大气物理与人工影响天气
Atmospheric Physics and Weather Modification

云物理及人工影响天气研究进展

1 云雾物理与人工影响天气关键技术

1.1 人工影响天气项目研究进展

2018年，中国气象局人工影响天气中心获批2项国家重点研发计划课题、3项专题、1项中国气象局修购专项、4项气科院基本科研业务费项目，建设完成具有国际先进水平的膨胀云室，在各类期刊发表论文18篇，获得软件著作权4项。“人工影响天气地基、机载监测装备研发与应用”项目获北京市2017年度科学技术三等奖。

1.2. 云水资源评估研究与利用示范

国家重点研发计划“云水资源评估研究与利用示范”项目完善了云水资源及其特征量的概念和评估理论方法，提出了云水资源观测诊断和数值模拟两种评估方法，并开展了实例应用和对比检验。研究得到近20年中国1° × 1° 分辨率的云水资源及其特征量观测评估数据集，揭示了中国云水资源及其特征量的时空分布特征及变化规律。研究给出云水资源开发利用对区域陆地水资源的影响，提出并建立固定目标区的云水资源精细开发优化技术，建立云水资源和陆地水资源耦合利用方案，并实例应用。项目进展在科技部组织的中期评估中获得优秀。（作业指挥与运行中心）

1.3 青藏高原云和降水与大气水循环研究

通过飞机、多波段雷达协同观测数据分析，揭示了高原独特的云微物理和降水过程；评估、改进了WRF-CAMS云物理参数化方案。飞机观测研究首次发现，青藏高原过冷液态水含量丰富，云滴浓度甚至比海洋清洁环境下的云粒子浓度小，但尺度大，表明高原云系统更容易产生降水。研究揭示了高原对流云和降水过程的显著日变化特征，指出高原日平均降水转化率较大，水分循环次数较同区域的干旱地区高，水分再循环（内循环）比较活跃。上述成果对于揭示高原云和降水形成机理，改进数值模式云物理方案，提高模式预报水平具有非常重要的价值和意义。（开放实验室）

1.4 青藏高原夏季对流云内空气垂直速度研究

利用第3次青藏高原大气科学试验期间（2014年7月1日至8月31日）的C波段调频连续波雷达观测的径向速度分布，估算了强对流内粒子下落速度，从而得到了强对流云内空气垂直速度的垂直分布。统计高原观测试验期间30个强对流样本内的空气垂直速度分布结果表明：高原强对流降水云内，空气垂直速度在0 ℃层以下，近地面500 m以下主要是以下沉运动为主，近地面500 m到0 ℃层空气上升运动较强；在混合相层内（0 ～ 15 ℃）存在明显的上下混合运动；在−15 ℃层以上，主要是以上升运动为主。总体而言，高原强对流内空气上升运动强于下沉运动：上升运动平均值为3.6 m/s，最大值为24.5 m/s，下沉运动最大值为14.2 m/s，平均值为2.1 m/s。（开放实验室）

1.5 气溶胶–云（雾）–降水相互作用及机制研究

2018年在中国气象局云雾楼楼顶继续开展雾霾的观测，在现有设备情况下继续收集典型个例，获

取了部分个例的数据资料。通过对华北地区持续性雾和霾的连续观测，研究了北京持续性霾和雾霾混合天气$PM_{2.5}$浓度、能见度和大气边界层高度的相互作用关系，提出了双逆温的形成及通过辐射效应产生的相互作用是形成更加稳定的边界层结构和持续性大雾的原因。通过模拟中高云在北京持续性大雾期间的辐射变化，发现云辐射效应在华北持续性大雾维持和发展中具有促进作用。（开放实验室）

1.6 云降水催化效果仿真模拟

改进人影催化模式的仿真催化模拟能力，完整实现飞机催化的仿真模拟功能。改进后的模式可以直接使用飞机飞行作业的GPS轨迹数据和作业信息进行催化模拟，能最大程度再现飞机实际作业的飞行播撒情况，从而实现仿真模拟。

结合丹江口人工增雨云水资源开发试验，开展了云降水催化效果仿真模拟研究。（1）针对飞机作业个例在作业前进行催化模拟预评估工作，模拟作业计划中设计航线上的飞机催化效果，进行催化的效果预评估。（2）对实际飞机的催化作业进行仿真模拟，对催化效果进行评估。针对3月4日丹江口流域飞机增雨作业，根据作业预案进行催化效果的预评估结果为平均增雨率1.5% ～ 2.1%，实际催化作业后的仿真模拟评估结果达到平均增雨率1.2%，其催化效果的小时雨量模拟评估结果与采用区域动态多参量物理检验K值法的效果评估结果（1.17 %）有比较好的一致性。（作业指挥与运行中心）

1.7 优化人影作业（保护）面积计算方法

优化发展了一套基于梯度输送理论的催化剂扩散影响计算方案，利用探空给出的催化层风场资料，考虑实际作业用量，通过给定浓度阈值计算催化剂的扩散时间与扩散范围，进而得到作业面积和影响时长。该方法目前已集成到CPAS系统，准业务化用于计算飞机和地面火箭增雨作业的效果评估中，在多次重大活动保障效果评估以及全国三年行动计划业务质量评估中得到广泛应用。

以11月5日“进博会”增雨减污服务为例。利用空中国王飞机，在播云潜力区开展催化作业，播撒方式为8字型催化。通过合理性分析认为此次冷云增雨作业时机把握较好，作业位置合理，基本实现催化剂的充分播撒。利用上述扩散计算方案，此次作业瞬时影响范围约760 km^2，作业开始后5 h累计影响面积约4500 km^2。在影响区周边雨带分布较均匀的区域选择多个对比区域，开展增雨效果的统计分析。作业后影响区雨量约0.6 mm，维持2 ～ 3 h。（作业指挥与运行中心）

1.8 机载SCMA系统数据质量控制方法

开展了机载SMCA系统的设计工作，完成了设备近期管路设计，为了排除相对湿度干扰，在采样器前端的采样管路加装了扩散式干燥装置；完成了飞机机舱内温度稳定度的测试，在整个飞行过程中，发现机舱内温度变化为 ±0.5 ℃，完全满足设备运行要求；完成了机载控压装置的设计工作，整个装置主要由压力传感器、限流孔，电磁阀和真空泵构成，装置最前端的限流孔起到减小压强和缓冲的作用，根据压力传感器测量，通过电磁阀和泵的联合作用稳定进气口压力。CCNc和SMPS流量总和为0.8 L/min。据计算，辅助气路流量设置在2～5 L/min，即可保证控压能力，又可尽量避免粒子损失。（飞机运行中心）

2 人工影响天气重大工程

2.1 国家人工影响天气能力建设工程进展

国家人工影响天气能力建设项目已完成可研报告上报。中国国际工程咨询有限公司对可研报告已完成评估，同步启动编制项目初步设计，已完成部分建设内容编制（贵州威宁冰雹防控试验场）。上报了2018年度、2019年度投资计划和绩效考核目标。组织完成了X波段双偏振雷达招标文件内审工作。

组织专家对我国人工影响天气发展进行了研讨。完成了2部自动气象站的采购工作，签署了采购合同。（区域中心管理办公室）

2.2 东北区域人工影响天气工程进展

全面启动竣工验收工作，完成子项目验收和集合验收、竣工决算审计，第三方机构从建设过程、业务能力提升、效益评估等方面编制完成了工程整体实施评价报告。空中国王增雨飞机投入业务试运行，成为第3架能在中国领空开展人工增雨作业任务和云物理探测研究的高性能人影作业飞机。申请飞机作业能力建设的设计变更及补充采购，新增采购“机载探测数据处理系统”应用软件，新增采购2套液氮致冷剂催化播撒装置，取消机载气溶胶质谱仪购置；先后举办了高性能人影作业飞机机载设备应用培训（美国）、人工影响天气探测和作业飞行设计及资料分析国际培训等6个培训班，共有176人次参加了培训，培训学时达535学时。完成“机载探测数据处理系统”采购工作。（区域中心管理办公室）

2.3 西北区域人工影响天气能力建设工程进展

西北区域人工影响天气能力建设工程已完成2架新舟60飞机和2架空中国王350飞机采购，飞机正在建造阶段。完成空中国王350飞机国内加改装论证，空中国王350遥感探测作业飞机改装集成已进入招标采购阶段；指挥作业系统已完成招标采购和合同签订。研究试验基地（点）已全部完成监测装备采购、布点和选址，部分设备已完成安装。完成研究试验7个分包招标采购和合同签订。协调干部培训学院开办6期西北人影项目培训班，区域办2人参与授课。编制完成3期西北人影项目简报和2019年投资计划。（区域中心管理办公室）

2.4 其他区域人工影响天气能力建设工程进展

完成中部区域人工影响天气能力建设工程可研报告编制，2017年8月报送国家发展改革委员会审批，并按发改委意见进行了修改完善；西南区域人工影响天气能力建设工程可研报告已上报中国气象局；华北、东南人影工程正在组织可研报告编修和技术审查，并委托第三方专业机构开展工程环境评价工作。（区域中心管理办公室）

3 科学观测试验

3.1 上海中国国际进口博览会增雨减污人影探索试验

联合上海市气象局、安徽省气象局，成功组织上海中国国际进口博览会增雨减污人影探索试验。充分集中气象、环境专家意见，聚焦人工增雨改善空气质量的科学机理认识和实践探索，编制完成工作方案、技术方案和实施方案。在10月16日至11月10日保障期间，3架飞机开展27架次飞行探测和增雨作业。通过典型个例分析，增雨作业合理有效，对污染物清除具有一定的作用。（作业指挥与运行中心，飞机运行中心，开放实验室）

3.2 不同云系飞机云物理观测试验

2018年9月4—29日，调配1架空中国王350国家增雨飞机（机号：B-10GD）停驻到珠海金湾国际机场，并以该机场为主停靠地，在广东省西南沿海地区开展针对华南地区强降水云系以及台风外围云系特征飞机探测。试验期间，联合广东省人影中心在珠海以及阳江区域共开展10架次飞行探测，累计飞行25.5 h，获得了该地区夏季云系不同层结的微物理特征，包括气溶胶、云和降水粒子的谱分布（0.1 ～ 19200 μm）、云与降水粒子（10 ～ 19200 μm）的形态与相态特征、云中液态水含量以及层结分布特征、云底和云顶气溶胶粒径谱特征等。这些云物理探测数据，为进一步认识华南地区云系特征和

气溶胶–云–降水相互作用研究奠定了基础。（飞机运行中心）

3.3 庐山云雾宏微观特征外场观测

庐山云雾外场几乎实现了全年观测，利用2015年11月至2018年2月庐山云雾试验站观测的云物理资料和九江站的雷达资料，统计分析了庐山云雾及降水的日、季节变化和宏微观物理特征。庐山强降水多发生在夏季，而云雾天多发生在秋、冬、春季。平均云和雾天数是13天/月，最高云和雾天数可达到25天/月。庐山秋冬季层状云、积层混合云和对流云降水分别占29%、44%和27%，春、夏季对流云和积层混合云降水分别占83%和17%。庐山降水的中小雨滴偏多，拟合的Gamma谱型向下弯曲。庐山云雾滴谱的数浓度较低，双峰结构显著，谱较宽。通过对云内降水的微物理观测发现，随着降水量级的增加，雨滴的数浓度和尺度不断增加，更易于启动碰并机制，使小于11 μm和大于30 μm云雾滴减少，导致11 μm的峰值更为显著。（开放实验室）

4 业务与服务

4.1 人工影响天气重大应急和重大服务保障

2018年主要开展了呼伦贝尔汪马和呼中林火重大应急服务，以及冬奥会、上合组织青岛峰会、宁夏60周年大庆活动保障、上海中国国际进口博览会等重大活动保障，共制作发布各类专报产品131期，专题会商35次。

应用新资料，完成内蒙古林火重大应急服务。针对2018年6月2日发生在内蒙古呼伦贝尔额尔古纳市和根河市的森林火灾，人影中心联合东北4省区人影部门，上下联动，启动应急服务保障。因火区周边雷达资料严重缺乏，利用反演的5 min一次的FY-4A卫星云特征参量产品，结合预报产品，考虑催化层风向风速，针对火点设计了充分播撒的飞机作业方案，确保催化剂播撒在火区上空。科学指导国家级增雨飞机6架次实施增雨作业，为成功扑灭森林大火发挥了关键作用，增雨灭火服务受到了地方政府和有关部门赞扬。

业务与科研相融合，圆满完成各项重大服务保障。充分利用FY-4卫星各类产品及云参量反演产品，为作业条件预报、监测预警和飞机探测、作业、催化方案设计提供有力支撑，派出专家组赴青岛、宁夏完成人影保障工作。在2018年10月16日至11月10日上海进博会期间，根据上海市政府的要求，与上海市气象局开展进博会人影增雨减污保障服务。积极开展冬奥会服务，开展复杂地形固定目标区小尺度人工增雪关键技术研究。（作业指挥与运行中心）

4.2 人影业务现代化建设三年行动计划圆满收官

编制《人工影响天气业务现代化和安全管理行动计划终期评估要点与方法》、《人工影响天气业务现代化和安全管理行动计划终期评估方案》，确定评估等级标准，细化评估指标，组织有关省级技术人员联合开展初评。组织人影咨评委员会专家采取专家审议和实地考核等方式开展评估，形成终期评估报告，上报中国气象局减灾司。落实局党组加强调查研究要求，实地调研西藏区级、市县级和作业点三级人影业务机构，具体指导西藏人影业务现代化和人影工程建设。（作业指挥与运行中心）

4.3 人影作业指挥业务

落实局党组发展生态修复型人工影响天气业务的要求，2018年5月29日，组织召开技术研讨会，来自河北、内蒙古、吉林、辽宁、黑龙江、江西、河南、湖北、重庆、陕西、青海等11省（区、市）人影办（人影中心）和国家人影中心的领导和技术人员参加了研讨。会议以生态修复型人工影响天气业务关键技术、服务流程、效益评价和体制机制为重点，交流讨论各省及国家级生态修复型人工影响

天气工作，编制《发展生态修复型人工影响天气业务的思考与建议》；凝练业务特点和关键技术，在长三角区域、湖北、陕西开展试点应用，组织撰写试点总结，提升了不同生态目标区服务的针对性和科学性。

调研各地服务需求，首次制定国家人影服务周年方案；认真做好全国人影业务指导，共发布《人影作业需求分析》、《人工影响天气作业信息报》、《全国人工影响天气作业信息质量报》等各类指导产品111期。

研发积冰/过冷水潜势预报产品，实现每日自动运行，并在过程预报中得到应用。对CPEFS_V1.0业务模式的运行机制进行多次调整优化，增加多种运行异常处理机制，提高了模式计算的稳定性，保证了业务的正常进行。

做好3个模式预报系统（CPEFS_V1.0、MM5-CAMS、GRAPES-CAMS）、云特征参量卫星反演系统、全国人影作业信息采集处理系统以及产品共享发布系统的稳定运行，确保正常发布预报、监测两类业务指导产品，实时获取各地的飞机和地面作业信息。

完成全国范围内空中云水资源分区域评估。根据中国气象局人影中心下发的《云水资源评估业务技术指南》，利用2000—2017年NCEP大气再分析资料和GPCP降水产品，对中国和6个人影分区的云水资源进行气候评估，形成评估结果和数据产品，并对中国和6个人影分区的大气水凝物总量、云水资源量、水凝物降水效率等云水资源特征量进行分析，形成评估报告。（作业指挥与运行中心）

4.4 国家人影飞机运行业务

全力做好3架国家增雨飞机的运行及安全管理，做好东北4省区重点作业区的抗旱减灾、河库增蓄、生态环境保护、森林草原防火等作业服务。春、夏季期间，根据抗旱增蓄及降低森林草原火险等级需要，增雨飞机B-3435和B-3726分别以长春龙嘉机场和沈阳桃仙机场为主降基地，增雨飞机B-10GD以黑龙江肇东北大荒机场和建三江机场为主降基地，并适时转场黑龙江大庆和内蒙古呼伦贝尔市开展抗旱增蓄作业服务。根据中原地区春、秋、冬季抗旱及常态化作业需求，2架国家增雨飞机分别以河南省新郑国际机场为基地，联合河南省人影部门开展辐射周边省市的飞机增雨作业服务。2017年12月5日至2018年1月31日，在新疆和田、喀什地区实施冬季昆仑山区飞机增雨雪作业服务。10月10—25日，在湖北省襄阳市以刘集机场为主降基地，参加湖北省农业抗旱工作。截至12月20日，3架国家级增雨飞机累计飞行195架次，总飞行时长约649.5 h，积累了宝贵的飞机观测资料。

组织飞机托管公司（三星通航和北大荒通航）分别在长春、沈阳、广汉和肇东机场按时保质地完成新舟60（30M，36M）和空中国王350ER增雨飞机（200H）的定检维修维护工作。按照机载探测设备使用与标定要求，完成3架国家增雨飞机粒子测量系统的定期检测与标定。每次飞行前后对机载探测、播撒、通信等各类设备进行维护保养，及时检修排除故障，确保设备系统处于正常运行状态。

参照气科院科技成果转化管理办法，推进《国家人工影响天气飞机作业技术服务经费管理暂行规定》的制定及落实；编制《国家人工影响天气作业飞机运行管理办法》，积极做好飞机运行管理调整有关工作。（飞机运行中心）

4.5 人影装备研发业务

参与完成3项技术审查报告：WR-1A型、HJD-82B型、BL-2A型44 mm增雨防雹火箭弹使用许可技术审查报告；2项新产品业务试用方案评审：RY-18型人工防雹增雨弹和JD-17型37 mm人工增雨防雹炮弹业务试用方案评审；1项定型试验大纲评审：18型人工防雹增雨弹（含弹头、弹底引信）设计定型试验大纲评审的工作，以及18型人工增雨防雹炮弹业务试用总结。（装备研发与保障室）

5 其他

5.1 科研成果转化与应用

2018年7月20日，完成新舟60增雨飞机系统气象科学技术成果评价，新舟60增雨飞机系统成果总体技术达到国际先进、国内领先水平，其中机载观测与播撒一体化技术、空地实时指挥及监控技术达到国际领先水平。全年国家增雨飞机科技成果转化服务5次，为地方经济社会发展做出了贡献。与中国商飞、哈飞等公司合作，开展飞机自然积冰探测试验研究，为我国国产大飞机自然结冰适航验证提供科技支撑。（飞机运行中心，作业指挥与运行中心）

5.2 学术交流与技术合作

积极配合中国气象局减灾司完成人影60年系列纪念活动。编制中国人影60年业务科技成就总结、承办全国人影科学技术交流大会等系列会议；全力配合编制了中国气象局人影60年宣传册、现代化成果展、回忆录、宣传片、宣传稿等材料。

积极组织国内大专院校人影领域专家开展协同攻关，联合5所高校、科研院所和西北工程参建省组建西北地形云研究试验团队，开展针对业务服务关键技术的试验研究；云雾物理实验室与中科院强对流实验室、北京市云降水实验室签署协同创新协议；参加WMO人工影响天气专家组会议，编制WMO报告，技术援助斯里兰卡等“一带一路”沿线国家，与美国、泰国、俄罗斯、德国等专家学者交流访问12次。（开放实验室，区域中心管理办公室）

Advances in Research on Cloud Physics and Weather Modification

1 Cloud physics and key technologies for weather modification

1.1 Progress in weather modification research projects

In 2018, the Weather Modification Centre was approved for 2 national key R&D plan projects, 3 sub-projects, 1 CMA repair special project, and 4 CAMS basic research fund projects. We have completed the construction of an expanding cloud chamber with international advanced level. A total of 18 papers in various journals have been published and 4 software copyrights are obtained. The Project "Development and Application of Weather Modification Ground and Airborne Monitoring Equipment" won the third prize of 2017 Science and Technology in Beijing.

1.2 Assessment research on cloud water resources and its utilization demonstration

The project has improved the concepts and assessment theories of cloud water resources and their characteristic quantities, and proposed two evaluation methods for cloud water resources observation, diagnosis and numerical simulation, and carried out case application and comparative tests. The project obtained cloud water resource and their characteristic quantity observation and evaluation data sets with a resolution of 1°×1° for recent 20 years in China; revealed the temporal and spatial distribution and variation of cloud water resources and their characteristic quantities in China, studied and found the impact of cloud water resources development and utilization on regional land water resources; proposed and established a fine development and optimization technology for cloud water resources in fixed target areas; established a coupling utilization plan for cloud water resources and terrestrial water resources, and found application examples. The progress of the project ranked excellent in the mid-term evaluation organized by MOST. (Operation Commanding and Running Centre)

1.3 Study of clouds and precipitation and atmospheric water cycle over the Tibetan Plateau

Through the analysis of coordinated observation data of aircraft and multi-band radar, the unique cloud microphysics and precipitation processes of the Tibetan Plateau are revealed; the WRF-CAMS cloud physical parameterization scheme is evaluated and improved. The aircraft observation study found for the first time that the Qinghai-Tibet Plateau was rich in super-cooled liquid water, and the cloud droplet concentration was even smaller than the cloud particle concentration in the marine clean environment, but the scale was large, indicating that the plateau cloud systems were more prone to precipitation. The study reveals the significant diurnal variation characteristics of convective clouds and precipitation processes in the Tibetan Plateau, pointing out that the daily average precipitation conversion rate of the plateau is large; the number of water cycles is higher than that in the same region; and the water recycling (internal circulation) is more active. The above results have very important value and significance for revealing the mechanisms of plateau clouds and precipitation formation, improving numerical model cloud physics schemes and improving model forecasting level. (Open Laboratory)

1.4 Study of air vertical velocity within convective clouds over the Tibetan Plateau in summer

Using the radial velocity distribution observed by the C-band frequency-modulated continuous-wave radar during the third Tibetan Plateau Atmospheric Scientific Experiment (July 1 to August 31, 2014), the

fall-speeds of particles within strong convective clouds are estimated, and the vertical distributions of air vertical velocity within strong convective clouds are obtained. Through the statistical analysis of the vertical velocity distribution of air in 30 strong convective precipitation cases during the Tibetan Plateau observation experiment, the results show that: within the strong convective precipitation clouds over the Tibetan Plateau, the air vertical velocities were mainly downward motions below 500 m above ground. The air ascending motions from the 500 m above ground to 0 °C layer were strong; among the mixed phase layer (0 to −15 °C), there were obvious up-and-down mixing motions; above −15 °C, there were mainly ascending motions. In general, the plateau strong convection air uplift is stronger than the sinking motion: the average value of the ascending motion is 3.6 m s^{-1}; the maximum is 24.5 m s^{-1}; and the maximum sinking motion is 14.2 m s^{-1}; with an average of 2.1 m s^{-1}. (Open Laboratory)

1.5 Study of aerosol-cloud (fog)-precipitation interactions and its mechanisms

In 2018, fog and haze observation continued on the roof of Yunwu Building of China Meteorological Administration. In the case of existing equipment, typical cases were collected and some data were obtained. Based on the continuous observation of fog and haze in North China, the relationship between $PM_{2.5}$ concentration, visibility and atmospheric boundary layer height for persistent haze, and fog-haze mixed events is studied. It is proposed that the formation of double inversion and the interaction through radiation effect are the reasons for the formation of more stable boundary layer structure and persistent fogs in Beijing. It is found that the radiation effect of middle and high cloud plays a promotive role in the maintenance and development of persistent fogs in North China. (Open Laboratory)

1.6 Simulative study of catalytic effect of cloud precipitation

The catalytic simulation capability of the weather modification catalytic model is improved to completely realize the simulation function of aircraft catalysis. The improved model can directly use the GPS trajectory data and operation information of the aircraft flight operation to perform catalytic simulation, which can reproduce the flight planting of the actual aircraft operation as much as possible, thereby realizing the simulation. Combined with the cloud water resources development experiment of precipitation enhancement in Danjiangkou, the simulation study of the catalytic effect of cloud precipitation was carried out: (1) For the case of aircraft operation, the catalytic simulation pre-evaluation was carried out before the operation, and the catalytic effect of the aircraft on the design route was simulated in the operation plan and the pre-evaluation of the effect of the catalysis was conducted. (2) Simulation of the actual aircraft catalytic operation was made to evaluate the catalytic effect. Aiming at the precipitation enhancement operation of the Danjiangkou River Basin on March 4, the pre-assessment results of the catalytic effect according to the operation plan were the average rainfall increase rate of 1.5% to 2.1%, and the simulation results after the actual catalytic operation reached an average rainfall increase rate of 1.2%. The simulation results of the hourly rainfall simulation of the catalytic effect were in good agreement with those of the regional dynamic multi-parameter physical test K-value method (1.17%).(Operation Commanding and Running Centre)

1.7 Optimizing the area calculation method of weather modification working (protection)

We optimized and developed a set of catalyst diffusion calculation schemes based on gradient transport theory. Using the wind field data of the catalytic layer given by radiosonda data, considering the actual operation dosage, calculating the diffusion time and diffusion range of the catalyst by the given concentration threshold, the operation area and duration of influence are obtained. The method has been integrated into the CPAS system, for the quasi-operationalization running and calculating the effect evaluation of aircraft and ground rocket rainfall enhancement operations. It has been widely used in the effect evaluation of several

major activities and the quality assessment of the National Three-year Action Plan.

Taking the rain and pollution reduction service of the "Shanghai Expo" on November 5 as an example, using the King Air aircraft, the catalytic operation was carried out in the potential area of the sowing cloud, and the spreading method was 8-shaped catalysis. Through the rationality analysis, it is believed that the timing of the cold cloud rain enhancement operation is better, the operation position is reasonable, and the full spread of catalyst is basically realized. Using the above diffusion calculation scheme, the instantaneous impact range of the operation is about 760 km^2, and after the start of the operation the cumulative impact area within 5 hours is about 4500 km^2. A plurality of contrasting areas are selected in a region where the rainband distribution is relatively uniform around the affected area, and the statistical analysis of the effect of increasing rainfall is carried out. After the operation, the rainfall in the affected area is about 0.6 mm and it is maintained for 2−3 h. (Operation Commanding and Running Centre)

1.8 Research on data quality control method of the airborne SCMA system

The design of the airborne SMCA system was carried out, and the recent pipeline design of the equipment had been completed. In order to eliminate the interferences of the relative humidity, a diffusion drying device was installed on the front-end of the sampler, and the temperature stability test inside the aircraft cabin had been completed. During the whole flight, the temperature changes in the cabin was found to be within ±0.5 ℃ , which satisfied the operation requirements of the equipment. In the design, the whole device is mainly composed of the pressure sensor, current limiting hole, solenoid valve and vacuum pump. The flow limiting hole at the front end of the device plays the role of pressure reducing and buffering. According to the measurement of the pressure sensor, the intake pressure is stabilized by combining the action of the solenoid valve and pump. The total flow ratio of CCNc and SMPS is 0.8 L min^{-1}. According to the calculation, when the auxiliary flow ratio is set at 2−5 L min^{-1}, the ability of pressure control can be guaranteed and the particle loss can be avoided as far as possible.(Aircraft Operational Centre)

2 Major weather modification projects

2.1 National weather modification capability building projects

The feasibility study report has been completed and submitted in the national weather modification capability building project. The China International Engineering Consulting Co., Ltd. has finished the evaluation of the feasibility study report, and initiated the preliminary design of the project, and completed the preparation of some construction contents tasks (Weining Hail Prevention and Control Test Site in Guizhou Province). The investment plans and performance appraisal of 2018 and 2019 were reported. The internal audit of the X-band dual-polarized radar bidding documents was completed. The Weather Modification Centre also organized experts to discuss the development of weather modification in China. The procurement of 2 automatic weather stations was completed and the contract was signed.(Regional Centre Administration Office)

2.2 Weather modification project of Northeast China

The Weather Modification Centre has started the completion and acceptance work, and completed the sub-project acceptance and collection acceptance, and final audit of the final project. The third-party organization will complete the evaluation report of the overall implementation of the project from the construction process, operating capability improvement and benefit evaluation. The King Air Rainfall Enhancement Aircraft has been put into operational trial operation, becoming the third aircraft capable of carrying out artificial precipitation enhancement tasks and cloud physics exploration and research in China's airspace. We applyed

for the design changes and supplementary procurement for aircraft operation capability building, and the newly added purchasing of the Airborne Detection Data Processing System application software, newly purchased two sets of the Liquid Nitrogen Refrigerant Catalytic Spread Device, canceled the purchase of Airborne Aerosol Mass Spectrometer, successively held six training courses, including the high-performance weather modification aircraft airborne equipment application training (USA), weather detection and international design for operational flight design and data analysis, in which a total of 176 people participated and the training time was 535 hours, and completed the procurement of the Airborne Detection Data Processing System. (Regional Centre administration office)

2.3 Weather modification capability building project of Northwest China

Two MA60 and two King Air 350 aircrafts have been purchased in the Northwest China Weather Modification Capability Building Project. The aircrafts are in the construction stage. The modification demonstration of the King Air 350 aircraft in China has been completed, and the integration of the King Air 350 remote sensing detection aircraft has entered the stage of bidding and procurement. The command operation system has completed bidding and procurement and contract signing. The research and test base (point) has completed the procurement and location, as well as the location of monitoring equipment, and some of the equipment has been installed. Seven sub-contracting bidding procurements and contract signing were completed. With the CMA Training Center, we jointly organized six training courses for the Northwest Weather Modification Project, and 2 participants from regional organizations participated in the teaching. We also prepared and completed three briefings of the Northwest Weather Modification Project and investment plan for 2019. (Regional Centre administration office)

2.4 Weather modification capability building projects of other regions

The feasibility study report has been completed in the Central China Weather Modification project, and submitted to the National Development and Reform Commission for approval in August 2017, and will be further revised and improved according to the feedback of the NDRC; the feasibility study report of the Southwest China Weather Modification project has been submitted to CMA. The feasibility study reports of the weather modification projects of North and Southeast China are under the compilation and technical review and a third-party professional organization was entrusted to carry out engineering environmental assessment. (Regional Centre administration office)

3 Scientific field experiment

3.1 Rain enhancement and pollution reduction weather modification exploration test for Shanghai Expo

In conjunction with the meteorological bureaus of Shanghai and Anhui Provinces, the exploratory experiment of rain enhancement and pollution reduction for the Shanghai Expo was successfully organized. Fully taking into the consideration of meteorological and environmental experts' opinions, focusing on the scientific mechanism understanding and practical exploration of precipitation enhancement to improve the air quality, and the working program, technical and implementation scheme was compiled. During the support period from October 16 to November 10, three aircrafts conducted 27 sorties of flight detection and rain enhancement operations. The analysis of the typical cases indicates that the operation of precipitation enhancement was reasonable and effective, which has a certain effect on the pollutant removal.(Operation Commanding and Running Centre, Aircraft Operational Centre, Open Laboratory)

3.2 Cloud physical observation experiments of different cloud systems

From September 4 to September 29, 2018, the King Air 350 National Rain Enhancement Aircraft (machine number is B-10GD) was deployed to the Zhuhai Jinwan International Airport, and the airport was used as the main docking site to carry out the detection of heavy precipitation cloud systems and typhoon peripheral cloud systems in the southwestern coastal areas of the Guangdong Province. During the experiment, Guangdong Provincial Weather Modification Centre carried out 10 flight surveys in Zhuhai and Yangjiang with a total flight time of 25.5 hours, obtained the microphysical characteristics of different layers of the summer cloud systems in the region, including the spectrum of aerosols, clouds and precipitation particles distribution (0.1−19200 μm), cloud and precipitation particle (10−19200 μm) morphology and phase characteristics, cloud liquid water content and layer distribution characteristics, cloud bottom and top aerosol particle size characteristics. These cloud physics detection data laid the foundation for the further understanding of cloud system characteristics and aerosol-cloud-precipitation interaction research in Southern of China.(Aircraft Operational Centre)

3.3 Macroscopic and microphysical features observation of clouds on Mount Lu

The observational experiment of clouds and precipitation features on Mount Lu has almost achieved whole-year observation. The diurnal and seasonal variations and macroscopic and microphysical features of the clouds/fogs and precipitation on Mount Lu were statistically analyzed with the cloud physics data from Mount Lu Cloud Experiment Station and the radar data from Jiujiang Station from November 2015 to February 2018. The heavy precipitation over the Mount Lu was frequent in summer, while the events of clouds and fogs occurred frequently in autumn, winter and spring. The average number of clouds and fog days was 13 days per month, and the maximum value reached 25 days per month. The stratiform, stratiform clouds with embedded convection and convective precipitation in the autumn and winter accounted for 29%, 44% and 27%, respectively, and convective and stratiform clouds with embedded convection precipitation in the spring and summer accounted for 83% and 17%, respectively. In the precipitation processes over Mount Lu the small and medium raindrops were predominant, led to the inferior fovea in the fitting Gamma distribution. The clouds and fogs were characterized by less number concentration, bimodal and wider spectra. The microphysical analysis of precipitation within clouds shows that with increasing precipitation grades, the more raindrops in number and larger raindrops in size were easier to initiate the coagulation mechanism, resulting in the reduction of cloud droplets smaller than 11 μm and larger than 30 μm, increasing the peak at 11μm.(Open Laboratory)

4 Weather modification operations and sevices

4.1 Weather modification major emergency response and service guarantee

In 2018, major emergency services for Hulunbeir Khanma and Huzhong forest fires were launched, as well as the Winter Olympic Games, the SCO Qingdao Summit, the 60th anniversary celebration of Ningxia, the Shanghai China International Import Expo and other major activities. A total of 131 issues of various special reports were produced and published, and 35 special meetings were held.

Applying new data, we completed the major emergency services for forest fires in Inner Mongolia. Aiming at the forest fires in Erguna City and Genhe City of Hulunbeir, Inner Mongolia, on June 2, the Weather Modification Centre jointly operated with the Weather Modification departments of the four northeastern provinces and autonomous regions to start the emergency service guarantee. Due to the serious shortage of radar data around the fire area, using the FY4A cloud characteristic parameter product inverted once every five minutes, combining with the forecast product, considering the wind direction and speed of the catalytic layer,

and aiming at the fire point, a fully sown aircraft operation scheme was designed to ensure that the catalyst was sown over the fire area, and scientifically guided the 6 sorties of the national rainfall enhancement aircrafts to carry out operation, which played an important role in successful forest fire extinguishment. The service has been praised by local governments and relevant departments.

Operational and scientific researches were integrated to successfully complete all major service guarantees. Making full use of FY-4 satellite products and cloud parameter inversion products to provide strong support for operational condition prediction, monitoring and early warning, as well as the aircraft detection, operation and catalytic scheme design, experts were sent to Qingdao and Ningxia to complete the support work. During the period of Shanghai Expo from October 16 to November 10, according to the requirements of the Shanghai Municipal Government, cooperated with the Shanghai Meteorological Bureau and we provided rain enhancement and pollution reduction services for the Expo. The Weather Modification Centre was actively involved in the Winter olympics services, and carried out the key technology research on small-scale snow enhancement in the fixed target area of complex terrain.(Operation Commanding and Running Centre)

4.2 The 3-year Action Plan for the modernization of the weather modification operation was successfully completed

The Weather Modification Centre has prepared the final points and methods for the final evaluation of the action plan for the modernization and safety management of weather modification, and the final evaluation plan for the modernization and safety management action plan of the weather modification operations, determined the evaluation level standards, refined the evaluation indicators, and organized relevant provinces to jointly conduct the initial evaluation. The Weather Modification Centre has organized the experts for Weather Modification Advisory to carry out the evaluation, by means of expert review and field assessment and so on, formed a final evaluation report, which was reported to the Disaster Mitigation Department. To implement the requirement of CMA to strengthen the investigation and researches, the field research on three-level weather modification operation organizations of the Tibet, was conducted, specifically guiding the modernization of Tibetan weather modification operation and the construction of the weather modification project. (Operation Commanding and Running Centre)

4.3 Weather modification operation commanding

For implementing the requirements of CMA to develop ecologically-renovated weather modification operation, a technical meeting was held on May 29, with participants from Weather Modification Centre/ Offices of 11 provinces including Hebei, Inner Mongolia, Jilin, Liaoning, Heilongjiang, Jiangxi, Henan, Hubei, Chongqing, Shanxi and Qinghai, and the National Weather Modification Center. The meeting focused on the key technologies, service processes, benefit evaluation and institutional mechanisms of the ecologically-repaired weather modification operation, exchanged and discussed the ecologically-repaired weather modification operation of various provinces and countries, and compiled the Thinking and Suggestions on the Development of Ecological Restoration Weather Modification Operation. Refining characteristics and key technologies of operations, pilot applications in the Yangtze River Delta region, Hubei, and Shanxi were organized, and the pilot summaries were prepared, which improved the pertinence and scientificity of services in different ecological target areas.

The Weather Modification Centre (WMC) has investigated the service demands of various regions, and formulated the annual national weather modification service plan for the first time; conscientiously provided the national operation guidance, and released various types of guidance products for 111 issus, e.g. the Weather Modification Operation Demand Analysis, Weather Modification Operation Work Information Report, Weather Modification Operation Quality Report, etc.

The WMC has developed ice/subcooled water potential forecast products to achieve daily automatic operation and been applied in process forecasting. The operation mechanism of the CPEFS_V1.0 service mode was adjusted and optimized multiple times, and various operational exception handling mechanisms were added to improve the stability of the model calculation and ensure the normal operation of the service.

The WMC maintained the stable running of three forecasting model systems (CPEFS_V1.0, MM5-CAMS, GRAPES-CAMS), the Cloud Feature Parameter Satellite Monitoring & Inversion System, the National Weather Modification Operation Information Collection & Processing System, and the Product Sharing & Distribution System, and ensured the normal releasing of two types of guidance products (forecasting and monitoing), and obtained the real-time job information on aircraft and ground-based operations.

The WMC has completed sub-regional assessment of airborne cloud water resources nationwide. According to the Technical Guidelines for Cloud Water Resources Assessment issued by the WMC of CMA. Using the 2000−2017 NCEP atmospheric reanalysis data and GPCP precipitation products, the climate assessment of cloud water resources in China and 6 partitioned areas has been carried out, which formed assessment results and data products ,and analyzed the characteristics of cloud water resources such as total atmospheric water condensate, cloud water resources, and water condensate precipitation efficiency in China and the 6 partitioned areas, and finally formed an assessment report. (Operation Commanding and Running Centre)

4.4 National weather modification aircrafts operations

Efforts had been made to improve the operations and safety management of three national precipitation enhancement aircrafts, and to provide the operational services such as drought resistance and disaster reduction, reservoir storage, ecological environment protection, forest and grassland fire prevention in significant operation areas of four Northeast provinces and regions. During the spring and summer, according to the requirements of drought resistance and fire risk reduction in forests and grasslands, the rain-enhancement aircraft B-3435 and B-3726 are based in Changchun Longjia Airport and Shenyang Taoxian Airport respectively. The rain enhancement aircraft B-10GD is based in Heilongjiang Zhaodong Beidahuang Airport and Jiansanjiang Airport, and transfers to Daqing City of Heilongjiang Province and Hulunbeir City of Inner Mongolia to conduct the drought-resistant and storage operation services in due time. According to the demands of drought resistance and normalization operation in spring, autumn and winter in Central Plain regions, two national rain enhancement aircrafts are based in the Xinzheng International Airport in Henan Province, and cooperated jointly with the Weather Modification Department of Henan Province to conduct the rain enhancement operation service in the surrounding cities and provinces. From Dec. 5, 2017 to Jan. 31, 2018, the airplane operation service of rain and snow enhancement in winter was implemented in the Hetian and Kashgar regions of Xinjiang. From October 10 to October 25, Liuji Airport was the main landing base in Xiangyang City, Hubei Province, we participated in the agricultural drought relief in Hubei Province. Up to December 20, 2018, 195 flights were made by three national rain enhancement aircrafts with a total flight time of 649 hours and 26 minutes; meanwhile, valuable aircraft observation data were accumulated.

We organized the aircraft hosting companies (Sanxing Aircraft Hosting Co. and Beidahuang Aircraft Hosting Co.) to complete the verification and maintenance of MA60 (30M, 36M) and the King Air 350ER Rainfall Enhancement Aircraft (200H) at Changchun, Shenyang, Guanghan and Zhaodong Airports on time with good quality. According to the requirements of the uses and calibration of airborne detection equipment, the periodic detection and calibration of the particle measurement system of 3 national rain enhancement aircrafts were completed. The maintenance of the airborne detection, broadcasting, communication and other equipment before and after each flight, timely maintenance and troubleshooting to ensure the equipment

system is in normal operations. Referring to the management measures for the transformation of scientific and technological achievements of CAMS, CMA, the formulation and implementation of the Interim Provisions for the Management of Funds for Technical Services of National Weather Modification Aircraft Operations were promoted, and the National Weather Modification Aircraft Operations Management Measures was compiled to actively adjust the airplane operation management.(Aircraft Operational Centre)

4.5 Weather modification equipment research and development

The Weather Modification Centre participated in the completion of 3 technical review reports: WR-1A, HJD-82B, BL-2A 44mm rainfall enhancement and hail-proof rocket projectile licensing technology review report; finished two new product operation trial scheme evaluation: RY-18 Artillery and JD-17 37 mm Artillery Projectile Trial Scheme Evaluation; one finalized test outline evaluation: 18-type Rainfall and Rainfall-proof Projectile (including warhead and bottom fuze); the evaluation of the design finalization test outline of warhead and bottom fuze, and the summary of the trial operation of artificial rain enhancement and hail suppression shells of 18 types. (Equipment R&D and Support Division)

5 Others

5.1 Transformation and application of scientific and technological achievements

On July 20, 2018, the meteorological science and technology achievement evaluation of the MA60 Rain Enhancement Aircraft System was completed. The overall technology of the MA60 Rain Enhancement Aircraft System achieved the international advanced and domestic leading level, among which the airborne observation-seeding integrated technology and the real-time air-land and command monitoring technology have reached the international cutting-edge level. In the whole year, achievements transformation services of the National Rain Enhancement Aircraft Science and Technology were provided for 5 times, contributing to the local economic and social development. We cooperated with companies such as COMAC and Hafei to conduct the experimental research on the natural ice accretion of aircraft, and provide the scientific support for the verification of natural icing of China's domestic large aircraft. (Operation Commanding and Running Centre, Aircraft Operational Centre)

5.2 Scientific exchange and technology cooperation

The Weather Modification Centre actively cooperated with the Disaster Mitigation Department to complete the 60-anniversary series of commemorative activities, compiled a series of conference proceedings on the achievements of China’s 60-year weather modifocation operation technology and achievements, and hosted a series of conferences such as the National Weather Modification Science and Technology Exchange Conference; mada great efforts in the preparation of the 60-anniversary brochure, modernization achievement exhibition, memoirs, promotional films, publicity materials and others.

The Weather Modification Centre actively organized experts in the field of education and scientific research institutions to carry out collaborative researches, cooperated with five research institutes and formed a research and development team with Northwest project participating provinces on the Northwest topographic clouds to conduct the experimental research on key technologies for operation services. The Cloud Physics Laboratory signed a collaborative innovation agreement with the CAS Strong Convection Laboratory and the Beijing Cloud Precipitation Laboratory, participated in the WMO Expert Meeting on Weather Modification, prepared WMO reports, technical assistance to countries along the “Belt and Road” in Sri Lanka, and exchanged visits with experts such as the United States, Thailand, Russia and Germany for 12 times.