Estimating Boundary Layer Depth at the South Pole Using Only Standard Meteorological Data to use in the Interpretation of Nitric Acid Concentrations

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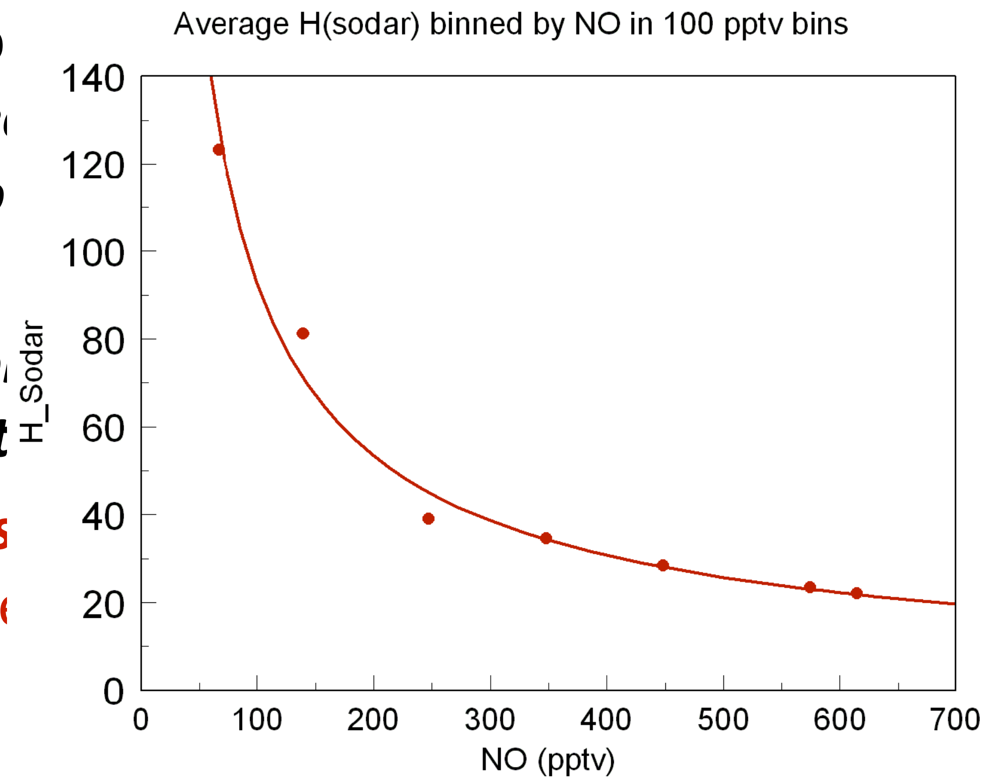
Based on a paper "**The Meteorology of High-NO_X Episodes at the South Pole**" by Neff and Davis (in preparation)

Background

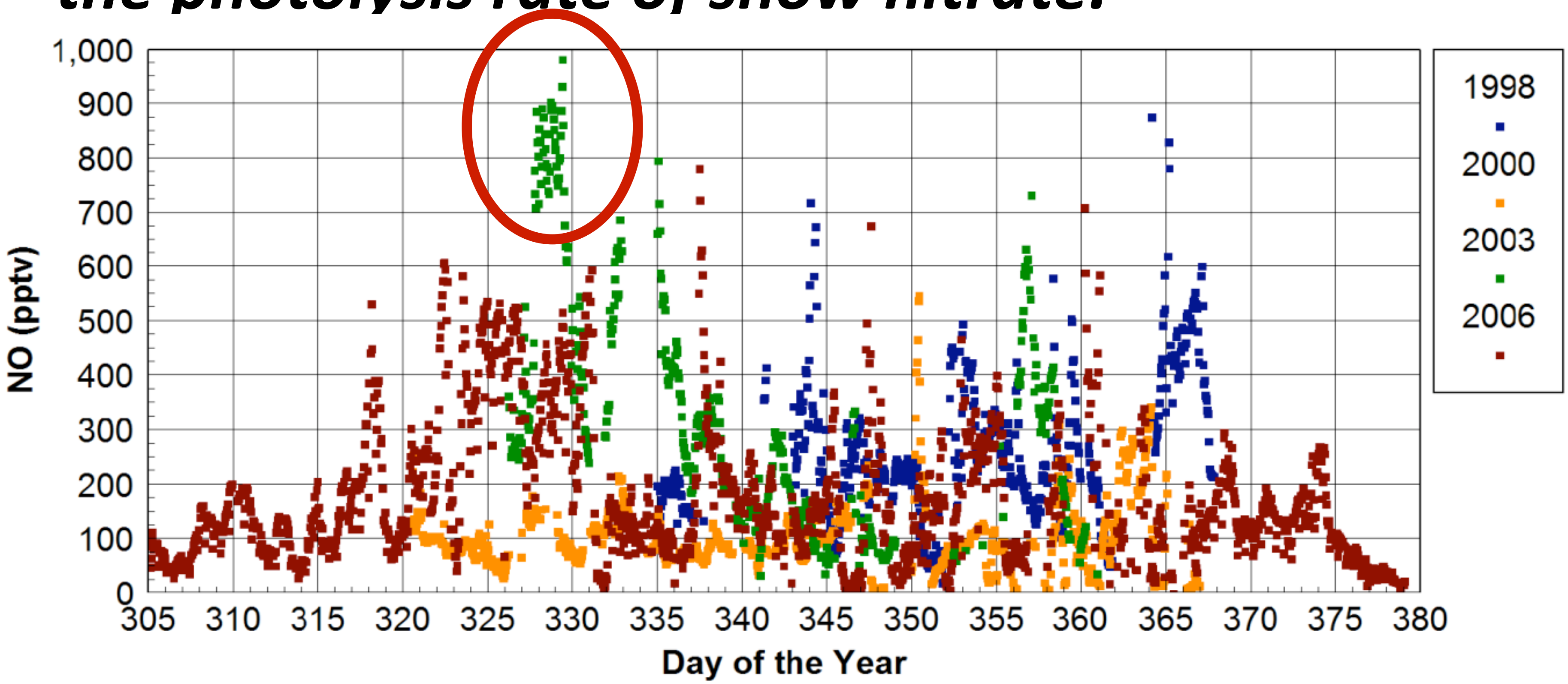
- ***A series of atmospheric chemistry experiments were carried out over four years at the South Pole*** primarily during November and December (1998, 2000, 2003, and 2006). These have b chemistry of ***unexpe discovered at the So***
- Based on a chemical ***there would be a no boundary layer dept***
- ***In 2003, a sodar was directly*** and confirm (Neff et al. 2008).



(Neff et al., 2008, *Atmos. Env.*):

Goal

Eliminate meteorological factors so as to isolate key chemical processes related to variability in the photolysis rate of snow nitrate.



What did we have to work with…

- *High resolution sodar data obtained from late November through the end of December 2003. Digital processing allowed a boundary-layer depth (BLD) detection algorithm to be applied.*
- *Coarser resolution Doppler sodar data were obtained in 1993 as part of another NSF Grant (Neff and Carroll). These data required manual scaling from facsimile recordings (5 m resolution) producing a data set from October through December. These data provided a test data set for the 2003 results.*

Two pieces to the analysis:

1) **Determine the influence of meteorology on the NO levels.**
2) **Use multiple linear regression results for BLD that could be applied to a variety of weather regimes.**

Nitric Acid and Meteorology

Use regression analysis (r^2)of each meteorological variable with nitric acid (NO) 1998,2000,2003,2006 to examine dependencies over four experiment seasons

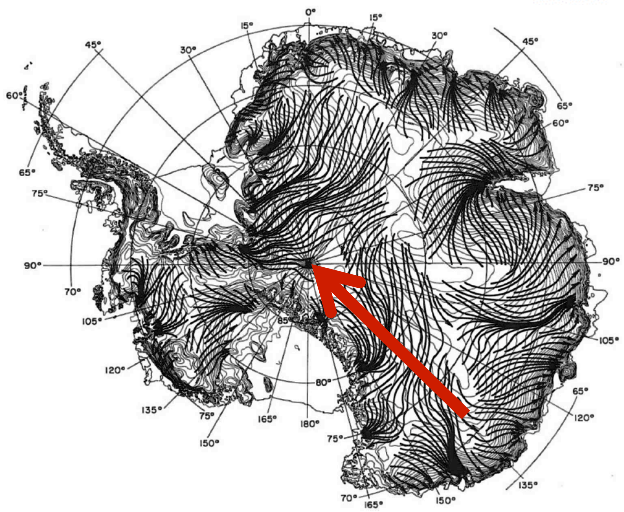
Meteorological variables available:

Wind speed and direction (WS,WD)
Temperature (T)
Temperature difference between 2 and 22 m (ΔT)
Cloud Fraction (CF)
Inversion strength (surface to T max from rawinsonde: ΔT_B)
Sun zenith angle (ZN)
Direct radiation (DR)

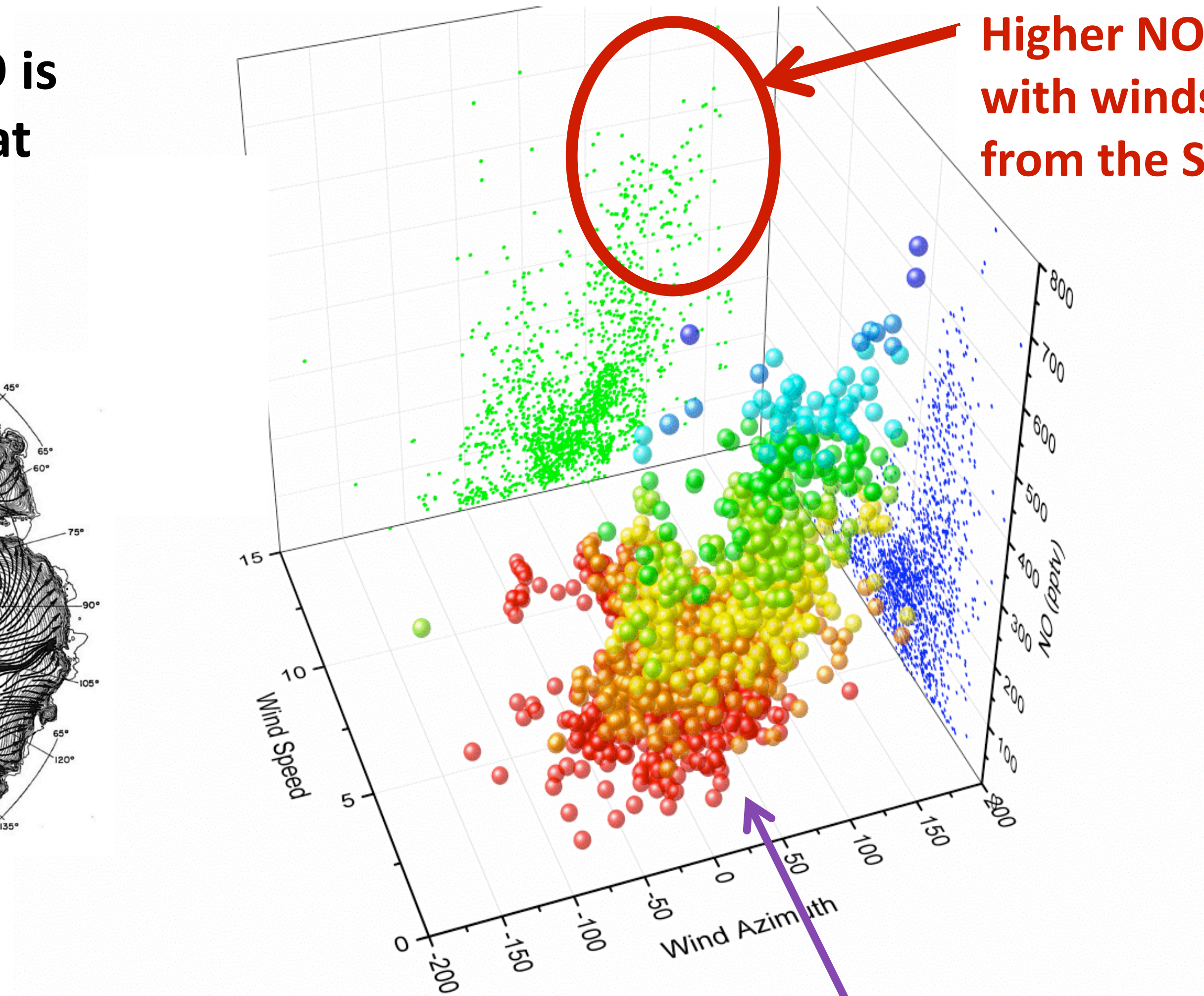
	WS	WD	T	ΔT	CF	ΔT_B	ZN	DR
NO 1998 (JD 335-365)	0.15	0.07	**0.26**	**0.26**	0.15	0.00	0.10	na
NO 2000 (JD 320-366)	0.14	0.16	0.11	**0.41**	0.08	0.01	0.00	na
NO 2003 (JD 326-361)	**0.29**	**0.45**	**0.51**	**0.25**	0.18	**0.34**	**0.37**	0.16
NO 2006 (JD 320-379)	0.18	**0.25**	**0.56**	**0.36**	0.06	**0.34**	0.07	0.00

2006: NO versus WS and WD

Origin of highest NO is perpendicular to that of simple katabatic flow.



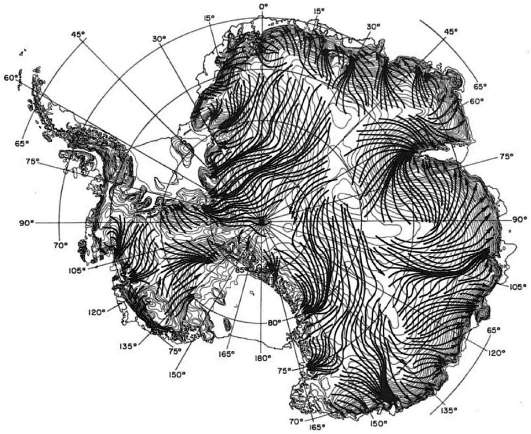
(Parish and Bromwich, 1987: Inversion winds)



Higher NO with winds from the SE

Avg Wind Direction

Large-scale vs. Local Topography



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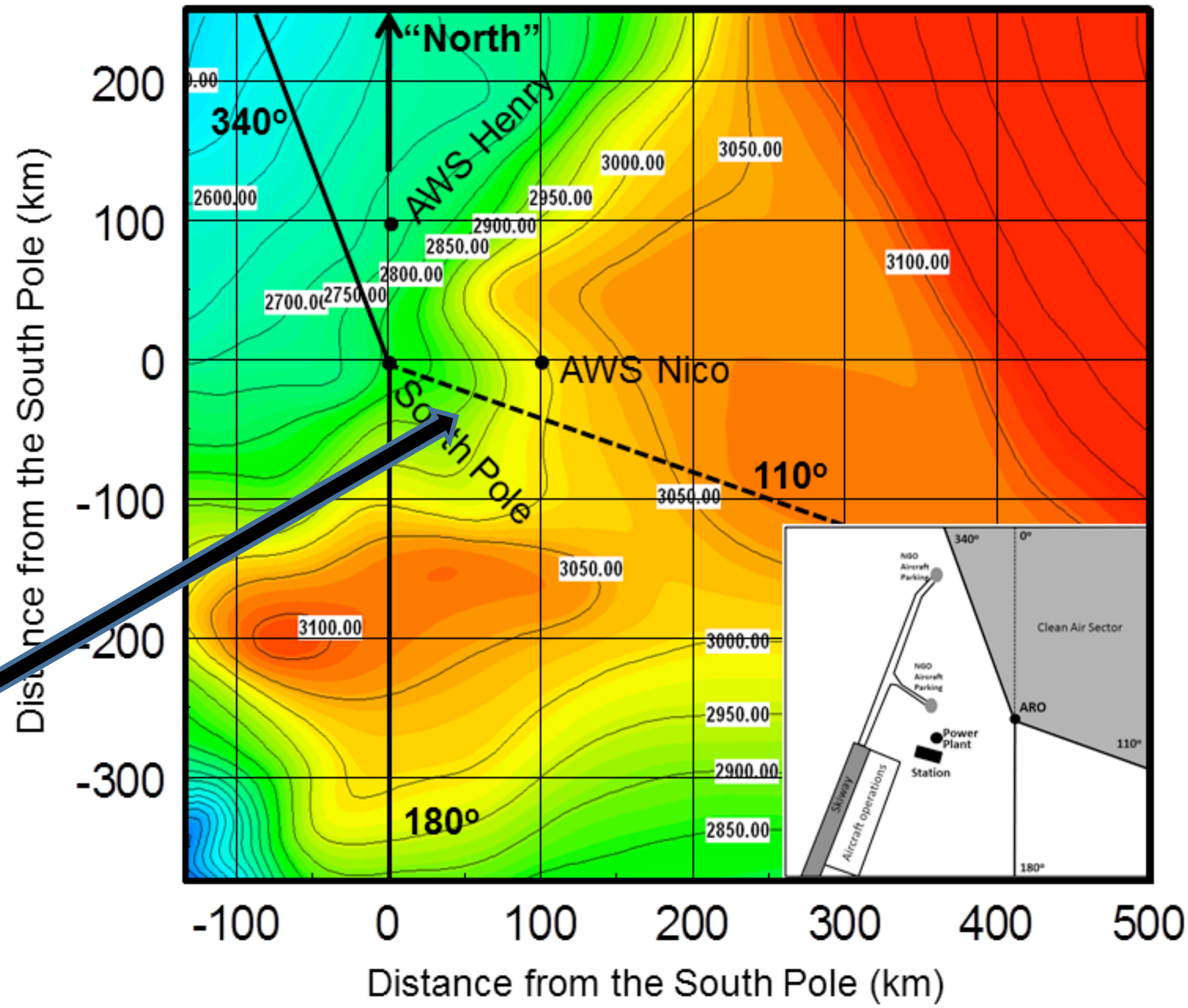
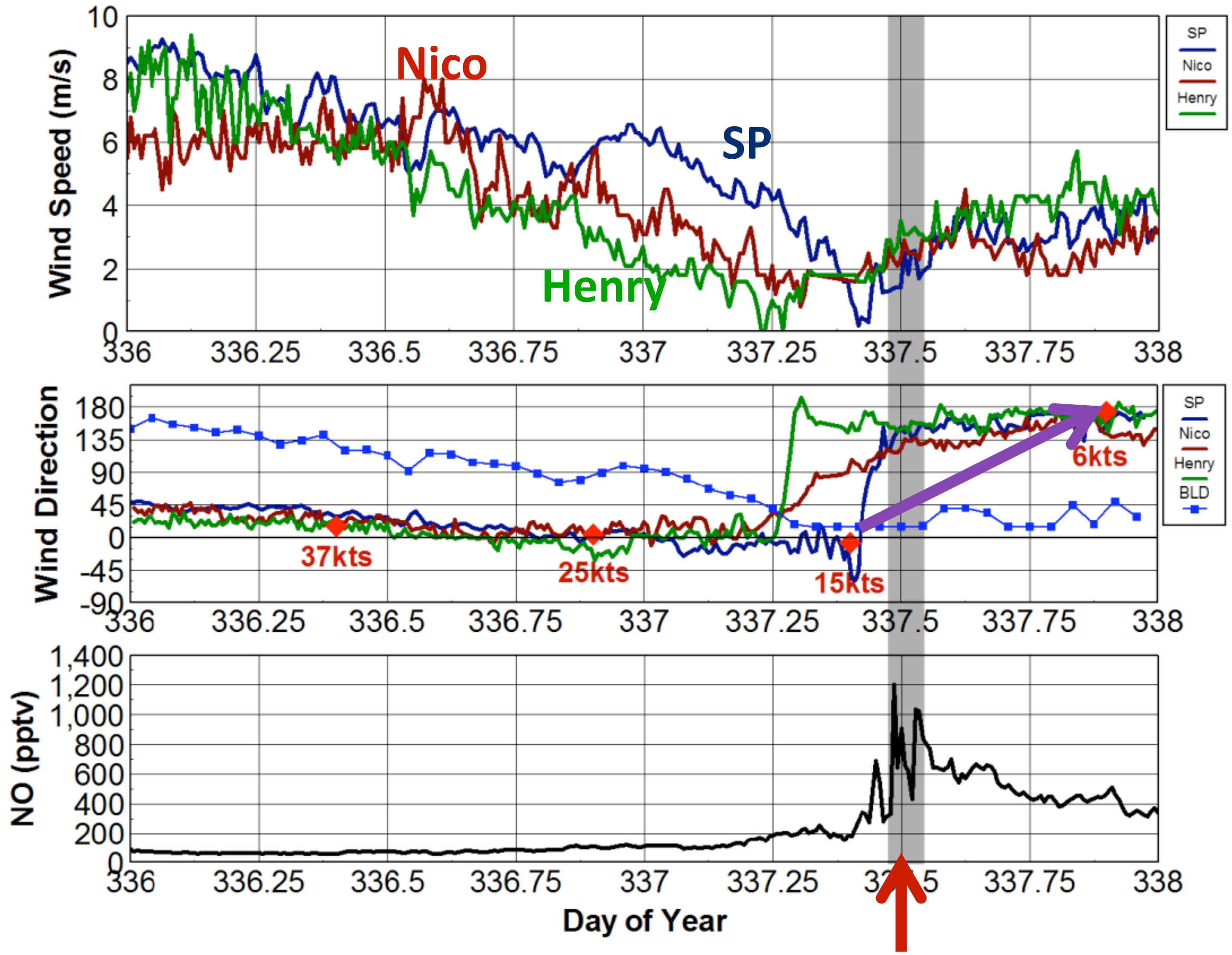


Origin of high-NO air in NW facing basin

2006: Case Study with AWS data



Surface wind speed drops systematically as 300 hPa speed drops

Wind at 300 hPa rotates from 0º to 180º over 12 hours: rapid surface wind shift to SE

High-NO case has a microfrontal appearance

Peak NO with wind from 135º

Summary: NO vs Boundary Layer Effects

- Local topographic effects are a key factor in high NO episodes: easterly to southerly flow bring high concentrations. Winds aloft a major controlling factor?
- Often, high NO episodes often appear as short term excursions (<1 day) and/or have a frontal like character.
- AWS stations show progression of meso-scale boundary layer structures across across the ice sheet. A challenge to modeling?

Meteorological variables vs. BLD 2003

Meteorological variables available:

Wind speed and direction (WS,WD)

Temperature (T)

Temperature difference between 2 and 22 m (ΔT)

Cloud Fraction (CF)

Inversion strength (surface to T max from rawinsonde: ΔT_B)

Sun zenith angle (ZN)

Direct radiation (DR)

Regression (r^2)of each variable with BLD in 2003

	WS	WD	T	ΔT	CF	ΔT_B	ZN	DR
BLD 2003 (JD 326-361)	**0.56**	0.10	**0.25**	**0.32**	0.03	0.14	0.13	0.07

1993 Test Data (sodar)

Regression (r^2) of Meteorological Variables with BLD, October-December, 1993 (r^2>0.2 in red)

	WS	WD	T	ΔT	CF	ΔT_B
OCT	0.25	0.08	0.16	0.28	0.22	0.25
NOV	0.37	0.20	0.02	0.27	0.05	0.00
DEC	0.64	0.01	0.15	0.24	0.01	0.00
JD 326-361	0.61	0.04	0.17	0.24	0.00	0.00

- Greatest dependence on **WS** and **ΔT** all months
- WD dependence greatest in November (transition month)
- October is unusual for **CF** and **ΔT_B**

Regression Results 1993 and 2003

2003 (mid-November-December):

BLD=62.5+18.9*WS +0.24 *WD +2.7*T -18.2 *DT

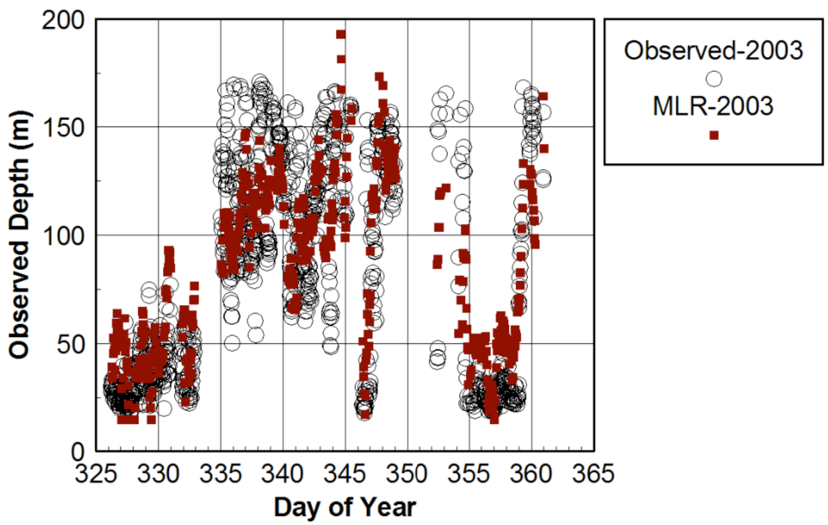
1993 (November and December):

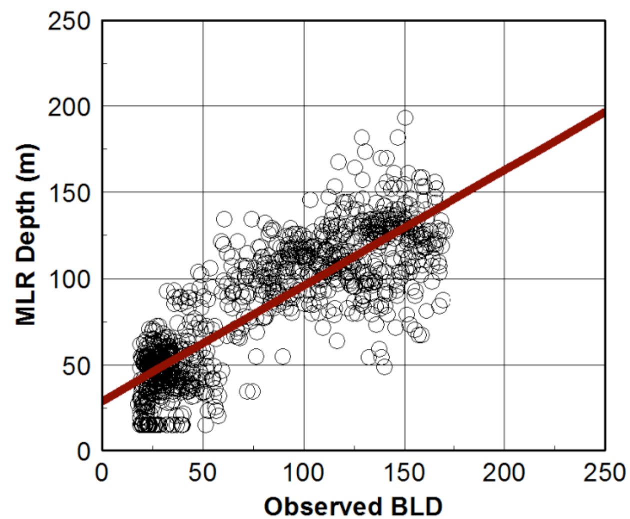
BLD=68.3+16.1*WS -0.04 *WD +2.3*T -10.0 *DT

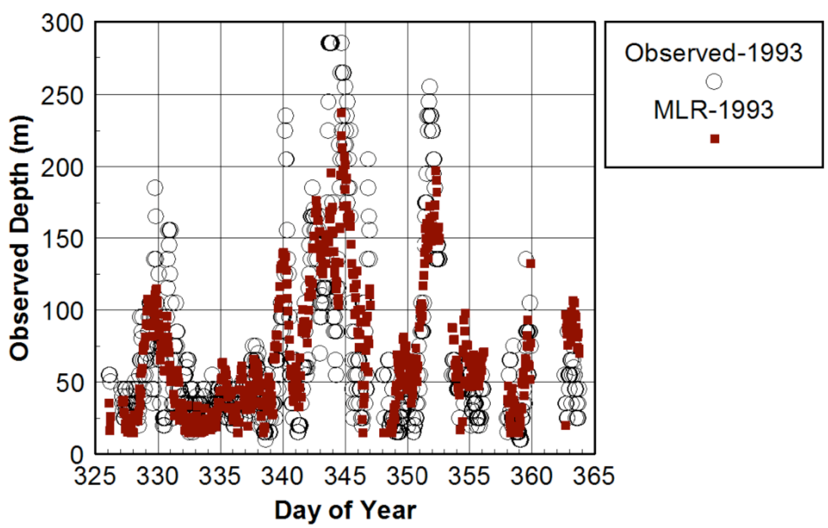
Note: Increasing wind direction normally associated with stronger surface inversion: effects can cancel.

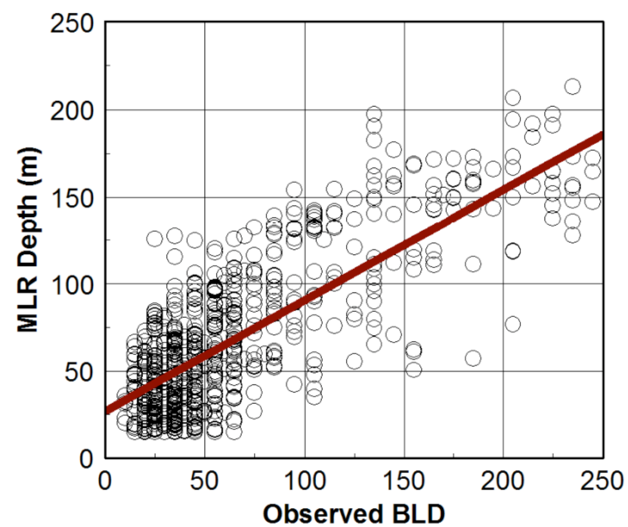
Multiple Linear Regression results for both 1993 and 2003 are consistent in dependence on the constant, WS, and T.
Difference in dependence in WD is probably due to Nov 1993 which had the highest correlation between BLD and WD.

MLR fits for 2003 and 1993 with observed data in those years:

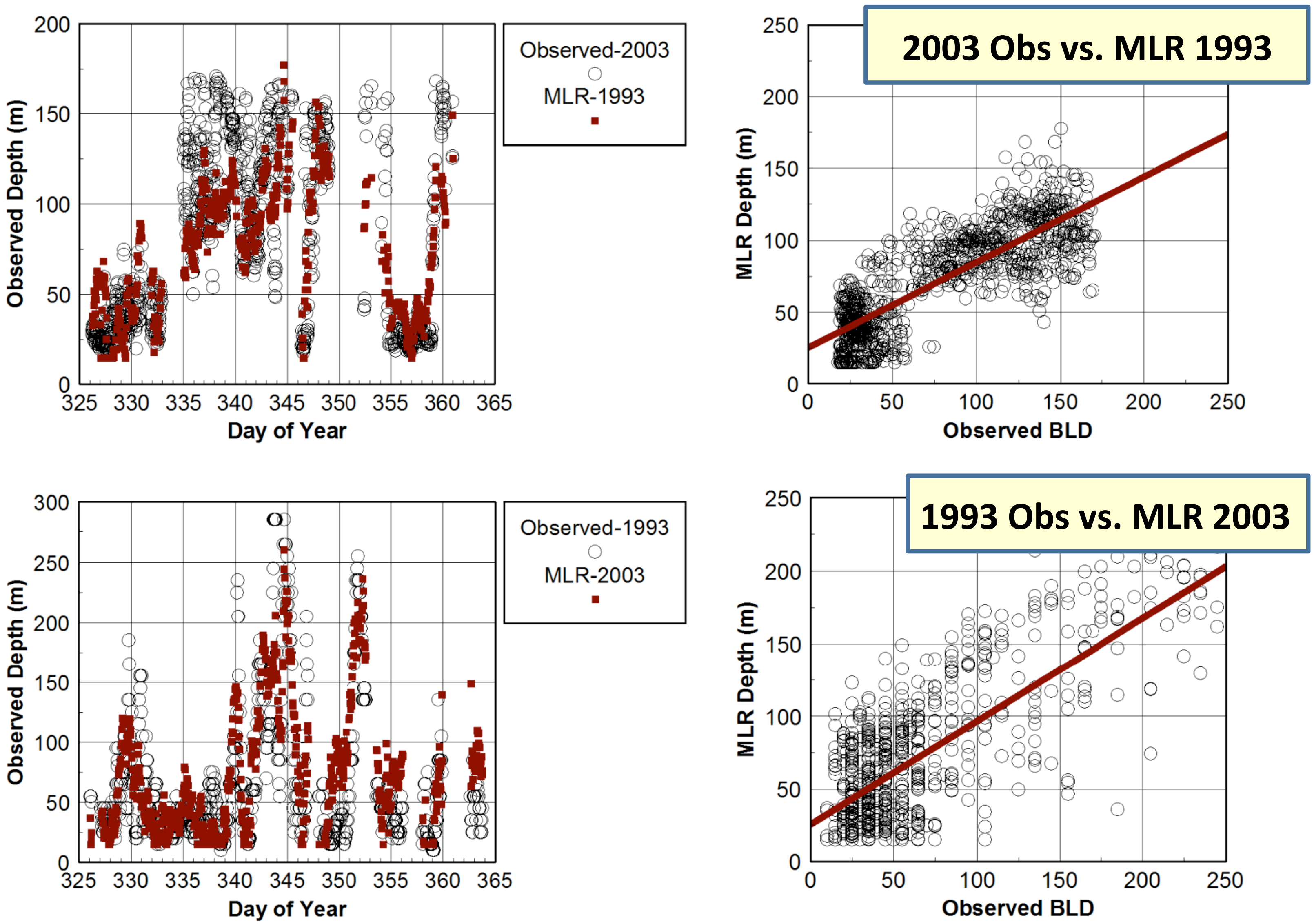




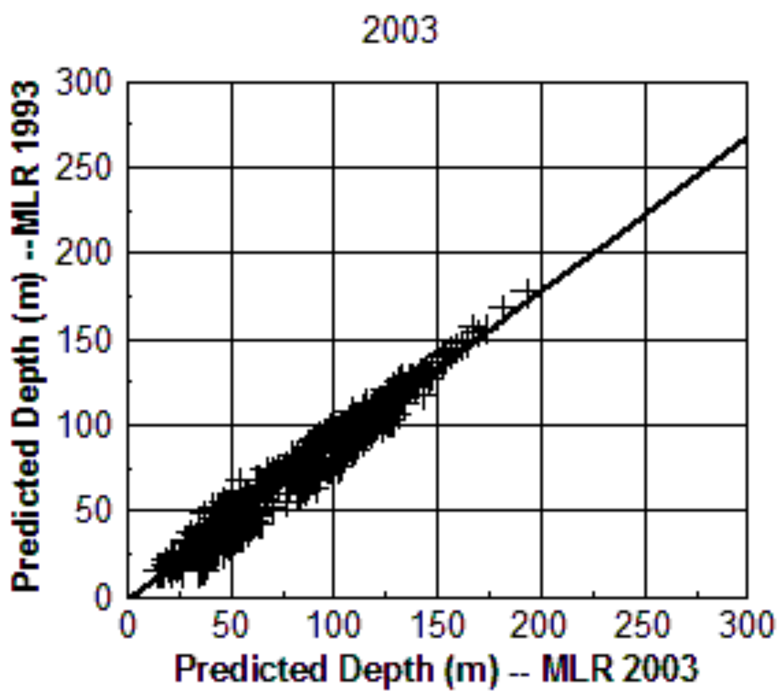


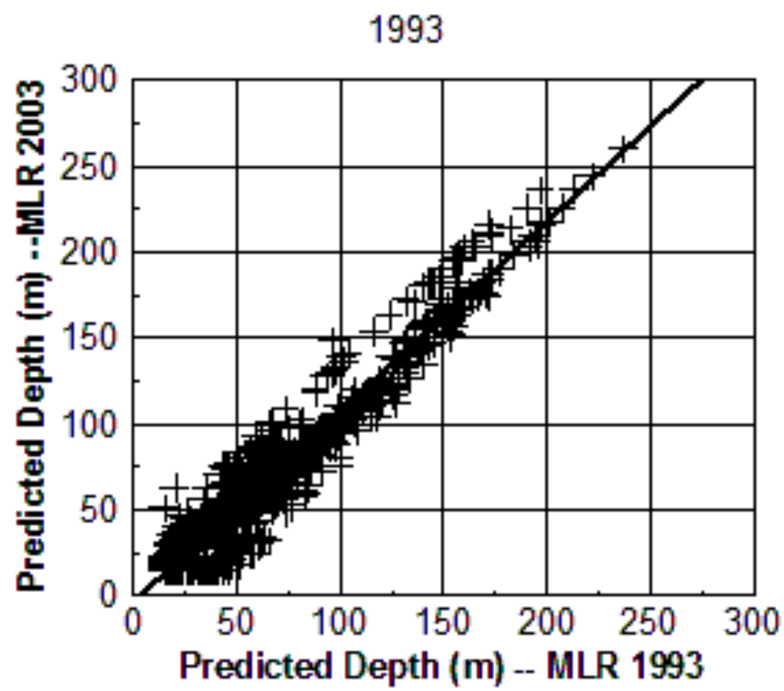


MLR fits for 2003 and 1993 with observed data in other years:



Comparing MLR fits from 2003 and 1993 to 2003 Obs (left) and 1993 Obs (right).





r^2 for 2003 data = 0.96

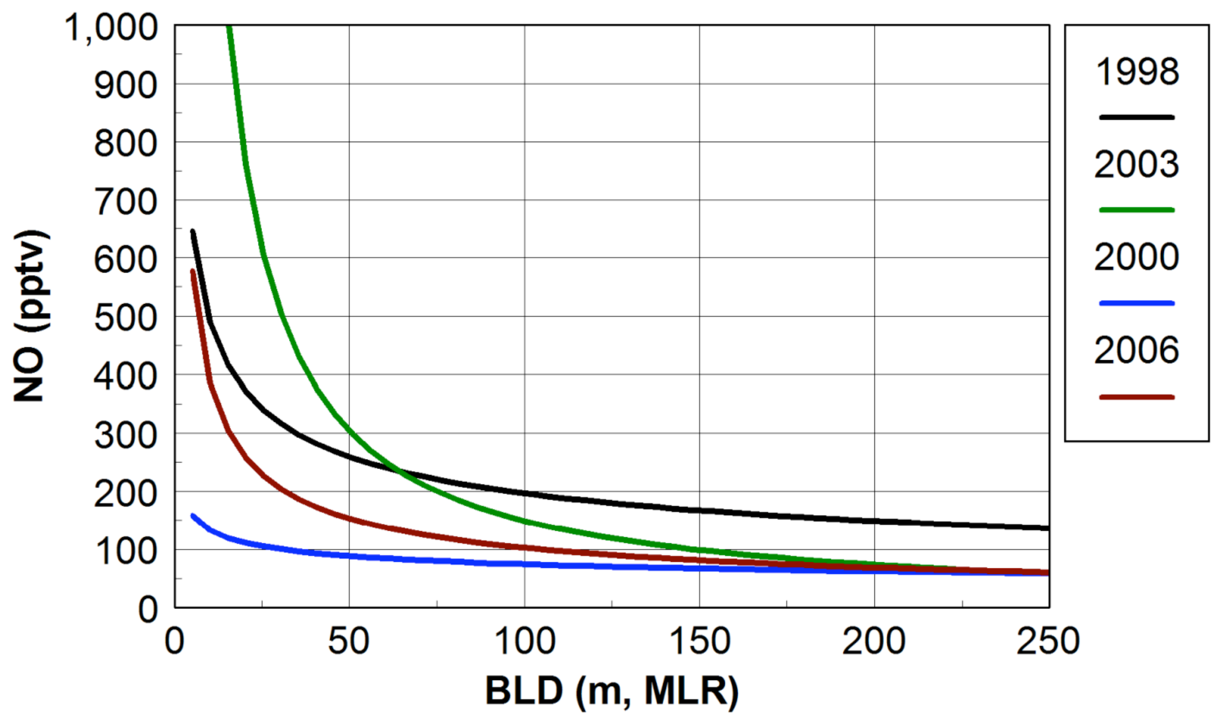
r^2 for 2003 data = 0.93

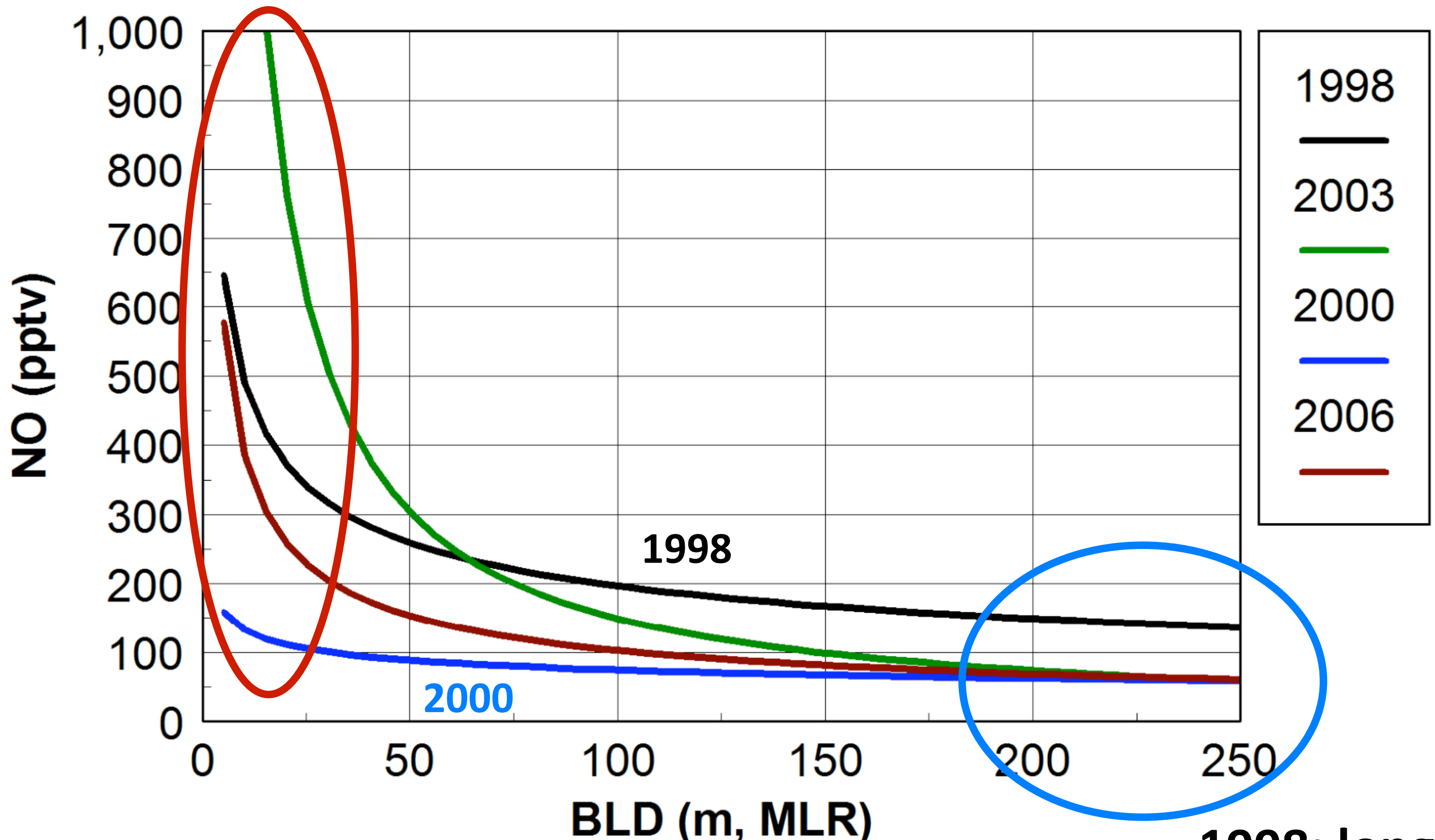
Note that two regimes appear to be present in 1993 data

Summary

2003 MLR fit to 2003 data: $r^2 = 0.71$
2003 MLR fit to 1993 data: $r^2 = 0.65$

Next step was to apply the 2003 MLR to all years





Year-to-year difference in flux of NO from the snow surface and fetch?

Year-to-year difference in snow nitrate levels and/or actinic flux (total column ozone)?

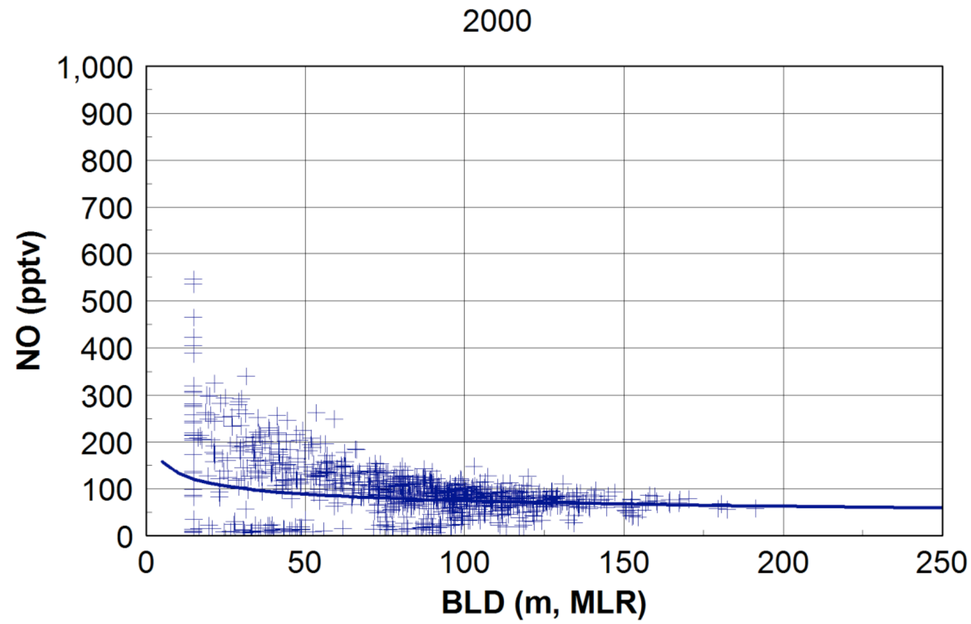
1998: longest lived ozone hole

2000: Earliest breakup of the ozone hole

Backup

The Effect of large scale meteorology

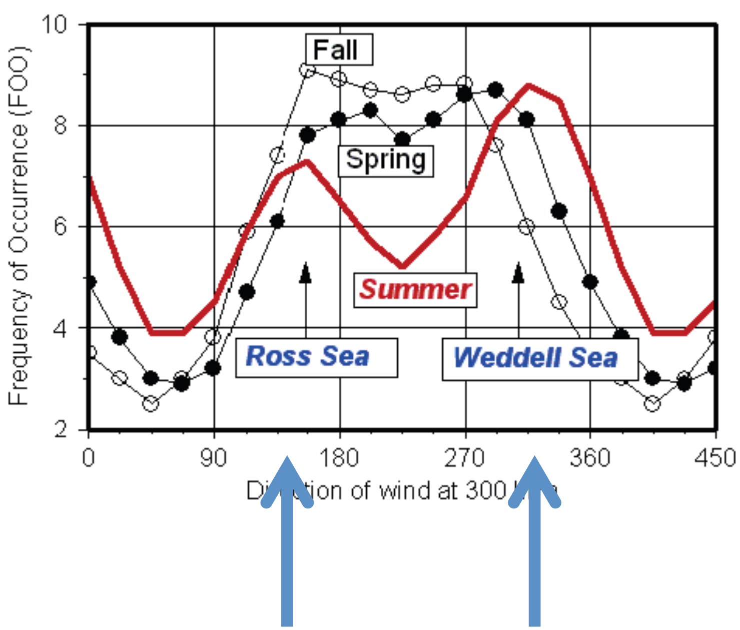
What was different in 2000?

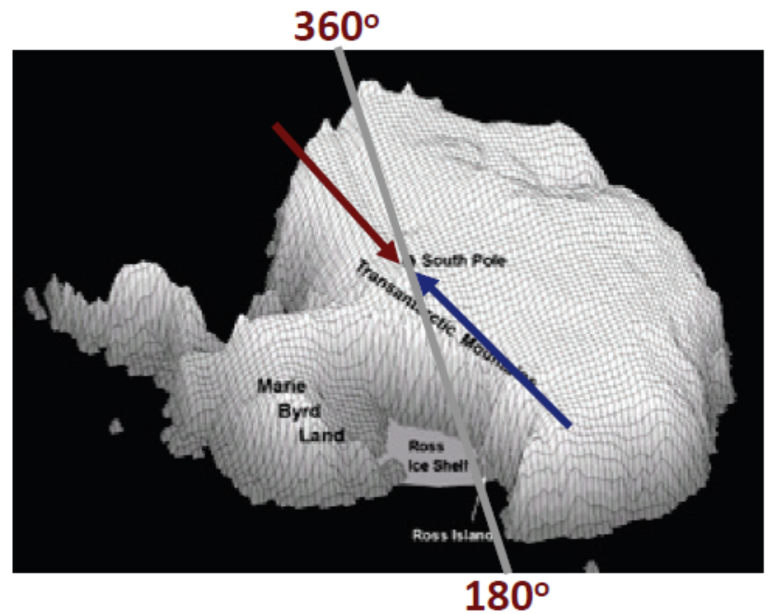


- ***Early breakup of the ozone hole***
- ***Fewer surface winds from the SE***
- ***Case study(ies) showed SE surface winds associated with winds aloft from the east to southwest.***
- ***Were there fewer SE winds aloft in 2000?***

Some possible explanations…

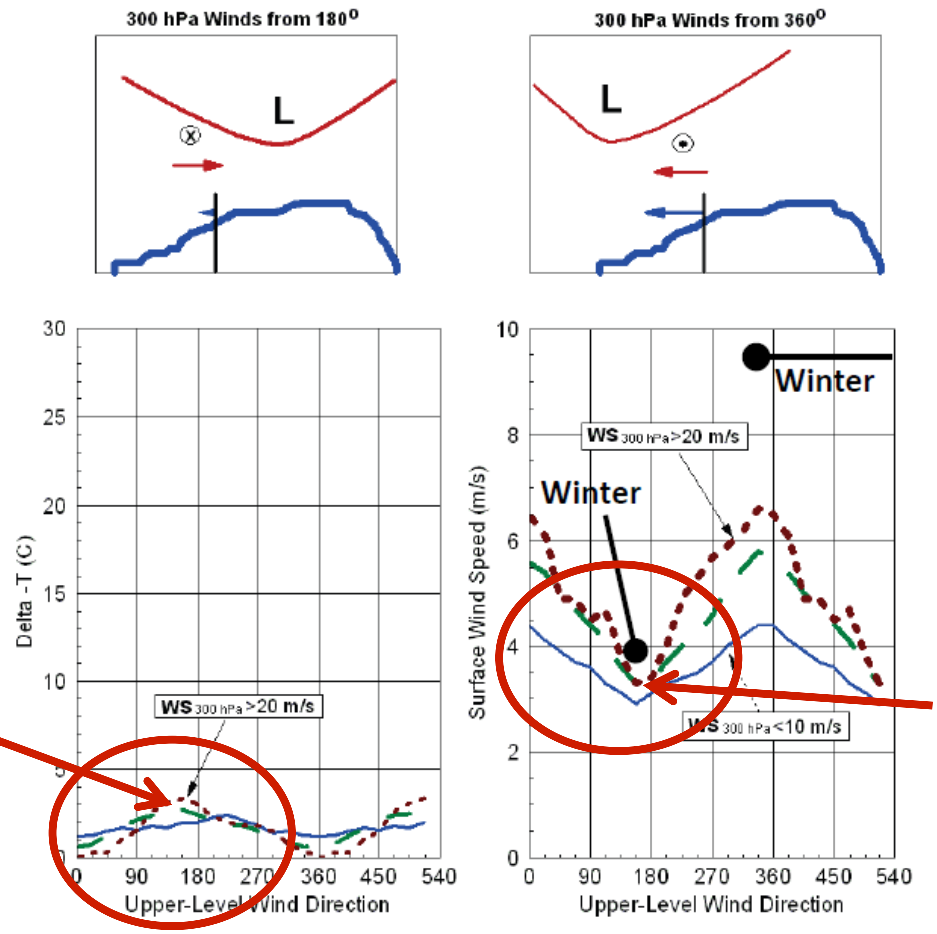
300 hPa-Winds become somewhat bimodal in the summer, following terrain contours





Clear skies **Cloudy skies**

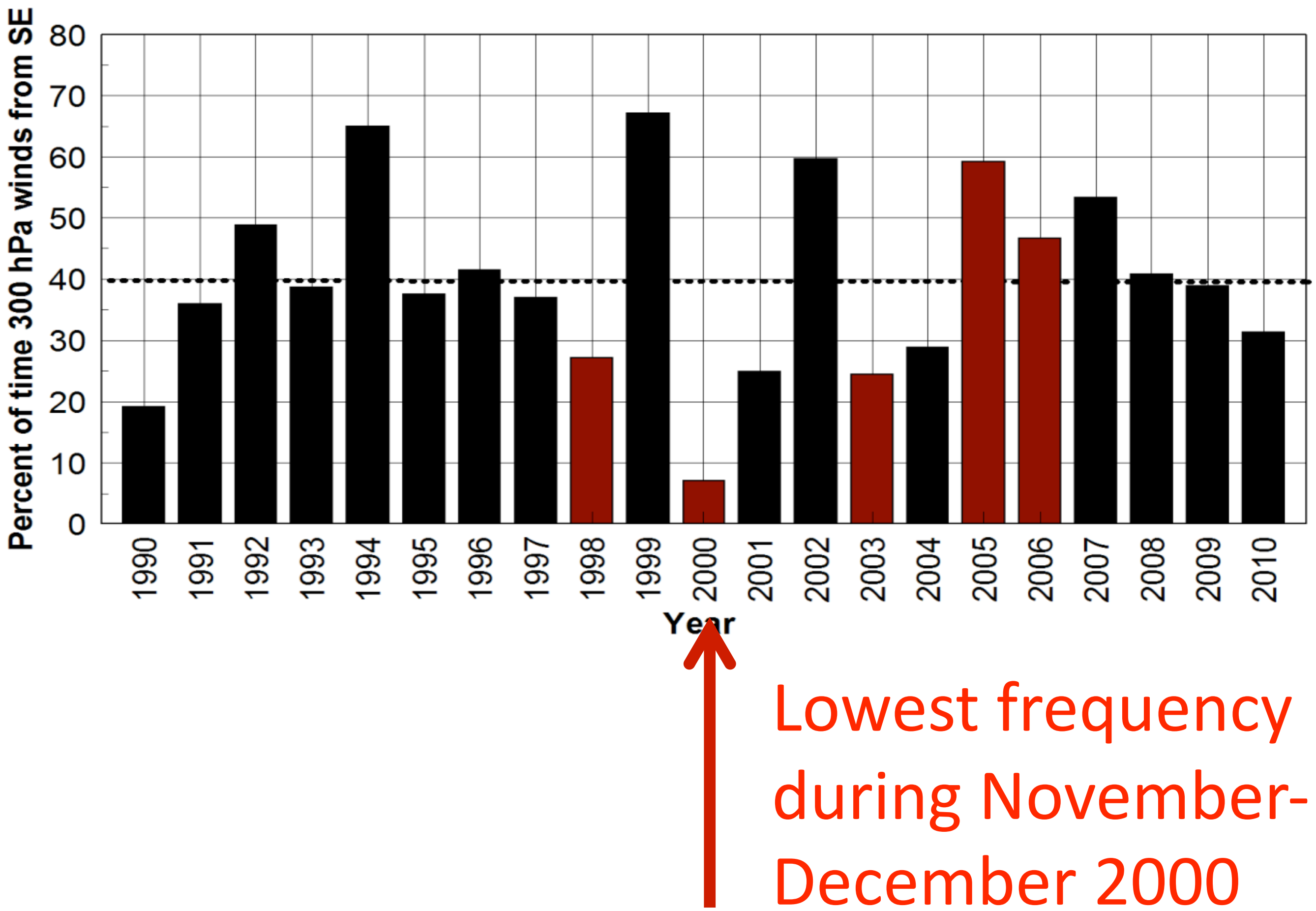
Strongest surface inversions form when the 300 hPa winds are from the east to southwest



Surface wind speeds with 300-hPa winds from the SE are almost the same in the summer as in winter.

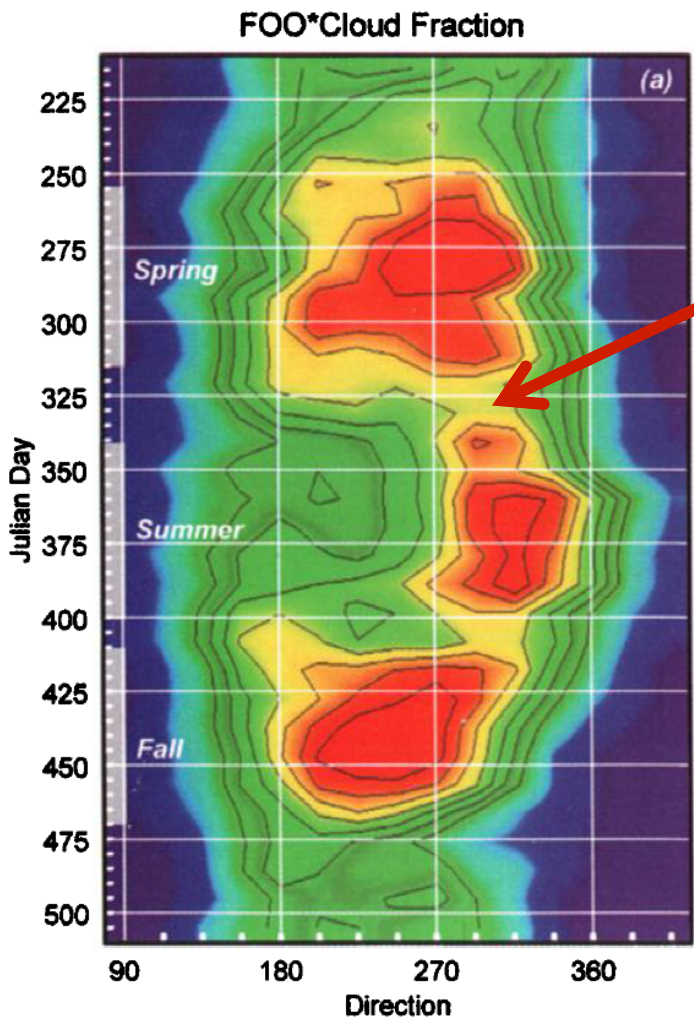
Wind Directions at 300-hPa

Climatology during the period of the ANTCI experiments

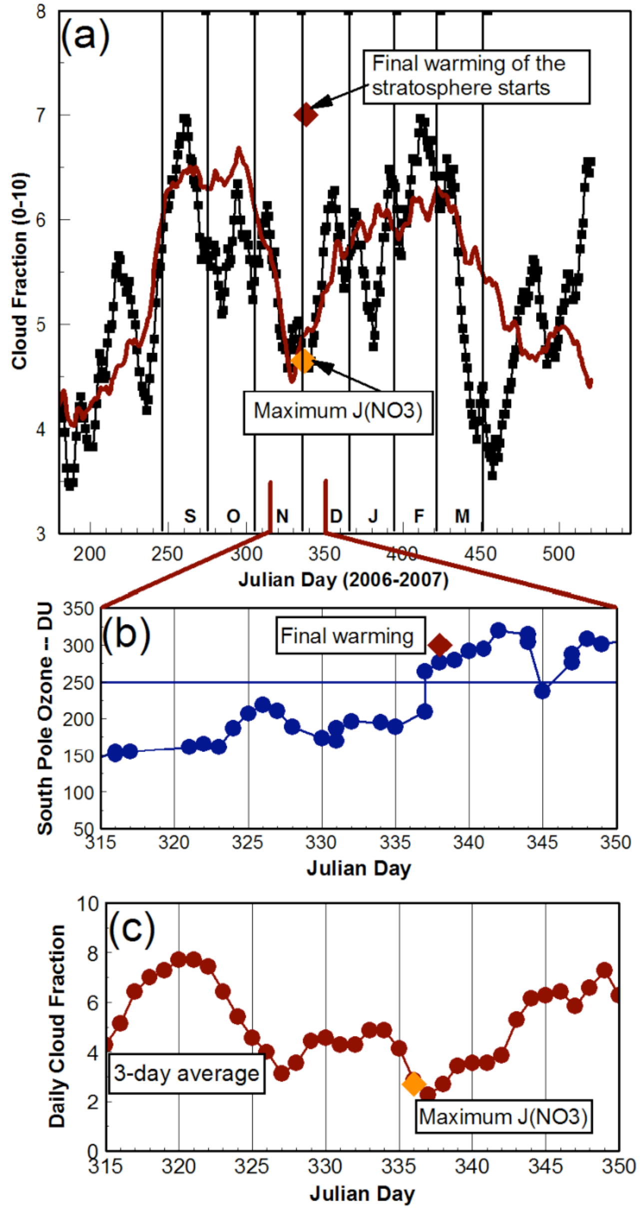


Lowest frequency during November-December 2000

The winter to summer transition



A major transition in moisture transport around the end of November—and a minimum in cloudiness



Coincidences:

- Maximum in photolysis rates occur just a tad before the final warming of the stratosphere
- Minimum in cloudiness (clear skies = stronger radiative cooling of the surface).
- Transitions in the transport regimes