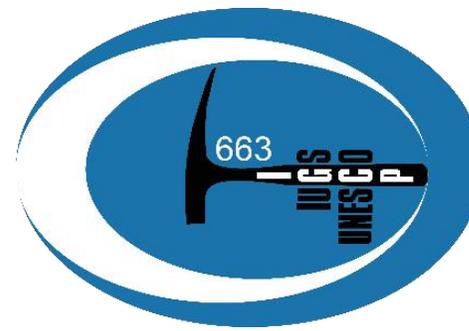




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International Geoscience  
Programme



# IGCP 663 : 沿海城市地面沉降 的影响、机理与监测

汇报人：史玉金



上海市地质调查研究院

Shanghai Institute of Geological Survey

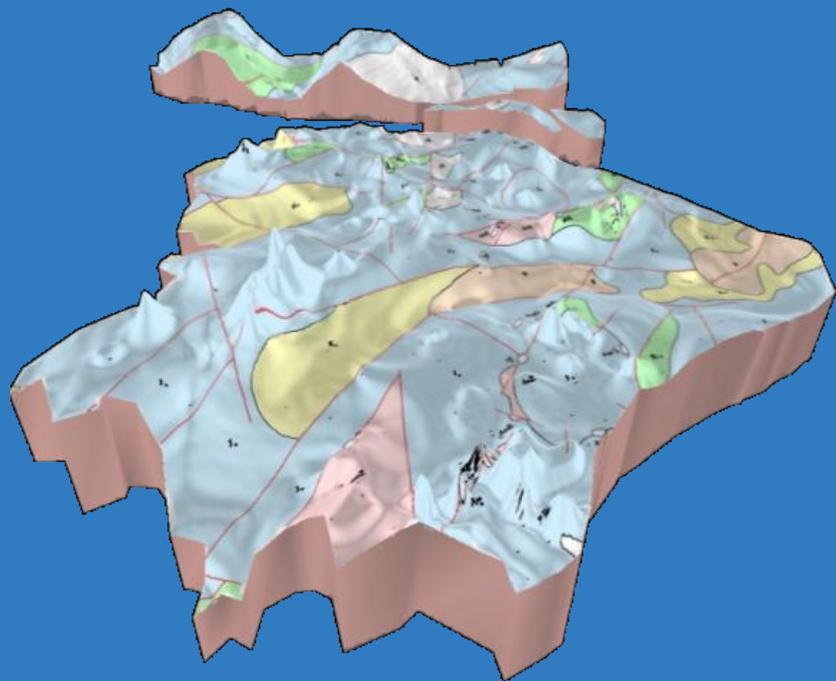
自然资源部地面沉降监测与防治重点实验室

Key Laboratory of Land Subsidence Monitoring and Prevention, Ministry of Natural Resources



# 报告提纲 OUTLINE

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- 一 项目概况
- 二 主要工作进展
- 三 下一步工作计划



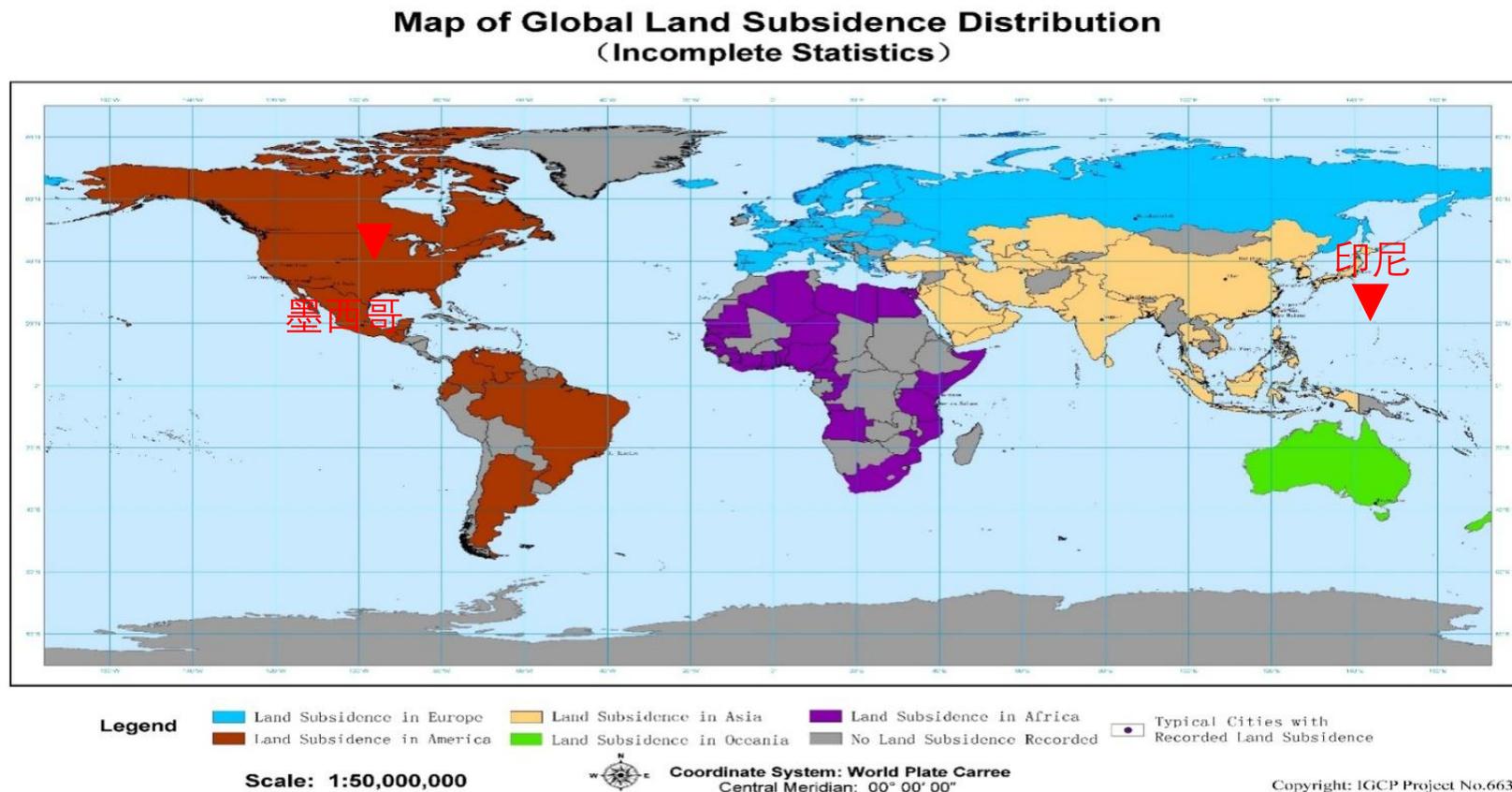
# 一、项目概况 Introduction



# 1.1 项目背景 Background

## 全球地面沉降灾害普遍发育并影响经济社会可持续发展

- ◆ 地面沉降是全球性问题，已有**超过100个国家**发现地面沉降灾害
- ◆ 代表性的国家有中国、美国、日本、荷兰、印度尼西亚、意大利、墨西哥、泰国、越南等



全球地面沉降分布图

# 我国地面沉降防治工作具有重要性和紧迫性



## ◆ 影响各地区经济社会的可持续发展

- 京津冀、粤港澳、长江经济带等均为地面沉降重要发育区
- 截至2021年，全国已有22个省（区、市）113个地级以上城市存在地面沉降
- 全国地面沉降速率大于50mm/年的严重区面积超过6000平方公里

## ◆ 严重威胁高铁、管道、大运河等生命线工程运营安全

- 京津城际、京沪高铁等8条已建高铁穿越地面沉降严重区
- 南水北调工程、西气东输穿越地面沉降严重区，
- 导致沿线局部地段地面高程降低

## ◆ 严重影响城市人文环境

- 引发城市洪涝、地下水污染等次生灾害
- 资源、生态、环境问题不断恶化



中国地面沉降现象分布广泛





## □ 项目名称

沿海城市地面沉降的影响因素、机理与监测

Impact, Mechanism, Monitoring of Land Subsidence in Coastal cities(IM2LSC)

## □ 项目周期

2018~2023年

## □ 项目目标

- 推动地面沉降科学技术进步与应用推广
- 提升全球地面沉降研究与防治能力





### □ 项目内容

#### ◆ 科学技术研究

- 全球地面沉降发育规律及防治管理调查研究
- 沿海新成陆地区地面沉降机制及影响因素研究
- 不同监测技术和综合网络的应用研究

#### ◆ 交流平台建设与成果技术推广

- 研究人员网络建设
- 远程授课与现场教学
- 举办项目会议/研讨会
- 跨区域交流与合作
- 现场考察
- 科普宣传





## 总负责人 首席科学家

中国

**严学新**，教授级高级工程师  
中国地质学会 会士  
上海市地质调查研究院 技术顾问委员会主任



## 联合 负责人

意大利

**Luigi Tosi**，意大利国家研究委员会，高级研究员

荷兰

**Esther Stouthamer**，荷兰乌特勒支大学，教授

印尼

**Heri Andreas**，印度尼西亚万隆理工学院，研究员

埃及

**Mahmoud Bakr**，埃及国家水资源研究中心，教授



## 项目组

汇聚了包括**联合国教科文组织地面沉降国际倡议计划（UNESCO LaSII）**在内的全球11个国家，120余名国际专家





## 二、主要工作进展

# Main Project Achievements



2.1 主要科技进展

2.2 项目成果

2.3 合作交流

2.4 年度会议

2.5 科普工作

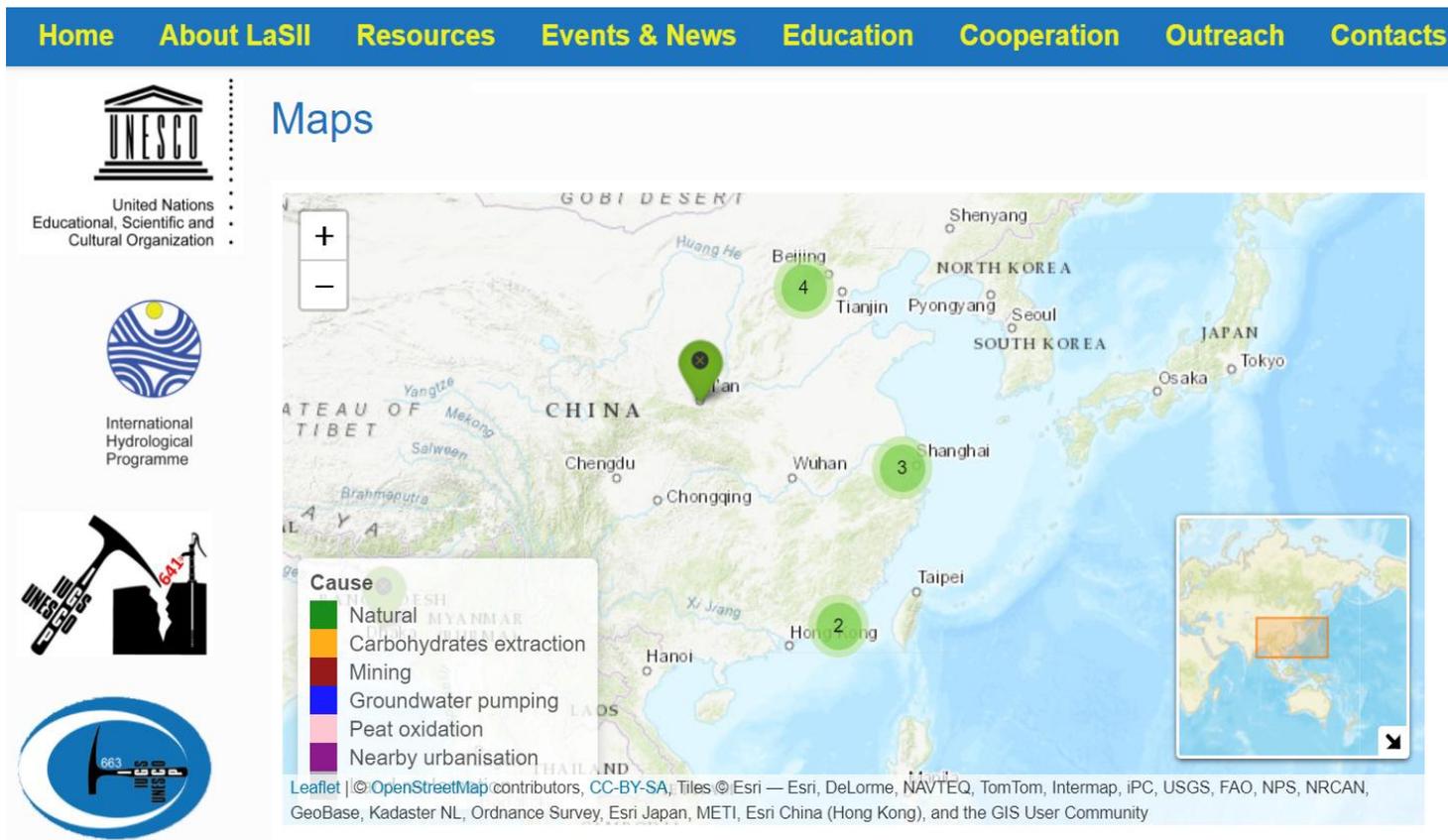


## 2.1 主要科技进展 General Scientific Achievements



### 2.1.1 全球地面沉降成因机理研究 Land Subsidence Mechanism

- ◆ 诱发因素：自然因素、抽取地下水、泥炭氧化作用、碳水化合物提取、采矿、城市化、土地改良等六大类。
- ◆ 地图+文献库：实现典型地区地面沉降发育状况及相关研究成果的查询与分析。



全球地面沉降发育与成因交互式地图  
(UNESCO LaSII、IGCP663、IGCP641)

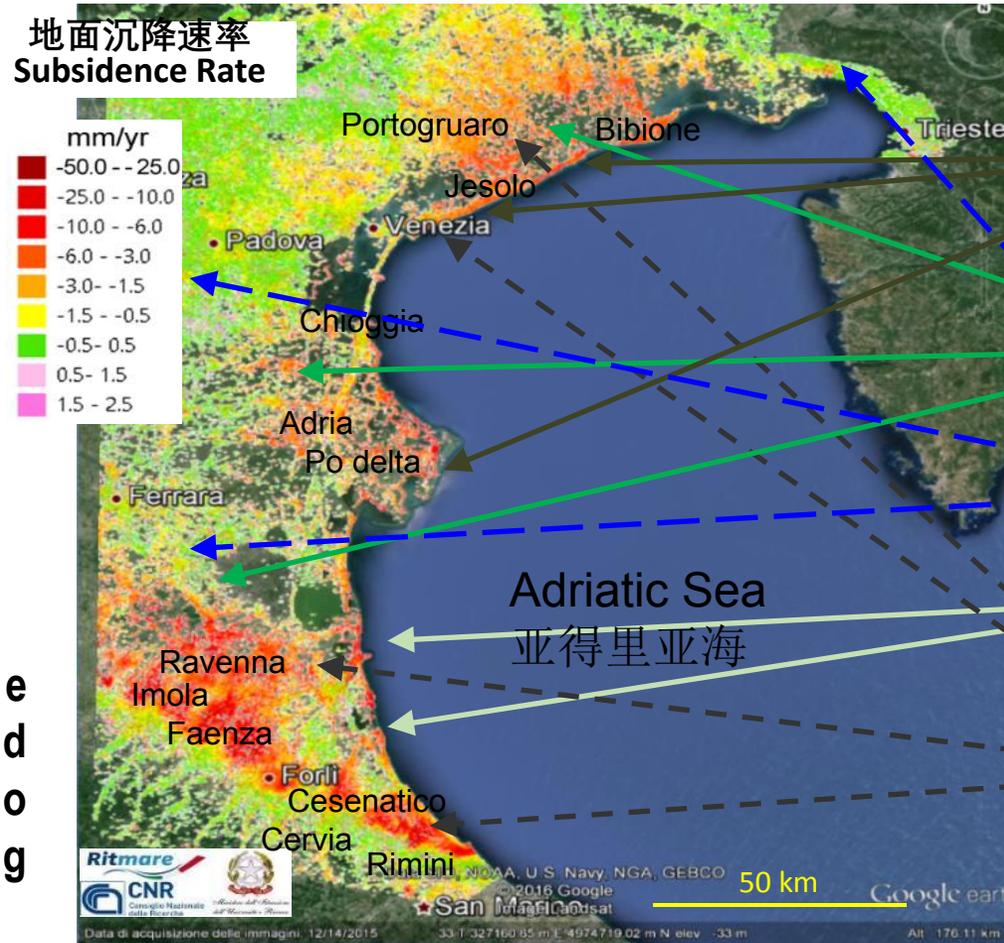




## 意大利亚得里亚海沿岸 Adriatic Sea Coast, Italy (Accomplished by Italian Team)

- 地下流体的开采、水力吹填和城市化发展等因素叠加引发的地面沉降远远超过了自然沉积固结过程

The extractions of subsurface fluids, hydraulic reclamations and urbanization growth superpose to the natural processes in driving subsidence.



## 沉降诱因 Causes

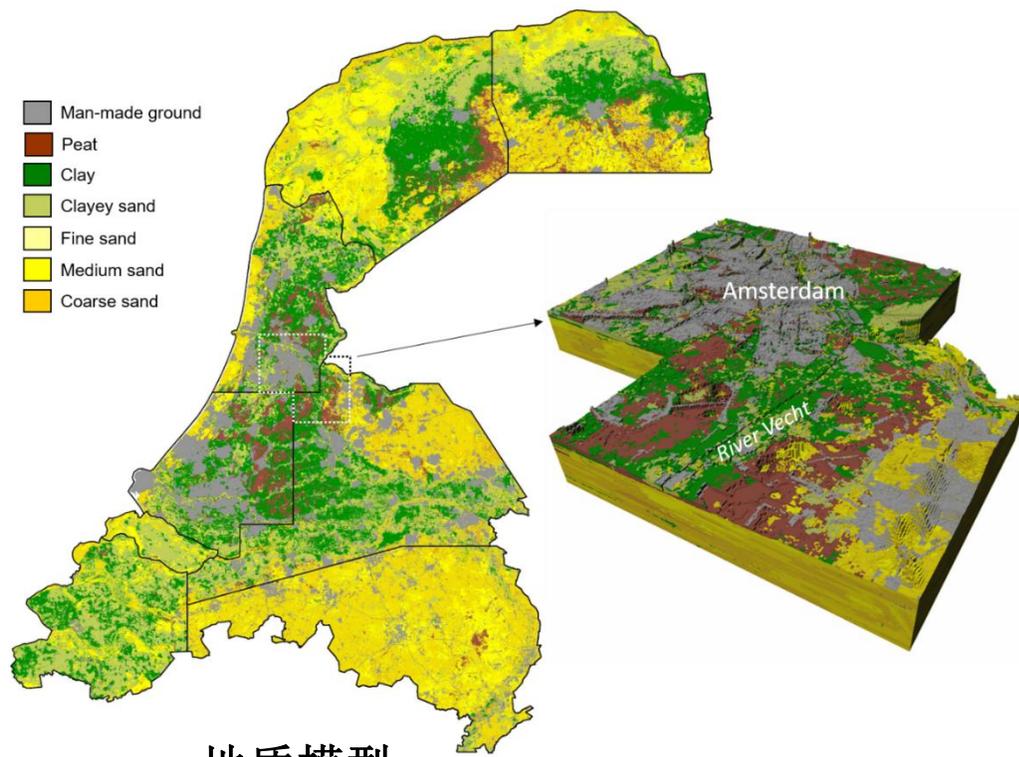
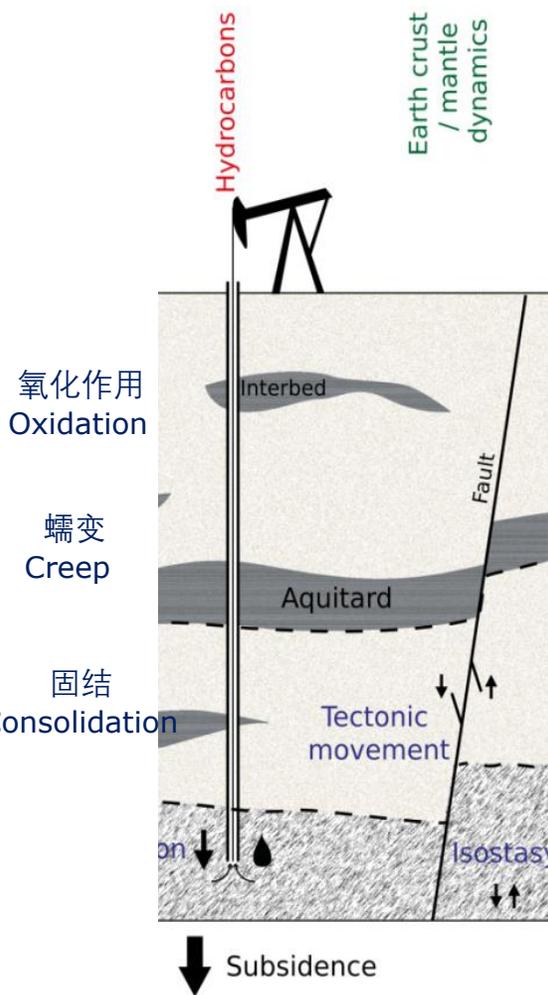
- 自然沉积固结沉降  
residual natural consolidation
- 再生泥炭土的氧化  
oxidation of reclaimed peatlands
- 构造运动  
tectonics
- 深部油气的开发  
development of deep gas reservoirs
- 地下水开采  
groundwater withdrawal





## 荷兰泥炭土地区 Subsidence studies based on GeoTOP (Accomplished by Dutch Team)

- 荷兰沿海地区广泛分布欠固结泥炭土，其氧化作用不仅会产生大量的温室气体，还会导致持续的、大范围的地面沉降
- 通过高分辨率的InSAR数据区分和量化不同诱因的地面沉降过程。
  - Focus on forecasting shallow subsidence processes
  - Primarily related to oxidation, compaction of peat and the shrinkage of clay



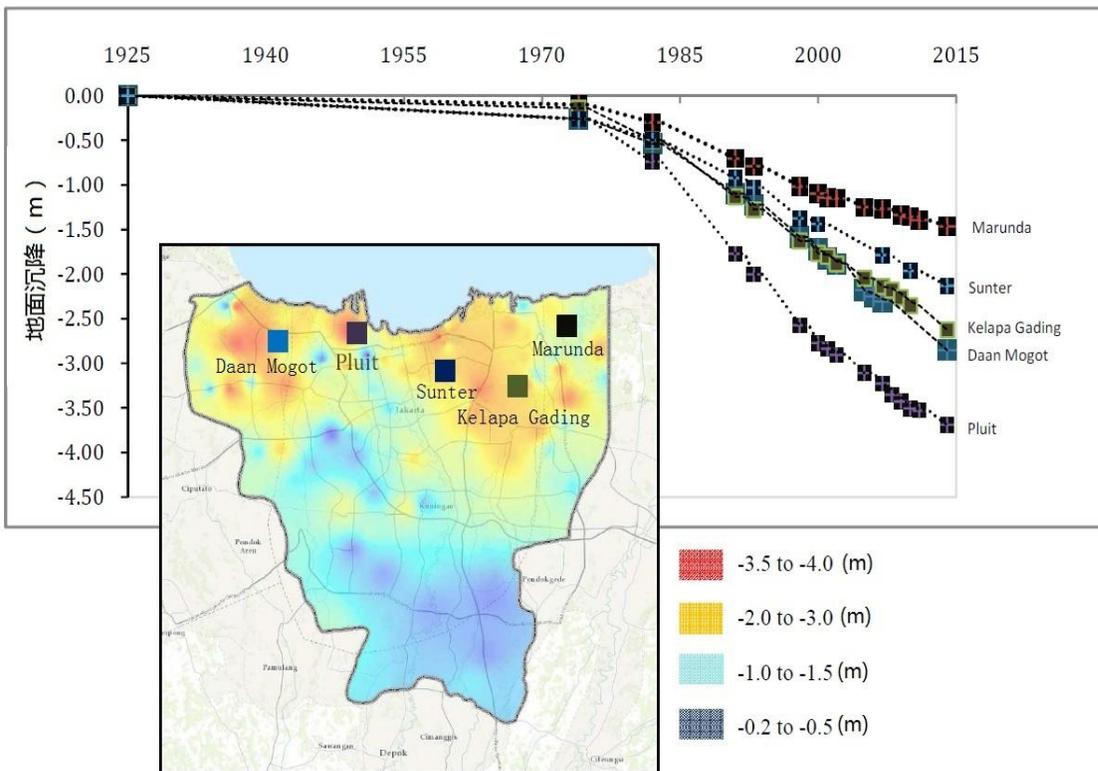
地质模型  
3D geological subsurface model



# ■ 地面沉降成因机理 Land Subsidence Mechanism



## 印度尼西亚雅加达 Jakarta City, Indonesia (Accomplished by Indonesian Team)



- 雅加达的地面沉降受构造活动影响有限，过度的地下水开采是导致当地地面沉降的主要因素之一
- 通过不断完善海堤工程来避免洪水泛滥、河道和排水系统的失效、海水倒灌等灾害
- **Groundwater overexploitation is the main causes derived subsidence in most regions of Indonesia.**
- **Dykes are establishing in order to protect the land from tidal inundation, sea level rise and LS.**

### 1925年到2015年雅加达典型地区地面沉降

Less value of LS occurred around Jakarta area for period 1925-1975. Significant LS started since 1975 up to now with mostly showing linier trend.



## 2.1.2 长江三角洲与红河三角洲地面沉降对比研究



□地面沉降危害在低海拔沿海地区尤为严重，如中国长江三角洲、越南红河三角洲等。

Land subsidence is particularly serious in low altitude coastal areas, such as the Yangtze River Delta, the Red River Delta and so on.

□长江三角洲与红河三角洲在三角洲形成、地貌类型、地质条件、地下水开发利用、经济社会发展、地面沉降诱因等方面都有相似性，开展对比研究很有意义。

The Yangtze River Delta and the Red River Delta are similar in delta formation, geomorphic types, geological conditions, groundwater utilization, economic and social development, land subsidence incentives and so on. It is very meaningful to carry out comparative study between the two deltas.



研究区域 Study area





## ■ 开展了多要素对比分析 Comparative analysis of multiple factors

一级要素Primary elements	二级要素Secondary elements	三级要素Three level elements	
地面沉降发育状况 Development of land subsidence	发育历史Development history	历程Development process	
	现状Current situation	现状特征Current situation and characteristics	
	危害hazard	现象Land subsidence phenomenon	
地质背景 Geological background	地形地貌Topographic features	高程特征Elevation features	
	第四纪地质Quaternary Geology	气象与水文特征Meteorological and hydrological characteristics	
	水文地质Hydrogeology	第四纪地层厚度Quaternary stratum thickness	第四纪地层厚度Quaternary stratum thickness
		水文地质结构Hydrogeological structure	水文地质结构Hydrogeological structure
	工程地质Engineering geology	地下水基本特征Characteristics of groundwater	物理力学性质Physical and mechanical properties
诱发因素 Causing factors	地下水利用Groundwater utilization	软土层厚度Thickness of soft soil layer	
		采灌特征Mining and irrigation characteristics	
	工程建设活动Construction activities	地下水位动态特征Dynamic characteristics of groundwater level	工程建设活动特征Characteristics
地面沉降调查监测 Land subsidence survey and monitoring	地面沉降调查Survey	调查内容Investigation content	
		调查技术方法Investigation techniques	
		调查成果Survey results	
	地面沉降监测Monitoring	监测技术方法Monitoring technology	
		监测网络Monitoring network	
		监测成果Monitoring results	



# Main causing factors

## ■ 研究提出了红河三角洲地面沉降主要诱发因素

### ➤ 地下水开发利用现状

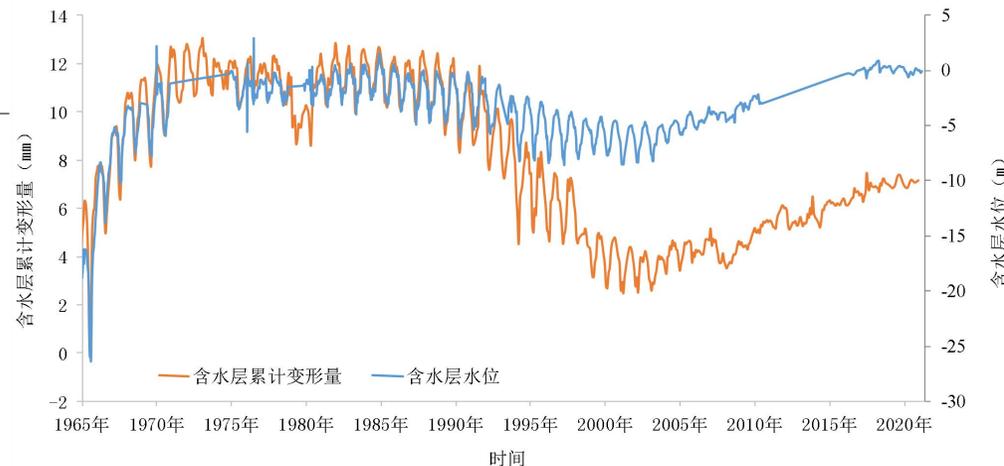
### Groundwater development and utilization

- **上海:** 地下水年度开采量已经小于100万吨, 对地面沉降的影响逐渐减小

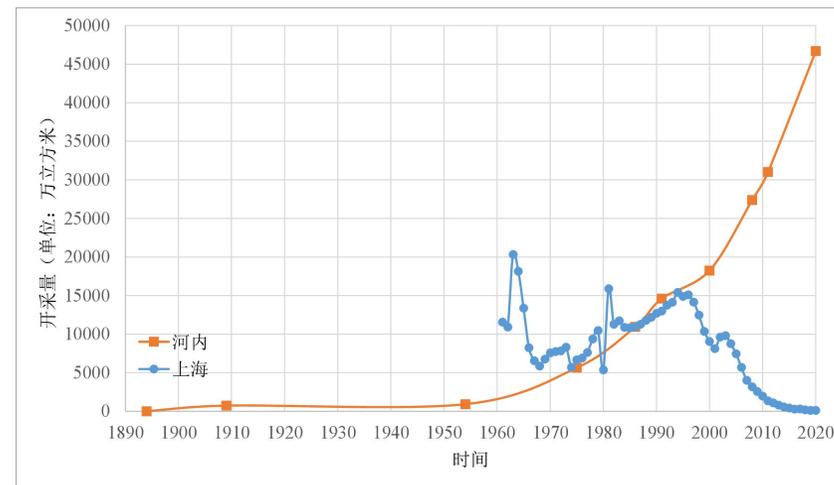
Shanghai: the annual exploitation of groundwater has been less than 1 million tons, and the impact on land subsidence is decreasing

- **河内:** 地下水开采量仍在不断增加, 年度开采量已经超过3亿吨

Hanoi: the exploitation of groundwater is still increasing, and the annual exploitation has exceeded 300 million tons, which is still the main inducement



上海某承压含水层土层累计变形量与地下水水位历时曲线  
Duration curve of cumulative deformation and groundwater level of a confined aquifer in Shanghai

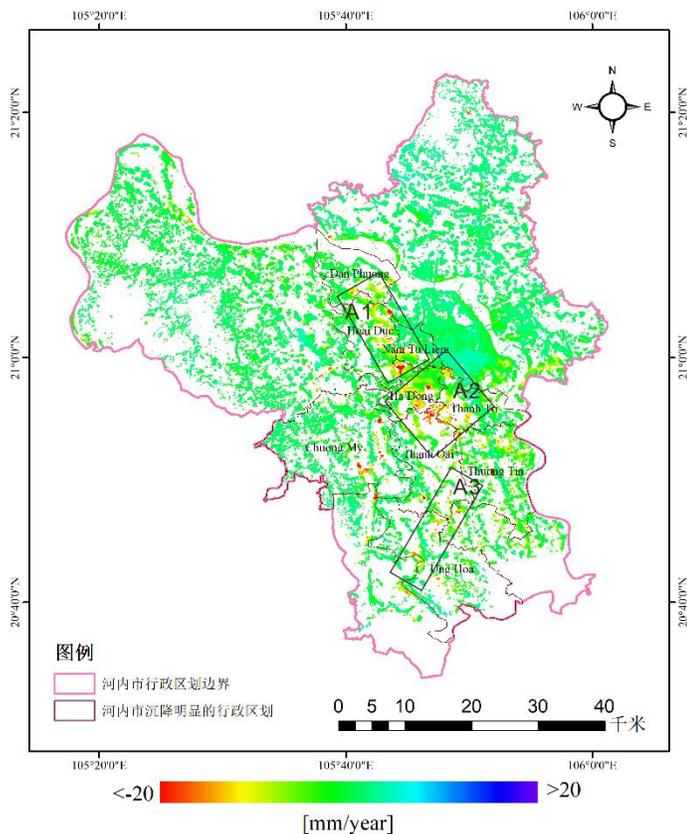


上海与河内年度地下水开采量对比曲线  
Annual groundwater exploitation between Shanghai and Hanoi ( Giao PH etc , 2018 )

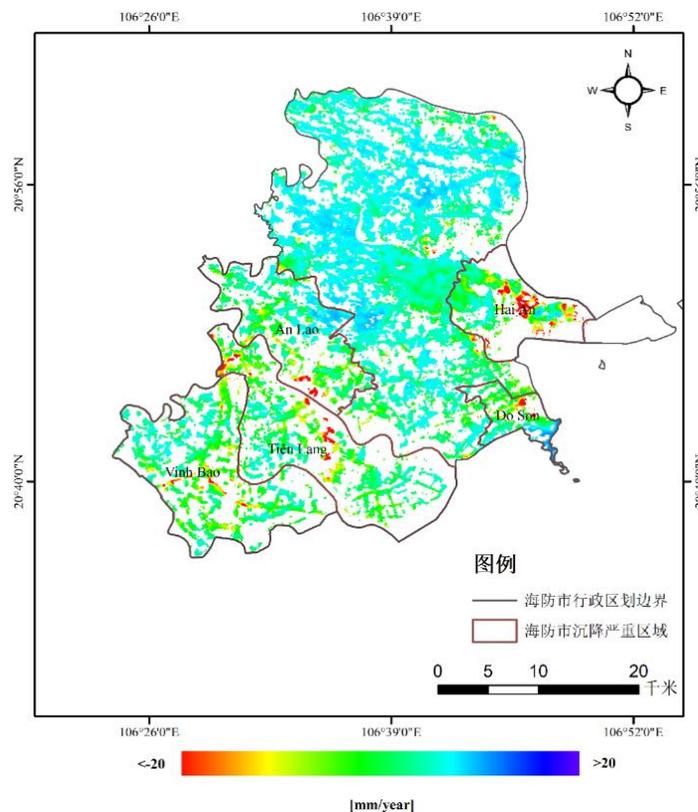




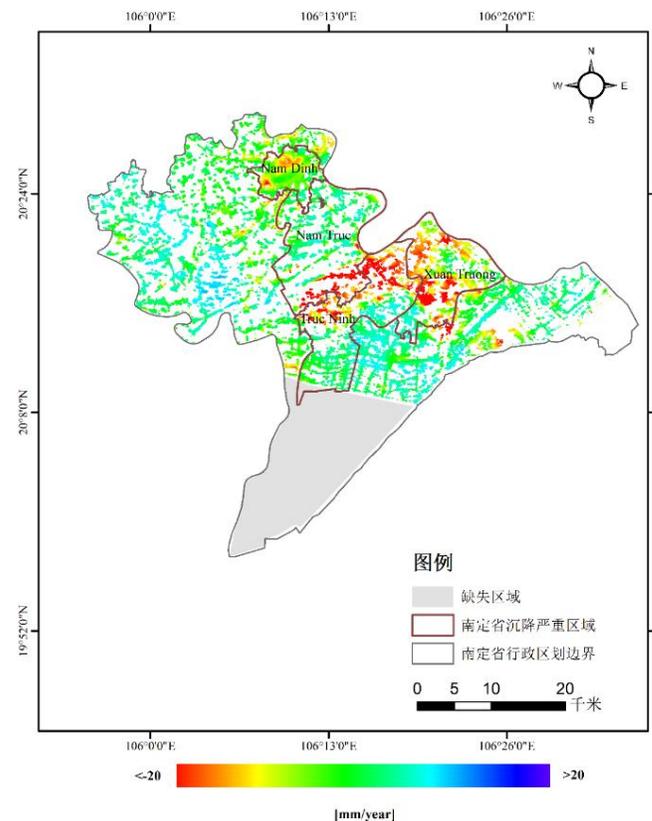
## 研究揭示了红河三角洲地面沉降空间分布特征



越南河内市年均形变速率图 (2017.3-2022.9)  
Annual deformation rate map of Hanoi City



越南海防市年均形变速率图 (2017.3-2022.9)  
Annual deformation rate map of Haiphong City



越南南定省年均形变速率图 (2017.3-2022.9)  
Annual deformation rate map of Nam Dinh Province

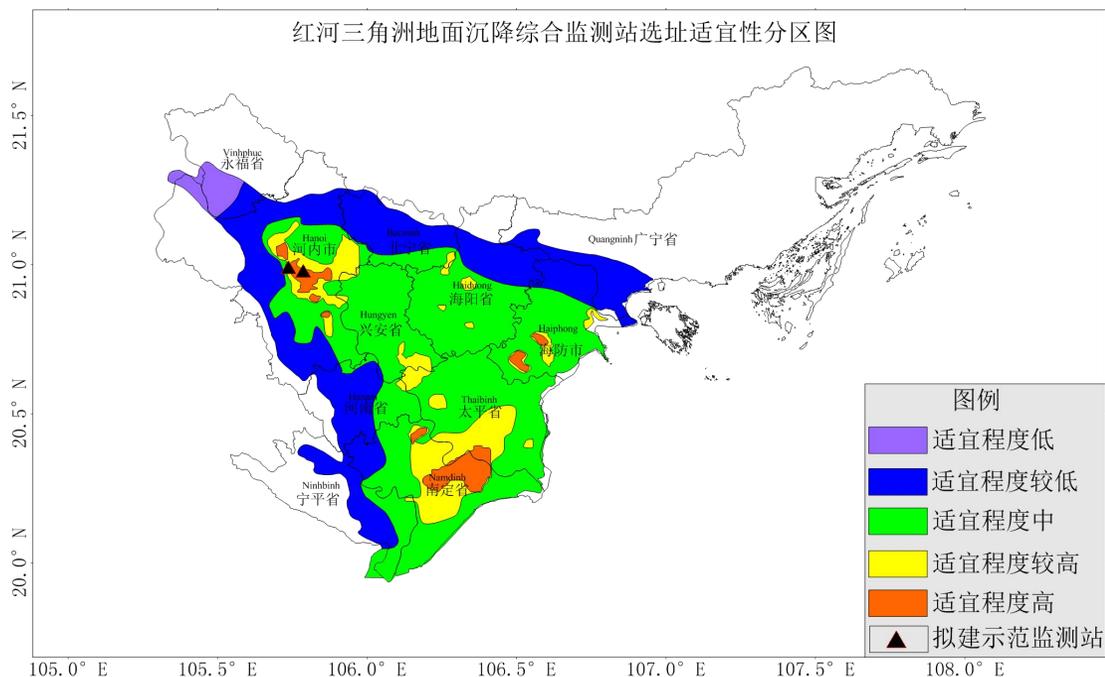




## ■ 为越南示范监测站建设提供了技术支持

Technical support for the construction of monitoring station in Vietnam

### ➤ 选址建议 Location suggestion



越南红河三角洲地面沉降综合监测站选址适宜性分区图  
Zoning map of site suitability of land subsidence monitoring stations in Red river delta, Vietnam

### □ 主要选址原则 Main site selection principles

- 地面沉降发育状况 Land subsidence development state
- 地面沉降易发程度高

High susceptibility of land subsidence

- 地下水大规模开发利用或城市重点建设地区

Large-scale exploitation of groundwater or urban construction

- 地面沉降危害大 High vulnerability of land subsidence

目前指导越方完成了2座示范监测站设计地址

The partner in Vietnam has selected two locations for demonstration monitoring stations.

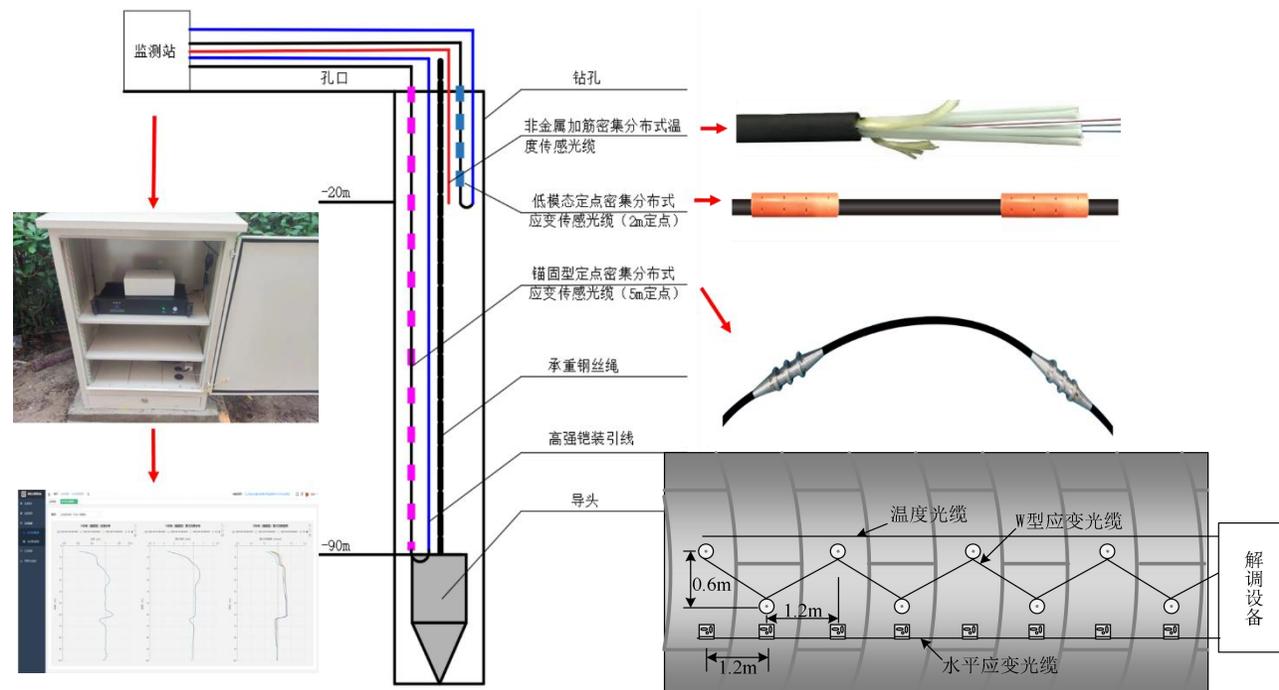


## 2.1.3 韧性城市地面沉降精准监控关键技术与示范



### 研究成果一、研究形成了一套地面沉降智能监测技术方法

- 研发了适用于上海地区的土体分层沉降光纤监测技术体系，在上海长兴岛、金山漕泾等开展了应用试验
- 研制了适用于长距离地铁隧道变形监测的“W”型光纤监测装置，在上海轨道交通10号线、2号线等监测区段进行现场应用试验
- 优化完善了地铁隧道收敛监测的移动三维激光扫描技术方法，为地铁隧道收敛变形监测提供了一种全新高效的解决方案



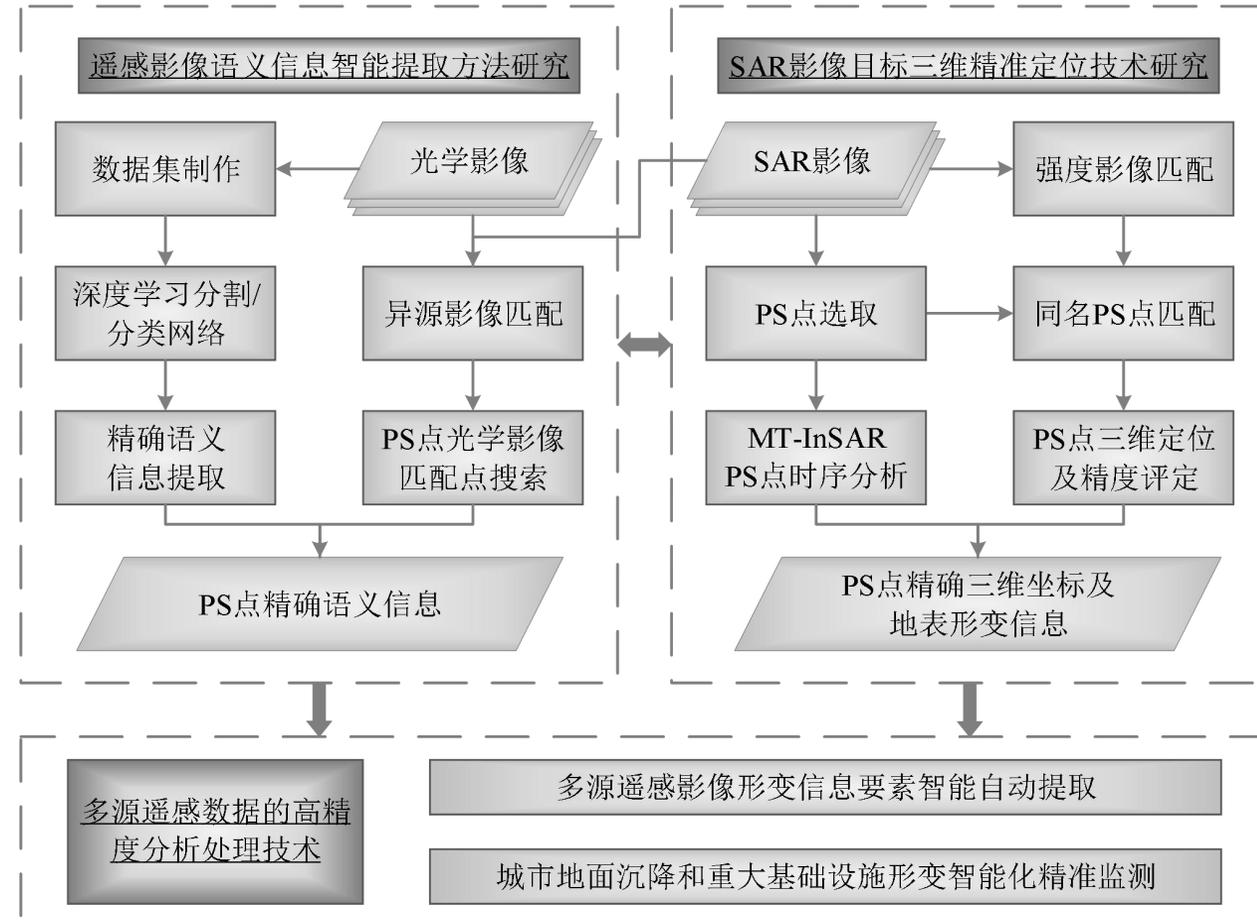
光纤监测光缆布设方案及实物图





## 研究成果二、研究提出了遥感精准监测关键技术方法及理论

- 研究提出并优化了**地面沉降SAR影像目标三维精准定位模型**
- 创新了**适用于大场景的多源异构影像匹配技术**，并且给出了不同国产影像上的应用示例
- 研究了利用光学影像进行定位方法，**实现DSM影像和光学-SAR影像匹配辅助下的PS点三维定位**
- 发展了适用于上海区域的**语义信息提取模型**，PS点的语义信息识别正确率为92.97%
- 针对天绘二号等**国产SAR影像数据**，开发数据转换和分析工具，研究提出适合于国产雷达卫星数据的数据处理技术



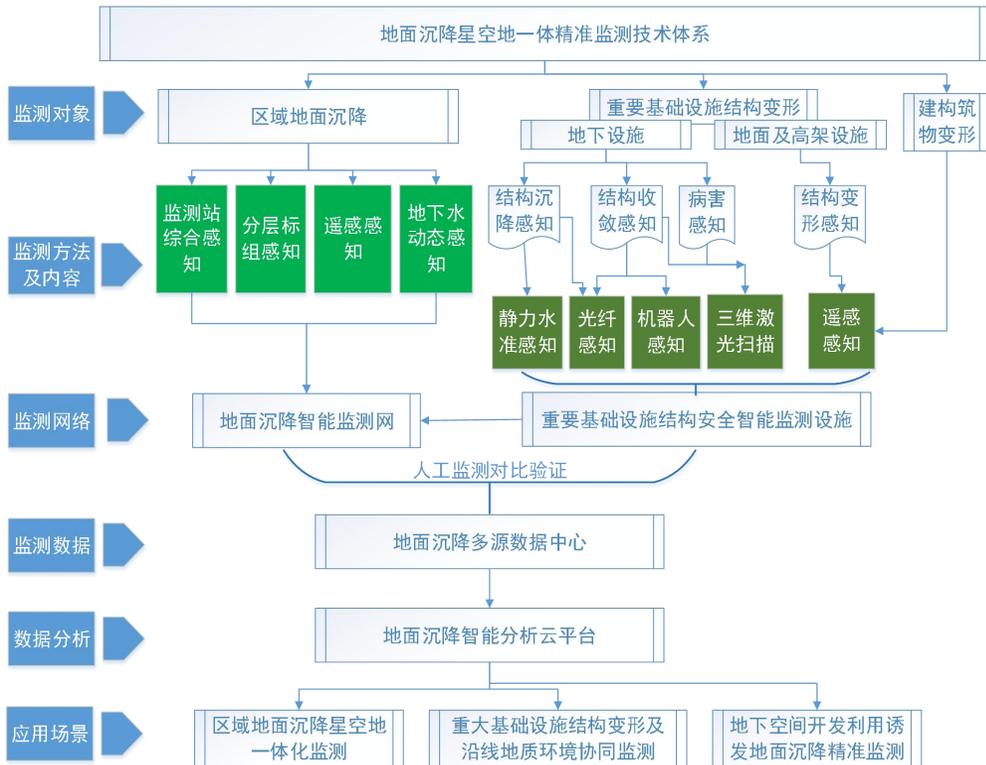
多源遥感数据的高精度分析处理技术路线



# ■ 韧性城市地面沉降精准监控关键技术与示范



## 研究成果三、创新构建了星空地一体精准监测技术体系，并进行应用示范



### 星空地一体精准监测技术体系框架

➤ 研究提出以感知监测技术为主、人工监测验证为辅的地面沉降星空地一体精准监测技术体系框架和实施路径

➤ 构建由基础设施服务层、平台服务层、软件服务层和应用服务层组成的地面沉降智能分析云平台

➤ 在大虹桥等典型地区开展地面沉降精准监测应用示范，系统评价地面沉降智能精准监测技术体系应用成效



## 2.1.4 典型地面沉降区地下水位抬升的地质环境问题及防控对策

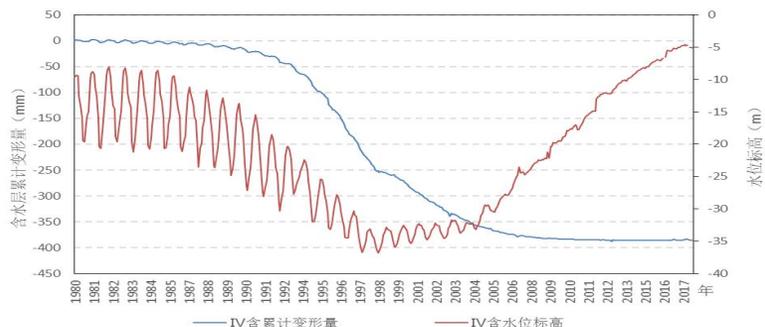


### ● 正面效应

- 地下水资源储量增加，泉水复涌
- 地面沉降减缓或得到有效控制



天下财经  
北京：地下水位六年回升9.36米 81处泉眼复涌



上海四含水水位与土层累计沉降历时曲线

### ● 负面影响

#### 对建（构）筑物影响

- 整体稳定性
- 渗漏水
- 结构上浮
- 结构腐蚀



上海某小区地下室渗漏水现象



上海某应急备用井渗漏水现象

#### 对地质环境影响

- 地基变形
- 地基承载力下降

#### 对生态环境影响

- 诱发土壤盐渍化、地下水污染等问题



# ■ 典型地面沉降区地下水位抬升的地质环境问题及防控对策



## 研究成果一、揭示了地下水位抬升对上海典型地铁隧道影响机制

相关系数 $R^2$ 均接近于1，拟合效果较好。斜率为水位抬升影响率，在**0.12~1.2mm/m**间。根据实测数据拟合得到水位抬升影响率为**0.21mm/m**，在模拟结果区间内。



地层变形速率0点在25~50m，**地层回弹范围不断增大**，水位抬升与地层抬升呈正相关。



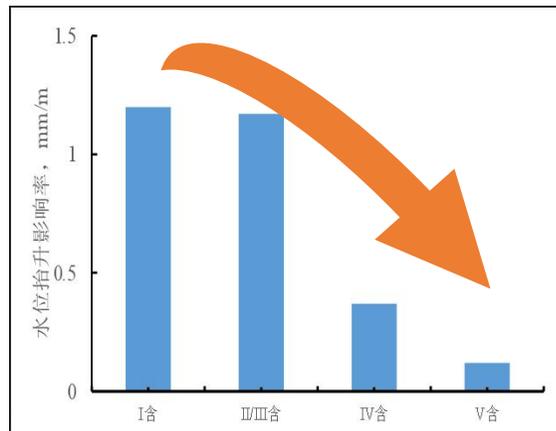
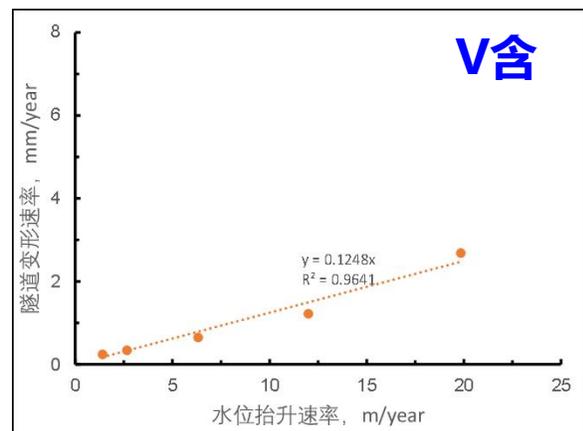
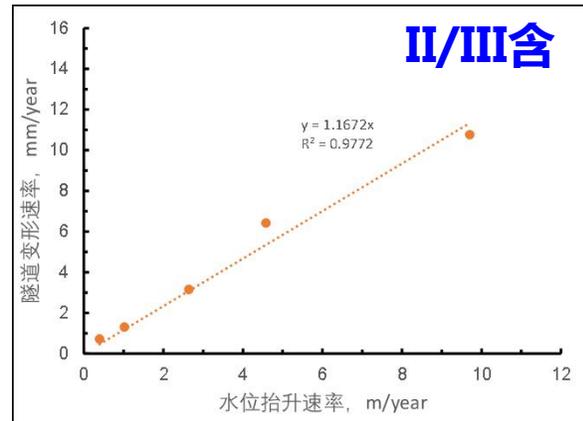
地铁**纵向变形与含水层变化**有一定相关性，车站抬升速率大于区间隧道



单一含水层发生水位持续抬升情况下，随含水层**埋深的增加**，对隧道管片变形和弯矩的**影响显著下降**



多层含水层持续抬升对隧道变形的影响存在较为明显的**耦合效应**。第I含水层和第II/II含水层同时发生水位抬升时将**显著增加**对隧道变形的影响



# ■ 典型地面沉降区地下水位抬升的地质环境问题及防控对策



## 研究成果二、提出了上海地下水位安全控制指标

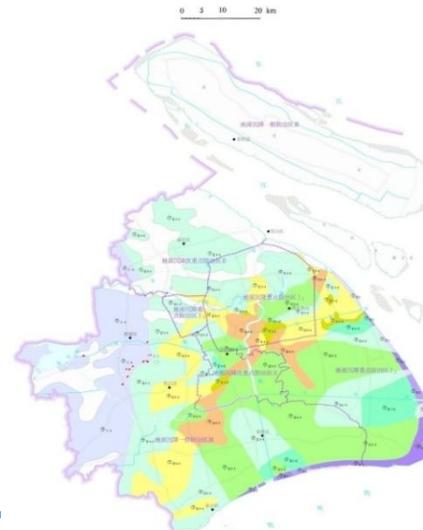
### 深部地下水位控制目标

- 高水位区：历时最高水位或当前高水位
- 低水位区：年变化速率或邻区正常水位

### 浅部地下水位控制目标

- 浅部含水层地下水无集中利用，主要以基坑降水等形式排泄为主，以单个基坑工程控制为主。
- 以**基坑工程安全**与地质环境安全为约束条件，综合确定基坑工程**排水量**和**水位降深**控制要求。
- 对已有建（构）筑物加强地下水位动态长期监测工作，定期开展地下水水位抬升情况下的**安全风险**评估。

区域地面沉降管理分区		二含 (m)		三含(m)	
		非漏斗区	漏斗区	非漏斗区	漏斗区
地面沉降重点防治 (I区)	I <sub>1</sub> 区	-2~-1	-2	-2~-1	-2
	I <sub>2</sub> 区	-2~-1	浦东周浦、新场: -2	-3~-2	/
地面沉降次重点防治区(II区)		-2~-1	嘉定安亭: -2	-3~-2	嘉定安亭: -3
地面沉降一般防治区(III区)		0~1	青浦练塘: -6	0~1	1.青浦白鹤: -6; 2.金山枫泾: -6



地面沉降控制分区	双控分区	分区特征	3H控制点水位降深控制指标 (m)	3H控制点地面沉降控制指标 (mm)
重点防治区 (I)	⑦II <sub>1,1</sub>	正常沉积⑦、⑨不沟通区	2.0	2.5
	⑦II <sub>1,2</sub>			3.0
	⑦II <sub>2,3</sub>	正常沉积⑦、⑨沟通区	1.0	2.0
	⑦II <sub>3,1</sub>	古河道⑦、⑨不沟通区	1.5	2.5
	⑦II <sub>3,2</sub>			3.0
	⑦II <sub>4,3</sub>	古河道⑦、⑨沟通区	0.5	2.5
次重点防治区 (II)	⑦IV <sub>2</sub>	新近成陆区	1.0	3.0
	⑦IV <sub>3</sub>			2.5
	⑦II <sub>1,1</sub>			3.5
一般防治区 (III)	⑦II <sub>1,2</sub>	正常沉积⑦、⑨不沟通区	2.0	4.0
	⑦II <sub>2,3</sub>			3.0
	⑦II <sub>3,1</sub>	古河道⑦、⑨不沟通区	2.0	3.0
	⑦II <sub>3,2</sub>			4.0
	⑦II <sub>4,3</sub>	古河道⑦、⑨沟通区	1.0	3.0
	一般防治区 (III)	⑦II <sub>1,1</sub>	正常沉积⑦、⑨不沟通区	2.0
⑦II <sub>1,2</sub>		4.5		
⑦II <sub>2,3</sub>		正常沉积⑦、⑨沟通区	1.5	3.5
⑦II <sub>3,1</sub>		古河道⑦、⑨不沟通区	1.5	3.5
⑦II <sub>3,2</sub>				3.5
⑦II <sub>4,3</sub>		古河道⑦、⑨沟通区	2.0	3.5
一般防治区 (III)	⑦IV <sub>2</sub>	新近成陆区	2.0	4.5
	⑦IV <sub>3</sub>			3.5
	⑦IV <sub>3</sub>			3.5





## 研究成果三、提出了上海地下水位抬升地质风险防控对策

### 管理措施

- 强化地下水水位长时序监测，进行水位抬升风险**分区管控**
- 建立地质风险**协调联动**管控机制和**应急处置**措施

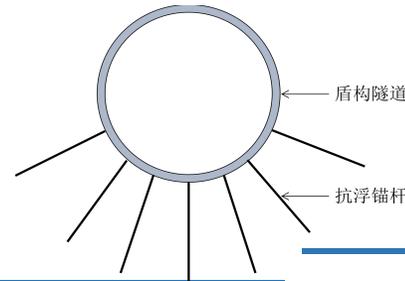
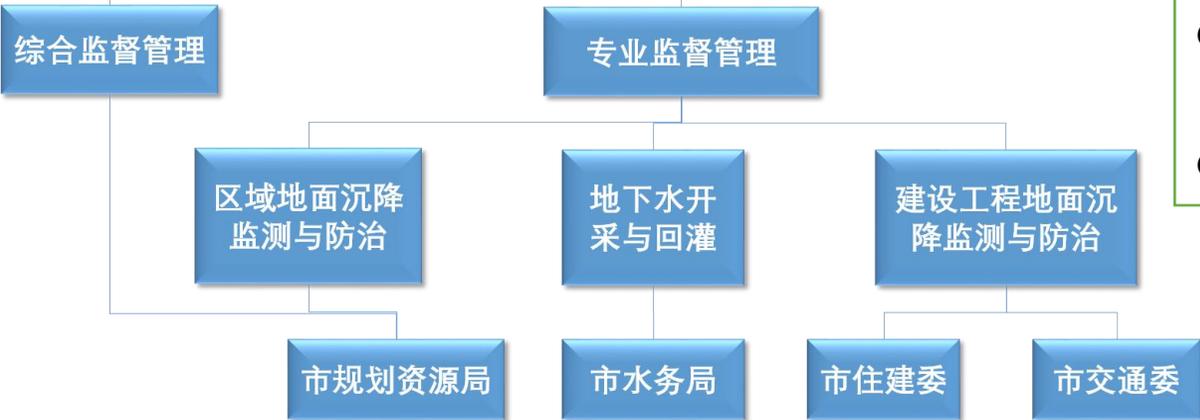
### 技术措施

- 在建工程，重视水文地质补勘，掌握地下水位动态变化趋势，抗浮设计考虑最不利水位，基坑降水**安全水位控制**等。
- 在用建筑，加强地下水位动态长期监测，进行建筑安全性评估，必要时制定地下水位开采控制方案。

### 工程措施

- 抗浮措施：配重、压顶梁、抗拔桩、抗浮锚杆、复合墙、设倒滤层、疏水等
- 防渗措施：注浆、增贴防水层等

“两局两委”机制



## ■ 2.1.5 《地面沉降监测与防治规范》推荐性国家标准研制



□ 成功申报《地面沉降监测与防治规范》推荐性国标，2023年8月获批立项

**主编单位**

**上海市地质调查研究院，中国地质环境监测院**

**华北平原**

北京市地质环境监测所  
天津市地质环境监测总站

**长三角**

江苏省地质调查研究院  
浙江省地质院

**汾渭盆地**

长安大学

**参编  
单位**

**珠三角**

广东省地质局第四地质大队

**水利水务**

水利部水利水电规划设计总院

**自然资源**

中国自然资源航空物探遥感中心

**建设交通**

中国铁路设计集团有限公司





## 拟解决的关键科学问题

### 解决全国地面沉降标准通用性

不同行业、不同地区、不同发展阶段、不同发育特征、不同防治目标等特性



### 适应全国地面沉降风险评估和区划的新要求

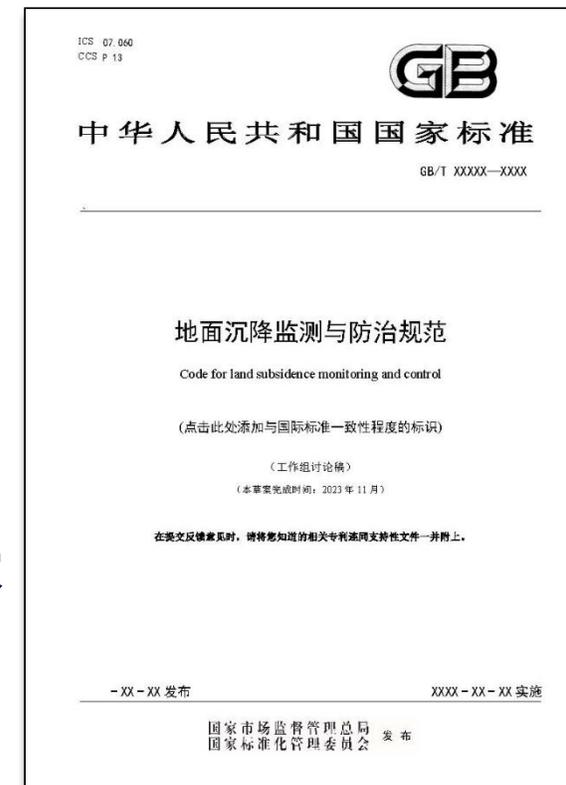
统一易发性、危险性、易损性评价技术要求

### 满足智能监测和信息化技术要求

建立统一的多技术方法融合的地面沉降智能监测技术体系

### 适应不同地区地面沉降防治技术

提出不同地质背景地区开展地面沉降防治的关键技术方法



# 2.2 项目成果 Outcomes

## □ 论文发表

• 项目组累计发表论文**23篇**（标注IGCP663），

其中SCI/EI检索论文**17篇**，包含**3篇**本项目

框架下的国际合作成果综述论文

## □ 其他成果

• 主编专著**2部**

• 主编行业和地方技术标准**6部**

• 获国家专利**4项**，计算机软件著作权**2项**

• 获国土资源科学技术**二等奖1项**，上海市决策咨

询**一等奖1项**，上海市科技进步奖**二等奖1项**



http://igcp.sigs.cn

上海市地质调查研究院  
Shanghai Institute of Geological Survey

### Report

by Xuesen Yan<sup>1,2</sup>, Yan Xu<sup>1,3,4</sup>, Tianliang Yang<sup>1,5,6</sup>, Luigi Tosi<sup>7</sup>, Esther Southamer<sup>8</sup>, Philip Minderhoud<sup>9,10</sup>, Pietro Teatini<sup>11</sup>, Henk Kool<sup>12</sup>, Heri Andreas<sup>13</sup>, Diota Pradipta<sup>14</sup>, Sandra Domicel<sup>15</sup>, and Roberta Boni<sup>16</sup>

### Sustainable development of coastal cities through control of land subsidence: activities of IGCP Project 663 in Jakarta

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https://doi.org/10.18814/igsjgs/2021.02.01014

The awareness on the importance that land subsidence plays on coastal processes at the regional scale is increased over the last two decades, and it clearly appears that land subsidence can contribute primarily to the relative sea level rise affecting coastal zones. Jakarta is one of the cities mostly affected by the combination of sea-level rise and land subsidence. In this paper, the activities carried out in Jakarta make the umbrella of the IGCP Project 663 were presented and the possible measures and best practices mitigating land subsidence for the research associates and potential stakeholders were provided with which can serve as inspiration for authorities and communities facing land subsidence. Meanwhile, major achievements of IGCP 663 in Jakarta were summarized and introduced, including dissemination sessions, scientific sessions and field trips. Specifically, major advances on coastal subsidence studies regarding the effect of relative sea level rise, subsidence mapping, monitoring and simulation, as well as the support of policy making are highlighted and summarized.

#### Introduction

The IGCP Project 663 (Impacts, Mechanisms, Monitoring of Land Subsidence in Coastal Cities) was initiated in 2019.

Vietnam and Pakistan attended the workshop, among which over 90% were from developing countries.

The workshop arranged a roundtable meeting, annual work reports, keynote lectures, and oral poster presentations by young professionals, technical teaching and training, field trips, etc. The Indonesian government held an official ceremony for the release of the "Road map for prevention and control of land subsidence in the coastal littoral of Indonesia". The vice president of the ITCSSCO (ASIA), Pietro Teatini, addressed the conference and gave a keynote lecture.

After the meeting, a field trip was organized in Jakarta, and four sites were seriously affected by land subsidence were investigated.

#### Dissemination Strategy

Low-budget constraints generally restricts a variety of environmental monitoring and assessment activities. However, substantial areas including valuable ecosystems, historical heritage and economic activities, which are severely jeopardized by land subsidence combined with sea-level rise. Within IGCP 663 we developed an analysis of the vulnerability of these environments to relative sea level rise (RSLR) considering an uneven land subsidence distribution that improved the assessment of vulnerability in RSLR at the regional scale. The outcome of the analysis are available to the authorities responsible for water resources and coastal protection (Wang et al., 2012; Tokani and Swoboda 2020; Yan et al., 2020).

Acta Geologica Sinica (English Edition), 2020, 94(1): 162-175

### Advances and Practices on the Research, Prevention and Control of Land Subsidence in Coastal Cities



YAN Xuesen<sup>1,2,4</sup>, YANG Tianliang<sup>1,3,4</sup>, XU Yan<sup>1,2,4</sup>, LUIGI TOSI<sup>5,6</sup>, ESTHER SOUTHAMER<sup>8</sup>, HERI ANDREAS<sup>13</sup>, PHILIP MINDERHOUD<sup>9,10</sup>, ANIRU LADAWADEE<sup>11</sup>, RAMON HANSEN<sup>12</sup>, GILLES ERKENS<sup>13,14</sup>, PIETRO TEATINI<sup>15</sup>, LIN JINXIN<sup>16,17</sup>, ROBERTA BONI<sup>18</sup>, JARINYA CHIMPALAE<sup>19</sup>, HUANG XINLEI<sup>2,3,4</sup>, CRISTINA DA LIO<sup>20</sup>, CLAUDIA MEISINA<sup>11</sup> and FRANCESCO ZUCCA<sup>13</sup>

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<sup>8</sup>Geodesy Research Division, Institute of Technology Bandung, Bandung 40132, Indonesia

<sup>9</sup>Distance Research Institute, Daboulsan 600, 3584 BK Utrecht, The Netherlands

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<sup>11</sup>Delft University of Technology, Faculty of Civil Engineering and Geosciences, Stevinweg 1, 2628 CN, Delft, The Netherlands

<sup>12</sup>Department of Civil, Environmental and Architectural Engineering, University of Padova, Via Mensurlo 9, Padova 35131, Italy

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Abstract: Land subsidence severely threatens most of the coastal plains around the world where high productive industrial and agricultural activities and urban centers are concentrated. Coastal subsidence damages infrastructures and exacerbates the effect of the sea-level rise at regional scale. Although it is a well-known process, there is still much more to be improved on the monitoring, mapping and modeling of ground movements, as well as the understanding of controlling mechanisms. The International Geoscience Programme recently approved an international project (IGCP 663) aiming to bring together worldwide researchers to share expertise on subsidence processes typically occurring in coastal zone and cities, including basic research, monitoring and observation, modelling and management. In this paper, we provide the research community and potential stakeholders with the basic information to join the participating teams in developing this project. Specifically, major advances on coastal subsidence studies and information on well-known and new case studies of land subsidence in China, Italy, The Netherlands, Indonesia, Vietnam and Thailand are highlighted and summarized. Meanwhile, the monitoring, dissemination, annual meeting and field trip are briefly introduced.

Key words: land subsidence, coastal cities, case studies, International Geoscience Programme

Citation: Yan et al., 2020. Advances and Practices on the Research, Prevention and Control of Land Subsidence in Coastal Cities. Acta Geologica Sinica (English Edition), 94(1): 162-175. DOI: 10.1111/1755-6724.14410

#### 1 Introduction

Land subsidence, the lowering of ground surface due to natural and human-induced processes occurring in the shallow and deep subsurface, is a worldwide geohazard. Land subsidence causes damages and has widespread

impacts on a variety of infrastructures, e.g., sewer systems, roads, buildings, subway tunnels and in coastal low-lying areas. In the cities in proximity to shorelines, such as Shanghai, Jakarta and Venice, it is particularly alarming as it reduces the ground elevation with respect to the sea level.

Nowadays the majority of coastal areas affected by land subsidence are characterized by a limited surface elevation

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### Article

by Yan Xu<sup>1,2,4</sup>, Xiaoliang Zhu<sup>1,2,1</sup>, Huan Zhang<sup>1,2,1</sup>, Kaiwen Shi<sup>1,2,1</sup>, Ye He<sup>1,2,1</sup>, Yujin Shi<sup>1,2,1</sup>, and Jianzhong Wu<sup>1,2,1</sup>

### Coupling deformation mechanism of geological stratification and metro tunnel structure in deep Quaternary sedimentary area

<sup>1</sup>Shanghai Institute of Geological Survey, Shanghai 200072, China; <sup>2</sup>Corresponding author: E-mail: yanxs@igs.com.cn; <sup>3</sup>Key Laboratory of Land Subsidence Monitoring and Prevention, Ministry of Natural Resources, Shanghai 200072, China; <sup>4</sup>Shanghai Engineering Research Center of Land Subsidence, Shanghai 200072, China

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The land subsidence characteristics in Shanghai were constantly developing with the change of groundwater level in the process of urban development, and had different effects on the deformation of metro tunnels buried in deep soft soil layers. In this study, the long time series field monitoring data obtained by leveling and stratification extensometer methods was analyzed, and the coupling deformation mechanism of geological stratification and metro tunnel in deep quaternary coastal areas for different periods and accuracy was revealed. The results showed that with the rapid rise of the groundwater level in Shanghai since 2005, the deep sedimentary strata gradually rebound, resulting in the universal rebound of underground metro tunnels. The deformation trends of soil layers and metro tunnel structure were inconsistent with the regional land subsidence due to different factors.

For metro lines built in different periods, the tunnel displacement was basically controlled by the deformation of sedimentary strata below the tunnel structure. The coupling deformation of geological stratification and metro tunnel structure in the deep Quaternary sedimentary area can be described in three conceptual calculation models: inverse settlement model, extension model and contract model. The hysteretic effects when the increase of water volume transformed to the rise of groundwater level and the soil layer deformation driven by rising water level were discussed.

The control of groundwater exploitation and the seawater intrusion in coastal area would lead to the continuous rise of groundwater level, and the resulting geological environment changes and infrastructure security risks have gradually aroused people's high attention. The rise of groundwater level in coastal cities caused damage to the underground structures. For example, the average increase of the critical water head in the central area of Tokyo was about 15 meters since 1970, reaching a maximum of 60 meters, resulting in cracking, water leakage, deformation, corrosion and damage of the existing underground structures (Hagihashi et al., 2009; Xu et al., 2014).

For metro engineering, due to the complex geological and hydrogeological conditions, as well as the strong interaction between structures and strata deformation, the deformation of soft soil layers poses a particularly significant threat to the operation safety of metro tunnel. With the sedimentary environment of deep Quaternary overlying layer in coastal cities, the factors causing long-term settlement and deformation of tunnels are complex and changeable (Li et al., 2019; Xu et al., 2020). Groundwater is one of the important inducing factors of land subsidence, especially regional subsidence, which will inevitably have an impact on underground tunnels. Many researchers have been carried out in theoretical analysis, model test and numerical simulation (Alnoori et al., 2009; Pak et al., 2016). However, it is still very important to obtain and analyze field data as much as possible in order to reflect and reveal the actual deformation mechanism more accurately.

In this study, the long time series field monitoring data obtained by leveling and stratification extensometer methods and the control factors of tunnel longitudinal displacement under the current geological environment conditions were analyzed, and the deformation mechanism

自然资源部地面沉降监测与防治重点实验室  
Key Laboratory of Land Subsidence Monitoring and Prevention, Ministry of Natural Resources

## 2.3 合作交流 Cooperation

### ➤ 2023年6月和8月，IGCP663项目**印尼**合作负责人、万隆理工学院研究员**Heri Andreas**带领团队两度来沪调研地面沉降防治工作

- 围绕地面沉降防治**工作起步**、**机构建立**、**制度建设**及**技术规范**等方面进行了深入交流互动
- 直观了解了地面沉降及城市地质相关工作对上海**城市安全保障**与**高质量发展**的支撑作用
- 详细探讨了有关成果在**印尼推广**及**开展技术合作**的可行性



印尼团队两度来沪调研考察

Indonesia and Chinese teams deepen cooperation in Shanghai



## 2.3 合作交流 Cooperation



### Future Earth Coasts Affiliated Activity

- 与“未来地球海岸”国际计划（Future Earth Coasts, FEC）建立合作关系
  - ✓ 2023年5月向FEC提交合作申请
  - ✓ FEC执委会于2023年7月审议并投票通过，正式建立双方合作关系
  - ✓ 有助于扩大IGCP663项目的朋友圈和影响力，拓展更广泛的国际合作机会
  - ✓ 有助于传播上海地面沉降防治的经验和技術，为世界沿海城市地面沉降防治贡献“中国方案”及“上海模式”

Dear Prof. Yujin Shi and Dr. Qing Zhan,

On behalf of the Executive Committee of Future Earth Coasts (FEC) we are delighted to inform you that "Impact, Mechanism, Monitoring of Land Subsidence in Coastal Cities (IM2LSC)" is now officially affiliated with FEC.

As previously noted during the application process, you are agreeing to include affiliation to FEC as appropriate and/or acknowledge FEC in publications. When acknowledging FEC in your publications please use the following phrase: "This work contributes to Future Earth Coasts, a Global Research Project of Future Earth".

We suggest you to consider the official journal of Future Earth Coasts, *Anthropocene Coasts*, for publication of results. Discounts on publications are available for FEC affiliates; please contact the IPO for details.

Should you wish to use a FEC logo in publications or presentations, please contact us at [fecchina@ecnu.edu.cn](mailto:fecchina@ecnu.edu.cn). The project description you provided with your application will be used on our website and/or newsletter. Affiliated activities may be asked to provide short summaries and/or picture material for reporting and documentation purposes and for non-exclusive use in publications (print, online and/or presentations) by FEC.

You are also agreeing to FEC values. For reference find more on them in our governance provisions.

The affiliation ends with the termination of your activity.

We are keen to promote your activities and results among our community. Please feel free to pass information you wish to distribute to us, and alert us of noteworthy events and results.

Please feel free to contact us if you need any further information, have any questions or need any kind of support from us.

We are looking forward to follow the progress of your project and working with you these coming years.

Sincerely,

Prof. Anja Scheffers  
Executive Director (Capacity and Networks)

Dr. Xiaoyu Fang  
Executive Director (Communication and Engagement)

FEC International Project Office - Australia  
Southern Cross Geoscience,  
Southern Cross University,  
Lismore Campus, NSW, Australia

FEC International Project Office - China  
State Key Laboratory of Estuarine and Coastal Research,  
East China Normal University,  
No.500 Dongchuan Road, Shanghai, China

The International Project Office is jointly hosted by:



## ■ 2.4 项目会议

### □ 历年会议

- **IGCP663项目2018年度工作会议**  
2018.10.30—11.2，上海，中国
- **第五届全国地面沉降防治学术研讨会**  
2018.11.1—11.4，南京，中国
- **UNESCO地面沉降倡议计划年会**  
2018.11.4 — 11.7，上海，中国
- **IGCP663项目2019年度工作会议**  
2019.9.17—9.21，雅加达，印度尼西亚
- **IGCP663项目2022年度工作会议**  
2022.11.10—11.11，上海，中国（online）





## ■ 2.4 项目会议 Project Meetings

### • IGCP663项目2023年度工作会议

• 2023. 4. 22, 代尔夫特, 荷兰

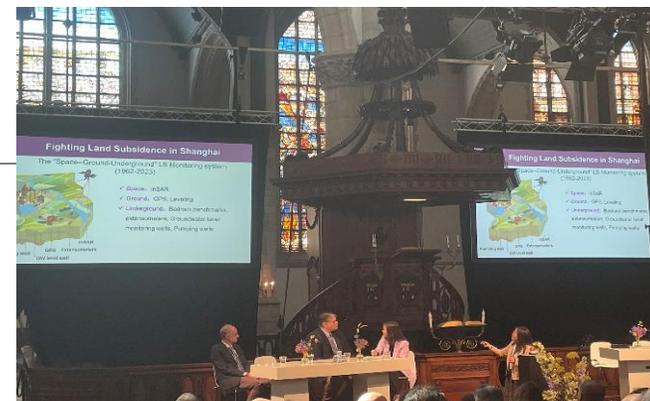
- ✓ 会议交流了IGCP663项目成果, 提出了下一步工作方向与内容, 重点讨论和确定了新一轮IGCP项目团队组建和申报文本编制等事宜
- ✓ 会议期间, 项目组还在Esther教授的带领下现场考察了荷兰典型地面沉降现象及遗迹



2023 Annual Meeting of IGCP Project 663,  
Apr. 22, 2023, Delft, the Netherlands.



## ■ 2.4 项目会议 Project Meetings



### • 协办第十届中国地面沉降研讨会，代尔夫特，荷兰

10th International Symposium on Land Subsidence, Apr. 17-21, 2023, Delft, the Netherlands

- ✓ 本次会议由荷兰代尔夫特理工大学承办，会议主题是“与地面沉降共存”
- ✓ IGCP663项目组深度参与本次会议的组织与筹办工作，受邀并在会议期间作学术报告10余场，展示与交流成果海报20余幅



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上海市地质调查研究院  
Shanghai Institute of Geological Survey

自然资源部地面沉降监测与防治重点实验室  
Key Laboratory of Land Subsidence Monitoring and Prevention, Ministry of Natural Resources

## ■ 2.4 项目会议 Project Meetings



### • 主办第六届全国地面沉降防治学术研讨会，北京，中国

6th National Chinese Symposium on Land Subsidence, Nov. 8-11, 2023, Beijing, China

- 来自**中国、意大利**等国内外**30多所高校**，**30多个企事业单位**的**200多名专家、学者和研究生**代表参加了会议
- 本次研讨会设置**7个专场**，共包括**14个特邀报告**、**49个口头报告**
- 共同探讨我国地面沉降防治的前沿、热点问题及发展方向。



## ■ 2.4 项目会议 Project Meetings



### • 受邀参与第二届大河三角洲国际会议，上海，中国

2nd International Mega-Delta Meeting, Nov. 5-8, 2023, Shanghai, China

- IGCP663项目组作为“未来地球海岸”国际计划合作方受邀参会，并作学术报告交流
- 与来自中国、越南、埃及、荷兰、等17个国家的200余位专家学者汇聚一堂，共议全球20余个河口三角洲的最新研究成果，为三角洲地区的未来发展蓝图建言献策



## ■ 2.5 科普工作 Science Popularization



■ **科技讲座：** 累计线上线下专题讲座**50余场**

- **科学普及：**
- 每年开展地学科普讲座进社区、进校园活动**20余次**
  - 累计为**6000余名**大中小學生和社会公众提供地学科普讲座



2023. 4. 23, “上海科普高端论坛”



2023年科普圆桌论坛  
——跨越冈身 上海古文明与地质环境变迁





## 三、下一步工作计划



# 下一步工作计划



	工作内容
总体计划	· 拟申报新一轮IGCP项目
申报主题	· 聚焦气候条件变化下地面沉降带来的城市安全影响等问题
参与国家	· 中国，意大利，荷兰，印度尼西亚，墨西哥，巴基斯坦，埃及
合作内容	· 技术应用：推进与不发达国家和地区地面沉降监测与防治技术合作 · 平台搭建：持续拓展地面沉降研究国际专家网络 · 科技推广：开展技术教学、科普教育活动





请指正，谢谢！



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