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Storm Damage to Distribution Lines in the GVRD/Lower Mainland Region of B.C.

Report commissioned by:

Distribution Emergency Restoration
Business Process Improvement Team
(B.C. Hydro)

Prepared by:

Dr. Matthias Roth
Consulting Meteorologist

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SECTION 1: INTRODUCTION

1.1 Statement of Problem

High winds often cause power outages to residents in the Vancouver (GVRD)/Lower Mainland area (referred to henceforth as 'study area') of B.C. (Fig. 1). In these cases distribution lines are usually damaged by fallen trees or tree branches. In the case of severe storms, thousands of B.C. Hydro customers may be affected. In the 1998/99 winter season alone more than 100'000 and 70'000 customers, respectively, were without power in the wake of two major storms. Because of its particular geographic location at a latitude of 49 degrees North on the west coast of a continent, the study area is often exposed to strong storms which are embedded in the general westerly flow which is strongest in winter when the equator-pole temperature gradient is largest in the Northern Hemisphere. The extent of the damage and the geographic distribution of the damage locations therefore depend on the season or month of the year but also on the particular setting of the study area at the mouth of a coastal valley which is bounded by up to 1500 m high mountains to the north and east.

In fall of 1998 B.C. Hydro commissioned this report in an effort to (1) better understand the relationship between the severity of storms (given by the relatively easily available wind speed) and the extent of the damage, (2) research potential patterns in the geographic distribution of the damage locations and (3) assess the suitability of a numerical weather prediction model to capture cyclones which produce extensive damage to power lines. The Eventual objective of this exercise is to be able to give sufficient advanced notice to repair crews so they are able to restore power to affected B.C. Hydro customers in a timely fashion.

1.2 Procedure

To achieve the objectives of this report the following individual steps, which are detailed in subsequent sections, were performed:

- Analysis of Distribution Trouble Reporting System (DTRS) data to determine time periods when particularly large number of Troubles due to high winds where reported (Section 2). Based on this data 12 weather Events were identified and subsequently analyzed in more detail.
- Analysis of Distribution Trouble and Outage Reports (DTOR) to generate detailed time charts of damage procession for selected locations in the study area for each Event (Section 2).
- Analysis of all available wind observations in the study area from weather stations run by the Grater Vancouver Regional District (GVRD) and Atmospheric Environmental Service (AES), respectively (Section 3).
- Analysis of wind forecasts from the high-resolution MC2 numerical weather prediction model run by the Atmospheric Science group at U.B.C. (Section 4).
- Combining the previous steps to generate time charts for each Event which compare the number of Troubles with actual wind observations and wind forecasts from the MC2 model (Section 5).
- Recommendations (Section 6).

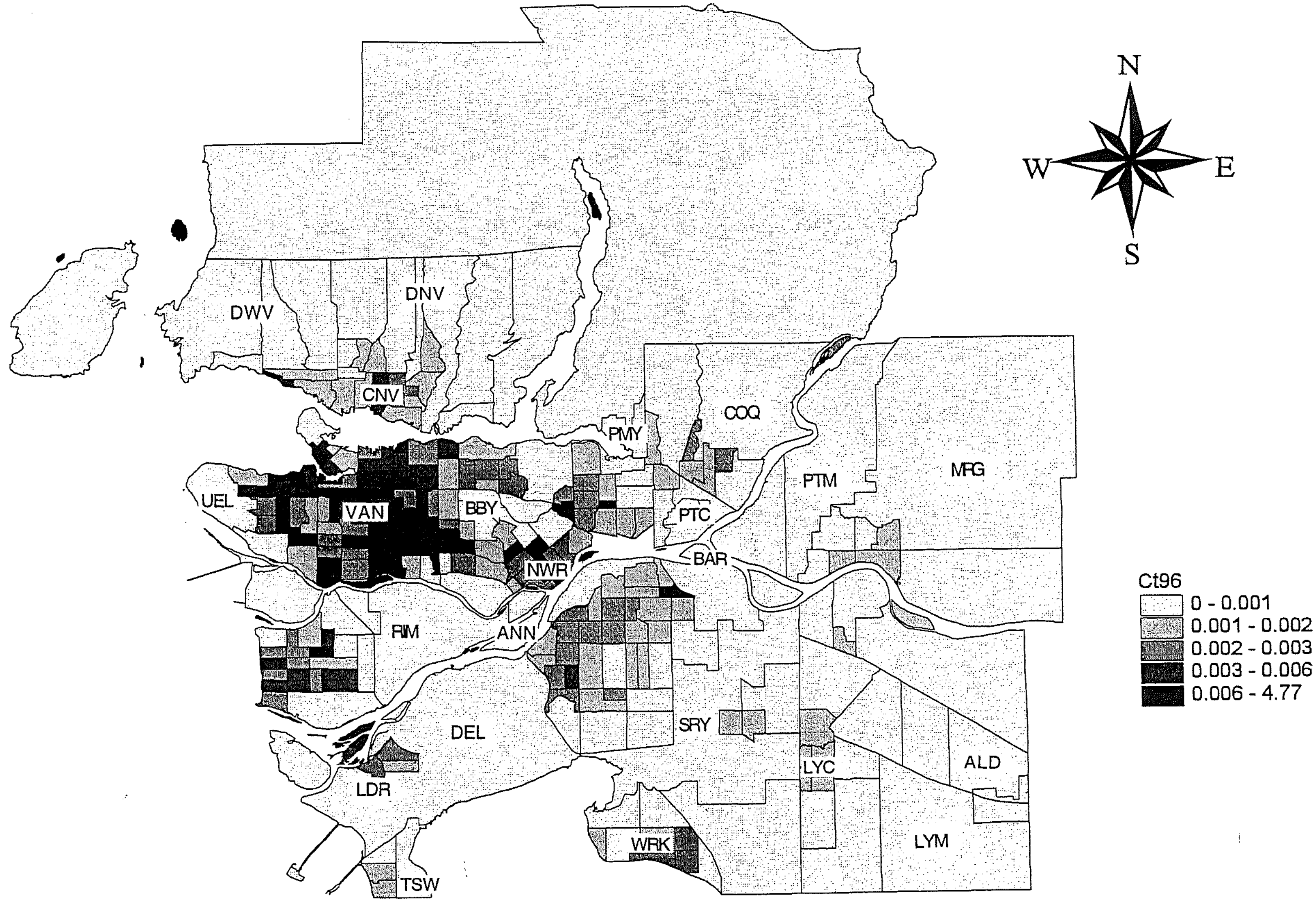


Figure 1: Map of municipalities (code according to B.C. Hydro) in the study area. Population density is in persons/square meter.

SECTION 2: ANALYSIS OF DTRS DATA

2.1 Climatology of Weather Events

Analysis of all available DTRS data reveals some interesting information. Assuming that more than 100 TO's dispatched per day is a unusually high number compared to a "normal" daily total (J. Rennie, personal communication), a first series of "Events" was identified for the period 1993 - 1998. These Events together with the weather code (as on the DTOR's) are listed in Table 1. The number of weather Events resulting in substantial damage over the last 6 years is fairly constant at about 10 per year. More importantly, Table 1 shows that 80% of the Events are occurring between the end of October and March, apparently the "storm season". Most of the damage during the storm season is caused by high winds and less due to snow fall. From April to September damage is mainly caused by lightning and the occasional high wind Event. It is further important to note that most of the Events occurred in November and December.

	1993	1994	1995	1996	1997	1998	Total
Jan.	S			S	S		3
Feb.		W	W	W		W	4
March	W	L; W	W(3)	W	W		8
April				L	W		2
May							0
June	L	W				W	3
July					L		1
Aug.		L			L		2
Sept.	W	L	L			L	4
Oct.	W	W(2)	W	W	W		6
Nov.	W(3)	S, W(3)	W(2)	S	L	W(4)	15
Dec.	W(2)	W	W(2)	W, S(3)	W	W(2), S(2)	14
Total	10	13	10	10	8	11	62

Table 1: Climatology of major weather events (>100 TO's dispatched) in the period 1993 - 1998. Weather Codes: W - wind; S - snow; L - lightning.

2.2 Selection of "Storm Events"

One of the objectives was to compare observed wind observations with those from the MC2 model. Because some of the input data necessary to run the numerical model was only available for certain years, selection of weather Events was limited to 1995 and 1997 to present. Similar to Section 2.1 time periods were identified when extensive damage to power lines were reported (i.e. TO's > 100). The daily totals of TO's dispatched and the daily number of phone calls handled for 1995, 1997 and 1998/99 are plotted in Figure 2. Each large spike can be attributed to a weather Event (caused by high winds, heavy rain, snow, lightning, etc.). Because the purpose of this study was to analyze damage due to high winds only, other cases were eventually excluded and the numbers on Figure 2 correspond to the twelve wind Events selected for final analysis.

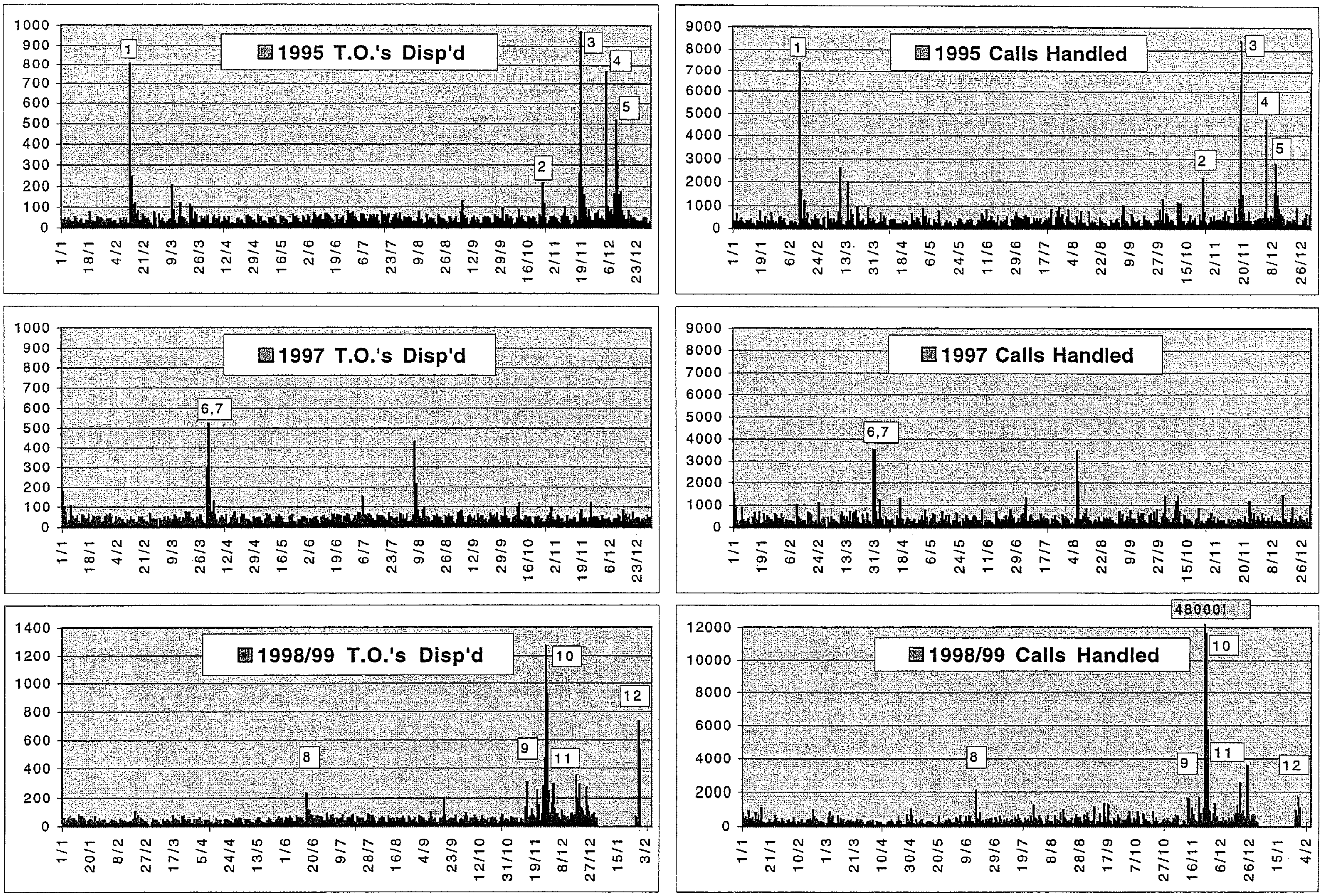


Fig. 2: Summary of trouble orders (TO's) dipatched and calls handled in 1995, 1997 and 1998/99. Selected storms are indicated by their particular Event number (from YRSTATS.xls). Note the different scales on the y-axes.

Table 2 provides a concise summary of DTOR statistics over the Event period. Also indicated is the municipality which reported the highest number of Troubles. A detailed summary of the selected Events is given in Table 3. The various DTOR statistics are broken down according to the cause detail for each day of an Event. It can be seen that strong winds (Weather Code W) were mostly responsible for the damage. It should be noted, that the statistics in Figure 1 and Tables 1 - 3 include DTOR's from the entire FVR and MET regions (due to convenience). In the final analysis the municipalities outside the study area (namely BEL, BIU, HOP, PEN, SCR, SEC and SQH) were, however, not included. The statistics reported are still representative because the municipalities excluded usually did not report a lot of Outages.

Event No.	Dates	Total TO's	Total Calls	Total Troubles	Total Cust. Ints.	Main Damage location
1	12-15/2/1995	1283	10583	531	60804	MRG (SRY)
2	25-26/10/95	328	2895	169	11178	SRY
3	17-19/11/1995	1423	11140	563	111555	MRG (COQ)
4	3-5/12/1995	902	5889	375	55780	VAN
5	9-13/12/1995	1326	7188	323	94585	SRY
6	30/3-1/4/1997	1510	7734	344	24063	VAN
7	2-4/4/1997	266	1929	84	19043	VAN
8	14-16/6/1998	368	2706	141	11718	SRY
9	12-14/11/1998	488	3706	91	5463	LYM
10	23-28/11/1998	3256	68203	1666	227521	SRY
11	30/11-2/12/1998	561	2626	152	18905	VAN
12*	27-30/1/1999	1372	4351	451	51028	LYM

Table 2: Summary of DTOR statistics (from all Weather Codes) for all Events. "Total TO's" and "Total Calls" (from YRSTATS.xls) as well as "Total Troubles" and "Total Cust. Ints." are from the entire FRV and MET regions. * - DTOR statistics may not include late entries.

2.3 Analysis of DTOR's to Locate Trouble Points

For the selected Events information to help locate each individually reported Trouble was extracted from the DTOR's. Relevant information included: "Date of Trouble", "Time of Trouble", "Municipality", "Substation", "Circuit ID", "Weather Code", "Cause Detail", "Crew Location", "Comments", etc. Based on this data it was possible to determine the exact time and cause of the trouble. Determination of the location of the Trouble proved to be more difficult. First the Circuit ID or Feeder was used as a geographic pointer. However, since some of the Feeders are long, cross municipal boundaries and it would have been to laborious to locate each Trouble on a map, "Municipality" was selected as the smallest geographic unit. Geographic resolution is still good enough since the observed wind data are only available at an even smaller resolution. Eventually Troubles from all Weather Codes (not just W) were included because although the codes were given as R, N or D, it was clear from the Cause Detail or the Comments that the Trouble was related to high wind. The data extracted from this part of the analysis (hourly number of Troubles for each municipality in the study area) are summarized in Appendix A and are used as input in the Figures in Appendix B.

Trouble Date	Weather	Troubles	Outages	Cust. Ints.	Cust. Hrs.	DTORS
Event No. 1						
2/12/95	C	3	1	10	15	3
	N	2	2	200	1374.9	2
	S	1	0	0	0	1
	W	415	385	59774	213193.3	150
2/13/95	C	1	1	1	5.1	1
	N	5	2	151	710.2	5
	W	21	11	362	1781	21
2/14/95	C	1	0	0	0	1
	N	3	0	0	0	3
	S	6	3	19	19.4	6
	W	23	11	18	53.5	23
2/15/95	D	1	0	0	0	1
	I	2	1	1	1.8	2
	N	5	2	51	39.7	5
	R	1	0	0	0	1
	S	29	9	158	468.4	29
	W	12	6	59	141	12
Event No. 2						
10/25/95	D	2	0	0	0	2
	N	14	10	208	2045.5	14
	R	6	5	462	407.4	6
	W	88	69	8635	17122.4	88
10/26/95	D	1	0	0	0	1
	N	15	10	1080	1830.7	15
	R	5	2	217	542.1	5
	W	38	24	576	4421.6	38
Event No. 3						
11/17/95	L	2	2	4573	33074.2	2
	N	5	3	5002	3410.2	5
	R	7	2	14	283.3	7
	W	126	114	65124	382434.9	111
11/18/95	D	3	2	3180	56511.6	3
	N	19	11	71	448.7	19
	R	13	11	634	655.6	13
	S	2	2	121	1023.4	2
	W	330	307	32094	68522.7	117
11/19/95	D	1	1	12	9	1
	N	9	6	184	350.3	9
	W	46	35	546	2387.1	32
Event No. 4						
12/3/95	R	1	1	1	0.3	1
	S	1	1	50	237.5	1
	W	33	28	18429	56157.1	33
12/4/95	C	6	0	0	0	6
	N	46	21	683	1822.7	46
	W	228	154	35489	82377.1	228
12/5/95	C	5	0	0	0	5
	N	25	10	41	74.7	25
	W	30	19	49	272.6	30

Table 3: Detailed listing of DTOR statistics (for all of FRV and MET regions) for all Events analyzed. I - ice; N - normal; R - rain; S - snow; W - wind. * - DTOR statistics may not contain late entries.

Trouble Date	Weather	Troubles	Outages	Cust. Ints.	Cust. Hrs.	DTORS
Event No. 5						
12/9/95	D	4	4	601	2939.9	4
	I	21	19	9241	40766.2	21
	R	4	3	46	290.3	4
	W	27	25	35445	102562.1	27
12/10/95	D	4	4	9	150.6	4
	I	15	11	809	7277.2	15
	L	1	1	325	920.8	1
	N	8	3	27	42.9	8
	R	13	3	3	9.9	13
	W	50	39	41766	76980.4	50
12/11/95	D	3	1	1	8.8	3
	I	3	2	602	6612.7	3
	N	7	2	2	1	7
	R	17	3	205	158.1	17
	W	19	7	211	886.8	19
12/12/95	D	3	2	2	3.3	3
	I	1	0	0	0	1
	N	10	6	1568	9166.4	10
	R	18	10	324	1138.1	18
	W	20	8	1045	1744.9	20
12/13/95	D	5	1	6	7.2	5
	I	1	0	0	0	1
	N	11	3	4	10.4	11
	R	15	6	1055	344.9	15
	W	43	29	1298	1460.1	43
Event No. 6						
3/30/97	C	1	1	1	1.6	1
	N	3	1	1	20.5	3
	R	1	1	99	495	1
	W	95	79	17254	68508.5	95
3/31/97	C	3	1	27	264.6	3
	N	25	8	51	343	25
	R	2	2	437	624.8	2
	W	133	95	4228	5749.4	124
4/1/97	C	4	1	22	14.6	4
	D	1	0	0	0	1
	L	1	0	0	0	1
	N	30	11	2071	2078	30
	R	1	0	0	0	1
	W	44	12	90	298.2	44
Event No. 7						
4/2/97	C	3	1	2	23.3	3
	L	1	0	0	0	1
	N	16	6	25	19	16
	W	3	2	2401	3000.8	3
4/3/97	L	1	0	0	0	1
	N	14	3	3	6.1	14
	S	1	0	0	0	1
	W	35	23	13876	30594.1	35
4/4/97	C	1	1	1	0.1	1
	N	8	3	2734	12382.3	8
	W	1	1	1	1	1

Table 3 continued.

Trouble Date	Weather	Troubles	Outages	Cust. Ints.	Cust. Hrs.	DTORS
Event No. 8						
6/14/98	N	2	2	16	22.6	2
6/15/98	N	25	10	366	1671.6	25
	R	4	4	400	909.1	4
	W	85	56	10863	30443	85
6/16/98	D	1	0	0	0	1
	N	15	5	72	97.2	15
	R	1	0	0	0	1
	W	8	1	1	0	8
Event No. 9						
11/12/98	L	2	0	0	0	2
	N	1	1	60	133	1
	R	13	5	443	1106.3	13
	W	29	19	4598	10754.3	29
11/13/98	D	2	1	1	0.3	2
	L	2	1	1	0.5	2
	R	15	5	157	1275.1	15
	W	17	11	184	854.8	17
11/14/98	N	1	0	0	0	1
	R	8	5	18	62.8	8
	W	1	1	1	49.9	1
Event No. 10						
11/23/98	N	4	2	2	2.3	4
	R	1	1	2	2.1	1
	W	95	89	91297	634829.9	95
11/24/98	C	1	0	0	0	1
	D	2	2	56	378.3	2
	N	1	1	1	10	1
	R	22	10	331	4271.7	22
	S	1	0	0	0	1
	W	1083	1052	131896	1083893	352
11/25/98	N	2	1	3	54.6	2
	R	9	8	234	1807.5	9
	S	1	1	9	122.4	1
	W	188	172	1615	17279.9	81
11/26/98	L	1	1	4	80.4	1
	N	2	1	30	7.5	2
	R	9	5	16	234.1	9
	W	188	181	1555	21914.9	53
11/27/98	C	1	0	0	0	1
	D	3	2	11	25.8	3
	N	4	1	1	0.7	4
	R	8	6	65	21.9	8
	W	19	10	341	2492	19
11/28/98	C	7	3	7	20	7
	D	1	1	1	1.9	1
	N	6	2	22	14.9	6
	R	1	1	20	27	1
	W	6	2	2	1.1	6

Table 3 continued.

Trouble Date	Weather	Troubles	Outages	Cust. Ints.	Cust. Hrs.	DTORS
Event No. 11						
11/30/98	C	1	1	1	4.8	1
	D	2	0	0	0	2
	N	12	3	4	14.7	12
	R	4	0	0	0	4
	W	10	4	1525	4886.2	10
12/1/98	D	2	0	0	0	2
	N	5	3	7	21.6	5
	R	20	6	24	14.1	20
	W	56	39	17256	21870.9	56
12/2/98	C	4	1	12	318.2	4
	D	3	1	1	3.3	3
	N	13	5	9	41.2	13
	R	8	6	6	11.7	8
	S	2	2	56	365	2
	W	9	4	4	4.7	9
Event No. 12*						
1/27/99	R	1	1	114	214.7	1
	W	15	10	718	580.5	15
1/28/99	I	2	2	42	224.5	2
	N	1	1	2	1	1
	R	6	4	12	31.9	6
	S	3	2	305	1687.6	3
	W	11	9	416	3961.1	11
1/29/99	N	12	7	190	3616.9	12
	R	20	18	974	5892	20
	S	1	1	1	2	1
	W	334	278	47845	170006.7	235
1/30/99	C	1	1	1	0.7	1
	N	6	5	112	925.6	6
	W	38	33	296	2328.9	38

Table 3 continued.

In the case of big storm Events (No. 1, 3, 6, 10 and 12) some of the DTOR's include Storm Summaries which condense large amounts of individual Troubles into one DTOR. Whereas it is still possible to extract the location of the Trouble, information about the exact time is lost in the DTRS data base. This was the case for Events No. 1 and 3 (both from 1995). On the other hand the time information could be recovered for the other Events by using DTOR information not saved in DTRS.

SECTION 3: ANALYSIS OF WEATHER DATA

3.1 Analysis of GVRD and AES Wind Observations

One purpose of this report was to compare the severity and geographic distribution of damage to the distribution system with actual wind observations. Both, GVRD and AES maintain a network of climate stations in the study region. The GVRD network primarily serves to provide meteorological information for air quality purposes. As a consequence the weather stations are usually located in urbanized areas and concentrated along Burrard Inlet which is prone to high air pollution episodes. The AES stations on the other hand provide standard climatological information and therefore are ideally situated in open terrain (e.g. on airports). Figure 3 shows that the stations available for this study are not very well distributed. They are relatively sparse in areas which often report large numbers of Troubles (e.g. DEL, SRY and MRG).

A further complication is due to the fact that the wind sensors of the AES stations are at a nominal height of z_s = 10 m above ground, whereas the GVRD sensor heights vary between 7 and 18 m (Table 4). A field visit to each GVRD site was necessary to determine the exact heights and other information. During the visit it became obvious that some GVRD stations have less than ideal exposure. For example station SUE is partly surrounded by about 8 m high trees; trees taller than 15 m are to the SW of station LAN. As a consequence of differences in heights the MC2 model predictions have to be adjusted to these individual levels or vice versa (see below). Further, the GVRD observations are averages over 60 min whereas the AES data represent an average over 2 min only at the top of each hour. Direct comparison of the two data sets is possible for stations PMA (AES) and PIM (GVRD) which have wind sensors installed at identical heights and are both located in open terrain. For 75% of the peak velocities analyzed the observations are within 10% of each other. It is of course always possible that the 2-min AES average is from a period of relatively lower or higher wind speed, in general, however, the agreement is satisfactory.

The damage locations (i.e. municipalities) were matched with wind observations from the weather stations based on Fig. 3. Because of the irregular distribution of weather stations it is inevitable that some areas are better represented than others. The idea was to find at least one weather station which could represent one or a group of municipalities (Table 5). The Troubles reported within these groups (or from one municipality only) where then summarized and plotted against the wind observations from that particular station. This procedure is fairly inaccurate but the best that can be done. For example, SRY could be associated with both NOD or SUE; DEL with RIS or NOD. Further, TSW and WRK are too far away from any weather station to warrant inclusion and because of its open terrain LDR would not be well represented by weather station RIS. These three municipalities usually did not report a lot of troubles and were excluded from further analysis. BBY is represented by two weather stations, COP and BUS, because the latter was only available for Events No. 8 - 12 (i.e. since 1998).

3.2 MC2 Model Forecasts

In an effort to evaluate the suitability of a numerical weather prediction model to forecast the storm Events, the DTOR data and actual wind observations were compared to the MC2 wind forecasts. The Mesoscale Compressible Community (MC2) model is a fully compressible, non-hydrostatic numerical model developed at the University of Quebec and the Recherche en Prévision Numérique (RPN) group of Environment Canada. The dynamics are based on semi-Lagrangian discretization, with a semi-implicit time discretization. State of the art model physics, including sub-grid scale parameterization schemes, are similar to what is being used operationally by the Canadian Meteorology Centre (CMC). The semi-Lagrangian formulation along with the parallel implementation put the MC2 among the fastest mesoscale models in the world.

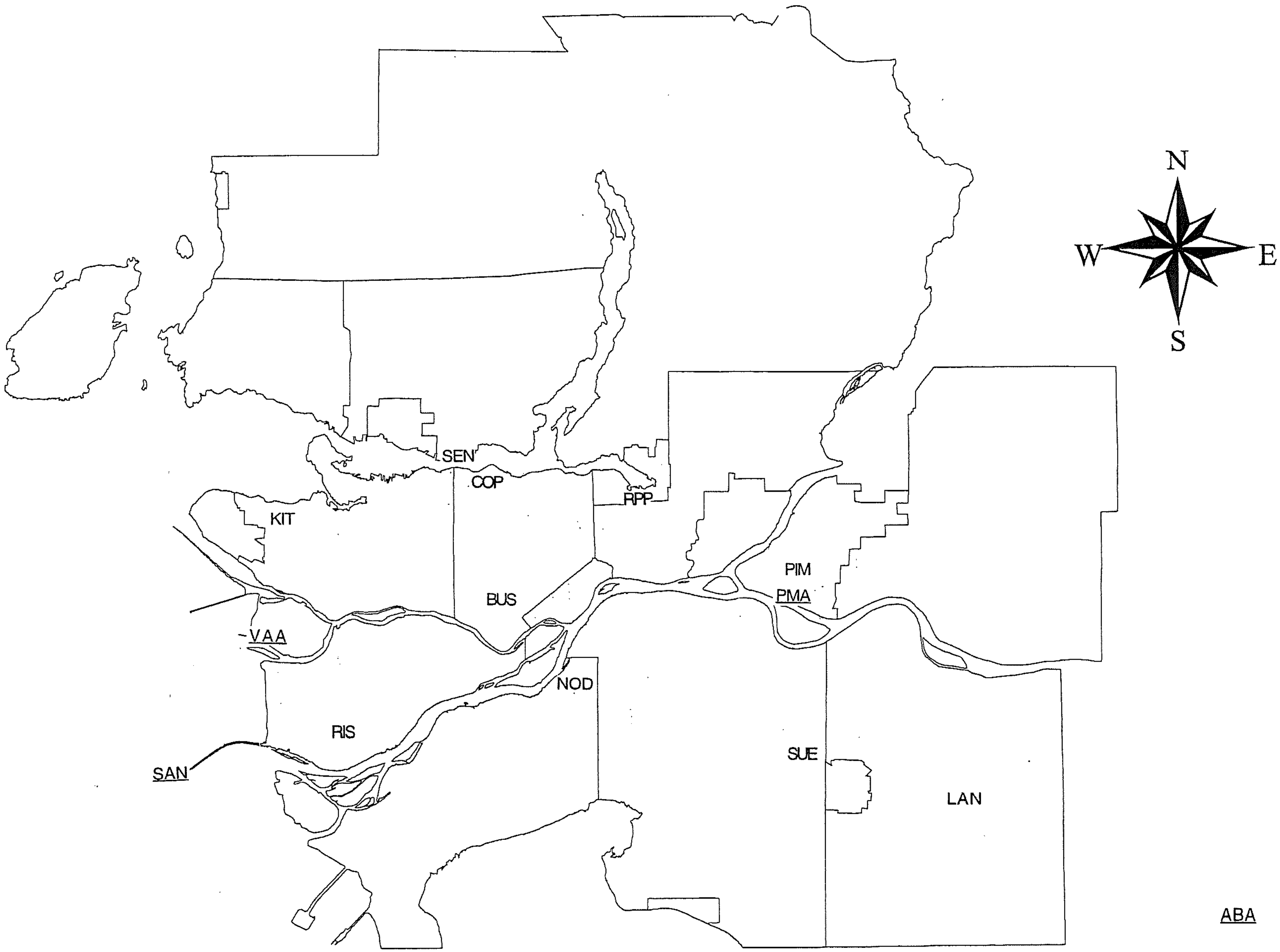


Figure 3: Distribution of GVRD and AES (underscored codes) weather stations in the study area.

Code	Latit. (N) /Long. (W)	Location	Address	Elev. (m)	z_H (m)	z_s (m)	z_0[1] (m)	z_d[1] (m)	cf
GVRD stations									
RIS	49°08'31"/ 123°06'28"	Richmond South	Williams & Aragon, Richmond	1	5	8	0.5	2.5	0.65
KIT	49°15'45"/ 123°09'45"	Kitsilano	2550W 10th Av., Vancouver	50	6	10	0.6	3	0.7
SEN	49°18'08"/ 123°01'08"	Second Narrows	75 Riverside Dr., North Vancouver	3	3	8	0.3	1.5	0.73
COP	49°17'00"/ 123°00'00"	Confederation Park	Pandora St. & Alpha Ave., North Burnaby	n/a	5	7	0.3	1.5	0.69
RPP	49°16'51"/ 122°50'53"	Rocky Point Park	Ft. of Murray St., Port Moody	5	1	7	0.2	0.5	0.76
NOD	49°09'30"/ 122°54'03"	North Delta	8544 116th St., Delta	95	5	14	0.5	2.0	0.86
SUE	49°07'58"/ 122°41'36"	Surrey East	19000 Blk. 72nd Av., Surrey	66	<8	18	0.5	3	0.92
LAN	49°05'46"/ 122°33'59"	Langley	23752 52nd Av., Langley	63	<15	15	0.3	1.5	0.91
BUS*	49°12'56"/ 122°58'57"	Burnaby South	5455 Rumble, Burnaby	110	5	18	0.5	2.0	0.94
PIM*	49°15'00"/ 122°42'36"	Pitt Meadows	Meadowland E. Sch. 18477 Dewdney	10	0	10	0.1	0	0.87
AES stations									
SAN	49°6'/123° 18'	Sandheads	End of jetty in Steveston	15	0	10	0.01	0	1.0
VAA	49°11'/123 °10'	Vancouver Airport	Near South Side Terminal	2	n/a	10	0.03	0	0.9
PMA	49°13'/122 °42'	Pitt Meadows Airport		5	n/a	10	0.05	0	0.88
ABA	49°2'/122° 22'	Abbotsford Airport		58	n/a	10	0.03	0	0.9

Table 4: Summary of GVRD and AES meteorological station locations and relevant height scales. z_s - height of wind sensors; z_0 - aerodynamic roughness length; z_d - zero-plane displacement height; z_H - approx. height of roughness elements; cf - correction factor as defined in Appendix C; n/a - not available. [1]Estimated based on field visit and used in Eqs. C.1 - C.4. *Only available for Events No. 8 - 12.

Code	Location	Municipality
GVRD stations		
RIS	Richmond South	RIM
KIT	Kitsilano	UEL, VAN
SEN	Second Narrows	CNV, DNV
COP	Confederation Park	BBY
RPP	Rocky Point Park	PMY, COQ
NOD	North Delta	DEL, ANN
SUE	Surrey East	SRY, LYC
LAN	Langley	LYM, ALD
BUS*	Burnaby South	NWR, BBY
PIM*	Pitt Meadows	PTM, PTC, BAR, MRG
AES stations		
SAN	Sandheads	Reference station
VAA	Vancouver Airport	RIM
PMA	Pitt Meadows Airport	PTM, PTC, BAR, MRG
ABA	Abbotsford Airport	ABT, MIS, CHK, ALZ

Table 5: Summary of municipality codes associated with a particular meteorological station. *Only available for Events No. 8 - 12.

MC2 can be run using various resolutions between 90 and 3.3 km. At 3.3 km (i.e. one forecast point per 3.3 x 3.3 km grid) this model has the highest resolution of all currently available models which provide forecasts for the study area. This is an important characteristic because the complex geographic environment of the study area (islands, complex coast line, mountains) result in small spatial complexities of the flow, which can only be resolved with a model which has the necessary high resolution. In contrast, AES currently provides weather forecasts (using the CMC model) based on a grid spacing of 24 km only. The forecasts for the twelve storm Events covered in this report were provided by the Atmospheric Science group at U.B.C. (headed by Prof. R. Stull) under a separate contract. This group is using the same model to provide research-grade weather forecasts to a number of commercial user in B.C.

The model provides outputs of various meteorological variables at several levels in the atmosphere. The analysis for this study concentrated on the wind data (wind speed and direction) at the lowest model level z_m = 10 m. Hourly model output was available for each observation station (because of memory limitations MC2 usually provides only one output every 3 hours, however, for the purpose of this study the interval was changed to 1 hour). The forecasts are available as movies of coloured wind speed vectors (at 10 m) or plots of time series of wind speed and direction at locations corresponding to the meteorological stations. A synopsis of the general weather pattern for each Event together with hardcopies from the movie files at hours when the peak winds were predicted are given in Appendix B. Also included is a comparison of time series of observations with model predictions.

To be able to compare the model wind speeds (given at 10 m and assuming little surface roughness) with those from the GVRD and AES stations (which are at various heights), the former had to be adjusted to take into account the heights of the observations and the specific surface characteristics (roughness) surrounding the stations (see Appendix C for outline of procedure). These adjusted values are also included in the comparison with the observations given in Appendix B (for Events No. 10 and 12 only). Assuming that the wind direction change is insignificant over the height ranges considered, wind direction was not corrected.

SECTION 4: VALIDATION OF MODEL RESULTS

Before damage due to winds can be discussed in detail, it is necessary to assess how well the MC2 model predicts the observed winds. This can be done visually by comparing the model values and observations in the time series plots given in Appendix B. A more detailed analysis was performed for the peak winds which are the primary targets of this study. The magnitudes of the observed and modelled peak winds are summarized in Table 6. Also included in this Table are the corresponding wind speed and peak time differences (0 in both cases would mean perfect agreement between observations and model).

The model has a tendency to over-predict the observed wind speeds, on average by about 4.4 km/h. The standard deviation, however, is large as exemplified by Events No. 5 and 6 which are over- and under-predicted by 16.1 and 5.2 km/h, respectively. The times of the wind speed peaks are predicted almost 2 hours earlier than observed. Again, however, the standard deviation is large and in the extreme cases the model peaks occur 9 and about 4 hours earlier and later, respectively than observed. Model forecasts leading the observations by a few hours is a known feature of numerical weather models in this geographic region. It is possible that the models do not take adequately into account the effects of increased surface friction (due to islands) when approaching the B.C. coastline and the Coast Mountains which would both act to slow down the speed of cyclones.

	Wind speed, U (km/h)		ΔU (km/h) (mod.-obs.)	Δt (h) (mod.-obs.)	Wind direction
Event No.	Observations	Model			
1	27.4	35.3	7.88	0.38	E
2	27.5	36.7	9.27	2.18	SE
3	37.3	36.2	-1.1	-8.4	SE
4	40.5	28.5	-12	-8.9	W
5	28.8	44.8	16.1	3.67	SE
6	37.5	32.4	-5.2	-7	SE
7	32.5	31.6	-0.9	3.18	W
8	27.2	27.7	0.46	0.23	W
9	28.5	29.9	1.36	-1.1	SE
10	38.2	49	10.8	-2.4	SE
11	37.4	48.4	11.1	-2.1	SE
12	32.5	47.4	14.9	-0.4	SE
Average	32.9	37.3	4.39±8.6	-1.7±4.3	

Table 6: Comparison of peak wind speeds from observations and model forecasts for individual events. Values are averages over all weather stations for a particular event. ΔU - wind speed difference between model and observations; Δt - time difference (in hours) between model peak forecast and observed peak (e.g. -8.4 means model predicted peak 8.4 hours *before* it was observed).

Above comparison is incomplete because it does not consider the particular positioning of the wind sensors at the various weather stations. As pointed out previously, some sensors are located at heights different from 10 m (the height of the model forecast) and may be surrounded by large houses or trees which affect the locally observed wind speeds. Instead of comparing the results averaged over all stations for individual Events as in Table 6, a similar comparison is provided in Table 7 for all individual weather stations but averaged over all Events. Closest agreement between observed and modelled wind speeds would be expected for sensors located at 10 m in open terrain (e.g. Airport stations). Indeed most of the AES stations show favourable statistics, in particular VAA and ABA. The largest differences are found for the urban stations, in particular RIS and KIT which are both surrounded by houses and trees and/or are located at relatively low heights. The large positive deviations for NOD and SUE are possibly due to the complex surroundings of the two stations which may slow the winds considerably for certain wind directions.

A full validation of the model would require a much more rigorous study. In a first attempt to include the local effects a correction factor (*cf*) was defined (Table 4 and Appendix C) to adjust the model output. Corresponding results are included in time series plots in Appendix B for Events No. 10 and 12. As shown in Figs. B.10.4-7 and B.12.3-6 the "adjusted" values are as expected generally lower and closer to the observations.

	Wind speed, U (km/h)		ΔU (km/h) (mod.-obs.)	Δt (h) (mod.-obs.)
Station	Observations	Model		
SAN	65.5	59.7	-5.8	-1.6
VAA	53.3	52	-1.3	-1.4
RIS	23.9	53.9	30	-1.6
KIT	21.1	40.6	19.7	-1.9
SEN	21.6	23.7	2.7	-0.8
COP	22.2	29	6.8	-1.2
RPP	18.8	25	6.2	-1.2
ABA	39.6	40.9	1.30	-2.2
BUS*	39.6	44.1	4.6	-2.7
NOD	29	45.8	16.7	-1.6
SUE	31.7	41.8	10.1	-0.8
LAN	36.7	41.7	5	-1.6
PMA	34.4	26	-8.4	-1.6
PIM*	33.4	24.7	-8.7	-1.6

Table 7: Comparison of peak wind speeds from observations and model forecasts for individual weather stations. Values are averages over all Events for a particular weather station. ΔU - wind speed difference between model and observations; Δt - time difference (in hours) between model peak forecast and observed peak (e.g. -0.8 means model predicted peak 0.8 hours *before* it was observed). Underscored codes are AES stations. *Only for Events No. 8 - 12.

SECTION 5: DISCUSSION

5.1 Geographic Distribution of Trouble Locations

It is useful to know which areas in the study region generally experience most of the damage. The Troubles reported for each municipality were added up to provide totals for each Event. As shown in Table 8 there are about 6 municipalities which are usually hit hardest. SRY is consistently reporting Troubles within the top three followed by LYM, VAN and possibly MRG. Other municipalities likely to experience larger than average damage are ABT and BBY. There are of course exceptions such as DNV (Event No. 3) or MIS and CHK (Event No. 12) which occasionally report large Outage numbers.

The geographic distribution of the damage patterns is expected to be complex. It is probably a function of wind speed, wind direction and population density. The wind speed factor will be discussed in more detail in the following section. For storms associated with westerly flow (Events No. 4, 7 and 8) the municipalities on the western edge of the study region (VAN, BBY and to a lesser extent RIM) report relatively large numbers of Troubles. Under the same conditions damage in the eastern municipalities (e.g. MRG, LYM and ABT) is reduced (Table 8).

The influence of the built-up surface on the wind speed becomes obvious when trying to correlate the damage locations with population density. One would expect the highest Outage numbers to be associated with highly populated areas (from Fig. 1: VAN, RIM, BBY and NWR). The discussion above demonstrates that this is not necessarily true. Because buildings, tress and other obstacles slow down the flow the wind speeds observed in these municipalities are relatively low (Table 7). This is clearly demonstrated by stations VAA and RIS which are situated in the same general area (Fig. 3), the former, however, is located on an open field close to the sea whereas the latter is surrounded by buildings. Even considering the difference in heights VAA consistently reports much higher wind speeds. It is interesting to note that for all Events despite its high population density negligible Troubles were reported for NWR.

5.2 Wind Speeds and Number of Troubles

Peak mean wind speeds (observed and modelled), wind direction during the peaks and number of Troubles reported are listed individually for each Event and weather station in Table 9. This information is used to determine wind speed ranges which are likely to produce large number of Troubles. The data in Table 9 are graphically reproduced in Figure 4. Any relationship between the observed wind speeds and the number of Troubles is lost in the scatter of the data plotted on an either linear or logarithmic scale as shown on the first two panels of Fig. 4.

Because of differences in the physical characteristics of the individual weather stations the data are better analyzed and plotted for each station individually (Fig. 4). Despite the large scatter it is now possible to identify threshold wind speeds above which relatively large number of Troubles can be expected. The values in Table 10 reflect the lowest mean peak wind speeds observed and modelled from each of the twelve Events for a particular weather station. Also included are the adjusted (to model conditions using the *cf* factor in Table 4) mean wind speeds which are the wind speeds which should be predicted by the model. Further, damage to distribution lines will not only be due to sustained mean winds but probably also instantaneous gusts. Relationships derived in Appendix D were used to calculate the gust speeds in Table 10 which correspond to the individual mean peak velocities.

The data in Table 10 demonstrate that even relatively low mean wind speeds can contribute to distribution failures. Table 10, however, includes all cases with any number of Troubles reported near a particular weather station. To determine a more meaningful threshold wind speed the data in Table 8 were analyzed to find the lowest peak winds which resulted in at least 50 Troubles in a

Munici-pality	Event No. 1 (E)	2 (SE)	3 (SE)	4 (W)	5 (SE)	6 (SE)	7 (W)	8 (W)	9 (SE)	10 (SE)	11 (SE)	12 (SE)	Total
MRG	300 (25)	18	226 (43)	18	17	21	5	7	21	129	7	91	860 (402)
SRY	43	48	52	34	39	89	31	19	20	319	16	95	805
VAN	5	3	17	111	9	105	41	12	5	193	21	45	567
LYM	38	24	11	11	33	37	7	5	25	139	6	156	492
ABT	5	2	8	26	25	34	2	1	5	90	10	114	322
COQ	6	0	110 (55)	21	10	17	12	9	2	65	7	12	271 (216)
BBY	7	0	15	31	9	38	7	13	6	95	11	29	261
MIS	2	1	1	3	30	9	4	0	6	36	3	81	176
DEL	8	6	11	3	8	19	8	2	8	75	14	14	176
CHK	1	1	0	7	17	8	2	3	9	29	3	82	162
RIM	3	3	0	5	3	16	10	9	4	49	2	3	107
DWV	11	7	13	9	9	12	0	4	2	28	5	3	103
DNV	10	0	25	7	6	10	1	7	1	11	2	7	87
PTC	1	0	1	8	11	8	1	3	0	13	0	5	51
ALD	0	0	1	0	0	1	0	0	1	13	2	31	49
CNV	3	0	4	1	1	4	1	2	0	19	2	4	41
WRK	2	0	0	0	1	2	0	2	2	25	2	4	40
PTM	1	0	1	6	1	3	0	2	1	8	2	4	29
PMY	0	0	0	2	1	6	2	1	4	8	1	0	25
LYC	0	0	0	0	2	2	0	1	0	2	0	4	11
LDR	0	1	0	0	0	1	0	0	1	6	2	0	11
TSW	0	0	0	0	0	0	1	0	0	4	0	0	5
ANN	0	1	0	0	0	2	0	0	0	0	0	0	3
NWR	0	0	0	0	0	0	0	0	0	2	0	0	2
ALZ	0	0	0	0	0	0	0	0	0	0	0	0	0
UEL	0	0	0	0	0	0	0	0	0	0	0	0	0
BAR	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	446 (171)	115	496 (258)	303	232	444	135	102	123	1358	118	784	4656 (3714)

Table 8: Summary of total Troubles for each municipality in the study area. Numbers in parenthesis reflect totals without Troubles from Storm Summaries. Codes in parenthesis are wind directions

Station	Variable	Event 1	2	3	4	5	6	7	8	9	10	11	12
SAN	Troubles	-	-	-	-	-	-	-	-	-	-	-	-
	U_{mod} (km/h)	56	54	59	34	65	-	61	36	39	71	69	78
	U_{obs} (km/h)	54	67	67	70	61	-	69	48	59	80	78	61
	DIR_{obs}	ENE	SSE	SE	WSW	SE	-	WNW	W	SE	SE	SE	SE
VAA	Troubles	3	3	0	5	3	16	10	9	4	49	2	3
	U_{mod} (km/h)	43	51	53	39	58	47	52	37	38	64	64	62
	U_{obs} (km/h)	39	43	56	70	37	65	70	52	48	59	61	48
	DIR_{obs}	ENE	SE	SSE	WSW	E	SE	WNW	W	SE	SE	SE	SE
RIS	Troubles	3	3	0	5	3	16	10	9	4	49	2	3
	U_{mod} (km/h)	47	50	52	-	59	47	53	36	36	65	65	61
	U_{obs} (km/h)	24	20	27	-	18	31	26	22	20	32	26	24
	DIR_{obs}	E	SE	SE	-	ESE	SE	WNW	W	SE	SE	SE	SE
KIT	Troubles	5	3	17	111	9	105	41	12	5	193	21	45
	U_{mod} (km/h)	29	38	38	32	44	36	40	34	29	50	51	50
	U_{obs} (km/h)	24	14	20	39	15	24	32	25	14	25	21	17
	DIR_{obs}	ENE	ESE	SE	W	E	SE	W	W	SE	SE	SE	SE
SEN	Troubles	13	0	29	8	7	14	2	9	1	30	4	11
	U_{mod} (km/h)	20	20	20	21	26	22	15	21	15	30	32	28
	U_{obs} (km/h)	22	12	25	30	18	24	26	26	21	27	19	21
	DIR_{obs}	E	E	SE	W	E	SE	W	W	SE	E	SE	SE
COP	Troubles	7	0	15	31	9	38	7	13	6	95	11	29
	U_{mod} (km/h)	23	23	23	23	31	23	18	23	21	60	36	30
	U_{obs} (km/h)	16	14	26	34	15	28	24	23	19	30	23	24
	DIR_{obs}	E	ESE	SE	W	E	SE	WNW	W	SE	SSE	SE	SE
RPP	Troubles	6	0	110*	23	11	23	14	10	6	73	8	12
	U_{mod} (km/h)	19	22	20	18	26	21	12	20	16	55	32	27
	U_{obs} (km/h)	25	10	19	30	15	23	19	26	11	21	19	15
	DIR_{obs}	ENE	SE	SE	W	SE	SE	W	W	ESE	-	SE	ESE
ABA	Troubles	8	4	9	36	72	51	8	4	20	155	16	277
	U_{mod} (km/h)	43	36	37	28	46	30	23	-	34	60	50	55
	U_{obs} (km/h)	57	26	46	37	37	56	19	-	28	43	41	56
	DIR_{obs}	NE	S	S	SW	S	SSE	SW	-	S	S	SSE	S
BUS	Troubles	7	0	15	31	9	38	7	13	6	97	11	29
	U_{mod} (km/h)	-	-	-	-	-	-	-	30	34	48	51	47
	U_{obs} (km/h)	-	-	-	-	-	-	-	23	37	51	44	41
	DIR_{obs}	-	-	-	-	-	-	-	W	S	SSE	SE	S

Table 9: Summary of number of Troubles, predicted (U_{mod}) and observed (U_{obs}) peak wind speeds, and directions (DIR_{obs}) for all Events and weather stations. * - Values include Storm Summaries. Underscored codes are AES stations.

Station	Variable	Event 1	2	3	4	5	6	7	8	9	10	11	12
NOD	Troubles	8	7	11	3	8	21	8	2	8	75	14	14
	U_{mod} (km/h)	38	44	-	34	51	39	-	32	39	52	57	58
	U_{obs} (km/h)	27	28	-	31	28	34	-	24	25	34	34	30
	DIR_{obs}	E	S	-	W	SE	SE	-	W	SSE	SE	-	SSE
SUE	Troubles	43	48	52	34	41	91	31	20	20	321	16	99
	U_{mod} (km/h)	34	-	-	32	49	35	29	28	40	50	53	58
	U_{obs} (km/h)	26	-	-	40	29	41	26	21	29	36	36	35
	DIR_{obs}	ENE	-	-	W	S	SSE	W	W	S	S	SSE	SSE
LAN	Troubles	38	24	12	11	33	38	7	5	26	152	8	187
	U_{mod} (km/h)	38	41	37	34	53	35	30	27	37	60	55	53
	U_{obs} (km/h)	27	38	48	26	35	48	28	15	34	56	47	38
	DIR_{obs}	NE	SE	SE	SSE	SE	S	S	SW	S	SSE	SSE	-
PMA	Troubles	302*	18	228*	32	29	32	6	12	22	150	9	100
	U_{mod} (km/h)	22	25	23	19	30	21	15	19	23	31	34	34
	U_{obs} (km/h)	43	30	39	39	37	39	19	24	33	43	39	41
	DIR_{obs}	NE	S	SE	W	SE	SSE	SE	W	S	SSE	SE	S
PIM	Troubles	302*	18	228*	32	29	32	6	12	22	150	9	100
	U_{mod} (km/h)	-	-	-	-	-	-	-	17	17	25	29	28
	U_{obs} (km/h)	-	-	-	-	-	-	-	25	21	44	35	40
	DIR_{obs}	-	-	-	-	-	-	-	W	S	SSE	SE	S

Table 9 continued.

region associated with a particular weather station. Only stations with at least 3 such occurrences were selected (for a better statistical representation). 50 is somewhat arbitrary but judging from Fig. 4 seems to be a reasonable figure which reflects most of the cases which are distinctively separated from the usually predominant lower values which can be associated with a wide wind speed range. From Table 11 it is concluded that a lower threshold value for observed wind speeds (at GVRD or AES weather stations) causing considerable outages is between 24 km/h (densely built areas) and 51 km/h (relatively open areas). Peak gusts associated with these values are between 33 and 80 km/h. It is probably more convenient to take an average to define a generally applicable threshold value. The adjusted (to model conditions) mean wind speed is 42 km/h which is very close to the model value of 44 km/h. This means that these threshold values are well predicted by the UBC MC2 model.

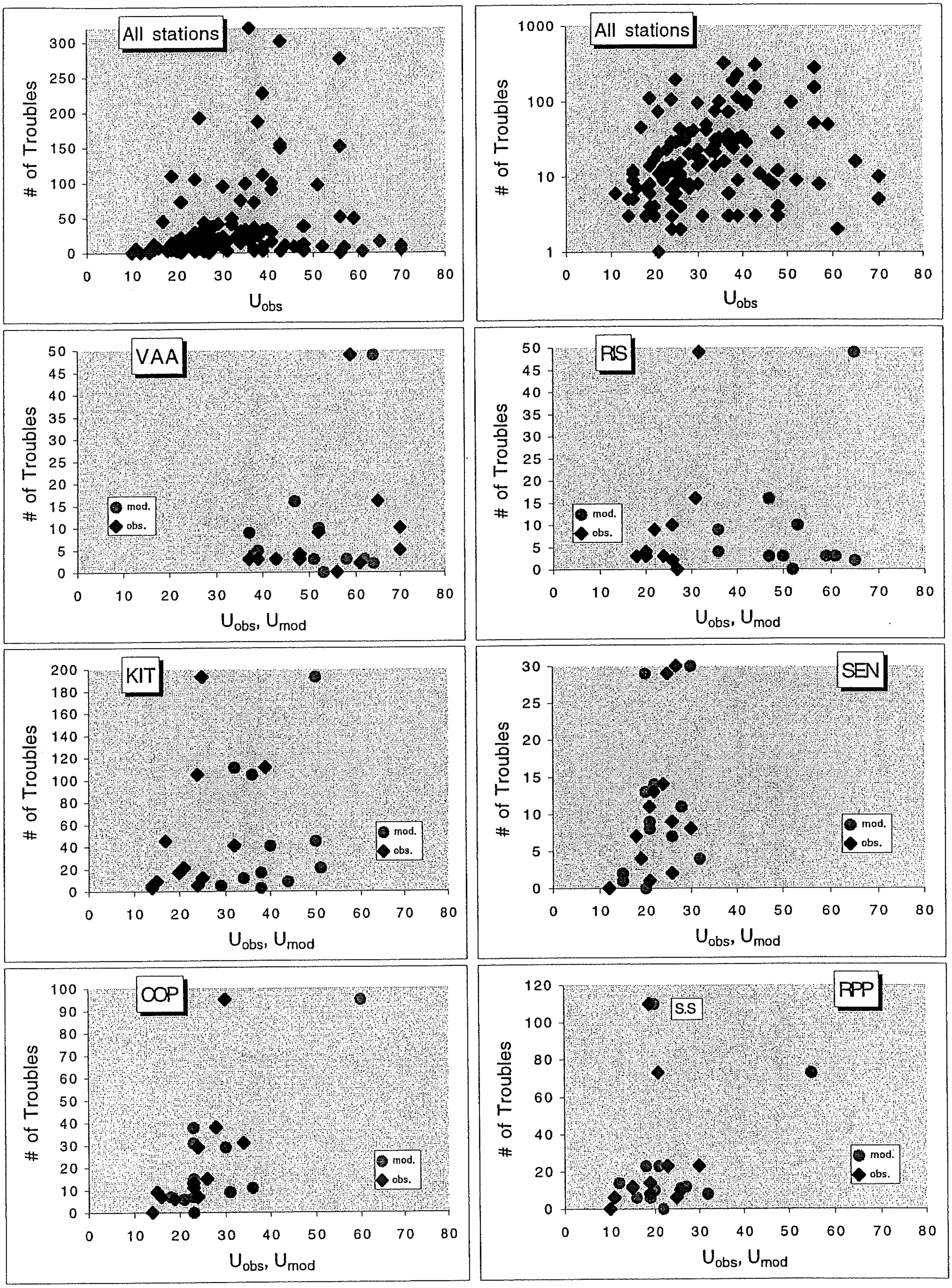


Figure 4: Number of Troubles plotted against observed (obs) and modelled (mod) peak wind speeds for each event at all weather stations. S.S. - values contain data from Storm Summaries. Note different scales on y-axes. See text for discussion.

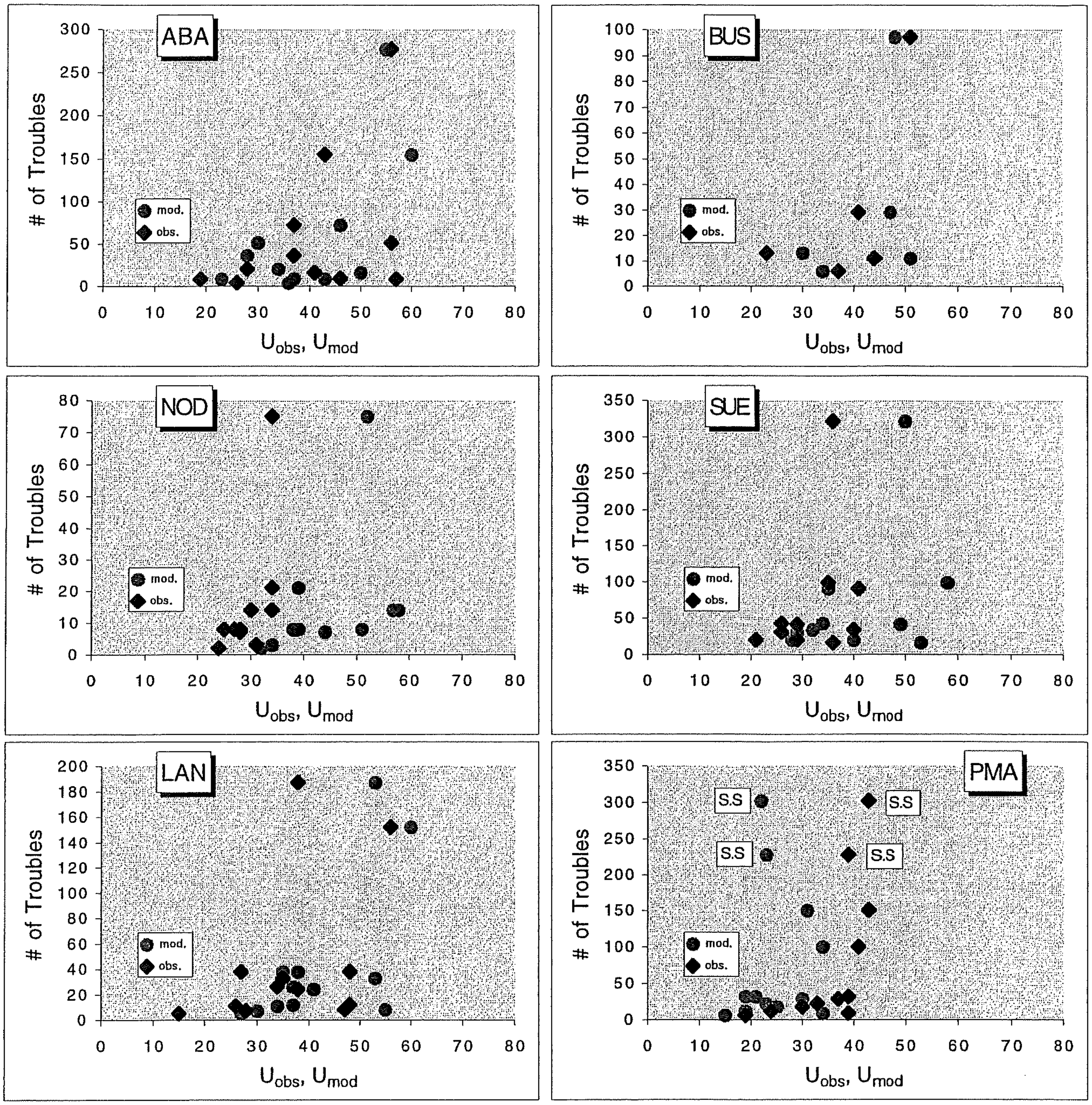


Figure 4 continued.

Station	U_{obs} (km/h)	U_{gust} (km/h)	U_{mod} (km/h)	U_{adj} (km/h)
VAA	37	56	37	41
RIS	18	25	36	28
KIT	14	19	29	20
SEN	12	17	15	16
COP	14	19	18	20
RPP	10	14	12	13
ABA	19	32	23	21
BUS*	23	32	30	24
NOD	24	33	32	28
SUE	21	29	28	23
LAN	15	21	27	16
PMA	19	37	15	22
PIM*	21	29	17	24
Average	19±7	28±11	25±8	23±7

Table 10: Lowest observed (U_{obs}) and predicted (U_{mod}) peak winds from all Events. Observed peak gusts (U_{gust}) are based on actual observations and according to relationship in Fig. D.1 for AES and GVRD stations, respectively. Adjusted (to model conditions) wind speed (U_{adj}) is based on correction factors in Table 4 applied to U_{obs}. Underscored codes are AES stations. *Only for Events No. 8 - 12.

Station	U_{obs} (km/h)	U_{gust} (km/h)	U_{mod} (km/h)	U_{adj} (km/h)
SUE	35	48	58	38
LAN	38	52	53	42
KIT	24	33	36	34
ABA	37	80	46	41
BUS*	51	70	48	54
PMA	39	70	23	44
Average	37±9	59±17	44±13	42±7

Table 11: Lowest observed (U_{obs}) and predicted (U_{mod}) mean peak wind speeds from all Events which cause at least 50 Troubles in the region associated with a particular weather station. Observed peak gusts (U_{gust}) are based on actual observations and according to relationship in Fig. for AES and GVRD stations, respectively. Adjusted (to model conditions) wind speed (U_{adj}) is based on correction factors in Table 4 applied to U_{obs}. Underscored codes are AES stations. *Only for Events No. 8 - 12.

5.3 Identification of Typical Storm Patterns

It is useful to analyze the storm patterns which cause the individual Events in more detail. This will help to identify potential threatening storm situations which are known to result in high winds and subsequently high damage to distribution lines. The conditions associated with each Event are discussed below and summarized in Table 12.

The case of an occluded or decaying cyclone in the Gulf of Alaska is repeated frequently throughout a typical winter, and produces high-wind Events 2, 3, 11, and 12. The Lower Fraser Valley (LFV) is then impacted by an occluded front stretching from the low centre to the Oregon or California coast. While the low-pressure system is filling, the intensity of the occluded front can be maintained by advection of a mid-tropospheric vorticity maximum over the point of occlusion (where the warm, cold, and occluded fronts meet). Often the point of occlusion passes just south of the LFV. The vorticity advection aloft contributes to upward vertical motion, maintaining convergence at the surface. This fits the idea that the occlusion process occurs when a system is near its maximum in kinetic energy.

A similar situation may occur when a propagating short-wave aloft "catches up" to an occlusion point that is losing kinetic energy. The vorticity maximum in the short-wave can re-initiate development at this point, giving the front a new source of energy and causing wind speeds to increase further. This is called an instant occlusion, and a new low-pressure centre can form that takes on a life of its own, tapping into the temperature gradient that still surrounds the warm and cold fronts.

The case of a developing cyclone that impacts B.C. from the southwest is another common wintertime situation, and produces high-wind Events 4, 5, 6, and 10. These storms usually form and travel quickly because they are taking advantage of baroclinity over the Eastern Pacific. As these storms develop, the strong upward motions create steep mean sea level pressure (MSLP) gradients, forcing high winds. Because they develop so quickly, they are difficult to forecast, and

Event	Front near LFV	State of associated cyclone	Wind direction in LFV[1]	OMLC
1	Stationary	n/a	NE (outflow)	
2	Occluded	Decay	SSE	X
3	Cold	Decay	SSE	X
4	Cold	Development	NW	
5	None	Development	SE, S	
6	Cold	Development	SE	
7	None	Mature	NW	
8	None	Mature	NW	
9	None	n/a	SW	X
10	None	Development	SSE, SW	
11	Occluded	Decay	S	X
12	Occluded	Decay	S	X

Table 12: Storm characteristics for each Event. LFV - Lower Fraser Valley; OMLC - Olympic Mountain lee convergence; [1]General wind direction over Event period and as such may be different from the directions associated with the peak winds given in Tables 8 and 9.

their intensity at landfall is difficult to determine and highly dependent on the stage of development. Exact landfall location is also difficult to forecast. As a general rule, however, these storms are vigorous with respect to precipitation and winds, and enter and exit the affected region quickly.

Events 7 and 8 correspond to synoptic patterns that occur less frequently in the winter over B.C., but are more likely in the late spring, summer, or early fall when the storm track is through northern B.C. and the Yukon. Coastal B.C. is largely protected by ridging at all levels. MSLP troughs associated with these systems can sweep across the LFV along the downstream branch of the ridge, and bring strong gradients.

Event 1 is the outflow case, where arctic air and high pressure form just east of the Rockies, and an upper-level ridge reaches from the north Pacific well over the Yukon and northern Alberta. The MSLP gradient is normally perpendicular to the coast and is maintained by the continental-marine air-mass differences. The upper-level pattern also supports off-shore flow aloft, promoting channeling of the winds through the mountain passes.

Event 9 is a less-common scenario where a pressure gradient is maintained parallel to the coast by air-mass differences that are not destroyed by the land-sea interface.

The Olympic Mountains lee convergence (OMLC) noted in Table 12 is an often observed feature associated with decaying cyclones in the Gulf of Alaska. The highest wind speeds often occur just before or after a front has passed over the study region. Cyclones which approach from the west are usually associated with fronts which break down when the system moves across Vancouver island. The generally south-westerly flow is split by the Olympic Mountains with one branch being funneled through Puget Sound. This southerly flow merges with the initial front which is rebuilding in the wake of Vancouver island and may result in a strong convergence zone, the OMLC, which is characterized by high mean wind and gust velocities. Research on the mechanics of the OMLC is still at the beginning and a much more rigorous study would be needed to understand its details. A typical example of this process is given in Figure B.12.2 which shows the north-south running OMLC situated over the western edge of the study region. The SE winds often associated with peak winds can be observed just ahead of the front. Based on above discussion the groups in Table 13 can be identified.

It is worth noting that the often (in wintertime) occurring case of a low-pressure centre making landfall to the south of B.C. does not show up in this study. Often, this takes place when a high-amplitude trough cuts off (creates a closed circulation) adjacent to Oregon or California. As the surface low-pressure centre crosses the coast, the LFV usually experiences weak pressure gradients and therefore light winds because it lies in the northern regions of the trough axis. Thus, often when it is raining heavily in California, the weather is relatively calm in southern B.C.

Event No.	Comments
2, 3, 11, 12	Decaying in the Gulf of Alaska
4, 5, 6, 10	Developing cyclone from SW crossing central/southern BC coast; the dual-peak Events occurred when the cyclone crossed closer to Vancouver, therefore no fronts
7, 8	Mature cyclone from Northern BC to Southern AB, with ridging over north Pacific
1, 9	Unique Events

Table 13: Classification of Events according to storm patterns (based on trajectory and state of associated cyclone).

SECTION 6: RECOMMENDATIONS

A number of findings and recommendations follow from this study. They should provide some guidance in assessing the damage potential of storms:

- The "storm season" was identified to last from the end of October until March. Outside this period damage caused by high winds are rare events.
- The mean wind speed threshold value (adjusted to a height of 10 m) above which unusually large numbers of Outages are likely was determined to be between 40 - 45 km/h (60 km/h for gust speeds). The standard deviation associated with this value is quite large but it is the best possible estimate available at this time.
- The geographic distribution of damage patterns is complex and depends on wind speed, population density and less on wind direction. SRY consistently leads the municipalities in reported Outages (because of a combination of high winds and high population density), followed by LYM (high winds) and VAN (relatively low wind speeds but very high population density). Based on the few cases available westerly flow during the peak winds tends to increase (decrease) Outages in VAN and BBY (MRG, LYM and ABT).
- When peak winds are observed at around midnight or early morning, outages are usually not reported until a few hours later, between say 0700 - 1000 PST.
- Most of the generally occurring wintertime weather patterns can potentially result in high winds in the study region. A classification reveals two groups which, however, are predominant: 1) Decaying cyclones in the Gulf of Alaska (fronts are often intensified by the OMLC); and 2) developing cyclones from the SW when the center crosses close to Vancouver (may result in a double wind speed peak).
- The UBC-MC2 model accurately predicts the threshold wind speed magnitude mentioned above. On average it is leading the observed peak times by about 2 hours. Given the complexity of the geographic setting of the study region and the data void over the Pacific ocean (i.e. only very few data is available to initializing the model) it is concluded that the MC2 model is performing very well and should be a valuable tool in predicting high wind speed events.

Acknowledgements. Data for this study was procured from a variety of sources. I would like to thank J. Rennie and N. Gill (B.C. Hydro) for quick and direct access to DTRS data. J. Swalby (GVRD) and G. Meyers (AES) provided the meteorological data. Dr. R. Stull and J. Hacker (U.B.C.) supplied the MC2 forecasts. J. H. also contributed to the description of the Events and the discussion of the storm patterns.

APPENDIX A

(Time and Location of Trouble Points)

The tables in this Appendix (Table A.1 - A.12) summarize the dates, hours and locations (municipalities) of Troubles reported for a particular Event.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
2/12/95	1																													0
2/12/95	2																													0
2/12/95	3																													0
2/12/95	4					1																								1
2/12/95	5																													0
2/12/95	6											1		1																2
2/12/95	7			3					4																					7
2/12/95	8	1				1			277*			2		1																5
2/12/95	9					1						1		1		3														6
2/12/95	10			2		1			1		1	1		1					1											8
2/12/95	11			1		3						1																		5
2/12/95	12			2		4					1	1		1		1		1												11
2/12/95	13		1			2			1		1	1					1													7
2/12/95	14			2		1			2							1			1											7
2/12/95	15			4					1		1	1																		7
2/12/95	16	1	1	1		3																								6
2/12/95	17	1		2		1					2	1																		7
2/12/95	18	1		3		2			1					1																8
2/12/95	19			3		3			1		1																			8
2/12/95	20			1		1																			1					3
2/12/95	21			1		2																								3
2/12/95	22								1							1														2
2/12/95	23			2		2																								4
2/12/95	24			1		1																								2
2/13/95	1					1																								1
2/13/95	2																													0
2/13/95	3			1																										1
2/13/95	4					1																								1
2/13/95	5																													0
2/13/95	6																													0
2/13/95	7								1																					1
2/13/95	8	1																												1
2/13/95	9										1														1					2
2/13/95	10													1																1
2/13/95	11													1																1
2/13/95	12		1	1		1																								3
2/13/95	13																													0
2/13/95	14												1																	1
2/13/95	15			1		2							1	1																5
2/13/95	16					1	1																							2
2/13/95	17																													0
2/13/95	18																													0
2/13/95	19																													0
2/13/95	20																													0
2/13/95	21																													0
2/13/95	22																													0
2/13/95	23			1			1																							2
2/13/95	24																													0
2/14/95	1																													0
2/14/95	2																													0
2/14/95	3					1																								1
2/14/95	4																													0
2/14/95	5																													0
2/14/95	6																													0
2/14/95	7								1																					1
2/14/95	8								1																					1
2/14/95	9						1		2																					3
2/14/95	10					1																								1
2/14/95	11								1																					1
2/14/95	12			1				1	1					1																4
2/14/95	13																													0
2/14/95	14																													0
2/14/95	15			1				1	2																					4
2/14/95	16								2				1																	3
2/14/95	17			1										1																2
2/14/95	18																													0
2/14/95	19																													0
2/14/95	20																													0
2/14/95	21																													0
2/14/95	22																													0
2/14/95	23																													0
2/14/95	24																													0
2/15/95	1																													0
2/15/95	2																													0
2/15/95	3					1																								1
2/15/95	4		1			1																								2
2/15/95	5																													0
2/15/95	6																													0
2/15/95	7			1																										1
2/15/95	8	1				1																								2
2/15/95	9	1		1																										2
2/15/95	10																													0
2/15/95	11																			1										1
2/15/95	12		1																1											2
2/15/95	13																													0
2/15/95	14																													0
2/15/95	15					1																								1
2/15/95	16					1	1																							2
2/15/95	17			1		1																								2
2/15/95	18																													0
2/15/95	19						1																							1
2/15/95	20																													0
2/15/95	21																													0
2/15/95	22																													0
2/15/95	23																													0
2/15/95	24																													0
Total		7	5	38	0	43	5	2	23	0	8	10	3	11	0	6	1	1	3	1	0	0	0	0	2	0	0	0	169	169

Table A.1: Summary of hourly Trouble totals for Event No. 1. Columns are municipalities.
* - contain Storm Summaries.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
10/25/95	1																													0
10/25/95	2																													0
10/25/95	3																													0
10/25/95	4																													0
10/25/95	5																													0
10/25/95	6																													0
10/25/95	7																													0
10/25/95	8																													0
10/25/95	9																													0
10/25/95	10			2																										2
10/25/95	11										1																			1
10/25/95	12								1																					1
10/25/95	13																													0
10/25/95	14										1																			1
10/25/95	15					1				1				1																3
10/25/95	16			1		1								1																3
10/25/95	17					1								2																3
10/25/95	18			6		6					1			1																14
10/25/95	19			4		8			2										1							1				16
10/25/95	20			4		5			6										1											16
10/25/95	21		2			1			5					1																9
10/25/95	22			2		1																								3
10/25/95	23			1																										1
10/25/95	24					1			1																					2
10/26/95	1					2		1			1																			4
10/26/95	2					1																								1
10/26/95	3			1		1																								2
10/26/95	4					1																								1
10/26/95	5																													0
10/26/95	6																													0
10/26/95	7																													0
10/26/95	8					1			1																					2
10/26/95	9			1		2					1																			4
10/26/95	10			1		8	1																							10
10/26/95	11		1			4																								5
10/26/95	12						1		1										1											3
10/26/95	13																													0
10/26/95	14																													0
10/26/95	15					2														1										3
10/26/95	16																													0
10/26/95	17										1																			1
10/26/95	18					1								1																2
10/26/95	19			1					1																					2
10/26/95	20																													0
10/26/95	21																													0
10/26/95	22																													0
10/26/95	23																													0
10/26/95	24																													0
Total		0	3	24	0	48	2	1	18	1	6	0	0	7	0	0	0	0	3	1	0	0	0	0	0	1	0	0	115	115

Table A.2: Summary of hourly Trouble totals for Event No. 2. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
11/17/95	1															1														1
11/17/95	2																													0
11/17/95	3																													0
11/17/95	4								1							1														2
11/17/95	5															1														1
11/17/95	6																													0
11/17/95	7															1														1
11/17/95	8	1														8*														1
11/17/95	9																													0
11/17/95	10		1																											1
11/17/95	11										1					1														2
11/17/95	12															10*														0
11/17/95	13																													0
11/17/95	14		1																											1
11/17/95	15																													0
11/17/95	16															2														2
11/17/95	17							1								1														2
11/17/95	18					2										1														3
11/17/95	19			1		1																								2
11/17/95	20																													0
11/17/95	21	1	1			18	2		4		1					2														29
11/17/95	22		1	3		9	6		4		1					3														27
11/17/95	23	2	1			2						1																		6
11/17/95	24	2	1	1								6	1	2																13
11/18/95	1					1			4		2	1	1			1														10
11/18/95	2		1			1			1			1																		4
11/18/95	3		1			1																								2
11/18/95	4	1	1	1							1																			4
11/18/95	5										1					1														2
11/18/95	6	1		1							1																			3
11/18/95	7					1			3							5														9
11/18/95	8					1			85*			2		1		9														13
11/18/95	9		1	1					1			2	1	2		8														16
11/18/95	10	1				1			1		1	2				2														8
11/18/95	11	1		1		1			10							2														15
11/18/95	12								55*			3				19*														3
11/18/95	13								1			1				1														3
11/18/95	14		1						1			1																		3
11/18/95	15		1									2		4																7
11/18/95	16					1			1				1			2														5
11/18/95	17	1	1						1			1				1														5
11/18/95	18	2	1								1	1		1																6
11/18/95	19					1						1		1																3
11/18/95	20		1			3										1														5
11/18/95	21					2															1									3
11/18/95	22	1	1																											2
11/18/95	23								43*																					0
11/18/95	24					1																								1
11/19/95	1								2							4														6
11/19/95	2								1																					1
11/19/95	3								3																					3
11/19/95	4	1																												1
11/19/95	5								1							18*	1													2
11/19/95	6																													0
11/19/95	7																													0
11/19/95	8																													0
11/19/95	9		1													2														3
11/19/95	10															1														1
11/19/95	11					1			1																					2
11/19/95	12								1									1												2
11/19/95	13																													0
11/19/95	14																													0
11/19/95	15																													0
11/19/95	16																													0
11/19/95	17					2																								2
11/19/95	18					1								1		1														3
11/19/95	19			1										1																2
11/19/95	20			1		1			1		1																			4
11/19/95	21																													0
11/19/95	22																													0
11/19/95	23																													0
11/19/95	24																													0
Total		15	17	11	0	52	8	1	43	0	11	25	4	13	0	55	1	1	0	0	1	0	0	0	0	0	0	0	258	258

Table A.3: Summary of hourly Trouble totals for Event No. 3. Columns are municipalities.
* - contain Storm Summaries.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
12/3/95	1																													0
12/3/95	2																													0
12/3/95	3																													0
12/3/95	4																													0
12/3/95	5																													0
12/3/95	6																													0
12/3/95	7	1																												1
12/3/95	8																			1										1
12/3/95	9					1																								1
12/3/95	10																													0
12/3/95	11		1																											1
12/3/95	12						1																							1
12/3/95	13																													0
12/3/95	14																													0
12/3/95	15					1																								1
12/3/95	16																													0
12/3/95	17																													0
12/3/95	18																													0
12/3/95	19																													0
12/3/95	20						1																							1
12/3/95	21																													0
12/3/95	22																													0
12/3/95	23		1			1						1							1											4
12/3/95	24	1	1			5						1			1	1														10
12/4/95	1		6			8			2			2			1		1													20
12/4/95	2	4	1	3					1							1														10
12/4/95	3	2	4											1				1												8
12/4/95	4	1	8	2		2			1							1														15
12/4/95	5		5													1		2												8
12/4/95	6	3	6															1												10
12/4/95	7	1	3				1							1		1		1												8
12/4/95	8	1	2			1	4													1										9
12/4/95	9	1	8				1		3							1				4										18
12/4/95	10		6	1		1	2		2					3		1	2													18
12/4/95	11		9					1	1							1														12
12/4/95	12	1				1	11											1												14
12/4/95	13	1	6						2					2																11
12/4/95	14	1	4				2													1										8
12/4/95	15	1	1				1																							3
12/4/95	16	4	6									1				1														12
12/4/95	17		2											1																3
12/4/95	18	1	2	1																										4
12/4/95	19		1																											1
12/4/95	20		1																											1
12/4/95	21		6													1														7
12/4/95	22		7			4							1																	12
12/4/95	23	4	1			3			1										3											12
12/4/95	24					3			1		1					3	1													9
12/5/95	1															3														3
12/5/95	2		1																											1
12/5/95	3																													0
12/5/95	4		2																											2
12/5/95	5																													0
12/5/95	6																													0
12/5/95	7																													0
12/5/95	8		1																											1
12/5/95	9		2			1										1														4
12/5/95	10			1			1	1	1			1		1																6
12/5/95	11	2	1									1					1													5
12/5/95	12	1		1		1			1							1	1													6
12/5/95	13		1						1										1											3
12/5/95	14			1												1														2
12/5/95	15		3				1				1					1														6
12/5/95	16		1														1													2
12/5/95	17		1	1		1		1									1													5
12/5/95	18										1					1														2
12/5/95	19								1																					1
12/5/95	20																													0
12/5/95	21																													0
12/5/95	22																													0
12/5/95	23																													0
12/5/95	24																													0
Total		31	111	11	0	34	26	3	18	0	3	7	1	9	2	21	8	6	5	7	0	0	0	0	0	0	0	0	303	303

Table A.4: Summary of hourly Trouble totals for Event No. 4. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
12/9/95	1							2																						2
12/9/95	2							1																						1
12/9/95	3						3																							3
12/9/95	4																													0
12/9/95	5							1																						1
12/9/95	6																													0
12/9/95	7																													0
12/9/95	8																													0
12/9/95	9																													0
12/9/95	10							1			1																			2
12/9/95	11																													0
12/9/95	12																			1										1
12/9/95	13																													0
12/9/95	14																													0
12/9/95	15					1																								1
12/9/95	16																													0
12/9/95	17																													0
12/9/95	18		1	1																										2
12/9/95	19							1																						1
12/9/95	20	1							1		1																			3
12/9/95	21			1		1	1	1																						4
12/9/95	22		1			2	4	1									1		1											10
12/9/95	23						2		3					1		1	1													8
12/9/95	24			3		1	2	3			1			2			1													13
12/10/95	1					2								1				1												4
12/10/95	2	1																	1	1										3
12/10/95	3			1			1		1							1				1										5
12/10/95	4																			1										1
12/10/95	5																													0
12/10/95	6			1		1	2																							4
12/10/95	7																													0
12/10/95	8						1																							1
12/10/95	9																			1										1
12/10/95	10					1						1								1										3
12/10/95	11	1	1	1			2							1			2													8
12/10/95	12							2						1		1														4
12/10/95	13		1																											1
12/10/95	14		1	1																										2
12/10/95	15					1								1		1				1										4
12/10/95	16	1									1						2													4
12/10/95	17	1		1							1																			3
12/10/95	18			1		1																								2
12/10/95	19																													0
12/10/95	20																													0
12/10/95	21	1										1				1														3
12/10/95	22																													0
12/10/95	23																													0
12/10/95	24																													0
12/11/95	1																													0
12/11/95	2			3		2																								5
12/11/95	3	1				1			1		1					1														5
12/11/95	4																													0
12/11/95	5																													0
12/11/95	6																													0
12/11/95	7			1		1																								2
12/11/95	8																													0
12/11/95	9			1																										1
12/11/95	10	1		1				1											1											4
12/11/95	11																													0
12/11/95	12		1																											1
12/11/95	13		1	2								1		1			1													6
12/11/95	14					2							1																	3
12/11/95	15			2																										2
12/11/95	16			1																										1
12/11/95	17																													0
12/11/95	18	1																												1
12/11/95	19																													0
12/11/95	20			1																										1
12/11/95	21											1																		1
12/11/95	22																													0
12/11/95	23																													0
12/11/95	24																													0
12/12/95	1								1																					1
12/12/95	2																													0
12/12/95	3																													0
12/12/95	4																													0
12/12/95	5			1																										1
12/12/95	6																													0
12/12/95	7		1																											1
12/12/95	8						2													1										3
12/12/95	9			1			1	1	1																					4
12/12/95	10			1												1				1										3
12/12/95	11					1																								1
12/12/95	12																1													1
12/12/95	13					1														1										2
12/12/95	14			1												1														2
12/12/95	15						1		1											2										4
12/12/95	16					1																								1
12/12/95	17											1					1			1										3
12/12/95	18																													0
12/12/95	19																													0
12/12/95	20			1	1																									2
12/12/95	21			1																										1
12/12/95	22					1																								1
12/12/95	23				1							1																		2
12/12/95	24			1		3			1								1													6

Table A.5: Summary of hourly troubles for Event No. 5. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
12/13/95	1								3						1	2														6
12/13/95	2						1																							1
12/13/95	3																													0
12/13/95	4			1				1																						2
12/13/95	5					1																								1
12/13/95	6																													0
12/13/95	7					1		2	1																					4
12/13/95	8					1			2																					3
12/13/95	9										1														1					2
12/13/95	10					1																								1
12/13/95	11					3	1	3	1		1																			9
12/13/95	12			1		1		1						1						1										5
12/13/95	13					1		2												1										4
12/13/95	14			1		2	1	1												2										7
12/13/95	15					1																								1
12/13/95	16							3																						3
12/13/95	17							1																						1
12/13/95	18					1		1																						2
12/13/95	19																													0
12/13/95	20																													0
12/13/95	21																													0
12/13/95	22					1																								1
12/13/95	23		1																											1
12/13/95	24					1																								1
		9	9	33	2	39	25	30	17	0	8	6	1	9	1	10	11	1	3	17	0	0	0	0	1	0	0	0	232	232

Table A.5 continued.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
3/30/97	1																													0
3/30/97	2																													0
3/30/97	3																													0
3/30/97	4																													0
3/30/97	5																													0
3/30/97	6																													0
3/30/97	7																													0
3/30/97	8																													0
3/30/97	9		1																											1
3/30/97	10	1																												1
3/30/97	11																													0
3/30/97	12		1																											1
3/30/97	13		1			1																								2
3/30/97	14		2			2																								4
3/30/97	15	2	2	1		1	3																							9
3/30/97	16	3	2	1		1	1	2											1											11
3/30/97	17		1				1				2				1	1														6
3/30/97	18		5			1						1	1			1														9
3/30/97	19	4	1	1		3									1															10
3/30/97	20		1			5		1	1			1																		9
3/30/97	21		3			3				1		1																		8
3/30/97	22	3	1			5			2			1							1											13
3/30/97	23					1			3			2			1															7
3/30/97	24		2	3		3											1													9
3/31/97	1		1			2																			1	1				5
3/31/97	2	4	6			2										1														13
3/31/97	3		2	1			3				1	1		1						1										10
3/31/97	4	1	1			6	2													1										11
3/31/97	5		1	1		1	2		1																					6
3/31/97	6										1			1																2
3/31/97	7			2		1					1					1														5
3/31/97	8					3					1					1														5
3/31/97	9			1		2													1							1				5
3/31/97	10		6						1																					7
3/31/97	11	2	10	1		1	3		1																					18
3/31/97	12	2	5	2		4		1	2		1				1		1		3											22
3/31/97	13		5	2		3			1		2				1			1												15
3/31/97	14	1	2	2	1															1										7
3/31/97	15	2	4	2			1		1		1					1		1	2	1										16
3/31/97	16	3	10	1		6	5		1				1			1					1									29
3/31/97	17	2		2		4	1										1													10
3/31/97	18	2	1	2		3			2								1													11
3/31/97	19	1	1	1		4			1		1																			9
3/31/97	20		1						1							1			1											4
3/31/97	21					2	1																							3
3/31/97	22		1			1	2	1			1								1											7
3/31/97	23					1																								1
3/31/97	24																													0
4/1/97	1																													0
4/1/97	2		4	1												1														6
4/1/97	3										1			1																2
4/1/97	4																													0
4/1/97	5													2																2
4/1/97	6						3													2										5
4/1/97	7		1					1	2							1														5
4/1/97	8		2			1					1						1	1												6
4/1/97	9	1	3	1		3	1							1		1														11
4/1/97	10		3	1		1	1	1						1	1															9
4/1/97	11	1	2	1	1						1	1	1	1		1			2											12
4/1/97	12	1	2	1		3	1				2		1	2		1	1		1	2					1					19
4/1/97	13	1		1		3	2		1			1		1			1													11
4/1/97	14		3	1				1											1											6
4/1/97	15	1	1			2					1	1				1	1		1											9
4/1/97	16			1		1		1			1					1														5
4/1/97	17		1	1		1	1												1											5
4/1/97	18					1								1		1														3
4/1/97	19																													0
4/1/97	20		1	1												1														3
4/1/97	21		1	1																										2
4/1/97	22		1																											1
4/1/97	23					1																								1
4/1/97	24																													0
Total		38	105	37	2	89	34	9	21	1	19	10	4	12	6	17	8	3	16	8	1	0	0	0	2	2	0	0	444	444

<u>Table A.6:</u> Summary of hourly Troubles for Event No. 6. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
4/2/97	1																													0
4/2/97	2																													0
4/2/97	3																													0
4/2/97	4																													0
4/2/97	5																													0
4/2/97	6																													0
4/2/97	7																													0
4/2/97	8	1				2					1																			4
4/2/97	9			1		1										3														5
4/2/97	10		2	1		1		2	1		1					2														10
4/2/97	11	1	1			2					1								1											6
4/2/97	12	1					1										1													3
4/2/97	13					2		1			2					1														6
4/2/97	14					3	1																							4
4/2/97	15		2			2																	1							5
4/2/97	16					1																								1
4/2/97	17								1																					1
4/2/97	18			1																										1
4/2/97	19		1													2				1										4
4/2/97	20					1					1																			2
4/2/97	21		1																											1
4/2/97	22																													0
4/2/97	23																													0
4/2/97	24																													0
4/3/97	1																													0
4/3/97	2																													0
4/3/97	3																													0
4/3/97	4																													0
4/3/97	5																													0
4/3/97	6																													0
4/3/97	7																													0
4/3/97	8		4	1		1					1																			7
4/3/97	9		6	1		4																								11
4/3/97	10		7			1			1			1				2			2											14
4/3/97	11	1	3			1			1						1	1			1											9
4/3/97	12	2	1			2													1	1										7
4/3/97	13		4	1		1													3											9
4/3/97	14		5			1			1		1				1				1											10
4/3/97	15	1	1					1					1																	4
4/3/97	16		1	1		2																								4
4/3/97	17					2										1														3
4/3/97	18		1																											1
4/3/97	19																		1											1
4/3/97	20		1			1																								2
4/3/97	21																													0
4/3/97	22																													0
4/3/97	23																													0
4/3/97	24																													0
Total		7	41	7	0	31	2	4	5	0	8	1	1	0	2	12	1	0	10	2	0	0	1	0	0	0	0	0	135	135

Table A.7: Summary of hourly Trouble totals for Event No. 7. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
6/14/98	1																													0
6/14/98	2																													0
6/14/98	3																													0
6/14/98	4																													0
6/14/98	5																													0
6/14/98	6																													0
6/14/98	7																													0
6/14/98	8																													0
6/14/98	9																													0
6/14/98	10																													0
6/14/98	11																													0
6/14/98	12																													0
6/14/98	13																			1										1
6/14/98	14																													0
6/14/98	15																													0
6/14/98	16																													0
6/14/98	17																													0
6/14/98	18																													0
6/14/98	19																													0
6/14/98	20																													0
6/14/98	21																													0
6/14/98	22																													0
6/14/98	23																													0
6/14/98	24																													0
6/15/98	1																													0
6/15/98	2																													0
6/15/98	3																													0
6/15/98	4																													0
6/15/98	5																													0
6/15/98	6																													0
6/15/98	7																													0
6/15/98	8																													0
6/15/98	9	1																	1											2
6/15/98	10		1																											1
6/15/98	11	3				1			1								1	1	1											8
6/15/98	12	1	1			2						1				1			1						1					8
6/15/98	13	1									1		1			4	1													8
6/15/98	14			1		1			1					1			1		1											6
6/15/98	15	1	1			5			3		1		1			2				1										15
6/15/98	16	1	1			1									1				1											5
6/15/98	17	1	2	2		1								1		1														8
6/15/98	18	3	1	1		2						1																		8
6/15/98	19	1			1				1			3							2											8
6/15/98	20		2			1								1																4
6/15/98	21					1																								1
6/15/98	22		1													1														2
6/15/98	23								1																					1
6/15/98	24																													0
6/16/98	1																													0
6/16/98	2																													0
6/16/98	3																													0
6/16/98	4																													0
6/16/98	5																													0
6/16/98	6																													0
6/16/98	7																													0
6/16/98	8																													0
6/16/98	9					1														1					1					3
6/16/98	10					1																								1
6/16/98	11						1																							1
6/16/98	12					1						1																		2
6/16/98	13																													0
6/16/98	14		1																											1
6/16/98	15																													0
6/16/98	16			1															1											2
6/16/98	17					1												1												2
6/16/98	18													1																1
6/16/98	19											1																		1
6/16/98	20																													0
6/16/98	21		1																1											2
6/16/98	22																													0
6/16/98	23																													0
6/16/98	24																													0
Total		13	12	5	1	19	1	0	7	0	2	7	2	4	1	9	3	2	9	3	0	0	0	0	2	0	0	0	102	102

Table A.8: Summary of hourly Trouble totals for Event No. 8. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
11/12/98	1																													0
11/12/98	2																													0
11/12/98	3																													0
11/12/98	4																													0
11/12/98	5																													0
11/12/98	6																													0
11/12/98	7																													0
11/12/98	8																													0
11/12/98	9																													0
11/12/98	10		1																											1
11/12/98	11			1											1															2
11/12/98	12																													0
11/12/98	13		1																											1
11/12/98	14																													0
11/12/98	15			1																										1
11/12/98	16			1										1						1										3
11/12/98	17			2							1																			3
11/12/98	18					2					1				1															4
11/12/98	19			2		3	1		1																					7
11/12/98	20			8		2		1	1		2																			14
11/12/98	21			2		1		1	2					1	1	1														9
11/12/98	22		1			1									1					1										4
11/12/98	23			1																										1
11/12/98	24					1																								1
11/13/98	1			1					1																					2
11/13/98	2			2		1																								3
11/13/98	3					1			1										1											3
11/13/98	4	1		1																1										3
11/13/98	5																													0
11/13/98	6																													0
11/13/98	7																													0
11/13/98	8	1							1		1								1						1					5
11/13/98	9		1						2		1																			4
11/13/98	10	1				1	2		2										1	1										8
11/13/98	11	1						3			1									2										7
11/13/98	12					1		1	1										1											4
11/13/98	13			1					1												1									3
11/13/98	14					1			1																					2
11/13/98	15			1					1	1																				3
11/13/98	16								2																					2
11/13/98	17					1			1											1										3
11/13/98	18																													0
11/13/98	19					1																								1
11/13/98	20					1																			1					2
11/13/98	21																													0
11/13/98	22																													0
11/13/98	23						1																							1
11/13/98	24																													0
11/14/98	1																													0
11/14/98	2					1																								1
11/14/98	3																													0
11/14/98	4																													0
11/14/98	5																													0
11/14/98	6																													0
11/14/98	7																													0
11/14/98	8																			1										1
11/14/98	9	1							1																					2
11/14/98	10										1																			1
11/14/98	11						1		1											1										3
11/14/98	12					1										1														2
11/14/98	13			1																										1
11/14/98	14											1																		1
11/14/98	15	1																												1
11/14/98	16																													0
11/14/98	17																													0
11/14/98	18		1																											1
11/14/98	19																	1												1
11/14/98	20																													0
11/14/98	21								1																					1
11/14/98	22																													0
11/14/98	23																													0
11/14/98	24																													0
Total		6	5	25	0	20	5	6	21	1	8	1	0	2	4	2	0	1	4	9	1	0	0	0	2	0	0	0	123	123

Table A.9: Summary of Trouble totals for Event No. 9. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
11/23/98	1																													0
11/23/98	2																													0
11/23/98	3																													0
11/23/98	4																													0
11/23/98	5																													0
11/23/98	6																													0
11/23/98	7	1	1																											2
11/23/98	8					1						1																		2
11/23/98	9		1				1		2									1		1										6
11/23/98	10		2			1					1		2			1			1											8
11/23/98	11										1									1										2
11/23/98	12			1		2	1									1			1											6
11/23/98	13		1			2		1											1	1					1					7
11/23/98	14		1			1										1				1	1									5
11/23/98	15			1		1			1				1		1															5
11/23/98	16		2	1		3	1																							7
11/23/98	17					1					1									1										3
11/23/98	18																													0
11/23/98	19	2		1																										3
11/23/98	20		2			2						1																		5
11/23/98	21		1			1								1					1											4
11/23/98	22			1										2											1					4
11/23/98	23			3		3					3			2					1											12
11/23/98	24	1	4	1		3			1				1	2		1			1						3					18
11/24/98	1	3	3			9	2		1		1		2	2		3			5											31
11/24/98	2	3	3	9		15	2		1		2		1	1		3									2					42
11/24/98	3	1	5	4		7		1	3		4	3		3					3											34
11/24/98	4	2	1	2		8	2	2	8		7	1				1	3													37
11/24/98	5			4		9	3	5	1				1		1					1	1				1					27
11/24/98	6	1	4	8		4	6	4	2				1		1	5					1									37
11/24/98	7	4	5	12		11	4	2	2		3	1		1	1	3		1	2											52
11/24/98	8	5	14			11	6	2			2	1			1	2	1		1	2			1		1					50
11/24/98	9	7	10			15	4	3		1	3		3	2	1	1					2									52
11/24/98	10		2			5	1	2			2		2	1					2	1										18
11/24/98	11	1				2	1				2		1						2	1										10
11/24/98	12		5	2		3	1								1		1		1	2					2					18
11/24/98	13	2	2			2				2						1			1											10
11/24/98	14	1		2		3					1					2														9
11/24/98	15	3	5	6		12			4	1	2					3					1									37
11/24/98	16	1	3	6		8	5	2	4		3	1				1				1					1					36
11/24/98	17		1			3	9	4	2		4		1	2						6										32
11/24/98	18	1	1			2	4			2								1	3		1									15
11/24/98	19					1	2																2							5
11/24/98	20	2	8	17		19	5		10		3								1	1					4					70
11/24/98	21	2	6	17		11	6		5		1					1	1		3						2					55
11/24/98	22	3	5	1		7	6		6		4					1		1	1		3				1					39
11/24/98	23	2	7	1		10	1	1	5		2			5	1	1														36
11/24/98	24	4	1			6			2		4	1				2	1		1											22
11/25/98	1		3	3					1																					7
11/25/98	2		1																											1
11/25/98	3			2							1						1													4
11/25/98	4	1																		1										2
11/25/98	5																													0
11/25/98	6	2	1			2		1								1									1					8
11/25/98	7	3	2	1					3		1														1					11
11/25/98	8	2	3			1	2	1	2				1			1														13
11/25/98	9	1		1		2	3	1	2		1		1			1	1			1										15
11/25/98	10										1									1										2
11/25/98	11	1	2			3			2										1											9
11/25/98	12	5	6	2		3	1	1			1					2				1										22
11/25/98	13	4	8		1	1	2		1		1						1		1											20
11/25/98	14	2	7			3	2				1					2														17
11/25/98	15	1				4	1							1				2												9
11/25/98	16	3	3	1		5			6							1			2						1					22
11/25/98	17	2	3			10	1		2		1					2			1	2	1									25
11/25/98	18	1		3		6			10		1					4					1									26
11/25/98	19			2		6	1		2		1										1									13
11/25/98	20		1	5		1		1	3		2					1														14
11/25/98	21	2	3			3			3							1												1		13
11/25/98	22	1	1		1	1																			3					7
11/25/98	23					2			3																					5
11/25/98	24					1										2														3
11/26/98	1			1					1																					2
11/26/98	2															1														1
11/26/98	3					1																								1
11/26/98	4																													0
11/26/98	5																													0
11/26/98	6		1						1																					2
11/26/98	7					1			1																					2
11/26/98	8		1	2		2			5		2					2				1			1							16
11/26/98	9	2	4	3		10	2	1	2		1			1		1	1		1	1								1		31
11/26/98	10	3	1			3			5							2	1			1										16
11/26/98	11	1	5	2		6										2		1	3											20
11/26/98	12	2	7	1		12		1	4		2					1	1		1											32
11/26/98	13	2	7			4			1							1														15
11/26/98	14		2	4		4			1		1					1			3											16
11/26/98	15		3	1		3																								7
11/26/98	16	1	2	1		2			1					1					2											10
11/26/98	17		1	1		3																								5
11/26/98	18		1			2			3				1	1																8
11/26/98	19		2			3	1		3		1	1				2		1	1											15
11/26/98	20	1	2	1					1										1											6
11/26/98	21		2	1		1	1																							5
11/26/98	22		1	1																										2
11/26/98	23		1			3																								4
11/26/98	24					1																								1
Total		95	193	139	2	319	90	36	129	6	75	11	19	28	8	65	13	8	49	29	13	0	4	0	25	0	0	2	1358	1358

Table A.10: Summary of hourly Trouble totals for Event No. 10. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
11/30/98	1																													0
11/30/98	2						1																							1
11/30/98	3						1																							1
11/30/98	4																													0
11/30/98	5																													0
11/30/98	6																													0
11/30/98	7						1																							1
11/30/98	8																													0
11/30/98	9	1										1																		2
11/30/98	10		1																											1
11/30/98	11	1																												1
11/30/98	12			1		1		1	1																					4
11/30/98	13																	1												1
11/30/98	14						1		1							1														3
11/30/98	15	1	1																											2
11/30/98	16	1					1																							2
11/30/98	17																													0
11/30/98	18																													0
11/30/98	19																													0
11/30/98	20																													0
11/30/98	21	1																												1
11/30/98	22																													0
11/30/98	23																													0
11/30/98	24																													0
12/1/98	1																													0
12/1/98	2																													0
12/1/98	3																													0
12/1/98	4																													0
12/1/98	5																													0
12/1/98	6																													0
12/1/98	7																													0
12/1/98	8							1																						1
12/1/98	9					1																								1
12/1/98	10		1						1											1										3
12/1/98	11		3							2																				5
12/1/98	12					1	1				2			2				1	1	1										9
12/1/98	13		4			1																								5
12/1/98	14	3	2	1		2		1	1		1			1		1														13
12/1/98	15					1			1		2																			4
12/1/98	16		3			1	2				2	1	2	2	1	2									1					17
12/1/98	17		1				1									2														4
12/1/98	18	1	1			1			1		1																			5
12/1/98	19	1																												1
12/1/98	20															1														1
12/1/98	21																													0
12/1/98	22																													0
12/1/98	23										1																			1
12/1/98	24																													0
12/2/98	1																													0
12/2/98	2																													0
12/2/98	3																													0
12/2/98	4																													0
12/2/98	5																													0
12/2/98	6																													0
12/2/98	7										1																			1
12/2/98	8			1																										1
12/2/98	9																													0
12/2/98	10			1																										1
12/2/98	11		2			1																			1					4
12/2/98	12																			1										1
12/2/98	13					1			1		2																			4
12/2/98	14	1	1	1			1																							4
12/2/98	15					1													1											2
12/2/98	16					1																								1
12/2/98	17					1															1									2
12/2/98	18										2																			2
12/2/98	19			1																	1									2
12/2/98	20					2																								2
12/2/98	21																													0
12/2/98	22		1																											1
12/2/98	23																													0
12/2/98	24																													0
Total		11	21	6	0	16	10	3	7	2	14	2	2	5	1	7	0	2	2	3	2	0	0	0	2	0	0	0	118	118

Table A.11: Summary of hourly Trouble totals for Event No. 11. Columns are municipalities.

Date	Hour	BBY	VAN	LYM	LYC	SRY	ABT	MIS	MRG	LDR	DEL	DNV	CNV	DWV	PMY	COQ	PTC	PTM	RIM	CHK	ALD	ALZ	TSW	UEL	WRK	ANN	BAR	NWR		Total
1/27/99	1		1																											1
1/27/99	2																													0
1/27/99	3																													0
1/27/99	4																													0
1/27/99	5																													0
1/27/99	6																													0
1/27/99	7										1																			1
1/27/99	8					2														2										4
1/27/99	9																1													1
1/27/99	10		1																1											2
1/27/99	11		2			2					1																			5
1/27/99	12		1			1																								2
1/27/99	13	2				1					1	1																		5
1/27/99	14	1	2			1													1											5
1/27/99	15		1	1				1																						3
1/27/99	16		3	2		3							1			1														10
1/27/99	17								1		1			1			1				1									5
1/27/99	18	1		1		1			1																					4
1/27/99	19				1																									1
1/27/99	20			1			1																							2
1/27/99	21																													0
1/27/99	22																													0
1/27/99	23		1																											1
1/27/99	24	1	1																											2
1/28/99	1																													0
1/28/99	2																													0
1/28/99	3																													0
1/28/99	4																													0
1/28/99	5																													0
1/28/99	6																													0
1/28/99	7								1																					1
1/28/99	8										1																			1
1/28/99	9		1																											1
1/28/99	10		1									1				1														3
1/28/99	11		1	1			1																							3
1/28/99	12			1		1	1		1		1																			5
1/28/99	13	1				3																								4
1/28/99	14		1										1																	2
1/28/99	15		1								1					1														3
1/28/99	16	1																1												2
1/28/99	17		1	1																										2
1/28/99	18		1																											1
1/28/99	19						1																							1
1/28/99	20					1					1																			2
1/28/99	21		1																											1
1/28/99	22						1																							1
1/28/99	23																													0
1/28/99	24	1					2	2				1		1																7
1/29/99	1	1	1	2			1		1											1										7
1/29/99	2			2		1	3	1													1									8
1/29/99	3			3			1	1	1			1																		7
1/29/99	4			1			2	2												1	1									7
1/29/99	5	1		4		1	4	4	3								1			3										21
1/29/99	6	1	1	4		1	5	1	4											1	1									19
1/29/99	7			3		7	3	2	2		1						1			4										23
1/29/99	8	3		10		3	2	4	2			1								3	1									29
1/29/99	9	2	4	15		9	4	3	11				1	1		3				10	7				1					71
1/29/99	10	4	3	11		4	9	3	15			1				2				11	3									66
1/29/99	11	1	5	11	1	10	11	7	21							1		1		8	5				1					83
1/29/99	12	1	1	8		2	12	3	5		2					1				7										42
1/29/99	13	2	1	14		4	4	2	2							1	1			3										34
1/29/99	14			4		2	3	2	4		1								1	6	3									26
1/29/99	15	1		6		2	1	4	4									1		4	2									25
1/29/99	16	1	1	9		4	5	2	2				1							1										26
1/29/99	17		1	7	1	5	4	3	1											2										24
1/29/99	18		1	6		4	2	7										1		2										23
1/29/99	19		2	5		1	3	3												3										17
1/29/99	20		1	8		2	6	6								1				1										25
1/29/99	21			2		2	2	3																						9
1/29/99	22			1		1	3																							5
1/29/99	23																													0
1/29/99	24						2													2										4
1/30/99	1	1																												1
1/30/99	2			2		1																								3
1/30/99	3					1															1									2
1/30/99	4						1	1																						2
1/30/99	5																				1									1
1/30/99	6			1			1																							2
1/30/99	7							1																						1
1/30/99	8			1			1																							2
1/30/99	9					1	1														2									4
1/30/99	10			3				1	2												1				1					8
1/30/99	11			1					1			1																		3
1/30/99	12			1		1	2	1	1												1									7
1/30/99	13					1	2																							3
1/30/99	14			1				3	3		2									4										13
1/30/99	15		1	2	1			2												1										7
1/30/99	16					2	4	1												1										8
1/30/99	17		1					3	1																					5
1/30/99	18	1				4	1	1	1											1					1					10
1/30/99	19							1																						1
1/30/99	20					3																								3
1/30/99	21	1																												1
1/30/99	22						1																							1
1/30/99	23						1																							1
1/30/99	24																													0
Total		29	45	156	4	95	114	81	91	0	14	7	4	3	0	12	5	4	3	82	31	0	0	0	4	0	0	0	784	784

Table A.12: Summary of hourly Trouble totals for Event No. 12. Columns are municipalities.

APPENDIX B

(Model Charts; Time Series of Model Predictions, Observations and Troubles)

The Events identified earlier (e.g. Table 3) are discussed in more detail in this Appendix. For each Event the following are provided: (1) A text summary of the synoptic conditions. (2) Coloured charts of the predicted (by MC2) wind field at the time of the maximum wind speeds (usually one chart per Event) at the highest resolution possible (3.3 km) to demonstrate the small-scale characteristics in the study region and at a smaller resolution (90 km) to characterize the synoptic conditions. (3) Time series plots of the observations compared to the model predictions and the number of Troubles at each GVRD or AES weather station in the study region. These plots form the basis of the validation (or evaluation of performance) of the model as summarized in Tables 6 and 7.

Event No. 1 (Feb. 11 - 15, 1995)

A persistent, elongated, low-pressure centre stretched from the coast of Oregon and Washington to northern Colorado. A strong continental high in northern B.C. and the Yukon contributed to cold-air damming along the east side of the coast mountains ranges and the Rockies. Strong pressure and temperature gradients (stationary front) formed between these air masses perpendicular to the southern B.C. coast. These were maintained for several hours by upper-level ridging reaching from the north Pacific into northern B.C. The result was sustained NE winds over the lower Fraser Valley (LFV) and classic outflow conditions.

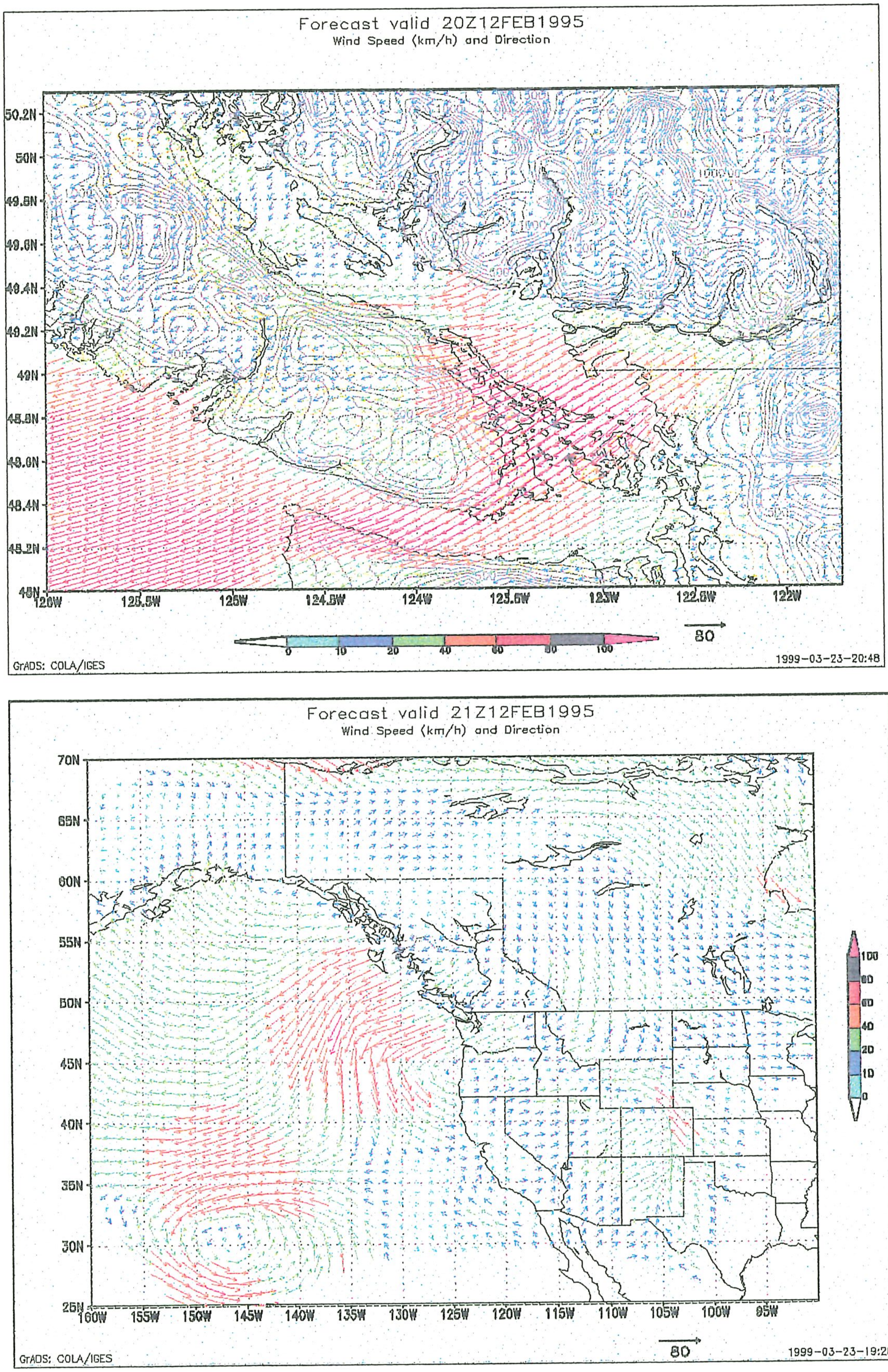


Fig. B.1.1: MC2 wind forecast for Event No. 1 at 1200 PST on Feb. 12, 1995. Top: 3.3 km resolution, bottom: 90 km resolution.

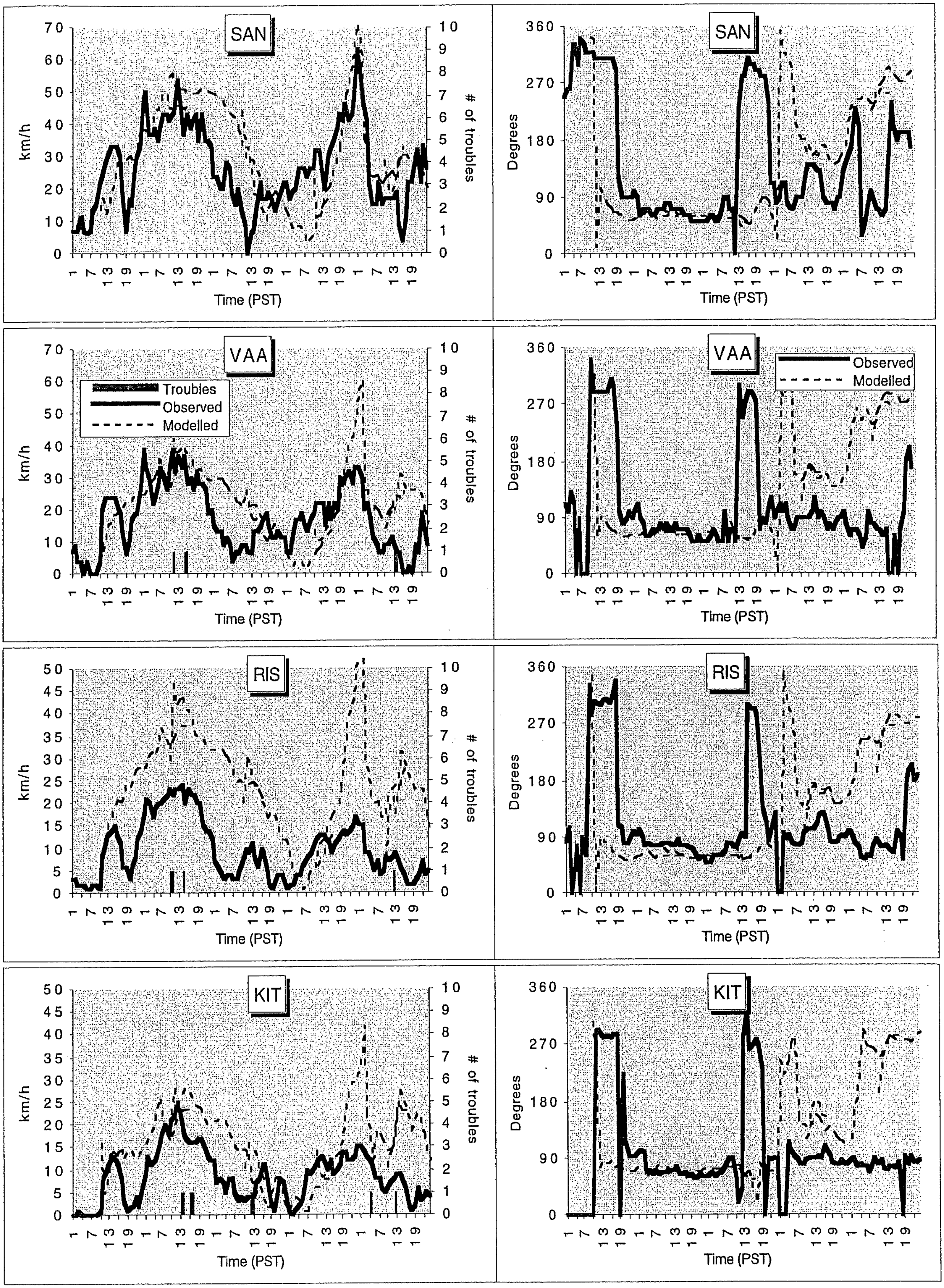


Fig. B.1.2: Observed winds compared to model prediction and # of Troubles for Event No. 1 (Feb. 11 - 15, 1995).

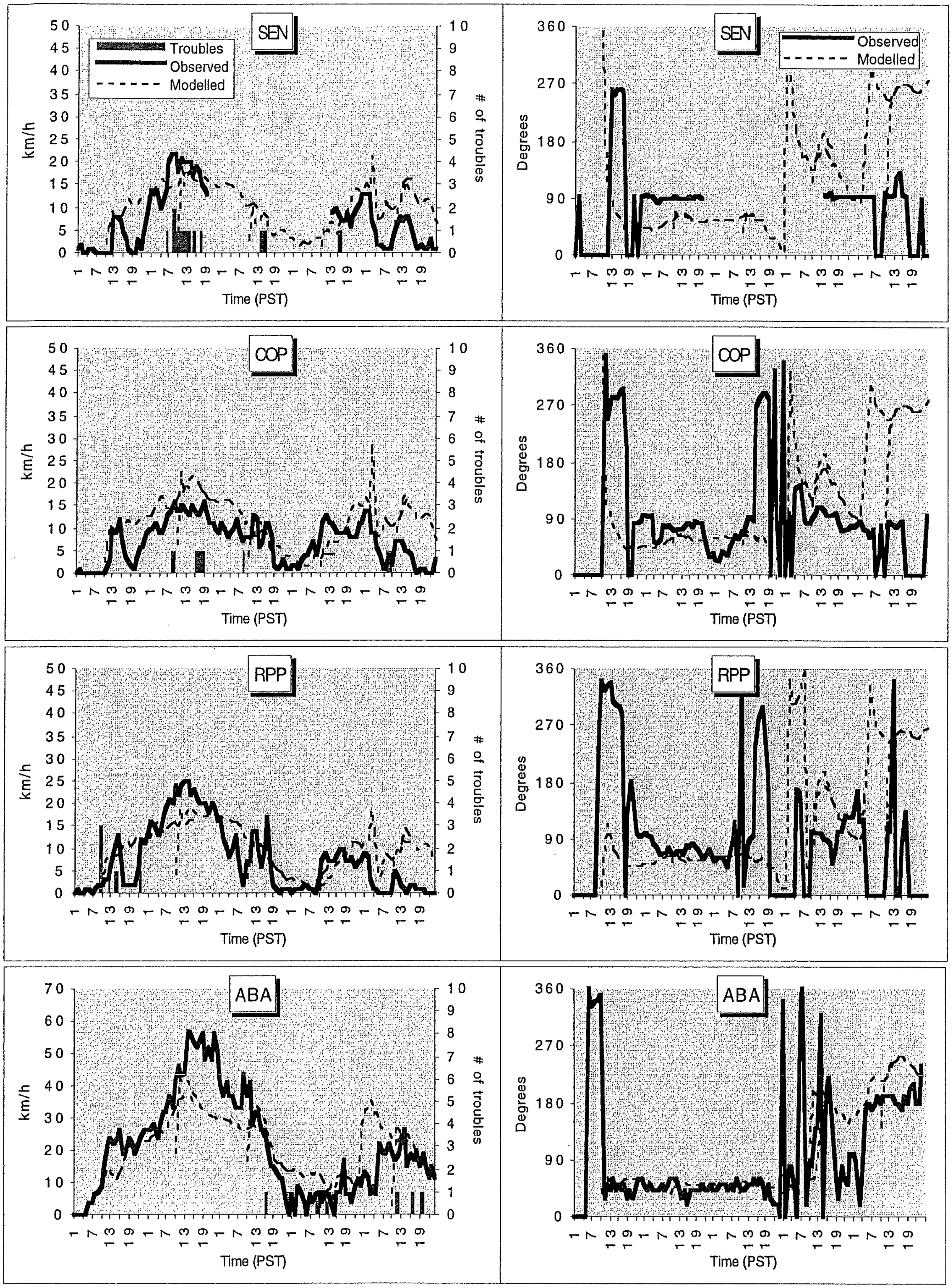


Fig. B.1.3: Same as Fig. B.1.2 (Event No. 1).

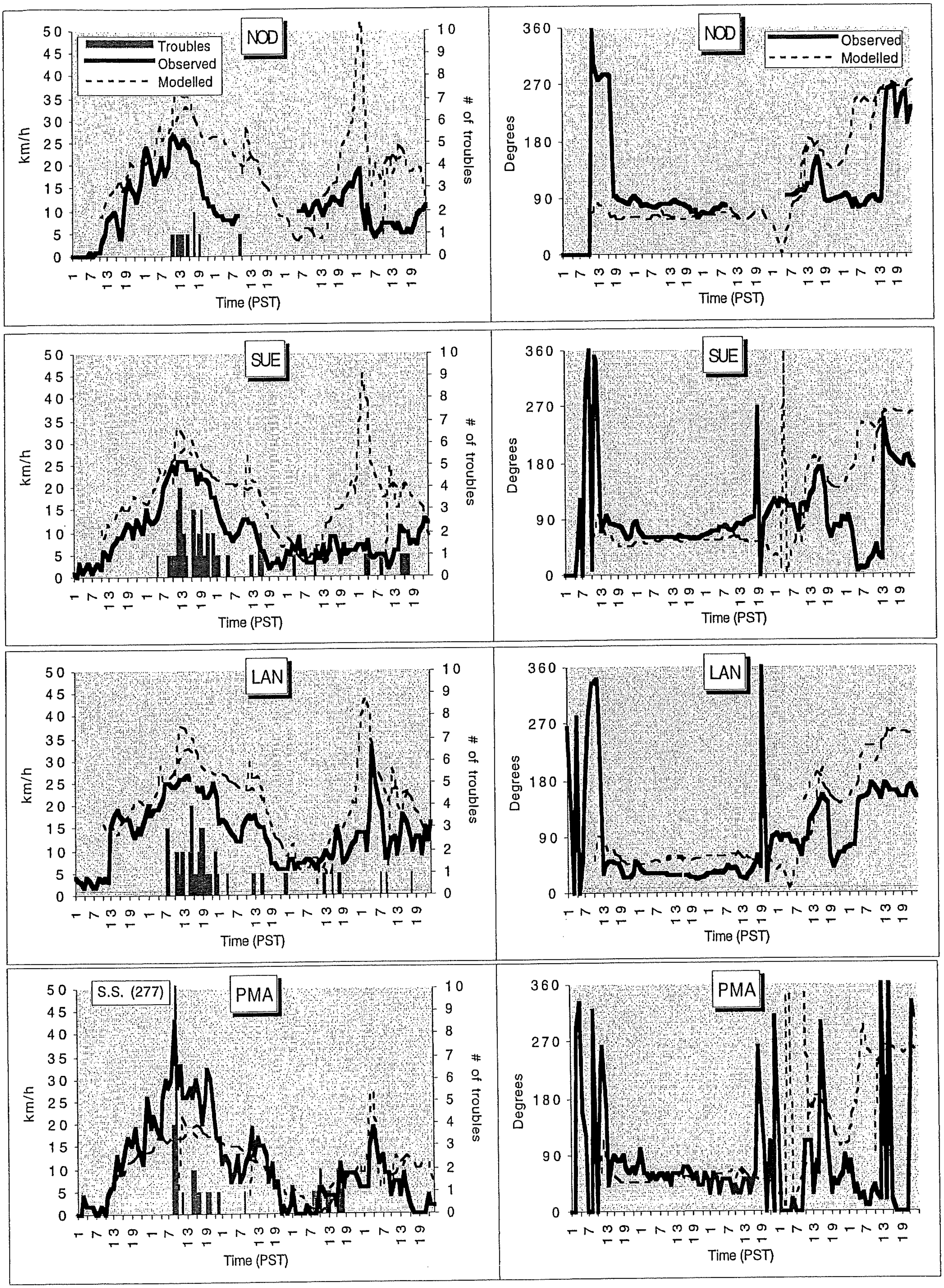
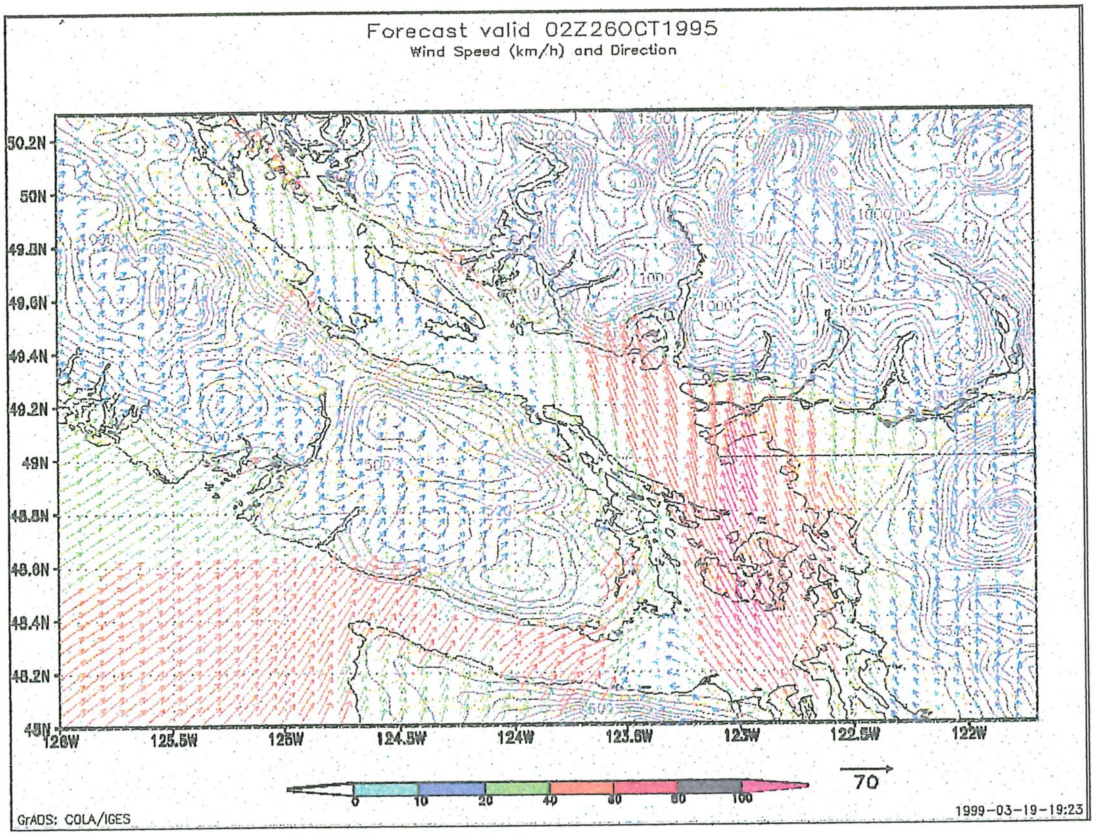


Fig. B.1.4: Same as Fig. B.1.2 (Event No. 1). S.S. - Storm Summary.

Event No. 2 (Oct. 25 - 26, 1995)

A vigorous occluded surface front passed the LFV between 1800 and 2200 PST on Oct. 25, 1995 (02 and 06 UTC on Oct. 26), associated with a low-pressure center spinning down in the Gulf of Alaska. A weak mean sea level pressure (MSLP) minimum marked passage of the front, which was supported by a strong positive vorticity aloft, along the front. The pressure gradient was nearly due south, causing down-gradient SSE winds at the surface just ahead of the front. The convergence associated with the front and the wind speed downstream were enhanced in the lee of the Olympic Mountains, over the Strait of Georgia and the LFV.



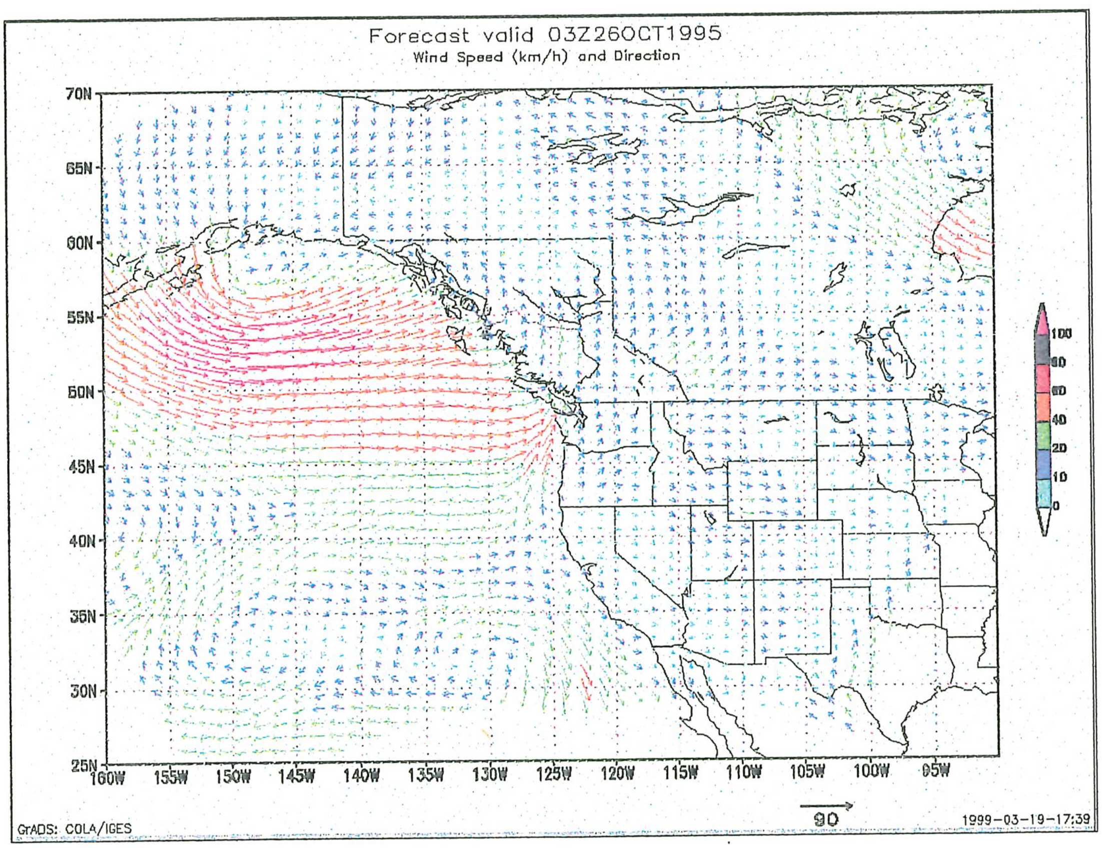


Fig. B.2.1: MC2 wind forecast for Event No. 2 at 1800 PST on Oct. 25, 1995.
Top: 3.3 km resolution, bottom: 90 km resolution.

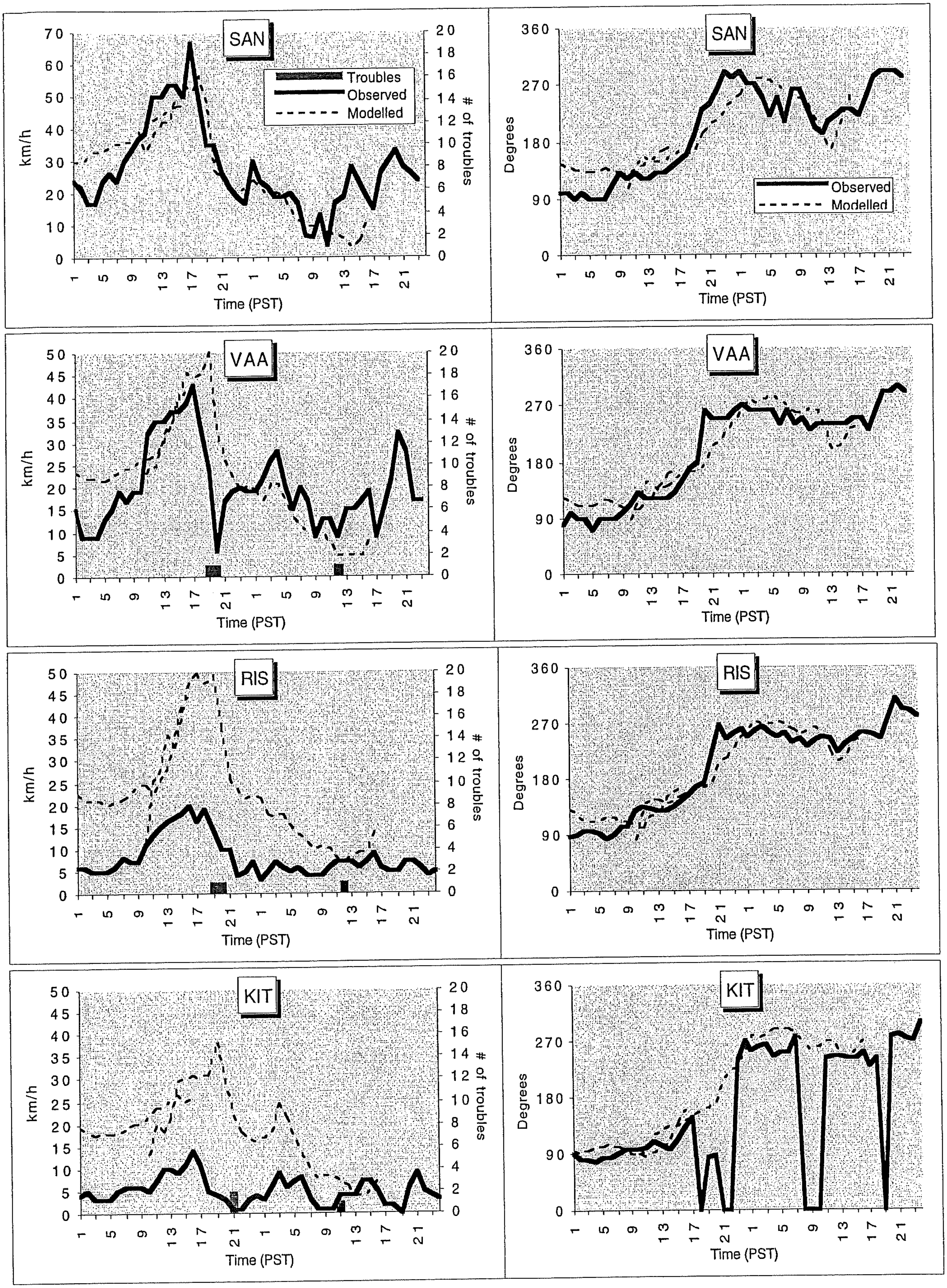


Fig. B.2.2: Same as Fig. B.1.2 but for Event No. 2 (Oct. 25 - 26, 1995).

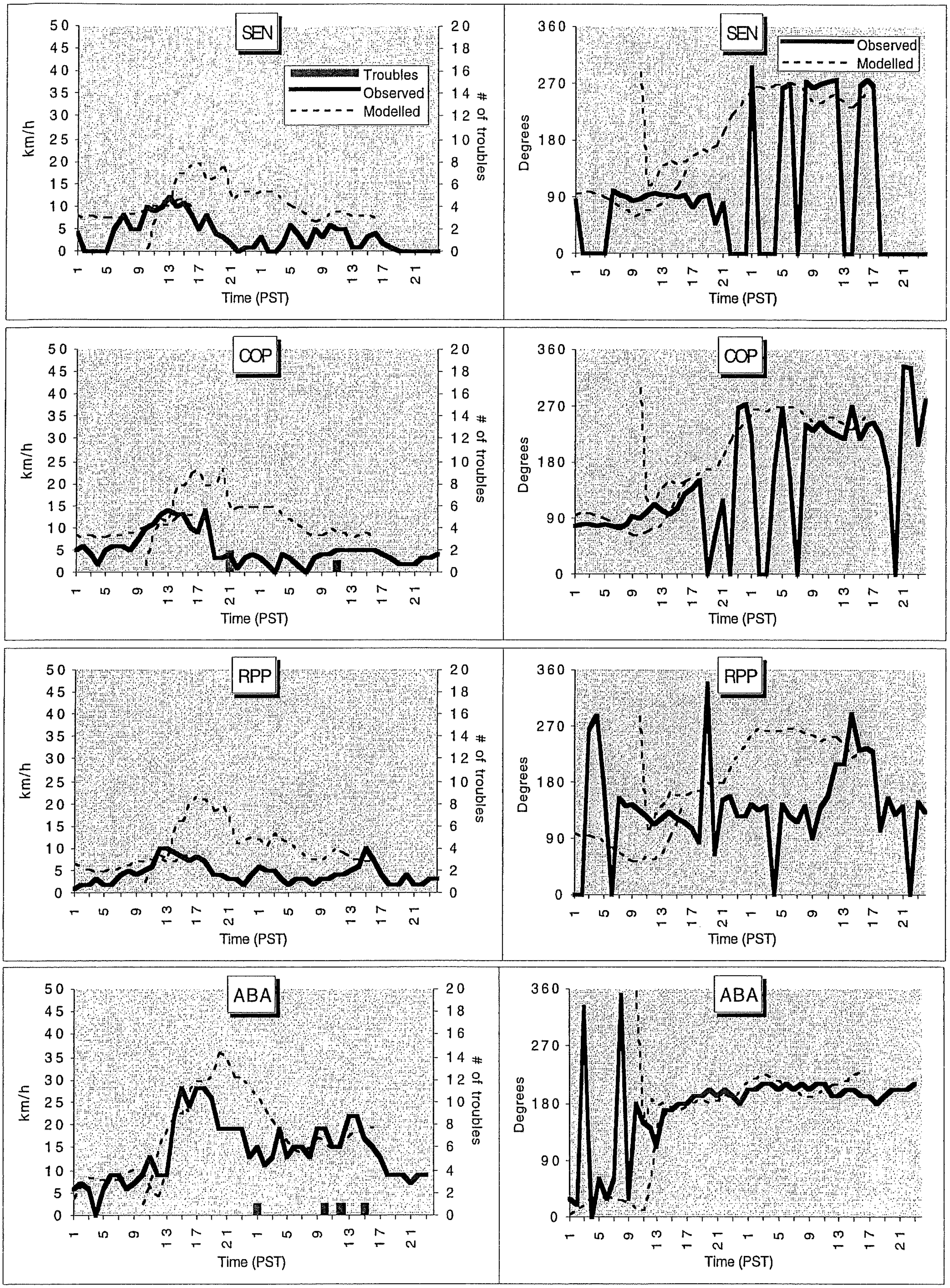


Fig. B.2.3: Same as Fig. B.1.2 but for Event No. 2 (Oct. 25 - 26, 1995).

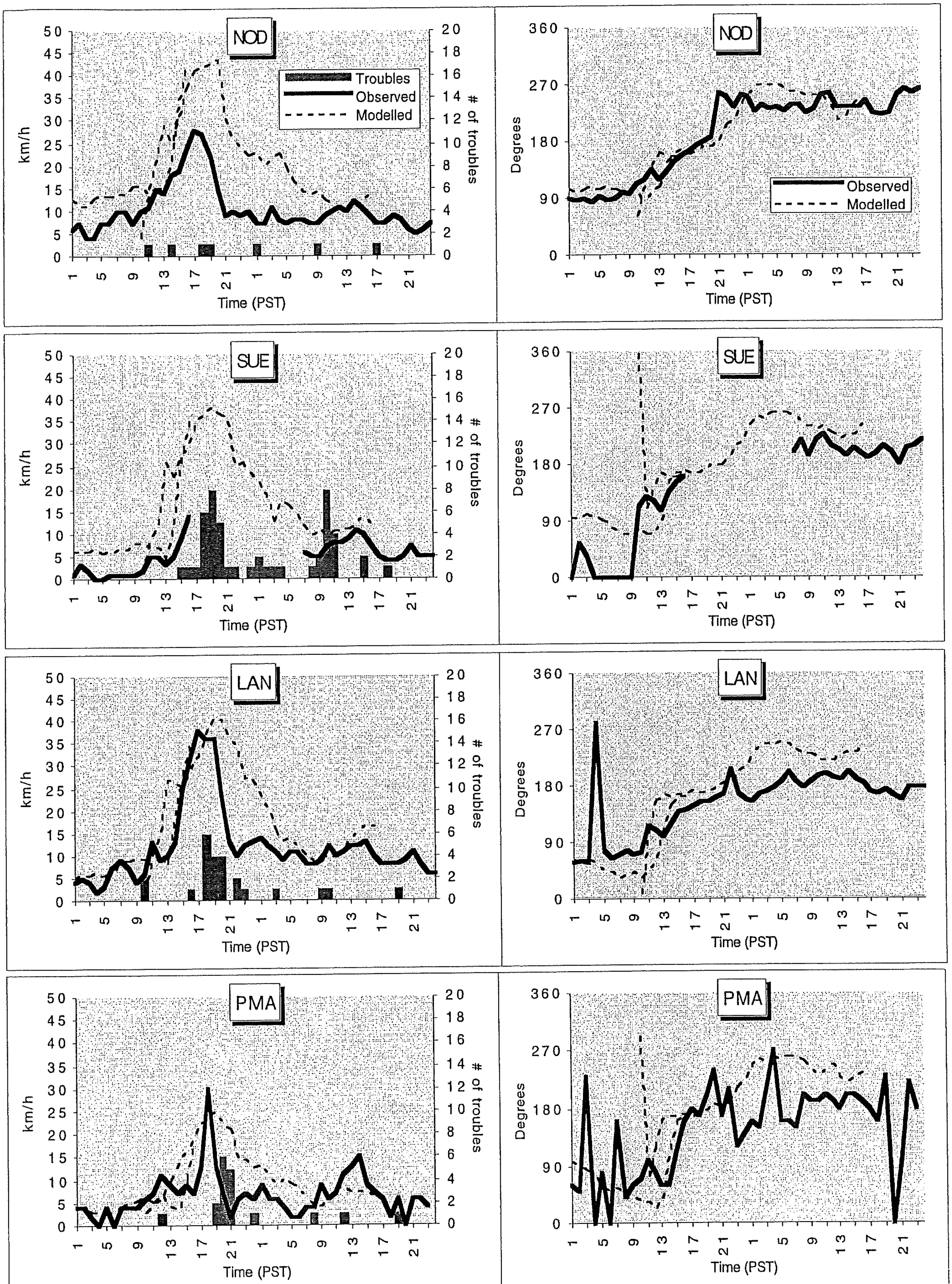
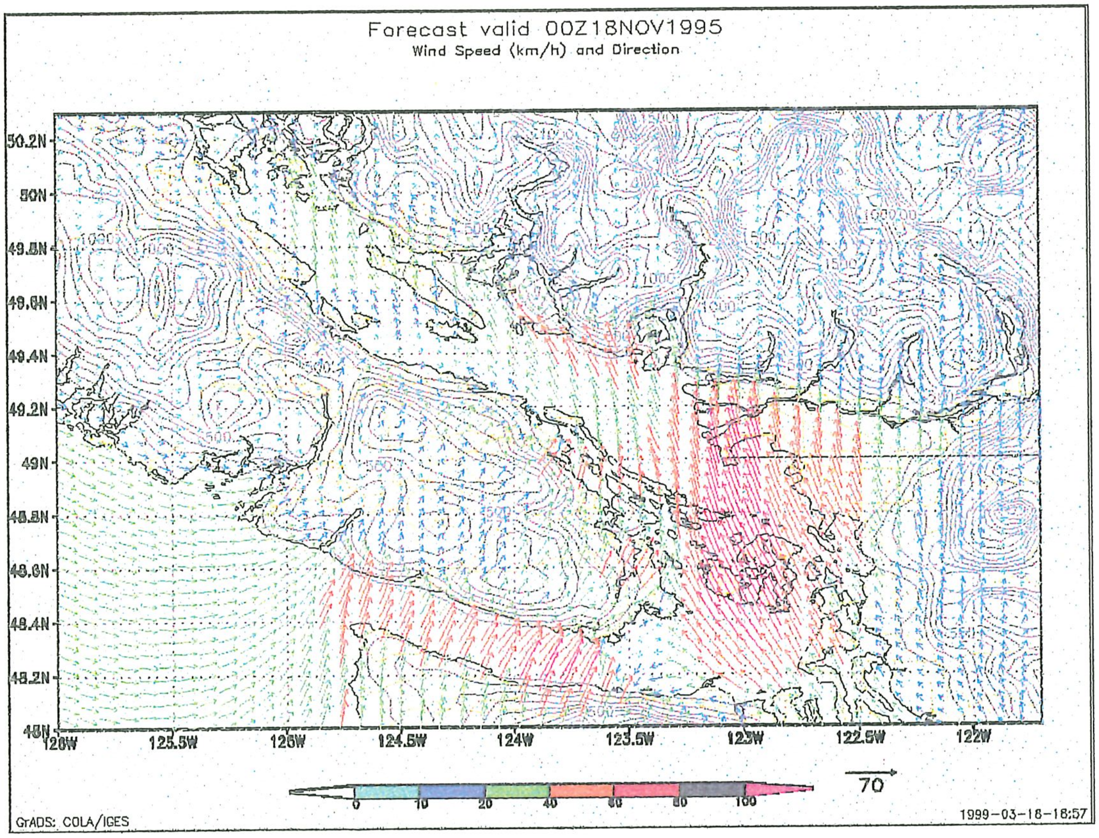


Fig. B.2.4: Same as Fig. B.1.2 but for Event No. 2 (Oct. 25 - 26, 1995).

Event No. 3 (Nov. 17 - 19, 1995)

A cold front associated with an occluding system in the Gulf of Alaska passed the LFV between 1600 and 1900 PST on Nov. 17, 1995 (00 and 03 UTC on Nov. 18). The point where the warm and cold fronts were occluding passed over the northern tip of Vancouver island a few hours earlier. The cold front owed its energy to a vorticity maximum upstream, over the pacific. As the MSLP trough approached the LFV, the pressure gradient was oriented down the Strait of Georgia, leading to down-gradient SSE winds ahead of the front. The convergence associated with the front and the wind speed downstream were enhanced in the lee of the Olympic Mountains, over the Strait and the LFV.



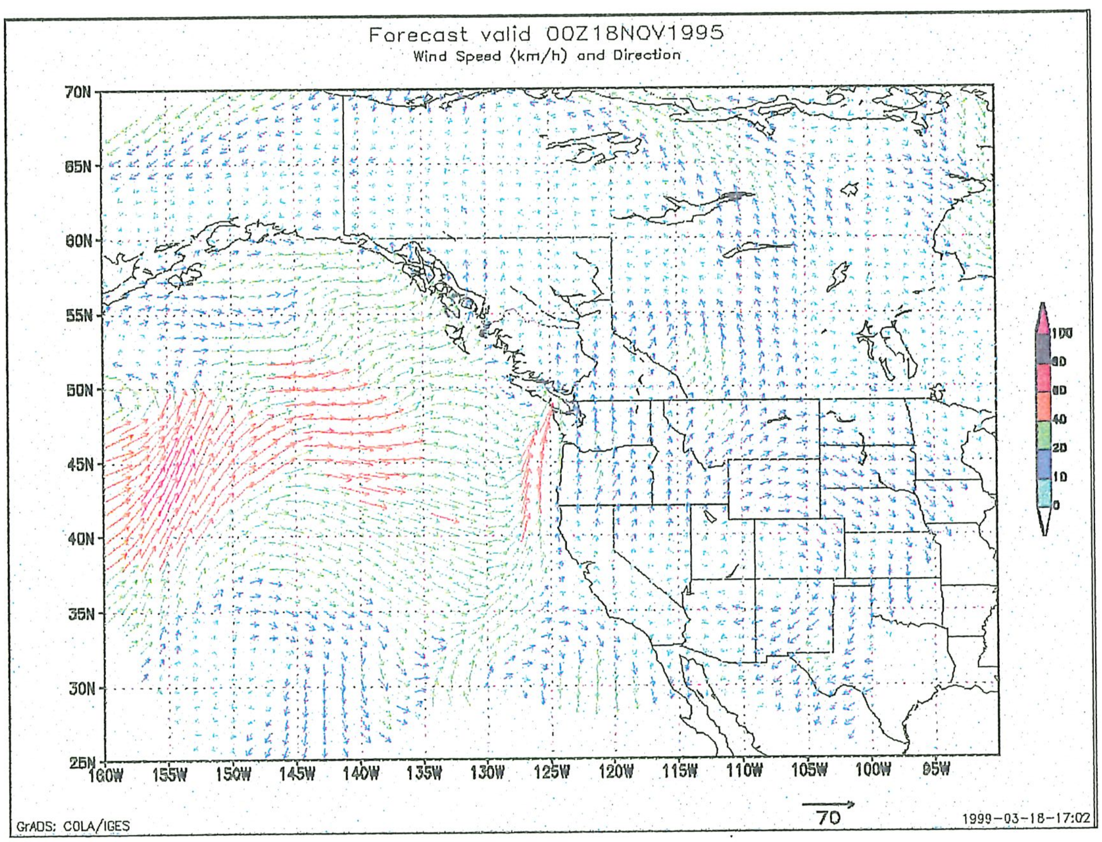


Fig. B.3.1: MC2 wind forecast for Event No. 3 at 1600 PST on Nov. 17, 1995. Top: 3.3 km resolution, bottom: 90 km resolution.

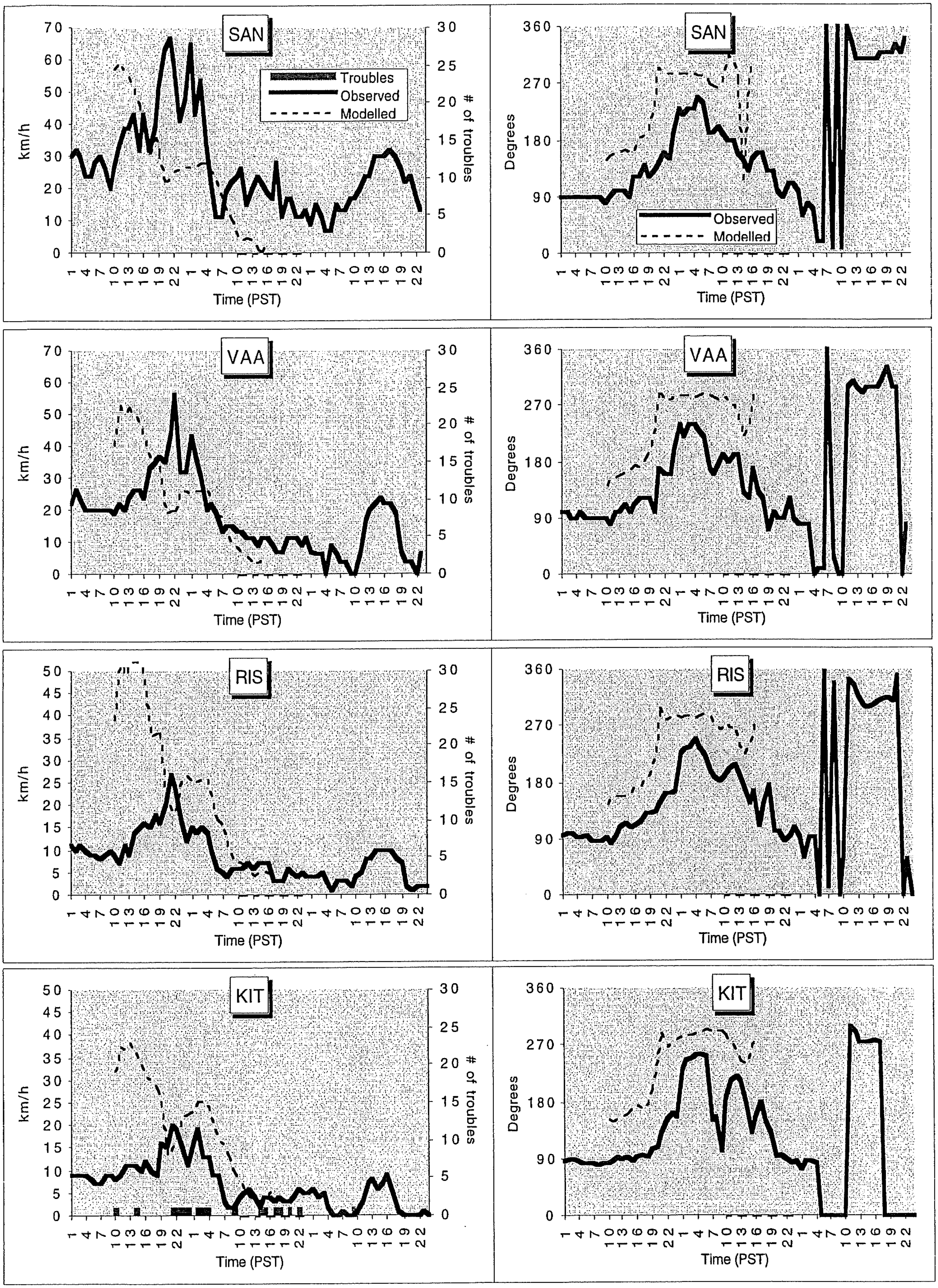


Fig. B.3.2: Same as Fig. B.1.2 but for Event No. 3 (Nov. 17 - 19, 1995).

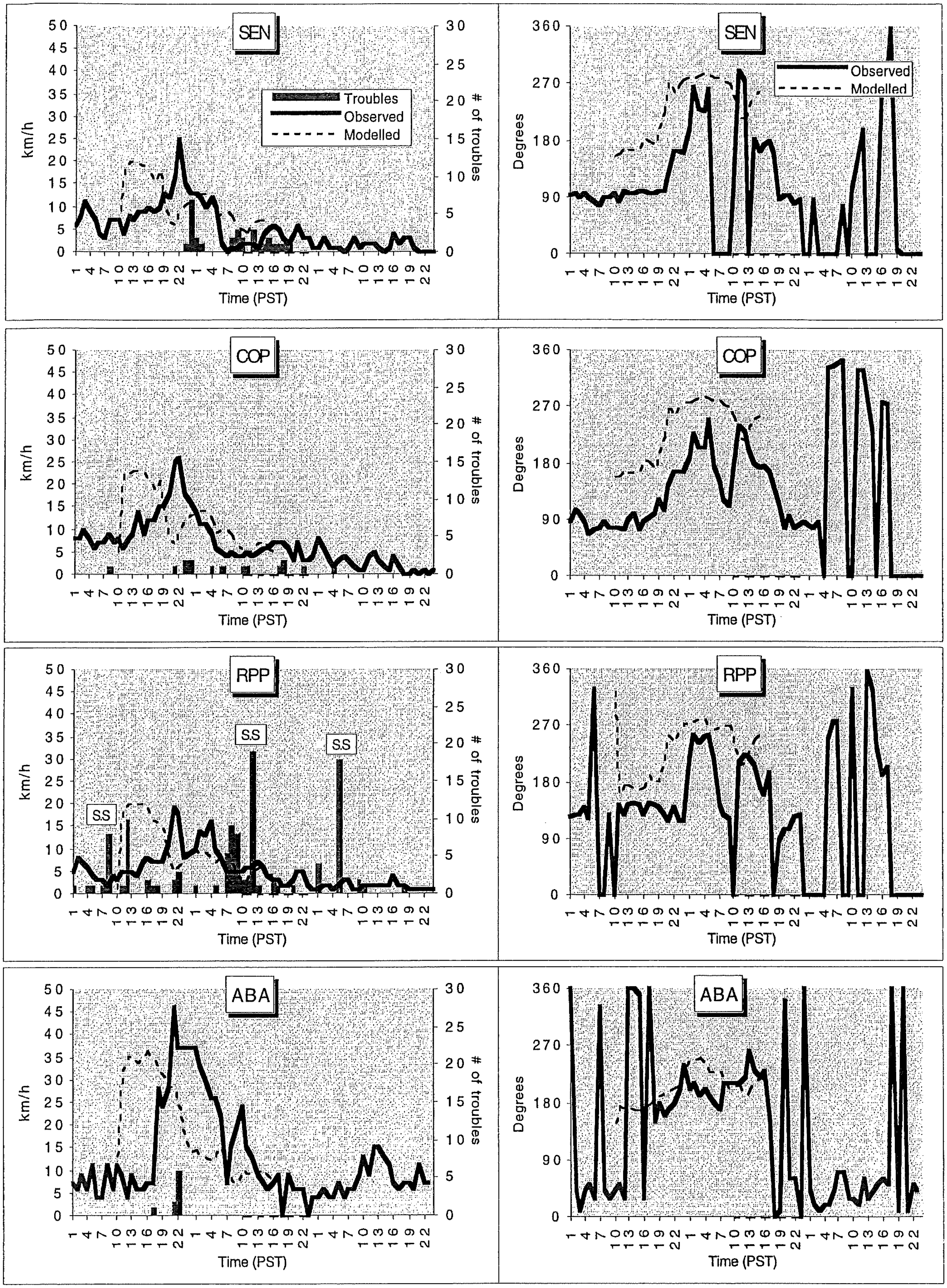


Fig. B.3.3: Same as Fig. B.1.2 but for Event No. 3 (Nov. 17 - 19, 1995). S.S. - Storm Summary.

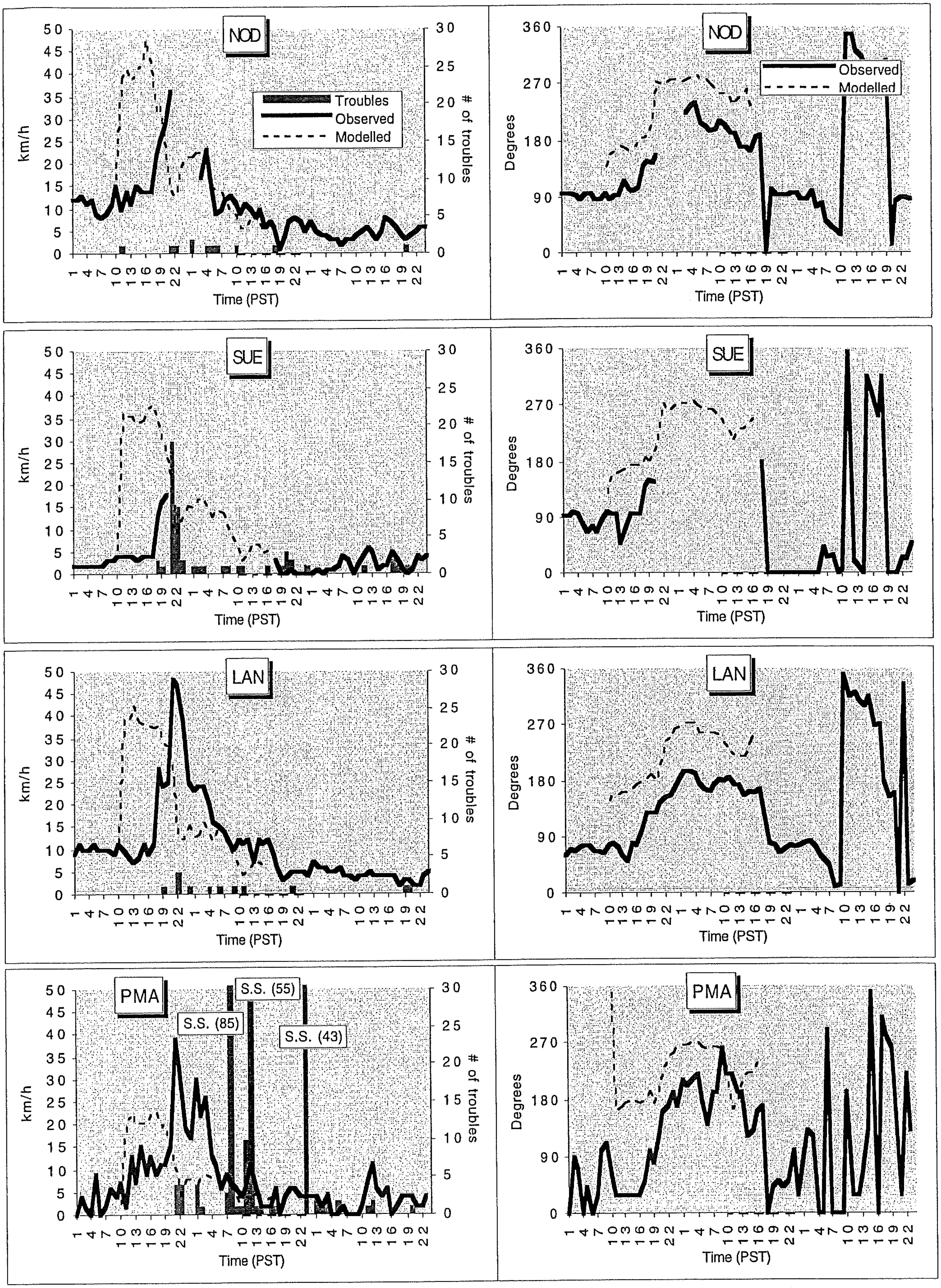
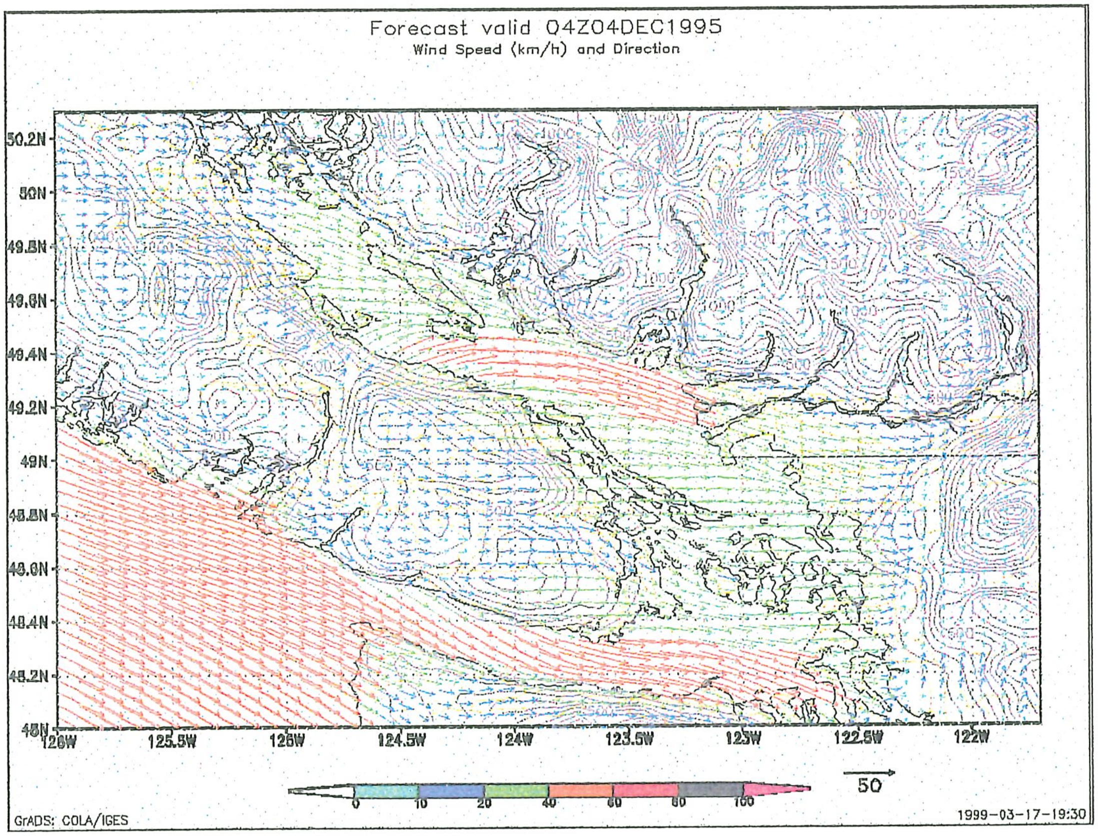


Fig. B.3.4: Same as Fig. B.1.2 but for Event No. 3 (Nov. 17 - 19, 1995). S.S. - Storm Summary.

Event No. 4 (Dec. 3 - 5, 1995)

A rapidly-moving short-wave aloft and an associated surface low-pressure centre tracked over the central B.C. coast near 1600 PST on Dec. 3, 1995 (00 UTC on Dec. 4). The system's cold front crossed the LFV a couple of hours later. By 2000 PST (04 UTC), the pressure gradient was oriented off shore, causing post-frontal NW winds over the open ocean. The strongest winds occurred just in the wake of the cold front. The NW winds were channeled down the Strait of Georgia, and through the Strait of Juan de Fuca and the Qualicum gap.



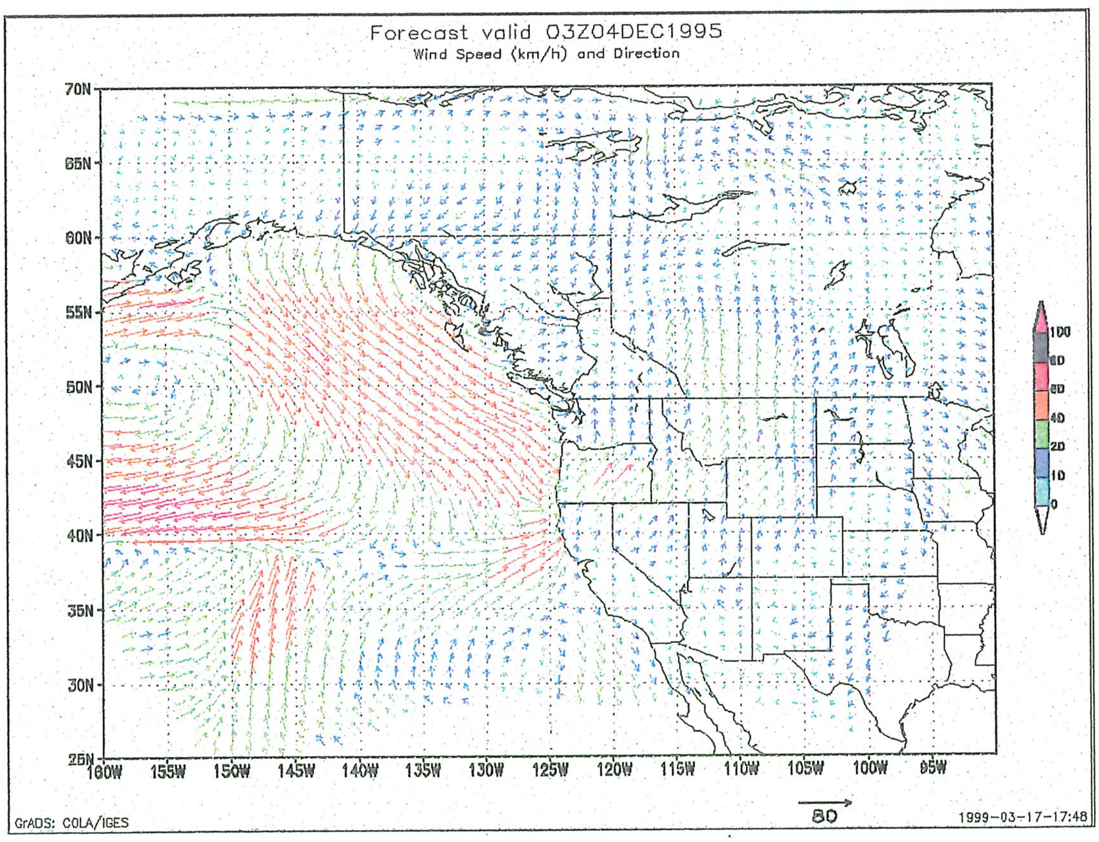


Fig. B.4.1: MC2 wind forecast for Event No. 4 at 2000 PST on Dec. 3, 1995.
Top: 3.3 km resolution, bottom: 90 km resolution.

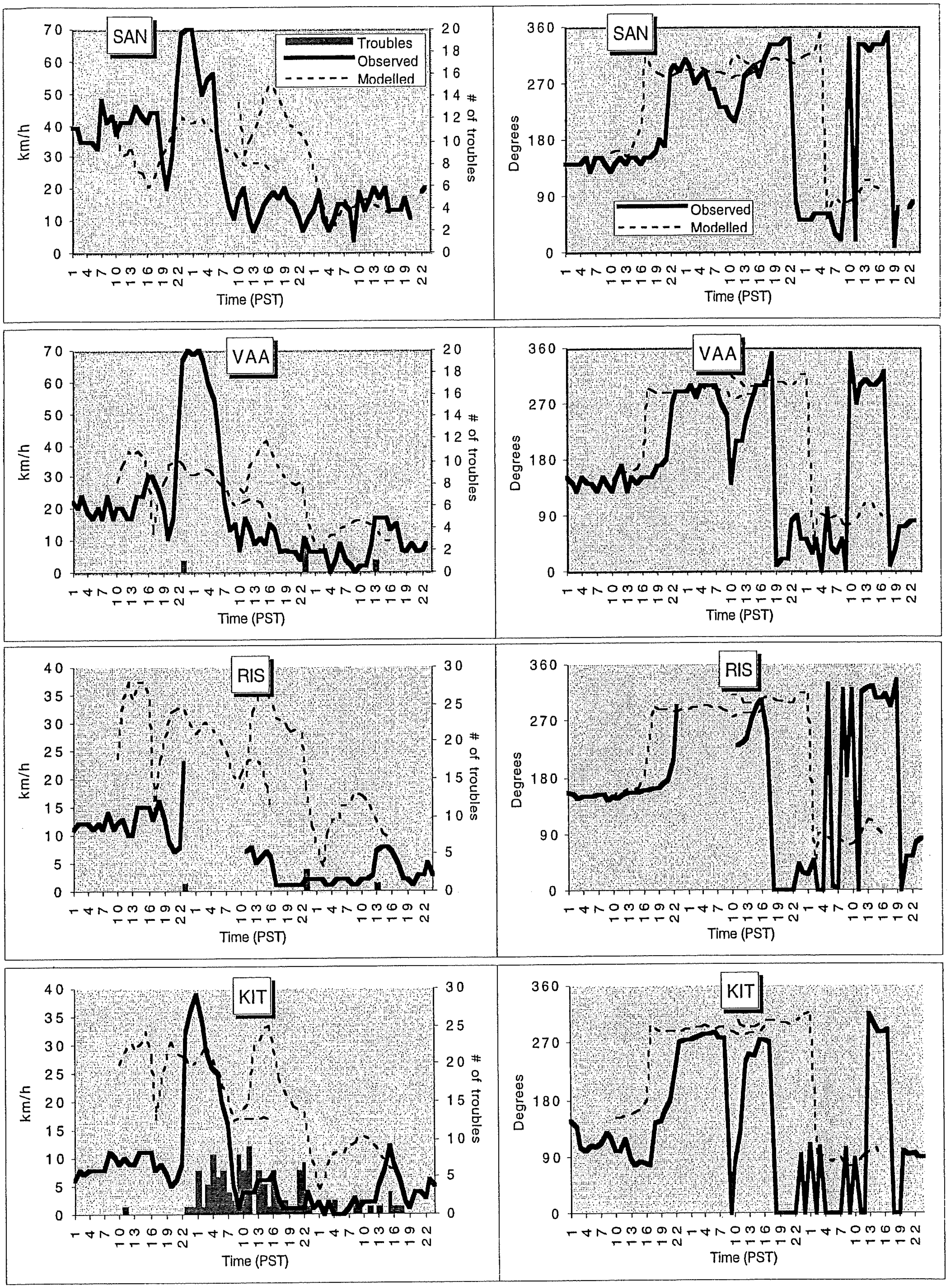


Fig. B.4.2: Same as Fig. B.1.2 but for Event No. 4 (Dec. 3 - 5, 1995).

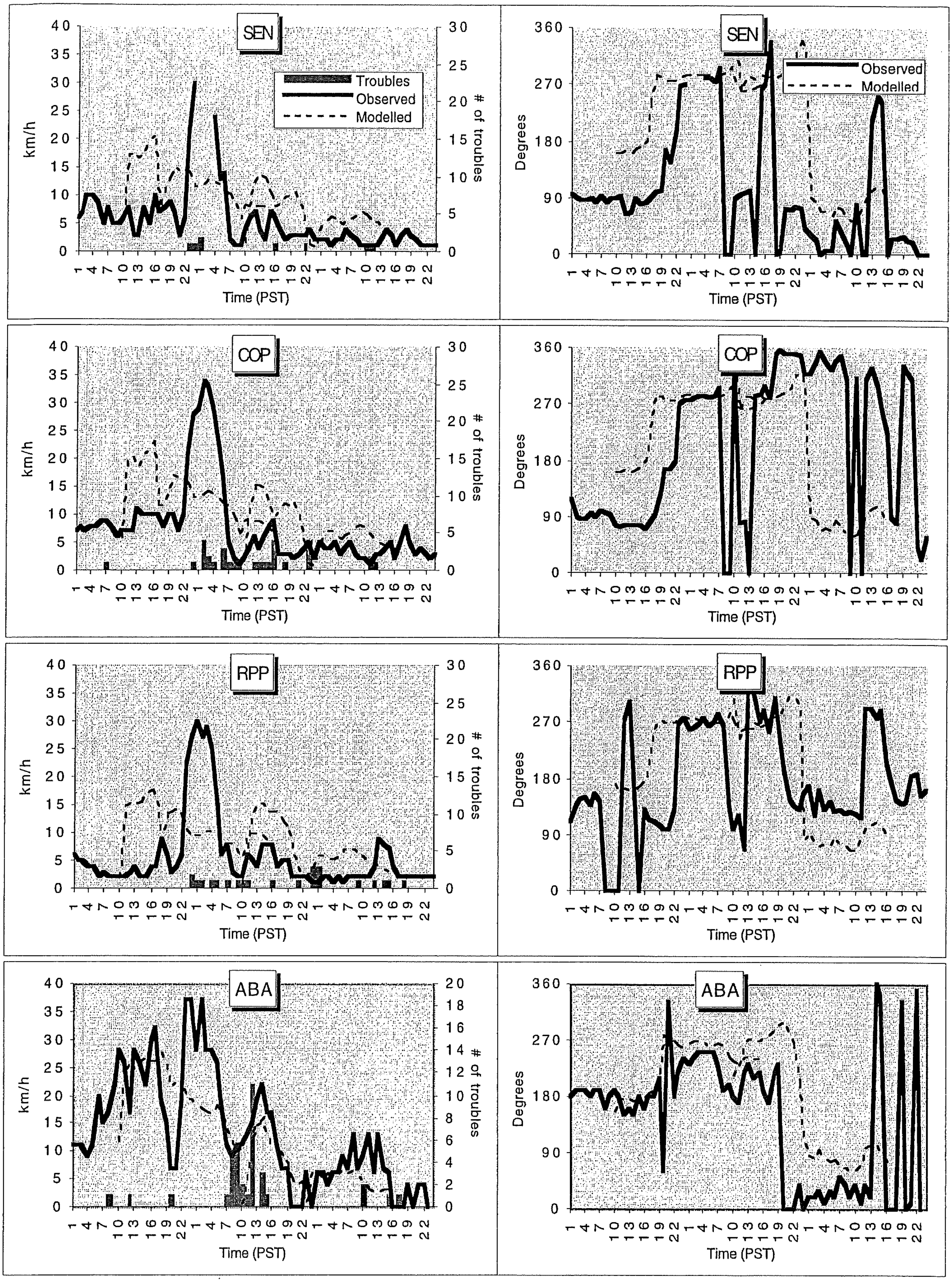


Fig. B.4.3: Same as Fig. B.1.2 but for Event No. 4 (Dec. 3 - 5, 1995).

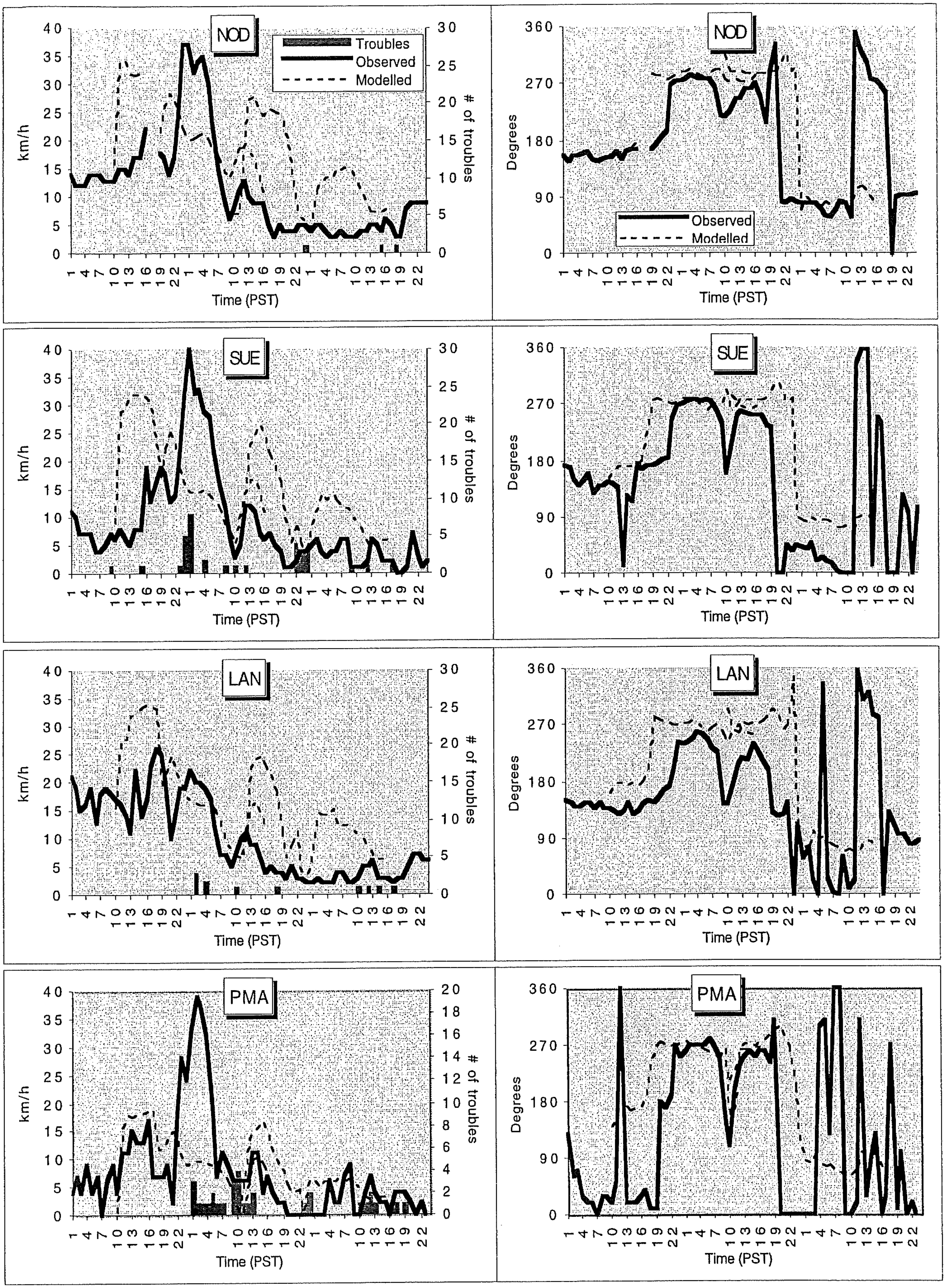
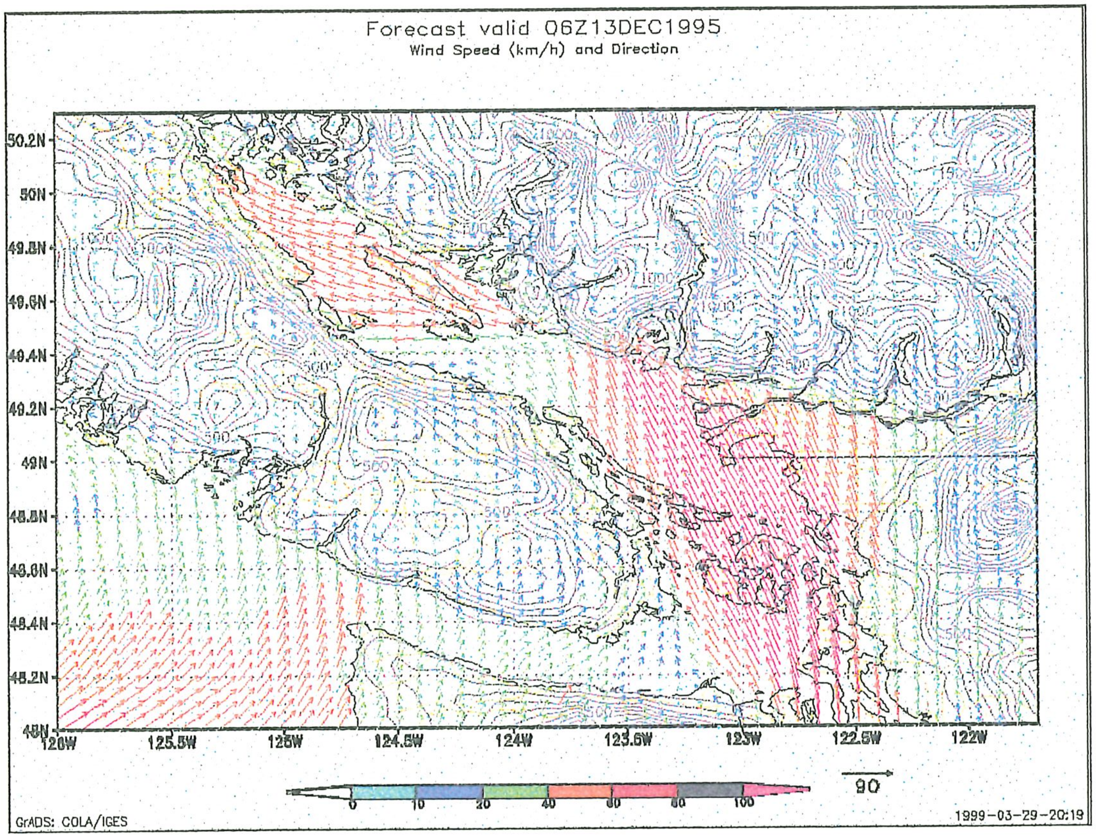
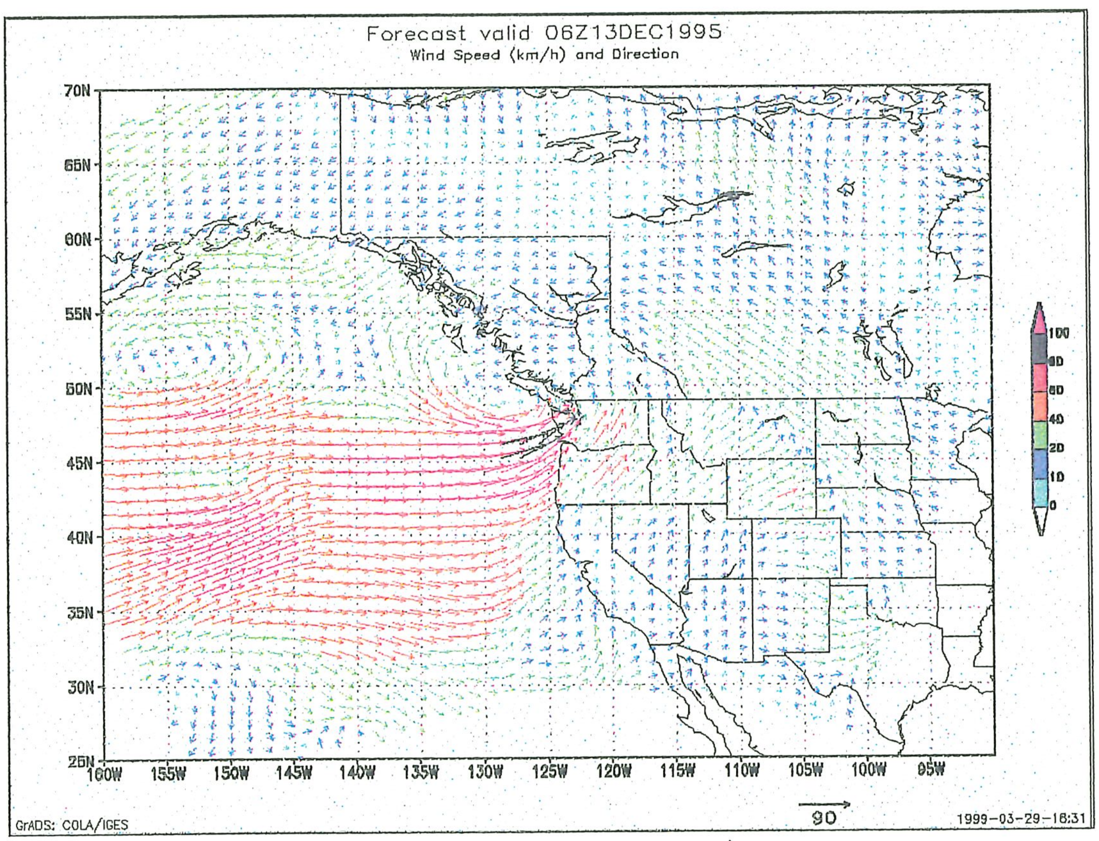


Fig. B.4.4: Same as Fig. B.1.2 but for Event No. 4 (Dec. 3 - 5, 1995).

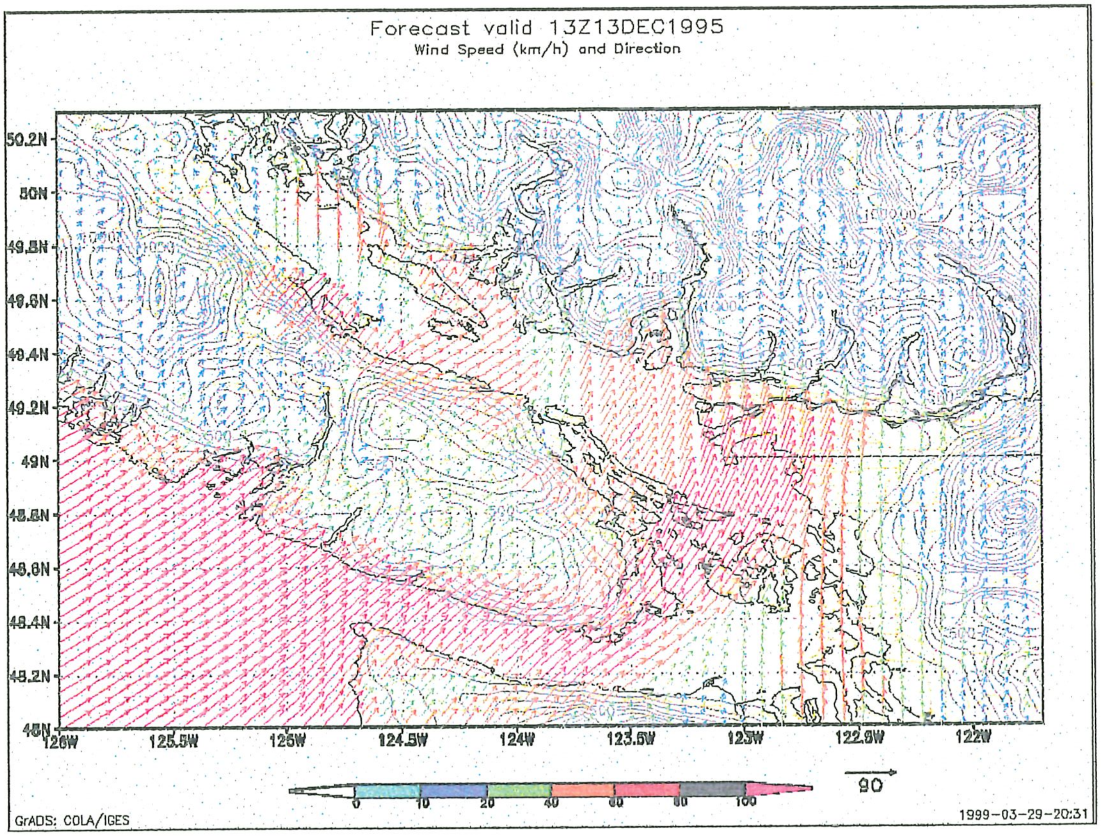
Event No. 5 (Dec. 9 - 13, 1995)

A deep surface low-pressure centre and cut-off short-wave aloft tracked from the southwest over the southern B.C. coast beginning 1900 PST on Dec. 12, 1995 (03 UTC on Dec. 13). As the low crossed the coast, the pressure gradient shifted from NW to N. Strong SE winds ahead of the low subsided with the pressure minimum, then shifted S and strengthened again behind. This resulted in two wind speed maxima over the LFV.





<u>Fig. B.5.1:</u> MC2 wind forecast for Event No. 5 at 2200 PST on Dec. 12, 1995.
Top: 3.3 km resolution, bottom: 90 km resolution.



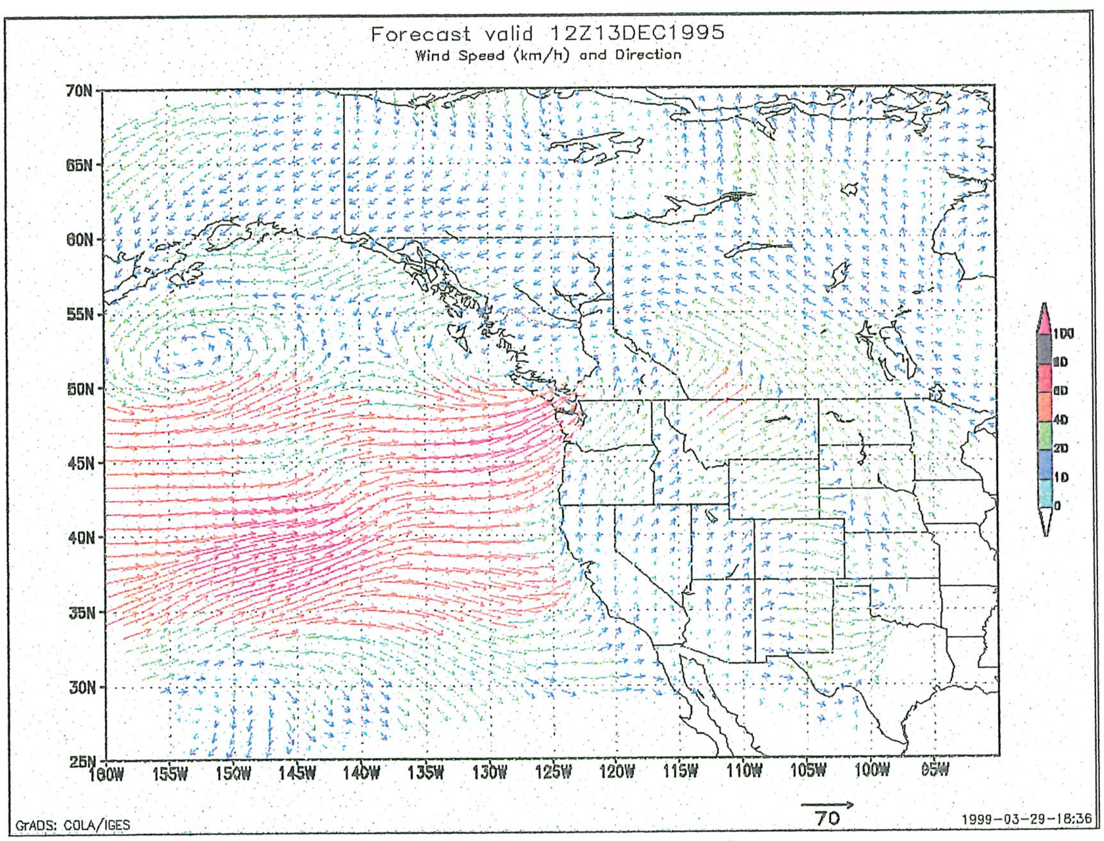


Fig. B.5.2: MC2 wind forecast for Event No. 5 at 0500 PST on Dec. 13, 1995.
Top: 3.3 km resolution, bottom: 90 km resolution.

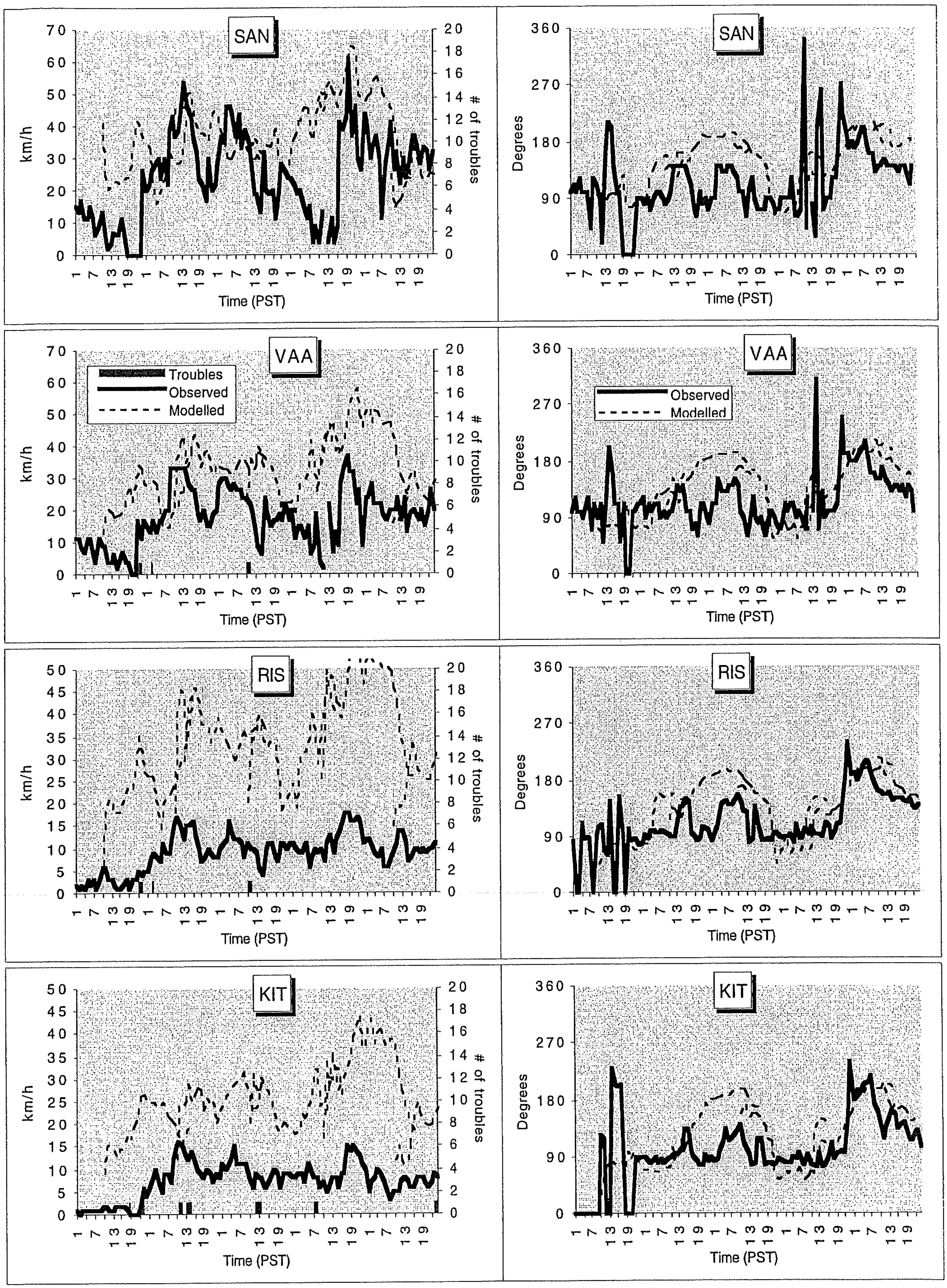


Fig. B.5.3: Same as Fig. B.1.2 but for Event No. 5 (Dec. 9 - 13, 1995).

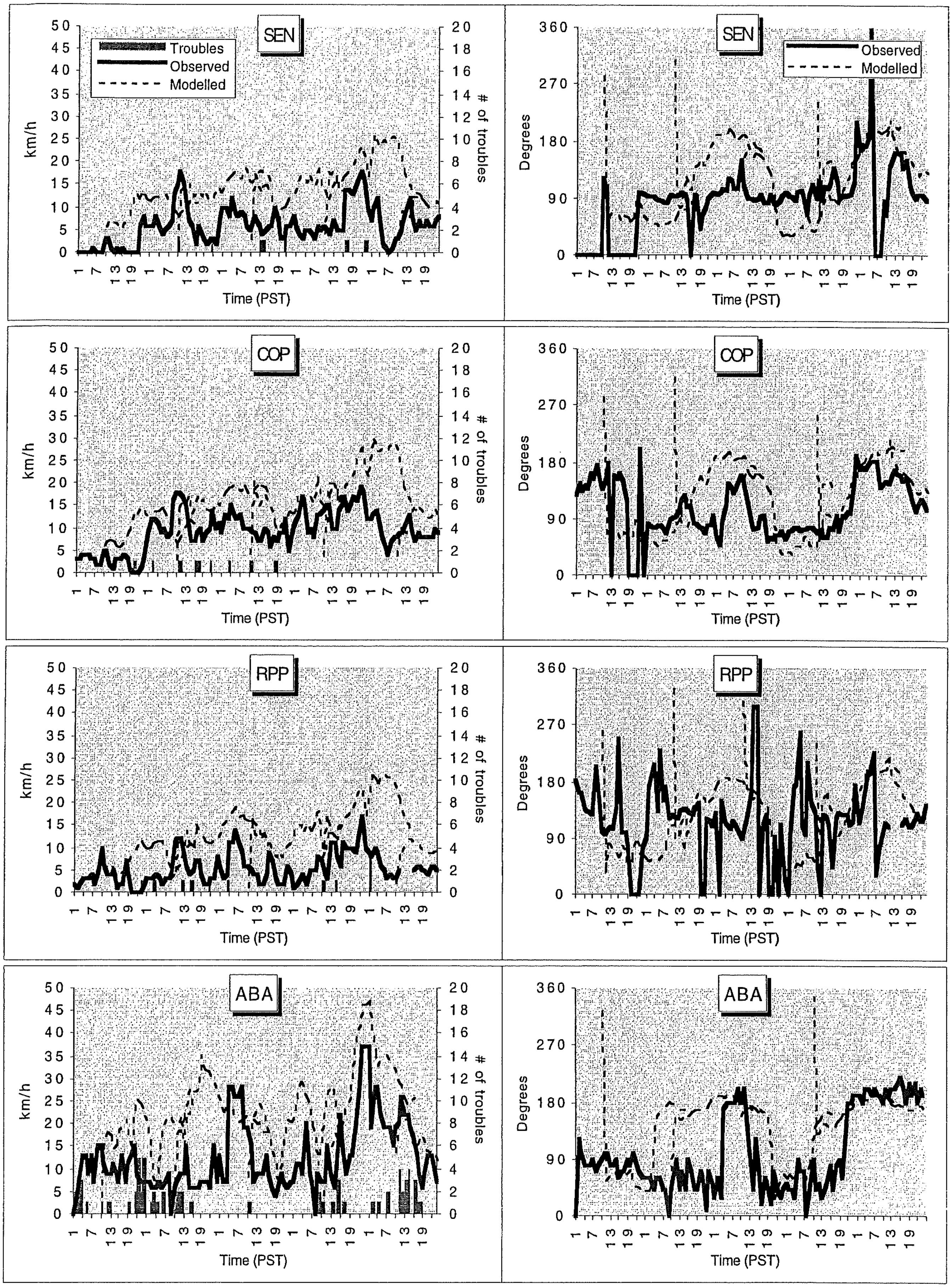


Fig. B.5.4: Same as Fig. B.1.2 but for Event No. 5 (Dec. 9 - 13, 1995).

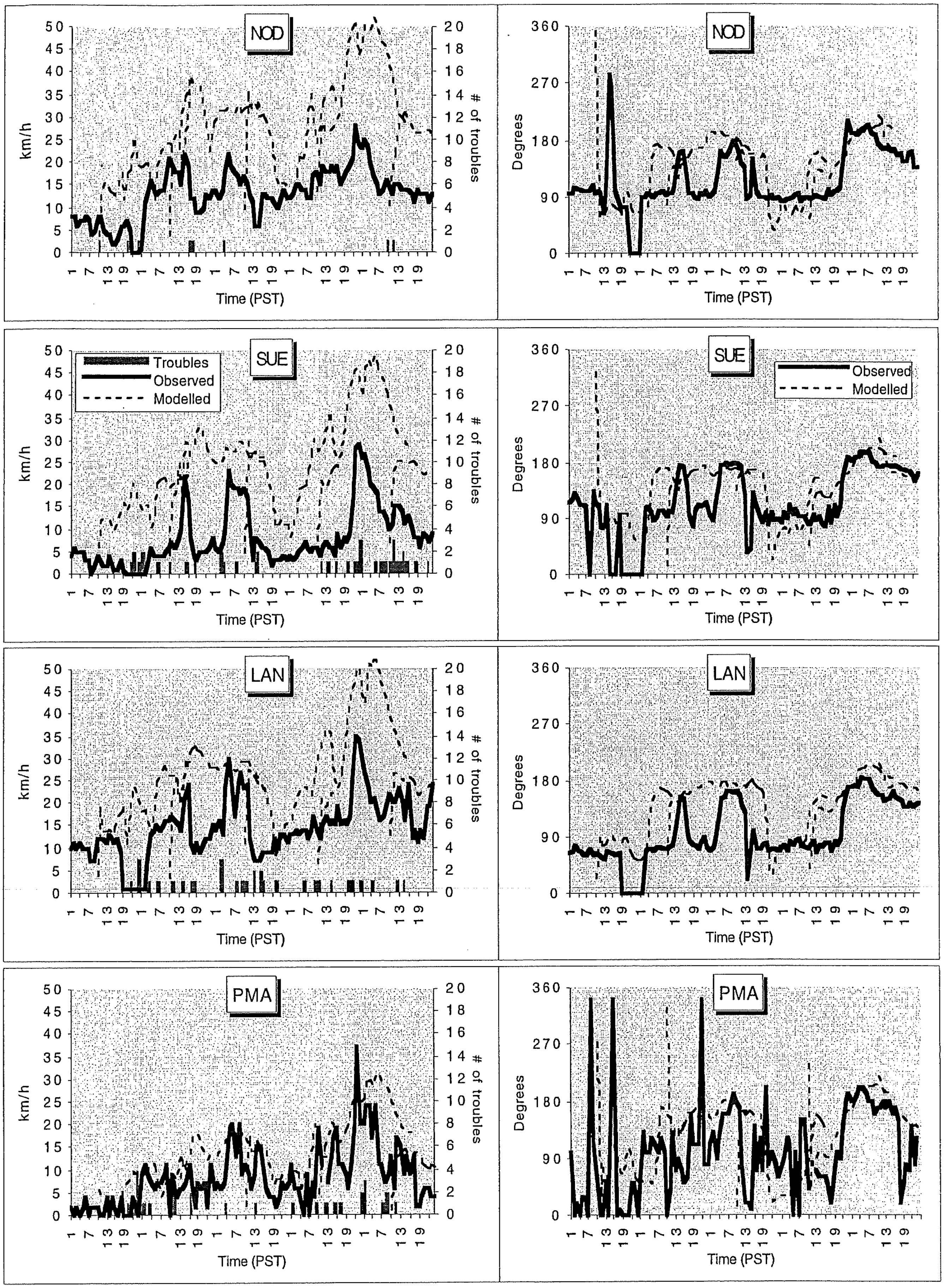


Fig. B.5.5: Same as Fig. B.1.2 but for Event No. 5 (Dec. 9 - 13, 1995).

Event No. 6 (March 29 - April 1, 1997)

A short-wave trough aloft and a rapidly-developing surface low-pressure centre tracked from the southwest over the central coast of B.C. near 1300 PST on March 30, 1997 (21 UTC on March 30). The associated cold front and MSLP minimum passed the LFV at about the same time. Convergence and wind speed along the frontal band was enhanced in the lee of the Olympic mountains, as NW winds channeled through the Strait of Juan de Fuca met S winds channeled up the Georgia Basin.

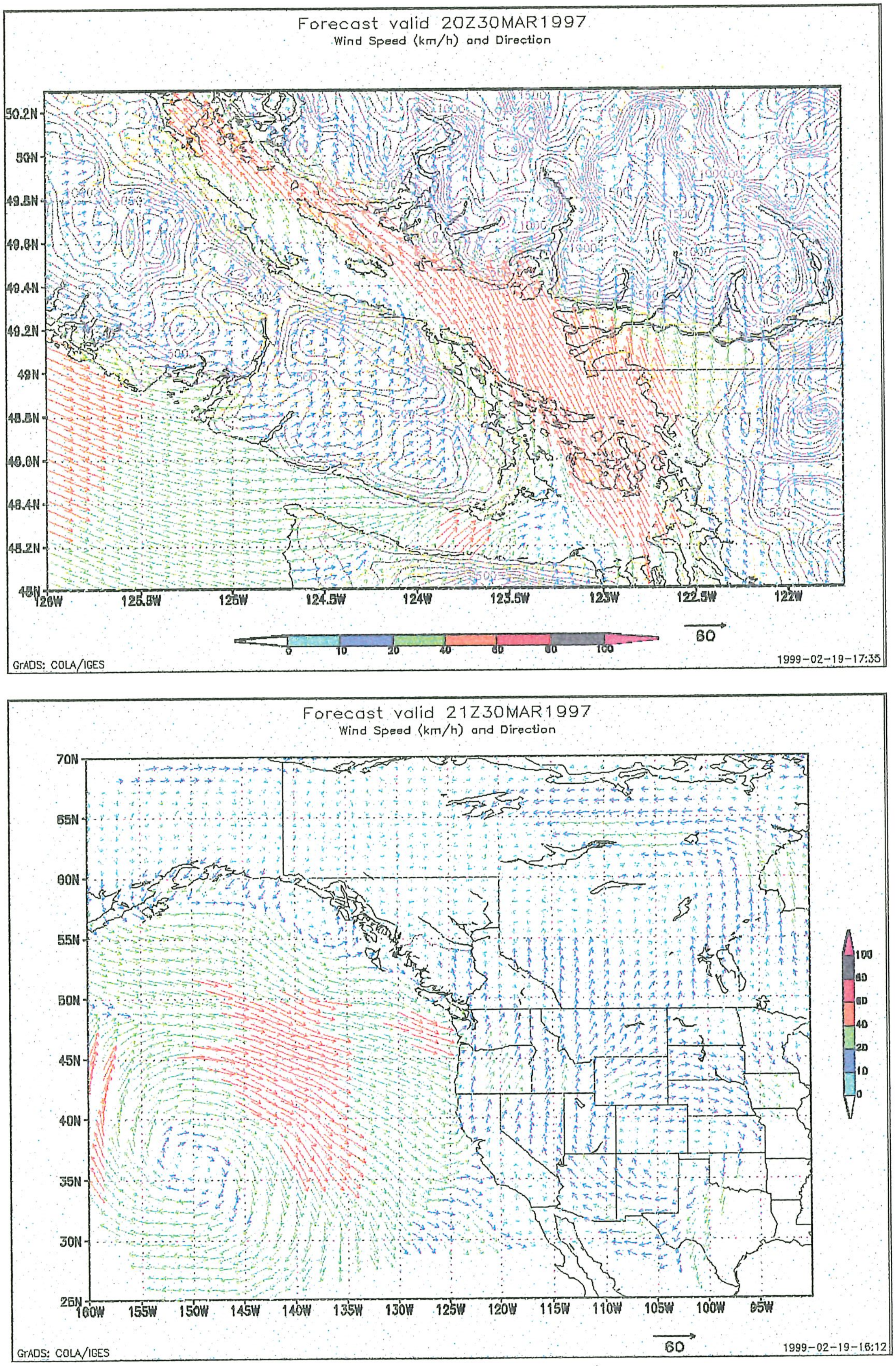


Fig. B.6.1: MC2 wind forecast for Event No. 6 at 1200 PST on Mar. 30, 1997.
Top: 3.3 km resolution, bottom: 90 km resolution.

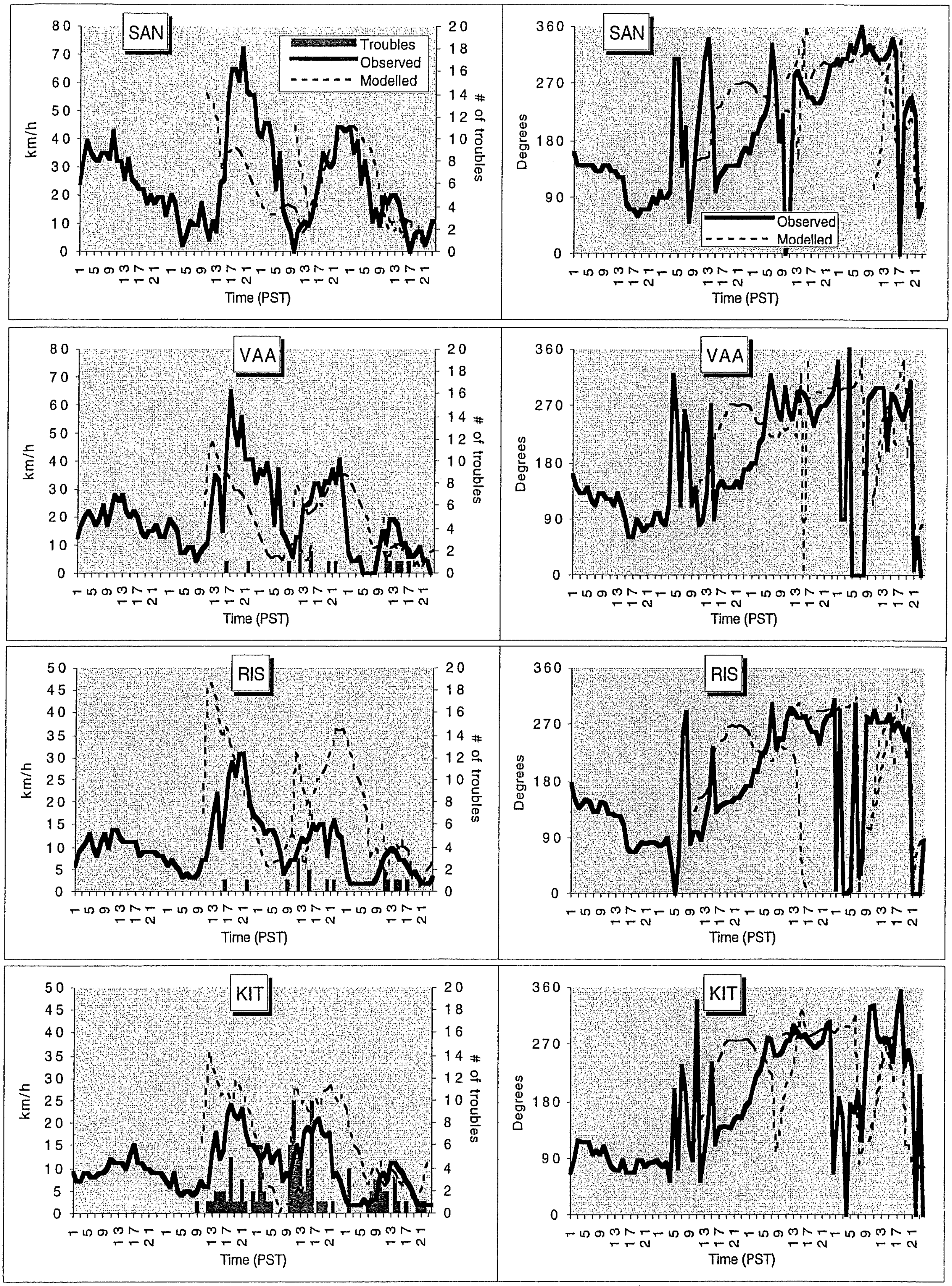


Fig. B.6.2: Same as Fig. B.1.2 but for Event No. 6 (March. 29 - April 1, 1997).

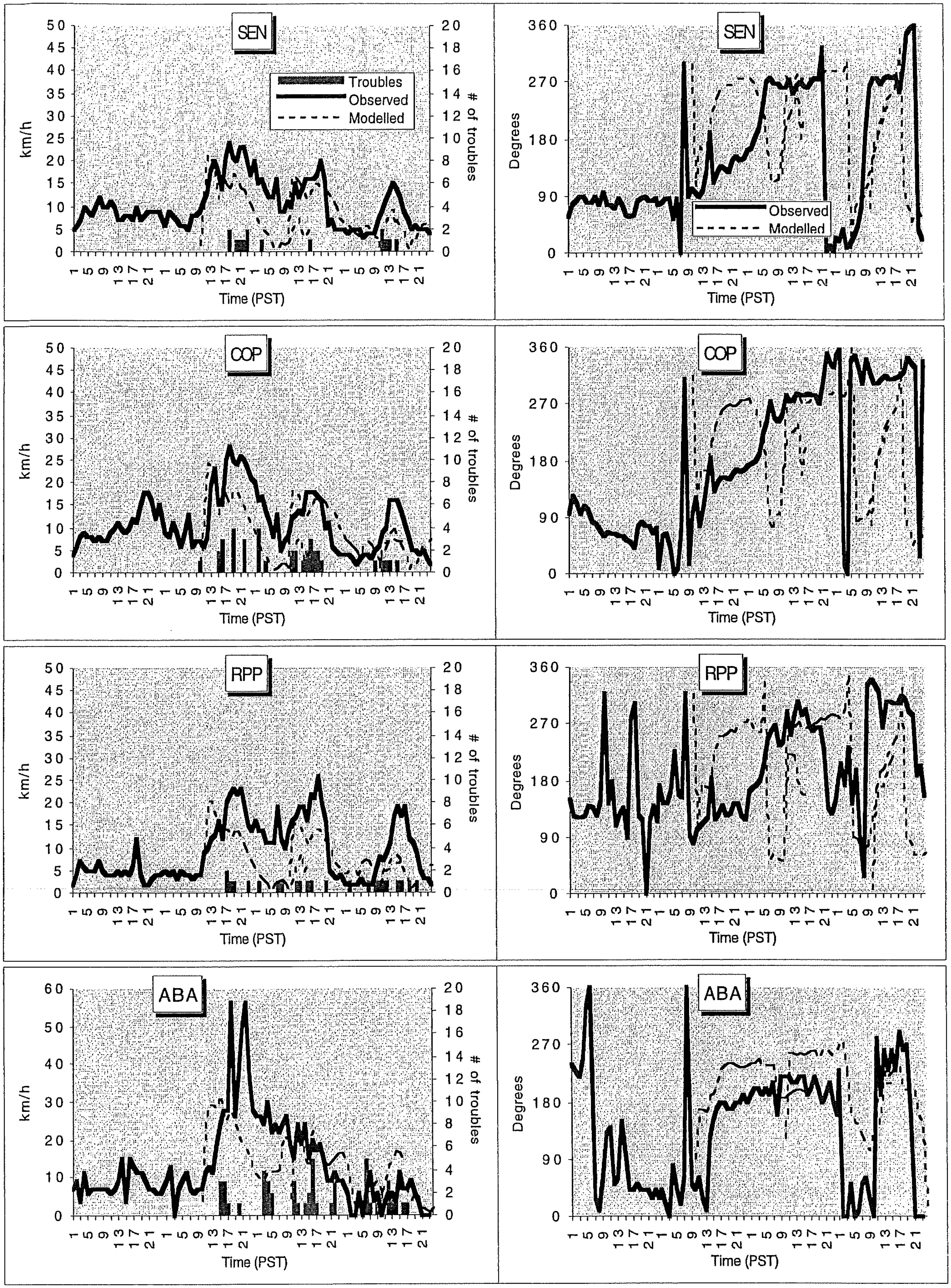


Fig. B.6.3: Same as Fig. B.1.2 but for Event No. 6 (March. 29 - April 1, 1997).

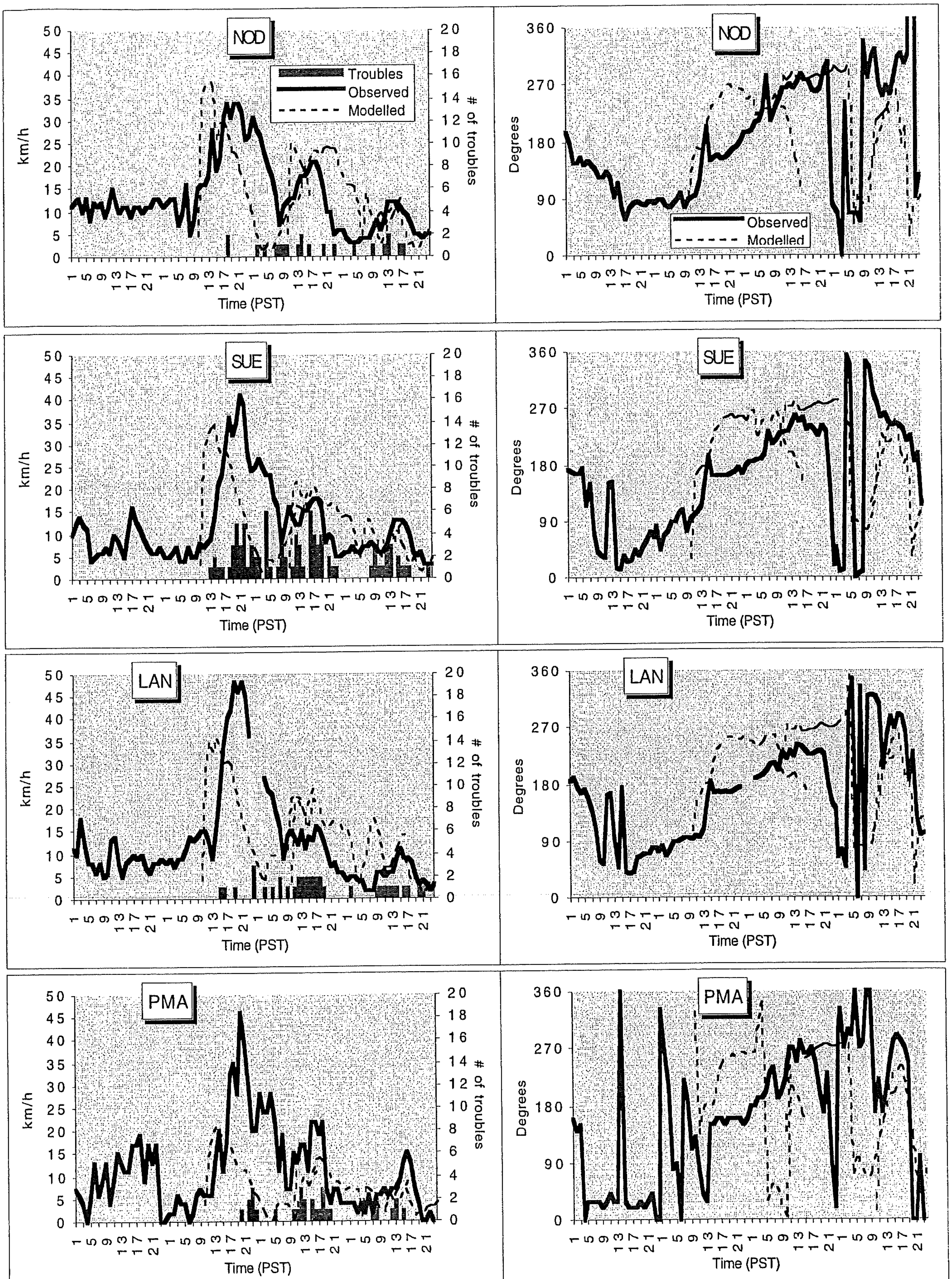


Fig. B.6.4: Same as Fig. B.1.2 but for Event No. 6 (March. 29 - April 1, 1997).

Event No. 7 (April 2 - 4, 1997)

A short-wave trough aloft and its associated surface low-pressure centre rapidly tracked around a ridge axis over the north Pacific and through northern B.C. on April 29, 1997. As the system moved into Alberta, a trailing surface trough brought its strong pressure gradient over the LFV at about 1000 PST on April 30, 1997 (18 UTC on April 30), oriented nearly due west. This caused strong winds down the axis of the Strait of Georgia.

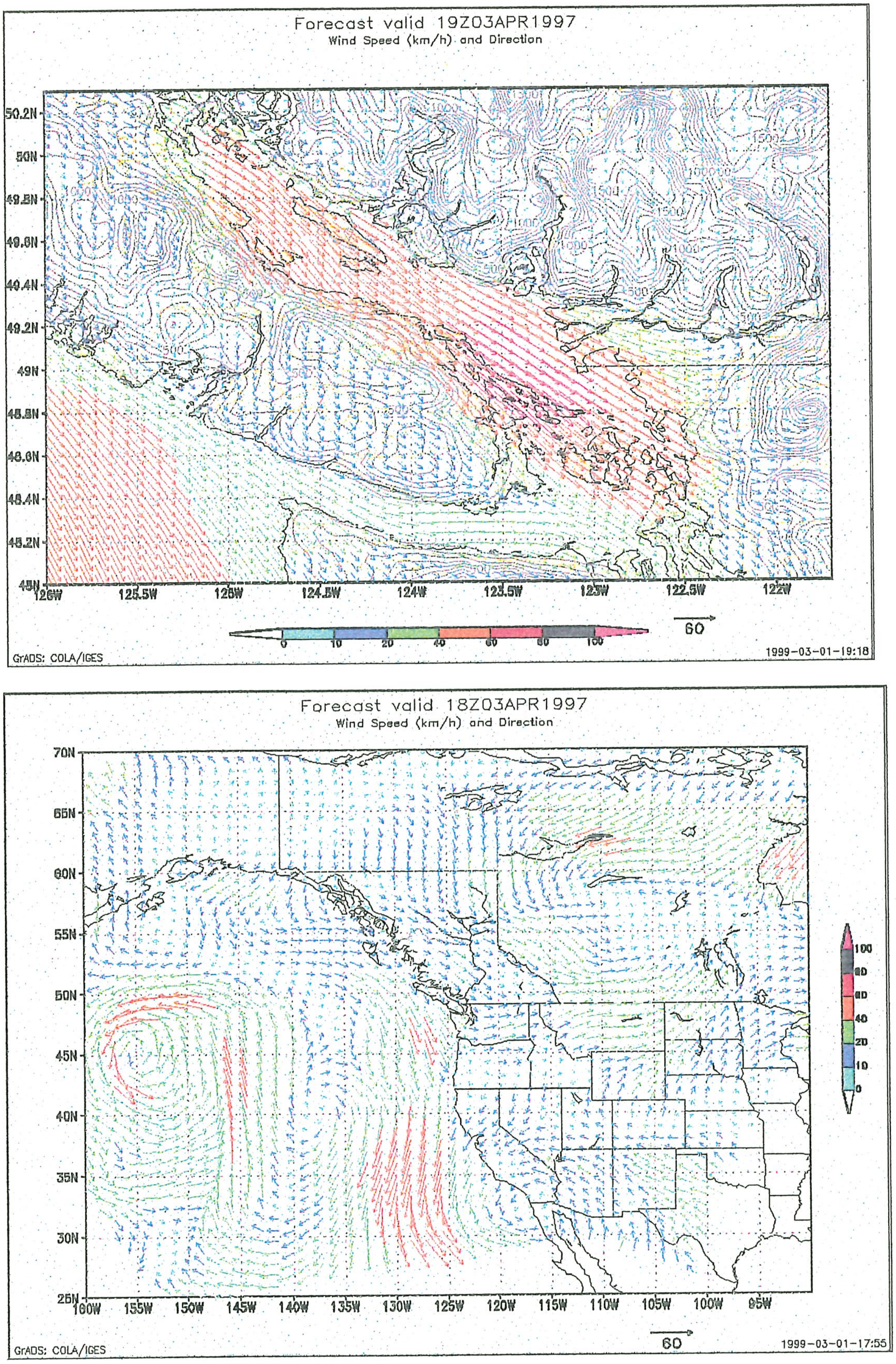


Fig. B.7.1: MC2 wind forecast for Event No. 7 at 1100 PST on Apr. 3, 1997. Top: 3.3 km resolution, bottom: 90 km resolution.

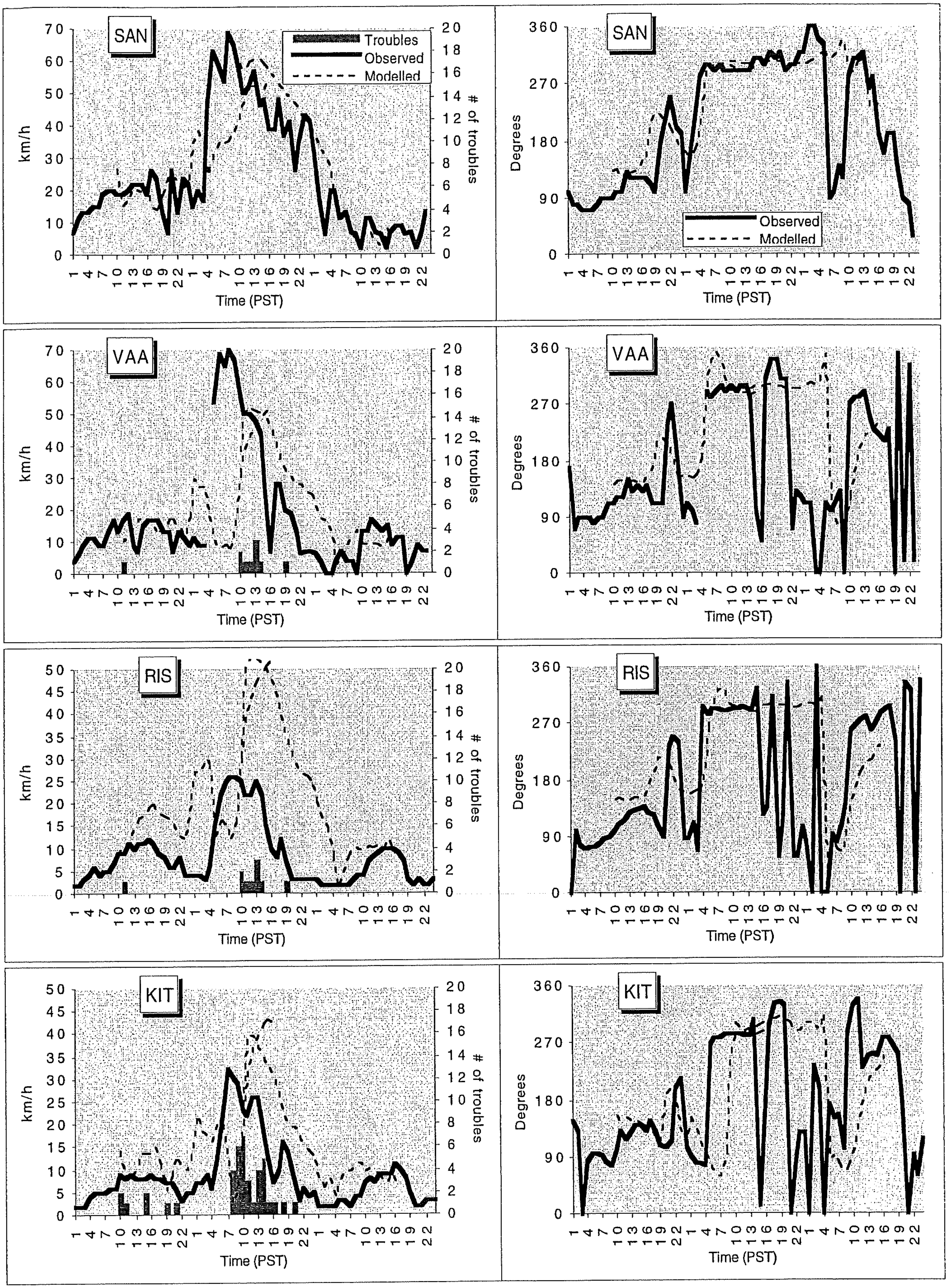


Fig. B.7.2: Same as Fig. B.1.2 but for Event No. 7 (April 2 - 4, 1997).

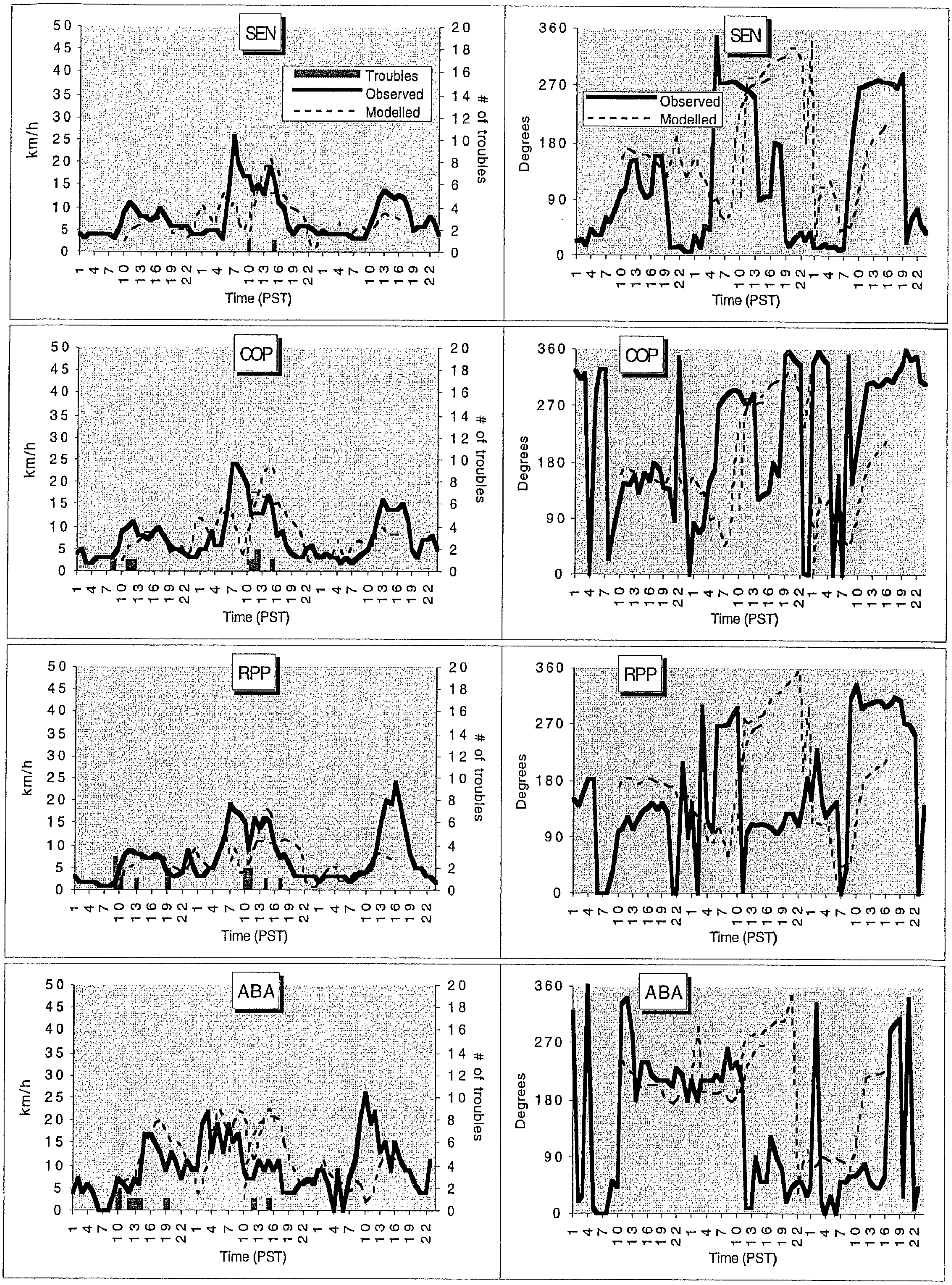


Fig. B.7.3: Same as Fig. B.1.2 but for Event No. 7 (April 2 - 4, 1997).

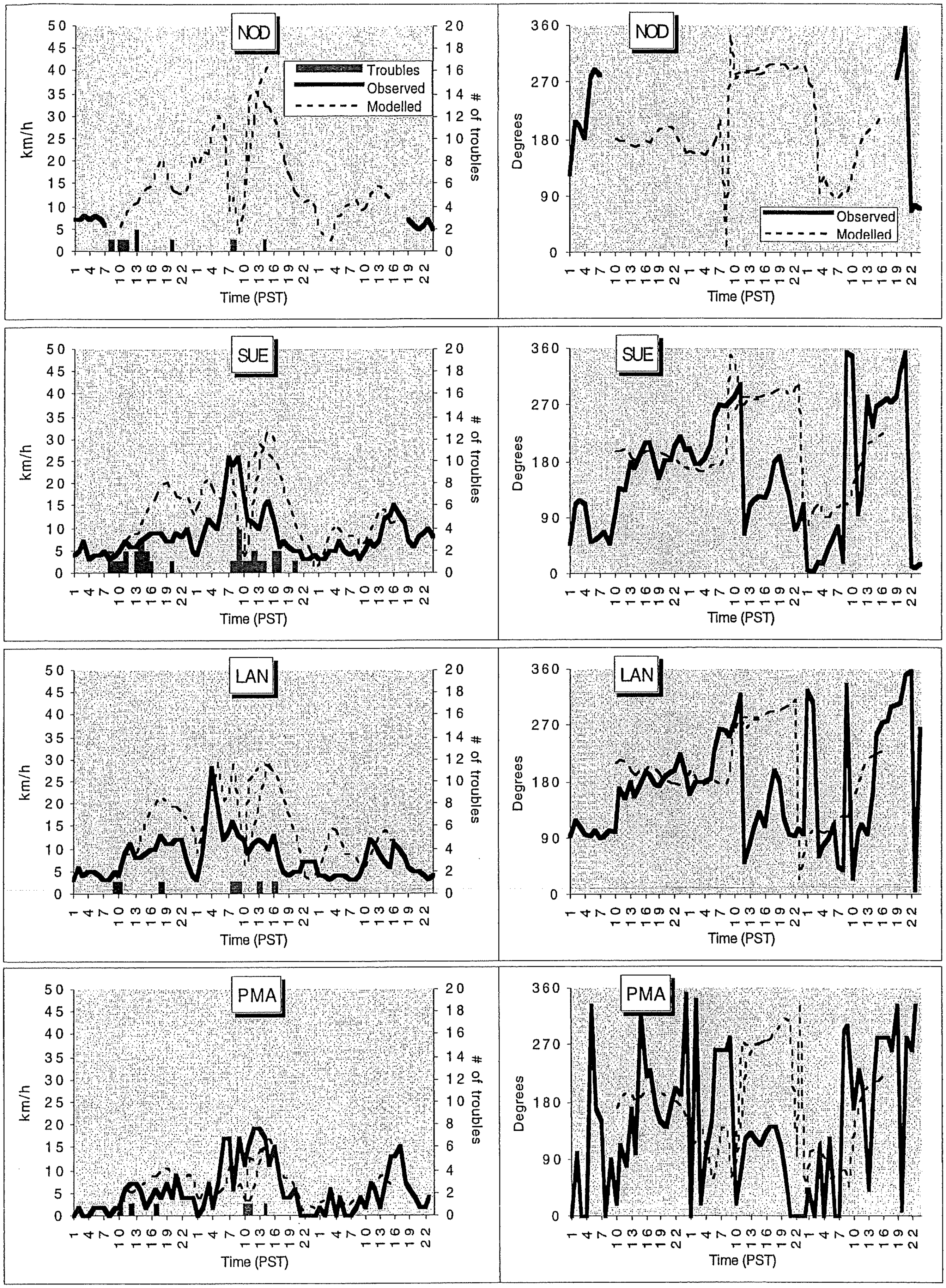
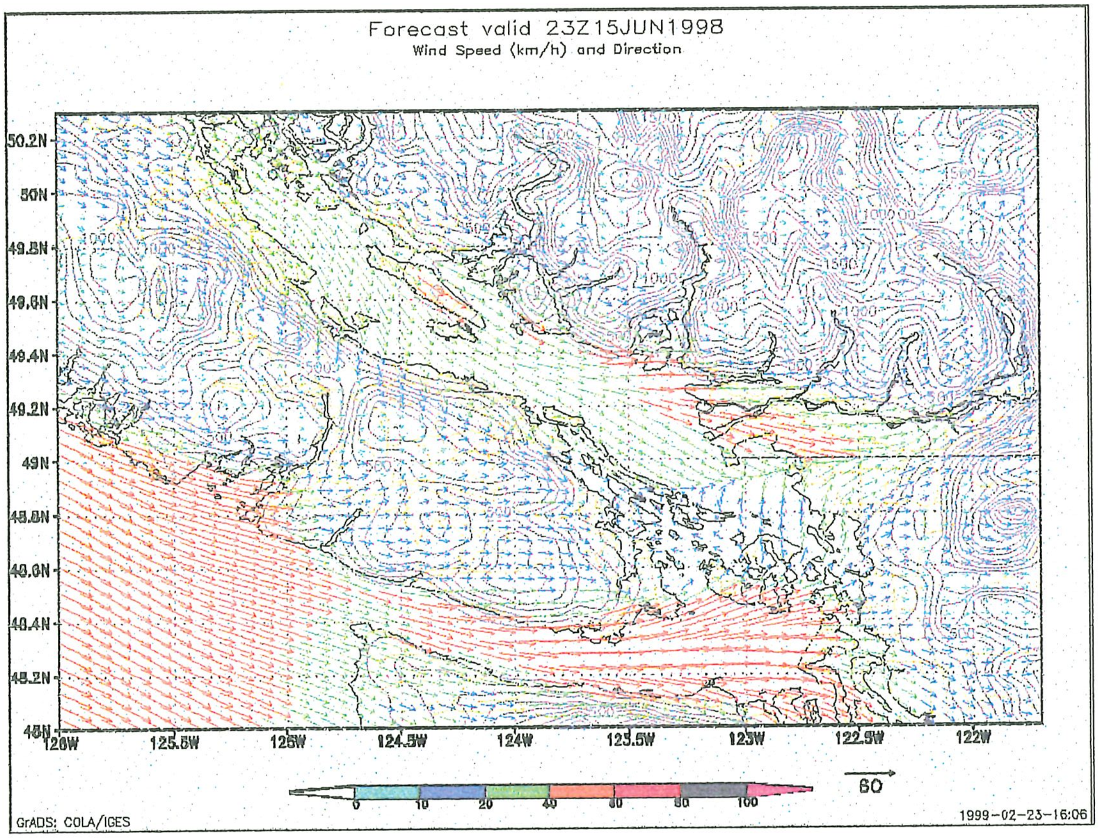


Fig. B.7.4: Same as Fig. B.1.2 but for Event No. 7 (April 2 - 4, 1997).

Event No. 8 (June 14 - 16, 1998)

A short-wave trough aloft and its associated surface low-pressure centre rapidly tracked around a ridge axis over the north Pacific and through northern B.C. on June 14 and early June 15, 1998. As the system stalled over southern Alberta, a strong WSW pressure gradient set up over the LFV, forcing a maxima as the NW winds were channeled down the Strait of Georgia.



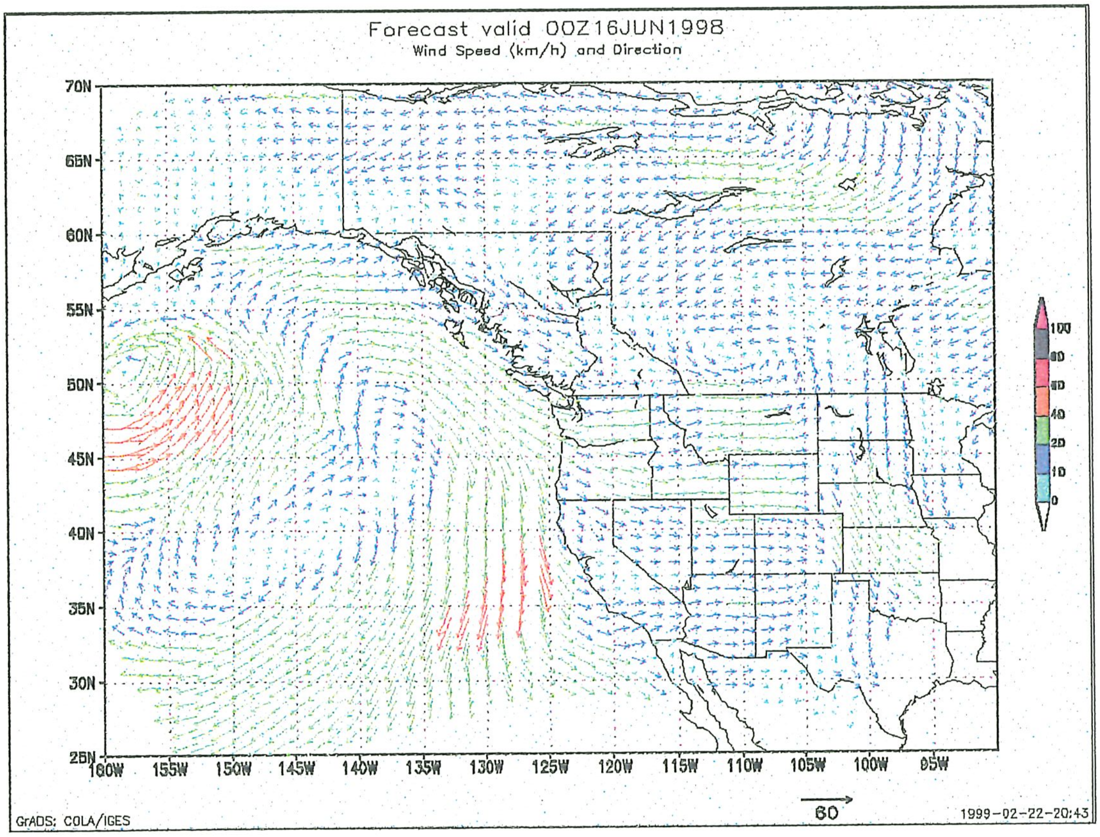
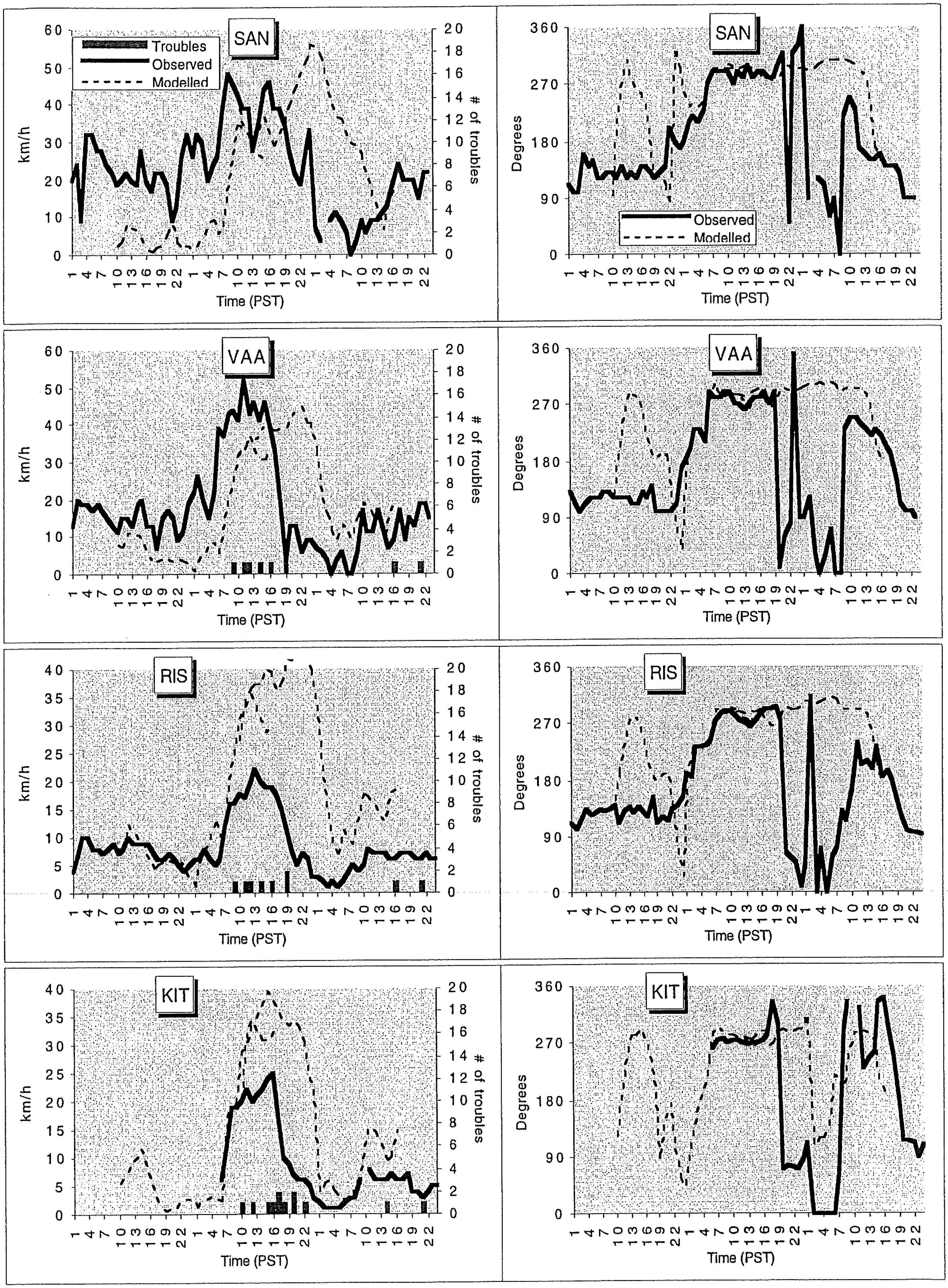


Fig. B.8.1: MC2 wind forecast for Event No. 8 at 1500 PST on Jun. 15, 1998. Top: 3.3 km resolution, bottom: 90 km resolution.



<u>Fig. B.8.2:</u> Same as Fig. B.1.2 but for Event No. 8 (June 14 - 16, 1998).

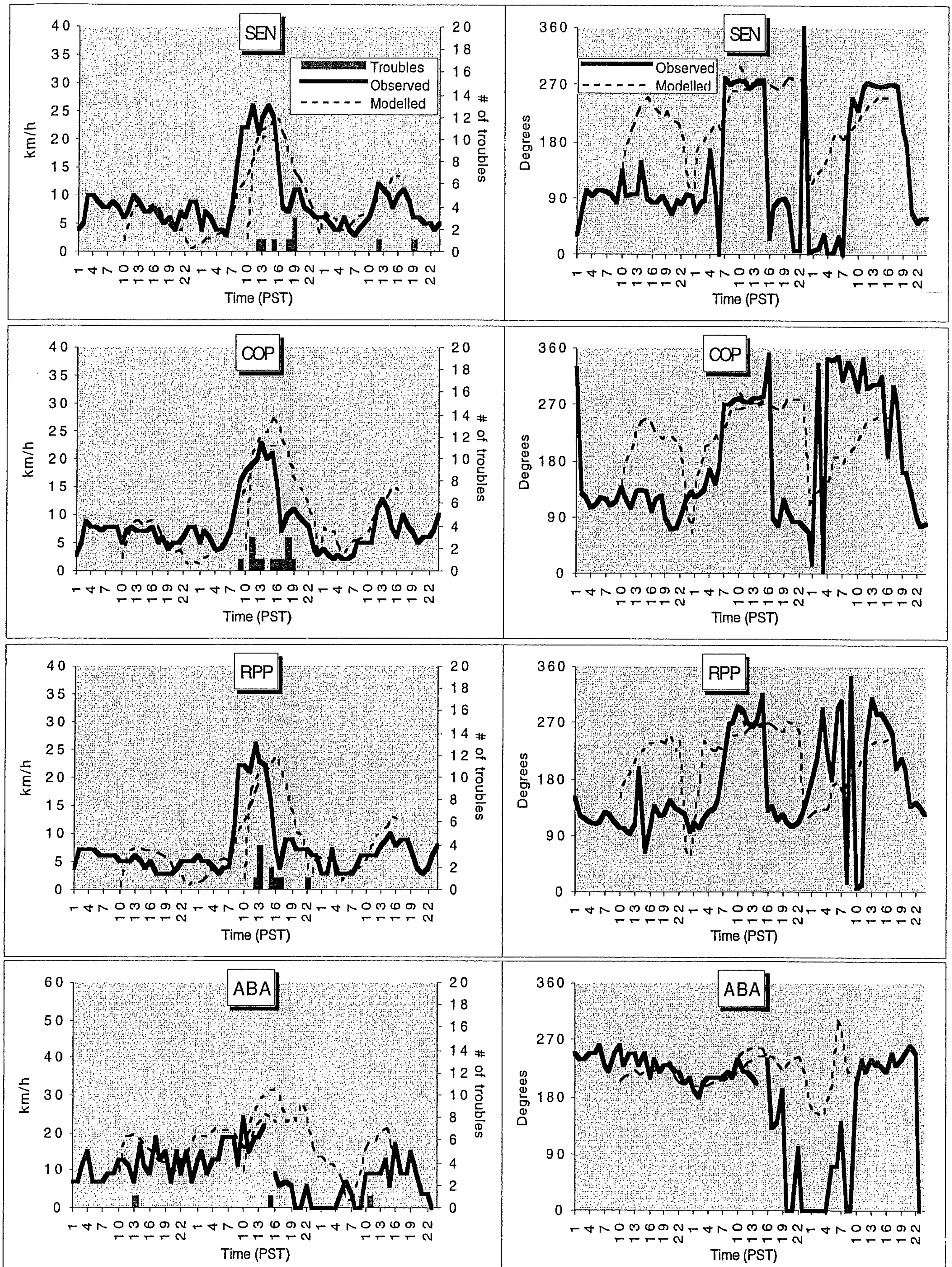


Fig. B.8.3: Same as Fig. B.1.2 but for Event No. 8 (June 14 - 16, 1998).

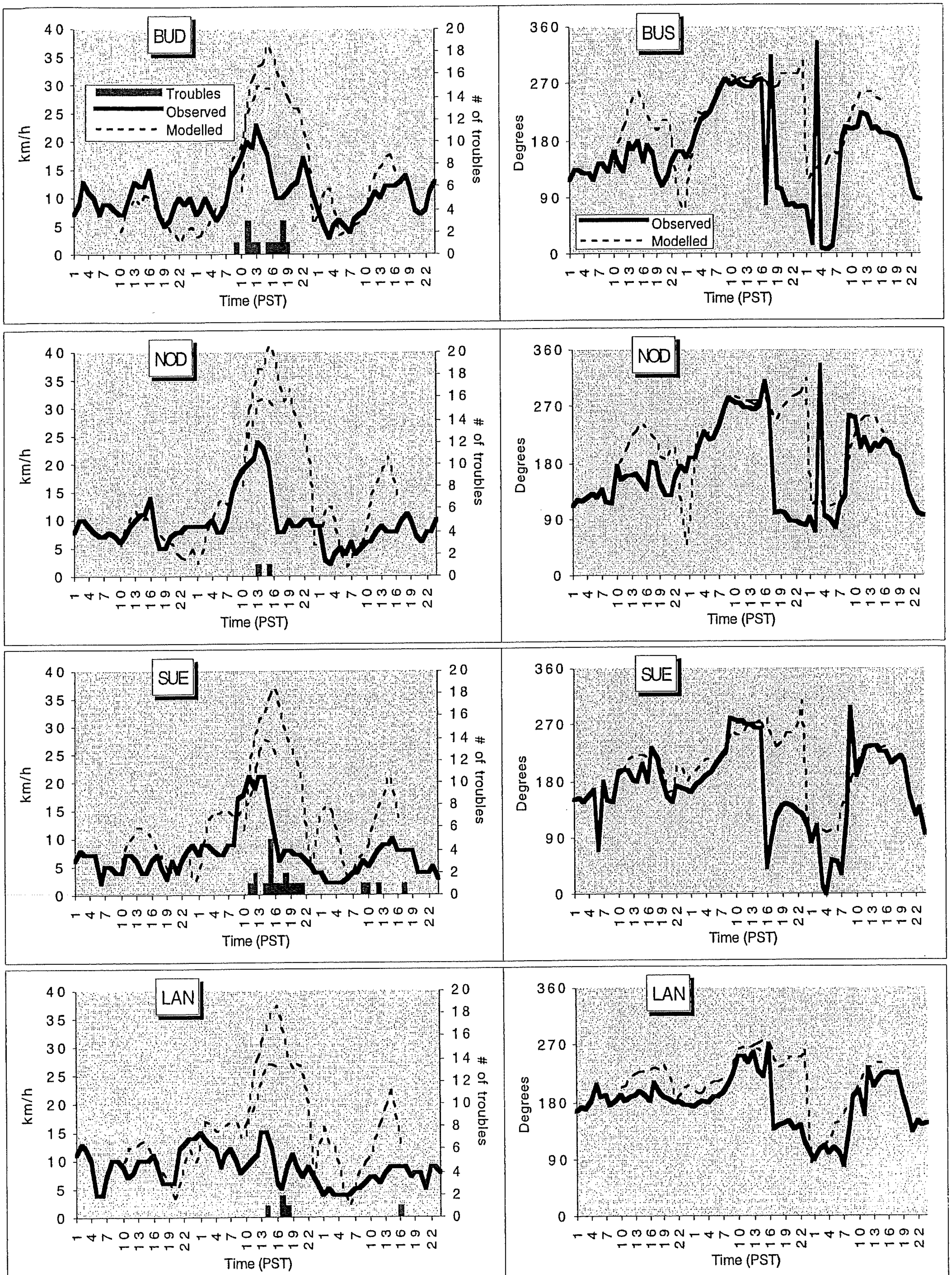


Fig. B.8.4: Same as Fig. B.1.2 but for Event No. 8 (June 14 - 16, 1998).

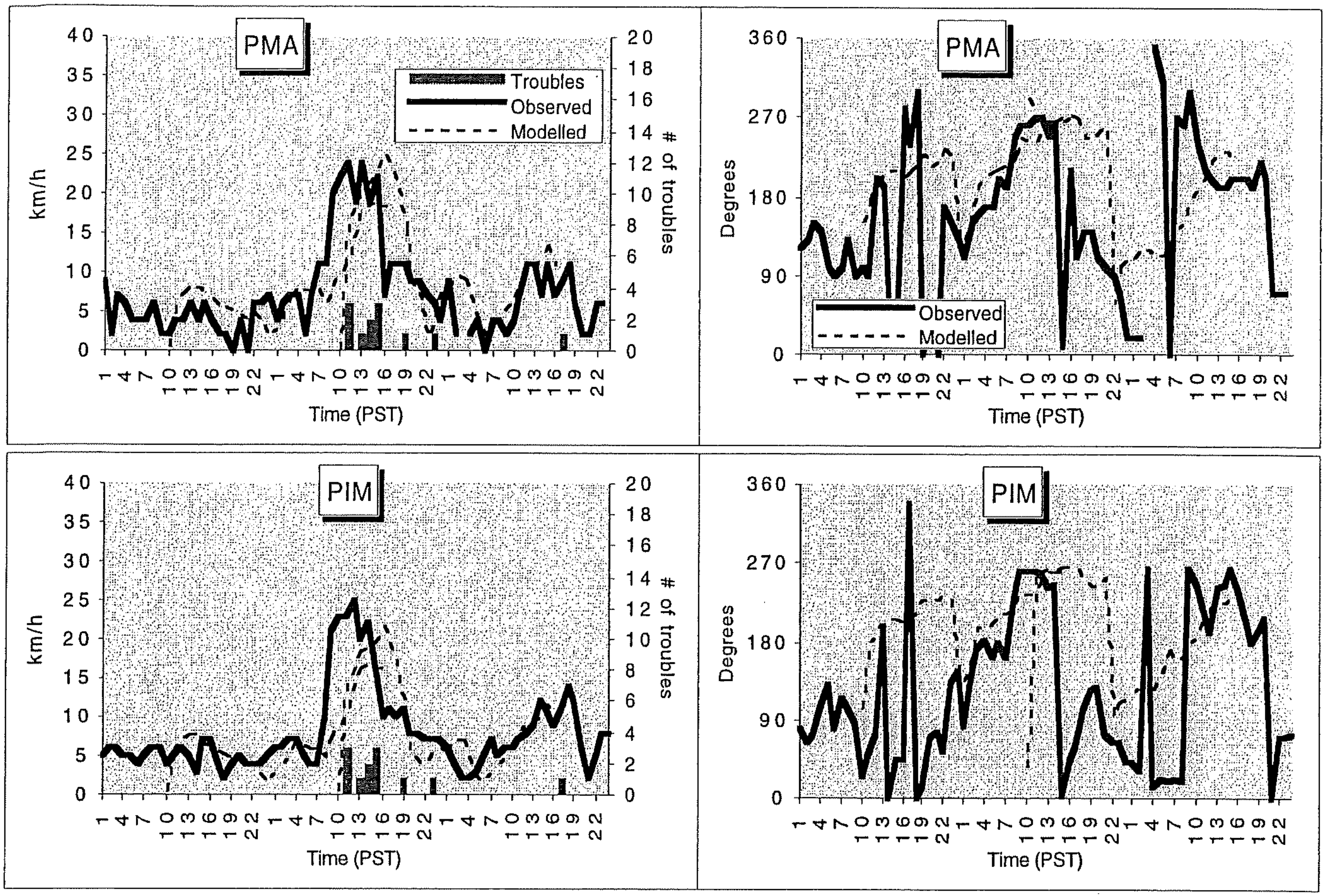
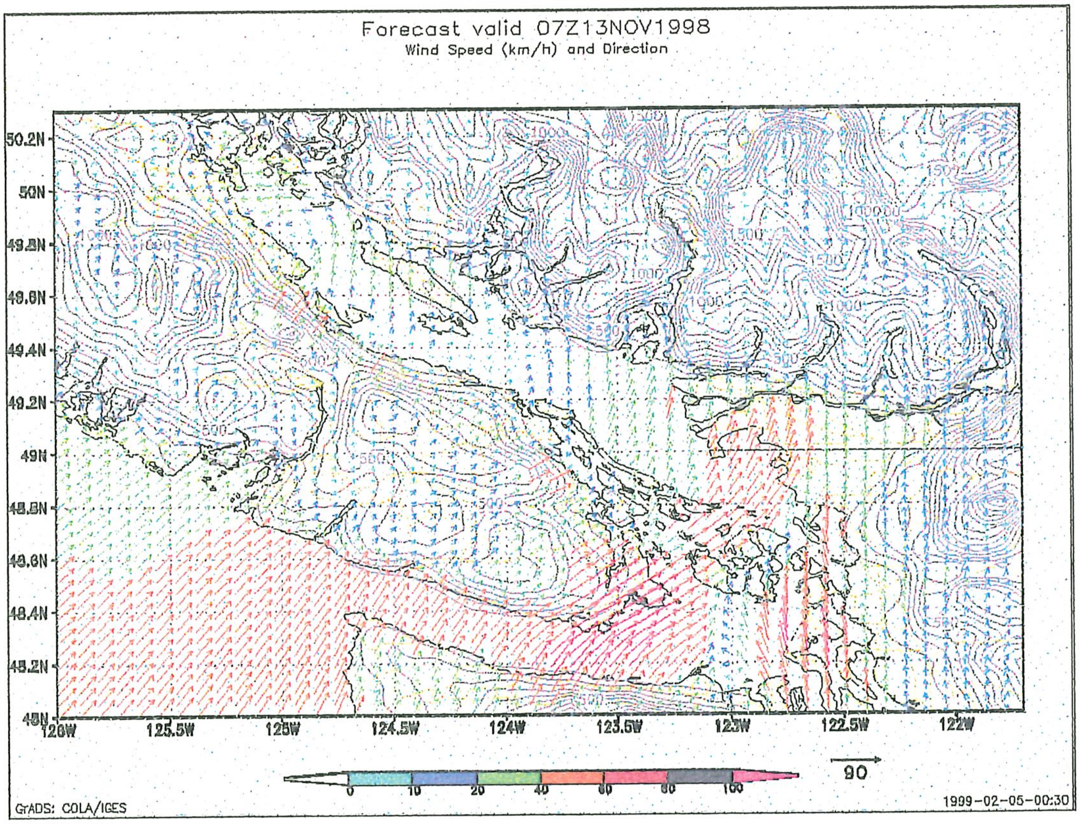


Fig. B.8.5: Same as Fig. B.1.2 but for Event No. 8 (June 14 - 16, 1998).

Event No. 9 (Nov. 11 - 14, 1998)

An upper-level long-wave ridge axis slowly shifted from over the pacific on Nov. 12, 1998 to over the western U.S. the next day. As it shifted, the surface high strengthened over the U.S. Great Basin and the upstream trough shifted slightly southeastward. This allowed a strong pressure gradient along the upstream branch of the ridge, oriented NW, to stall over the LFV. The result was strong SW winds intersecting the Olympic mountains, which converged and strengthened in the lee, over the southern Strait of Georgia.



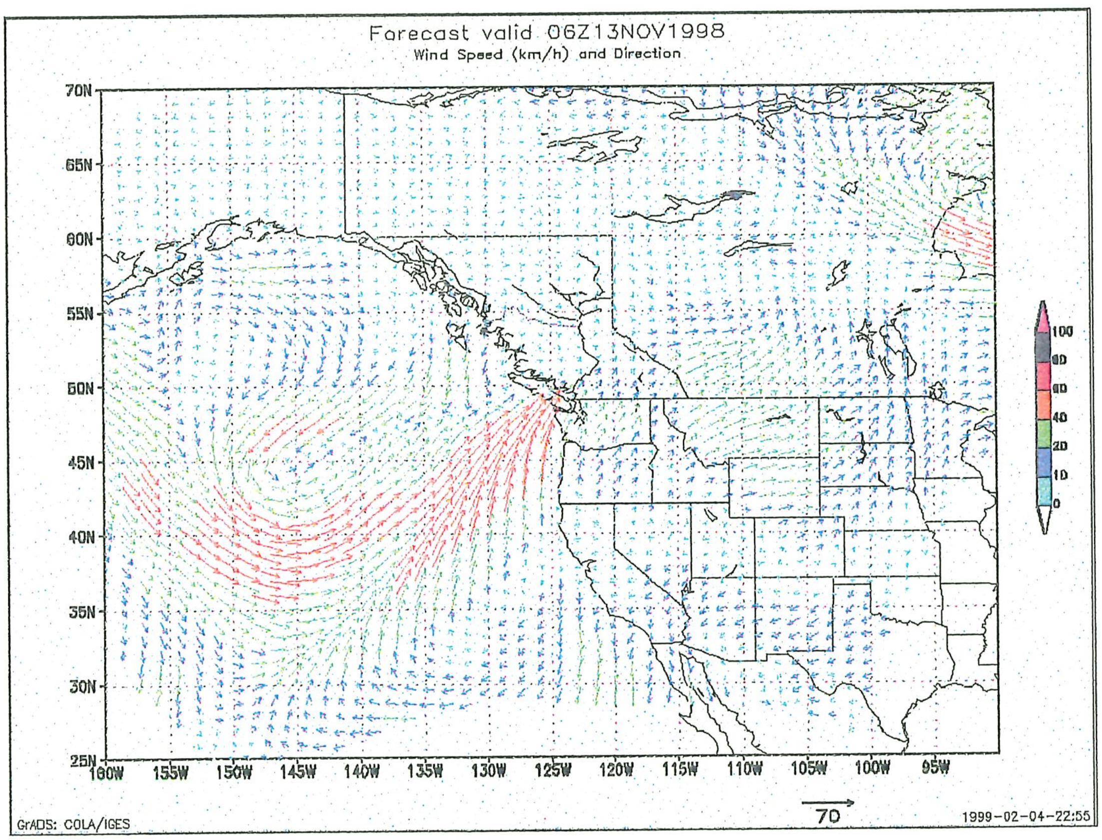


Fig. B.9.1: MC2 wind forecast for Event No. 9 at 2300 PST on Nov. 12, 1998.
Top: 3.3 km resolution, bottom: 90 km resolution.

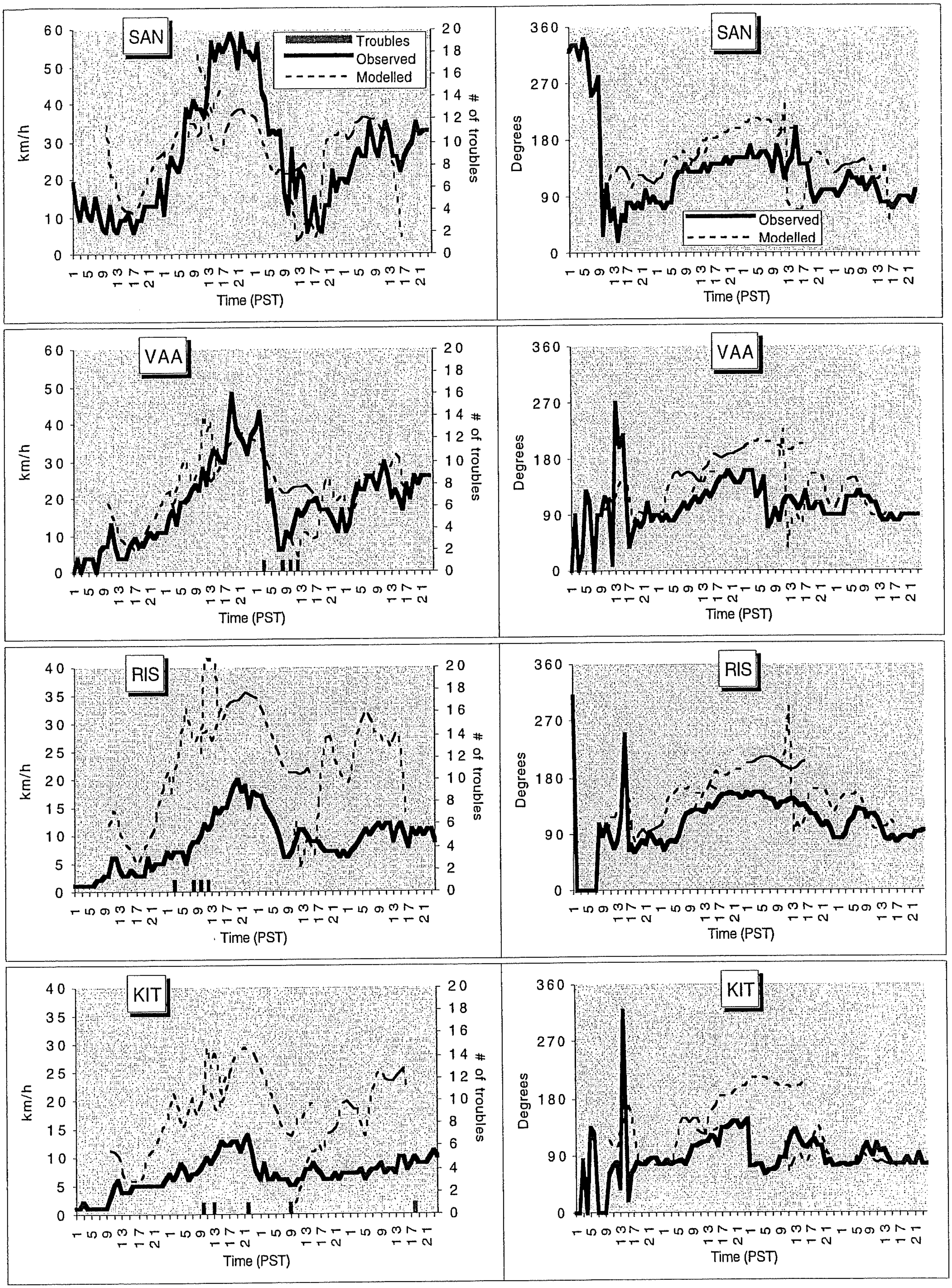


Fig. B.9.2: Same as Fig. B.1.2 but for Event No. 9 (Nov. 11 - 14, 1998).

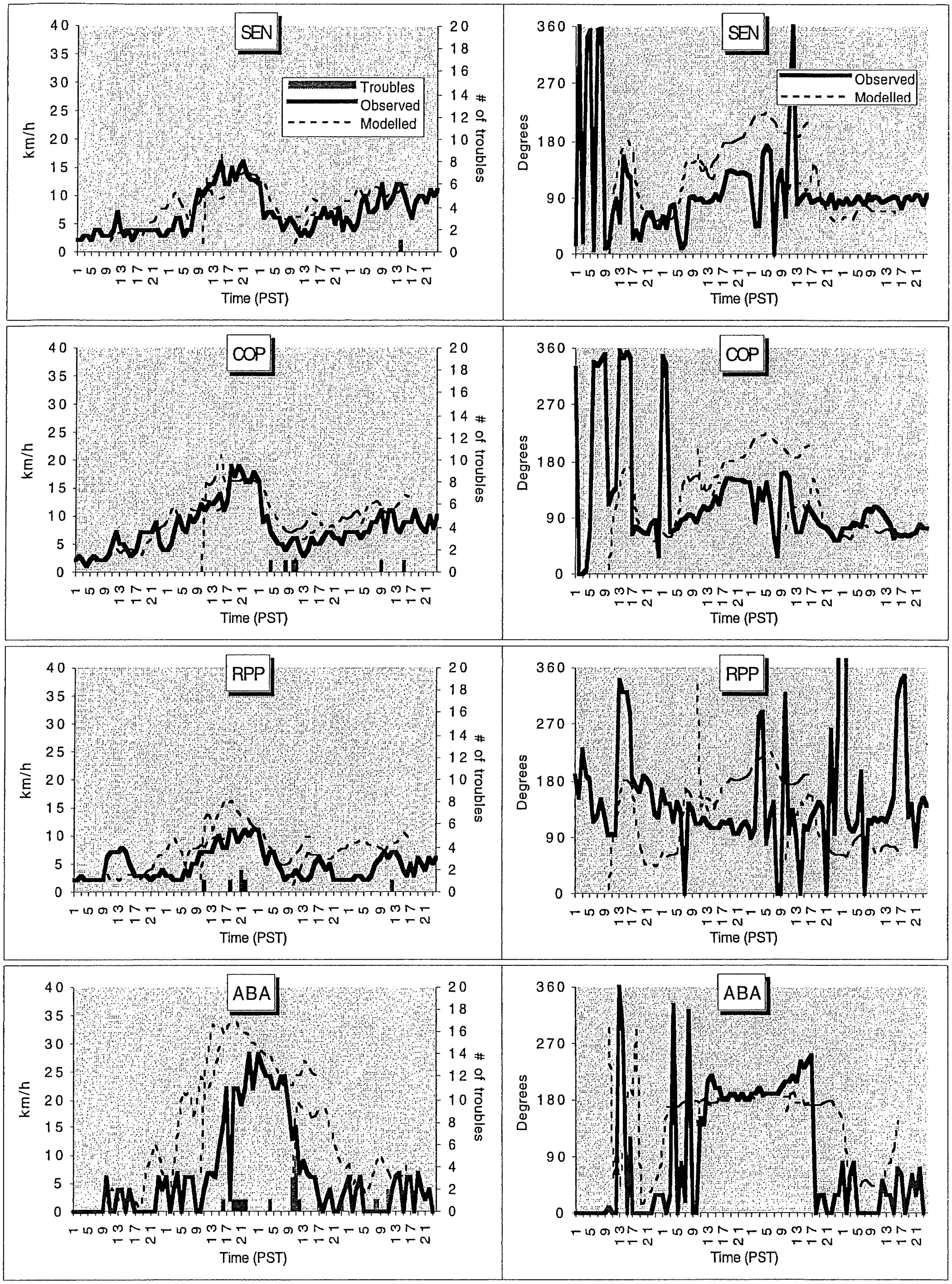


Fig. B.9.3: Same as Fig. B.1.2 but for Event No. 9 (Nov. 11 - 14, 1998).

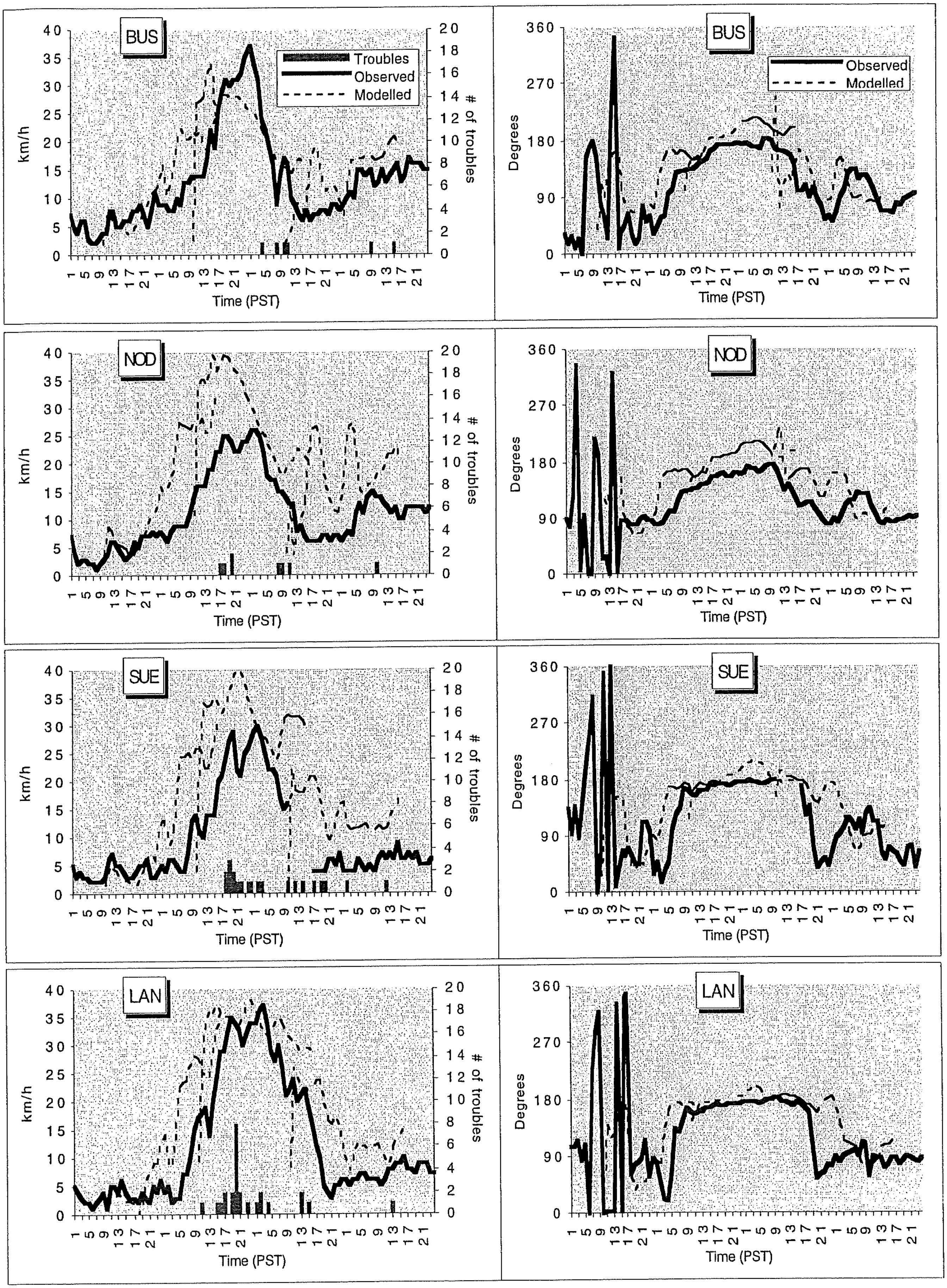


Fig. B.9.4: Same as Fig. B.1.2 but for Event No. 9 (Nov. 11 - 14, 1998).

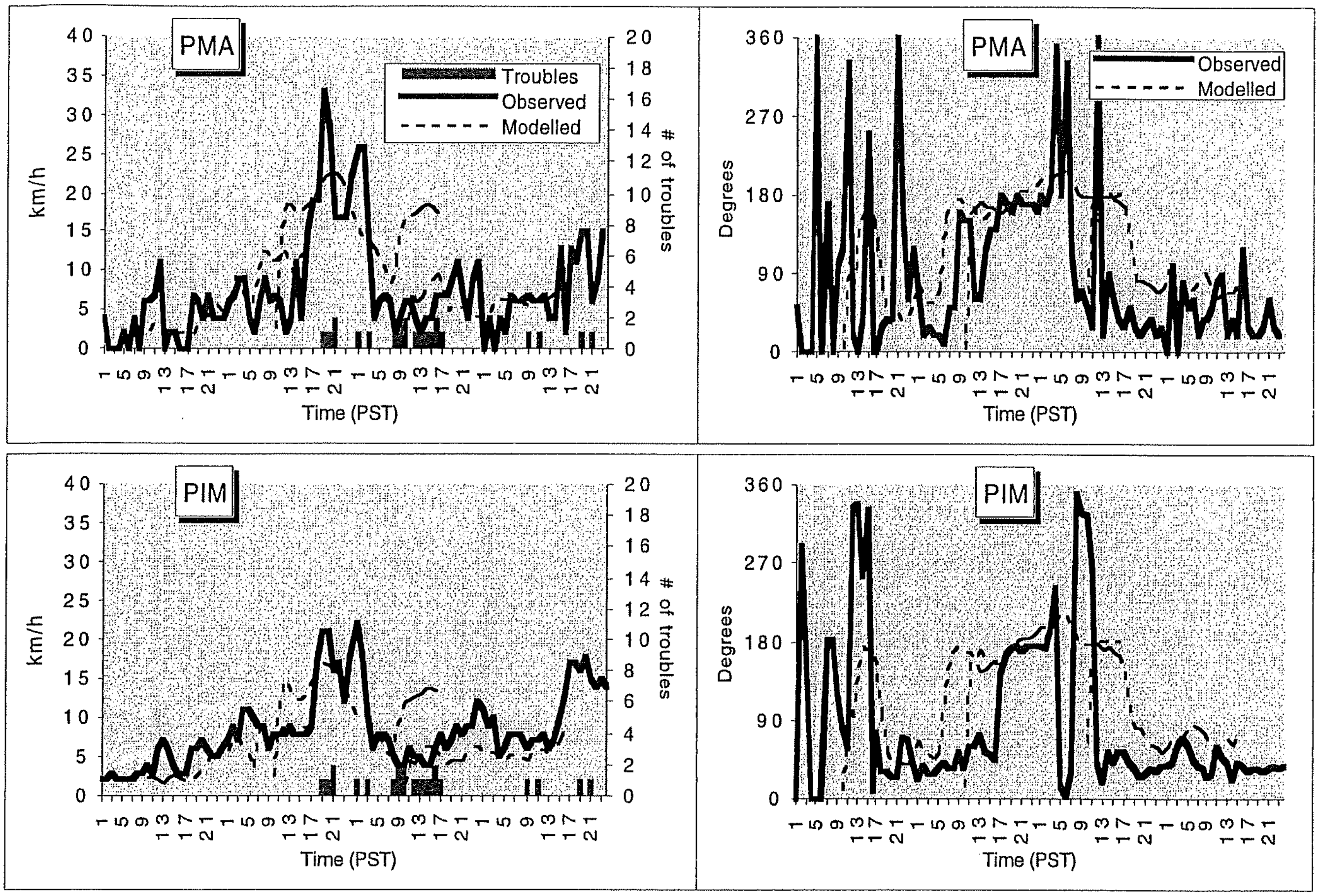


Fig. B.9.5: Same as Fig. B.1.2 but for Event No. 9 (Nov. 11 - 14, 1998).

Event No. 10 (Nov. 23 - 26, 1998)

The centre of a deep low-pressure system and accompanying short-wave aloft tracked from the southwest across central Vancouver island and the sunshine coast. Strong pressure gradients ahead and behind the low were responsible for the two wind maxima, with a local wind speed minima as the low centre crossed the mainland coast at about 2200 PST on Nov. 23, 1998 (06 UTC Nov. 24). Because of the proximity of the low-pressure centre to the LFV, its passage had similar effects as a tropical storm making landfall might have. That is, the "eye" of the storm produced a relative wind minimum and the major destruction occurred as the "walls" crossed the lower mainland. Here, the walls were just the areas around the pressure minimum that displayed the greatest pressure gradient. The direction of the gradient shifted as the MSLP minimum passed the LFV, causing the wind direction to shift from SSE at the first maximum to SW at the second.

Less than a day later, at about 2200 PST on Nov. 24 (06 UTC Nov. 25), another high-wind Event was caused by a second rapidly-moving, mature system that tracked zonally across the Pacific and the central B.C. coast. The wind maximum occurred with passage of the associated occluded front.

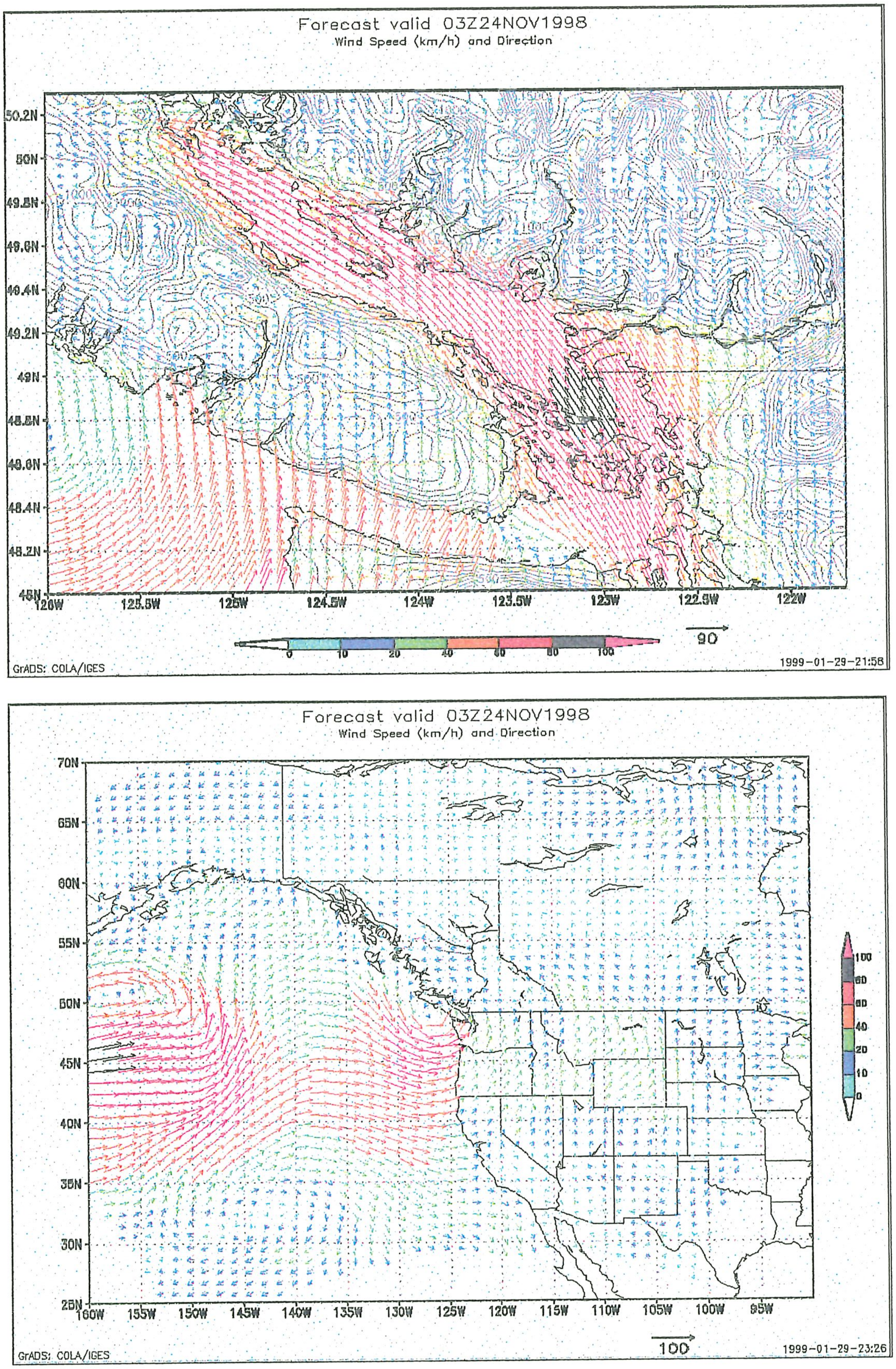
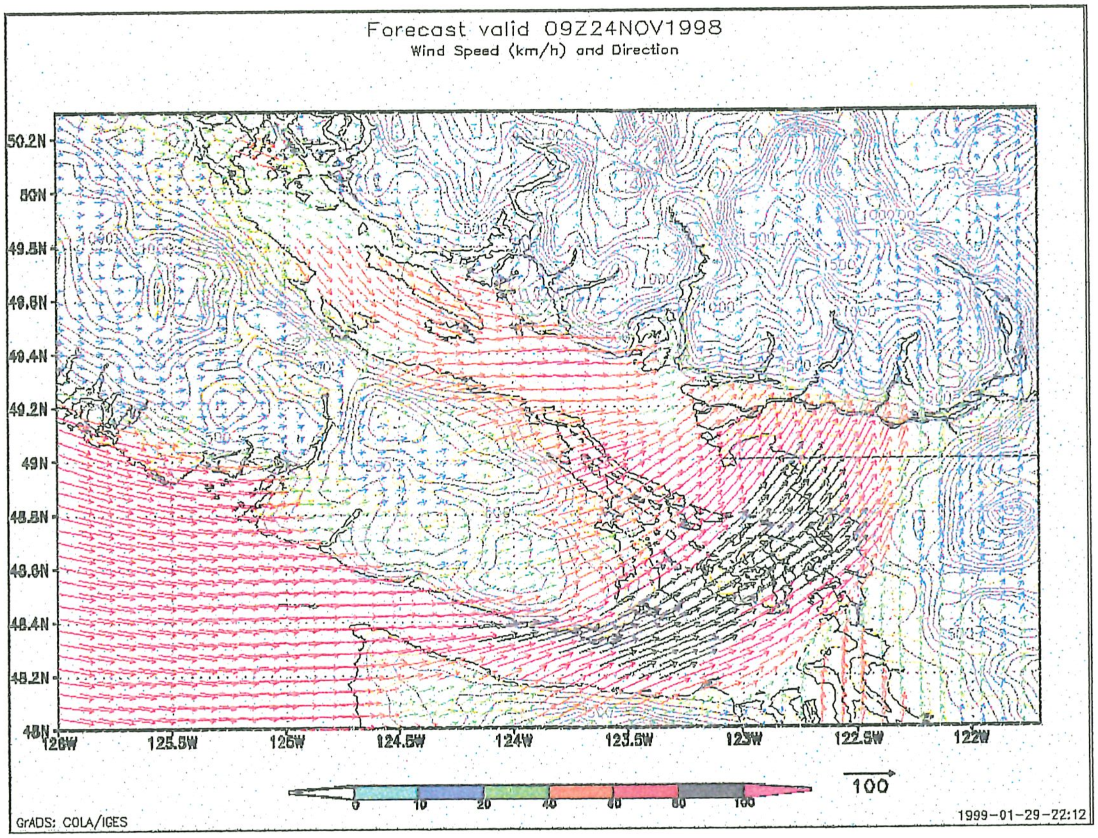


Fig. B.10.1: MC2 wind forecast for Event No. 10 at 1900 PST on Nov. 23, 1998.
Top: 3.3 km resolution, bottom: 90 km resolution.



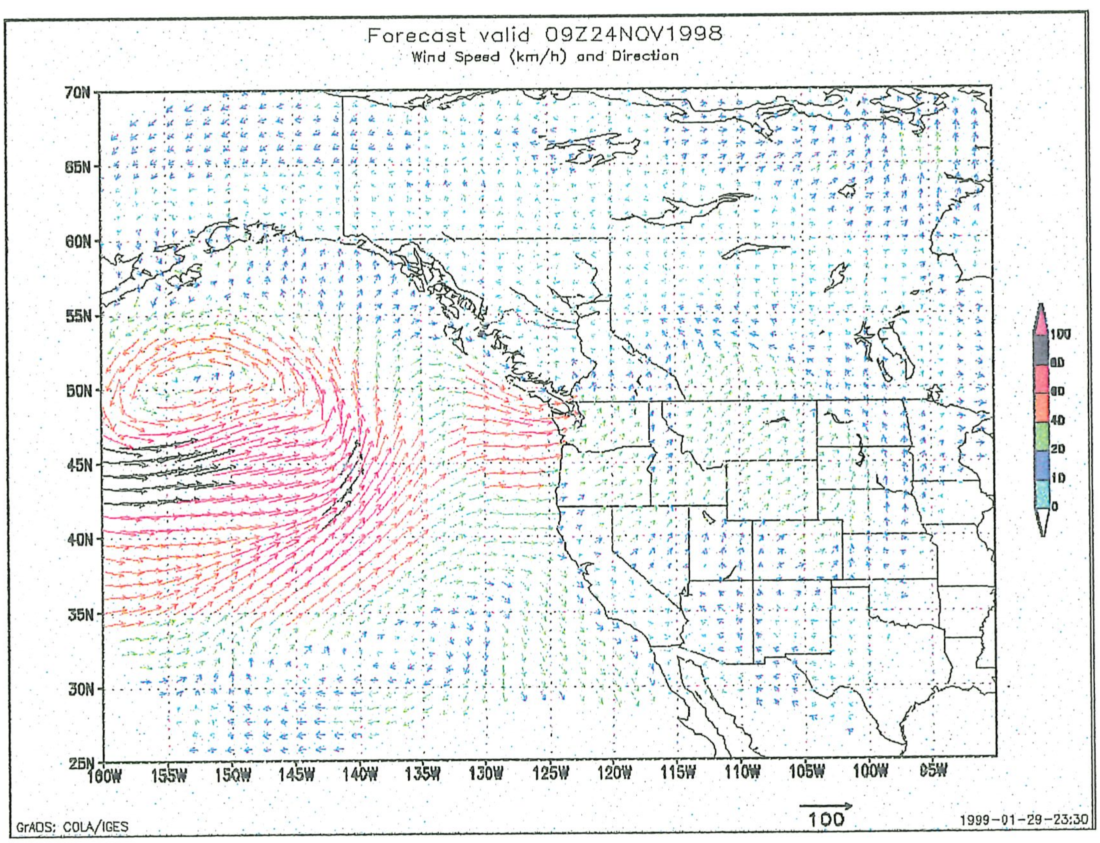


Fig. B.10.2: MC2 wind forecast for Event No. 10 at 0100 PST on Nov. 24, 1998. Top: 3.3 km resolution, bottom: 90 km resolution.

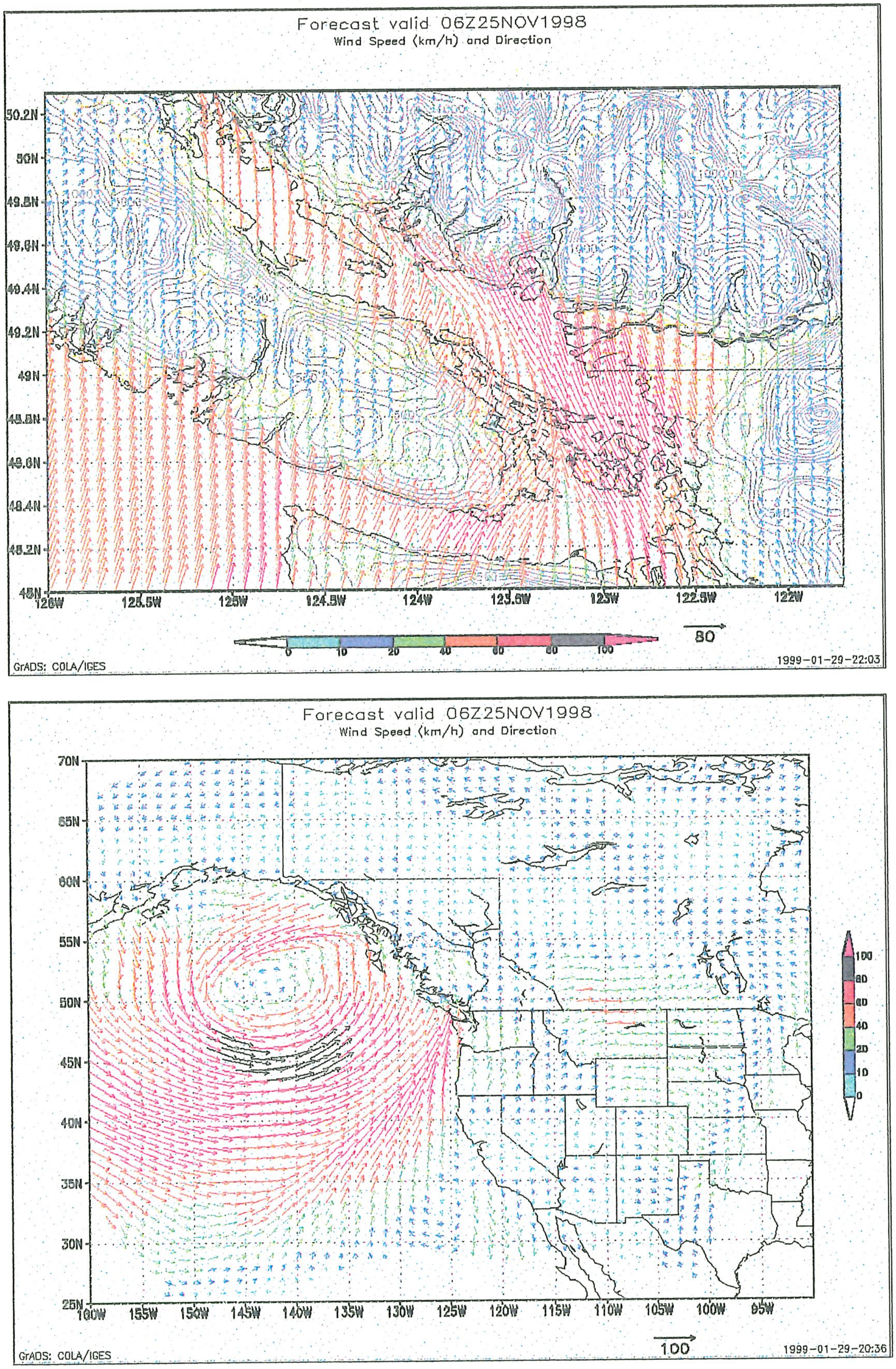


Fig. B.10.3: MC2 wind forecast for Event No. 10 at 2200 PST on Nov. 24, 1998. Top: 3.3 km resolution, bottom: 90 km resolution.

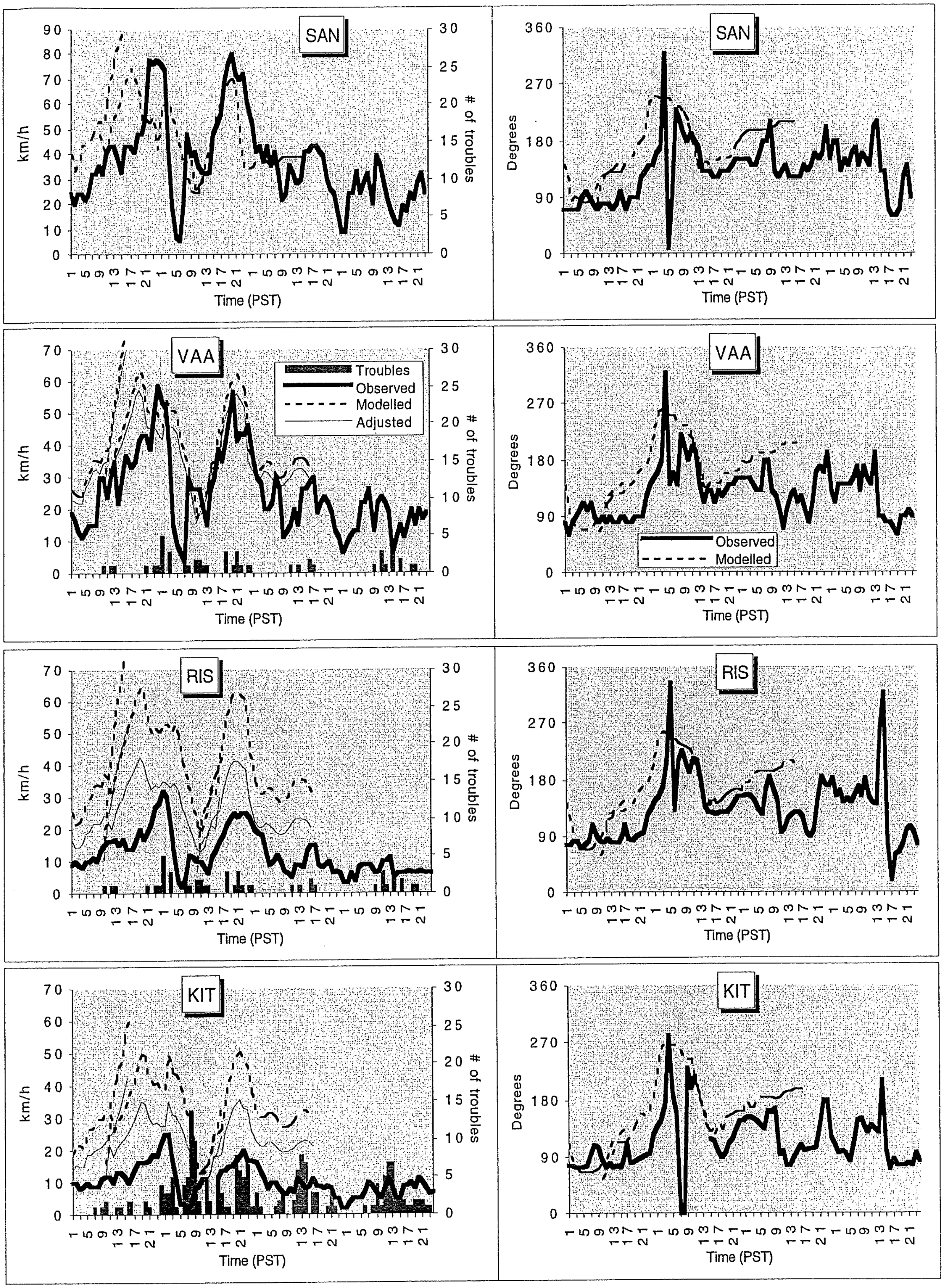


Fig. B.10.4: Same as Fig. B.1.2 but for Event No. 10 (Nov. 23 - 26, 1998).

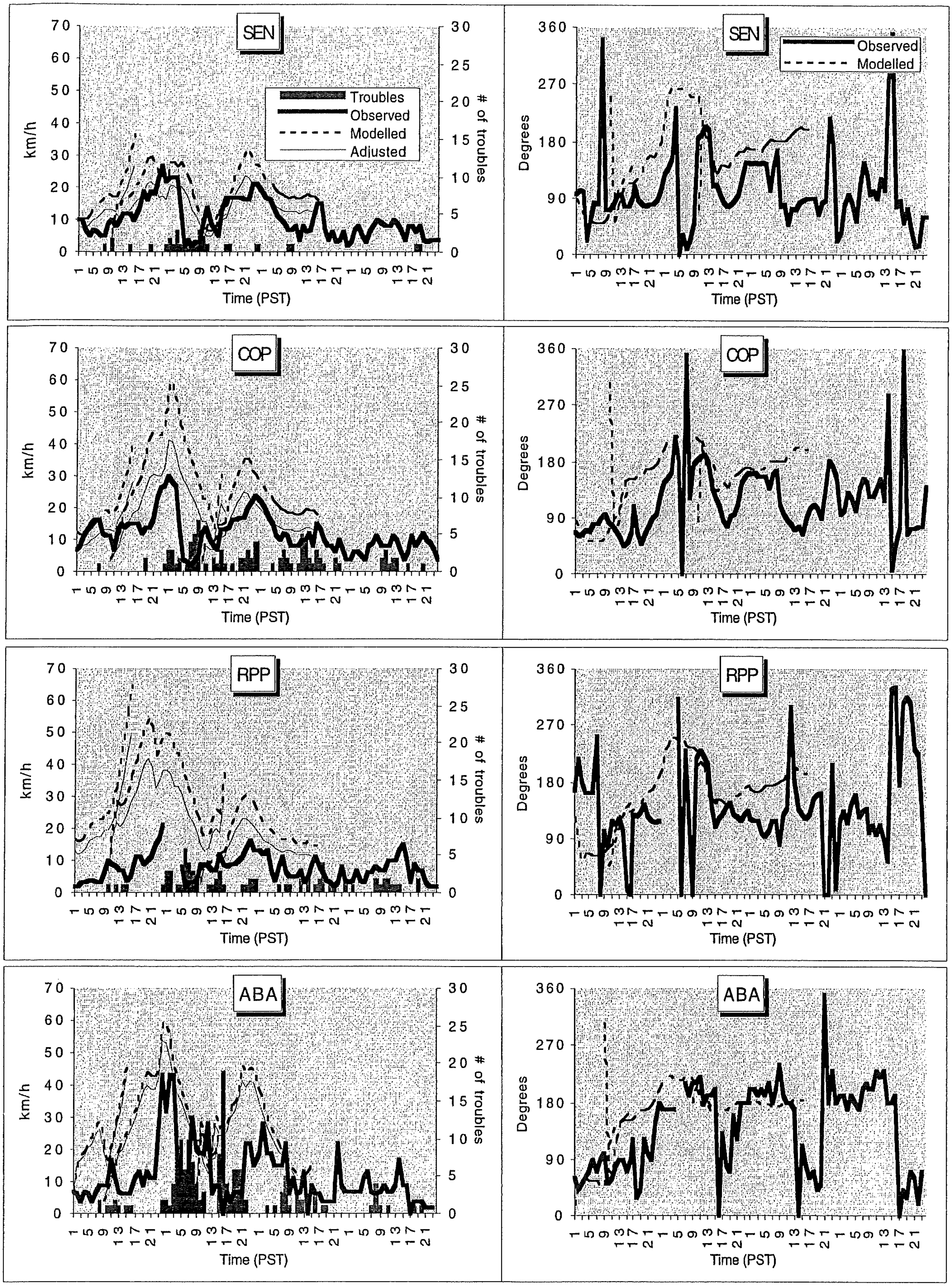


Fig. B.10.5: Same as Fig. B.1.2 but for Event No. 10 (Nov. 23 - 26, 1998).

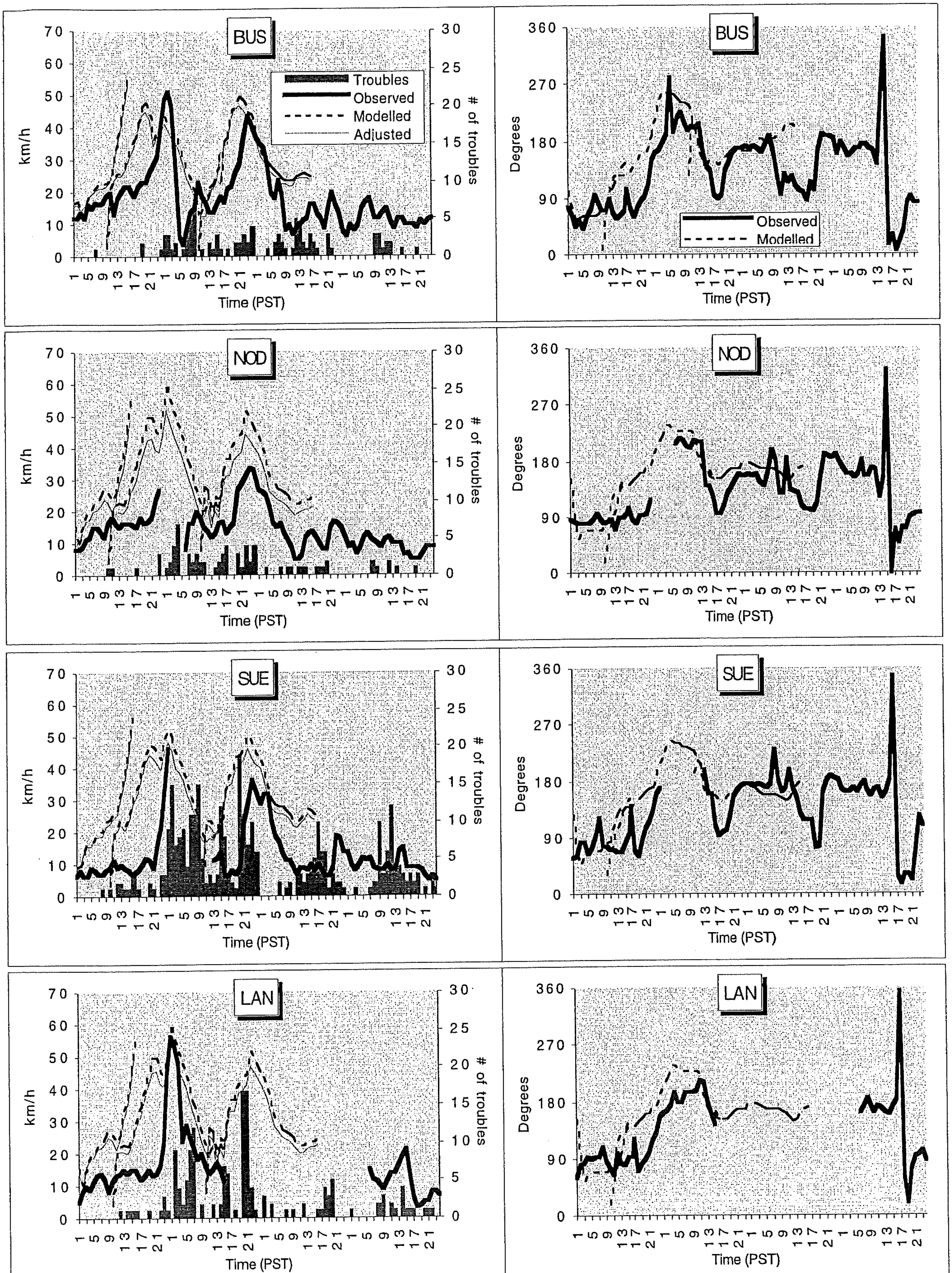


Fig. B.10.6: Same as Fig. B.1.2 but for Event No. 10 (Nov. 23 - 26, 1998).

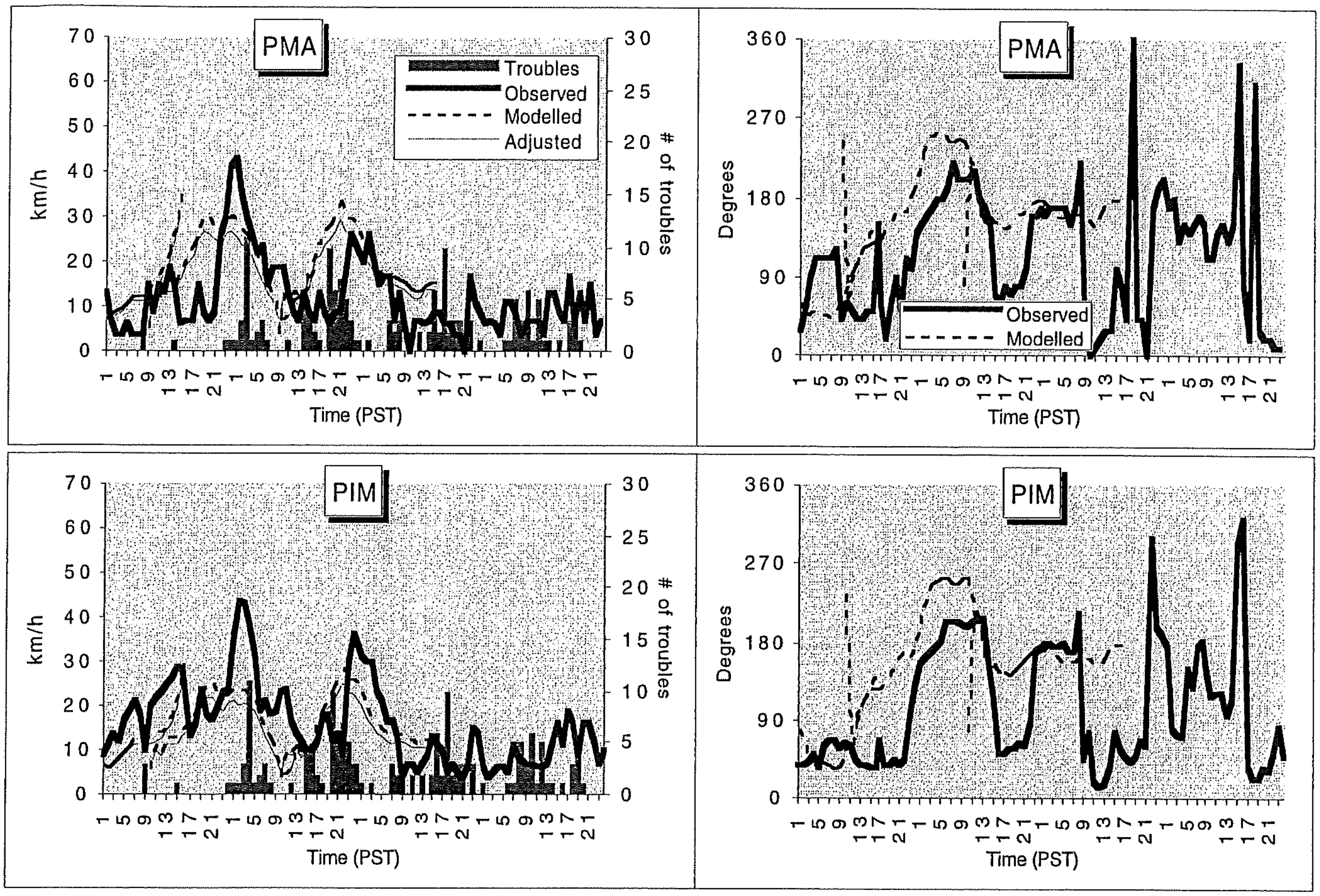


Fig. B.10.7: Same as Fig. B.1.2 but for Event No. 10 (Nov. 23 - 26, 1998).

Event No. 11 (Nov. 30 - Dec. 2, 1998)

A surface occluded front associated with a decaying cyclone in the Gulf of Alaska crossed the LFV about 1300 PST on Dec. 1, 1998 (21 UTC on Dec. 1). Frontal strength was maintained by a vorticity maximum aloft. Surface frontal passage was marked by a pressure minimum at this time. Just ahead of the front, the MSLP gradient was oriented down the Strait of Georgia, causing strong SSW winds that were enhanced by channeling up the Georgia Basin and convergence in the lee of the Olympic Mountains.

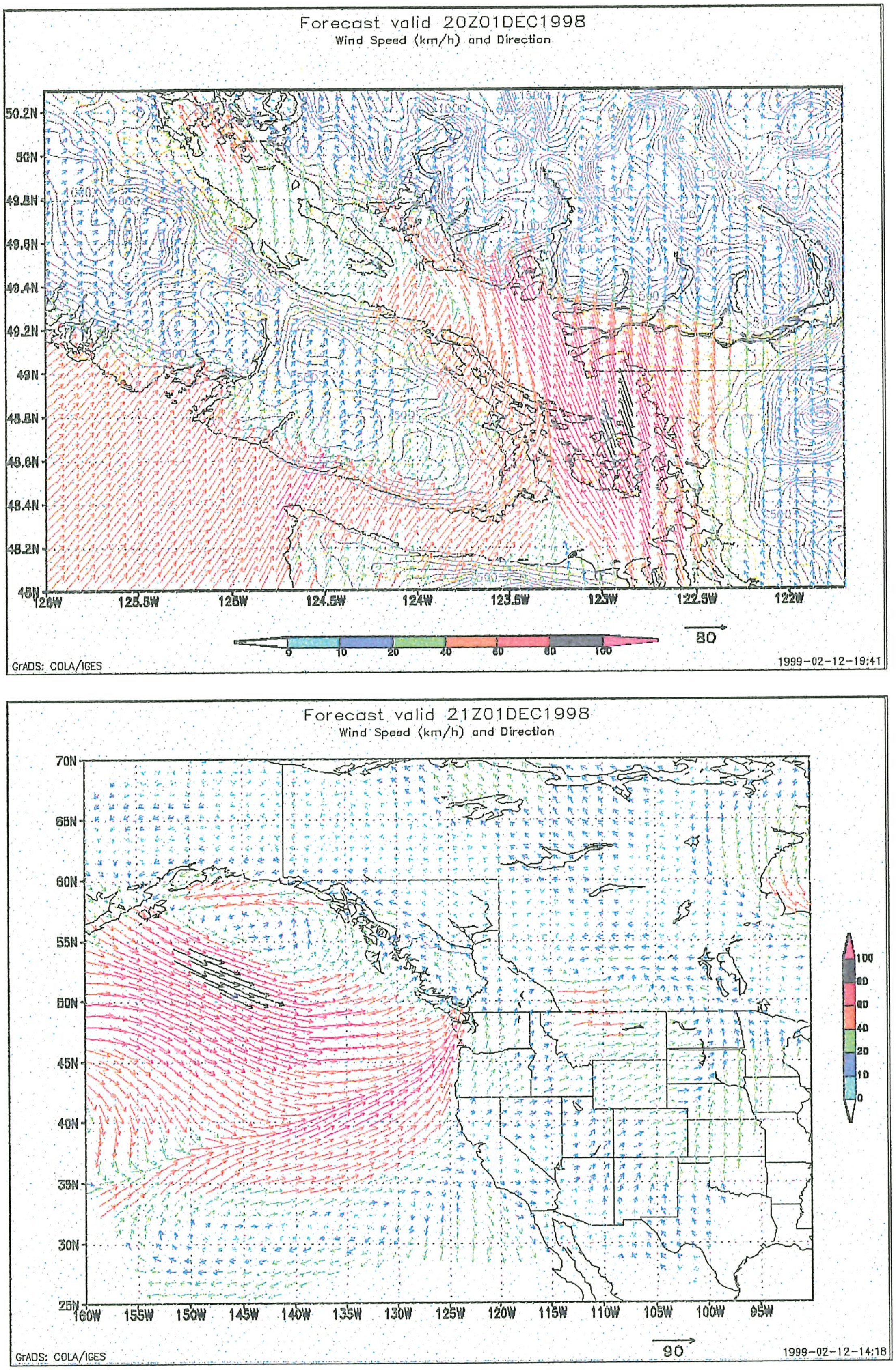


Fig. B.11.1: MC2 wind forecast for Event No. 11 at 1200 PST on Dec. 1, 1998.
Top: 3.3 km resolution, bottom: 90 km resolution.

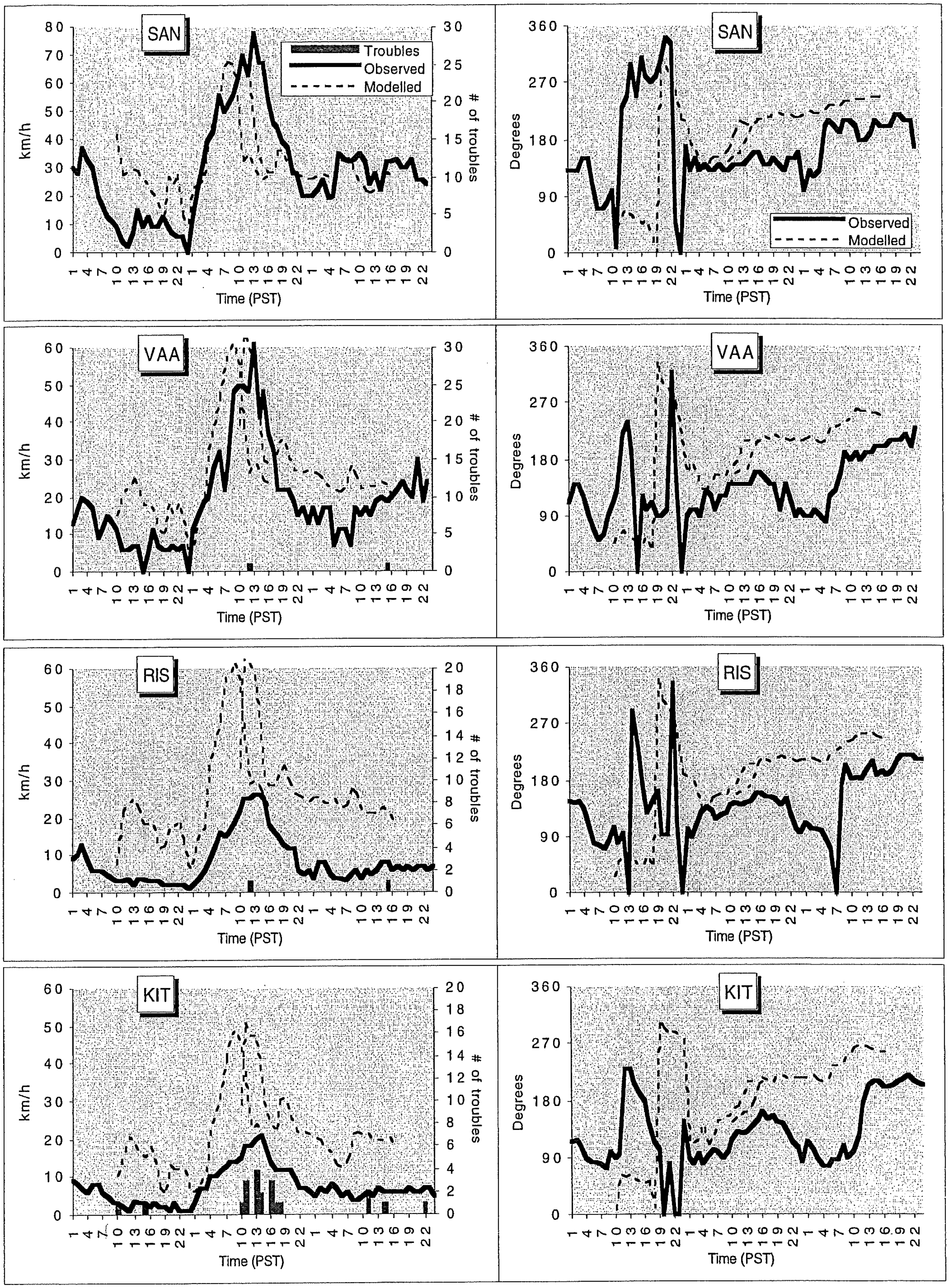


Fig. B.11.2: Same as Fig. B.1.2 but for Event No. 11 (Nov. 30 - Dec. 2, 1998).

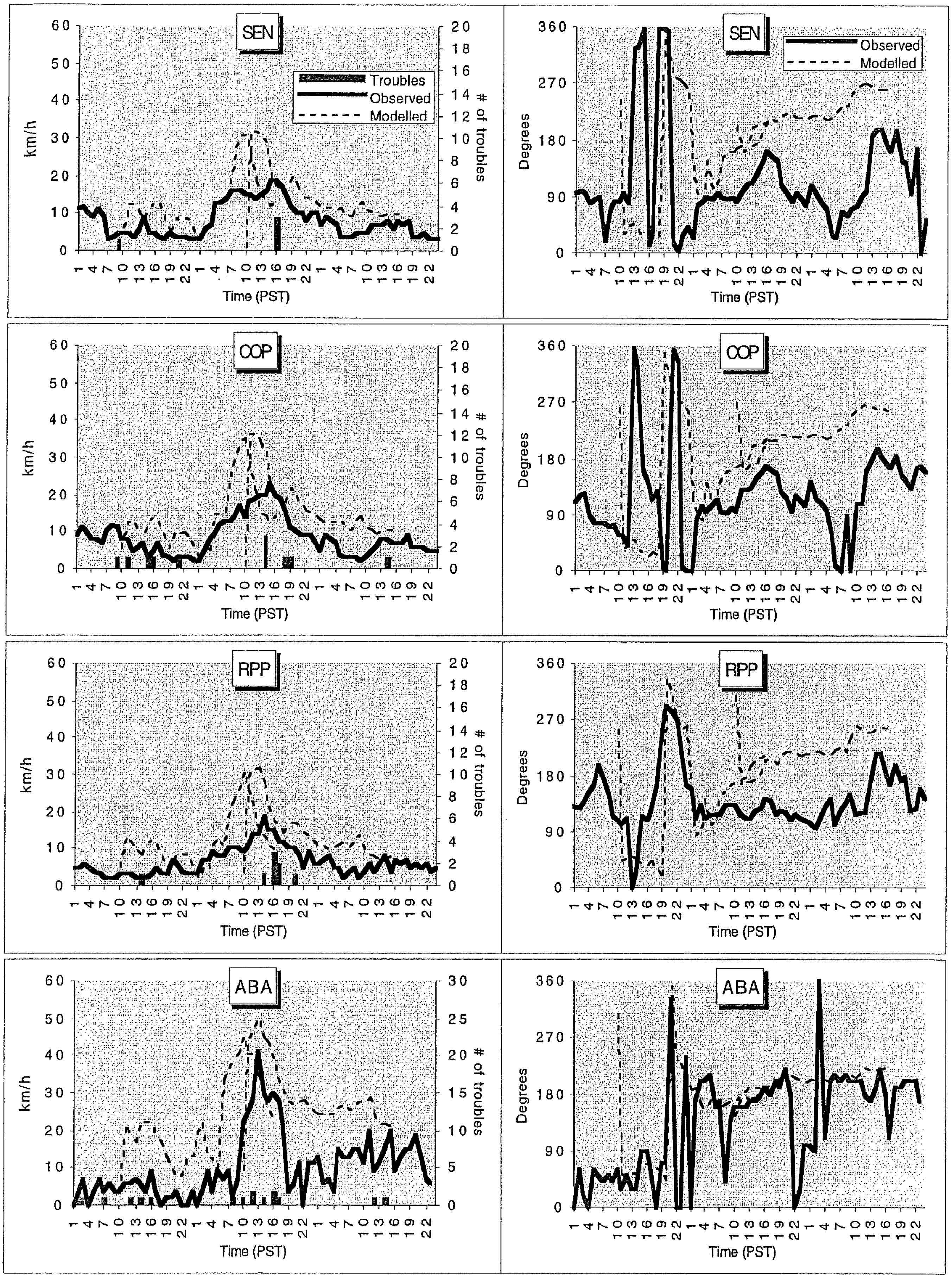


Fig. B.11.3: Same as Fig. B.1.2 but for Event No. 11 (Nov. 30 - Dec. 2, 1998).

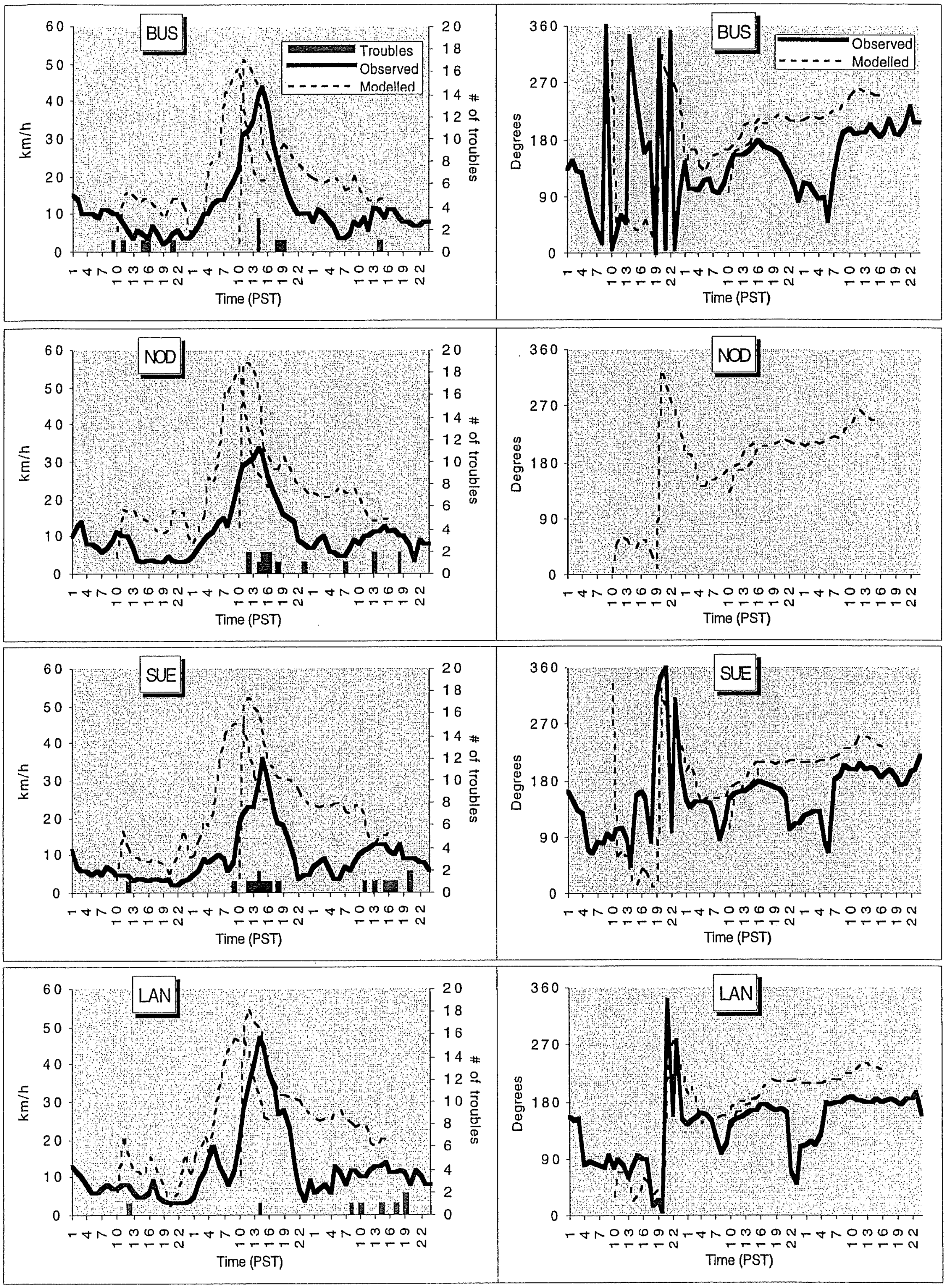


Fig. B.11.4: Same as Fig. B.1.2 but for Event No. 11 (Nov. 30 - Dec. 2, 1998).

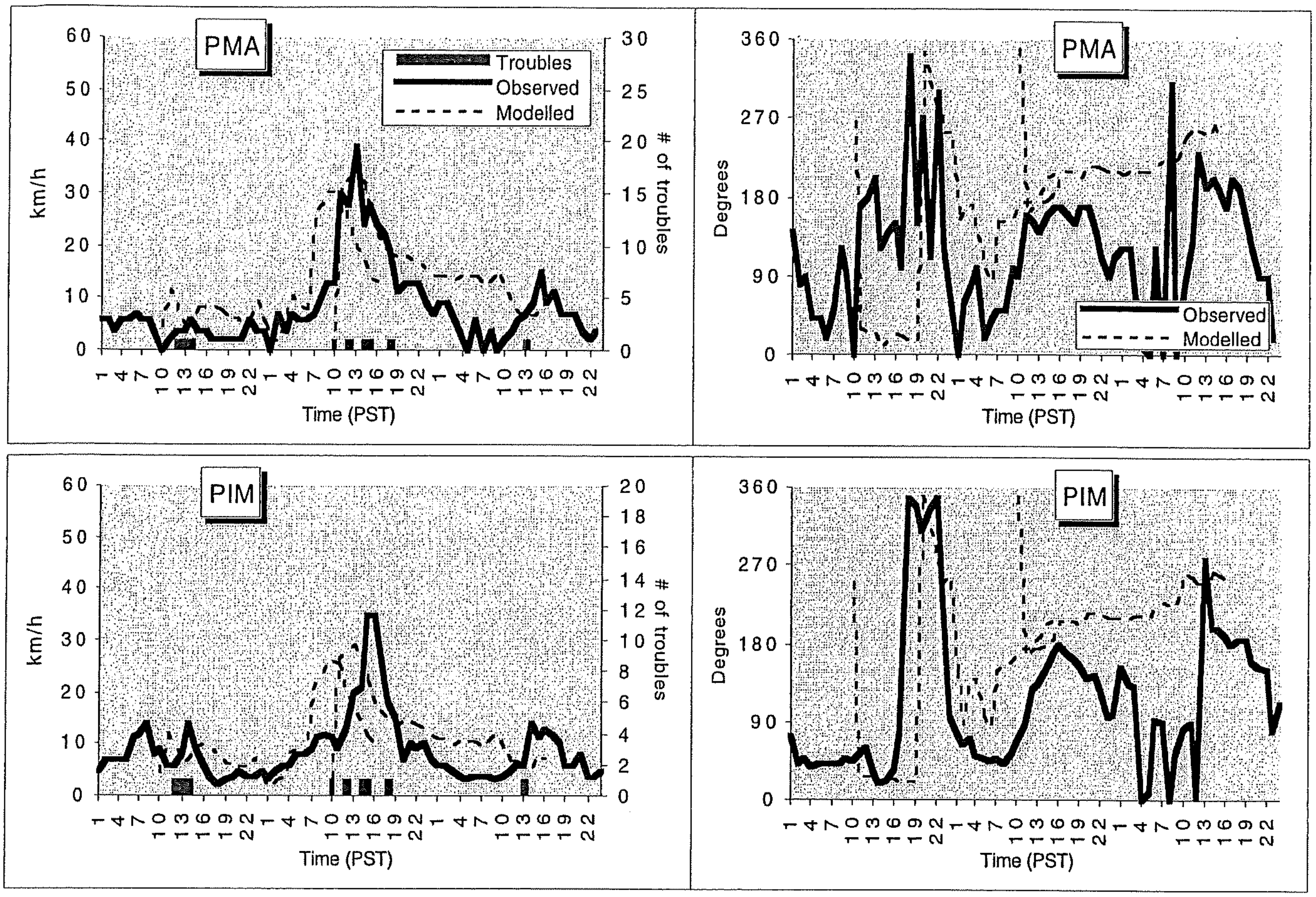
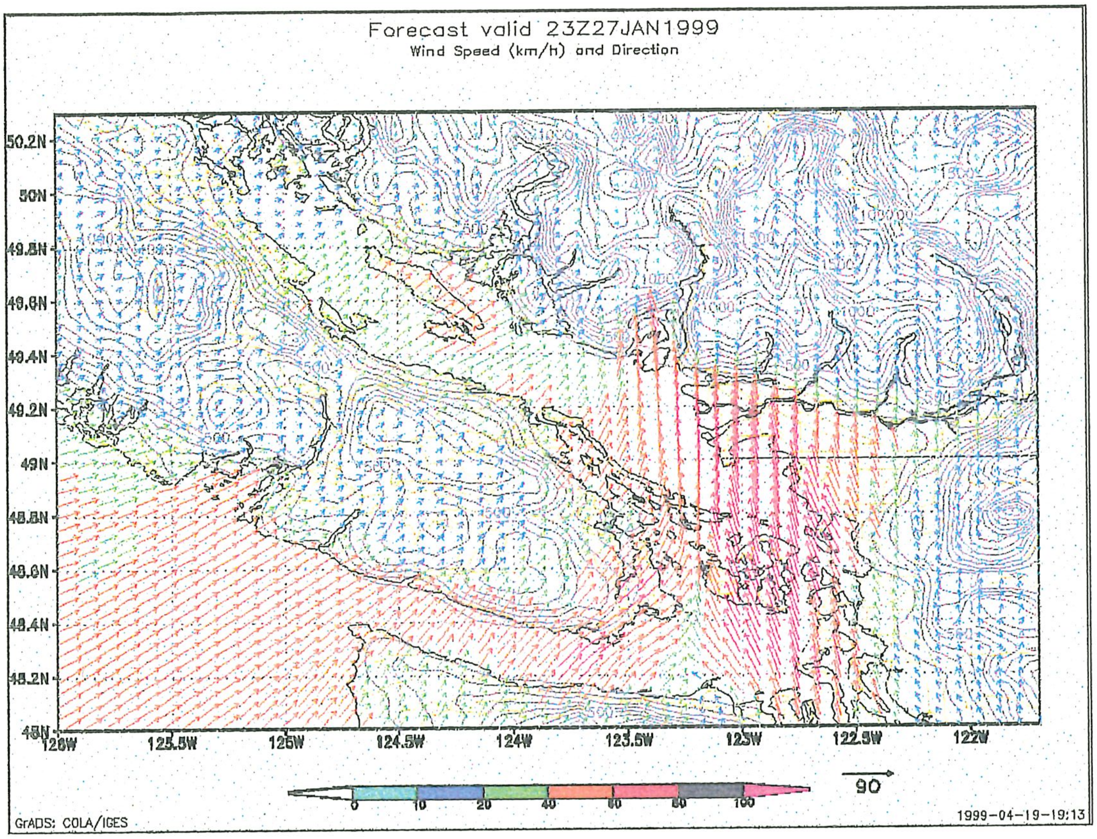


Fig. B.11.5: Same as Fig. B.1.2 but for Event No. 11 (Nov. 30 - Dec. 2, 1998).

Event No. 12 (Jan. 26 - 30, 1999)

A surface occluded front and its signature MSLP minimum cross the LFV about 1500 PST on Jan. 27, 1999 (23 UTC on Jan. 27). It was associated with a dying cyclone in the Gulf of Alaska and supported by a positive vorticity maximum aloft. Ahead of the front, strong SW winds were enhanced by channeling up the Georgia Basin and convergence in the lee of the Olympic Mountains.

About 1500 PST on Jan. 29, 1999 (23 UTC on Jan. 29), another wind Event affected the LFV. A short-wave trough aloft propagated around the dying low-pressure centre in the Gulf of Alaska. It was associated with a surface cold front that was advected southward from the Aleutian Islands. As the cold air pushed southward, a long baroclinic zone formed that stretched from the B.C. coast into the central Pacific. This, along with the short-wave, forced development of a new low-pressure centre just off of the central B.C. coast. The pressure deepened rapidly, and the associated cold front bent toward the southeast. A wind maximum in the LFV occurred just ahead of the cold frontal passage.



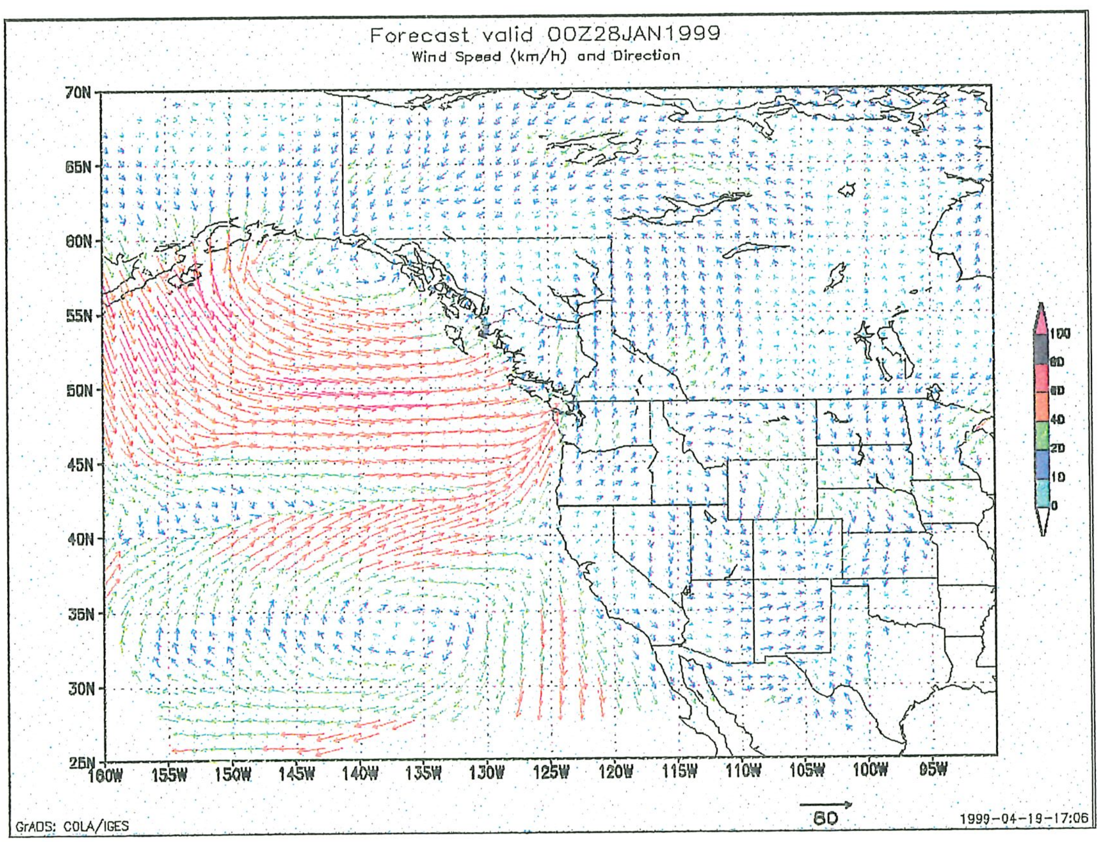
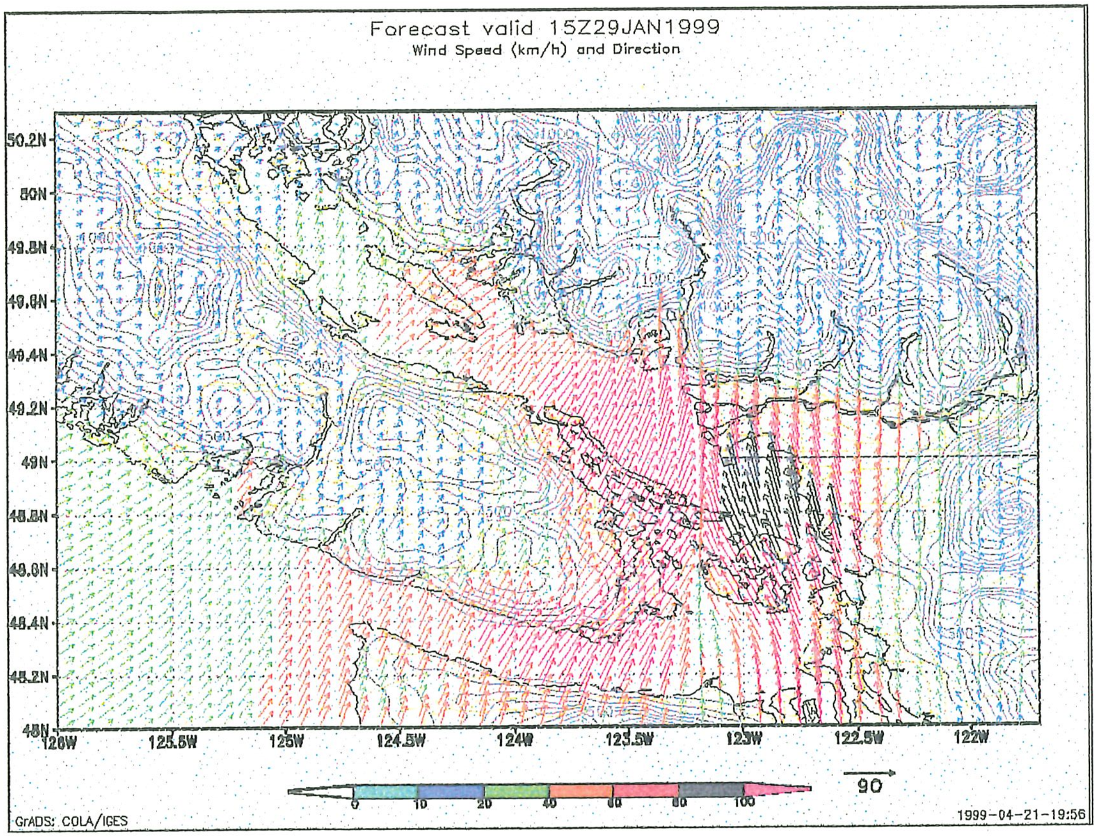


Fig. B.12.1: MC2 wind forecast for Event No. 12 at 1500 PST on Jan. 27, 1998. Top: 3.3 km resolution, bottom: 90 km resolution.



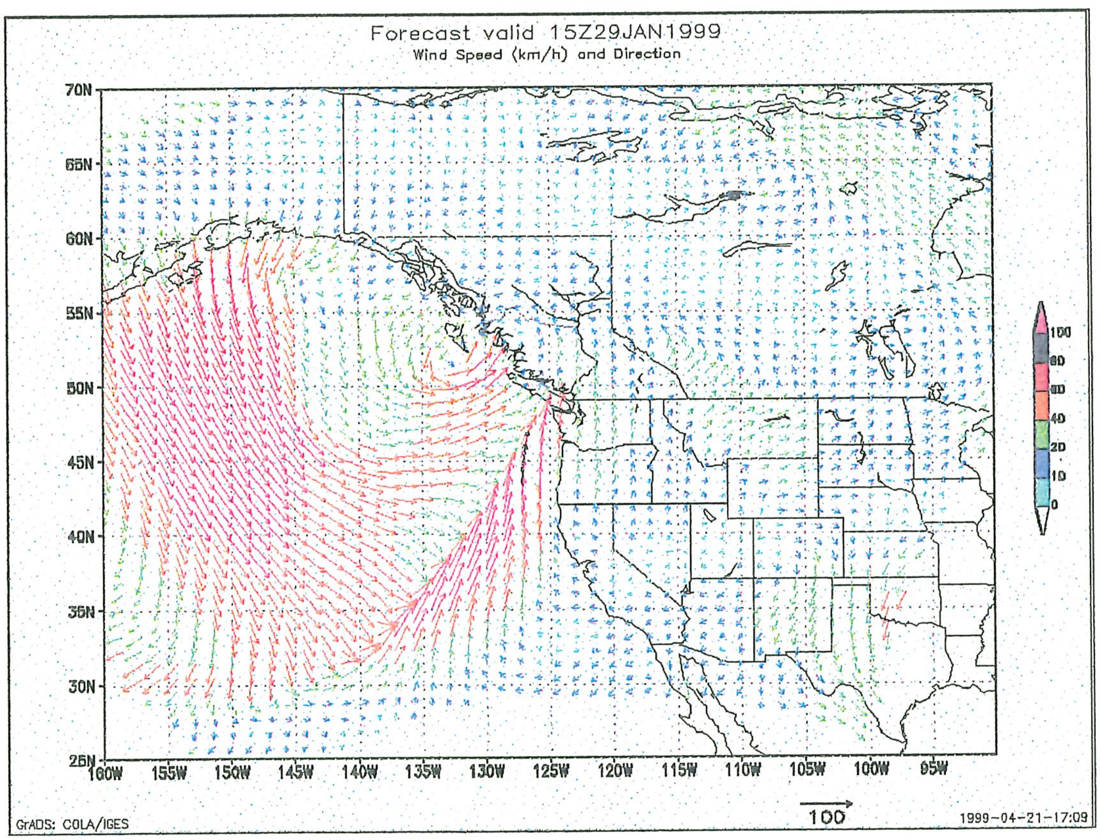


Fig. B.12.2: MC2 wind forecast for Event No. 12 at 0700 PST on Jan. 29, 1999.
Top: 3.3 km resolution, bottom: 90 km resolution.

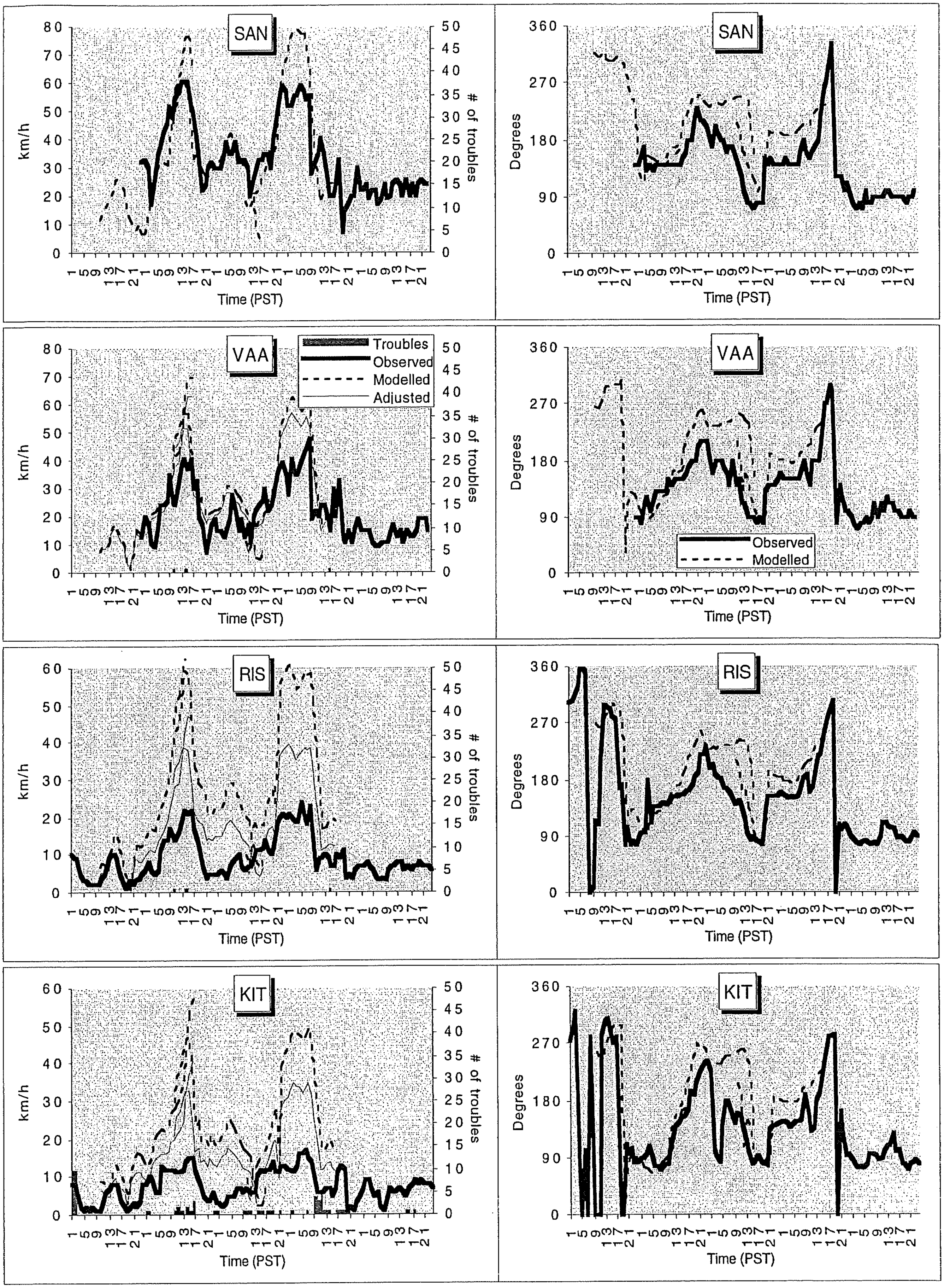


Fig. B.12.3: Same as Fig. B.1.2 but for Event No. 12 (Jan. 26 - 30, 1999).

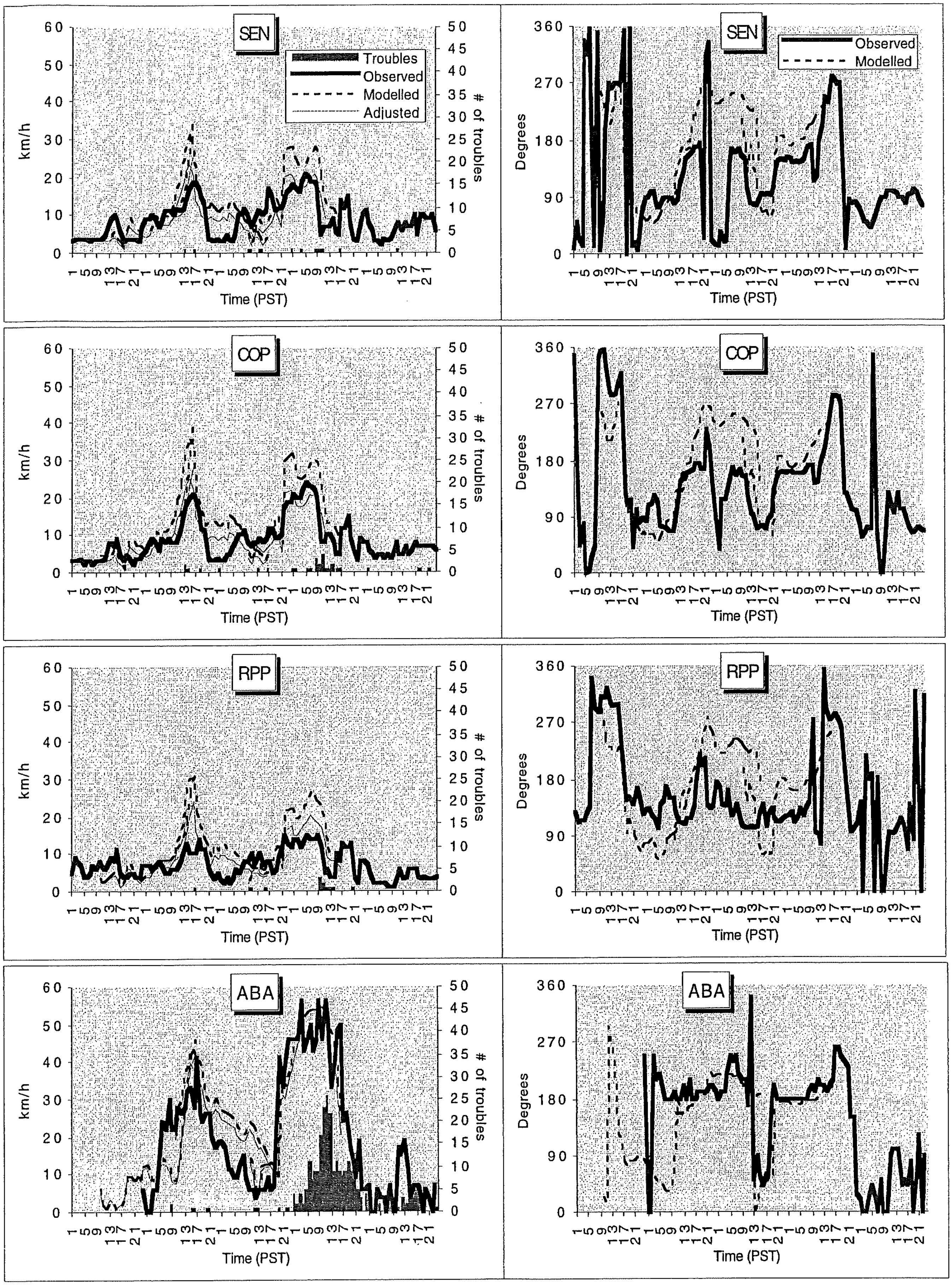


Fig. B.12.4: Same as Fig. B.1.2 but for Event No. 12 (Jan. 26 - 30, 1999).

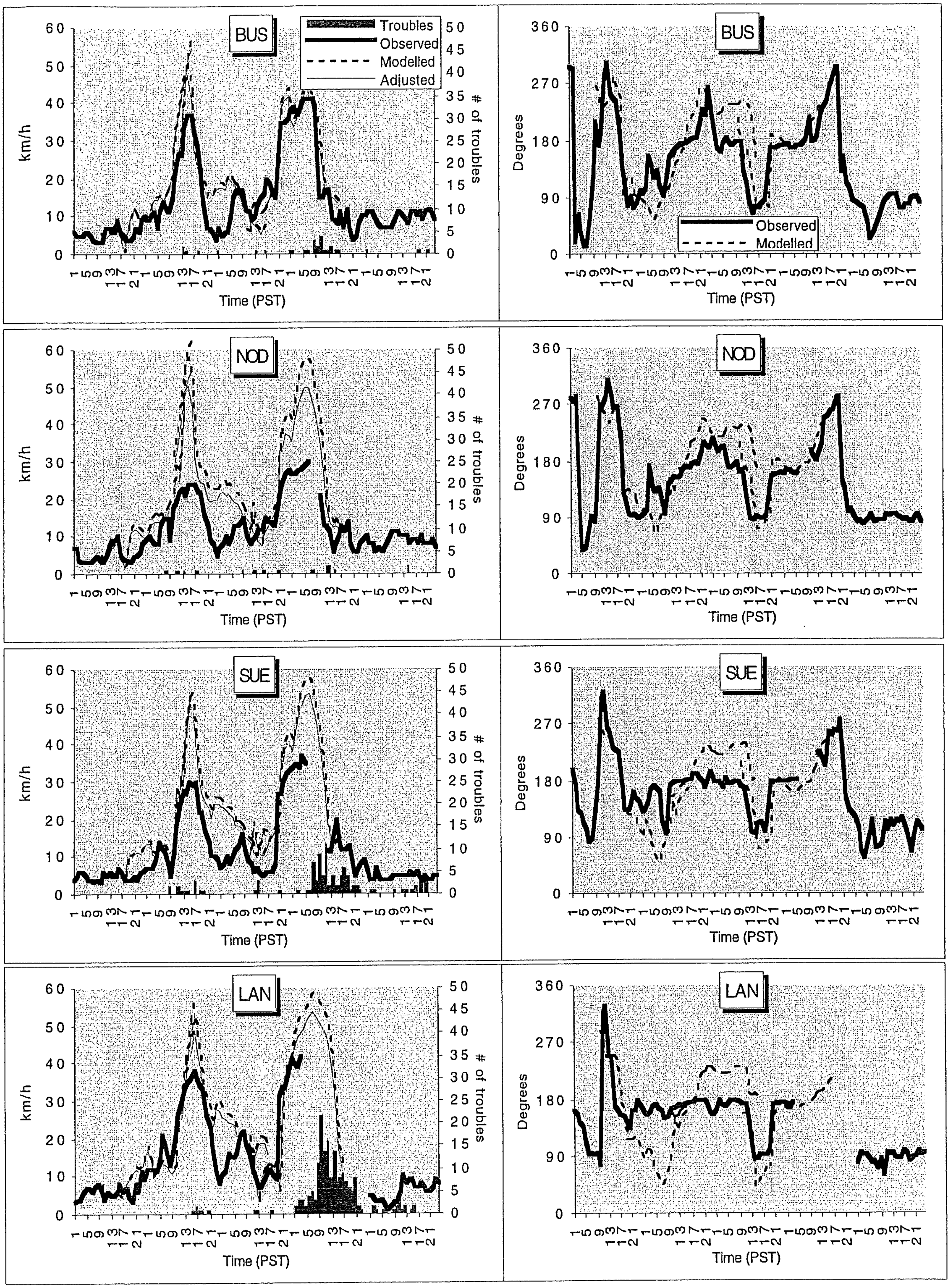


Fig. B.12.5: Same as Fig. B.1.2 but for Event No. 12 (Jan. 26 - 30, 1999).

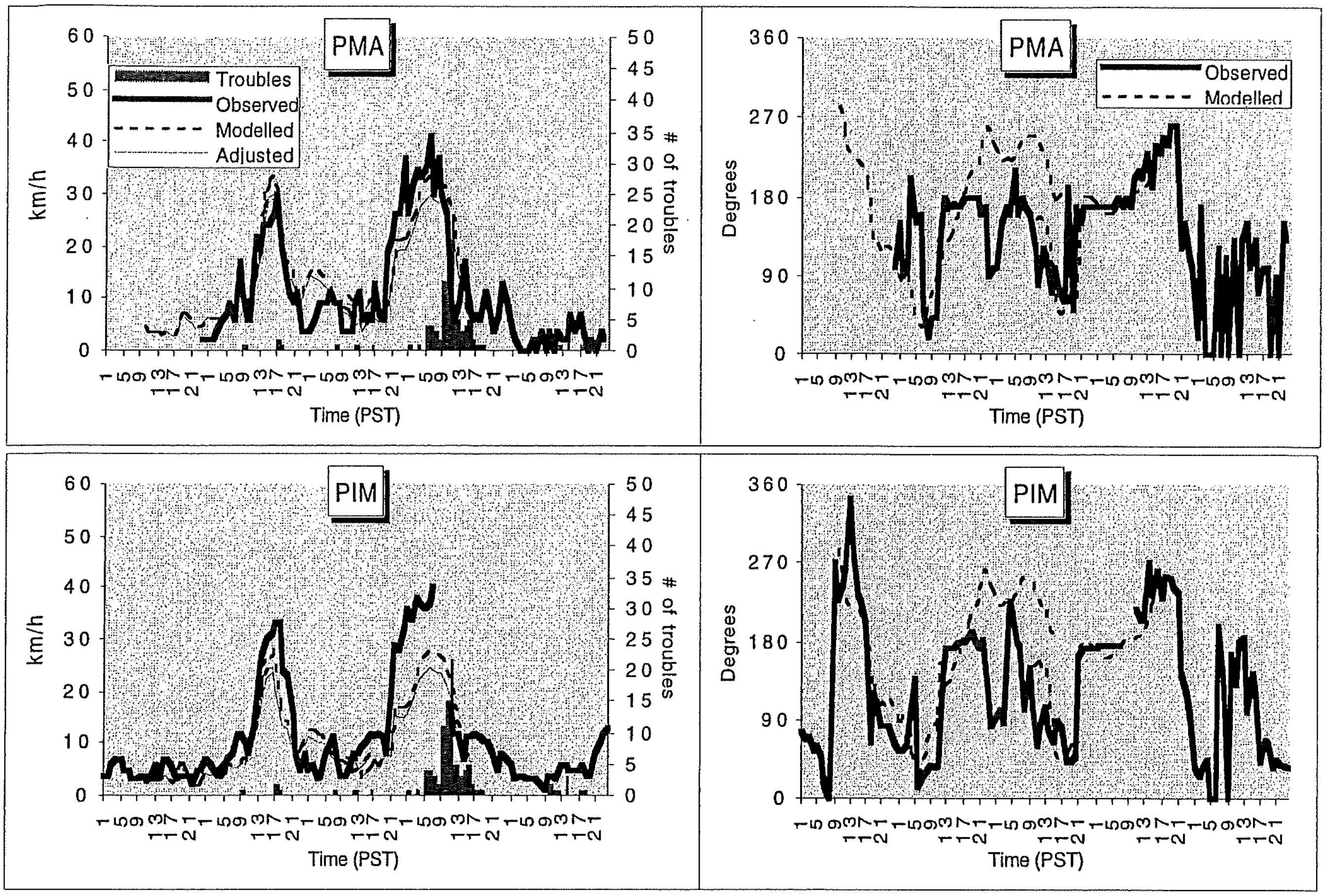


Fig. B.12.6: Same as Fig. B.1.2 but for Event No. 12 (Jan. 26 - 30, 1999).

APPENDIX C

(Modification of Model Wind Speeds Using the Log Law)

The lowest MC2 model output is at z_m = 10 m and corresponds to a surface roughness which is an unknown function of the terrain in the study area. The observations, however, are taken somewhere between z_s = 7 - 18 m and the meteorological stations (especially for GVRD) are often located within suburbs which are characterized by relatively large z_0 values (i.e. large roughness). To correct for the height difference between the levels of the model output and the observation and to account for the difference in surface characteristics, the model values were adjusted to conform to the respective observation level for each station (or vice versa). The procedure to do this follows micro-meteorological theory, using the logarithmic wind profile law which approximates the wind speed variation with height under neutral stability conditions (which can be assumed for high winds). The so-called logarithmic wind profile law is defined as:

$$\overline{u}_{z_{obs}} = \frac{u_*}{k}\ln\left(\frac{z_{s_{obs}} - z_{d_{obs}}}{z_{0_{obs}}}\right) \tag{C.1}$$

where $\overline{u}$ is the mean wind speed, u_* is the friction velocity, k is the von Karman constant (= 0.4), z_s is height above ground, z_0 is the aerodynamic roughness length, z_d is the zero-plane displacement length and *obs* stands for observation. z_0 and z_d characterize the roughness of the surface and generally increase with increasing height and density of the roughness elements (e.g. houses and trees). The corresponding values for each station (Table 4) are based on the height of the roughness elements estimated during the field visit. Similar for the model output we can write:

$$\overline{u}_{z_{mod}} = \frac{u_*}{k}\ln\left(\frac{z_{s_{mod}} - z_{d_{mod}}}{z_{0_{mod}}}\right) \tag{C.2}$$

where *mod* stands for model.

Assuming that u_* is constant, u_* in (C.1) can be substituted by u_* from (C.2) which results in a new equation for $\overline{u}$ at z_{obs}:

$$\overline{u}_{z_{obs}} = \overline{u}_{z_{mod}}\left[\ln\left(\frac{z_{s_{obs}} - z_{d_{obs}}}{z_{0_{obs}}}\right)\Big/\ln\left(\frac{z_{s_{mod}} - z_{d_{mod}}}{z_{0_{mod}}}\right)\right] \tag{C.3}$$

or:

$$\overline{u}_{z_{obs}} = \overline{u}_{z_{mod}} \cdot cf \tag{C.4}$$

where cf is a correction factor which is unique for each station (given in Table 4). To adjust the model output to be compatible with the observations, the model values have to be multiplied by cf. As seen from Eq. C.3 cf is a function of z_0 of both the observations and the model. The former was estimated based on the roughness height and density in the vicinity of the meteorological stations. The latter is more difficult to obtain because it is not possible to separate the terrain and roughness effects which are combined in the model roughness length. Assuming that the model probably does not fully take into account the high roughness presented by urbanized areas but still accounts for some terrain roughness, $z_{0_{obs}}/2$ was used as $z_{0_{mod}}$ in the calculation of cf.

APPENDIX D

(Relationship Between Mean Wind Speeds and Gust Velocities)

A limited data set (covering only few stations and Event dates) was available to derive a relationship between mean wind speeds and gust velocities. The results are provided in Figure D.1. Compared to AES stations the regression coefficient is higher in the case of the GVRD stations. This is probably because the GVRD mean velocities are averaged over 60 min whereas the AES values are averages over 2 minutes only and therefore are readily affected by short-lived gusts or lulls.

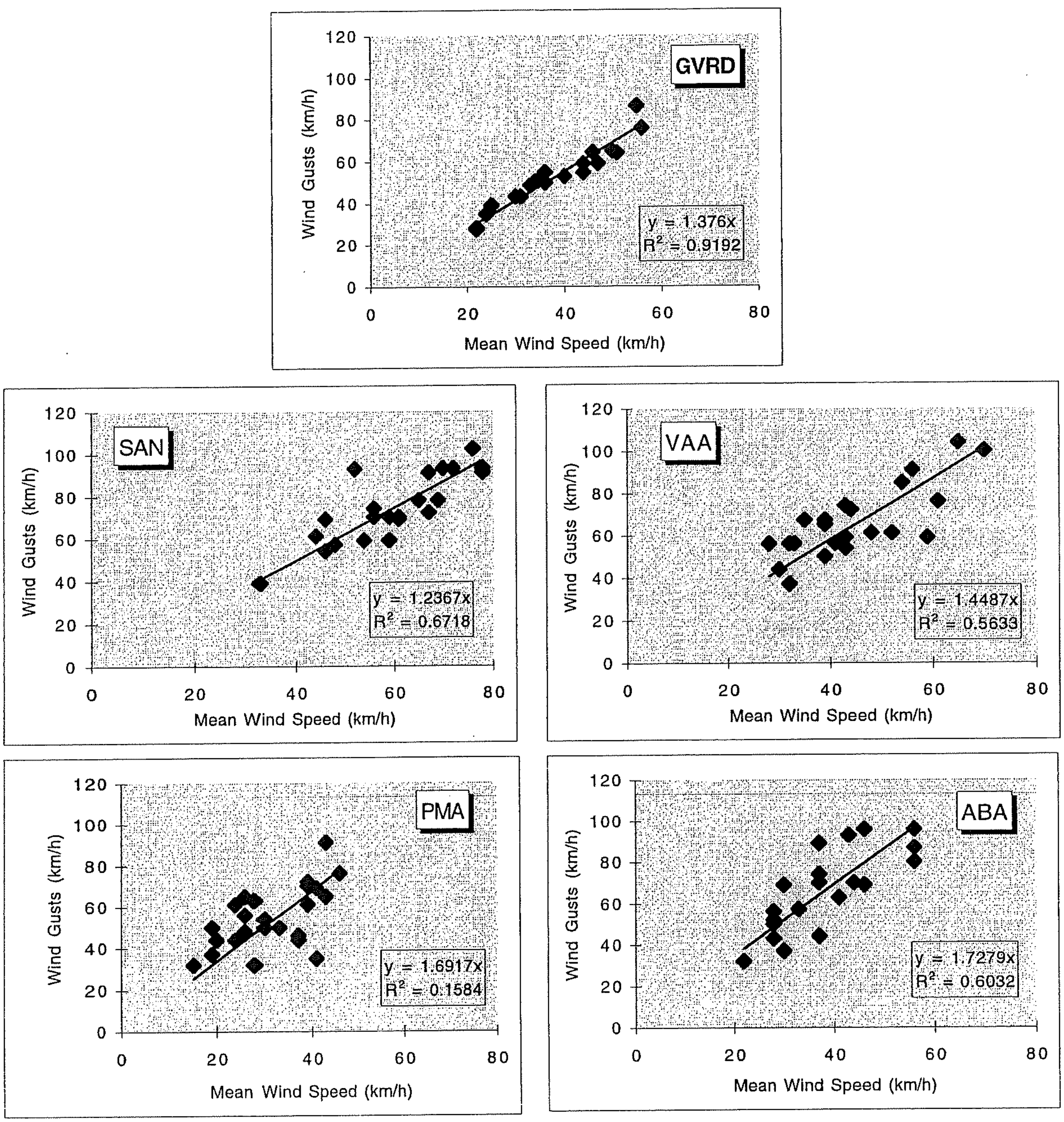


Figure D.1: Relationship between mean wind speed and wind gusts for GVRD (Events No. 1 - 12) and AES (all Events) weather stations. Station codes are as in Table 4.