Boundary Layer Depth Estimation for Chemical Box Model Applications at the South Pole using Short-Tower Meteorological Measurements

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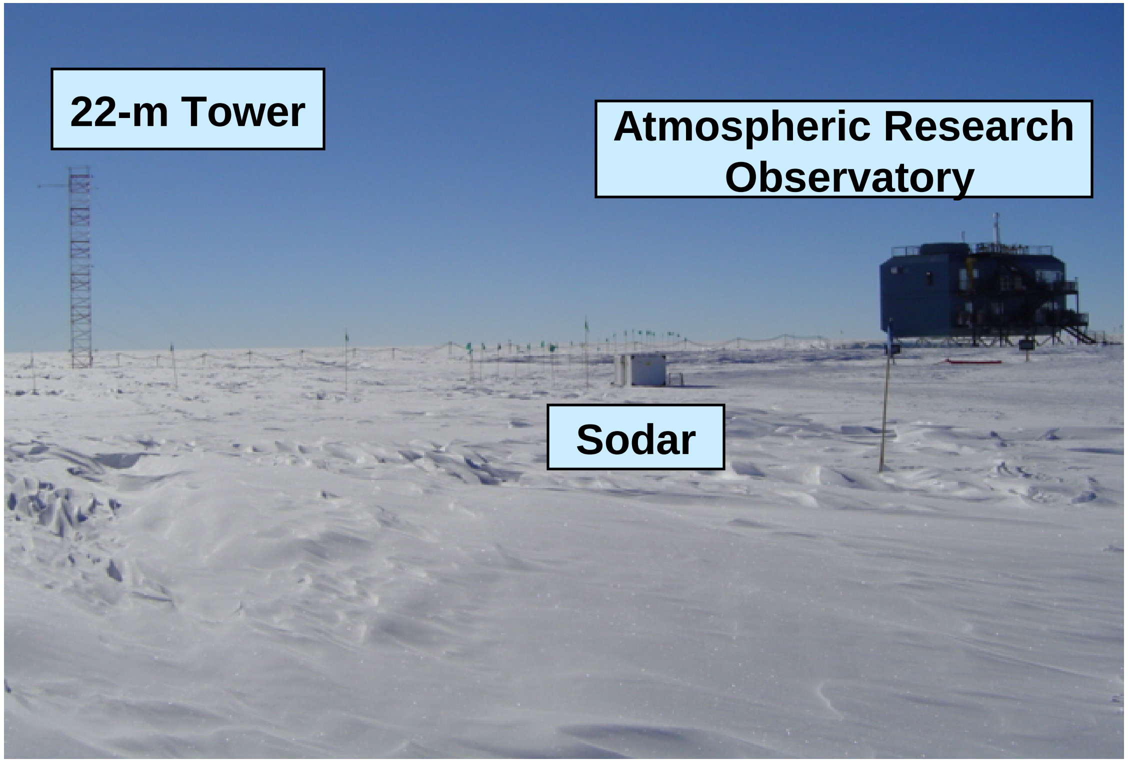

Key Early Results:

South Pole NO_x Chemistry: an assessment of factors controlling variability and absolute levels

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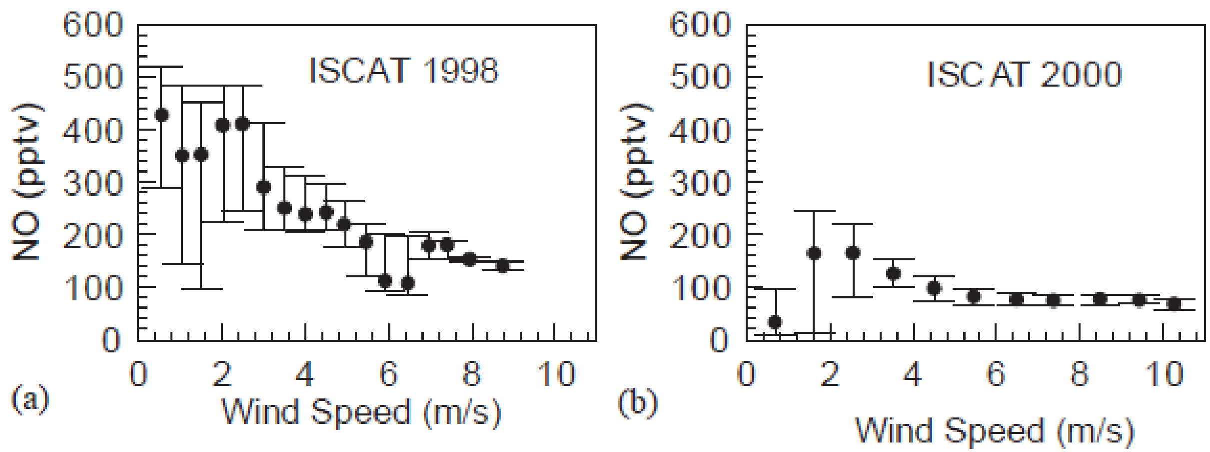
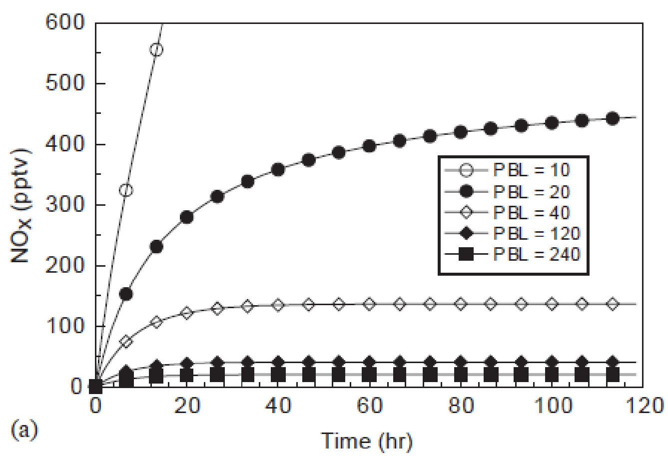
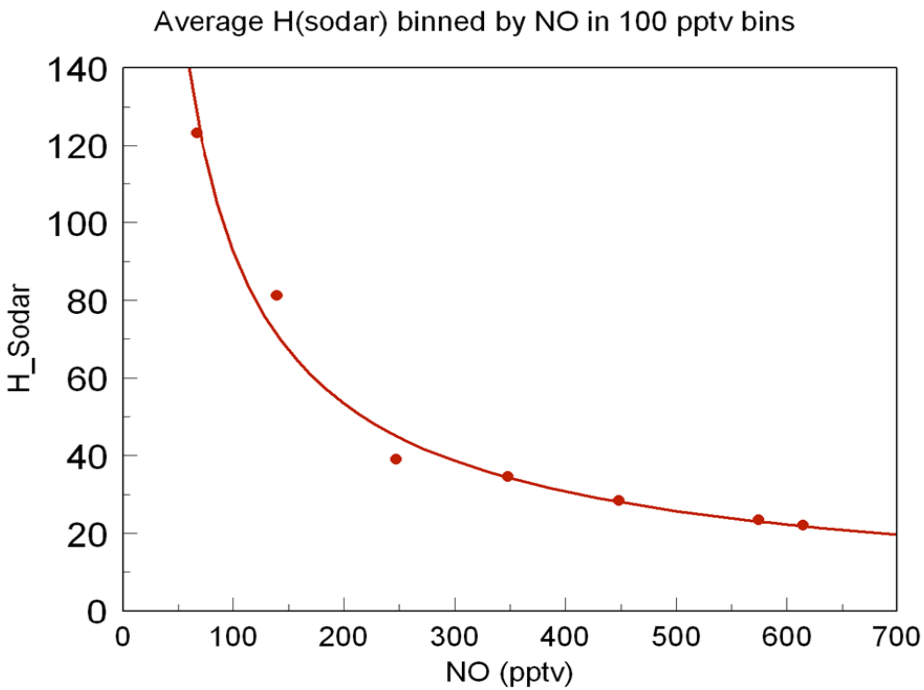




High NO concentrations related to

- Lower wind speeds
- Shallow boundary layers

2003 Field Experiment: first use of a sodar to detect boundary layer depths



The result was a well-behaved relationship between boundary layer depth and NO.

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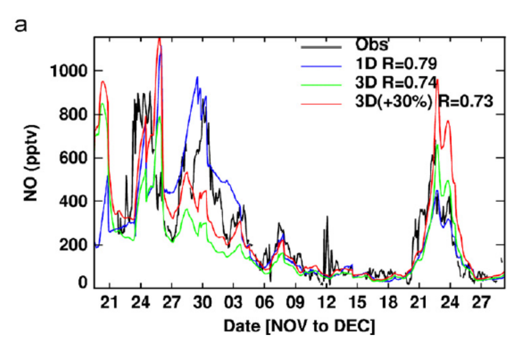
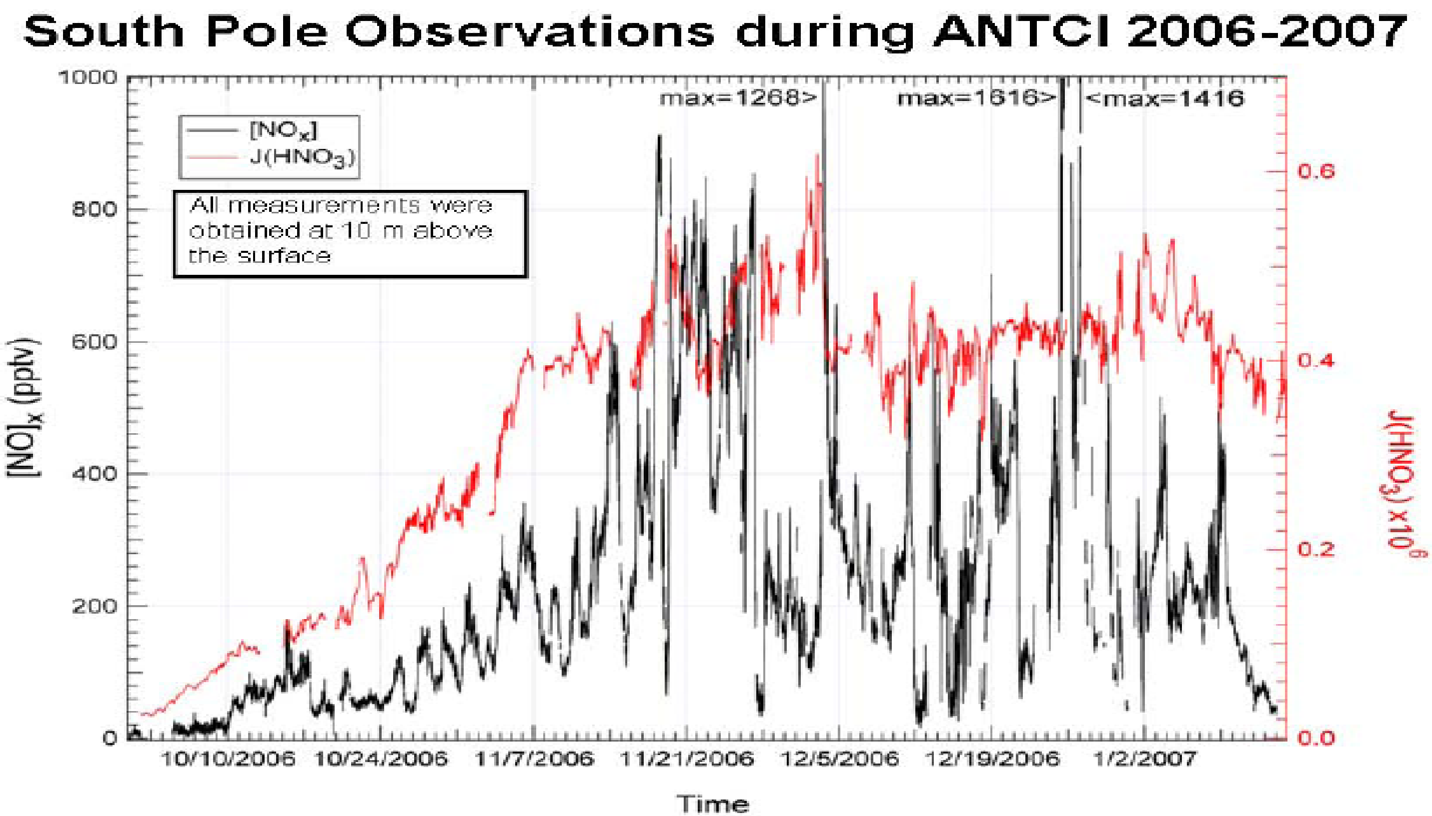
A study of boundary layer behavior associated with high NO concentrations at the South Pole using a minisodar, tethered balloon, and sonic anemometer

W. Neff[a,*], D. Helmig[b], A. Grachev[c], D. Davis[d]

These direct BL depth measurements were then used to guide/test atmospheric chemistry models to estimate surface emission rates.
-- Wang et al., Atmos. Env., 2008



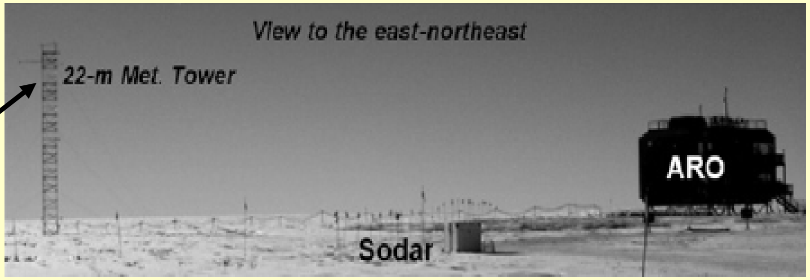
In 2006-2007, a sunrise-to-sunset measurement program was carried out, but without direct BL measurements.
This presented a problem for atmospheric chemistry box-model calculations because there was no knowledge of the height of the "box."



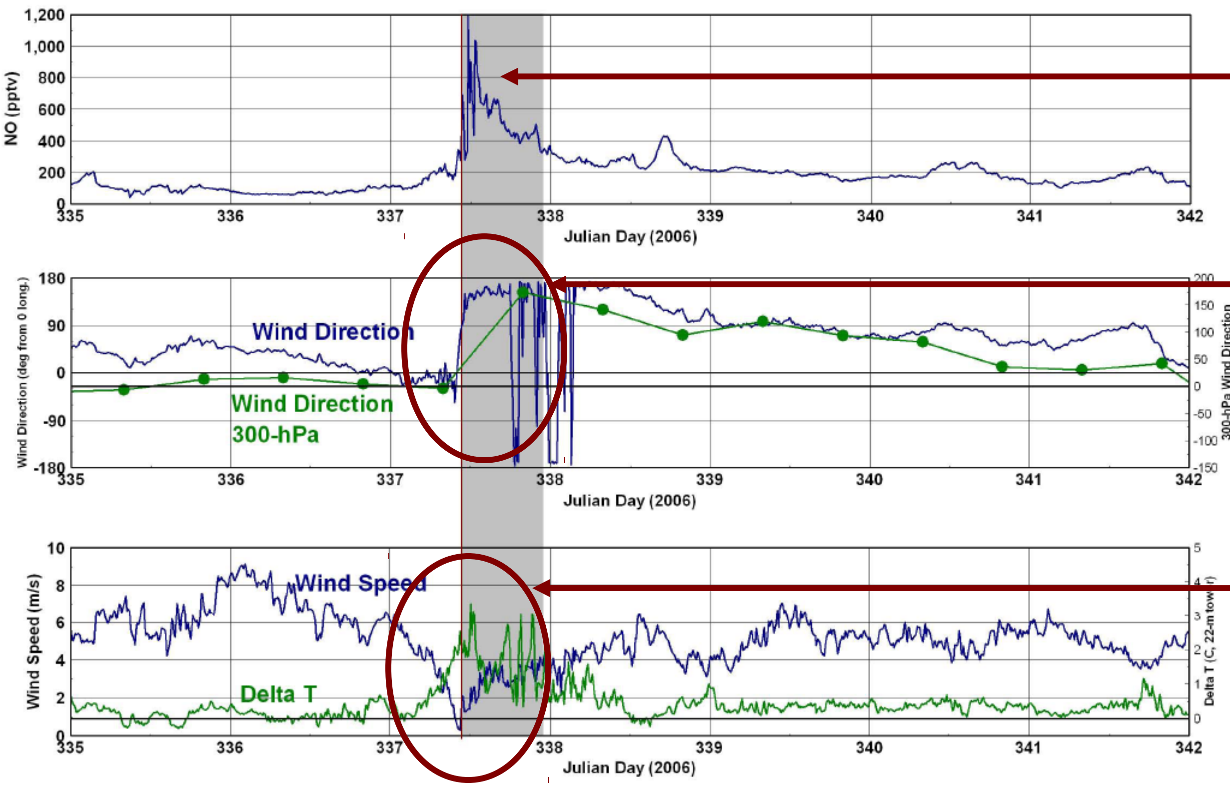
Approach: Use observed BL depth data and standard meteorological observations obtained at the South Pole with multiple linear regression.

Potential data:

- Wind Speed
- Wind Direction
- Delta T over 22-m tower
- Cloud Fraction
- Delta T across surface based inversion from twice-a-day rawinsonde
- Wind Direction aloft



Case Discussion: Role of wind direction at the surface and aloft



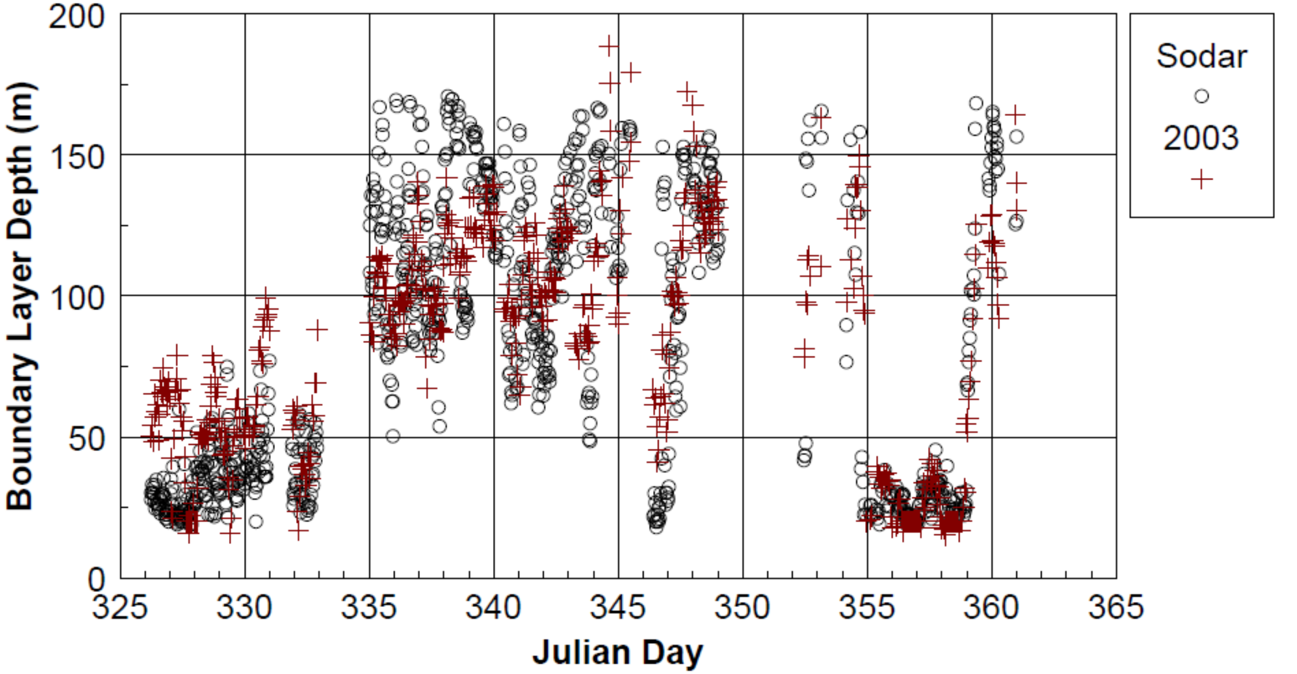
Time (Julian Days)

- Increase in NO
- Surface wind shift to southeast (and aloft)
- Wind speed drops and Delta T_{tower} increases

Multiple linear regression fit for ANTCI 2003. Table shows individual r^2 for each variable with sodar-derived BL depth. Daily cloud fraction was neglected in final results: $r^2 = 0.67$

$$BLD = -27.2 + 21.2 * WS + 0.31 * WD - 16.2 * \text{Delta } T_{\textbf{Tower}} - 4.2 * (\text{Delta } T_{\textbf{Bulk}})$$

	r^2
Wind Speed	0.56
Wind Direction	0.10
Delta T (22m)	0.32
Cloud Fraction	0.03
Bulk Delta T	0.14



Comparison with another data set and inclusion of early spring data: 1993 Sodar deployment at the South Pole.

- During 1993, a Doppler sodar operated concurrently with a 915-MHz radar wind profiler. Because of the Doppler mode, the boundary layer resolution was degraded resulting in boundary layer depths appearing about 15 m deeper than actual.
- The digital amplitude data were recorded with less dynamic range than more recent instruments so routine processing was not possible.
- For these reasons, the depth data was obtained manually for October and November 1993 with 1-h resolution.
- For 1993, wind speed and direction were available along with tower delta-T measurements.
- These meteorological data were used to estimate BL depths (using a reduced algorithm fit to 2003 data) to compare with observations as well as obtaining a best fit 1993 algorithm.

Evaluation with 1993 data:

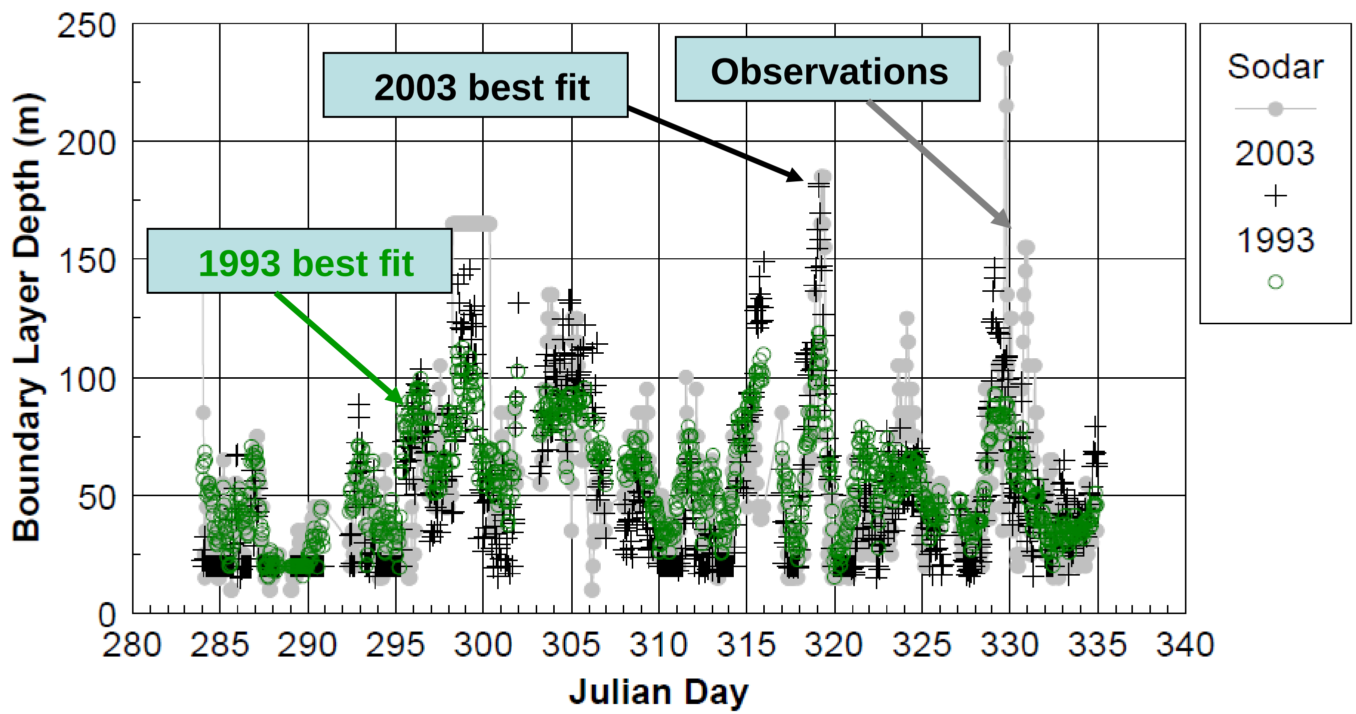
1993 Best fit:

BLD=+20.7+ 9.6*WS -0.07*WD -4.8*Delta T_{Tower}- 0.58*(Delta T_{Bulk})

2003 Best fit:

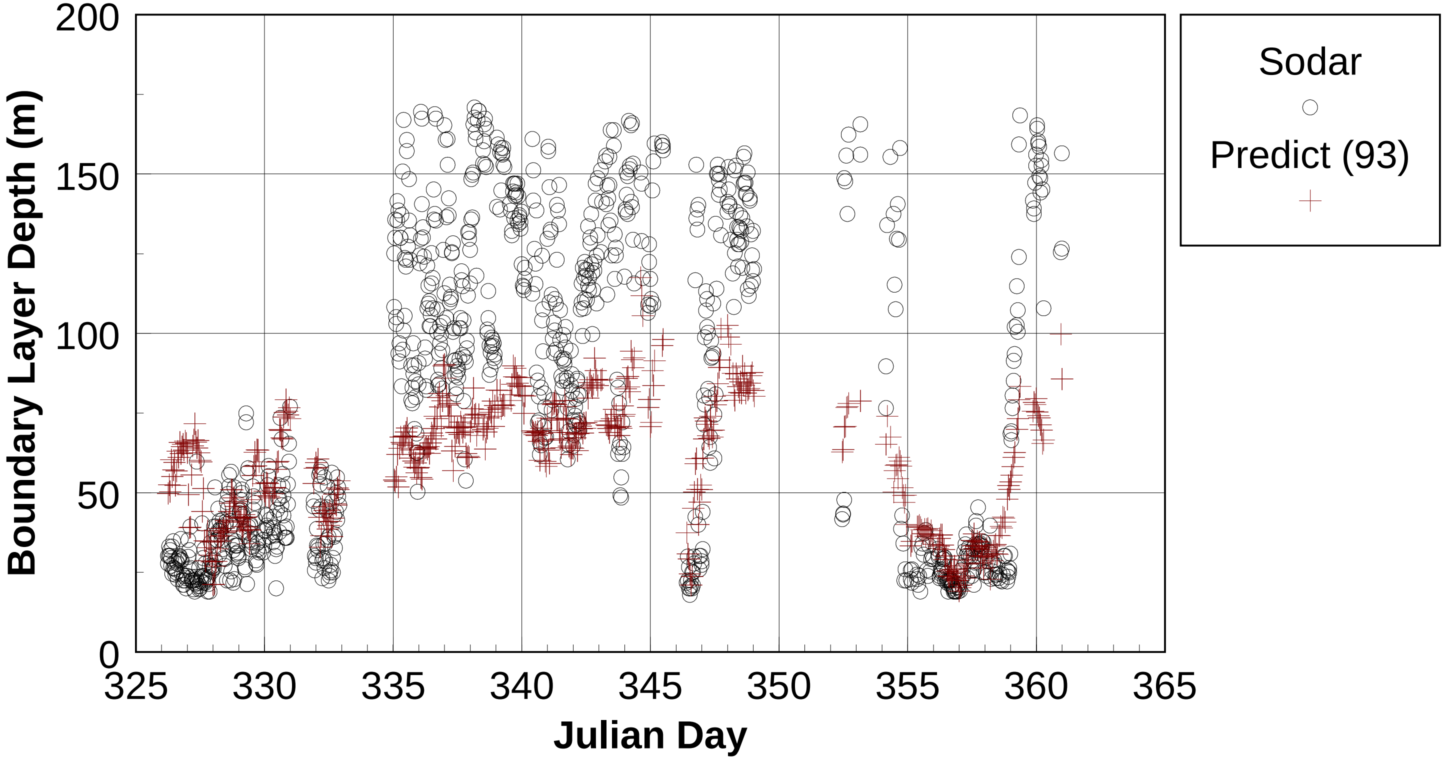
BLD=-27.2+ 21.2*WS +0.31*WD -16.2*Delta T_{Tower} - 4.2*(Delta T_{Bulk})

	r^2
Wind Speed	0.30
Wind Direction	0.10
Delta T (22m)	0.16
Cloud Fraction	0.03
Bulk Delta T	0.02



How well does the 1993 best fit work with 2003 data?

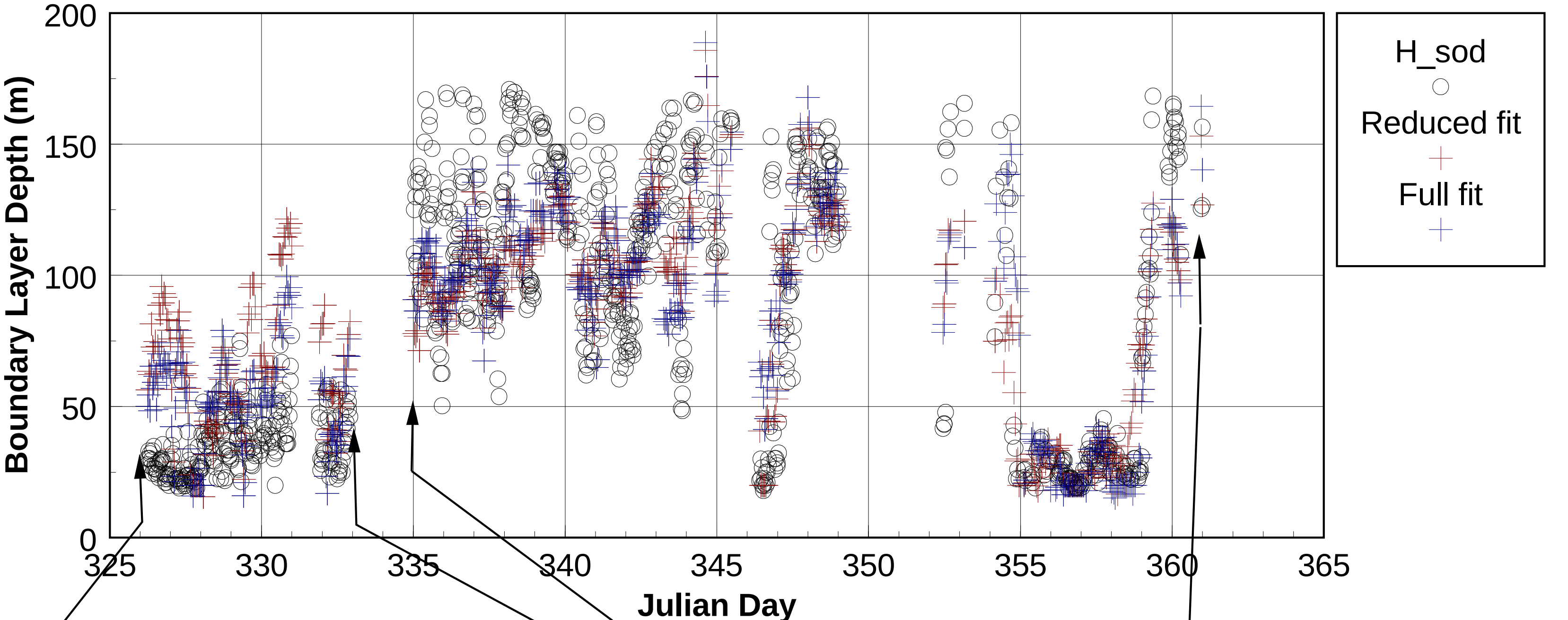
Result: 1993 best fit works well with the shallow boundary layer periods in 2003 but not for the deeper (higher wind) boundary layer regimes.



Summary this far:

- The 2003 analysis showed the best linear regression fit (r^2=0.67).
- The linear regression fit for 1993 (r^2=0.37) and the 2003 best-fit applied to 1993 (r^2=0.32) both account for only about a third of the variance.
- Analyses from 1993 do not extend well to 2003 for deeper BL depths: in part, this is due to improved quality of data during 2003 and the range of BL characteristics observed.

We carried out a further reduction in the analysis using only wind speed, direction and near-surface temperature difference (over 22 m) as shown below ("Reduced fit") and then compared the results that also included the daily inversion strength from rawinsonde data ("Full fit").



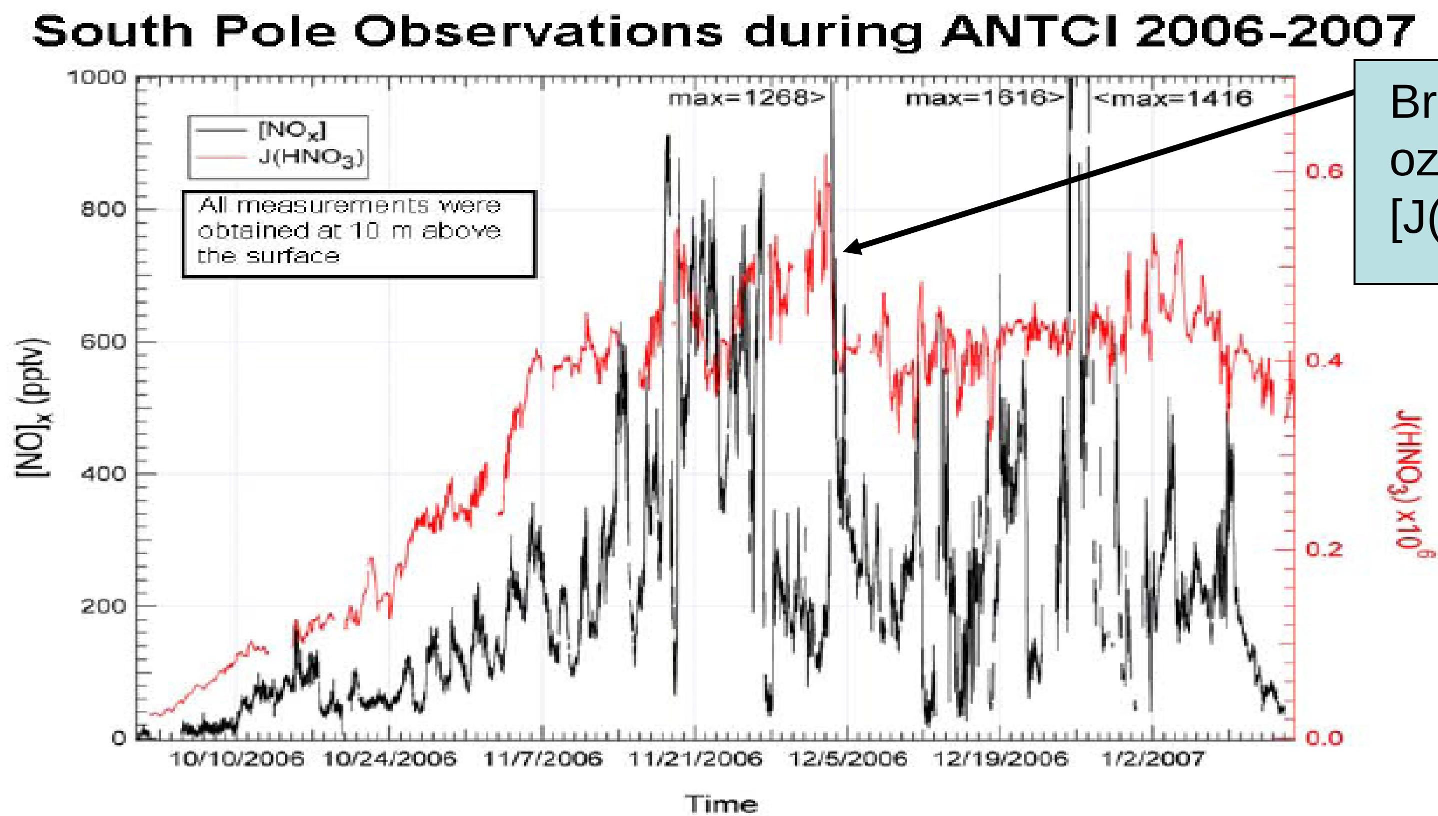
Full fit - Sodar: +17m
Reduced fit - Sodar: +27 m

Full fit - Sodar: -4.8m
Reduced fit - Sodar: -6.1m

Using the reduced set of parameters produces a slight overestimate in early period.

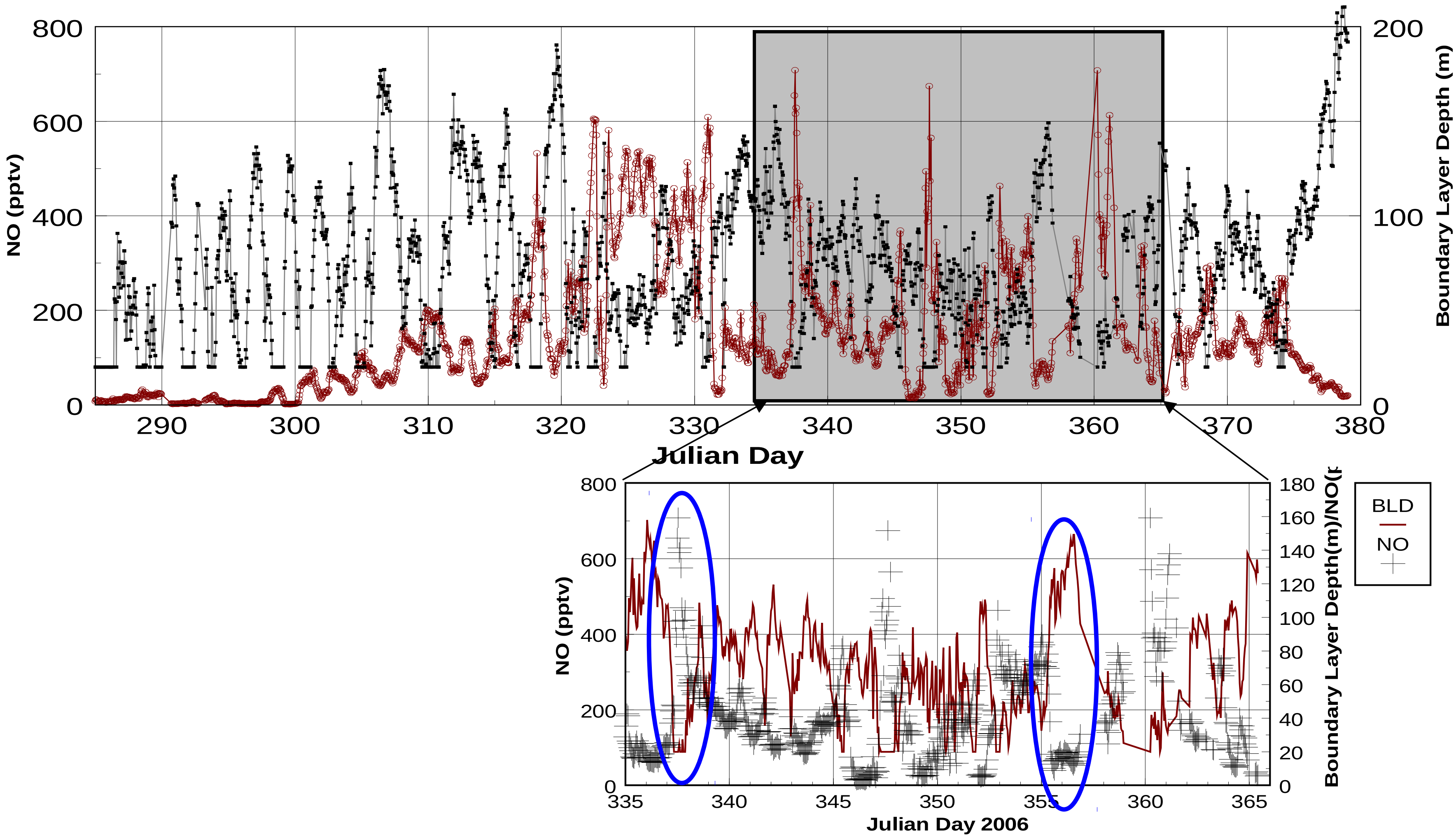
Next step was to apply to 2006-2007 data:

- $J(HNO_3)$ measures the rate of photoloysis of snow nitrate (dependent on both sun elevation and total column ozone)
- Note the large variability of NOx relative to radiative forcing – due to effects of meteorology.

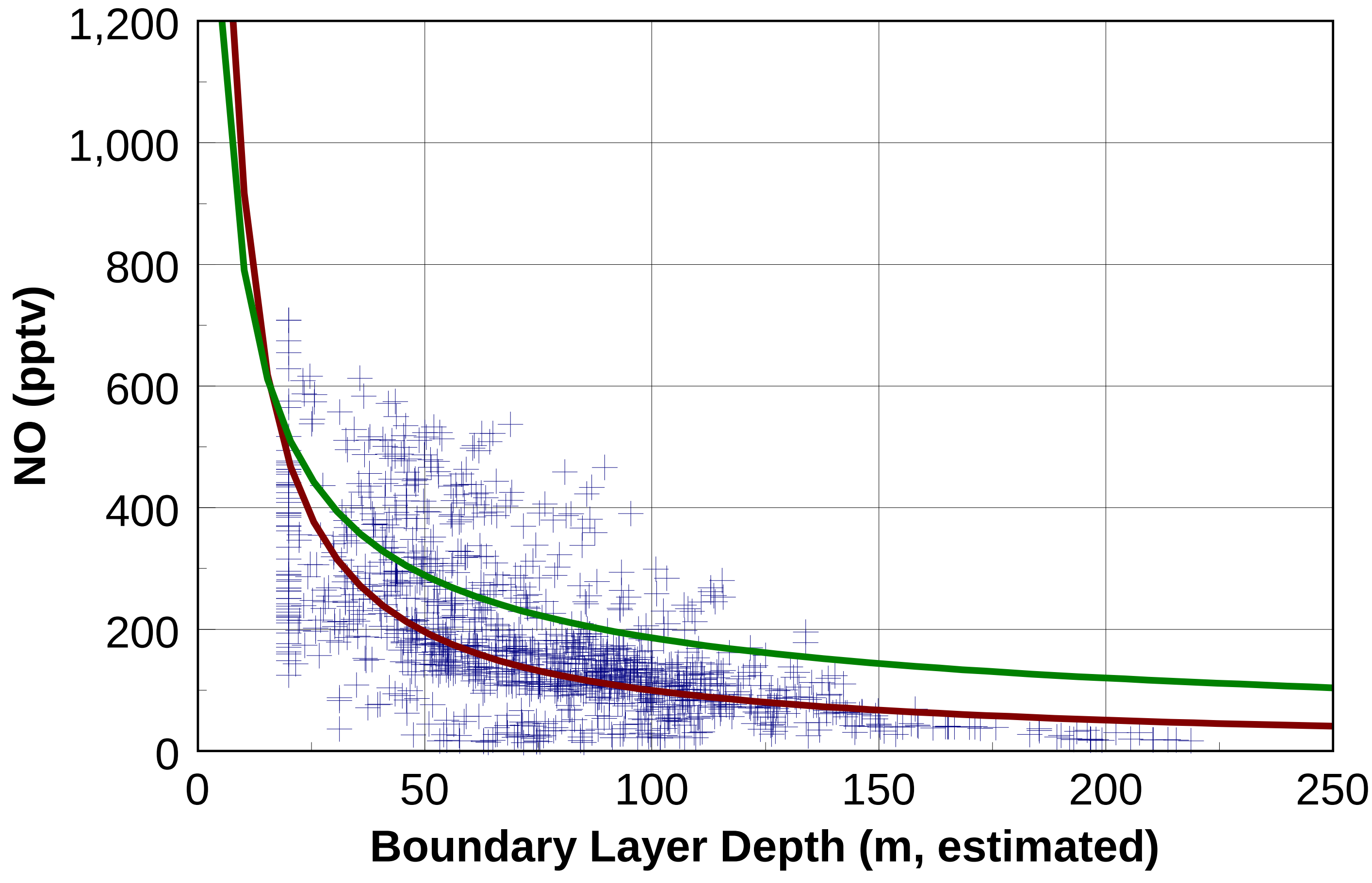


Breakup of ozone hole [$J(HNO_3)$]

Time series of predicted BL depth (black) and observed NO (red) are shown (below) for October, November and December using 1-hr average data. Note the effect of increasing sunlight on the production of NO and the effect of shallower BL depths even in October. (Note the difference in vertical scales.)



Summary of behavior of [NO] as a function of boundary layer depth estimated from meteorological observations with verification (2003-power law fit: green line) and those estimated for 2006 without verification (red line/blue markers).



Next steps:

- Carry out chemical box model calculations and compare with observations.
- Major concern is the uncertainty in the surface flux of NOx from the snow surface (initial results suggest factor of five differences from those predicted by current chemical models).