Computing Challenges in Food-Energy-Water Nexus
: A Perspective

Oct. 30th, 2017 AIChE Annual Meeting
"Topical Conference on Food, Energy, Water Nexus"

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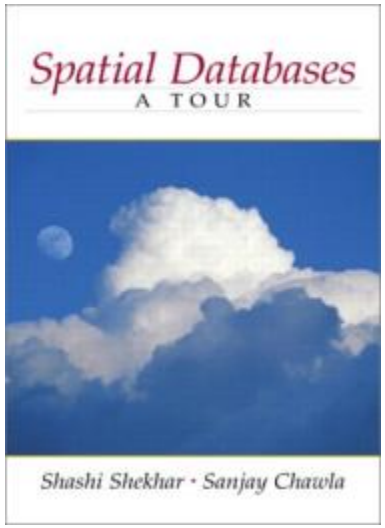
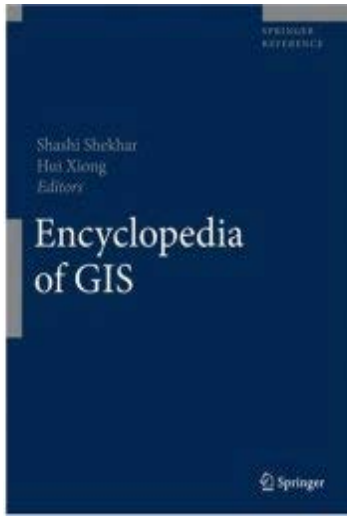
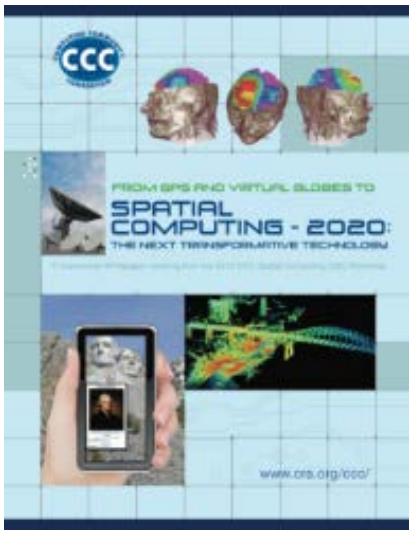
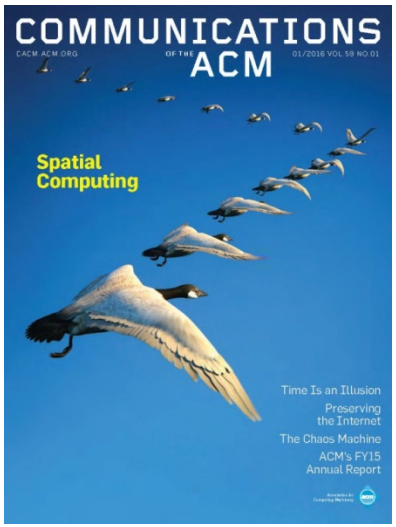








Outline

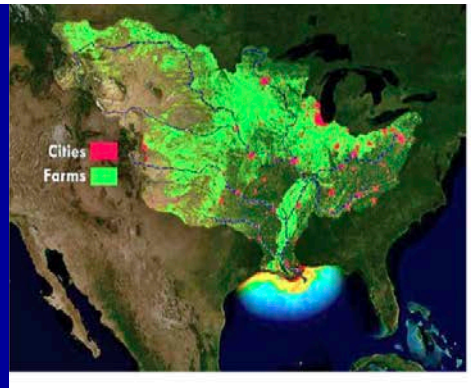
- FEW Nexus
  - Context
  - History
- Role of Computing
- Computing Challenges in FEW Nexus
- Next

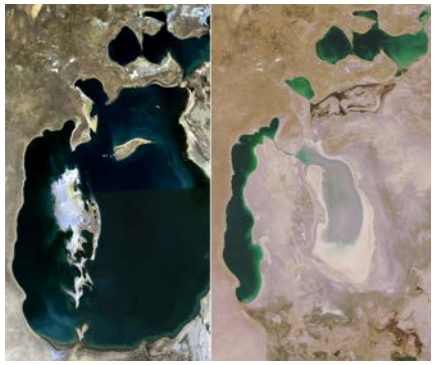
U.N. Sustainable Development Goals 2030

includes Food (2), Energy (7), Water (6), Climate Action (13), …

Downside of Piece-meal Approach

- Piece-meal policies => unanticipated problems
  - Ex. Fertilizers affect Water quality (e.g., Great Lakes, Mississippi River)
  - Ex. Bio-fuel subsidy => Rise in food prices (2008)



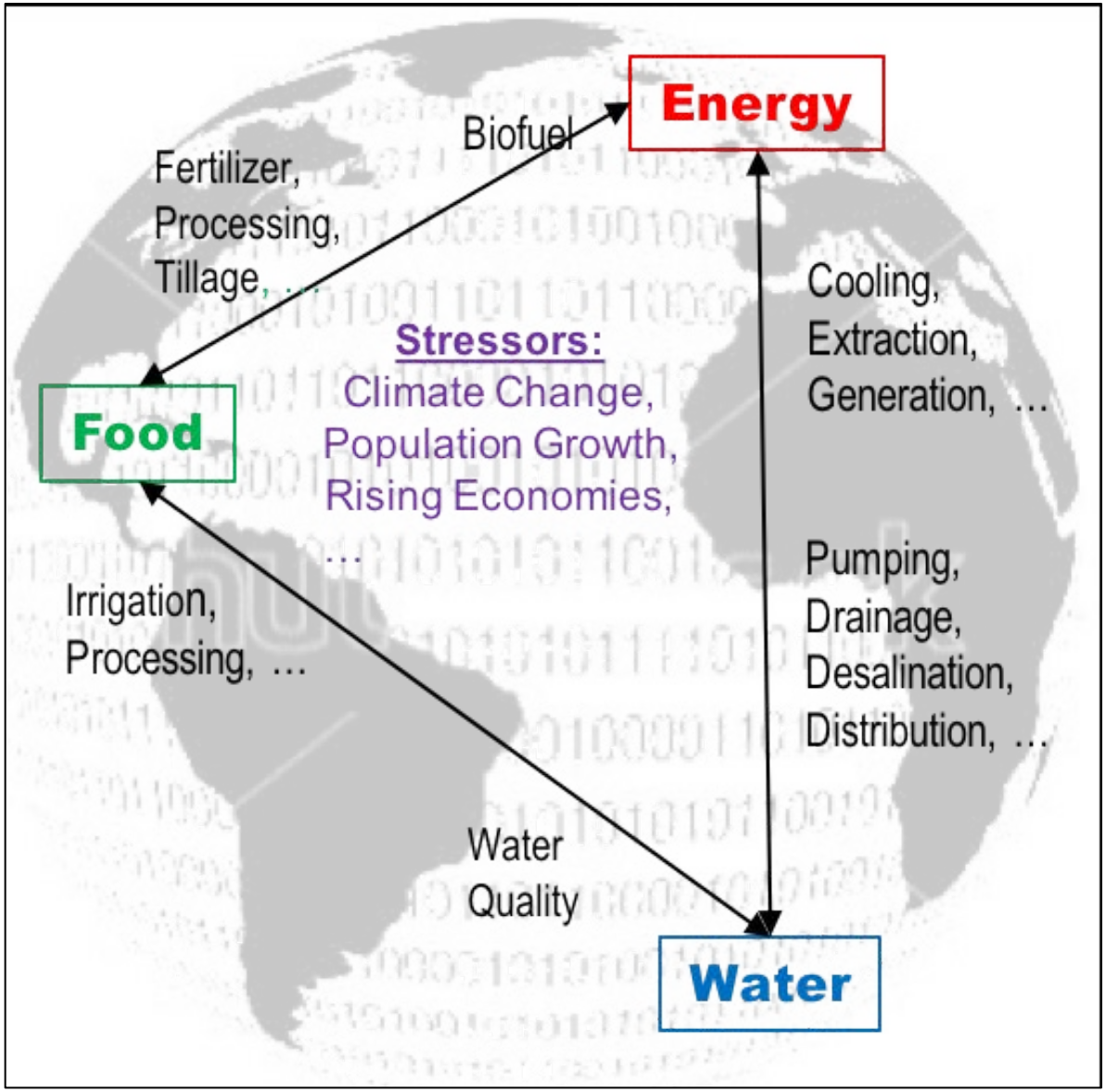


Courtesy: Wikipedia

- Crucial to understand interactions across Water, Food, Energy Systems
  - National priority
    - Reports: USDOD/NIC, NSF, USDA USDOE, USGS, …
    - Research Initiatives: NSF/USDA, USDOE
  - Global priority with initiatives from U.N. University and many countries

Interactions among Food, Energy, Water Systems

- Piecemeal decisions in one affect the other
- **Efficiency** or abundance in one reduces scarcity in others!
- **Chokepoint:** Scarcity in one constraints growth in others!
- **Stressors:**
  - Population Growth
  - Climate Climate
  - Rising Economy



Outline

- FEW Nexus
- Role of Computing
  - Precision Agriculture
  - Crop Monitoring
- Computing Challenges in FEW Nexus
- Next

Deconstructing Precision Agriculture

#AgInnovates2015

Wednesday, March 4, 2015
Reception | 5:00 to 7:00 pm

House Agriculture Committee Room,
1300 Longworth House Office Building,
Washington, DC

Think Moon landing.

Think Internet.

Think iPhone and Google.

Think bigger.

Come hear U.S. farmers, leading agriculture technology companies, and scientists tell how they work together to fuel U.S. innovation and the economy to solve this global challenge.

The event will exhibit three essential technologies of precision agriculture that originated from a broad spectrum of federally funded science: Guidance Systems and GPS, Data & Mapping with GIS, and Sensors & Robotics.

Moderator

Raj Khosla, Professor of Precision Agriculture at Colorado State Univ.

Farmers

David Hula, of Renwood Farms in Jamestown, Virginia

Rod Weimer, of Fagerberg Produce in Eaton, Colorado

Del Unger, of Del Unger Farms near Carlisle, Indiana

Speakers

Mark Harrington, Vice President of Trimble

Carl J. Williams, Chief of the Quantum Measurement Division at NIST

Bill Raun, Professor at Oklahoma State Univ.

Marvin Stone, Emeritus Professor at Oklahoma State Univ.

J. Alex Thomasson, Professor at Texas A&M Univ.

Dave Gebhardt, Director of Data and Technology at Land O'Lakes/WinField

Shashi Shekhar, Professor at the Univ. of Minnesota

RSVP

http://bit.ly/1CoOYoa

Hosted by the Congressional Soils Caucus

In partnership with

Agricultural Retailers Association
American Society of Plant Biologists
American Physical Society
American Society of Agronomy
Association of Equipment Manufacturers
Coalition for the Advancement of Precision Agriculture
Computing Research Association
CropLife America
Crop Science Society of America
PrecisionAg Institute
Soil Science Society of America
Task Force on American Innovation
Texas A&M AgriLife
Trimble
WinField

This is about feeding the world.

Precision Agriculture

- Reduce fertilizer run-offs, water use
- Improves yield
- Computing is critical
  - Cyber-Physical Systems
  - Data & Data Science Elements

Yield Monitors	Direct & Remote Sensing	Precision Navigation	Variable Rate Technology

Global Positioning Systems

Geographic Information Systems

Support (Farm-level) Decisions and (Insurance) Policy

CLIMATE FIELDVIEW

Seamless Field Data Collection

THE CLIMATE CORPORATION

MONSANTO

Customized Insights for Decision Making

View Field Data in Real Time

Compare Data Layers

Analyze Crop Performance in Season

Manage Nitrogen Applicatoons

Create Seeding Prescription

Monsanto, DuPont and others are pitching 'prescriptive planting' services to increase crops

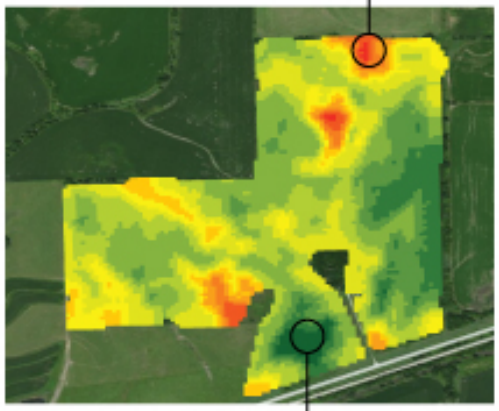
How data-driven planting services work:

1. The farmer provides field boundaries, historic crop yields, soil conditions and other data to a company.
2. The company analyzes the data and its own information about seed performance in different areas and soil types.
3. The company sends a computer file with recommendations back to the farmer, who uploads it into a planter.
4. The farmer's equipment then plants based upon the recommendations. The company monitors weather and other factors, advising farmers on how to manage crops as they grow.

Source: Monsanto

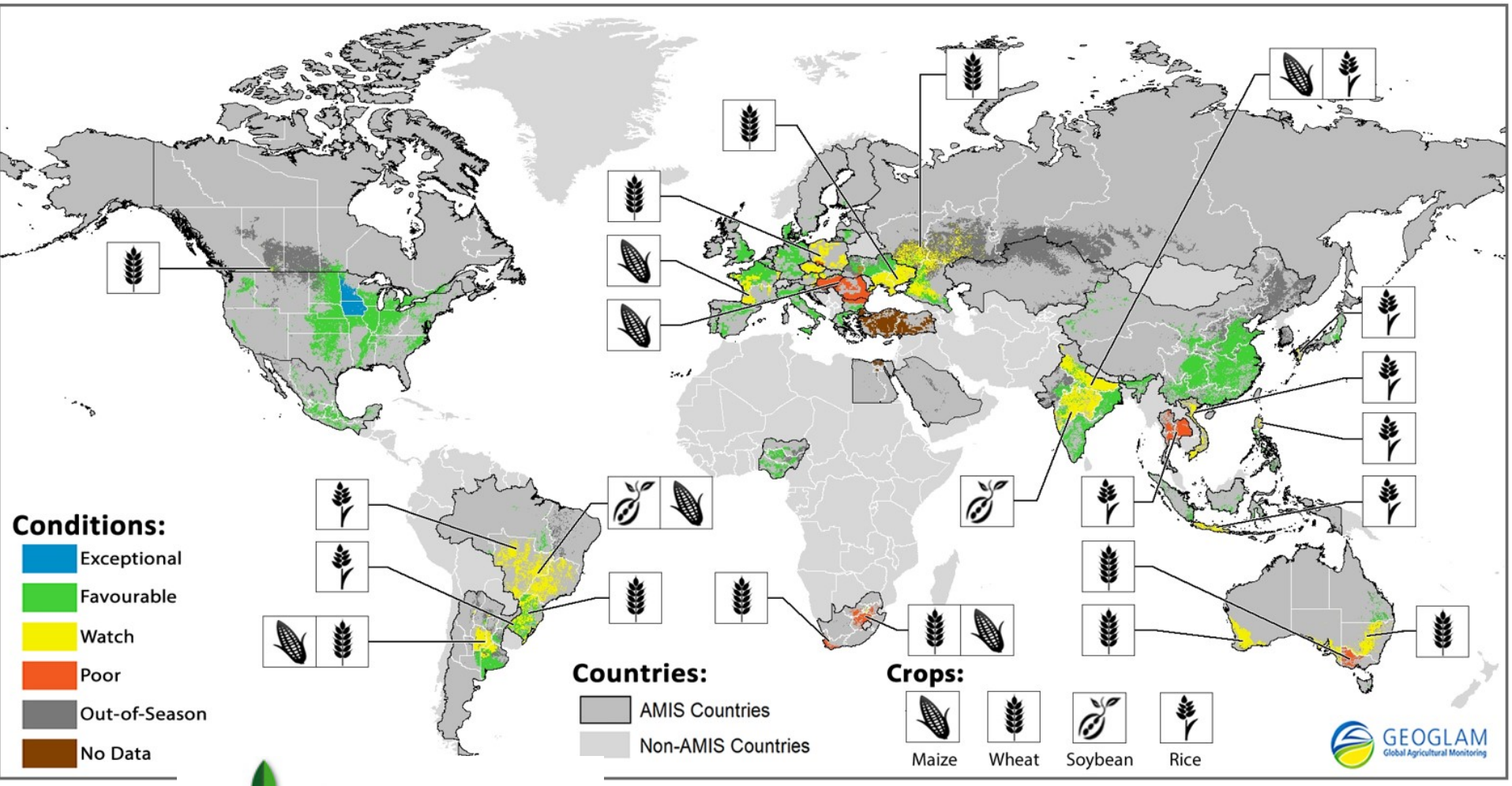
A cornfield analysis in Iowa:

Red areas: Lower number of seeds per acre recommended



Green areas: Portions of the field that can grow more corn and can take more seeds per acre

Support (Global) Decisions and Policy Making



AMIS Agricultural Market Information System

GEOGLAM Global Agricultural Monitoring

Monitor resources & trends to detect risks

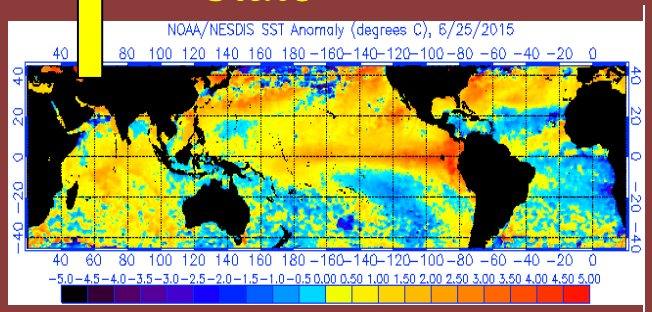
Communicate with public and stakeholders

Aral Sea Shrinkage (1978-2014)
Due to Cotton Farms

Alerts

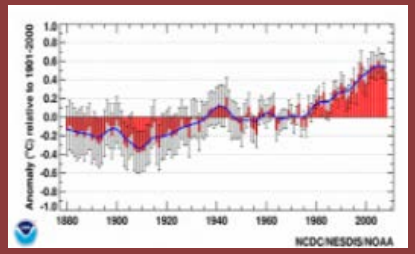
Nexus Dashboard

State

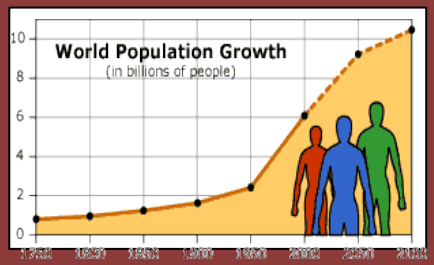


Sea-Surface Temperature Anomaly

Trends



Global Temperature



Global Population

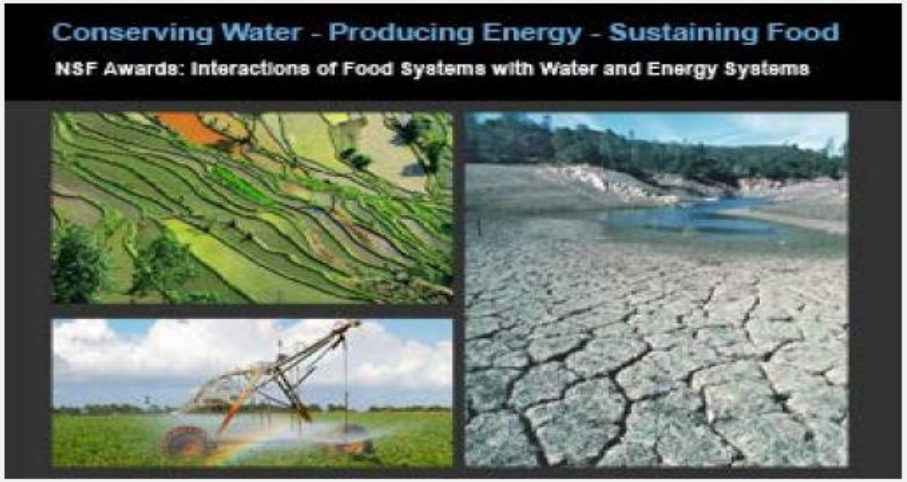
Outline

- FEW Nexus
- Role of Computing
- Computing Challenges in FEW Nexus
  - NSF INFEWS Data Science Workshop (Oct. 2015)
  - Data and Data Science Gaps
- Next

Press Release 15-090

New grants foster research on food, energy and water: a linked system

Amid population growth, drought and increased urbanization, understanding food, energy and water availability is increasingly important



How food, water and energy systems interact: a photo gallery.
Credit and Larger Version

August 14, 2015

In a world where a growing number of people lack food, water and sources of energy, providing these resources has become a challenge.

To find new answers, the National Science Foundation (NSF) has funded 17 grants, totaling $1.2 million, to support workshops on the interactions of food, energy and water, or FEW. Additionally,

- 17+ NSF Workshop grants
  - Planned across the country
  - Facilitate partnerships across disciplines, sectors
  - Define fundamental sc. & eng. research needs & questions
- Two workshop with CISE PIs
  - Technology & Information Fusion
  - Data Science

2015 Workshops

Proposal	Title	PI	PI institution	Amount	Confirmed Dates	Workshop Location
1542770	FEW NSF Workshop: Closing the Human Phosphorus Cycle	Platz	U Hawaii Hilo	$ 87,873	Jun 8 - 9, 2015	Arlington
1541880	FEW: Developing Intelligent Food, Energy,and Water Systems (DIFEWS)	Potts, Matthew D.	University of California-Berkeley	$ 49,863	Sept 28-29, 2015	UC Berkeley
1541838	FEW Workshop: "Scaling Up" Urban Agriculture to Mitigate Food-Energy-Water Impacts	Newell, Joshua	University of Michigan Ann Arbor	$ 69,242	Oct 5-7, 2015	Univeristy of Michigan, Michigan League
1541876	FEW: A Workshop to Identify Interdisciplinary Data Science Approaches and Challenges to Enhance Understanding of Interactions of Food Systems and Water Systems	Shekhar, Shashi	UMN	$ 50,000	Oct. 5-6, 2015	USDA/NIFA, Washington DC
1541883	FEW: Food-Energy-Water Nexus Workshop to Develop System Approaches and Sustainability Metrics for Evaluation	Schuster, Darlene S	American Institute of Chemical Engineers	$ 94,929	Oct. 7-9, 2015	Washington, DC
1541790	FEW: Coupling Economic Models with Agronomic, Hydrologic, and Bioenergy Models for Sustainable Food, Energy, and Water Systems	Catherine Kling	Iowa State University	$ 45,922	Oct 11-12, 2015	Iowa State University; Ames, Iowa
1541771	FEW: Food-Energy-Water infrastructure systems, engineering solutions and institutions	John L Sabo	Arizona State University	$ 94,905	Oct 13 - 15, 2015	ASU Campus
1541807	FEW: Workshop to Identify Opportunities and Challenges for Nanotechnology to Optimize and Unify Food, Energy and Water Systems	Lowry, Gregory V.	Carnegie-Mellon University	$ 58,358	Oct 19-20, 2015	Pittsburgh, PA
1541736	FEW: A sustainable rural framework workshop for the upper Great Plains.	Stone, James J	South Dakota School of Mines and Technology	$ 50,000	Oct 19 - 20, 2015	SDSM&T in Rapid City, SD
1541799	FEW Workshop - Planned Migration as a Strategy to Sustain Agricultural Production	McNider, Richard (1049050 NIFA)	University of Alabama in Huntsville	$ 56,335	Oct 21-23, 2015	NCAR, Boulder
1541866	Few Workshop: Food, Energy, and Water Nexus in Sustainable Cities	Assaf-Anid, Nada M	New York Institute of Technology	$ 98,877	Oct 20-21, 2015	Beijing, China
1541844	FEW: Conference on Environmental Change, Migration, and the Resilience of Regional Food, Water, and Energy Systems	Elena Irwin	Ohio State U	$ 97,496	Nov 4-5, 2015	Ohio State Univ.
1541868	FEW Workshop: Water- and Energy-efficient Food Production: Solutions for America's Bread Basket	Rezac, Mary E.	Kansas State University (EPSCoR)	$ 50,000	Nov 19-20, 2015	Manhattan, Kansas; Governor's Conference Nov. 18 - 19
1541642	FEW: Development and Application of Analytical Tools in Support of Food-Energy-Water Nexus Planning	Miralles-Wilhelm, Fernando R	University of Maryland College Park	$ 99,980	Oct. 27-28, 2015	Washington DC
1541890	FEW: Towards Food, Energy and Water Security in California under Changing Conditions: the Nexus Perspective	Gebremichael, Mekonnen	University of California-Los Angeles	$ 49,680	Dec 2-4, 2015	UCLA, Los Angeles, California
1541863	FEW: Technology and Information Fusion Needs to Address the Food, Energy, Water Systems (FEWS) Nexus Challenges	Ebert, David	Purdue	$ 60,105	Nov. 5-6	Napa Valley Marriott Hotel and Spa
1541694	FEW: River FEWs: Workshop to explore the nexus between food, energy and water in a large international river system	Holtgrieve, G.W.	University of Washington	$ 98,367	Dec. 10-12, 2015	U. Washington, Seattle

NSF INFEWS Data Science Workshop

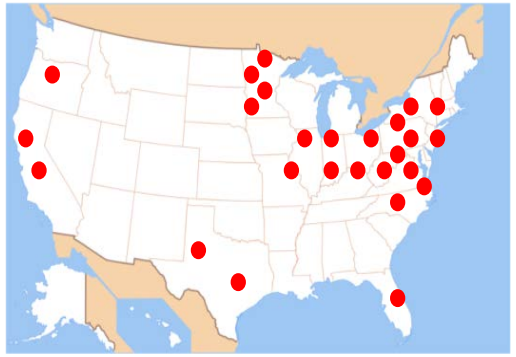
- **Goals**
  - Develop visions, Identify gaps
  - Develop a research agenda
- **At** USDA NIFA, Oct. 5th-6th, 2015
- **Co-organizers:** Shekhar, Mulla, Schmoldt
- **URL:** www.spatial.cs.umn.edu/few

- **Draft report available for comments:**
  http://www.spatial.cs.umn.edu/few/few_report_draft.pdf

- **55 Participants** (Data-driven FEW & Data Sciences)

Gov.	Aca.	Industry
26	24	5

Food	Energy	Water	DataSc.
14	10	11	20



Multi-disciplinary Multi-sectoral Participation

Data Science	Names
Data Collection, Remote Sensing	Peggy Agouris David Corman (NSF) Thomas G. Dietterich Paul Gader Raju Vatsavai
Data Exploration, Management, Dissemination	Chandra Krintz Dieter Pfoser Hanan Samet Tom Shapland (Farmlink) Goce Trajcevski
Data Extrapolation …	Chid Apte (IBM) Vasant Honavar (CCC) Zico Kolter Vipin Kumar Sanjay Ranka …

FEW	Names
Food	Parag Chitnis (USDA) Jason Hill Rattan Lal L. K. Matukumalli (USDA) Rachel Melnick Rabi Mohtar Sonny Ramaswamy (USDA) Susan Jean Riha Paul Tanger Luis Tupas (USDA)
Energy	Noel M.Bakhtian (USDOE) Robie Lewis (USDOE) Bob Vallario (USDOE) Tamara Zelikova
Water	Richard Alexander (USGS) Brad Doorn (NASA) Alan Hecht (EPA)
Cross-cutting, Social Sc., …	Inna Kouper Zachary Hayden Moira Zellner Ariela Zycherman (NSF)

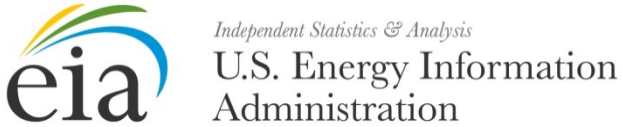
Panels, Presentations & Breakouts

- **Panel:** Data-Driven FEW Nexus Science and Application Innovations
  - FEW Nexus Overview (with life-cycle analysis): Rabi Mohtar (TAMU)
  - **Energy - Water** Nexus: Bob Vallario (USDoE)
  - **FEW : A NIFA Perspective**: Sonny Ramaswamy (NIFA)
  - **Water - Food** Nexus: Rich Alexander (USGS)
  - **Energy - Food** Nexus: Louis Tupas (NIFA)
  - Drivers of FEW Nexus: Rattan Lal (OSU)

- **Panel:** Data Sci. Research Needs to Understand & Innovate for FEW Nexus
  - Data Science Challenges in **Sustainable Energy**: Zico Kolter (CMU)
  - Open-Source **Precision Agriculture** and Analytics Driven Decision Support: Chandra Krintz (UCSB)
  - **Machine Learning** Challenges: Thomas Dietterich (Oregon U)
  - **Trustworthiness** and Sustainability: Data Science for FEW Nexus in the Developing Regions: Inna Kouper (Indiana U)
  - **Informatics** Challenges: Vasant Honavar (Penn State)
  - **Remote Sensing** and Water: Brad Doorn (NASA)

Outcomes: F-E-W Nexus Data Gaps

- Water: Need US water census
  - Equivalent of Ag. Census and US-EIA



- Other Data Needs:
  - Energy, Food– consumption & FEW Interaction data
  - A FEW nexus data community (BD FEW Spoke)

- Data Integration Challenges
  - Varied data collection (e.g., aquifer withdrawal meter in TX & CA)
  - Heterogeneous data format (e.g., raster climate data, vector population)

Outcomes: Data Science Gaps

1. Methods to help stakeholders reach consensus on FEW issues
   - Social science methods: scenario-based discussion, design exercises, etc.
   - Computational tools: visualization, explainable/interpretable models, interactive simulation and optimization

2. Spatio-temporal modeling
   - Dealing with data collected multiple spatial, temporal scales,
   - missing values

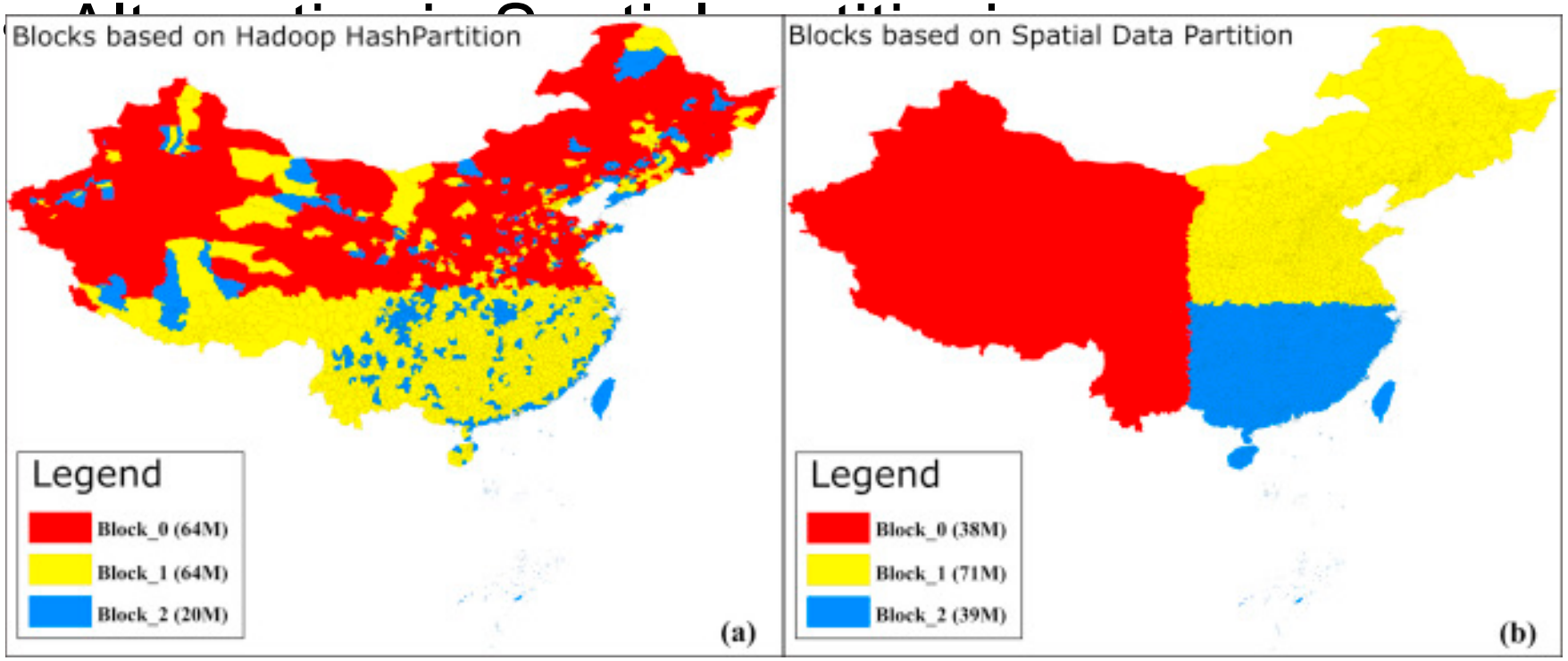
3. Fusion of multiple model types
   - Data-driven, process-driven, economic, etc.

4. Lifecycle thinking for the FEW Nexus
   - modeling human behavior, understanding indirect effects of perturbations, supply chains, opportunity costs, agent-based modeling

5. Data uncertainty, incompleteness, bias
   - provenance, conflict of interest, capturing and visualizing uncertainty

Limitations of Hadoop

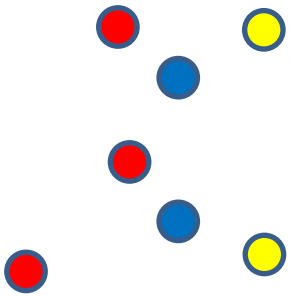
- Hadoop uses Hash (i.e. Random) partitioning
  - related objects scattered, not grouped



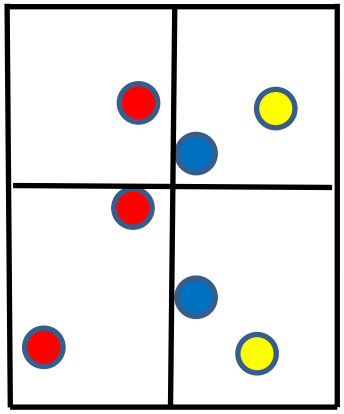
Source: Spatial coding-based approach for partitioning big spatial data in Hadoop, X. Yao et al., Computers & GeoScience, 106:60-67, September 2017, Elsevier.

Food Big Data Analysis

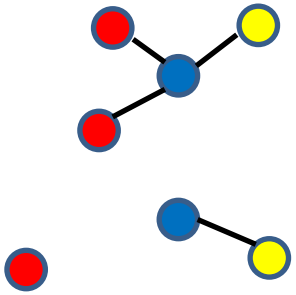
- Simulation, Statistics, Data Mining, Machine Learning
- Challenge: One size does not fit all
  - Prediction error vs. model bias, Cost of false positives, …
- Ex. Interaction patterns



(a) a map of 3 features



(b) Spatial Partitions

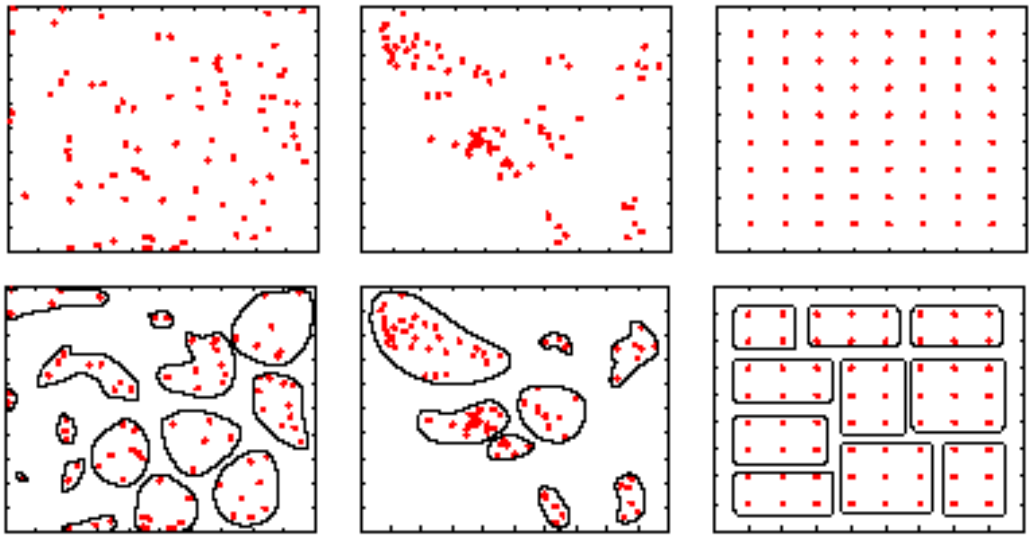


(c) Neighbor graph

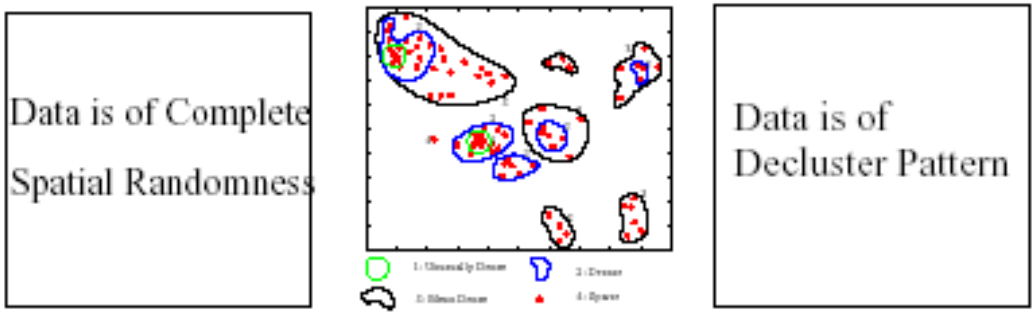
	Pearson's Correlation	Ripley's cross-K	Participation Index

Limitation of Traditional Clustering

- Simulation, Statistics, Data Mining, Machine Learning
- Challenge: One size does not fit all
  - Prediction error vs. model bias, Cost of false positives, …
- Ex. Clustering: Find groups of tuples



Traditional Clustering
(K-means always finds clusters)

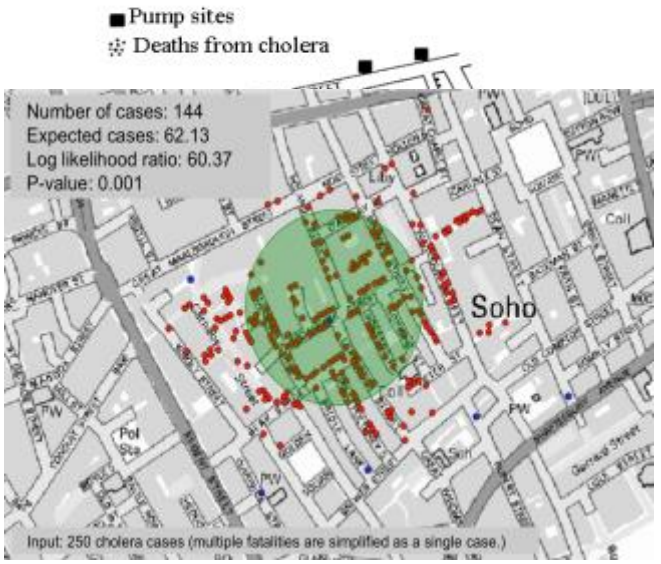


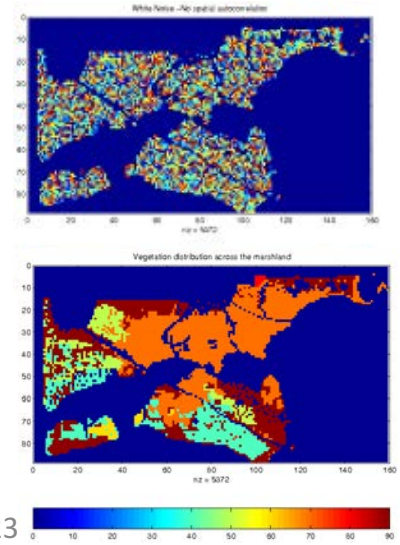
Spatial Clustering begs to differ!

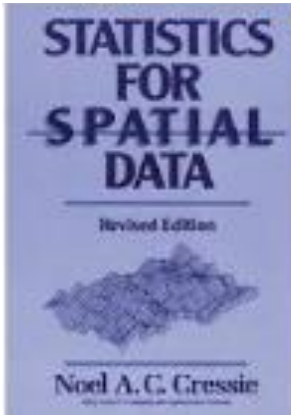
Sensor Big Data Analysis: Spatial Methods

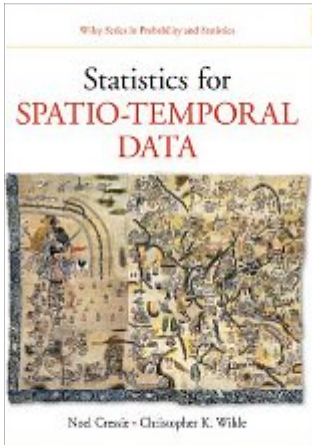
- Spatial Statistics, Spatial Data Mining
  - Quantify uncertainty, confidence, …
  - Is it (statistically) significant?
  - Is it different from a chance event or rest of dataset?
    - e.g., SaTScan finds circular hot-spots

- Auto-correlation, Heterogeneity, Edge-effect, …





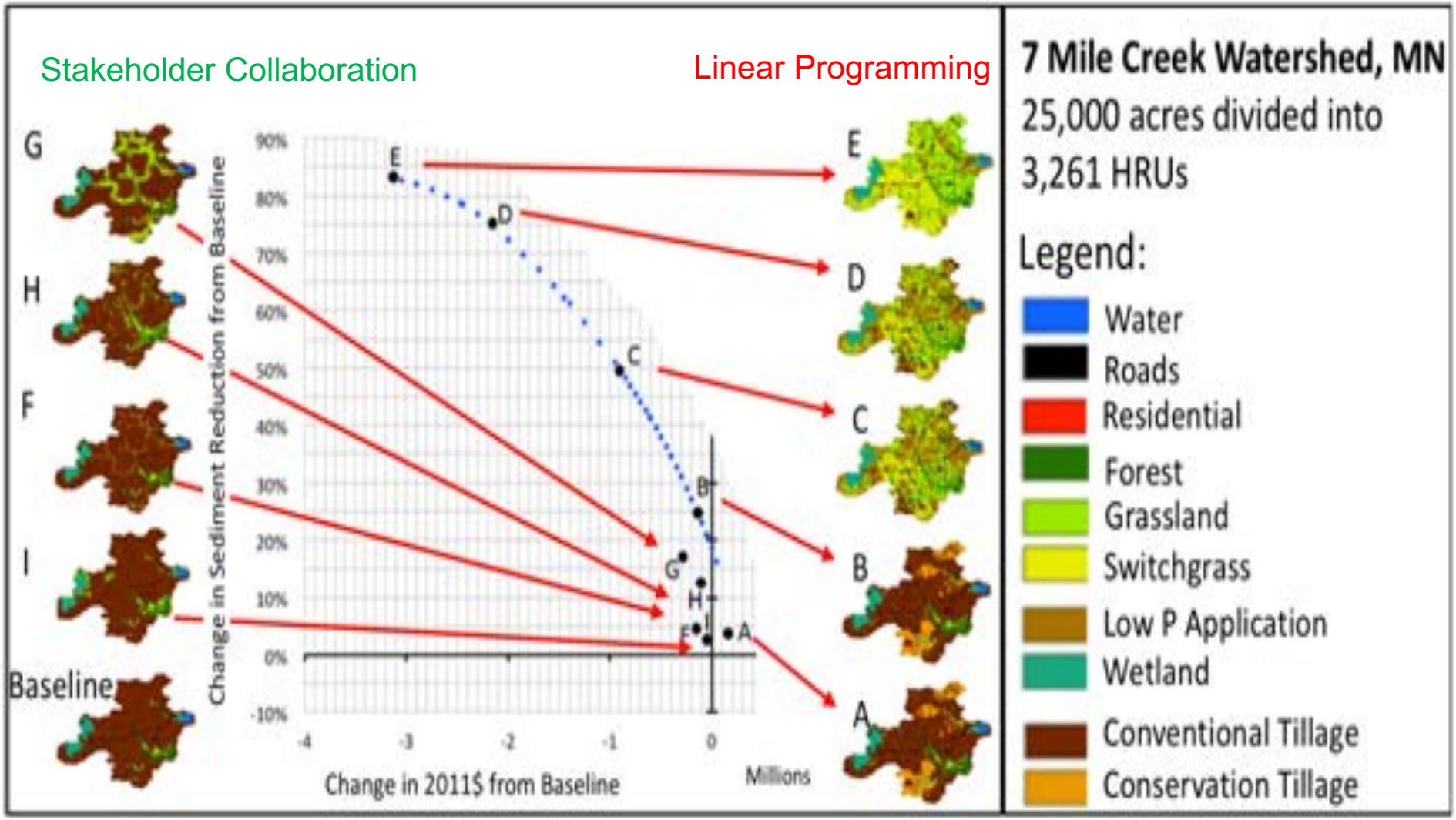




Gap Example: Spatial Fragmentation in Optimization

Landscape geodesign

- stakeholder collaboration (designs F, G, H, I)
- linear programming (designs A, B, C, D, and E)



Outline

- F-E-W Nexus
- Role of Computing
- Computing Challenges
- Related Events
  - Dec. 2015: NSF INFEWS Solicitation
  - Jan. 2016 : NCSE
  - Mar. 2016: Midwest Big Data Hub – FEW Spoke
  - Mar. 2016: Whitehouse Water Summit
  - Aug. 2016: ACM SIGKDD Workshop on FEW
  - Dec. 2016: AGU session proposal

Innovations at the Nexus of Food, Energy and Water Systems (INFEWS)

PROGRAM SOLICITATION
NSF 16-524

National Science Foundation
Directorate for Geosciences
Directorate for Engineering
Directorate for Computer & Information Science & Engineering
Directorate for Mathematical & Physical Sciences
Directorate for Social, Behavioral & Economic Sciences
Directorate for Education & Human Resources
Office of International Science and Engineering
Office of Integrative Activities

National Institute of Food and Agriculture

Full Proposal Deadline(s) (due by 5 p.m. proposer's local time):

March 22, 2016

IMPORTANT INFORMATION AND REVISION NOTES

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised NSF Proposal & Award Policies & Procedures Guide (PAPPG) (NSF 16-1), which is effective for proposals submitted, or due, on or after January 25, 2016. Please be advised that proposers who opt to submit prior to January 25, 2016, must also follow the guidelines contained in NSF 16-1.

Anticipated Funding Amount: $50,000,000

With $9,000,000 to $15,000,000 for Track 2, Visualization and Decision Support for Cyber-Human-Physical Systems at the FEW Nexus;

INFEWS Goals

Four Tracks

1. Significantly **advance our understanding** of the food-energy-water system through quantitative and computational **modeling**, including support for relevant cyberinfrastructure;

2. Develop real-time, cyber-enabled interfaces that improve **understanding of the behavior** of FEW systems and increase **decision support** capability;

3. Enable research that will lead to **innovative** system and technological **solutions** to critical FEW problems; and

4. Grow the scientific **workforce** capable of studying and managing the FEW system, through **education** and other **professional development** opportunities.

The Food-Energy-Water Nexus

16th National Conference and Global Forum on Science, Policy and the Environment

January 19-21, 2016

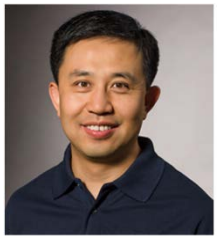
Hyatt Regency Crystal City at the Washington, DC National Airport

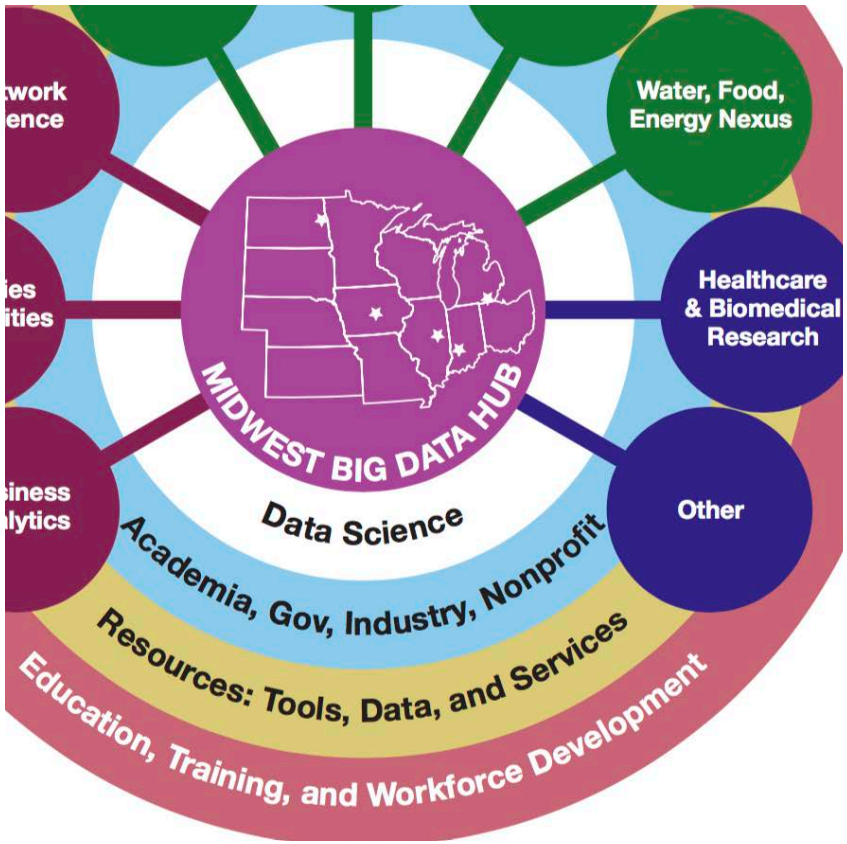
- Highlights:
  - Participation from NSF, USDA, USDOE, NOAA, USGS, NASA, USFS, etc.
  - Many sessions related to NSF INFEWS
  - Ex. S-E2: Towards a F-E-W nexus data science community

NSF Director Córdova (right) with former NSF Director Rita Colwell, who received a lifetime achievement award from National Council for Science & Environment (NCSE).

Community Building: NSF MBDH FEW Spoke







Lead: Klara Nahrstedt
Assisted by Shashi Shekhar, Shaowen Wang

Over 40 partners

Multi-disciplinary

- Food: AgMIP/GABBS (Purdue)
- Energy: NWU Inst … Ren. Energy
- Water: Env. Eng. (UIUC, IU), Water Center at UMN & NWU,
- UMN Institute on Env., MN Population Center
- NCSA CyberGIS

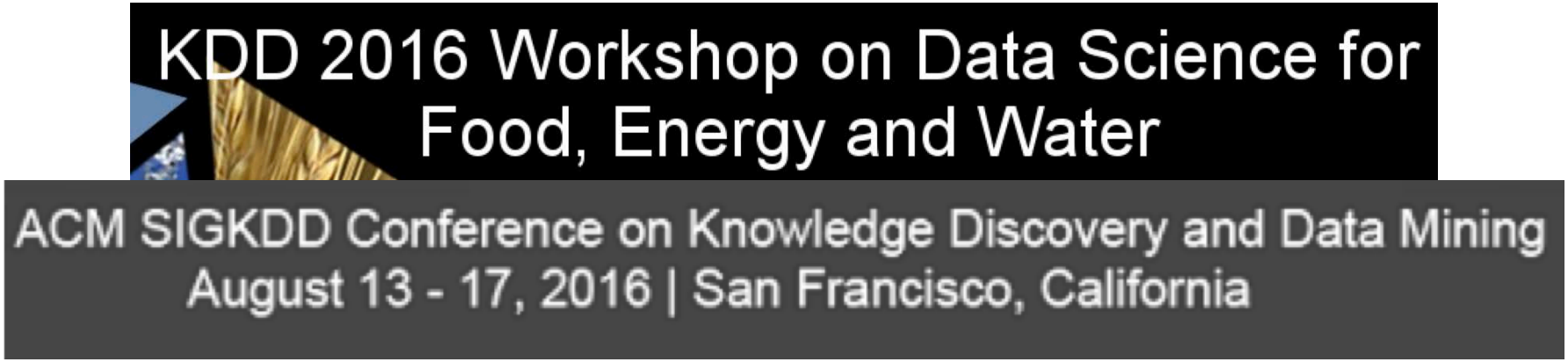
Multi-sector

- Academic: TAMU, NCSU, U Glasgow, …
- Industry: IBM, Climate Corp.
- Govt.: Chicago Water Distr., NCAR, USGS, …
- NGO: Nature Conservancy
- International: U Glasgow, Govt. of Canada

KDD 2017: FOOD, ENERGY, AND WATER

DATA SCIENCE FOR INTELLIGENT FOOD, ENERGY, AND WATER (DSIFER)

Monday, August 14th, 2017.
http://ai4good.org/few17/



Details @ https://sites.google.com/site/2016dsfew/home

Thanks: NSF MBDH Travel Support for Early Career Researchers

White House Water Summit: March 22, 2016

Commitments to Action on Building a Sustainable Water Future

The New York Times MARCH 17, 2016

Water Is Broken. Data Can Fix It.

NSF Multi-year Cross-Directorate Initiative

News: https://foodenergywater.wordpress.com/

Research:

- Innovations for F, E, W Nexus (INFEWS)

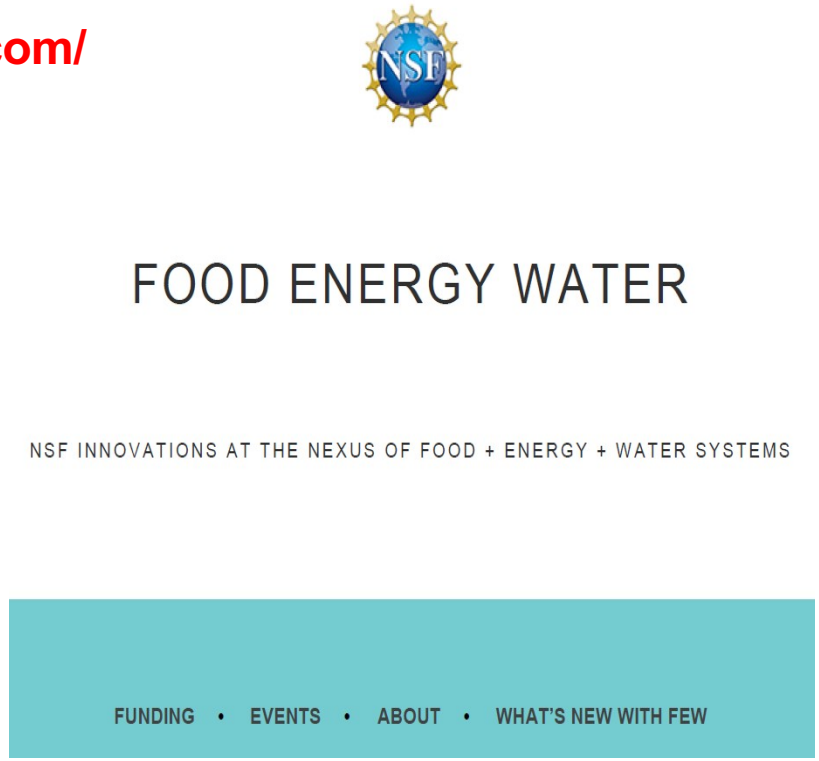
Education:

- NRT solicitation - INFEWS as a priority

Infrastructure & Community Building:

- Big Data Hub, Big Data Spoke

EPSCoR



INFEWS Data Science Workshop Draft report available for comments:
http://www.spatial.cs.umn.edu/few/few_report_draft.pdf

Outline

- Agriculture Big Data (AgBD) Examples
- Data Management Tools
  - Limitation of traditional tools
  - Promising Spatial Tools
- Data Mining Tools
- Collaboration Opportunities

Food Big Data & Collaboration Opportunities

- Current Big Data Tools are too generic
  - Click stream mining
  - false positive costs negligible

- One size big data tools do not fit all .Ag big data

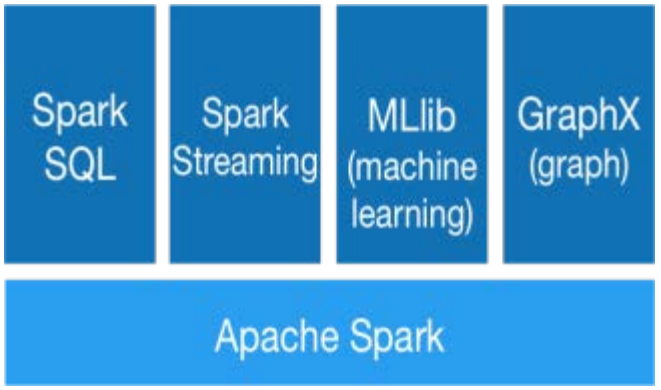
-

Big DataTools

- Current Big Data Tools (e.g., Machine Learning, Hadoop)
  - For click-stream mining to choose advertisements
  - False positive cost negligible, Sanity Check via A/B expt.
  - Google Flu Trends experience

- One size big data tools do not fit all (Food) big data

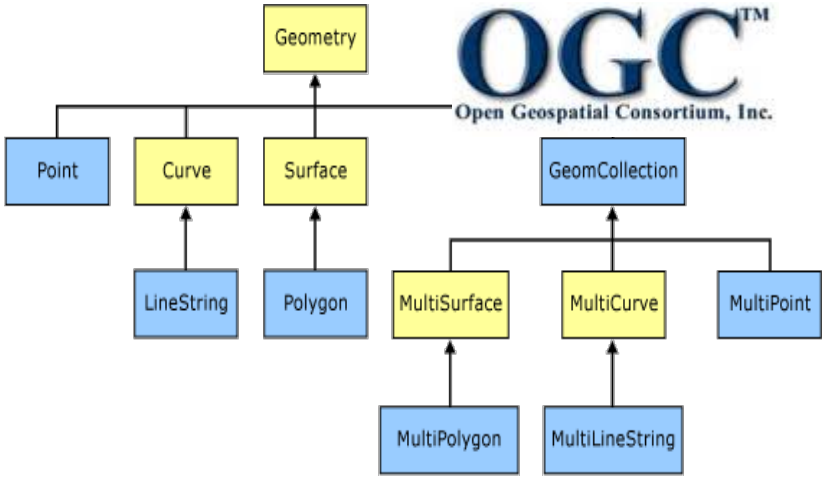
- Farm to Table Food Data
  - Physical Spaces: farms, precision agriculture, remote sensing, …
  - Location-aware
  - Spatio-temporal context, e.g., neighbors
  - False positive costs may be high

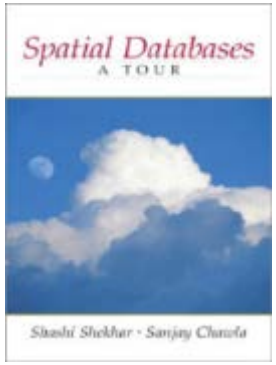


Food Big Data Curation

- Meta-data, Schema, DBMS (SQL, Hadoop)
- Challenge: One size does not fit all!

- Ex. Spatial Querying
  - Geo-tag. Checkin, Geo-fence
- Spatial Querying Software
  - OGC Spatial Data Type & Operations
  - Data-structures: B-tree => R-tree
  - Algorithms: Sorting => Geometric
  - Partitioning: random => proximity aware





Outline

- Agriculture Big Data (AgBD) Examples
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Food Big Data Mining

- Current Big Data Mining Tools are generic
  - Click stream mining
  - false positive costs negligible

- One size big data mining tools do not fit all sensor big data

- Food Big Data
  - are often in Physical Spaces
  - High cost of false positives

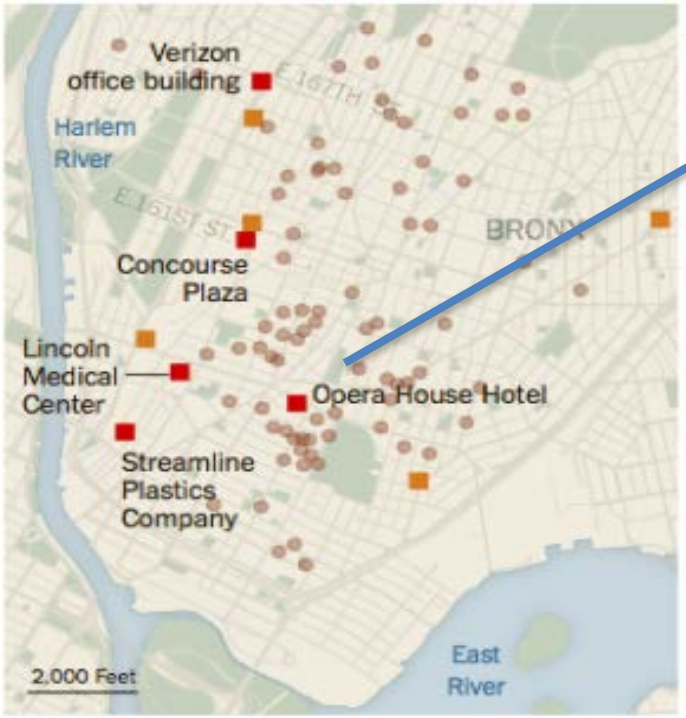
Hotel That Enlivened the Bronx Is Now a 'Hot Spot' for Legionnaires'

By WINNIE HU and NOAH REMNICK AUG. 10, 2015

Contaminated Cooling Towers

Five buildings have been identified as the potential source of the Legionnaires' disease outbreak in the South Bronx.

- Possible sources of Legionnaires' outbreak
- Additional sites found with legionella bacteria
- Locations of people with Legionnaires'

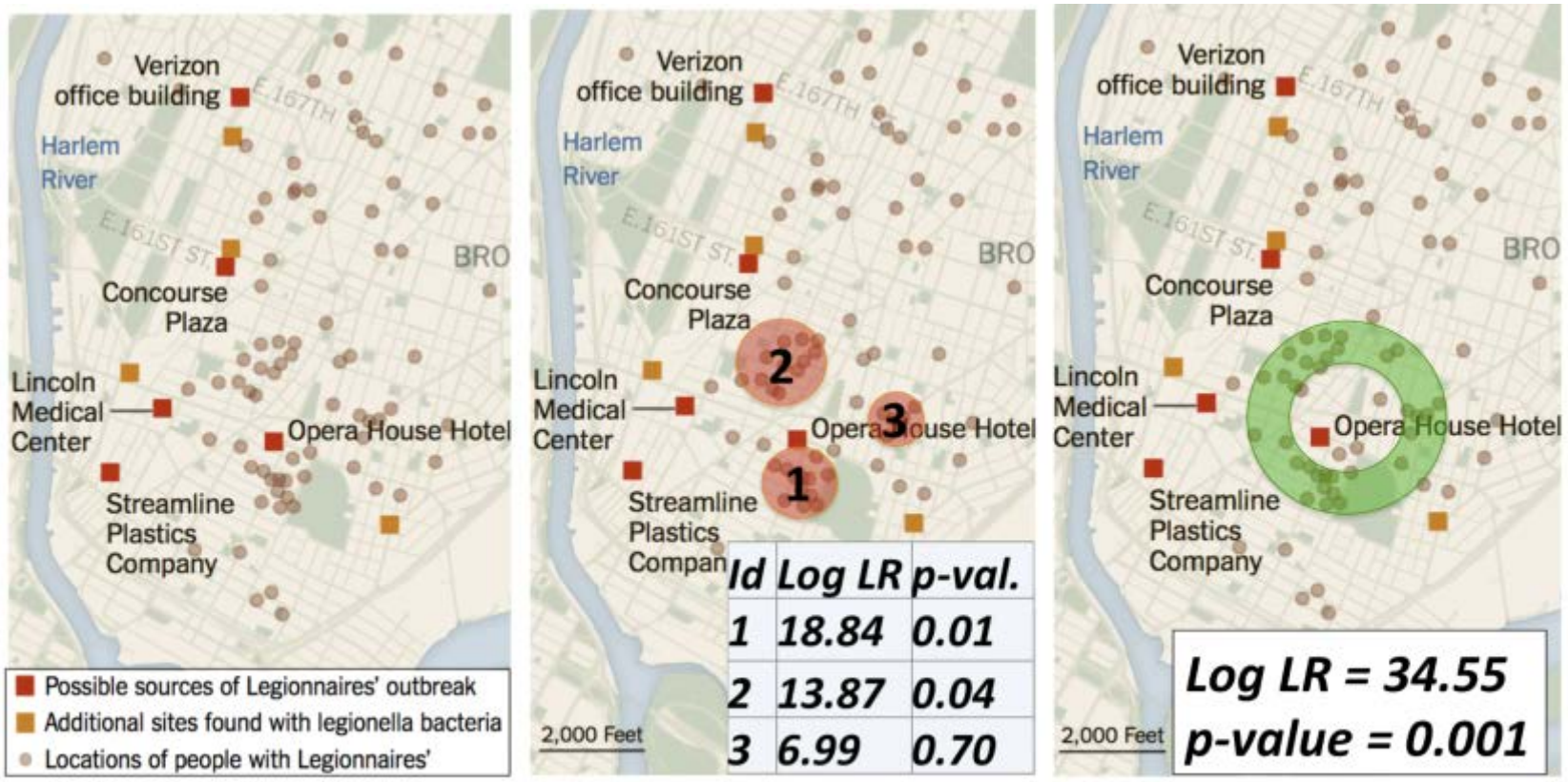


Source: New York Mayor's Office

By The New York Times

The Opera House Hotel is at the center of the outbreak. Edwin J. Torres for The New York Times

Legionnaires' Disease Outbreak in New York



(a) Legionnaire's in New York (2015)

(b) Output of SaTScan

(c) Output of RHD

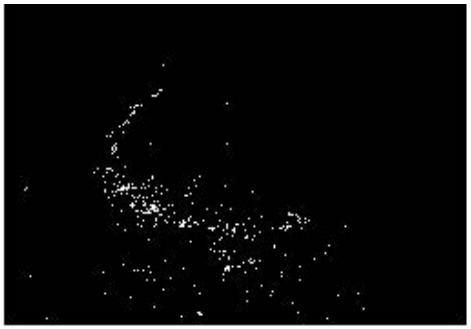
Source: Ring-Shaped Hotspot Detection: A Summary of Results, IEEE ICDM 2014 (w/ E. Eftelioglu et al.)

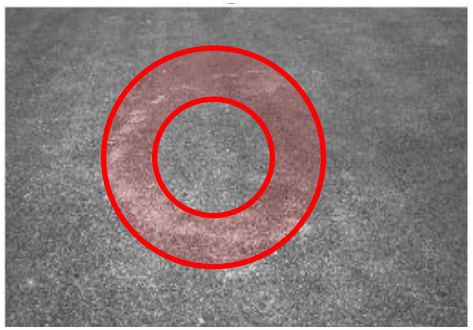
Necrotic Ring Spot Detection

Original Image

Grayscale

Bitmap (0,1)





Log Likelihood Ratio: 3129
p-value: 0.01

Number of Pixels Included: 4169
Inner Radius: 179 pixels
Outer Radius: 229 pixels

Outline

- Agriculture Big Data (AgBD) Examples
- Data Management Tools
- Data Mining Tools
- Collaboration Opportunities

  - USDA/NIFA FACT

  - NSF: INFEWS, CPS/Ag, NRI/Ag, …

NIFA Food & Ag Cyberinfo. Tools (FACT)

NIFA Introduces New Vision for Data Science in Agriculture

Tuesday, October 18, 2016

The U.S. Department of Agriculture's National Institute of Food and Agriculture (NIFA) convened a summit to identify the frontiers and future of data in agriculture and build on existing U.S. government-wide efforts and investments in big data.

The summit featured distinguished leaders in the fields of data science and agriculture and engaged a diverse array of stakeholders to identify new opportunities for data science in agriculture. The meeting was held in conjunction with the Midwest Big Data Hub All-Hands Meeting in Chicago, Ill.

At this summit, NIFA Director Sonny Ramaswamy announced a new initiative, Food and Agriculture Cyberinformatics and Tools (FACT), designed to develop data-driven solutions for addressing complex problems facing agriculture today. "Data, technology, and approaches that integrate individual and societal considerations are essential to meeting this challenge," said Dr. Ramaswamy in his welcome address. "To achieve this, NIFA envisions a future for agriculture that is connected, data-driven, personalized, and sustainable."

- Data-driven advances in agriculture and the food production system;
- Cross-sector advances in data applications;
- Data-driven advances to address societal well-being and consumer demands;
- Data management and application;
- Developing a data literate workforce and end-user; and
- Big data in communication, property rights, and communities

NSF CPS/Ag

Excerpts from NSF 17-529: Cyber Physical Systems (CPS)

II.C.5 National Institute of Food and Agriculture (NIFA)

NIFA is pursuing an aggressive research agenda to meet the "grand challenges" for agriculture and society identified by the President's Council of Advisors on Science and Technology in its December 2012 report titled *Report to the President on Agricultural Preparedness and the Agriculture Research Enterprise*. These challenges have a common underlying theme: delivering food, fiber, fuel, and feed within a changing global climate while reducing agriculture's environmental footprint and managing biotic threats to production. NIFA has embarked on a multi-horizon research agenda that is addressing these challenges. Foundational and applied research in cyber-physical systems are an important element of this agenda.

For this solicitation, NIFA encourages projects that advance science and technology applied to Smart & Connected Communities (both rural and urban) and to real-time agricultural data analytics and control.

Real-Time Agricultural Data Analytics and Control:

Addressing many of the agricultural grand challenges demands new advances in the integration of cyber-physical systems (including sensors, communication systems, and control systems) with real-time information and analytic engines tightly coupled with agriculture and food systems. This integration forms a large-scale cyber-physical system that enables data collected throughout the supply chain to be analyzed and used for control and decision-making in other stages of production, processing, distribution, storage, and consumption. Much agricultural data is currently single-use and static. For

NSF CPS/Ag

Smart & Connected Communities (S&CC):

The "sharing economy" has explored and built new business models, new marketing opportunities, and new options for consumers. Much of that sharing has been facilitated by location-aware, take-anywhere technology, such as the smart phone. Now, by overlaying that expanded level of human connectivity with networks of connected devices and infrastructure, not just mobile phones, we create new possibilities to enhance the livability and sustainability of communities in both urban and rural settings. While the same basic needs for environmental, social, and economic sustainability exist for both urban and rural communities, solutions to meet those needs can vary quite dramatically.

The following two NIFA **goals** have been identified for S&CC in urban and rural settings, respectively:

1. Increased food and nutritional security through the development of high-output and efficient controlled-environment urban agriculture technologies and systems; and
2. More resilient, robust, and reliable agricultural systems leading to more viable and thriving rural communities.

CPS **technology challenges** that are directly relevant to NIFA goals for S&CC include:

- Robust and intelligent control systems and sensors to help monitor, optimize, and manage an entire controlled-environment urban agriculture facility including physical environment (lighting, temperature, water, and fertilizers);
- Model-based development and control integrating horticultural knowledge of pests, cultivars tailored to controlled environments, and companion production;
- Integration of renewable energy sources such as solar technology and improved high-efficiency lighting based upon physics and photonics advances; and
- New connectivity paradigms and applications for integrated devices, communications, control systems, and databases in dispersed rural settings that enable overlain software to bring quality-of-life improvements to citizens for benefits such as education, health, economic development, mobility, or environmental quality.

References

1. Spatial Computing, Communications of the ACM, 59(1), Jan. 2016.

2. From GPS and Virtual Globes to Spatial Computing 2020, Computing Community Consortium Report, 2013. www.cra.org/ccc/visioning/visioning-activities/spatial-computing

3. Spatiotemporal Data Mining: A Computational Perspective , ISPRS International Journal on Geo-Informtion, 4(4):2306-2338, 2015 (DOI: 10.3390/ijgi4042306).

4. Identifying patterns in spatial information: a survey of methods , Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 193-214, 1(3), May/June 2011. (DOI: 10.1002/widm.25).