中国气象局人工影响天气中心
CMA Weather Modification Centre (WMC)

Progress of Scientific Experiment and Research

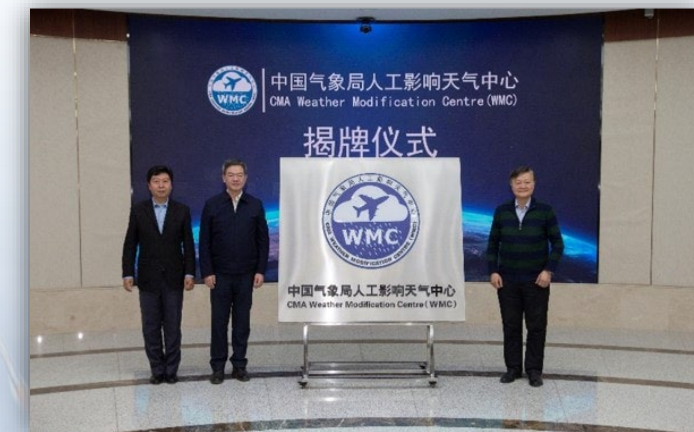
LOU Xiaofeng， DUAN Jing
Thailand, 2024/10/20

Outlines

1. **Overview of WMC**
2. **Systems and Techniques for Weather Modification**
3. **Field Bases and Experiments**

Weather Modification Centre, CMA

History



1965.10

Jiangxi

Lushan Cloud and Fog Physics Research Institute of CMA

1978.5

Beijing

Institute of Weather Modification, Chinese Academy of Meteorological Sciences (CAMS), CMA

2006.11

Beijing

Weather Modification Centre, CAMS, CMA

2012.8

Beijing

National Weather Modification Centre

Affiliated with CAMS and operates relatively independently

2021.12

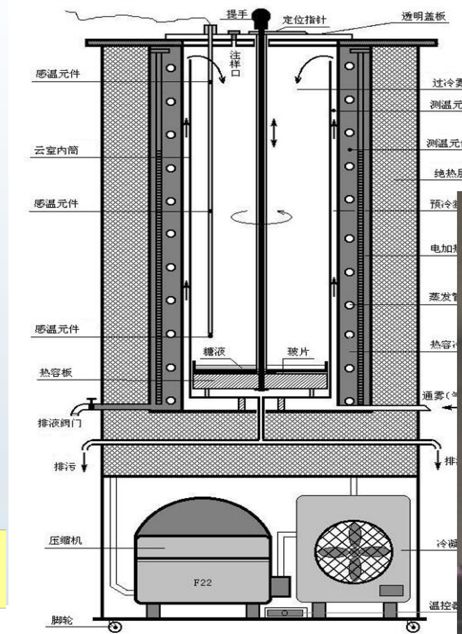
Beijing

CMA Weather Modification Centre

Started to be a public institution under CMA, public welfare category II, Bureau-Director level, and operate independently.

cloud chamber

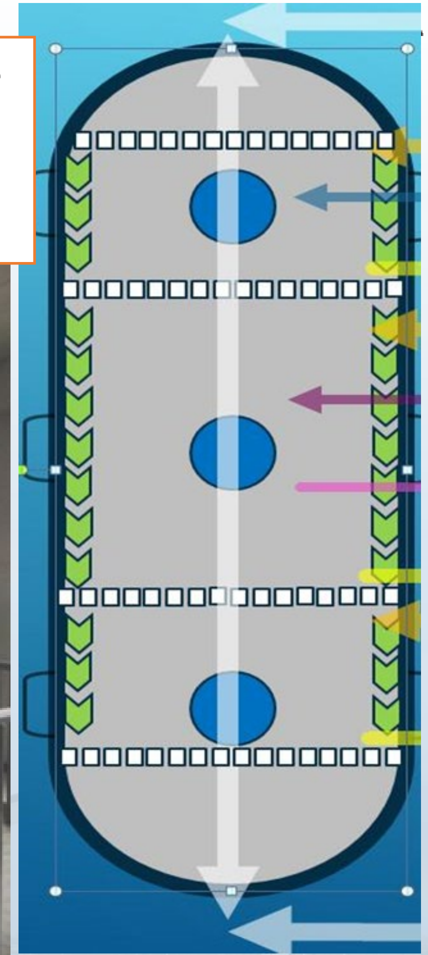
1m³ isothermal chamber



15L isothermal cloud chamber

70m³
T:-45℃～50℃
P: 1hpa～2000hpa

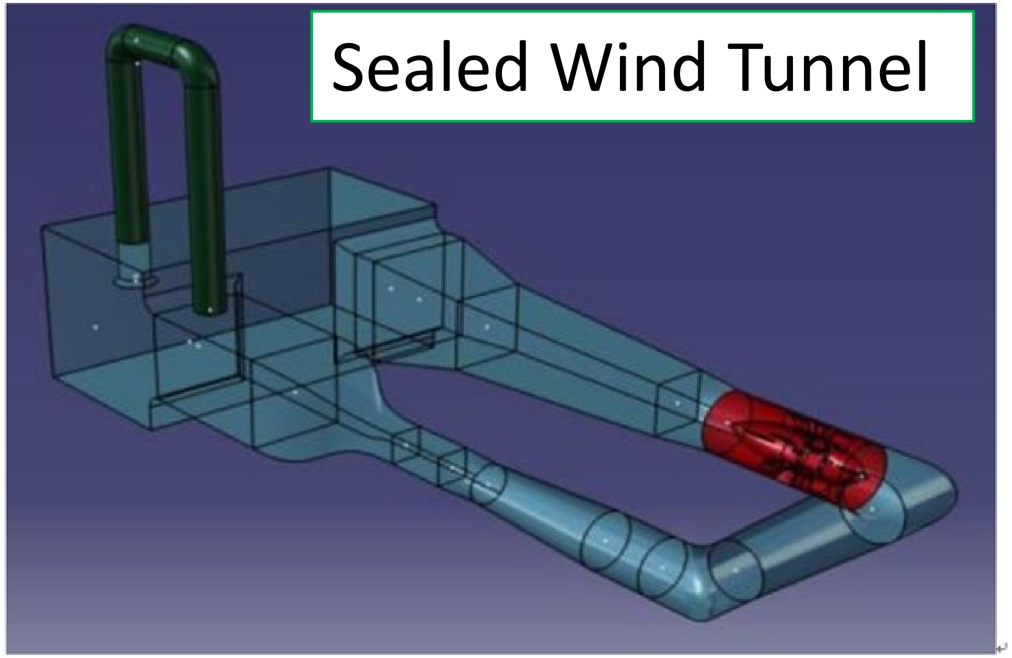
Temperature
Visibility
Fog
aerosol



6 m³ expansion cloud chamber

Cloud physics research, new seeding agent development, seeding technique.

Wind Tunnel:The Hygroscopic Flare Test Facility



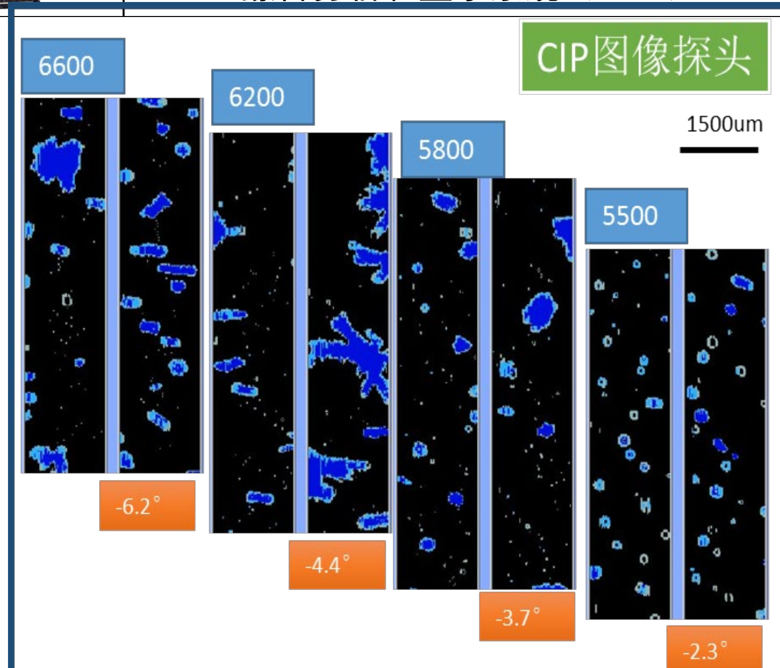
Wind speed： 5m/s - 100m/s
Pressure: 300hpa-1000hpa
Temperature: -40℃-40℃
Seeding agent aerosols can be measured off-line or on-line for IN and CCN

M60 aircraft equipped with advanced probes have been developed:CIP,PIP,PCASP, to detect aerosol, cloud and precipitation particles

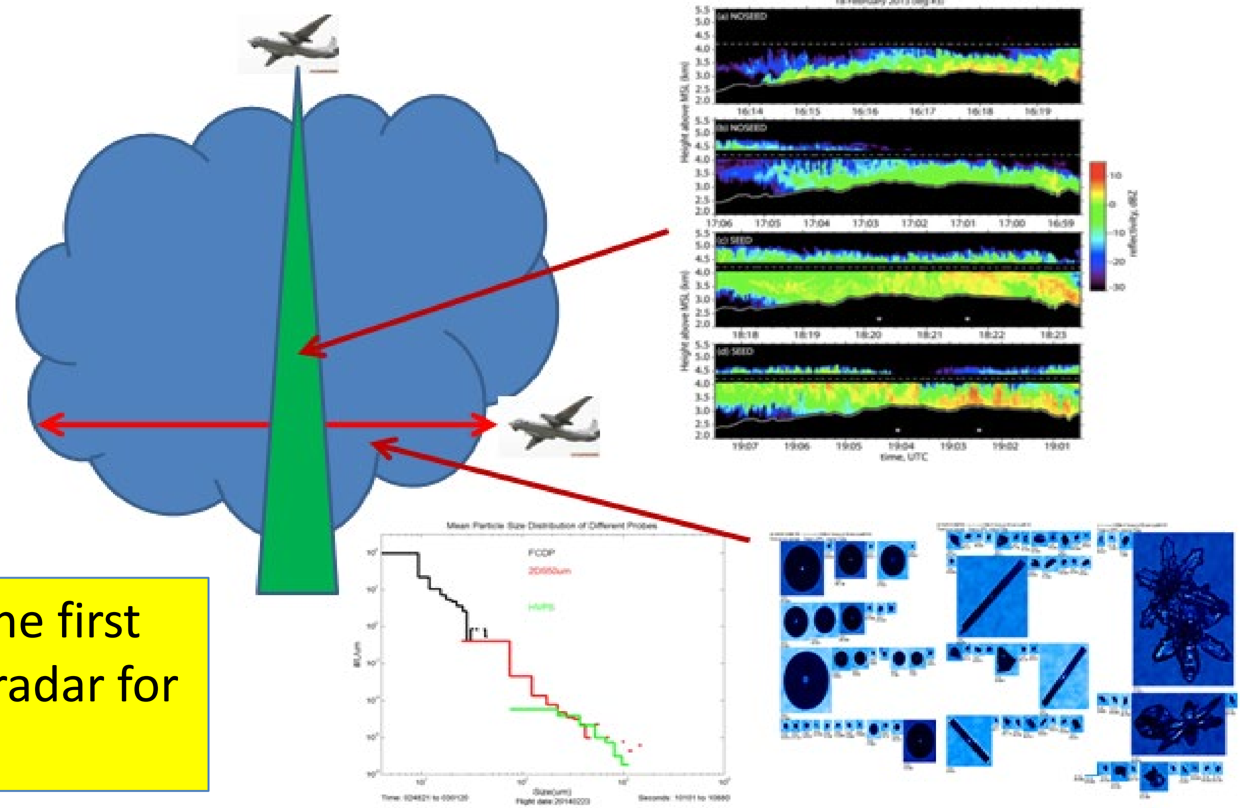
机型	最大飞行高度	航程	载重
MA60	7620 m	2450km	5500Kg

MA60

探头	名称/测量范围、内容
	气溶胶探头（PCASP−100X） 0．1−3 μm
	云粒子谱探头（CDP−2） 2−50 μm
	云降水粒子组合探头（CIP） 25−1550 μm
	降水粒子图像探头（PIP） 100−6200 μm
	后向散射云微物理特性探头（BCP） 7−75 μm
	飞机综合气象测量设备（AIMMS−20） 温压湿风等气象要素
	热线含水量仪（LWC−300） 0．05−3g/m^3
	云凝结核计数器（CCN−200） 0．75−10 μm
	综合分析和显示系统（PADS）



King Air 350ER

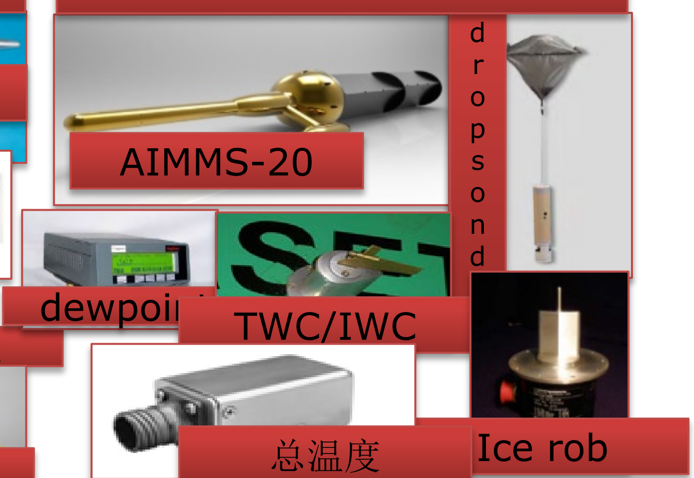


Air-borne more equipments than M60. The first lidar in one of King Air, the first airborne radar for weather modification in China

Cloud microphysical detection equipment

Aerosol physical and chemical properties detecting device

气象要素探测设备



人影装备—火箭
Equipment: Rocket

火箭发射装置既有车载也有牵引式和固定式的；各型号火箭架一次装填火箭数量3枚~20枚，射程从3千米~8千米不等，每枚火箭弹的催化剂从20克~50克不等。精准化和智能化的火箭已经成熟并列装。

Currently, vehicle-mounted and towed or fixed ; each type of rocket carrier can be loaded with 3 to 8 rockets at a time, ranging from 3 km to 8 km, and the catalyst of each rocket varies from 20 g to 50 g. Precision and intelligent rockets have matured and are mounted side by side.

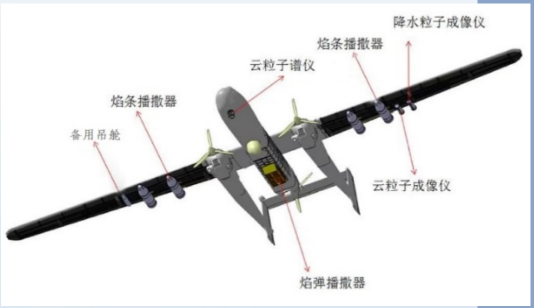
体播撒火箭结构示意图
stereo broadcast rocket structure diagram

人影火箭发射架及火箭发射
Weather modification rocket launcher and rocket launch

人影装备—无人机
Equipment: Unmanned Aerial Vehicle (UAV)

近年来无人机发展迅速，应用无人机开展人工影响天气也是人影装备发展的热点。近几年，多种型号的大中小型无人机开展了人影试验，除固定翼外，还有旋翼甚至滑翔翼等型号。其中，大型无人机在祁连山、青藏高原地区开展的人工增雨试验有代表性，取得了较好的效果。

In recent years, with the development of UAV, the application of UAV to carry out weather modification is also a hot spot in the development of weather modification equipment. In recent years, various types of large, medium and small UAV have carried out weather modification tests. In addition to fixed wings, there are also rotors and even gliding wings fro UAV. Among them, the artificial rain enhancement experiment carried out by large UAV in Qilian Mountains and Qinghai-Tibet Plateau is representative and has achieved good results.



大型人工影响天气无人机
Large-scale weather modification UAV

2 Systems and Techniques for Weather Modification

中国气象局人工影响天气中心
CMA Weather Modification Centre(WMC)

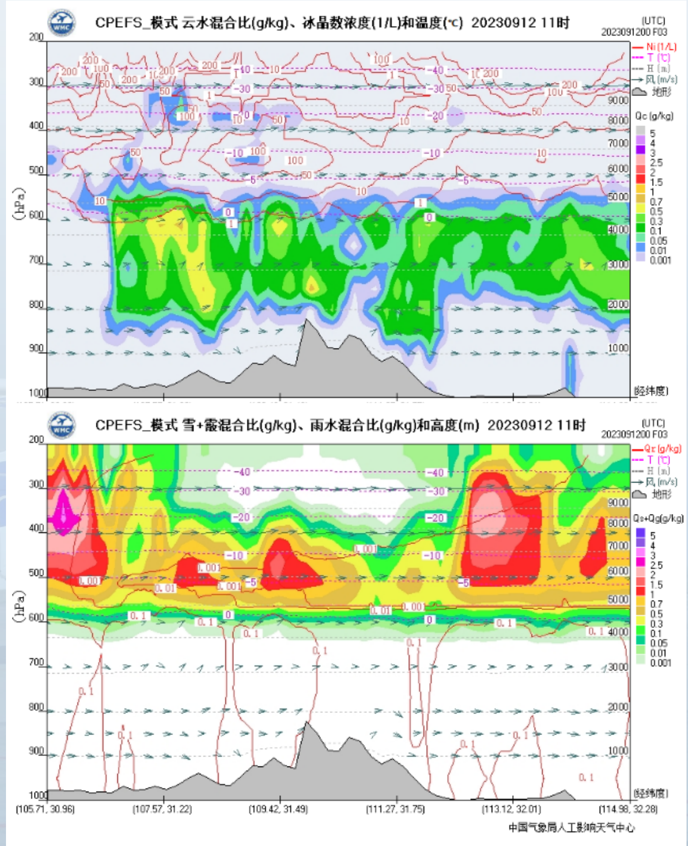
Cloud and Precipitation Explicit Forecast System

The CMA-CPEFS (China Meteorological Administration - Cloud and Precipitation Explicit Forecast System) supports the fine prediction of cloud and precipitation with a horizontal resolution of 3 km, covering the entire nation. It generates over 30 different forecast products, including macro&micro characteristics of cloud and precipitation. Additionally, it is equipped with the capacity to predicte the effect of seeding schemes and evaluate the operation effects.

Model	year	variables
1-D mix-phased two-moment convective cloud model	1987	qv,qc,qr,qi,qg,qh,ni,nr,ng,nh,Fc
3-D nested convective cloud model	1993	qv,qc,qr,qi,qg,qh,ni,nr,ng,nh,Fc
3-D cloud series model **(CAMS)**	2003	qv,qc,qr,qi,qs,qg,Nr,Ni,Ns,Ng,Fc

coupled to MM5, GRAPES, WRF

MM5_CAMS, GRAPES_CAMS,WRF_CAMS



Forecast water substances and cloud structure

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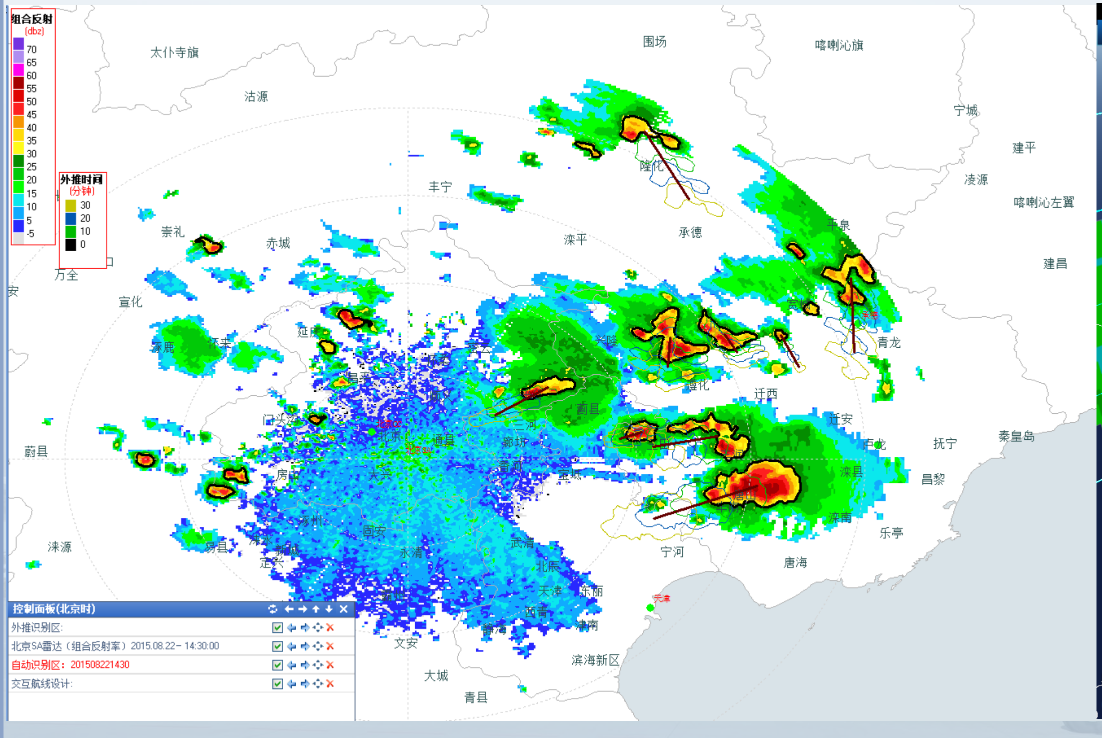
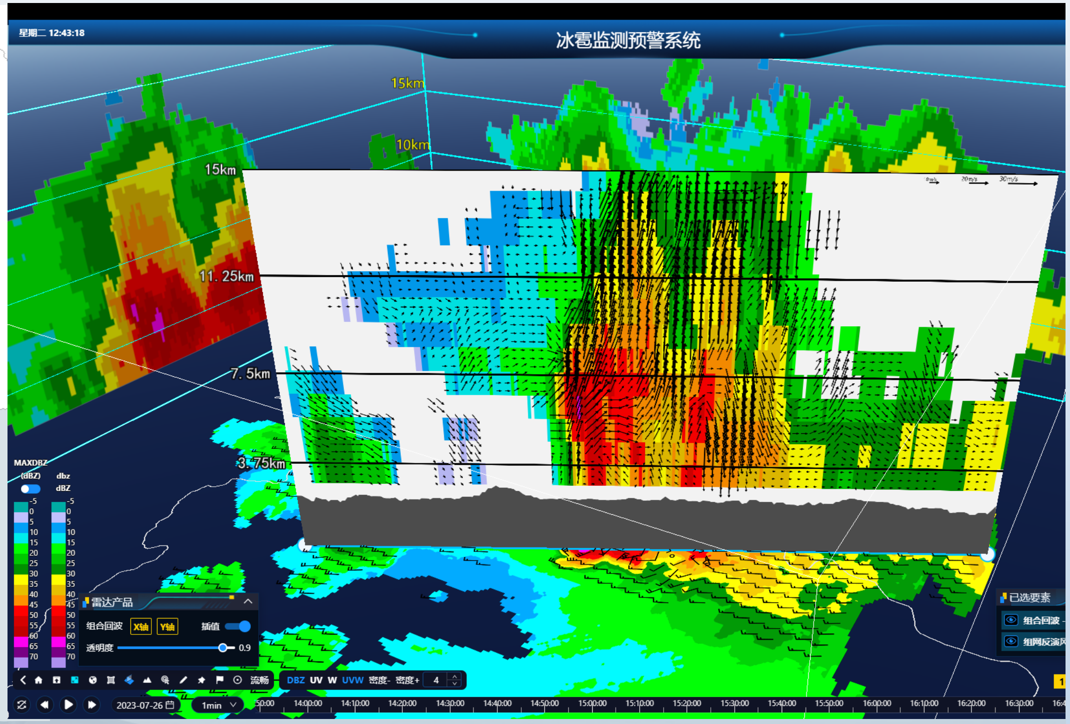
CMA Weather Modification Centre(WMC)

Three-dimensional cloud, precipitation and wind field retrieval from radar



Seeding cell echo identify, track and extrapolation



Radar echo and three-dimensional wind filed

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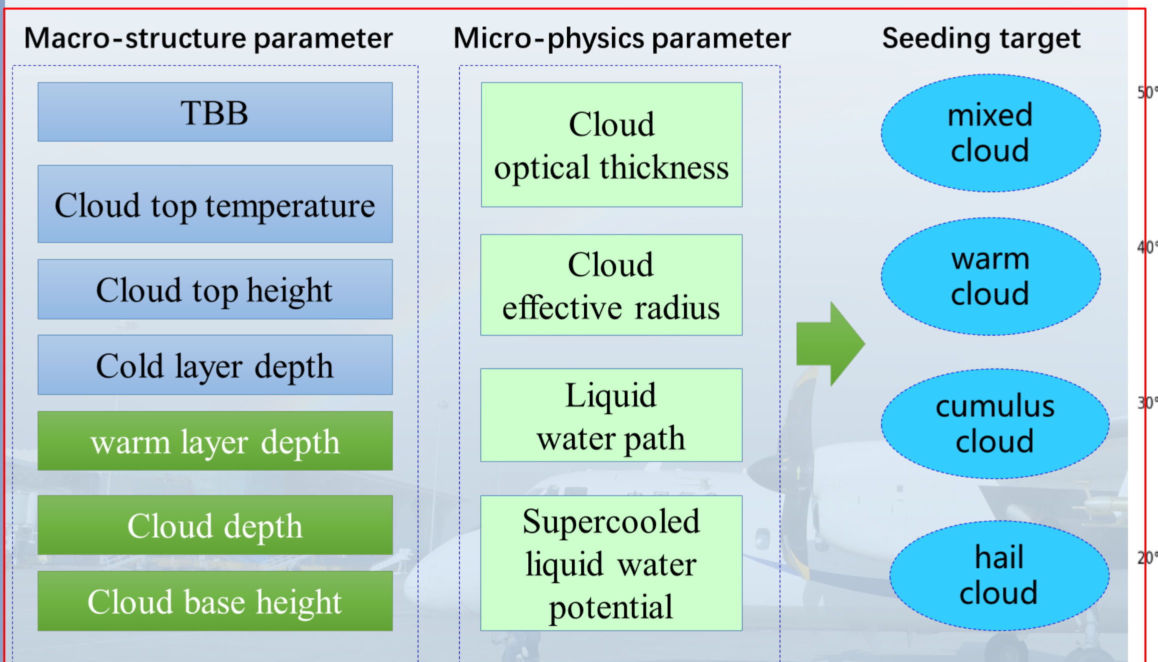
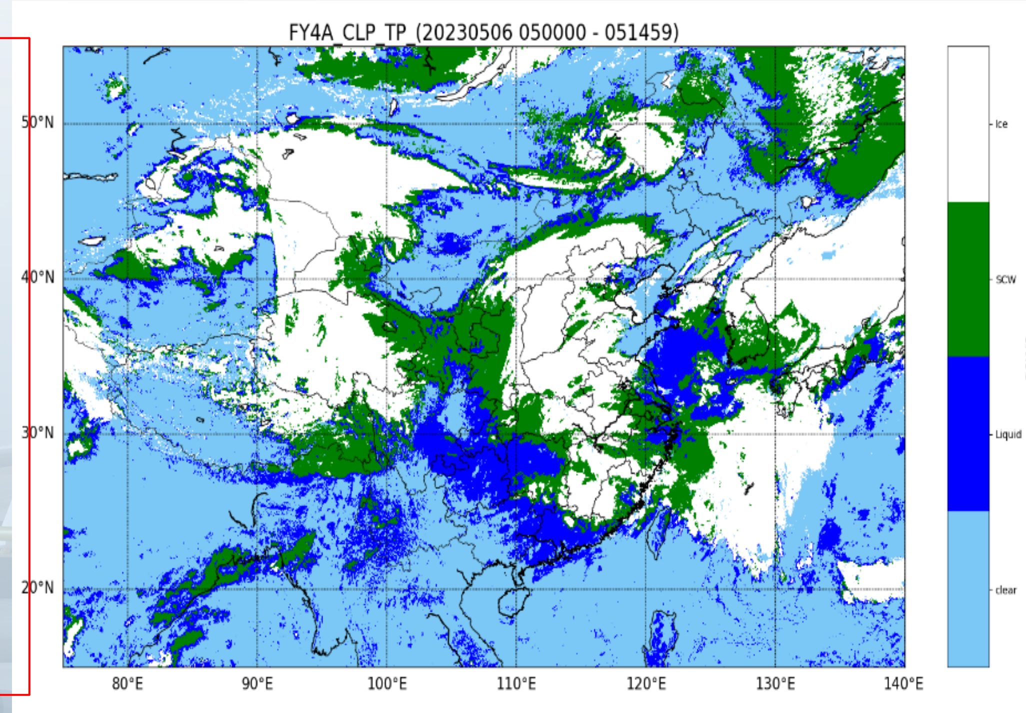
Cloud products retrieved from FY4 Geo-stational satellite, sounding and ground observation



Satellite retrival product of cloud parameters



FY4 SCLW potential region

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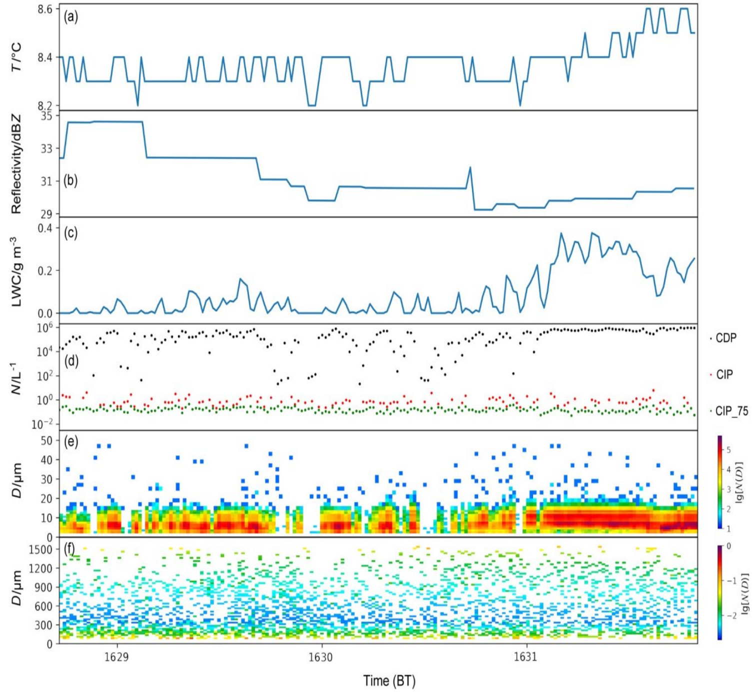
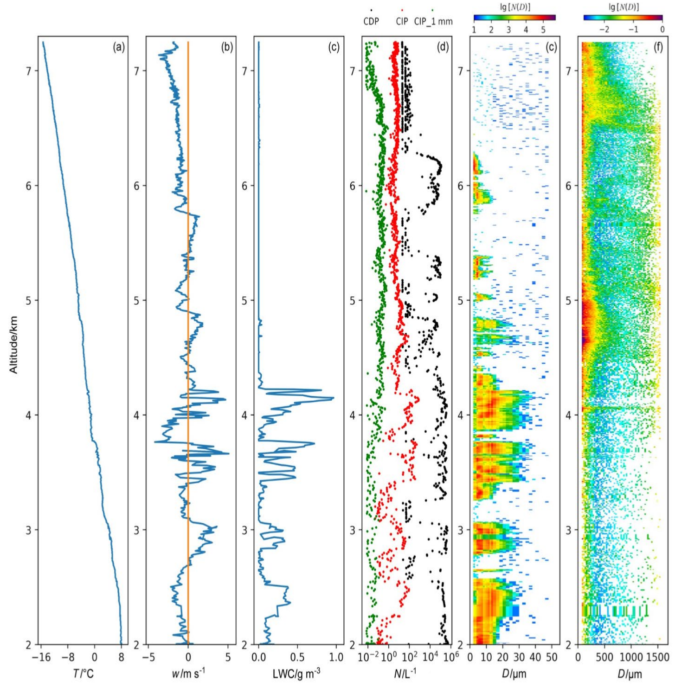
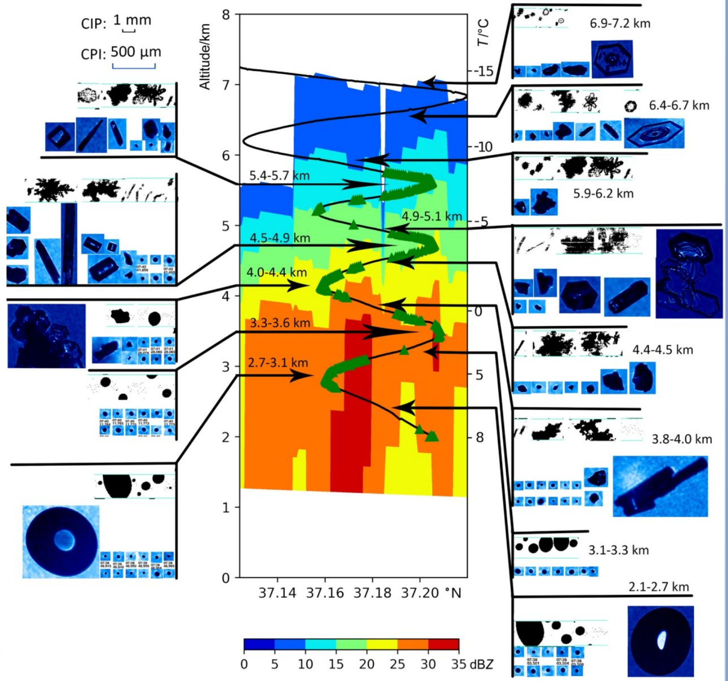
Analysis and application of aircraft observation data



Horizontal distribution



vertical structure of cloud microphysical characteristics

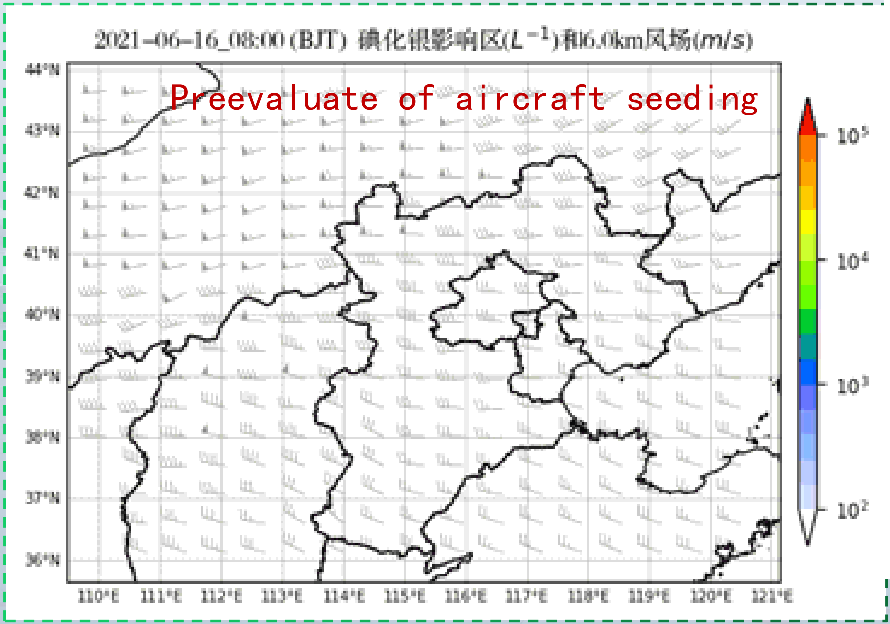


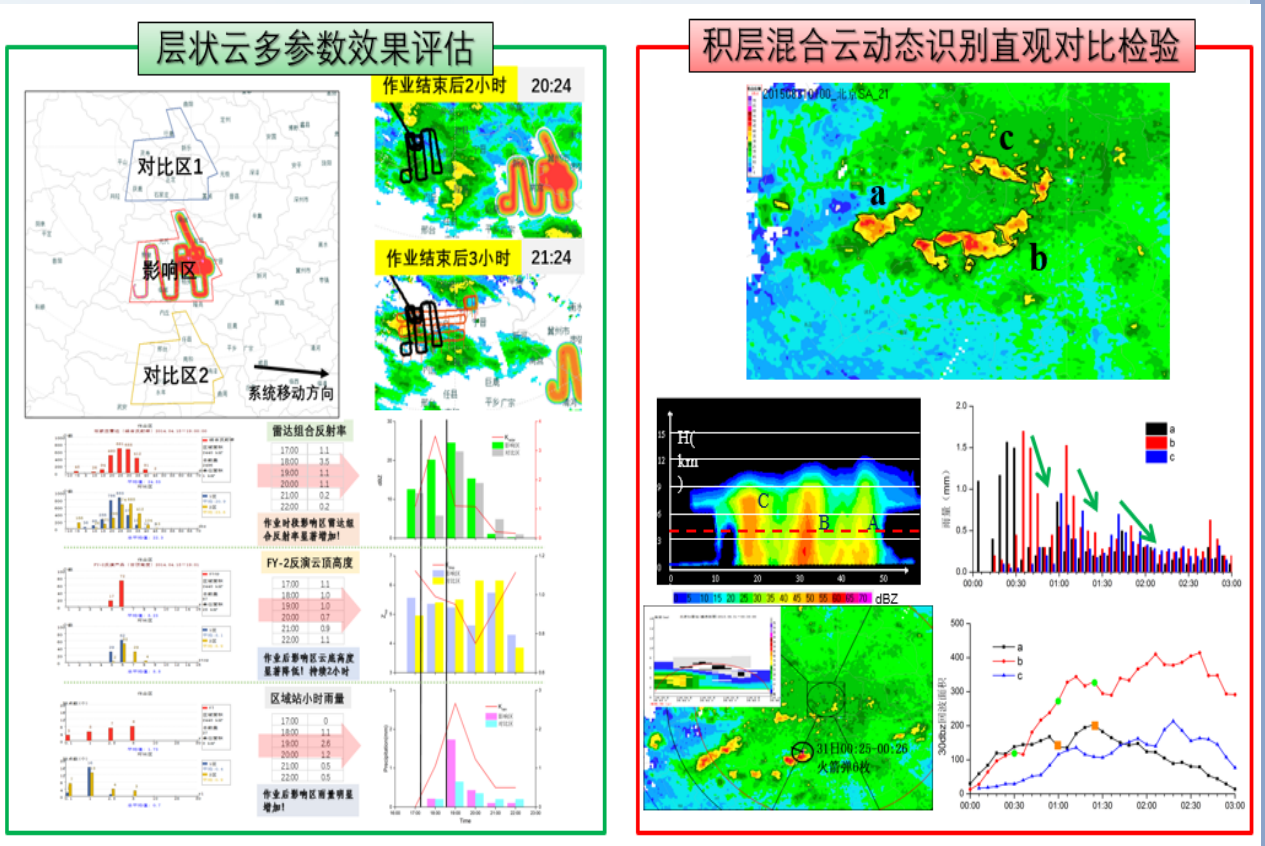
Images of cloud particles at different heights

Effect evaluation technology

The effectiveness evaluation technology is the key to the scientific and accurate operation

- Comprehensive use of **physical, statistical and numerical model** methods to evalute artificial rain enhancement effect.
- The application of artificial intelligence (**AI**) technology may be an important method.





Multi-parameter effect evaluation

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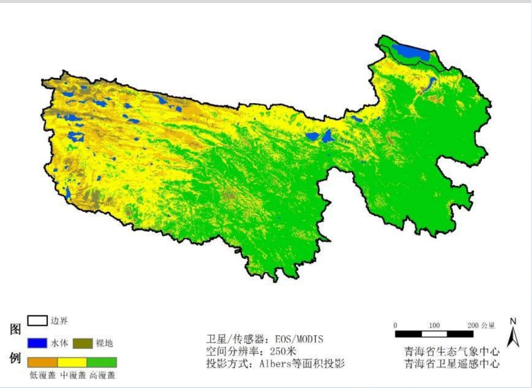
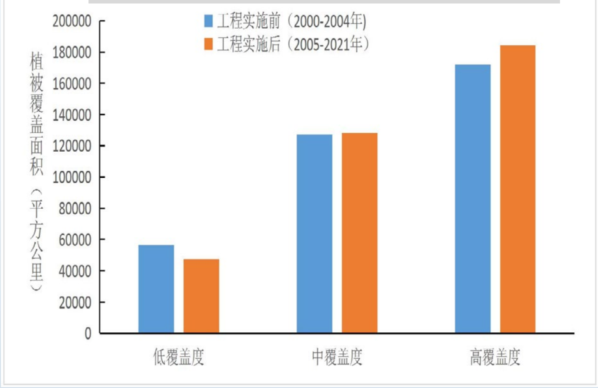
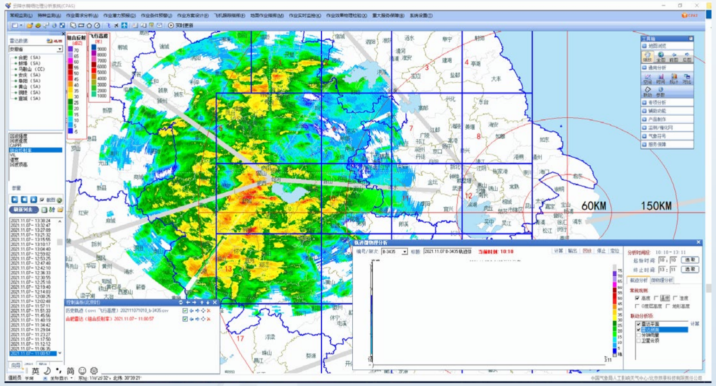
Effect evaluation technology

2021 年三江源植被覆盖度遥感监测图



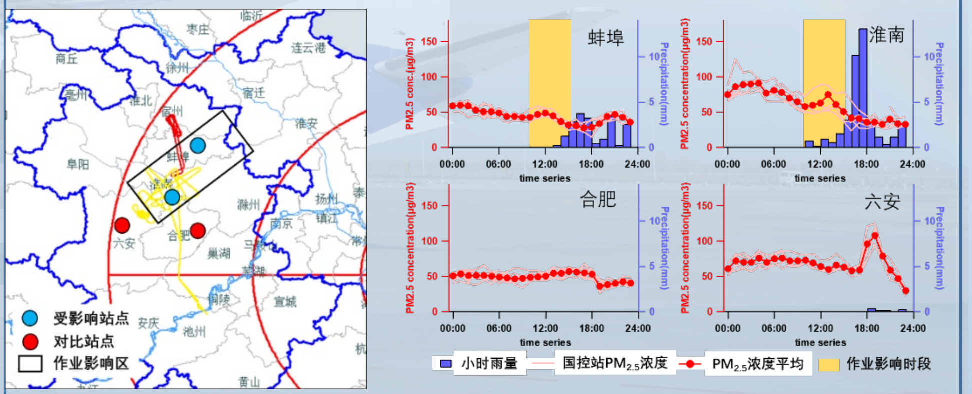
青海三江源增雨助力生态修复





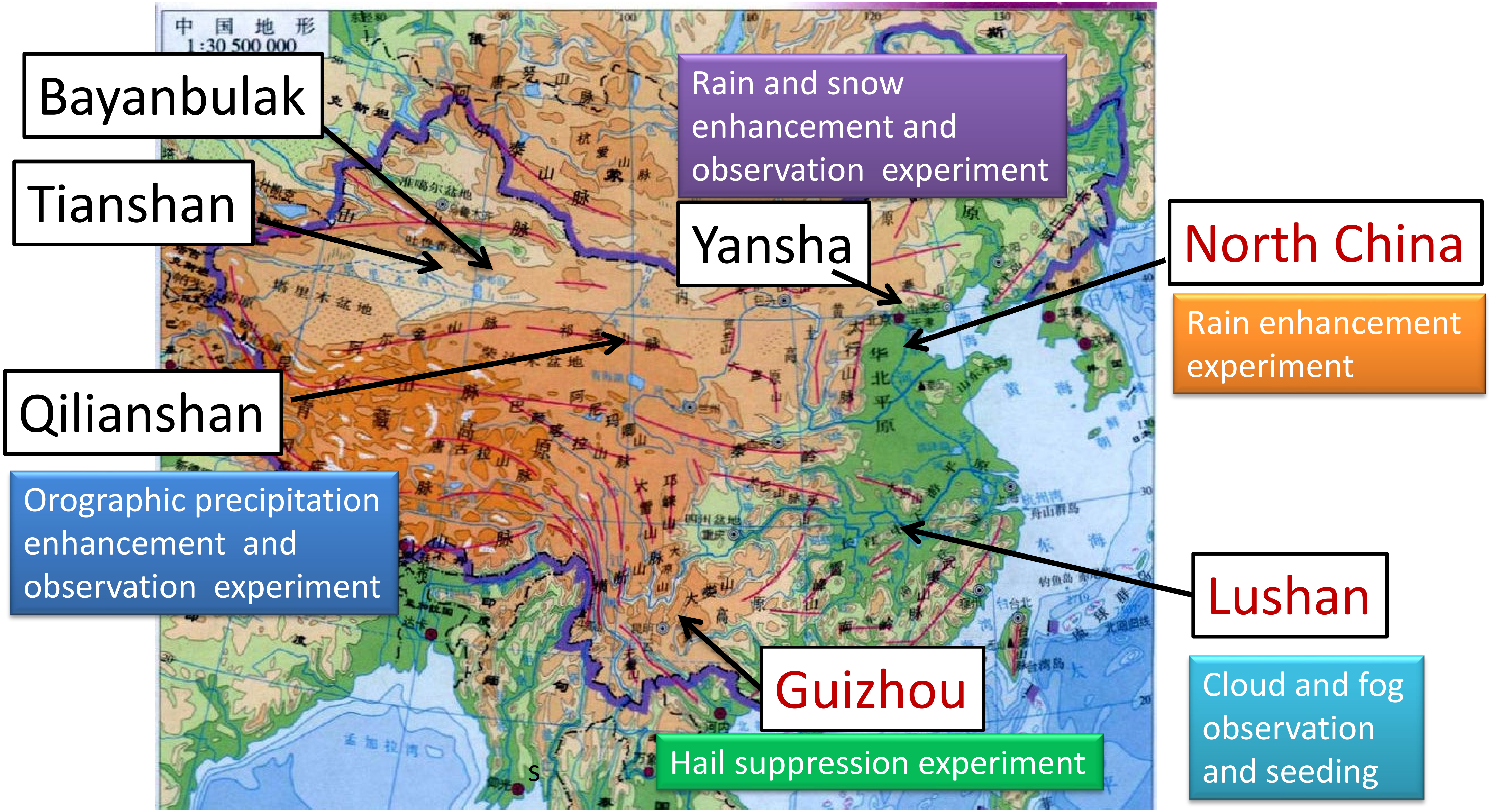
- The effect evaluation of artificial rain enhancement has two stages: rain enhancement effect evaluation and comprehensive benefit evaluation.
- The comprehensive benefit evaluation: evaluate the contribution of rain enhancement to weather modification service objectives, e.g., water resources conservation, ecological vegetation restoration and air quality improvement. It is currently in its initial stage.

增雨改善空气质量

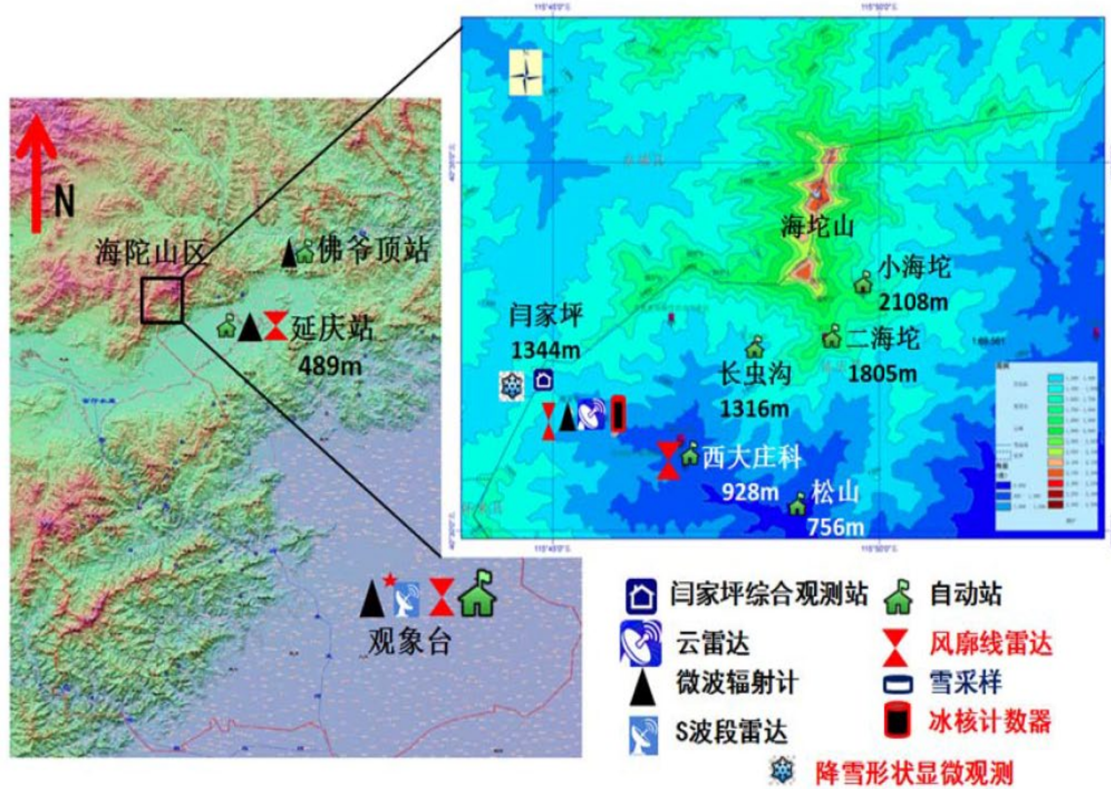


3 Field Bases and Experiments

Established Observation and Seeding Experiment Base



Yanshan base



Cloud radar

Wind profile radar

Microwave radiometer

IN counter

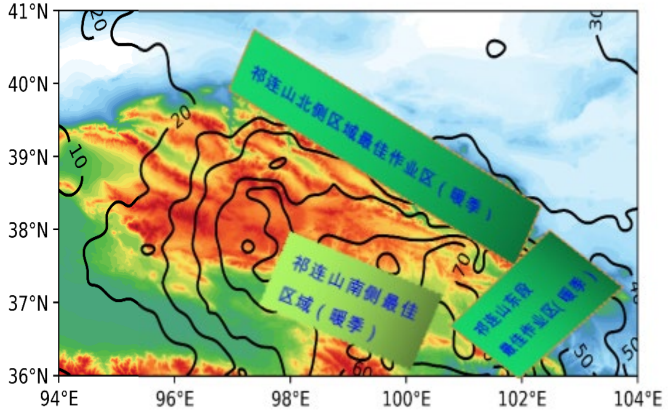
S-band radar

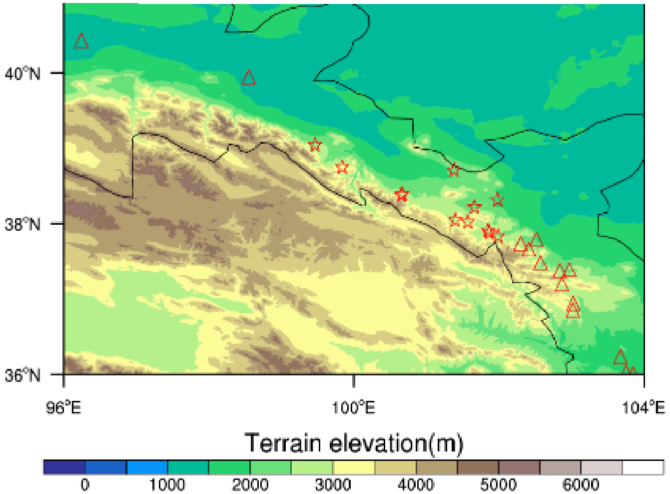
Snow particle shape microscopic observation

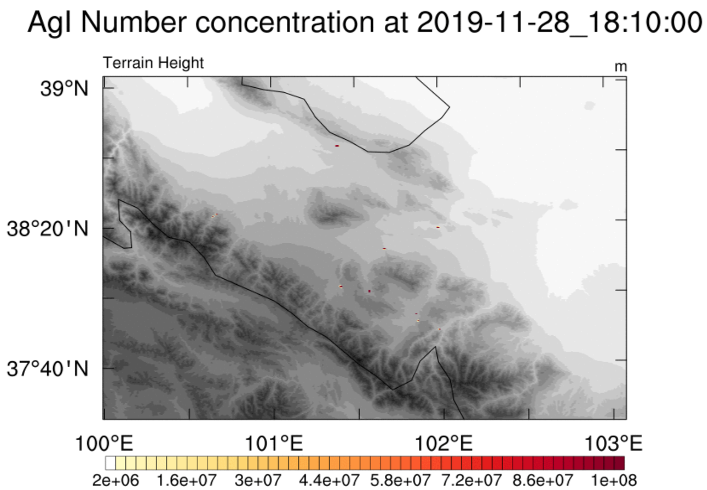
Around Beijing, Yanshan Mountain, for 2022 winter Olympic games.
Cloud observation, IN measuring and snow particle shape observation.
Snowfall seeding experiment.

Precipitation enhancement over the Qilian Mountain Base

- **Establishing a conceptual model of precipitation enhancement for orographic clouds over the Qilian Mountains**
- **Using WRF and HYSPLIT models to optimize the layout of generators in the Qilian Mountain by sensitive tests.**



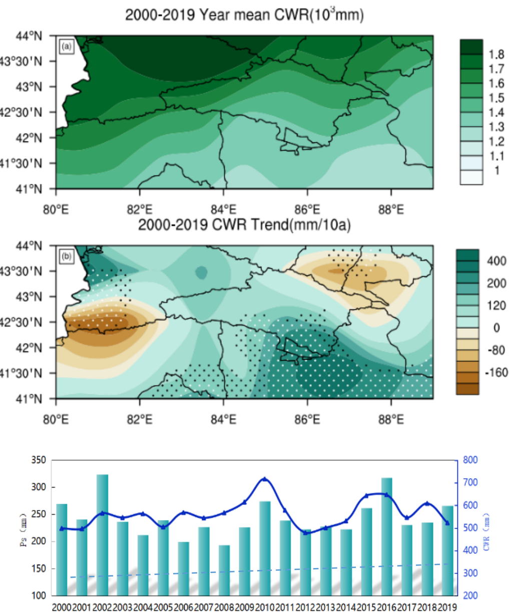


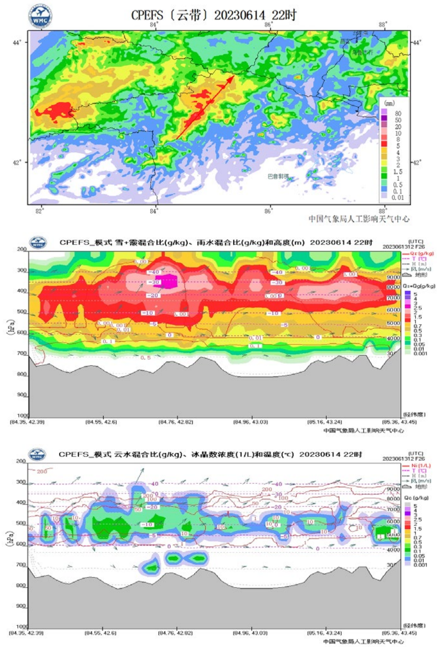


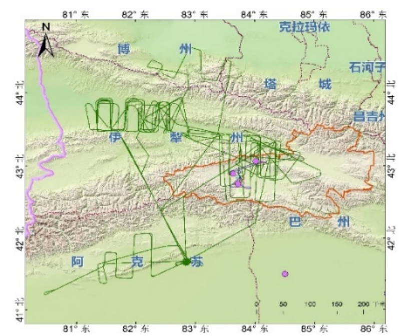
The development of cloud water resources in the Bayanbulak mountainous area

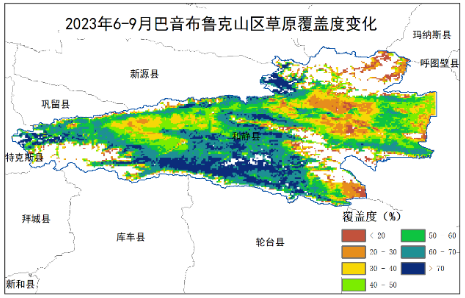
- Quantified the cloud water resources in the Bayanbulak mountainous area，and learned its climatic characteristics.
- Establish a high-precision（1km×1km，hourly ）numerical forecast system based on operational CPEFS V2.0 model

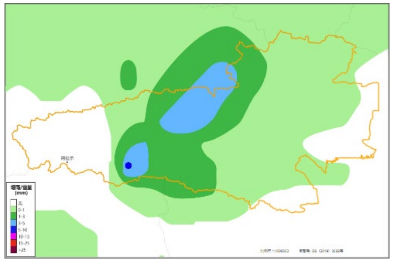
- Based on physical validation methods and numerical catalytic, the seeding effect of precipitation(snow) enhancement from June to December 2023 was evaluated.
- The ecological benefits brought by precipitation enhancement are evaluated using satellite remote sensing data.

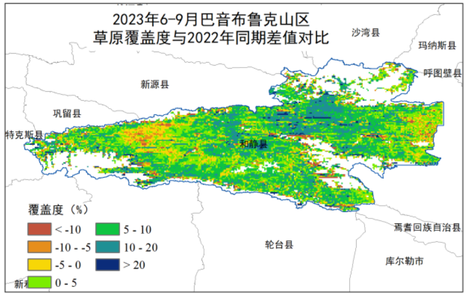






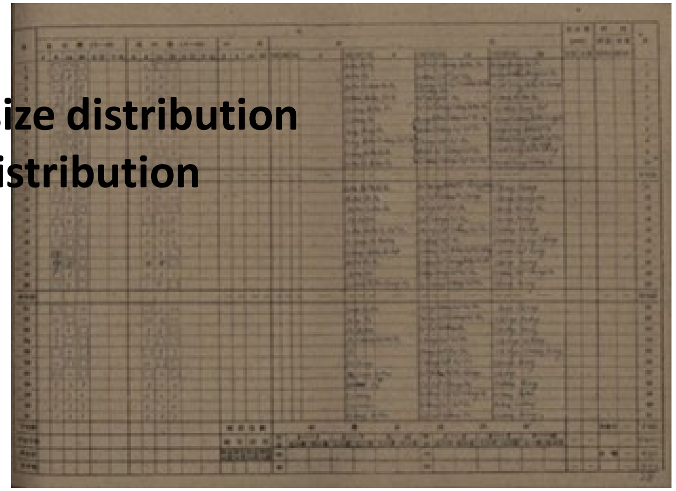






National Lushan cloud and fog experiment station (LSCES)

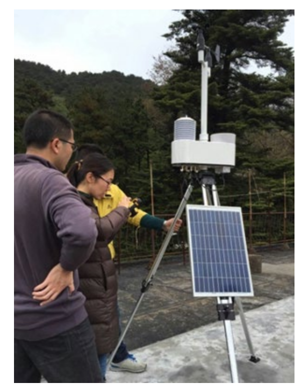
1958-1970
cloud droplet-size distribution
raindrop size distribution
salt nucleus
acid rain



To continue the cloud observation
,to get long-term data
In 2015, rebuilt observation platform

编号	
2	Fog Monitor
3	Disdrometer
m	Microwave radar
5	ceilometer
6	Visibility meter
7	AWS
8	Rain gauge

Daily Observation:
Fog, Hail, snow,
frozen rain,
heavy storm

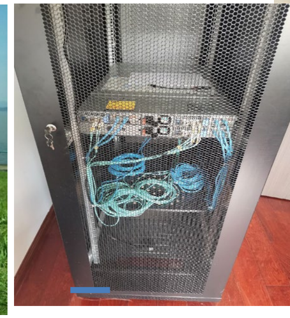


2019-2024: 30 equipment

毫米波云雷达、拉曼激光雷达

微波辐射计

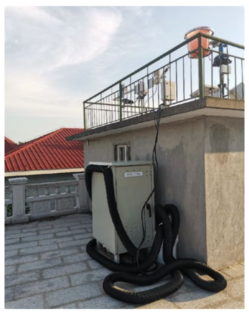
大容量存储器



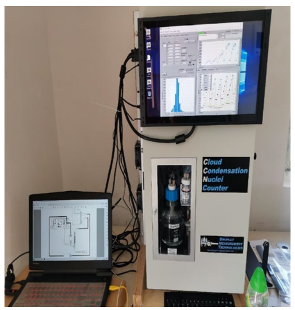
2DVD雨滴谱仪

微雨雷达

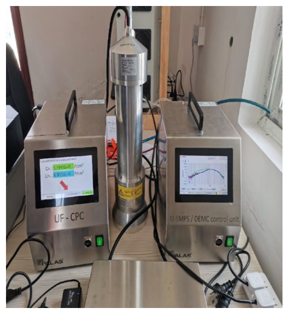
进气采样系统



云凝结核计数器



扫描电迁移



气溶胶粒径仪

雾滴谱仪

云粒子成像仪

激光云高仪

雨滴谱仪

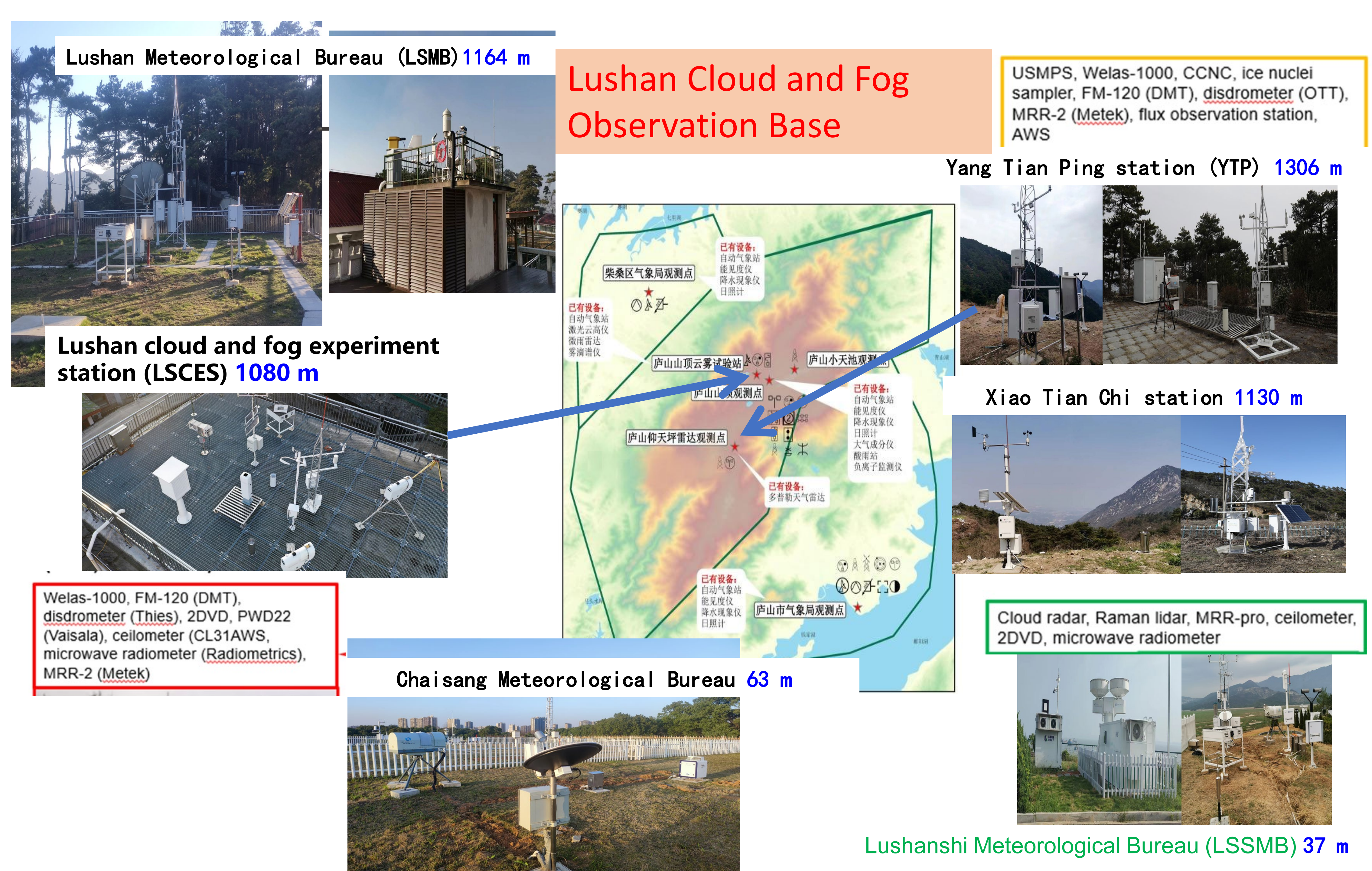
全天空成像仪

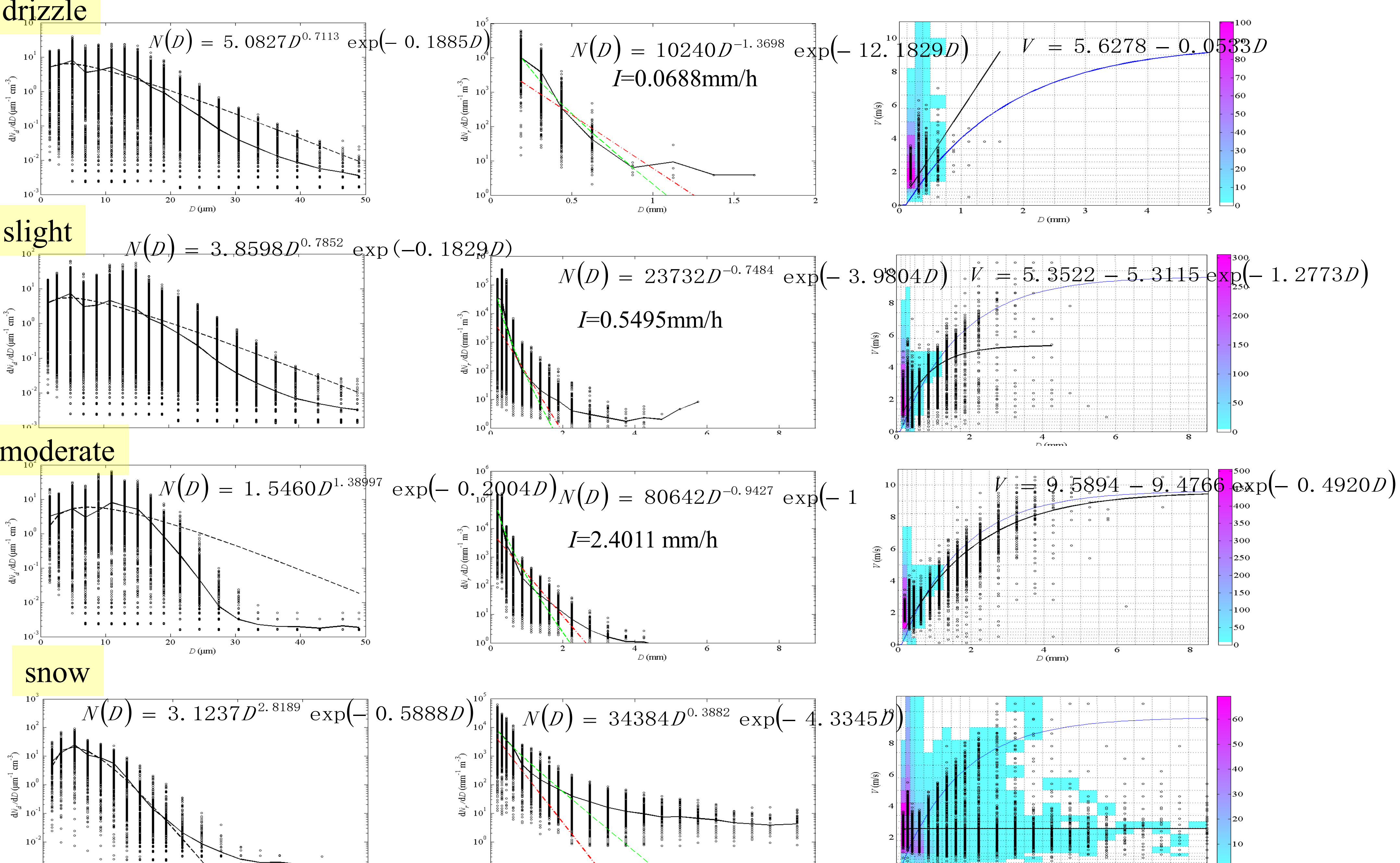
通量观测系统

辐射观测系统

结冰传感器

CCN Counter
fog monitor
disdrometer
microwave radiometer
ceilometer
visibility sensor
microwave rain radar
rain gauge
2DVD
fog water collector
all-sky imager
radiation observation system
cloud radar
Raman lidar


Lushan Meteorological Bureau (LSMB) 1164 m
Lushan Cloud and Fog Observation Base
USMPS, Welas-1000, CCNC, ice nuclei sampler, FM-120 (DMT), disdrometer (OTT), MRR-2 (Metek), flux observation station, AWS
Yang Tian Ping station (YTP) 1306 m
Lushan cloud and fog experiment station (LSCES) 1080 m
柴桑区气象局观测点
已有设备：
自动气象站
能见度仪
降水现象仪
日照计
已有设备：
自动气象站
激光云高仪
微雨雷达
雾滴谱仪
庐山山顶云雾试验站
庐山小天池观测
庐山山顶观测点
庐山仰天坪雷达观测点
已有设备：
自动气象站
能见度仪
降水现象仪
日照计
大气成分仪
酸雨站
负离子监测仪
已有设备：
多普勒天气雷达
已有设备：
自动气象站
能见度仪
降水现象仪
日照计
庐山市气象局观测点
Xiao Tian Chi station 1130 m
Welas-1000, FM-120 (DMT), disdrometer (Thies), 2DVD, PWD22 (Vaisala), ceilometer (CL31AWS, microwave radiometer (Radiometrics), MRR-2 (Metek)
Cloud radar, Raman lidar, MRR-pro, ceilometer, 2DVD, microwave radiometer
Chaisang Meteorological Bureau 63 m
Lushanshi Meteorological Bureau (LSSMB) 37 m



spectro distribution and falling velocity of different precipitation types

The cloud seeding experiment in 2022 and 2023: Instruments and data

Instruments	Measurement	Measurement range
U-SMPS (Palas)	Aerosol particle size distribution, N_a	Size: 4-850 nm
Welas-1000 (Palas)	Aerosol particle size distribution, N_a	Size: 0.3-17 μm
Fog monitor 120 (DMT)	Cloud droplet size distribution, N_c, LWC, D_e, mean diameter (D_m)	Size: 2-50μm
Disdrometer (OTT)	Particle size distribution, Rainfall rate	Size: 0.125-25 mm
MRR2 (Metek)	Radar reflectivity factor, fall velocity, rain rate, LWC, drop size distribution density	Raindrop size: ~5mm Height: 0-3.1km
CCN counter (DMT)	Activated aerosol spectrum, N_{ccn}	Size: 0.75-10 μm
Automatic Weather Station	Temperature, pressure, relative humidity, wind, and rainfall	
Wind profile radar	Horizontal and vertical wind profile	Height: 50-2500 m
Cloud radar (35GHz)	Radar reflectivity	Height: 0-20 km
MRR-pro （Metek）	Radar reflectivity factor, fall velocity, rain rate, LWC, drop size distribution density	Height: 0-6.2 km
Microwave radiometer	Surface temperature, RH, pressure; and Temperature, vapor density, relative humidity, LWC profile	Height: 0-10 km

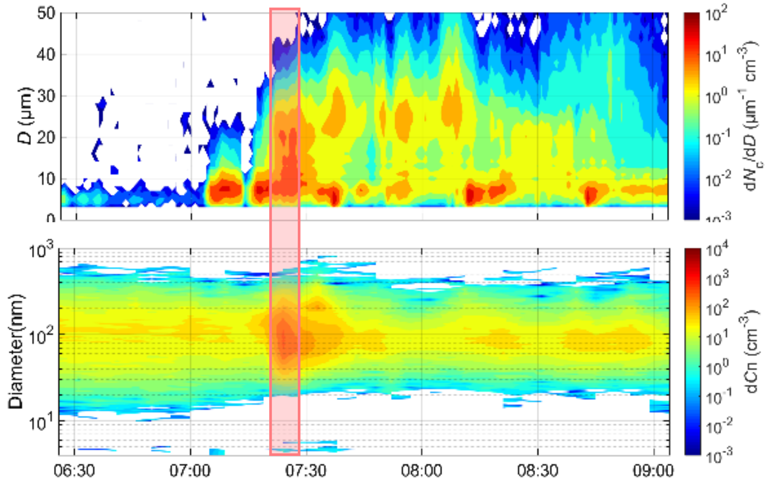
YTP at mountain top, in-situ observation

LSSMB at the foot of mountain, remote sensing observation

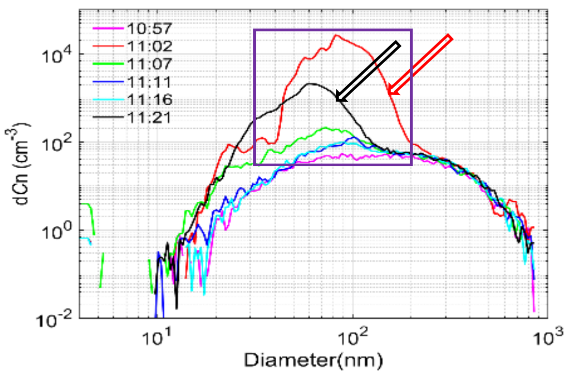
The cloud seeding experiment in 2022, 2023

seeding with ground-based generator

DSD and PSD before and after seeding

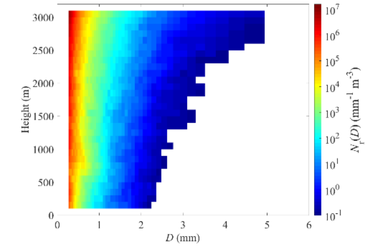


size distribution after seeding

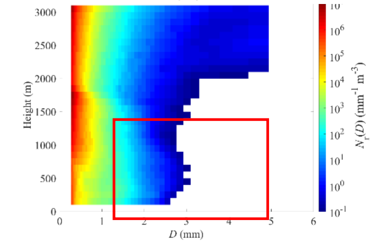


seeding with hygroscopic powder

rain size distribution



LSCES (noseed)



YTP (seed)

Hail suppression hypothesis

The World Meteorological Organization (1995) identified six (!) different scenarios for hail formation:

- 1) Growth-limiting competition among hail embryos (beneficial competition),
- 2) Early rainout (from a zone of hail embryos),
- 3) Glaciation of cloud water,
- 4) Trajectory lowering,
- 5) Promotion of coalescence in inefficient weak storm cells,
- 6) seeding for dynamic effects.

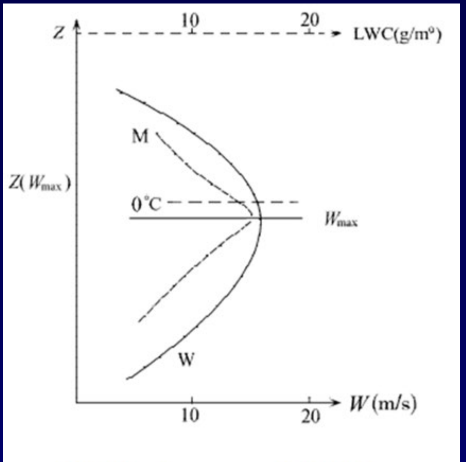
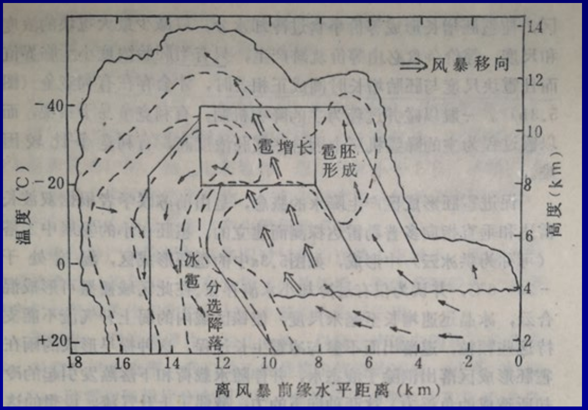
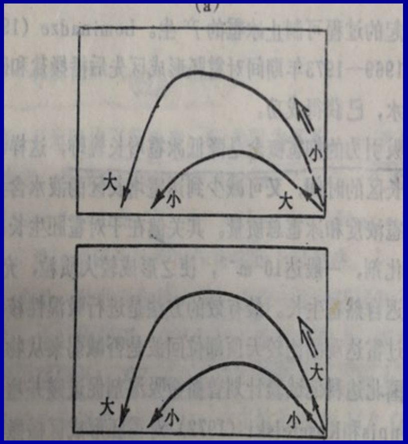


图 2.13 Сулаквилидзе 概念模型

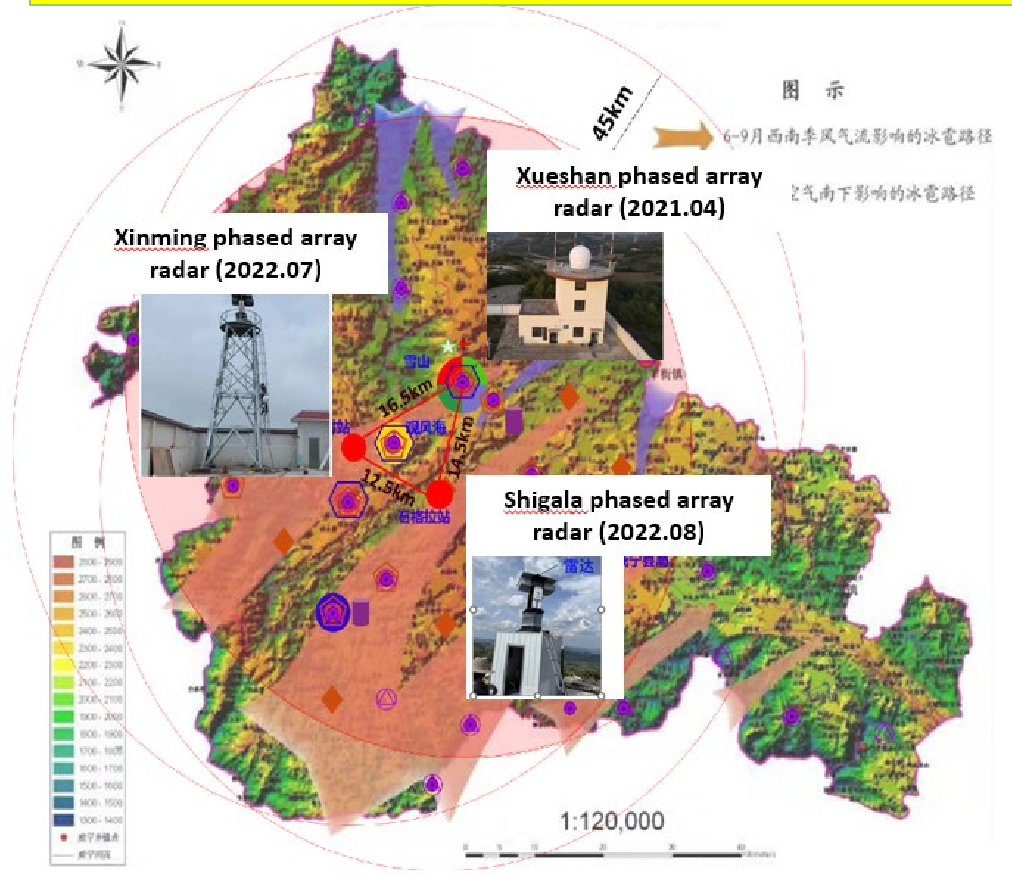




National (Guizhou) Hail Suppression Base

The first National Hail Suppression Base in China

To obtain three dimensional wind field,Liquid and ice-phased particles distribution in hail cloud

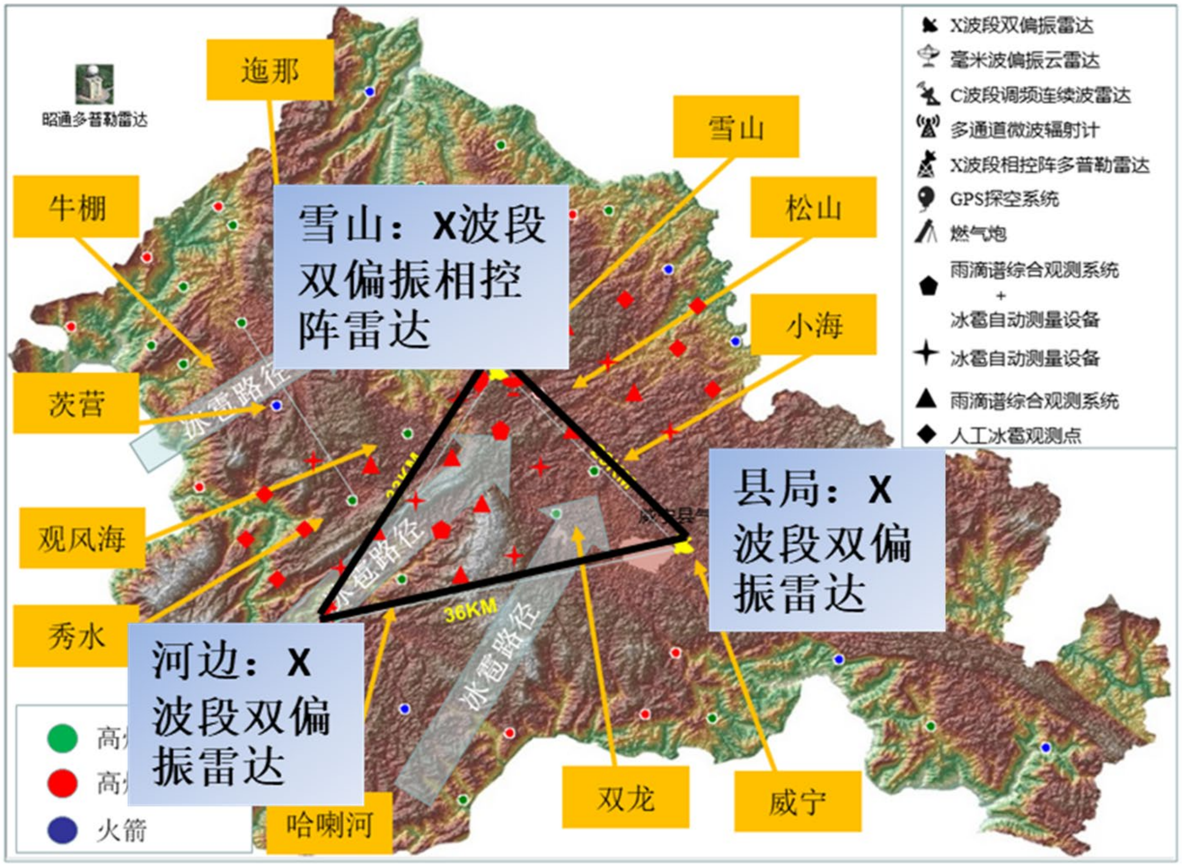


Instrument	Number
X-band Polarimetric phased array radar	3
X-band Polarimetric radar	2
C-FMCW radar	1
Millimeter wave polarization cloud radar	1
Micro rain rad	10
Distrometer	10
Microwave radiometer	1
GPS-Radiosonde	1
Wind-profiler radar	1

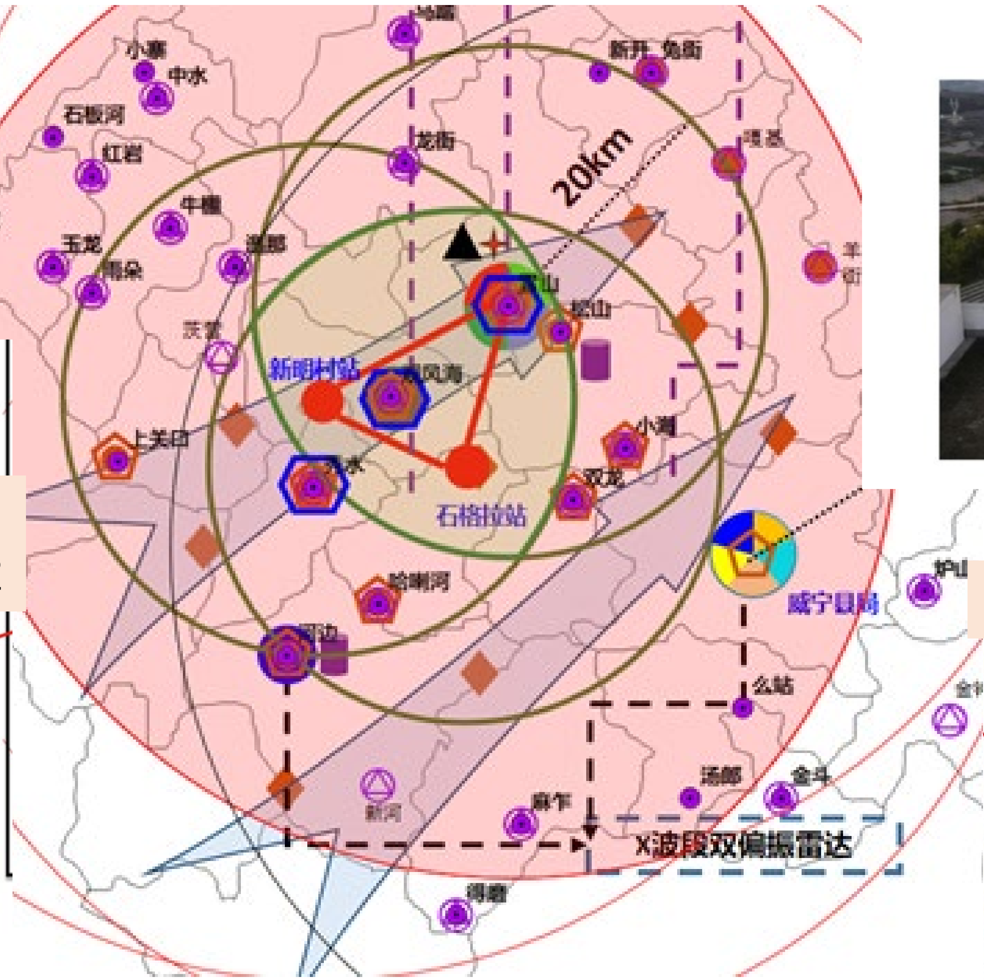
Xueshan Mountain super station

Modern high-precision equipment:
X-band dual-polarization phased array radars,
C-band frequency-modded continuous wave radar

Three X-band dual-polarization radars network:△30km



Three phased array radars network:△20km



Xueshan April， 2021

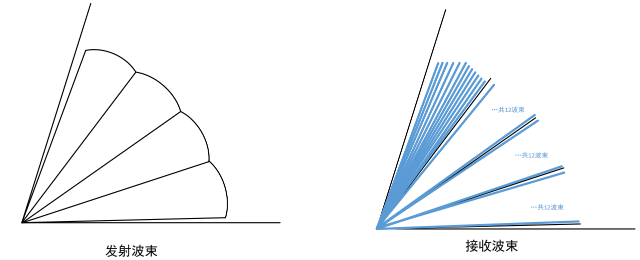
Xinmingcun June， 2022

Shigela August, 2022

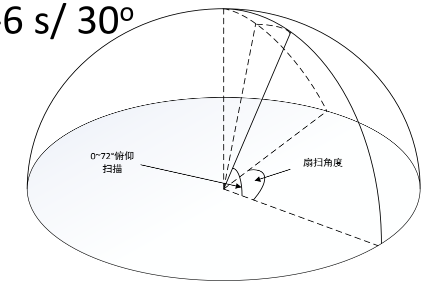
X-band dual-polarization phased array radar

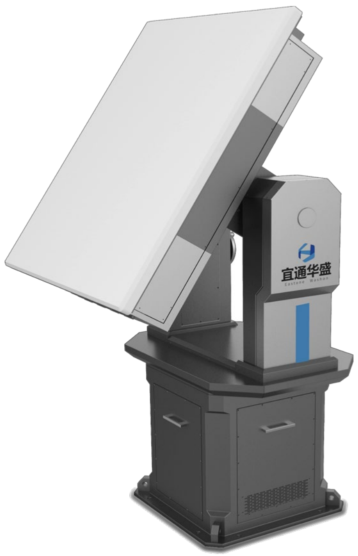
parameters of detection	Range	**45 km**
	Volume scan	azimuth: 0～360° (mechanical scanning) elevation: 0～72° (electric scanning)
Scanning mode	Volume scan,Fan sweep,RHI	
resolution	range	30m

Volume scan
: 1min, 48 PPIs



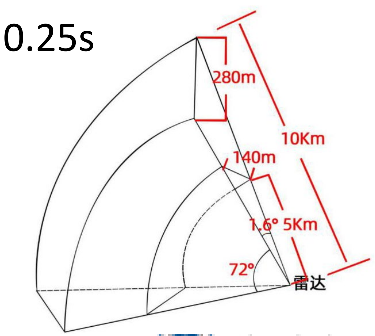
Fan sweep: 5-6 s/ 30°





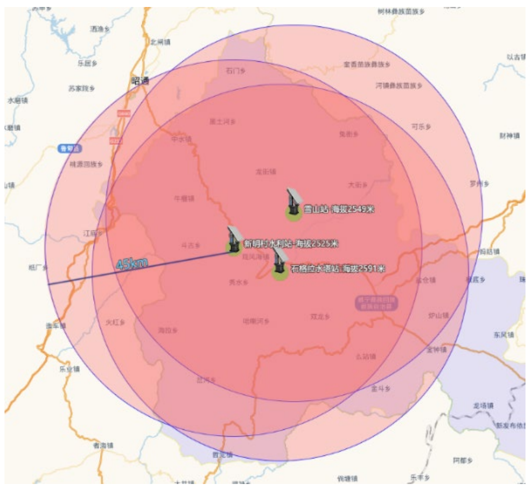
High temporal resolution observation data to detect seeding effect on wind fields, ice-phased particles, radar echoes, to analyze seeding effect of hail suppression.

RHI: 0.25s

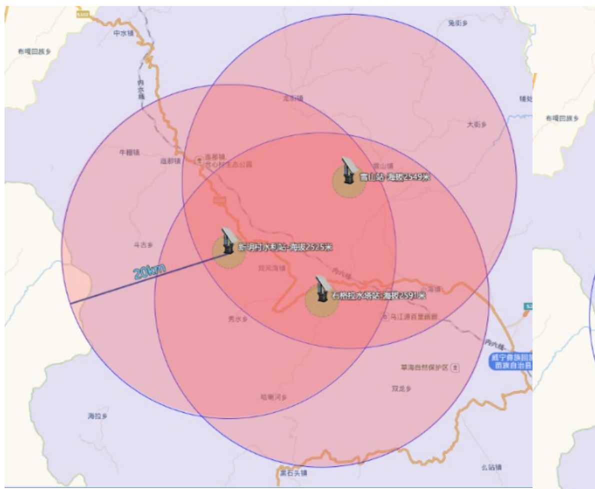


3 X-band dual-polarization phased array radars network cooperative observation scheme

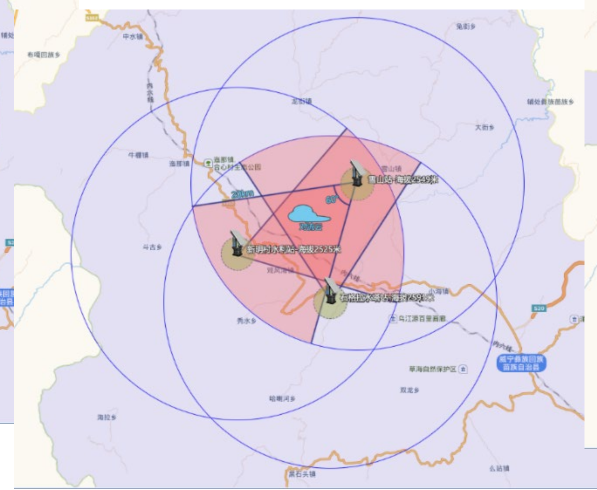
By installed three radars in an approximate equilateral triangle, a three-dimensional, stereoscopic observation area can be achieved, providing three dimension wind flow. According to the distance and position of cloud to network,the radar observation modes can also be flexibly set andto improve the observation of convective clouds.



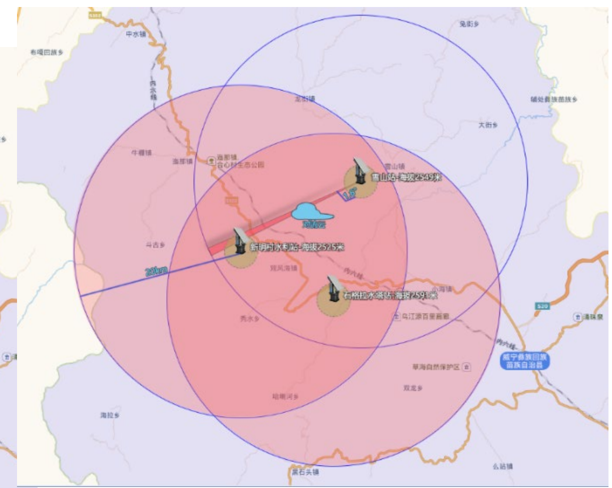
3-radar VOL of 45 km



3-rader VOL of 25



3-radar FAN of 25 km

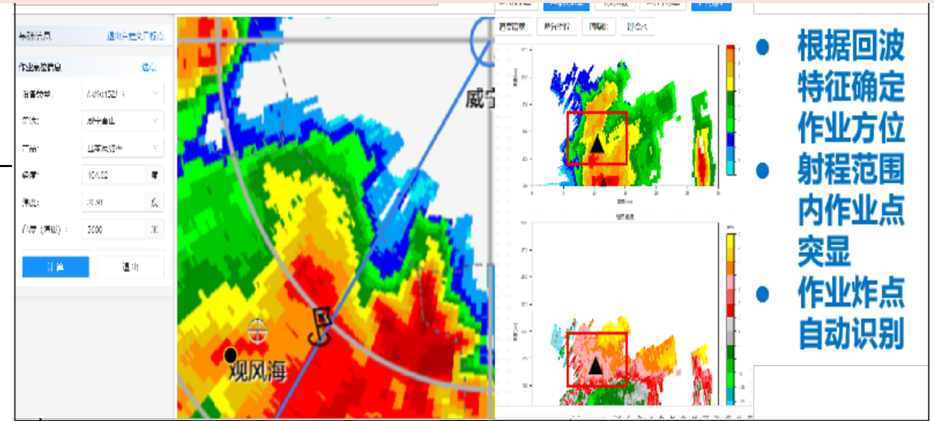


2-rader VOL of 25km,
1-radar RHI

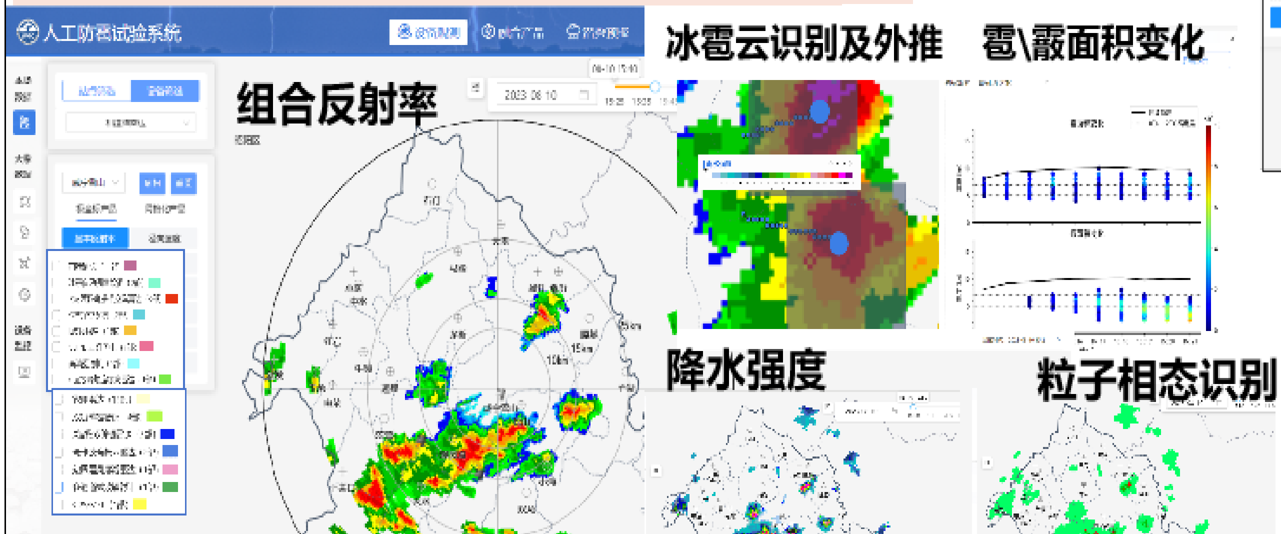
Real time data collection and analysis system

- real time collection data of 35 equipment including radar data, 150G/d
- analysis and retrieval: 3–d radar echo, wind field, ice phase particle, hail stone size
- **Seeding operation, seeding effect**

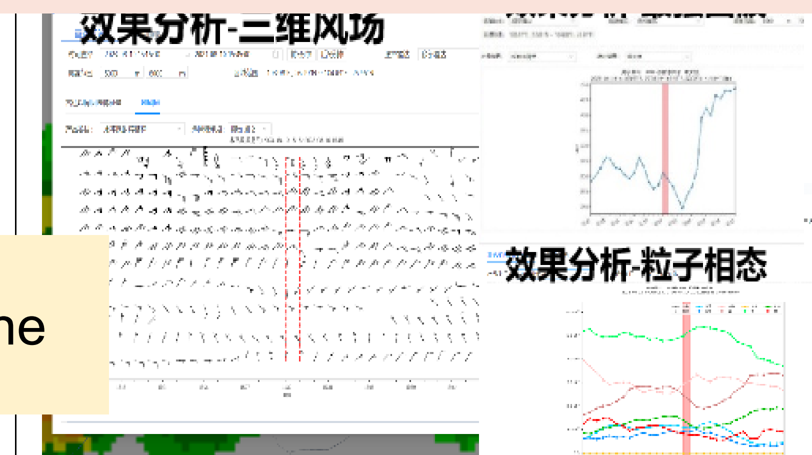
Helps to seeding experiment operation



Multi–source data fusion analysis
hail identification,
hail aera calculation



Helps to seeding effect evaluation: wind, maxium echo, particle phase



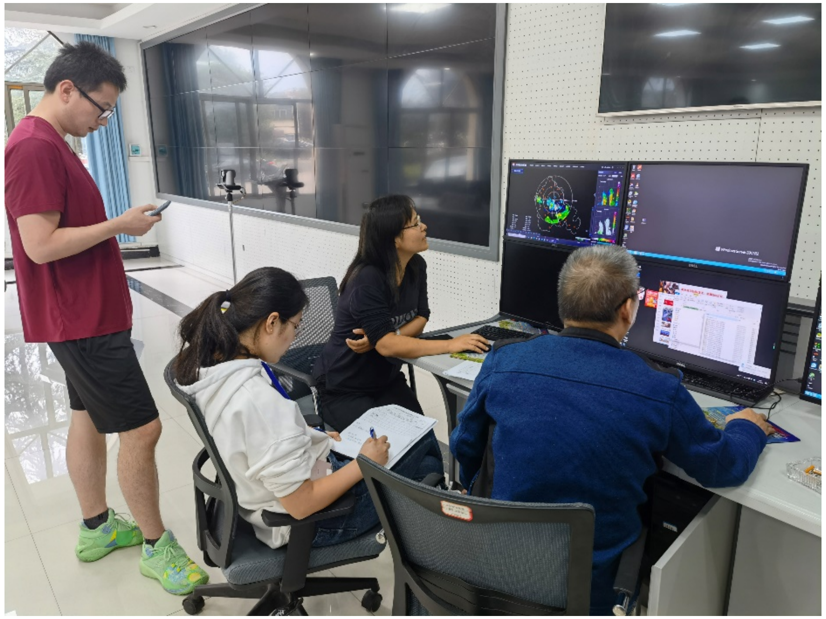
Developed 3 X-band randars cooperative observation module. Seeding informations automatically input to the software real time, locating the first seeded pisition.

Hail suppression seeding and observation experiment since 2021

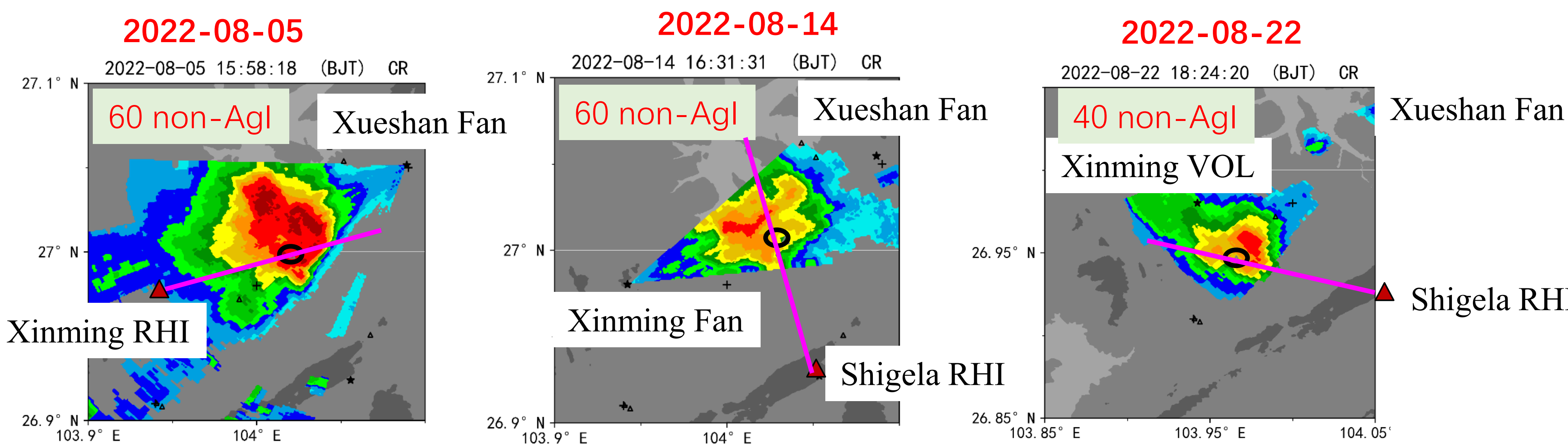
For four consecutive years from 2021 to 2024, observation experiments were conducted for 242 days, with 61 hail days ;

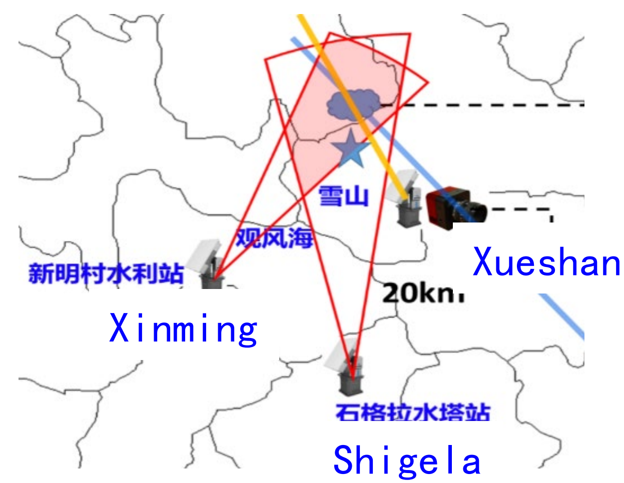
30 tests were conducted on convective clouds;

Twice daily. When a hail case, launches radiosonde balloon, helps to assess the current state of the atmosphere: temperature, humidity, winds.



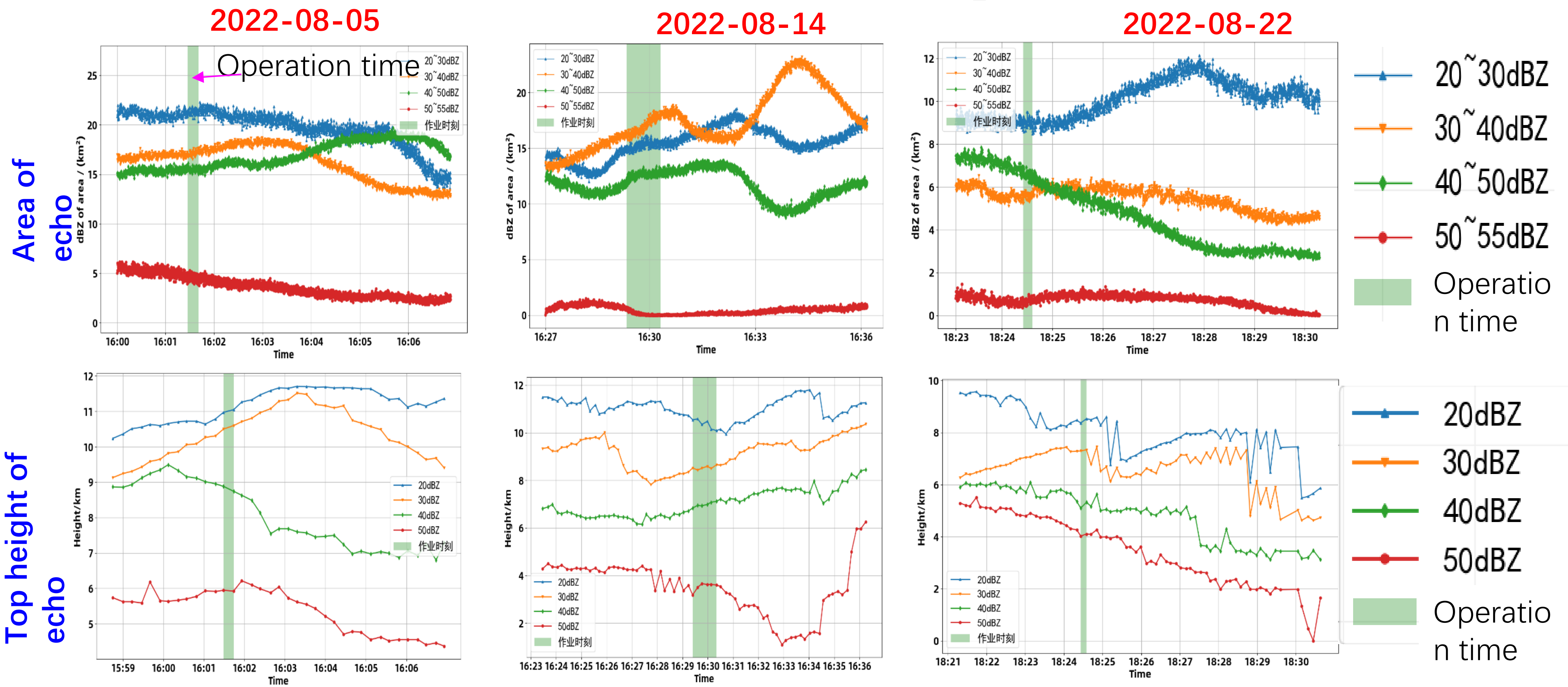
(1) High temporal resolution observation by RHI or fan-scan mode





Only effect of explosion: artillery shells with non-AgI in the experiment.

High temporal resolution observation of the impact of explosion on convective clouds (Fan sweep/RHI)



- All convective clouds weakened after operation:
- Area of intense echo larger than 40 dBZ or 50 dBZ reduced
- Top height of 50 dBZ descended.

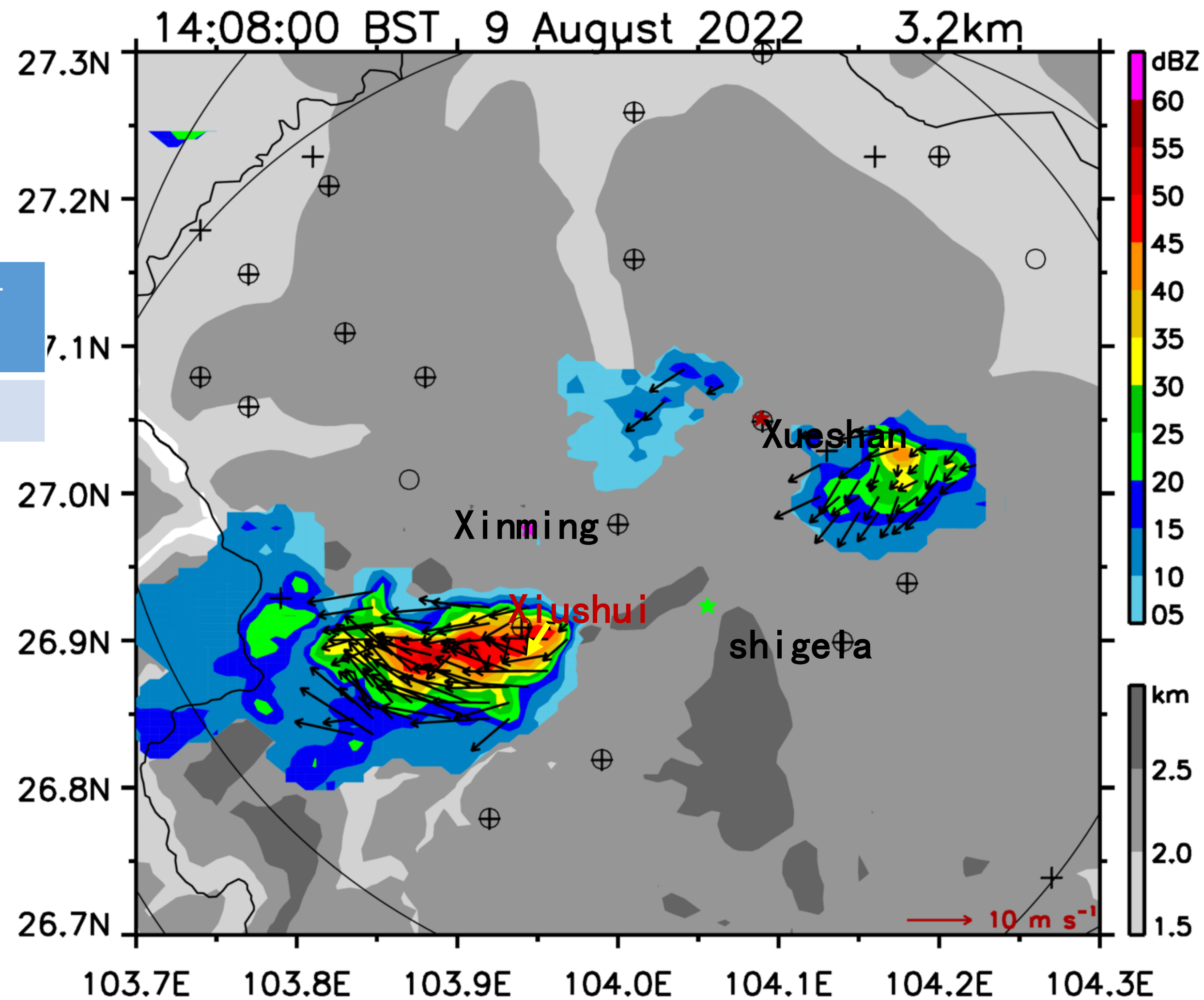
(2) Observation of three dimension structure by volume scan mode

Time and location of the hail case:

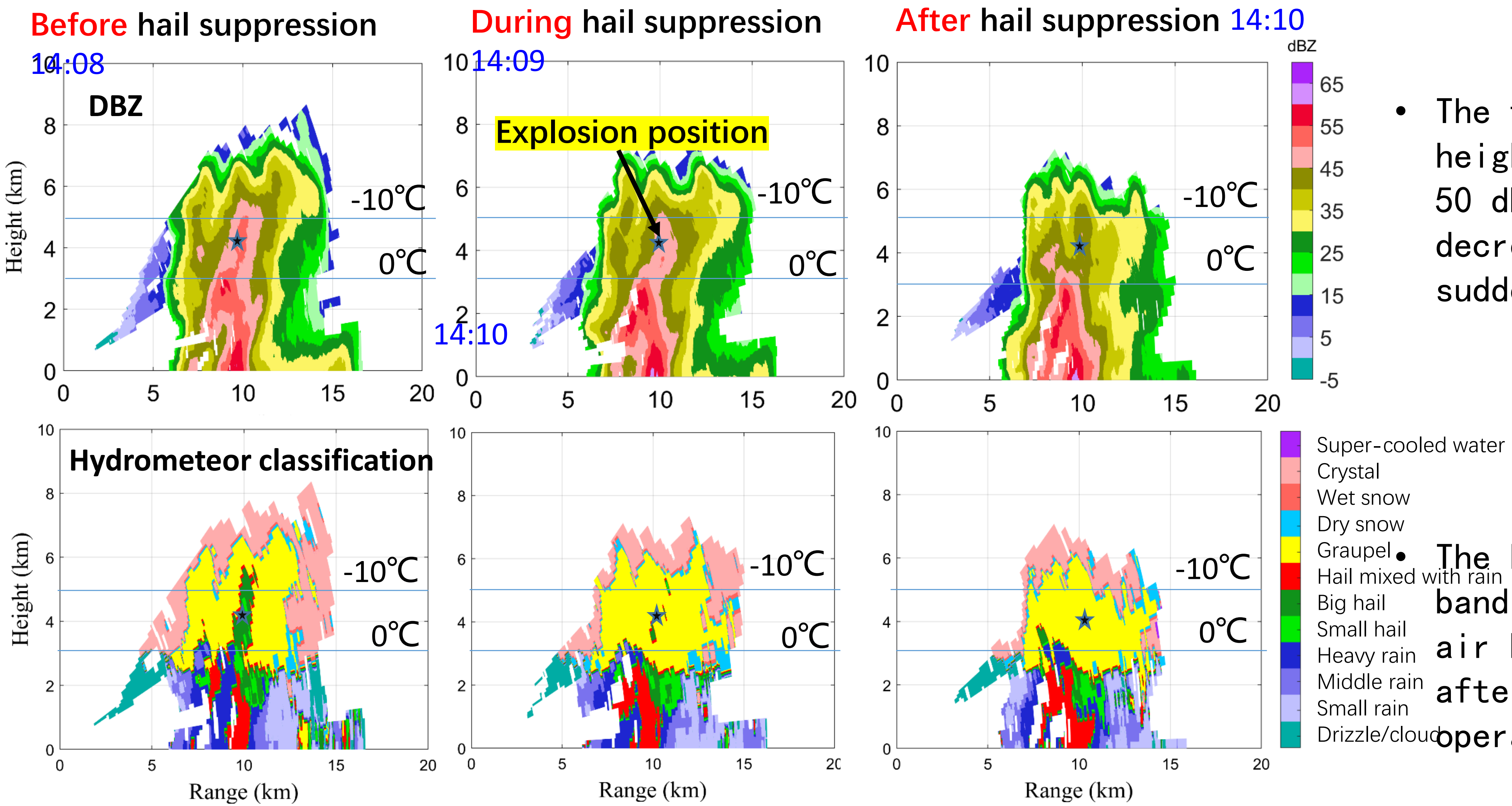
14:08-14:09, August 9, 2022, Xiushui Town

Time	azimuth angle	Elevation	Shell number
14:09	220	63	60

The hail suppression operation is conducted by artillery at Xiushui site.



Variation characteristics of Echo intensity and hydrometeor classification before and after operations

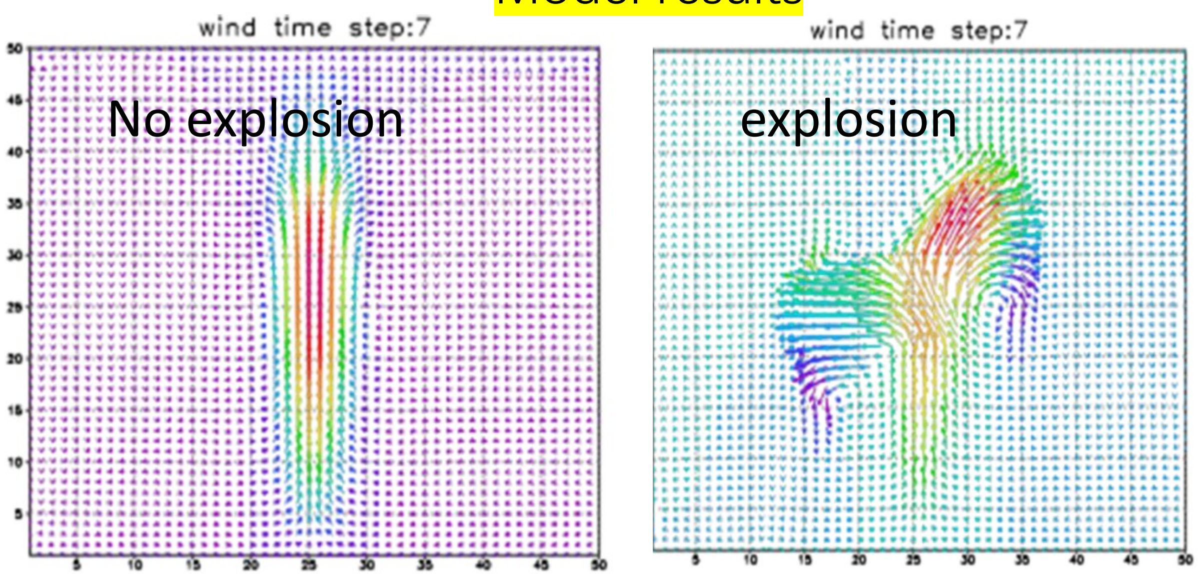


- The top height of 50 dBZ decreases suddenly.
- The hail band in the air brokens after operation.

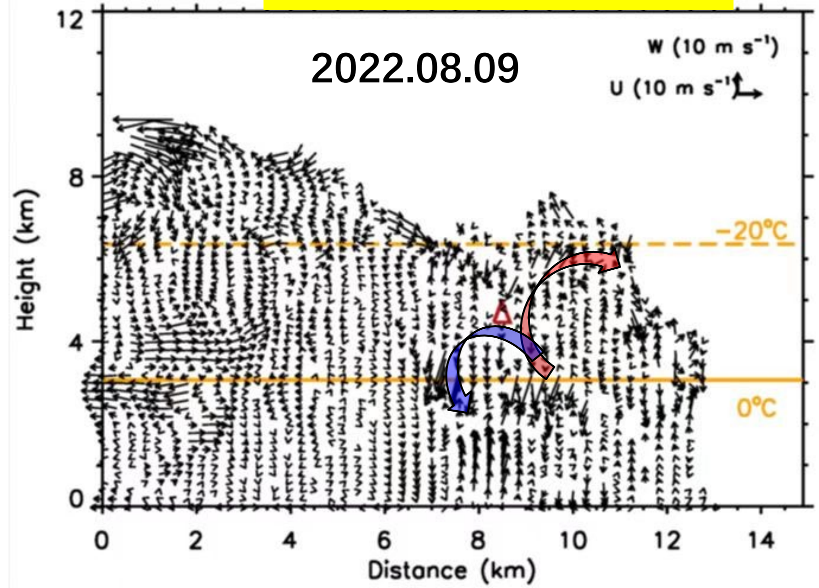
Dynamic effect of explosion

Explosion generates local disturbance. The Reynolds stress field generated by the local disturbance field pushes and distorts the basic flow, so that vortex pairs can be generated in the original field and change the convective flow pattern.

Model results



observational results



By Xu (2001)

谢谢

Thnak you for your attention