The 2013 Ozone Garden Network: Building Upon the Success of the St. Louis Ozone Garden

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A Presentation to the
Air Quality Applications Science Team
College Park, MD
June 4, 2013
Summer 2012: St. Louis Ozone Garden Highlights and Challenges

- Successful Planting
  - Opening on May 5
  - Science Center’s Youth Exploring Science (YES) Students participated
  - Garden grew despite record heat

- Challenges
  - Tweaking irrigation system (bad valves; too wet; too dry)
  - Buggy pests: tender young snap beans (2nd planting used seedlings)
  - Critters (probably rabbits) found entry into garden despite taking precautions
  - Communication from monitor in garden to laptop inside building
The St. Louis Regional Network of Ozone Gardens

• Installation of Ozone Garden at Grant’s Farm
  - 15 km SW of Forest Park
  - Extremely high traffic area (~1,000,000 /yr)

• Installation at Southwestern Illinois College
  - 40 km ESE of Forest Park
  - Part of Sustainability Demonstration:
    will operate on solar polar
  - New Campus:
    awaiting final approval for placement
National Network of Ozone Gardens
New Sites Started at Harvard, NASA Goddard and Virginia Living Museum (Newport News)

- Bed of Ozone Sensitive Plants outside of NASA Goddard Visitor Center

- Plants at Harvard as Part of Harvard’s Community Garden

- Ozone Garden started in 2012 at Virginia Living destroyed by historic flash floods
Harvard Students Teach Community about Atmospheric Chemistry Using LEGO Blocks
Future Expansion: Collaboration with Raluca Ellis

• Raluca primary person behind establishment of Harvard Ozone Garden

• Joined Franklin Institute (Philadelphia) in March to lead effort in sustainability education

• Franklin Institute is lead Science Center in a consortium consisting of:
  - Philadelphia
  - Queens, NY
  - Pittsburgh
  - Washington DC
A National Network of Ozone Gardens Using AQAST Members
Figure from Presentation at AQAST-2 (Nov. 2011)
A National Network of Ozone Gardens Is Evolving
Six Gardens by Summer 2013
Ozone Garden at the Saint Louis Science Center’s McDonnell Planetarium
Plants are thriving in 2013 relative to 2012

Common Milkweed  June 6, 2012

Coneflower  June 6, 2012

May 21, 2013

May 21, 2013
Visualizing the Impact of Global Change on the Environment: 
The St. Louis Ozone Garden

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February 2013
Revised
(June 2013)
Primary Message of BAMS Paper

• Dirty Air Has Become Cleaner
• Clean (Background) Air (where crops are grown) Has Become Dirtier
• Concentrations in Background Air Now Above Concentrations where Plant Damage Begins
• Damage is Observable in Plants in the Ozone Garden:
  - Ozone Garden is an education/public outreach tool for visualizing “Global Change”

• Analysis of 32 years of St. Louis Air Quality data shows increase of 6-7 ppb since 1980 in “clean” air

• Results from Fishman et al. (2010):
  - No (measured) decrease in yield at $O_3 < 49$ ppb
  - Statistically significant yield decrease at 54 ppb
• Has the threshold been crossed in the 21st century?
Plants in St. Louis ozone gardens in 2013

Perennials

• Common milkweed (*Asclepias syriaca*)
• Cutleaf coneflower (*Rudbeckia laciniata*)
• Yellow crownbeard (*Verbesina occidentalis*) NEW IN 2013

Annuals

• Snap bean (*Phaseolus vulgaris*) O₃ sensitive and tolerant
• Soybean (*Glycine max*) O₃ sensitive and tolerant NEW IN 2013
• Potato (*Solanum tuberosum*) O₃ sensitive and tolerant NEW IN 2013
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Choice of Soybean Cultivars Based on Research by Betzelberger et al. 2010
Seeds supplied by Lisa Ainsworth at University of Illinois

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Table 2.2 Seed yield (kg ha⁻¹) and standard error of soybean cultivars exposed to ambient and elevated [O₃] in 2007 and 2008. Significant differences between ambient and elevated [O₃] within a cultivar and year are shown with asterisks. *p<0.05, **p<0.01, ***p<0.001

Data from Amy Betzelberger PhD Dissertation, ”Current and Future Consequences of Tropospheric Ozone on Soybean Biochemistry, Physiology, and Yield,” Univ. Illinois, 2013

• At the end of the 2013 growing season, we will compare the difference in the two types of cultivars at all three St. Louis sites
Late planted snap beans 2012:
Average pod number and dried weight (g) of ozone sensitive and tolerant plants \( (n=12) \)
Plants Exposed to Ozone Have Different Spectral Signature

Within each image, the two leaves on the left-hand side grew in control chambers, and the two leaves on the right-hand side grew in chambers with moderately elevated ozone concentrations. Purples and blues in ozone-exposed leaves indicate that the leaves are carrying out photosynthesis less efficiently than leaves in the control chambers, where deeper reds and yellows appear.

A Potential New Use of Air Quality Data for Use by the USDA

Can Air Quality Satellite Data be Used to Improve Crop Forecasts?
Production Estimates and Crop Assessment Division (PECAD) Model: LCLU Satellite Data Used as Input

**WMO STATION DATA**
- Daily station data for rainfall, snowfall, temperature, wind speed, and other climatic parameters.
- Archives from various sources.

**COARSE-RESOLUTION DATA** (Air Force Weather Agency)
- Data sources:
  - METEOSAT
  - GOES
  - SSN

**MEDIUM-RESOLUTION SATELLITE DATA**
- Data sources:
  - AVHRR/NOAA
  - MODIS
  - METEOSAT
  - GOES

**HIGH-RESOLUTION SATELLITE DATA**
- Data sources:
  - SPOT
  - IKONOS
  - Landsat
  - Fosseidon
  - Jason

**RADAR ALTMETER SATELLITE**
- Data sources:
  - Pre-1992
  - Jason

**GRIB (RASTER)**
- Data sources:
  - Rainfall images (6-hourly)

**AGRMET (GRID CELLS)**
- Daily grid cell data (25-514 m) for rainfall, snow, temperature, wind, and solar radiation.
- Archive from 1994.

**PC WORKS (Image analysis)**
- Time-series data
- Crop yield and forecast products
- Interactive data extraction

**2-LAYER SOIL MOISTURE MODEL**
- Estimates soil moisture daily for grid cells and regions.

**CROP STRESS (ALARM) MODELS**
- Crop humidity algorithm monitors crop stress for corn, wheat, and sorghum.
- Act as a warning system for early detection of crop stress conditions.
- Ranges regional weather anomalies that exceed temperature and soil moisture thresholds for the particular crop.

**CROP MODELS**
- Crop calendar model for corn, wheat, soybean, sorghum, and barley.
- Crop water production functions that estimate relative yield reductions.

**BASELINE REFERENCE DATA**
- Historical crop yield data for various regions.

**CONVERGENCE OF EVIDENCE ANALYSIS**
- Production estimation
  - Yield x Area

**ECONOMIC INFORMATION**
- Attach event reports (USDA/FS) for area served, yields, and production.

**PECAD REGIONAL CROP ASSESSMENT ANALYSTS**
- 12 regional analysts monitoring 100 countries.

**PSD ONLINE**
- Preliminary Production (PDS)
- Final Production (FDS)
- "Lookup" and USDAs World Outlook Board
- USDA official production estimates released on the second week of each month.

**Data Processed by NASA/GIMMS**
- Time-series data
- Crop yield and forecast products
- Interactive data extraction

**CADRE DBMS**
- Archive from 1994
- Automated data extraction

**Convergence of Evidence Analysis**
- Production = Yield x Area
Production Estimates and Crop Assessment Division (PECAD) Model
Satellite Data Input Included

Can Inclusion of TEMPO Data Improve Crop Forecasts?

PECAD REGIONAL CROP ASSESSMENT ANALYSTS
12 regional analysts

CROP STRESS (ALARM) MODELS

Crop hazard algorithm monitors crop stress for corn, wheat, soybean, sorghum, and barley.

- Crop calendar model crop stages for corn, wheat, soybean, sorghum, and barley.
- Crop water production functions estimate relative yield reductions.
- Models include wheat (CERES), corn (AGRISTARS & UCROCP), soybean (Sinclair), sorghum (AGRISTARS) & barley (UCROCP), DSSAT, etc.

Data Processed by NASA/GIMMS
- Time-series DBs
- Approximate output produces
- Monitored conditions by analysis.

Archive Explorer http://151.121.3.218 for all USDA agencies

Automated lake elevations (176) every 10-days

75 offices monitoring 110 countries

MEDIUM-RESOLUTION SATELLITE DATA
AVHRR/NOAA
GAC (8-km)

HIGH-RESOLUTION SATELLITE DATA
SPOT
IKONOS
Landsat
Poseidon
Jason

RADAR ALTIMETER SATELLITE

TEMPO
Tropospheric Emissions: Monitoring of Pollution

Can Inclusion of TEMPO Data Improve Crop Forecasts?
TEMPO case study

Business case
- U.S. soybean crop, a $42 billion commodity in 2012

Background
- This study was built upon CALIPSO business development analyses, i.e., scan of commodities market, applications research knowledge, and discussions with TEMPO mission representatives.

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E-mail excerpt from J. Fishman (21 March 2013)

... I'll look forward to seeing what you come up with. I think there's a real potential to use TEMPO to help with improving agricultural predictions. I've never given it serious consideration, so thanks for bringing up the subject.
Re-frame the science in a business perspective

Business problem
- U.S. crop losses to ground level ozone: $1 - $3 billion annually (Ainsworth Laboratory, n. d.)

Proposed Solution
- Incorporate TEMPO data, coupled with Fishman and co – authors’ soybean – ozone crop stress research, into the USDA’s processing system for estimating global crop production.

Socio-economic value
- USDA decision makers obtain a clearer understanding of potential damage to the U.S. soybean crop.
- The commodities market receives the most accurate monthly estimate of U.S. soybean production.

Questions
- Is this the best solution? What is the return on investment?
Questions remain, including:

- Would the USDA crop stress modelers/users accept a national soybean – ozone crop stress model?

- What are the timelines for (1) developing, (2) yield testing, and (3) widespread use of ozone tolerant cultivars?

- Is it feasible to leverage Sentinel-4 and GEMS? If so, what are the costs?
  - Chappius band not included on Sentinel-4 and GEMS
Recommended next step

Leverage NASA’s resources

- Answer ROSES call: Topical Workshops, Symposia, and Conferences
  - Invite key stakeholders, including:
    - Elizabeth Ainsworth – USDA
    - Kent Burkey – USDA
    - Jack Fishman – TEMPO
    - NASA (Ali Omar, Brad Doorn)
    - Richard Joost – United Soybean Board
    - Relevant USDA, EPA, industry, and academia personnel
  
- Allow for information exchange
  - Determine the return on investment to develop and deploy a national soybean - ozone crop stress model
  - Consider alternative/additional options
Summary

- Prototype St. Louis Garden in 2012 Expanded into Network of Six Gardens in 2013
  - Greater St. Louis Regional Network
    - Characteristic regional gradient of O$_3$ is prevalent
    - Tolerant and sensitive soybean cultivars planted
  - National Education/Public Outreach Network
    - Gardens co-located with Existing Science Centers/Gardens
      * Harvard University (Cambridge MA)
      * Goddard Space Flight Center (Greenbelt MD)
      * Virginia Living Museum (Newport News VA)

- Journal Article Submitted to BAMS

- Potential New Use of TEMPO Data to Improve Crop Yield Forecasts Being Studied
Back-up Slides
Late planted snap beans:
O$_3$ damaged vs. undamaged leaf count 10/02/12

*O$_3$ sensitive plants had more leaves, which were observed to be smaller on average than leaves of the O$_3$ tolerant plants.
Tactic: Scan the environment
Monitor connected to laptop (for data storage and internet access) intended to be housed indoors

- Usually ozone is pumped to the monitor through a long Teflon tube
- For us, a reliable wireless connection from the monitor in the Ozone Garden (outside) to the computer (inside) had to be designed
Ozone and Temperature Measurements at St. Louis Ozone Garden:

- Ten consecutive days with >100°F high T; 2nd longest streak in St. Louis
- June 28th – 108°F highest ever recorded in June (109°F at Ozone Garden)
- 146 ppb reading on July 2nd - can be traced to wind shift from east
High Concentrations of 2 July Seen Within Region

St. Louis Monitoring Network Comprised of 11 Stations
High O₃ event seen at other STL monitors, but not all of them
Quantum Weather at SLU

Through a collaborative effort between SLU’s meteorology department and Ameren UE (Missouri’s electric utility), a unique capability is available to provide small-scale meteorological analyses for use in regional and urban studies.

~ 80 automated sensors are deployed through this network providing T, p, wind, cloud and precipitation information.

WS600 automated weather sensor

Parameters Measured
• Air temperature
• Relative humidity
• Precipitation intensity
• Precipitation type
• Precipitation quantity
• Air pressure
• Wind direction
• Wind speed
• Wind gusts

Data downloaded every minute

11:00 a.m. CDT

Noon CDT

1:00 p.m. CDT

Highly Unusual Circulation Pattern Coincident with 146 ppb O$_3$
Data from Airnow Network Suggests Pollution Plume from St. Louis

Daily Peak Ozone AQI
Monday, July 02, 2012

Generated: 2012-07-03 16:53:56Z
Within the Metropolitan St. Louis Area, Illinois Not in Compliance prior to 2012

(Both Missouri and Illinois non-compliant in 2012, based on preliminary data)
2012 Findings at the Ozone Garden: Snap beans

- Differences observed between ozone-tolerant (above) and ozone-sensitive (right panels) varieties

- The first planting, seeded in May, did not exhibit typical ozone-damage symptoms due to nitrogen deficiency; interestingly, the sensitive variety showed more damage than the tolerant variety

- The second planting, transplanted in August, exhibited classic ozone leaf damage, especially in the sensitive variety
- The O₃ sensitive snap beans had more leaves than the O₃ tolerant snap beans, and the leaves were observed to be smaller.
- The sensitive snap beans had more O₃ damaged leaves, and a higher percentage of damaged leaves than the tolerant snap beans (n=12 for sensitive and tolerant).
**In previous presentations**

**From our AQAST Award Letters:**

...“NASA policy strongly encourages participation in Education and Public Outreach (E/PO) activities by members of the science community. As a research investigator whose proposal has been selected for award, you ...[are] ... eligible to propose a supplemental Education or Outreach effort.”

At the AQAST Meeting in May 2011, Jack Fishman volunteered to lead a coordinated effort for the entire team with the intent of establishing a **Network of Ozone Gardens** sponsored by AQAST members.

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**The Ozone Garden Project** Builds upon 2 Projects of Personal Interest:
- Quantifying the Effect of Ozone Pollution on the Biosphere
- Rejuvenation of an Education/Outreach Activity (GLOBE) Started In 1998

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**The St. Louis Ozone Garden** was opened in May 2012
- It will serve as the prototype for future gardens
- Lessons learned from 2012 will be applied as network becomes established
- Comprehensive proposal to be developed for network that will start in 2013
In previous presentations

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ROSES CALL FOR E/PO PROPOSALS IN 2013 CANCELLED!

- Pursue Additional Funding Sources
  - AQAST Tiger Team for Summer 2013 (????)
    - Joint proposal with Harvard (Raluca Ellis) submitted
  - Non-government sources being pursued
    - Wallace Global Fund
    - Cedar Tree Foundation
    - Busch Family
    - U.S. Soybean Growers
    - Others...

- Development of New Education Tools for Educators to Quantify Plant Damage

- Formation of New Partnerships for Air Quality Applications
  - East-West Gateway Council of Governments through its Air Quality Advisory Committee
  - Partnership with Ameren UE (local electric utility) for Power Plant Monitoring
Timeline for Establishing Network of Ozone Gardens
(from earlier presentations)

- Several Years Down the Road
  - Eventually Expand Network (7-10 Gardens)
- Initial Cost: $15-25k per garden (cost sharing with host or local sponsor possible)
  - Fence, gate, irrigation, ozone monitor
- Annual Maintenance Cost: $5-15k per year
- Plants maintained at and provided by central location (Saint Louis University)
- NASA Proposal to be written in March 2013: Looking for collaborators
  - 2-3 initially; 3-5 total during out years
- Pursue Additional Funding Sources
  - NSF, USDA
  - Non-government
    (St. Louis: Monsanto, Enterprise Rental Car, U.S. Soybean Board, others)