CHAPTER 5

PRECIPITABLE WATER IN THE ATMOSPHERE OVER BANGALORE AND NANDI HILLS AND ITS VARIATIONS

5.1 Introduction

General

The instruments and techniques used for the measurement and computation of precipitable water in the atmosphere over two stations Bangalore and Nandi Hills were described in the previous three chapters. Systematic measurements of precipitable water over the two stations were made during the cloudfree months for four years 1977-1981 using three different infrared spectral hygrometers and for the whole year 1980-81, using a microwave radiometer. Computations of precipitable water were made for the Bangalore region using radiosonde data, for a period of 8 years from 1970-74 and 1979-81 the data being provided by the Central Observatory, Bangalore, for all the years except the period 1979-80, when in the absence of radiosonde ascents at the Central Observatory, they were made by the Meteorological Unit of the Raman Research Institute at Bangalore and Nandi Hills. A fairly clear picture of the amount of precipitable water over the two stations and

and their seasonal and interannual variations is now available. The present chapter summarises these results, particularly the differences in precipitable water caused by differences in altitude. The suitability of Nandi Hills for millimeter wave telescope observations is also discussed.

5.2 Measurements

Chapters 3 and 4 described the measurements of precipitable water made at Bangalore and Nandi Hills during 1980-81, using the infrared spectral hygrometer and microwave water vapour radiometer constructed by the author. Chapter 2 gave an account of computation of precipitable water, from radiosonde ascents, made during the period 1979-81. The radiosonde ascents were primarily made to calibrate the infrared hygrometer and the microwave water vapour radiometer, but have also served as an additional source of data on the precipitable water over Bangalore and Nandi Hills.

Additional measurements were made during 1977-79, with two infrared spectral hygrometers obtained on temporary loan from the Meudon Observatory, France and the Physical Research Laboratory (PRL), Ahmedabad. The instruments used and the measurements made with them are described in the following paragraphs.

The Meudon Observatory spectral hygrometer was one of the instruments made by the former Scientific Advisory Group for Millimetre Astronomy (SAGMA), now the Institute for Millimetre Radioastronomy (IRAM), and used for the millimetre wave telescope site survey conducted by them. It is described in the final report of the SAGMA-IRAM on the site survey (1975). Designed for measurements of low amounts of precipitable water in the range 5 to 20 mm, it uses the infrared wavelengths 1.85 μ and 1.65 μ as the water vapour absorption and reference bands. It is mounted on an automatic sun tracker and gives continuous records of precipitable water during the day. It had been originally calibrated against radiosonde measurements at Bordeaux, France and also compared with the reference instruments built by Low of the National Science Foundation and by Westphal (1972) of the National Aeronautics and Space Administration, U.S.A.. The calibration curve supplied with the instrument is shown in Fig 5.1.1. The calibration was checked against radiosonde data obtained at Bangalore and Nandi Hills and Fig 5.1.2 shows that the original calibration is maintained.

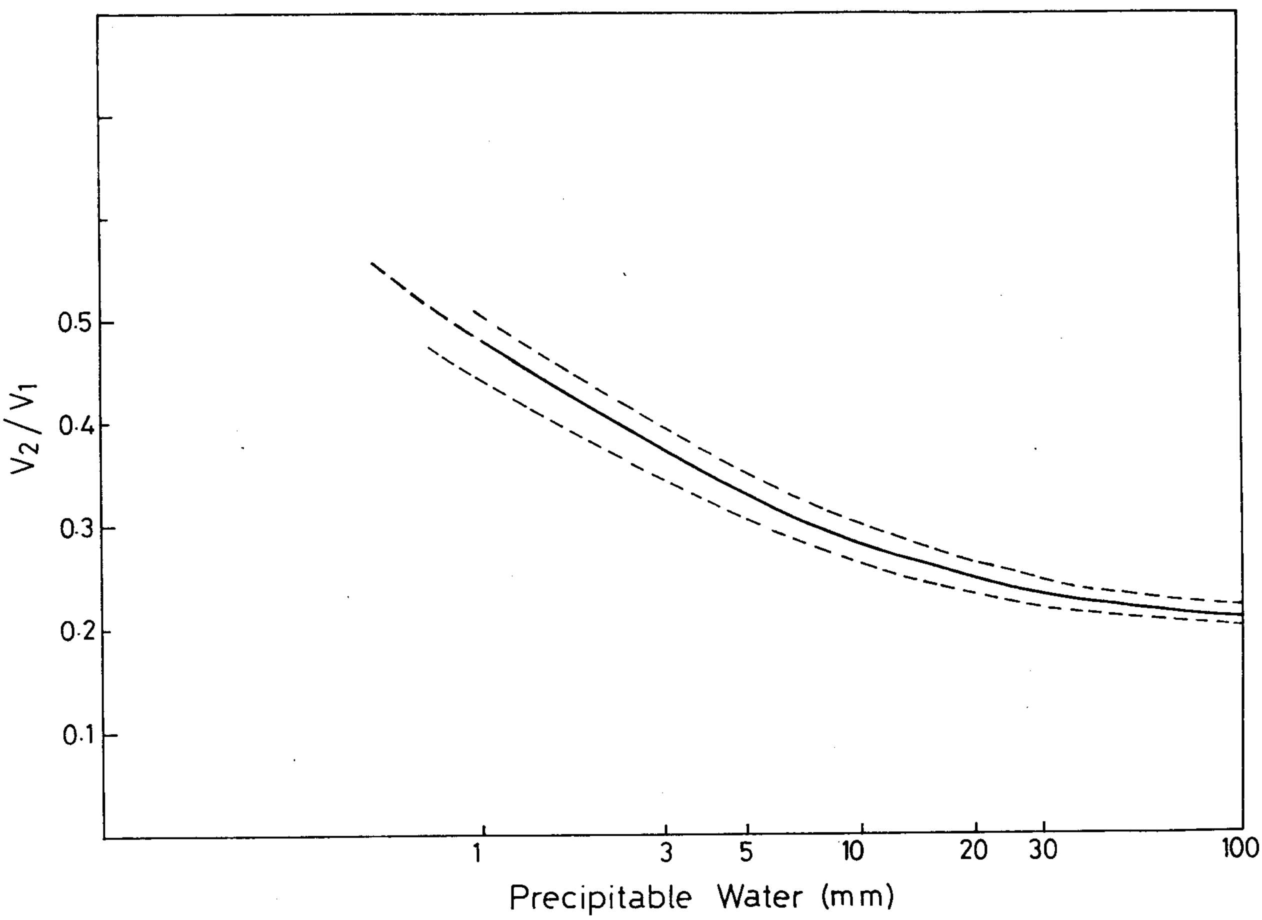


Fig. 5.1.1 Calibration curve of the IRAM infrared spectral hygrometer supplied with the instrument

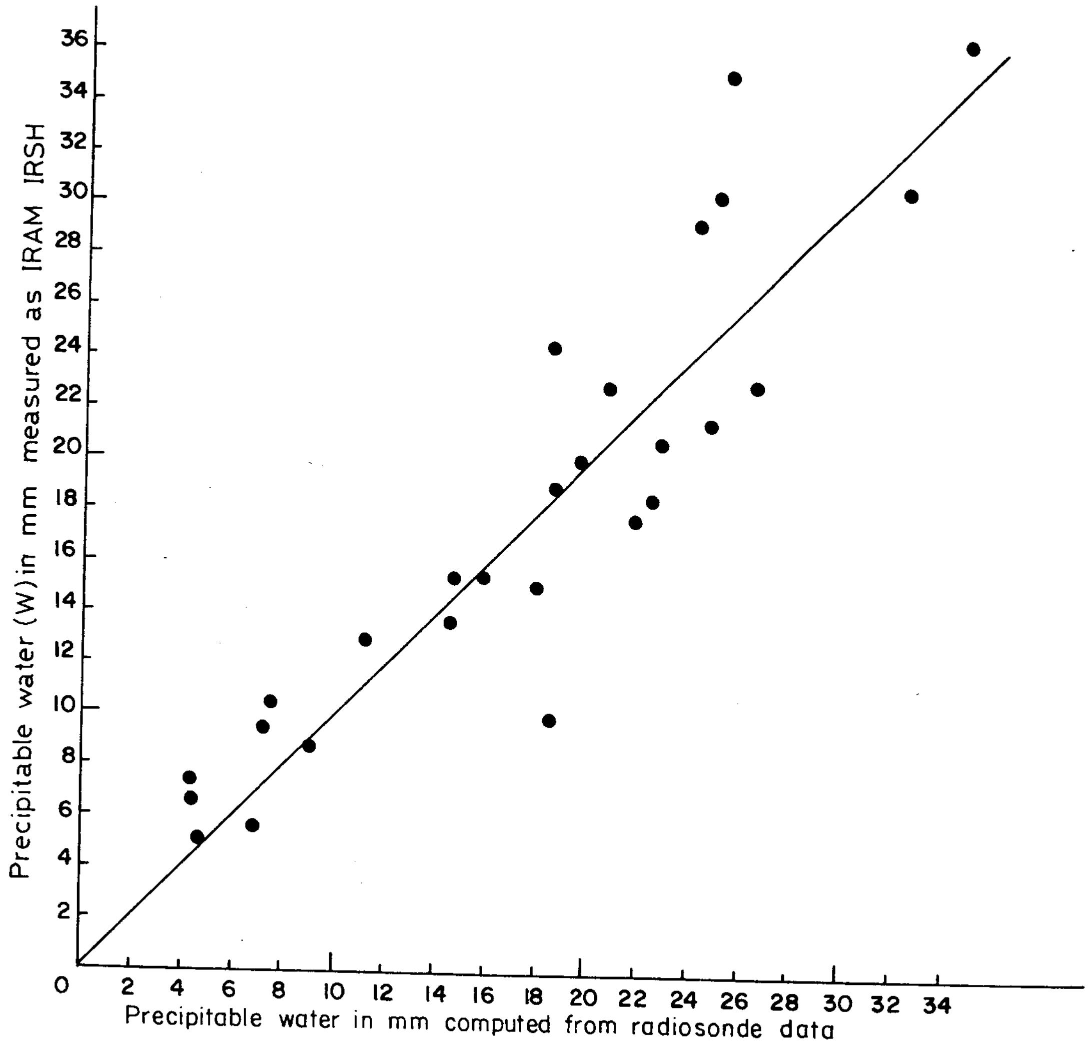


Fig.5.1.2 Comparison of the IRAM infrared spectral hygrometer with radiosonde data at Bangalore and Nandi Hills.

The PRL infrared spectral hygrometer uses the wavelengths 0.935 μ and 1.06 μ as the absorption and reference bands and was calibrated against radiosonde data obtained at Ahmedabad and Bangalore. The calibration curve of the PRL instrument obtained with reference to the IRAM instrument is given in Fig 5.2. The calibration curves obtained against radiosonde data for the infrared spectral hygrometer and microwave water vapour radiometer constructed by the author are given in Chapters 3 and 4 respectively, in Figs 3.14 and 4.15.

Table 5.1 gives, in tabular form, a statement of the individual measurements of precipitable water made at Bangalore with the 3 infrared spectral hygrometers and the microwave water vapour radiometer and the values of precipitable water computed from radiosonde data. Table 5.2 gives similar data obtained at Nandi Hills. Fig 5.3 depicts the schedule of observations made at both stations during the years 1977-1981, using the three different spectral hygrometers and microwave radiometer and with radiosonde ascents.

Infrared spectral hygrometer measurements were made with the IRAM and PRL instruments, alternately at

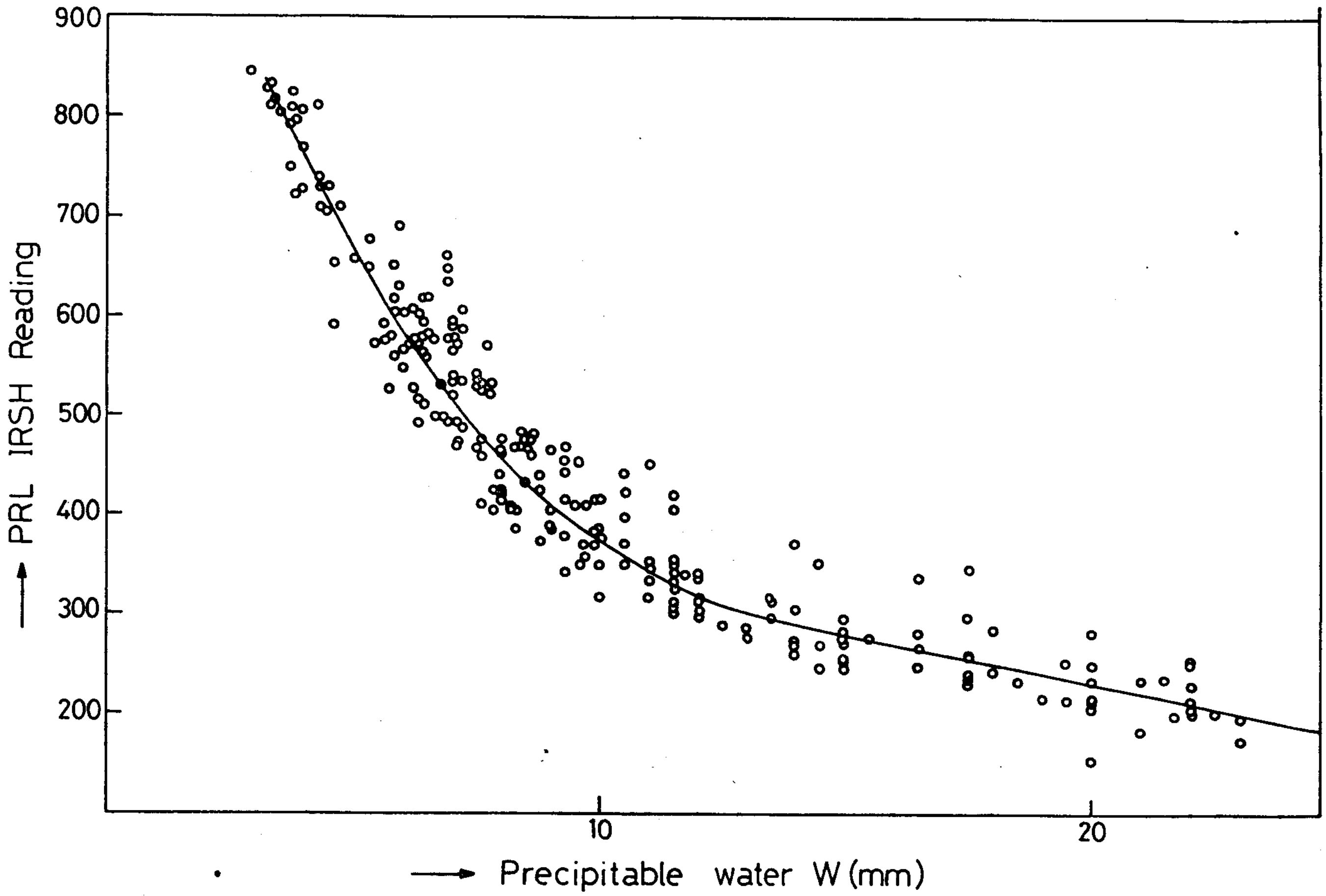


Fig. 5.2 Calibration curve of PRL infrared spectral hygrometer against IRAM IRSH

TABLE 5.1. MEASURMENTS OF W (MILLIMETRE) MADE WITH THE INFRA RED SPECTRAL HYGROMETER (IRSH), MICROWAVE WATER VAPOUR RADIOMER (MWR) AND COMPUTED FROM RADIOSONDE DATA AT BANGALORE DURING 1977-81.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1977 OCT.	3	22						1977 DEC	12	5						1978 JAN	24			13			
	4	28							13	6							25			15			
	5	35							14	10							26			16			
	6	22							15	7							27			12			
	7	25							16	7							28			8			
	11	16							17	10							29			8			
	12	21							18	18							30			5			
	13	22							19	11							31			9			
	21	23							20	8													
	22	18							21	12						FEB	1			14			
	27	16							23	10							2			12			
	28	12															4	14					
	29	11						1978 JAN	5	10							5	14					
	31	20							6	10							6	13					
									7	15							7	15					
NOV	1	24							9	11							8	12					
	2	15							10	9							9	14					
	3	18							11	11							10	14					
	4	14							12	12							11	15					
	8	19							13	10							12	12					
	9	10							14	7							13	11					
	11	17							16	7							14	6					
	17	15							17	6							15	12					
	18	17							18	3							17			17			
	19	21							19	6							18			19			
	21	14							23			11					19			21			

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1978 FEB	20			18				1978 MAR	20			16				1978 APR	22			23			
	21			16					21			20					24			20			
	22			20					22			19					26			22			
	23			21					23			20					28			22			
	24			19					28	13							29			27			
	25			10					29	17													
	26			8					30	15						MAY	2	20					
	27			8					31	15							3	26					
	28			9													5	28					
								APR	2	18							6	31					
MAR	1			8					3	16							9	37					
	2			9					4	13							10	29					
	4	11							5	12							11	36					
	5	15							6	14							16	31					
	6	10							7	18							17	24					
	7	12							8	21							18	28					
	8	17							9	19							19	20					
	9	12							10	23							20	26					
	10	11							11	25													
	13			16					12	21						OCT	3	19					
	14			15					14			22					4	16					
	15			14					17			24					5	15					
	16			19					19			18					6	27					
	17			19					20			19					7	33					
	18			21					21			22					9	22					

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1978 OCT	10	40						1978 NOV	21	9						1979 JAN	1			15			
	14	20							22	9							3	15					
	16	22							23	7							4	9					
	17	23							26			18					5	12					
	21	25							27			16					6	15					
	23	24							28			9					10	11					
	24	29							29			10					11	11					
	25	30							30			12					12	10					
	26	25															13	10					
	27	37						DEC	1			14					14	8					
	29	29							2			19					15	12					
	31	25							4			18					16	16					
									5			15					17	12					
NOV	9	20							7			15					18	15					
	10	17							9			18					20	21					
	11	13							15			11					21	10					
	12	23							16			12					22	16					
	13	33							17			15					24	21					
	14	15							18			11					25	17					
	15	17							19			11					26	21					
	16	19							20			8					27	12					
	17	13							21			8					29	13					
	18	12							22			14					30	31			27		
	19	11																					
	20	10																					

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1979 FEB	5				14			1979 MAR	27	17						1979 MAY	17				22		
	7				27				28	19							19				21		
									29	29							21				25		
MAR	1	20							30	27							22				24		
	2	12			15				31	33			26				24				22		
	3	21			22												25				26		
	5	22						APR	1	26							28				12		
	6	25							2	28													
	7	19			19				5	27			21			OCT	13	21					
	8	24							6	27							16	21					
	9	25							7	16							17	14					
	10	22							9	14							18	23					
	12	9							10	19							19	24					
	13	18							11	24			25				20	21					
	14	11							12	29													
	15	16							14	26						DEC	14	26					20
	16	18							16	36			35				15	22					19
	17	14							19	29			25				16	23					15
	19	23			19				20	31			33				17	18					15
	20	21							23	30							18	17			16		16
	21	20							24	31			24				19	15			11		15
	22	27							25	24			20				20	18					15
	23	26															21	20					16
	24	14						MAY	13				15				22	18					16
	26	27							16				19				23	22					20

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1979 DEC	24	18					20	1980 JAN	23		11				11	1980 FEB	24		12		13		14
	25	21					18		24		14				10		25		11		18		11
	26	20					16		26		12				7		26		11				13
	27	12					12		30		15				13		27		11				13
	28	10					9		31		14				11		28		12				17
	29	13			7		8										29		14				
	30	10			7		8	FEB	1		15		10										
	31	7			4		8		2		24				18	MAR	1		15				18
									3						14		2				31		27
1980 JAN	3		11				17		4		23				17		3		14				20
	4		11				13		5		22				20		4		14				20
	5		9		9		11		6		19		14		13		17		11				
	7		9				14		7		19		15		14		18		7		7		
	8		10		12		13		8		12				8		19		10				
	9		10				13		9		11		8		6		20		11				14
	10		9				11		10						8		21		13				18
	11						9		11		15		13		11		22		11				18
	12						11		12		15				11		24		15				17
	14		9		15		10		17						14		25		10				16
	15		8		9		10		18		16				12		26		14				13
	16		7		7		11		19		15				13		27		10				13
	17		8		11		11		20		14				14		28		14				19
	18		8		10		8		21		14				12		29		23				29
	19		9		9		11		22		12		13		11		31		28				33
	22		12		13		12		23		12		10		14								

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1980 APR	1		-				32	1980 MAY	1						36	1980 JUNE	6						39
	2		19				31		2						39		7						38
	3		16				27		7						37		8						38
	4		-				24		8				25		31		9						37
	5		17				24		9						35		10						37
	7		-				32		10						32		11						45
	8		-				27		13						36		12						44
	9		15				25		14						33		13						41
	10		16				28		15						30		14						41
	11		19				32		16						31		15						44
	12		14		17		29		17						39		16						46
	13		-				24		18						32		17						45
	14		12				23		19						30		18						42
	15		15				28		20						28								
	16		13				25		21						31	JULY	16						41
	17		-				32		22						31		17						34
	18		21				37		24						24		18						34
	19		22				35		25				16		23		19						34
	21		18		22		35		26						28		21						39
	22		-				34		27						34		22						38
	23		12				30		28						37		23						37
	24		14				35		30						36		24						37
	25		14				36										25						37
	26		18				40	JUNE	2						40		26						36
	28		12				32		3						42		27						36
	29		11				30		4						42		28						38
	30						28		5						42		29						38

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1980 JULY	30						38	1980 SEP	11						22	1980 OCT	17					-	26
	31						38		12					32	23		18					33	28
									13					26	23		19					33	25
AUG	1						39		14					25	16		20					32	25
	2						32		15					23	19		21					42	30
	4						36		16					20	16		22						30
	5						40		17					37	19		23						33
	6						43		18					-	21		24						34
	7						39		19					31	21		25						31
	27						30		20					40	25		26					28	25
	28						23										27					24	16
	29						23	OCT	2					43	-		28					17	15
	30						30		4					36	-		29		15			15	10
	31						34		5					19			30		18			15	12
									6					25	21		31		17			12	11
SEP	1						28		7					26	20								
	2						29		8					29	23	NOV	1		17			20	10
	3						30		9					33	28		2		17			14	12
	4						36		10					37	32		3		21			-	15
	5						33		11					39	35		4		28			25	20
	6					38	26		12					29	-		5		-			36	26
	7					26	24		13					23	21		6		-			26	18
	8					34	26		14						20		7		18			19	15
	9					38	25		15					26	21		8		17			20	13
	10					26	21		16					30	19		9		-				10

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH FRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH FRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH FRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1980 NOV	10		22				18	1980 DEC	13		17			18	14	1981 JAN	6					11	12
	11		-				34		14		-			13	7		7					10	11
	21		27			27	22		15		7			8	4		8		9			9	11
	22		23			28	19		16		7			8	3		9		13			14	16
	23						18		17		16			21	11		10					21	18
	24		18			17	15		18		20			21	17		11		17			13	17
	25		18			20	12		19		16			16	14		12		16			-	18
	26		18			17	12		20		10			9	10		13		16			15	17
	27		15			16	11		21		-			15	11		14		-			17	17
	28		10			10	7		22		19			35	25		15		18			19	20
	29		17			24	15		23		-			30	27		16		-			31	31
	30		21			23	24		24		18			20	15		17		21			16	-
									25		-			13	-		18		-			24	21
DEC	1		14			20	13		26		-			23	-		19		-			21	20
	2		15			19	15		27		-			20	-		20		17			17	17
	3		12			12	17		28		-			18	-		21		14			15	15
	4		-			40	36		29		14			14	-		22		14			21	16
	5		-			32	29		30		16			7	13		23		16			21	18
	6		-			33	29		31		14			15	14		24		17			24	19
	7		-			22	21										25		-			-	20
	8		14			-	16	1981 JAN	1		17			16	14		26		19			16	21
	9		15			16	16		2		19			18	16		27		13			15	16
	10		14			15	15		3		20			20	18		28		13			12	15
	11		15			18	13		4					9	10		29		12			14	14
	12		23			24	17		5					11	9		30		-			7	14
																	31		9			9	11

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1981 FEB	1		-			11	-
	2		10			13	15
	3		8			12	14
	4		7			2	13
	5		14			14	20
	6		14			18	19
	7		15			19	21
	8		-			16	18
	9		13			21	19
	10		12			20	18
	11		12			15	18
	12		12			15	19
	13		11			17	18
	14		-			23	21
	15		-			13	-
	16		10			11	13
	17		6			-	-
	18		6			3	9
	19		7			11	11
	20		10			-	-
	21		11			9	-
	22		13			12	14
	23		8			8	10
	24		10			-	13
	25		11			11	14

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1981 FEB	26		9			9	10
	27		9			10	10
	28		10			10	-
MAR	1		13			12	13
	2		11			14	12
	3		12			13	12
	4		10			11	10
	5		9			10	10
	6		13			14	10
	7		16			13	13
	8		-			17	16
	9		13			16	15
	10		20			24	20
	11		27			27	25
	12		-			25	-
	13		-			22	-
	14		14			19	-
	15		-			19	-
	16		17			21	21
	17		19			18	22
	18		25			29	27
	19		23			18	25
	20		25			34	27
	21		26			31	30

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1981 MAR	22		-			35	-
	23		23			15	26
	24		18			23	23
	25		22			20	22
	26		22			-	25
	27		24			-	27
	28		21			29	33
	29		15			16	24
	30		16			19	24
	31		22				25
APR	1		-			19	26
	2		-			26	29
	3		-			23	27
	4					-	27
	5					43	29
	6					26	25
	7					23	24
	8					-	22
	9					15	17
	10					10	14
	11		13			20	16
	12		-			17	16
	13		11			10	16

Table 5.1 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	RADIOSONDE C.O.	MWR
1981 APR	14		20			21	23																
	15		27			29	28																
	16		30			42	33																
	17		27			37	26																
	18		29			35	30																
	19		-			35																	
	20		22			26	22																
	21		21			18	21																
	22		25			23	26																
	23		21			28	26																
	24		21			19	23																
	25		16			24	23																
	26		21			22	26																
	27		21			27	29																
	28		16			21	26																
	29		21			26	28																
	30		24			36	31																

Table 5.2: **Measurements of W(mm) made with the infrared spectral hygrometer (IRSH) and computed from from radiosonde data at Nandi Hills during 1977-80**

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL
1977 NOV	22	12			1978 JAN	3	7			1978 FEB	11			8	1978 MAR	8			11	1978 APR	4			9
	23	11				4	7				12			7		11	11				5			7
	24	15				20	6				13			5		12	8				6			9
						21	6				14			3		13	10				7			10
DEC	1	7				22	7				16	10				14	7				8			16
	2	12				23	6				17	9				15	9				9			12
	3	8				24	6				18	12				16	11				10			14
	4	9				25	7				19	12				17	11				11			16
	5	7				26	8				20	10				18	11				12			13
	6	7				27	6				21	9				19	11				13	13		
	8	6				28	5				22	13				20	11				14	14		
	9	6				29	4				23	14				21	14				15	18		
	10	4				30	3				24	11				22	9				16	18		
	11	2				31	5				25	6				24	17				17	15		
	24	3									26	5				25	11				18	14		
	25	4			FEB	1	6				27	5				26	13				19	11		
	26	3				2	6				28	7				27	14				20	13		
	27	3				3	8									28			8		21	14		
	28	6				4			7	MAR	1	6				29			10		22	14		
	29	4				5			8		2	6				30			9		23	16		
	30	5				6			7		3	10				31			9		24	16		
	31	6				7			10		4			6							25	20		
						8			6		5			8	APR	1			11		26	15		
1978 JAN	1	8				9			9		6			7		2			13		27	15		
	2	5				10			8		7			7		3			11		28			12

Table 5.2 contd.

YEAR AND MONTH	DATE	TRSH IRAM	TRSH RRI	TRSH PRL	RADIOSONDE RRI	YEAR AND MONTH	DATE	TRSH IRAM	TRSH RRI	TRSH PRL	RADIOSONDE RRI	YEAR AND MONTH	DATE	TRSH IRAM	TRSH RRI	TRSH PRL	RADIOSONDE RRI
1978 APR	29			15		1978 NOV	26	13				1979 FEB	17	8			
	30			13			27	10					18	10			
							28	5					19	-			
MAR	1			14			29	6					21	12			
	2			10			30	9					22	14			
													23	12			
OCT	20			19		DEC	1	10					24	15			
	21			14			2	13					25	8			
	22			13									26	10			
	23			11		1979 FEB	1	9					27	9			
	24			17			2	8					28	19			
	25			14			3	14									
	26			15			4	13				APR	27	9			23
	27			15			5	9					28	11			19
	28			17			6	10					29	17			18
	29			19			7	10					30	21			22
	30			19			8	13									
	31			17			9	16				MAY	5	20			
							10	13					6	17			
NOV	2			13			11	12					7	17			
	8			10			12	17					8	15			
	9			9			13	17					9	18			
	10			9			14	10					10	21			
	11			7			15	13					15	11			
	12			11			16	9					16	10			

Table 5.2 contd.

YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI	YEAR AND MONTH	DATE	IRSH IRAM	IRSH RRI	IRSH PRL	RADIOSONDE RRI
1979 MAY	17	13.				1980 JAN	12			7		1980 MAR	16			9	12
	18	18					14			5			19			7	
	19	13					15			5			20			8	
	20	14					16			5			21			11	
	21	13					17			5			22			11	
	22	14					26			5			28			15	
	23	11					30			9			29			20	
	24	14					31			8							
	25	14										DEC	7			18	
	26	17				FEB	1			6			8			10	
	27	18					2			11			9			10	
	28	17					3			11			10			10	
	29	20					4			12			11			9	
	30	20											12			16	
	31	22				MAR	5		13		20		13			12	
							6		11		10		14			6	
1980 JAN	1	10			9		7		13		14						
	2	6			5		8		20								
	4			8			9		14		14						
	5			6			10		15		13						
	7			8			11		26								
	8			9			12		23		25						
	9			9			13			11	11						
	10			7			14		10		10						
	11			6			15			9	11						

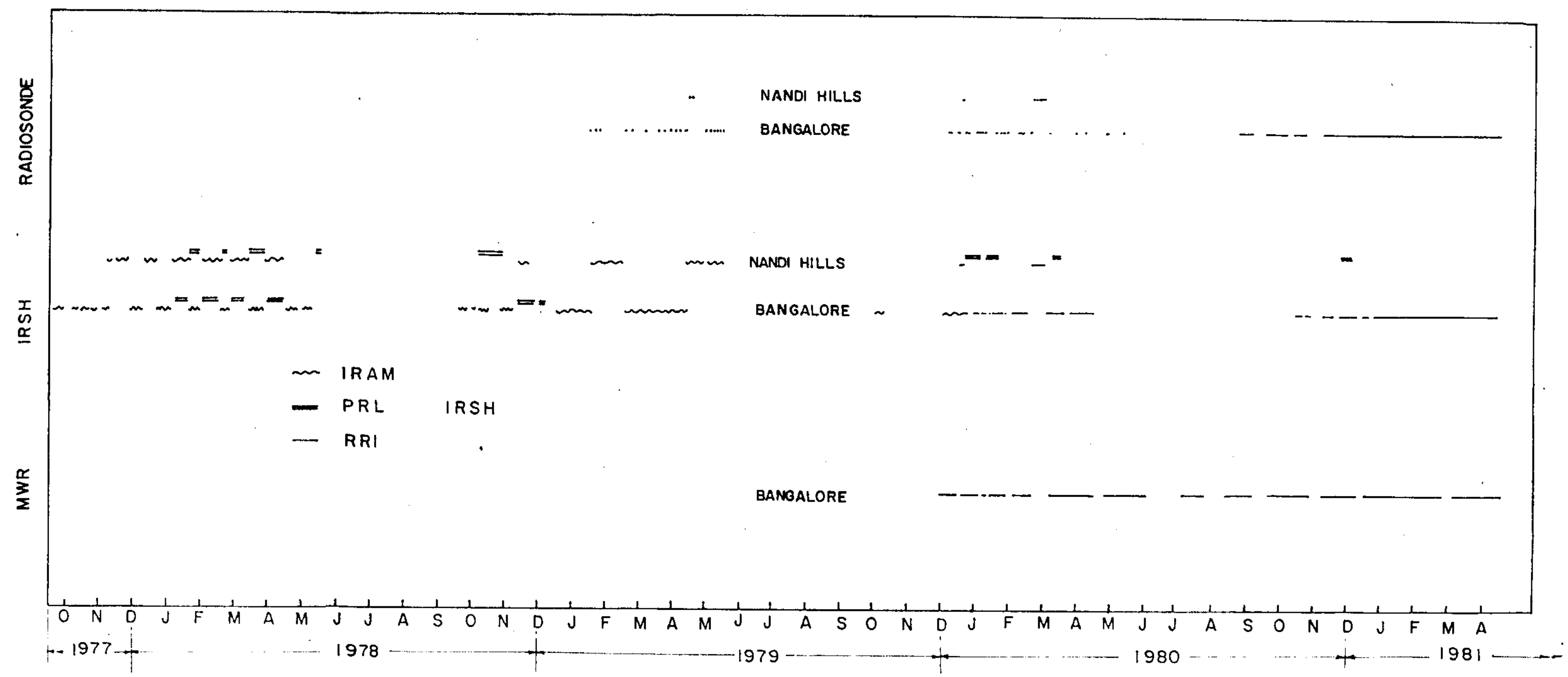


Fig.5.3 Schedule of observations 1977-81

Bangalore and Nandi Hills, during the cloud free dry months November to May during 1977-79. On clear days as many as 15 measurements were made daily from 1000 to 1700 hours IST. Similar readings were made with the instrument constructed by the author during 1980-81.

Microwave water vapour radiometer measurements were made continuously from December 1979 to April 1981 using a millivoltmeter recorder for continuous recording of data. The measurements were made mostly at Bangalore on the dates given in Tables 5.1 and 5.2.

Radiosonde ascents to synchronise with IRSH and MWR observations were made at Bangalore and Nandi Hills during 1979-80. As the radiosonde takes about 90 minutes to reach 30 km levels, spectral hygrometer and radiometer observations were made as far as possible throughout this period. Radiosonde ascents at the Central Observatory from 1981 were made at internationally prescribed hours of observations 00 and 12 GMT. Simultaneous comparisons were always not possible, but MWR observations could be made to synchronise with radiosonde observations.

The original calibration curve of the IRAM infrared spectral hygrometer, received with the instrument, was based on radiosonde observations at a sea level station, Bordeaux (Maiya and Dierich, 1981). In order to allow for pressure broadening and to make it applicable to Bangalore (950m amsl) and Nandi Hills (1479m amsl) altitudes, it was necessary multiply the precipitable water value W obtained with the IRAM hygrometer by $(P_o/P)^{1/2}$ where P_o is the sea level pressure and P the actual pressure of the atmosphere at Bangalore and Nandi Hills. The PRL hygrometer was used only for one season during 1978, as changes in the instrument made its readings unreliable after 1978.

5.3 Comparison of infrared and microwave absorption and radiosonde techniques

In Fig 5.4 the values of precipitable water obtained with the infrared spectral hygrometers are plotted against those obtained with the microwave radiometer. The least square fit line is also shown. Considerable scatter is seen, with an average rms deviation over the intermediate range of W of about 3.5 mm. At about 15 mm the spectral hygrometer and radiometer agree better, the relative error being less than 10%. Even assuming the presence

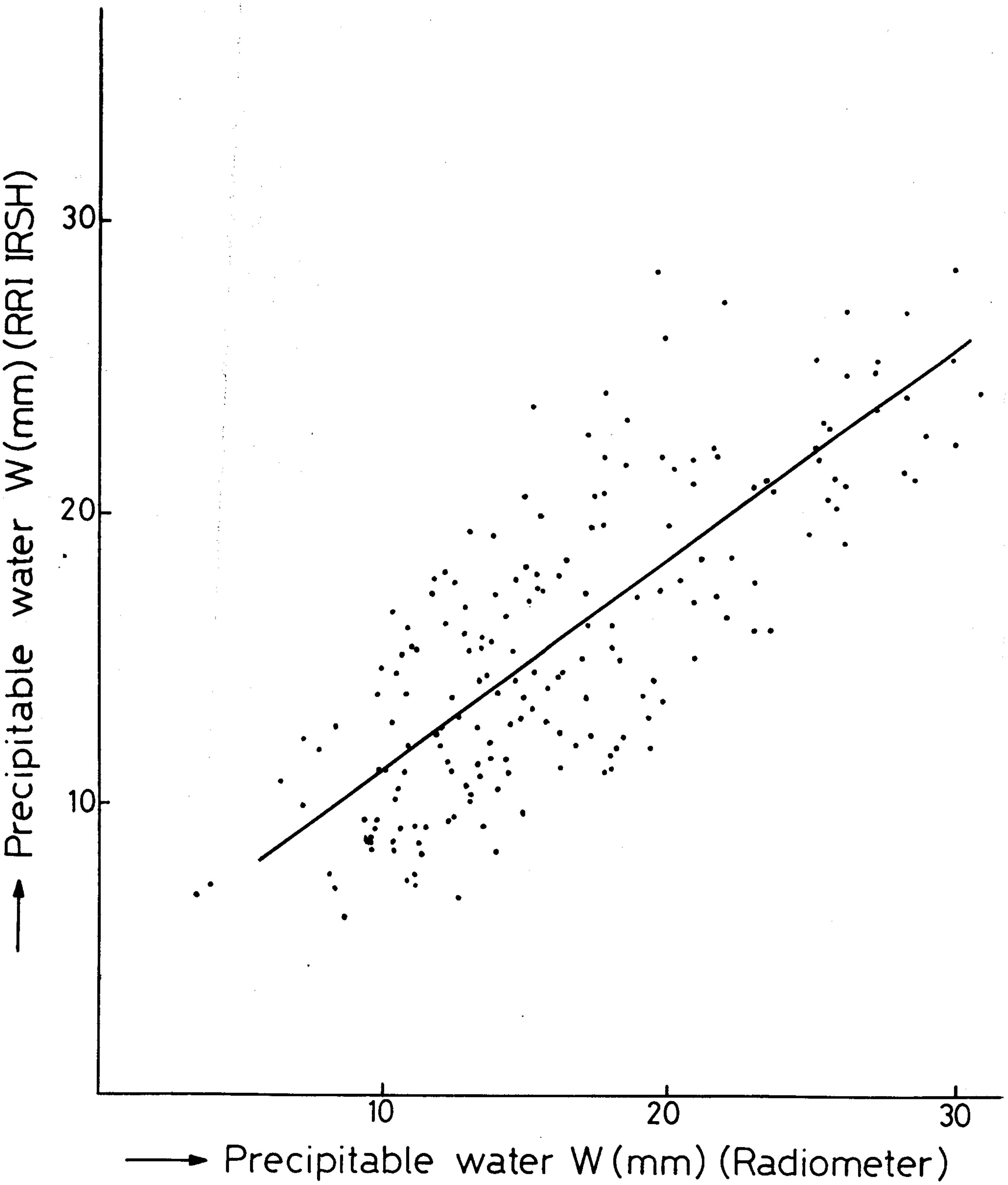


Fig 5.4 Comparison between the RRI IRSH and MWR

of systematic errors in the calibration data, it would appear that any single measurement made with either of these instruments will have an absolute measurement error of less than 25%.

One possible reason for getting somewhat different values of W when the two instruments are used simultaneously is the following. The radiometer is always pointed at the zenith and yields directly the zenith value of W. But the corresponding value is derived from the spectral hygrometer on the assumption of a horizontal stratification of atmosphere. If the assumption is not true there would arise an error which would be greater, the greater the zenith angle of the sun. For this reason, during calibration against radiosonde ascents, the error of the radiometer should be less than that of the spectral hygrometer, because the sensing path of the radiosonde and the radiometer are better matched. Differential scattering and differential absorption, if any, at the two wavelengths due to dust in the atmosphere (particularly at low elevation angles of the sun), could contribute to some disagreement. So also could changes in the vertical distribution of water vapour. To summarise the radiosonde technique remains the most reliable method for the evaluation of precipitable water in the atmosphere and is therefore used to calibrate all other instruments. It is, however, both expensive and time-consuming, apart from the fact that continuous real-time measurements are not possible with this technique. The microwave radiometer is superior to the infrared spectral hygrometer in that continuous measurements are possible with it day and night except during rain, while the spectral hygrometer can be used only during the day and when the sun and the sky surrounding it are free from clouds. Both these instruments have accuracies of the order of 25 percent, while with radiosondes slightly higher accuracies are possible. Both the spectral hygrometer and microwave radiometer have the advantage of being light and portable instruments, easy to operate and with negligible time lag.

5.4 Results

5.4.1 General

The daily values of W obtained using all three techniques during 1977-81 are plotted in Figs 5.5.1, 5.5.2 and 5.6. Fig 5.5.1 gives the daily values obtained with the spectral hygrometers at Bangalore during 1977-81 and Fig 5.5.2 the daily values obtained from radiosonde

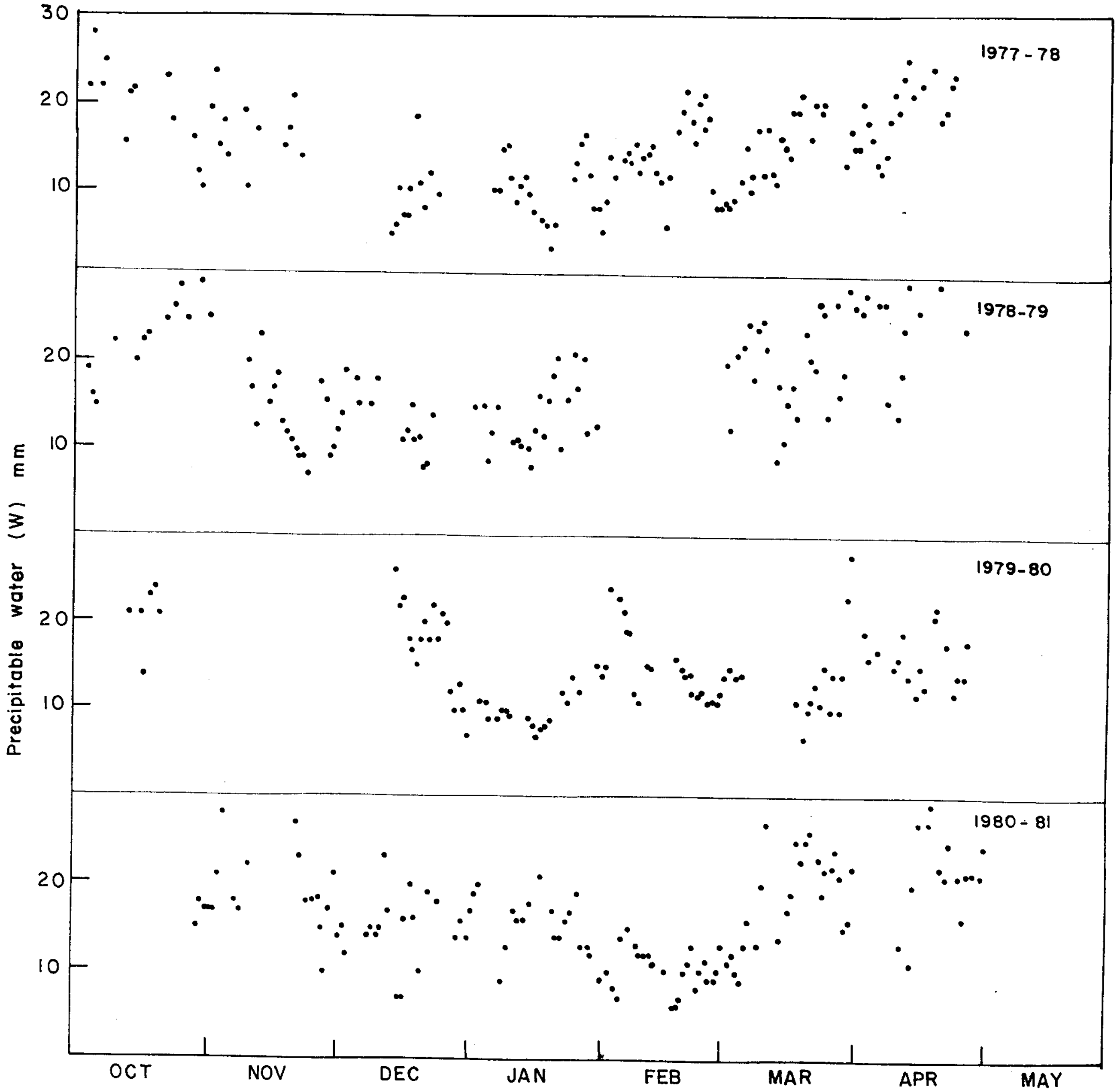


Fig 5.5.1 Daily mean W from IRSH's over Bangalore, 1977-81

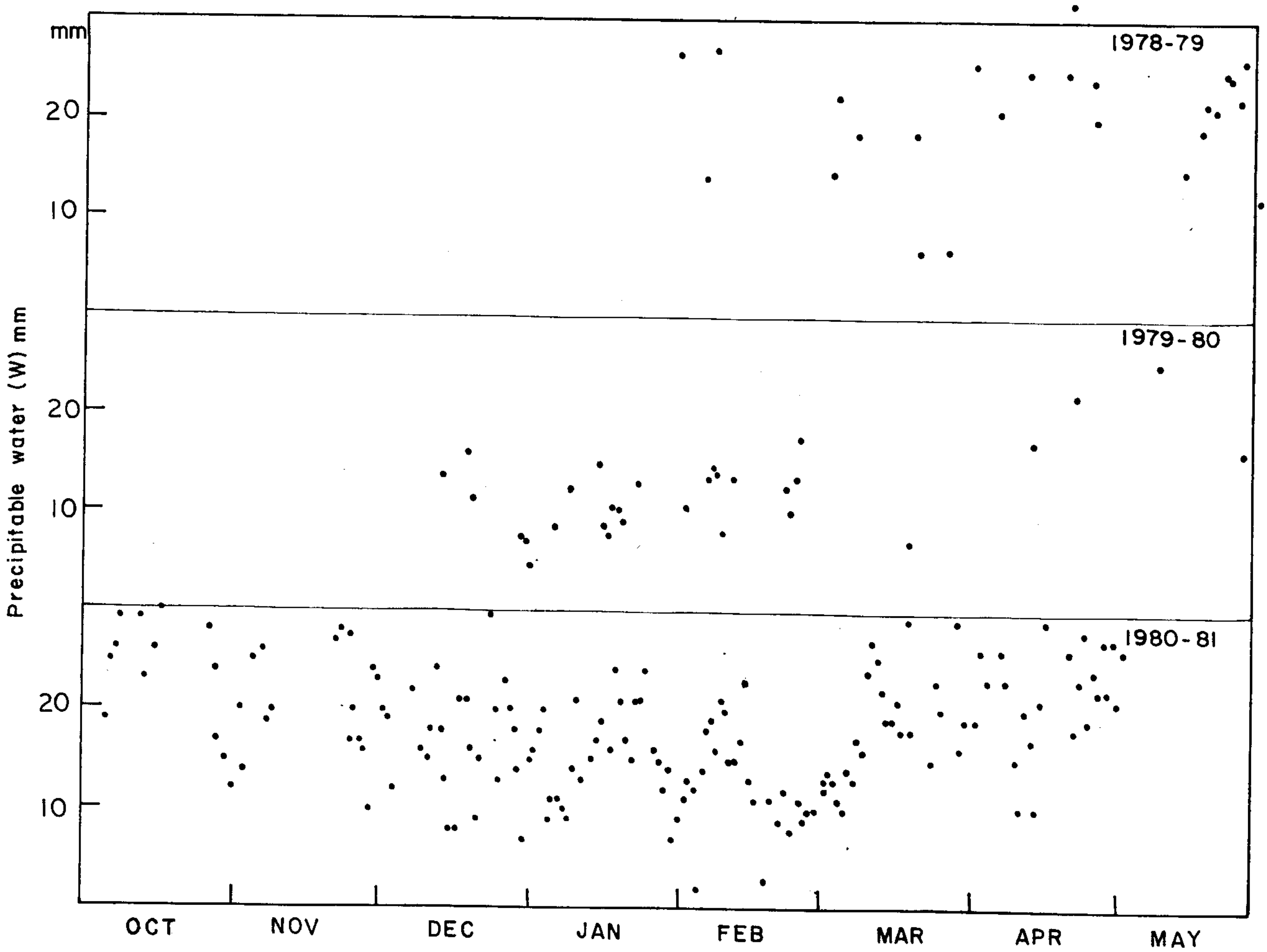


Fig.5.5.2 Daily mean W from radiosonde data over Bangalore, 1979 - 81.

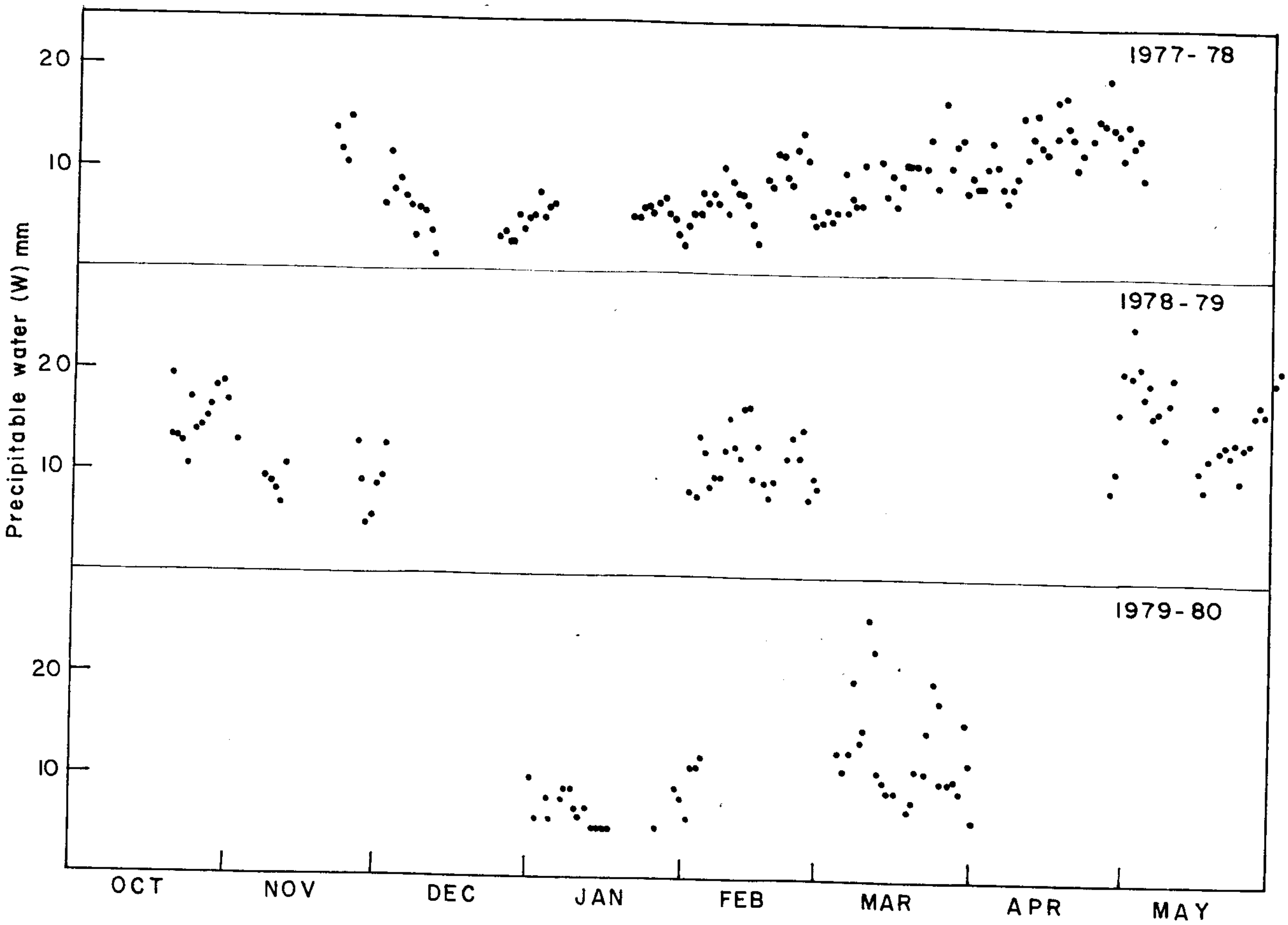


Fig. 5.6 Daily mean W from IRSH over Nandi Hills, 1979-81

ascents at Bangalore during 1979-81. The daily values of W obtained with the microwave radiometer was given in Fig 4.16. Fig 5.6 gives the daily values of W obtained with spectral hygrometers at Nandi Hills and Fig 2.2 similar values from radiosonde ascents.

The daily mean values of W show day-to-day variations with low values in the clear season November to March and high values in the cloudy or partly cloudy months from April to October.

5.4.2 Month-to-month variations of precipitable water

The monthly mean values of precipitable water for the months October to April, obtained using all three techniques at Bangalore and Nandi Hills during 1977-1981, are plotted in Fig 5.7 for Bangalore and Fig 5.8 for Nandi Hills.

It will be seen that W shows a marked fall at both stations during the months December to March, the values falling steadily from October and rising again after February to reach the October values in May. The minimum occurs during December-January. The highest W recorded during the clear months is about 39 mm at Bangalore in May and 25 mm at Nandi Hills in March and the lowest

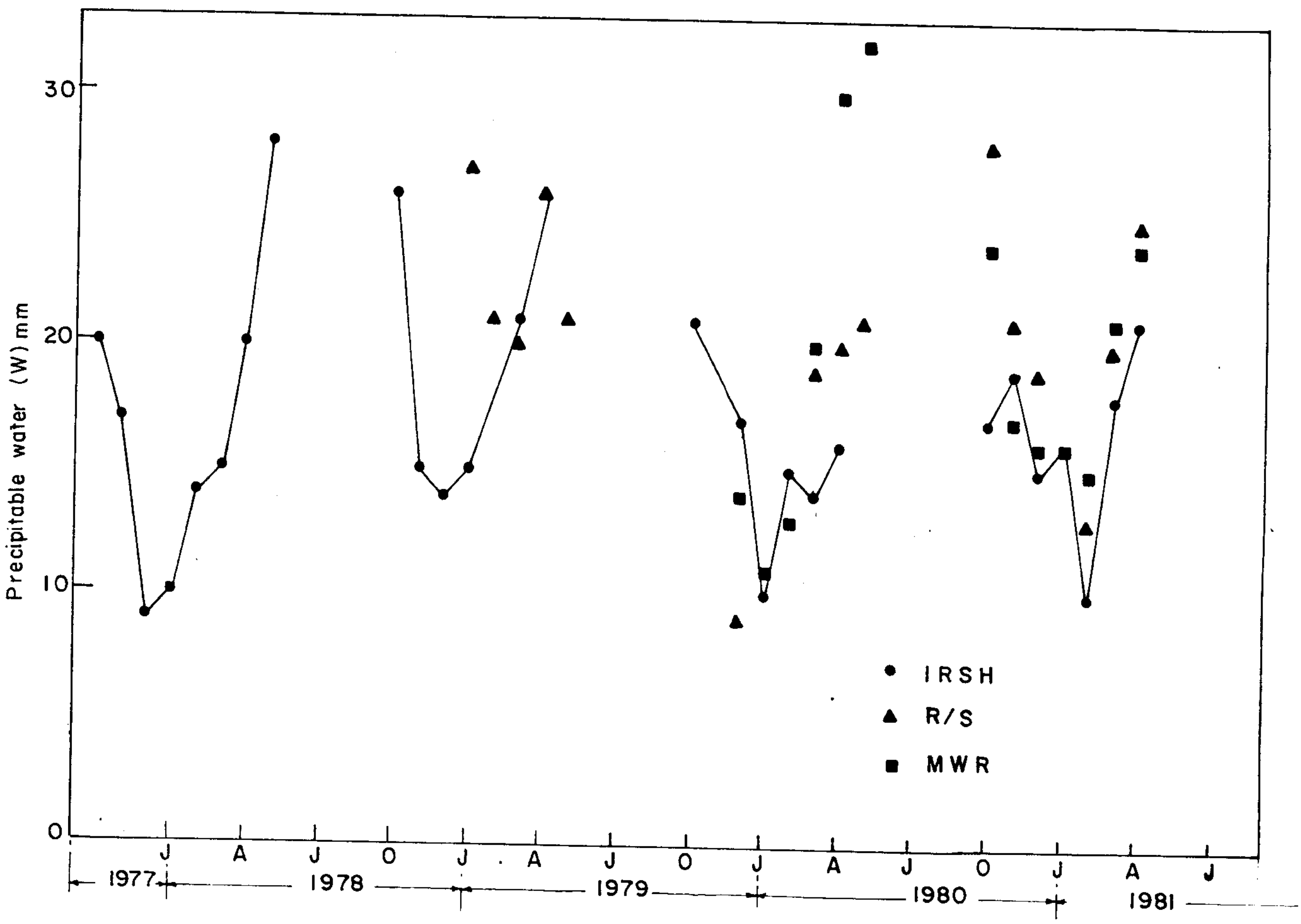


Fig. 5.7 Monthly mean W for the clear months at Bangalore from all data.

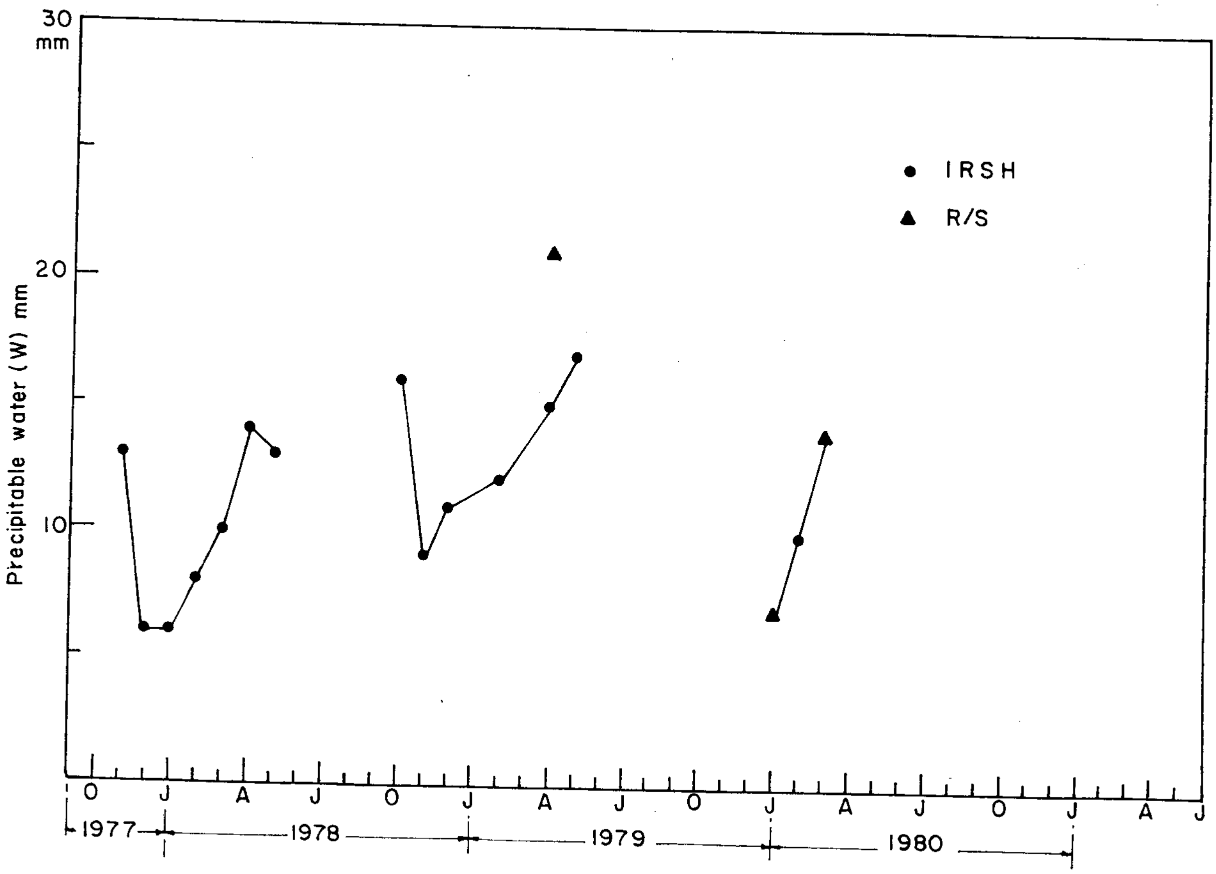


Fig. 5.8 Monthly mean W for the clear months at Nandi Hills for all data

recorded is about 6 mm at Bangalore and 3 mm at Nandi Hills both in January. Bangalore recorded values of 35 mm and above on 10 days and 6 mm or lower on 8 days. Similarly Nandi Hills recorded values of 20 mm and higher on 5 days and 3 mm or lower on 4 days in the months of observations from October to May. There were 220 days with W less than 15 mm at Bangalore during 1977-81 and 17 days with less than 5 mm at Nandi Hills.

The monthly mean values of W obtained using all three techniques during the months October to May are given in Table 5.3.1 and Table 5.3.2 respectively for Bangalore and Nandi Hills.

Table 5.4 gives the monthly mean values of W over Bangalore computed from radiosonde data for the periods 1970-74 and 1980-81, based on ascents taken at the Central Observatory, Bangalore. The 1970-74 data were taken with the Fan type radiosondes then in use and the 1980-81 data with the audiofrequency modulated radiosondes introduced later. The two types of sondes give values of W that agree surprisingly well considering that the sondes use different types of temperature and humidity sensors.

Table 5.3.1: Monthly mean values of W obtained using all three techniques at Bangalore during 1977-81

	JAN	FEB	MAR	APR	MAY	OCT	NOV	DEC	MEAN
1977									
IRSH						20 (13)	17 (11)	9 (11)	15
1978									
IRSH	10 (23)	14 (26)	15 (23)	20 (22)	28 (13)	26 (18)	15 (20)	14 (14)	18
1979									
IRSH	15 (23)	-	21 (26)	26 (16)		21 (6)	-	17 (18)	20
R/S	27 (1)	21 (2)	20 (5)	26 (7)	21 (9)			9 (5)	21
MWR								15 (18)	15
MEAN	21	21	21	26	21	21		14	
1980									
IRSH	10 (19)	15 (22)	14 (16)	16 (18)		17 (3)	19 (16)	15 (20)	15
R/S	11 (9)	13 (9)	19 (2)	20 (2)	21 (2)	28 (23)	21 (16)	19 (30)	19
MWR	11 (21)	13 (23)	20 (14)	30 (26)	32 (22)	24 (25)	17 (21)	16 (26)	20
MEAN	11	14	18	22	27	23	19	17	
1981									
IRSH	16 (20)	10 (24)	18 (26)	21 (18)					16
R/S	16 (29)	13 (25)	20 (28)	25 (28)					19
MWR	16 (30)	15 (22)	21 (26)	24 (29)					19
MEAN	16	13	20	23					

No. of days of observations given within brackets

Table 5.3.2: Monthly mean values of W obtained using all three techniques at Nandi Hills during 1977-81

	JAN	FEB	MAR	APR	MAY	OCT	NOV	DEC	MEAN
1977									
IRSH							13 (3)	6 (19)	10
1978									
IRSH	6 (16)	8 (27)	10 (28)	14 (30)	13 (2)	16 (12)	9 (11)	11 (2)	11
1979									
IRSH		12 (27)		15 (4)	17 (27)				15
R/S				21 (4)					21
MEAN		12		18	17				
1980									
IRSH	7 (17)	10 (4)	14 (18)					11 (18)	11
R/S	7 (2)		14 (10)						11
MEAN	7	10	14					11	

No. of days of observations given within brackets

Table 5.4: Monthly mean values of precipitable water over Bangalore (in mm) computed from radiosonde data (average of OOGMT and 12GMT) for all days during the years 1970-74 and 1980-81 based on ascents at Central Observatory, Bangalore.

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	REMARKS
1970							36	38	36	31	25	16	
1971	20	19	19	25	35	36	35	35	37	34	23	22	
1972	15	20	17	24	32	35	35	34	34	35	28	25	
1973	16	20	16	25	34	37	33	37	35	32	26	15	
1974	14	15	17	24	32	33	35	32	36	33	23	17	
1979		20 (2)	20 (5)	26 (7)	21 (9)	-	-	-	-	-	-	9 (6)	
1980	11 (9)	13 (11)	19 (2)	19 (2)	21 (2)	-	-	-	30*	29*	21*	19*	
1981	16*	13*	20	26									

* 12 GMT

Data for February 1979 to May 1980 are from radiosonde ascents taken at Raman Research Institute. No. of observations are given within brackets.

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	REMARKS
1961 to 1965	19	19	21	28	33	36	37	37	35	33	26	23	Mokashi (1971)
1971 to 1975	15	17	15	23	30	35	35	34	34	31	22	19	Rangarajan and Mani (1982)

Taking the year as a whole, the highest values of W are observed in the cloudy monsoon months June to October, with values of W of the order of 30-37 mm. There is a sudden rise in May from about 25 mm in April to 30 mm in May with the influx of moist air over the station. There is again a dramatic fall in November with the retreat of the monsoon.

Mokashi (1971) and Rangarajan and Mani (1982) have published precipitable water data for Bangalore based on radiosonde ascents. Their values of W for Bangalore are reproduced in Table 5.4. The present results are seen to be in good agreement with the earlier published data.

5.4.3 Frequency distribution of W

The cumulative frequency distribution of daily W at Bangalore for the clear months is shown in Fig 5.9 and W at Nandi Hills in Fig 5.10. The data are based on infrared spectral hygrometer measurements. The curve indicates the percentage of time for which W is equal to or less than a particular value. A similar curve for Bangalore obtained from radiosonde data

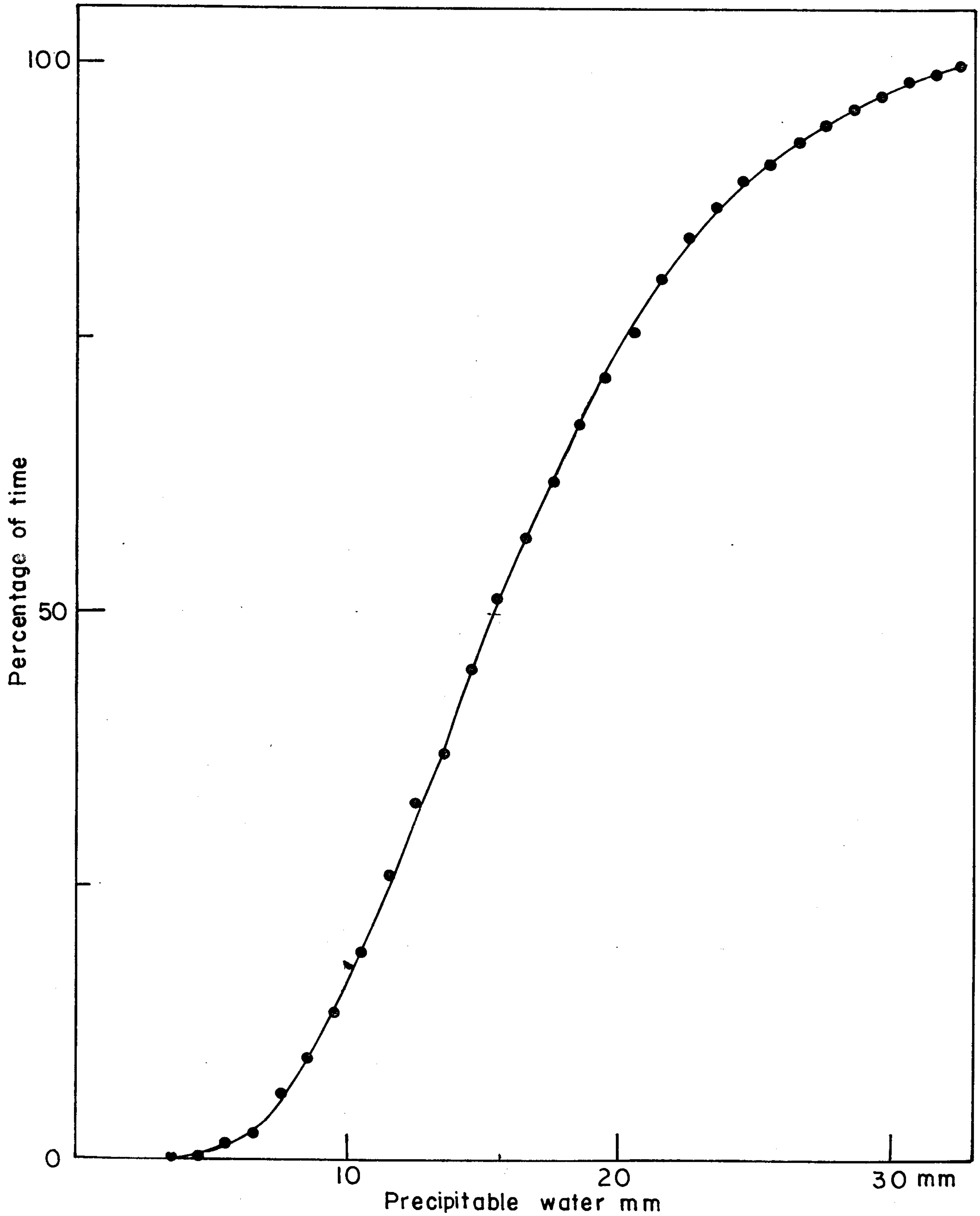


Fig 5.9 Frequency distribution of W at Bangalore from IRSH

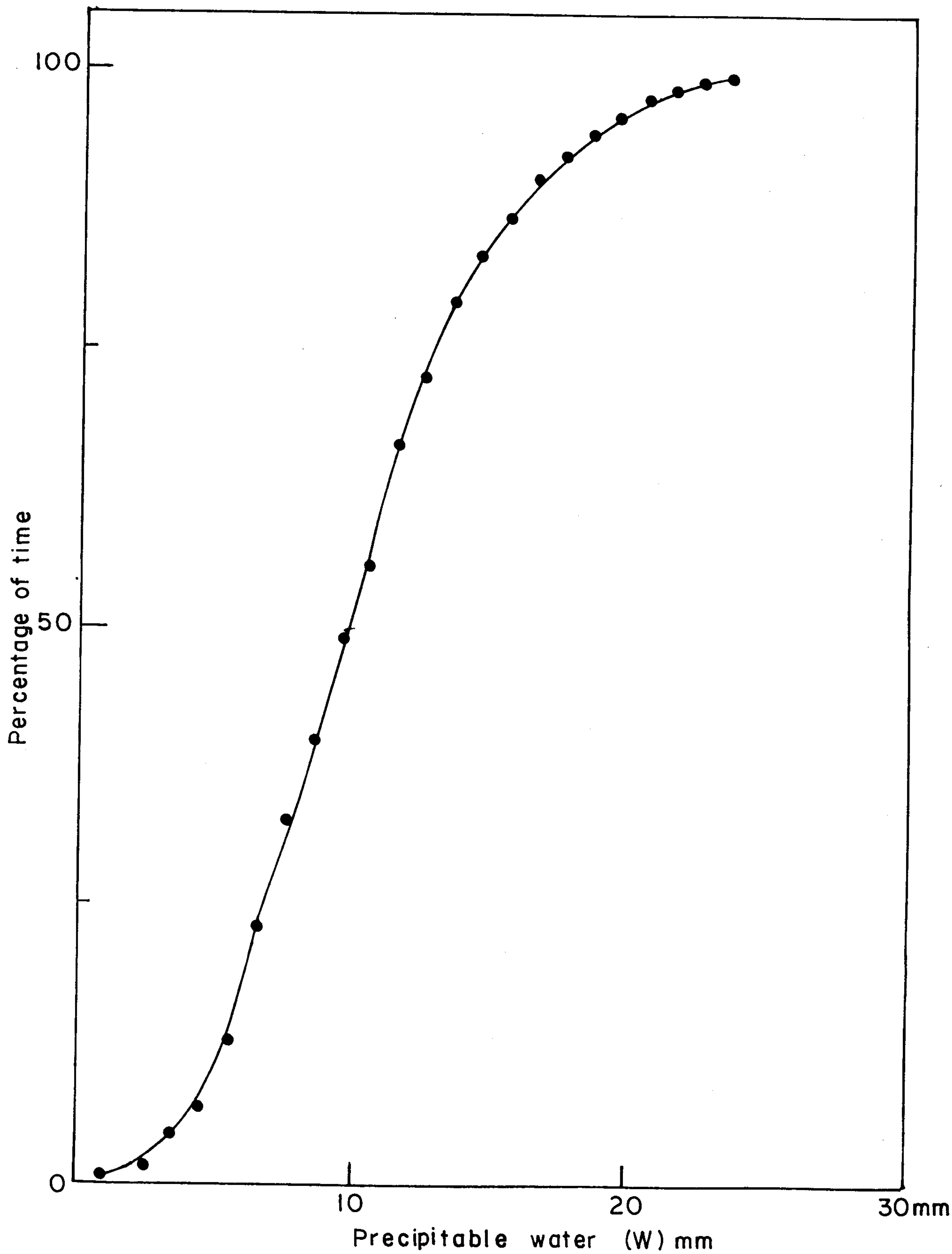


Fig.5.10 Frequency distribution of W at Nandi Hills from IRSH

for 1980-81 are plotted in Fig 5.11 and that obtained from MWR in Fig 5.12. It will be seen that while W is equal to or less than 16 mm, 50 per cent of the time at Bangalore in all three diagrams, during the clear months, the corresponding value for Nandi Hills is about 9 mm. Generally the value of W which corresponds to 50% is taken into consideration, while selecting the suitability of a site for a millimeter wave telescope. This figure rises to 20 mm or more for Bangalore, if data for September and April are included in the analysis, as shown in Figs 5.11 and 5.12.

5.4.4 Diurnal variations in W at Bangalore and Nandi Hills

A study of the hourly variation of W at Bangalore and Nandi Hills on a few representative days showed that at Bangalore (Fig 5.13) W increases slightly towards the afternnon and decreases thereafter on most days, while at Nandi Hills (Fig 5.14) W increases steadily with time reaching a maximum about 1700 hours.

No increase in W during the day were observed during 1980-81 with the microwave water vapour radiometer. On the other hand, the period from early morning till noon shows the minimum W, with the highest values around midnight, the values showing a steady increase with time (Fig 5.15).

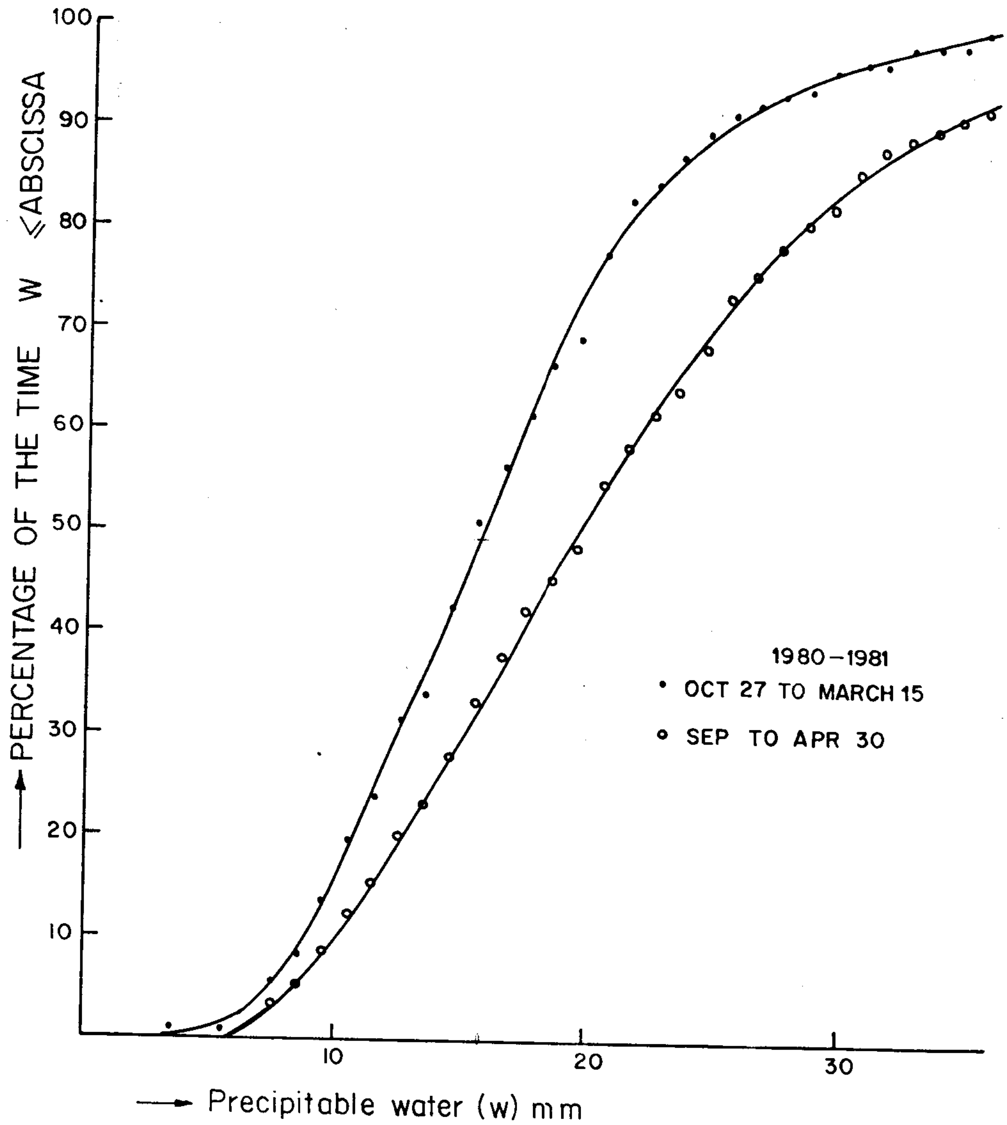


Fig.5.11 Frequency distribution of W at Bangalore from R/S

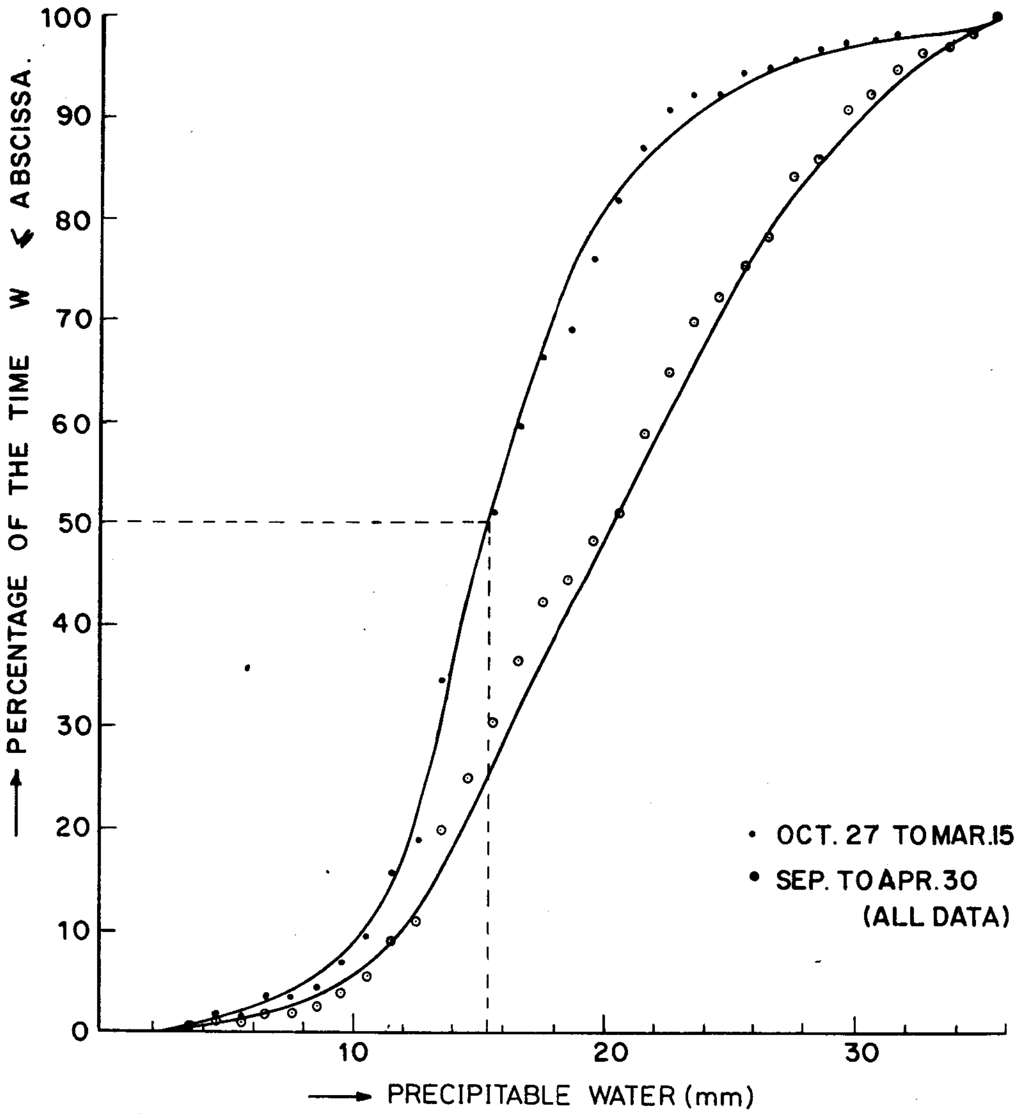


Fig 5.12 Frequency distribution of W at Bangalore from microwave water vapour radiometer.

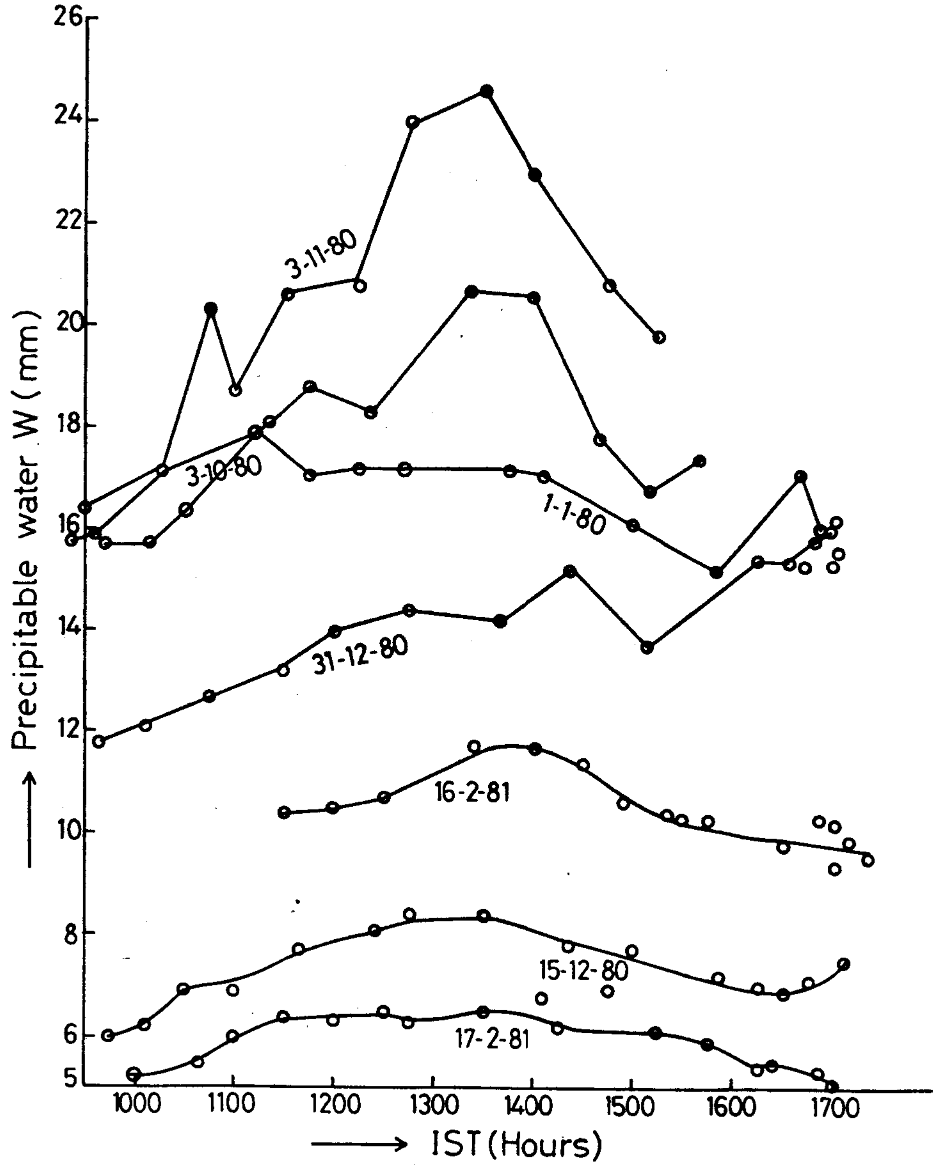


Fig. 5.13. Diurnal variation of W over Bangalore with RRI IRSH

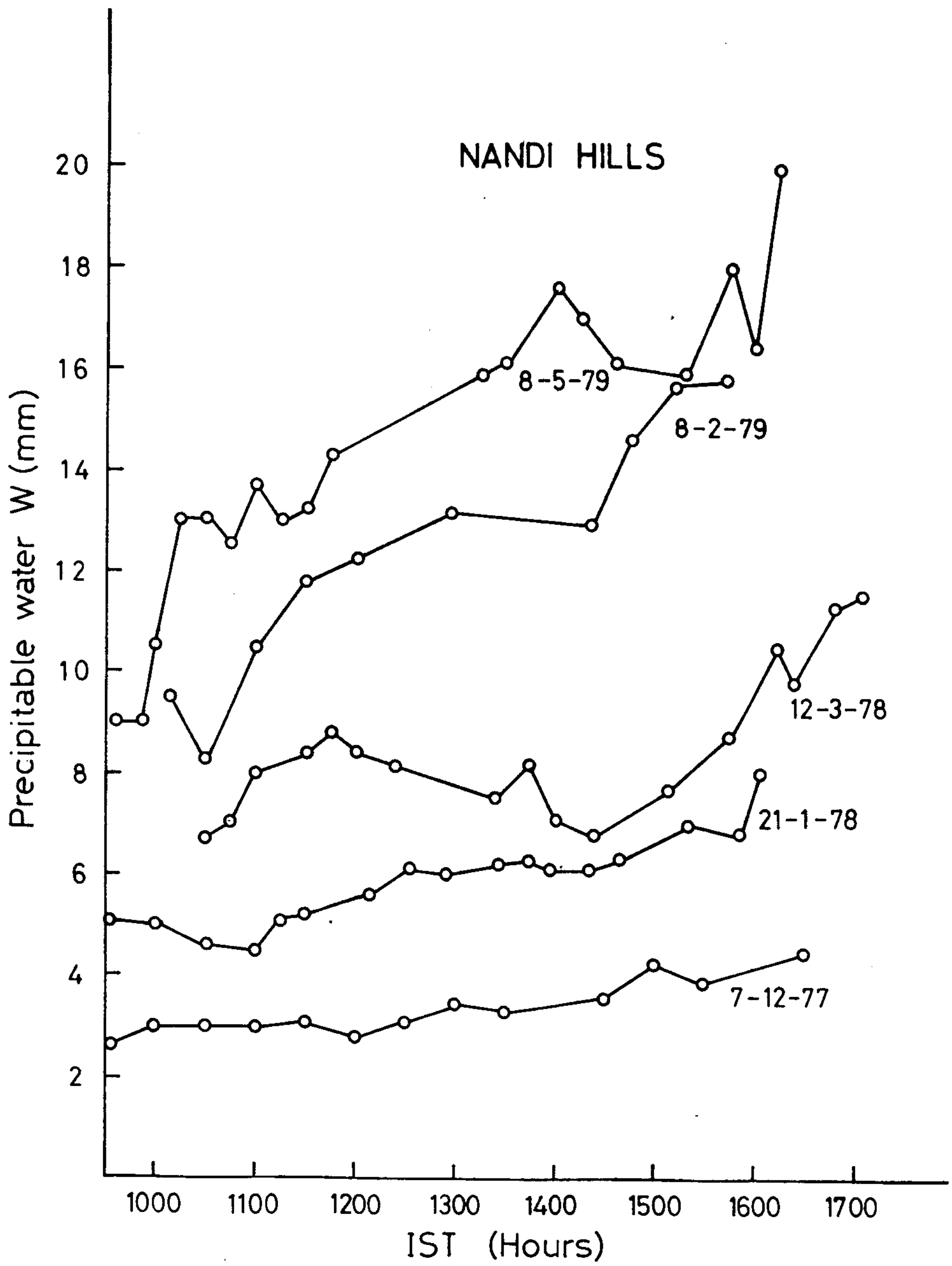


Fig.5.14 Diurnal variation of W over Nandi Hills, with IRAM IRSH

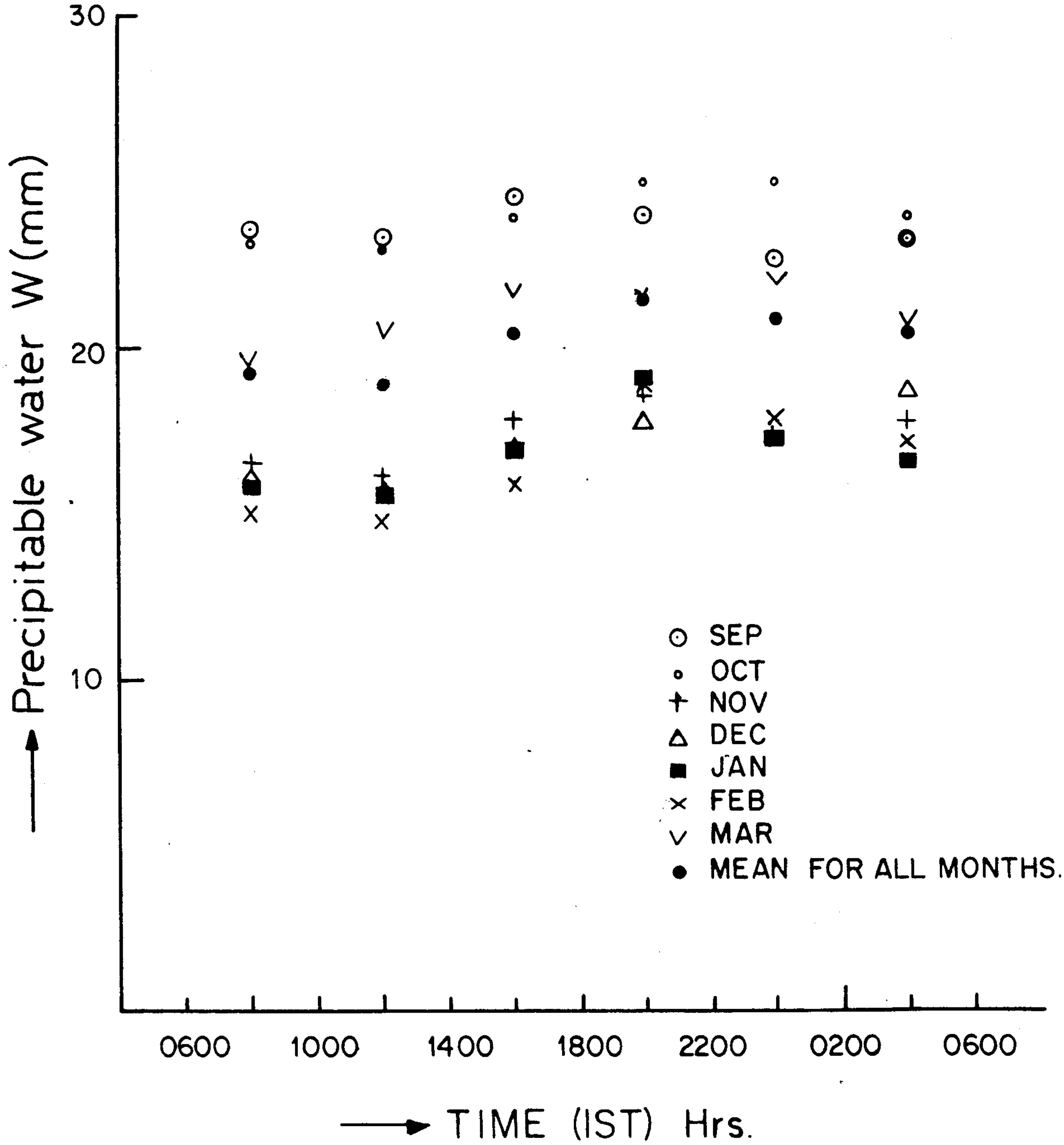


Fig. 5.15 Diurnal variation of W over Bangalore with MWR

Ananthakrishnan et al (1965) had reported a difference in W computed from radiosonde ascents made at 0000 and 1200 GMT, the latter values being higher. Rangarajan and Mani (1982) observed no such changes in W during the day. A number of workers in Europe and USA have reported sudden changes in W during a day. Considering the possible accuracy of measurement and the small differences in W noticed, instrumental errors appear to be more likely to cause the observed differences. For example, the increase observed with the IRAM spectral hygrometer were of the order of 40% while those observed with the RRI instrument were of the order of 15% particularly at large zenith angles. Differential scattering and absorption in the atmosphere might affect the two instruments differently in view of the different absorption frequencies used. A comparison of the daily variations in surface humidity d_v and precipitable water W recorded every 3 hours on a few representative days (Fig 5.16) showed only a negative correlation between the two on most days. This substantiates the earlier conclusion that the observed diurnal variations in W lie well within the error of observations and are not significant.

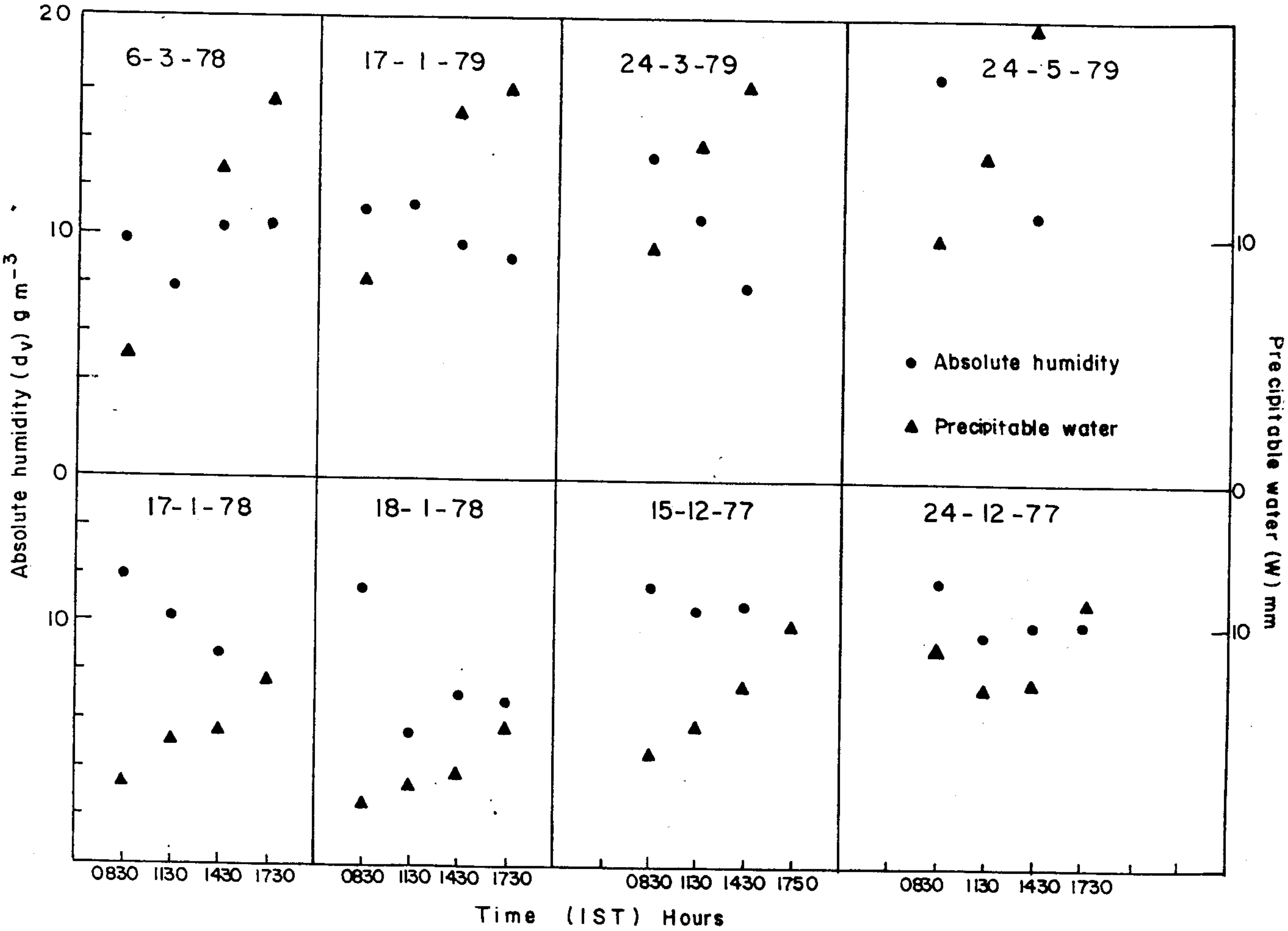


Fig. 5.16 Diurnal variation of d_V and W at Bangalore

5.4.5 Interannual variations in W

The year-to-year variations of W are large. Despite the marked seasonal trend, the pattern that is repeated is not identical each year, with the minimum occuring in different months and the magnitude varying from year to year (Fig 5.7 and Fig 5.8). As these arise from changes in large scale weather patterns, it is difficult to predict the possible occurrence of low W days even in the clearest and driest of months in any year. A similar conclusion was arrived at by Roosen and Angione (1977).

5.5 Variations of precipitable water with altitude

The data presented in Tables 5.1 and 5.2 and Figs 5.5 and 5.6 show the marked influence of altitude on precipitable water in the atmosphere. Table 5.5 lists the values of W at a number of stations in addition to Bangalore and Nandi Hills (Maiya and Dierich, 1981). 50% of the time at the station, the noon value of precipitable water is less than or equal to W given in the table. The W values are corrected for the pressure broadening effect. The last column gives W in a line of sight at the declination of the galactic centre for clear season noon. All the values were obtained with instruments of the IRAM series.

Table 5.5: Comparison of W at different locations

	Latitude °N	Altitude (m)	W (noon) mm H_2O Summer	W (noon) mm H_2O Non Summer	Clear days	Clear nights	W Non Summer (mm)
Bangalore (India)	13	950	22.	20	50	110	26.9
Nandi Hills (India)	13.3	1480	16.5	10	60	75	13.8
Montbel (France)	44.5	1220	25	-	80	100	-
Bordeaux (France)	45	0	27	12	80	100	43.5
Padrille (France)	42.3	2300	8	5	80	110	15.6
Bure (France)	44.5	2550	4.8	1.9	100	135	6.7
Pico Veleta (Spain)	37	3400	3.2	1.9	100	170	4.7
Mauna Kea (Hawaii) (Morrison et al 1973)	19.8	4200	1.2(AV)		198	204	1.8
White Mountain (USA) (Cudaback et al 1973)	37.6	4340	3.2	1.3	155	190	3.3

(Maiya and Dierich, 1981)

Cumulative frequency distributions of W at six stations, Bangalore, Nandi Hills, Bure and La Padrelle and Bordeaux, in France and White Mountain in the USA are given in Fig 5.17 (Maiya and Dierich, 1981).

From the point of view of precipitable water amounts, Nandi Hills stands closer than ~~to~~ Bangalore to stations selected for mm wave telescopes. At Nandi Hills, for 50% of the time during December to March W would be $\leqslant$10mm.

Measurements of the intensity of solar radiation at Bangalore and Nandi Hills (Mani and Chacko, 1980) had shown that on an average, about 18-27% is absorbed by water vapour, carbon dioxide, molecular oxygen, ozone and dust in the lower stratosphere and troposphere. More than half of this absorption 9-18% was found to be due to water vapour in the lower troposphere. The total depletion due to scattering and absorption by atmospheric gases and aerosols was found to be 20% over Nandi Hills and 30% over Bangalore during very clear days. This increased to 37 and 40% respectively with a hazy sky.

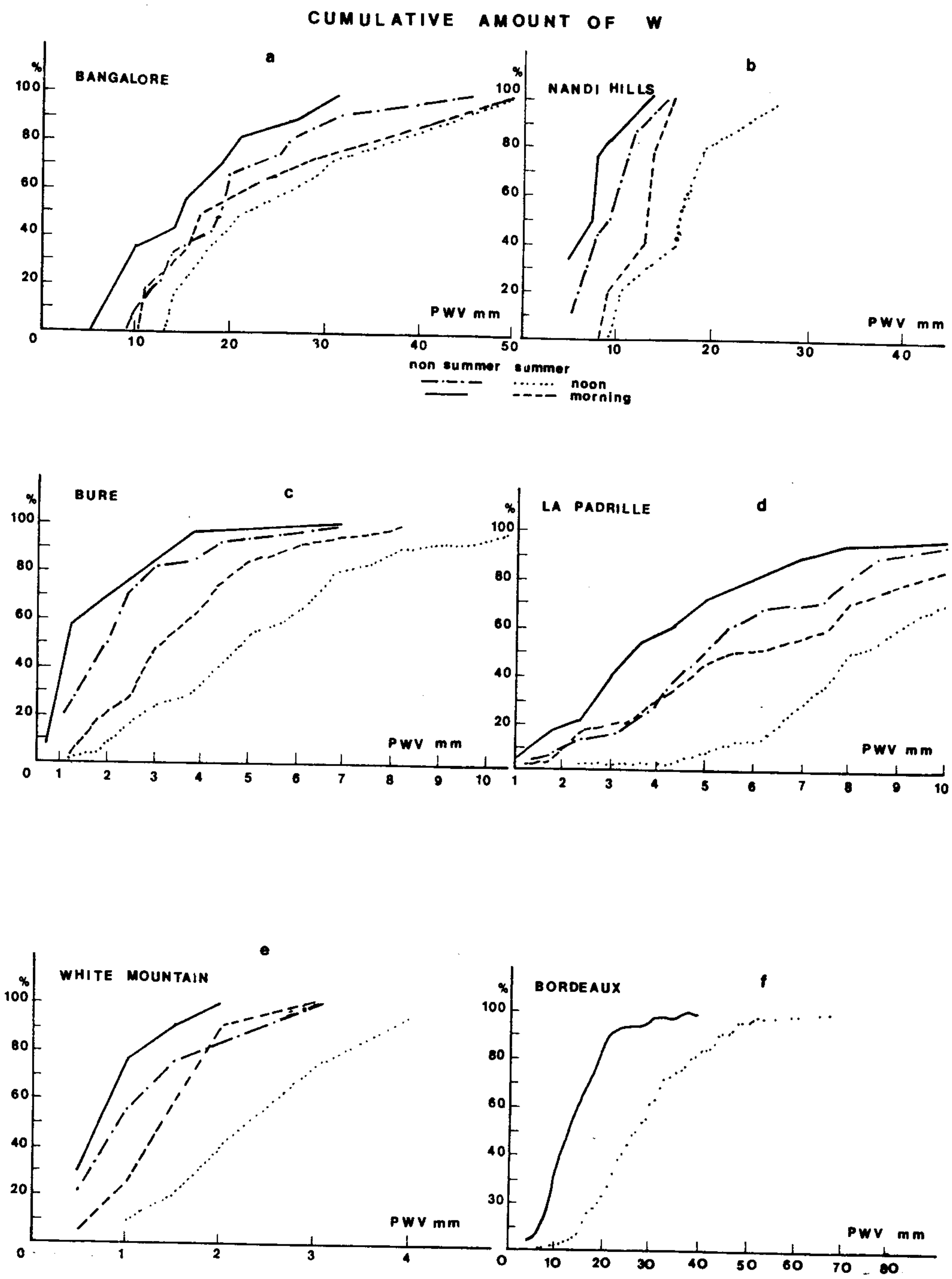


Fig 5.17 Cumulative frequency distribution at Bangalore, Nandi Hills, Bure, La Padrille, White Mountain and Bordeaux.

5.6 Evaluation of Nandi Hills as a suitable site for millimeter wave telescope

From the present study it has been found that at Nandi Hills for 50% of the time of observation, precipitable water is $\leqslant$ 10mm. Assuming this value, an analysis was made to assess the quality of Nandi Hills as a site for a millimeter wave radio observatory, in comparison with other millimeter wave observatories in the world, from the point of view of atmospheric noise. A figure of merit parameter γ can be defined to take into account the degradation due to atmospheric attenuation and noise as the ratio of the actual signal to noise ratio to its ideal value (in the absence of atmospheric attenuation). It is a number always $\leqslant 1$, the ideal value being 1.

It can be shown that:

$$\gamma = \frac{T_s e^{-\tau A}}{T_s + T_m\left(1 - e^{-\tau A}\right)} \qquad (5.1)$$

where T_s is the receiver system temperature, T_m, the temperature of the medium, τ the zenith optical depth due to water vapour and oxygen, A is the air mass in the direction of the source (= sec z) where z is the zenith angle of the source. The zenith angle of a source depends upon the declination δ, hour angle H of the source and latitude ϕ of the place of observation as:

$$\cos z = \cos\delta \cos H \cos\phi + \sin\delta \sin\phi .$$

This figure Υ is calculated for two observing frequencies 115 GHz and 230 GHz for latitudes 13°N (corresponding to that of Nandi Hills), 20°N, 30°N and 40°N. Sagitrius A (Sgr.A) and Orion A (Ori.A) sources which are rich in molecules of various kinds, are taken as the observing radio sources. All the stations are assumed to be at an altitude of 2 km and hence oxygen attenuation is taken to be the same as 0.231 nepers (Ulich, 1980) for 115 GHz and neglected for 230 GHz. Attenuation due to water vapour per mm of precipitable water is assumed as 0.010 neper and 0.062 neper for 115 GHz and 230 GHz respectively. T_m is assumed to be 300°K. The following typical receiver system temperatures T_s for Cassegrain operation are assumed:

Frequency GHz	Uncooled receiver ^oK	Cooled receiver ^oK
115	1200	300
230	2000	600

γ is calculated for W values of 20 mm, 10 mm (corresponding to that of Nandi Hills), 6mm and 3mm. As a result of such calculation the four plots (5.18.1, 5.18.2, 5.18.3 and 5.18.4) are obtained. Fig 5.18.1 and 5.18.2 show γ as a function of hour angle (H.A) for various W and latitudes, for Sgr. A at frequency of operation of 115 GHz and 230 GHz respectively for cooled and uncooled receiver. Fig 5.18.3 and 5.18.4 show the corresponding figures for Ori.A. Fig 5.19.1 and 5.19.2 give variations of γ with latitude (ϕ) and W for meridian observation of Sgr.A and Ori.A respectively.

Table 5.6 gives the maximum value of γ the figure of merit (for H.A. = 0) for Nandi Hills, picked from Fig 5.18. It is about 0.5 for a 115 GHz receiver for a

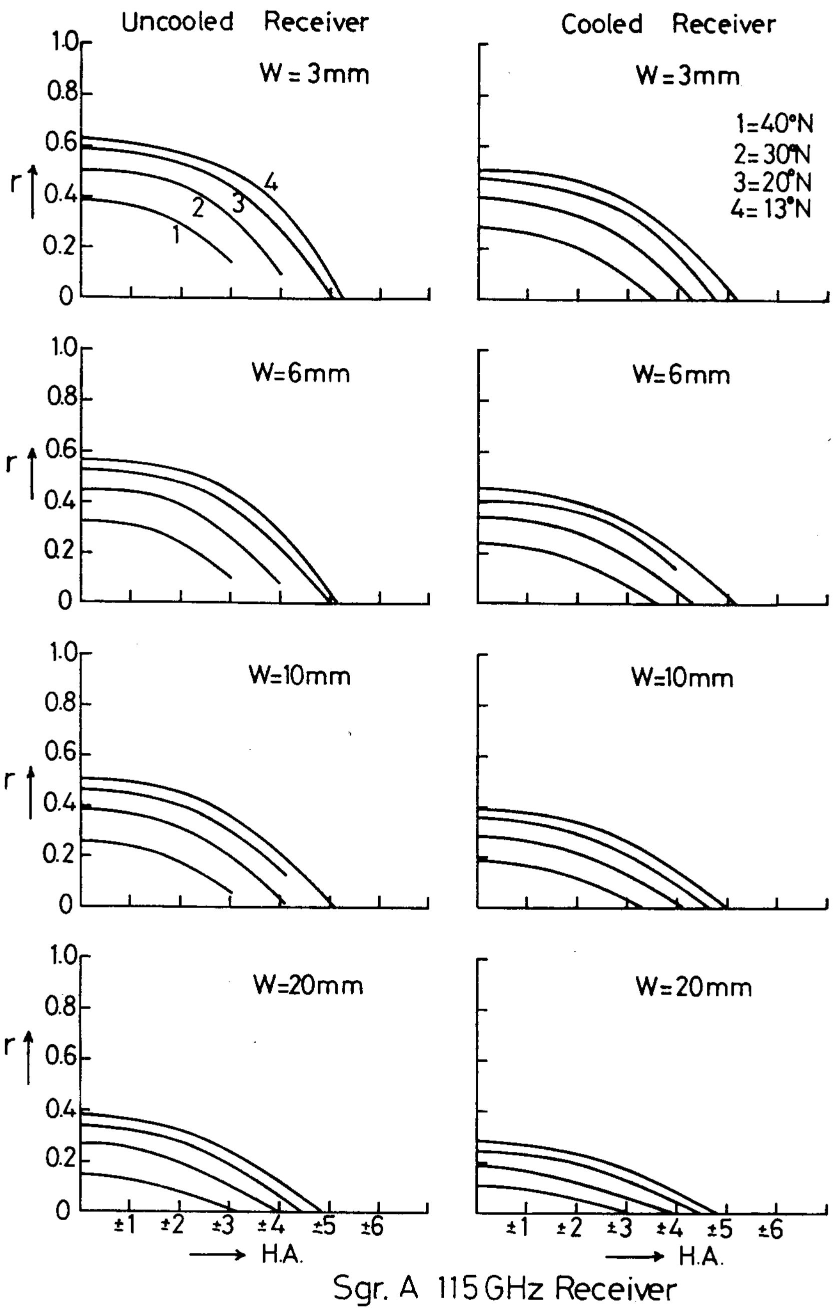
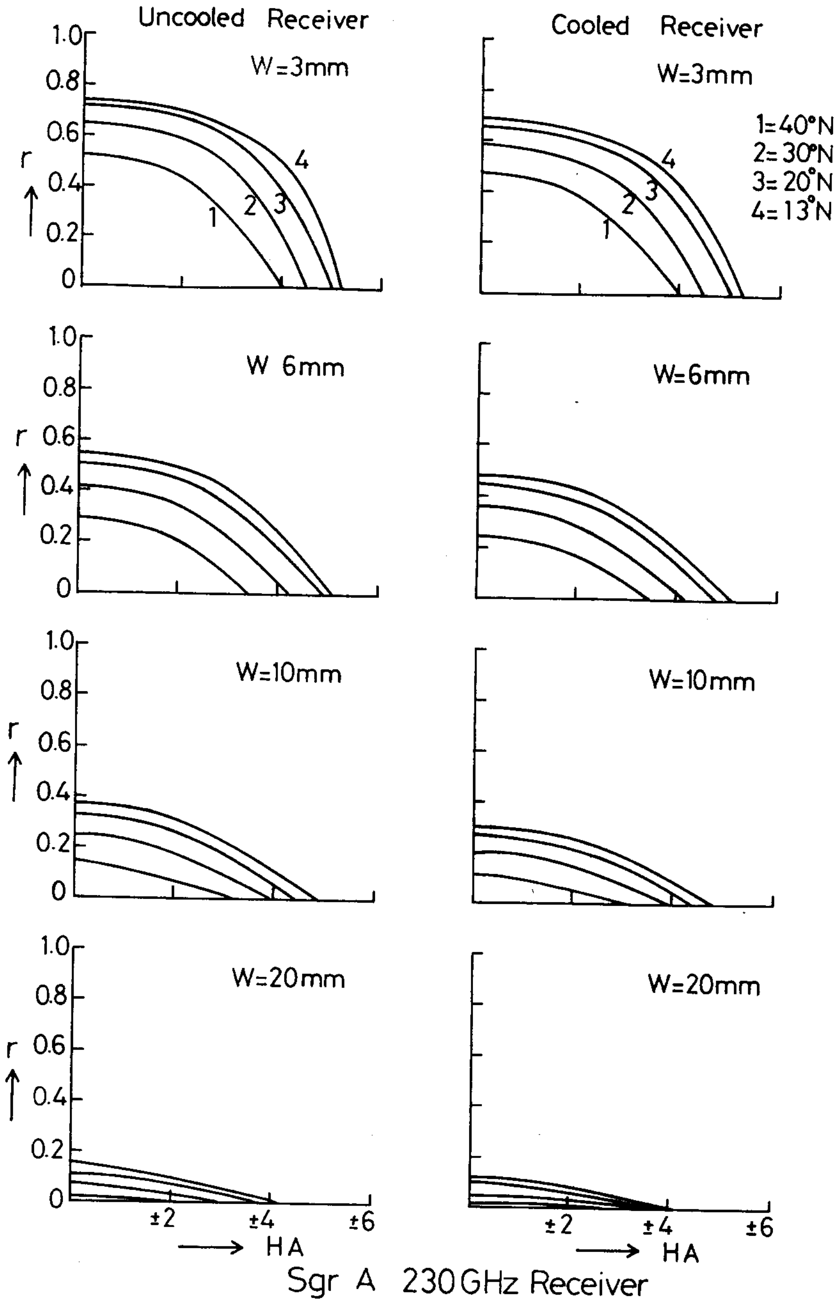


Fig 5.18.1 Figure of merit of atmospheric noise r as a function of hour angle (H.A) for various latitudes and precipitable water W for Sgr. A at 115 GHz for cooled and uncooled receivers.



Sgr A 230GHz Receiver

Fig. 5.18.2 Figure of merit of atmospheric noise r as a function of hour angle (H.A) for various latitudes and precipitable water W for Sgr. A at 230 GHz for cooled and uncooled receivers.

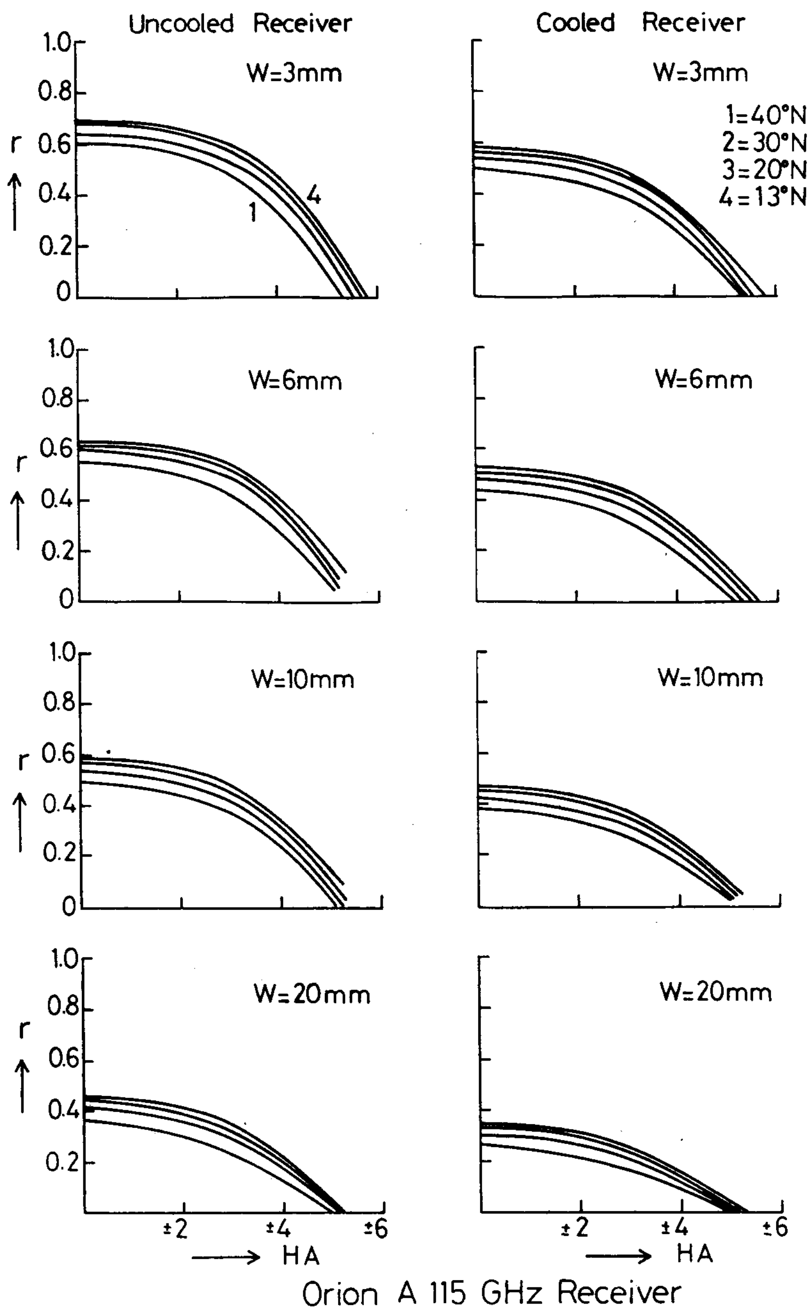


Fig. 5.18.3 Figure of merit of atmospheric noise r as a function of hour angle (H.A) for various latitudes and precipitable water W for Ori A at 115 GHz for cooled and uncooled receivers.

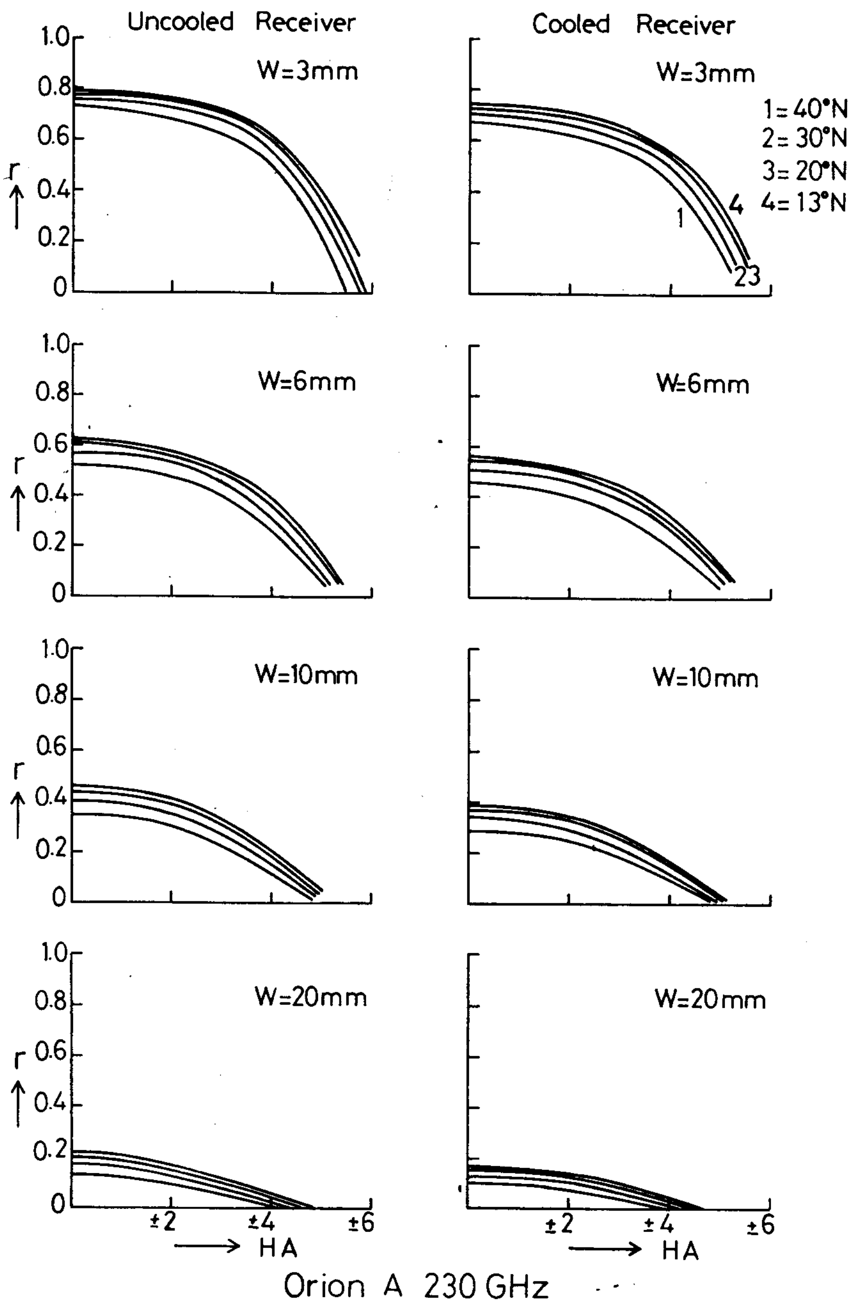


Fig.5.18.4 Figure of merit of atmospheric noise r as a function of hour angle (H.A) for various latitudes and precipitable water W for Ori. A at 230 GHz for cooled and uncooled receivers

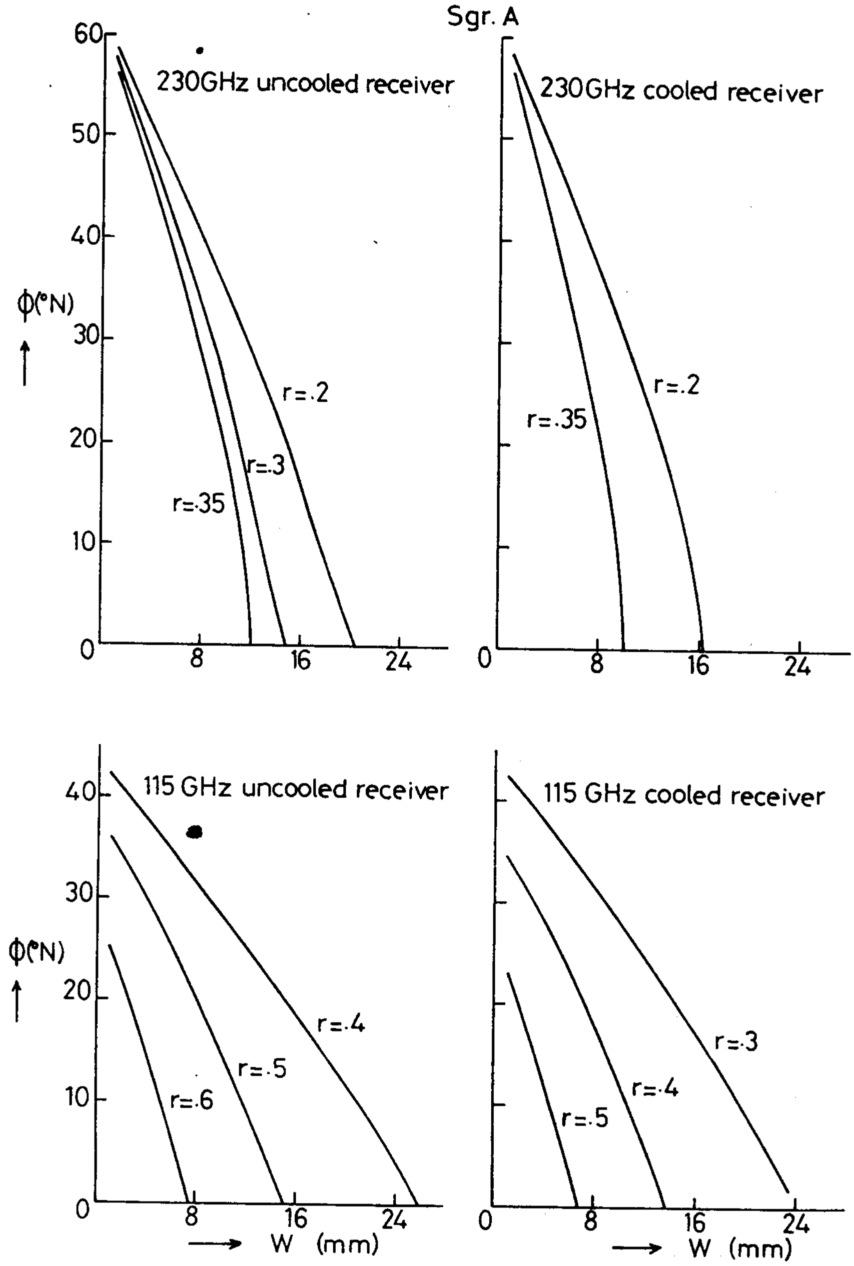


Fig 5.19.1 Variation of atmospheric noise figure of merit r with latitude φ and precipitable water W for meridian observation of Sgr. A at different frequencies and for cooled and uncooled receivers

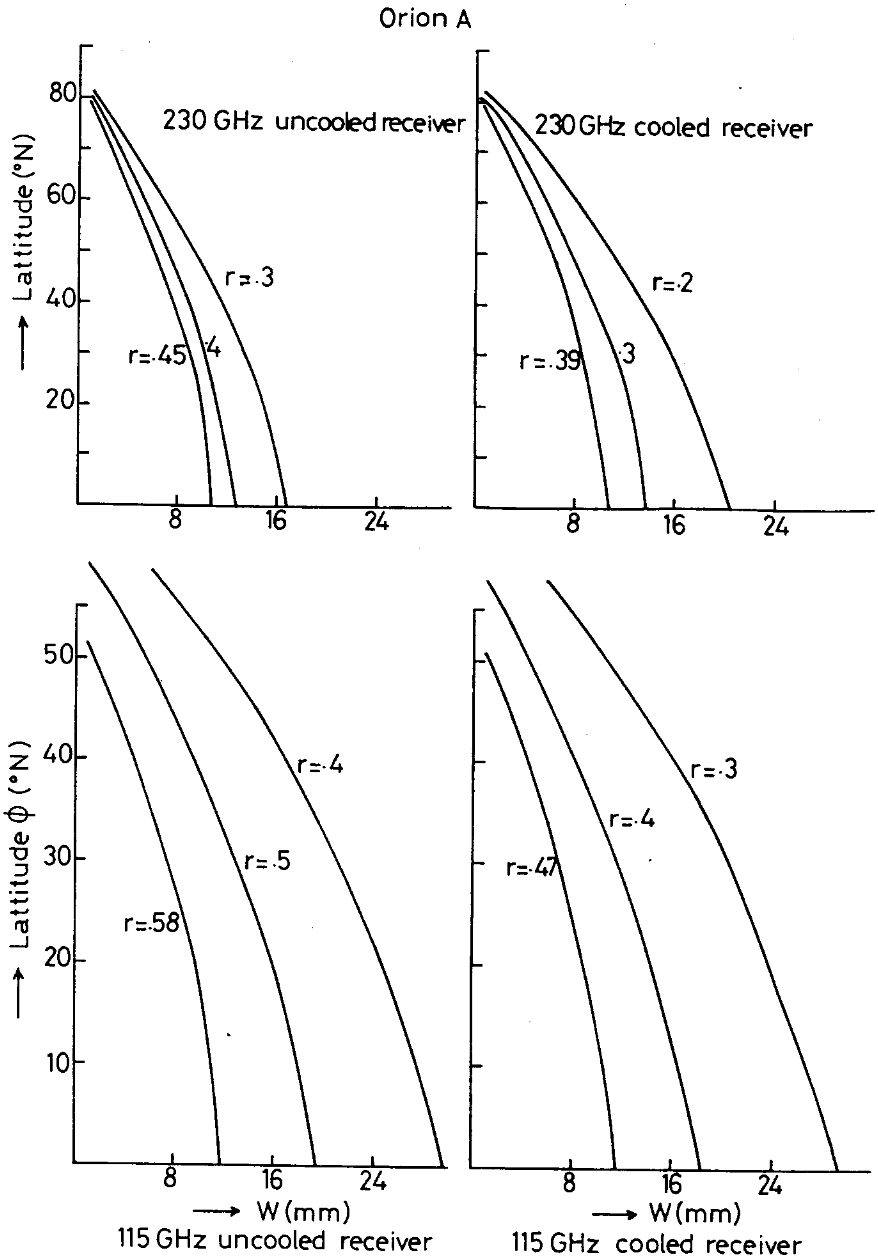


Fig. 5.19.2 Variation of atmospheric noise figure of merit r with latitude ϕ and precipitable water W for meridian observation of Ori. A at different frequencies and for cooled and uncooled receivers.

Table 5.6: Precipitable water W corresponding to a given γ at various latitudes ϕ compared with that of Nandi Hills

Source	Receiver freq. GHz	γ	Nandi Hills Wmm	ϕ= 20°N	ϕ= 30°N	ϕ= 40°N
Sgr.A	115 UC	0.5	10	8	4	0
	115 C	0.4	10	7	3	0
	230 UC	0.4	10	9	7	5
	230	0.3	10	8.5	6.5	5
Ori.A	115 UC	0.6	10	9	7	4
	115 C	0.5	10	9	7	4.5
	230 UC	0.5	10	9.5	9	7.5
	230 C	0.4	10	9.5	8.5	7.5

C = cooled receiver

UC = uncooled receiver

period of about 2 hours when the sources make a meridian transit. Even for 230 GHz receivers, γ is about 0.38. It is to be remembered that for 50% of the time, observations can be made which will be better than indicated by the figures.

Table 5.6 also gives the amount of water vapour content at different latitudes which correspond to a given γ, for H.A. = 0 (The result will hold roughly even for higher H.A.). These are picked from figures 5.19.1 and 5.19.2 It will be seen that in observing Sgr.A at 115 GHz, the Nandi Hills site is equivalent to those at 30°N with a water vapour content of about 4 mm and to those to 40°N with very little W. For Ori.A, at this frequency, Nandi Hills would be as good as a site at 30°N with W of 7 mm and at 40°N with 4 mm of W. Almost similar is the situation for Sgr.A at 230 GHz. These figures suggest that for observations at 115 GHz particularly towards the galactic centre region, Nandi Hills is as good a site as some of the drier sites situated at higher latitudes, and equipped with similar receivers. At 230 GHz, in making observations on Ori.A, Nandi Hills compares well with those sites at higher latitudes with intermediate water vapour content.

The quality of a location for a millimeter wave telescope is also affected by the period for which a given source would be observed with good atmospheric transmission. The number of hours of observations possible in a day, of Sgr.A and Ori.A at the two frequencies with $\Upsilon \geqslant 0.3$ for Nandi Hills and for the northern latitudes considered, are given in Table 5.7. The figures demonstrate that more hours of observation on Sgr.A can be obtained at Nandi Hills than at higher latitudes. All this illustrates that Nandi Hills would be a very reasonable location (atmospheric noise-wise) for siting a telescope to make spectral line observations at 115 GHz of galactic sources.

5.7 Summary

A study of the result of measurements and computation of precipitable water over Bangalore and Nandi Hills during a four-year period 1977-1981 shows that while marked day-to-day, month-to-month and interannual variations in W occur at both stations, the seasonal trend remains basically unaltered with least precipitable water amounts over both stations from December to January. The mean values of W over Nandi Hills are roughly half that over Bangalore and this location, 1479 m above mean sea level,

Table 5.7: Number of hours of observation with $\gamma \geq .3$

Source	Receiver freq. GHz	Nandi Hills W=10mm	ϕ = 20°N W=6mm	ϕ = 20°N W=3mm	ϕ = 30°N W=6mm	ϕ = 30°N W=3mm	ϕ = 40°N W=6mm	ϕ = 40°N W=3mm
Sgr.A	115 UC	7.2	7	7.8	5.4	6.2	2	4
	115 C	5.2	5.4	6.4	3.2	4.4	0	0
	230 UC	4.4	6.6	8.6	4.8	7.4	0	5.4
	230 C	2	5.8	8.4	3.6	7	0	5.2
Ori.A	115 UC	8.6	8.8	9.6	8.6	9.0	7.8	8.4
	115 C	7.2	7.8	8.6	7.2	8.0	6.2	7.4
	230 UC	6.4	8.6	10.4	8.2	9.8	7.6	9.4
	230 C	5.4	8	10	7.6	9.6	6.4	9.0

C = cooled receiver

UC = uncooled receiver

is found to be as good a site for radioastronomical observations as drier sites at higher altitudes and higher latitudes.

LIST OF FIGURES

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5.18.1 Figure of merit of atmospheric noise Υ as a function of hour angle (H.A) for various latitudes and precipitable water W for Sgr.A at 115 GHz for cooled and uncooled receivers.

5.18.2 Figure of merit of atmospheric noise Υ as a function of hour angle (H.A) for various latitudes and precipitable water W for Sgr.A at 230 GHz for cooled and uncooled receivers.

5.18.3 Figure of merit of atmospheric noise Υ as a function of hour angle (H.A) for various latitudes and precipitable water W for Ori.A at 115 GHz for cooled and uncooled receivers.

5.18.4 Figure of merit of atmospheric noise Υ as a function of hour angle (H.A) for various latitudes and precipitable water W for Ori.A at 230 GHz for cooled and uncooled receivers.

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5.19.1 Variation of atmospheric noise figure of merit Γ with latitude ϕ and precipitable water W for meridian observation of Sgr.A at different frequencies and for cooled and uncooled receivers.

5.19.2 Variation of atmospheric noise figure of merit Γ with latitude ϕ and precipitable water W for meridian observation of Ori.A at different frequencies and for cooled and uncooled receivers.

LIST OF TABLES

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