LETTER

Reply to Wang et al.: Snow cover and air temperature affect the rate of changes in spring phenology in the Tibetan Plateau

We appreciate the comments on our recent study (1) from Wang et al. (2). Our study showed that the start of the growing season (SOS), derived from analysis of Normalized Difference Vegetation Index (NDVI), continued to advance in the Tibetan Plateau (TP) from 1982 to 2011. Wang et al. (2) agreed with this conclusion but stated that the SOS advancement rate could be overestimated after comparison with a few in situ herbaceous observations *ca*. 1990–2003 (3). As we discussed earlier (1), there are limited in situ long-term data to evaluate the rate of SOS advancement in the TP. Another study that used longer observations (*ca*. 1987–2007) at the same sites (3) reported a higher rate of SOS advancement (4). In addition, our results also showed that the rates of SOS advancement during 2000–2011 varied dependent upon the dataset used, for example, 13.5 d per decade for Système Pour l'Observation de la Terre vegetation (SPOT-VGT), and 7.8 d per decade for Moderate Resolution Imaging Spectroradiometer (MODIS) (1). Therefore, it remains challenging to quantify the rate of SOS advancement from remote sensing datasets.

Snow cover dynamics affect NDVI-based SOS retrieval algorithms and SOS itself. Wang et al. (2) presented that snow cover changes in the nongrowing season (January–April) may affect long-term trends in SOS, through a spatial comparison between snow cover fraction (SCF) and NDVI data in January–April from 2000 to 2011, and a correlation analysis between NDVI in January–April and SOS from ref (1). The January–April SCF analysis could miss information on monthly snow variation and snow melt-out dates (SMOD). We used the same SCF dataset and did analysis by month (Fig. 1). The results show that the areas with significant decreases in snow cover (Fig. 1 *A*–*E*, *Insets*) were smaller than the areas with significant increases in NDVI (Fig. 1 *F*–*J*, *Insets*), which indicates that the snow cover dynamics cannot explain the NDVI increase completely. At the Plateau scale, the correlations between SOS and snow cover are significant in April and May but insignificant in January–March (Fig. 1*K*), which suggests that snow cover and SMOD in April and May could affect SOS, but snow cover in January–March hardly affects SOS.

The effect of snow cover on SOS is further complicated by air temperature after SMOD. When air temperature rises in spring, snow melts, soil thaws, and vegetation greens up. The time lag between SMOD and SOS varies between 1 to 2 wk (5), dependent upon air temperature after SMOD. Vegetation tends to have earlier green-up with higher-than-average air temperature after SMOD whereas vegetation tends to have later green-up with lower-than-average air temperature after SMOD. Normally the late SMOD would lead to lower NDVI in the nongrowing season and late SOS estimate (Fig. 1*L*, red line). In 1998 (heavy snow year), however, high air temperatures sped up snow melting and vegetation green-up, and consequently the SOS advanced (Fig. 1*L*, green line) (1). This case indicates that the effect of snow cover on SOS is related to air temperature. Additional studies are needed to quantify the coeffects of snow cover and air temperature on SOS change in the near future.

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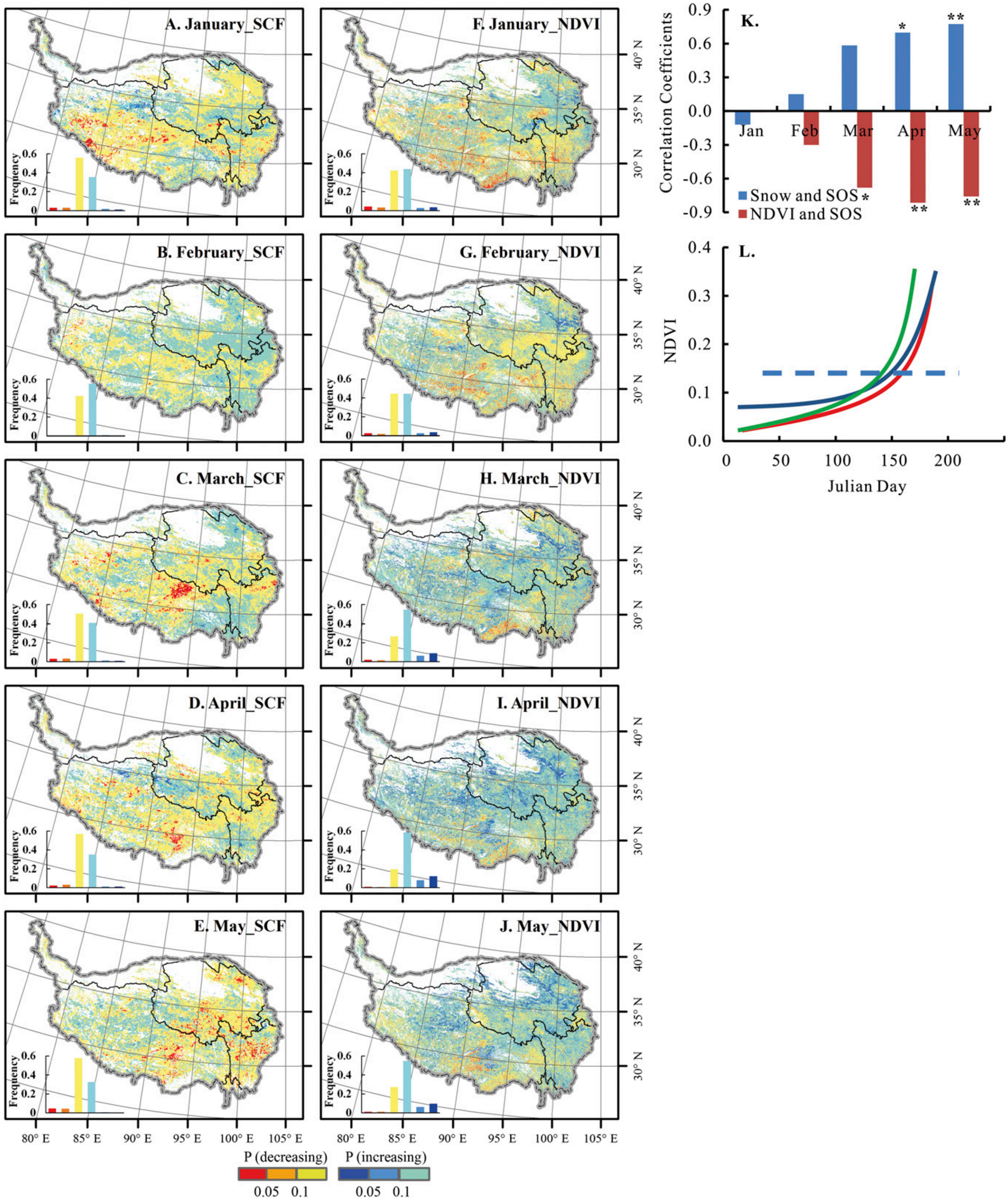

Fig. 1. Spatial distributions of the significances of linear trend in the MODIS-derived monthly snow cover fraction (SCF, %) (*A*–*E*) and NDVI (*F*–*J*) in the Tibetan Plateau from January to May during 2000–2011 (SCF and NDVI in January and February in 2000 were skipped due to data unavailability). The *Insets* show the frequency distributions of the corresponding significances of increased and decreased trends of SCF and NDVI. The maps only covered the pixels with averaged growing season NDVI (April–October) higher than 0.1. (*K*) The correlation coefficients between the start of growing season (SOS) and SCF as well as NDVI in January, February, March, April, and May at the plateau scale. * and ** mean significance level $P < 0.05$ and $P < 0.001$, respectively. (*L*) Two scenarios showcase the effects of large snow cover on SOS. The dark blue line is a reference with normal or less snow cover; the green and red lines represent the situations with heavy snow. The blue dash line represents the NDVI threshold for SOS retrieval. Both the advanced (green line) and delayed (red line) SOS were observed comparing to the reference scenario (blue line). The green line presents the situation in 1998 (1) when higher-than-the-average air temperature sped up snowmelt and vegetation green-up; and the red line shows another situation when the lower-than-the-average air temperature postponed snowmelt and vegetation green-up. An effective interpretation of 1998 SOS shows that our algorithm in ref. 1 was robust and that snow cover change could negligibly affect NDVI-based SOS algorithm.