The Sensor Web:
A Revolutionary Way of Seeing the Earth

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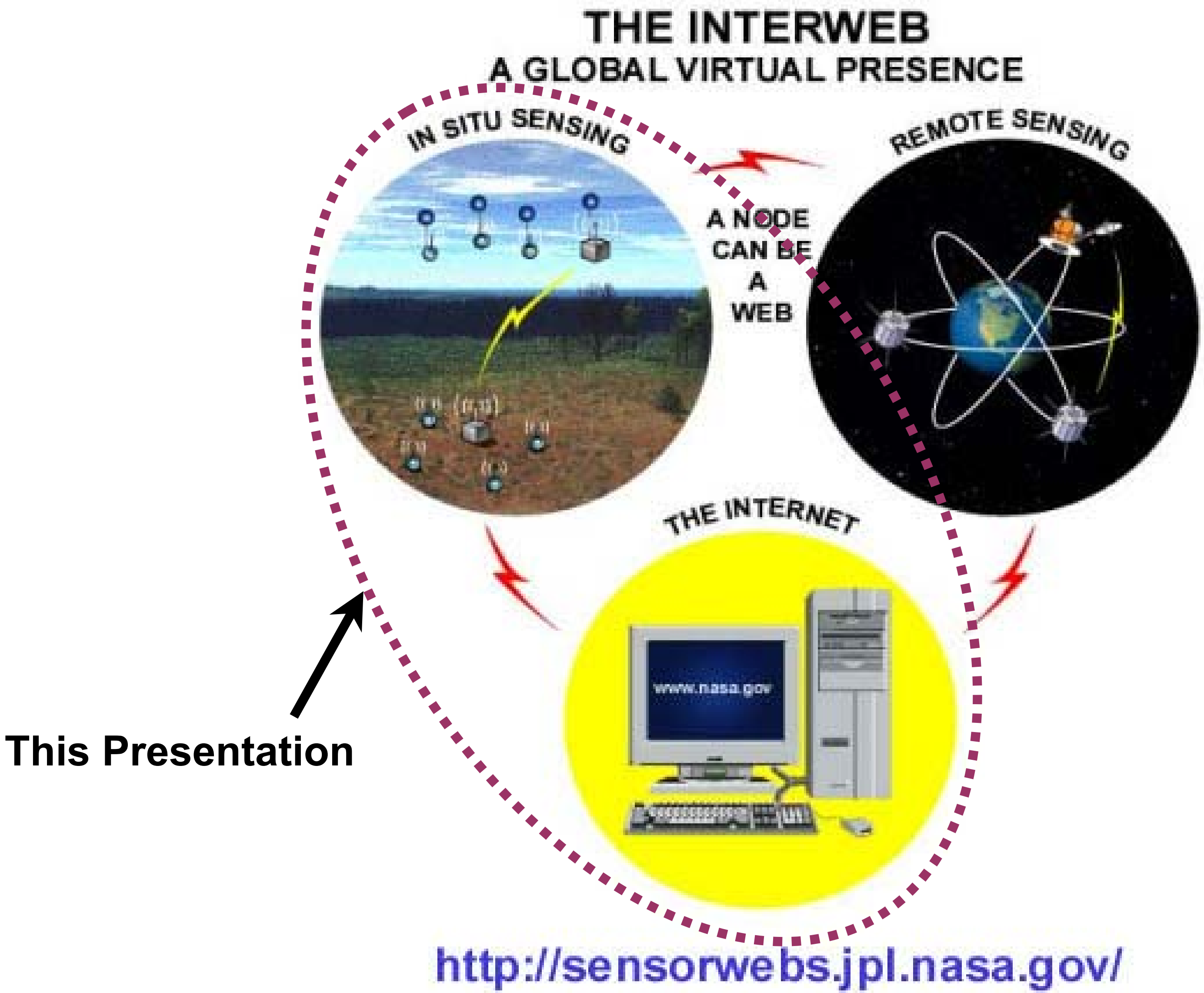
Sensor Web Overview



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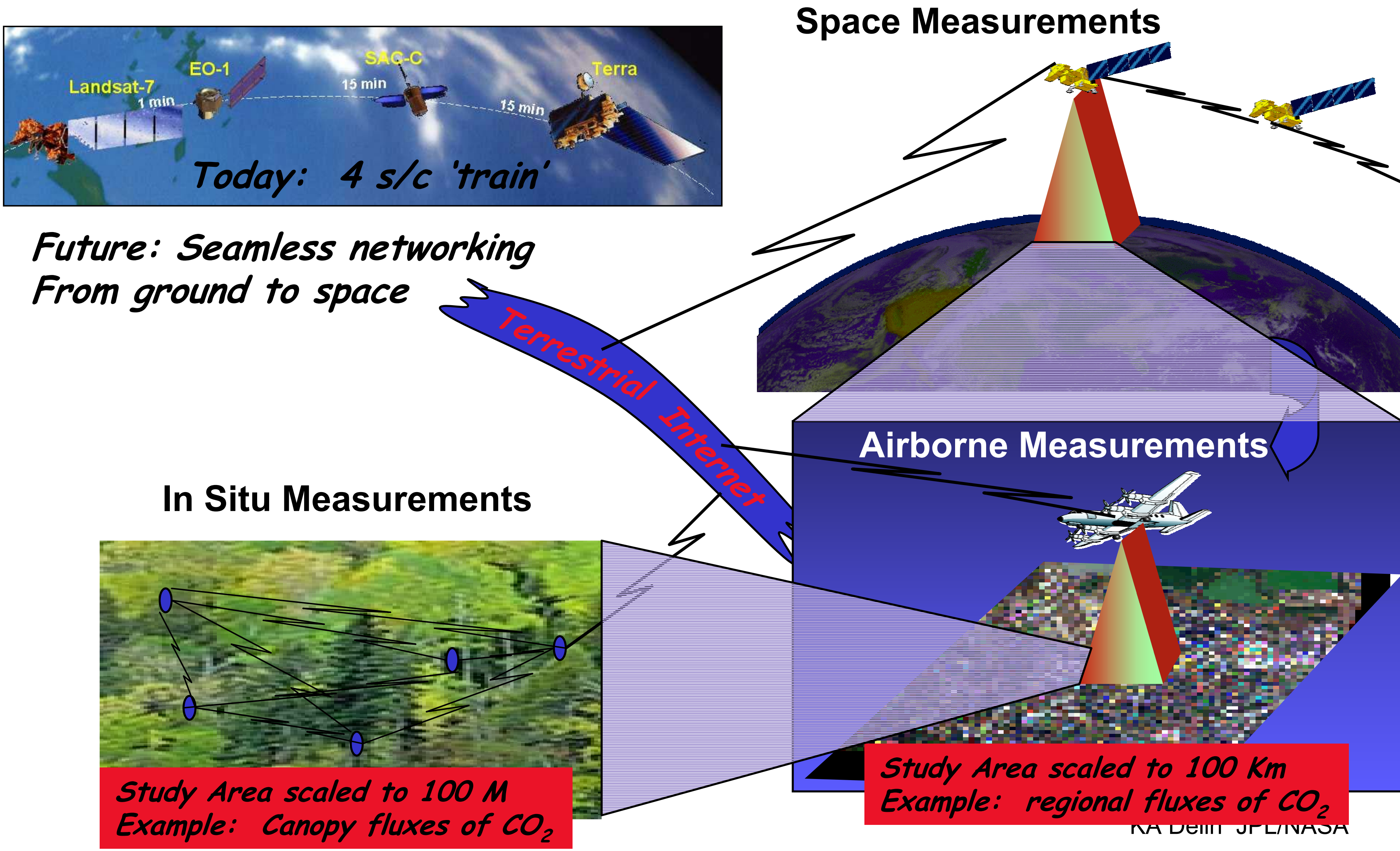
Sensor Web Overview: CO_2 Example



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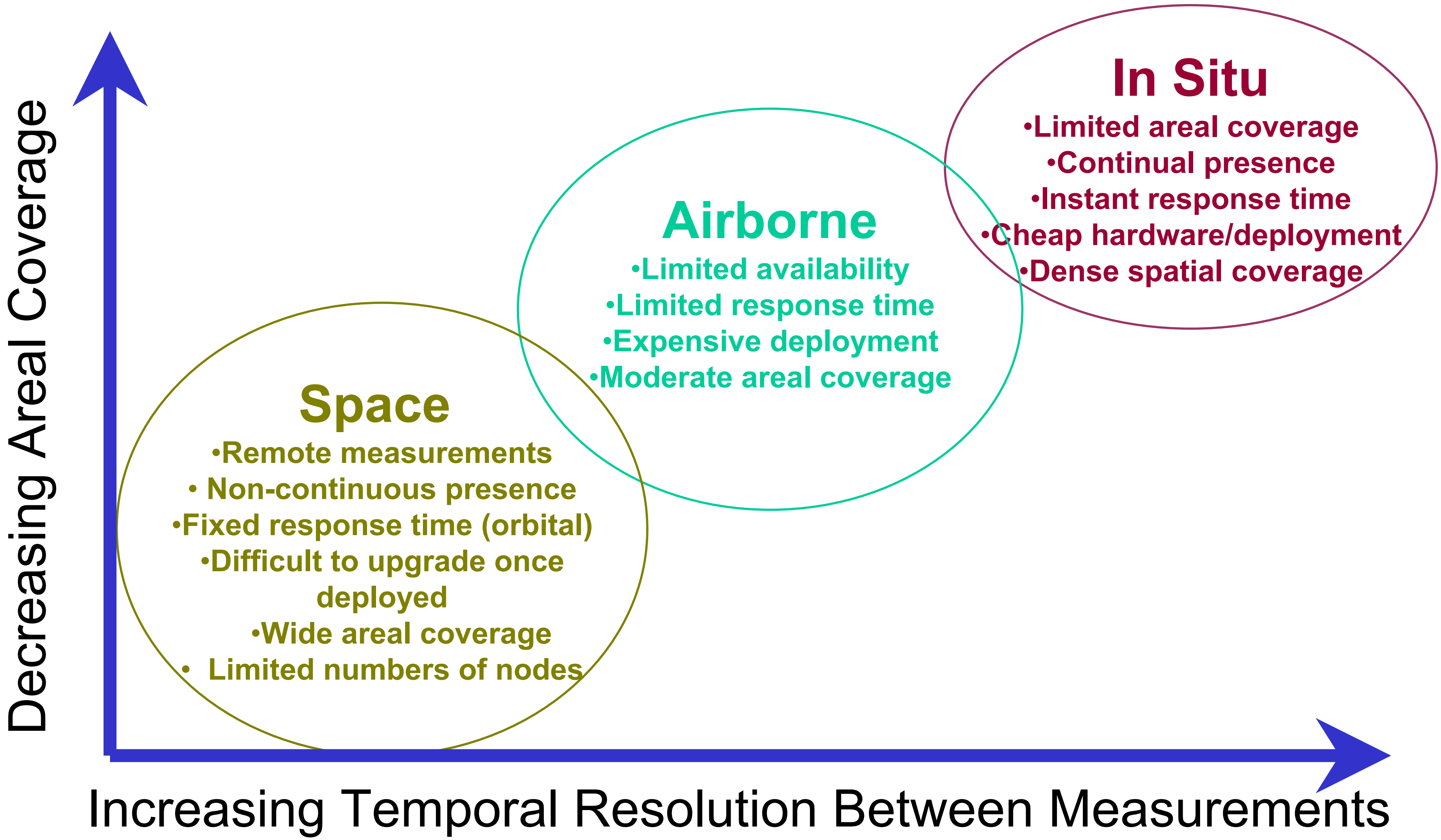
Sensor Web Regions of Applicability



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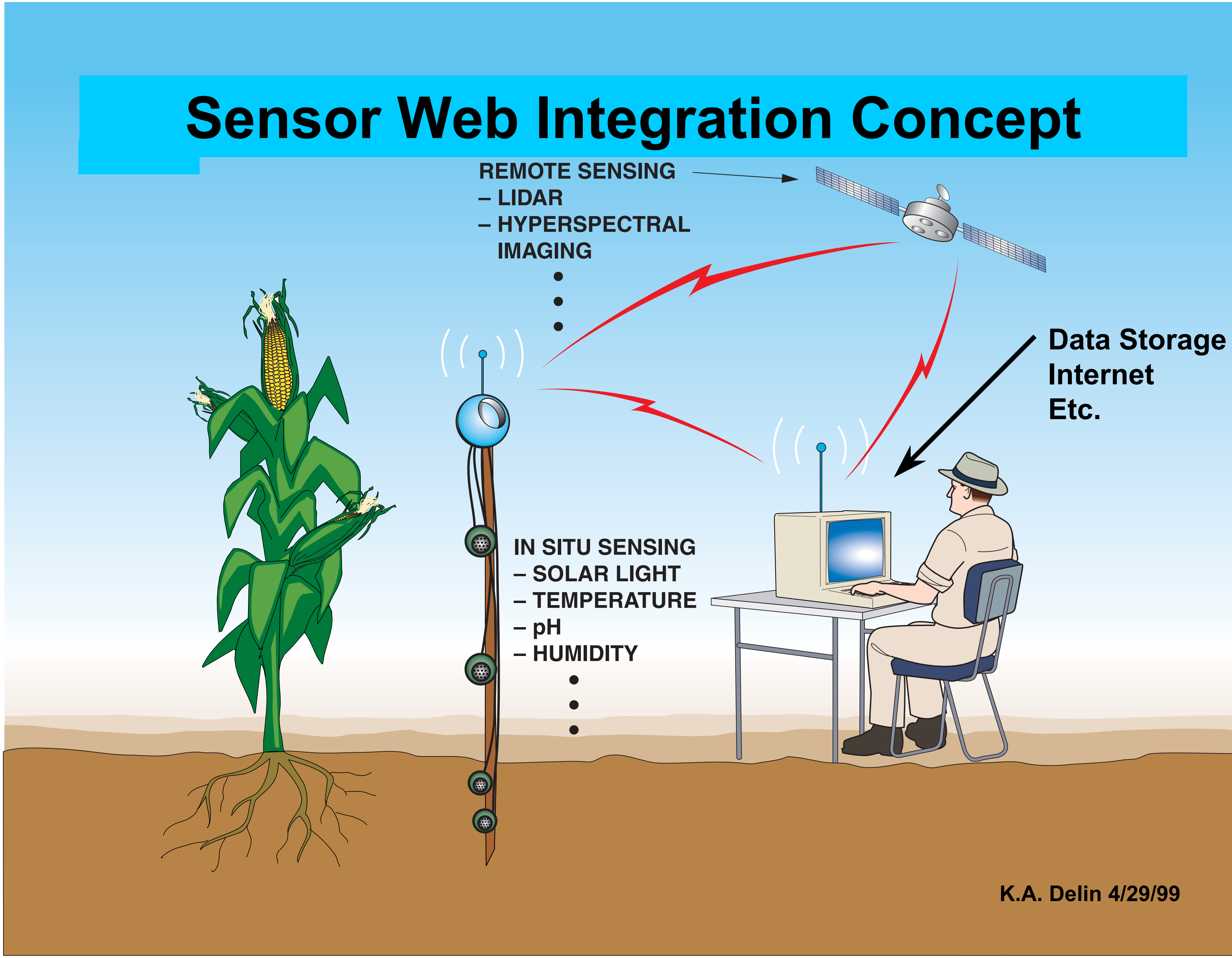
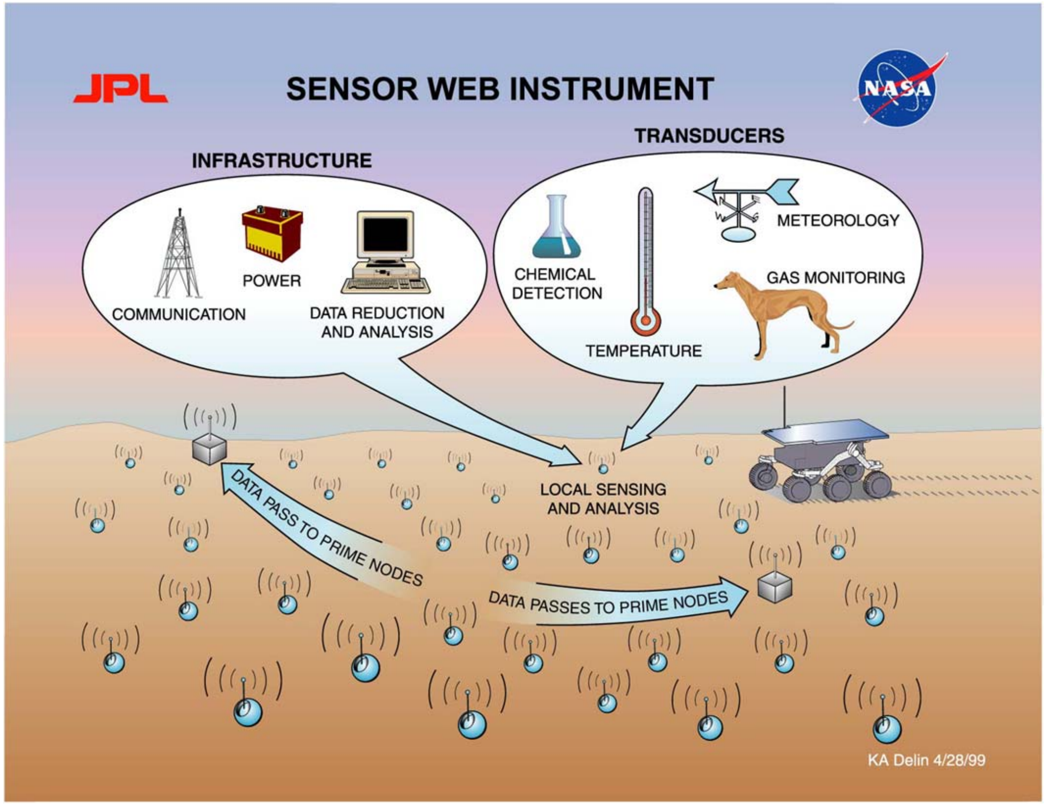
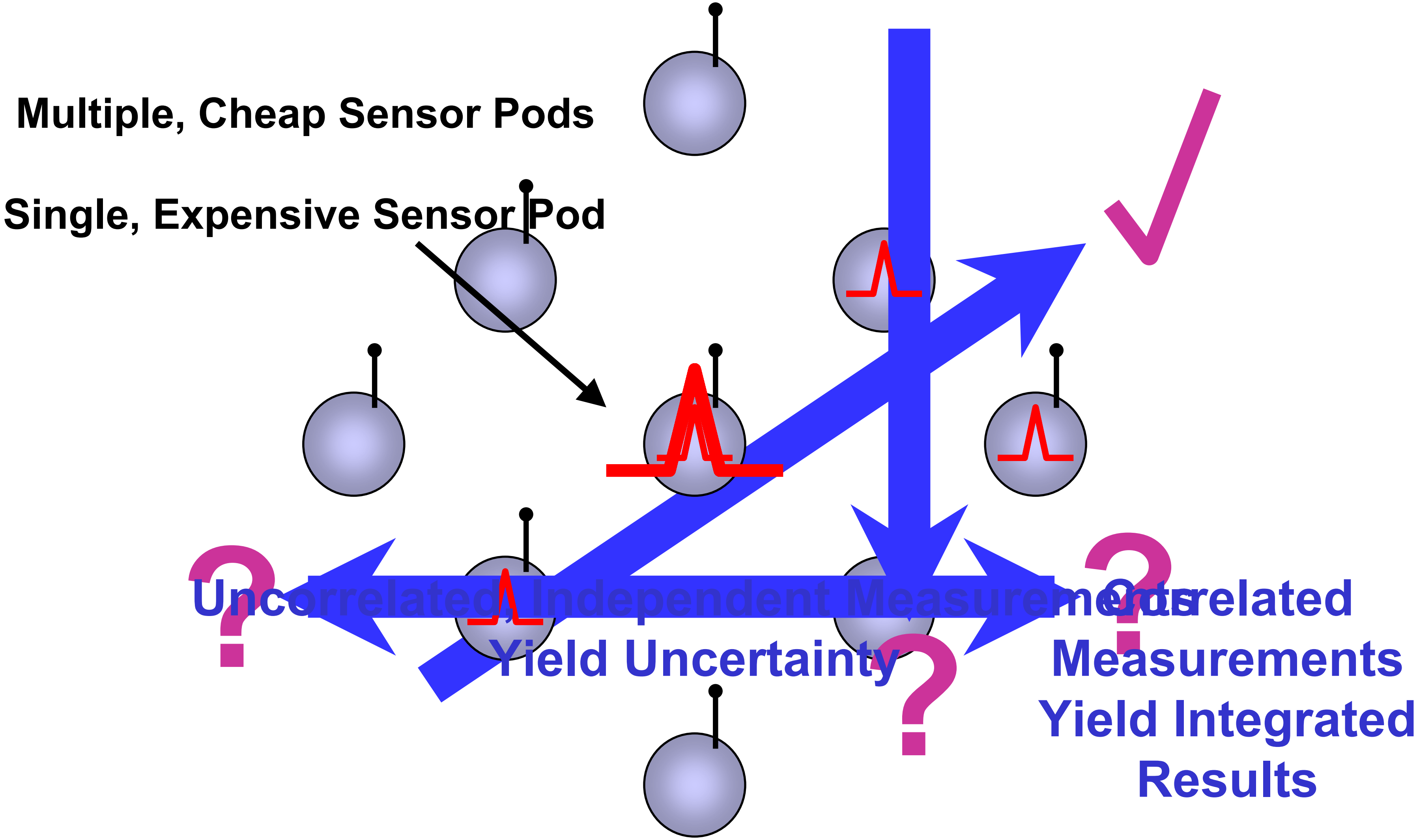

Sensor Web Integration Concept
REMOTE SENSING
– LIDAR
– HYPERSPECTRAL IMAGING
Data Storage
Internet
Etc.
IN SITU SENSING
– SOLAR LIGHT
– TEMPERATURE
– pH
– HUMIDITY
K.A. Delin 4/29/99

In Situ Sensor Web Characteristics



- Continual, virtual presence
- Limited geographical area
- Easily deployed
- Field-Evolvable Instrument (Field Upgradable / Field Programmable)

How In Situ Sensor Webs Work



In Situ Sensor Webs provide Spatio-Temporal Information!

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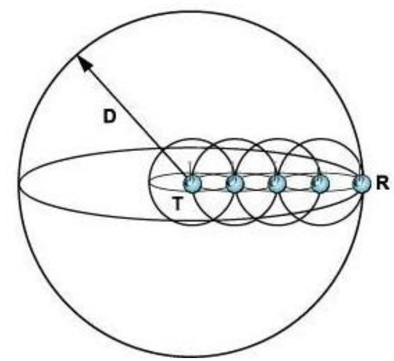
Key Req's for In Situ Sensor Web

FRIIS TRANSMISSION EQUATION: $P_{transmit} \propto r^m P_{receive} \quad (2 \leq m \leq 4)$

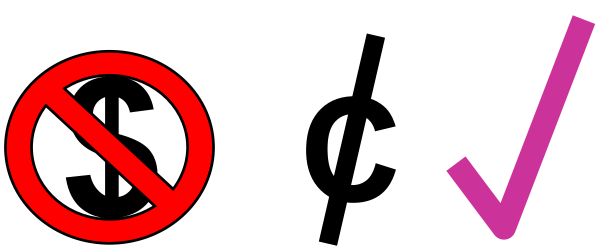
$$\Rightarrow P_{transmit} \propto \frac{1}{N^{(m-1)}} D^m P_{receive}$$



1. **Micro-Power:**
   Req: Long-lived pod operation
   Multi-Hopping is power efficient communication link.

2. **Micro-Bandwidth:**
   Req: Communication over limited data pipelines
   Eliminate TCP/IP

3. **Micro-Cost:**
   Req: Low cost pods to limit Sensor Web cost
   Leverage COTS technologies



	Sensor Web	Internet	Deep Space
7	Sensor Web Application Messages and other application protocols		
4	(none)	TCP	(none)
3	(none)	IP	CCSDS TM/ TC packets
2	Sensor Web Link Protocol	Ethernet, SONET	CCSDS TM/ TC frames
1	R/F	Cable, fiber	R/F

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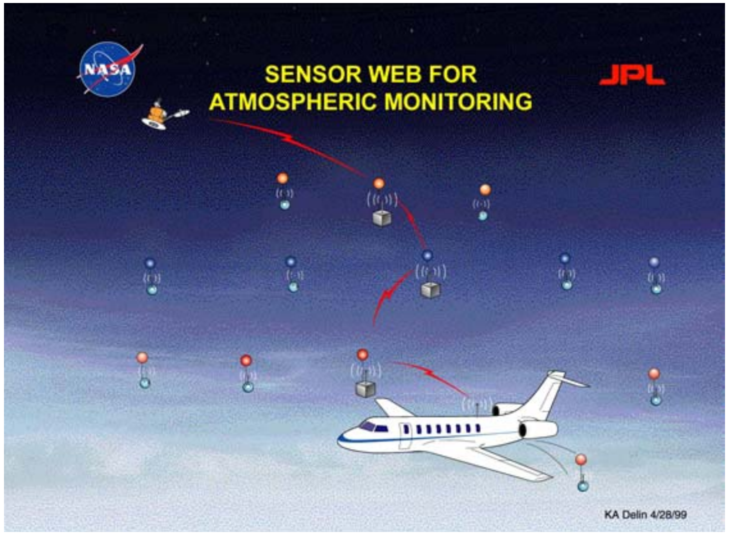
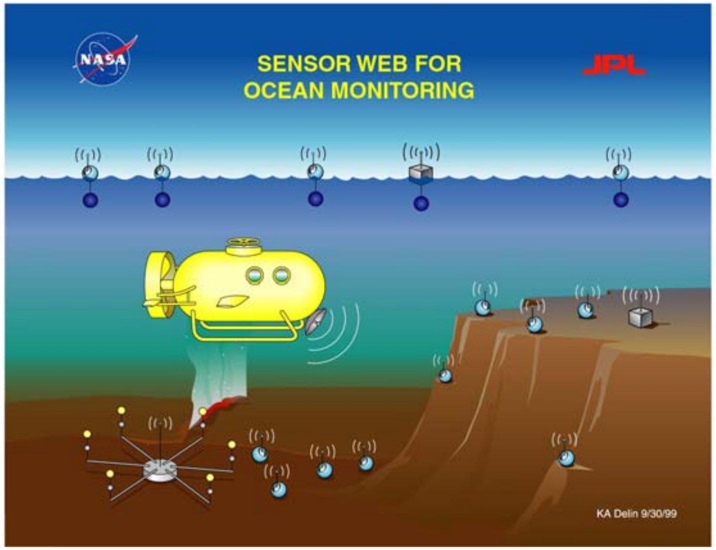
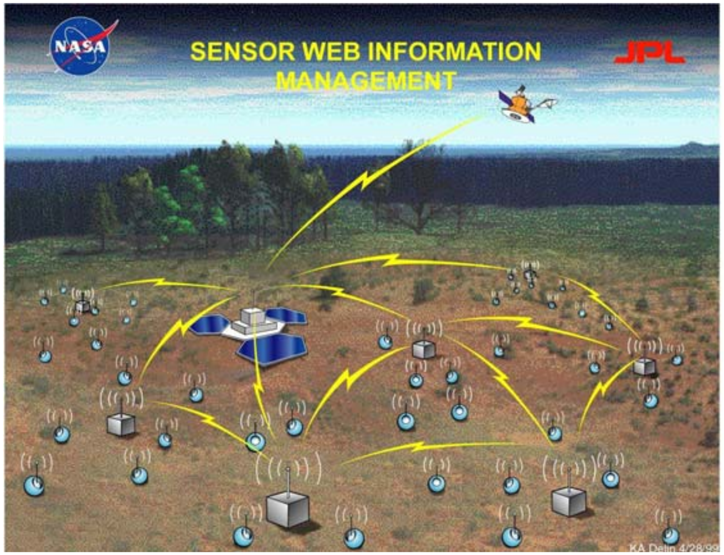
In Situ Sensor Web Applications

Considered here:

- Atmospheric Studies (Carbon Cycle)
- Ocean Studies (Run-Off)
- Land Management (Agricultural)







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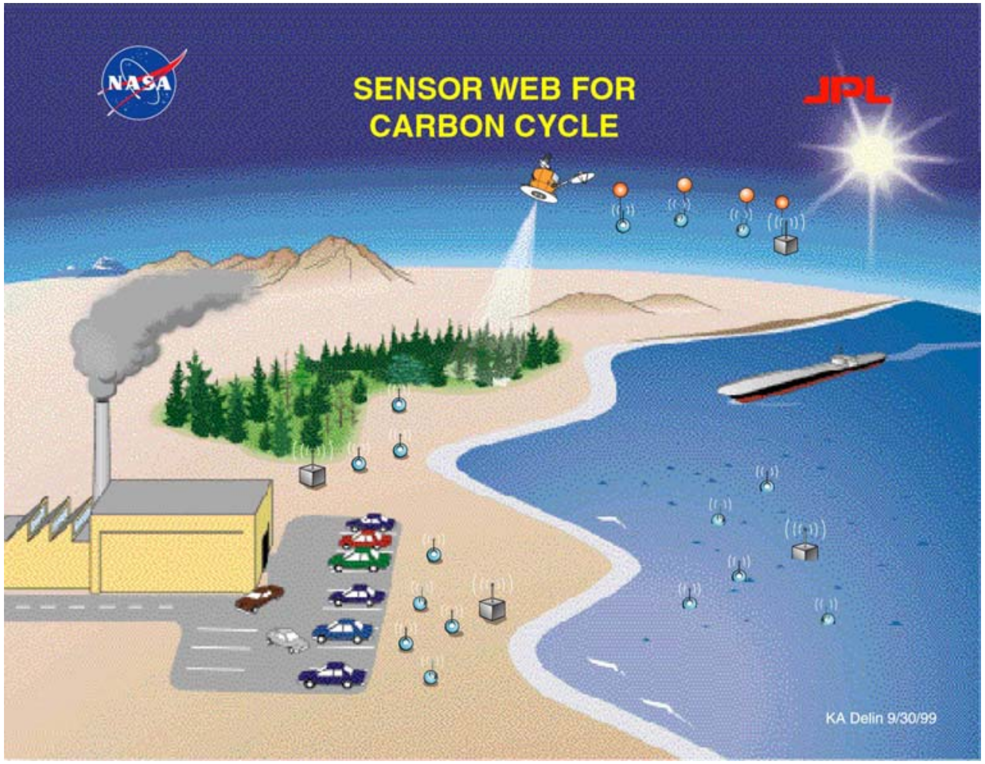
Sensor Webs and the Carbon Cycle

Sensor Web Approach:

- Permits a fine-mesh metric of quantitative CO_2 measurements and assessment of process variation which are interactive with other parameters across multiple environments.
- Embeds a heterogeneous set of sensors within a cognitive network.
- Measures primary and secondary cause and effect changes and optimizes measurement strategy for determination of process rates; performs spot-checks of accuracy and completeness by limited use of high-sensitivity, wide-bandwidth sensors and follow alert level occurrences.



- Learns to recognize a pattern and follow the development of patterns and the level of their repetitiveness.

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Carbon Cycle Sensor Web Specs

APPLICATION:	MONITOR ATMOSPHERIC TRACE GASES AT SURFACE, POLLUTION MONITORING
1.0 Sensor Web Description	
1.1 Goal of Web Usage	Passive monitoring
1.2 Passive Monitoring / Active Exploration	Internet, Laptops
1.3 Ultimate Point of Uplink / Downlink	NB - Upgrade trace monitoring to include isotopic measurements, or particulates
2.0 Spatial Scale	
2.1 Dimensionality	2D - or 1D of measurement - e.g. coastal region
2.2 Area Coverage	
2.2.1 Ideal	Ideal 30km x 30km for area of 300 km2
2.2.2 Minimum	Minimum 100 x 100km for area of $300km^2$
2.3 Average Distance Between Neighbors	~ 50km: Question: Can they talk to each other at this distance?
2.4 Distribution of pods	Clumpy is acceptable, esp. if clumps are in areas of interest.
3.0 Measurements	
3.1 Number of Measurements at each pod	Wind, concentration of a gas, isotope, temp, humidity. Possible ability to change what species is monitored.
3.2 Frequency of each Measurement	Max 4 x/day Min 1 x/week - or - series of continuous measurements ~ every 10 minutes.
3.3 Precision of each Measurement	
3.4 Local Processing / Reduction of Data	If continuous, send out average of a few hrs.
3.5 Total Lifetime	
3.5.1 Pod Lifetime	
3.5.2 Application Lifetime	

Sensor Webs and the Ocean

Sensor Web Approach:

- Characterize the physical and chemical properties of a storm water runoff plume in Santa Monica Bay, California.
- Continual presence captures dynamic and unpredictable events such as run-off (unlike remote).
- High spatio-temporal resolution: as close as 10 m (unlike single point *in situ*), as often as 1 minute.
- Integrated measurement approach: Sensor Web information augments and directs satellite and UAV acquisitions.

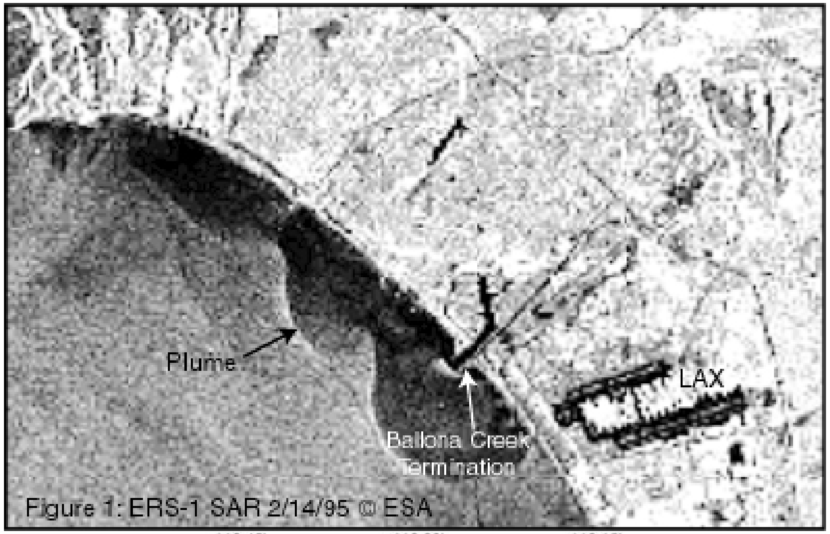
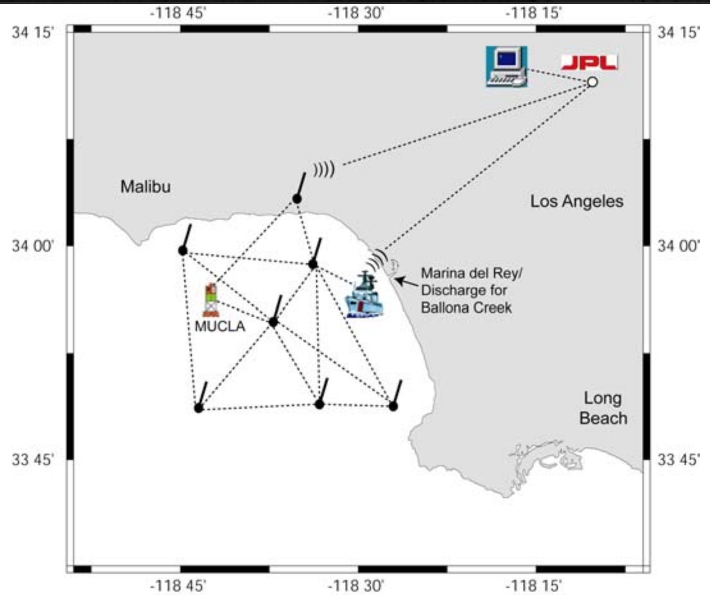


Figure 1: ERS-1 SAR 2/14/95 © ESA



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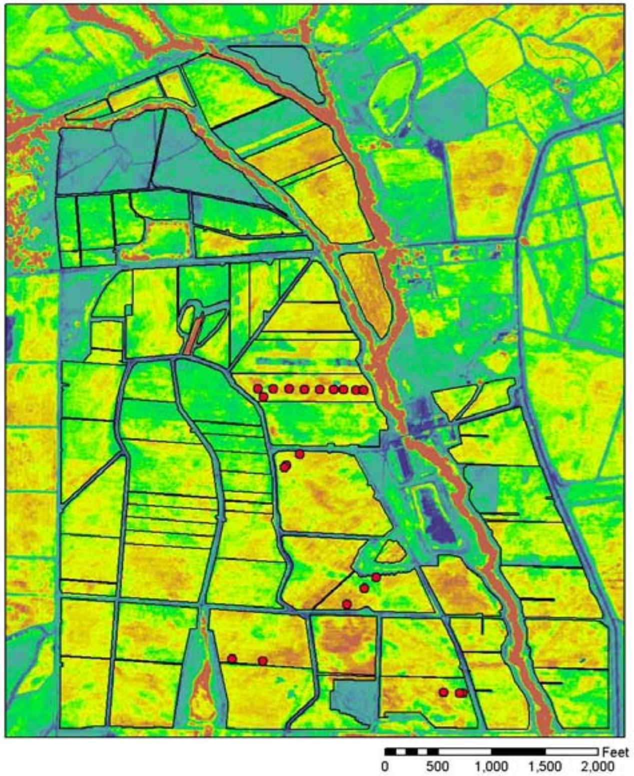
Ocean Sensor Web Specs

APPLICATION:	SEA FLOOR MOORING
1.0 Sensor Web Description	
1.1 Goal of Web Usage	Acquisition and distribution of sea floor and midwaterand surface sensors. System must be portable, configurable
1.2 Passive Monitoring / Active Exploration	Buoy on surface
1.3 Ultimate Point of Uplink / Downlink	
2.0 Spatial Scale	
2.1 Dimensionality	3 - D
2.2 Area Coverage	10's of meters
2.2.1 Ideal	100's of meters
2.2.2 Minimum	
2.3 Average Distance Between Neighbors	meters - 10's of meters
2.4 Distribution of pods	
3.0 Measurements	
3.1 Number of Measurements at each pod	
3.2 Frequency of each Measurement	Hz □ monthly
3.3 Precision of each Measurement	
3.4 Local Processing / Reduction of Data	Filtering of Seismic data
3.5 Total Lifetime	
3.5.1 Pod Lifetime	Months - years
3.5.2 Application Lifetime	Years

Sensor Webs and Land Management

Sensor Web Approach:

- Characterize the microclimates associated with high-yield crops such as grapes.
- Compare detailed *in situ* measurements, such as soil moisture and ground temperature, with leaf area index.
- High spatio-temporal resolution: as close as 1 m, as often as 5 minute (unlike remote).
- Integrated measurement approach: Sensor Web information augments satellite acquisitions.



Leaf Area Index for Mondavi Vineyard (Courtesy: L. Johnson)

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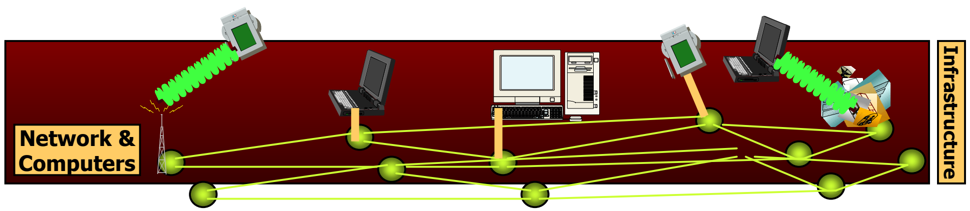
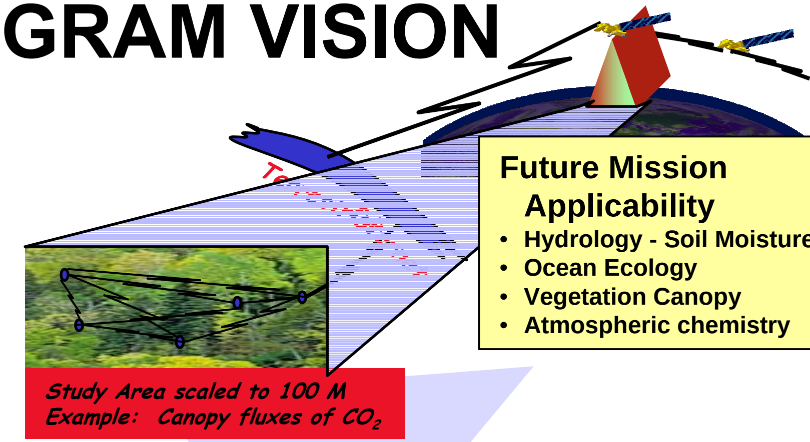
Land Management Sensor Web Specs

APPLICATION:	Vineyard Monitoring
1.0 Sensor Web Description	
1.1 Goal of Web Usage	Provide microclimate monitoring for optimimum graph growth
1.2 Passive Monitoring / Active Exploration	Passive
1.3 Point of Uplink / Downlink	Internet
2.0 Spatial Scale	
2.1 Dimensionality	2-D
2.2 Area Coverage	
2.2.1 Ideal	500 km^2
2.2.2 Minimum	10 km^2
2.3 Average Distance Between Neighbors	1-5 m
2.4 Distribution of pods	evenly throughout trellis
3.0 Measurements	
3.1 Number of Measurements at Pod	8 (2 soil temp, 2 soil moist, light, air temp, humidity)
3.2 Frequency of each Measurement	every 5 minutes
3.3 Precision of each Measurement	
3.4 Local Processing / Reduction of Data	trending to look at ground moisture
3.5 Total Lifetime	
3.5.1 Pod Lifetime	6 months
3.5.2 Application Lifetime	2 years

SENSOR WEB
TECHNOLOGY PROGRAM VISION



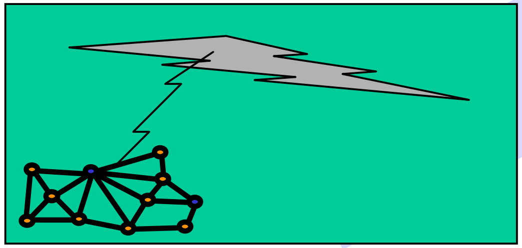
Scalable large system communications



Future Mission Applicability
- Hydrology - Soil Moisture
- Ocean Ecology
- Vegetation Canopy
- Atmospheric chemistry

Low power processors and communication

PAYOFF:
- Low cost calibration and validation
- Distributed measurements for temporal definitions
- Graceful degradation and transparent replacement



Interface to Internet

- *Chem/bio*
- *NMR/Mass spec/GC/LC*
- *Optical/IR*
- *Acoustic/Geophones*
- *Accelerometers*
- *Nuclear*
- *RF (coherent, incoherent)*
- *Magnetic*

2000 → 2010

Low-cost, low-power sensors

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