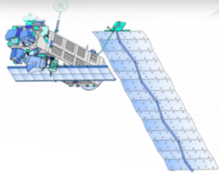
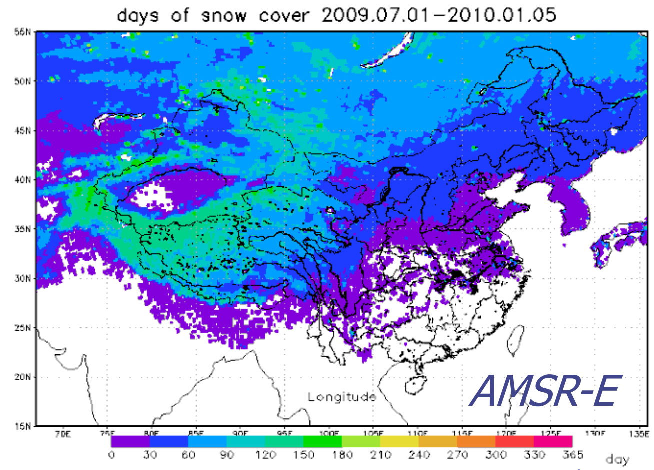


The possibility analysis of the passive microwave high-frequency signal in the shallow snow retrieval

Y.B. Qiu[1*], H.D. Guo[1], J.C. Shi[2], S.C. Kang[3]

J. Lemmetyinen[4], J.R. Wang[5]

1 Center of Earth Observation and Digital Earth, CAS, China
2 University of California, Santa Barbara, USA
3 Institute of Tibetan Plateau Research, CAS, China
4 FMI, Arctic Research Centre, Finland
5 NASA Goddard Space Flight Center, Greenbelt, USA



ybqiu@ceode.ac.cn

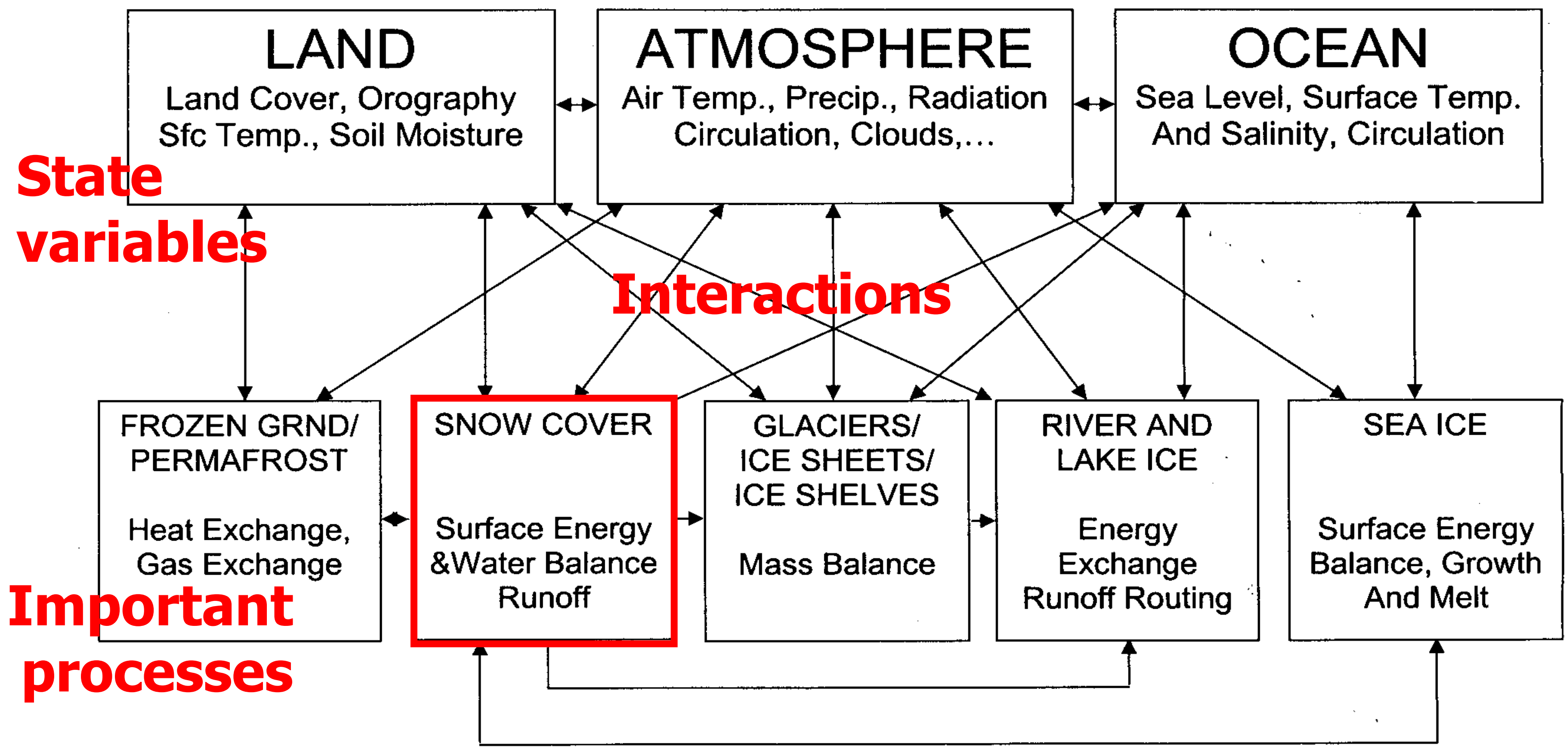
24th Sep. 2010

Outline

- **Part I: Snow Product Analysis in China**
  - Why Snow - a potentially sensitive factor of climate change - debate
  - Need more accuracy snow products, methods?
- **Part II: Passive Microwave remote sensing of snow**
  - Snow emission model – understanding the snow emission…
  - Nowadays, the operational algorithm – Gradient (36/18GHz)
  - Shallow snow situation in China
- **Part II: Possibility analysis of the high frequencies in the shallow snow retrieval**
  - Comparison: *In-situ* snow depth and SMMR, SMM/I, and AMSR-E emission signal
  - Possible algorithm development with high frequencies and analysis
- **Conclusion**

Why Snow?

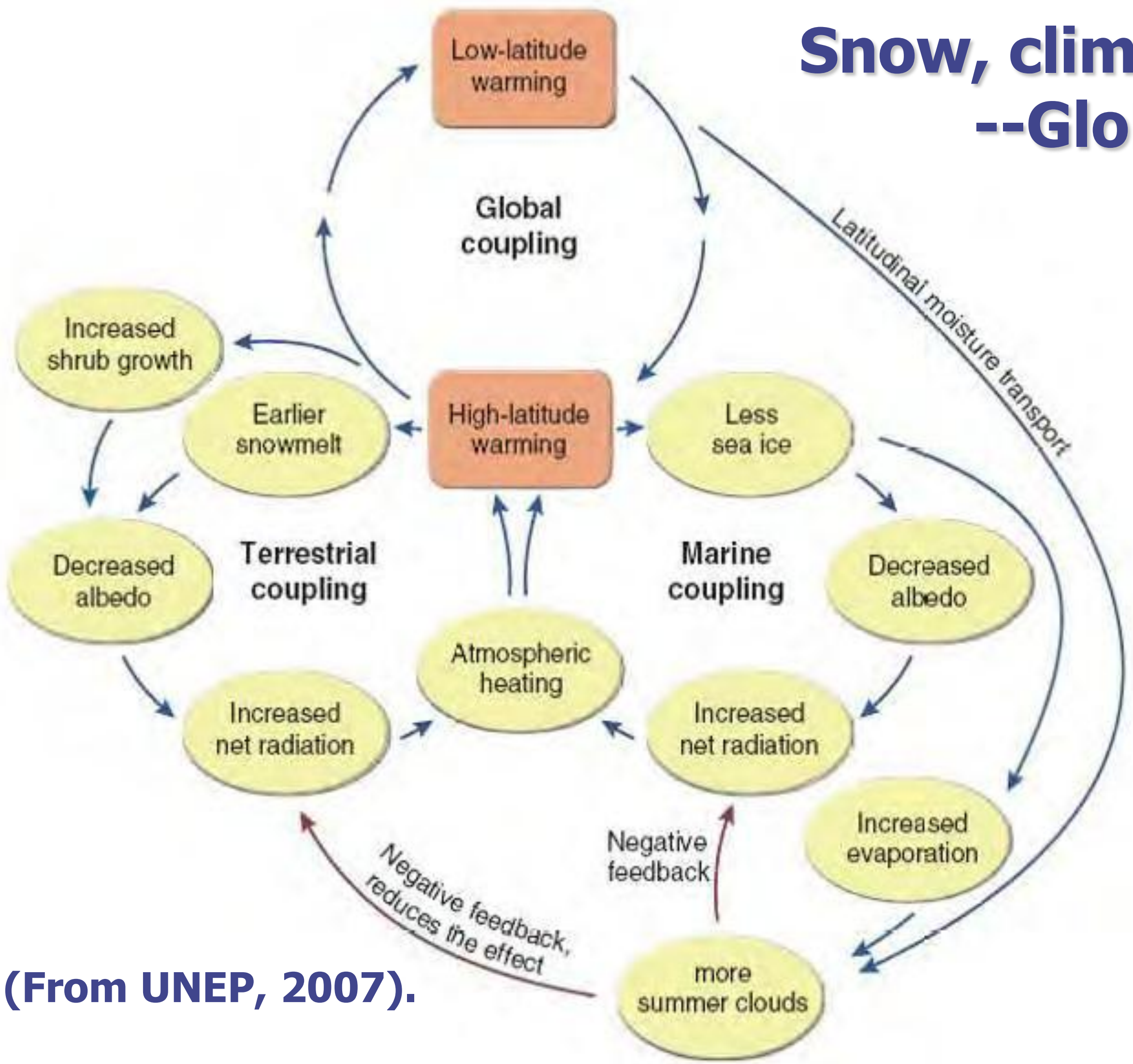
Cryosphere-Climate Interactions



- -List in upper boxes indicate important state variables
- -Lists in lower boxes indicate important processes involved in interactions.
- -Arrows indicate **direct** interactions

Why Snow?

Snow, climate and water cycle --Global warming--



(From UNEP, 2007).

Conceptual diagram on the connectivity of the positive ice/snow albedo feedback, terrestrial snow and vegetation feedbacks and the negative cloud/radiation feedback

Terrestrial Essential Climate Variables

SNOW

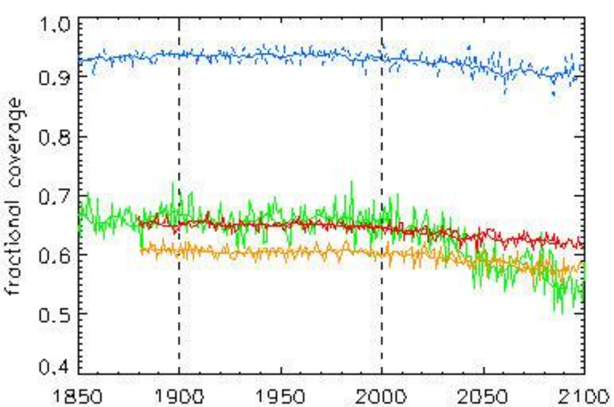
Snow cover

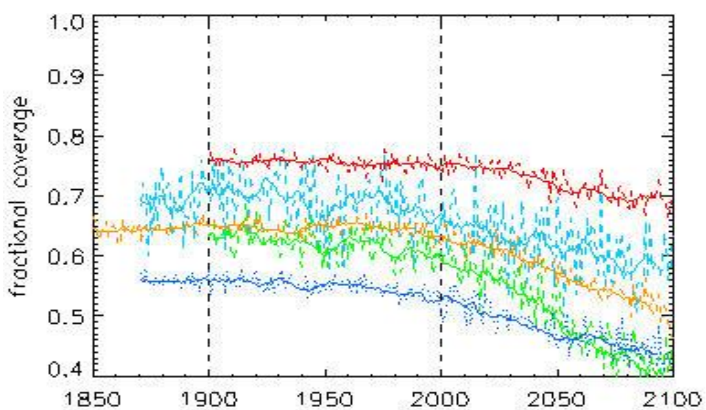
Why Snow?

Snow - a potentially sensitive factor of climate change

- Snow – very important
  - IPCC AR4(2007): Continental-scale snow cover extent (SCE) is a potentially sensitive indicator of climate change.
  - (Foster et al. 1982; Namias 1985; Gleick, 1987) said: Snow is not only a sensitive indicator of climate change, but makes feedbacks to it.
  - Snow has been proposed as a useful indicator in testing and monitoring global climate change (Robinson et al. 1990).
  - …

- Works support IPCC-AR4？





Nine GCM model: shrinking snow cover over Northern

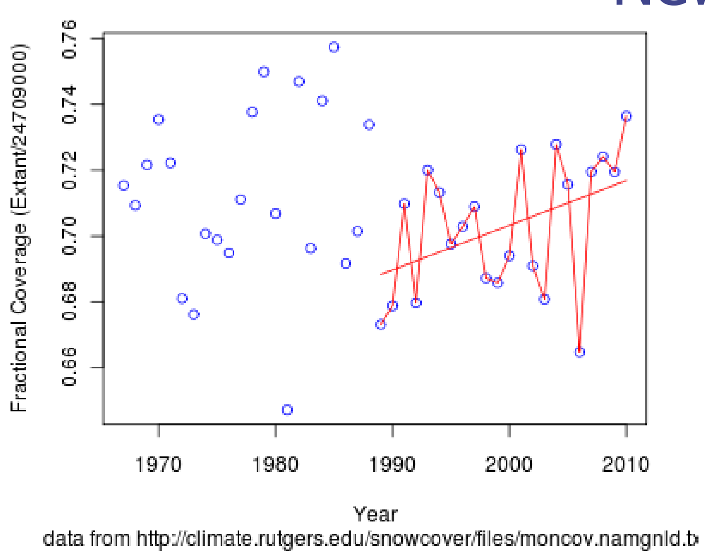
American

（Frei, A. and G. Gong, 2005. ）

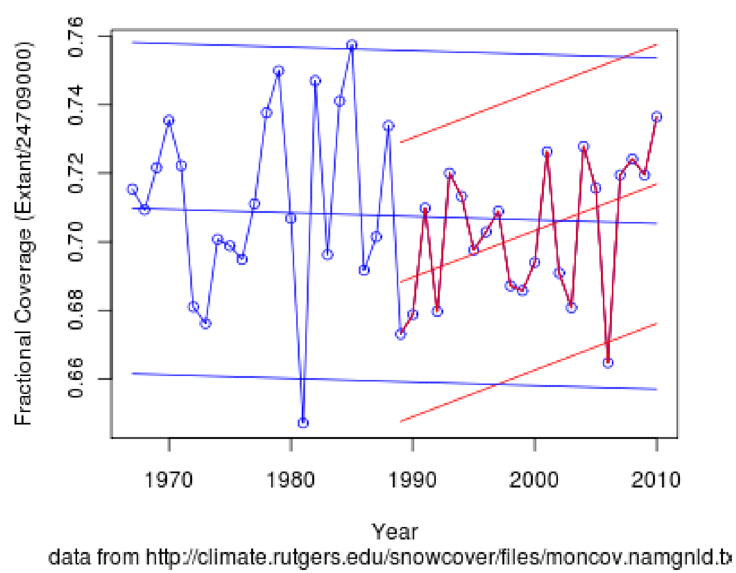
Why Snow? debate

Will Climate Change Affect Snow Cover Over North America?

- ***North American snow models miss the mark – observed trend opposite of the predictions***
  - Goddard uses data from Rutger's Global Snow Lab to claim that the latest 22-year trend for Winter (Dec, Jan, Feb) in the Northern Hemisphere invalidates the CMIP3 modeling of snow extent as presented by Frei and Gong in 2005.



New debate?



China – Publication's View

Snow Cover Distribution, Variability, and Response to Climate Change in Western China

QIN DAHE, 2006

- Data : *SMMR-SD, NOAA-SCA*
  - Results show that western China did not experience a continual decrease in snow cover during the great warming period of the 1980s and 1990s. The positive trend of the western China snow cover is consistent with increasing snowfall, but is in contradiction to regional warming.

Potential impact of climate change on snow cover area in the Tarim River basin

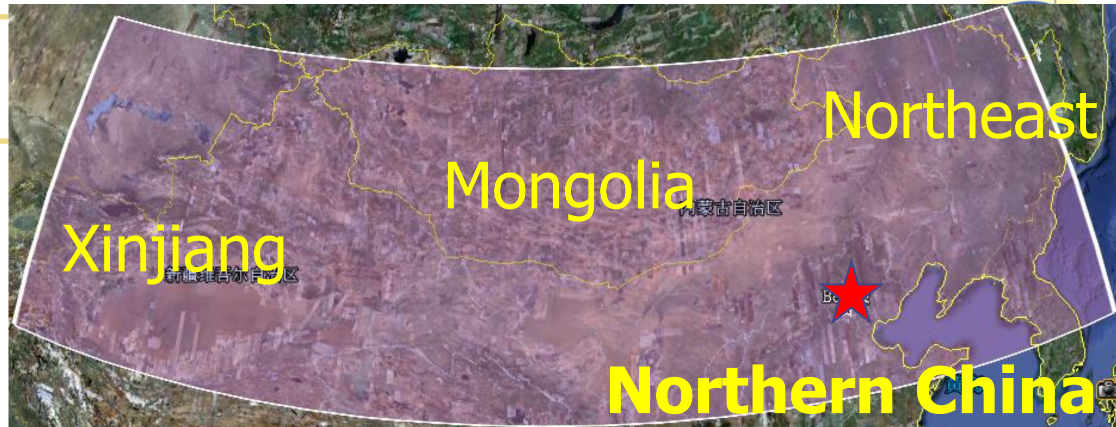
Xu Changchun, 2007

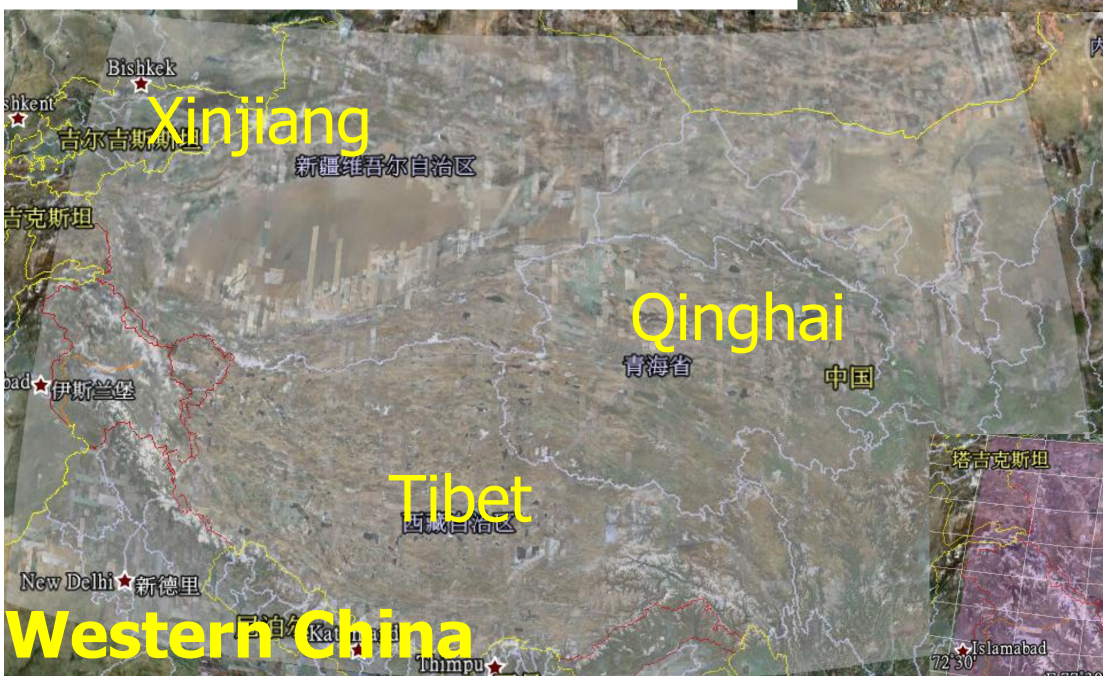
- Data: 1982–2001, station data
  - The SCA of the entire basin showed a slowly increasing trend.
  - Correlation analysis implied that the SCA change in the cold season was positively correlated with the contemporary precipitation change, but had no strong correlation with the contemporary temperature change.

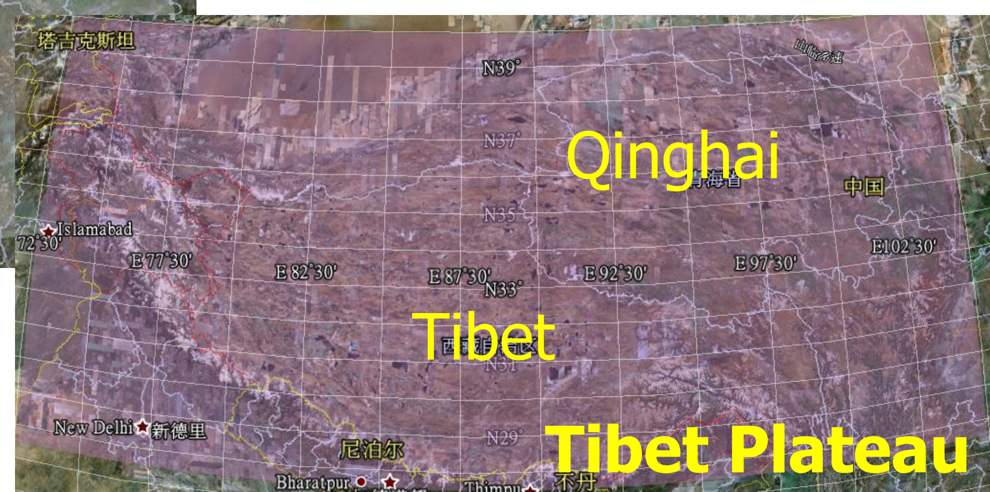
Our Analysis in China:

Data:

- ✓Rutger snow product
- ✓SSM/I SWE product
- ✓NOAA IMS 4Km/24Km

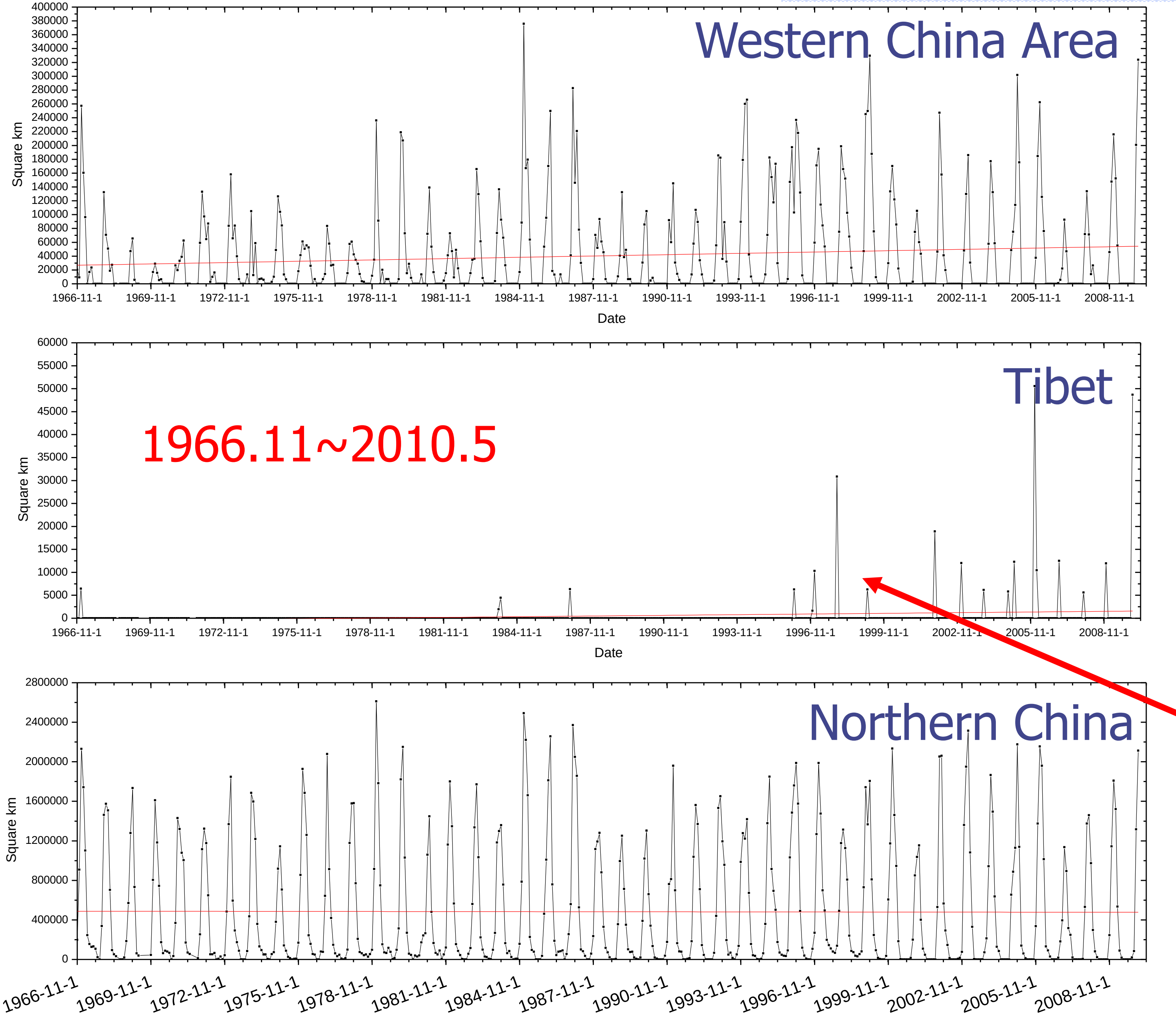






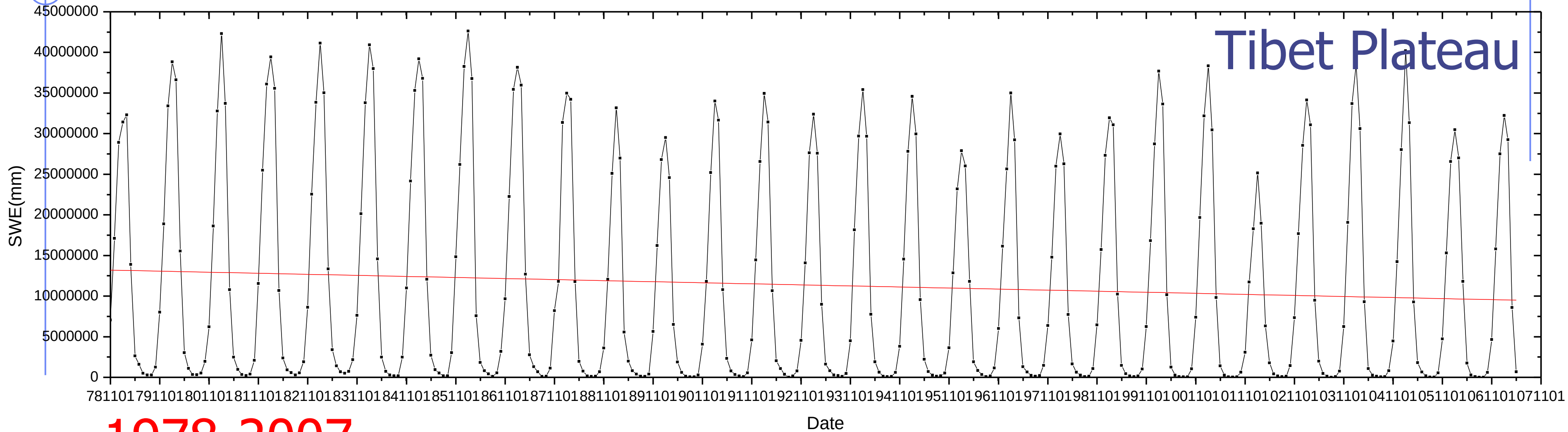
The select areas in China

Rutger snow product

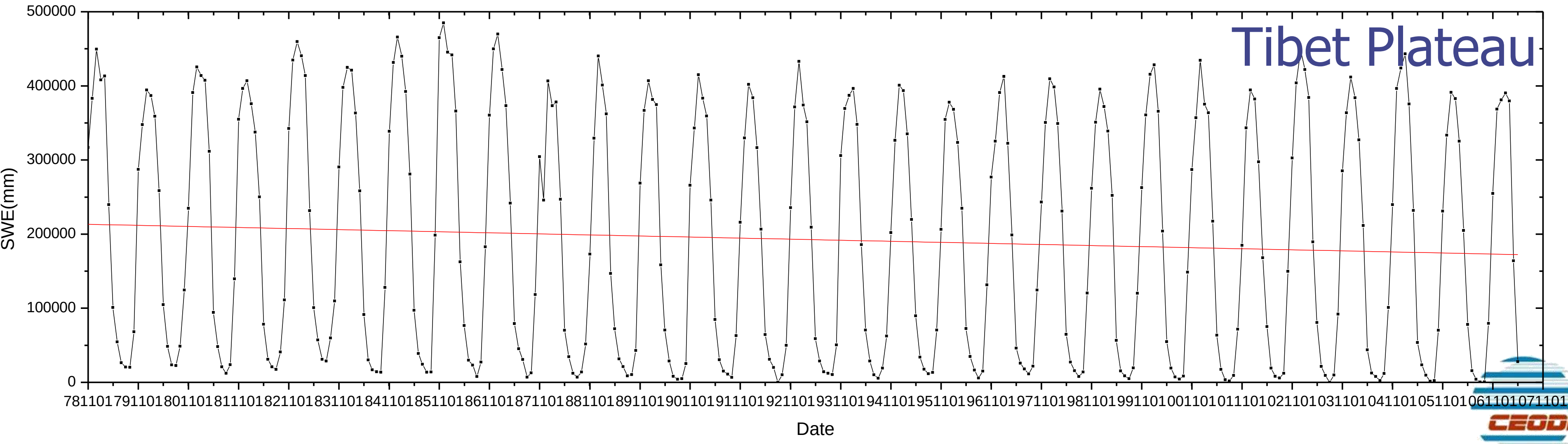


Agree well with the previous publication, but the snow cover area over Tibet is not quite right.

China – decreasing SCA/SWE over Tibet

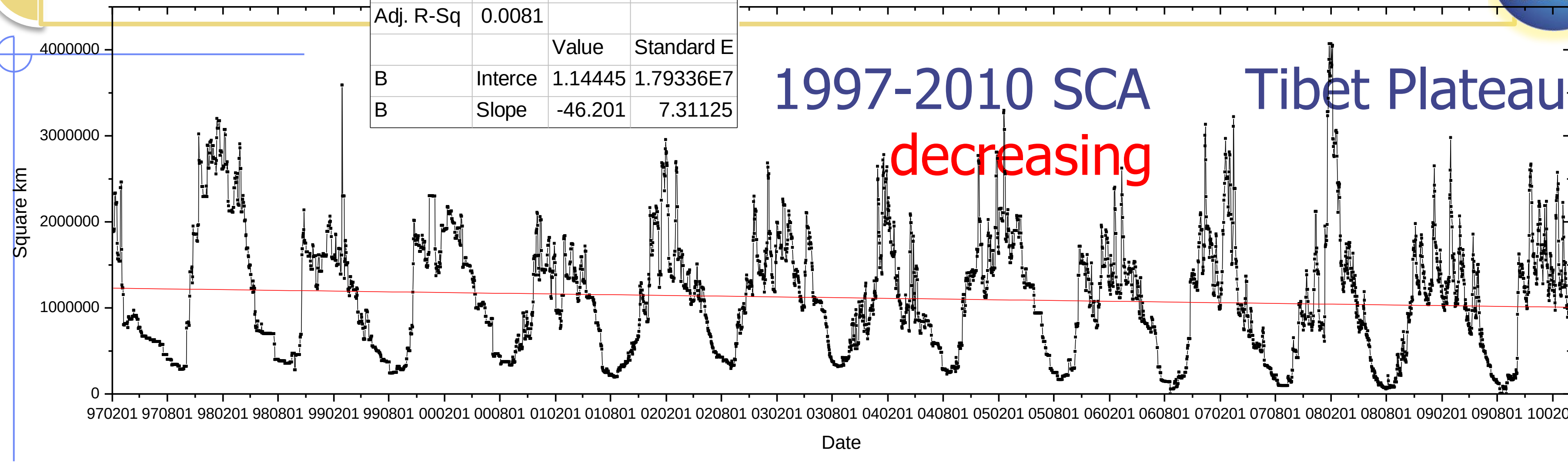


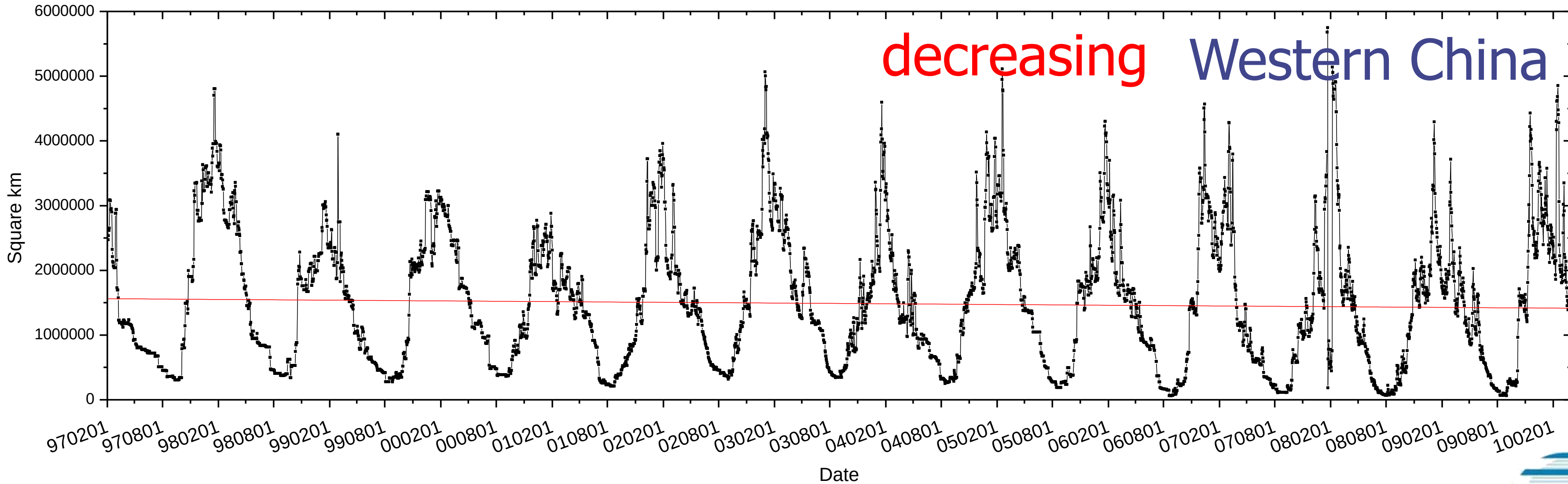
1978-2007



NOAA IMS

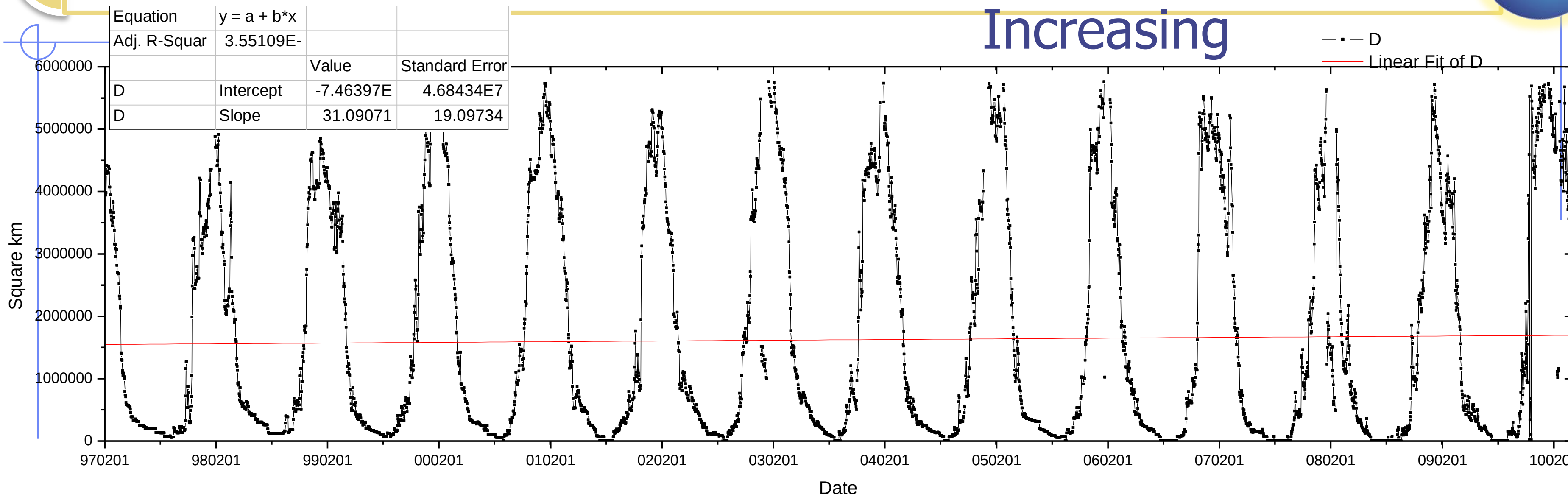
Equation	y = a +		
Adj. R-Sq	0.0081		
		Value	Standard E
B	Interce	1.14445	1.79336E7
B	Slope	-46.201	7.31125





NOAA IMS

1997-2010 SCA Northern China Increasing



The NOAA IMS show totally different Trend with above two products

We get:

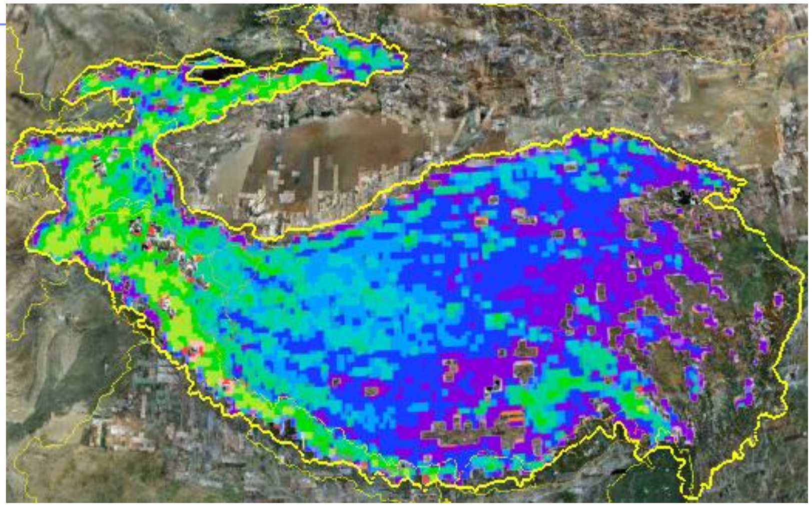
✓Different product provide different view on the snow factor

✓The SCA from Rugter is not quite right over Tibet China.

✓SWE is a quite valuable parameter for its long times series records (SMMR, SMM/I)

Need intercomparison and validation of certain snow cover products.

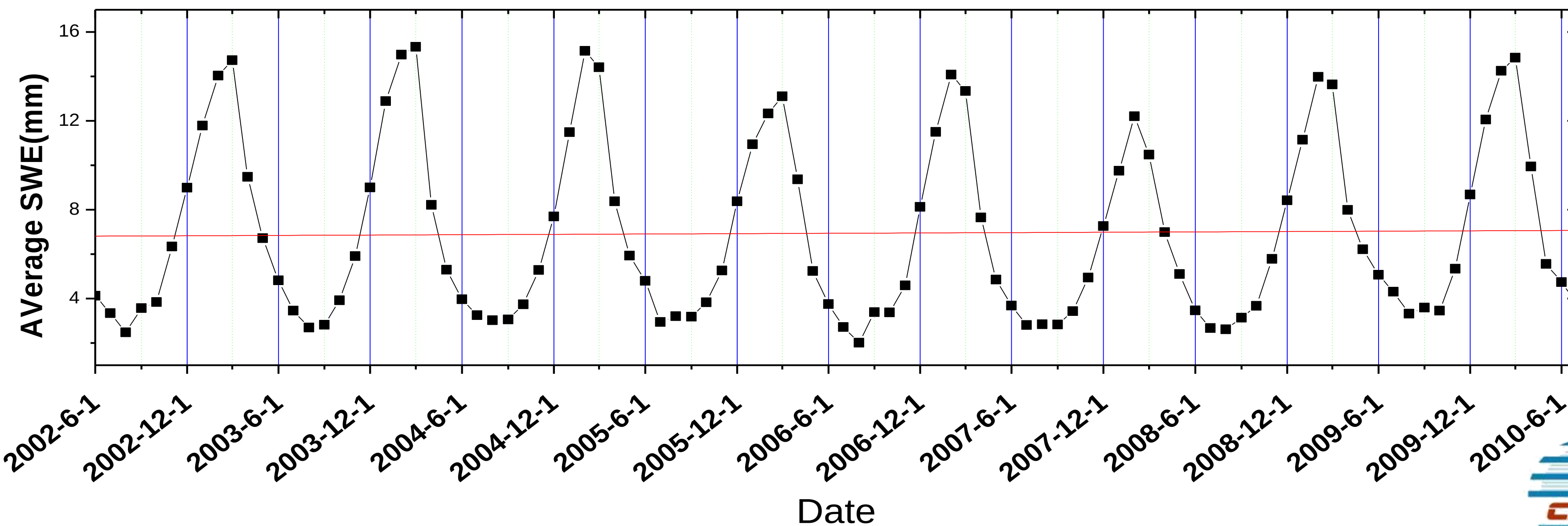
More Detail over Tibet Plateau – AMSR-E SWE product and MODIS SCF

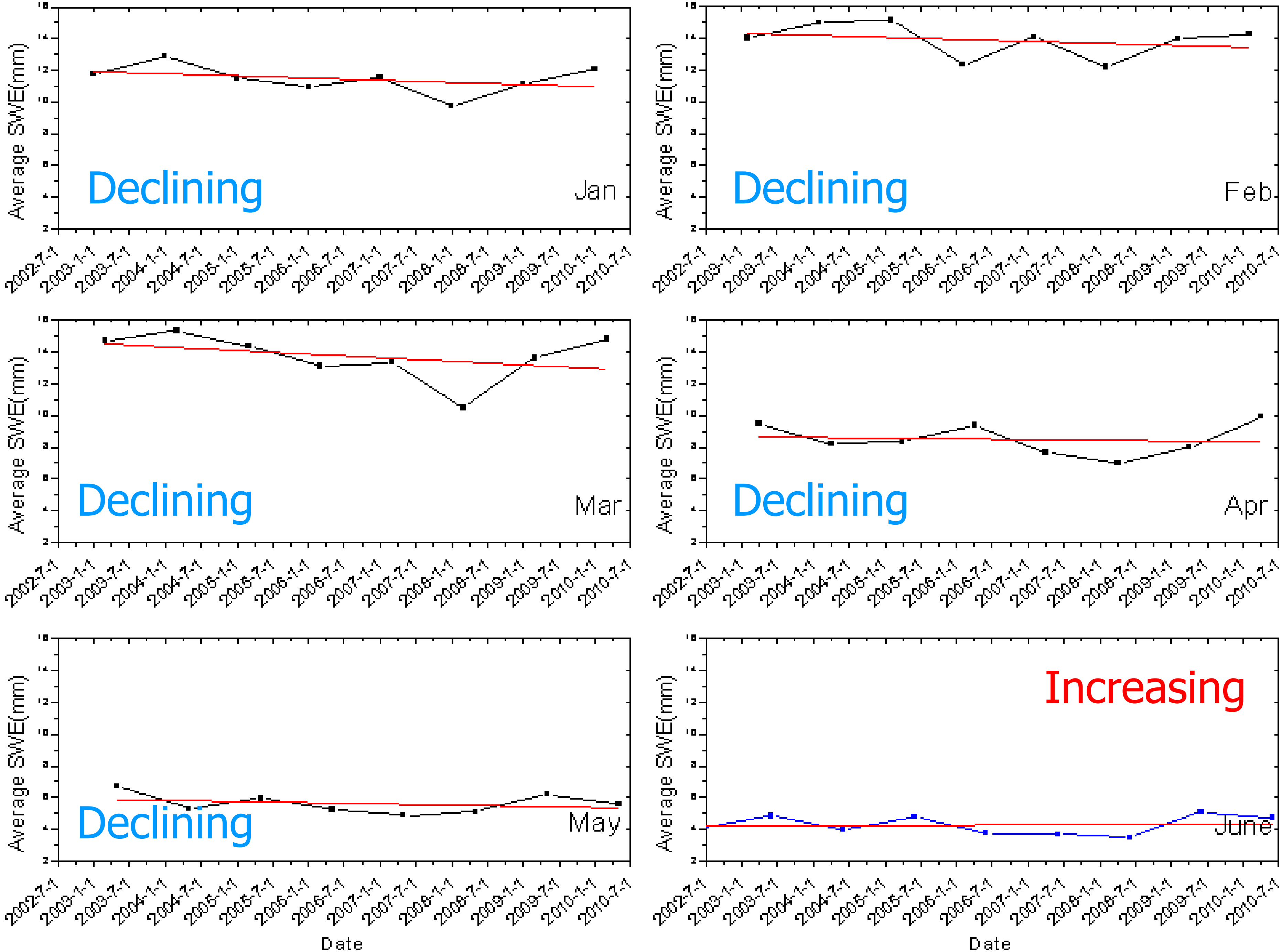


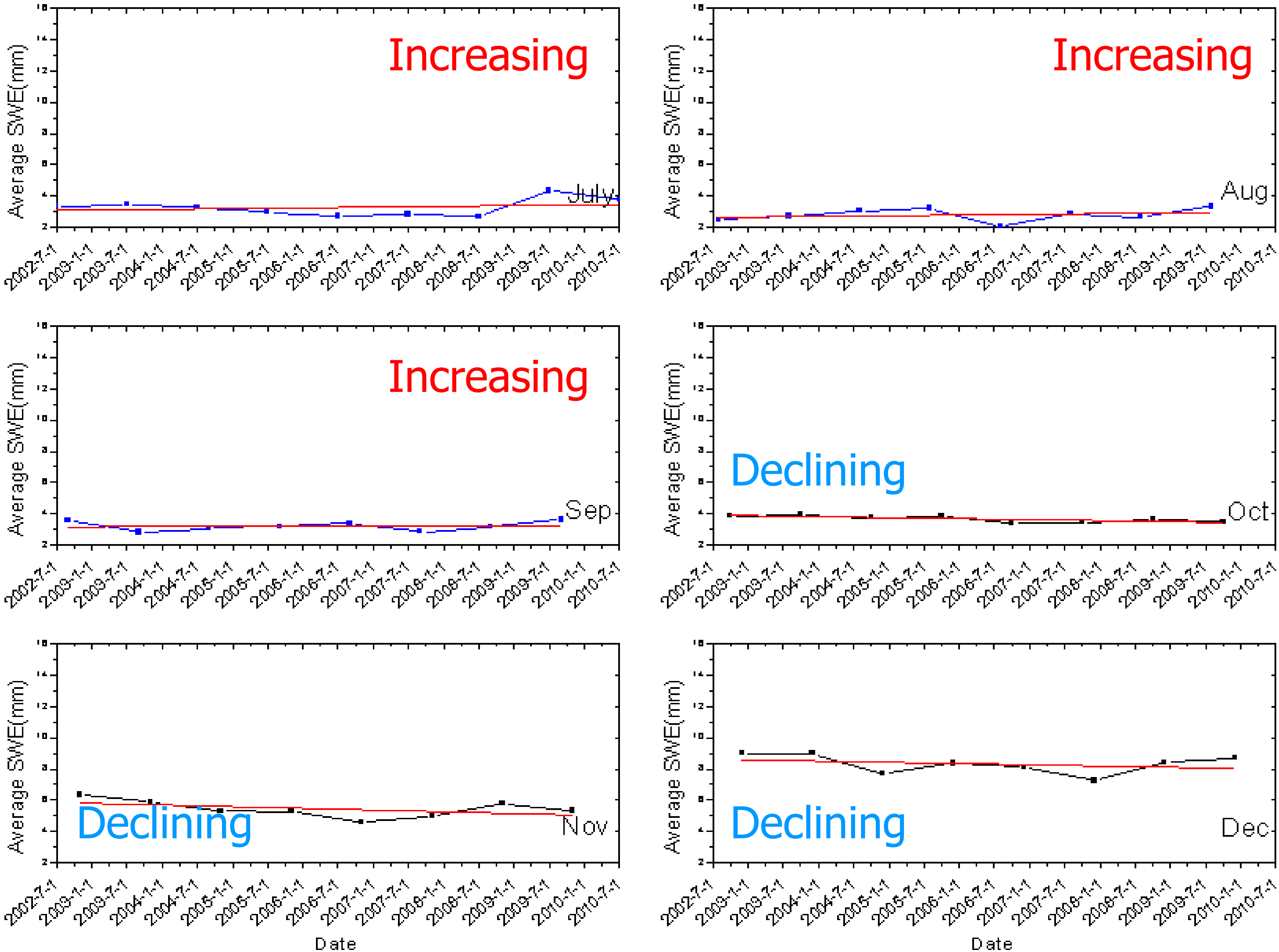
Tibet Plateau - according to the air pressure (<700hpa)

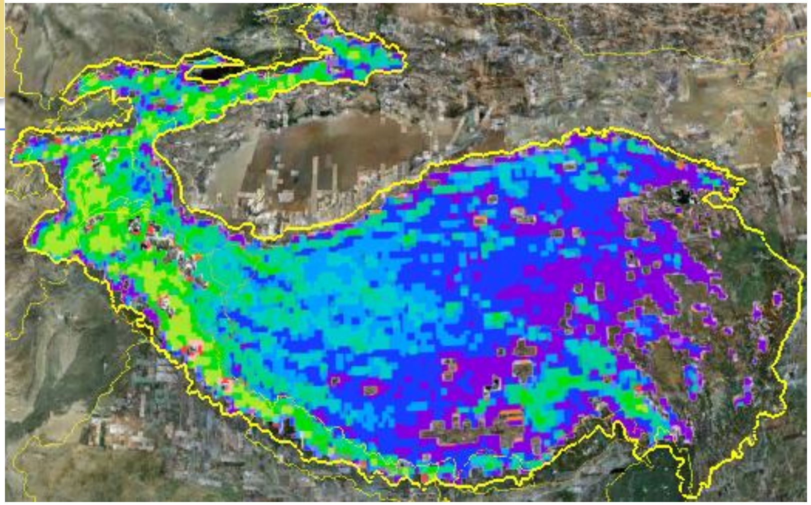
AMSR-E SWE

Trend of average AMSR-E SWE(mm) from 2002.6 to 2010.7




Average SWE(mm)
Declining
Jan
Declining
Feb
Declining
Mar
Declining
Apr
Declining
May
Increasing
June
2002-7-1
2003-1-1
2003-7-1
2004-1-1
2004-7-1
2005-1-1
2005-7-1
2006-1-1
2006-7-1
2007-1-1
2007-7-1
2008-1-1
2008-7-1
2009-1-1
2009-7-1
2010-1-1
2010-7-1
Date

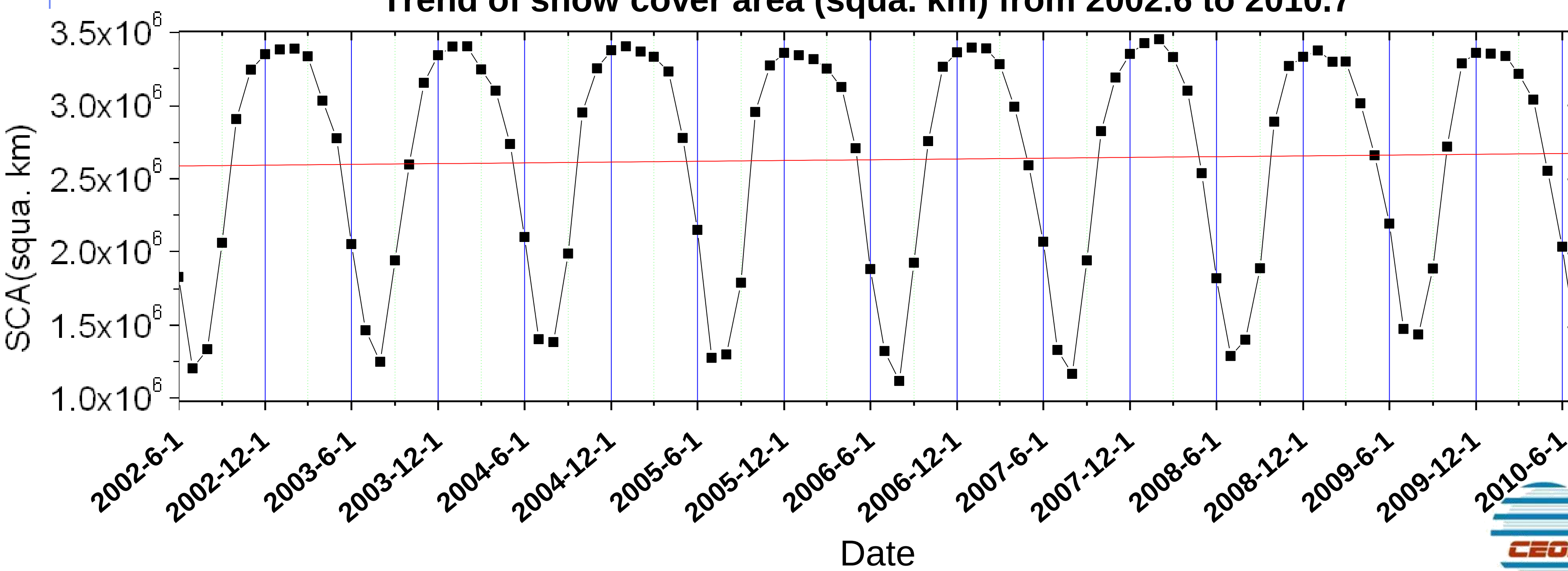

Increasing
July
Increasing
Aug
Increasing
Sep
Declining
Oct
Declining
Nov
Declining
Dec
Average SWE(mm)
2002-7-1
2003-1-1
2003-7-1
2004-1-1
2004-7-1
2005-1-1
2005-7-1
2006-1-1
2006-7-1
2007-1-1
2007-7-1
2008-1-1
2008-7-1
2009-1-1
2009-7-1
2010-1-1
2010-7-1
Date

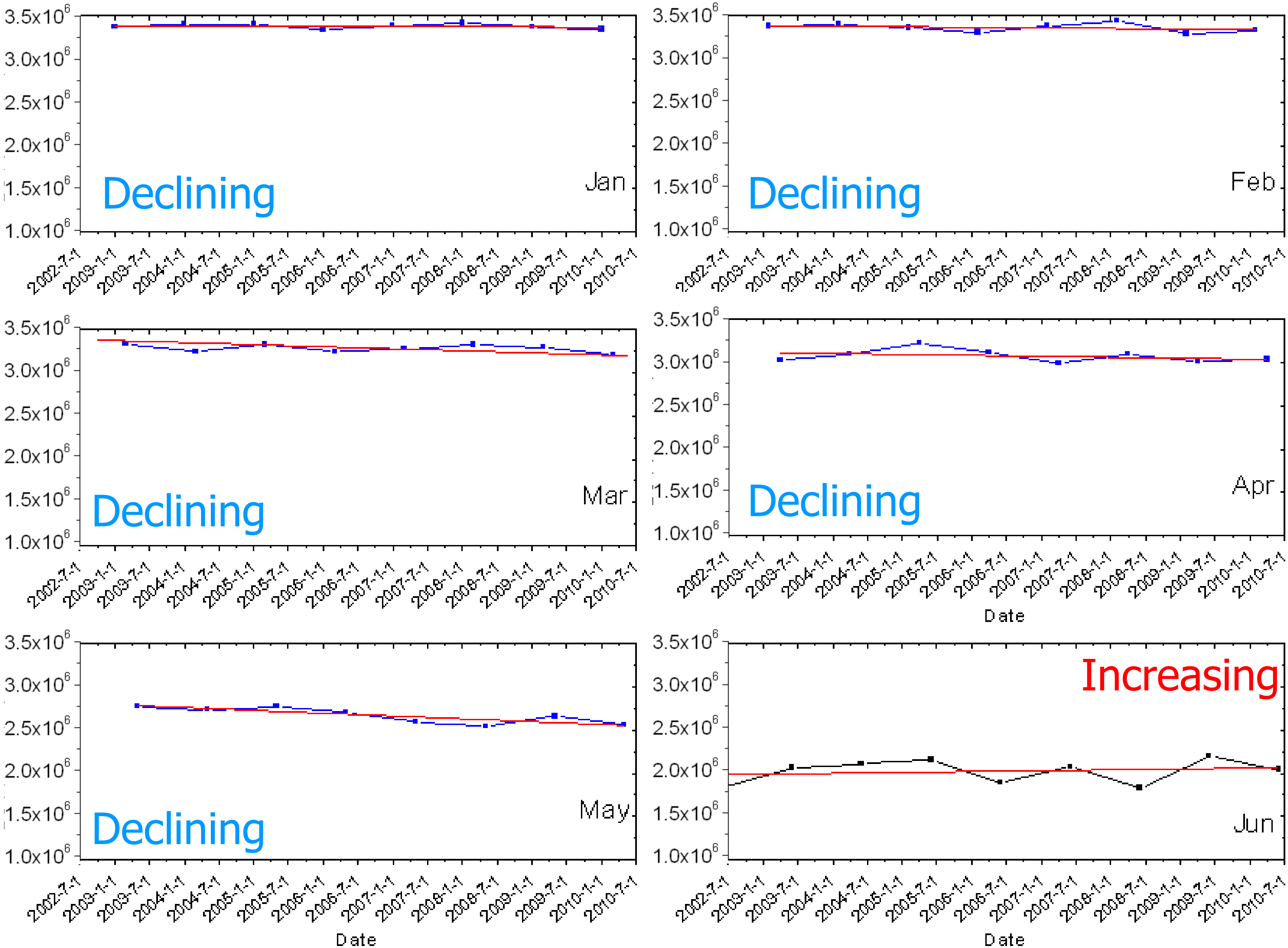


Tibet Plateau - according to the air pressure (<700hpa)

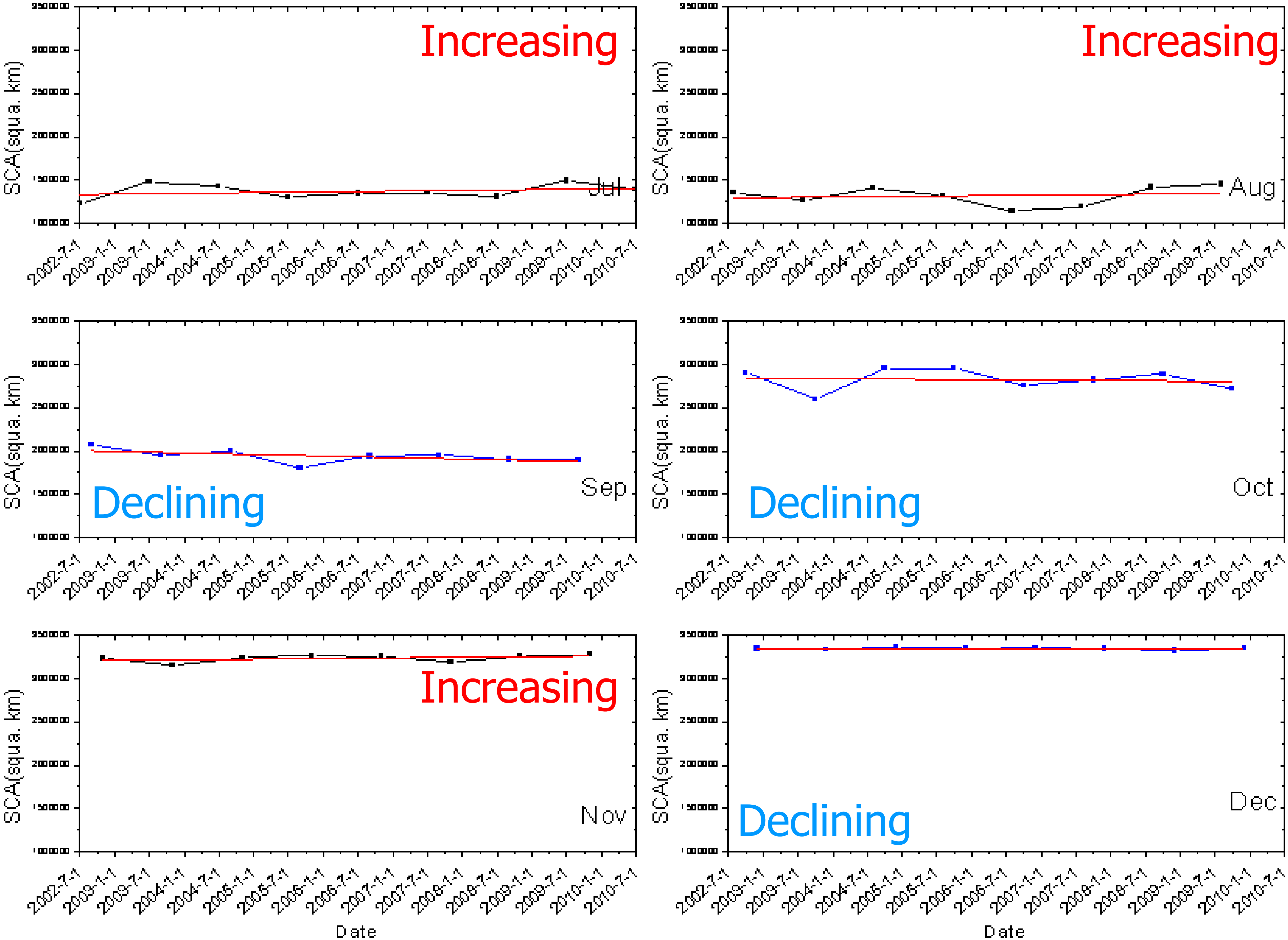
AMSR-E SCA

Trend of snow cover area (squa. km) from 2002.6 to 2010.7



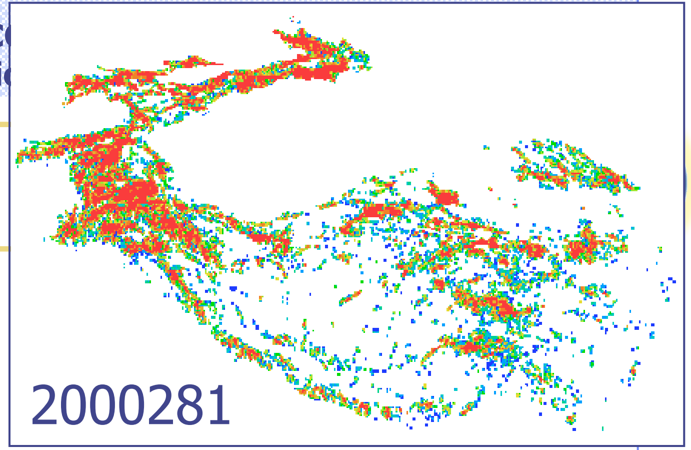


3.5x10^6
3.0x10^6
2.5x10^6
2.0x10^6
1.5x10^6
1.0x10^6
Declining
Jan
Declining
Feb
Declining
Mar
Declining
Apr
Declining
May
Increasing
Jun
2002-7-1
2003-1-1
2003-7-1
2004-1-1
2004-7-1
2005-1-1
2005-7-1
2006-1-1
2006-7-1
2007-1-1
2007-7-1
2008-1-1
2008-7-1
2009-1-1
2009-7-1
2010-1-1
2010-7-1
Date


Increasing
Jul
Increasing
Aug
Declining
Sep
Declining
Oct
Increasing
Nov
Declining
Dec
SCA(squa. km)
350000
300000
250000
200000
150000
100000
2002-7-1
2003-1-1
2003-7-1
2004-1-1
2004-7-1
2005-1-1
2005-7-1
2006-1-1
2006-7-1
2007-1-1
2007-7-1
2008-1-1
2008-7-1
2009-1-1
2009-7-1
2010-1-1
2010-7-1
Date

2010 ABC
Observati

MODIS SCF - SCA

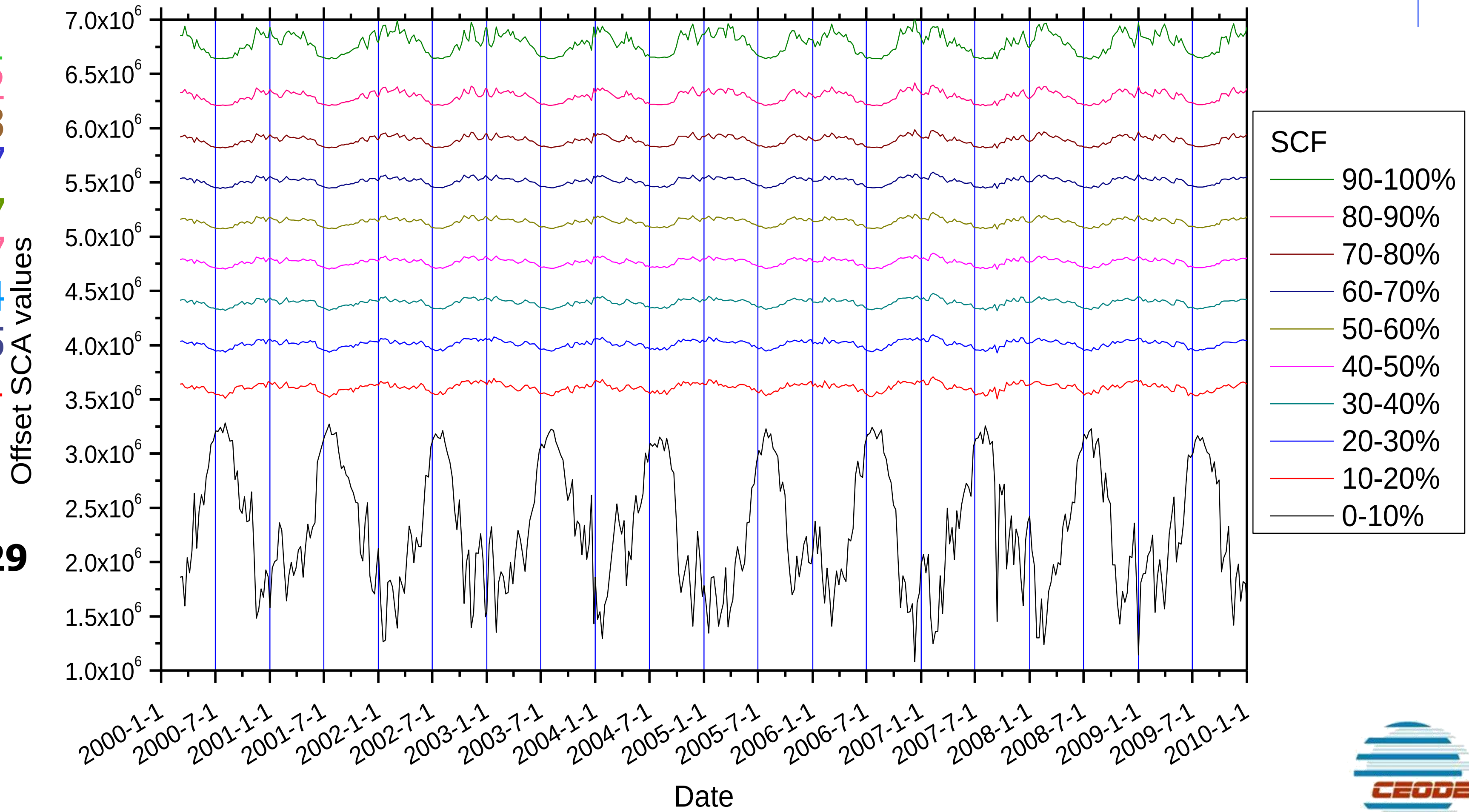


MODIS SCF – SCA - Terra

Trend Slope

3.94271
2.15802
1.63373
1.41097
1.41097
1.22657
1.26444
1.21955
1.57501

-24.41329

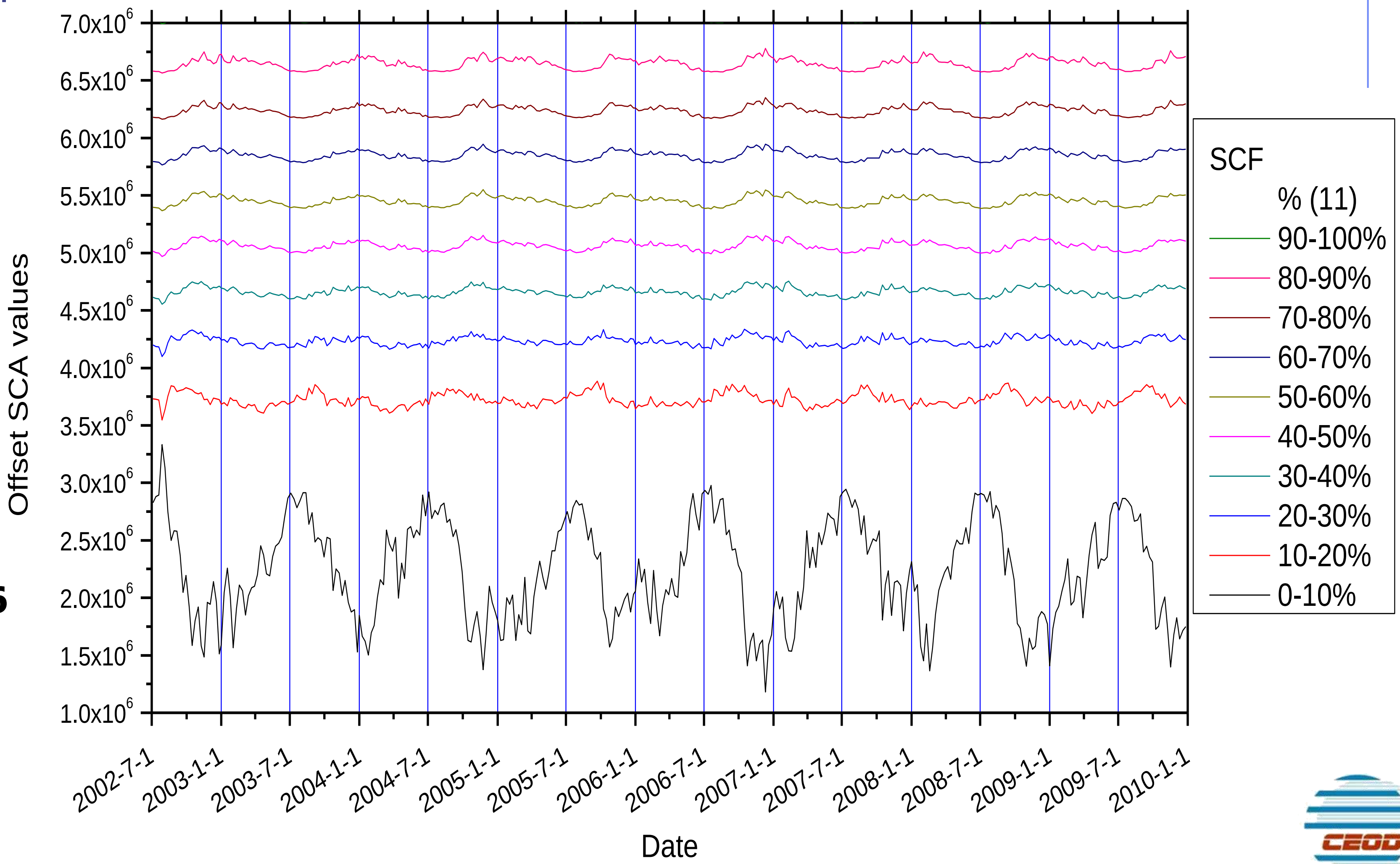


MODIS SCF - SCA

MODIS SCF – SCA - Aqua

Trend Slope
5.58434
2.89257
2.13665
1.60258
1.60258
1.43406
1.82755
1.69405
1.73758

-23.16836



We get:

- Over Tibet Plateau
  - AMSR-E and MODIS data show the increasing trend on SWE and SCA from the nowadays satellite data.
  - AMSR-E SWE and SCA are typically increasing in the summer time and decreasing in the winter time
  - MODIS SCA shows a increasing trend over the relative permanent snow cover area and only the SCF is less than 10% are quickly decreasing
- That indicates,
  - Snow cover over Plateau is quite different with other place over Northern Hemisphere
  - Need accuracy estimation of the snow cover parameters for a long time to convince the trend analysis to corresponding the global environment change
  - …

Need More accurate snow data

Research on snow and climate change

To evaluate how a warmer climate is likely to alter the snow cover

- Observation - measurement
  - QIN DAHE,2006， Xu Changchun,2007:
  - NSIDC etc…

- Computer-generated simulations
  - GCM snow product (Foster, 1996, Gong et al. 2004)
  - Steve Vavrus (2007) simulate the influence of snow in climate system
  - Mellander et al. 2005：physically based Soil-Vegetation-Atmosphere Transfer model - reproduced the variability in snow depths by different environment.
  - …

Measurement methods——EO for snow cover

In situ measurements

- Snow depth (Point- and line-measurement: snow stakes, snow ruler, Ultrasonic ranging device)
- Snow water equivalent (SWE) (Snow course)

Satellite measurements

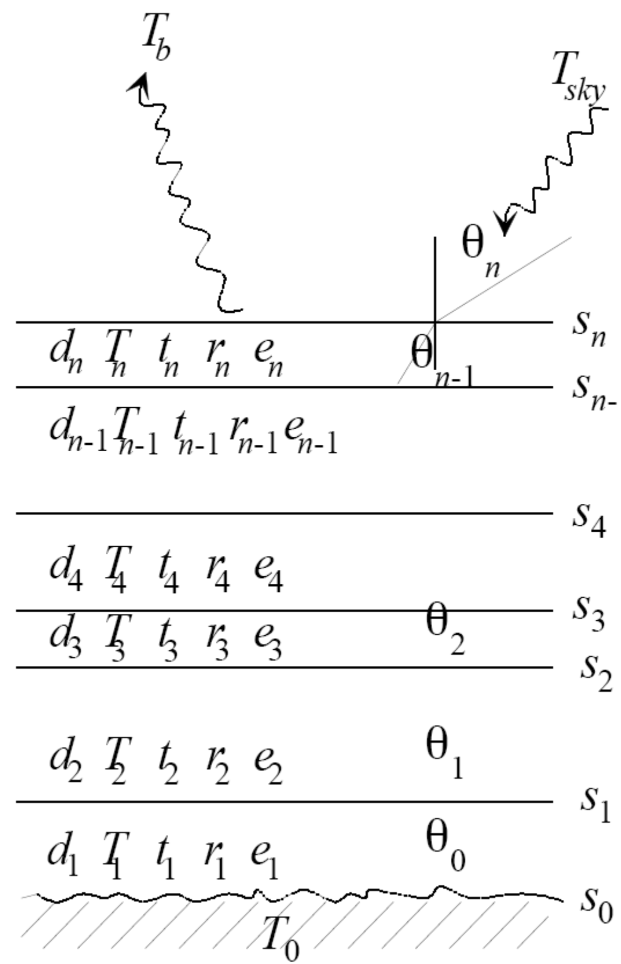
- Stated GCOS requirements for SWE include daily global satellite coverage at 25 km resolution—— satellite can…
- Optical remote sensing – cloud influence, only the SCA
- Microwave remote sensing - all weather, SCA, SWE/Snow depth
- …

Passive Microwave remote sensing of snow

- Snow emission model – understanding the snow microwave emission
  - DMRT – theoretical…
  - MELMES – multi-layer model
  - HUT Snow Emission Model
    - – 2010 now extent to multilayer modal
  - …

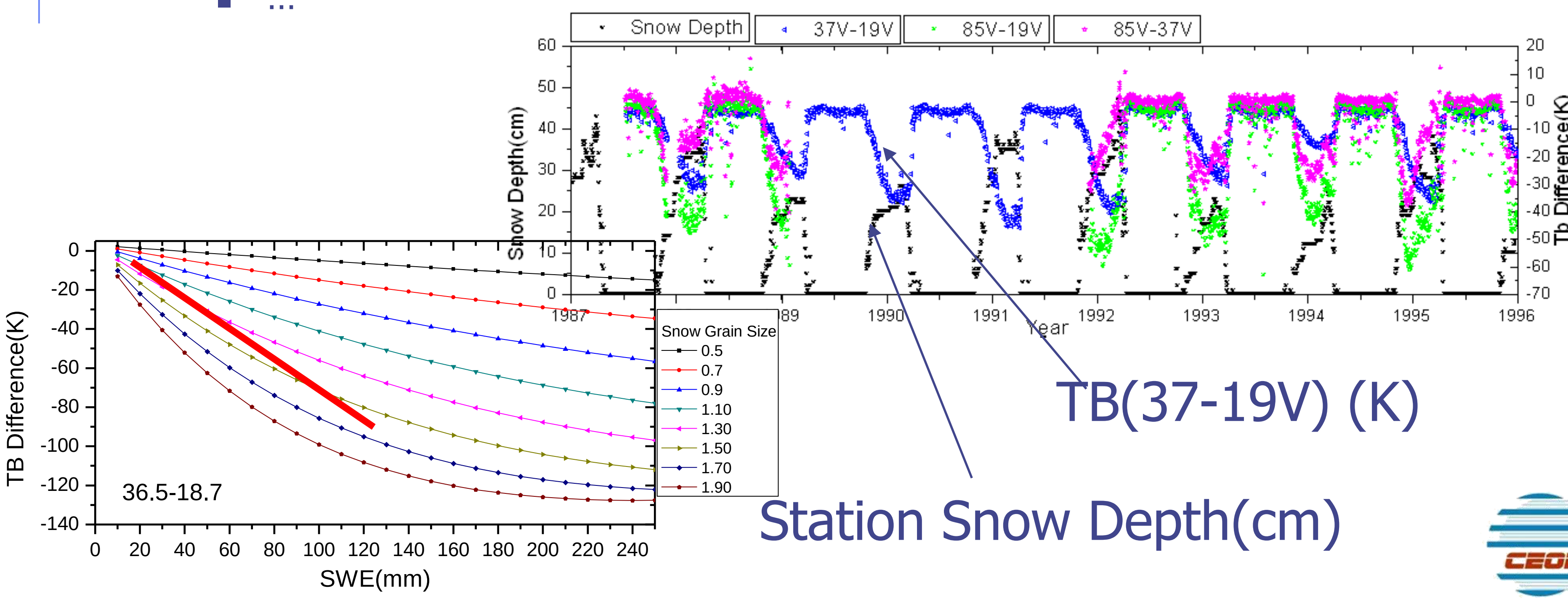
For dry snow

✓Snow Temperature Profile
✓Snow grain size profile
✓Snow density profile
✓Snow depth (SD)
✓Interface roughness

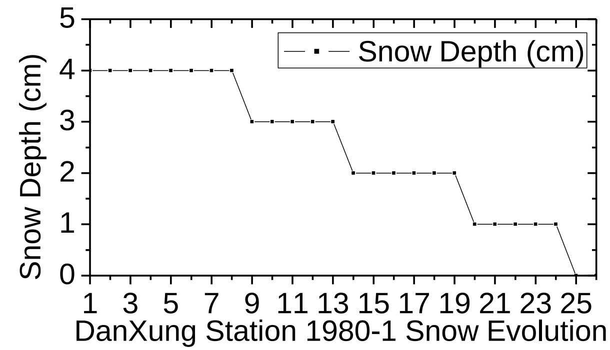


Passive Microwave remote sensing of snow

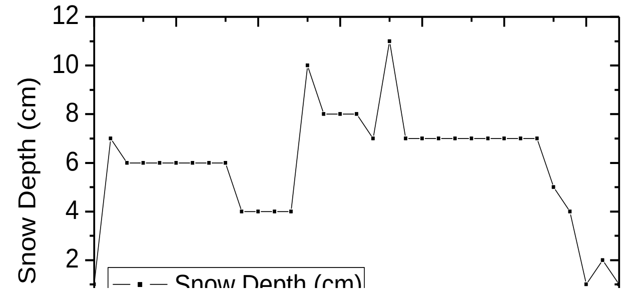
- Algorithms
  - Basically, base on the satellite brightness temperature (TB) difference between 36GHz and 18GHz
  - Goodison & Walker,1995:SMMR & SSM/I, TB(19V-37V)
  - Goita et al.,1997: forest area TB(19V-37V)
  - Kelly,Chang,Foster,& Hall,2001: second order of TB(19V-37V)
  - Pulliainen, & Hallikainen,2001, iteration algorithm (match)
  - …



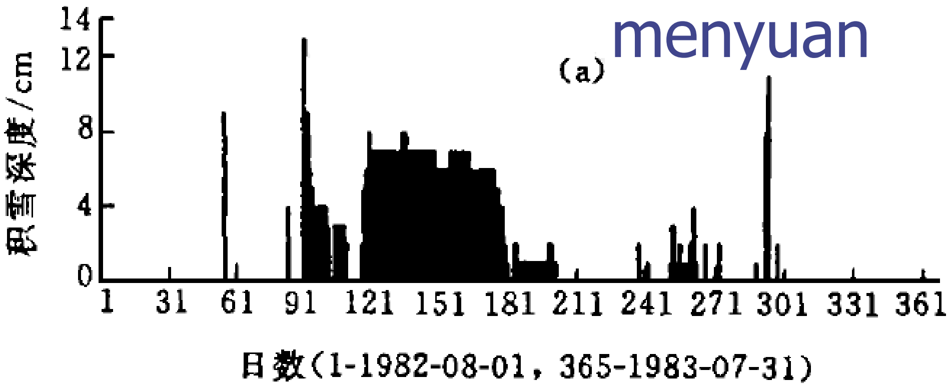
Shallow snow situation in China – western China, especially the Tibet area



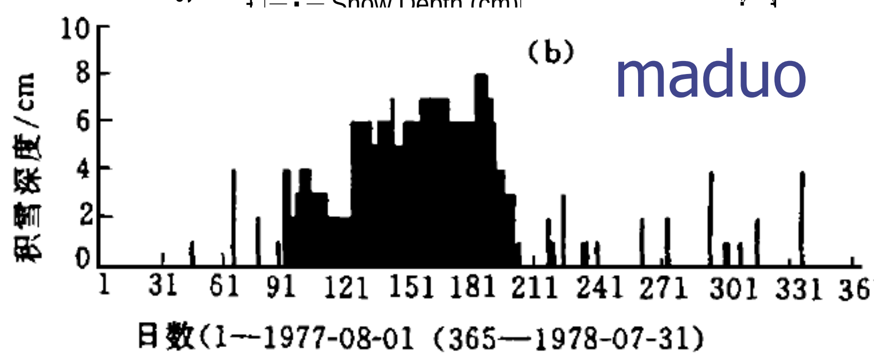
- ✓shallow snow over Tibet area
  - ✓<15cm or 20cm



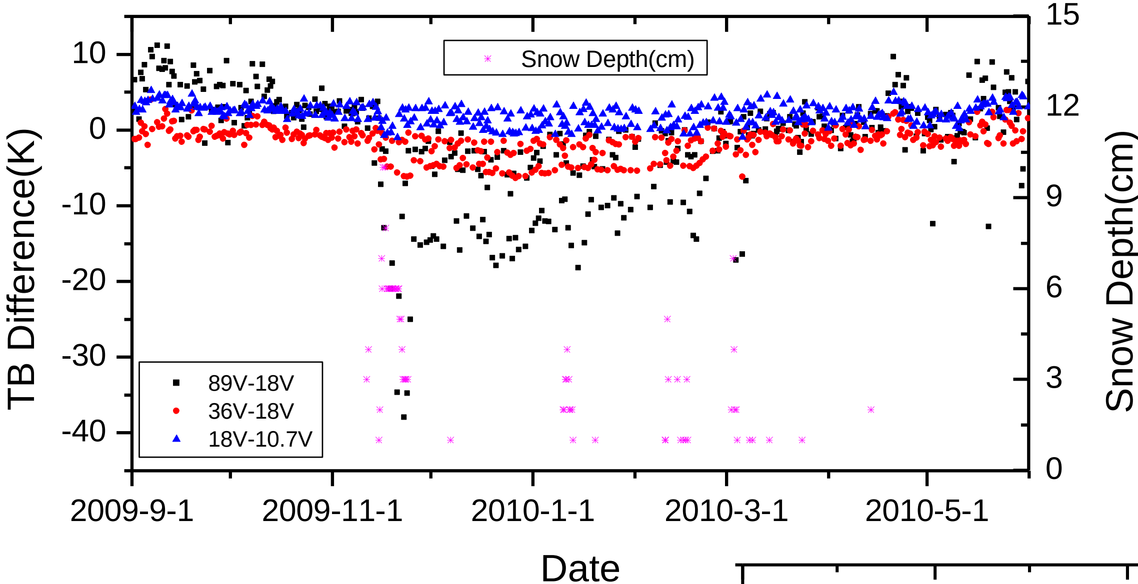
menyuan



maduo



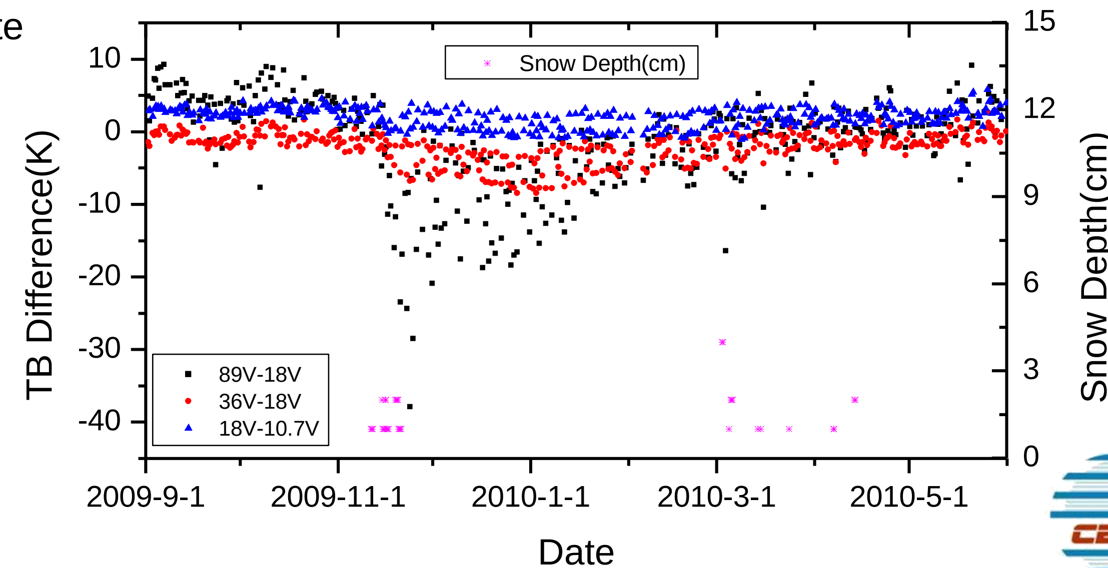
Shallow snow situation in China – western China



52985 Hezheng, Gansu (35.42N, 103.33E)

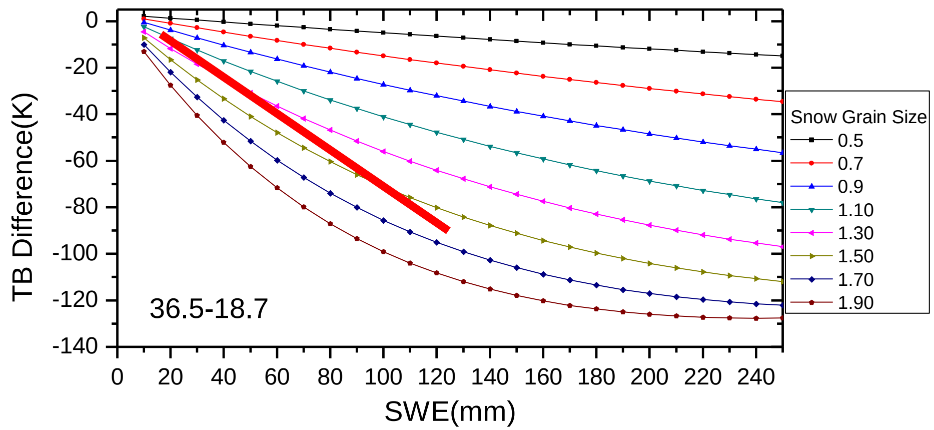
Snow depth < 10cm

56093 Minxian, Gansu (34.43N, 104.02E)

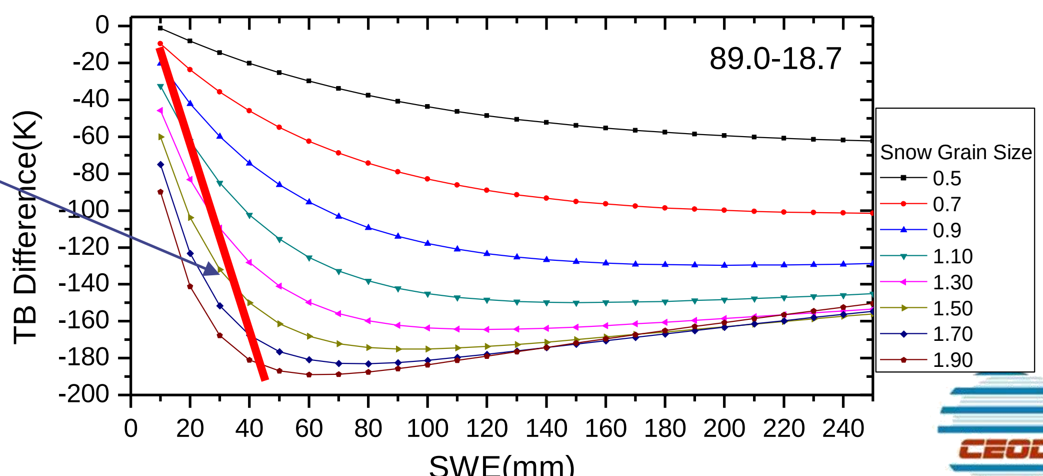


Possibility analysis of the high frequencies in the shallow snow retrieval

HUT snow model simulation

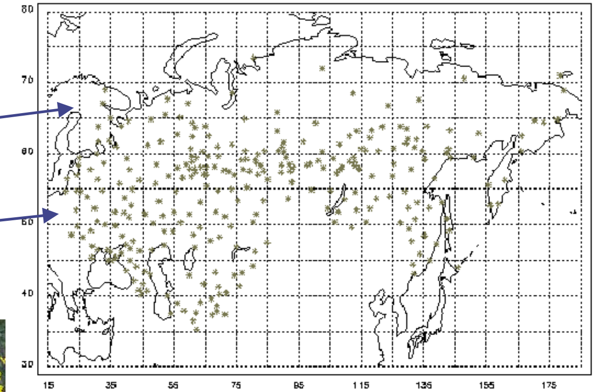


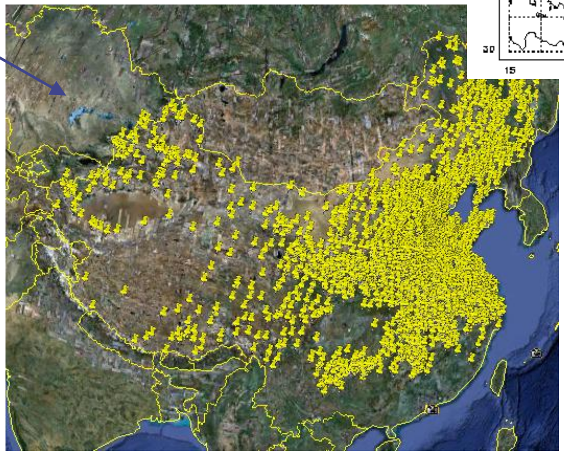
89GHZ gradient
Shallow snow sensitive

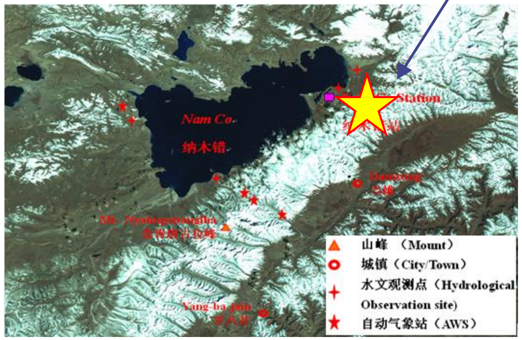


Comparison: In-situ snow depth and SMMR, SMM/I, and AMSR-E emission signal

- Snow depth (cm)
  - the Former Soviet 284 station records V2.0 (1966~1996)
  - The snow depth (cm) over China (2009.9~2010.5)
  - NamCo station snow measurement for one whole winter (2007~2008)
- Satellite dataset
  - SMMR(1978~1987)
  - SSM/I (1987~1996)
  - AMSR-E swath data

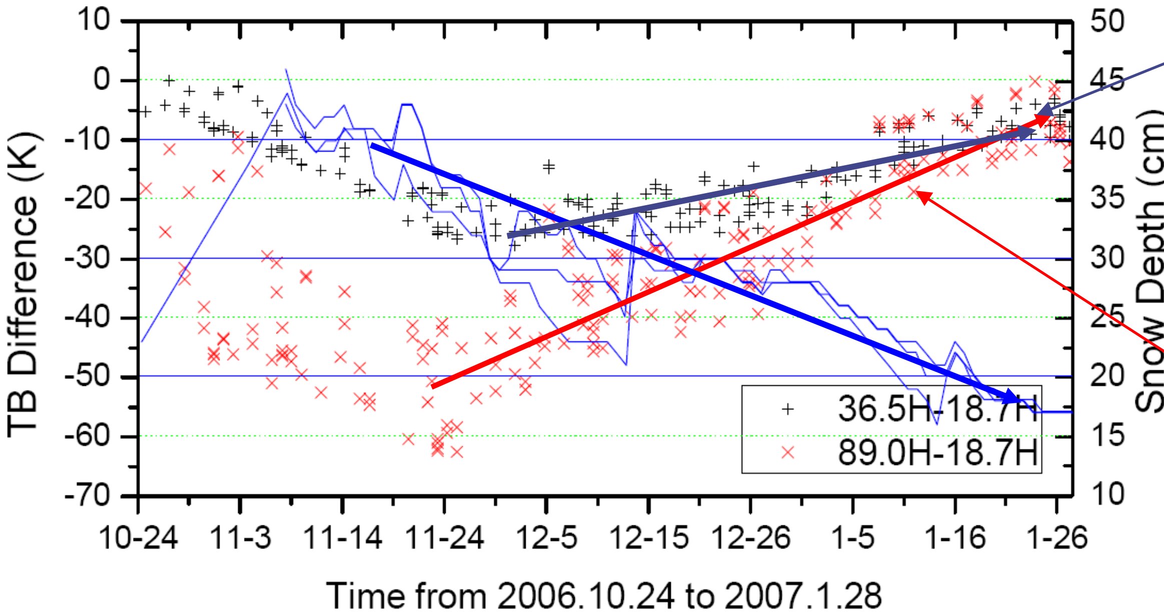






Comparison of the traditional algorithm records and Snow depth

Snow depth (cm) from NamCo station and AMSR-E TBs

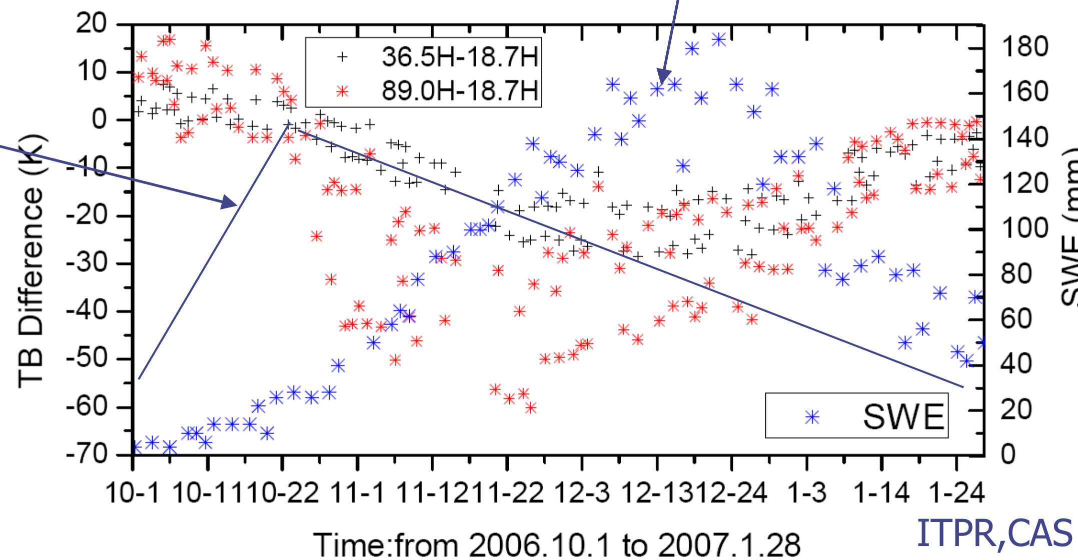


TB(35GHz-18.7GHz)

TB(89GHz-18.7GHz)

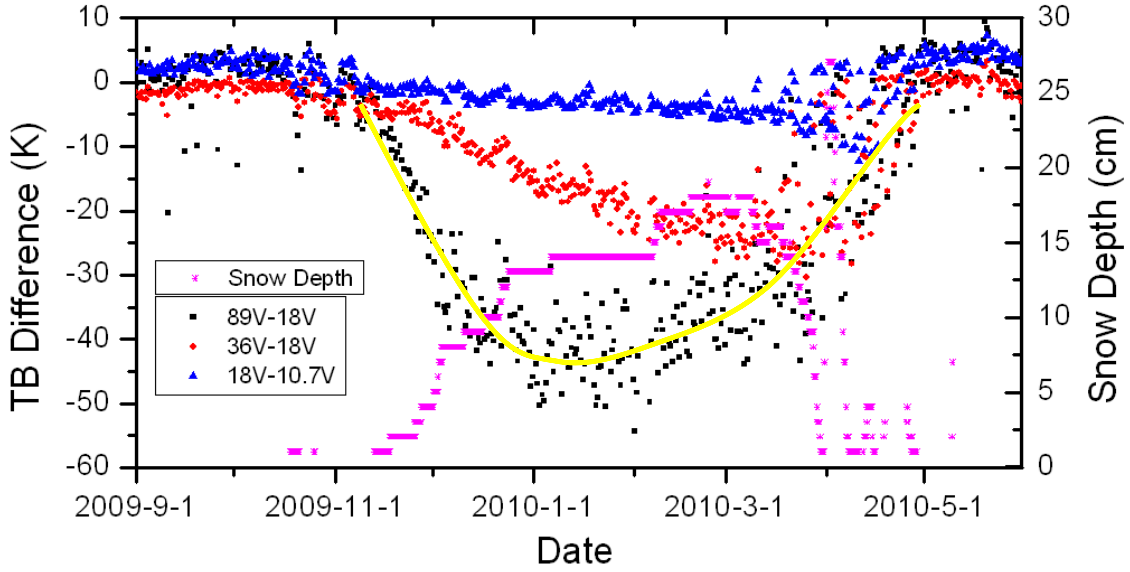
SWE (mm)

Snow depth (cm)

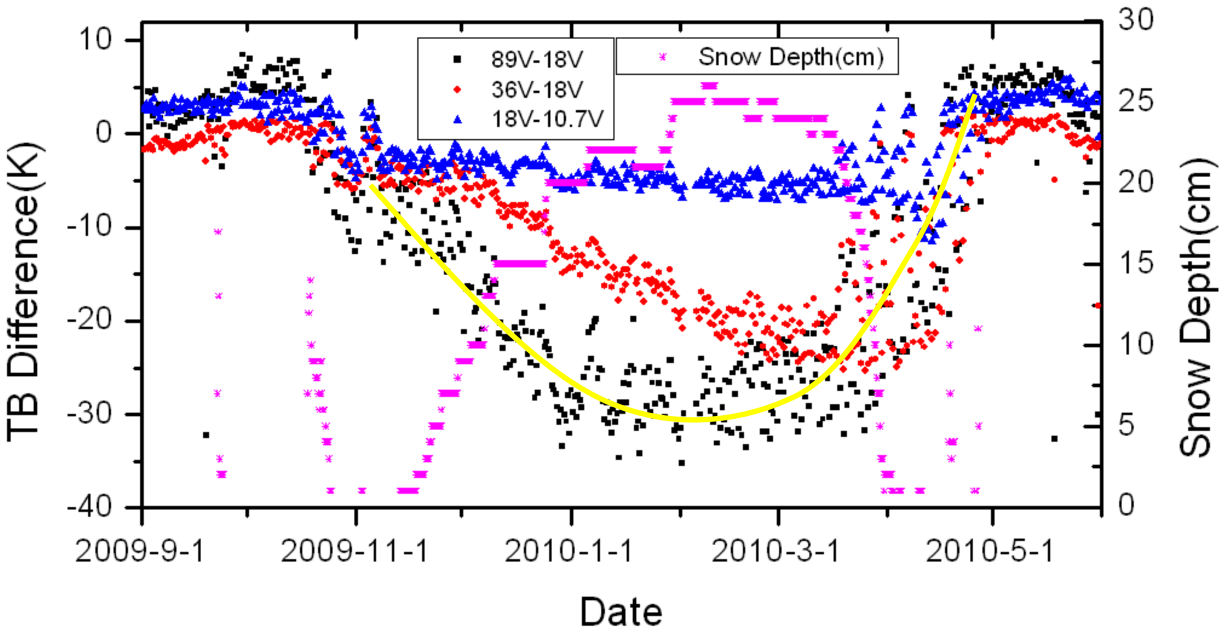


Compare with the NASA algorithm SWE result

Snow depth (cm) and AMSR-E TBs (2009~2010)

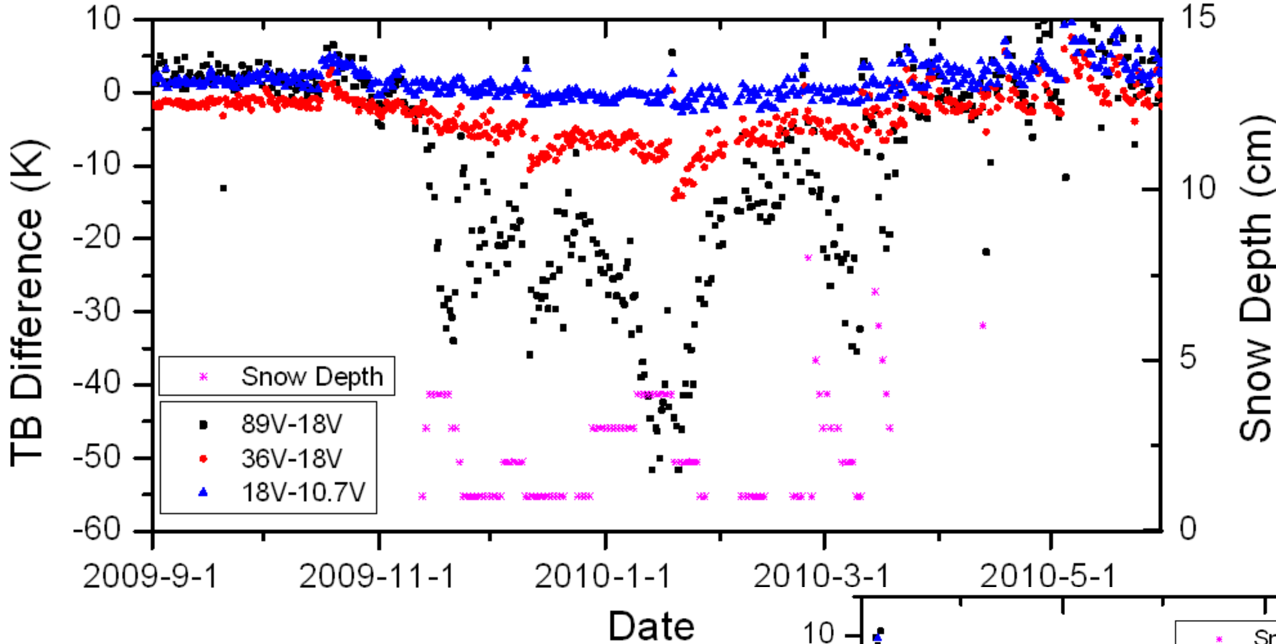


50727 (47.17N 119.93E)
Heilongjiang

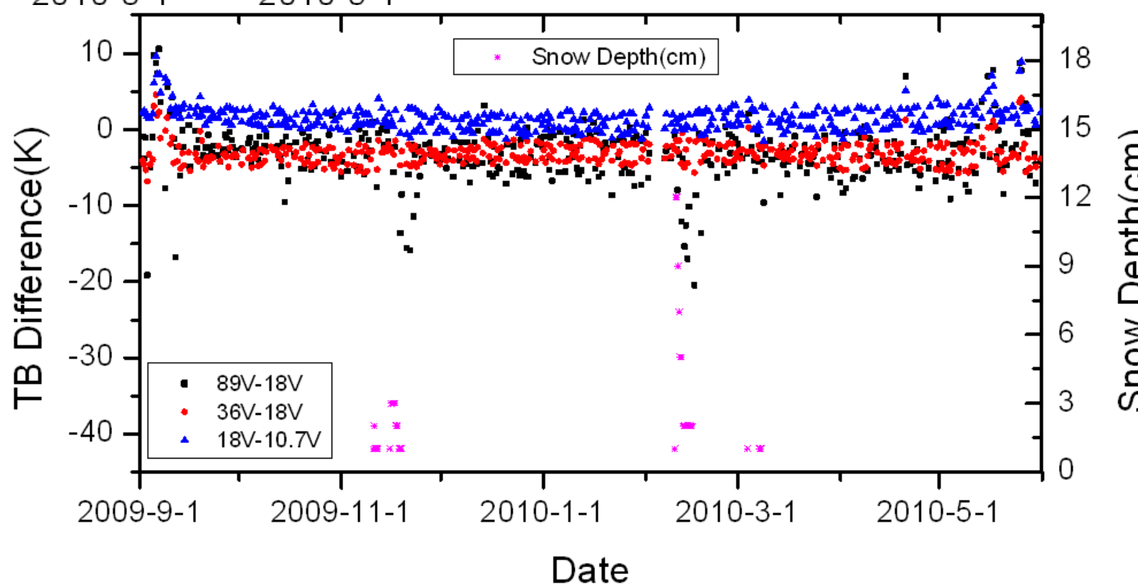


50434 50.48N 121.68E
Neimenggu

Snow depth (cm) and AMSR-E TBs (2009~2010)

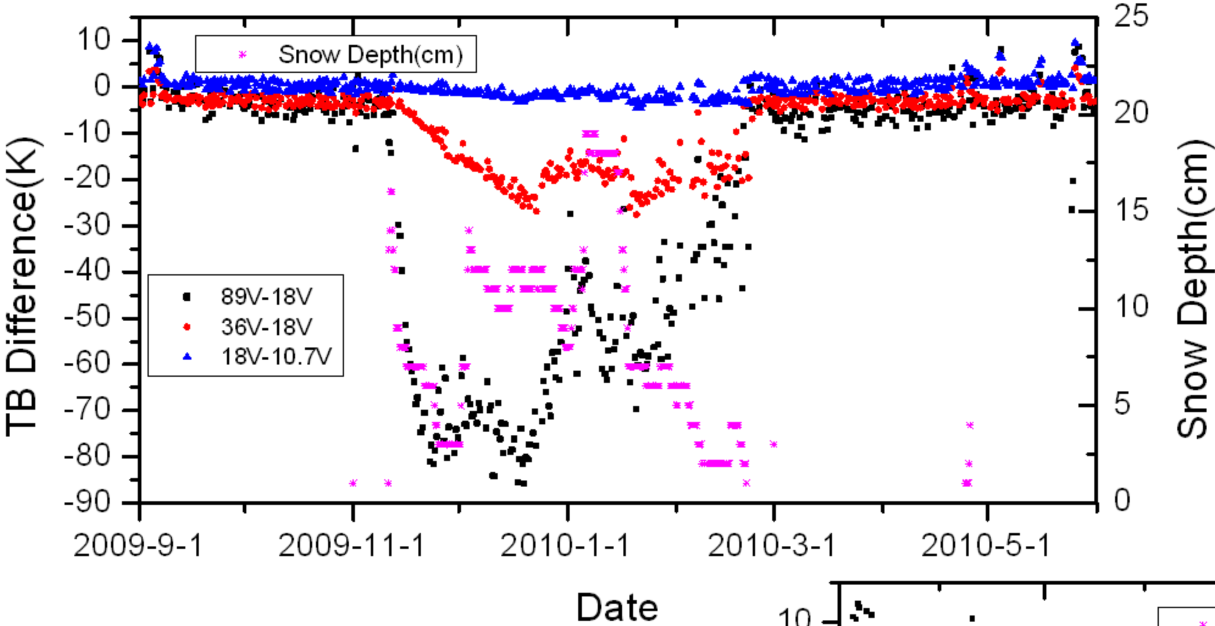


54049 44.25N 123.97E
Jilin



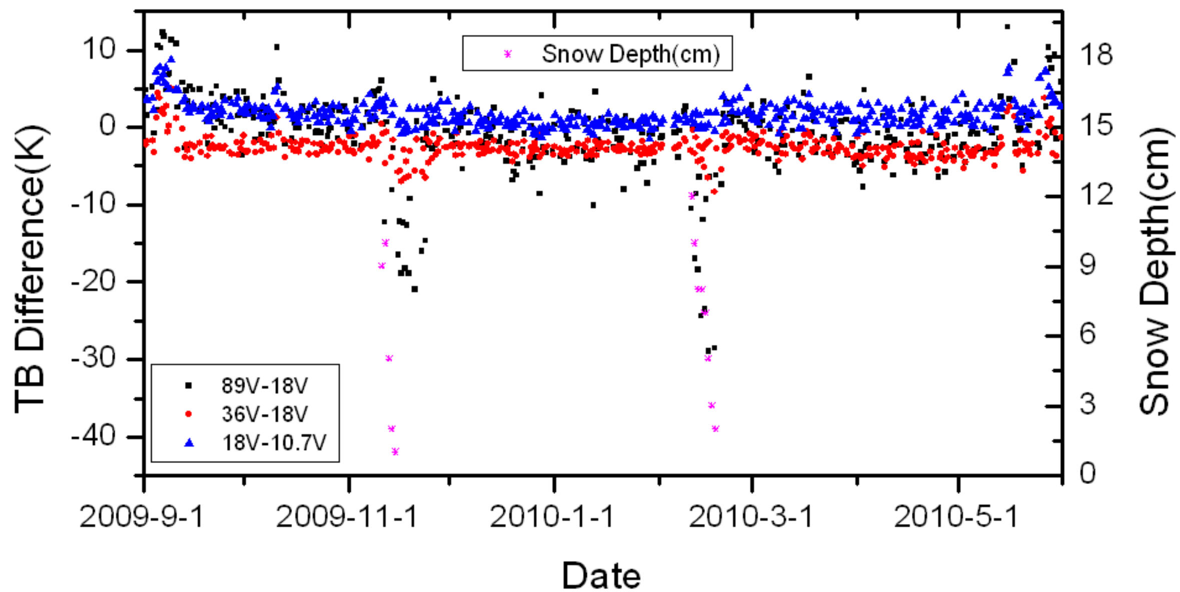
52681 38.63N 103.08E
Gansu

Snow depth (cm) and AMSR-E TBs (2009~2010)



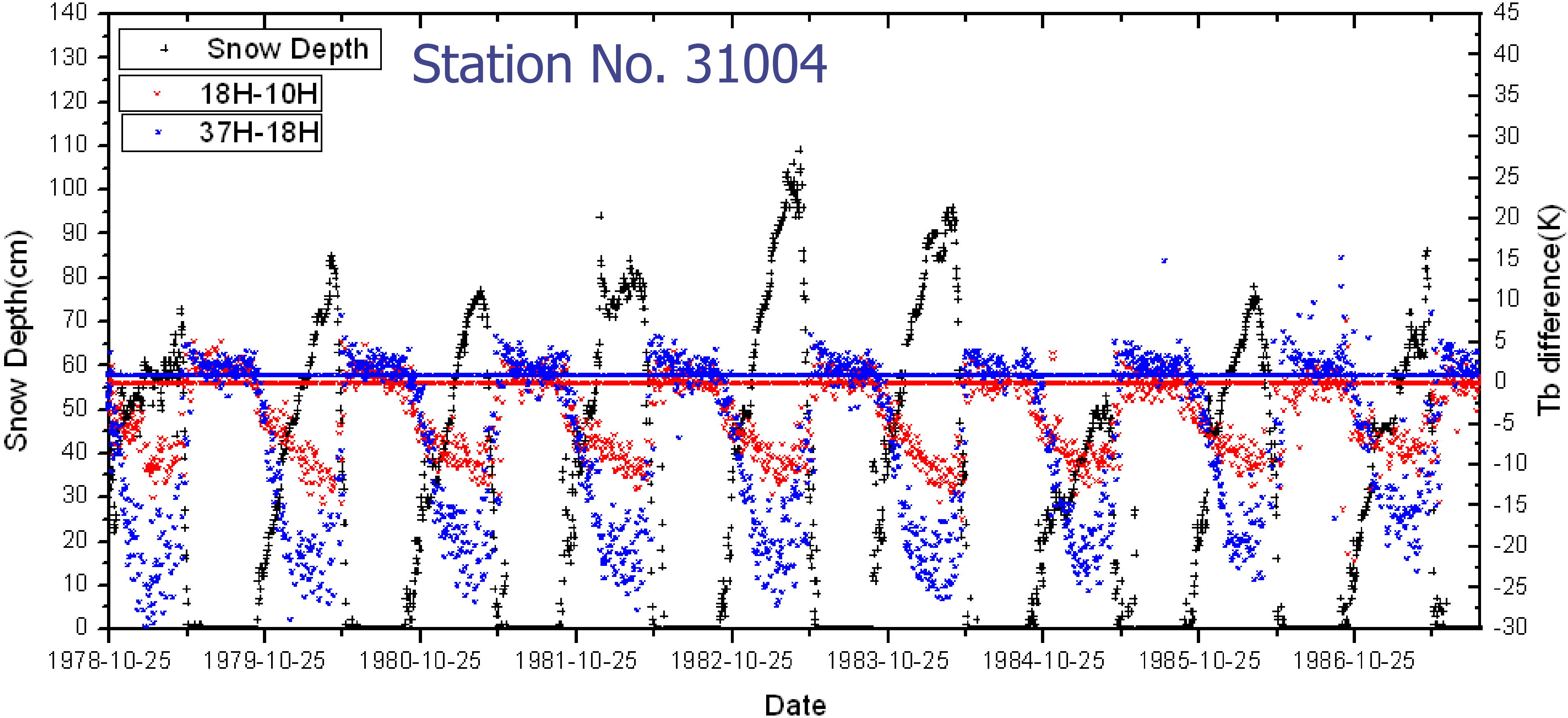
53231 41.40N 106.40E
Neimenggu

53519 39.22N 106.77E
Ningxia



89GHz is sensitive to the snow occurrence (fresh snow flake)

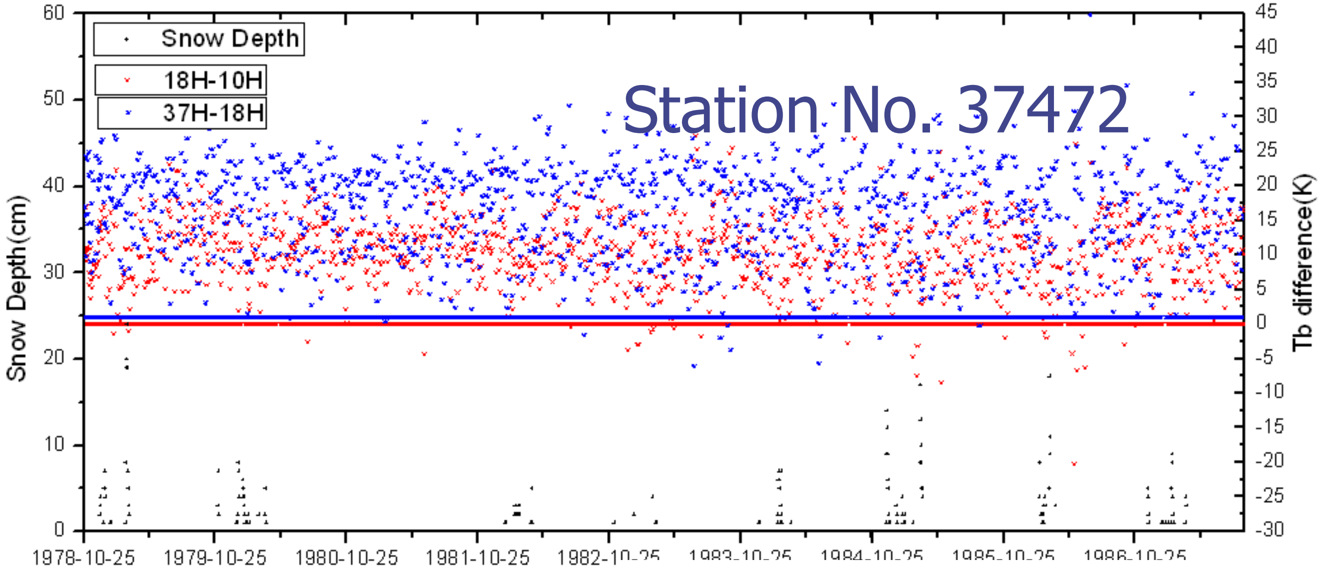
Snow depth (cm) and SMMR TB gradient



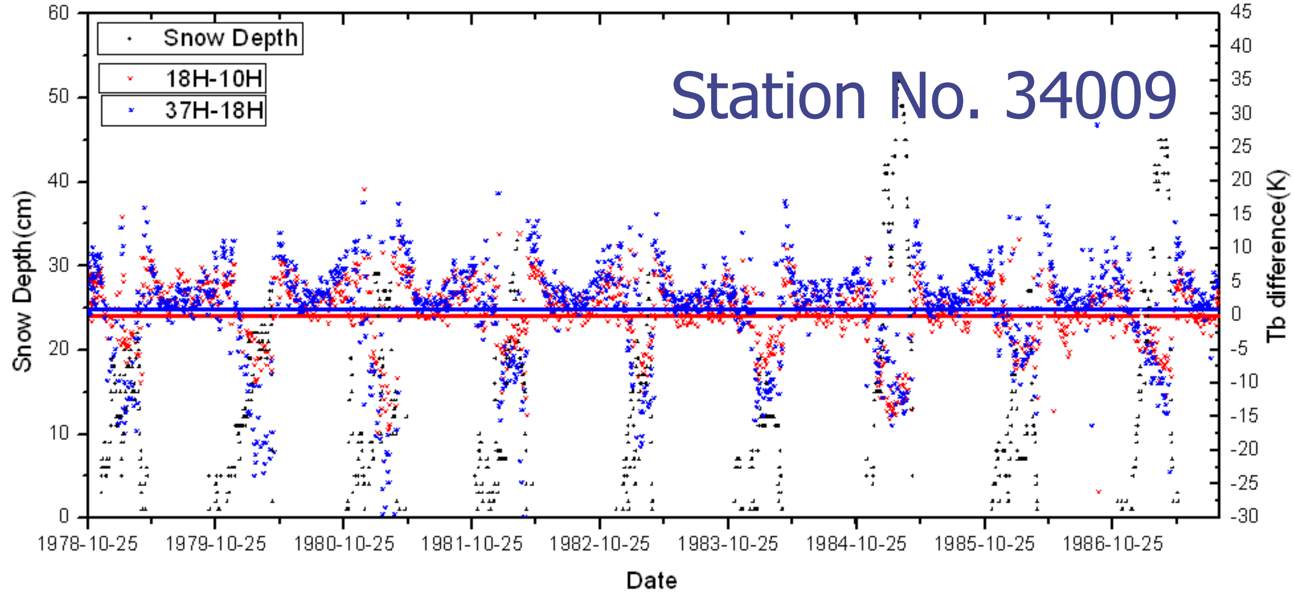
TB(37-18GHz) shows good ability for retrieval the relative thick snow, the TB(18-10GHZ) also expresses the thick snow ability

CHRIS DERKSEN, 2007, The Contribution of AMSR-E 18.7 and 10.7 GHz Measurements to Improved Boreal Forest Snow Water Equivalent Retrievals

Snow depth (cm) and SMMR TB gradient



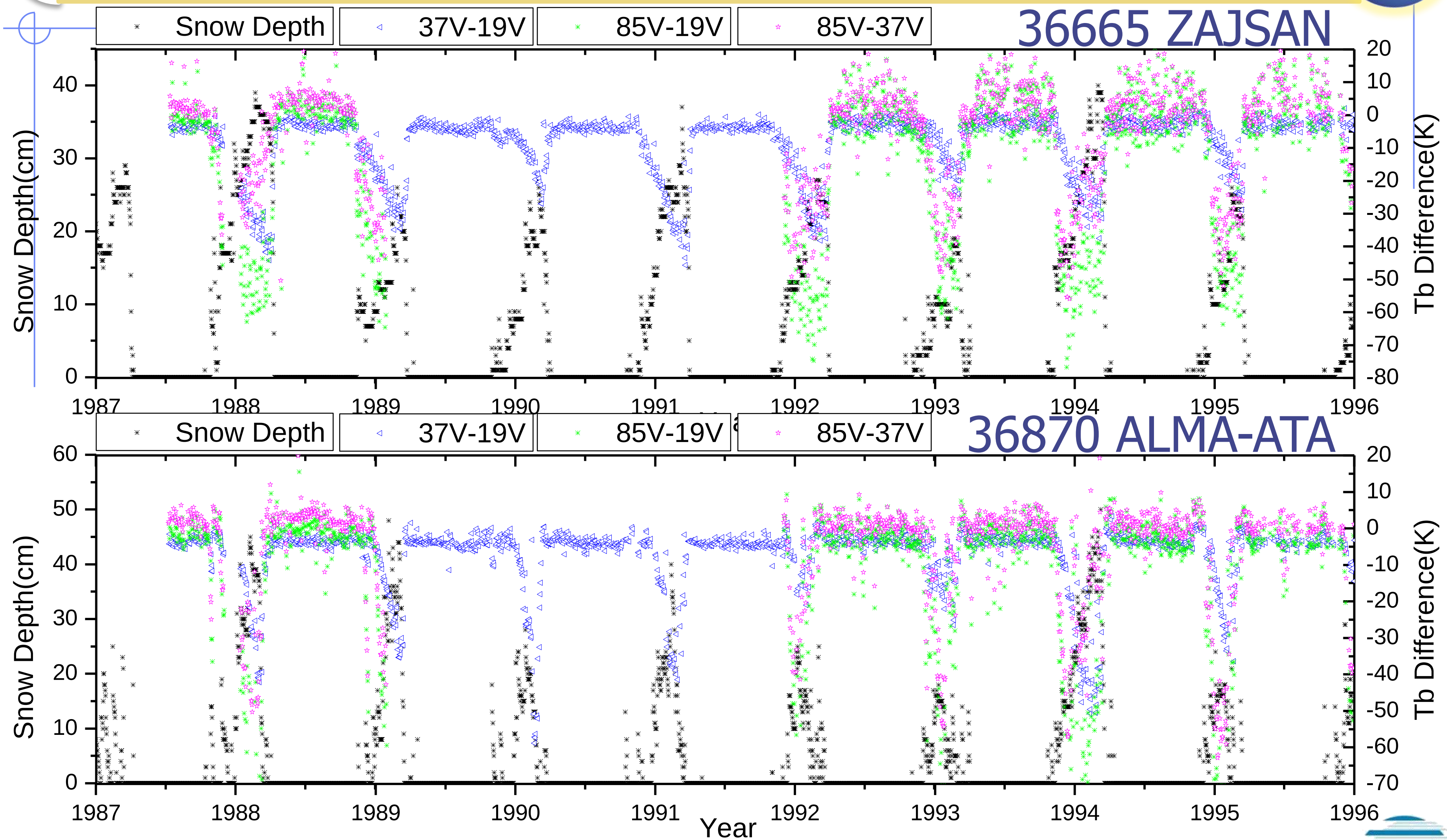
Shallow snow, the 37GHz-18GHz is invalid



Snow depth (cm) and SSM/I TB Gradient

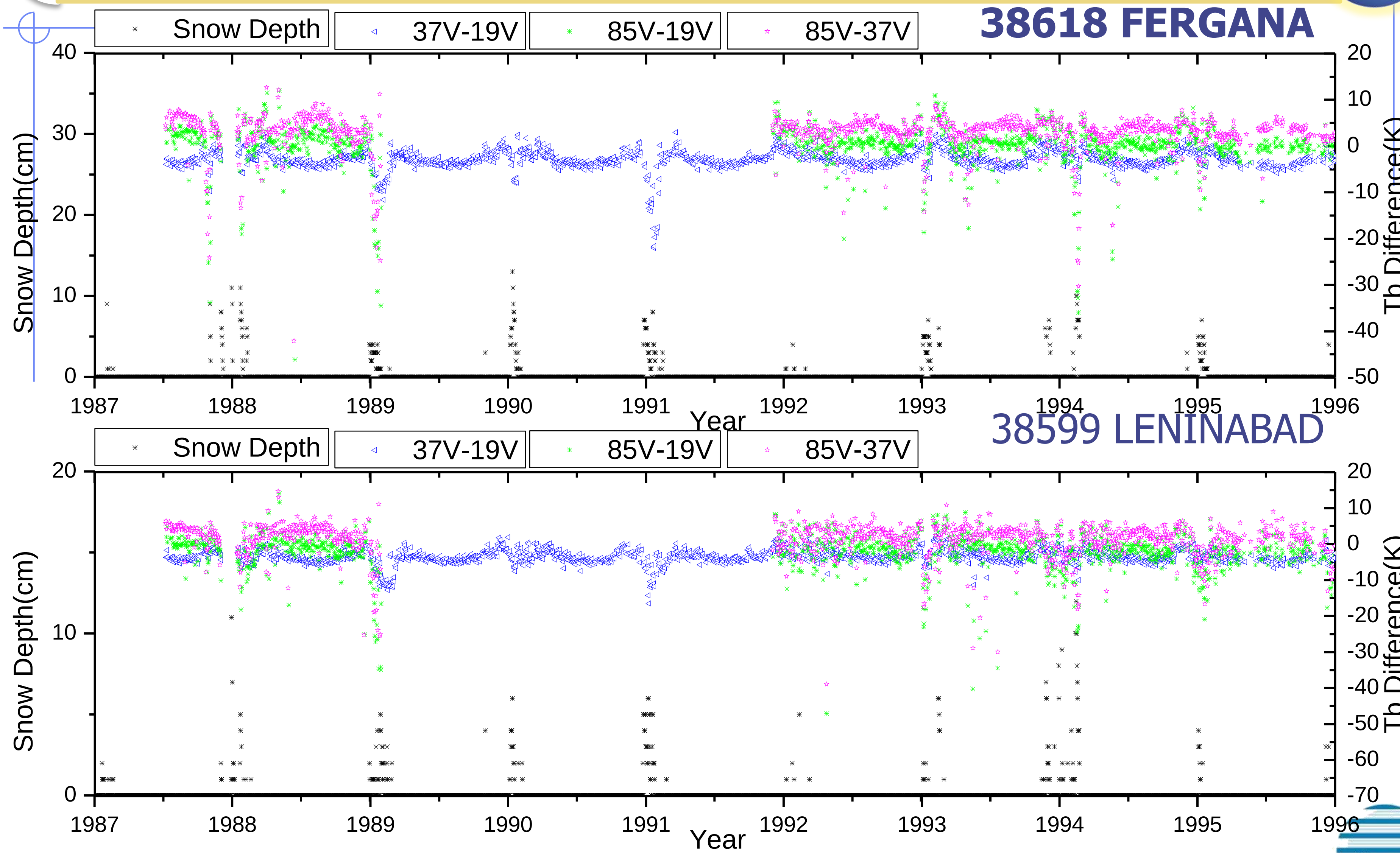
- ✓The select station, the altitude > 1500m
- ✓Near Tibet, China
- ✓Almost the shallow snow cover area
- ✓Sparse forest

Snow depth and SSM/I TB Gradient



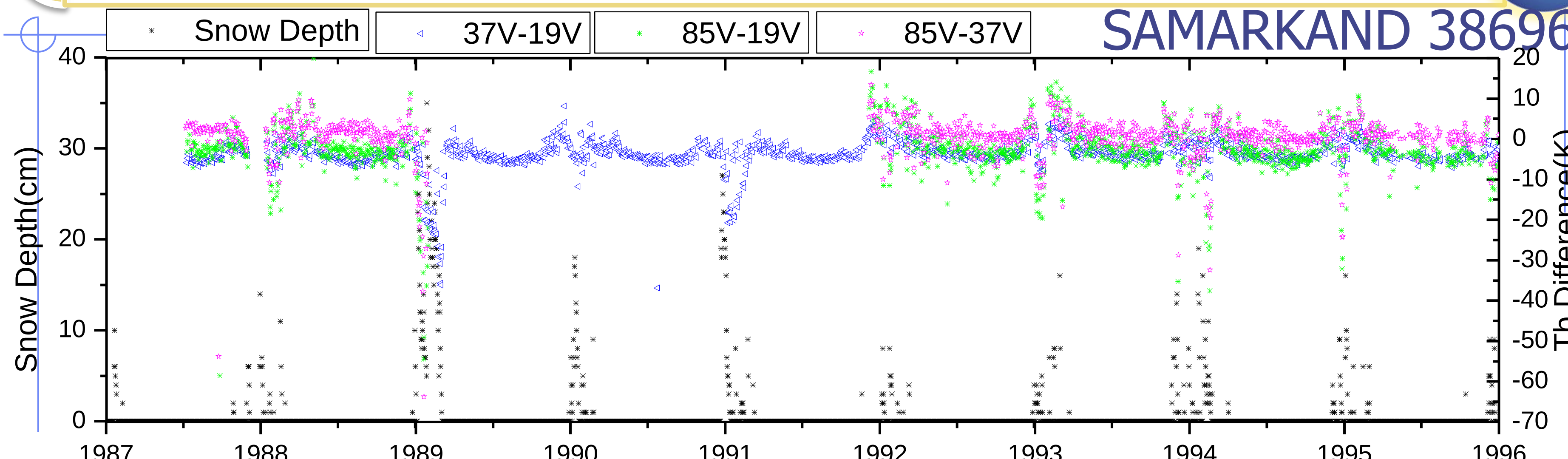
TB(37-19GHz) and TB(85-19GHz) 's response to the snow evolution

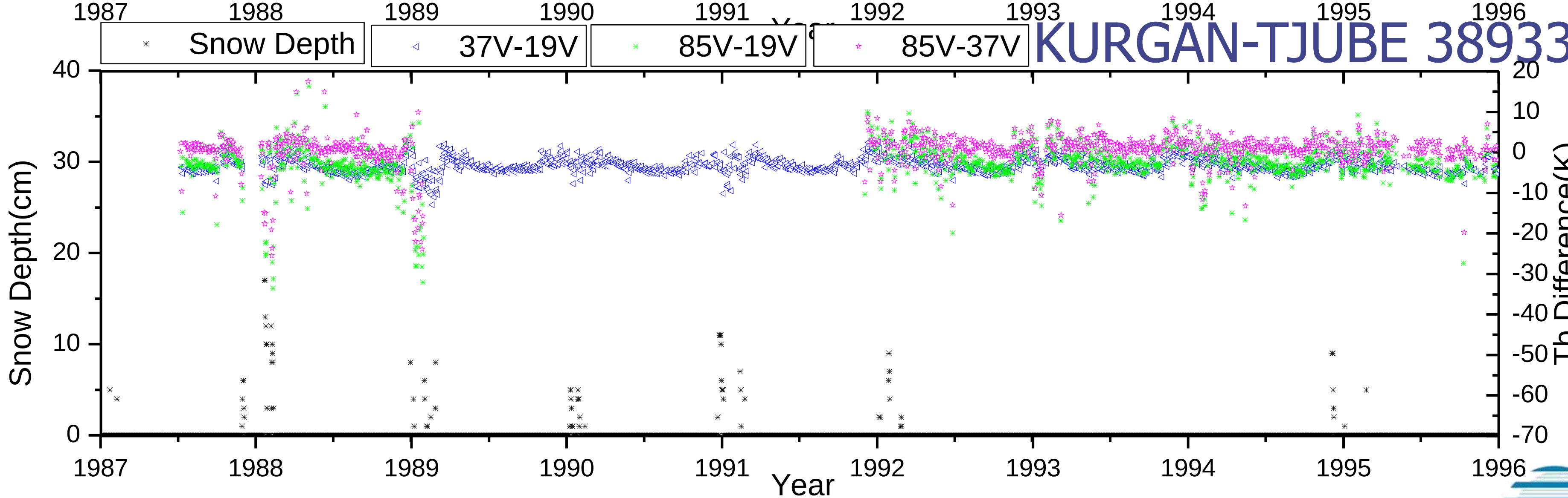
Snow depth and SSM/I TB Gradient



High frequency shows a sensitive response to the shallow snow

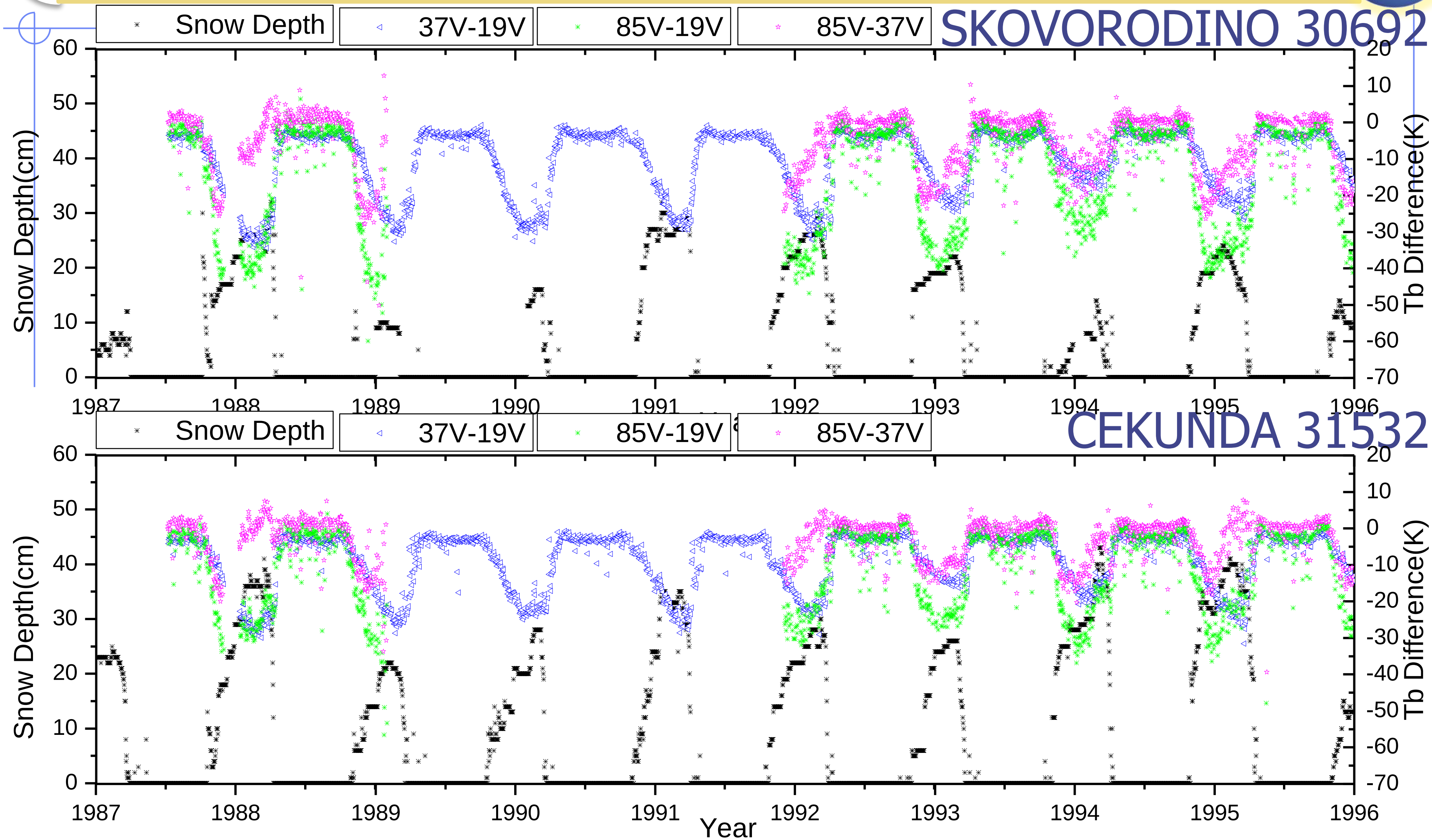
Snow depth and SSM/I TB





High frequency shows a sensitive response to the shallow snow

Snow depth and SSM/I TB Gradient

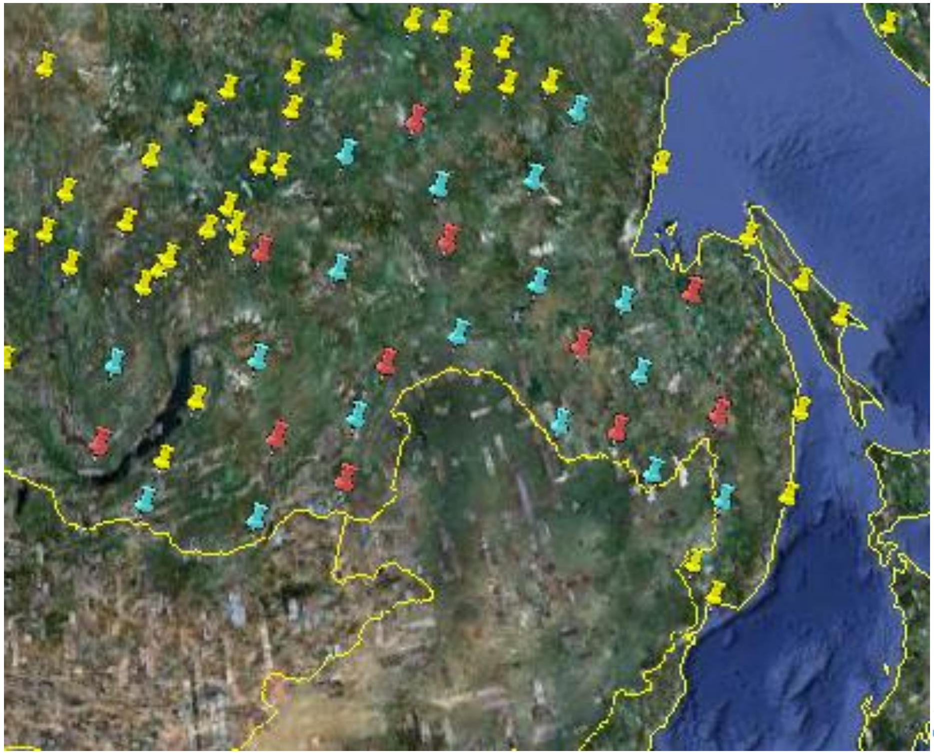


Sometimes, the 36.5GHz-18.7GHz show a good relationship when the snow depth < 20

Possible algorithm development with high frequencies and analysis

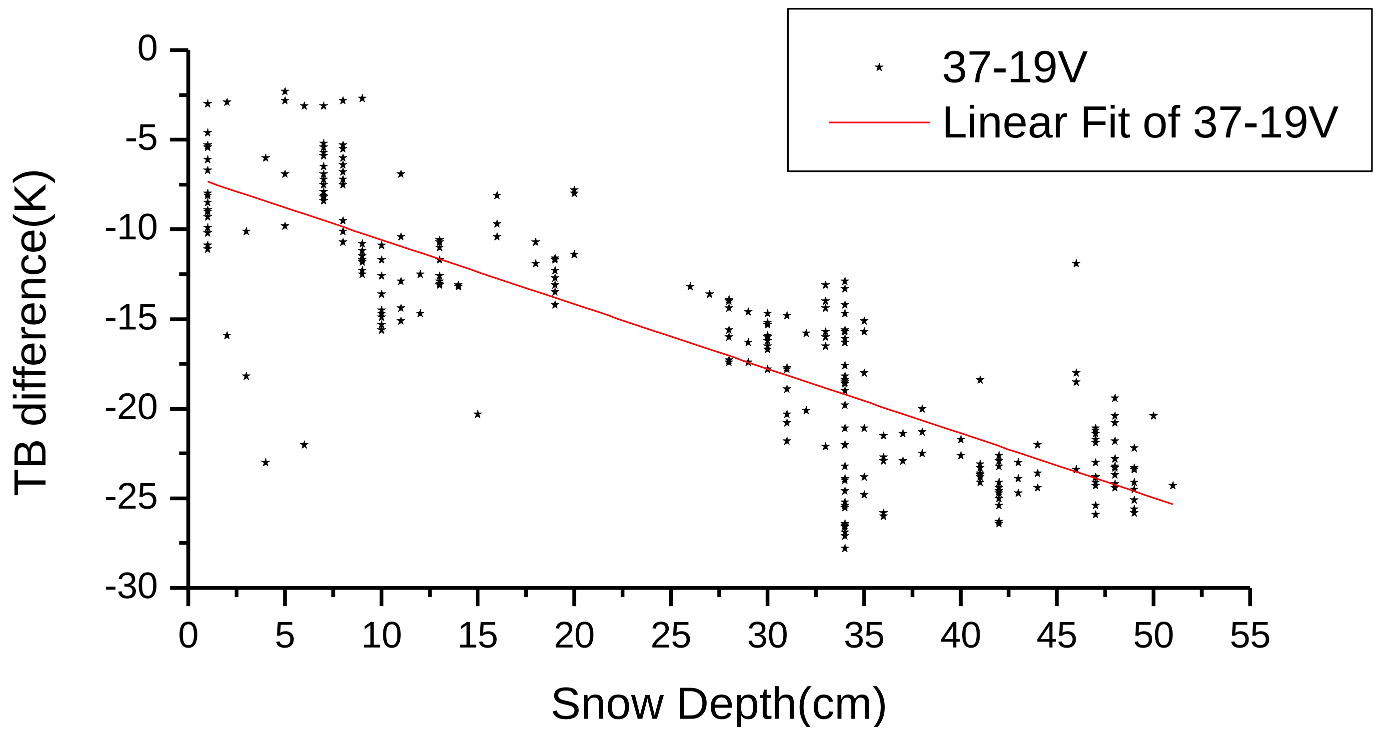
We simply apply the ATC Chang(1987) algorithm
SD = a* (Tb18H - Tb37H) + b

Firstly, we exam the relatively deep snow over rich forest area.



Possible algorithm development with high frequencies and analysis

1987-1991 snow depth and SMM/I Tbs, 261 samples

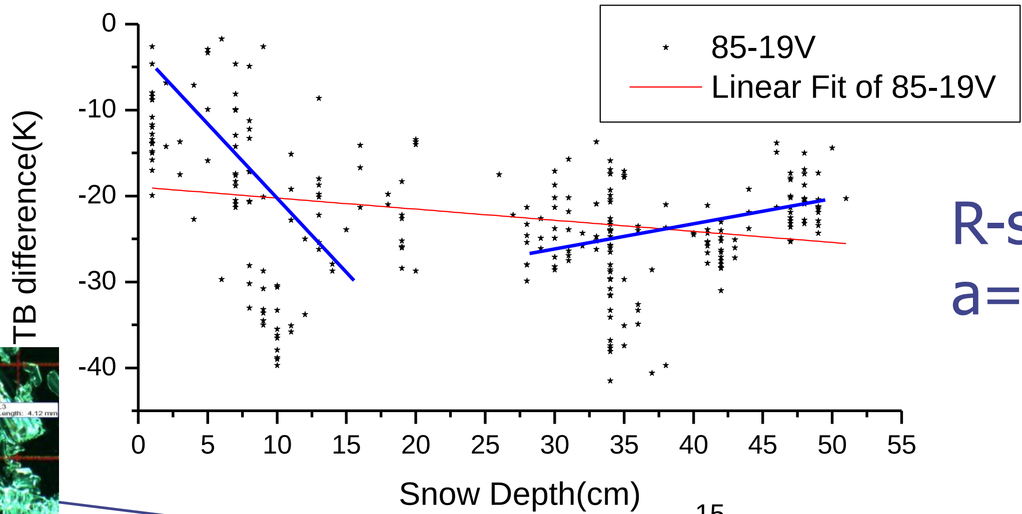


R-square: 0.71428

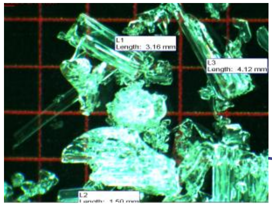
a=-6.98161 b= -0.35971

Possible algorithm development with high frequencies and analysis

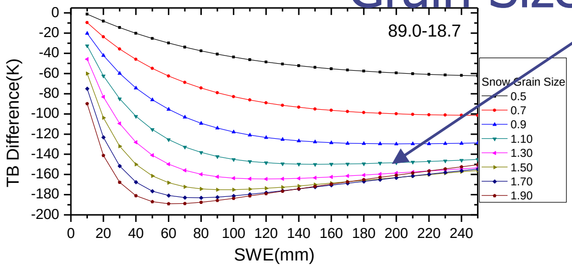
1987-1991 snow depth and SMM/I Tbs, 261 samples

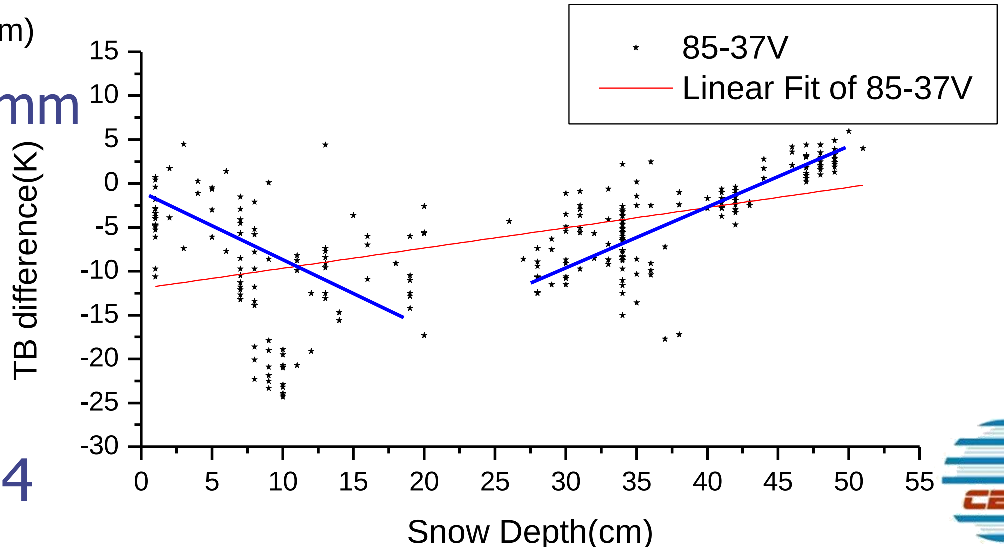


R-square: 0.05764
a=-18.95129 b= -0.12906



Grain Size =1.3~1.7mm

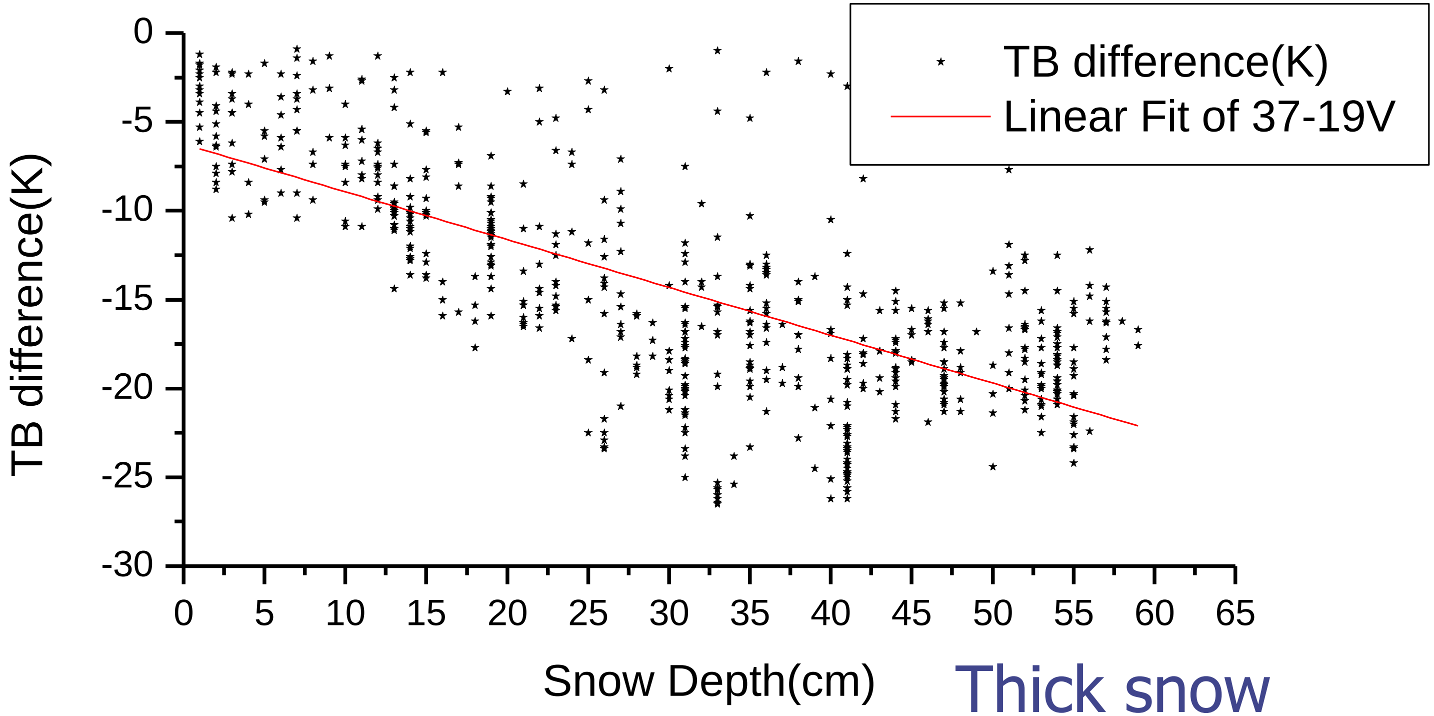




R-square: 0.2509
a= -11.96944 b= 0.23074

Possible algorithm development with high frequencies and analysis

1992-1995 snow depth and SMM/I Tbs, 640 samples



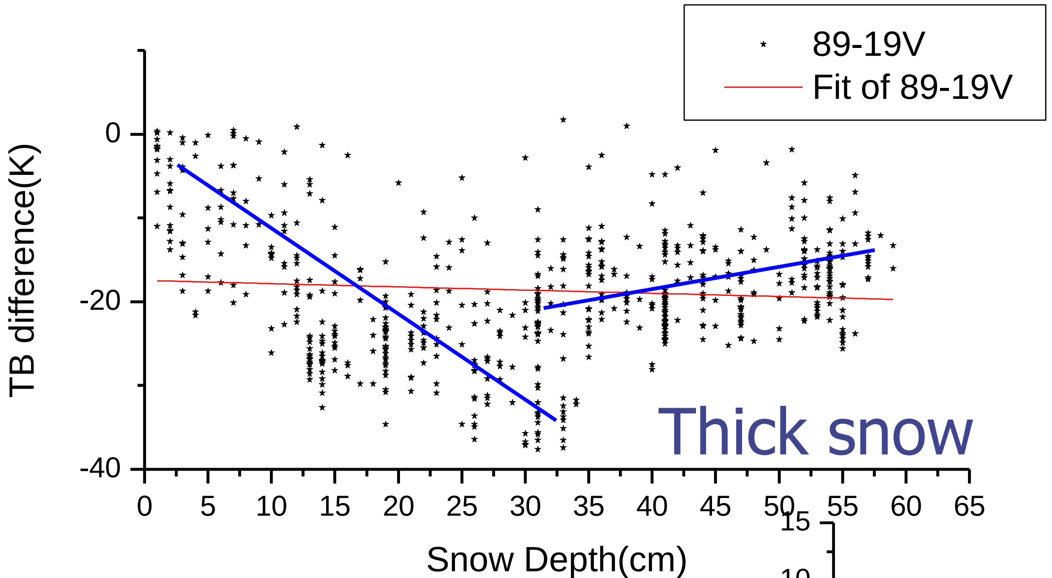
Thick snow

R-square: 0.48892

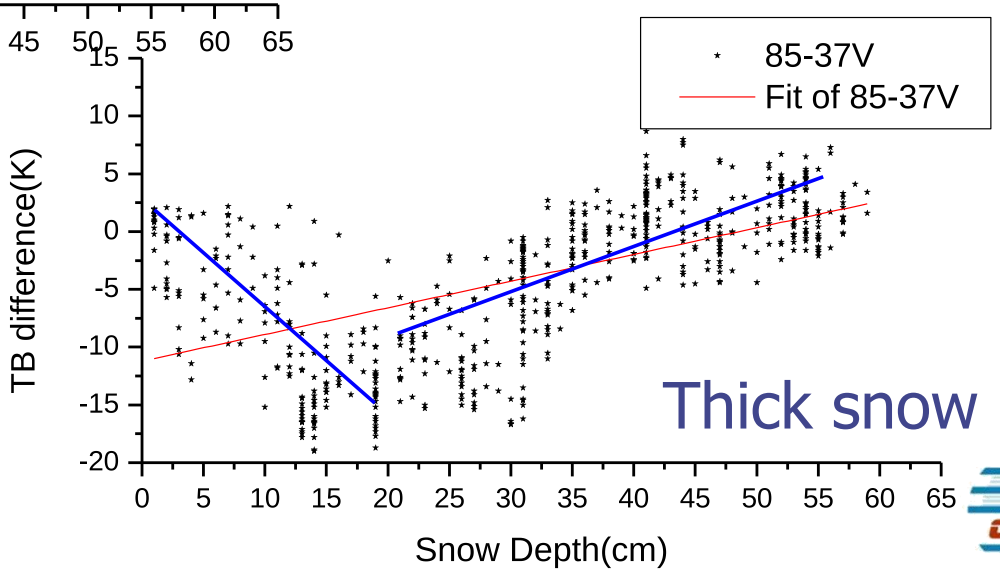
a= -6.24384 b= -0.26904

Possible algorithm development with high frequencies and analysis

1992-1995 snow depth and SMM/I Tbs, 640 samples



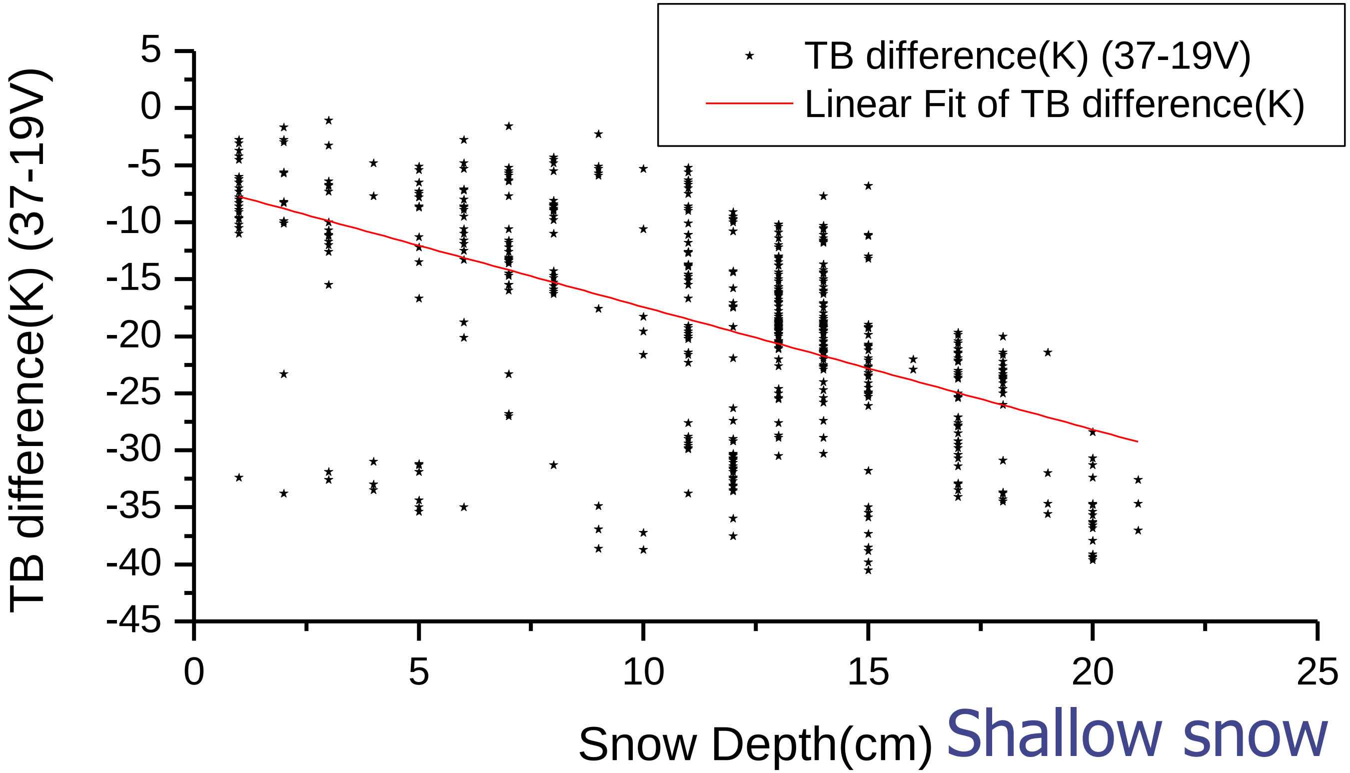
R-square: 0.00456
a= -17.45683 b= -0.03825



R-square: 0.33649
a= -11.21299 b= 0.23079

Possible algorithm development with high frequencies and analysis

1988-1995 snow depth and SMM/I Tbs, 420 samples

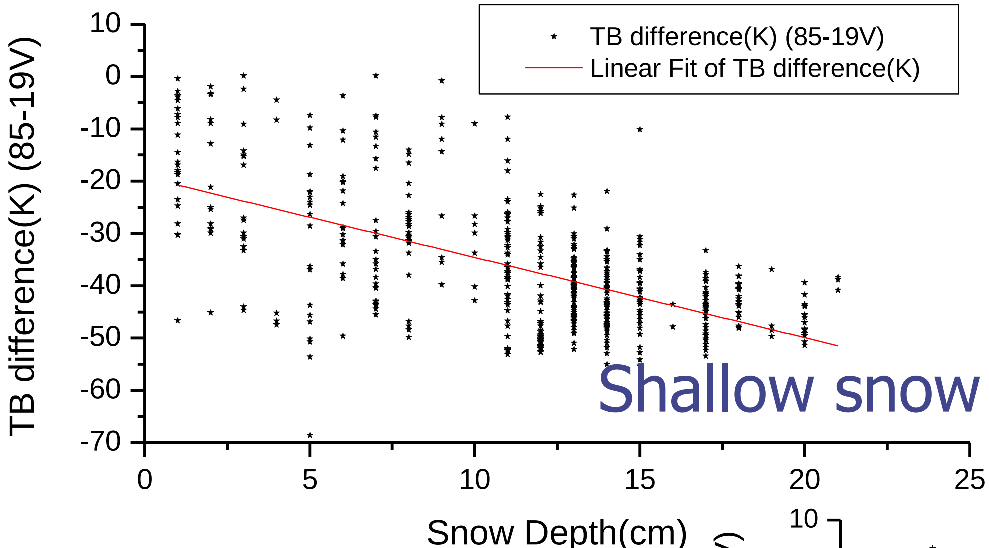


Shallow snow

R-square:0.31795
a= -6.66873 b=-1.07606

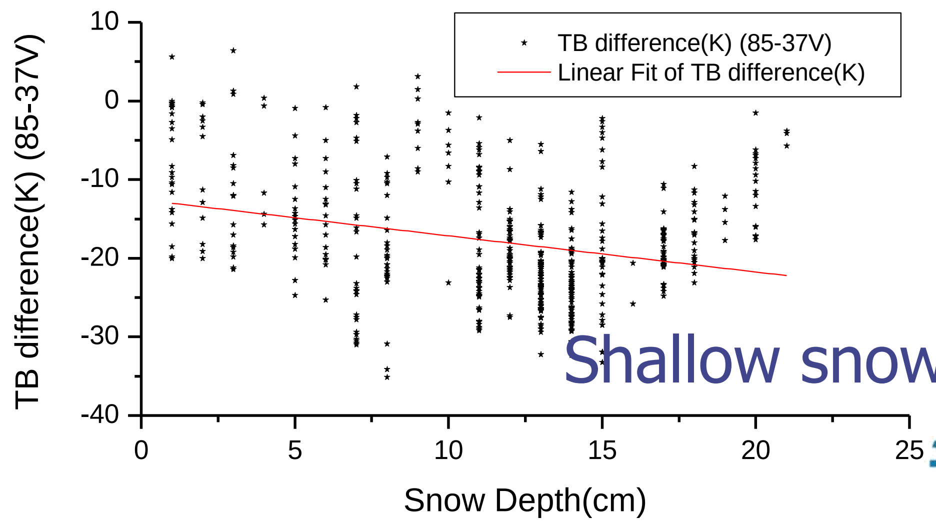
Possible algorithm development with high frequencies and analysis

1988-1995 snow depth and SMM/I Tbs, 420 samples



R-square:0.36473
a=-19.22 b=-1.5358

R-square: 0.07311
a=-12.54907 b=-0.46019

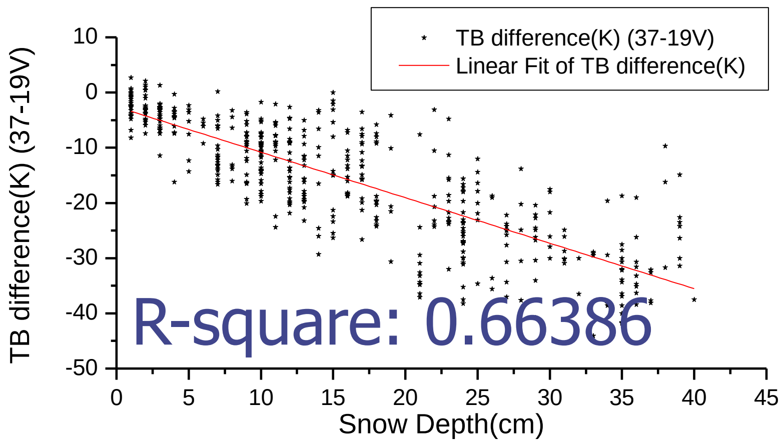


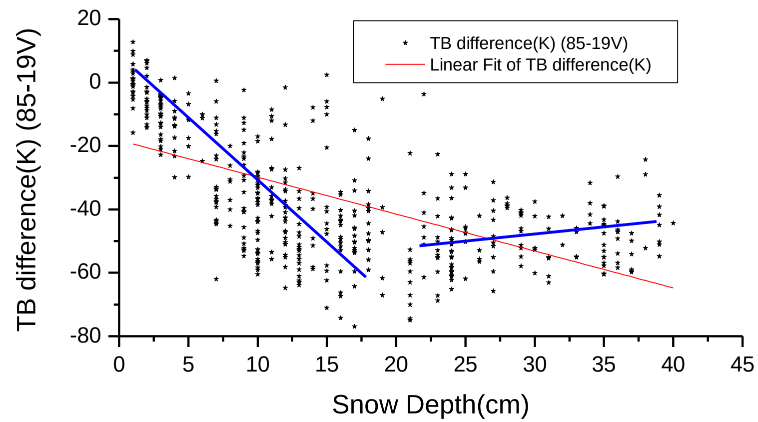
Possible algorithm development with high frequencies and analysis

Select area –Tibet Plateau

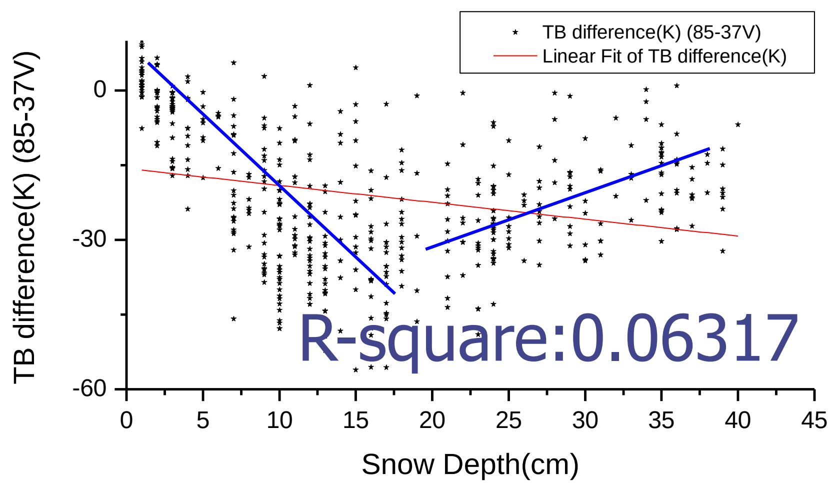
Possible algorithm development with high frequencies and analysis

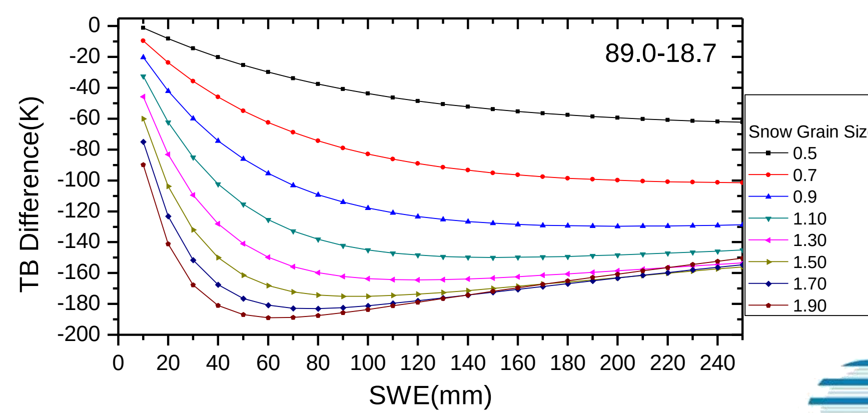
1987-1995 snow depth and SMM/I Tbs, 469 samples





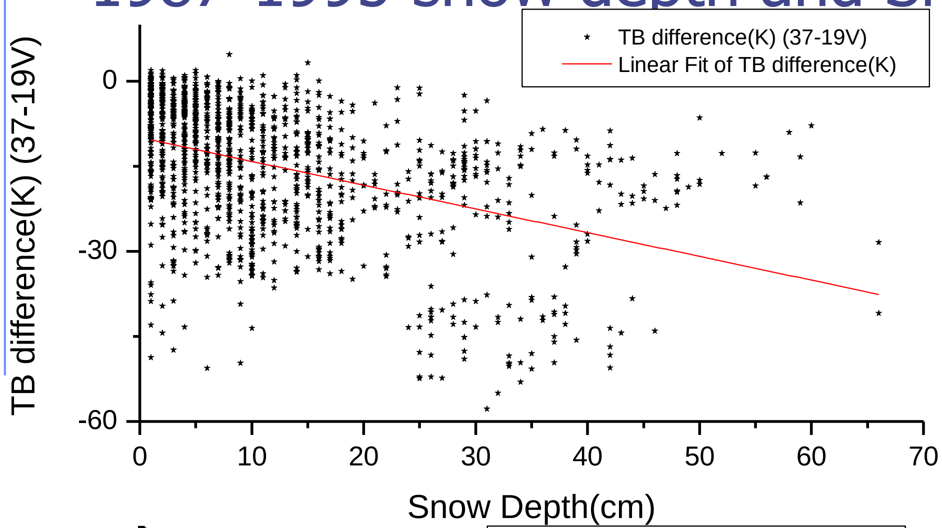
R-square: 0.06862

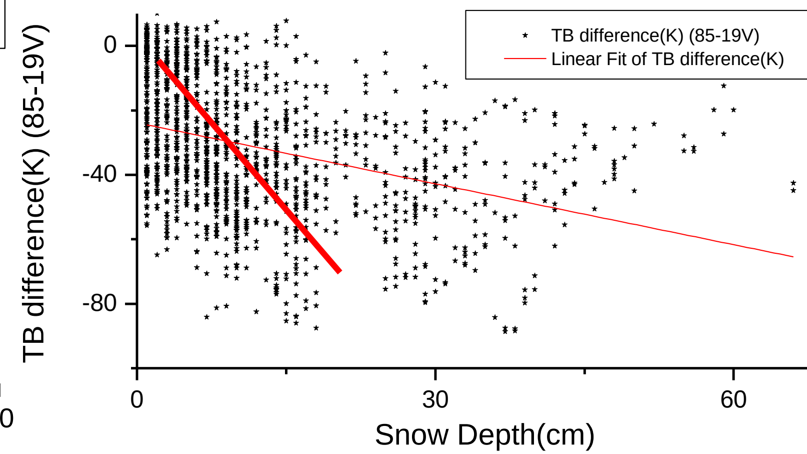


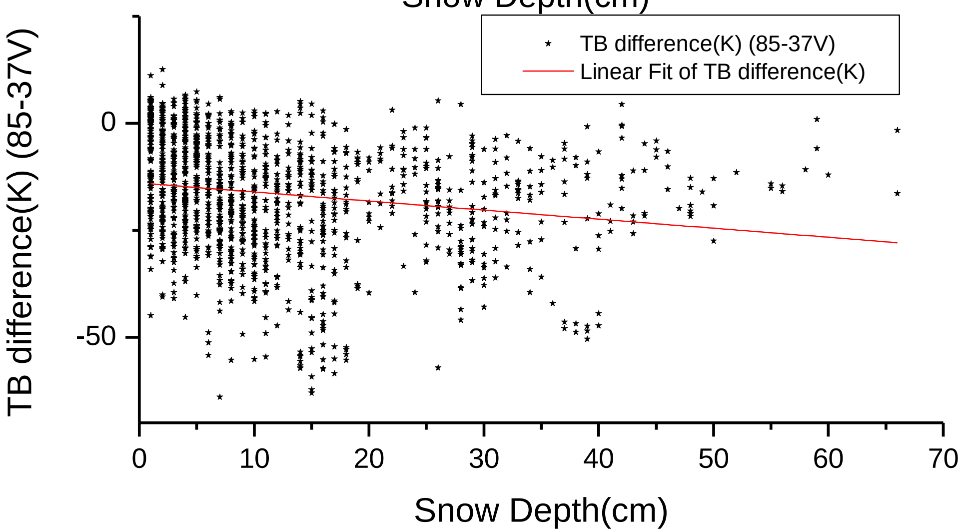


Possible algorithm development with high frequencies and analysis

1987-1995 snow depth and SMM/I Tbs, 1353 samples







The pair 85.0/19 shows its shallow snow retrieval ability and when the snow depth over 20cm, the signal is more variable and suspect.

Conclusion and discussion

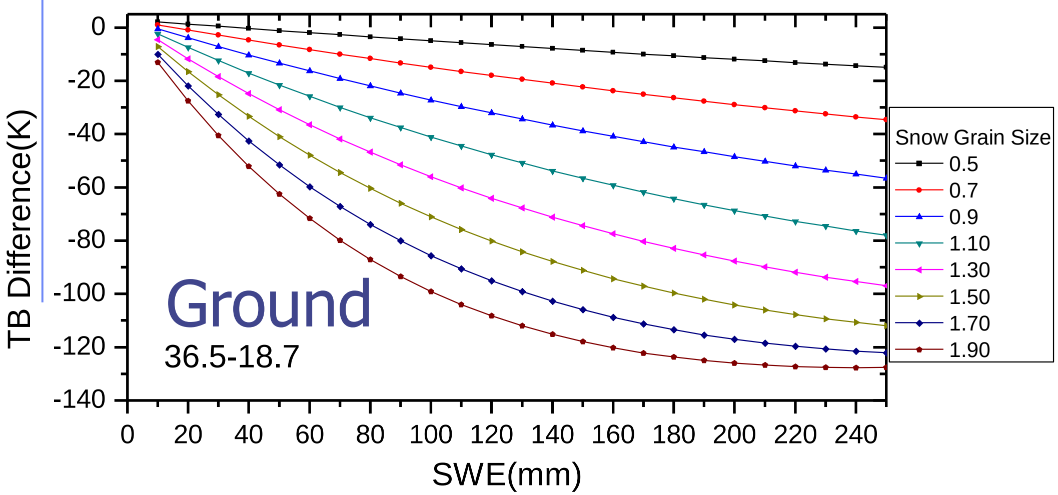
- Snow parameter is a critical climate indicator.
- Over western China, the snow products provide different trend regionally.
- The Tbs at18.7-10.7GHz are insensible to the snow evaluation except the deep snow depth (more than 60cm).
- Over relative deep snow (> 20cm) the Tbs at 36-18GHz are more reliable than that of high frequency, while over the shallow snow especially <15cm), the pair 36-18 is insensitive, but the high frequency pair (89/85-18) shows its distinct response.
- Over Westrern (shallow snow situation), encourage using the emission information at high frequency when snow depth (< 20cm) .
- Suggestion
  - The algorithm scheme could be separated into two parts: one over deep snow, the 36-19 gradient, while shallow using the 85/89-18Ghz.

End

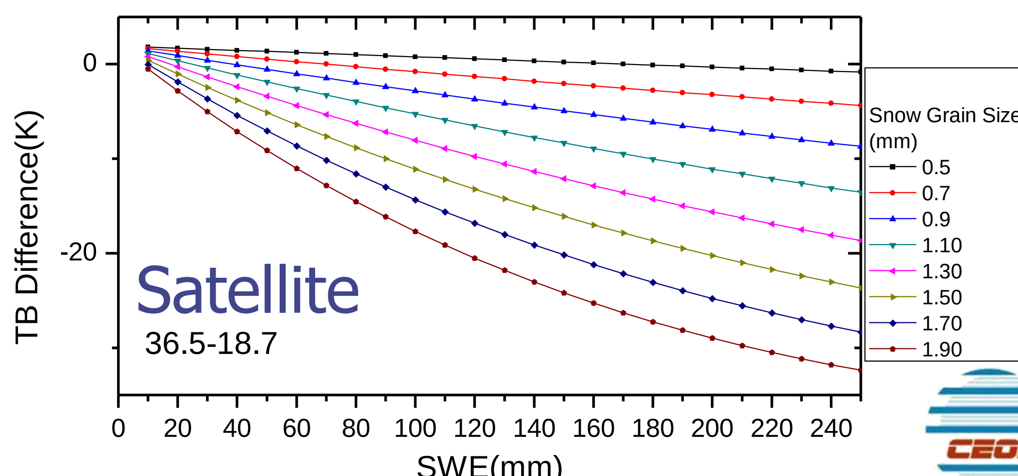
Thank you very much!

Atmosphere influence analysis

- HUT snow emission model (Satellite and Ground)

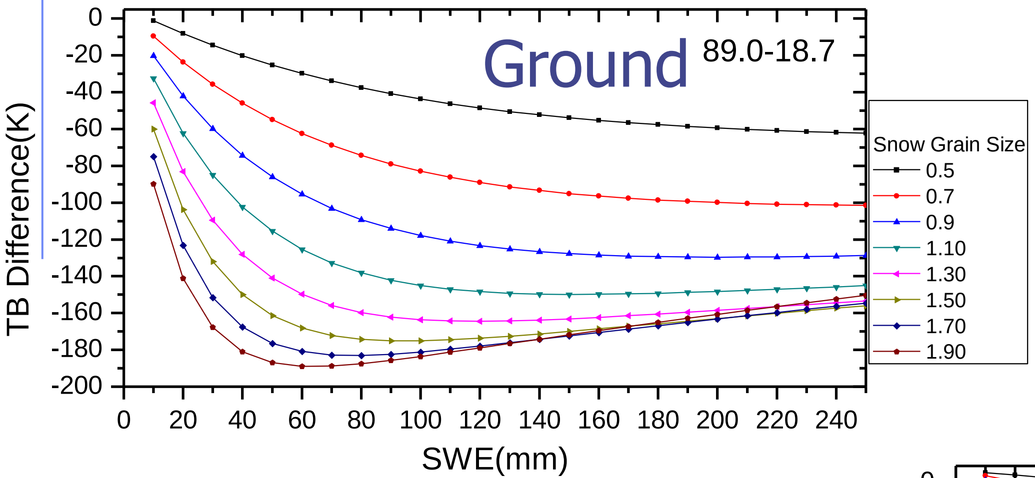


36.5GHz-18.7GHz



Atmosphere influence analysis

- HUT snow emission model (Satellite and Ground)



Atmosphere influence

89.0GHz-18.7GHz