K. E. Percy
Air Quality Effects Consulting Ltd.

Ozone Air Quality Standards and Vegetation: Where Are We?

Kevin Percy

K.E. Percy Air Quality Effects Consulting Ltd.

Fort McMurray, Alberta, Canada

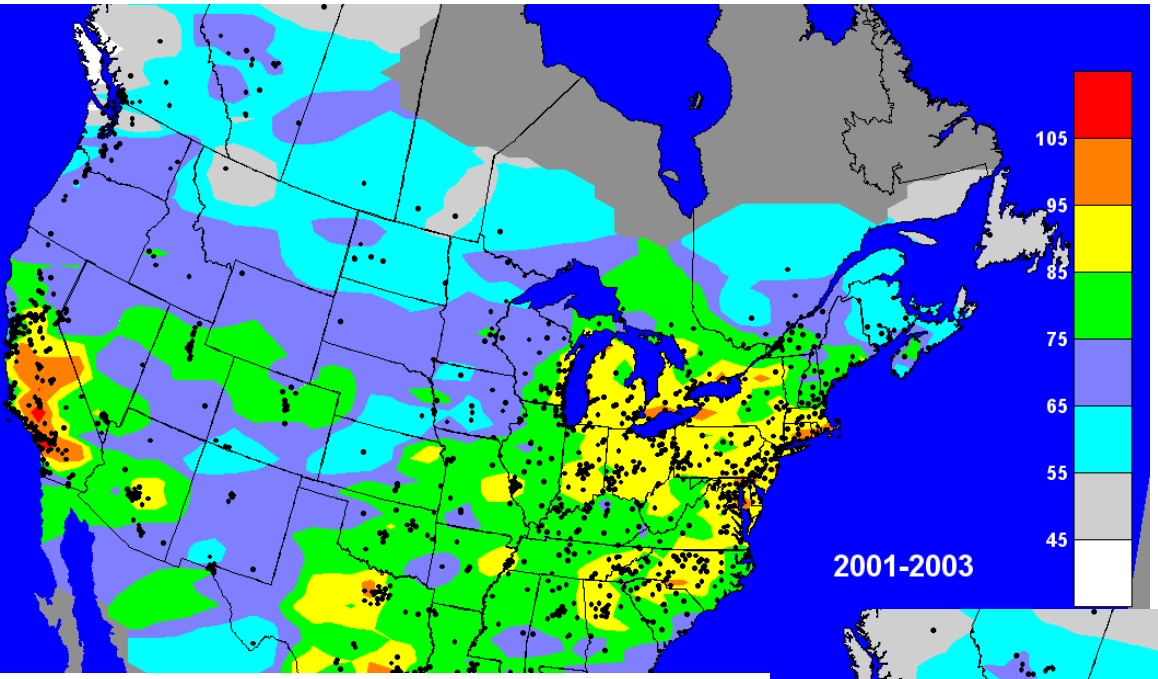
www.kepercyltd.com

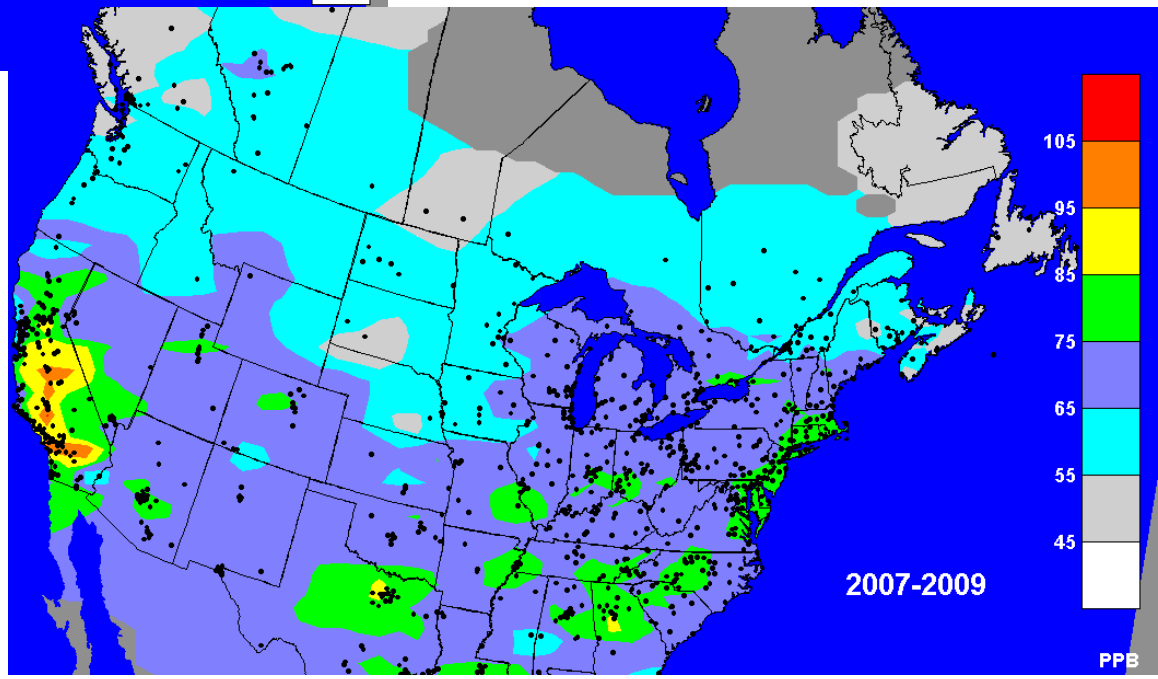
Presentation to A&WMA CPANS Luncheon, University of Alberta, Edmonton, December 3, 2010

OUTLINE

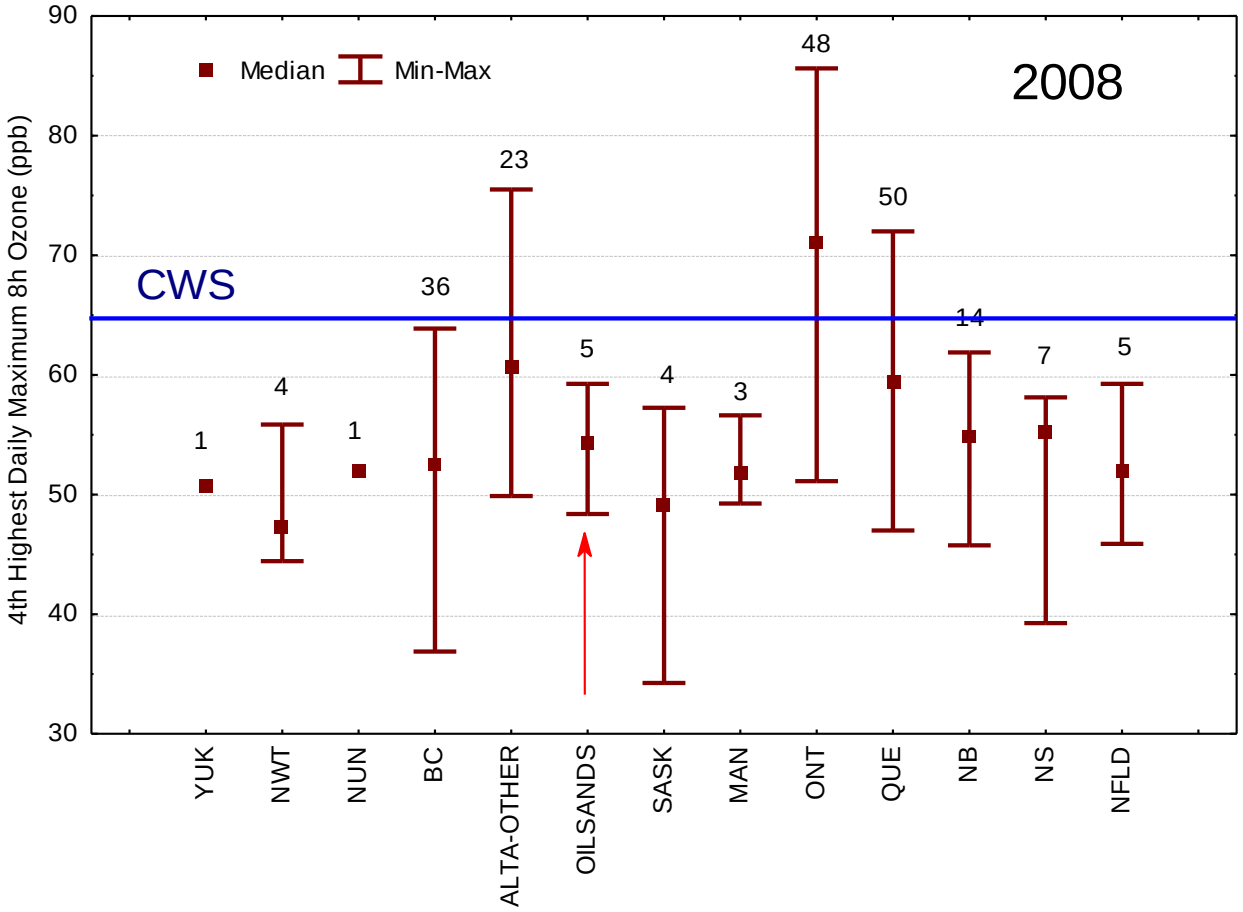
- Ambient O_3 concentrations
- Milestones in O_3 vegetation response
- Technologies used in dose-response
- Standards to protect vegetation
- Index evaluation
- Conclusions

North America Ambient Ozone 2001-2009



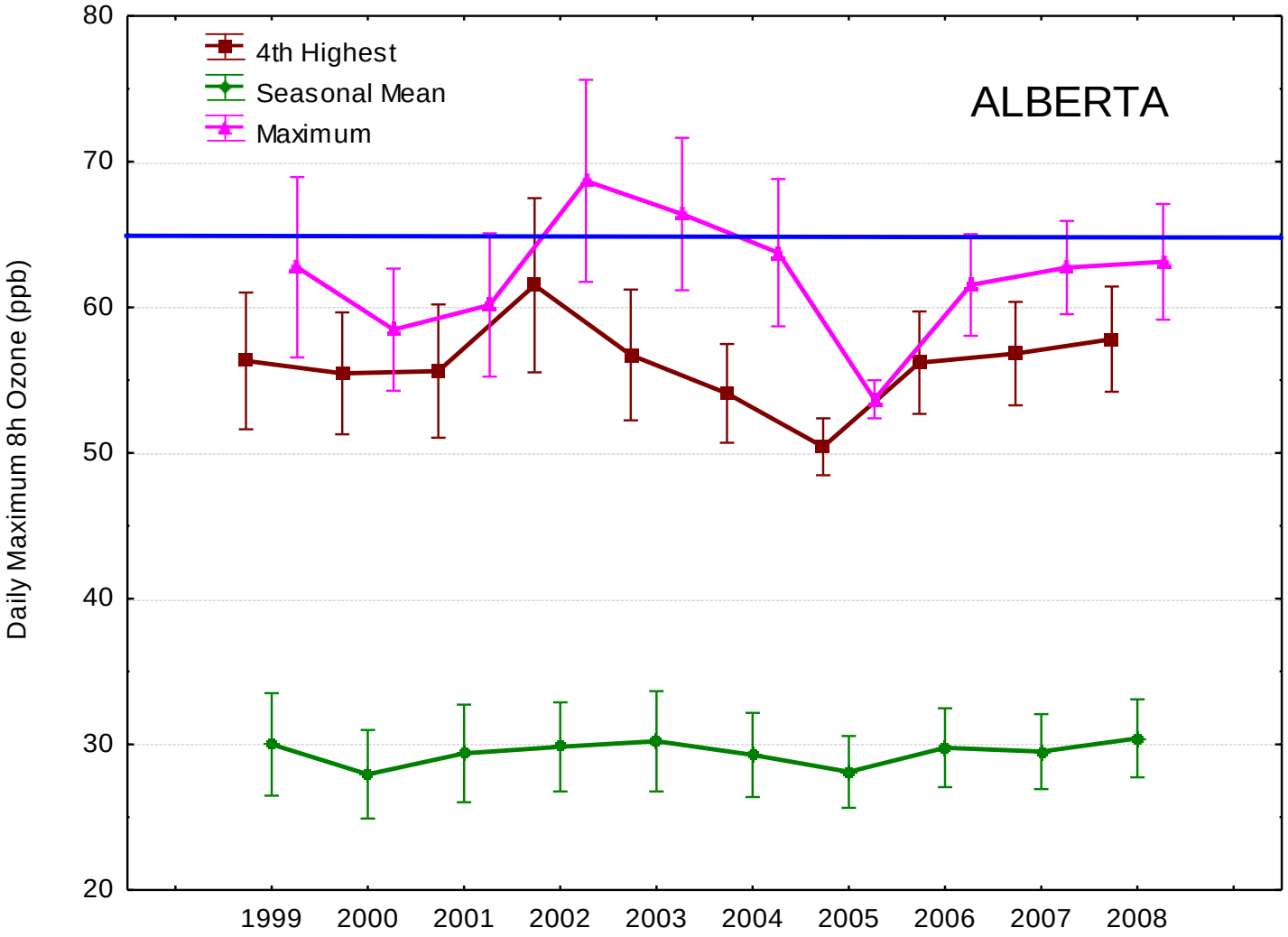


2008 provincial 4th highest daily maximum 8h O_3



Source: Tom Dann EC-NAPS

Yearly Variation in Ozone (ppb) from Alberta trend sites (1999-2008)



Source: Tom Dann EC-NAPS

Milestones in Ozone Forest Response

San Bernardino Mountains, CA (1980)

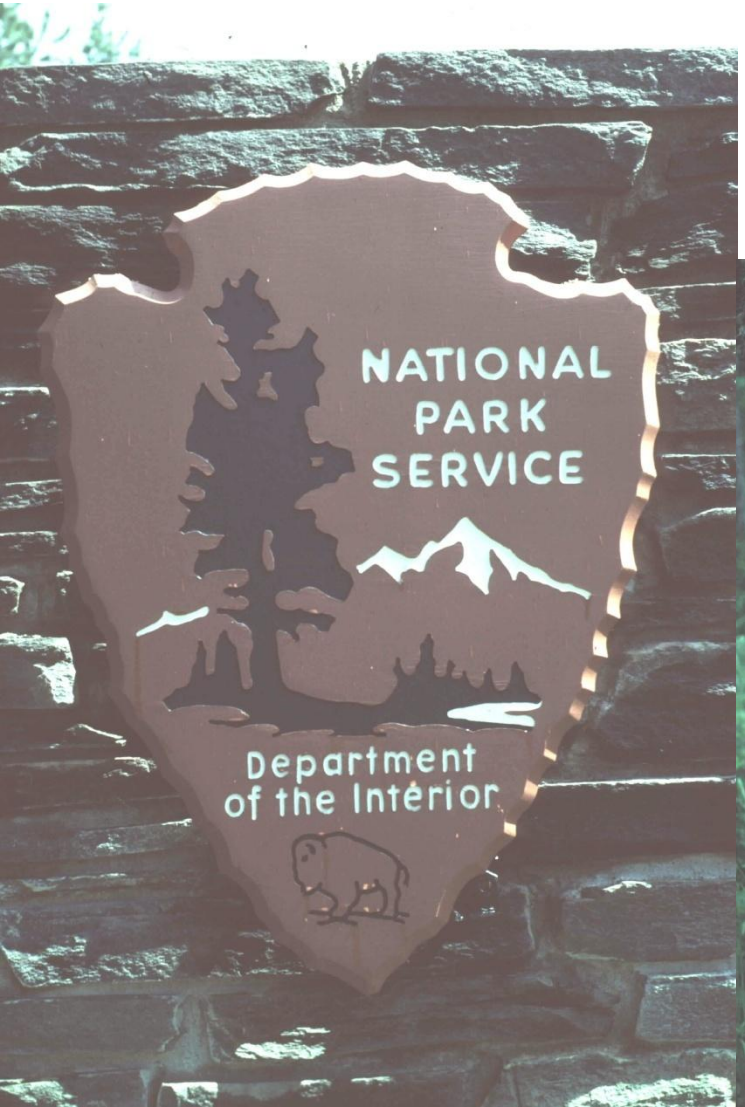
Key Historical Event I: The Discovery of Ozone's Phytotoxicity to Forest Trees in the U.S.

- **"X" disease of *Pinus ponderosa* determined to be caused by ozone 1960s.** (Miller *et al*. 1963; *Phytopathology* 53:1072-1076; Miller and Millecan, 1971. *Plant Dis. Rep*. 55:555-559.)

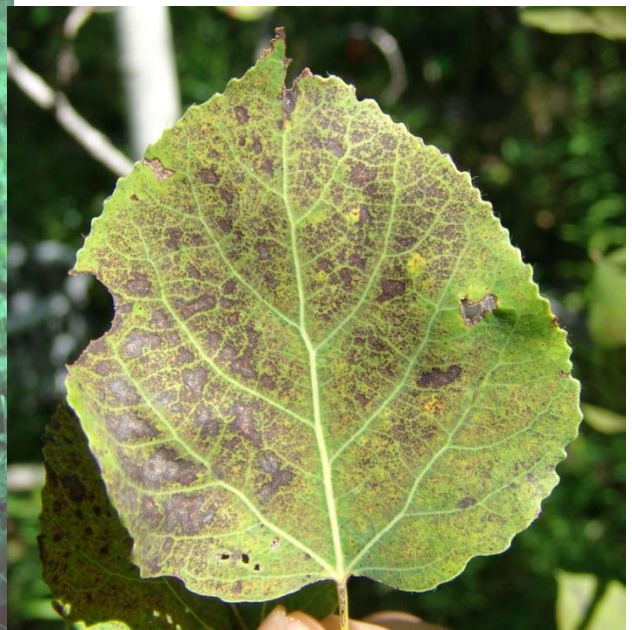
- **Chlorotic dwarf, blight, and emergence tip burn of *Pinus strobus* linked to ozone** (Berry and Ripperton, 1963; *Phytopathology* 53:552-557; Costonis and Sinclair, 1969. *Phytopathology* 59:1566-1574; Dochinger *et al*. 1970. *For. Sci*. 16:46-55.)

Dr. Paul Miller, USFS
(Photo from: Bytnerowicz *et al*. 2003)

Key Historical Event II: Population Changes Related to Ozone Documented in North American Forest Trees



- **Wild populations of *Populus tremuloides* from areas of high background ozone concentrations were shown to have been selected for ozone tolerance** (Berrang *et al*. 1986, *Can. J. For. Res.*16:1214-1216*;* 1989, *Can. J. For. Res*. 19:519-522; 1991, *Can. J. For. Res*. 21:1091-1097).



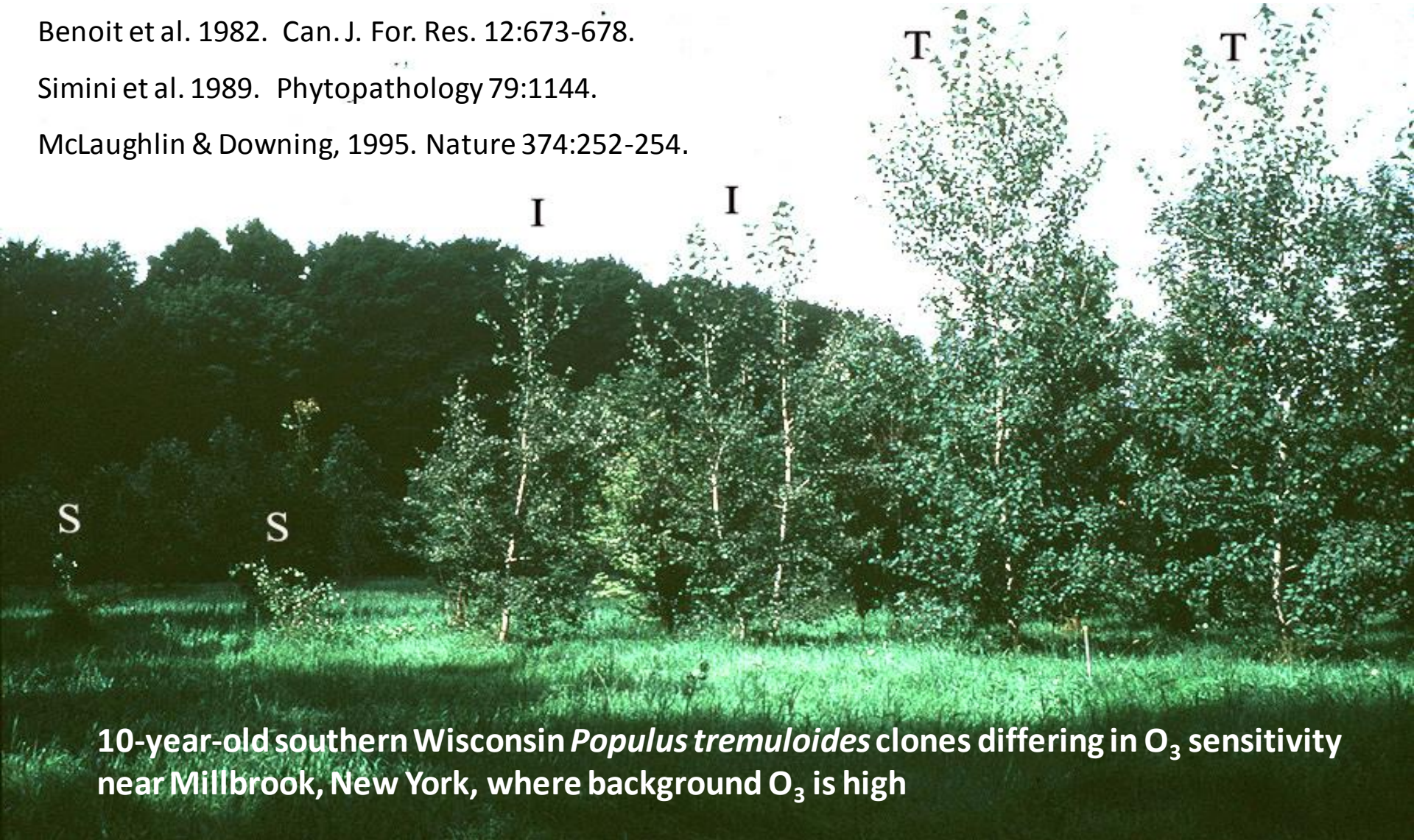
Key Historical Event III: Ambient O_3 Decreases Tree Growth and Productivity

Wang *et al*. 1986. *Can. J. For. Res*. 16:47-55.

Benoit et al. 1982. Can. J. For. Res. 12:673-678.

Simini et al. 1989. Phytopathology 79:1144.

McLaughlin & Downing, 1995. Nature 374:252-254.



10-year-old southern Wisconsin *Populus tremuloides* clones differing in O_3 sensitivity near Millbrook, New York, where background O_3 is high

Key Historical Event IV: O_3 Linked to Community Change

- **Documented replacement of ponderosa pine (*Pinus ponderosa*) in San Bernardino Mts. by white fir (*Abies concolor*)**

Miller 1973. Advances in Chemistry, Series 112:101-117.

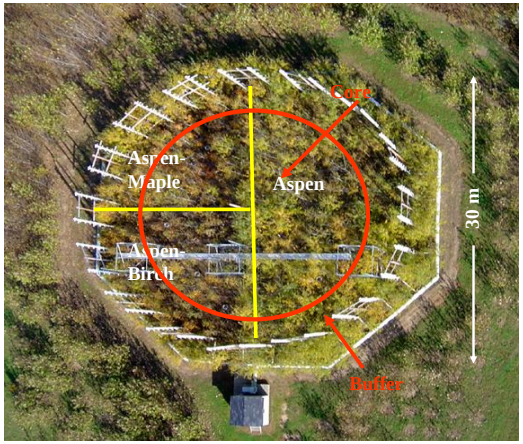
Miller & McBride (Eds.) 1999. *Oxidant Air Pollution Impacts in the Montane Forests of Southern California.* Springer-Verlag

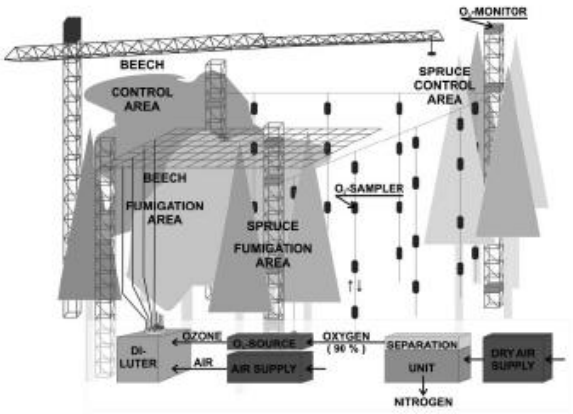
Experimental Technologies Used in O_3 Vegetation Response

Indoor Chambers (1970's)

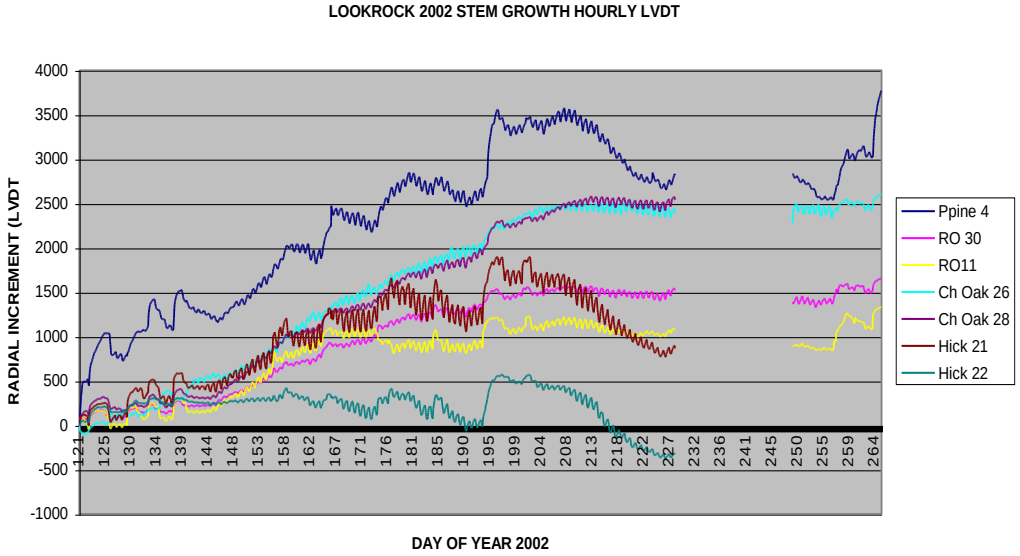
Open-top Chambers (1980's-1990's)

Ambient "Gradients"





Free-Air US and Germany 1998-2010



Automated (upper) and manual dendrometers monitor stem growth at time scales from minutes to days

McLaughlin et al. 2007a. Interactive effects of ozone and climate on tree growth and water use in a southern Appalachian forest in the USA. New Phytologist 174, 109-124.
McLaughlin et al. 2007b. Interactive effects of ozone and climate on water use, soil moisture content and stream flow in a southern Appalachian forest in the USA. New Phytologist 174, 125-136.

Common genetic material approach
(Karnosky et al.)

A. OTC study (Alberta, MI) 1986-96

B. Aspen FACE (Rhinelander, WI) 1998-2009

C. Ozone gradient study (Kenosha and Rhinelander, WI and Kalamazoo, MI) – 1995-2005

Common aspen genetic material reveals continuum of response mechanisms?

Measurement	OTC	FACE	O_3 Gradient
Visible symptoms	√	√	√
Premature leaf abscission	√	√	√
Pest occurrence	-	√	√
Stomatal conductance	√	√	√
Height and diameter	√	√	-
Clonal variation	√	√	√
Survival	-	√	√
Reproduction	-	√	√
√ = statistically significant O_3 effect found; - = not evaluated			

Karnosky, Darbah, Sober, Riikonen, Kets, Nelson, Kubiske, Percy 2006. In Critical Levels of Ozone: Further Applying and Developing the Flux-based Concept. Proceedings of Workshop 15-19 November, Obergurgl, Austria.

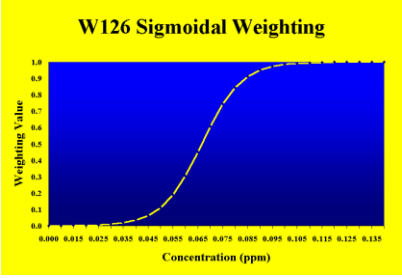
Standards to Protect Vegetation

- Standards-based
  - Three-year average of annual 4th highest daily max. 8 h O_3 (EPA, CCME)
  - WHO 2005 guideline = 100 µg m^{-3} (51 ppb) 8 hr mean
  - Alberta AAQO = 1 hr daily max. 82 ppb (160 µg m^{-3}) effective 1/2/2007
    - CASA PM and O_3 project team implementation?
- Cumulative-based
  - AOT40 (Führer et al., 1997)
  - SUM60 (Lefohn and Foley, 1992)
  - W126 (Lefohn and Runeckles, 1987)
  - Cumulative frequency distribution (Krupa et al. 1995)
- Flux-based
  - Matyssek et al. 2007. Promoting the O_3 flux concept for European forest trees. Environmental Pollution 146, 587-607.

Musselman, Lefohn, Massman, Heath 2006. A critical review and analysis of the use of exposure- and flux-based ozone indices for predicting vegetation effects. Atmospheric Environment 40, 1869-1888.

Percy, Karnosky 2007. Air quality in natural areas: interface between the public, science and regulation. Environmental Pollution 149, 256-276.

Proposed Federal Rule: Some limitations

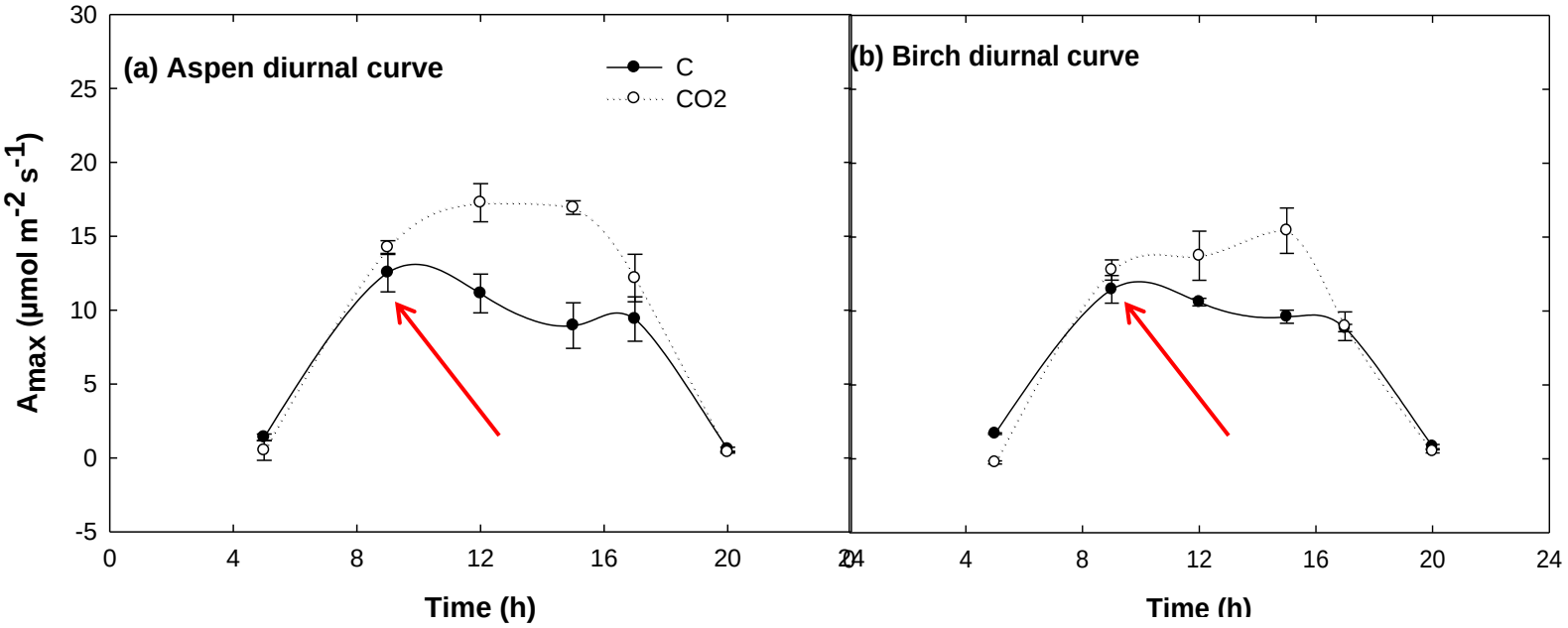


1. Highest weighting given to highest O_3 concentrations
2. **Weighting decoupled from known plant physiology**
3. No rationale for arbitrary exponent 4403 and constant 126 ppm
4. W126 claims integration of uptake, O_3 exposure defence?
5. Developed under a different O_3 climate in California in the 1980's
6. Developed largely from OTC experiments
7. **Statistical fit forced on biological response**
8. **Degree of W126 biological association not demonstrated in field**
9. Empirical, free-air evaluation shows lack of W126 biological association
10. Mathematically too complex: utility in standards?

Excerpted from K. Percy. 2010. Growth Responses of Trees to Tropospheric Ozone: Alternatives in Dose-Metrics to EPA's Proposed W126 Secondary NAAQS. Presentation to Congressional USDA-Agriculture Air Quality Task Force, Tallahassee, Florida, March 9-11.

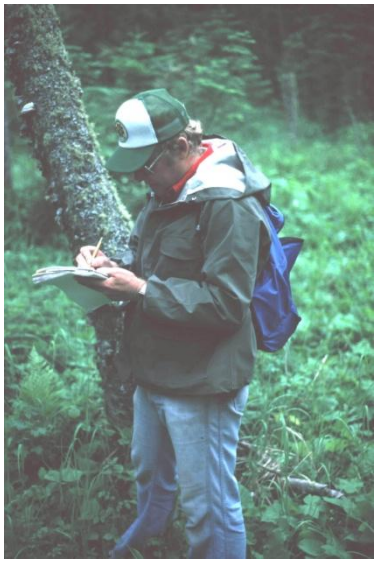
2. Lack of synchrony in O_3 exposure and plant uptake

- Grünhage *et al*. 1994. Environmental Pollution 85, 125-129.
  "atmospheric conditions that facilitate the daily occurrences of peak (highest) O_3 concentrations in general do not coincide with the conditions that promote plant uptake."

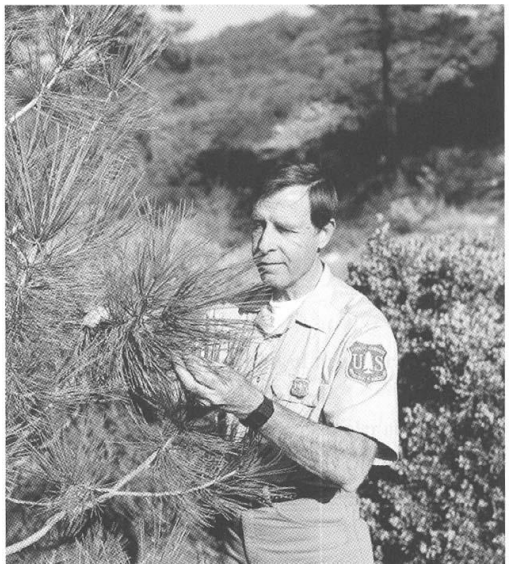


Darbah, et al. 2010. Environmental Pollution 158, 1008-1014.

We have been at this a very long time!



David F. Karnosky

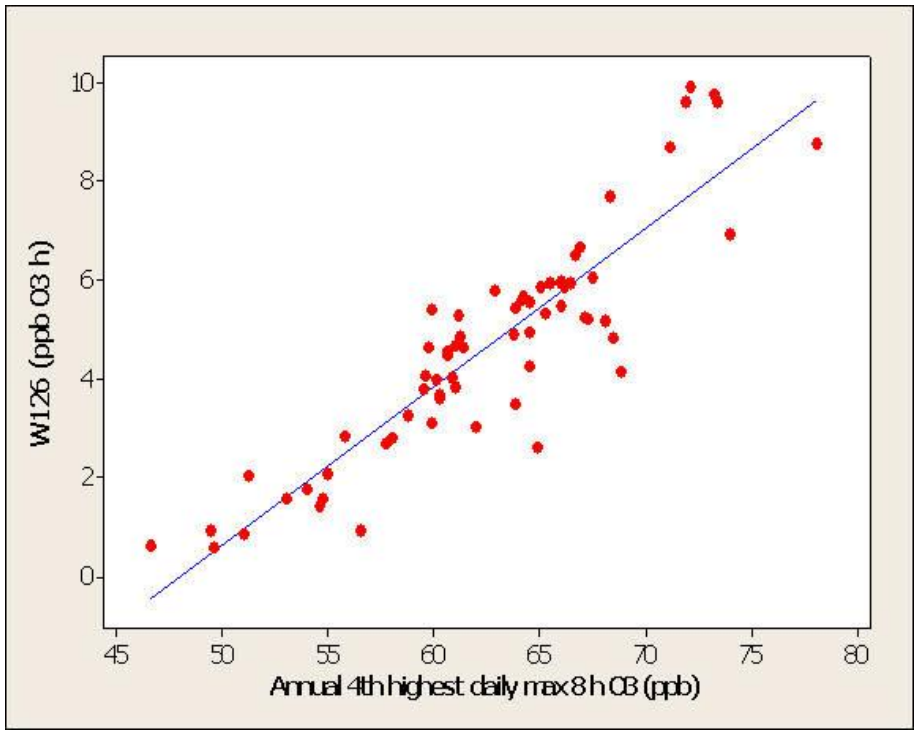


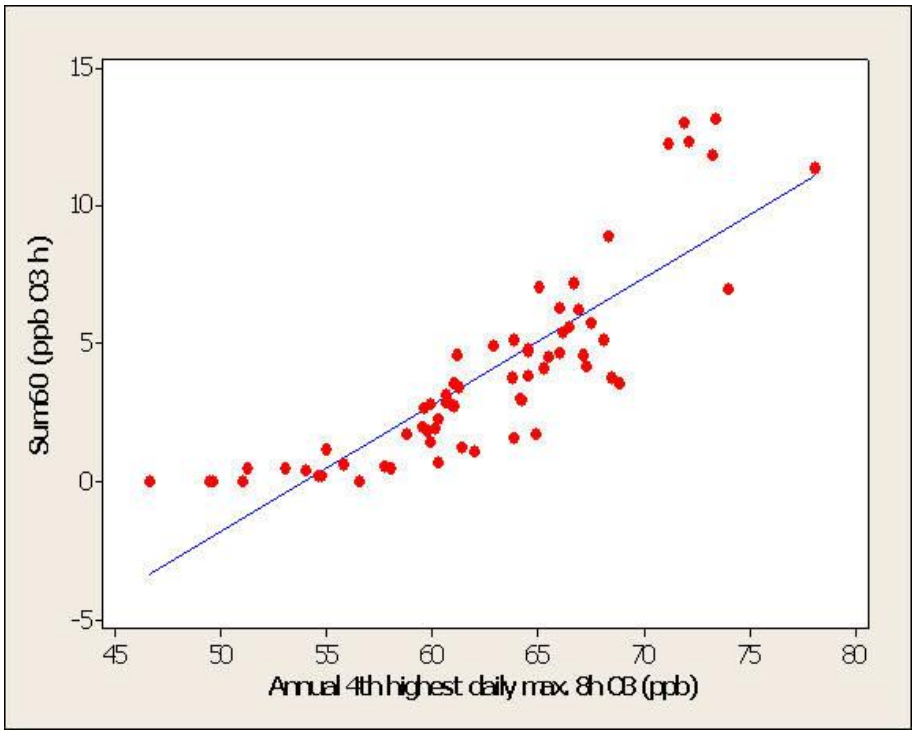
Paul R. Miller

Karnosky, Skelly, Percy, Chappelka 2007. Perspectives regarding 50 years of research on effects of tropospheric ozone air pollution on U.S. forests. Environmental Pollution 147, 489-506

Matyssek, Karnosky, Wieser, Percy, Oksanen, Grams, Kubiske, Hanke, Pretzsch, H. 2010. Advances in understanding ozone impact on forest trees: Messages from novel phytotron and free-air fumigation studies. Environmental Pollution 158, 1990-2006.

Alberta: Which Index?



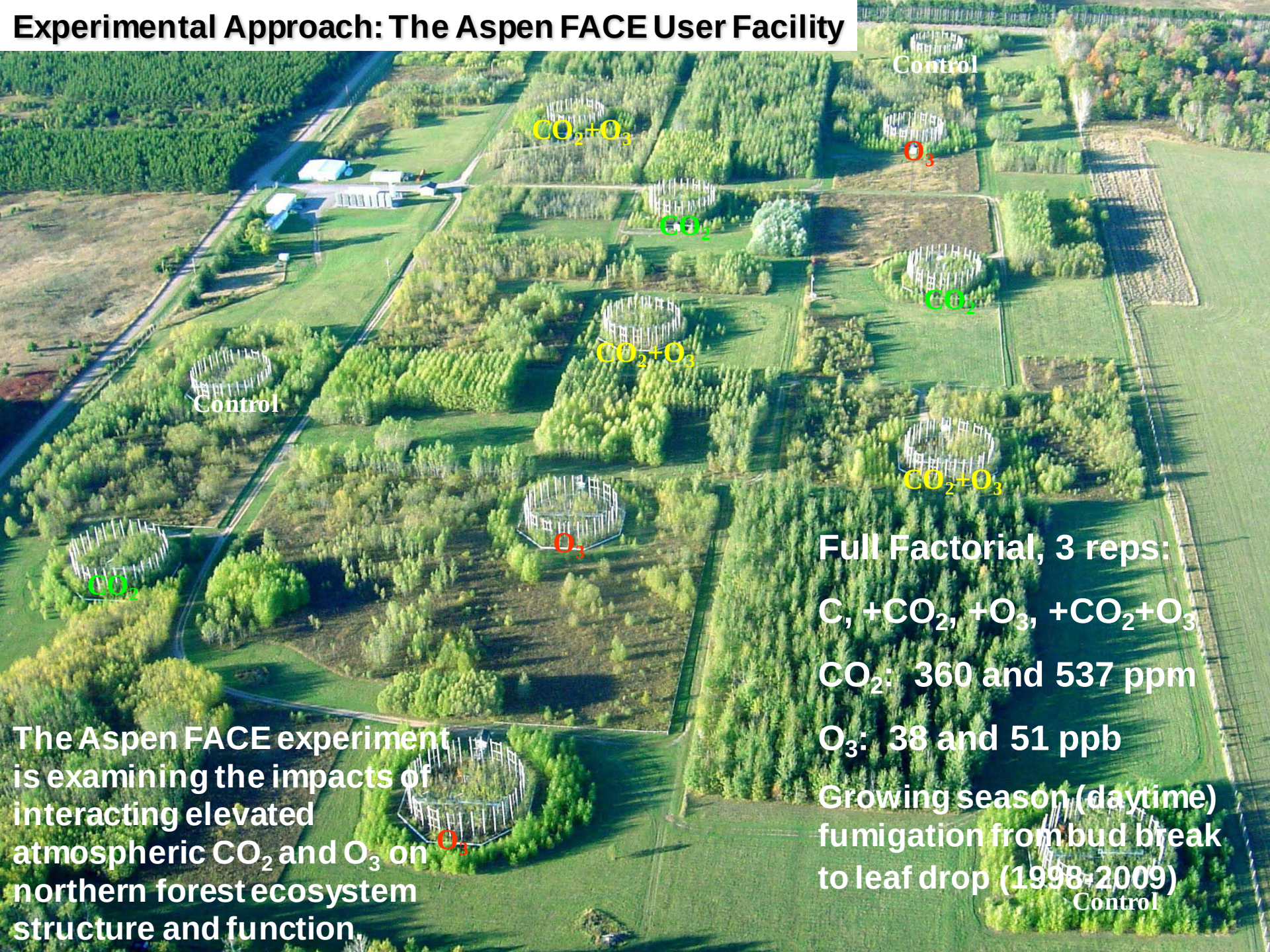


NAPS data from 7 rural AB stations with > 8 years of record

Index Evaluation in a Free-Air, Multi-Year Manipulative Experiment

Photo: aspen birch section Aspen FACE ring

Experimental Approach: The Aspen FACE User Facility



The Aspen FACE experiment is examining the impacts of interacting elevated atmospheric CO_2 and O_3 on northern forest ecosystem structure and function.

Full Factorial, 3 reps:

C, +CO_2, +O_3, +CO_2+O_3

CO_2: 360 and 537 ppm

O_3: 38 and 51 ppb

Growing season (daytime) fumigation from bud break to leaf drop (1998-2009)

Response of 5 aspen clones and white birch

Central GHG facility for the 32 ha FACE site

Can a simple model be developed using an air quality standard O_3 predictors?

Response variable

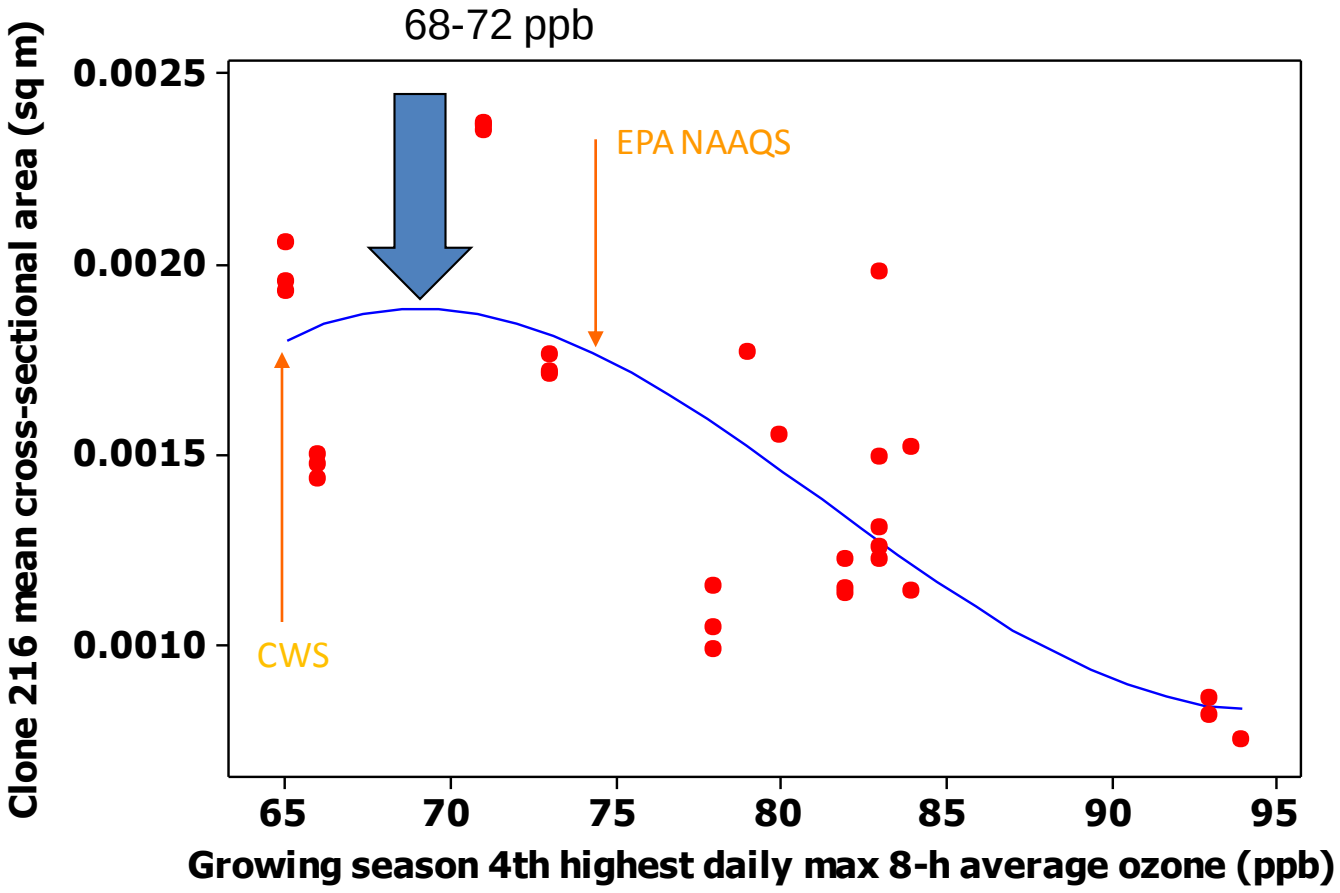
basal area (BA)

Predictor variables (6)

O_3 (annual, 4th highest daily max. 8h conc.)
Temp (cumulative GDD to base 10^0C)
Solar radiation (PAR seasonal sum)
Wind speed (seasonal average)
Precipitation (seasonal sum)
Soil moisture content (seasonal average, within stands)

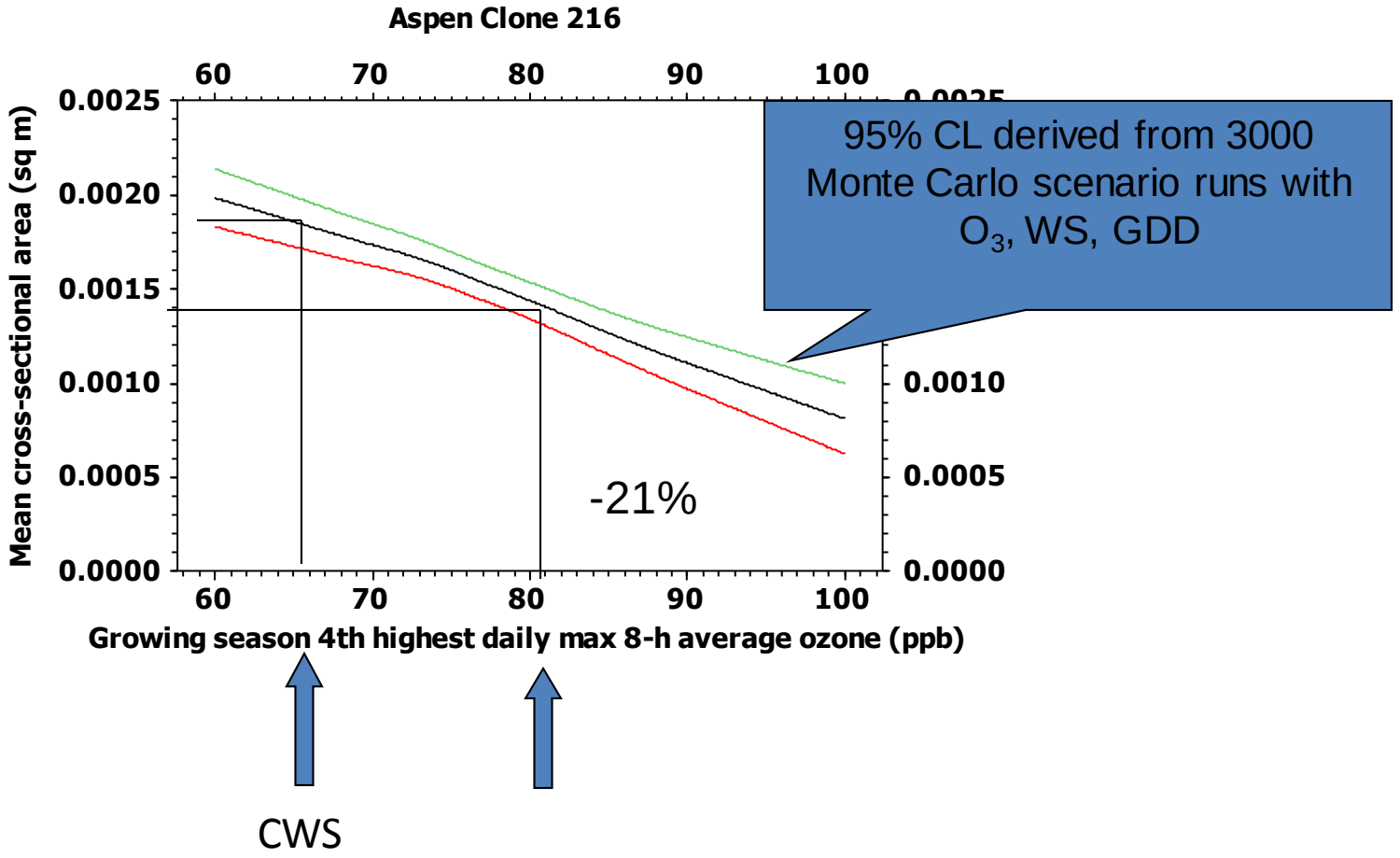
30 cases (3 rep O_3 rings, 3 rep control rings) x 5 years (1999-2003)
5 aspen clones (n=498 trees) and birch (n=444 trees)

What 8-hour level might be protective?



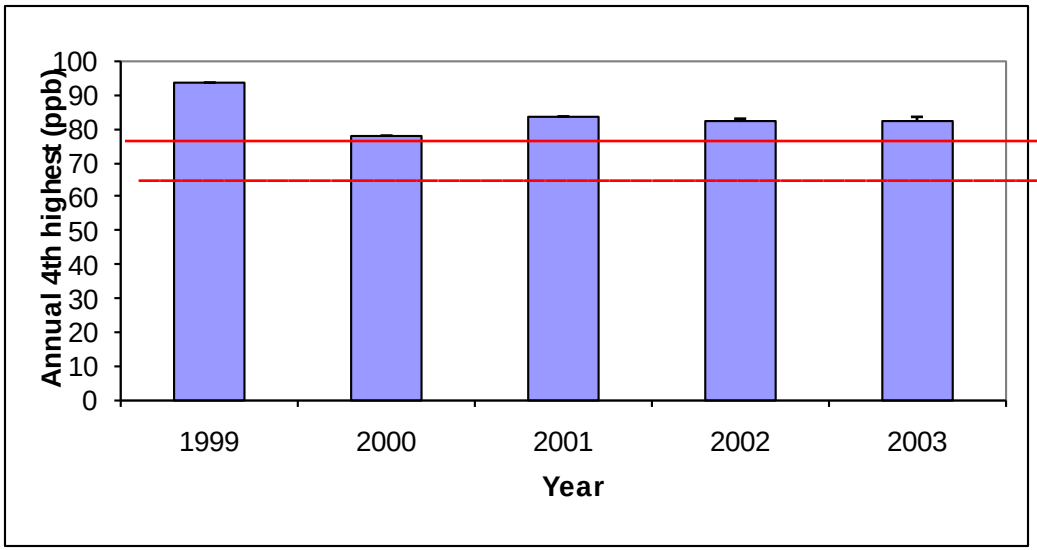
Percy, Nosal, Heilman, Sober, Dann, Legge, Karnosky. 2007. New exposure-based metric approach for evaluating O_3 risk to North American aspen forests. Environmental Pollution 147, 554-566.

Modified primary exposure-response function



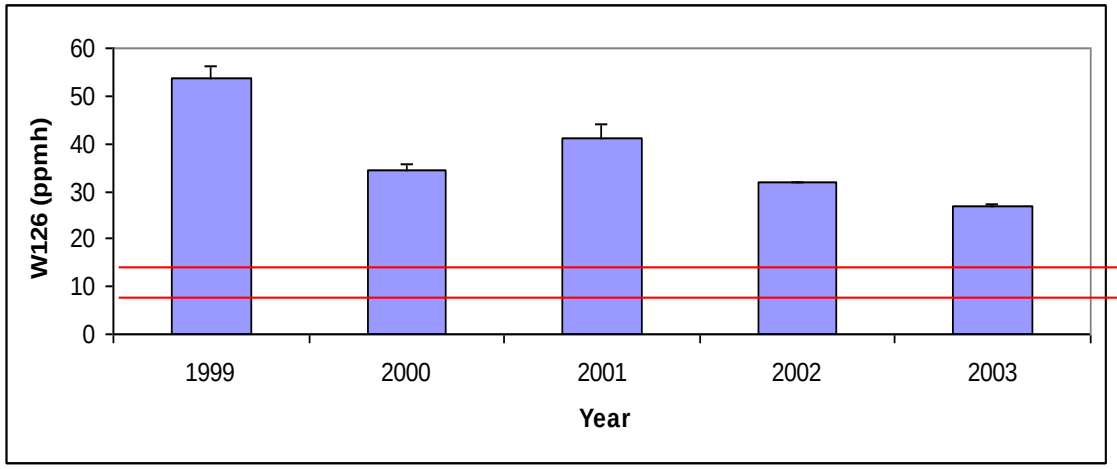
$$Y = 0.00684 - 0.000031 \text{ 4th highest } O_3 - 0.00551 \text{ WS} + 0.000003 \text{ GDD}$$

Aspen FACE O_3 exposure 1999-2003



EPA NAAQS

CWS



W126

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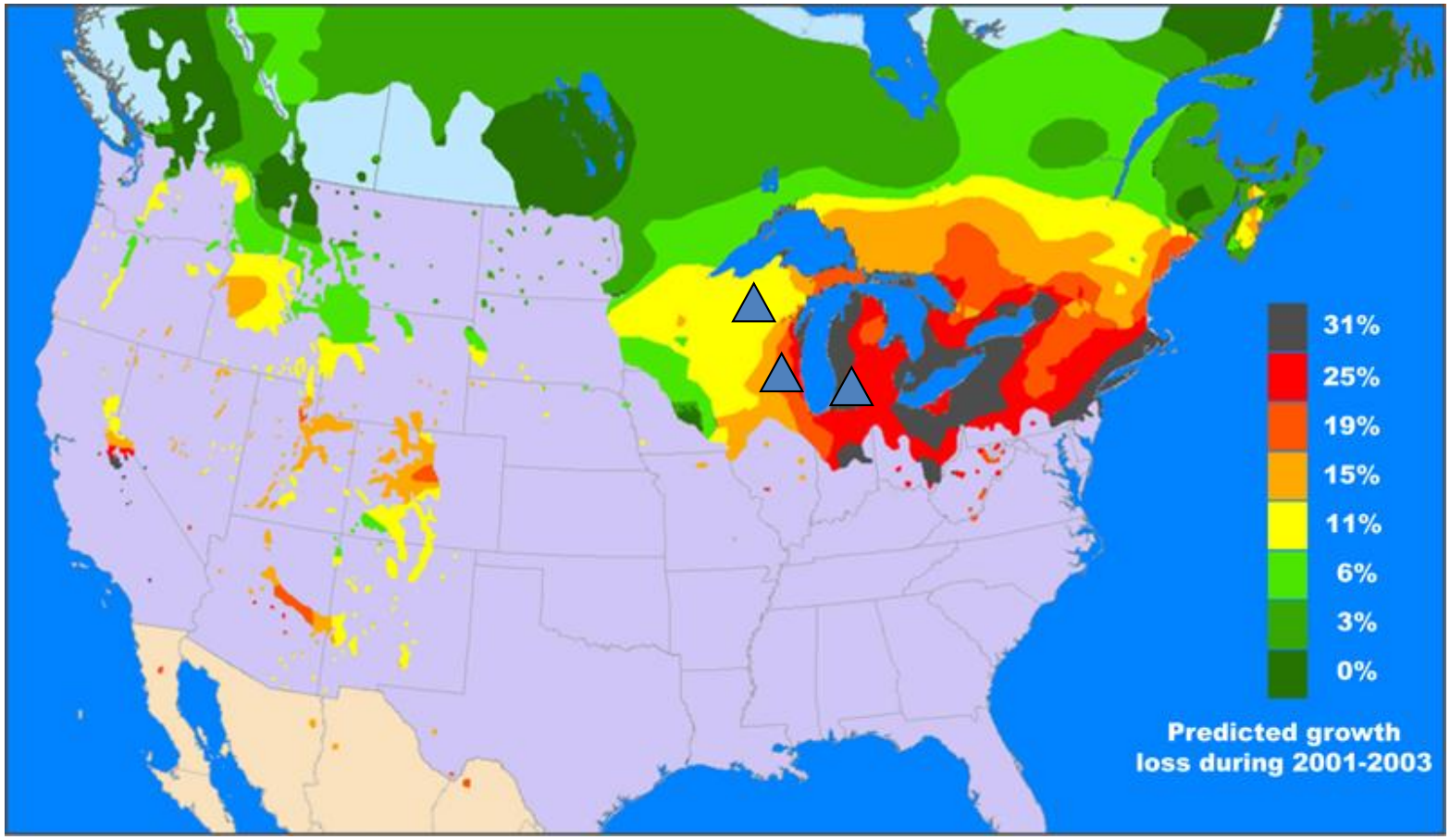
Evaluation of O_3 metrics as single predictors of basal area growth over five years

	Aspen clone			white birch
O_3 index	8L (pos.)	271 (tol.)	216 (med.)	
4th highest	0.354(0.078)	0.454(0.021)	0.479(0.017)	0.119(0.112)
SUM06	0.228(0.078)	0.228(0.160)	0.163(0.187)	0.031(0.251)
AOT40	0.375(0.067)	0.213(0.138)	0.190(0.159)	0.000(0.877)
Max1h	0.371(0.069)	0.197(0.152)	0.250(0.109)	0.331(0.015)
W126	0.647(0.006)	0.618(0.003)	0.648(0.002)	0.376(0.009)

Data are R sq. adj. (*P* value)

Percy, et al. 2009. Ozone Exposure-Based Growth Response Models for Trembling Aspen and White Birch. pp 263- 287 In A.H. Legge (Ed.) Developments in Environmental Science, Volume 9, Elsevier, Oxford.

Predicted aspen growth loss during 2001-2003



We have measured response close to predicted using common genetic material from Aspen FACE grown in 3 growth/biomass trials ▲

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Conclusions

- O_3 is a concern in some regions of Alberta
- Alberta should re-consider current O_3 82 ppb 1 hr AAQO
- SUM60, AOT40, W126 not suitable
- CWS form, averaging time, metric target level is suggested
- CWS biological association with 2 species, 5 genotypes over 5 years under free-air conditions, large inter-annual climate variation, stand dynamics, pest activity demonstrates utility
- changing averaging time to annual to protect sensitive vegetation

Photo: ozone ring Aspen FACE

Upcoming Air Pollution Meetings Fort McMurray

- International Symposium "Alberta Oil Sands: Energy, Industry and the Environment"
  - May 23
  - Industry, source to sink papers, 1 hr Panel Discussion
  - Book (18 chapters) to be published in Elsevier Developments in Environmental Science Series
- 43rd Air Pollution Workshop **(www.apworkshop.org)**
  - May 24-25
  - One-day Field Trip May 26


Thank You!