MIT
Science, Technology, and
Global Security Working Group

The Russian Early Warning Situation

Theodore A. Postol
Professor of Science, Technology, and National Security Policy
Massachusetts Institute of Technology
Voice: 617 253-8077; FAX: 617 258-5750; e-mail: postol@mit.edu

Nuclear Forces and Missile Defenses
October 7, 2013

The Russian Experience with the False Alert of January 25, 1995

Statements of Boris Yeltsin on January 26, 2006, the day after an accidental alert of Russia's early warning system.

"I indeed yesterday [January 26, 1995] used for the first time my 'black' suitcase with the button which is always carried with me."

"I linked up instantly with the minister of defense, with all those military leader-generals I need, and ***we tracked the path of this rocket from beginning to end.***"

PRESIDENT VLADIMIR PUTIN

Annual Address to the Federal Assembly
May 10, 2006
Moscow

What's more, the arms race has entered a new spiral today with the achievement of new levels of technology that raise the danger of the emergence of a whole arsenal of so-called destabilising weapons.

There are still no clear guarantees that weapons, including nuclear weapons, will not be deployed in outer space. There is the potential threat of the creation and proliferation of small capacity nuclear charges. Furthermore, ***the media and expert circles are already discussing plans to use intercontinental ballistic missiles to carry non-nuclear warheads. The launch of such a missile could provoke an inappropriate response from one of the nuclear powers, could provoke a full-scale counterattack using strategic nuclear forces.***

The Russian Experience with the False Alert of January 25, 1995

Chief of Staff of the Presidential Executive Office, Sergei Sobyanin, May 11, 2006

"Imagine a rocket that can be fired from a submarine. ***A nuclear state might not be able to react adequately to the firing of such a rocket. There is nothing written on it to say what sort of warhead it is—whether conventional or nuclear.*** It seems to me to be an irresponsible decision."

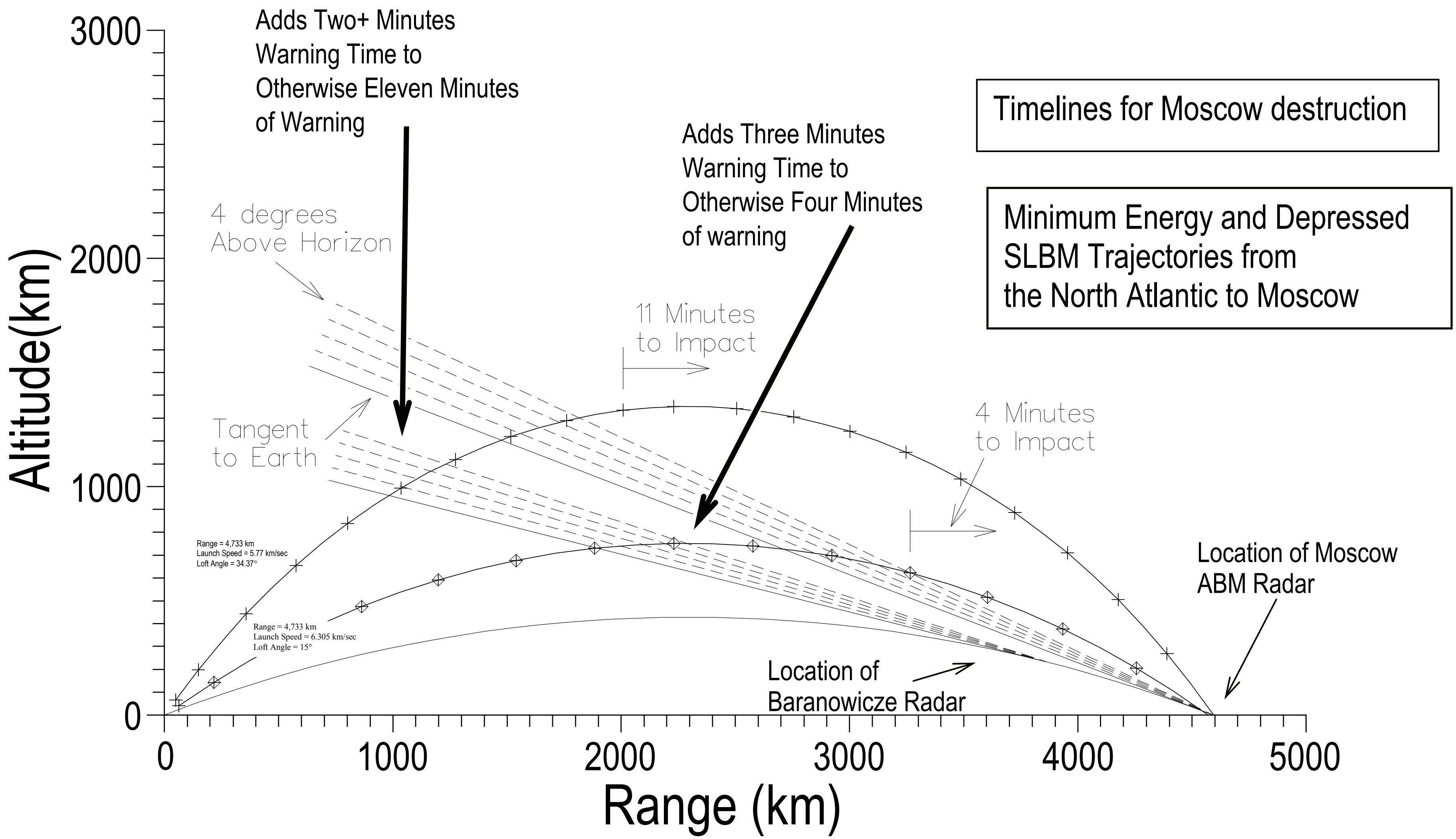
Relevance to the Proposed Missile Defense and Prompt Global Strike Systems

- Russia currently, and for the foreseeable future, does not have an operational global satellite early warning system that can provide reliable global warning against ballistic missile attacks.
- Because of this, Russia must rely *completely* on ground-based early warning radars against nuclear surprise attack.
- The Russian false alert of 1995 illustrates the serious dangers to the US from this limitation in Russia's Early Warning Systems.

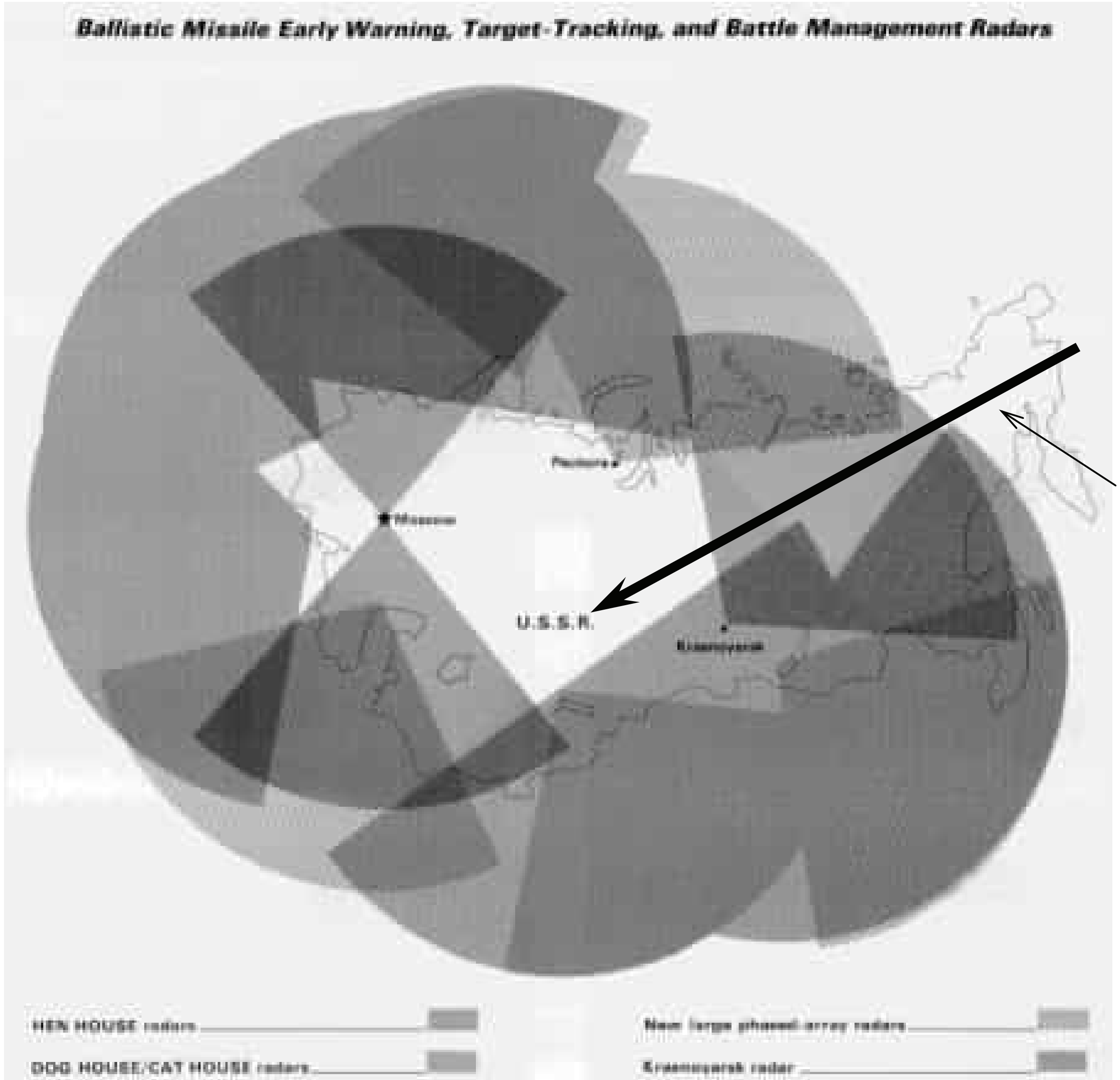
Russian Radar Early Warning Capabilities

Russian Radar Early Warning Timelines

Warning Times for Trajectories from North Atlantic Launch Areas to Moscow Within Baranowicze and Moscow Radar Fans



Developing Russian Early Warning Radar Network



Direction of attack chosen to underfly the radar search fans from Pechora and Mishelevka

By choosing a launch location south or north of the Aleutian Island chain off western Alaska, the Trident missile trajectory would be below the radar horizon for its entire flight period. For example, at the point where the Pechora early warning radar search fan intersects the trajectory shown above, the fan is at an altitude of over 1000 km, well above the altitude of the missile and its warheads.

Estimated Time Needed to Carry Out Nuclear Launch-Operations No Matter What Response Is Chosen

Time Needed to Carry Out Basic Nuclear Weapons Launch-Operations

Time for attacking missiles to rise over the horizon into the line-of-sight of early warning radars	1 minute
Time for radars to detect, track, and characterize detected targets, and to estimate the size and direction of motion of targets	1 minute
Military and civil command conference to determine response	1 to 3 minutes
Time for command and unit elements of silo-based forces to encode, transmit, receive, decode, and authenticate a launch order	2 to 4 minute
Time for missile crews to go through full launch procedures	1 to 3 minutes
Time for launched missile to reach a safe distance from its launch-silo	1 minute
Total time consumed in unavoidable and essential operations	7 to 13 minutes

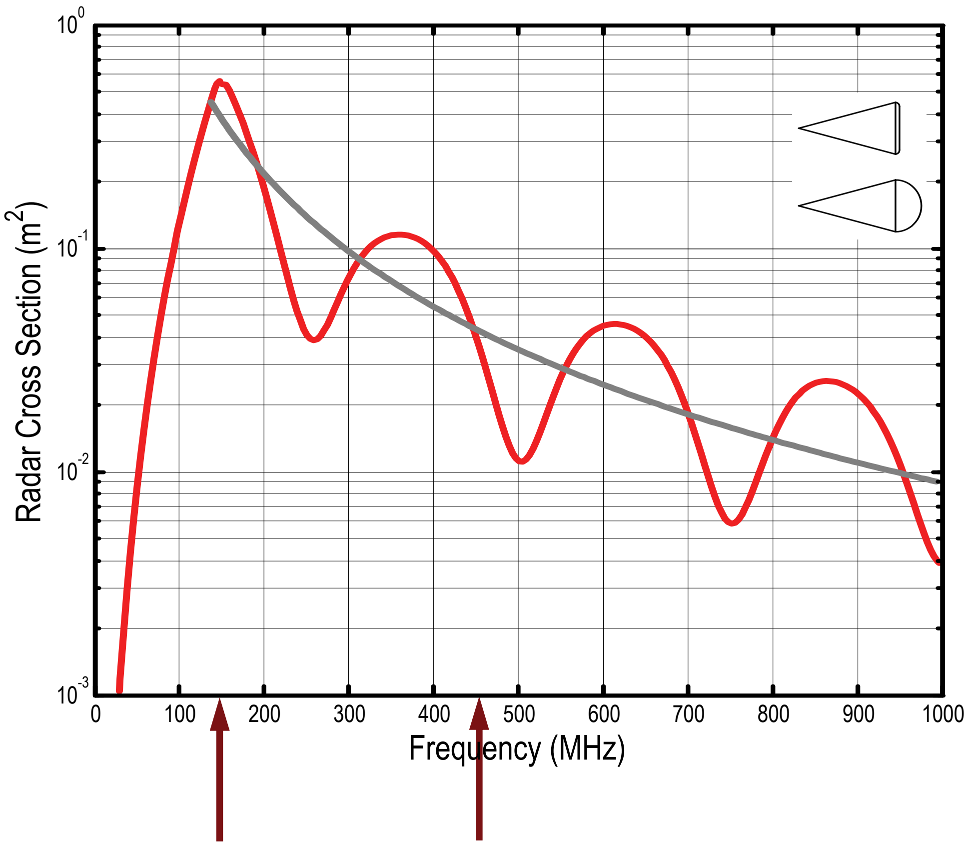
If a short time-line attack is attempted against Russia, a Russian response aimed at launching silo-based missiles before nuclear weapons detonate on them would require time for several technical operations. Time would also be needed by political leadership to assess the situation and decide whether or not to launch the silo-based missile force. The amount of time available for decision-makers to assess the situation and decide whether or not to launch silo-based nuclear forces is the difference between the time it takes for warheads to arrive at targets and the time needed to carry out operations no matter what response is chosen.

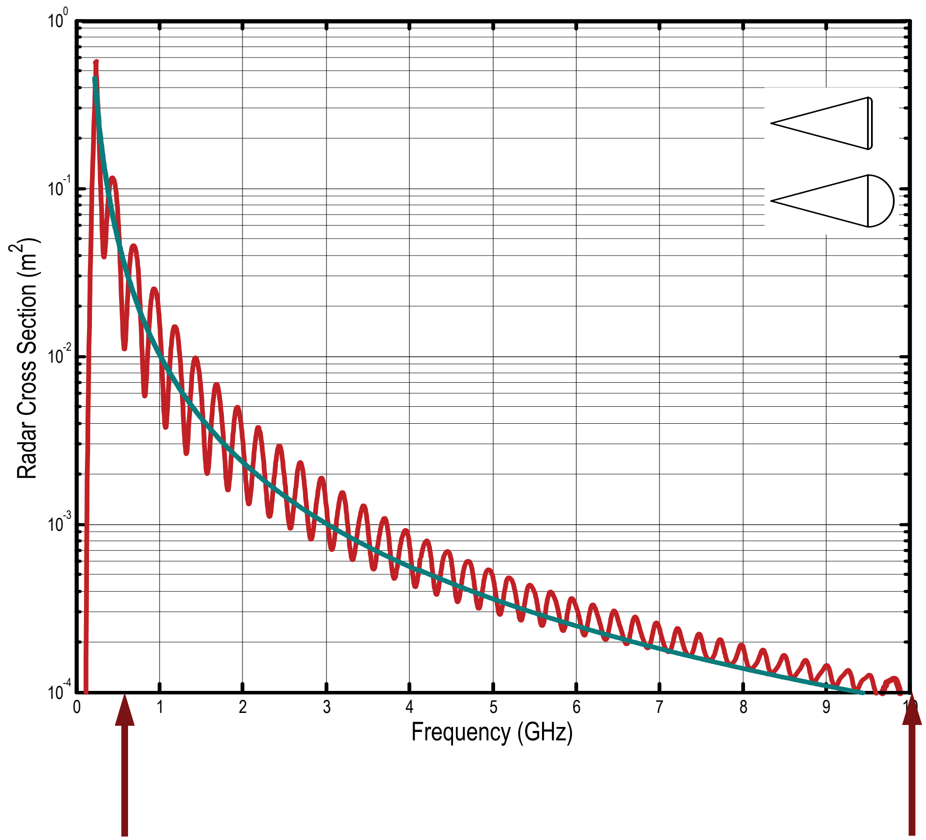
The Russian Experience with the False Alert of January 25, 1995

Operating Frequencies of Russia' Early Warning Radars

Radar Cross Section of Rounded-Back Cones

The operating frequency of Russia's Early Warning Radars was chosen so that the radar reflectivity of warheads approaching Russia would be as large as possible, thereby making it easier for the radars to detect the approaching warheads at very long range. However, a serious drawback associated with radars operating at these frequencies is that they highly vulnerable to blackout effects from high-altitude nuclear explosions.





Russian Hen House and Large Phased Arrays

US PAVE-PAWS and BMEWS Early Warning Radars

US Upgraded Early Warning Radars

US Ground-Based X-Band Radar

Russian Voronezh Class Third Generation Upgraded VHF Early Warning Radar that is Potentially Usable in a “Light” National Missile Defense System

The size of the FBX and its limited average power make it considerably less capably than large lower frequencies radars like the US UEWR and the Russian Voronezh VHF radars for acquiring and and tracking naturally stealthy ballistic missile warheads at long-range.

Russian Voronezh VHF Early Warning Radar

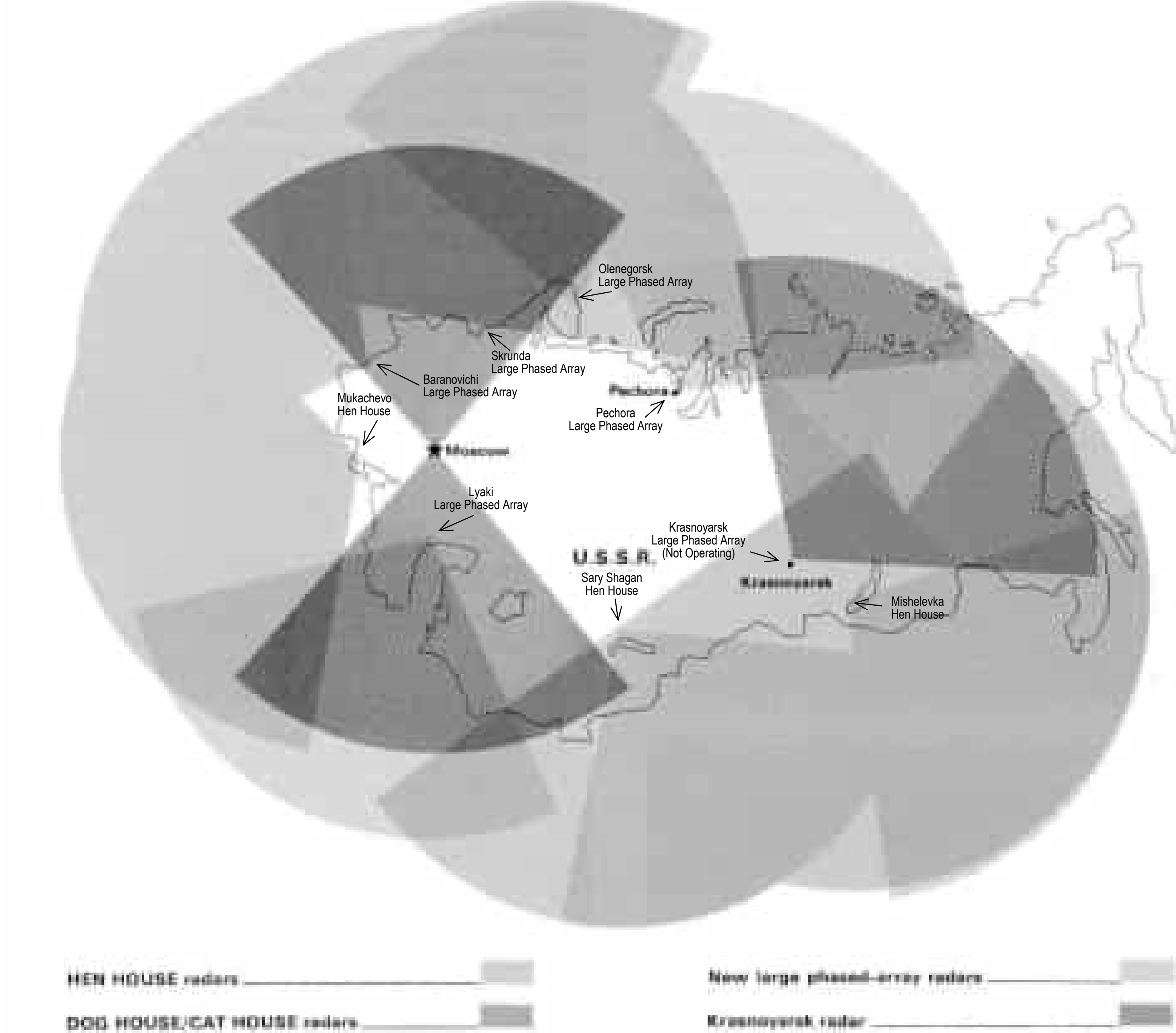
Arrow GreenPine Missile Defense Radar

Forward-Based X-Band Radar (FBX)

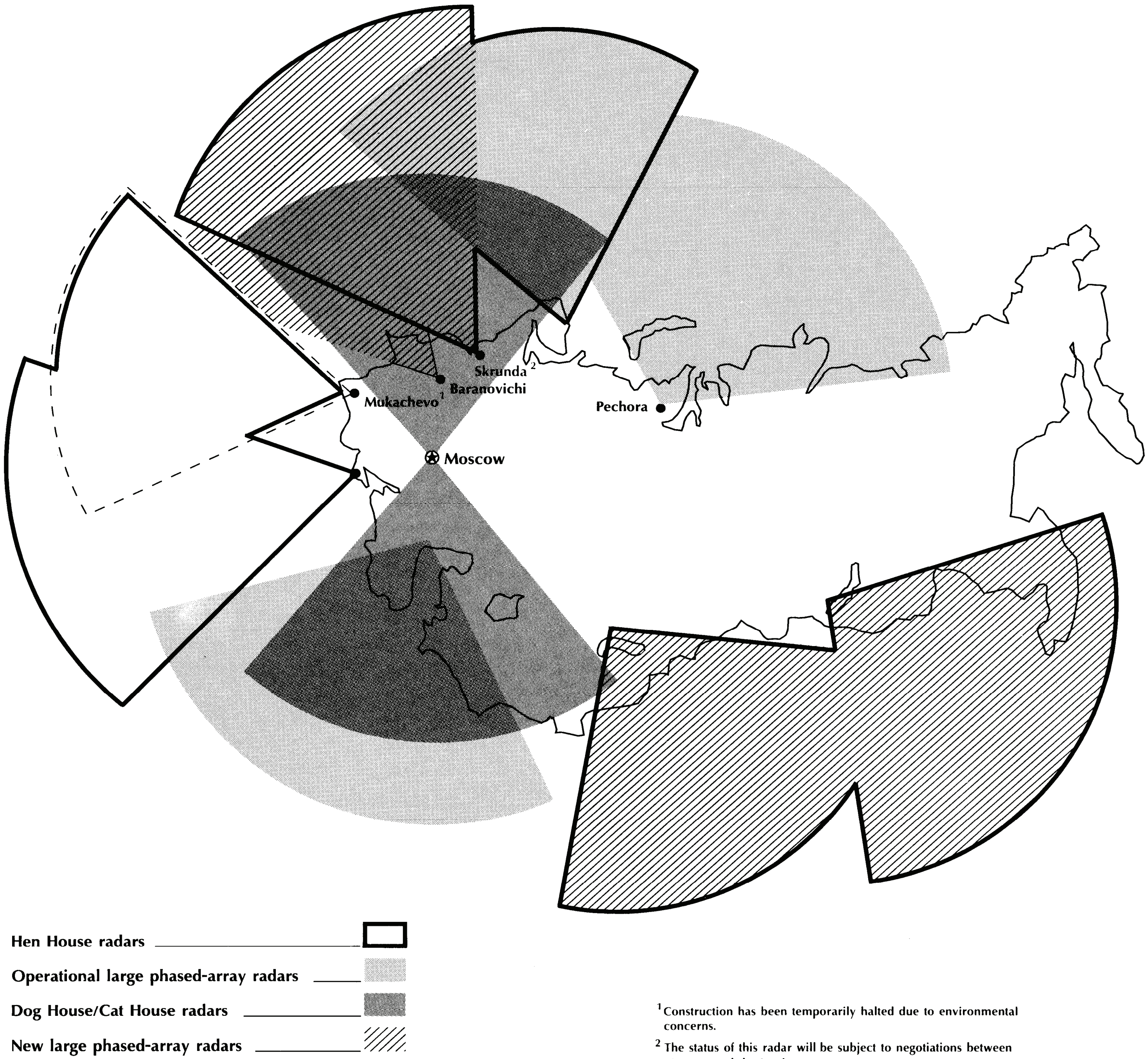
Phased Array Warning System (PAVE PAWS)
UHF Radar Being Used in National Missile Defense System

The size of the FBX and its limited average power make it considerably less capable than large lower frequencies radars like the US UEWR and the Russian Voronezh VHF radars for acquiring and and tracking naturally stealthy ballistic missile warheads at long-range.

Locations of the Radars of the Planned But Not Fully Completed Russian Radar Early Warning System



Locations of Russian Hen House and Large Phased Array Early Warning Radars in 1995



[1] Construction has been temporarily halted due to environmental concerns.

[2] The status of this radar will be subject to negotiations between Moscow and the Latvian government.

Russian Radars Currently Usable for Purposes of Early Warning

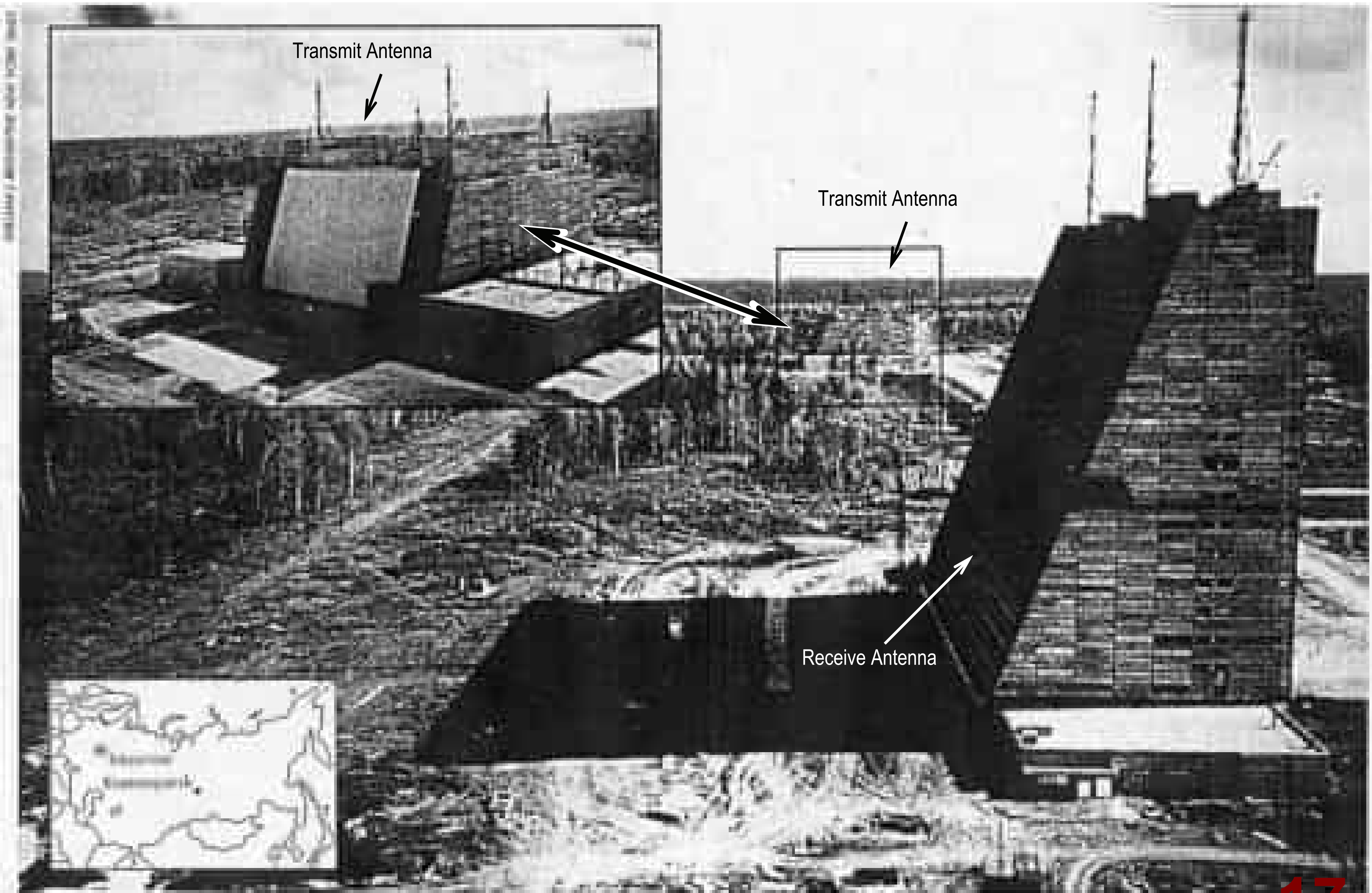

"Cat/Dog House" First Generation Russian ABM Radar

"Pushkino" Second Generation Russian ABM Radar

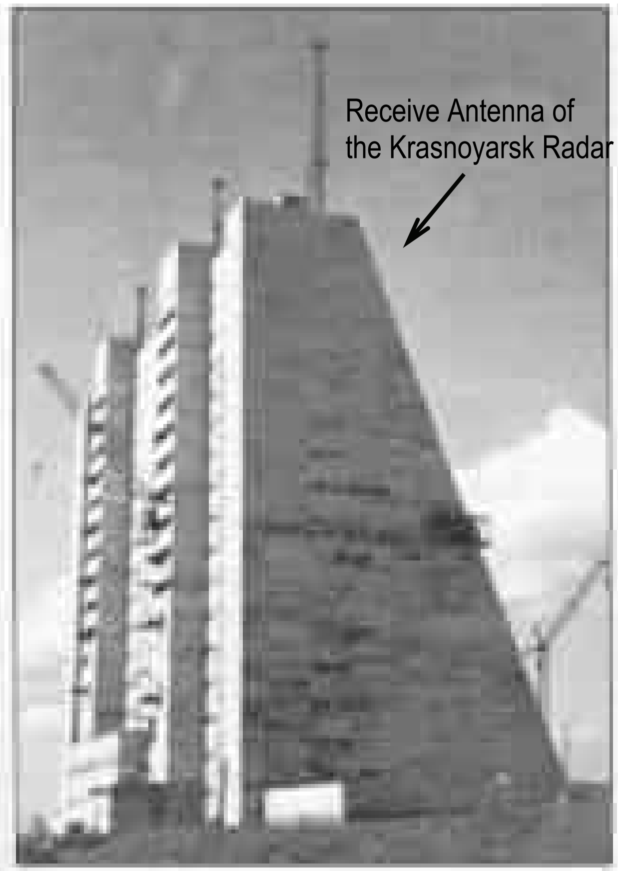

"Hen House" First Generation Russian Early Warning Radar


"Large Phased Array" Second Generation Russian Early Warning Radar

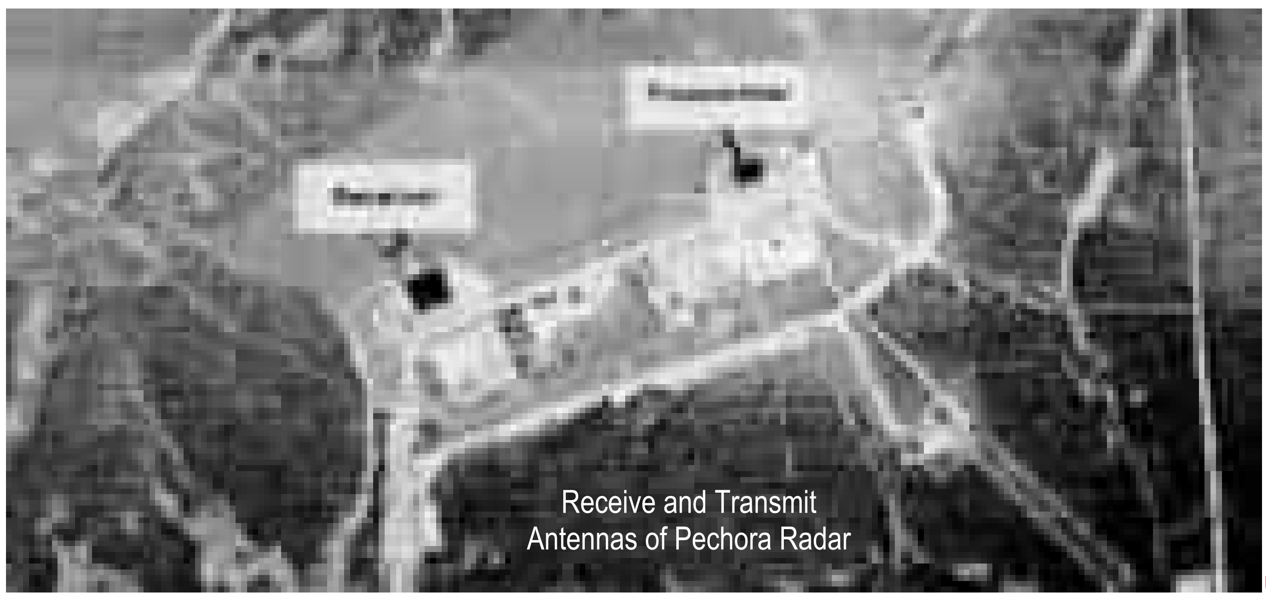
Russian Large Phased Array Early Warning Radar at Krasnoyarsk




Transmit Antenna of
the Krasnoyarsk Radar


Receive Antenna of
the Krasnoyarsk Radar


Face of the Receive Antenna
of the Krasnoyarsk Radar


Receive and Transmit
Antennas of Pechora Radar

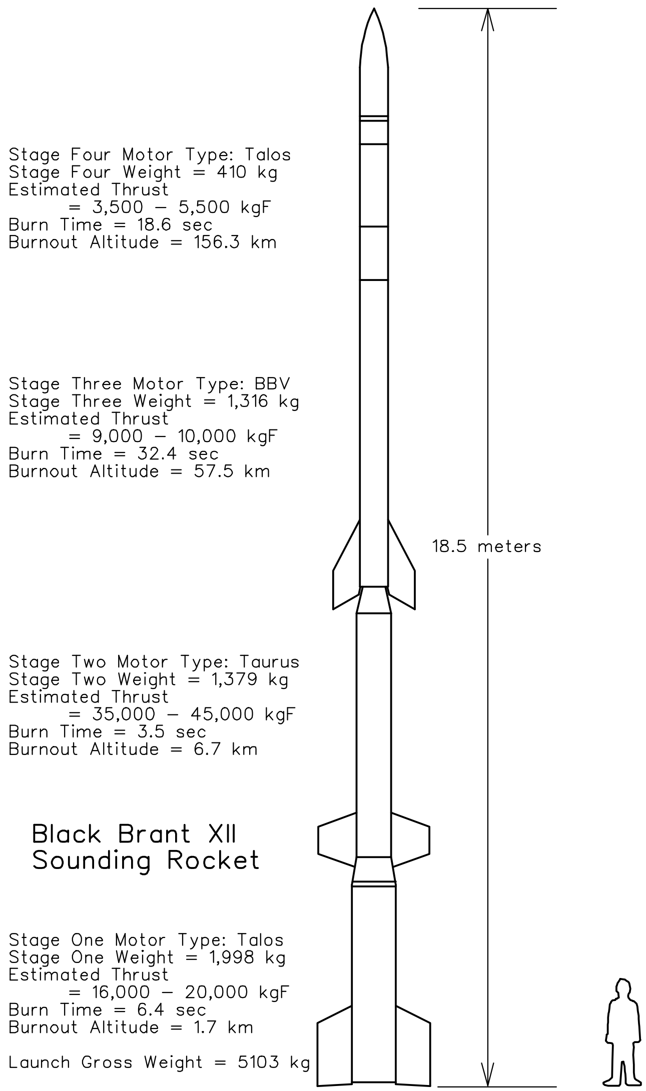
The Russian False Alert of January 1995

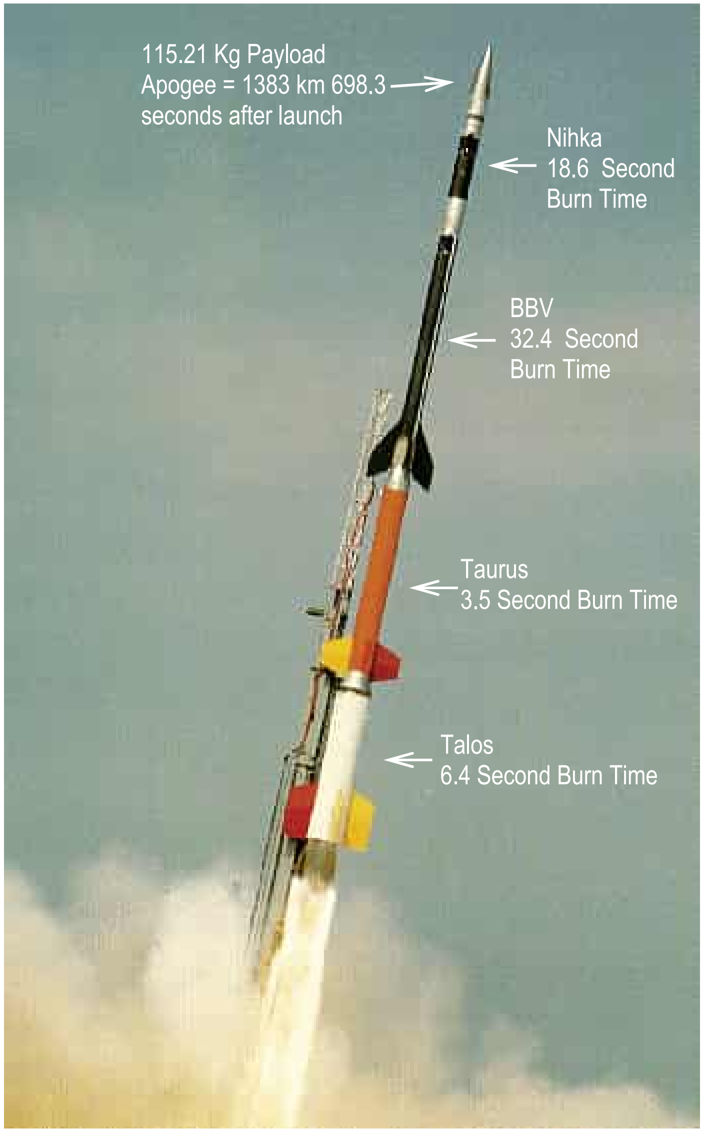
What seems to have happened?

What events led to the false alert?

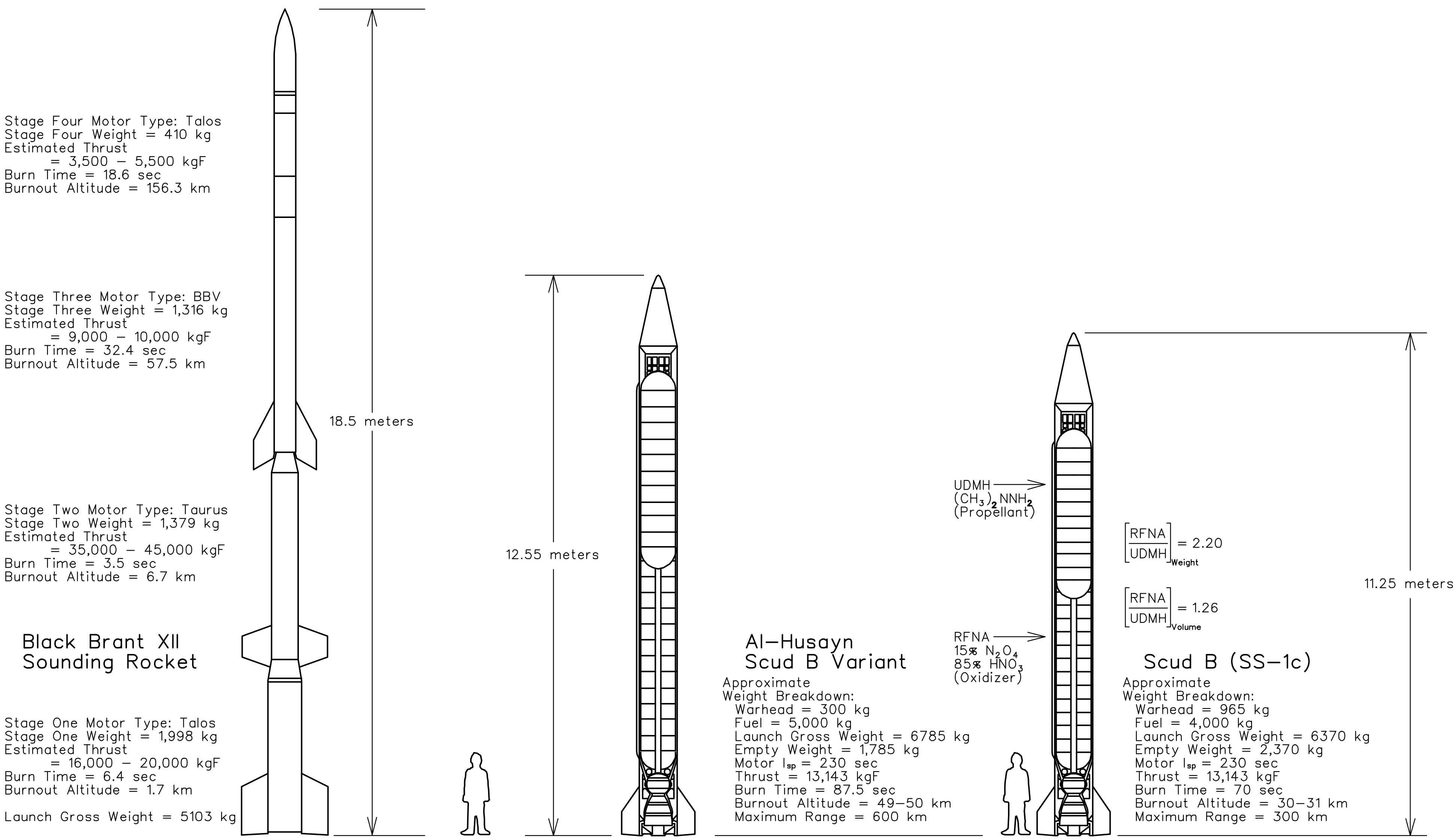
(“The Dog that Didn’t Bark)

The Russian Experience with the False Alert of January 25, 1995





The Russian Experience with the False Alert of January 25, 1995



The Russian Experience with the False Alert of January 25, 1995

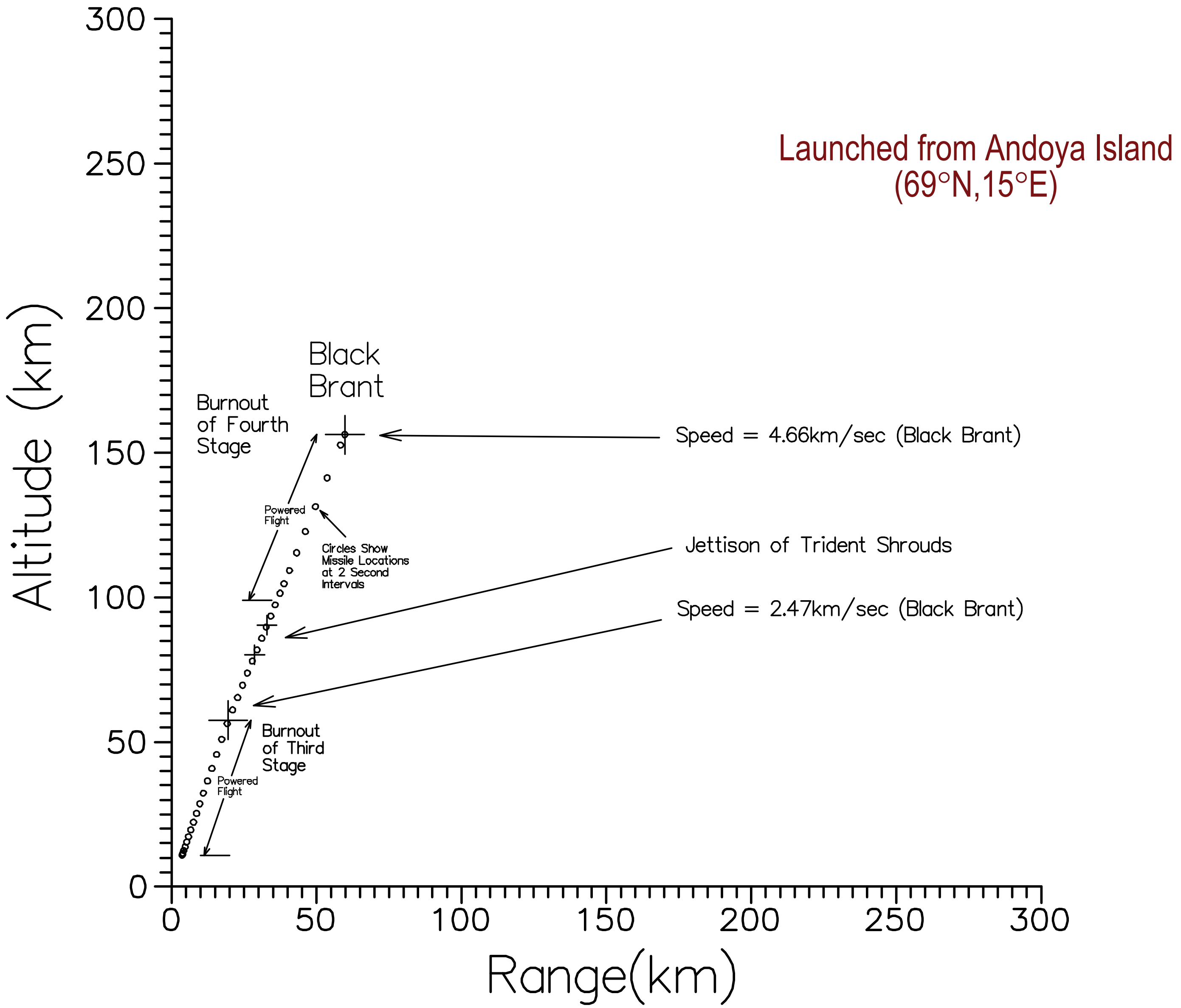
The Russian Experience with the False Alert of January 25, 1995

Black Brant XII
Nominal Sequence of Events
115.21 kg Payload

Event	Time (sec)	Altitude (km)	Range (km)	Velocity (mps)
Rail Exit	0.5	0.1	0.0	42.7
Spin Motor Ignition	0.9	0.1	0.0	72.8
Spin Motor Burnout	1.1	0.1	0.0	91.3
Talos Burnout	6.4	1.7	0.4	464.4
Taurus Ignition	14.0	4.7	1.1	341.7
Taurus Burnout	17.5	6.7	1.6	841.9
Taurus Separation	20.0	8.7	2.2	785.2
BBV Ignition	23.0	10.9	2.8	732.7
BBV Burnout	55.4	57.5	19.6	2472.0
Nose Cone Deploy	65.0	79.2	28.0	2385.3
LEO Slug Deploy	67.5	84.7	30.2	2362.9
BBV Separation	70.0	90.1	32.4	2340.7
Nihka Ignition	74.0	98.7	35.9	2305.4
Nihka Burnout	92.6	156.3	59.8	4656.6
Despin to 1.25 hz	96.0	170.6	65.7	4627.8
5.5 m Weitzmann Booms Deploy	99.0	183.3	71.0	4602.1
TECHS & E-field Booms Deploy	102.0	196.0	76.2	4576.6
HEEPS & BEEPS Deploy	105.0	208.6	81.5	4551.1
UNH HV & MSFC HV On	108.0	221.1	86.7	4525.8
Begin Data Period	180.5	500.1	207.5	3945.7
Apogee	698.3	1383.1	913.9	1529.3
End Data Period	1216.2	500.0	1618.5	3945.2
Ballistic Impact	1342.5	0.0	1829.1	

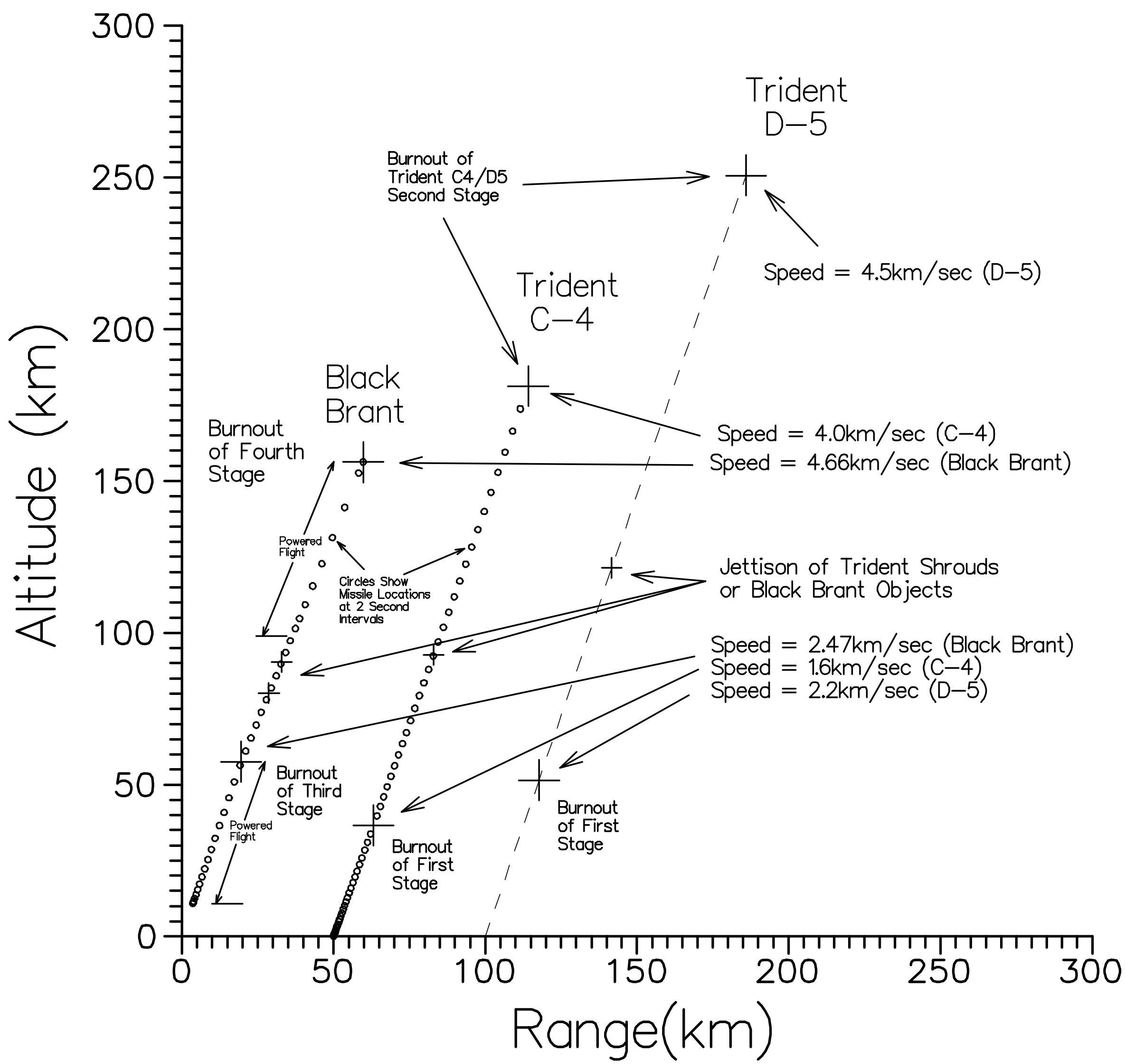
The Russian Experience with the False Alert of January 25, 1995

Locations and Speeds of the Black Brant XII NASA Sounding Rocket in Powered Flight in January 1995



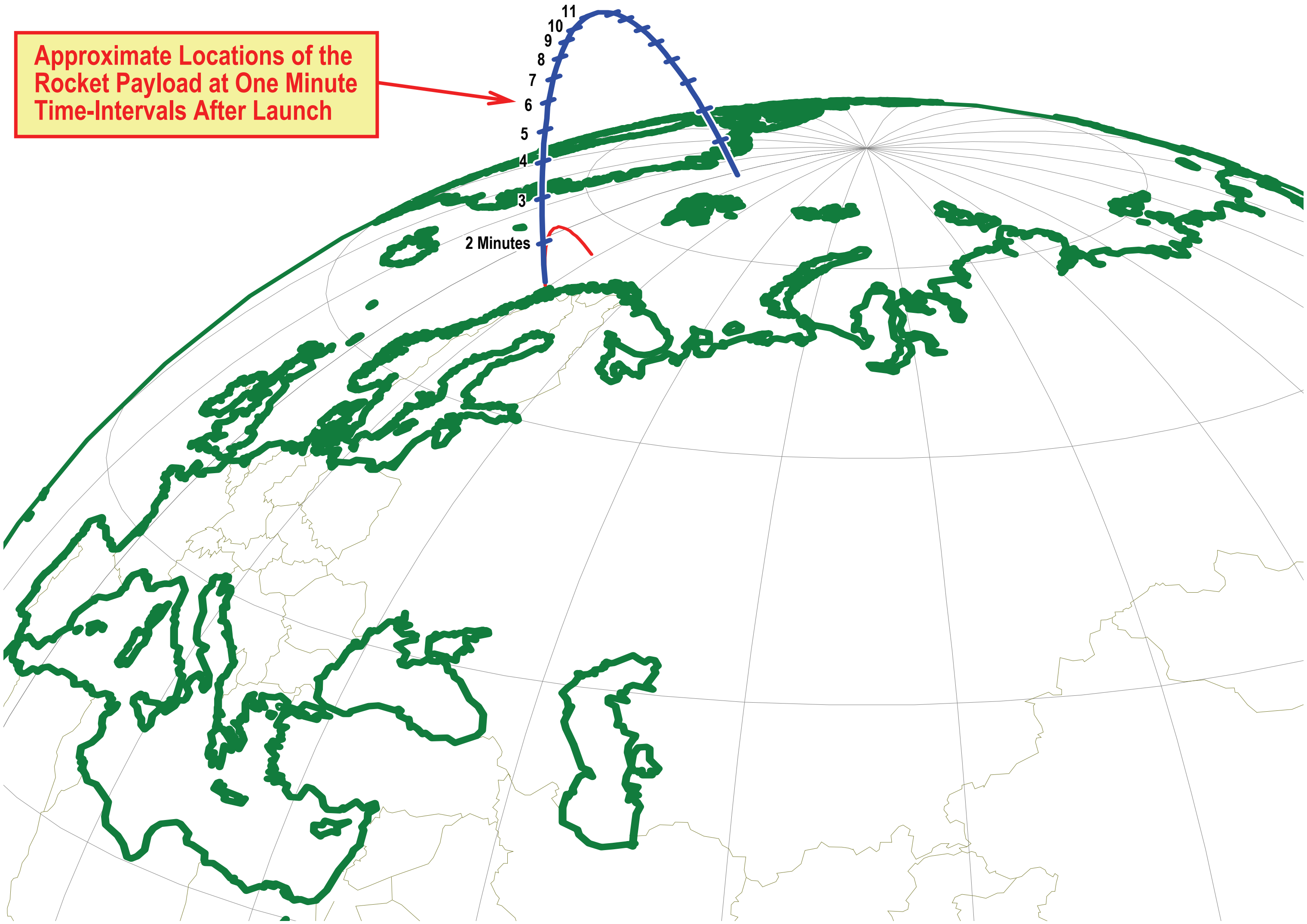
The Russian Experience with the False Alert of January 25, 1995

Comparison of the Locations and Speeds of the Black Brant XII NASA Sounding Rocket with the Powered Flight Trajectories of Trident C-4 and D-5 Missiles



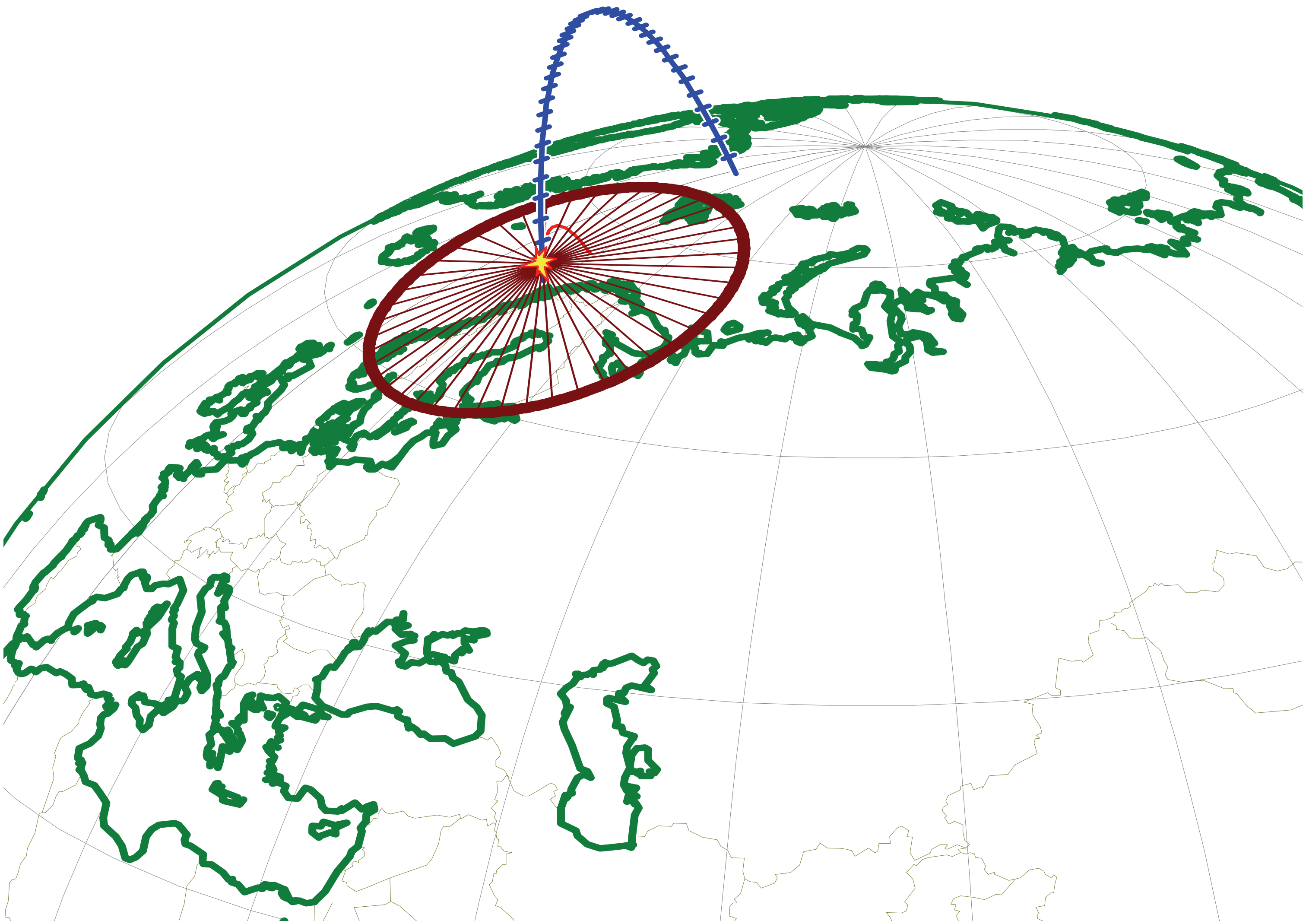
The Russian Experience with the False Alert of January 25, 1995

Trajectory of the Black Brant XII Sounding Rocket



The Russian Experience with the False Alert of January 25, 1995

Area of Radar-Blackout from a One Megaton Nuclear Explosion at 150 Kilometers Altitude



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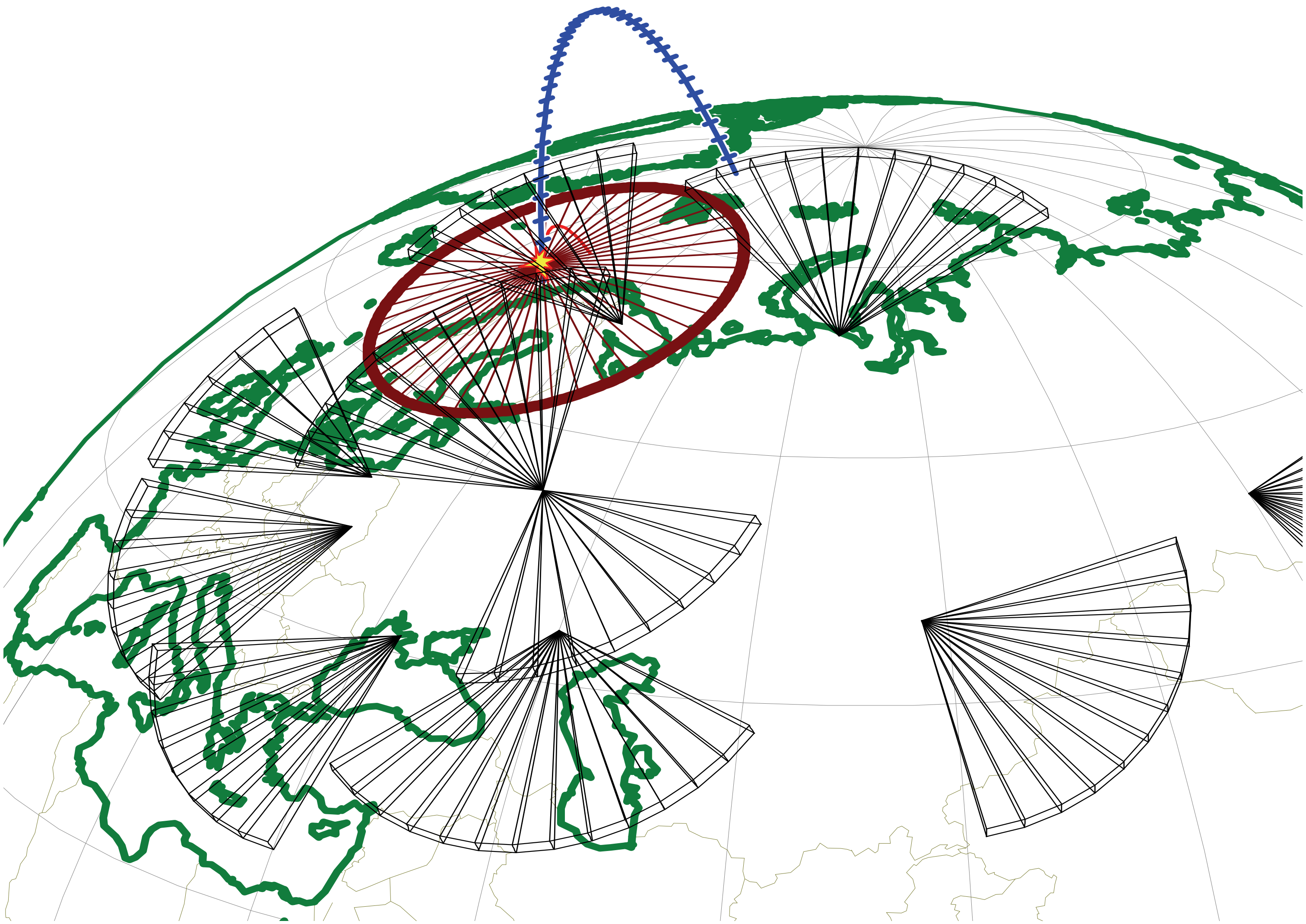

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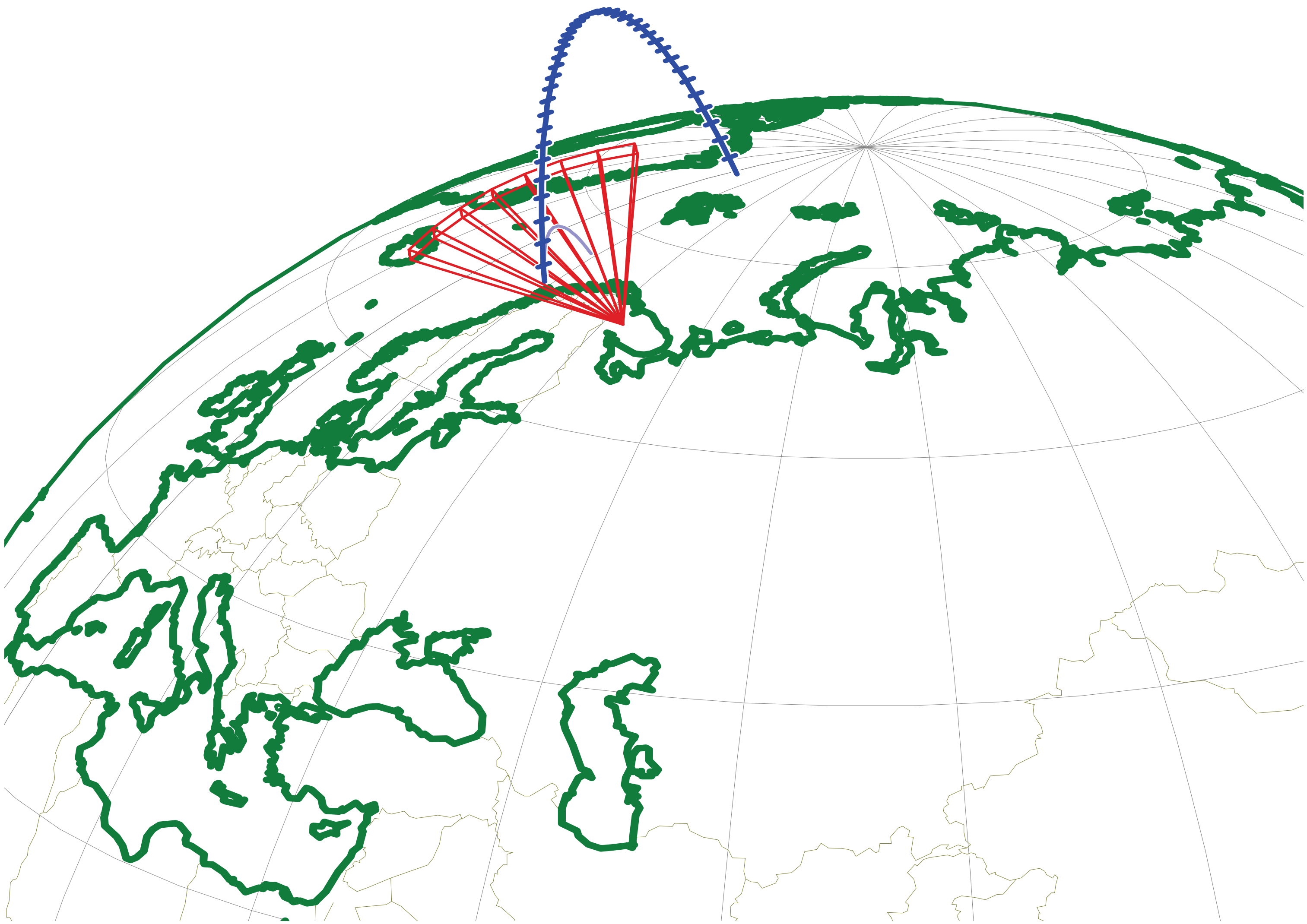

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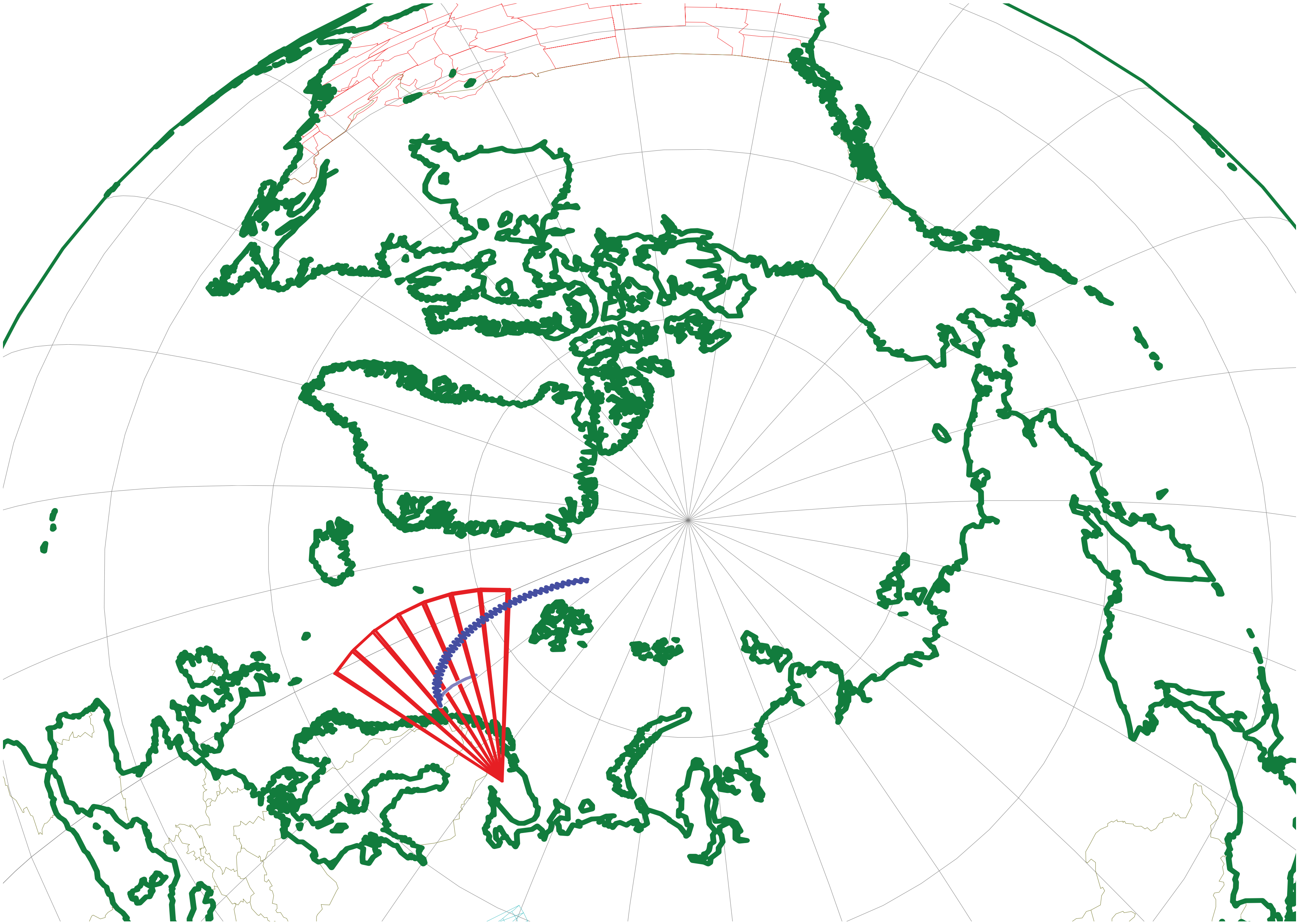

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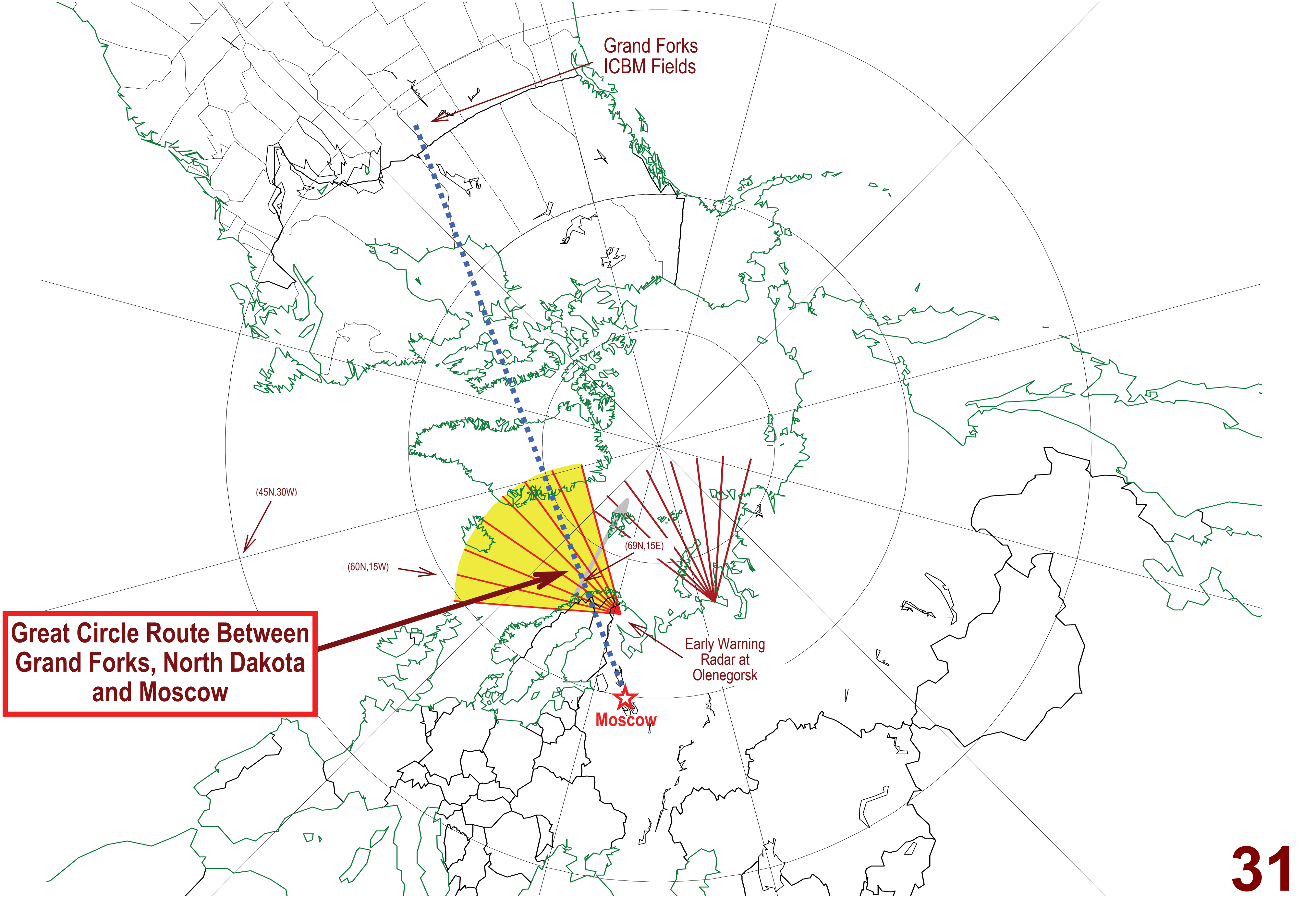
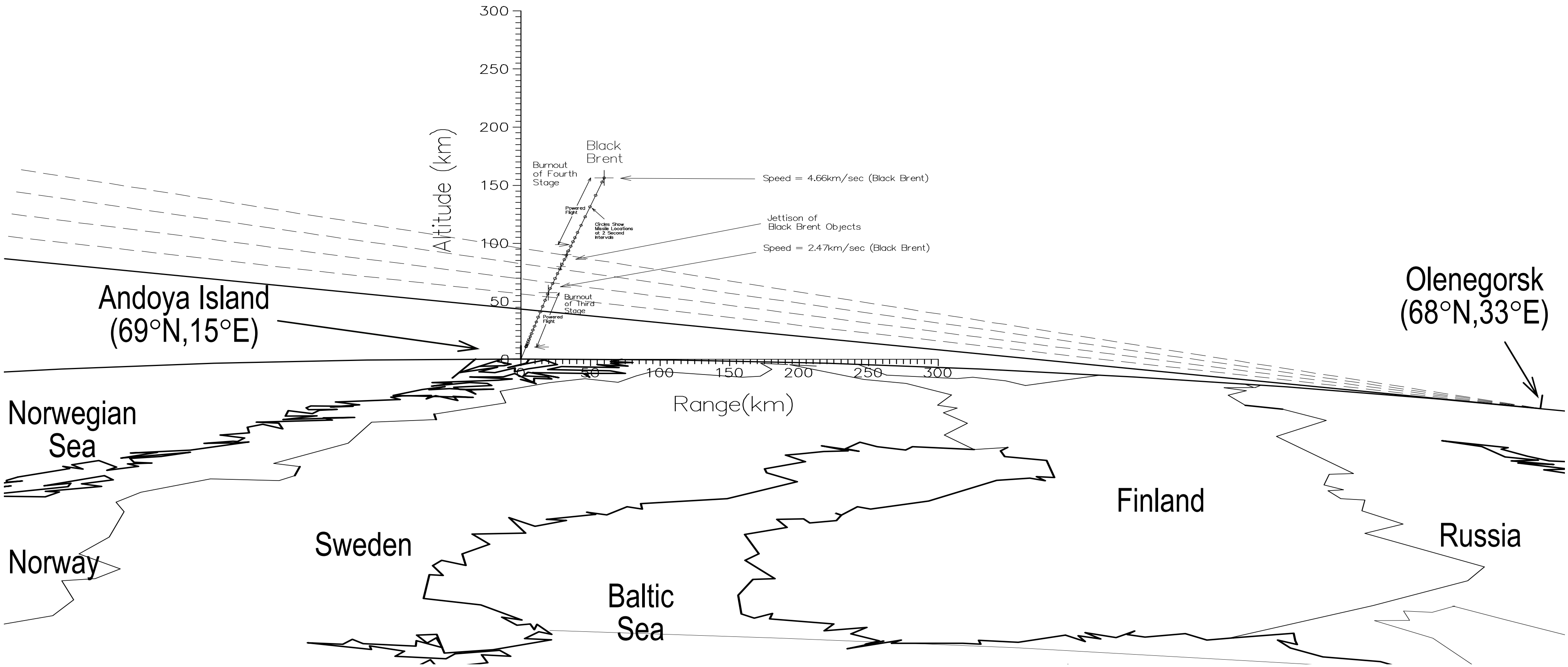


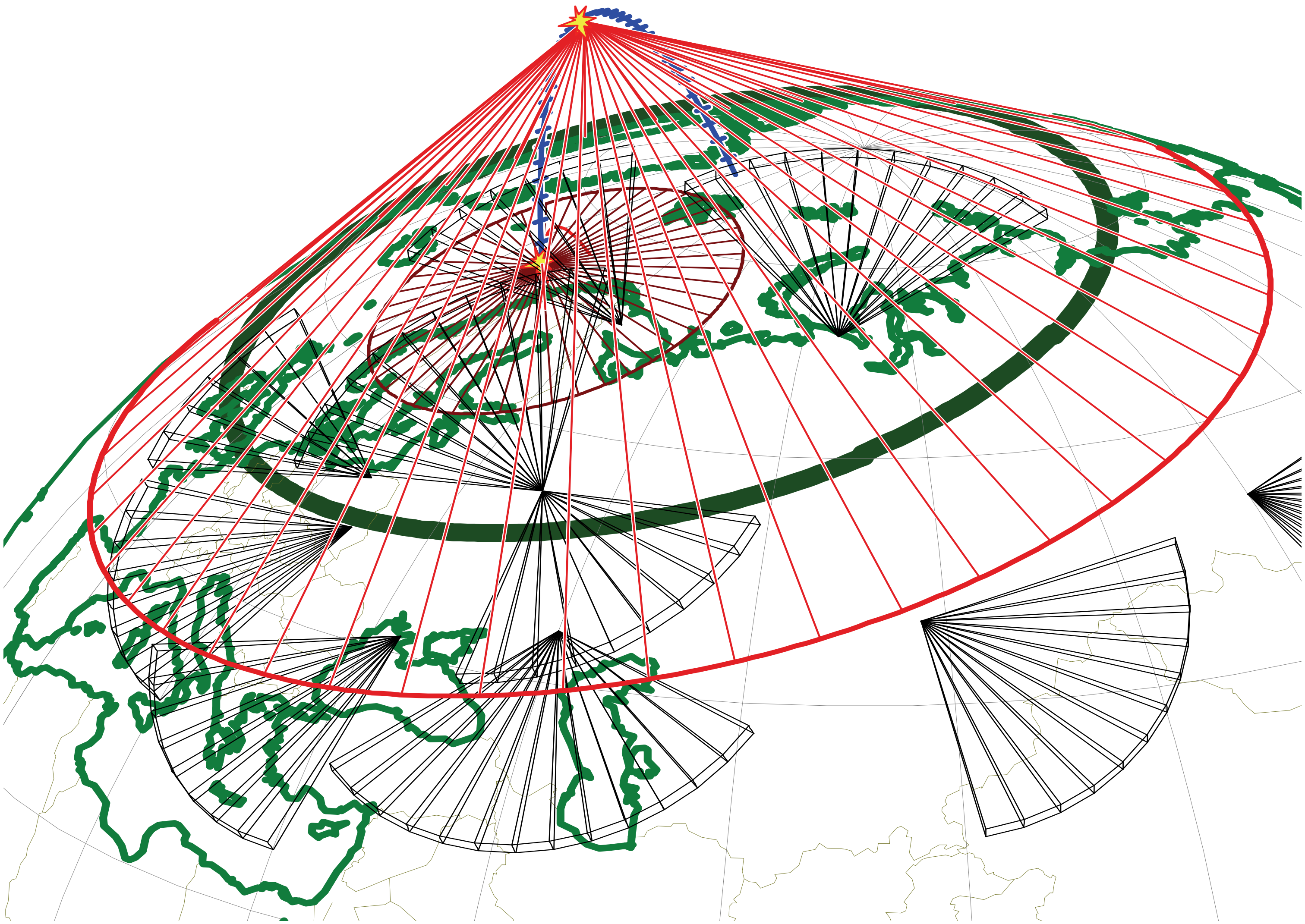
The Russian Experience with the False Alert of January 25, 1995

Observation Capabilities of the Russian Early Warning Radar at Olenegorsk
(Radar Frequency = 150 MHz; Range Resolution ≈ tens of meters, Azimuth Resolution ≈ kilometers)



The Russian Experience with the False Alert of January 25, 1995

Area of Radar-Blackout from a One Megaton Nuclear Explosion at 1350 Kilometers Altitude



The Russian Experience with the False Alert of January 25, 1995

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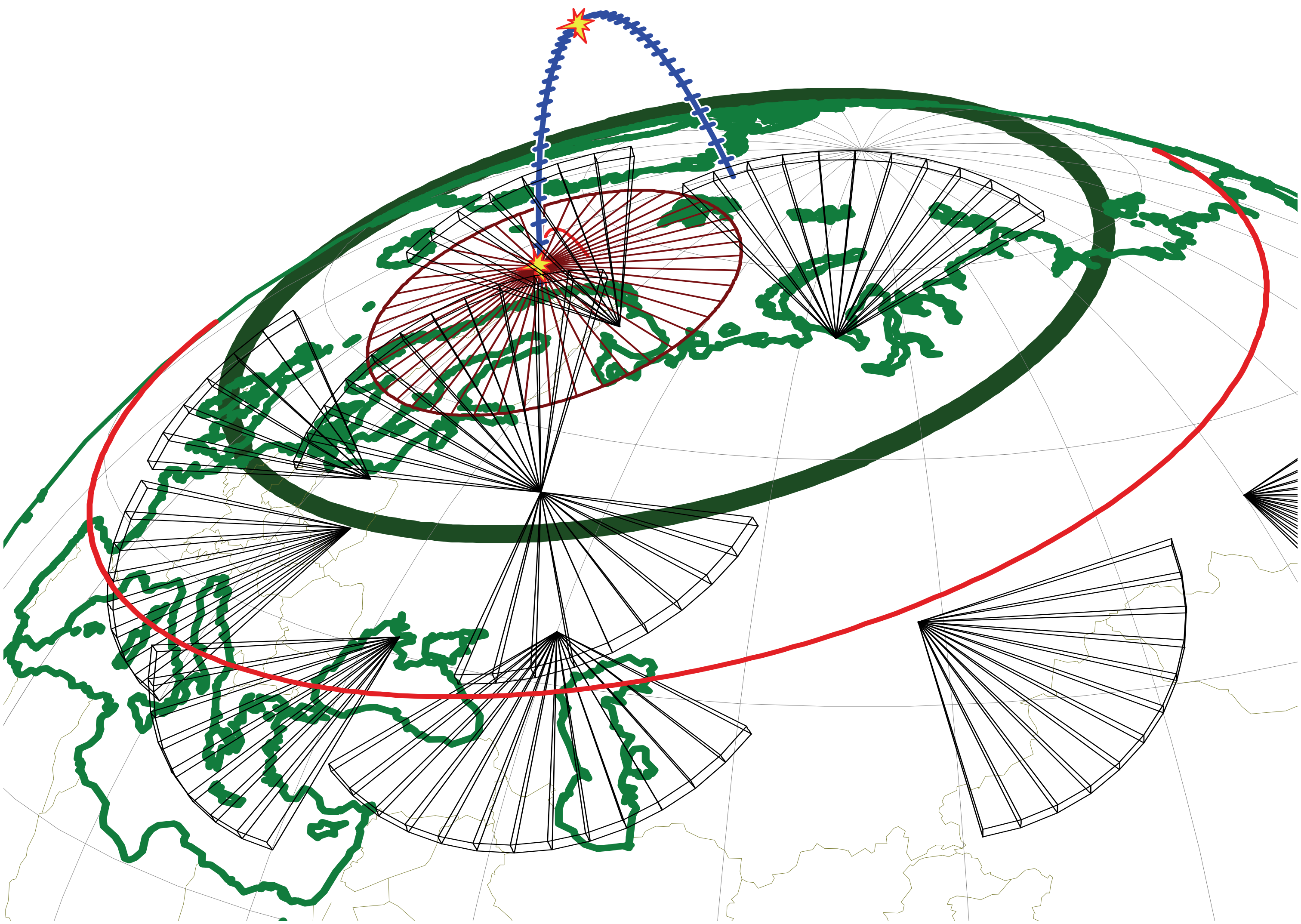
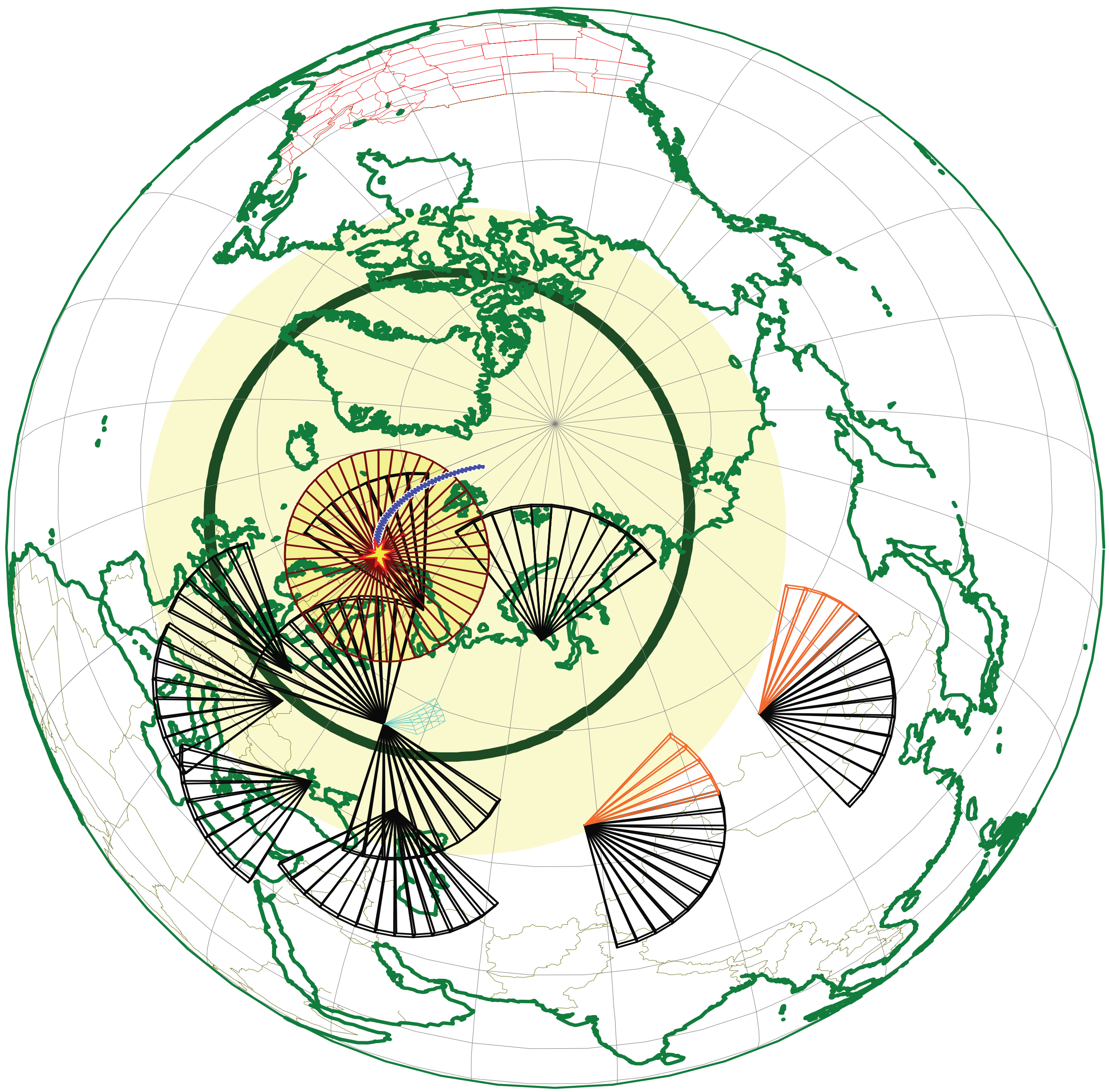


The Russian Experience with the False Alert of January 25, 1995

Areas of Radar-Blackout from a One Megaton Nuclear Explosion at 150 and 1350 Kilometers Altitude

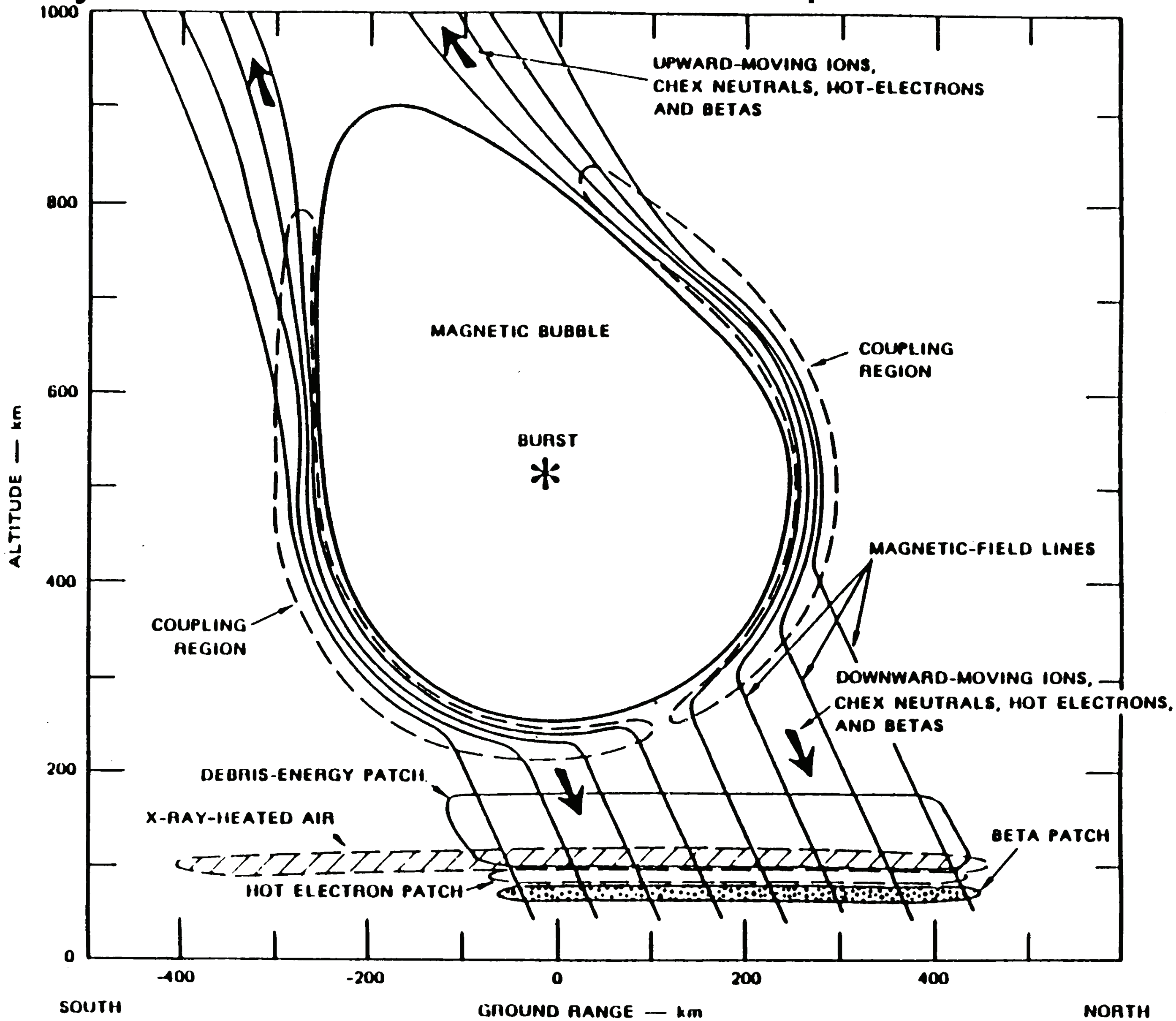


Why Should There Be Any Concern About a Lone Rocket on a Near Vertical Trajectory in the Middle of the Grand Forks to Russia ICBM Attack Corridor?

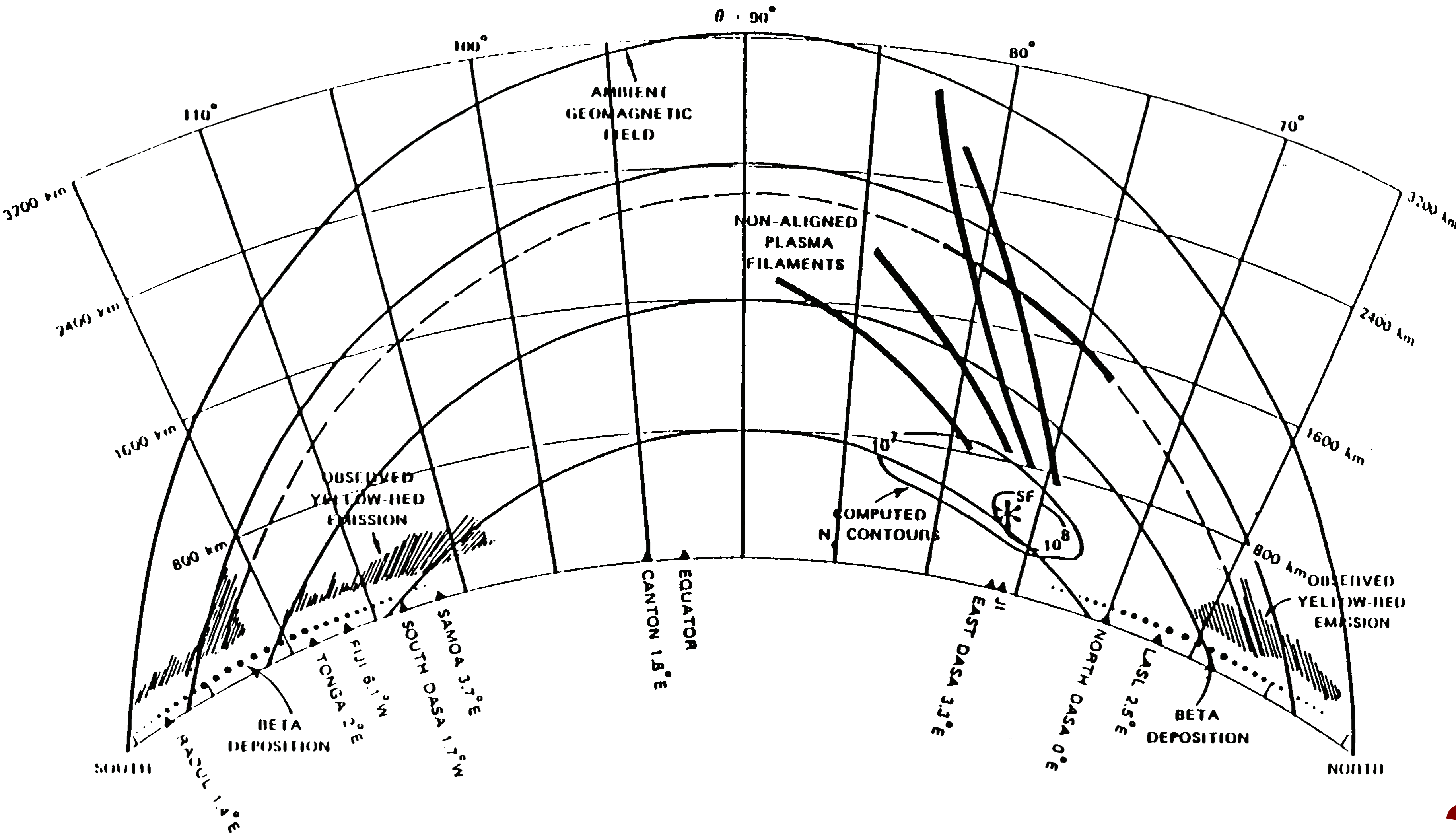
The Nuclear Danger from Shortfalls in Russian Early Warning Satellites

The upper left photo is the skyline of Honolulu moments before the Starfish high altitude nuclear explosion occurred near 11 p.m. on 9 July 1962. The 1.4 megaton explosion occurred at about 400 km altitude over Johnston Island nearly 800 miles away. Within a second the sky was lit to daylight conditions, and it stayed lit for many minutes thereafter. At electromagnetic frequencies a radar like the one at Olenegorsk attempting to search through the area of sky behind the explosion would be unable to do so for many tens of minutes. Thus, such an explosion could be used to effectively "screen" an incoming attack from an early warning radar.

Ionized Fireball and Magnetic Bubble Created by Starfish 1.4 Mt Nuclear Explosion on 9 July 1962



Ionized Regions Created by Beta Emissions following the Starfish 1.4 Mt High-Altitude Nuclear Explosion in 1962



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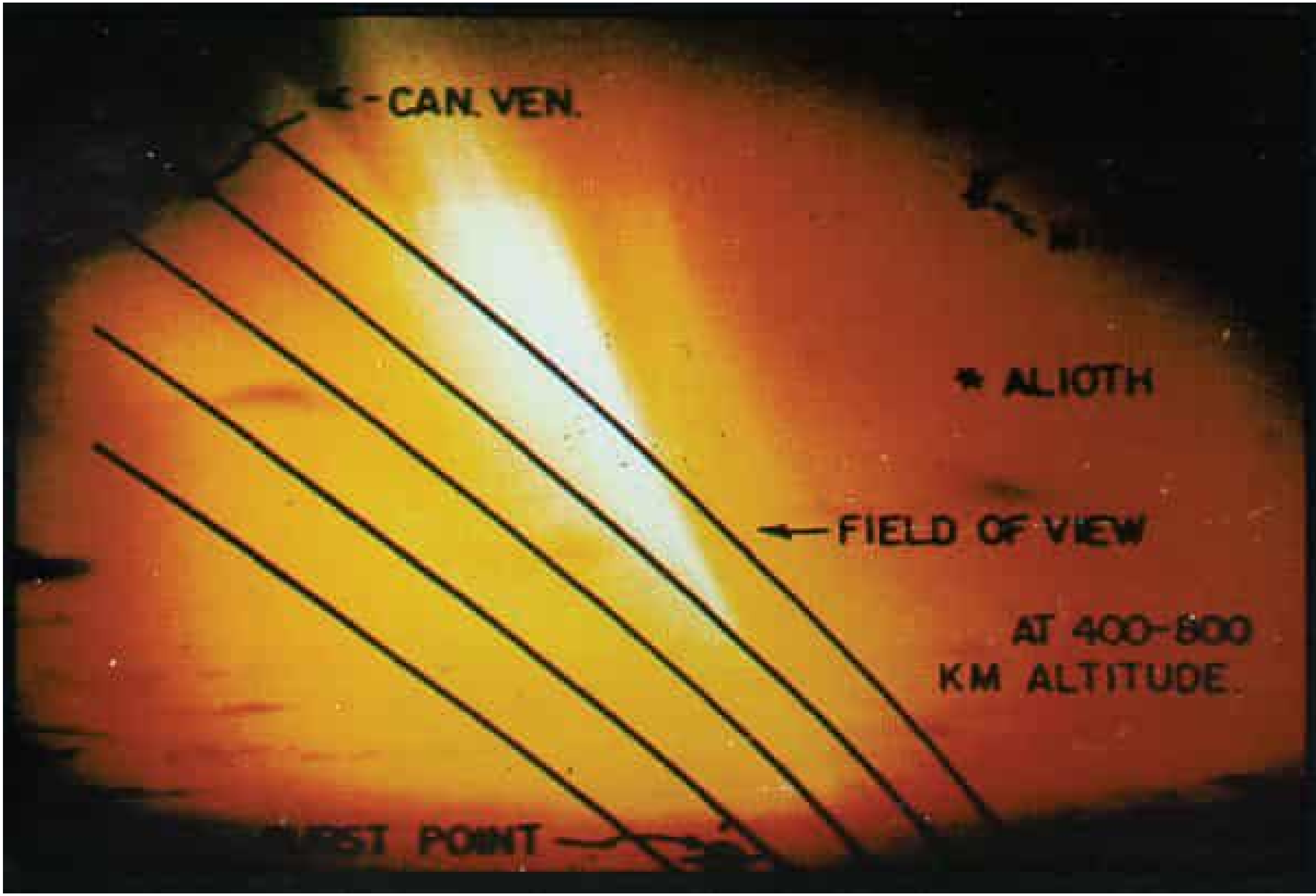
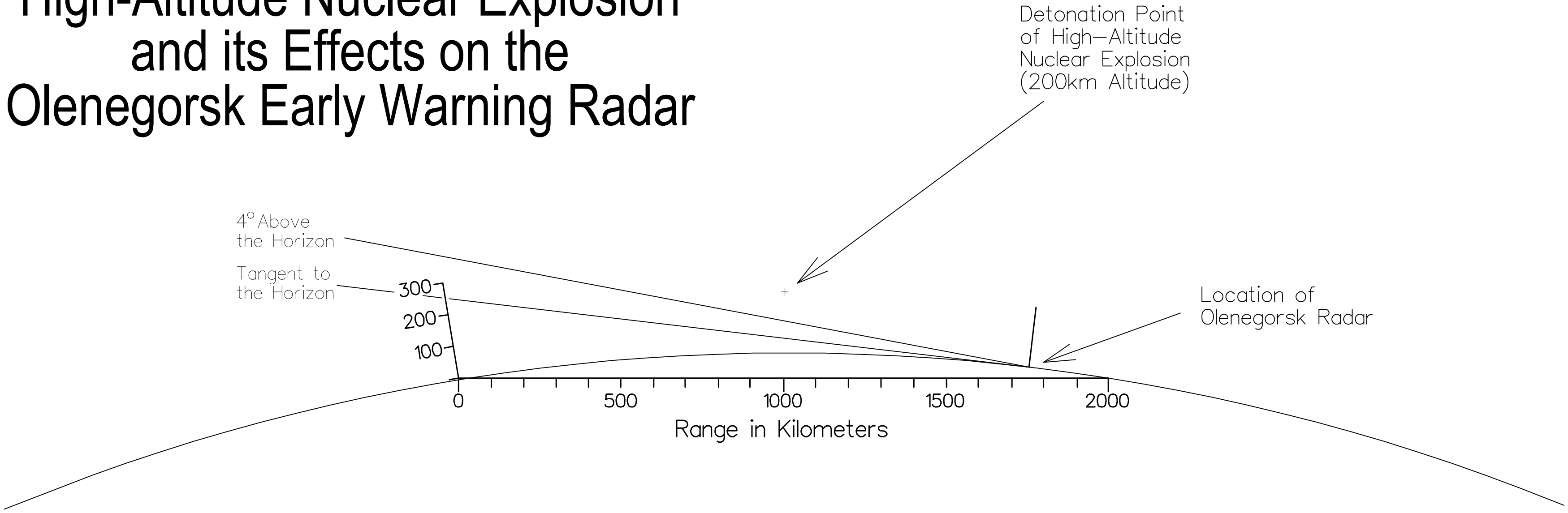
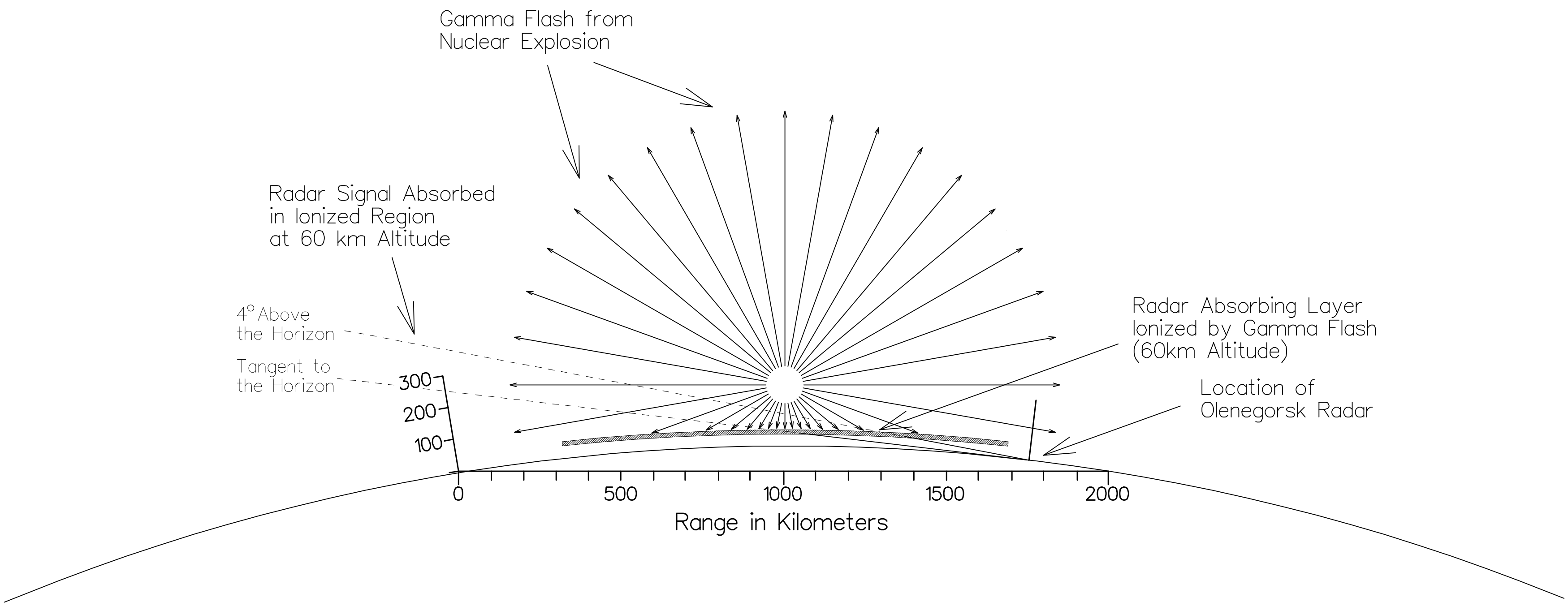


What Might Be the Sequence of Events in a Precursor Attack Designed to Blind Russian Early Warning Radars?

Sequence of Events Associated with a High-Altitude Nuclear Explosion and its Effects on the Olenegorsk Early Warning Radar





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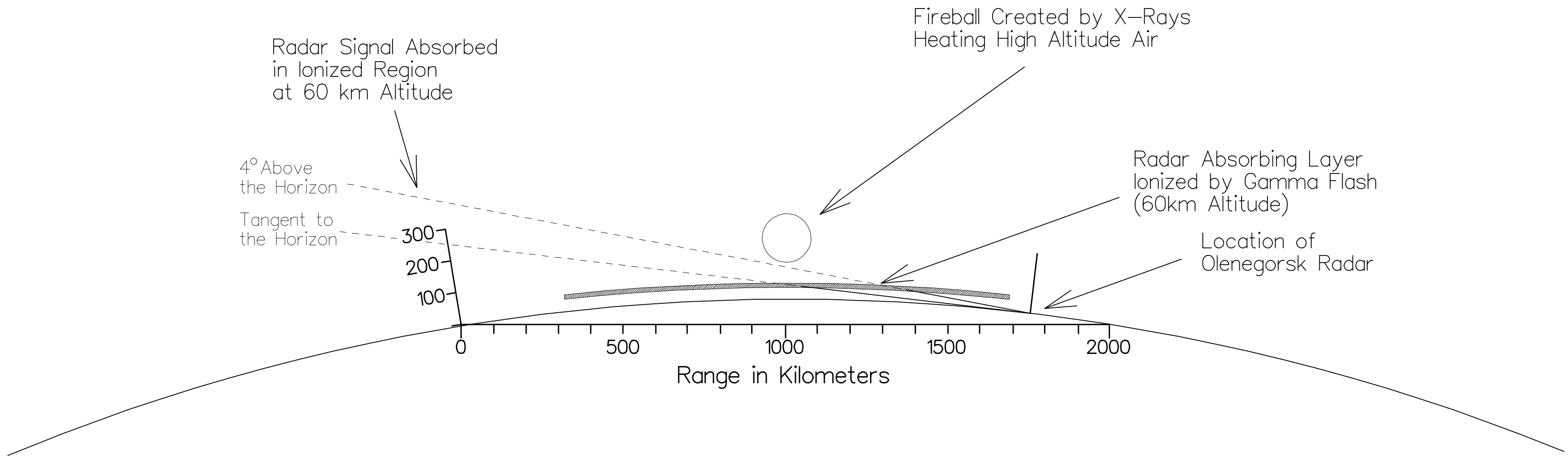
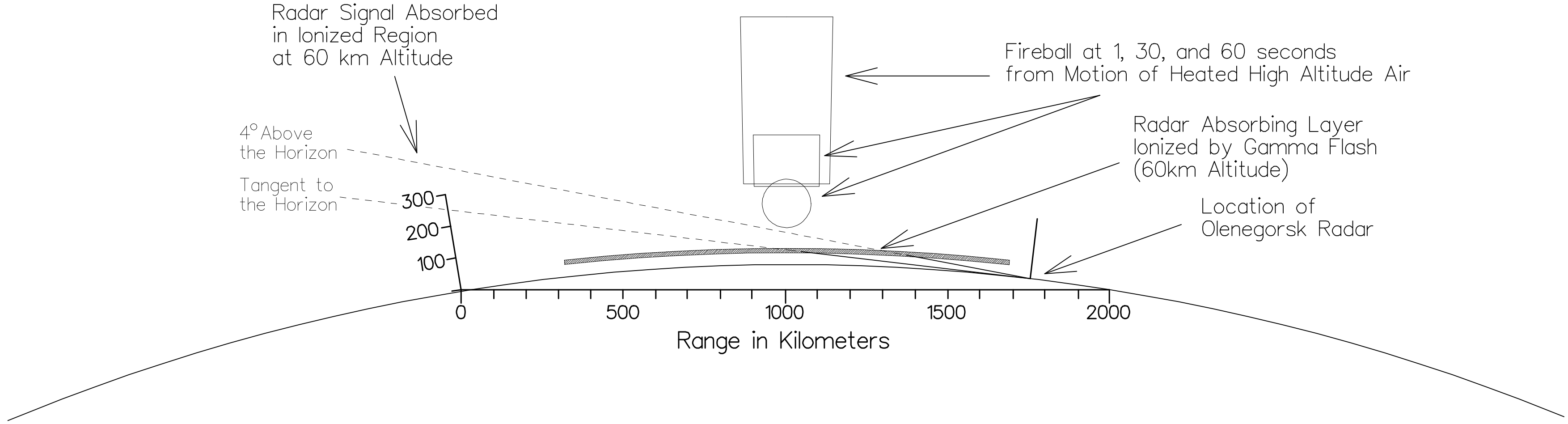
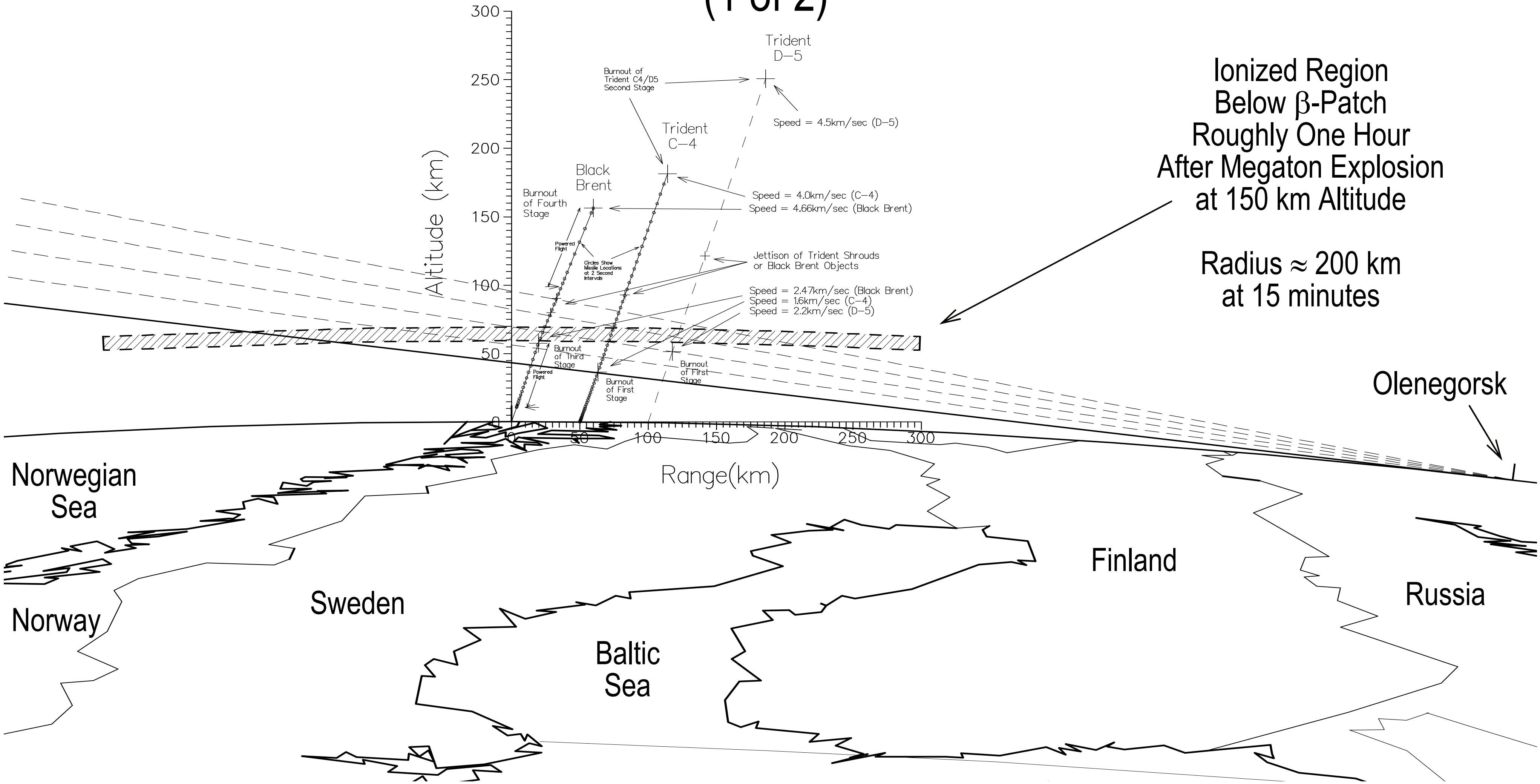




Sequence of Events Associated with a Precursor Attack Designed to Blind the Olenegorsk Early Warning Radar (1 of 2)



The Nuclear Danger from Shortfalls in Russian Early Warning Satellites

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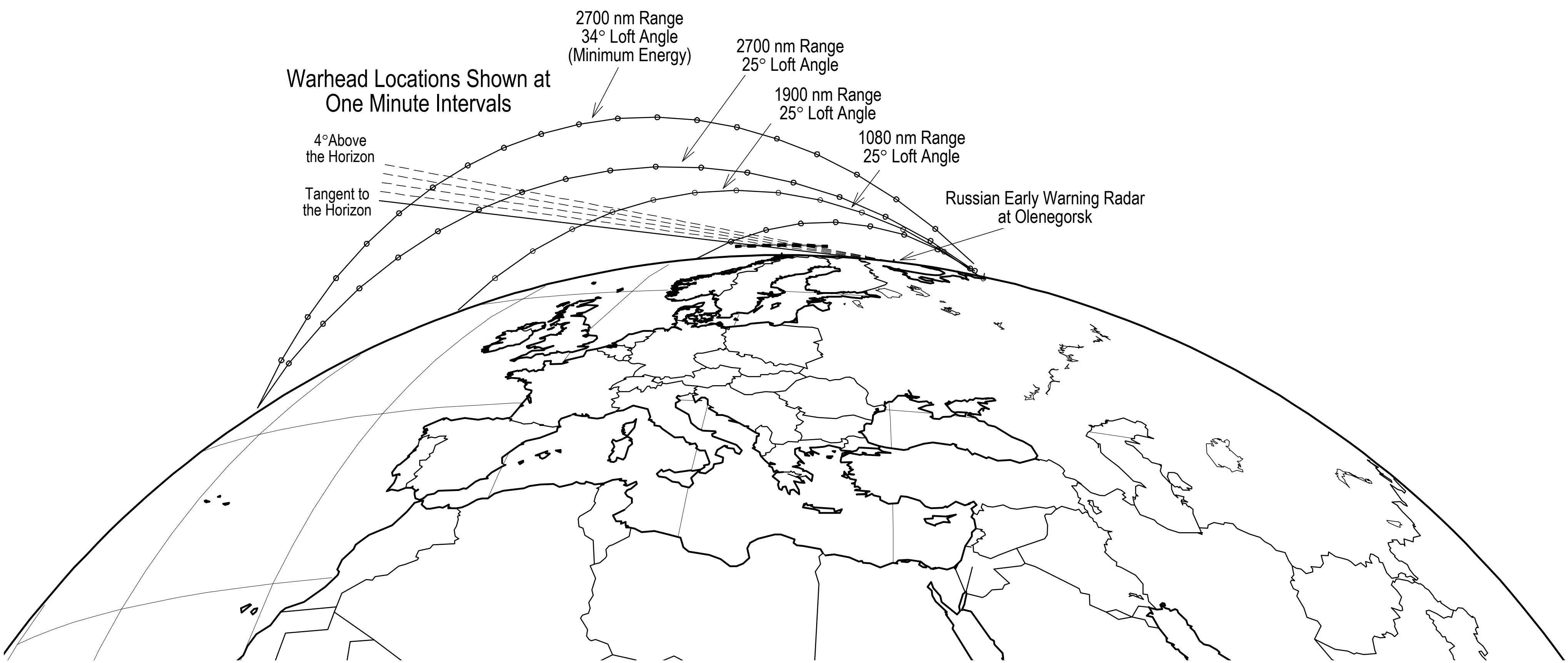
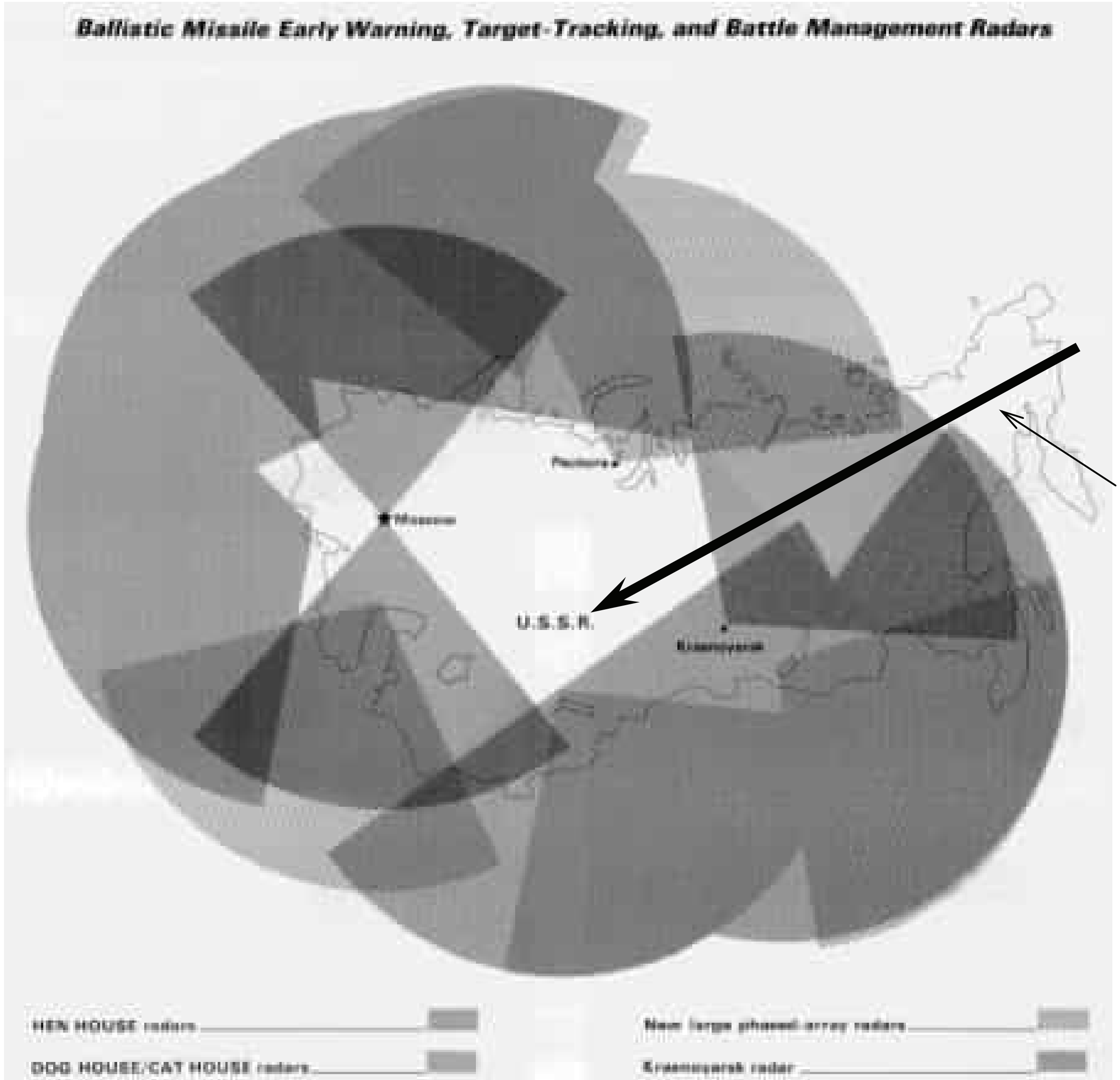


The Nuclear Danger from Shortfalls in Russian Early Warning Satellites



Direction of attack chosen to underfly the radar search fans from Pechora and Mishelevka

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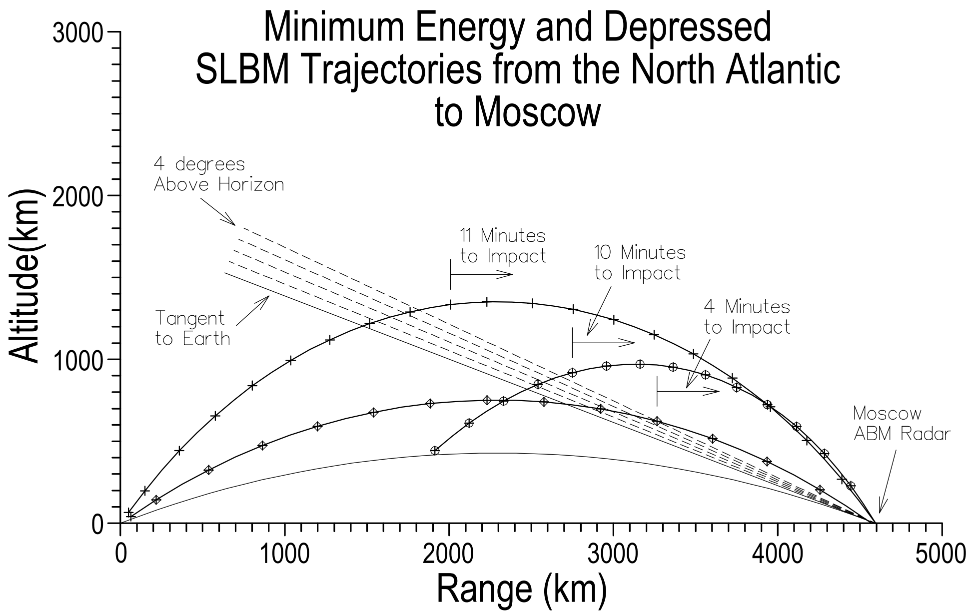
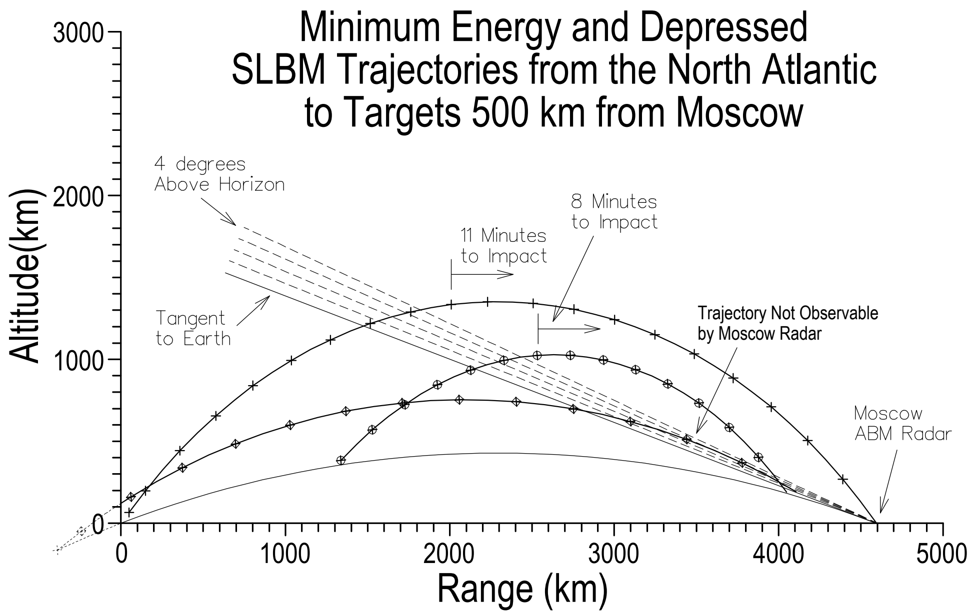
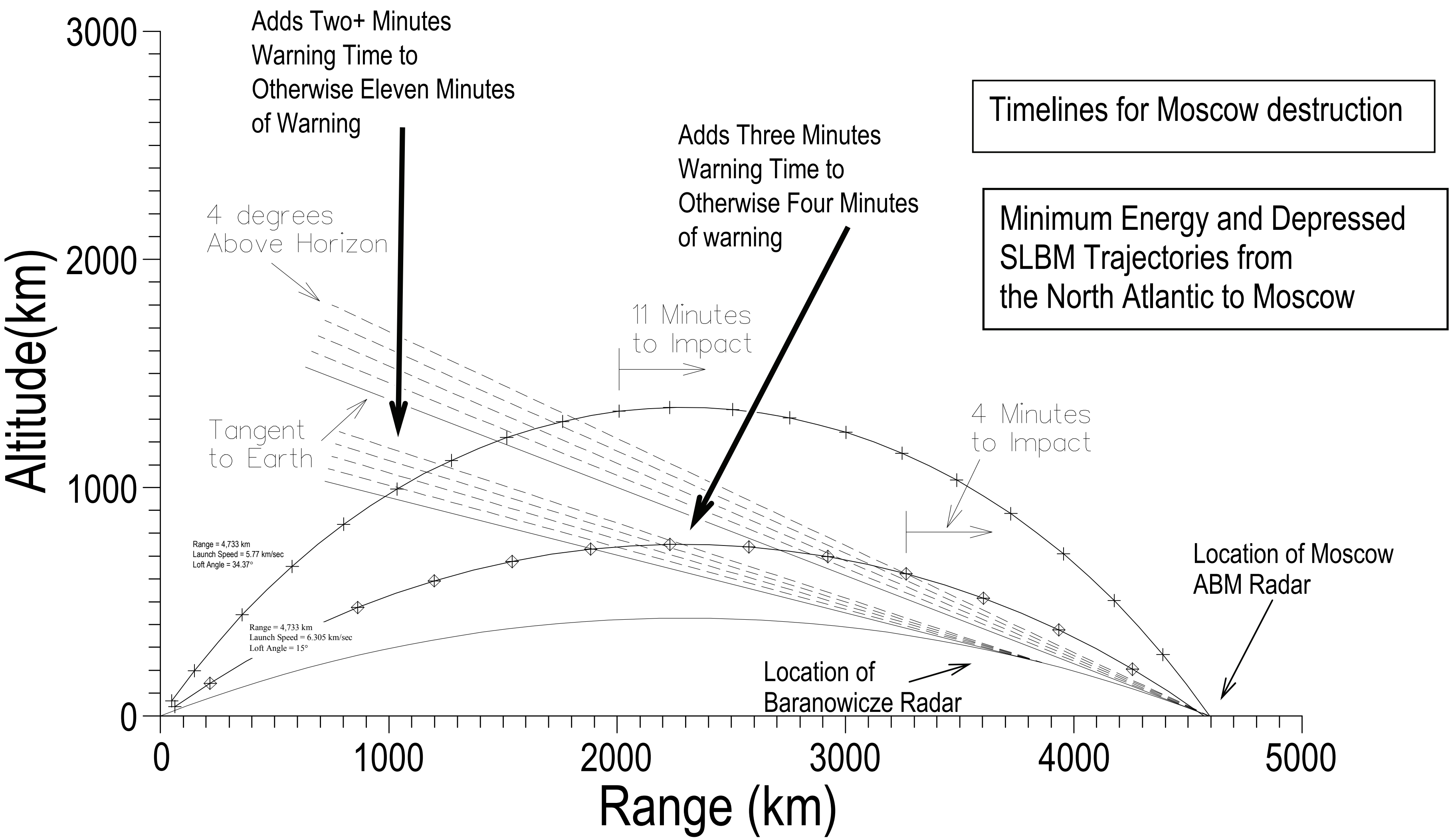
Timelines for SLBM Trajectories from North Atlantic Submarine Launch Areas that are Observable and Non-Observable by Moscow ABM Radars





Warning Times for Trajectories from North Atlantic Launch Areas to Moscow Within Baranowicze and Moscow Radar Fans



Estimated Time Needed to Carry Out Nuclear Launch-Operations No Matter What Response Is Chosen

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Time for command and unit elements of silo-based forces to encode, transmit, receive, decode, and authenticate a launch order	2 to 4 minute
Time for missile crews to go through full launch procedures	1 to 3 minutes
Time for launched missile to reach a safe distance from its launch-silo	1 minute
Total time consumed in unavoidable and essential operations	7 to 13 minutes

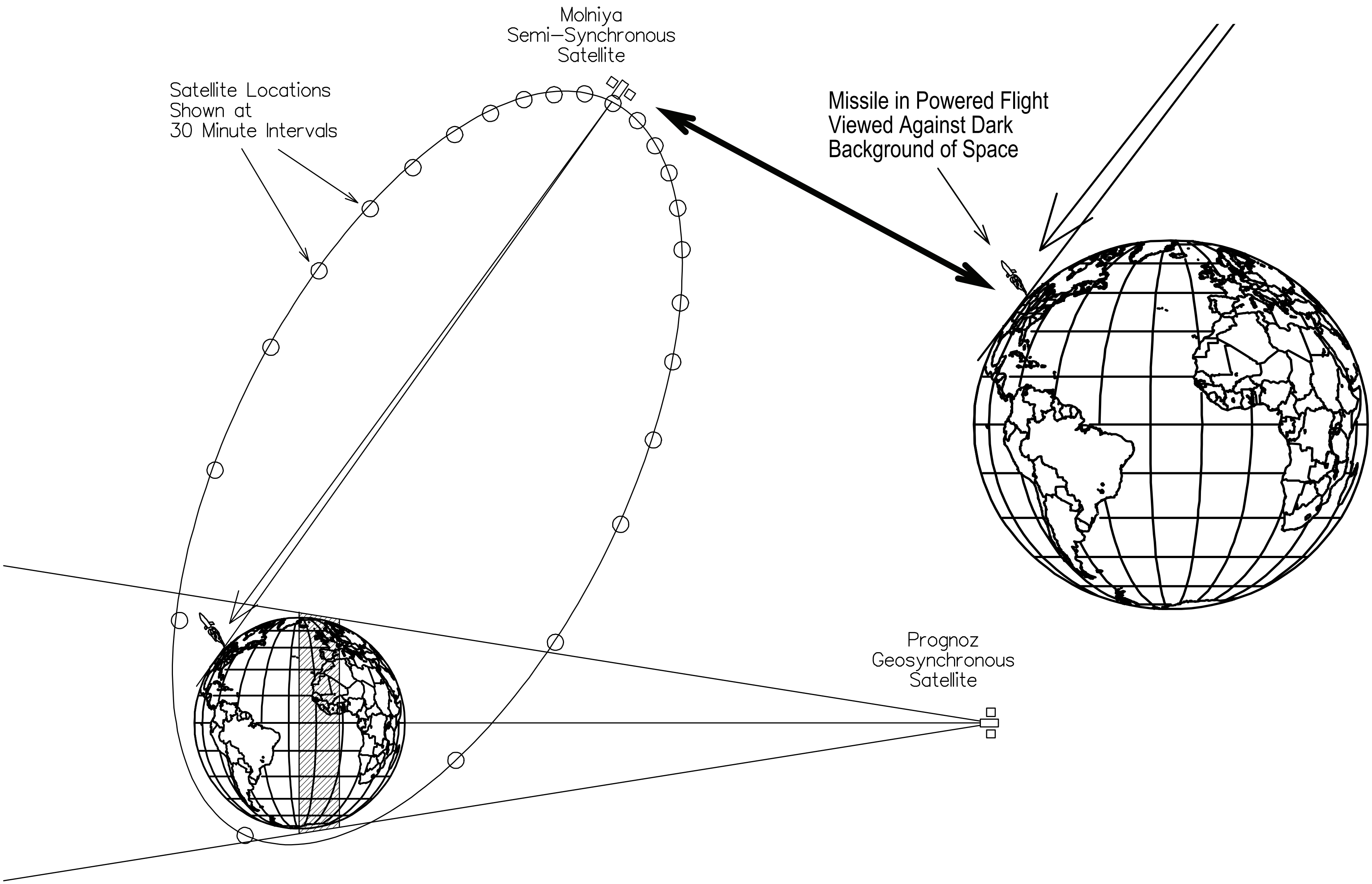
If a short time-line attack is attempted against Russia, a Russian response aimed at launching silo-based missiles before nuclear weapons detonate on them would require time for several technical operations. Time would also be needed by political leadership to assess the situation and decide whether or not to launch the silo-based missile force. The amount of time available for decision-makers to assess the situation and decide whether or not to launch silo-based nuclear forces is the difference between the time it takes for warheads to arrive at targets and the time needed to carry out operations no matter what response is chosen.

The State of Russian Space-Based Early Warning Systems

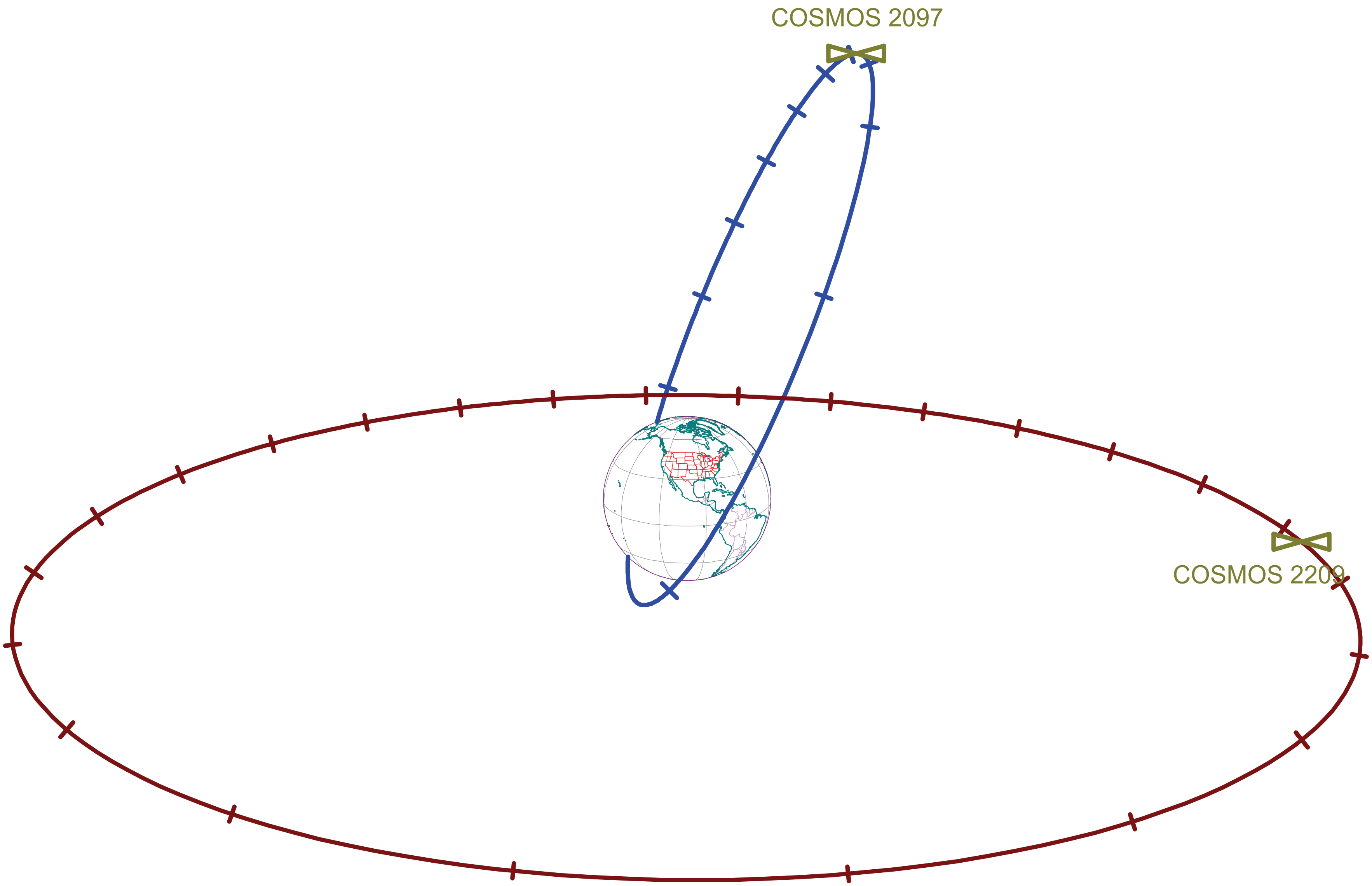
Russian Molniya and Prognoz Space-Based Early Warning Systems

Russian Molniya Infrared Early Warning Satellite Constellation

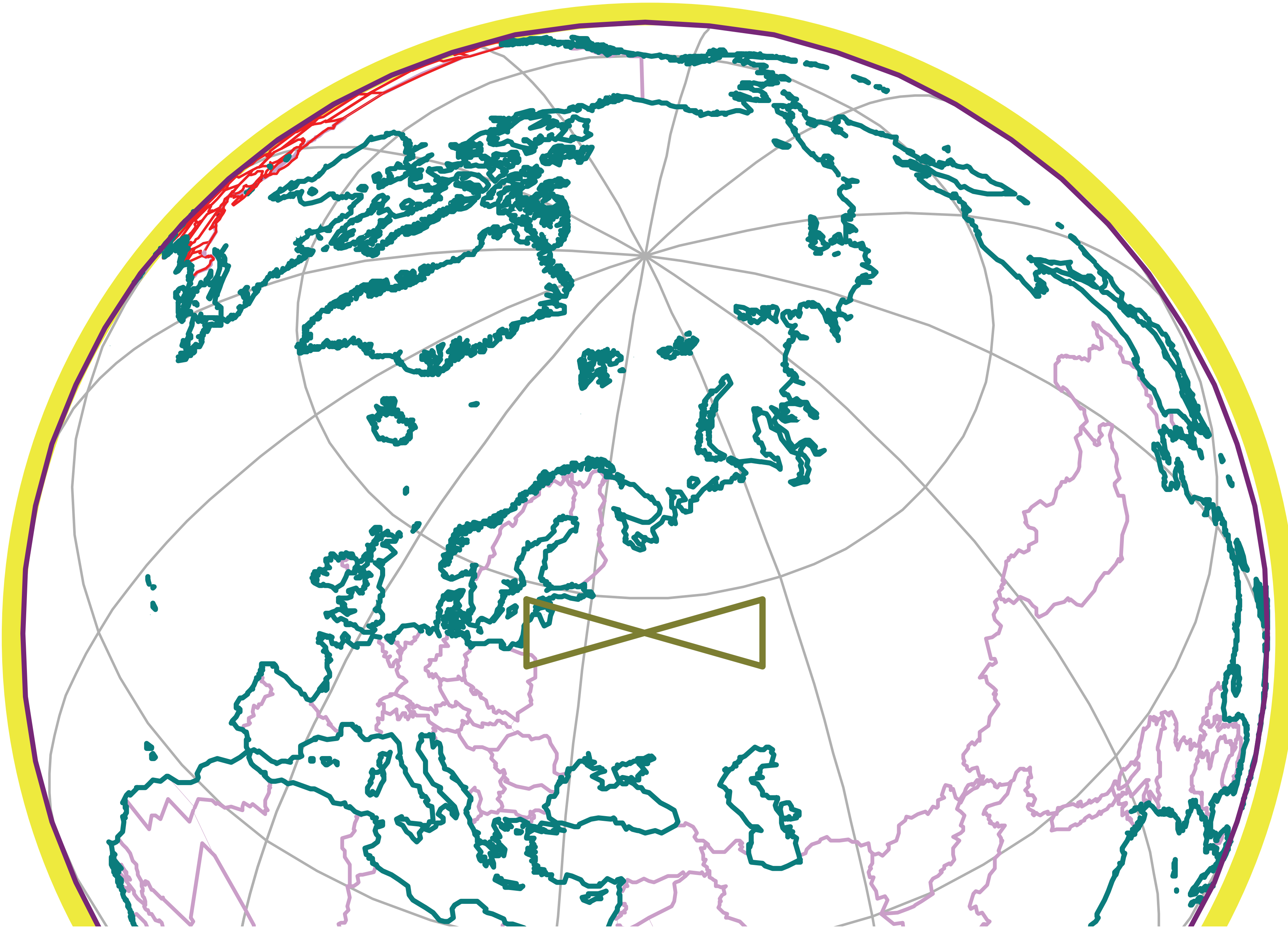
(Nine Satellites Required for 24 Hour Coverage. Only Five Are Currently Operational in July 1998)



View of Cosmos 2209 and Cosmos 2097 Orbits

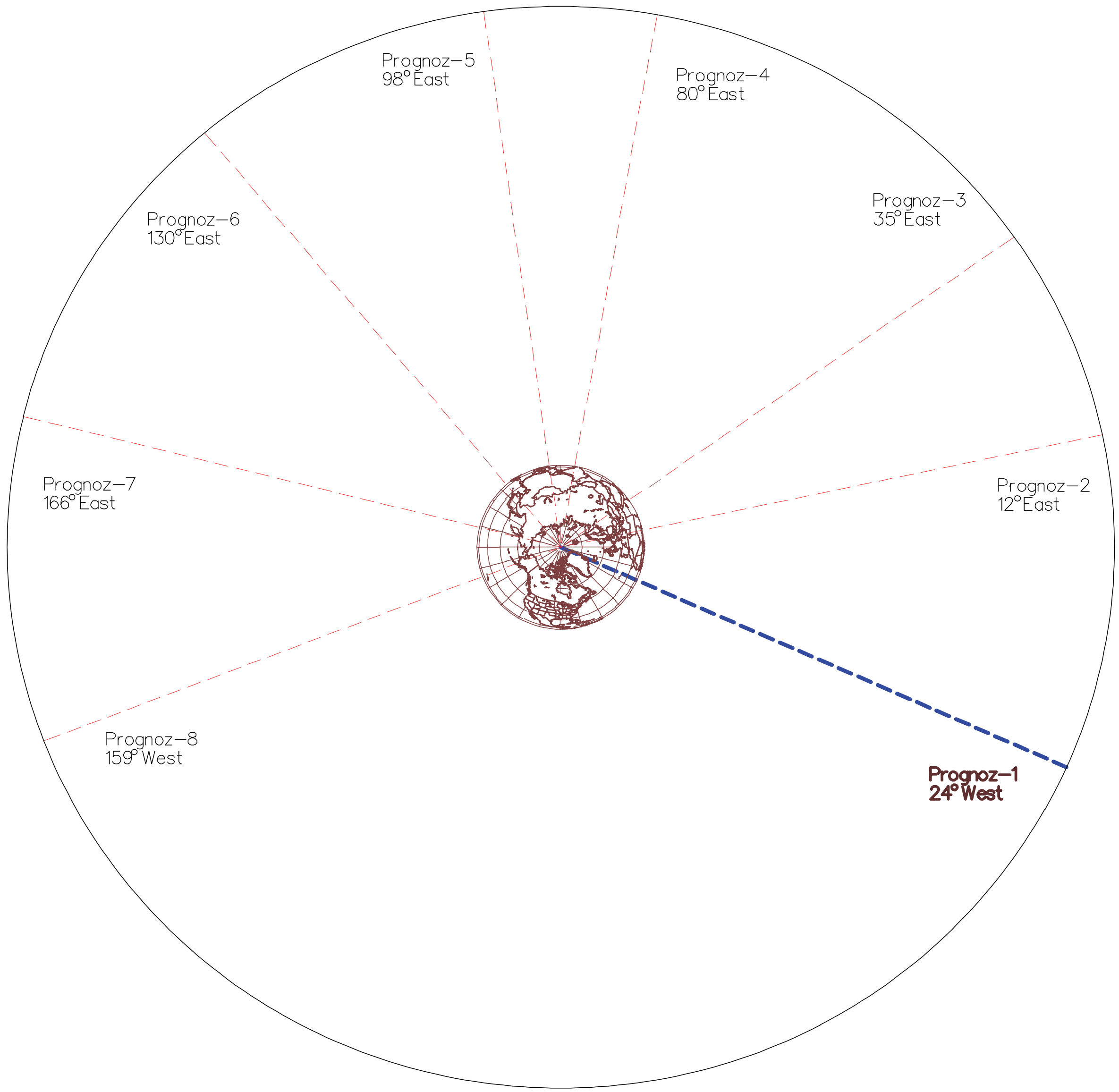


View of Earth from Cosmos 2097 at Apogee

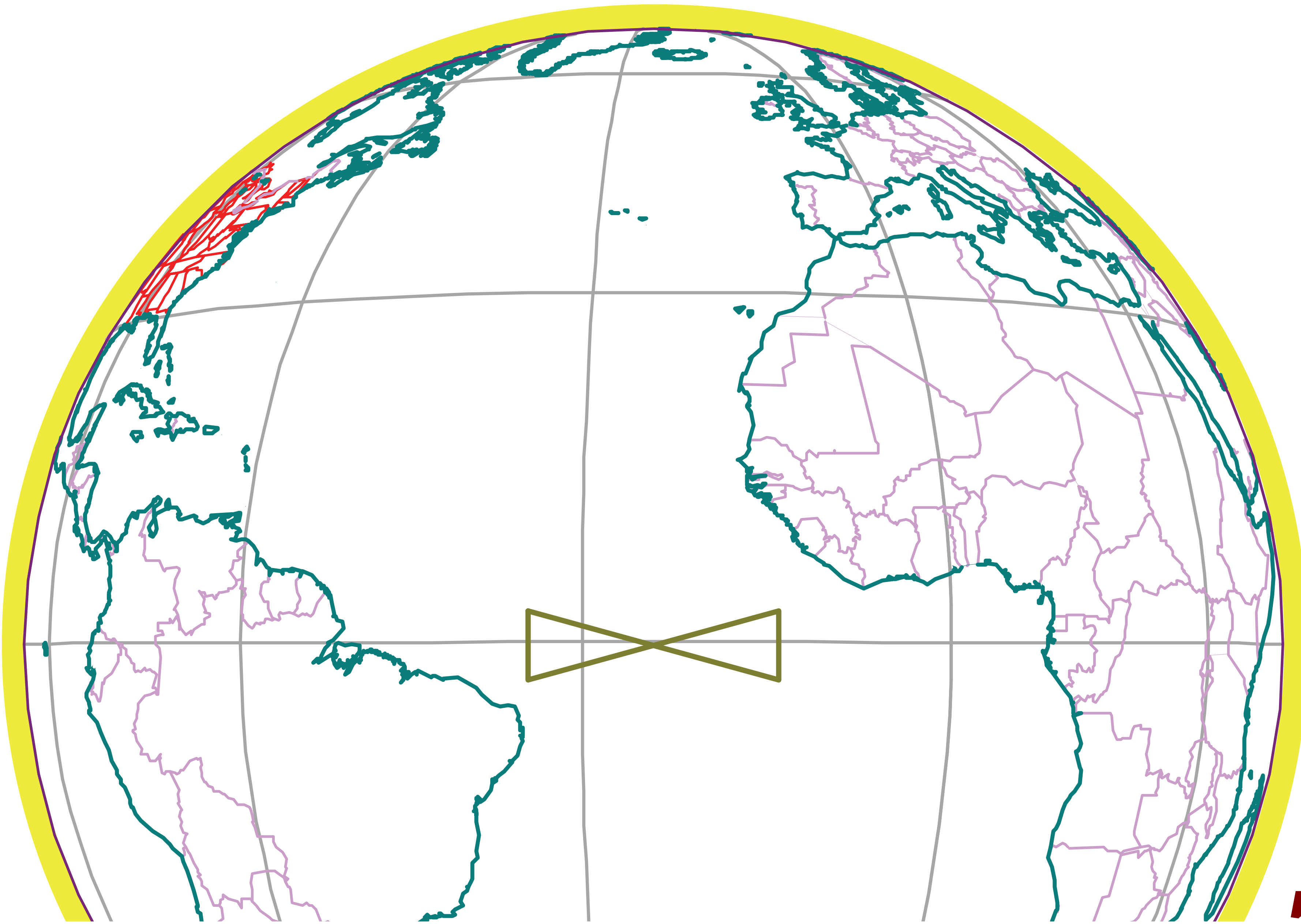


Russian and US Space-Based Early Warning Systems

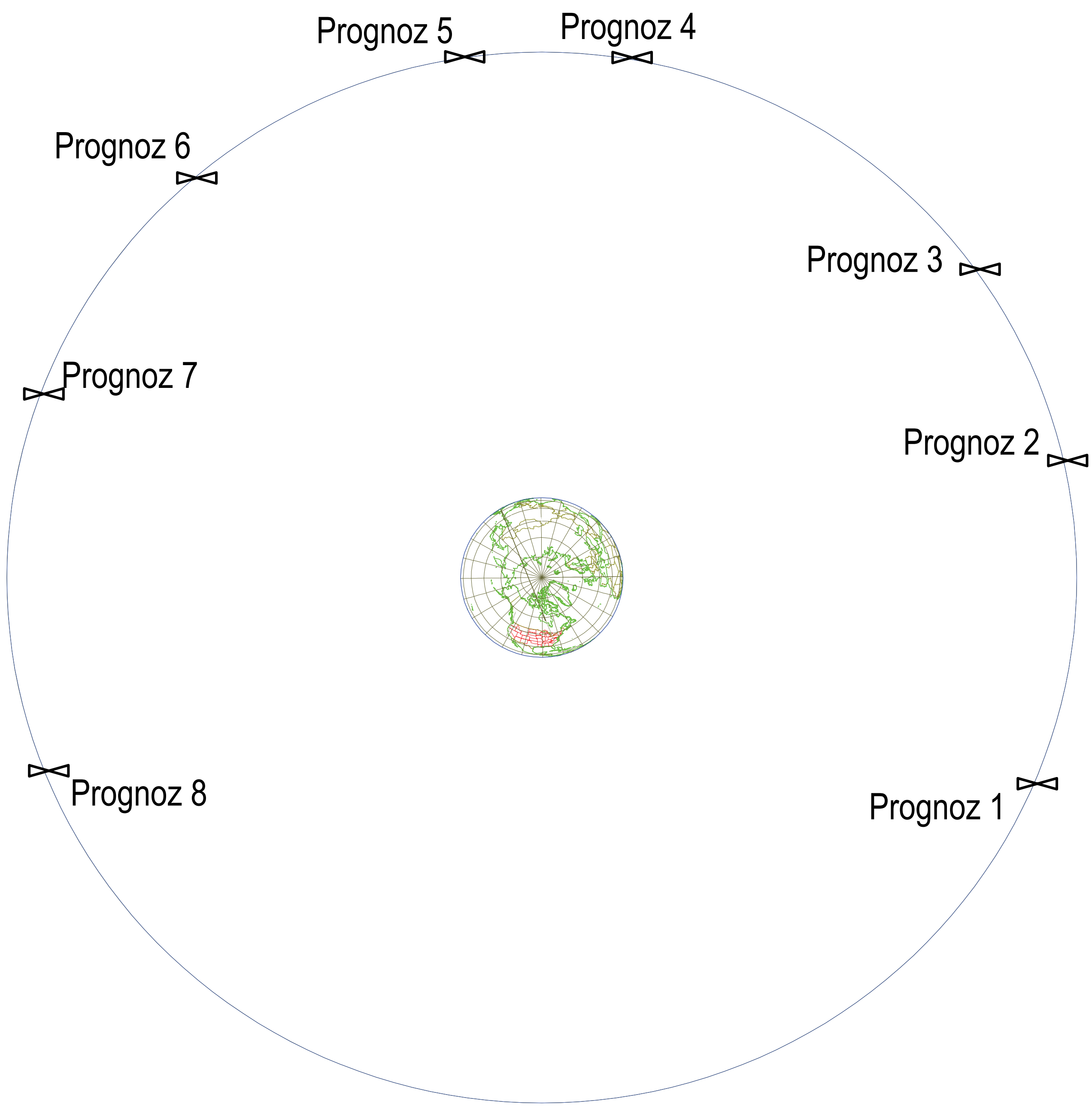
Geosynchronous Satellite Stations Reserved for (But Not Necessarily Occupied by) the Prognoz Early Warning Satellite System



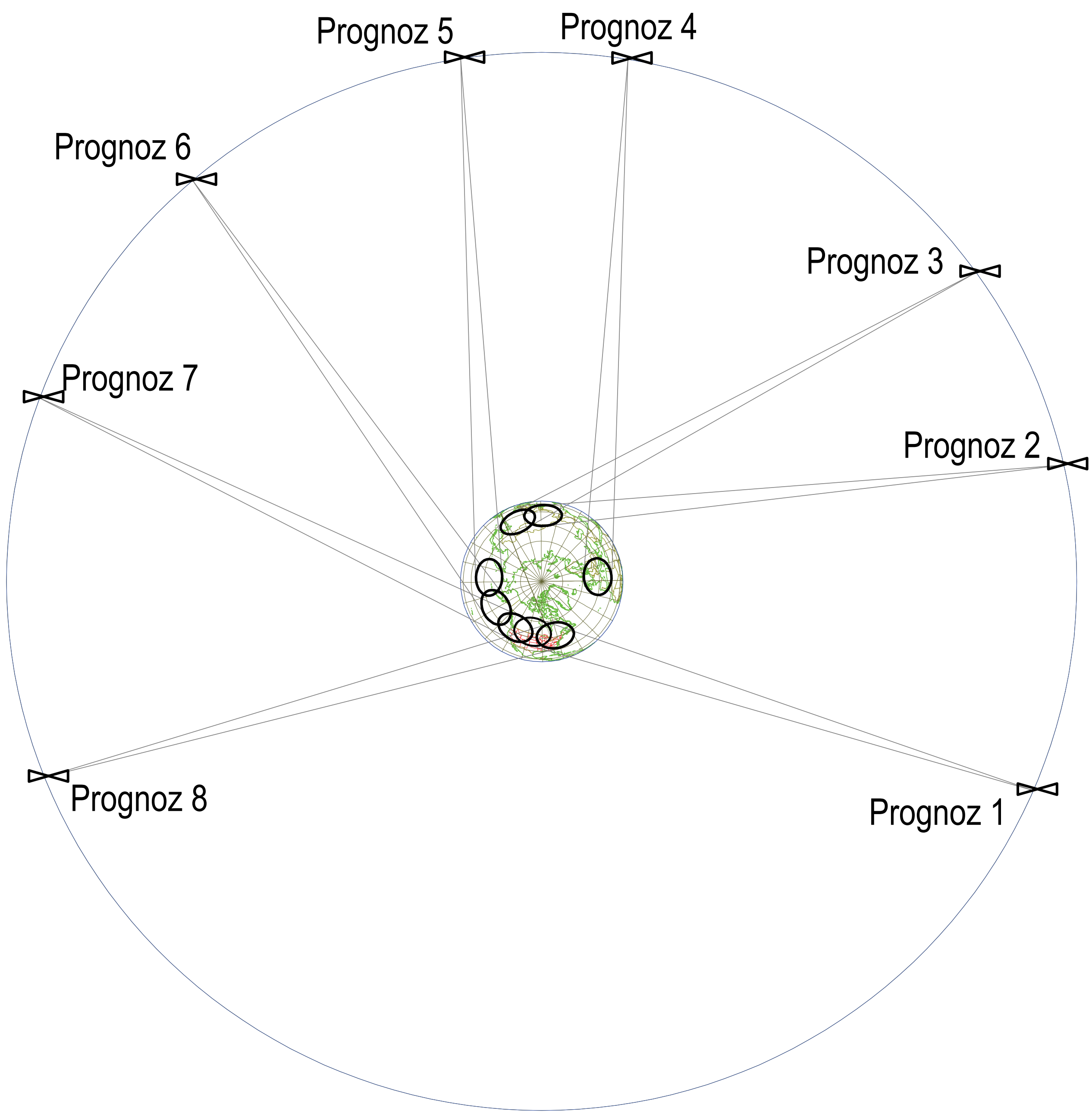
View of Earth from Cosmos 2297 at Apogee



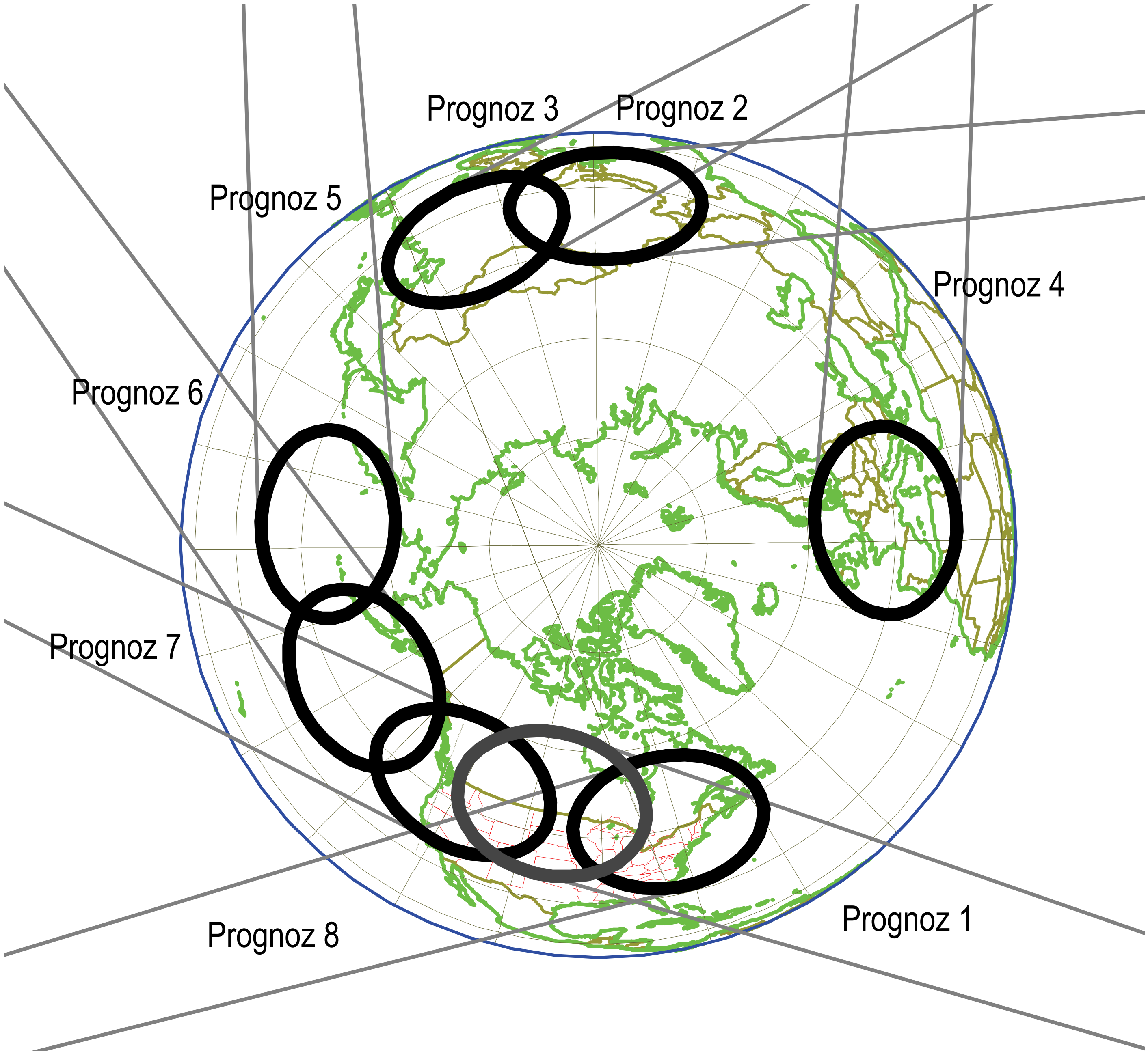
The Existing and Planned Locations of Prognoz Satellites



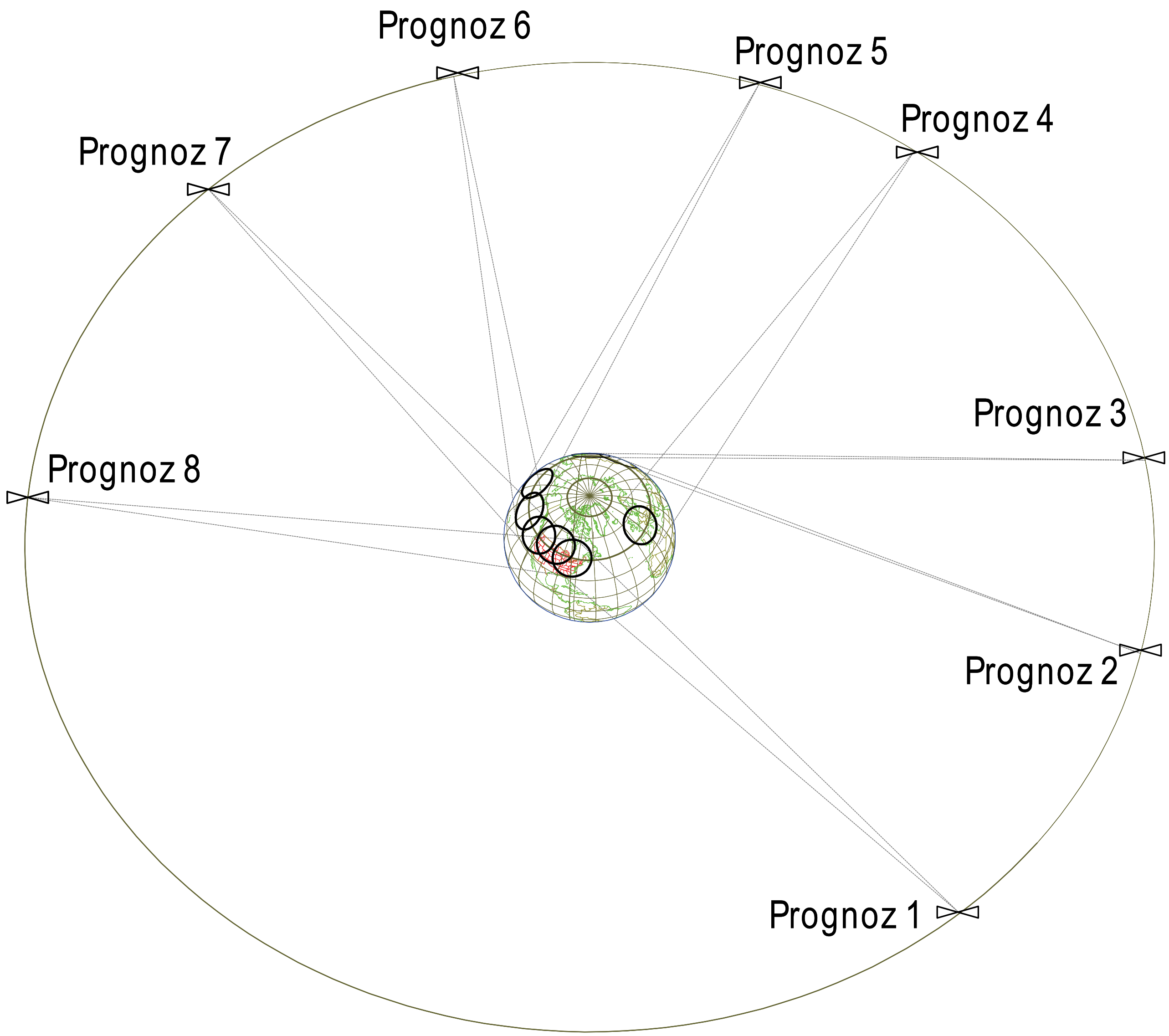
The Existing and Planned Locations of Prognoz Satellites



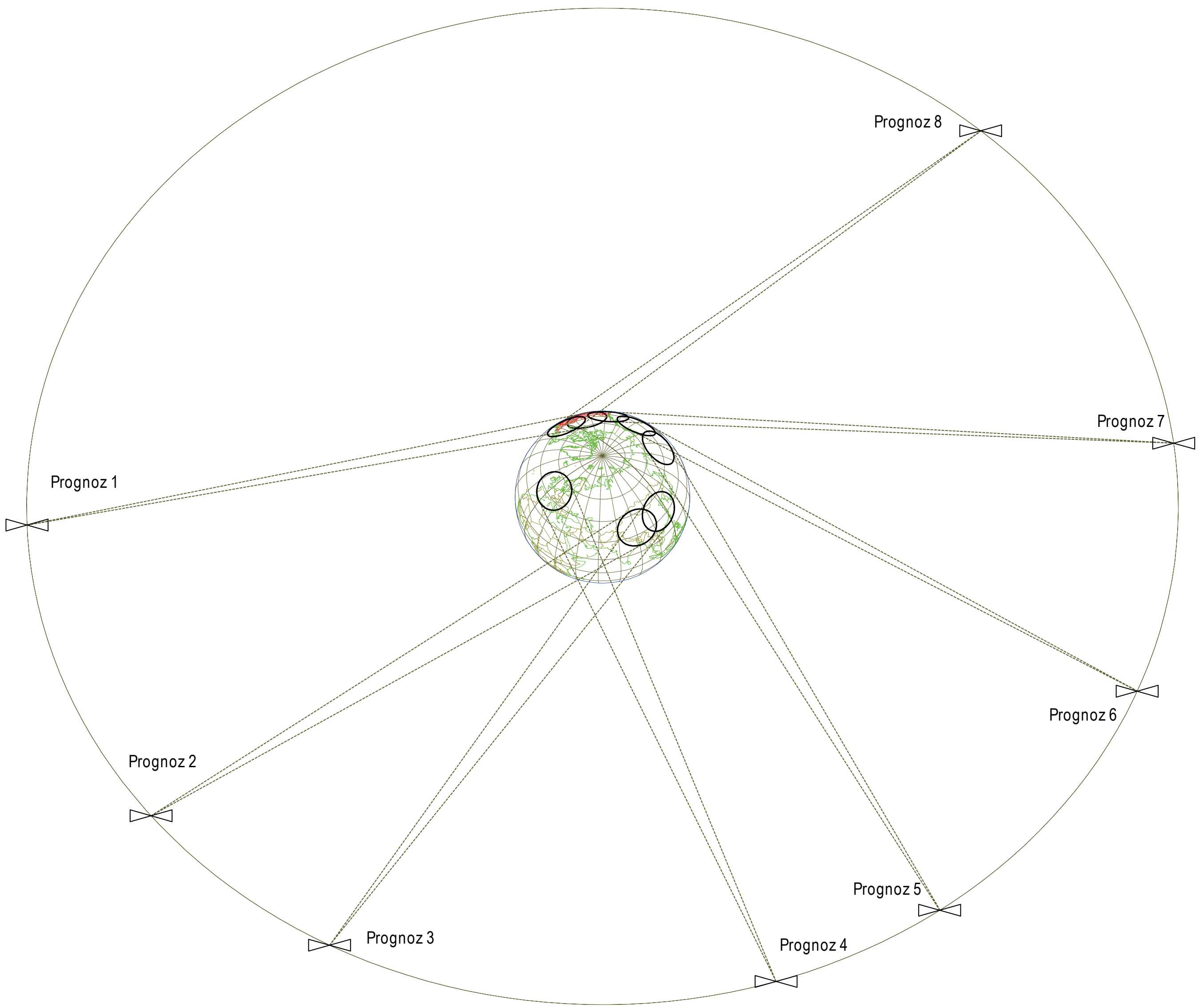
Areas Where the Prognoz Satellites Attempt to Observe Rocket Plumes



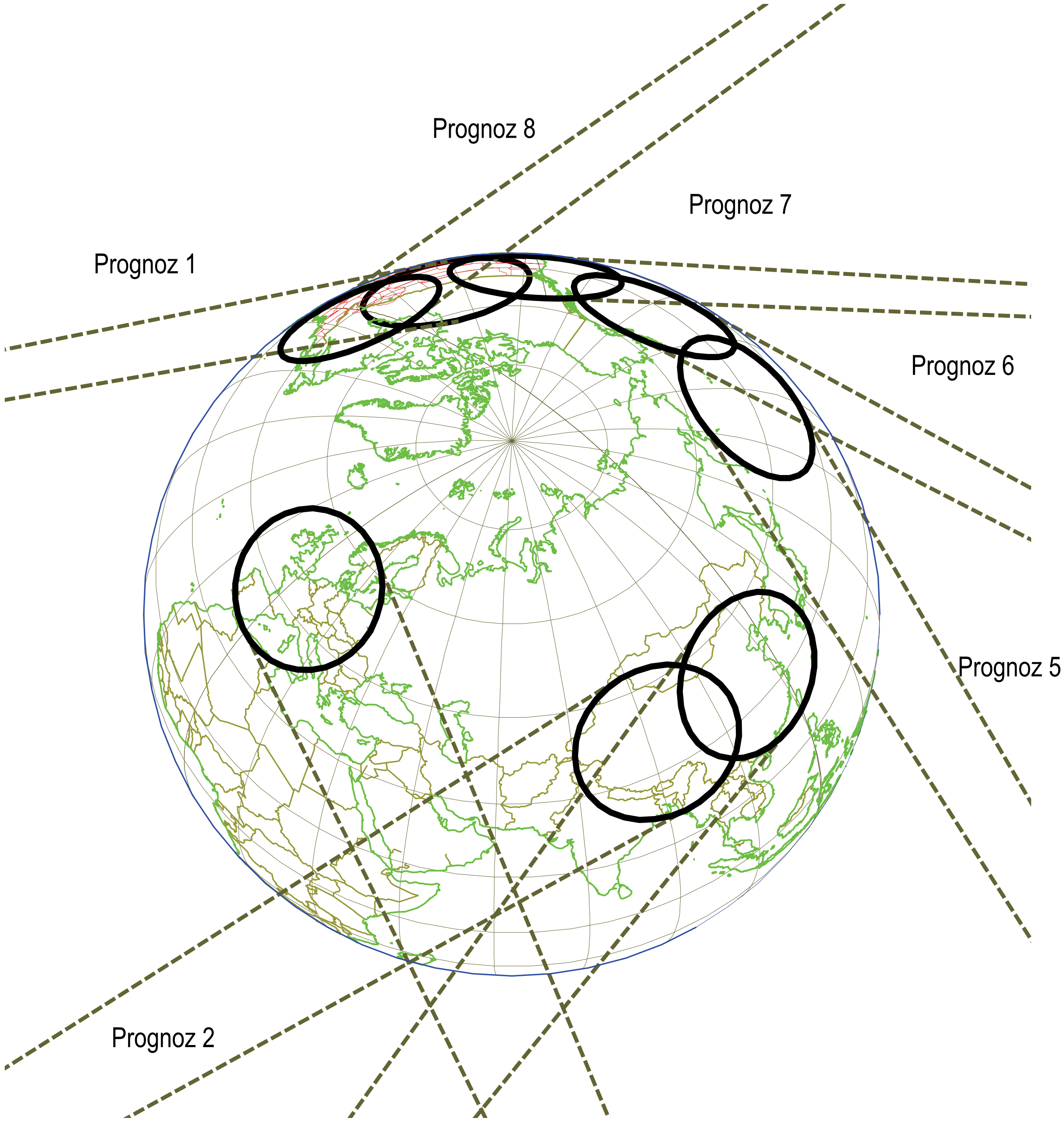
Areas Where the Prognoz Satellites Attempt to Observe Rocket Plumes



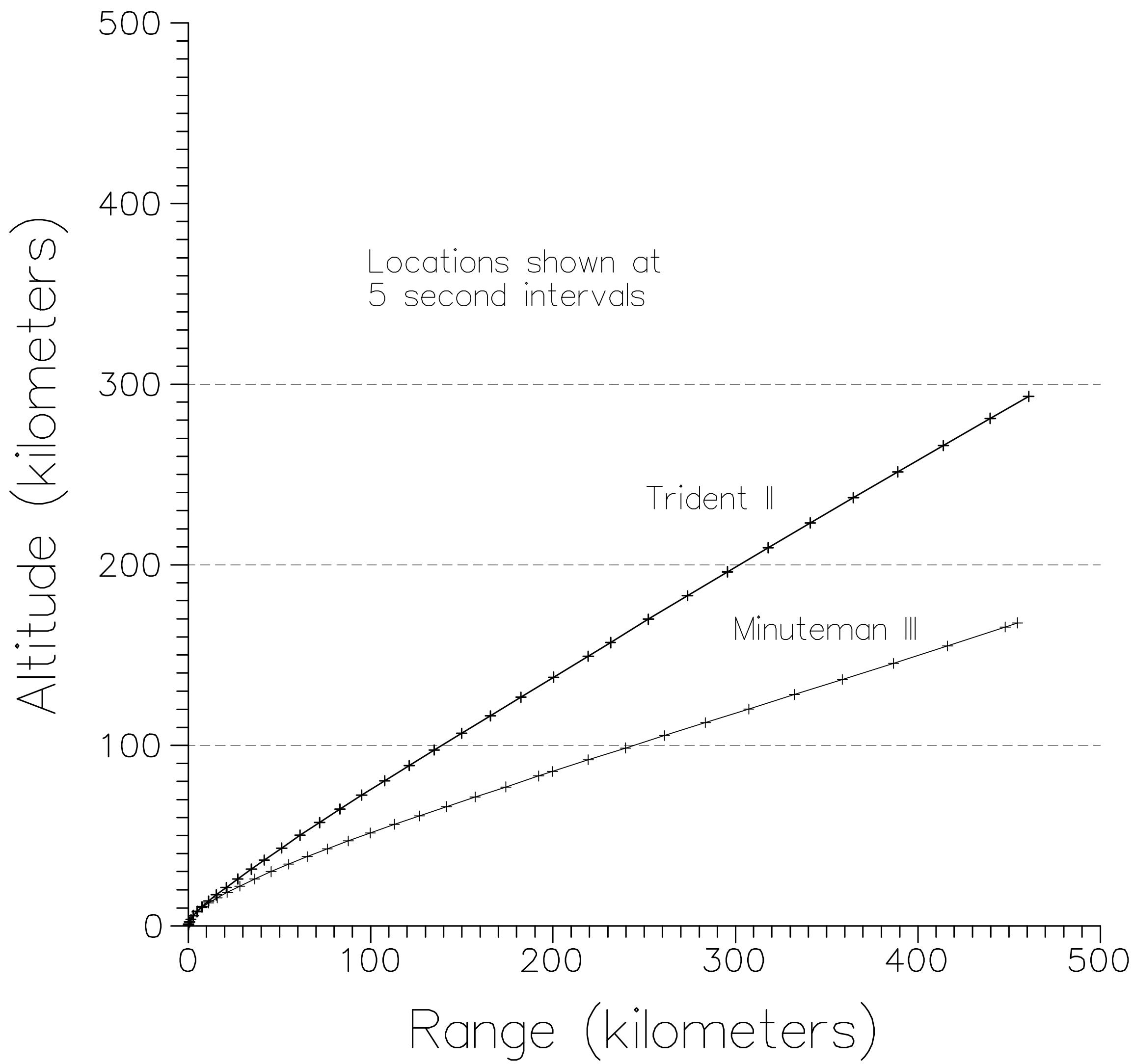
Areas Where the Prognoz Satellites Attempt to Observe Rocket Plumes



Areas Where the Prognoz Satellites Attempt to Observe Rocket Plumes

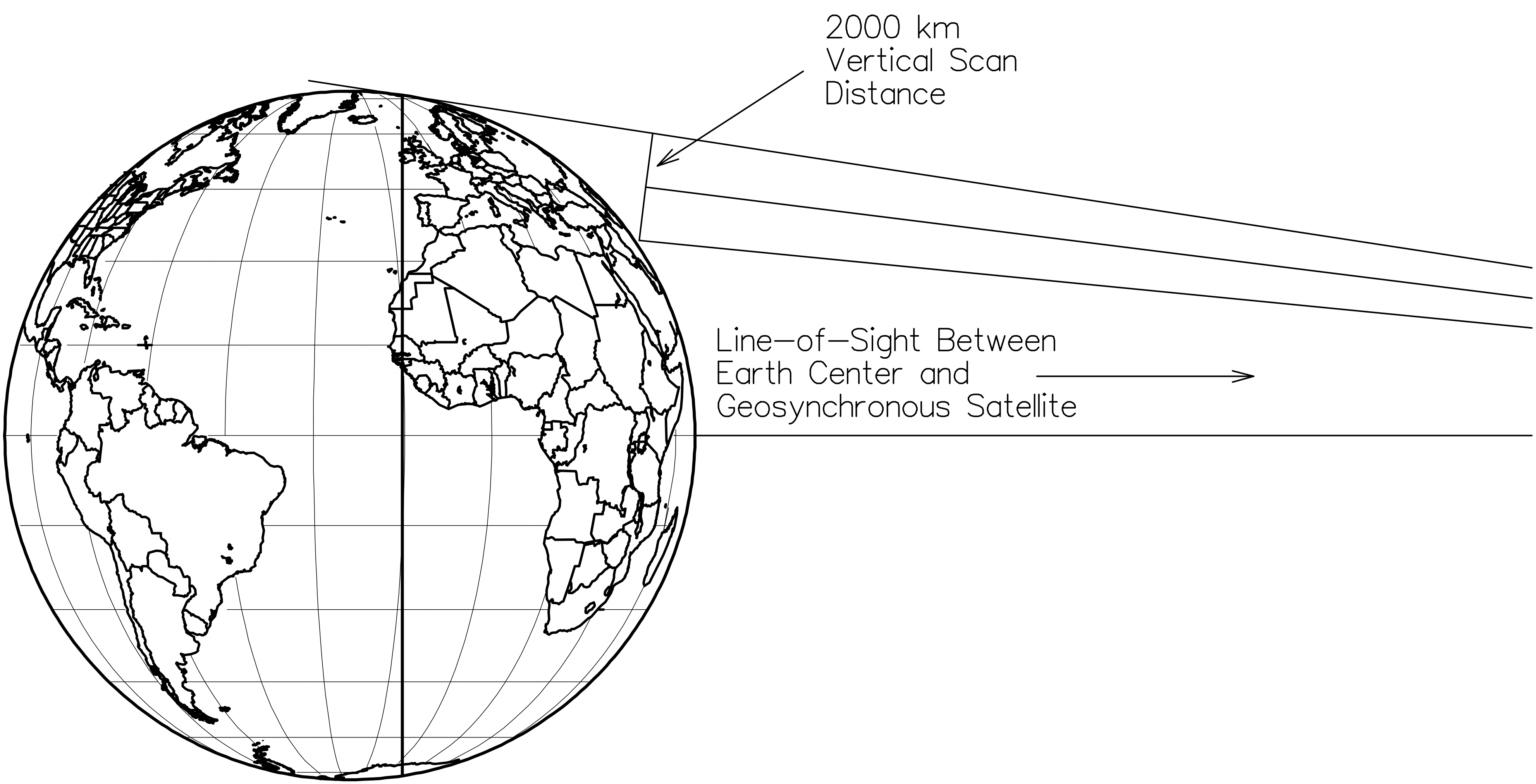


Rough Estimates of Altitude and Range Locations of Minuteman III and Trident II Missiles During Powered Flight

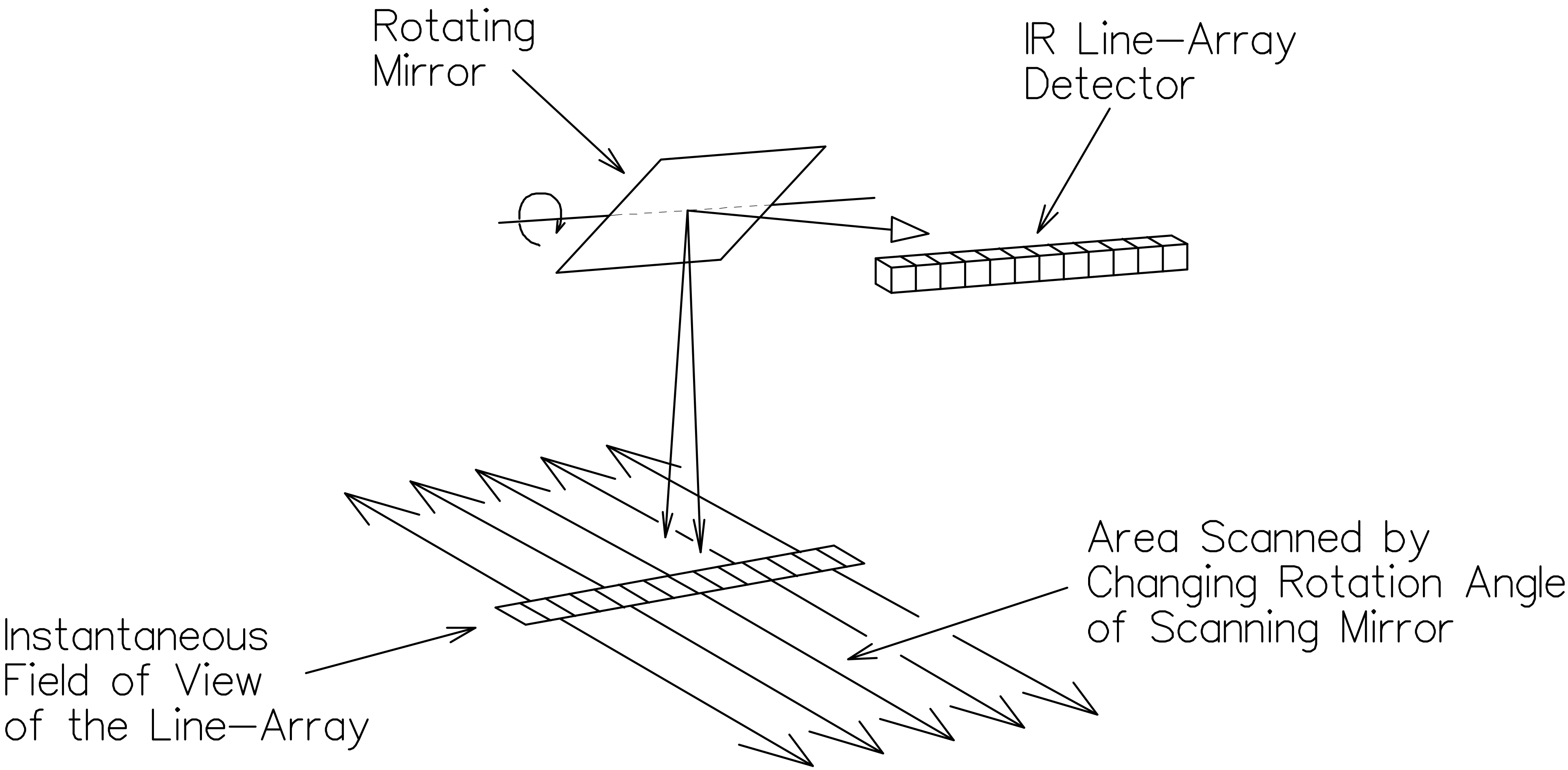


Russian Space-Based Early Warning Systems

Geometry for a Vertically Scanning Satellite Field of View from

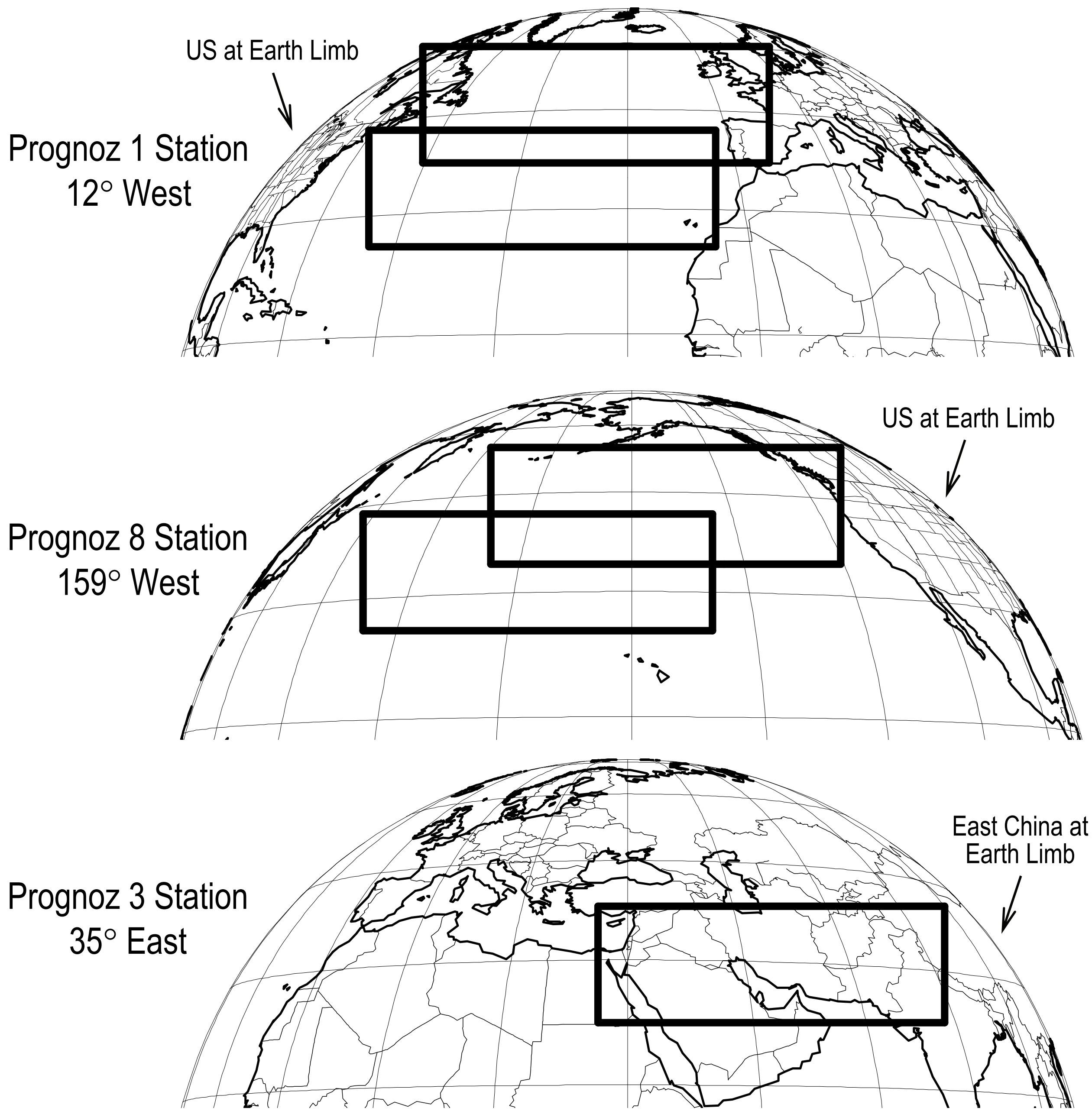


Rocking or Rotating Mirror Satellite Scanning System



Russian Space-Based Early Warning Systems

Rough Estimate of Prognoz Satellite Look-Down Field of View



Parameters Determining Estimate of Satellite Field of View

Downlink Data Rate = 15 MB /sec

Frame Time = 3 seconds

No On-Board Data Processing

Number of Linear Array Elements = 500

Sampling Rate = 5000 samples / sec

6 Bits Dynamic Range per Pixel (64 Intensity Levels)

Vertical Pixel Dimension = 3 km

Russian and US Space-Based Early Warning Systems

Known Facts from which Prognoz Satellite Look-Down Field of View Can Be Estimated

Data Rate of Prognoz Satellite Downlink = 15 MB/s

Rough Estimate of Dynamic Range of Raw Data ≈ 6 to 8 bits (64 to 256 levels)

1,500,000 to 2,000,000 intensities per second.

Assuming a 3 second Frame Time

4,500,000 to 6,000,000 intensities per frame

If pixels 2 km on a side, then satellite field of view is 9,000,000 to 12,000,000 km^2 (3,000 to 3,500 km on a side)

If pixels 1 km on a side, then satellite field of view is 4,500,000 to 6,000,000 km^2 (2,000 to 2,500 km on a side)

Assuming a Digital Sampling Rate ≈ 2500 to 5000 samples/sec

And a Dynamic Range of Raw Data ≈ 6 to 8 bits (64 to 256 levels)

Number of Array Elements ≈ $1.5\times10^7 / 5\times10^3 / 6$ = 500 to 1,000 Elements

Assuming 1970s US-DSP Sensor Technology then the Swath Width ≈ 3 km,

a 3 second Frame Time, and a Sweep Distance of 1500 km /sec, the swath width is 4500 km from Geosynchronous.

The Field of View is then

$$\theta_{Vertical} = \frac{1500}{36000}\frac{180}{\pi} = 2.4 \text{ deg} \quad \text{by} \quad \theta_{Horizontal} = \frac{4500}{36000}\frac{180}{\pi} = 7.1 \text{ deg}$$

Russian and US Space-Based Early Warning Systems

Ground Surveillance Areas for Scanning IR Satellite Fields of View With 250 to 1000 Element Line Arrays

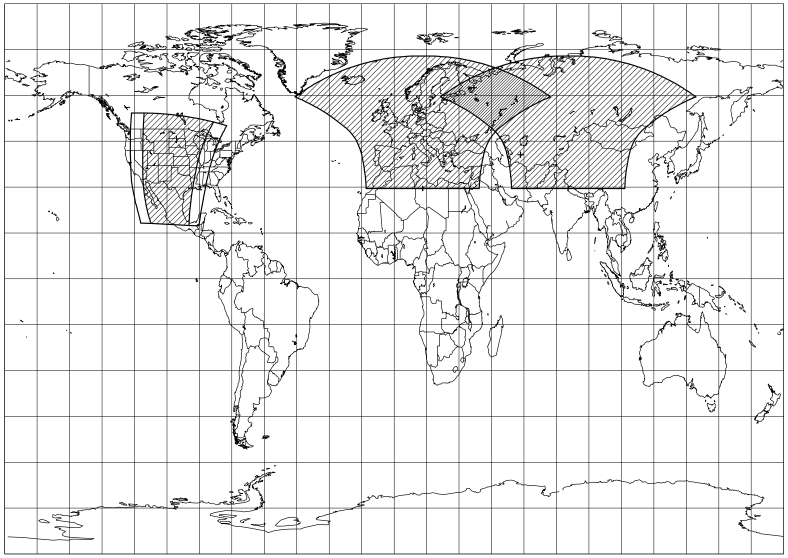
1000 Element Vertically Scanning Line–Array
(5 km Horizontal Distance Per Array Element)
5000 km Horizontal Scan Distance
2000 km Vertical Scan Distance

500 Element Vertically Scanning Line–Array
(5 km Horizontal Distance Per Array Element)
2500 km Horizontal Scan Distance
2000 km Vertical Scan Distance

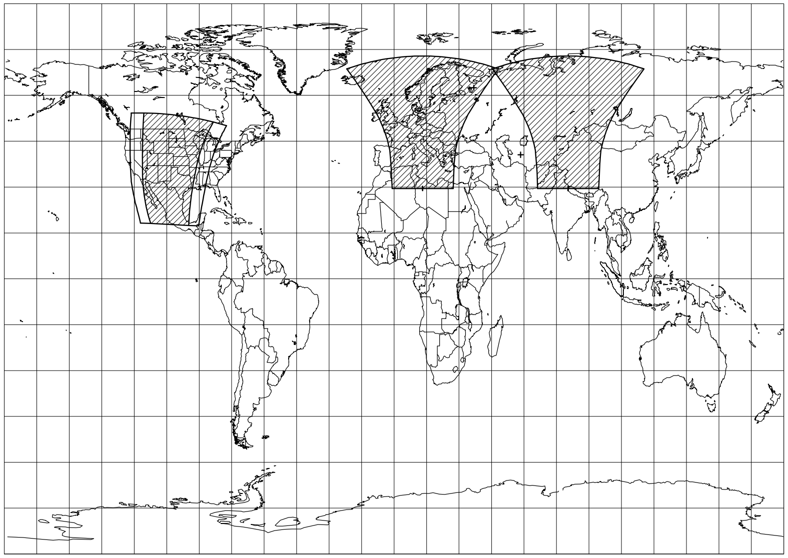
250 Element Vertically Scanning Line–Array
(5 km Horizontal Distance Per Array Element)
1250 km Horizontal Scan Distance
2000 km Vertical Scan Distance

250 Element Horizontally Scanning Line–Array
(5 km Horizontal Distance Per Array Element)
1250 km Vertical Scan Distance
2000 km Horizontal Scan Distance

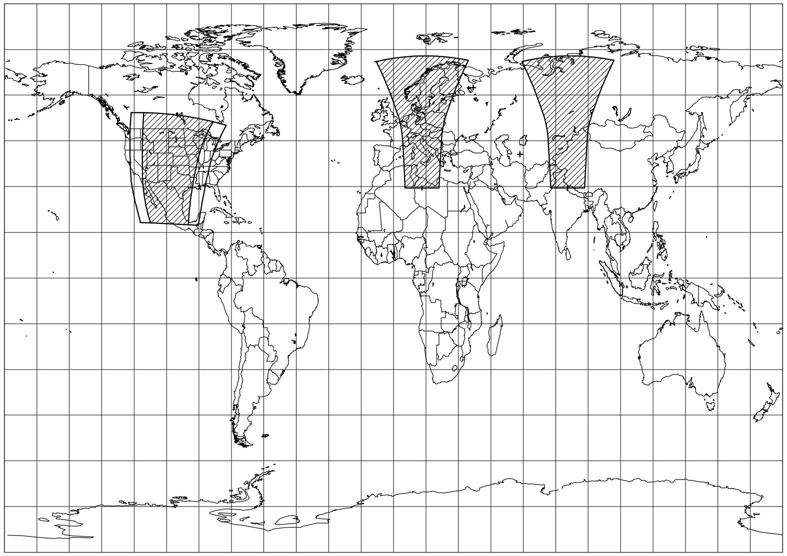
Russian and US Space-Based Early Warning Systems



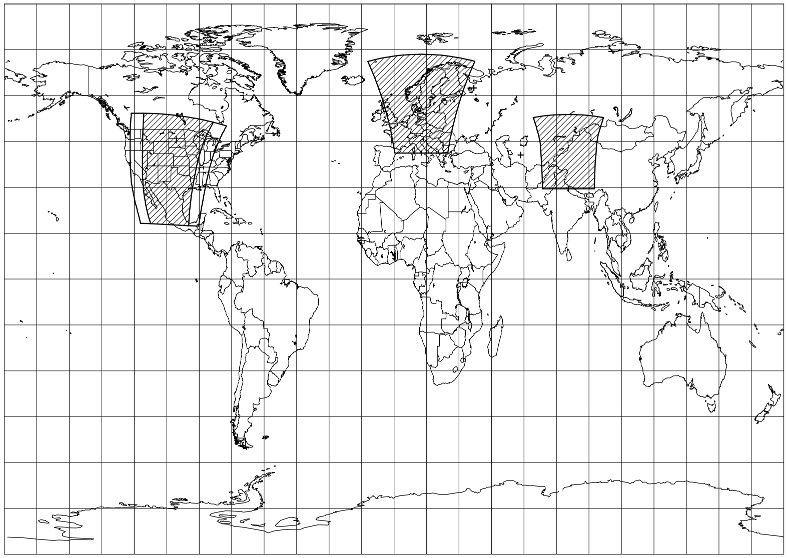
Surveillance areas for Earth-limb viewing and look-down satellite geometries. Look-down geometries assume 1000 element array scanned in 2000 km long vertical swath. Each array element is assumed to cover a 5 km horizontal swath. The scanning is assumed to be achieved with a rocking mirror with a period of one second per scan.



Surveillance areas for Earth-limb viewing and look-down satellite geometries. Look-down geometries assume 500 element array scanned in 2000 km long vertical swath. Each array element is assumed to cover a 5 km horizontal swath. The scanning is assumed to be achieved with a rocking mirror with a period of one second per scan.

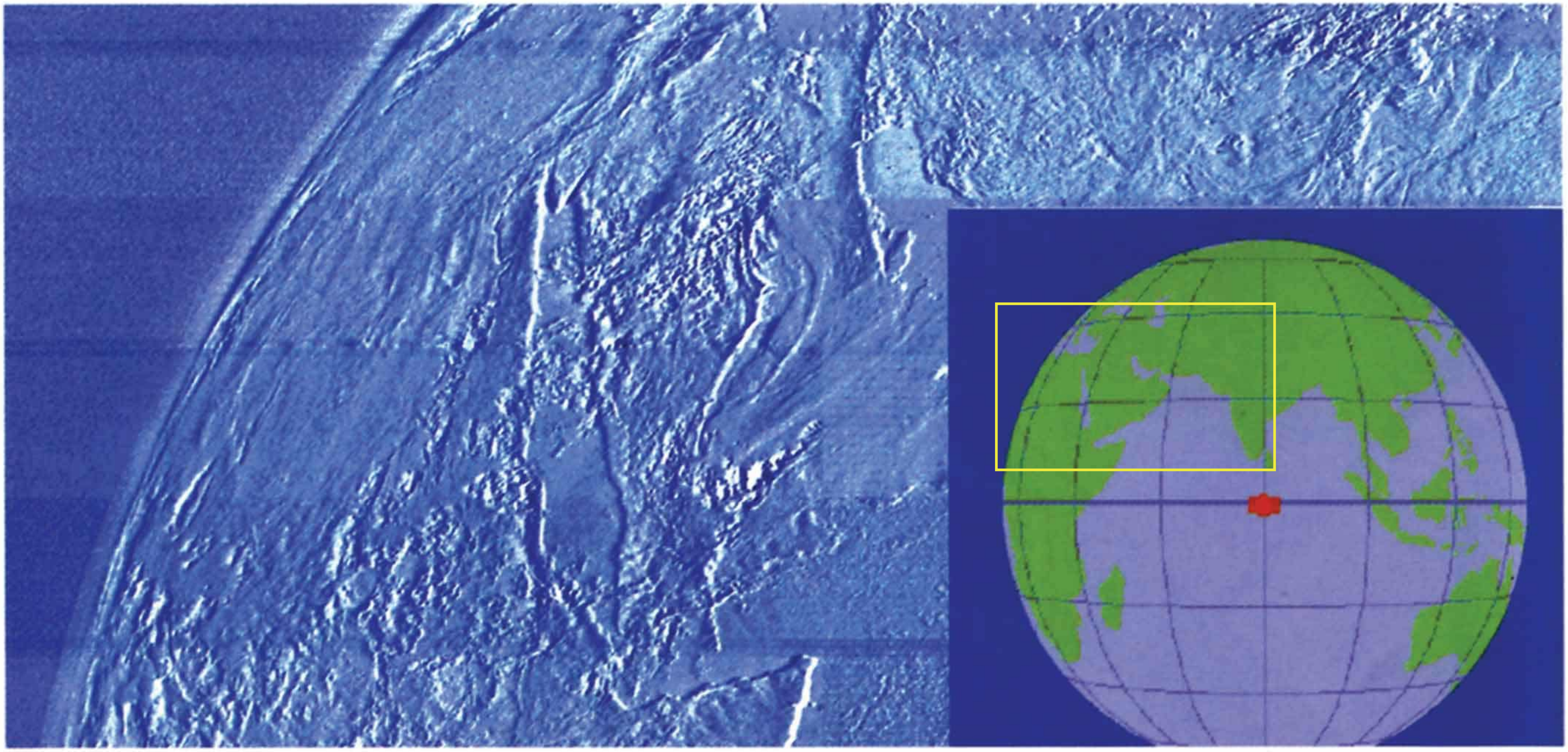


Surveillance areas for Earth-limb viewing and look-down satellite geometries. Look-down geometries assume 250 element array scanned in 2000 km long vertical swath. Each array element is assumed to cover a 5 km horizontal swath. The scanning is assumed to be achieved with a rocking mirror with a period of one second per scan.

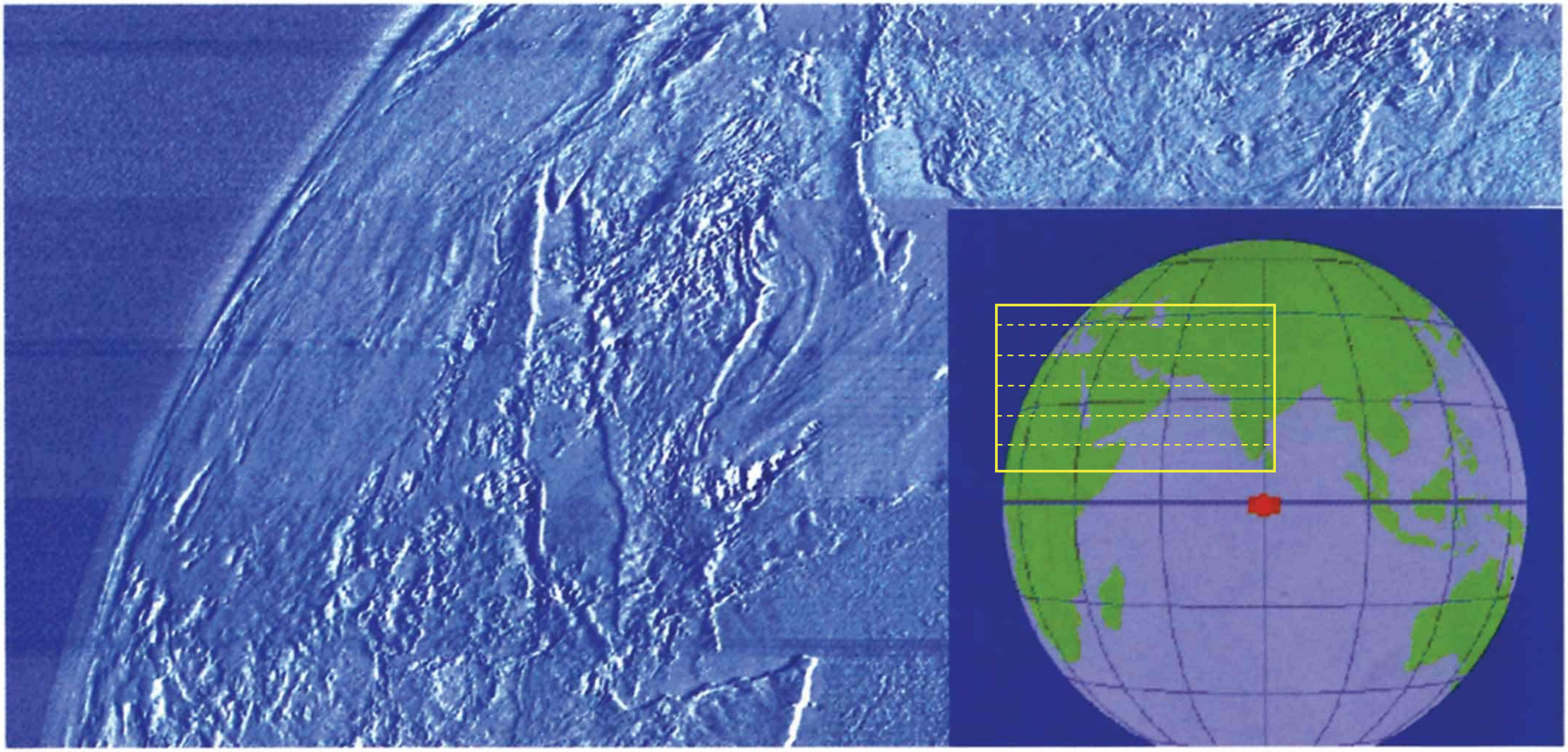


Surveillance areas for Earth-limb viewing and look-down satellite geometries. Look-down geometries assume 250 element array scanned in 2000 km long horizontal swath. Each array element is assumed to cover a 5 km vertical swath. The scanning is assumed to be achieved with a rocking mirror with a period of one second per scan.

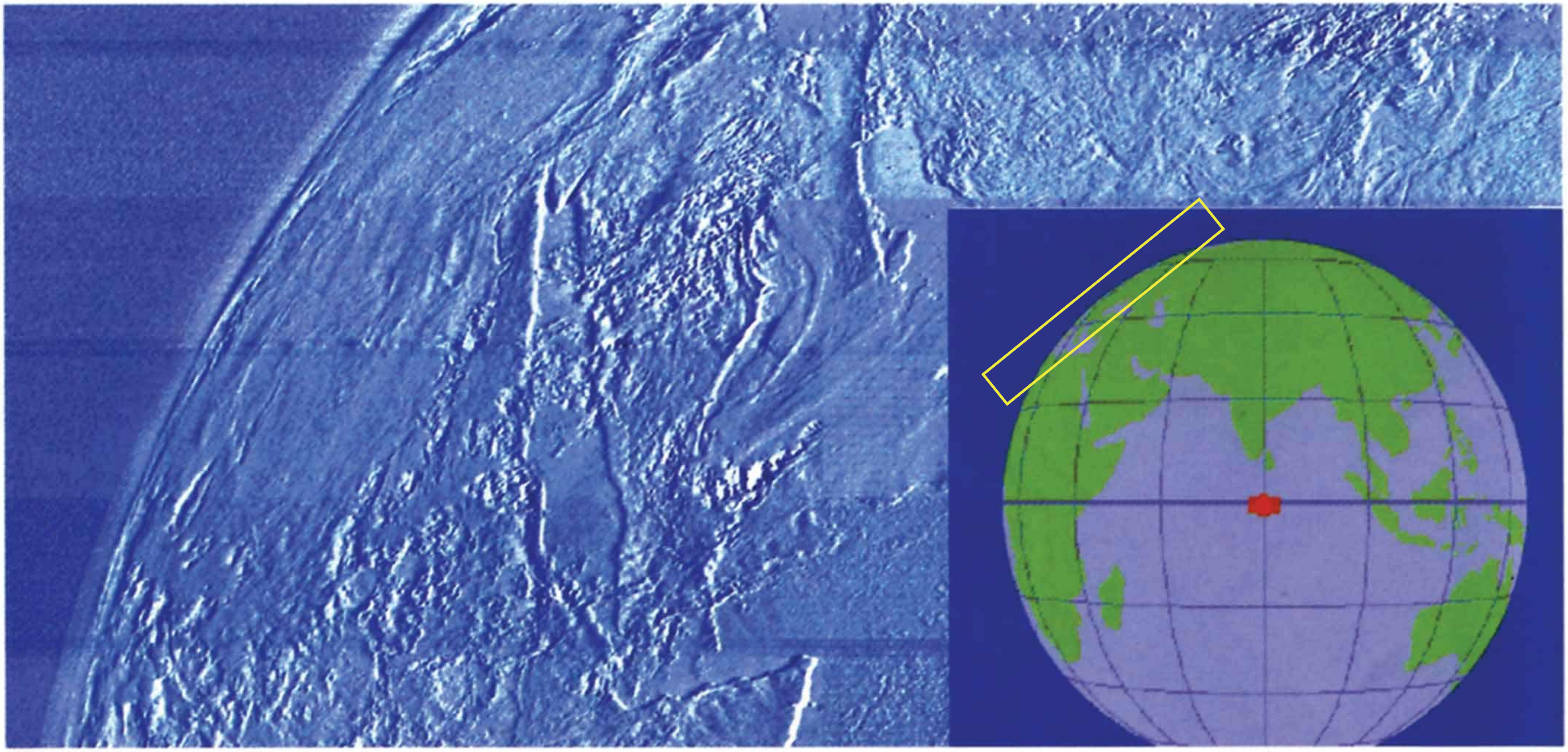
Infrared Image of the Earth from the Prognoz 4 Orbital Position



Infrared Image of the Earth from the Prognoz 4 Orbital Position

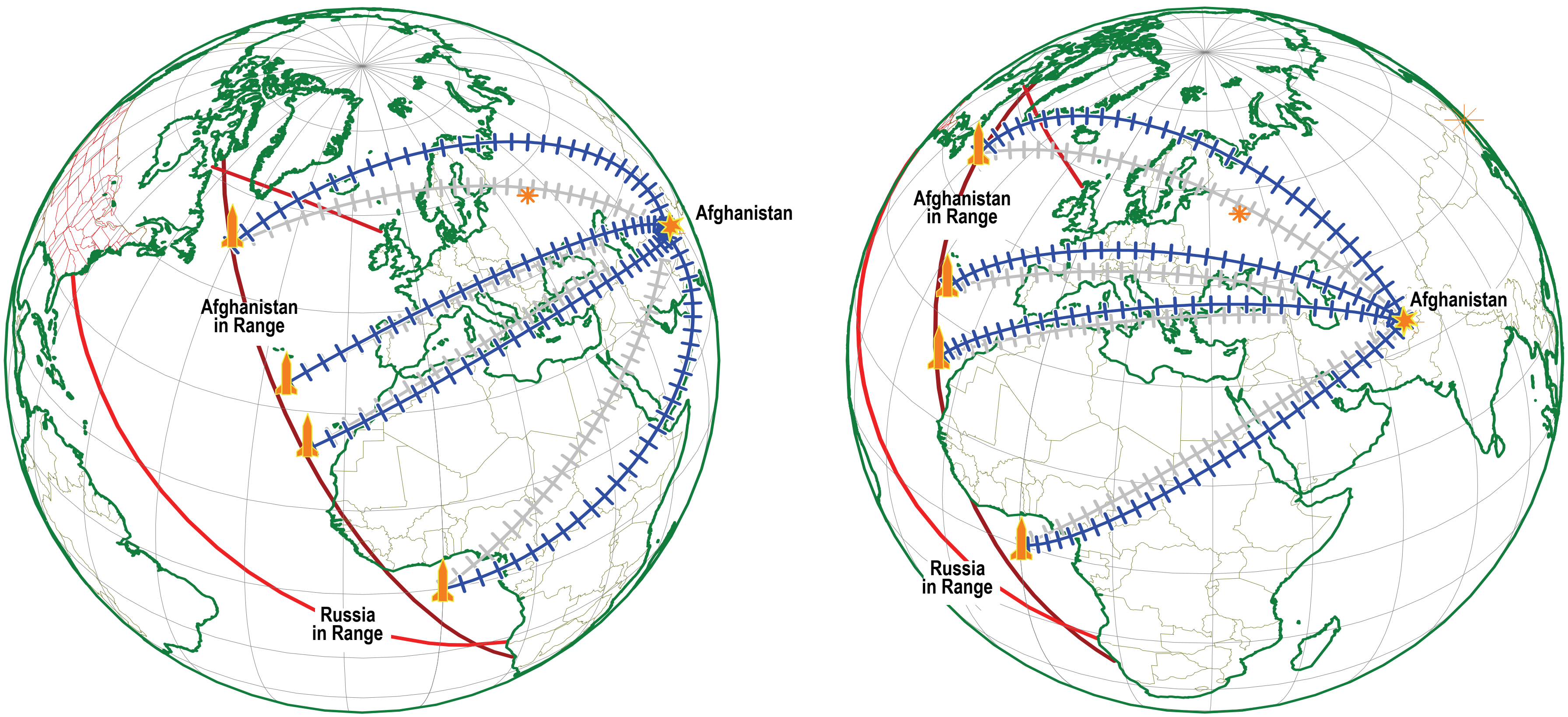


Infrared Image of the Earth from the Prognoz 4 Orbital Position

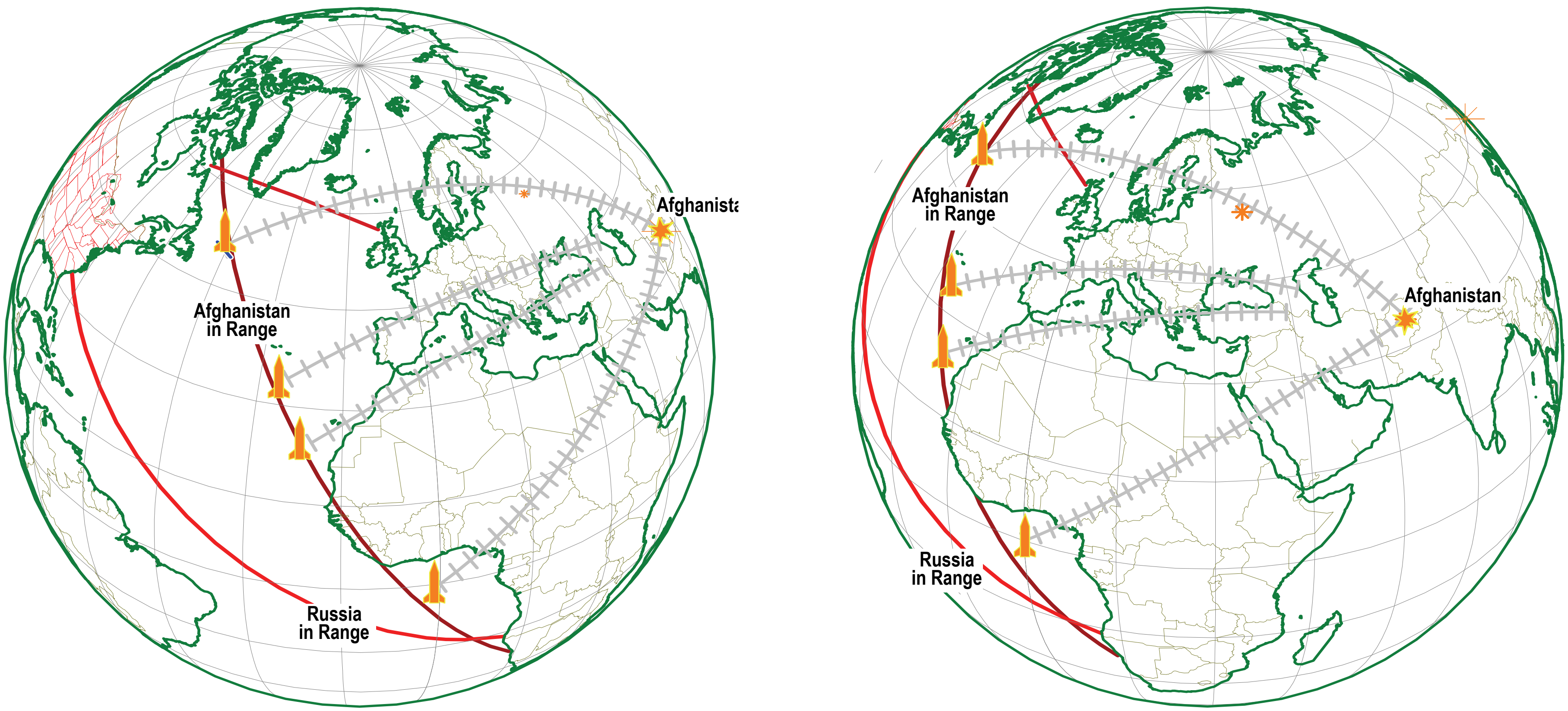


Potential Blackout Areas for US Conventionally-Armed SLBMs that Have been Misidentified as Nuclear-Armed by the Russian Early Warning System

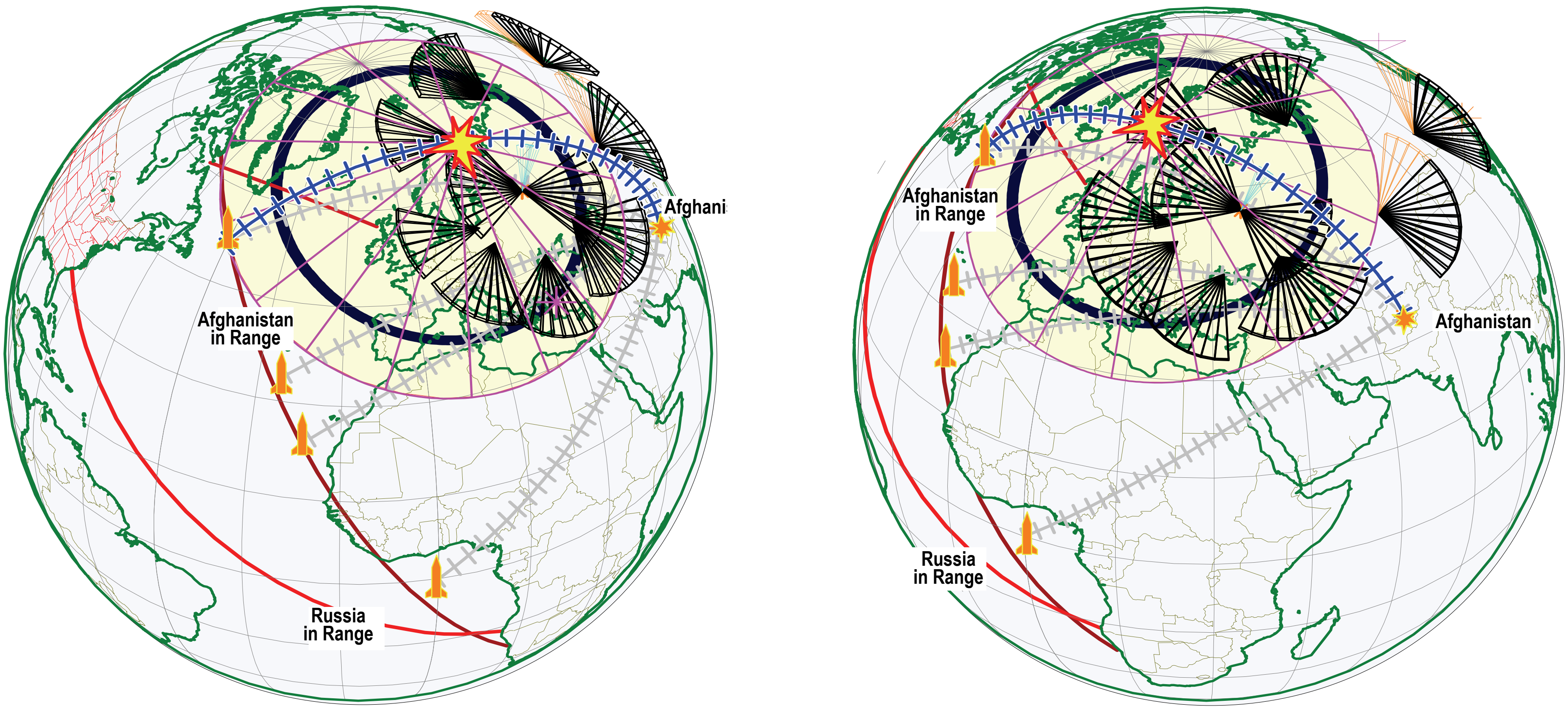
Atlantic Overflight Trajectories and Ground Tracks



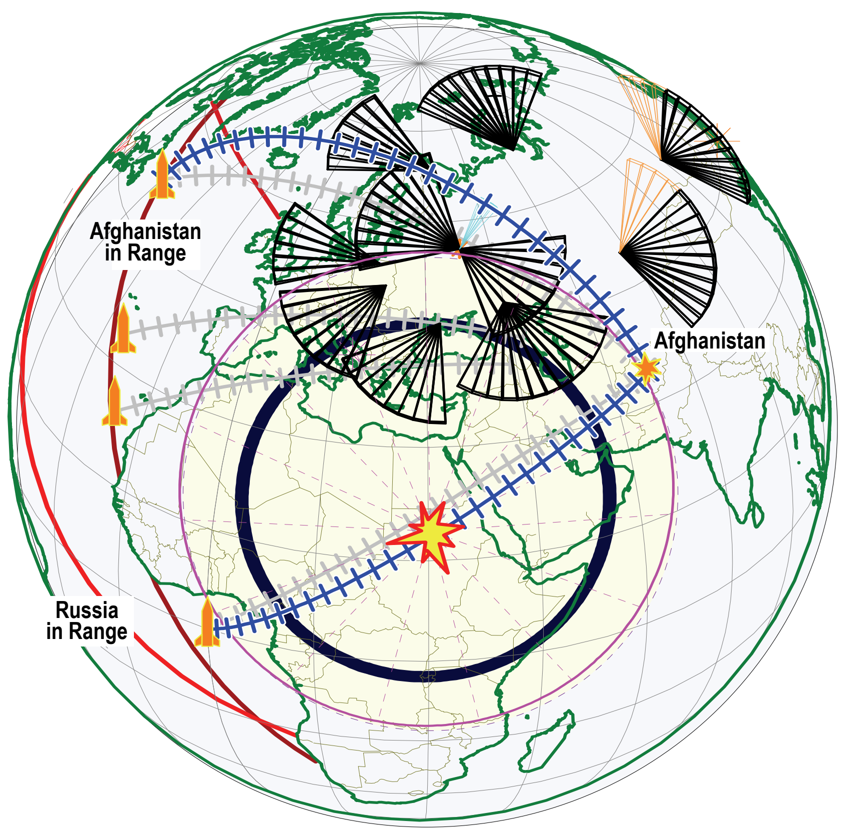
Atlantic Overflight Ground Tracks Only



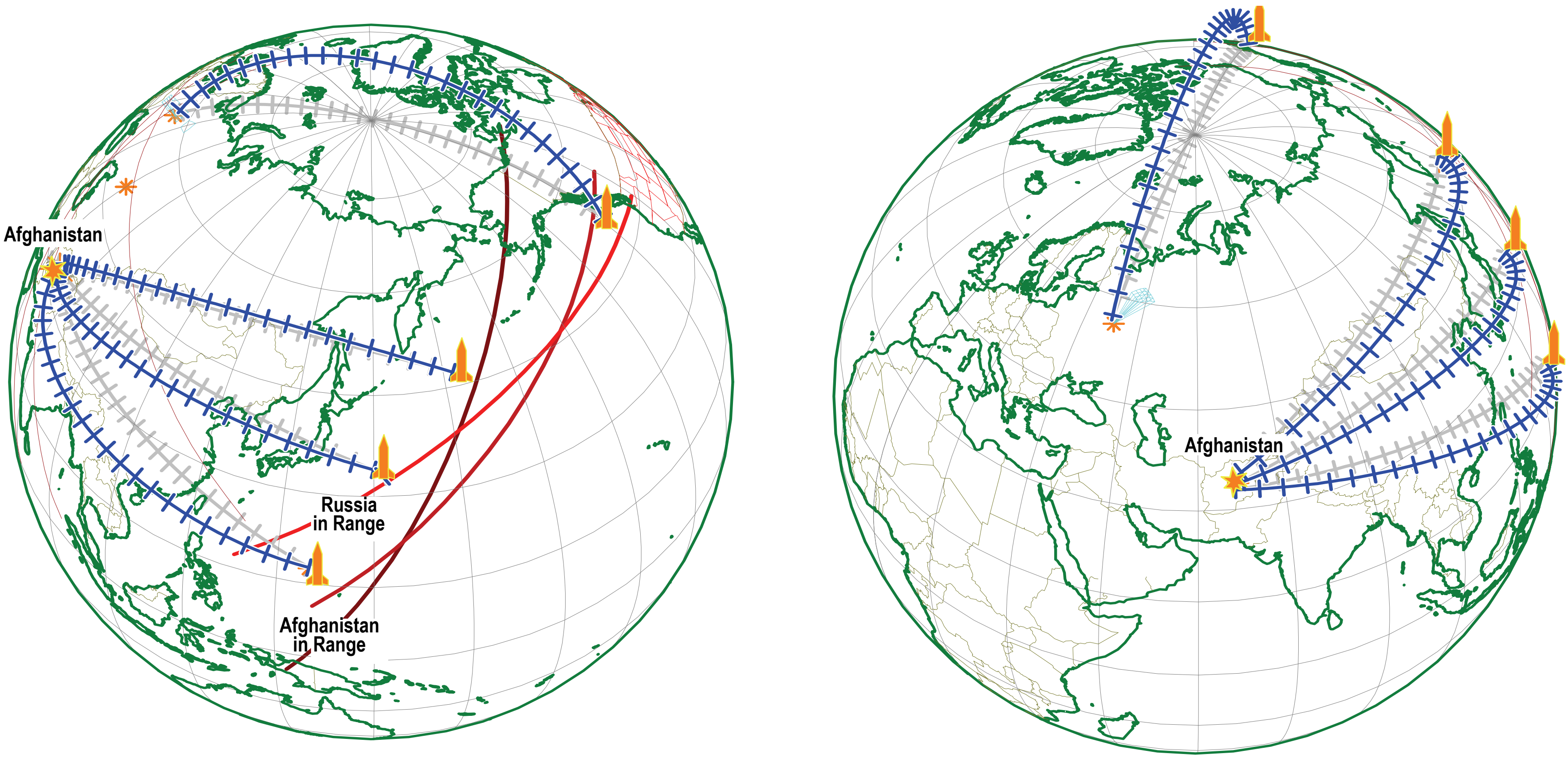
Atlantic Overflight Blackout Threat to Russian Radars



Atlantic Overflight Ground Tracks Only

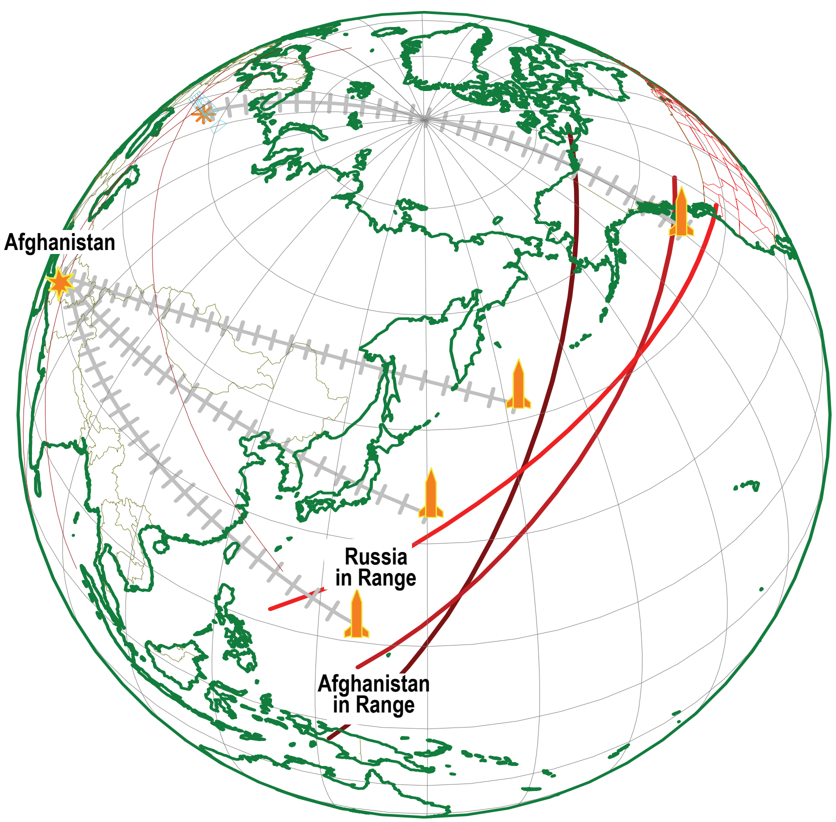


Pacific Overflight Trajectories and Ground Tracks

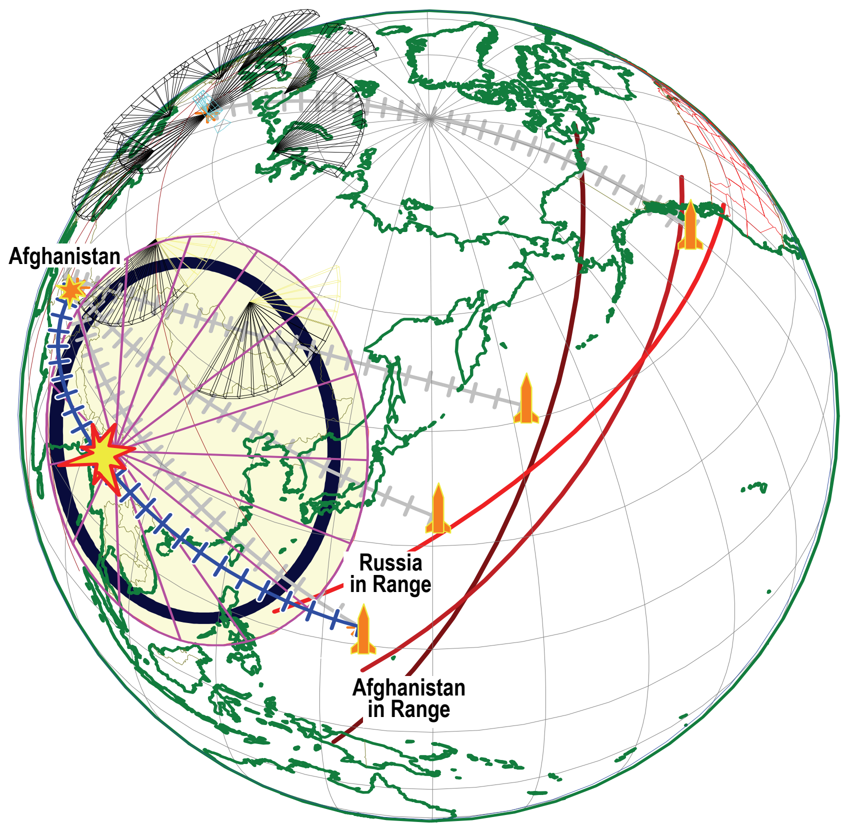


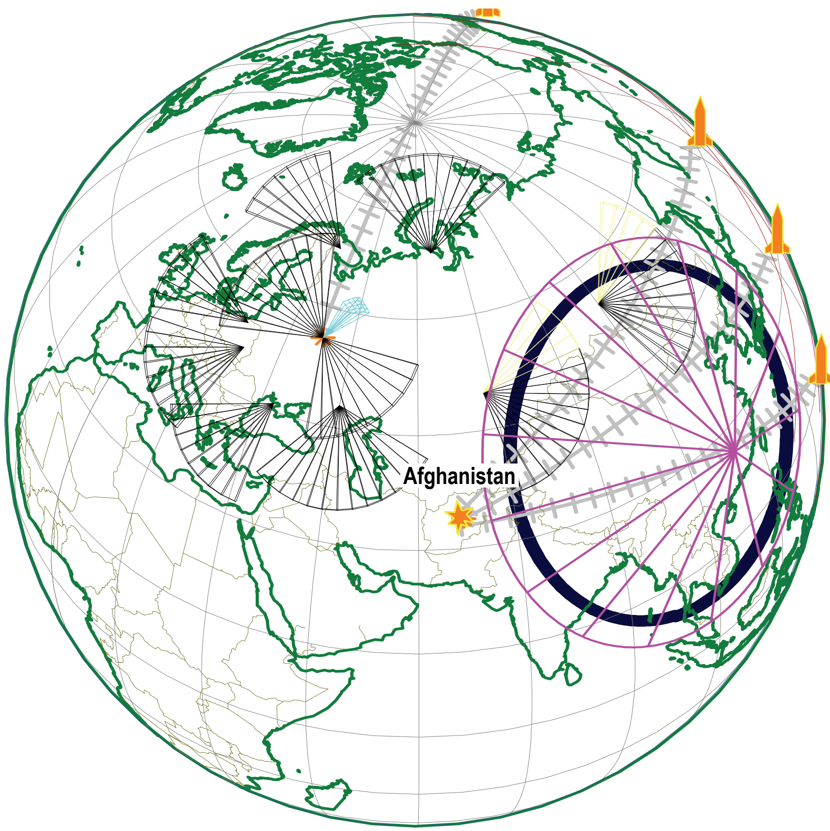
Trident Pacific Deployment Areas and Overflight Trajectories (2 of 3)

Pacific Overflight Ground Tracks Only

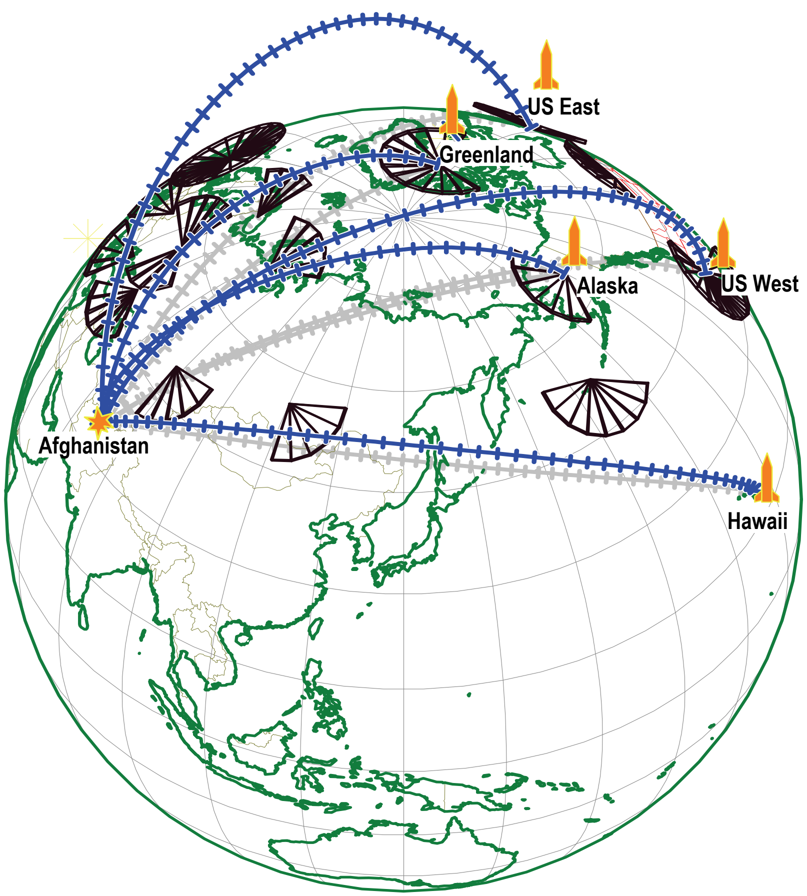


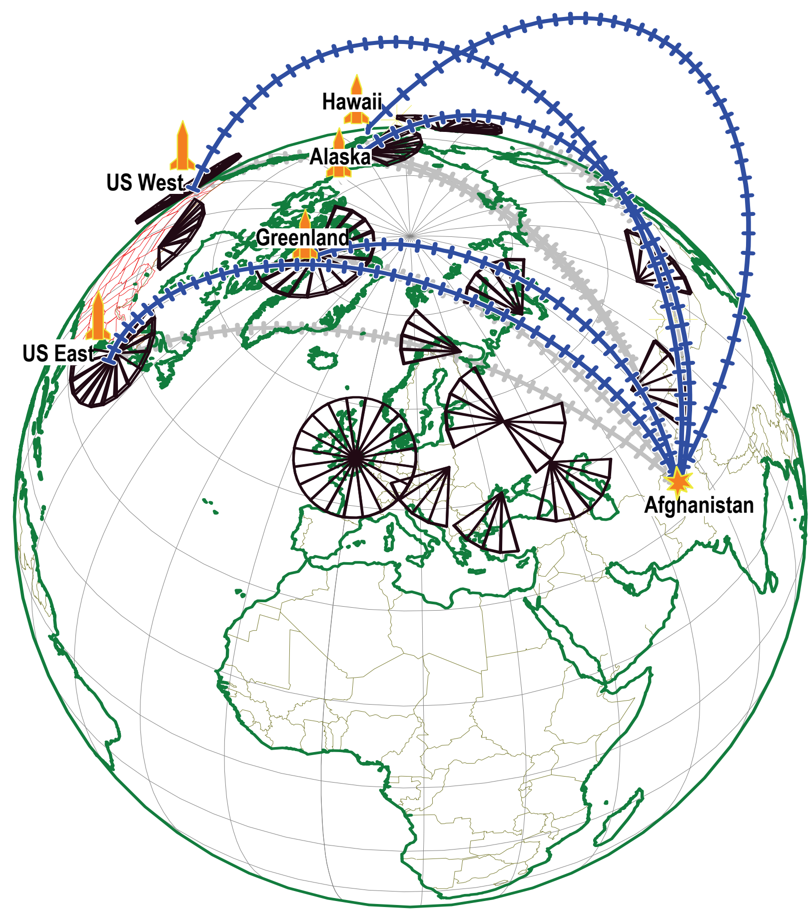
Pacific Overflight Blackout Threat to Russian Radars





Conventional ICBM Launch Locations and Overflight Trajectories





Possible Alternatives to the Global Strike System

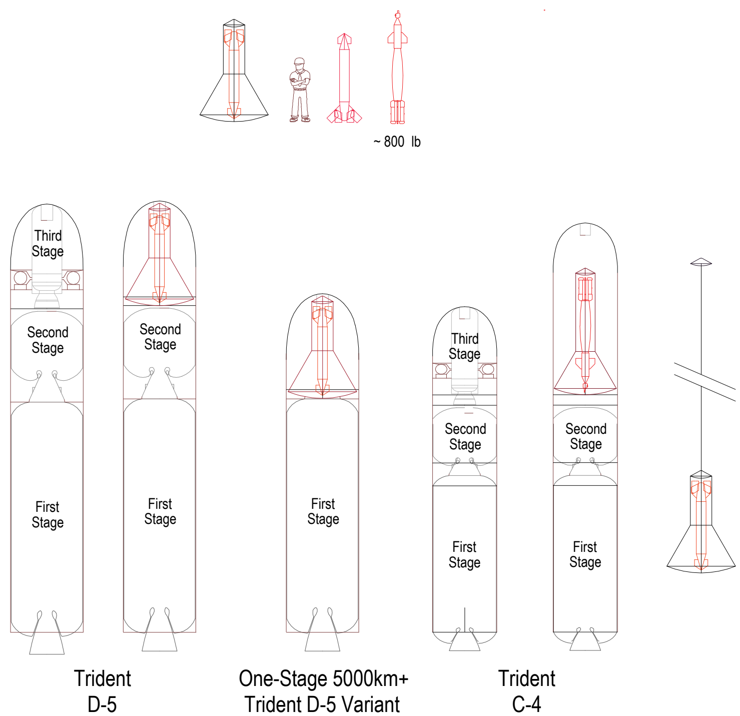
Alternatives to the Global Strike System

An alternative to the ballistic missile delivery system based on Atlantic, Pacific, and ground based long-range ballistic missiles could be deployed using Diego Garcia Island in the Indian Ocean as a base for ships carrying shorter range non-nuclear armed ballistic missiles (see next slide 2 of 4)). The advantage of using the Indian Ocean as a deployment area is that line-of-sight constraints due to the curvature of the Earth (see slide 3 of 4) would prevent in-flight non-nuclear strike ballistic missiles from being observed by Russian early warning radars. Since these missiles would never be detected or tracked by Russian early warning radars, there would be little or no chance of a missile launch leading to an alert of the Russian early warning system

Such an alternative strike system would provide rapid delivery of munitions to South, Southeast, and Southwest Asia, as well as North Africa. The system would require ballistic missiles of roughly 5000 km range, which would be smaller and lighter than long-range SLBMs and ICBMs. Such missiles could be deployed on surface ships, rather than much less efficient and more expensive submarine platforms. Basing some missiles on Diego Garcia as well as deploying them on ships would result in a highly efficient deployment of missiles. If ballistic missiles of longer range are used, the entire mission could be based on Diego Garcia.

The first stage of a Trident D-5 ballistic missile would be adequate for carrying non-nuclear payloads to ranges well in excess of 5,000 km. The first stage of a Trident D5 weighs about 90,000 pounds and could be housed in a capsule that when deployed could float on the surface of the ocean. Launching the shorter range Trident-derived one-stage missile from a floating capsule would make it possible to deploy such a Strike System using surface ships that have been modified to carry such encapsulated missiles. Another system variant could instead be based on modified Trident C-4 missiles that could also carry payloads several thousands of pounds of payload to well in excess of 5,000 km. The C-4 option would result in lighter and smaller floating-launch capsules relative to the one-stage D-5 option, which might make modifications to ships somewhat less demanding. Another variant of the C-4 option could potentially cover all target areas of potential interest from Diego Garcia alone.

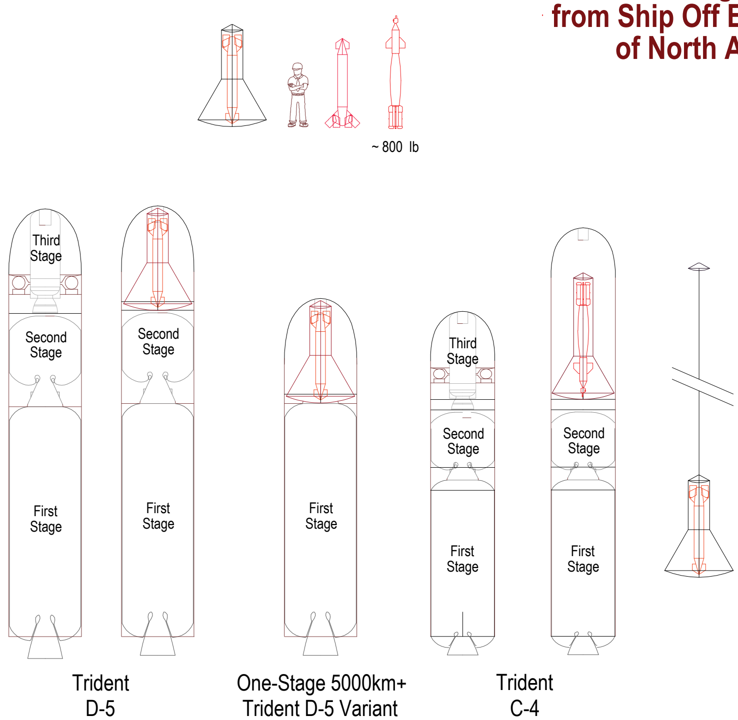
Ship and Island-Based 5000km+ C-4 or One-Stage Trident D-5 Variant?

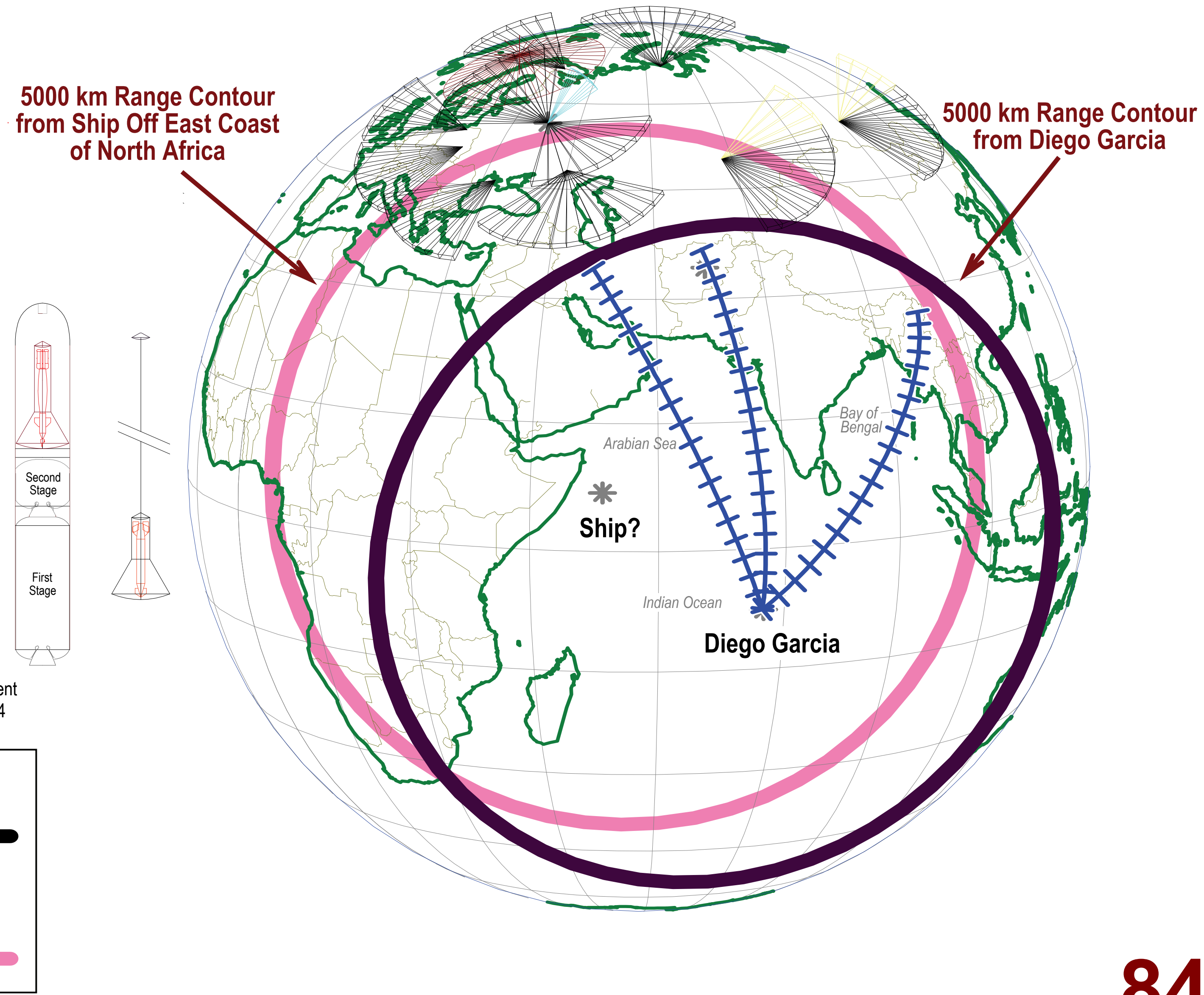


5000 km Range Contour from Diego Garcia

5000 km Range Contour from Ship Off East Coast of North Africa

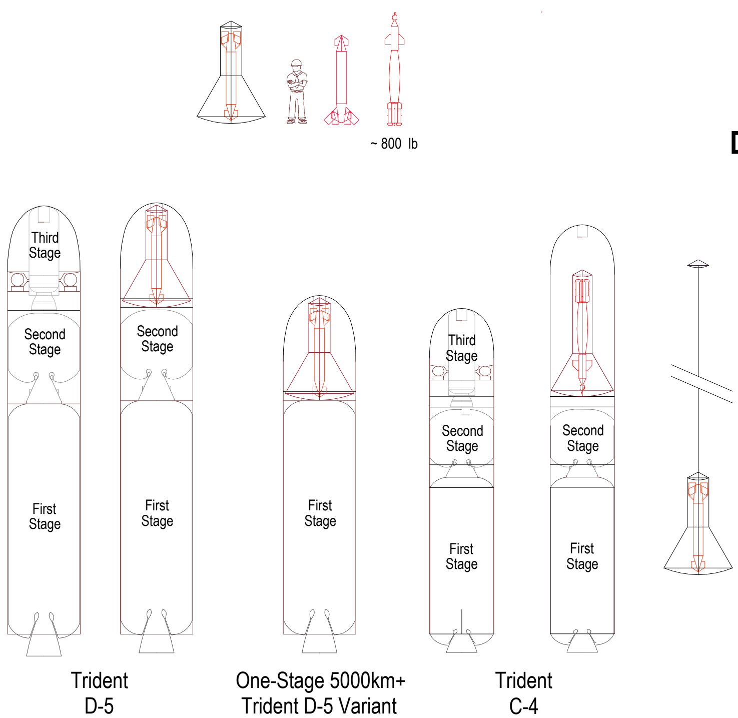
Ship and Island-Based 5000km+ C-4 or One-Stage Trident D-5 Variant?

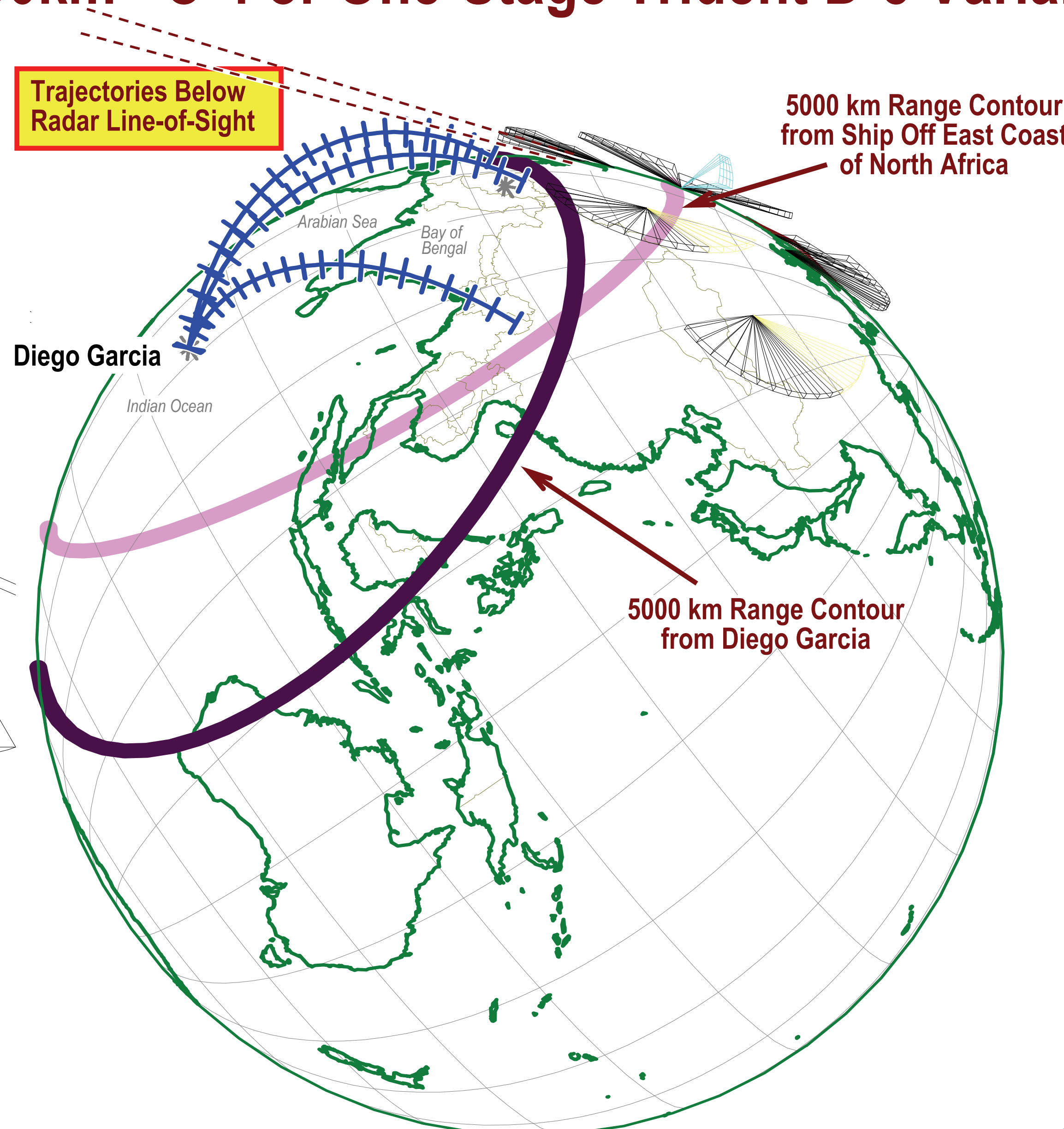




Possible Alternatives to the Global Strike System

Ship and Island-Based 5000km+ C-4 or One-Stage Trident D-5 Variant?

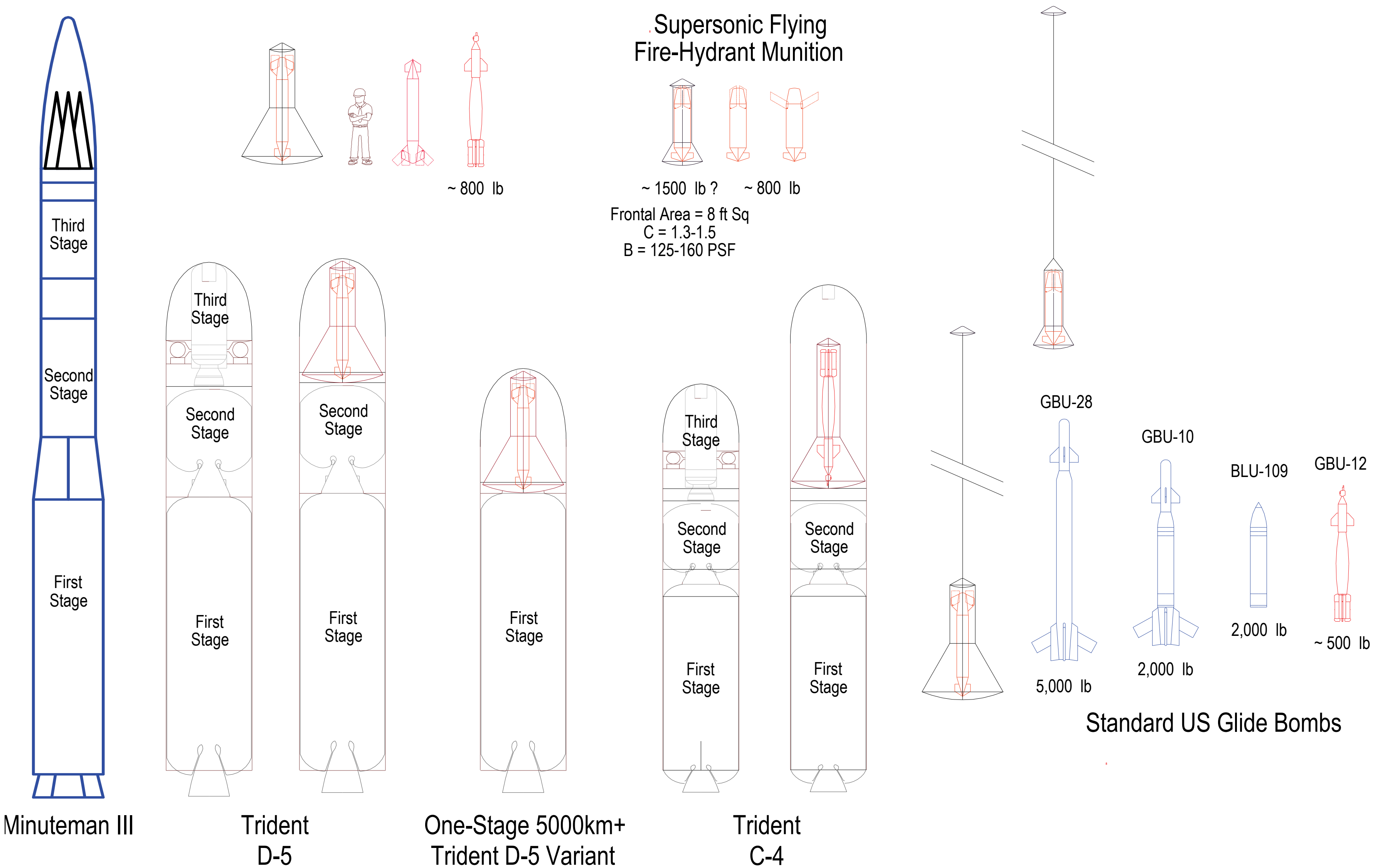




5000 km Range Contour from Diego Garcia

5000 km Range Contour from Ship Off East Coast of North Africa

Alternatives to the Global Strike System

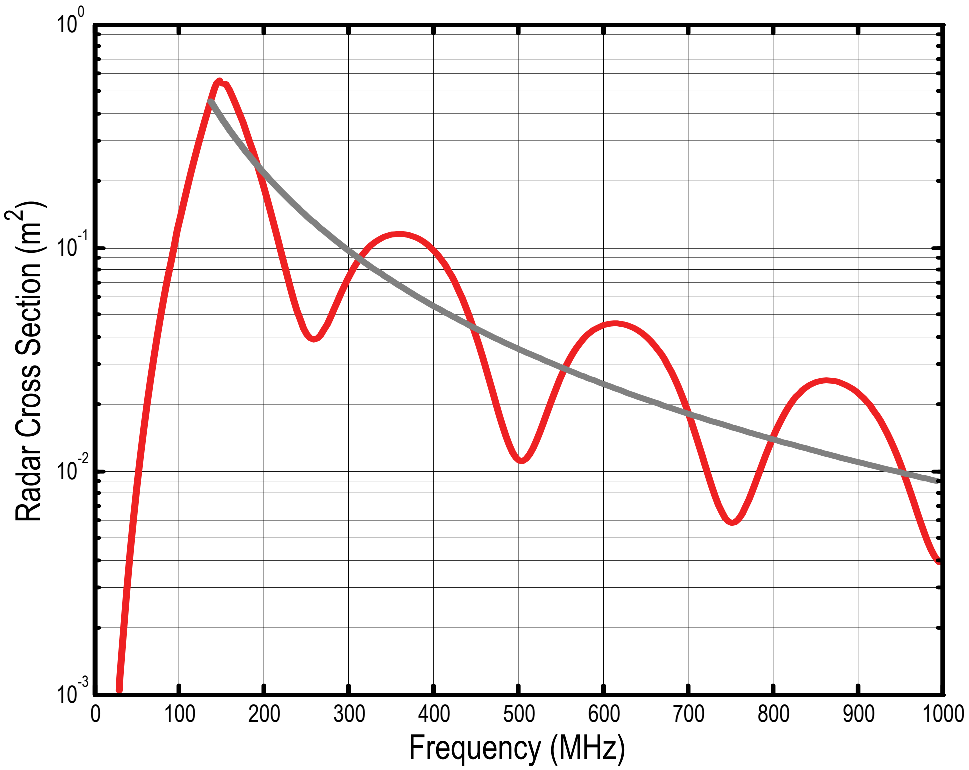


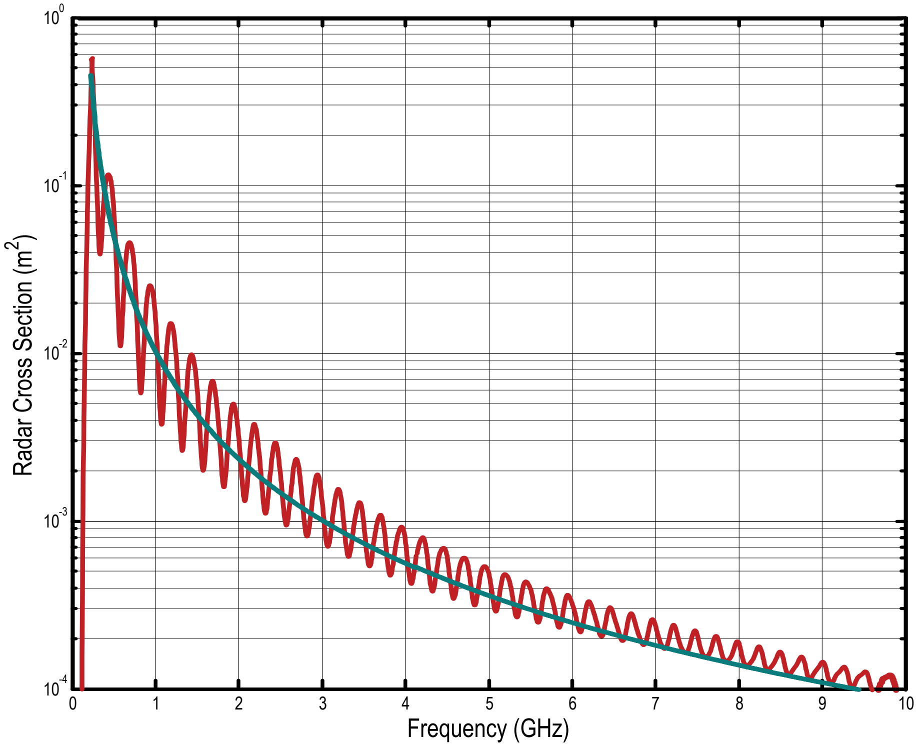
Appendix

Technical Description of Radar Blackout Effects Due to High Electron Densities from Nuclear Explosions at Varied Altitudes

Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

Radar Cross Section of Rounded-Back Cones





Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

We first calculate the X-ray energy per unit volume deposited in air and then divide by the ionization energy per molecule to get the number of electrons per unit volume of air.

The fraction of the energy released by a nuclear explosion of yield W that passes into a volume of air with cross sectional area δA and depth δX is,

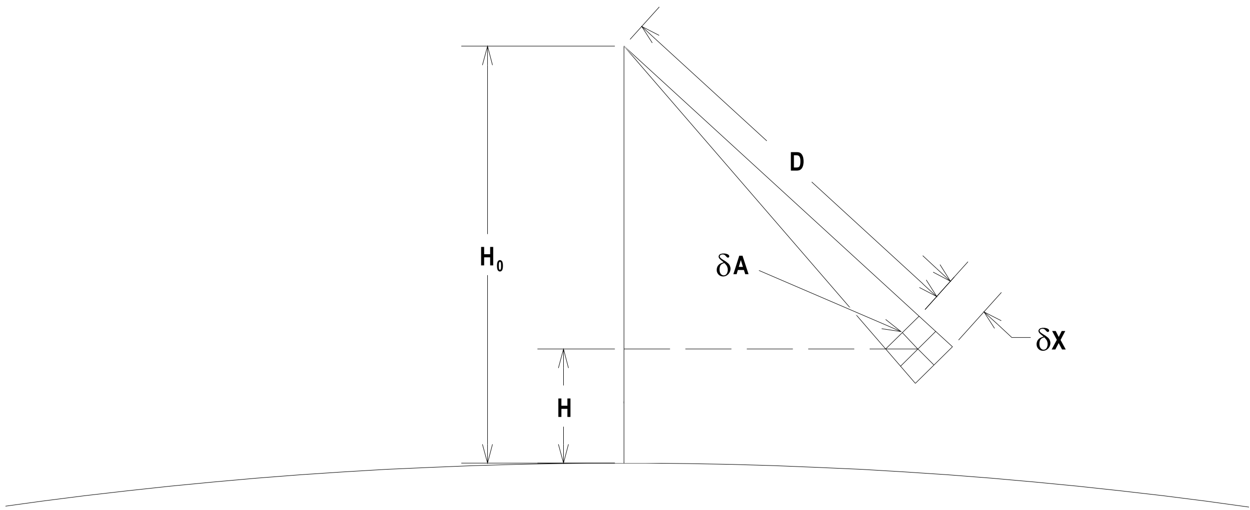


Figure 1. Shows the geometry and variables used in this derivation

The fraction of the energy released by a nuclear explosion of yield W that illuminates a volume of air with cross sectional area δA

$$\begin{matrix}\text{Fraction of Total Energy that Illuminates a} \\ \text{Volume of Air of Cross Sectional Area } \delta A\end{matrix} = W\left(\frac{\delta\Omega}{4\pi}\right) = W\left(\frac{\delta A}{4\pi D^2}\right)$$

And the total energy per unit volume is simply,

$$\begin{matrix}\text{Total Energy Deposited} \\ \text{per Unit Volume}\end{matrix} = W\left(\frac{\delta A}{4\pi D^2}\right)\left(\frac{1}{\text{Volume}}\right) = W\left(\frac{\delta A}{4\pi D^2}\right)\left(\frac{1}{\delta A\,\delta X}\right) = W\left(\frac{1}{4\pi D^2}\right)\left(\frac{1}{\delta X}\right)$$

Where δX is the depth of the volume.

Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

The mass absorption coefficient of air μ_m (in cm^2/g) and the density of air in the volume of interest ρ (g/cm^3) can be used to calculate the depth of air in which the energy is deposited. That is,

$$\delta X = \frac{1}{n\sigma} = \frac{1}{\left(\frac{n\sigma\rho}{\rho}\right)} = \frac{1}{\mu_m \rho}$$

Which then leads to the following expression for the amount of x-ray energy deposited per unit volume in the air,

$$\begin{matrix}\text{Total Energy Deposited} \\ \text{per Unit Volume}\end{matrix} = W\left(\frac{1}{4\pi D^2}\right)\left(\frac{1}{\delta X}\right) = W\left(\frac{1}{4\pi D^2}\right)(\mu_m \rho)$$

The x-rays that arrive at the surface of the volume of air have been attenuated by the intervening air mass by a factor of,

$$\exp(-n\sigma D) = \exp\left(-\frac{\rho n \sigma D}{\rho}\right) = \exp\left(-\frac{n\sigma}{\rho}\rho D\right) = \exp(-\mu_m \rho D) = \exp(-\mu_m M)$$

Where μ_m is the mass absorption coefficient (cm^2/g) of air and M is the Penetration Mass (g/cm^2) of the column of air through which the x-rays propagate to the volume of air where energy is deposited. This leads to the expression for the total energy per unit volume deposited at a point in air of,

$$\begin{matrix}\text{Total Energy Deposited} \\ \text{per Unit Volume}\end{matrix} = E_{Volume} = W\left(\frac{1}{4\pi D^2}\right)(\mu_m \rho)\exp(-\mu_m M)$$

Glasstone writes this expression in the following form,

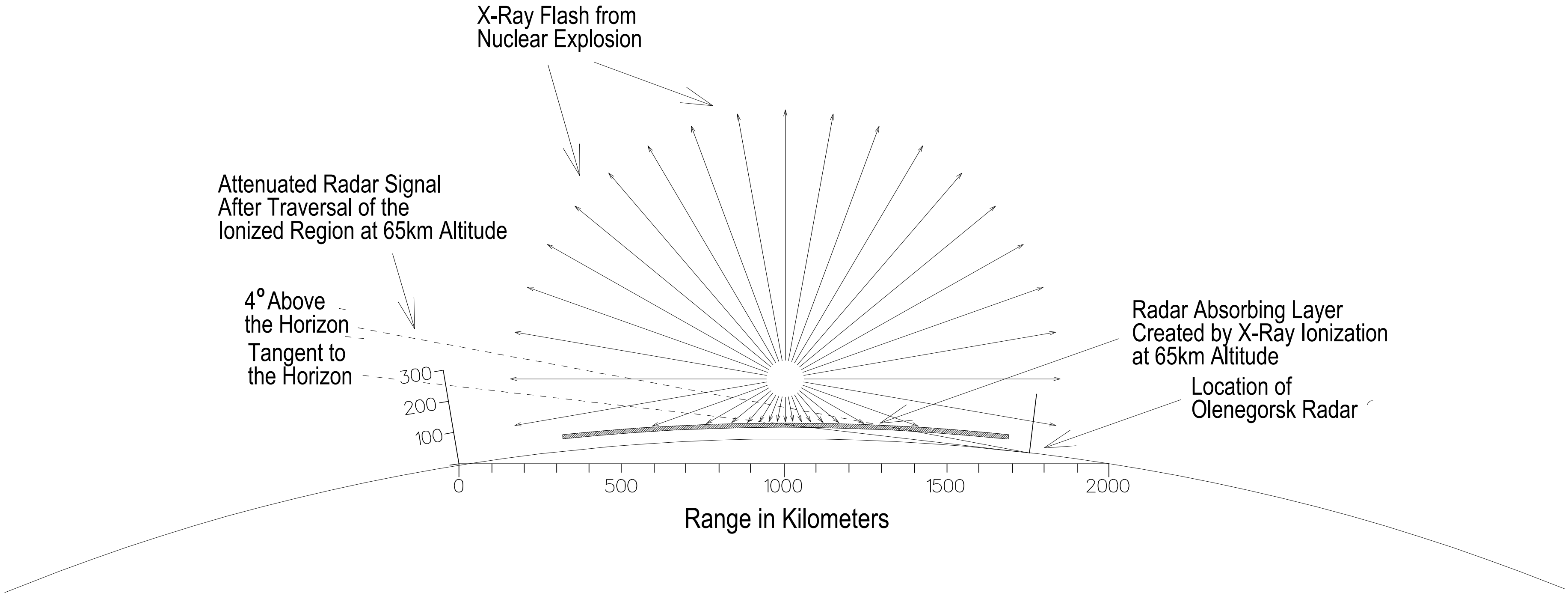
$$E_{Volume} = \left(\frac{kW}{4\pi D^2}\right)(\mu_m \rho)\, e^{(-\mu_m M)} = \frac{kW}{4\pi D^2}\mu_m \rho\, e^{(-\mu_m M)}$$

Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

The figure below shows how radar blackout occurs. When a nuclear explosion is detonated large amounts of radiation is released in the form of neutrons, gamma rays, and X-rays. The neutrons and gamma rays are a byproduct of the nuclear reactions that lead to the enormous release of energy associated with nuclear detonations. The x-rays from the explosion are caused by the expanding hot debris from the nuclear explosion. The high electron densities created at 65 km altitude are mostly due to the deposition of x-rays. An additional factor at 65 km altitude is that there is a relatively high density of either ionize or neutral atoms that the electrons can collide with. This creates a situation where he electrons accelerated by passing radio waves can collide with the atoms converting the radiowave into heat much like occurs in the microwave oven. The net result is the radio waves are attenuated as they pass through the layer of ionized air at 65 km altitude.

When the electron density is sufficiently high and the path length of the radio waves is sufficiently long high levels of attenuation can occur. In the cases of interest herein a loss-factor of 10 to 100 during the two-way traversal of the ionized region would greatly diminish or eliminate the radar’s ability to detect attacking warheads.

Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

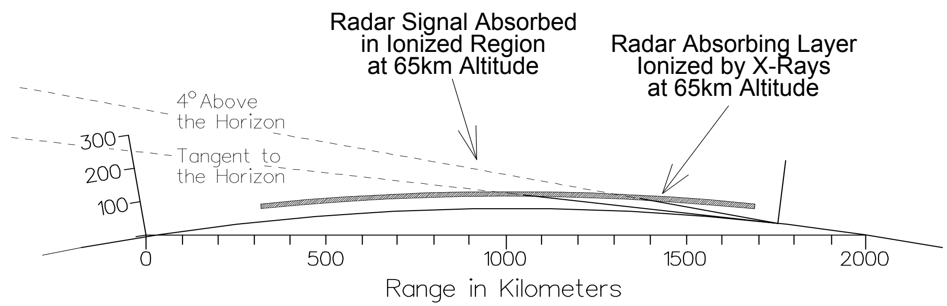


Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

The next figure shows the equation for estimating the attenuation of a radio signal through the ionized region created at 65 km altitude by the x-rays from a high-altitude nuclear explosion. Assuming that the radio signal passes through the layer at an angle of roughly 3° the two-way attenuation of the signal will be between 10 and 100 (10 and 20 dB) when the electron density in the layer is between 1×10^5 and 2×10^5 electrons/cm^3.

Attenuation of Electromagnetic Waves Traversing the D-Layer of the Earth's Ionosphere

$$A \approx 0.4 \frac{N_e}{f^2} \frac{1}{\sin(\varepsilon)}$$



Where

- A is the attenuation due to collisions with neutrals for one-way transmission through the ionized region of the D-layer between 60 and 80 km altitude.
- f is the frequency in MHz of the traversing electromagnetic waves
- ε is the elevation angle with respect to the ground of the radar beam (we choose 3°)
- N_e is the electron density in the D-layer in electrons/cm^3.

Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

The equation for the one-way attenuation of the radar signal can now be used to estimate the electron densities that would cause an attenuation of 10 to 100 (10 to 20 decibels) in the two-way radar signal.

$$N_e \approx A \frac{f^2 \sin(\varepsilon)}{0.4}$$

$$A = 5 \text{ to } 10$$

$$f = 150$$

$$\varepsilon = 3^\circ$$

Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

Assuming that the radio signal passes through the layer at an angle of roughly 3° the *one*-way attenuation of the signal will be between 3 and 10 (5 and 10 dB) when the electron density in the layer is between 1.5×10^4 and 3×10^4 electrons/cm^3.

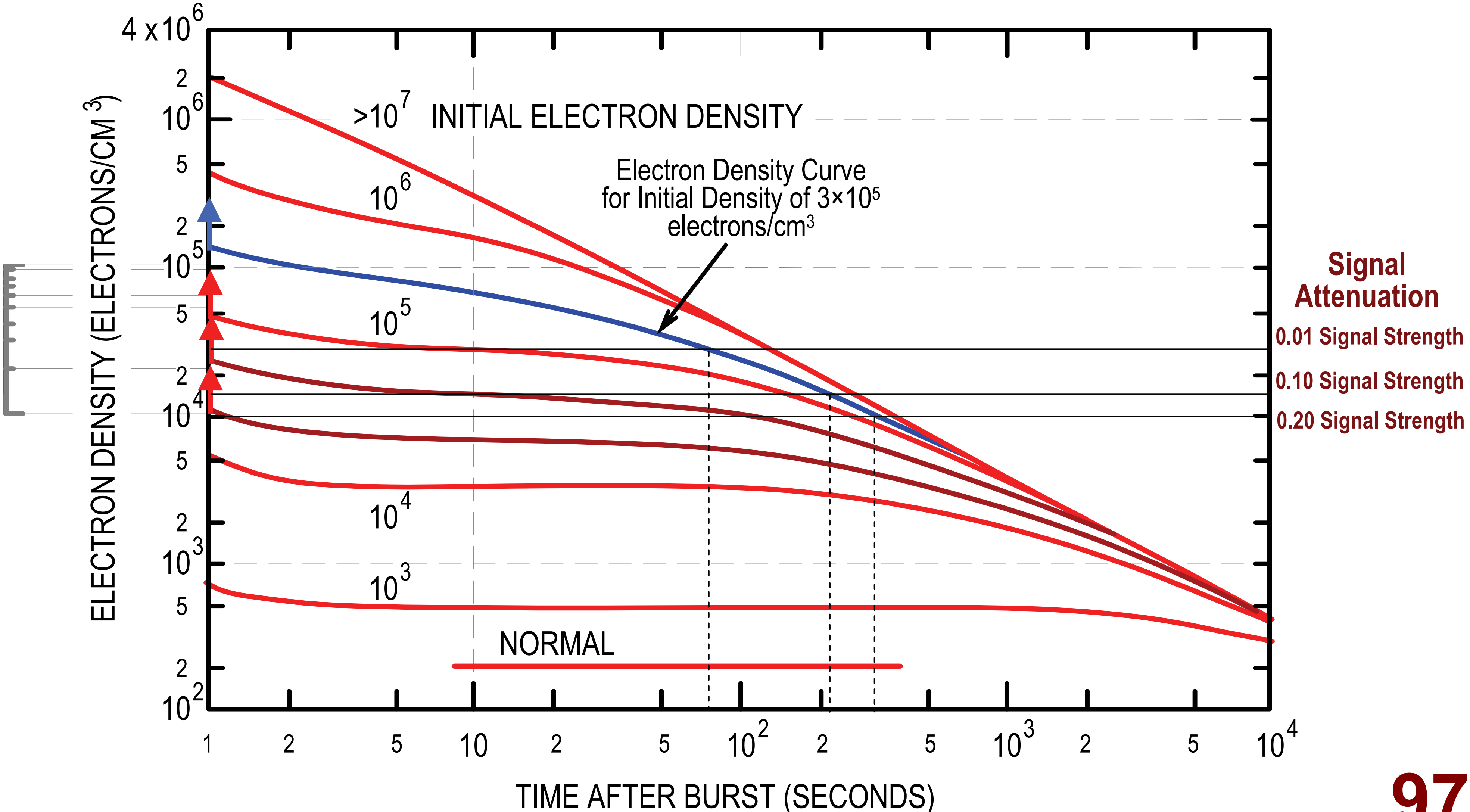
$$N_e \approx A\frac{f^2\sin(\varepsilon)}{0.4} = 5\times\frac{150^2\times0.0523}{0.4} \approx 1.5\times10^4\,\frac{\text{electrons}}{\text{cm}^3}$$

$$N_e \approx A\frac{f^2\sin(\varepsilon)}{0.4} = 10\times\frac{150^2\times0.0523}{0.4} \approx 3\times10^4\,\frac{\text{electrons}}{\text{cm}^3}$$

The two way attenuation is then 3×3~10 (10 dB) and 10×10~100 (20 dB).

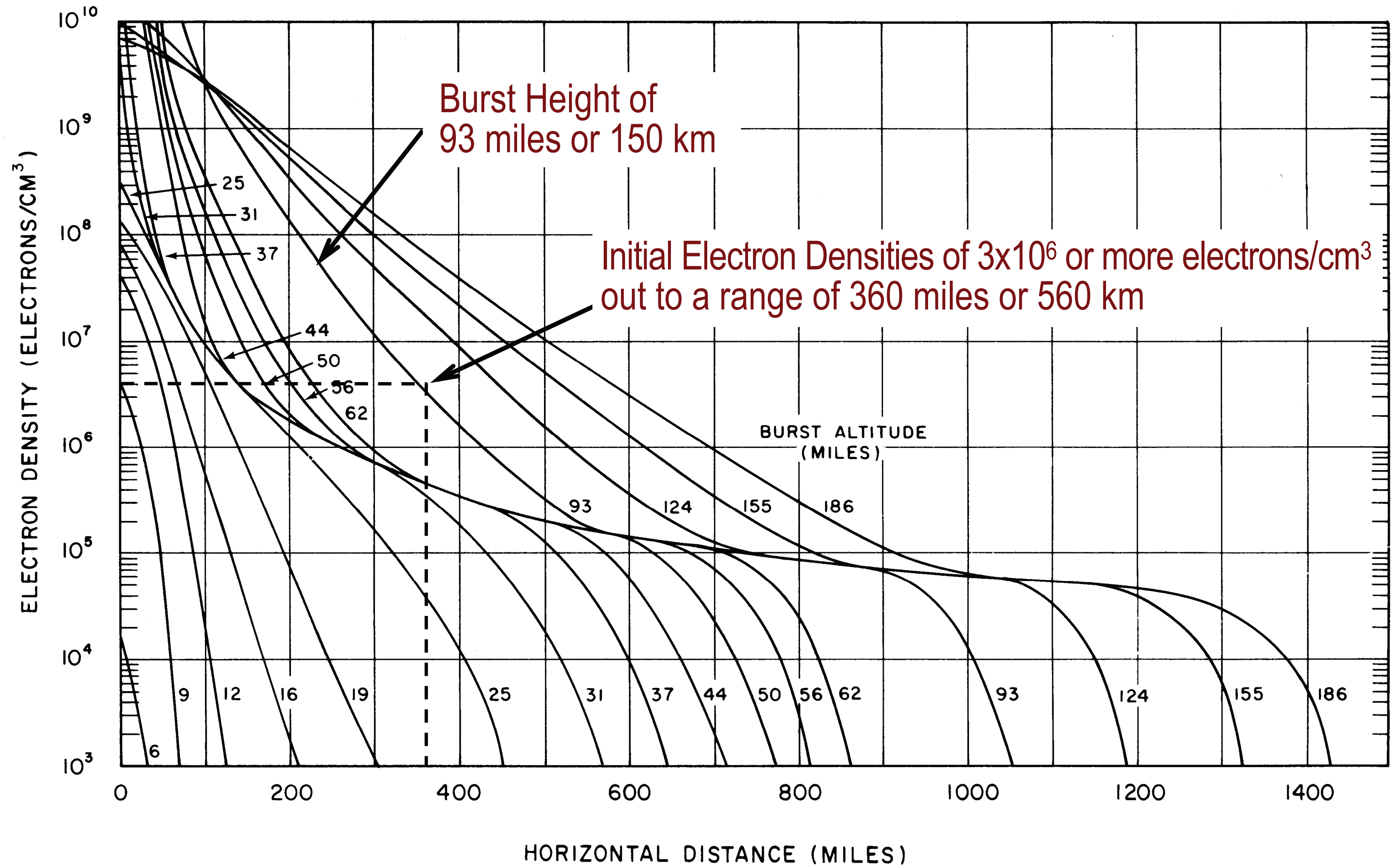
Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

Electron Density in the D-Layer as a Function of Time After a High Altitude Nuclear Explosion

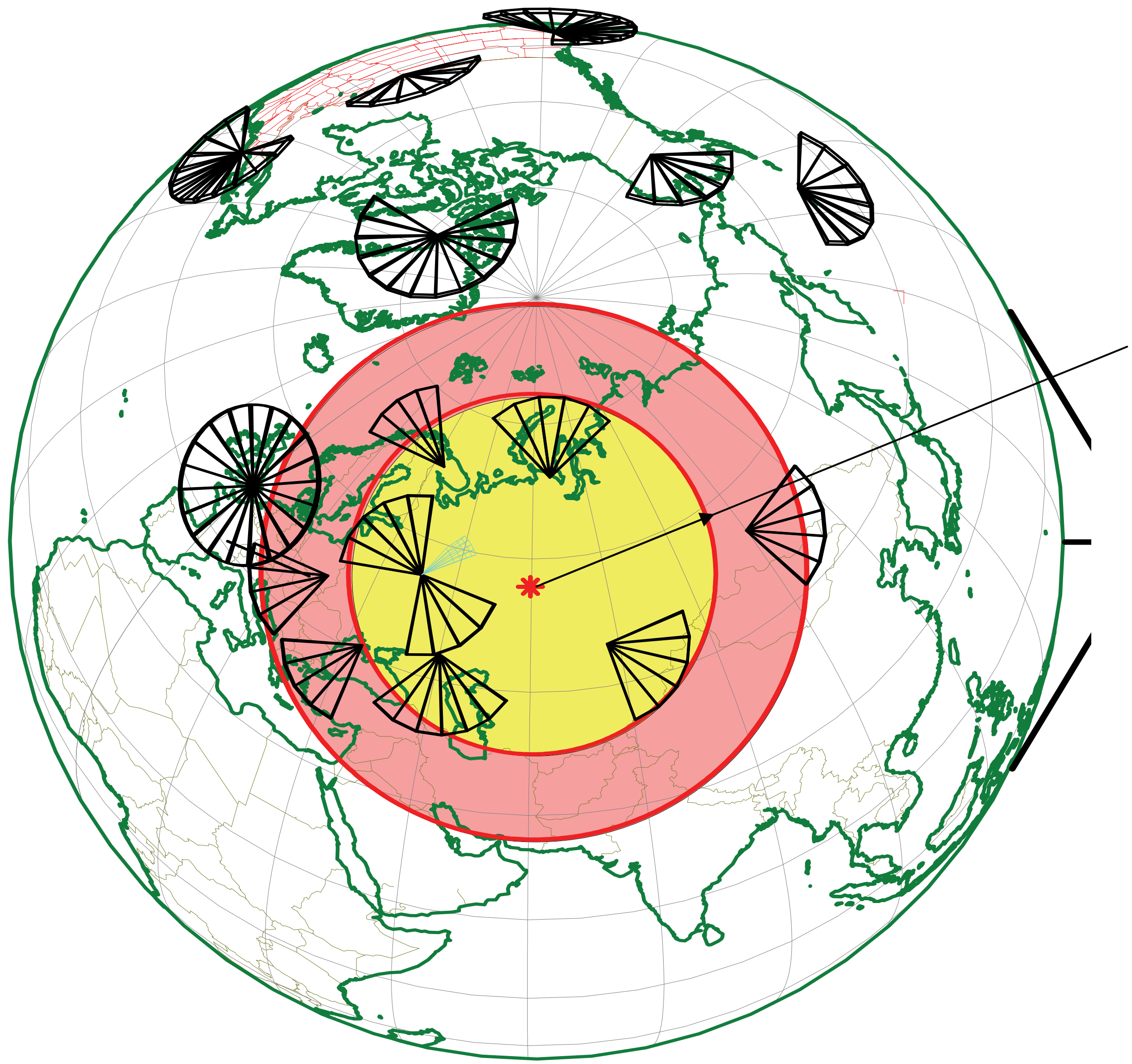


Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

Initial Electron Density at 60 km Altitude Produced by Prompt Radiation from a One Megaton Explosion as a Function of Distance and Burst Altitudes

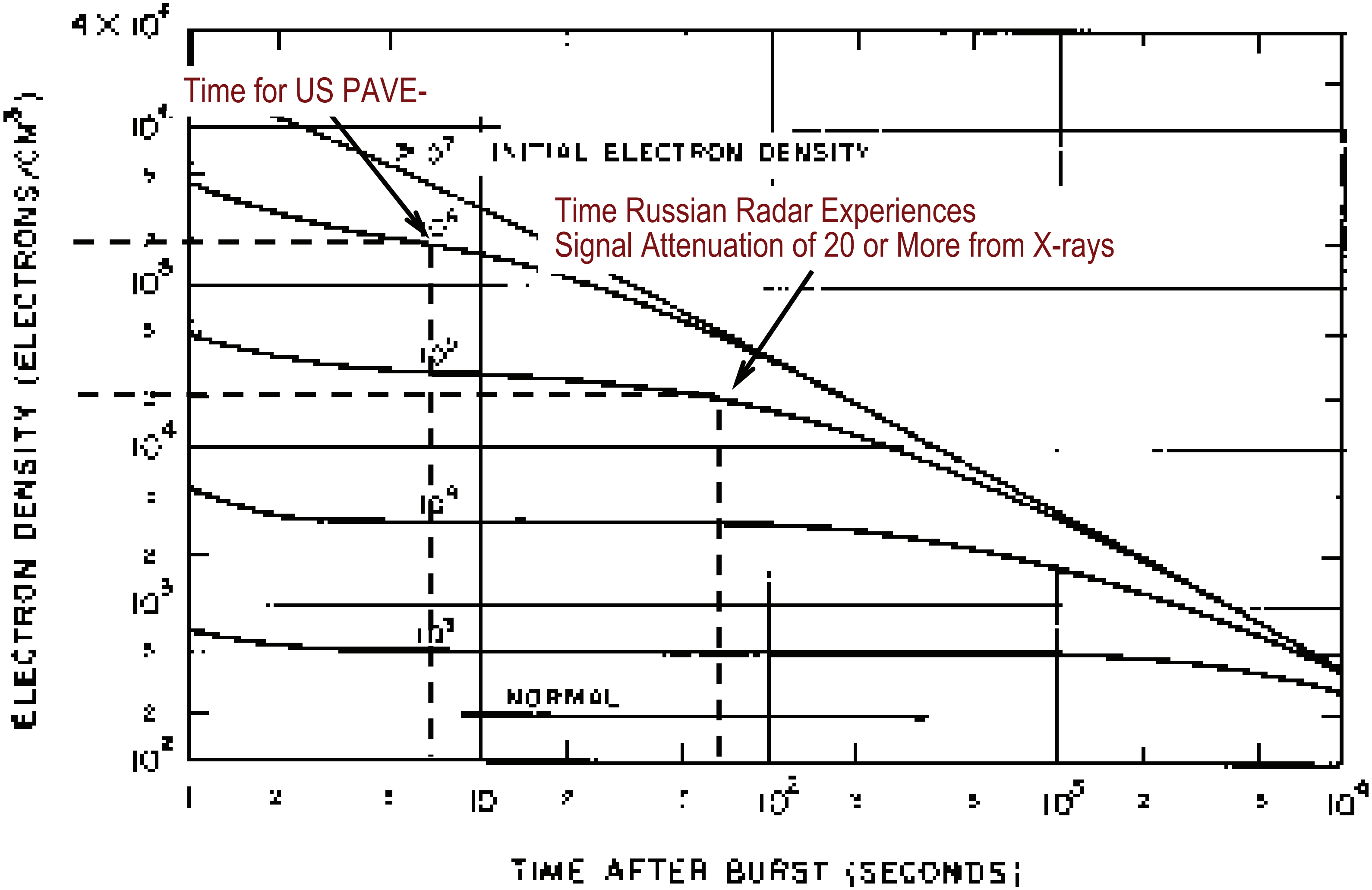


Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes



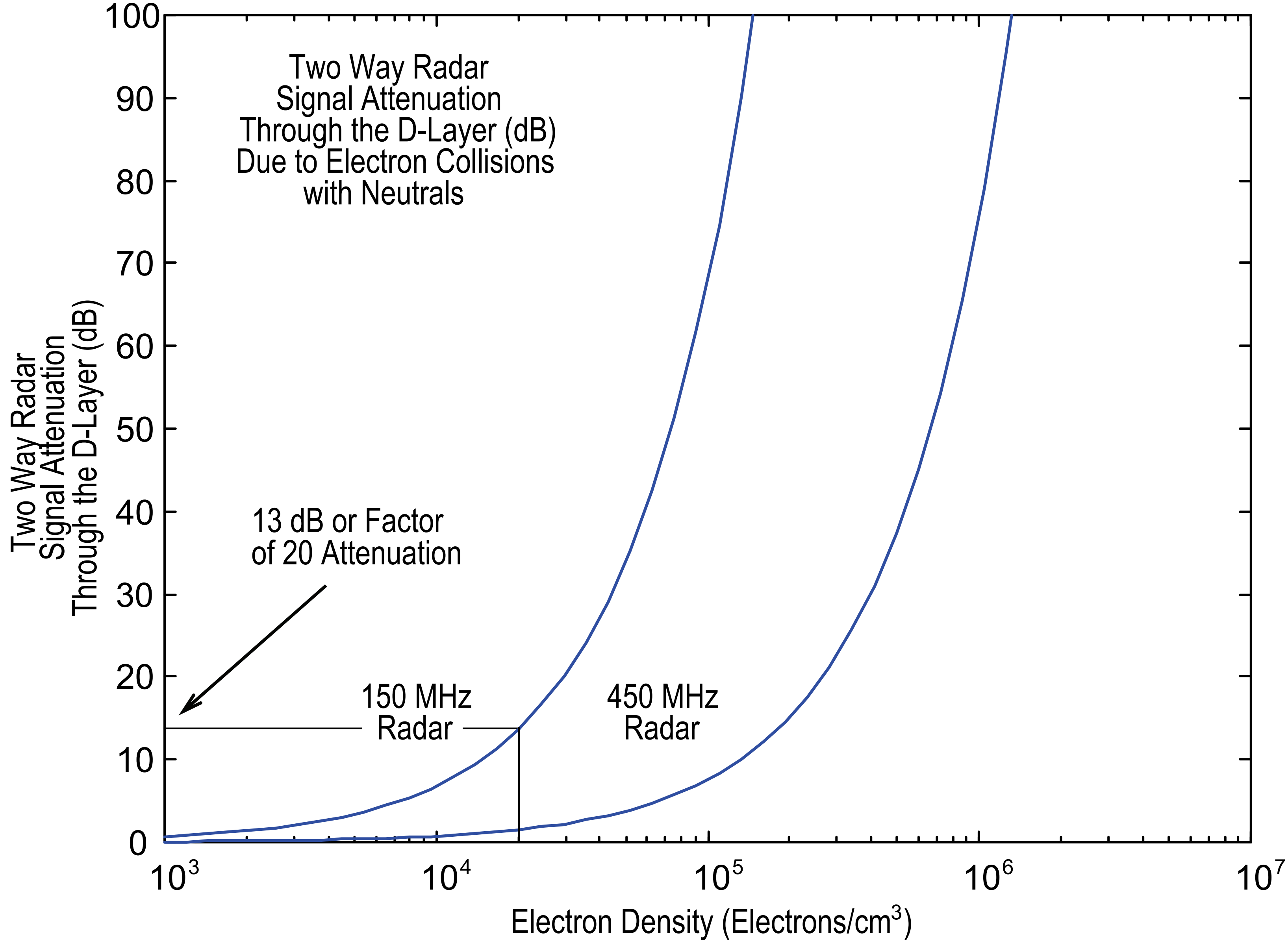
Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

Decay of Ionization at 60 km Altitude from Prompt Gamma Radiation



Decay of Ionization from Prompt Radiation at 65 Kilometers Altitude in Day Conditions

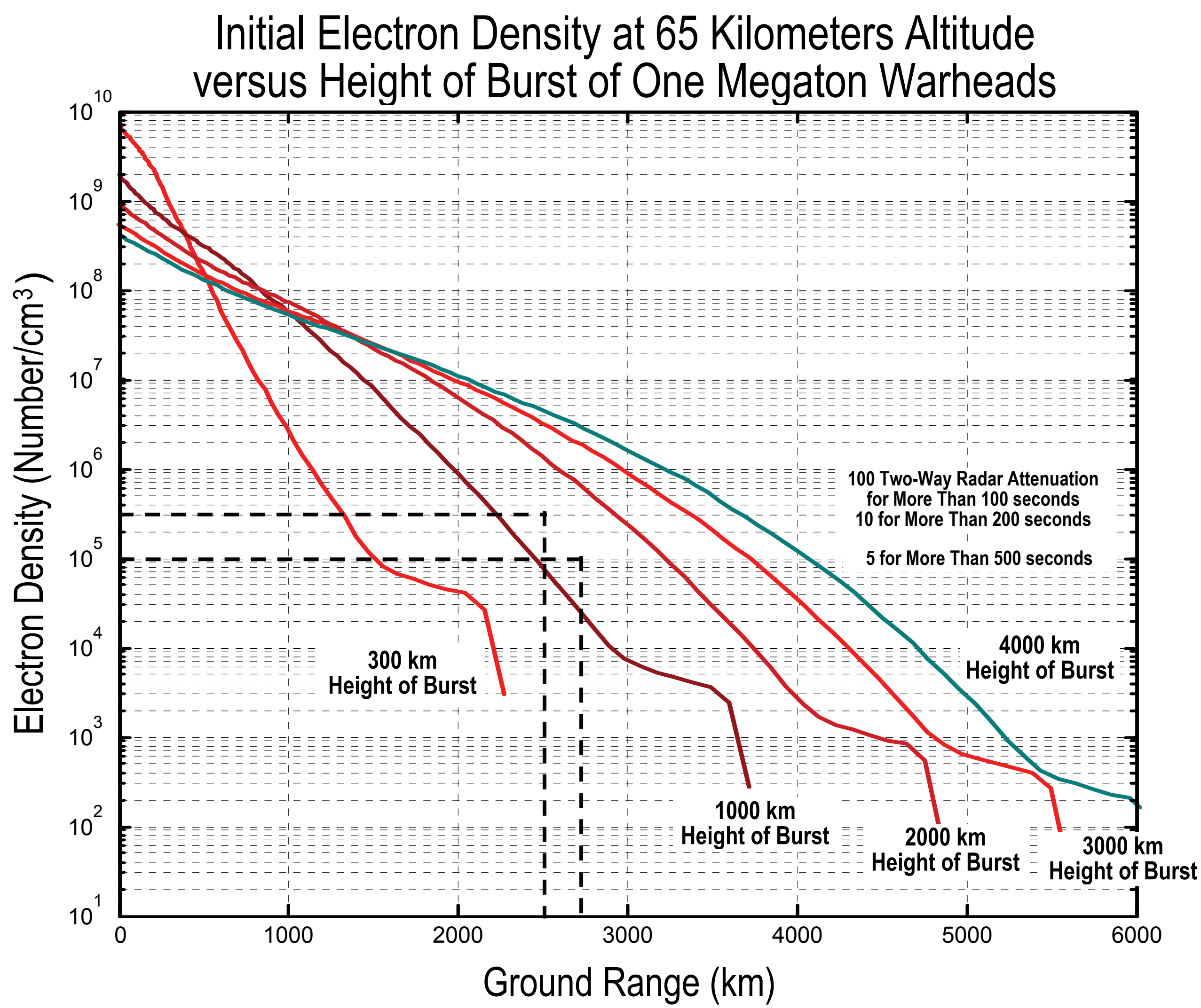
Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes



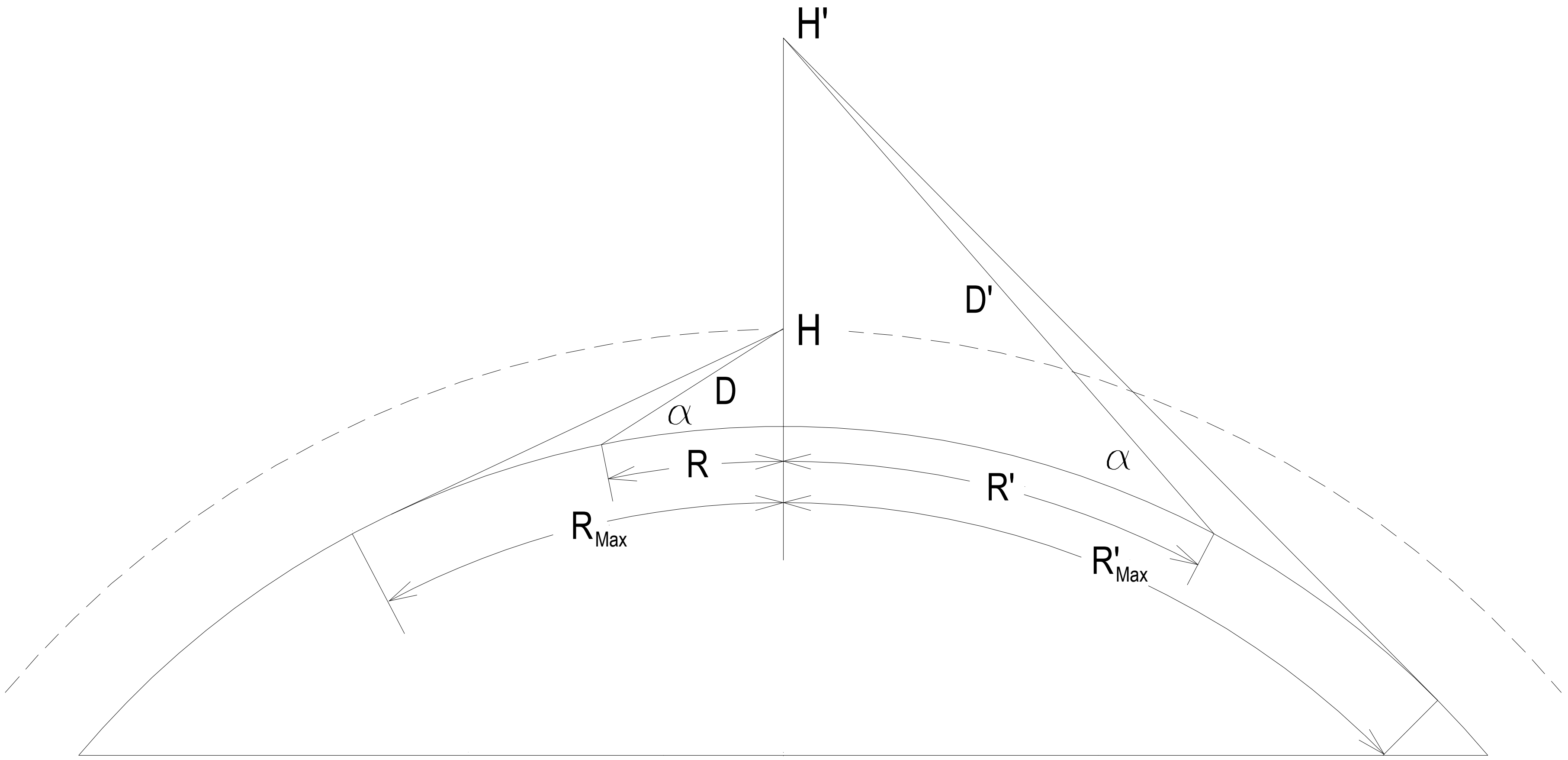
Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes

The figure below shows the electron density at 65 km altitude generated from the x-rays emitted by One-Megaton nuclear explosions at altitudes between 300 to 4000 km. the electron densities and 65 km altitude change due to two effects. The first, is simply due to the lower x-ray intensities from the nuclear explosion being at larger range. The second effect is due to absorption of x-rays at altitudes above 65 km.

Radar Blackout Effects from Nuclear Explosions at Varied High Altitudes



Technical Description of Radar Blackout Effects Due to High Electron Densities Generated from Nuclear Explosions at Varied High-Altitudes



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Appendix

Why Unexpected Launches of US SLBMs Could Be Dangerous

Why Unexpected Launches of US SLBMs Could Be Dangerous (1 of 4)

Lessons from the Russian False Alert of 1995

- Russia currently, and for the foreseeable future, does not have an operational global satellite early warning system that can provide global ballistic missile launch detection capabilities
- Because of this, Russia must *completely* rely on ground-based early warning radars against nuclear surprise attack.
- The Russian false alert of 1995 illustrates the serious dangers to the US from this limitation in Russia's Early Warning Systems.
- The false alert was caused by a single sounding rocket launched from Andoya Island off the coast of Norway.
- The sounding rocket was on a near vertical trajectory, going away from Russia towards the North Pole.
- However, the sounding rocket was essentially in the middle of a major US ICBM attack corridor from Grand Forks, North Dakota to Moscow.
- The Russian Early Warning System automatically treated the launch as a possible nuclear warhead that could detonate at high altitude, blinding the early warning radar that would be critical for observing such an attack.

Why Unexpected Launches of US SLBMs Could Be Dangerous (2 of 4)

Further Problems with Russia's Early Warning Systems

- Russia's satellite early warning system was inadequate in 1995.
- But since 1995, Russia's then inadequate early warning satellite system has now almost completely collapsed.
- Russia's early warning capabilities are thereby limited to line-of-sight early warning radars, which provide limited warning time due to constraints created by the curvature of the earth.
- Unlike the US early warning radars, Russia's radars operate at 150 MHz (US radars operate at 450 MHz), which makes them *extremely* vulnerable to being blinded by high altitude nuclear explosions.
- Such explosions could blind Russian radars for many minutes, leaving the Russians totally blind to an incoming nuclear attack.

Additional Circumstances that Further Increase the Chances of an Accidental Nuclear Launch

- Unlike the US, which has its largest and most capable nuclear forces dispersed at-sea, the vast bulk of Russian nuclear forces are land-based in silos or on soft mobile launchers that are almost always not dispersed
- The US SLBM force (Trident II *and* Trident I) is technically capable of destroying essentially this entire force – leaving Russia with only a very small number of deployed Russian nuclear submarines for retaliation.
- The Russian military is aware of this situation, and appears to be prepared to try to launch its land-based forces before such a US attack could succeed.
- The ability of Russia to launch these land-based forces rapidly requires a very streamlined decision making process.
- Such a process requires pre-delegation of launch authority, and possibly even automated launch procedures at some levels of command.

Additional Circumstances that Further Increase the Chances of an Accidental Nuclear Launch

- Any Russian effort to maintain or further streamline decision making and launch procedures will greatly increase the chances of an accidental massive launch of forces
- Making matters worse, the Russian system of early warning radars has holes in its coverage and many of the radars are now on foreign territory
- The situation is therefore now dangerous
  – and will certainly worsen if the capabilities of Russian early warning systems continue to decay

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