# Sensor Webs:
# A Geostrategic Technology for Integrated Earth Sensing


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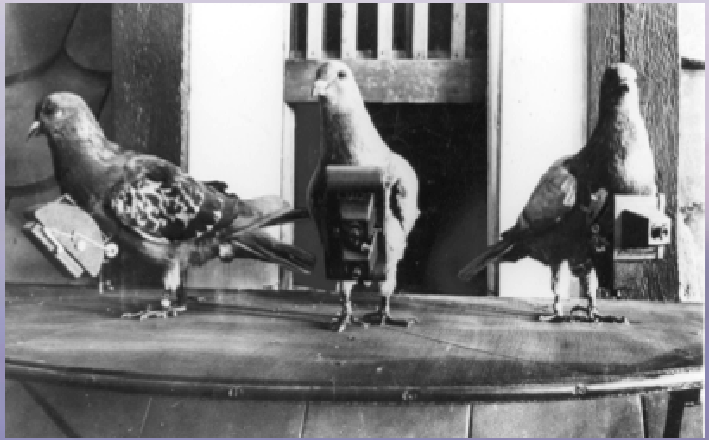
# Sensor Webs: A Geostrategic Technology for Integrated Earth Sensing

- **Definitions:**
  - **Remote, In-Situ and Proximal Sensing**
  - **Sensor Webs**
- **Integrated Earth Sensing**
- **Some Sensor Web Project Experience**
- **Geostrategic Technologies and Perspectives**

# Remote Sensing

# Chronology Interlude: Earth Remote Sensing History Highlights

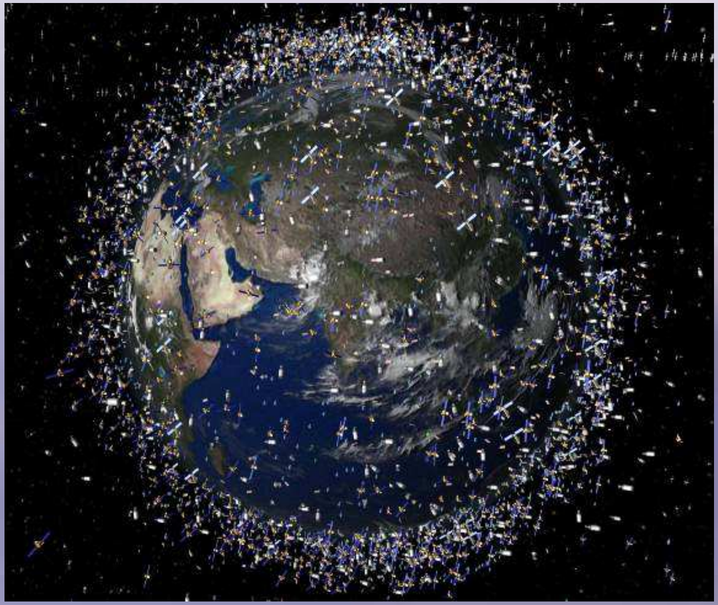
- **700 BC:** Socrates: “Man must rise above the atmosphere and beyond to fully understand the world in which he lives”
- **1859:** Aerial Balloon Photography (France)
- **1903:** The Bavarian Pigeon Corps
- **1909:** Photos from an Airplane
- **1959-1960:** First Weather Satellites



- **1972:** First Landsat Remote Sensing Satellite (ERTS-1)
- **2007:** US NRC publishes “Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond”

# Definitions

- **Remote sensing:**
  - ➢**"sensing from a great distance"**



- **In situ sensing:**
  - ➢**"sensing in place"**
- **Proximal sensing:**
  - ➢**"sensing from close range"**

# Definition: Sensor Web

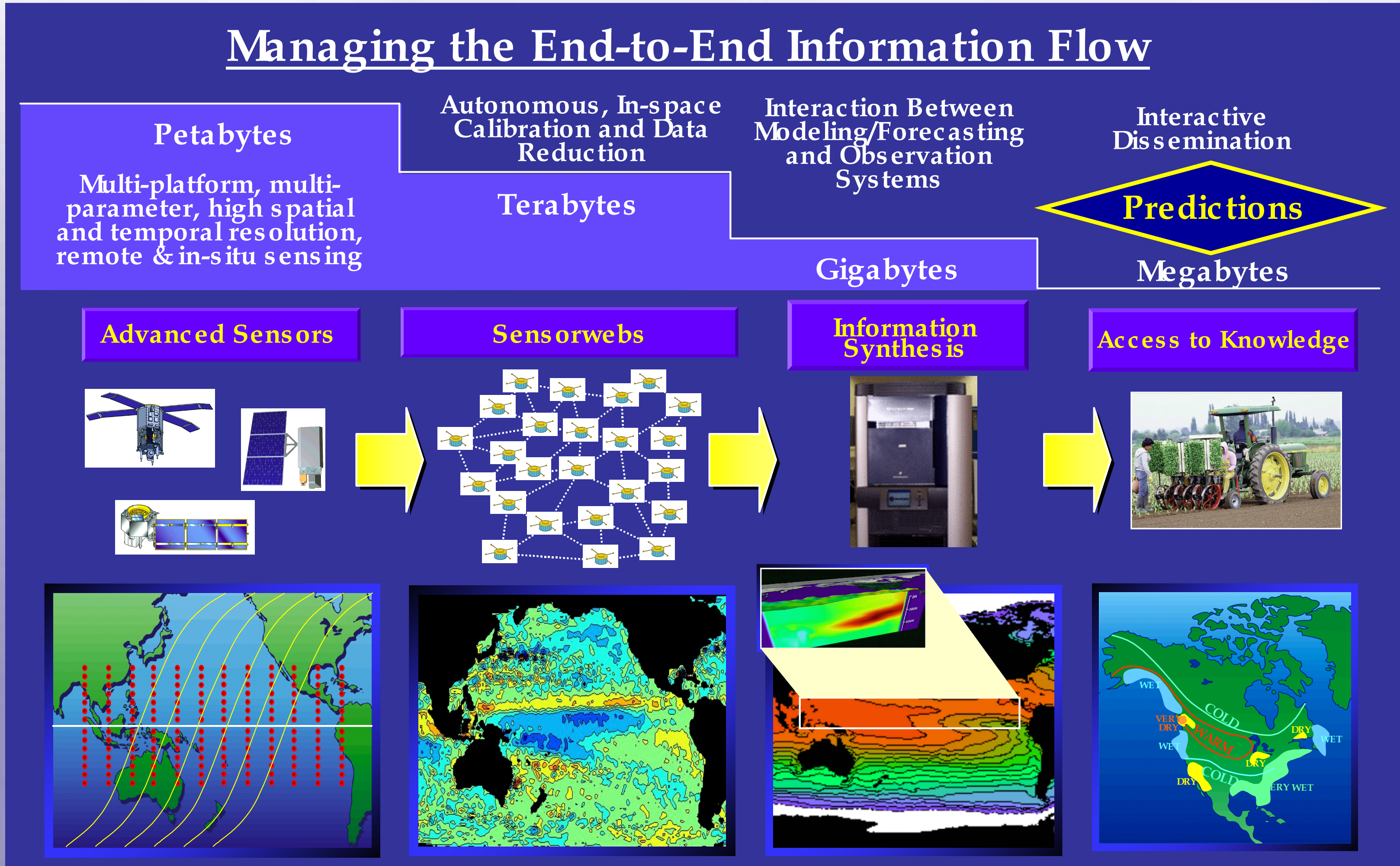
- A sensor web can be defined as:
  - A system of autonomous, wireless, intra-communicating, spatially-distributed sensor pods that can be deployed to monitor and explore new environments, i.e., a smart macro instrument for coordinated sensing (Delin, JPL).

- In space: Cooperating, interoperable satellite platforms and sensors (aka satellite webs).

- Sensor network elements collect data; sensor web elements collect and share data, and modify their behaviour on the basis of collected data. Sensor webs are also www-enabled.

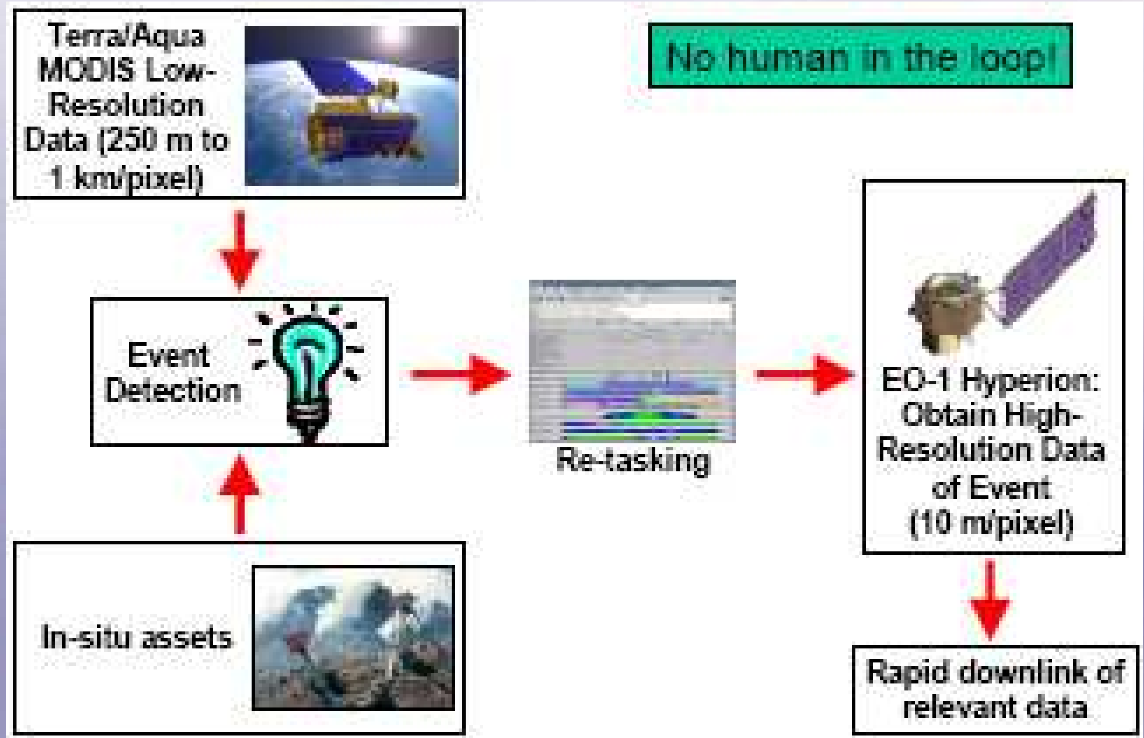
- Sensor webs are now seen by many as being more at the information level, connecting sensor networks.

# NASA’s Earth Science Vision: An Agricultural Example



# NASA's EO-1 Satellite Web Experiment

- **Earth Observing One (EO-1) launched November 2000: Advanced Land Imager (ALI); Hyperion (hyperspectral); Atmospheric Corrector (AC)**



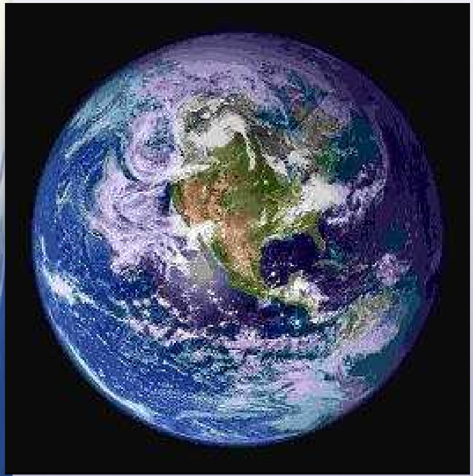

- **Sensor web detection and response architecture**

**(Sherwood et al., JPL, IEEE Aerospace Conference, 2006)**

# Chronology Interlude: Sensor Web History Highlights

- **1997: NASA/JPL (Delin et al.) start working on sensor webs**
- **1999: “The Earth Will Don An Electronic Skin”, Neil Gross in “21 Ideas for the 21st Century” in *Business Week Online***
- **2000: “Sensor Web Workshop I: Applications”, JPL Workshop, Monrovia, California**
- **2003: GeoSensor Networks Workshop, Portland, Maine**
- **2007-2008: First and Second Global Earth Observation System of Systems (GEOSS) Sensor Web Workshops, Cape Town, South Africa and Geneva, Switzerland**

# The Need for Integrated Earth Sensing



NASA and NOAA

"Ground-based (<u>in-situ</u>) monitoring systems are <u>inadequate</u> by several orders of magnitude. The majority of space agencies feel that an <u>integrated approach</u> to monitoring the Earth demands that the in-situ sensing be a <u>funded</u> part of the solution offered by space agencies."

*World Space Congress 2002 Panel on "An Integrated Approach to Monitoring Planet Earth"*

**Significant advancements in Earth sensing are expected to come about only by developing more systematic capabilities for the fusion of remote sensing observations and in-situ measurements for use in models, at relevant scales, to generate terrestrial information products for operational uses.**

# Chronology Interlude: Integrated Earth Sensing History Highlights

- **1983:** **International Satellite Land-Surface Climatology Project (ISLSCP) begins**
- **1986:** **International Geosphere-Biosphere Programme (IGBP) begins**
- **1996:** **Committee on Earth Observation Satellites (CEOS) ad hoc meeting on an integrated global observing strategy, Seattle, USA**
- **1996:** **Meeting on "In Situ Observations for the Global Observing Systems", Geneva, Switzerland**
- **1998:** **First Integrated Global Observing Strategy (IGOS) Partners Meeting, Paris, France**

# Chronology Interlude: Integrated Earth Sensing History Highlights

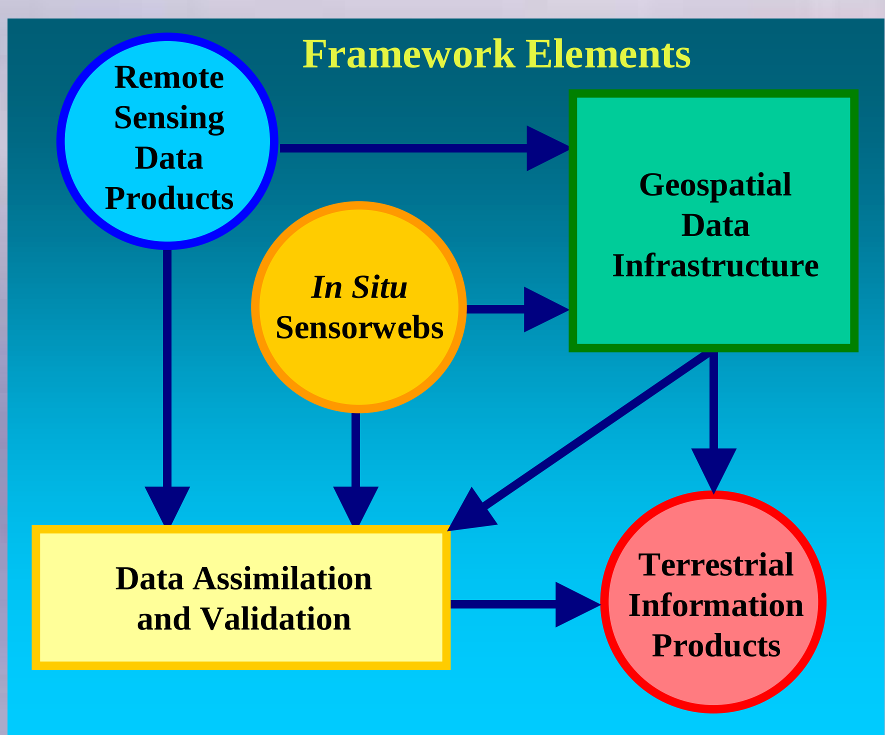
- **2000: Canada Centre for Remote Sensing (CCRS) begins an in situ sensing program and works towards integrated Earth sensing**
- **2001: Global Monitoring for Environment and Security (GMES) (now called Kopernikus) initiative adopted by the European Union**
- **2002: First International Workshop on Future Intelligent Earth Observation Satellites (FIEOS), Denver, Colorado**
- **2003: First global Earth Observation Summit in Washington, held in response to 2002 World Summit on Sustainable Development**
- **2005: Group on Earth Observations (or GEO) established and begins Global Earth Observation System of Systems (GEOSS)**

# CCRS Project Experience: Initial Framework 2001

## Objectives

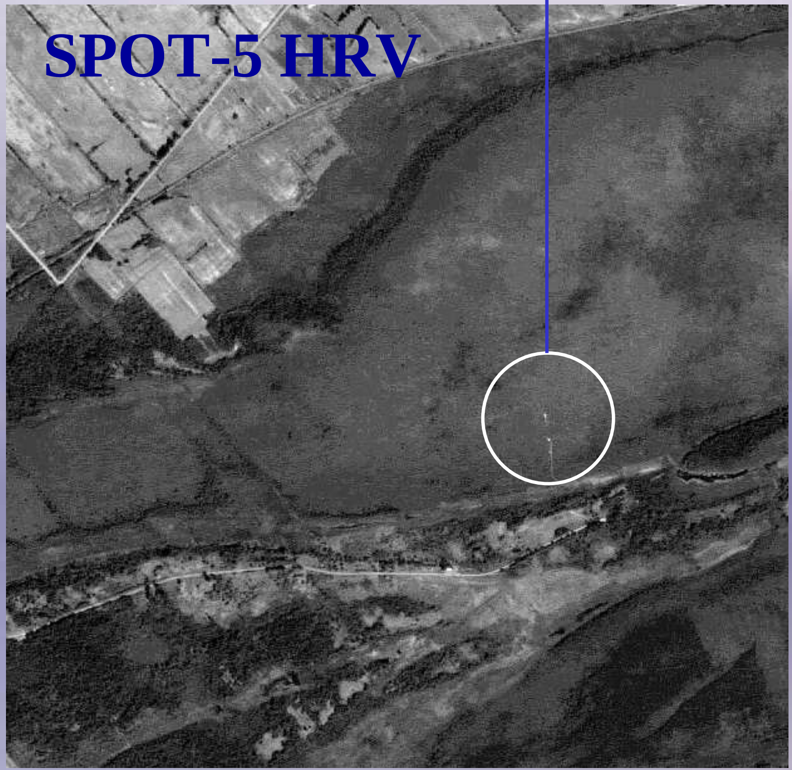
- Design, develop and deploy smart sensor webs for in situ data acquisition.
- Develop methods to fuse and assimilate in situ and remote sensing data into models that generate validated information.
- Facilitate the incorporation of in situ sensor data and/or metadata into on-line geospatial data infrastructures (GDIs).

**Goal:** To develop the capabilities to monitor remote environments, hazards and disasters, and natural resources using new data acquisition strategies and systems for integrated Earth sensing.



# CCRS Project Experience: Ottawa Deployment 2002

- Central Experimental Farm meteorological station in Ottawa
- Mer Bleue (McGill University meteorological station) near Ottawa
- CCRS building roof in Ottawa



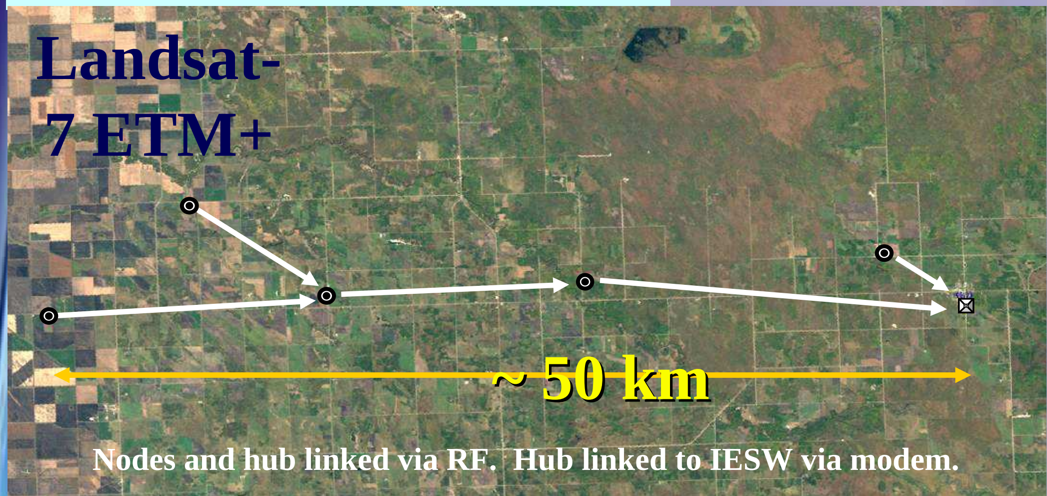

- Local outdoor environments
- Debugging of protocols between the microsensor-microcontroller packages and the satellite transceivers
- Testing of RF telemetry ranges

# CCRS Project Experience:
# Saskatchewan Deployment 2002

- Bratt's Lake Station (BLS), Saskatchewan, in collaboration with the Meteorological Service of Canada (MSC), Environment Canada.
- Ideal test deployment and RF conditions:
  - Homogeneous Chernozem soil [> 70 % clay]
  - < 2 m elevation change between sites
  - Station infrastructure
- Sensor measurements included:
  - Soil moisture (Adcon C-Probes with sensors at 15, 45, 75 cm deployed to match soil core sampling locations)
  - Relative humidity
  - Precipitation
  - Global radiation
  - Leaf wetness
  - Air and soil temperature
  - Rainfall
  - Wind speed and direction

# CCRS Project Experience: Manitoba Deployments 2002-2003


Roseau River (Red River Watershed)
Indian Reserve April 30, 1997

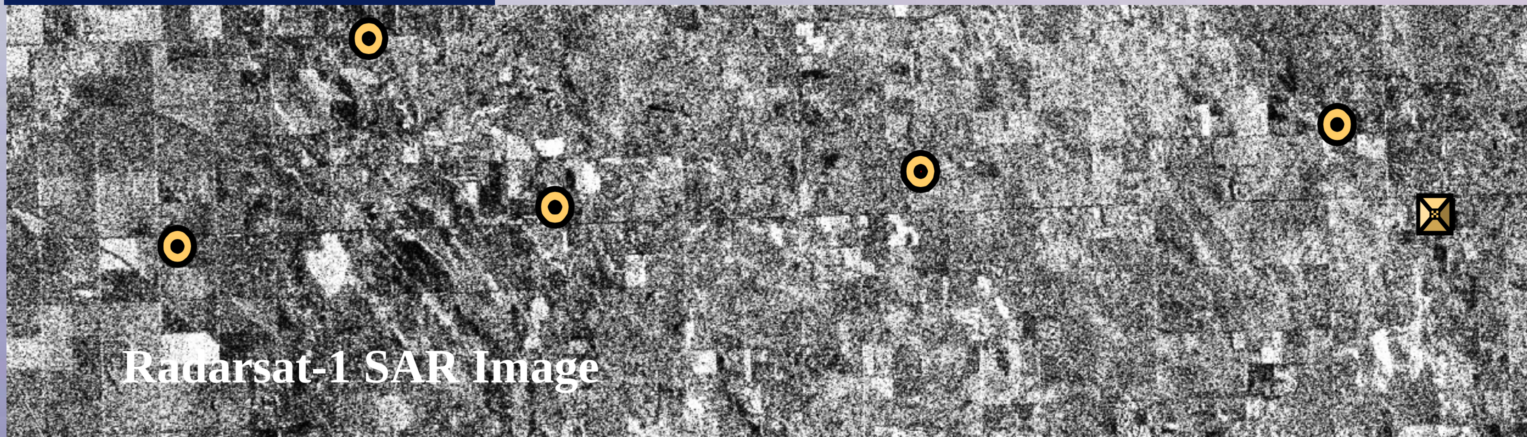



**Flood Hazard Monitoring**: Satellite-based soil moisture maps and strategically deployed in situ sensor webs can monitor soil moisture changes in space and time without ongoing field work. In collaboration with Environment Canada National Water Research Institute specialists.

- **Soil moisture** (Adcon C-Probes with sensors at multiple depths to match soil core sampling locations)
- Global radiation
- Relative humidity and precipitation
- Air and soil temperature
- Rainfall
- Wind speed and direction

# CCRS Project Experience: Manitoba Deployments 2002-2003


**5 network nodes and base station**
**For soil moisture probes only**



# CCRS Project Experience: Alberta Deployments 2004-2005

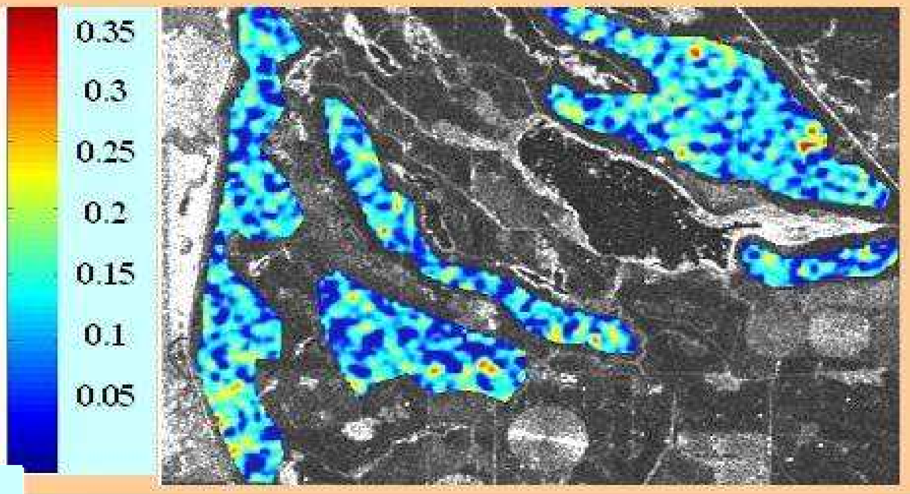
## Intelligent Sensorweb for Integrated Earth Sensing (ISIES)

Smart Sensorwebs

Vegetation Modeling Agents

OpenGIS Web Infrastructure

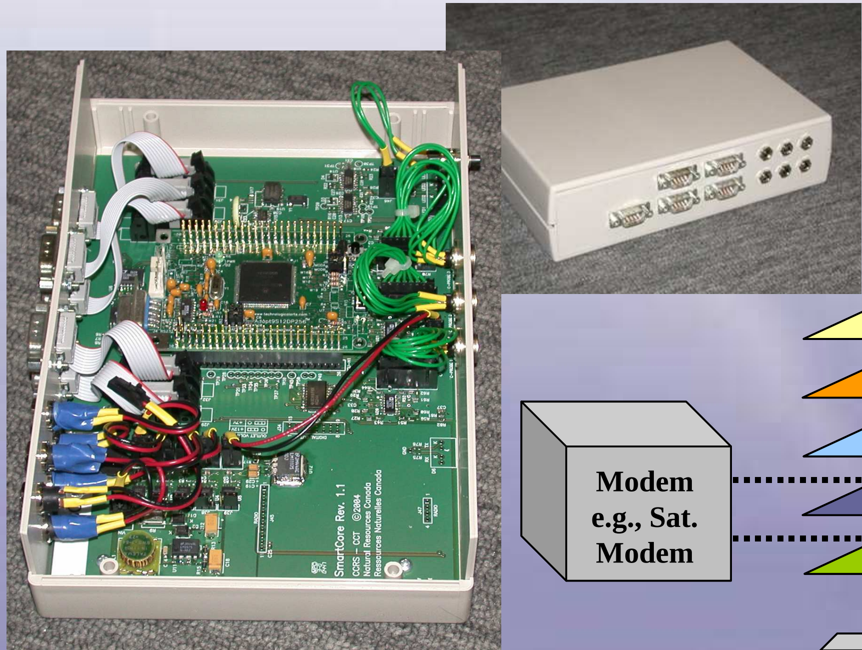
Surface Soil Moisture Maps (Rangeland)

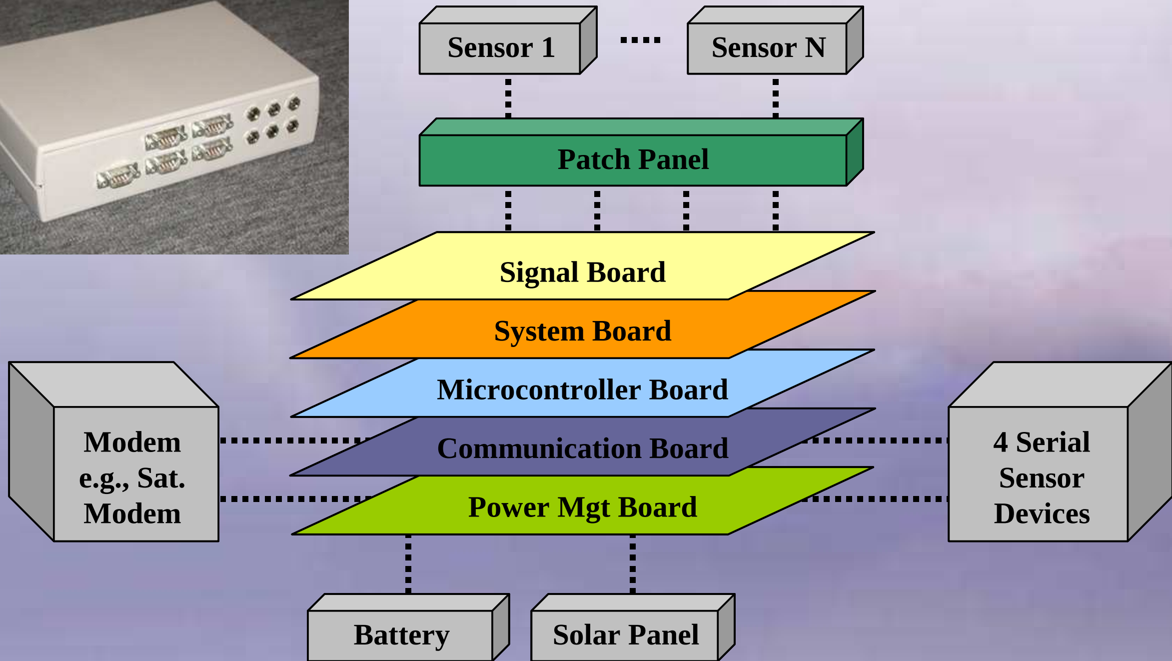



- Precarn Inc.
- MacDonald Dettwiler & Associates
- Natural Resources Canada (CCRS)
- Agriculture and Agri-Food Canada
- York University

Final Products: Improved Predictions of Crop Yield and Rangeland Productivity

# CCRS Project Experience: Alberta Deployments 2004-2005

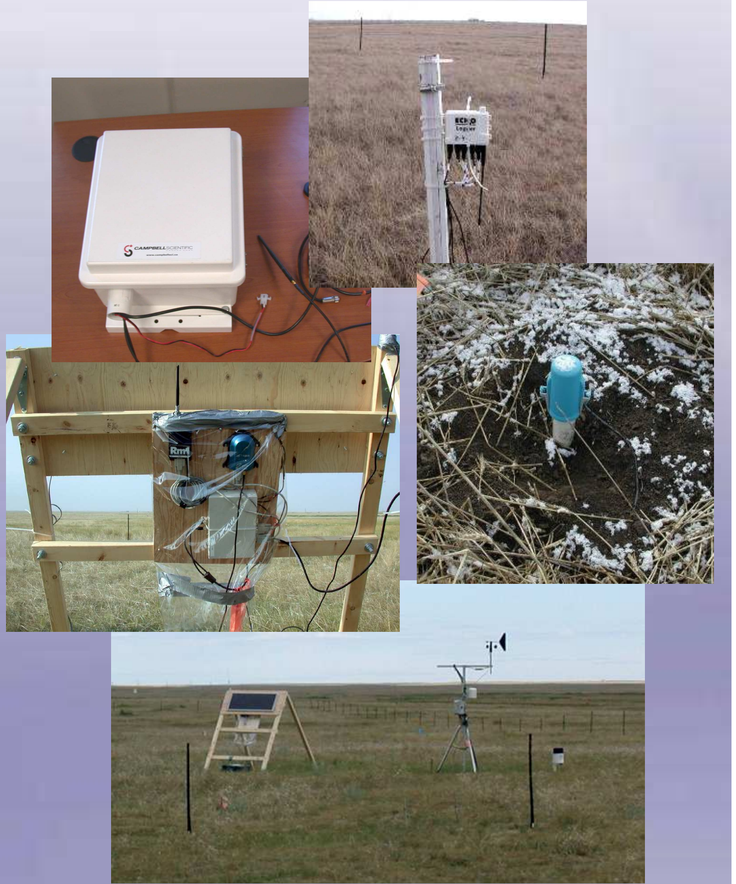


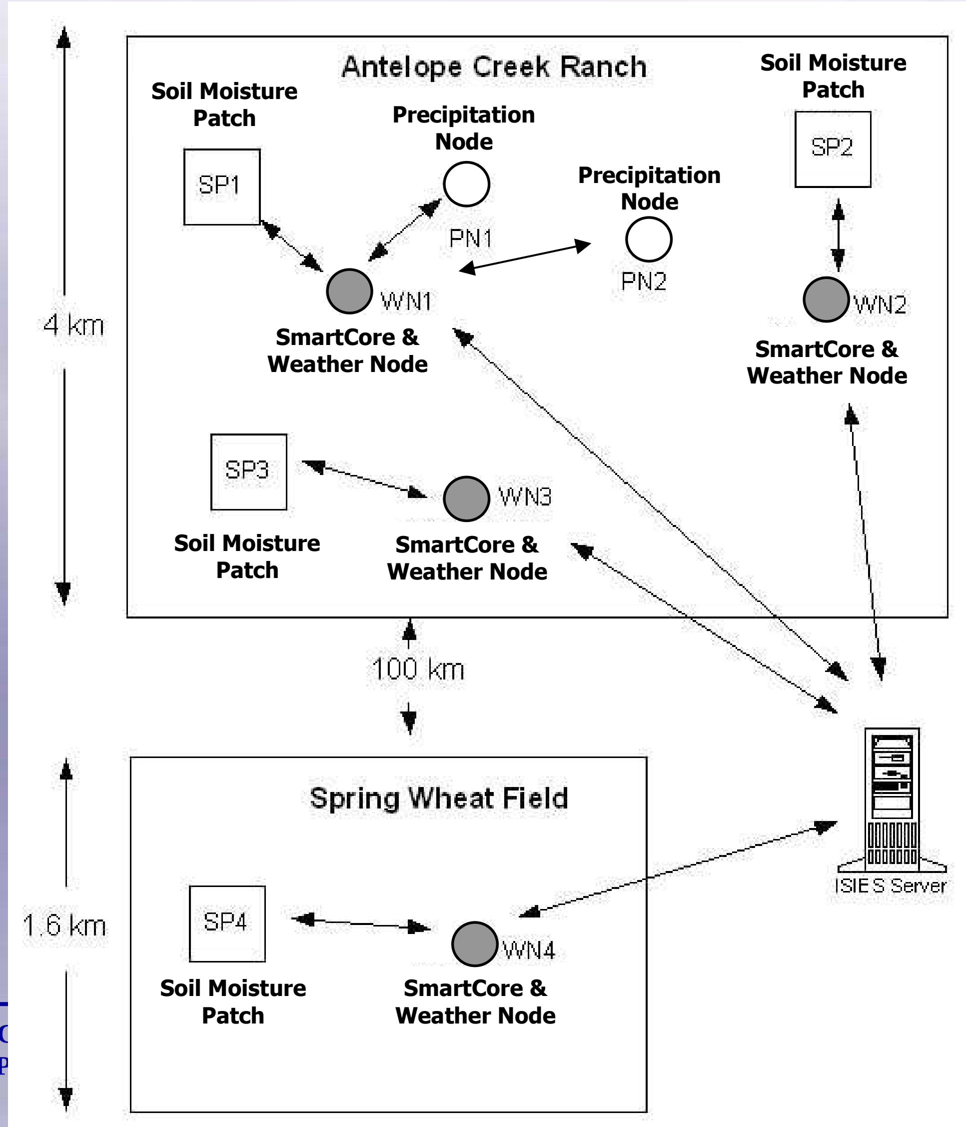



CCRS SmartCore Device

# CCRS Project Experience:
# Alberta Deployments 2004-2005

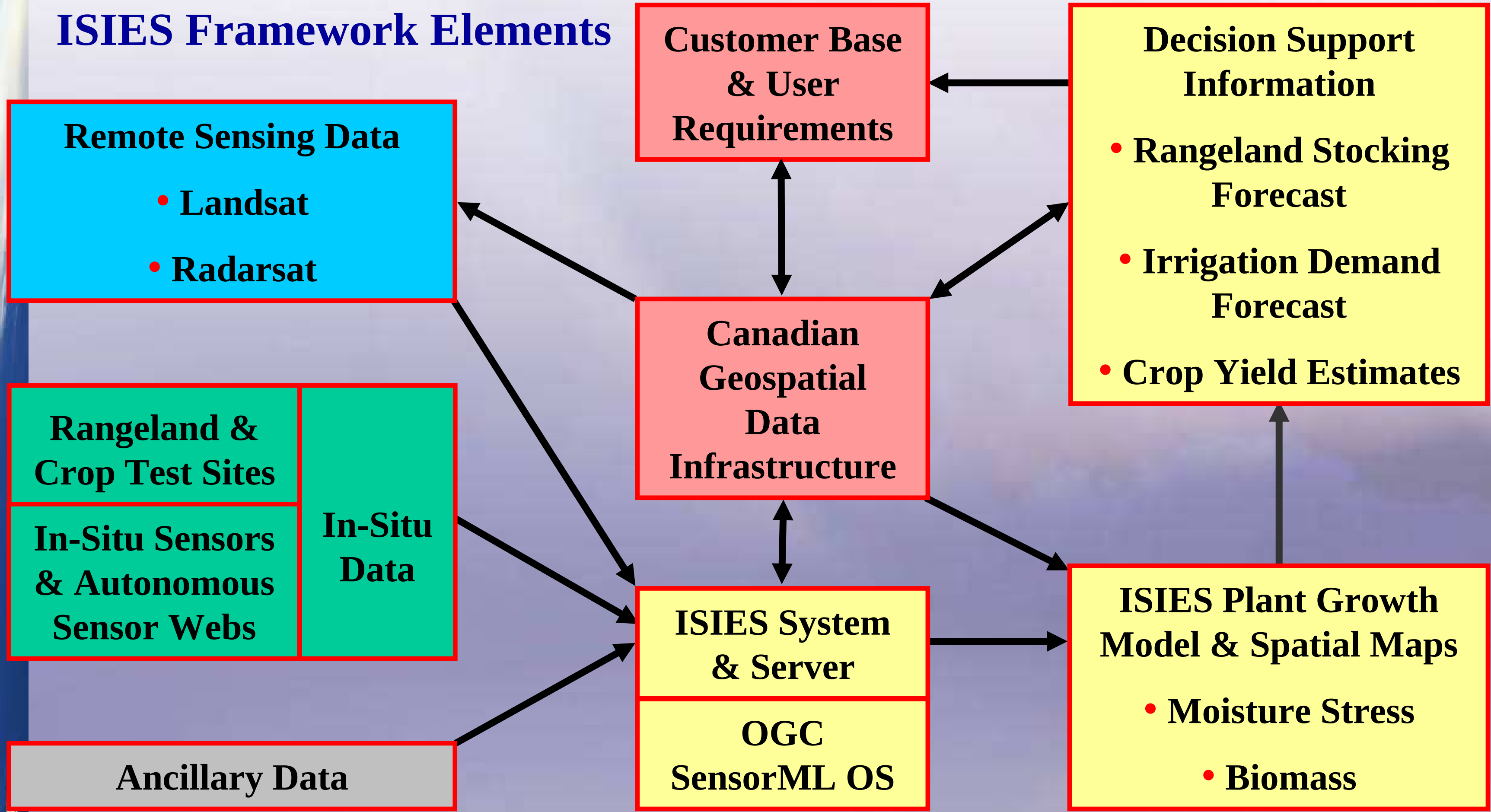
## ISIES Prototype Sensor Web



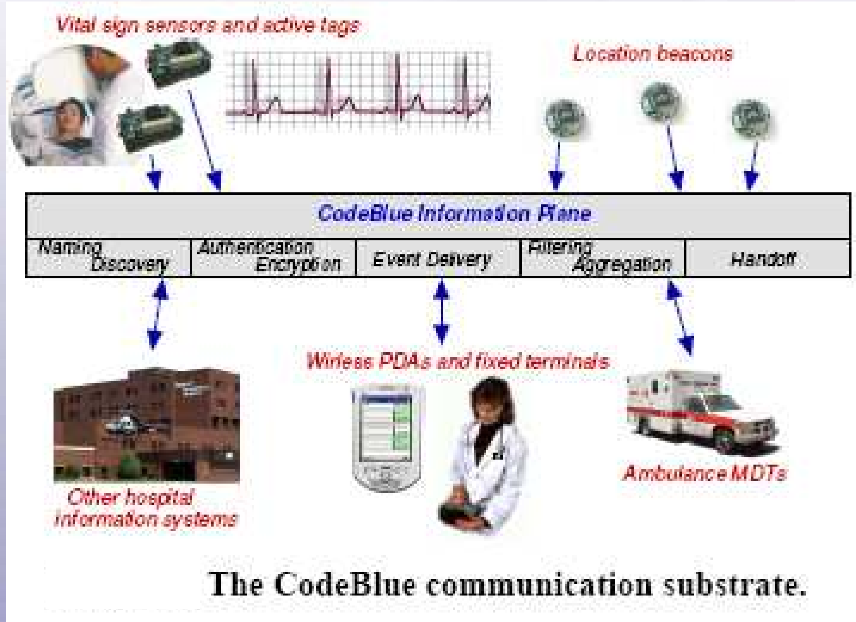


# CCRS Project Experience: Alberta Deployments 2004-2005

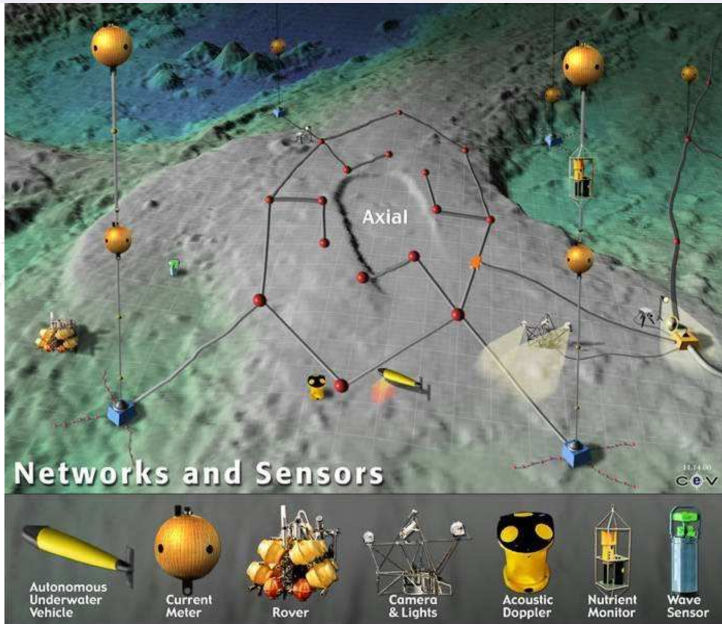
## ISIES Framework Elements



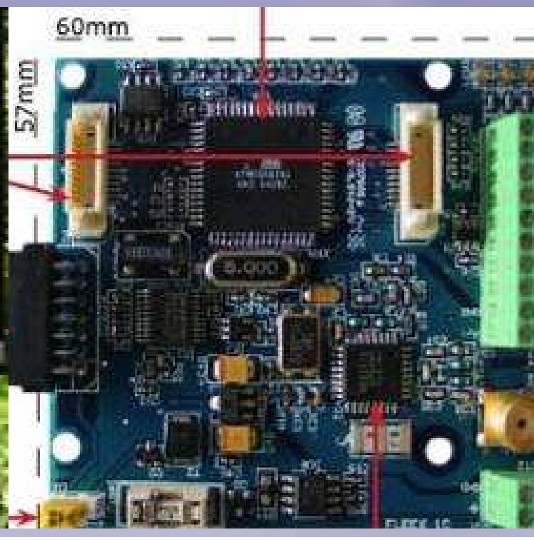
# Sensor Network Examples

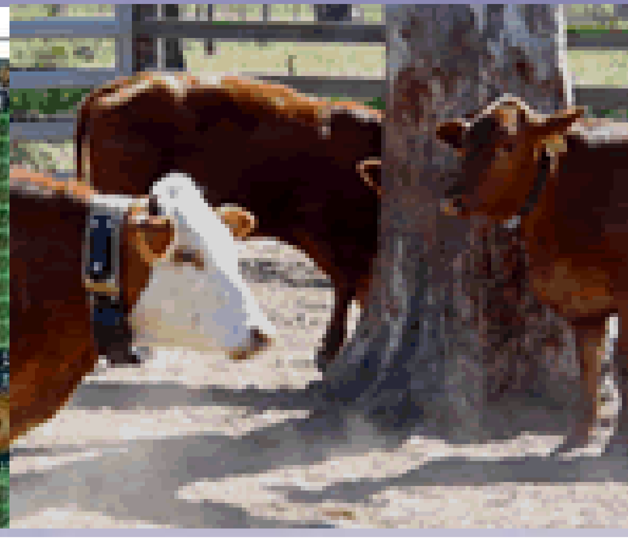


The CodeBlue communication substrate.







# Recommendations on Sensor Webs

- **Data Acquisition**
  - ➢ **Sensor web hardware and architecture: Automation and intelligence**
  - ➢ **Adaptation of converging advanced technologies: Reliable and robust performance**
  - ➢ **Sensor coverage: Densification by three orders of magnitude**
- **Data Quality**
  - ➢ **Calibration-validation: Standards for multi-source data and information products**
- **Data Integration**
  - ➢ **Integration and fusion of multi-source data: Challenging**
- **Information**
  - ➢ **Extraction and fusion of multi-source information: Challenging**
  - ➢ **Dissemination of information: Accessible, effective and easy-to-use**
  - ➢ **Answer science questions and provide decision support: Challenging**

# Recommendations on Sensor Webs in Support of Satellite Webs

- **Autonomous satellite image acquisition tasking decisions based on near-real-time data**
  - **Atmospheric optical conditions from autonomous ground-based measurements, satellite retrievals (same day), and modeling**
  - **Surface reflectance properties from autonomous ground-based spectrometer data and satellite optical sensor monitoring (same week), and modeling**
  - **Soil moisture conditions from autonomous ground-based measurements and satellite microwave sensor retrievals (same day), and modeling**

- **Use existing Earth observation calibration and validation test sites as sensor web R&D test-beds**

# Global Instrumented and Automated Network of Test Sites (GIANTS) for Post-Launch Spectroradiometric Calibration of Optical Sensors

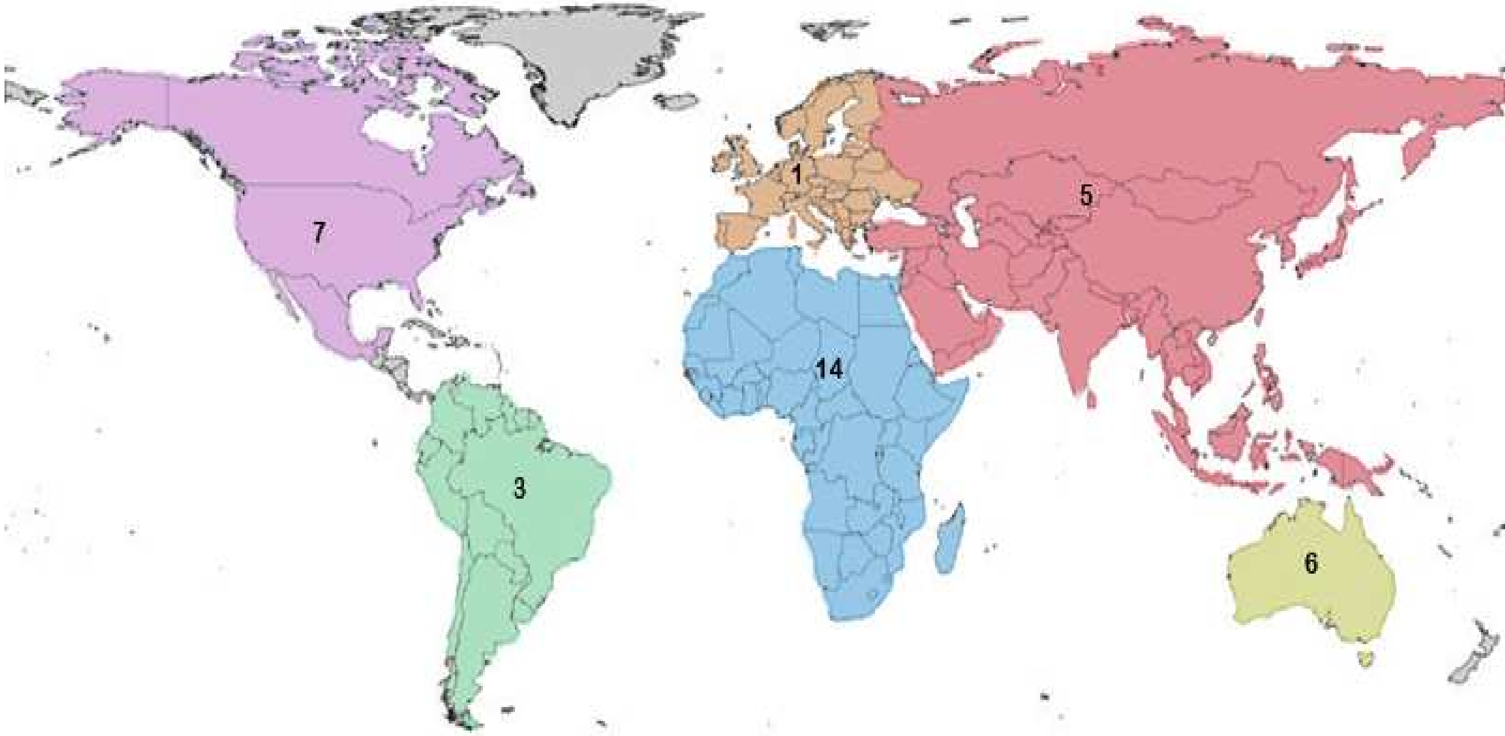
University of Lethbridge

USGS

NASA

CEOS

NPL National Physical Laboratory




Example: Railroad Valley Playa, Nevada

# Geostrategic Technologies and Perspectives

## Capabilities and Challenges

# Chronology Interlude: Geostrategic Technologies and Perspectives Highlights (1)

- **1925: Noosphere concept of Pierre Teilhard de Chardin**
- **1945: Arthur C. Clarke proposes satellite communication systems**
- **1951: F.L. Wallace envisions a subcutaneous human-body circuit in his short story "Tangle Hold"**
- **1963: Arthur C. Clarke's predicts "telesensory" devices by 2010 and a world brain by 2090 in *Profiles of the Future – An Inquiry into the Limits of the Possible***
- **1966: Harry Kleiner's film and Isaac Asimov's book *Fantastic Voyage* appear**
- **1982: William Gibson coins "cyberspace" in "Burning Chrome"**

# Chronology Interlude: Geostrategic Technologies and Perspectives Highlights (2)

- **1983: GPS is made available for civilian use**
- **1986: K. Eric Drexler's *Engines of Creation – The Coming Era of Nanotechnology* is published**
- **1989: World Wide Web created by Tim Berners-Lee**
- **1991: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it", Mark Weiser**
- **1994: Geospatial Web (GeoWeb) anticipated by Charles Herring in "*An Architecture of Cyberspace: Spatialization of the Internet*"**

# Chronology Interlude: Geostrategic Technologies and Perspectives Highlights (3)

- **1997: News that US Department of Defense and University of California-Berkeley are working on "smart dust"**

- **2000: "Robot technology today is where computer technology was in the 1970s", MIT AI Laboratory**

- **2001: Long envisioned in speculative fiction, work intensifies on the planetary computer**

- **2002: Douglas Mulhall's *Our Molecular Future – How Nanotechnology, Robotics, Genetics, and Artificial Intelligence will Transform Our World is* published**

- **2004: First release of Earth Viewer (which became Google Earth in 2006) and of NASA's WorldWind**

# What Might the World Look Like in 50 Years?

*Global Foresight Conference, 2002*
*Woodrow Wilson International Center for Scholars*

- **Among the top 10 goals selected by the conference participants:**

**#8. Develop the capability to understand and manage global systems**
**#10. Make the world into a truly global organism**

*Science & Technology Foresight – Looking Ahead to 2025,*
*NRC Scenarios Workshops, Ottawa, Canada, 2003*

- **Geostrategic technologies will include:**
  - **Geospatial data sensing**
  - **Ubiquitous peer-to-peer sensor webs**

# Selected Notes from the Millennium Project's *2007 State of the Future* Report

- **Cities augmented by ubiquitous computing for collective intelligence**
- **Decision-making augmented by integration of ubiquitous sensors**
- **Telemedicine, biochip sensors for self-diagnosis, and other systems**
- **Environmental sensors connected to global information systems**

**"It is clear that the world has the resources to address our common challenges. Ours is the first generation with the means for many to know the world as a whole, identify global improvement systems, and seek to improve them."**

# Geostrategic Technologies and Perspectives



This true-color image shows North and South America as they would appear from space 35,000 km (22,000 miles) above the Earth. The image is a combination of data from two satellites. The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Terra satellite collected the land surface data over 16 days, while NOAA's Geostationary Operational Environmental Satellite (GOES) produced a snapshot of the Earth's clouds.
Image created by Reto Stöckli, Nazmi El Saleous, and Marit Jentoft-Nilsen, NASA GSFC
Learn more about the Earth Observing System (http://eos.nasa.gov/)
Learn more about the Earth at the Earth Observatory (http://earthobservatory.nasa.gov/)
Get more Earth images at the Visible Earth (http://visibleearth.nasa.gov/)

# Thank You!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**"The power of technological convergence will bring measurable benefits to each and every individual."** ***Our Molecular Future*****, Douglas Mulhall (2002)**