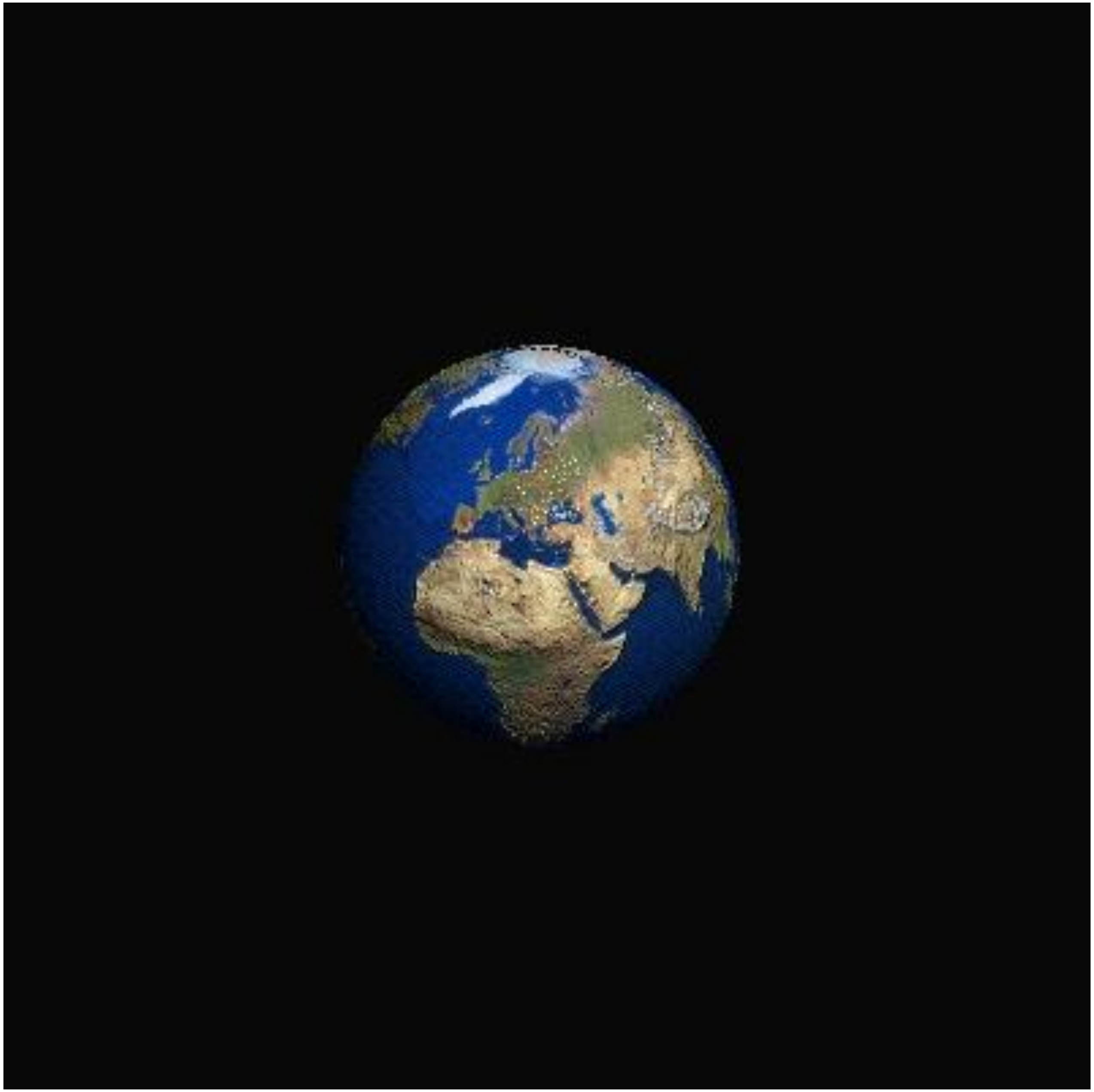
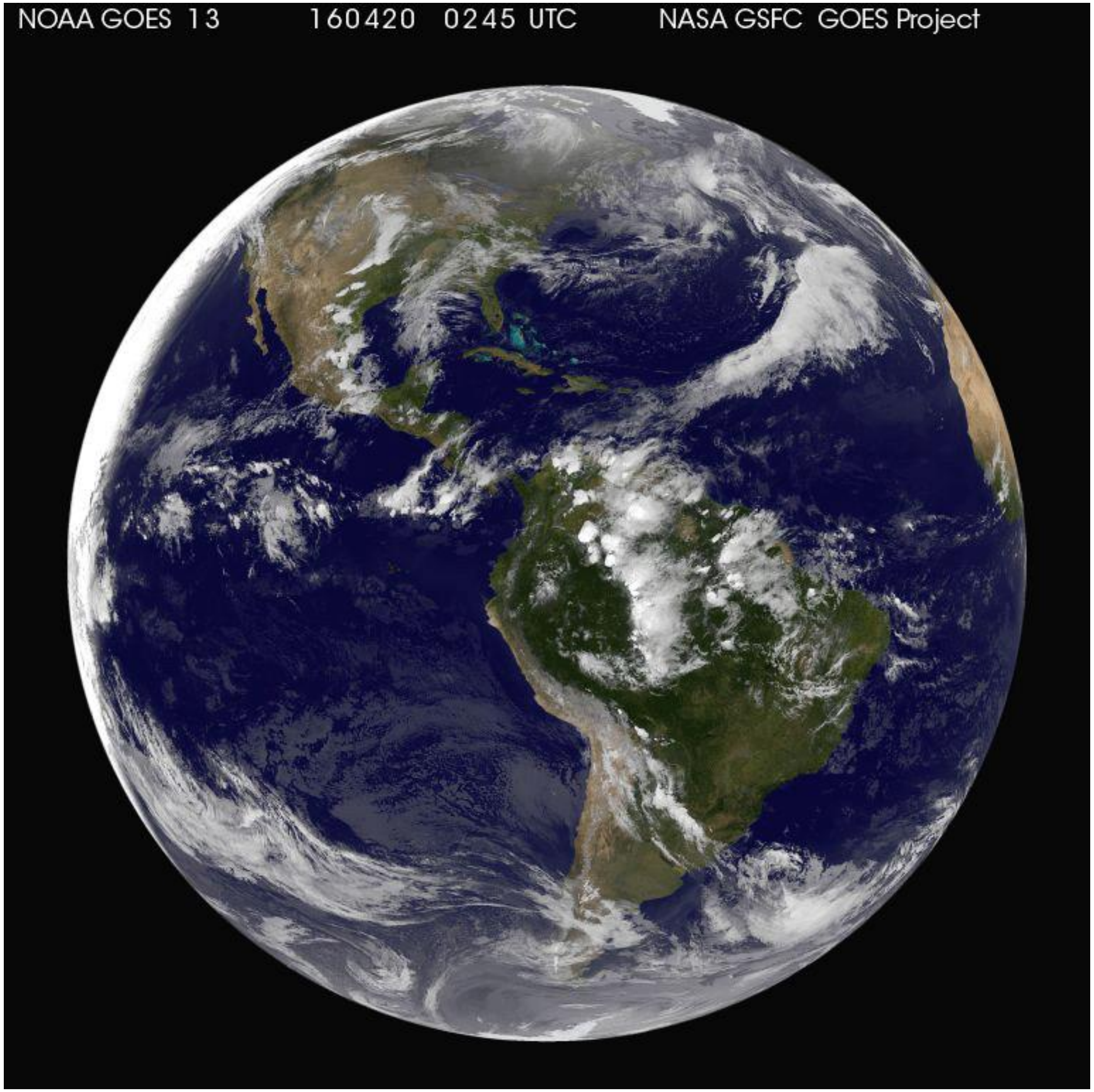
VTRC
Virginia Transportation Research Council

We bring innovation to transportation.

Application of Net Present Benefit to InSAR Monitoring

Audrey K. Moruza, Virginia Transportation Research Council (VDOT)

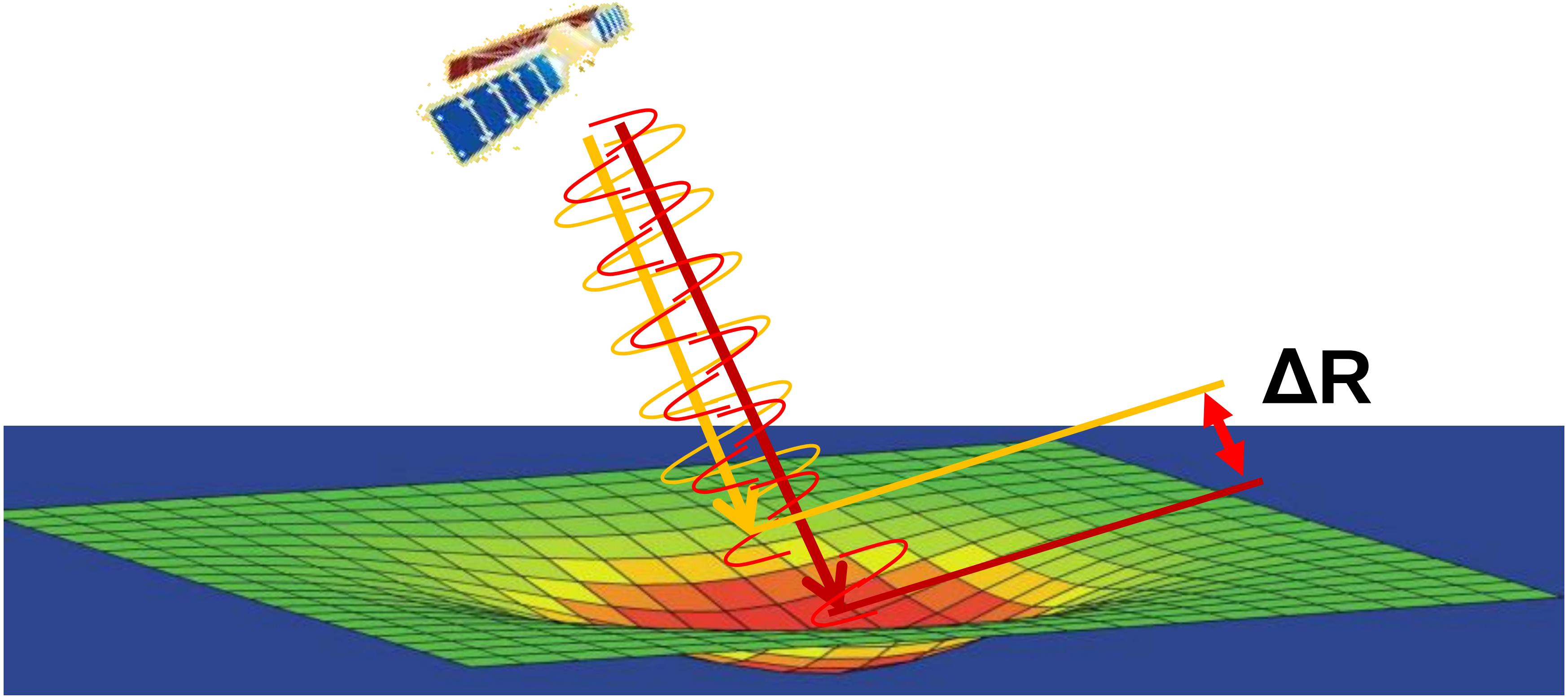



NOAA GOES 13
160420 0245 UTC
NASA GSFC GOES Project

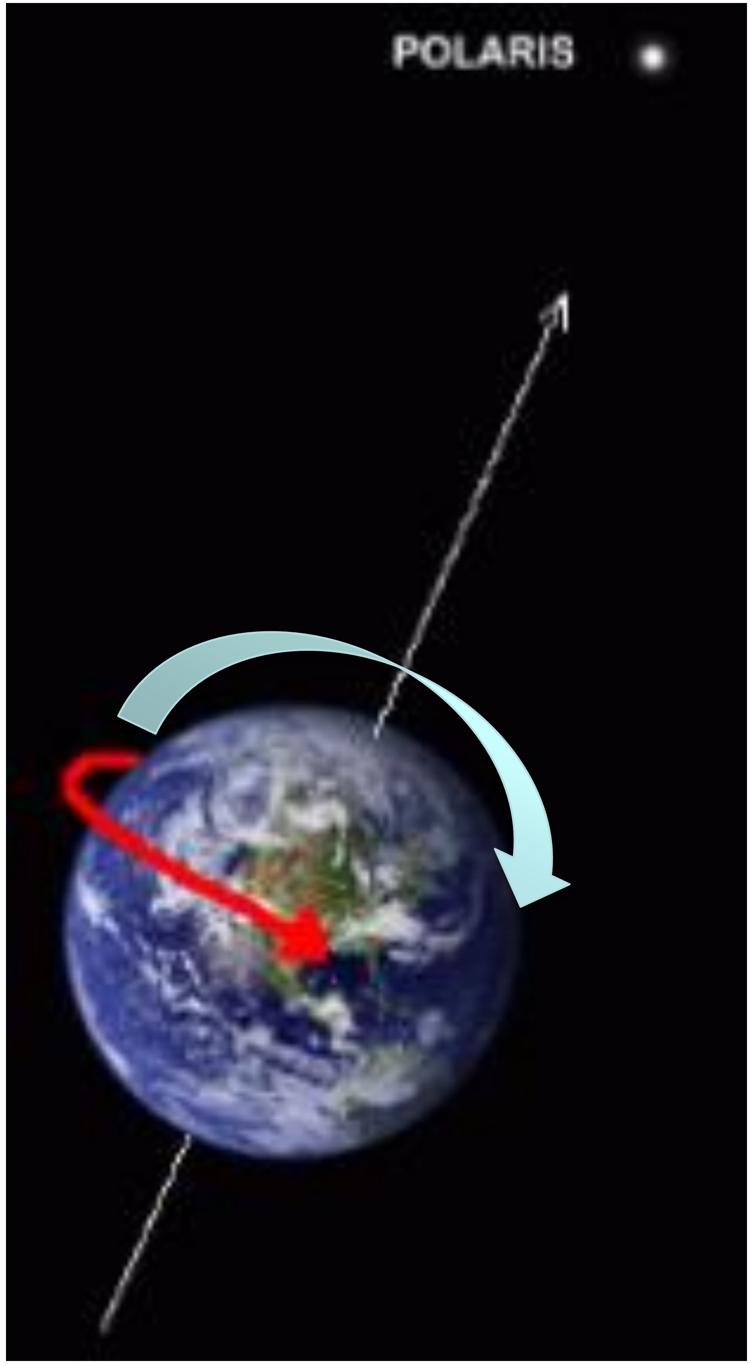
In	**Interferometric**
S	**Synthetic**
A	**Aperture**
R	**Radar**

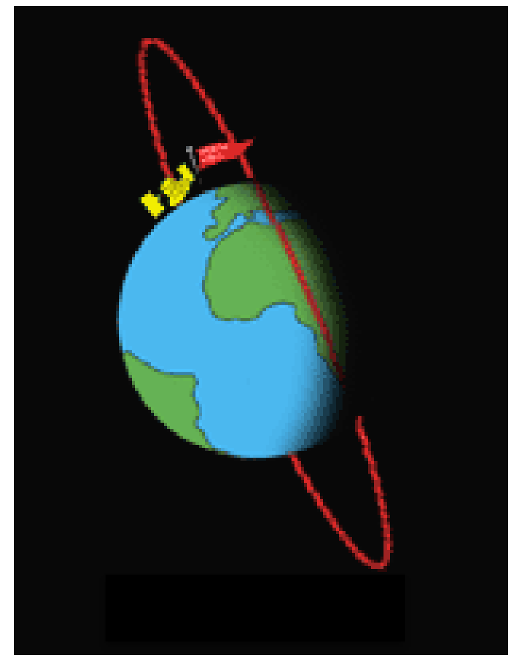
- Radar provides its own energy source to actively illuminate targets using microwave portion of EM spectrum, unlike passive optical systems;
- Sends microwave signal and receives a return signal as backscatter; notes strength and time delay of return signal;
- Synthetic aperture—created by forward motion of satellite platform and side-scanning operation of SAR device—is larger than physical antenna alone can give;
- Interferometry techniques use **phase change** of SAR signal over time (successive passes) to create 2-D images of remote surfaces;
- Measured differences in return signal **phase** are processed to produce images of surface elevation changes, precision on cm or even mm scale;
- Pixel resolution varies with signal bandwidth; horizontal resolution and area coverage are inversely proportional.

Radar measurement of deformation

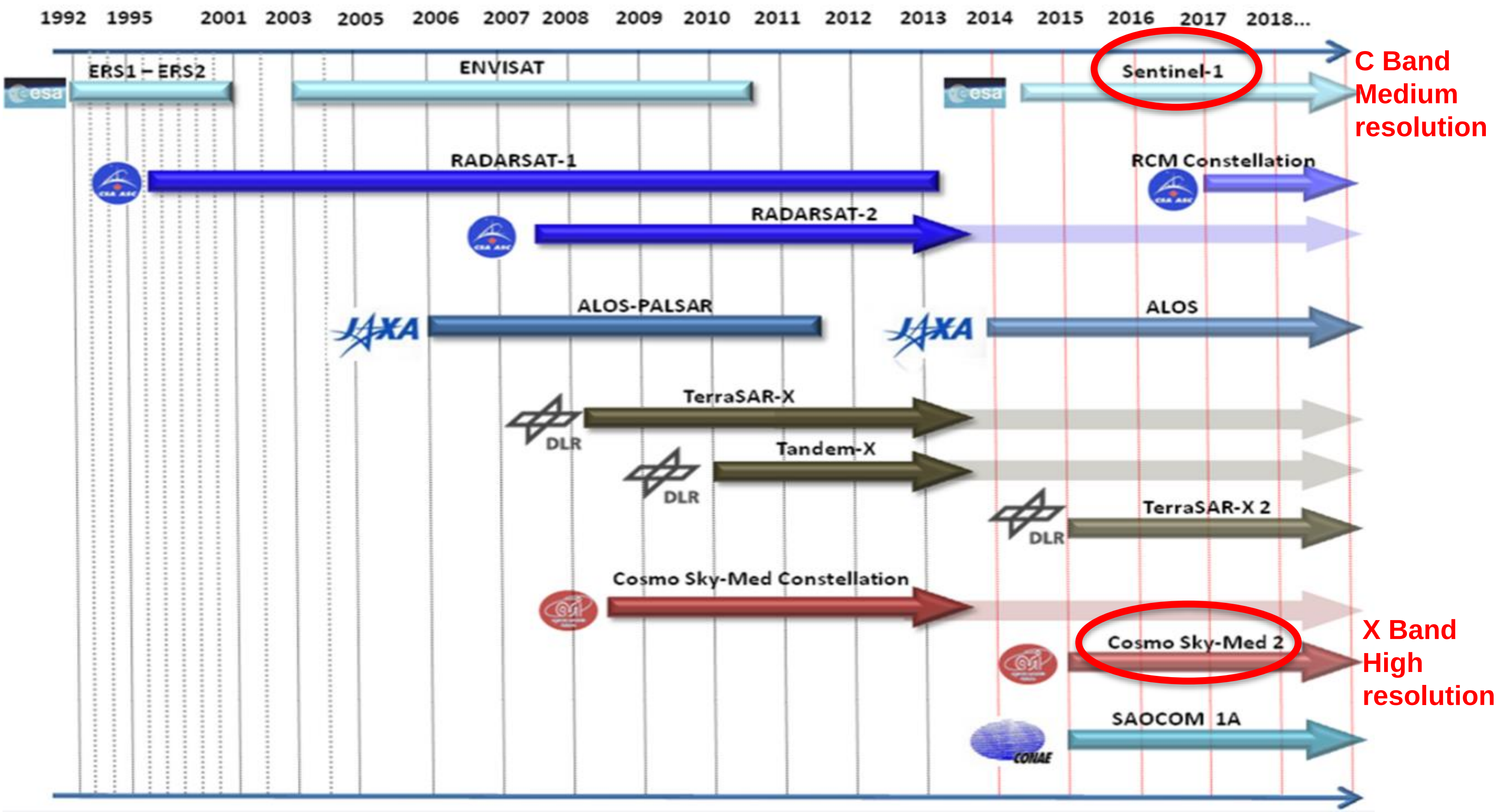


The rotation of the Earth on its axis under the path of the satellite allows two-directional imagery of the target area (descending and ascending)

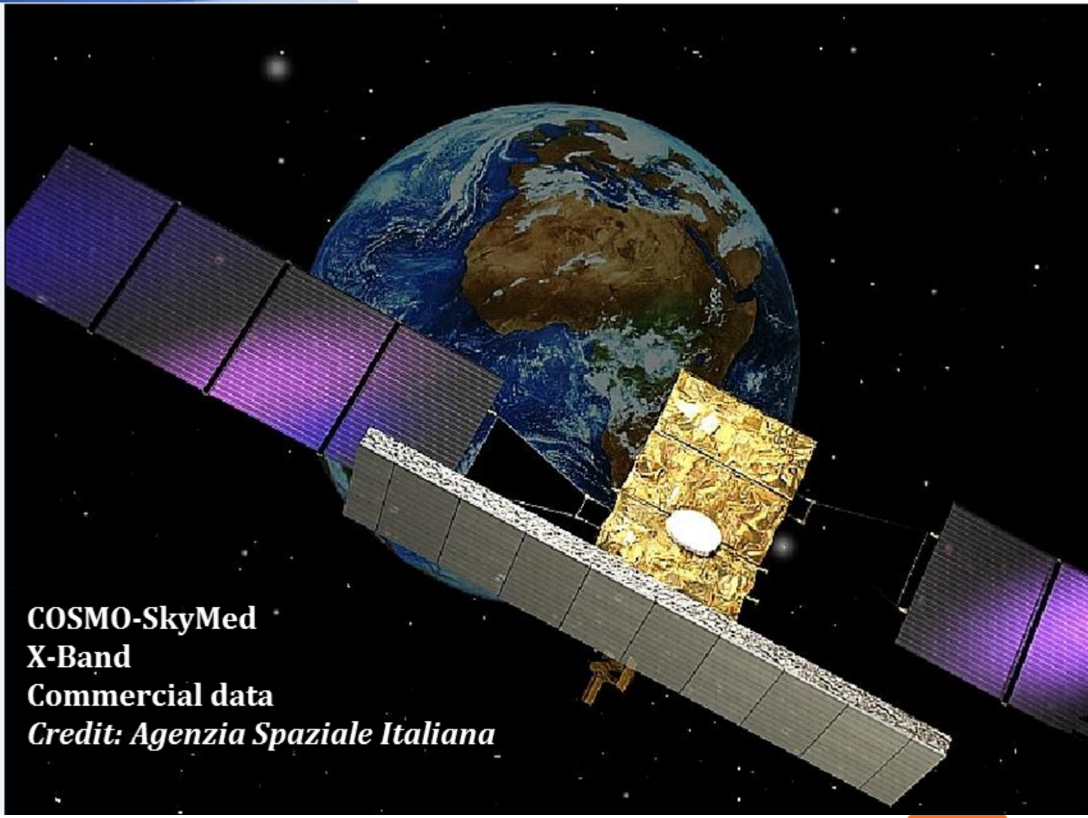




SAR Satellites, Past, Present and Future




Sentinel-1
C-Band
Free of charge data
Credit: European Space Agency


COSMO-SkyMed
X-Band
Commercial data
Credit: Agenzia Spaziale Italiana

Question

Can economic analysis inform a decision about trial of a technology when the benefits of the technology in specific applications are not **precisely** known?

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Answer

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How can error be minimized for a given analysis?

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Can economic analysis inform a decision about trial of a technology when the benefits of the technology in specific applications are not precisely known?

Answer

Yes, with accuracy in proportion to the order of the least accurate data or parameter value.

Question

How can error be minimized for a given analysis?

Answer

By gathering accurate data, using an appropriate performance measure, and identifying variable parameters.

Question

What features should be present in an economic analysis of a technology trial?

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Answer

- Accurate and current costs of activities potentially relieved by the technology
- Accurate and current cost(s) of the technology over the analysis period
- A relevant analysis period
- An explicit performance measure
- Variable parameters (quantities whose values are selected for the particular circumstances)

Case Study: InSAR Monitoring of VDOT Network

What inputs form the core of the economic analysis?

- Impacted VDOT activities and their current costs
- Costs of the technology
- Choice of relevant analysis period
- Choice of an explicit and appropriate performance measure
- Identified and variable parameters

Case Study: Core **Inputs**

- Impacted VDOT activities and their current costs
  - **Geohazards – slopes (slides), sinkholes**
    $9,151,823 average annual cost, FY 2013-2015
  - **Culvert replacements**
    $12,289,187 average annual cost, FY 2013-2015
- Analysis period
  - **5-year lease** of InSAR package (no storage costs)
- Performance measure
  - $\boldsymbol{Net\ Present\ Benefit} = \sum_i (B_i - C_i)\,/(1+\rho)^i$

Case Study: Core Inputs

- **Technology costs**
  - **Scenario 1**

    COSMO-SkyMed (CSK)

    X band: 3x3 meter pixel size (high resolution)

    16-day repeat → 22 frames per annual stack

    80 frames for network coverage

    Estimated annual cost = $9.52 million (data + processing)
  - **Scenario 2**

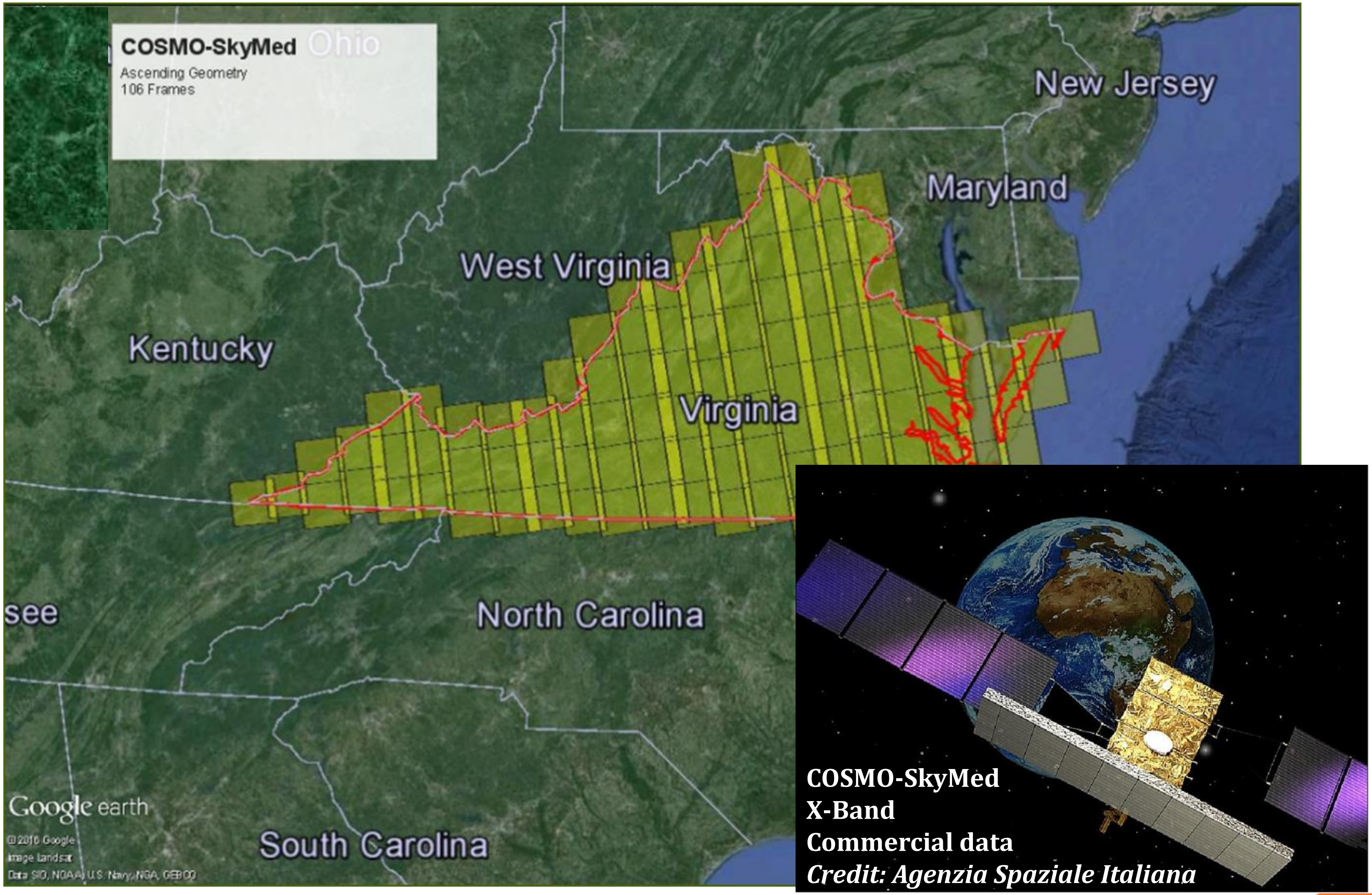
    Sentinel-1

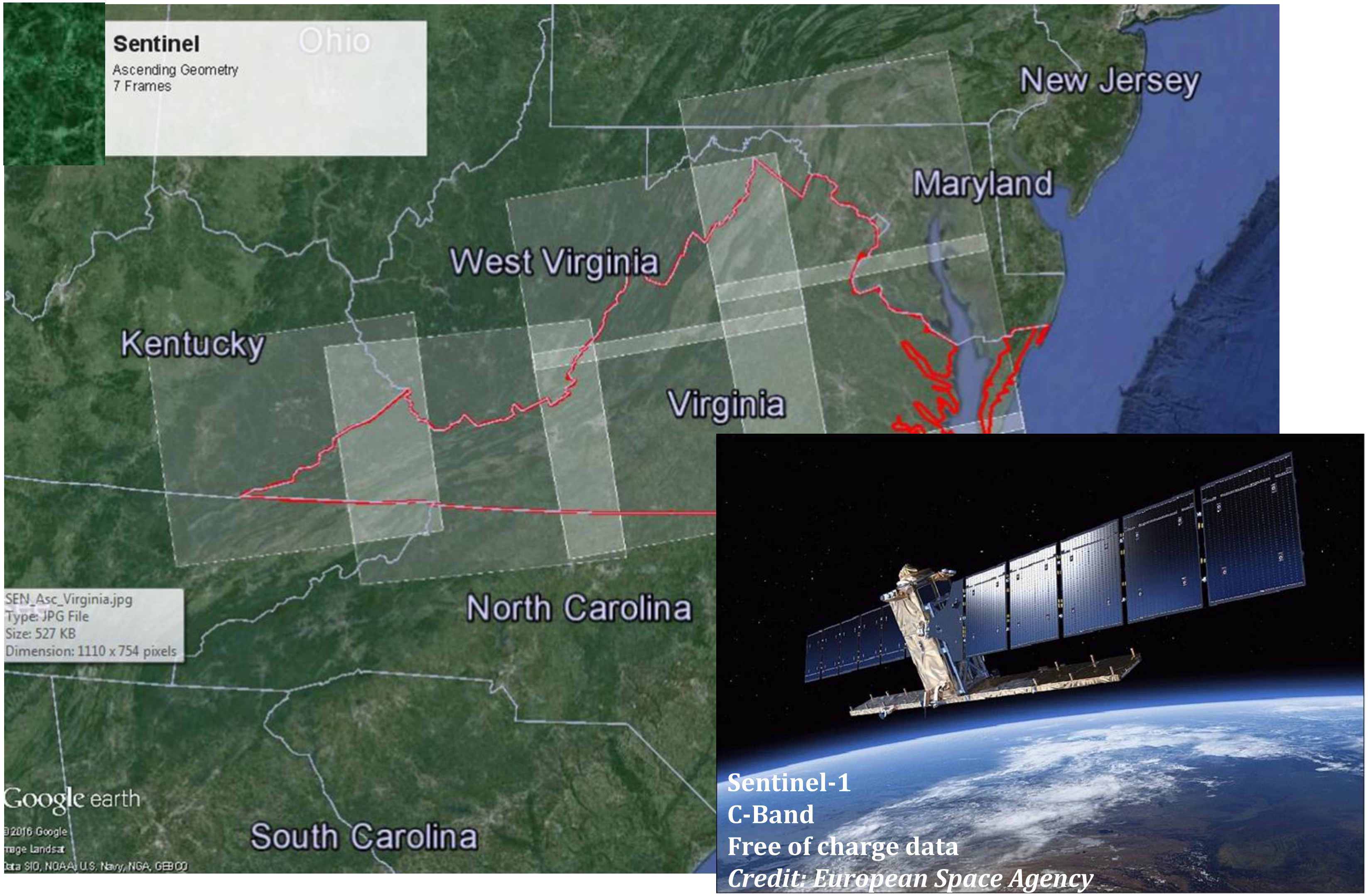
    C band: 5x20 meter pixel size (medium resolution)

    12-day repeat → 30 frames per annual stack

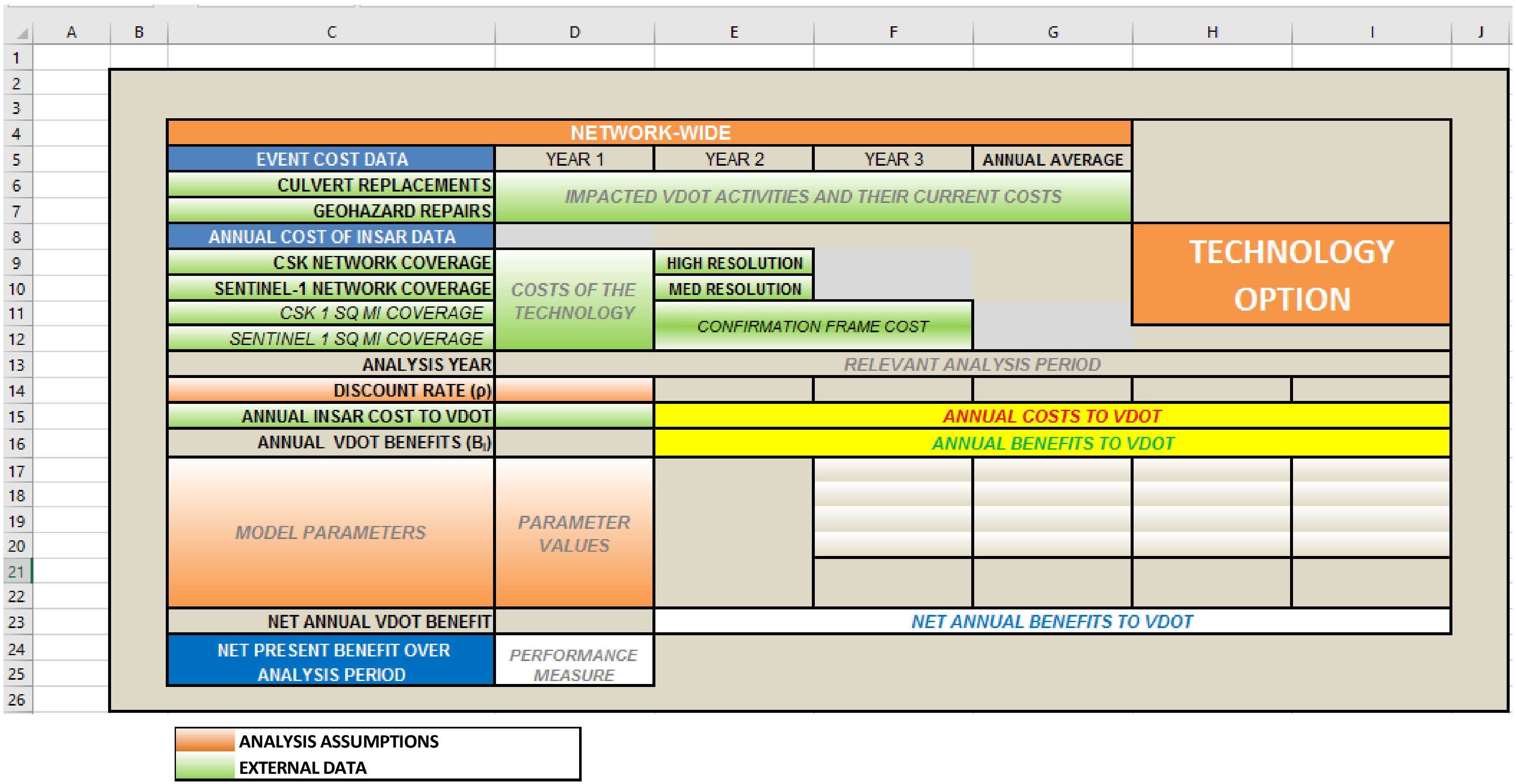
    Approximately 12 frames for network coverage

    Estimated annual cost = $648,000 (processing only)


COSMO-SkyMed
Ascending Geometry
106 Frames
Ohio
New Jersey
Maryland
West Virginia
Kentucky
Virginia
see
North Carolina
South Carolina
Google earth
COSMO-SkyMed
X-Band
Commercial data
Credit: Agenzia Spaziale Italiana


Sentinel
Ascending Geometry
7 Frames
Ohio
New Jersey
Maryland
West Virginia
Kentucky
Virginia
North Carolina
South Carolina
SEN_Asc_Virginia.jpg
Type: JPG File
Size: 527 KB
Dimension: 1110 x 754 pixels
Google earth
Sentinel-1
C-Band
Free of charge data
Credit: European Space Agency

Excel Model – Step 1 (Framework)



How Are Annual VDOT Benefits Defined?

"Benefits" in year *i* are defined as **reductions in VDOT expenditures** on culverts and geohazards due to (unspecified) interventions facilitated by InSAR techniques in year *i:*

$$B_i = \sum_{\substack{Culverts,\\ geohazards}} DR_{event,i} \cdot SR_{event,i} \cdot Average\ annual\ cost\ of\ event_i$$

where

i = 1,...5 (years)

Parameter DR = detection rate resulting from InSAR techniques (function of InSAR effectiveness);

Parameter SR = savings rate from interventions resulting from detection by InSAR techniques (function of agency effectiveness);

DR and *SR* measured as proportions of annual expenditures on events.

NOTE: See compendium paper 17-02179 for discussion of parameter values in VDOT model.

Excel Model – Step 2 (Input values and formulas)

	A	B	C	D	E	F	G	H	I	J
1										
2										
3										
4			NETWORK-WIDE							
5			EVENT COST DATA	2013	2014	2015	ANNUAL AVERAGE			
6			CULVERT REPLACEMENTS	$ 10,976,877	$ 13,457,522	$ 12,433,162	**$ 12,289,187**			
7			GEOHAZARD REPAIRS	$ 9,002,823	$ 8,114,545	$ 10,338,102	**$ 9,151,823**			
8			ANNUAL COST OF INSAR DATA					TECHNOLOGY OPTION		
9			CSK NETWORK COVERAGE	$ 9,520,000	HIGH RESOLUTION					
10			SENTINEL-1 NETWORK COVERAGE	$ 648,000	MED RESOLUTION					
11			*CSK (1 SQ MI COVERAGE)*	*$ 62,000*	*CONFIRMATION FRAME COST*					
12			*SENTINEL (1 SQ MI COVERAGE)*	*$ 26,000*						
13			ANALYSIS YEAR	0	1	2	3	4	5	
14			DISCOUNT RATE (ρ)	ρ						
15			ANNUAL INSAR COST TO VDOT							
16			ANNUAL VDOT BENEFITS (B_i)		NO BENEFITS IN FIRST YEAR	F17*F18*G6+ F19*F20*G7	G17*G18*G6+ G19*G20*G7	H17*H18*G6+ H19*H20*G7	I17*I18*G6+ I19*I20*G7	
17			INITIAL DETECTION RATE: CULV	20%		20%	20%	20%	20%	
18			INITIAL SAVINGS RATE: CULV	40%		40%	40%	40%	40%	
19			INITIAL DETECTION RATE: GEOHZ	10%		10%	10%	10%	10%	
20			INITIAL SAVINGS RATE: GEOHZ	50%		50%	50%	50%	50%	
21										
22										
23			NET ANNUAL VDOT BENEFIT		=E16-E15	=F16-F15	=G16-G15	=H16-H15	=I16-I15	
24			NET PRESENT BENEFIT OVER ANALYSIS PERIOD	=NPV(D14,E23,F23,G23,H23,I23)						
25										
26										

(orange)	ANALYSIS ASSUMPTIONS
(green)	EXTERNAL DATA

Excel Model – Step 3 (Optional: Efficiency gains over analysis period: increasing DR and SR)

NETWORK-WIDE						
EVENT COST DATA	2013	2014	2015	ANNUAL AVERAGE		
CULVERT REPLACEMENTS	$ 10,976,877	$ 13,457,522	$ 12,433,162	$ 12,289,187		
GEOHAZARD REPAIRS	$ 9,002,823	$ 8,114,545	$ 10,338,102	$ 9,151,823		
ANNUAL COST OF INSAR DATA					TECHNOLOGY OPTION	
CSK NETWORK COVERAGE	$ 9,520,000	HIGH RESOLUTION				
SENTINEL-1 NETWORK COVERAGE	$ 648,000	MED RESOLUTION				
CSK (1 SQ MI COVERAGE)	*$ 62,000*	*CONFIRMATION FRAME COST*				
SENTINEL (1 SQ MI COVERAGE)	*$ 26,000*					
ANALYSIS YEAR	0	1	2	3	4	5
DISCOUNT RATE (ρ)	3.0%					
ANNUAL INSAR COST TO VDOT						
ANNUAL VDOT BENEFITS (B_i)		*$ -*	*$ 1,440,726*	*$ 1,588,401*	*$ 1,751,212*	*$ 1,930,711*
INITIAL DETECTION RATE: CULV	20%	$ 2,457,837	20%	21%	22%	23%
INITIAL SAVINGS RATE: CULV	40%	$ 983,135	40%	42%	44%	46%
INITIAL DETECTION RATE: GEOHZ	10%	$ 915,182	10%	11%	11%	12%
INITIAL SAVINGS RATE: GEOHZ	50%	$ 457,591	50%	53%	55%	58%
ANNUAL GROWTH IN DETECTION RATE	*5%*					
ANNUAL GROWTH IN SAVINGS RATE	*5%*					
NET ANNUAL VDOT BENEFIT		*GROSS AND NET BENEFITS INCREASING OVER ANALYSIS PERIOD--->*				
NET PRESENT BENEFIT OVER ANALYSIS PERIOD	?					

(orange)	ANALYSIS ASSUMPTIONS
(green)	EXTERNAL DATA

Results for COSMO-SkyMed data (with more favorable assumptions)

NETWORK-WIDE						
EVENT COST DATA	2013	2014	2015	ANNUAL AVERAGE		
CULVERT REPLACEMENTS	$ 10,976,877	$ 13,457,522	$ 12,433,162	**$ 12,289,187**		
GEOHAZARD REPAIRS	$ 9,002,823	$ 8,114,545	$ 10,338,102	**$ 9,151,823**		
ANNUAL COST OF INSAR DATA						
CSK NETWORK COVERAGE	**$ 9,520,000**	HIGH RESOLUTION				
SENTINEL-1 NETWORK COVERAGE	**$ 648,000**	MED RESOLUTION				
CSK (1 SQ MI COVERAGE)	*$ 62,000*	*CONFIRMATION FRAME COST, SCENARIO 2*				
SENTINEL (1 SQ MI COVERAGE)	*$ 26,000*					
YEAR	0	1	2	3	4	5
DISCOUNT RATE (ρ)	3.0%					
ANNUAL INSAR COST TO VDOT	**$ 9,520,000**	$ 9,520,000	$ 9,520,000	$ 9,520,000	$ 9,520,000	$ 9,520,000
ANNUAL VDOT BENEFITS (B_t)		$ -	$ 9,491,586	$ 9,875,047	$ 10,273,998	$ 10,689,068
INITIAL DETECTION RATE: CULV	100%	$ 12,289,187	100%	102%	104%	106%
INITIAL SAVINGS RATE: CULV	40%	$ 4,915,675	40%	41%	42%	42%
INITIAL DETECTION RATE: GEOHZ	100%	$ 9,151,823	100%	102%	104%	106%
INITIAL SAVINGS RATE: GEOHZ	50%	$ 4,575,912	50%	51%	52%	53%
ANNUAL GROWTH IN DETECTION RATE	2%					
ANNUAL GROWTH IN SAVINGS RATE	2%					
NET ANNUAL VDOT BENEFIT		(9,520,000)	(28,414)	355,047	753,998	1,169,068
NET PRESENT BENEFIT OVER ANALYSIS PERIOD	**($7,266,217)**					

COSMO-SkyMed (X-Band) data

(orange)	ANALYSIS ASSUMPTIONS
(green)	EXTERNAL DATA

Results for Sentinel-1 data (with less favorable assumptions)

NETWORK-WIDE						
EVENT COST DATA	2013	2014	2015	ANNUAL AVERAGE		
CULVERT REPLACEMENTS	$ 10,976,877	$ 13,457,522	$ 12,433,162	**$ 12,289,187**		
GEOHAZARD REPAIRS	$ 9,002,823	$ 8,114,545	$ 10,338,102	**$ 9,151,823**		
ANNUAL COST OF INSAR DATA					Sentinel-1 (C-Band) data	
CSK NETWORK COVERAGE	$ 9,520,000	HIGH RESOLUTION				
SENTINEL-1 NETWORK COVERAGE	$ 648,000	MED RESOLUTION				
CSK (1 SQ MI COVERAGE)	*$ 62,000*	*CONFIRMATION FRAME COST, SCENARIO 2*				
SENTINEL (1 SQ MI COVERAGE)	*$ 26,000*					
YEAR	0	1	2	3	4	5
DISCOUNT RATE (ρ)	3.0%					
ANNUAL INSAR COST TO VDOT	$ 648,000	$ 648,000	$ 648,000	$ 648,000	$ 648,000	$ 648,000
ANNUAL VDOT BENEFITS (B_i)		$ -	$ 1,440,726	$ 1,440,726	$ 1,440,726	$ 1,440,726
INITIAL DETECTION RATE: CULV	20%		20%	20%	20%	20%
INITIAL SAVINGS RATE: CULV	40%		40%	40%	40%	40%
INITIAL DETECTION RATE: GEOHZ	10%		10%	10%	10%	10%
INITIAL SAVINGS RATE: GEOHZ	50%		50%	50%	50%	50%
ANNUAL GROWTH IN DETECTION RATE	*0%*					
ANNUAL GROWTH IN SAVINGS RATE	*0%*					
NET ANNUAL VDOT BENEFIT		(648,000)	792,726	792,726	792,726	792,726
NET PRESENT BENEFIT OVER ANALYSIS PERIOD	**$2,231,690**					

ANALYSIS ASSUMPTIONS
EXTERNAL DATA

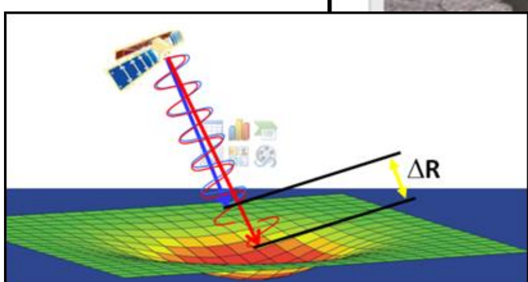
Conclusions

1. VDOT's costs for culverts and geohazards are insufficient to justify a trial of network-wide high-resolution InSAR data, even with favorable assumptions such as maximum possible detection rates (DR) and efficiency gains over the analysis period:
   - Assuming $DR_{culverts}$ = 100%, DR_{geohz} = 100%, $SR_{culverts}$= 40%, SR_{geohz} = 50%: Net Present Benefit for COSMO-SkyMed over 5 years is -$9.3 million.
   - Initial SR must be ≥ 60% (culverts) and ≥ 52% (geohazards) for Net Present Benefit > 0 (assuming no growth in DR, SR over the analysis period).

2. VDOT's costs are sufficient to justify a trial of network-wide medium resolution InSAR data, even without favorable parameter assumptions.
   - Assuming $DR_{culverts}$ = 20%, DR_{geohz} = 10%, $SR_{culverts}$= 40%, SR_{geohz} = 50%: Net Present Benefit for Sentinel-1 over 5 years is $2.2 million.
   - This cushion provides funds for follow-up frames of high (or medium) resolution.

Crews working to fix sinkhole in Virginia

WAVY
Published: October 11, 2016, 3:26 pm



SOUTHAMPTON COUNTY, Va. (WAVY) — Crews are working to fix a sinkhole that formed in the early morning hours of Tuesday on Southampton Parkway, near the Suffolk city line.