METHODS OF SNOW COVER CHANGE SCENARIOS DESIGN FOR SLOVAKIA IN 1951-2100

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ABSTRACT 1

- Snowfall and snow cover have several routine characteristics, such as daily new snow cover depth or daily fresh snow accumulation, daily total snow cover depth and winter (annual) sum of daily snow cover depths, number of days with snowfall, number of days with snow cover with depth one cm and more (5 cm, 10 cm, 25 cm, 50 cm and more), the first and the last day with snowfall or snow cover etc. These characteristics can be calculated (observed) in winter season (Dec. 1 to Feb. 28/29, Nov. 1 to March 31, July 1 to June 30 etc. Snow and temperature (precipitation) have good correlation.
- Totally 557 precipitation stations have uninterrupted series in 1950-2017. Mean annual precipitation totals vary between about 550 mm in the lowlands and 2200 mm in the High Tatras. About 700 stations measured each year.
- It is expected significant increase of air temperature as well as precipitation totals in winter seasons during the next decades (Figs.), that is why we prepared methods to estimate possible scenarios of snow cover development change in Slovakia up to the end of the 21st century. The first method is based on the modified atmosphere circulation models (GCMs and RCMs) outputs (snow cover water equivalent values in mm and new snow cover amount in mm at mean daily air temperature below +2°C…) and the second one on the regression (analogues) estimation on the basis of measurements.

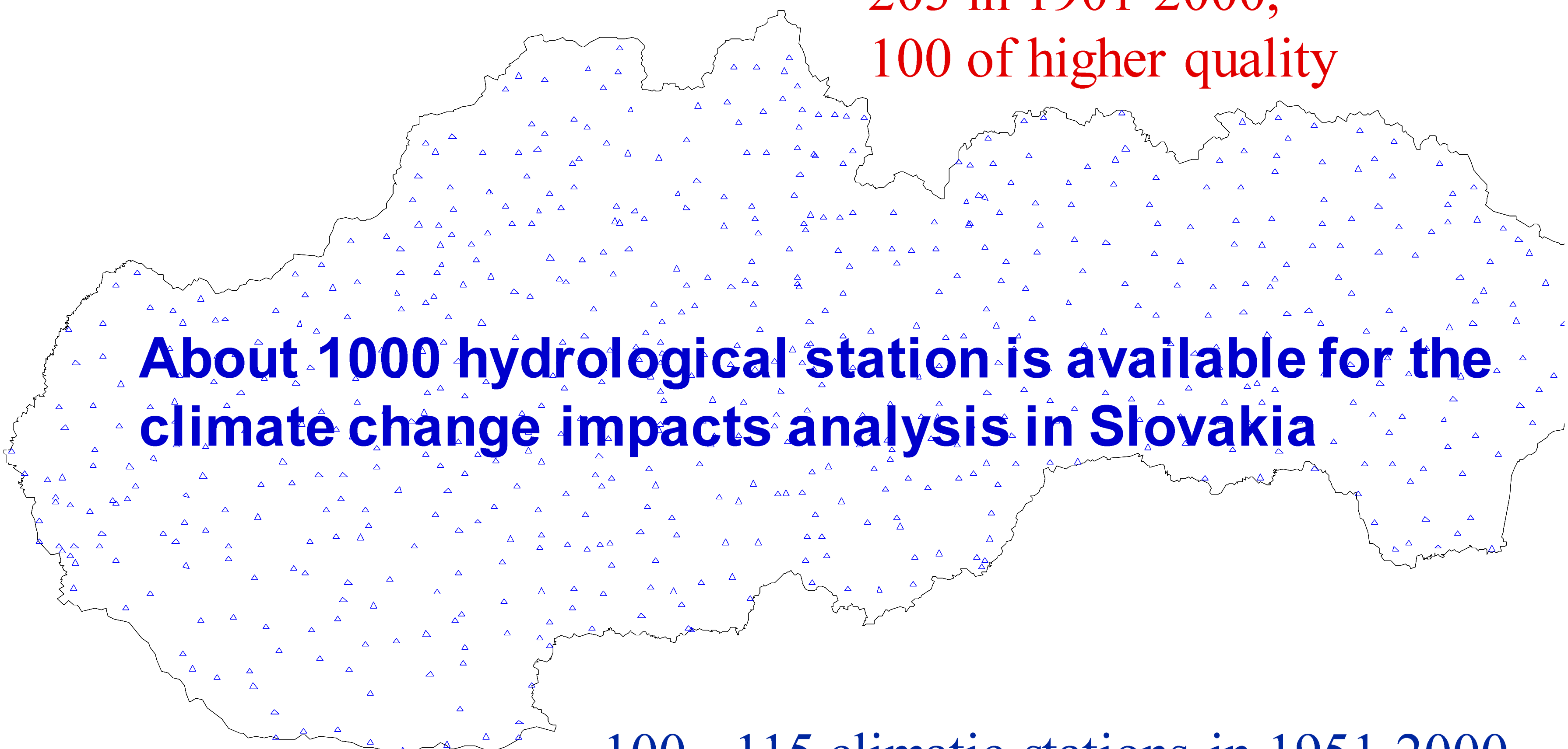
ABSTRACT 2

- The snowfall and the snow cover data and climatic characteristics are frequently used in the practice or requested by many users from several sectors. Recently it was found significant decrease in snow cover characteristics in the majority of Slovakia, but except the altitudes above 1200 m a.s.l. (4% of the territory). Reduction of snow cover is especially noteworthy below 800 m a.s.l.
- **Very important for the snow cover persistence is the occurrence of longer mild weather spells during winter (with temperature above +5°C) as well as high liquid precipitation totals. We analyzed such episodes (days with mean temperature above +5°C) in the modified GCMs and RCMs outputs data in 1951-2100 and compared them with measured ones in 1951-2016.**
- Climate Change impact studies (including snow cover and hydrologic balance) have been prepared mainly in agriculture, forestry, water sectors, and recreation (including winter sports conditions)
- **The SHMI issues regularly information on snow in Slovakia once a week (snow cover depth and snow cover water equivalent maps)**

PRECIPITATION STATIONS NETWORK IN SLOVAKIA

Figure 3 - National Observing System
Part D of the Surface Sub-system

607 stations in 1951-2000,
557 of higher quality
203 in 1901-2000,
100 of higher quality

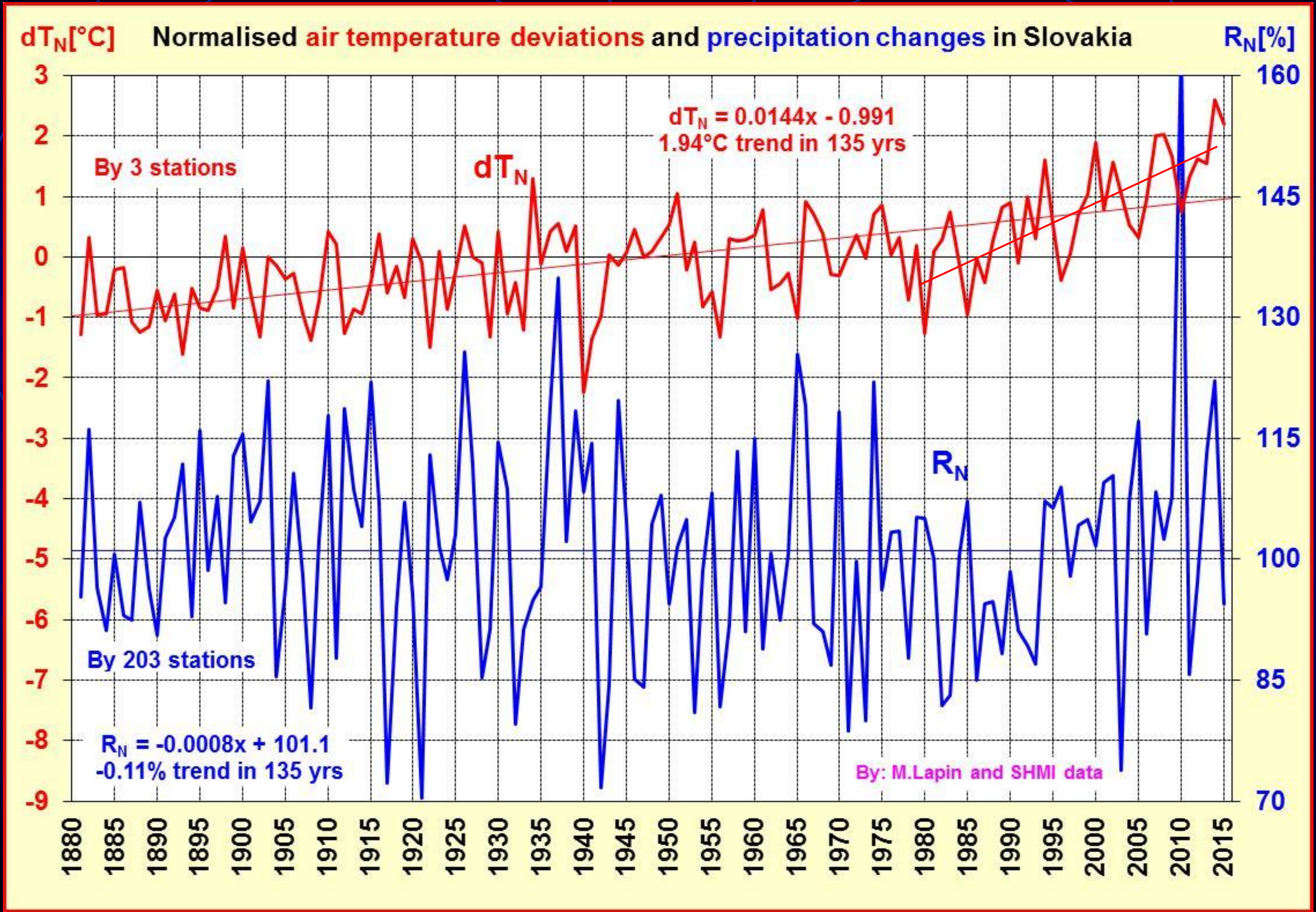


About 1000 hydrological station is available for the climate change impacts analysis in Slovakia

100 - 115 climatic stations in 1951-2000
35 complete stations in 1961-2000
3 complete in 1881-2000

D: Partial Observing System for Climatology - only stations with the Rainfall Programme (655)

TRENDS OF TEMPERATURE AND PRECIPITATION



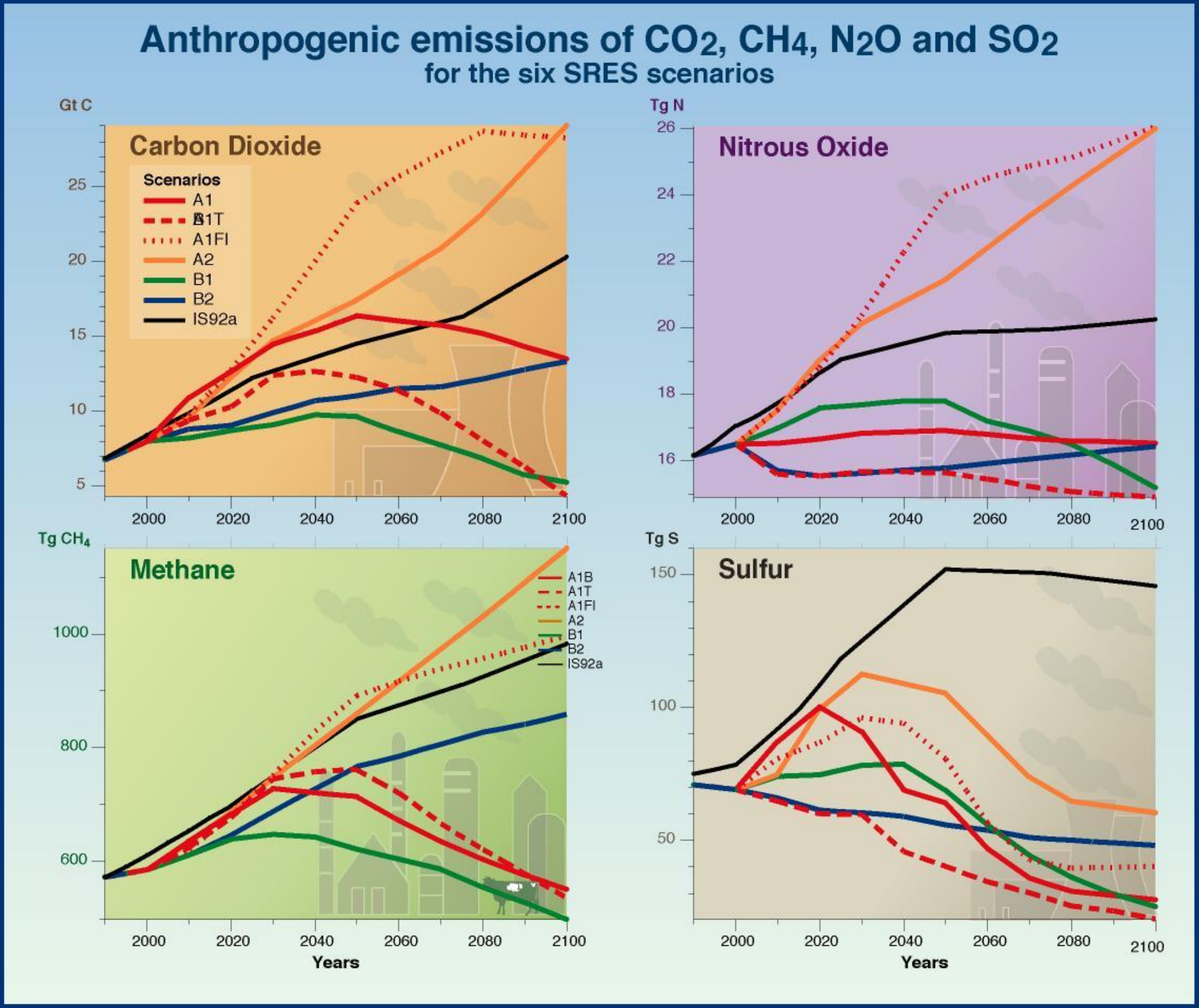
CLIMATE CHANGE SCENARIOS SUMMARY

- Scenarios based on the Atmosphere General Circulation Models - GCMs (Atmosphere-Ocean Models and Regional Models – RCMs, at present also in 10x10 km resolution)
- Scenarios based on historical analogues
- Incremental scenarios – acceptable for impact models testing only
- Stochastic weather generator based time series as scenarios
- Combined scenarios – 1. Step: selection of reliable T (temperature), R (precipitation) and s (specific humidity) GCMs scenarios and; 2. Step: calculation of analogs for other climatic/hydrologic elements using correlation/regression and simple modeling – scenarios for whole distribution range – **Priority in Slovakia**
- Scenarios for time frames, time series, selected events, extremes...
- The first series of scenarios in 1995, the second in 1997, then in 2000, 2010 and 2014-2017

IPCC SRES SCENARIOS

- Outputs of the CGCM3.1 and ECHAM5 models contain results by IPCC SRES A2, B1 and A1B emission scenarios assessments
- The first one represent pessimistic supposition of mankind behavior up to 2100 and the second the optimistic one, A1B is moderate one (IPCC 2000)
- Emission of **fossil Carbon** is supposed as 28.9 Gt by SRES A2 (cumulative 1773 Gt) and 5.2 Gt by SRES B1 (cumulative 989 Gt) in 2100.
- **A1B** – central scenarios family - balanced emphasis on all energy sources
- This difference is much more expressed in air temperature scenarios after 2040
- **New RCP series of emission scenarios in the IPCC AR5**

Emission scenarios A1, B1T, A1F1, A2, B1, B2 and older IS92a represent different ways of Climate Change mitigation



WG1 TS FIGURE 17

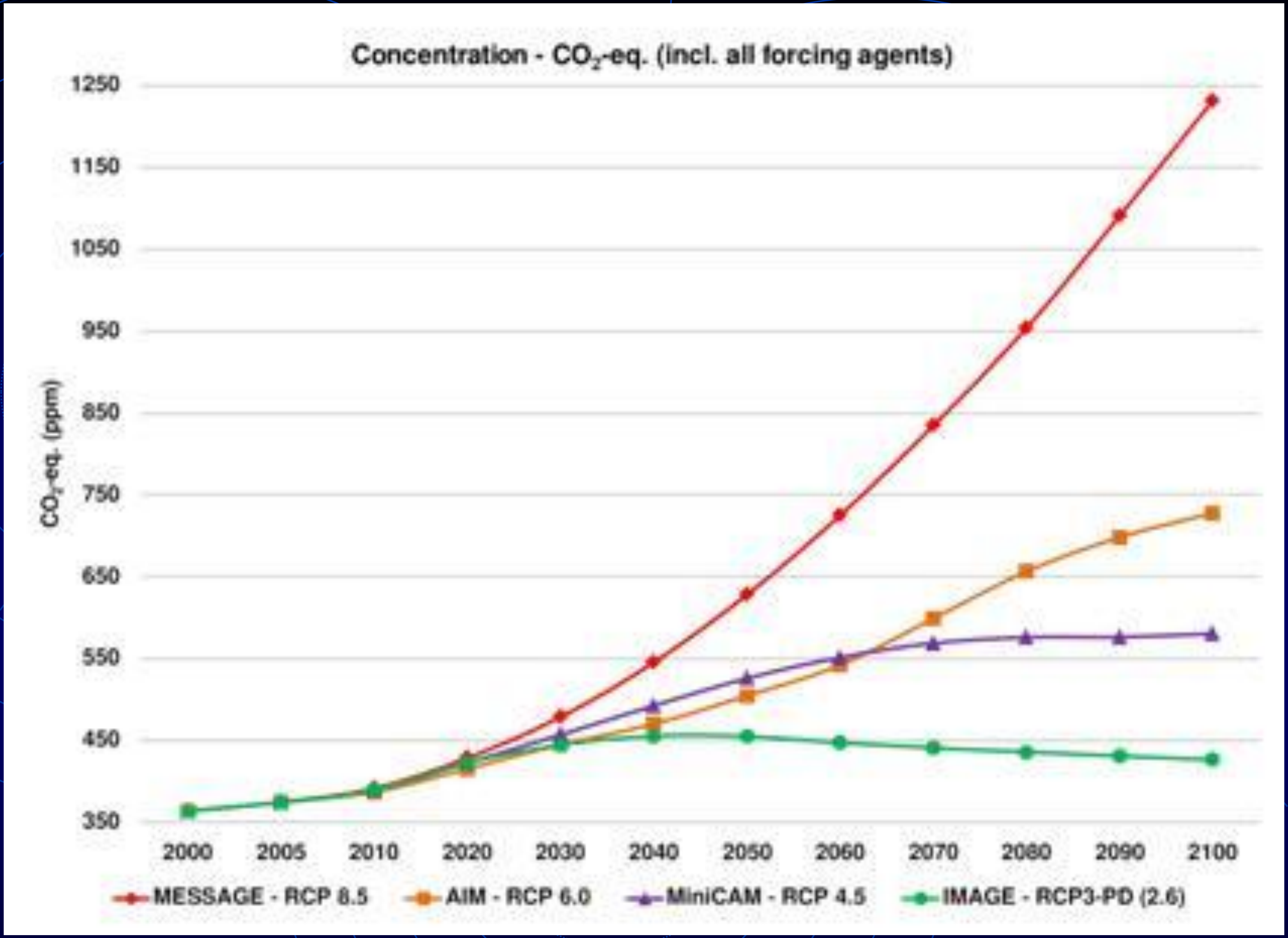
Alternative scenarios prepared by 6 different centers

Emission scenarios RCP 8.5, RCP 6.0, RCP 4.5, RCP 2.6

Older

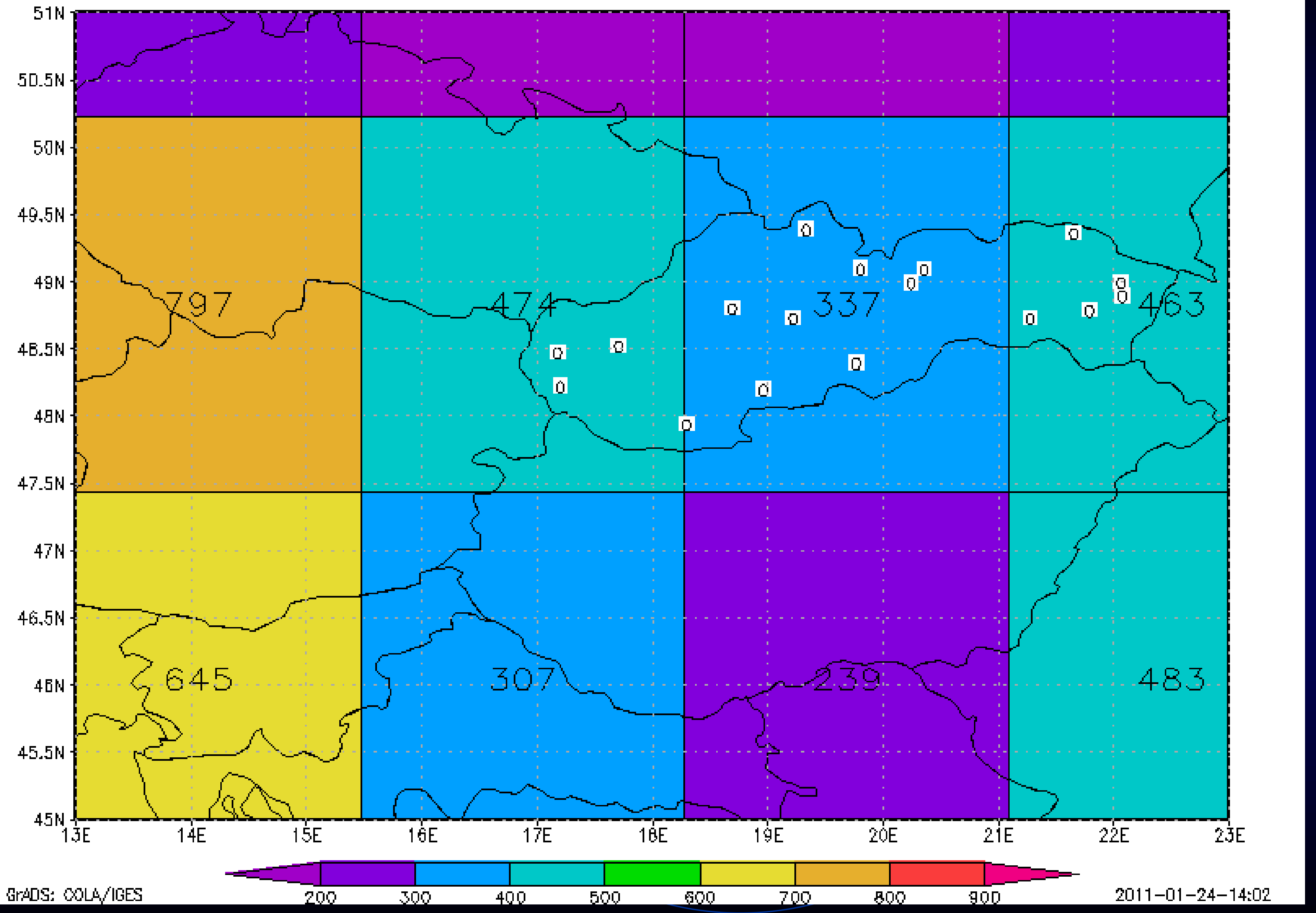
A1, B1T, A1F1, A1B, A2, B1, B2

and more older IS92a, IS92b, IS92c represent different ways of Climate Change mitigation



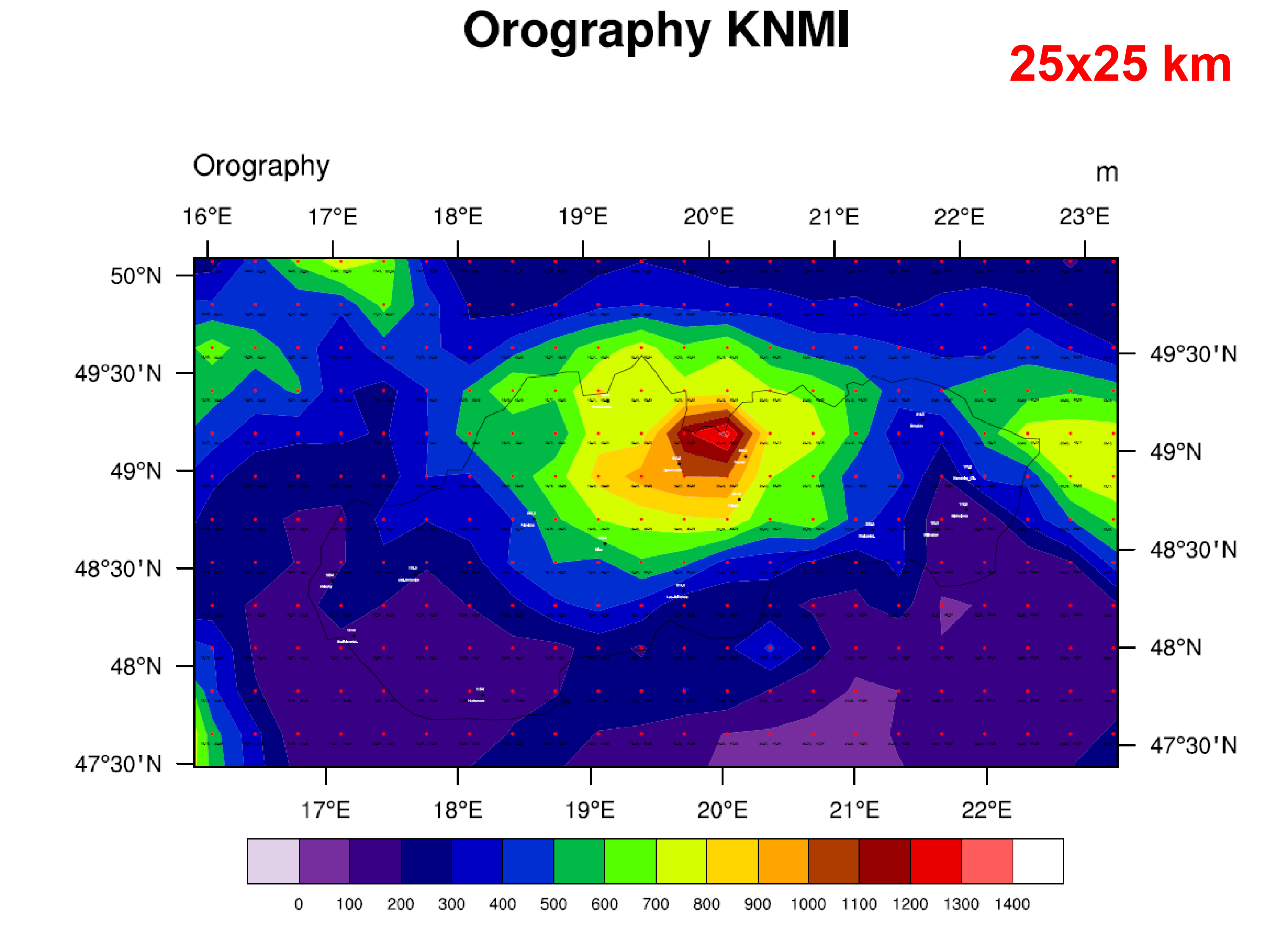
Alternative scenarios prepared by different centers and published in IPCC AR 5

About 250x250 km

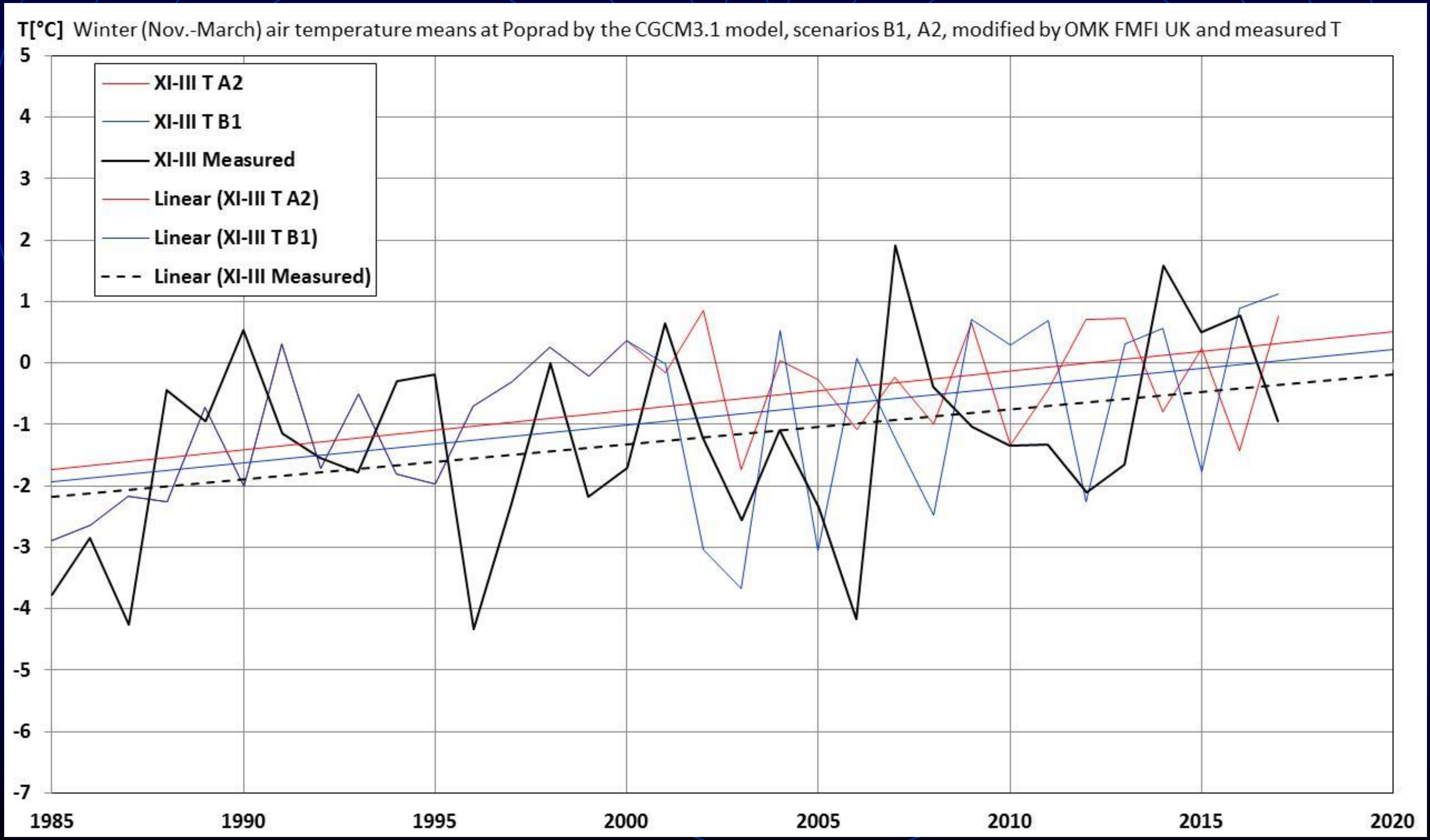


TOPOGRAPHY AND GRID POINTS AT RCMs

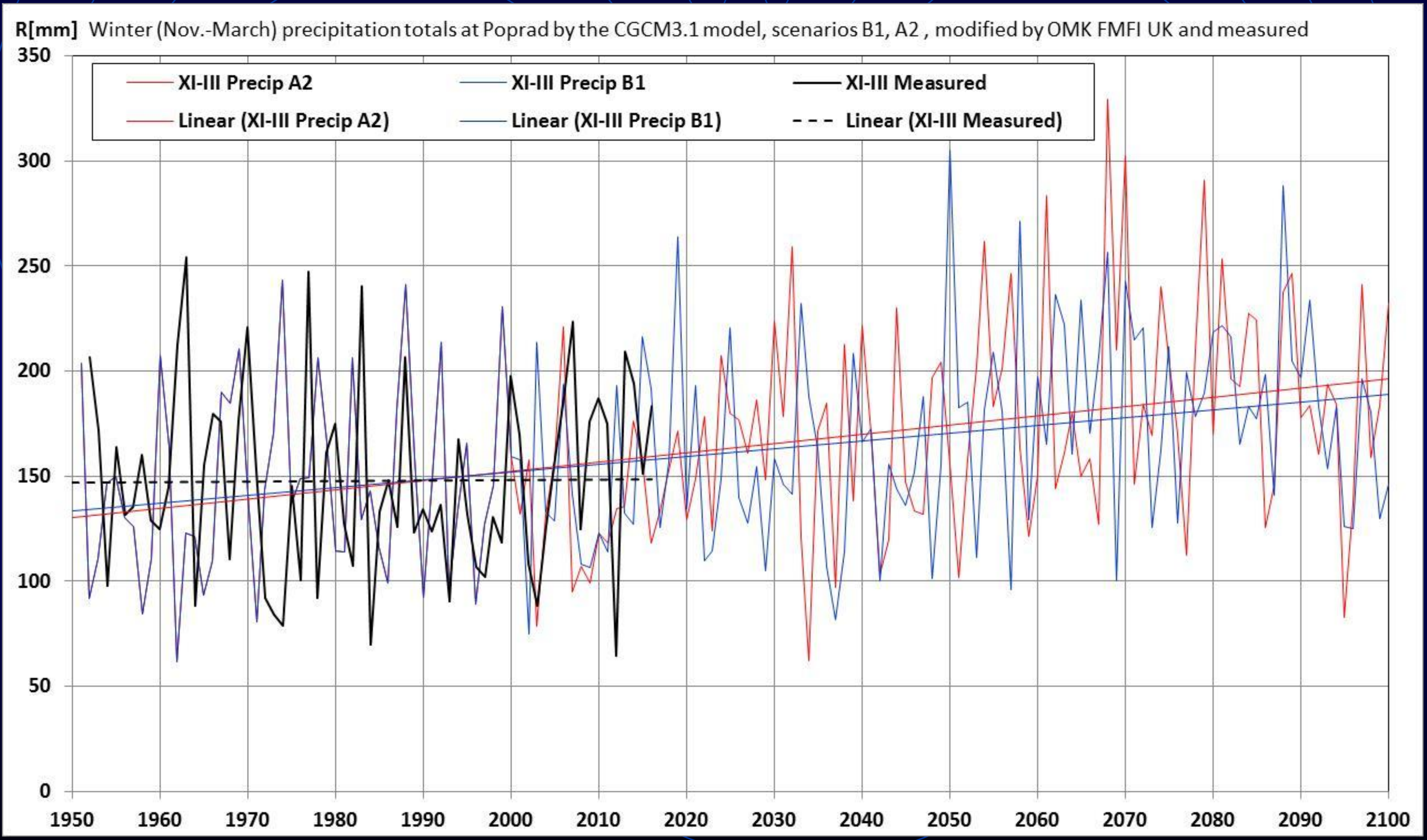
Dutch KNMI and German MPI with ECHAM5 boundary data



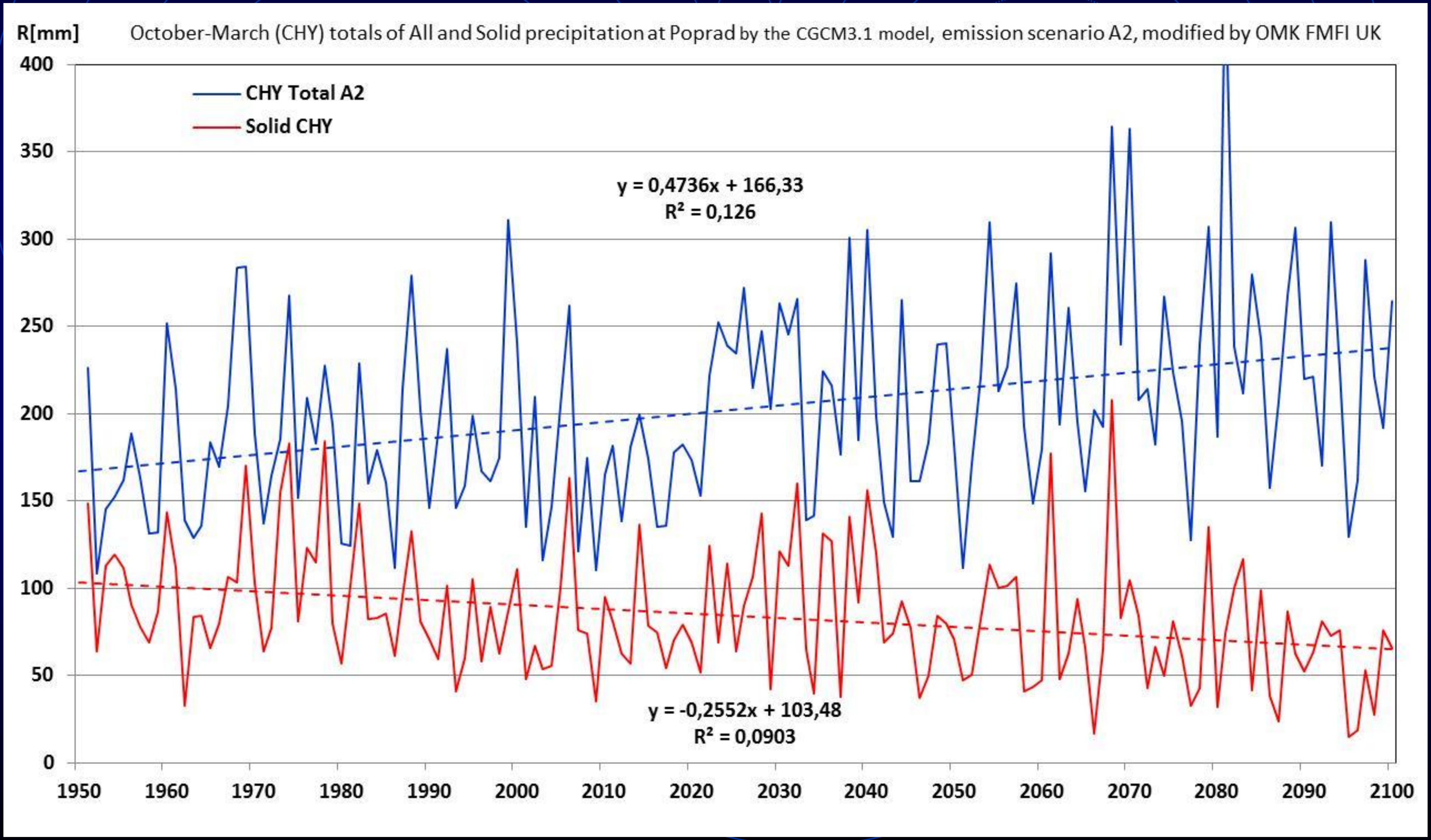
MEASURED (BLACK) AND MODELLED MEAN AIR TEMPERATURE IN THE WINTER SEASON (Nov.-March) AT POPRAD (695 m a.s.l., N Slovakia, GCM CGCM3.1, SRES A2 and B1, RCM KNMI, SRES A1B)



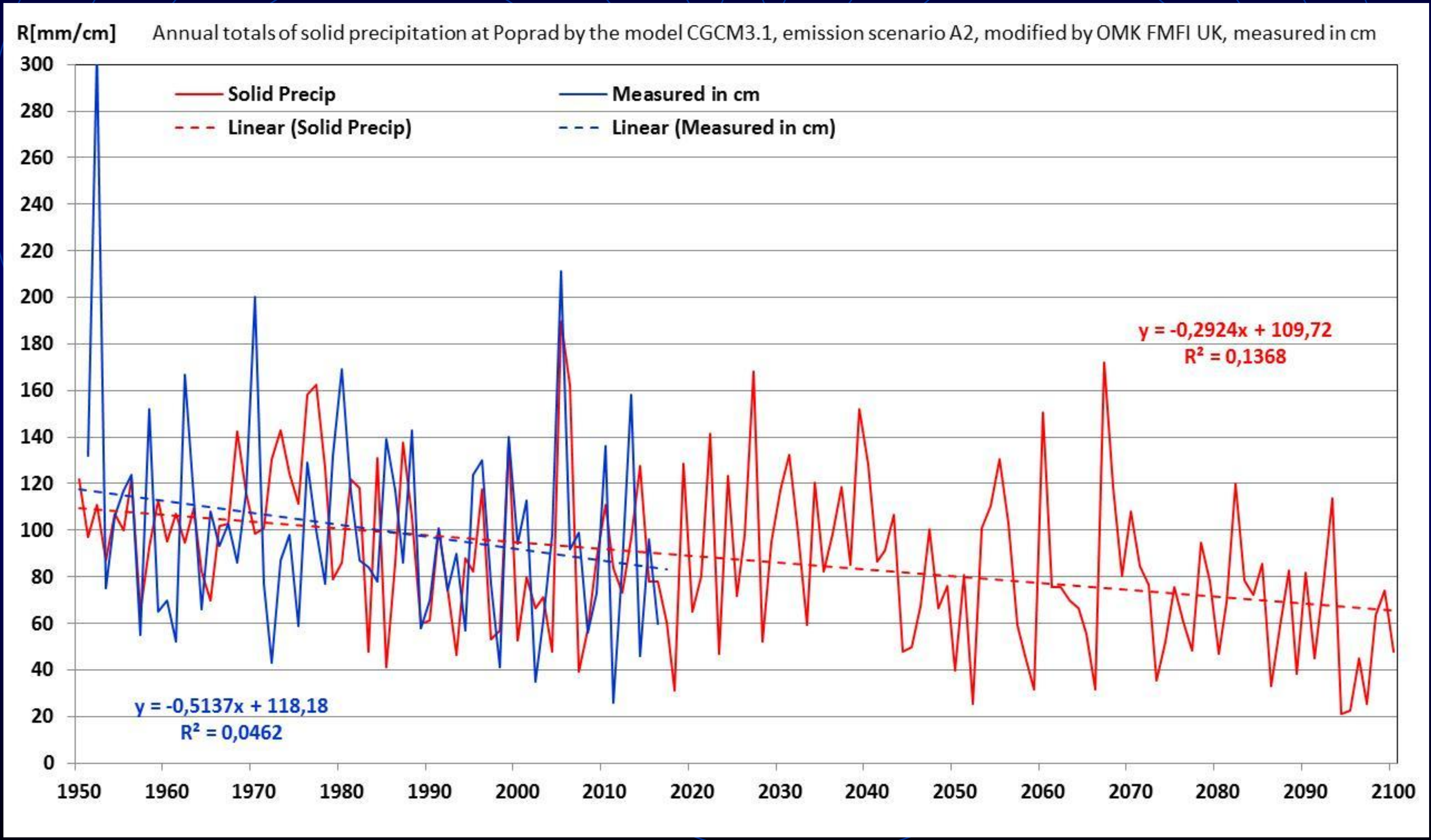
MEASURED (BLACK) AND MODELLED PRECIPITATION TOTALS IN THE WINTER SEASON (Nov.-March) AT POPRAD (695 m a.s.l., N Slovakia, GCM CGCM3.1, SRES A2 and B1)



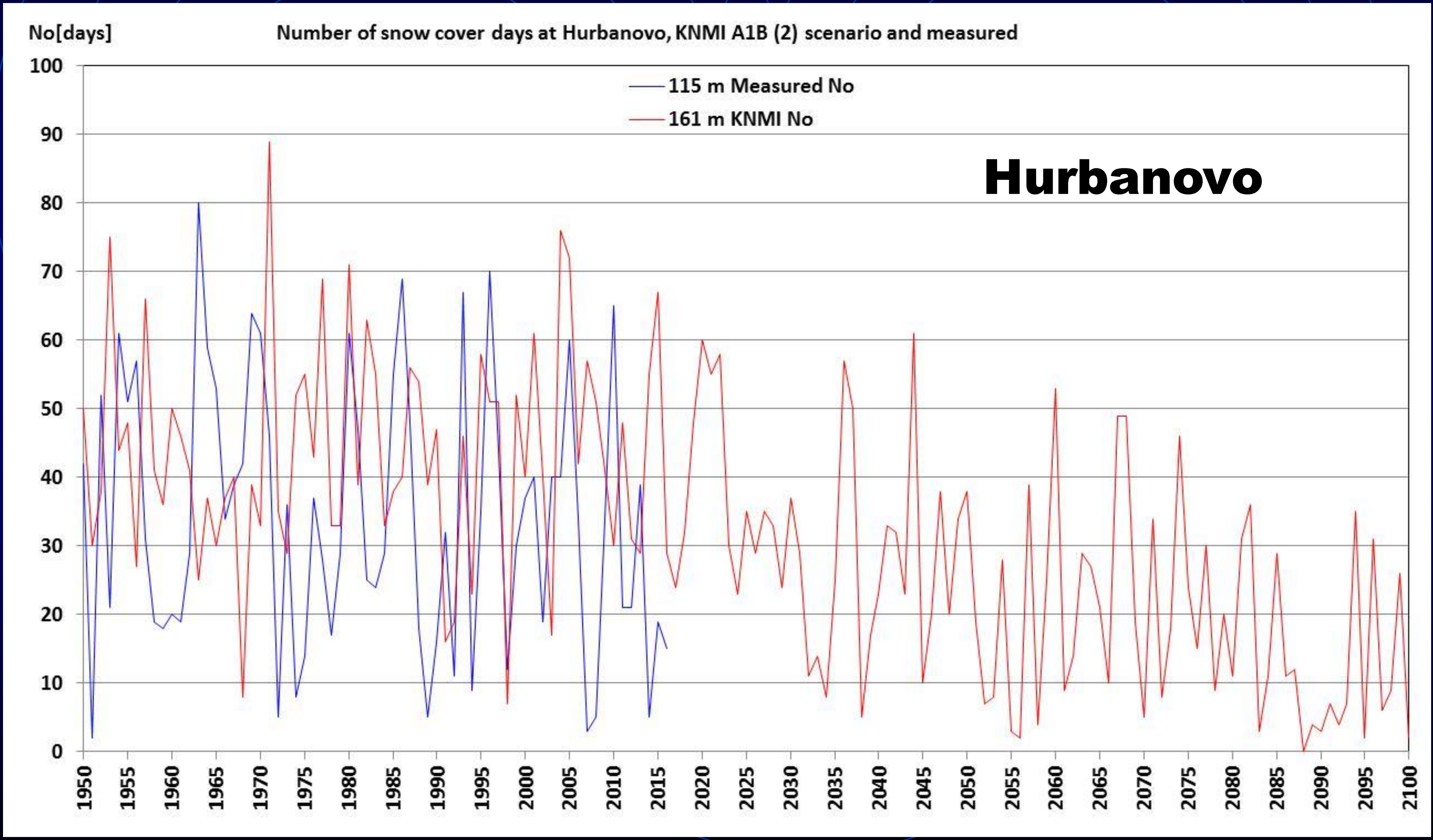
OCTOBER – MARCH AL PRECIITATION TOTALS (BLUE) AND SOLID PRECIPITATION TOTALS (RED) AT POPRAD (695 m a.s.l.)



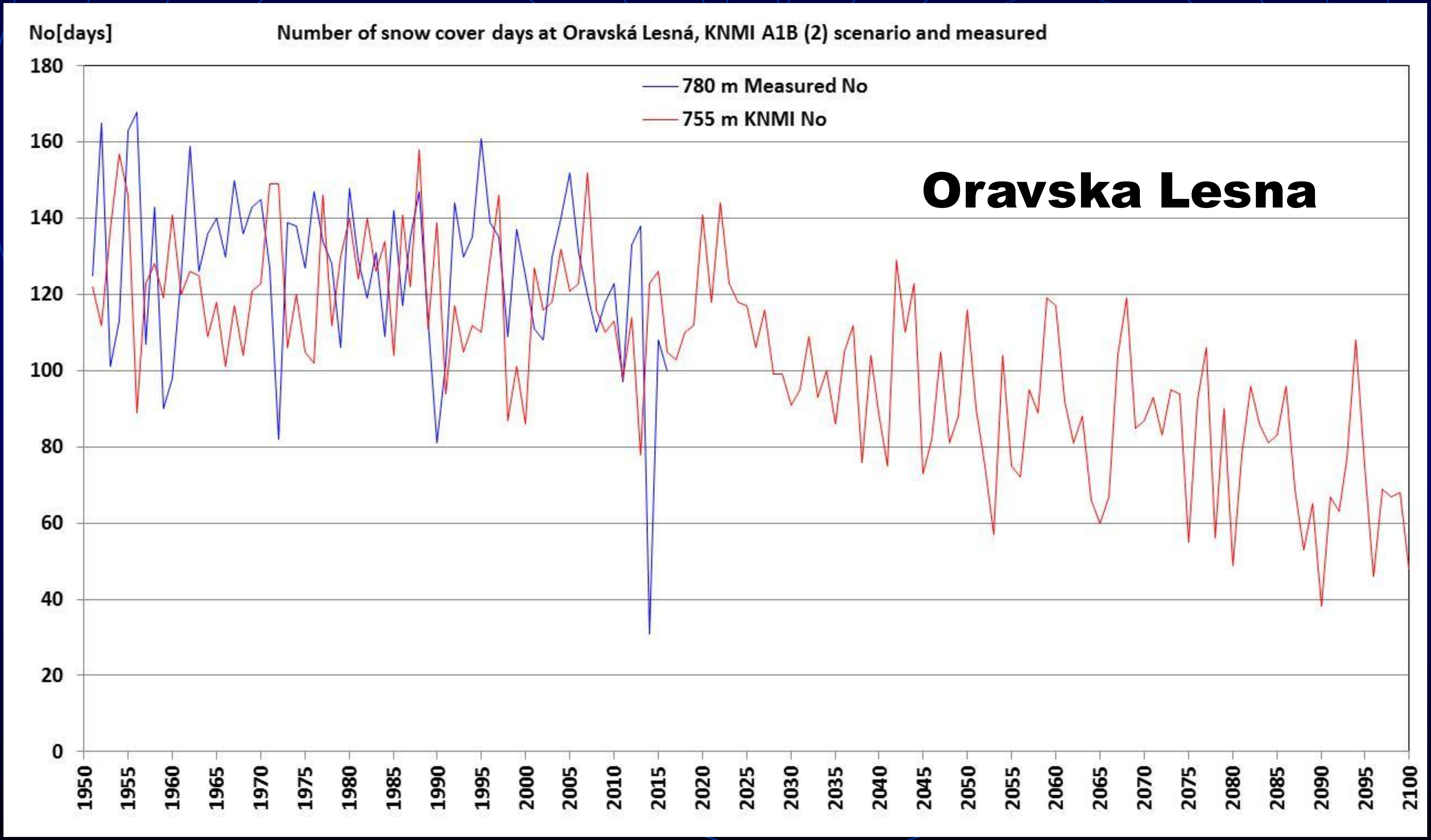
COMPARISON OF ANNUAL MEASURED SUM OF NEW SNOWCOVER (BLUE) AND MODELLED ANNUAL SOLID PRECIPITATION TOTALS AT POPRAD (695 m a.s.l.)



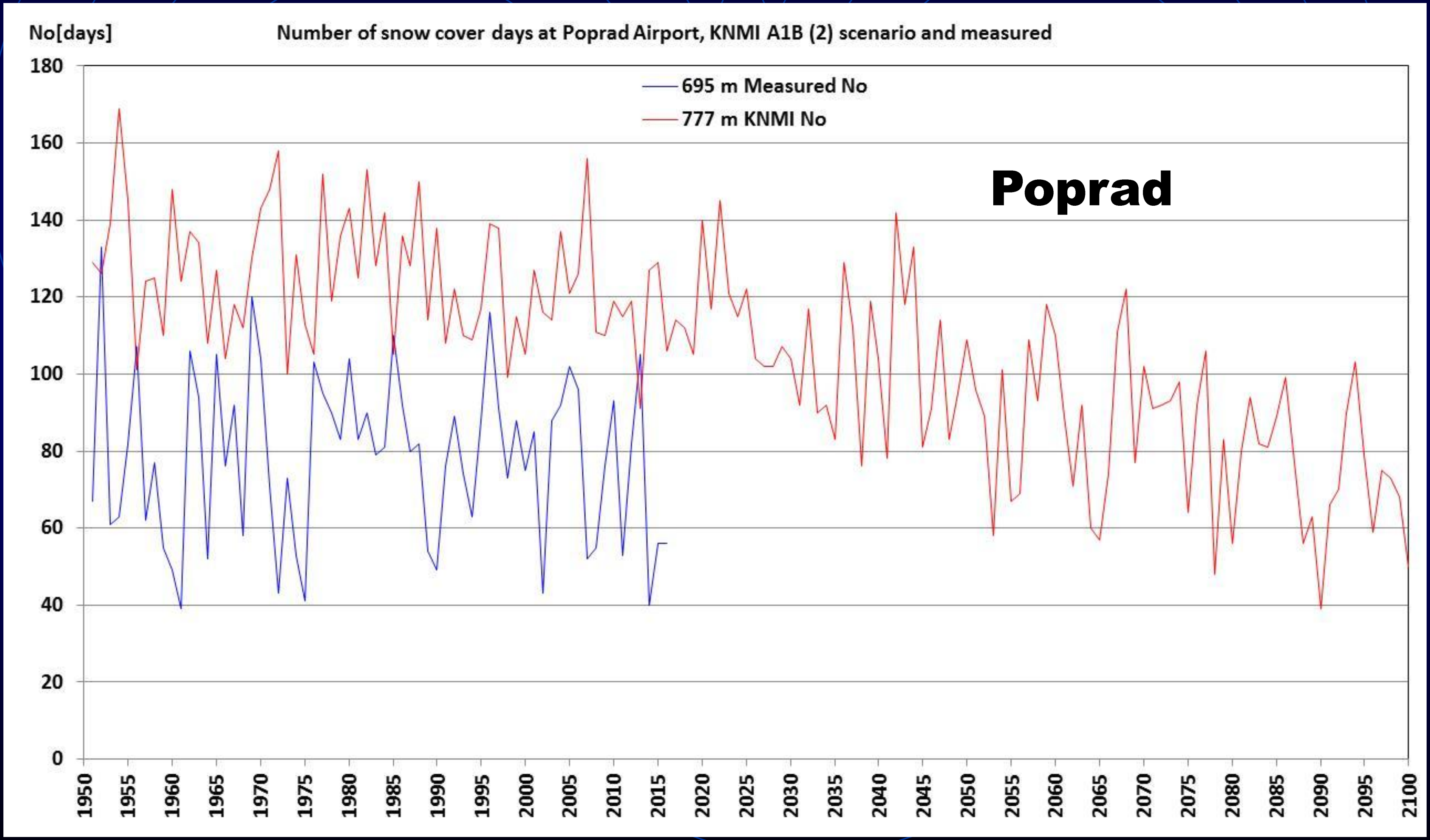
NUMBER OF ANNUAL DAYS WITH SNOWCOVER (MEASURED 115 m a.s.l. – BLUE, MODELLED KNMI 113 m a.s.l. and 161 m a.s.l. – RED) – without modification



NUMBER OF ANNUAL DAYS WITH SNOWCOVER (MEASURED 780 m a.s.l. – BLUE, MODELLED KNMI 810 m a.s.l. and 755 m a.s.l. – RED) – without modification



NUMBER OF ANNUAL DAYS WITH SNOWCOVER (MEASURED 695 m a.s.l. – BLUE, MODELLED KNMI 707 m a.s.l. and 777 m a.s.l. – RED) – without modification



SCENARIOS OF ANNUAL SNOWCOVER WATER EQUIVALENT SUM (mm) & SNOWCOVER DAYS AT 2 KNMI GRID POINTS (K m a.s.l.) AND MEASURED SNOW DATA (M) AT 2 STATIONS

Hurbanovo	1951 -980	1961 -990	1981 -010	2001 -050	2051 -100	%
K113 Sum [mm]	253	260	224	193	84	33.3
K113 N [days]	37.9	38.8	39.5	32.7	15.8	41.7
K161 Sum [mm]	288	286	254	227	92	32.0
K161 N [days]	43.3	43.6	43.8	36.3	18.1	41.7
M115 Sum [cm]	332	327	268			
M115 N [days]	36.4	36.6	34.1			

Sliač Airport	1951 -980	1961 -990	1981 -010	2001 -050	2051 -100	%
K477 Sum [mm]	1090	1226	1148	938	364	33.4
K477 N [days]	88.4	92.4	87.5	73.6	45.4	51.4
K701 Sum [mm]	1709	2034	2042	1613	604	35.3
K701 N [days]	112.9	114.3	107.8	95.8	64.9	57.5
M313 Sum [cm]	934	906	783			
M313 N [days]	68.2	64.9	60.8			

SCENARIOS OF ANNUAL SNOWCOVER WATER EQUIVALENT SUM (mm) & SNOWCOVER DAYS AT 2 KNMI GRID POINTS (K m a.s.l.) AND MEASURED SNOW DATA (M) AT 2 STATIONS

Oravská Lesná	1951 -980	1961 -990	1981 -010	2001 -050	2051 -100	%
K810 Sum [mm]	2323	2621	2563	1997	1053	45.3
K810 N [days]	122.4	123.8	119.8	108.3	78.5	64.1
K755 Sum [mm]	2397	2655	2606	2055	1172	48.9
K755 N [days]	123.2	124.1	120.5	108.4	79.8	64.7
M780 Sum [cm]	4764	4918	4874			
M780 N [days]	131.3	129.6	126.1			

Poprad Airport	1951 -980	1961 -990	1981 -010	2001 -050	2051 -100	%
K707 Sum [mm]	1886	2443	2720	1827	854	45.3
K707 N [days]	119.2	120.8	115.6	102.4	72.0	60.5
K777 Sum [mm]	2114	2563	2832	2072	1097	51.9
K777 N [days]	128.6	128.7	123.9	111.8	81.6	63.5
M695 Sum [cm]	933	855	785			
M695 M [days]	78.6	80.1	80.5			

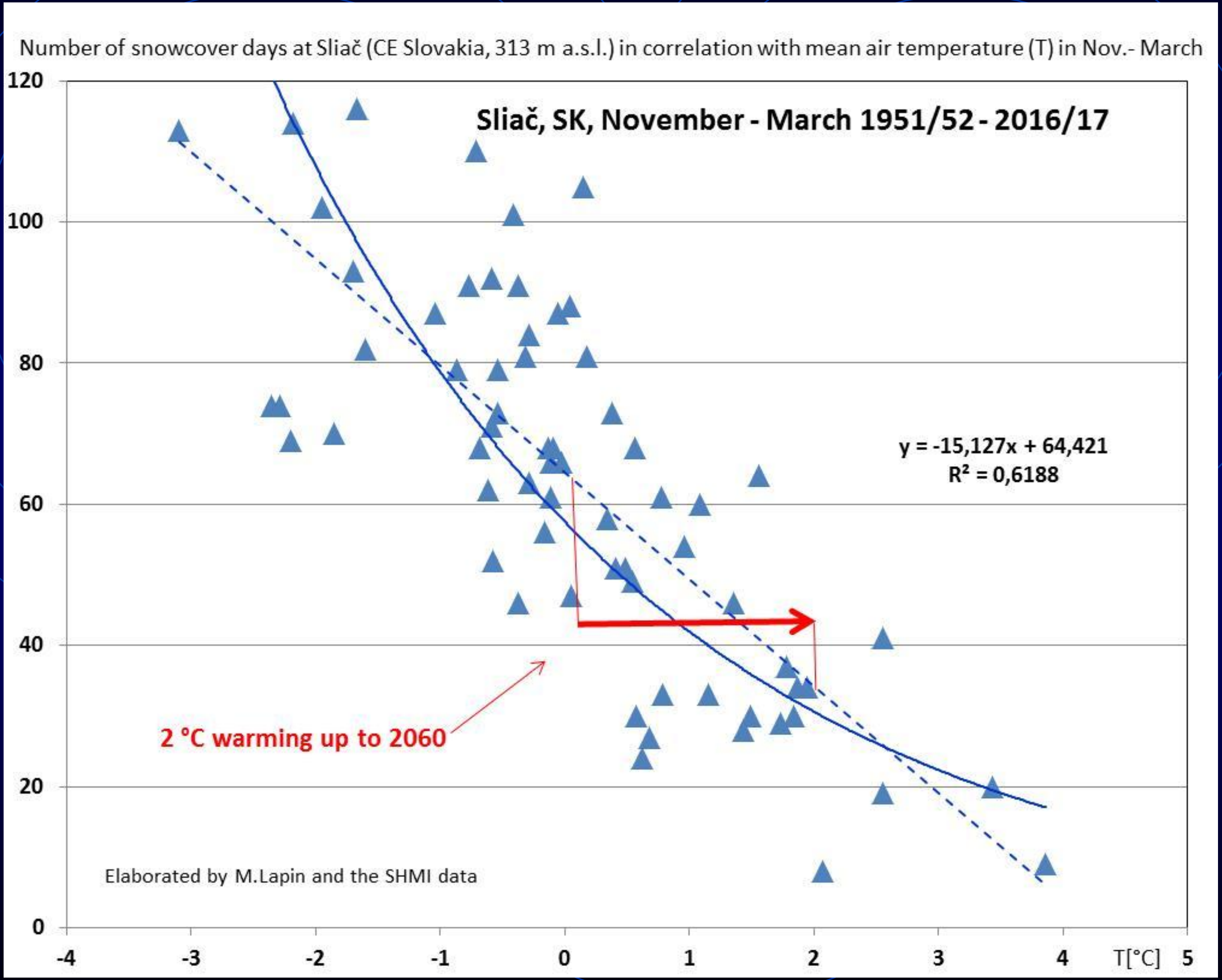
REGRESSION METHOD

- At least 30-year time series elaborated
- Correlation of monthly and seasonal snow characteristics and mean air temperature is very significant at the level α =0.05 and some times also at α = 0.01
- Changes in mean temperature between -5°C and +2°C seems the best interval for significant correlation
- Correlation of monthly and seasonal snow characteristics and precipitation totals is significant at the level α =0.10 (new snow cover), mostly insignificant also α = 0.20
- Better correlation between snow characteristics and precipitation totals seems at air temperature below -5°C (also for number of snow cover days and sums of daily snow cover depths, not only at new snow cover)

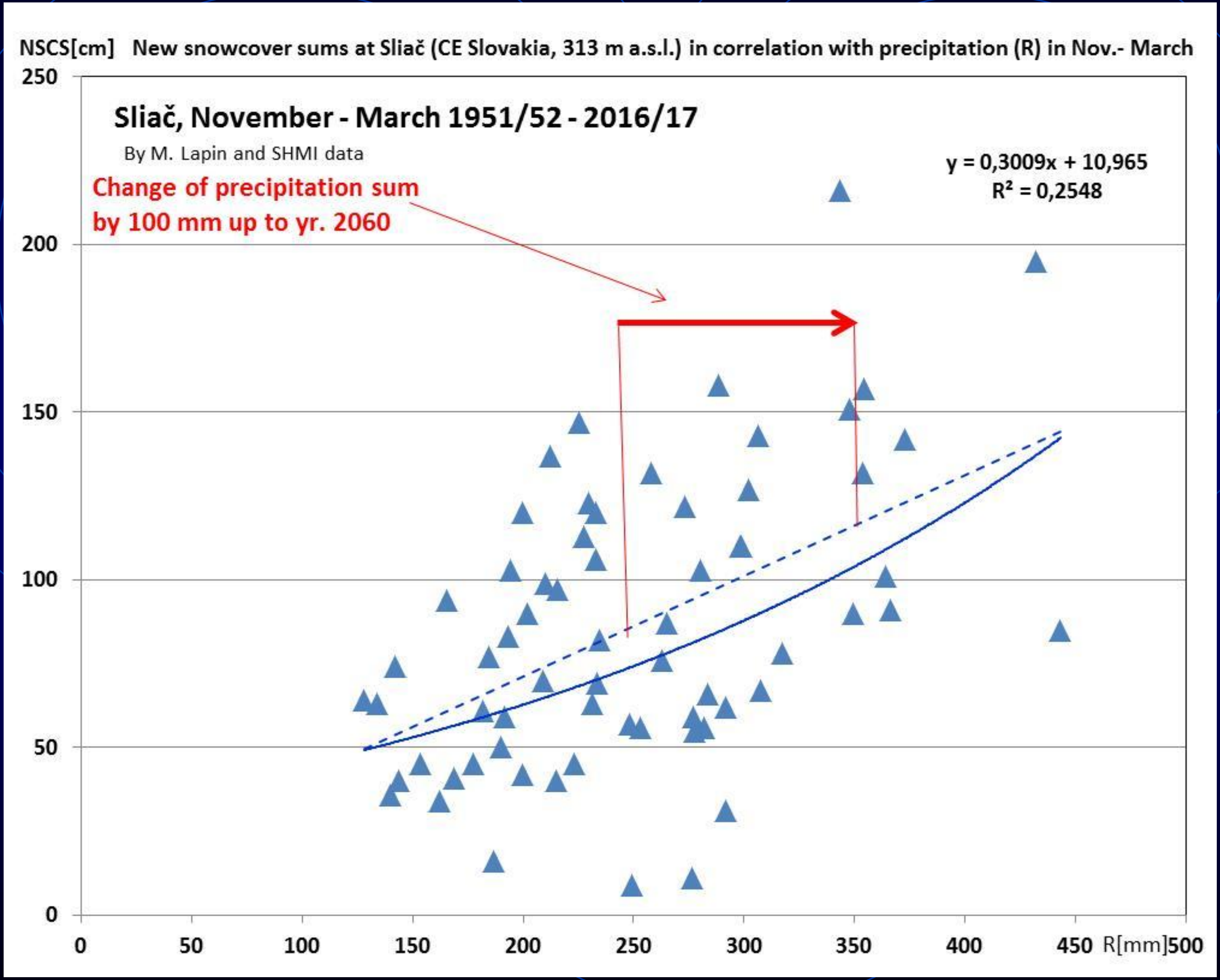
REGRESSION METHOD

- Comparison of measured monthly snow cover data with air temperature and precipitation in the period 1951-2010 enabled to prepare simple method for monthly snow cover characteristics scenarios design in 2011-2100 period.
- It was found that there are serious differences among altitudes below 500 m a.s.l., 500 to 1000 m a.s.l. and above 1000 m a.s.l.
- Examples are in the next Figures

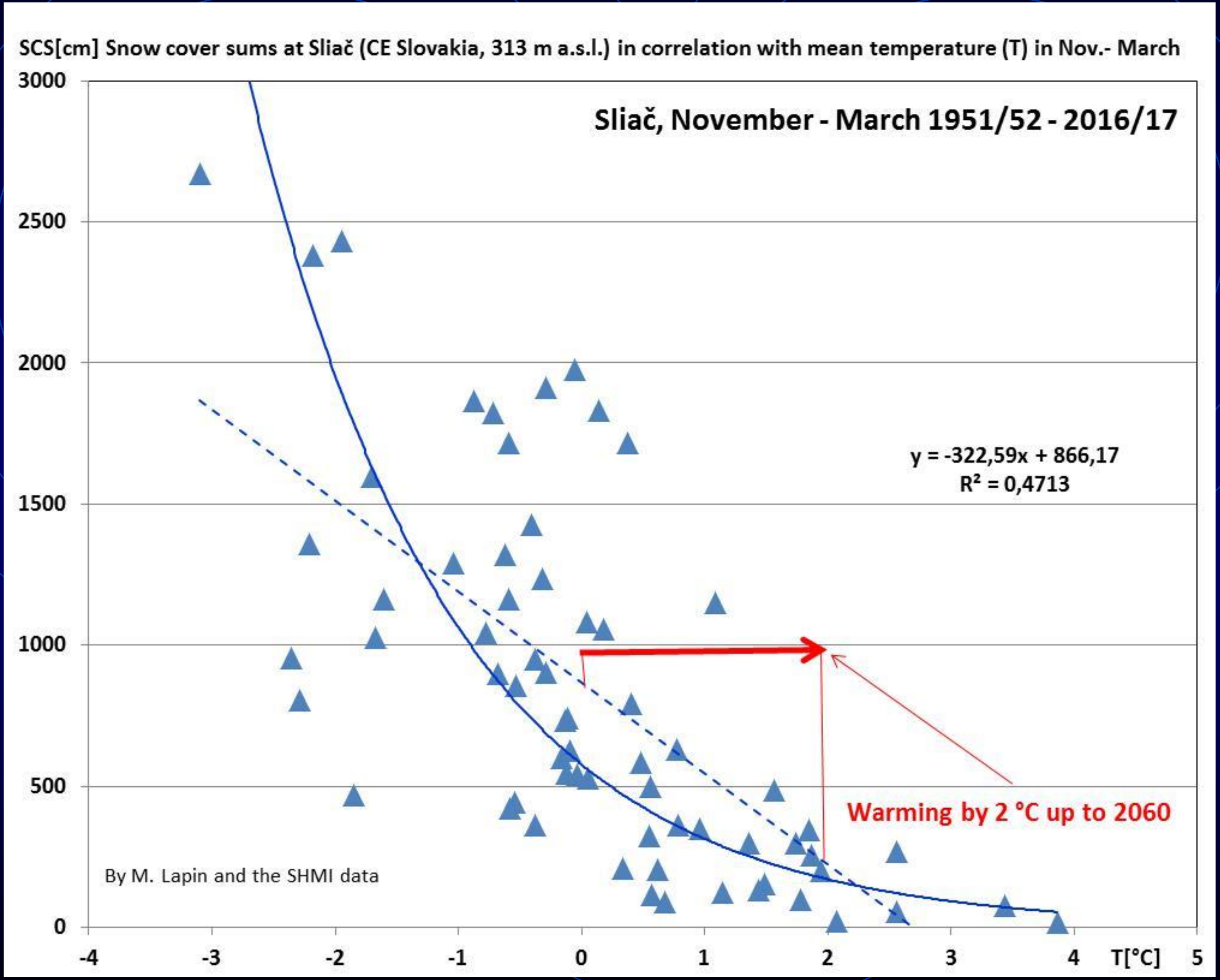
CORRELATION OF SNOW COVER DAYS NUMBER AND MEAN AIR TEMPERATURE (T) AT SLIAC IN NOV.-MARCH 1951/52-2016/17



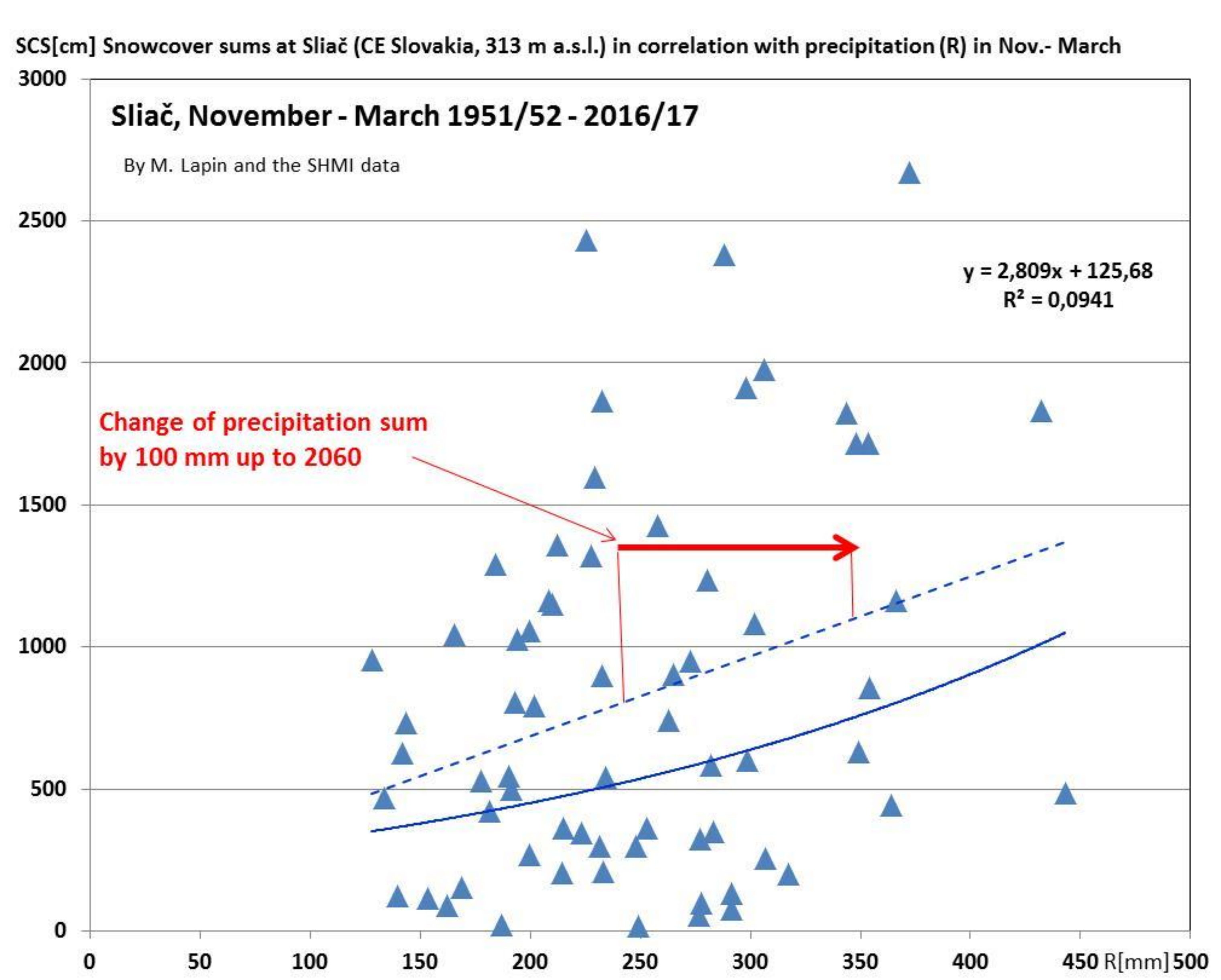
CORRELATION OF NEW SNOW COVER SUMS AND PRECIPITATION TOTALS (R) AT SLIAC IN NOV.-MARCH 1951/52-2016/17



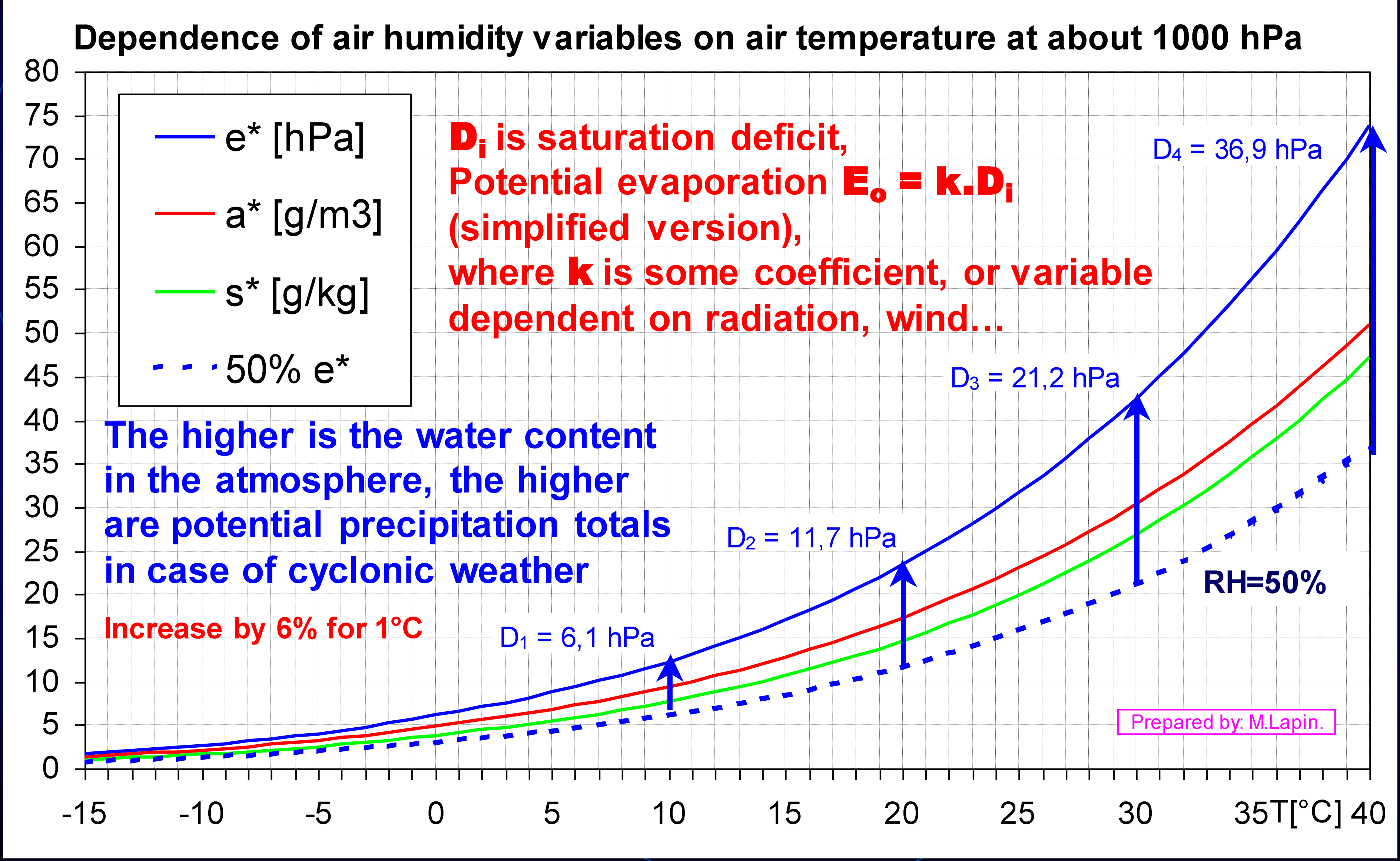
CORRELATION OF SNOW COVER SUMS AND MEAN AIR TEMPERATURE (T) AT SLIAC IN NOV.-MARCH 1951/52-2016/17



CORRELATION OF SNOW COVER SUMS AND PRECIPITATION TOTALS (R) AT SLIAC IN NOV.-MARCH 1951/52-2016/17



AIR HUMIDITY AND AIR TEMPERATURE



SCENARIOS OF SNOWCOVER DAYS NUMBER CHANGE (in %) AT 1°C WARMING (TOP) AND AT INCREASE OF PRECIPITATION TOTALS BY 10% (BOTTOM) AT 4 MOUNTAIN REGIONS AND 2 STATIONS IN SLOVAKIA (H is altitude in m a.s.l., II, III, XI, XII are months)

Region	H	XII-II	XI-III	H	XII-II	XI-III
Kysuce	600	-7	-10	1200	0	-3
Orava	600	-7	-10	1200	0	-3
Lomnica	850	-10	-14	1500	-1	-2
Jasná	1000	-5	-6	1500	-1	-2
Sliač	313	-17	-24			
Hurbanovo	115	-27	-32			

Region	H	XII-II	XI-III	H	XII-II	XI-III
Kysuce	600	1.5	1.1	1200	0.4	0.3
Orava	600	1.5	1.1	1200	0.4	0.3
Lomnica	850	1.0	0.8	1500	0.3	0.3
Jasná	1000	0.5	0.4	1500	0.3	0.3
Sliač	313	1.7	1.6			
Hurbanovo	115	3.4	3.1			

SCENARIOS OF DAILY SNOWCOVER SUMS CHANGE (in %) AT 1°C WARMING (TOP) AND AT INCREASE OF PRECIPITATION TOTALS BY 10% (BOTTOM) AT 4 MOUNTAIN REGIONS AND 2 STATIONS IN SLOVAKIA (H is altitude in m a.s.l., II, III, XI, XII are months)

Region	H	XII-II	XI-III	H	XII-II	XI-III
Kysuce	600	-15	-28	1200	-8	-14
Orava	600	-15	-29	1200	-8	-14
Lomnica	850	-20	-35	1500	-7	-15
Jasná	1000	-17	-25	1500	-7	-15
Sliač	313	-26	-39			
Hurbanovo	115	-37	-48			

Region	H	XII-II	XI-III	H	XII-II	XI-III
Kysuce	600	5	3	1200	4	2
Orava	600	5	3	1200	4	2
Lomnica	850	5	4	1500	3	2
Jasná	1000	4	2	1500	3	2
Sliač	313	4	3			
Hurbanovo	115	5	4			

SCENARIOS OF NEW SNOWCOVER SUMS CHANGE (in %) AT 1°C WARMING (TOP) AND AT INCREASE OF PRECIPITATION TOTALS BY 10% (BOTTOM) AT 4 MOUNTAIN REGIONS AND 2 STATIONS IN SLOVAKIA (H is altitude in m a.s.l., II, III, XI, XII are months)

Region	H	XII-II	XI-III	H	XII-II	XI-III
Kysuce	600	-8	-9	1200	-4	-5
Orava	600	-8	-9	1200	-4	-5
Lomnica	850	-8	-12	1500	-3	-5
Jasná	1000	-4	-7	1500	-3	-5
Sliač	313	-14	-21			
Hurbanovo	115	-24	-29			

Region	H	XII-II	XI-III	H	XII-II	XI-III
Kysuce	600	5.5	3.8	1200	3.8	2.4
Orava	600	5.5	3.8	1200	3.8	2.4
Lomnica	850	7.0	3.5	1500	3.5	2.0
Jasná	1000	4.0	2.5	1500	3.5	2.0
Sliač	313	4.5	3.5			
Hurbanovo	115	8.1	5.6			

Average number of warm days (with mean temperature above +5°C (days)) in winter (Dec.-Feb., 90 days) and sum of precipitation (mm) during these warm days by CGCM3.1 model, SRES A2 scenario (H – Hurbanovo, SW Slovakia, 115 m a.s.l., P – Poprad Airport, 695 m a.s.l., O – Oravská Lesná, NW Slovakia, 780 m a.s.l., % - share of warm days from all days in winter and precipitation during warm days from all precipitation in winters 2071-2100 in %)

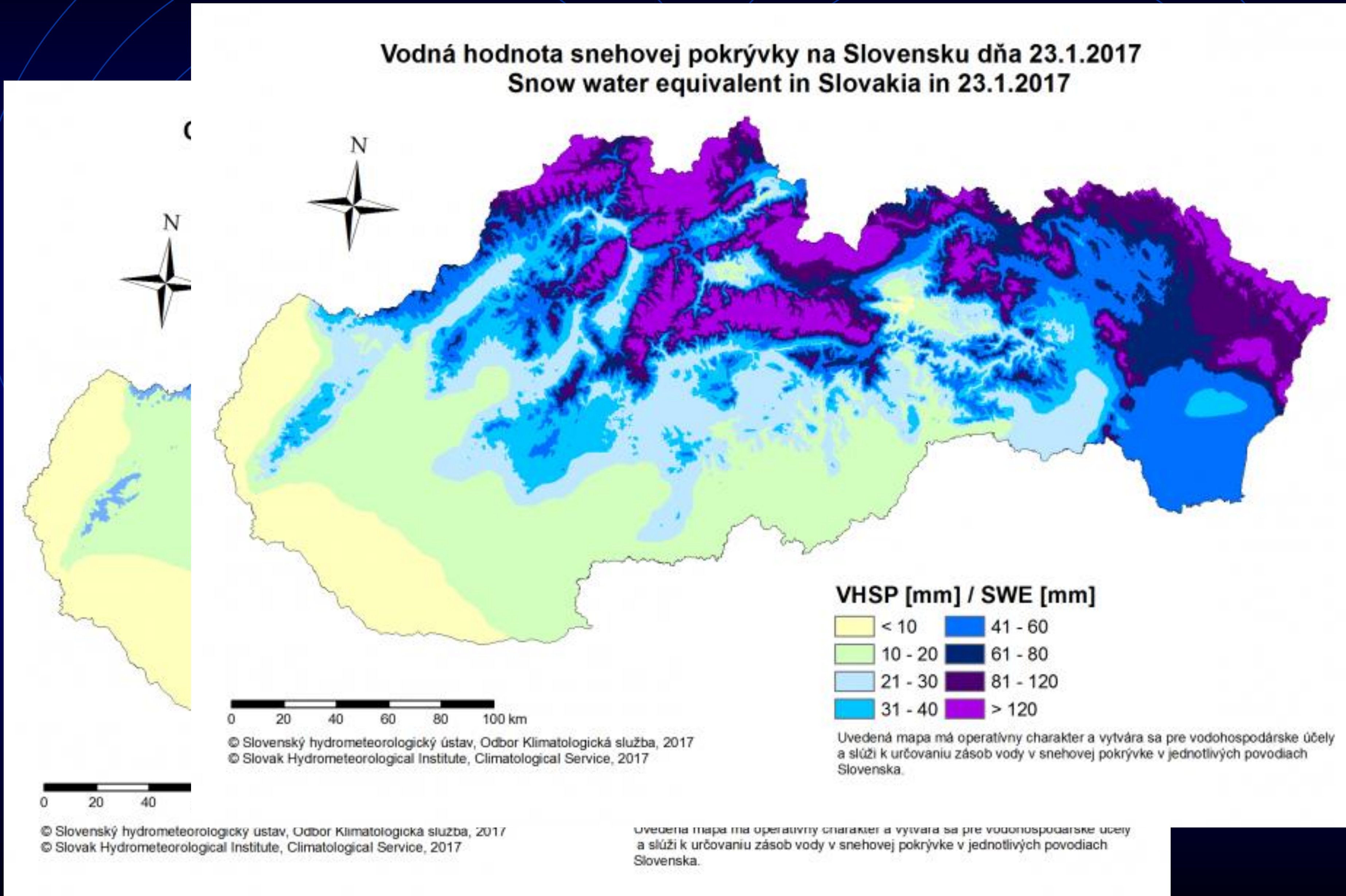
Station	1951-1980	1961-1990	1981-2010	2011-2040	2041-2070	2071-2100	%
H days	11.5	11.6	14.9	21.4	26.2	40.9	45.4
H mm	26.5	27.7	34.1	45.5	59.6	106.3	62.7
P days	1.4	1.4	2.4	4.4	6.9	12.1	13.4
P mm	2.7	3.3	5.6	6.9	10.7	18.2	18.2
O days	2.2	2.3	3.6	6.7	8.8	14.3	15.9
O mm	9.9	13.0	22.2	28.3	37.9	65.4	21.8

Average number of days with temperature < -1°C and < 0°C (bottom) by the CGCM3.1 model, SRES A2 scenario in the long winter season Nov. to March (totally 161 days) for the stations Hurbanovo, Sliač Airport, Poprad Airport, Oravská Lesná, Štrbské Pleso (N Slovakia, 1360 m a.s.l.) and Chopok (CE Slovakia, 2008 m a.s.l.), % - share of such days in 2071-2100.

Station	1951-1980	1961-1990	1981-2010	2011-2040	2041-2070	2071-2100	%
Hurban	43.2	40.7	32.0	24.6	19.8	8.0	4.9
Sliač	65.1	61.6	52.1	44.2	36.1	21.9	13.6
Poprad	84.4	80.3	70.4	62.1	50.7	32.7	20.3
OLesná	79.5	75.9	66.5	58.3	47.7	31.6	19.6
ŠPleso	100.9	97.0	85.1	75.8	62.1	40.0	24.9
Chopok	139.2	137.7	132.5	129.9	119.2	102.6	63.7

Station	1951-1980	1961-1990	1981-2010	2011-2040	2041-2070	2071-2100	%
Hurban	53.7	51.3	42.0	32.8	26.5	13.7	8.5
Sliač	75.6	72.3	63.4	54.7	44.5	28.8	17.9
Poprad	96.7	92.4	81.8	74.2	60.5	41.9	26.0
OLesná	91.3	87.3	76.9	70.5	57.3	40.1	24.9
ŠPleso	112.7	109.4	98.6	89.6	75.8	53.1	33.0
Chopok	143.3	142.6	139.8	137.5	129.0	115.3	71.6

EXAMPLE OF SNOW COVER DEPTH AND SNOW COVER WATER EQUIVALENT INFORMATION BY THE SHMI EACH WEEK



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a slúži k určovaniu zásob vody v snehovej pokrývke v jednotlivých povodiach
Slovenska.

CONCLUSIONS

- As seen from the Tables and Figures, snow conditions in Slovakia have changed and the negative tendency will continue probably up to 2100 at least (based on climate change scenarios)
- The most dramatic changes are expected in lower altitudes, mainly below 800 m a.s.l. and only above 1000 m a.s.l. (5.4% of Slovak territory) will have unchanged or something better conditions for winter sports, namely skiing
- Increase of accumulated snow cover is expected only above 1200 m a.s.l., about 4% of the territory
- This conclusion comes from the detail analysis of measured snow characteristics and also from the models output.
- Some differences among modeled results are based on different scenarios of air temperature and precipitation increase in winter seasons Dec. to Feb. or Nov. to March.
- Generally higher increase of air temperature is expected at the SRES A2 emission scenario (higher emission of Greenhouse gases)
- We are ready to present these results in a form of comprehensive papers or chapters in monograph

THANK YOU FOR THE ATTENTION

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