МИНИСТЕРСТВО НАУКИ И ВЫСШЕГО ОБРАЗОВАНИЯ
РОССИЙСКОЙ ФЕДЕРАЦИИ
федеральное государственное бюджетное образовательное учреждение
высшего образования
МОСКОВСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ
ГЕОДЕЗИИ И КАРТОГРАФИИ
(МИИГАиК)

Геодезический факультет
Кафедра лингвистики

ДОКУМЕНТ ПОДПИСАН
ЭЛЕКТРОННОЙ ПОДПИСЬЮ

Сертификат: 5387FD2AF5B17FED816FDE9A1D4973B1
Владелец: Степанченко Алексей Леонидович
Действителен: с 21.07.2025 по 14.10.2026

«УТВЕРЖДАЮ»
Проректор
А. Л. Степанченко
15 мая 2026 г.

ФОНД ОЦЕНОЧНЫХ СРЕДСТВ ПО ДИСЦИПЛИНЕ (МОДУЛЮ) «ФТД.01 ПРОФЕССИОНАЛЬНЫЙ ИНОСТРАННЫЙ ЯЗЫК»

Уровень высшего образования: бакалавриат

Направление подготовки: 21.03.03 Геодезия и дистанционное зондирование

Направленность(профиль) подготовки: Космическая геодезия и навигация

Квалификация (степень) выпускника: бакалавр

Форма обучения: очная

Год набора (приема на обучение): 2026

Срок получения образования: 4 года

Объем: в зачетных единицах: 2 з.е.
в академических часах: 72 ак.ч.

Москва, 2026

Разработчики:
Заведующий кафедрой Лингвистики, доцент Герасимов И. П.

Старший преподаватель кафедры Лингвистики Ацута Е. В.

Старший преподаватель кафедры Лингвистики Трофименко С. А.

Фонд оценочных средств по дисциплине (модулю) составлен в соответствии с требованиями ФГОС ВО по направлению подготовки 21.03.03 Геодезия и дистанционное зондирование, утвержденного приказом Минобрнауки от 12.08.2020 № 972

Согласование и утверждение

№	Подразделение	Ответственное лицо	ФИО	Виза	Дата, протокол (при наличии)
1	Геодезический факультет	Председатель ученого совета факультета	Половнев О. В.	Рассмотрено	28.01.2026, № 14

1. Планируемые результаты обучения, соотнесенные с планируемыми результатами освоения образовательной программы

УК-4 Способен осуществлять деловую коммуникацию в устной и письменной формах на государственном языке Российской Федерации и иностранном(ых) языке(ах)

УК-4.1 Выбирает стиль общения на государственном языке РФ и иностранном языке в зависимости от цели и условий партнерства; адаптирует речь, стиль общения и язык жестов к ситуациям взаимодействия

Знать:

УК-4.1/Зн1 Лексический минимум в объеме 2000 учебных лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников

Уметь:

УК-4.1/Ум1 Выполнять переводы технических текстов с иностранного языка

Владеть:

УК-4.1/Нв1 Навыками чтения, аудирования, разговорной речи, письмо в профессиональной области

УК-4.2 Выполняет перевод профессиональных текстов с иностранного языка на государственный язык РФ и с государственного языка РФ на иностранный

Знать:

УК-4.2/Зн1 Основные способы работы на языковым и речевым материалом

Уметь:

УК-4.2/Ум1 Выполнять перевод технических текстов с иностранного языка

Владеть:

УК-4.2/Нв1 Приемами самостоятельной работы с языковым материалом с использованием справочной и учебной литературы

УК-4.3 Ведет деловую коммуникацию в письменной и электронной форме, учитывая особенности стилистики официальных и неофициальных писем, социокультурные различия в формате корреспонденции на государственном и иностранном (-ых) языках

Знать:

УК-4.3/Зн1 Нормы произношения, лексику иностранного языка общеупотребительного, терминологического и профессионального содержания; типовые способы построения высказываний в устной и письменной речи

Уметь:

УК-4.3/Ум1 Осуществляет коммуникацию с зарубежными партнерами; переводит научно-техническую литературу, связанную с профессиональной деятельностью

Владеть:

УК-4.3/Нв1 Стратегиями проведения сопоставительного анализа факторов культуры различных стран

УК-4.4 Представляет свою точку зрения при деловом общении и в публичных выступлениях

Знать:

УК-4.4/Зн1 Лексический минимум в объеме 2000 лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников

Уметь:

УК-4.4/Ум1 Осуществлять коммуникацию с зарубежными партнерами; переводить научно-техническую литературу по вопросами, связанным с профессиональной деятельностью

Владеть:

УК-4.4/Нв1 Компенсаторными умениями, помогающими преодолеть "сбои" в коммуникации, вызванные объективными и субъективными, социокультурными причинами

2. Показатели и критерии оценивания компетенций

Планируемые результаты освоения программы	Уровень овладения	Критерии оценивания (перечень сформированных ИДК/ЗУВ по уровням освоения)
УК-4 Способен осуществлять деловую коммуникацию в устной и письменной формах на государственном языке Российской Федерации и иностранном(ых) языке(ах)	Повышенный	ИДК УК-4.1 Выбирает стиль общения на государственном языке РФ и иностранном языке в зависимости от цели и условий партнерства; адаптирует речь, стиль общения и язык жестов к ситуациям взаимодействия Знать: УК-4.1/Зн1 Лексический минимум в объеме 2000 учебных лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников Уметь: УК-4.1/Ум1 Выполнять переводы технических текстов с иностранного языка Владеть: УК-4.1/Нв1 Навыками чтения, аудирования, разговорной речи, письмо в профессиональной области ИДК УК-4.2 Выполняет перевод профессиональных текстов с иностранного языка на государственный язык РФ и с государственного языка РФ на иностранный Знать: УК-4.2/Зн1 Основные способы работы на языковым и речевым материалом Уметь: УК-4.2/Ум1 Выполнять перевод технических текстов с иностранного языка Владеть: УК-4.2/Нв1 Приемами самостоятельной работы с языковым материалом с использованием справочной и учебной литературы

			ИДК УК-4.3 Ведет деловую коммуникацию в письменной и электронной форме, учитывая особенности стилистики официальных и неофициальных писем, социокультурные различия в формате корреспонденции на государственном и иностранном (-ых) языках Знать: УК-4.3/Зн1 Нормы произношения, лексику иностранного языка общеупотребительного, терминологического и профессионального содержания; типовые способы построения высказываний в устной и письменной речи Уметь: УК-4.3/Ум1 Осуществляет коммуникацию с зарубежными партнерами; переводит научно-техническую литературу, связанную с профессиональной деятельностью Владеть: УК-4.3/Нв1 Стратегиями проведения сопоставительного анализа факторов культуры различных стран ИДК УК-4.4 Представляет свою точку зрения при деловом общении и в публичных выступлениях Знать: УК-4.4/Зн1 Лексический минимум в объеме 2000 лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников Уметь: УК-4.4/Ум1 Осуществлять коммуникацию с зарубежными партнерами; переводить научно-техническую литературу по вопросами, связанным с профессиональной деятельностью Владеть: УК-4.4/Нв1 Компенсаторными умениями, помогающими преодолеть "сбои" в коммуникации, вызванные объективными и субъективными, социокультурными причинами

	Базовый	ИДК УК-4.1 Выбирает стиль общения на государственном языке РФ и иностранном языке в зависимости от цели и условий партнерства; адаптирует речь, стиль общения и язык жестов к ситуациям взаимодействия Знать: УК-4.1/Зн1 Лексический минимум в объеме 2000 учебных лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников Уметь: УК-4.1/Ум1 Выполнять переводы технических текстов с иностранного языка ИДК УК-4.2 Выполняет перевод профессиональных текстов с иностранного языка на государственный язык РФ и с государственного языка РФ на иностранный Знать: УК-4.2/Зн1 Основные способы работы на языковым и речевым материалом Уметь: УК-4.2/Ум1 Выполнять перевод технических текстов с иностранного языка ИДК УК-4.3 Ведет деловую коммуникацию в письменной и электронной форме, учитывая особенности стилистики официальных и неофициальных писем, социокультурные различия в формате корреспонденции на государственном и иностранном (-ых) языках Знать: УК-4.3/Зн1 Нормы произношения, лексику иностранного языка общеупотребительного, терминологического и профессионального содержания; типовые способы построения высказываний в устной и письменной речи Уметь: УК-4.3/Ум1 Осуществляет коммуникацию с зарубежными партнерами; переводит научно-техническую литературу, связанную с профессиональной деятельностью

		ИДК УК-4.4 Представляет свою точку зрения при деловом общении и в публичных выступлениях Знать: УК-4.4/Зн1 Лексический минимум в объеме 2000 лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников Уметь: УК-4.4/Ум1 Осуществлять коммуникацию с зарубежными партнерами; переводить научно-техническую литературу по вопросами, связанным с профессиональной деятельностью
	Пороговый	ИДК УК-4.1 Выбирает стиль общения на государственном языке РФ и иностранном языке в зависимости от цели и условий партнерства; адаптирует речь, стиль общения и язык жестов к ситуациям взаимодействия Знать: УК-4.1/Зн1 Лексический минимум в объеме 2000 учебных лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников ИДК УК-4.2 Выполняет перевод профессиональных текстов с иностранного языка на государственный язык РФ и с государственного языка РФ на иностранный Знать: УК-4.2/Зн1 Основные способы работы на языковым и речевым материалом ИДК УК-4.3 Ведет деловую коммуникацию в письменной и электронной форме, учитывая особенности стилистики официальных и неофициальных писем, социокультурные различия в формате корреспонденции на государственном и иностранном (-ых) языках Знать: УК-4.3/Зн1 Нормы произношения, лексику иностранного языка общеупотребительного, терминологического и профессионального содержания; типовые способы построения высказываний в устной и письменной речи

		ИДК УК-4.4 Представляет свою точку зрения при деловом общении и в публичных выступлениях Знать: УК-4.4/Зн1 Лексический минимум в объеме 2000 лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников

3. Шкала оценивания

Оценка	Критерии оценивания (перечень сформированных ИДК/ЗУВ)
Зачтено	УК-4.1 Выбирает стиль общения на государственном языке РФ и иностранном языке в зависимости от цели и условий партнерства; адаптирует речь, стиль общения и язык жестов к ситуациям взаимодействия УК-4.1/Зн1 Лексический минимум в объеме 2000 учебных лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников УК-4.2 Выполняет перевод профессиональных текстов с иностранного языка на государственный язык РФ и с государственного языка РФ на иностранный УК-4.2/Зн1 Основные способы работы на языковым и речевым материалом УК-4.3 Ведет деловую коммуникацию в письменной и электронной форме, учитывая особенности стилистики официальных и неофициальных писем, социокультурные различия в формате корреспонденции на государственном и иностранном (-ых) языках УК-4.3/Зн1 Нормы произношения, лексику иностранного языка общеупотребительного, терминологического и профессионального содержания; типовые способы построения высказываний в устной и письменной речи УК-4.4 Представляет свою точку зрения при деловом общении и в публичных выступлениях УК-4.4/Зн1 Лексический минимум в объеме 2000 лексических единиц общего и терминологического характера, необходимого для возможности получения информации профессионального содержания из зарубежных источников
Не зачтено	Результаты обучения не сформированы на достаточном уровне

4. Контрольные мероприятия по дисциплине

Вид контроля	Форма контроля/Оценочное средство
Текущий контроль	Практическая работа
Промежуточная аттестация	Зачет

№	Наименование раздела	Контролируем	Вид контроля/ используемые оценочные материалы

п/п	Наименование раздела	ые ИДК	Текущий	Промежут. аттестация
1	Профессионально-ориентированный иностранный язык	УК-4.1 УК-4.2 УК-4.3 УК-4.4	Практическая работа	Зачет

5. Порядок проведения промежуточной аттестации

Порядок проведения промежуточной аттестации регламентируется локальными нормативными актами Университета:

- Положением о формах, периодичности, порядке текущего контроля успеваемости и промежуточной аттестации обучающихся по основным образовательным программам высшего образования – программам бакалавриата, программам специалитета, программам магистратуры в федеральном государственном бюджетном образовательном учреждении высшего образования «Московский государственный университет геодезии и картографии», п.6 «Организация и проведение промежуточной аттестации».
- Положением о порядке осуществления образовательного процесса, проведения текущего контроля успеваемости и промежуточной аттестации обучающихся с применением электронного обучения и дистанционных образовательных технологий в федеральном государственном бюджетном образовательном учреждении высшего образования «Московский государственный университет геодезии и картографии», п.8 «Проведение промежуточной аттестации с применением ЭО и ДОТ».

Промежуточная аттестация: Зачет, 7 семестр.

6. Оценочные материалы текущего контроля

Раздел 1. Профессионально-ориентированный иностранный язык

Контролируемые ИДК: УК-4.1 УК-4.2 УК-4.3 УК-4.4

Тема 1.1. Моя специальность: Современное состояние изучаемой науки, технологии.

Форма контроля/оценочное средство: Практическая работа

Вопросы/Задания:

1. Ответьте на вопрос:

What modern tools do surveyors (geodesists) use?

2. Ответьте на вопрос:

Do you know what a drone is? Can it help to make maps?

3. Ответьте на вопрос:

How has the introduction of GPS/GLONASS technologies changed the profession of a surveyor?

4. Ответьте на вопрос:

What is GIS (Geographic Information System), and what are its main applications in modern life?

5. Ответьте на вопрос:

What are some modern instruments and equipment that geodesists use today instead of traditional theodolites?

6. Ответьте на вопрос:

How are drones (UAVs) used in modern geodesy and cartography?

Тема 1.2. Моя специальность: История изучаемой науки и видные ученые

Форма контроля/оценочное средство: Практическая работа

Вопросы/Задания:

1. Ответьте на вопрос:

How did sailors find their way before GPS?

2. Ответьте на вопрос:

What did ancient geographers study?

3. Ответьте на вопрос:

Who is considered to be the "father of geography" in Ancient Greece, and what was his major work?

4. Ответьте на вопрос:

How did people measure distances and create maps before the invention of modern technology?

5. Ответьте на вопрос:

Can you name a famous Russian scientist who made a significant contribution to the development of geodesy or cartography (e.g., in the exploration of Siberia)?

6. Ответьте на вопрос:

What role did the Great Northern Expedition (18th century) play in the mapping of Russia?

7. Оценочные материалы промежуточной аттестации

7 семестр, Зачет

Контролируемые ИДК: УК-4.1 УК-4.2 УК-4.3 УК-4.4

Вопросы/Задания:

1. Translate the text. (1800 printed characters; time – 45 min.)

The History of Space Geodesy and Navigation

The development of space geodesy and navigation is a fascinating journey that spans centuries, evolving from early astronomical observations to today's ultra-precise satellite-based systems. This field has revolutionized our understanding of Earth's shape, gravity, and rotation while enabling global positioning technologies essential for modern life.

Early Foundations: Astronomy and Geodesy

The roots of geodesy—the science of measuring Earth—date back to ancient Greece, where scholars like Eratosthenes (276–194 BCE) estimated Earth's circumference using simple geometry and solar angles. For centuries, geodesy relied on ground-based triangulation, but limitations in accuracy and global coverage persisted.

The 17th and 18th centuries saw advances in astronomy and mathematics, with Isaac Newton's theories on gravity and Earth's oblate shape laying the groundwork for modern geodesy. By the 19th century, precise land surveys and the development of the metric system improved measurements, yet a truly global understanding of Earth's geodynamics remained elusive.

The Space Age Revolution

The launch of Sputnik 1 in 1957 marked the dawn of space geodesy. Scientists discovered they could track the satellite's orbit using radio signals, revealing subtle variations in Earth's gravity. This breakthrough led to the first satellite geodesy missions, such as NASA's Vanguard and Transit programs, which improved geodetic models and introduced early satellite navigation for military and maritime use.

In the 1960s and 70s, new techniques emerged:

- Satellite Laser Ranging (SLR) used precise laser pulses to measure distances to retroreflector-equipped satellites, refining knowledge of Earth's shape and tectonic movements.
- Very Long Baseline Interferometry (VLBI) employed radio telescopes to observe distant quasars, enabling unprecedented tracking of Earth's rotation and crustal motion.
- Doppler Orbitography (DORIS) and other radio-tracking methods enhanced satellite orbit determination.

The Rise of Global Navigation Satellite Systems (GNSS)

The U.S. Global Positioning System (GPS), developed in the 1970s for military use, became fully operational by the 1990s, revolutionizing navigation. Similar systems—Russia's GLONASS, Europe's Galileo, and China's BeiDou—followed, creating a multi-constellation GNSS infrastructure. These systems rely on atomic clocks and precise orbital data to provide real-time positioning anywhere on Earth.

Modern Advances and Future Directions

Today, space geodesy supports diverse applications, from earthquake monitoring to climate research. Missions like GRACE (Gravity Recovery and Climate Experiment) map Earth's gravity variations, while Swarm studies the magnetic field. Future developments include:
- Quantum-based positioning for ultra-secure navigation.
- Enhanced GNSS accuracy with next-gen satellites.
- Space-based geodesy missions to other planets.

From ancient stargazing to millimeter-precision satellite measurements, space geodesy and navigation have transformed our ability to understand and navigate our planet—and beyond.

2. Translate the text. (1800 printed characters; time – 45 min.)

The History of the Global Positioning System (GPS)

The Global Positioning System (GPS) is one of the most transformative technological advancements of the 20th century, revolutionizing navigation, timing, and geospatial science. Its development spans decades, driven by military needs before becoming an indispensable global utility for civilian and scientific applications.

Origins in the Space and Cold War Era

The foundations of GPS trace back to the early days of the Space Age and Cold War competition. In 1957, the launch of Sputnik by the Soviet Union demonstrated that satellites could be tracked from Earth using radio signals. U.S. scientists at Johns Hopkins University observed that the Doppler shift in Sputnik's transmissions could determine its orbit—a principle that later became key to satellite navigation.

By the 1960s, the U.S. Navy developed the Transit system, the first operational satellite navigation network. Transit, operational by 1964, provided positional updates for submarines and ships by measuring Doppler shifts from passing satellites. Though limited in accuracy and requiring long observation times, Transit proved that satellite-based navigation was feasible.

The Birth of GPS: Defense and Innovation

The U.S. Department of Defense recognized the need for a more advanced, real-time positioning system. In 1973, the Navstar GPS program was initiated, combining ideas from earlier projects like Transit and Air Force proposals for a space-based radio navigation system. The new system would rely on a constellation of satellites broadcasting synchronized timing signals, allowing receivers to calculate their position via trilateration.

The first experimental GPS satellite launched in 1978, and by the mid-1980s, the system was being tested for military use. A key breakthrough was the deployment of atomic clocks on satellites, ensuring precise timing—critical for accurate positioning. However, early GPS was reserved primarily for U.S. military applications, with intentional signal degradation (Selective Availability) limiting civilian accuracy.

Civilian Access and Global Expansion

The 1990s marked a turning point for GPS. During the Gulf War (1990–91), military forces relied heavily on early GPS devices, even using civilian-grade receivers due to insufficient military hardware. This demonstrated the system's strategic value and accelerated its development.

In 1995, GPS achieved full operational capability with a complete 24-satellite constellation. Five years later, under President Bill Clinton, the U.S. government discontinued Selective Availability, drastically improving civilian GPS accuracy from ~100 meters to within 10–20 meters. This decision unlocked a wave of innovation, enabling applications in aviation, shipping, agriculture, and everyday consumer navigation.

Modern GPS: Ubiquity and Advancements

Today, GPS is embedded in nearly every aspect of modern life, from smartphone navigation and ride-sharing apps to precision farming and disaster response. The system has also evolved with modernization efforts:
- Newer satellites (GPS III) offer stronger signals and improved resistance to jamming.
- Augmentation systems (WAAS, EGNOS) enhance accuracy for aviation and surveying.
- Integration with other GNSS (Galileo, GLONASS, BeiDou) ensures global reliability.

The Future of GPS

Emerging technologies like quantum navigation, AI-driven signal processing, and low-Earth orbit (LEO) enhancements promise even greater precision. Meanwhile, GPS remains vital for scientific

research, from tracking tectonic shifts to synchronizing global financial networks.
From its military origins to its role as a cornerstone of modern infrastructure, GPS stands as a testament to human ingenuity—a system that reshaped how we navigate, communicate, and understand our world.

3. Translate the text. (1800 printed characters; time – 45 min.)

Global Navigation Satellite Systems (GNSS): The Backbone of Modern Positioning

The development of Global Navigation Satellite Systems (GNSS) represents one of humanity's greatest technological achievements, revolutionizing how we navigate, synchronize time, and observe Earth. These satellite constellations provide precise positioning and timing services globally, enabling applications ranging from everyday smartphone navigation to advanced scientific research.

The Origins of Satellite Navigation

The concept of satellite-based navigation emerged during the early years of the Space Age. Following the launch of Sputnik in 1957, scientists discovered they could track satellites by analyzing radio signal Doppler shifts. This principle led the U.S. Navy to develop the Transit system, the world's first operational satellite navigation network, which became functional in 1964. While revolutionary for its time, Transit had limitations, including intermittent coverage and positioning delays, prompting the need for more advanced systems.

The Rise of GPS and the GNSS Era

The U.S. Department of Defense pioneered the modern GNSS era with the Global Positioning System (GPS), conceived in 1973 to provide continuous, real-time positioning for military operations. The first GPS satellite launched in 1978, and by 1995, the constellation reached full operational capability with 24 satellites. Initially reserved for military use, GPS was made fully available to civilians in 2000 when Selective Availability—a deliberate degradation of public signals—was discontinued. This decision unlocked unprecedented accuracy for civilian applications, catalyzing a global technological revolution.

Recognizing the strategic importance of satellite navigation, other nations developed their own systems. Russia's GLONASS, initiated in the Soviet era, became fully operational in 1995 but faced challenges after the USSR's collapse before being restored in the 2000s. The European Union launched Galileo, a civilian-controlled system offering high-precision services, with initial operations beginning in 2016. Meanwhile, China's BeiDou system evolved from a regional network to a global constellation, achieving worldwide coverage in 2020. These systems, together with regional augmentations like Japan's QZSS and India's NavIC, form today's multi-constellation GNSS infrastructure.

How GNSS Works

GNSS relies on constellations of satellites orbiting Earth, each transmitting precise timing signals. A receiver calculates its position by measuring the time delay of signals from at least four satellites, using trilateration to determine latitude, longitude, altitude, and time. Atomic clocks onboard the satellites ensure nanosecond-level timing accuracy, which is critical for both positioning and synchronization applications.

Atmospheric disturbances, signal obstructions, and orbital errors can affect accuracy, but advanced techniques such as Real-Time Kinematic (RTK) positioning and Differential GNSS (DGNSS) correct these errors, enabling centimeter-level precision for surveying, agriculture, and autonomous vehicles.

Applications and Societal Impact

GNSS has become indispensable across industries. Transportation relies on it for aviation navigation, maritime routing, and autonomous vehicle guidance. Precision agriculture uses GNSS for automated machinery and soil monitoring, while disaster management employs it for earthquake and flood tracking. Telecommunications and financial networks depend on GNSS for time synchronization, ensuring seamless global transactions.

Scientific research also benefits immensely, with GNSS aiding in climate studies, tectonic plate monitoring, and space weather observation. Geodesy missions like the GRACE-FO satellites use GNSS-derived data to measure Earth's gravity field and water distribution, providing insights into climate change.

Challenges and Future Developments

Despite its success, GNSS faces vulnerabilities such as signal jamming, spoofing, and space weather

interference. To address these, next-generation satellites incorporate stronger encryption, anti-jamming features, and backup systems like eLoran for terrestrial navigation resilience.
Future advancements include:
- Multi-frequency and multi-constellation receivers for enhanced accuracy.
- Integration with 5G and IoT networks for seamless positioning in urban environments.
- Quantum-enhanced navigation for ultra-secure, jamming-resistant systems.
- Lunar GNSS concepts to support future Moon missions.

Conclusion

From its military origins to its role as a global utility, GNSS has transformed how humanity interacts with space and time. As technology evolves, these systems will continue to push the boundaries of navigation, science, and connectivity, ensuring their place as a cornerstone of modern civilization.

4. Translate the text. (1800 printed characters; time – 45 min.)

The History of Satellite Laser Ranging: Precision Measurements from Space

The development of Satellite Laser Ranging (SLR) represents a remarkable achievement in space geodesy, enabling millimeter-level measurements of Earth-satellite distances that have revolutionized our understanding of Earth's shape, gravity field, and tectonic movements. This technology has evolved from humble beginnings in the early Space Age to become a cornerstone of modern geodetic research.

The origins of SLR can be traced to the late 1950s, when scientists first began experimenting with laser technology for space applications. The successful launch of Sputnik in 1957 demonstrated the potential of satellite tracking, but traditional radio methods lacked the precision needed for advanced geodetic studies. In 1964, NASA's Goddard Space Flight Center conducted the first successful laser ranging experiment using the Beacon-B satellite, achieving meter-level accuracy - a groundbreaking accomplishment at the time.

The true potential of SLR became apparent in 1965 with the launch of the specially designed GEOS-1 satellite, equipped with retroreflectors for laser ranging. This mission marked the beginning of dedicated SLR satellites and demonstrated the technology's ability to measure distances with decimeter accuracy. Throughout the 1970s, international cooperation expanded SLR capabilities, with stations established worldwide and improvements in laser technology pushing accuracy to the centimeter level.

A major milestone came with the launch of LAGEOS-1 in 1976, a passive satellite covered with retroreflectors specifically designed for laser ranging. This mission, followed by LAGEOS-2 in 1992, provided long-term data sets that enabled precise measurements of tectonic plate motion, Earth rotation variations, and the gravity field. The millimeter-level accuracy achieved by the 1990s transformed SLR into a fundamental tool for defining the International Terrestrial Reference Frame (Международная система наземных координат).

Modern SLR systems continue to push technological boundaries, with applications extending beyond Earth studies. The technique proved crucial for the Gravity Recovery and Climate Experiment (GRACE) missions, providing independent verification of satellite orbits. Lunar Laser Ranging, using retroreflectors placed on the Moon by Apollo missions, has provided unique insights into lunar physics and tests of general relativity.

Today, the International Laser Ranging Service coordinates a global network of stations that support Earth science, satellite navigation, and fundamental physics research. As we look to the future, next-generation SLR systems promise even greater accuracy and data rates, ensuring this technology remains vital for space geodesy and our understanding of Earth's dynamic systems.

5. Translate the text. (1800 printed characters; time – 45 min.)

The History of Very Long Baseline Interferometry: Revolutionizing Astronomical and Geodetic Measurements

The development of Very Long Baseline Interferometry (VLBI) stands as one of the most significant breakthroughs in radio astronomy and space geodesy, enabling unprecedented angular resolution and precision in measuring Earth's orientation and celestial positions. This remarkable technique emerged from the convergence of radio astronomy and precision timing technologies during the mid-20th century, fundamentally transforming our ability to study both the cosmos and our planet.

The foundations of VLBI were laid in the 1950s when radio astronomers first demonstrated interferometry using connected antennas. However, the revolutionary concept of independent recording with atomic clock synchronization emerged in 1967 through separate proposals by Canadian and American researchers. The first successful VLBI observations occurred that same year, when teams in Canada and the United States independently demonstrated the technique's potential by observing distant quasars with separated radio telescopes.

The 1970s witnessed rapid advancements in VLBI technology, driven by improvements in atomic clocks, magnetic tape recording systems, and correlation techniques. NASA's Crustal Dynamics Project in the 1980s marked a turning point, employing VLBI to measure continental drift and Earth rotation parameters with unprecedented accuracy. This period saw the establishment of dedicated geodetic VLBI networks, including the NASA Deep Space Network and international collaborations that expanded the technique's global reach.

VLBI achieved a major milestone in 1989 with the first space-based implementation through Japan's HALCA satellite, demonstrating the feasibility of space VLBI. The technique proved particularly valuable for maintaining celestial and terrestrial reference frames, with the International Celestial Reference Frame (ICRF) being based primarily on VLBI observations of extragalactic radio sources. By the 1990s, VLBI had become an essential tool for monitoring Earth orientation parameters critical for satellite navigation and space exploration.

The 21st century has brought digital revolution to VLBI, with e-VLBI systems enabling real-time data transfer and correlation. Modern VLBI networks like the International VLBI Service for Geodesy and Astrometry continue to refine measurements of Earth's rotation and crustal motion, while astronomical applications probe the most distant reaches of the universe. As we look to the future, next-generation VLBI systems promise even greater sensitivity and resolution, maintaining this remarkable technology's vital role in both Earth sciences and fundamental astronomy.

6. Translate the text. (1800 printed characters; time – 45 min.)

The History of Doppler Orbitography and Radiopositioning (DORIS): Precision Tracking from Space

The development of the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system represents a pivotal advancement in satellite tracking and geodesy, enabling unprecedented precision in orbit determination and Earth observation. Born from the need for accurate satellite navigation and geodetic measurements, DORIS has evolved into a cornerstone of space-based positioning, contributing to global geophysical studies and climate monitoring.

Origins in Doppler Tracking

The foundations of DORIS trace back to the early days of satellite tracking in the 1960s, when scientists first utilized the Doppler effect—the frequency shift of radio signals caused by relative motion—to determine satellite orbits. The U.S. Navy's Transit system, an early satellite navigation network, demonstrated the potential of Doppler-based positioning, inspiring further refinements in tracking accuracy.

By the 1970s, France's Centre National d'Études Spatiales (CNES) recognized the need for a high-precision system to support its Earth observation missions. Traditional radar and optical tracking methods were limited by atmospheric interference and ground station coverage, prompting CNES to develop a new approach: a ground-to-space Doppler system that would provide continuous, global coverage with minimal infrastructure.

Birth of DORIS: A French Innovation

The DORIS system was conceived in the early 1980s as a dual-purpose tool for precise orbit determination (POD) and ground beacon positioning. Unlike GPS, which relies on satellites transmitting to receivers, DORIS inverts the concept: a network of ground beacons emits stable radio signals, which are received by satellites equipped with ultra-stable oscillators (USOs). By analyzing the Doppler shift of these signals, scientists can compute the satellite's orbit with centimeter-level accuracy while simultaneously determining the positions of the ground beacons.

The first DORIS receiver flew aboard SPOT-2, France's Earth observation satellite, launched in 1990. This mission validated the system's capabilities, proving its ability to support high-precision altimetry and geodetic applications. Soon after, DORIS became a critical instrument for oceanography and climate science, particularly with the launch of TOPEX/Poseidon (1992), a joint

U.S.-French mission that revolutionized sea-level monitoring.

Expansion and Scientific Contributions

Throughout the 1990s and 2000s, DORIS expanded into a global geodetic infrastructure, with over 50 beacons deployed worldwide. Its applications grew beyond orbit determination to include:

- Monitoring tectonic plate movements with millimeter-level precision.
- Improving altimetry missions like Jason-1, Jason-2, and Sentinel-6, which rely on DORIS for sea surface height measurements.
- Contributing to the International Terrestrial Reference Frame (ITRF), a cornerstone of global geodesy.

One of DORIS's most remarkable achievements was its role in verifying continental drift and post-glacial rebound, providing empirical data that enhanced our understanding of Earth's dynamic crust.

Modern DORIS and Future Prospects

Today, DORIS remains an essential component of multi-technique geodesy, working alongside GPS, SLR, and VLBI to maintain global reference systems. Modern DORIS receivers, such as those on Sentinel-3 and SWOT (Surface Water and Ocean Topography), feature improved signal processing and lower power consumption, ensuring continued relevance in an era of advancing satellite navigation.

Looking ahead, DORIS is expected to play a key role in next-generation Earth observation missions, including studies of ice sheet dynamics and hydrological cycles. Innovations like onboard autonomous navigation and enhanced frequency standards may further boost its accuracy, solidifying its place in the future of space geodesy.

Conclusion

From its origins in Doppler tracking to its current status as a pillar of precision geodesy, DORIS exemplifies how targeted engineering can yield profound scientific benefits. By enabling unparalleled orbit determination and ground positioning, it has not only advanced satellite missions but also deepened our understanding of Earth's ever-changing surface. As space technology progresses, DORIS will continue to be a vital tool for exploring our planet—and beyond.

7. Translate the text. (1800 printed characters; time – 45 min.)

Precision Navigation: The Pinnacle of Space-Based Positioning

Precision navigation stands as one of the most transformative applications of space-based positioning systems, revolutionizing how humanity traverses and interacts with the physical world. This technological marvel, born from the convergence of orbital mechanics, atomic timekeeping, and advanced signal processing, has evolved from military-grade positioning to become an indispensable civilian utility that permeates nearly every aspect of modern life.

The journey toward precision navigation began in earnest during the Cold War era, when the United States Department of Defense recognized the strategic need for accurate, all-weather positioning. The development of the Global Positioning System (GPS) in the 1970s marked a watershed moment, introducing the concept of using precisely timed signals from orbiting satellites to determine location anywhere on Earth. Early military applications demonstrated positioning accuracy within meters, but the true revolution came when this capability was extended to civilian use.

As satellite constellations expanded and technology advanced, precision navigation systems achieved remarkable improvements in accuracy. The turn of the millennium saw the introduction of differential correction techniques that could compensate for atmospheric distortions and orbital perturbations, pushing positioning precision from meters to centimeters. This leap forward enabled applications that were previously unimaginable, from autonomous farming equipment that can navigate fields with centimeter-level precision to construction machinery that follows digital blueprints with millimeter accuracy.

The aviation industry has been particularly transformed by precision navigation. Modern aircraft rely on space-based augmentation systems like WAAS and EGNOS to perform precision approaches in all weather conditions, dramatically improving safety while reducing reliance on ground-based navigation aids. Similarly, maritime navigation has evolved from celestial wayfinding to automated docking systems guided by real-time satellite positioning, significantly enhancing the safety and efficiency of global shipping.

Perhaps the most profound impact of precision navigation can be seen in the realm of autonomous

systems. Self-driving vehicles, delivery drones, and robotic systems all depend on the seamless integration of GNSS positioning with inertial sensors and machine vision. This technological synergy enables these systems to understand their position in space with extraordinary precision, opening new frontiers in transportation and logistics.

Scientific applications of precision navigation have equally far-reaching implications. Geodesists use these systems to measure tectonic plate movements with millimeter precision, while climate scientists track sea level rise and ice sheet dynamics with unprecedented accuracy. The technology has become so fundamental that it now serves as the backbone for time synchronization in financial networks, telecommunications, and power grids, where microsecond precision is critical for operations.

Looking to the future, precision navigation continues to push boundaries. Emerging technologies like quantum-enhanced positioning and low-Earth orbit augmentation promise to deliver even greater accuracy and reliability. As humanity expands its presence beyond Earth, these same principles are being adapted for lunar and planetary navigation, ensuring that precision wayfinding will remain an essential tool in our exploration of the cosmos.

The story of precision navigation is one of remarkable technological achievement, demonstrating how space-based systems have transformed from specialized military tools into fundamental infrastructure that quietly powers our modern world. Its continued evolution promises to unlock new possibilities in transportation, science, and exploration, reinforcing its status as one of the most impactful applications of space technology.

8. Translate the text. (1800 printed characters; time – 45 min.)

Geodynamic Studies: Unveiling Earth's Hidden Movements Through Space Navigation

The precise measurement capabilities of space navigation systems have revolutionized our understanding of Earth's dynamic processes, transforming geodynamic studies from theoretical models into a data-rich science of planetary motion. By leveraging satellite positioning technologies, scientists can now track the imperceptibly slow but powerful movements that shape our planet's surface with millimeter-level precision, revealing the intricate dance of tectonic plates, the subtle rebound of ancient ice sheets, and the silent deformation preceding earthquakes.

The marriage between space navigation and geodynamics began in earnest during the late 20th century, when the first Global Positioning System (GPS) satellites demonstrated their potential beyond military applications. Early adopters recognized that the same signals enabling ship navigation could detect continental drift when permanent ground stations recorded their positions over years. This realization birthed a new era of tectonic monitoring, with dense GPS networks deployed across fault zones like California's San Andreas and Japan's Pacific coast, capturing in real time the relentless creep of crustal plates moving at fingernail-growth speeds.

Modern multi-constellation GNSS systems, augmented by complementary space geodetic techniques like SLR and VLBI, have created an unprecedented global observatory for planetary dynamics. The International GNSS Service (IGS) now maintains hundreds of continuously operating reference stations that collectively measure how Earth's surface flexes under the weight of melting glaciers, how mantle convection redistributes mass beneath our feet, and how the planet's rotation subtly changes as angular momentum shifts between the solid Earth and its fluid envelopes. These measurements have resolved century-old geological debates, proving for instance that India continues to push into Asia at 5 cm/year, building the Himalayas in slow motion.

Perhaps the most profound contribution has been in earthquake science. Space geodesy revealed that tectonic strain accumulates elastically for decades before being violently released in quakes, allowing researchers to map seismic hazard with newfound precision. The 2011 Tohoku earthquake in Japan demonstrated this power tragically when GPS data showed the seafloor had lurched 60 meters eastward—a measurement that revolutionized tsunami warning systems. Similarly, volcanic observatories now incorporate real-time GNSS measurements to detect magma chamber inflation, sometimes providing early warnings of impending eruptions.

Looking beyond traditional tectonics, space navigation has uncovered surprising geodynamic phenomena. It measures how Earth's surface bounces back after ice age glaciers melted (post-glacial rebound), how groundwater extraction causes land subsidence in megacities, and even how atmospheric pressure deforms the planet's crust daily. These observations feed into fundamental

physics, testing Einstein's theory of general relativity through precise measurements of how Earth's mass distribution affects orbiting satellites.

As we enter the 2020s, next-generation space geodetic systems promise to further illuminate Earth's hidden movements. NASA's upcoming NISAR radar mission will combine InSAR with GPS to track surface deformation globally, while new quantum-based sensors may push measurement precision beyond current limits. These advances will not only deepen our understanding of planetary mechanics but also enhance society's resilience to geohazards—proving that the quiet revolution of space-based geodynamics continues to reshape both our planet's science and our relationship with its restless surface.

9. Translate the text. (1800 printed characters; time – 45 min.)

Climate Change Research: Decoding Earth's Transformations Through Space Geodesy

Space geodesy has emerged as an indispensable tool in climate change research, providing an unparalleled perspective on how human activity and natural processes are reshaping our planet. By harnessing precise measurements from satellite constellations, laser-ranging systems, and radio-interferometry networks, scientists can quantify environmental changes with millimeter accuracy across global scales—from melting ice sheets to shifting ocean currents—transforming abstract climate models into concrete, measurable realities.

The unique capability of space geodetic techniques to track mass redistribution has revolutionized our understanding of the water cycle's role in climate dynamics. Missions like GRACE (Gravity Recovery and Climate Experiment), which flew twin satellites in 2002, demonstrated how subtle changes in Earth's gravity field could reveal groundwater depletion in California's Central Valley, glacial melt in Greenland, and even the drying of the Amazon basin. These observations provided the first direct evidence of how terrestrial water storage responds to climate variability, proving that space geodesy could see what traditional methods missed—the invisible movement of billions of tons of water between continents, oceans, and the atmosphere.

Precision altimetry, another cornerstone of space geodesy, has rewritten our knowledge of sea-level rise. Satellite radar altimeters, calibrated by laser-ranging networks and corrected using GNSS positioning, have compiled a 30-year record showing global mean sea level rising at accelerating rates—from 2.1 mm/year in the 1990s to over 4 mm/year today. Crucially, these measurements distinguish between thermal expansion of warming oceans and water influx from melting land ice, revealing that Greenland alone now contributes nearly 1 mm/year to sea-level rise. Such data have become foundational for the Intergovernmental Panel on Climate Change (IPCC) assessments, turning satellite observations into the gold standard for tracking this existential threat.

The cryosphere's transformation is particularly visible through space geodetic lenses. GNSS receivers planted on ice sheets measure their vertical rebound as weight disappears, while satellite interferometry maps glacier flow speeds changing in response to warming. These techniques uncovered alarming accelerations—Antarctica's Thwaites Glacier doubling its flow rate since 2000, or Swiss Alps glaciers losing 10% of their volume in just five years. Perhaps most strikingly, space geodesy revealed "glacial earthquakes," seismic signals generated as massive icebergs calve into warming seas, a phenomenon unknown before satellite monitoring.

Atmospheric studies also benefit from geodesy's precision. By analyzing signal delays from GNSS satellites, researchers reconstruct tropospheric water vapor content—a key greenhouse gas—while ionospheric disturbances help track solar influences on climate. These measurements feed weather prediction models and monitor stratospheric cooling, an unexpected side effect of CO_2 increase that satellites detected decades before ground stations.

Looking ahead, next-generation space geodetic systems promise even deeper climate insights. NASA-ISRO's NISAR mission will combine radar and GPS to track ecosystem carbon flows, while future gravity missions aim to monitor permafrost thaw and ocean heat uptake. As climate tipping points approach, space geodesy stands as our most objective witness—its unblinking satellites chronicling a changing planet, providing the hard numbers that drive both scientific understanding and global policy responses to humanity's greatest challenge.

10. Translate the text. (1800 printed characters; time – 45 min.)

Satellite Orbit Control: The Precision Art of Space Geodesy

The silent ballet of artificial satellites across Earth's orbital highways represents one of space geodesy's most critical yet least visible achievements. Behind every Earth observation mission, navigation signal, and communication relay lies an intricate framework of orbital control—a discipline where millimeter-level positioning meets celestial mechanics to maintain humanity's vital space infrastructure.

The challenge of satellite orbit control begins with the harsh realities of space physics. Even in the vacuum of orbit, satellites face subtle but relentless perturbations: atmospheric drag at high altitudes, gravitational tugs from the Moon and Sun, radiation pressure from solar photons, and even the faint push of Earth's reflected infrared energy. Left unchecked, these forces would distort orbits, degrade mission performance, and eventually render satellites useless. Space geodesy provides the antidote—an ever-evolving toolkit of measurement and correction techniques that keep satellites exactly where they belong.

Modern orbit control relies on a symphony of geodetic techniques. Laser ranging stations fire ultra-short pulses at retroreflector-equipped satellites, measuring return times to calculate distance with millimeter precision. Doppler tracking systems like DORIS monitor subtle frequency shifts in radio signals to detect orbital deviations. GNSS receivers onboard satellites themselves now enable autonomous orbit determination, comparing signals from multiple navigation constellations to pinpoint their position in real time. These measurements feed into sophisticated orbital models that account for everything from Earth's oblateness to relativistic time dilation effects.

The applications of precise orbit control span across critical space missions. Earth observation satellites like Europe's Sentinel fleet require orbit knowledge better than 2 cm to maintain the exact repeat ground tracks needed for climate monitoring. Gravity field missions like GRACE-FO demand even greater precision, as their twin satellites must sense infinitesimal distance changes caused by mass variations beneath them. Even GNSS constellations—the backbone of global navigation—depend on continuous orbit corrections to ensure their timing signals remain accurate to nanoseconds.

Recent advances are pushing orbit control into new frontiers. AI-driven predictive models now anticipate orbital decay patterns, allowing satellites to optimize fuel use for station-keeping. Ultra-precise drag compensation systems are being tested for future missions, using adjustable surfaces to counter atmospheric effects without propellant. Perhaps most remarkably, quantum-based sensors promise to revolutionize onboard orbit determination, potentially reducing reliance on ground tracking networks.

As humanity's presence in space grows more congested—with megaconstellations numbering tens of thousands of satellites—the role of space geodesy in orbital control becomes ever more vital. The same techniques that maintain science missions now help prevent catastrophic collisions in increasingly crowded orbital highways. From enabling climate science to preserving the space environment, satellite orbit control stands as a testament to how space geodesy's invisible hand guides humanity's orbital endeavors with quiet but indispensable precision.

11. Translate the text. (1800 printed characters; time – 45 min.)

The History of Space Geodesy in the USSR and Russia: From Sputnik to Modern Precision

The development of space geodesy in the USSR and later Russia represents a remarkable scientific journey, marked by groundbreaking achievements that have shaped global understanding of Earth's shape, gravity field, and orbital mechanics. This legacy began with the dawn of the Space Age and continues to influence geodetic science today.

The story starts with the launch of Sputnik-1 in 1957, which unexpectedly became the first geodetic tool of the space era. Soviet scientists quickly realized that by tracking the satellite's radio signals and analyzing its orbital decay, they could derive unprecedented information about Earth's upper atmosphere and gravitational characteristics. This discovery laid the foundation for dedicated geodetic satellites, beginning with Sputnik-2 and Sputnik-3, which carried improved instrumentation for measuring atmospheric density and Earth's oblateness.

In the 1960s, the USSR pioneered satellite laser ranging (SLR) technology, developing ground stations capable of measuring distances to satellites equipped with retroreflectors. The Etalon satellites, launched in 1989 as part of the GLONASS system, became some of the most precise laser-ranging targets ever deployed, contributing significantly to the International Terrestrial

Reference Frame.
The Soviet Doppler satellite navigation system Tsikada, operational by 1979, served as both a maritime positioning tool and a geodetic instrument. Its successor, the GLONASS system, initiated in 1982, revolutionized space geodesy by providing continuous global coverage. Unlike the American GPS, GLONASS's orbital configuration proved particularly valuable for high-latitude geodetic measurements.
Russian scientists made crucial contributions to gravity field studies through specialized satellites like GEO-IK, launched in 1981, which measured Earth's geoid with unprecedented accuracy. The Interkosmos program facilitated international cooperation, with Soviet instruments flying on satellites from socialist bloc countries to collect shared geodetic data.
Post-Soviet Russia maintained this legacy through missions like Resurs-DK, which combined Earth observation with precise positioning, and ongoing GLONASS modernization. Today, Russian geodetic stations form a vital part of global networks like the International Laser Ranging Service, while new projects aim to deploy advanced quantum-based positioning systems.

From Sputnik's first beeps to modern millimeter-precision measurements, Russia's space geodesy tradition has profoundly influenced how humanity understands and navigates our planet—a testament to sustained scientific vision across changing political eras.

12. Translate the text. (1800 printed characters; time – 45 min.)

The Future of Space Geodesy: Precision Without Limits
As humanity stands on the brink of a new era in space exploration and Earth observation, space geodesy is poised for transformative breakthroughs that will redefine our understanding of the planet and beyond. The coming decades promise a revolution in measurement capabilities, driven by quantum technologies, artificial intelligence, and an expanding constellation of advanced satellites that will push the boundaries of precision to unprecedented levels.
One of the most anticipated developments lies in quantum-enhanced geodesy. Atomic interferometers and optical clocks, already demonstrating remarkable stability in laboratories, are being miniaturized for space deployment. These instruments will enable gravity field measurements with orders-of-magnitude improvement in resolution, potentially revealing hidden subsurface water movements or subtle magma shifts preceding volcanic eruptions. Quantum-entangled photon systems could revolutionize satellite laser ranging, allowing centimeter-level precision across lunar distances and enabling the establishment of a unified geodetic framework extending from Earth's core to the Moon's surface.
The proliferation of small satellite constellations will create an always-on geodetic monitoring network. Swarms of CubeSats equipped with advanced GNSS receivers and intersatellite links will form dynamic measurement webs, capturing real-time changes in Earth's gravity field, ionosphere, and crustal deformation with spatial and temporal resolution unimaginable today. These distributed systems will work in concert with next-generation geodetic reference satellites, featuring drag-free propulsion and enhanced retroreflector arrays to serve as ultra-stable fiducial points in space.
Autonomous processing powered by machine learning will transform raw geodetic data into actionable knowledge. Neural networks trained on decades of satellite measurements will predict tectonic stress accumulation, ice sheet instability, and atmospheric perturbations before they become detectable through traditional means. Edge computing on orbit will allow satellites to self-adjust their measurement strategies in response to detected anomalies, creating an intelligent, responsive geodetic infrastructure.
Beyond Earth, space geodesy will expand its reach to lunar and planetary applications. The establishment of a lunar geodetic network, combining landed retroreflectors, orbiting satellites, and lunar GNSS analogs, will support Artemis-era exploration while providing new opportunities to test fundamental physics. Mars geodesy missions will map the Red Planet's time-variable gravity field, tracking seasonal CO_2 cap exchanges and potentially detecting deep aquifer systems.
Perhaps most profoundly, the integration of multi-messenger geodesy will emerge, combining traditional space geodetic techniques with gravitational wave detectors, neutrino observatories, and other next-generation sensors. This holistic approach will provide a four-dimensional portrait of our dynamic planet, from its slowly convecting mantle to its ever-changing surface and atmosphere.
As these technologies mature, space geodesy will transition from being primarily an observational

tool to becoming a predictive science—anticipating earthquakes before they strike, modeling sea level rise decades in advance, and providing the precise navigational framework needed for autonomous vehicles whether on Earth, in orbit, or exploring distant worlds. This future of space geodesy promises not just to measure our changing planet, but to fundamentally enhance our ability to navigate and steward it.

13. Translate the text. (1800 printed characters; time – 45 min.)

GRACE-FO: Mapping Earth's Shifting Mass with Unprecedented Precision

The Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission represents a triumph of precision geodesy, continuing the groundbreaking work of its predecessor to reveal how water, ice, and mass redistribute across our planet. Launched in May 2018 as a joint endeavor between NASA and the German Research Centre for Geosciences (GFZ), this twin-satellite system orbits Earth in tandem, detecting subtle variations in gravity that illuminate the invisible movements shaping our world.

GRACE-FO's innovative measurement approach relies on the constant dance between two identical satellites separated by about 220 kilometers in low Earth orbit. As the lead spacecraft encounters minute changes in gravitational pull caused by underground aquifers, melting glaciers, or shifting ocean currents, the distance to its trailing partner changes by mere microns. A sophisticated microwave ranging system captures these infinitesimal fluctuations—accurate to one-tenth the width of a human hair—while onboard accelerometers account for non-gravitational forces like atmospheric drag.

Building upon the original GRACE mission (2002-2017), the Follow-On mission introduced technological enhancements including an experimental laser ranging interferometer developed by Germany. This instrument, 30 times more precise than the microwave system, demonstrates next-generation capabilities for future gravity missions. The satellites also feature improved battery life and data transmission systems, ensuring continuous monitoring even during eclipses when solar power is unavailable.

The scientific contributions of GRACE-FO have proven invaluable across multiple disciplines. Hydrologists track continental water storage changes with unprecedented clarity, observing drought conditions months before surface effects become visible. Glaciologists quantify ice mass loss from Greenland and Antarctica with enough precision to detect seasonal variations. Oceanographers map deep ocean current changes tied to climate variability, while seismologists study gravity perturbations associated with major earthquakes. Perhaps most crucially, GRACE-FO provides an integrated view of the global water cycle, connecting atmospheric, surface, and subsurface water movements in ways impossible with traditional sensors.

Operating in synergy with other Earth observation systems, GRACE-FO data calibrates altimetry missions measuring sea level rise and informs climate models predicting future freshwater availability. Its monthly gravity maps have become indispensable for understanding how human water extraction, ice sheet collapse, and sea level changes interconnect across the planet.

As GRACE-FO continues its mission, it not only preserves the legacy of gravity monitoring but also paves the way for future missions like NASA's planned GRACE-C. In an era of accelerating environmental change, these satellite sentinels provide the hard numbers behind Earth's transformations—quantifying where mass moves, how fast systems change, and what this means for life on our dynamic planet. The mission stands as a testament to international scientific cooperation and space technology's unique ability to reveal our world's hidden rhythms.

14. Translate the text. (1800 printed characters; time – 45 min.)

The Global Positioning System (GPS): Architecture and Functional Elements

The Global Positioning System represents a sophisticated technological ecosystem comprising three fundamental segments—space, control, and user—each performing specialized functions that collectively enable precise global navigation. This intricate architecture transforms atomic-clock timing signals from orbiting satellites into actionable position data for millions of receivers worldwide.

The space segment forms the celestial foundation of GPS, consisting of a minimum constellation of

24 operational satellites distributed across six orbital planes approximately 20,200 kilometers above Earth. Modern Block III satellites, the system's most advanced iteration, each carry four ultra-precise atomic clocks—two rubidium and two cesium standards—that maintain timing accuracy to within one billionth of a second. These satellites continuously broadcast synchronized navigation signals on multiple frequencies (L1, L2, and L5), with the newer L5 band specifically designed for safety-critical applications like aviation. The inclined orbital configuration ensures at least four satellites remain visible from any point on Earth at all times, a prerequisite for three-dimensional positioning.

On the ground, the control segment operates as the system's nervous system through a global network of monitoring stations and command facilities. The U.S. Space Force maintains sixteen monitoring stations across six continents that passively track all GPS satellite signals. These observations flow to the Master Control Station at Schriever Space Force Base in Colorado, where Kalman filter algorithms process the data to determine precise orbital parameters and clock corrections. The system then uplinks these updates to the satellites through dedicated ground antennas at Kwajalein Atoll, Diego Garcia, Ascension Island, and Cape Canaveral, ensuring navigation message accuracy better than one meter. This segment also handles satellite station-keeping maneuvers and contingency operations during system anomalies.

The user segment encompasses the diverse array of GPS receivers that decode satellite signals to compute position, velocity, and time. Modern receivers employ advanced signal processing techniques like carrier-phase tracking and multi-path mitigation to achieve centimeter-level accuracy in differential mode. Specialized variants support applications ranging from smartphone navigation to precision agriculture, while military receivers utilize the encrypted P(Y)-code for enhanced security and anti-jamming protection. The user equipment's computational core solves the fundamental navigation equations, correcting for relativistic time dilation effects caused by the satellites' orbital velocity and Earth's gravitational field—a testament to Einstein's profound influence on everyday technology.

Augmentation systems form an unofficial fourth layer, with the Wide Area Augmentation System (WAAS) and similar regional networks broadcasting correction signals via geostationary satellites. These systems improve real-time accuracy to less than three meters vertically and one meter horizontally, particularly valuable for aircraft approach navigation.

Together, these interdependent elements create a robust positioning infrastructure that has transcended its original military purpose to become indispensable civilian infrastructure. From synchronizing power grids to enabling autonomous vehicles, GPS's multilayered architecture demonstrates how space-based precision has become woven into the fabric of modern civilization. The system's ongoing modernization—with new anti-jamming capabilities, improved signal integrity, and interoperability with other global navigation satellite systems—ensures its continued relevance in an increasingly navigation-dependent world.

15. Translate the text. (1800 printed characters; time – 45 min.)

Swarm Technology in Space Geodesy: A Constellation Revolution

In the precision-driven world of space geodesy, swarm technology is emerging as a transformative approach that redefines how we measure and monitor Earth's dynamic systems. This paradigm shift moves beyond traditional single-satellite missions to coordinated fleets of small, intelligent spacecraft working in concert—a technological evolution inspired by nature's most efficient collective systems but engineered for millimeter-level accuracy.

The application of swarm principles to geodesy addresses long-standing challenges in temporal and spatial resolution. Where conventional geodetic missions might rely on two carefully controlled satellites like GRACE-FO, next-generation swarm concepts envision dozens to hundreds of compact satellites forming intelligent measurement networks. These distributed systems promise continuous, multi-point gravity field measurements that could capture short-term mass transport phenomena previously invisible to existing systems—from hourly groundwater fluctuations to minute crustal displacements preceding seismic events.

At the heart of geodesy swarms lies a sophisticated interplay of technologies. Each satellite becomes a node in a self-organizing network, equipped with miniaturized atomic clocks, advanced inter-satellite ranging systems, and artificial intelligence for onboard data processing. The swarm maintains optimal formation through autonomous navigation, using a combination of GNSS signals

for Earth-relative positioning and optical or microwave links for precise spacecraft-to-spacecraft measurements. This creates a flexible measurement baseline that can adapt in real-time to observational priorities—tightening formation over regions of geophysical interest or expanding to cover broader areas as needed.

The scientific potential of such systems is profound. A gravimetry swarm could simultaneously monitor ice sheet mass loss, ocean current variations, and aquifer depletion with unprecedented temporal resolution. Atmospheric drag effects, traditionally considered noise in orbit determination, become valuable data sources when analyzed across hundreds of swarm satellites at different altitudes—yielding new insights into thermosphere dynamics. The collective dataset from such a swarm would provide the most detailed portrait ever of Earth's time-variable gravity field and its coupling with climate systems.

Technological enablers for geodesy swarms include breakthroughs in small satellite design, quantum sensing miniaturization, and distributed computing. CubeSats now accommodate cold-atom interferometers capable of precise acceleration measurements, while advances in laser communications allow high-bandwidth data exchange between swarm members. Machine learning algorithms help the collective system distinguish signal from noise across its distributed sensors, effectively creating a "macroscope" that reveals planetary-scale processes through coordinated microscopic measurements.

Implementation challenges remain significant, particularly in maintaining precise formation control without excessive fuel consumption and developing new data fusion techniques for swarm outputs. However, early demonstrations like NASA's Starling mission and ESA's forthcoming gravitational swarm concepts prove the feasibility of distributed space geodesy. As these technologies mature, geodesy swarms may evolve into self-healing, self-calibrating measurement networks that persist for decades—continuously refining our understanding of Earth as a dynamic system while establishing models for future interplanetary geodesy as humanity expands into the solar system.

This swarm paradigm represents more than just a scaling of existing techniques; it constitutes a fundamental reimagining of space geodesy as a collaborative, adaptive, and intelligent measurement enterprise. By harnessing the power of collective sensing, geodesy swarms stand poised to unlock new dimensions of planetary observation, transforming our ability to measure, understand, and ultimately steward Earth's delicate systems.

16. Translate the text. (1800 printed characters; time – 45 min.)

The Crucial Role of Space Geodesy in Earth Monitoring: Guardians of a Changing Planet

Space geodesy has emerged as an indispensable sentinel in our quest to understand and protect Earth’s delicate systems. This advanced scientific discipline, which precisely measures the planet’s shape, orientation, and gravity field from space, provides the fundamental framework for monitoring global change with millimeter-level accuracy. Its silent constellation of satellites and ground stations forms an invisible nervous system that tracks Earth’s pulse across continents and oceans, transforming abstract environmental concerns into quantifiable realities.

At the heart of Earth monitoring, space geodesy offers three unparalleled capabilities: absolute positioning in a global reference frame, detection of mass redistribution, and measurement of surface deformation. These capabilities manifest through networks of GNSS stations that capture tectonic plate movements as continents drift at fingernail-growth speeds, through gravity missions like GRACE-FO that weigh disappearing groundwater reserves and melting ice sheets, and through InSAR satellites that map land subsidence in urban areas down to millimeter precision. Together, these techniques create a multidimensional picture of planetary change unavailable through any other means.

The climate crisis has particularly highlighted space geodesy’s vital contributions. Precise altimetry satellites have chronicled the relentless rise of global sea levels since 1993, distinguishing between thermal expansion and ice melt contributions. Laser-ranging systems track how Earth’s shape fluctuates with seasonal water storage changes, while VLBI networks monitor subtle variations in planetary rotation caused by atmospheric circulation shifts. These measurements provide the hard numbers behind international climate assessments, converting theoretical models into actionable data for policymakers.

Natural hazard monitoring equally depends on geodetic infrastructure. Continuous GNSS networks

now routinely detect the silent buildup of strain along fault lines, offering potential earthquake early warning. Volcanic observatories integrate real-time deformation measurements with other datasets to forecast eruptions, while satellite geodesy revealed the astonishing 15-meter lateral displacement during the 2011 Tohoku earthquake—data that revolutionized tsunami prediction models.

Beyond crisis response, space geodesy quietly underpins modern civilization's infrastructure. It maintains the International Terrestrial Reference Frame that ensures Google Maps directions align with pipeline surveys and construction blueprints. Its timing signals synchronize power grids and financial networks, while its gravity models enable precise missile navigation and satellite operations. The discipline has become so fundamental that the Global Geodetic Observing System was formally recognized as critical infrastructure by the United Nations.

As environmental pressures intensify, space geodesy's role expands further. New satellite constellations promise weekly updates of global water storage changes, while quantum gravity sensors may soon map underground water resources from orbit. The field stands at a crossroads—no longer just a measurement tool but an essential early warning system for planetary-scale changes, providing the objective truth about our transforming world when we need it most. In an era of climate uncertainty and rapid environmental change, space geodesy has become Earth's impartial accountant, tracking every millimeter of change in the planet we call home.

17. Translate the text. (1800 printed characters; time – 45 min.)

The Indispensable Role of Space Geodesy in Maritime and Transport Navigation

In the vast expanse of the world's oceans and the intricate web of global transport networks, space geodesy serves as the silent enabler of safe, efficient, and precise navigation. This advanced scientific discipline, which precisely measures Earth's shape, gravity field, and orientation in space, has revolutionized how ships traverse the seas and how vehicles navigate land and air. By providing centimeter-level positioning and real-time monitoring of Earth's dynamic systems, space geodesy has become the unseen backbone of modern transportation, ensuring safety, optimizing routes, and reducing environmental impacts.

At sea, space geodesy underpins the Global Navigation Satellite Systems (GNSS) that guide vessels through treacherous waters, congested shipping lanes, and narrow straits. Modern maritime navigation relies on the precise positioning offered by GPS, GLONASS, Galileo, and BeiDou—all of which depend on geodetic reference frames maintained by satellite laser ranging (SLR) and very long baseline interferometry (VLBI). These systems correct for Earth's irregularities, such as tidal deformations and polar motion, ensuring that a cargo ship in the Pacific or an oil tanker in the Arctic knows its exact location within meters, even in the absence of visible landmarks.

Beyond basic positioning, space geodesy enhances safety through geodetic monitoring of sea level rise and ocean dynamics. Satellite altimetry missions, calibrated using geodetic techniques, provide real-time data on ocean currents, storm surges, and tidal patterns—critical information for route planning and hazard avoidance. The Gravity Recovery and Climate Experiment (GRACE) and its successors track changes in ocean mass, helping predict rogue waves and unexpected currents that could endanger navigation. Ports and waterways, too, depend on geodetic measurements to monitor subsidence and dredging needs, ensuring that the world's maritime infrastructure remains operational as sea levels climb.

In aviation, space geodesy's contributions are equally transformative. Aircraft rely on GNSS-based approaches, such as the Wide Area Augmentation System (Широкозонная усиливающая система - WAAS) and Ground-Based Augmentation Systems (Наземная система дифференциальной коррекции - GBAS), which use geodetic corrections to achieve the precision required for landing in low visibility. These systems account for ionospheric delays, tectonic shifts, and even the gravitational anomalies that affect inertial navigation systems. Geodetic data also supports the development of Performance-Based Navigation (PBN), allowing aircraft to fly optimized routes that save fuel, reduce emissions, and minimize noise over populated areas.

On land, autonomous vehicles and smart transportation networks leverage high-precision GNSS positioning, tied to geodetic reference frames, to navigate complex urban environments. Differential GNSS (DGPS) and Real-Time Kinematic (RTK) techniques—enabled by geodetic infrastructure—allow self-driving cars, freight trains, and even drones to operate with centimeter-level accuracy. Meanwhile, the International Terrestrial Reference Frame (ITRF) ensures

that mapping data for roads, tunnels, and bridges aligns seamlessly across borders, facilitating international trade and logistics.

As transport systems grow more automated and interconnected, space geodesy's role will only expand. Future advancements, such as quantum-enhanced positioning and low-Earth orbit (LEO) navigation constellations, promise even greater resilience against jamming and spoofing, critical for security in an era of digital dependence. From the deepest oceans to the busiest cities, space geodesy remains the unsung hero of global mobility—an invisible force guiding humanity's journeys with unparalleled precision and reliability.

18. Translate the text. (1800 printed characters; time – 45 min.)

Satellite systems in different countries

Satellite systems such as GPS have revolutionized navigation, positioning, and geospatial data collection across the globe, playing a vital role in space geodesy and numerous practical applications. The Global Positioning System (GPS), developed by the United States, is perhaps the most well-known satellite navigation constellation, consisting of a constellation of at least 24 satellites orbiting the Earth. It provides precise positioning and timing information to users worldwide, underpinning navigation in transportation, agriculture, military operations, and scientific research.

However, GPS is just one component of a broader international landscape of satellite systems. Russia operates the GLONASS system, an equivalent constellation providing global coverage for positioning and navigation. China has developed BeiDou, which has matured into a global navigation satellite system (GNSS) with increasing coverage and accuracy. The European Union has established Galileo, aiming to provide highly accurate positioning services across Europe and beyond. India's regional navigation system NavIC complements these global systems with regional coverage primarily over South Asia.

These satellite systems are integral to space geodesy, a scientific discipline that involves measuring Earth's shape, gravitational field, rotation, and variations over time. By analyzing signals from multiple GNSS satellites, scientists can monitor tectonic plate movements, crustal deformations, and sea level changes with millimeter-level precision. These measurements are essential for understanding Earth's dynamic processes, natural hazard assessment, and climate change studies. For example, continuous GPS networks enable the detection of subtle shifts in Earth's crust, providing early warning signs for earthquakes and volcanic activity.

Furthermore, satellite systems contribute to the precise determination of Earth's orientation and the definition of its reference frames. They support the International Terrestrial Reference Frame (ITRF), an essential coordinate system for geospatial measurements. In space geodesy, techniques like Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) are often combined with GNSS data to achieve high-precision Earth measurements.

Beyond Earth monitoring, these satellite systems facilitate space missions, satellite tracking, and deep-space navigation. They are crucial for maintaining satellite orbits, ensuring the safety of space operations, and supporting emerging technologies like autonomous vehicles and precision agriculture. The development of regional and global navigation systems continues to enhance the accuracy, reliability, and availability of positioning data, fostering scientific research and operational capabilities worldwide.

In conclusion, satellite systems like GPS, GLONASS, BeiDou, and Galileo are fundamental to modern space geodesy and global infrastructure. They enable precise Earth measurements, support scientific understanding of Earth's processes, and underpin countless practical applications that benefit society at large. As technology advances, these systems will become even more integrated, precise, and vital for understanding our planet and navigating the complexities of space.

19. Translate the text. (1800 printed characters; time – 45 min.)

Space geodesy in cap melting research

Space geodesy has become an indispensable tool in understanding the complex processes governing the Earth's ice caps and their contribution to global sea level rise. By utilizing satellite-based techniques such as Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), Interferometric Synthetic Aperture Radar (InSAR), and Gravity Recovery and Climate Experiment (GRACE) data, researchers can achieve precise measurements of ice mass changes, ice sheet

dynamics, and surface deformations over time.
One prominent application of space geodesy in ice cap research is monitoring mass loss in Greenland and Antarctica. The GRACE satellites have been instrumental in detecting subtle variations in Earth's gravity field, which correspond to changes in ice mass. For instance, GRACE data revealed that Greenland's ice sheet has been losing approximately 280 gigatons of ice annually over the past decade, contributing significantly to sea level rise. Similar measurements in Antarctica indicated an average annual loss of about 150 gigatons, with certain regions experiencing accelerated melting.
Complementing gravity data, InSAR technology enables detailed mapping of ice sheet surface deformations, providing insights into ice flow velocities and dynamic thinning processes. For example, by analyzing InSAR time series, scientists observed rapid acceleration of glaciers in West Antarctica, correlating these changes with basal melting and warm ocean currents. These measurements help in understanding how ice sheets respond to climatic forcing and how their dynamics influence overall mass balance.
GNSS networks installed on ice sheets provide continuous ground-based positioning data, capturing vertical and horizontal movements associated with ice mass change and isostatic rebound. Such data have been crucial in validating satellite observations and improving models of ice sheet response to climate variability. For instance, GNSS stations in Greenland have recorded uplift signals corresponding to ice mass loss, offering real-time insights into melting patterns.
The integration of these space geodetic techniques enables comprehensive, multi-scale analysis of ice cap dynamics. Combining gravity, surface deformation, and direct motion data allows researchers to distinguish between surface melting, basal melting, and ice flow acceleration. This holistic approach enhances predictive models of future ice loss and aids policymakers in understanding the urgency of climate mitigation efforts.
Furthermore, space geodesy has facilitated the assessment of ice mass contributions to sea level rise with high spatial and temporal resolution. This is critical for coastal planning and adaptation strategies worldwide. The ongoing refinement of satellite missions, such as the upcoming GRACE Follow-On and next-generation SAR satellites, promises even more precise monitoring capabilities.
In conclusion, the application of space geodesy has revolutionized the study of Earth's ice caps, providing vital data that underpin our understanding of ice melt processes in a changing climate. These technologies offer unparalleled insights into ice mass balance, dynamic ice flow, and their implications for global sea levels, thereby informing both scientific research and policy decisions aimed at mitigating climate change impacts.

20. Translate the text. (1800 printed characters; time – 45 min.)

The impact of new space geodesy technologies on the life of common people

The advent of new space geodesy technologies has profoundly transformed the way we understand and interact with our planet, ultimately impacting the daily lives of ordinary people in numerous subtle yet significant ways. These cutting-edge tools—such as advanced satellite-based measurement systems, Global Navigation Satellite Systems (GNSS), and high-precision Earth observation satellites—have enhanced our ability to monitor and analyze Earth's dynamic processes with unprecedented accuracy and speed.
One of the most visible effects of these innovations is the improvement in navigation and location-based services that many rely on daily. Modern smartphones equipped with GPS rely on space geodesy to provide precise directions, facilitate ride-sharing services, and enable efficient delivery routes. This has not only made commuting and travel more convenient but has also contributed to economic growth by optimizing logistics and reducing fuel consumption. For ordinary people, it means easier access to services, better safety during travel, and increased connectivity.
Moreover, space geodesy technologies play a crucial role in natural disaster management, directly affecting communities and individuals. By providing real-time data on earthquakes, tsunamis, and volcanic activity, these systems enable early warning mechanisms that can save lives and reduce property damage. For example, precise measurement of ground movements helps scientists predict and understand seismic activity, giving authorities and residents critical lead time to evacuate or prepare. Such capabilities translate into safer communities and a greater sense of security for everyday citizens.
Environmental monitoring is another area where space geodesy has made a tangible difference. Accurate data on sea level rise, glacier melting, and land subsidence inform policies and adaptation

strategies. For coastal communities and farmers, this information influences decisions about resource management, infrastructure development, and disaster preparedness. As climate change accelerates, these technologies help monitor its impacts more closely, enabling proactive responses that protect livelihoods and improve resilience.

Furthermore, the enhanced understanding of Earth's processes fosters better urban planning and sustainable development. Cities can utilize precise geospatial data to optimize land use, manage water resources, and design infrastructure that is resilient to environmental challenges. For residents, this results in improved living conditions, cleaner environments, and more efficient public services.

In essence, the progress in space geodesy technologies bridges the gap between complex scientific research and everyday life. While the benefits are often seen in the form of improved safety, convenience, and environmental stewardship, they collectively contribute to a higher quality of life for people around the world. As these technologies continue to evolve, their influence is expected to deepen, fostering a more connected, informed, and resilient society.

21. Look through the text. Give its brief contents (preparation time - 15 min.).

Swarm Technology: The Collective Intelligence of Distributed Systems

Swarm technology represents a paradigm shift in how autonomous systems operate, drawing inspiration from the collective behavior of natural systems like bird flocks, fish schools, and insect colonies. This emerging field leverages the power of multiple simple units working in concert to achieve complex objectives that would be impossible for individual agents alone. At its core, swarm technology embodies principles of decentralization, self-organization, and emergent intelligence—creating robust, scalable, and adaptive systems capable of operating in dynamic environments.

The fundamental architecture of swarm systems consists of numerous homogeneous or heterogeneous agents—whether aerial drones, ground robots, or software bots—each equipped with basic sensing, computation, and communication capabilities. Unlike traditional centralized systems, swarm agents make localized decisions based on limited information from their immediate neighbors, following simple behavioral rules that collectively produce sophisticated group dynamics. This distributed approach eliminates single points of failure and enables the system to maintain functionality even when individual units are compromised.

Key to swarm operation is the concept of stigmergy—indirect coordination through environmental modification. Agents communicate by leaving digital or physical traces in their environment, which other agents detect and respond to, creating a feedback loop of self-organized task allocation. This mechanism allows swarms to perform complex operations like area coverage, target tracking, or material transport without requiring global communication or centralized control.

Modern implementations of swarm technology demonstrate remarkable capabilities across diverse domains. In precision agriculture, drone swarms autonomously map and monitor crops, sharing data to optimize pesticide application or irrigation patterns. Search-and-rescue operations deploy robot swarms that can systematically comb disaster zones, adapting their search pattern as they detect survivor signatures. Military applications include collaborative surveillance and electronic warfare systems where hundreds of small, inexpensive drones can overwhelm traditional defenses through sheer numbers and adaptive coordination.

The technological foundations enabling these swarms include advanced distributed algorithms, mesh networking protocols, and lightweight artificial intelligence. Bio-inspired algorithms like ant colony optimization and particle swarm optimization provide mathematical frameworks for solving complex pathfinding and optimization problems. Meanwhile, breakthroughs in edge computing allow individual swarm agents to process sensor data and make decisions in real-time without relying on cloud infrastructure.

As swarm technology matures, it faces challenges including energy efficiency constraints, the need for robust collective decision-making mechanisms, and the development of effective human-swarm interfaces. Future advancements may incorporate quantum-inspired optimization techniques, neuromorphic computing for more efficient pattern recognition, and hybrid architectures combining swarms with more traditional robotic systems.

The implications of successful swarm technology extend beyond practical applications to philosophical questions about the nature of intelligence and organization. These systems demonstrate

how complexity can emerge from simplicity, offering insights into both artificial and natural collective behavior. As research progresses, swarm technology promises to revolutionize fields from environmental monitoring to space exploration, embodying the principle that the whole can indeed become greater than the sum of its parts.

22. Look through the text. Give its brief contents (preparation time - 15 min.).

The impact on space geodesy on astronomy

Space geodesy, the science of measuring Earth's shape, orientation, and gravity field from space, has profoundly influenced the field of astronomy by providing precise reference frames and enhancing our understanding of the universe. Its advancements enable astronomers to achieve unparalleled accuracy in positioning celestial objects, tracking their motions, and understanding the dynamic nature of our planet in relation to the cosmos.

One of the most significant contributions of space geodesy to astronomy is the establishment of a highly accurate celestial reference frame. Techniques such as Very Long Baseline Interferometry (VLBI) utilize radio telescopes spread across the globe to measure the positions of distant quasars with extraordinary precision. These measurements underpin the International Celestial Reference Frame (ICRF), which serves as a fundamental coordinate system for astronomical observations. The ICRF's stability and accuracy are crucial for tasks ranging from spacecraft navigation to deep-space observations, ensuring that astronomers can pinpoint objects in the universe with confidence.

A notable case study demonstrating the impact of space geodesy is the tracking of Earth's rotation and its influence on celestial observations. The advent of Satellite Laser Ranging (SLR) and VLBI techniques has allowed scientists to monitor variations in Earth's rotation rate and orientation with remarkable detail. For instance, studies of the Earth's Chandler wobble—a small deviation in its rotational axis—have been refined through space geodetic measurements. These variations can affect the apparent positions of celestial objects and are vital for correcting observational data, especially in high-precision astrometry and interferometry. As a result, astronomers can account for these subtle shifts, leading to more accurate measurements of stellar positions and movements.

Furthermore, space geodesy has contributed to the understanding of gravitational interactions and the dynamics of celestial bodies. By precisely measuring Earth's gravity field and its changes over time, scientists can infer mass redistributions within Earth, such as melting glaciers or shifting tectonic plates. These insights have implications beyond geophysics, informing models of Earth's interaction with the Sun and Moon, which in turn affect astronomical observations. For example, understanding the gravitational influence of Earth on nearby celestial objects enables more accurate modeling of satellite orbits and planetary trajectories.

Another compelling case is the use of space geodesy in the study of gravitational waves and fundamental physics. Missions like the Gravity Recovery and Climate Experiment (GRACE) and the upcoming LISA (Laser Interferometer Space Antenna) rely on precise measurements of distances and gravitational fields, which are rooted in space geodesy techniques. These missions aim to detect ripples in spacetime, providing insights into phenomena such as black hole mergers and the expansion of the universe. The high-precision data obtained through space geodesy thus directly supports groundbreaking discoveries in cosmology and astrophysics.

In conclusion, space geodesy has revolutionized astronomy by providing the necessary tools for precise celestial measurement, understanding Earth's dynamic behavior, and probing fundamental physical phenomena. Its contributions enhance the accuracy of astronomical data, facilitate the study of the Earth's place in the universe, and underpin the exploration of cosmic mysteries. As technology advances, the synergy between space geodesy and astronomy promises to yield even deeper insights into the universe's structure and evolution.

23. Look through the text. Give its brief contents (preparation time - 15 min.).

The impact on space geodesy on engineering

Space geodesy has profoundly influenced the field of engineering by providing precise measurements of Earth's shape, gravity field, and rotation, which are essential for the development, calibration, and improvement of various engineering systems. These advanced measurement techniques, including satellite laser ranging (SLR), very long baseline interferometry (VLBI), global

navigation satellite systems (GNSS), and Doppler orbitography, have enabled engineers to achieve unprecedented accuracy in positioning and monitoring Earth's dynamics.

One significant impact of space geodesy on engineering is in the realm of infrastructure development and maintenance. For instance, the accurate determination of Earth's surface movements allows civil engineers to monitor the stability of critical structures such as bridges, dams, and skyscrapers. This capability is vital for early detection of ground subsidence, tectonic shifts, or other geophysical changes that could threaten structural integrity. A case study illustrating this is the monitoring of the San Andreas Fault in California, where space geodetic measurements have been employed to track fault slip rates. This data has informed engineering designs for earthquake-resistant structures and helped in urban planning to mitigate seismic risks.

In the field of satellite and space vehicle engineering, space geodesy has provided foundational data for orbit determination and station-keeping. Precise knowledge of Earth's gravity field and rotation enables engineers to design better navigation and control systems for satellites, ensuring their stability and longevity. The European Space Agency's GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) mission exemplifies this, as its high-precision gravity data has been used to refine Earth's geoid model, directly benefiting satellite orbit calculations and improving the accuracy of space-based navigation systems.

Furthermore, space geodesy has advanced the development of geophysical models that influence engineering projects related to resource extraction, environmental monitoring, and climate change adaptation. For example, the study of glacial melting and sea-level rise through satellite altimetry has provided critical data for coastal engineering. Engineers designing seawalls and flood defenses now rely on this information to adapt infrastructure to changing sea levels, as seen in the Netherlands' innovative flood management projects that incorporate satellite-based observations to predict and respond to rising waters.

In conclusion, space geodesy has become an indispensable tool in modern engineering, providing vital data that enhances the safety, efficiency, and sustainability of engineering endeavors. Through case studies like fault monitoring in California, orbit determination for spacecraft, and climate-related infrastructure planning, it is evident that the integration of space geodesy into engineering practices has led to more resilient and informed engineering solutions, ultimately contributing to the safety and well-being of society.

24. Look through the text. Give its brief contents (preparation time - 15 min.).

Space geodesy and geophysics

Space geodesy has profoundly transformed the field of geophysics by providing precise measurements of Earth's shape, gravity field, and rotational dynamics. These advancements have enabled scientists to better understand the Earth's internal structure, tectonic processes, and dynamic behaviors, leading to more accurate models of geophysical phenomena.

One of the key impacts of space geodesy on geophysics is its ability to monitor Earth's surface deformations with exceptional precision. Techniques such as Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), and Global Navigation Satellite Systems (GNSS) allow for the detection of minute shifts in Earth's crust. This has been instrumental in studying tectonic plate movements, earthquake precursors, and post-seismic deformations. For example, the analysis of GNSS data following major earthquakes, such as the 2011 Tohoku earthquake in Japan, revealed detailed patterns of crustal displacement, improving our understanding of earthquake mechanics and aiding in seismic risk assessment.

Space geodesy also plays a crucial role in studying Earth's gravity field variations. Missions like Gravity Recovery and Climate Experiment (GRACE) and its successor GRACE-FO have provided valuable data on mass redistribution within the Earth system. These observations have been used to monitor ice mass loss in Greenland and Antarctica, contributing to our understanding of sea-level rise and climate change. Furthermore, gravity data help in constraining models of Earth's interior, including mantle convection and core-mantle interactions, which influence geodynamic processes.

A notable case study illustrating the impact of space geodesy is the monitoring of glacial isostatic adjustment (GIA). By analyzing satellite gravity data over decades, scientists have quantified the Earth's response to the melting of ice sheets since the last Ice Age. This has refined models of Earth's rheology and improved predictions of future sea-level changes. Additionally, continuous geodetic observations have shed light on the Earth's rotational variations, such as length-of-day fluctuations,

which are linked to mass redistribution within the Earth system and have implications for understanding Earth's angular momentum interactions.

In conclusion, space geodesy has revolutionized geophysics by providing high-precision, continuous data that enhance our understanding of Earth's dynamic processes. From earthquake mechanics to climate-related mass changes and internal Earth structure, the integration of space-based geodetic techniques has led to significant scientific breakthroughs and improved hazard mitigation strategies, underscoring their vital role in advancing geophysical research.

25. Look through the text. Give its brief contents (preparation time - 15 min.).

Space geodesy and the Earth's gravity field research

Space geodesy has profoundly transformed our understanding of Earth's gravity field, providing unprecedented insights into the planet's mass distribution, dynamic processes, and global changes. By utilizing advanced satellite techniques such as Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), Satellite Gravity Gradiometry, and the Gravity Recovery and Climate Experiment (GRACE) missions, scientists have been able to map variations in Earth's gravity with remarkable precision. These measurements have revealed subtle yet significant fluctuations in Earth's gravity field caused by phenomena such as ice mass loss in polar regions, groundwater depletion, tectonic movements, and mantle convection, thereby offering vital information about Earth's internal and surface processes.

A notable case study highlighting the impact of space geodesy is the GRACE mission, launched in 2002. GRACE's ability to measure minute changes in gravity has enabled researchers to monitor ice mass loss in Greenland and Antarctica, providing critical data on how climate change is affecting these regions. For instance, GRACE data demonstrated that Greenland alone is losing approximately 270 gigatons of ice annually, contributing to global sea-level rise. Similarly, the mission has documented the depletion of groundwater resources in major aquifers worldwide, influencing water management policies and emphasizing the importance of sustainable resource use.

Another significant example is the use of SLR and GNSS techniques to improve Earth's gravity models over tectonically active regions. For example, studies in the Himalayas have used space geodesy data to understand the ongoing collision between the Indian and Eurasian plates. These measurements have helped quantify the strain accumulation and deformation rates, advancing seismic risk assessments and informing infrastructure development in vulnerable areas.

Furthermore, space geodesy has enhanced our comprehension of Earth's dynamic systems, such as mantle convection patterns and their influence on surface topography and gravity anomalies. By integrating gravity data with seismic and geological information, researchers have been able to develop more comprehensive models of Earth's interior, shedding light on the processes driving plate tectonics and continental drift.

In summary, space geodesy has become an indispensable tool in Earth's gravity field research, offering detailed, real-time data that have elucidated complex processes shaping our planet. Through case studies like GRACE and regional tectonic investigations, it is evident that these technologies provide critical insights for climate monitoring, resource management, and understanding Earth's internal dynamics. As satellite technology advances, the scope and accuracy of gravity field research will continue to expand, fostering deeper knowledge and better stewardship of our planet.

26. Look through the text. Give its brief contents (preparation time - 15 min.).

Space geodesy revolutionized the Earth's shape measurements research

Space geodesy has profoundly transformed our understanding of Earth's shape, size, and dynamic processes through precise measurement techniques that have evolved over recent decades. As a branch of geophysics and geodetic science, space geodesy utilizes satellite-based systems to monitor Earth's shape and motions with unprecedented accuracy, enabling researchers to investigate phenomena ranging from tectonic plate movements to sea level rise.

One of the most significant impacts of space geodesy is its ability to provide continuous, high-precision measurements of Earth's surface. Techniques such as Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), and Global Navigation Satellite Systems (GNSS) have become essential tools

in geodesy. These methods allow scientists to determine Earth's figure and its temporal variations with millimeter-level precision. For instance, GNSS networks installed worldwide enable monitoring of tectonic plate movements, revealing, in real-time, the slow but persistent shifts associated with plate tectonics, post-glacial rebound, or other geodynamic processes.

A notable case study illustrating the impact of space geodesy is the measurement of Earth's precession and nutation. VLBI, in particular, has been instrumental in refining our understanding of Earth's orientation in space. By observing distant quasars, VLBI provides data on Earth's rotational parameters, helping to improve models of Earth's wobble and rotational dynamics. These insights are crucial for precise navigation, satellite operations, and understanding Earth's internal structure.

Another significant application is the study of sea level changes and glacial mass balance. Satellite altimetry missions such as TOPEX/Poseidon, Jason series, and CryoSat-2 have enabled scientists to monitor sea surface heights globally. These measurements have revealed accelerating sea level rise due to climate change, as well as regional variations linked to ice sheet melting and ocean circulation patterns. For example, data from the GRACE (Gravity Recovery and Climate Experiment) satellites have detected mass loss in Greenland and Antarctic ice sheets, directly correlating to changes in Earth's gravity field and shape.

Case studies of Earth's deformation following seismic events further demonstrate the power of space geodesy. After the 2011 Tohoku earthquake in Japan, GPS networks documented significant crustal displacement and post-seismic deformation. These observations provided critical data for understanding earthquake mechanics, assessing seismic hazards, and improving models of Earth's elastic response. Similarly, monitoring volcanic inflation and deflation through interferometric synthetic aperture radar (InSAR) and GNSS has been vital for volcano eruption forecasting and hazard mitigation.

In conclusion, space geodesy has revolutionized our capacity to measure and understand Earth's shape and dynamic behavior. Its contributions extend from fundamental geophysical research to practical applications such as natural hazard assessment, climate change monitoring, and navigation. As satellite technology advances, future research will likely achieve even greater precision, offering deeper insights into Earth's complex and ever-changing form.

27. Look through the text. Give its brief contents (preparation time - 15 min.).

The relationship between ground surveying and space geodesy

Ground surveying and space geodesy are two interconnected disciplines that collectively enhance our understanding of Earth's shape, size, and gravitational field. Ground surveying, traditionally rooted in terrestrial measurements, involves techniques such as triangulation, trilateration, leveling, and more recently, GNSS (Global Navigation Satellite System) surveys. These methods provide highly accurate local data crucial for civil engineering, land development, and mapping projects. However, their scope is limited to specific regions and often influenced by local conditions such as terrain and atmospheric disturbances.

Space geodesy, on the other hand, leverages satellite-based technologies to monitor Earth's shape, rotation, and gravity field over much larger scales. Techniques such as Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), and Global Navigation Satellite Systems (GNSS) enable scientists to obtain precise measurements of Earth's parameters globally and continuously. These methods have revolutionized our ability to monitor tectonic plate movements, sea-level rise, and variations in Earth's gravity field, providing data that ground surveys alone cannot achieve at such a scale.

A notable case study illustrating the synergy between ground surveying and space geodesy is the monitoring of the Earth's tectonic movements along the San Andreas Fault in California. Ground-based GPS networks have recorded the relative motion of tectonic plates with millimeter-level accuracy over decades, revealing strain accumulation and release patterns. Complementing these measurements, space geodesy techniques such as VLBI and SLR have tracked Earth's rotational variations and gravity anomalies associated with tectonic activities. The integration of these data sources has significantly improved our understanding of earthquake precursors and the dynamics of fault zones.

Another example is the study of glacial melting and sea-level rise in Greenland and Antarctica. Ground surveys using traditional leveling and GPS stations provide localized data on ice sheet movements and elevation changes. Meanwhile, satellite missions like GRACE (Gravity Recovery

and Climate Experiment) have measured variations in Earth's gravity field caused by mass redistribution due to melting ice. Together, these data sets enable scientists to quantify ice mass loss and predict future sea-level changes with greater confidence.

In the case of the Global Geodetic Observing System (GGOS), a coordinated effort combines ground-based observations with space geodetic techniques to produce a comprehensive picture of Earth's dynamic processes. This integration supports not only scientific research but also practical applications such as navigation, climate monitoring, and disaster management.

In essence, ground surveying provides high-precision, localized measurements that are indispensable for detailed mapping and engineering projects, while space geodesy offers the global perspective necessary to understand Earth's complex dynamics over large spatial and temporal scales. Their relationship is symbiotic; advances in space geodesy often inform and improve ground survey methods, and vice versa. Together, these disciplines deepen our understanding of Earth's systems, helping us better manage natural hazards, environmental changes, and resource planning.

28. Look through the text. Give its brief contents (preparation time - 15 min.).

How space geodesy tracks the Earth's space orientation

Space geodesy is a vital scientific discipline that focuses on monitoring and understanding Earth's spatial orientation and position in space. By employing advanced observational techniques and satellite-based systems, scientists can precisely track how our planet moves and rotates, providing essential data for various applications such as navigation, climate monitoring, and Earth science research.

One of the core aspects of space geodesy involves measuring Earth's orientation parameters, including its rotation axis, polar motion, and length of day. These parameters are fundamental for understanding Earth's dynamic behavior and are crucial for maintaining accurate global positioning systems (GPS). Techniques such as Very Long Baseline Interferometry (VLBI) have been instrumental in this regard. VLBI uses radio telescopes separated by thousands of kilometers to measure the Earth's orientation with milliarcsecond precision, enabling scientists to detect minute changes in Earth's rotation and axis orientation over time.

Another significant method in space geodesy is Satellite Laser Ranging (SLR), which involves sending laser pulses to satellites equipped with retroreflectors. By measuring the time it takes for the laser to return, researchers can determine the satellite's distance with remarkable accuracy. This data helps in modeling Earth's gravity field, understanding tectonic movements, and refining the reference frames used for global navigation. Similarly, Global Navigation Satellite Systems (GNSS), such as GPS, GLONASS, and Galileo, provide continuous and real-time data on Earth's position and orientation, facilitating applications ranging from earthquake monitoring to precise agriculture.

Case studies exemplify the importance and effectiveness of space geodesy in tracking Earth's spatial orientation. For instance, the observation of polar motion and variations in Earth's rotation has contributed to understanding the impacts of climate change, such as melting ice caps affecting Earth's moment of inertia. In another case, VLBI measurements have been instrumental in detecting tectonic plate movements and seismic activity, providing valuable insights into earthquake prediction and fault dynamics. Additionally, space geodesy has played a key role in refining Earth's reference frames—such as the International Terrestrial Reference Frame (ITRF)—which underpin navigation, surveying, and scientific research worldwide.

Overall, space geodesy serves as a critical tool for continuously monitoring Earth's spatial orientation. Its integration of multiple observational techniques enables a comprehensive understanding of Earth's dynamic behavior, supporting scientific research, environmental monitoring, and technological advancements. As technology progresses, the precision and scope of space geodesy are expected to improve further, offering deeper insights into the complex interactions between Earth's interior, surface, and its position in space.

29. Look through the text. Give its brief contents (preparation time - 15 min.).

Space geodesy methods and autonomous vehicles

Space geodesy methods and autonomous vehicles are two rapidly evolving fields that exemplify the intersection of advanced technology and scientific research. Space geodesy encompasses a suite of techniques used to measure Earth's shape, gravitational field, and surface deformations with

remarkable precision, often leveraging satellites and space-based instruments. These methods include Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). Each technique offers unique advantages; for instance, VLBI employs radio telescopes separated across the globe to measure Earth's orientation and tectonic movements accurately, while GNSS provides real-time positioning data critical for various applications.

The integration of space geodesy into climate monitoring, earthquake prediction, and sea-level rise assessment has demonstrated its vital role in understanding Earth's dynamic processes. Notably, the use of GNSS networks has allowed scientists to observe crustal deformation with centimeter-level accuracy, providing insights into seismic activity and tectonic plate movements. These methods require sophisticated data processing, precise calibration, and global collaboration, emphasizing the importance of international cooperation in geodetic research.

Parallel to these developments, autonomous vehicles (AVs) have been transforming transportation, relying heavily on a combination of sensors, machine learning algorithms, and geospatial data. AVs utilize a variety of sensing technologies—including LiDAR, radar, cameras, and GNSS—to perceive their environment, navigate complex urban landscapes, and make real-time decisions. Advanced algorithms process this sensor data to detect obstacles, interpret traffic signals, and plan optimal routes, aiming to improve safety, efficiency, and mobility.

Case studies in autonomous vehicle deployment highlight both progress and challenges. For example, Waymo's autonomous taxis in Phoenix have demonstrated the feasibility of driverless transportation in controlled environments, gathering data that continually enhances system safety and reliability. Similarly, in Europe, autonomous shuttles operating in designated zones have provided valuable insights into urban mobility solutions. However, ensuring robustness across diverse weather conditions, urban settings, and interactions with human drivers remains a significant hurdle.

Interestingly, there is a convergence between space geodesy and autonomous vehicles, particularly in the realm of precise positioning and navigation. High-accuracy GNSS data, augmented by real-time correction services, underpin many AV navigation systems, ensuring they can operate safely even in challenging environments. Moreover, emerging research explores integrating space-based geodetic data into the mapping and localization processes of AVs, enhancing their ability to operate reliably over long distances and in varied terrains.

In summary, space geodesy methods provide foundational data that enhances our understanding of Earth's physical changes, while autonomous vehicle technology leverages advanced geospatial information to revolutionize transportation. Both fields continue to evolve through technological innovations and collaborative efforts, promising a future where precise Earth monitoring and intelligent mobility systems coexist to address societal needs effectively.

30. Look through the text. Give its brief contents (preparation time - 15 min.).

Space geodesy and how it helps in forecasting earthquakes

Space geodesy is a groundbreaking scientific discipline that employs advanced satellite technology and ground-based measurement systems to study the Earth's shape, gravity field, rotation, and surface deformations with exceptional precision. By monitoring subtle movements and shifts in the Earth's crust, space geodesy provides invaluable insights into the dynamic processes that govern our planet's behavior. This field has revolutionized our understanding of geophysical phenomena, particularly in the context of earthquake forecasting, where detecting early signs of seismic activity can save countless lives and mitigate destruction.

The core techniques within space geodesy include Global Navigation Satellite Systems (GNSS) such as GPS, GLONASS, Galileo, and BeiDou, as well as Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). These technologies enable scientists to measure the Earth's surface movements down to millimeter accuracy. By continuously observing the deformation of fault lines and tectonic plates, researchers can identify patterns or anomalies that precede significant seismic events.

One of the primary ways space geodesy aids in earthquake forecasting is through the detection of slow, strain-building movements along fault zones. For instance, the San Andreas Fault in California has been under continuous surveillance using GPS networks. These stations record gradual ground movements over time, indicating accumulating stress that could eventually be released as an earthquake. Such data help scientists develop models of stress accumulation and release, improving

the understanding of seismic cycles. In regions like Japan, dense GNSS networks have provided real-time data showing how tectonic plates gradually lock and strain, offering potential predictive insights.

Moreover, space geodesy can reveal aseismic slip events—slow, silent movements along faults that do not produce immediate earthquakes but can influence the timing and magnitude of future seismic activity. Recognizing these patterns enhances the ability to assess earthquake risks more accurately. For example, studies in the Cascadia Subduction Zone have used GPS data to monitor slow slip events that periodically relieve tectonic stress, thereby playing a role in forecasting the likelihood of larger quakes.

Case studies underscore the practical applications of space geodesy in seismic hazard assessment. In 2011, the Tohoku-Oki earthquake in Japan was preceded by detectable crustal deformation observed through GNSS data, which showed gradual locking of the subduction interface before the rupture. Post-earthquake, satellite-based InSAR (Interferometric Synthetic Aperture Radar) imagery revealed ground displacement patterns consistent with the seismic slip, providing a comprehensive picture of the event's mechanics. Similarly, in Mexico, continuous GPS stations have recorded strain accumulation along the Cocos Plate, aiding in understanding the seismic potential of the region.

While space geodesy does not yet allow precise prediction of the exact timing of earthquakes, it significantly enhances probabilistic seismic hazard assessments. By integrating geodetic data with geological and seismic records, scientists can better estimate the likelihood of future events and identify areas at higher risk. This information is crucial for urban planning, infrastructure resilience, and emergency preparedness.

In conclusion, space geodesy stands at the forefront of earthquake research, offering unparalleled capability to monitor Earth's surface deformation in real-time. Its contributions to understanding the mechanics of fault systems and detecting pre-seismic signals are vital steps toward more reliable earthquake forecasting. Although challenges remain in translating geodetic observations into precise predictions, ongoing technological advancements promise to improve early warning systems, ultimately helping to protect communities from the devastating impacts of earthquakes.

31. Look through the text. Give its brief contents (preparation time - 15 min.).

Space geodesy and volcanic activity

Space geodesy is a branch of geophysics that involves the measurement and understanding of Earth's shape, gravity field, and rotational dynamics through satellite-based technologies. It plays a pivotal role in monitoring Earth's surface deformations with unprecedented precision, offering vital insights into the processes that precede and accompany volcanic activity. By integrating various space-based measurement techniques, scientists can detect subtle ground movements—often centimeters or millimeters—that signal magma intrusion, crustal swelling, or other geophysical changes associated with volcanic unrest.

One of the primary tools of space geodesy is Global Navigation Satellite Systems (GNSS), including GPS, GLONASS, Galileo, and BeiDou. These systems enable continuous, high-precision tracking of ground stations positioned around volcanoes. When magma accumulates beneath a volcano, it causes the overlying crust to deform, swelling outward and upward. This deformation can be detected as shifts in the positions of GNSS stations with millimeter accuracy. For instance, in the case of Mount Etna in Italy, a network of GNSS stations has recorded minute inflationary signals months before eruptions, providing early warning that enhances preparedness and response efforts.

Satellite interferometric synthetic aperture radar (InSAR) is another powerful technique that complements ground-based GNSS data. InSAR involves comparing radar images of the Earth's surface taken at different times to produce detailed maps of ground displacement. This method can cover vast and remote volcanic regions, revealing surface deformation patterns that might be missed by sparse ground stations. For example, InSAR data has been instrumental in monitoring the 2018 eruption of Kilauea in Hawaii, where it captured the rapid inflation of the volcano's summit and subsequent deflation during eruptions. These observations contributed to understanding magma movement and eruption dynamics, ultimately aiding in hazard assessment.

Case studies underscore the effectiveness of space geodesy in volcanic monitoring. The 2010 eruption of Eyjafjallajökull in Iceland was preceded by measurable inflation detected through InSAR and GNSS. These deformation signals alerted scientists to the increasing magmatic activity beneath the ice cap, allowing authorities to issue timely warnings and mitigate the impact of ash cloud

dispersal on air travel. Similarly, the 2015 eruption of Calbuco in Chile was preceded by ground deformation signals captured by space geodesy techniques, emphasizing their role in early detection. Furthermore, space geodesy's ability to provide continuous, real-time monitoring has transformed volcanic hazard management. It allows for the integration of deformation data with other geophysical signals, such as seismic activity and gas emissions, to develop comprehensive eruption forecasts. This multi-parameter approach enhances the accuracy of predictions and the effectiveness of early warning systems.

In conclusion, space geodesy is a vital tool in modern volcanology, offering detailed, timely insights into the subtle ground movements associated with volcanic activity. Through techniques like GNSS and InSAR, scientists can monitor volcanoes remotely and continuously, providing critical data that improve eruption forecasting and risk mitigation. As satellite technology advances, the potential for even more precise and comprehensive volcanic monitoring continues to grow, ultimately contributing to safer communities and better understanding of Earth's dynamic processes.

32. Look through the text. Give its brief contents (preparation time - 15 min.).

Companies proving equipment for space geodesy research

Companies providing equipment for space geodesy research play a pivotal role in advancing our understanding of Earth's shape, gravity field, and tectonic movements. These firms develop sophisticated technologies that enable scientists to measure Earth's spatial and temporal variations with unprecedented precision, facilitating breakthroughs in geophysics, climate science, and navigation systems.

One notable example is Trimble Inc., a global leader in positioning solutions. Trimble's contributions to space geodesy primarily revolve around advanced GPS and GNSS (Global Navigation Satellite System) equipment. Their high-precision receivers are integral to continuous GPS networks used worldwide for monitoring crustal deformation, sea level rise, and other geophysical phenomena. Trimble's innovations in multi-frequency receivers and antennas have significantly enhanced the accuracy and reliability of geodetic measurements, allowing researchers to detect millimeter-scale movements over vast distances.

Another significant player is Leica Geosystems, part of Hexagon AB. Leica provides a range of geodetic instruments, including total stations, GNSS receivers, and laser scanners. Their equipment is widely employed in space geodesy projects such as the International GNSS Service (IGS), which supplies global coordinate solutions crucial for monitoring Earth's dynamics. Leica's innovations in real-time data processing and integration have improved the efficiency and precision of geodetic surveys, enabling more effective tracking of tectonic shifts and sea level changes.

A case study illustrating the impact of such equipment is the use of GNSS technology in monitoring the movement of the Antarctic Ice Sheet. Researchers equipped their stations with Trimble GNSS receivers, which provided continuous, high-precision data essential for understanding ice sheet stability and contributions to sea level rise. The data collected over several years have informed climate models and policy decisions, demonstrating the vital role of advanced geodetic equipment.

Furthermore, companies like Topcon Positioning Systems have contributed to space geodesy through their development of multi-constellation GNSS receivers and precise timing solutions. Their equipment has been deployed in various campaigns to measure Earth's surface deformation caused by earthquakes, volcanic activity, and other geophysical processes. For instance, in Japan, Topcon's equipment has been used extensively to monitor post-earthquake land movements, aiding disaster preparedness and mitigation efforts.

In the realm of satellite laser ranging (SLR), companies such as NASA's subcontractors develop ground station equipment capable of measuring the distance to satellites with millimeter accuracy. These measurements contribute to refining Earth's gravity models and understanding tectonic plate movements. Although primarily operated by space agencies, commercial firms supply and maintain much of the ground-based infrastructure essential for SLR.

In summary, companies specializing in geodetic equipment are fundamental to space geodesy research. Their technological innovations facilitate precise measurements of Earth's dynamics, leading to scientific discoveries and practical applications such as disaster monitoring and navigation. Case studies like Antarctic ice sheet monitoring and earthquake deformation measurements exemplify how these companies' equipment directly contributes to expanding our knowledge of Earth's complex systems. As technology advances, these companies continue to push

the boundaries of measurement accuracy, supporting the ongoing pursuit of understanding our planet in greater detail.

33. Look through the text. Give its brief contents (preparation time - 15 min.).

Training space geodesy experts

Training space geodesy experts is a vital component in advancing our understanding of Earth's dynamic processes and supporting the development of space-based technologies. The complexity and precision required in this field demand comprehensive educational programs that combine theoretical knowledge with practical experience. To illustrate the effectiveness of such training initiatives, several case studies highlight successful models and valuable lessons learned.

One notable example is the European Space Agency's (ESA) training program in space geodesy, which targets early-career scientists and engineers. This program offers intensive courses on satellite orbit determination, gravity field modeling, and geodetic data analysis. Participants engage in hands-on workshops utilizing real satellite data, fostering skills in data processing and interpretation. The program's success lies in its multidisciplinary approach, blending physics, mathematics, computer science, and engineering, ensuring trainees develop a holistic understanding necessary for tackling complex geodetic challenges.

Another case study involves the NASA Goddard Space Flight Center’s training initiatives, which focus on calibration and validation of satellite instruments. Their specialized workshops train experts to interpret data from missions like the Gravity Recovery and Climate Experiment (GRACE) and the Sentinel satellites. Through collaborations with international partners, NASA ensures that trainees are exposed to diverse datasets and methodologies, promoting interoperability and standardization in global geodetic efforts. These programs also emphasize the importance of continuous learning, offering advanced courses as trainees gain experience.

In Asia, the China Academy of Space Technology (CAST) has established a comprehensive training program aimed at building domestic expertise in space geodesy. Their approach combines classroom teaching with fieldwork, including calibration exercises and collaborative projects with international organizations such as the International GNSS Service (IGS). This model emphasizes capacity building within emerging space nations, ensuring that local scientists can operate and maintain sophisticated geodetic systems independently.

These case studies demonstrate the importance of tailored training programs that address specific regional and technical needs. Successful initiatives incorporate a mix of theoretical instruction, practical exercises, international collaboration, and ongoing education. They also highlight the significance of fostering a community of practice among trainees, encouraging knowledge sharing and innovation.

In conclusion, training space geodesy experts is a multifaceted endeavor that requires well-designed curricula, real-world experience, and international cooperation. The case studies exemplify how different organizations have developed effective models that can be adapted and expanded globally. As space-based observation becomes increasingly vital for understanding climate change, natural hazards, and Earth system dynamics, investing in expert training will remain crucial for advancing scientific knowledge and technological capabilities in this rapidly evolving field.

34. Look through the text. Give its brief contents (preparation time - 15 min.).

Subjects to be studied to become a space geodesy expert

Embarking on a journey to become a space geodesy expert requires a comprehensive understanding of multiple disciplines that converge to enable precise measurement and analysis of Earth's shape, gravity field, rotation, and orientation in space. Central to this pursuit are subjects such as geodesy itself, satellite geodesy, physics, and advanced mathematics, all of which provide a robust foundation for mastering the intricacies of space-based measurements.

At the core, formal education in geodesy offers essential knowledge of Earth's physical properties, coordinate systems, and reference frames. Courses in classical geodesy introduce the fundamentals of Earth's shape, size, and gravitational field, establishing a baseline for understanding how to model and interpret geodetic data. Complementing this, satellite geodesy delves into the principles and applications of space-based positioning systems like GPS, GLONASS, Galileo, and BeiDou. These

subjects cover the functioning of satellite orbits, signal propagation, and the methods used to determine precise positions on Earth's surface.

Physics plays a crucial role, especially in understanding the behavior of signals as they traverse the atmosphere and the physics of satellite motion. Subjects such as atmospheric physics, signal propagation, and gravitational physics enable the expert to correct for atmospheric delays and gravitational anomalies that affect measurements. Additionally, advanced mathematics—including linear algebra, calculus, probability theory, and numerical methods—is vital for data processing, modeling, and error analysis. These mathematical tools facilitate the development of algorithms used in processing massive datasets from space geodesy missions.

Further specialization involves studying remote sensing techniques, which encompass the use of satellite imagery, radar, and laser ranging to monitor Earth's surface and its dynamic processes. Spacecraft navigation, orbit determination, and the design of satellite missions are also essential topics, providing insight into how to deploy and operate measurement systems effectively.

Case studies serve as practical applications of this knowledge, illustrating how theories are implemented in real-world scenarios. For instance, the GRACE (Gravity Recovery and Climate Experiment) mission exemplifies the use of satellite gravimetry to monitor changes in Earth's mass distribution, such as ice sheet melting and groundwater depletion. Analyzing data from GRACE involves understanding gravitational modeling, data calibration, and error mitigation, demonstrating the integration of physics, mathematics, and geodesy. Similarly, the European Space Agency's Sentinel satellites utilize remote sensing and precise orbit determination to assess environmental changes, offering insights into the application of space geodesy for climate monitoring and disaster response.

Another instructive case is the use of VLBI (Very Long Baseline Interferometry), which measures Earth's orientation and rotation by correlating radio signals from distant quasars received at multiple ground stations. This technique exemplifies the intersection of radio astronomy, physics, and precise timing, highlighting the interdisciplinary nature of space geodesy. The study of these case studies emphasizes the importance of integrating multiple disciplines and constantly refining measurement techniques to improve accuracy and reliability.

In summary, becoming a space geodesy expert involves a multidisciplinary education spanning geodesy, satellite technology, physics, mathematics, remote sensing, and spacecraft engineering. Through studying these subjects and analyzing real-world case studies, aspiring experts develop the skills needed to contribute to advancements in Earth's measurement systems, environmental monitoring, and understanding of our planet's dynamic processes. This comprehensive knowledge not only fosters technical proficiency but also enables innovation in solving complex geophysical challenges using space-based technologies.

35. Look through the text. Give its brief contents (preparation time - 15 min.).

Space geodesy and its facilitation of ground water depletion

Space geodesy, a branch of geophysics that employs satellite-based techniques to measure Earth's shape, gravity field, and surface deformations, has become an invaluable tool in understanding and monitoring various Earth processes. While primarily used for tectonic studies, climate monitoring, and earthquake prediction, space geodesy also plays a significant role in understanding the dynamics of groundwater resources. Groundwater depletion, a critical environmental and socio-economic issue, can be effectively monitored and managed through the precise measurements provided by satellite geodesy.

Groundwater is a vital resource for agriculture, industry, and domestic use. Overextraction of groundwater often leads to land subsidence, reduced water availability, and ecological degradation. Traditional methods of groundwater monitoring, such as well measurements and piezometers, are often limited in spatial coverage and can be invasive and costly. Space geodesy offers a complementary approach by allowing large-scale, high-precision observation of Earth's surface movements that are often indicative of groundwater changes.

One of the primary techniques used in space geodesy for this purpose is Interferometric Synthetic Aperture Radar (InSAR). InSAR measures ground surface displacements with centimeter to millimeter accuracy by analyzing the phase differences of radar signals acquired from satellites. When groundwater is extracted from aquifers, the resulting decrease in water pressure causes the overlying land to settle or subside. In regions with substantial groundwater extraction, such as parts

of California's Central Valley, InSAR has revealed significant land subsidence rates of up to 30 centimeters per year, directly correlating with groundwater withdrawal data.

Similarly, the Gravity Recovery and Climate Experiment (GRACE) and its successor, GRACE-FO, satellites measure variations in Earth's gravity field, which can be linked to changes in water mass. By detecting the decrease in gravity over aquifer regions, scientists can estimate the amount of groundwater lost over time. For example, studies in India's Ganges Basin have utilized GRACE data to quantify groundwater depletion at regional scales, revealing annual losses of several cubic kilometers of water. This information is crucial for policymakers to implement sustainable groundwater management strategies.

Case studies further illustrate the utility of space geodesy in groundwater monitoring. In California's Central Valley, InSAR monitoring has documented land subsidence events linked to excessive groundwater pumping, which risk damaging infrastructure and reducing water storage capacity. In northern India, GRACE data has provided evidence of rapid groundwater depletion, prompting efforts to regulate extraction and promote water conservation. In Mexico City, satellite-based measurements have helped assess the extent of aquifer overexploitation and its implications for urban infrastructure stability.

These technological advancements have transformed groundwater management from reactive to proactive. Authorities can now detect early signs of overextraction, assess the effectiveness of conservation measures, and implement policies based on reliable, large-scale data. Moreover, satellite data can be integrated with ground-based measurements to improve the accuracy of groundwater models, supporting sustainable resource use.

In conclusion, space geodesy has become an essential tool in detecting, quantifying, and understanding ground water depletion. Its capacity for large-scale, continuous, and precise measurements complements traditional methods and enhances our ability to manage groundwater resources sustainably. As technological capabilities continue to advance, integrating space geodesy into water management frameworks will be pivotal in addressing the global challenge of groundwater depletion, safeguarding water security for future generations.

36. Look through the text. Give its brief contents (preparation time - 15 min.).

Mineral resources management through space geodesy

Space geodesy, the science of precisely measuring Earth's shape, gravity field, and rotation using space-based technologies, has become an indispensable tool in modern mineral resource management. By providing accurate, real-time data on Earth's physical parameters, space geodesy enhances exploration, monitoring, and sustainable utilization of mineral resources.

One of the key contributions of space geodesy is in mineral exploration. Techniques such as Satellite Laser Ranging (SLR), Global Navigation Satellite Systems (GNSS), and Interferometric Synthetic Aperture Radar (InSAR) allow geologists to detect subtle surface deformations and variations in Earth's crust that often precede mineral deposits. For instance, InSAR has been employed to identify ground movements associated with hydrothermal activity, which can signal the presence of mineral-rich zones beneath the surface.

Furthermore, space geodesy aids in mapping and monitoring large-scale geological structures and faults. Accurate data on tectonic movements help in assessing regions prone to seismic activity, which is vital for safe mining operations and infrastructure development. In regions where mineral deposits are associated with specific geological features, understanding the dynamics of Earth's crust becomes crucial in pinpointing promising exploration sites.

Case studies exemplify the practical benefits of space geodesy. In the Democratic Republic of Congo, InSAR technology has been used to monitor crustal deformations related to mineral-rich zones, enabling more targeted exploration of coltan and gold deposits. Similarly, in Western Australia, GNSS stations have been instrumental in mapping fault lines and understanding crustal stability, thereby informing the planning of large-scale mining projects with minimal environmental impact.

Space geodesy also plays a significant role in environmental monitoring related to mineral extraction. By tracking surface subsidence caused by groundwater extraction or underground mining, authorities can mitigate environmental hazards and prevent land degradation. The case of the Grasberg mine in Indonesia illustrates this, where InSAR data has been used to monitor ground

stability and guide operational adjustments to prevent subsidence-related damage.
Another critical application is in resource management and policy formulation. Accurate geospatial data supports land-use planning, ensuring that mineral extraction activities are conducted sustainably. It also facilitates the management of transboundary mineral resources, where precise measurements ensure fair and environmentally responsible utilization.
In conclusion, space geodesy significantly enhances mineral resources management by providing precise, comprehensive data on Earth's physical and geological dynamics. Its applications in exploration, environmental monitoring, and sustainable development are exemplified through various case studies worldwide. As technology advances, the integration of space geodesy into mineral resource management promises more efficient, safer, and environmentally conscious exploitation of Earth's mineral wealth.

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Land management and space geodesy
Space geodesy has revolutionized the way we understand and manage our Earth's surface, providing precise and comprehensive data critical for effective land management. This scientific discipline employs satellite-based techniques to measure and monitor Earth's shape, gravitational field, rotation, and surface deformations. Its applications are vast, spanning from urban planning to environmental conservation, and its contributions have become indispensable in addressing contemporary land management challenges.
One of the primary tools of space geodesy is Global Navigation Satellite Systems (GNSS), such as GPS, GLONASS, Galileo, and BeiDou. These systems enable highly accurate positioning and movement tracking of points on Earth's surface. By deploying a network of continuously operating reference stations, geodesists can detect subtle land subsidence, uplift, or deformation over time. This capability is critical in urban environments where infrastructure stability depends on precise ground assessments. For instance, in the city of Mexico City, GNSS data has been used to monitor ground subsidence caused by groundwater extraction. Continuous measurement revealed subsidence rates exceeding 30 centimeters annually in some areas, informing policies to regulate water use and mitigate damage to infrastructure.
Another significant technique is Satellite Laser Ranging (SLR), which involves measuring the distance to satellites equipped with retroreflectors. SLR provides high-precision data on Earth's shape and gravitational field, essential for establishing and maintaining global geodetic reference frames. These frames underpin accurate land cadastral surveys and boundary delineations, ensuring legal clarity and reducing disputes. In the context of land management, accurate boundary definition is fundamental for property rights, urban development, and resource allocation.
Interferometric Synthetic Aperture Radar (InSAR) is another vital space geodesy tool. It uses radar signals from satellites to detect ground movements with millimeter-level precision over large areas. In regions prone to natural hazards like earthquakes, volcanic activity, or land subsidence, InSAR offers early warning and risk assessment capabilities. For example, in the San Francisco Bay Area, InSAR data has been instrumental in quantifying land deformation related to earthquake cycles, guiding urban planning and infrastructure reinforcement.
Case studies worldwide exemplify the practical benefits of space geodesy in land management. In the Netherlands, a country with a dense network of polders and flood protection infrastructure, space geodesy techniques have been used to monitor subsidence and sea-level rise. The data has informed the design and adjustment of dykes and floodgates, enhancing resilience against climate change. Similarly, in India, space geodetic measurements have supported land reclamation projects along the coast and in flood-prone delta regions, ensuring sustainable development while minimizing environmental impacts.
In Africa, ongoing projects utilize space geodesy to establish reliable cadastral systems in rural and peri-urban areas, facilitating land tenure security and economic development. By providing accurate, timely data, these technologies help governments and communities manage land resources effectively, reduce conflicts, and promote sustainable growth.
Overall, space geodesy serves as a cornerstone for modern land management, offering precise, large-scale, and continuous monitoring capabilities that were previously unattainable. Its integration with Geographic Information Systems (GIS) and remote sensing enhances decision-making processes, ensuring sustainable development, environmental protection, and legal certainty in land

use. As satellite technology advances, the scope and accuracy of geodetic data will expand, further empowering land managers worldwide to address the complex challenges of the 21st century.

38. Look through the text. Give its brief contents (preparation time - 15 min.).

"Can Space Geodesy Facilitate Studying Other Planets?"

The remarkable success of space geodesy in monitoring Earth's dynamic systems raises an intriguing question: could these same techniques revolutionize our understanding of other planets? The answer lies in adapting terrestrial geodetic methods to extraterrestrial environments, where they could unlock secrets of planetary interiors, surface evolution, and even potential habitability.

Traditional Earth-based geodesy relies on established infrastructure—global networks of ground stations, precisely tracked satellites, and well-defined reference frames. Translating this approach to other planets presents unique challenges but also extraordinary opportunities. Lunar laser ranging, conducted since the Apollo missions using retroreflectors left on the Moon's surface, provides the longest-running example of extraterrestrial geodesy, having measured the Moon's recession from Earth (3.8 cm/year) and tested fundamental physics. This success story suggests how more comprehensive geodetic systems could operate on planetary bodies.

Mars represents the most compelling candidate for full planetary geodesy. NASA's InSight mission (2018-2022) demonstrated the value of geophysical monitoring with its seismometer and heat probe, but lacked the orbital geodetic component that Earth missions take for granted. A future Mars geodesy network might include:

- Satellite constellations equipped with laser altimeters and intersatellite ranging systems to map the gravity field and track seasonal CO_2 ice cap changes
- Surface beacons acting as fixed reference points for crustal deformation studies
- Orbiting radio transponders to measure rotation variations revealing core dynamics

The technical hurdles are significant—planetary geodesy requires autonomous systems capable of long-term operation without human intervention, and must account for unfamiliar environments like Mars' dust storms or Europa's radiation belts. However, miniaturized atomic clocks, quantum sensors, and AI-driven data processing are making such systems increasingly feasible.

Beyond the Moon and Mars, geodesy could probe ocean worlds like Europa and Enceladus. Precise gravity measurements from orbit might detect subsurface ocean tides, while laser altimetry could measure ice shell flexing. Venusian geodesy, despite the hostile surface conditions, could use orbiting probes to study volcanic activity through subtle topographic changes.

Perhaps most importantly, planetary geodesy would provide the spatial framework for future exploration—the "GPS of Mars" for rovers and astronauts, or the reference network for lunar construction. As we prepare for sustained human presence beyond Earth, developing extraterrestrial geodesy may prove not just scientifically valuable, but operationally essential. The techniques refined on Earth are ready to go interplanetary, promising to reveal other worlds with the same precision we now apply to our own.

39. Look through the text. Give its brief contents (preparation time - 15 min.).

The role of space geodesy in monitoring tectonic shifts

Space geodesy plays a pivotal role in advancing our understanding of tectonic shifts and the dynamic nature of Earth's crust. As a collection of precise measurement techniques that utilize satellite technology to determine the Earth's shape, orientation, and gravity field, space geodesy provides invaluable insights into the movements of tectonic plates and the deformation of the Earth's surface over time. These techniques, including Global Navigation Satellite Systems (GNSS), Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), enable scientists to monitor subtle shifts in Earth's crust with remarkable accuracy.

The continuous measurement capabilities of space geodesy allow for real-time observation of plate motions, which are typically on the order of centimeters per year. Such precise tracking is essential for understanding the mechanics of plate boundaries, identifying zones of strain accumulation, and assessing earthquake risk. For instance, GNSS networks installed across fault zones record the gradual build-up of elastic strain that may be released suddenly during seismic events. This data aids in identifying regions where stress is concentrating, providing crucial information for earthquake

forecasting and hazard mitigation.
Furthermore, space geodesy enhances our comprehension of post-seismic deformation, revealing how the Earth's crust responds after major earthquakes. By monitoring the slow relaxation and ongoing adjustments in the crust, scientists can better model the seismic cycle and improve predictions of future activity. Beyond earthquakes, these techniques are instrumental in studying ongoing tectonic processes such as continental drift, mountain building, and the formation of rift valleys.
Another significant contribution of space geodesy is in the validation and refinement of geophysical models of Earth's interior and surface processes. Precise measurements of tectonic plate velocities and deformation patterns inform theories about mantle convection, crustal rheology, and the forces driving plate motions. This integrated understanding helps to contextualize tectonic shifts within broader geodynamic frameworks.
In addition, space geodesy contributes to global efforts to monitor and respond to natural hazards. By providing accurate, high-resolution data on crustal movements, it supports early warning systems for earthquakes and volcanic activity, ultimately aiding in disaster preparedness and resilience. Its applications also extend to monitoring glacial rebound, sea-level rise, and other climate-related processes that influence tectonic behavior.
In summary, space geodesy serves as an essential tool in the modern study of Earth's tectonics. Its ability to produce highly precise, continuous measurements of Earth's surface movements has revolutionized our understanding of tectonic shifts, enabling scientists to better predict, prepare for, and respond to the Earth's dynamic processes. As satellite technology advances, the role of space geodesy in monitoring Earth's tectonic activity will only become more vital, fostering deeper insights into our planet's ongoing evolution.

40. Look through the text. Give its brief contents (preparation time - 15 min.).

Does AI Play Any Role in Space Geodesy? A Case Study of Modern Geodetic Revolution
The integration of artificial intelligence into space geodesy has transformed this precision-driven science from a data-processing discipline into a predictive, self-optimizing system. A compelling case study emerges from the European Space Agency's (ESA) Swarm mission, where machine learning algorithms have revolutionized how we interpret Earth's magnetic field data—demonstrating AI's growing indispensability across geodetic applications.
When ESA launched the Swarm constellation in 2013 to study Earth's magnetic field, scientists faced an unexpected challenge: the satellites' vector field magnetometers required continuous calibration against solar wind disturbances. Traditional physical models struggled with the complex, nonlinear interactions between spacecraft systems and the space environment. The breakthrough came when researchers implemented neural networks trained on historical satellite telemetry and solar activity data. These AI systems now autonomously correct instrument drifts in real-time, improving data accuracy by 35% compared to conventional methods—equivalent to recovering an entire year's worth of scientific observations from the mission's lifespan.
This success story reflects broader AI applications reshaping space geodesy. In satellite orbit determination, recurrent neural networks now predict atmospheric drag effects with 90% greater accuracy than physical models alone, crucial for maintaining precise positioning of geodetic satellites. The NASA-ISRO NISAR mission will employ AI to automatically classify surface deformation patterns from interferometric radar data, distinguishing between earthquake precursors, groundwater extraction effects, and volcanic inflation without human intervention.
Perhaps most remarkably, AI enables synergistic analysis across geodetic techniques. At the German Geodetic Research Institute, a transformer-based model assimilates data from GNSS stations, gravity satellites, and InSAR measurements to predict crustal strain accumulation. During 2021 testing in California, the system identified anomalous deformation patterns along the San Andreas Fault that conventional analysis missed—patterns later confirmed by seismic monitoring networks.
The challenges remain significant: AI models require meticulous training using curated geodetic datasets, and their "black box" nature sometimes clashes with geodesy's demand for metrological traceability. Yet the benefits—automated signal extraction from noisy data, real-time system adjustments, and discovery of hidden patterns in multi-terabyte geodetic datasets—are propelling AI

from auxiliary tool to core methodology. As quantum positioning systems and next-generation gravity missions come online, AI's role will only expand, making space geodesy not just more precise, but profoundly more intelligent about our changing planet.

41. Answer the question

In which fields is space geodesy applied?

42. Answer the question

What principles is GPS based on?

43. Answer the question

Where in everyday life do we see the impact of space geodesy technologies?

44. Answer the question

What global navigation systems are you familiar with?

45. Answer the question

What are the main structural elements of any global navigation system?

46. Answer the question

What event marked the advent of space geodesy?

47. Answer the question

How can space geodesy be defined?

48. Answer the question

Where was the Global Positioning System developed?

49. Answer the question

What event laid the foundation for the Russian GLONASS system?

50. Answer the question

How does space geodesy facilitate maritime and transport navigation?

51. Answer the question

Does space geodesy contribute to Earth monitoring? If so, how?

52. Answer the question

Are you familiar with swarm technology? What does it refer to?

53. Answer the question

What is the principle of precise point positioning—is it based on time or distance signal delay measurement?

54. Answer the question

How many satellites are needed to calculate a point's position?

55. Answer the question

What three techniques form the foundation of space geodesy?

56. Answer the question

Which companies producing geodetic equipment are you familiar with?

57. Answer the question

What are the main tasks of space geodesy?

58. Answer the question

At what stage of space geodesy research is AI currently important?

59. Answer the question

What is the purpose of the Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) mission?

60. Answer the question

What is the name of the Russian global navigation system?