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RECENT LARGE-SCALE FOREST FIRES IN BOREAL FORESTS AND CLIMATE CHANGE
- Discussion based on weather data in Alaska and Sakha -

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1. INTRODUCTION

The boreal forest (Taiga) occupies one-third of the world's forest area. During summer, the risk of fire is high in this region due to relatively low rainfall (average <300mm); Kasischke (2000). Recent trends toward warmer, drier summers associated with global climate change are expected to increase the number and size of boreal forest fires; Campbell and Flannigan (2000). Recent regional fire events appear to support these predictions.

In 2002, many large-scale forest fires occurred near Yakutsk, the capital of the Sakha Republic in Siberia, burning a total area estimated at over 23,000km^2 -- the largest reported in Sakha since 1955 and about ten times greater than mean burnt area, or about 2,400km^2.

In 2003, forests burned near the Baikal Lake in Siberia were especially severe, and burnt area in Russia (Siberia) totaled in excess of 234,000km^2.

In 2004, many large-scale forest fires occurred in Alaska due to record-breaking lightning strikes aggravated by severe drought conditions and the occurrence of foehn winds. The total burnt area in 2004 was about 26,000km^2, the largest on historical record since 1956.

In 2005, many large-scale forest fires recurred in Alaska. Many fires became very active in the middle of August due to drought and foehn winds. The total burnt area in 2005 was about 26,000km^2, the third largest area since 1956. Active fire occurrence of two consecutive years has seldom occurred.

Trends in and features of large forest-fire occurrence and weather hold the key to understanding how climate change may affect boreal ecosystems, and fire in the boreal forest is now being actively researched. Kasischke et al. (2002) studied the patterns of large fires over the last 50 years in Alaska by analyzing the large-fire database (LFDB) and other information. The influence of El Niño weather events was investigated by Hess et al. (2001), who concluded that many of the largest fire years occurred during or just after a warm ENSO episode. Stevens and Dallison (2005) urged that recent climate change in the boreal forest could substantially impact on the number and size of wildfires in Alaska and should be more thoroughly studied. New fire-management strategies may need to be explored under climate change to protect crucial wildlife habitats, subsistence resources, and human inhabitants in the boreal forest from incendiary impacts. The authors are now seeking strategies through comparative studies of forest fires and weather in Alaska, North America, and Sakha, Far Eastern Siberia.

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2. ALASKA AND SAKHA

Alaska, the largest of the 50 United States of America, is located at the northwesternmost corner of the North American Continent, mainly located between North Latitude 58^o to 71^o and West Longitude 141^o to 166^o. Forest in Alaska is so-called boreal forest and mainly exists in interior Alaska surrounded by Brooks and Alaska Ranges. Fairbanks located at North Latitude 64.8^o and West Longitude 147.9^o is the center of interior Alaska. Alaska's forest, which cover about 460,000 km^2, consist mostly of black spruce, white spruce, aspen, birch, sphagnum moss, and lichens. Forest fires in Alaska sometimes spread due to so-called crown fires, and lightning is mainly responsible for large burnt areas.

Sakha, a Russian Federation republic located in Far-Eastern Siberia, lies located between North Latitude 56^o to 73^o and East Longitude 106^o to 160^o. Sakha's boreal forest or taiga lie mainly in the southern Arctic Circle. Yakutsk, the capital of Sakha, is located at North Latitude 62.1^o and East Longitude 129.8^o. Sakha's forest area covers about 1,430,000 km^2 and consists mainly of larch, pine, spruce, vaccinium vista-idaea, moss, and lichens. Crown fires are not so often but fires caused by human activity are responsible for the majority of fires.

Table 1 compares of forest-fire occurrence and weather trends in Alaska and Sakha.

Table 1 Comparison of Alaska and Sakha

	Alaska	Sakha	Ratio(S/A)
Land Area, km^2	1,518,800	3,103,200	2.04
Forest Area, km^2	460,000	1,430,000	3.11
Number of Fires	463*	546**	1.18
Burnt Area, km^2	3,821*	1,797**	0.47
Remarks	1956-2005	1955-2005	

Table 1 shows that forest area in Sakha is three times larger than that of Alaska, yet the number of forest fires in both is almost the same and burnt area in Sakha is smaller than that in Alaska. This is mainly due to fire statistics in Sakha only for control forest which area is 42% of whole forest area. Evaluating these facts would improve our knowledge of forest fires in both places.

3. FOREST FIRES IN ALASKA

3.1 *History*

Alaskan Forest fire history data from 1956 provided by the University of Alaska Fairbanks and the Alaska Fire Service was analyzed to distinguish anthropogenic fires from natural or lightning-caused fires (Fig.1). The bar graph in Fig.1 indicates burnt area and the line graph shows the number of fires. Smaller bars and lower lines indicate lightning-caused forest fires. There is a big difference between the two lines but the difference between the two bars is very small, indicating that forest fires in Alaska are mainly caused by lightning and account for much of the burnt area and for about 40% of the number of fires.

In 2004, many fires occurred despite markedly high precipitation in May for most of Alaska. Rainfall was observed in mid-May through mid-June due to strong convection, but a long drought of about one month in June-July and strong Foehn winds increased the activity of fires ignited by lightning, making the total burnt area in 2004 the largest since 1956.

In 2005, precipitation in August was only 6.1mm -- the lowest since 1956. Many fires become very active due to severe drought in August despite high precipitation from May to July. Strong Foehn winds during a severe drought in August increased fires, making the total burnt area in 2005 the third largest since 1956.

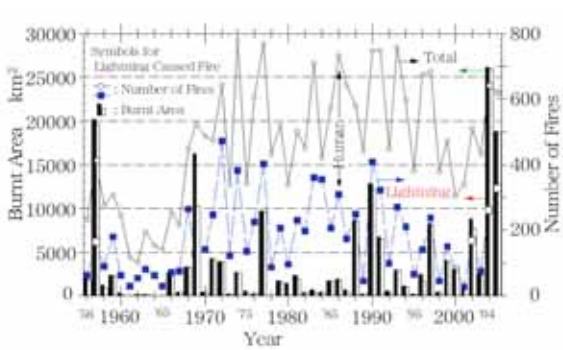

Fig.1 Forest Fire History in Alaska (1956-2005)

3.2 *Forest Fires and Weather Trends*

3.2.1 ***General Trends***

Alaskan forest fire and weather trends are summarized in Table 2 using weather data from the Alaska Climate Research Center, University of Alaska Fairbanks. The average number of fires and area burned each year for three periods -- 1956-2005, 1956-1989, and 1990-2005 -- are summarized to show the increase in fire activity in Alaska between 1990 and 2005. The average number of fires and burnt area from 1990 to 2005 are clearly greater than in the other two periods. Average burnt area from 1990 to 2005 is 2.3 times greater than that of between 1956 and 1989.

To determine the cause of this recent increase in fire activity in Alaska, we studied precipitation and average maximum temperature, summarized in Table 2. The decrease in precipitation in spring (March to May) from 1990 to 2005 ranged from 0.2 and 0.9mm compared to that between 1956 and 1989. The recent increase in maximum temperatures in spring (March to May) ranged between 1.1 to 2.8^{o}C compared to those from 1956 to 1989. A marked temperature rise of 2.8^{o}C occurred in April.

In addition to this spring weather change, trends of lower precipitation and higher temperature are found in June, when precipitation was -0.7mm lower and 0.4^{o}C warmer than normal. This drier trend in June may slightly increase lightning activity and fire-ignition probability by lightning.

Weather changes in April and June thus indicate drier springs, increased lightning activity, and a slightly high ignition probability by lightning – all of which may be important causes of recent increased fire occurrence in Alaska.

3.2.2 ***High fire years and weather***

The top ten forest fires in Alaska are listed in Table 3. Six of these occurred after 1990. In Alaska, lightning causes most forest fires in June and July, peaking around July 1 and corresponding to the first lightning occurrence peak. Most large fires, the 10 largest fires in that 14-year period (1986-1999) in Alaska started from June; Hayasaka, et. al.(2003). This is because forest fires could last several weeks due mainly to low precipitation and could become active flaming fire under favorable weather conditions such as low humidity, high temperature, and proper wind velocity.

To determine the cause of the top ten fires from 1956 in Alaska, precipitation and the average maximum temperature are summarized in Table 3. Departures from averages for both $\Delta\overline{P}_{10}$ (precipitation) and $\Delta\overline{T}_{10}$ (temperature) are showed in Table 3 for easier understanding. Average departures $\Delta\overline{P}_{10}$ and $\Delta\overline{T}_{10}$ for the top ten fires and average absolute values for precipitation and temperature are listed in the bottom two columns in Table 3.

Precipitation and temperature in summer (June to August) may be very important to large-scale fires. Large negative values of less than -20mm are easily found in columns for the three months of June through August in Table 3. These large negative values for precipitation are found mainly in columns in the top four fire years. Values exceeding 3^{o}C are also easily found in temperature columns in Table 3, but these temperatures are found mainly in columns in the top five fire years. These abnormal conditions for precipitation and temperature may be strongly related to fire activities. The three months of June through August show very low precipitation and high temperature in the first and second fire years, i.e., 2004 and 1957. Three months of low precipitation and high temperature also found in 1997. Two months of such conditions were found in 1977. Four other fire years except for 1990 and 2002 had one month of low precipitation and high temperature.

Summer weather changes in precipitation and temperature also indicate drier summers. Average departures of $\Delta\overline{P}_{10}$ indicate drier summers, especially in June and August, but average departures of $\Delta\overline{T}_{10}$ clearly show markedly high temperatures of 1 or 2^{o}C from March to August or spring and summer. This temperature trend may be one of the most important causes of the recent increased in fire occurrence in Alaska.

3.2.3 ***Low forest-fire years and weather***

Low forest-fire years in Alaska are listed in Table 4. Four of five occurred in the 1960s. Table 4 shows surprisingly low burnt areas compared to the average of 2,690km^2 in Table 3. The lowed burnt area is found in 1964 totaling only 14km^2 or about 1/192 of the average area.

To clarify the reason for low burnt area, departures from average, ΔP_5 and ΔT_5, and average departures, $\Delta\overline{P}_5$ and $\Delta\overline{T}_5$, are shown in Table 4 as in Table 3.

For large fires, low precipitation and high temperature in summer were essential weather condition, while high precipitation and low temperature were key weather condition for low fires occurrence. No markedly high precipitation departure is found in Table 4, however, but high precipitation such as 80, 70, and 48mm are found in Table 3. This indicates that fire activity does not depend on precipitation much in Alaska. Precipitation exceeding 100mm is needed to suppress fires completely, but no such large precipitation is expected because annual precipitation in Alaska is about 250mm and originally as low as in the desert.

Low temperature departures of less than -1 ^{o}C were easily found in Table 4. Markedly low temperatures from March to May were found in the low forest-fire years of 1964 and 1961. In 1965, a low temperature trend starting in April lasted until August. In 1978 and 1963, markedly low temperatures and high precipitations occurred in June – the month most important for fire activity in Alaska.

Based on the above discussion of the correlation between fire and weather conditions lead us to conclude that forest fires in Alaska are mainly controlled by temperature rather than precipitation.

4. FOREST FIRES IN SAKHA

4.1 History

Forest fire history data provided by the Sakha Ministry of Forestry was used to determine fire trends (Fig.2). The bar graph in Fig.2 indicates burnt area and the line graph shows the number of fires. Unfortunately, there are no precise data related to lightning is available in Sakha, but it is believed that forest fires in Sakha are mainly caused by human activity. The author previously found that several fires in 2002 ignited by lightning became large fires, and it is expected that trends similar to those in Alaska will be found in the future based on lightning observation.

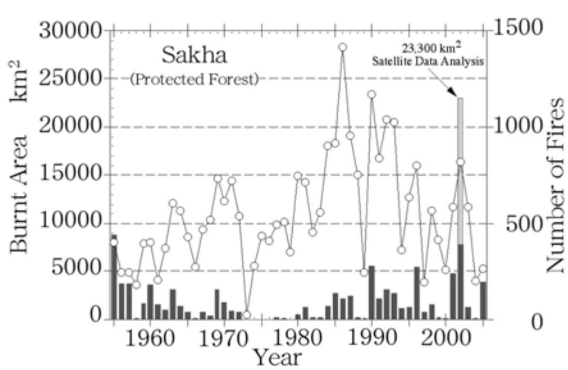

Fig.2 Fire History in Sakha (1955-2005)

In 2002, fires started from May under conditions of strong southerly maximum wind velocities of 8 m/s and high air temperatures near 30 ^{o}C, causing many fires near the Lena River. After these fires, no marked rainfall exceeded 5 mm/day until the beginning of June. Major fires stared just after a cyclone with rain and lightning passed near Yakutsk in the beginning of June. Major fires also occurred in mid-August and September, mainly from so-called holdover fires; Latham and Williams (2001), as confirmed by satellite images from NASA MODIS. The total area of protected forest burned in 2004 became the second largest since 1955 (Fig.2). The total burnt area was about 23,300 km^2, if that for unprotected forests and fields is included; Hayasaka, et. al. (2004).

4.2 *Forest Fires and Weather Trends*

<u>4.2.1 *General Trends*</u>

Sakha forest fire and weather trends are summarized in Table 5. The average number of fires and area burned each year for three different periods -- 1955-2005, 1955-1989, and 1990-2005 -- are summarized to show how fire activity increased in Sakha between 1990 and 2005. The average number of fires and burnt area from 1990 to 2005 exceeded that for the other two periods. The average burnt area from 1990 to 2005 is 1.85 times greater than that between 1955 and 1989.

To determine the cause of this increase in fire activity in Sakha, we studied the precipitation and average temperature, summarized in Table 5. Weather data from Jan. 1955 to July 2002 is from the Sakha Weather Station. The decrease in precipitation during the fire season from April through September from 1990 to 2002 ranged between 2.7 and 16.9mm compared to that between 1955 and 1989. Precipitation markedly decreased at 16.9mm in August, but the increase in temperatures during the fire season ranged from 0.4 to 1.6^{o}C compared with those from 1955 to 1989. No marked temperature rise such as that in Alaska was found, but warmer spring trends from April through June are clear.

In addition to this spring weather change, trends in lower precipitation and higher temperature also found in August, when precipitation was -16.9mm lower than normal and 0.4^{o}C warmer than normal. This drier trend in August may provide an opportunity for holdover fires to reignite previous fires.

<u>*4.2.2 High fire years and weather*</u>

The top ten forest fires in Sakha since 1956 are listed with weather data in Table 6 to determine the cause of large fires in Sakha. Five out of these top ten forest fires occurred after 1990. Table 6 is made similar manner of Table 3. The recent weather data from July 2002 to September 2005 was obtained from the measurement tower at the Nelger experimental site located about 35km northwest of Yakutsk.

For large-scale fires, precipitation and temperature in summer time (June to August) may be very important. Actually, large minus values less than -20mm are easily found in columns in three months (June to August) in Table 6. Number of these large minus values is greater than these of Alaska and these large minus values are not limited in columns in top four fire years. On the other hand, large values higher than 3^{o}C are not so easily found in temperature columns in Table 6. In other words, drastic dependant on temperature was not found like in Alaska. But these abnormal weather conditions in precipitation and temperature may have strong relationship with fire activities in Sakha, too. Finally, two or three months (June to August) in very low precipitation and high temperature conditions were found in top five fire years in 2002, 1990, 1996 and 2001. Three months in low precipitation conditions were also found in largest forest fire year in 1955.

Thus, the summer weather change found in precipitation and temperature implies also drier summer. In other words, lower precipitation summer lost so-called self-extinguish ability of forest fires by rain. This tendency may be one of the most important causes of recent increased fire activity in Sakha.

4.2.3 Low forest-fire years and weather

Low forest fire years in Sakha were listed in Table 7. Four out of five occurred in 1970's. From this Table 7, you will notice surprisingly small burnt areas compared with the average area of 1,420km^2 in Table 6. Smallest burnt area is found in 1973 and it is only 3km^2 and about 1/473 of the average area. Table 7 is made similar manner of Table 4.

For large fires, low precipitation and high temperature in summer time were essential weather condition. On the contrary, high precipitation and low temperature must be key weather condition for small fires. But remarkable low temperature was not found in Table 7. And average temperature departures, $\Delta\overline{T}_5$ from June to September are almost zero. But average precipitation departures, $\Delta\overline{P}_5$ in June to July are 13 and 17 mm, respectively. These tendencies imply that fire activity depends on precipitation mainly and not on temperature in Sakha.

5. CONCLUSIONS

Statistical analysis of a half-century of forest fire and weather data clearly shows that forest fires increased from the 1990s in both Alaska and Sakha.

In Alaska, annual burnt area increased 2.3 times over that before the 1990s -- a difference that may be due to global climate change. Apparent climate change from the 1990s in Alaska was found in the temperature rise from March to July that reached a maximum of 2.8 $^{\circ}$C in April. Forest conflagrations occurred consecutively in 2004 and 2005 in Alaska. Precise analysis of forest fires and weather data clearly shows that drought and high temperatures in August led to fatal fires. Drought in August may also be one phenomenon of global climate change because August in Alaska is usually the wettest month.

In Sakha, annual burnt area increased 1.8 times over that before the 1990s – a difference that may be due to global climate change. Apparent climate change from the 1990s in Sakha was found in the temperature rise from April to July, but a more drastic change was found in precipitation in August, which was only 50 % of that before the 1990s. Precise analysis of forest fires and weather data clearly shows that precipitation change may be a key indicator of forest fire activity in Sakha.

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Table 2 Trends of Forest Fire and Weather in Alaska

	Number of Fires	Burnt Area km^2	Precipitation mm						Ave. Max. Temperature ℃					
			Mar	Apr	May	Jun	Jul	Aug	Mar	Apr	May	Jun	Jul	Aug
0. Average 1956-2005	463	3,821	8.6	7.5	15.2	32.2	47.4	46.9	-4.4	5.8	15.5	21.7	22.4	19.0
1. Average 1956-1989	424	2,690	8.9	7.8	15.3	32.4	43.4	46.2	-4.9	4.9	15.1	21.4	22.3	19.1
2. Average 1990-2005	547	6,225	8.0	7.0	15.0	31.8	56.0	48.5	-3.3	7.7	16.2	22.3	22.7	18.9
Difference (2.-1.)	123	3,536	-0.9	-0.7	-0.2	-0.7	12.6	2.4	1.6	2.8	1.1	1.0	0.4	-0.2

Table 3 Large Top Ten Forest Fire Years and Weather in Alaska

Rank	Year	Number of Fires	Burnt Area km^2	ΔP_{10} (precipitation) mm						ΔT_{10} (max. temp.) ^{0}C					
				Mar	Apr	May	Jun	July	Aug.	Mar	Apr	May	Jun	Jul	Aug
1	2004	645	26,142	-2	-7	35	-25	-15	-37	-2	3	2	4	1	4
2	1957	416	20,197	-5	-6	-13	-27	-33	-36	4	1	0	4	0	3
3	2005	623	18,648	-2	-3	17	17	44	-40	5	2	4	1	-0	0
4	1969	522	16,260	6	-8	9	-23	-10	6	1	4	1	5	-2	-3
5	1990	750	12,906	-6	-6	-5	12	80	45	5	4	4	1	2	1
6	1977	769	9,661	-2	1	26	44	-3	-36	-4	-2	-0	-1	1	4
7	2002	510	8,850	-5	70	-6	-13	23	31	2	-3	1	-1	-1	-2
8	1988	579	8,639	-6	-2	23	25	-17	3	3	2	2	1	2	1
9	1997	686	8,203	-7	-8	-13	-6	-16	-3	-2	5	1	3	2	1
10	1991	748	6,750	48	-8	-13	-23	-23	-16	1	4	2	3	-1	-2
Average Departure $\Delta\overline{P}_{10}$, $\Delta\overline{T}_{10}$				2	2	6	-2	3	-8	1	2	2	2	1	1
Average (56-89)		424	2,690	9	8	15	32	43	46	-5	5	15	21	22	19

Table 4 Small Forest Fire Years and Weather in Alaska

Rank	Year	Number of Fires	Burnt Area km^2	ΔP_{5} (precipitation) mm						ΔT_{5} (max. temp.) ^{0}C					
				Mar	Apr	May	Jun	July	Aug.	Mar	Apr	May	Jun	Jul	Aug
46	1963	194	66	44	5	-12	18	-9	45	-1	-2	1	-4	-1	-1
47	1978	432	33	-7	-4	-4	11	-13	-15	2	3	1	-4	1	2
48	1965	141	28	-2	4	-12	-3	-8	-9	7	-1	-3	-3	-1	-2
49	1961	116	21	-6	2	-9	-16	8	26	-4	-3	1	-0	-1	-1
50	1964	153	14	-4	10	9	1	-11	14	-5	-3	-7	-0	-1	-0
Ave. Departure $\Delta\overline{P}_{5}$, $\Delta\overline{T}_{5}$				5	3	-6	2	-6	12	-1	-1	-1	-2	-1	-1

Table 5 Trends of Forest Fire and Weather in Sakha

Peroiod	Number of Fires	Burnt Area km^2	Precipitation* mm						Ave. Temperature* ℃					
			Apr	May	Jun	Jul	Aug	Sep	Apr	May	Jun	Jul	Aug	Sep
0. Average 1955-2005	546	1,797	9.0	18.4	34.9	36.1	35.8	28.5	-6.3	6.7	15.7	18.8	15.0	5.7
1. Average 1955-1989	517	1,420	9.9	17.6	35.6	37.2	39.9	28.5	-6.7	6.4	15.3	18.6	14.9	5.8
2. Average 1990-2005	609	2,624	6.6	20.6	32.9	33.0	23.0	28.8	-5.2	7.6	16.9	19.3	15.3	5.5
Difference (2.-1.)	92	1,204	-3.4	3.0	-2.7	-4.2	-16.9	0.3	1.4	1.1	1.6	0.7	0.4	-0.3

(*: data from Jan. 1995 to Jul. 2002)

Table 6 Large Top Ten Forest Fire Years and Weather in Sakha

Rank	Year	Number of Fires	Burnt Area km^2	ΔP_{10} (Precipitation) mm						ΔT_{10} (Ave. Temperature) ^{0}C					
				Apr	May	Jun	July	Aug.	Sep	Apr	May	Jun	Jul	Aug	Sep
1	1955	404	8,834	-4	-8	8	-18	-17	-6	-3	1	0	-2	-0	-0
2	2002	818	7,749	-7	-11	-30	-8*	-24*	-13*	4	2	3	1	1	-1
3	1990	1,169	5,568	-7	1	-26	44	-29	12	1	3	2	-1	2	-1
4	1996	798	5,445	-3	6	-16	18	7	-5	1	1	2	0	-2	-0
5	2001	582	4,805	-2	10	-25	-33	-27	-17	-1	2	1	4	0	-2
6	2005*	263	3,955	--	24*	-27*	48*	9*	-21*	--	1	1	-1	-3	2
7	1956	244	3,703	-3	-4	6	-21	30	-7	-4	-3	1	1	-0	1
8	1957	244	3,703	0	6	-14	-14	-20	-11	0	0	-0	0	1	-2
9	1960	402	3,638	-5	-8	-30	25	81	-6	-3	1	1	0	-1	0
10	1963	601	3,092	10	2	10	-19	-14	7	-2	-3	-0	0	1	1
Average Departure $\Delta\overline{P}_{10}$, $\Delta\overline{T}_{10}$				-2	2	-14	2	-1	-7	-1	0	1	0	-0	-0
Average(55-89)		517	1,420	10	18	36	37	40	28	-7	6	15	19	15	6

(*Recent weather data in 2002 and 2005 from Nelger Tower)

Table 7 Small Forest Fire Years and Weather in Sakha

Rank	Year	Number of Fires	Burnt Area km^2	ΔP_5 (Precipitation) mm						ΔT_5 (Ave. Temperature) ^{0}C					
				Apr.	May	Jun	July	Aug.	Sep	Apr	May	Jun	Jul	Aug	Sep
47	1979	353	51	-6	9	11	-3	47	-2	-0	1	-1	-2	-1	-1
48	1975	434	51	-4	-1	2	46	14	-3	3	3	3	-2	-2	-0
49	1976	412	45	-1	-1	-15	24	-9	14	4	-0	-0	-2	1	1
50	1974	280	19	14	-9	14	16	42	-13	2	2	-1	0	-0	-0
51	1973	28	3	1	-14	-15	-20	-7	3	-3	2	1	2	2	2
Ave. Departure $\Delta\overline{P}_5$, $\Delta\overline{T}_5$				1	-3	-1	13	17	-0	1	2	0	-1	-0	0