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Chill unit models and recent changes in the occurance of Winter chill and Spring frost in the United Kingdom

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SUMMARY
Following concern that a trend towards milder Winters may have a detrimental impact on bud break and fruit quality, we have investigated the choice of existing chill accumulation model that best explains year-to-year differences in the spread in flowering date in soft fruit, and have characterised the changes in Winter chill that have occurred in recent decades in the UK. As part of this study, we compared the major methods currently used to accumulate chill. As some of these models require hourly temperature data, we have also evaluated methods to estimate hourly temperatures from daily maximum and minimum records. All chill accumulation methods, with the exception of the 'Utah' model (which uses a complex weighting scheme for accumulation of chilling temperatures), showed a trend of declining Winter chill over the last three decades. The model that performed best in terms of its ability both to explain the variation in spread of bud burst in any year, and to describe differences in chill with geographical location and over time, was one that accumulated time below 7.2°C (the '< 7.2°C model). A significant declining trend in Winter chill has occurred in tandem with reduced Spring frost. Both have agronomic implications. The largest changes in these climatological factors have occurred in southern regions of England, with a much less pronounced decline in the North of the UK (Tayside).

Chilling temperatures are important in fruit production because they stimulate full dormancy, which is an essential prerequisite for effective and synchronous bud-break and flowering. A common symptom of sub-optimal chilling is poor and protracted bud-break, which can lead to extended and partial flowering, followed by poor fruit set and final yield (Oukabli et al., 2003; Weinberger, 1950; 1954). The actual date of flowering is a less good indicator of chill than is the spread of flowering, as the former depends both on satisfying the chilling requirement to complete dormancy, and on the subsequent weather being warm enough to allow bud burst.

A number of models have been proposed to estimate, from meteorological data, the amount of physiologically significant chilling required by woody perennials (see Cesaraccio *et al.*, 2004). An early attempt to quantify Winter chill (Weinberger, 1950), after an unpublished paper by Hutchins (1932), applied a system of 'hours of chilling' below a threshold of 7.2°C. This was based on observations of the number of hours of chilling that were required to break dormancy in a number of peach cultivars grown at Fort Valley, GA, USA, and enabled development of a ranking system based on chilling requirement. Various studies have shown responses to chilling temperatures, with the largest effects often occurring above freezing (Lamb, 1948; Eggert, 1950; Erez and Lavee, 1971). For example, the optimal chilling temperature was found to be 2°C for some apple cultivars (Thompson *et al.*, 1975). Therefore, as an alternative to the '< 7.2°C' model, a '0 – 7.2°C' chill model has been adopted in a number of studies (Byrne and Bacon, 1992). In both these models, a single chill unit is accumulated for every hour within the stipulated temperature range. Based on observations of peach bud development at different temperatures (Erez and Lavee, 1971), Richardson *et al.* (1974) proposed a more sophisticated weighting scheme (Table I), now termed the 'Utah' model, to estimate "rest completion" in peach cultivars. Similar weighting models have been proposed by a number of authors (e.g., Gilreath and Buchanan, 1981; Shaltout and Unrath, 1983; Linsley-Noakes *et*

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