Light Brown Apple Moth, Epiphyas postvittana (Walker), Phenological Model
Analysis by Len Coop, Integrated Plant Protection Center, Oregon State University, Jun 18, 2012

Summary of final proposed model:	DD ©	DD (F)
Tlow:	7	45
Thi:	30	88
Start Date: Jan 1		
Peak OW/1st gen. pheromone trap catch:	275	495
Peak OW/1st gen. egg-laying:	364	656
Peak 2nd gen. Egg-hatch:	491	884
Peak 2nd gen. larvae	694	1250
Peak 2nd gen trap catch:	1052	1894
Peak 3rd gen. Egg-hatch:	1350	2430
Peak 3rd gen. larvae	1597	2875
Peak 3rd gen trap catch:	1827	3288
Peak 4th gen. Egg-hatch:	2296	4134
Peak 4th gen. larvae	2543	4578
Peak 4th gen trap catch:	2602	4683

Sources:

1. Danthanarayana 1975 (interpreted by Thomkins, A.R., D.R. Penman, R.B. Chapman, and S.P. Worner. 1987. An Evaluation of a phenological model (PETE) to assist insect pest control in apple orchards in Canterbury, New Zealand. New Zealand J. of Exp. Agric. 15:3, 381-388.

		Tlow (C)	Thi (C)	Tlow (F)	Thi (F)	Tlow (F)	Thi (F)
	Tlow, Thi	7	31	44.6	87.8	45	88
Deg-days:	Egg	138		248.4		240.5	
	Larvae	363		653.4		632.5	
	Pupae	142		255.6		247.4	
	Pre-ov	33		59.4		57.5	
	Adult	183		329.4		318.9	
	Ca. Generatio	749.2		1348.56		1305.4	

Ca. Overwintering distribution:	Eggs:	65.00%
as per PETE model	Larvae:	33.00%
	Pupae:	2.00%

Biofix Date: 9/20 @ 120DD accumulated equiv. To 3/20 in Northern Hemisphere
in other words this PETE model biofix resets DD accum. To 120 on Sept. 20 as a default

2. Gutierrez et al. 2010. Limits to the potential distribution of light brown apple moth in Arizona-California based on climate suitability and host plant availability.
based on Danthanarayan 1975, 1976, and 1983

			b	1.36	
Tmin	6.8	Day	Tavg	phi(T)	Fecundity
Tmax	31.5	1	15	0.673042968	0
Tmidx	19.15	2	18	0.827655789	0
		3	20	0.903462427	0
		4	22	0.957454206	0
		5	24	0.989631124	0

		6	26	0.999993183	0
Eggs	Larvae	7	26	0.999993183	0
Tlow =	7.5 Tlow =	8	26	0.999993183	0
1/slope =	1/slope =	9	26	0.999993183	0
		10	26	0.999993183	0
		11	26	0.999993183	0

3. Zalom, F. UC Davis Presentation (slide on DD req.s, analysis based primarily on Geier and Breise 1981)
http://ucanr.org/sites/UCNFA/files/28824.pdf

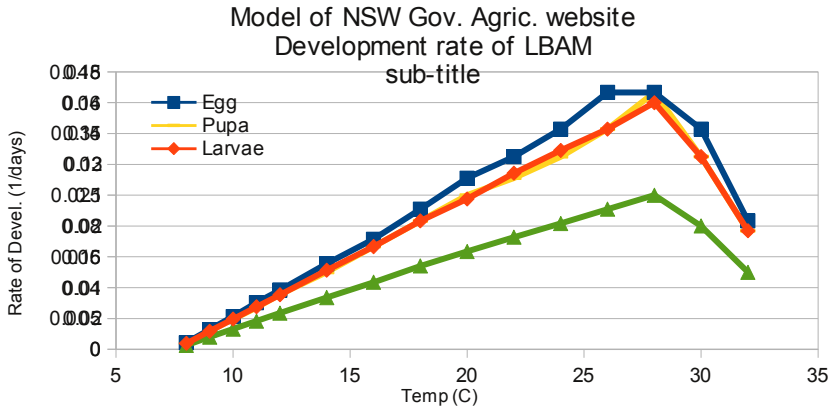
	(C)	(F)
Tlow	7	45
Thi	31	88
Dds dev Egg	131	236
Larvae	381	685
Pupae	132	238
Pre-ov	30	54
50% OV	83	149
Egg to 1st Egg	621	1117
Egg to 50% eg	673	1212

5. Geier and Briese 1981 Summarized from below

(C)	(F)	(F) see 6 below
7	44.6	45
31	87.8	88
131	236	228
360	648	627
132	238	230
28	50	48
74	132	128
711	1279	1238
757	1362	1318

Notes: Use female larval development on young apple leaves
as most appropriate for generation time modeling. Male development
on old apple is most appropriate for OW generation flight
on young apple is most appropriate for 1st generation flight

4. NSW Australia Online LBAM development calculator, http://www.dpi.nsw.gov.au/agriculture/horticulture/citrus/health/pests/lbam-calculator



daily avg T ©	Rate of dev (1/days) Egg	Larvae	Pupa	Total Gen	Days (Time to develop) Egg	Larvae	Pupa	Total Gen	interpret as minimum gen time v Est ELP,Mate, Pre-OV+50% OV
8	0.004273504	0.0009823183	0.00390625	0.000661813	234	1018	256	1511	2557.417961
9	0.012820513	0.0029498525	0.011764706	0.001980198	78	339	85	505	
10	0.021276596	0.0049019608	0.019607843	0.003278689	47	204	51	305	

		11	0.03030303	0.0068965517	0.027027027	0.004587156	33	145	37	218
		12	0.038461538	0.0088495575	0.035714286	0.005882353	26	113	28	170
		14	0.055555556	0.0128205128	0.05	0.008403361	18	78	20	119
		16	0.071428571	0.0166666667	0.066666667	0.010869565	14	60	15	92
		18	0.090909091	0.0208333333	0.083333333	0.013513514	11	48	12	74
		20	0.111111111	0.0243902439	0.1	0.015873016	9	41	10	63
		22	0.125	0.0285714286	0.111111111	0.018181818	8	35	9	55
		24	0.142857143	0.0322580645	0.125	0.020408163	7	31	8	49
		26	0.166666667	0.0357142857	0.142857143	0.022727273	6	28	7	44
		28	0.166666667	0.04	0.166666667	0.025	6	25	6	40
		30	0.142857143	0.03125	0.125	0.02	7	32	8	50
		32	0.083333333	0.0192307692	0.076923077	0.0125	12	52	13	80
		33					none			
							E+L+P	Est Mate + Pre-OV	Est 50% OV	Est. Time to 50% OV
	Slope		0.008881143	0.0019438842	0.007678171	0.001225102		ca. 21 days max OV period (Danth. 1975)		
	Intercept		-0.06764181	-0.014494632	-0.05705002	-0.00895588	Celsius			
DD req.s:	1/slope		112.60	514.43	130.24	816.26	757.27	58.99	111.1111111	931.2095807
Tlow/X-intrcpt:	-a/b		7.62	7.46	7.43	7.31				
approx. upper threshold =			30	30	30	32				
Same converted to deg. F:							Fahrenheit			8 days
			202.68	925.98	234.43	1469.27	1363.09	106.18	200	200 70F
Tlow/X-intrcpt:			45.71	45.42	45.37	45.16				
approx. upper threshold =			86.00	86.00	86.00	89.60				
Standardize Tlow=45F		Egg		Larvae	Pupa		E+L+P	Est Mate + Pre-OV		Est ELP, Mate, Pre-OV+50% OV
DD req.s:			205	930	235		1370.00	106	200	1676.177245

5. Geier and Briese 1981. The LightBrown Apple Moth, Epiphyas postvittana (Walker): a native leafroller fostered by European settlement.

pp. 131-155. In R. Kitching and R. Jones [eds.], 1981. The Ecology of Pests. Pub. By CSIRO, Melbourne, Australia. 254 pp.

Based on Fig. 3.		Rate of dev (1/days)		Note: on Shorey Media in Lab (less optimal than apple lvs)
Deg.s C		Egg	Fem:Larv+Pup	Male:Larv+Pu Total Gen
	Slope	0.00753	0.00159	0.00178
	Intercept	-0.0524	-0.0109	-0.0126
DD req.s:	1/slope	132.80	628.93	561.80
Tlow/X-intrcpt:	-a/b	6.96	6.86	7.08
approx. upper threshold =		30	30	30
Same converted to deg. F:				
		239.04	1132.08	1011.24
Tlow/X-intrcpt:		44.53	44.34	44.74
approx. upper threshold =		86.00	86.00	86.00

Standardize Tlow=45F				Est Fem:Larv	Est Male:Larv	
DD req.s:		231	1096	979	866	749

Based on Table 6.

	Egg	Larvae Males on young apple l	Larvae Males on old apple	Larvae Females on young apple	Larvae Females on old apple	Pupa	Males time v Total Gen OV to 1st moth	Females time v Total Gen OV to 1st moth	Females Est ELP,Mate, Pre-OV, OV to 5% OV	Females Est ELP,Mate, Pre-OV, OV to 50% O\	Females Est ELP,Mate, Pre-OV, OV to 75% O\	Females Est ELP,Mate, Pre-OV, OVto95%OV
Deg.s C base 7.0								On young apple leaves (assume gen 1-2)				
DD req.s:	131	360	468	420	510	132	623	683	711	757	793	863
Tlow	7											
Thi	30											
Deg.s F base 44.6												
DD req.s:	236	648	842	756	918	238	1121	1229	1279	1362	1427	1553
Tlow	44.6											
Thi	86											
Deg.s F base 45												
DD req.s:	228	627	815	732	889	230	1086	1190	1238	1318	1381	1504
Tlow	45											
Thi	86											

	Females time v Total Gen OV to 1st moth	Females Est ELP,Mate, Pre-OV, OV to 5% OV	Females Est ELP,Mate, Pre-OV, OV to 50% OV	Females Est ELP,Mate, Pre-OV, OV to 75% O\	Females Est ELP,Mate, Pre-OV, OV to 95% OV
Deg.s C base 7.0	On older apple leaves (assume Gen 3+)				
DD req.s:	773	801	847	883	953
Tlow	7				
Thi	30				
Deg.s F base 44.6					
DD req.s:	1391	1441	1524	1589	1715
Tlow	45				
Thi	86				
Deg.s F base 45					
DD req.s:	1347	1395	1475	1538	1661
Tlow	45				
Thi	86				

Oviposition Dds including Pre-OV: based on Fig. 4

base 7C	Cohort 1	Cohort 2	Avg
Time to 5% OV	20	35	28
Time to 50% OV:	60	87	74
Time to 75% OV:	92	127	110
Time to 95% OV:	170	190	180
base 45F			
Time to 5% OV	36	63	48

Time to 50% OV:	108	156.6	128
Time to 75% OV:	165.6	228.6	191
Time to 95% OV:	306	342	314

6. Empirical conversion from Tlow of 44.6 to 45 deg. F

	Egg to 50% egg laying		Same Date	
Replicate	DD (44.6)	Date	DD (45)	Percent
Corvallis OR	1360	07/05/12	1311	0.963970588
San Lois Obispo	1363	04/28/12	1323	0.970652971
Salinas CA	1371	05/06/12	1328	0.968636032
Sacramento CA	1367	05/09/12	1327	0.970738844
Average				0.968499609

Result: multiply DD req.s by 0.968 to convert base 44.6 to base 45 degree-days

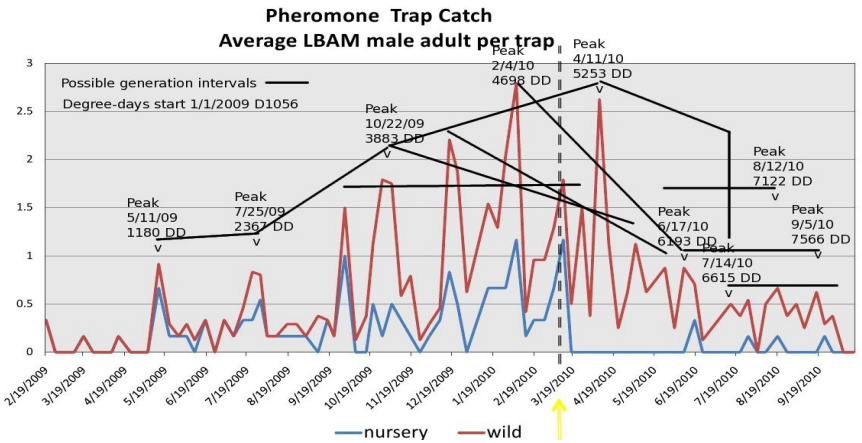
7. Analysis of trapping data from Santa Cruz California 2009-2010 (Gold Rush Nurs., Santa Cruz, CA, nearst wea stations: D1056 (medium), AR172 (warmest), CQ127 (coolest))
Data from Steve Tjosvold, UC Cal. Extension 3/7/2011 http://sfp.ucdavis.edu/events/11conference/tjosvold.pdf

Peak pheromone trap catch (males) occurred on 7/25/2009, 10/30/2009, 2/4/2010, 3/11/2010, 4/11/2010, and (less obviously) 6/11/2010
Peak bait trap catch occurred on 10/30/2009, 1/12/2010, and 4/11/2010
Peak UV light trap catch (males&females) occurred on 10/22/2009 but not again until 6/17/2010
For analysis use deg. F, 1362 DD gen time (Mar-Jun), 1524 DD gen time (Jul-Feb) (error in not using final gen DD of 1318 and 1475 DD ca. 2 days each event)

	Station:	AR172		CQ127	
	Date	Dds > 1/1/10	Dds > 1/1/09	Dds > 1/1/10	Dds > 1/1/09
no data->	12/08/08				
peak ptrap->	05/11/09		1326		1131
	06/30/09		2148		1845
	07/25/09		2641		2274
peak->	07/30/09		2727		2360
sm peak →	08/19/09		3125		2721
sm peak →	08/31/09		3390		2962
	09/30/09		4028		3523
peak->	10/04/09		4090		3580
peak all 3 traps->	10/28/09		4455		3911
peak ptrap->	12/19/09		4903		4336
	12/31/09		4972		4403
peak bait->	01/12/10	118	5090	105	4508
peak ptrap->	02/04/10	262	5234	248	4651
sm peak →	02/24/10	416	5388	395	4798
peak ptrap->	04/11/10	804	5776	758	5161
sm peak →	05/02/10	1038	6010	950	5353
sm peak →	05/17/10	1218	6190	1118	5521
peak ptrap, UV trap	06/17/10	1753	6725	1600	6003
sm peak →	07/14/10	2180	7152	1985	6388
sm peak →	08/12/10	2654	7626	2419	6822
some flight->	09/05/10	3144	8116	2845	7248
some flight->	10/08/10	3744	8716	3411	7814

	Station:	D1056 (used for analysis)		Gen. Time backtracking			Gen. time forwardtracking			
	Date	Dds > 1/1/10	Dds > 1/1/09	Dds > 1/1/09	Dds > 1/1/09	Dds > 1/1/09	Dds > 1/1/09	Dds > 1/1/09	Dds > 1/1/09	Notes
no data->	12/08/08		-182	-182						
peak ptrap->	05/11/09		1180	---------^			---------v			
	06/30/09		1927				“ |			
	07/25/09		2367				“ v			
peak->	07/30/09	(to 8/04/09)	2450			2451		2542	---------v	
sm peak →	08/19/09		2813		“	^			“ |	
sm peak →	08/31/09		3045	3047	“	|			“ |	
	09/30/09		3572	“ ^	“	|			“ |	
peak->	10/04/09		3627	“ |	“	|	3729		“ v	---------v
peak all 3 traps->	10/28/09		3975	“ |	---------^	“	^	---------v	3974	“ |
peak ptrap->	12/19/09		4414	“ |		“	|	“ |		“ | ---------v
	12/31/09		4478	“ |		“	|	“ |		“ | “ |
peak bait->	01/12/10	93	4571	---------^		“	|	“ |		“ | “ |
peak ptrap->	02/04/10	220	4698			“	|	“ |		“ v “ |
sm peak →	02/24/10	356	4834			4831	“ |	“ |	---------v	5151 “ | Started
peak ptrap->	04/11/10	775	5253		“	^	---------^	“ v	“ |	---------v “ | mating
sm peak →	05/02/10	1021	5499		“	|		5499	“ |	“ | “ v disruption
sm peak →	05/17/10	1204	5682	5682	“	|			“ v	“ | 5938 03/15/10
peak ptrap, UV trap	06/17/10	1715	6193	“ ^	---------^			---------v	6196	“ v (reduces trap
sm peak →	07/14/10	2149	6627	“ |				“ |		6615 catch; obscures
sm peak →	08/12/10	2644	7122	---------^				“ v		“ | peaks)
some flight->	09/05/10	3088	7566					7555		“ v 1460
some flight->	10/08/10	3661	8139							8139

Discussion: Some but not all flight peaks during 2009 were singular rather than bimodal or multimodal, whereas, either because of mating disruption or increasingly overlapping generations, singular flight peaks are difficult to distinguish during 2010. Generation times determined by Dds do assist in explaining potential flight peaks and in showing which peaks are likely not linked by generations. A lack of winter frost kill (station CG127; coldest temps were 12/6-9/2009 at 28-32F and 12/24-25/2009 at 31-33F) may help explain the 2010 overlapping of life stages and generations. Data from Steve Tjosvold, UC Cal. Extension 3/7/2011



8. Estimation of biofix or 1st flight peak from OW populations: Average stage surviving winter is 4th instar larvae (probably actually 5th instar due to supernumerary molts occuring during winter time. Assuming 4th instar is at ca. 55% of development for larvae stage on Jan. 1 (nominal biofix);

Larval & pupal dev. (DDs) — Factor for % completion of larval development on Jan 1: **0.45**

	Males		Females	
	young apple	old apple	young apple	old apple
Deg.s C (7.0Tlow)	360	468	420	510
0.45	162	211	189	230
pupal Dev	132	132	132	132
remain larv+pupal	294	343	321	362
Deg.s F (44.6 Tlow)	748	842	756	918
0.45	337	379	340	413
pupal Dev	132	132	132	132
remain larv+pupal	469	511	472	545
Deg.s F (45 Tlow)	724	815	732	889
0.45	326	367	329	400
pupal Dev	128	128	128	128
ca. pk flight:				
remain larv+pupal	454	495	457	528

First peaks spring 2010 Santa Cruz (Fig above):

03/11/10	DD (45F)	450
04/11/10	DD (45F)	775

8b. Approx. biofix/start of first gen. In Dds using March 31 for 1st peak flight, from Zalom #3 above:

		D1056	CQ127	AR172	
03/31/09	DD (45F)	663	642	781	
03/31/10		680	681	723	average:
03/31/11		601	677	693	688.5454545
03/31/12		NA	668	765	

Discussion: these DD values are very much in range of other estimates, avg. value 689 DD

9. Reference Table from #5-8 above:

Tlow	45
Thi	88
Dds dev Egg	228
Larvae (male young apple)	627
Larvae (male old apple)	815
Larvae (female young apple)	732
Larvae (female old apple)	889
Pupae	230
Pre-OV to 5% egg laying	48
Pre-OV to 50% OV	128
Egg to 5% egg laying, young apple leaves	1238
Egg to 50% egg laying, young apple leaves	1318
Egg to 5% egg laying, old apple leaves	1395
Egg to 50% egg laying, old apple leaves	1475

10. Model based on #5-9 above using 495 DD estimated 1st peak flight in pheromone traps, 528 DD 1st female peak flight (subject to change):

	(F)	(C)	
Tlow:	45	7.2	
Thi:	88	31.1	DD (F)
Overwintering/Spring Generation:	DD (F)	DD (C)	Cell ref formula
Peak OW/1st gen. pheromone trap	495	275	“=C316
Peak OW/1st gen. egg-laying:	656	364	"=E316+D341
Peak 2nd gen. Egg-hatch:	884	491	"=C353+D334
Peak 2nd gen. larvae	1250	694	"=C354+D337/2
Peak 2nd gen trap catch:	1894	1052	"=C353+D342
Peak 3rd gen. Egg-hatch:	2430	1350	"=C354+D343+D334
Peak 3rd gen. larvae	2875	1597	"=C357+D338/2
Peak 3rd gen trap catch:	3288	1827	"=C356+D344
Peak 4th gen. Egg-hatch:	4134	2296	"=C357+D345+D334
Peak 4th gen. larvae	4578	2543	"=C360+D337/2
Peak 4th gen trap catch:	4683	2602	"=C359+D344