
Technical Effectiveness of European Ballistic Missile Defense Options

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Wilton Park

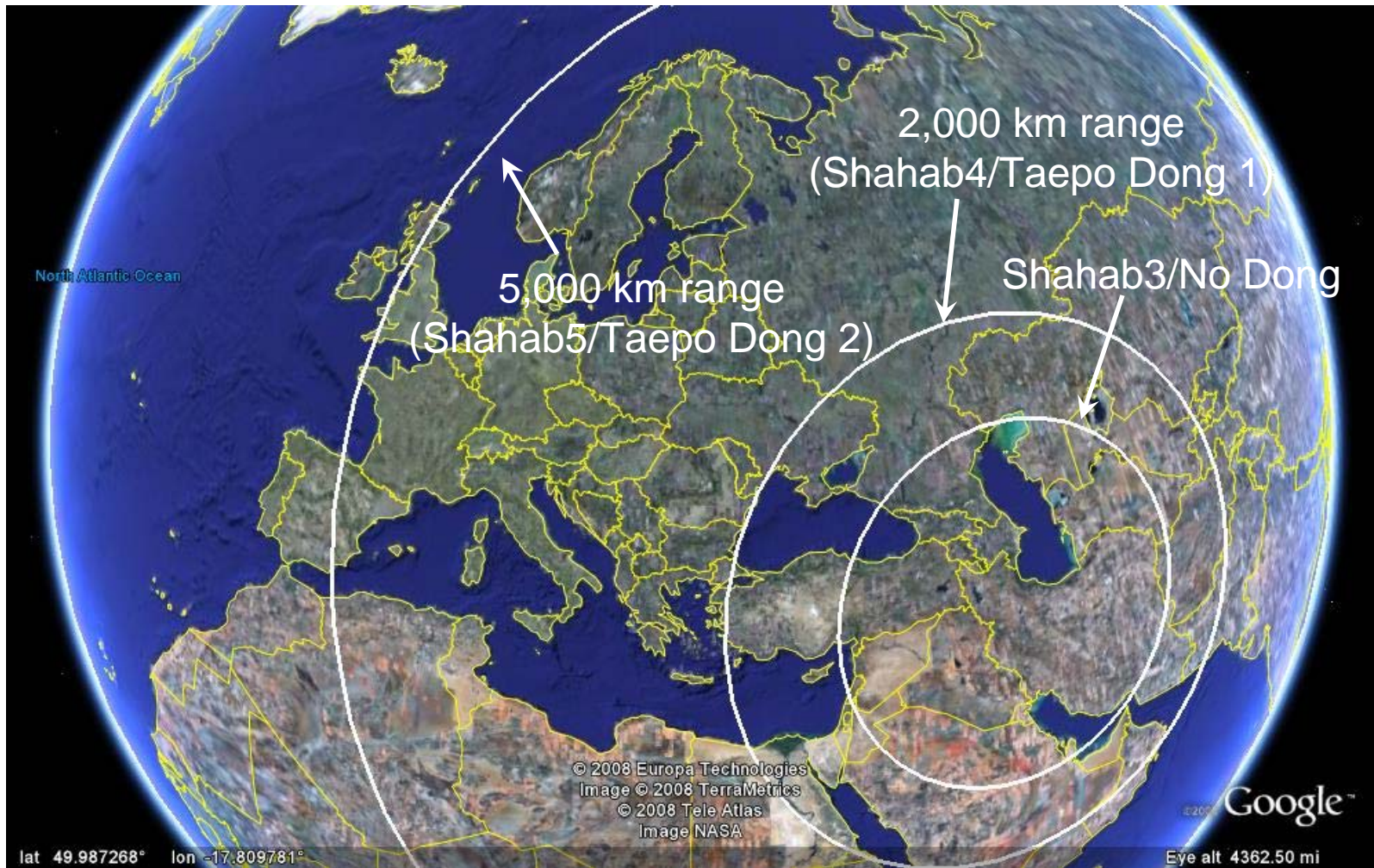
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**Center for International Security and Cooperation
Stanford University**

Outline

- **Introduction: BMD “footprints”**
- **Polish-Czech BMD System**
- **Alternate European BMD Architectures**
 - **Notional Bulgarian BMD System**
 - **Notional Turkish BMD System**
 - **Aegis BMD System in the Black Sea**
 - **Aegis BMD + netted Turkish EMR System**
- **Issues Addressed**
 - **How well can these systems defend Europe against ballistic missiles launched from Iran?**
 - **How well can they handle depressed trajectory threats?**
 - **How well can they handle reduced radar cross section threats?**
 - **Can they defend the United States from ICBMs launched from Iran?**
 - **Can they defend the United States from ICBMs launched from Russia?**

Hypothetical Iranian Missile Range



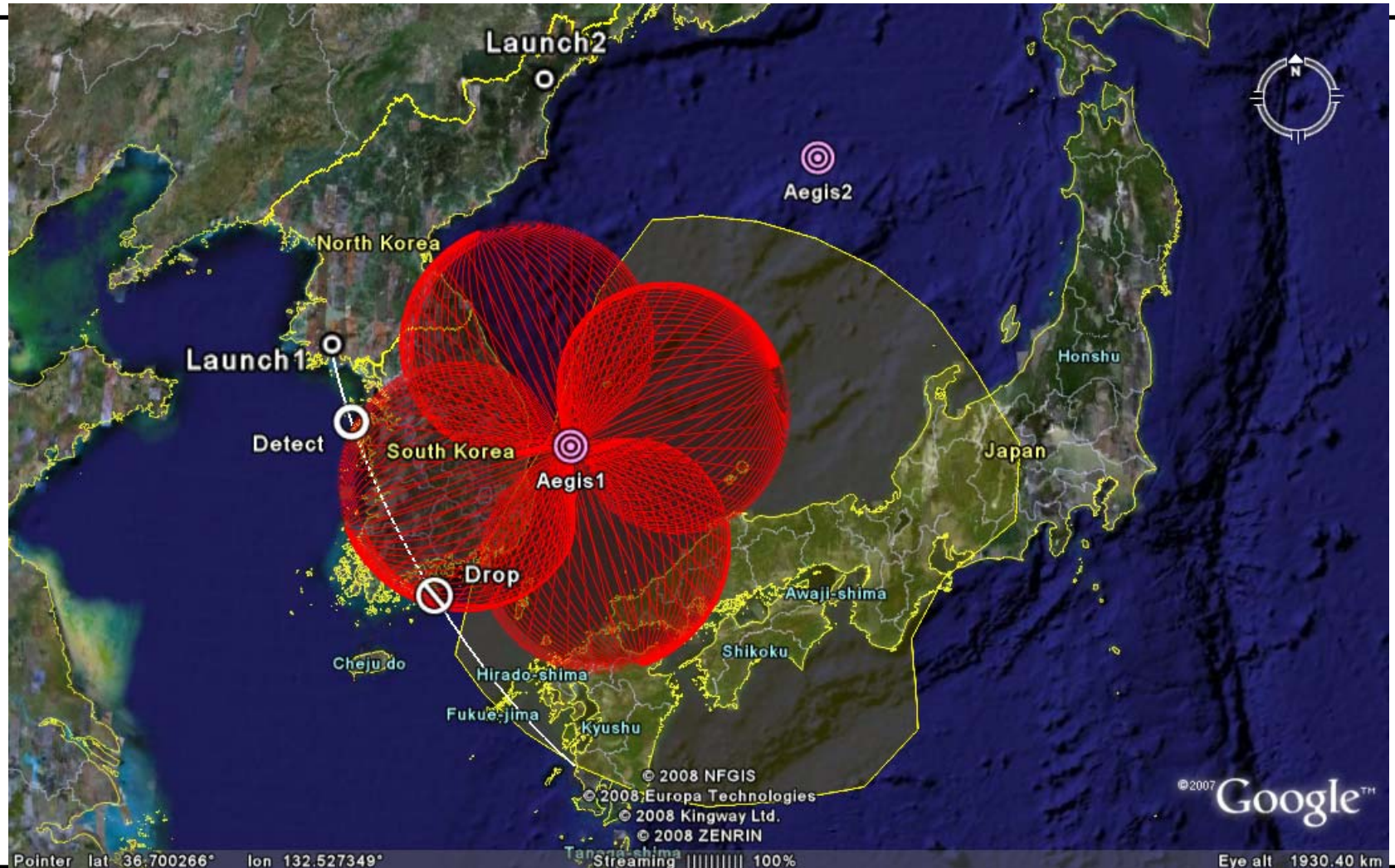
Hypothetical Iranian ICBM Trajectories to the United States



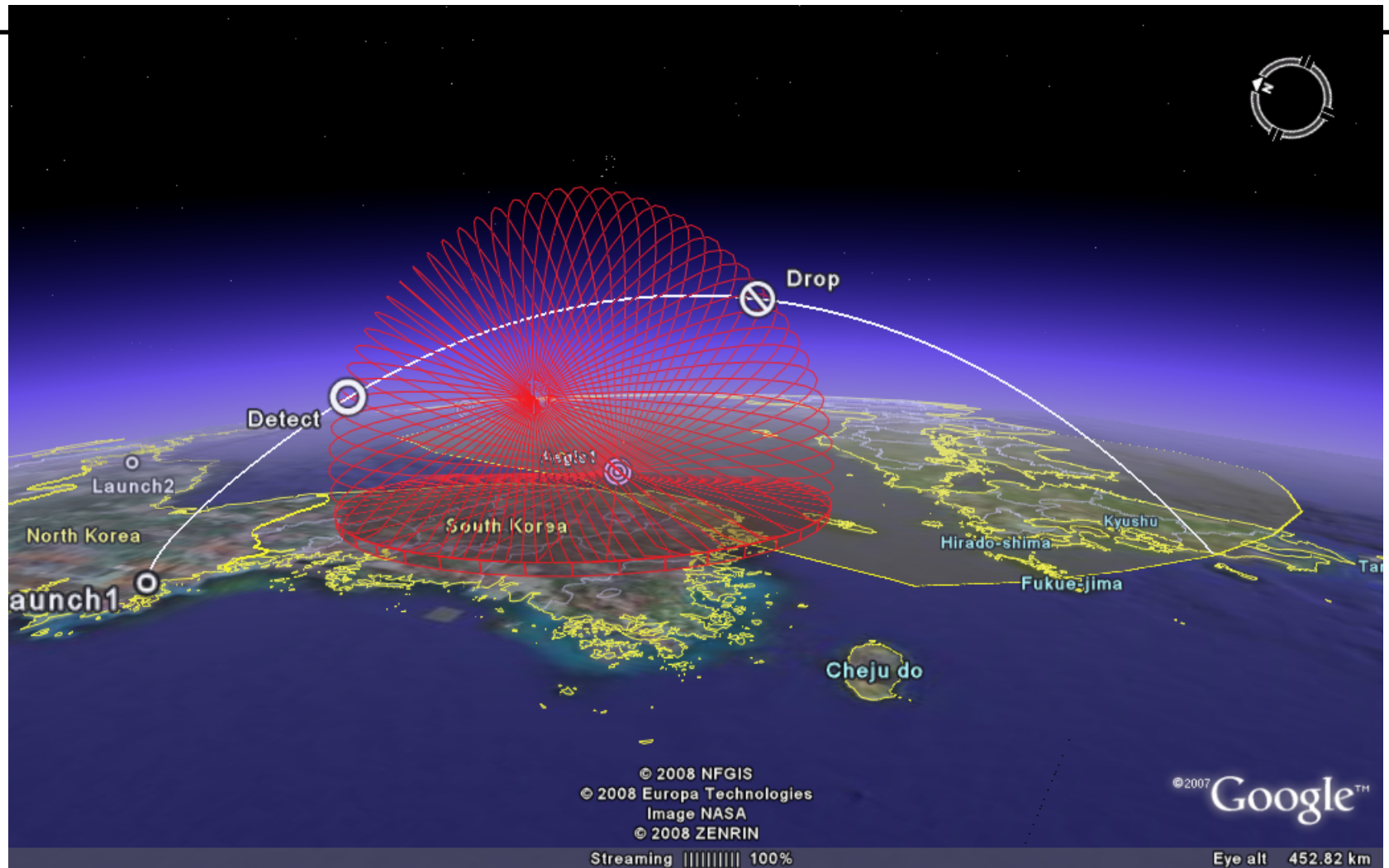
BMD Effectiveness Depends On:

- **Area that can be defended (BMD “footprint”)**
 - **Target characteristics**
 - Radar cross section (RCS) and target trajectory (**countermeasures possible**)
 - **Radar architecture**
 - Number, location, detection range and netted operation
 - **Interceptor characteristics**
 - Flyout speed, available flight time and minimum intercept altitude
- **Probability of successful intercept**
 - **Probability of correctly identifying the warhead from decoys/debris (**countermeasures possible**)**
 - **Probability of kill given correct warhead identification**
 - End-game homing (target signature, kinetic kill vehicle dynamics)
- **Size of the defense**
 - **Number of interceptors vs. attack size, including objects that cannot be discriminated from real warheads (**countermeasures possible**)**

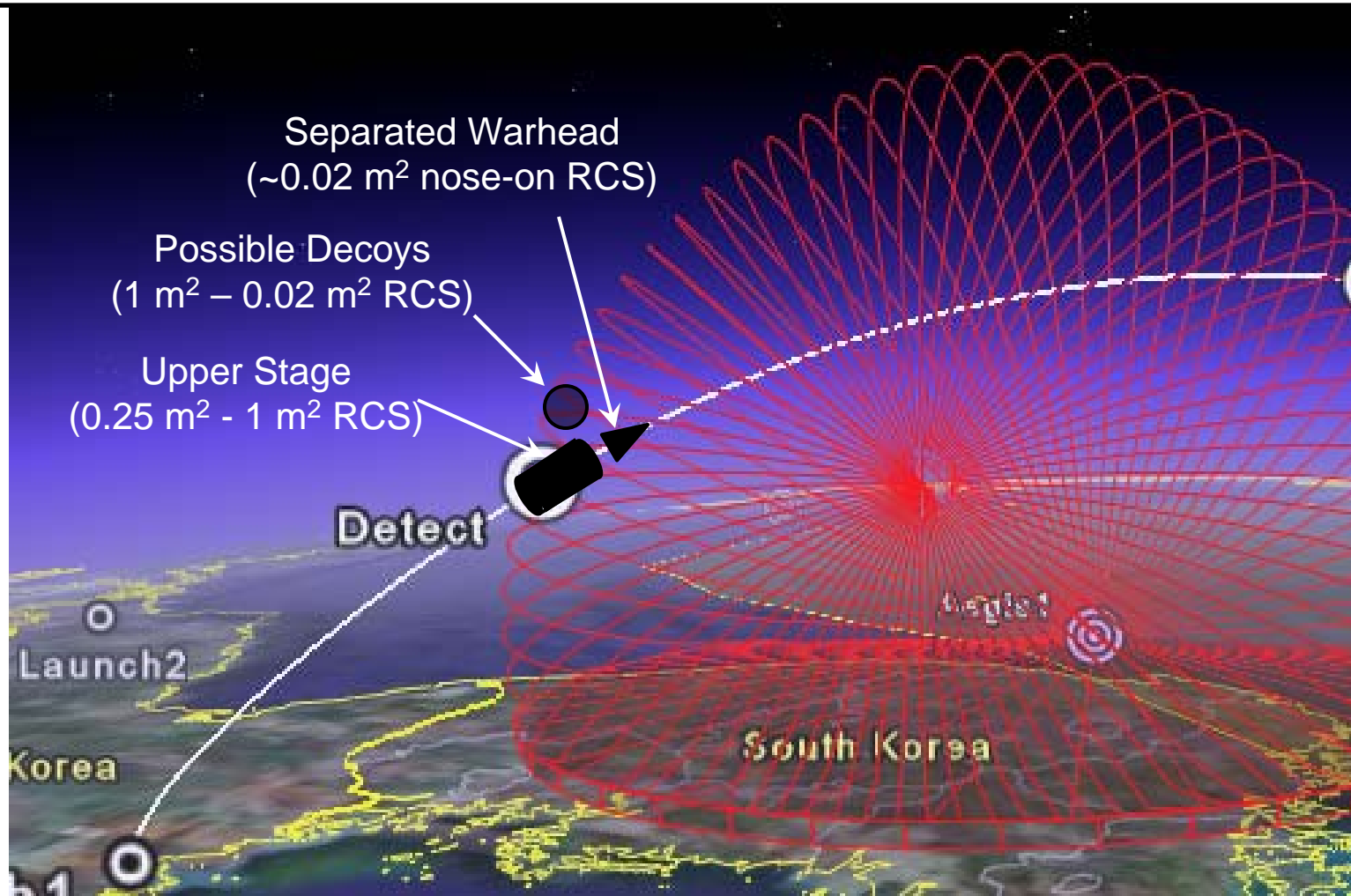
Missile Defense Footprints



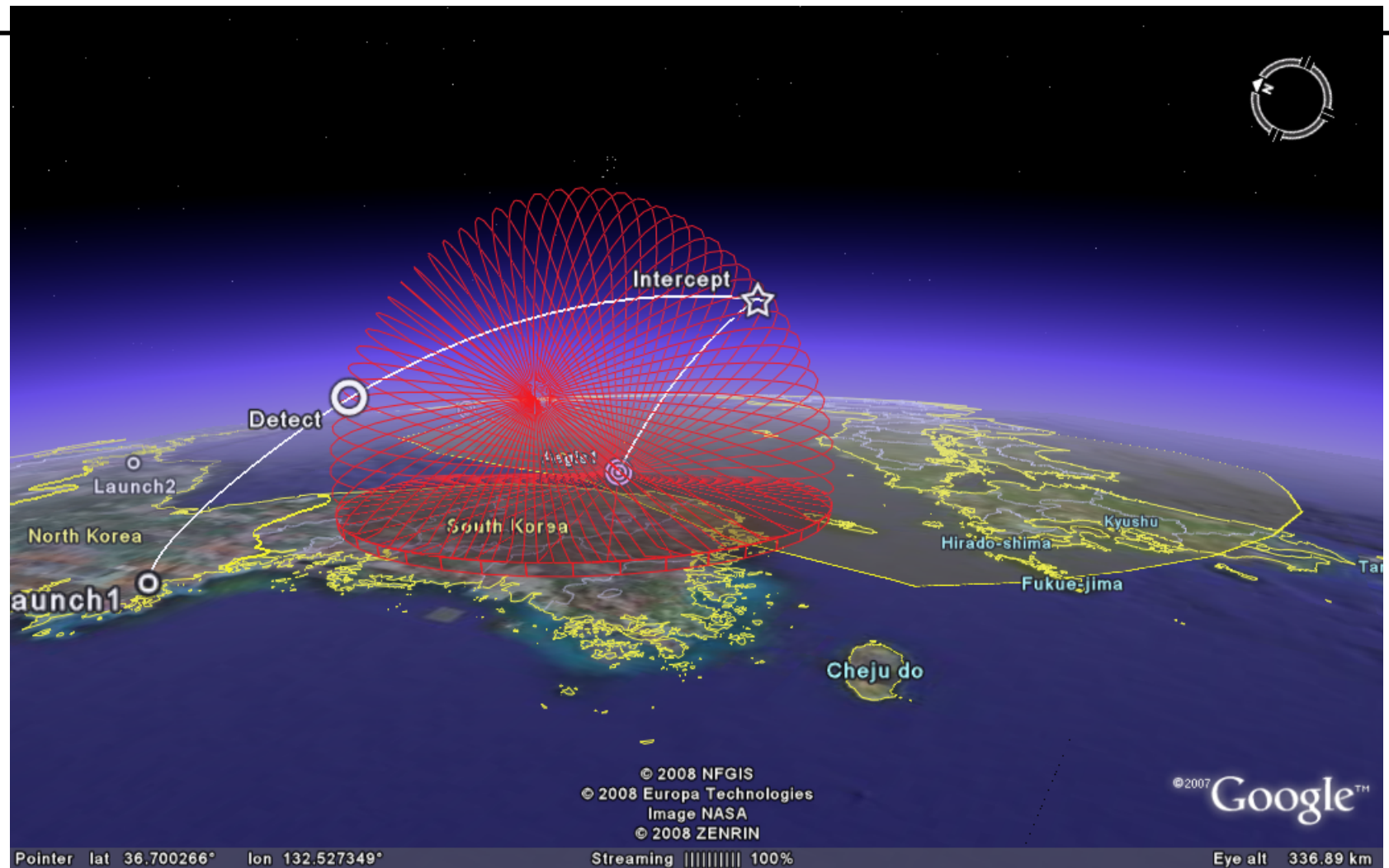
Radar Detection and Tracking



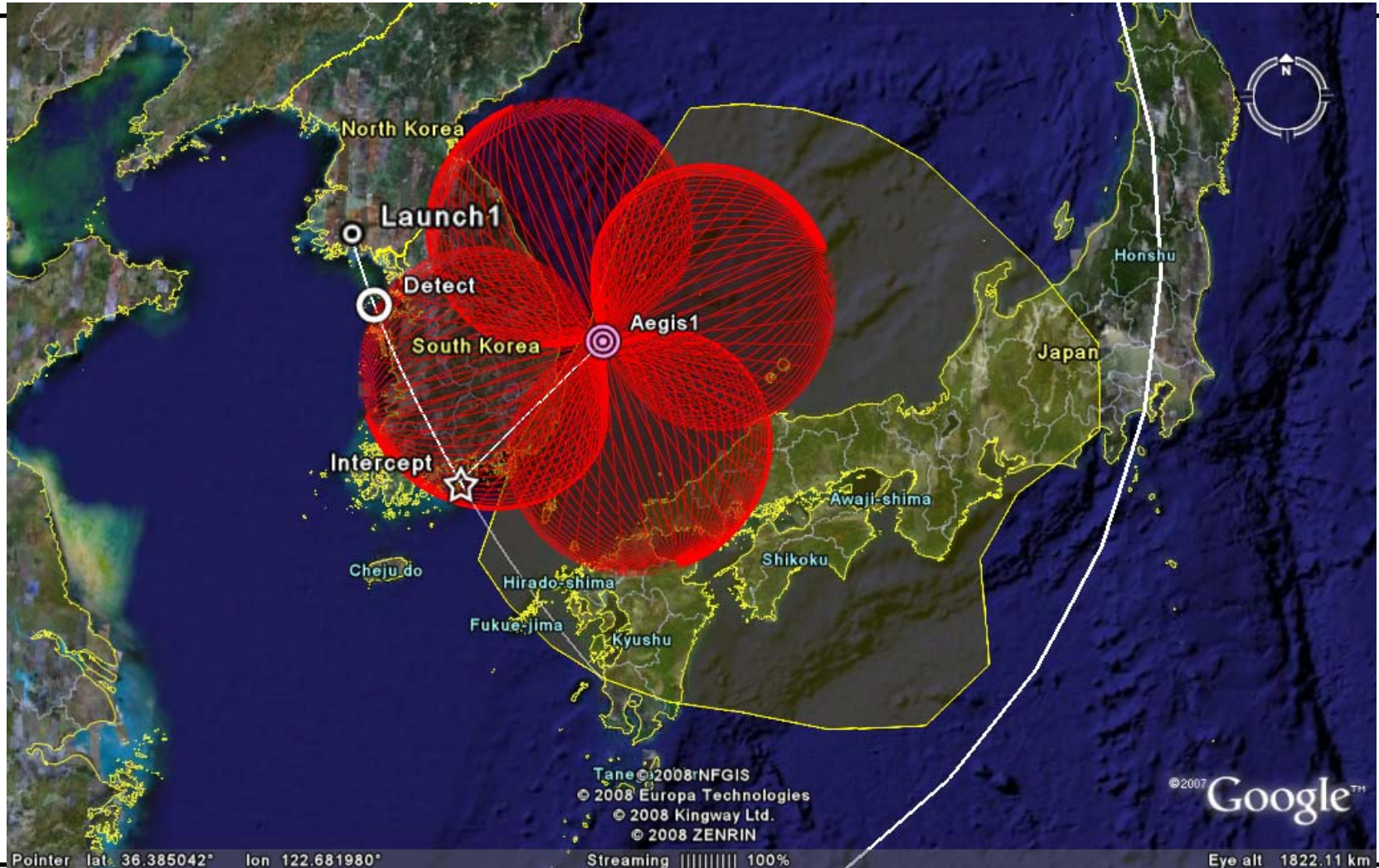
Radar Detection and Tracking



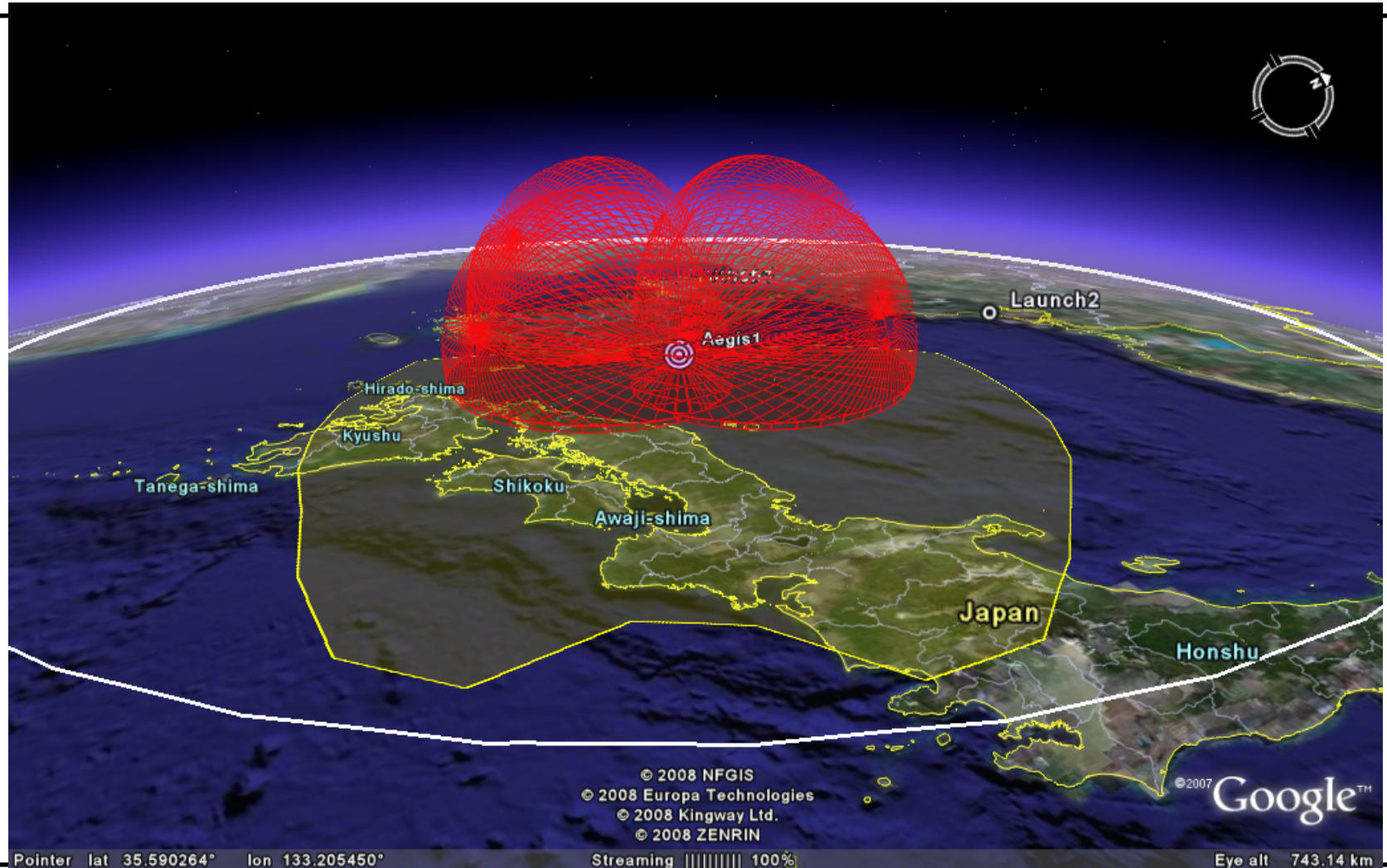
Interceptor Flyout



Target Intercept



BMD Footprint



European BMD Systems

- **Current Polish-Czech BMD Plans**
 - **10 GBI based in Poland**
 - Agreement signed on August 20, 2008
 - SOF Agreement yet to be signed
 - Ratification needed by Polish parliament
 - **European Midcourse X-band radar (EMR) in Brdy, Czech Republic**
 - Agreement signed on July 8, 2008
 - SOF Agreement yet to be signed
 - Ratification needed by Czech parliament
- **FBX near Caspian Sea**
- **Alternate European Systems**
 - **Notional Bulgarian BMD System**
 - **Notional Turkish BMD System**
 - **Aegis BMD in the Black Sea + Turkish EMR**

2-Stage Ground-Based Interceptor



2-stage GBI Characteristics

Total Mass	22,600 kg
Payload Mass	200 kg
Ideal ΔV	7.6 km/sec
Actual Burnout Speed	~6.5 km/sec
Total Burn Time	138 sec
Stage 1	
Mass	17,670 kg
Propellant Mass Fraction	0.85
Thrust (vac)	613.9 kN
ISP (vac)	285
Burn time	68.4 sec
Stage 2	
Mass	4620 kg
Propellant Mass Fraction	0.85
Thrust (vac)	10.3 kN
ISP (vac)	289
Burn time	69.4 sec

Czech European Midcourse X-band Radar (EMR)



Czech X-band Radar Characteristics

Ave. Power	20.3 kW
Aperture	11.5 m diameter
Antenna Efficiency	0.76
Aperture weighting	1.23
Beam Height x Width	0.18° x 0.18°
Radar Frequency	10 GHz
PRF	25 Hz
Radar Losses	10 dB
Receiver Noise Temperature	500 °K
Radar Cross Section	1 m²/0.02 m²
Swerling Target Type	4
Pulses Integrated	
Surveillance	1
Tracking	1
Probability of Detection/FA	0.9/10 ⁻⁶
Detection Range	
Surveillance	2700 km/1000 km
Tracking	2700 km/1000 km

FBX Radar (i.e., THAAD Radar)



Assumed FBX Radar Characteristics

Ave. Power	76 kW
Aperture	2.0 m X 4.6 m
Antenna Efficiency	0.61
Aperture weighting	1.18 x 1.25
Beam Height x Width	1.07° x 0.49°
Radar Frequency	9.5 GHz
PRF	75 Hz
Radar Losses	8 dB
Receiver Noise Temperature	500 °K
Radar Cross Section	1 m²/0.02 m²
Swirling Target Type	4
Pulses Integrated	
Surveillance	1
Tracking	2
Probability of Detection/FA	0.9/10 ⁻⁶
Detection Range	
Surveillance	1000 km/380 km
Tracking	1300 km/490 km

Upgraded Early-Warning Radars (Fylingdales, UK)



BMEWS Radar Characteristics

Ave. Power	255 kW
Aperture	25.6 m diameter
Antenna Efficiency	0.82
Aperture weighting	1.18
Beam Height x Width	1.8° x 1.8°
Radar Frequency	440 MHz
PRF	25 Hz
Radar Losses	10 dB
Receiver Noise Temperature	500 °K
Radar Cross Section	1 m²/0.1 m²
Swerling Target Type	4
Pulses Integrated	
Surveillance	6
Tracking	6
Probability of Detection/FA	0.9/10 ⁻⁶
Detection Range	
Surveillance	5200 km/2900 km
Tracking	5200 km/2900 km

European Radar: Fylingdale BMEWS

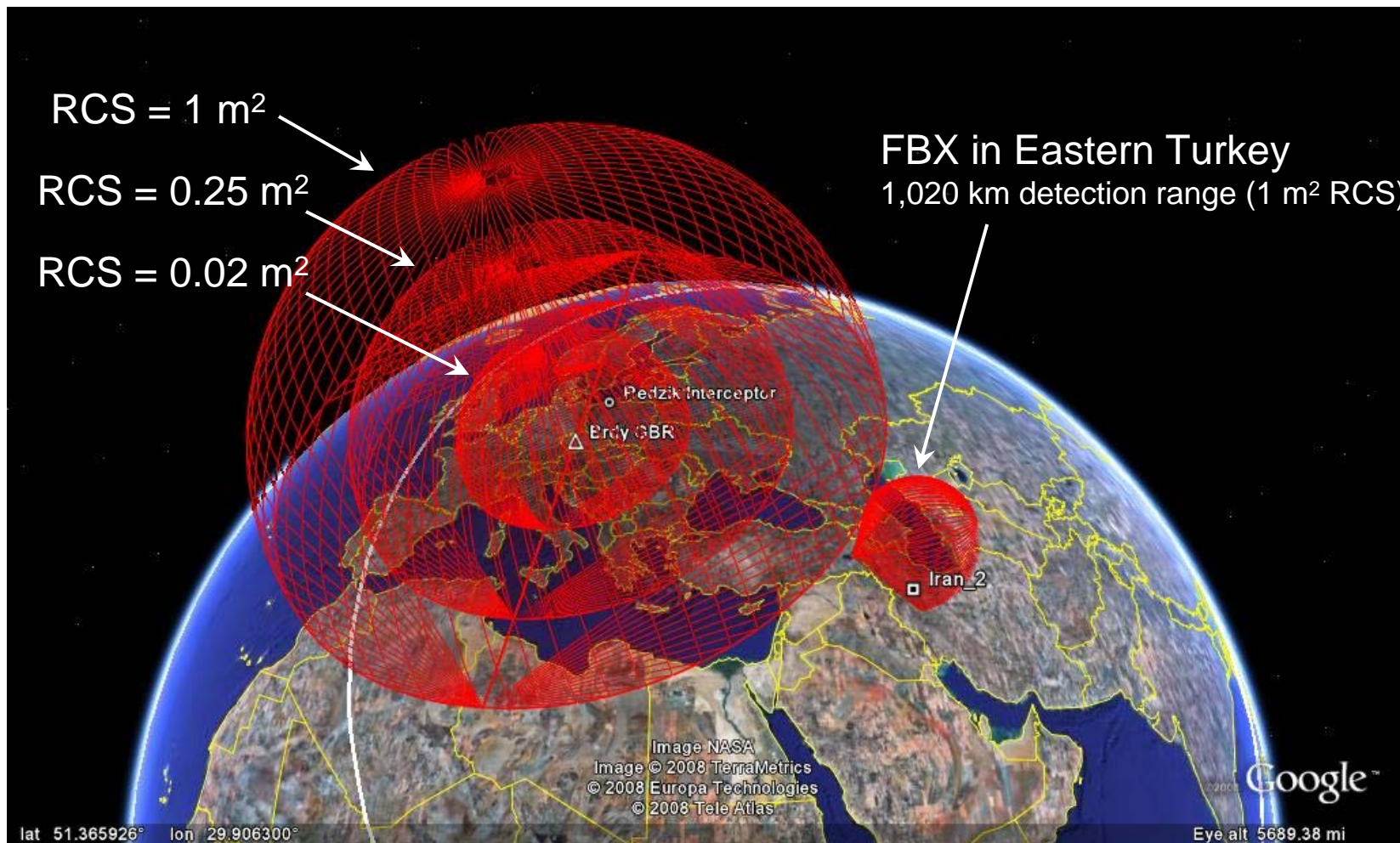
(5200 km detection range against 1 m² target)



Alternate European BMD Systems

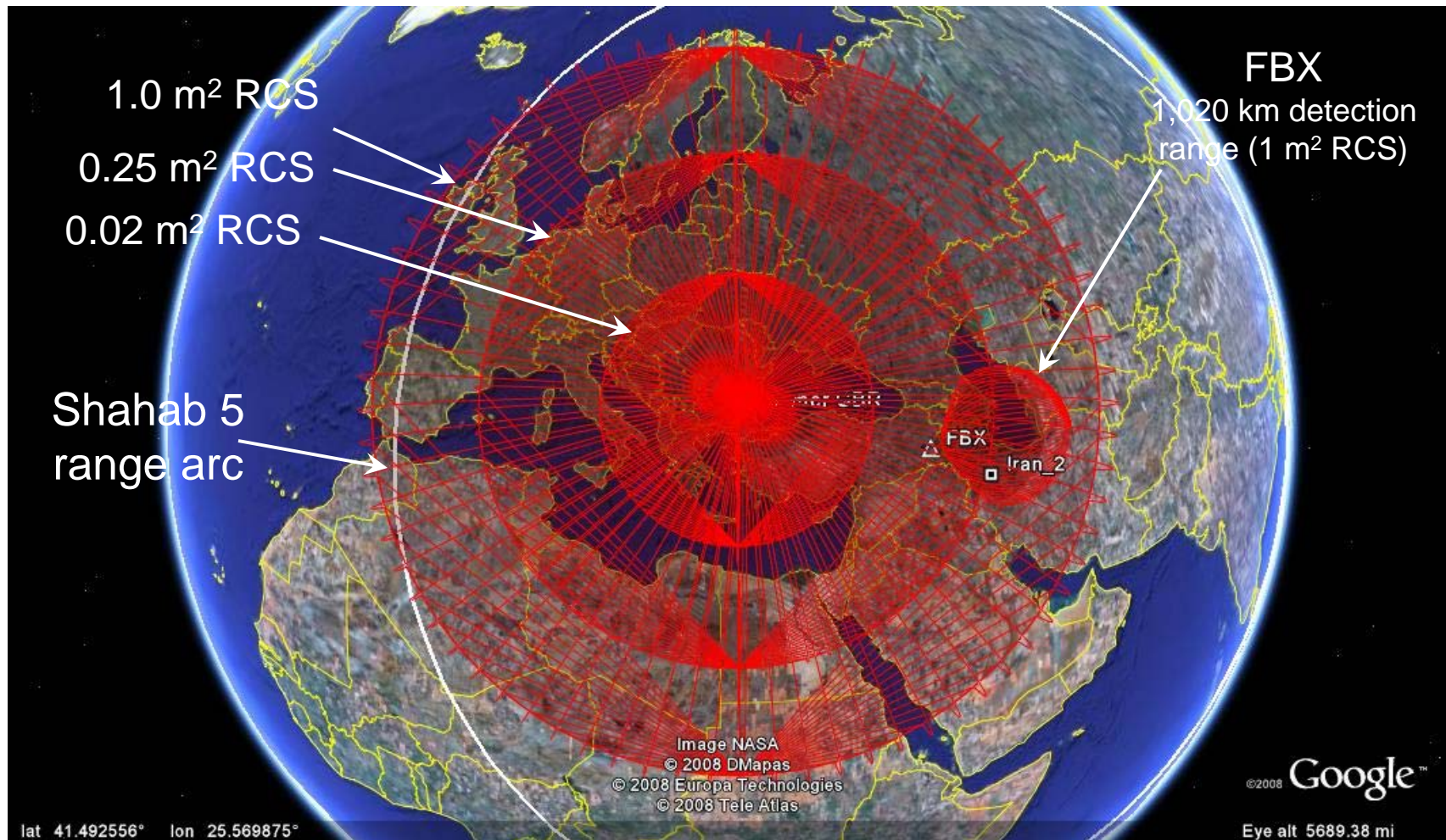
Czech X-band EMR

(2,700 km detection range against 1 m² target)



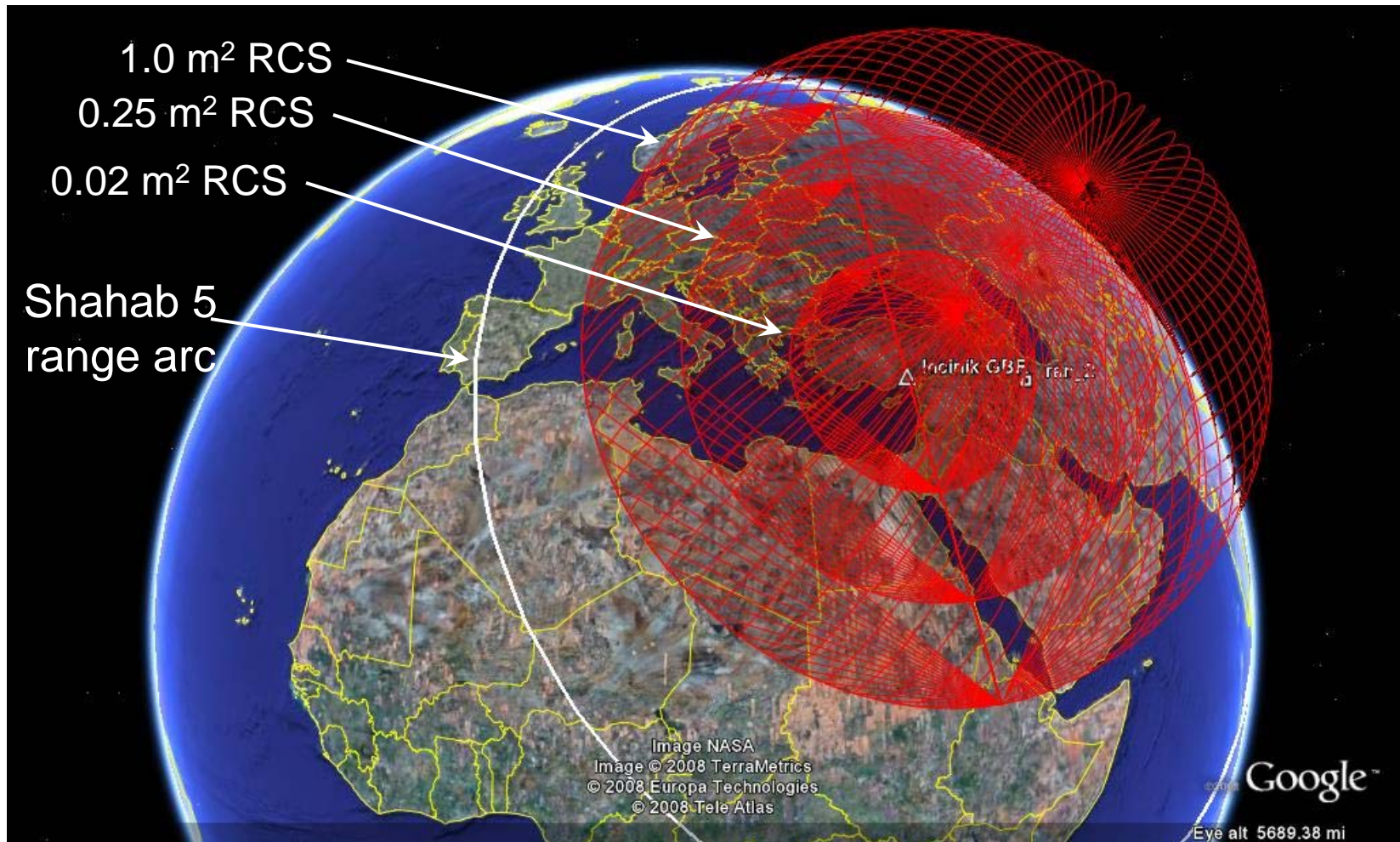
Bulgarian X-band EMR

(2,700 km detection range against 1 m² target)

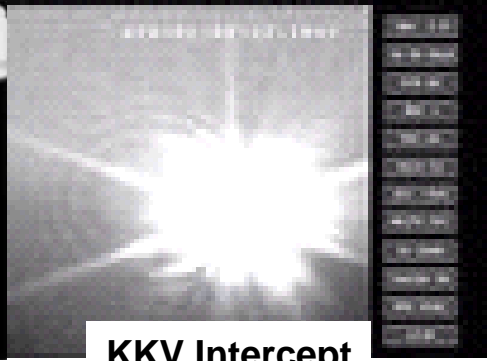
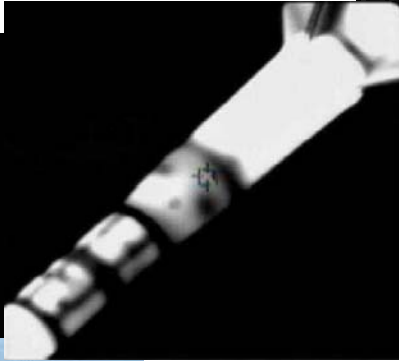


Turkish X-band EMR

(2,700 km detection range against 1 m² target)

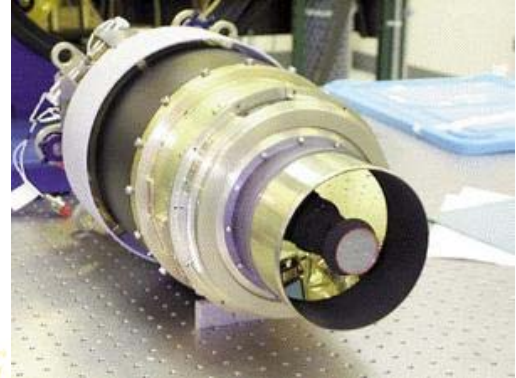


Aegis Missile Defense System



KKV IR Target Image







KKV Intercept



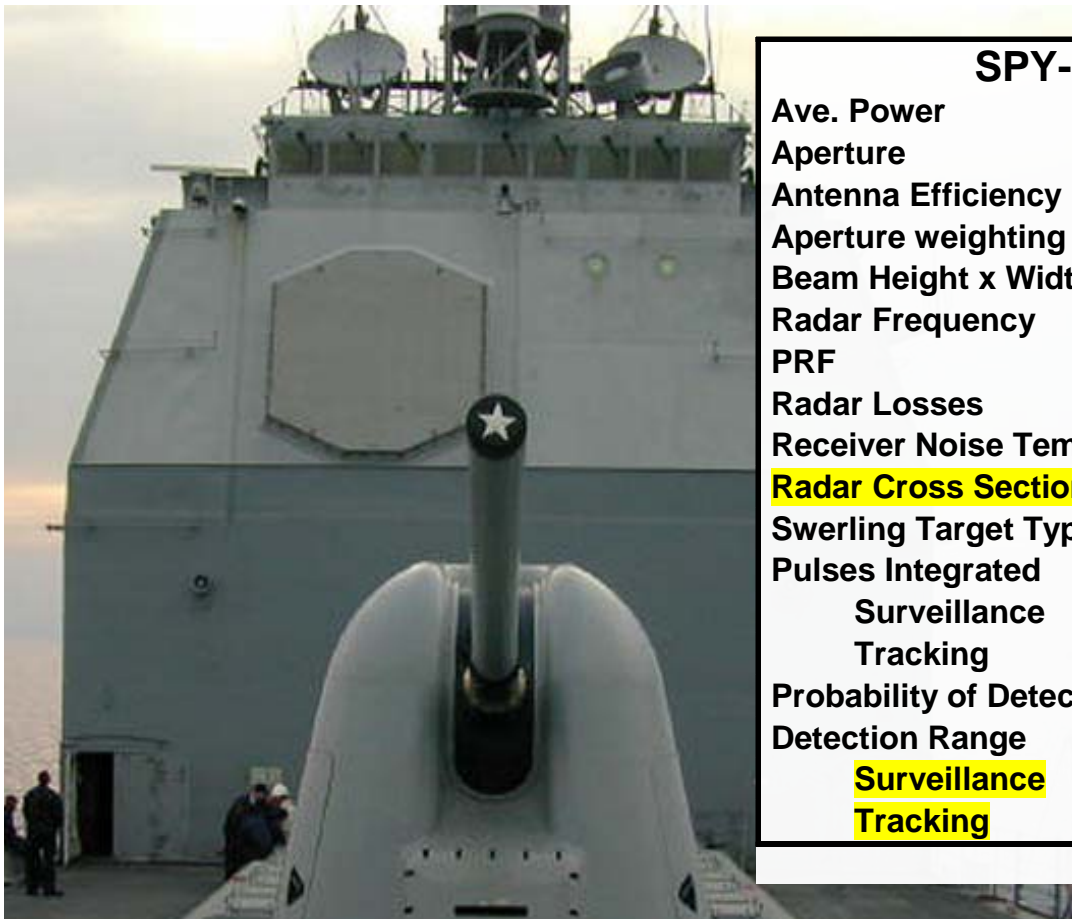


SM-3 Evolution

Aegis BMD

Block IA	Block IB	Block II	Block IIA
 <p>Block 2004</p> <ul style="list-style-type: none"> • 1-Color Seeker • Pulsed DACS <p>Block 2006</p> <ul style="list-style-type: none"> • All-Reflective Optics (ARO) • Advanced Signal Processor (ASP) 	 <ul style="list-style-type: none"> • 2- Color Seeker <ul style="list-style-type: none"> - Increased IR Acquisition - Improved Discrimination • TDACS <ul style="list-style-type: none"> - Increased Divert - Lowers AUR Cost 	<p>High Velocity Variant</p>  <ul style="list-style-type: none"> • Block IB Seeker • TDACS <ul style="list-style-type: none"> - If Not in Block IB • 21" Propulsion <ul style="list-style-type: none"> - 2nd & 3rd Stage - Increased Missile $V_{bo} = xx$ • 21" Clanshell Nosecone (JCR) • MK 41 VLS Compatible 	<p>High Divert Variant</p>  <ul style="list-style-type: none"> • Large Diameter KW <ul style="list-style-type: none"> - Adv Discrim Seeker - High Divert DACS • 21" Propulsion <ul style="list-style-type: none"> - 2nd & 3rd Stage - Increased Missile $V_{bo} = yy$ • 21" Clanshell Nosecone (JCR) • MK 41 VLS Compatible 
Block 2004 / 2006	Block 2008	Block 2010 / 2012	Block 2012 / 2014

AN/SPY-1D Radar Characteristics

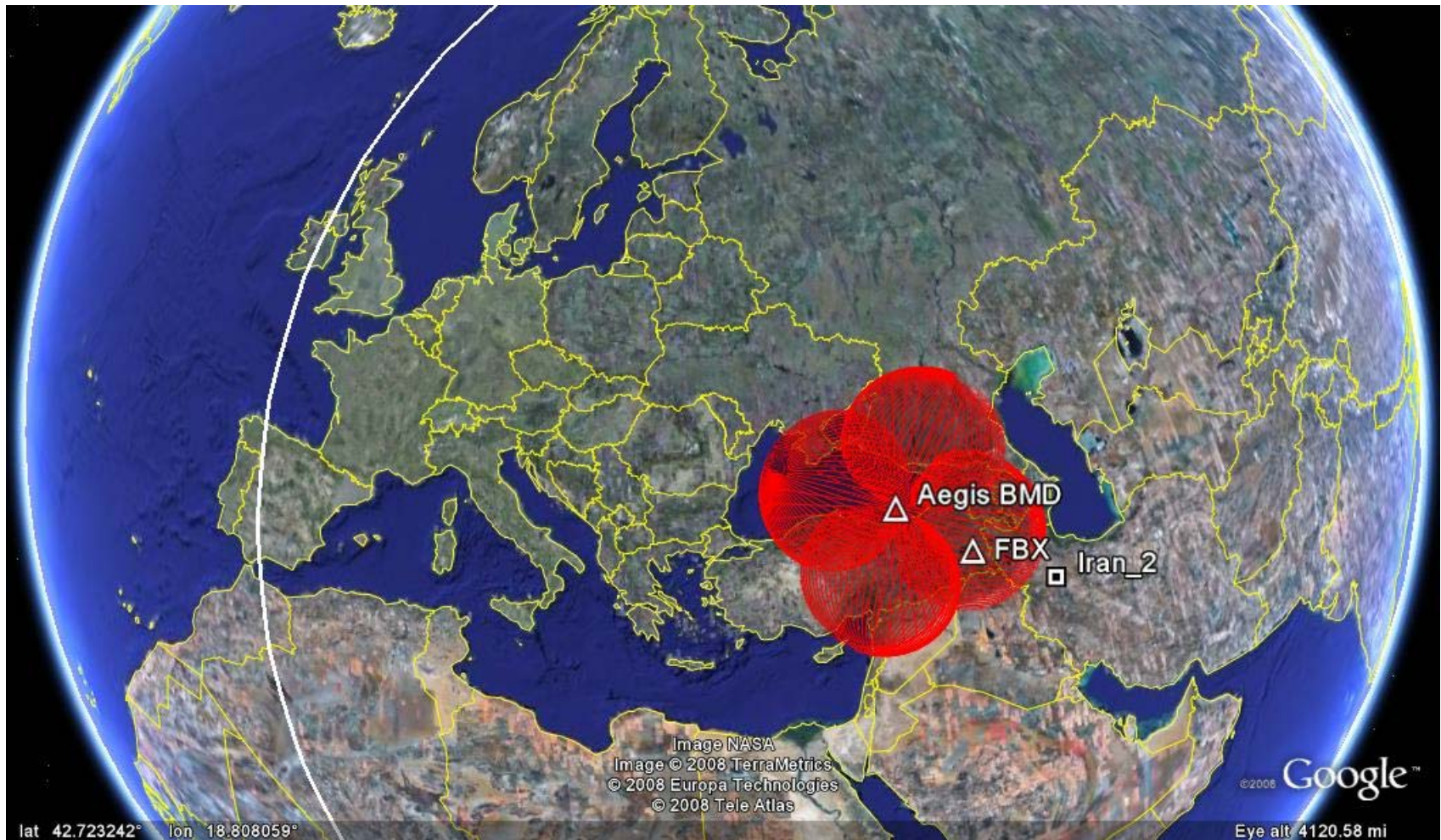


SPY-1D Radar Characteristics

Ave. Power	58.0 kW
Aperture	3.65 m X 3.65 m
Antenna Efficiency	0.61
Aperture weighting	1.25 x 1.18
Beam Height x Width	1.8° x 1.7°
Radar Frequency	3.3 GHz
PRF	150 Hz
Radar Losses	13.2 dB
Receiver Noise Temperature	500 °K
Radar Cross Section	1 m²/0.014 m²
Swerling Target Type	4
Pulses Integrated	
Surveillance	2
Tracking	9
Probability of Detection/FA	0.9/10 ⁻⁶
Detection Range	
Surveillance	550 km/190 km
Tracking	800 km/280 km

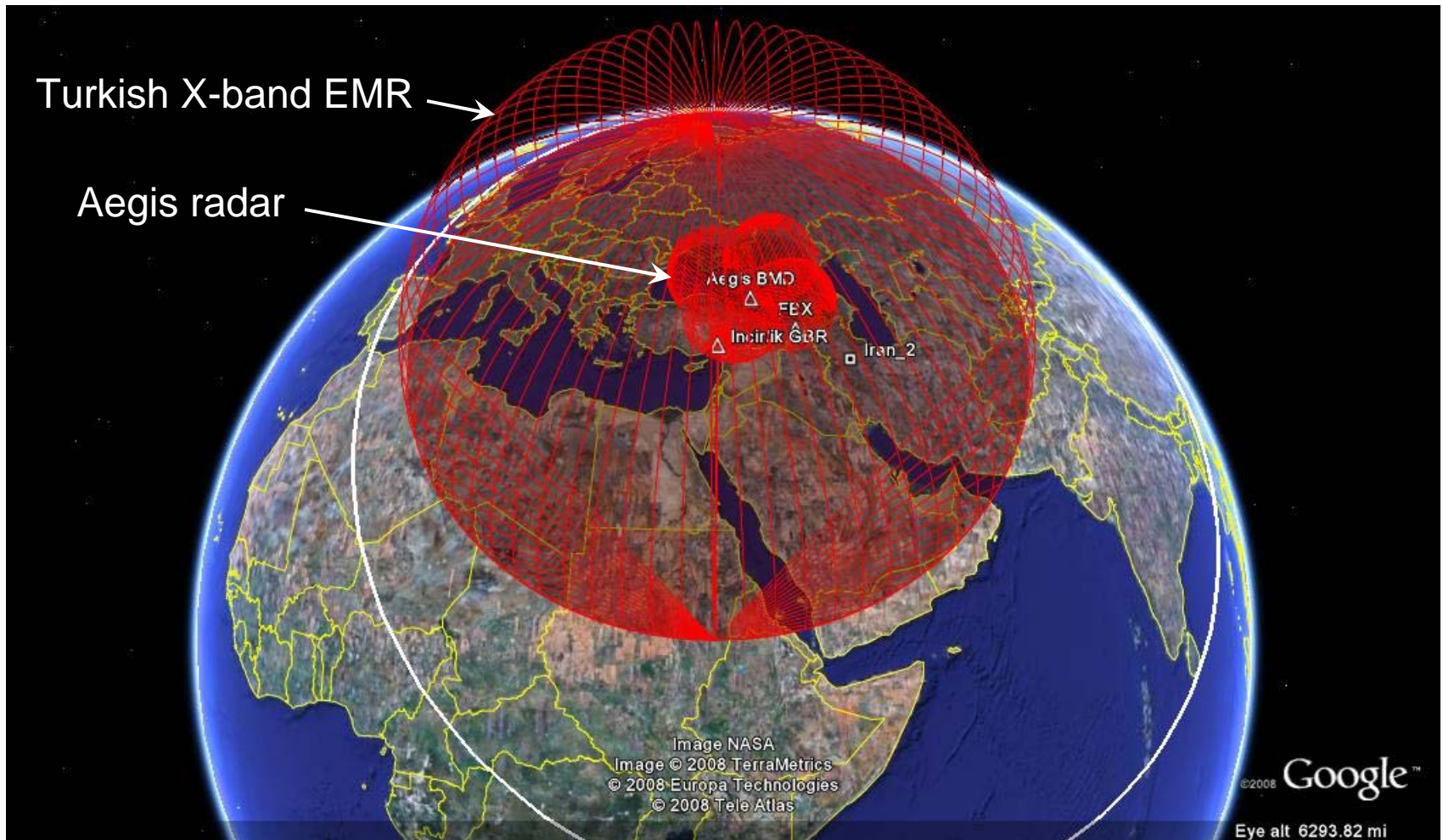
Aegis BMD System

(800 km detection range against 1 m² target)



Aegis BMD+Turkish EMR

(Turkish EMR, 1 m² RCS)



How Well Can These BMD Systems Defend Europe From Hypothetical Iranian Missile Threats?

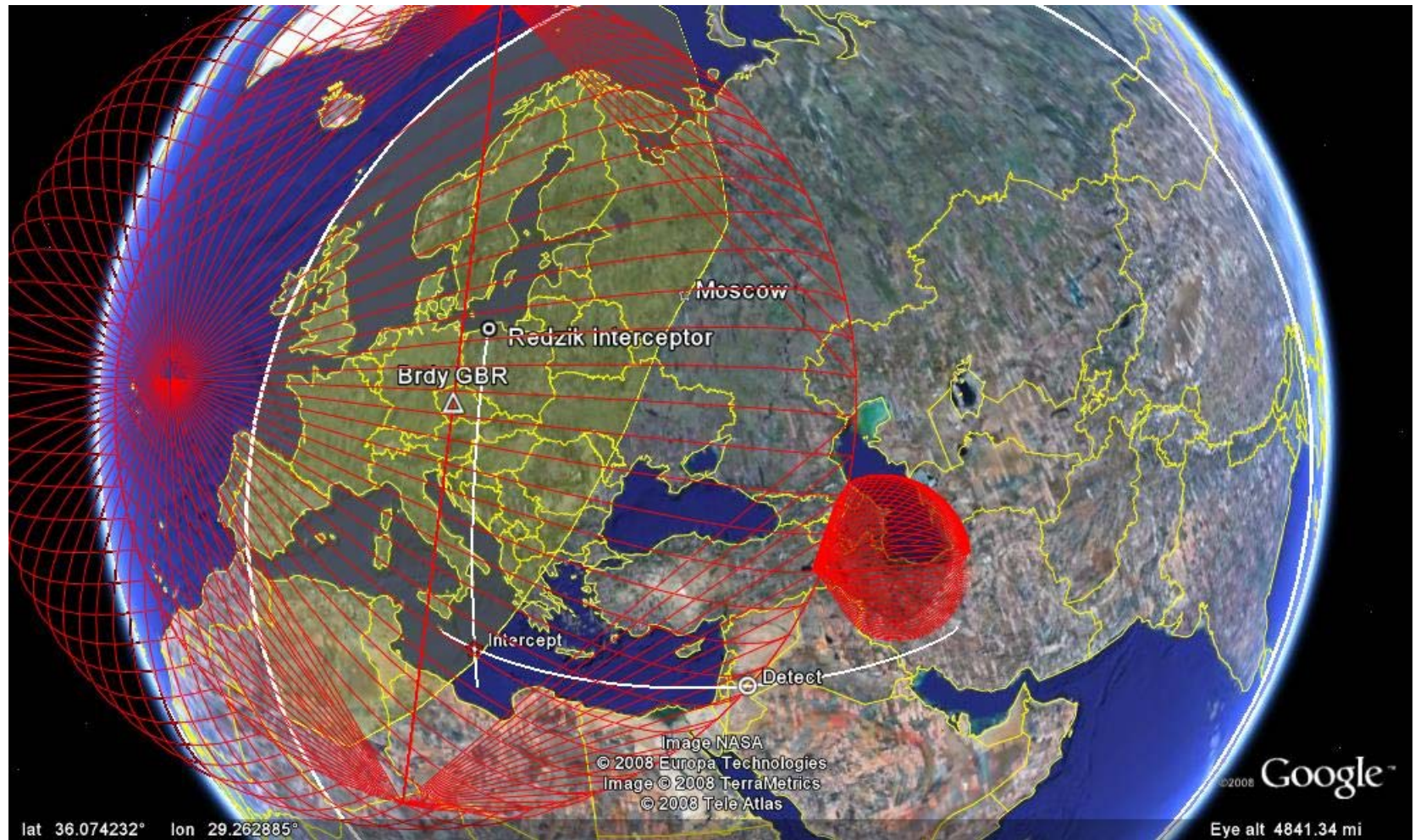
Czech-Polish BMD: Shahab 5

(Czech EMR + Fylingdale UEW, 2-stage Interceptor in Poland)



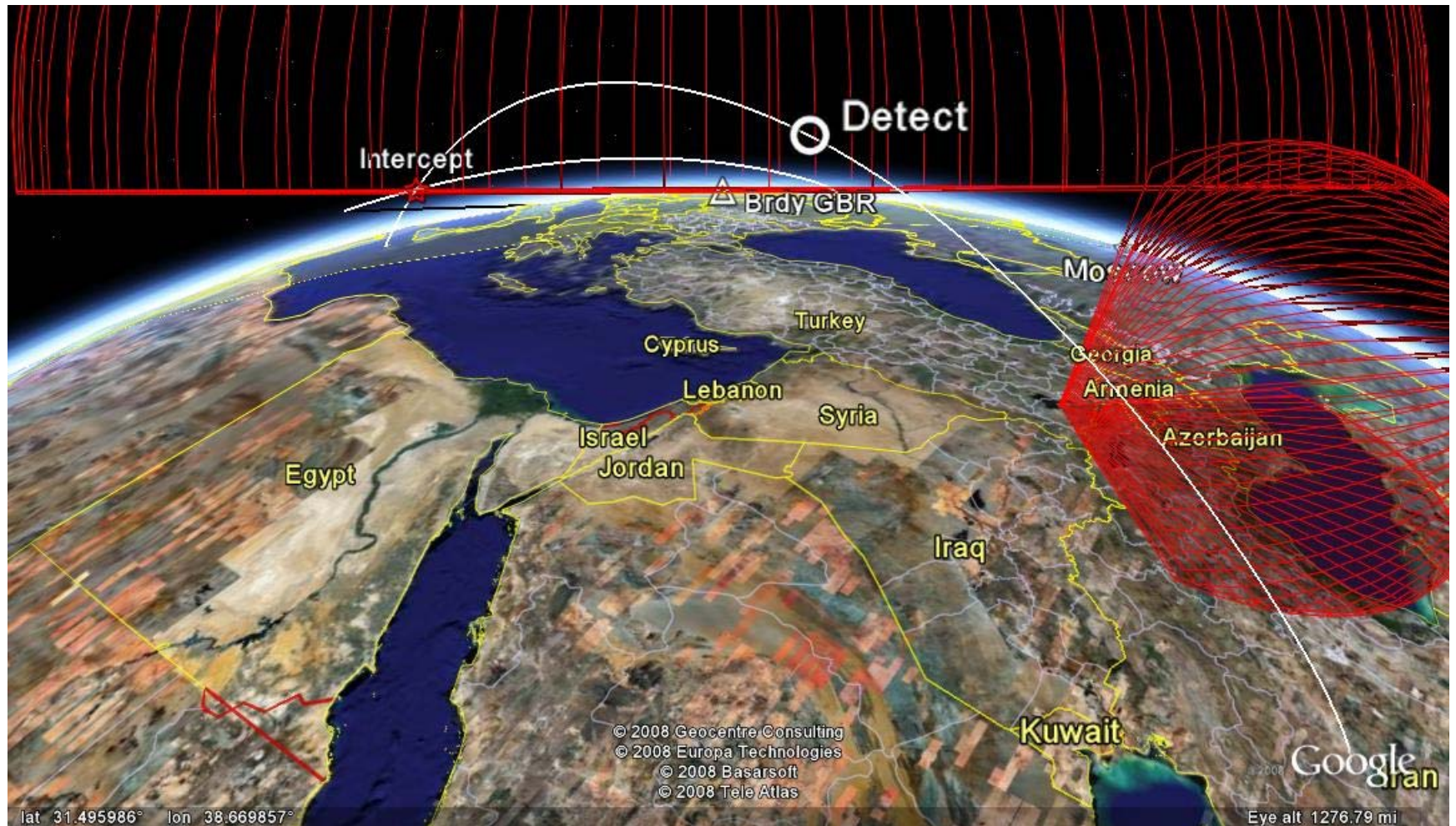
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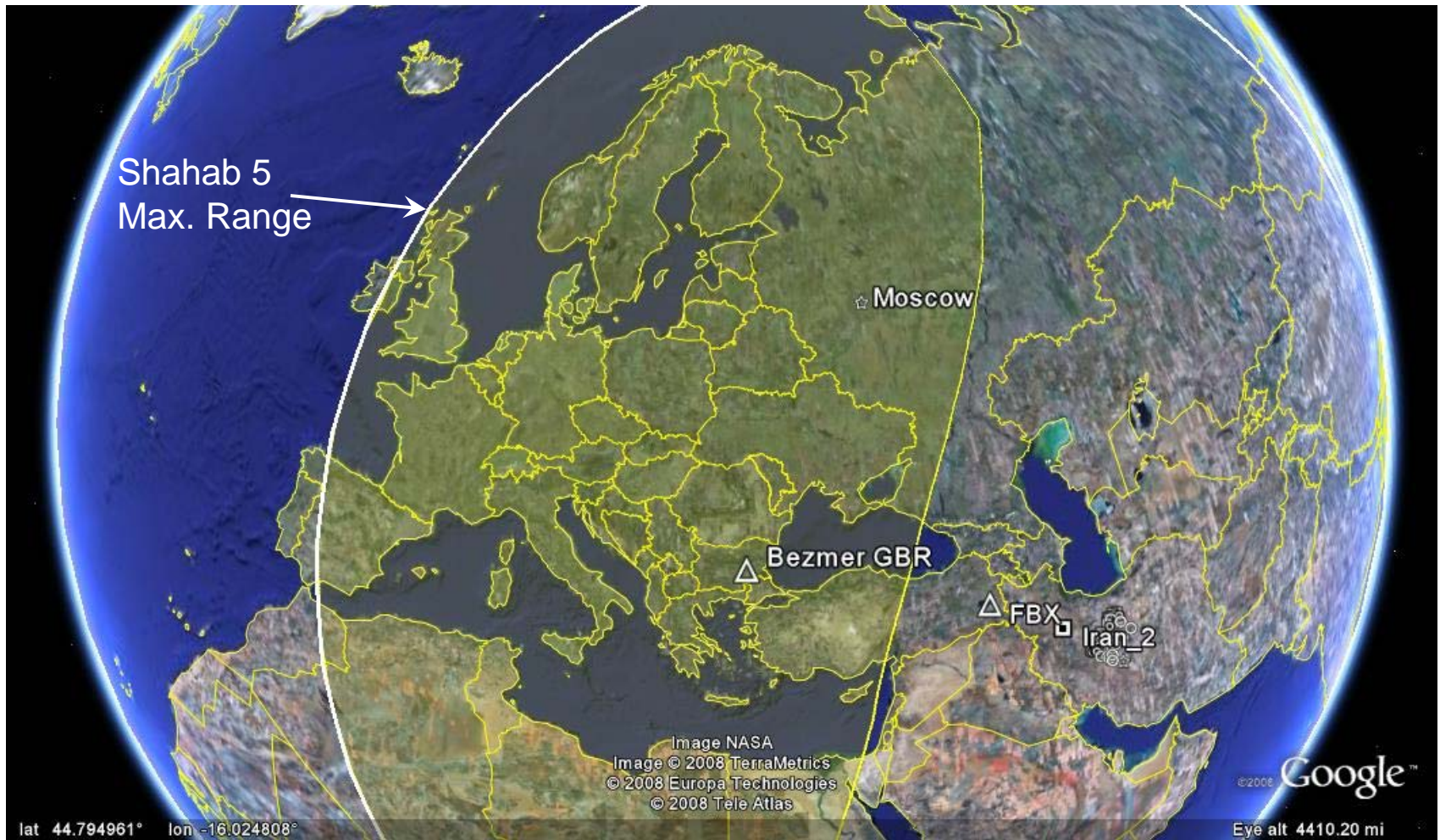
Czech-Polish BMD: Shahab 5

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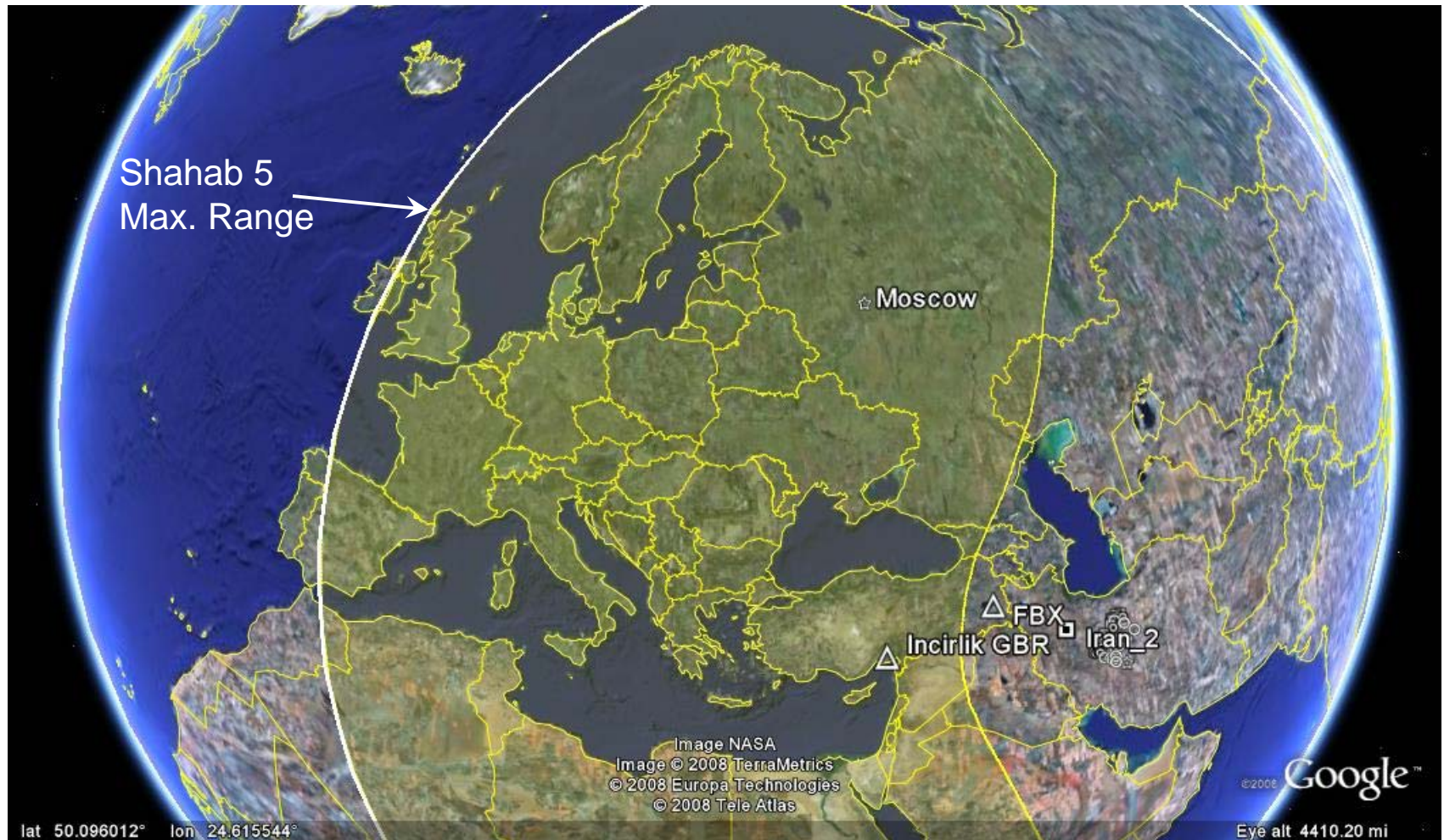
Bulgarian BMD: Shahab 5

(Bulgarian EMR + Fylingdale UEW, 2-stage Interceptor at Bezmer)



Turkish BMD: Shahab 5

(Incirlik EMR + Fylingdale UEW, 2-stage Interceptor at Incirlik)

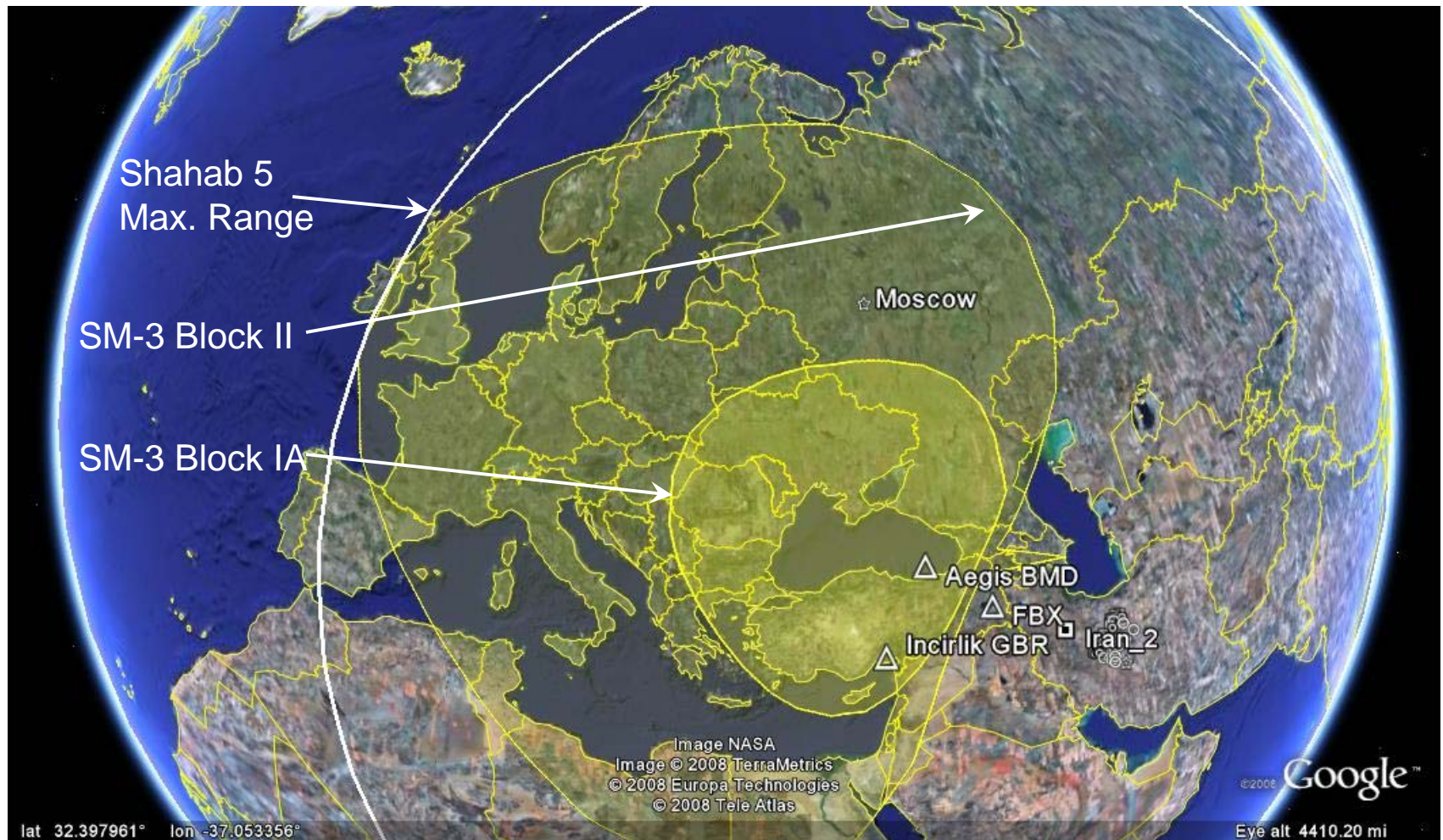


Aegis BMD: Shahab 5

(1 m² RCS, SM-3IA & SM-3II Interceptors)



Aegis BMD+Turkish EMR: Shahab 5 (Turkish EMR at Incirlik)

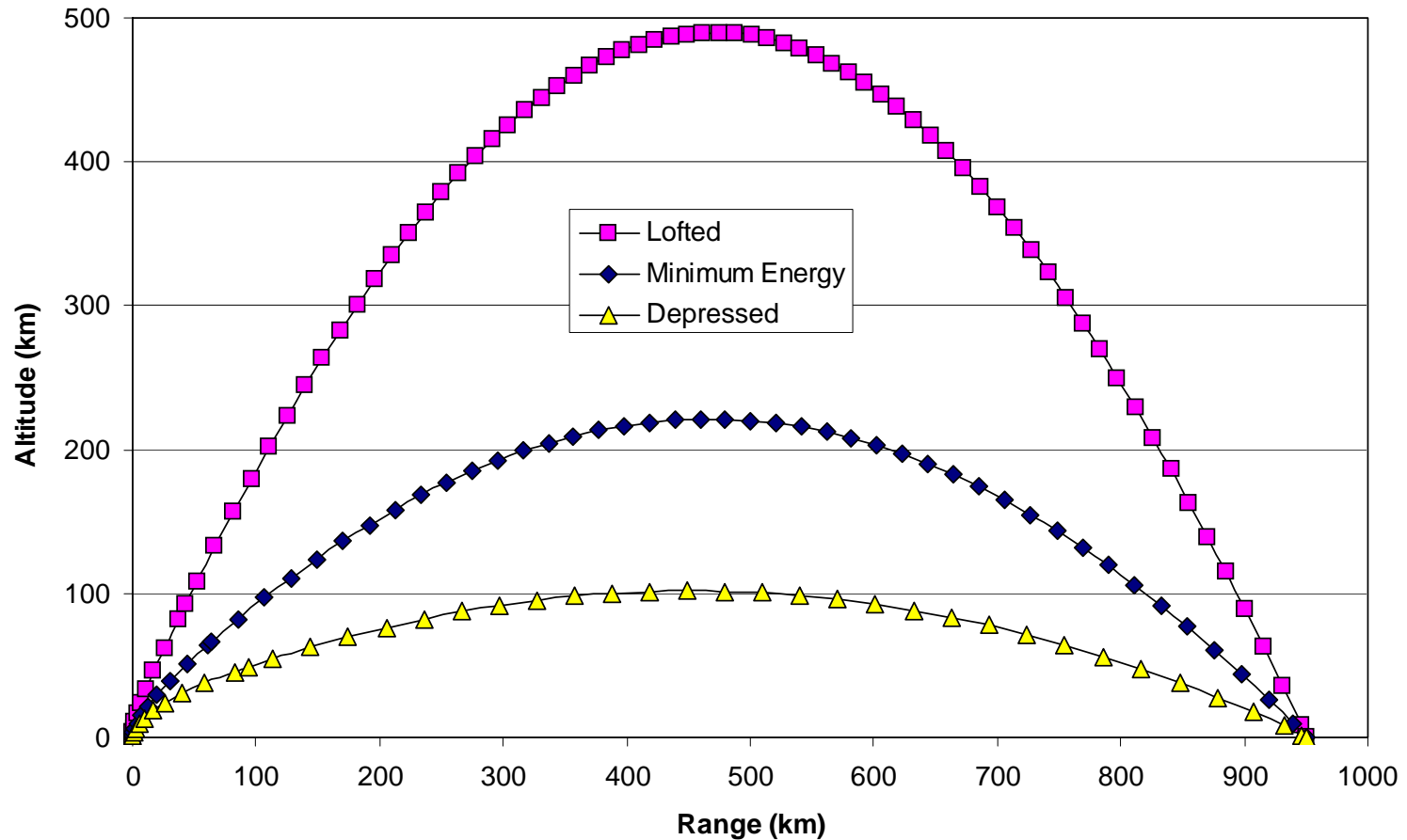


Summary for 1 m² RCS Targets

- **Polish-Czech system cannot cover southeastern Europe**
- **Notional Bulgarian and Turkish BMD systems cover all of Europe (including Moscow!)**
- **Aegis by itself provides little coverage**
- **Aegis netted with Turkish EMR can cover most of Europe**
 - Only with SM-3 Block II interceptor
- **NB: 1m² RCS implies EMR cannot discriminate the warhead from the upper stage; hence, the system is more vulnerable to countermeasures!**

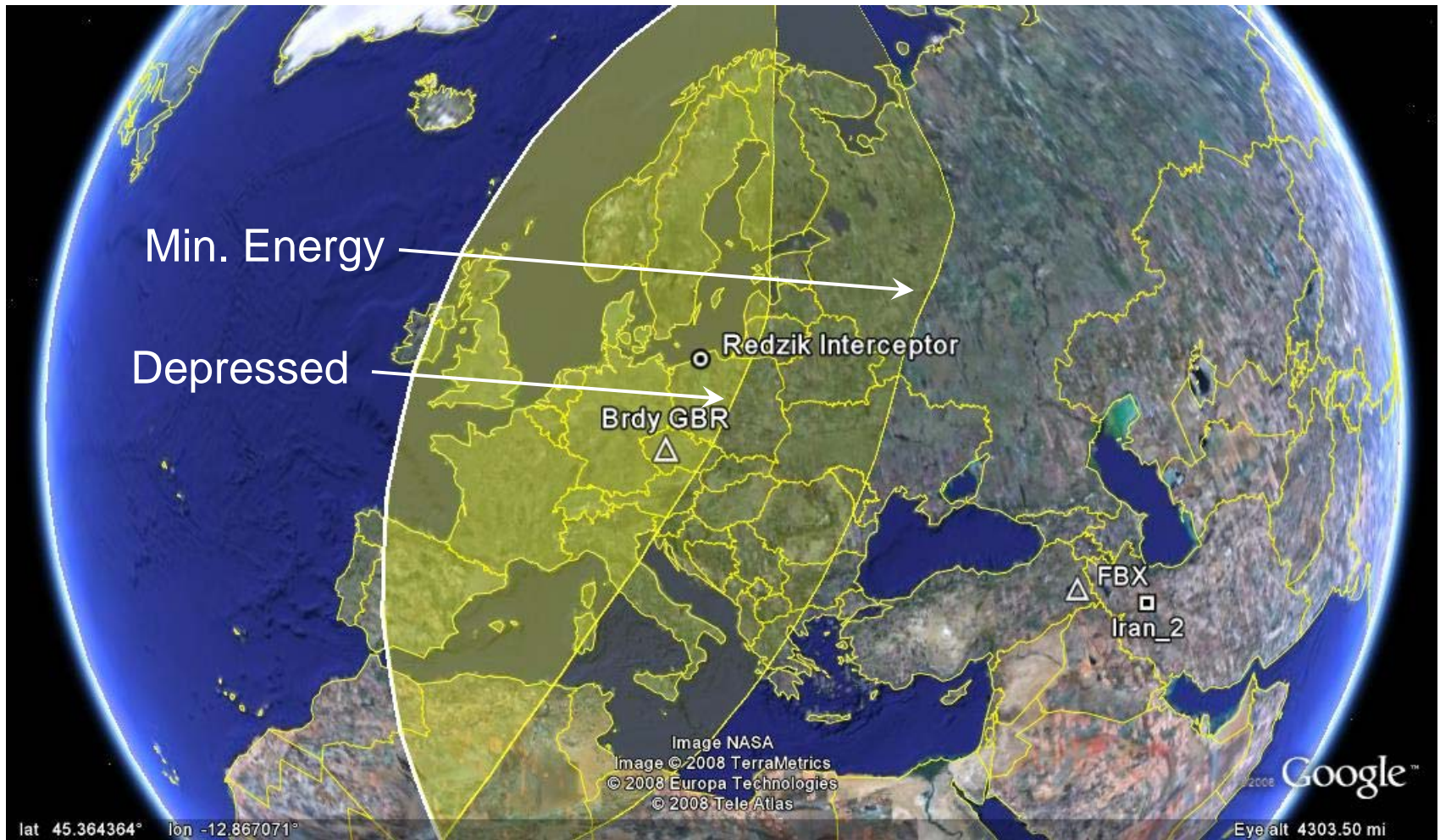
What is the impact of depressed trajectories?

Ballistic Missile Trajectories (Shahab 3)



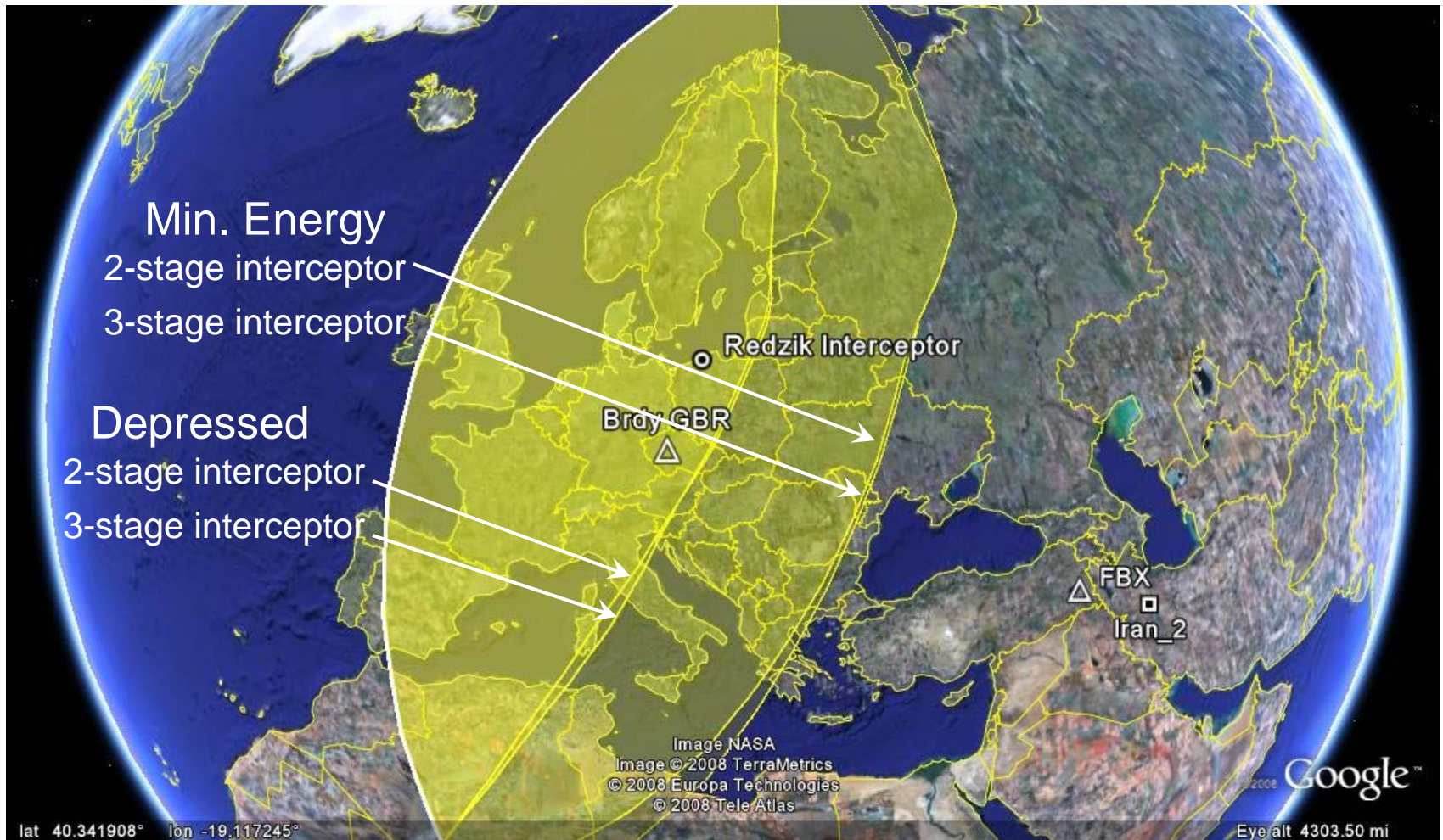
Czech-Polish BMD: Depressed Trajectory

(Czech EMR + Fylingdale UEW (1 m² RCS), 2-stage Interceptor in Poland)



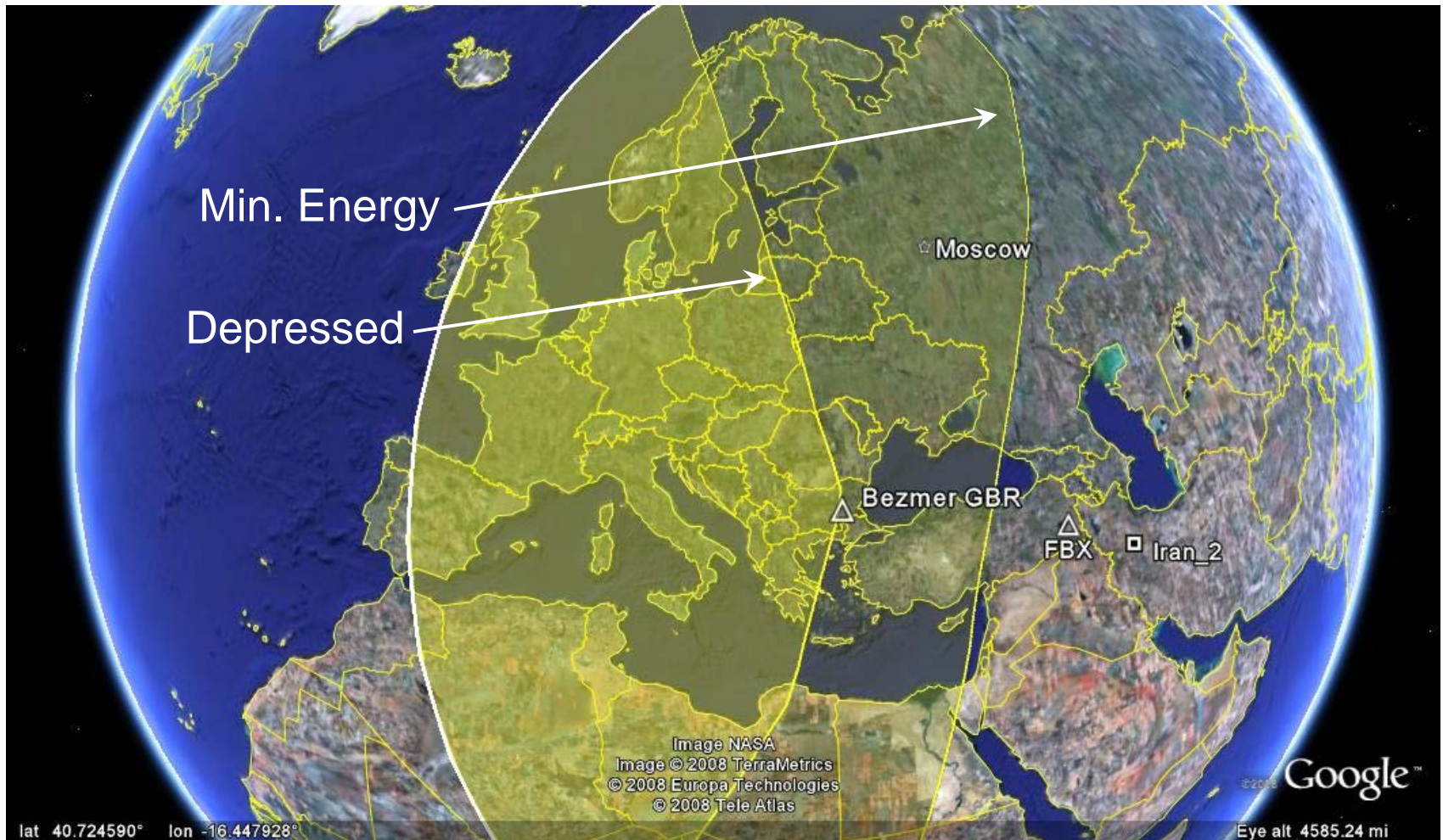
Czech-Polish BMD: 3-stage Interceptor

(Czech EMR + Fylingdale UEW (1 m² RCS))



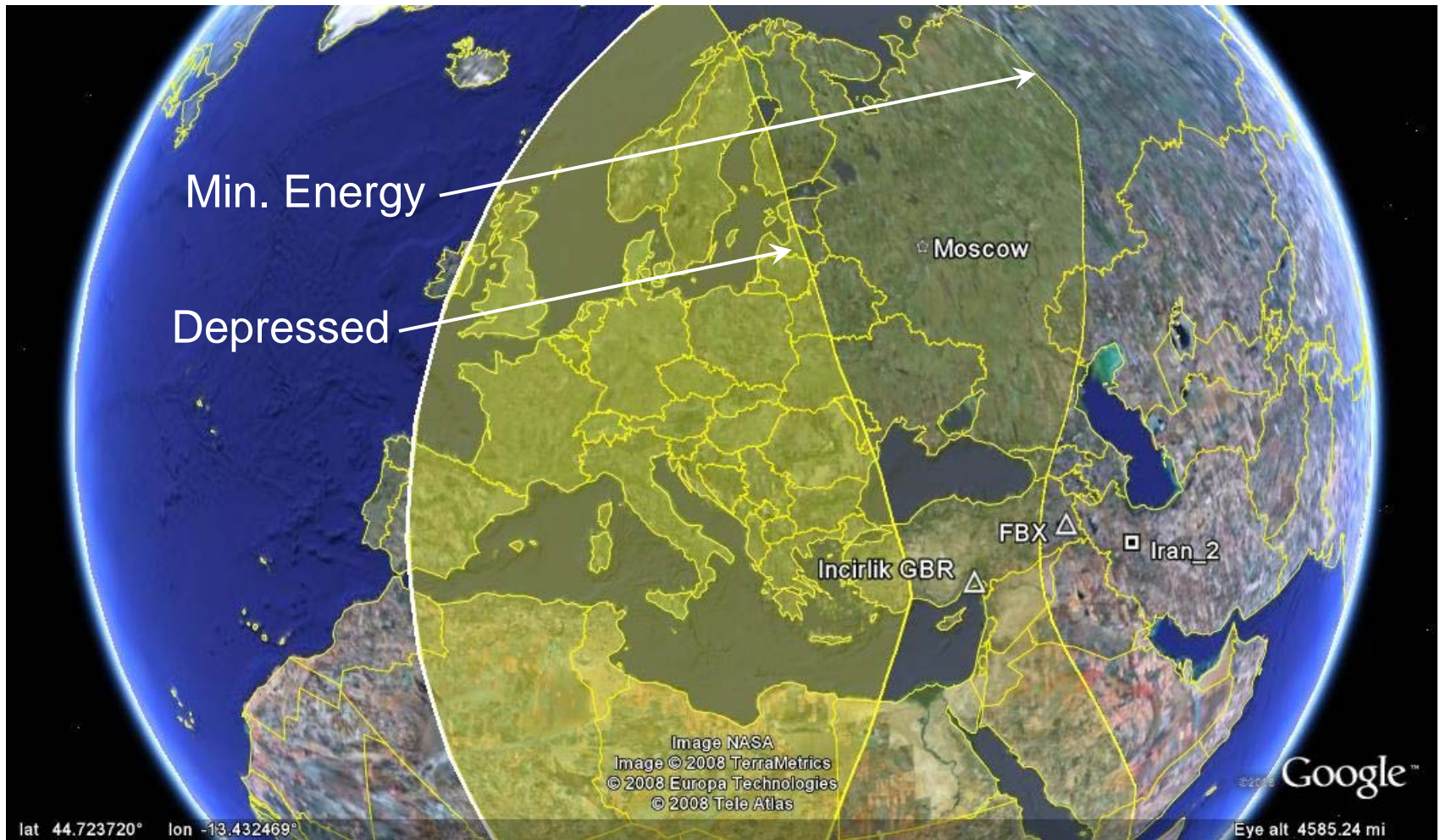
Bulgarian BMD: Shahab 5

(Bulgarian EMR + Fylingdale UEW (1 m² RCS), 2-stage Interceptor at Bezmer)



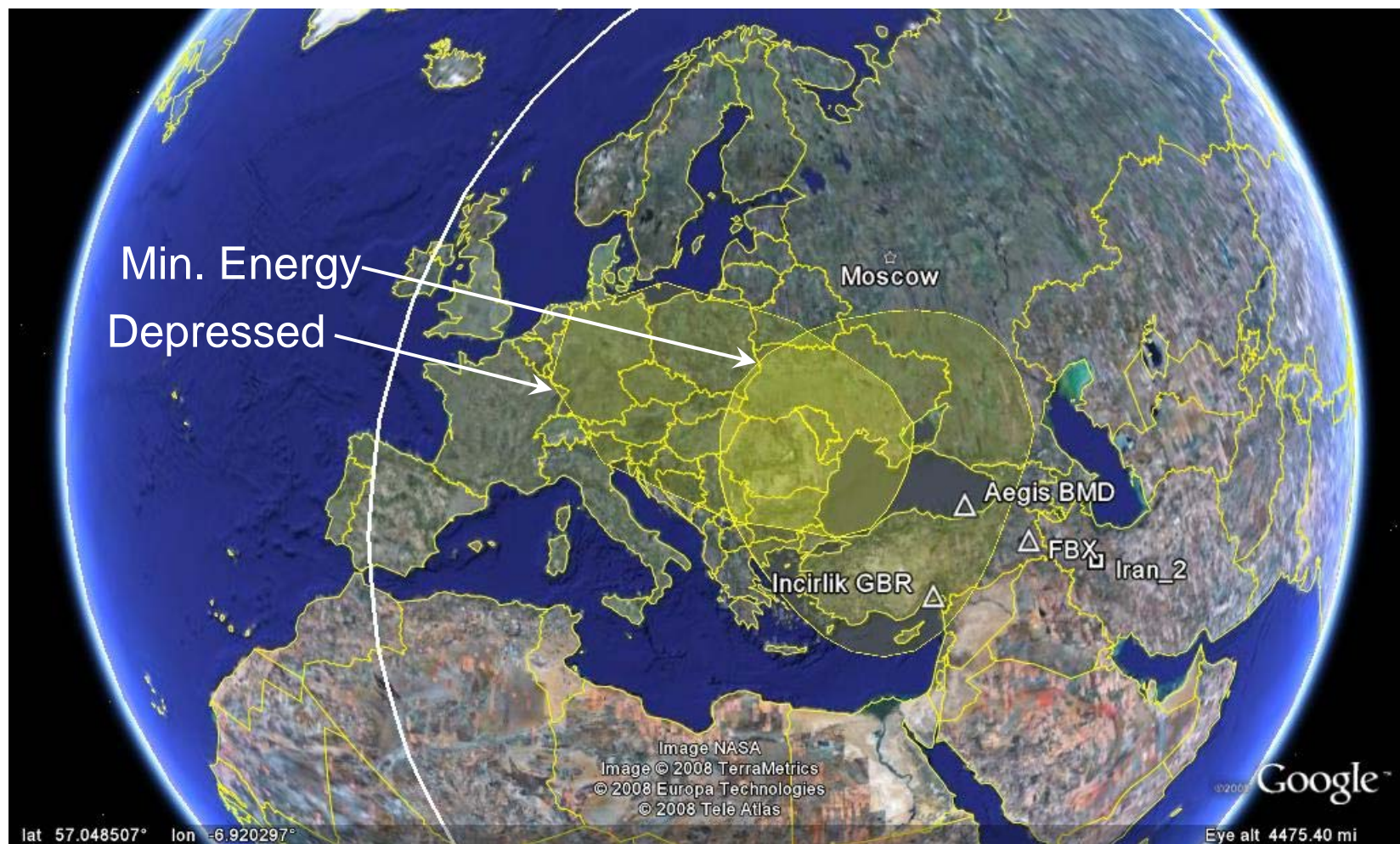
Turkish BMD: Shahab 5

(Turkish EMR + Fylingdale UEW (1 m² RCS), 2-stage Interceptor at Incirlik)



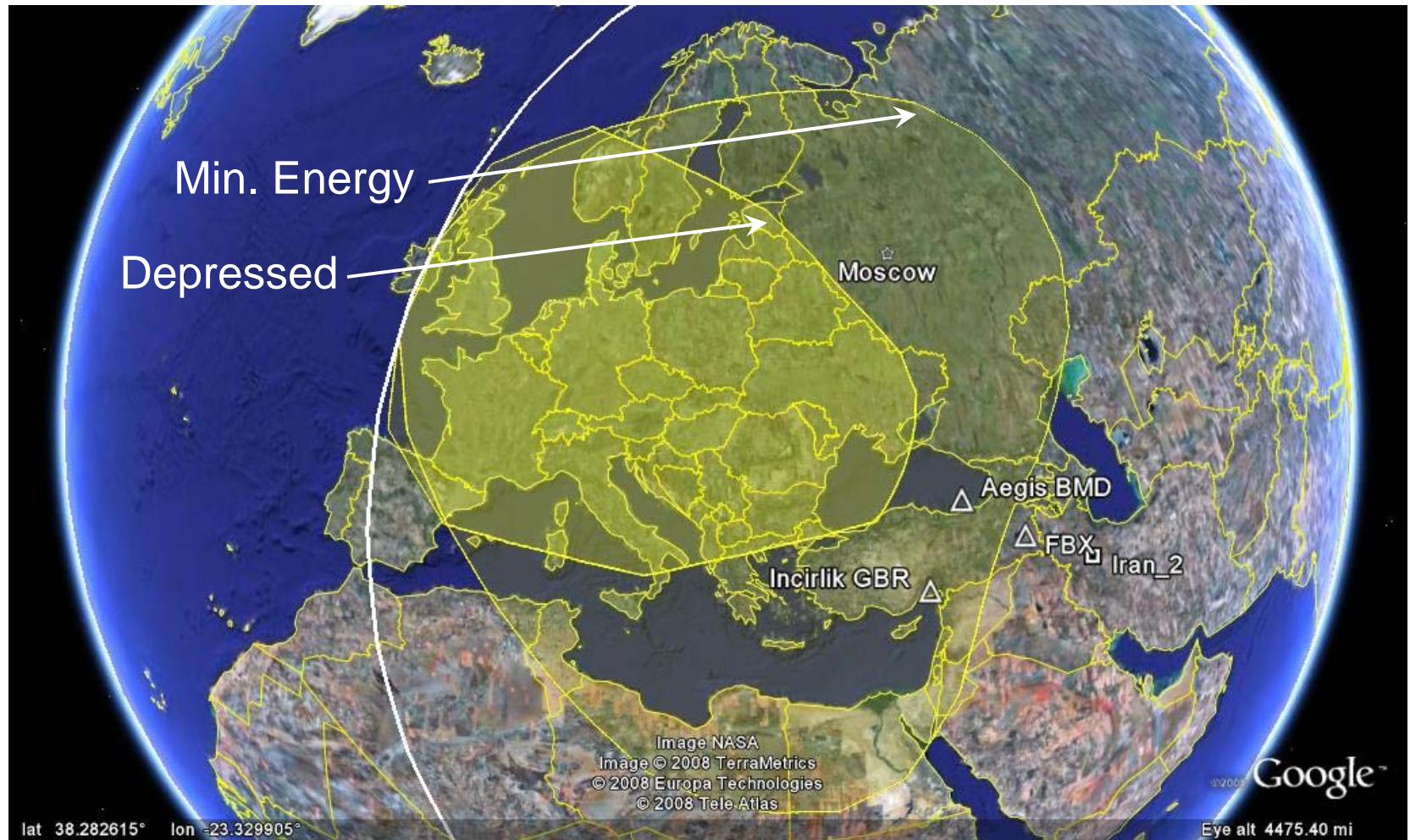
Aegis SM3-IA BMD+Turkish X-band EMR

(Turkish EMR at Incirlik)



Aegis SM3-II BMD+Turkish X-band EMR

(Turkish EMR at Incirlik)



Summary for Depressed Trajectories

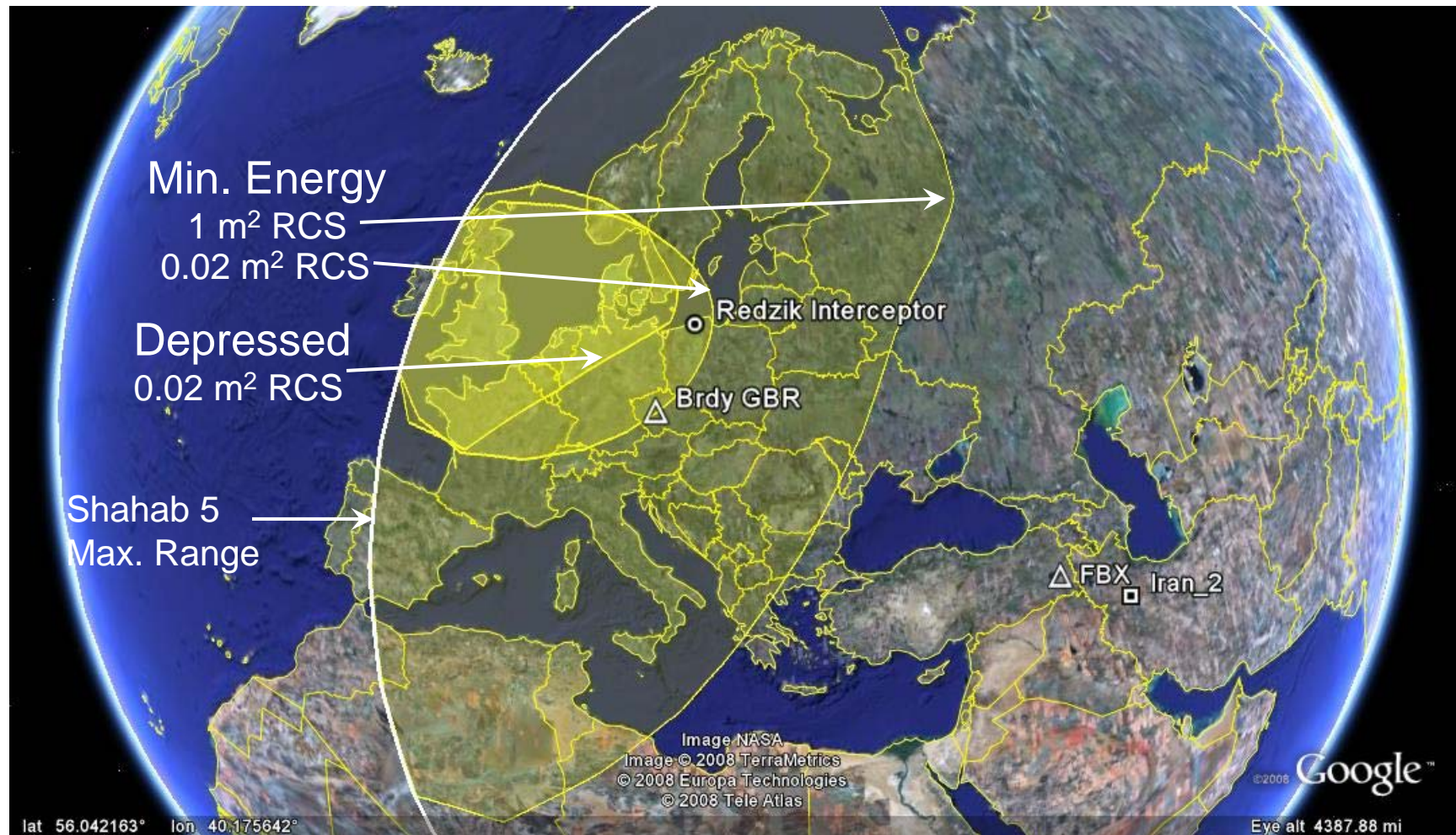
(1 m² RCS target)

- **Polish-Czech system covers only half of Europe**
 - 3-stage interceptor does not help
- **Notional Bulgarian and Turkish BMD systems cover most of Europe (except eastern Turkey)**
- **Aegis netted with Turkish EMR**
 - SM-3 Block IA interceptor can cover central Europe
 - SM-3 Block II interceptor covers most of Europe except for Turkey
- **NB: 1m² RCS implies EMR cannot discriminate the warhead from the upper stage; hence, the system is more vulnerable to countermeasures!**

What if intercept must occur while the EMR is able to track 0.02 m² warheads (to help discriminate decoys)?

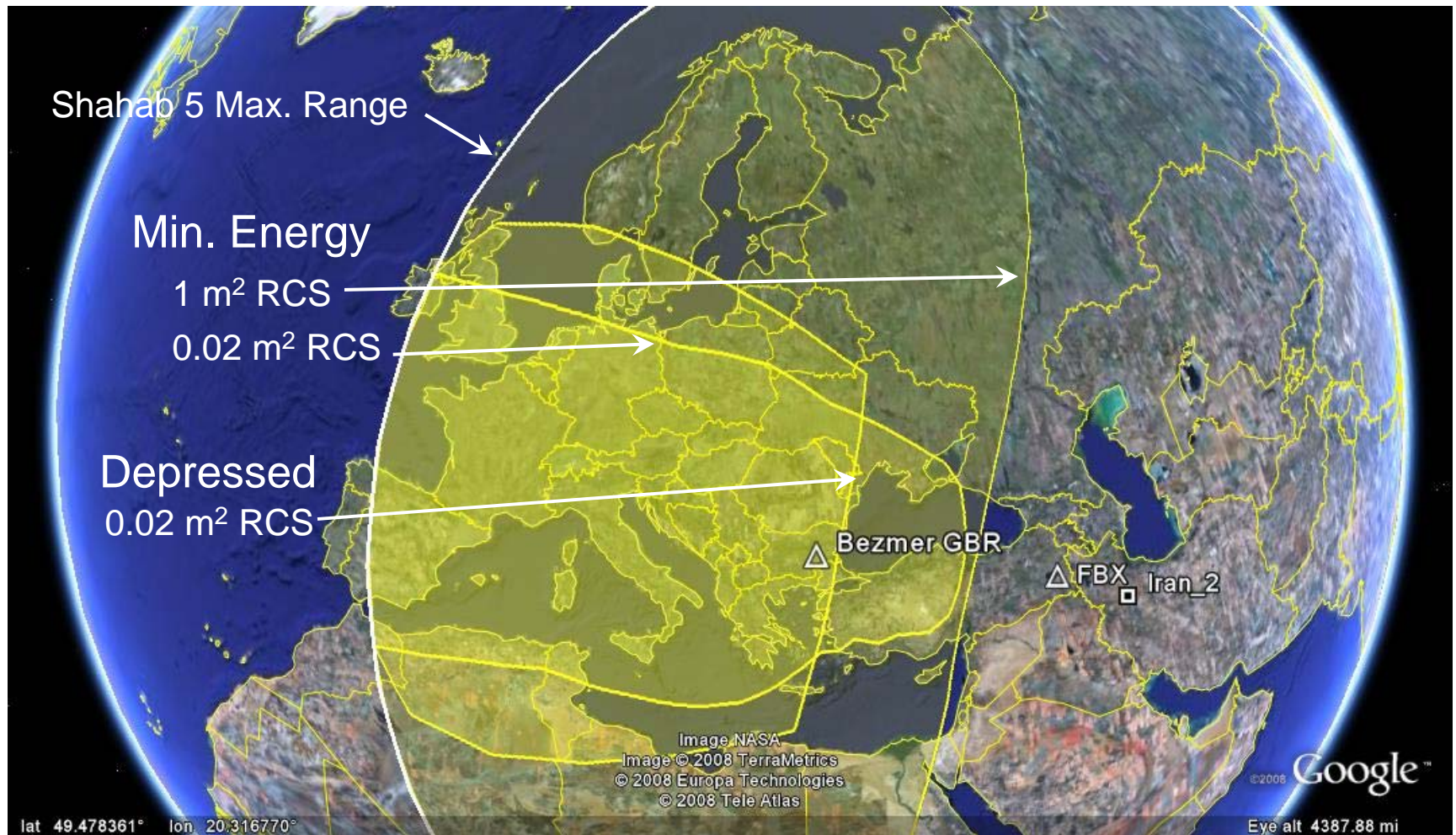
Czech-Polish BMD: 0.02 m² RCS

(Interceptor launched only after Czech EMR warhead acquisition)



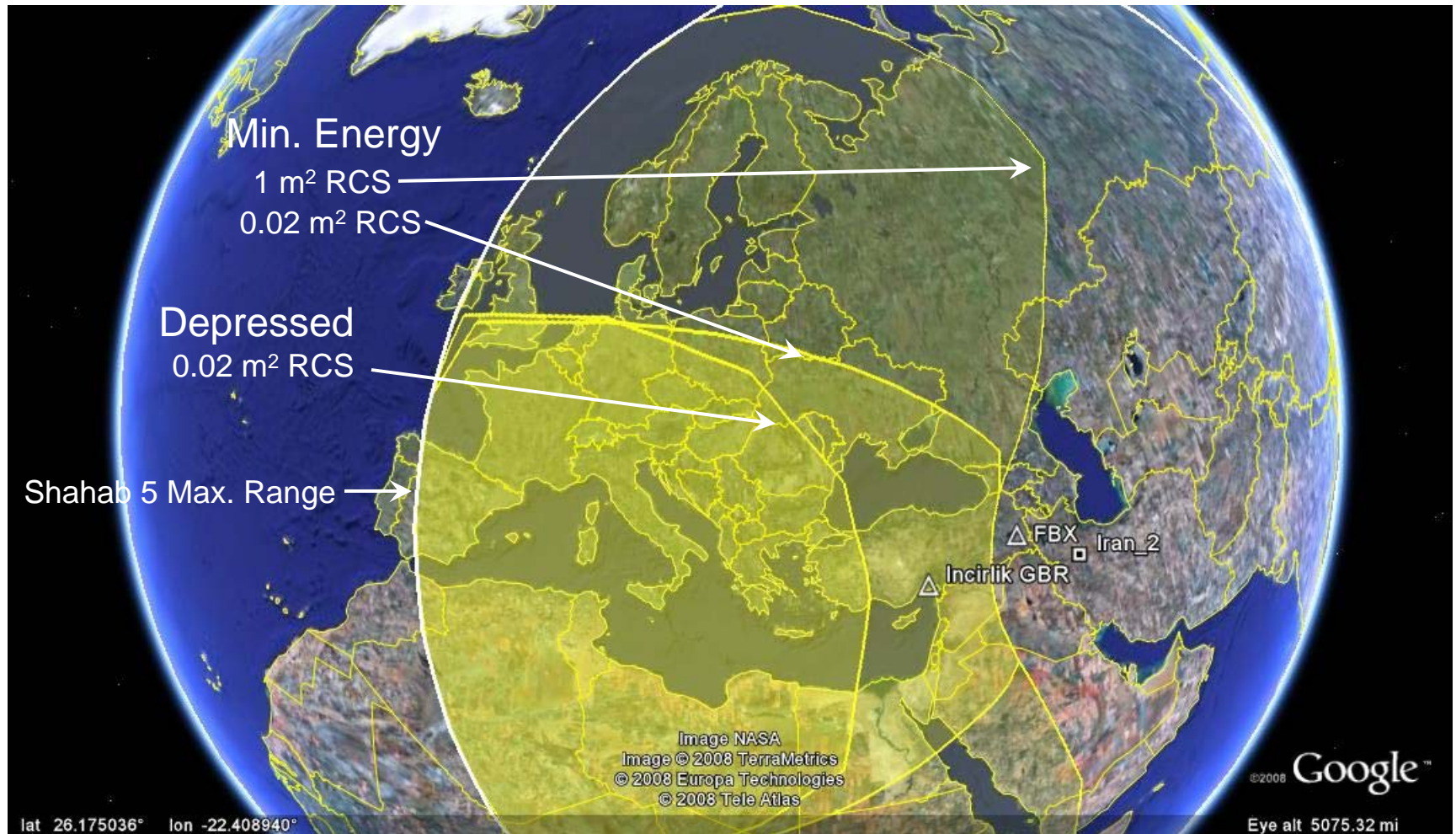
Bulgarian BMD: 0.02 m² RCS

(Bulgarian EMR; 2-stage Interceptor at Bezmer launched on FBX track, intercept occurs under EMR coverage)

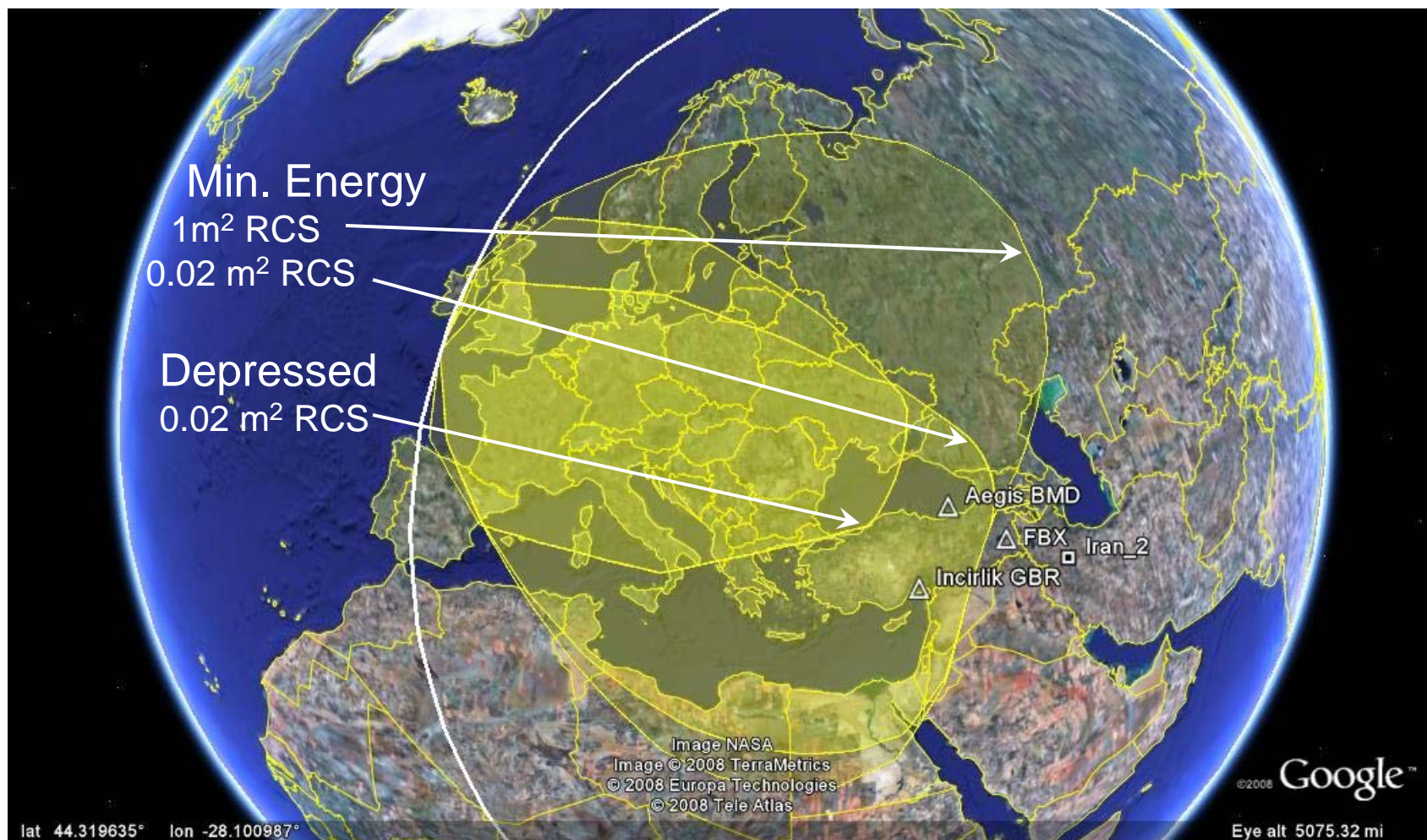


Turkish BMD: 0.02 m² RCS

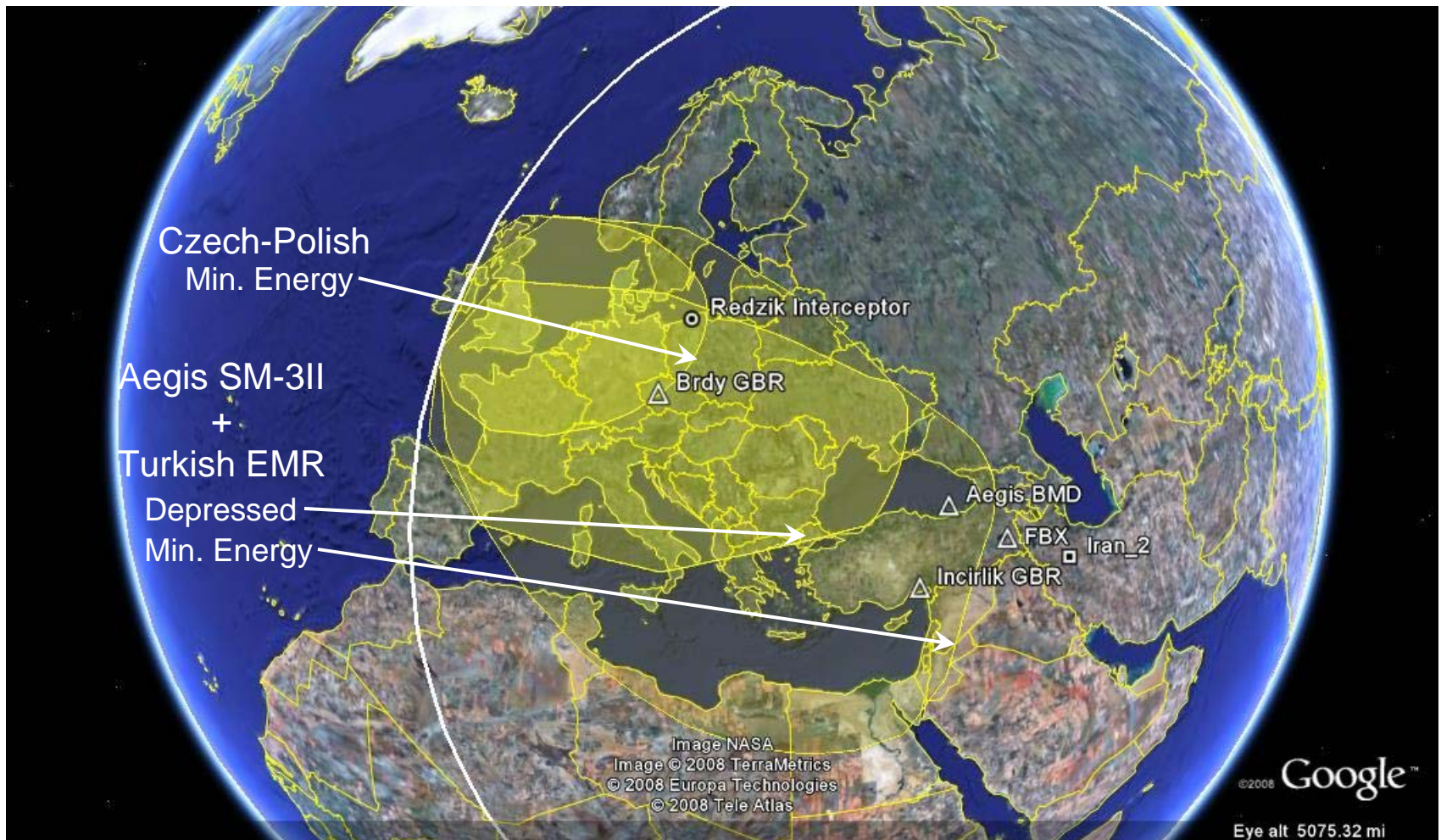
(Turkish EMR, 2-stage Interceptor at Incirlik launched based on FBX track, intercept occurs under EMR coverage)



Aegis SM3-II BMD+Turkish X-band EMR (0.02 m² RCS) (Turkish EMR at Incirlik)



Comparing European BMD Footprints for 0.02 m² RCS

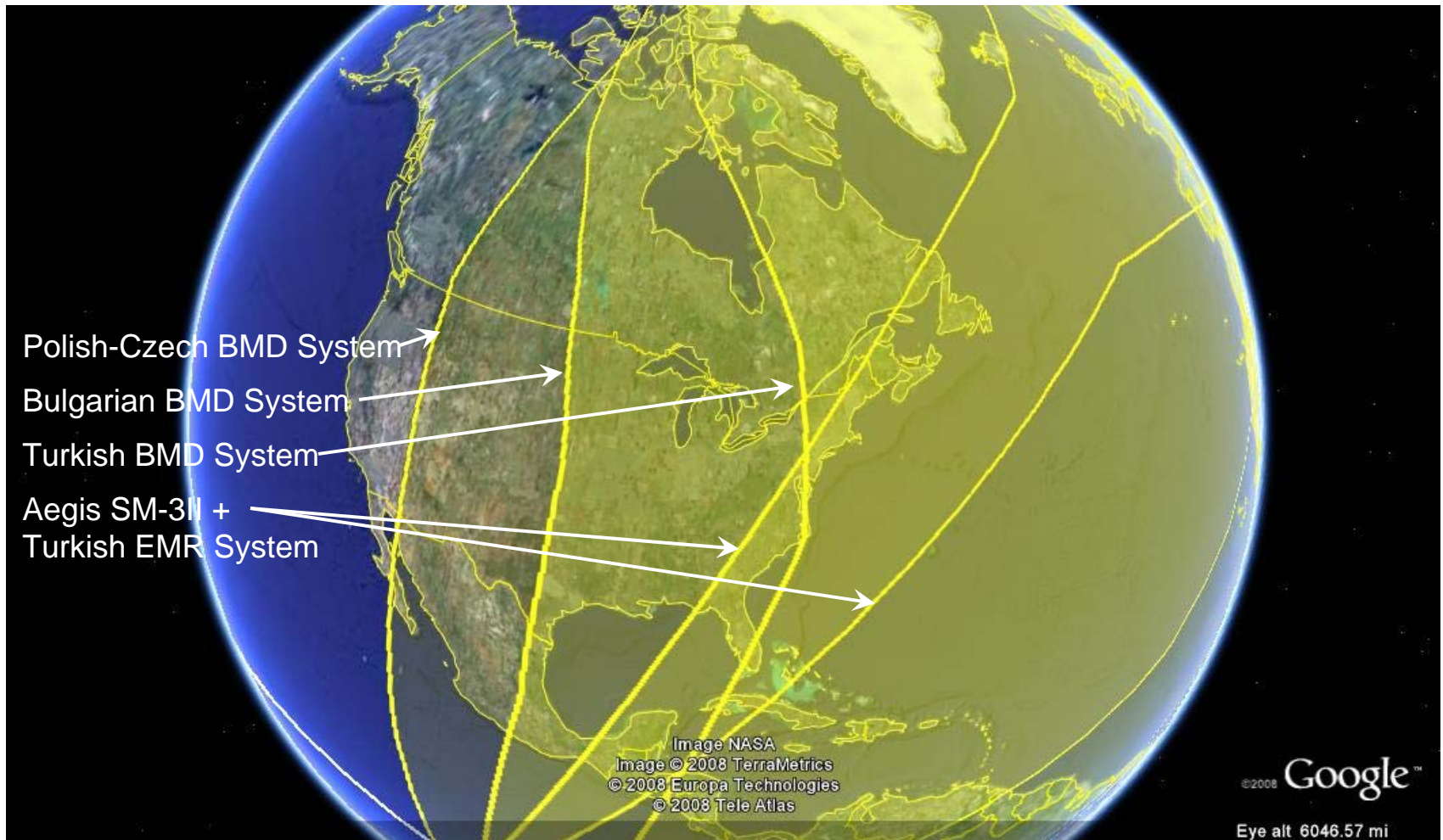


Summary for 0.02 m² Targets

- **Polish-Czech system is inadequate**
- **Bulgarian BMD system covers central and southern Europe**
 - Scandinavian countries remain vulnerable
 - Turkey is vulnerable to depressed 0.02 m² targets
- **Turkish BMD system covers central and southern Europe**
 - Scandinavian countries remain vulnerable
 - Eastern Turkey is vulnerable to depressed 0.02 m² targets
- **Aegis SM-3 Block II BMD system netted with Turkish EMR covers central and southern Europe**
 - Scandinavian countries remain vulnerable
 - Turkey is vulnerable to depressed 0.02 m² targets

Can European BMD Systems Intercept Iranian ICBMs Heading to the United States?

European BMD Coverage of the United State from Iranian ICBMs (1 m² RCS, 2-stage GBI)



US Ground-based Midcourse Defense (Ft. Greely, AK & Vandenberg, CA)



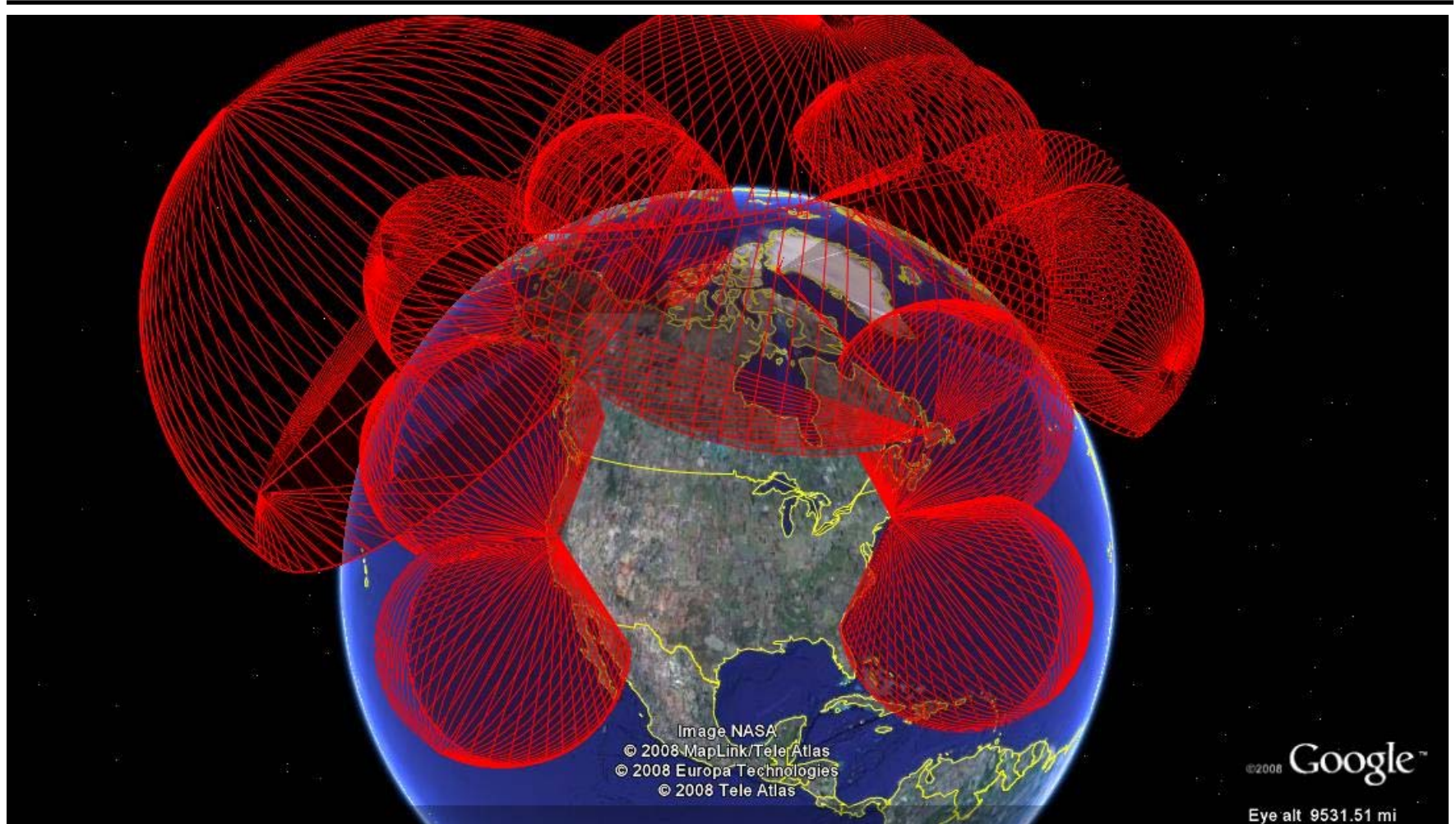
**PAVE PAWS/
BMEWS**



SBX



US UEW and SBX Radar Network



US BMD Coverage Against Iranian ICBMs (1)

(US EW Radar + SBX, Ft. Greely 3-stage GBI)



Can European BMD Systems Intercept Russian ICBMs Heading to the United States?

European BMD Coverage Against Russian ICBMs Heading to the US

(1 m² RCS; 2-stage 6.5 km/sec interceptor; Vypolzovo SS-25)



US BMD Coverage Against Russian SS-25 (US EW Radar + SBX, Ft. Greely 3-stage GBI)



Summary of European BMD Options

- **Polish-Czech System**
 - Reasonable coverage for non-stressing threats
 - Fails against depressed trajectory and low RCS targets
 - 2-stage GBI *can barely* intercept Russian ICBMs heading to northeastern United States
 - Sensitive to actual interceptor burn out speed
 - Provides best coverage against Iranian ICBMs heading to the United States
- **Alternate BMD architectures that move the EMR and interceptor closer to the Middle East *work better* for the defense of Europe**
 - Covers all of Europe for non-stressing threats
 - Aegis needs netted EMR to be effective
 - Can cover central and southern Europe against depressed and low RCS threats
 - Turkey remains vulnerable to depressed low RCS threats
 - Does not pose any threat to Russian ICBMs
 - Less useful for protecting the United States from Iranian ICBMs