

# Numerical Weather Prediction

A Summary of the Convective Storm Initiation Project Intensive Observation Periods



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The Convective Storm Initiation Project (CSIP) is a collaborative project between groups within several British universities under the aegis of the Universities' Facility for Atmospheric Measurement (UFAM), the Met Office and the Institut für Meteorologie und Klimaforschung, Universität Karlsruhe, Germany. The British universities involved are: Aberystwyth, Bath, Leeds, Manchester, Reading, and Salford. UFAM is funded by the Natural Environment Research Council following an initial award from the HEFCE Joint Infrastructure Fund. The Chilbolton Observatory, around which the project is based, is owned by the Council for the Central Laboratory of the Research Councils.

## Abstract

The Convective Storm Initiation Project (CSIP) is a joint project between a consortium of universities, funded by the Natural Environment Research Council, and the Met Office. It is designed to understand precisely where and how convective clouds form and develop into showers. A major aim of CSIP is to compare the results of the fine-resolution Met Office weather forecasting model with detailed observations of the early stages of convective clouds and to use the newly gained understanding to improve the predictions of the model.

This documents provides a summary of the synoptic conditions during the 18 CSIP Intensive Observation periods as well as a brief description of the development of convection on that day. A summary of the instruments operating on each day, including the times and locations of all the radiosondes launched, is also included. Finally, there is a brief assessment of the performance of the 12, 4 and 1 km Met Office Mesoscale Models.



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# CHAPTER 1

## Introduction

The Convective Storm Initiation Project (CSIP) is a joint project between a consortium of universities, funded by the Natural Environment Research Council, and the Met Office. It is designed to understand precisely where and how convective clouds form and develop into showers. A major aim of CSIP is to compare the results of the fine-resolution Met Office weather forecasting model with detailed observations of the early stages of convective clouds and to use the newly gained understanding to improve the predictions of the model.

A large array of ground-based instruments, from the NCAS Universities' Facility for Atmospheric Measurement (UFAM) and the Institute for Meteorology and Climate Research (IMK) Karlsruhe, were deployed in southern England, over an area centred on the Chilbolton radars, during an observational period covering June, July and August 2005 (Fig. 1.1). The deployment of the instrumentation was influenced by experience gained during the CSIP Pilot project held in July 2004. In addition to a variety of ground-based remote-sensing instruments, numerous radiosondes were released at up to hourly intervals from 6 different sites. In addition, two aircraft complemented the ground-based instruments. The Met Office weather radar network and Meteosat satellite imagery were also used to provide context for the observations made by the instruments deployed during CSIP. Further details can be found in the CSIP Operations Plan, available from <http://www.env.leeds.ac.uk/csip/>.

### 1.1 At-a-glance summary of IOPs

Tables 1.1, 1.2 and 1.3 gives the dates of the 18 intensive observation periods (IOPs) carried out during June, July and August 2005 as part of CSIP. The IOPs have been subjectively classified into  $\alpha$ ,  $\beta$  and  $\gamma$ , depending on how well the meteorological events that occurred on that day fulfilled the aims of the CSIP observational campaign: namely, the detailed observation of the initiation

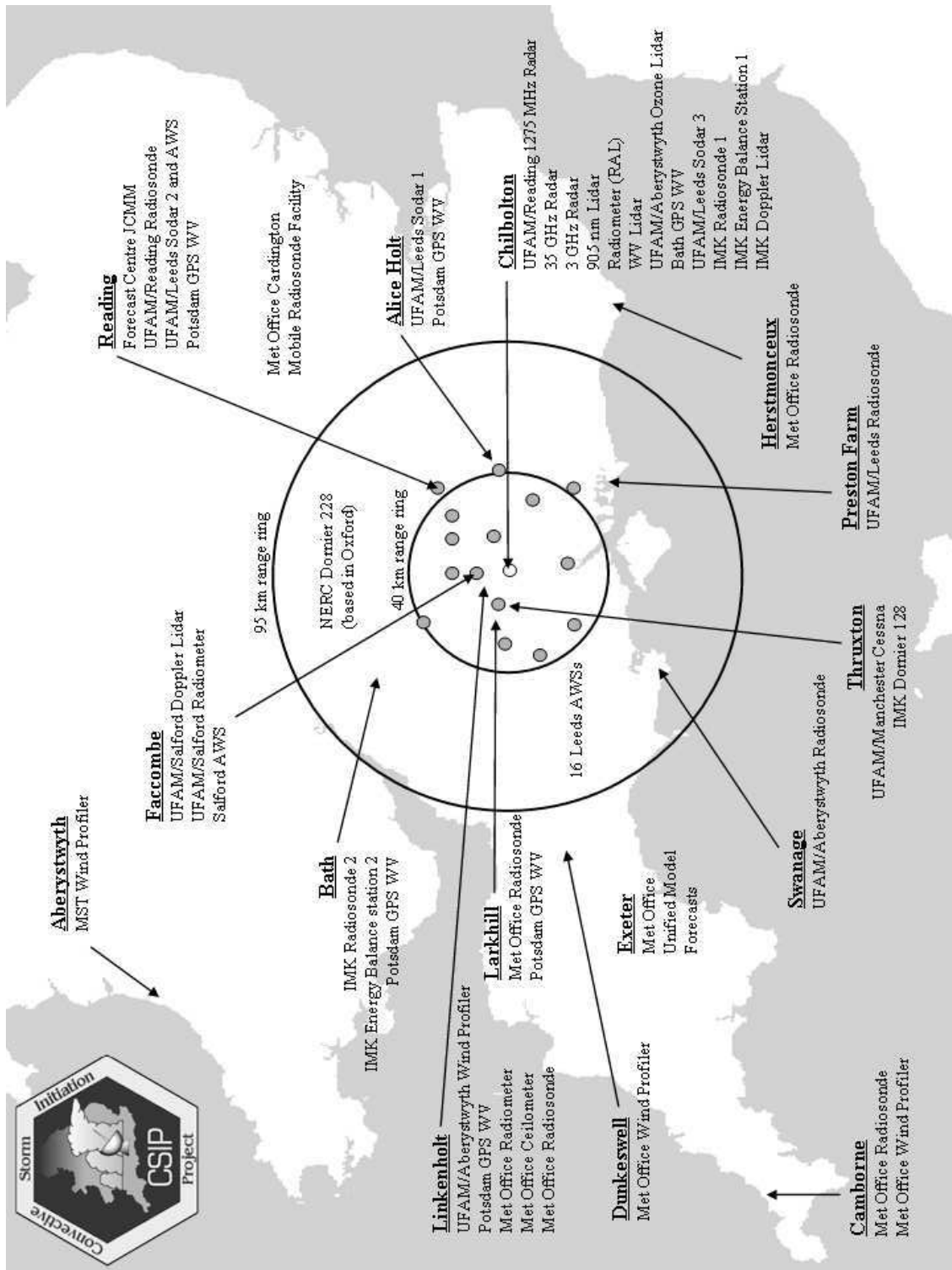


Figure 1.1 A map showing the locations of the instruments deployed during CSIP in 2005.

IOP	Date	Comments
1	Wednesday 15 June	Triggering downstream of Cornwall. In association with peninsula convergence possibly modulated by upper trough.
5	Wednesday 29 June	Shower initiation within CSIP area affected by surface forcing modulated by shadowing from orphaned anvils. Penetration of second lid affected by upper-level forcing leading to an E-W line producing flash floods in Oxfordshire.
6	Monday 4 July	Continuous stream of cells originating in NW-ly flow over Wales, with some further triggering and organisation in CSIP area.
8	Wednesday 13 July	S coast sea breeze, intermediate lid and little triggering.
9	Monday 18 July	Narrow line of showers associated with mesoscale convergence along a surface cold front beneath an upper-level PV anomaly.
12	Thursday 28 July	Initially shallow, and later deep convection developed within longitudinal cloud streets. (One of these led to an F2 tornado in Birmingham.)
18	Thursday 25 August	W-ly flow beneath upper trough. Development of organised convection leading to a strong cold pool with subsidence behind and a gust-front ahead of it.

**Table 1.1** The CSIP IOPs which have been categorised as  $\alpha$ .

of convection within an area of 100 km radius, centred on Chilbolton. This is a region which will henceforth be referred to as the “CSIP area”. The  $\alpha$ -rated IOPs tend to be those for which there is thought to be well-defined scientific themes or hypotheses that can be tested.

For each of the IOPs, Table 1.4 summarises which of a number of phenomena and mechanisms related to convective initiation were observed to occur. For each of the categories in the table, the phenomenon is counted as having occurred if it was well observed within the “CSIP area”. A more thorough analysis may show that various phenomena occurred on some of the other occasions too.

IOP	Date	Comments
3	Friday 24 June	Glastonbury floods. Elevated convection.
7	Thursday 7 July	Showers in N-ly flow.
11	Sunday 24 July	A few shallow showers initiated in the CSIP area in a rather strongly suppressed dry slot.
13	Monday 1 August	S coast and Kent/Sussex initiation. Intermediate lid with only a couple of cells becoming deep ( $\sim 9$ km).
14R	Thursday 11 August	IOP declared retrospectively - no full operation. Isolated shower beneath a WV dark zone, triggered along a marked convergence line (possibly influenced by a sea breeze).
16	Thursday 18 August	An ADC leading to a compact outbreak of showers in a weak, broadly S-ly, flow ahead of a band of cold-frontal rain advancing slowly from the W.
17	Friday 19 August	An area of showers formed in the vicinity of Bath but decayed as they undercut the cirrus canopy associated with the cloud head.

**Table 1.2** The CSIP IOPs which have been categorised as  $\beta$ .

IOP	Date	Comments
2	Sunday 19 June	Intense thunderstorms giving floods in Yorkshire. No triggering in CSIP area because of strong lid.
4	Tuesday 28 June	Strong CIN totally inhibiting deep convection.
10	Saturday 23 July	Strongly suppressed convection with isolated showers initiated near outer limits of the CSIP area.
15	Saturday 13 August	Shallow showers beneath a WV dark zone behind cold front.

**Table 1.3** The CSIP IOPs which have been categorised as  $\gamma$ .

Phenomena / IOP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Primary initiation	1	0	0	0	1	1	0	0	0	1	1	1	1	1	0	1	1	1
Secondary initiation	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	1	1
Intense showers	1	0	1	0	1	1	1	0	1	0	0	1	1	1	0	0	1	1
Upper-level forcing	1	0	0	0	1	1	1	0	1	0	1	1	0	1	1	0	0	1
Hill effects	0	0	0	0	1	1	0	1	0	0	1	1	1	0	0	1	0	0
Coastal effects	1	0	0	0	0	0	0	1	0	0	1	0	1	1	0	0	0	0
Mesoscale low-level convergence	1	0	0	0	0	0	0	1	1	1	0	1	1	1	0	1	0	1
Cloud shadowing	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0
Multiple lids	1	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0
Main lid height varies	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
Highly organised showers	0	0	1	0	1	0	1	0	1	0	0	1	1	0	1	0	0	1

**Table 1.4** All the CSIP IOPs rated according to the presence or absence of various phenomena within the CSIP area; 1: it was a major feature; 0: it wasn't noted as such (although a more detailed analysis may show otherwise).

## 1.2 Summary of rest of document

Chapter 2 summarises the times of operation of all the instruments involved during the CSIP IOPs, while chapter 3 summarises the times and locations of all radiosondes launched. Chapter 4 provides a preliminary assessment of the Met Office's 12, 4 and 1 km Mesoscale Models. Chapters 5 to 22 provide overviews of each of the individual IOPs. These overviews are necessarily superficial and are intended merely to give an indication of the broad nature of each event and some of the scientific issues that they raise.

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## CHAPTER 2

### Instruments Summary

The subsequent tables indicate the times of operation of each instrument for each IOP.



Date	15 June	19 June	24 June	28 June	29 June	4 July	7 July	13 July	18 July
Instrument/IOP	1	2	3	4	5	6	7	8	9
DO 128	NO	NO	1156-1247	NO	0857-1240 1320-1554	0819-1015 1245-1505	0953-1247 1449-1808	0956-1308 1434-1648	NO
Cessna	NO	NO	NO	NO	1044-1140	1048-1135	NO	1023-1312 1438-1623	NO
3 GHz	0730-1505	0707-1524	0659-1642	0710-1746	0720-1627	0636-1817	0707-1842	0707-1842	0945-1821
1275 MHz	0730-1505	0707-1524	0659-1642	0710-1746	0720-1627	0636-1817	0707-1842	0707-1842	0945-1821
35 GHz	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
WV lidar	1122-1313	NO	0941-1305 (gaps)	0920-1225	NO	NO	NO	0931-1345	NO
Ozone lidar	00-07 11-22 (gaps)	11-24	Cont	00-1730 18-24	Cont (gaps)	Cont	08-24	Cont (gaps)	11-24
UFAM Doppler lidar	NO	NO	NO	NO	NO	NO	NO	NO	1130-1257 1730-2105
IMK Doppler lidar	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
UFAM Wind Profiler	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont (gap 10-1130)	Cont
UFAM Radiometer	NO	NO	1125 on	Cont - 18:00	NO	NO	NO	Cont	Cont - 1817
MO Radiometer	NO	NO	NO	NO	NO	NO	NO	NO	Cont
Chlbtn sodar	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100
Alice Holt sodar	NO	NO	NO	0700-2100	0700-2100	0700-1540	0700-2100	0700-2100	0700-2100
Reading sodar	NO	NO	NO	NO	NO	NO	NO	NO	0700-1700
Leeds r/s	08-14	07-11 13	8 11-15 (at Bath)	6 7 9 12	08-16	07-10 12-16	9-11 13-14	9-16	NO?
Reading r/s	08-14	07-14	06-15	6 7 9 12	08-16	06-16	09-17	9-16	14-18
Manchester r/s	NO	07-14	06-17	8 9 12	08-16	07-17	08-17	09-16	12-18
IMK Chlbtn r/s	NO	07-14	6 8 10-12 14	7 9 12 16	8-10 12 14-16	8 10 12 14-17	09-17	09-17	15 17 18
IMK Bath r/s	NO	NO	8 11-15	6 7 9 12	08-16	07-15	08-16	09-17	12-15
MO mobile r/s	(Bath) 9 11 12 13	NO	(Mdhurst) 8-15 17	NO	NO	NO	(Oxford) 9-16	NO	NO
Chlbtn energy bal	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
Bath energy bal	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
GFZ GPS	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont

Date	23 July	24 July	28 July	1 Aug	11 Aug	13 Aug	18 Aug	19 Aug	25 Aug
Instrument/IOP	10	11	12	13	14	15	16	17	18
DO 128	NO	NO	NO	NO	NO	NO	NO	NO	NO
Cessna	NO	NO	NO	NO	1546-1657	NO	1218-1308 1409-1551	1411-1614	0805-1011 1324-1444
3 GHz	0730-1743	0722-1907	0710-1707	0900-1700	0934-1859	1054-1810	1024-1928	1058-1835	0722-1637
1275 MHz	0730-1743	0722-1907	0710-1707	0900-1700	0934-1859	1054-1810	1024-1928	1058-1835	0722-1637
35 GHz	NO	NO	Cont	Cont	Cont	Cont	Cont	Cont	Cont
WV lidar	NO	NO	NO	NO	1220-1555 (gap)	NO	1206-1625	NO	0815-1035
Ozone lidar	21-24	Cont	0945-2400	10-14	NO	NO	Cont (gaps)	0-21 (gaps)	NO
UFAM Doppler lidar	NO	NO	0952-1811	NO	0837-1712	NO	0856-1810	1040-1849	0655-1854
IMK Doppler lidar	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
UFAM Wind Profiler	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
UFAM Radiometer	Cont	Cont	Cont	Cont	Cont	0938 on	Cont	Cont	Cont
MO Radiometer	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
Chlbltn sodar	0700-2100	0700-2100	0700-2100	0700-2100	NO	0700-2100	0700-2100	0700-2100	0700-2100
Alice Holt sodar	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100	0700-2100
Reading sodar	NO	NO	NO	NO	NO	NO	NO	NO	NO
Leeds r/s	08-17	11-18	08-17	NO	NO	12-17	11-16	11-18	08-16
Reading r/s	08-17	13-18	08-17	10-17	NO	13-17	11-16	11-18	08-16
Manchester r/s	08-17	10-18	09-17	NO	NO	12-17	12-18	12-17	08-16
IMK Chlbltn r/s	08-17	12-18	NO	NO	NO	12 13 15 17	17 18	16-18	13 15
IMK Bath r/s	08-17	11-18	08-17	NO	NO	NO	11 13 15 17 18	11 13 14 16 18	08-16
MO mobile r/s	NO	NO	NO	NO	NO	NO	NO	NO	(Bath) 8-16
Chlbltn energy bal	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
Bath energy bal	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont
GFZ GPS	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont	Cont

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## CHAPTER 3

### Radiosonde Launch Times

The tables below summarise the times at which radiosondes were launched from the various sites involved in CSIP.

B	Bath
C	Chilbolton
R	Reading
P	Preston Farm
L	Larkhill
LI	Linkenholt
H	Herstmonceux
CA	Camborne
M	Midhurst
O	Oxford
CN	Cardington

**Table 3.1** Key to the abbreviations used in the subsequent tables.

IOP 1	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
15/06/05 WED	B <sup>a</sup>					0938		1104	1205	1305					
	C														
	R				0810	0925	1000	1100	1215	1315	1400	1440			
	S														
	P				0806	0907	0957	1058	1158	1258	1358				
	L	0541			0813		1002		1200		1359		1559		
	H				0815			1115			1415			1715	
	CA				0816			1115			1416			1716	
IOP 2	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19/06/05 SUN	B														
	C			0659	0803	0902	0959	1101	1204	1302	1402				
	R			0710	0840		1010	1107	1200	1300	1400				
	S			0724	0809	0910	1000	1106	1204	1300	1400				
	P			0659	0758	0856	0958	1058		1312					
	L														
	H				0815			1115			1415			1715	
	CA				0818			1117			1418			1717	

**Table 3.2** Radiosonde launch times for IOPs 1 and 2: 15 and 19 June 2005.

<sup>a</sup>Launched by Met Office - Cardington

IOP 3	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
24/06/05 FRI	B				0806			1057	1203	1300	1401	1457			
	C		0559		0759		1006	1059	1159		1400				
	R		0604	0700	0759	0900	1023	1045	1200	1300	1355	1500			
	S		0610	0708	0805	0905	1000	1100	1205	1300	1401	1504	1607	1711	
	M <sup>a</sup>				0836	0926	1014	1104	1204	1303	1407	1508		1736	
	L	0539			0841		1022		1201		1402				
	H	0515			0815			1115			1415			1752	
	CA	0515			0816			1115			1420			1715	
IOP 4	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
28/06/05 TUE	B		0602	0700		0900			1200						
	C			0700		0900			1207				1557 <sup>b</sup>		
	R		0559	0703		0902			1200						
	S				0800	0900			1204						
	P		0549	0651		0845			1144						
	L	0537			0802		1001		1155		1400		1600		1759
	H	0515			0815			1115			1415			1715	
	CA				0815			1114			1415			1715	

**Table 3.3** Radiosonde launch times for IOPs 3 and 4: 24 and 28 June 2005.

<sup>a</sup>Launched by Met Office - Cardington

<sup>b</sup>Launched by Leeds

IOP 5	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
29/06/05 WED	B				0800	0900	1000	1100	1200	1300	1400	1502	1559		
	C				0800	0859	1000		1200		1400	1500	1600		
	R				0745	0859	1000	1115	1200	1302	1402 & 1416	1507	1602		
	S				0800	0900	1000	1100	1200	1300	1400	1500	1600		
	P				0757	0859	0958	1059	1157	1258	1358	1458	1556		
	L	0542			0803		0959		1159		1400		1601		
	H				0815			1115					1608		
	CA				0818			1115			1422				
IOP 6	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
04/07/05 MON	B			0709	0801	0900	1004	1100	1200	1302	1403	1504			
	C				0759		1002		1202		1359	1459	1607	1705	
	R		0558	0700	0800	0902	1002	1103	1205	1308	1401	1502	1608	1700	
	S			0700	0800	0900	1000	1123	1218	1300	1349	1500	1600	1700	
	P			0655	0800	0903	1011		1151	1252	1358	1507	1605		
	L	0543			0813		0954		1210		1408				
	H	0555			0830			1115			1415			1715	
	CA	0532			0820			1115			1418			1715	

**Table 3.4** Radiosonde launch times for IOPs 5 and 6: 29 June and 4 July 2005.

IOP 7	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
07/07/05 THU	B				0800	0900	1000	1100	1200	1300	1400	1504	1600		
	C					0859	1013	1103	1202	1300	1403	1457	1604	1701	
	R					0857	0958	1100	1210	1300	1343	1450 & 1530	1628	1723 <sup>a</sup>	
	S				0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	
	P					0859	1020	1128		1255	1413				
	O					0903	1003	1102	1202	1303	1402	1503	1602		
	L	0549			0808		0958		1206		1401	1533			
	H	0515			0815			1115			1415			1715	
	CA	0515			0820			1114			1416			1715	
IOP 8	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
13/07/05 WED	B					0902	1000	1100	1200	1300	1400	1500	1604	1700	
	C					0904	1000	1058	1156	1259	1407	1503	1600	1700	
	R					0900	1019	1115	1204	1303	1405	1502	1602	1703	
	S					0900	1000	1100	1200	1300	1400	1501	1604		
	P					0859	0959	1058	1158	1300	1359	1459	1600		
	L	0543			0807		1000		1200		1402				
	H	0515			0815			1115			1415			1715	
	CA	0520			0815			1115			1418			1715	
	LI			0713		0900	1000	1101	1200		1353		1557	1703	

Table 3.5 Radiosonde launch times for IOPs 7 and 8: 7 and 13 July 2005.

<sup>a</sup>No data retrieved

IOP 9	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
18/07/05 MON	B								1159	1300	1400	1500			
	C											1508		1657	1800
	R										1410	1525	1605	1715	1810
	S								1208	1300	1400	1459	1600	1657	1759
	P														
	L	0532					1003		1158		1401		1606		
	H							1115			1415			1715	
	CA							1116							
IOP 10	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
23/07/05 SAT	B				0800	0900	1000	1059	1200	1305	1404	1500	1609	1659	
	C				0800	0900	0959	1100	1159	1259	1400	1500	1559	1659	
	R				0800	0900	1002	1104	1205	1303	1400	1500	1600	1700	
	S				0807	0900	1000	1100	1200	1300	1400	1500	1600	1700	
	P				0759	0859	0959	1059	1159	1259	1400	1459	1558	1659	
	L														
	H	0515			0815			1115			1441			1715	
	CA	0516			0829			1115							

**Table 3.6** Radiosonde launch times for IOPs 9 and 10: 18 and 23 July 2005.



IOP 11	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
24/07/05 SUN	B							1100	1200	1300	1400	1500	1600	1700	1800
	C								1206	1259	1359	1459	1559	1706	1758
	R									1302	1401	1500	1601	1702	1802
	S						1009	1102	1200	1300	1400	1500	1604	1700	1756
	P							1058	1201	1259	1359	1501	1600	1659	1759
	L														
	H	0515			0815			1115			1415			1715	
	CA	0516			0819			1116			1417			1715	
IOP 12	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
28/07/05 THU	B				0800	0859	1000	1100	1159	1300	1400	1503	1600	1700	
	C														
	R				0803	0902	1004	1102	1200	1303	1403	1502	1604	1703	
	S					0855	1027	1109	1201	1259	1401	1500	1604	1654	
	P				0801	0859	1000	1100	1203	1301	1400	1500	1600	1701	
	L	0530			0801		0954		1203		1410		1602		
	H				0815			1115			1415			1715	
	CA				0818			1116			1415			1715	
	CN									1346			1615		

Table 3.7 Radiosonde launch times for IOPs 11 and 12: 24 and 28 July 2005.

IOP 13	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
01/08/05 MON	B														
	C														
	R						0956		1200		1407	1527		1702	
	S														
	P														
	L	0543					0955		1200		1405		1606		
	H					0916		1116			1423				
	CA							1123							
	LI									1246	1415		1546	1645	
IOP 14R	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
11/08/05 THU	B														
	C														
	R														
	S														
	P														
	L	0544					1038								
	H	0515			0825			1115							
	CA	0516			0814			1118							
	CN									1349					

**Table 3.8** Radiosonde launch times for IOPs 13 and 14R: 1 and 11 August 2005.

IOP 15	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
13/08/05 SAT	B														
	C								1158	1258 & 1333		1539		1701	
	R								1200 & 1219	1259	1405 & 1430	1519	1615		
	S								1157	1258		1500	1600	1700	
	P								1201	1301	1400	1459	1600	1659	
	L														
	H	0515			0815			1115			1415				1756
	CA	0510			0815			1116			1418			1716	
IOP 16	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
18/08/05 THU	B							1100		1300		1500		1700	1800
	C													1700	1802
	R							1058	1158	1300	1400	1502	1603	1702	1801
	S								1216	1305	1409	1503	1600	1700	1759
	P							1100	1200	1301	1401	1501	1600		
	L	0539			0803		1007		1202		1401				
	H	0515			0815			1115			1415			1715	
	CA	0515			0822			1118			1417			1721	
	CN							1058	1200	1304	1401	1500	1601		

Table 3.9 Radiosonde launch times for IOPs 15 and 16: 13 and 18 August 2005.

IOP 17	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19/08/05 FRI	B							1100		1300	1400		1600		1800
	C												1604	1702	1800
	R								1159	1300	1400	1500	1600	1710	1805
	S								1147	1300	1400	1457	1600	1700	
	P							1101	1159	1300	1400	1500	1601	1700	1800
	L	0531			0800		0959		1208		1404				
	H							1115							
	CA							1120							
IOP 18	LOCN	5	6	7	8	9	10	11	12	13	14	15	16	17	18
25/08/05 THU	B <sup>a</sup>					0800	0900	1001	1101	1200	1300	1405	1503	1602	
	C									1309		1507			
	R				0812	0900	0959	1100	1200	1310	1403	1500	1601		
	S				0817	0900	1000	1100	1200	1303	1400	1500	1600		
	P				0800	0900	1000	1100	1158	1300	1400	1500	1604		
	L		0543		0803		0957		1208		1404		1606		
	H	0515			0829			1115			1415			1715	
	CA	0517			0818			1130			1424			1717	

**Table 3.10** Radiosonde launch times for IOPs 17 and 18: 19 and 25 August 2005.

<sup>a</sup>Launched by Met Office - Cardington

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## **CHAPTER 4**

### **Met Office Model Evaluation**

This chapter summarise the performance of the 1, 4 and 12 km versions of the Met Office Mesoscale Model.

OP	Date	Comments	Forcing and triggering	12 km Model Performance	4 km Model Performance	1 km Model Performance	Overall Comments
1	15/06/2005	Triggering over SW peninsula convergence possibly modulated by upper trough. Alpha.	Convergence line, SW peninsula. Probably sea breeze.	Random over SW Peninsula, including correct location too early (08:30). Picks out downstream line. Doesn't penetrate lid at 700–750 hPa.	Very good location and timing. Triggers early (08:30? cf 09:15), very close to correct location. Some spurious excess over Cornwall.	Very good location and timing. Excessive small scale triggering and too linear. Triggers early (08:30? cf 09:15) and resulting storm is therefore too far downstream (< 30 km).	Very good 4 and 1 km forecasts, main problem being excessive small scale precipitation in 1 km. Cause of convergence line. Role of upper level forcing? Reason for false alarm in UK model.
2	19/06/2005	Yorkshire floods – no triggering in CSIP area. Gamma.			False alarm in UK 4 km.		
3	24/06/2005	Glastonbury floods. Upper front, organised N–S lines of convection. Beta.	No obvious low level triggering	Loses main system after 11 Z over Bedfordshire. Hint of linear organisation in second line (Dorset, 11:30). Mid-level triggered (if at all).	Strong linear structures, but generally very poor location.	Largely follows 4 km.	Very complex evolution, poorly forecast at small scale. Deserves study but will be very difficult.

IOF	Date	Comments	Forcing and Triggering	12 km Model Performance	4 km Model Performance	1 km Model Performance	Overall Comments
4	28/06/2005	Large scale organised ('spiral') bands around low centre. Gamma.	No obvious low level triggering, though likely cold pool/subsidence zone later (1900Z)		Not yet run.	Not yet run.	
5	29/06/2005	Oxford flood – organised E-W line associated with upper level forcing or cirrus modulated surface forcing. Alpha.	Uncertain role of cirrus in modulating surface heating. Possible frontogenesis? CIN early in day. Also mid-level lid (650 hPa).	Spurious convection over most of southern England by 13Z, spreading from SW. Band in right place ~1245Z but also spurious closer to coast.	Spurious, probably shallowish, convection new S coast ~10Z, goes on to form band a little too far N at ~12Z. Clear surface convergence at 10Z precursor to precipitation.	Much spurious, probably shallowish convection near S coast ~10 Z goes on to form band a little too far N (~30 km) at ~12Z, similar to 4 km. Band also moves N too fast. Spurious small scale convection continues throughout forecast. Role of cirrus?	Generally good 4 km and 1 km forecasts except for small scale triggering of 1 km and location of band too far N. More correct location of band in 12 km model may suggest upper level forcing is of more relevance.
6	04/07/2005	Continuous stream of cells originating in NW flow over Wales, with some triggering and organisation in CSIP area. Alpha.	Clear Land surface forcing, with help from convergence lines. No CIN, weakish CAPE.	Picks up convergence from Anglesea and Pembroke well. Main problem is Welsh coast. V good accumulations. All models have slight positional error of residual low/cloud head.	Generally good location.	Generally good location, though excessive.	Some question over small phase error in large scale position of cold pool contaminating results. Otherwise 1 km model will benefit from larger domain including Wales to pick up role of coast and orography in forming convergence lines. It would also appear that some convergence lines in the model generated cells which did not exist in reality – why? Secondary initiation will be major interest in 1 km model.

OP	Date	Comments	Forcing and Triggering	12 km Model Performance	4 km Model Performance	1 km Model Performance	Overall Comments
Z	07/07/2005	Showers in N flow. Beta.	No obvious surface forcing apart from edge of warmer air (cloud cover). John Marsham suspects GW. Weak CCB ascent?	Much more linear (N-S) than actual. Otherwise, generally sensible. Strong convergence down spine of England – difficult to distinguish from convection. No obvious cold pool till (possible) weak signal late in forecast.	Much more linear (N-S) than actual. Otherwise, generally sensible. Strong convergence down spine of England – difficult to distinguish from convection. Clear cold pool associated with line of showers (15Z).	Clear cold pool behind line of showers (15Z). Far too much rain and too much small scale convection.	Appears closely coupled to upper level PV. John Marsham has hypothesised modulation by GW from Yorkshire, which appears absent from the model. Would need V large domain.
8	13/07/2005	Surface forced along Chilterns, S coast sea breeze, intermediate lid and little triggering. Alpha.	Very obvious surface and orographic forcing.	Overdone. Overall, 12/4/1/pretty similar	Overdone. Clear sea breeze convergence lines, one in right place for actual triggering.	Overdone.	Likely to be a very good test for boundary layer/Cumulus treatment in model. Currently not very good, though whether this is physics or initial state requires analysis. Likely to be sensitive to BL moisture.
9	18/07/2005	A narrow line of convective showers associated with the passage of a surface cold front. Alpha.		Overdone convective precip to N on front.	Overdone convective precip to N on front.	Good line structures. Cold pool formed later (17Z) and pushed convection ahead of front.	Potentially a good DA example – small location errors. Is the cold pool realistic?



IOP	Date	Comments	Forcing and triggering	12 km Model Performance	4 km Model Performance	1 km Model Performance	Overall Comments
10	23/07/2005	Isolated showers eventually breaking out late in day after suppression by lid at 2 km.  Gamma.		Overdone convective precipitation.	Overdone convective precipitation.	Overdone convective precipitation.	Need to establish whether forecast precip was breaking through lid because lid was too weak relative to surface forcing, or simply that shallow convection produced too much precipitation.
11	24/07/2005	Beta.		Main problem seems to be error in location of low centre, leading to substantial displacement of convective bands to North. Applies to all models.			Should look at impact of DA on later runs. Otherwise, probably of low interest.
12	28/07/2005	Cloud Streets from S. Coast, Birmingham tornado.  Alpha.	Clearly related to BL development, then dry intrusion overrunning cold front.	Excessive convection in dry slot, too little at front.	Good individual cells forced by convergence line and uplift.	Picks out cloud streets and general development. Main clouds out of area.	Trigger mechanism for main tornadic cells of interest as well as role of cloud streets. main cell located close to triple point. Need larger area 1 km run.

IOP	Date	Comments	Forcing and triggering	12 km Model Performance	4 km Model Performance	1 km Model Performance	Overall Comments
13	01/08/2005	S Coast and Kent/Sussex initiation, intermediate lid with only 1 or 2 cells going deep to ~9 km. Beta.	Surface forced. No CIN.	All models very comparable (and pretty good)	4 km adds little.	1 km adds little.	Why do some cells manage to go deep?
14	11/08/2005	Retrospective IOP – no full operation. Isolated shower – possible sea breeze or upper level triggering. Beta.		General area pretty good if a little E. All models very comparable.	Location good. Possible convergence lines.	Excessive triggering, location good. Possible convergence lines.	Earlier forecast was poor – indicated strong lid. What changed? What was the role of low level convergence lines.
15	13/08/2005	Shallow showers behind cold front. Gamma.					
16	18/08/2005	Weak, broadly southerly flow ahead of a band of cold-frontal rain advancing slowly from the west. Shallow showers developing later in evening. Beta.	Lid lifting from west.	Develops too early. Otherwise, very good. All models very comparable.	Develops too early (1130Z first cells, secondary development in right place at 1345Z cf 1530Z). Complex network of convergence lines.	Develops too early (11Z first cells, secondary development in right place at ~1315 cf 1530Z). Usual small scale showers.	Why too early? Why right place (role and cause of convergence line)? 12 km parametrized shows similar good location. Role of Cirrus in suppressing triggering.

OP	Date	Comments	Forcing and Triggering	12 km Model Performance	4 km Model Performance	1 km Model Performance	Overall Comments
17	19/08/2005	Scattered showers in Wales and the north-west Midlands in the north-westerly flow behind Cloud Head(s) during the early afternoon, followed by the formation of a line of showers just west of Bath.	Likely surface convergence.	Location and timing not bad.	Location and timing reasonable, though suspicion is that actual cells in model do not correspond with actual cells – there is a hint of weak cells in the right place which die out. These are associated with a clear low level convergence line.	Similar to 4 km.	Mechanism for triggering. Why do cells on convergence line die out? Needs larger domain 1 km.
		Beta.					
18	25/08/2005	Westerly flow beneath upper trough – development of organised convection with strong cold pool/subsidence/gust front system. Alpha.		Triggers over land far too soon. Propagates too fast E. No cold pool.	Triggers ~0815 over Bristol Channel just S of Weston-super-Mare cf earlier triggering to W in reality, though there is clear intensification as cells reach this point. Reality has linear structure by 0900, but model still has main cell in right place. Good subsidence behind organised system. Superb cold pool, though propagates too slow.	Triggers ~0800 over Bristol Channel just S of Weston-super-Mare cf earlier triggering to W in reality, though there is clear intensification as cells reach this point. Reality has linear structure by 0900, but model still has main cell in right place. Good cold pool, though propagates too fast and rather ragged. Suggestion of splitting.	Mechanism for primary triggering and formation of linear structure.  Rate of cold pool propagation. Sensitivity to microphysics and turbulence schemes.  Possible experiments with convection scheme in 4 km model.

## CHAPTER 5

### IOP 1: Wednesday 15 June 2005

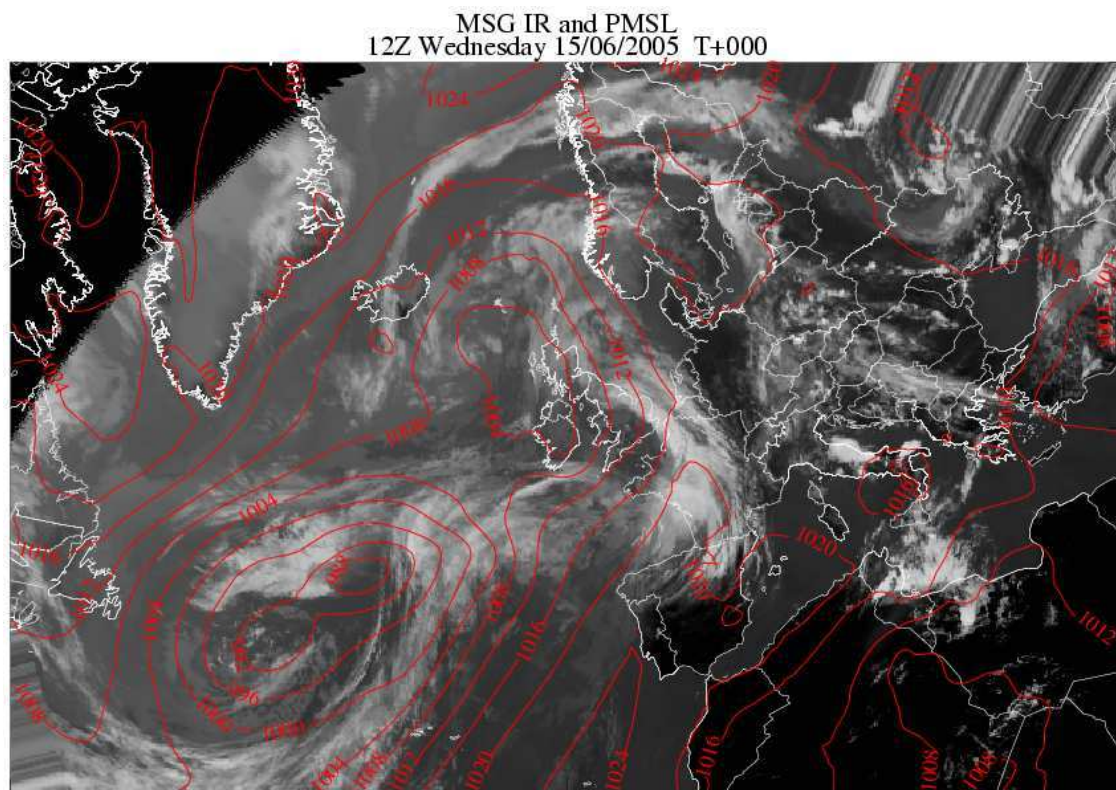
#### 5.1 Overview

A small weak upper-level vortex crossed southern England behind an active cold front. Figure 5.1 shows the cold front over eastern England. Light scattered showers occurred after the frontal clearance mainly along an apparent convergence line extending along, and downwind, of the spine of the south-west peninsula. A major lid was constraining the depth of the convection: it was situated at roughly 3 km, although the radar RHI scans suggested that it may have been lifted about 500 m higher over a 20-30 km wide strip along (at least part of) the convergence line.

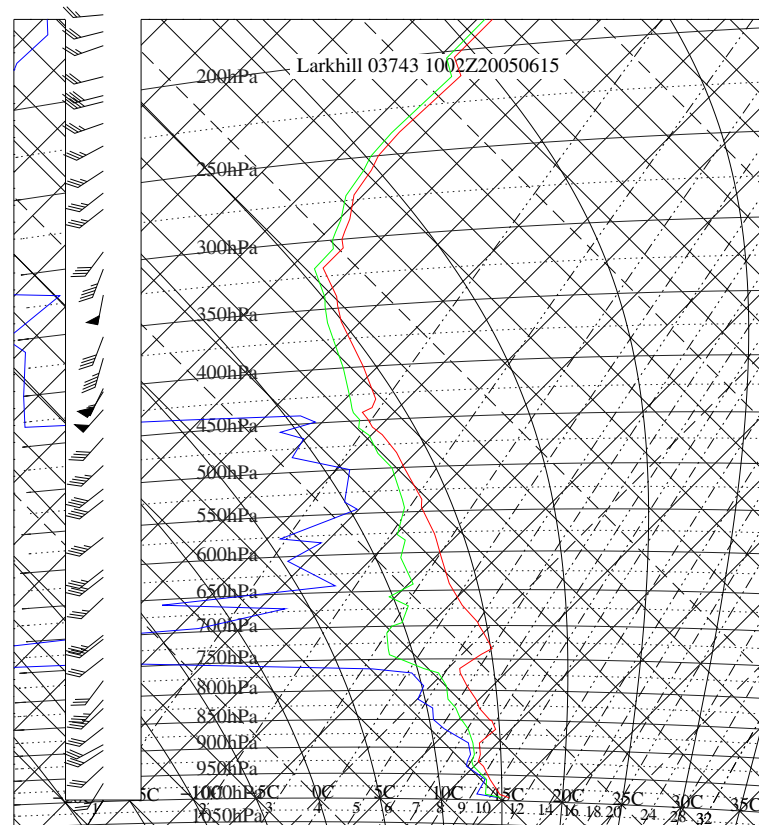
The showers formed in the region of the convergence line. Most were constrained by the lid and produced only light rain. However, at least one shower penetrated it and rose to above 6 km before developing into a single isolated thunderstorm cluster. A combination of radar data and serial radiosondes ascents from Bath, Larkhill, Reading, Preston Farm and Herstmonceux will enable the space-time evolution of the lid to be diagnosed in relation to the shower development. The UM mesoscale model appeared to forecast the showers fairly well. We need to ascertain what aspect(s) of its reproduction of the situation was key to its success.

#### 5.2 Hypotheses

1. Light warm rain/drizzle showers with tops up to Lid B (at about 3 km) were initiated along a boundary-layer convergence zone extending from the spine of Cornwall NE'wards into Central Southern England.
2. (a) One cluster of the above showers became intense when its top penetrated through Lid B to reach Lid C (see Fig. 5.2).  
  
(b) this occurred where a N-S oriented upper-level trough intersected the boundary-layer



**Figure 5.1** MSLP analysis and satellite infra-red cloud at 1200 UTC. The heavy isolated shower can just be seen to the east of the mouth of the Severn estuary.



**Figure 5.2** Tephigram for the 1200 UTC radiosonde ascent from Larkhill showing the presence of three lids: Lid A at 875 hPa, Lid B at 750 hPa and Lid C at 440 hPa.

convergence line.

3. The above-mentioned intersection existed over a period of time but the precise time when the juxtaposition triggered the deep convection was determined by diurnal surface heating and possible also by local topography.

### 5.3 Additional plots

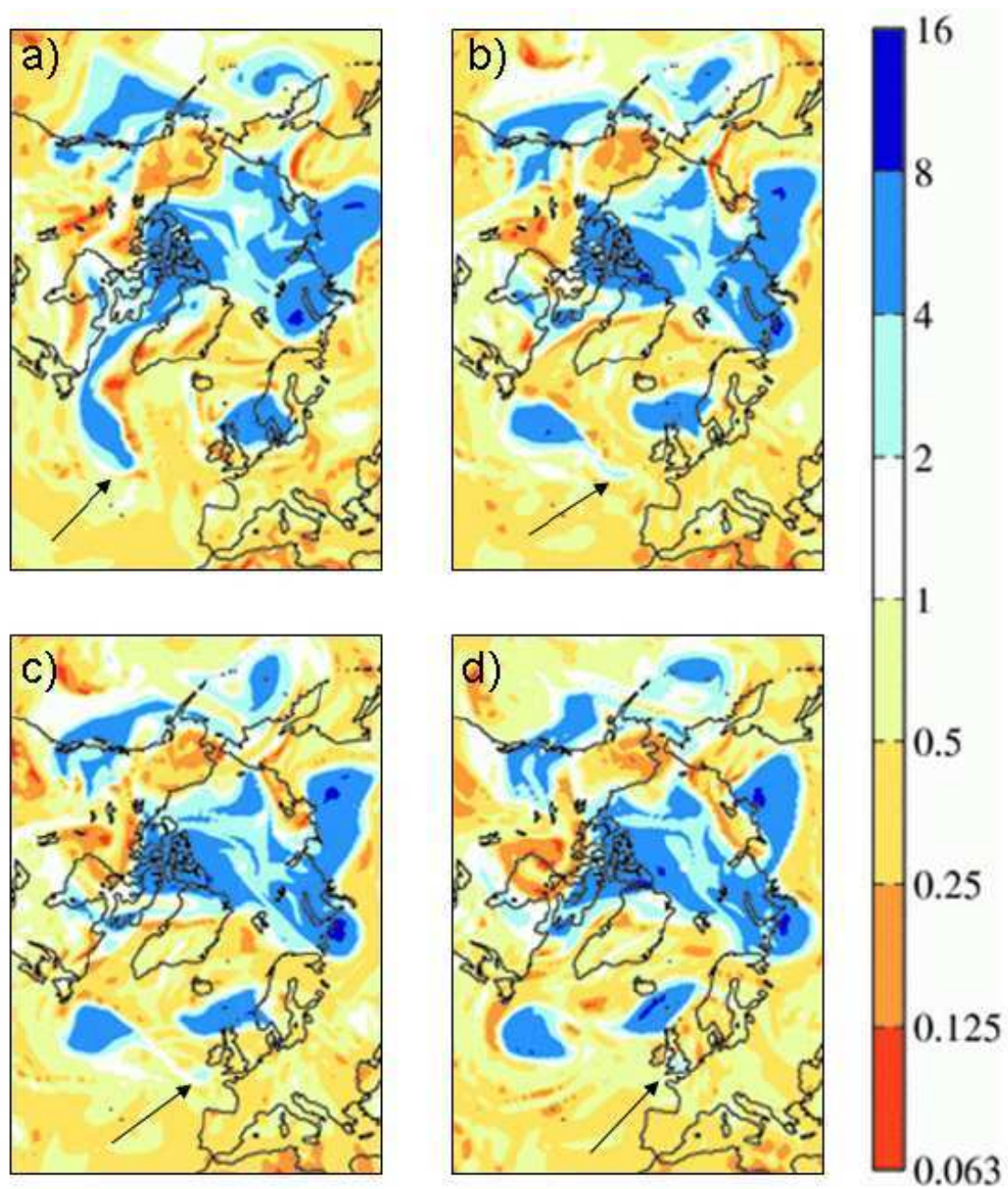
The four panels in Fig. 5.3 are taken from an animation of PV on the 315 K isentrope for the week including the 15 June obtained from the ECMWF analyses. There is a small region of high PV which passes over the CSIP area around 1200 UTC on 15 June 2005. This upper-level PV anomaly can be seen to have originated from a larger high-PV filament in the middle of the Atlantic a few days before. That high-PV region itself can be tracked back to the Labrador Sea region.

The contrast-enhanced Meteosat Water Vapour Channel for 1200 UTC (Fig. 5.4) shows a darker, drier region over Wales and central southern England associated with this positive PV anomaly. In the middle of this dry region there is very small white, i.e. moist, area which is due to the storm that developed at that time. At 1200 UTC, this storm was near Oxford, as shown by the radar network picture in Fig. 5.3.

A zoomed composite image is shown in Fig. 5.6, giving radar rainrate (top left), MSG-derived cloud-top height (top right), MSG high-resolution visible (bottom left), and the orography (bottom right). Range rings and azimuth markers are shown for convenience as are the locations (crosses) of the radiosonde launching sites (from west to east): Camborne, Bath University, Durlston Head (Swanage), Larkhill, Chilbolton, Reading University, Preston Farm (near Chichester) and Herstmonceux.

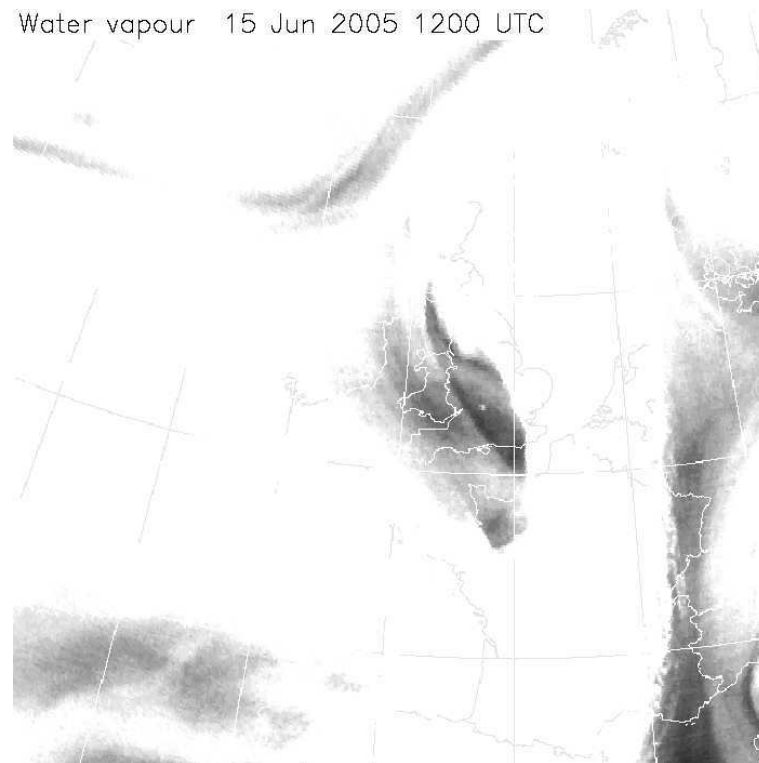
Figure 5.7 shows a sequence of RHIs from the S-band radar at Chilbolton at 1200 UTC along azimuth 310. The scans are approximately towards the north-west and show evidence of the convergence line. The plot of reflectivity (first panel) shows the convective cells between 50 and 60 km range penetrating up to 4 km altitude. Nearby cells penetrated to 8 km. The cells featured in this RHI scan penetrated a stable layer at 1 km and are beginning to penetrate a lid at 2 km which





**Figure 5.3** Four frames showing the PV (in PV units) on the 315 K isentropic surface from the ECMWF analyses at: a) 1800 UTC on 13 June, b) 1800 UTC on 14 June, c) 0000 UTC on 15 June and d) 1200 UTC on 15 June.

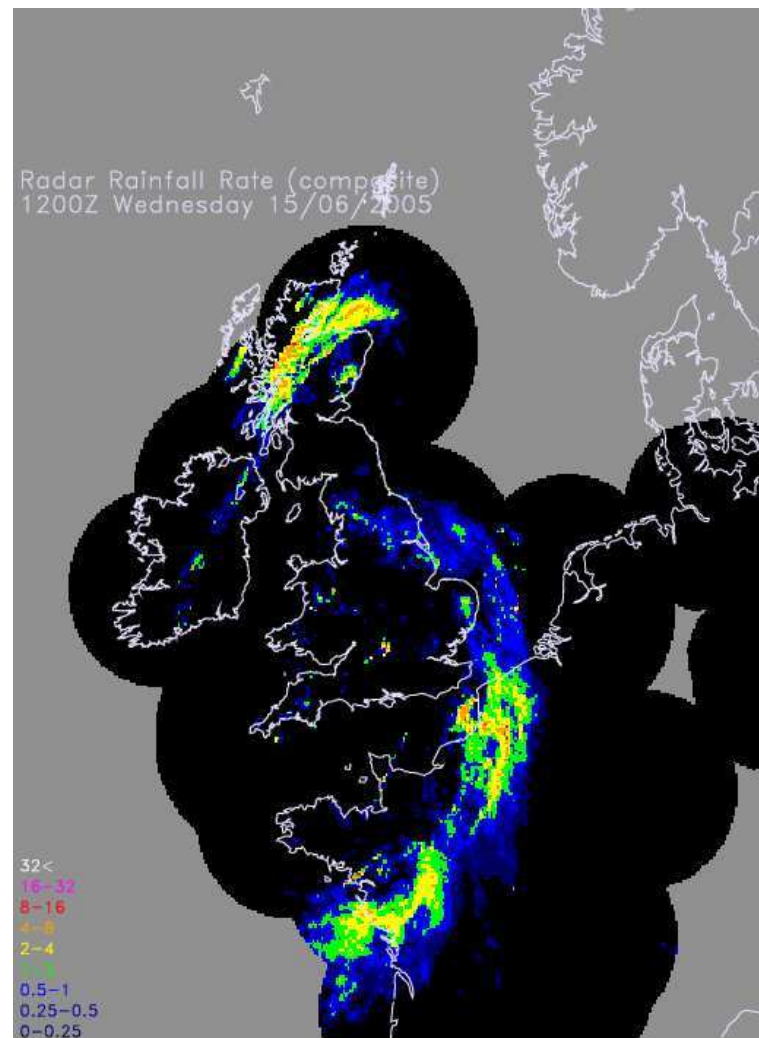




**Figure 5.4** Contrast-enhanced water vapour channel from the Meteosat rapid-scan satellite.

has been lifted above 2.5 km between about 45 and 70 km, presumably as a result of the mesoscale vertical circulation associated with the convergence line. The layers at 1 and 2 km show up in the differential reflectivity plot (second panel). The colour change in the Doppler plot (fourth panel) from red through white to blue (N.B. the velocities have folded!) at 2.5 km, is a manifestation of the divergence at the top of the circulation and the reverse change from white to purple to red below 1 km is a manifestation of the low-level convergence. The height and intensity of the lids can be derived in the x-y plane by plotting data from the serial radiosonde ascents repositioned according to the known system velocity. This work is in progress.

The final diagram (Fig. 5.8) is an analysis of 10m wind speed and direction from the Met Office NIMROD system, showing the convergence line downwind of the Cornish peninsula. It would be worth integrating several hours worth of such convergence data to see if a clearer signal could be found.



**Figure 5.5** Radar network rainrate for 1200 UTC on 15 June 2005.

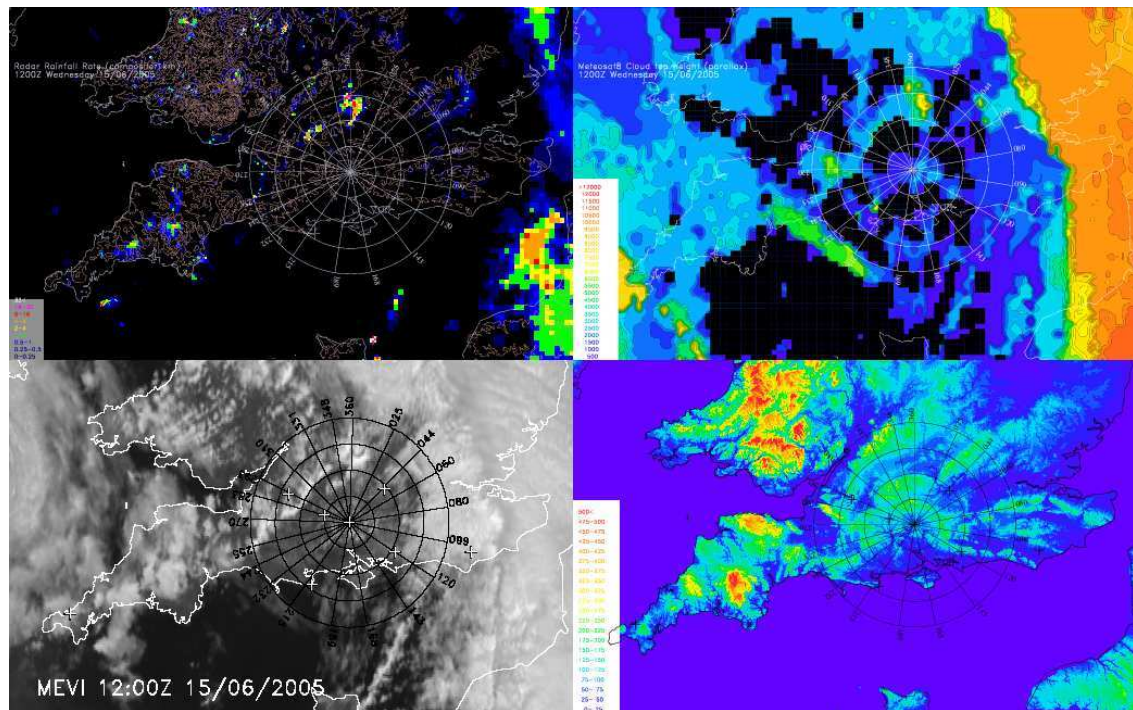
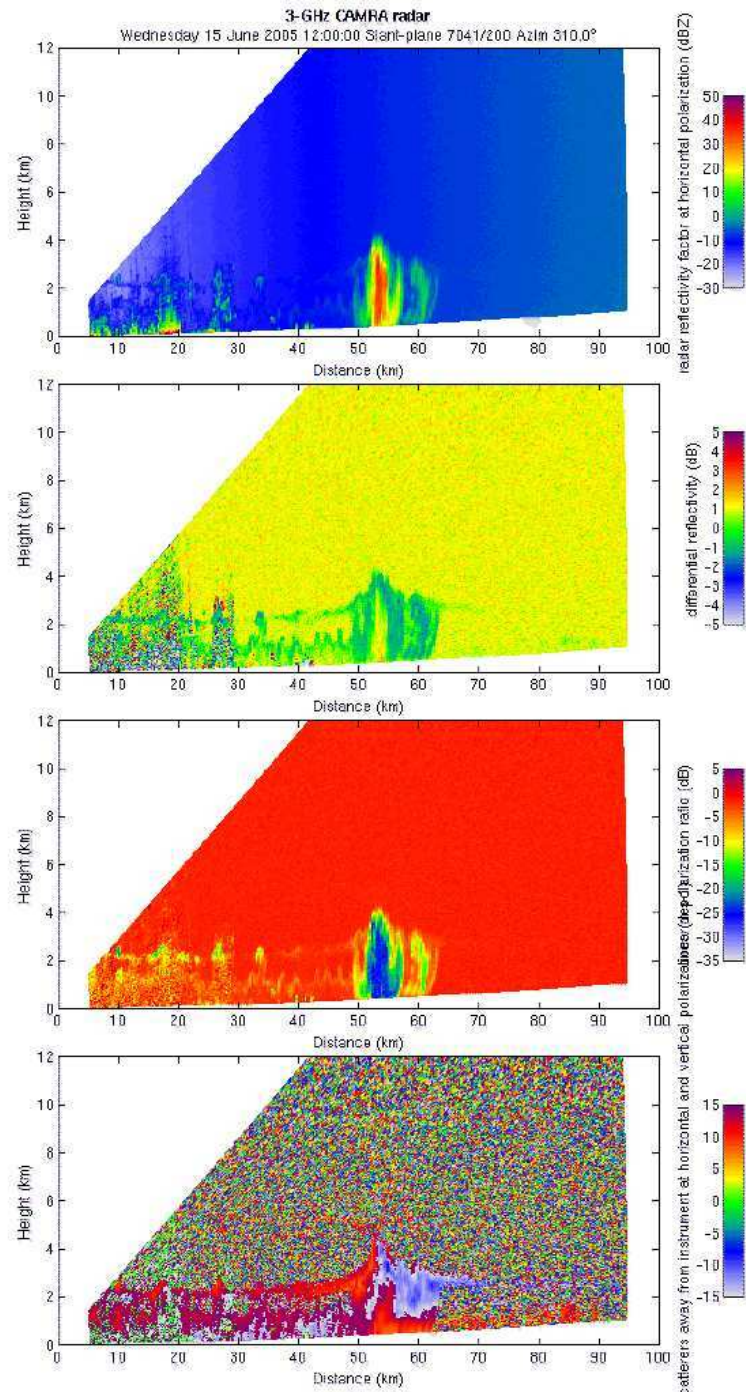


Figure 5.6



**Figure 5.7** RHI obtained using the Chilbolton 3 GHz radar, along azimuth 310 at 1200 UTC. The four panels show: a) reflectivity ( $Z$ ), b) differential reflectivity ( $Z_{dr}$ ), c) linear depolarisation ratio ( $L_{dr}$ ) and d) Doppler velocity.



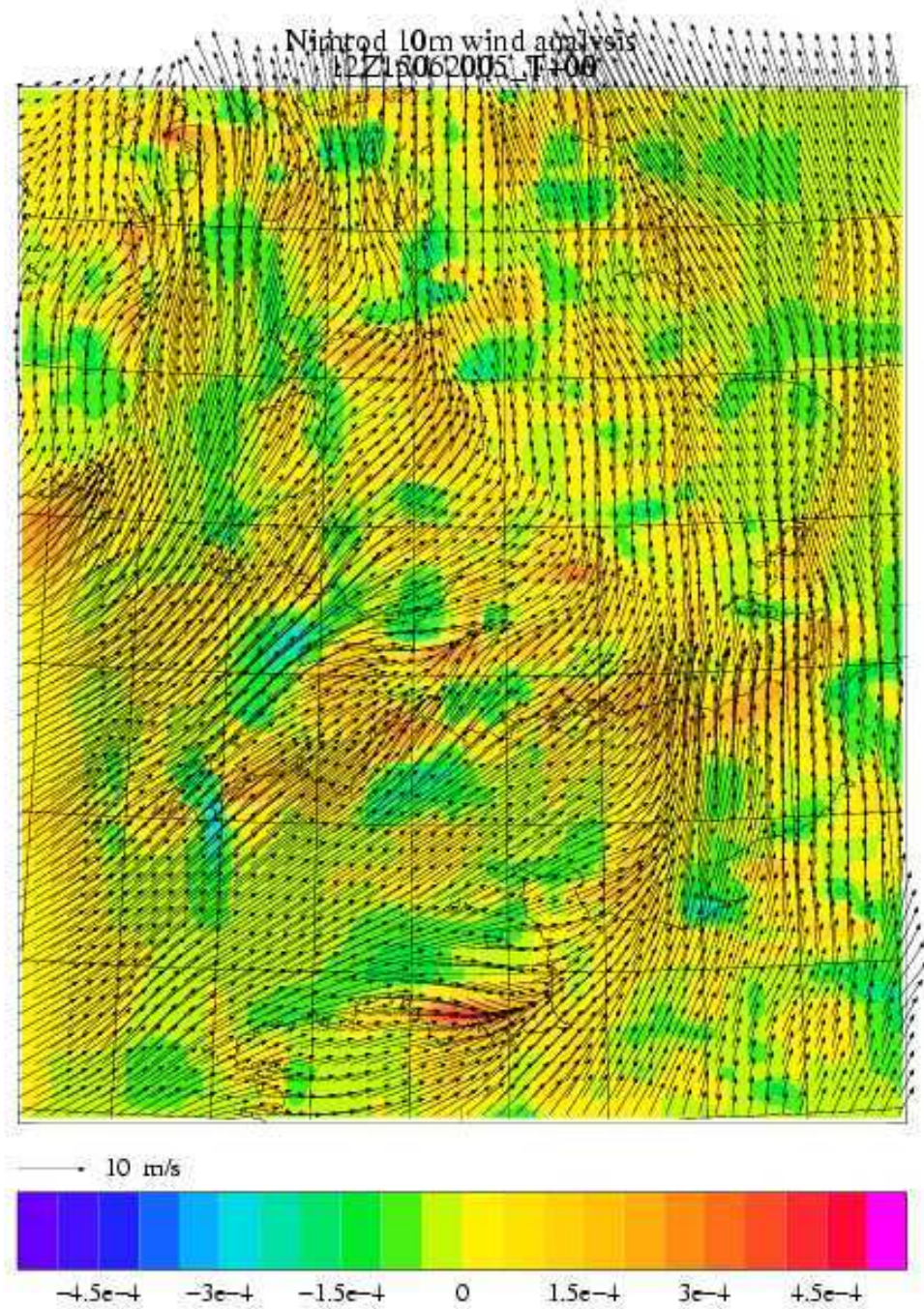


Figure 5.8

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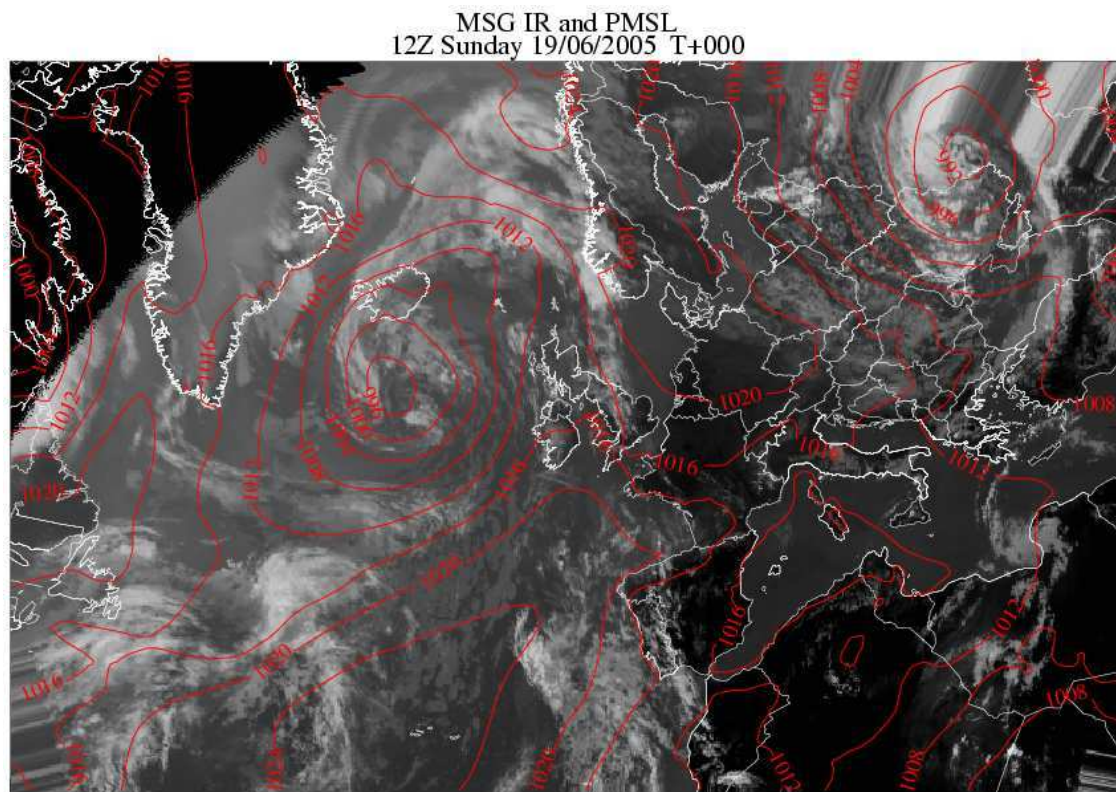
## CHAPTER 6

### IOP 2: Sunday 19 June 2005

Figure 6.1 shows the 1200 UTC mean-sea-level pressure analysis from the Met Office along with the infra-red imagery from MSG. A cold front remained slow-moving to the west of the CSIP area and intense thundestorms broke out at 1300 UTC in a line from the border of mid-Wales northwards. In the CSIP area the boundary-layer convection remained capped by a strong lid whose space-time evolution was described by serial sonde ascents from Chilbolton, Reading, Durlston Head and Preston Farm. These ascents were started at 0700 UTC and terminated between 1400 and 1500 UTC by which time the southern end of the storms was still beyond range in the West Midlands and extending into Yorkshire where severe flooding occurred in and around Helmsley (Fig. 6.2). The Met Office raingauge at Topcliffe measured 40 mm over a three-hour period, 29 mm of which fell between 1600 and 1700 UTC. In Hawnby, these storms led to 69 mm of rain. The River Rye burst its banks and forced motorists to abandon their cars (Source: BBC News Website).

At one stage there was evidence of deepening of the boundary layer locally in Hampshire but this was not sustained. Although the storms to the north were beyond the unambiguous range of the Chilbolton radars, there is some evidence that Acrobat and Camra detected some of the storms as third or forth-trip echoes.





**Figure 6.1** MSLP analysis and satellite infra-red cloud at 1200 UTC.



**Figure 6.2** Flooding in (a) Helmsley, (b) Balk (near Thirsk) and (c) in Sutton-under-Whitstonecliffe, and a map of the area in (d).

## CHAPTER 7

### IOP 3: Friday 24 June 2005

This was a synoptically forced event with widespread thunderstorms throughout southern Britain and the Midlands. Sustained thunderstorm activity affected the north-west of the CSIP area (leading to a flash flood at the Glastonbury Festival). Further south and east, lines of thunderstorms oriented north-south developed during the day, crossing the entire CSIP area from west to east. These storms were not fed by air from the surface; rather it was a plume of warm moist air above 850mb that was feeding convection which penetrated through the cold dry upper levels, up to 8-10km. The plume of high  $\theta_w$  air came from the south and the convection in it may have been triggered by successive pulses of cold air over-running from the south-west. Long sequences of serial radiosonde ascents from several sites will enable this process to be clarified. Measurements of the boundary layer obtained from several of the CSIP instruments may be less informative than usual because of the failure of the boundary-layer air to contribute to the thunderstorm up-draughts. However, it may be that some downdraughts were able to penetrate down to the surface later in the day. Figure 7.1 shows the synoptic situation at 1200 UTC on 24 June 2005. Figure 7.2 shows the radar and satellite imagery for 1245 UTC.

#### 7.1 Some radar RHIs and hypotheses

RHIs showing differential reflectivity ( $Z_{dr}$ ) along azimuths 25 and 120 degrees are given in Figs. 7.3 and 7.4. The former was to the east of the region of showers. The latter was through a region of developing showers (see Fig. 7.2).

We hypothesise that:

1. The red layers correspond to the elevated plume of high- $\theta_w$  air.
2. The green-blue echoes are mantle echoes due to refractive index inhomogeneities at the



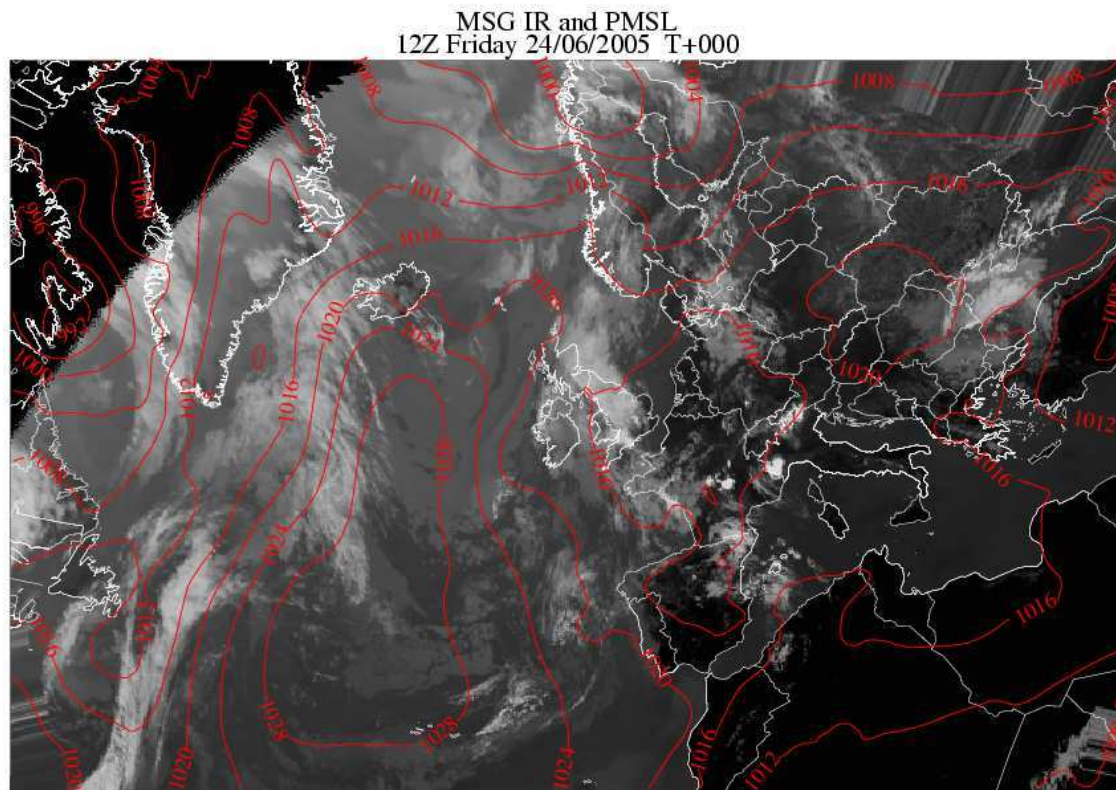
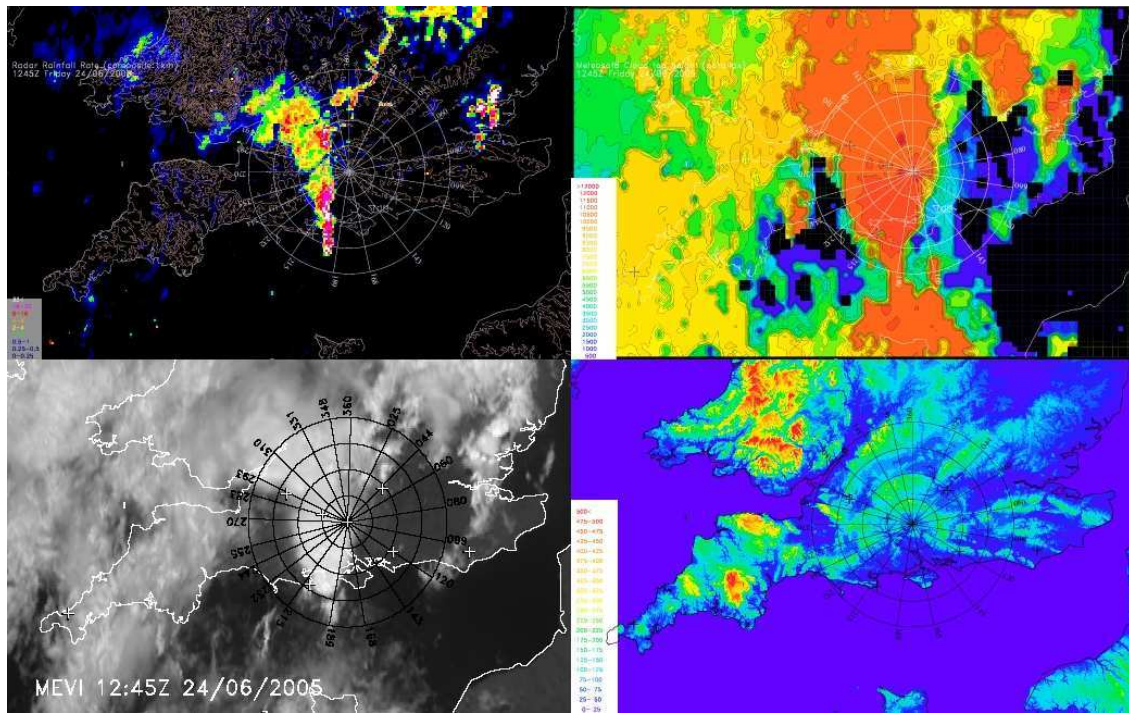
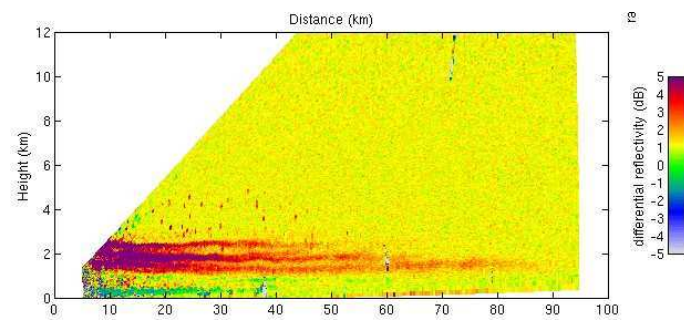


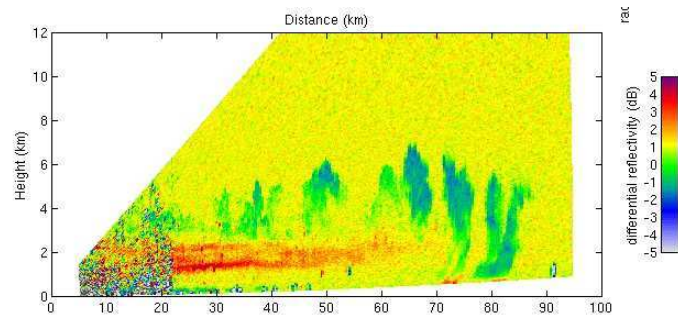
Figure 7.1 MSLP analysis and satellite infra-red cloud at 1200 UTC.



**Figure 7.2** Composite showing radar network rain-rate (top left), cloud-top height (top right), MSG high-resolution visible imagery (bottom left) and orography (bottom right) at 1245 UTC on 24 June 2005.



**Figure 7.3** RHI of ZDR at 12:41 on 24 June 2005, along azimuth 120 degrees.



**Figure 7.4** RHI of ZDR at 12:49 on 24 June 2005, along azimuth 25 degrees.

boundaries of convective cells initiating from the elevated plume of high- $\theta_w$  air. Some cells also show initiation of precipitation which can be seen descending through the inert boundary layer.

We further hypothesise that the elevated plume of high- $\theta_w$  air is rich in insects and these give rise to the red echo (ie high Zdr) whereas the edges of the convective cells are regions of clear-air Bragg scattering from refractive index inhomogeneities (green echoes with low Zdr).

The target classification performed at Reading University as part of CloudNET using data from the 35 GHz vertically pointing radar, may be able to confirm that the layer echoes are indeed due to insects.

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## CHAPTER 8

### IOP 4: Tuesday 28 June 2005

The synoptic situation is summarised in Fig. 8.1. Data were collected by the Chilbolton radars and from the radiosonde sites for a few hours early in the day. Data collection was halted around midday due to the presence of excessive convective inhibition detected in the soundings carried out that morning.

The decision to abort was also influenced by the expectation of more favourable conditions the following day. Outbreaks of convective storms within the CSIP area were expected, and did appear, later; however, these were not expected until late in the day and after the period during which CSIP sondes could have been launched.

The tephigram in Fig. 8.2 shows the Larkhill sounding at 1200 UTC. There is a lot of CIN, preventing the outbreak of convection.



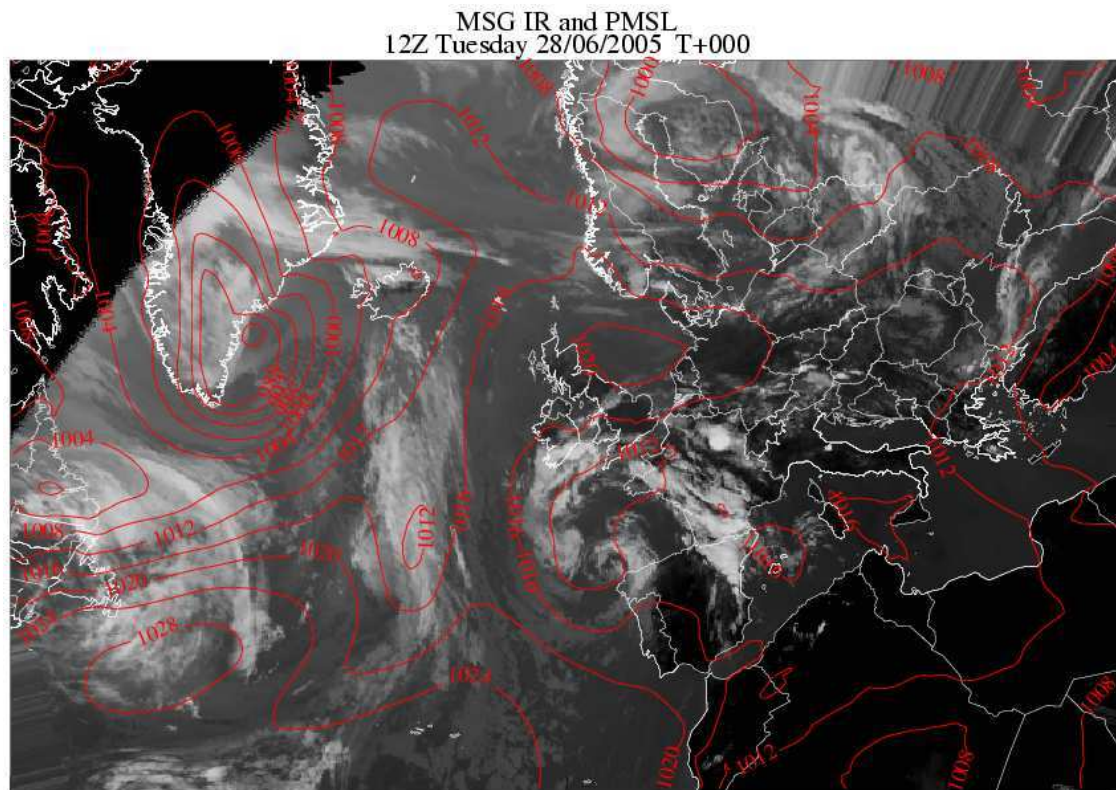
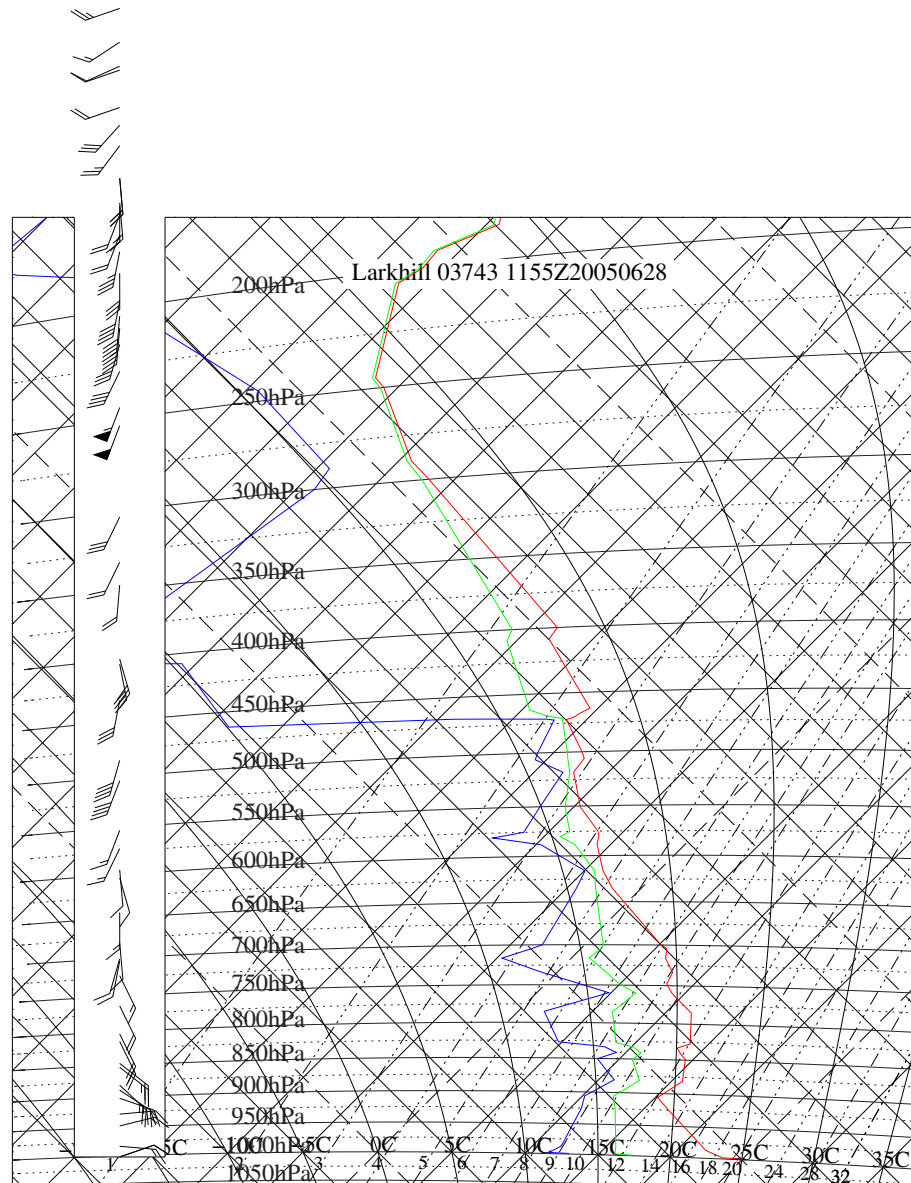


Figure 8.1 MSLP analysis and satellite infra-red cloud at 1200 UTC.



**Figure 8.2** Tephigram for the 1200 UTC Larkhill sounding, showing the large amount of CIN prevailing at the time when IOP 4 was aborted.

## CHAPTER 9

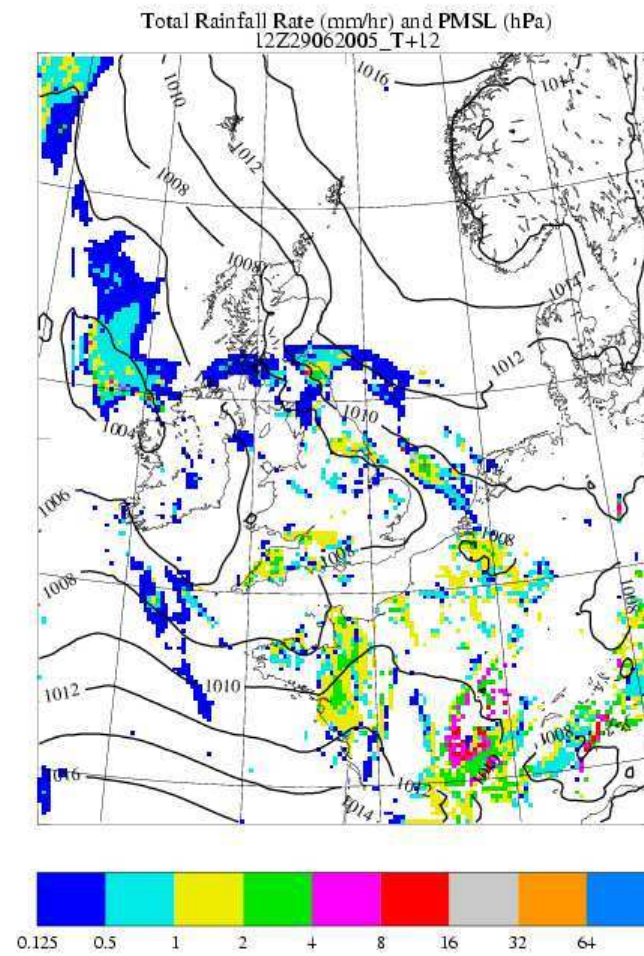
### IOP 5: Wednesday 29 June 2005

The mesoscale model forecast in Fig. 9.1 shows widespread showers in the CSIP area by 1200 UTC. The forecast time-height plots of  $\theta_s$  for Chilbolton in Fig. 9.2 shows shallow showers commencing before 1000 UTC, with the tops of the convective cells reaching tropopause level by 1200 UTC. In the event, the showers became widespread slightly later than this within the CSIP area but they did become intense enough to produce flash floods during the afternoon.

The observations acquired on the 29 June 2005 could turn out to be an excellent dataset for describing the initiation of precipitating convection in the CSIP area. By 1500 UTC a well organised band of heavy showers and thunderstorms was extending roughly west-east from mid-Wales (Aberystwyth) to East Anglia. (It is worth looking to see if the MST radar at Aberystwyth detected anything of interest). This band may well have been organised by a small upper level trough associated with one of the mesoscale "Water Vapour dark zones" circulating northwards around the leading edge of an upper level vortex (cut-off low) centred off Lands End. However, the details of the initiation of convection were probably controlled by the pattern of boundary-layer convergence due to topography and also by the patchy high cloud cover from orphaned anvils produced by earlier storms over western France.

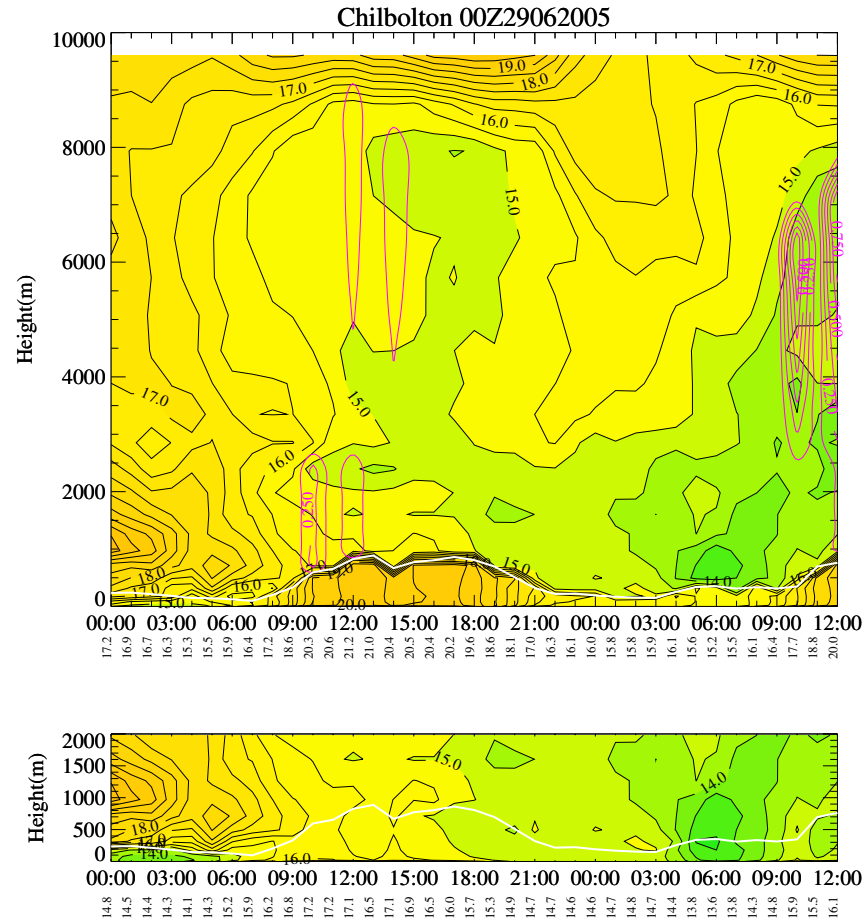
The first convective cells associated with the presumed upper-level trough formed in the late morning in the CSIP area. Three of the earliest cells formed near sites where serial radiosondes were being released. One cell (Cell 1) passed close to Larkhill at 1100 UTC: it was evident in the MSG imagery but failed to produce significant precipitation, perhaps because convection was stifled by an orphaned anvil.

The composite images in Figs. 9.3, 9.4 and 9.5 show: (a) radar rainrate, (b) cloud-top height from MSG, (c) high resolution visible from MSG and (d) orography. Range rings (25km apart) are shown centred on Chilbolton. The azimuths along which RHI scans were performed are also indicated. The locations of the following radiosonde sites are indicated by + signs, from west



**Figure 9.1** MSLP and rain-rate forecast for 1200 UTC.





**Figure 9.2** Forecast time-height plots for Chilbolton for the 36 hours commencing at 0000 UTC on 29 June. The white line in the upper plot shows the lifting condensation level: above this the contours and shading represent  $\theta_s$  and below this they represent  $\theta$ . (Surface values of  $\theta$  are specified along the time axis.) The lower plot shows  $\theta_w$ . Red contours in the upper plot indicate convection triggered within the model.

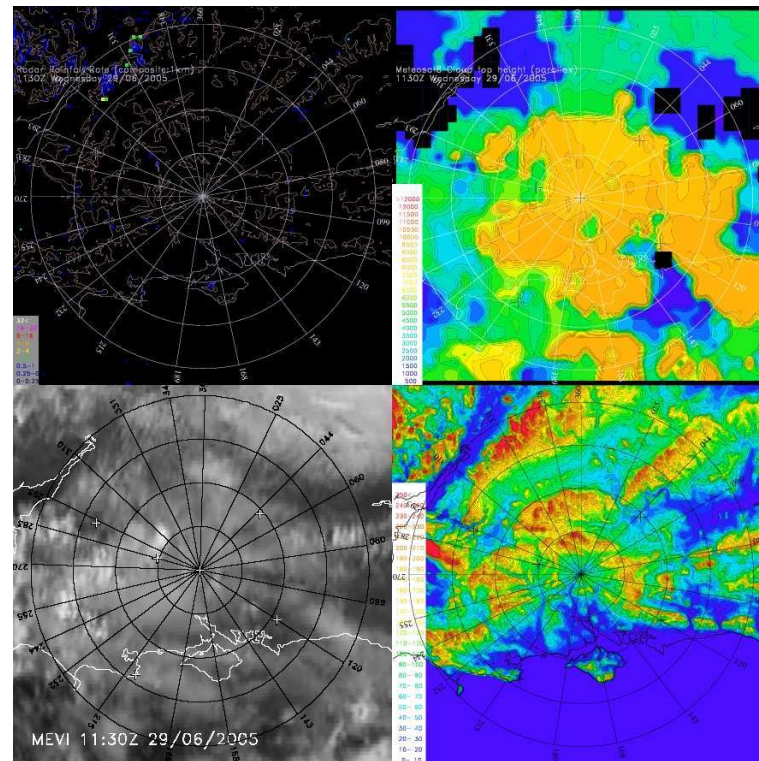


Figure 9.3

to east: Bath, Durlston Head, Larkhill, Chilbolton, Reading, Preston Farm. In Fig. 9.3, we see the Cell 1, along azimuth 293 degrees, 30 km from Chilbolton at 1130 UTC, just after it had passed over Larkhill and just before it decayed. This cell may have failed to intensify due to reduced insolation from the shade of the orphaned anvil, leading to the ascending parcels having insufficient buoyancy to overcome the lid at 4km (See Fig. 9.6 later).

A second cell (Cell 2) passed near Bath at 1145 UTC. Figure 9.4 shows some bright convective clouds in the region at 1200 UTC. Cell 2 produced a little precipitation around 1215 UTC. (See CAMRa data rather than radar network). A third cell (Cell 3) passed over Reading at 1250 UTC, having produced its first radar-network echo at 1240 UTC. A nearby cell can be traced back to 12 UTC as a very bright cloud in the visible image as a developing cumulus congestus cloud 20 km ENE of Chilbolton, along azimuth 70 degrees (Fig. 9.4). Note that the bright white cloud in the visible image at 1200 UTC, is located close to a thinning between the anvil clouds (Fig. 9.4(b)). It is possible that the initiation of convection was not possible in the shade of the anvil, while in the gap in the anvil cloud there would have been sufficient surface heating to initiate convection.

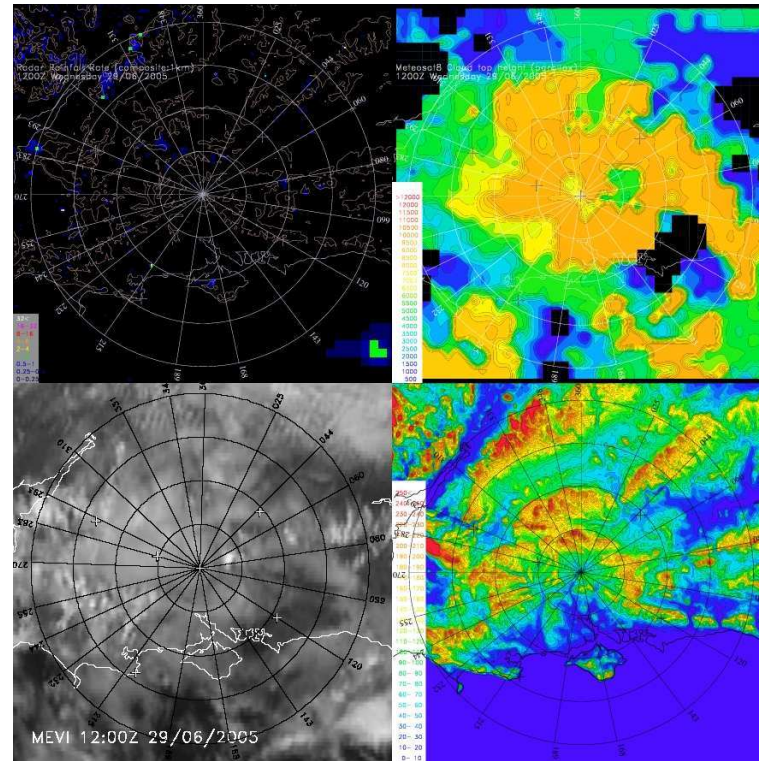


Figure 9.4

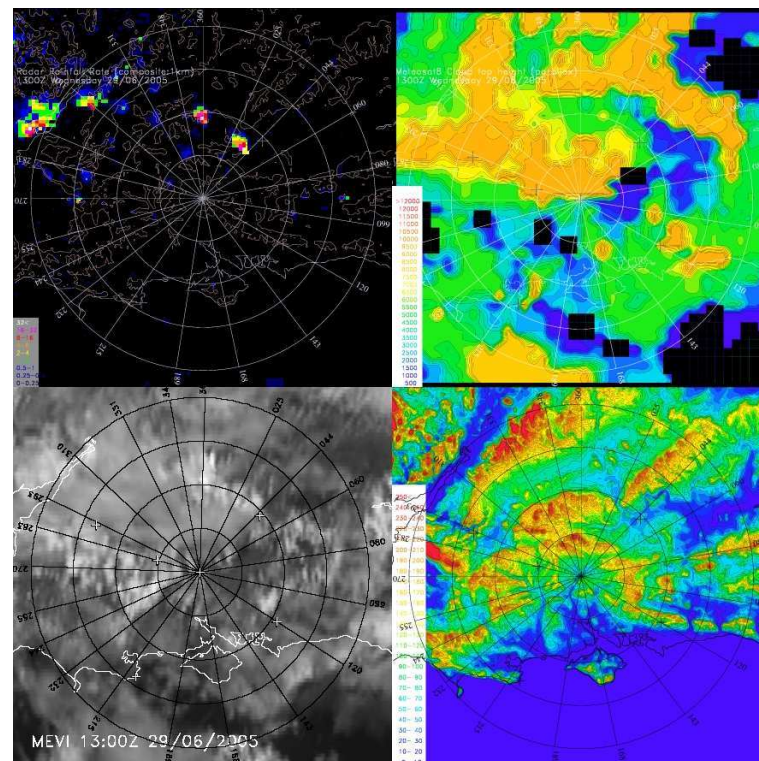


Figure 9.5

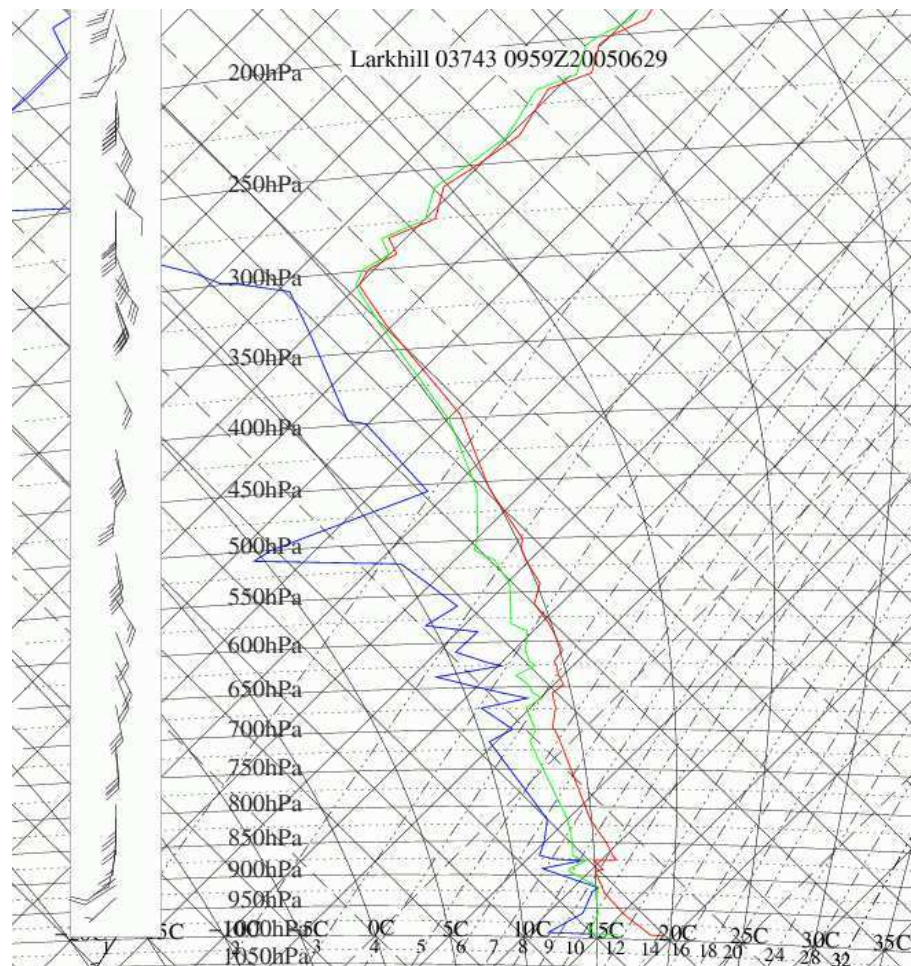
The composite at 1300 UTC (Fig. 9.5), shows the beginning of a line of cloud cells to the north of Chilbolton, with heavy showers now developing to the north and north-east over Wantage and Theale respectively and also in the north-west near the Severn Estuary. It is interesting to note that, in the visible image, the convective clouds appear to form on the flanks of the anvils. Further analysis of the shadowing effect of the anvils can be done by integrating some satellite cloud data over an hour or two, and by comparing with surface insolation measurements, such as those made using radiometers, or alternatively by looking at the record of the voltage input from the solar panels used in the AWSs in the meso-network. Another region of convection formed in the south of the CSIP area behind the first region of convection. This convection failed to penetrate far into the middle levels and produced only light precipitation.

Early in the day boundary-layer convection was constrained by a stable lid near 1 km (e.g. the Lid A at 875 hPa in the tephigram of the 1000 UTC Larkhill ascent, Fig. 9.6). When convection finally broke through Lid A it ascended to a second lid at roughly 4 km (Lid B in Fig. 9.6) leading to some very light showers. Eventually the convection penetrated the second lid and rose toward the tropopause level to produce intense thunderstorms, some of which produced flash flooding in Oxfordshire after 1500 UTC. This occurred near the northern boundary of the CSIP area. Although few of the storms produced heavy precipitation in the CSIP area, the observations collected will be representative of the air that fed these storms.

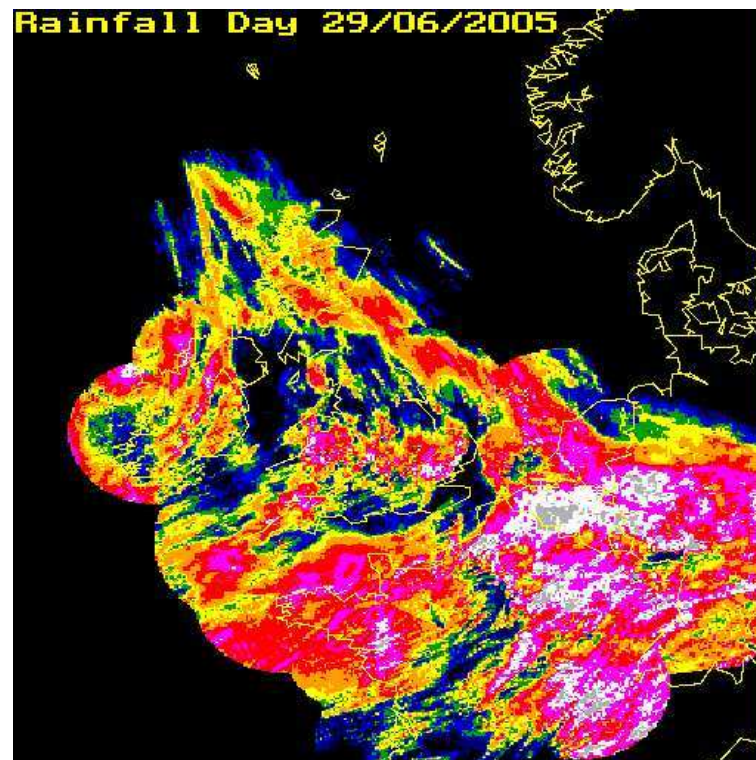
The plot in Fig. 9.7 shows the radar-derived accumulated rainfall for the day. The band of showers stretching west-to-east can be seen in central England and Wales, surrounded by relatively dry areas over southern and northern England. Even heavier showers occurred over France.

The sferics plot in Fig. 9.8 shows the location of lightning strikes and illustrates that the showers which initiated in the CSIP area produced lightning as they moved north. (The storms over France produced even more abundant lightning).

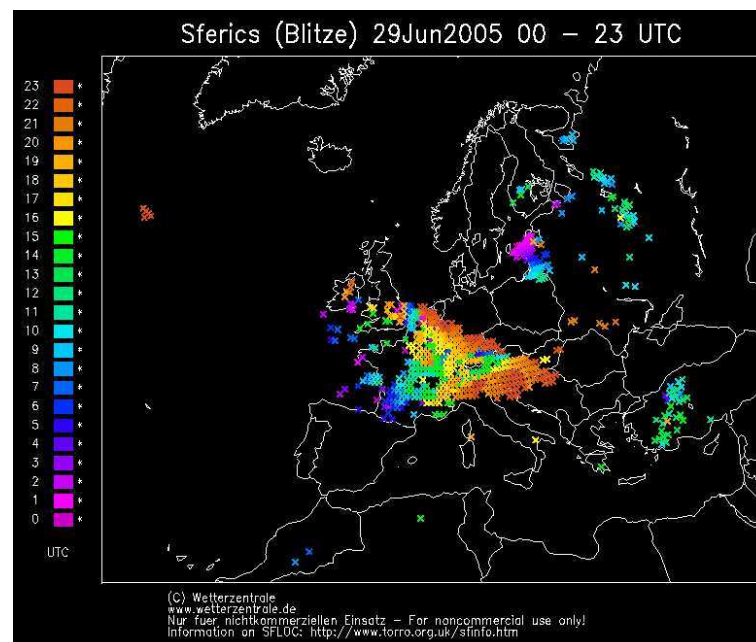




**Figure 9.6** Tephigram for the 1000 UTC Larkhill ascent showing Lid A at 875 hPa and Lid B at 650 hPa.



**Figure 9.7** Radar-derived accumulated precipitation for the day. (No colour scale was available for this image)

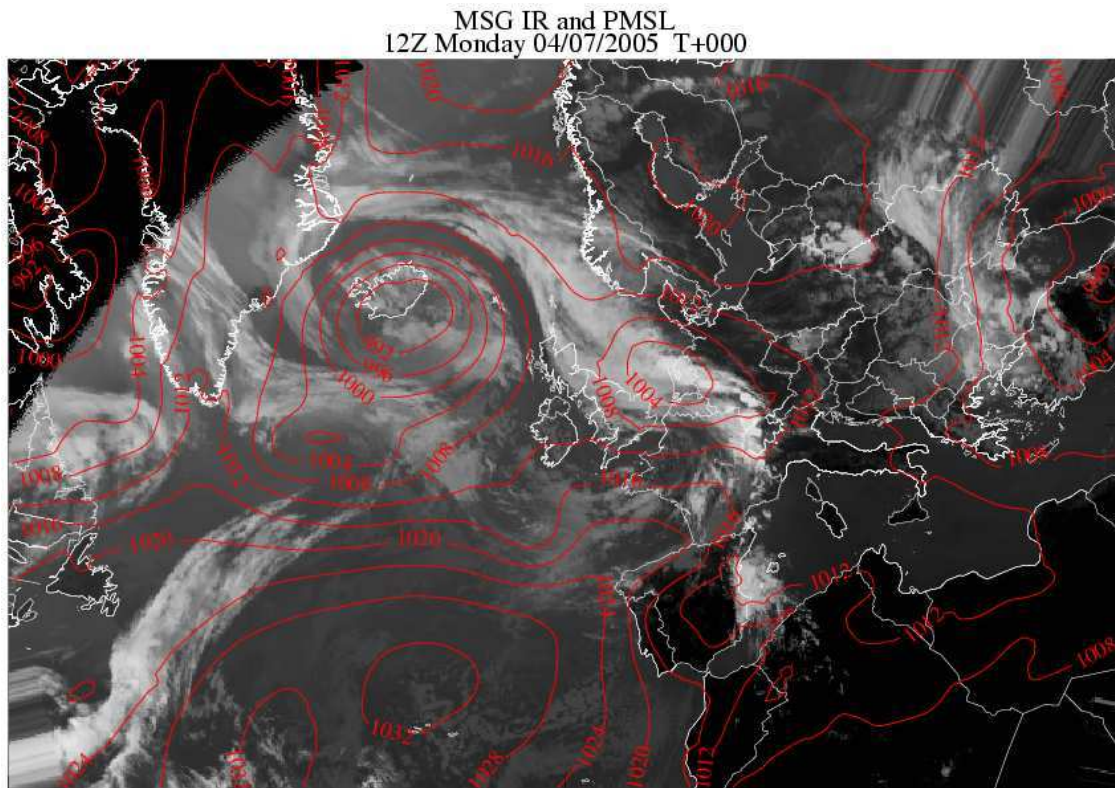


**Figure 9.8** The timing and location of lightning strikes on 29 June 2005.

## CHAPTER 10

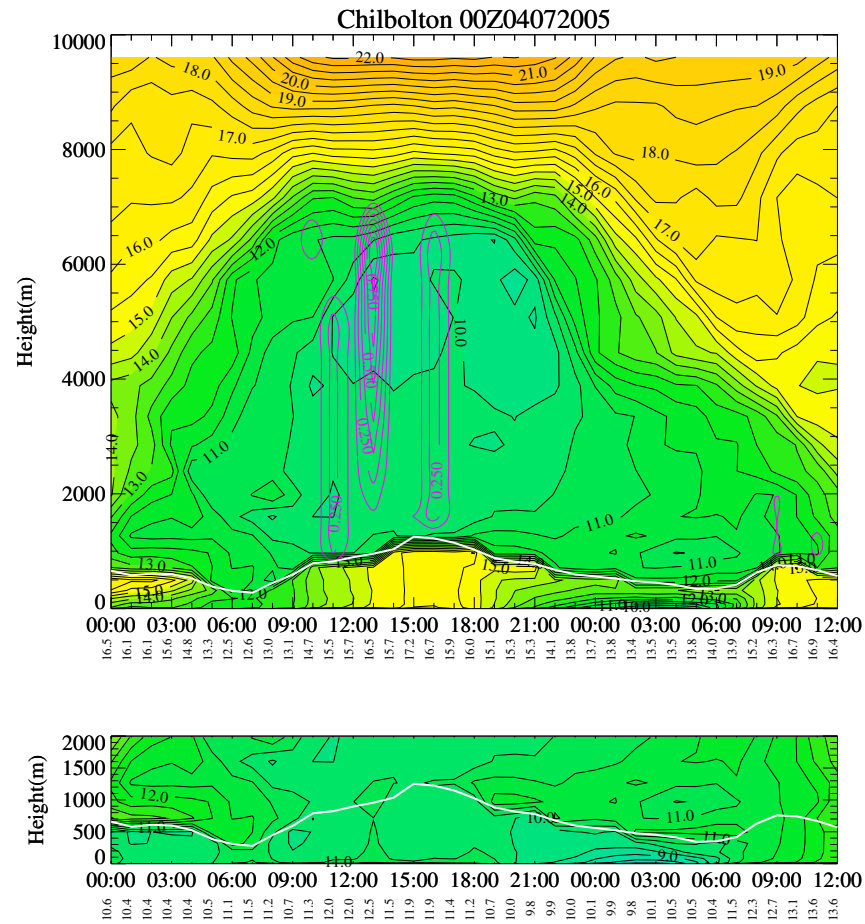
### IOP 6: Monday 4 July 2005

The synoptic situation at 1200 UTC is shown in Fig. 10.1. It shows that the CSIP area was under the influence of a rather strong north-westerly flow behind a low centred off the coast of East Anglia. Widespread showery activity was focussed on the CSIP area. A cut-off low was over the area, characterised by low tropopause and cold air aloft (theta-s values were as low as 10 degrees C, as shown by the forecast time-height plot of theta-s in Fig. 10.2). This led to modest CAPE, but with instability extending to about 7 km, and CIN was very small indeed. The resulting showers began early in the morning and continued being observed by the CSIP network until late afternoon. They were moderately intense with tops close to tropopause level. They produced a little lightning and some hail (up to 1 cm in diameter at Durlston Head, for example).



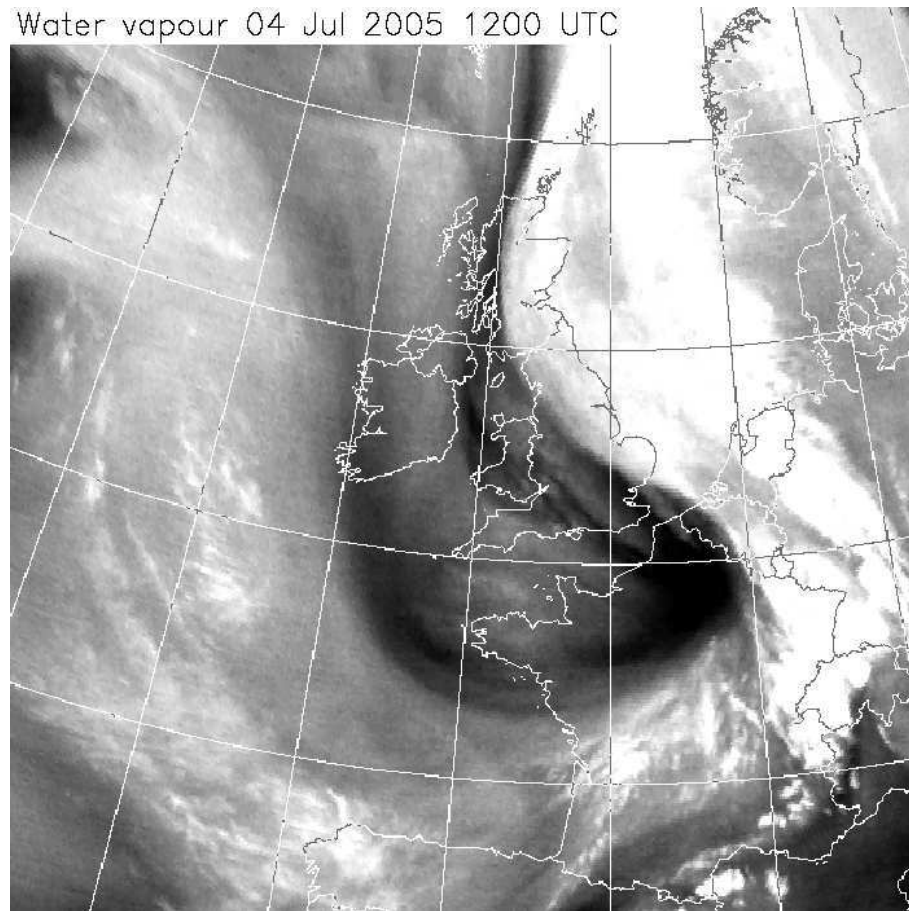
**Figure 10.1** MSLP analysis and satellite infra-red cloud at 1200 UTC.





**Figure 10.2** Model time-height forecast of  $\theta_s$  for Chilbolton



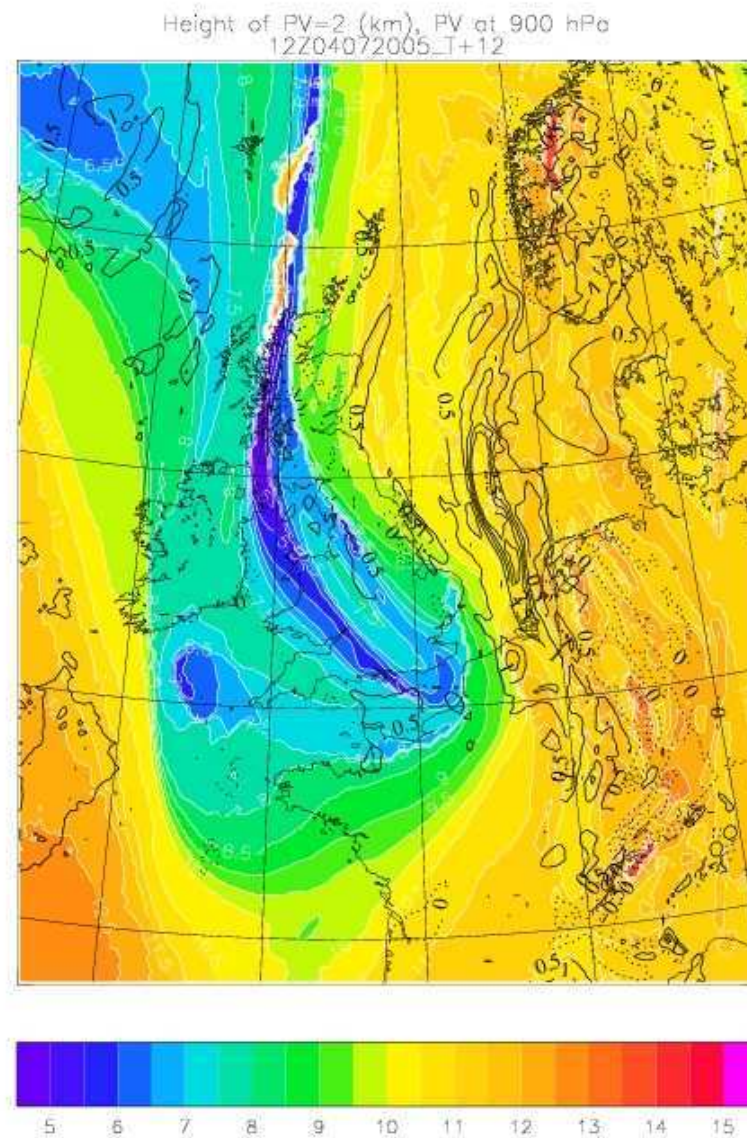


**Figure 10.3** Water-vapour satellite imagery for 1200 UTC on 4 July 2005.

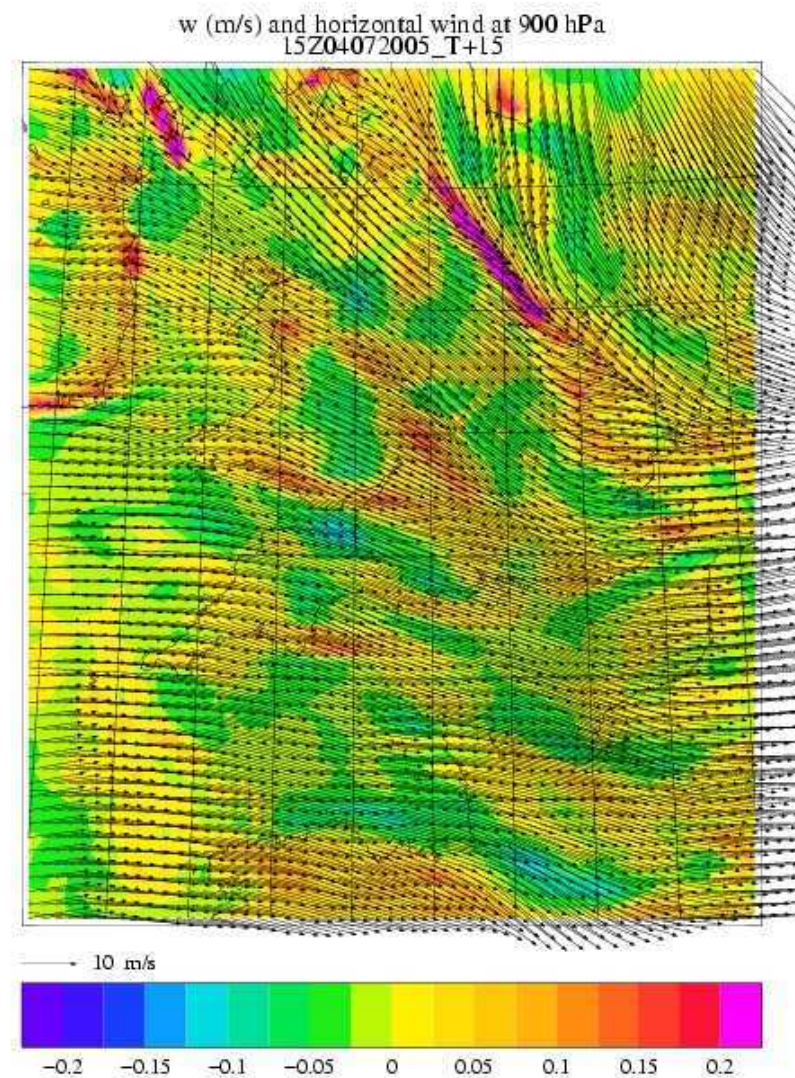
Figure 10.3 shows the water vapour image for 1200 UTC on 4 July. This should be compared to the model-derived height of the  $PV=2$  surface, shown in Fig. 10.4. Note that the dry, dark zone, corresponds to the positive PV anomaly. There is some banding apparent in the WV and PV images; this may be a result of the anvils from the bands of showers, or it may be indicative of bands of mesoscale ascent responsible for organising the showers.

Figure 10.5 shows the vertical and horizontal winds at 900 hPa at 1500 UTC. Convergence lines can be seen extending south-eastwards from northern England, north Wales, south Wales, Exmoor and Dartmoor. It is possible that the bands of showers were forced by these convergence lines.

A major proportion of the showers advected (quite rapidly) in from the west-north-west, often following similar tracks, but some did initiate within the CSIP area and we hypothesise that topography may have played a significant role in influencing their location. The showers were sufficiently numerous that useful statistics may be obtained for the initiation of individual con-

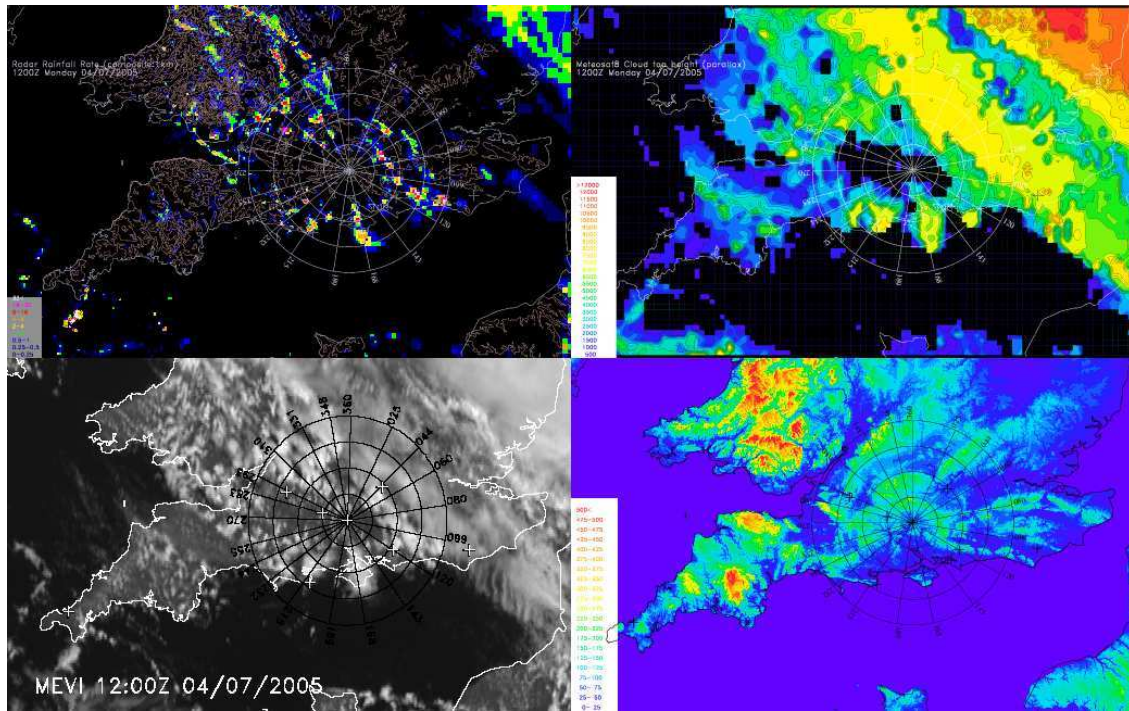


**Figure 10.4** Model forecast of the height of the PV=2 surface at 1200 UTC (T+12) on 4 July 2005.



**Figure 10.5** Forecast of vertical wind (shaded) and horizontal wind (arrows) at 900 hPa at 1500 UTC (T+15) on 4 July 2005.





**Figure 10.6** Radar rain-rate (top left), cloud-top height (top right), MSG high-resolution visible(bottom left) and orography (bottom right) at 1200 UTC on 4 July 2005.

vective clouds, but because they were so abundant it may be necessary to analyse them using automated tracking algorithms. The detailed structure and role of the upper-level PV anomaly may be another interesting issue.

Figure 10.6 is a composite for 1200 UTC on 4 July 2005, showing radar rain-rate (top left), cloud-top height (top right), MSG high-resolution visible(bottom left) and orography (bottom right). Note the cloud structures associated with each of the showers to the north-west of Chilton. Figure 10.7 is a zoomed-in view of of the MSG image over the area seen by CAMRa. It seems that for each shower there was a flanking line of deepening cumuli to the south of it. To the north-west of each shower, there is a cloud anvil, with a slight shadow between the turret and the anvil due to the angle of insolation. There are probably some good RHIs from CAMRa and ACROBAT that will have observed the early stages of these cloud structures.

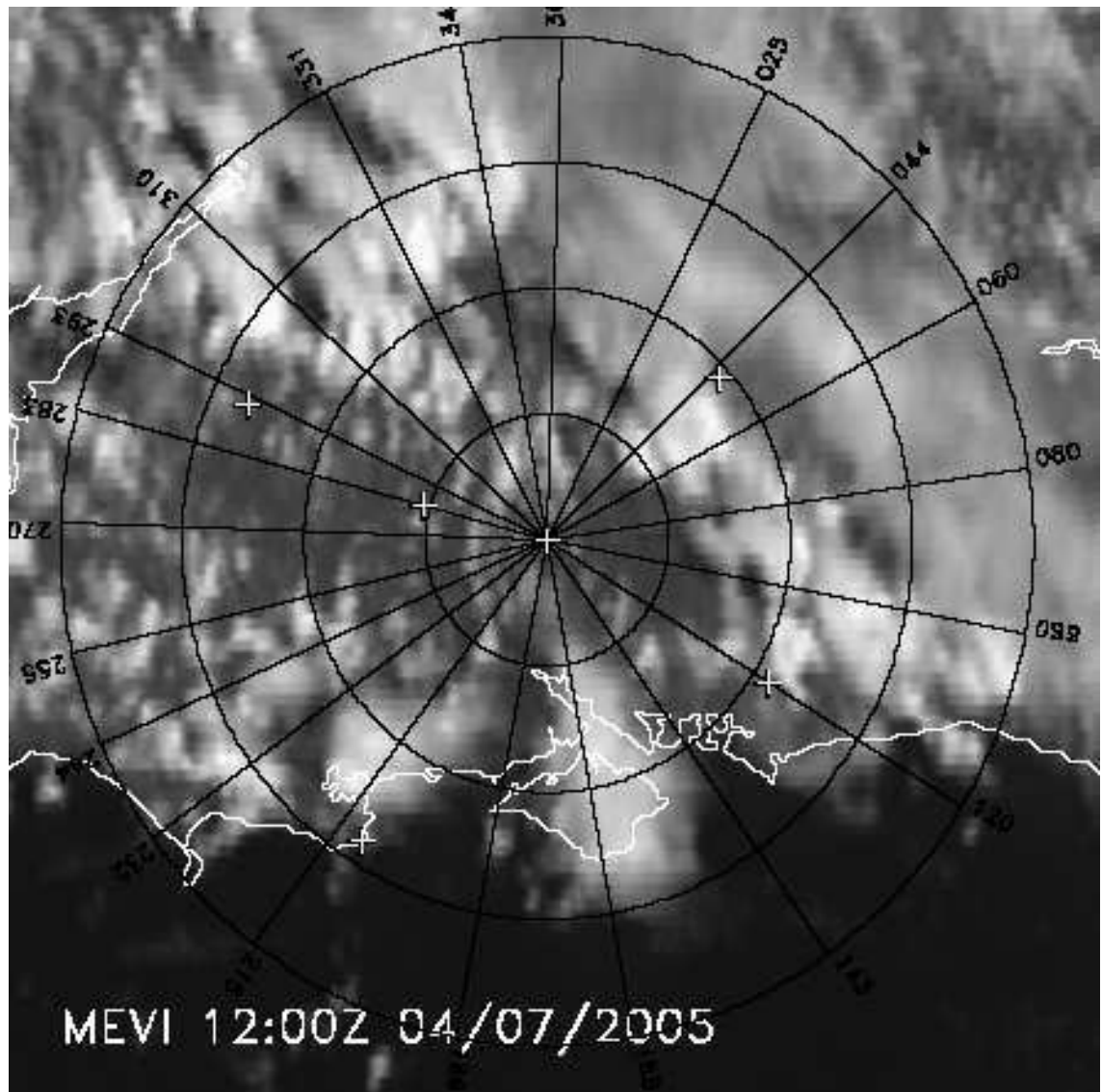


Figure 10.7

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## CHAPTER 11

### IOP 7: Thursday 7 July 2005

The synoptic situation at 1200 UTC is shown in Fig. 11.1. England was affected by a cold northerly airstream. Light to moderately heavy showers travelled south from the East Midlands crossing the north-east boundary of the CSIP area after 13 UTC following an overcast morning which had inhibited the development of convection. Several arcs of shower clouds passed over the Reading radiosonde site and launches were made before and after each passage. The western edge of some of the arcs passed close to the radiosonde sites at Chilbolton, Larkhill and Oxford. The PPI display from the Chenies radar display at 1500 UTC (not shown) shows the second arc passing over Farnborough, with the third, major, arc approaching Reading. The corresponding MSG high-resolution visible image also shows the arcs (Fig. 11.2). Most, but not all, of the showers advected into the area rather than being initiated within it. Tops were mainly to between 3 and 4 km, but reaching 5 km late in the day. The CAPE was small.

The showers formed beneath, or close to, the eastern edge of a water vapour dark zone (upper-level PV filament), which was oriented north-south (Fig. 11.3). The mesoscale model forecast of the height of PV=2 surface is shown in Fig. 11.4 for comparison.

A weak trough is suspected in association with the arcs but there was little evidence of local variability aloft in the WV/PV filament that might have been related to the arcs.

The 4 km version of the mesoscale model succeeded in representing an arc of shower clouds (Fig. 11.5) but it was too early and it also failed to predict the multiple arcs that developed.

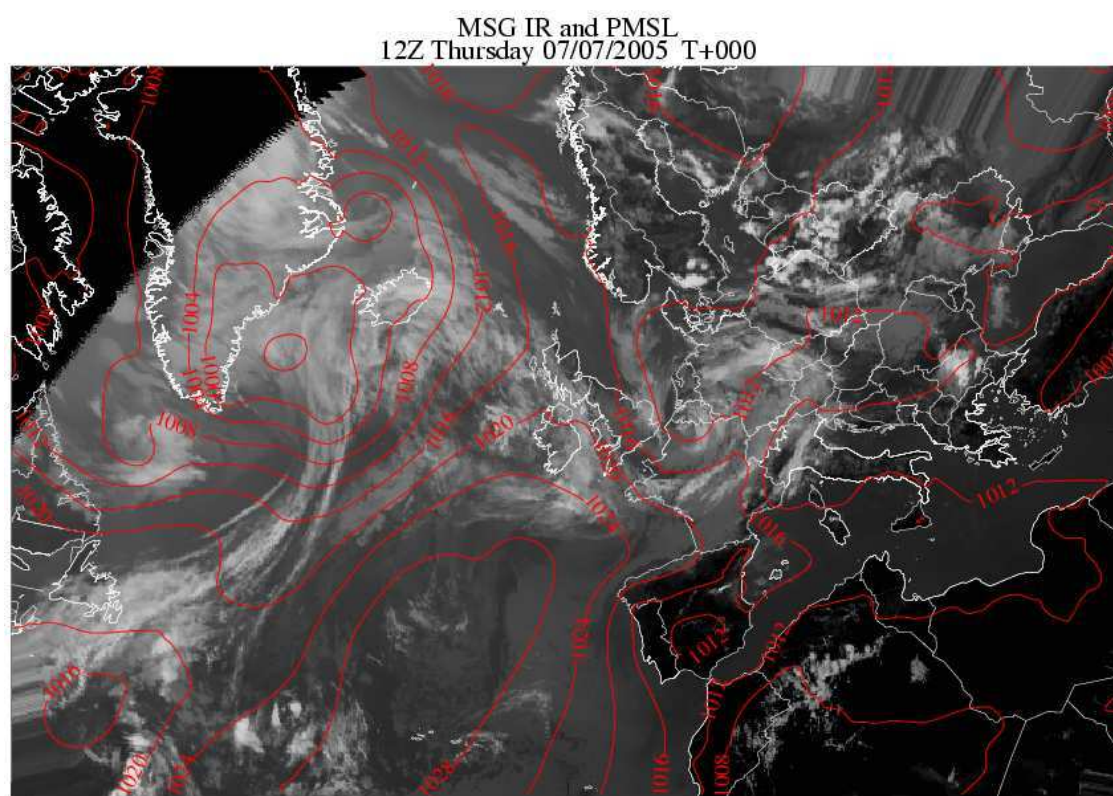
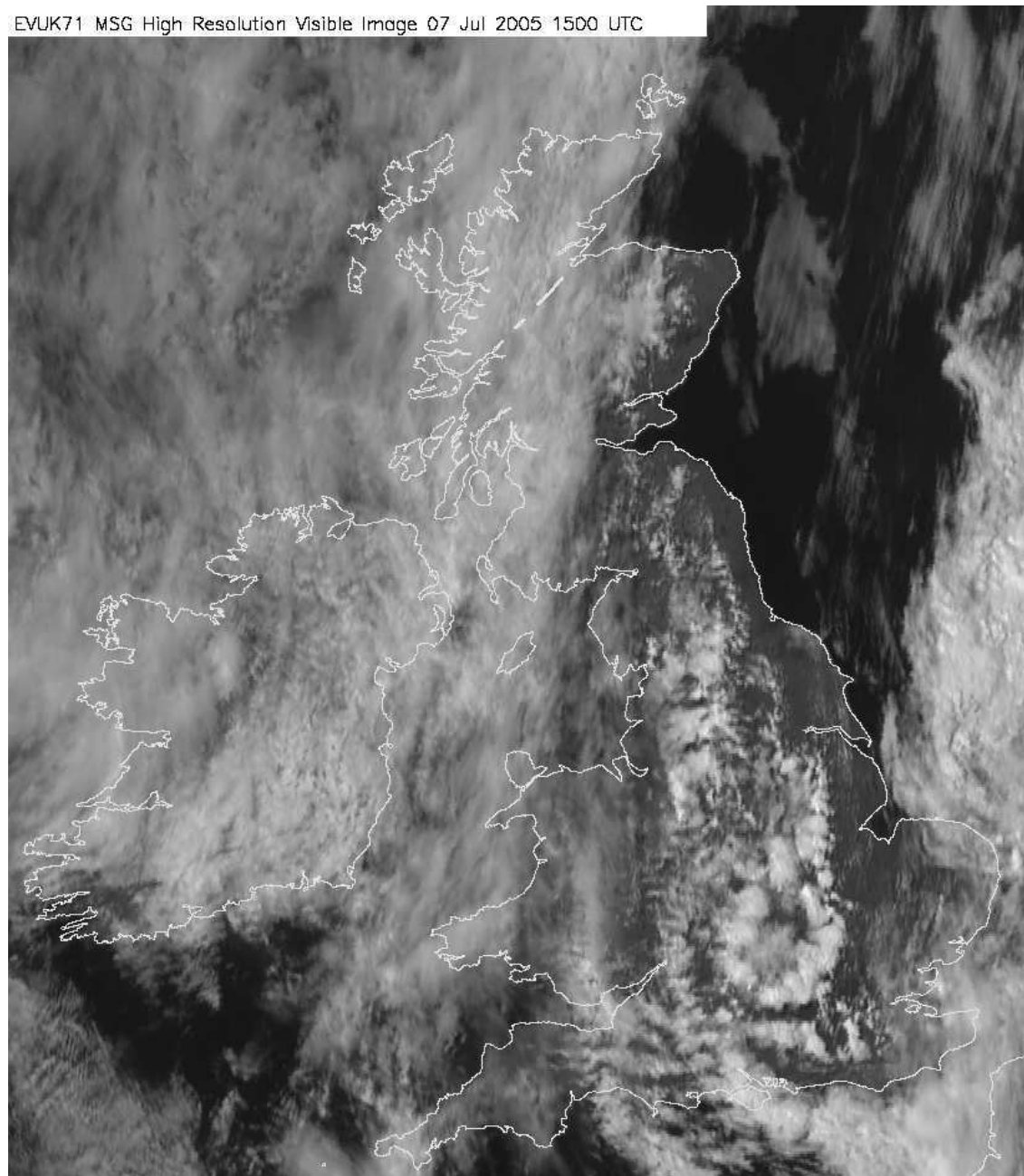
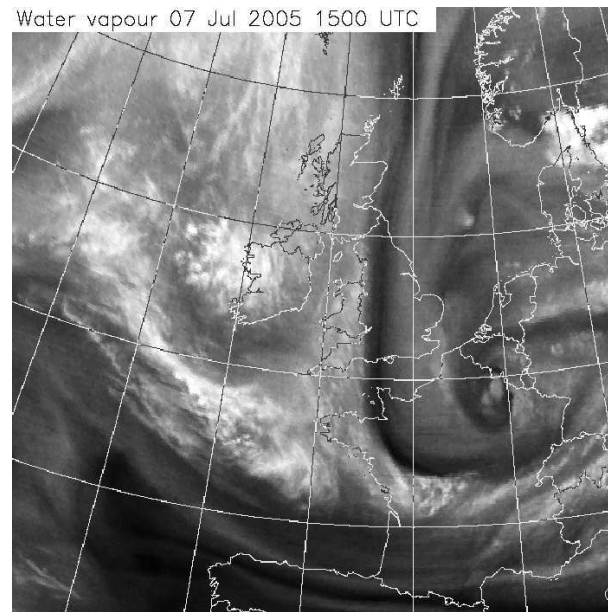


Figure 11.1 MSLP analysis and satellite infra-red cloud at 1200 UTC.

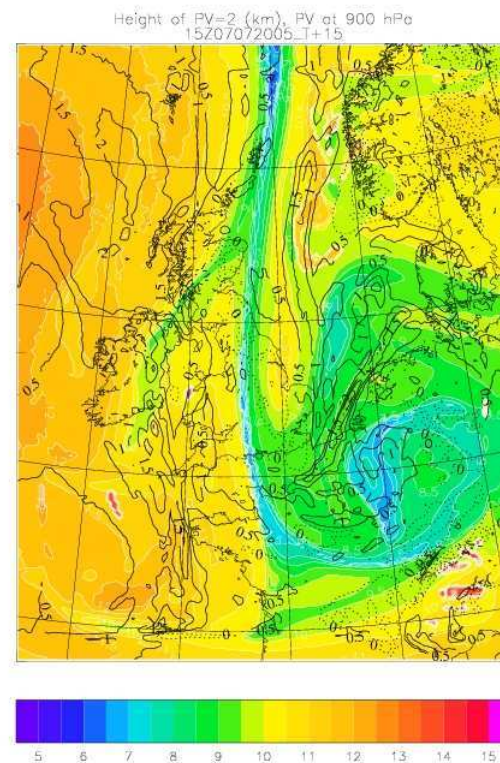


**Figure 11.2** MSG high-resolution visible imagery for 1500 UTC on 7 July 2005.

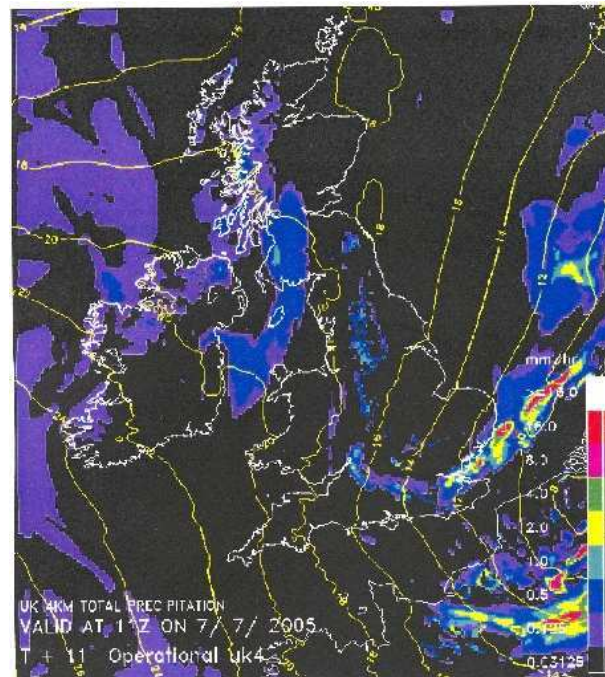




**Figure 11.3** Satellite water-vapour imagery at 1500 UTC on 7 July 2005.



**Figure 11.4** Mesoscale model forecast of the height of the PV=2 surface at 1500 UTC (T+15) on 7 July 2005.



**Figure 11.5** Mesoscale model forecast of rain-rate and MSLP at 1100 UTC (T+11) on 7 July 2005.

## CHAPTER 12

### IOP 8: Wednesday 13 July 2005

The surface analysis for 12 UTC (see Fig. 12.1) shows a ridge extending across the central UK. A very weak north-north-westerly flow covered the CSIP area with surface temperatures reaching 29 degrees C in Chilbolton (see Fig. 12.2) and Reading. Soundings showed modest amounts of CAPE and small CIN.

Convection developed over the CSIP area in association with the diurnal heating cycle. There was a lot of cumulus congestus but only a few of these developed. None did more than produce brief light showers in the CSIP area. These were mainly in the north-east of our area. Even farther to the north-east there were a few heavier showers, particularly towards the Cambridge area. The depth of the convection was affected by several rather weak warm lids; the 1000 UTC sounding for Larkhill (see Fig. 12.3) shows the lids at 1 and 3 km prior to the development of significant cumulus convection.

The T+15 forecast from the 12-km mesoscale model shows a convergence line extending from Exeter to London, and beyond to The Wash, at 1500 UTC (see Fig. 12.4). It also shows convective showers along much of its length including in the CSIP area. The location of the convergence line was well predicted but the convective showers in the CSIP area were over-predicted. The observed evolution of the convection along the convergence line is summarised below.

#### 1100 UTC

The first cumulus clouds formed along a band oriented SW-NE, as can be seen in the MSG high-resolution visible imagery at 1115 UTC (see Fig. 12.5). The L-band RHI for 1109 UTC along 331 degrees (Fig. 12.6) shows layers at 1 km and around 2.5 km, broadly consistent with stable layers shown in the above 1000 UTC Larkhill sounding (Fig. 12.3). Mantle echoes can be seen penetrating to the first lid up to around 1.5 km.

#### 1300 UTC

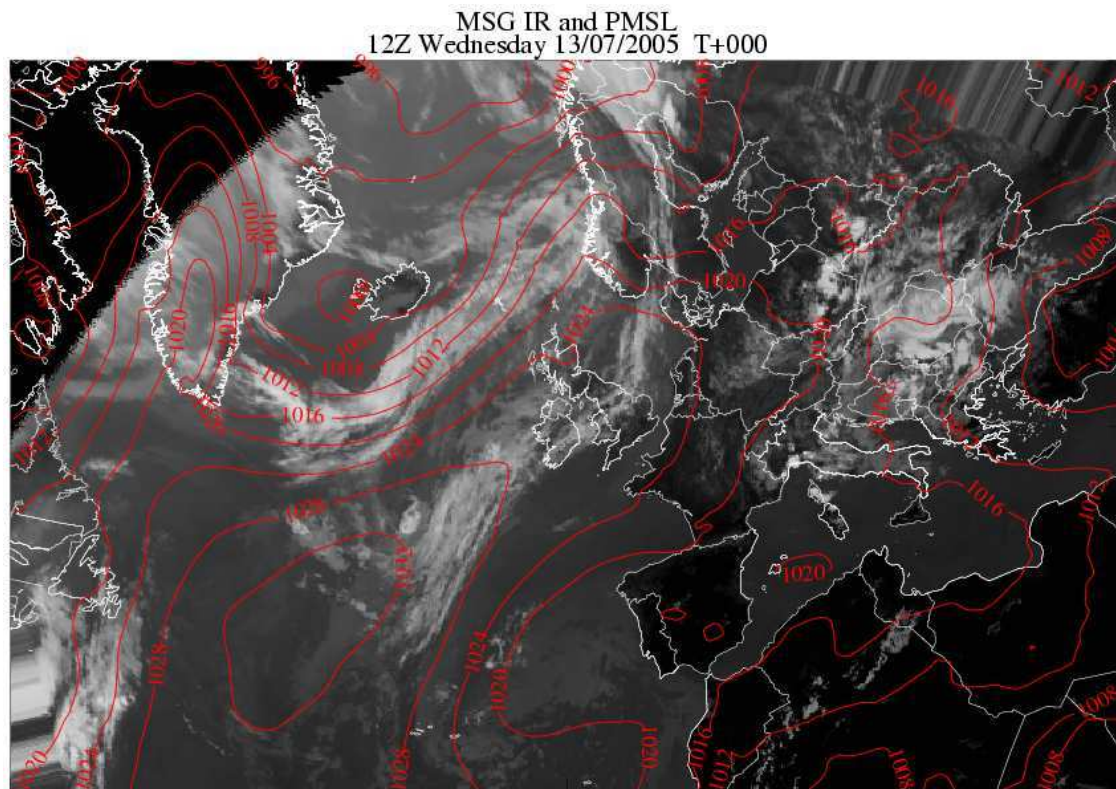


Figure 12.1 MSLP analysis and satellite infra-red cloud at 1200 UTC.

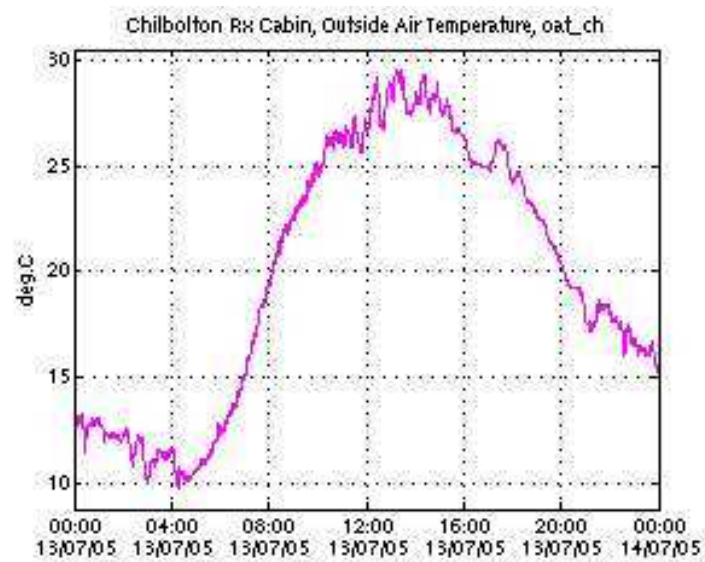
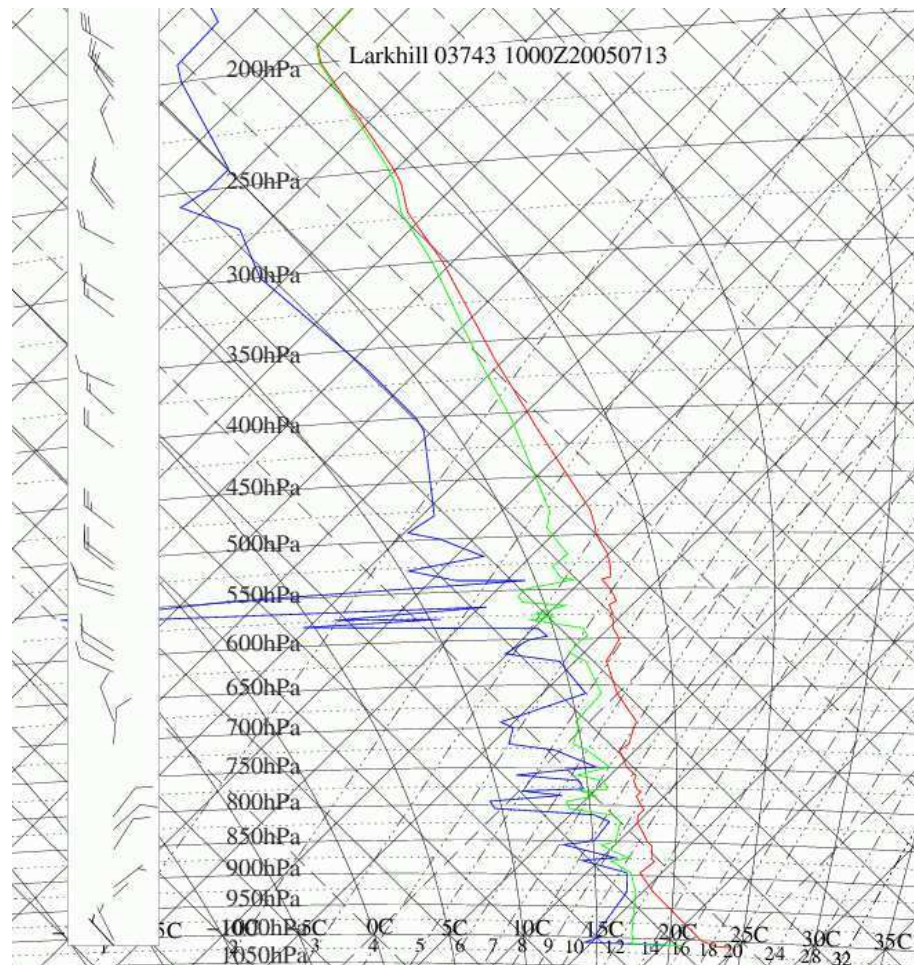
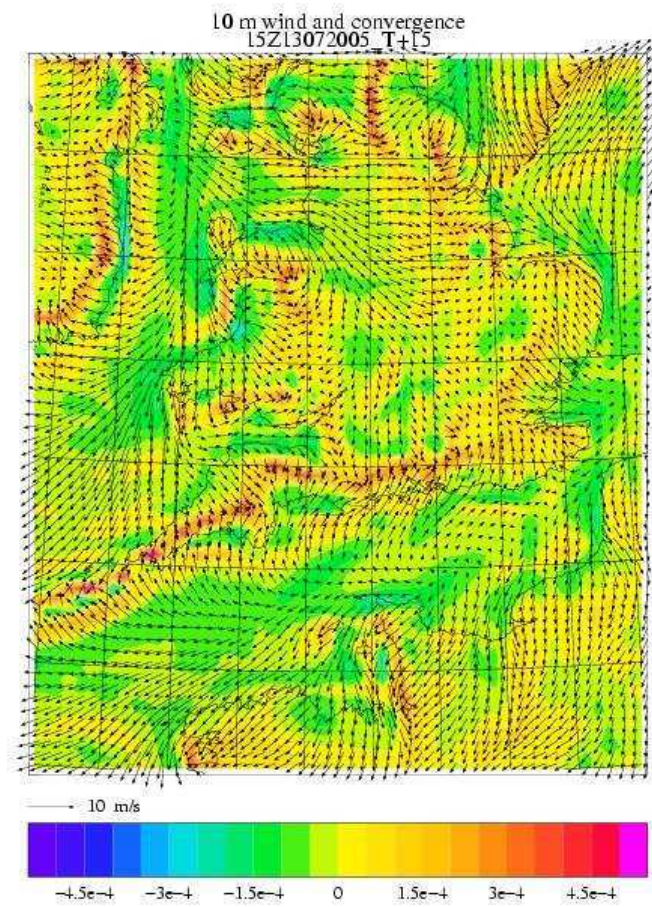


Figure 12.2 Surface temperature measured at Chilbolton on 13 July 2005.





**Figure 12.3** Tephigram for the Larkhill sounding at 1000 UTC on 13 July 2005.



**Figure 12.4** Mesoscale model forecast of 10m wind and convergence for 1500 UTC (T+15) on 7 July 2005.

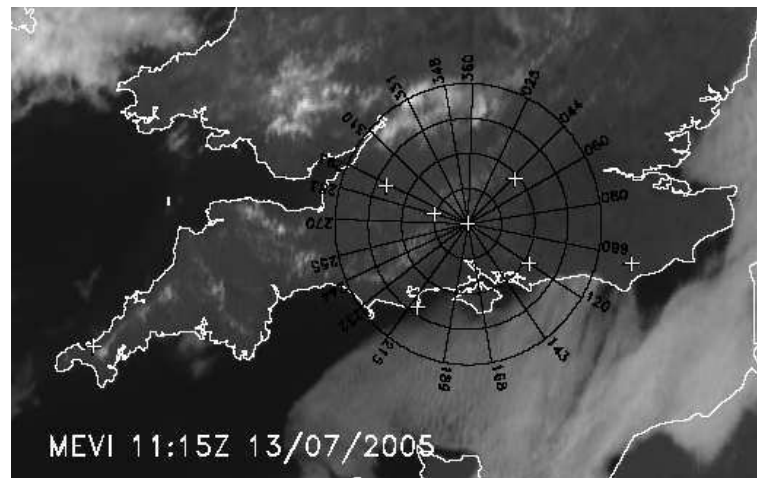


Figure 12.5 MSG high-resolution visible imagery for 1115 UTC on 13 July 2005.

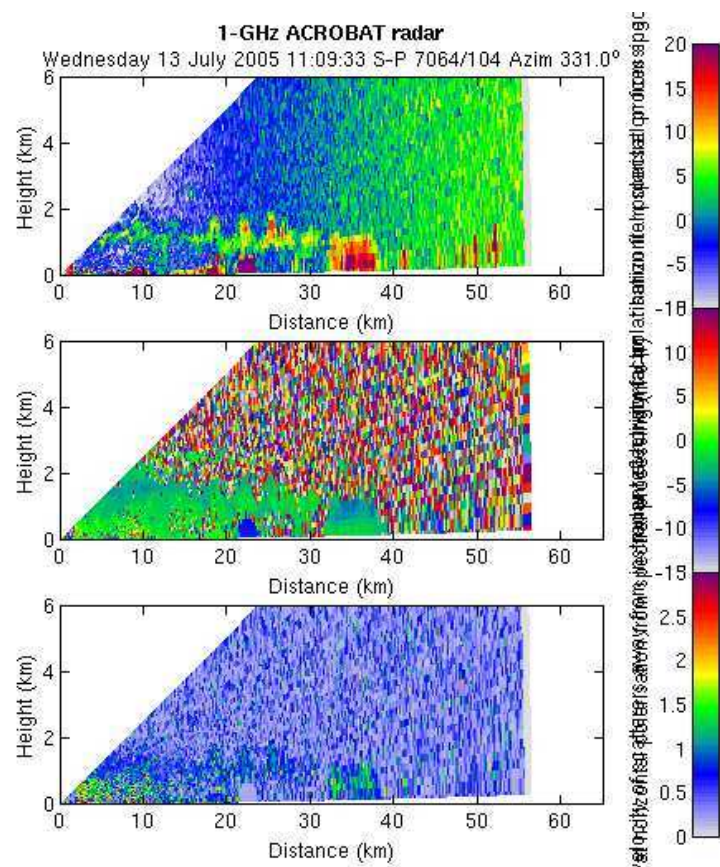
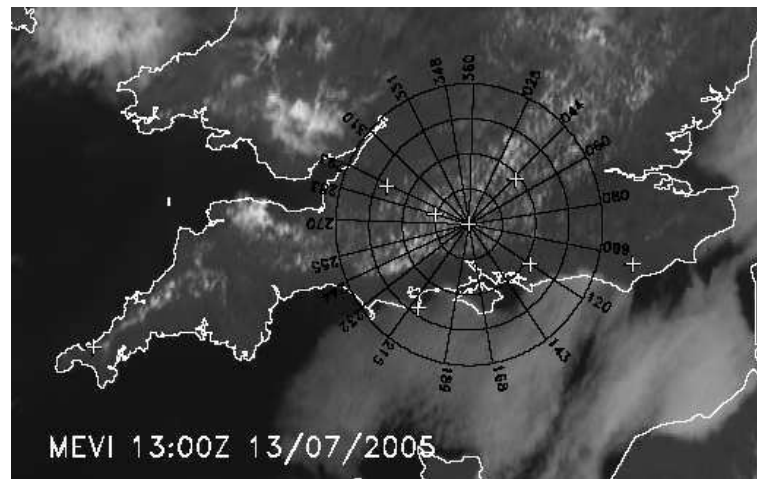


Figure 12.6 L-band RHI along azimuth 331 degrees at 1109 UTC on 13 July 2005.





**Figure 12.7** MSG high-resolution visible imagery for 1300 UTC on 13 July 2005.

The band of cumulus has now broadened but a sea breeze penetrating inland from the south coast is seen to be cutting off convection at the southern end of the band (see the MSG high-resolution visible imagery at 1300 UTC, Fig. 12.7). The L-band RHI for 1306 UTC along 331 degrees (Fig. 12.8) shows a layer at 1 km, with mantle echoes now penetrating up to 3 km.

### 1500 UTC

The sea-breeze has now penetrated inland about as far as Chilbolton (from where its structure was well observed by the Karlsruhe lidar scanning in RHI). Ahead of it, the overall band of convection was oriented in a more WSW-NNE direction (see the MSG visible imagery at 1500 UTC, Fig. 12.9). This is broadly consistent with the forecast low-level wind pattern in Fig. 12.4. Some of the convective clouds were deeper by this time, but the only significant showers were far to the north-east, towards Cambridge. The 3 GHz, S-band, RHI for 1453 UTC along 67 degrees (see Fig. 12.10) shows a weak layer at 3 km with some convection penetrating to 5 km. Notice the clear-air mantle echo surrounding an inner core of echo possibly due to newly-forming precipitation particles.

### 1700 UTC

The band of surface convergence is a well-defined feature in the NIMROD 10-metre wind analysis for 1700 UTC (see Fig. 12.11). The 1630 UTC composite (Fig. 12.12) shows that the associated band of convective cloud (bottom left panel) remains much as it was at 1500 UTC (Fig. 12.9). However, a few of the cumulus congestus have reached the stage where they are produc-

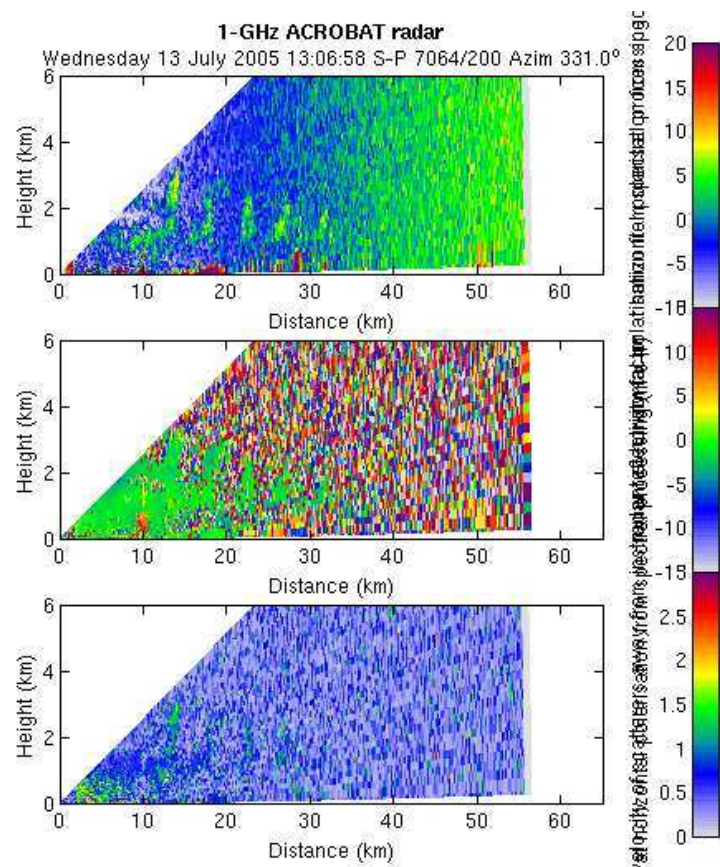


Figure 12.8 L-band RHI along azimuth 331 degrees at 1306 UTC on 13 July 2005.

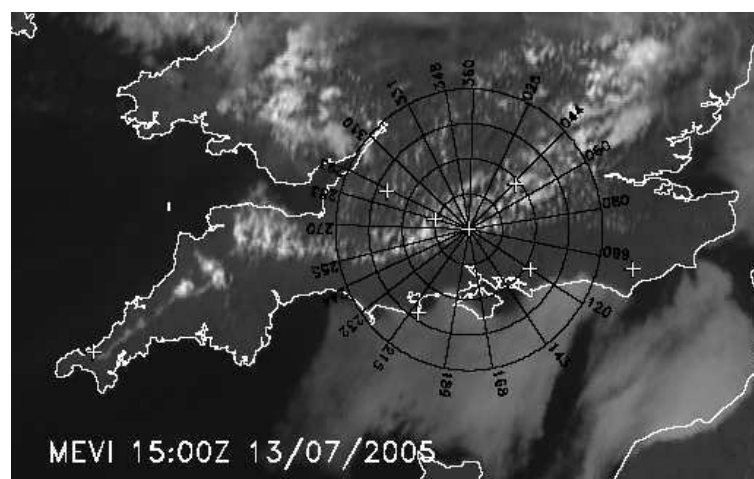
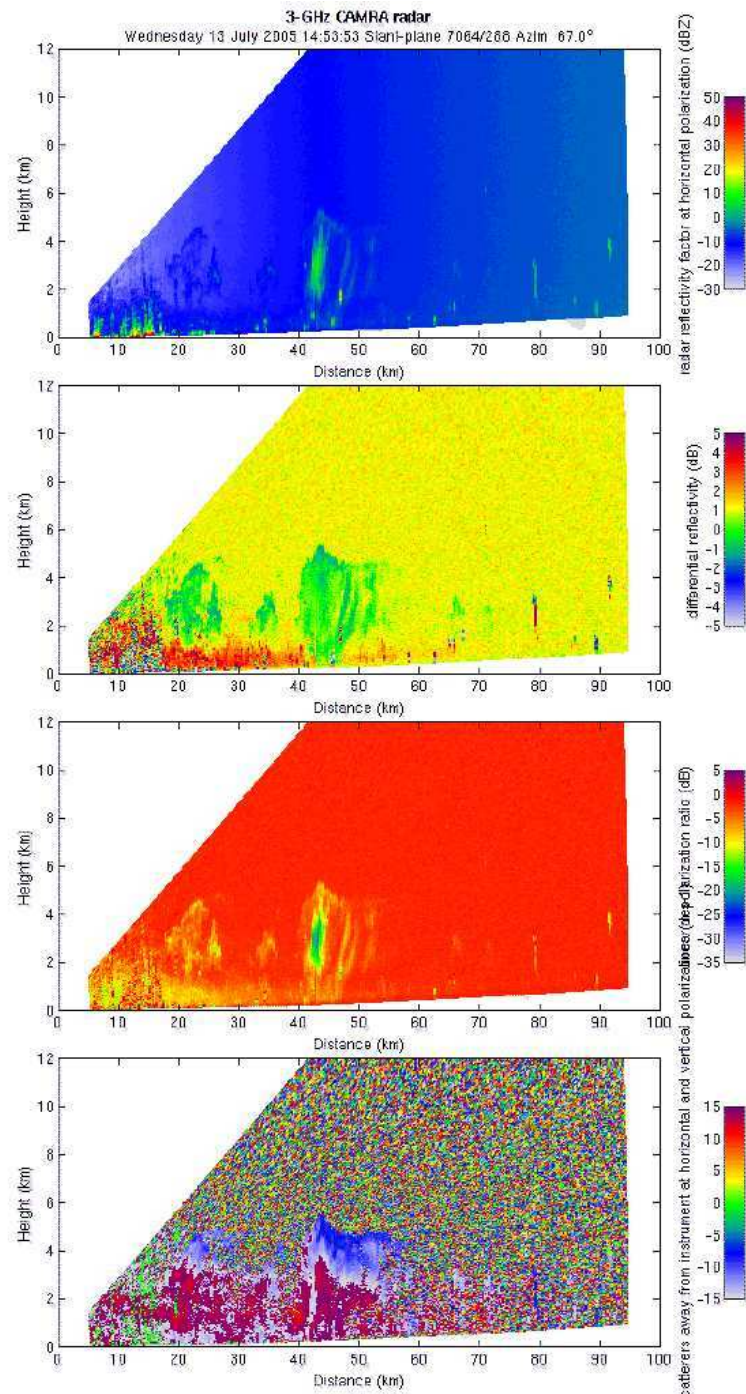
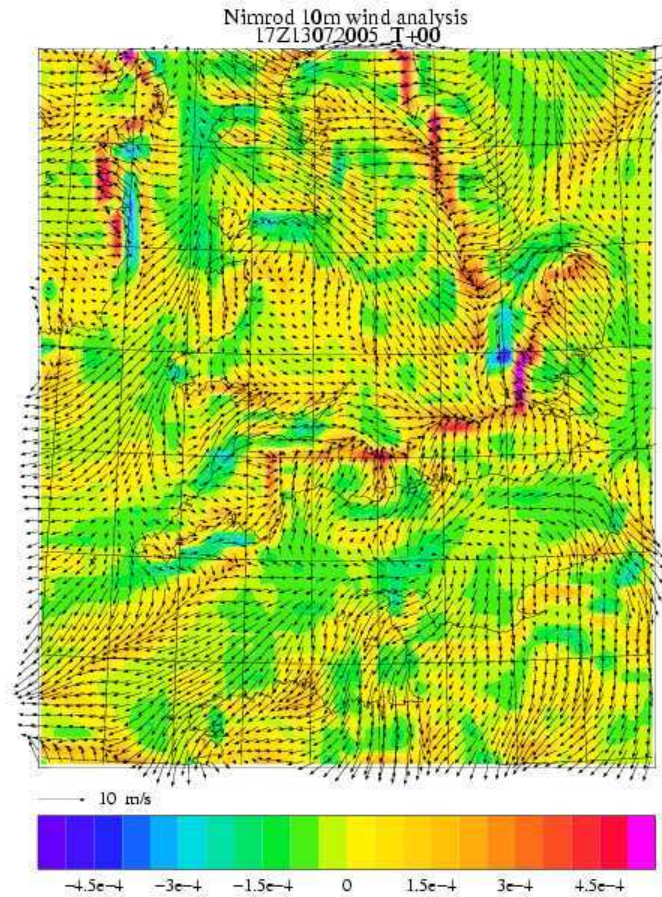


Figure 12.9 MSG high-resolution visible imagery for 1500 UTC on 13 July 2005.



**Figure 12.10** RHIs from the 3 GHz radar at Chilbolton at 1453 UTC, along azimuth 67 degrees. The four panels show: a) reflectivity ( $Z$ ), b) differential reflectivity ( $Z_{dr}$ ), c) linear depolarisation ratio ( $L_{dr}$ ) and d) Doppler velocity.

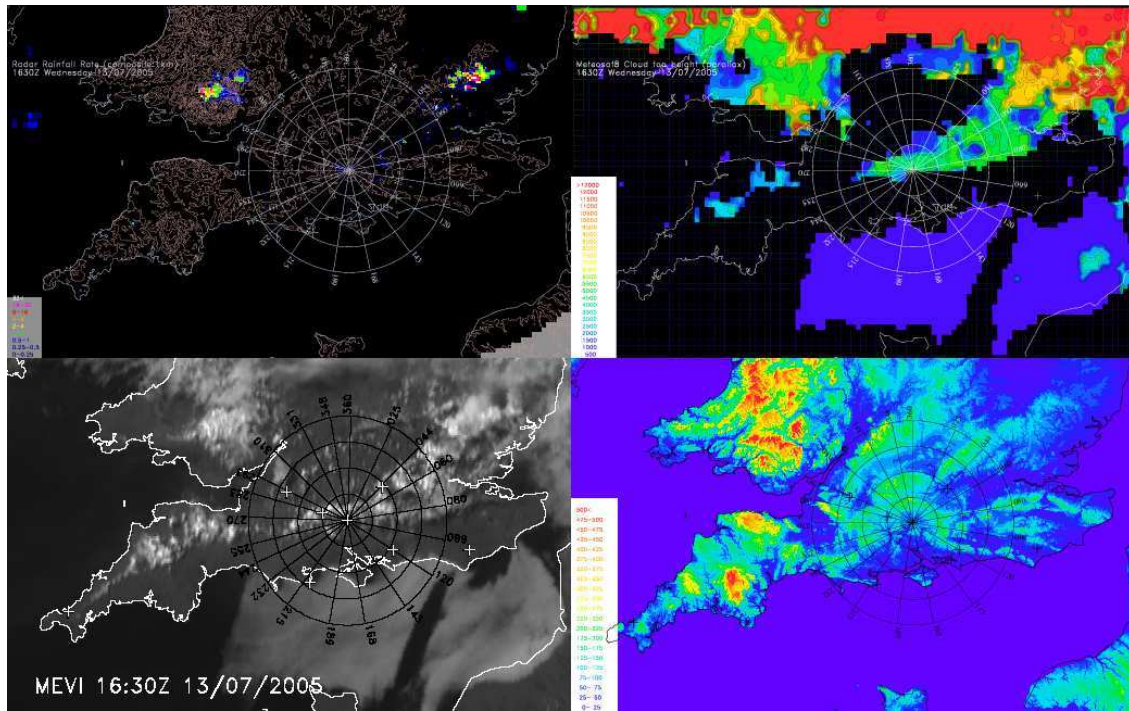


**Figure 12.11** NIMROD 10 metre wind analysis for 1700 UTC on 13 July 2005.

ing very brief showers in the Reading area. The Chenies 2-km radar display (not shown) shows two evanescent showers between Reading and Farnborough to the south, with somewhat heavier showers farther to the north-east. There were no further significant developments of showers during the rest of the day.

An interesting feature of this IOP is the variation in time and space of the various stable lids. Their detailed evolution is likely to have made the difference between mere cumulus congestus and cumulonimbus. It will be instructive to compare the observed behaviour of the lids with that predicted by the Met Office NWP models to determine what it was that caused the models to over-predict the occurrence of showers in the CSIP area despite handling the overall behaviour of the





**Figure 12.12** Composite for 1630 UTC on 13 July 2005 showing: a) radar rain-rate, b) cloud-top height, c) MSG high-resolution visible imagery and d) orography.

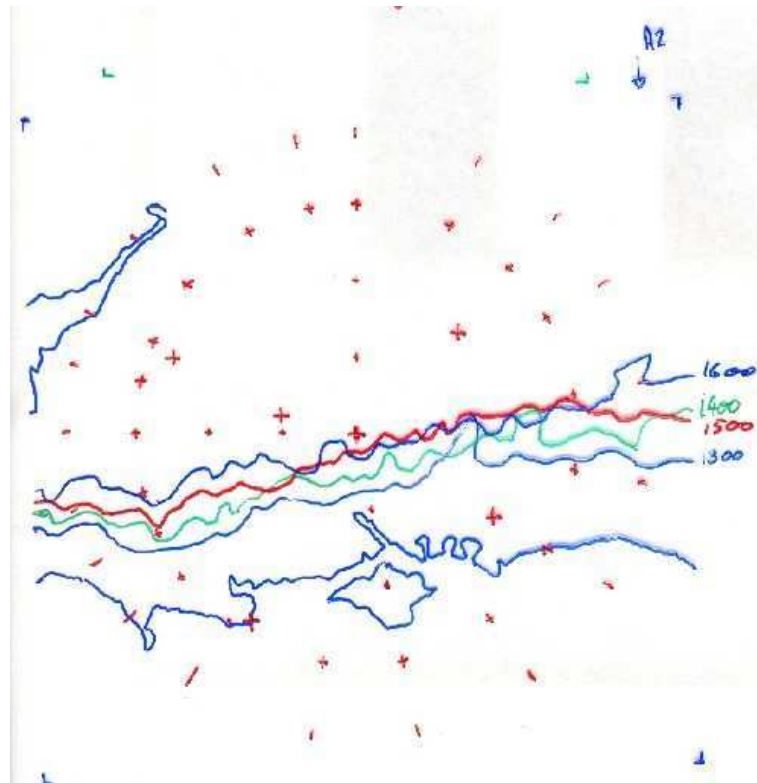
convergence lines quite well. Another possible issue is the role of the high aerosol concentration in suppressing the development of warm rain.

The weak showers that formed between 50 and 100 km north-east of Chilbolton may have been associated with convective clouds that were initiated along the Chilterns Hills.

What makes this IOP especially interesting, however, is not so much the initiation of convective showers but, rather, the novel observations of the sea-breeze front obtained from a variety of sources.

## 12.1 Ingredients for a possible paper on the novel observations of a sea-breeze front (SBF).

- Show one plot of MSG along with the location of the analysed sea-breeze front.
- Then show a plot of the analysed SBF locations as a function of time (i.e. a neater version



**Figure 12.13** Quick tracings of the southern-most flank of the cloudy region as a function of time and hence showing the penetration of the sea-breeze front inland. This should be compared with refractivity, AWS, radar and lidar measurements.

Fig. 12.13).

- The leading edge of the SBF can be tracked using MSG high-resolution visible imagery (see Fig. 12.13) but it can also be done by looking at a series of S-band PPIs.
- Show one plot of S-band PPI showing the SBF.
- Show plots of L-band refractivity fields at the same times as those for which the analysed SBF locations are shown. The Fabry analysis suggests that strong horizontal moisture gradients were associated with the band of convection.
- Show some L-band refractivity PPIs when there are cumuli to the north and it is clear to the south of Chilbolton (as shown by MSG images).
- Include some more refractivity fields showing the approach and passing of the SBF.
- Show some AWS measurements of the passage of the SBF.
- Mention that some of the Cessna aircraft legs show moist/dry/moist transitions consistent with the locations of the sea-breeze and cumulus regions.
- Show the RHIs from the Karlsruhe lidar along with some lidar PPIs showing the bulges, or instability, along the leading edge of the SBF.
- Mention the UHF wind-profiler showing mantle penetrating the multiple lids with a clear updraught surrounded by downdraughts below the region where the mantle is seen.
- Questions: Was the SBF stalling as it got well inland, and approached Chilbolton, as appeared to be the case? We need to look at the change in velocity of the motion of the SBF. Can this decrease in velocity be related to the smaller change in surface temperature seen by the AWSs further inland compared to those nearer the coast?
- Compare the observed SBF velocity to that which would be expected from gravity current theory. We know  $\Delta T$  from the AWSs, and can estimate  $\Delta h$  from the Karlsruhe lidar RHIs.
- Read up on theoretical description of bulges appearing along the leading edge of a density current. (Herbert Huppert at DAMTP has almost certainly written some papers on this). What does their wavelength depend on and do the bulges seen in the observations agree with the predictions from theory?



- The Karlsruhe lidar RHIs show some very nice Kelvin-Helmholtz (KH) billows behind the nose of the density current associated with the SBF. The wavelength of these KH billows should be  $2\pi\Delta z$ , where  $\Delta z$  is the depth of the shear layer (see e.g. Lilly, 1986, “Instabilities”, in *Mesoscale Meteorology and Forecasting*, p. 264).  $\Delta z$  can be estimated from the Doppler lidar RHIs. Do these observations agree with the theory?
- Although sea-breeze fronts are well understood and have been studied previously using networks of AWS and radiosondes, and modelled in high-resolution numerical models, some features of this IOP make the observations we have collected unique: the Doppler lidar RHIs showing very high resolution vertical cross-sections through the gravity current combined with the L-band Refractivity PPIs, showing the approach of the moister air.

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## CHAPTER 13

### IOP 9: Monday 18 July 2005

The synoptic situation at 1200 UTC is summarized in Fig. 13.1. A narrow line of convective showers was associated with the passage of a surface cold front during the late afternoon. The main band of cold-frontal cloud at middle-levels was situated ahead of it. The narrow line of convection at the surface front was visible for many hours as it advected towards the CSIP area. For most of the time it was quite weak but part of it intensified as it moved across the CSIP area, and it produced heavy rain as it passed over Reading at 1645 UTC (see Fig. 13.2).

The mesoscale model predicted that a stable lid would prevent convection from the surface from rising above 3 km (see the time-height plot of  $\theta$ -s for Reading from the 0600 UTC forecast run, Fig. 13.3) but, in the event, some tops reached 4 km. Evidence from some RHI scans suggest that these somewhat higher tops were embedded in a region of mesoscale ascent that had raised the stable lid from 3 km to 4 km (see Fig. 13.4). The lifted lid shows up best in differential reflectivity ( $Z_{dr}$ ) in the second panel down.

The mesoscale lifting may have been due to an upper-level PV-anomaly, evidence for which could be seen in a small WV Dark Zone that travelled from southern Ireland to southern England (see contrast-enhanced example in Fig. 13.5). The intensified convection occurred within this Dark Zone.

Issues for this day include the degree of mesoscale lifting of the lid in the vicinity of the surface cold front and the role of the upper-level PV anomaly and its representation by the model. Other factors, such as possible horizontal variability of  $\theta$ -w in the boundary layer and topographical effects, may have determined why only a small portion of the line of convection actually became intense.

The 4 km Met Office Mesoscale Model produced a good forecast of this case.

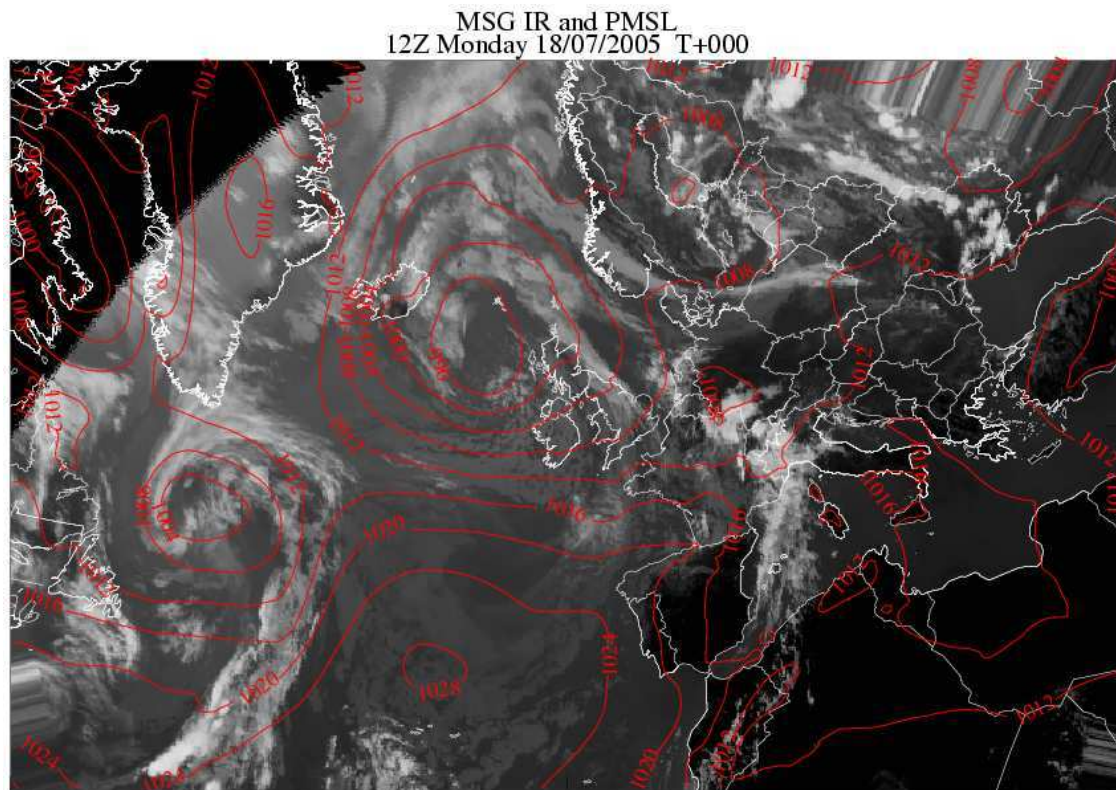
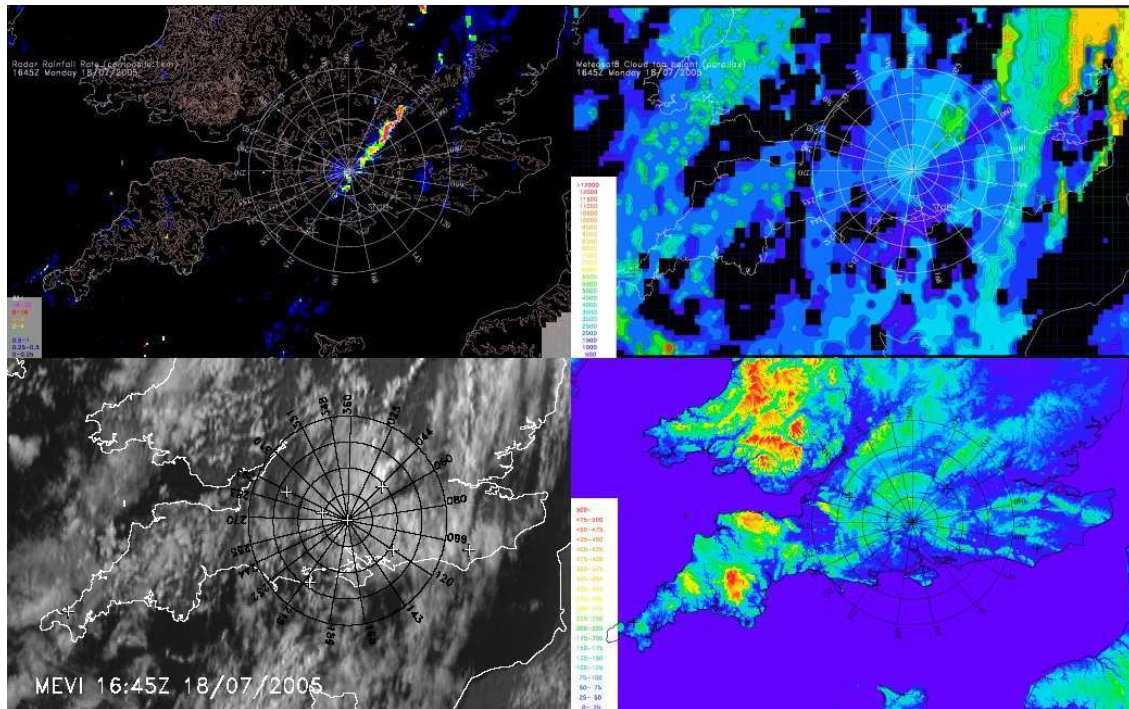
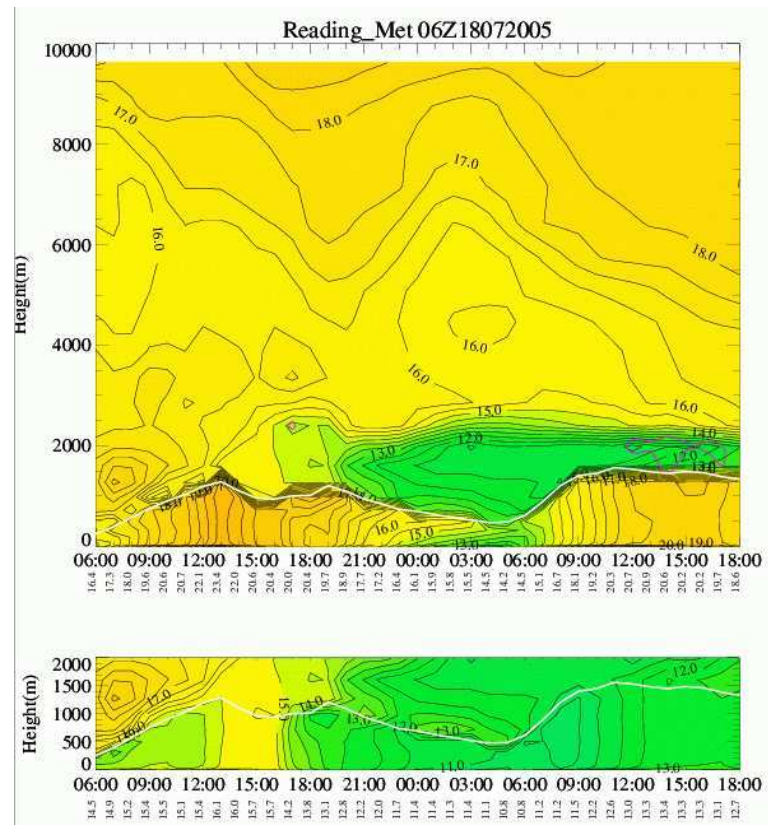


Figure 13.1 MSLP analysis and satellite infra-red cloud at 1200 UTC.



**Figure 13.2** Composite showing: a) radar rain-rate, b) cloud-top height, c) MSG high-resolution visible and d) orography, at 1645 UTC on 18 July 2005.



**Figure 13.3** Time-height theta-s forecast for Reading, from the 0600 UTC run of the Met Office mesoscale model.



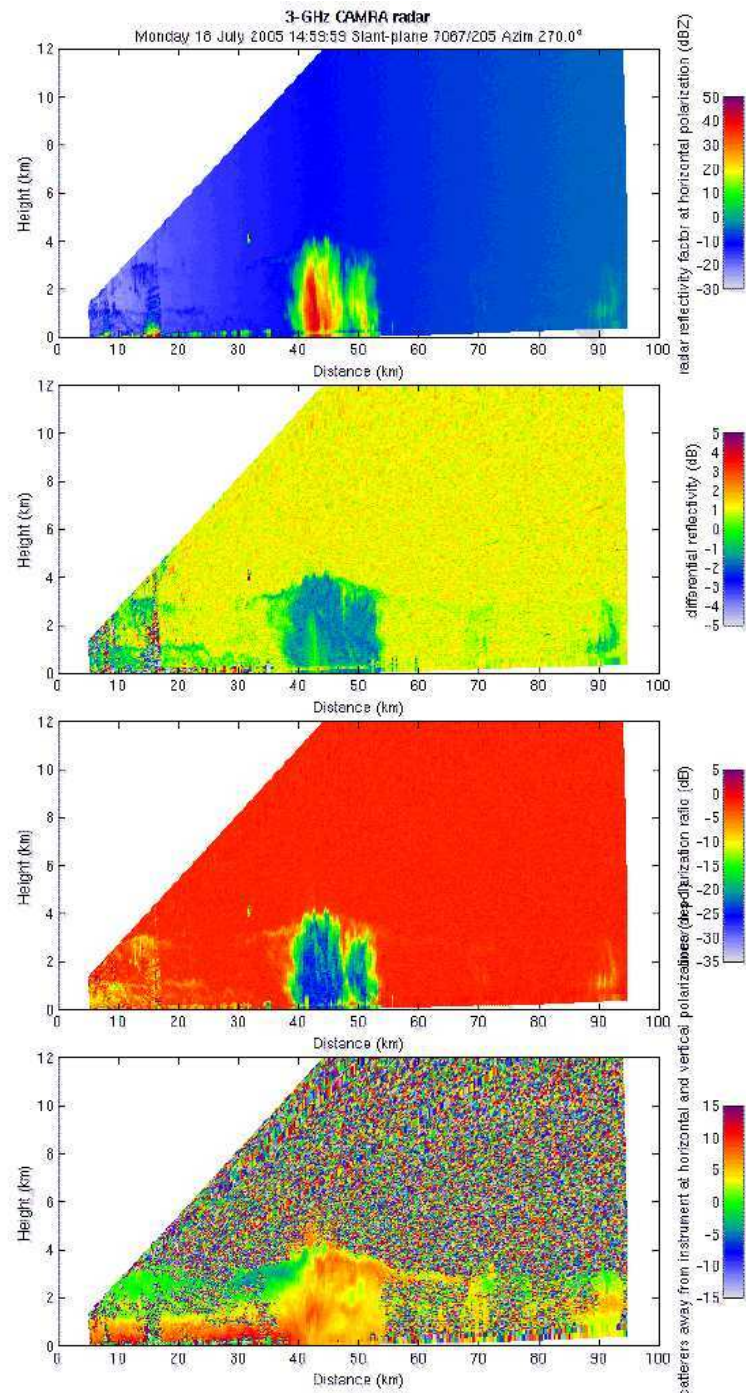
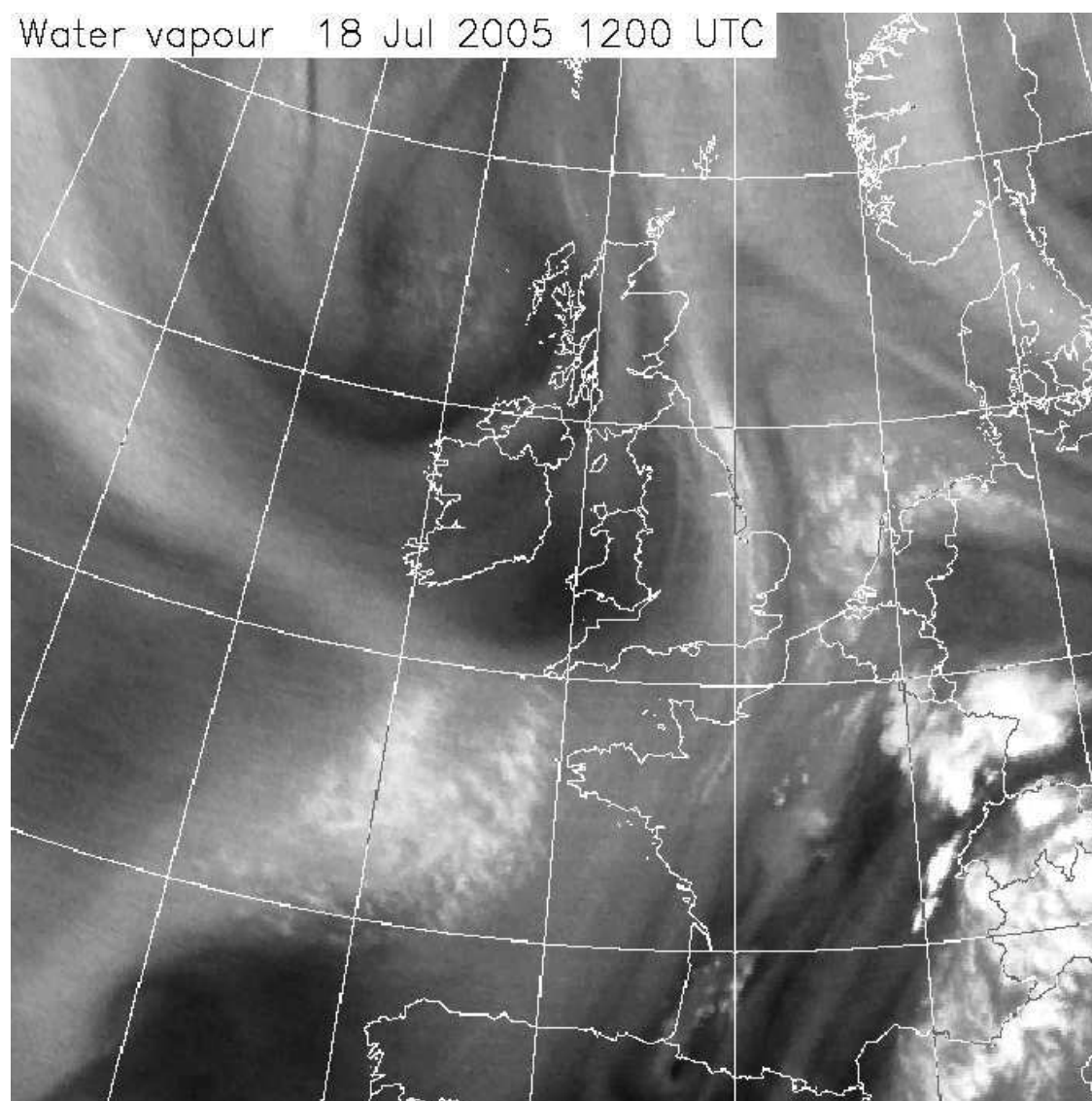


Figure 13.4 RHIs from the 3 GHz radar at Chilbolton along azimuth 270 degrees at 1459 UTC.



**Figure 13.5** Contrast-enhanced water-vapour imagery for 1200 UTC on 18 July 2005.



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## CHAPTER 14

### IOP 10: Saturday 23 July 2005

The synoptic situation at 1200 UTC is shown in Fig. 14.1. A full day's operation was performed during which a lid at 2km (Fig. 14.2) continued to suppress convection (Fig. 14.3) until late afternoon when a very few showers formed to the north-east between Reading and London (see e.g. Fig. 14.4 at 1830 UTC). The showers to the west were mainly light and short-lived, being mainly below 4km and 40dBz. Some of those to the north-east were moderately intense. Models had predicted more shower activity. A contributory factor to the suppression of activity may have been the extensive cover of low cloud which did not show any breaks until well into the afternoon. Onshore winds also suppressed convective activity close to the south coast. Fairly persistent mesoscale bands of surface convergence developed during the day (Fig. 14.5) but they were not always clearly related to the locations where showers initiated.

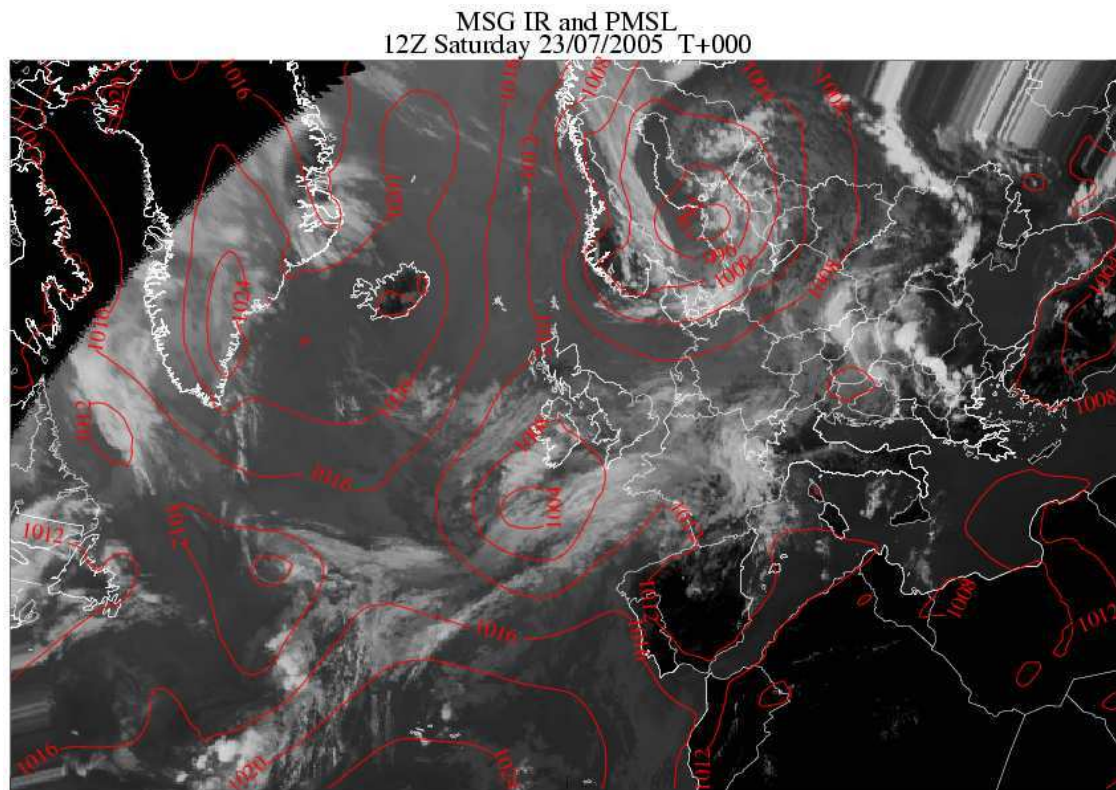
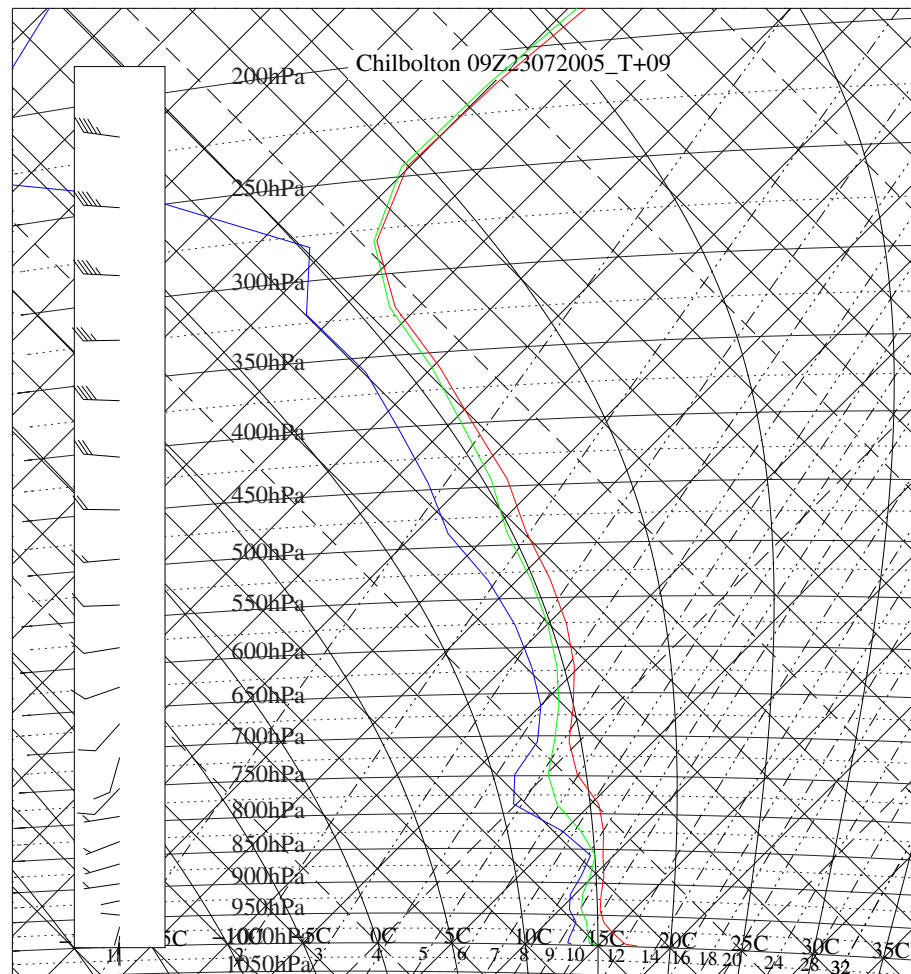


Figure 14.1 MSLP analysis and satellite infra-red cloud at 1200 UTC.



**Figure 14.2** Forecast tephigram for Chilbolton at 0900 UTC on 23 July 2005, showing a lid at 700 hPa suppressing convection.



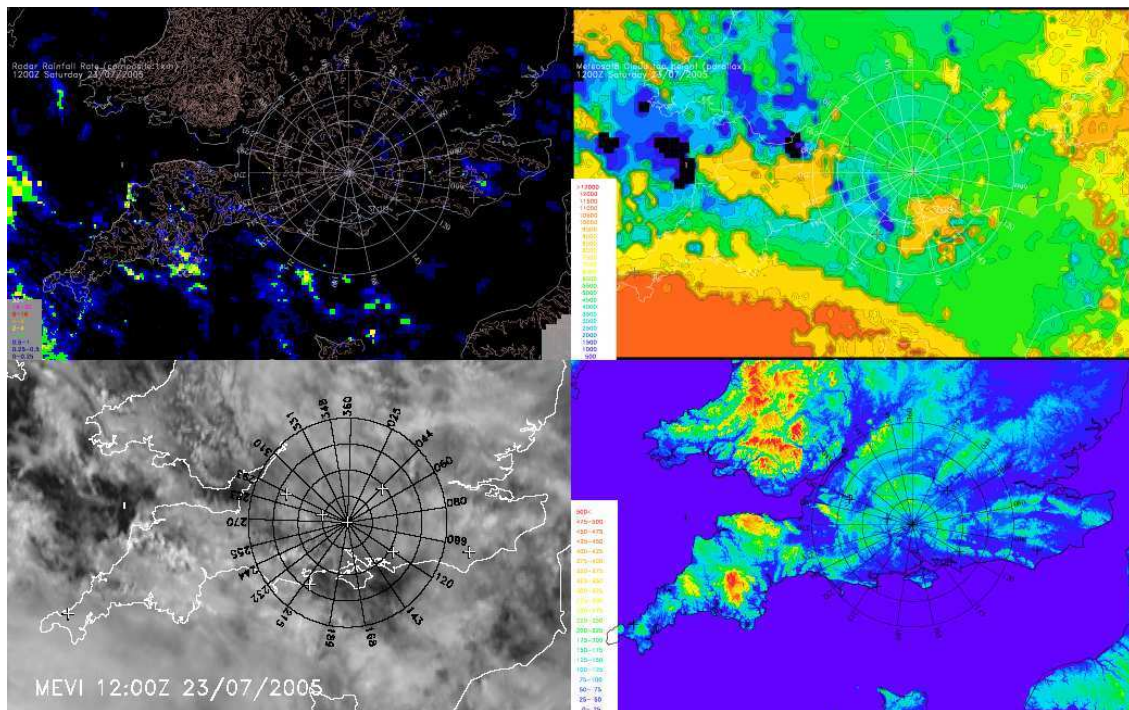


Figure 14.3

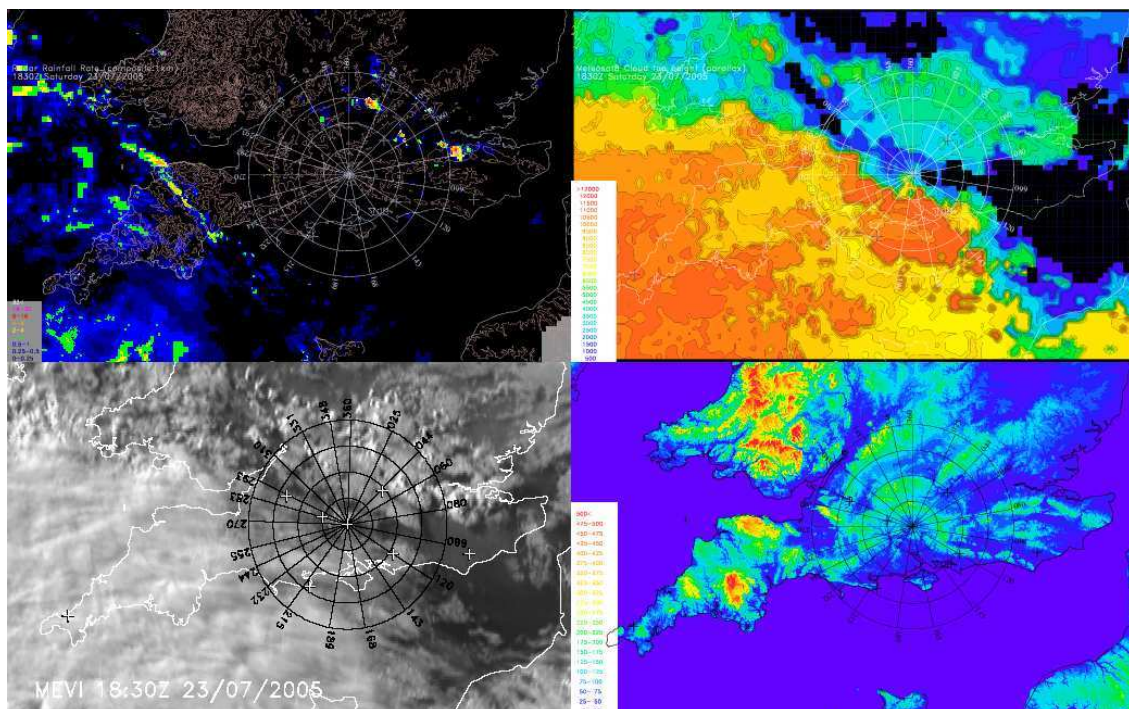
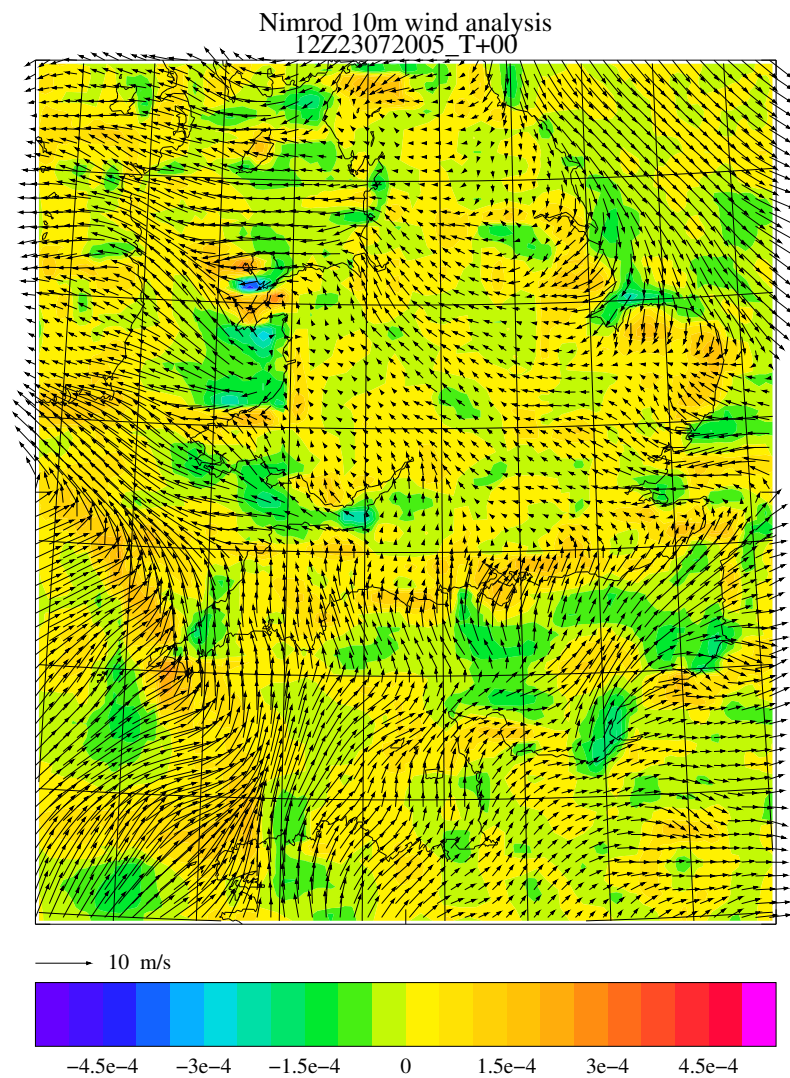


Figure 14.4



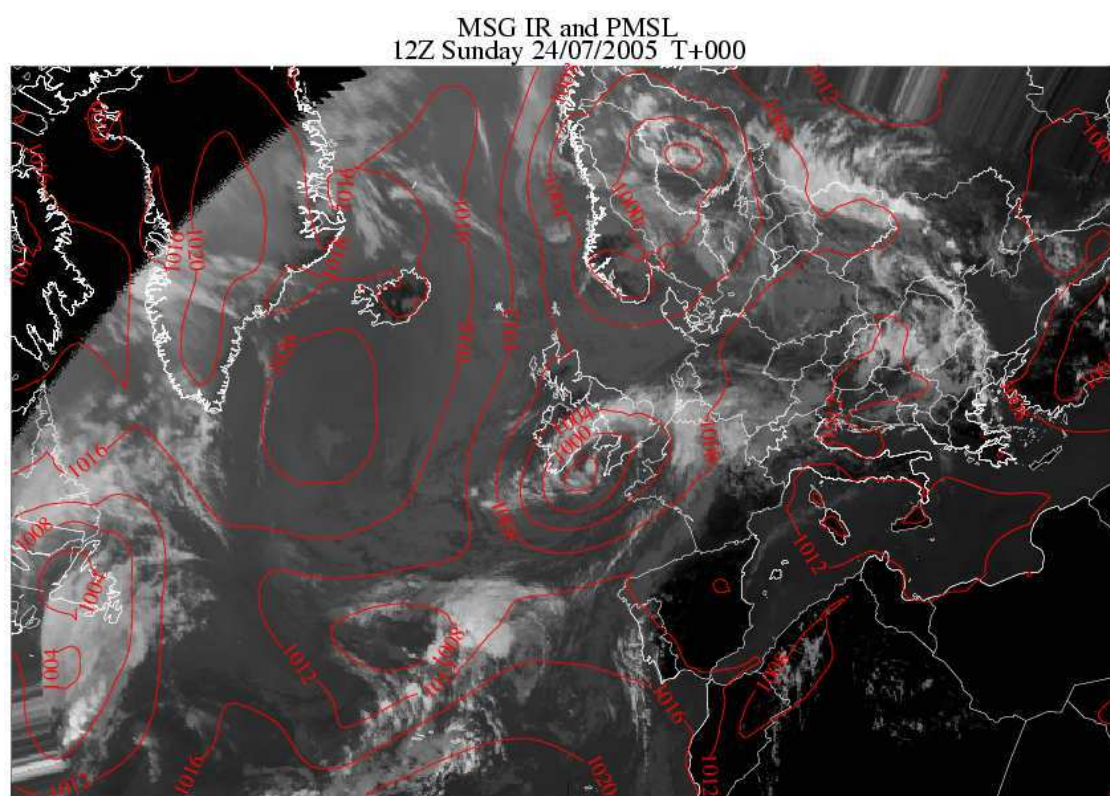
**Figure 14.5** NIMROD 10 metre wind analysis for 1200 UTC on 23 July 2005.

## CHAPTER 15

### IOP 11: Sunday 24 July 2005

A vigorous low just south of Ireland (with a well defined cloud head off SW Ireland) (Fig. 15.1) was associated with a pronounced WV dark zone and tropopause depression (see 0010 UTC image in Fig. 15.2). A broad belt of heavy rain associated with an occlusion travelled northwards and cleared the CSIP area by early afternoon (see Fig. 15.3). This was followed by a dry slot, with very dry recently-descended air at middle levels. The main IOP commenced with the arrival of the dry slot. (The term dry slot does not imply the absence of any precipitation within it.) Shallow convective cloud lines, transverse to the flow, formed within the dry slot in the CSIP area (see Fig. 15.4). These were beneath a lid at 2 to 3km, which suppressed shower development in this region (Fig. 15.5). Farther west there were some lines or arcs of showers which were seen to circulate around the low located near the north coast of Cornwall. A few clouds rose to 3km and produced brief light showers in the west of the CSIP area. Preliminary indications suggest that their brief intensification may have been affected by the hills (eg. Cranborne Chase). Later, well defined convective rainbands approached the area from SW England. These broke through the lid and produced thunderstorms in one of the lines in south Wales (Fig. 15.4). In the west of the CSIP area there were moderate showers with tops to 5km in the late afternoon, indeed up to the time (1800 UTC) of the last CSIP sondes (see Fig. 15.6). In the east of the area the lid at 2 to 3km inhibited shower formation altogether.





**Figure 15.1** MSLP analysis and satellite infra-red cloud at 1200 UTC.

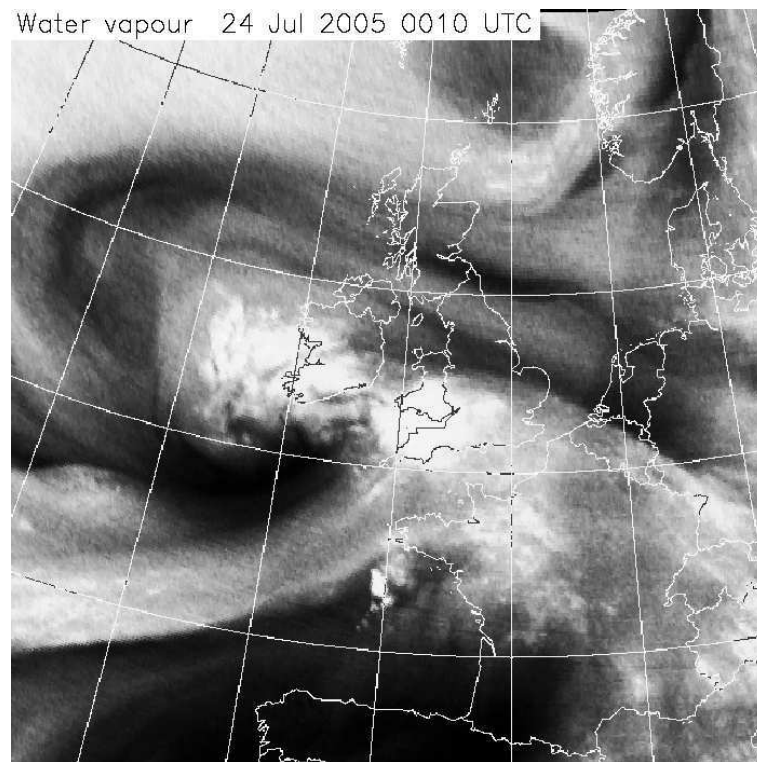


Figure 15.2

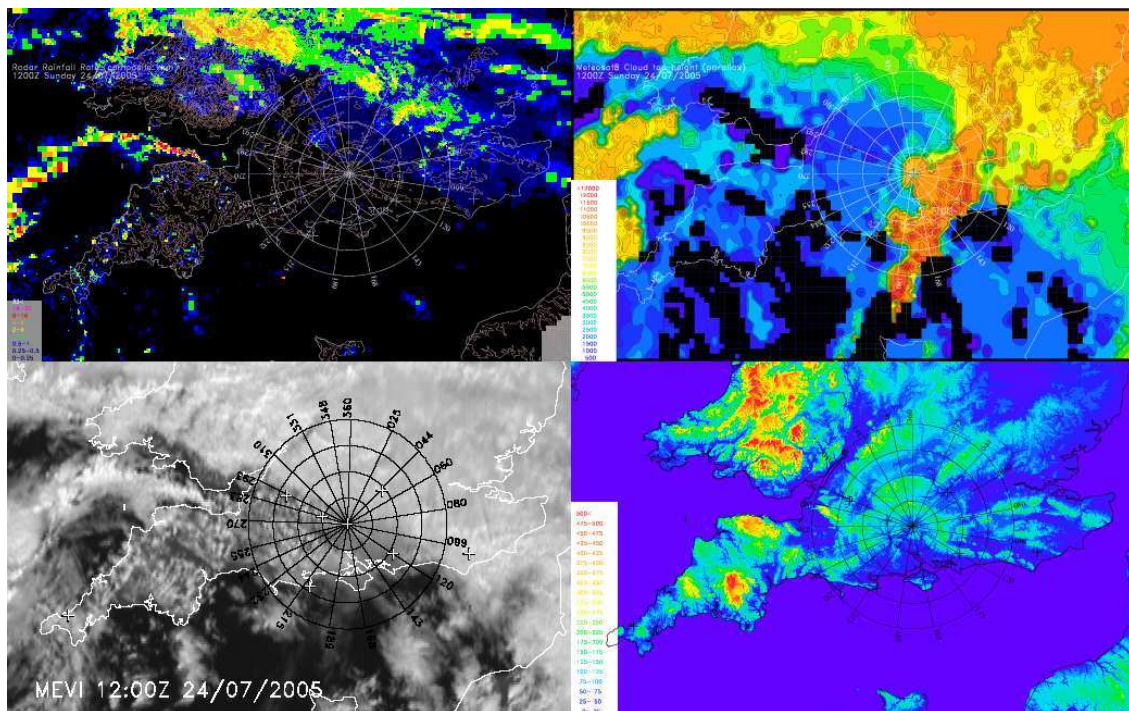


Figure 15.3



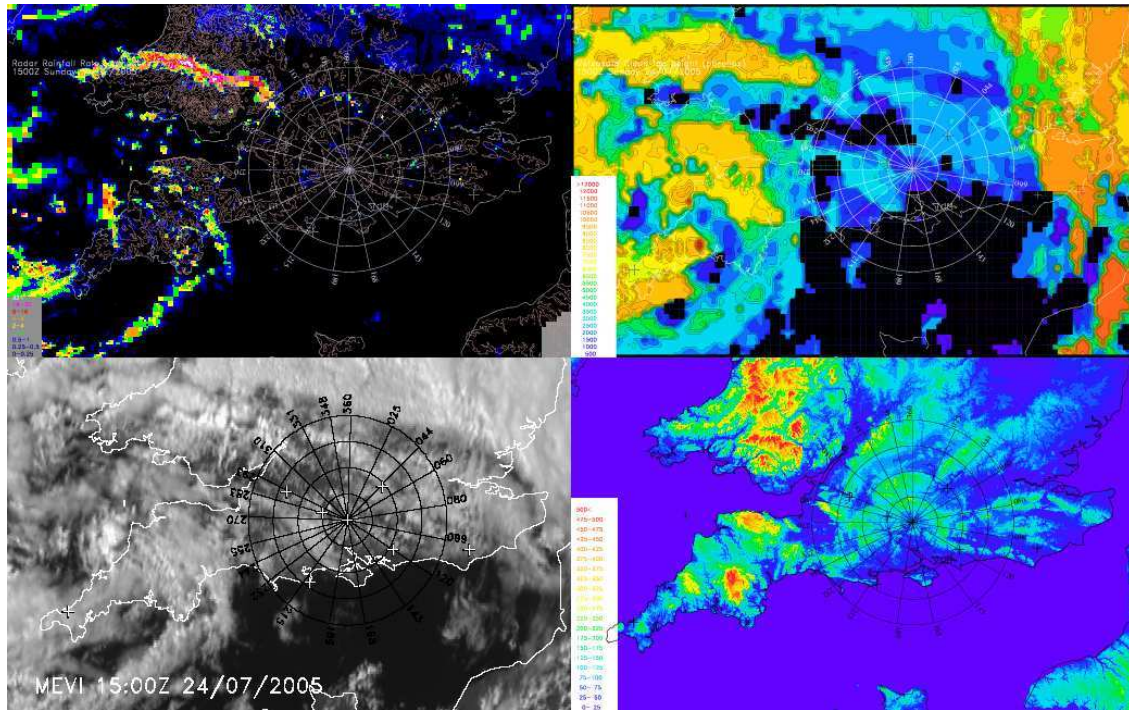


Figure 15.4

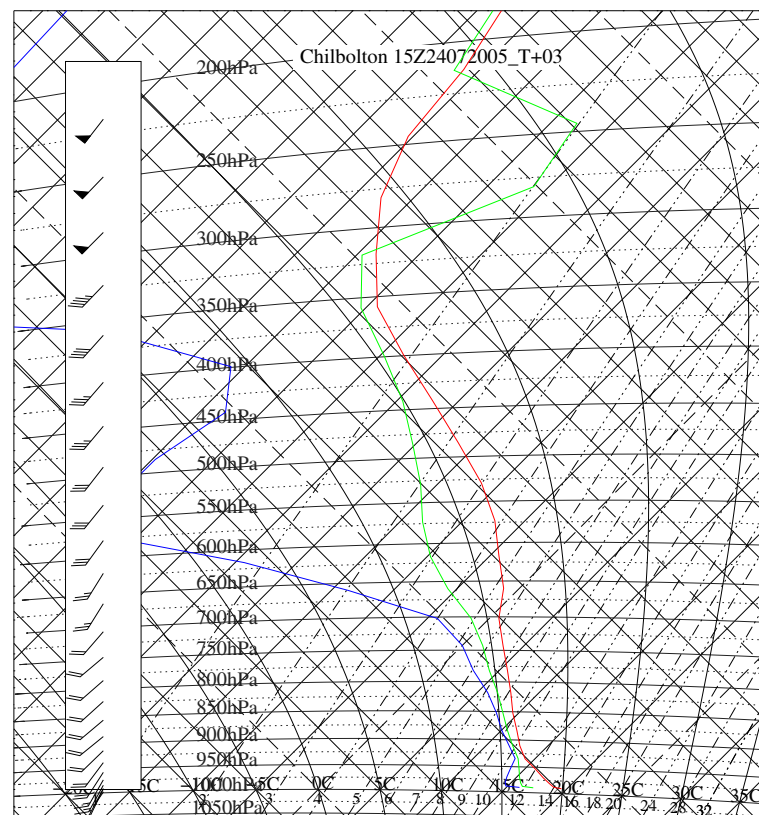


Figure 15.5 Forecast tephigram for Chilbolton at 1500 UTC (T+3) on 24 July 2005.

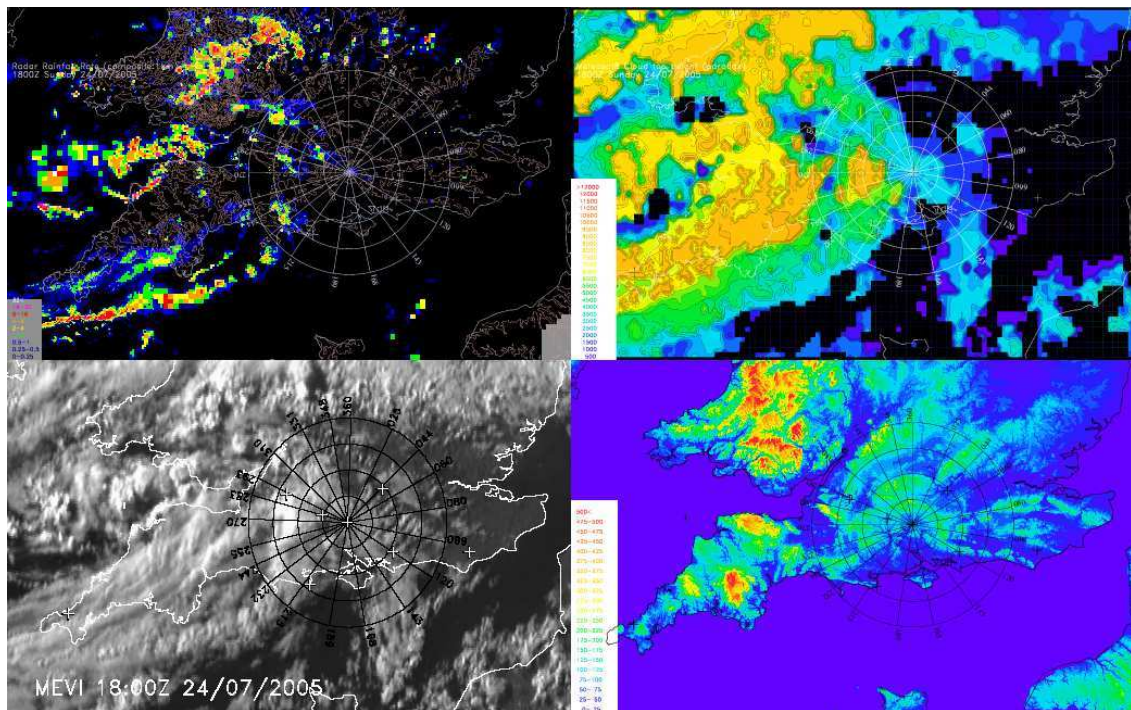


Figure 15.6

## CHAPTER 16

### IOP 12: Thursday 28 July 2005

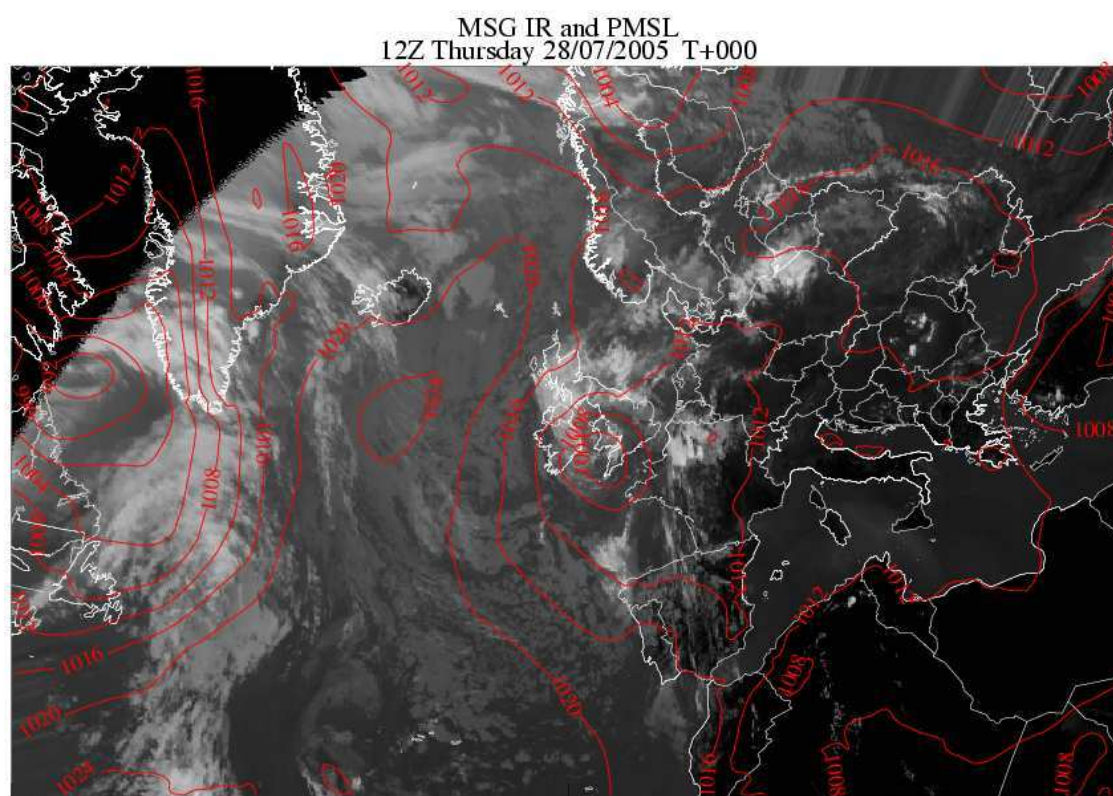
The CSIP area was characterised on 28 July by a dry slot ahead of a low that was centred near SW England (see Figs. 16.1 and 16.2).

Bands of showery rain at the leading edge of the dry slot cleared away during the early morning and for a while it was dry in the CSIP area with only shallow cumulus clouds. Because of the strong wind, the cumulus were aligned in cloud streets orientated along 190-010deg. They had a narrow spacing of about 6 km at this time (see Fig. 16.3). The Larkhill sounding for 1000 UTC (Fig. 16.4) was launched close to where the first rain echo formed shortly afterwards. It shows a lid at 825hPa which was just beginning to be penetrated at this time. This can be seen in the CAMRa RHI data for 0958 UTC in Fig. 16.5, which shows the lid just below 2 km and a convective top penetrating to 3 km at 70 km range,

By 1030 UTC (Fig. 16.6) the cloud streets were being modulated, perhaps by the topography, so as to give transverse bands of brighter, taller clouds (aligned along 100-280). Some of the first rain echoes formed within three of these bands between 50 and 75 km west of Chilbolton between 1000 and 1100 UTC (Fig. 16.6). By 1130 UTC (Fig. 16.7) there were bands of showers associated with two of these bands oriented roughly perpendicular to the cloud streets; this is shown more clearly in the CAMRa PPI data in Fig. 16.8. The southernmost of these shower bands soon decayed but the showers in the other band intensified and developed in lines along each individual longitudinal cloud street, the spacing of which had increased to about 12 km by 1215 UTC (Fig. 16.9). All of this convective initiation occurred WITHIN the area covered by the project radars and serial radiosondes. Reading radiosondes, for example, were launched at 1100, 1200 and 1300 UTC just prior to, in between and after several of the showers which formed in the vicinity soon after 1145 UTC.

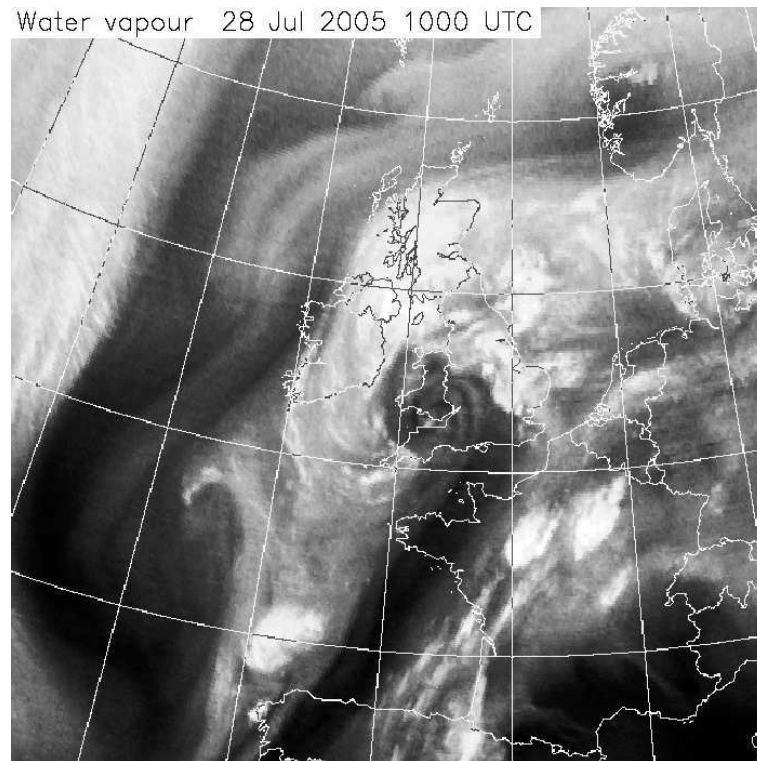
One of the showers depicted in the above figures went on to give an F2 tornado in Birmingham, probably at around 1430 BST (1330 UTC). Some photographs of tornado damage and flooding





**Figure 16.1** MSLP analysis and satellite infra-red cloud at 1200 UTC.





**Figure 16.2** Satellite water-vapour imagery for 1000 UTC on 28 July 2005.

from this event are shown in Fig. 16.10. This also corresponds to the time and location of the first sferics recorded in England on this day (Fig. 16.11). A radar network picture for 1330 UTC (Fig. 16.12) shows radar-derived rain-rates of more than  $32 \text{ mm hr}^{-1}$  over Birmingham. A preliminary assessment suggests that the Birmingham storm began as a developing cumulus north of Dorchester (Dorset) at 1000 UTC. It then travelled NNE'wards giving its first rain echo at 1045 UTC. Its top then rose rapidly from roughly 3 km at 1045 UTC to nearer 9 km at 1115 UTC by which time it was over Bath where serial ascents were being made.

Throughout much of the day there was a particularly pronounced cloud street downwind of the Isle of Wight. Some of the showers that started precipitating when near Reading formed along it. Later in the day, from 1430 UTC onwards, further showers developed along the Isle of Wight cloud street. They formed between the sonde sites at Chilbolton and Preston Farm and just over an hour later, at 1545 UTC, a heavy shower from this line passed over Reading where further serial sondes were being released. This storm had an isolated top probably to about 8 km (Fig. 16.13).

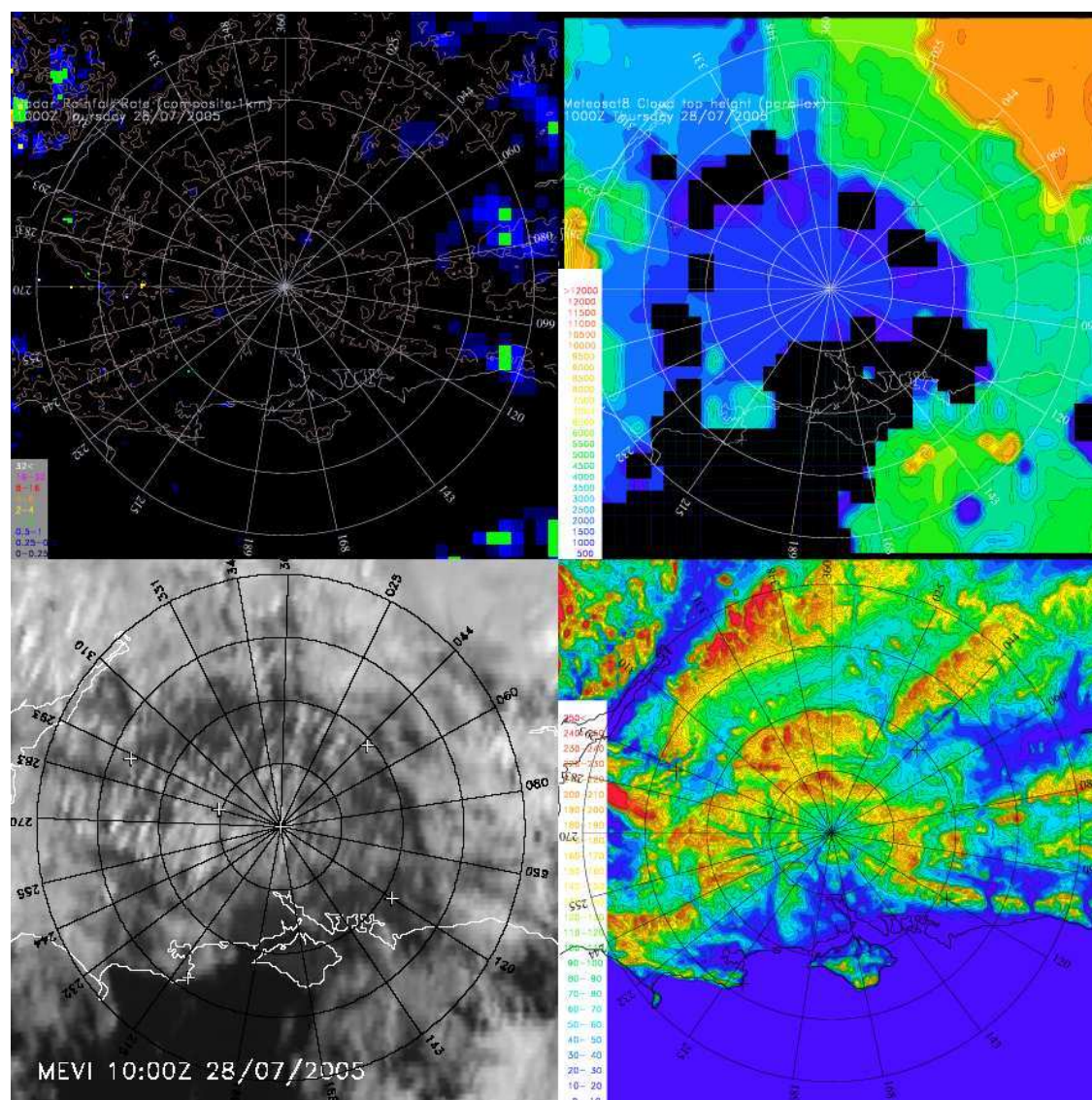
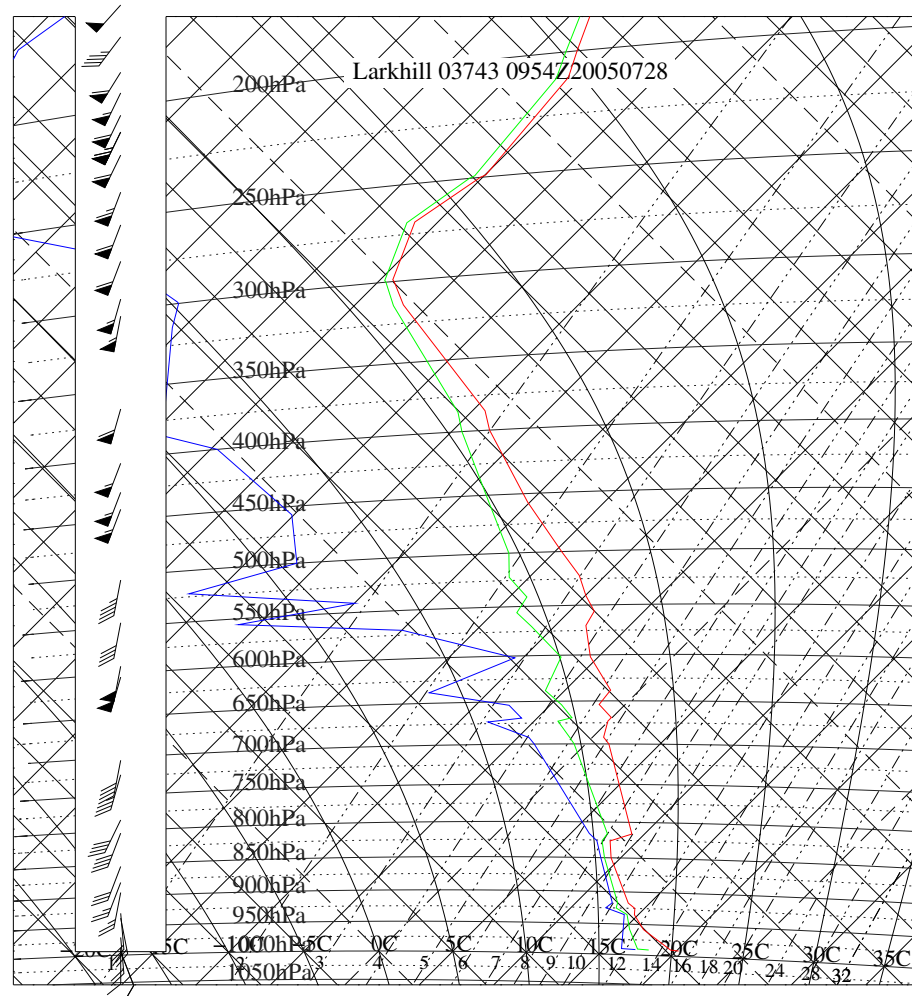


Figure 16.3



**Figure 16.4** Tephigram for the 1000 UTC Larkhill radiosonde ascent.

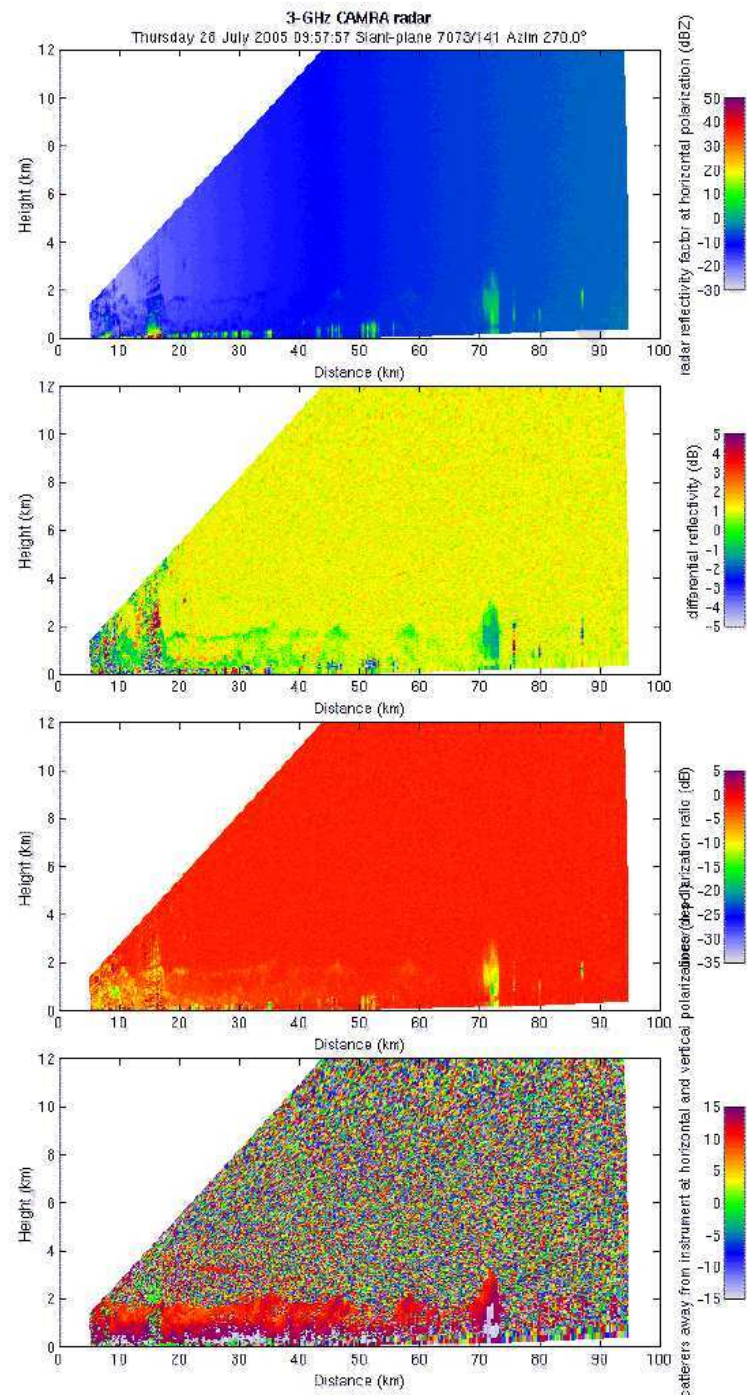


Figure 16.5



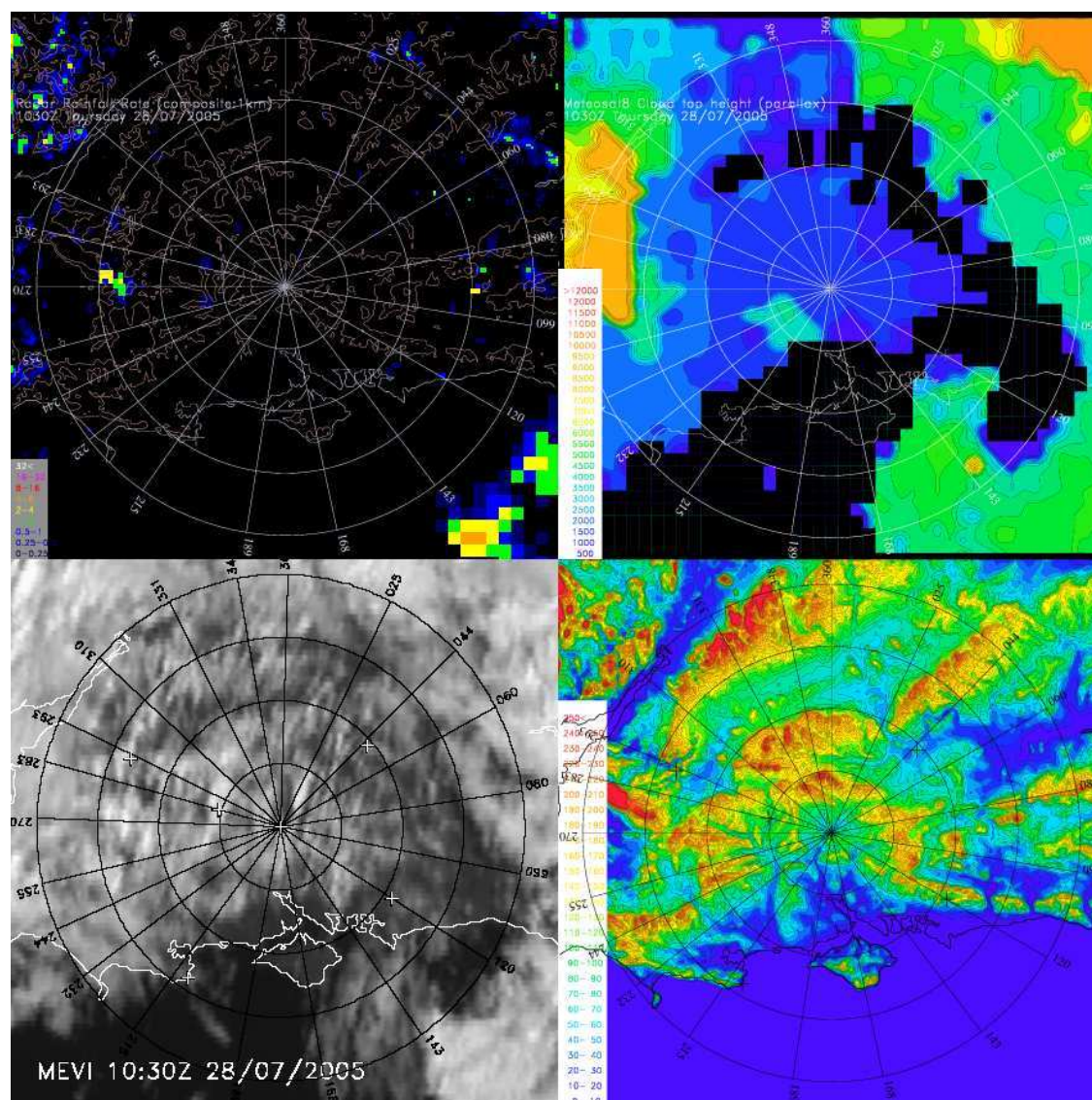


Figure 16.6



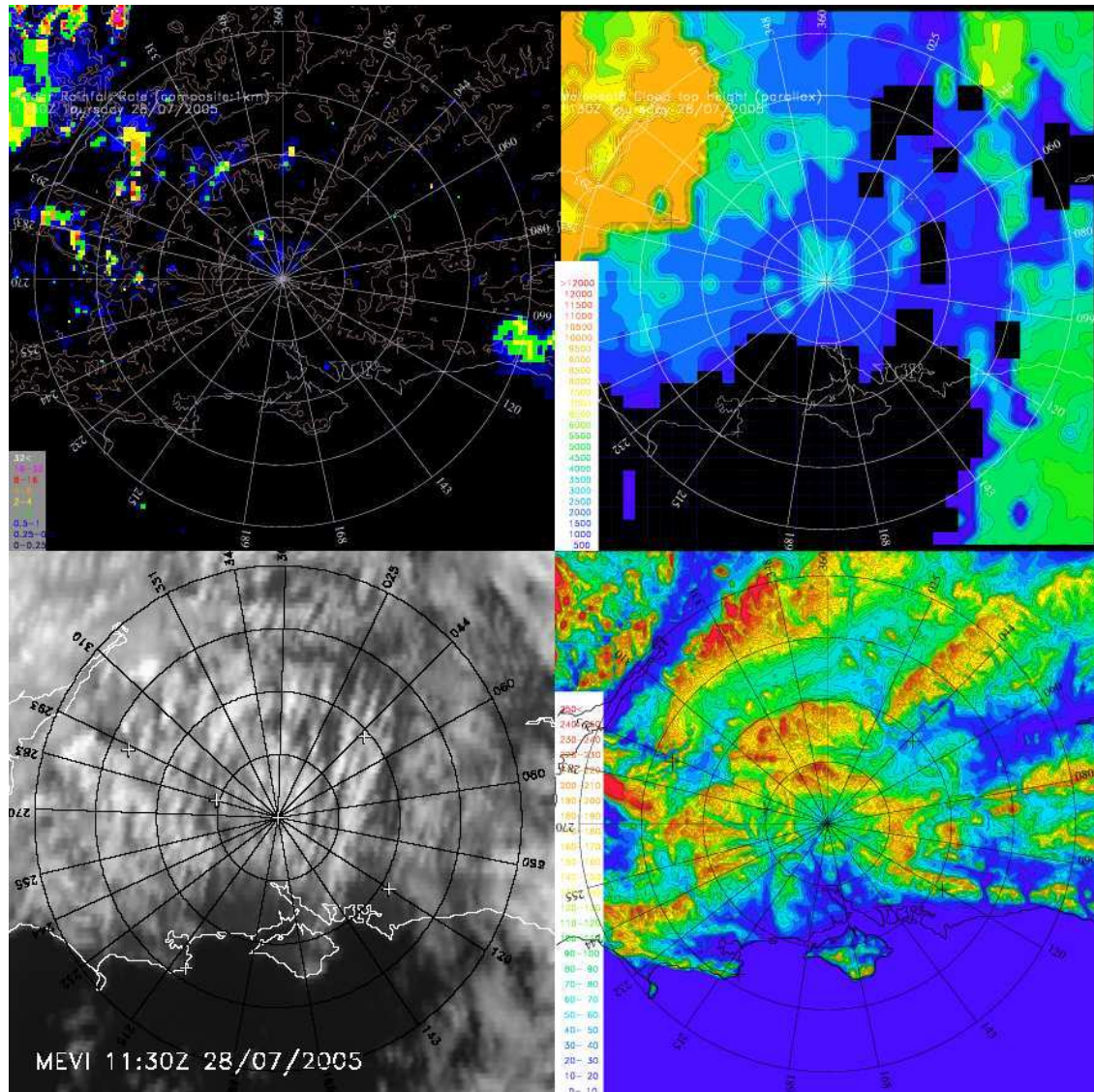
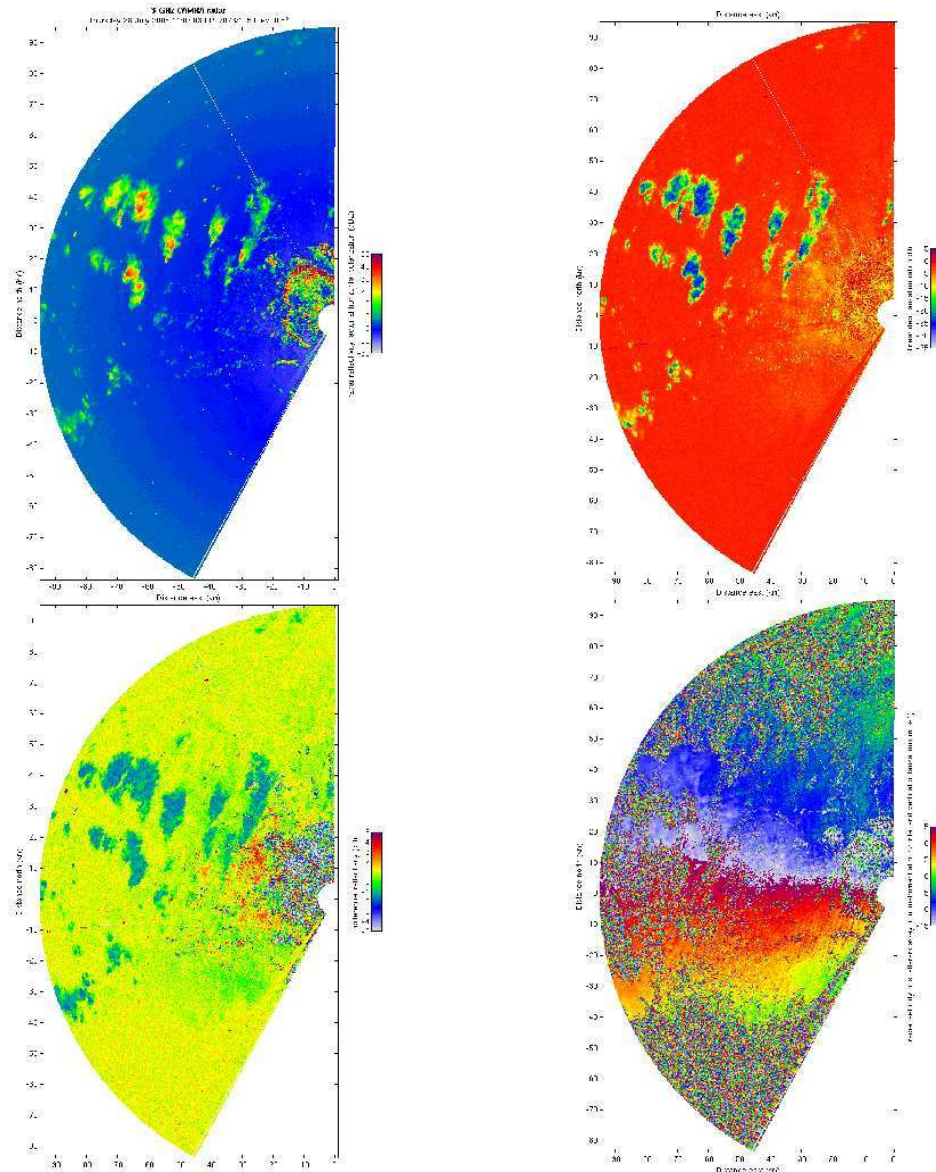


Figure 16.7



**Figure 16.8** CAMRa PPI at 1103 UTC on 28 July 2005. The panels show: reflectivity (top left), linear depolarisation ratio (top right), differential reflectivity (bottom left) and Doppler velocity (bottom right). Note shear on edge of cells.



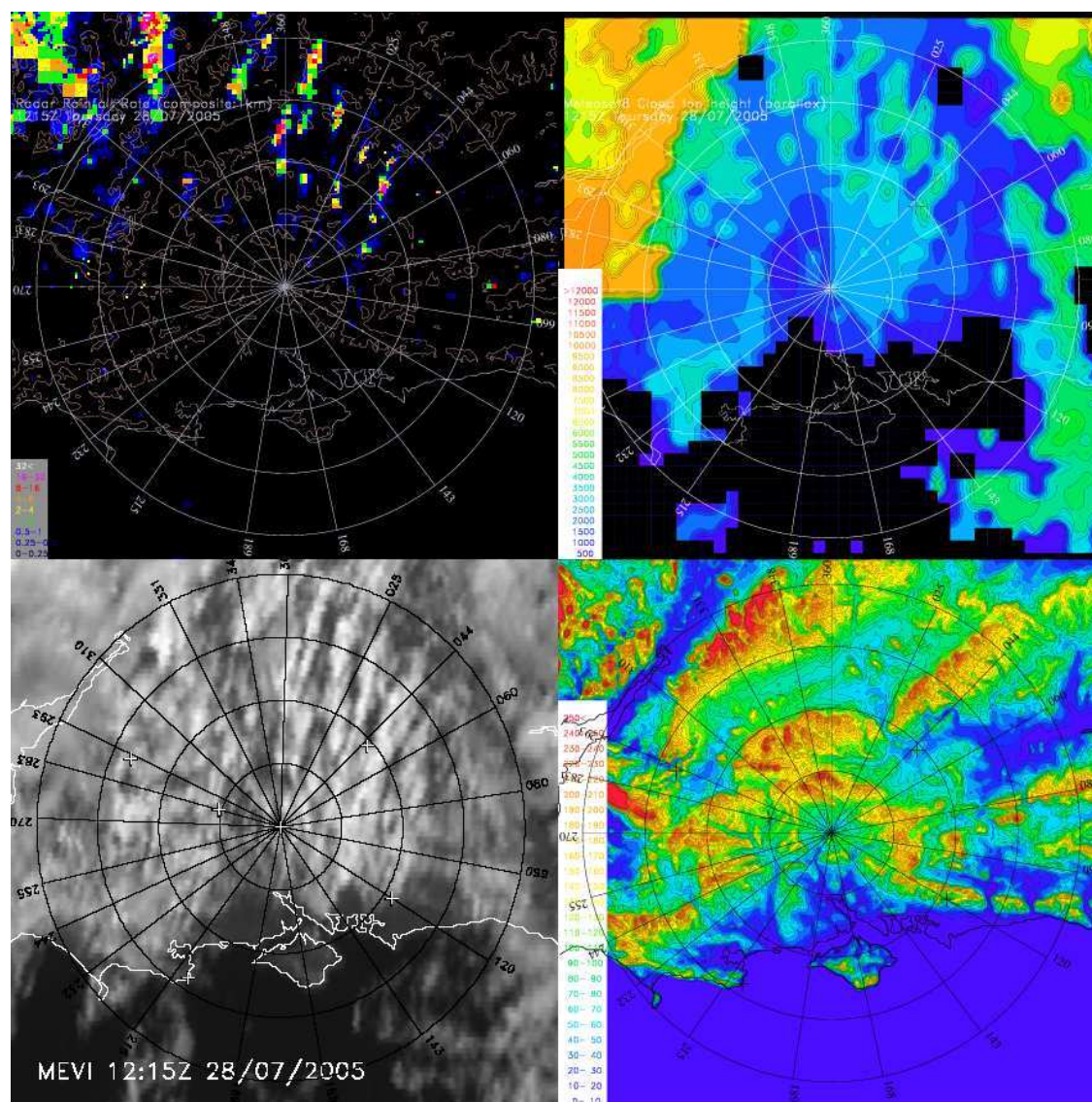
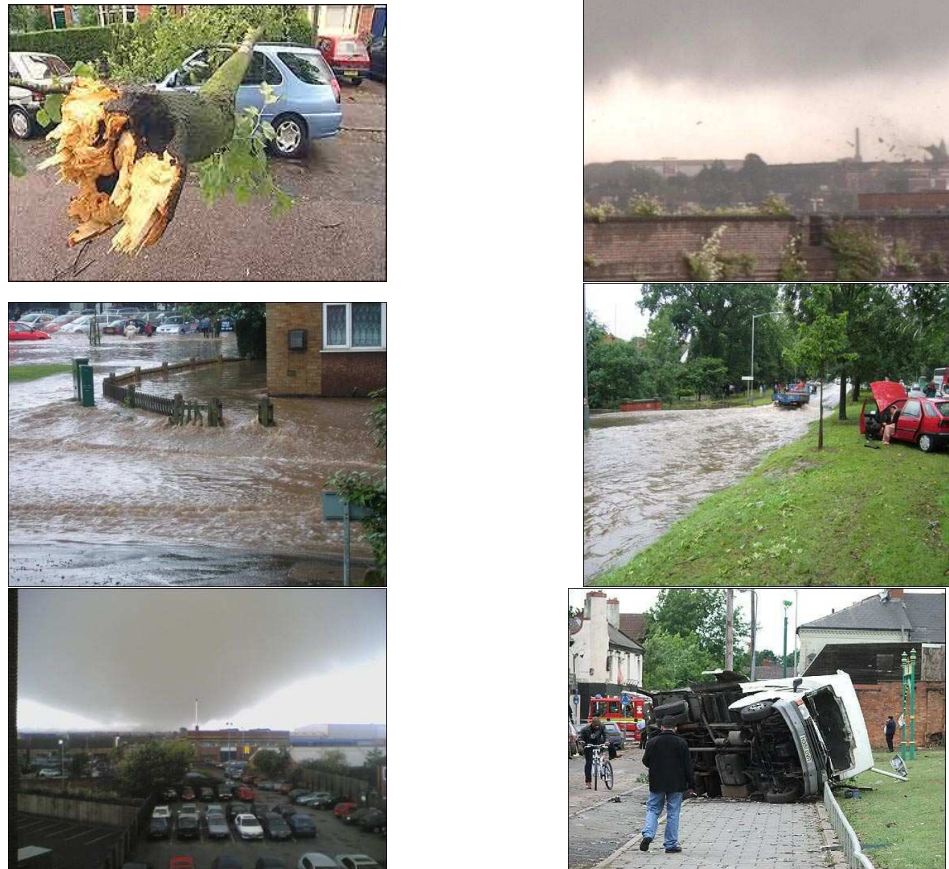
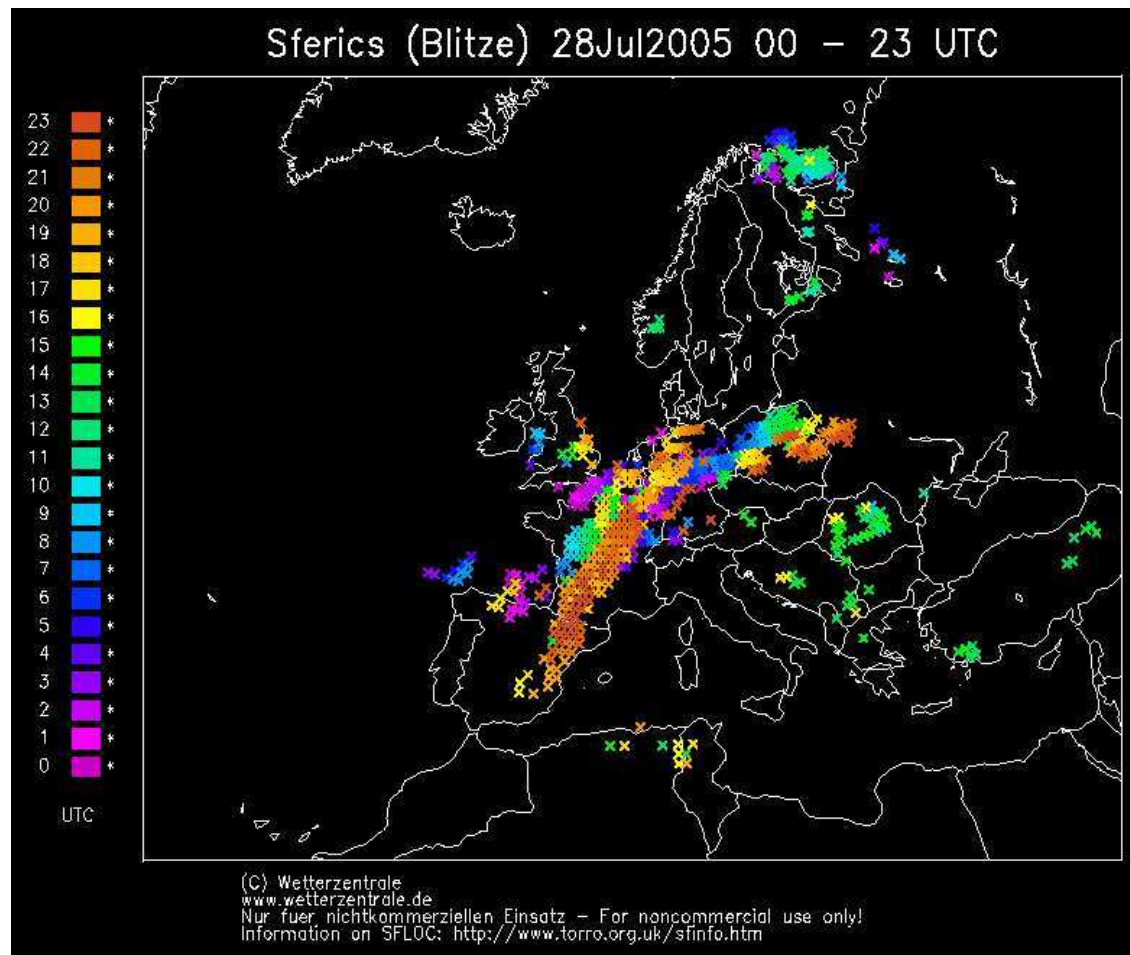


Figure 16.9



**Figure 16.10** Photographs of tornado damage, flooding and flying debris in Birmingham. (Collected from BBC News website.)



**Figure 16.11** Timing and location of lightning strikes on 28 July 2005.



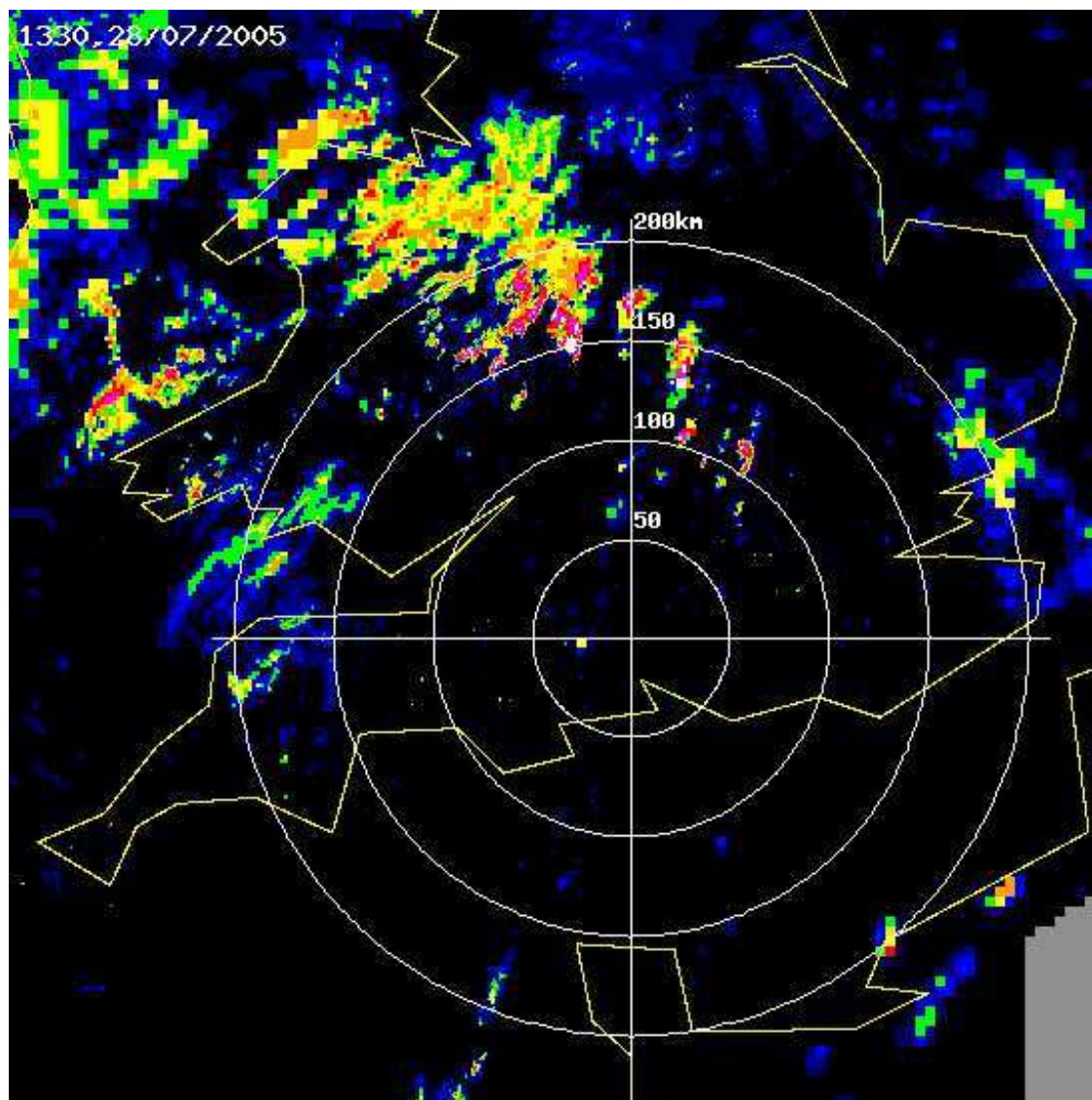


Figure 16.12 Radar network rain-rate at 1330 UTC on 28 July 2005.

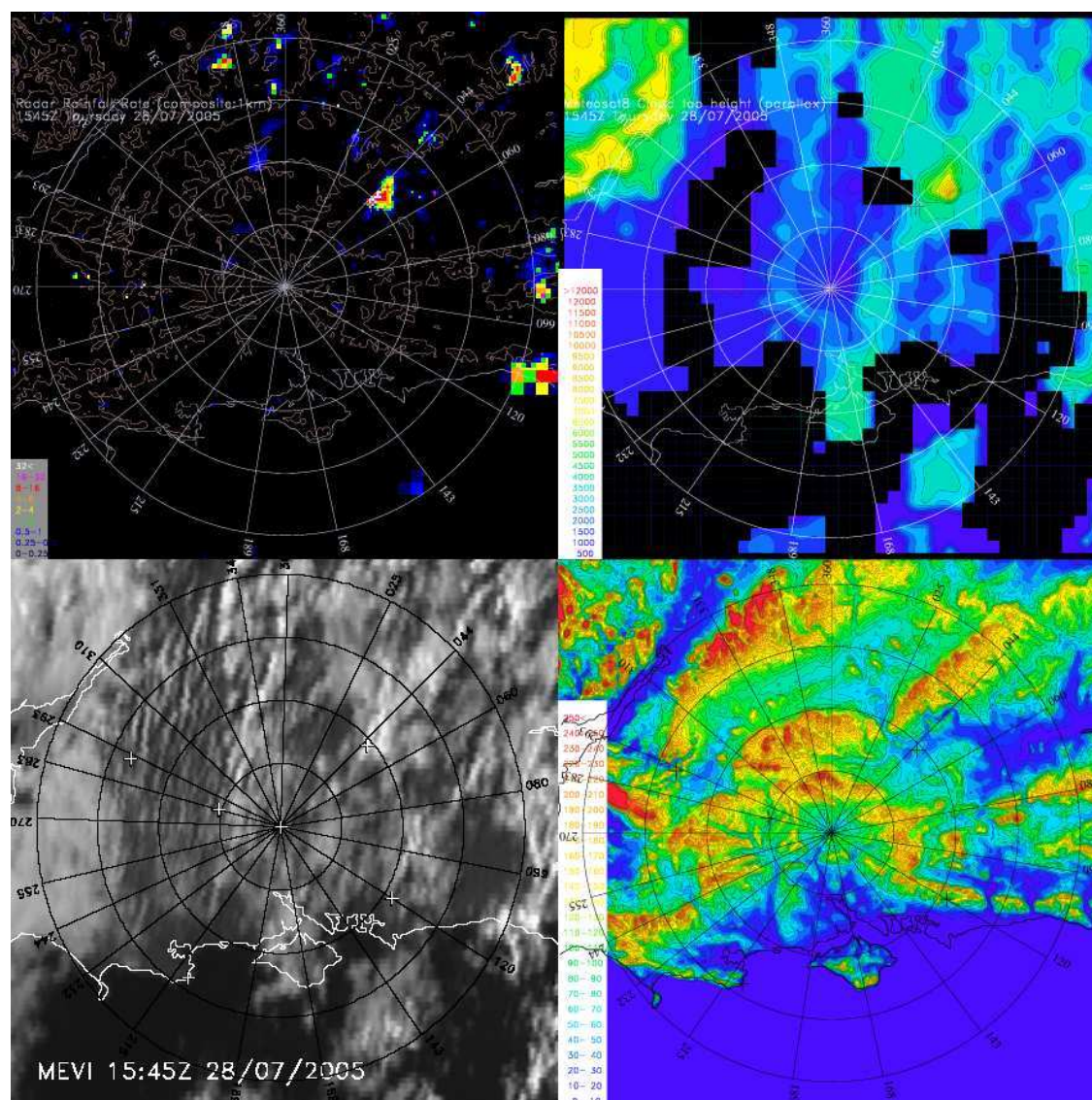


Figure 16.13

This IOP should provide an excellent dataset for studying the initiation of showers in a strong-wind situation with low CIN and multiple weak lids that were successively penetrated by a small fraction of clouds as the diurnal heating progressed. The case embraces the following features:

- (1) Longitudinal cloud streets forming within a strong flow . The spacing of the streets increased with time as the depth of the convective boundary layer grew.
- (2) Transverse modulation of these streets early in the day, perhaps due to topographical effects.
- (3) Some of the convective clouds developed into heavy rainstorms as the convection penetrated successive lids ( and a few grew into thunderstorms as they progressed to the north of the CSIP area ).
- (4) Perhaps because of the very strong wind shear, combined with dry air permitting the generation of cold downdraughts, at least one of these storms developed tornadoes as they travelled north of the CSIP area. One of these with intensity F2 caused considerable damage in Birmingham. Trees were uprooted, roofs were damaged, 19 people were injured, and several areas were flooded due to the heavy rain.

Alec Bennett (PhD student at Reading) has some electric field measurements showing the approach of a non-thunderly shower, which shows remarkable agreement with the change in electric field expected from the an electric dipole moving over the measurment site with the observed wind speed.

## CHAPTER 17

### IOP 13: Monday 1 August 2005

This IOP was declared late, during a stand-down period, and so sequential sondes were organised from only 3 sites (Larkhill, Herstmonceux, and Reading). Nevertheless it was an interesting day with some useful data. The main feature was a broad band of almost stationary showers of moderate, and occasionally fairly high, intensity affecting the CSIP area. Radar-estimated 24-hr totals exceeded 10mm extensively within this band, with a few totals over 20mm. A weak trough was centred over the south coast of England on 1 August and the winds were very light indeed (Fig. 17.1). After the clearance of overnight showers fed by high-theta-w air at 900mb, convection from the surface broke out early in the morning in association with a convergence line along the south coast. By 1000 UTC a belt of convective showers was extending from Dorset to Sussex (Fig. 17.2). It was still there at 1200 UTC (see Fig. 17.3). The corresponding NIMROD 10m convergence analysis for 1200 UTC (Fig. 17.4) shows only a weak relationship to the shower region.

The Larkhill sounding for 1200 UTC shows significant CAPE but a strong lid at mid-levels (Fig. 17.5). Tops of the convection were mainly capped by this lid, at 3 to 4 km (see for example Fig. 17.6). However, this lid was penetrated by a few showers; some of these reached 8 km (see for example Fig. 17.7). A reflectivity of 50 dBz was reached locally. The Larkhill sounding in Fig. 17.5 shows very little CIN and hardly any shear. Perhaps because of this, the individual showers were short-lived; however, the band within which they formed was persistent. Coastal effects are thought likely to have influenced the position of the overall band, although there was some unexplained banded sub-structure orthogonal to the coast (see for example, the imagery for 1415 UTC in Fig. 17.8). Individual hills may have influenced the precise position of individual convective cells, but a careful analysis will be required to substantiate this.



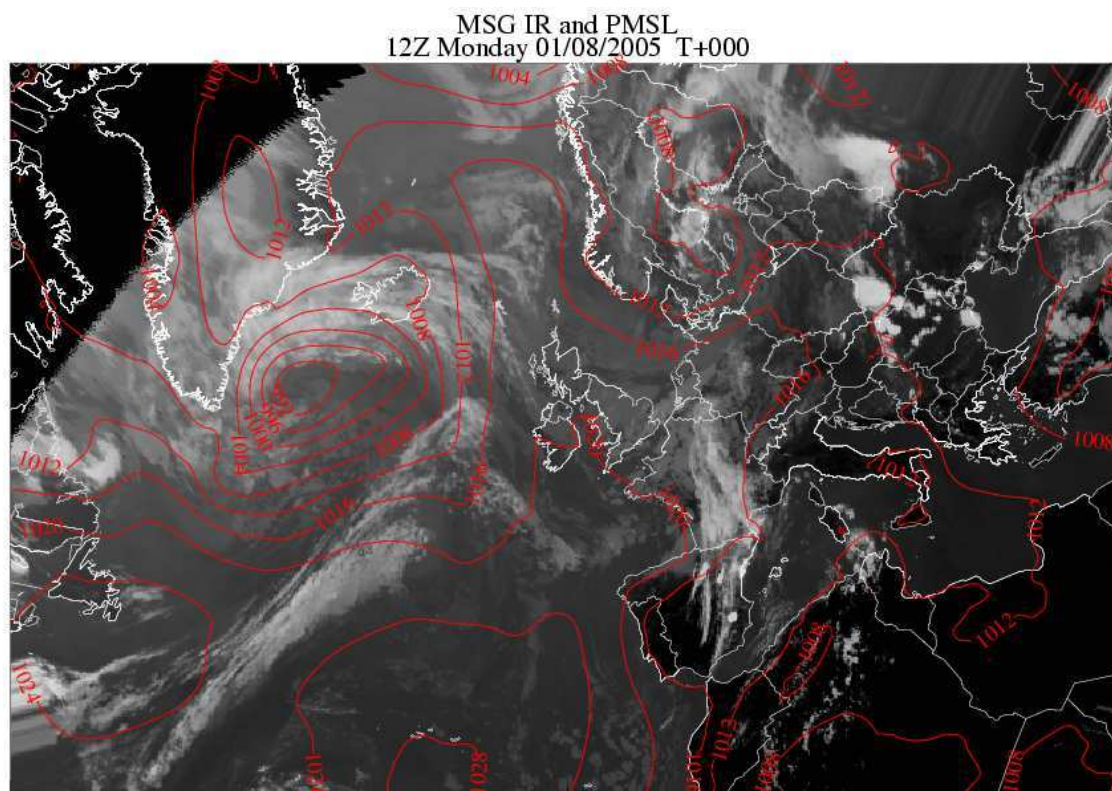


Figure 17.1 MSLP analysis and satellite infra-red cloud at 1200 UTC.

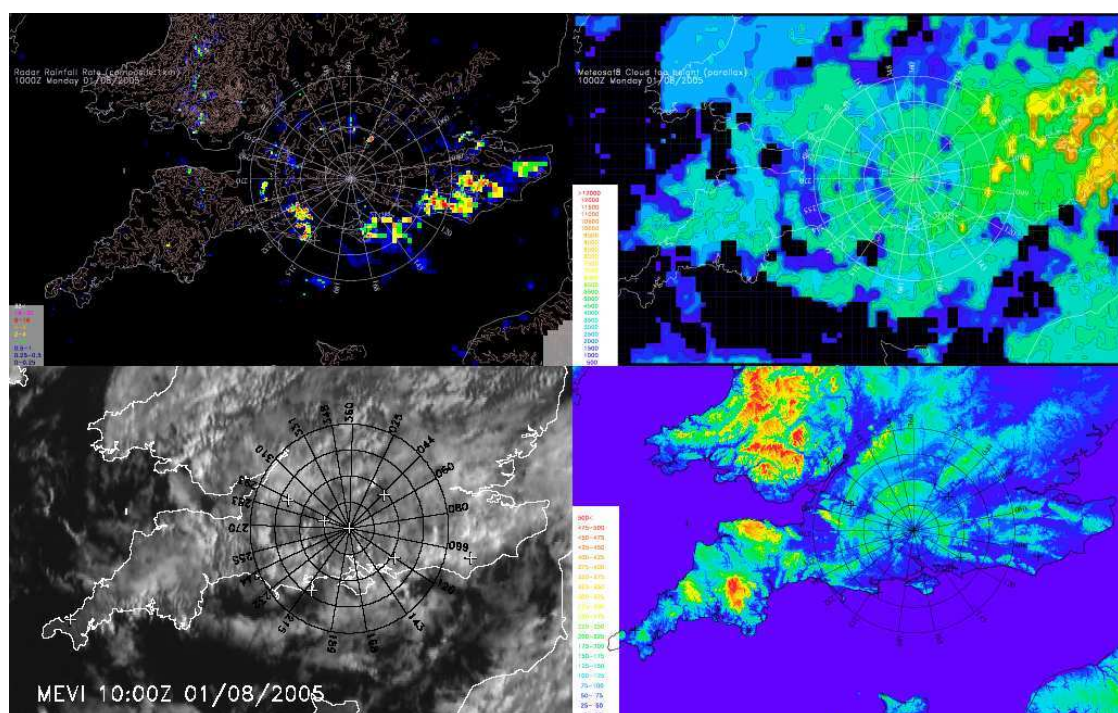


Figure 17.2



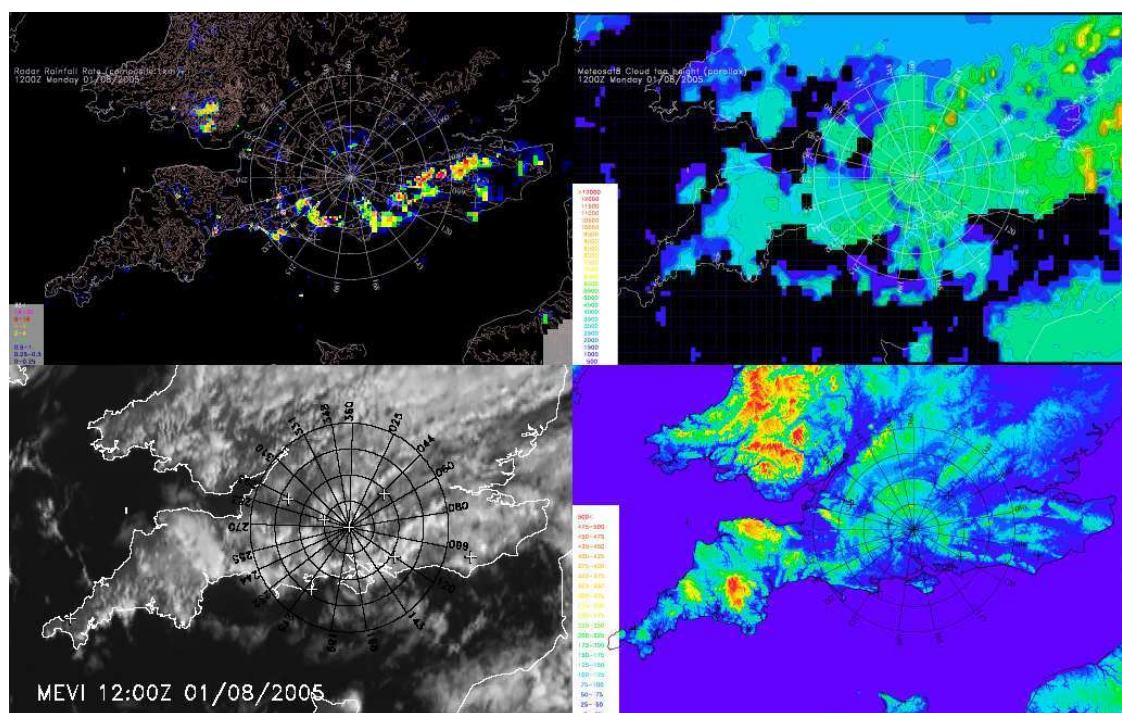
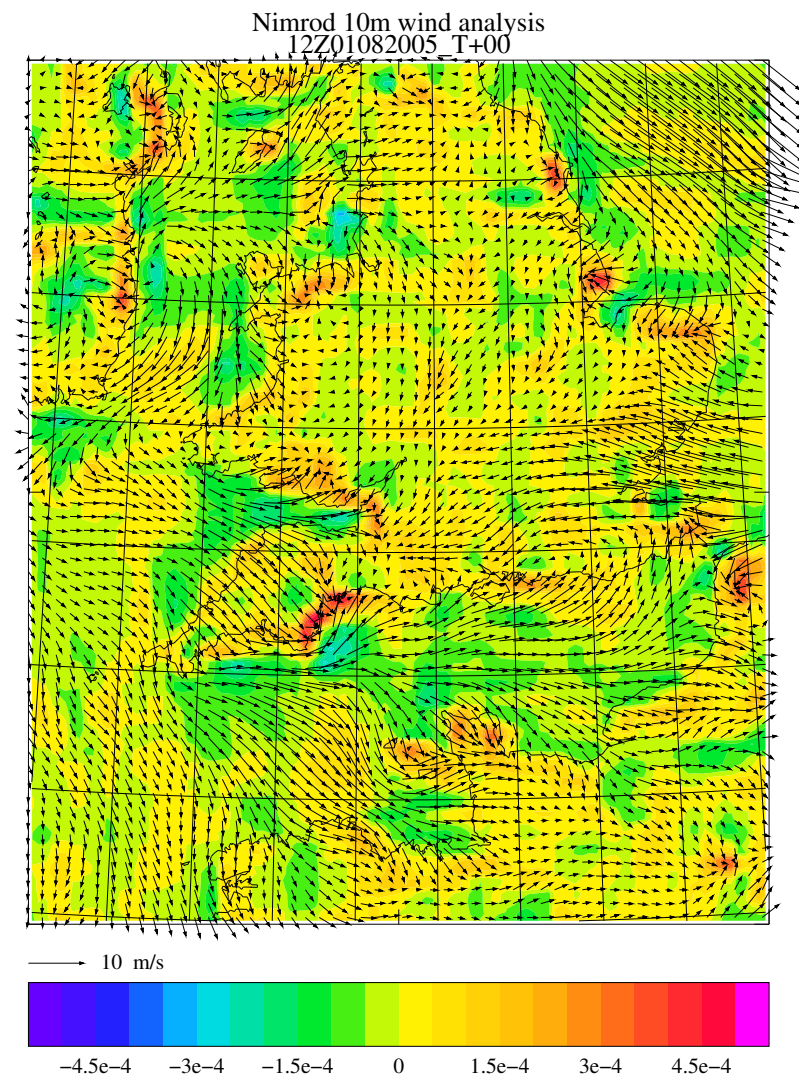
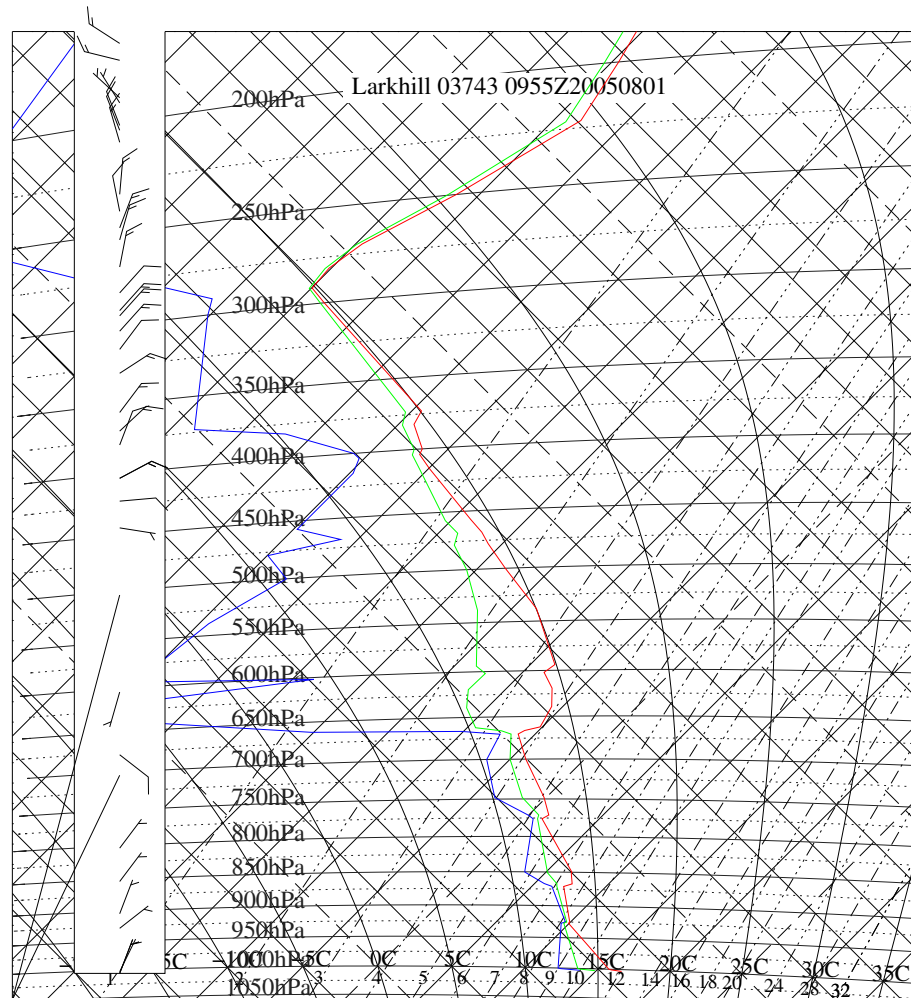


Figure 17.3



**Figure 17.4** NIMROD 10-metre wind analysis for 1200 UTC on 1 August 2005.



**Figure 17.5** Tephigram for the 1000 UTC ascent from Larkhill.



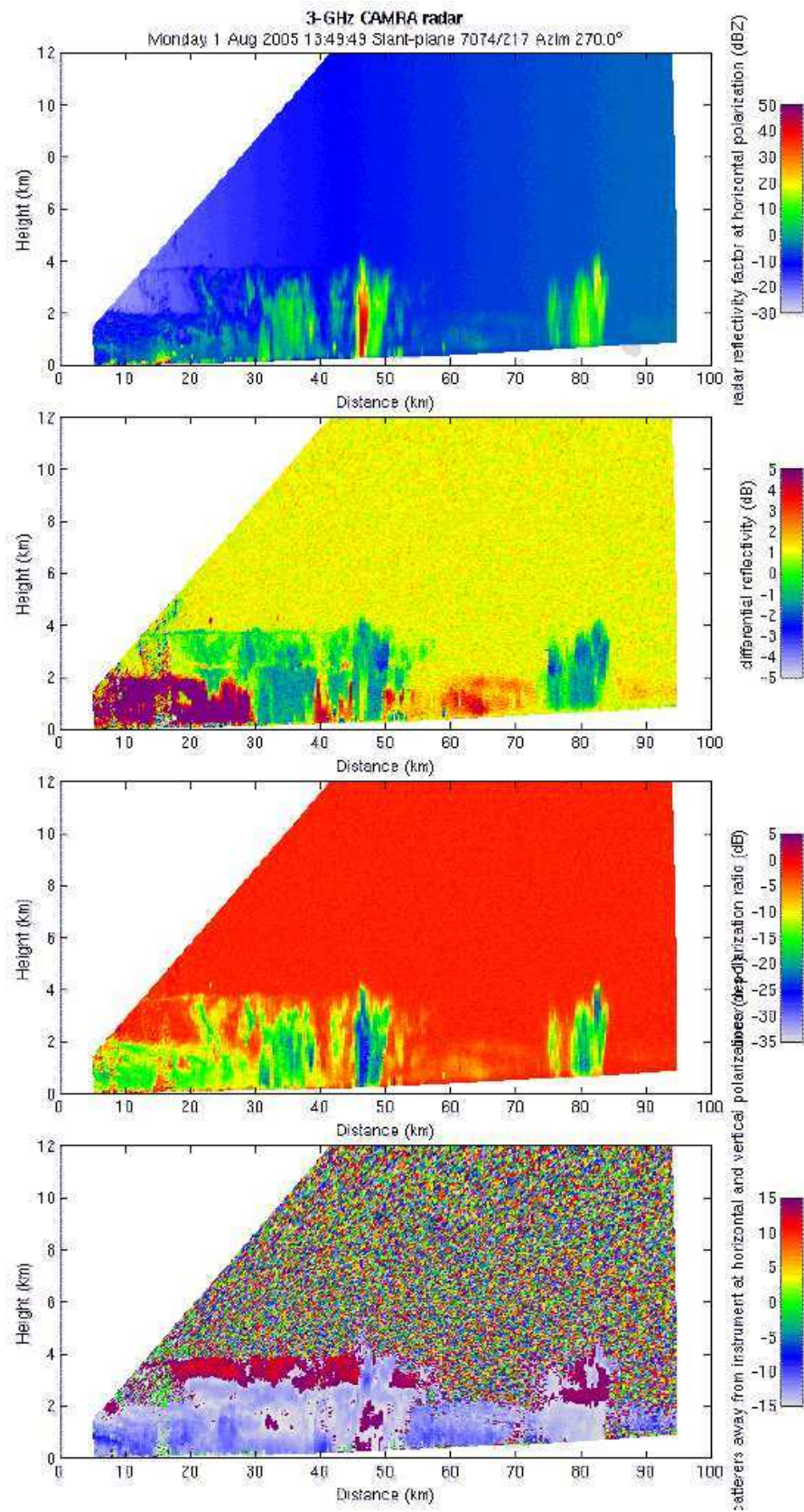


Figure 17.6 CAMRa RHIs at 1349 UTC along azimuth 270 degrees.

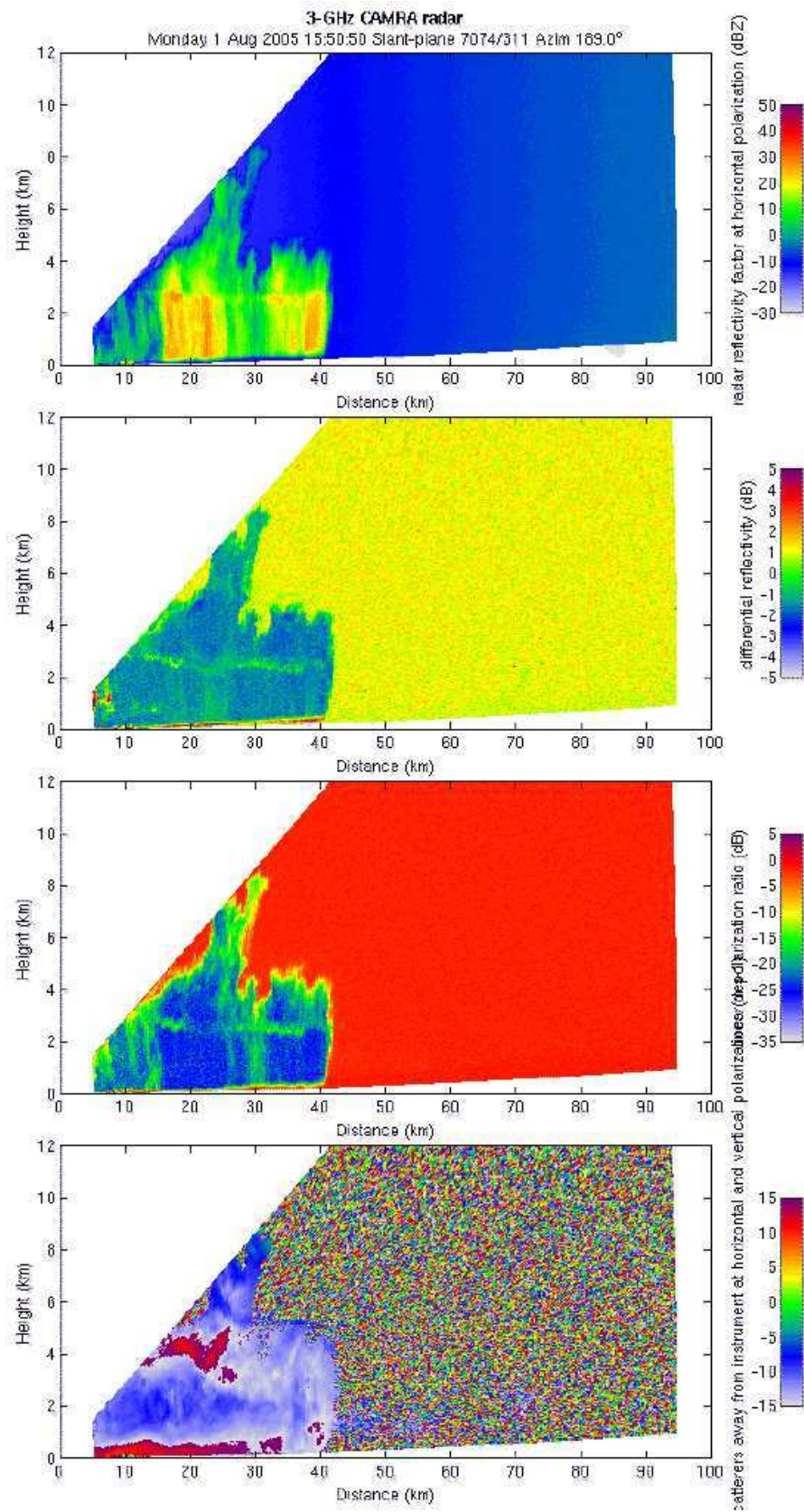


Figure 17.7 CAMRa RHIs at 1550 UTC along azimuth 255 degrees.



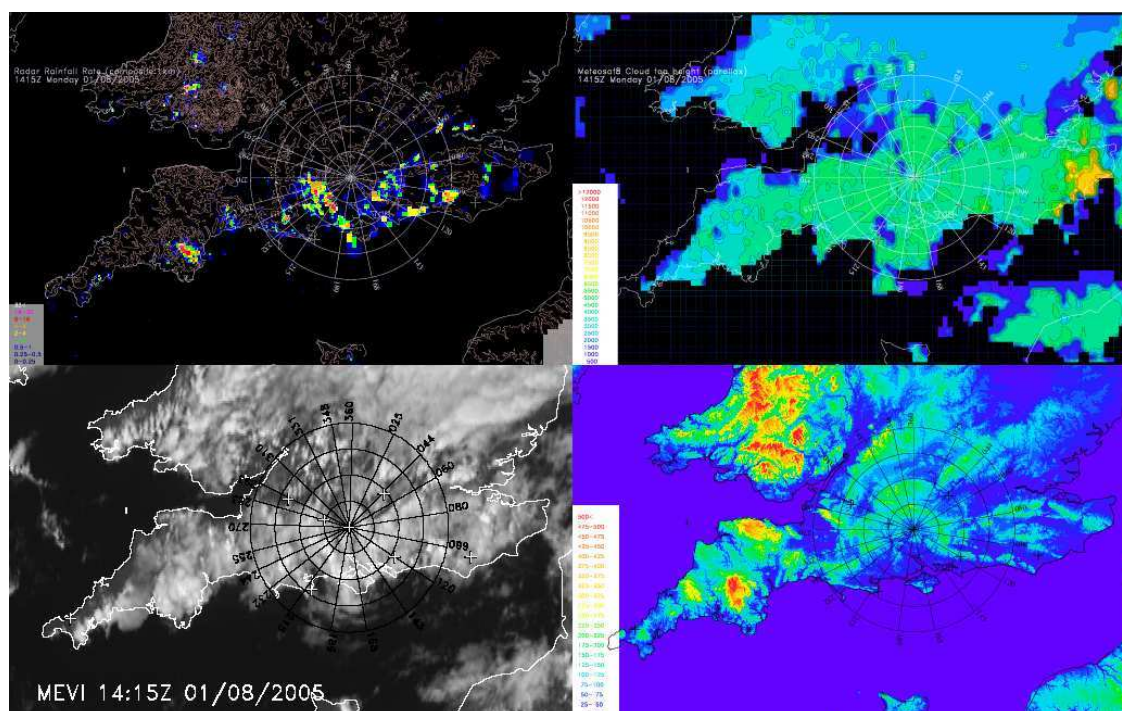


Figure 17.8

## CHAPTER 18

### IOP 14R: Thursday 11 August 2005

Figure 18.1 shows the synoptic situation at 1200 UTC. This IOP was declared retrospectively (R), so no special radiosonde ascents were made and there were only partial observations from the Chilbolton radar. However, the Cessna did fly during the period of interest which was during the mid- and late afternoon and there are likely to have been interesting observations from some of the continuously operating ground-based instrumentation.

A fairly isolated shower, reaching 50 dBz and with tops over 6 km, developed near Chilbolton during the late afternoon. It is located directly over Chilbolton at 1715 UTC (Fig. 18.2). A few other cells triggered on the periphery of this cell, so this may be secondary initiation. One of these passed around 5 km south of Reading at 1815 UTC (Fig. 18.3). Some sferics were recorded in eastern England (Fig. 18.4).

The interest in this case stems from the fact that the Met Office models led us to expect no showers in the CSIP area (e.g. Fig. 18.5) and so it would be instructive to determine the reasons for this. The model predicted a strong lid inhibiting significant convection; however, the observations contained evidence of a well-defined convergence line which may have lifted the lid sufficiently for it to have been penetrated locally. Operational NIMROD surface analyses showed the development of the convergence line (Fig. 18.6) and these analyses can be refined using the CSIP AWSs. The ACROBAT radar also showed a well-defined gradient in refractive index close to the storm over Chilbolton (Fig. 18.7). Parts of the Cessna flight pattern may have been in the appropriate area. The MSG satellite and weather-radar-network data showed the development of the convection that affected the CSIP area. The convection was on the southern flank of an upper-level PV anomaly. The MSG images show a corresponding of a WV Dark Zone crossing the area at about the right time (Fig. 18.8). However, the models representation of the upper-level PV anomaly shows that the forecast perhaps took it too far to the north (Fig. 18.9).





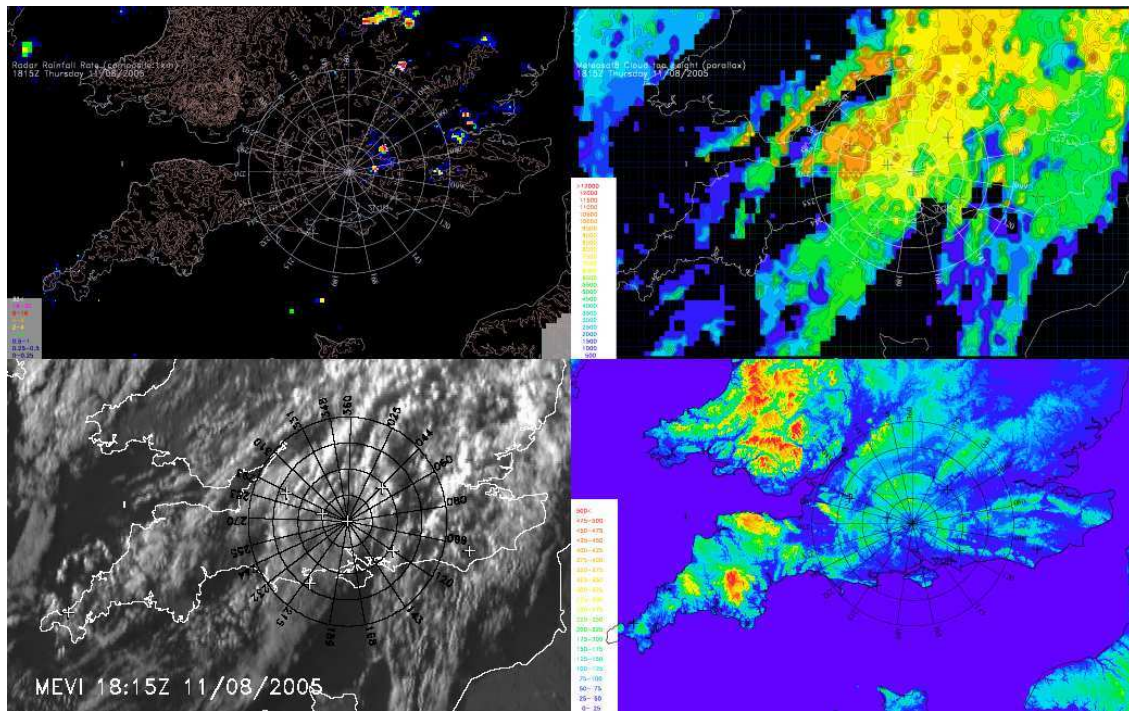


Figure 18.3

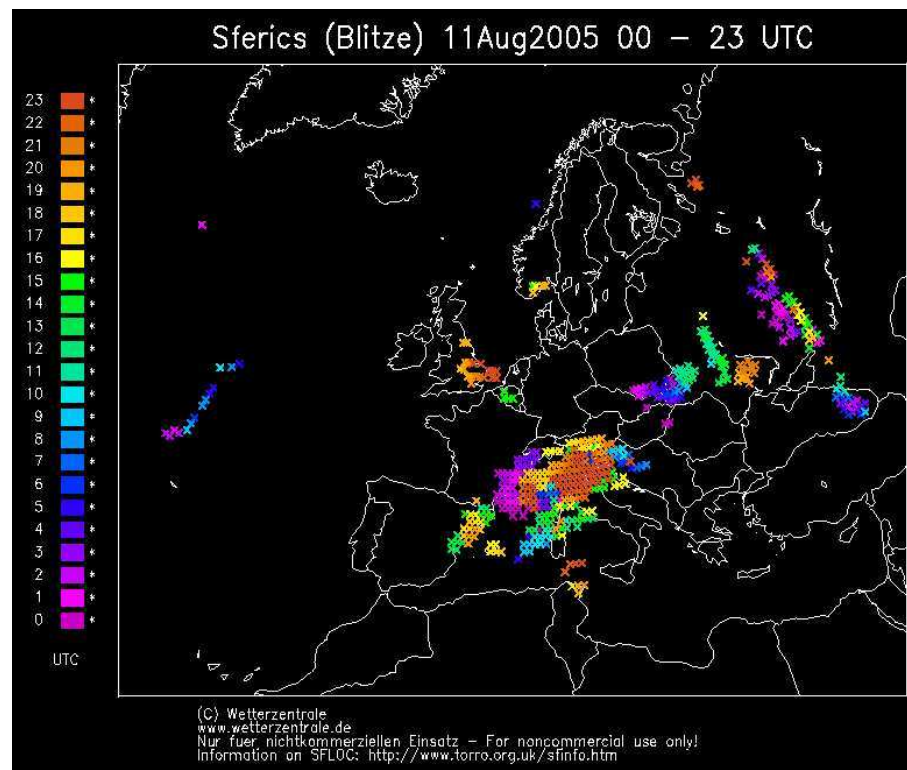
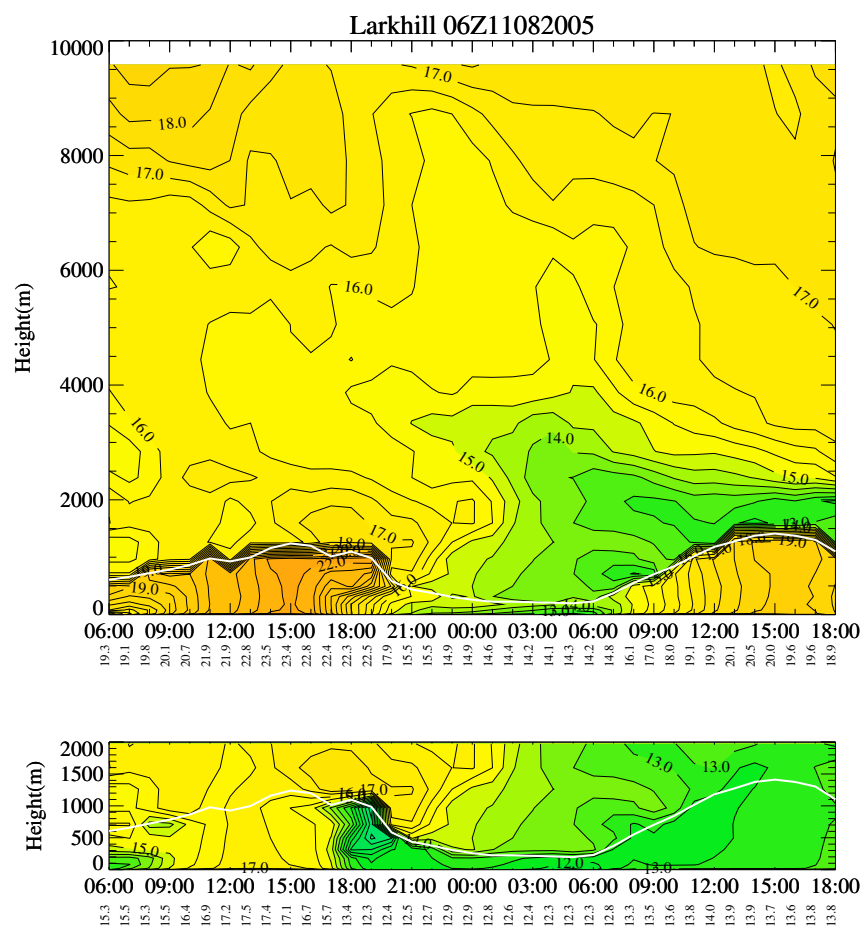
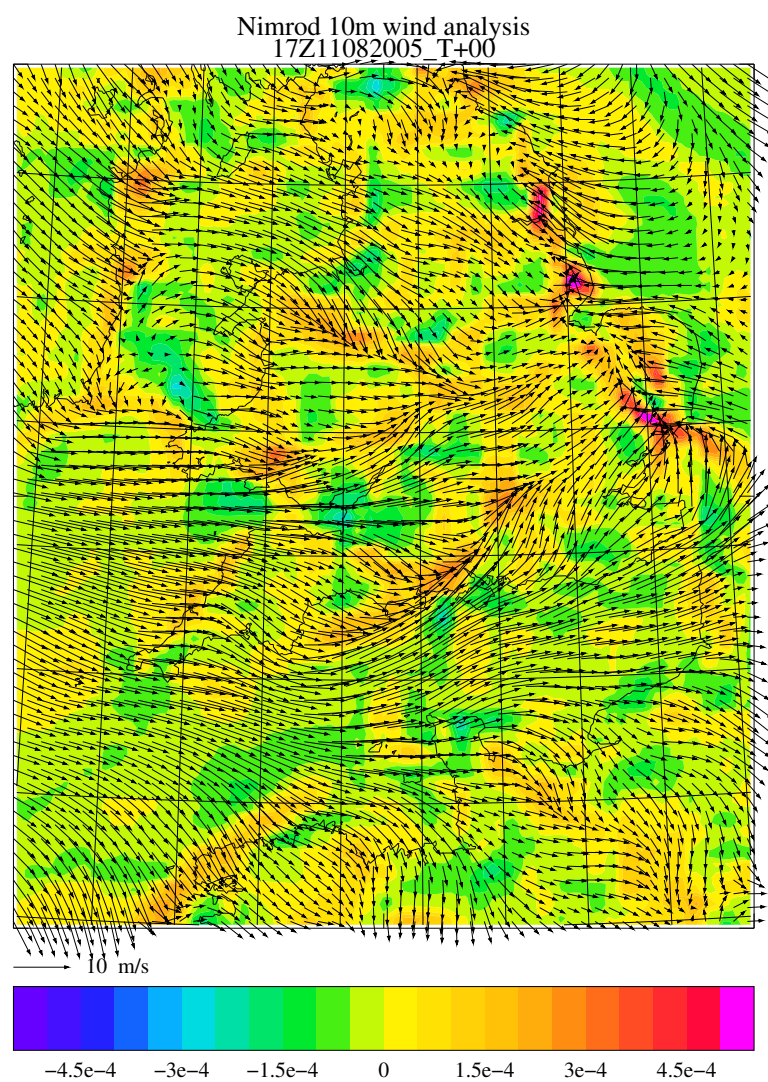


Figure 18.4 Timing and location of lightning strikes on 11 August 2005.

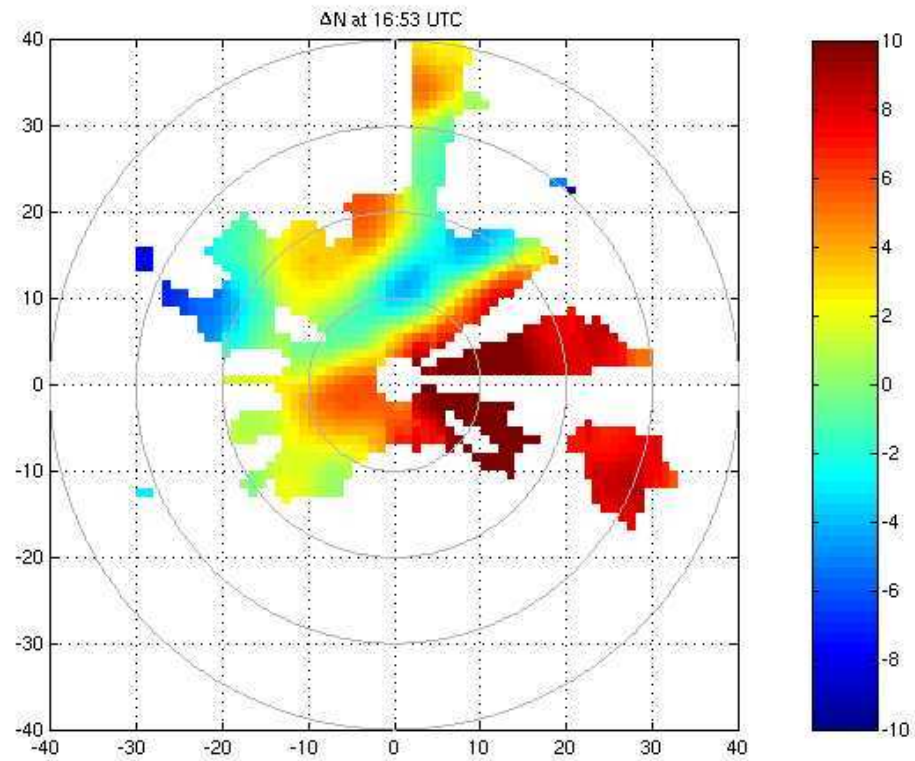


**Figure 18.5** Forecast time-height cross-section of  $\theta_s$  over Larkhill.

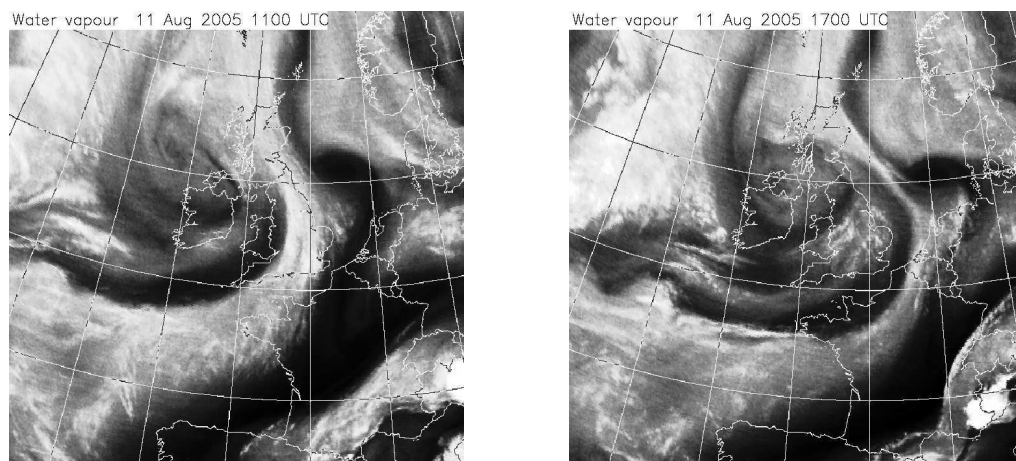




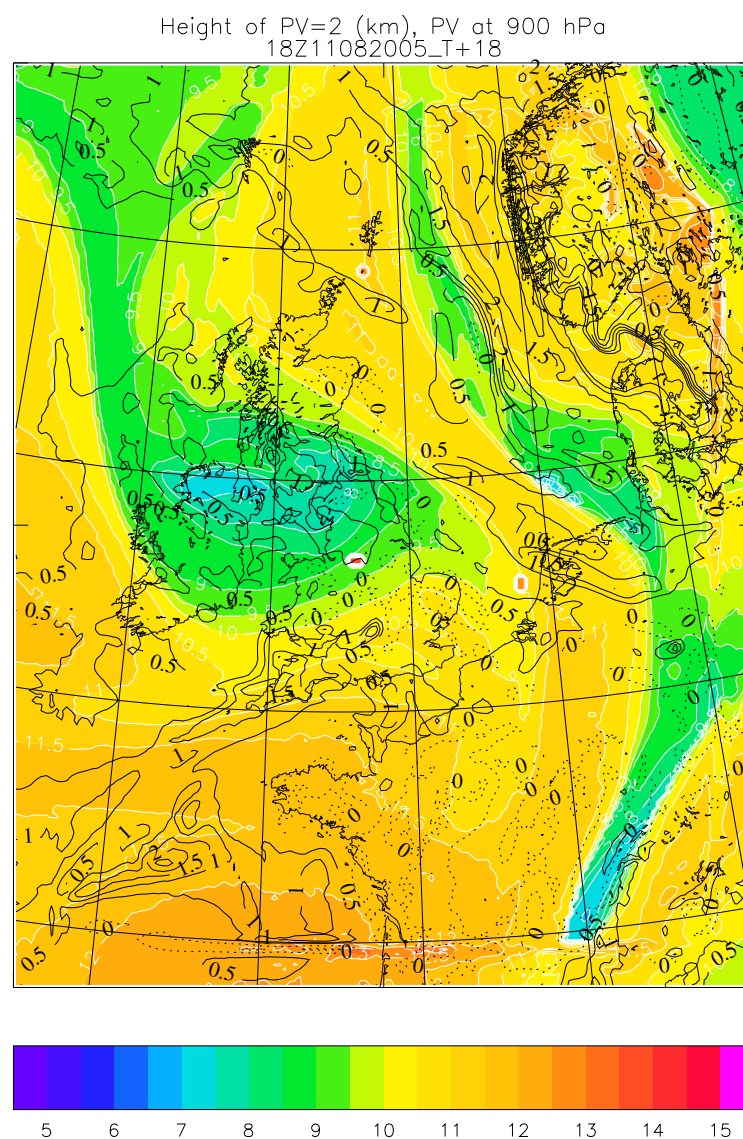
**Figure 18.6** NIMROD 10-metre wind analysis for 1700 UTC on 11 August 2005.



**Figure 18.7** PPI of variation in refractive index. Positive anomalies are associated with moister warmer air.



**Figure 18.8** Satellite water-vapour imagery at 1100 and 1700 UTC on 11 August 2005.



**Figure 18.9** Model forecast of the height of the PV=2 surface at 1800 UTC (T+18) on 11 August 2005.

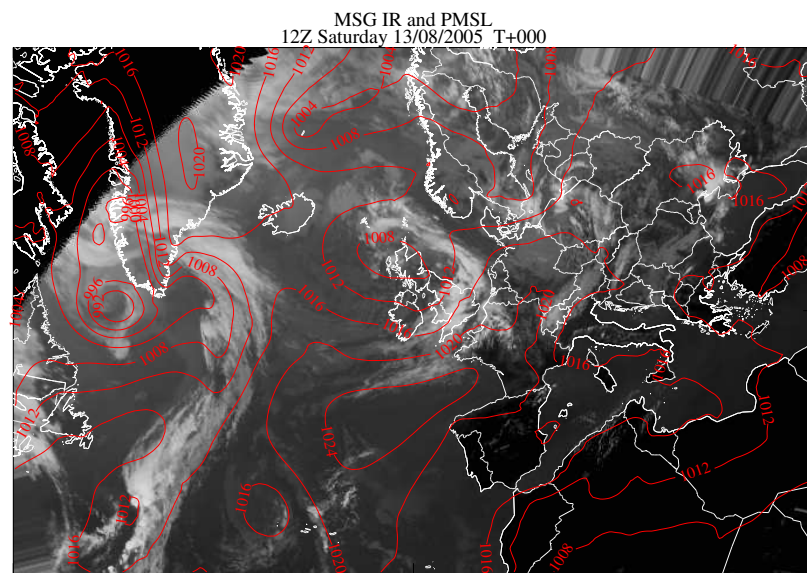
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## CHAPTER 19

### IOP 15: Saturday 13 August 2005

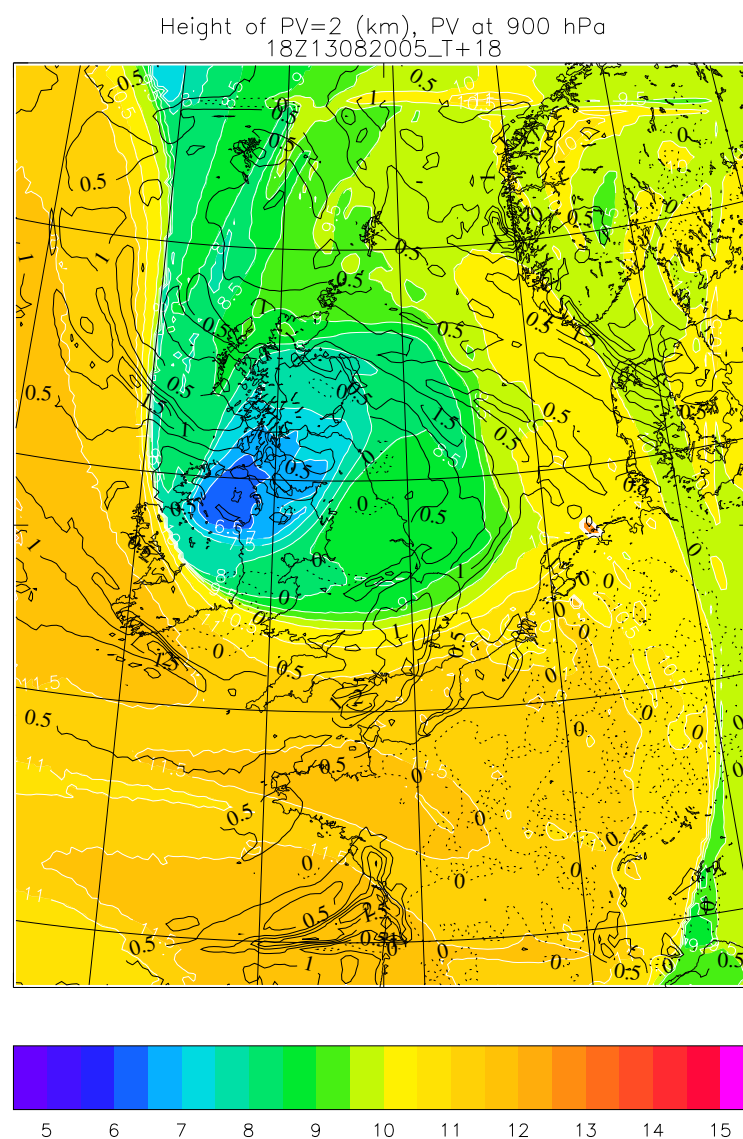
A broad band of frontal cloud with rain and some embedded middle and upper-level convection crossed the CSIP area during the middle of the day (Fig. 19.1) followed by a few narrow lines of showers orientated along the westerly wind direction. The frontal rainband entered the CSIP area at 1030 UTC and had exited it by 1700 UTC. The part of the frontal rainband that crossed the CSIP area was characterised by ill-defined arc-shaped regions of a kind that have been previously documented (using the Chilbolton radar and other data) (Dixon *et al.* (2002)). Serial radiosonde ascents were made during the passage of this rainband and the ensuing showers.

Most of the showers behind the frontal rainband formed upwind and advected into the CSIP area. They were capped by dry air on the southern flank of an upper-level cold-pool/vortex with a well marked PV signature (Fig. 19.2) and WV Dark Zone (Fig. 19.3). Although small in horizontal and vertical extent, these showers were surprisingly sharp (see the red echoes in the line crossing Chilbolton at 1730 in Fig. 19.4). Farther north the cold-pool/vortex triggered some much heavier showers and also the development of a well-defined Cloud Head topped by transverse cloud bands of a kind that have also been documented recently (Browning *et al.* (2002)).

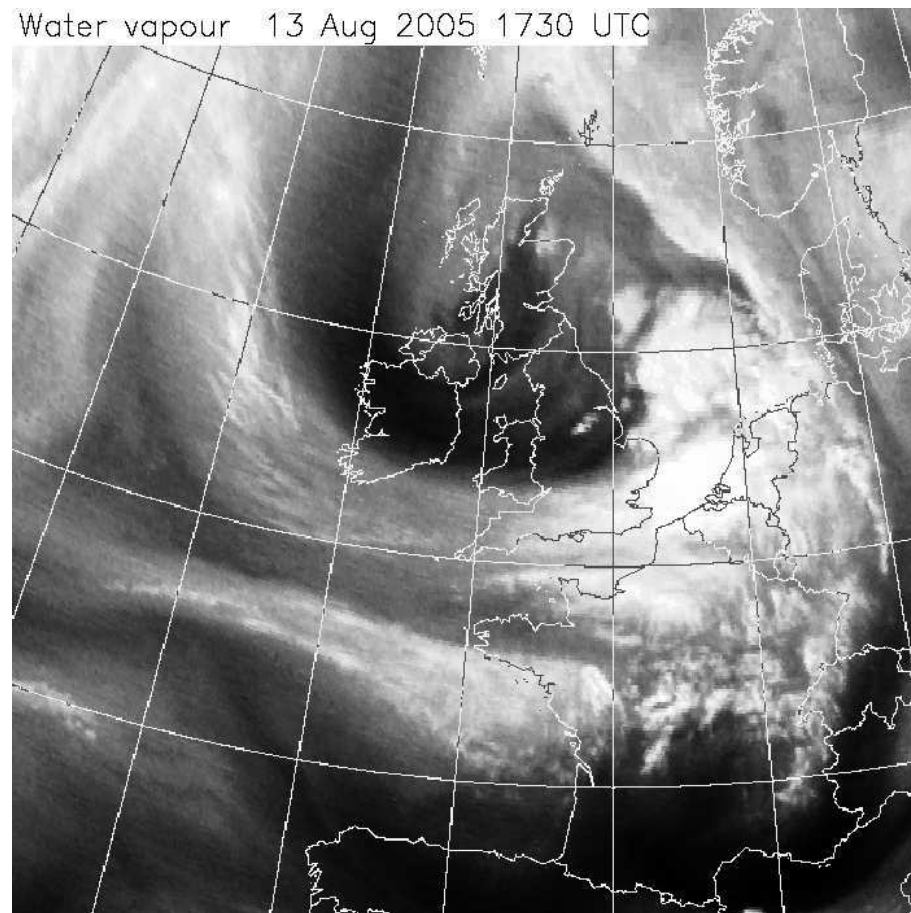


**Figure 19.1** MSLP analysis and satellite infra-red cloud at 1200 UTC.





**Figure 19.2** Model forecast of the height of the PV=2 surface at 1800 UTC (T+18) on 13 August 2005.



**Figure 19.3** Water-vapour imagery for 1730 on 13 August 2005.

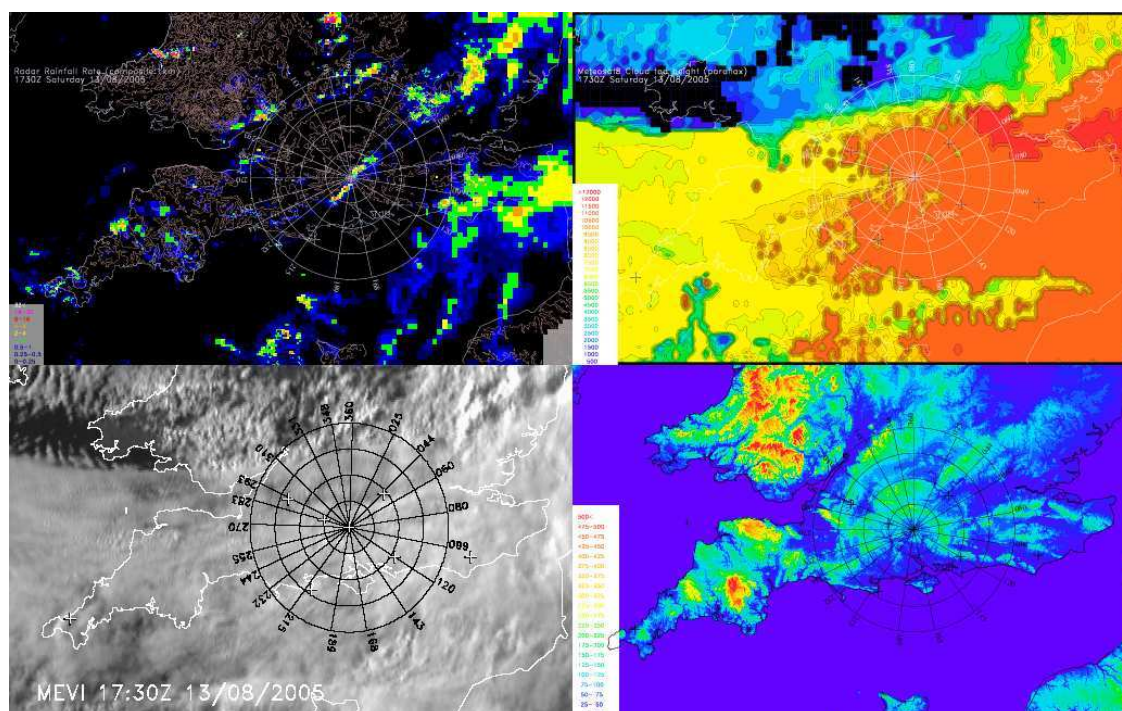
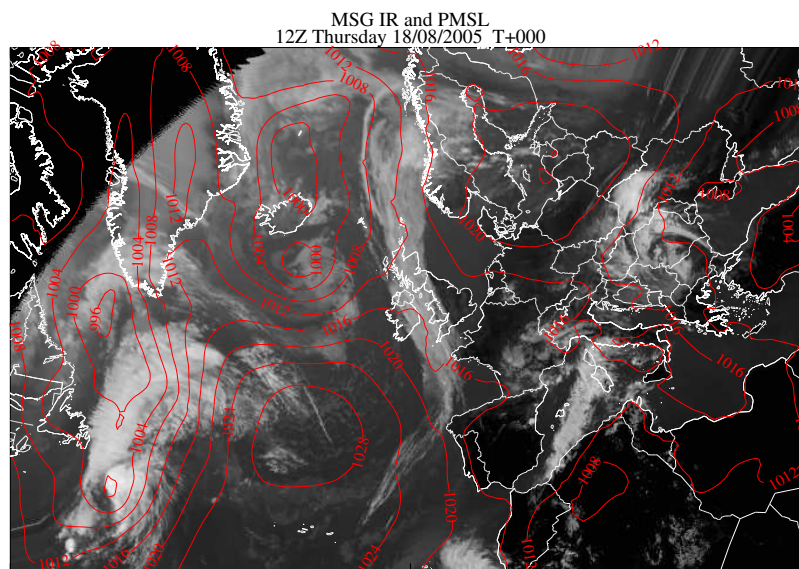


Figure 19.4

## CHAPTER 20

### IOP 16: Thursday 18 August 2005

The CSIP area was covered by a weak, broadly southerly flow ahead of a cold-frontal cloud belt advancing slowly from the west (Fig. 20.1). Much of the region experienced a warm mainly sunny day with only shallow convection. The first cumulus were tied very closely to topography in south-east England and the south Midlands (see the high-resolution visible MSG image for 1100 UTC in Fig. 20.2). The cumulus soon became more widespread but their development was for a long time restricted to below 3 km by a strong lid (Fig. 20.3) and possibly by the reduction in insolation as the frontal cirrus spread in from the west.



**Figure 20.1** MSLP analysis and satellite infra-red cloud at 1200 UTC.

By late afternoon, however, the lid had weakened to the west of Chilbolton and isolated showers developed. The early phase (1516-1519 UTC) of the clouds that developed into these showers is



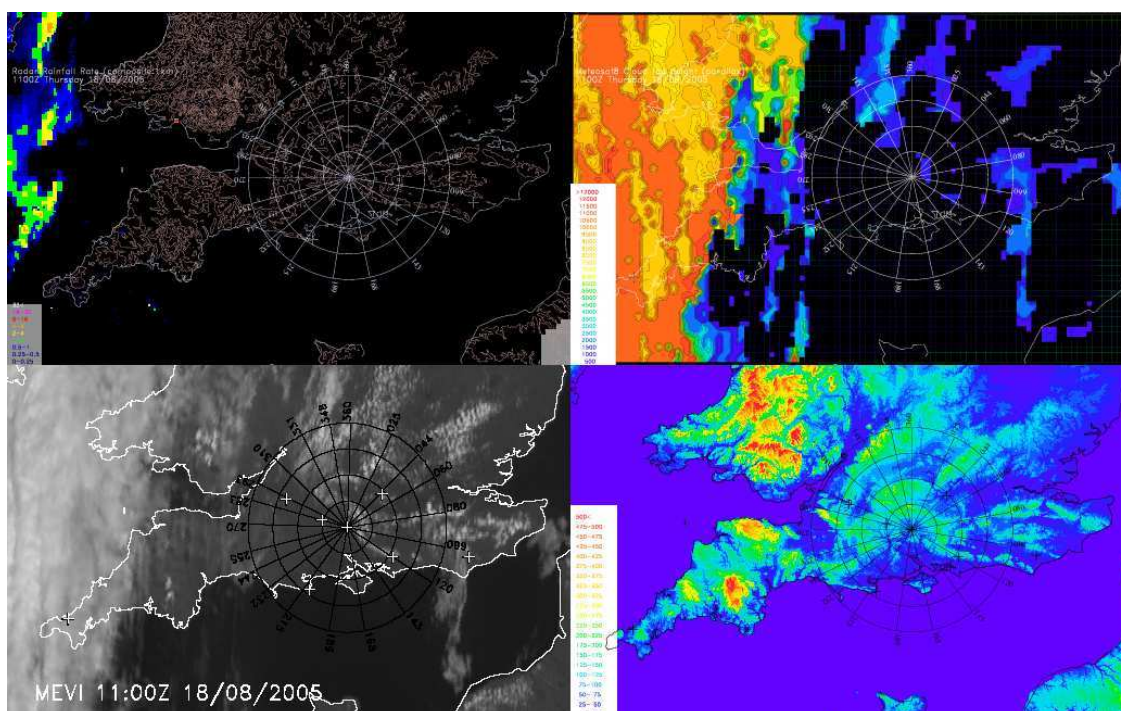


Figure 20.2

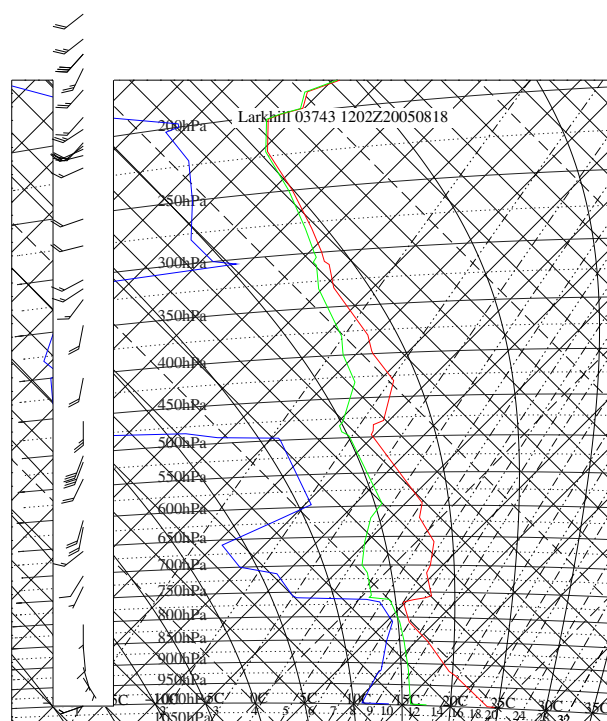


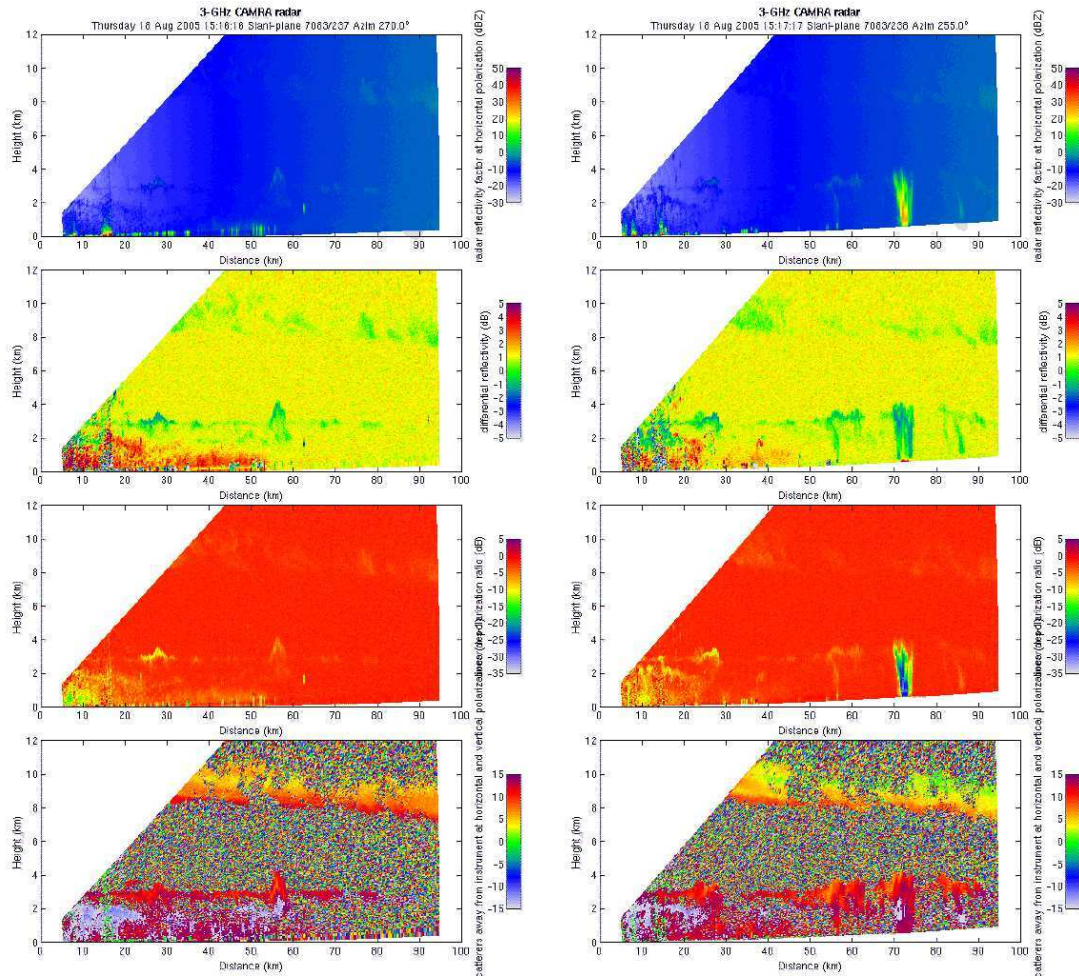
Figure 20.3 Tephigram for Larkhill at 1200 UTC on 18 August 2005.



shown in Figs. 20.4 and 20.5, which depict a set of CAMRa RHIs along 270, 255 and 244 degrees and a PPI sector between 255 and 244 degrees. Note the mantle echoes with top to 4 km due to convection penetrating the lid at 3 km. (Note that one of the mantles, in the 244 degree RHI, has some red echo in its interior in the Zdr plot; might this be due to insects lofted by the updraught?) The cirrus canopy can be seen above 8 km. There is evidence of general uplift of the lid in the 255 degree RHI corresponding to a mesoscale Area of Deep Convection (ADC). This shows up in the visible imagery in Fig. 20.6 as a mesoscale area of slightly brighter clouds. Forty minutes later (Fig. 20.7) the tops of the convective clouds are still at 4 km; however, by 1630 UTC, an area of significant showers can be seen on the radar network (Fig. 20.8) at the eastern edge of the mesoscale area of brighter cumulus clouds (see the MSG visible imagery in Fig. 20.8). The CAMRa PPI for 1622 UTC in Fig. 20.9 shows an intriguing boundary around these showers in the Zdr signal.

The RHI in Fig. 20.10 shows that by 1633 UTC the shower tops were up to almost 6 km. These showers continued to intensify while still remaining isolated, as shown by the radar display for 1700 UTC in Fig. 20.11. By 1900 UTC a few more showers had broken out to the north (Fig. 20.12). The main band of cold-frontal rain at this time was still far to the west but the associated frontal cirrus canopy extending ahead of it had become more intense in the region of the showers. Nevertheless, the showers went on to intensify, leading to an intense line of precipitation over the Midlands by 2200 UTC (Fig. 20.13).

The nature and location of these showers was predicted well by the 4km Met Office model but the onset of the showers was significantly later than predicted. This case may provide a good opportunity to compare the actual and modelled evolution of an isolated patch of showers from a developing ADC. However, although the ADC was close to the radiosonde sites at Bath, Larkhill and Durlston head, it did unfortunately remain between rather than over these sites for much of its early development.



**Figure 20.4** CAMRa RHIs at 1516 and 1517 UTC along azimuths 270 and 255 degrees.

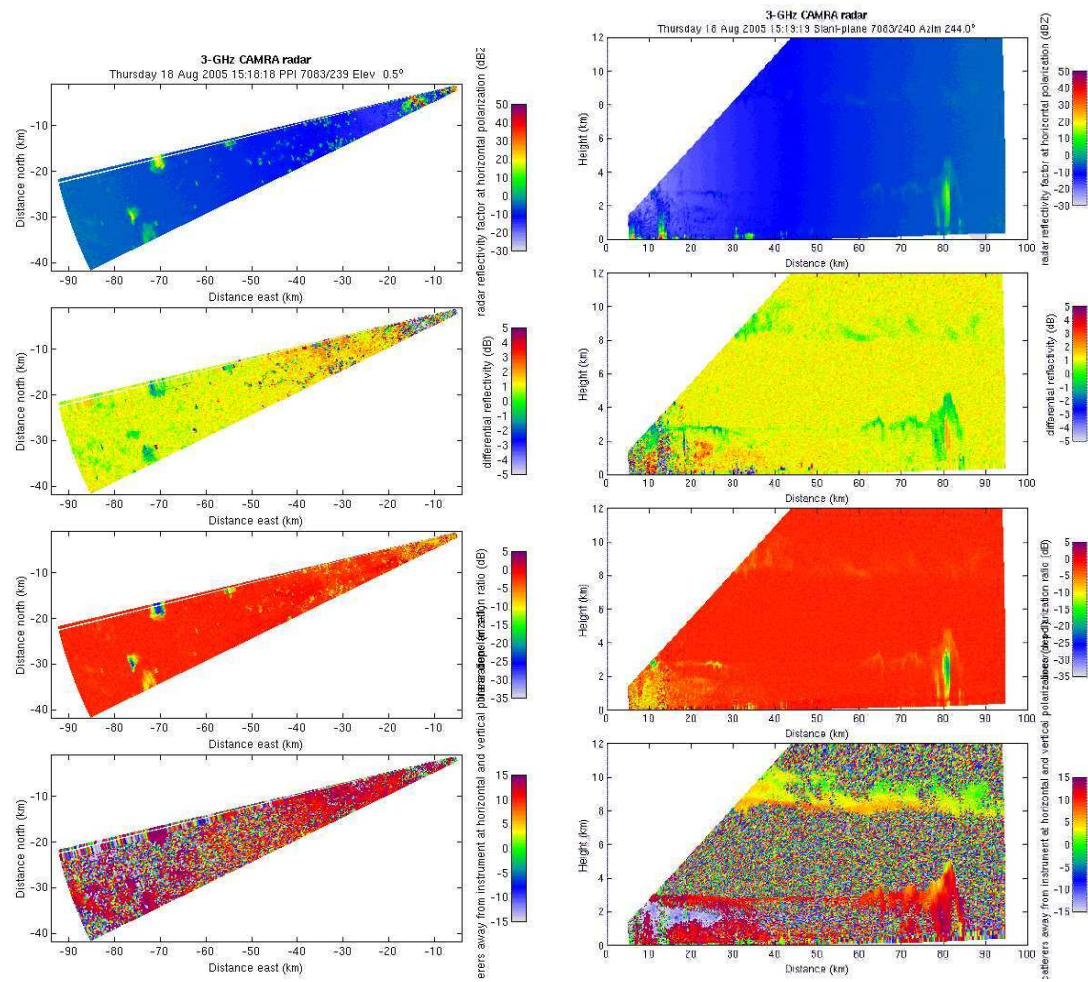


Figure 20.5 CAMRa PPI at 1518 and RHI at 1519 UTC along azimuth 244 degrees.

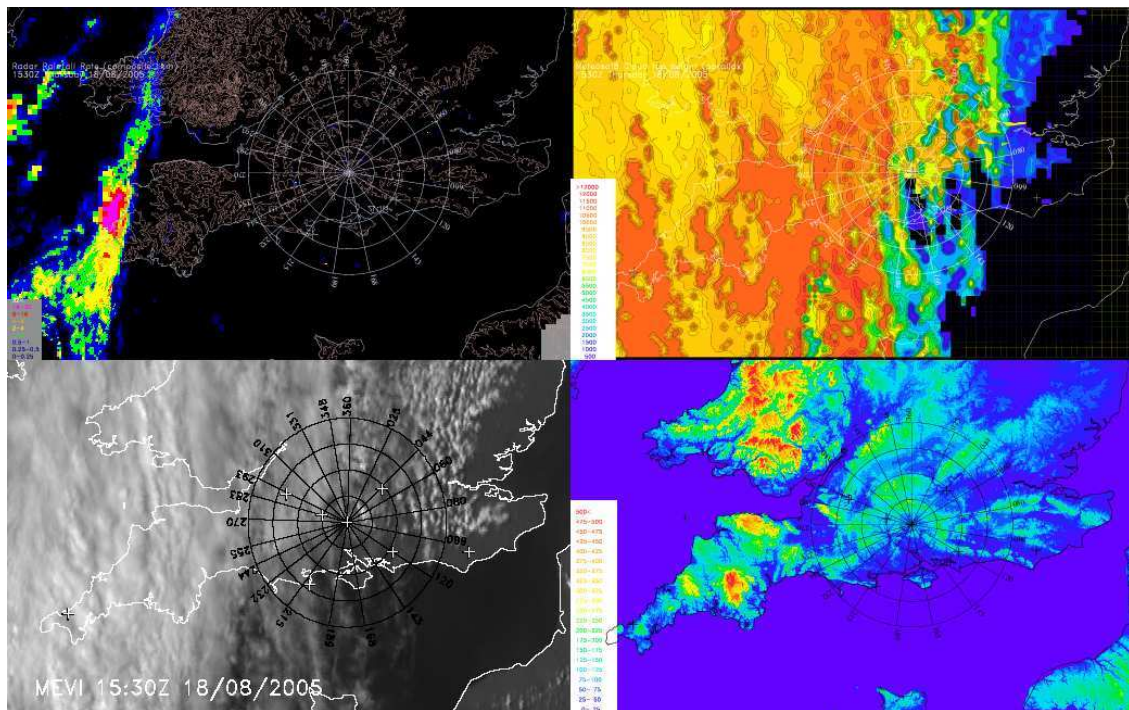
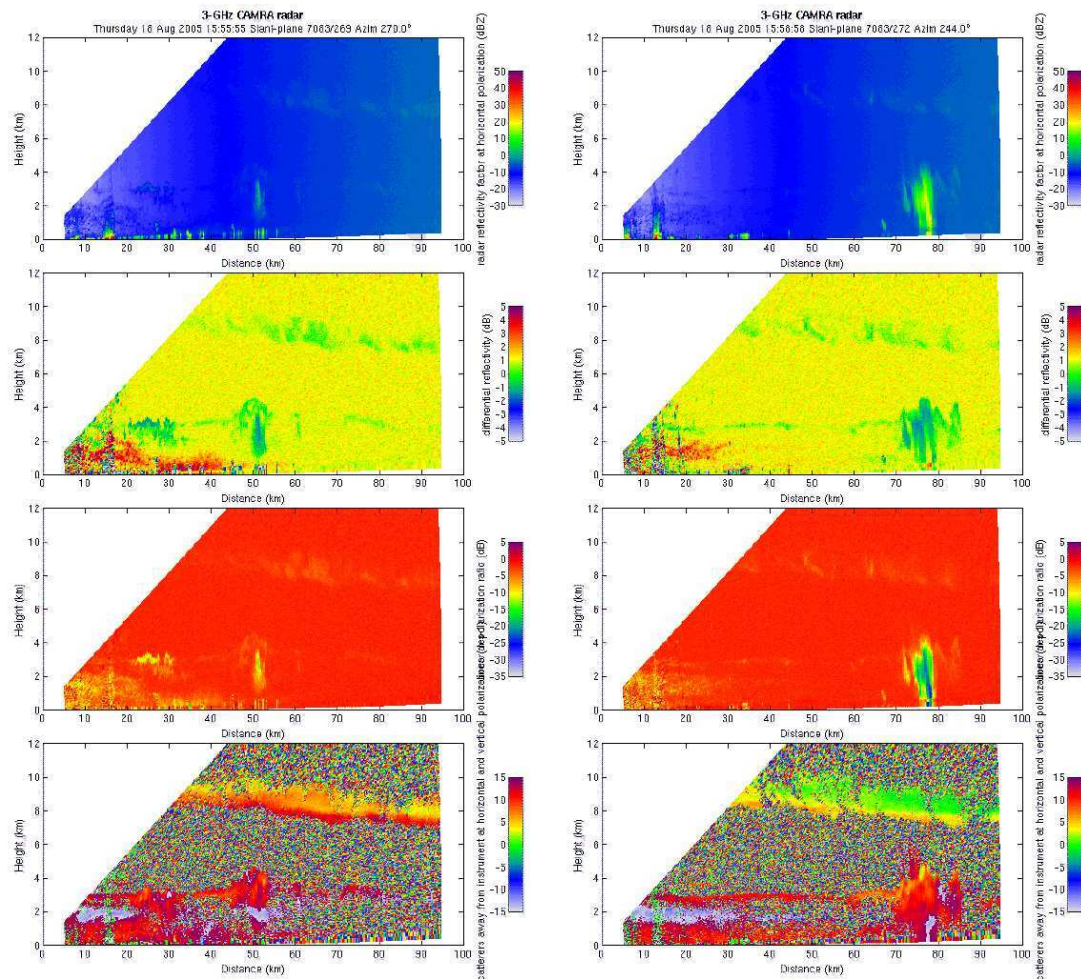


Figure 20.6





**Figure 20.7** CAMRa RHIs at 1555 and 1558 UTC along azimuths 270 and 244 degrees.



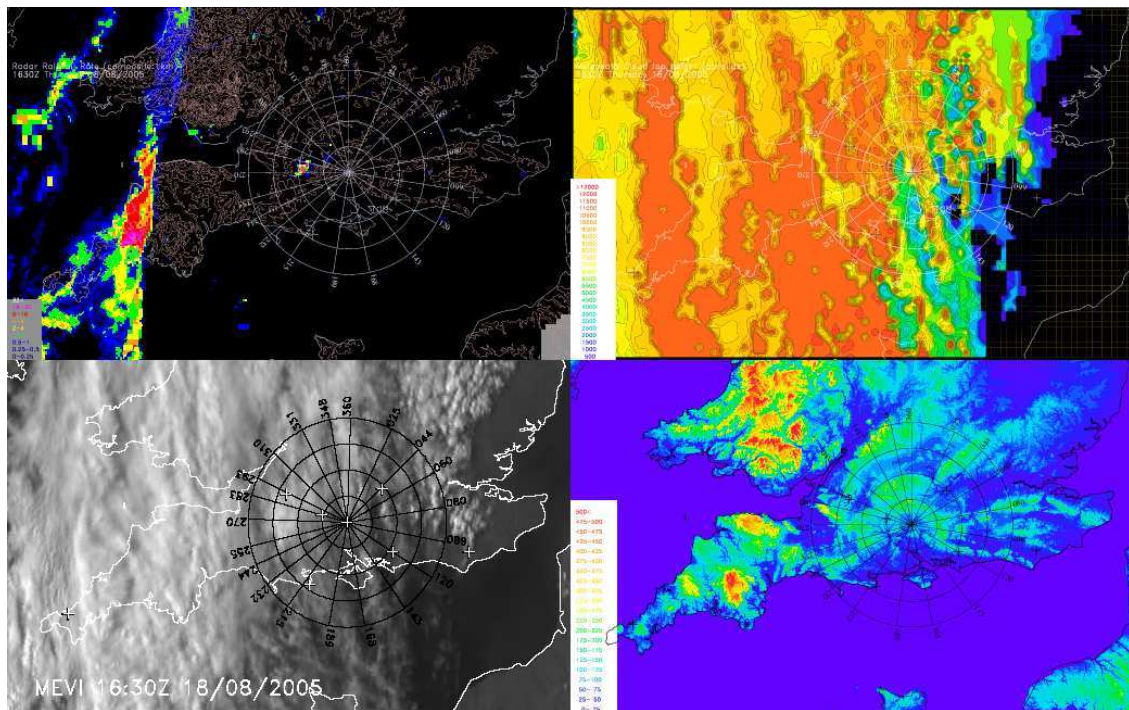
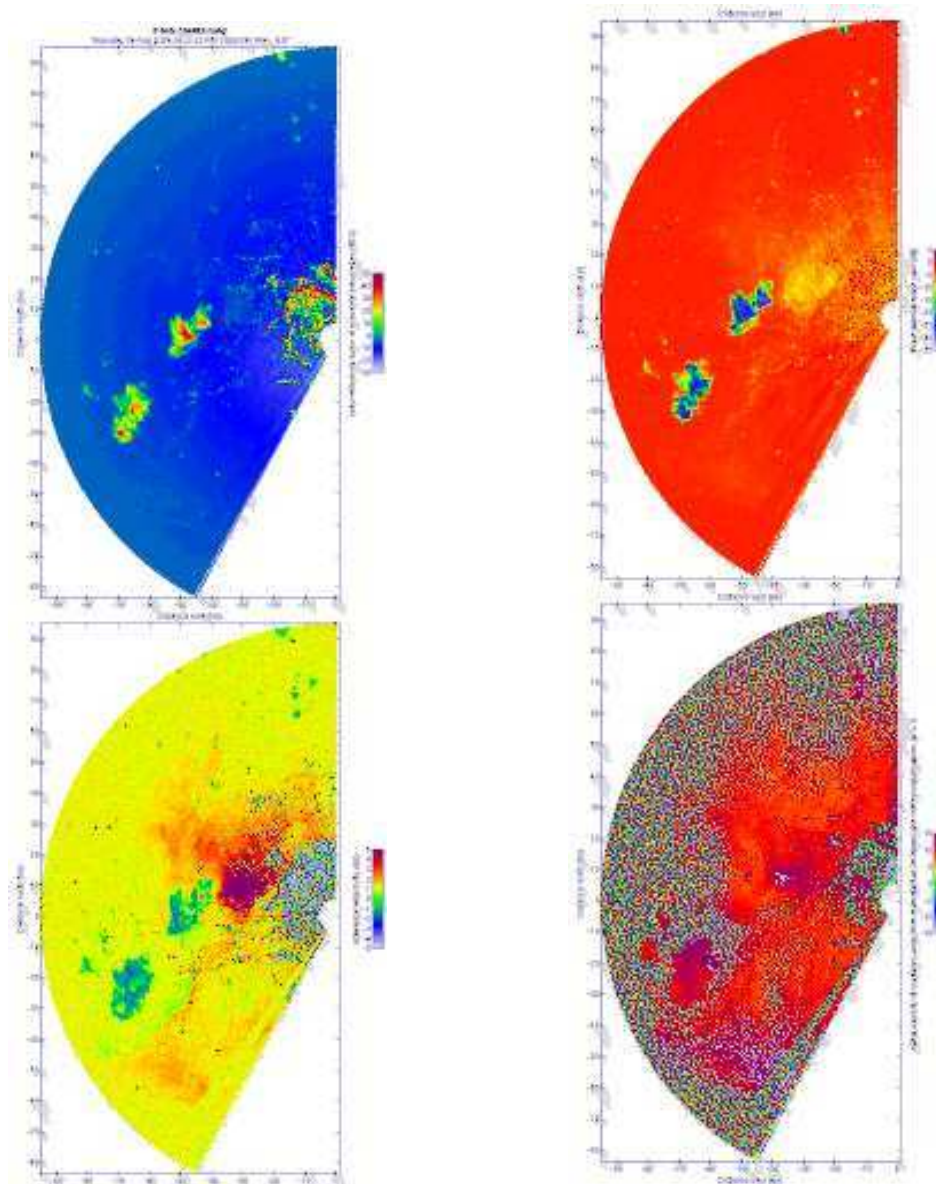
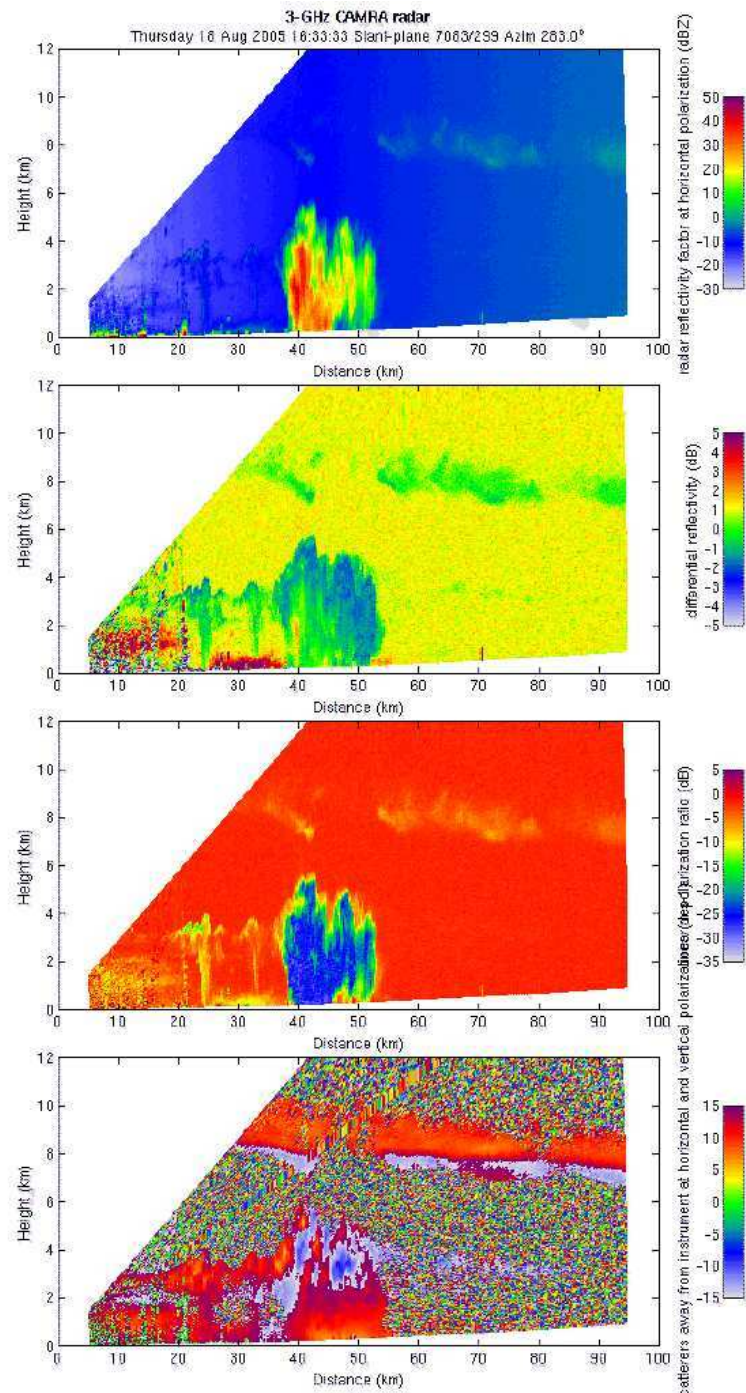


Figure 20.8



**Figure 20.9** CAMRa PPI at 1622 UTC. The four panels show: reflectivity (top left), linear depolarisation ratio (top right), differential reflectivity (bottom left) and Doppler velocity (bottom right).



**Figure 20.10** CAMRa RHI at 1633 UTC along azimuth 283 degrees.



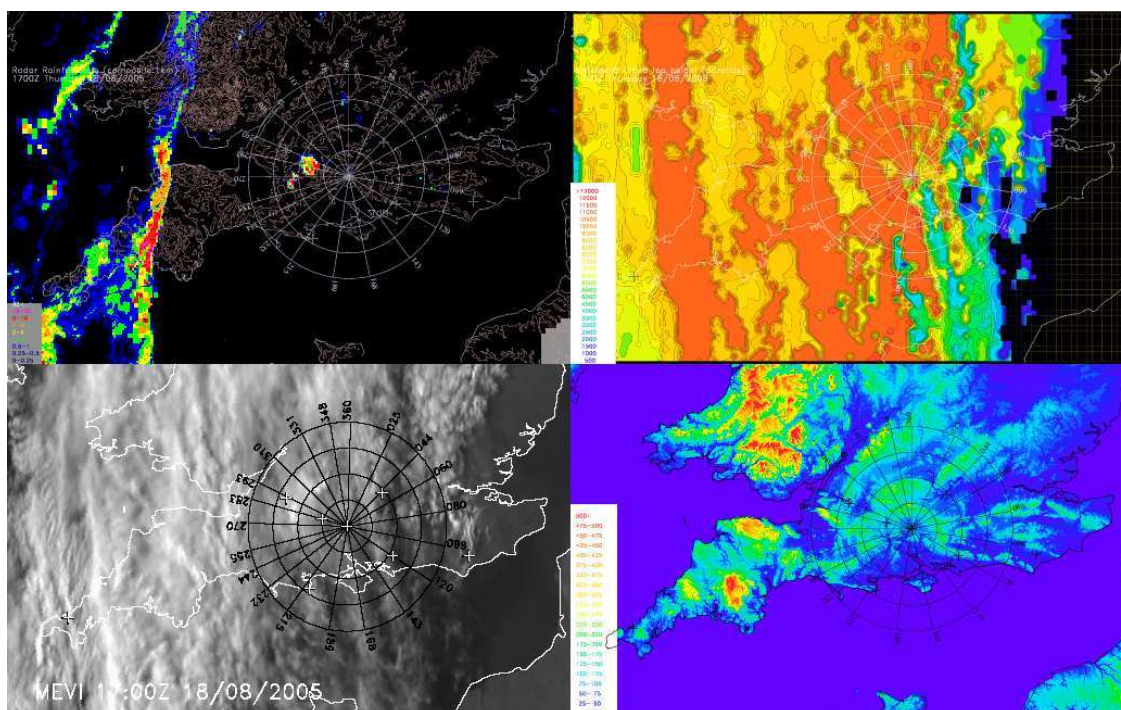


Figure 20.11

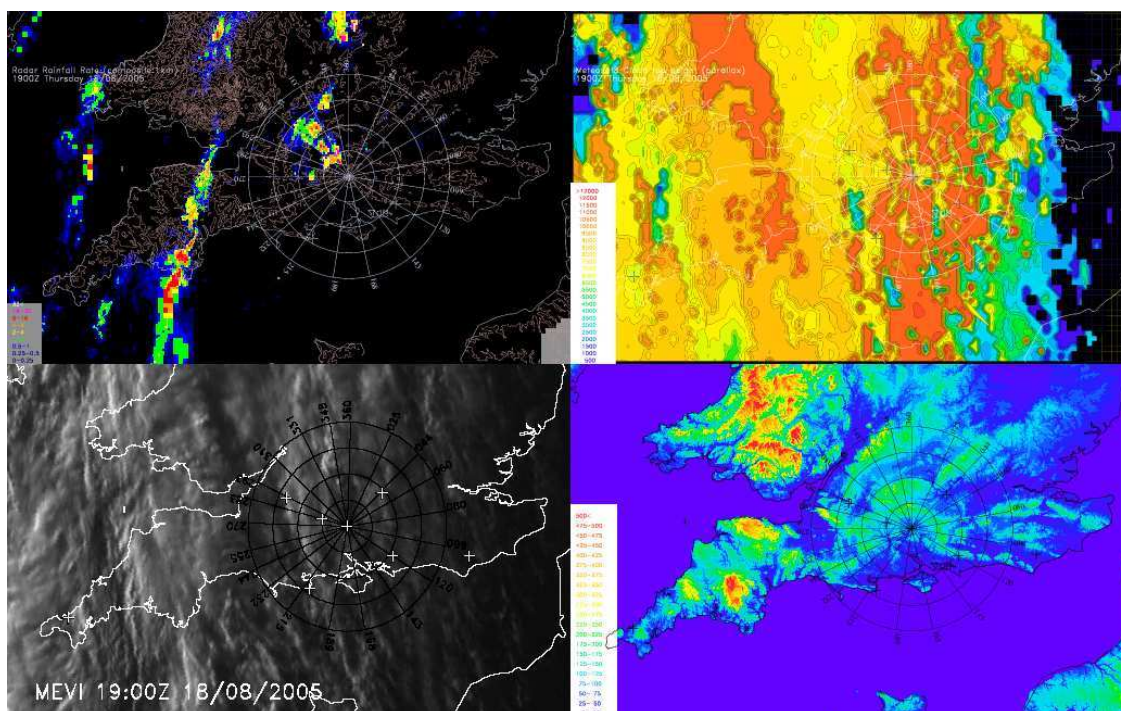


Figure 20.12

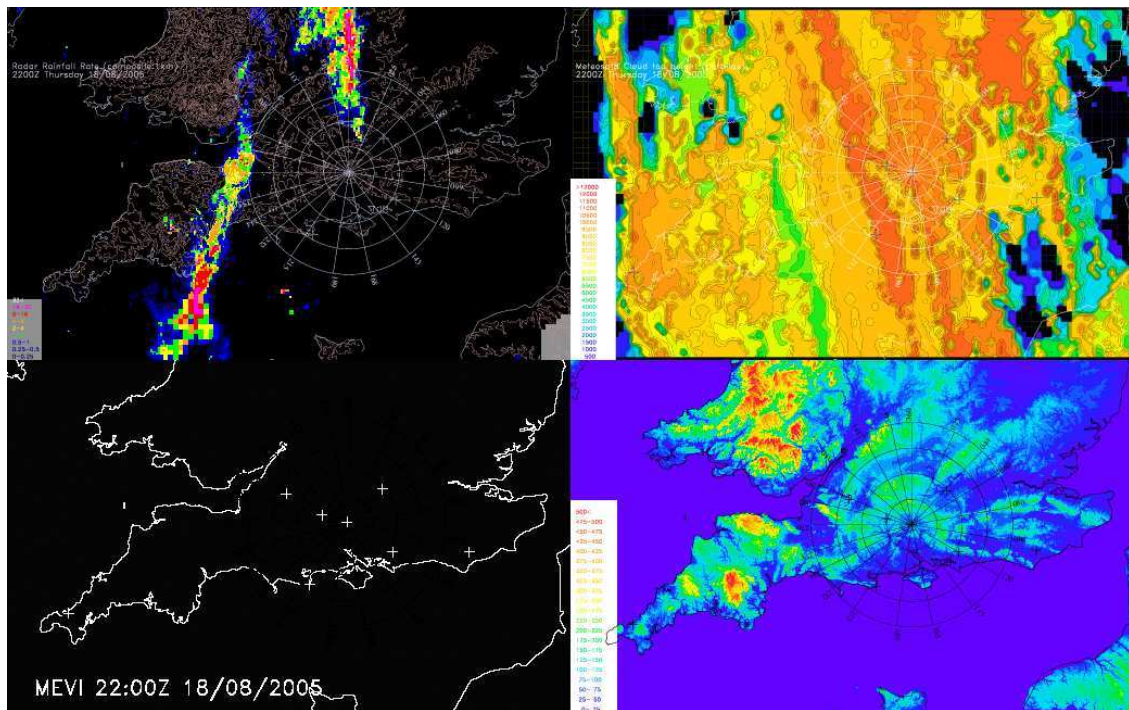


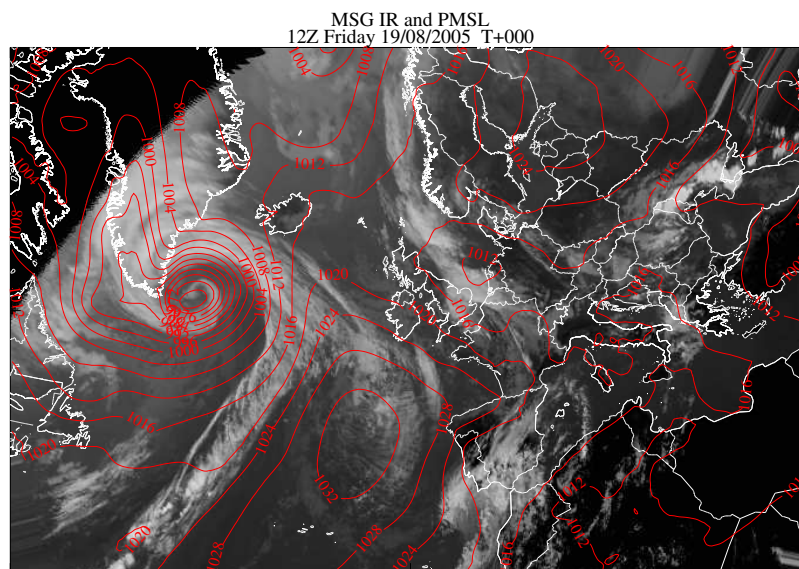
Figure 20.13



## CHAPTER 21

### IOP 17: Friday 19 August 2005

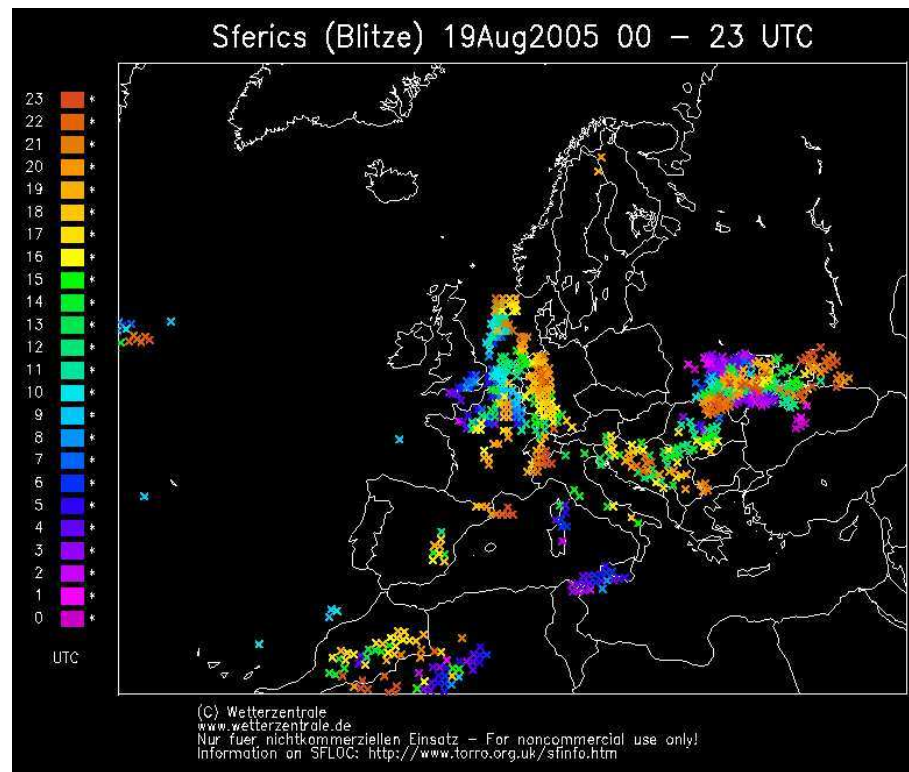
#### Cloud-head circulations observed prior to the CSIP IOP



**Figure 21.1** MSLP analysis and satellite infra-red cloud at 1200 UTC.

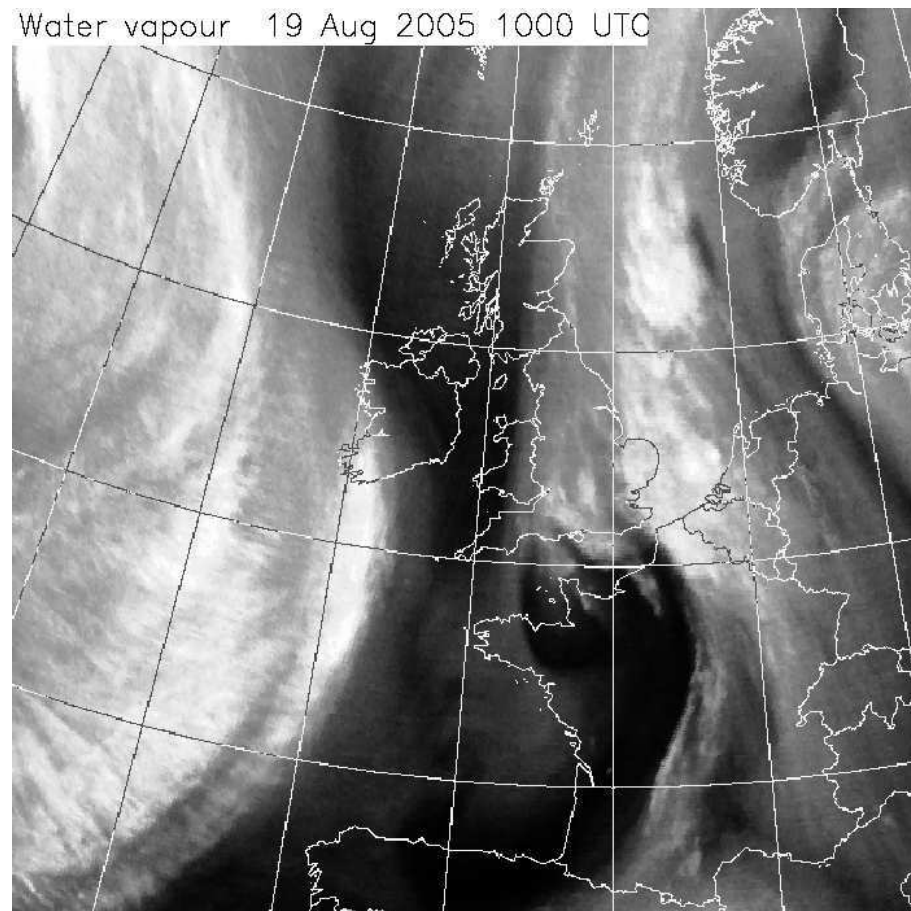
Figure 21.1 shows the synoptic situation at 1200 UTC. The day began with prolonged rain over the eastern half of the CSIP area. This was due to developing Cloud Heads behind a waving cold front. Embedded thunderstorms led to flash floods near the South Coast early in the morning (Fig. 21.2). The multiple cloud heads were associated with an upper-level vortex characterised by a pronounced dark zone in the water-vapour imagery (Fig. 21.3).

The development of the Cloud Heads caused the clearance of the cloud and the start of the CSIP IOP proper, to be delayed until the afternoon. Nevertheless some interesting and unique radar and radiosonde data were obtained before then, which may shed light on the possible role of CSI



**Figure 21.2** Timing and location of lightning strikes on 19 August 2005.

in creating multiply-stacked transverse circulations within the Cloud Heads. These circulations were well observed by Doppler radar (see, for example Fig. 21.4) and by the 6 degree PPI scans obtained for possible use in the data-assimilation research (see, for example the PPI in Fig. 21.5). The pattern of the Cloud Heads is shown in the MSG cloud-top-height plots for 1000 and 1230 UTC (see Figs. 21.6 and 21.7); their leafed shapes is shown most clearly in Fig. ??.



**Figure 21.3** Water vapour imagery for 1000 UTC on 19 August 2005.

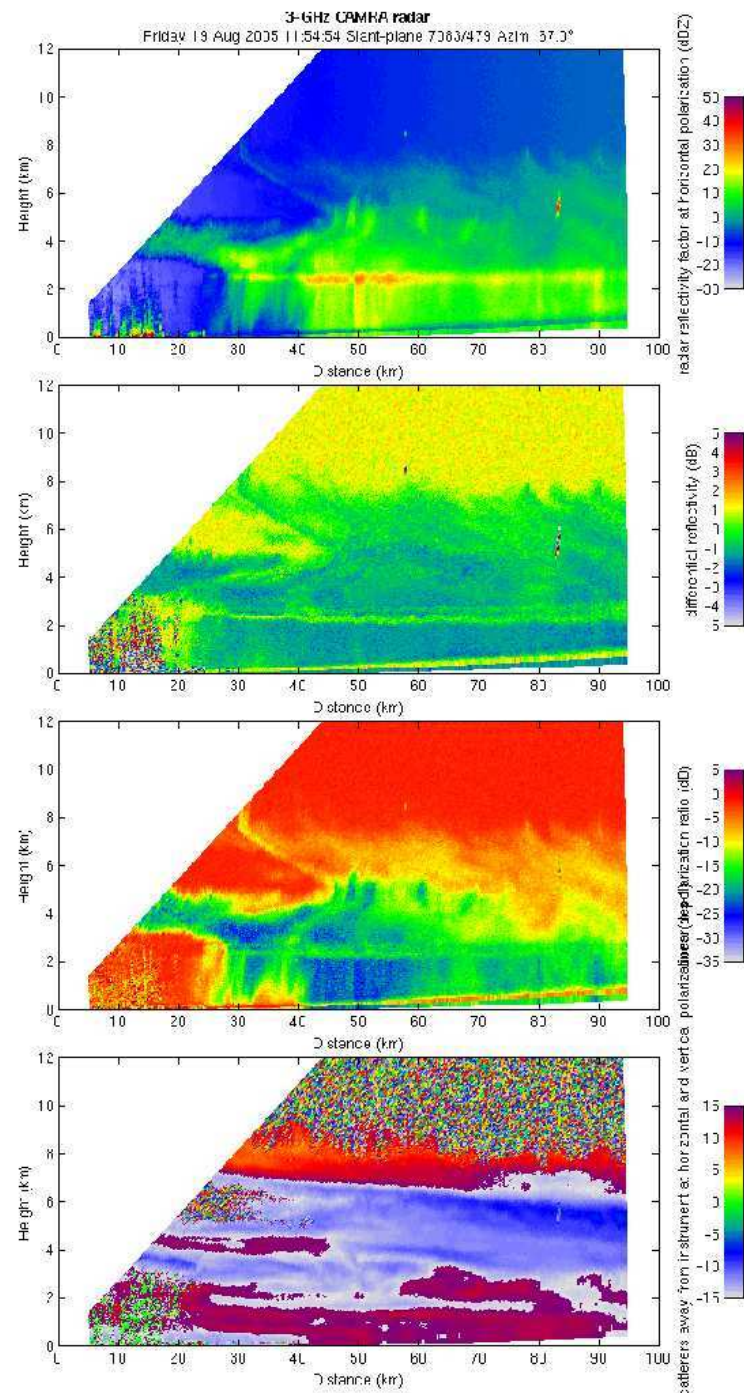


Figure 21.4 CAMRa RHI at 1155 UTC along azimuth 67 degrees.



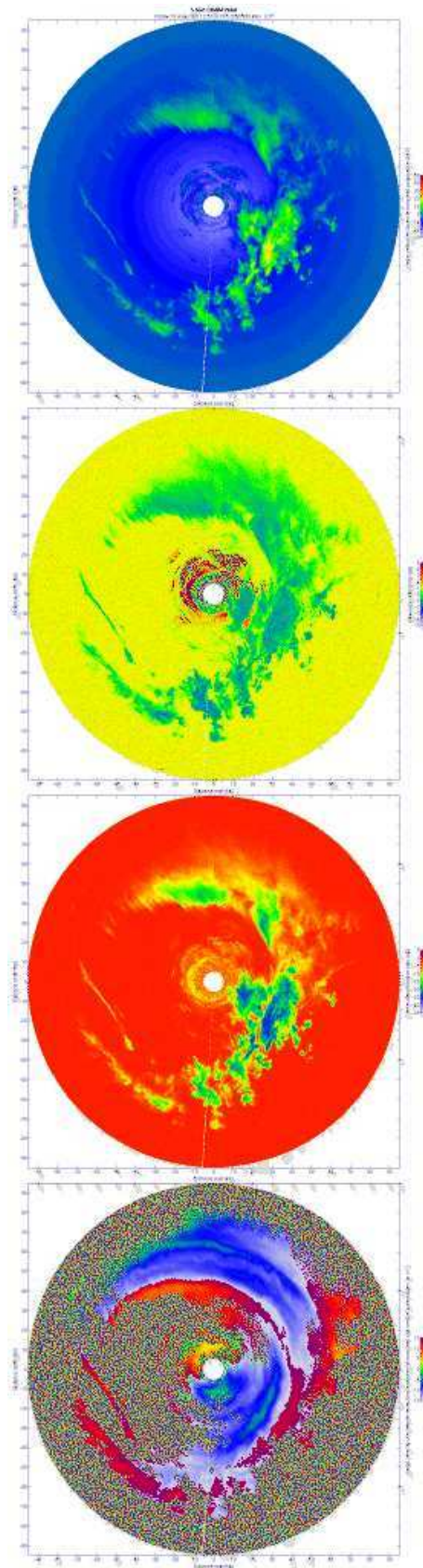


Figure 21.5 CAMRa PPI at 1233 UTC at 6 degree elevation.

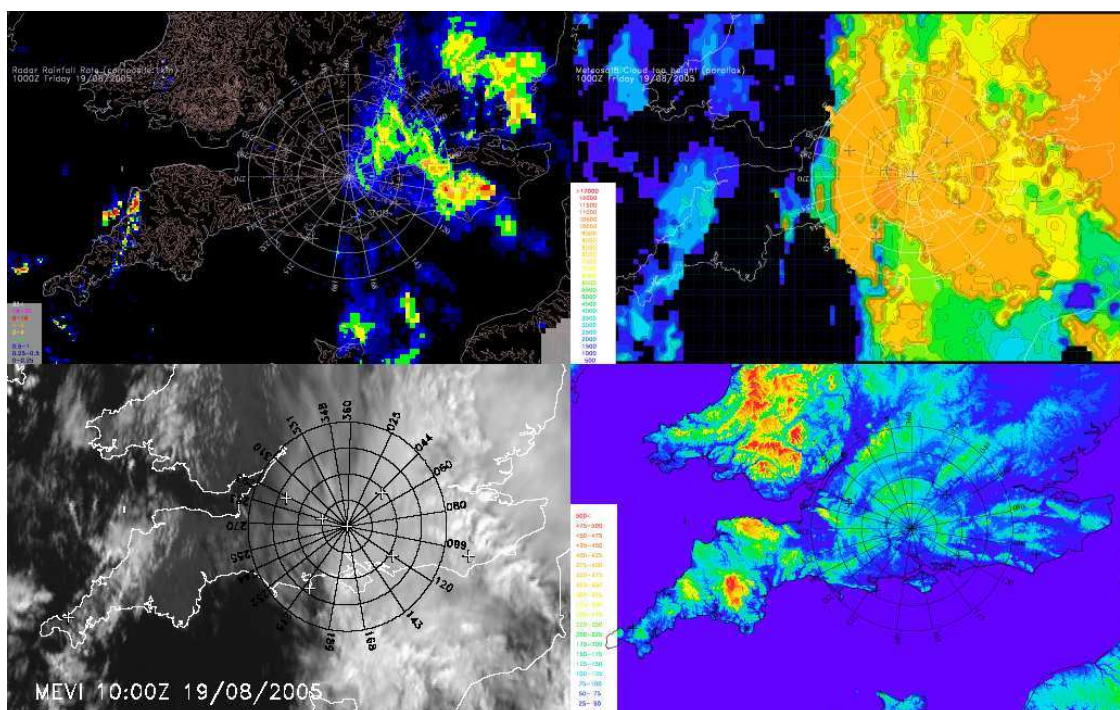


Figure 21.6

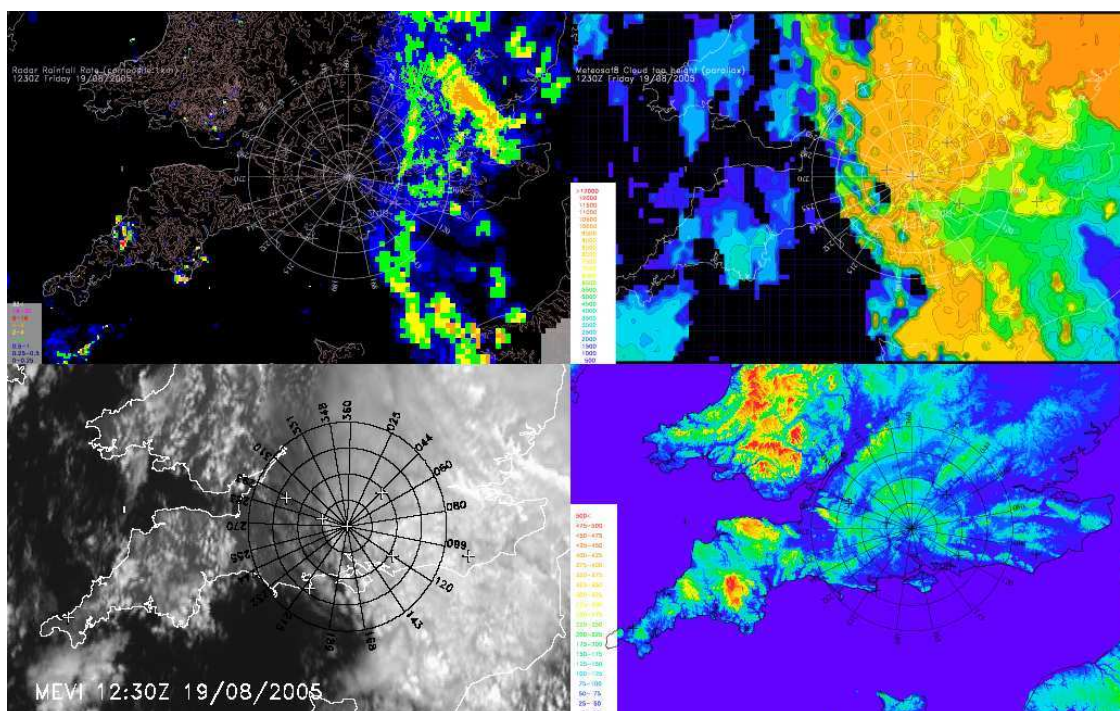


Figure 21.7

### **The main CSIP IOP**

Scattered showers broke out in Wales and the north-west Midlands in the north-westerly flow behind the Cloud Head(s) during the early afternoon. They were followed by the formation of a line of showers just west of Bath from 1345 UTC. The line reached a peak intensity, with tops to 6km, at 1500 UTC by which time it had extended downwind to a point midway between Larkhill and Swanage (Fig. 21.8). A weakening trend was evident by 1600 UTC as the showers came beneath the western edge of the cirrus canopy associated with the Cloud Heads. However, new showers were still being initiated close to Larkhill and Bath (Fig. 21.9). The overall weakening continued and by 1700 UTC the area of weakening showers extended from east of Bath to the Isle of Wight (Fig. 21.10). There were no showers in the eastern part of the CSIP area which was closer to the main part of the Cloud Heads.

In summary, the sets of serial radiosondes are likely to have documented well the evolution of CAPE and CIN that led to the initiation and decay of this small area of moderately intense showers. The T+18 forecast from the 0000 UTC run of the mesoscale model (Fig. 21.11) shows that this run identified the area of showers fairly well.



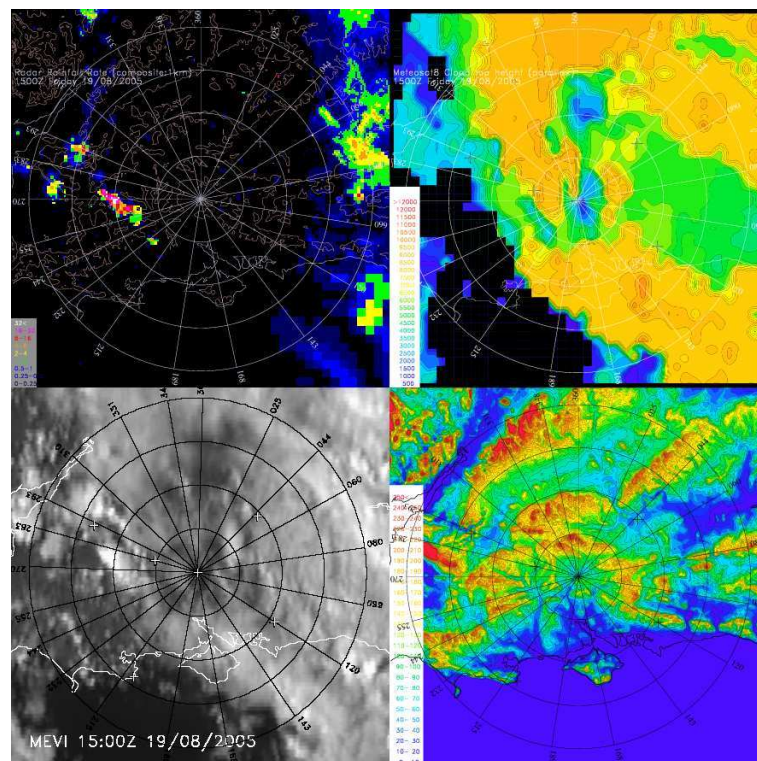


Figure 21.8

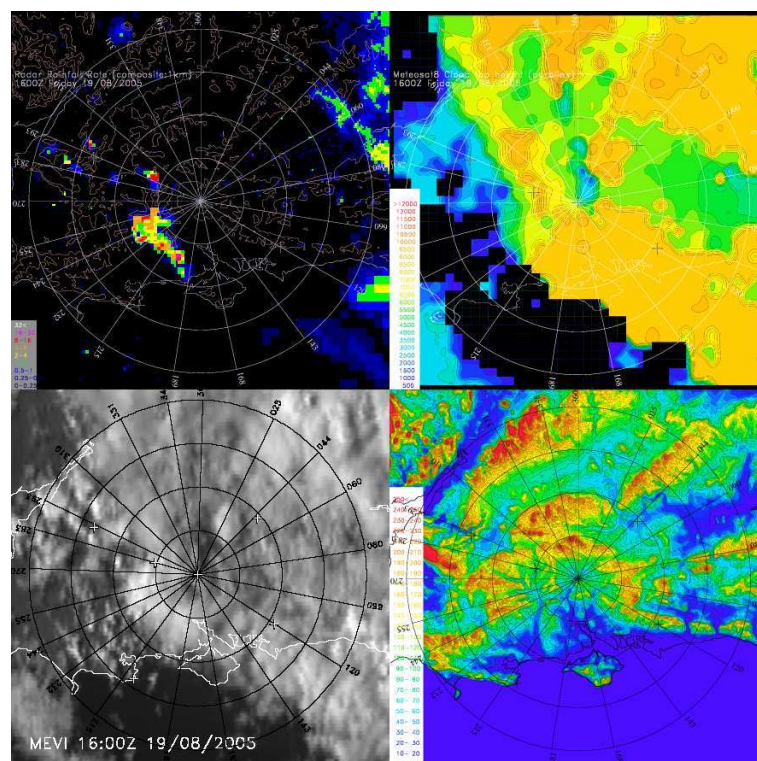


Figure 21.9



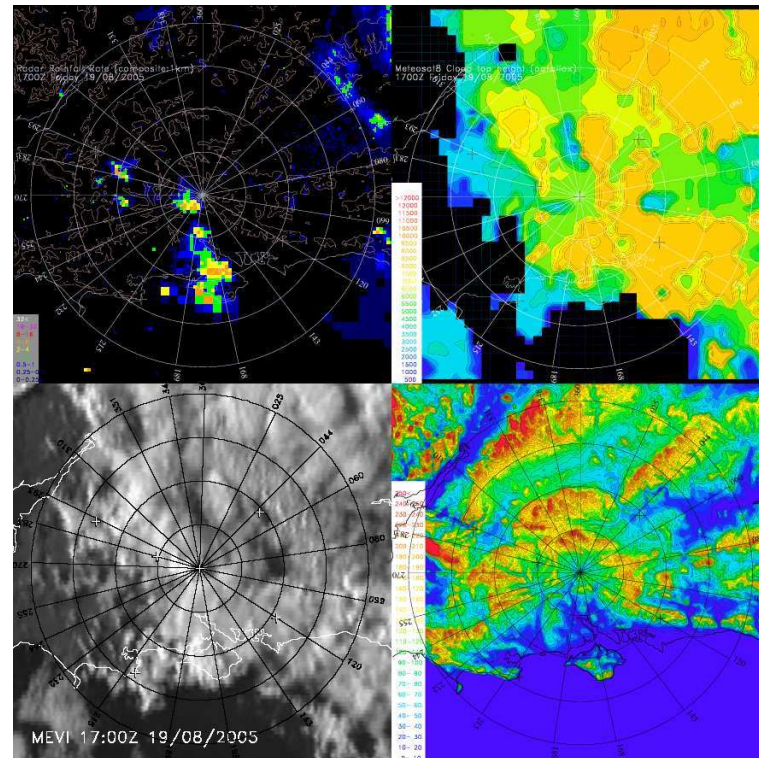
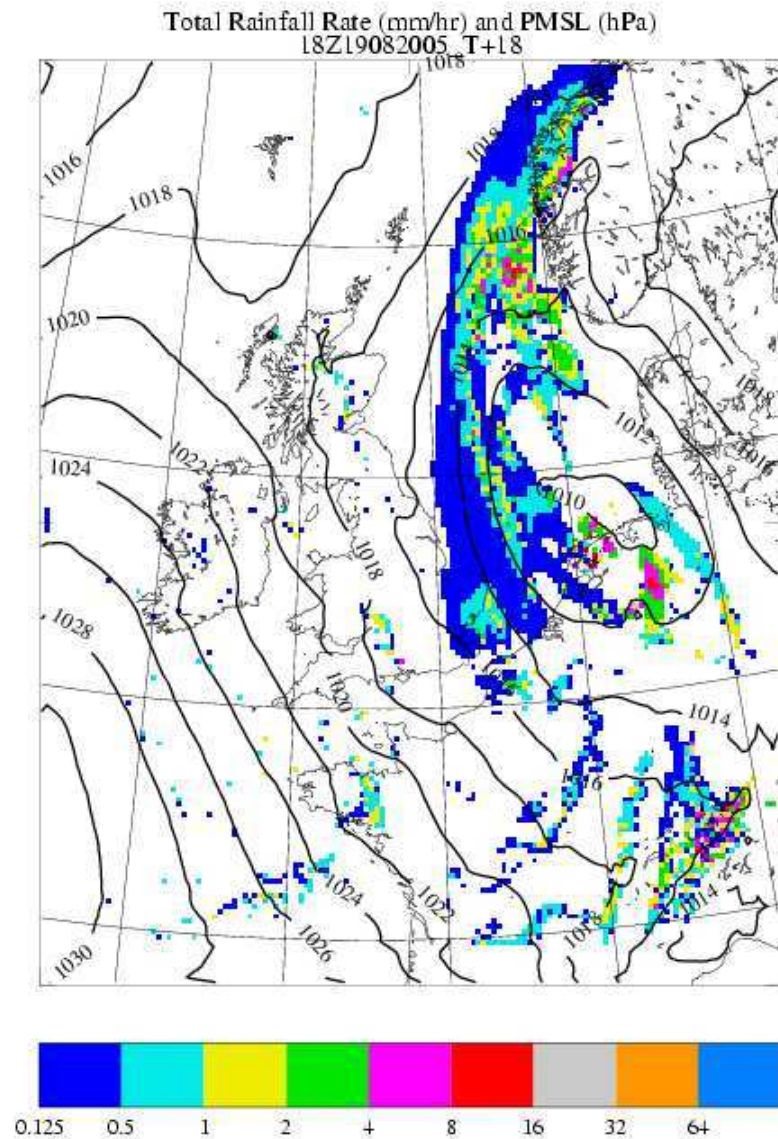


Figure 21.10



**Figure 21.11** Mesoscale model forecasts of MSLP and total rain-rate for 1800 UTC (T+18) on 19 August 2005.

## CHAPTER 22

### IOP 18: Thursday 25 August 2005

The synoptic situation consisted of a westerly flow following the passage of a cold front associated with a low that was surprisingly deep for this season (Fig. 22.1). A south-west north-east oriented line of showers entered the CSIP area from the west around 0900 UTC (Fig. 22.2) and passed just south of Bath at 0930 UTC. The clouds associated with these showers can be tracked back to near Lundy at 0530 UTC and were precipitating before they reached Morte Point. This line of showers intensified and new cells formed ahead of it within the CSIP area. Some of these new cells appeared on the radar network between 1015 and 1045 UTC around 5 km to the east of the main line.

The line of showers passed over Larkhill between 1020 and 1050 UTC and reached Chilbolton around 1100 UTC. The north-eastern end of this line of showers passed just south of Reading at 1130 UTC while several of the showers near its southern end passed over Swanage between 1100 and 1300 UTC (and are seen on the 1-minute-update webcam overlooking Swanage Bay - see Fig. 22.3). The trailing south-western end of the line of showers can still be seen close to the Swanage area at 1245 UTC (Fig. 22.4).

Part of the line of showers can be seen Fig. 22.4 to have formed a large cluster of intense showers near the Preston Farm radiosonde site. RHI scans from CAMRa at 1227 UTC along 120 degrees (Fig. 22.5) and at 1229 UTC along 100 degrees (Fig. 22.6), show evidence of a density current, with an up to  $15 \text{ ms}^{-1}$  radial velocity change across its nose (near 70 km range in Fig. 22.5). The outflow from this large cluster of showers led to the formation of a detached arc of cloud over part of the English Channel (see Fig. 22.7 at 1400 UTC) and we suspect that some of the private AWSs along the coast near Brighton - outside of the CSIP area - or the Greenwich Light Vessel may have detected the passage of this outflow at the surface. Showers started forming in this arc of cloud from 1330 UTC, with a clear arc-shaped "bow echo" apparent in the radar network images by 1430 UTC as the showers neared the French coast.

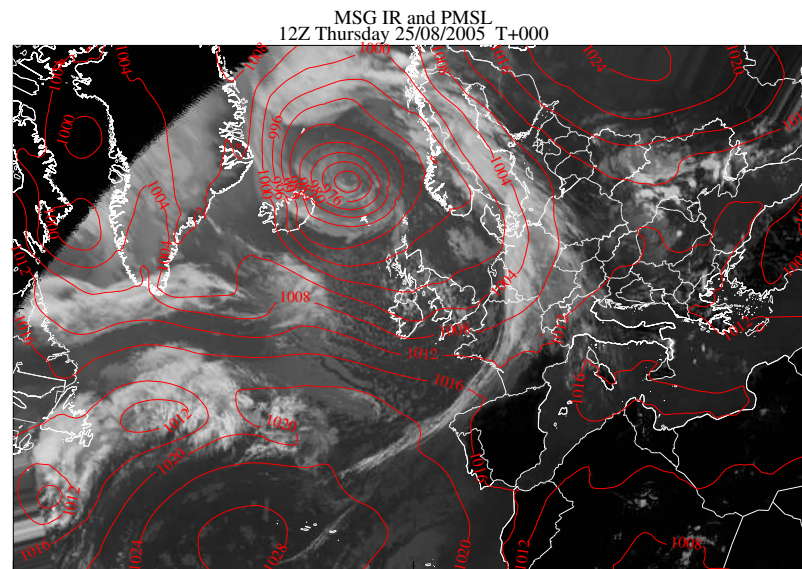


Figure 22.1 MSLP analysis and satellite infra-red cloud at 1200 UTC.

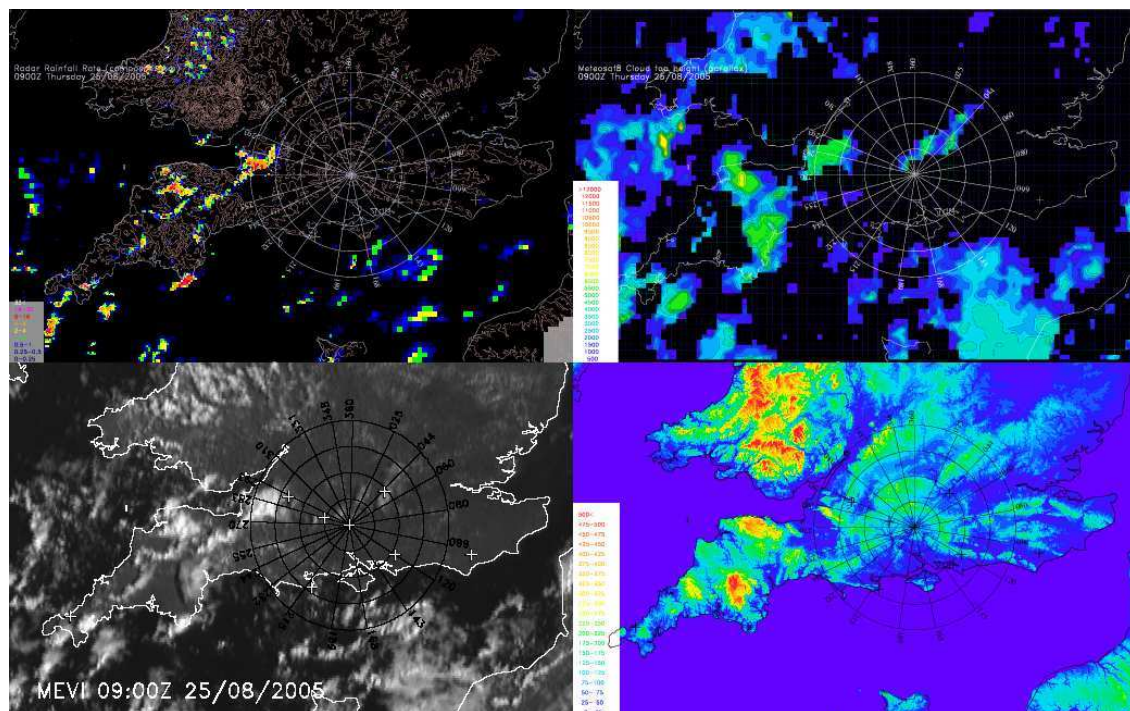


Figure 22.2





Figure 22.3

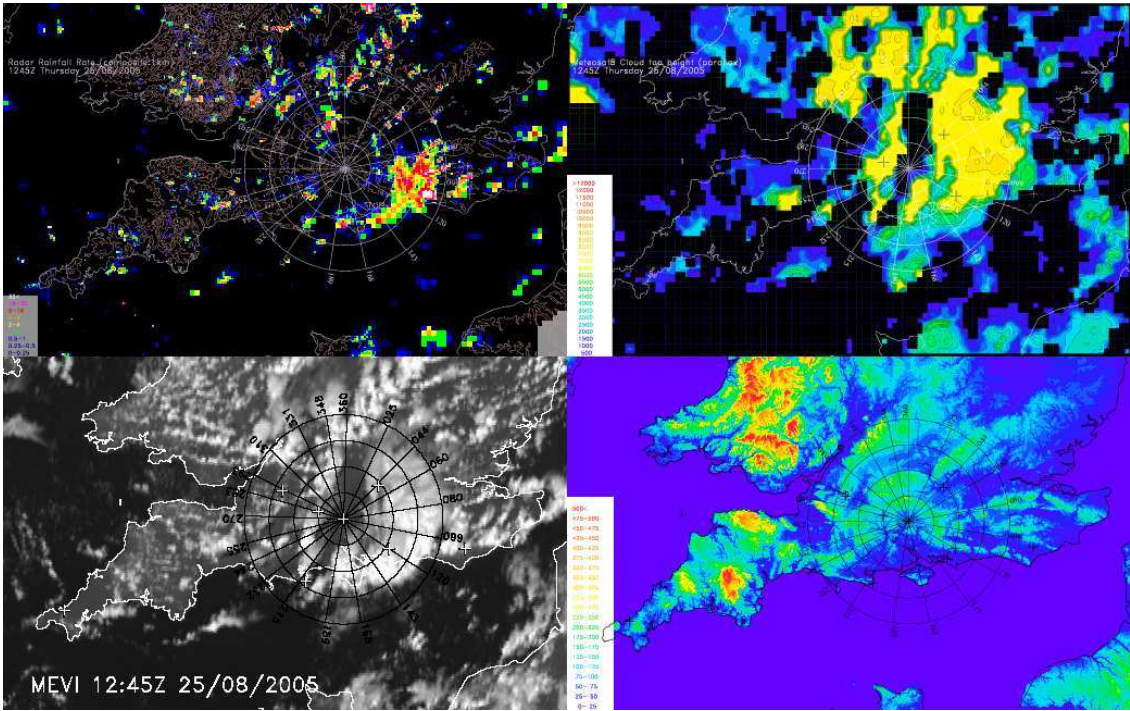


Figure 22.4

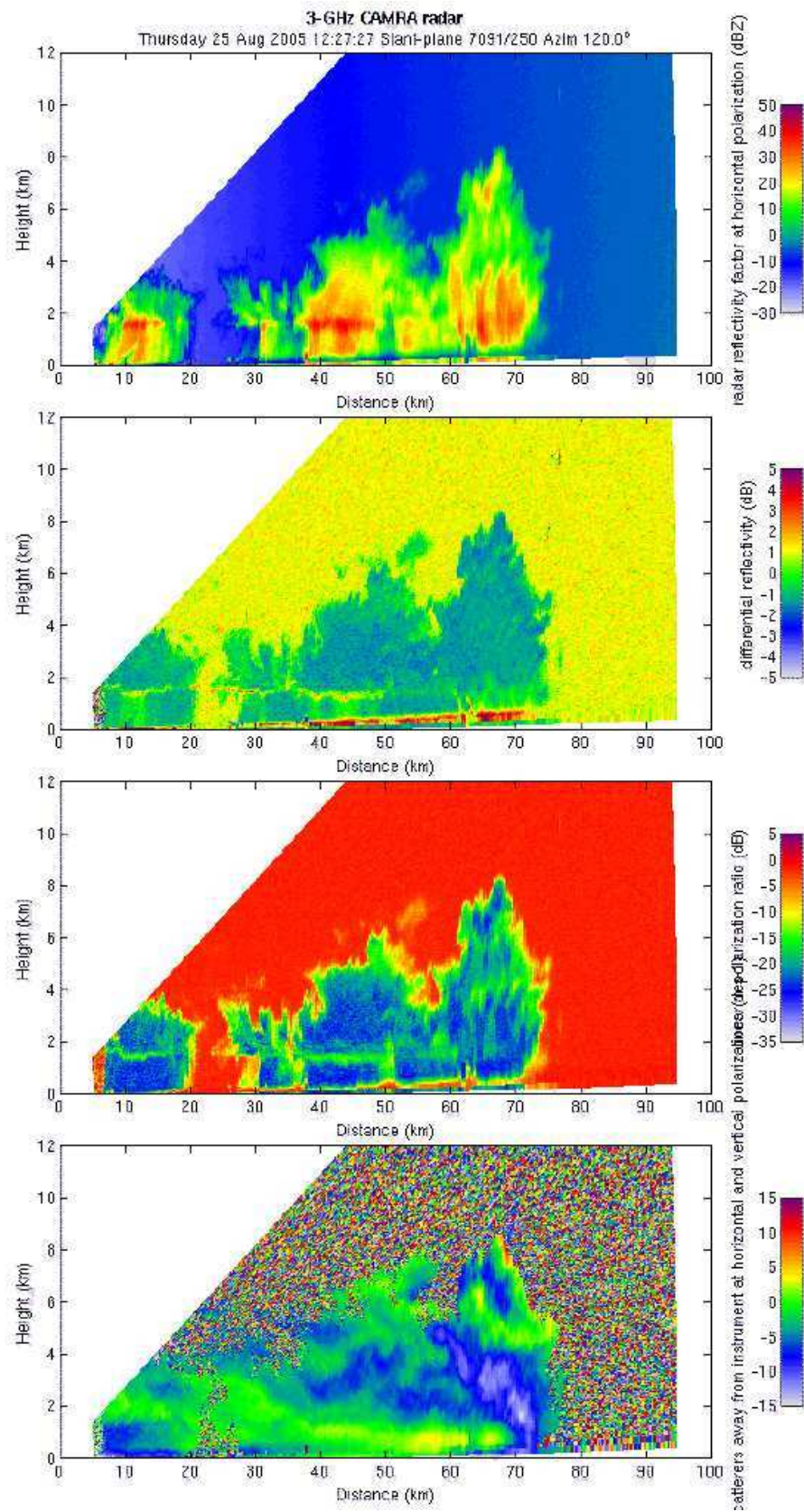


Figure 22.5



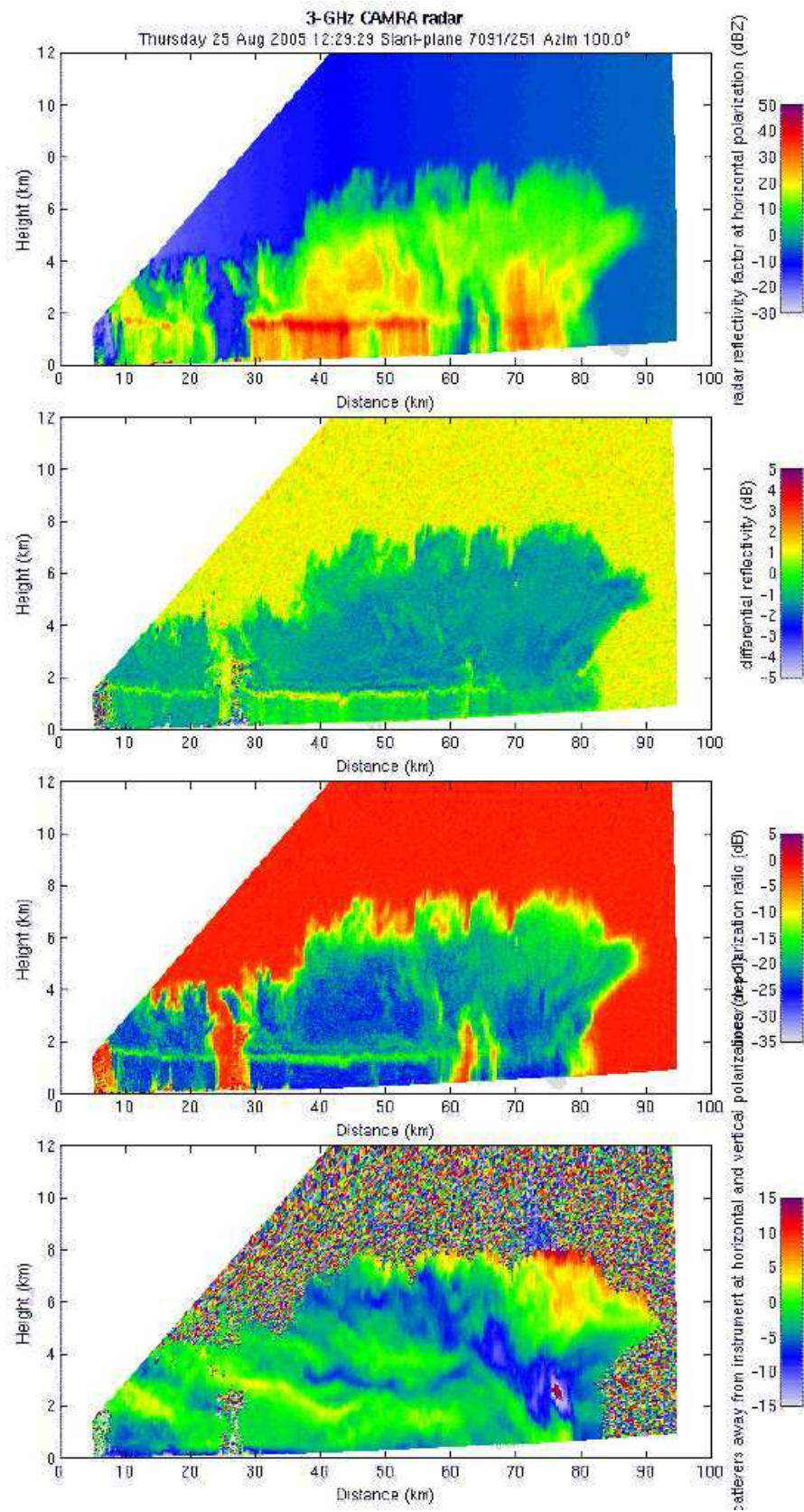


Figure 22.6

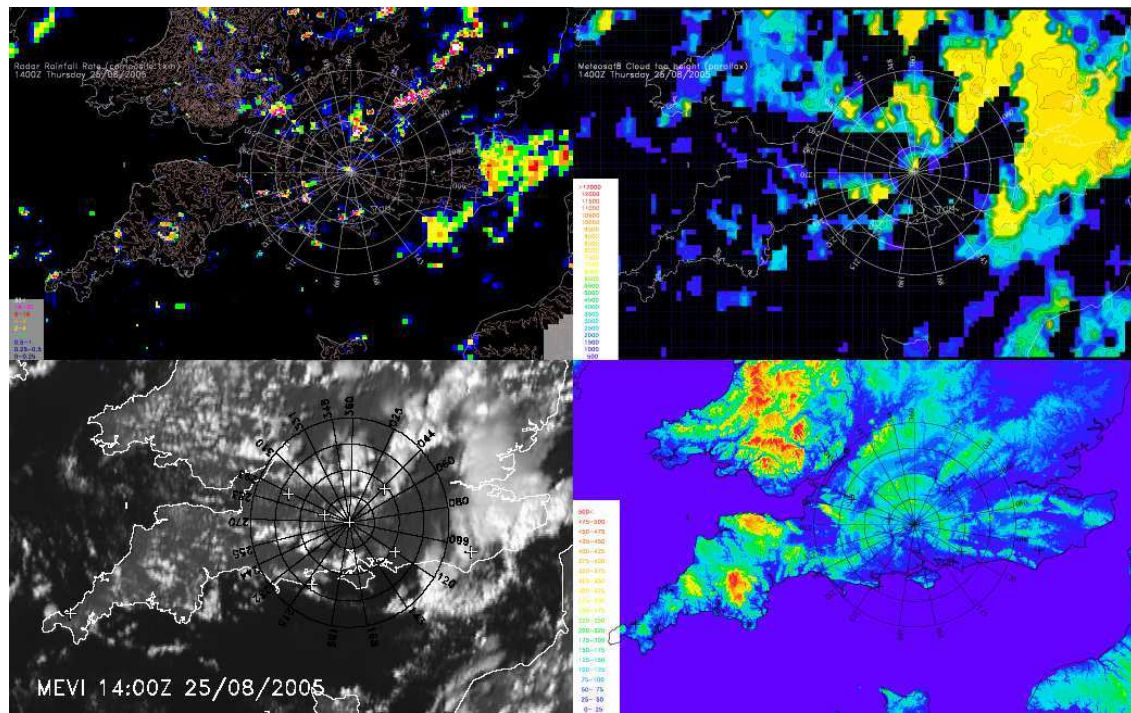


Figure 22.7

Interestingly, there is a cloud free region behind these showers (in the east of the CSIP region at 1400 UTC in Fig. 22.7). This cloud-free region was also evident at 1245 UTC when it was directly above Chilbolton (Fig. 22.4). This cloud free region is presumed to be where the subsidence from the storms to the east are preventing fresh convection from breaking out. This hypothesis is thought to be backed up by observations of the boundary layer made by the clear-air radar at Chilbolton. These observations suggest a reduction in the height of the boundary layer and an absence of mantle echoes while the cloud free region is overhead, compared with a deeper boundary layer, convective mantles, and deeper convective activity in the cloudy regions to either side. This hypothesis may be further validated by means of a detailed analysis of the height of the boundary layer as observed by the network of hourly CSIP radiosondes as well as by the wind profiler, lidar and sodars.

A separate shower started precipitating near Gosport at 1045 UTC ahead of the main cluster of showers, having probably been initiated in the Solent. It moved eastwards passing just to the south of Preston Farm around 1120 UTC, while the leading edge of the main cluster of showers reached Preston Farm at 1200 UTC. Numerous other scattered showers initiated in the CSIP area after the passage of the above-mentioned subsidence zone, including one that started precipitating



at 1300 UTC, 50 km from Chilbolton along azimuth 283 degrees. It passed over Larkhill at 1345 UTC, over Chilbolton at 1400 UTC and then moved along azimuth 99 degrees becoming more intense just as it moved out of CAMRa range. Other showers initiated to the north of the area around 1130 UTC and merged with showers moving eastwards from mid/south Wales to form an intense line with rain-rates above  $32 \text{ mm hr}^{-1}$  over north London and parts of Essex.

A heavy shower, with lightning, thunder and hail of up to 8 mm diameter passed over the Reading radiosonde site at 1445 UTC. This precipitation event lasted 42 minutes and led to a total of 4.4 mm at the Reading field site. As radiosondes were launched hourly, they clearly show the moistening and subsidence that occurred in the lowest few hundred metres after the shower had passed over. The Reading shower appears to have been initiated within the CSIP area ahead (to the south-east) of a pre-existing shower which had advected eastwards into the CSIP area from south Wales, where it had started precipitating around 0915 UTC. Based on its trajectory, it is likely to have been initiated near St David's Head, the northernmost of the two Pembrokeshire peninsulas. The sferics show a clear track for the Reading hail storm, starting near Gloucester. Alec Bennett (PhD student at Reading) has some measurements of electric field strength that show the approach and passage of this thunderstorm.

Overall, this should be an excellent case for studying the initiation of convection and also the evolution of a mesoscale cold pool from a cluster of showers, with associated development of a bow echo ahead and suppressed convection behind.

## REFERENCES

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- Dixon, R. S., Browning, K. A., and Shutts, G. J. (2002). The relation of moist symmetric instability and upper-level potential vorticity anomalies to the observed evolution of cloud heads. *Q. J. R. Meteorol. Soc.*, **128**, 839–859.