Earth System Research Laboratory
Global Monitoring Annual Conference
May 19-20, 2015
Boulder, Colorado

Comparison of seasonal cycles of tropospheric ozone from three Chemistry-Climate Models (CCMs) with measurements

Focus on Trinidad Head - upwind of U.S.

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Comparison of seasonal cycles of tropospheric ozone from three Chemistry-Climate Models (CCMs) with measurements

Focus on Trinidad Head - upwind of U.S.

Goal:

Characterize systematic variation of tropospheric O_3 concentrations with as few parameters as possible to provide metrics for comparing models with measurements

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Home | Registration | Agenda | Directions | Lodging | GMD Home

Acknowledgements:

Sam Oltmans, Bryan Johnson, Michael Ives, Irina Petropavlovskikh – NOAA/ESRL/GMD

Results from 3 CCMs:

J.-F. Lamarque – NCAR CAM-chem

V. Naik, L. Horowitz – NOAA GFDL-CM3

D. T. Shindell - GISS-E2-R

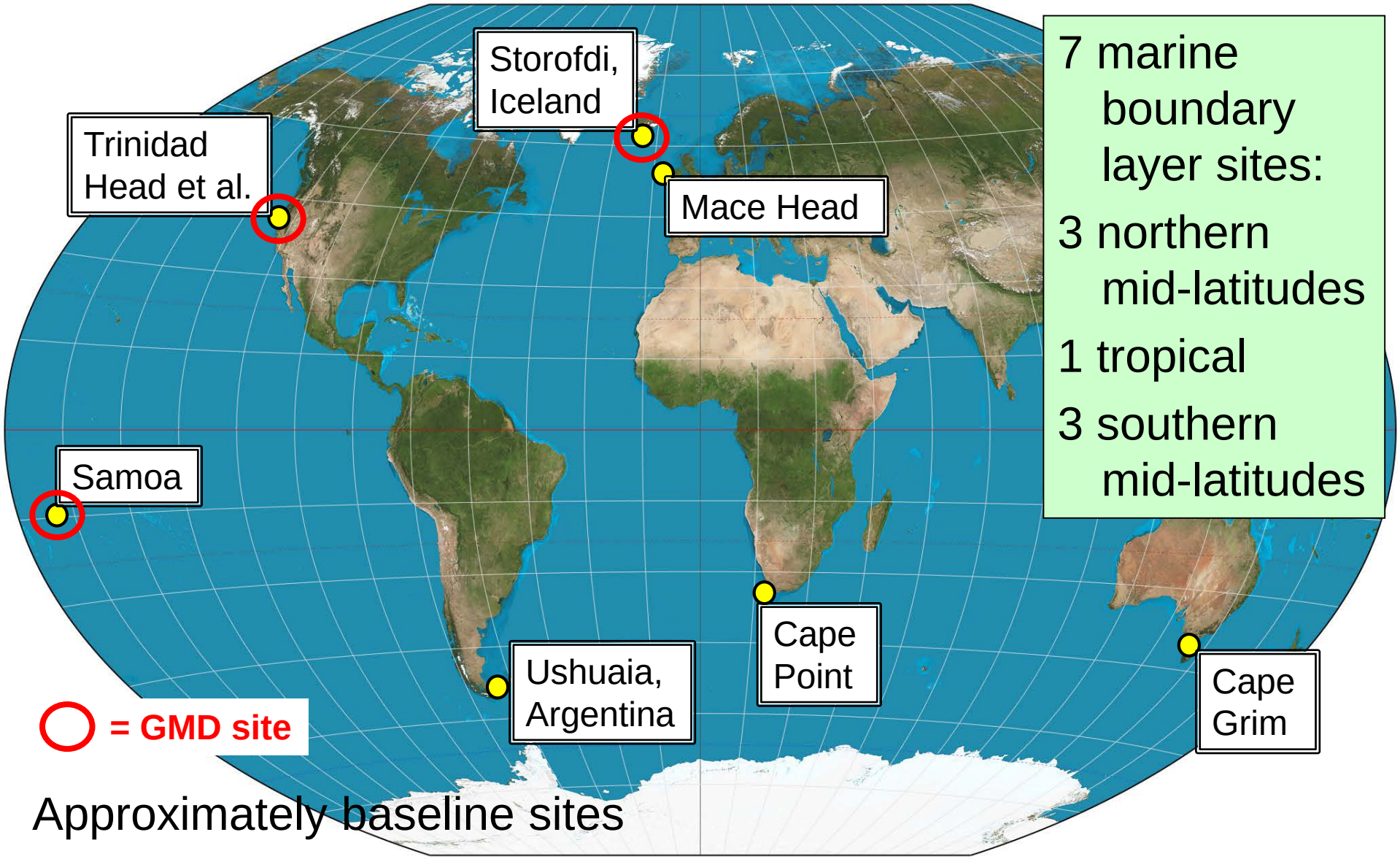
Free running meteorology with similar emissions

Used for latest IPCC Report AR5

Related models calculate "background" O_3 for air quality policy formulation

Quantify and compare measured and modeled

Seasonal cycles of O_3 in the MBL



7 marine boundary layer sites:

3 northern mid-latitudes

1 tropical

3 southern mid-latitudes

Approximately baseline sites

Quantify and compare measured and modeled

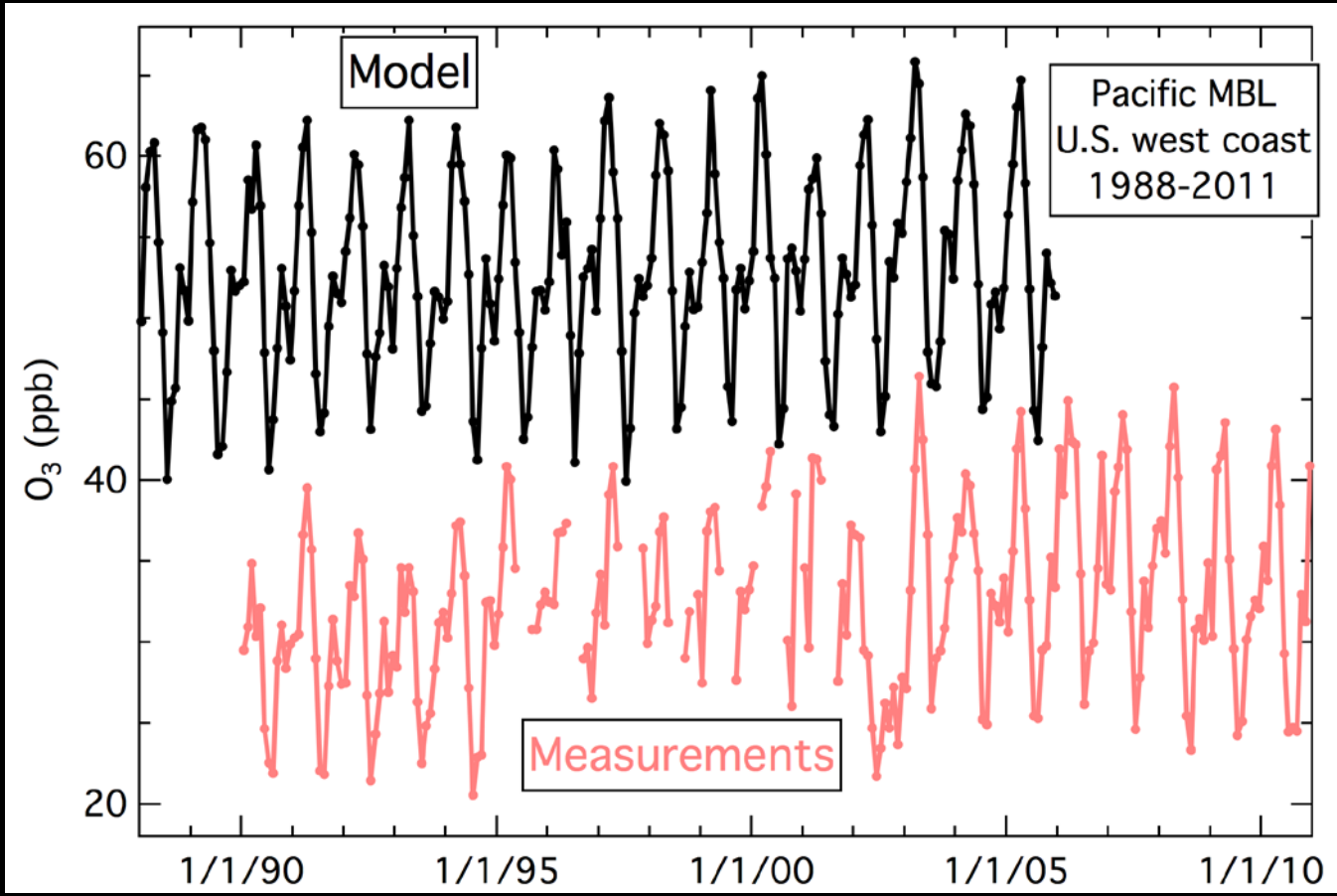
Seasonal cycles of O_3 in the MBL

21 years of monthly averages; Trinidad Head and other west coast sites

Monthly mean data and model results

Measurements selected for high onshore winds

All model results included – 250 km west



Detrend, Calculate Fourier Transform

Quantify and compare measured and modeled

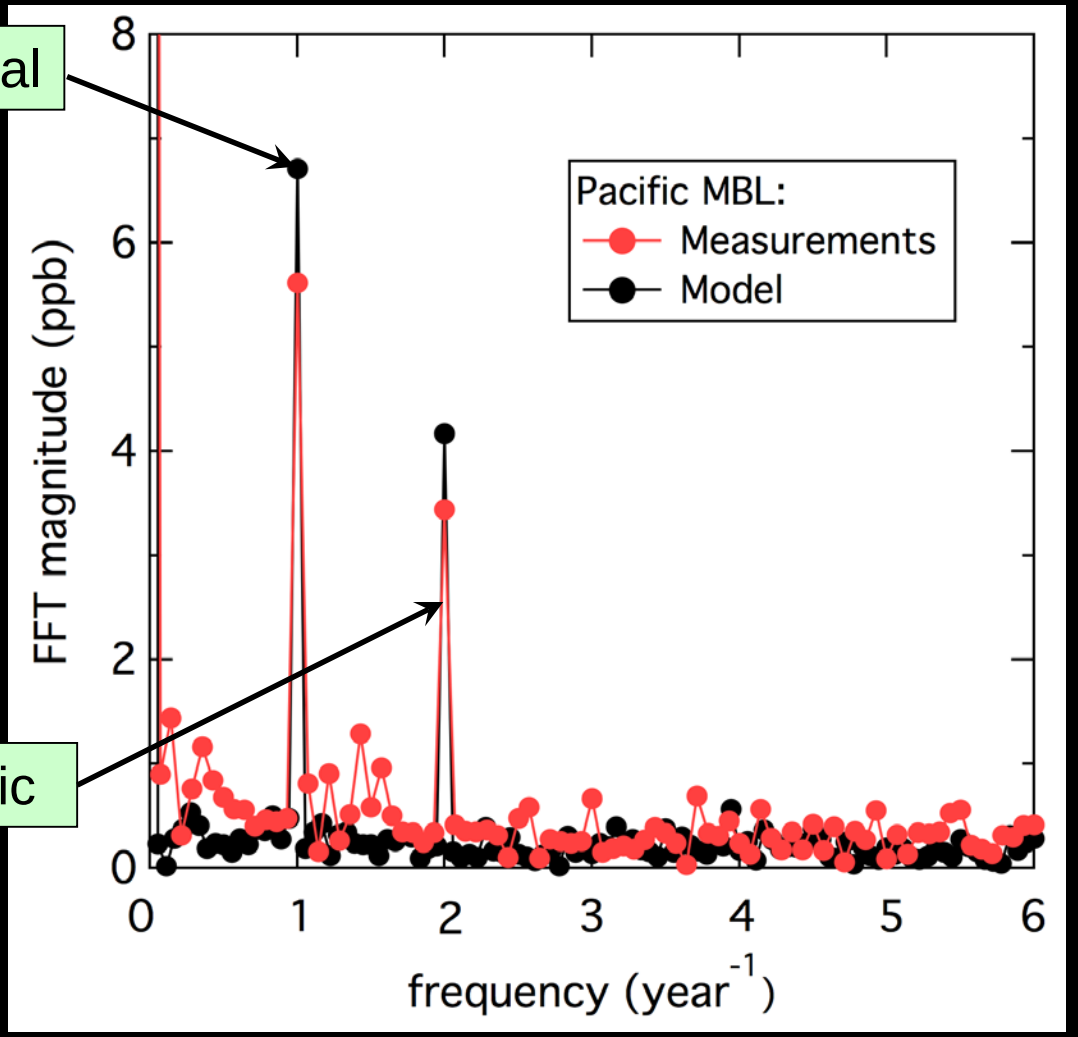
Seasonal cycles of O_3 in the MBL

Fundamental

2nd Harmonic

Only fundamental and 2nd harmonic significant.

Two, and only two, terms are significant in measured and all modeled seasonal cycles at all 7 sites.



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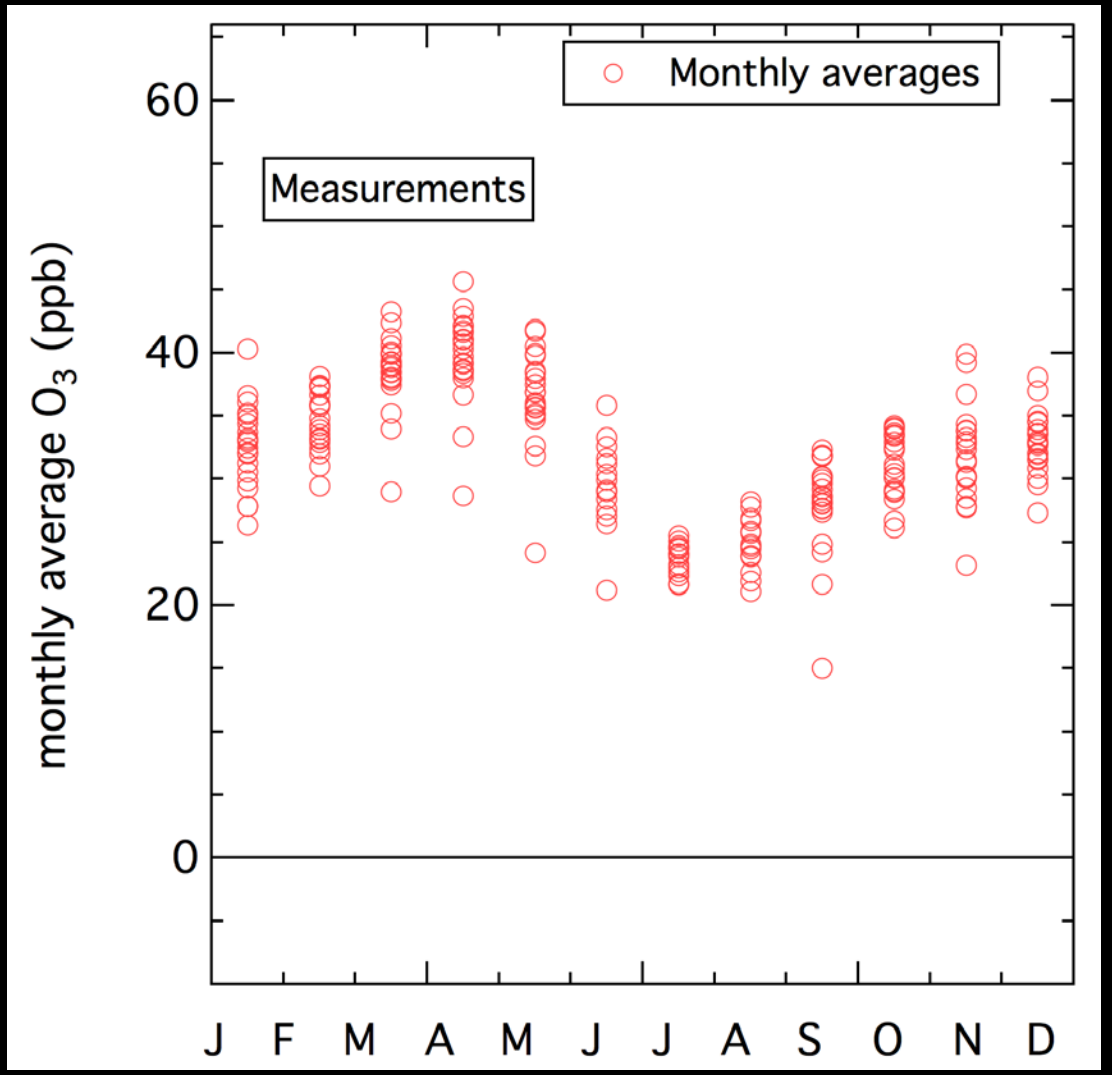


Fit sine functions to fundamental and 2nd harmonic

Quantify and compare measured and modeled

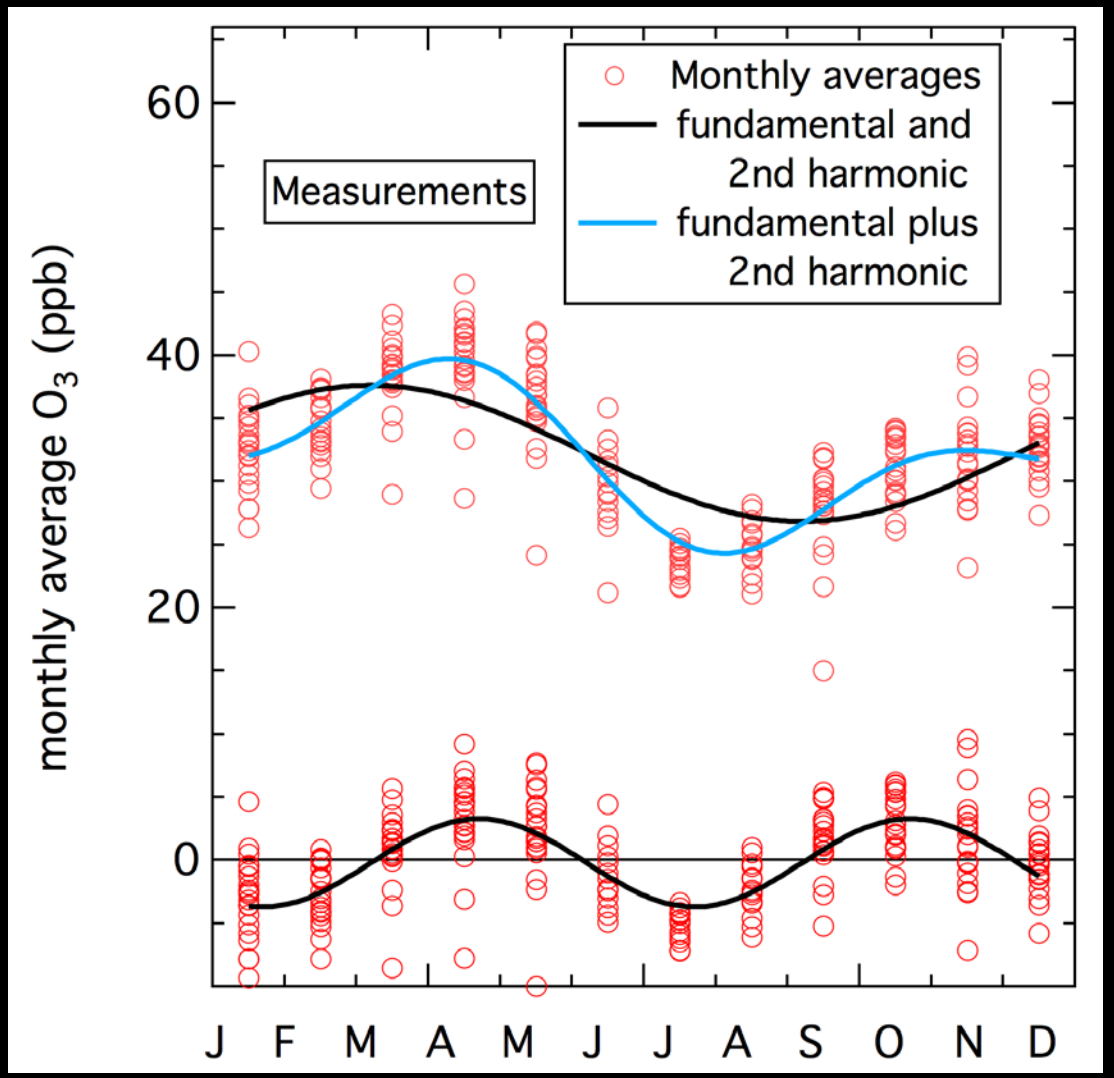
Seasonal cycles of O_3 in the MBL

5 parameters define average seasonal cycle:

- Annual average (Y_0)
  32.0 ± 0.4 ppb
- 2 magnitudes (A_1, A_2)
  5.7 ± 0.6, 3.5 ± 0.6 ppb
- 2 phases (ϕ_1, ϕ_2)
  0.48 ± 0.11, -2.30 ± 0.17 radians

RMSD = 3.2 ppbv

Provide basis for quantitative comparisons



Fit sine functions to fundamental and 2nd harmonic

Quantify and compare measured and modeled

Seasonal cycles of O_3 in the MBL

5 parameters define average seasonal cycle:

- Annual average (Y_0)

  52.8 ± 0.3 ppb

- 2 magnitudes (A_1, A_2)

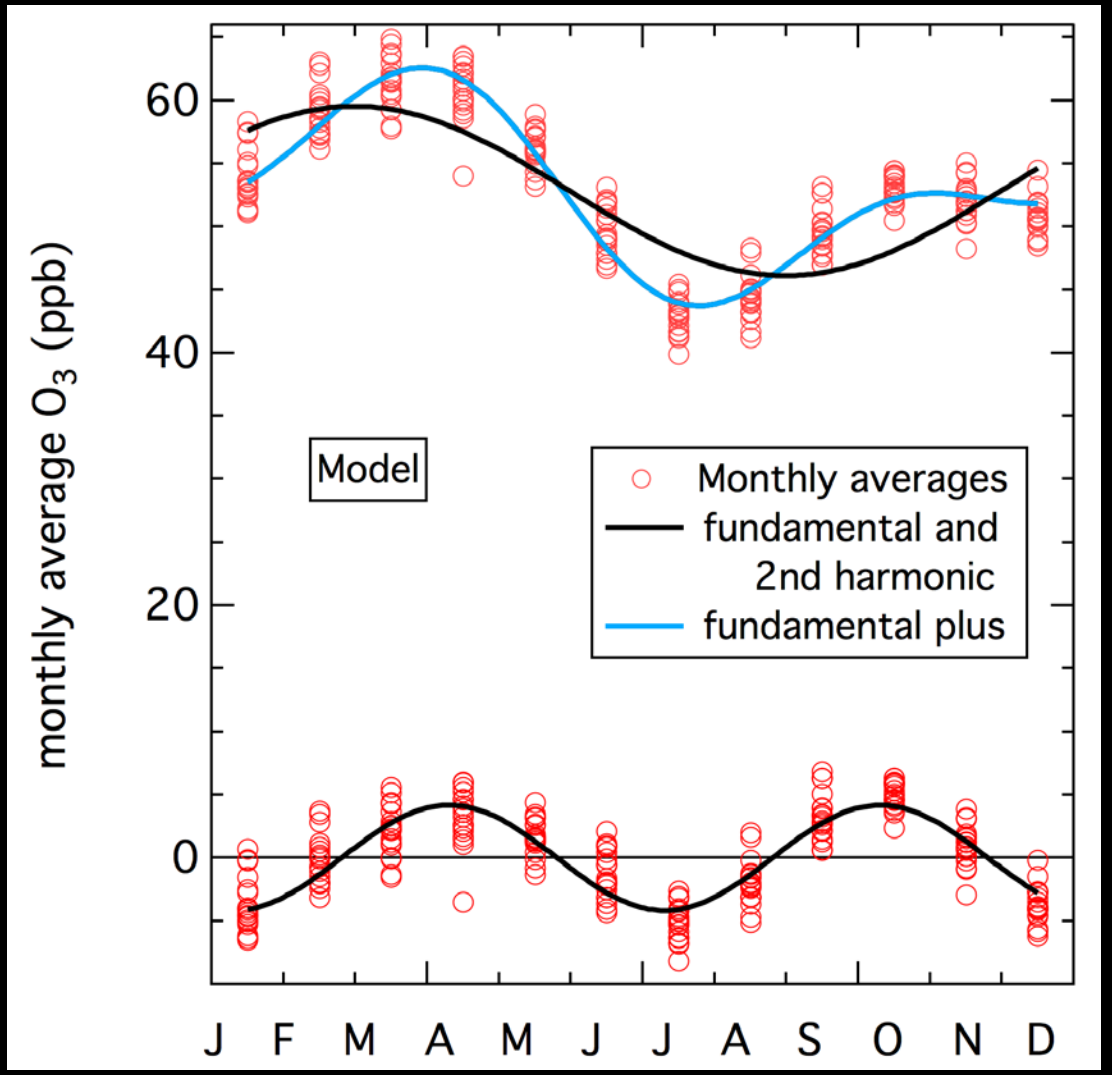
  6.7 ± 0.4, 4.2 ± 0.4 ppb

- 2 phases (ϕ_1, ϕ_2)

  0.53 ± 0.06, -1.89 ± 0.09 radians

RMSD = 2.0 ppbv

Provide basis for quantitative comparisons



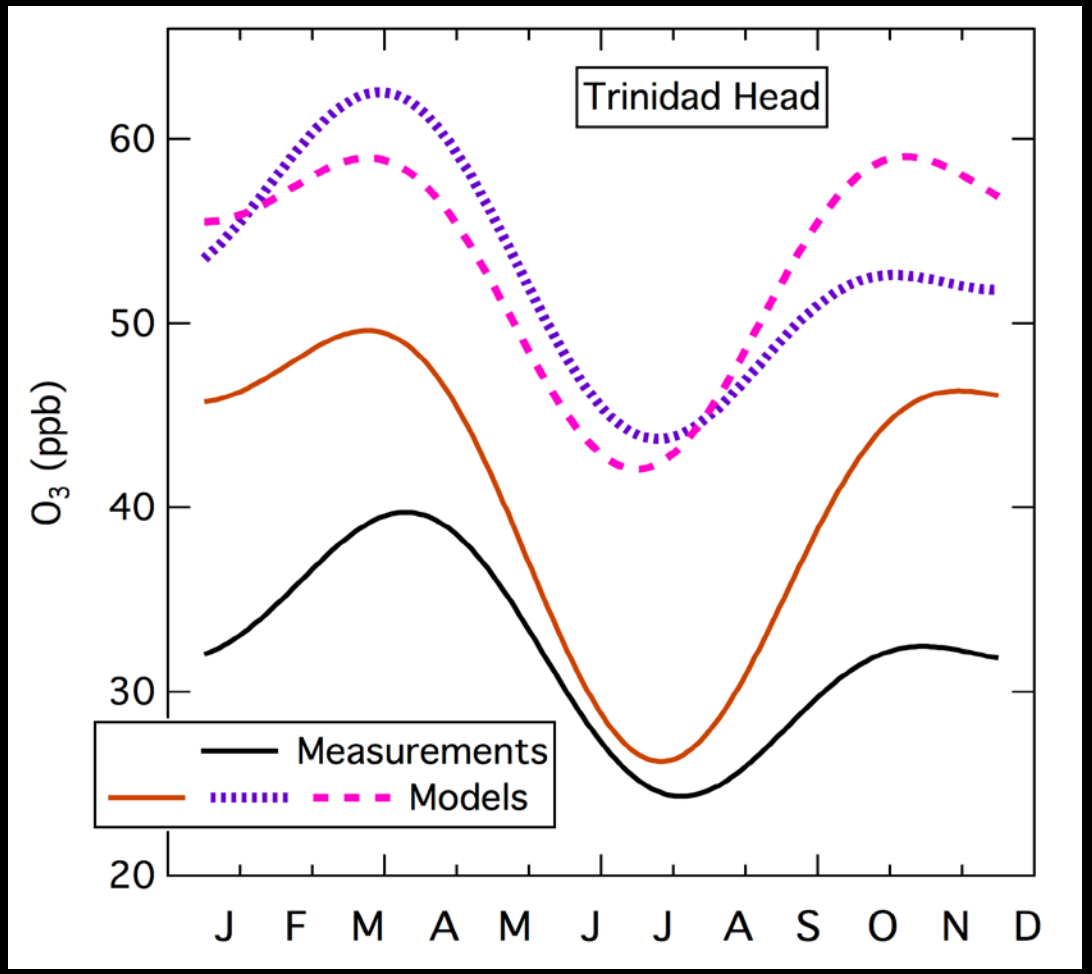
Fit sine functions to fundamental and 2nd harmonic

Quantify and compare measured and modeled

Seasonal cycles of O_3 in the MBL

Trinidad Head:

- 2nd harmonic is large relative to fundamental; secondary maximum in fall
- Models overestimate MBL baseline O_3 by 10-21 ppb (30-65%)
- Relative contributions of fundamental and second harmonic differ widely
- Spatial resolution of models may affect comparisons.



Fit sine functions to fundamental and 2nd harmonic

Quantify and compare measured and modeled

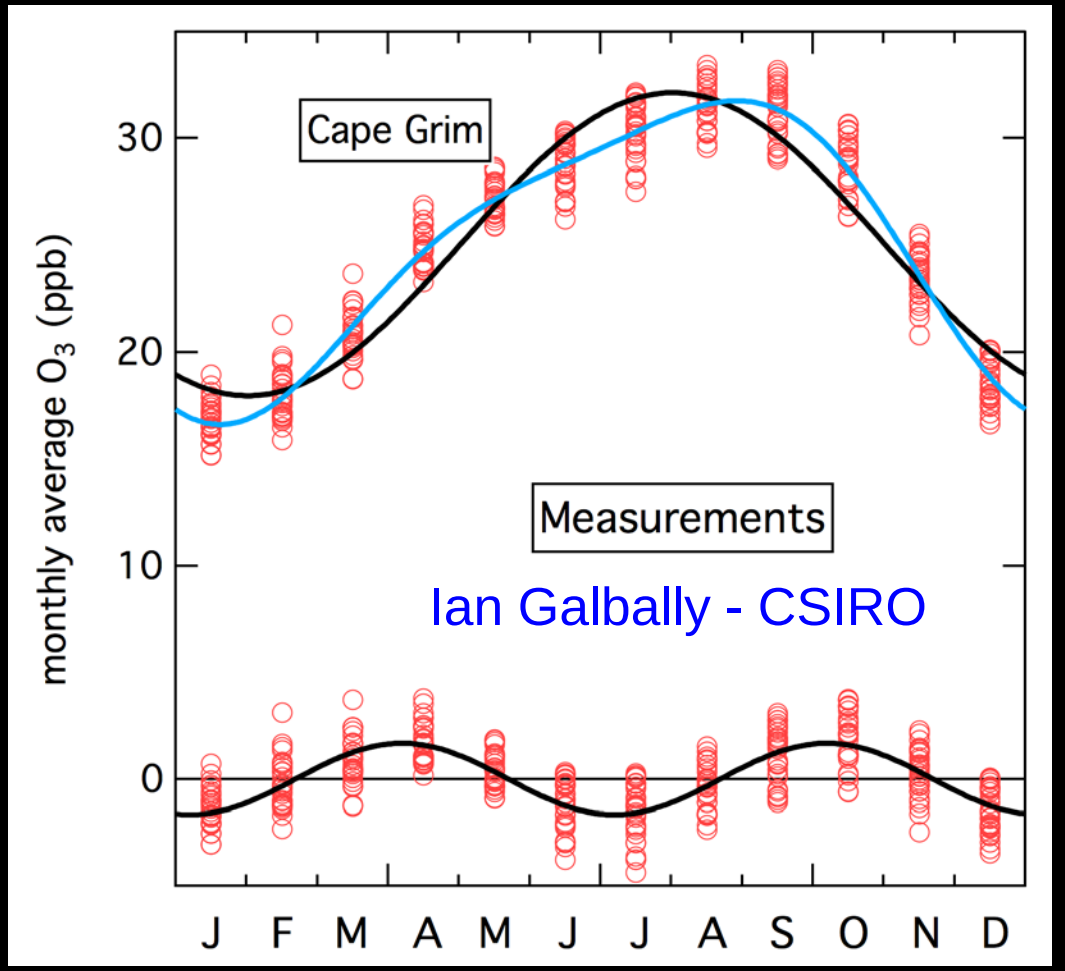
Seasonal cycles of O_3 in the MBL

Question:

What causes the 2nd harmonic?

What causes the 2nd harmonic?

O_3 seasonal cycle



Only fundamental and 2nd harmonic significant in measurements and all 3 models.

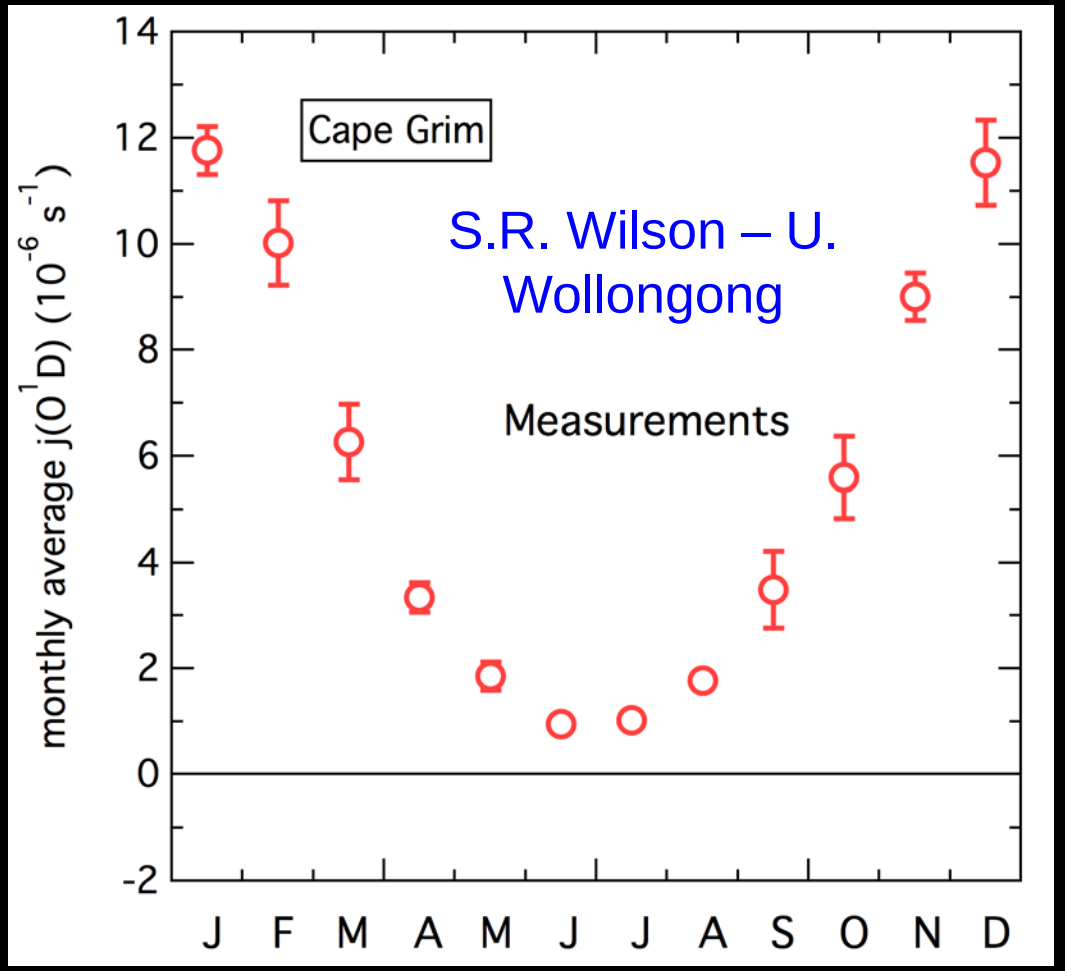
Similar to Trinidad Head, except 6 months phase difference

Fit sine functions to fundamental and 2nd harmonic

What causes the 2nd harmonic?

Photochemical destruction drives O3 seasonal cycle in MBL

$j_{O3}(^1D)$ seasonal cycle



Wilson, S. R. (2014), *Atmos. Chem. Phys. Discuss., 14*, 18389–18419.

Fit sine functions to fundamental and 2nd harmonic

What causes the 2nd harmonic?

Photochemical destruction drives O3 seasonal cycle in MBL

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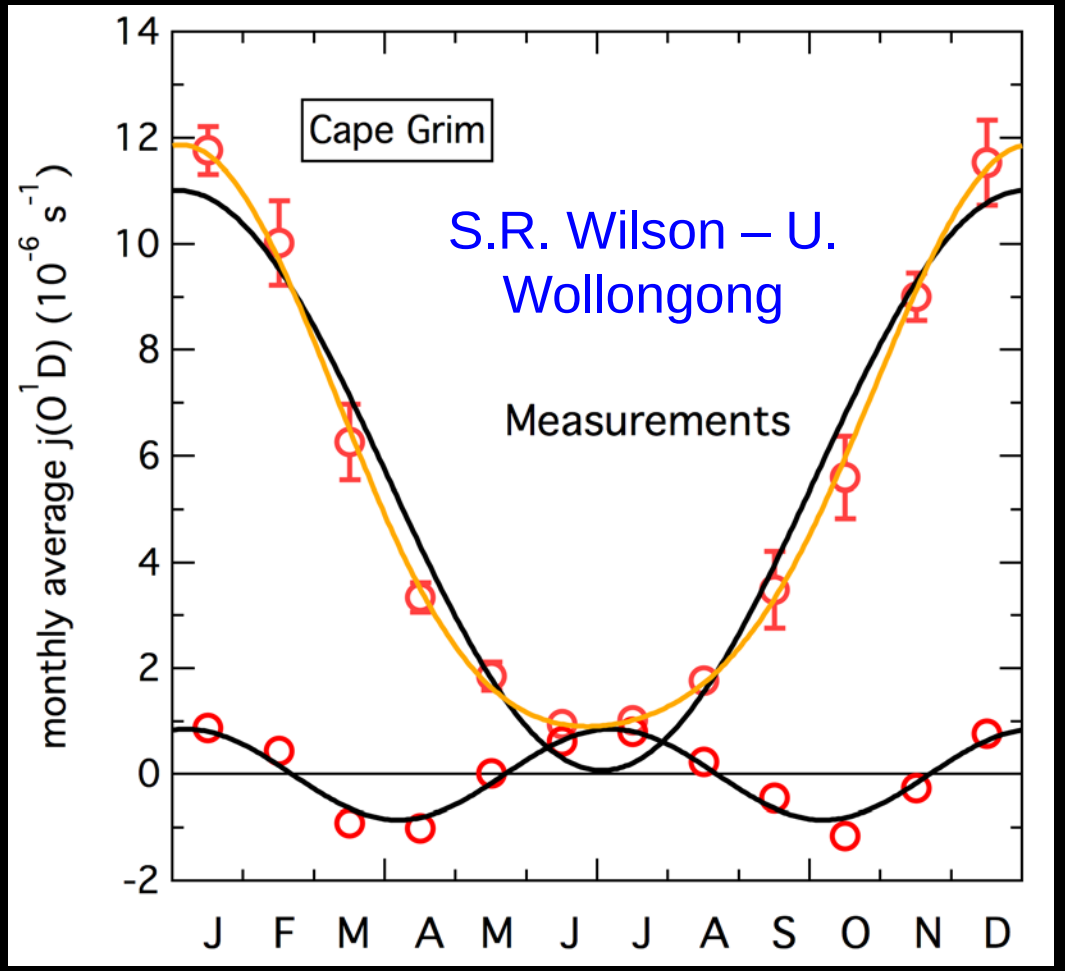


Only fundamental and 2nd harmonic significant.

2nd harmonic exactly out of phase with that of O_3

Wilson, S. R. (2014), *Atmos. Chem. Phys. Discuss., 14*, 18389–18419.

Fit sine functions to fundamental and 2nd harmonic

Quantify and compare measured and modeled

Seasonal cycles of O_3 in the MBL

Question:

Is the seasonal cycle different in the free troposphere?

Quantify and compare measured and modeled

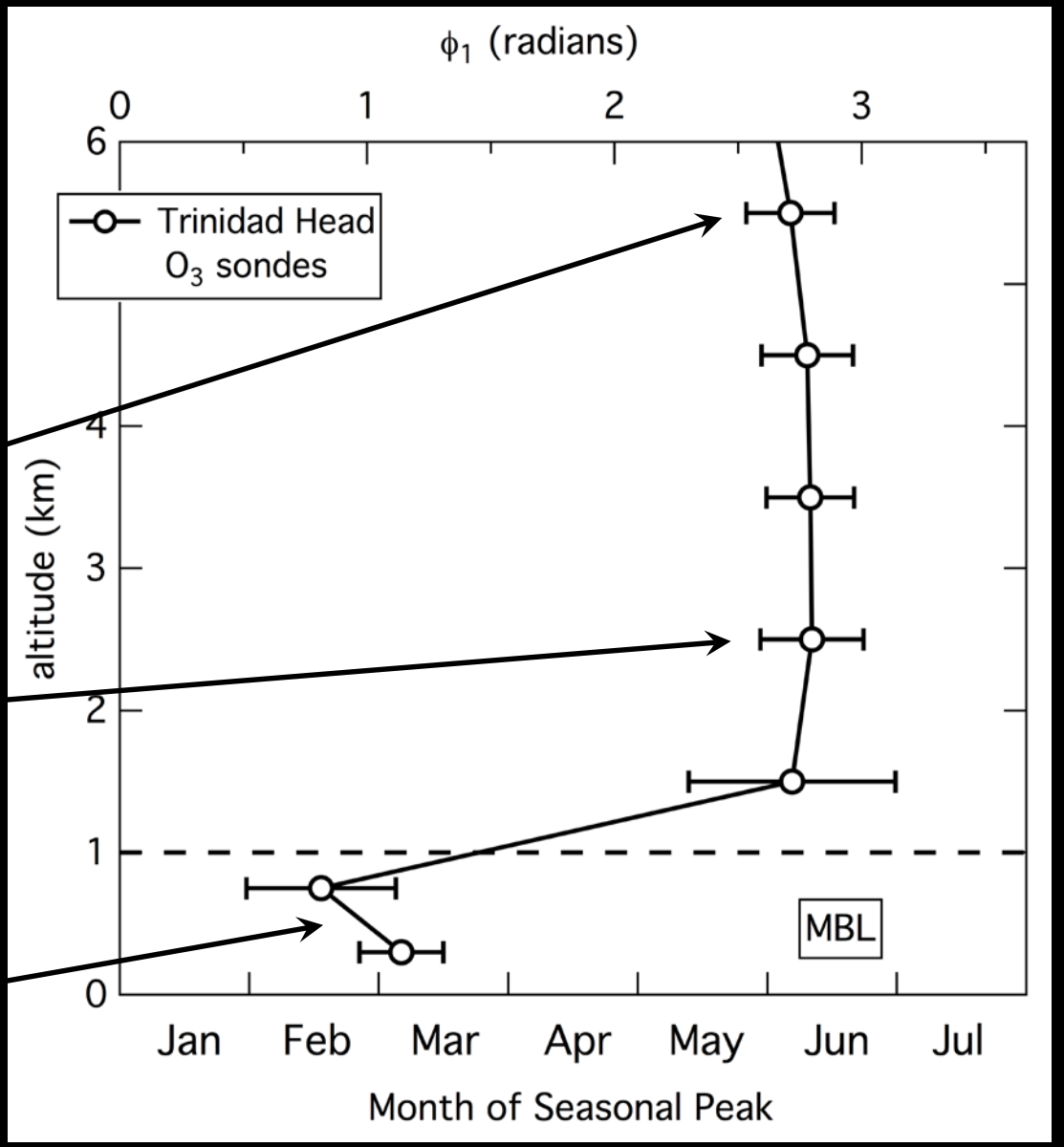
Altitude dependence of seasonal cycles

Hypothetical Picture:

Stratospheric influence dominates in upper FT – spring seasonal max

Photochemical production dominates in lower FT – May-June seasonal max

Photochemical destruction dominates in MBL – summer minimum, late winter seasonal maximum



Fit sine functions to fundamental and 2nd harmonic

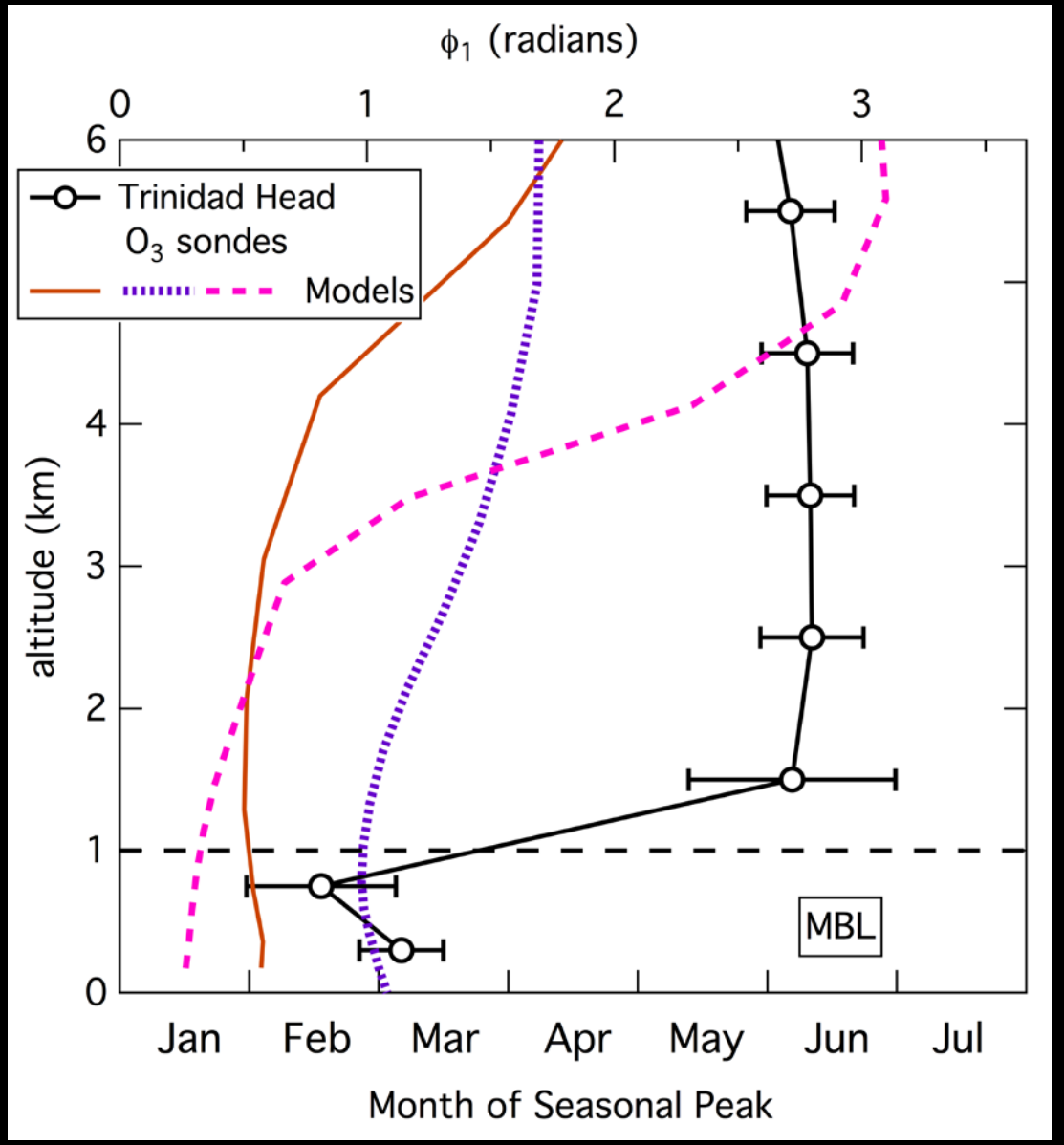
Quantify and Compare measurements and models

Altitude dependence of seasonal cycles

Hypothetical Picture:

Model results do not fit this hypothetical picture:

No strong shift in seasonal cycle above MBL



Fit sine functions to fundamental and 2nd harmonic

Quantify and Compare measurements and models

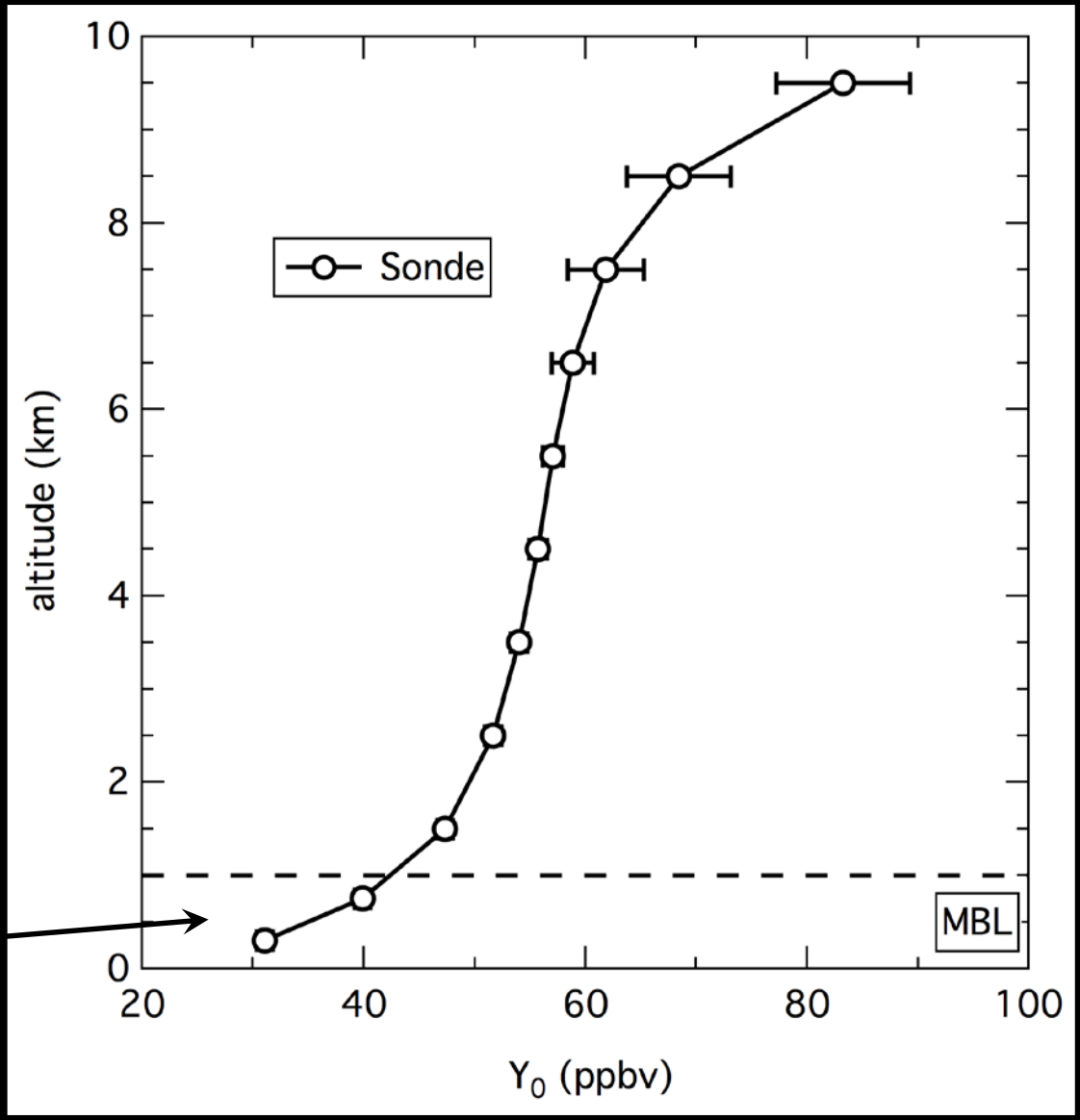
Altitude dependence of seasonal cycles

Hypothetical Picture:

Model results do not fit this hypothetical picture:

No strong shift in seasonal cycle above MBL

O_3 sharply reduced in MBL



Quantify and Compare measurements and models

Altitude dependence of seasonal cycles

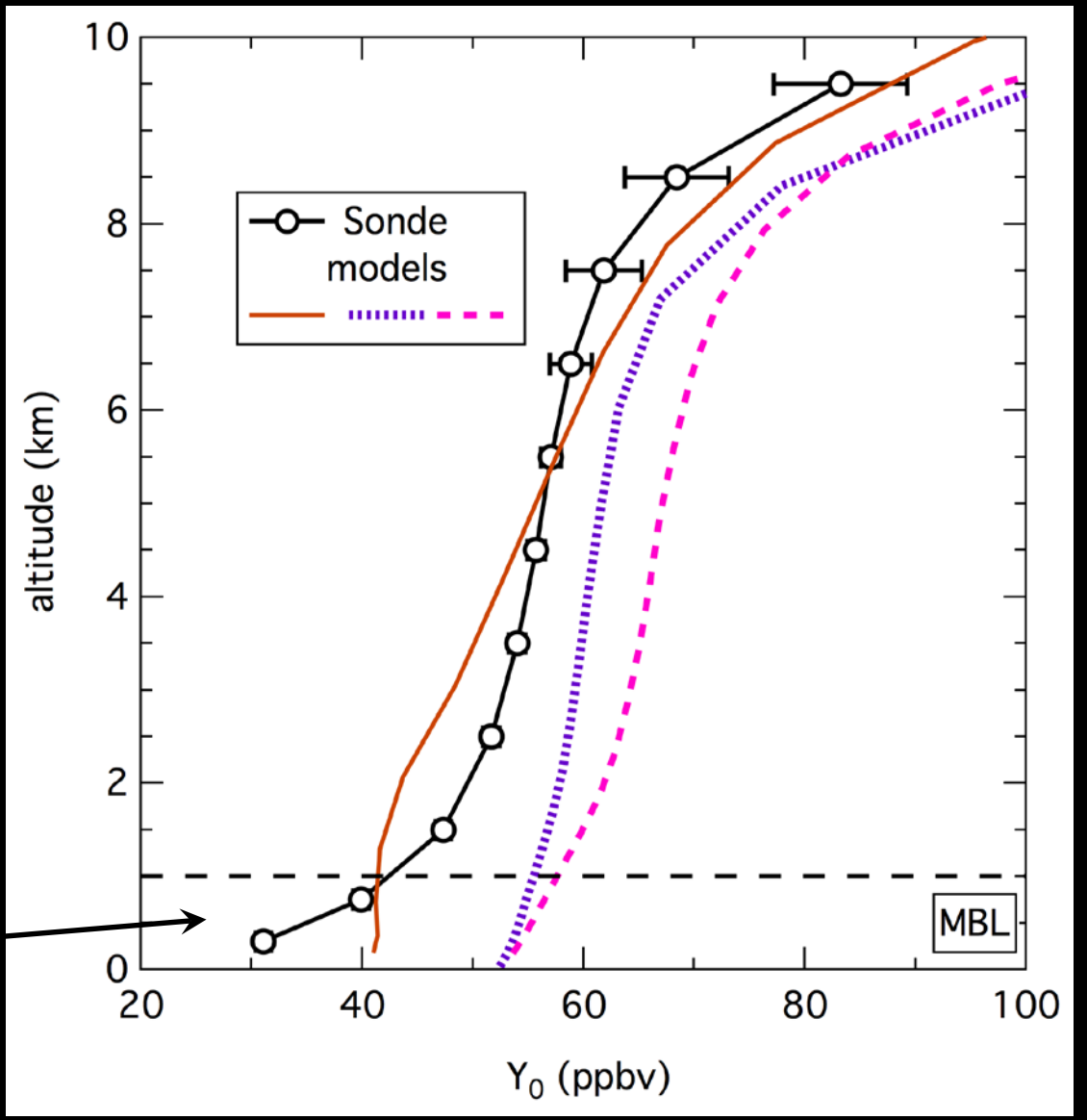
Hypothetical Picture:

Model results do not fit this hypothetical picture:

No strong shift in seasonal cycle above MBL

No sharp reduction in O_3 within MBL

O_3 sharply reduced in MBL



Quantify and Compare measurements and models

Altitude dependence of seasonal cycles

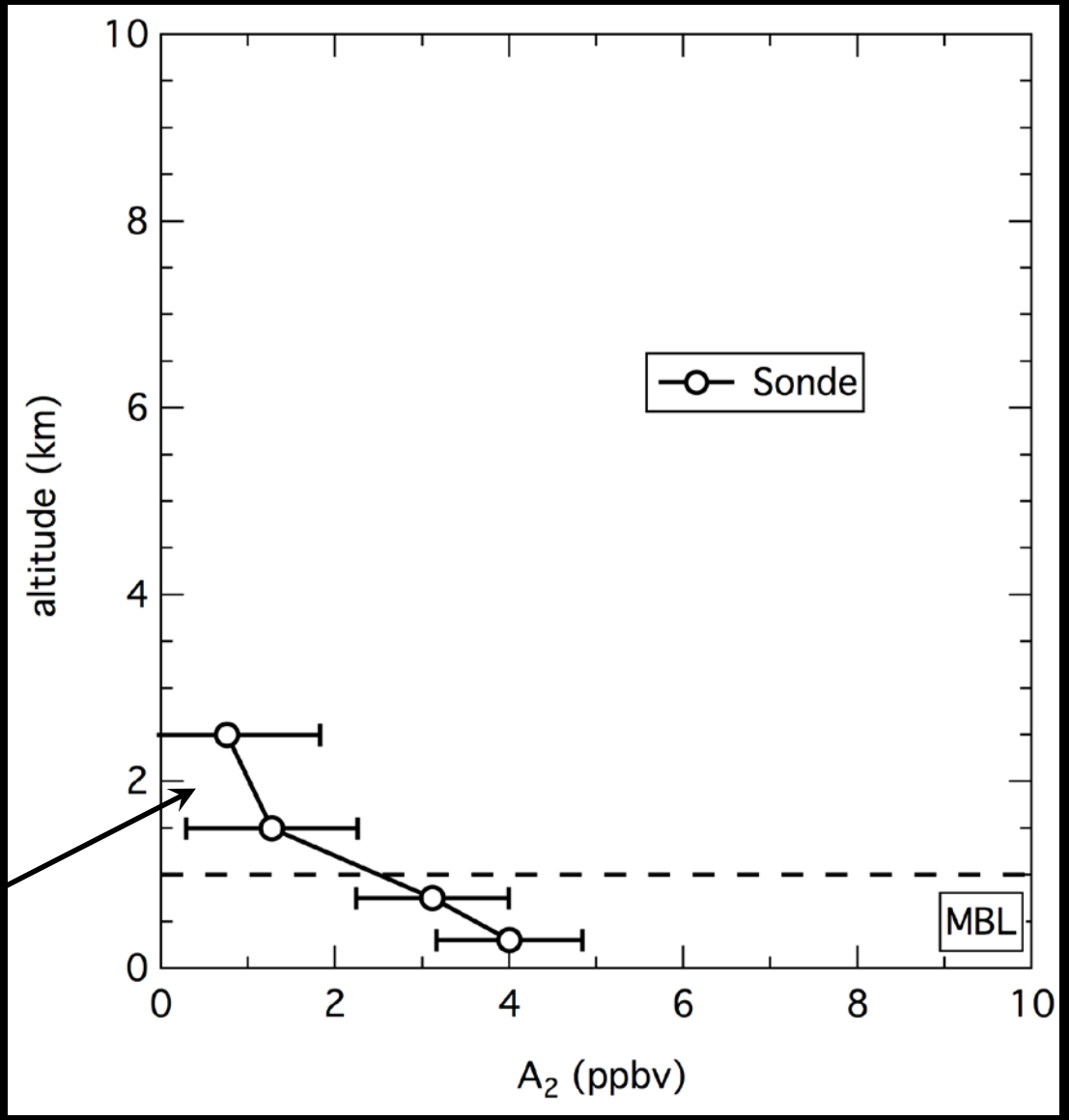
Hypothetical Picture:

Model results do not fit this hypothetical picture

No strong shift in seasonal cycle above MBL

No sharp reduction in O_3 within MBL

2nd harmonic confined to MBL

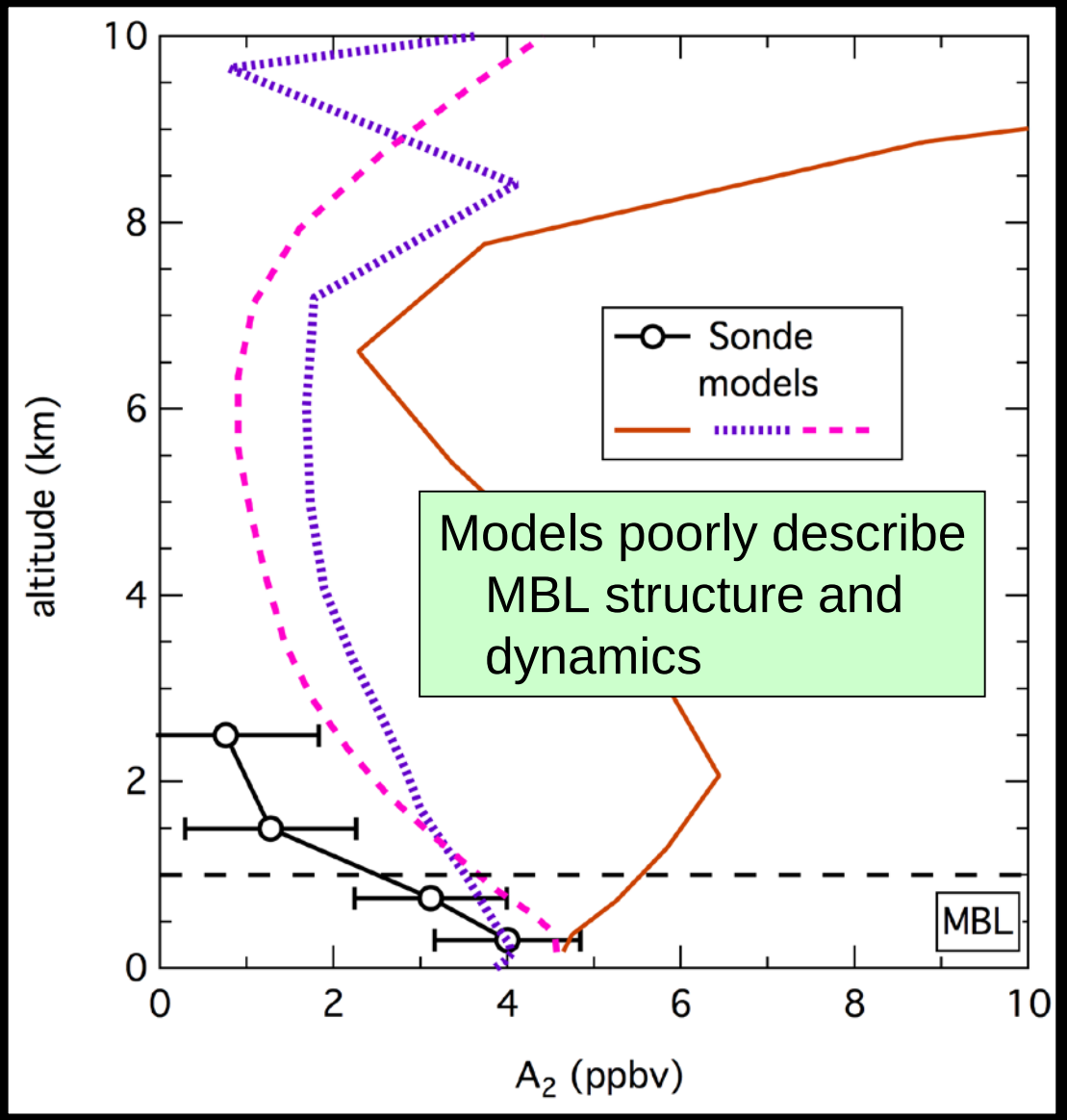


Quantify and compare measured and modeled

Altitude dependence of seasonal cycles

Hypothetical Picture:

- Model results do not fit this hypothetical picture
- No strong shift in seasonal cycle above MBL
- No sharp reduction in O_3 within MBL
- 2nd harmonic term of seasonal cycle present throughout troposphere



Summary:

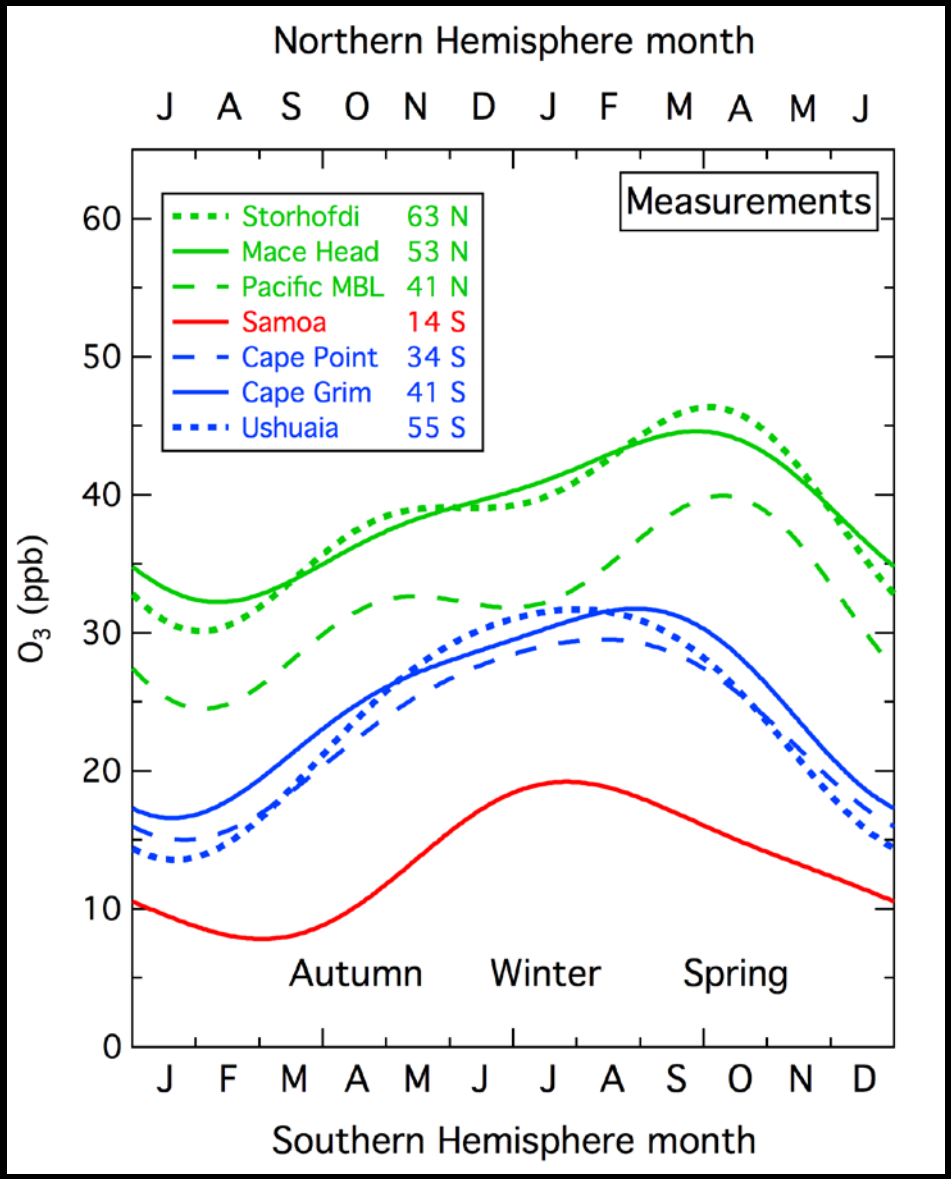
A 2nd harmonic term is a ubiquitous feature of the O_3 seasonal cycle in the MBL – measurements and models – but absent in free troposphere

Models (at least these 3 CCMs) overestimate MBL O_3 by 30-65%, and fail to reproduce other aspects of the seasonal cycles

Models poorly describe marine boundary layer dynamics

Quantify and compare measured and modeled

Seasonal cycles of O_3 in the



All sites have a late winter to early spring maximum and a summer minimum

Highest ozone at northern mid-latitudes, lowest in tropics

Fit sine functions to fundamental and 2nd harmonic

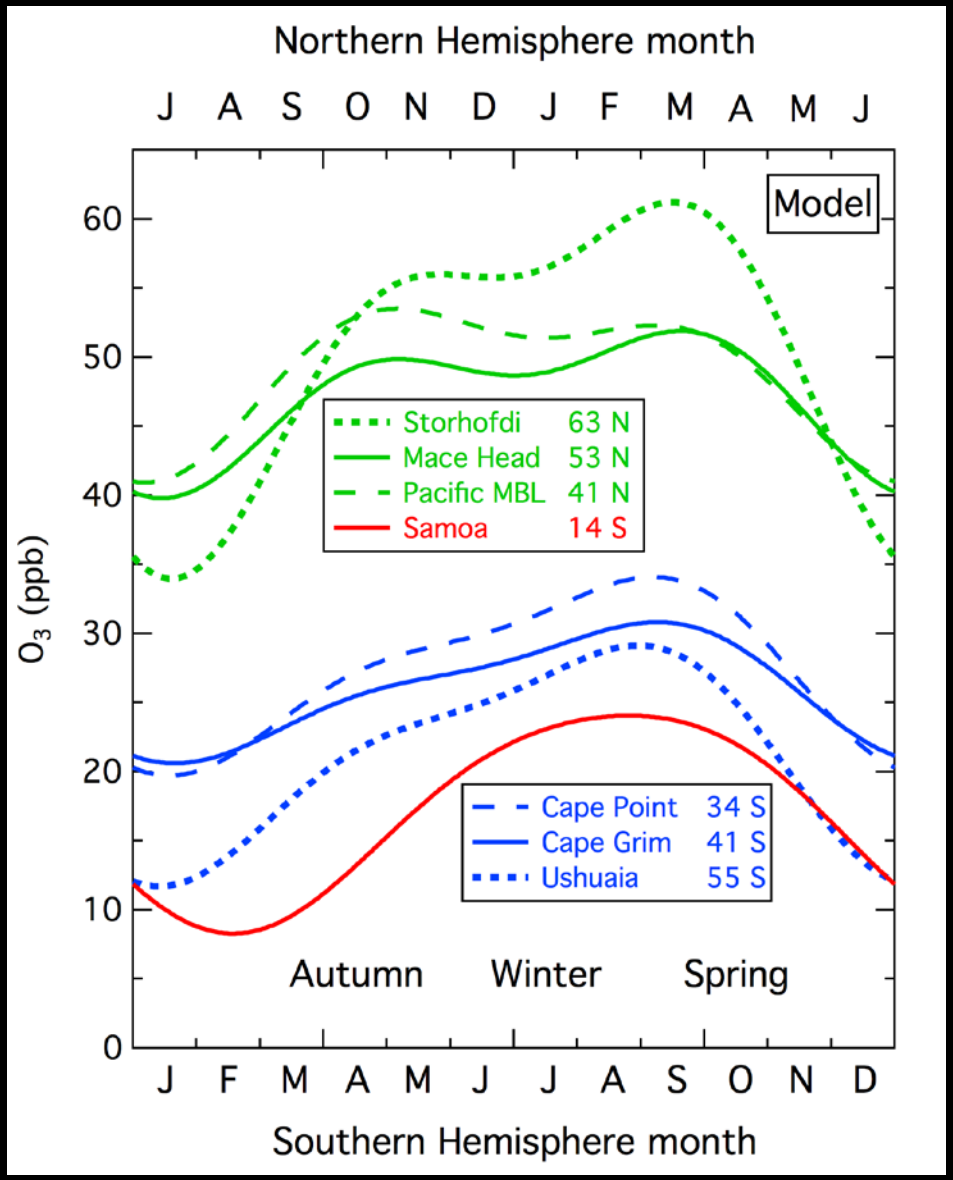
Quantify and Compare measurements and models

Seasonal cycles

All sites have a late winter to early spring maximum and a summer minimum

Highest ozone at northern mid-latitudes, lowest in tropics

Models reproduce seasonal cycles reasonably well in the marine boundary layer



Fit sine functions to fundamental and 2nd harmonic