Near Real-time Remote Sensing Data and Earth Science Priorities

A Conceptual Perspective Focused on Satellite Based Systems

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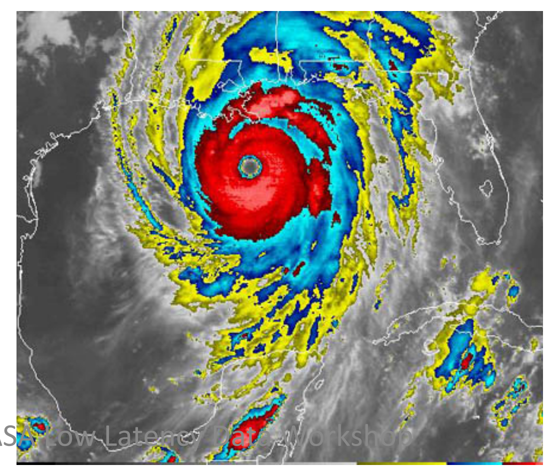
The Potential of NRT Remote Sensing

Access to information from remote sensing sources in 'reactionable' timescales has broad implications for earth science, hazard response, and security:

- Continuous passive monitoring for unanticipated anomalies
- Automated target prioritization
- New/improved application domains
  - e.g., hazard response
  - e.g., tactical observation of transient phenomena
  - e.g., informed, coordinated field campaigns



TSRS: Natural Hazard Response

A far from complete list.....

- Fire (Galindo *et* al. 2003; Laneve *et* al. 2006; Visser and Dawood 2004)
- Earthquakes (Cervone *et* al. 2006)
- Volcanoes (Davies et al 2006)
- Landslides (Joyce *et al.,* 2008)
- Flooding (Ip *et al.*, 2006)

Operational Programs:

- USGS Hazards Data Distribution System (HDDS)
- University of Hawaii near-real-time monitoring of thermal hotspots (MODIS and GOES)
- Geoscience Australia near-real-time monitoring of thermal hotspots (MODIS and AVHRR)
- University of Maryland Fire Information System
- Sentinel Asia
- The International Charter 'Space and Major Disasters'

TSRS: Other Examples

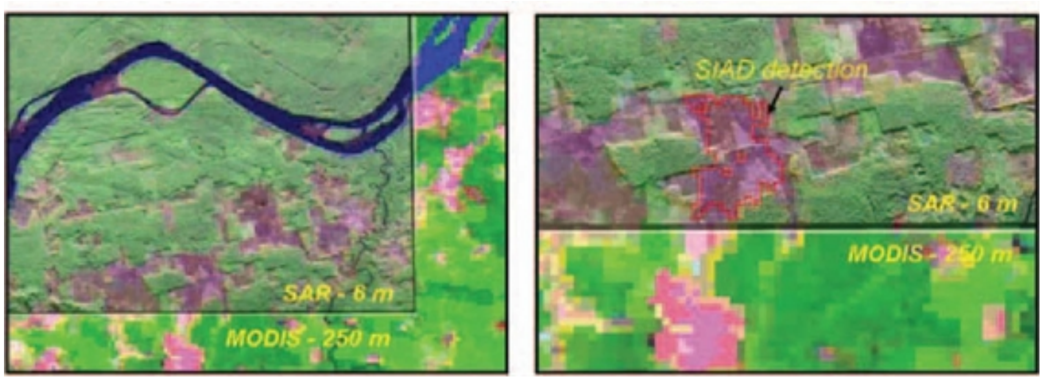
A far from complete list.....

Anthropogenic hazards

- Oil slick detection (Brekke and Solberg 2005)
- Air Pollutants (Simonds et al. 1994)

Resource Management

- Precision agriculture (Seelan et al. 2003)
- Wildlife management and food security (Sannier et al. 1998)
- Deforestation monitoring (Ferreira et al. 2007)



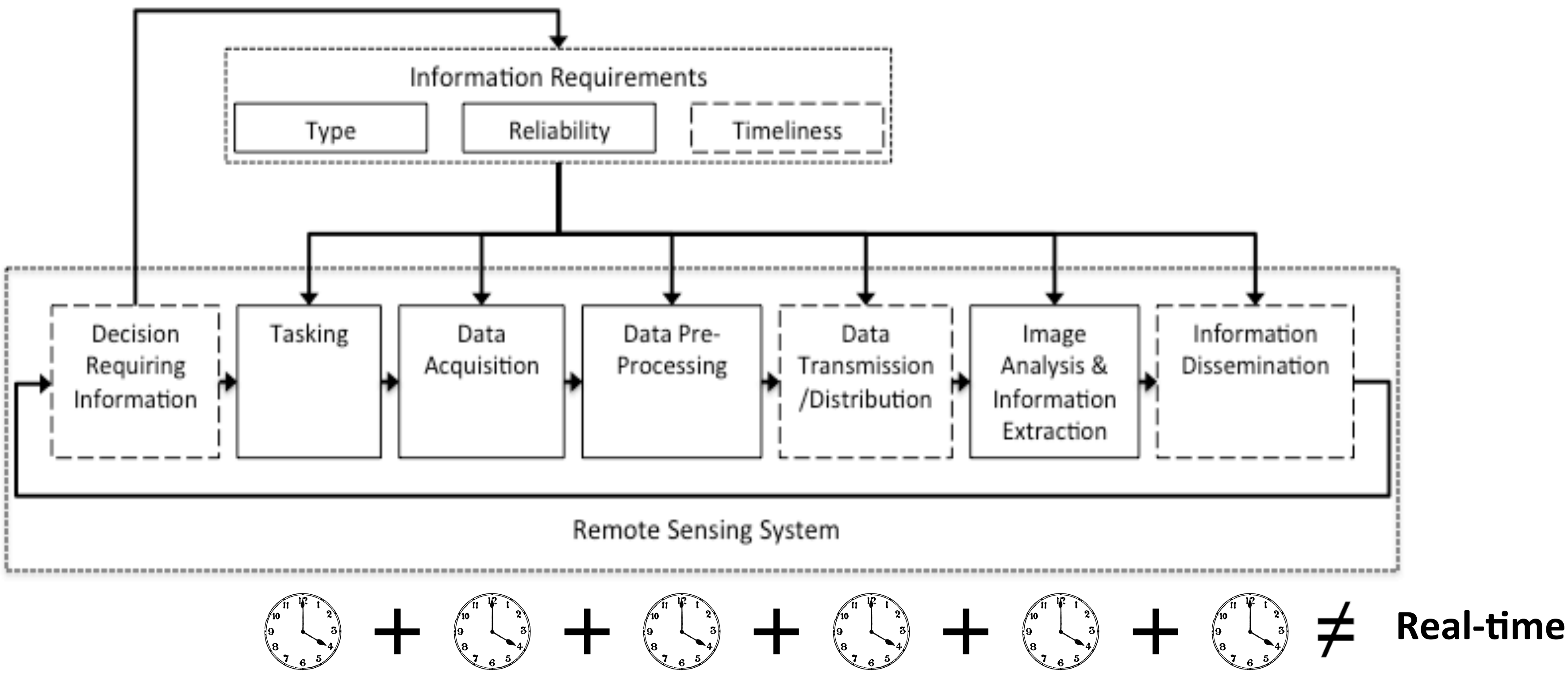
The use of Remote Sensing to Inform Time-Sensitive Decisions

"*there is a critical need for real-time data and information….There was certainly ample evidence from the 11th September 2001 events that time dependence, scale, and even organizational issues (including interoperability, connectivity, and agency cooperation) thwarted the use of remote sensing imagery*" (p. 443, Cutter 2003)

The effective use of GIScience technologies for hazard response requires that all data sources, processing flows, and distribution mechanisms be determined before the event they are intended to monitor

Not just a technical problem!

Time-Sensitive Remote Sensing



"Given that airborne and satellite sensor systems are inherently remote and that the data they collect are rarely employed in their raw form (i.e., voltages or exposed silver halide crystals) or near their origin (i.e. the sensor), time is inherent in the remote sensing process." *(Lippitt, Stow, and Clarke 2014)*

What is Time-Sensitive Remote Sensing?

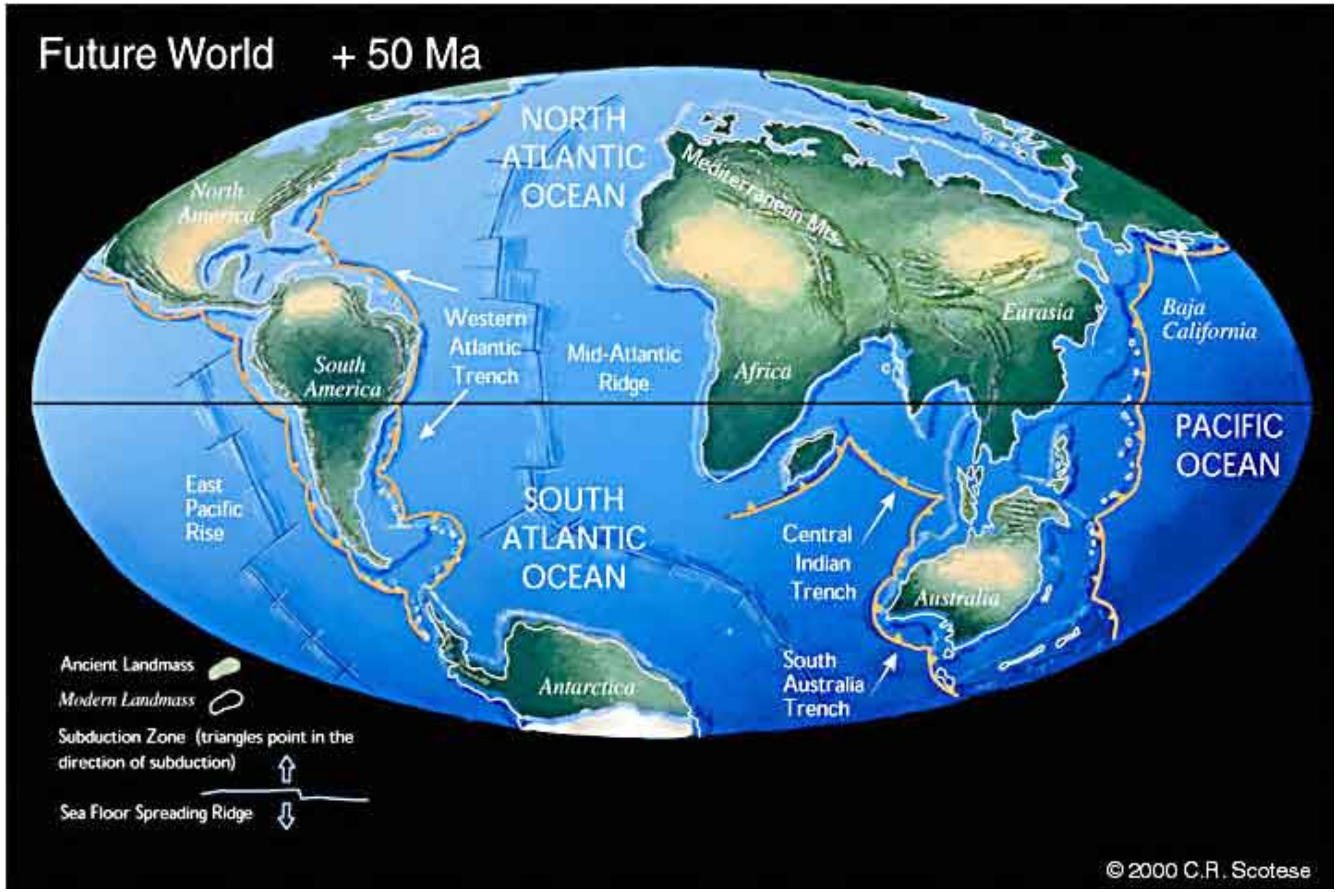
A Decision
Turn back? Or keep going?

Consequence
Splat

Information Required
What direction is the next car coming from?

"the use of remote sensing systems and methods to gather information where the utility of that information to inform a given decision changes as a function of time." (Lippitt, Stow, and Clarke 2014)

What is Time-Sensitive Remote Sensing?



A Decision
Where to evacuate?

Consequence
Destruction of civilizations dating to the start of human history

Information Required
What land areas will still be inhabitable

Utility of Information
Present
50 million years

If present plate tectonic trends continue, Africa will collide with Europe, Australia will collide with Asia, and California may become home to a King Crab fishing fleet

"From a practical perspective however, it is only when information from a remote sensing source is required within timescales that ***approach the limits of current technology and practice*** *that timeliness becomes a dominant control on the effectiveness of the decisions in which that information is employed. Therefore, we consider only these cases to be TSRS."* (Lippitt, Stow, and Clarke 2014)

Remote Sensing System Definition

All systems and methods required to measure electromagnetic energy intensity, interpret it into information, and deliver it to a user

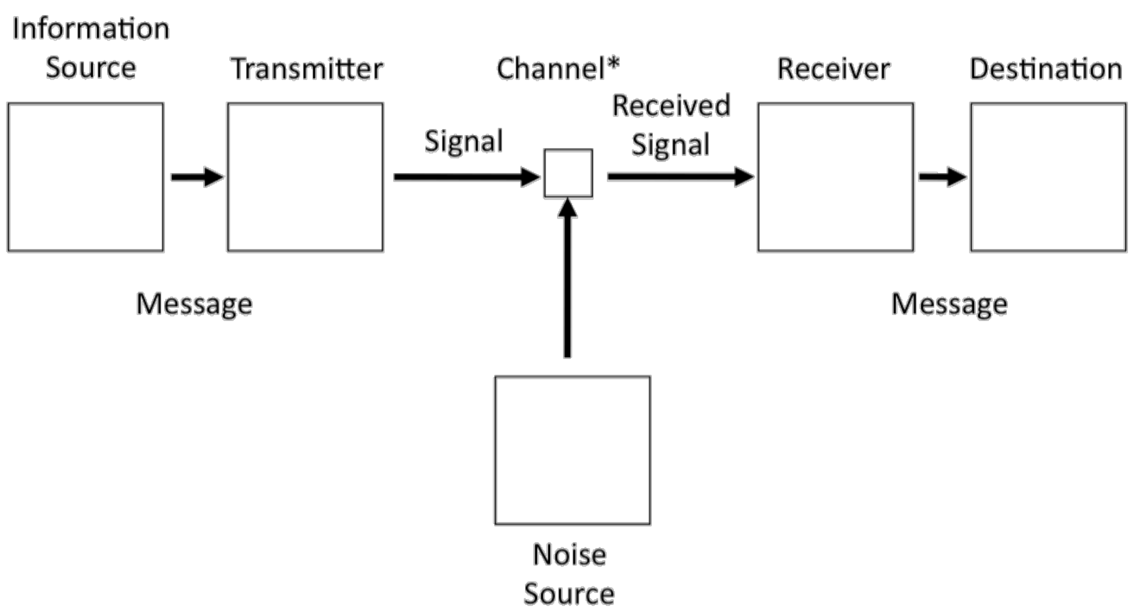
Sensors and platforms become components of that system

Timeliness is therefor the time from information deficit to a decision being informed by that information

A Mathematical Theory of Communication

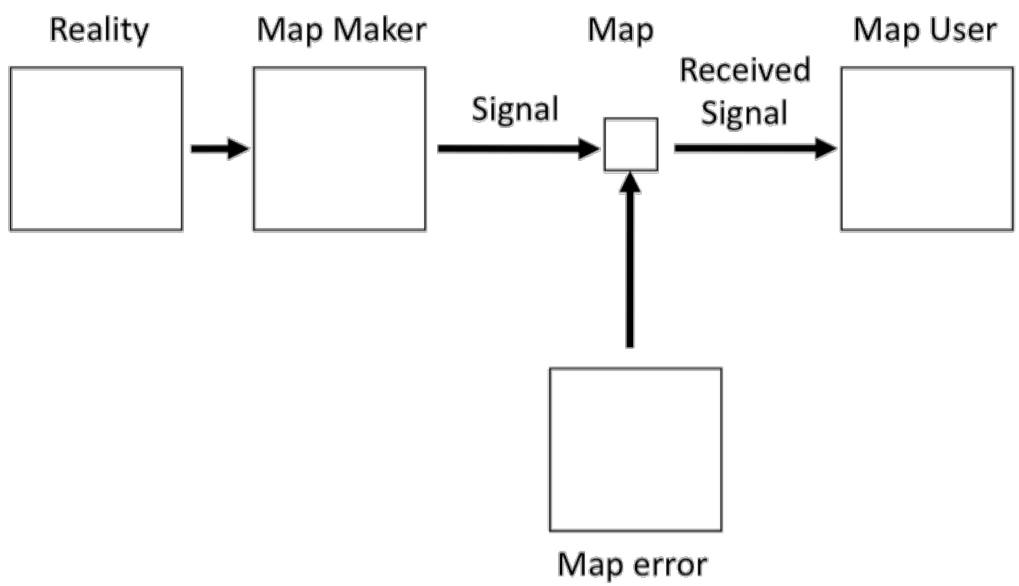
Proposed by Shannon (1948) and elaborated on by Shannon and Weaver (1963)

- Foundation of what is now known as 'Information Theory'
- the problem of "reproducing at one point either exactly or approximately a message selected at another point"



The Map Communication Model

- Conceptualizes the map as a channel
- Emphasizes that what is encoded by the cartographer is different that what is perceived by the map-reader
- Demonstrates the use of communication models to explain the production and consumption of geographic information (Robinson and Petchenick 1976).



The Map Communication Model

"**cartographic work cannot obtain its maximum effect if the cartographer looks upon the production and the consumption of the map as two independent processes**. That maximum effect can only be obtained if he considers the creation and utilization of works of cartography to be two components of a coherent and in a sense **indivisible process in which cartographical information originates, is communicated, and produces an effect**…" (Kolacny 1968)

Communication

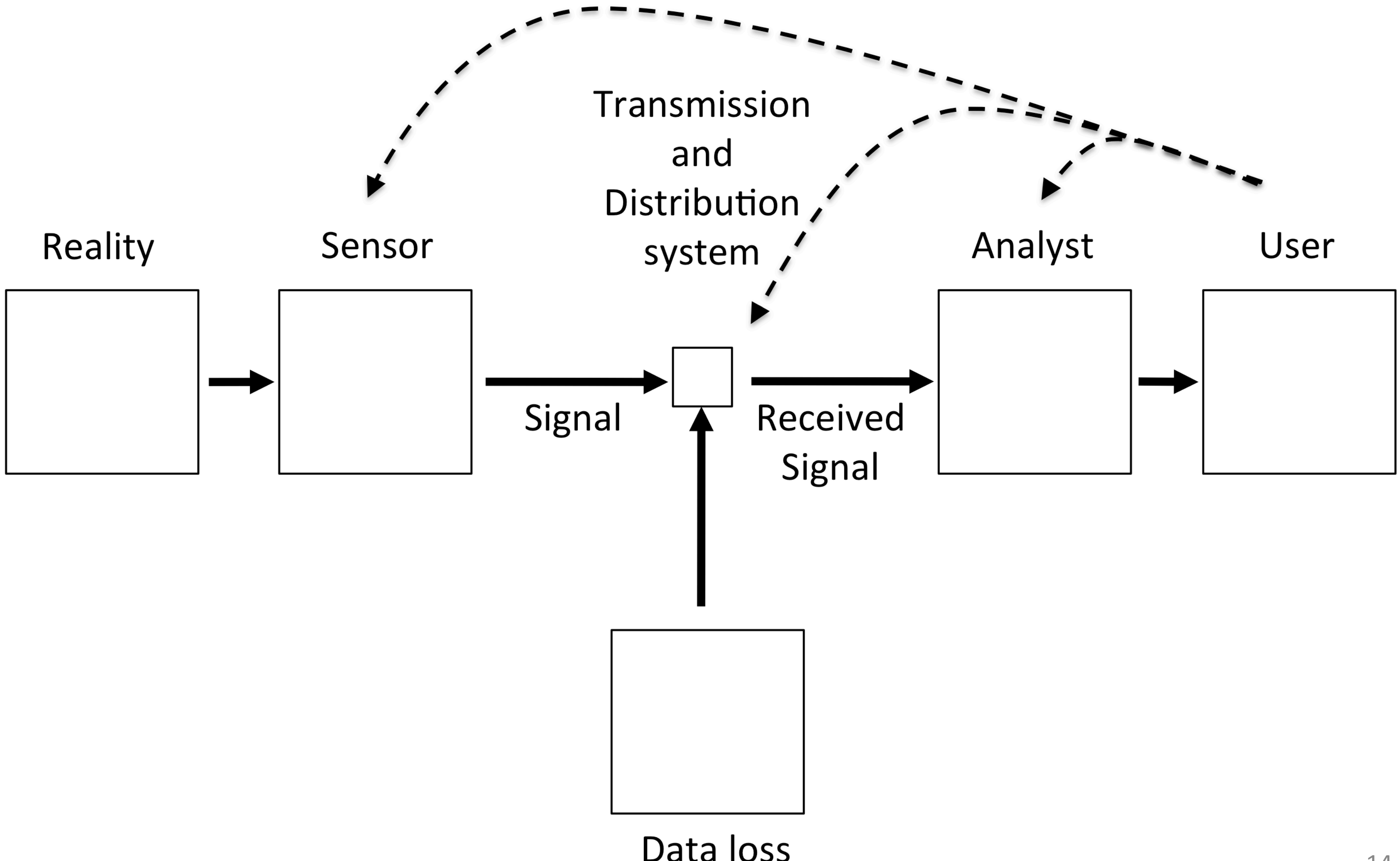
Shannon and Weaver (1963) argue that information value is affected by three levels of communication:

<u>Level A</u> the accurate transmission of symbols (i.e., the Technical problem),

<u>Level B</u> the proper interpretation of those symbols into a given meaning (i.e., the Semantic problem) and

<u>Level C</u> the effect of the receipt of those interpreted symbols (i.e., the Effectiveness problem)

The Remote Sensing Communication Model



Adapted from Lippitt, C.D., D.A. Stow, and K. Clarke, 2014. International Journal of Remote Sensing

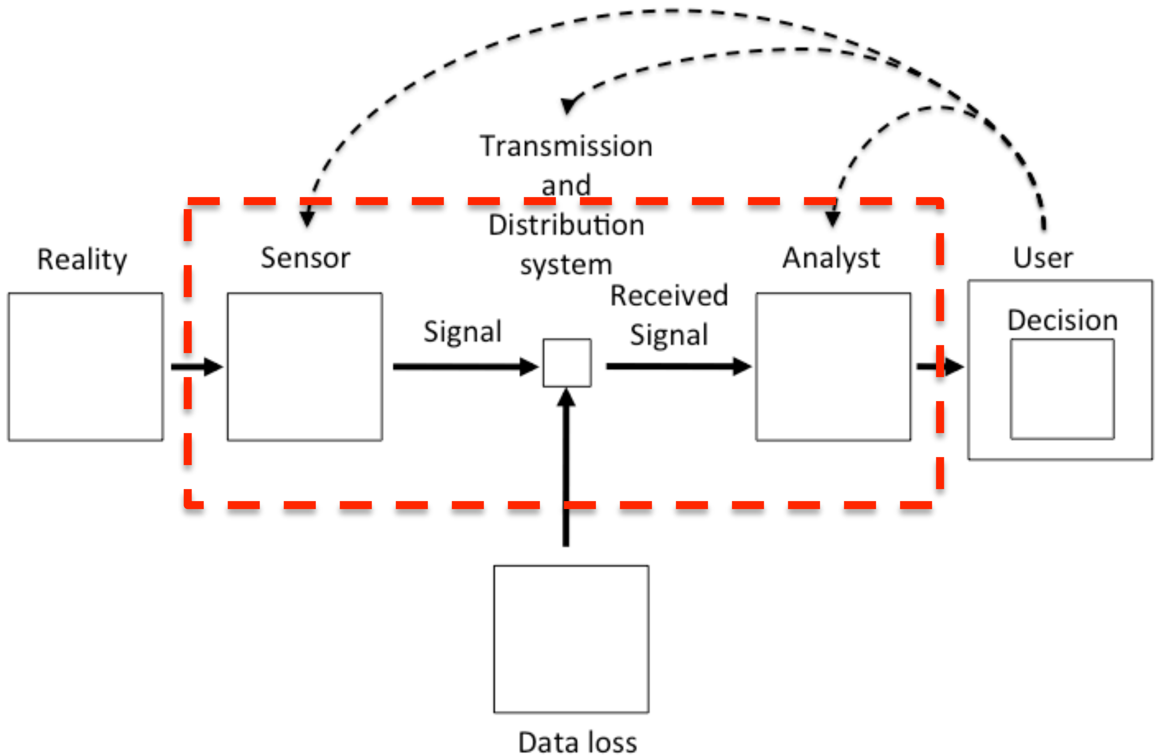
The Remote Sensing Communication Model

According to Shannon and Weaver		A Remote Sensing System
the accurate transmission of symbols (i.e., Technical problem),	→	data delivered to an analyst must accurately characterize the phenomena of interest
the proper interpretation of those symbols into a given meaning (i.e., Semantic problem)	→	analyst must properly interpret those data into information that is relevant to the user
the effect of the receipt of those interpreted symbols (i.e., Effectiveness problem)	→	the information must produce an effect when delivered to the user

Remote Sensing is fundamentally an information production system – its about decisions!

The Remote Sensing Communication Model

Transmitters (Sensors), Channels (Transmission and Distribution Systems), and Receivers (Analysts) all have a capacity in Volume/Unit time



The Goal

To maximizing the effectiveness of the information produce by Remote Sensing System(s?)

- Minimize time-to-information (Maximize the capacity) of Remote Sensing System(s?)
- Maximize product utility

Sensor (Transmitter) Capacity

Sensor Capacity

A product of platform and sensor characteristics

$$C_S = \beta B_A$$

$$T_A = \frac{B_S}{C_S} + T_D + T_M(N-1)$$

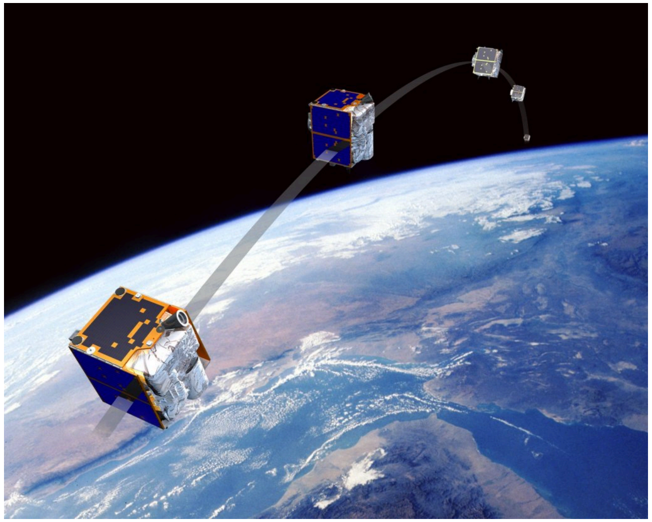
C_S = sensor capacity in bits per unit time
β = rate of acquisition in area per unit time assuming no end lap or side lap
B_A = bits per unit ground area

T_A = total acquisition time
T_D = time required to deploy to the scene
T_M = time required to maneuver the platform between flight lines or paths
N = number of flight lines or paths required to image the scene
B_S = total number of bits required to image a given scene

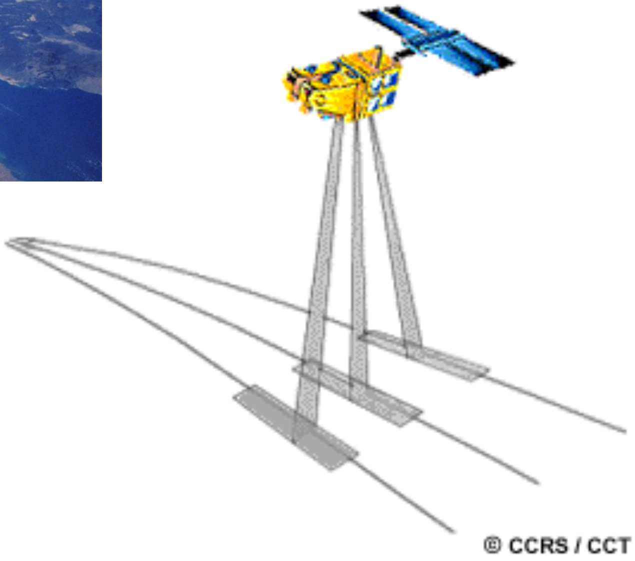
Sensor (Transmitter) Capacity

Options to minimize time:

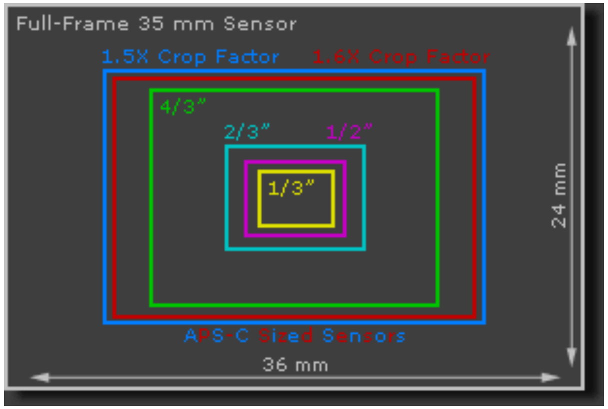
Constellations



Point able Sensors



Larger Detectors



A caveat: timeliness is not just about rates – its also about observing at the right time

Channel Capacity

Channel Capacity

A product of communication mechanisms

$$T_C = \sum_{i=1}^{n} \frac{B_S}{C_{C,i}} + L_i$$

T_C = time required to transmit data from the sensor to the analyst

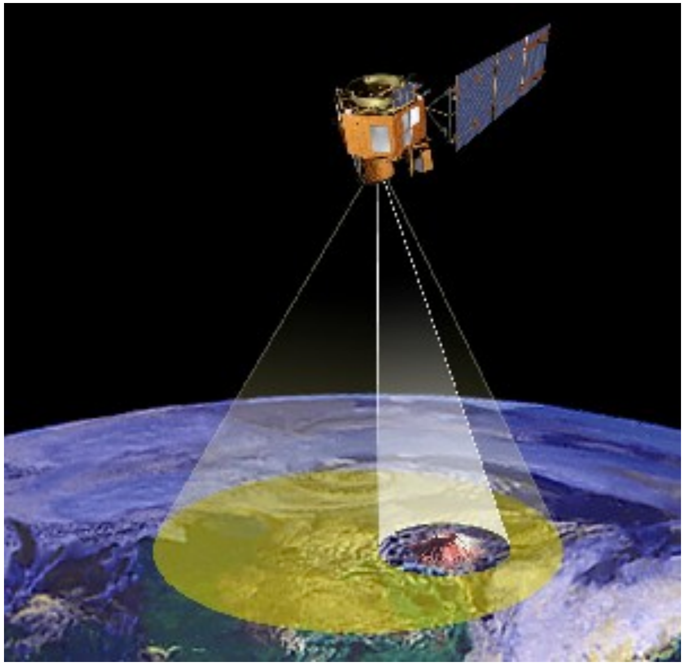
$C_{C,i}$ = channel capacity in bits per unit time for channel segment *I*,

L_i = latency in the system for channel segment *i* in units of time

Channel Capacity

Options to minimize time;

- Reduction of resolution (Spectral, Spatial, Radiometric)
- Shorter transmission path
- Higher bandwidth
- Onboard processing



ase.jpl.nasa.gov

Analyst (Receiver) Capacity

Receiver Capacity: Automated

A product of the desired information relative to the data received

$$C_{Aa} = \frac{h}{\phi}$$

$$\phi = \frac{\sum_{i=1}^{n} a_i}{P_S}$$

$$a_i \in \{\log P_S, .., P_S, .., P_S \log P_S, .., {P_S}^2, .., P_S!\}$$

$$T_R = \frac{P_S + P_R}{C_{Aa}}$$

C_{Aa} = receiver capacity in records per unit time

h = rate of processing in hertz (sec^{-1})

ϕ = computational cycles per record required to extract the required information

P_S = total number of samples required to image a scene

P_R = number of records of ancillary data

Analyst (Receiver) Capacity

Receiver Capacity: Human

A product of the desired information relative to the data received

$$T_R = \left(\frac{O_A}{A_S}\right)\frac{1}{C_{Ah}}$$

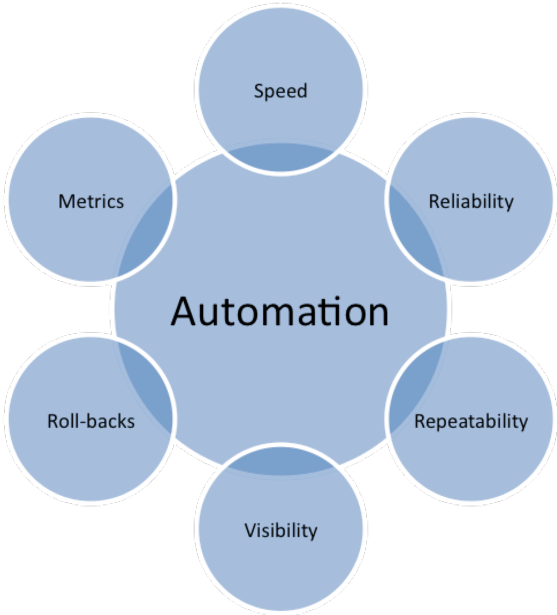
O_A = the minimum mapping unit

C_{ah} = the efficiency of an analyst at interpreting the phenomena of interest from the image of interest in units of the number of O_A per unit time

Analyst (Receiver) Capacity

Options to minimize time

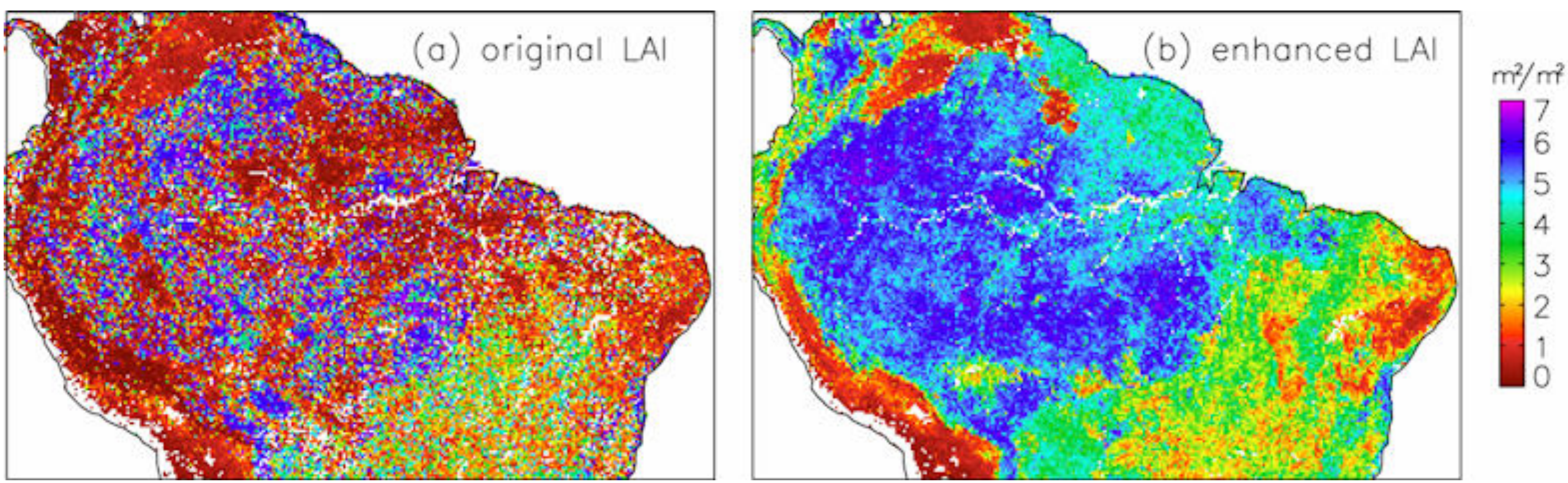
- More resources (Hardware/Human)
- More customized resources (e.g., FPGA, GPU)
- Automated workflows



Level A: The Technical Problem

"Data delivered to an analyst must accurately characterize the phenomena of interest"

The traditional strength of Remote Sensing



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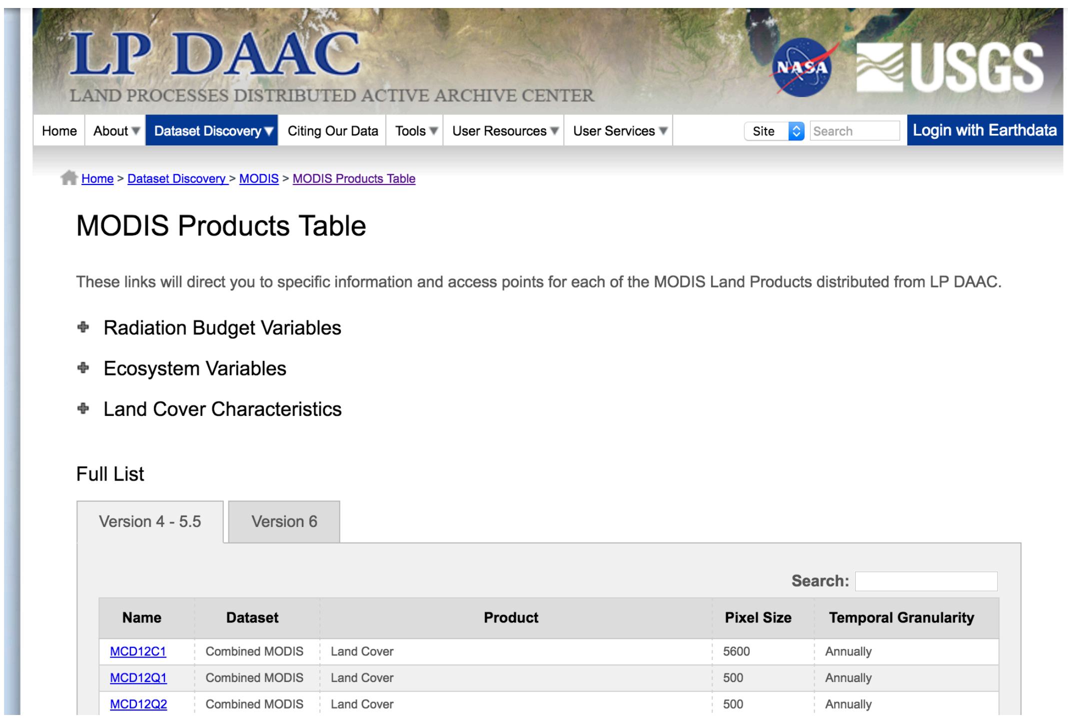
Level B: The Semantic Problem

"analyst must properly interpret those data into information that is relevant to the user"



Products targeted to specific user groups (e.g., hazard managers) help better satisfy the semantic problem

What if we separate the technical problem from the semantic?

Level C: The Effectiveness Problem

"information must produce an effect when delivered to the user"

- Requires integrating into SOPs
  - reliable standardized products
- Outreach/training
- Making Remote Sensing more 'accessible'
  - Reducing costs required (hardware, software, bandwidth)
  - Reducing training requirements
  - Engineering products for ease of use
- User-type customized access/portals

I believe this is our 'last mile' and principle challenge

So What?: Recommendations for Increasing the Effectiveness of Current and Future Remote Sensing Systems

- Continue to 'MODISize'
  - Automated products customized to specific user groups, but this does not need to be, and perhaps should not be, done by NASA directly
  - Offer API that allows users to automate custom products
- Move toward constellations of lower cost sensors
- Move preprocessing onboard
- Continue to automate processing routines

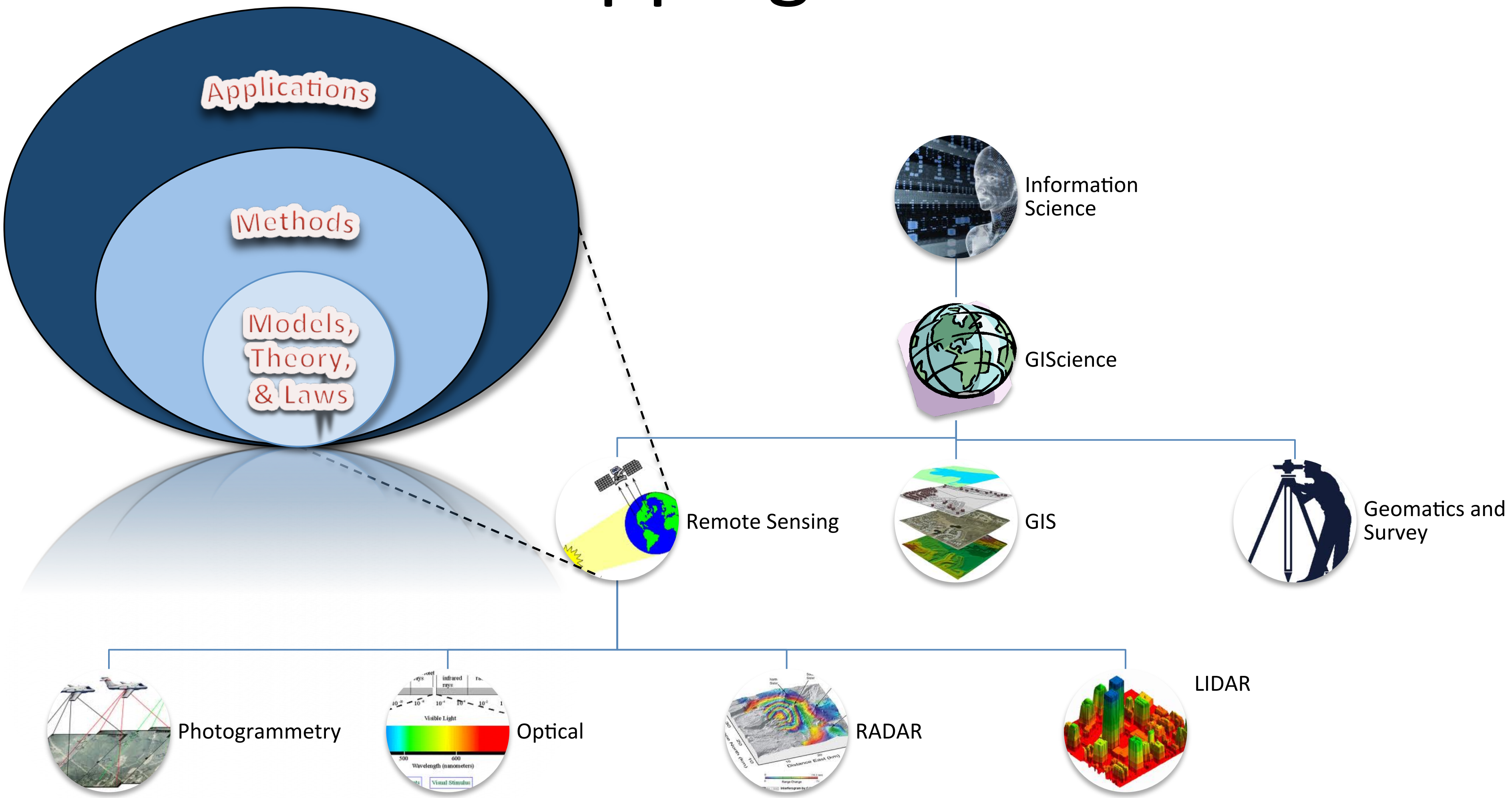
Recommendations for Increasing the Effectiveness of Current and Future Remote Sensing Systems

- Work toward high level, easy to use products
- Enable construction of user-type specific portals through a high level Web 2.0 architecture for accessing and manipulating products
- Strongly encourage portal developer programs to integrate remote sensing into user SOPs
- Produce 'flat' low volume, user specific products

Some Thoughts on Timeliness

- Everything effects timeliness
- There are options/tradeoffs, so maximizing effectiveness requires consideration of the entire RSS
- Real-time and NRT are relative to the user, but tags (e.g., a. <5min, b. <1hr) are useful for data sensor (data available) time
- Temporal resolution doesn't effect timeliness, but does effect 'Window of Opportunity', and therefor system effectiveness

Stepping Back



Theory and models required to inform the engineering exercise

Thank You

For more information, contact:

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Also see: Lippitt, C.D. 2015. Remote Sensing from Small Unmanned Platforms; a paradigm shift. *Environmental Practice 17 (3): 235-6.*

Lippitt, C.D., D.A. Stow, and K. Clarke. On the Nature of Models for Time-Sensitive Remote Sensing. International Journal of Remote Sensing 35 (18): 6815-41.

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