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Climate change impacts on apple production

-- Sunburn and frost damage --

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[1] Introduction

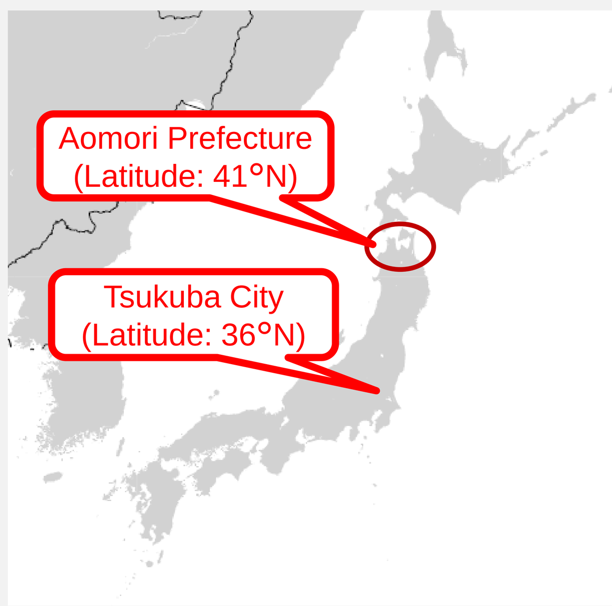
In Tohoku Region, located in the northern part of Japan, the apple is one of the most common fruit crops. Although changing climates can potentially threat apple production in the near future, few quantitative assessments have been made so far. We present climate impact assessments on apple production -- (1) sunburn and (2) frost damage -- under future climate.

[Annex] Expected climate change in Aomori Prefecture

Future climate in Aomori prefecture, located in the northern part of Japan, will get warmer than the present climate by more than 3°C under the SRES A1B scenario. Since the apple favors chilly climates (annual mean temperature of 6 to 14°C) , projected future temperature approaches this upper limit.

Table 1 Future temperature change (annual mean) in Aomori Prefecture with the SRES A1B scenario using the data set of *Global Warming Projection Vol. 8* provided by Japan Meteorological Agency.

[°C]	Reference 1980-2000	Observed 1981-2010	Near future 2016-2036	Future 2076-2096
Hirosaki	10.0	10.2	+1.2	+3.3
Aomori	10.2	10.4	+1.2	+3.2
Hachinohe	10.0	10.2	+1.4	+3.5
Mutsu	9.4	9.5	+1.3	+3.3
Fukaura	10.6	10.7	+1.1	+3.1



[2] Sunburn

What is sunburn?

Sunburn is an irreversible damage on apple fruit skin. When skin temperature goes up beyond 52°C or 46-49°C, the skin turns black or brown (Fig. 1). Such damaged apples cannot be sold as fresh fruits. In 2012, early-maturing variety *Tsugaru* was severely damaged by sunburn, 23% of apples were not shipped as fresh fruits.

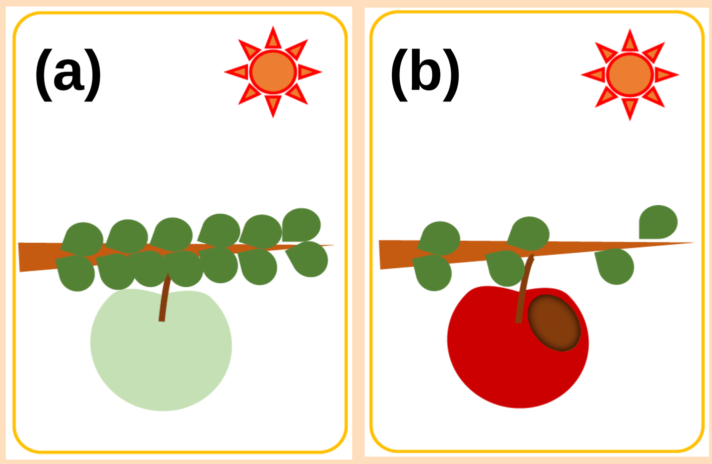


Fig. 1 Apple farmers' dilemma between sunshine and sunburn. **(a)** Apples require sunshine to make their skin red. However, **(b)** too much sunshine brings sunburn damage on the fruit skin.

How to assess sunburn risk?

We evaluated skin temperature by solving heat budget on an apple fruit as the worst-case condition (sunlit surface) under given climate conditions (air temperature, humidity, solar radiation, wind, etc.). Since wind speed on apple skin is expected to be smaller than wind speed on open field, the wind speed was reduced to 25%. Based on future climate projection under the SRES A1B scenario (Table 1), the daily maximum skin temperature was simulated during apple's ripening season (July to October).

Results

Fig. 2 shows the result of the daily maximum skin temperature. Sunburn risk (red or black) will increase in the future, both in seasonal extension and severity: In the current climate, the daily maximum temperature going up ≧46℃ mostly occurs in August, whereas in the future climate, this condition can occur even in September. Consecutive high temperature days are also observed in July-August under the future climate. Number of hours exceeding the sunburn threshold temperature will also increase in the future (Table 2).

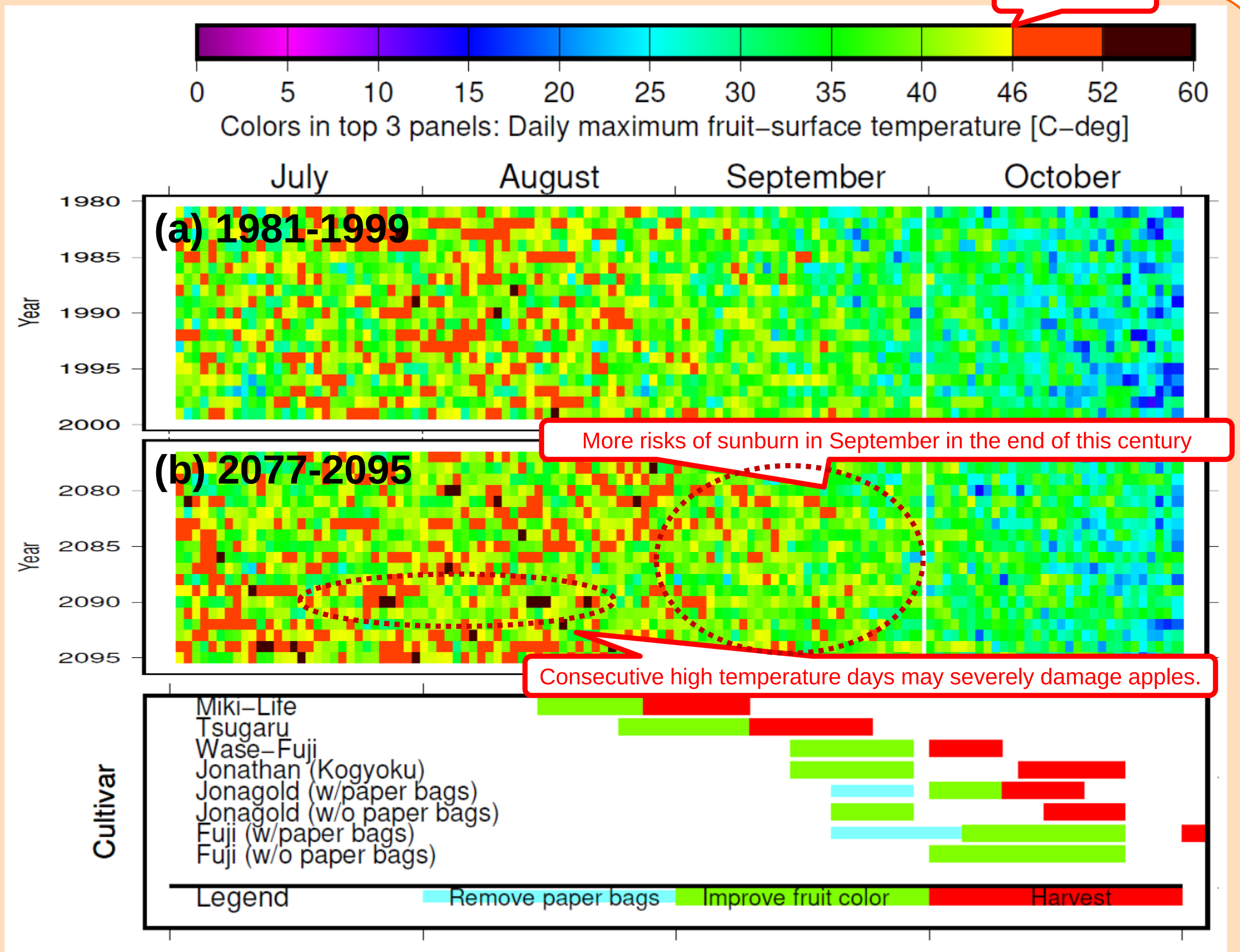


Fig. 2 Simulated **(a)** current and **(b)** future daily maximum temperature on apple skin at Hirosaki with the SRES A1B scenario. The lower panel indicates apple crop calendar for different cultivars.

Table 2 Number of hours exceeding the threshold temperatures of sunburn. "Change" shows the change ratio with respect to the 1981-1999 values.

Years	Skin temperature ≧46℃					Skin temperature ≧52℃				
	July	Aug.	Sept.	Oct.	July -Oct.	July	Aug.	Sept.	Oct.	July -Oct.
1981-1999	440	364	25	0	829	175	3	0	0	178
2017-2035	419	367	42	0	828	176	7	0	0	183
change [%]	-4.8	+0.8	+68.0		-0.1	+0.6	+133.3			+2.8
2077-2095	602	489	97	0	1188	187	23	0	0	210
change [%]	+36.8	+34.3	+288.0		+43.3	+6.9	+666.7			+18.0

[3] Frost damage

Why we consider frost damage despite warming climates?

Please see a schematic example (Fig. 3). Since global warming raises air temperature, straightforwardly, frost risk will be reduced in the future (Fig. 3(b)). On the same time, growing season of plants will be advanced due to high temperature (Fig. 3(c)). Considering the compound effects of these two aspects is necessary to assess future frost risk. Some plants have less tolerance against cold temperature during bud bursts or flowering (e.g., blue horizontal lines shown in Fig. 3).

How to assess frost risk? – Preliminary analysis

Plant growth can be modeled by effective cumulative temperature (ECT, hereafter), a degree-day index after a plant begins to growth (e.g., January or February). By evaluating the ECT at the last frost date, we judged whether a plant will experience the last frost at earlier/later growth stages under future climate.

Prior to the analysis, we determined the daily minimum temperature at the last frost day by using historical meteorological records for 1991-2010. We obtained +2.0℃ as the air minimum temperature at the last frost date. In this preliminary analysis, we neglected varying tolerance levels of temperature against coldness for different growth stages, but introduced a uniform tolerance temperature (+2.0℃) throughout the growth stages.

Results

Fig. 4 shows the results for Tohoku region under warming climate (SRES A1B). Last frost date will be advanced by 10 to 15 days at most sites (Fig. 4(b)). Until this advanced last frost date in the future, a plant will gain more ECT in the southern Tohoku area and less ECT in the northern or mountainous area (Fig. 4(d)).

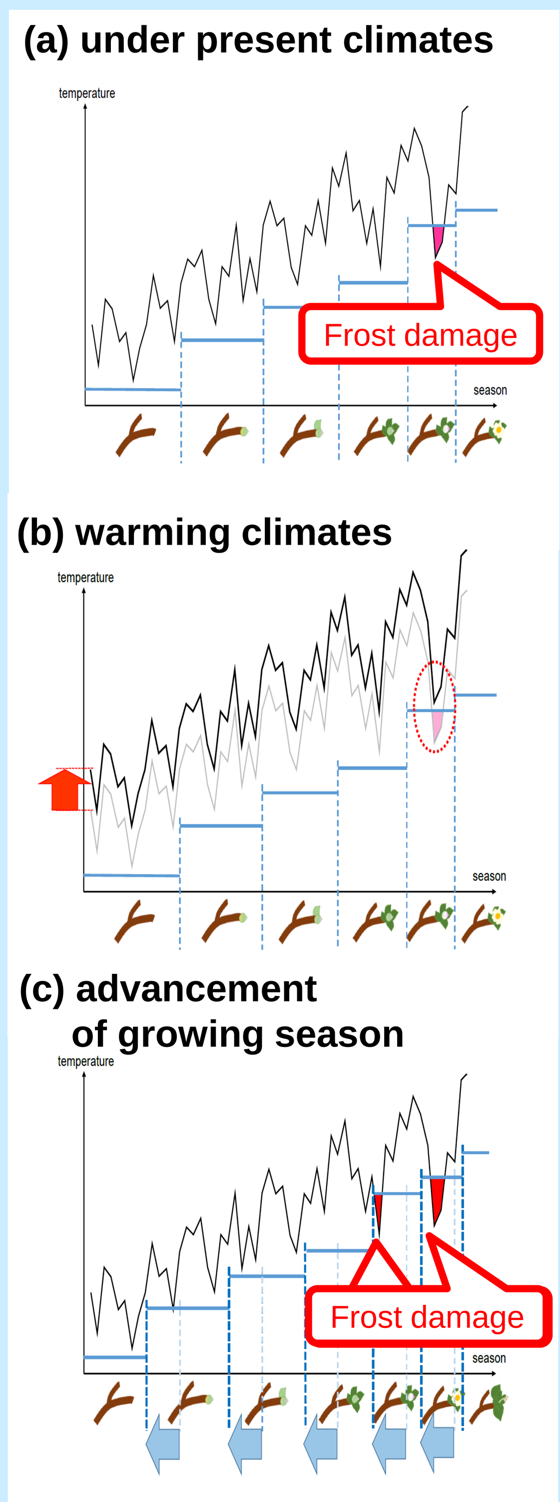


Fig. 3 Schematic explanation of future frost risk. Blue horizontal lines show the tolerance temperature of this hypothetical plant against frost (coldness): If the temperature gets below this level, plants may be suffered from frost damage. In this example, **(a)** under the current climate, frost damage occurs just before flowering. **(b)** If the temperature rises, frost risk will diminish because the temperature will go well above the tolerance level. **(c)** However, growing stage of the plant will be advanced due to high temperature, plants may be suffered from frost damage.

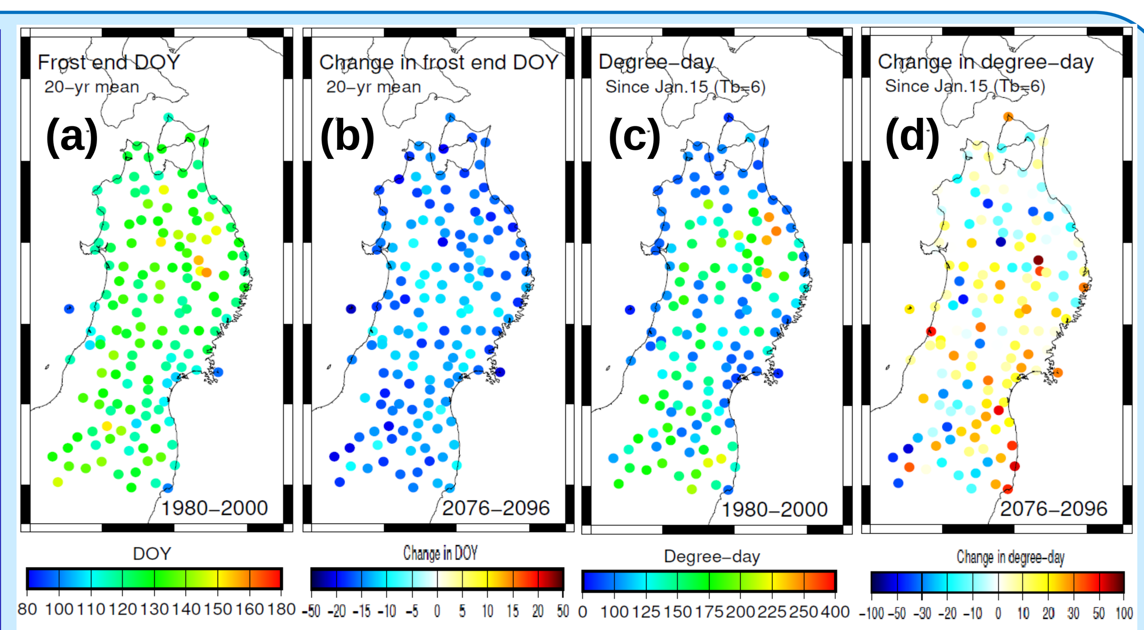


Fig. 4 **(a)** The last frost date (DOY; day of year) under the current climate. **(b)** Change in the last frost date in the future. **(c)** Effective cumulative temperature from the reference date (Jan. 15) until the last frost date under the current climate. **(d)** Change in the effective cumulative temperature under the future climate.

Acknowledgment: Regional climate projection was originally simulated by Japan Meteorological Agency (JMA) (see Reference [1]). These data were provided through the database website of Data Integration and Analysis System (DIAS,DIAS-P).

[References] 1) JMA (2013), Global Warming Projection Vol.8, 131pp.