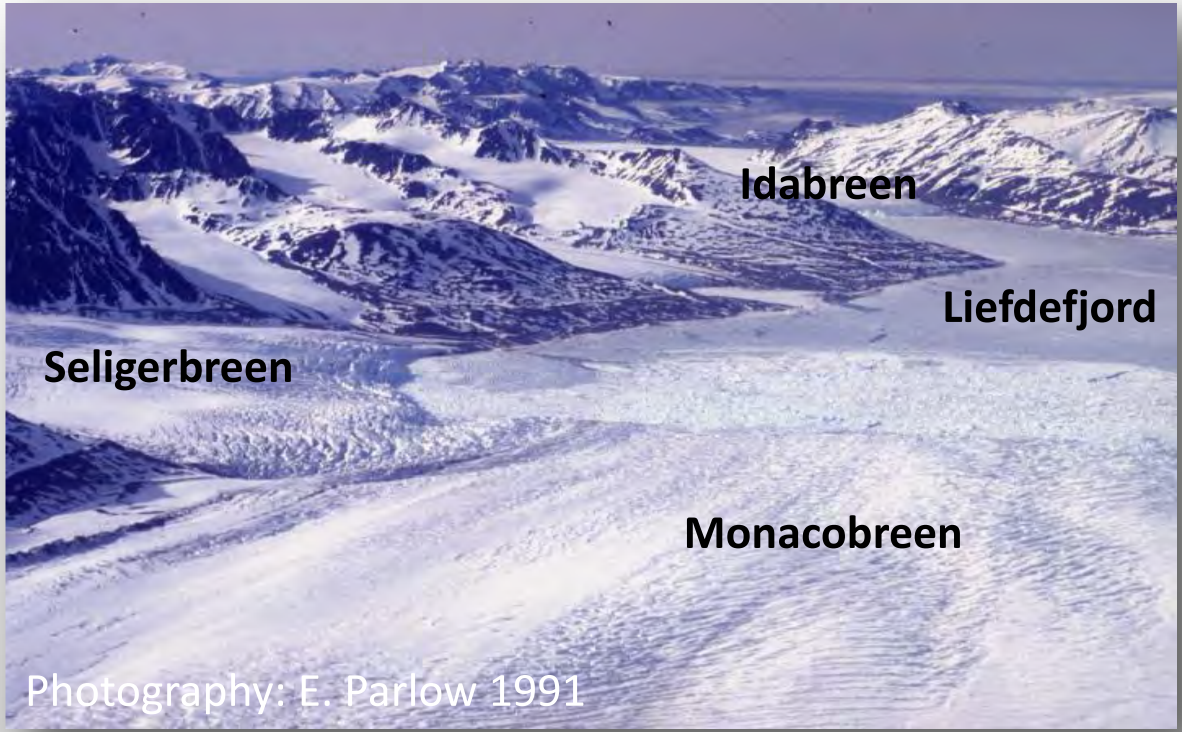

# Study Site

- Liefdefjord region
- NW-Spitsbergen
- 79.5° N – 13° E
- Monaco-Glacier calving into Liefdefjord with 80 – 100 m high calving front




Annual mean temperatures show positive trend over last 30 years

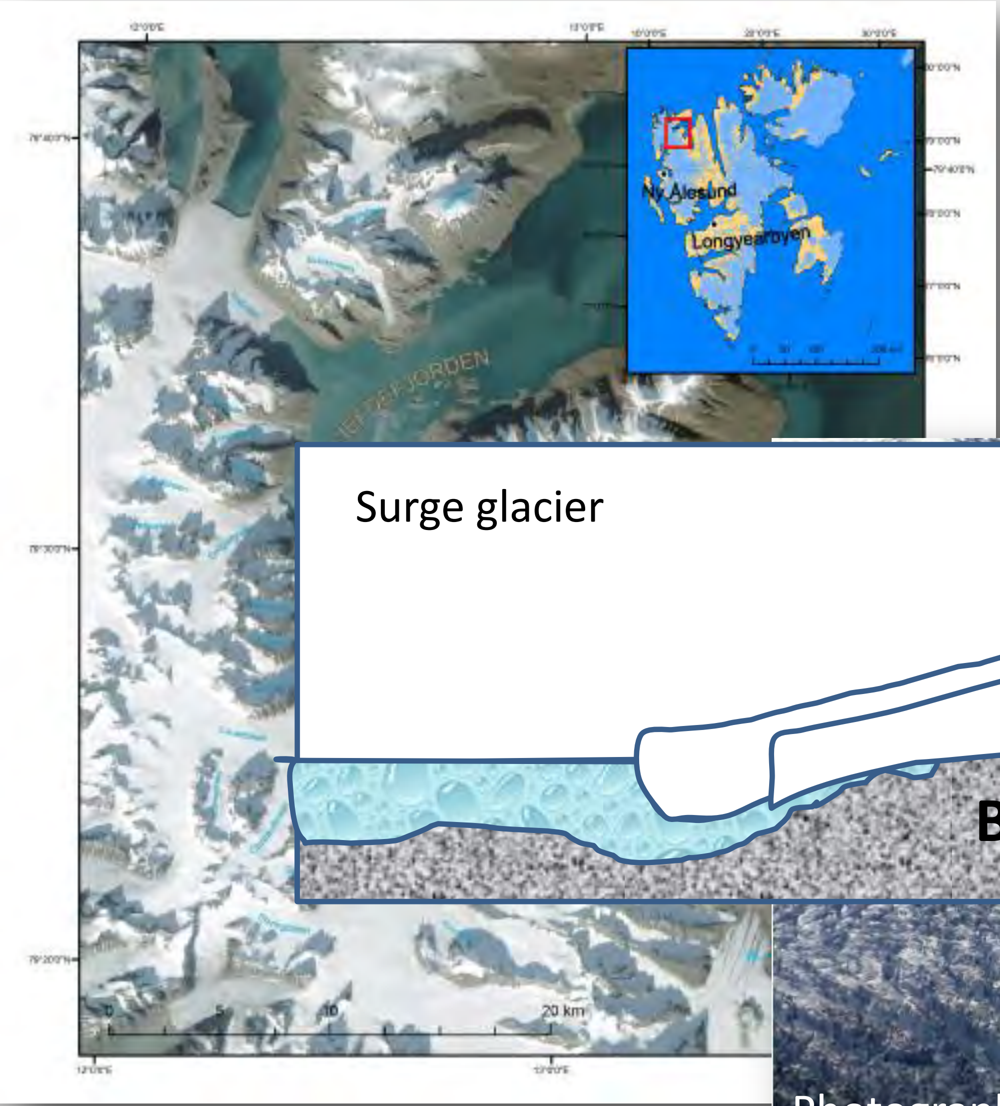
# View over Monaco-Glacier/Liefdefjord/Svalbard



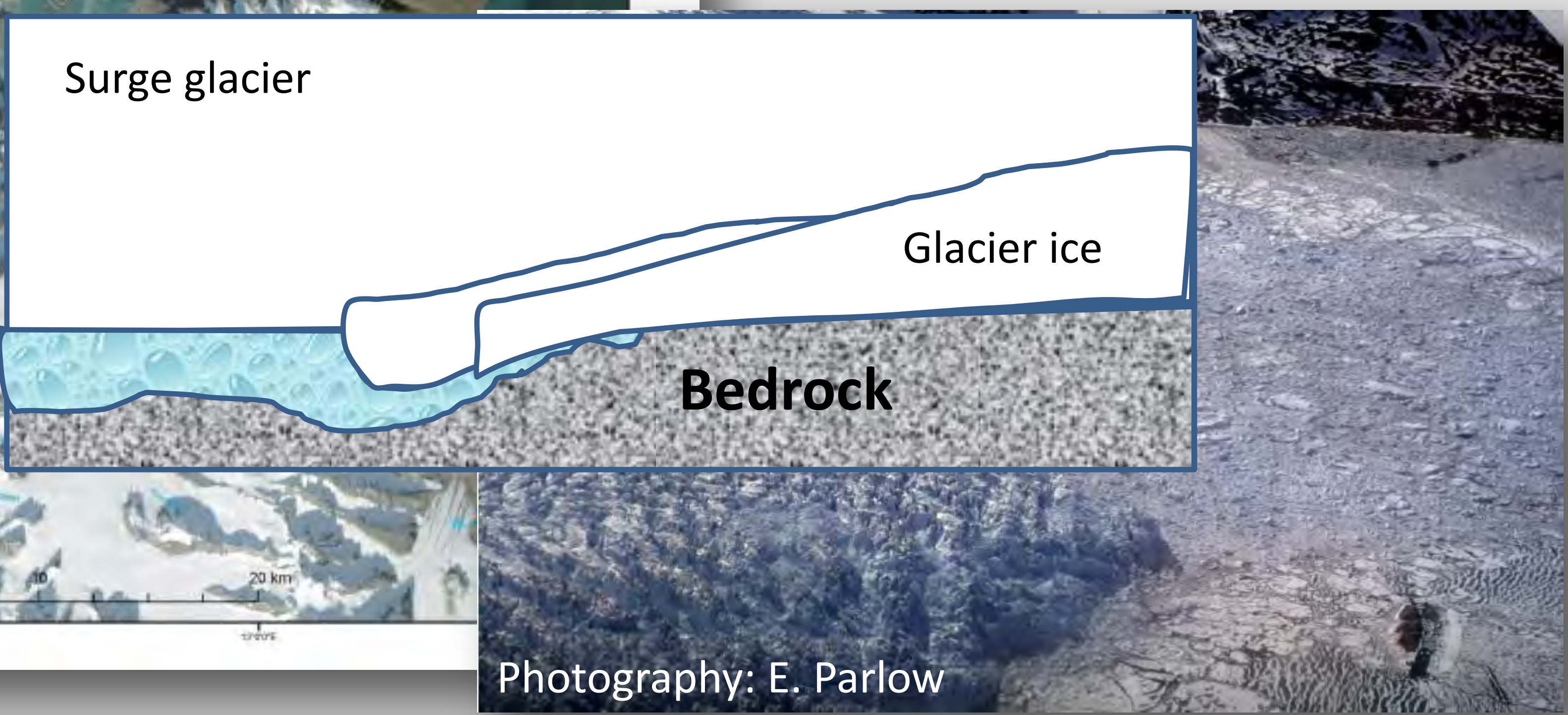

Photography: E. Parlow 1991

Fridolin: our semi-domestic polar fox was keen on Mortadella !
and frequent visits of polar bears

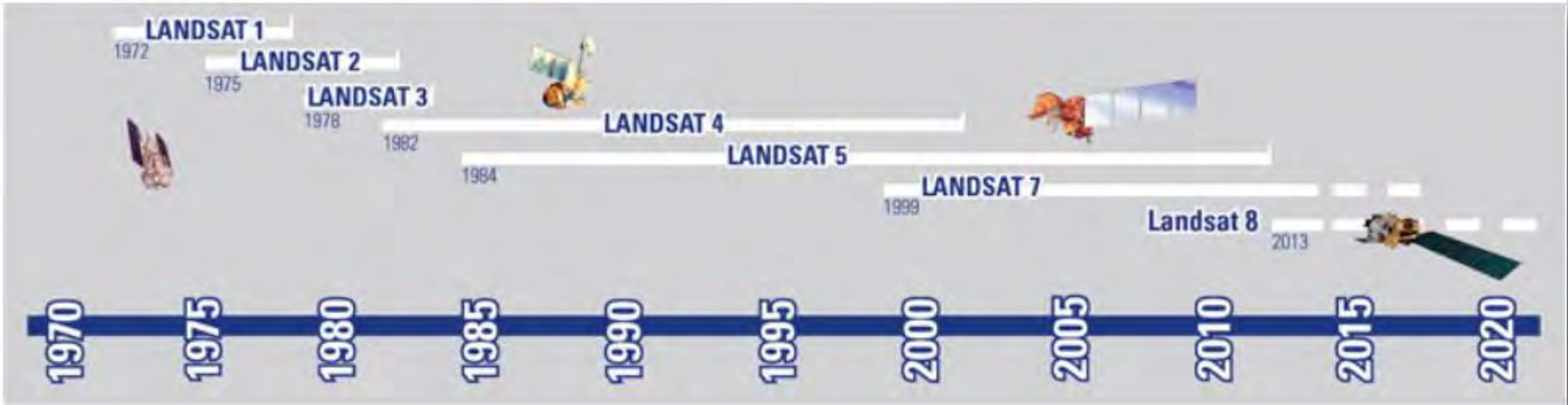
# Monaco-Glacier is a so-called «Surge-Glacier»




Due to variable flow velocities the glacier changes frontal position quite frequently and rapidly.
This is not necessarily related to global warming effects rather than to instabilities of glacier bed.

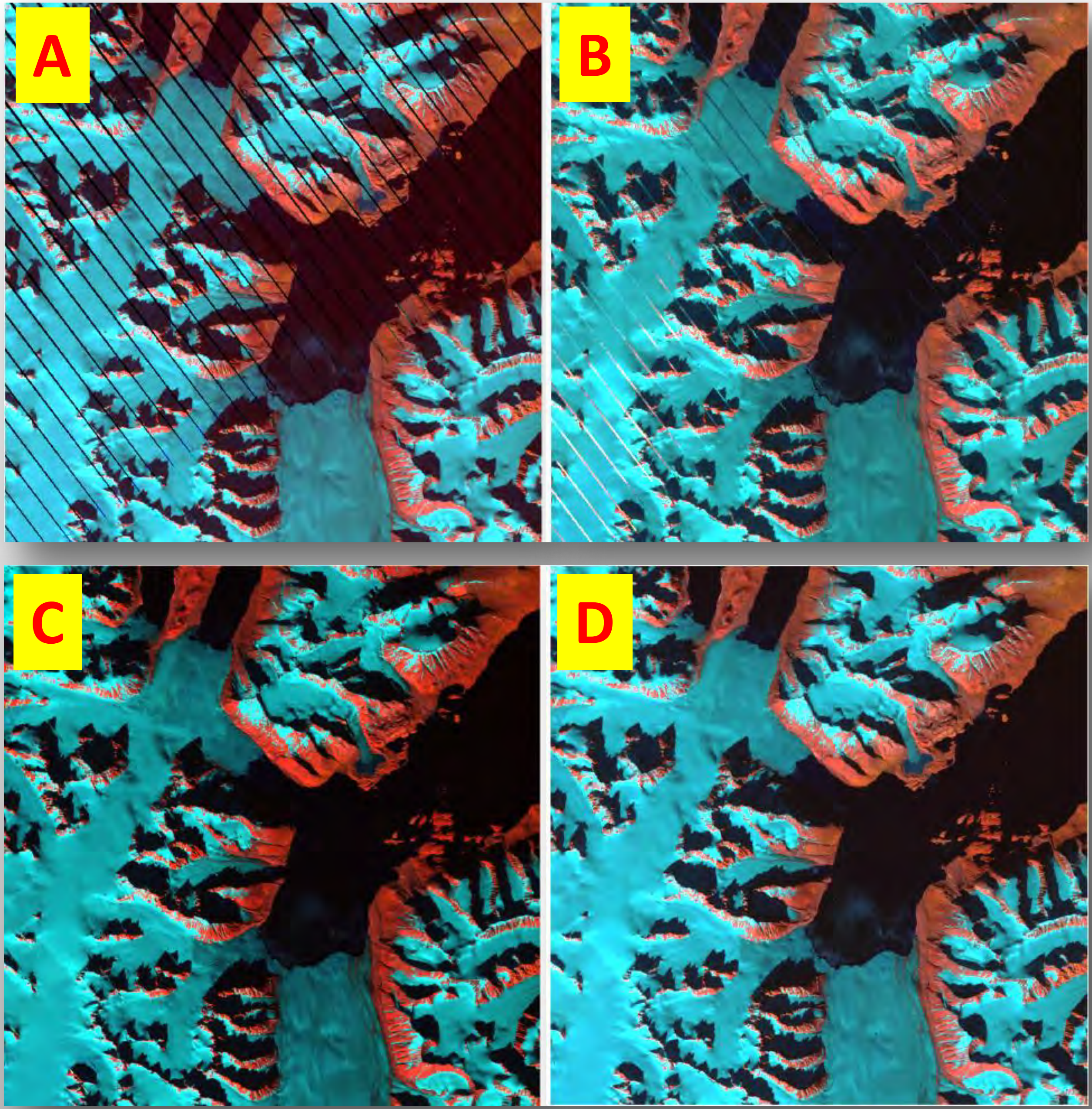


# Time-series analysis using Landsat-Data




| Platform and Sensor | ID (Path/Row) | Recording date | Satellite ID | Processing level |
|---|---|---|---|---|
| Landsat 1 MSS | 224/002 | 07.10.1976 | LM22400021976192AAA05 | L1G |
| Landsat 5 TM | 219/003 | 03.08.1985 | LT52190031985215KIS00 | L1G |
| Landsat 5 TM | 217/003 | 31.07.1989 | LT52170031989212KIS00 | L1G |
| Landsat 5 TM | 223/002 | 08.08.1994 | LT52230021994220KIS00 | L1G |
| Landsat 5 TM | 224/002 | 26.08.1998 | LT52240021998238KIS00 | L1G |
| Landsat 7 ETM+ | 217/003 | 11.07.2002 | LE72170032002192EDC00 | L1G |
| Landsat 7 ETM+ | 222/002 | 23.08.2006 | LE72220022006206EDC00 | L1G |
| Landsat 7 ETM+ | 220/003 | 23.08.2010 | LE72200032010235EDC00 | L1G |
| Landsat 8 OLI | 241/025 | 20.08.2014 | LC80252412014232LGN00 | L1Gt |

Data archive has been updated and many more scenes are available




# Availability of Landsat-Data

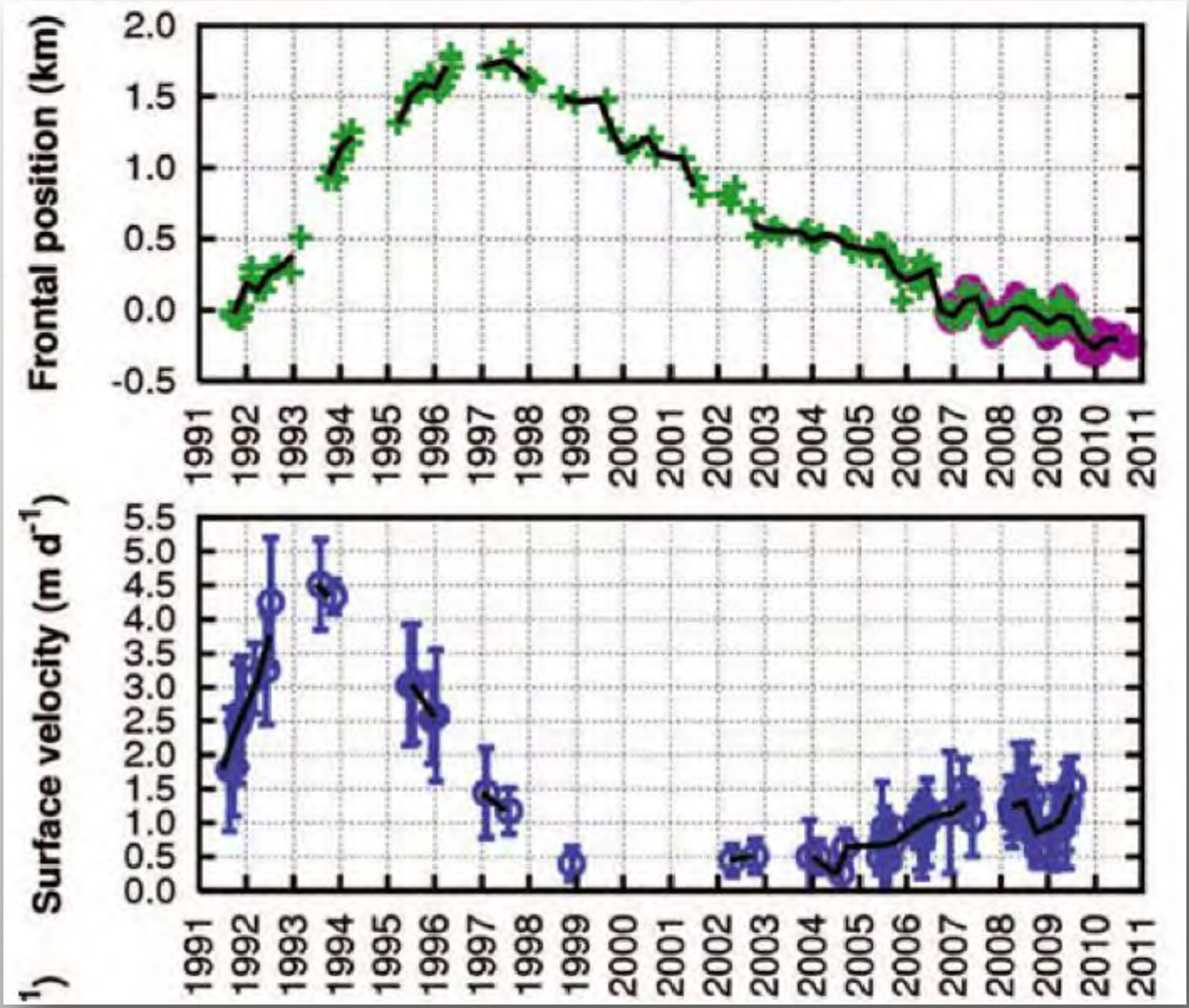
## at 80°N

Due to an extreme side-overlap of orbits at 80° North of > 80% many satellite scenes from **16 path/row pairs** could be analysed and SLC-off-data from Landsat-7-ETM could easily be used and gap-filled.

## Gap-fill of SLC-off-data

A: Original image
B: Global Histogram Matching Method
C: Local Histogram Method
D: Single Gap-fill Method implemented as ENVI add-on

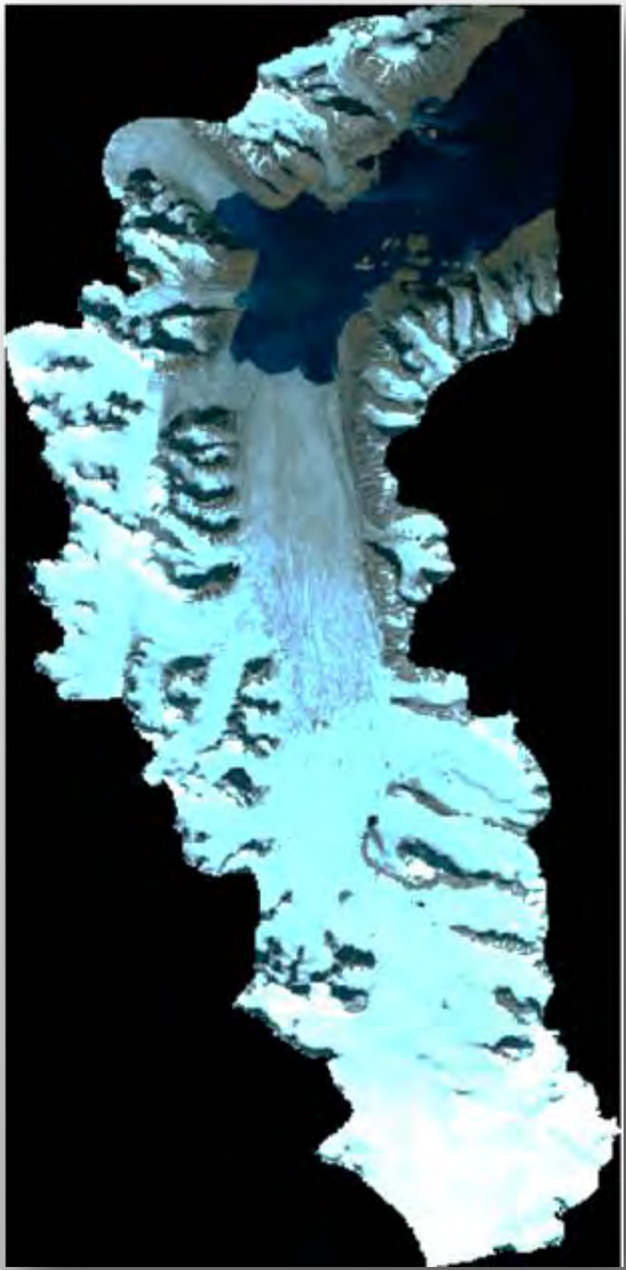
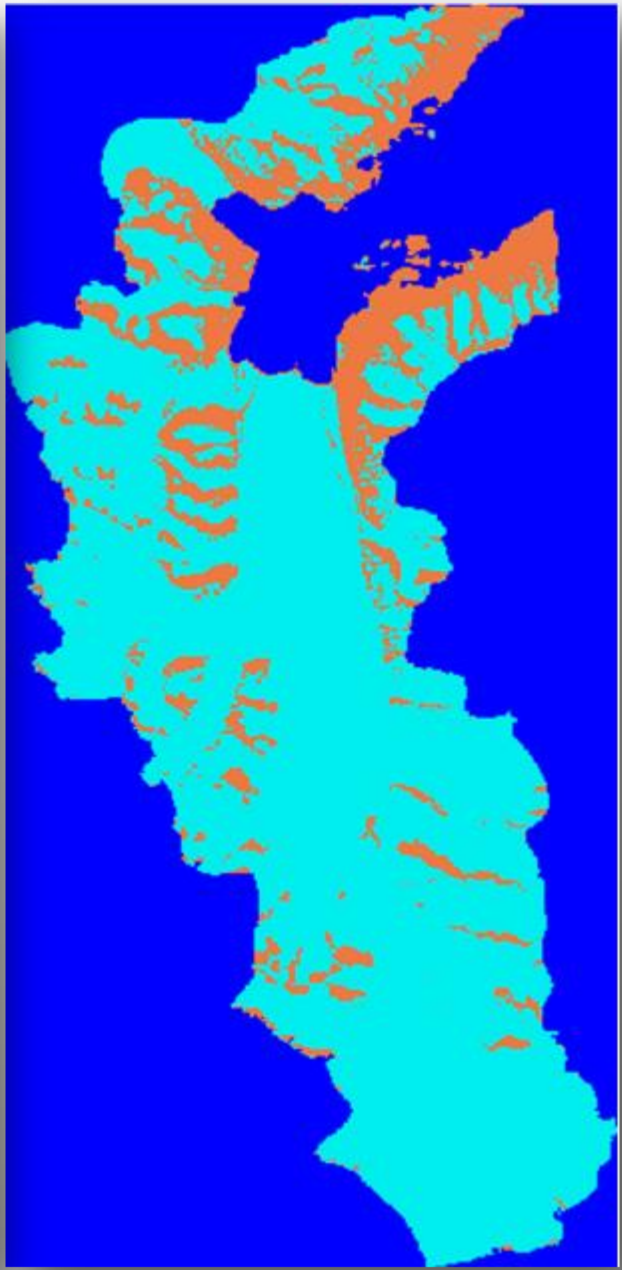
# Frontal position & flow velocities of Monacobreen 1991 - 2011



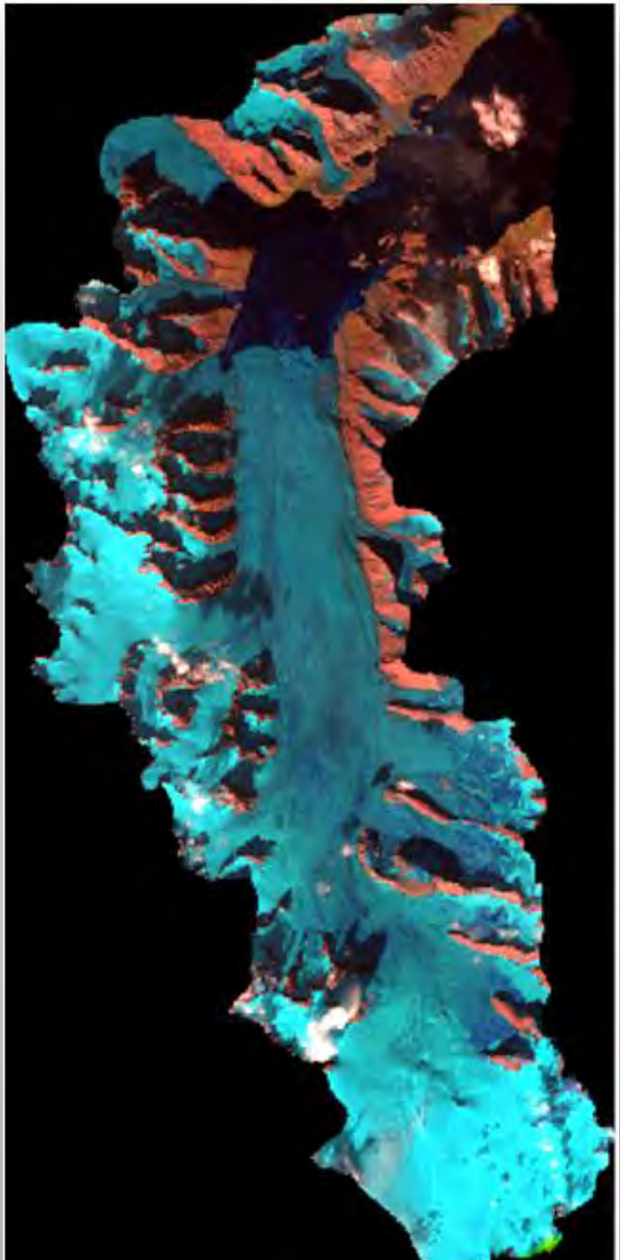

Maximum surge around 1997/98 with a glacier approach of 1.8 km.

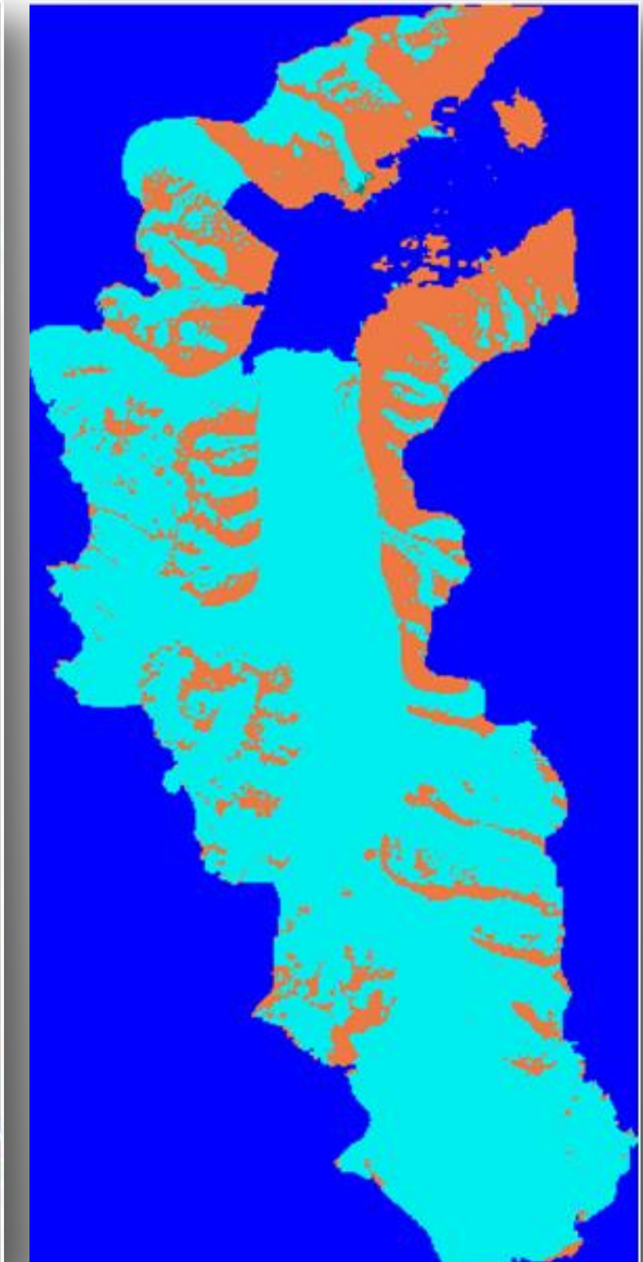
Source:
Mansell et al. 2012

Mansell et al. used ERS SAR and ALOS PALSAR images over 20 years.

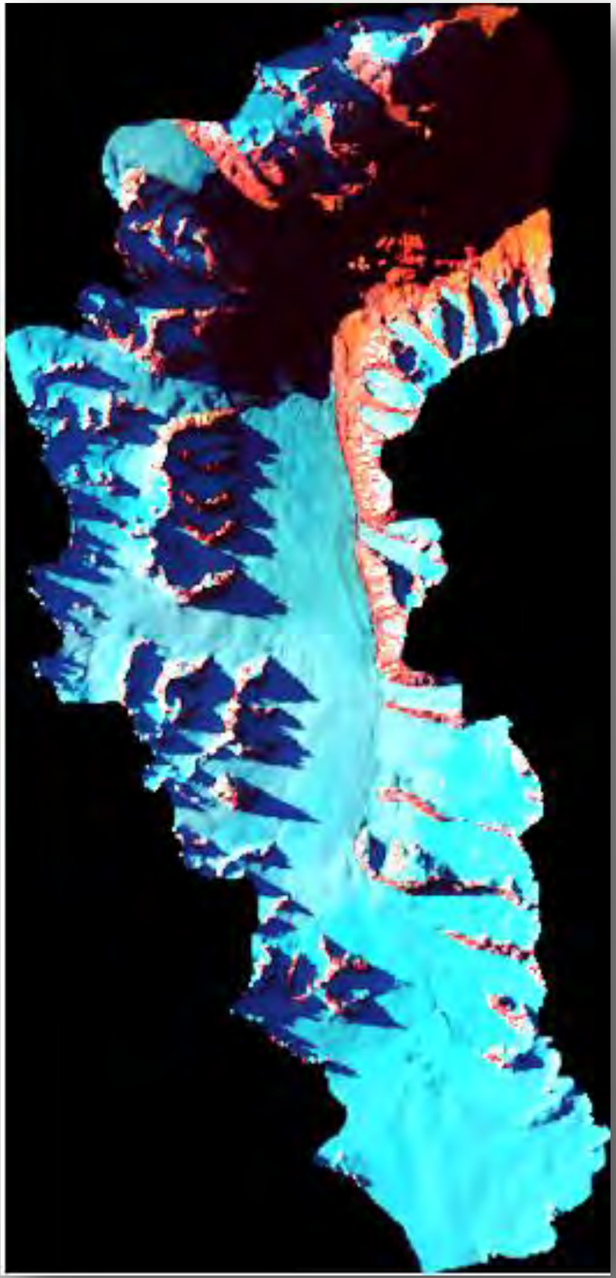
# Classification of glacier area Landsat-1-MSS (1976)

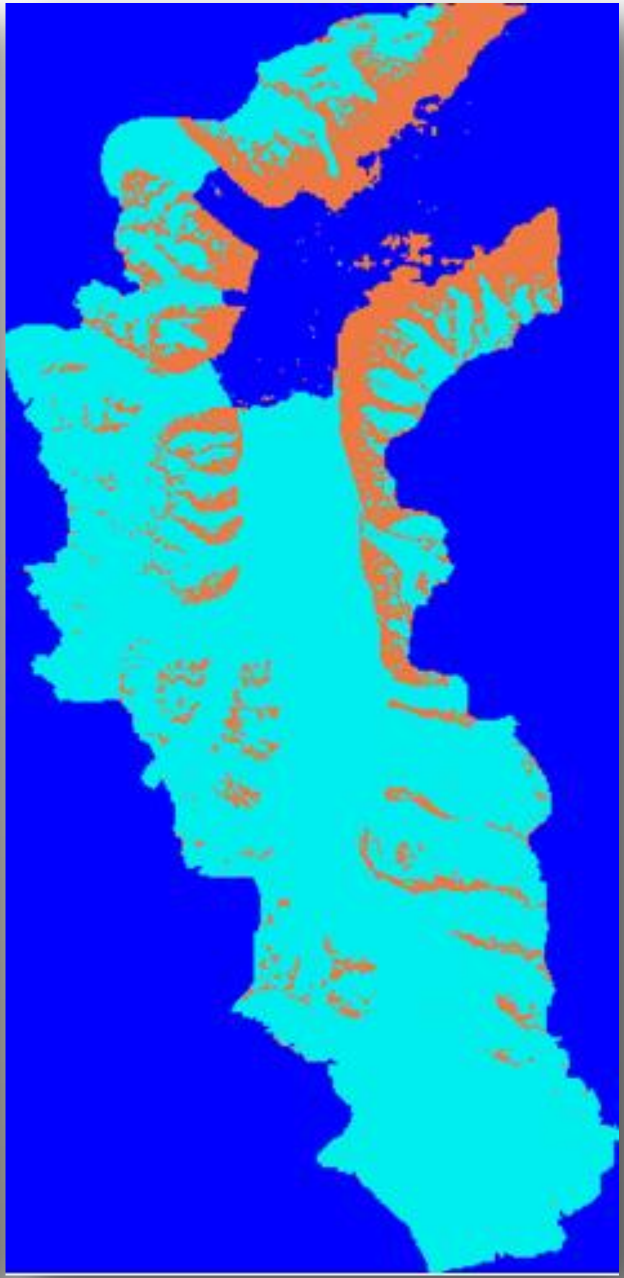




# Classification of glacier area Landsat-5-TM (1998)

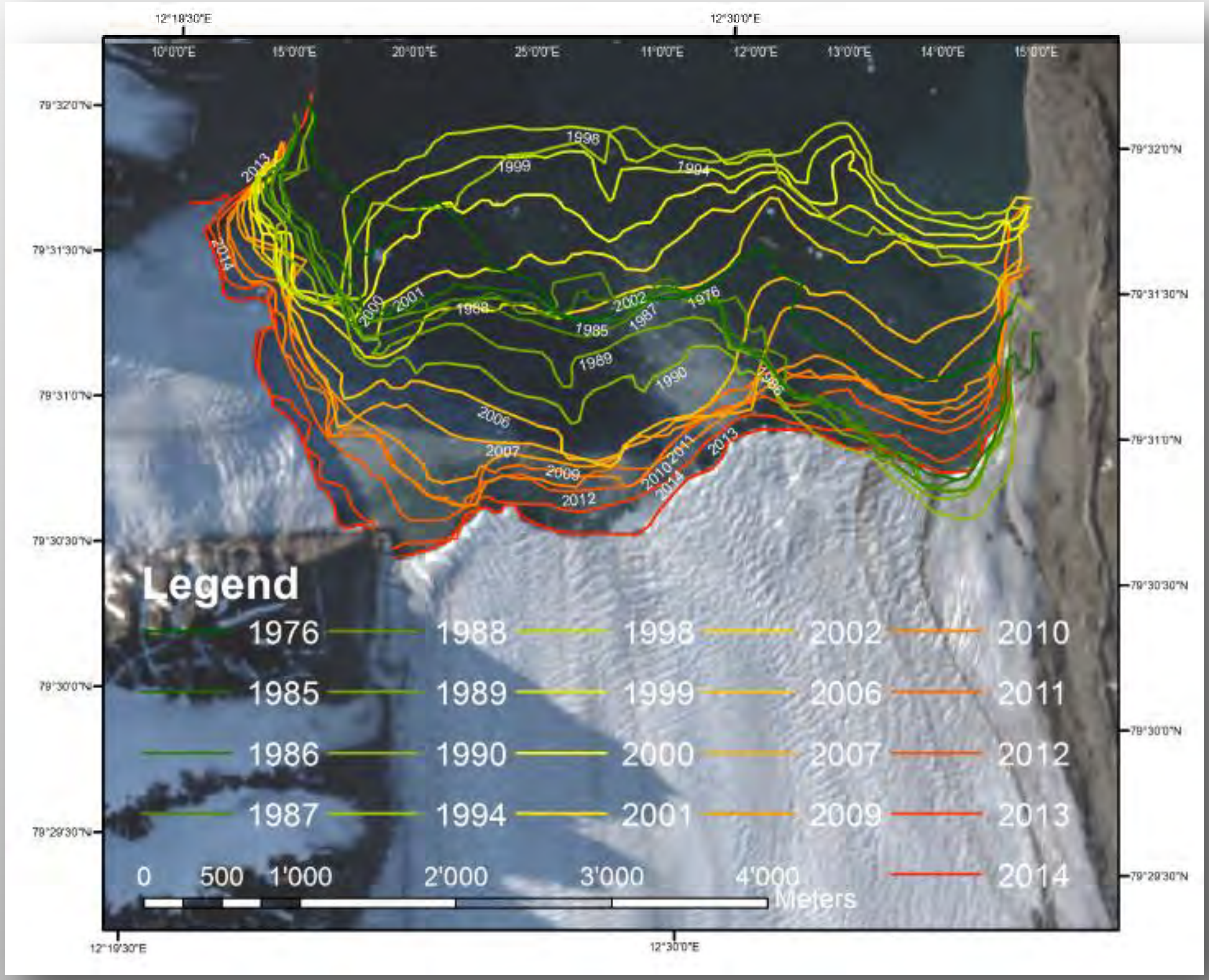
Year of maximum frontal position according to Mansell et al. (2012)

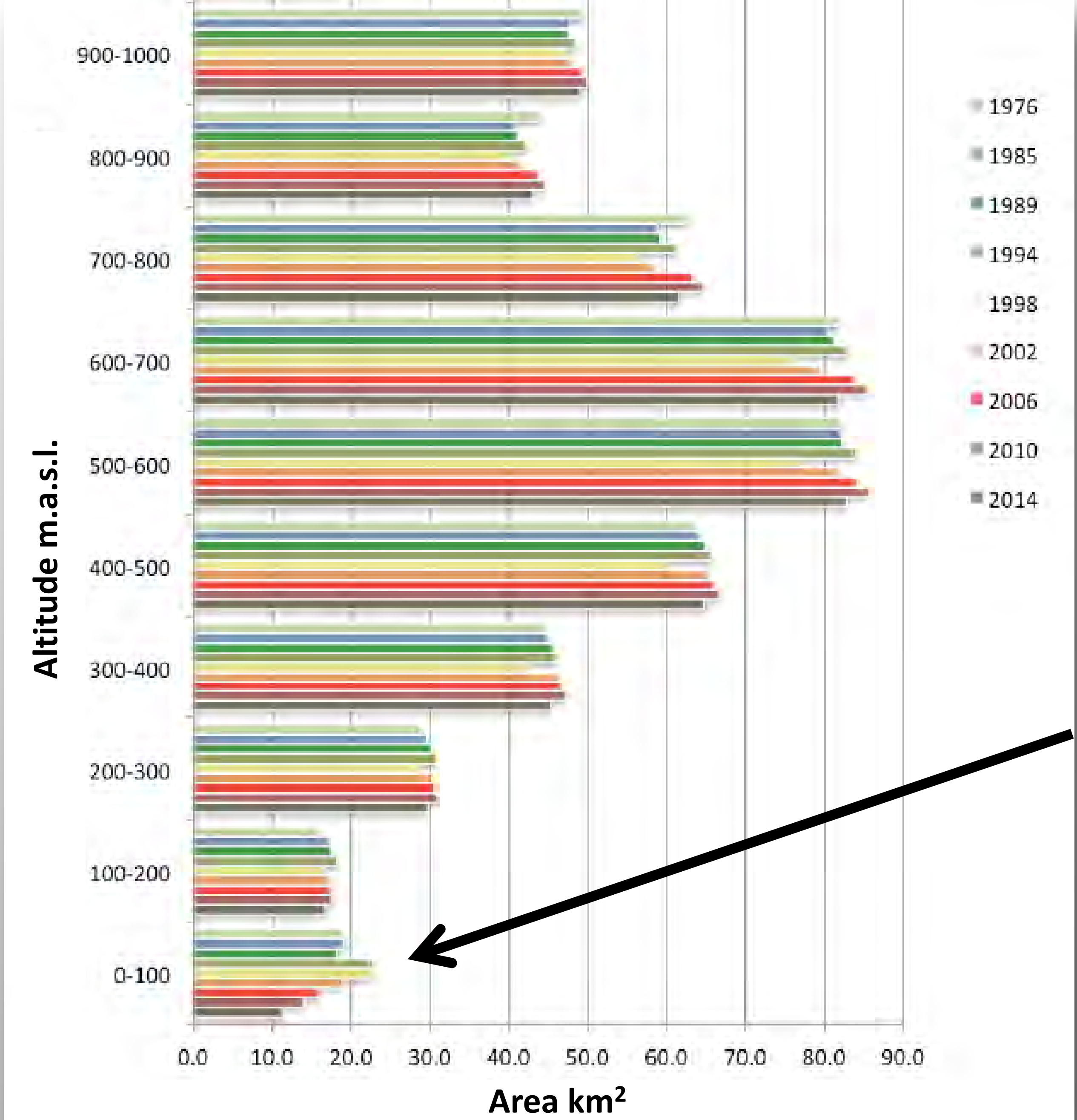




# Classification of glacier area Landsat-8-OLI (2014)

# Changes of frontal position of Monacobreen/Svalbard over 38 years using 22 Landsat-scenes (1976 – 2014)

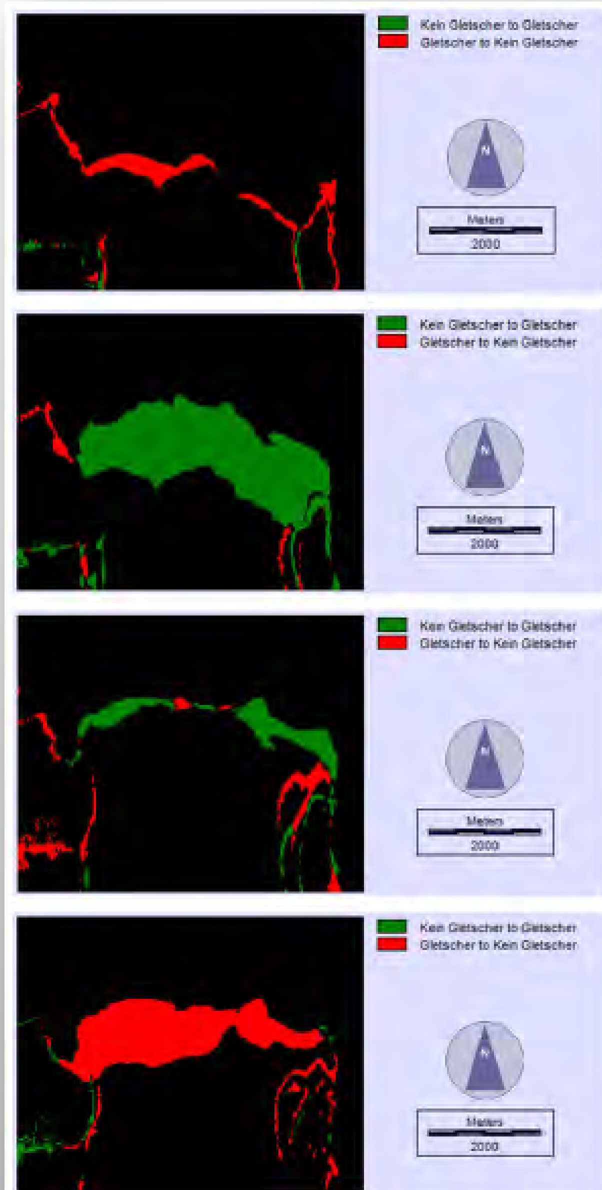


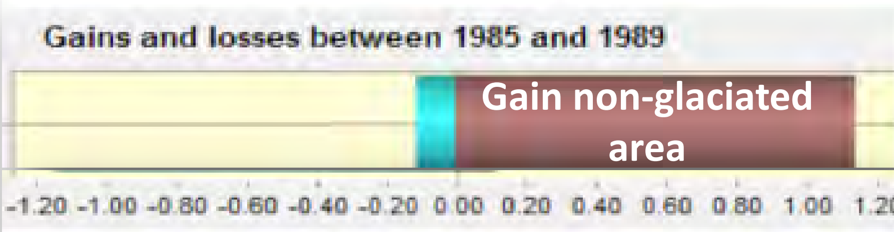


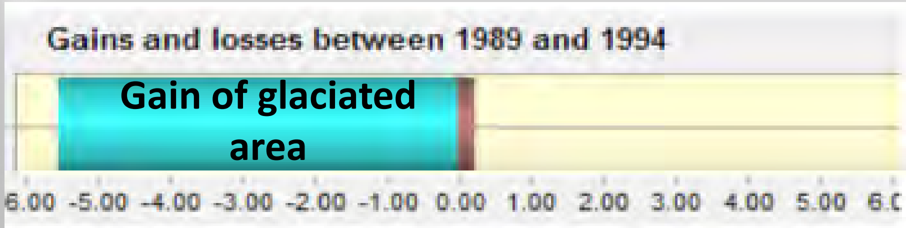

# Changes of glacial area in 100-m-intervalls 0 – 1000 m asl ($km^2$)

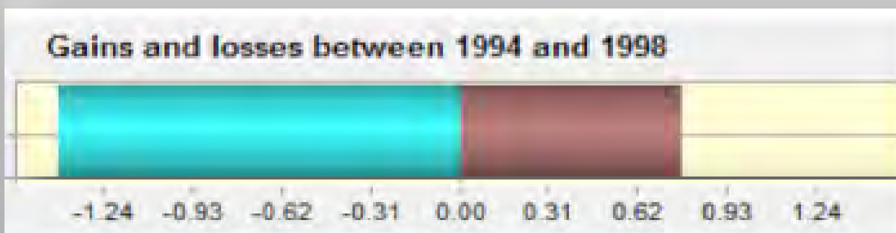
In most altitudinal belts the glacier extend is quite stable. The lowest (0–100 m) intervall shows the changes at the frontal position of Monacobreen

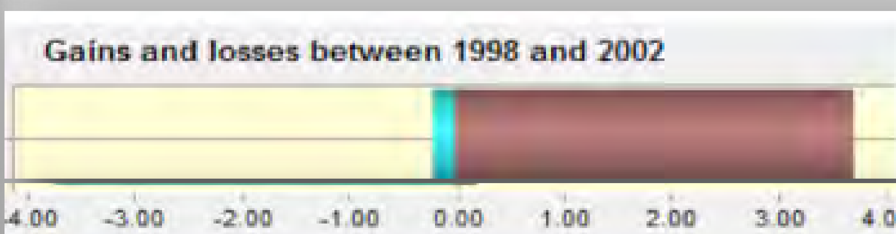
# Gains and losses of land resp. glaciers ($km^2$)




!!!! Different scales on X-axis !!!!

# Summary

- It was possible to analyse the complex spatio-temporal dynamics of a surge glacier in Svalbard
- Even Landsat-ETM-SLC-off data could well be used after a gap-filling procedure
- The side-overlap of orbits of > 80 % reduces cloud problems and offers a huge data archive for this type of investigation (16 p/r pairs)
- One certain problem is the separation of snow and ice esp. with Landsat 1-4-MSS due to lower spectral and spatial resolutions
- The largest glacier surge could be documented for the year 1998 with a maximum approach of 2800 m (1000 m more vs. Mansell et al. 2012)
- Minimum frontal position could be detected for 2014
- Since 2013 Monaco- and the neighbouring Seligerbreen are separated
- Exept for the lowest altitude (0 – 100 m asl) the total glaciated area in the study area is quite stable over the 4 decades and is ≈ 500 $km^2$


Calving front of Monacobreen

# Rain & fog in the Namib Desert: spatio-temporal dynamic of the rainy season 2010-2011 in Namibia

Eberhard Parlow, Roland Vogt, Nicola Möckli & Kathrin Alber
Meteorology, Climatology and Remote Sensing (MCR Lab)
Department of Environmental Sciences
University Basel, Switzerland

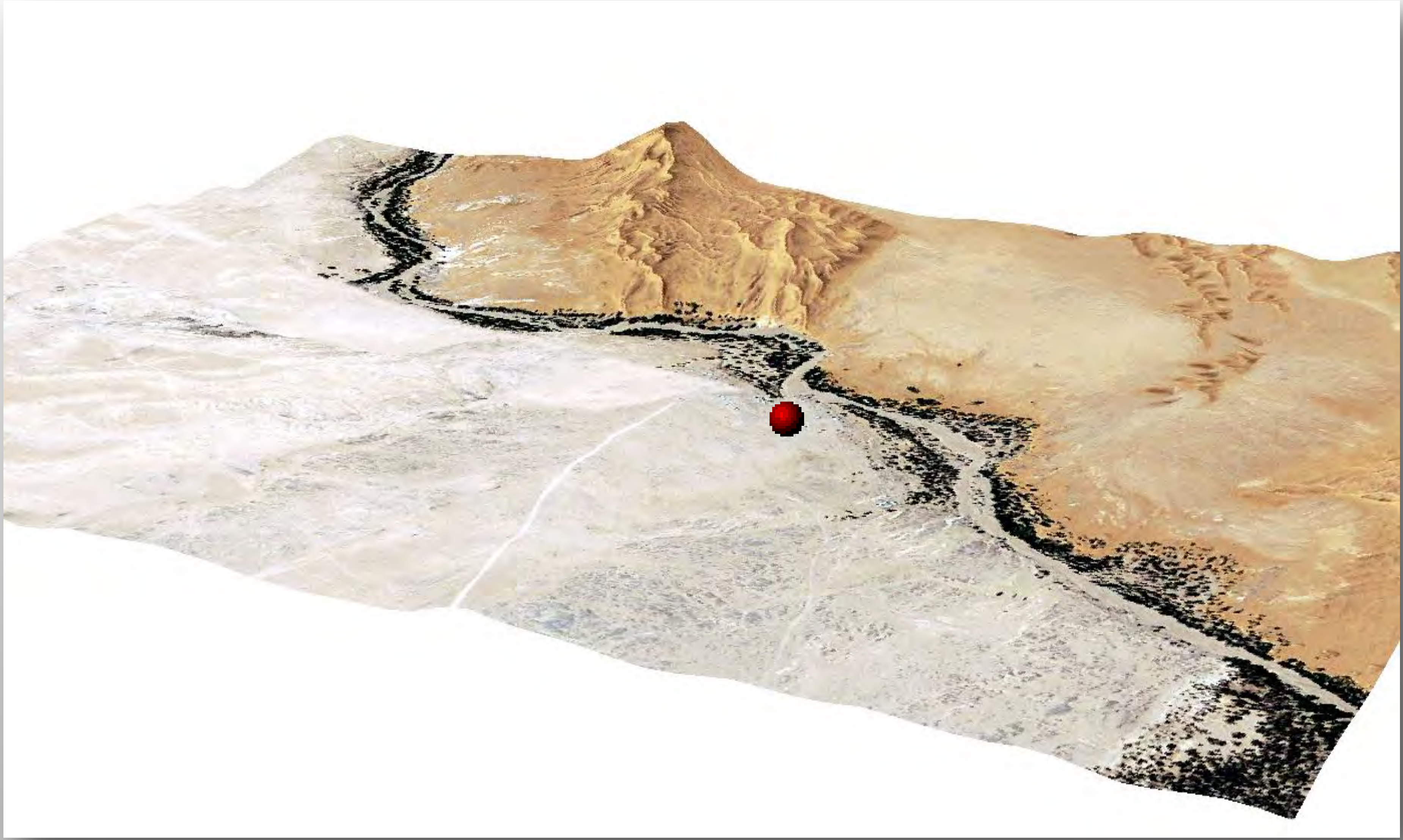
# Geographic situation of Gobabeb Research Station

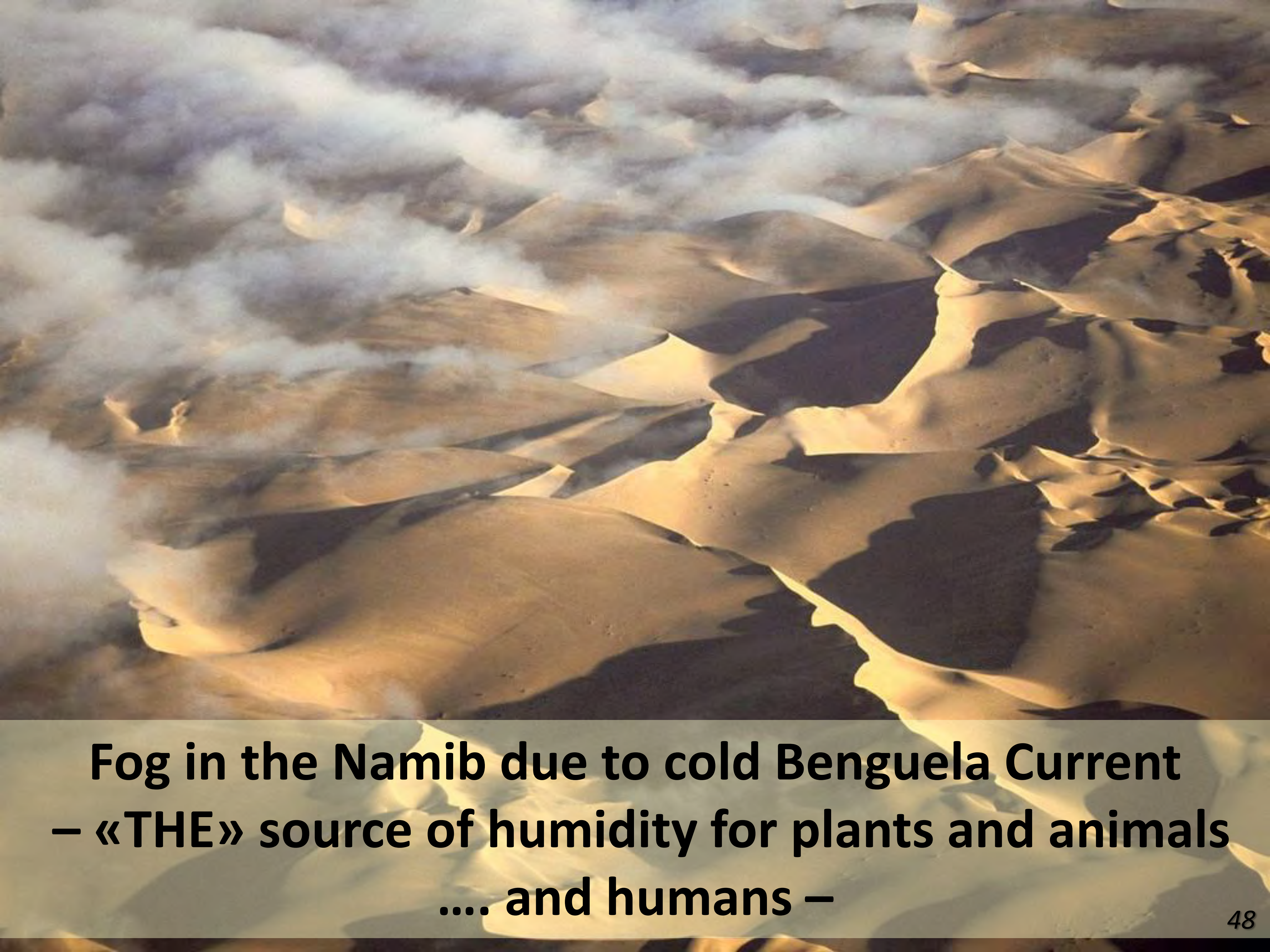


## Gobabeb Desert Research Station

- At 23.5 ° S
- Transition of dune and gravel Namib
- Ø annual precipitation: < 30 mm
- Numerous research co-operations with international institutions (MPI, NASA, KIT…

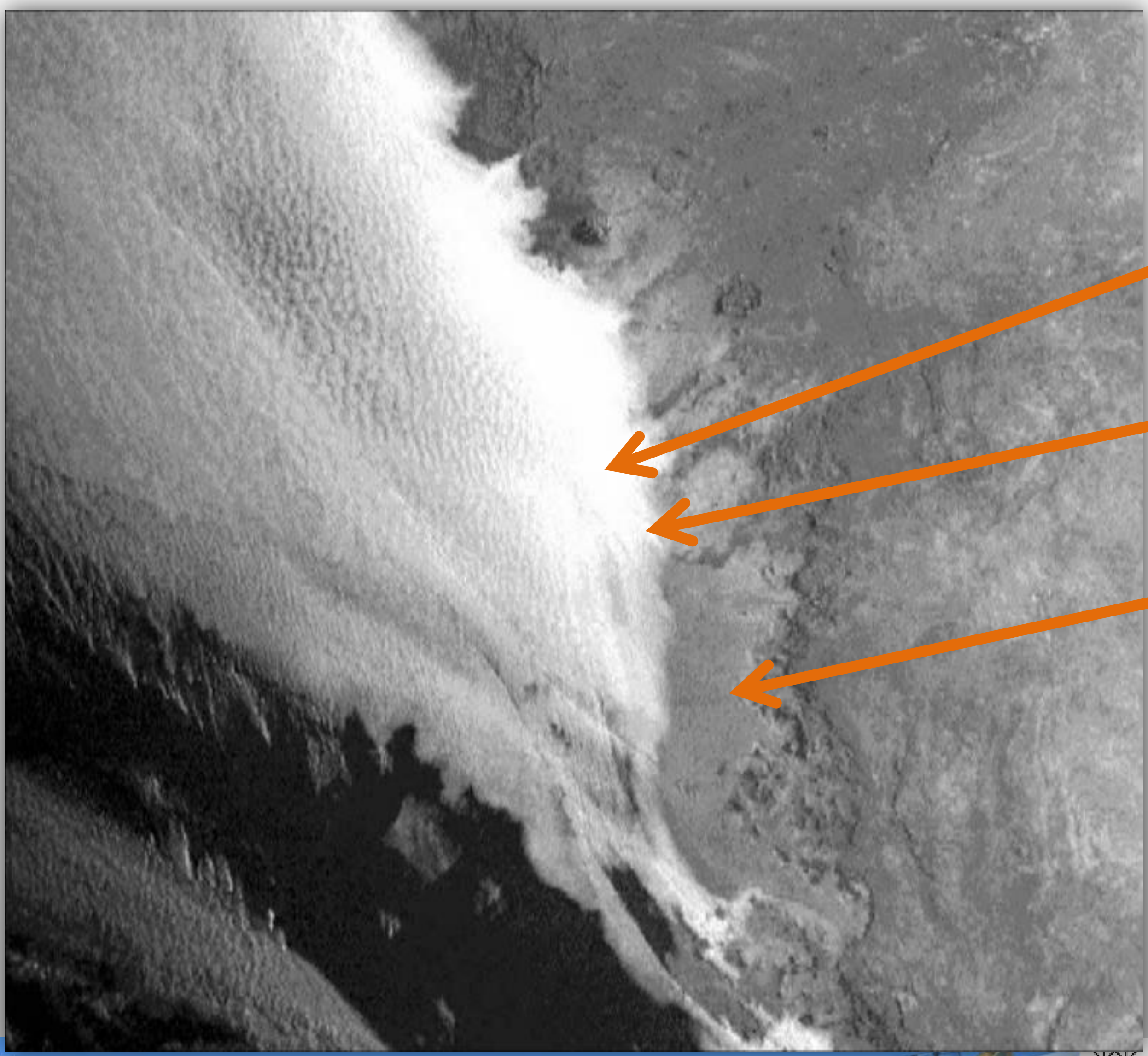
# Gobabeb Research Station and Kuiseb-River



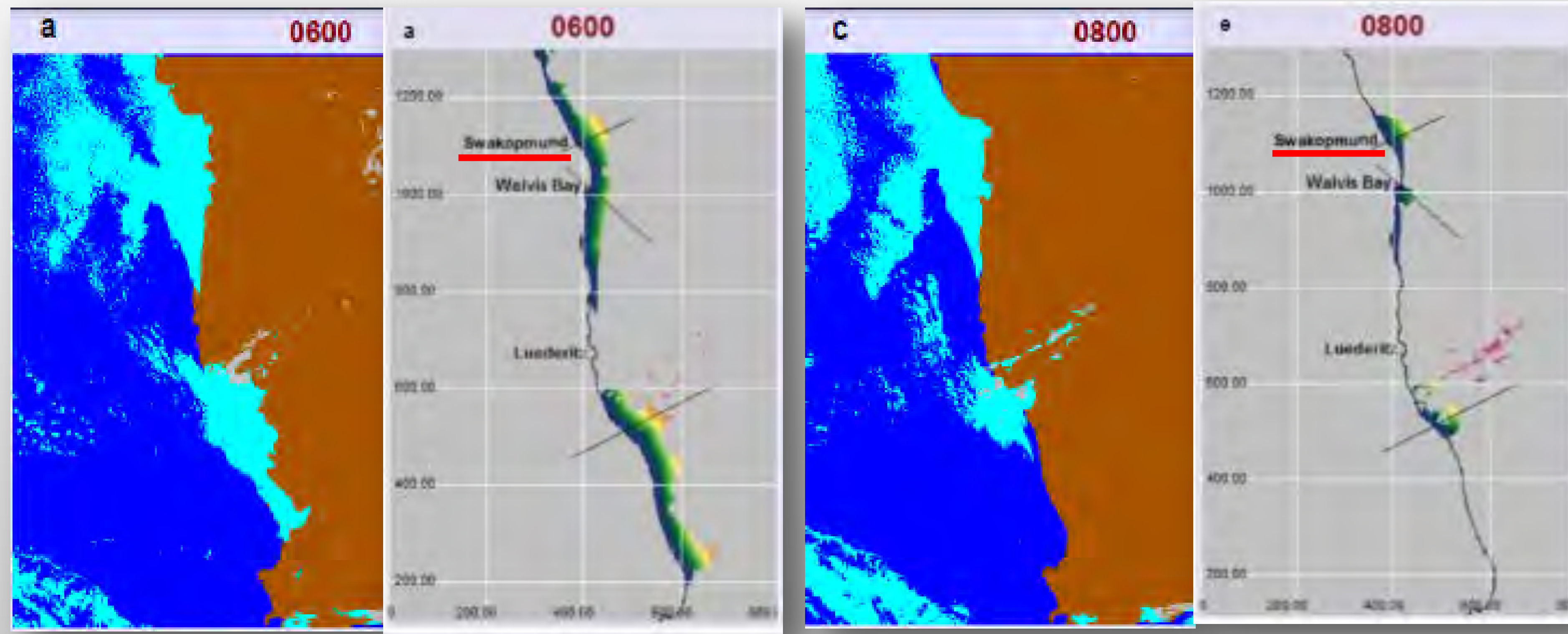


**Fog in the Namib due to cold Benguela Current – «THE» source of humidity for plants and animals …. and humans –**

# Fog situation at the Atlantic coast (using Meteosat-MSG-Data)
(Data frequency : 15 min)    8.8.2010   06:00 – 15:45 UTC

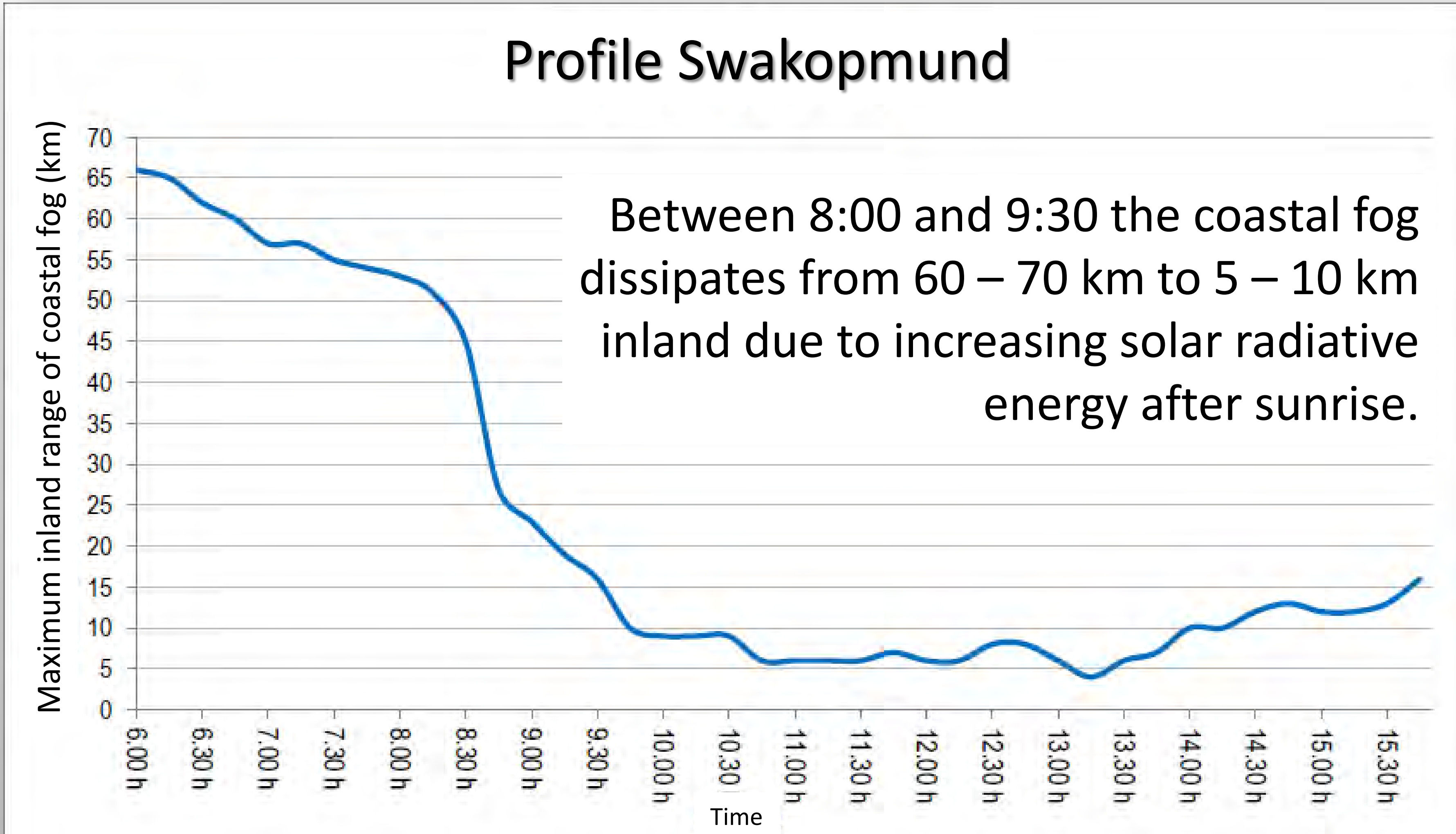


# Temporal development and range of coastal fog in Namibia using Meteosat MSG data in 15 min temporal resolution



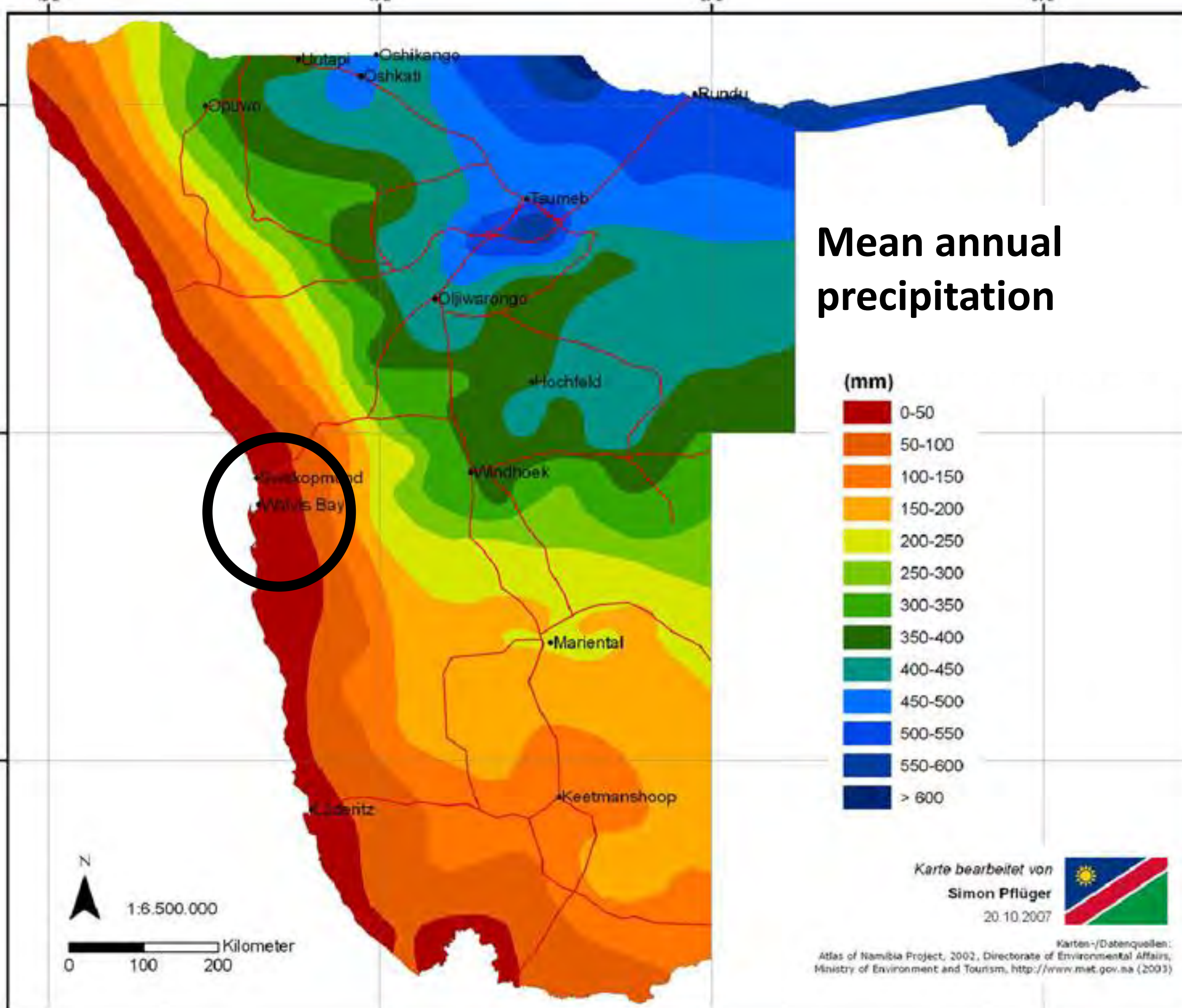

Only two examples of data time series analysis are presented. Along several selected profiles (e.g. Swakopmund) the fog distribution were examined according to range inland and temporal dynamic.

# Temporal development of coastal fog



# The Super Rainy Season 2010/2011 in Namibia

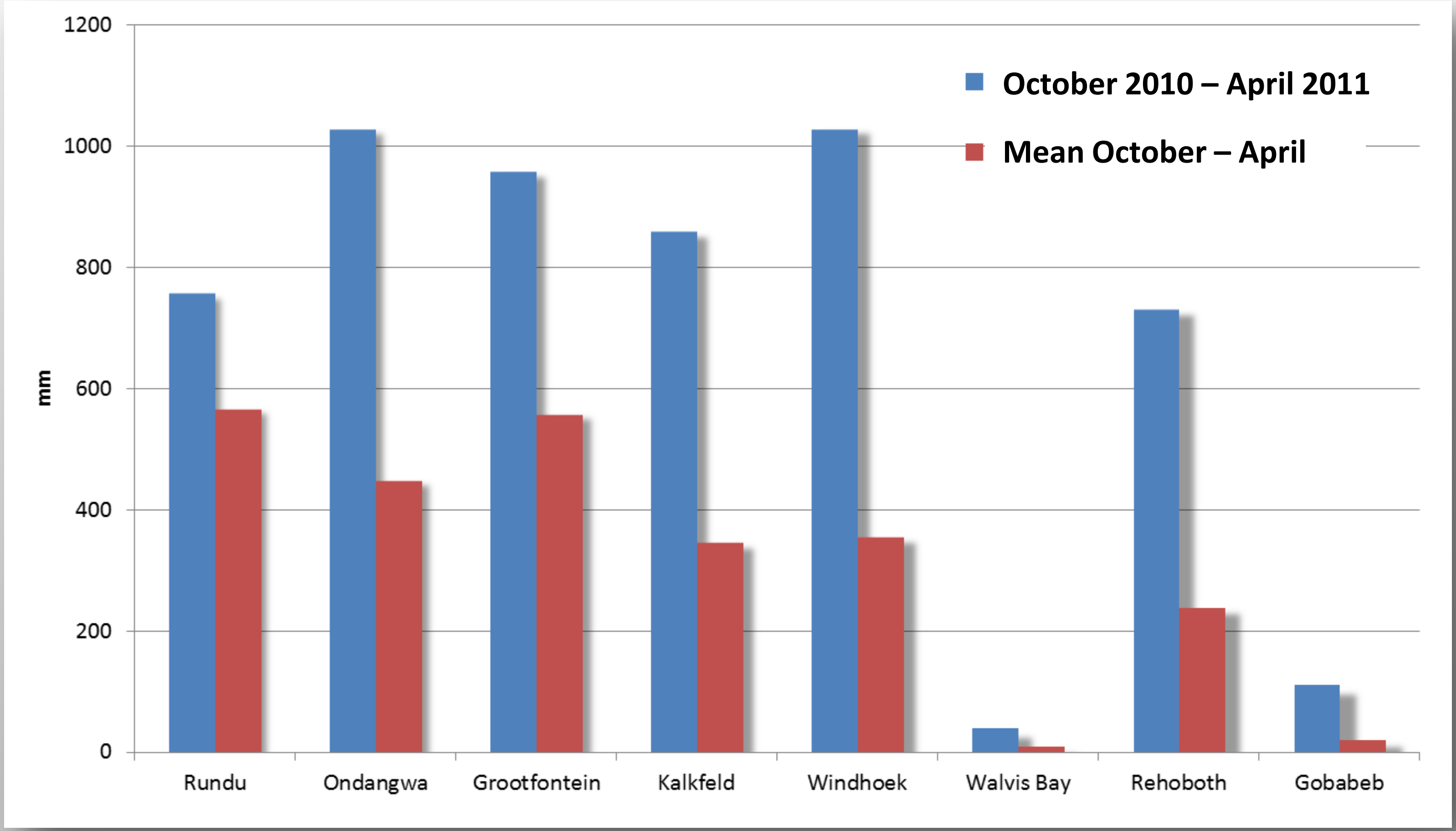
# Mean annual precipitation



In nearly all parts of the country the rainy season was extreme. Only in the south it was «normal». The Namib "Desert" was green like a meadow, Kuiseb River was flowing like an alpine river over weeks (!!) and eroded the dunes !!

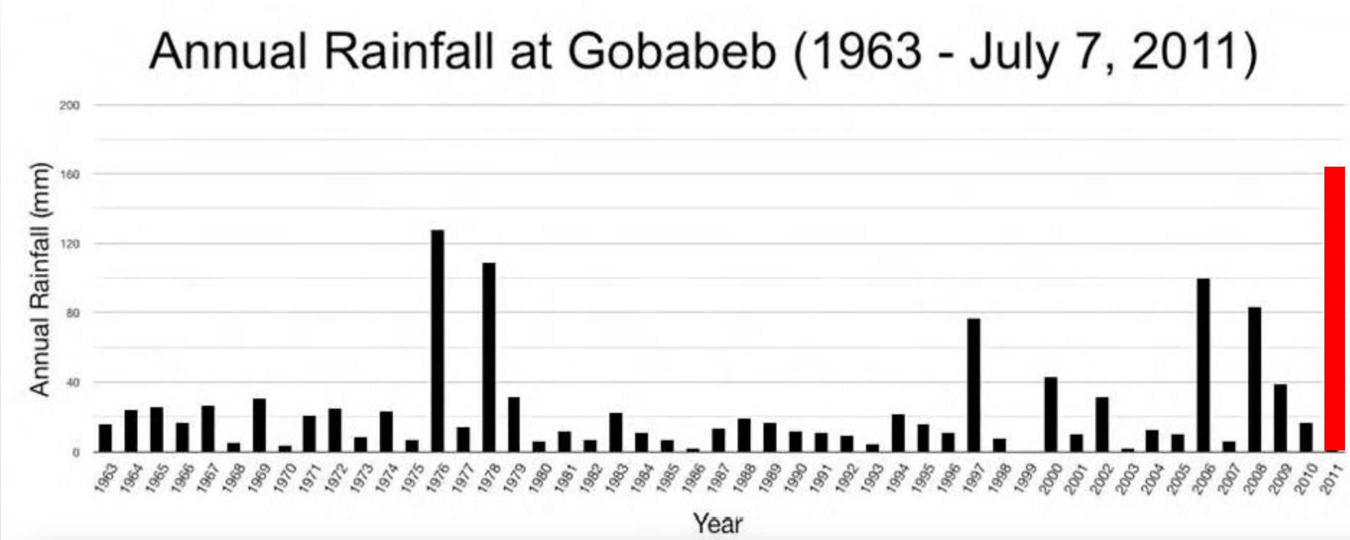
# Kuiseb on 9.2.2011  about 10 km down-stream from Gobabeb

# Precipitation during rainy season (October – April)
## selected locations

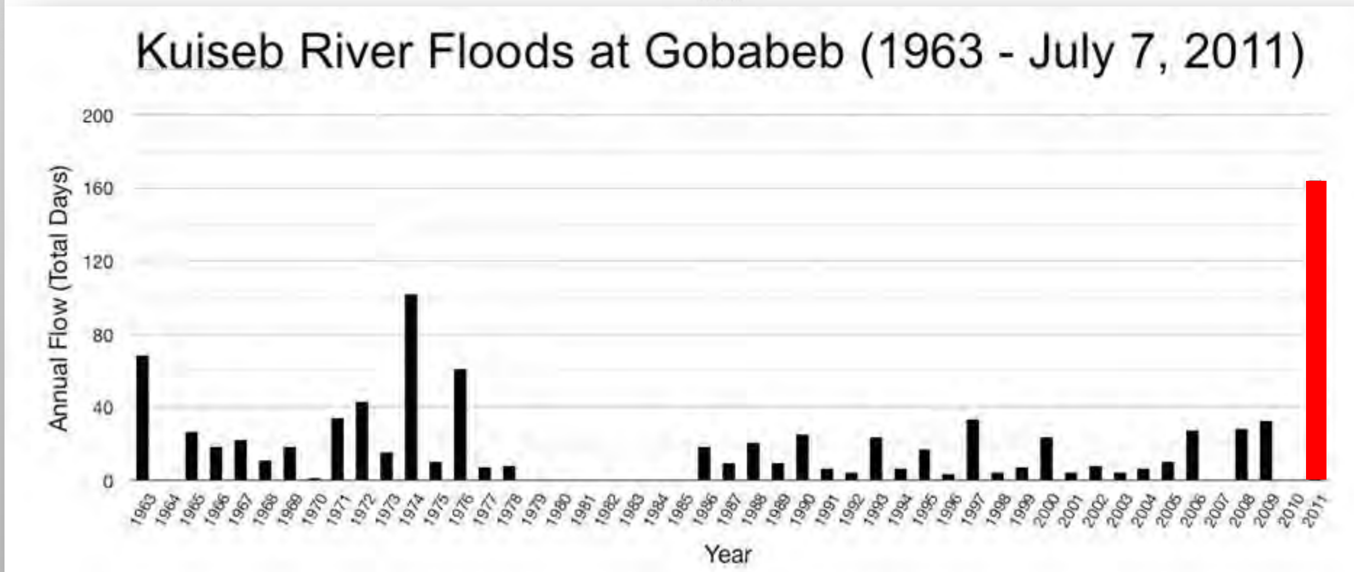



Rain gauges are rare and in most parts of Namibia very sparsely distributed. That makes studies of spatio-temporal precipitation dynamics difficult if not impossible.

# The rainy season (October 2010 – April 2011) in comparison



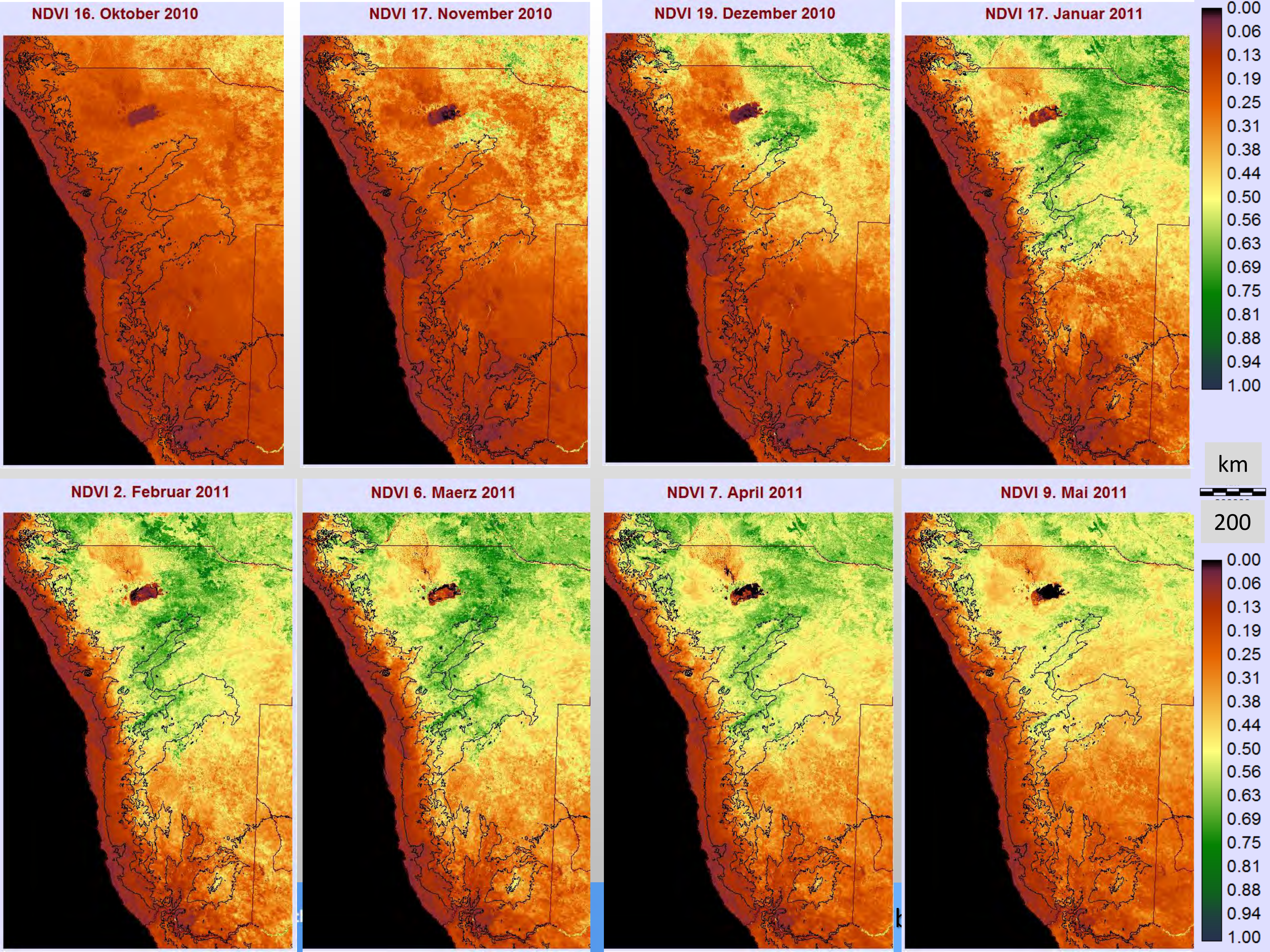

≥ 160 mm




≥ 160 days

# Use of MODIS-data to investigate vegetation dynamics in Namibia during rainy season 2010/2011

- In an arid area like Namibia vegetation growth is directly related to rainfall events
- Therefore NDVI or EVI indicated time and intensity of precipitation
- MODIS (Moderate Resolution Imaging Spectro-Radio-meter)
- Data availability since February 2000
- Grid size 250 m
- 16-days composite of NDVI & EVI
- Freely available via (NASA)


NDVI 16. Oktober 2010
NDVI 17. November 2010
NDVI 19. Dezember 2010
NDVI 17. Januar 2011
NDVI 2. Februar 2011
NDVI 6. Maerz 2011
NDVI 7. April 2011
NDVI 9. Mai 2011
0.00
0.06
0.13
0.19
0.25
0.31
0.38
0.44
0.50
0.56
0.63
0.69
0.75
0.81
0.88
0.94
1.00
km
200
0.00
0.06
0.13
0.19
0.25
0.31
0.38
0.44
0.50
0.56
0.63
0.69
0.75
0.81
0.88
0.94
1.00

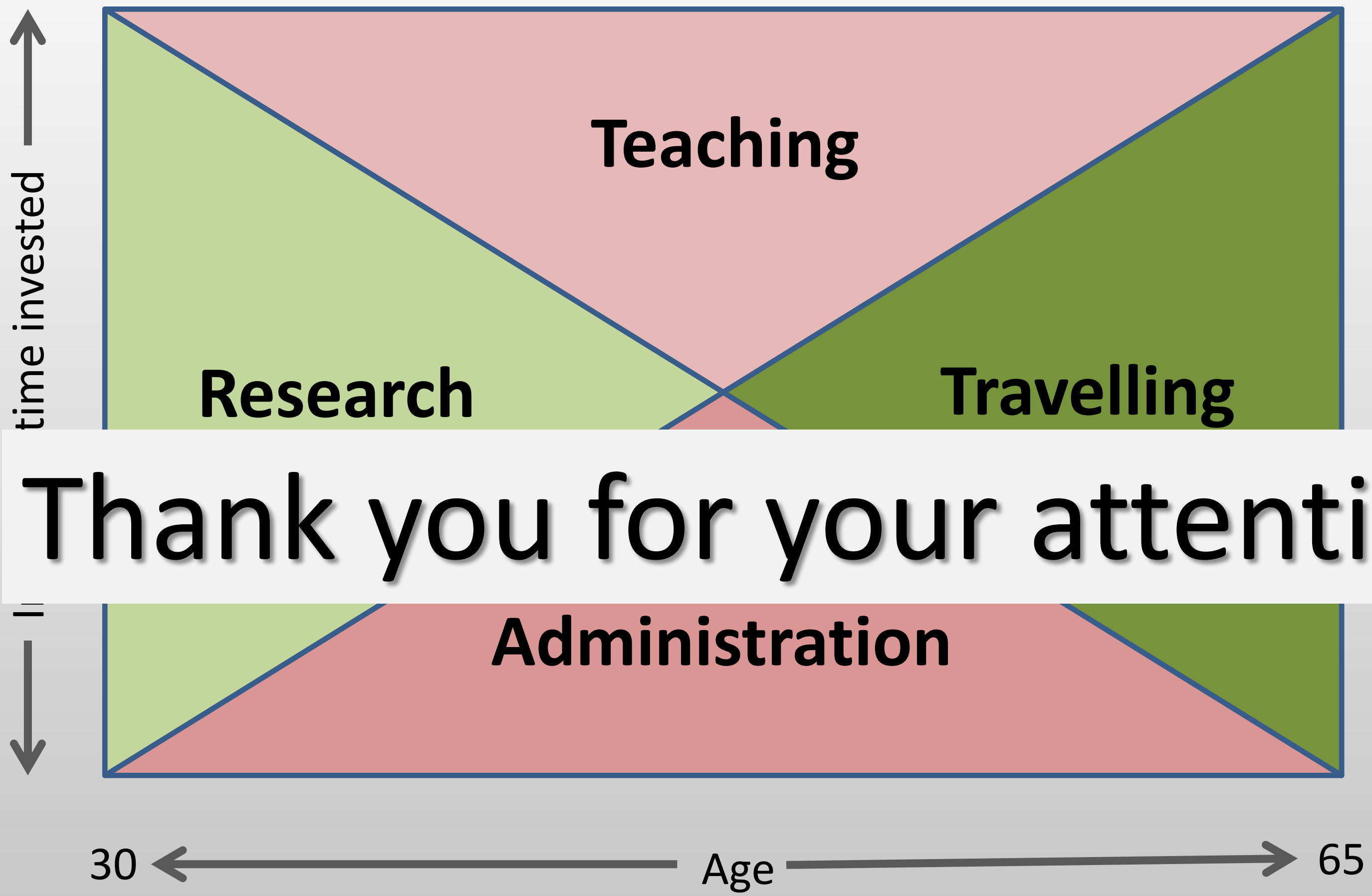
# Our flux tower at Gobabeb

(and our BSRN station - the only in Africa at the moment)

BSRN : Baseline Surface Radiation Network
a GEWEX and WCRP activity

Foto: Folke Olesen

# What is this ?????




# Thank you for your attenti☺n

It's **NOT** a rectangular !!! It's the life of a scientist ☺ ?