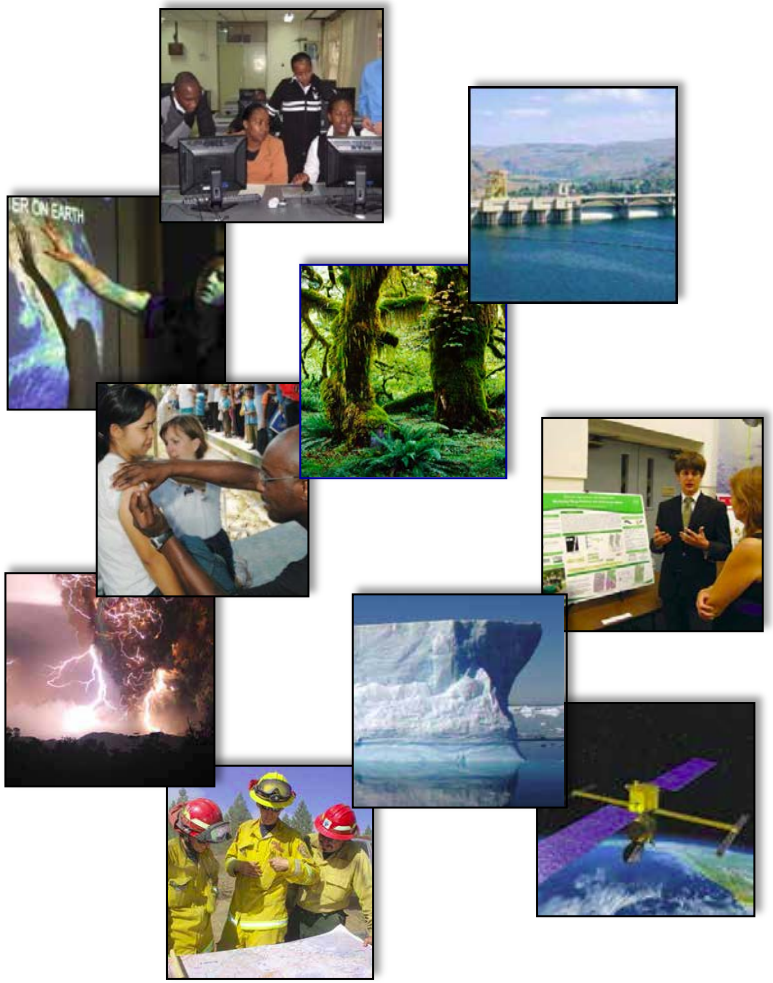


NASA Earth Science Applied Sciences Program

Impact Assessment and the Value of Remote Sensing

Lawrence Friedl, NASA

Water Resources Applications Meeting • March 3-4, 2015

Say What ?!?

A Tale of Two Terminologies

Economics & Policy Analysis

- » Shadow Price
- » Discount Rate
- » Contingent Valuation
- » Cobb Douglas Function
- » Revealed Preference
- » Marginal Utility
- » Price Elasticity
- » Net Present Value

Earth Science, Remote Sensing, GIS

- » Spectroradiometer
- » Synthetic Aperture
- » Normalized Difference Vegetation Index
- » Nearest Neighbor
- » Supervised Classification
- » Passive Microwave
- » Backscatter
- » Orthorectification

Terms shared by both (though meanings may differ)

- » Productivity
- » Probability Density Functions
- » Markov Processes
- » Sensitivity Analysis
- » Monte Carlo
- » Lagrangian Function

Impact Analysis 101

Socioeconomic impact analysis is an approach to specify, assess, qualify, or quantify the economic, environmental, social, and other impacts that result from decisions and actions.

In an Earth-observations context, the actions analyzed are directly influenced by the information and insights provided by Earth science data or models.

<u>Overview of Talk</u>

- Key Terms and Principles
- Methods for Assessment and Analysis
- Generalized Steps in an Assessment

Impact Analysis 101

Socioeconomic impact analysis is an approach to specify, assess, qualify, or quantify the economic, environmental, social, and other impacts that result from decisions and actions.

In an Earth-observations context, the actions analyzed are directly influenced by the information and insights provided by Earth science data or models.

Qualitative v Quantitative

Project/Action Value or Information Value

Monetization of impacts – not always necessary or appropriate

Impacts

Impact: A positive or negative benefit

Positive benefit
Things regarded to be a good change (e.g., cases of malaria avoided; clean air and water)

Negative benefit
Things regarded to be a bad change (e.g., reduced privacy from surveillance; increased traffic)

Tangible impact
Directly quantifiable (e.g., increases in forest cover; fish harvested)

Intangible impact
Difficult to directly quantify (e.g., aesthetics of a national park)

Cost: Expenditures of effort or resources to obtain an outcome.

Approaches

Retrospective Analysis (ex post)
Review of impacts already realized

Prospective Analysis (ex ante)
Forecast of impacts that may be obtained in the future

Impact metrics after project – **Impact metrics in baseline projection** = **Impact attributable to the project**

Methods for Assessment & Analysis

Impact Assessments

» Time-Series/Statistical Analysis
Comparing historical trends before & after project completion

» Expert Opinion
Using expert judgement or prior analyses to estimate project impacts. E.g., delphi method, logical decision models

» Value of Information
Analyzing decisions under uncertainty "with and without" information from project

Cost-Based Assessments

» Benefit-Cost Analysis
Comparing monetized impacts with financial costs of project; used to assess worth or to compare projects with different objectives

» Cost-Effectiveness Analysis
Comparing costs of achieving desired impacts (does not require monetizing impacts); used to compare projects with similar objectives

Impact Monetization

Impact Monetization Methods

» Market Valuation
Using prices paid for goods and services related to project impacts

» Standards-based Valuation
Using standardized prices (from industry or government) for impacts in lieu of market data

» Stated Preferences Valuation
Using surveys and analysis to estimate stakeholders' willingness to pay for project impacts.

» Revealed Preferences Valuation
Using stakeholder behavior to estimate willingness to pay for project impacts (e.g., travel cost analysis, hedonic analysis)

Discount Rate & Net Present Value

Discount Rate

Preference for money today compared with money at a later date, expressed as a % per year.

10% Discount Rate: A person is equally satisfied with $100 today or $110 in one year.

Net Present Value

$$NPV(p) = \sum_{t=0}^{\infty} \frac{p_t}{(1+r)^t}$$

Sum of series of payments/benefits over time, expressed as equivalent received today.

p is payments/benefits; t is time period; r is discount rate

Socioeconomic Impacts: A Primer

Purpose:

Inform the Earth science community and project teams about the language, key principles, techniques, and applications of socioeconomic impact analyses.

http://AppliedSciences.NASA.gov/pdf/SocioeconomicImpactsPrimer.pdf

http://AppliedSciences.NASA.gov under "Documents & Resources"

General Approach & Steps

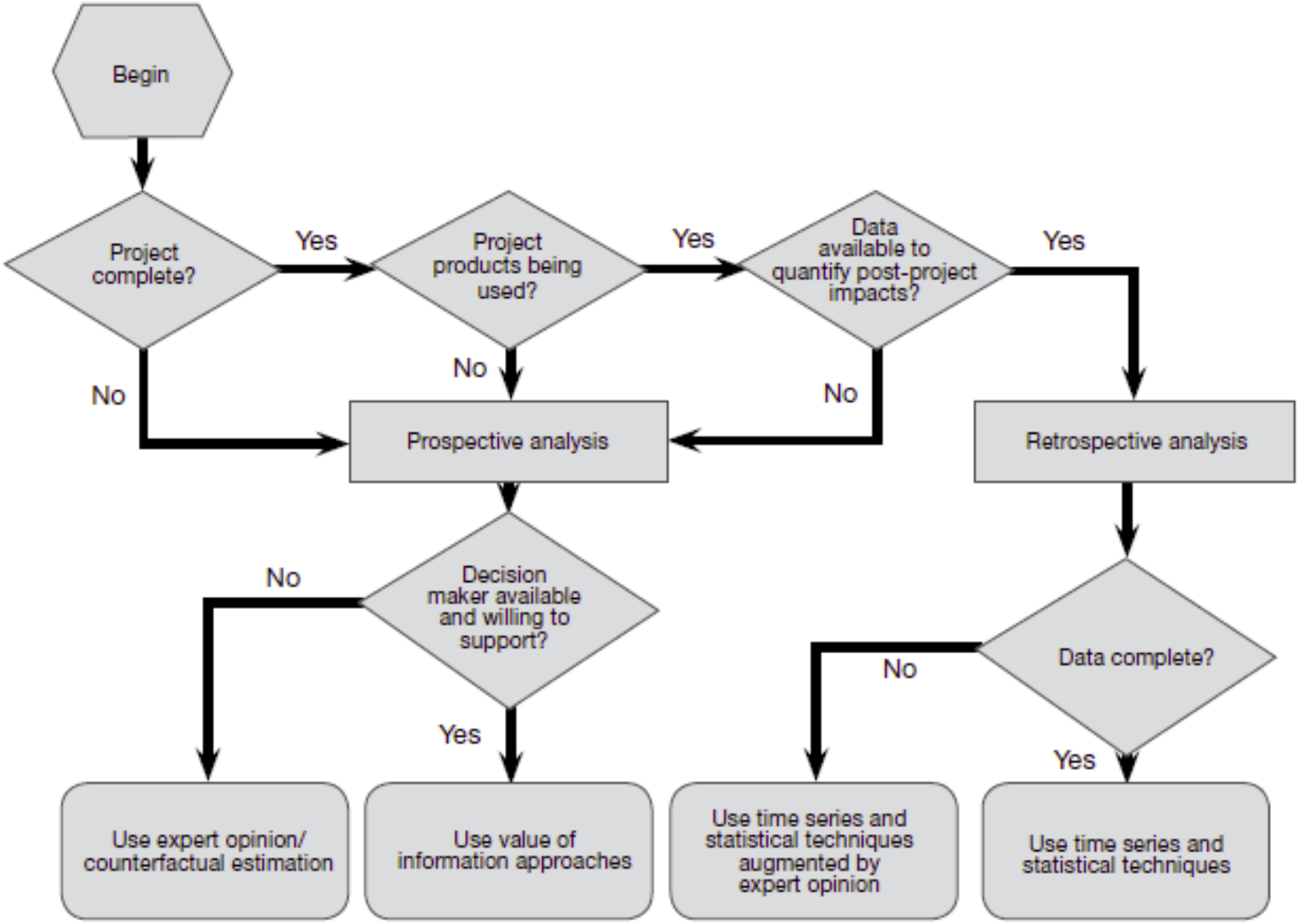
General Approach

Suggested flow for socioeconomic analysis:

1. Choose an analytic approach.
2. Specify impact metrics.
3. Identify impact relationships.
4. Collect and condition data.
5. Estimate baselines.
6. Quantify impacts.
7. Monetize impacts (if appropriate).
8. Report results.

Choose analytic approach	• Prospective/Retrospective • Time-series/Expert opinion/VOI
Specify impact metrics	• Physical (e.g., mortality, biodiversity) • Financial (e.g., NPV) • Tangible (e.g., property value)
Identify impact relationships	• From theory • Implied by data • Include confounding variables
Collect data	• Identify • Normalize • Cleanse
Estimate baselines	• Impacts in absence of project
Quantify impacts	• Impacts due to project • Uncertainties • Sensitivities
Monetize impacts (if able/desired)	• Market valuation • Non-market valuation
Report results	• Monetized impacts • Non-monetized impacts • Uncertainties • Sensitivities • Comparison with costs (e.g., BCR, ROI)

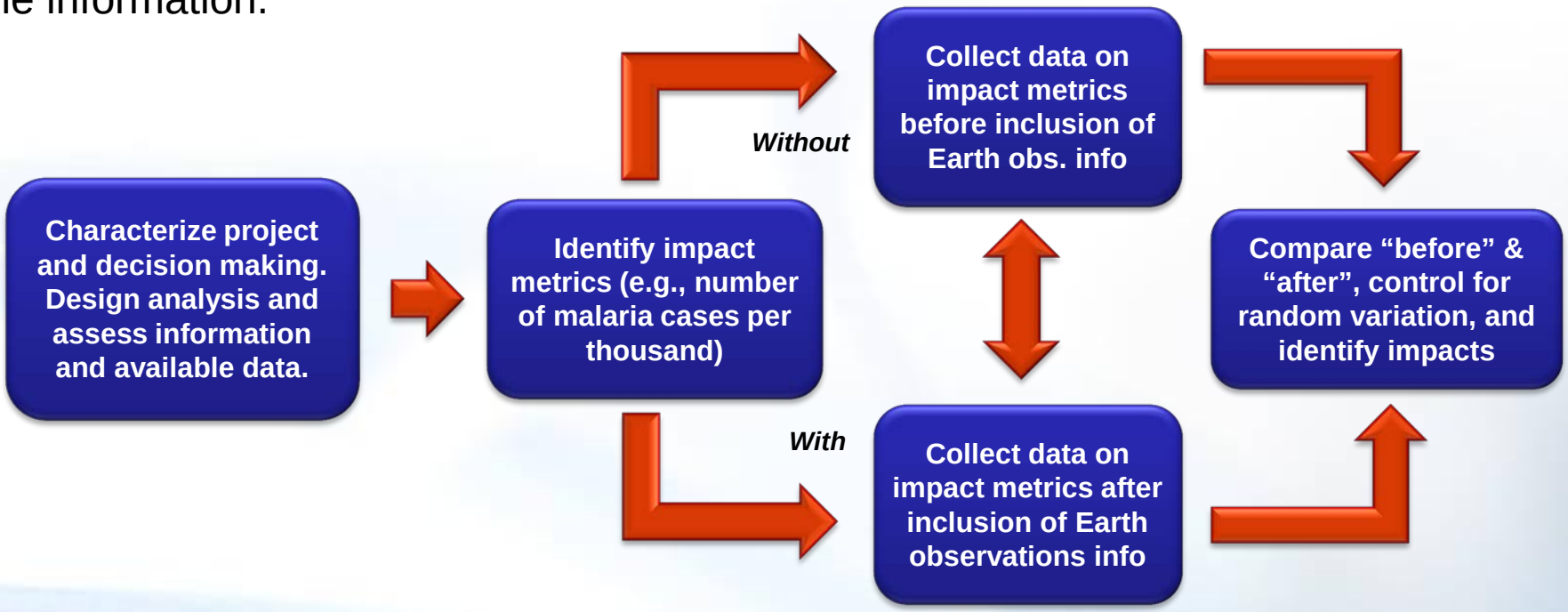
Flowchart on Choosing an Approach



Value of Information / Impact Assessment

General Approach

An adapted expected value of information methodology to assess the benefits. The value of information is a function of the benefits that result from a decision *with* information compared to the decision that would have been made *without* the information.

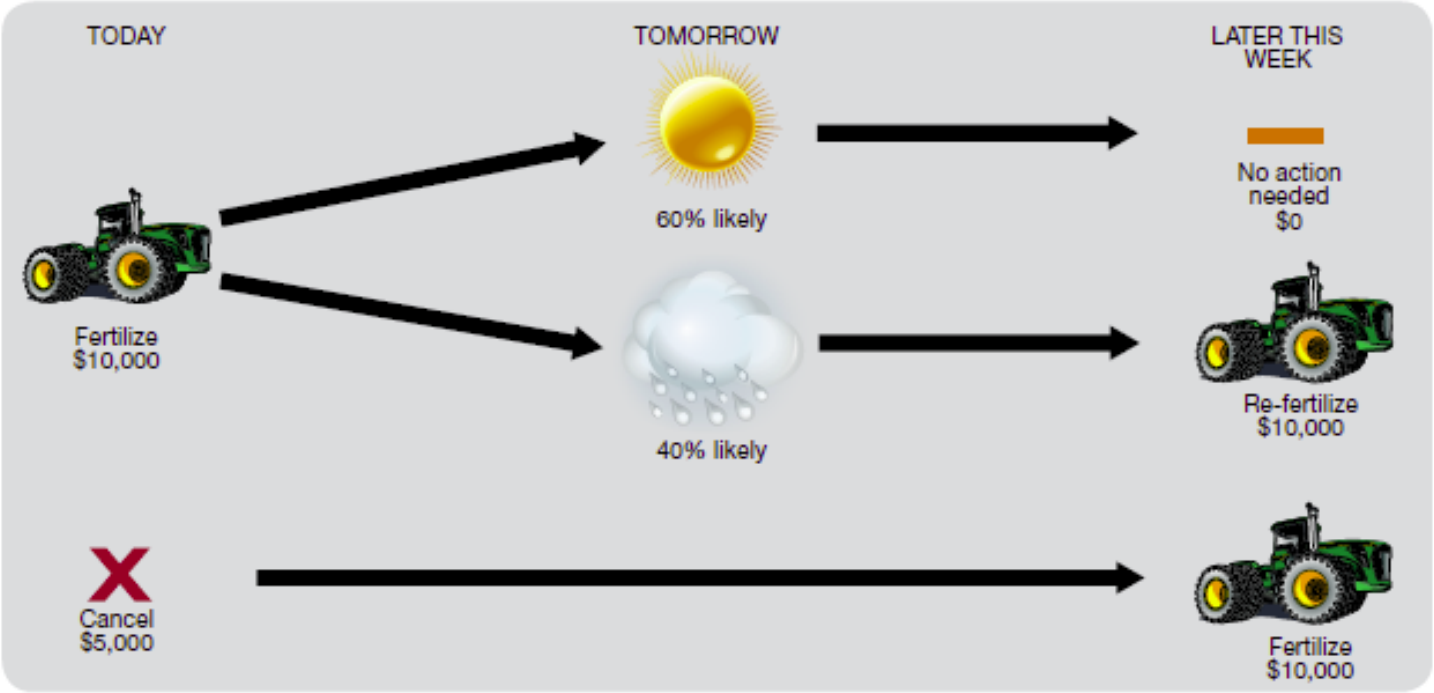


Using this approach, the value of information provided by a project would be:

Value of Earth obs. info = (Outcome with information – Outcome without information)

Value of Information: Example

Scenario A: Decision Under Uncertainty



$14,000

Or

$15,000

<u>Choice:</u>

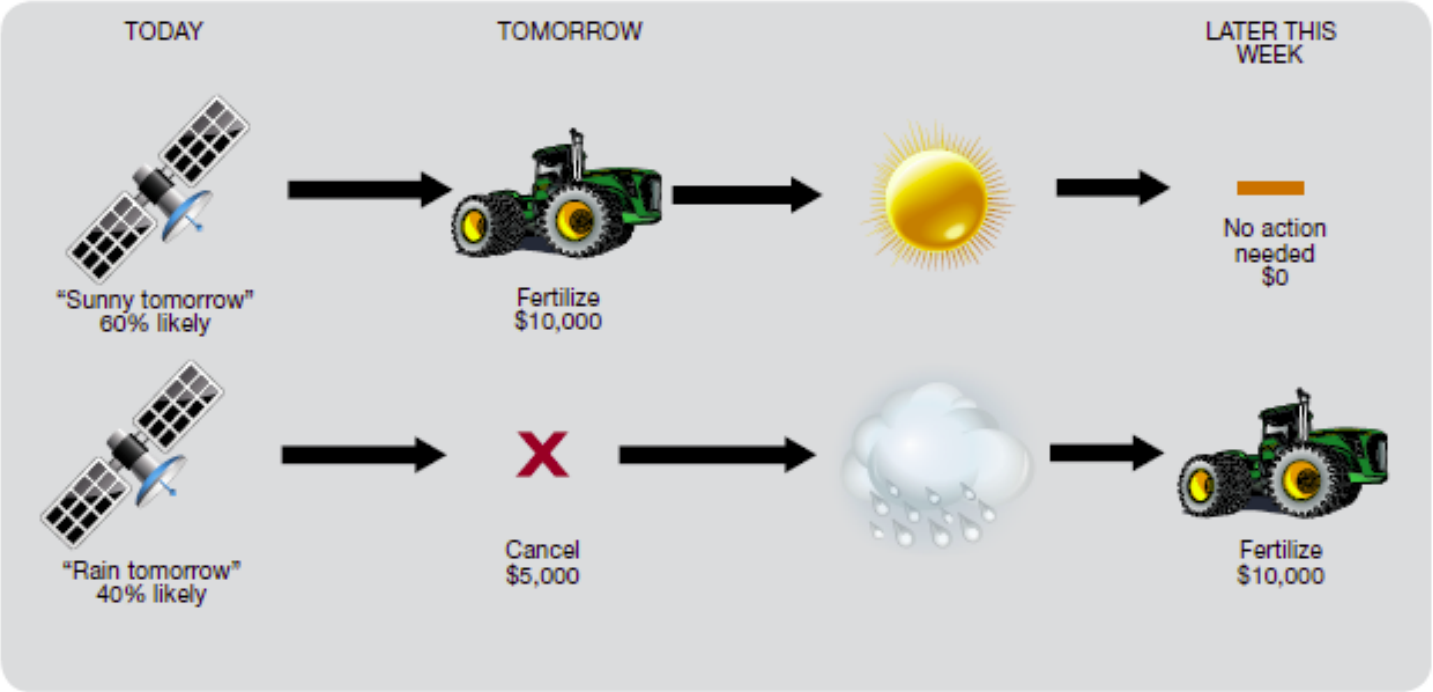
$10,000 + (60% * $0) + (40% * $10,000) = $14,000

or

$5,000 + 10,000 = $15,000

Value of Information: Example

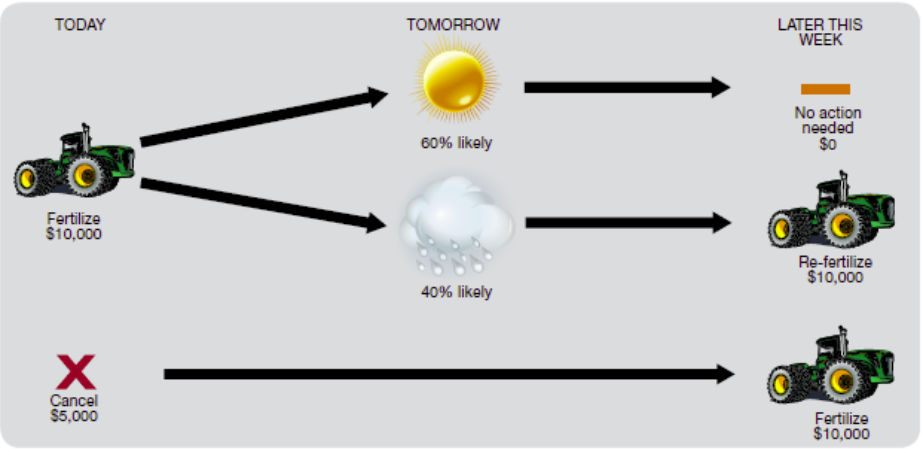
Scenario B: Decision Under Uncertainty With Information



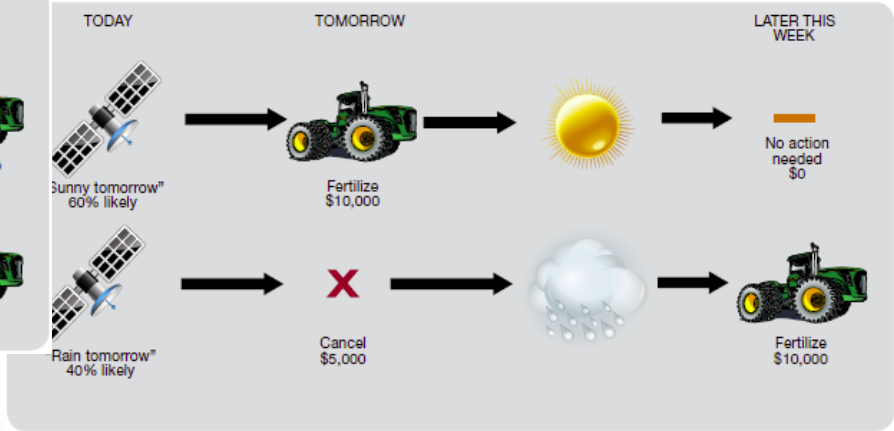
(60% * $10,000) + (40% * $15,000) = $12,000

Value of Information: Example

Expected Value of Information



$14,000



$12,000

Thus, the "expected value of information" for the Earth observations is:

$2000 (i.e., $14,000 - $12,000)

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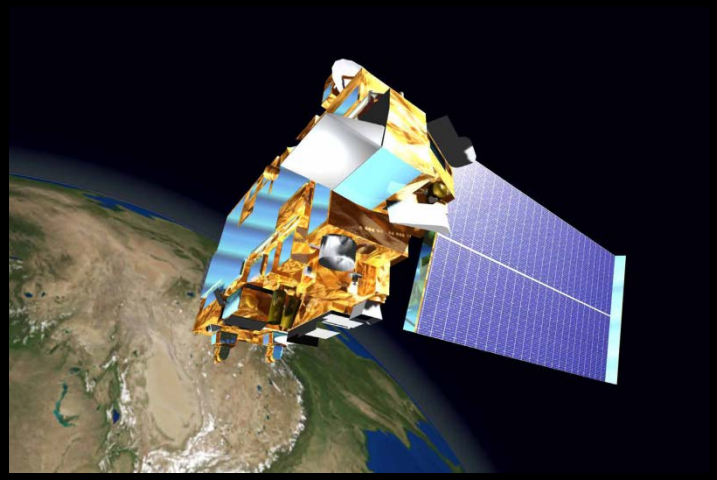
Impact Assessments

Approach	Focus	Considerations	Sections
Impact Assessment			
Time-Series/ Statistical Analysis	Comparing historical trends before and after project completion	Retrospective; based primarily on objective data; therefore data-intensive and dependent upon availability of data	3.1, 3.6, 4.1
Expert Opinion	Using expert judgment or prior analyses to estimate project impacts	Can be retrospective or prospective; feasible in situations with limited data, but based on subjective or proxy data	3.1, 3.6, 4.2
Value of Information	Analyzing decisions under uncertainty with and without information from project	Usually prospective; requires availability and cooperation of decision maker; mix of subjective and objective basis	3.1, 3.6, App. B
Cost-Based Assessment			
Benefit-Cost Analysis	Comparing monetized impacts with financial costs of project	Allows financial comparison of projects with different objectives; requires both impact and cost analyses; monetizing impacts can be difficult and controversial	5.1
Cost-Effectiveness Analysis	Comparing costs of achieving desired impacts	Allows financial comparison of projects with similar objectives; requires both impact and cost analyses; does not require monetizing impacts	5.2
Impact Monetization			
Market Valuation	Using prices paid in open markets for goods and services related to project impacts	Objective; requires market data; applicable only if markets exist for goods and services related to the project impact	3.7
Standards-Based Valuation	Using standardized prices from government or industry for project impacts in lieu of market data	Can be controversial, depending on standardizing source; simplifies monetization process; available for only a limited number of impacts	3.7
Benefits Transfer from Prior Research	Adapting existing studies to monetize impacts similar to those from the project	Can be controversial, depending on relative similarity of project benefits to those in prior research	3.7
Stated Preferences Valuation	Using surveys, augmented by analysis, to estimate stakeholders' willingness to pay for project impacts (e.g., conjoint analysis)	Tendency for biased responses by stakeholders who are only conceptually spending money for the impacts; requires survey development and analysis	3.7
Revealed Preferences Valuation	Using stakeholder behavior to estimate willingness to pay for project impacts (e.g., travel cost analysis, hedonic analysis)	Based on actual behavior rather than conceptual surveys; relationship between priced item and project impact may be indirect and thus controversial	3.7



Examples:

Volcanic Ash Advisories

Malaria Early Warning

Examples in Primer;
Charts in back-up materials

National Aeronautics and Space Administration

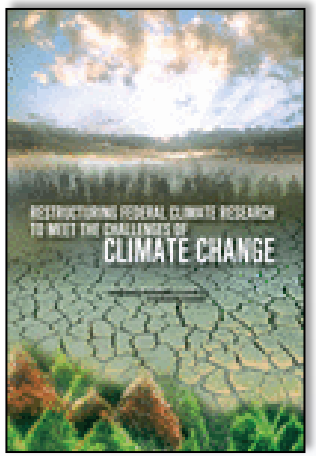
Human Dimensions in Earth System Science:

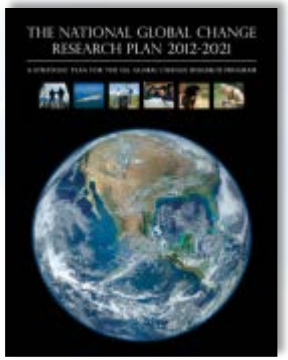
Social, Behavioral, and Economic

Human Dimensions in Earth System Science: Integration of Natural and Social Sciences

Restructuring Federal Climate Research (NRC/BASC, 2009)
"Reorganize … to facilitate crosscutting research focused on understanding the interaction among the climate, human, and environmental systems …"

"Such a re-structuring around scientific-social issues is required to help the program become more cross disciplinary, more fully embrace the human dimensions component, and encourage an end-to-end approach (from basic science to decision support)."





USGCRP Strategic Plan, 2012-2021
Numerous references to the integration of physical, chemical, biological, and social sciences; to collaborations among researchers in natural and social sciences; to a workforce capable of bridging the natural and social sciences.

Planet Under Pressure: *State of the Planet Declaration* (2012)
"The international global-change research community proposes a new contract between science and society in recognition that science must inform policy to make more wise and timely decisions …"

Proposed a major research initiative, *Future Earth: research for global sustainability*

Terminology Transfer in Interdisciplinary Work

Economics & Policy Analysis

- Shadow Price
- Discount Rate
- Contingent Valuation
- Cobb Douglas Function
- Revealed Preference
- Marginal Utility
- Price Elasticity
- Net Present Value

Earth Science, Remote Sensing, GIS

- Spectroradiometer
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- Orthorectification

Terms shared by both (though meanings may differ)

- Productivity
- Probability Density Functions
- Markov Processes
- Sensitivity Analysis
- Monte Carlo
- Lagrangian Function

Resources & Information

GROUP ON EARTH OBSERVATIONS

Socioeconomic Benefits Community –

A Community of Practice for socioeconomic benefits and assessment of environmental information

http://www.socioeconomicbenefits.org/

- Annual Workshops & other fora
- Impact analysis reports
- Shared database of experiences and lessons learned
- Glossary of terms, reference material, and list of experts;
- Assembling compendium of case studies and methodologies
- Developing research agenda on methods, analysis techniques & impact communication

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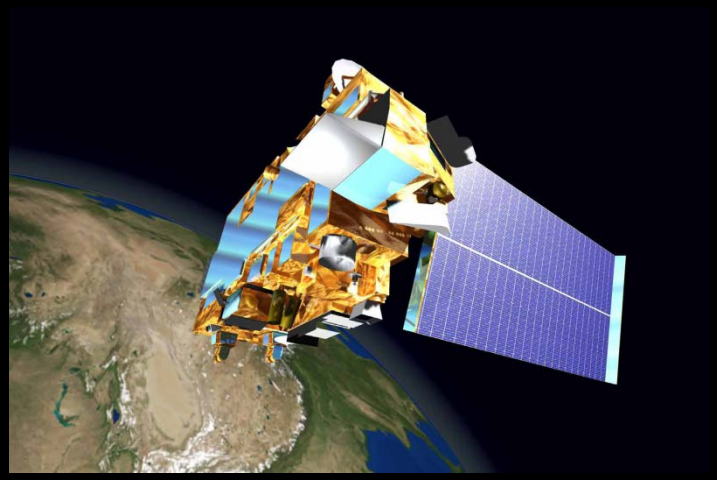
Backup Materials



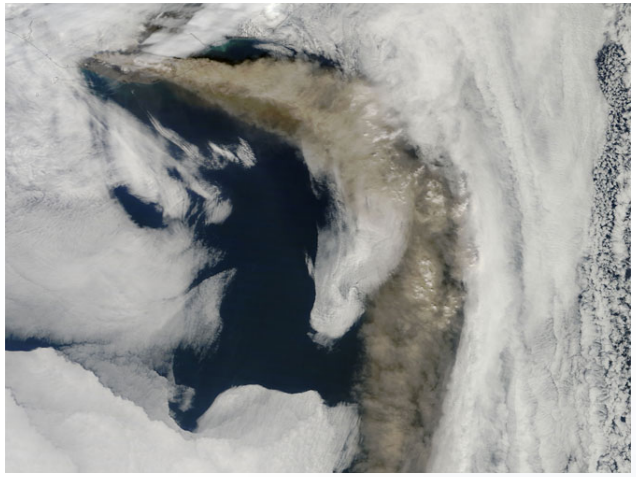
Example:

Volcanic Ash Advisories

Volcanic Ash Advisories

Background

- Volcanic ash can cause damage to engines, windscreens and fuselages, making it necessary to reroute, delay, or cancel flights to protect the aircraft and passenger safety
- Aura/OMI data enables reliable detection of volcanic ash clouds using SO_2 data.
- SO_2 is a reliable marker for fresh ash clouds; discrimination between volcanic plume and clouds
- NASA/Applied Sciences project with NOAA and FAA to integrate Aura data products into the Volcanic Ash Advisory Centers (VAAC)
- Initial focus on 2 of 9 VAACs in the U.S.



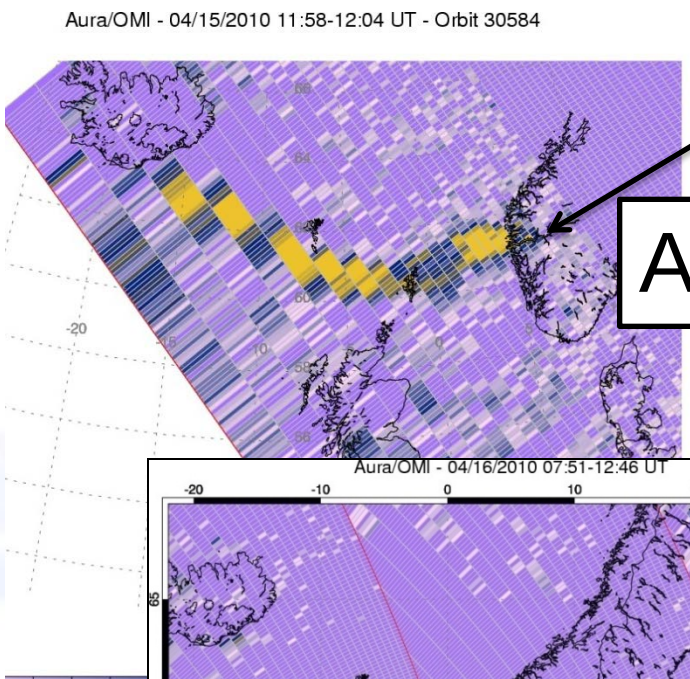
Terra/MODIS: Ash plume in 2010 during the Eyjafjallajokull eruption in Iceland.

Eyjafjallajokull Eruption

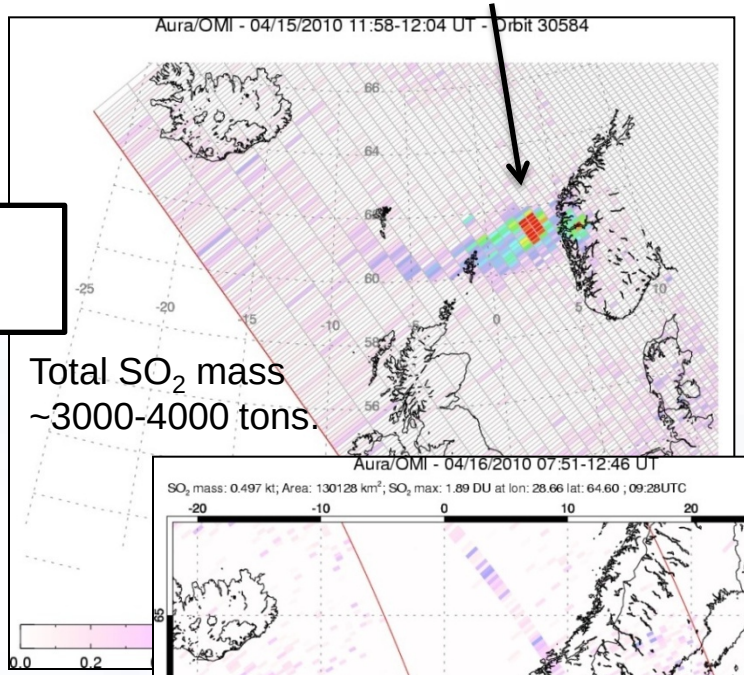
- VAACs in Europe did not use Aura/OMI data
- 19.April.2010, US began to provide this information to London VAAC for sectors covering Iceland and Northwest Europe

Volcanic Ash Detection with Aura/OMI

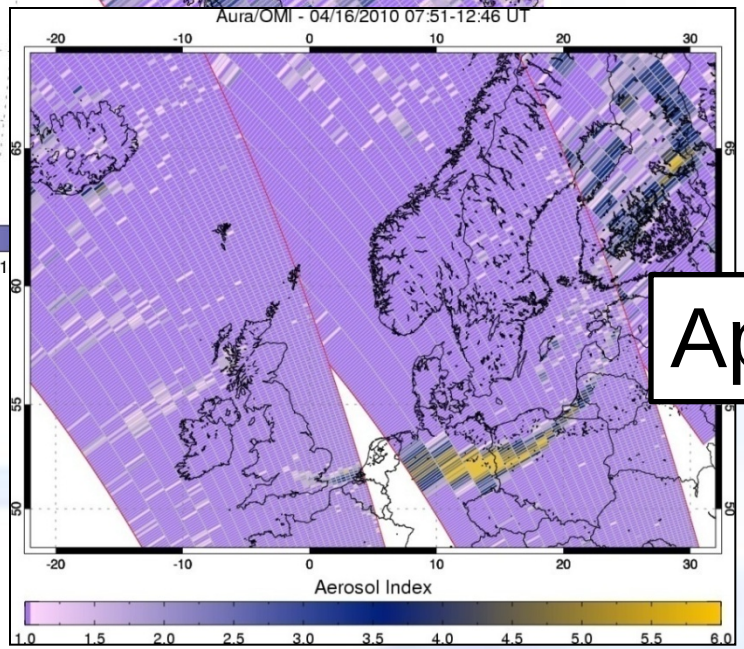
OMI detects ash (Aerosol Index, AI) and SO_2



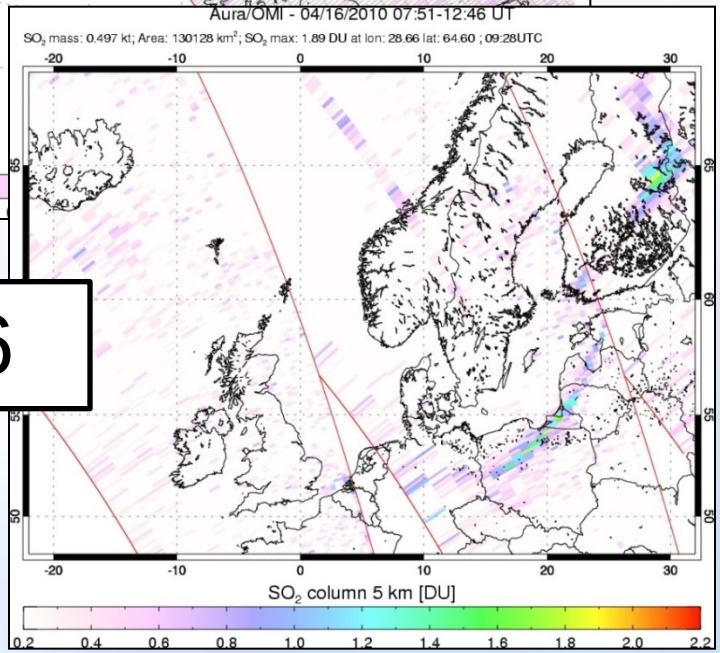
April 15



Total SO_2 mass ~3000-4000 tons.



April 16



The Eyjafjallajokull (Iceland) 2010 eruption was unusual because effusive eruptions typically emit limited ash that falls locally. Here, glacial melt produced much phreatic fine ash that drifted at relatively low altitudes.

Volcanic Ash Advisories – Impact Analysis

Overall Objective

I. *Specific Case:*
Calculate the portion of **avoided revenue losses and aircraft damages** that could be attributed to the use of the Earth observations in the decision making, based on the likelihood that an aircraft would have encountered the ash cloud from the Eyjafjallajokull eruption in 2010.

II. *General Case:*
Estimate the **potential annual impact** from the use of Earth observations by the VAACs.

Volcanic Ash Advisories – Impact Analysis

Analytic Approach

A combined time-series and VOI approach to develop an estimate of how much the introduction of the Aura data would reduce the uncertainty about the level of ash threat.

The team applied this risk reduction to the estimates of potential impacts in order to estimate the risk-adjusted value of the observations.

Volcanic Ash Advisories – Impact Analysis

Analytic Approach – cont.

- Estimate the probability of any given passenger aircraft flight being damaged by volcanic ash before and after the integration of Earth observations into the U.S. VAAC system in 2007.

- Estimate how much the observations would reduce the uncertainty about the level of ash threat. Apply this risk reduction to the estimates of potential costs to determine the risk-adjusted value of the observations.

- Examine the counterfactual cases – What would have happened if the Earth observations were not available to the VAACs?
  Presumably:

  a) reopened flight routes slowly because of uncertainties about the volcanic ash danger, OR
  b) reopened flight routes with greater risk of aircraft damage.

Volcanic Ash Advisories – Impact Analysis

Metrics, Logic Model, and Impacts

Impact Metrics*: Avoided revenue losses and
Avoided aircraft damages.

Logic Model: Better VAAC information and more reliable predictions on the location and movement of the volcanic ash clouds could result in better decision making by air traffic control authorities and airlines regarding the closure of airspace, the cancellation of flights, and route adjustments.

Impacts/Benefits: (a) smaller revenue losses from more-targeted flight cancellations, and
(b) avoided or reduced aircraft damages from better route adjustments and ash cloud avoidance.

** The team considered but decided not to include several other potential benefits metrics, such as potential casualties, social cost of time to stranded passengers, and fuel rerouting costs.*

Volcanic Ash Advisories – Impact Analysis

Data Collection

Probability of an Incident – Data for 1996-2010

Historical frequencies of aircraft damage from volcanic ash

Number of significant passenger aircraft incidents involving volcanic ash, the number of significant volcanic eruptions with effluent reaching commercial flight levels, eruption index, and the number of passenger flight departures.

Generated an "incidences per flight" figure

A weighted probability of a given flight encountering a volcanic ash incident.

Examined two periods: 1996-2006 and 2007-2010

Output: Use of the Earth observations reduces the probability of an aircraft's experiencing a volcanic ash incident by approximately 12 percent.

Volcanic Ash Advisories – Impact Analysis

Data Collection – cont.

Revenue Loss

Data from the International Air Transport Association (IATA) on the reduction of flights and estimated loss in revenue.

Daily figures for the period of April 15–21, 2010, spanning a time around the introduction of the Earth observations.

Day of greatest impact (April 18), approximately 80% of European flights were canceled, resulting in approximately $450 million in lost revenue. Cancellations and losses began to decline on April 19, and flight operations were gradually restored on April 20–21.

Output: $450 million was the maximum possible daily revenue loss that could have been avoided if decision makers had had perfect information about the location of dangerous volcanic ash clouds.

Volcanic Ash Advisories – Impact Analysis

Data Collection – cont.

Avoided Damages

Information on incidents of aircraft encountering ash clouds provide the types of damage caused, such as damaged engines and wind screens.

One source (Boeing): Repairing an engine with foreign-object damage can cost up to $1.6 million per engine and that replacing an engine can cost up to $10 million.

Second source: Engine replacement ranged from $3-8million and engine repair (from foreign-object damage) ranged from $250,000 to $500,000.

Output: For conservative assessment, the analysis assumed engine repair at $500,000 each.

Note: The team did not consider related, indirect costs such as an increase in insurance premiums, litigation judgments, or potential fines imposed by air regulators.

Volcanic Ash Advisories – Results I

Quantification of Impacts: Specific Case

If reopened more rapidly: high-risk

Likely that aircraft would have flown into volcanic ash. Team assumed 2 engines would need repair *plus* regulators would have closed air space in wake of incidents, so a revenue loss on April 20 & 21.

Damages: $1 million

Revenue Loss: $24 million

Total: $25 million

If reopened more slowly: low-risk

If regulators had been uncertain on conditions (without the Earth obs), some flights would have been canceled unnecessarily. There would have been greater revenue loss on those days. 12% additional revenue would have been lost.

Damages: $0.

Revenue Loss – April 19: $48 million

Revenue Loss – April 20: $24 million

Total: $72 million

Estimate: Use of the Earth observations beginning April 19th saved between $25-$72 million in avoided revenue losses due to unnecessary delays and avoided costs due to aircraft damages.

Estimate: Additional $132 million if used from start of eruption for April 15-18.

Volcanic Ash Advisories – Results II

Quantification of Impacts: General Case

Global extrapolation to potential annual impact from use of the Aura data (accounting for the annual frequency and magnitude of volcanic eruptions)

Avoided Revenue Losses

Typical length of eruption (≤10days). Assuming one small event (1/10th Eyjafjallojokull) occurring every other year, the estimate is:

Revenue Loss avoided: $10million

Avoided Damages

Used weighted probability with & without the Earth obs. based on number of flights in 2010 and assumption of two engines needing repair.

Damages avoided: $150,000.

Estimate: Expected value of up to $10 million annually
(majority from avoided revenue losses than equipment damage)

Note: This estimate should be interpreted as an "expected value" of cost avoided – the long-run average rather than the actual avoided costs in any given year.

Impact Analysis – Lessons Learned

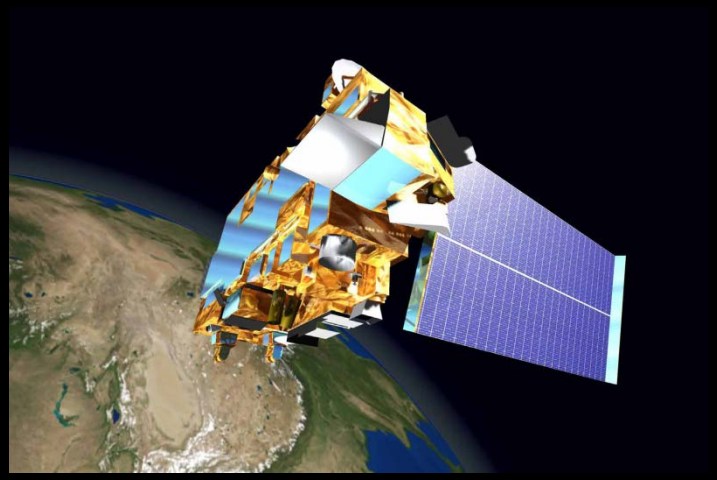
Volcanic Ash Advisor Case: Lessons Learned

I. The number of potential impacts of a project may be large and may require prioritization for analysis.

II. Historical data alone may not be sufficient to develop a single baseline case; it may be necessary and appropriate to examine multiple baselines.

III. Impacts that accrue during infrequent events may be more difficult to estimate statistically than impacts that occur broadly in time.

IV. Impacts during specific, infrequent events may not necessarily be representative of the steady state; impact analyses should consider the frequency of the event in conveying impacts appropriately to the audience.



Example:

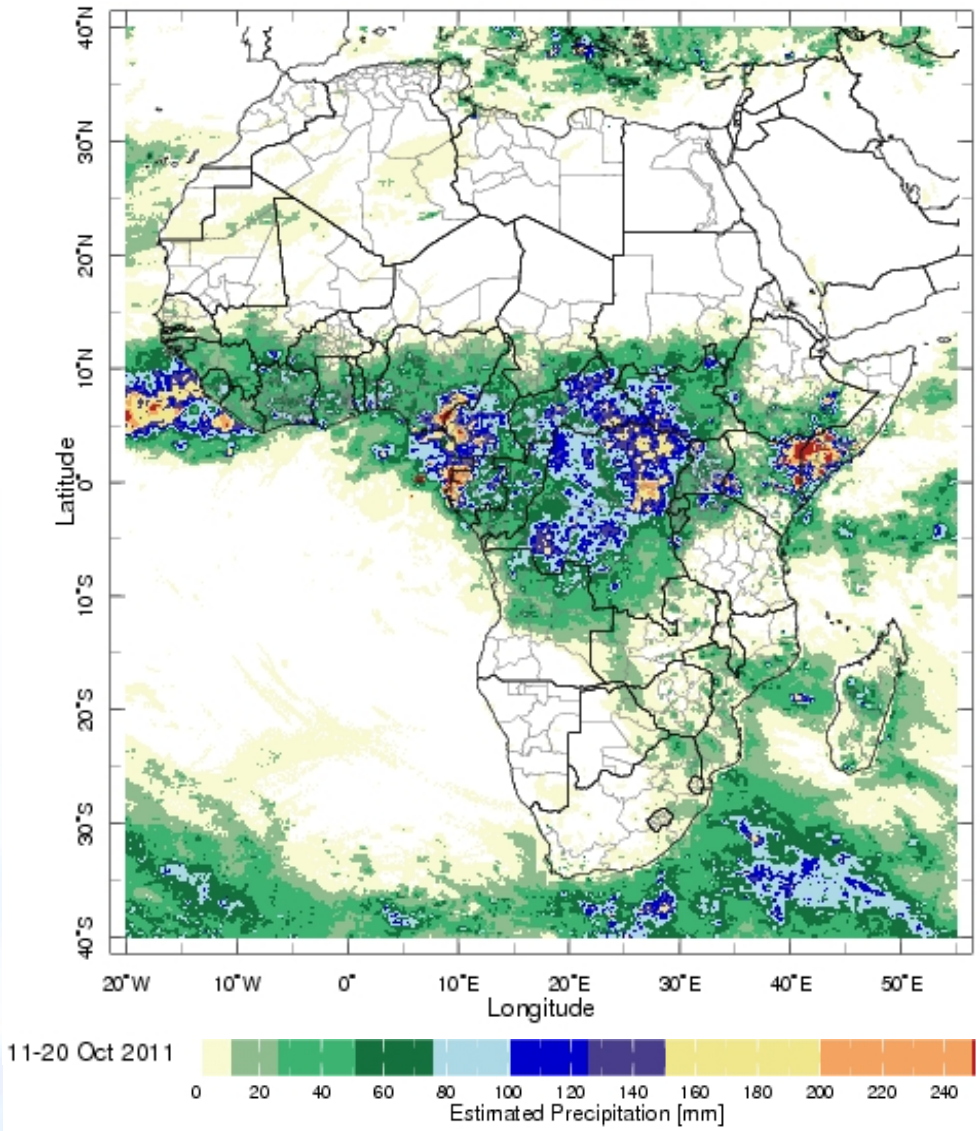
Malaria Early Warning System

Malaria Early Warning System (MEWS)

Climate Suitability for Malaria Transmission
≡ 18-32° C + 80mm + RH>60%

Rainfall largely responsible for creating conditions allowing sufficient surface water for mosquito breeding. Explosive epidemics often occur in these regions after excessive rains.

MEWS interface provides a contextual perspective of recent precipitation. Precipitation analysis by merging gauge obs. and 3 kinds of satellite sensor estimates (GPI, SSM/I, and AMSU).

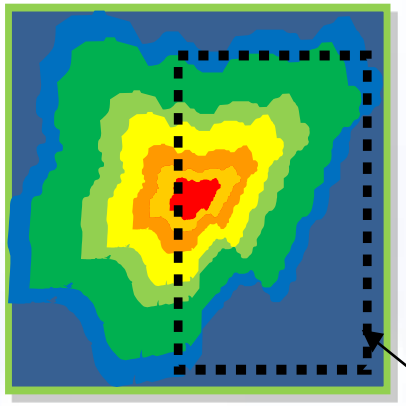


Map shows ~10-day est. precip.

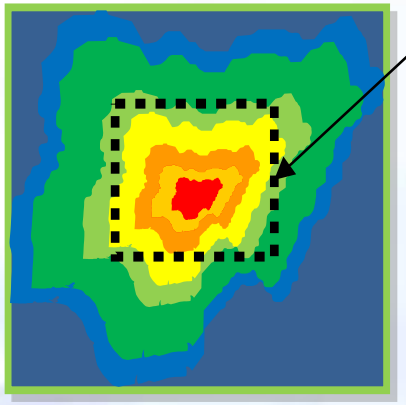
MEWS Impact Analysis

General concept: Where to apply control measures?

Planned without Earth Observations



Refined and Executed Using Earth Observations



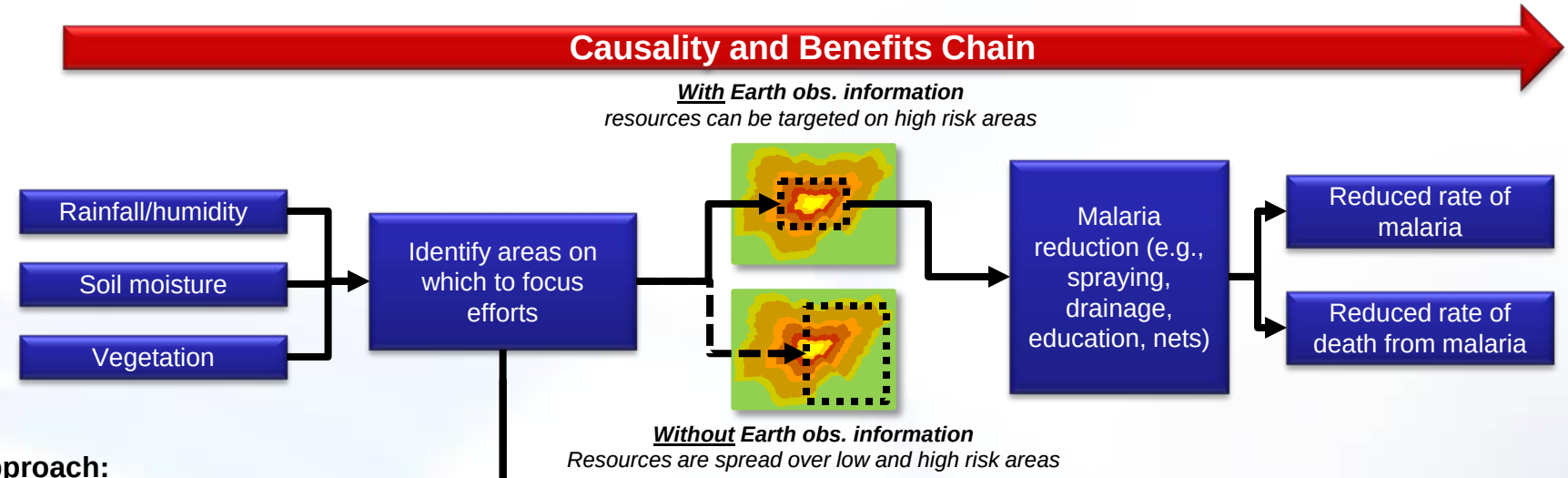
Treatment Area

Actual Soil Moisture Levels
(Not fully known to manager)

- **Very high**
- **High**
- **Moderate**
- **Low**

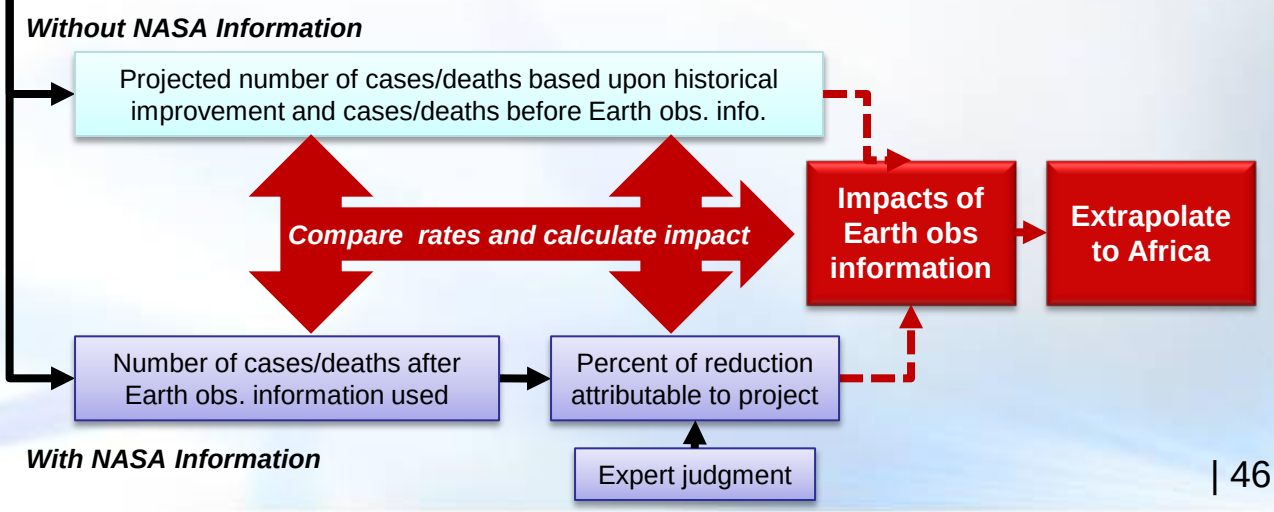
Malaria Early Warning System

Using Earth observations information with the MEWS system helps national malaria programs better target malaria prevention activities, which can contribute to reduced malaria cases and reduced deaths from malaria



Approach:

- The analysis focused on Botswana as the Botswanan program has the best data and makes the most use of MEWS
- Rate of controlled malaria before and after the use of Earth obs. information was calculated, a "no-Earth obs" rate was developed and compared to the actual rate



MEWS: Impact Assessment

Based on the analysis, as a result of integrating Earth observations data and information into MEWS:

- ***Additional Improvement in Reduction of Cases of Malaria:*** On the average, the number of cases of malaria reported in Botswana decreased approximately 21 percent per year before completion of the NASA data project. In the first year NASA data was used, the number of cases decreased by 27 percent

- ***Reduced Cases of Malaria and Malaria Deaths:*** Around 400 cases of malaria and around 1 death were likely avoided in Botswana in 2008 as a result of the project

- ***Potential Africa-Wide Benefits:*** If the other 28 Sub-Saharan countries used MEWS (with Earth observations) as Botswana does, approximately 1 million cases per year could be avoided

... but, not statistically significant