THE LINE OF LIGHT

Sensing at the Brink of Sensibility (2023)

Graduate thesis at the Cooper Union by

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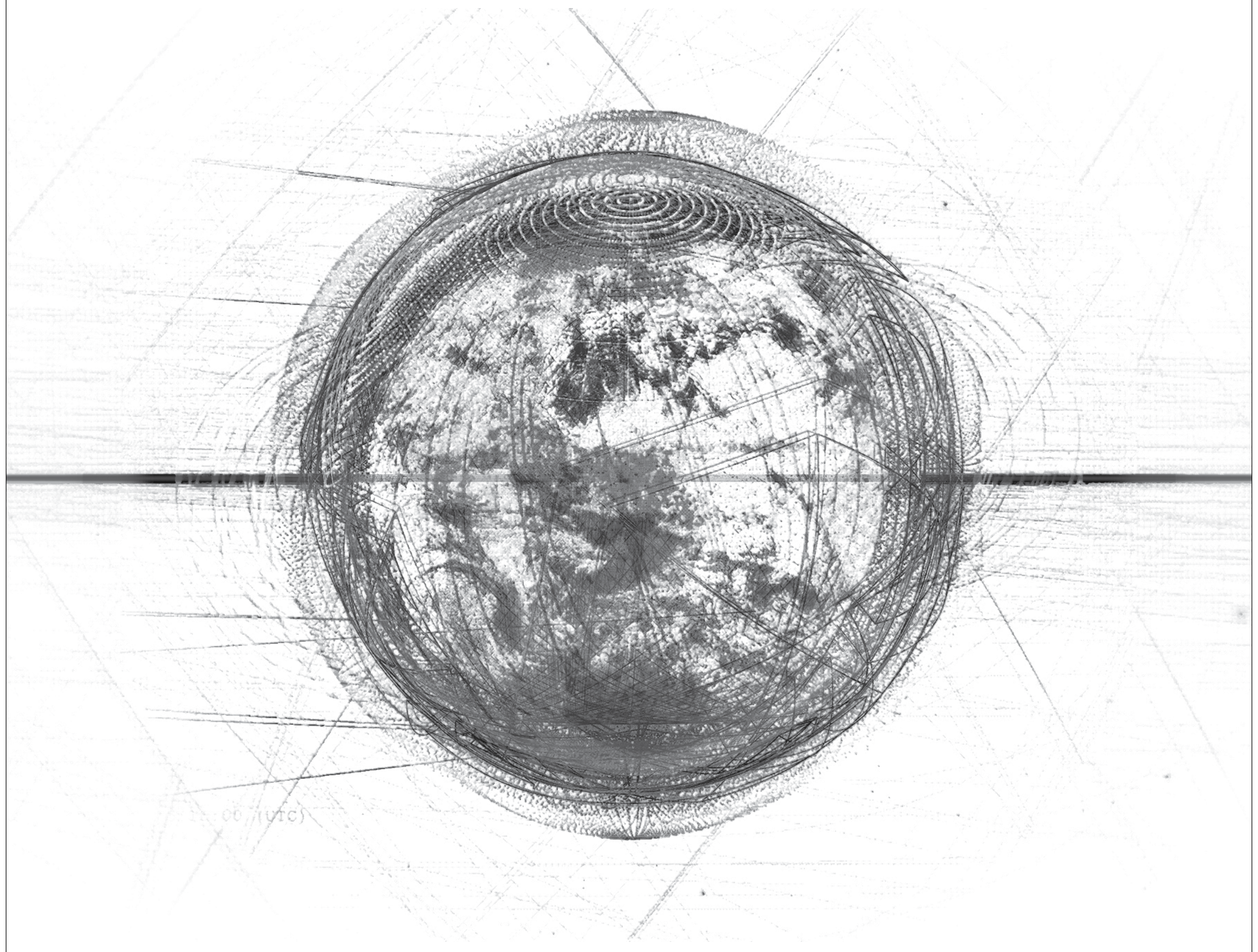


ABSTRACT

We are surrounded by Light and Energy: from visible light to a vast spectrum of radiation, electromagnetic waves propagate the space around us, constantly traveling and transmitting energy. Most of these waves are invisible to the human eye, yet they enable us to sense beyond human sensorium by mediating between sensor and invisible matter, as if they communicate in a different dimension.

Modern technologies rely on these invisible energy transmissions, as exemplified by the ubiquitous integration of satellite communication from transportation and geolocation to information and data management. While the satellites orbit the Earth each at a different distance and direction, tethered by gravity, together they form a network so efficient that we rely on it for reference constantly. It marks a shift within the systems of sensing, particularly how their framework transitioned from tangible to abstract, from macro-scale to micro-scale. This phenomenon challenges the concept of territory by terrestrial marking, and prompts a new Copernican inquiry into the situation of Earth and our situation within it.

This project is a series of investigation of the media and representation of Earth within digital context. By questioning the instances where the numerical binary draws a line, it aims to reveal the alienation between technological detection-measurement and human sensorium, and further unveil the power structure that upholds the systems of sensing.

From the launch of Sputnik to the moon landing, space expeditions have been instrumental in the advancement of society. Like aviation, material science, information technology, innumerable industries carry the legacy of space technology, embodying a shared ideology from the space age: to transcend beyond earthly conditions.

Meanwhile our vision of the Earth evolves as new discoveries emerge. Photographs of the Earth captured onboard Apollo missions exposed the duality of our space aspiration, which was not only an expedition to travel and see further, but to also look back at the Earth from a distance. Rising against the line of gravity and into space, these vessels of transcendence alleviate the weight of the human condition.

The origin of the International System of Units dates back to the 18th century, and the units were originally derived from the properties of Earth: meter relates to the distance between the equator and poles, second to the period of rotation.

Since the 1980s, these units have been redefined by a series of abstracted constants, with references to invisible phenomena at the micro atomic scale.

Standardized systems of measurement allow us to communicate across realms of time, culture, discipline etc. However as our scope of knowledge expands into the vast universe, these measures are no longer adequate. While concepts like length, weight, and time interval are still relevant and sufficient for daily life, sensing at a planetary scale operates in a different realm. The universe challenges the universality of a system to which our sensibilities have become attuned; we hesitate to draw the line

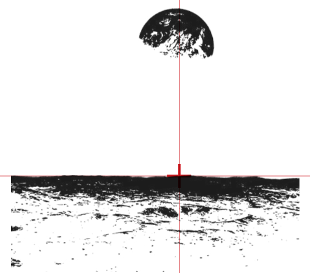
A more accurate definition of the term would be “the electromagnetic spectrum”; it encompasses all forms of radiation within the infinite range of wavelengths. Defined as 299,792,458 m/s in the International System of Units (ISU), the speed of light marks the boundary of our sensing capacity. All forms of electromagnetic radiation travel at the speed of light. Adopted as a constant by the ISU, it is the sole reference for the definition of speed. A fraction of the speed of light, denoted by the arbitrary number of 1/299,792,458, establishes the unit of meter per second.

Light is the ultimate unit of measurement.

ATLAS

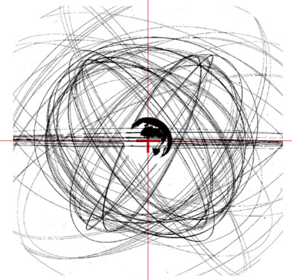
THE LINE OF LIGHT

HORIZON



EARTHRISE

Apollo and the Genesis of World-Image

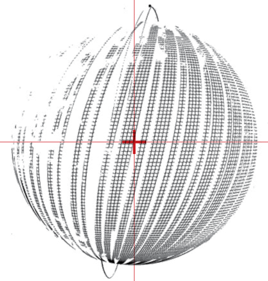


APOLLO'S EYE

Gaze Turned Inwards

ORBIT, SCENE, RESOLUTION

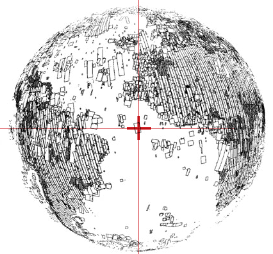
Landsat and Optical Imaging



THE LINE OF SIGHT

LATENT VISION

Synthetic Aperture



SEA LEVEL

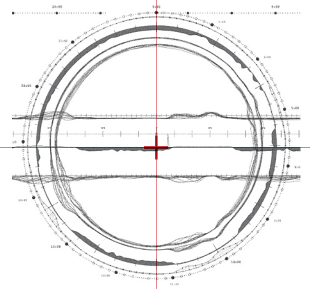
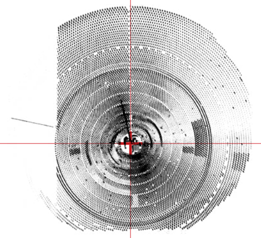


IMAGE TERRITORY

Land, Ocean, Coastline and Shoreline

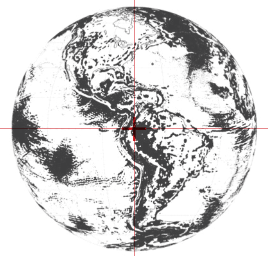


FACTORY OF THE SUN

Energy and the Image of Attention

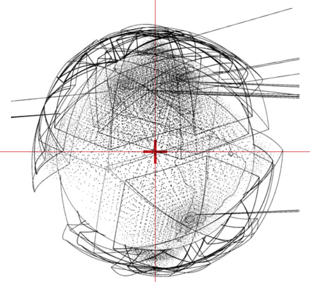
GRAVITY AND GRACE

Gravity Recovery and Climate Experiment



GROUND AND NETWORK

Equatorial Lines of Communication



EQUATOR

THE LINE OF GRAVITY

ATLAS

EARTHRISE

Apollo and the Genesis of World-Image

SYNOPSIS

The horizon has been the extent of human vision of the world; that was until the age of space. On October 4, 1957, the Soviet Union launched the first artificial satellite Sputnik 1, signaling the dawn of an era characterized by technological advancements, spurred by the space race between the United States and the Soviet Union.

The Apollo program was one of the most significant projects carried out by NASA, with its primary goal of landing humans on the Moon. The Apollo missions not only laid the technological groundwork for later satellite technology, the many experiments taking place onboard also led to other initiatives. From Earthrise to the Blue Marble, we began to perceive Earth as a unified entity, unrestricted by the horizon, illuminated with visible lights, and absent of borders. Since then, space imaging has profoundly shifted the paradigm of cartography. The demarcation of territory is intertwined with another dimension, and the lines become indistinct.

EARTHRISE

Earthrise was taken on December 24, 1968, by Apollo 8 astronaut William Anders. Along with The Blue Marble, taken by the crew of Apollo 17 four years later, Earthrise was the icon of environmental movements of the 1970s.

The photograph was included in *100 Photographs that Changed the World* by *Life* magazine in 2003.

> It is possible to see that Earthrise marked the tipping point, the moment when the sense of the space age flipped from what it meant for space to what it means for Earth.
> — Robert Poole, 2008

READING OF GENESIS

On the same day Earthrise was captured on Christmas Eve of 1968, the crew of Apollo 8 read from the Book of Genesis as they orbited the moon. The reading was broadcasted globally and reached people in more than 30 countries.

> [T]hey took turns reading..., ceremonially dedicating humanity's foray off its home planet to the principles of medieval creationism.
> — Benjamin H. Bratton, 2019

[Bill Anders]

We are now approaching lunar sunrise, and for all the people back on Earth, the crew of Apollo 8 has a message that we would like to send to you.

In the beginning God created the heaven and the earth.
And the earth was without form, and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters.
And God said, Let there be light: and there was light.
And God saw the light, that it was good: and God divided the light from the darkness. (1:1-4)

[Jim Lovell]

And God called the light Day, and the darkness he called Night. And the evening and the morning were the first day.
And God said, Let there be a firmament in the midst of the waters, and let it divide the waters from the waters.
And God made the firmament, and divided the waters which were under the firmament from the waters which were above the firmament: and it was so.
And God called the firmament Heaven. And the evening and the morning were the second day. (1:5-8)

[Frank Borman]

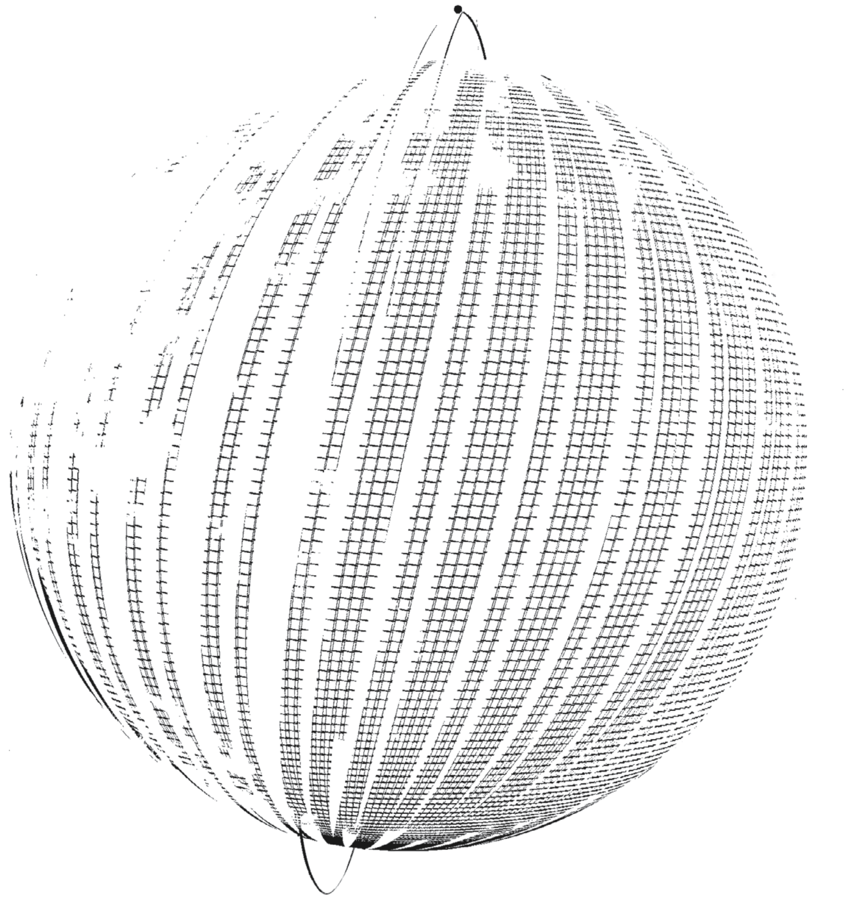
And God said, Let the waters under the heaven be gathered together unto one place, and let the dry land appear: and it was so.
And God called the dry land Earth; and the gathering together of the waters called he Seas: and God saw that it was good. (1:9-10)

And from the crew of Apollo 8, we close with good night, good luck, a Merry Christmas — and God bless all of you, all of you on the good Earth.

— Genesis 1:1-10, King James Version

ORBIT, SCENE, RESOLUTION

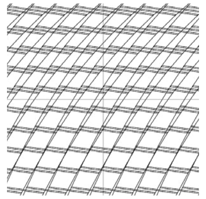
Landsat and Optical Imaging



The curiosity sparked by the Apollo missions' legacy led to the launching of Landsat, a satellite mission designed to observe and document Earth's geographical conditions using optical imaging technology.

Landsat orbits in a near-polar, sun-synchronous path, enabling it to cover most of Earth's surface as the planet rotates. Simultaneously, the satellite's orbit remains synchronized with the sun, ensuring a consistent relationship between the satellite and the sun. The satellites are equipped with sensors that capture electromagnetic radiation including not only visible wavelengths, but also infrared and thermal bands. These sensors collect data as the satellite orbits; the data is subsequently rendered into images that represent land conditions. Each Landsat scene maintains a consistent size, measuring approximately 170 km (106 miles) north-south and 183 km (114 miles) east-west. However, due to its near-polar orbit, Landsat's coverage is unequal, leading to more frequent imaging of certain areas and leaving others as blind spots.

LANDSAT ORBIT PATH (ASCENDING)



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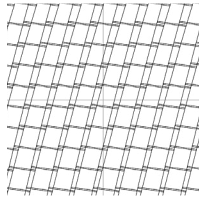

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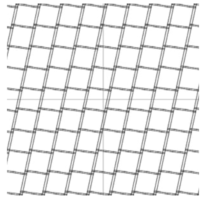

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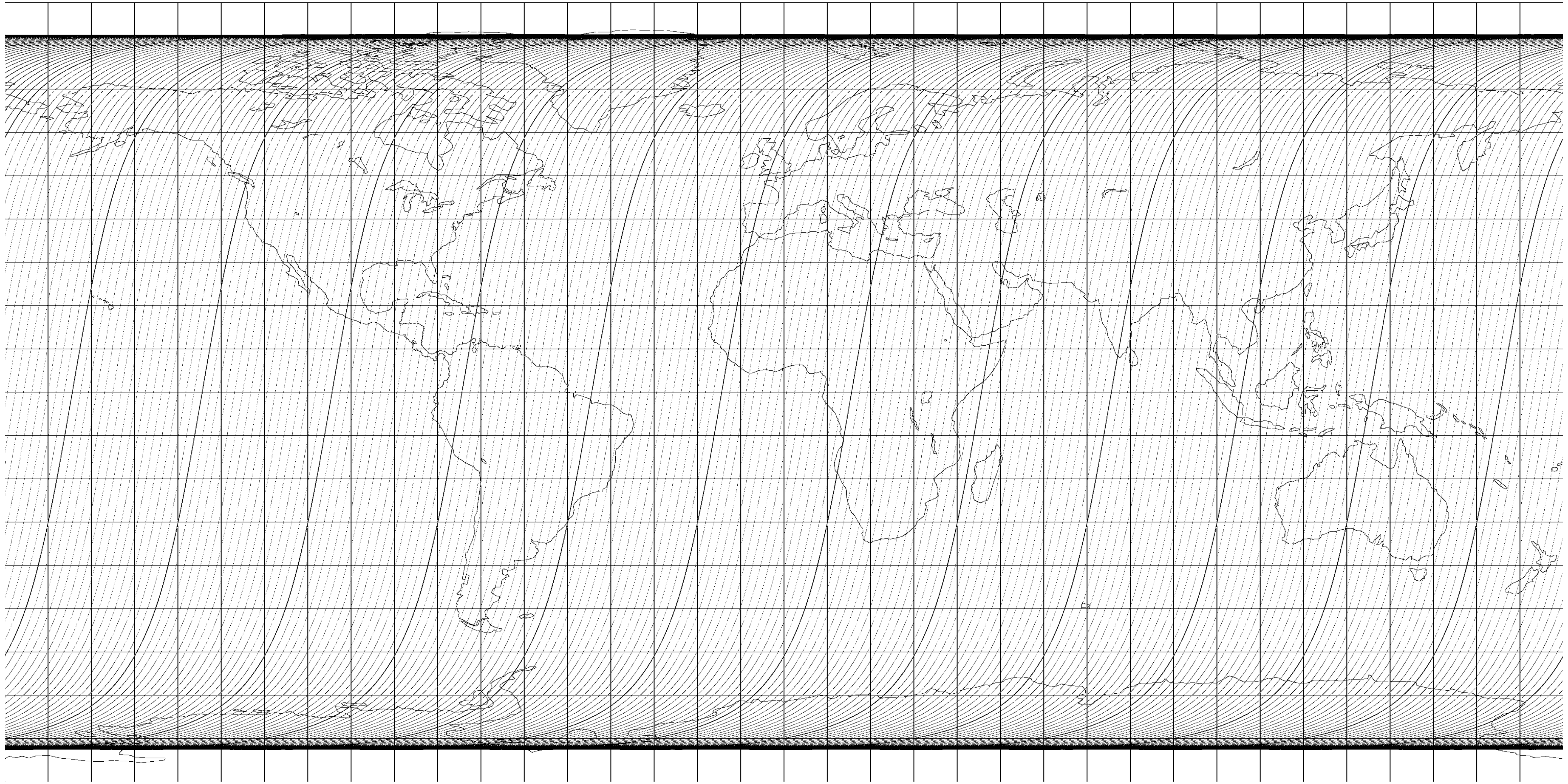
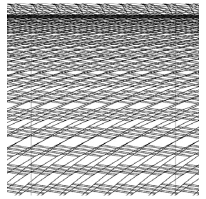
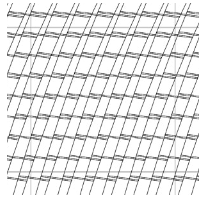
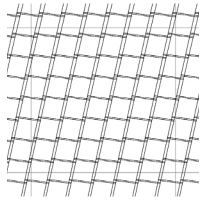




75°N

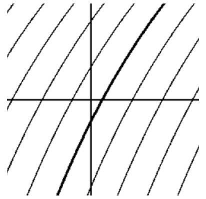


45°N



15°N

LANDSAT SCENE PATH (ASCENDING)



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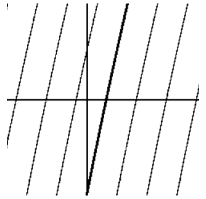
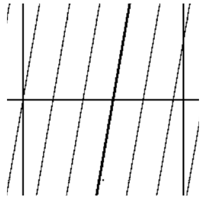
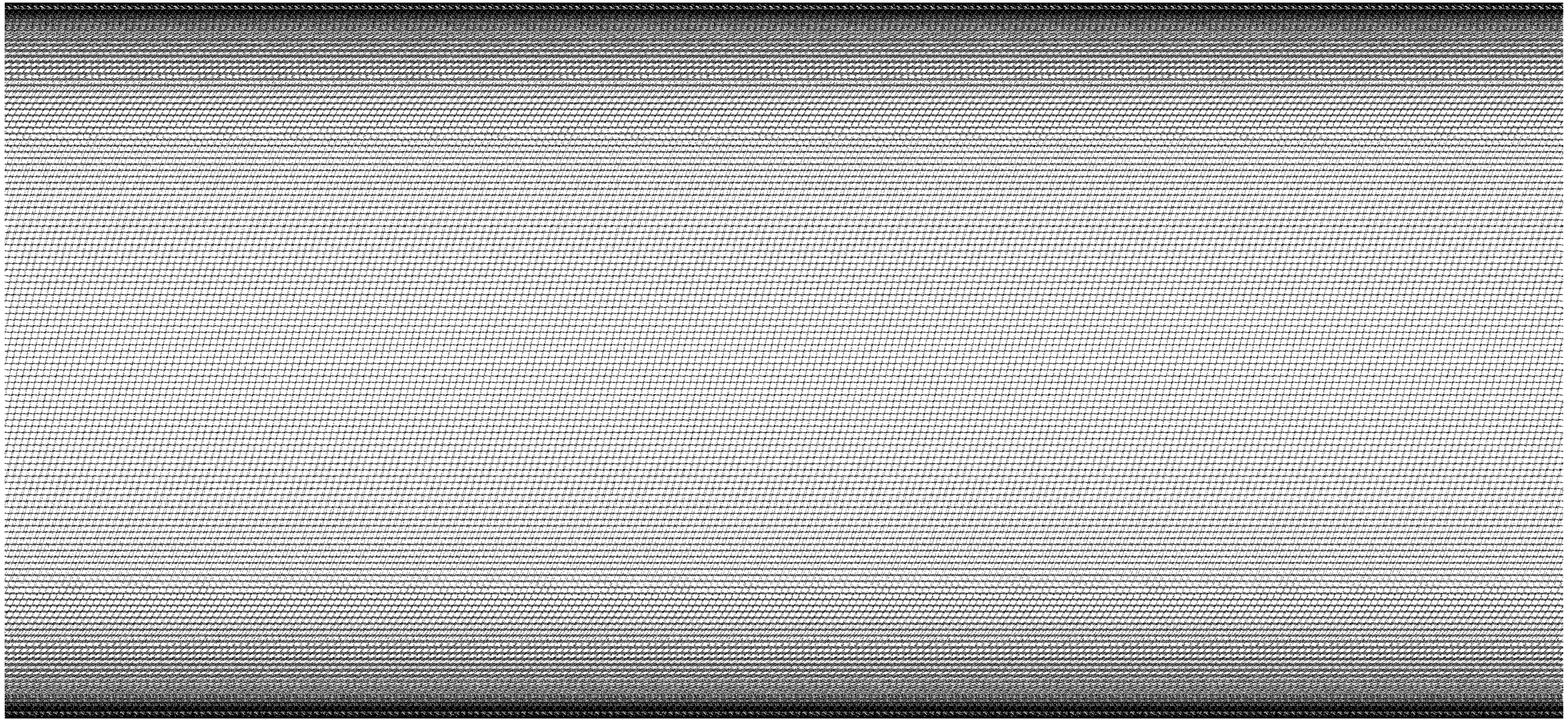
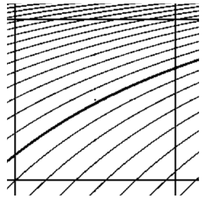


30°N



0°N





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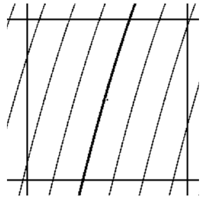

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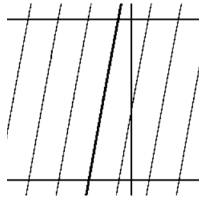
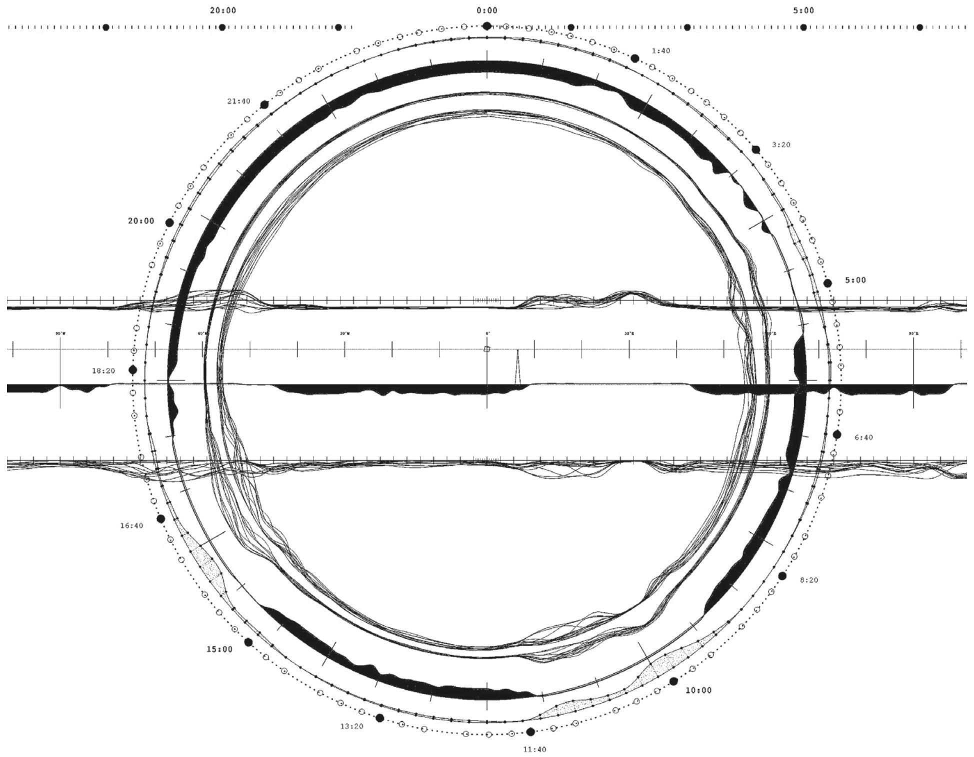


15°N

IMAGE TERRITORY

Land, Ocean, Coastline and Shoreline

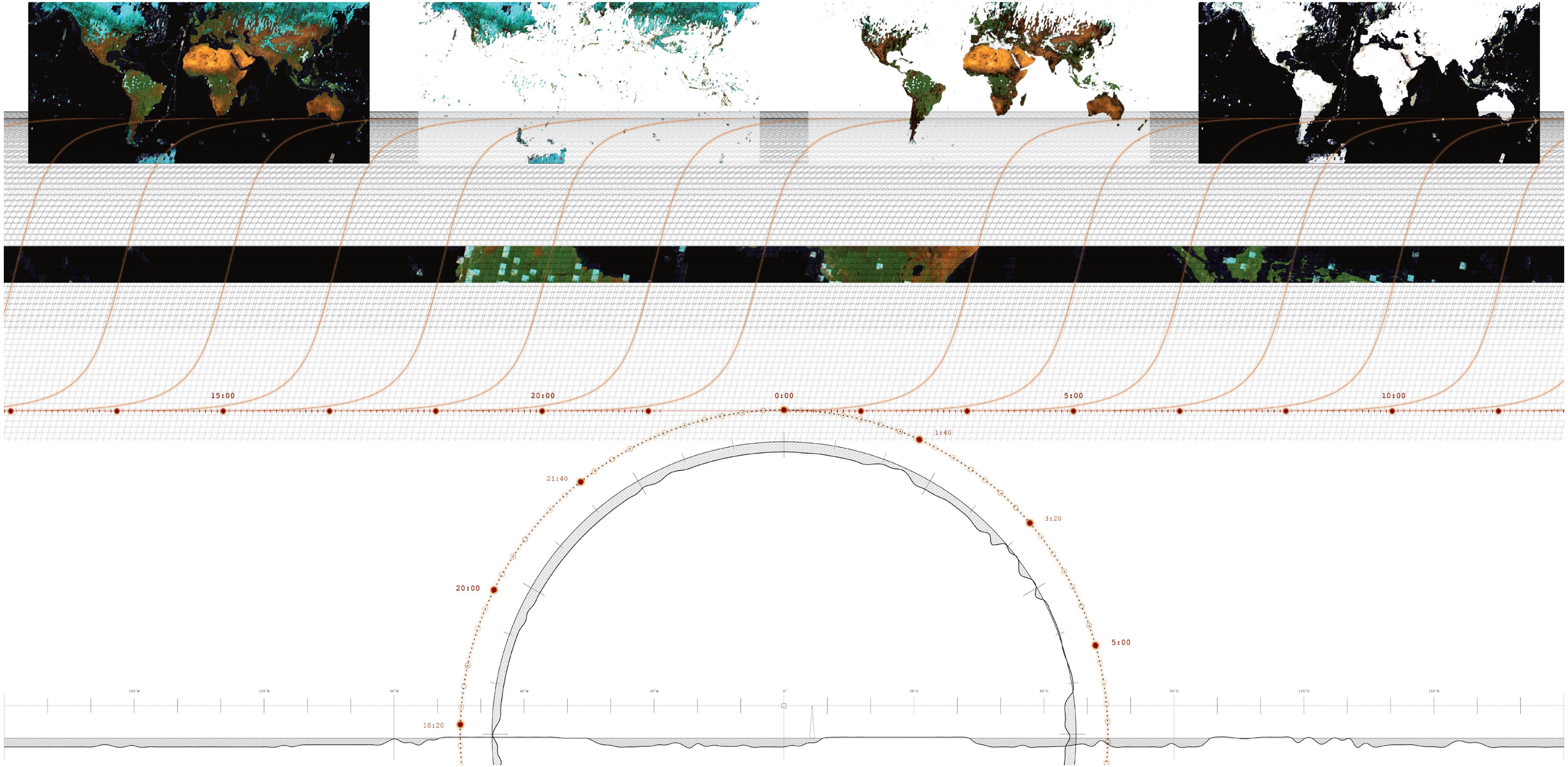


SYNOPSIS

While Landsat’s main emphasis is on capturing images of the Earth’s land surface, its orbital pattern implies an inherent homogeneity.

Conventional cartography employs maps for demarcating territories on land and bathymetric charts for navigating through the ocean. However, satellite images do not inherently connotes those purposes. Their primary focus revolves around mediating the depth of atmosphere to capture the Earth’s surface and differentiate geographic features through visual rendition.

In principle, a satellite image does not register land and ocean as seperate territories in representation. Yet the advantages and limitations of optical satellite imaging are inherently dictated by the nature of the medium itself. Ocean becomes the blind territory for optical imaging. The brink of its sensing capacity coincides with coastlines, signifying a particular ambiguity.



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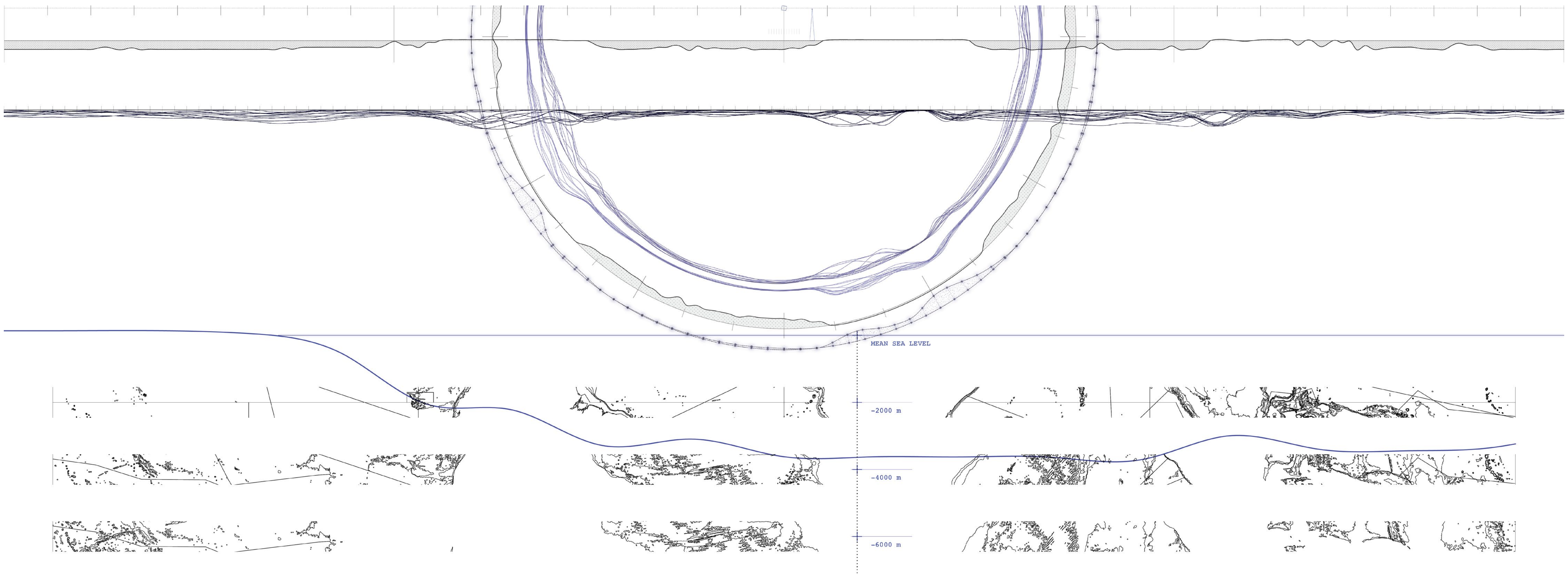
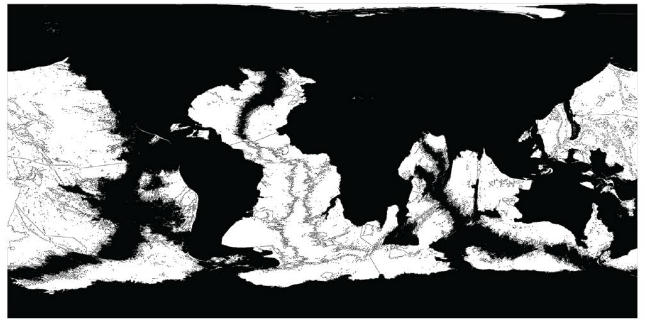
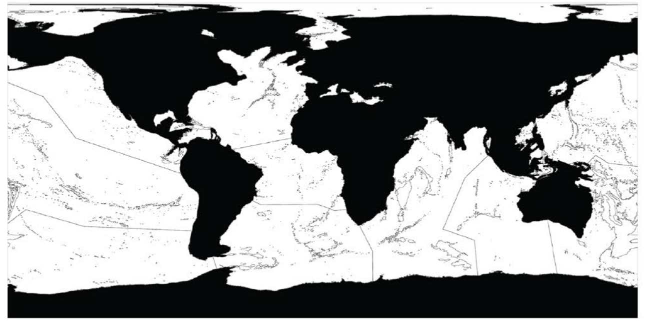


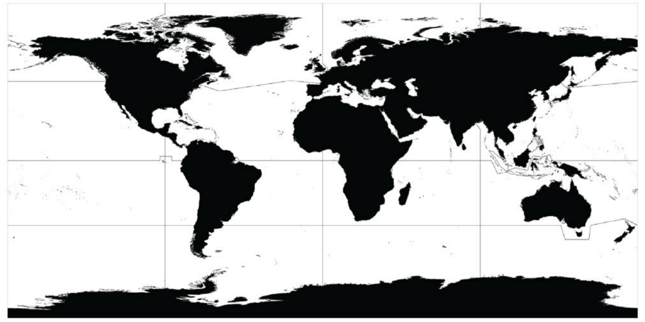
-6000 m



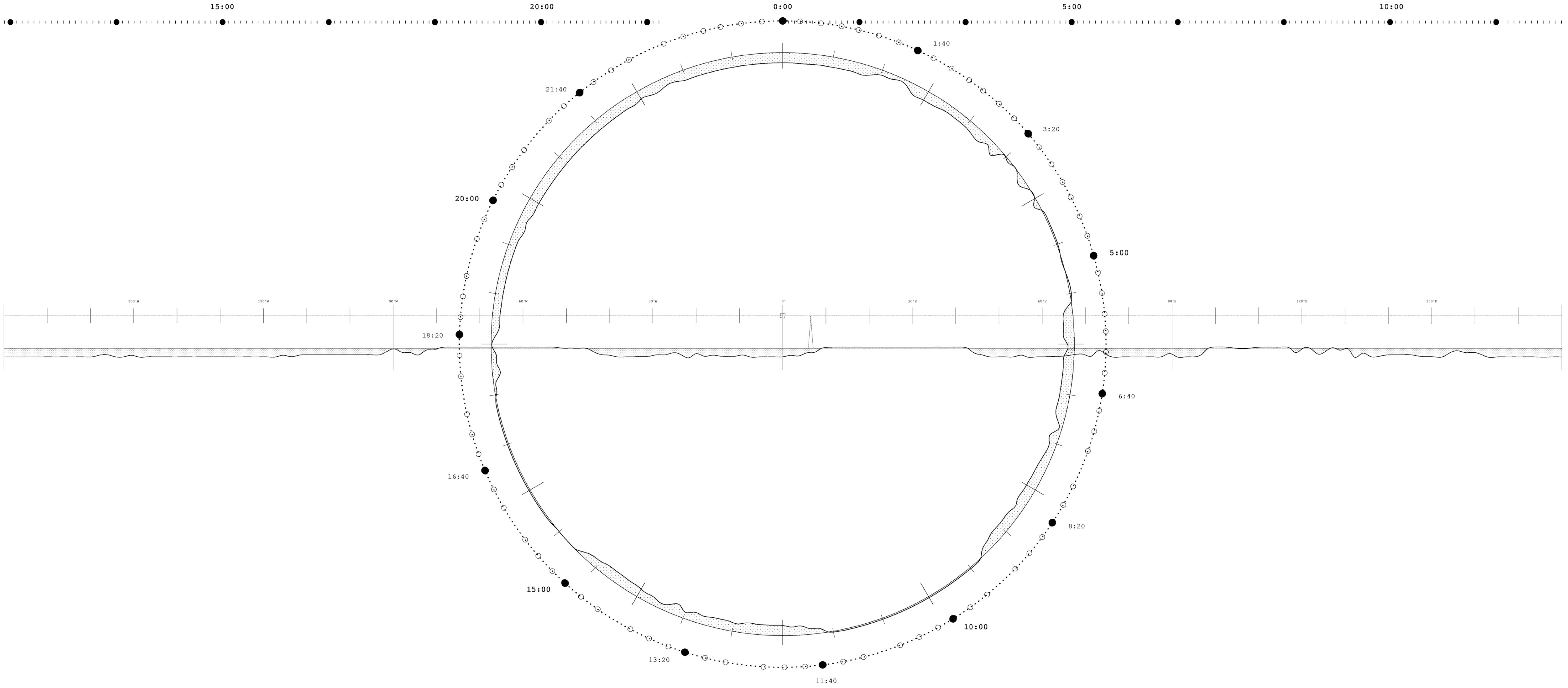
-4000 m



-2000 m



MEAN SEA LEVEL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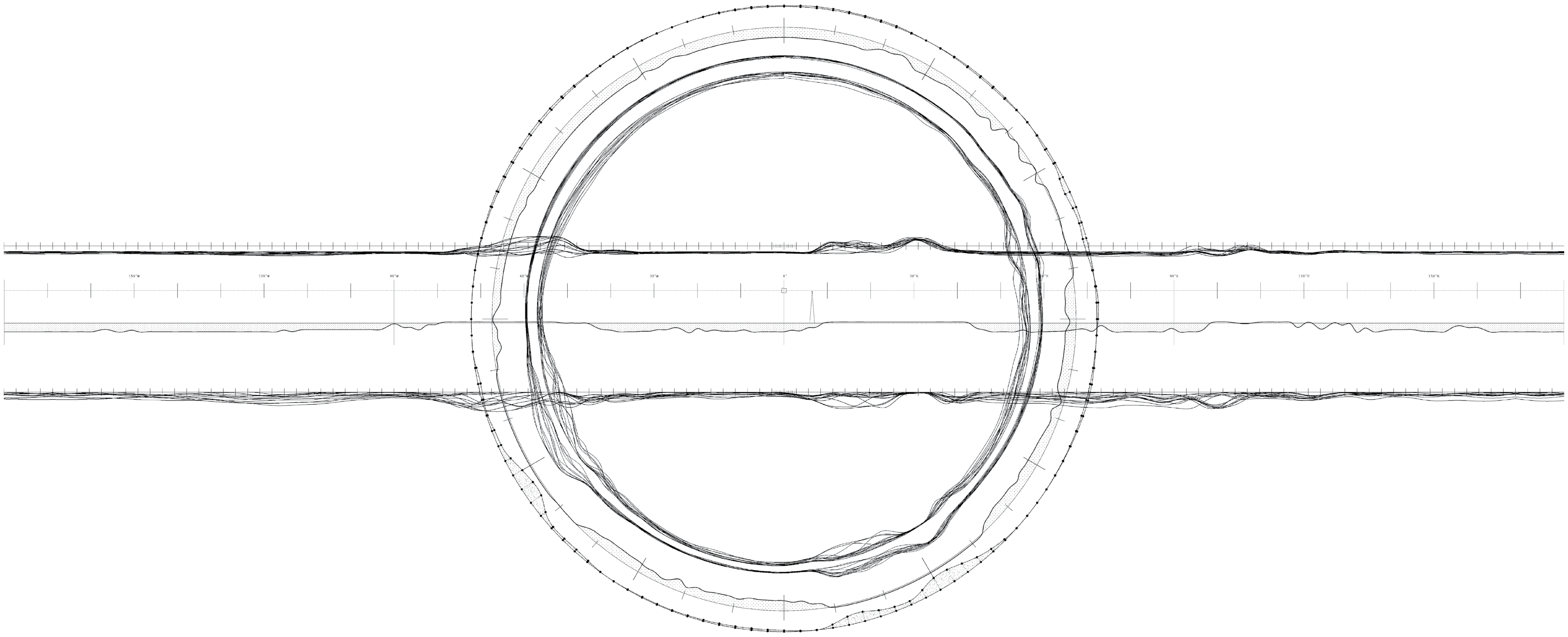
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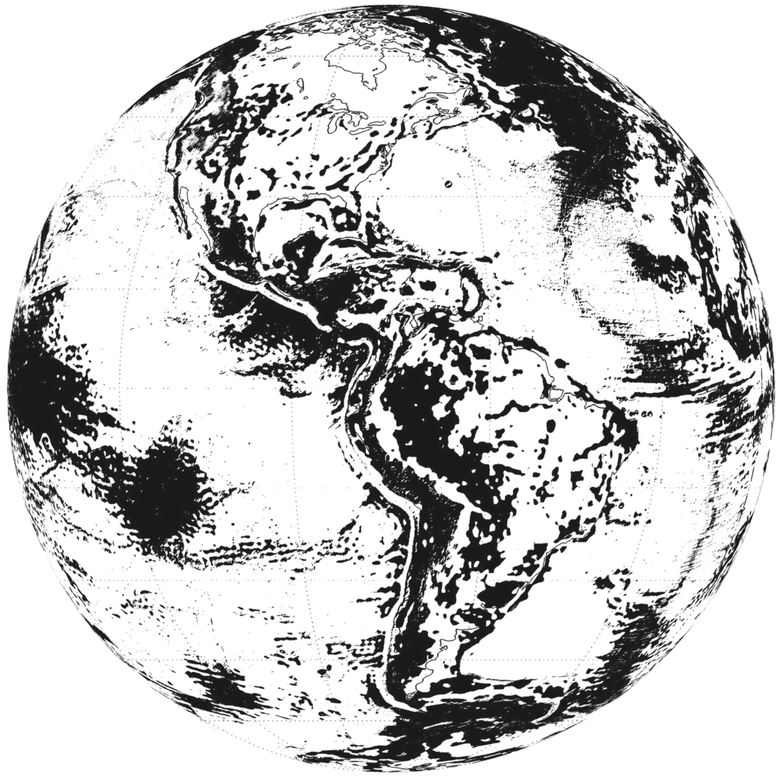
GRAVITY AND GRACE

The Gravity Recovery and Climate Experiment



The Gravity Recovery and Climate Experiment (GRACE) is launched in March 2002 by NASA. The mission consists of two twin satellites, orbiting along the same trajectory at a consistent speed, one after the other. The two satellites continuously monitor and measure their distance between one another. At anytime, changes in their relative positions would indicate gravity anomaly: when the leading satellite encounters a change in the distribution of Earth's mass, gravity pulls it away from its projected trajectory while the trailing one remains and detects the deviation.

The GRACE satellites launched in 2002 were replaced in 2018 by GRACE-FO to carry on the same mission. Initiated as an experiment to observe gravity, GRACE-FO has since expanded its scope to utilize the data for climate analysis and tracking water movement across the globe.

The flux in water mass causes gravity to constantly change across the globe, along with the LINE that is the sea level. By observing it, GRACE destabilizes the constant that is Earth gravity.

For mapping anomaly, a model of “norm” is established, which will serve as the baseline. For gravity, the baseline is the “mean gravitational field”, which is derived from averaging long-term gravitational conditions. The method of averaging is common and usually entails sampling across an expanded range of data, whether it’s a long period of time or a large area. The baseline marks the numerical “0” where everything is measured from. In a larger context, the mean sea level determines the plane of 0 in height where topographic measurement builds upon. As GRACE zooms in incredibly closely into the baseline and measures with great precision, it reveals the minuscule range of oscillation, which transforms the concept of baseline completely.

Dehomogenizing gravity furthers the distinctions between ocean and land, as water becomes the indicator for gravity. As Newton’s universal law of gravitation states, gravitational force is proportional to mass; and “mass changes can be thought of as concentrated in a very thin layer of water thickness changes near the Earth’s surface“ (NASA JPL), gravity anomaly is indicated by the property of Equivalent Water Thickness (EWT), in the unit of centimeter.

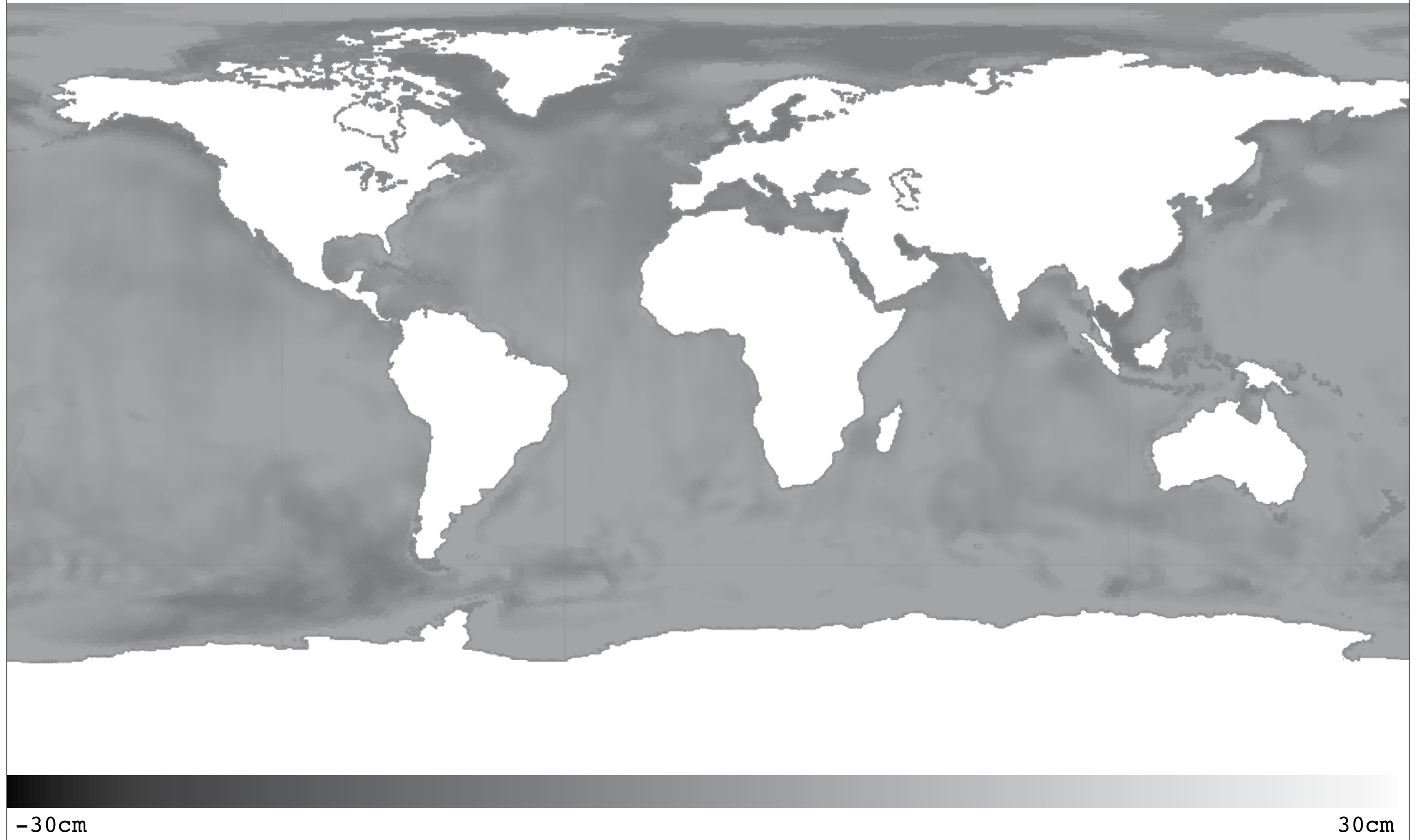
Data collected from GRACE and GRACE-FO are released in two separated sets, OCEAN and LAND, with varying scales. The OCEAN grids map EWT ranging from -5cm to 5cm, the LAND grids are at a greater scale of -30cm to 30cm; since water movements would affect the land more significantly. This difference is also reflected in data processing methods for the two separate data sets, in regards to range and exactitude.

Panta Rhei (“Everything flows”).
— Heraclitus

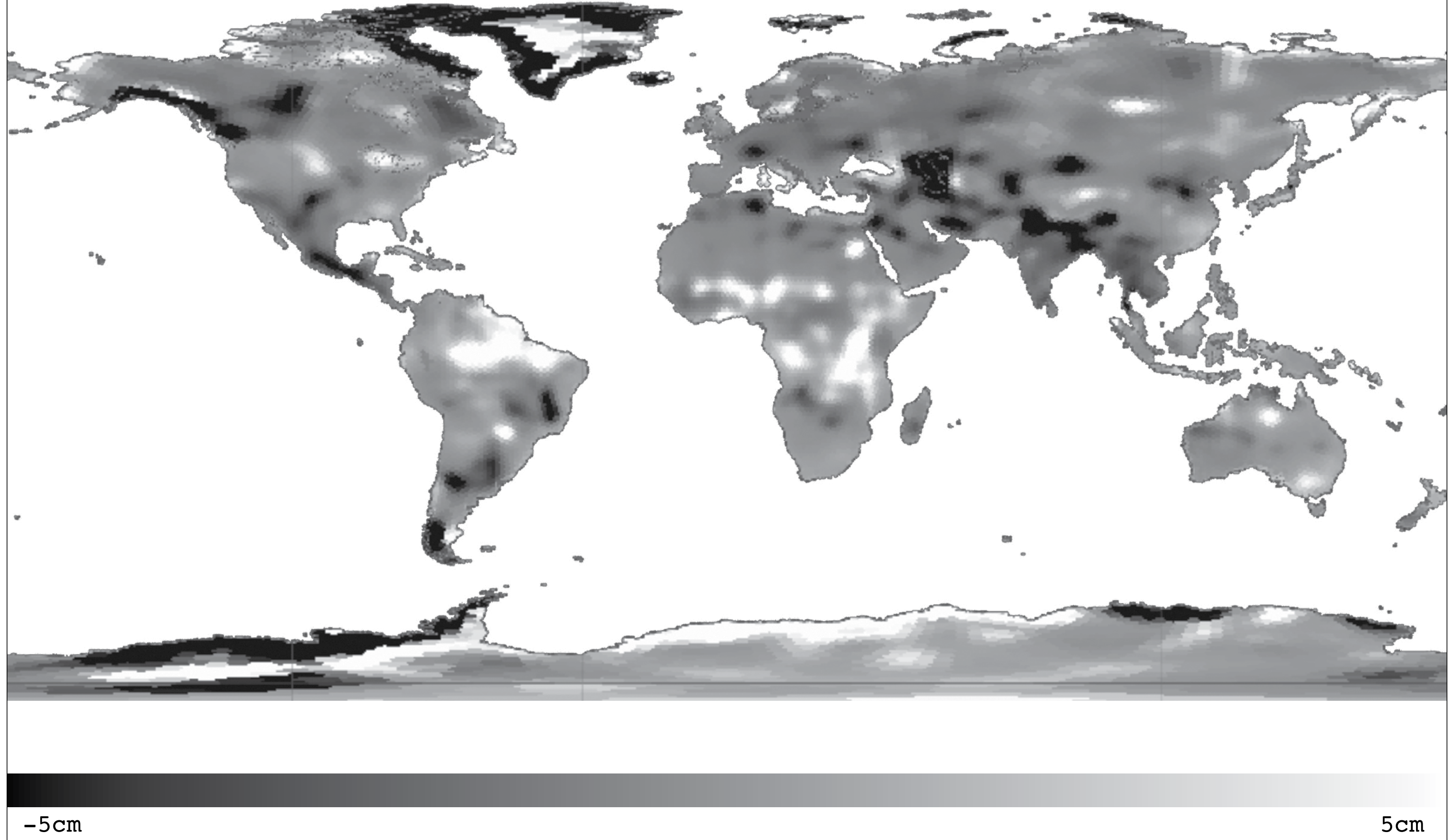
An ocean model is used to remove high frequency (6-hourly to sub-monthly) wind and pressure-driven ocean motions that might otherwise alias into the monthly gravity solutions. The resulting gravity fields would not reflect ocean variability if the model were perfect.
— “Overview - Monthly Mass Grids.” NASA JPL

Although the Earth’s surface is not uniform, for the most part, the variations are constant over very long time intervals.
— “Gravity/Gravitational Field.” NASA JPL

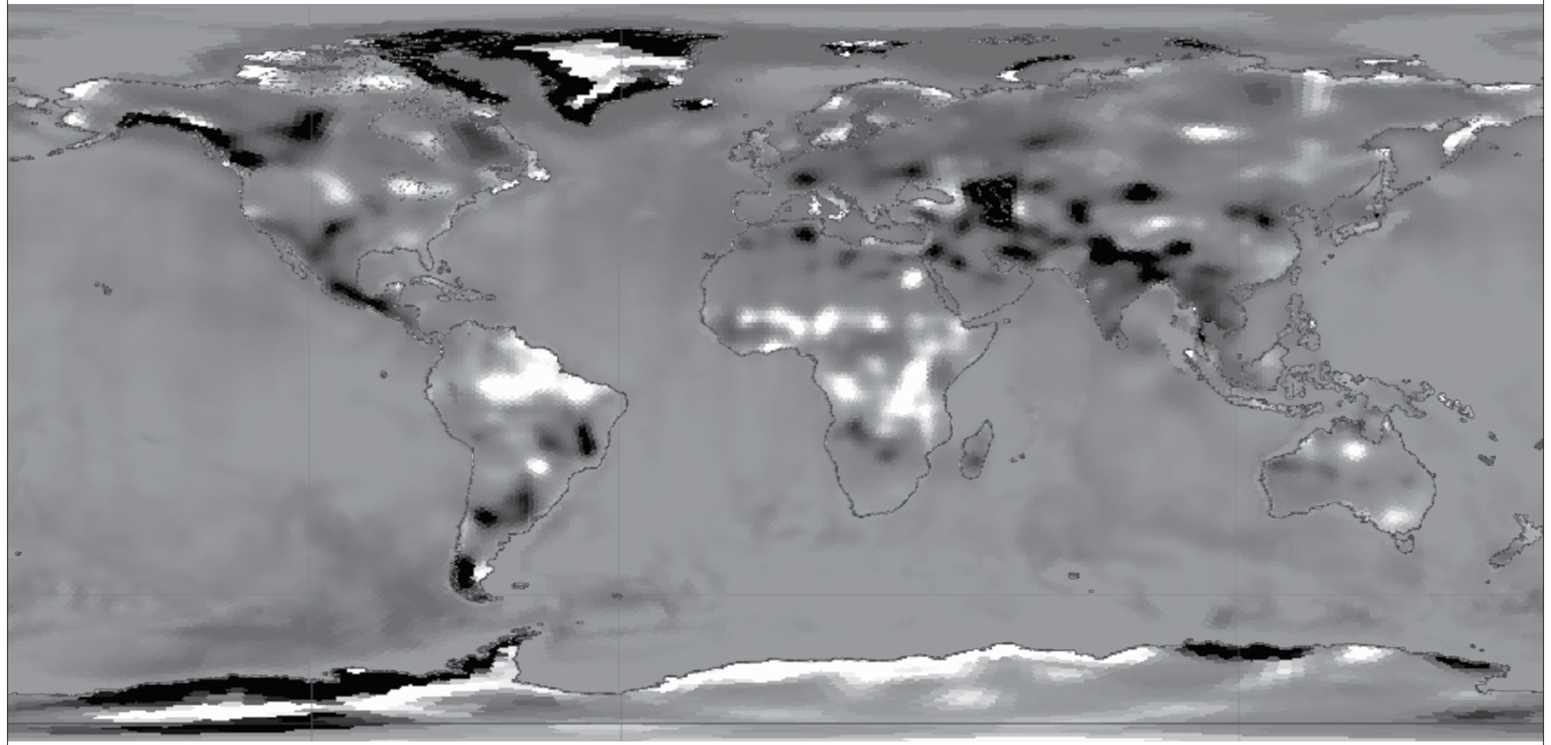
MONTHLY MASS GRIDS - OCEAN



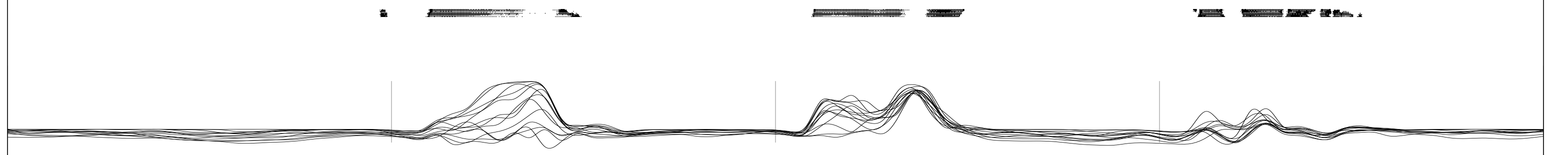
MONTHLY MASS GRIDS - LAND



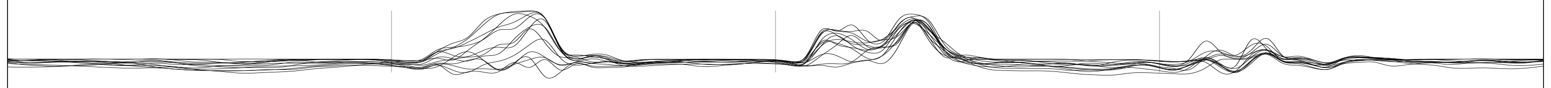
EWT [-30CM, 30CM]



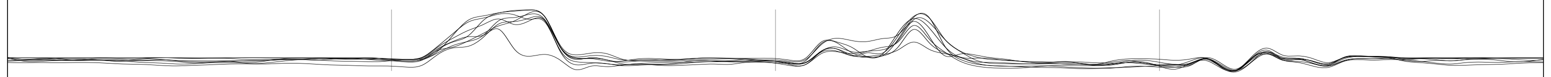
Equatorial Land Gravity Anomaly



Land-scale Gravity Anomaly

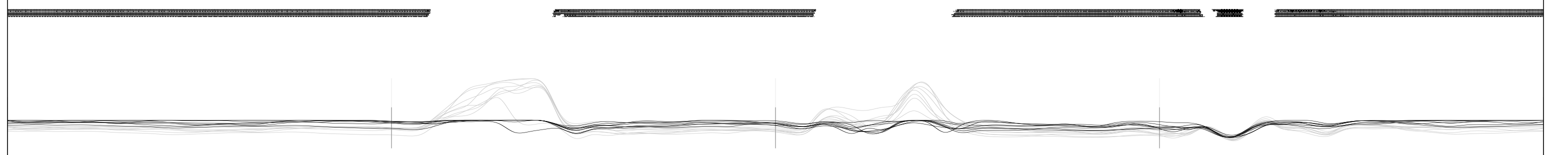


2022/06-2023/06 - monthly

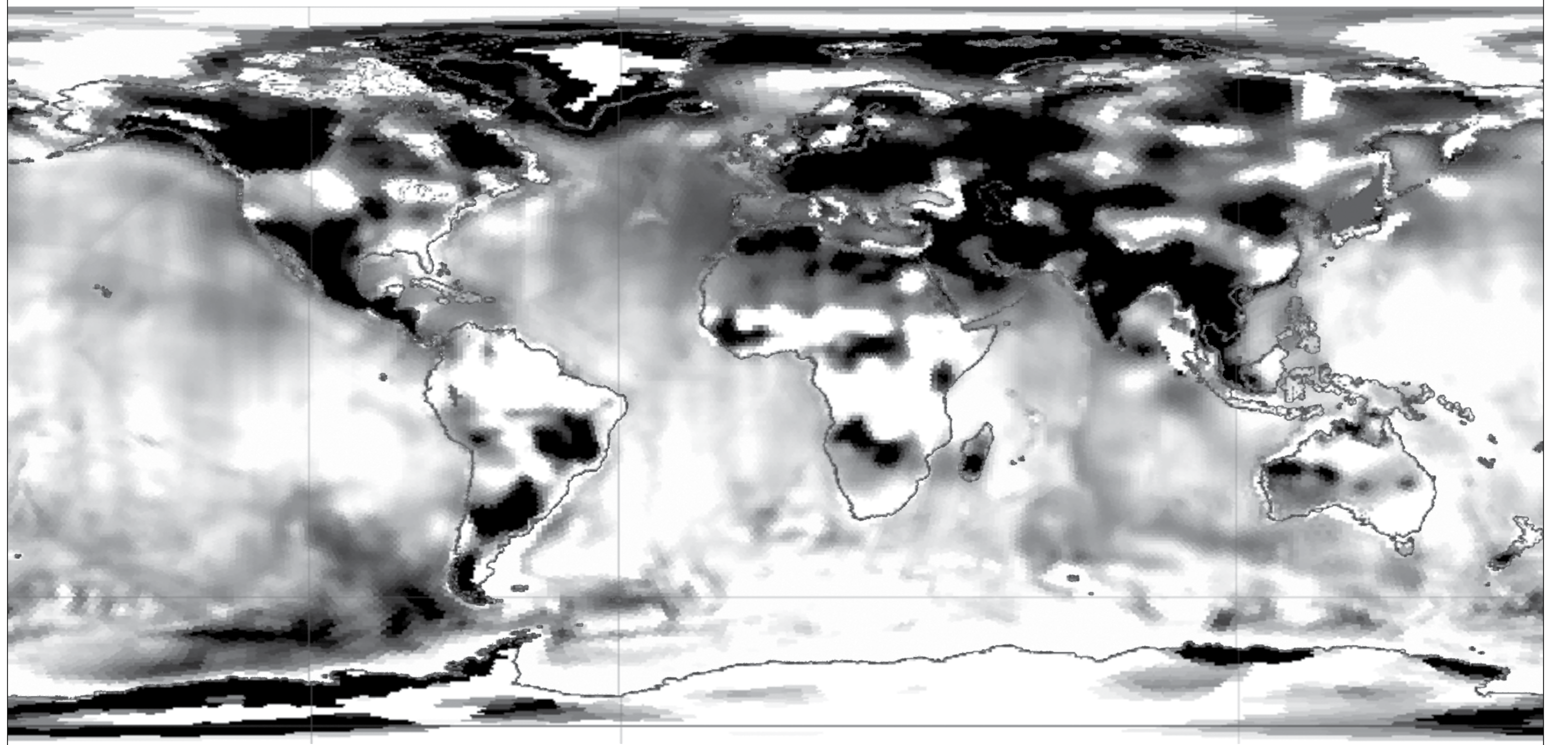


2017/06-2023/06 - annual

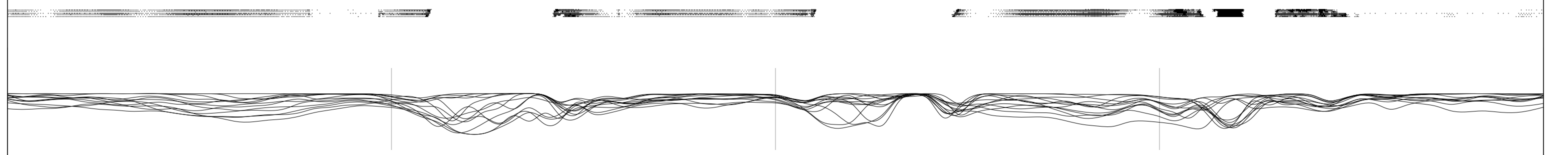
Land-scaled Global Gravity Anomaly



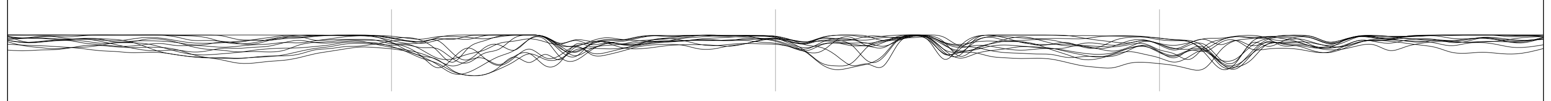
EWT [-5CM, 5CM]



Equatorial Ocean Gravity Anomaly



Ocean-scale Gravity Anomaly



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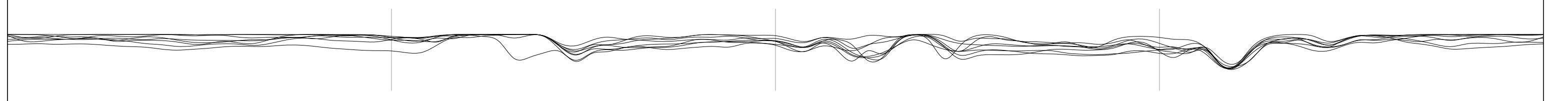
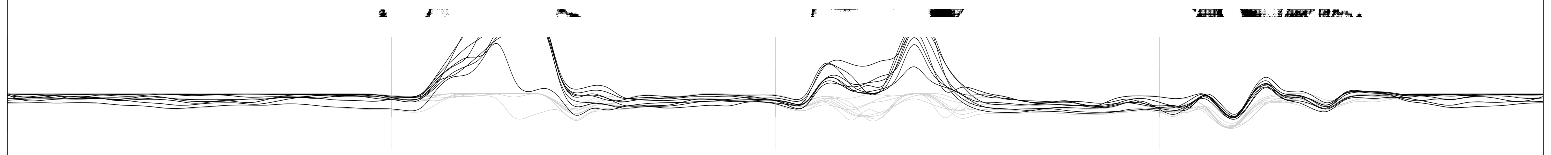


2017/06-2023/06 - annual

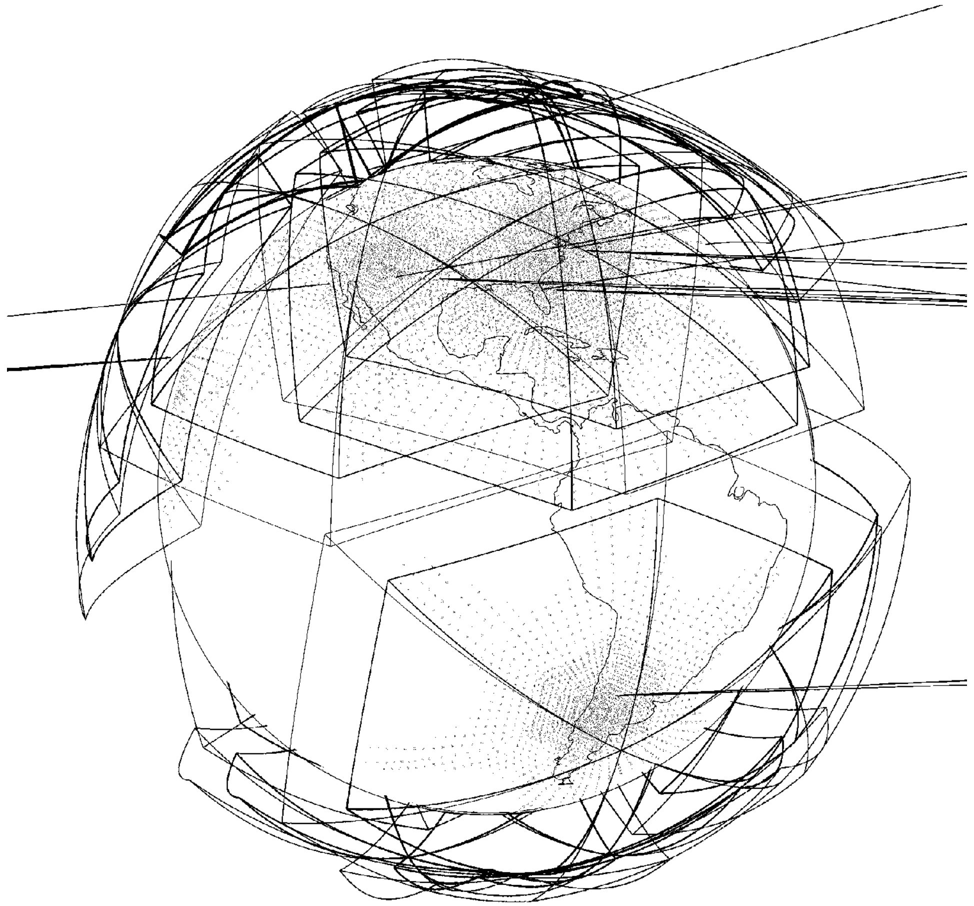
Ocean-scaled Global Gravity Anomaly



Every instrument of sensing is tuned to a certain range and level of precision, with consideration to its subject. The larger-scale baseline for land is stabilized by the vastness of the ocean; when this baseline is destabilized, the mapping of land flux is affected greatly. Within the same scope, mass flux of land ranges much greater than that of ocean; on the other hand, measuring ocean mass flux calls for greater precision.

GROUND CONTROL

The Near Space Network



SYNOPSIS

The populating satellite networks and their ever-expanding capacity to monitor and measure the Earth bring about a Copernican question on Earth's position: while satellites orbit along a trajectory tethered by the Earth's gravity, space-based experiments like GRACE challenge the position of Earth as the sole reference point. Since none of Earth's property is not absolutely constant, the system of control requires further references.

A series of satellites form a network; they track their relative positions between one another in order to calibrate, reposition, and altogether stabilize the system within the network. Ground stations constitute a segment of this network and function as communication terminals on the ground, tethering the space elements to Earth. While the satellites are constantly calibrating the position of Earth, they are also being calibrated and repositioned by the ground stations. The network is strategically dispersed across the globe to provide sufficient reference points for every satellite at any time.

NASA	National Aeronautics and Space Administration
SANSA	South African National Space Agency
KSAT	Kongsberg Satellite Services
SSC	Swedish Space Corporation

NASA

Alaska Satellite Facility, Fairbanks, Alaska	64.8600383157049°N 147.8488712812279°W
Kennedy Uplink Station, Florida	28.521975070471886°N 80.681423028512°W
McMurdo Station, Antarctica	77.84633000408735°S 166.6678817048752°E
Ponce de Leon Station, Florida	29.067123767530205°N 80.9131372765235°W
Wallops Ground Station, Virginia	37.946375883862814°N 75.4587819912013°W
White Sands Ground Station, New Mexico	32.50585272651342°N 106.61236214008167°W

SANSA

Hartebeesthoek, South Africa	25.890403826622656°S 27.684842459086468°E

KSAT

Sentosa Satellite Station, Singapore	1.2476771245998823°N 103.83714822697583°E
Svalbard Satellite Station, Norway	78.22994270545938°N 15.407700169319668°E
Troll Satellite Station, Antarctica	72.01108128985531°S 2.533986645442668°E

SSC

Kiruna, Sweden	67.84748661113684°N 20.260240488460962°E
Santiago, Chile	33.14919349010179°S 70.66674426989752°W
Dongara, Australia	29.046246°S 115.3448523°E

GEO Geosynchronous Equatorial Orbit, Geostationary;
Positions on 2023/11/23.

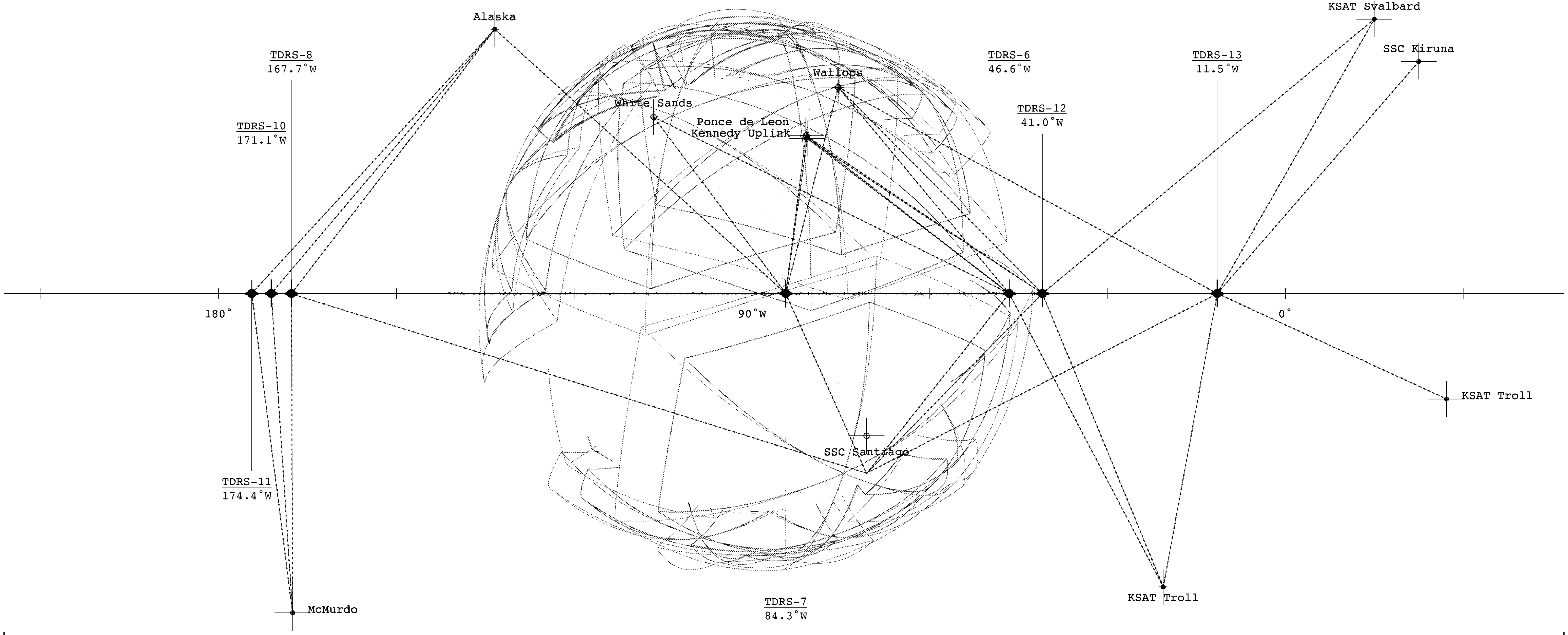
[Retired]

TDRS-1	91.0˚W
TDRS-2	N/A
TDRS-3	48.8°W
TDRS-4	164.3˚W
TDRS-5	166.6°W
TDRS-9	71.8°W

[Active]

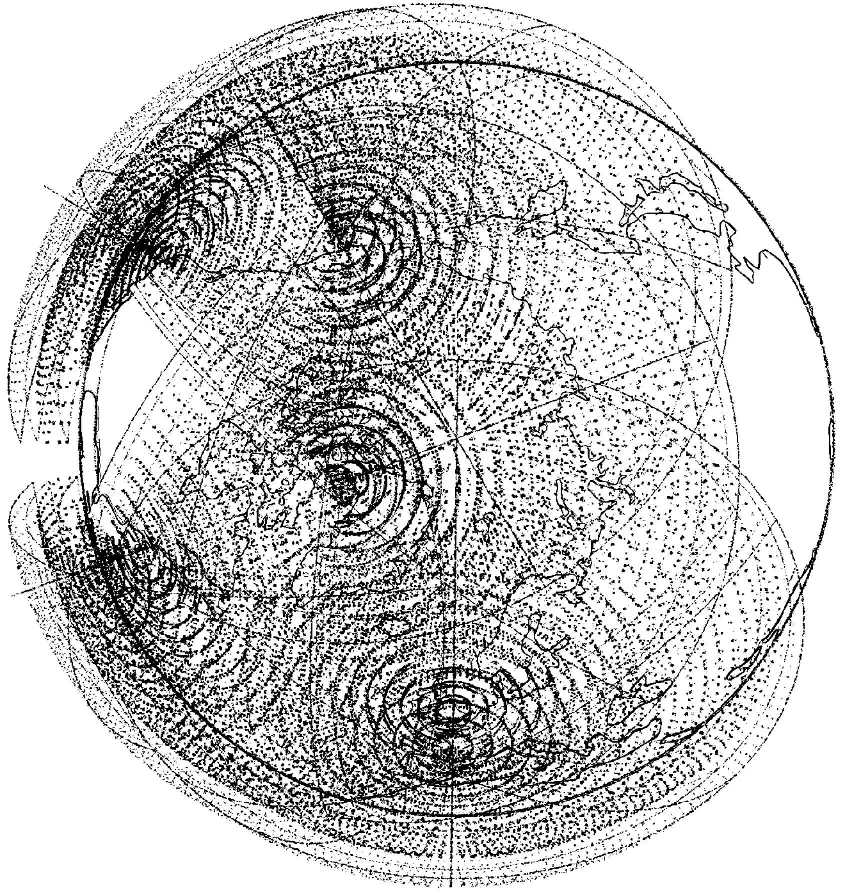
TDRS-6	46.6˚W
TDRS-7	84.3°W
TDRS-8	167.7°W
TDRS-10	171.1°W
TDRS-11	174.4°W
TDRS-12	41.0˚W
TDRS-13	11.5˚W

NEAR SPACE NETWORK



OVER-THE-HORIZON

Solid State Phased Array Radar System

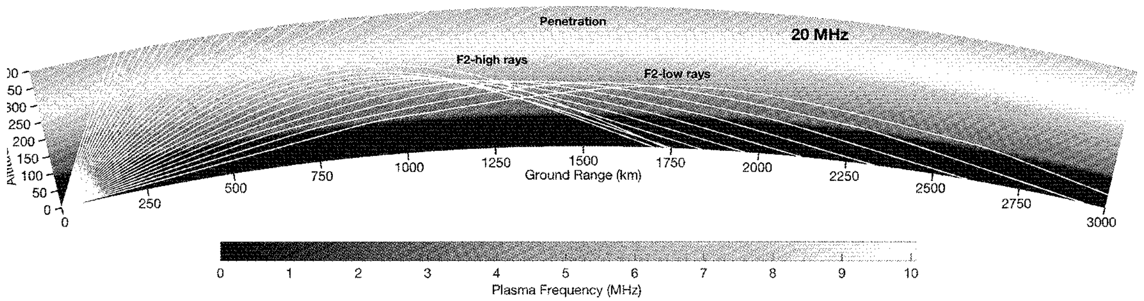


SYNOPSIS

Radar, or Radio Detection and Ranging, is among one of the methods of detecting activities over significant distances. Initially developed for military purposes, radar played a crucial rule in World War II. In principle, radio waves travel in a straight line at the speed of light in a vacuum. Much like the optical horizon, the radar horizon defines the line-of-sight for radar systems. Radar horizon refers to the maximum distance at which a radar system can detect or track objects. It is determined by the curvature of the Earth and the altitude of the radar antenna. Beyond the radar horizon, objects are hidden from the radar's view, and radar signals cannot reach them.

While the concept of "line of sight" pertains to the unobstructed path of transmission of light and electromagnetic waves, anything beyond the visible range of the spectrum is inherently invisible. Existing only in abstraction, radar sensing cannot operate without systems of signal processing, upheld by algorithmic functions. Within this system, all physical points of reference are obliterated.

Over-the-horizon backscatter (OTH-B) radar is a type of ground radar system that possess the ability to detect targets over extended distances, ranging from 500 to 1,800 nautical miles. Using the ionosphere to reflect signals, OTH radar can receive from beyond the radar horizon, which is around 250 nautical miles for ordinary radars.



Typical microwave and other radars which require line of sight to the target for detection and tracking, therefore have a relatively small range for tracking. The OTH radar using ionospheric refraction is not limited by line of sight.
— OTH Handbook. 1995.

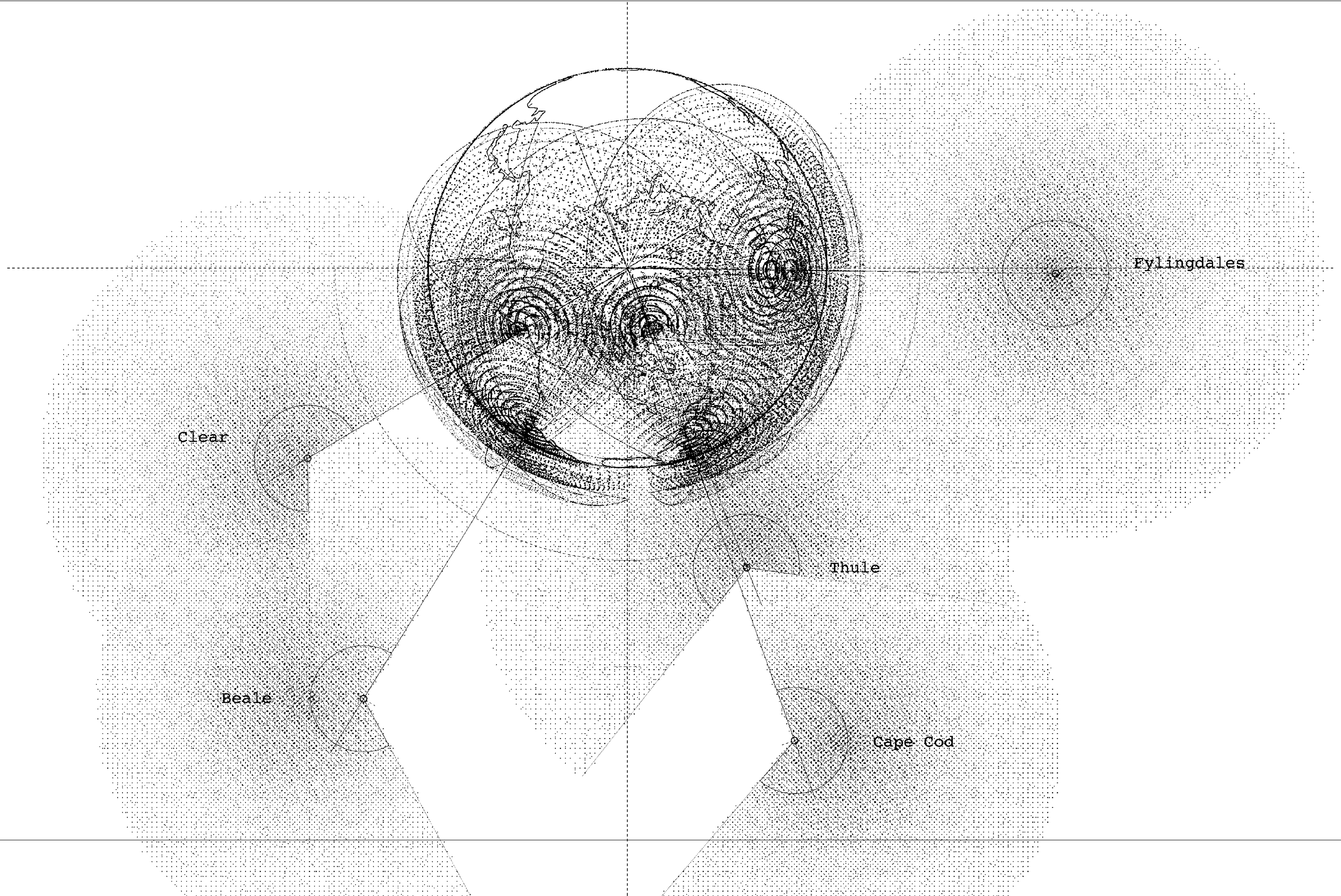
Perhaps most importantly, backscatter radar picks up more than planes and missiles. Ocean waves and ground echo can be 100 times more powerful than reflections of interest. These must be deleted in a tactical radar system.
— Robert Russell, 1984

In all systems, noise is the unwanted signal in the system against which the wanted signal (for an OTH system that of the target) has to be observed. In the OTH-system... [t]his noise is due to natural (cosmic or atmospheric), and manmade emissions and under certain conditions due to backscatter of the radar’s own signal from ionospheric and auroral irregularities.
It is against this noise background that the target must be detected. When the noise from ionospheric and auroral scatter exceeds the target signal level... detection of the target will be impossible.
— OTH Handbook. 1995.

Range: ~3,000 nautical miles

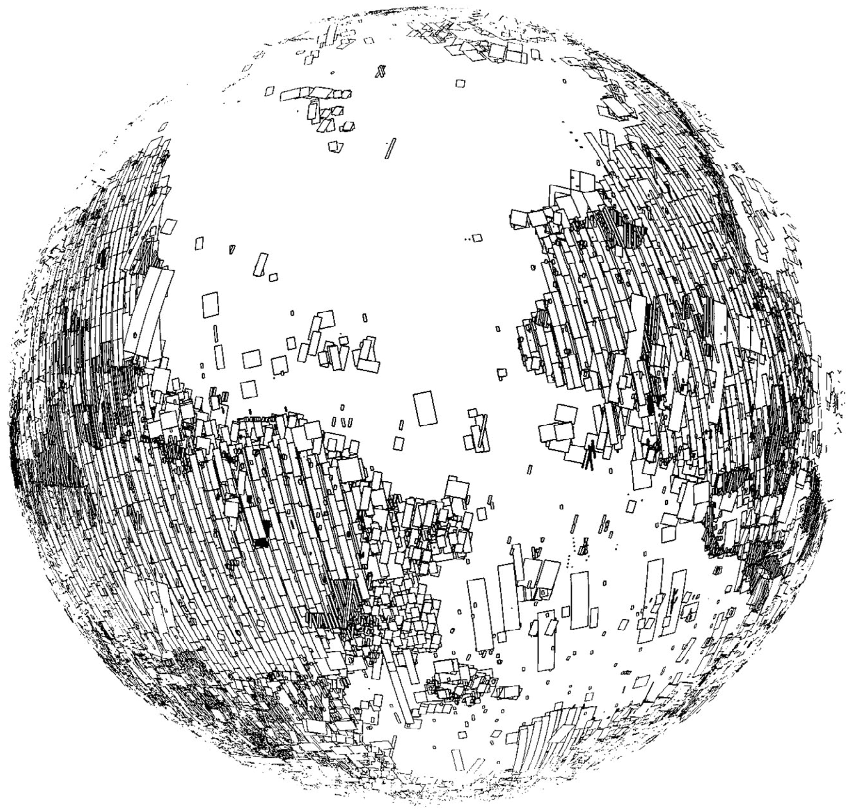
Cape Cod Space Force, Massachusetts, US	41°45’12”, -70°32’19” Coverage: 240˚
Thule Air Base, Greenland	76°34’04”, -68°17’03” Coverage: 240°
Beale Air Force Base, California, US	39°08’10”, -121°26’11” Coverage: 240°
Clear Space Force, Alaska, US	64°17’26”, -149°11’13” Coverage: 240°
RAF Fylingdales, UK	54°21’32”, -0°40’11” Coverage: 360°

SOLID STATE PHASED ARRAY RADAR SYSTEM



LATENT VISION

Synthetic Aperture Radar

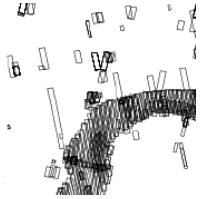


Synthetic Aperture Radar (SAR) is a remote sensing technology that uses radar to create high-resolution images of the Earth's surface. Unlike optical sensors, SAR can operate under any weather conditions, regardless of day or night, since it does not rely on visible lights to observe and capture Earth's conditions.

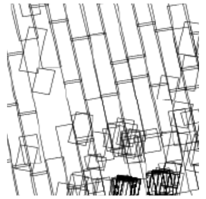
SAR utilizes microwave frequencies, providing the ability to penetrate clouds and vegetation, making it valuable for applications such as terrain mapping, environmental monitoring, and disaster management. The technology captures reflections of radar signals to construct detailed and three-dimensional images of the Earth's surface.

While optical imaging technology used in Landsat captures light reflected from the subject's surface passively, SAR actively emits radar signals and constantly calcuates information based on the way their return and diffusion patterns.

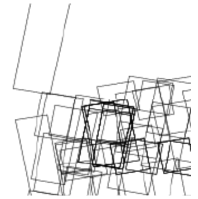
TERRASAR-X COVERAGE



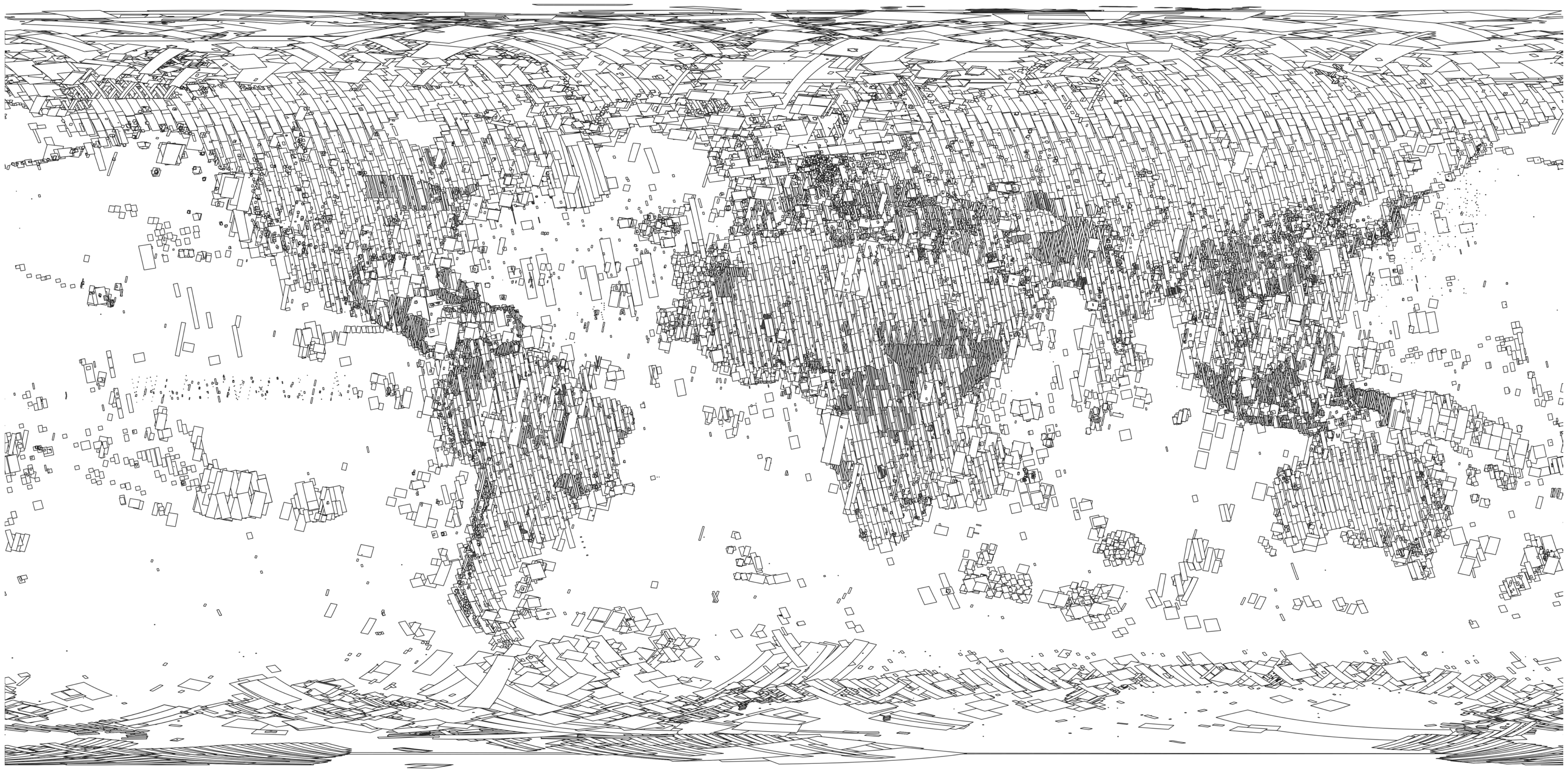
SM



SC



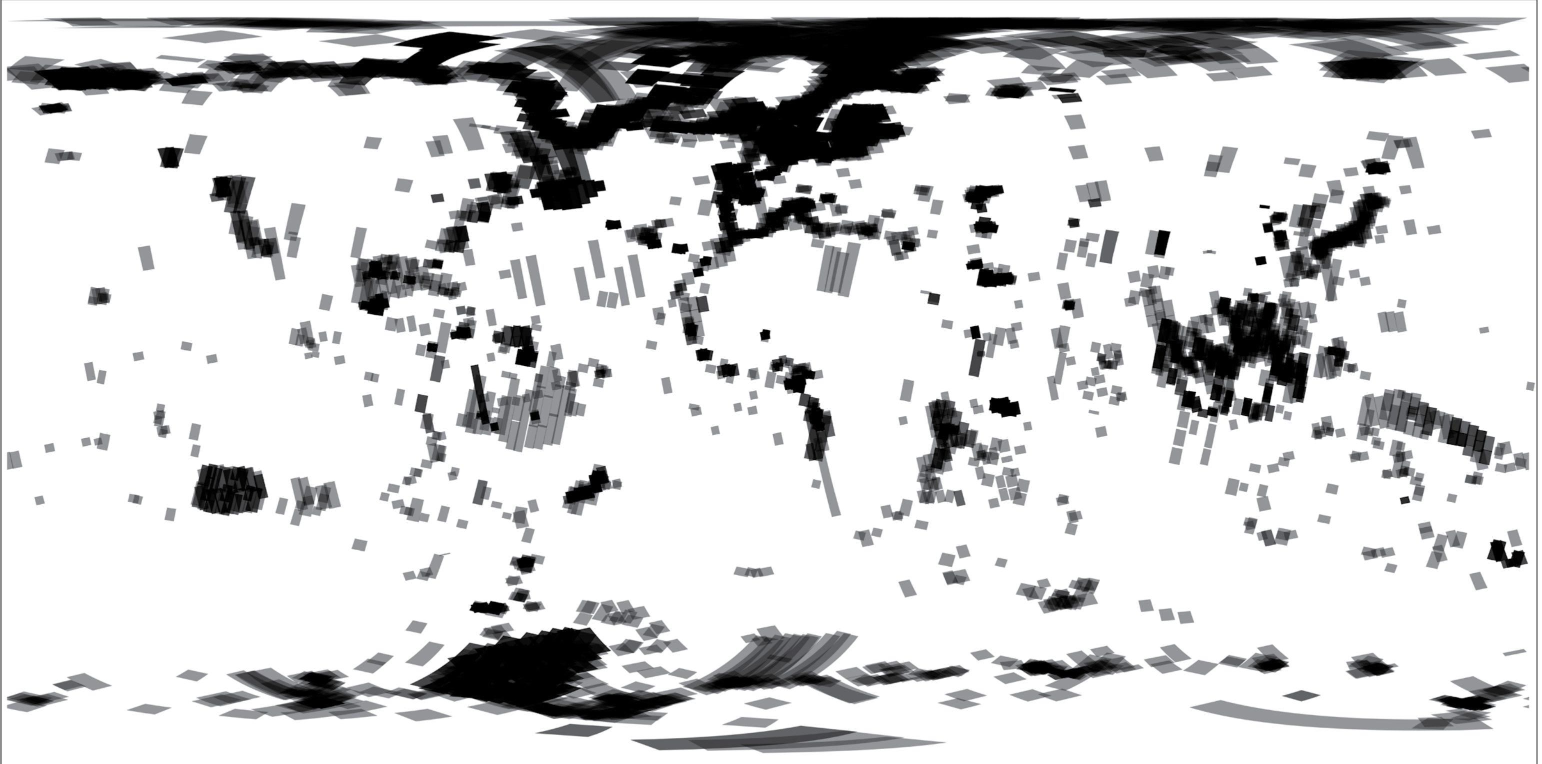
WS



ST

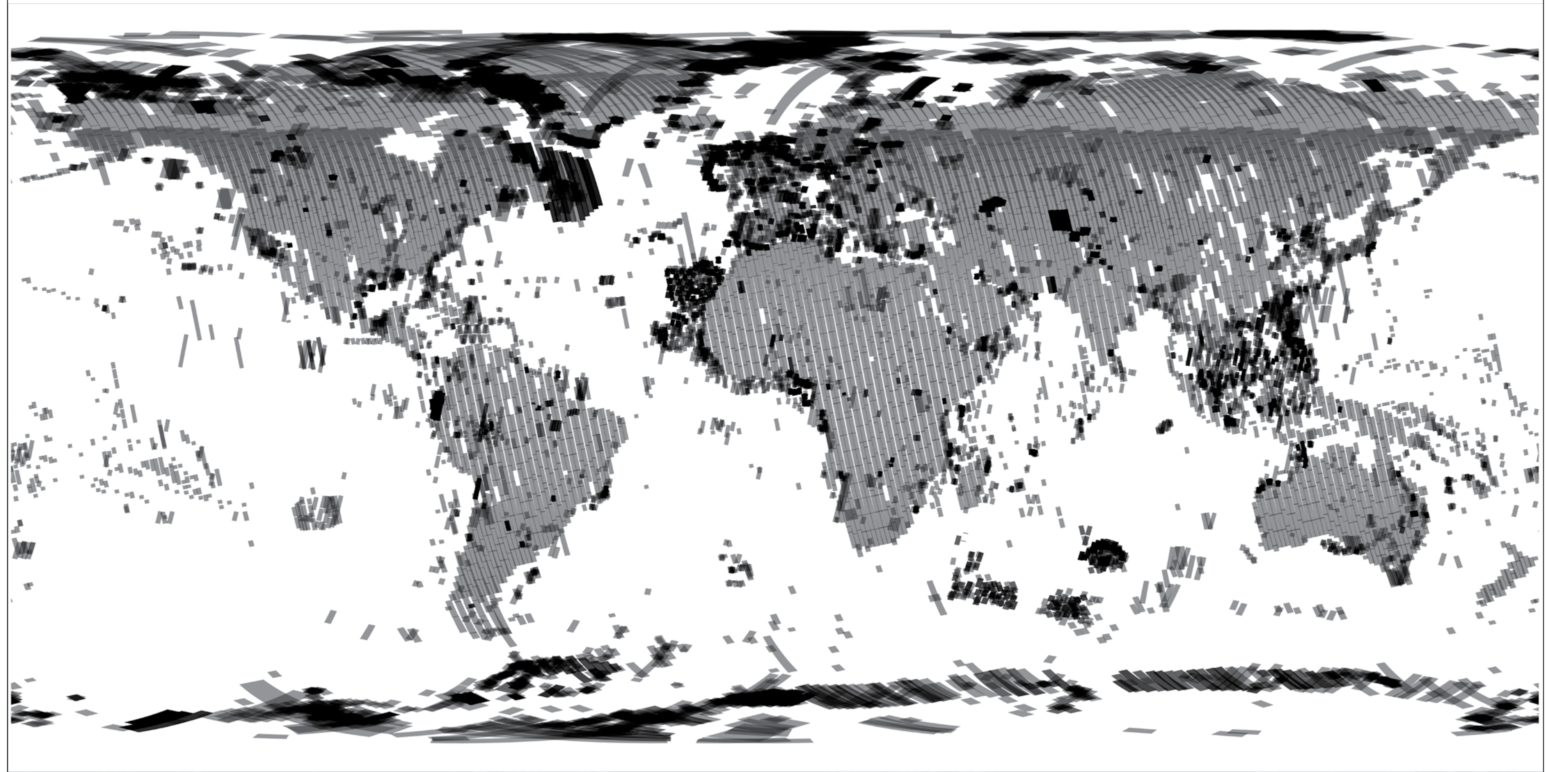
HS

SL



Wide ScanSAR

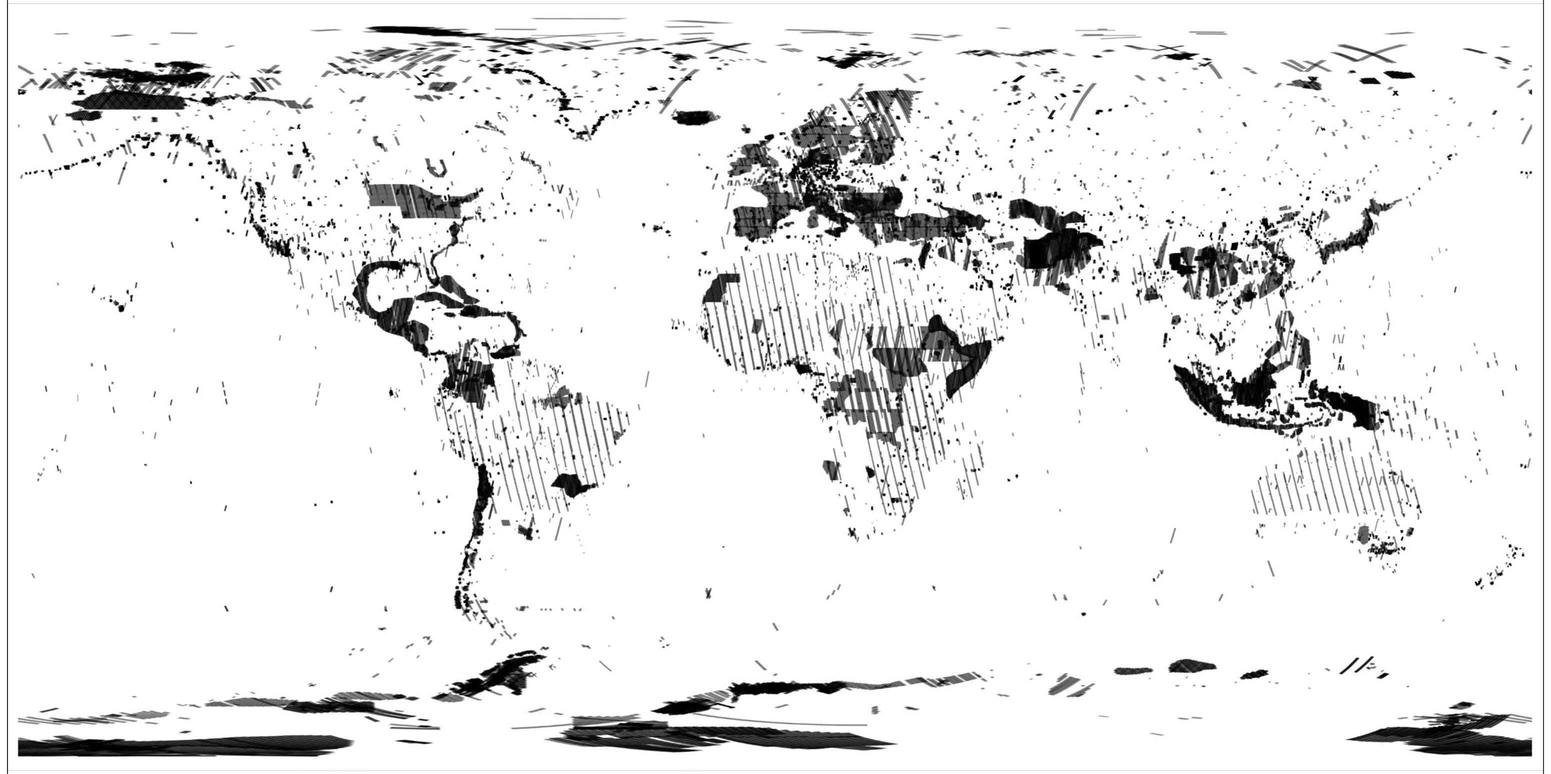
Basic and Maritime pack



ScanSAR

Basic and Maritime pack

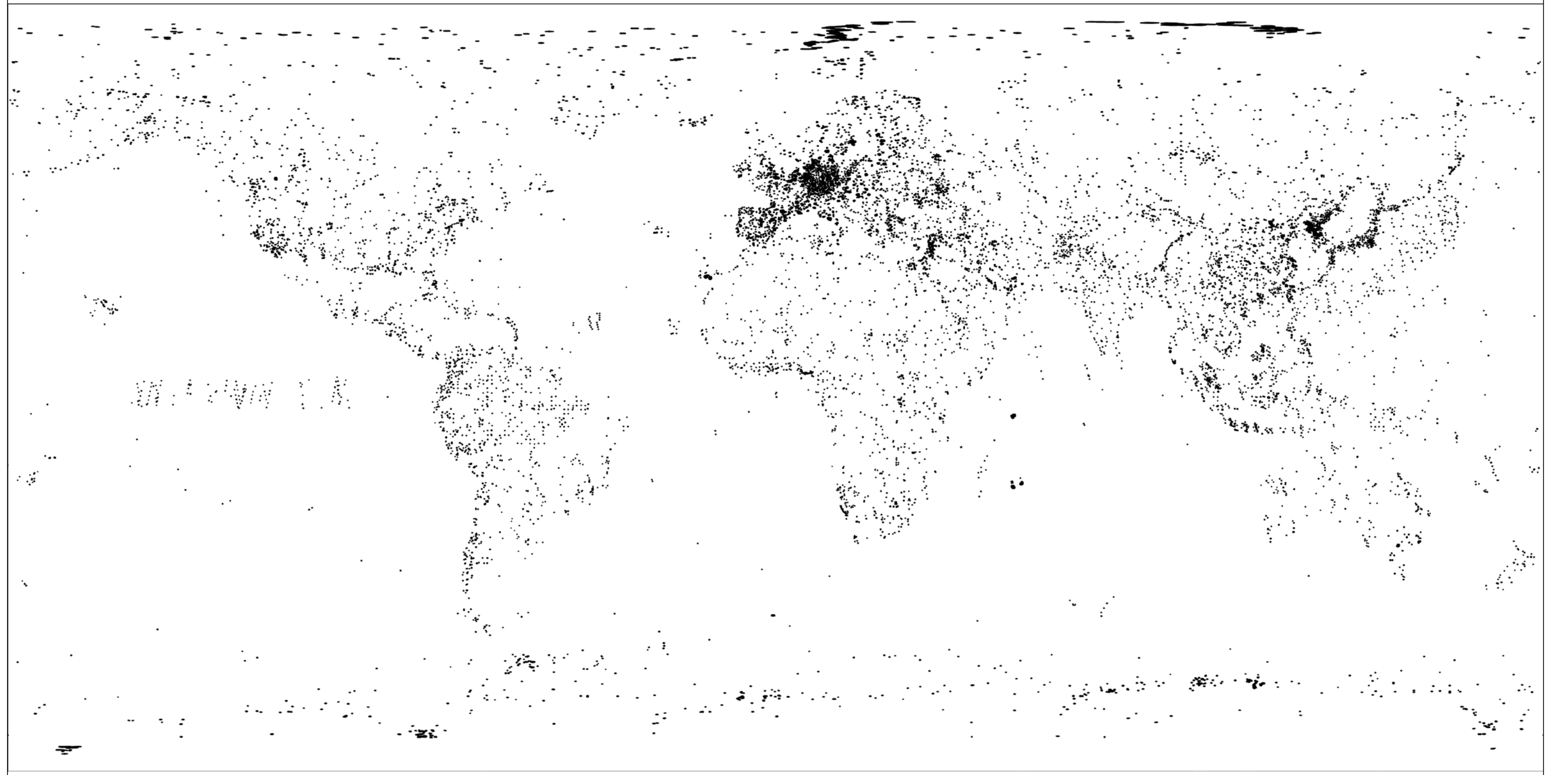
TERRASAR-X IMAGE MODES - SM



StripMap

Basic, Interferometric pack, and Maritime pack

TERRASAR-X IMAGE MODES - SL, HS, ST

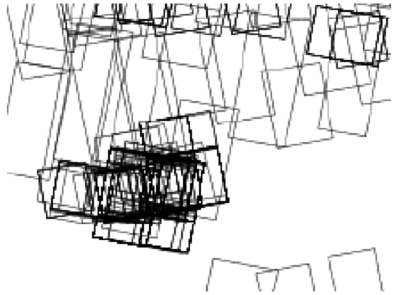


SpotLight; High Resolution SpotLight; Staring SpotLight

Basic, Interferometric pack, and Maritime pack

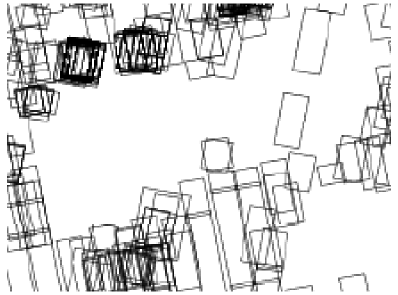
INSTRUMENTS, RESOLUTIONS, SCENE SIZES

WS



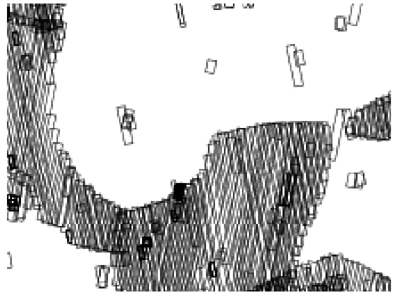
Wide ScanSAR
40 m
270x200 km^2
(up to 270x1500)

SC



ScanSAR
18 m
100x150 km^2
(up to 100x1650)

SM



StripMap
3 m
30x50 km^2
(up to 30x1650)

SL

SpotLight
2 m
10x10 km^2

HS

High Res SpotLight
1 m
10x5 km^2

ST

Staring Spotlight
.25 m
4x3.7 km^2