Sensor data management software, requirements and considerations

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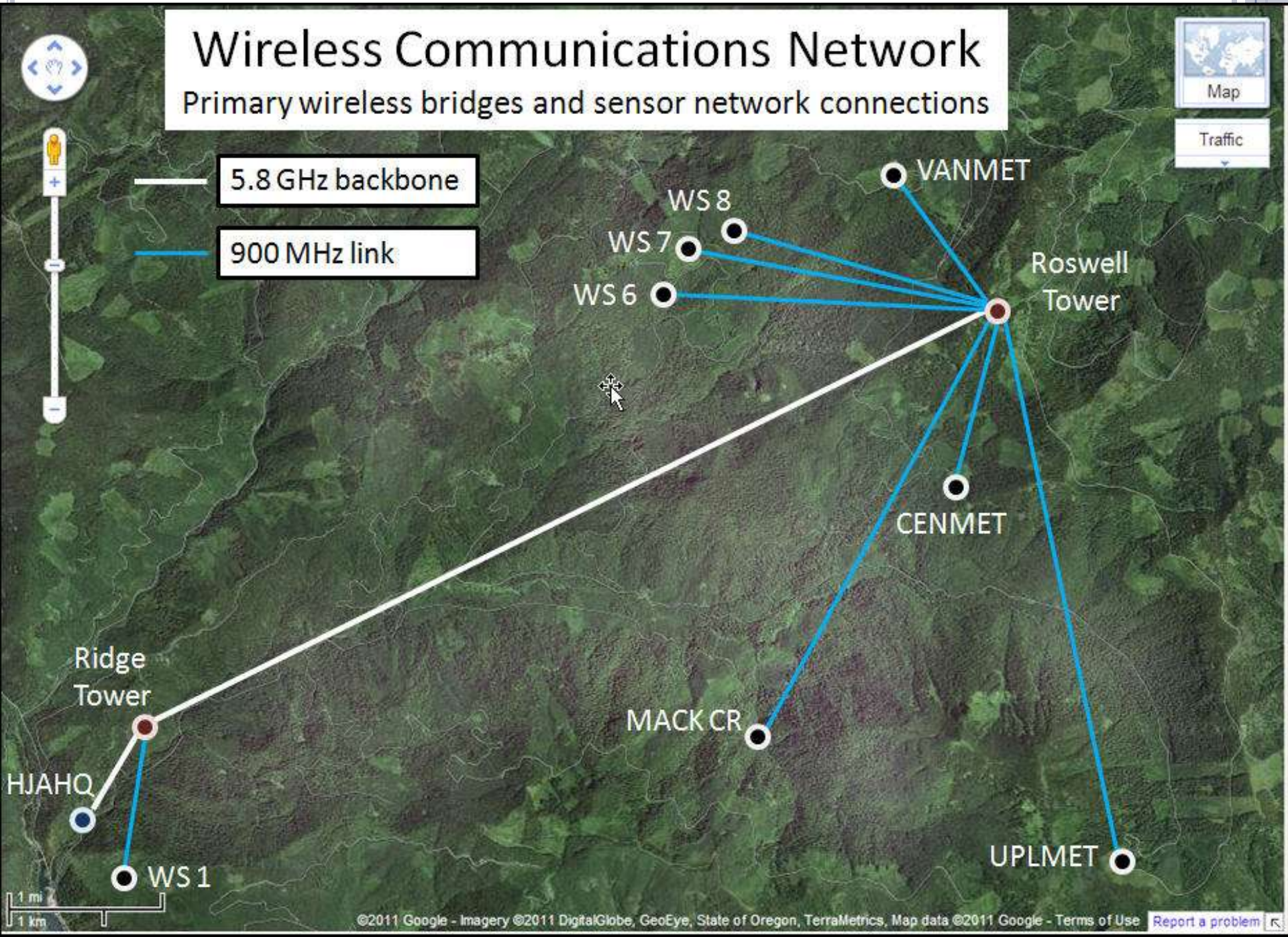
Wireless Communications Network
Primary wireless bridges and sensor network connections
5.8 GHz backbone
900 MHz link
VANMET
WS 8
WS 7
WS 6
Roswell Tower
CENMET
MACK CR
UPLMET
Ridge Tower
HJAHQ
WS 1
Map
Traffic
1 mi
1 km
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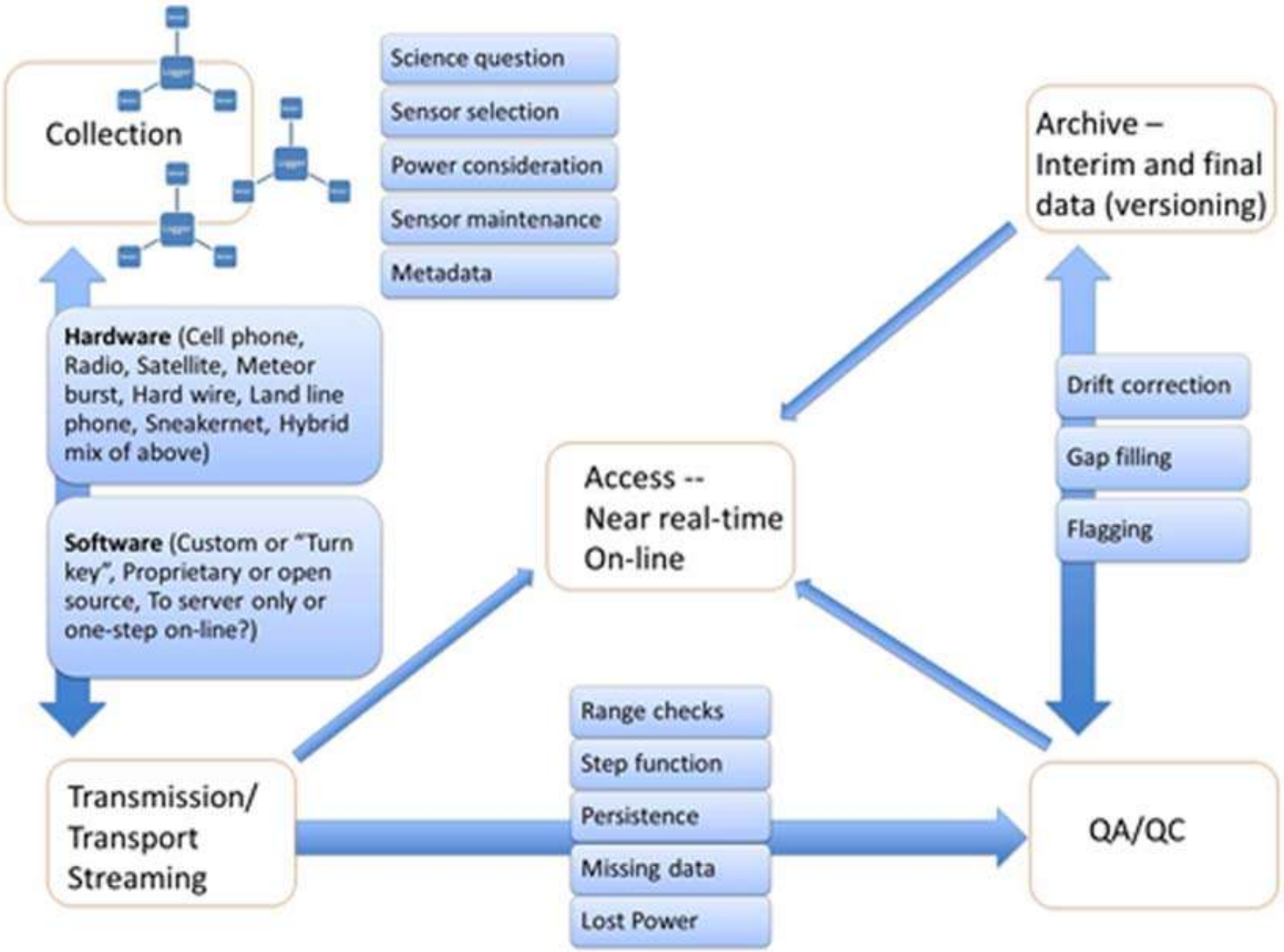
Report a problem


Collection
Science question
Sensor selection
Power consideration
Sensor maintenance
Metadata
Archive – Interim and final data (versioning)
Hardware (Cell phone, Radio, Satellite, Meteor burst, Hard wire, Land line phone, Sneakernet, Hybrid mix of above)
Drift correction
Gap filling
Flagging
Access -- Near real-time On-line
Software (Custom or "Turn key", Proprietary or open source, To server only or one-step on-line?)
Range checks
Step function
Persistence
Missing data
Lost Power
Transmission/ Transport Streaming
QA/QC

Common Themes from participating sites

Joint NERC Environmental Sensor Network/Sensor NIS Workshop, Hubbard Brook Experimental Forest, NH, October 25-27TH, 2011

- Approaches
  - Top down (NEON, USGS)
    - More uniform, faster implementation, less flexible
  - Bottom-up (LTER network sites, individual sites)
    - Less standardization, customized approaches and software
    - Adopting solutions – how do you decide?
      - Reluctance to invest time and energy
      - Lack of mature software
      - Steep learning curve
    - Do we need light-handed standardization?
      - E.g., software, methods, controlled vocabulary, units, etc.

Common Themes from participating sites

Joint NERC Environmental Sensor Network/Sensor NIS Workshop, Hubbard Brook Experimental Forest, NH, October 25-27TH, 2011

- Greatest Needs
  - Middleware between sensor/data logger and database /applications
  - Programming support
  - Training workshops to disseminate knowledge & solutions
  - Ways to share experiences with software and tools that are useful
    - Clearinghouse for sharing code and solutions
    - Knowledge Base (web page) organized by topics (http://im.lternet.edu/resources/im_practices/sensor_data)

- Dataloggers
  - Campbell Scientific - most common (http://www.campbellsci.com/)
  - Hobo (www.onsetcomp.com)
  - Nexsens Technology (http://nexsens.com)
  - GRAPE - NEON (http://www.neoninc.org/)

Sensor Data Management Middleware/Software

- Purpose of middleware
  - Data storage / data handling
  - Data aggregation, formatting, filtering
  - Documentation
  - Automated QA/QC on data streams
  - Archiving
- Software/middleware – Proprietary
  - Campbell LoggerNet (most common)
  - Hobo
  - Vista Data Vision
  - YSI EcoNet
  - Custom applications: Matlab, Excel, SQLServer
- Open Source
  - Environments (see next slide)
  - Custom applications (Python, PHP, MySQL, etc.)

Sensor Data Management Middleware Open Source Environments for Streaming Data

- Matlab GCE toolbox (Proprietary/ limited open source)
  - GUI, visualization, metadata-based analysis, manages QA/QC rules and qualifiers, tracks provenance
- Open Source DataTurbine Initiative
  - Streaming data engine, receives data from various sources and sends to analysis and visualization tools, databases, etc., TiVo-like functionality
- Kepler Project (open source)
  - GUI, reuse and share analytical components/workflows with other users, tracks provenance, integrates software components and data sources
- R-project libraries (open source)
  - Statistical and graphical capabilities, analysis tools, code reuse and sharing, integrated environment

Sensor Management System Components

- Develop protocols for installation of sensors
- Develop calibration / maintenance schedules
  - System alerts (nagging system)
- Build and maintain sensor network metadata
  - Data collection documentation
  - Annotation of sensor events / Sensor history
- Data workflows /processing
- Quality Control / Flagging data
- Archiving
  - Creating a “citable” database
  - Versioning (monthly vs. annual ; provisional v. final)
  - Periodic snapshots or queries
  - Tracking changes to the data, e.g., audit trail

Key Metadata for Sensor Networks

- Sensor descriptions
  - Sensor relocations or replacement (automate w/barcodes?)
  - Sensor events and failures
  - Calibration events / maintenance history
- Data collection documentation
  - Sensor deployment information, incl. station-level
  - Geo-location / operational time span
  - Sampling frequency
  - Methodology changes, e.g., temperature radiation shield change
  - Photo points for station, e.g., hemispheric photos, track local conditions and changes
- Data processing documentation
  - System requirements / Hardware configuration / history
  - Data processing workflow
  - Datalogger program versions / wiring diagrams with labels
  - Attribute / Flag definitions

Sensor Management

- SensorML standard
  (http://www.opengeospatial.org/standards/sensorml)
  - Framework for observational characteristics of sensors
  - Covers station, deployment, sensor, parameter
  - Tools being developed - Lacking production-grade software?

- CUAHSI HIS / Observation Data Model
  - Relational database model for individual observations
  - Provide maximum flexibility in data analysis through the ability to query and select individual observation records
  - Record level metadata

Quality Assurance – preventative measures

- Sensor redundancy
  - Ideal: Triple the sensor, triple the logger!
  - Practical: Cheaper, lower cost, lower resolution sensors, or correlated (proxy) sensors
  - Side Effect: establish user-confidence in data products
- Routine calibration and maintenance
  - Schedule or stagger to minimize data loss
- Continuous monitoring and evaluating of sensor network
  - Early detection of problems
  - Limited budgets and increased volume of data precludes past manual sensor auditing practices
  - Automated alerts or streaming QC

Quality control on Streaming Data: Quality Levels

- Quality control is performed at multiple levels
- Quality level important to describe in metadata,
  - Description differs among programs
  - Examples: NASA, CUAHSI, Ameriflux
- http://ilrs.gsfc.nasa.gov/reports/ilrs_reports/9809_attach7a.html
- http://his.cuahsi.org/documents/ODM1.pdf p.18

- Level 0 (Raw streaming data)
  - Raw data, no QC, no data qualifiers applied (data flags)
  - Preservation of original data streams is essential
  - Some datalogger conversion of units and formats may be acceptable (Level ½)

Quality control on Streaming Data: Quality Levels

- Level 1 (QC'd, calibrated data, qualifiers added)
  - Provisional level (near real-time preparation)
    - Typically for internal use, if released, provisional data must be labeled clearly
    - Data qualifiers are added from initial QC
    - Infill and flag missing datetimes
  - Published level (delayed release)
    - QC process is complete
    - Data is unlikely to change – data set is unique
- Comments:
  - Only logger missing value codes should be deleted from streams, e.g. contention that even impossible values may have information
  - *Immediate* Qc is important in near real-time, and *subsequent* QC as trends become apparent (e.g., sensor drift, degradation)
  - Foremost, identify what QC has been done
    - Identify streaming QC methods, thresholds, assumptions
    - If no QC, that should be made clear too

Quality control on Streaming Data: Possible quality control checks in near real-time

- Timestamp integrity (Date/time)
  - Sequential, fixed intervals, i.e., checks for time step or frequency variation
- Range checks
  - Sensor specifications - identify impossible values; not unlikely ones
  - Seasonal/reasonable historic values
    - Highly dependent on the sensor – should be based on domain expertise
- Variance checks – indicator of sensor degradation
  - Running averages or change in slope checks, e.g., outlier detections, spikes
  - Sensitivity is specific to site and sensor type
- Persistence checks
  - Check for repeating values that may indicate sensor failure
    - E.g., freezing, sensor capacity issues
- Internal (plausibility) checks
  - E.g., TMAX-TMIN>0, snow depth> SWE
  - Consistency of derived values
- Spatial checks
  - Use redundant or related sensors, e.g., sensor drift

Quality control on Streaming Data: Data Levels: Gap Filling

- Level 2
  - Gap-filled, estimated, or aggregated data
  - Involves interpretation – multiple algorithms possible
    - different methods will lead to different products
    - some researchers may still want to download Level 1 data to apply preferred methods

- Obligation to provide gap filling?
  - Controversial – can seriously compromise stats, analyses and lead to misinterpretation
  - Desirable when generating summarized data, but transparency critical
  - Probably unsuitable for streaming data – much later in data cycle with expert attention
  - Most critical to document gap-filling, and flag all estimated values to allow removal

Quality control on Streaming Data: Data Qualifiers

- Many vocabularies – desirable to harmonize, but impractical (may crosswalk across vocabularies)
- Good approach
  - Rich vocabulary of fine-grained flags for streaming data – intended to guide local review
  - Simpler vocabulary of flags for "final" data for public consumption, e.g.,
    - 'Verified', 'Accepted', 'Suspicious', 'Missing', 'Estimated'
    - Pass-fail indicator (include in analysis?)
- Certain types of qualifiers may be better as data columns
  - Method shifts, sensor shifts
  - Place key documentation as close to data value as possible

Knowledge Base: A Best Practices Manual for Networked Sensors

- Online guide which summarizes the community's collective knowledge
- Organize by topics
  - Summary of topic
  - Populate through community crowdsourcing
    - 1-pagers to highlight expertise, experience
  - Cite various protocols, e.g., USGS, NOAA, NERRS, NEON, US Forest Service, CUAHSI
  - Let a page "manager" be responsible for updating the summary periodically
  - Discussion blog associated with each topic

http://im.lternet.edu/resources/im_practices/sensor_data