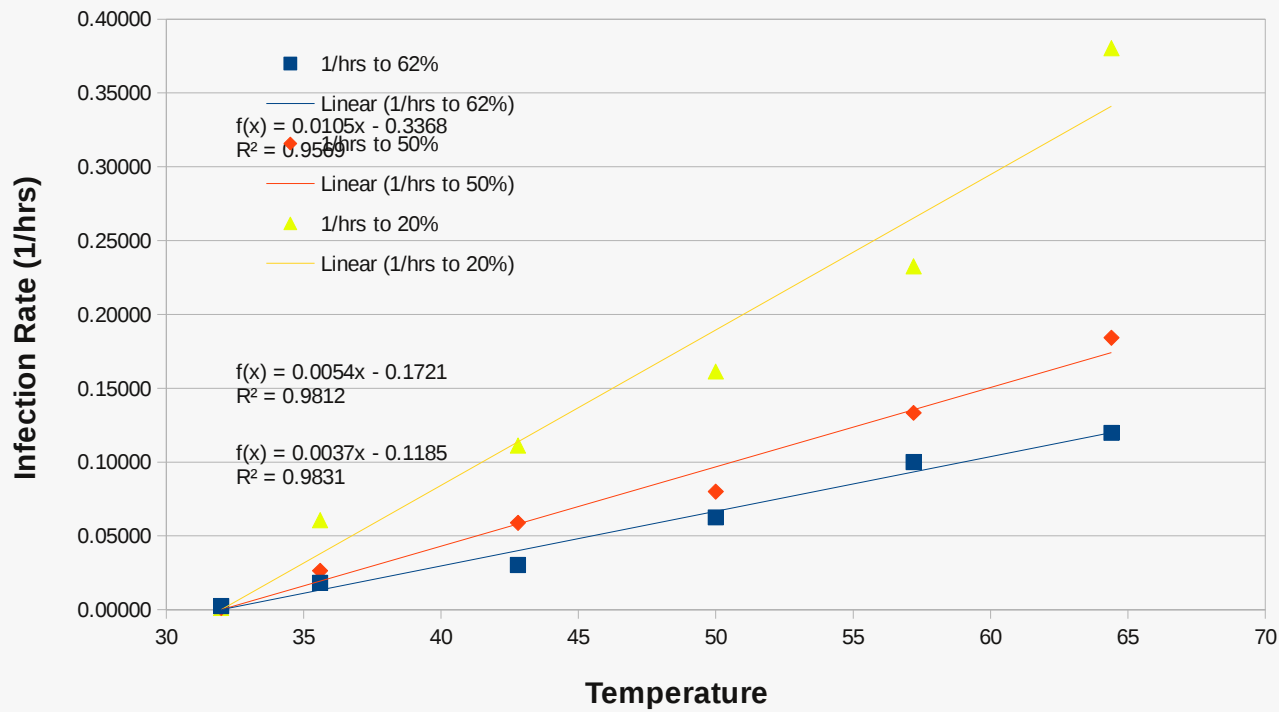


IPPC Plant Disease Model Development by Len Coop, July 2013 Draft vers. 1.1							
Updates 9/17/2014-10/6/2014							
Introduction: studies suggest that this disease can utilize 2 models following approach used for apple and pear							
Scab: 1 model predicts infection risk using degree-hours during periods of leaf wetness (a la inverted Mills table for apple scab), the second model is for determining the start and end of the primary ascospore season using degree-days.							
Model #1. Infection risk from ascospores using heat units and leaf wetness							
Infection risk model for Mummy berry of Blueberry – based on several published sources							
Source 1. Hildebrand, P.D. and P.G. Braun. 1991. Factors affecting infection of lowbush blueberry by ascospores of Monilinia vaccinii-corymbosi. Can. J. Plant Pathol. 13:232-240.							
From Table 5 – extract 20%, 30%, 50%, 62%, and 80% infection rate info							
Temp. C.	Temp. F.	hrs to 20%	hrs to 30%	hrs to 50%	hrs to 62%	hrs to 80%	
2	35.6	16.5	20.5	38	55	>50	
6	42.8	9	9.5	17	33	>50	
10	50	6.2	7.5	12.5	16	35	
14	57.2	4.3	5.5	8.5	10	12	
18	64.4	2.63	5	7	8.35	10	
Notes: it appears that Tlow is less than 35.6F (2C) for this process							
Same data used to develop infection risk model (see graph below):							
Temp. F.	1/hrs to 62%	1/hrs to 50%	1/hrs to 20%	hrs to 62%	hrs to 50%	hrs to 20%	
2	35.6	0.01818			55		
6	42.8	0.03030			33		
10	50	0.06250			16		
14	57.2	0.10000			10		
18	64.4	0.11976			8.35		
0	32	0.00250			400		
2	35.6		0.02632			38	
6	42.8		0.05882			17	
10	50		0.08000			12.5	
14	57.2		0.13333			7.5	
18	64.4		0.18420			5.43	
0	32		0.00125			800	
2	35.6			0.06061			16.5
6	42.8			0.11111			9
10	50			0.16129			6.2
14	57.2			0.23256			4.3
18	64.4			0.38030			2.63
0	32			0.00125			800

Orig:	Y-intercept (a)	-0.13084	-0.13792	-0.21504
	Slope (b)	0.00401	0.00449	0.00712
	-a/b	32.61325	30.71763	30.19758
	1/slope	249.26057	222.72062	140.42774
	R2=	0.98006	0.99337	0.98480
Forced:	Y-intercept (a)	-0.11849	-0.17206	-0.33676
	Slope (b)	0.00370	0.00538	0.01052
X-intercept:	-a/b	32.00030	32.00026	32.00023
Dhs:	1/slope	270.06596	185.97843	95.02383
	R2=	0.98312	0.98120	0.95695

Mummyberry - *M. vaccinii-corymbosi*
20%, 50%, and 62% Ascospore Infection Rates vs. Temperature
 data from Hildebrand and Braun 1991 Table 5.



Source 2. Ramsdell, D.C., J.W. Nelson and R. Myers. 1974. Phytopathology 64:222-228									
An Epidemiological Study of Mummy Berry Disease of Highbush Blueberry									
results from Table 2. M.v-c ascospore germination and germ tube length were greatest at 15C (59F), and slightly better at 20C (68F) than at 5C (41F). taking only 6hr at all 3 temperatures for germination and showing continuing germ tube growth from 6 to 48hr at all three temps.									
Notes: conclude that Tlow is less than 41F (5C)									
Model #1. Rules for blueberry mummy berry Infection Risk: using degree hours during leaf wetness (DH/LW) model:									
Algorithm (deg. F): Mummy berry degree-hour (DH) infection model: compute every hour using hourly data									
If no moisture for past 1 hour then:									
DH = 0									
Else if moisture for past 1 hour > moisture_threshold then:									
If Temp <= 32 then DH = 0									
If Temp > 32 & <= 68 then DH = Temp - 32									
If Temp > 68 & <= 78 then substitute 68 for Temp; so DH = (68 - 32) = 36									
If Temp > 78 then DH = 0									
Update Cumul_DH (Cumul_DH += DH)									
If Cumul_DH = 95 then 20% infection rate from ascospores expected if inoculum present (low risk)									
If Cumul_DH = 185 then 50% infection rate from ascospores expected if inoculum present (moderate risk)									
If Cumul_DH = 270 then 62% infection rate from ascospores expected if inoculum present (high risk)									
Lookup Rules: If no moisture for 8 hours or more then Cumul_DH = 0									
Extension related links to mention:									
http://perennia.ca/Fact%20Sheets/Horticulture/Fruit/Highbush%20Blueberry/Management%20of%20Mummy%20Berry									
http://msue.anr.msu.edu/news/managing_mummy_berry_shoot_strike_infections									
http://pnwhandbooks.org/plantdisease/blueberry-vaccinium-corymbosum-mummy-berry									
Model formulation: Assumptions:									
1) High temperature results not available; Assume infection risk units are horizontal between 68F and 78F (DH= 68-32). Above 78 assume no DH units accumulate									
These assumptions should be valid in northern climates in the early season when these models are in use. (very few warm and wet days in early spring when ascospores are being disseminated)									
Model #2. Ascospore seasonal release model (predict bud break, first, 50%, and last release of ascospores from overwintering apothecia)									
Source 3. Milholland 1974. Factors Affecting Apothecium Development of Monilinia Vaccinii-corymbosi from Mummied Highbush Blueberry Fruit. Phytopathology 64:296-300									
data from Fig. 3 - Effect of temp and degree of burial of mummiedighbush blueberry									
work done in SE North Carolina									
Emergence percent was highest at 16C (60.8F), about same at 10C (50F) & 5C (41F), much lower at 21C (70F), and near zero at 27C (80.6F)									
Apothecia percent development was highest at 16C (60.8F), much lower at 10 (50F) and 21C (70F), and zero at 5 (41F) and 27C (80.6F)									
5 C was sufficient to stimulate germination of apothecia.									

Source 4. Wharton, P.S. and A.M.C. Schilder. 2005. Effect of temperature on apothecial longevity and discharge by apothecia of *Monilinia vaccinii-corymbosi*. Plant Disease 89:397-403.

Analysis: standard x-intercept regression to determine DD and temperature thresholds

Tables 1 & 2 Effect of temperature on ascospore discharge by apothecia of *M. v-c.*

Temp C	Days to 95% discharge	Year	Temp F	1/days – 2003	1/days – 2002	both yrs
0	8000		32	0.0001		0.0001
10	13	2003	50	0.0769		0.0769
15	8	2003	59	0.1250		0.1250
20	2.2	2003	68	0.4545		0.4545
25	1.9	2003	77	0.5263		0.5263
10	6	2002	50		0.1667	
15	6	2002	59		0.1667	0.1667
20	2.15	2002	68		0.4651	0.4651
25	1.95	2002	77		0.5128	0.5128
0	8000	forced	32		0.0001	0.0001
					slope	0.0122
					intercept	-0.4505

*Forced data points Removed data point

Note 1: ignore 10C 2002 due to early termination of experiment 1/slope 81.7896

also: Batra 1983 at 12C no conidia released after 6days. -a/b 36.8470

Note 2: like apple and pear scab; could be used for a Degree-day R-square 0.853

end of primary infection season model

Basis for start of the model: either calendar date or bud Break and shoot elongation.

Model 1 (no forcing) : 58.6 DDs (base 45F), R-sq=0.93 after bud break 95% of ascospore release

Model 2 (points forced through 32F): ca. 82 DD base 37, R-sq=0.853

comparison with data in Source 5: ca. 7 days at 13.3C vs 6-8 days at 13.3 – similar results!

From source 3 above: consider using 80F as an upper threshold for degree-day accumulation.

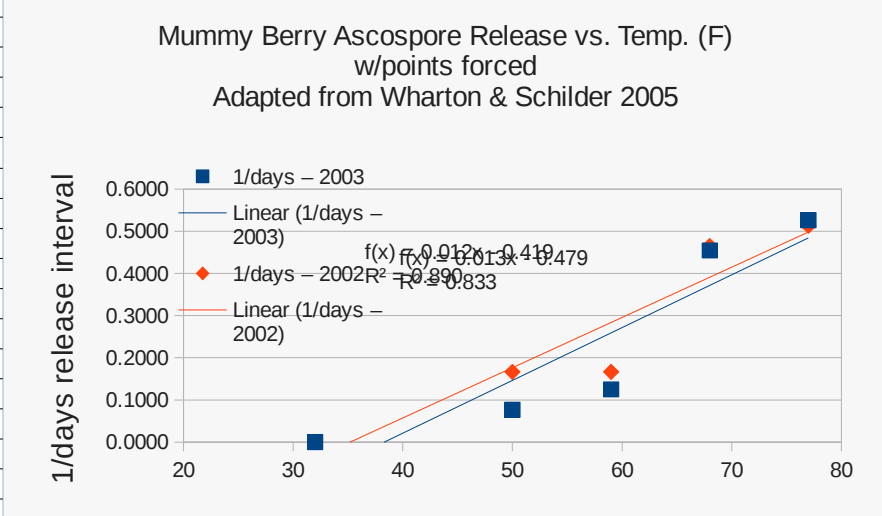
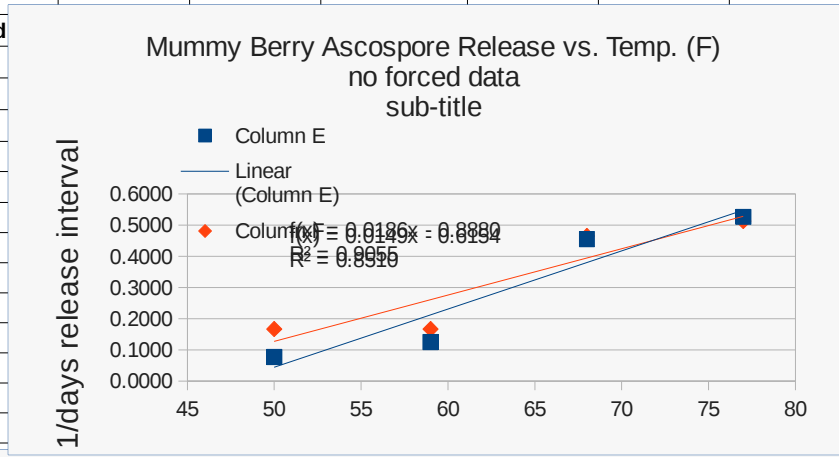
Same lab data using lowest C.V. method to find model:

Temp C	Days to 95% d	Year	Temp F	Tlow (F)					
				32	34	38	43	44	45
				Dds	Dds	Dds	Dds	Dds	Dds
10	13	2003	50	234.0	208.0	156.0	91.0	78.0	65.0
15	8	2003	59	216.0	200.0	168.0	128.0	120.0	112.0
20	2.2	2003	68	79.2	74.8	66.0	55.0	52.8	50.6
25	1.9	2003	77	85.5	81.7	74.1	64.6	62.7	60.8
10	6	2002	50	108.0	96.0	72.0	42.0	36.0	30.0
15	6	2002	59	162.0	150.0	126.0	96.0	90.0	84.0
20	2.15	2002	68	77.4	73.1	64.5	53.8	51.6	49.5
25	1.95	2002	77	87.8	83.9	76.1	66.3	64.4	62.4
			mean	131.2	120.9	100.3	74.6	69.4	64.3
			st. dev.	64.2	56.9	42.9	28.4	26.3	24.7
			C.V.	48.9	47.0	42.8	38.0	37.9	38.4

Lowest CV results: very high C.V. values (all greater than 35), lowest C.V. using all data Tables 1 & 2 is 44 F, at 69 Dds for 95% spore release. At 32 F (proposed threshold

using field data Pscheidt et al., see below), 131 Dds vs. 285 Dds field data results.

X-intercept method results: this study lacks low temperature treatments and the data indicate a rather high lower threshold compared to other primary ascospore release models



(both apple and pear scab use 32F as lower threshold); Pscheidt et al field data lowest C.V. only gives good results (C.V. of ca. 10 or less) using 32F-36F as base, with 32F best overall Tlow. Therefore this model had points added at 32F to better compare with other results. Even with the 2 forcing points added, the model indicates somewhat faster release rates than observed in the field (100 DD at 38C vs Pscheidt et al. data: 184 DD at 38C from lowest C.V. below) These differences may be due to local adaptation (MI vs. OR), genetic differences, lack of microclimate variability in lab, moisture differences, sampling error, and other differences field vs. lab such as varying depths of apothecia in soil, frost effects etc. Conditions (from M & M) near saturated relative humidity, conditions may have been more ideal than would be found in the field where humidity fluctuates diurnally. Alternative approach: with more temperature treatments (more data) we could try to fit a nonlinear model, or use piecewise linear regression. Conclusion: above study results should be discounted or considered secondary vs. field results for model development

Source 5. Hildebrand, P.D. and P.G. Braun. 1991. (cited above)

In materials and methods: ascospores were released (in lab at Day: 16C=60.8F 16h; Night=8C=46.4F 8h) from mature apothecia for approx. 6-8 days
 Estimate of Dds under these lab conditions 16h/day * 60.8-32 = 460.8 DH + 8h/day * 46.4-32 = 115.2 DH (night)/24 = 24 DD/day * 8 days = 192 DD release period 1st to last ascospores

	Temp C	Temp F	DH	DD/day	total DD (8 days)
Day DH	16	60.8	460.8	est DD/day=	
Night DH	8	46.4	115.2	24	192 DD
Wtd average for 16:8 photop	13.3	56.0	576.0	24.0	192.0

Results: 192 DD32 for first to last release of ascospores from apothecia compares favorably to ca. 285 DD32 from Pscheidt et al field results below. Lab conditions are ideal and have less population, microclimatic, and sampling error or variation than in the field.

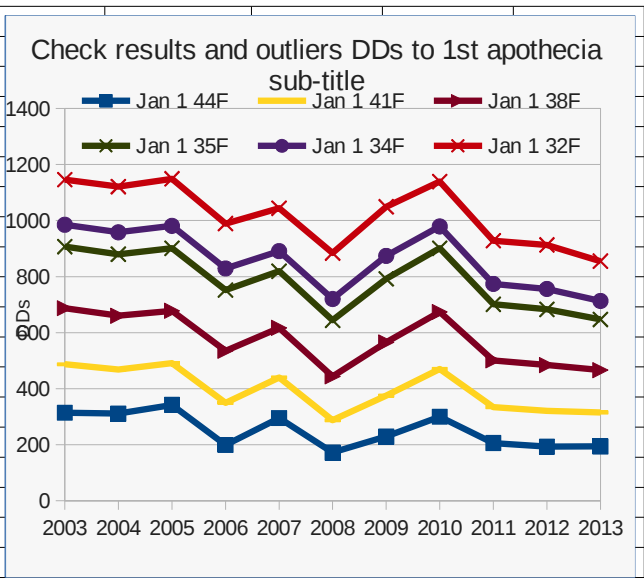
Source 6. Data from Pscheidt et al. Corvallis Oregon 2003-2013 (unpublished)

Corvallis OR (CRVO weather station) (Low Temp Thresold Tlow=48F unless specified)

	Date	Days	Dds Bud	Date 1 st	Date last	Days 1 st to	% mummy	Dds to 1 st	Dds to last	Dds to 1 st	Dds to last	
	Bud Break	Start date	after Jan 1	Break	Apothecia	Apothecia	last apothec.	berry obs.	Apothecia	Apothecia	Apothecia	Apothecia
2003	03/14/03	01/01/03	73	120	03/26/03	04/15/03	20	12	22	101	142	221
2004	03/15/04	01/01/04	74	110	03/28/04	04/05/04	8	10	57	98	167	208
2005	03/11/05	01/01/05	70	139	04/01/05	04/11/05	10	10	61	86	200	225
2006	03/10/06	01/01/06	69	56	03/27/06	04/17/06	21	4	19	95	75	151
2007	03/12/07	01/01/07	71	96	03/28/07	04/09/07	12	9	61	116	157	212
2008	03/24/08	01/01/08	83	65	04/03/08	04/23/08	20		8	50	73	115
2009	03/30/09	01/01/09	89	72	04/08/09	04/18/09	10		28	58	100	130
2010	03/15/10	01/01/10	74	115	03/22/10	04/12/10	21	41	15	70	130	185
2011	03/24/11	01/01/11	83	87	03/28/11	04/25/11	28	61	2	75	89	162
2012	03/19/12	01/01/12	78	72	03/26/12	04/16/12	21	58	8	70	80	142
2013obs	03/18/13	01/01/13	77	79	03/25/13	04/15/13	21	44.00%	7	114		
2014obs					03/17/14	04/07/14	21					
2014est												
	avg		76.4	93.2	avg		17.1		28.1	81.9	121.3	175.1
	stdev		6.6	27.3	stdev		6.6		23.0	20.8	44.4	40.3
	CV		8.7	29.3	CV		38.5		82.0	25.4	36.6	23.0

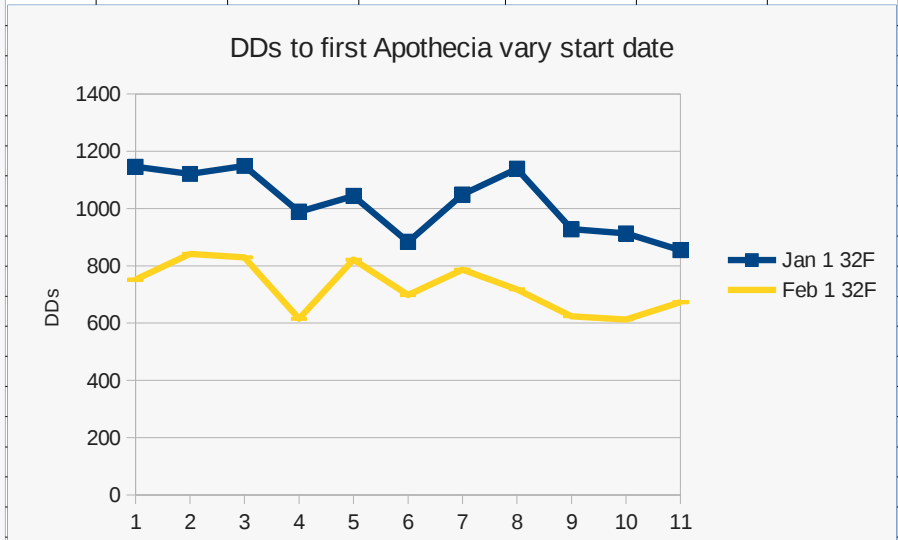
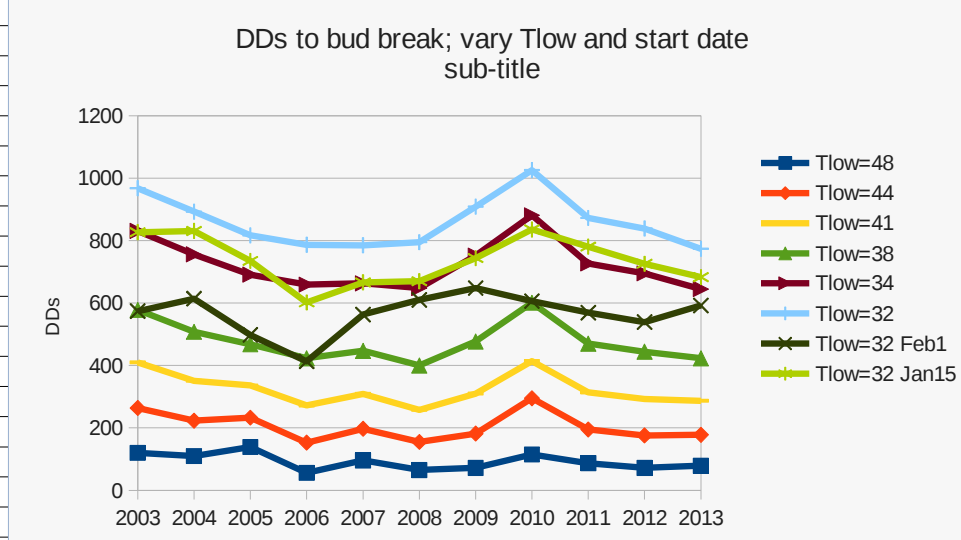
Notes: CV very high with assumption of high Tlow; test for lower Cvs (better fit) using lower Tlow values

	Dds Jan1 to Bud Break	Dds Jan1 to Bud Break	Dds Jan1 to Bud Break	Dds Jan1 to Bud Break	Dds Jan1 to Bud Break	Dds Jan1 to Bud Break	Dds Feb1 to Bud Break	Dds Jan15 to Bud Break
	Tlow=48	Tlow=44	Tlow=41	Tlow=38	Tlow=34	Tlow=32	Tlow=32 Feb	Tlow=32 Jan15
2003	120	264	410	578	831	968	574	827
2004	110	223	351	508	756	893	614	831
2005	139	233	336	468	691	817	498	735
2006	56	153	272	423	659	787	413	602
2007	96	197	309	447	663	785	563	666
2008	65	155	258	400	648	795	610	670
2009	72	182	310	477	752	909	648	744
2010	115	295	414	601	881	1026	606	836
2011	87	195	314	470	727	873	569	781
2012	72	176	293	444	695	839	539	726
2013	79	178	287	423	645	774	592	683
avg	91.9	204.6	323.1	476.3	722.5	860.5	566.0	736.5
stdev	26.2	44.9	51.3	63.6	77.3	82.3	64.9	77.1
CV	28.5	21.9	15.9	13.3	10.7	9.6	11.5	10.5



Results: Tlow of 32 and start=Jan 1 appears best for bud break data.

Graphs from data above and below:



	Dds to 1 st	Dds to last	Dds to 1 st	Dds to last	Dds to 1 st	Dds to last								
	Apothecia	Apothecia	Apothecia	Apothecia	Apothecia	Apothecia						Date 1 st	Date last	
	Jan 15 32F	Jan 15 32F	Feb 1 32F	Feb 1 32F	Feb 1 35F	Feb 1 35F						Apothecia	Apothecia	
2003	1006	1358	752	1105	599	891						03/26/03	04/15/03	
2004	1059	1195	842	979	678	792						03/28/04	04/05/04	
2005	1067	1219	830	982	664	786						04/01/05	04/11/05	
2006	804	1173	615	984	470	776						03/27/06	04/17/06	
2007	925	1132	822	1028	660	831						03/28/07	04/09/07	
2008	758	1037	698	977	528	748						04/03/08	04/23/08	
2009	884	1041	787	945	606	734						04/08/09	04/18/09	
2010	948	1251	718	1021	573	813						03/22/10	04/12/10	
2011	836	1269	624	1057	472	824						03/28/11	04/25/11	
2012	800	1141	613	954	464	741						03/26/12	04/16/12	
2013	764	1169	673	1078	522	863						03/25/13	04/15/13	
												obs	03/17/14	04/07/14
Mean	895.5	1180.5	724.9	1010.0	566.9	799.9						pred	03/26/14	04/10/14
St. Dev.	113.7	94.9	87.8	52.1	81.0	50.3								
C.V.	12.7	8.0	12.1	5.2	14.3	6.3								
Results: Jan 1 and Tlow = 32F (5C) looks to be best overall model for Dds to 1st and last apothecia; although Tlow=32 Feb 1 & Tlow=35 Feb 1 are both a bit better for last apothecia														
Check Dds 1st to last apothecia lowest C.V.														
		Jan 1 44F	Jan 1 41F	Jan 1 38F	Jan 1 35F	Jan 1 34F	Jan 1 32F	Jan 15 32F	Feb 1 32F	Feb 1 35F				
2003		130	179	233	293	313	352	352	353	292				
2004		59	75	94	114	122	136	136	137	114				
2005		47	68	95	123	133	152	152	152	122				
2006		132	184	244	306	327	369	369	369	306				
2007		84	110	139	171	183	206	207	206	171				
2008		76	116	165	221	239	279	279	279	220				
2009		53	75	102	129	138	157	157	158	128				
2010		87	129	181	240	261	302	303	303	240				
2011		139	203	275	352	379	433	433	433	352				
2012		111	160	218	278	299	341	341	341	277				
2013		169	221	280	342	363	405	405	405	341				
Mean		98.8	138.2	184.2	233.5	250.6	284.7	284.9	285.1	233.0				
St. Dev.		40.0	54.4	70.6	88.4	94.4	106.7	106.6	106.5	88.4				
C.V.		40.5	39.4	38.3	37.8	37.7	37.5	37.4	37.4	37.9				
Results: It does not seem to matter what Tlow to use: 1 st apothecia is not a very good predictor of last apothecia														

