A Comparison Of Two Sources Of Environmental Data And Three Model Outputs For Primary Apple Scab In 2012 At The UMass Cold Spring Orchard

Jon M. Clements and Daniel R. Cooley
University of Massachusetts

In a previous *Fruit Notes* article (Cooley & Clements, 2009) we pointed out that the source of weather data, and the models used to analyze it can produce very different recommendations with regard to treatment of sooty blotch and flyspeck. In this article, we look at two important components in apple scab management, apple scab ascospore maturity and primary infection periods, and compare two different data sources and four analytical tools that produce recommendations. Ascospore maturity and primary infection periods are important because they drive fungicide spray decision-making and management during the primary apple scab season.

In 2012, weather data was collected from two sources, SkyBit (skybit.com) and an on-site weather station, a Rainwise MKIII LR (rainwise.com). SkyBit is an agro-meteorology service that provides daily reports of recorded and predicted hourly weather data via email. Longitude and latitude coordinates, and elevation for the UMass Orchard were given to SkyBit hence the data is location-specific. The Rainwise weather station is located at the UMass Orchard, is connected to the internet and sends weather data to the Network for Environment & Weather Applications (NEWA, newa.cornell.edu).

We used four different systems to analyze the data and produce recommendations. The NEWA system uses on-site data, and provides a graphic output for ascospore maturity, as well as precipitation (Figure 1) and tabular output for infection periods (Figure 2). Orchard Radar (pronewengland.org/AllModels/RadarIntro.htm) uses SkyBit weather data, and provides graphic or table output of ascospore maturity estimates and rainfall (Figure 3) and a separate graphic and table output estimating the risk of apple scab infection (Figure 4). In addition to weather data, the SkyBit service can provide recommendations for apple scab, and provides a table with estimates of ascospore maturity and risk of infection, as well as related rain, temperature and leaf wetness data (Figure 5). RIMPro uses Rainwise on-site data, and provides graphic output of ascospore maturity and the risk of infection.

The method for calculating the risk of infection during an individual wetting period varies with each model, but all are based largely on revised Mills criteria (MacHardy and Gadoury, 1989). NEWA uses the revised Mills criteria without modification. Orchard Radar uses the revised Mills model, but incorporates other factors such as relative amount of leaf area and susceptibility of the tissue (Ficke et al., 2002). SkyBit likely modifies the revised Mills model and it's methods are proprietary. … . RIMPro's capabilities are beyond the scope of this article as we have really no actual user experience, however, we are pursuing looking at it more closely in the future. For now, see the RIMpro website for more information: www.biofruitadvies.nl/rimpro/rimpro_e.htm.

All four models calculate accumulated ascospore maturity (ASM) using degree days base 32º F. starting at 50% McIntosh green tip (Gadoury and MacHardy, 1982)1982 with adjustments for prolonged dry periods (Stensvand et al., 2005). The ASM model is used to estimate when large amounts of ascospores are ready to be released, high risk periods, and when ascospores are no longer available, the end of primary season. It predicts that 99%, or for practical purposes all, of the

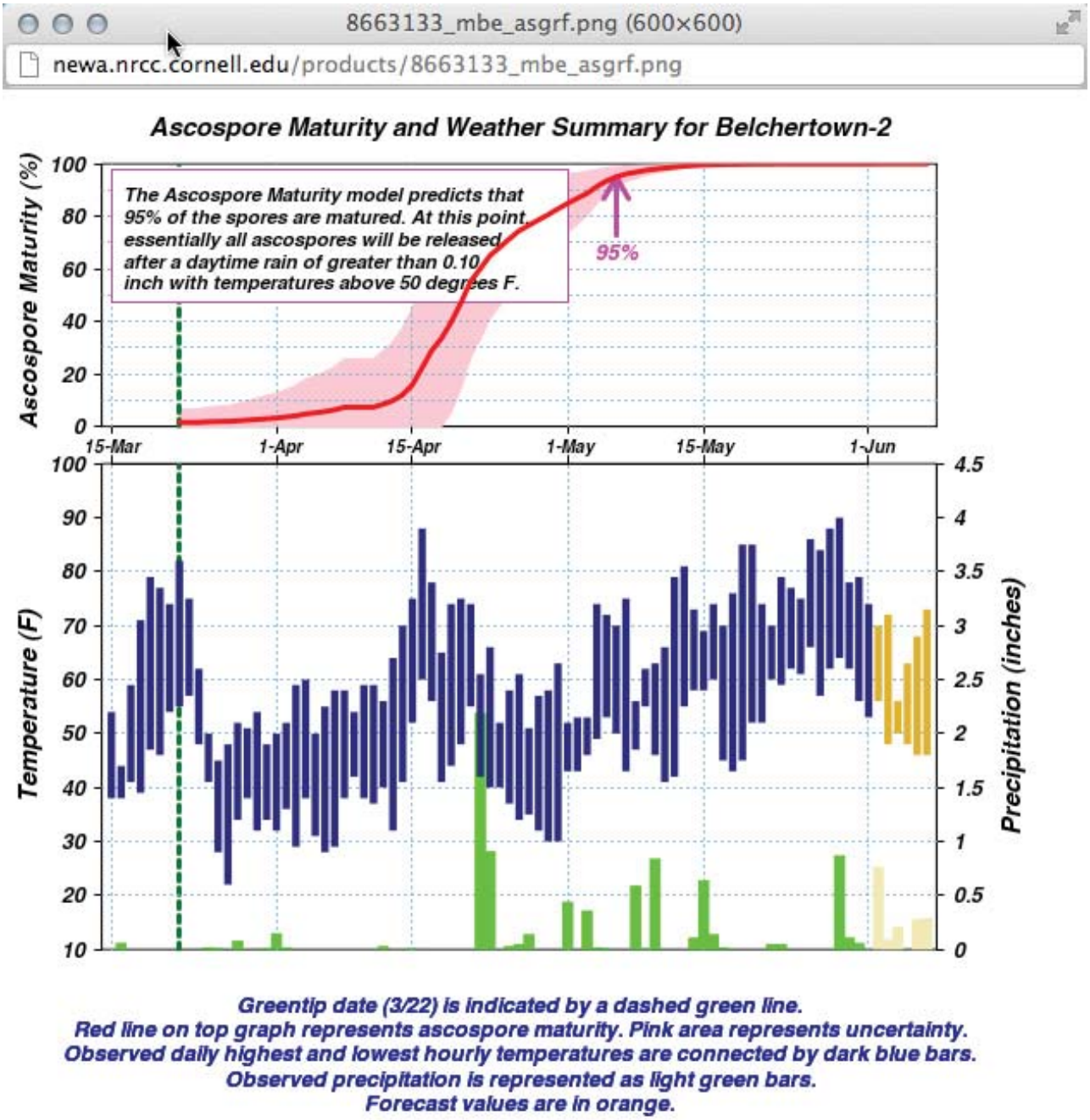

Figure 1. NEWA ascospore maturity.

ascospores for a season have matured when 900 DD (base 32º F.) have accumulated from green tip. Once this point is reached, the last primary inoculum is released with the next rain. Using the model is at least as accurate as actually observing ascospore maturity and release directly and saves significant expense in terms of skilled labor (Gadoury et al., 2004). Once all ascospores have been released from overwintering leaves, the risk of primary infection is over.

It is worth pointing out that the researchers who developed the ASM model included confidence "belts" in it. That is, the model makes an estimate, but in reality the estimate varies. One year it might be high, the next low. Based on many years of data, however, the model

Ascospores were essentially all released on May 8. Orchards are still at risk for conidial infections. Continue to monitor scab infection events and maintain spray coverage accordingly for at least two more weeks, or until May 22. Scout orchards for primary scab infections after this time.

The Ascospore Maturity degree day model begins at 50% green tip on McIntosh flower buds. To recalculate ascospore maturity for your orchard, enter your green tip date:

Green Tip Date: 3/22/2012

Apple Scab Infection Events (March 1 - June 1)

Start Date & Time	End Date & Time	Wet Hours	Temp Avg. (F)	Rain (in.)	Days to Symptoms	Combined Event
May 29 8:01 PM	May 31 3:00 AM	21	64	1.04	9-10	Yes
May 22 3:01 AM	May 22 2:00 PM	11	63	0.05	9-10	
May 14 6:01 AM	May 17 2:00 AM	50	60	0.91	9-10	Yes
May 8 2:01 AM	May 10 10:00 AM	56	55	1.44	14	
May 3 1:01 AM	May 5 12:00 PM	42	52	0.39	15	Yes
May 1 3:01 AM	May 1 7:00 PM	16	46	0.44	17	
April 26 5:01 PM	April 27 7:00 AM	14	48	0.19	17	
April 22 1:01 AM	April 23 11:00 AM	27	45	3.09	17	Yes
Dry conditions last 44 hours at download					Download Time: 6/1/2012 23:00	

Figure 2. NEWA infection periods.

estimates that there's a 90% chance (9 out of 10) that all spores will have matured between 765 DD and 1080 DD, or a range of 315 DD. That corresponds to about 10 to 14 days in early June, the time when ascospore maturation generally ends. The take home message is that ASM estimates are approximations, not precise to within a day, or even few days. The four models here, however, give a date when 100% ascospore maturity occurs, and only Orchard Radar includes the 90% confidence range.

Add to this variability the fact that measuring temperatures can also vary. In these four models, SkyBit estimates temperature remotely, and Orchard Radar uses the SkyBit estimates. NEWA uses temperatures measured with on-site weather equipment, and that data was also used in the RIMPro model.

Table 1 depicts the end date (i.e., 100% ASM) for the four models. The model estimates of 100% ASM spanned about a week. NEWA was the earliest, while RIMpro was the latest. Another way of looking at this is that on 15-May, Orchard Radar estimated approximately 10% of the seasons scab inoculum had not yet matured and been released, while NEWA estimated that it all had.

Table 1. Date of 100% ASM of four models.

Model	Date of 100% ASM
NEWA (Fig. 1)	15-May (app.)
SkyBit (Fig. 5)	17-May (100% ASM)
Orchard Radar (Fig. 3)	22-May (app.)
RIMpro (Fig. 6)	23-May (app.)

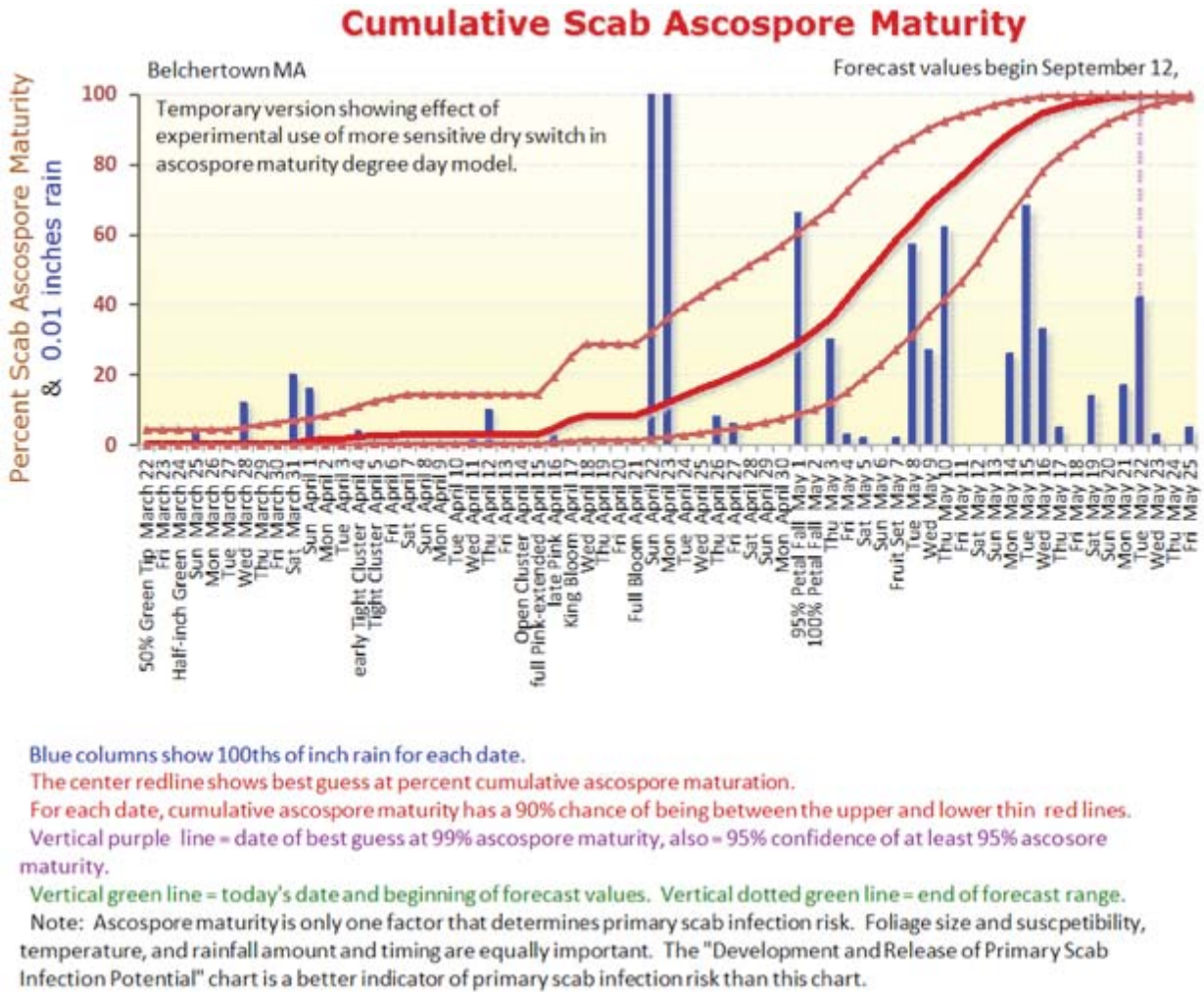

Figure 3. Orchard Radar ascospore maturity.

During most years, the average end of primary scab season in Massachusetts is around May 31. Growers typically maintain fungicide coverage into the first week of June. In 2012, the models estimated the end of to be one to two weeks earlier than that. And the season started 2-3 weeks early based on phenology and degree-days. But, based on actual observation of spore release in the region, it was suspected the primary season was really not over until sometime around June 1. Despite the early spring, dry weather at the onset likely delayed maturity, despite the degree-day accumulation, hence the delayed maturity. In most years the degree-day based maturity model is reliable, but in early, dry springs it may declare the risk of primary infection over when in fact it is not. Further research and refinement on this bugaboo is necessary.

Infection Periods

Infection periods are triggered by a combination of temperature, precipitation, and leaf wetness based on the Mills Table. Table 2 depicts the incidence of infection periods declared by the four models.

All four models were largely in alignment when declaring infection periods and would have predicted a grower would need to have applied 5-7 preventive sprays to control primary scab infection risk. These protectant sprays, for a total of 5-7 depending on model

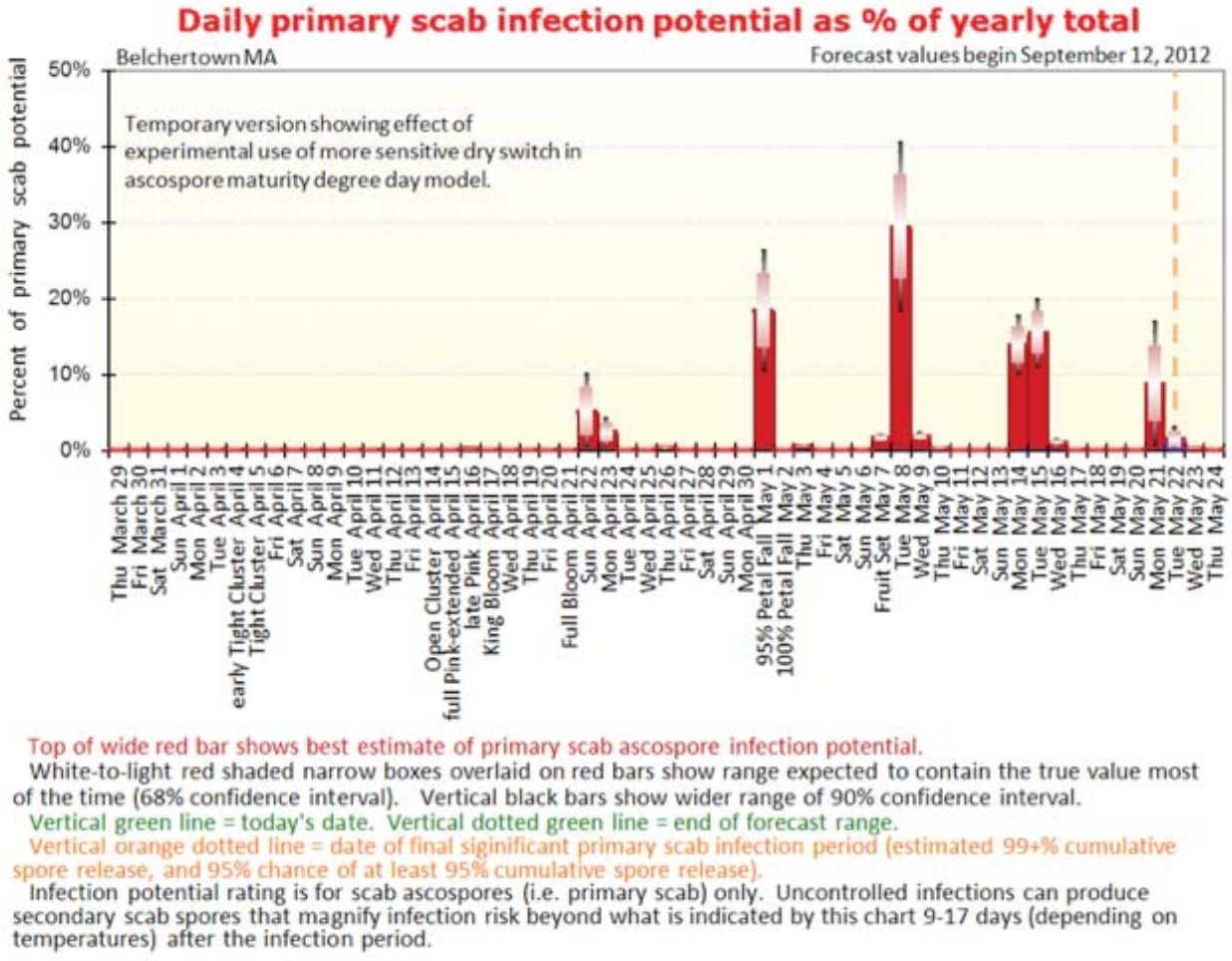

Figure 4. Orchard Radar infection periods/risk.

would have been applied at a minimum:

1. 21-22 April
2. 25-26 April (SkyBit and NEWA only)
3. 30-April to 5-May
4. 7-8 May
5. 13-17 May
6. 20-23 May (21-26 May for SkyBit)
7. 30-31 May (SkyBit and NEWA only)

In addition, infection events beginning on 1-May and continuing on-and-off through 10-May were extended and occurred when the risk of infection was particularly high. Hence, one or two spray(s) with kickback would have been advised. Therefore, based on the models, the primary apple scab season should have been controlled by no more than 7-9 fungicide sprays at the UMass Orchard.

One caveat was the fact that green tip was very early (March 22) and the degree-day maturity model started ticking but it was very dry, hence there were no infection periods/risk of scab infection recorded hence, no sprays. Unfortunately powdery mildew was infecting developing growth during this period and it turned out to be a bad powdery mildew year which was exacerbated by the fact no fungicide sprays were being applied to control scab.

Comments & Conclusions

It appears all four models based on two sources of weather data were pretty much in agreement and would be useful information in managing primary scab. So, choice of model is not as important as *actually using* a model to help manage primary scab and determine

E-WEATHER SERVICE
For: MA-BELCHERTOWN-HORTRESCENTER

	WEATHER					APPLE SCAB 120321			
	TMX	TMN	PREC	ARH	LW	ASM	AW	TW	PW
Date	F	F	in	%	hr	%	hr	F	
BASED ON OBSERVATIONS									
0323	72	55	0.00	49	0	0	0	-	+
0324	57	47	0.00	36	0	0	0	-	+
0325	47	43	0.03	73	9	0	2	46	+
0326	45	30	0.00	49	0	0	0	-	+
0327	47	25	0.00	23	0	0	0	-	+
0328	52	35	0.12	60	11	1	11	48	+
0329	48	39	0.00	65	0	1	0	-	+
0330	50	34	0.00	37	0	1	0	-	+
0331	44	33	0.20	70	13	1	13	39	+
0401	48	32	0.17	77	15	1	9	42	+
0402	52	34	0.00	51	9	1	18	41	+
0403	57	29	0.00	31	0	1	0	-	+
0404	60	38	0.04	39	8	1	8	46	+
0405	49	34	0.00	51	1	1	9	45	+
0406	52	28	0.00	44	0	1	0	-	+
0407	54	30	0.00	40	0	2	0	-	+
0408	55	39	0.00	42	0	2	0	-	+
0409	54	43	0.00	47	0	2	0	-	+
0410	57	40	0.00	41	0	3	0	-	+
0411	54	37	0.04	56	3	3	3	43	+
0412	52	38	0.08	67	20	3	4	52	+
0413	62	32	0.00	48	6	4	14	39	+
0414	68	38	0.00	37	0	5	0	-	+
0415	74	51	0.03	58	1	7	1	63	+
0416	85	56	0.00	58	9	10	10	61	++
0417	77	54	0.00	37	0	14	0	-	+
0418	59	45	0.00	45	0	17	0	-	+
0419	68	41	0.00	55	0	21	0	-	+
0420	74	45	0.00	57	0	26	0	-	+
0421	73	55	0.03	70	1	34	1	56	+
0422	55	43	1.54	88	24	38	25	48	++
0423	60	43	0.93	83	22	43	47	50	++
0424	53	43	0.00	58	0	48	0	-	+
0425	56	37	0.00	57	0	52	0	-	+
0426	59	33	0.10	67	8	55	8	53	+
0427	51	38	0.04	56	7	59	15	50	++
0428	56	34	0.00	35	0	62	0	-	+
0429	57	33	0.00	30	0	65	0	-	+
0430	61	31	0.00	38	0	69	0	-	+

E-WEATHER SERVICE
For: MA-BELCHERTOWN-HORTRESCENTER

	WEATHER					APPLE SCAB 120321			
	TMX	TMN	PREC	ARH	LW	ASM	AW	TW	PW
Date	F	F	in	%	hr	%	hr	F	
BASED ON OBSERVATIONS									
0501	50	46	0.66	85	23	72	23	47	++
0502	53	45	0.00	81	9	76	32	47	++
0503	53	47	0.30	90	24	79	24	50	++
0504	65	50	0.03	88	21	84	42	53	++
0505	64	53	0.02	82	14	87	17	56	++
0506	64	47	0.00	68	0	90	0	-	+
0507	70	43	0.04	61	5	92	1	59	+
0508	56	50	0.55	83	24	94	26	54	++
0509	63	56	0.34	93	24	95	50	57	++
0510	61	47	0.55	72	11	96	61	56	++
0511	64	45	0.00	48	0	97	0	-	+
0512	77	39	0.00	47	0	98	0	-	+
0513	80	51	0.00	55	0	98	0	-	+
0514	69	58	0.30	80	16	99	8	62	++
0515	68	59	0.64	84	23	99	18	62	++
0516	72	59	0.35	87	20	99	29	63	++
0517	68	48	0.03	54	7	100	11	55	++
0518	71	42	0.00	56	0	100	0	-	+
0519	79	46	0.14	53	2	100	2	69	+
0520	81	51	0.00	53	0	100	0	-	+
0521	68	52	0.19	80	11	100	11	65	++
0522	66	61	0.40	90	24	100	35	64	++
0523	75	60	0.03	80	19	100	47	64	++
0524	74	61	0.00	79	12	100	13	65	++
0525	73	60	0.05	85	20	100	8	69	++
0526	82	63	0.00	73	11	100	19	69	++
0527	80	58	0.00	61	0	100	0	-	+
0528	82	63	0.00	73	0	100	0	-	+
0529	82	65	0.48	80	11	100	6	69	+
0530	75	64	0.13	79	20	100	17	68	++
0531	77	59	0.01	58	8	100	16	65	++

Figure 5. SkyBit ascospore maturity and infection risk. Abbreviations in the SkyBit table: Date = day of the month with the first two digits as month and the last two as day; TMX F = the maximum temperature for the day in degrees Fahrenheit; TMN F = the minimum temperature for the day in degrees Fahrenheit; PREC in = the inches of rain; ARH % = relative humidity; LW hr = the number of hours leaves were wet; ASM % = the accumulated percent of ascospores that have matured by the date; AW hr = the accumulated wet hours on the date; TW F = the temperature in degrees Fahrenheit during the wetting period; PW = recommendation where "-" is inactive, "+" is active but not infectious, and "++" is potential infection warning.

when fungicide sprays are appropriate and declaring the end of primary scab season. Specifically, models aligned well in infection periods, but differed more in declaring end of primary scab season based on 100% ASM. And in 2012, just because there are no apple scab infection periods called during the early part of

Table 2. Estimated apple scab infection periods (Yes) of four models.

Date	SkyBit	Orchard Radar	NEWA	RIMpro
16-Apr	Yes			
17-21 Apr				
22-Apr	Yes	Yes	Yes	Yes
23-Apr	Yes	Yes	Yes	Yes
24-25 Apr				
26-Apr			Yes	
27-Apr	Yes		Yes	
28-30 Apr				
1-May	Yes	Yes	Yes	Yes
2-May	Yes		Yes	Yes
3-May	Yes		Yes	Yes
4-May	Yes		Yes	Yes
5-May	Yes		Yes	Yes
6-May				
7-May		Yes		Yes
8-May	Yes	Yes	Yes	Yes
9-May	Yes	Yes	Yes	Yes
10-May	Yes		Yes	Yes
11-13 May				
14-May	Yes	Yes	Yes	Yes
15-May	Yes	Yes	Yes	Yes
16-May	Yes	Yes	Yes	
17-May	Yes		Yes	
18-20 May				
21-May	Yes	Yes		
22-May	Yes	Yes	Yes	Yes
23-May	Yes			Yes
24-May	Yes			
25-May	Yes			
26-May	Yes			
27-28 May				
29-May			Yes	
30-May	Yes		Yes	
31-May	Yes		Yes	
Total inf. periods	8	5	7	5

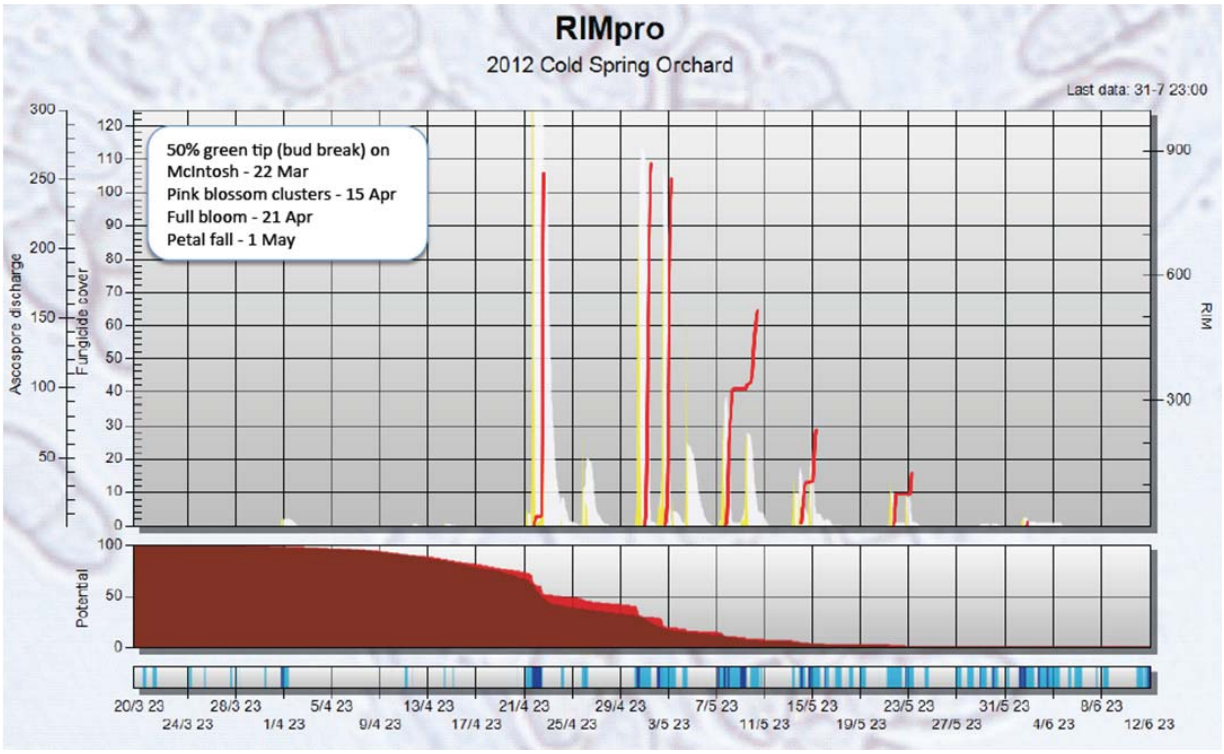

Figure 6. RIMpro ascospore maturity and infection risk.

the season leading up to bloom (because of unusually dry weather) that does not mean you can ignore applying fungicides to control mildew in some years. One advantage of using SkyBit (and Orchard Radar) is the predictive forecasts. (Although forecast data can be incorporated into the other two, NEWA and RIMPro to get model output and predictive risk of infection.) All four models using two sources of weather data were/are very useful in managing sprays and apple scab during the primary season and should be used by all growers/ Extension/consultants.

Literature Cited

Cooley, D.R., & Clements, J. 2009. Effective use of models in the management of sooty blotch and flyspeck. *Fruit Notes*. 74: 19-31.

Ficke, A., Gadoury, D. M. & Seem, R. C. 2002. Ontogenic resistance and plant disease management: A case study of grape powdery mildew. *Phytopathology*, 92, 671-675.

Gadoury, D. M. & MacHardy, W. E. 1982. A model to estimate the maturity of ascospores of *Venturia inaequalis*. *Phytopathology*, 72, 901-904.

Gadoury, D. M., Seem, R. C., MacHardy, W. E., Wilcox, W. F., Rosenberger, D. A. & Stensvand, A. 2004. A comparison of methods used to estimate the maturity and release of ascospores of *Venturia inaequalis*. *Plant Disease*, 88, 869-874.

MacHardy, W. E. & Gadoury, D. M. 1989. A revision of Mills criteria for predicting apple scab infection periods. *Phytopathology*, 79, 304-310.

Stensvand, A., Eikemo, H., Gadoury, D. M. & Seem, R. C. 2005. Use of a rainfall frequency threshold to adjust a degree-day model of ascospore maturity of *Venturia inaequalis*. *Plant Disease*, 89, 198-202.