

Lecture 4 Characterizing the Vegetation, Part 3: Geographic Distribution of Plants and Phenology

Instructor: Dennis Baldocchi
Professor of Biometeorology
Ecosystem Science Division
Department of Environmental Science, Policy and Management
345 Hilgard Hall
University of California, Berkeley
Berkeley, CA 94720

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This lecture will discuss:

1. Geographic distribution of plants
2. phenology, the timing of canopy characteristics such as leaf out and flowering.
3. impact of phenology on weather and climate

Web Resources:

Phenology Home page

(<http://www.uwm.edu/~mds/markph.html>)

Growing Degree Day Tracker

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/

Phenocam

<https://phenocam.sr.unh.edu/webcam/>

L4.1 Phenology

Phenology is a branch of science dealing with the relations between climate and the timing of biological phenomena, such as bud burst, leaf out and plant flowering.

“Phenology: the study of the timing of recurring biological phases, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species.”

Many phenological relations exist in folklore. Jackson et al. (2001) cite the aphorism, “seed should be sown when oak leaves are as big as sow’s ears”, for example. When

living in Nebraska, I commonly heard that corn should be “knee high by the Fourth of July”.

A biometeorologist requires information on the timing of leaf out for it has drastic consequences on the direction and magnitude of carbon, water, heat fluxes, as well as the interception of radiation. The timing of spring leaf out has major implications on the status of the atmosphere, through variance biosphere-atmosphere feedbacks. Most obvious is a change of surface energy balance, as the new presence of leaves alters the surface albedo and its surface conductance. It will also perturb the regional carbon balance, as the surface will switch from losing to gaining carbon. The physical nature of the surface layer (as measured by its lapse rate and maximum temperature thickness) changes strongly in spring. The timing of leaf out also affects the humidification of the atmosphere through a triggering of transpiration (Schwartz, 1992; Schwartz and Crawford, 2001; Wilson and Baldocchi, 2000).

A general sequence of events for annuals include: **emergence, growth** (early vegetated stage), **late vegetated stage, flowering, fructification, senescence**. To develop a phenological model observations of leaf development are needed. Five stages for phenological assessments of bud elongation are:

- b0: bud dormancy
- b1: bud swelling
- b2: first green leaf, beginning
- b3: real bud burst, young leaves protrude beyond scales
- b4: young leaves are free of bud scales

The majority of phenology models in the literature are empirical. They tend to use concepts such as summation of **heat units, chilling units** (to avoid frost and to experience sufficient dormancy and **photoperiod** (day length). These triggers have some physiological basis, as day length does affect certain hormonal signals that regulate plant metabolism. Heating units scale with the thermodynamics of the plant soil system and affect the delivery and availability of water and nutrients.

Jackson et al. (2001) describe three elements that are contained in a phenology model. They include a period of:

- a) **chilling during the autumn and winter;**
- b) **period of warming in the late winter and spring;**
- c) and a **photoperiod trigger.**

Hari and Hakkinen (1991) define five classes of phenology models for budburst:

1. critical time or day length
2. temperature sum model
3. model based on respiration
4. period unit model
5. model with feedback development

Many phenological models are based on the concept of **Degree Day**. A degree day is defined as the difference between the daily mean temperature and some base temperature. The daily mean temperature is generally computed as the average of the daily maximum and minimum temperature. Over the course of the year, daily heat units are summed. Empirical evidence shows that phenological events are often triggered when a critical sum is exceeded.

Critical growing degree sums for native and non-native plants growing in Sardegna were recently reported by Spano et al (1999). In their study, they found that growing degree sums provided good indicators of Mediterranean species, which have adapted to the seasonal and sparse rainfall. Phenological development of non-natives, on the other hand, was severely affected by spring rain.

Table 1 Cumulative heat units for bud break, flowering and ripening. Spano et al. 1999

Species	Bud break	flowering	Full ripe fruit
<i>Pistacia lentiscus, L</i>	1102	1219	4490
<i>Spartium junceum, L</i>	1021	1296	2963
<i>Olea europea, L</i>	1008	1504	4808
<i>Quercu ilex, L</i>	1494	1598	4974
<i>Myrtus communis, L</i>	1426	2348	5011

Kramer (1995) discusses a two-stage model for a deciduous plant would include:

1. rest phase. bud dormant period. Chilling units are accumulated during this phase,

$$S_{chill} = \sum_{t_0}^t R_{chill}$$

2. quiescent period. buds fail to grow due to unfavorable conditions. Forcing units are accumulated during this period.

Nizinski, J.J. and B. Saugier. (1988) counted cumulative mean temperature after March 1 and base of 0 C. They show that the heat sum required for bud burst is a decreasing function of day length (minutes). The required sum of temperature heat units is a decreasing function of day-length (d, minutes)

$$\sum T = \frac{0.0242d}{0.00141d - 1}$$

The denominator can't be negative, so it sets the minimum date, 4.1 (983-D')

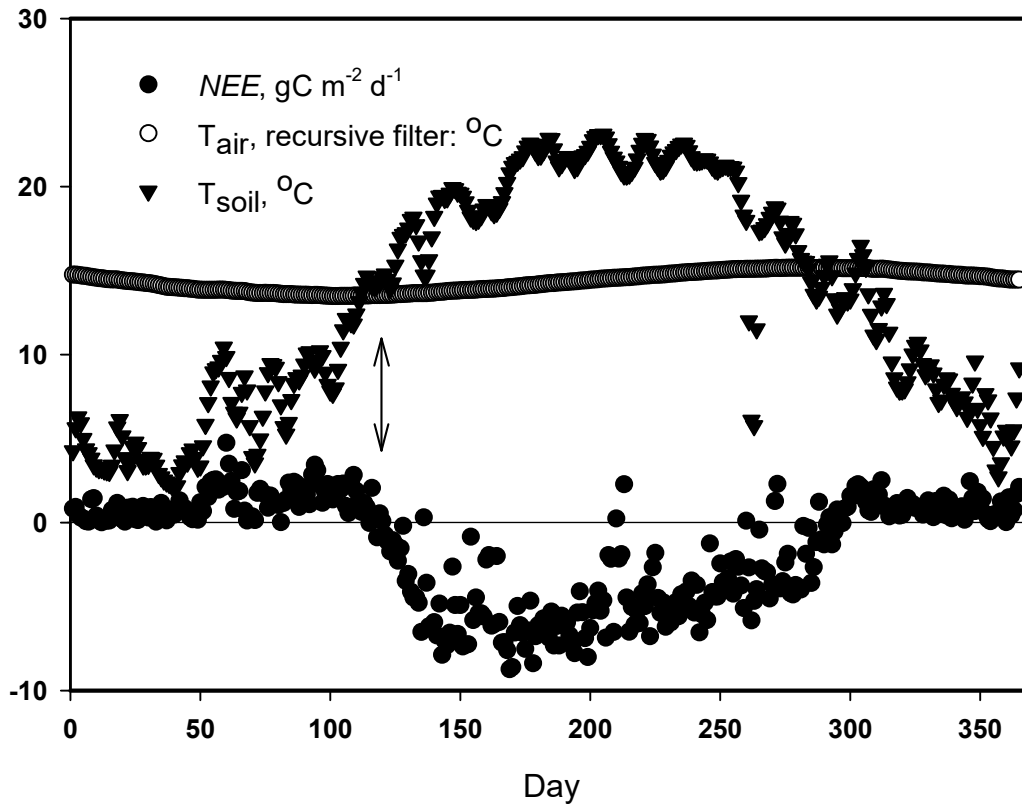
Kaduk and Heimann (1997) use an NPP-based model that initiates budburst of grass, tundra and tropical biomes ($dNPP/dLAI > 0$). For other biomes they use a scheme that counts the number of growing degree days below 5oC. Bud burst occurs when the

number of 5 degree growing degrees days exceeds a function of the number of days below 5 degrees:

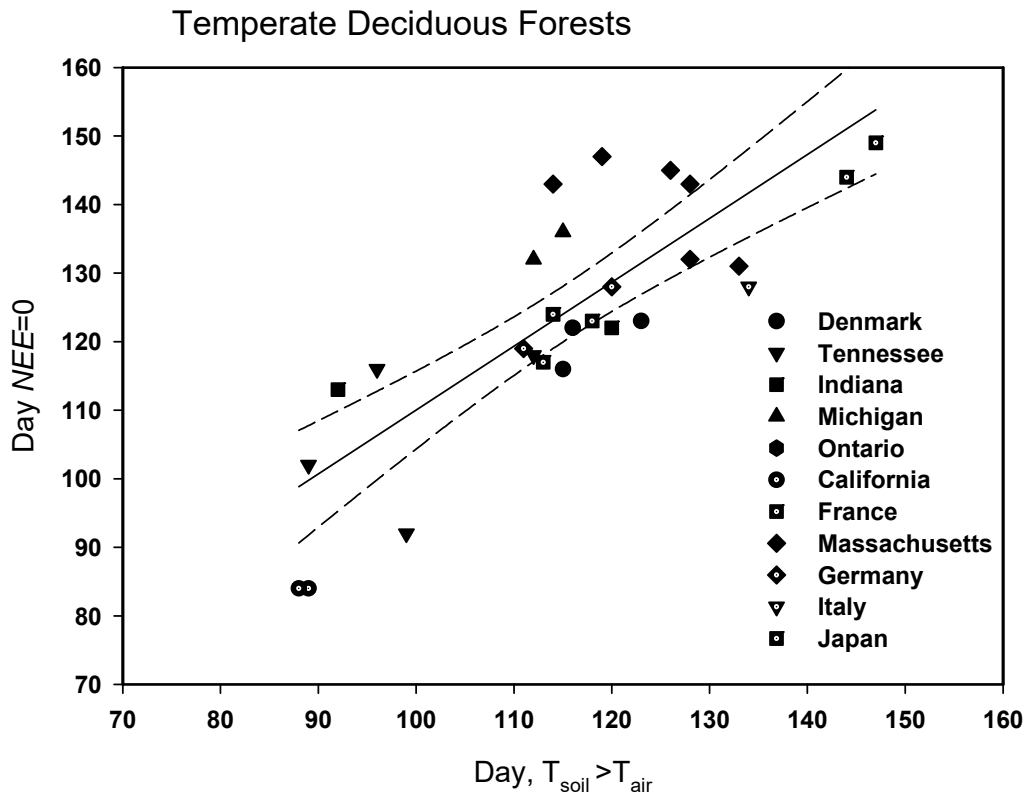
$$GDD_{5C} \geq a + b \exp(ct_{<5})$$

Preliminary data, from our research (in association with the FLUXNET project), is showing that leaf out is correlated with soil temperature equal to the mean annual temperature. One anecdotal observation of colleagues at Oak Ridge, was that leaf out occurred when the soil temperature was near 13 °C. Obviously the entire deciduous biome does not leaf out at this temperature as the soil of northern deciduous forests may not even reach this level. On the other hand, this value was suspiciously close to the annual air temperature. It prompted the question, do deciduous trees adapt to their local environment by gauging leaf out to this metric, the mean annual temperature. Using data from the FLUXNET project, spanning North America, Japan and Europe, we found that leaf out, as denoted by the onset of photosynthesis corresponded with the time when mean annual temperature crossed soil temperature.

Oak Ridge, TN
Mixed Oak/Maple Forest
1996



Applying this criterion for a network of field sites from across the northern hemisphere produced support for this idea.



In a similar vein, White et al. (1999) recently developed a relation between growing season length and mean annual temperature. The length of the growing season ranges from about 140 to 210 days as mean temperature ranges from about 7 to 19 °C. A one degree change in annual temperature perturbs the growing season by about 5 days. But this scheme does not tell us when the growing starts and ends.

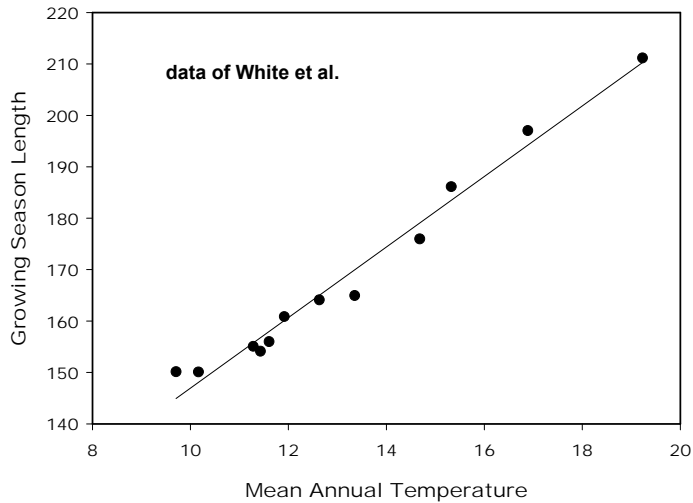


Figure 1 data of White et al for eastern US Deciduous Forests

Because temperature varies with latitude, there will be a global distribution of the growing season length. A continental map for the onset of greenness has been produced by White et al. 1990.

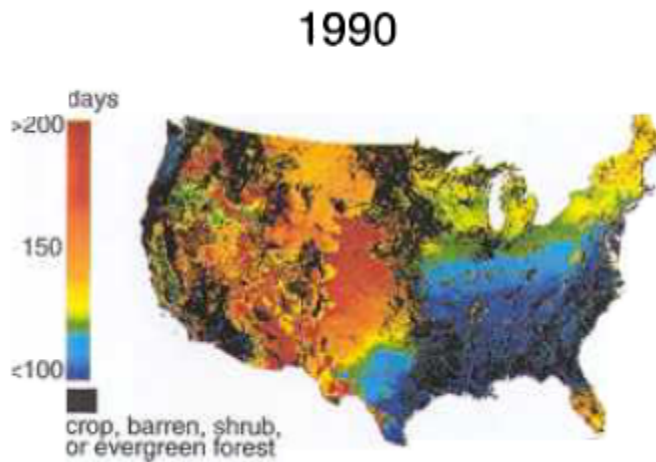


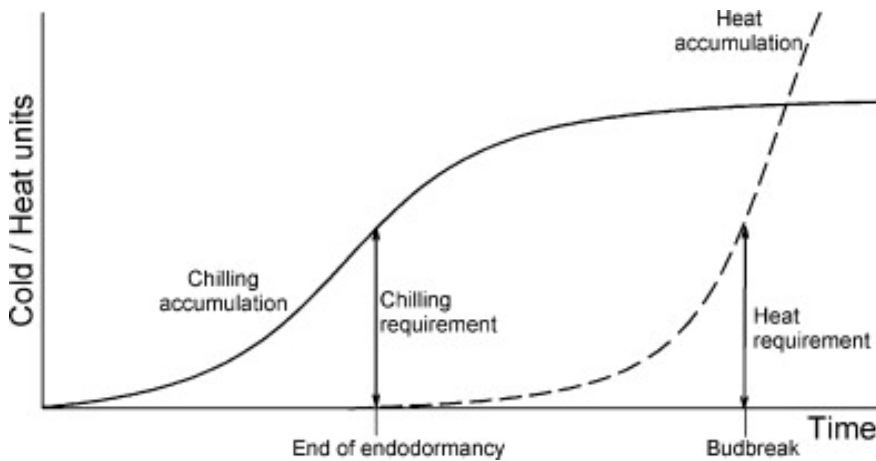
Figure 2 continental map of phenology and length of growing season (White et al. 1997).

In fact we now can view the annual greening of the Earth from space with the MODIS project.

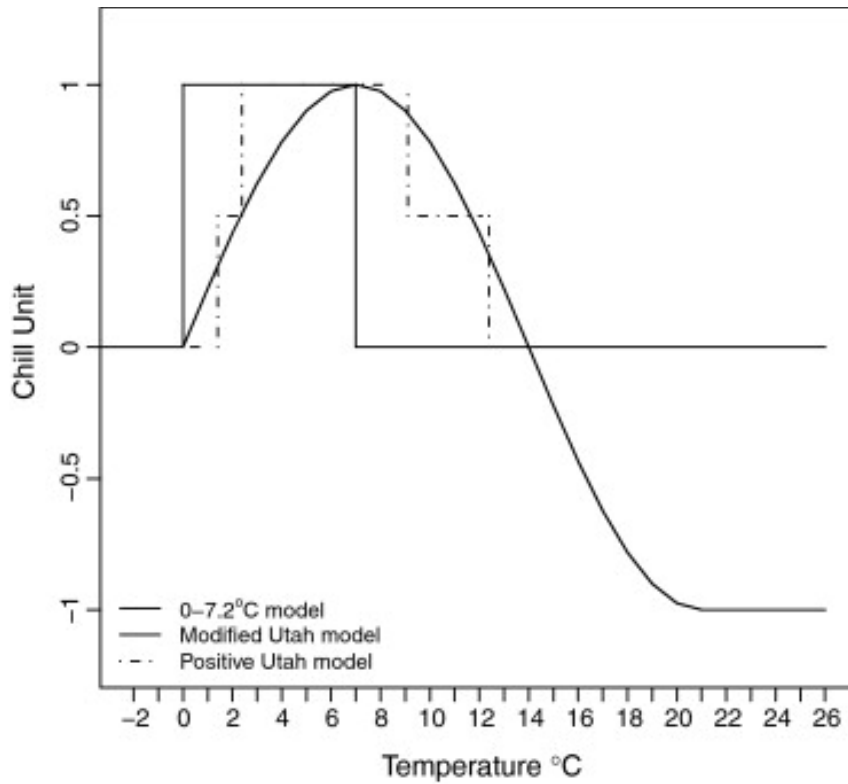
Hopkins Law of Phenology. Hopkins, an entomologist, concluded that phenology differs by four days for every degree of latitude and 1 day per 100 feet of altitude.

Dormancy

Nut and fruit tree growers are interested in how well their trees achieve dormancy during the winter. The plants need a certain amount of chilling requirements then heat to break dormancy (Luedeling et al., 2009b).



Several types of models exist for computing dormancy. Including the simplest growing degree model and versions of the Utah model (Darbyshire et al., 2011).



Phenology and Global Change

Thermometers have many problems with sampling, exposure and calibration, with regards to measuring global change and global warming. The biosphere, however, is a great integrator of temperature and watching changes in phenology are one way to attempt to document global warming if it is indeed occurring.

Recently, Chmielewski et al (2004) reported a link between length of growing season and temperature in Europe. They found that warming in spring, by 1 C advanced the growing season by 7 days.

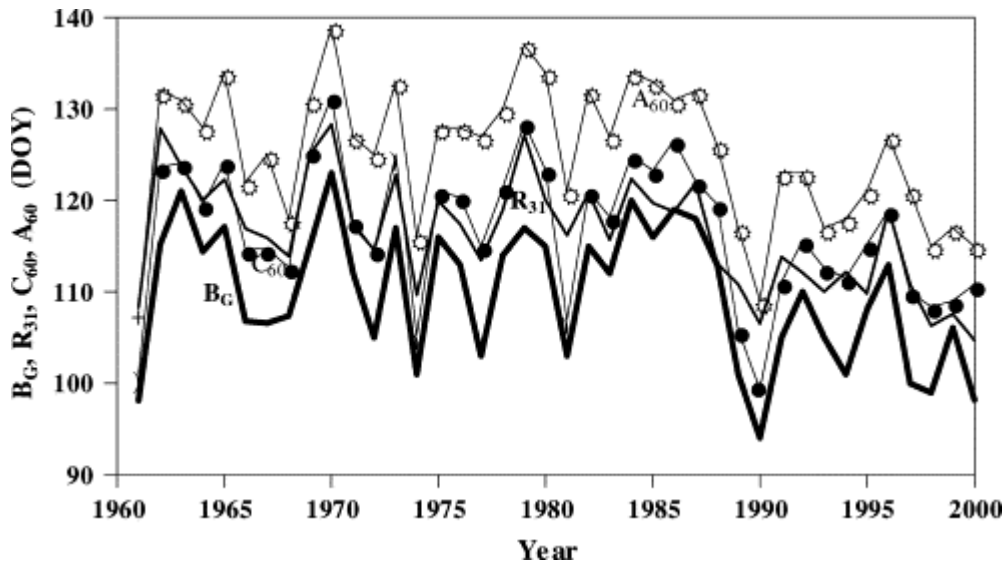


Figure 3 Average dates of the beginning of growing season (B_G), beginning of stem elongation for winter rye (R_{31}), beginning of cherry tree blossom (C_{60}) and beginning of apple tree blossom (A_{60}) in Germany, 1961–2000.

Menzel et al (1999) also report an apparent increase the mean annual growing season in Europe. They report an increase of 10.8 days, which are in accord with an analysis of satellite data from 1981 to 1991. The results of Menzel et al also are consistent with data on the advance in the seasonal cycle (~ 7 days) which has been inferred from CO_2 data taken between the 1960s and early 1990s, with most of the effect occurring after 1980

Fitzjarrald et al 2001 has studied the timing of spring for an assortment of climate stations in the northeast. They are finding that spring is occurring 4 to 6 days earlier, since the 1960s. The timing of leaf out has a marked effect on evaporation from the landscape, the growth of the planetary boundary layer and its warming and humidification.

New advances are being made to assess phenology with the use of Satellite measurements and global models (Moulin et al, Kaduk and Heimann, 1996; Myneni et al. 1998; Jackson et al. 2001). Myneni et al. (1998, 1999), for instance, have used the NOAA AVHRR satellite to access the normalized difference vegetation index (NDVI). They found that sea surface temperature anomalies are affecting global phenology. In the latitude band north of 45 degrees, there was a linear trend in time (over 1981-1992) in the NDVI anomaly. It was attributed, in part, to the timing of the spring 'green-up' (which was about 8 days earlier, on average over the course of the study period) and a prolongation by 4 ± 2 days of the declining phase, which together are a lengthening of the growing season by 12 days.

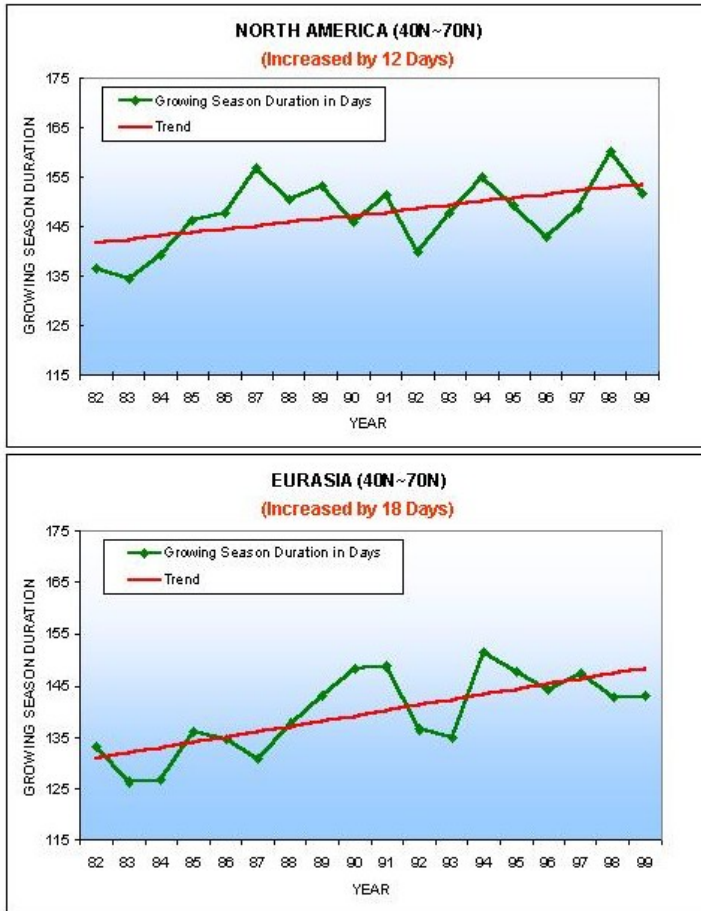
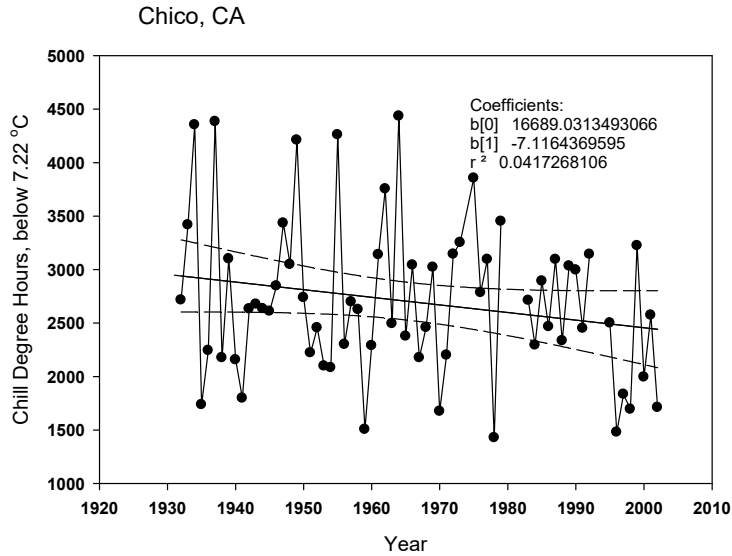


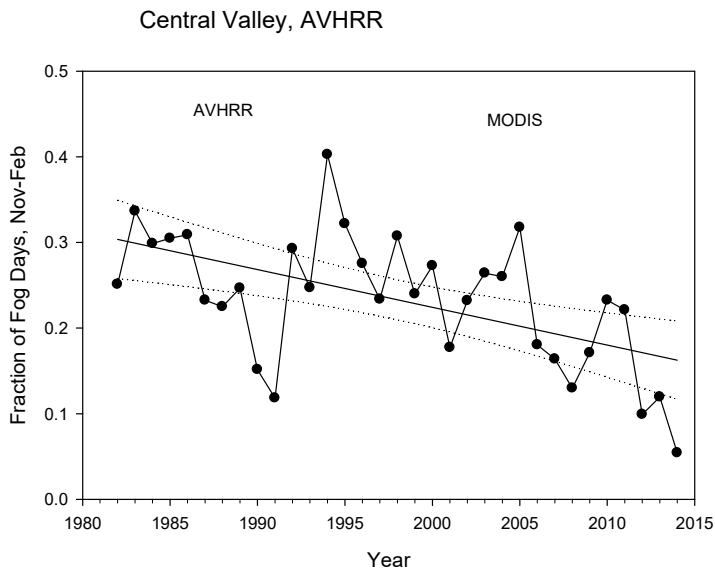
Figure 4 Myneni et al.

Obviously, if we are to understand global change issues better and model the response of whole ecosystems we will need to assess changes in phenology and must be able to model such changes with accuracy.

There is growing concern that many fruit trees are not achieving a sufficient sum of dormancy with global warming, especially in California where nuts and fruits produce several billion dollars of produce per year (Baldochi and Wong, 2008; Luedeling et al., 2009a).



One possible explanation, and co-occurrence is the reduction of winter fog in the Central Valley (Baldocchi and Waller, 2014). With less fog there is more sunshine and warmer air and bud temperatures.



Phenology and Weather

So far we have shown how weather variables affect the timing of plant activity. The converse can be shown too. Whether plants are transpiring or not affects boundary layer

moisture and temperature. Schwartz has produced a series of papers showing how phenology affects vapor pressure deficit of eastern forests.

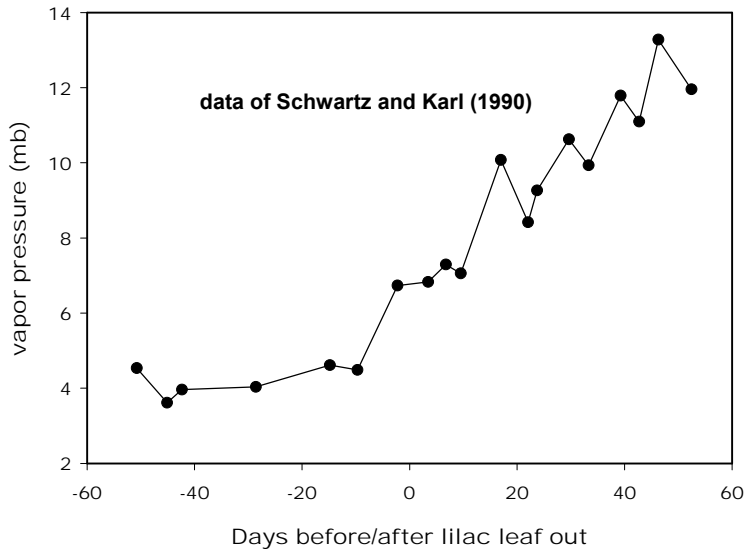


Figure 5 after Schwartz and Karl (1990)

In the western US a different link between vpd and phenology occurs. Data from a California grassland shows how vapor pressure deficits accelerates in the late spring of after the grasses die.

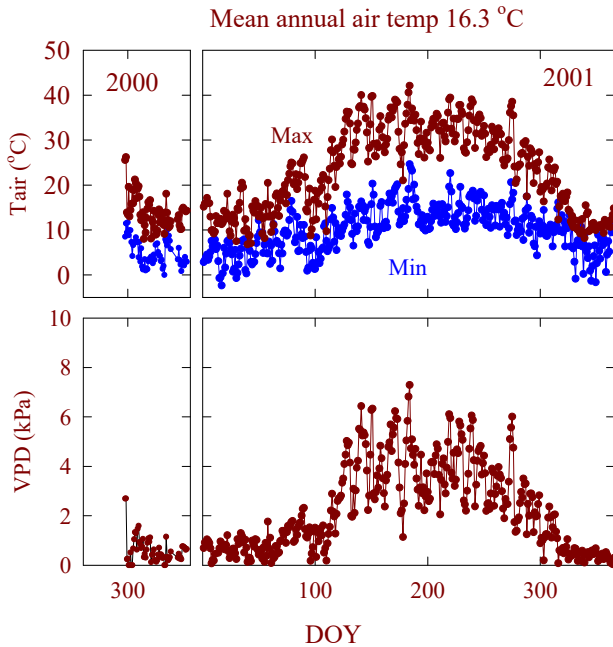


Figure 6 dat of Xu and Baldocchi. Annual grassland near Ione Cal

Summary

- The distribution of plant functional types is associated with climatic thresholds such as minimum temperature, occurrence of frost or freezing, and water balance.
- New biogeographical theories and remote sensing measurements are able to help us map the global distribution of potential and existing vegetation with greater accuracy.
- Phenology concerns us with the timing of plant activities. The timing of leaf out is one of the most distinct phenological events and can cause dramatic switches in atmospheric humidity, surface energy balance and carbon uptake.
- Phenology is often estimated using growing degree days.
- Many new studies are showing that global warming is causing length of growing season to lengthen, hence a feedback of temperature on phenology, besides kinetics.
- Timing of phenology also has a major impact of the warming and the humidification of the atmosphere and the growth of the planetary boundary layer.

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