Technical Basis of the 2012 SJV $PM_{2.5}$ Plan Modeling

Please e-mail questions to webcast@valleyair.org any time during this presentation

Karen Magliano, MS
Ajith Kaduwela, PhD

Planning and Technical Support Division
California Air Resources Board

Introduction

- ARB conducted a science symposium in April to present:
  - Current understanding of $PM_{2.5}$ in the Valley
  - Modeling approach
- The Modeling Protocol was reviewed by ARB, District, U.S. EPA, and academia
- Presentations and Modeling Protocol are posted on District's website

Presentation Outline

- Modeling Requirements and Process
- Current Scientific Knowledge of $PM_{2.5}$ Formation in the San Joaquin Valley
- Modeling Results and Precursor Sensitivities
- Acknowledgements

Modeling Requirements and Process

Consistency with U.S. EPA Guidance

- Appropriate model(s) and other analyses
- Need for modeling protocol document
- Application and evaluation of model(s)
- Model attainment test
- Supplemental analyses
- Use of the best possible science

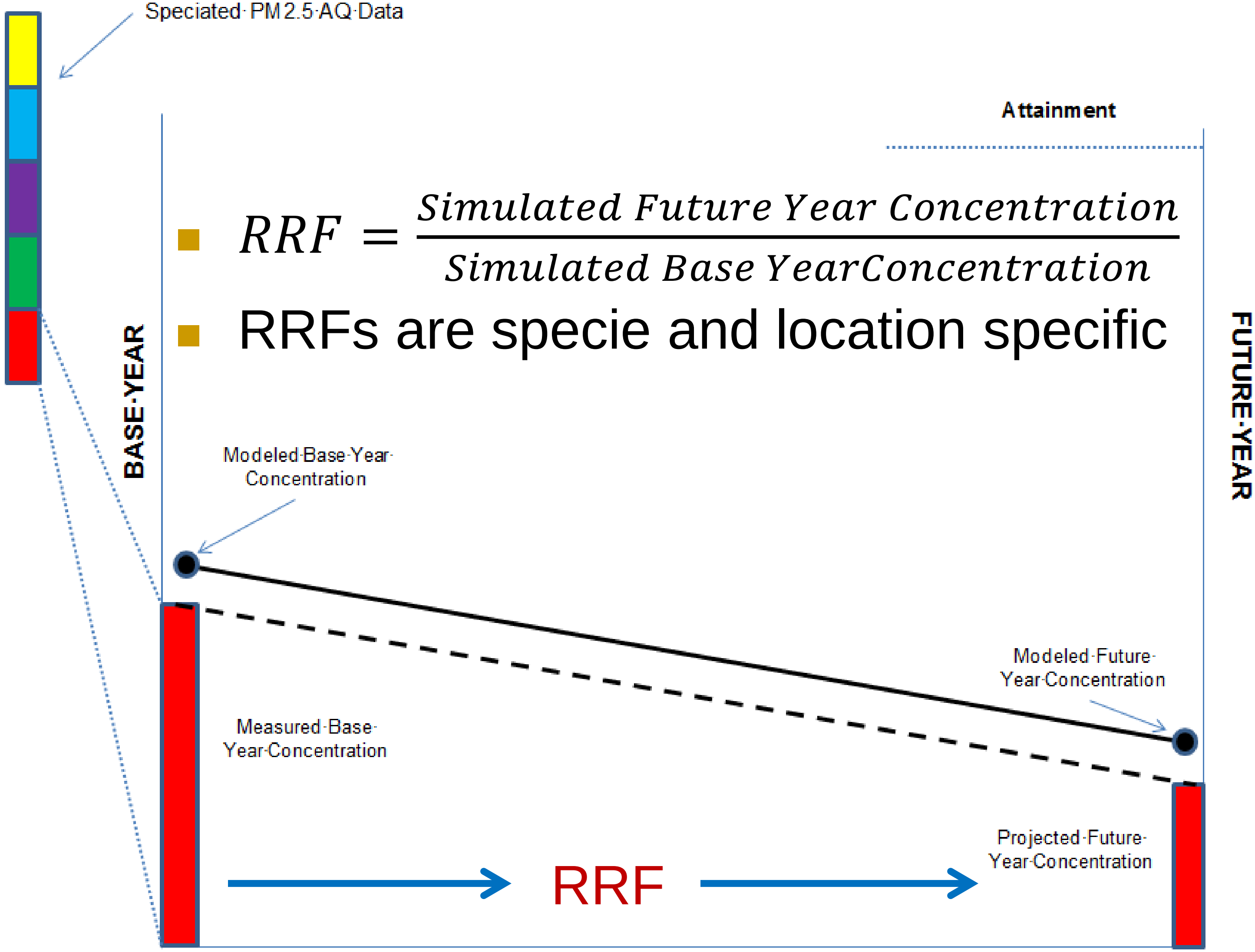
Weight of Evidence Approach for Attainment

- Use all available technical information in a corroborative manner to determine best attainment strategy:
  - Grid-based photochemical modeling
  - Supplemental analyses:
    - Air quality trends
    - Emission trends
    - Source – receptor modeling

Use and application of Photochemical Models

- Identifying the most effective mix of pollutants to control
- Establishing attainment targets
- Models are best used in a relative (rather than absolute) sense
  - Relative Response Factors (RRFs)
- Attainment test combines measures data and modeling to project air quality into the future
  - **S**peciated **M**odel **A**ttainment **T**est (SMAT)

- $$RRF = \frac{Simulated\ Future\ Year\ Concentration}{Simulated\ Base\ Year Concentration}$$
- RRFs are specie and location specific



“Speciating” the FRM Filter

- Speciated Model Attainment Test (SMAT), which uses RRFs, requires speciated $PM_{2.5}$
- Federal Reference Method (FRM) filters are not speciated
- Four FRM sites have co-located speciation monitors
- Use Sulfate, Adjusted Nitrate, Derived Water, Inferred Carbonaceous material balance approacH (SANDWICH) to estimate FRM speciation

Air-Quality Modeling

- US EPA's CMAQ model
- SAPRC-99 chemistry
- Solves coupled sets of differential equations for advection, diffusion, and chemistry
- MOZART global model provides initial and boundary conditions
- 15 vertical layers up to 100 mb

CMAQ – Community Multi-scale Air Quality
SAPRC – Statewide Air Pollution Research Center
MOZART – Model of Ozone and Related Trace Species

Quality Assurance

- Does the model replicate the observed nature of the $PM_{2.5}$ problem?
- Requires:
  - Iterative model runs
  - Re-generating meteorology and emissions inputs
  - Evaluating predictions for each specie
  - Focus evaluation on seasons / months contributing to high $PM_{2.5}$

Model Performance Evaluation

- Operational (quantitative) – Ability to reproduce observed temporal and spatial patterns for meteorological parameters and pollutants
- Phenomenological (qualitative) – General comparisons of observed features
- Diagnostic (semi-quantitative) – How accurate is the model in characterizing the sensitivity of $PM_{2.5}$ (and species) to changes in emissions?
- Corroborative (qualitative) – Model consistent with other analyses?

Current Scientific Knowledge of $PM_{2.5}$ Formation in the San Joaquin Valley

Role of Science Studies

- Provide ambient measurements to expand our understanding of the nature of $PM_{2.5}$
- Improve the algorithms in models and their ability to simulate air quality conditions
- Support model applications to predict future air quality and the response to controls

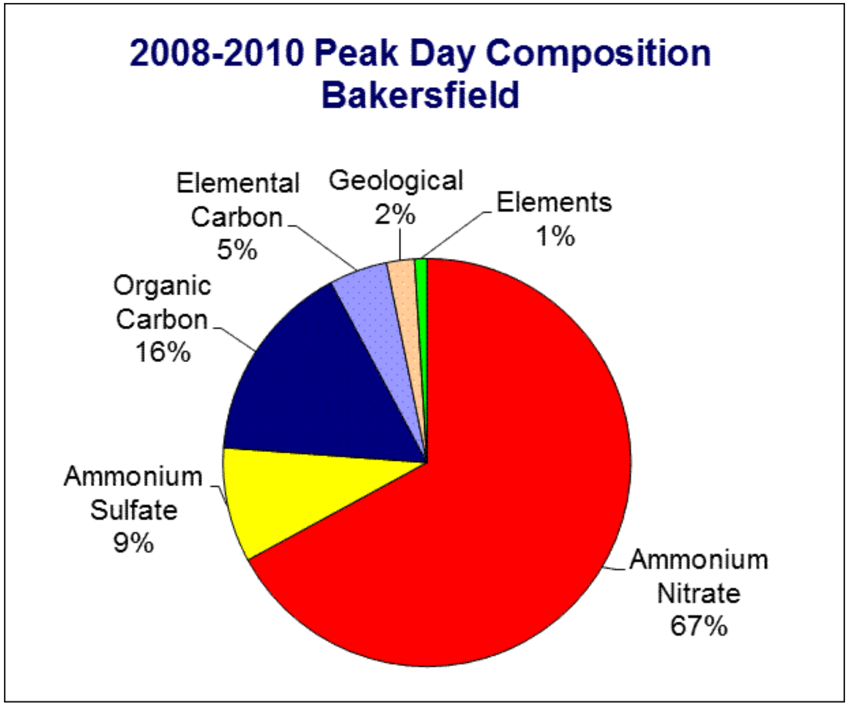
California Regional Particulate Matter Air Quality Study (CRPAQS)

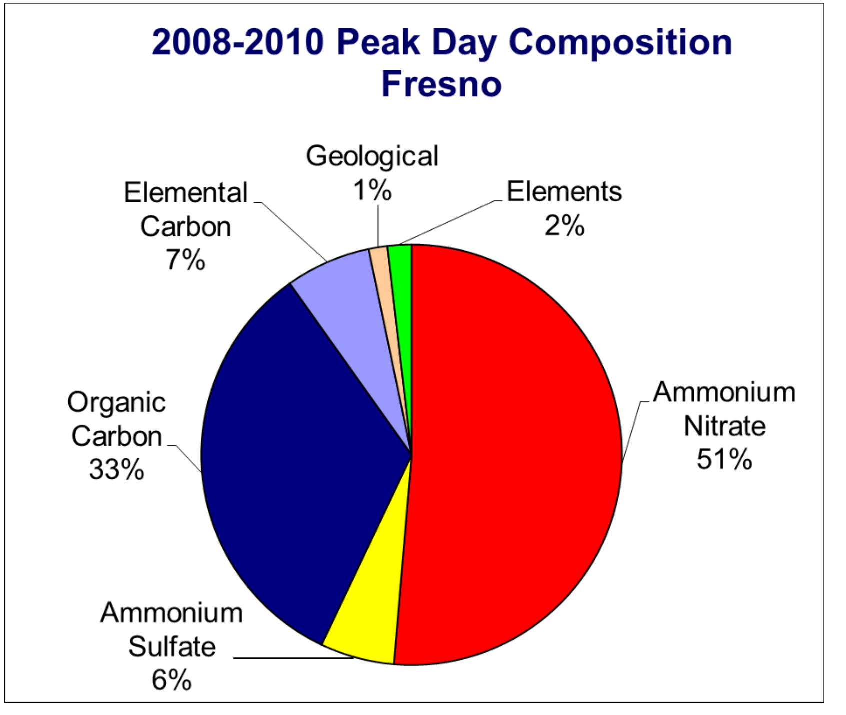
- Major field study conducted in 2000
- Funded by a public / private partnership
- Provided the fundamental science behind annual plan and current 24-hour plan
- Most comprehensive data and science in the country on the origin and fate of $PM_{2.5}$
- Continues to be a cornerstone of $PM_{2.5}$ research

CRPAQS Findings

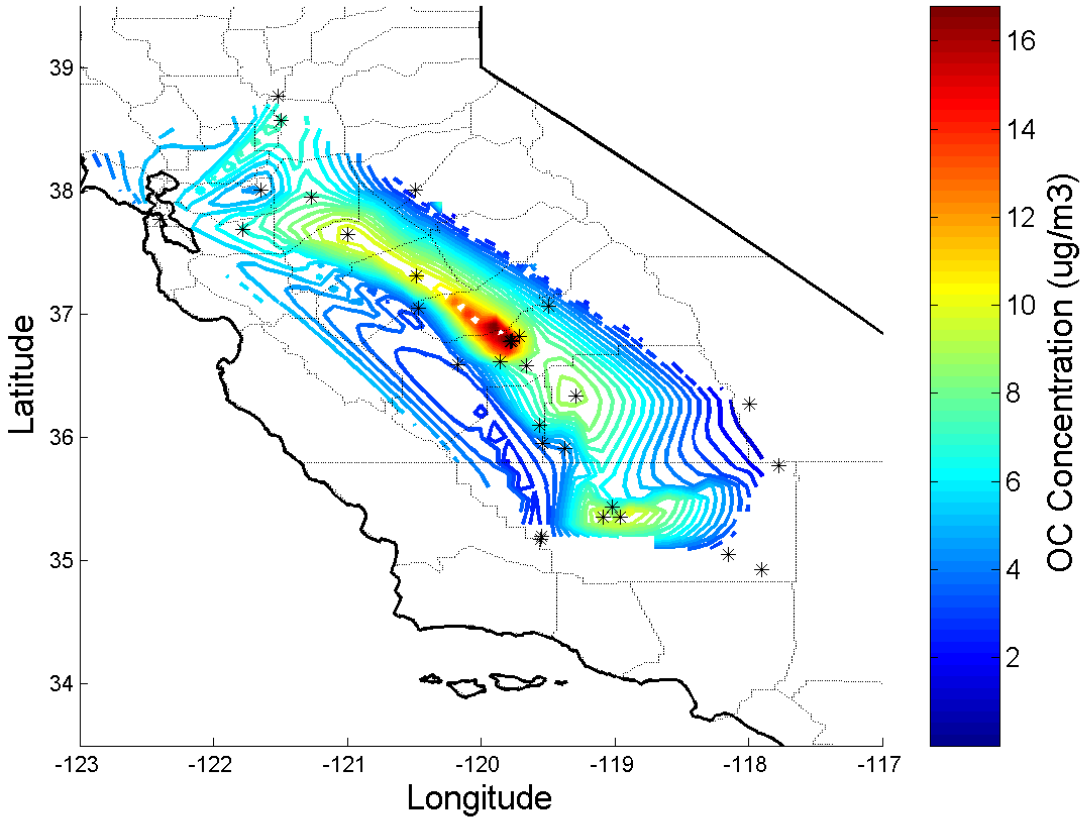
- Winter $PM_{2.5}$ episodes are driven by multi-day periods of stagnation, cool temperatures, and high humidity
- Transport is limited during these winter episodes
- Key $PM_{2.5}$ constituents are ammonium nitrate and carbon compounds

$PM_{2.5}$ Chemical Composition



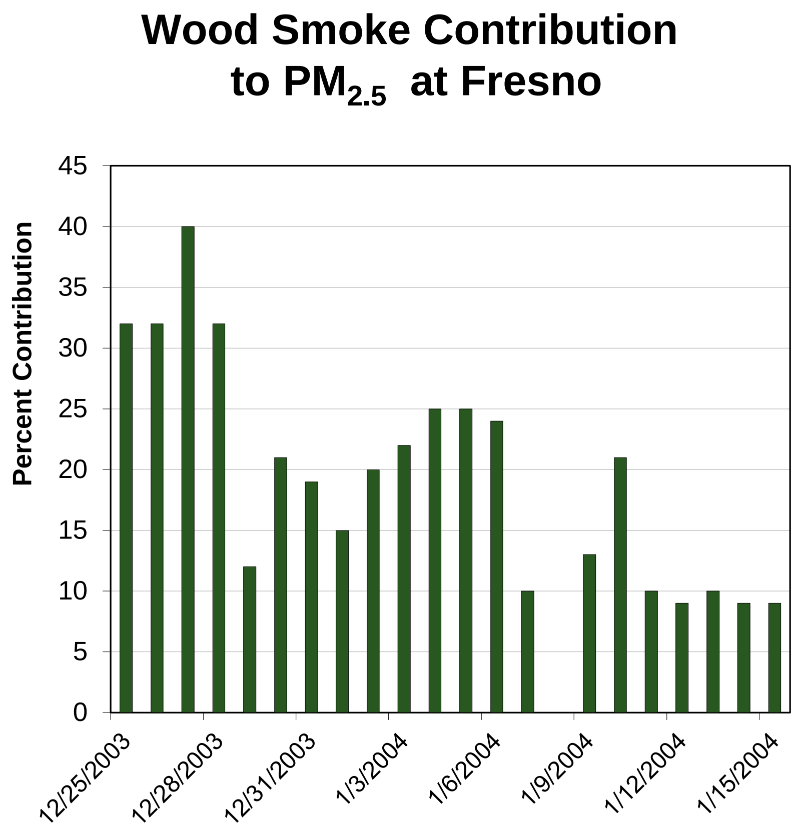


Distribution of Organic Carbon



Carbon compounds are highest in urban areas due to contributions from wood burning, cooking, and mobile sources

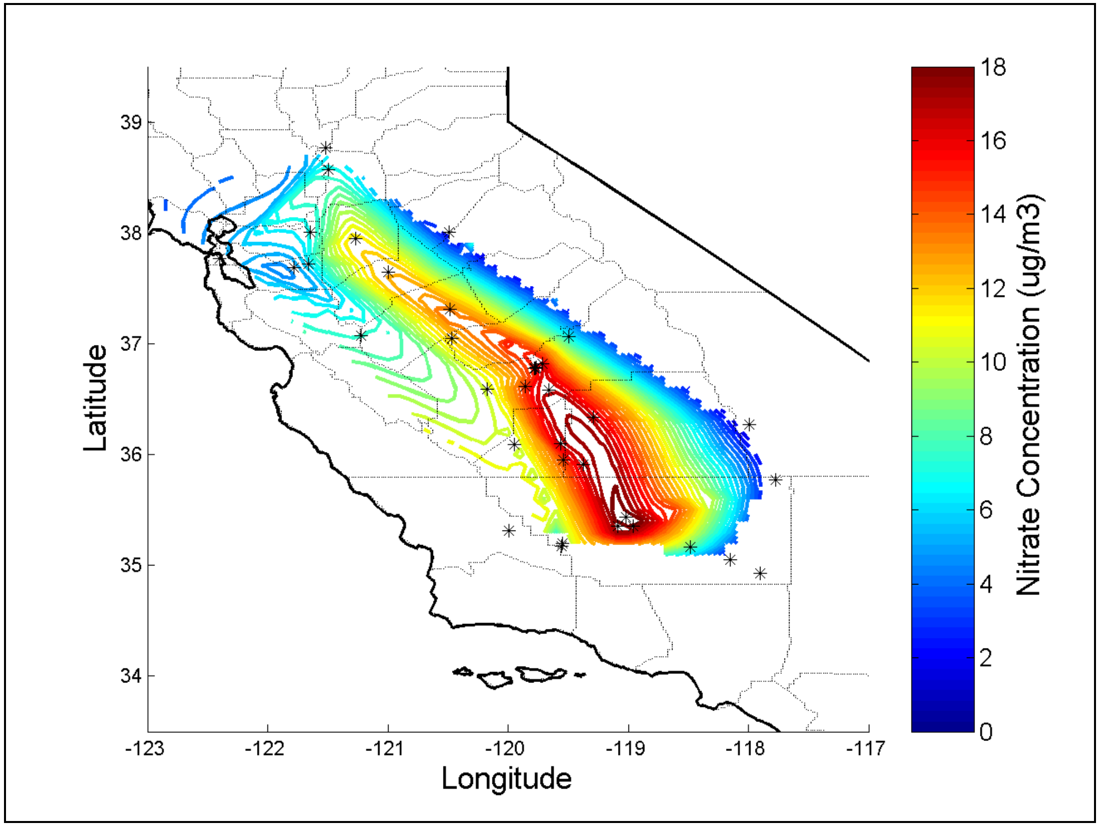
Sources of Organic Carbon



Gorin et. al. 2005

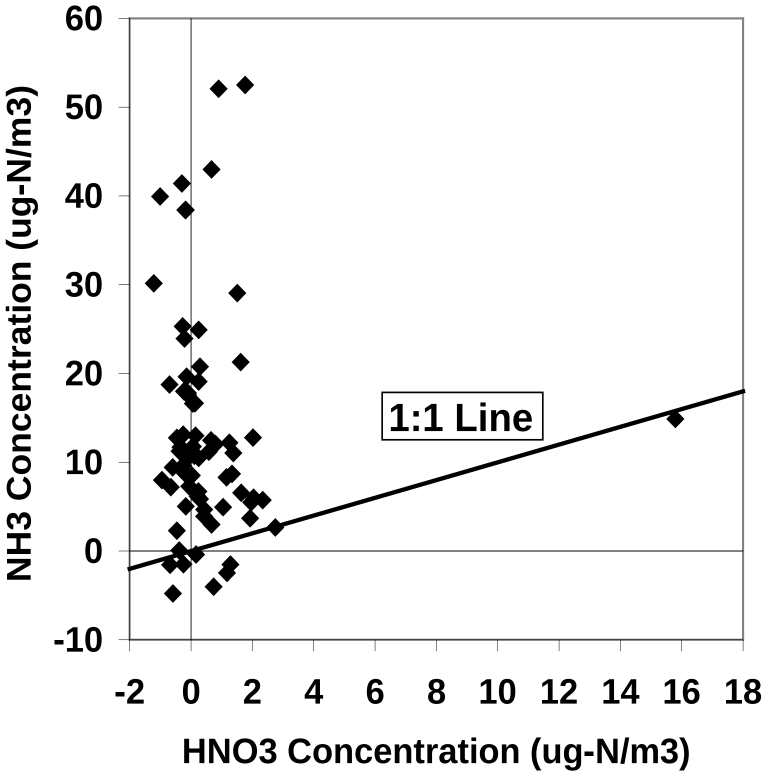
- Residential burning a significant contributor in the winter
- New markers for wood combustion helped identify impacts

Distribution of Ammonium Nitrate



Elevated ammonium nitrate concentrations occur in both urban and rural areas

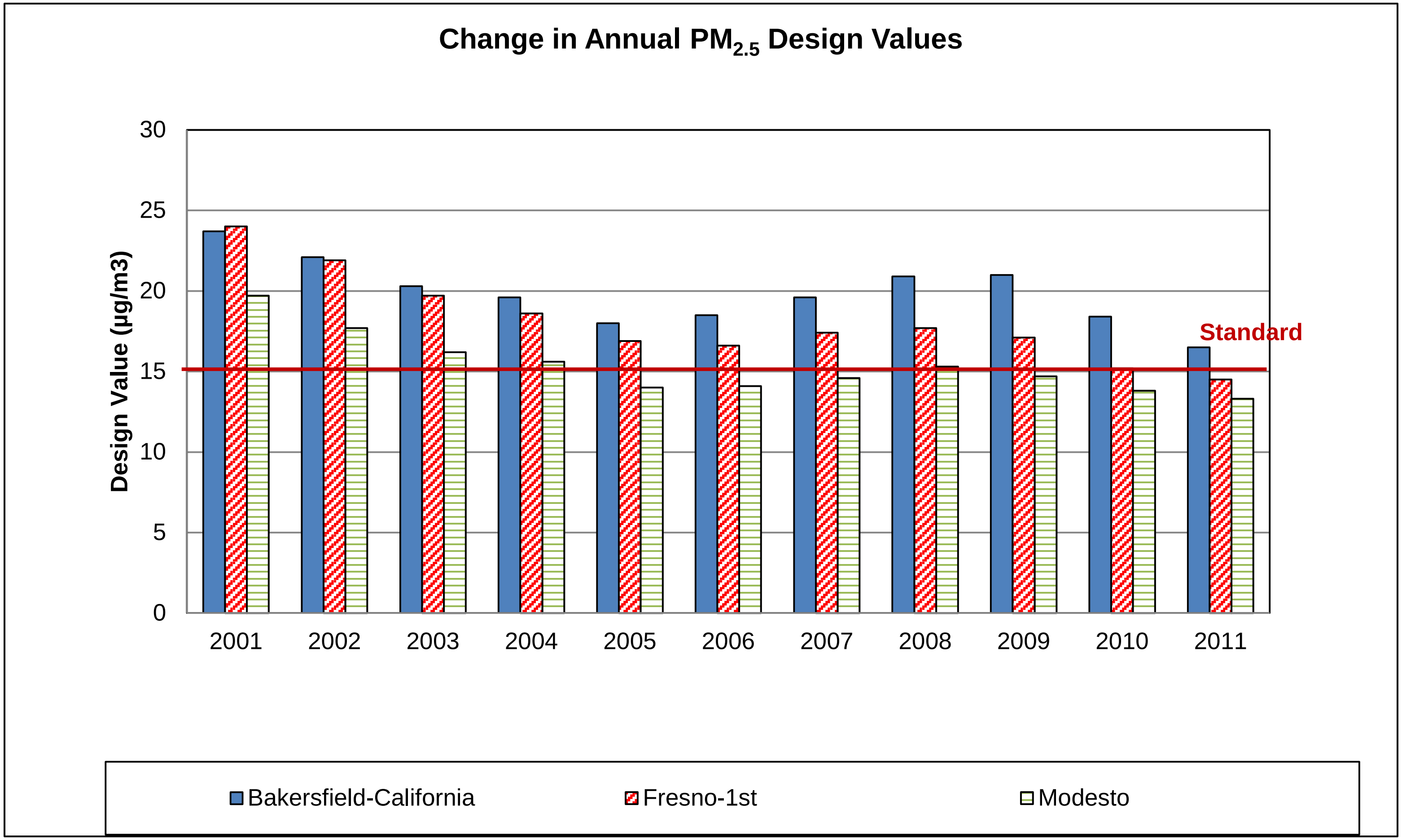
Precursors to Ammonium Nitrate



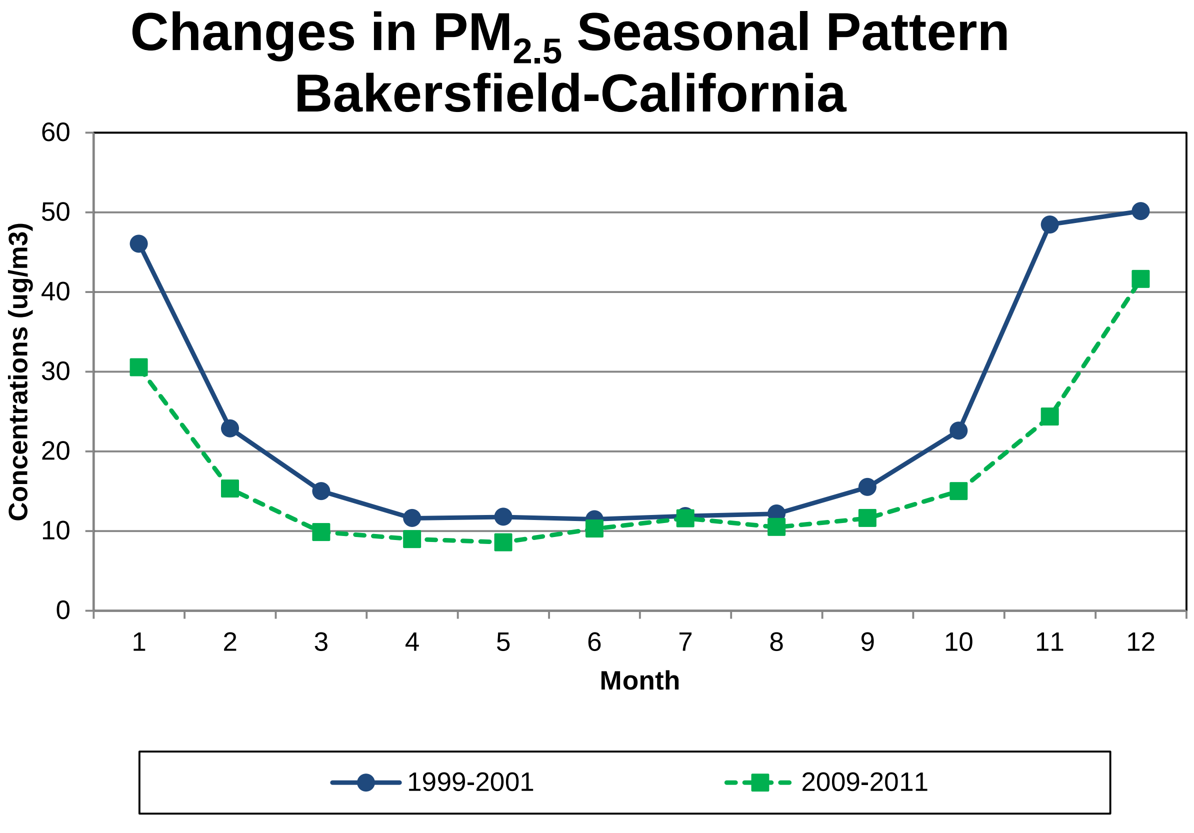
- Nitric acid (HNO_3) and ammonia (NH_3) are precursors to ammonium nitrate
- Measured HNO_3 concentrations are much lower than concentrations of NH_3

McCarthy et. al. 2005

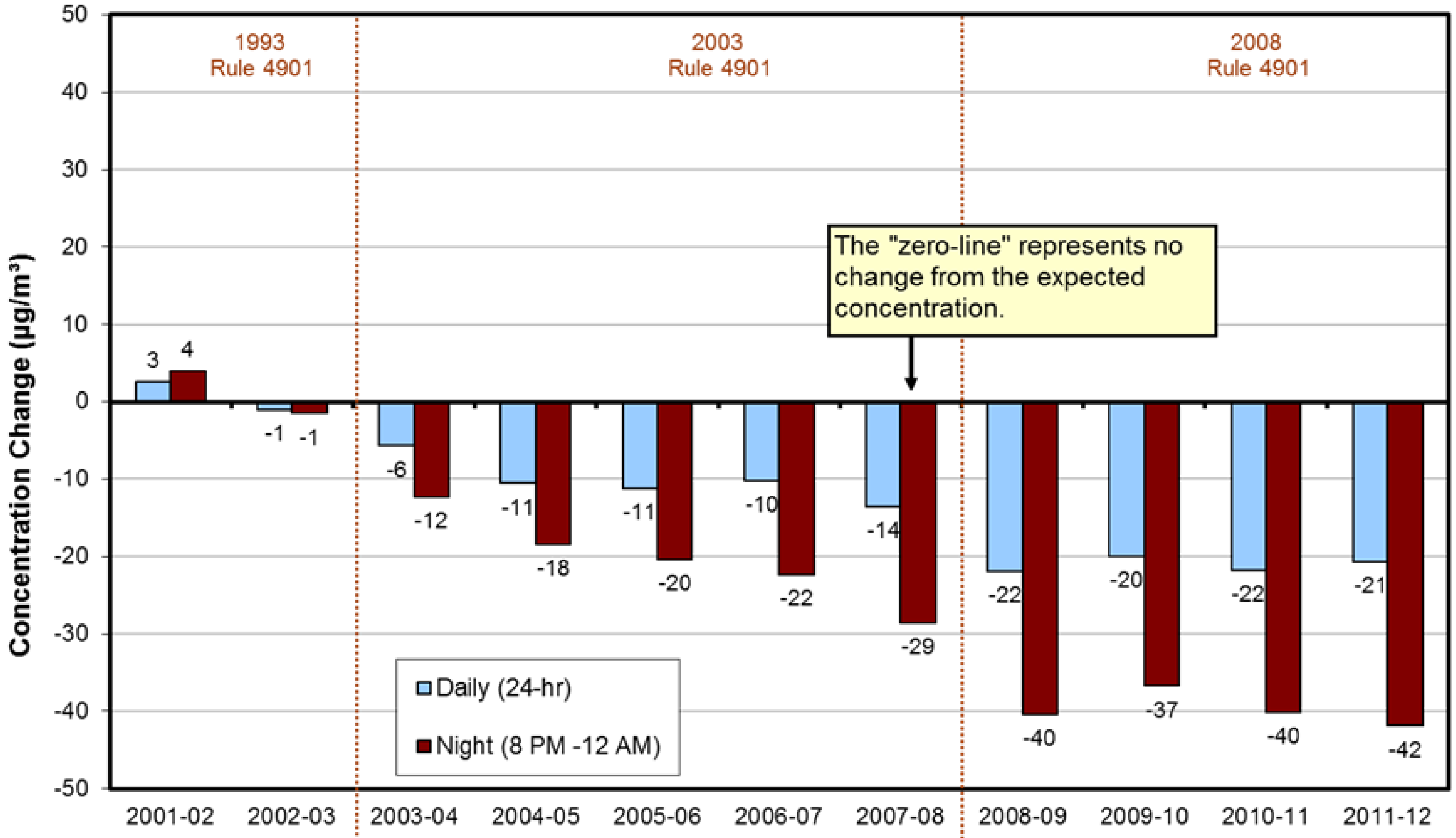
Annual Average $PM_{2.5}$ Trends



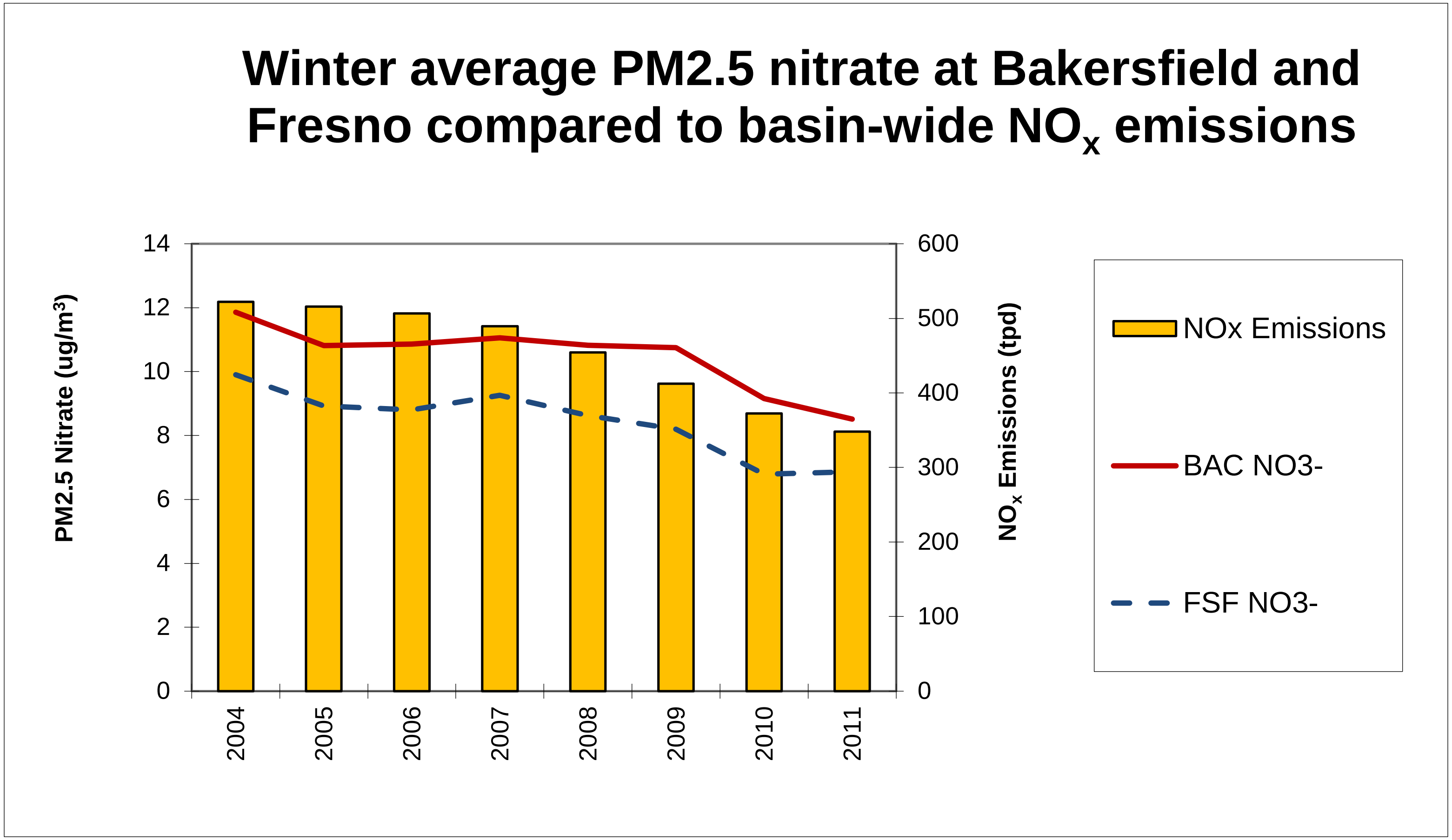
Trend in $PM_{2.5}$ Seasonal Pattern



Effectiveness of Wood Burning Controls



Effectiveness of NO_x Controls



Ongoing Efforts to Improve Science

- Annual science meetings:
  - *International Conference on Atmospheric Chemical Mechanisms*
  - *International Aerosol Modeling Algorithms Conference*
- Field studies to improve modeling databases:
  - *U.S. EPA / ARB Advanced Monitoring Initiative (Feb. 2007)*
  - *ARCTAS (June 2008)*
  - *CalNex (May-July 2008)*
  - *DiscoverAQ (Jan-Feb 2013)*

Attainment Demonstration Modeling Results

Attainment Demonstration Modeling

- Attainment predicted in all counties except Kern and Kings based on implementation of ongoing control program
- Most sites in northern and central Valley expected to attain prior to 2019
- Scenario with enhanced wood burning curtailment program predicts attainment in all counties except Kern

Ongoing Emission Reductions

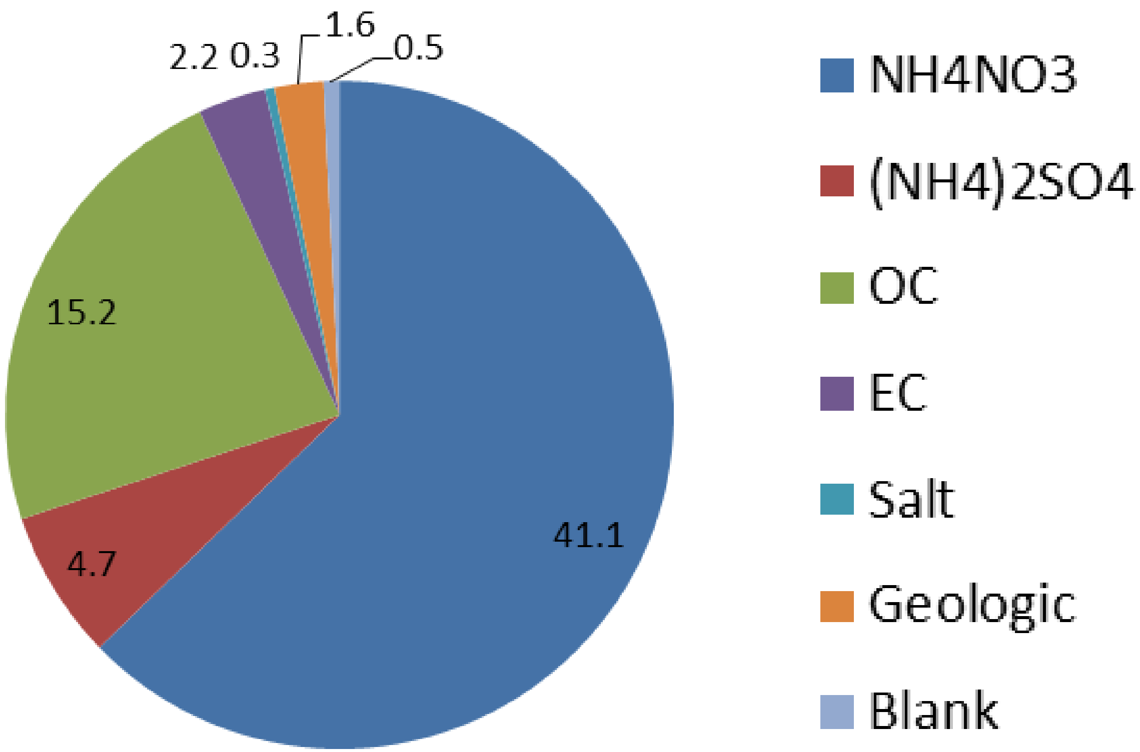
- New emission reductions each year from implementation of ongoing ARB and District control programs
- As a result between 2007 and 2019:
  - NO_x emissions will decrease by over 50%
  - $PM_{2.5}$ emissions will decrease by over 25%
  - SO_x emissions will decrease by 30%

Base/Future Design Values

Monitoring Station	2007 DV	2019 DV
Bakersfield – California	65.6	35.7
Bakersfield – Planz	67.8	32.9
Fresno – First Street	63.0	30.5
Fresno – Hamilton	61.2	28.6
Clovis	58.4	28.6
Modesto – 14th Street	54.8	24.7
Merced – M Street	48.3	22.6
Stockton – Hazelton St.	44.7	21.4
Visalia – N Church St.	58.2	29.4
Corcoran – Patterson	60.8	32.1

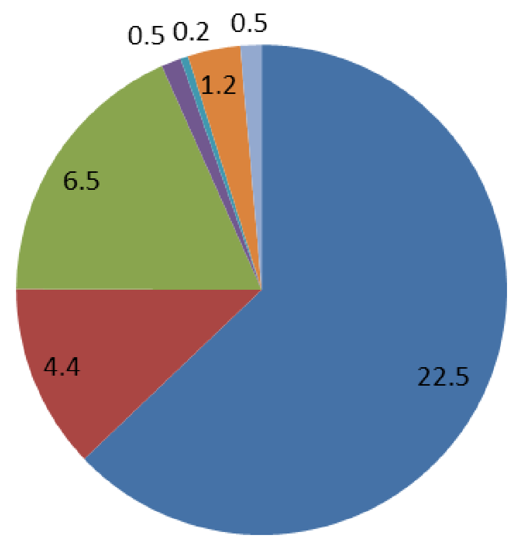
Base/Future DV Composition

2007



65.6 μg/m³

2019



35.7 μg/m³

Attainment Demonstration at Bakersfield - California Site

2007 Design Value (ug/m3)	2019 Design Value with Wood Burning Program Enhancement (ug/m3)	2019 Final Design Value (ug/m3)
65.6	35.7	35.4

- Attainment predicted based on implementation of ongoing control program plus enhanced wood burning curtailment and commercial cooking measures

Precursor Sensitivity Analysis

Determining Precursor Sensitivity - 1

- Air quality models provide the best tool to evaluate the potential effectiveness of controlling different $PM_{2.5}$ precursors
- This analysis has been done as part of previous modeling efforts for CRPAQS as well as the current $PM_{2.5}$ plan
- The current plan integrates the results of all these studies in determining the most effective control approach

Determining Precursor Sensitivity - 2

- ARB conducted multiple modeling sensitivity runs to compare the effectiveness of:
  - Directly emitted $PM_{2.5}$
  - NO_x
  - SO_x
  - VOCs
  - Ammonia
- Results are expressed in terms of reduction in the 2019 Design Value

Modeled Effect of 25% Precursor Reductions at Bakersfield – California

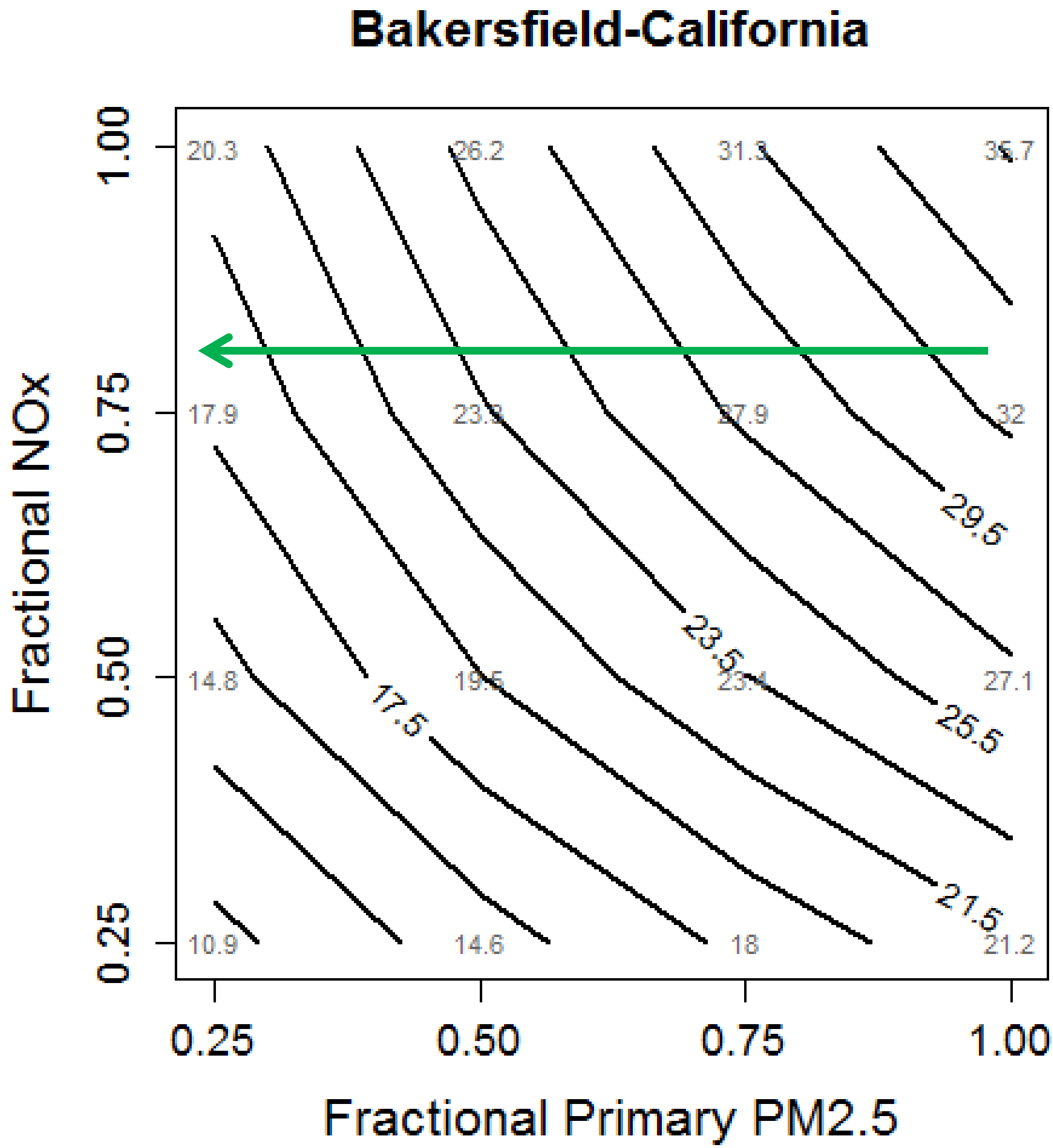
Precursor	$PM_{2.5}$ Reduction ($\mu g/m^3$)	Tons of Emissions	$\mu g/m^3$ Reduction/ton
Primary $PM_{2.5}$	4.44	15	0.29
NO_x	3.75	42	0.09
NH_3	0.55	72	0.008
SO_x	0.18	4	0.04
VOC	-0.09	87	-0.001

Benefits of Direct $PM_{2.5}$ Controls

- Direct $PM_{2.5}$ has substantial amounts of organic carbon (OC)
- OC is a major component of future $PM_{2.5}$
- Reduction of direct $PM_{2.5}$ leads to less OC
- This leads to a significant reduction in the design value

25% Reduction in $PM_{2.5}$ reduces design value by 12%

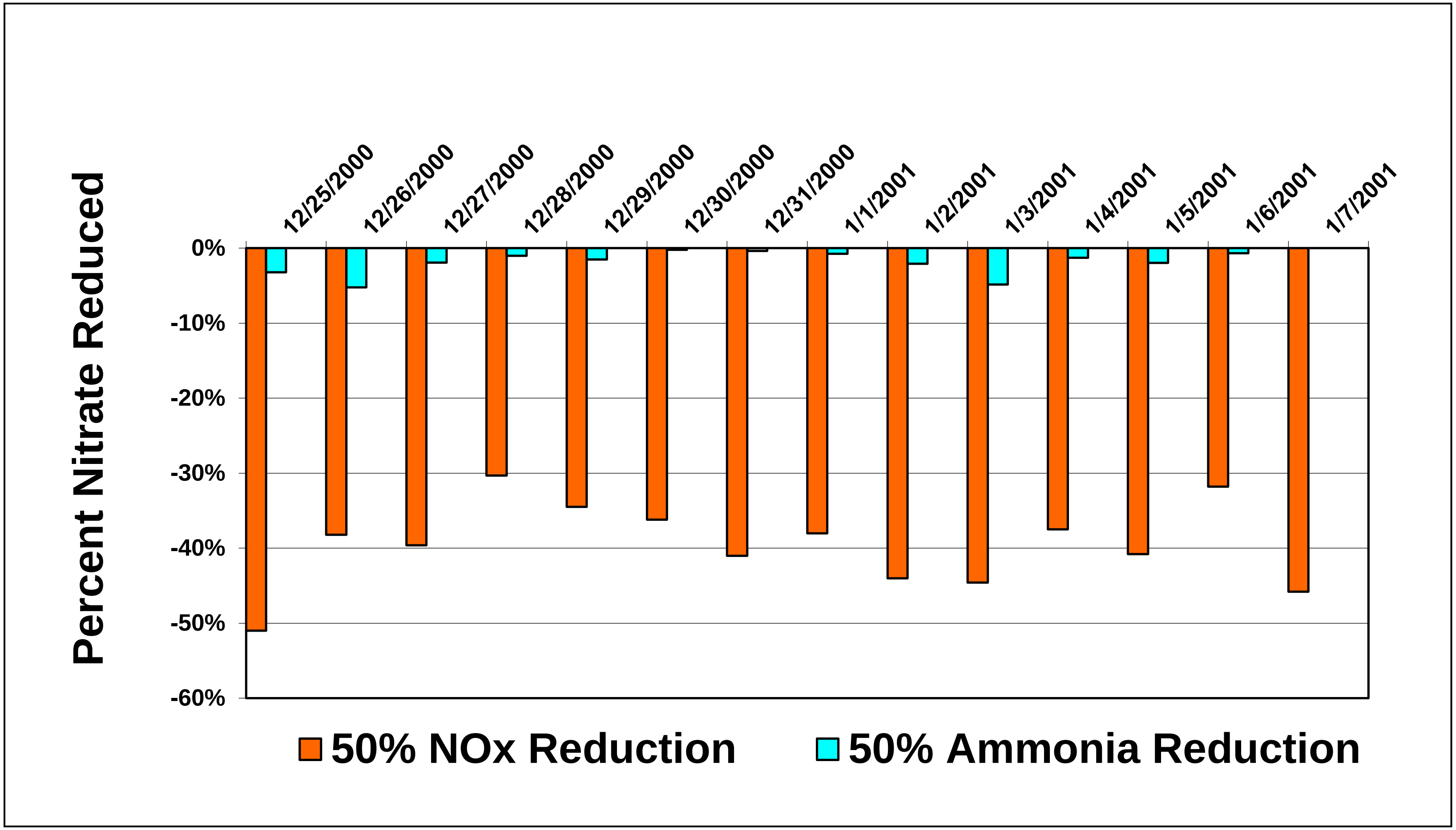
$PM_{2.5}$ – NO_x Diagram



Benefits of NO_x vs. Ammonia Control – Previous Studies

- Previous modeling studies indicated:
  - Large reductions in NO_x led to generally commensurate reductions in ammonium nitrate
  - Large reductions in ammonia were much less effective, particularly in urban areas
  - Observed reductions in ammonium nitrate and ambient NO_x track reductions in NO_x emissions

CRPAQS NO_x and Ammonia Sensitivity

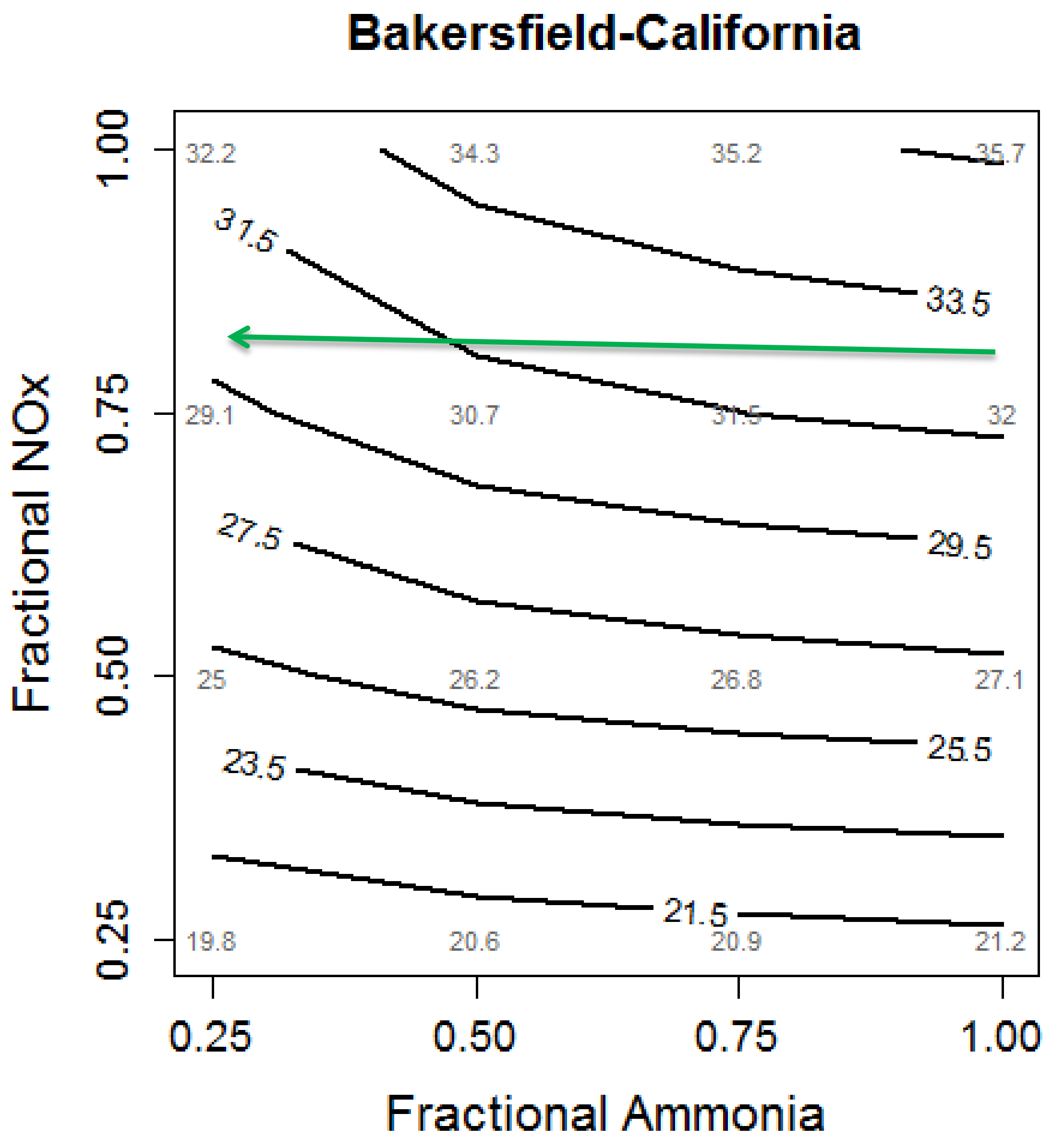


Benefits of NOx versus Ammonia Controls – Current Modeling

- Ammonia is in excess compared to nitric acid, so atmosphere is more response to NO_x than ammonia reductions
- Isopleths nearly parallel to ammonia axis means small benefits (relative to NO_x reduction)

25% reduction in NOx reduces design value by 10%
25% reduction in NH3 reduces design value by 1.5%

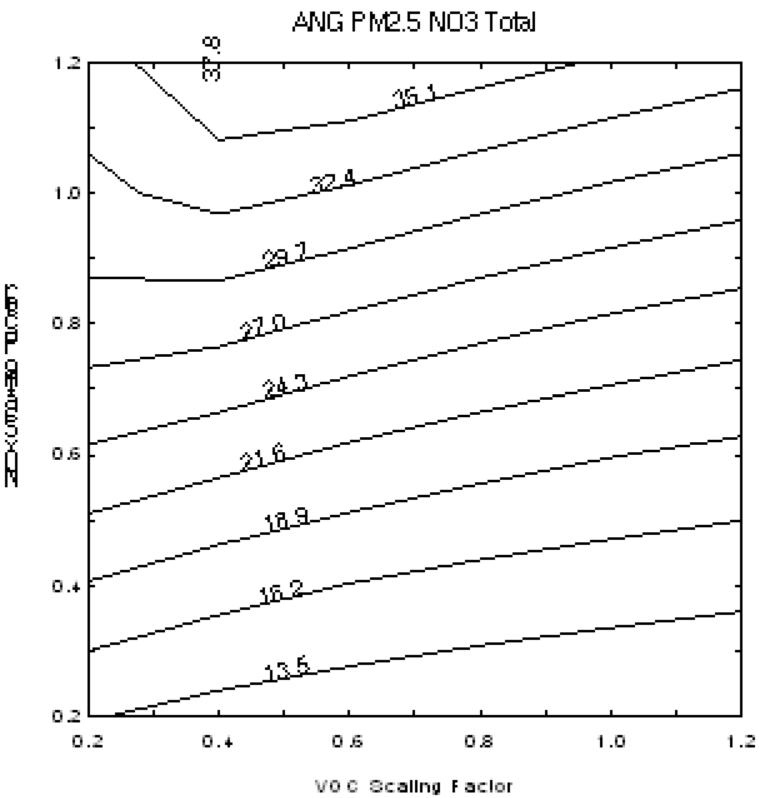
Ammonia – NO_x Diagram

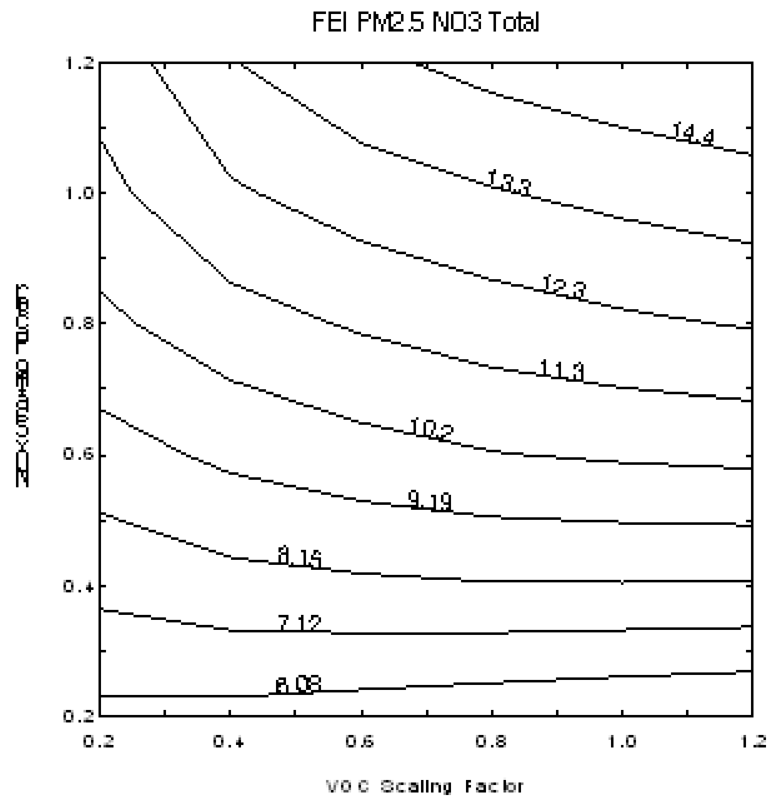


Benefits of NO_x Versus VOC Control – Previous Studies

- Previous modeling studies indicated:
  - At current NO_x and VOC concentrations, further VOC controls produce little benefit, and may actually increase ammonium nitrate slightly
  - Secondary organic aerosol formation from VOCs is negligible in winter

CRPAQS VOC Sensitivity





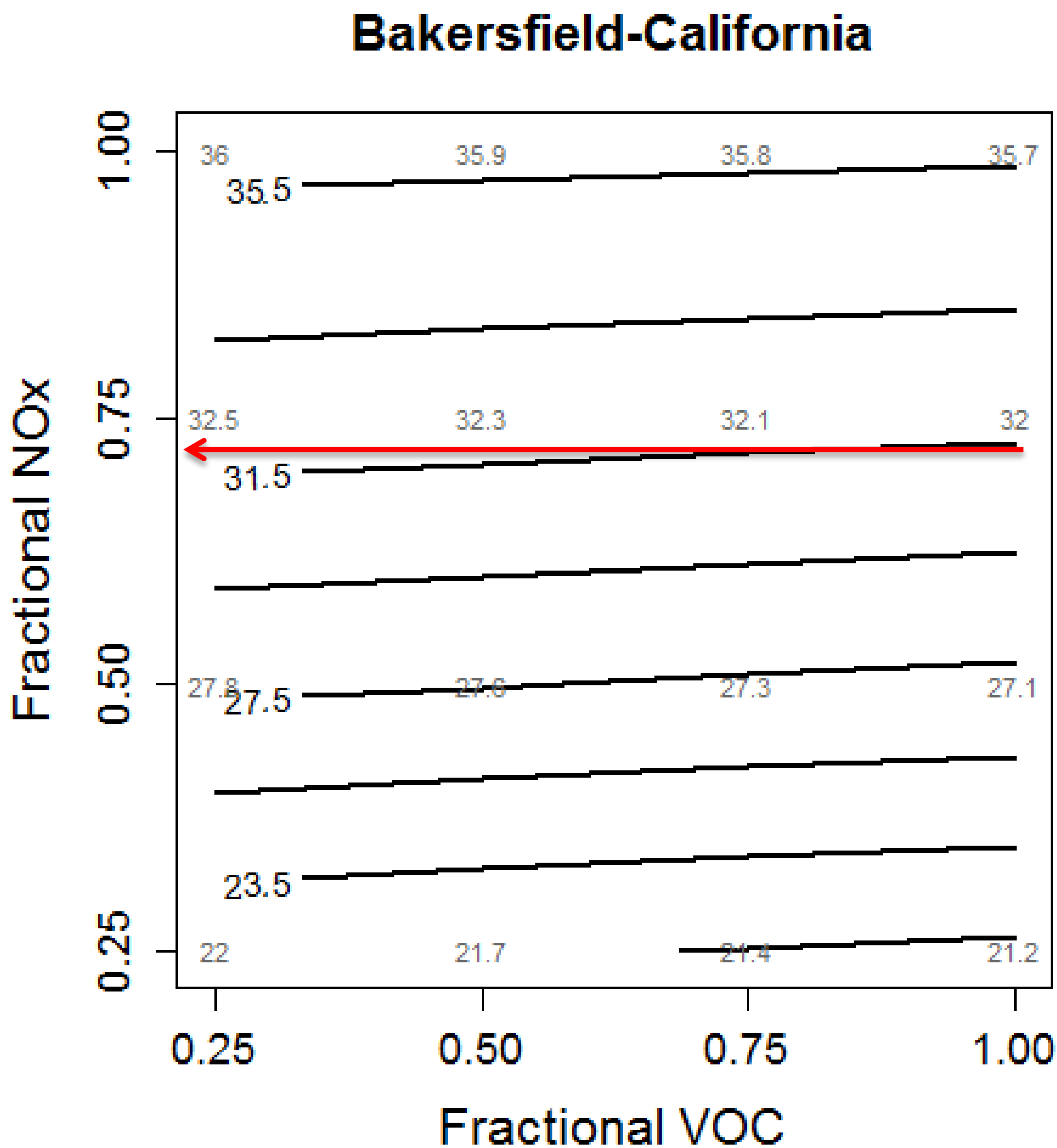
Source: Kleeman, M.J., personal communication, May 2008

Benefits of NO_x versus VOC controls – Current Modeling

- For ozone, VOC controls may have varying amounts of benefits
- For $PM_{2.5}$, VOC controls lead to minor disbenefits by making more NO_x available for nitric acid (HNO_3) formation
- HNO_3 + ammonia (NH_3) = Ammonium Nitrate

25% reduction in VOCs increases design value by 0.2%

VOC – NO_x Diagram

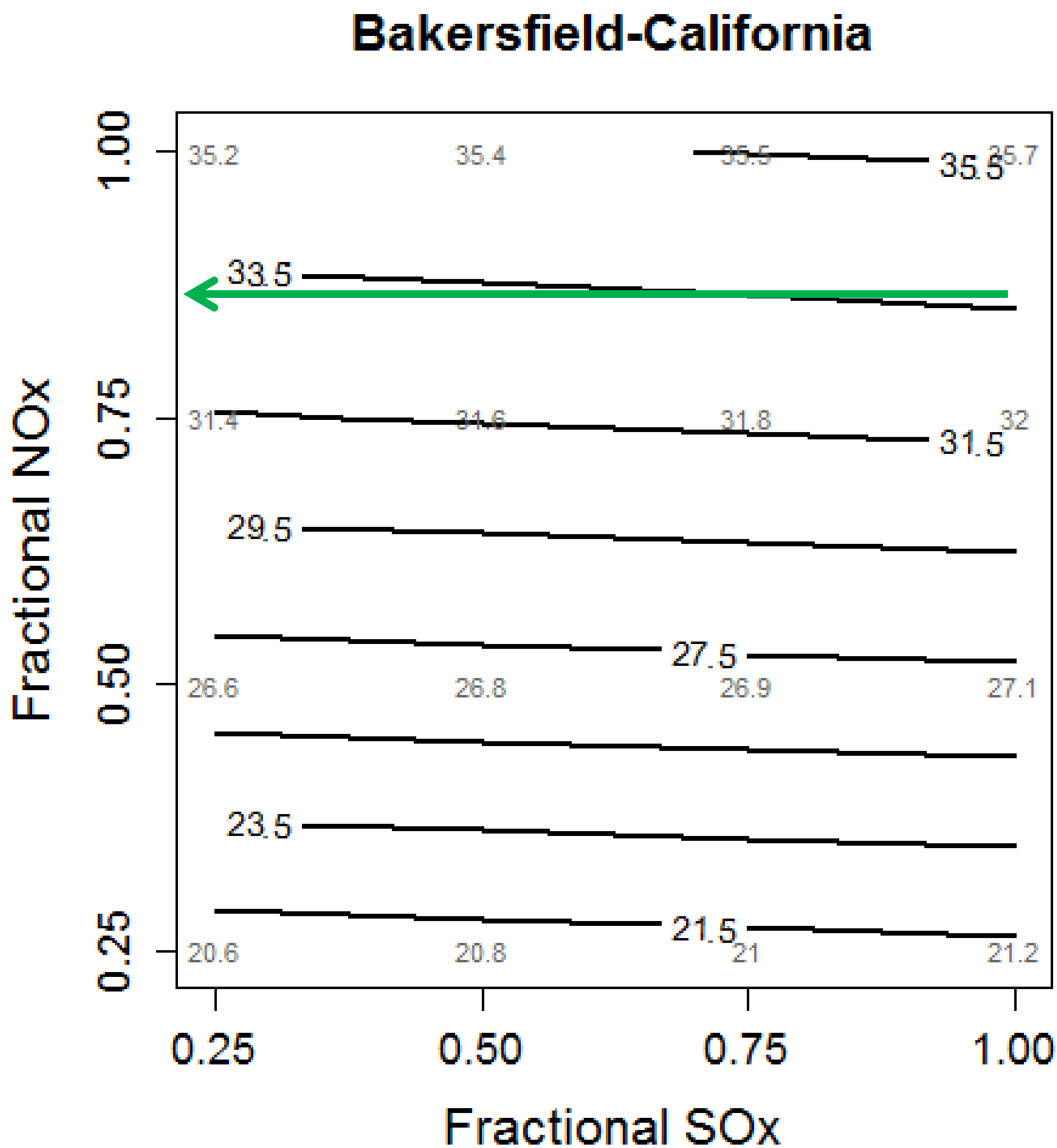


Benefits of SO_x Control

- SO_x controls lead to less sulfuric acid (H_2SO_4)
- Less H_2SO_4 leads to less ammonium sulfate
- Sulfate is a small component of $PM_{2.5}$ resulting in minor impacts in reducing the design value

25% reduction in SOx reduces design value by 0.5%

SO_x – NO_x Diagram



Benefits of Localized Reductions

- ARB also conducted sensitivity runs examining benefits of further NO_x and $PM_{2.5}$ control in Kern County only
- Reductions in the Bakersfield design value were somewhat smaller than seen from Valleywide reductions, but the benefit per ton was greater:
  - $PM_{2.5}$: 1.0 µg/m^3 per ton benefit
  - NO_x: 0.12 µg/m^3 per ton benefit

Summary of Precursor Findings

- Reductions in direct $PM_{2.5}$ are the most beneficial
- NO_x controls also provide large benefits
- NH_3 and SO_x controls offer very small benefits
- VOC controls produce very small disbenefits

Summary

Current Multi-Pollutant Control Approach

- Current efforts have focused on implementing commitments for meeting annual $PM_{2.5}$ and 8-hour ozone standard
- NO_x reductions are key for both ozone and $PM_{2.5}$ progress
- Diesel risk reduction program also provides important PM and health benefits

Progress Towards Annual Standard

- Current NO_x control strategy, coupled with focus on wood burning has been effective
- Annual design values have decreased 30% to 40% over the last decade
- When variations in meteorology are considered, even greater progress is seen
- Most sites in northern and central Valley now attain the standard

Progress Towards 24-Hour Standard

- 24-hour design values have decreased 30% to 40% over the last decade
- After accounting for variations in meteorology, the number of exceedance days has decreased over 60%
- Concentrations during severe episodes are 40% lower than they were ten years ago
- Despite progress, addressing the 24-hour standard remains a challenge

Current Science on 24-Hour $PM_{2.5}$

- $PM_{2.5}$ concentrations build up over long periods with stagnant weather
- Key components are ammonium nitrate and carbon
- Ammonium nitrate is distributed more regionally, while carbon is more localized in urban areas

Reducing Carbon

- The most important sources of organic carbon are mobile sources, wood burning, and commercial cooking
- Control strategy focuses on:
  - Ongoing mobile source control program
  - Enhancement of wood burning curtailment program
  - Control of commercial cooking operations
- As a result, organic carbon concentrations are predicted to decrease by 65% and elemental carbon by 80%

Reducing Ammonium Nitrate

- Reducing NO_x is most effective in reducing ammonium nitrate concentrations
- Control strategy focuses on:
  - Ongoing mobile source control program
  - District control program for stationary sources
- As a result, ammonium nitrate concentrations are predicted to decrease by more than 45%

Weight of Evidence

- 24-Hour design values have decreased 30-40% over the last decade
- Air quality trends demonstrate past effectiveness of NO_x and $PM_{2.5}$ emission reductions
- Emissions of NO_x and $PM_{2.5}$ are expected to drop over 50% and 25% respectively by 2019
- Modeling predicts ammonium nitrate will decrease by over 45% and organic carbon by 65%
- This results in attainment throughout the Valley by 2019

Acknowledgements

We greatly benefited from the collaboration with the staff of the San Joaquin Valley Air Pollution Control District during the modeling process

Please e-mail your questions to
webcast@valleyair.org

Thank you very much for your attention!

“Bare-Knuckle” Supercomputing

- Partly funded by the San Joaquin Valley-wide Air Pollution Study Agency