Multiple ISR observations of upper atmospheric long-term cooling

Shunrong Zhang
MIT Haystack Observatory

ISR PIs
Millstone Hill (P Erickson)
Sondrestrom ISR (A. Stomme)
Poker Flat /Chatnika ISR (M. Nicolls
St Santin

Method

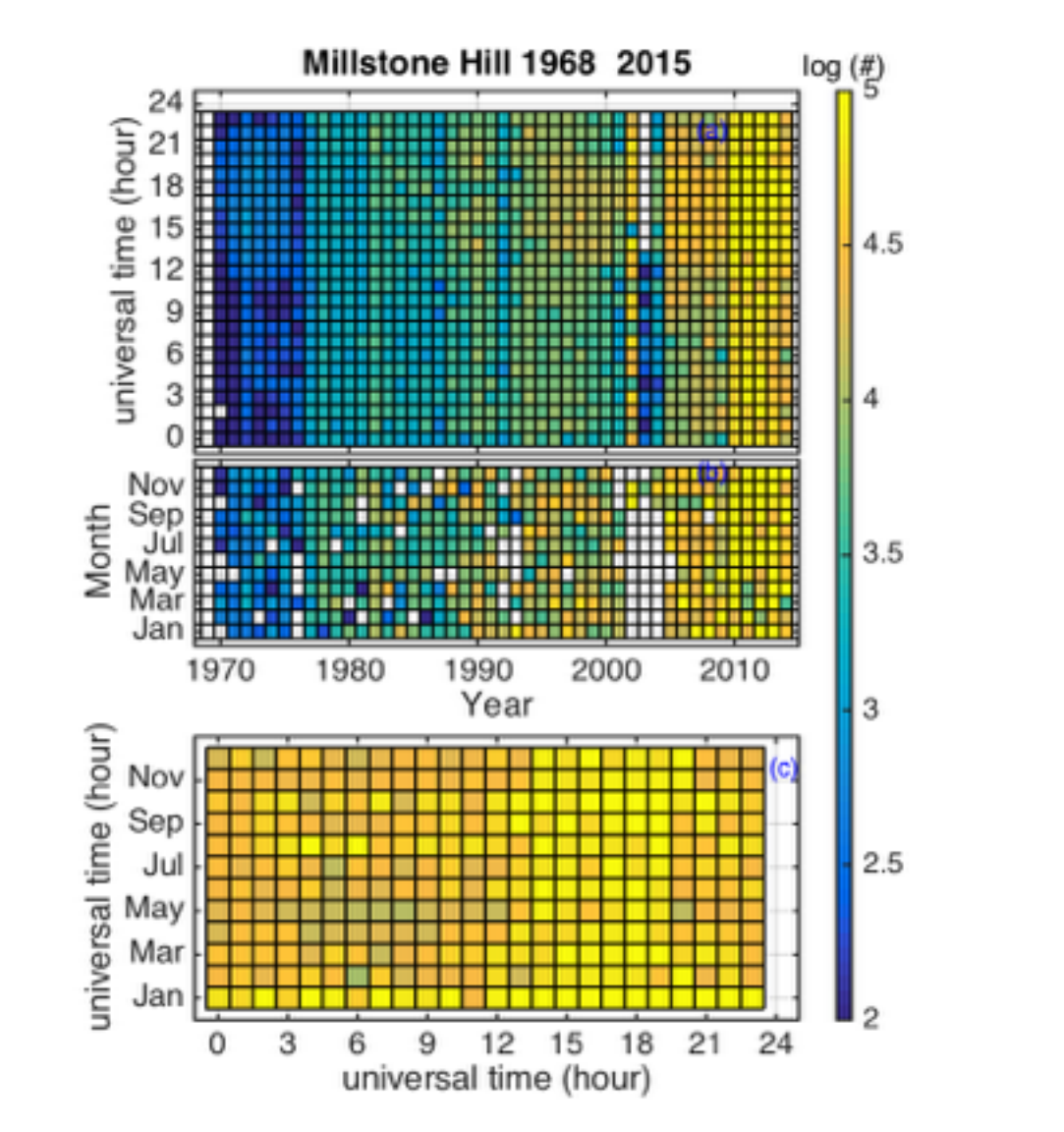
- Getting data
- Binning according to h, LT, month
- Fitting / modeling

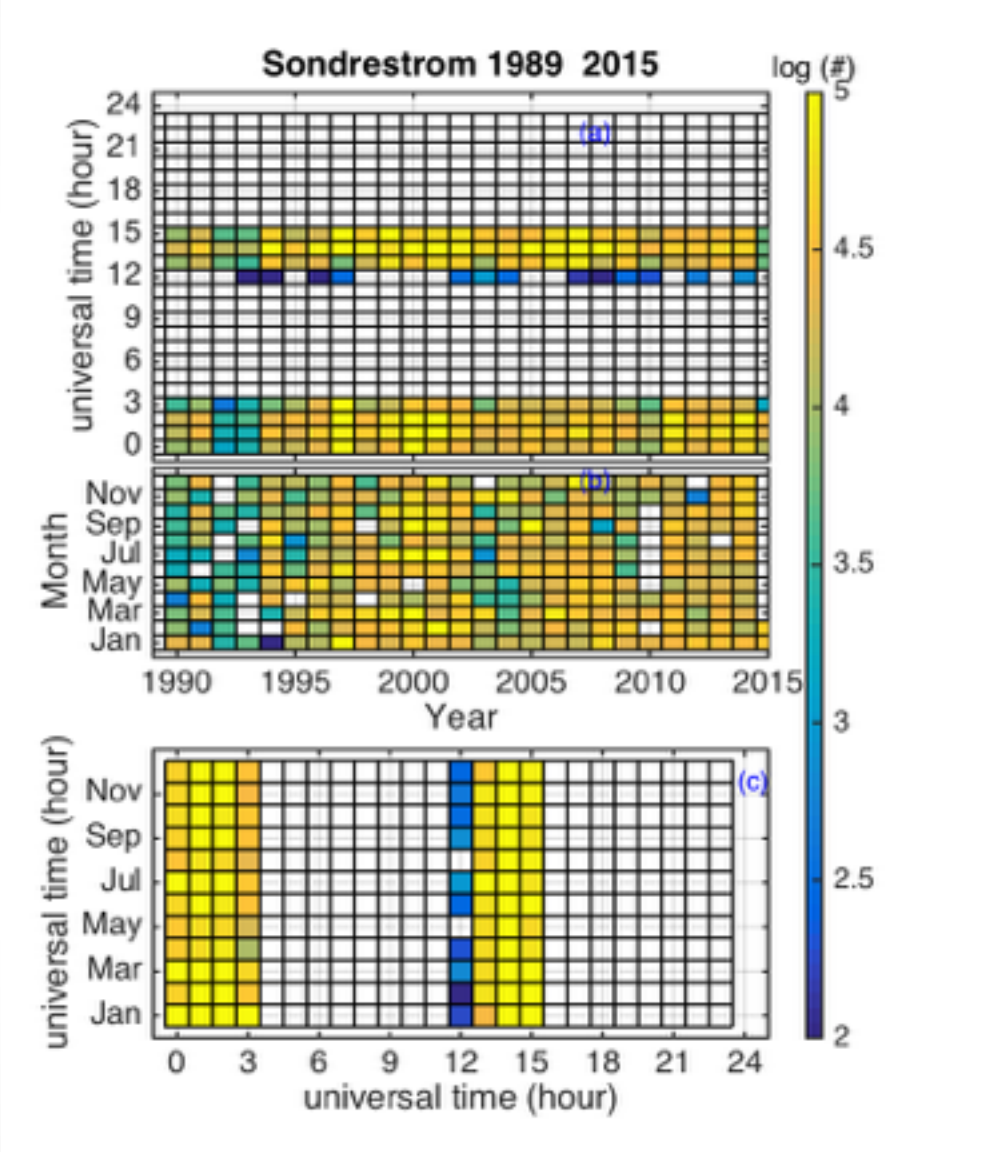
$$T_i = P_0 \text{ (background)} + P_1 \text{ Year} + \text{(long-term trend)} + P_2 f + P_3 f^2 + \text{(solar flux)} + P_4 a \text{ (magnetic activity)}$$

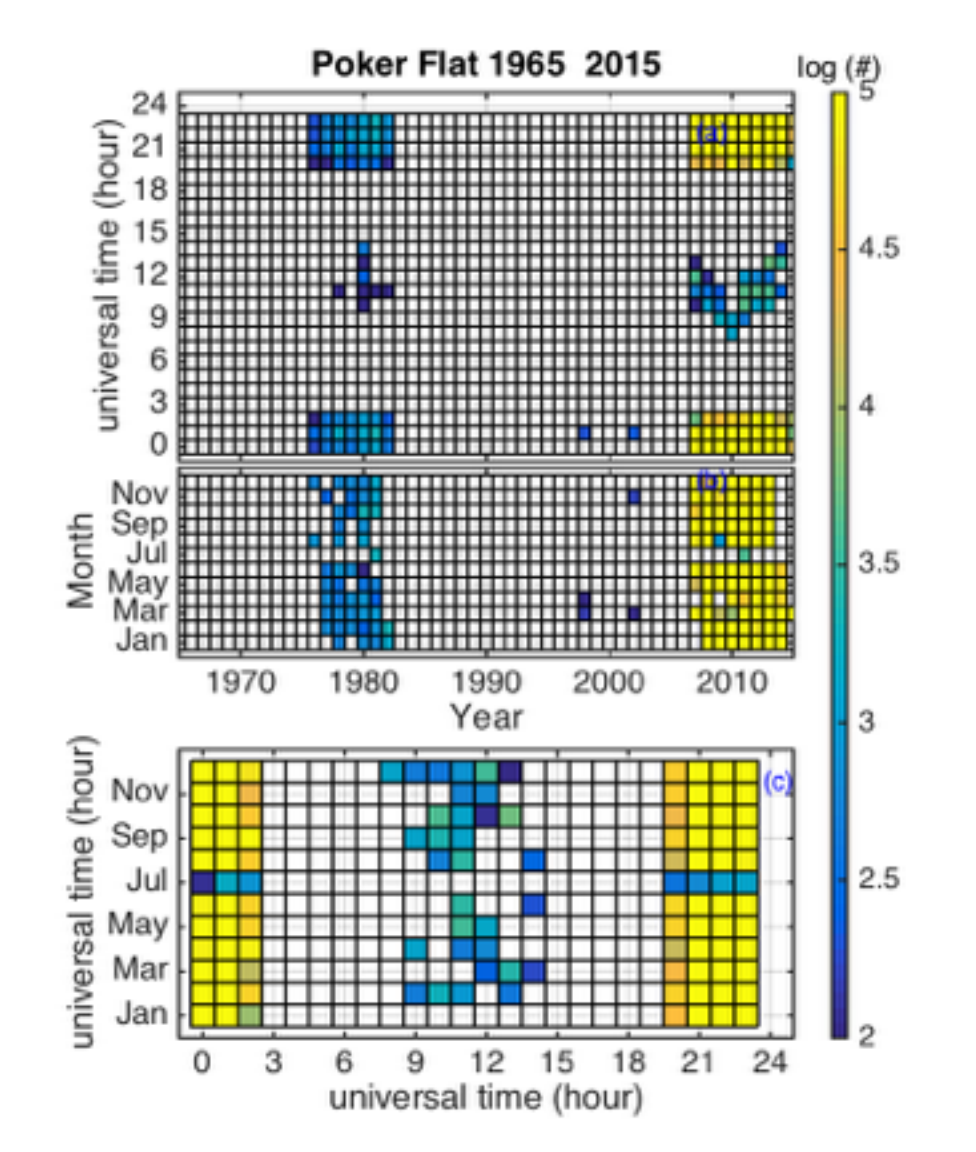
$f = F107 - \underline{F107}$

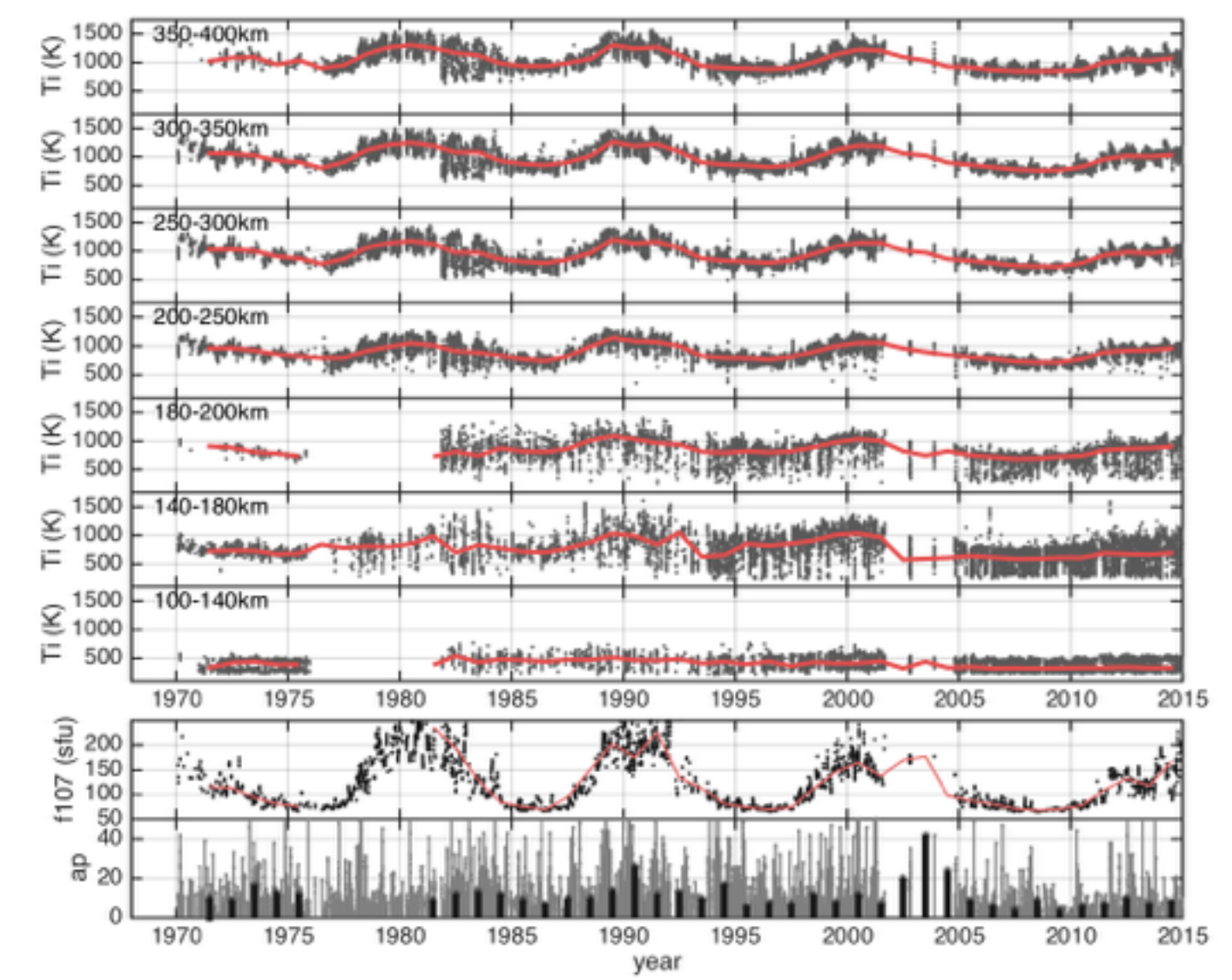
$a = ap3 - \underline{ap3}$

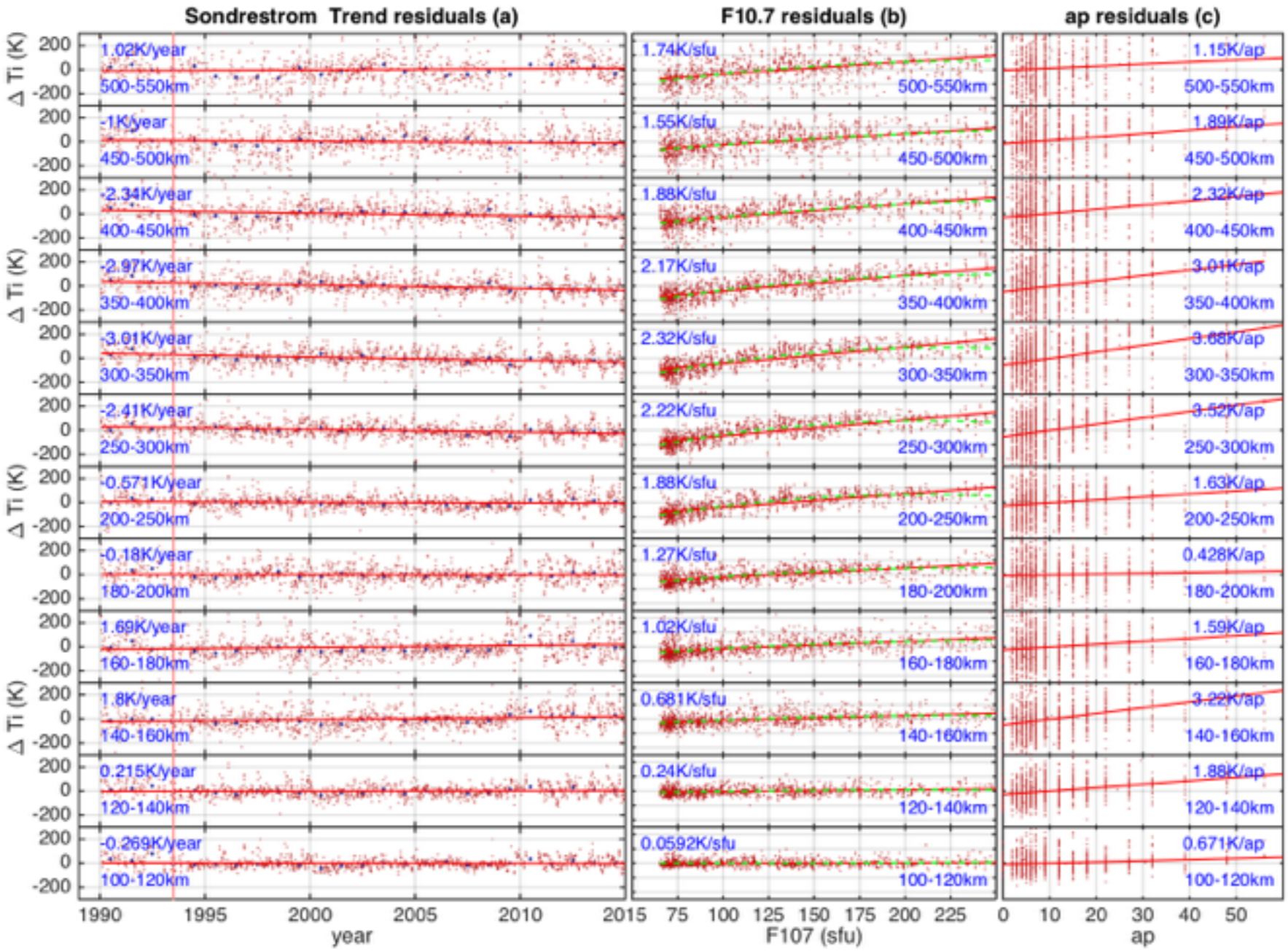
- Determining the trend
- Error estimate

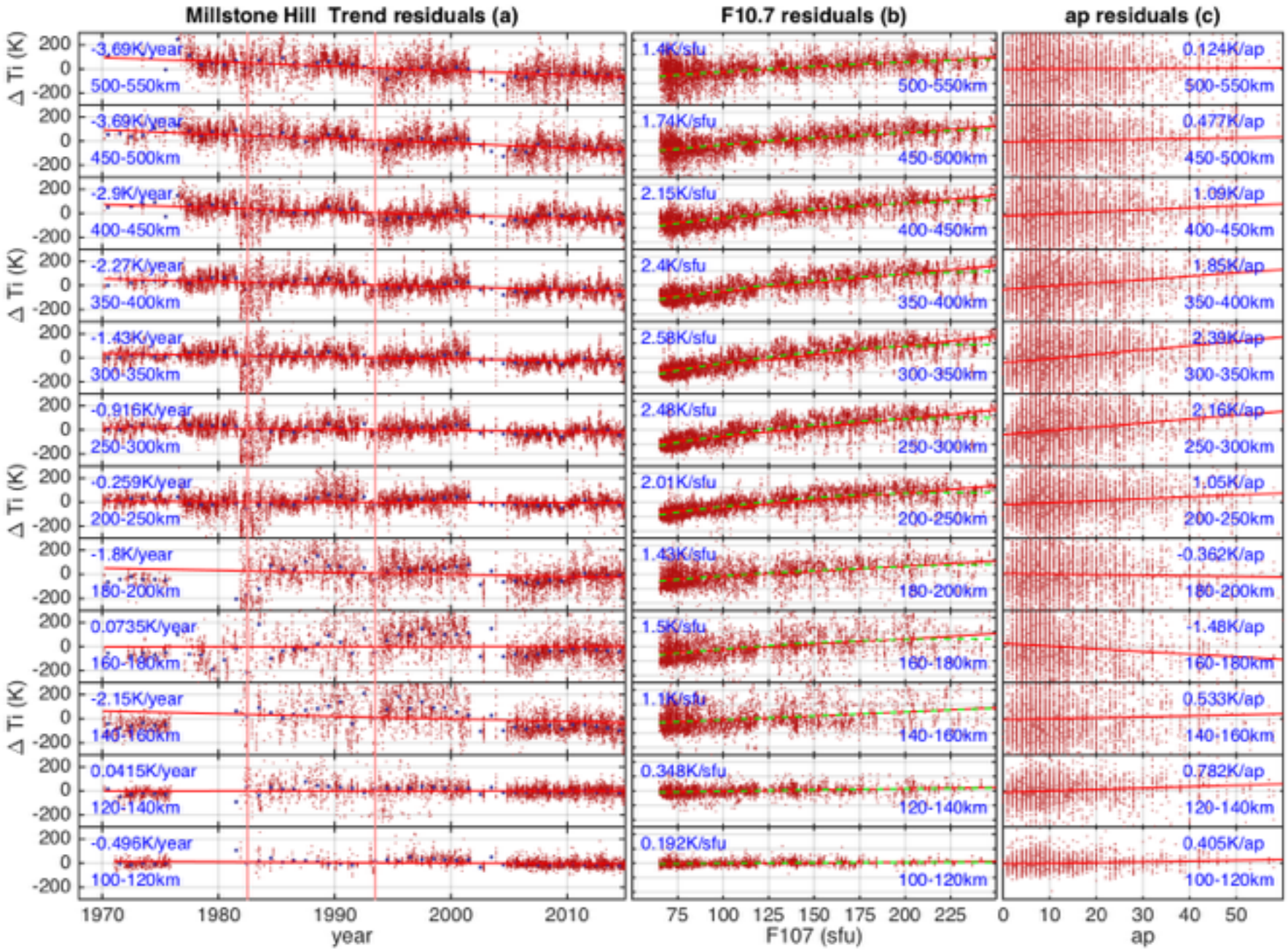

Millstone Hill 1968 2015
log (#)
universal time (hour)
24
21
18
15
12
9
6
3
0
(a)
Month
Nov
Sep
Jul
May
Mar
Jan
(b)
1970
1980
1990
2000
2010
Year
universal time (hour)
Nov
Sep
Jul
May
Mar
Jan
(c)
0
3
6
9
12
15
18
21
24
universal time (hour)
5
4.5
4
3.5
3
2.5
2

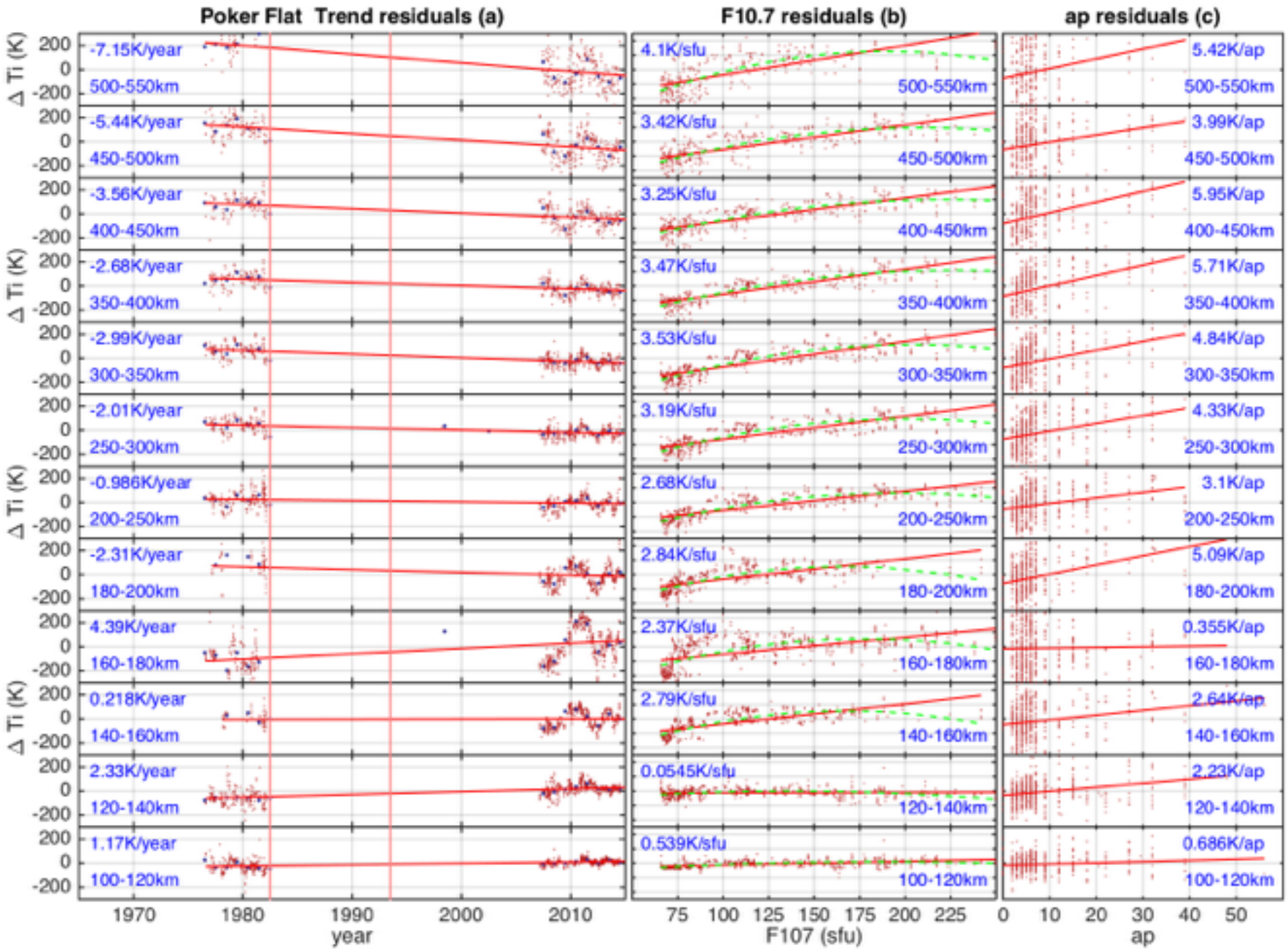

Sondrestrom 1989 2015
log (#)
5
4.5
4
3.5
3
2.5
2
(a)
universal time (hour)
24
21
18
15
12
9
6
3
0
(b)
Month
Nov
Sep
Jul
May
Mar
Jan
1990
1995
2000
2005
2010
2015
Year
(c)
universal time (hour)
Nov
Sep
Jul
May
Mar
Jan
0
3
6
9
12
15
18
21
24
universal time (hour)


Poker Flat 1965 2015
log (#)
universal time (hour)
24
21
18
15
12
9
6
3
0
(a)
Month
Nov
Sep
Jul
May
Mar
Jan
(b)
1970
1980
1990
2000
2010
Year
universal time (hour)
Nov
Sep
Jul
May
Mar
Jan
(c)
0
3
6
9
12
15
18
21
24
universal time (hour)
5
4.5
4
3.5
3
2.5
2

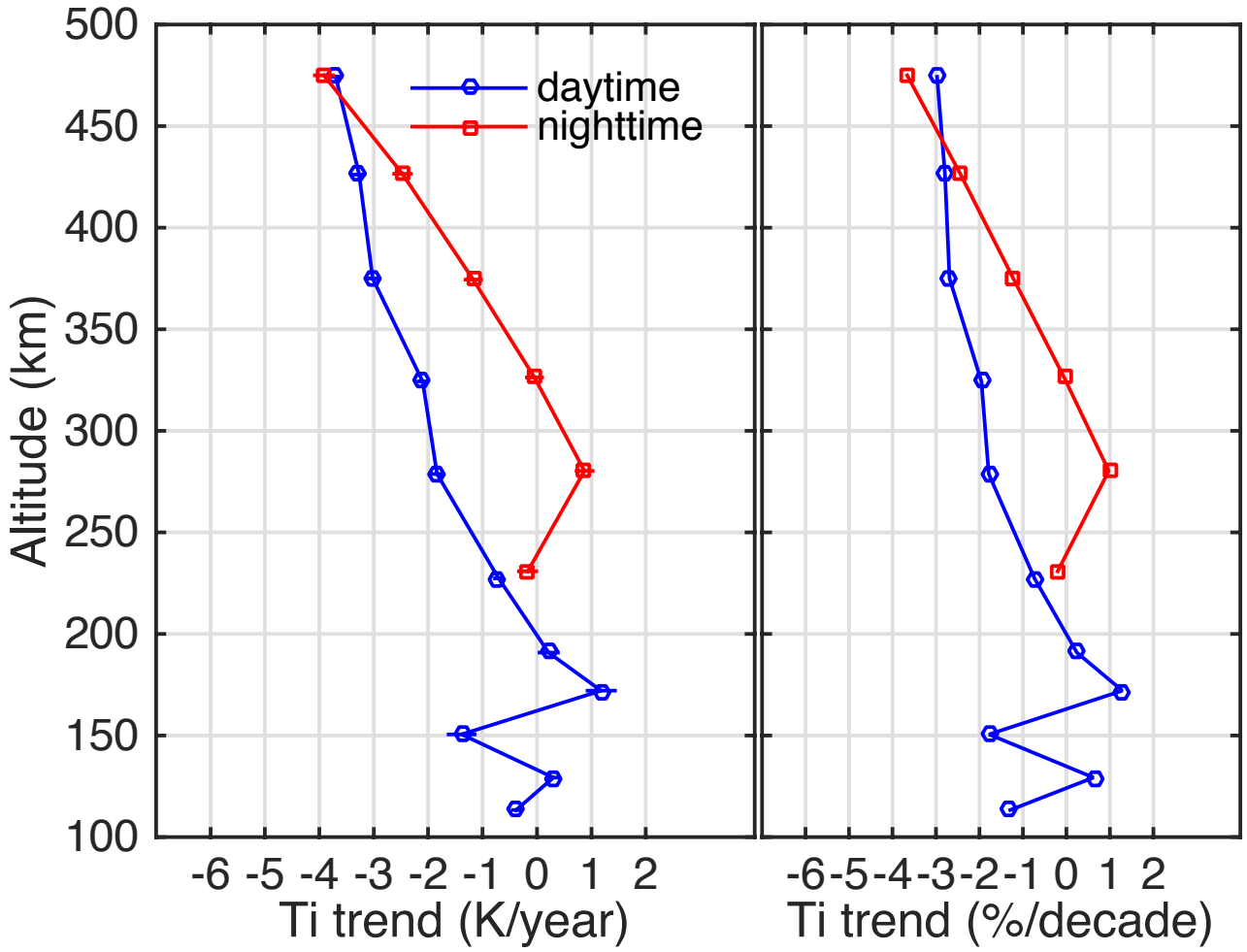

350-400km
300-350km
250-300km
200-250km
180-200km
140-180km
100-140km
Ti (K)
1500
1000
500
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
f107 (sfu)
200
150
100
50
ap
40
20
0
year


Sondrestrom Trend residuals (a)
F10.7 residuals (b)
ap residuals (c)
Δ Ti (K)
1.02K/year
500-550km
-1K/year
450-500km
-2.34K/year
400-450km
-2.97K/year
350-400km
-3.01K/year
300-350km
-2.41K/year
250-300km
-0.571K/year
200-250km
-0.18K/year
180-200km
1.69K/year
160-180km
1.8K/year
140-160km
0.215K/year
120-140km
-0.269K/year
100-120km
1.74K/sfu
1.55K/sfu
1.88K/sfu
2.17K/sfu
2.32K/sfu
2.22K/sfu
1.88K/sfu
1.27K/sfu
1.02K/sfu
0.681K/sfu
0.24K/sfu
0.0592K/sfu
1.15K/ap
1.89K/ap
2.32K/ap
3.01K/ap
3.68K/ap
3.52K/ap
1.63K/ap
0.428K/ap
1.59K/ap
3.22K/ap
1.88K/ap
0.671K/ap
1990
1995
2000
2005
2010
2015
year
75
100
125
150
175
200
225
F107 (sfu)
0
10
20
30
40
50
ap


Millstone Hill Trend residuals (a)
F10.7 residuals (b)
ap residuals (c)
Δ Ti (K)
-3.69K/year
500-550km
1.4K/sfu
0.124K/ap
-3.69K/year
450-500km
1.74K/sfu
0.477K/ap
-2.9K/year
400-450km
2.15K/sfu
1.09K/ap
-2.27K/year
350-400km
2.4K/sfu
1.85K/ap
-1.43K/year
300-350km
2.58K/sfu
2.39K/ap
-0.916K/year
250-300km
2.48K/sfu
2.16K/ap
-0.259K/year
200-250km
2.01K/sfu
1.05K/ap
-1.8K/year
180-200km
1.43K/sfu
-0.362K/ap
0.0735K/year
160-180km
1.5K/sfu
-1.48K/ap
-2.15K/year
140-160km
1.1K/sfu
0.533K/ap
0.0415K/year
120-140km
0.348K/sfu
0.782K/ap
-0.496K/year
100-120km
0.192K/sfu
0.405K/ap
1970
1980
1990
2000
2010
year
75
100
125
150
175
200
225
F107 (sfu)
0
10
20
30
40
50
ap

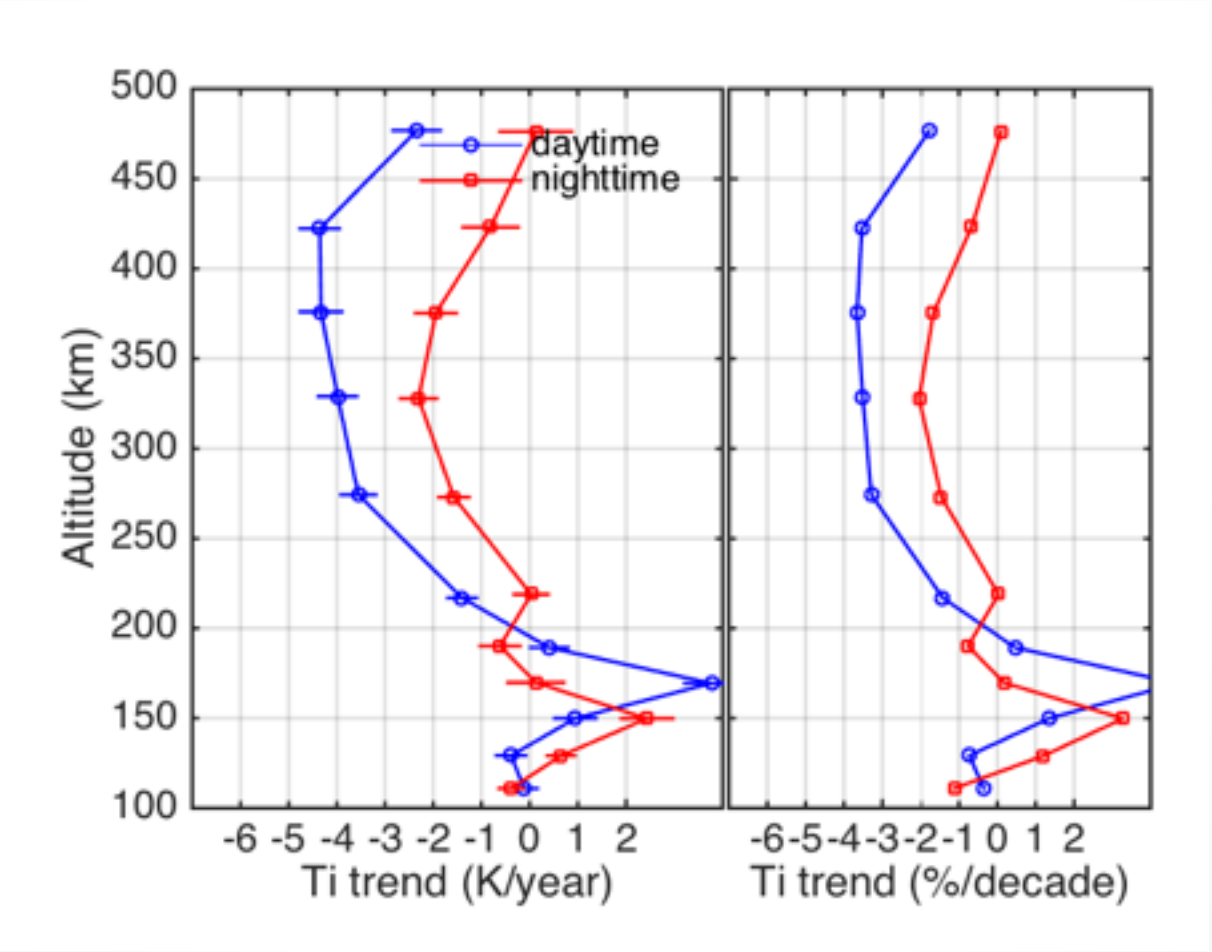

Poker Flat Trend residuals (a)
F10.7 residuals (b)
ap residuals (c)
Δ Ti (K)
-7.15K/year
500-550km
4.1K/sfu
5.42K/ap
-5.44K/year
450-500km
3.42K/sfu
3.99K/ap
-3.56K/year
400-450km
3.25K/sfu
5.95K/ap
-2.68K/year
350-400km
3.47K/sfu
5.71K/ap
-2.99K/year
300-350km
3.53K/sfu
4.84K/ap
-2.01K/year
250-300km
3.19K/sfu
4.33K/ap
-0.986K/year
200-250km
2.68K/sfu
3.1K/ap
-2.31K/year
180-200km
2.84K/sfu
5.09K/ap
4.39K/year
160-180km
2.37K/sfu
0.355K/ap
0.218K/year
140-160km
2.79K/sfu
2.64K/ap
2.33K/year
120-140km
0.0545K/sfu
2.23K/ap
1.17K/year
100-120km
0.539K/sfu
0.686K/ap
1970
1980
1990
2000
2010
year
75
100
125
150
175
200
225
F107 (sfu)
0
10
20
30
40
50
ap

Millstone Hill

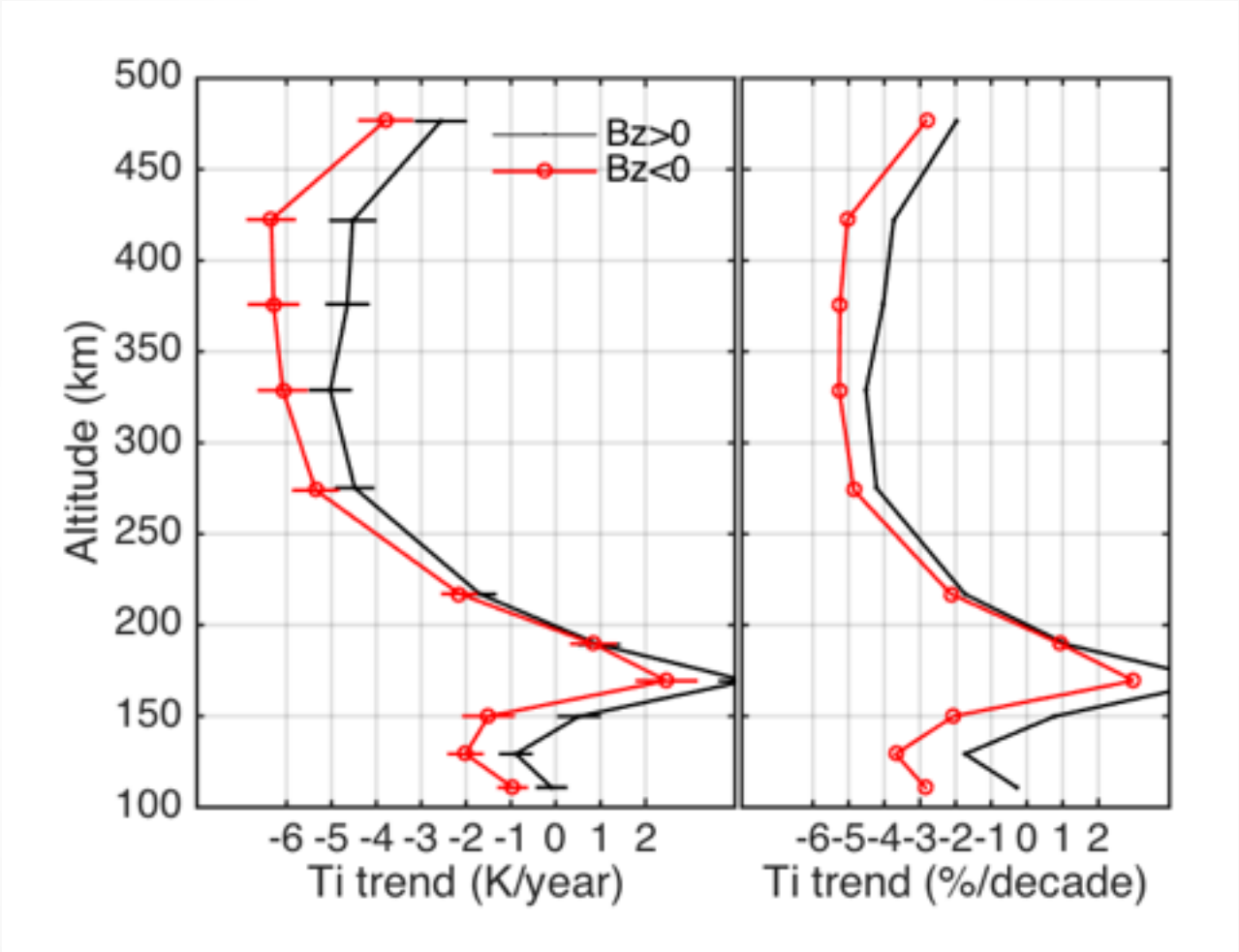


- **Increasing cooling with height**
- **Stronger daytime cooling**

Sondrestrom

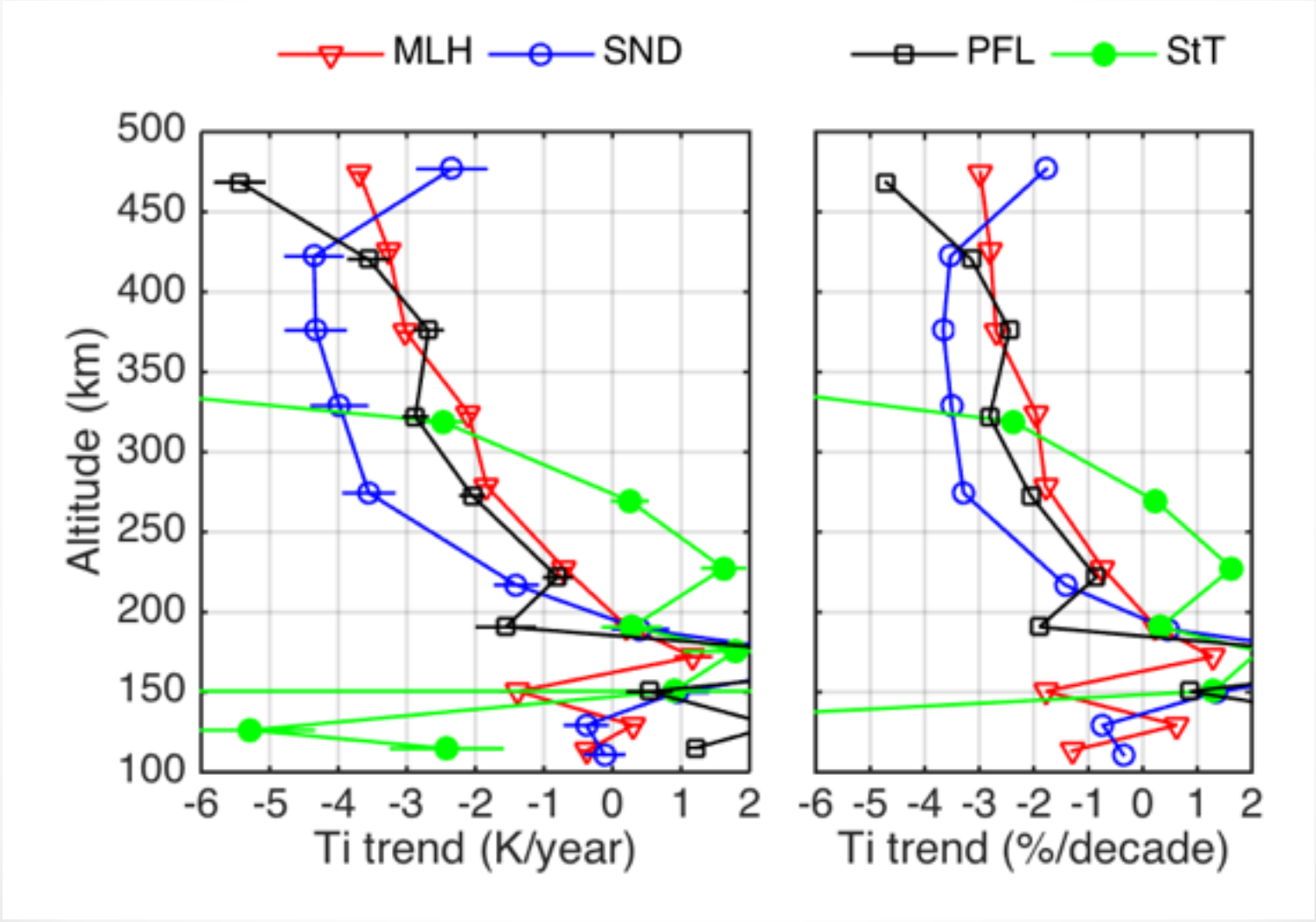


Sondrestrom

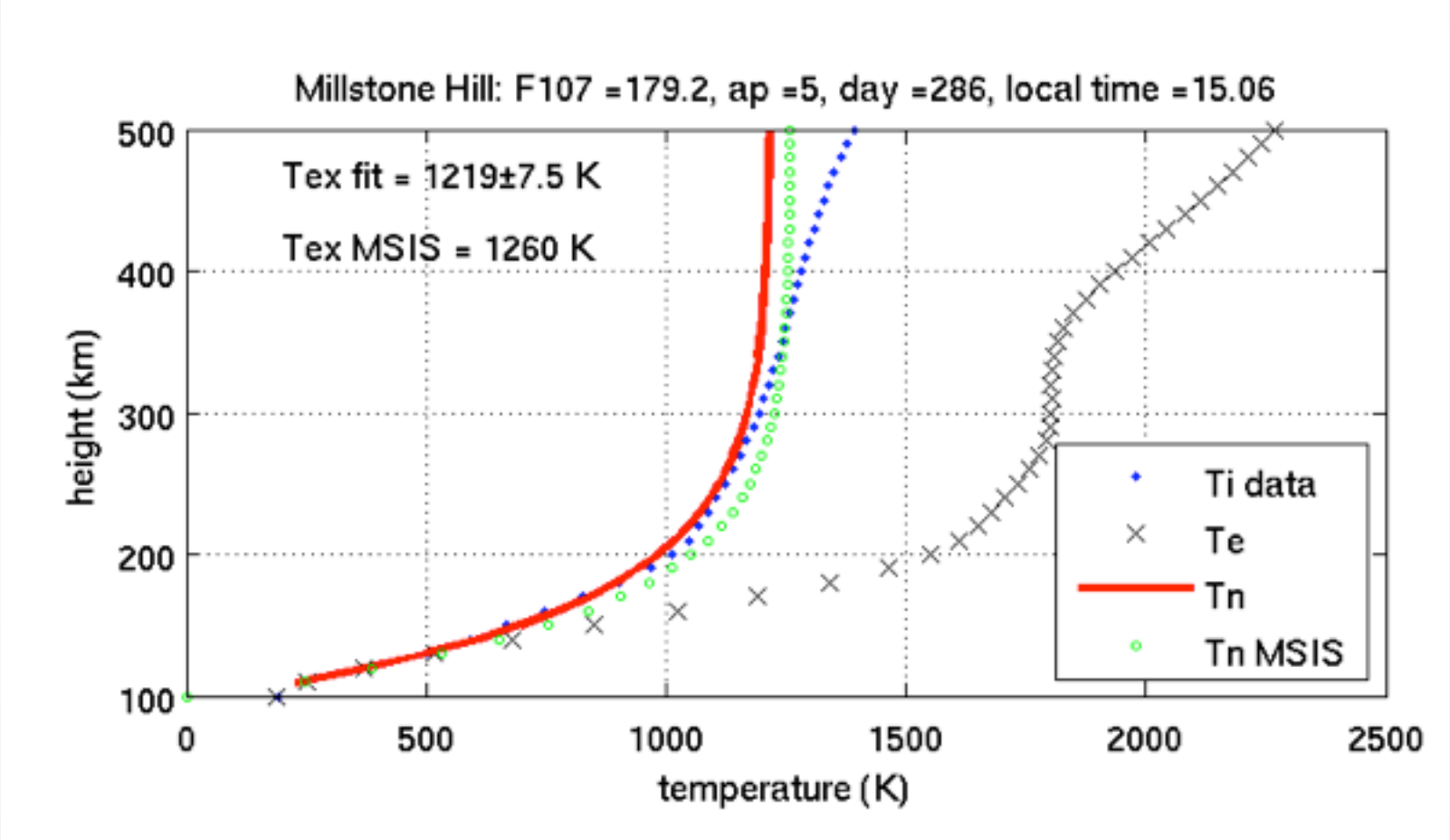


Dayside, with Bz > and Bz <0

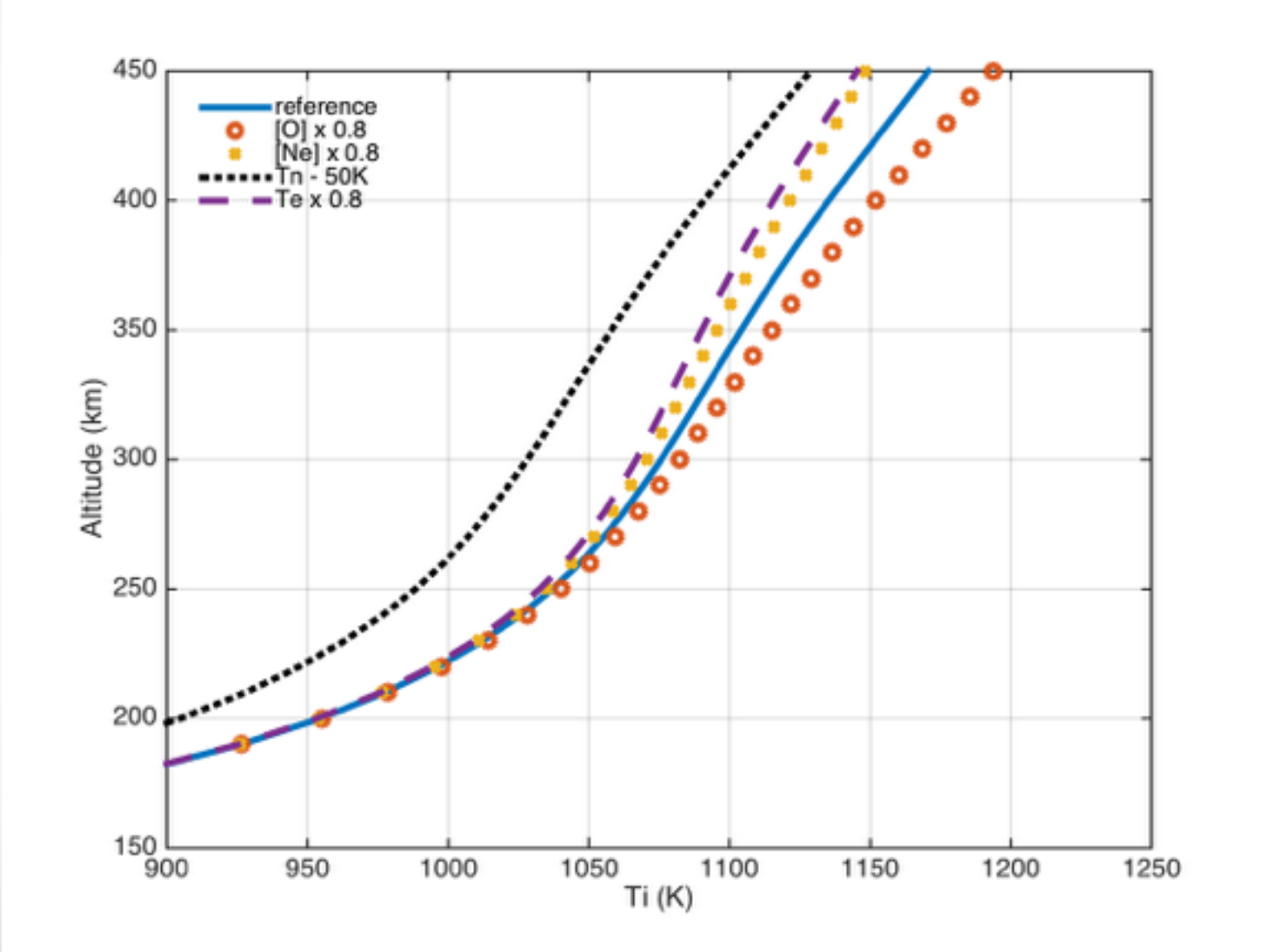
Daytime Comparison



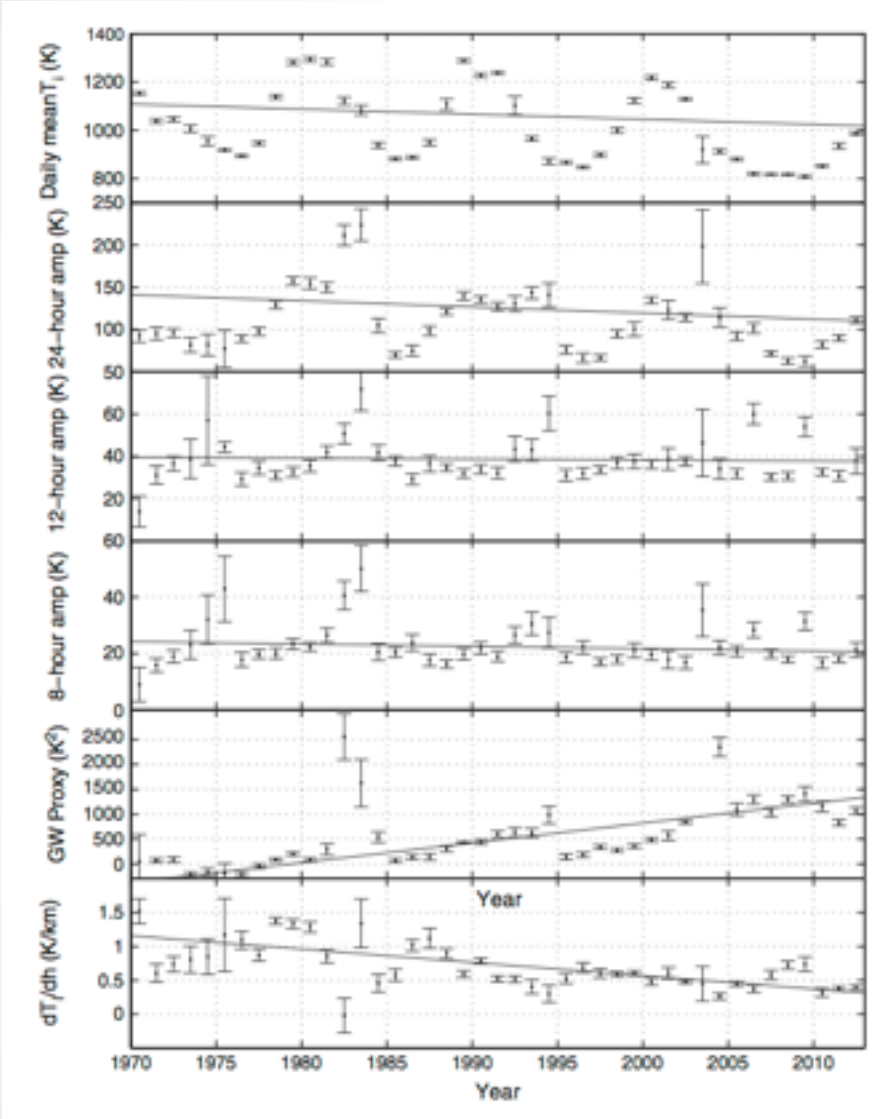
Ti, Te, and Tn


Millstone Hill: F107 =179.2, ap =5, day =286, local time =15.06
Tex fit = 1219±7.5 K
Tex MSIS = 1260 K
height (km)
500
400
300
200
100
0
500
1000
1500
2000
2500
temperature (K)
Ti data
Te
Tn
Tn MSIS

Ti dependency on Tn, [O], Ne, and Te



Gravity waves trends?



(a) the climate regime shift of 1976–1977 launched slow Rossby waves across the oceans which continue to propagate to this day,

(b) winds over this increasingly corrugated ocean have launched increasing fluxes of gravity waves into the atmosphere,

(c) these increasing fluxes of gravity waves have propagated to the thermosphere to produce increasing amounts of cooling

Oliver, W. L., S.-R. Zhang,, and L. P. Goncharenko (2013), Is thermospheric global cooling caused by gravity waves, J. Geophys., Res., 118, 1–11, doi:10.1002/jgra.50370.

Summary

- Similarities exist between Ti trends derived from MH, Sondrestrome and Poker Flat / Chatanika
  - Height dependency
  - Day-night difference
  - Strong cooling: ~90K (daytime average) in 45 years; or 45K (day+night)
- Questions:
  - Stronger cooling than expected (from CO2 effect)
  - Day-night difference