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ISACS技术总结报告

会议学术委员会主任丁一汇研究员

干旱气候变化与可持续发展国际学术研讨会是由中国气象局,甘肃省人民政府,国家自然科学基金委员会,加拿大环境部气象局气候适应性和影响对策研究所,AIACC/START/TWAS,美国国家大气研究中心,美国自然科学基金委员会和澳大利亚气象局研究中心主办,由甘肃省气象局承办。研讨会经过两天激烈的讨论,得到了许多有价值的科研成果。

在过去的两天里,大约有170多位专家就有关8个方面的议题进行了大会报告和海报张贴。这8个议题(如下)几乎涵盖了干旱气象的所有重要方向:

1.干旱气候变化及其预测研究
2.极端气候事件及其与干旱气候变化的关系
3.干旱气候变化对环境的影响
4.干旱环境蠕变问题
5.干旱区陆面过程特征及模拟
6.干旱区气候资源和水资源合理利用
7.干旱气候变化与可持续发展
8.干旱防御工程技术与管理

1 干旱环境的演变和形成

根据中国西部干旱环境中的风化、水蚀和古生物化石沉积方面的证据,对于包括塔里木、准葛尔、河西走廊和鄂尔多斯在内的内陆盆地干旱沉积地层的时空分布以及沉积特征分析表明,中国内陆干旱环境主要形成于晚侏罗世,其演化过程经历了晚侏罗世亚热带干旱加强期、白垩纪亚热带干旱鼎盛期、早第三纪亚热带干旱减弱期、晚第三纪亚热带干旱向温带干旱转型期、第四纪温带干旱发展期等5大阶段。其中,前第四纪亚热带干旱的演化与全球气温波动有关,晚第三纪以来的温带干旱主要与新构造运动引起的高原和山脉隆升有关。

水资源短缺严重制约了中国西部地区社会经济的可持续发展。据研究,祁连山区气温变化过程同地表径流量及其时空分布有着非常密切的关系,气温变化极大地影响着黑河流域的社会经济发展及生态环境状况。目前,这一地区气候有了较大改变,20世纪90年代气温同1960~1990年30 a平均温度相比,增加了0.5~1.1 ℃,20世纪90年代的降水同50年代降水相比增加了18.5 mm,同1960~1990年平均降水量相比,则增加了6.5 mm;而水资源20世纪90年代同50年代相比减少了2.6×10^8 m^3,同1960~1990年均值相比,则减少了0.4×10^8 m^3。

山区温度、降水同平原地区存在着明显差异。尽管山区降水有微弱增加,但是仍无法抵消由于气温升高导致蒸发增加所损失的水分,并由此引起出山径流减小,雪线上升,冰盖缩小,植被退化,从而造成了山体滑坡增加,草地荒漠化日趋严重。

环境蠕变问题是指在较长的时间范围内,由人类活动引起的负面环境变化,这种变化通常是渐进的、缓慢的,但将不断累积,并最终以灾害的形式爆发。研讨会上就这一方面的问题进行了讨论,包括如何识别环境蠕变及其开始的特征;怎样处理这种不确定性;怎样预测社会环境中这种不确定性的原因。所有这些问题都面临挑战。各种自然灾害与环境变化密切相关。人们往往忽略身边每天发生的环境变化,而在灾害发生之后才追悔莫及。其最重要目的就是要通过多学科交叉领域的研究,为政策制定者和决策者提供环境变化的综合分析和评估,从而提前准备并发出预警,减少自然灾害带来的损失。

2 极端气候事件及其与干旱气候变化的关系

在全球变暖背景下,极端天气和气候事件频发,受到了越来越多的关注。在本次研讨会上,众多的参与者就20世纪以来发生的诸如干旱、浮尘和沙尘暴等极端气候事件的时空变化特征,未来趋势,与干旱气候关系,风险评估及预测等方面的最新研究进展作了交流。研究发现,几十年来澳大利亚也存在着增温的一些潜在趋势,而在温带地区则明显存在极端事件多发趋势,诸如整个地区夜间变暖,降雨趋势同空间分布不一致等,这些趋势所产生的后果就是澳大利亚干旱化日趋严重。这种后果并不完全是由于降雨变化所致,主要是因为温度变化造成热量和蒸发变化。对澳大利亚过去30 a蒸发量的分析表明其存在着明显的年代际变化,就年际尺度或更长时间尺度的分析,其变化同降水存在强的负效应。然而,降水变化并不能完全用于揭示澳大利亚所有地区的蒸发量变化。另一方面,由于澳大利亚相对较低的气溶胶浓度,全球天空变暗对该地区的蒸发量似乎并没有产生明显的影响。

中尺度数值模式MM5模拟了2004年3月26~28日内蒙古中部偏北地区发生的强沙尘暴过程。结果表明干空气侵入对强沙尘暴的形成发展起了重要作用。它将对流层高层高位涡带入低层,促进了对流层低层气旋及对流运动的发展,从而引起强沙尘暴的发生。

3 干旱气候变化原因和监测,干旱气候变化及预测

全球气候变暖是一个人所共知的事实。参会者对温度、降水和土壤含水量的最新研究试图证明,过去几十年,在全球变暖的前提下,世界各地的干旱气候变化有着独特的区域特征。例如,在一些内陆国家,当年均温增加时,甚至年均降雨有轻微减小或变化都可能造成干旱频发。以色列特拉维夫大学的气候学家们经过调查后认为以色列北部地区由于全球变暖导致降水量减少,而南部和中部地区降水量增加,他们将这种变化归因于南部和中部灌溉农业发展使得植被覆盖度增加。这可能是由于反照率减小和蒸发导致湿度增大,从而增加了半干旱地区降水。中国科学家们研究认为中国西北地区气候正从暖干向暖湿过渡,并利用模式模拟不同情景下21世纪后30 a中亚干旱地区气候状况,结果表明温度将可能增加7~9 ℃,降水可能增加6%~25%,到21世纪末气候将比中世纪暖期更暖些,同全新世温度最适宜期大致相同,地球系统也可能相应地对气候变暖作出响应。

参加研讨会的科学家们一方面从不同角度回顾和分析了干旱气候变化的信号,诸如温度和降水变化。同时也对东亚季风区域特征,亚洲夏季风季节进退,全球季风分布,季风年际和年代际变化,以及海表面温度和季风异常的关系,夏季风界限等进行了讨论。另一方面,其他一些科学家则根据几十年或者上百年气候变化的事实,针对世界不同地区全球气候变暖和干旱气候变化的关系进行了交流。当然,对全球气候变暖的成因分析也是一个焦点所在。目前,已经得到了许多有用的研究成果,为以后进一步的研究打下了坚实的基础。另外,全球和区域气候模式在干旱气候和气候变化研究中正起着愈来愈重要的作用,大会上也对进一步了解模式模拟地、气相互作用的内在物理过程进行了大量的讨论。借助于区域气候模式,对植被改变导致的区域气候变化对中国的影响进行了模拟试验,结果表明大范围的植被变化作为区域气候变化的主要影响因子之一,不仅对本地降水和气温产生影响,而且对东亚季风也产生深远影响。

中国北方地区严重的荒漠化导致许多地区降水减少,尤其是中国北部和西北地区,但是造成西南降水增加。结果使本地气候愈加干旱,更加不适宜植被再生。

相反地,中国西北地区退耕还林使黄河流域降水增加,缓解了此地的干旱,但造成长江流域和中国南部夏季降水减少,使这些地区的洪涝灾害减少。另一方面,由于有更多的水分输入大气中,加之低层风减弱,会使冬季气温增加,夏季气温降低,从而一定程度上减少了沙尘暴发生的次数。此外,植被变化也对东亚季风强度有显著影响,并进而影响中国东部地区夏季降水的分布和冬季低温冷害事件的发生。

通过区域气候模式模拟显示,中国北方地区植被恢复对大气环流和降水分布有显著的区域影响。如果沙漠、半沙漠地区全部被草地覆盖的话,地表净辐射和地表到大气的总的热通量均会增加,这会促进该地区的上升运动和水分向大气输送,使整个地

区降水增加。但降水增加很大程度上是由于降水强度的增加而不是降水频次增加的结果。而缺少频繁的降水,尤其是在地势较低的地方,要维持一个具有较好植被覆盖的地表则较为困难。这也说明了,目前进行植被恢复将很大程度上局限于那些水资源相对充足的地区,或者是那些主要依靠灌溉的地区;地势较高地区径流增加将对地势较低地区的灌溉是十分重要的;较高地势区域和偏东的地区由于本来就降雨频繁,再加上降水增加,会有助于维持这些地区修复的植被。

在模拟中,试验区域增强的上升运动气流使得在其东侧形成的补偿下沉气流得以加强,主要集中在黄河三角洲和山东半岛上空,导致了那里的高压和反气旋环流异常,使这些地区降水减少。这种反气旋环流异常严重造成了低空东北风的异常,当它们遇到西南季风气流,则使得长江流域和华南的气旋性环流切变涡度加大,造成华南和四川盆地的上升运动异常,因此增加了这些地区的降水。

另外,会上还进行了有关利用诸如遥感、GIS和GPS等非常规手段进行环境和干旱气候监测研究方面的讨论。可以预见在不久的将来,这些运用精确的探测手段获取的反映广泛区域特点的资料,将毋庸置疑地在干旱气候变化、水分循环和碳循环及气溶胶输送等领域起着越来越重要的作用。

4　干旱区陆面过程特征及模拟

研讨会上,与会代表们论述了中国西北干旱区地、气相互作用试验的意义、目的及试验方案。另外,近些年有关这些研究的一些成果及研究进展会议上也作了总结,展示了一些有关地面辐射、热量平衡,陆面过程参数,通量的参数化,地表水循环,陆面模式的改进和陆面过程的模拟等一些重要发现和新想法。而且,对近几年来开展的一些在非均一陆面状况条件下能量和水循环的外场试验进行了总结和介绍,同时获得了干旱区半干旱区非均一地理背景下陆面变量的区域分布以及植被变量和表面热通量的变化特征。

我们还进行有关气溶胶粒子、热量和风场间相互作用的边界层综合数值模拟试验以研究气溶胶粒子对中国北方和西部地区亚洲沙尘源区辐射平衡的影响。初步结果表明,由于气溶胶短波辐射造成白天边界层热量明显增加,一小时内温度增加超过1 K,风速相应变化约0.3 m/s。底层TSP浓度趋于减小,但高层则趋向增加。夜间,气溶胶长波辐射造成地面附近气温增加,但大气底层温度减小(约0.1~0.2 K/h),风速和TSP浓度也相应变化。

研讨会也展开了基于MODIS和LANDSAT等遥感资料计算蒸散的讨论。结果表明,在海河流域降水和蒸散是主要的水分平衡因素。近几年,通过蒸散损耗的水分比降水多了大约4%。1998年,地下水过度开采约63亿m^3,造成过去30 a地下水位剧烈下降,引发了许多生态和地质问题。因此,只有蒸散减少才能恢复水分平衡,逐渐解决海河流域水资源短缺问题。

5　干旱气候变化影响,适应和可持续发展

专家们仔细分析探讨了干旱气候变化的成因、影响和对策,以及如何利用它的正效应,抑制其负效应。交流论文也涵盖了农业、植被、土地利用、水资源、能源供应、城市发展和公共利益等方面。主要包括以下研究:大尺度大气循环和区域气候间的相互作用,由气候变化引起的能源需求变化,冷季和暖季由于全球变暖对水分平衡的影响,以及对沙漠化的影响等。有关干旱气候生态监测系统研究也已初步展开,这迈出了十分有利的一步。而且,目前依靠GIS和遥感监测干旱系统也已经建立,这些系统能够给决策者制定相应的政策法规提供科学依据,而数值模式的开放结构特征也为模式进一步的改进研究,打下了良好的基础。

有关人类对干旱气候和气候变化的影响存在科学不确定性和区域差异,但无疑干旱气候变化对人类社会的影响已经涉及到了方方面面。研讨会讨论了有关不同的社会环境状况下,不同区域可持续发展对干旱气候变化的响应问题。无论怎样,人类都必须考虑干旱气候变化对可持续发展的影响。

通过用RIEMS模式模拟了以后50 a 13个省份土地利用变化对区域气候的潜在影响。将涉及GDP、人口、市场和科技进步等因素在不同状况下代入情景模式,模拟从2000年到2050年中国北方地区6种土地利用变化状况。结果显示6种土地利用变化情景模式都可能对中国北方地区,尤其是沿东北到西南的干旱半干旱地区的夏季气候产生重大影响。例如,比较情景C(GDP和人口迅速增加,农业产量增加)和情景F(GDP和人口缓慢增加,农业产量稳定)的结果,很

明显，情景C结果显示夏季气温平均会下降0.5 ℃，而日降雨量则可能增加1~3 mm/d，这将改善中国东北西部地区和中国西北东部地区干旱半干旱地区的环境状况；但在情景F下，相同区域的气候变化正好相反，即温度将会增加0.5 ℃，而降水会减小1~3 mm/d。

参加研讨会的科学家们就极地区域和青藏高原地区的气候变化展开了广泛而深入的讨论。有关20世纪这些区域的温度变化均有讨论，青藏高原地区能源和水分循环变化成为本次会议焦点。青藏高原作为地球上一个高耸的热源（汇）在亚洲季风和东亚气候中起着重要作用。这一区域冬季干燥，夏季湿润。研究表明整个冬季季风前的时段潜热占主要地位，整个季风发生时段感热占主要地位，同时对其年变化也作了研究。利用GMS数据和NOAA数据测定了地表温度，已有的过去7 a的记录显示，地表最低日温年增加0.16 K。另外，科学家研究认为极地地区气候变化对世界其它地区有影响，或者说有关联。研究表明，Amundsen 海低压（ASL）和东南极高压（EAH）之间的跷跷板结构同南美及新西兰之间的跷跷板现象保持同步关系，而且极向输送指数（TPI）可以较好地指示极涡的移动方向，太阳活动很有可能是极涡中心在年代际尺度上移动的一个主要驱动因子。上世纪的澳大利亚南部干旱事件发生在低TPI位相阶段，而此时极涡正好偏离澳大利亚地区。

对气溶胶源地、排放及其对气候变化影响的监测，尤其是气溶胶对气候的辐射作用在此次会议上也被广泛讨论，Weizmann研究所和Hebrew大学研究组研究了Yatir森林碳汇作用，该森林在Beer Sheva东北部区域，年降雨量仅约300 mm，他们发现森林中每年每公顷会吸收约2 t左右的碳。全球大约有20亿hm^2半干旱灌木和草地，如果种植保持完好，即使只是一部分，也将会吸收全球人类制造的大气CO_2的相当一部分。

6 有关人口，区域和系统脆弱性研究

研讨会上，加拿大环境部气象中心适应及影响研究组组织专门做了EC-AIRG-C5-AS25的专题会议。依据国际间对气候变化和生物多样性的合作研究，达成了以下共识：

人口压力以及对生态系统和生物多样性造成负面影响都是空前的。这些负面影响由土地利用状况变化，污染，过度利用，外来物种引入及气候变化等造成。在许多区域，生物多样性已经受到近期气候变化的影响，尤其是21世纪的气候变化。本世纪气候的预期变化比过去的10 000年都要发生的更迅猛些。随着土地利用变化和外来物种的扩张，气候变化很可能限制物种移植和降低物种在脆弱环境生存的能力。

目前已经进行了有关影响黑河地区资源系统脆弱性的主要影响因子分析。也就是说，资源脆弱性是这些影响因子的共同作用，这些因子包括气候，区域经济活动，土地利用，资源利用尺度，资源利用效率，供需价格弹性，环境保护，政策制定（经济，技术或政策），以及同收入增长和人口增加有关的生活方式。

利用优化监测技术和气候变化模拟，评估20世纪全球和区域尺度的温度变化。主要进行了9个领域的分析：1）全球；2）北半球，包括北半球30 °~70 °N的4个地区；3）欧亚大陆；4）北美大陆；5）仅陆地；6）30 °~70 °N整个纬度带；7）加拿大南部；8）欧洲；9）中国。结果表明，全球尺度下人类明显对气候造成了影响。温室气体和硫化物气溶胶20世纪后50 a在9个区域对年平均和季节平均温度变化均造成了影响，而且这种影响可以区分开来。结果也存在不确定性，主要是由于空间尺度较小造成的。集合模式进行温室气体和硫化物气溶胶粒子强迫以及气候系统内在变率的响应评估有了较大的完善。用模式模拟气候变率加倍时，温室气体也会持续发生变化。

该研讨会实际上已经揭示了大量重要的科学发现。但是干旱气候和气候变化是非常复杂的。许多问题还需要进一步研究。对于关注的问题两天的交流和讨论是远远不够的。我们相信通过世界各地科学家们进一步的努力，我们将会更加全面深入地了解有关干旱气候和气候变化规律及其成因机理。

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The Scientific Summary for ISACS

Prof. Ding Yihui, Chairman of Scientific Steering Committee (Lanzhou, Gansu, China, 24May 2005)

The International Symposium on Arid Climate Change and Sustainable Development (ISACS) is co-sponsored jointly by China Meteorological Administration (CMA), People's Government of Gansu Province of China, National Natural Science Foundation of China (NSFC), Meteorological Service of Canada, Environment Canada (MSC/EC), AIACC/START/TWAS, National Center for Atmospheric Research (NCAR), USA, National Science Foundation (NSF), USA, and Bureau of Meteorological Center (BMRC), and Australia. Under the organization of Gansu Meteorological Bureau (GMB), China, the Symposium have had two days' active discussion and deliberation, and produced valuable scientific outcomes.

In the past two days, about 170 oral and poster presentations were made for about eight topics. These eight topics cover almost all important aspects of arid climate:

1. Studies on arid climate, including its variability, predictability and potential change
2. The relationship of extreme climate events and arid climate change
3. The impact of climate change on environment
4. Creeping environmental problems in arid and semi-arid regions
5. Characteristics and modeling of land surface processes in arid regions
6. Rational use of climate and water resources in arid regions
7. Arid climate change and sustainable development
8. Drought mitigation and engineering technology

Based on the wide range of presentations, the major results may be summarized as follows:

1 Evolution and Formation of Arid Environment

Based on deposits of weathering, aqueous, and paleontologic evidences in the arid environments of west China, the temporal and spatial distribution of sedimentary strata and sedimentary characteristics in the inland basins including Tarim, Junggar, Hexi Corridor and Ordos etc. were analyzed. The analytical results show that the inland arid climates in China mostly had been formed since the late Jurassic period. Since then they have gone through five major developmental stages, namely the late Jurassic subtropical drought-intensifying stage; Cretaceous subtropic drought maximum stage; early Tertiary subtropic drought-weakening stage; late Tertiary transformation stage from subtropic drought to temperate drought; and Quaternary temperate drought development stage. The geologic evolution processes of the arid climate in West China were caused by global temperature fluctuations during the greenhouse period and ice house period superimposed upon the environmental effects of tectonic movement.

In sustainable development of the western China, water resources are the greatest factor restricting the development of society and economy in the area. There is a very consanguineous relationship between the temporal and spatial distribution of surface runoff and its amount, and the variation process of air temperature in the Qilian mountains area, and the variation of air temperature will affect the development of society and economy and ecological environment of the Heihe River Basin to a great extent. Studies indicate that the climate in this region has significant change, with the temperature increasing extent reaching 0.5~1.1 ℃ in 1990s compared to average value of period 1960~1990, precipitation increasing extent reaching 18.5 mm in 1990s compared to 1950s, and 6.5 mm in 1990s compared to average value of period 1960~1990, water resources decreasing extent reaching 2.6×

10^8 m^3 in 1990s compared to 1950s, and 0.4×10^8 m^3 in 1990s compared to average value of period 1960~1990.

The temperature and precipitation vary in mountaineous areas markedly compared with the plain areas. Despite the precipitation has smaller rising, but this increasing cannot counteract the evaporation increasing caused by the temperature rising. So the runoff flowing out mountain is decreasing and snow line rising and ice cover decreasing and vegetation cover degenerating, and make the mud-slide disaster increasing, and lead to grassland hungriness.

Related with the society problem, creeping environmental problems, which is an adverse environmental change with long term, low grade, incremental and cumulative process, has been addressed appropriately in this Symposium, including how to identify creeping environmental problems and the devising of ways to identify thresholds before; how to meet the need to cope with instability as well as seeking to forecast the causes of (precursors to) instability in ecosystems and societies. All these problems present challenges, including applying lessons of managing drylands use; making "what ought to be" the proper use of drylands "the actual use of drylands"; convincing governments to consider the limits of exploitation of the natural environment; convincing governments to plan beyond their tenure in office; and convincing governments to put a proper value on nature.

2 Extreme Weather and Climate Events and Arid Climate Change

Under the background of the global warming, the frequencies of a variety of extremes weather and climate events attract increasing attention and concern. At the Symposium, the participants present the latest advances in their research on the temporal and spatial characters, future trends, relation with arid climate, risk assessment and predictability of extreme events such as droughts and sand and dust storms, which took place since the beginning of the 20th century. It is found that, In Australia, there has been an underlying trend of increasing temperature for several decades. While there are significant trends in extremes in temperature, such as an increasing frequency of warm nights across the region, trends in precipitation are not so spatially coherent or well-defined. A consequence of these features is that major droughts in Australia may be increasing in severity, not so much due to rainfall trends, but because the increasing temperature imposes increased stresses from heat and evaporation. Indeed analysis of the climate record for pan evaporation in Australia suggests that there has been significant inter-decadal variability over the last thirty years, with the variability on annual and longer time scales having a strong negative correlation with rainfall. However, rainfall variations do not explain all the observed variability in pan evaporation across Australia. On the other hand, owing to the relatively low concentration of aerosols across Australia, it is unlikely that "global dimming" has had a significant influence on pan evaporation in Australia.

A meso-scale numerical model MM5 (V3) was used to simulate a strong duststorm process occurred in the north of the middle Neimenggu during the period from March 26 to March 28, 2004. The results showed that dry air intrusion played an important role in the development of the duststorm process. It transported the high PV from high level to the low level and caused the cyclone and convection development.

3 Detection and Attribution of Arid Climate Change, and Arid Climate Variability and Predictability

Global warming is a widely recognized fact. With their latest study on the temperature, precipitation, and soil moisture, the participants of the Symposium are trying to prove that in the context of global warming, arid climate change over the past century in different parts of the world have specific regional features. Take a few examples. In some inland countries, while the annual mean temperature is rising, even a slight variation or decline of annual precipitation may lead to increased frequency of droughts. Investigations carried out by climatologists of the Tel Aviv University, Israel, have shown that while the quantity of rains in the northern part of Israel diminishes, which they attribute to the global warming, at the same time the central and southern part of Israel enjoy

an increase in the quantity of precipitation. They attribute this augmentation to the increase in vegetation cover since irrigated agriculture expanded in this region. In other words, the decrease of the albedo (back radiation from the soil) and increase in humidity due to evapotranspiration increased the precipitation over a semi-arid region. Research conducted by Chinese scientists indicates that the climate feature of northwestern China is changing from a warm and dry climate to a warm and wet one. Results show that a warming of 7~9 ℃ and increasing of precipitation by 6%~25% over Central Asian arid region by the last 30 years of the 21st century might appear as projected by the climate models with various emission scenarios. It will be much warmer than the Medieval Warm Period and similar to the Holocene Maximum period by the end of the 21st century. The Earth system might be responded to the obvious warming.

Many scientists participating in the Symposium on one hand have reviewed and analyzed from different perspectives the signals of arid climate change, such as temperature and precipitation. The regional feature of East Asian monsoon, the seasonal march of Asian summer monsoon, the global monsoon distribution, monsoon interannual-interdecadal variations, relationship between sea surface temperature and monsoon anomalies, and the last boundary of summer monsoon are reviewed and discussed. On the other hand, many others have focused on the study of the relations between the global warming and arid climate changes in various regions of the world on the basis of climate change at time scales from decades to centuries. Of course, analysis on the cause of global warming is also of a concern. A number of useful results have been achieved which have laid down a sound foundation for the further studies on these issues in future. The global and regional climate models are playing increasing role in the research of arid climate and climate change. The improvement of understanding on the internal physical process of land-air interaction by model simulations has been discussed in a great deal in this Symposium. By using the regional climate model (NCC/RegCM), two modeling experiments are undertaken to investigate the regional climate impact of changed vegetation over China, and results indicate that vegetation variations in large regions not only have significant local and regional effects on rainfall and air temperature, but also have far-reaching effects on the East Asian monsoon, as one of main influence factors of the regional climate change.

Heavy desertifications in North China result in rainfall decreasing over many regions, especially in North China and Northwest China, but increasing in Southwest China, as a result, the local climate having more droughts and being unsuitable for vegetation regrowing.

On the contrary, reforestation in Northwest China tends to increase rainfall in Yellow River basin, and hence, lightening drought over there, but rainfall over the Yangtze River basin and south China decrease in summer, which tends to decrease flood occurrence over there. On the other hand, local air temperature become warmer in winter and cooler in summer, with more moisture supplying to atmosphere and low-level wind decreasing, thus reducing dust storm weather in some degree.

Furthermore, vegetation changes also have obvious effects on the intensity of East Asian monsoon, and thus would influence the distribution of summer rainfall over East China and the occurrence of cold events in winter.

The local and remote effects of vegetation restoration in northern China via regional climate model simulations are also investigated. The results indicate that such re-greening has both significant local and regional effects on the atmospheric circulation and rainfall distribution. Replacing desert and semi-desert areas with grass in the test area increases net radiation at the surface, and hence total heat flux from the surface to the atmosphere. This results in enhanced ascending motions and moisture supply to the atmosphere over the test area. Consequently, rainfall increases in the whole test area. However, the increase in rainfall largely occurs due to an increase in intensity rather than an increase in frequency. Lack of frequent rainfall, especially in the lowlands of the test area, makes it very difficult to maintain a vegetated surface. This implies that the current vegetation restoration activities will be largely limited to areas where water resources are relatively abundant, or they will

depend heavily on irrigation. The increased runoff at higher elevations could be important for providing water for irrigation in the lowlands. The increase in rainfall in the highlands and far eastern parts of the test area, which already receive more frequent rainfall, may help support a restored vegetation cover in these regions.

The enhanced ascending motions over the test area are compensated by increased subsidence to the east, centered over the Yellow River Delta and Shandong Peninsula, resulting in a higher-pressure and anticyclonic circulation anomaly there. Consequently, rainfall decreases at these areas. This anticyclonic anomaly provides significant low-level anomalous northeasterly winds that enhance cyclonic shear vorticity in the Yangtze River Basin and South China when they meet southwesterly monsoonal flow. This causes strong ascending anomalies over southern China and the Sichuan Basin, and increases rainfall in these regions.

Quite a few papers concerning the environmental and arid climate monitoring and studies using non-traditional data acquired through satellite remote sensing, GIS and GPS have been presented at the Symposium. In the foreseeable future, the accumulation of such data sources that feature wide coverage and accurate sounding will undoubtedly play a more and more important role in the research fields relating to the monitoring of arid climate change, water cycle, carbon cycle and the transport of aerosol.

4 Characteristics and modeling of land surface processes in arid regions

At the Symposium, the participants illustrates briefly the scientific meaning, experiment scheme and scientific objectives of NWC-ALIEX (Land-atmosphere Interaction Experiment in Arid Region of Northwest China) that is supported by the National Key Programme for Basic Sciences, the Research on the Formation Mechanism and Prediction Theory of the Heavy Climate Disasters in China. Some of the research advances and achievements in recent years are summed up. It presents us some important discoveries and new ideas of the Program on the surface radiation and the heat balance, the bulk transfer coefficients, the land surface process parameters, the parameterization of turbulent flux, the surface water recycle, the improvement on land surface model and simulating of the land surface process, etc. Further, the results of the field experiments on the Energy and Water Cycle under the Heterogeneous (oasis-desert) Surface Conditions launched in recent years are also presented in this Symposium. The regional distributions of land surface variables (surface reflectance and surface temperature), vegetation variables (NDVI, MSAVI, vegetation coverage and LAI) and land surface heat fluxes (net radiation flux, soil heat flux, sensible heat flux and latent heat flux) over inhomogeneous landscape in arid and semi-arid areas are obtained.

To investigate the effects of aerosols on the radiation budget over Asian dust source regions in western north China, a synthetic numerical boundary layer model has been developed with respect to interactions of aerosols, heat, and wind fields. Preliminary results indicate an obvious heat increase in the boundary layer during daytime due to the effect of aerosol short radiative wave. The temperature increases more than 1 K in an hour. The corresponding variation of the wind speed is about 0.3 m/s. TSP concentrations on the lower layers tend to decline, but on the higher layers they tend to increase. At night, aerosol long wave radiative effect produces an increase in atmospheric temperature near the ground, but the temperature will drop in the lower layer (25~300 m) of the atmosphere, varying about 0.1~0.2 K/h. Wind speed and TSP concentration tend to make corresponding variations.

Some corresponding algorithms for Monitoring Evapotranspiration(ET), based on the using of satellite data of Landsat, MODIS, etc., have been developed and introduced in this Symposium. The results show that the precipitation and the ET are major water balance components of the Hai River basin. Water depletion through ET exceeds the precipitation by about 4% in recent years. The extra amount, about 6.3 billion m^3 in 1998, was mainly from excess exploration of ground water, which causes a great depression of water table in last 30 years and induces ecological and geological problems. Only the reduction of comprehensive ET can restore the water balance, and resolve gradually the shortage of water resources in the Hai River Basin.

5 Arid Climate Change Impact, Adaptation and Sustainable Development

The participating experts have made a careful analysis of causes and impacts of arid climate change and measures, discussed how to make use the beneficial effects to mitigate its adverse effect. The presentations and papers have covered such areas as agriculture, vegetation, land use, water resources, energy supply, city development and public benefit. They include the studies of the interaction between large scale atmospheric circulation and regional climate, the changing energy demand by arid climate change, the impact on water balance by global warming in cool and warm seasons, the impact on desertification and so on. The study of arid climatic ecological monitoring system has been initiated, which is a useful attempt. Moreover, Based on GIS, the system of drought monitor by remote sensing is set up. This system can provide to decision-makers the useful scientific results for making decisions. The character of open structure of the model lays a good foundation for its further refinement.

It is true that there are scientific uncertainties and regional differences with regard to the human impact on arid climate and climate change. But it is a undisputable fact that the impact of arid climate change is felt in all aspects of the life of human society. The Symposium has proposed various ideas on the sustainable options to respond to arid climate change in different regions under different social and environment conditions. Whatever the case, the sustainable development is an inevitable choice by mankind to respond to arid climate change.

A set of numerical experiments is implemented to study the potential impacts of land use scenarios changes on the regional climate in 13 provinces of Northern China in the next fifty years using a regional integrated environmental model system (RIEMS). After the different "what-if" scenarios controlled by GDP, population, market and technology advancement were built, six kinds of land use scenarios changes (namely, A, B, C, D, E and F) in the northern China from 2000 to 2050 were simulated. The results from RIEMS show that the six kinds of land use scenarios changes could have different significant influence on summer climate in different regions of North China, especially in the arid/semi-arid region along northeast southwest. For example, comparing the simulation results of the scenario C (importing to the system, GDP and population growing rapidly, and the grain yield per unit increasing) with the results of the scenario F (exporting from system, GDP and population growing slowly, and the grain yield per unit standing), it shows clearly the scenario C would improve the environmental conditions of the arid/semi arid regions covering west part of Northeast China and east part of Northwest China, since the summer temperature averagely changes with a cooling of about 0.5 ℃, while the precipitation increases with an amplitude of 1~3 mm/d. But in scenario F, the climate changed reversely in the same region, namely the temperature changes with a warming of about 0.5 ℃, while the precipitation decreases with an amplitude of 1~3 mm/d.

The scientists participating in the Symposium have conducted a broad and in-depth discussions on arid climate change in both Polar Regions and that over Tibetan Plateau. The temperature changes over these regions in 20th century have been discussed. The changes of energy and water cycle over Tibetan Plateau are also their concern. The Tibetan plateau plays an important role in the Asian monsoon and the climate in East Asia as an elevated heat source/sink. Dry winter and wet summer characterize the area. Reflecting this, the measurements showed that the sensible heat is dominant during winter to pre-monsoon season and the latent heat is dominant during monsoon. The inter-annual variation is also observed. Using GMS data and NOAA data, the land surface temperature was first estimated. For the record over seven years, the warming trend of 0.16 K/a was found in the daily minimum of land surface temperature. Scientists also showed that the climate change in Polar Regions may have influence on or may be related to the climate change of other regions of the world. The study shows that the seesaw of Amundsen Sea low (ASL) and East Antarctic high (EAH) keeps the same pace with seesaw between South America and New Zealand, and Trans-polar Index (TPI) can be used a good indicator for the shifting of polar vortex in this direction. The solar activity is probably one of the major forcings for the decadal-scale shifting of the polar vortex center. The drought events of the southern Australian for the last century were in coinci-

dence with that of the low TPI periods, when the polar vortex shifted away from Australian side.

Monitoring of aerosols, its source and emission, its impact on climate change, in particular the radiative forcing of aerosols on climate are discussed. A team of Weizmann Institute and of the Hebrew University at Rehovot investigated the carbon sequestering of the forest of Yatir planted northeast of Beer Sheva in an area, which gets only about precipitation 300 mm/a. They found out that each hectare in this forest sequesters about 2 tons of carbon per year. on the global scale, there are about 2 billion hectares of semi arid shrub and grassland, which if planted, even partly, will sequester a remarkable percentage of the global anthropogenic atmospheric carbon.

6 Study on the Vulnerable People, Places and Systems

At the Symposium, an EC-AIRG-C5-AS25 special session organized by Adaptation and Impacts Research Group, Meteorological Service of Canada, Environment Canada. According to the International Action on Biodiversity and Climate Change, we have a common knowledge as follows:

Human pressures and stresses on our planet's ecosystems and biodiversity are unprecedented. These pressures include land-use change, pollution, over-harvesting, the introduction of alien species and impacts from a changing climate. In many regions, biodiversity has already been affected by recent changes in climate, with all aspects of biodiversity likely to be significantly impacted by the changes projected for the 21st century. The projected changes in climate over the current century are expected to occur faster than any recorded in at least the past 10,000 years. When combined with land use change and exotic/alien species spread, the changes in climate are likely to limit both the capability of species to migrate and the ability of species to persist in fragmented habitats.

Several major factors which influence resource system vulnerability in the Heihe River region of China have been considered. In other words, resource vulnerability is a function of these factors including: climate, economic activities in the region, land users, size of resource use activities, resource use efficiency, the price elasticity of supply and demand, environmental protection, policy options (economical, technical, or policy), lifestyle associated with income increasing, and population growth.

Using an optimal detection technique and climate change simulations produced with four GCMs, the causes of 20th century temperature changes from global to regional scales have been assessed. The analysis is conducted in 9 spatial domains: 1) the globe; 2) the Northern Hemisphere; and four regions in the Northern Hemispheric mid-latitudes covering 30 °~70 °N, including; 3) the Eurasia and 4) the North American continents; 5) land only; 6) the entire 30 °~70 °N belt; 7) southern Canada; 8) Europe and 9) China. The results show that the effect of anthropogenic forcing on climate is clearly detectable at global to regional scales. The effect of combined greenhouse gases and sulfate aerosols forcing changes is detectable in all nine domains in annual and seasonal mean temperatures observed during the second half of the 20th century. The effect of greenhouse gases can also be separated from that of sulfate aerosols over the period at the continental and regional scales. Uncertainty in these results is larger at smaller spatial domains. Detection is improved when an ensemble of models is used to estimate the response to greenhouse gases and sulfate aerosols forcing and the underlying internal variability of the climate system. Our detection results hold after removal of NAO related variability in temperature observations, variability that may, or may not, be associated with anthropogenic forcing. They also continue to hold when the model simulated climate variability is doubled.

This Symposium has indeed witnessed a lot of important scientific findings. But arid climate and climate change are very complicated. Many difficult problems are still waited for study. A two days forum of exchanges and discussion is far from being enough to exhaust all the questions concerned. We believe that through further joint efforts by the world scientists, we will know about the things behind arid climate and climate change better and better.