WORLD METEOROLOGICAL ORGANIZATION

PROGRAMME ON PHYSICS AND CHEMISTRY OF CLOUDS AND WEATHER MODIFICATION RESEARCH

WMP

REPORT SERIES

No. 37

REGISTER OF NATIONAL WEATHER MODIFICATION PROJECTS

1999

(includes a preliminary analysis of trends in weather modification activities reported by WMO Members for the period 1975-1999)

WMO/TD - No. 1060

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I. INTRODUCTION

As part of the activities which WMO carries out in its Programme on the Physics and Chemistry of Clouds and Weather Modification Research, a Register of National Weather Modification Projects is kept. The Register has existed since 1975 when the Seventh World Meteorological Congress agreed that an inventory of activities within Member countries related to weather modification should be initiated and maintained. Periodic reviews have all recommended that the Register be continued.

This present Register is the twenty second such publication issued. It is based on information obtained from Member countries on experiments and operations sponsored by government agencies or private concerns that took place during 1999. A feature of this report is a preliminary analysis of the trends (number of countries, methods, types of activity, etc.) reported by WMO Members since the beginning of these registers in 1975. The analysis can be found in Section IX.

To assist the reader in understanding the content of each of the 12 columns used in the tabular presentation found within, detailed explanations are provided in Section II. These columns contain information that was obtained from WMO Member countries in response to questionnaires sent to them in June 2000.

The names of Member countries who provided the information reported in this Register are listed in Sections III. Section VII provides summaries of completed projects and Section VIII indicates which countries reported that no weather modification activities had taken place in 1999.

Requests for further information concerning the projects reported may be addressed to the reporting agency for each country which is indicated in Section V. The WMO Secretariat would be pleased to assist if requested.

II. DETAILED EXPLANATION OF INFORMATION COLUMNS

Column 1: WMO Register No.

This consists of country indicator letters (according to the ISO Standard 3166-1974) and a serial number for each project.

Column 2: Objective of project, type of organization carrying it out

Dev.	=	Development	PE	=	Precipitation Enhancement
Ext.	=	Extend wet period	(E)	=	Emergency
Fog	=	Fog dissipation	(R)	=	Routine
Hail	=	Hail suppression	PR	=	Precipitation Redistribution
Inc.	=	Increase during wet period	Res.	=	Research
Op.	=	Operational			

Column 3: Approximate size of project area

Given in square kilometres for target and control (if any) areas.

Column 4: Name of project

Reference numbers are also quoted when supplied.

Column 5: Location of project area

In some cases where co-ordinates of several points delineating the area were given, these have been replaced by a single point at approximately the centre of the area. Towns and islands may be denoted by name; A/P = Airport.

Column 6: Year project commenced and continuity

Date	--	year project started
Every year	--	indicates project has operated every year
Interrupted	--	indicates project has not operated every year
No	--	indicates project will not be continued
Yes	--	indicates project will be continued
(?)	--	indicates project status is unknown

Column 7: **Nature of organization sponsoring project**

Indicated by abbreviations as follows:

Agr.	=	Agricultural	Muni.	=	Municipal
Def.	=	Defense	(P)	=	Private
Enr.	=	Energy	Rec.	=	Recreation
For.	=	Forestry	Res.	=	Research
(G)	=	Government	Trans.	=	Transportation
Hyd.	=	Hydrological	Wea. Serv.	=	Meteorological

Column 8: **Apparatus, seeding location**

Abbreviations are as follows:

Air	=	Airborne	G/B	=	Ground-Based
A/C	=	Aircraft	Temp.	=	Temperature

Column 9: **Agents, dispersal rates**

Self-explanatory.

Column 10: **Characteristics of clouds treated, seeding criteria**

LWC	=	Liquid Water content	Temp.	=	Temperature
Obs.	=	Observations			

Column 11: **Active period during reporting year**

Months of activity are inclusive.

Jan	=	January	July	=	July
Feb	=	February	Aug	=	August
Mar	=	March	Sept	=	September
Apr	=	April	Oct	=	October
May	=	May	Nov	=	November
June	=	June	Dec	=	December

Column 12: Documentation

"EIS" indicates that an environmental impact study has been made; "C/B" indicates that a costs and benefits analysis has been made.

III. MEMBER COUNTRIES REPORTING 1999 PROJECTS

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IV. REGISTER OF 1999 REPORTED PROJECTS

AUSTRIA											
AUS-1	Op. Hail	1,800 km^2	Hail Test Program – STYRIA	(46°50' N 15°45' E)	1985 Every year Yes	Agr. (P)	3 A/C with acetone burners and pyrotechnic flares for seeding cloud bases	AgI 11 l/hour Annual consumption 153 kg	Convective clouds, bases colder than 10°C and tops colder than -20°C. Seeding criteria: subjective decision based on regional weather forecasts and C-Band radar data	April-August	Evaluation based on historical records, crop damage and hail pad data, a 15-year report planned for 2001 EIS-No C/B – No
AUS-2	Op. Hail	500 km^2	Hail Test Programme Lower Austria (HTP-NOE)	48°25' N 15°35' E, Lower Austria	1981 Every year Yes	Agr. (P)	3 A/C with acetone burners and pyrotechnic flares for seeding cloud bases	AgI, 11 l/hour Annual consumption 32 kg	Convective clouds with bases colder than 10°C and tops colder than -20°C. Seeding criteria:. subjective decision based on regional weather forecasts and C-Band radar data	April - Sept 19 days.	Evaluation, based on historical records, crop damage and hail pad data, report planned for 2001 EIS-No C/B –No
BULGARIA											
BG-1	Op. Hail	15,360 km^2	Bulgarian Hail Suppression Project	NW Bulgaria 43° 20' –44° 00'N 22°30' –24°40' E South Bulgaria 42° 00'–42° 35'N 24° 00' –26° 30'E	1969 Interrupted Yes	Agr. (G)	Rocket-based pyrotechnic flares for in-cloud seeding at temperatures 0 to –10 C	AgI, 41 g/rocket Annual consumption: 106,5 kg	Convective clouds, bases warmer than 10°C, tops colder than -20°. Seeding criteria based on radar echo, cloud heights or cloud top temperature and reflectivity	June - Sept. 32 days	Evaluation based on comparison with historical records. Evaluation document done but not available to WMO EIS – No. C/B – No.
BURKINA FASO											
BF-1	Res. Op. PE Ext. Inc	Total: 40,000 km^2 Target: 15,000 km^2	SAAGA	Central Burkina Faso Nakambe River Basin	1998 Every year Yes	Environ-mental agency (G)	Ground - based seeding at temperatures –5 and –10°C with 9 acetone burners	A mixture of AgI, NaCl and acetone at a rate of 1 l/hour, propane also used.	Convective clouds, bases warmer than 10°C, top temperatures between 0 and -20°C. Seeding criteria : presence of crystals and in-cloud temperatures between –5 and –12°C.	June- July 17 days	Evaluation based on a comparison with historical records. EIS – No. C/B – No.

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CANADA											
CAN-1	Op. Hail	26,400 km^2	Alberta Hail Suppression Project	Province of Alberta (Lacombe to High River)	1996 Every Year Yes	Ins. (P)	Seeding cloud-base and cloud-top at temp. –5 to –10°C with acetone burners and pyrotechnic flares from 3 A/C	AgI, Flares: one 20g flare every 5 sec. In cloud top and 150g flare / run at cloud base. Annual consumption: 184 . 3 kg and 20.4 kg AgI acetone solution	Convective clouds bases colder than 10°C, tops colder than -20°C. Seeding criteria : radar-defined cells with max. reflectivity of no less than 35dBz above -5°C level.	15 June-15 Sept , 46 days	Evaluation based on comparison with historical records, no document planned EIS-No C/B - No
CHINA											
CN-1	Dev. PE Hail				1959 Interrupted Yes		In-cloud seeding of growing cells at temperatures below 0°C using rockets and artillery shells	AgI, 1-3 g per shell. Total consumption : 29.6 kg	Convective clouds with bases warmer than 10°C and tops colder than –20°C. Seeding criteria based on type of synoptic system and radar data	April - Sept.	Evaluation based on comparison with historical records and crop damage data. No document planned. EIS - No C/B – No
CN-2	Res. Op. Dev. PE Hail	150,000 km^2				Agr. (G) Res (G) Wea. Ser. (G)	In-cloud seeding at temp. –6 to – 12°C with 4 A/C, rockets and shells ; Ground-based seeding with 800 acetone burners.	AgI. Annual consumption : 100 kg	Convective and stratiform clouds with bases warmer than 10°C and tops colder than –20°C. Seeding criteria: cloud top temperature not less than – 10°C.	April - August, 160 – 200 days	Evaluation based on comparison with historical records and crop damage data. Some experiments were randomized. No document planned. EIS - No C/B – Yes

IV. REGISTER OF 1999 REPORTED PROJECTS

CN-3	Res. PE (E) (R) Hail Fog	Target: 6,800 km^2 Control: 2,000 km^2	Precipitation Enhancement	Catchments of two reservoirs in Beijing province	1990 Every year Yes	Agr. (G)	In-cloud seeding with one A/C using liquid nitrogen generators. Rockets and artillery shells used for hail suppression.	Liquid nitrogen, 1,080 kg/hour Total consumption : 980 kg	Stratiform clouds with bases colder than 10°C, top temperature being between 0 and –20°C. Seeding criteria presence of stratiform clouds.	January – December for precipitation enhancement May – October for hail suppression	Evaluation based on randomization No document planned. EIS - Yes C/B – No
CN-4	Res. Dev. Op. PE (E) (R) Hail	Target: 150,000 km^2	Project of Precipitation Enhancement and Hail Suppression of Shandong Province	Shandong Province	1987 Every year Yes	Wea. Ser. (G)	In-cloud seeding at –5 to –10°C with 2 A/C using acetone burners. Rockets and artillery shells used for hail suppression.	AgI, 320 or 640 g per hour. Total consumption (including rockets and shells) : 39.1 kg	Convective and stratiform clouds with bases colder than 10°C, top temperature being between 0 and –20°C. Seeding criteria : cloud top temperature between –10 and –25°C, the cloud base lower than 1.5 km, cloud depth in excess of 2 km. In-cloud liquid water content is measured.	March – October , 157 days	Evaluation based on randomization No document planned. EIS - Yes C/B – Yes
CN-5	Res. Op. PE (R) Hail	Target: 200,000 km^2 Control: 600,000 km^2		Jilin Province	? Every year Yes	Agr. (G) For (G) Hyd (G) Wea. Ser. (G)	Ground-base cloud top and in-cloud seeding at temperatures below -10°C and – 20°C. Rockets used for hail suppression.	Dry ice, 100 – 1000 g per km. Annual consumption: 1100 kg	Stratiform and convective clouds with bases colder than 10°C and tops colder than –20°C. Seeding criteria: cloud base below 1.5 km, cloud depth in excess of 600 m, cloud top above the –20°C level	April - July, 100 days	Evaluation based on comparison with historical records and hail pad data. Evaluation document is available. EIS – No C/B – Yes

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CN-6	Dev. Op. PE (E) Inc. Hail	Target: 3,500 km^2	-	-	-	Agr. (G,P)	In-cloud seeding with rockets and artillery shells at temp. –6 to –15 C .	AgI, 10 g per min Total annual consumption: 200 kg	Convective, orographic and stratiform clouds with bases colder than 10 C and tops colder than – 20 C. Seeding critaria: For hail suppression – cloud top height 4 – 7 km, radar reflectivity 40 dBz; For precipitation enhancement – Radar reflectivity 25 dBz.	May - October for precipitation enhancement May - September for hail suppression. Totally, 240 days	Evaluation based on comparison with historical records, crop damage and hail pad . EIS- No C/B- No
CN-7	Op. PE (E) (R) Hail	Target: precipita-tion enhance ment – 10,000 km^2 hail - 11,000 km^2	Project of Precipitation Enhancement and Hail Suppression	32 – 39 N 106 – 111 E Shaanxi Province	1988 Every year Yes	Agr. (G,P)	In-cloud seeding with one A/C, rockets and artillery shells at temp. below – 5 C .	AgI, 1.75 kg/hour during precipitation enhancement and 200 g per cloud during fog suppression. Total annual consumption: 35 kg	Convective and stratiform clouds with bases warmer than 10 C and top temp. between 0 and – 20 C. Seeding critaria: Radar reflectivity in excess of 15 dBz, cloud base below 1000 m, cloud top above 5.0 km	For precipitation enhancement - March-June and Set. – Oct., totally, 40 days. For hail suppression – totally 30 days.	Evaluation based on comparison with historical records and hail pad data. No document available EIS-No C/B-Yes
CN-8	Res. PE (E)	Target: 2,500 km^2	The Experiment of Precipitation Enhancement with Rockets	Hubei Province	1996 Every year Yes	Res. (G)	In-cloud seeding with pyrotechnic flares on rockets at temp. between – 3 C and – 6 C.	AgI. Total annual consumption: 500g	Convective clouds with bases warmer than 10 C and top temp. between 0 and – 20 C. Seeding critaria: Radar reflectivity no less than 30 dBz, cloud top above 7 km	June - September	Evaluation based on comparison with historical records . EIS-No C/B-Yes

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CN-9	Op. PE (R) Hail	Target: 150,000 km^2	Precipitation Enhancement in Spring	Guangxi Province	1990 Every year Yes	Agr. (G) Hyd. (G)	Cloud-top and in-cloud seeding with one A/C, rockets and artillery shells at temp. below – 2 C .	AgI, 250 g/hour . Total annual consumption: 20 kg	Convective and orographic clouds with bases warmer than 10 C and top temp. between 0 and – 20 C. Seeding critaria: cloud top above 5.0 km or Radar reflectivity in excess of 25 dBz	For precipitation enhancement - March-June and Set. – Oct., totally, 40 days. For hail suppression – totally 30 days.	Evaluation based on comparison with control area and hail pad data. No document available EIS- Yes C/B-Yes
CN-10	Op. PE (E) (R) Inc. Hail	Target: 10,000 km^2	Yunnan Weather Modification	-	1960's Every year Yes	Agr. (G) Enr. (G) For. (G) Hyd. (G) Wea. Ser. (G)	In-cloud seeding with explosives and pyrotechnic flares on rockets and artillery shells at temp. between 0 and –10 C .	AgI, 30 g/cloud . Total annual consumption: 90 kg	Convective clouds with bases warmer than 10 C and top temp. between 0 and – 20 C. Seeding critaria: Radar reflectivity in excess of 30 dBz	May – October 150 days	Evaluation based on comparison with historical records, crop damage and hail pad data. No document available EIS- No C/B-Yes
CN-11	Op. PE (E) (R) Inc. Hail	Target: 100,000 km^2	National Precipitation Enhancement and Hail Suppression	38^{0}30'–43^{0}30' N 119^0 –126^0 E Liaoning	1992 Every year Yes	Agr. (G)	In-cloud seeding with explosives on rockets and artillery shells and with acetone burners on 2 A/C	AgI, 0.36 kg/hour Total annual consumption: 11 kg	Convective and stratiform clouds with bases warmer than 10 C and top temp. between 0 and – 20 C.	April -August	Evaluation based on comparison with historical records. No document available EIS- Yes C/B-Yes

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CN-12	Res. Dev. Op. PE (E) (R) Inc. Hail	Target: 167,000 km^2	Weather Modification and Hail Suppression Optimal Technique Research	Hehah Province	1988 Every year Yes	Agr. (G)	Cloud-base and in-cloud seeding with 300 acetone burners from ground and 1 A/C and with explosives on rockets and artillery shells . In-cloud seeding is performed at temperatures between – 4 and –10°C.	AgI Total annual consumption: 10 kg	Convective and stratiform clouds with bases colder than 10°C and top temp. between 0 and – 20°C.	March – November, March – July, 57 days	Evaluation based on comparison with historical records. Evaluation document available EIS- Yes C/B-Yes
CROATIA											
CR-1	Op. Hail	24,000 km^2	Hail Suppression	North Croatia, between Sava and Drava Rivers	1970 Every year Yes	Agr. (G) Wea. Ser. (G) Ins. (P)	Ground- based seeding with 491 acetone burners and in-cloud seeding with rockets.	AgI, 10.5 kg per seeding day. Total consumption: 630 kg	Convective clouds with bases warmer than 10°C and tops colder than –20°C. Seeding criteria: cloud tops above –28 C level and top of 45 dBz echo in excess of 1.4 km above 0C level.	May – Sept. 60 days	Document on evaluation planned and will be available internationally when finished. EIS-No C/B -No
FRANCE											
FR-1	Res. Op. Hail	Target: 60,000 km^2 Control: 420,000 km^2	ANELFA	Aguitan and Rhodanian basins and Loire valley	1952 Every year Yes	Agr. (P)	Ground based seeding with 661 acetone burners	AgI, 8g/hour per burner. Total consumption : 1002 kg	Convective clouds with bases warmer than 10°C and tops colder than –20°C. Seeding criteria: hailstones with diameter exceeding 15mm predicted	April - Oct. 54 days	Evaluation based on data on measured hail diameter EIS-Yes C/B Yes

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GERMANY											
GE-1	Res. Op. Hail	4,000 km^2	Hagelabwehr/ Hagelforschungs-verein Rosenheim	Northern side of the Alps , hilly terrain between 500-1900m	1975 Every year Yes	Municipal	Cloud base seeding with acetone burners from 2 A/C	AgI, 0.5kg/hour Total annual consumption: 40 kg	Convective clouds with bases warmer than 10°C and tops colder than 0°C but warmer than –20°C. Seeding criteria: based on temp, type of advection, vertical windspeed, humidity, fronts, troposphere height, radar echoes, infrared satellite photos and sferics	May - Sept. 19 days	Estimation based on documented hailfall. Evaluation document available. EIS-No C/B-No
GE-2	Res. Dev Fog	-	University Cottbus	Berlin	1999 Yes	Res. (P)	Ground-based seeding with dry-ice	-	Fogs Seeding criterion: presence of fog	November	Evaluation based on fog microstructure measure-ments. Evaluation document exists but not available internationally. EIS- Yes C/B - Yes
GREECE											
GR-1	Res. Op. Hail	2,500km^2	Hellenic National Hail Suppression Project	NW Greece	1984 Interrupted Yes	Agr. (G)	Cloud base, in-cloud and cloud top seeding with pyrotechnic flares from 2A/C. In cloud seeding between –8°C to –10°C	AgI	Convective clouds with bases colder than 10°C and tops colder than -20°C..	Apr - Sept.	Evaluation based on comparison with historical records., crop damage and hail pads. Final evaluation available in 2000 EIS-Yes C/B-Yes (to be available in 2000)

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ISRAEL											
IS-1	Op. PE (R)	Target 5,000 km^2 Control 1,500 km^2	Israel Enhancement Project	Northern Israel	1960-1975 Experi- mental. Since 1975- operational Every year Yes	Agr (G) Hyd (G)	40 G/B acetone burners and 3 A/C with acetone burners seeding at cloud base	AgI G/B at 12 g/hour each. A/C at 500 g/hour each	Convective clouds with bases colder than 10°C, tops both warmer and colder than –20°C. Microstructure of unseeded clouds measured. Seeding criteria cloud tops below –8°C .	Nov - April	Evaluation based on historical records. Document available EIS-No C/B-Yes
JAPAN											
JP-1	Res. PE (E) PR	500 km^2	Study on feasibility Of orographic snow cloud modification by seeding	Nigata and Gunma prefectures	1994 Every year Yes	Wea. Serv. (G)	Cloud top seeding with dry ice from 1A/C	Orographic clouds with bases colder than 10°C with tops colder than 0°C but warmer than –20°C. Microstructure of unseeded clouds measured. Seeding criteria: cloud top temp warmer than –25°C, depth- integrated liquid water content in excess of 0.2 mm, horizontal uniformity of clouds	Dry ice at 30g per second Consumption 200 kg per season	Jan - March Nov - Dec. 21 days	No evaluation planned EIS-No C/B-No

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JORDAN											
JOR-1	Op. PE (E) (R) PR Ext. Inc.	23,000 km^2	Jordan Precipitation Enhancement Project PEPJ	North and West Jordan	1986 Every year Yes	Wea. Serv.	G/B seeding With 22 acetone burners. Cloud top and in-cloud seeding from 1A/C	Convective and orographic clouds with tops colder than 0°C but warmer than –20°C. Seeding criteria: approach of depressions and/or unstable conditions	Airborne : AgI, 240 g/hr G/B : 12 g/hr from each acetone burner. Total annual consumption: 50 kg	Jan - May and Oct. to Dec.	Evaluation to be made available EIS-No C/B-Yes
MACEDONIA, THE FORMER YUGOSLAV REPUBLIC OF											
MAC-1	Op. Hail	25,000 km^2	Hail Suppression Project	Republic of Macedonia	1971 Every year Yeas	Agr. (G) Wea. Serv.	In-cloud seeding with rockets and artillery shells at –4 to –10 C	Ag I, 400 g per each rocket/shell. Total annual consumption: 50 kg	Convective clouds with bases colder than 10 C and tops colder than – 20 C. Seeding critaria based on weather forecast and numerical models	June-Oct	Evaluation based on comparison with historical records and crop damage statistics. EIS – No C/B - No
MADAGASCAR											
MAD-1	Op. PE Ext.	10.000 km^2	-	17°30' S 48°30' E	? Interrupted (?)	Agr. (G) Wea. Serv. (G)	In cloud seeding from A/C at positive temperatures (1-2 C)	NaCl , 5 kg/hour	Convective clouds with bases colder than 10°C and tops warmer than –20°C but colder than 0°C. Seeding criteria: favorable conditions for convection, presence of convective and Cb clouds	January – February, December	Evaluation based on comparison with historical records.

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MALAYSIA											
MA L-1	Op. PE(E)	Whole country	Drought Operation	Whole country	1997 Every year Yes	Wea. Serv. (G)	In cloud seeding With NaCl liquid spray from 2 A/C	NaCl , 100 kg per day Total annual consumption : 5,400 kg	Convective clouds with bases warmer than 10°C top warmer than –20°C but colder than 0°C. Seeding criteria: Cu cloud with top at least 15,000 ft.	July – August, 54 days	No evaluation provision EIS-No C/B-No
MOLDOVA											
MO L-1	Op Hail	21,250 km^2	Prevention of Hail Damage	60 % of the national territory	1964 Every year Yes	Agr (G)	In-cloud seeding from rockets with pyrotechnic flares at the –6 to –9°C level	AgI Total consumption: 70 kg	Convective clouds with bases warmer than 10°C and tops colder than –20°C. Seeding criteria: top of convection level, wind shift, height of the freezing level, radar reflectivity and mesoscale conditions.	May to August About 31 days	Evaluation based on comparison with historical records and crop damage. Report available EIS-Yes C/B-Yes
MOROCCO											
MO -1	Op. Res. Dev. PE (E) R Inc.	16,400 km^2 target 9,600 km^2 control	Al Ghait	High Atlas Central basin of Oum-Rbia Basin oued el Abid	1984 Every year Yes	Wea. Serv. (G)	Seeding cloud tops , bases and in-cloud with 15G/B acetone burners and pyrotechnic flares from 2 A/C. Seeding performed in region 0°C to –5°C in the presence of both ice crystals and supercooled water as determined by A/C	G/B seeding AgI at 20g/hour Airborne seeding: AgI at 320 g/hour . Total annual consumption: 60 kg	Convective and orographic clouds with bases colder than 10°C and tops colder than 0°C but warmer than –20°C. Seeding criteria: LWC>0.2 g/m^3 for stratiform clouds and 0.3g/m^3 for convective clouds	Jan-April, Nov-Dec	Evaluation based on comparison with historical records. Report available EIS-Yes C/B-Yes

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RUSSIAN FEDERATION

RF-1	Op. Hail	Target: 20,000 km^2 Control: 12,000 km^2	Antihail Crop Protechtion with Rockets	Northern Caucasus	1960 Every year Yes	Agr. (G) Wea. Ser. (G)	In-cloud seeding with pyrotechnic flares on rockets at temp. - 4 - -5 C.	AgI. Total annual consumption: 30 kg	Convective clouds with bases colder than 10°C and tops colder than –20°C Seeding criteria based on radar reflectivity and its vertical distribution, degree of convective instability.	Apr. - Sept . 40 days	Evaluation based on comparison with historical record, crop damage, and hail pads. Report available EIS-Yes C/B-Yes
RF-2	Res. Op. Dev. PE	Target: 60,000 km^2	Airborne Precipitation Enhancement	Northern Caucasus	1986 Every year Yes	Agr. (G) Wea. Ser. (G)	In-cloud seeding from 3 A/C at temp. -4 - -5°C.	AgI , dry ice and liquid nitrogen. Total annual consumption: 10 kg , 5,000 kg and 1,000 kg, respectively.	Convective and stratiform clouds with bases colder than 10°C and top temp. between 0 and –20°C . Microphysics of unseeded clouds is measured. Seeding criteria: Cloud top temp. not more than -10° C, cloud depth no less than 2 km.	May – October 60 days	Evaluation based on comparison with historical records. Report available EIS-Yes C/B-Yes
SAUDI ARABIA											
SA A-1	Res. PE Inc.	130,000 km^2	Saudi Arabia Rain Enhancement Project	South –western Saudi Arabia	1998 Interrupted (?)	Wea. Serv. (G)	-	Snowmax	Convective and orographic clouds with bases warmer than 10°C and top temp. between 0 and –20°C. Seeding criteria based on information from A/C and radar	-	-

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SOUTH AFRICA											
SA-1	Res Dev PE R	10,000 km^2	South African Rainfall Enhancement Programme	Northern Province South Africa	1997 Every Year ?	Hyd. (G) Res. Found. (G) Wea. Serv. (G)	Seeding cloud base with hygroscopic flares from 2 A/C	NaCl and KCl in hygroscopic flares, 2 kg/ 4 min. Total annual consumption: 200 kg	Convective clouds with bases warmer than 10°C and top temp. between 0 and –20°C. Seeding criteria: rardar reflectivity 30 dBz and updraft area at cloud base as determined by A/C	October - December	Evaluation based on comparison with historical records and radar data, the pairing of seeded storms with natural storms. Report available EIS-Yes C/B-Yes
SPAIN											
SP-1	Op. Hail	2500 km^2	1999 Hail suppression project in Aragon	Various township in Zaragoza and Teruel	1970 Every Year Yes	Agr (G)	G/B seeding from 83 acetone burners	AgI, 10.76 litres per generator Total annual consumption 894 litres	Convective clouds with tops colder than –20°C. Seeding criteria based on met. forecasts of possible hail	May – September, 49 days	Evaluation based on crop damage. No report EIS-No C/B-No
SYRIAN ARAB REPUBLIC											
SY-1	Dev . Op PE, Inc.	Target: 125,000 km^2 Variable control area	Precipitation Enhancement Project	Countrywide	1992 Every year Yes	Agr (G)	Cloud top and in-cloud seeding with pyrotechnic flares from 4 A/C	AgI at various consumption rates	Convective and orographic clouds with bases colder than 10°C and tops colder than 0°C but warmer than –20°C, some tops being colder than –20° C.	Jan - May Novemb er-April 50 days	Evaluation based on comparison with historical records. Report available EIS-No C/B-Yes
TAJIKISTAN											
TD-1	Op. Hail	-	Hail in Tajikistan	Gissar and Vakhsh Velleys	1962 Every year (?)	Agr. (G)	In-cloud seeding with rockets	AgI	Convective clouds with bases warmer than +10° C and top temp. between 0° and – 20° C	-	Evaluation document planned. EIS – No C/B - Yes

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UGANDA											
UG-1	Res. PE	-	-	-	-	Agr. (G) Hyd (G) Wea. Ser. (G)	-	-	-	-	-
UNITED STATES OF AMERICA											
US-1	PE Snow Augme n tation	435 km^2	NOAA 98-1002 99-1030	Mokalumne California		(P) Pacific Gas and Electricity Company		Agl. Total consumption 5.8 kg		Jan –Feb 12days Nov -Dec 10 days	Report available
US-2	PE Snow augmen tation	1,280 km^2	NOAA 98-1001 99-1031	Lake Almanor California		(P) Pacific Gas and Electricity Company		Ag (I) Total consumption 39.732 kg		Jan – Apr 25 days Nov - Dec 6 days	Report available
US-3	PE Snow augmen tation	256 km^2	NOAA 98-980 99-1022	Central Colorado		(P) Western Weather Consul tants		Agl total Consumption 17.079 kg		Jan , 21 days Nov-Dec 23 days	Report available
US-4	PE Snow augmen tation	512 km^2	NOAA 98-987 99-1032	Northern Utah		Muni Cache County		Agl Total consumption 25.136 kg		Jan – March 25 days Dec 4 days	Report available
US-5	PE Snow augmen tation	25,600 km^2	NOAA 98-1000 99-1033	Central and Southern Utah		(P) Utah Water Resource Develop ment Corpo ration		Agl Total consumption 61.488 kg		Jan – Apr 30 days Nov - Dec 11 days	Report available
US-6	PE Snow augmen tation	722 km^2	NOAA 99-1013	Wind River Wyoming		Eden Valley Irrigation and Drainage District		Agl. Total consumption 0.282 kg		Jan 4 days	Report available
US-7	PE	1,587 km^2	NOAA 99-1011	Santa Barbara California		Muni		Agl. Total consumption 11.249 kg		Jan – March 15 days	Report available
US-8	PE Snow augmen tation	8,235 km2	NOAA 98-984 99-1027 Carson-Walker Project	Nevada		Municipial		Agl. Total consumption: 15.836 kg		Jan-Jun, Nov-Dec 37 days	Report available

IV. REGISTER OF 1999 REPORTED PROJECTS

US-9	PE Snow augmen tation	2,790 km2	NOAA 98-985 99-1025 Trackee Tahoe Project	Nevada		Municipial		Agl, Total consumption: 6.734 kg		Jan-Mar, Nov-Dec 18 days	Report available
US-10	PE	8,960 km^2	NOAA 99-1009	Colorado River Texas		Colorado River Municipal Water District		Agl. Total consumption 4.245 kg		Apr-September 32 days	Report available
US-9	PE Hail	2,980 km^2	NOAA 99-1017	North Dakota District I		N. Dakota Atmos pheric research Board		Agl and dry ice. Total consumption 20.0 kg and 500 kg, respectively		June - August 19 days	Report available
US-11	PE Hail	22,920 km^2	NOAA 99-1018	North Dakota District II		N. Dakota Atmos pheric Research Board		Agl and dry ice. Total consumption 126.08 kg and 600 kg, respectively		June – August 35 days	Report available
US-12	PE Hail	41,605 km^2	NOAA 99-1016	West Kansas		W Kansas Ground-Water Manage ment District I		Agl and dry ice. Total consumption 135.443 kg and 1447 kg, respectively		Apr.- Sept. 68 days	Report available
US-13	PE	1,152 km^2	NOAA 98-981	Eastern Sierra California		Muni		Agl. Total consumption 18,940 kg		Jan - Dec 24 days	Report available
US-14	PE	1,280 km^2	NOAA 98-989	Kaweah River California		Kaweath Delta Water Conser vation District		Agl. Total consumption 5.274 kg		Jan - Dec 18 days	Report available
US-15	PE	3,072 km^2	NOAA 98-990	Kern River California		North Kern Water Storage district		Agl. Total consumption 8,789 kg		Jan – Dec 18 days	Report available
US-16	PE	4,096 km^2	NOAA 98-991	Kings River California		Kings river Conser vation District		Agl. Total consumption 13.774 kg		Jan - May 22 days	Report available
US-17	PE Snow augmen tation	880 km2	NOAA 98-986	Klark County, Idaho		Easter Idaho Counties Irr. Dist.		Agl. Total consumption: 5.441 kg		Jan-Mar, 30 days	Report available

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US-18	PE	3,072 km^2	NOAA 98-992	San Joaquin River California		(P) Southern California Edison Company		Agl. Total consumption 22.621kg		Jan - Nov 54 days	Report available
US-19	PE	3,072 km^2	NOAA 98-993	Tuolumne River California		Turlock Irrigation District		Agl. Total consumption 12.950 kg		Jan – Mar 15 days	Report available
US-20	PE Snow augmen -tation	1,216 km2	NOAA 98-994 99-1026 Tuscarora	Nevada		Municipial		Agl. Total consumption: 10.749 kg		Jan-Mar 24 days	Report available
US-21	PE Snow augmen tation	1,220 km2	NOAA 98-995 Toiyabe Nevada	Nevada		Municipial		Agl. Total consumption: 1.910 kg		Jan-Jun 6 days	Report available
US-22	Fog	2.5 km2	NOAA 98-996	Salt Lake City Airport		Delta Airlines		Dry ice 960 kg		Jan-Dec 3 days	Report unavailable
US-23	PE	40,000 km^2	NOAA 99-1012	Central and Southern High Plains Texas		High Plains Under ground Water Conser vation		Agl. Total consumption 54.461kg		Mar - Sept 65 days	Report available
US-24	PE	178,950 km^2	NOAA 99-1014	Oklahoma		Oklahom a Wea Mod		Agl. Total consumption 77.187 kg		Sept-Dec 19 days	Report available
US-25	PE	14,880 km^2	NOAA 98-1004	Texas		Texas Border Weather Modifi cation Associa tion		Agl.. Total consumption 24,631 kg		May-Oct 30 days	Report available
US-26	PE Snow augm entation	256 km^2	NOAA 99-1035	Alta/Snowbird Utah		Snowbird Ski Resort (P)		Agl. Total consumption 2.572 kg		Oct -Dec 16 days	Report available
US-27	PE Snow augmen tation	8,166 km2	NOAA 98-983 99-1028	Ruby Mountains, Nevada		Muni		Agl, 26,558 kg		Jan-Apr Nov-Dec 34 days	Report available
US-28	PE Snow augmen tation	128 km^2	NOAA 98-982	Central Utah		Emery County		Dry ice , Total consumption: 300 kg		Jan – Mar 14 days	Report not available
US-29	PE	1,024 km2	NOAA 99-1008	San Gabriel Mountains California		Municipial		Agl.Total consumption 5.280 kg		Jan-Apr Nov-Dec 28 days	Report available

IV. REGISTER OF 1999 REPORTED PROJECTS

US-30	PE	154	NOAA	Telluride -		South		Agl.Total		Jan	Report available

VI. MEMBER COUNTRIES REPORTING ON COMPLETED PROJECTS

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VII: MEMBER COUNTRIES REPORTING ON COMPLETED PROJECTS

LOCATION AND TERRAIN	PURPOSE AND DURATION	AGENT AND ALTITUDE OF SEEDING	REFERENCES TO PUBLISHED RESULTS	CONTACT FOR INFORMATION
BULGARIA				
Northern Danube plain and upper Tracian lowland (42° N and 24°E). Hilly and flat terrain. Target area 2, 000 km^2 , fixed. No control area.	Precipitation redistribution 1991 to 1994 during April to September period.	Airborne seeding AgI and PbI2 (1991- 1992) at 3.2 – 4.6 km in individual convective clouds Seedabilily: cloud top temp. between –10 and –30° C. Experimental unit: individual cloud. Randomized experiment, with 118 seeded and 116 unseeded units in 58 days. Results: qualitative- longer rainfall period, larger rainfall area, rain redistribution; quantitative – seed/no-seed ratio 1.56-1.96 (0.05 significance level).	1. Boev, P., R. Petrov, P. Konstantinov, L. Boeva (1994). An Experiment for Rainfall Enhancement from Convective Clouds over Thracian Lowland. Proc. Of VI WMO WMO Sci. Conf. On Weather Modif., v. II, 357-360, WMO/TD No 546, Geneva 2. Boev, P., R. Petrov (1995). Variation of Precipitation Characteristics After Cloud Seeding. Bulgarian Journal of Meteorology and Hydrology (BJMH), v.6, No 3-4 p85-90, Sofia (in Russian) 3. Boev, P. (1996). Modification of the Cloud Convention Characteristics and Convective Rainfall Regime, BJMH, v.7 No1-2, 60-68, Sofia (in Russian).	National Institute of Meteorology and Hydrology 66, Tsarigradsko shaussee, 1784 SOFIA, Bulgaria
CHINA				
Area near Beijing. Target:6,800 km^2. Control: 2,000 km^2. Both fixed	Precipitation enhancement	Airborne seeding of stratiform clouds with liquid nitrogen at a rate of 1080 kg/hour at altitudes 3 to 5 km along tracks more than 100 km long. Standard seeding period: 3 hours. Results: more precipitation	-	Beijing Weather Modification Office 44, Zizhnyuan Road Haidian District BEIJING, China
Flat and hilly terrain in Shandong Province. Target area 150, 000 km^2. Variable. Control area chosen depending on target location. .	Precipitation enhancement during March-October for a 10 –year period. Precipitation enhancement during Mar-Oct	Airborne seeding of stratiform and frontal clouds with AgI at a rate of 0.32-0.64 kg/hour at altitudes 3 to 5 km. Seeding criteria: cloud base below 1.5 km, cloud depth in excess of 2 km, cloud top temp. –10 to –25° C. Standard seeding period : 51.5 hours. Verification quantities: precipitation (122 gauges), radar reflectivity and cloud microphysics (as determined with PMS). Total duration of seeding: 240 days.	Chen Wenxuan et. Al. A study of the Microphysical Precipitation Mechanism for a Cold Vortex Process. 7th WMO Scientific Conference on Wea. Mod. ,1999, vol.1, p.p. 229-231. Feng Guili. The Study of Evaluation of Cost-Effectiveness for Shandong Artificial Precipitation with Wheat Yield. Ibid., p.p. 169-171Wang Yilin et al. The Method of Effect Evaluation of Artificial Precipitation in Movable Target Station. Ibid., p.p. 187-190.	Shandong province Research Institute of Meteorology. Wuyingshan Road, JINAN, Shandong Province.

Mountainous , hilly and flat terrain in northwestern China. Variable target area of 15,500 km^2	Precipitation enhancement from all types of clouds and hail suppression during March-October.	Airborne seeding of all types of clouds at an altitude of about 5 km. Seeding criteria based on wind field parameters (velocity, vorticity, divergence) and humidity. Totally, 210 days with seeding. Results: no difference in precipitation amounts but less hail.	-	The Office of Artificial Weather Modification of Gansu 1234, Dongangdonglu, Lanzhon, 730020, GANSU
Mountainous and hilly tarrain in Yunnan Province. Fixed target area 10,000 km^2. No control area	Precipitation enhancement and hail suppression from convective clouds during March-October.	Ground-based seeding with AgI using 560 generators. Seeding criteria based on radar data. Seeding unit: day Total number of seeded units: 200 Results: more precipitation and less hail.	-	Yunnan Office of Weather Modification 77, Xichang Road, KUNMING 650034 China
FRANCE				
Hilly terrain in southwest, centre, centre east and southeast of France. Target 60,000km^2. Fixed	Hail suppression from both convective and frontal clouds during 47 years. 15 April to 15 October	Agent: AgI from 661 ground- based generators. Verification aided by a network of 1000 hail pads installed in target zone. Experimental unit: 1 day. Decision on seeding based on forecast of hail greater than 15mm diameter . Seeding period 8 hours per day. Evaluation method : correlation between AgI seeding rate and hailfall intensity. Quantitative results show 42% decrease of hail with diameters more than 7mm (statistical significance: 0.01).	Dessens J.J., 1999. A physical evaluation of a hail suppression project with silver iodide ground burners in Southwestern France. J. Appl. Meteorology, v.37, p.p. 1588-1599. Dessens, J. and R. Fraile , 2000. The effect of silver iodide seeding on hailstone size distributions. J. Wea. Modification, v. 32, p.p. 26-30.	Association Nationale d'Etude et de Lutte contre les Fléaux Atmosphériques 52 rue Alfred Duméril 31400 TOULOUSE

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JORDAN				
Hilly area. Target: 23,000km^2. Fixed . No control area.	Extending the wet period and increasing precipitation from orographic and frontal clouds in Oct-May during a 14-year period .	Ground and air-based seeding with 2% solution of AgI and NaI in acetone. Seeding with 22 G/B generators at a rate of 12g/hr each and 120g/hr from each of two aircraft. Seeding at level about 3.5 – 4 km along 50 km tracks. Precipitation measured with 80 gauges . Seeding criteria: cloud top temperatures between -12 and -20°C and appropriate cloud liquid water content and ice particle concentrations. Standard seeding period 70hrs. Statistical test: actual versus horizontal data; analysis of precipitation efficiency maps. Results: a 15-20% increase in annual rainfall. From precipitation efficiency maps effects of seeding extends beyond eastern borders of Jordan. Quantitative results: seed/no seed ratio 1.17 at a 5% statistical significance level. Extended area effect: a 10-14 % increase in rainfall over a territory of 40,000 km^2, the effect decreasing eastwards.	Tahboub,I.K., "A study of a 10-year period of cloud seeding over Jordan".	Jordan Meteorological Department PEP J, P.O. Box 341011 Marka Airport, AMMAN
MACEDONIA, THE FORMER YUGOSLAV REPUBLIC OF				
Hilly terrain , fixed target of 25,000 km^2. No control area	Hail suppression activities in June-October for a 29-year period	Seeding AgI with rockets at levels with temp. – 6 - -12C.	-	Republic Hydrometeorological Institute Skupi bb, 1000 SKOPJE Republic of Macedonia

VII: MEMBER COUNTRIES REPORTING ON COMPLETED PROJECTS

MADAGASCAR				
A fixed 10,000 km^2 target on hilly terrain.	Precipitation enhancement from orographic and convective clouds during November-April.	Airborne seeding with NaCL at a rate of 5 kg/hour and at altitudes 1.5 – 3.0 km, the track length being 100 to 200 km. Seeding unit: 4-10 days. Seeding criteria: favorable conditions for moist convection , the Cb amount in excess of 50%. Results: more precipitation.	-	Direction de la Meteorologie and de l'Hydrologie B.P. 1254 ANTANANARIO Madagascar
UZBEKISTAN				
Mountainous terrain. Fixed target, 7,380km^2	Hail suppression for protection of crops during a 31-year period in April – August. Both convective and frontal clouds treated.	Ground-based AgI seeding using rockets. Fifty eight precipitation guages in target area. Verification quantities: radar reflectivity and presence or absence of crop damage as determined from visits to target area. Duration of unit: 2-30 minutes, max: 1,5 hours. Seeding criteria: radar reflectivity $R_{10} \geq 10^{-8}$ cm vertical depth of cloud with $R_{10} = 10^{-9}$ cm should be greater than or equal to 2.5km. Units seeded: 152 Results: reduction in radar reflectivity and hozrizontal size of clouds. Rainfall was found to be uneffected by seeding operations.	1. Methodological Instructions for forecasting hail processes in mountains of central Asia by R.G. Shadeeva, Ch.A. Imadjanov, Tashkent 1987, 17pp 2. Ch. A. Imadjanov: Parameterization of hail clouds, proceed. SANII No.100, - Gidrometeoizdat, 1984. p.36-40 3. Kamalov B.A., Sabaev W.W., Usmanov I.U.. Assessing hail prevention activities in the Valley of Fergan, Proceedings of SANIGMI No.100, 1984. p.56-75 4. Ch.A. Imadjanov, Hail in NE Uzbekistan, Proceedings of SANIGMI, No.110, 1990, p.87-95.	Main Administration of Hydrometeorology 72 Makhsumov street TAKSHKENT 700052

VIII. MEMBER COUNTRIES REPORTING *NO* WEATHER MODIFICATION PROJECTS IN 1999

Armenia
Australia
Azerbaijan
Bahrain
Benin
Botswana
Cameroun
Cape Verde
Chile
Colombia
Congo
Czech Republic
Denmark
Ecuador
Guyana
Korea, Republic of
Iceland
India
Ireland
Latvia
Lebanon
Lithuania
Malta
Mauritius
Nigeria
Norway
Pakistan
Peru
Philippines
Romania
Singapore
Slovenia
St. Lucia
Sri Lanka
Switzerland
Sweden
Tanzania, United Republic of
United Kingdom
Uruguay
Venezuela
Viet Nam
Yemen

IX: TRENDS IN WEATHER MODIFICATION ACTIVITIES REPORTED BY WMO MEMBER COUNTRIES FROM 1975 – 1999

A preliminary analysis

1. INTRODUCTION

The aim of this report is to provide an insight into changes that have occurred in the last 25 years in WMO Member countries with respect to various types of weather modification activities and, to a certain extent, in commitments to technologies used for such activities. The report summarizes information on the worldwide and regional activities during the period 1975 – 1999 as reported by the WMO Members. With few exceptions, the reporting agencies are the National Meteorological and Hydrological Services (NMHSs).

It is well known that not all national weather modification projects are reported to WMO. Among the reasons for under-reporting of projects is that weather modification activities are carried out by many different organizations and there is a possibility that not all projects within a given country are known by the NMHS. In some cases the questionnaires are not returned although other sources indicate weather modification activities were conducted. In addition, not all of the requested information is provided in the returned questionnaires.

For all these reasons, the information summarized below should be considered with caution. Nevertheless, some general tendencies have emerged from an analysis of the information from Members over the past 25 years.

2. DATA SOURCES AND AVAILABILITY

2.1 Data requested from Member countries

The data used in this analysis were obtained from questionnaires sent annually to each Member country of the World Meteorological Organization and compiled and published by the WMO Secretariat in the WMO "Register of National Weather Modification Projects". The data are reported on a project basis and include:

- objective(s) of the project and the organization carrying it out;
- approximate size of project area (target and control);
- location of the project area;
- year project commenced and its continuity (whether interrupted or not);
- nature of organization sponsoring project;
- apparatus used for agent delivery and seeding location;
- agents and dispersal rates;
- characteristics of clouds treated and seeding criteria;
- months of active period;
- information on whether environment impact studies and cost-benefits analyses had been conducted.

2.2 Responses

When considering the response level from Member countries one has to keep in mind that during 1975 – 1999 there was an increase in the number of WMO Member countries (Fig. 2.1). For this reason it has been necessary to adjust the number of responses in each year to the total number of Member countries (Fig. 2.2).

Generally, there was no trend in the number of responses. However, the percentage of responding countries declined as the number of Members increased. This result is statistically significant at the 0.02 level.

3. WORLDWIDE TRENDS IN WEATHER MODIFICATION ACTIVITIES

3.1 Level of Member country involvement and project objectives

The data on number and percentage of the WMO Member countries involved in any kind of weather modification activities shows no significant trend (Fig. 3.1, 3.2). At the same time there has been a gradual decrease in percentage of countries reporting no weather modification activities. The trend is statistically significant at a level of 0.02. This, in conjunction with data in Fig. 2.1, suggests that countries with no activities tend not to respond to the questionnaires.

The types of reported weather modification activities precipitation enhancement, hail suppression and, to a lesser degree, fog dissipation. The term "precipitation enhancement" implies all operations aimed at precipitation increase during wet period, extension of wet period or, precipitation redistribution.

The number of WMO Member countries with hail suppression projects (Fig. 3.3) generally varied from 8-11 in the mid 70s to 13-16 in 1992-1994 and 1997-1999. The rise being attributed to emergence of new independent states in Europe and Asia.

The number of countries involved in precipitation enhancement and redistribution peaked in 1979-1980 and 1991-1993. The peaks were separated by a period of a relatively low interest with only 8 countries reporting such activities in 1984. The corresponding percentages (adjusted to account for the increased WMO membership) are given in Fig. 3.4.

Fog dissipation activity was much lower. Cold fog dissipation operations aimed at improving visibility were regularly reported in Norway, in the USA and occasionally, in the USSR and Russian Federation in the early part of the period but in 1999, only one project of that kind was still operating in the USA.

3.2 Continuity of weather modification activity

The continuity of a given project is described by the number of years it has been carried out without interruption. This information for hail suppression and precipitation enhancement projects active in 1999 is presented in Fig. 3.5. Unfortunately, this statistic does not take into account projects in the USA because the US questionnaire responses do not include this characteristic.

The number of years a project has continuously existed is an indirect indication of a level of satisfaction from the sponsoring organizations. The data suggest that hail suppression projects are more likely to be implemented year after year than is the case with precipitation enhancement projects. In 1999, hail suppression projects have been in operation for 47 years (France), 39 years (Russian Federation), 37 years (Tajikistan), 35 years (Moldavia) and for 32 years in Yugoslavia. On the other hand, there was only one new hail suppression project established (or, to be more precise, renewed) in the last 3 years (in Canada).

The existing precipitation enhancement projects are generally younger, the majority of them being 6-15 years old. The longest living project has been implemented in Israel beginning in 1960. There are 4 projects (Burkino Faso, Japan, Malaysia and Saudi Arabia) that have been established in the last 5 years.

3.3 Project characteristics

3.3.1 Total target areas

When reviewing the total worldwide target areas, one has to bear in mind that in some countries (mainly China and the USA), hail suppression and precipitation enhancement activities are often carried out in the same target areas and no indication is given as to what part of the area is exposed to each specific kind of activity. This might lead to some over-estimation of the worldwide total target area for hail suppression.

The worldwide total target areas for hail suppression and precipitation enhancement obtained by summing the individual project areas are presented in Fig. 3.6. A statistical estimation suggests a gradual growth in the total area for hail suppression at an annual rate of 33×10^3 km ^{2} statistically significant at the 0.007 level.

Contributions of the individual Member states to the total worldwide target area for hail suppression have changed dramatically between 1975 and 1999 (Fig. 3.7). In 1977, the largest share of hail suppression activities were USA (34% of the worldwide total area), France (22 %) and the USSR (16%). In 1988, the roles changed, with the largest areas being served by the USSR (34%), China (33%), France (18%), and USA (8%). By 1999, China had about 76% of the global area with hail suppression operations.

The worldwide total target area with precipitation enhancement (redistribution) experienced a fall in the mid 80s (to about 200 thousand km ^{2} in 1984) and a 70 thousand km ^{2} annual growth (significant at the 0.04 level) up to the late 90s (see Fig. 3.6). The contributions of the individual WMO Member countries to that total target area in 1977, 1988 and 1999 are given in Fig. 3.8.

3.3.2 Types of clouds treated for precipitation enhancement

Types of clouds treated for precipitation enhancement vary from one project to another depending on climate conditions and target terrain orography. Table 3.1 summarizes these data for 1983, 1991 and 1999. Prior to 1983, the data on types of treated clouds were not requested in the WMO questionnaires. The US responses do not include these data even now.

The table indicates that individual convective clouds have been the most common object of weather modification efforts. Precipitation enhancement of stratiform clouds has decreased while embedded convective clouds (i.e. convective and stratiform) attract more interest now than in 1983.

Table 3.1

Percentage of worldwide precipitation enhancement projects treating various types of clouds. Data on USA projects not included.

Year	Convective clouds	Convective and orographic clouds	Orographic clouds	Convective and stratiform clouds	Stratiform clouds	All types of clouds
1983	35	23	6	6	23	7
1991	47	6	-	23	12	12
1999	35	18	4	35	4	4

3.3.3 Types of agent used

The types of agents used for seeding purposes depend on the type of microphysical processes they are intended to interfere with. Cloud modification for hail suppression exclusively involved cold-type processes and ice-forming agents, mostly AgI or, much more seldom, some other silver-bearing materials.

For precipitation enhancement other ice-forming agents are also used such as dry ice, propane, liquid nitrogen, and SNOWMAX (a product based on certain crystal-forming bacteria). To enhance rain formation in warm clouds (with tops below the 0° C level) seeding with hygroscopic materials (NaCl, KCl, urea solution) is common. The number of countries using various types of agents is presented in Table 3.2

Table 3.2

Number of countries using various types of agents in the precipitation enhancement projects in 1977, 1988, and 1999

Year	AgI	Dry ice	Propane	Liquid nitrogen	SNOW MAX	Hygroscopic material
1977	7	2	1	-	-	2
1988	7	4	2	-	-	4
1999	7	3	-	1	1	4

The table suggests that there is a growing interest to "non-traditional" ice-forming agents (liquid nitrogen, SNOWMAX) and to hygroscopic agents which have a wider application under slightly negative or positive cloud temperatures.

3.3.4 Seeding delivery systems

The agent can be delivered to the cloud by aircraft, rockets, artillery shells or updraft air currents from ground-based generators. The selection of the seeding delivery system depends on a number of objective and subjective factors including adopted weather modification hypothesis, available resources and nature of target terrain. Usually, projects in the same country use one or two methods for delivery. The number of countries employing each kind of seeding delivery system in 1977, 1988 and 1999 are given Table 3.3.

Table 3.3

Percentage of countries using various seeding delivery systems for hail suppression and precipitation enhancement in 1977, 1988 and 1999

Year	Aircraft	Aircraft and ground-based generators	Ground-based generators	Rockets and shells	Aircraft, ground-based generators, rockets and shells
Hail Suppression					
1977	30	10	10	50	-
1988	30	-	10	60	-
1999	31	7	12	50	-
Precipitation Enhancement					
1977	62	13	25	-	-
1988	83	17	-	-	-
1999	61	20	7	6	6

As shown in the table, in the majority of countries hail suppression technologies are dominated by rockets and shells, while precipitation enhancement activities involve mainly airborne delivery.

4. TRENDS IN REGIONAL ACTIVITIES

The degree of regional activity was evaluated by using the number of countries of each WMO Regional Association involved in either hail suppression or precipitation enhancement and the total target area covered by each activity. These data are presented in Fig. 4.1 – 4.10.

There has been no reported hail suppression activity in RA I (Africa) except for a one-year project in Tunisia in 1977. For precipitation enhancement (Fig. 4.1), there appears to be a decline in the total target area while the number of countries remained generally unchanged, or even slightly increased.

In RA II (Asia), a pronounced rise in the total target area is evident (Fig. 4.2-4.3) for both hail suppression and precipitation enhancement. The rise can safely be attributed to activities in China (see Fig. 3.7 – 3.8).

Weather modification activity in RA III (South America) was generally low and showed no trend (Fig. 4.4-4.5) .

In RA IV (North and Central America, Fig. 4.6 – 4.7), the total target area for both hail suppression and precipitation enhancement decline from the mid 70s to the mid 80s. After that the target areas began to expand, especially for hail suppression. The number of countries involved with precipitation enhancement declined from 2 – 5 in the 70s to one (USA) by the late 90-ties.

In RA V (Southwest Pacific) countries, no hail suppression projects have been reported. With respect to precipitation enhancement, a clear-cut minimum in the total target area existed throughout the 80s (Fig. 4.8). More recently, the target area began to grow.

In RA VI (Europe) there was a rise in the total target areas for hail suppression in the late 70s with no further apparent changes since then (Fig. 4.9). A rise in the number of countries active in this area after 1992 can be attributed to the emergence of new independent states. With precipitation enhancement activities, the data show a sharp rise in the total target area and, to a lesser extent, in the number of countries involved (Fig. 4.10).

5. SPONSORS OF WEATHER MODIFICATION ACTIVITIES

The available information on organizations sponsoring weather modification activities is summarized in Table 5.1. The abbreviations used in the table are as follows:

Agr. (P) = private agricultural sector;
Agr. (G) = the state-owned agricultural sector;
Ins. = the insurance industry;
Res. = the research institutions;
Wea. Ser. = NMHSs;
Hyd. = the water supply system;
Ener. = the energy production sector.

Table 5.1
Percentage of organizations sponsoring weather modification activities in 1977, 1988 and 1999

Year	Agr. (P)	Agr. (G)	Ins.	Res.	Wea. Ser.	Hyd.	Ener.	Others
1977	12	20	6	29	9	9	3	12
1988	5	41	1	5	23	12	8	5
1999	8	37	3	5	27	10	2	8

The table suggests that during 1977-1999 there has been growth in the sponsoring activity of the NMHSs and, to some extent, by agricultural organizations. On the other hand, interest by research institutions (or, at least, their sponsoring capabilities) has decreased.

The cost/benefit estimations are important in decision – making on whether to sponsor of a weather modification project. According to the Member countries reports, in 1988, cost / benefit estimations were made for 38% of the projects while in 1999 this figure had risen to 63%.

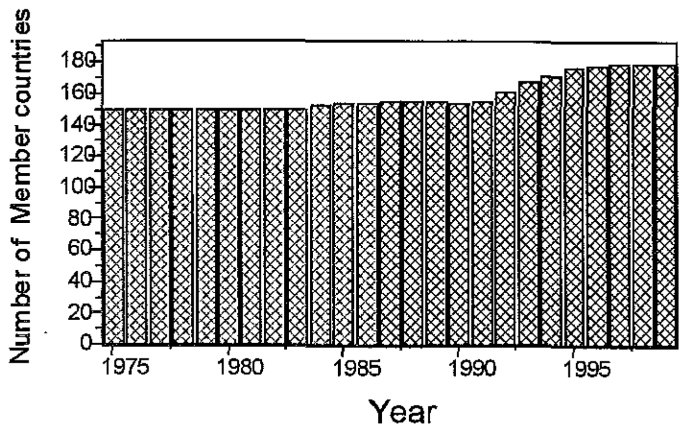

Fig. 2.1 Number of WMO Member countries as a function of year (territories are not included).

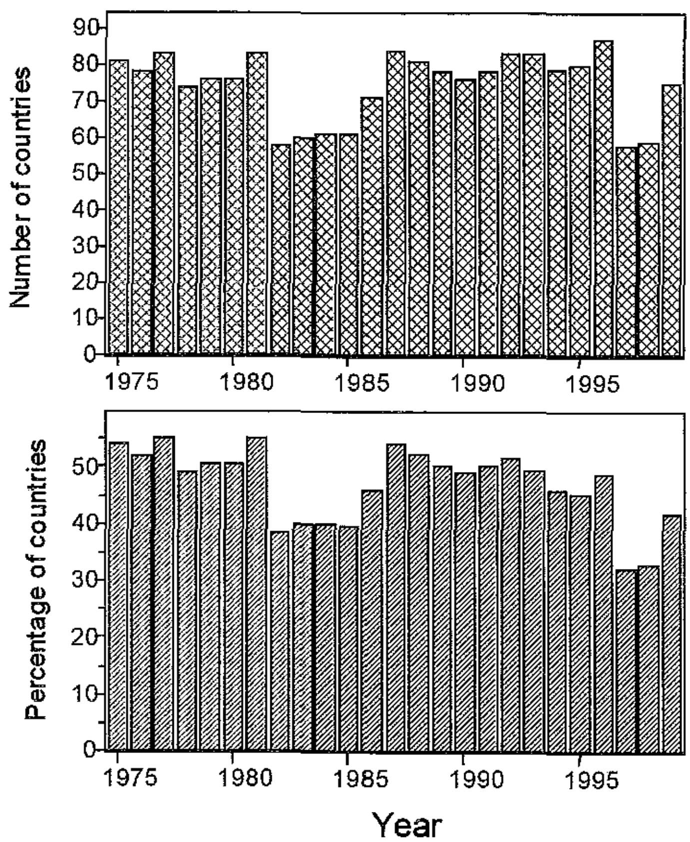

Fig. 2.2 Number (top) and percentage (bottom) of WMO Member countries responding to questionnaire as a function of year

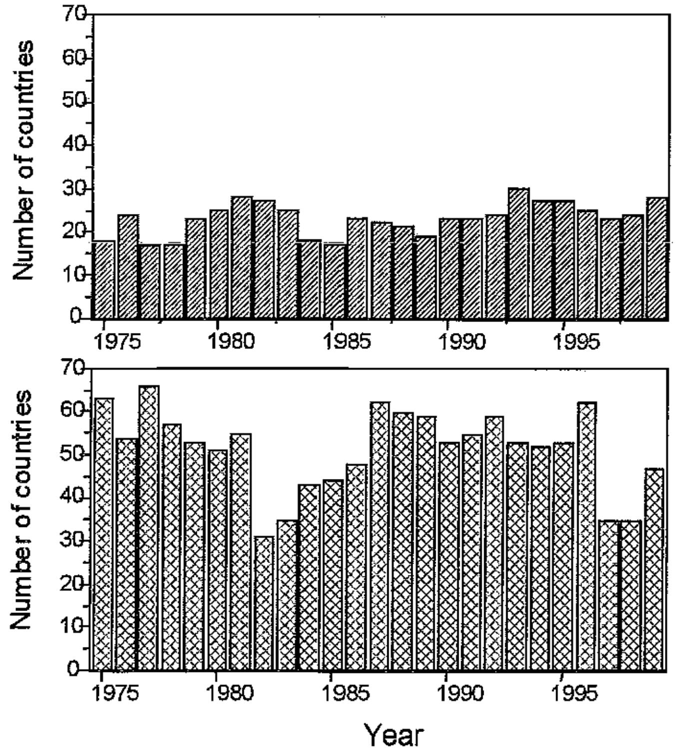

Fig. 3.1: Number of WMO Member countries reporting weather modification activities (top) and no activities (bottom) as a function of year

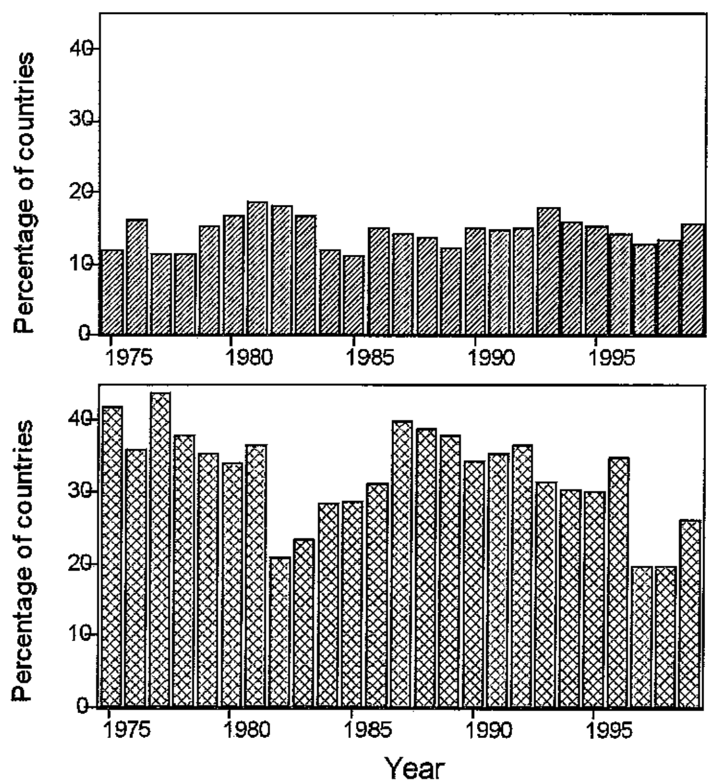

Fig. 3.2: Percentage of WMO Member countries reporting weather modification activities (top) and no weather modification activities (bottom) as a function of year

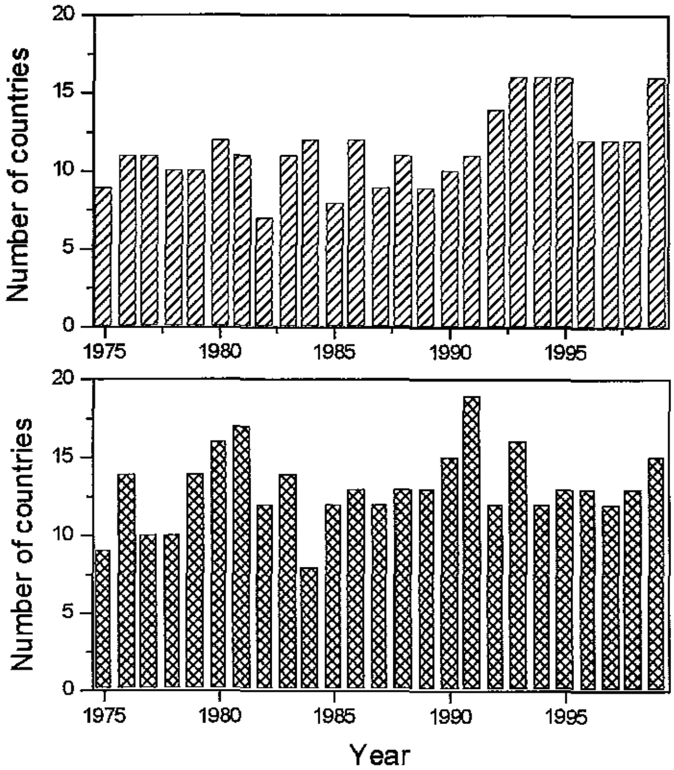

Fig. 3.3 Number of WMO Member countries with reported hail suppression (top) and precipitation enhancement (bottom) activities as a function of year

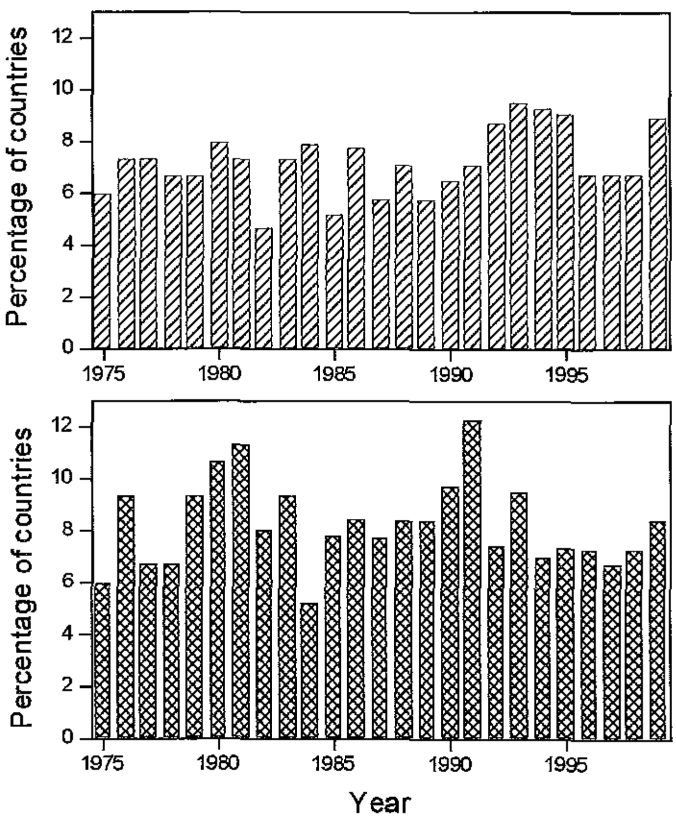

Fig. 3.4 Percentage of WMO Member countries with reported hail suppression (top) and precipitation enhancement (bottom) activities as a function of year.

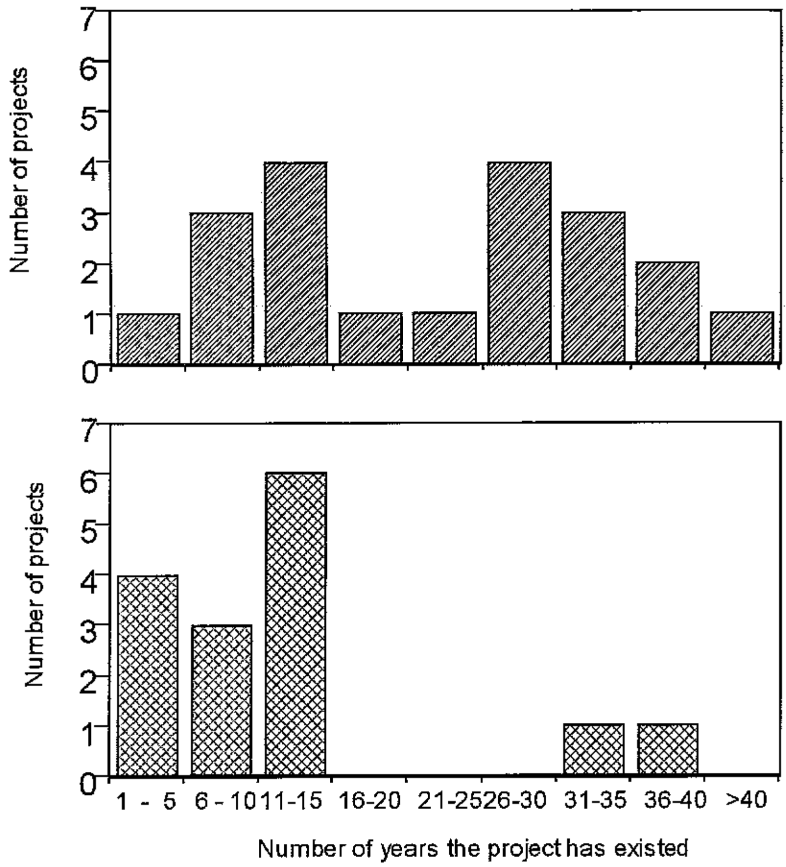

Fig. 3.5 Number of hail suppression (top) and precipitation enhancement (bottom) projects active in 1999 (US projects not included) as a function of a number of years of their continued existence.

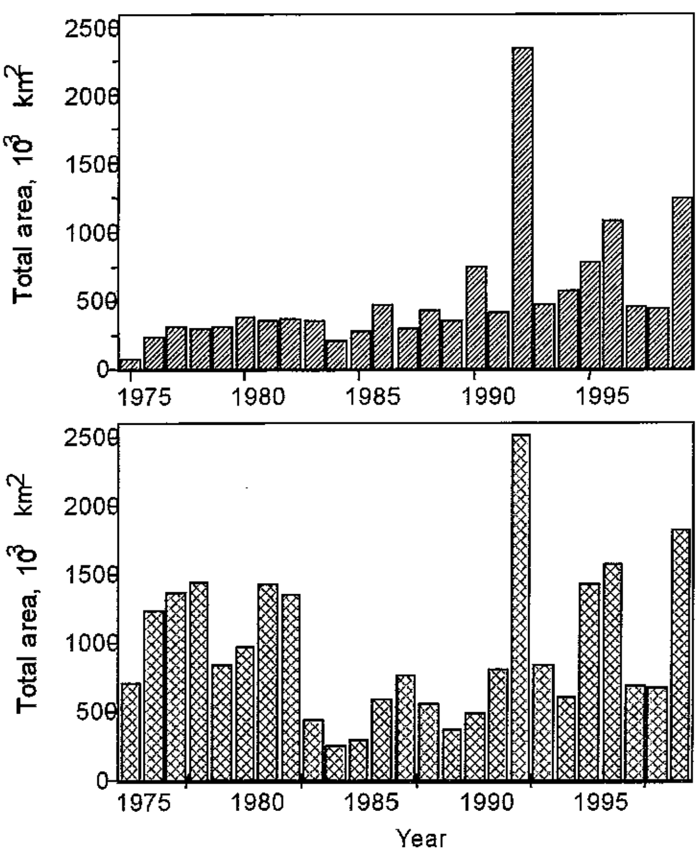

Fig. 3.6 Worldwide total target areas in reported hail suppression (top) and precipitation enhancement (bottom) projects as a function of year.

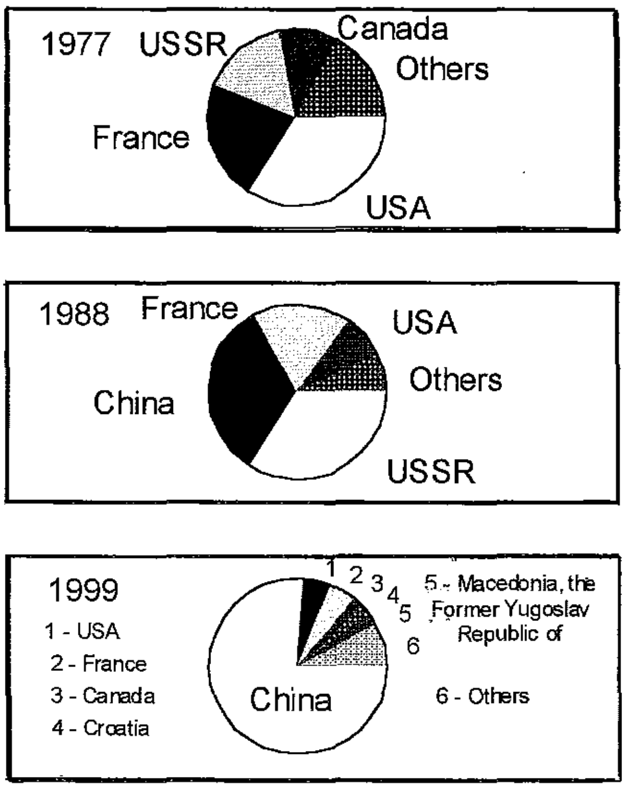

Fig. 3.7: Relative size of target areas for hail suppression projects in 1977, 1988 and 1999.

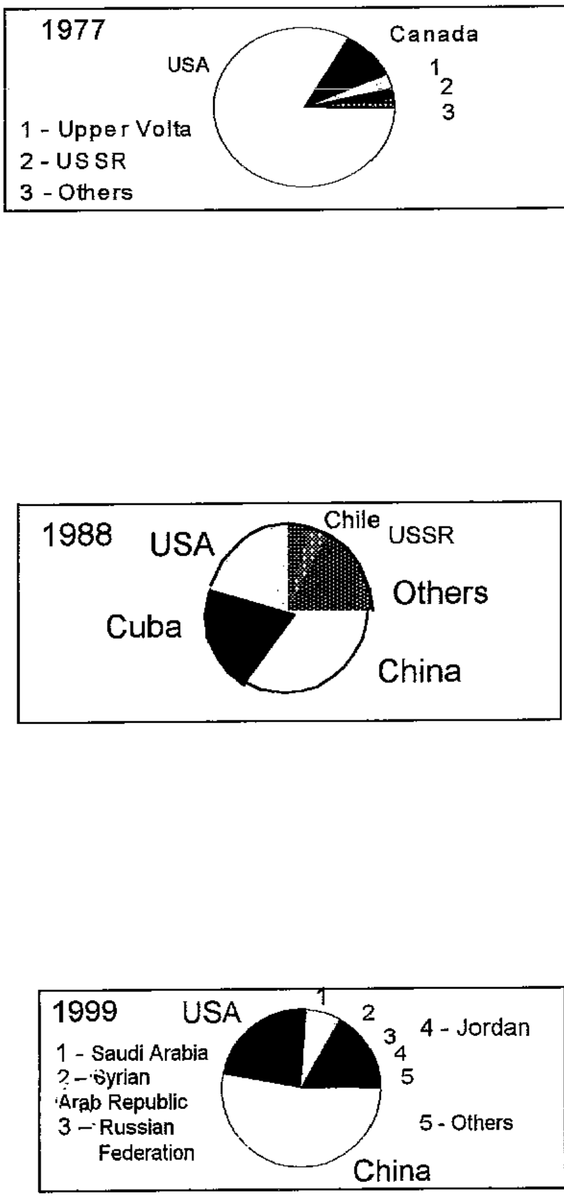

Fig. 3.8 Relative size of target areas for precipitation enhancement projects in 1977, 1988 and 1999.

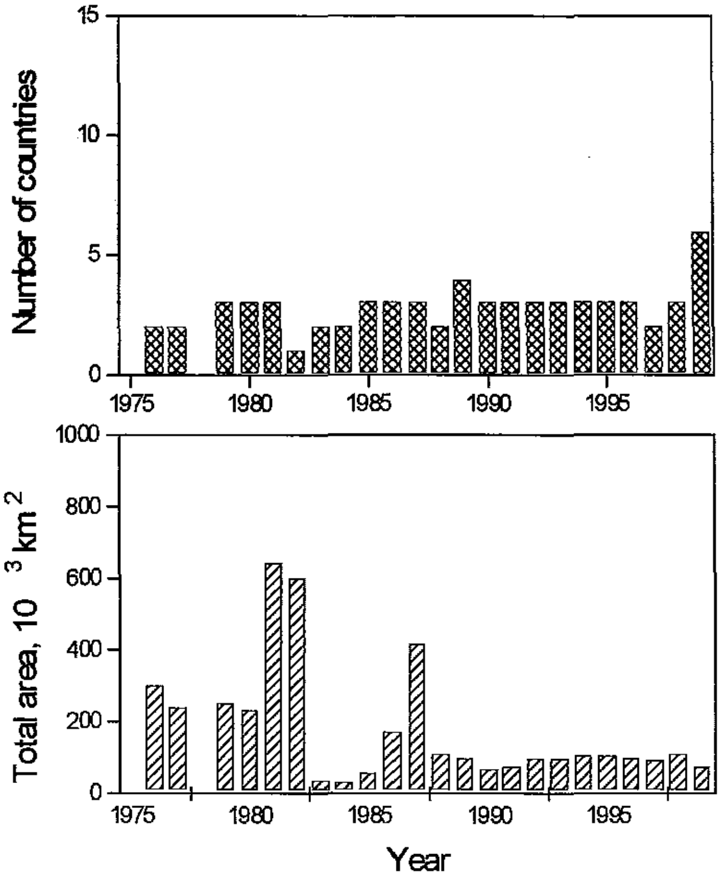

Fig. 4.1 Number of WMO RA I countries involved in precipitation enhancement activities (top) and total target area covered by them (bottom).

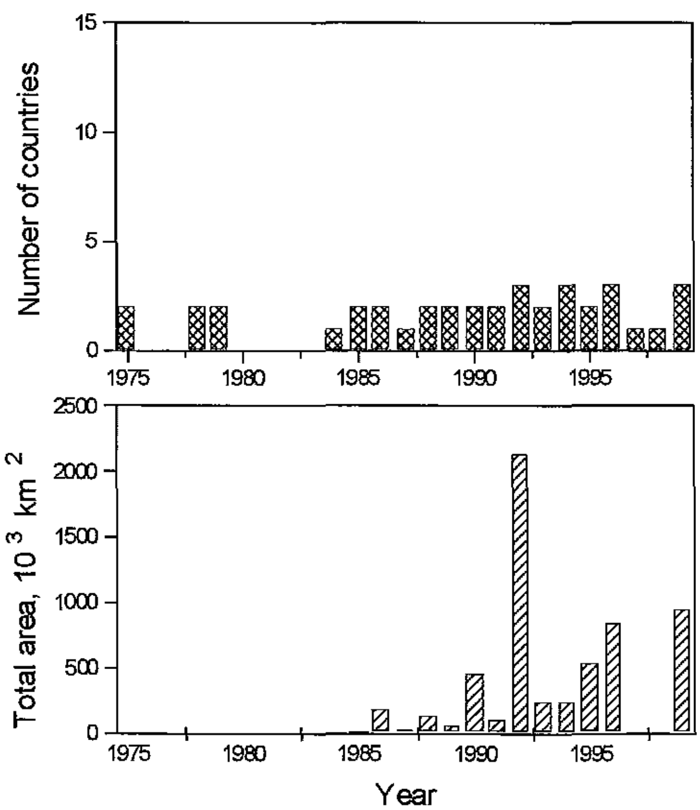

Fig. 4.2 Number of WMO RA II countries involved in hail suppression activities (top) and total target area covered by them (bottom).

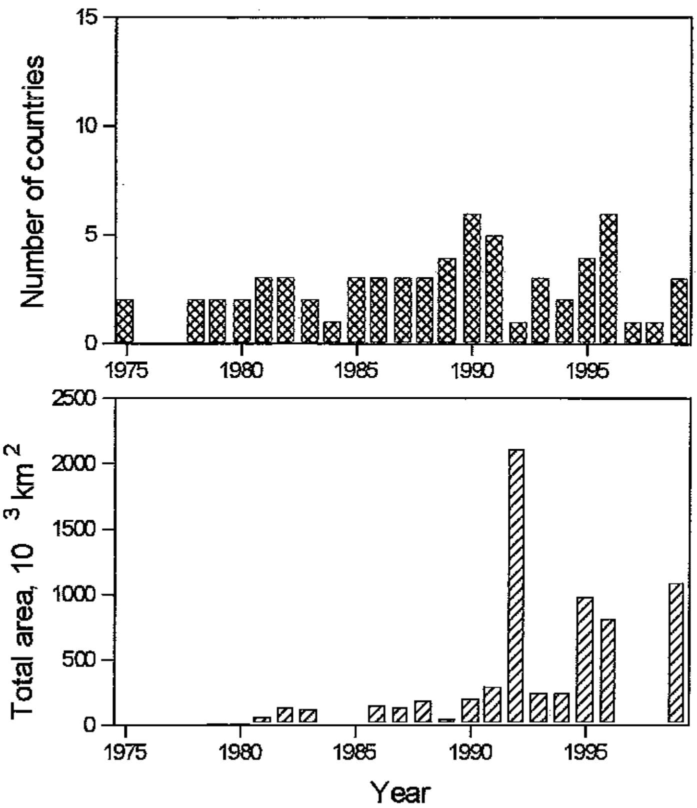

Fig. 4.3 Number of WMO RA II countries involved in precipitation enhancement activities (top) and total target area covered by them (bottom).

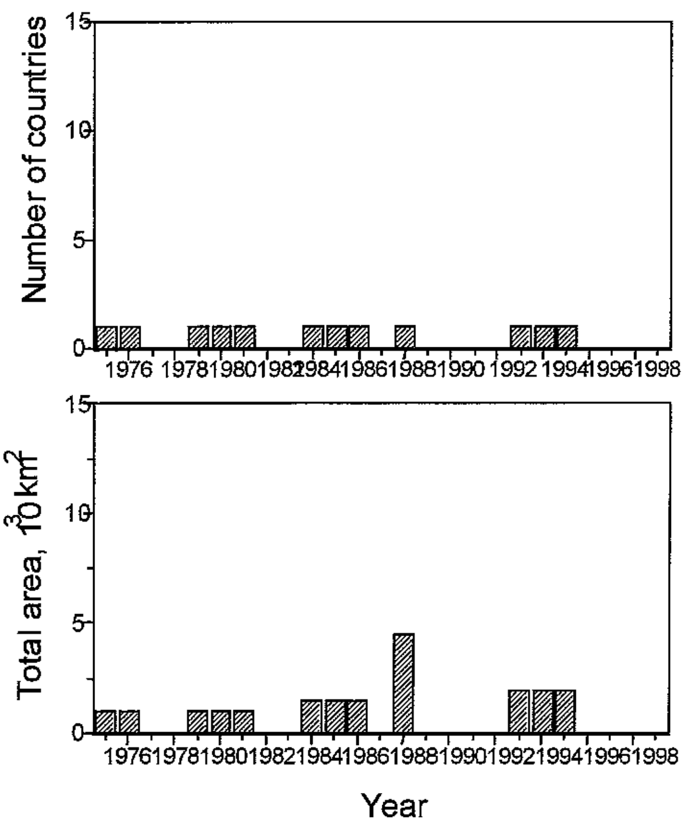

Fig. 4.4 Number of WMO RA III countries involved in hail suppression activities (top) and total target area covered by them (bottom)

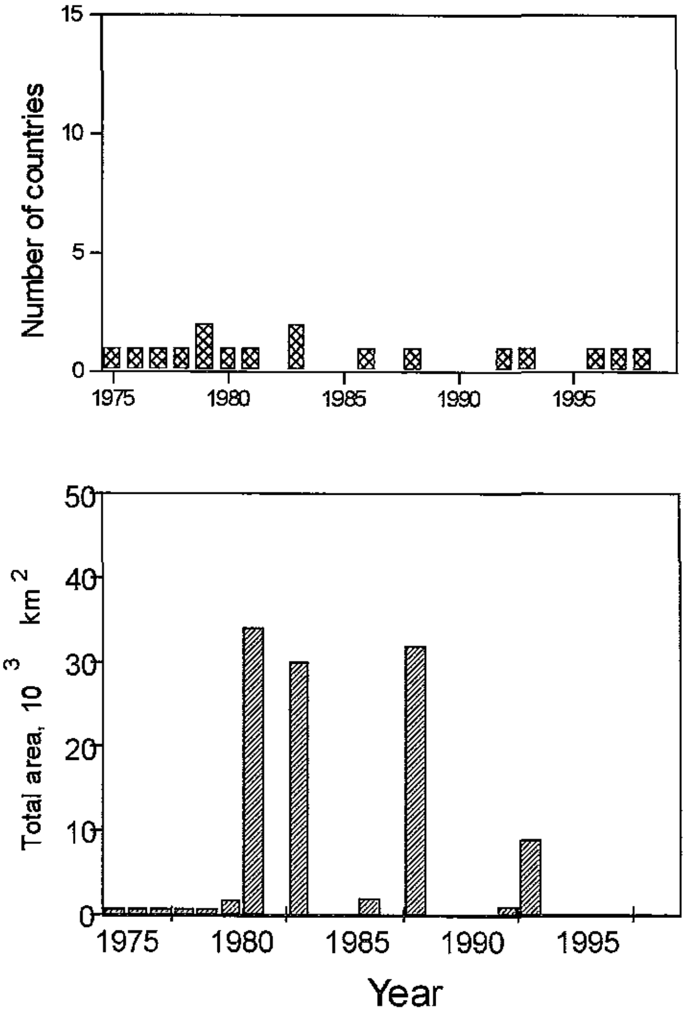

Fig. 4.5 Number of WMO RA III countries involved in precipitation enhancement activities (top) and total target area covered by them (bottom).

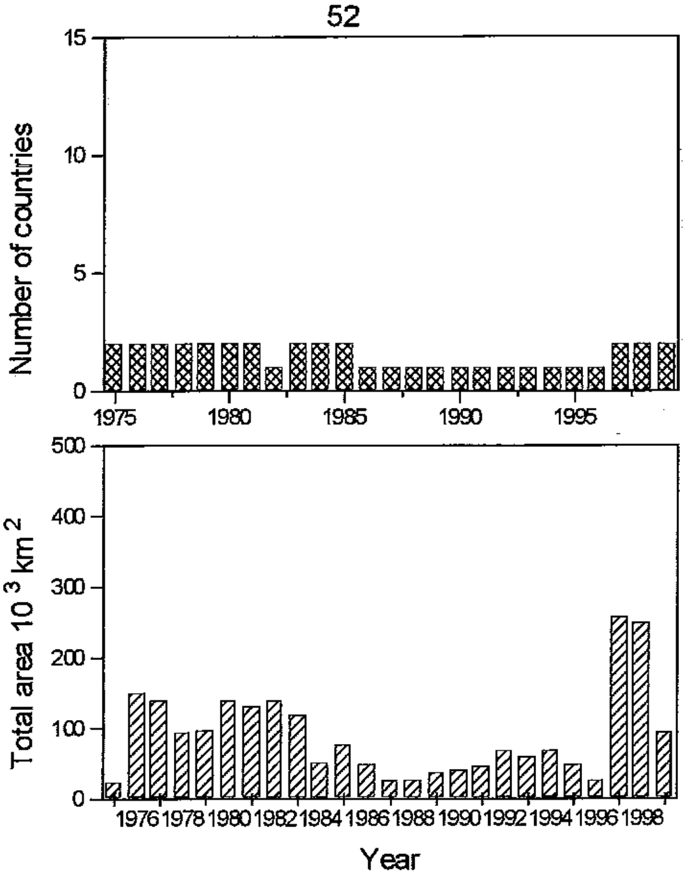

Fig. 4.6 Number of WMO RA IV countries involved in hail suppression activities (top) and total target area covered by them (bottom).

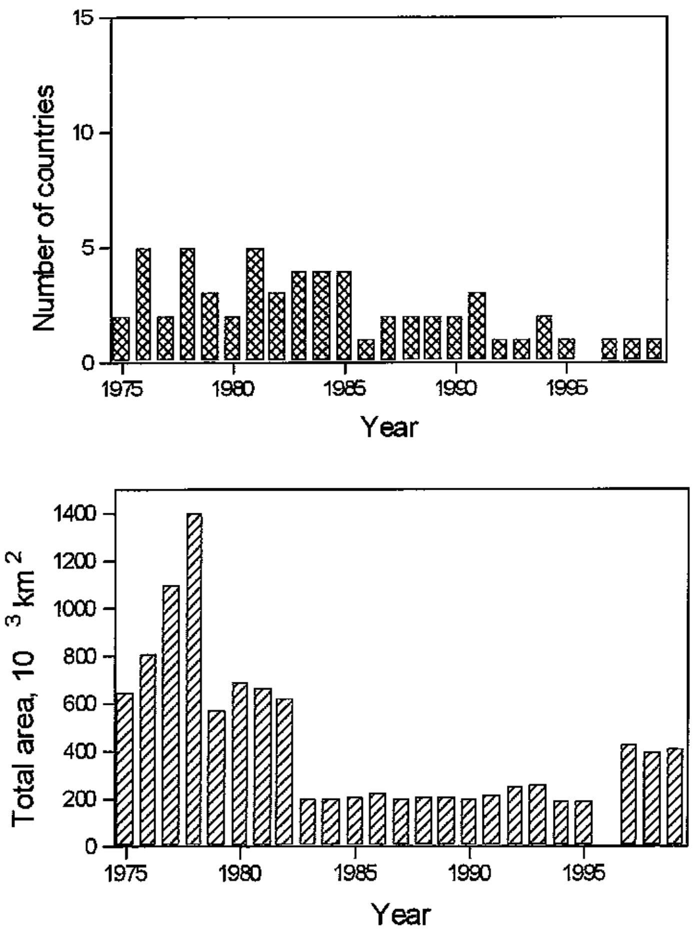

Fig. 4.7 Number of WMO RA IV countries involved in precipitation enhancement activities (top) and total target area covered by them (bottom).

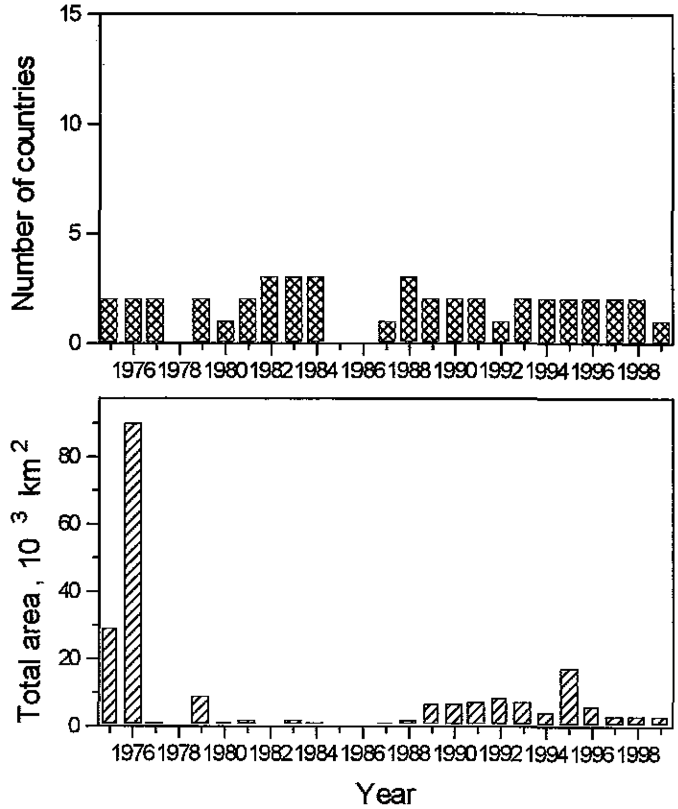

Fig. 4.8 Number of WMO RA V countries involved in precipitation enhancement activities (top) and total target area covered by them (bottom).

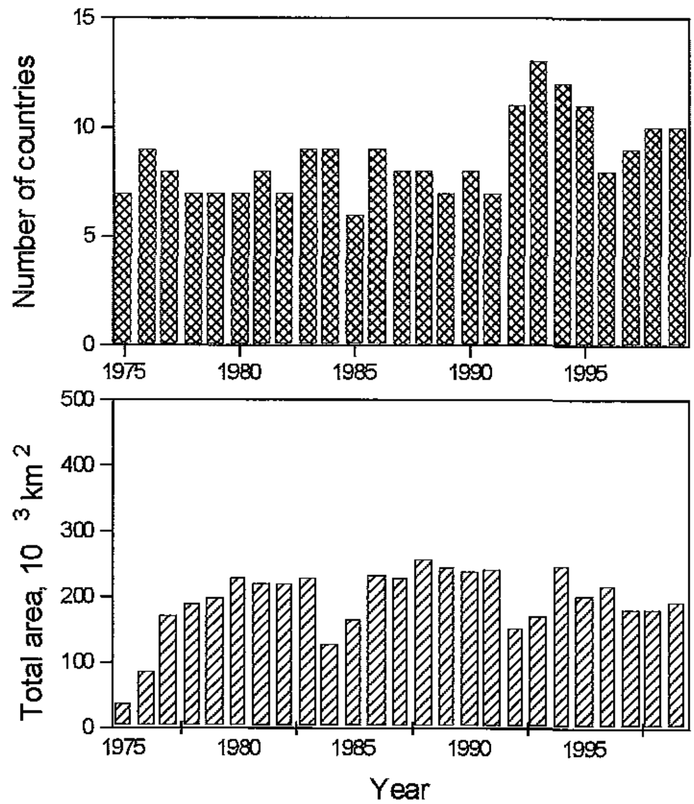

Fig. 4.9 Number of WMO RA VI countries involved in hail suppression activities (top) and total target area covered by them (bottom).

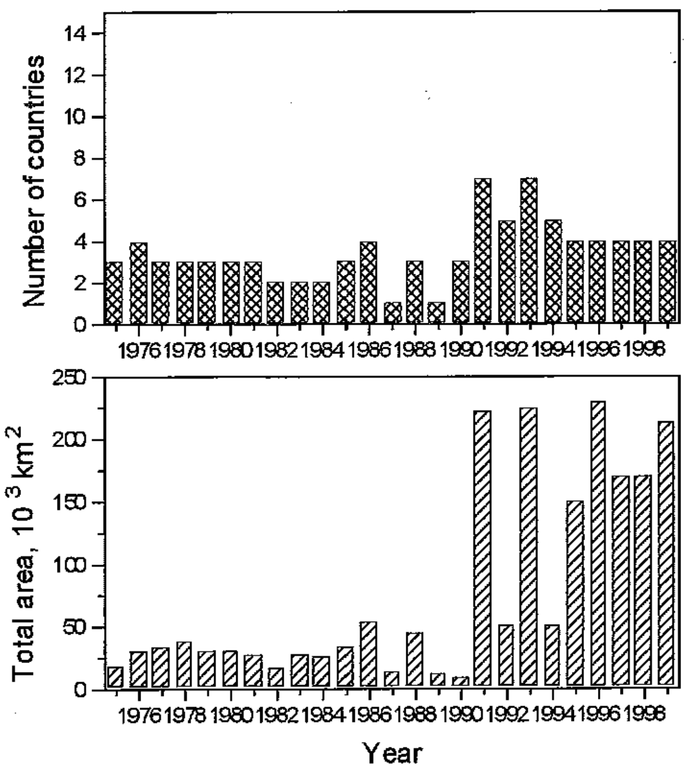

Fig. 4.10 Number of WMO RA VI countries involved in precipitation enhancement activities (top) and total target area covered by them (bottom).

WEATHER MODIFICATION PROGRAMME REPORTS

1. Review of Warm Cloud Modification by Bh. V. Ramana Murty (September 1984) (TD No. 5)

2. Papers presented at the Fourth WMO Scientific Conference on Weather Modification (Honolulu, Hawaii, 12-14 August 1985) (TD No. 53)

3. Notes for the International Cloud Modelling Workshop/Conference (Irsee, Federal Republic of Germany, 15-19 July 1985 (out of print) (TD No. 57)

4. Register of National Weather Modification Projects 1983 (November 1985) (TD No. 78)

5. The Evaluation of Hail Suppression Experiments – Report of Meeting of Experts (March 1986) (TD No. 97)

6. Information concerning Weather Modification directed to Government Decision-Makers (June 1986) (TD No. 123)

7. Trends in Weather Modification 1975-1983 (L.R. Koenig, Geneva, November 1986)

8. Report of the International Cloud Modelling Workshop (Irsee, Germany, 15-19 July 1985) (TD No. 139)

9. Register of National Weather Modification Projects – 1984 and 1985 (Geneva, July 1987) (TD No. 182)

10. Register of National Weather Modification Projects – 1986 (Geneva, December 1988) (TD No. 208)

11. Report of the Second International Cloud Modelling Workshop (Toulouse, 8-12 August 1988) (TD No. 268)

12. Papers submitted to the Fifth WMO Scientific Conference on Weather Modification and Applied Cloud Physics (Beijing, China, 8.-12 May 1989) (TD No. 269)

13. Register of National Weather Modification Projects – 1987-1988 (TD No. 330)

14. Register of National Weather Modification Projects 1989 (Geneva, May 1991) (TD No. 417)

15. Report of a Meeting of Experts to Review Findings and Make Recommendations on the Saudi Arabia Cloud Physics Experiments (SACPEX), (Geneva, 14-16 November 1990)

16. Report of the Seventeenth Session of the Executive Council Panel of Experts/CAS Working Group on Physics and Chemistry of Clouds and Weather Modification Research (Geneva, 19-23 November 1990)

17. WMO Meeting of Experts on the Role of Clouds in the Chemistry, Transport, Transformation and Deposition of Pollutants (Obninsk, 30 September – 4 October 1991) (TD No. 448)

18. Register of National Weather Modification Projects 1990 (TD No. 449)

19. Proceedings – WMO Workshop on Cloud Microphysics and Applications to Global Change [illegible]

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