Unravelling long-term behaviour in historic geophysical data sets

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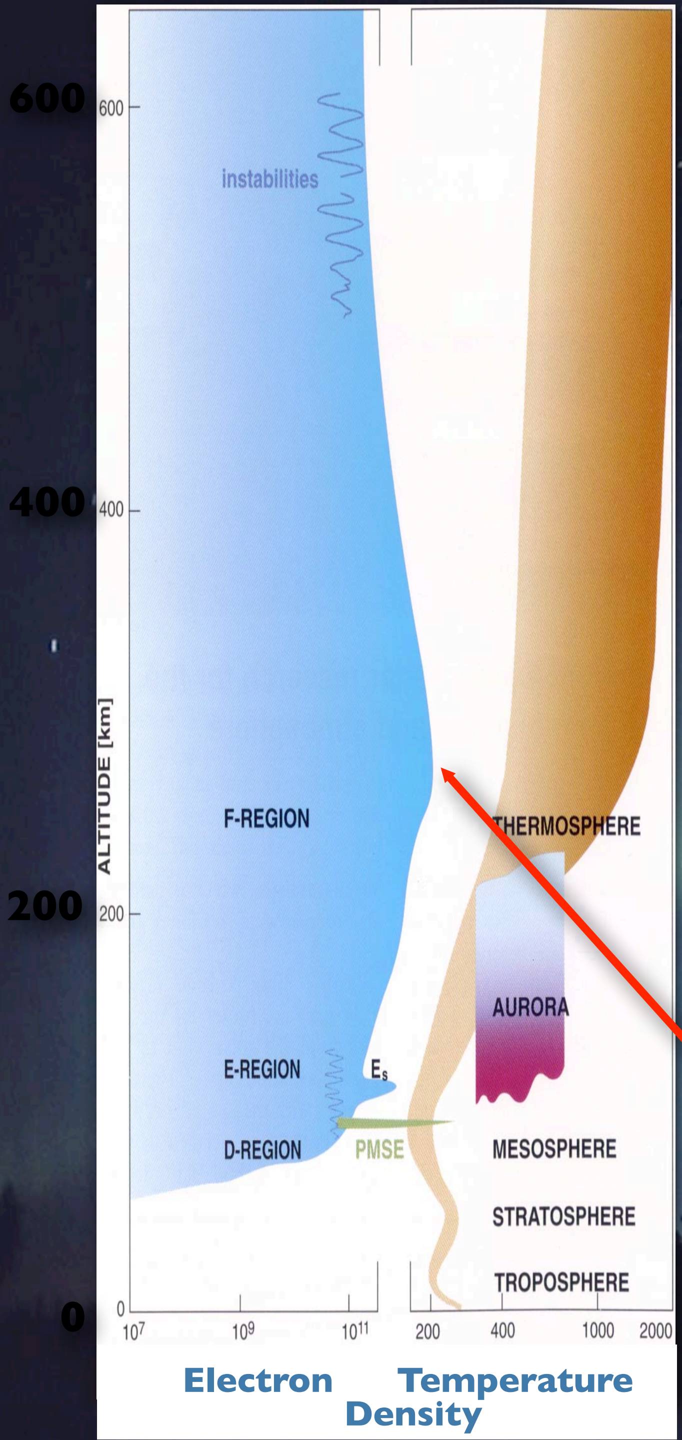
(2013-07-31)

Sodankylä Geophysical Observatory

- ➡ First observations during the International Polar Year 1882/83.
- ➡ Established 1913.
- ➡ Finland independent from Russia in 1917.
- ➡ Part of University of Oulu since 1997.
- ➡ Oldest scientific research institute in Northern Finland.

Where we are...

- ✔ **European Arctic**
- ✔ **High Latitude**
- ✔ **Auroral Zone**



Greenhouse Cooling

Doubling of [CO_2] and [CH_4]

cools

Mesosphere by **10 K** and
Thermosphere by **50 K**.

Atmosphere shrinks.

Layer of maximum electron density *lowers* by 15-20 km.

Greenhouse high up?

- Model results, assuming doubling of CO_2 and CH_4:
- Stratopause cools by 8 K, stratosphere by 15 K.
  (Brasseur & Hitchman, 1988)
- Mesosphere and thermosphere cool by 10 K and 50 K, respectively.
  (Roble & Dickinson, 1989)
- F2-layer peak (hmF2) lowers by 15-20 km.
  (Rishbeth, 1990)
- Riometer absorption decreases.
  (Serafimov & Serafimova, 1992)
- Stratopause cools by 14 K, mesosphere by 8 K, thermosphere by 50 K.
  (Akmaev & Fomichev, 1998)

Ionosonde

G Breit and M A Tuve,
A radio method of
estimating the height of
the conducting layer,
Nature, 116, p. 357, 1925.

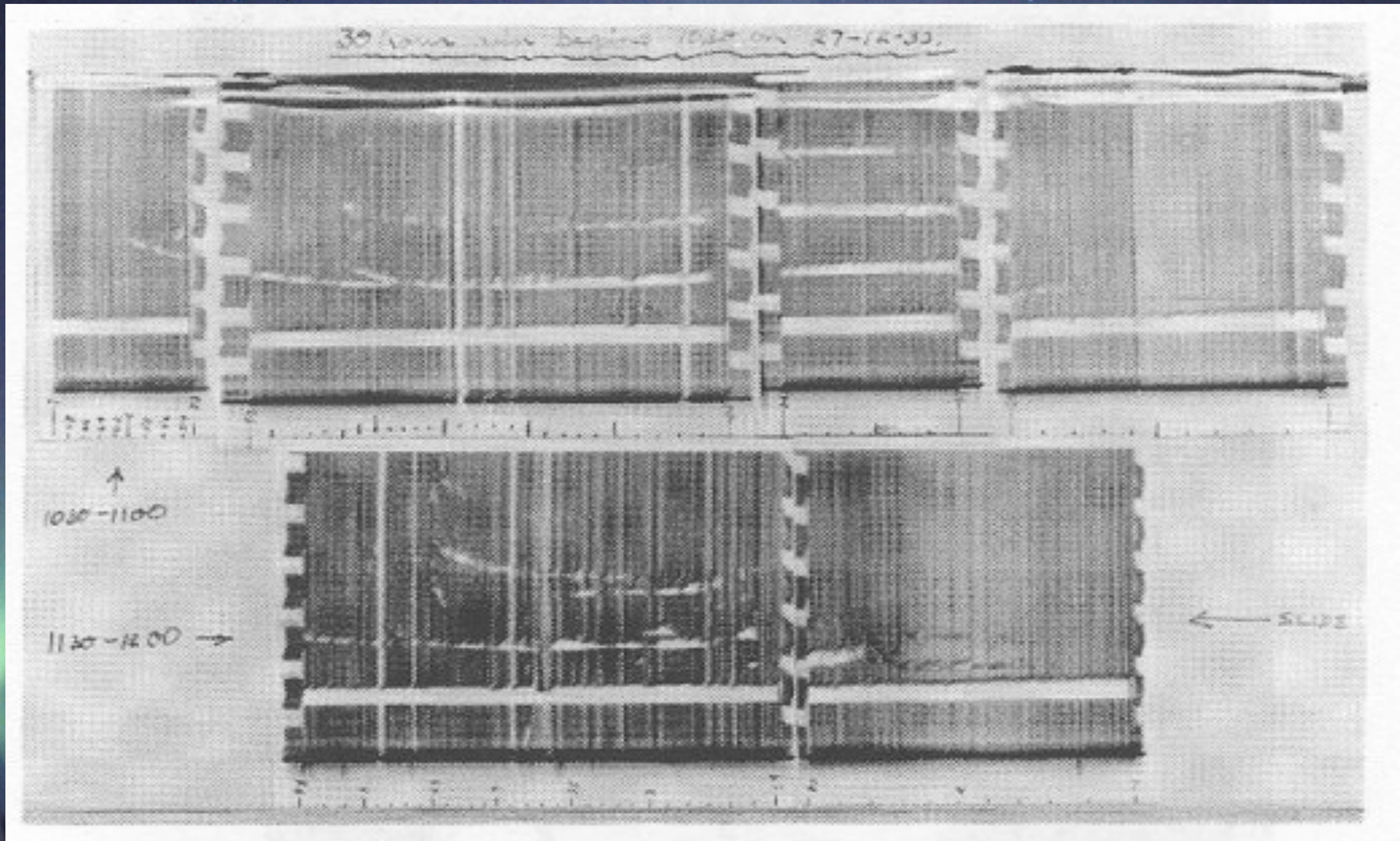
Gregory Breit

(14 July 1899 - 11 September 1981)

Merle Tuve

(27 June 1901 - 20 May 1982)

Early Slough Ionogram

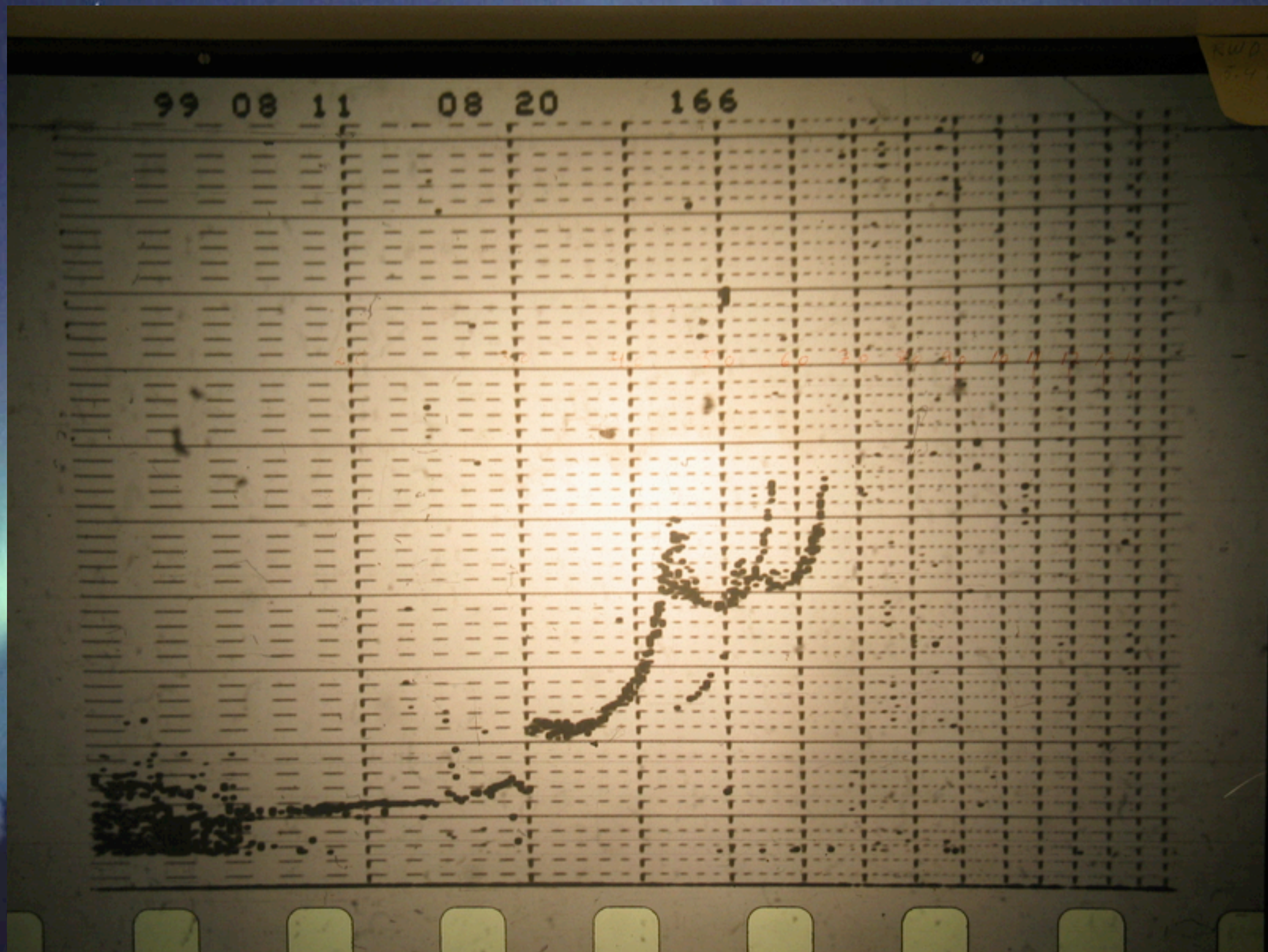


Radio Research Station Slough, Buckinghamshire
27th December 1933, 10:30-11:00 UTC and 11:30-12:00 UTC.

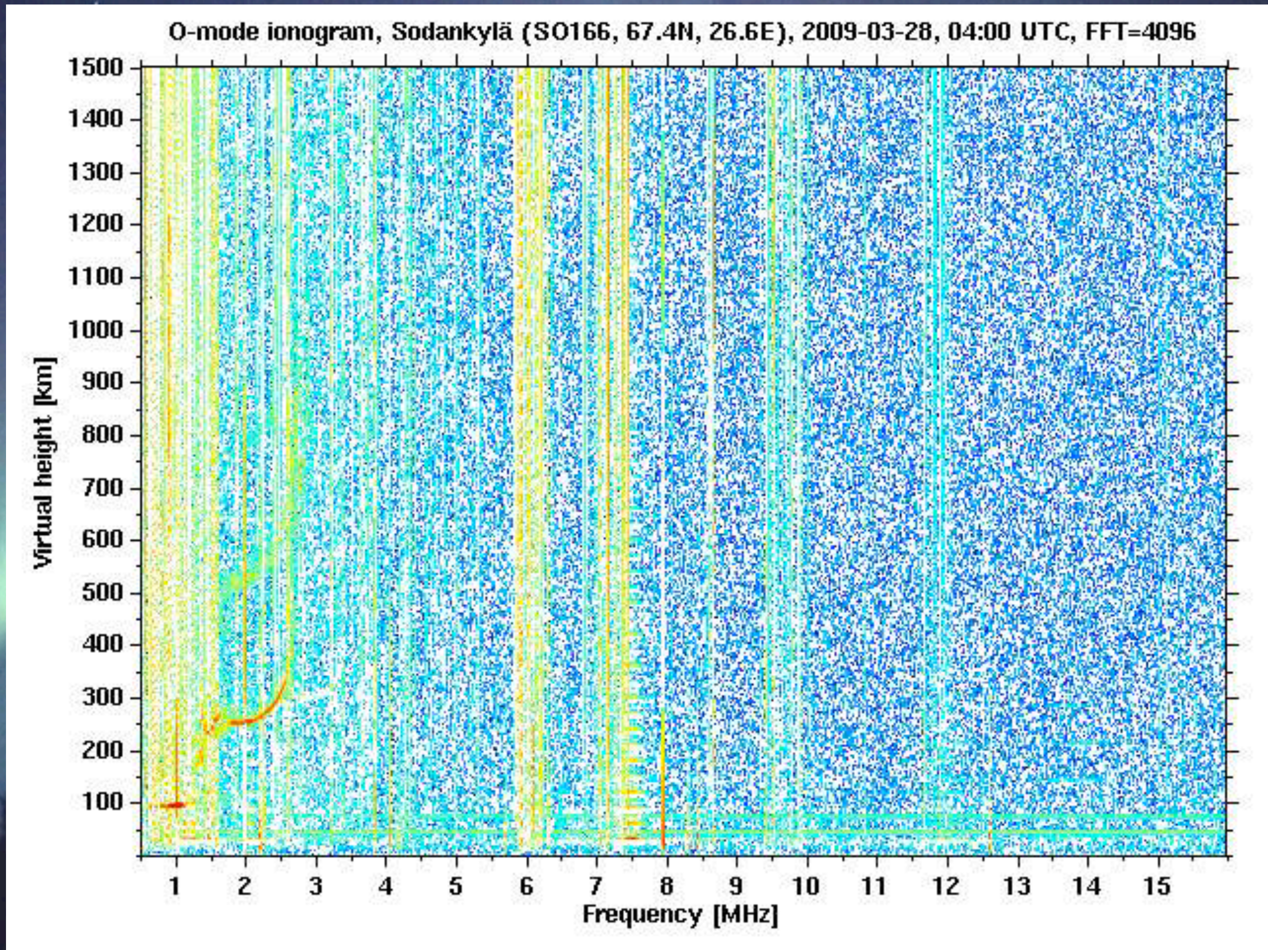
Sodankylä Ionosonde

- Sodankylä ionosonde measurements began 1st August 1957.
- Until Nov 2005: 1 sounding per 30 min.
- Until Mar 2007: 1 sounding per 10 min.
- IPY (Apr ´07-Mar ´08): 1 sounding per minute.
- April 2008: we forgot to turn off IPY mode.
- Millionth ionogram: before May 2007.
- High data quality:
  first 800.000+ ionograms were analysed by the very same person!

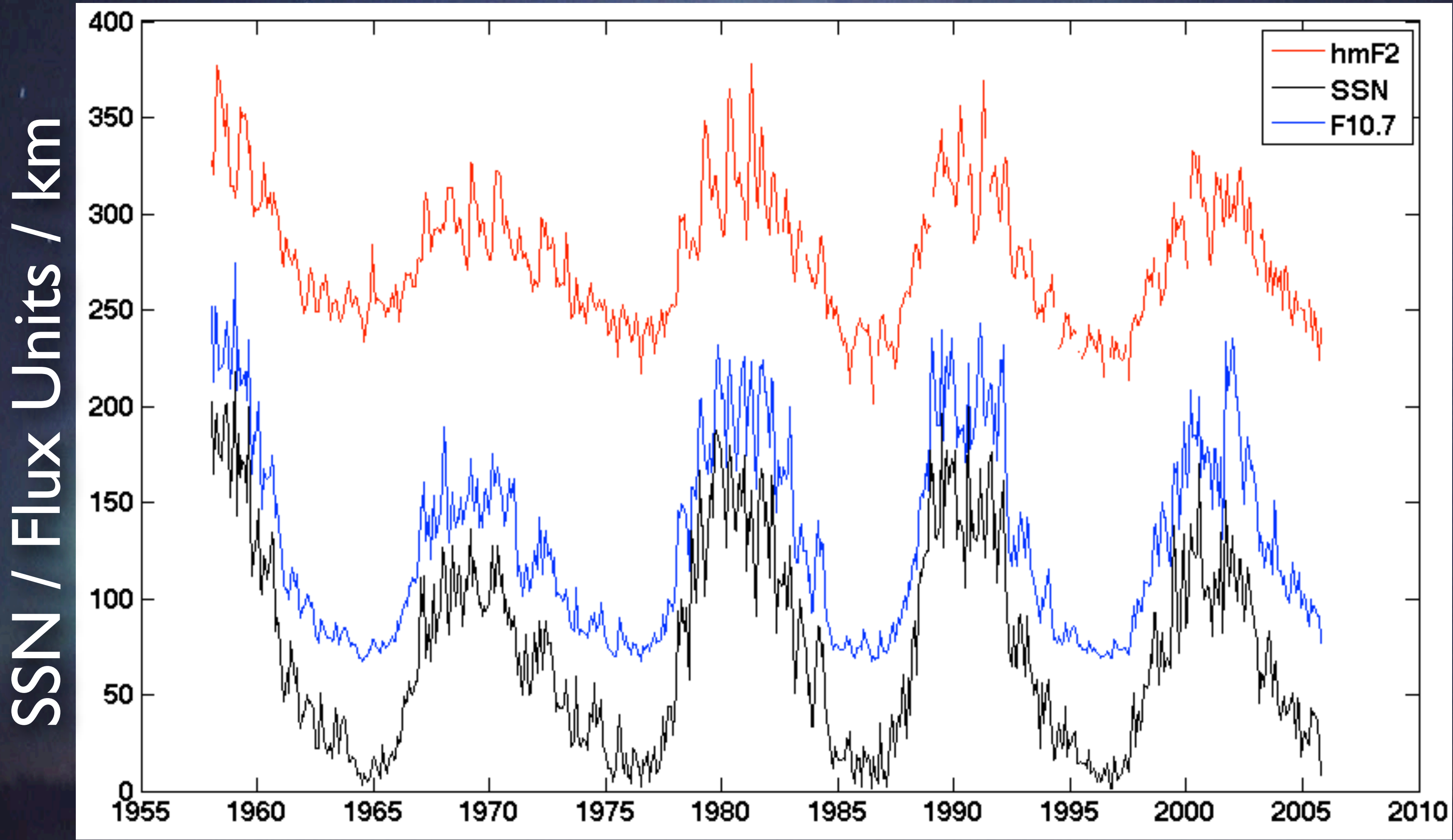
Sodankylä Ionosonde



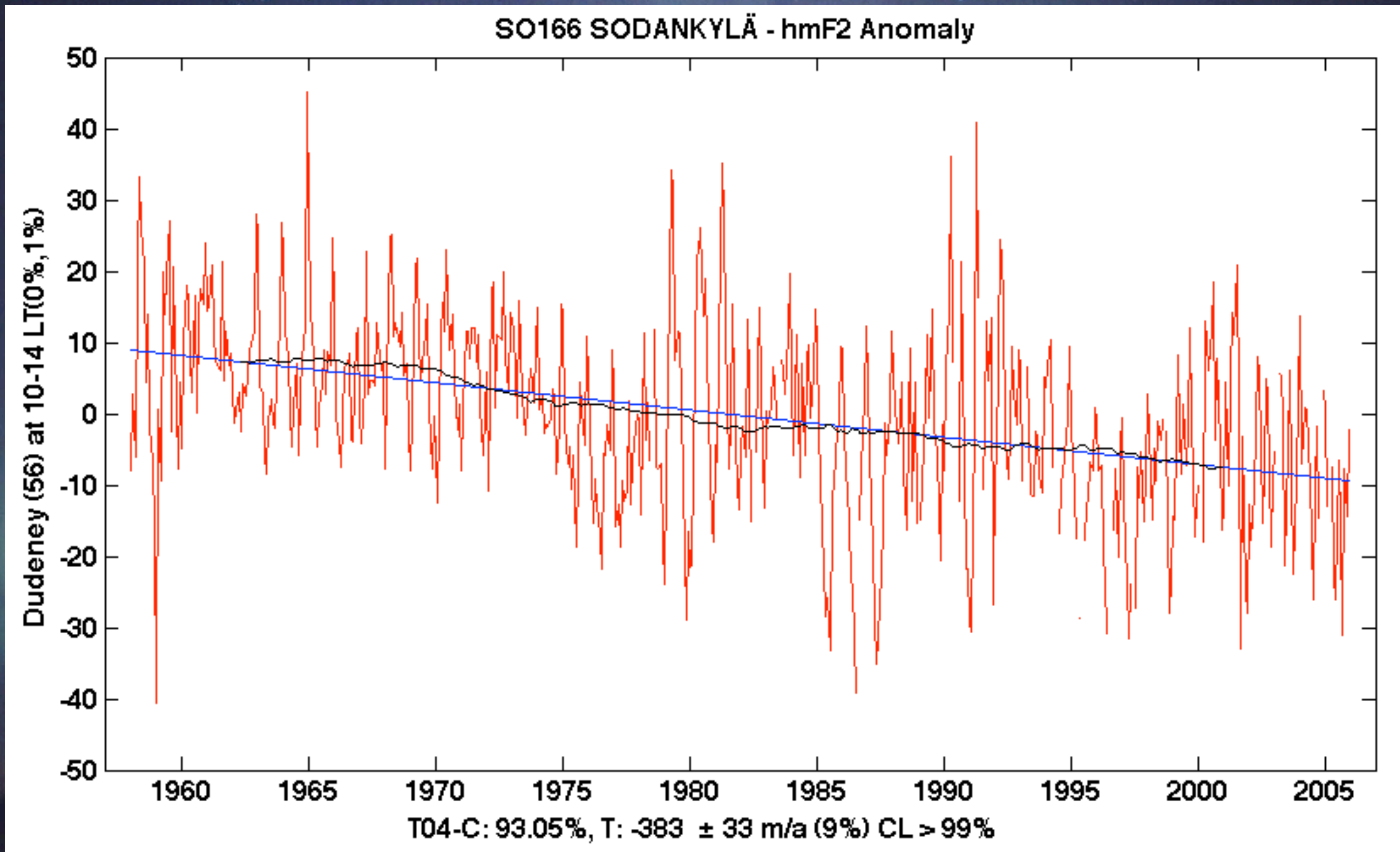
Sodankylä Ionosonde



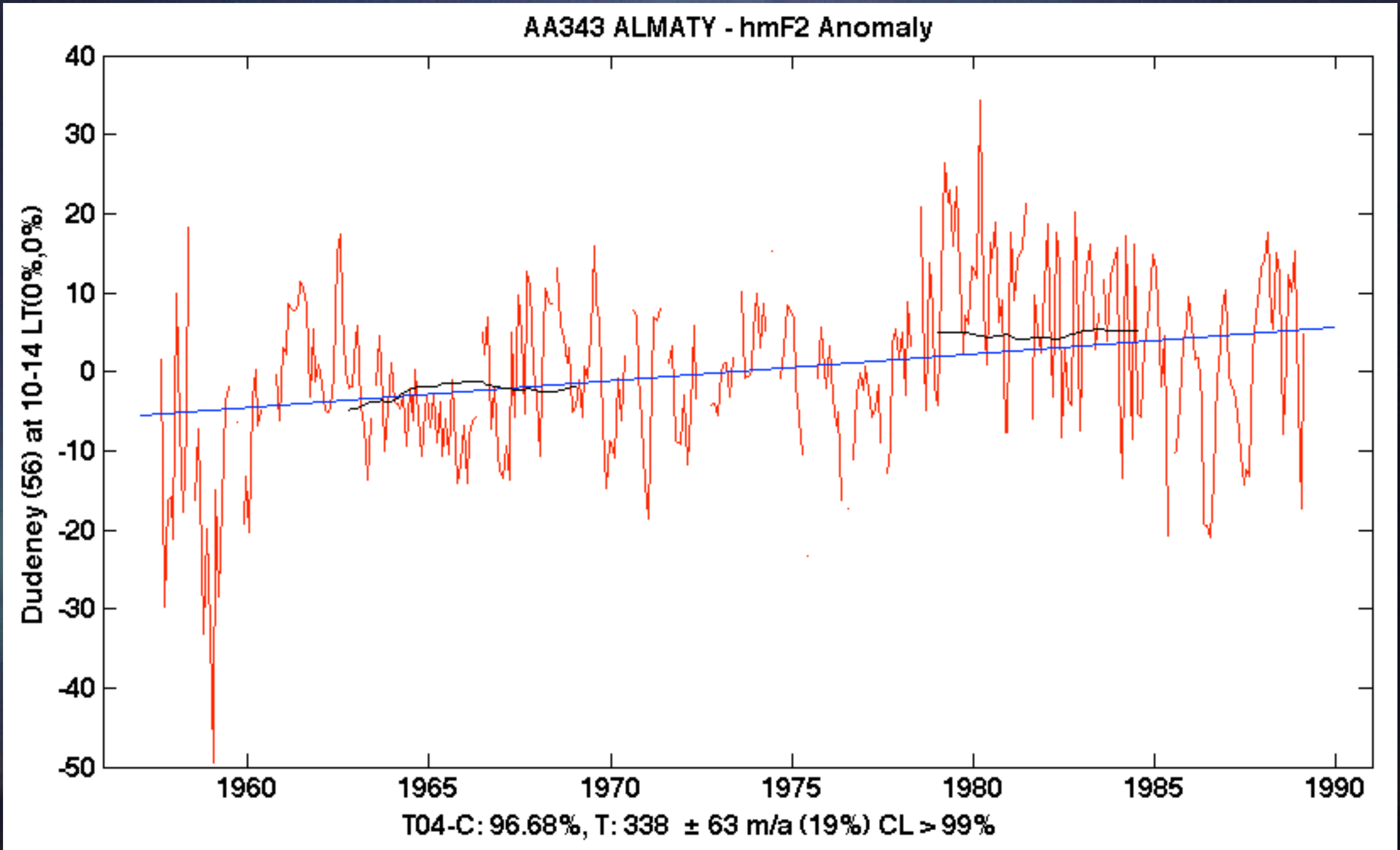
hmF2 & Solar Activity



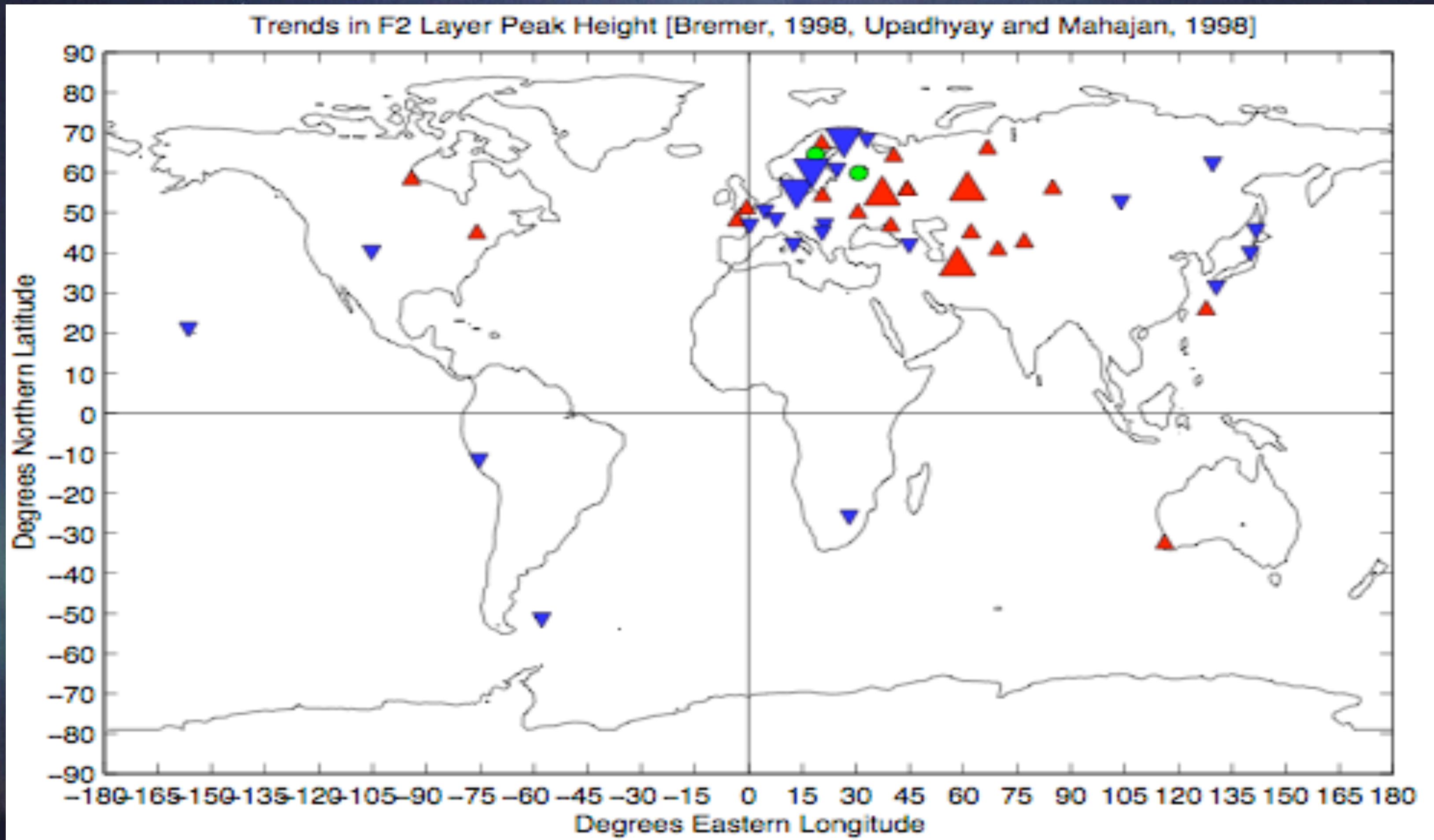
Sodankylä hmF2 Trend



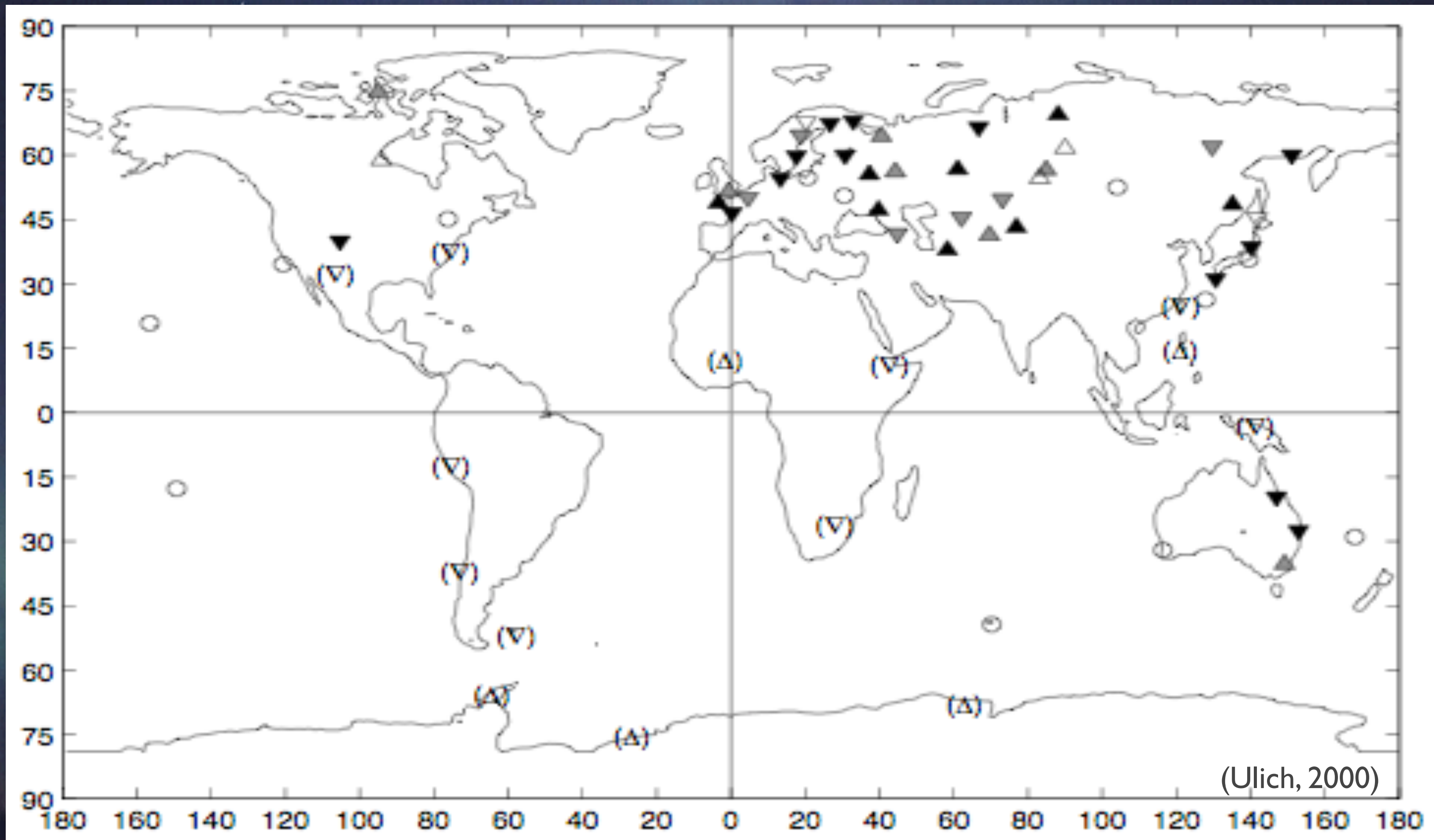
Almaty hmF2


AA343 ALMATY - hmF2 Anomaly
Dudeney (56) at 10-14 LT(0%,0%)
40
30
20
10
0
-10
-20
-30
-40
-50
1960
1965
1970
1975
1980
1985
1990
T04-C: 96.68%, T: 338 ± 63 m/a (19%) CL > 99%

hmF2 Trends


Trends in F2 Layer Peak Height [Bremer, 1998, Upadhyay and Mahajan, 1998]
Degrees Northern Latitude
Degrees Eastern Longitude
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
−180 −165 −150 −135 −120 −105 −90 −75 −60 −45 −30 −15 0 15 30 45 60 75 90 105 120 135 150 165 180

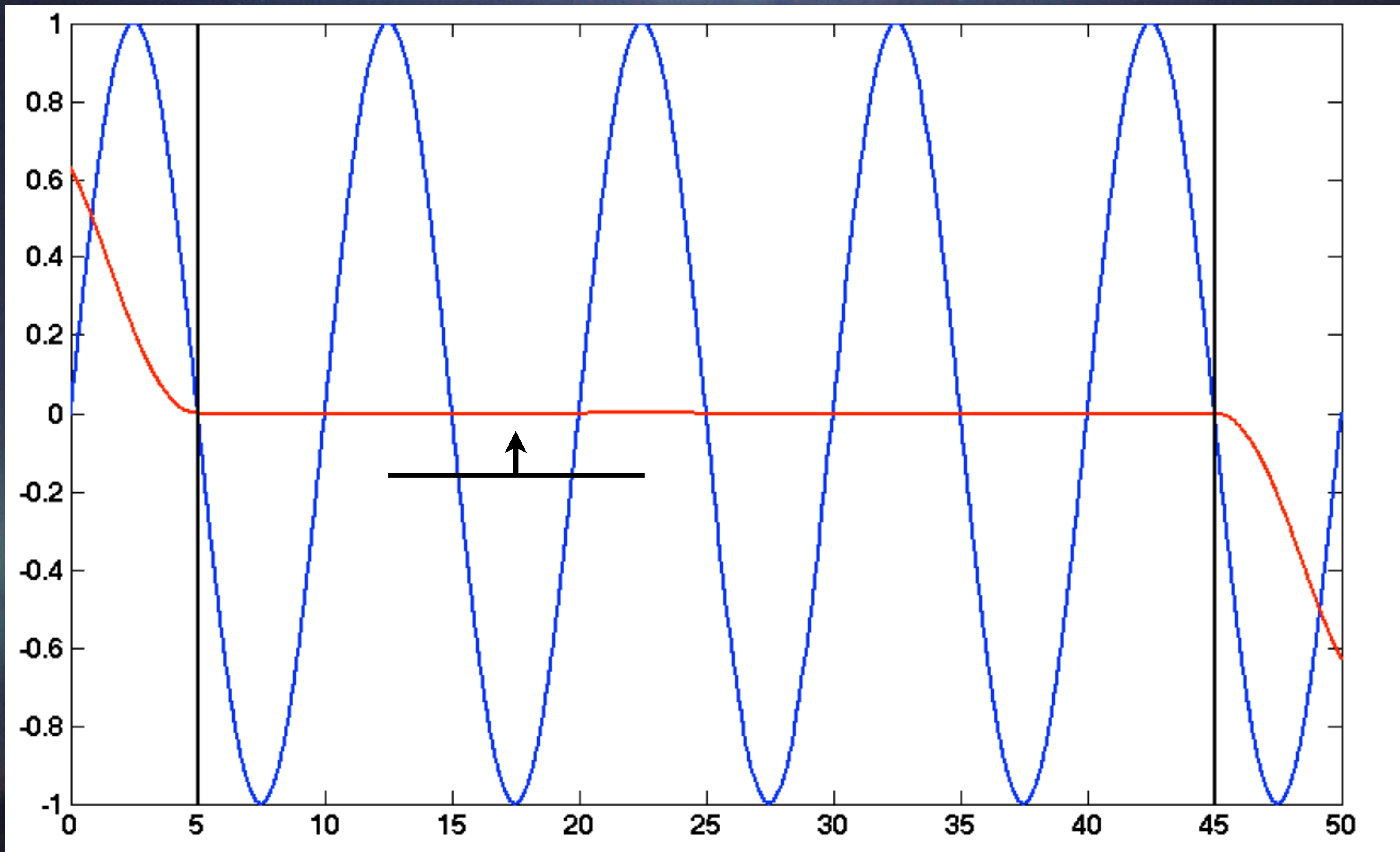
Global hmF2 Trends



Problems

- Data resolution (h, 3-h, day, month(?), ...)
- Low-pass filtering or polynomial fitting...

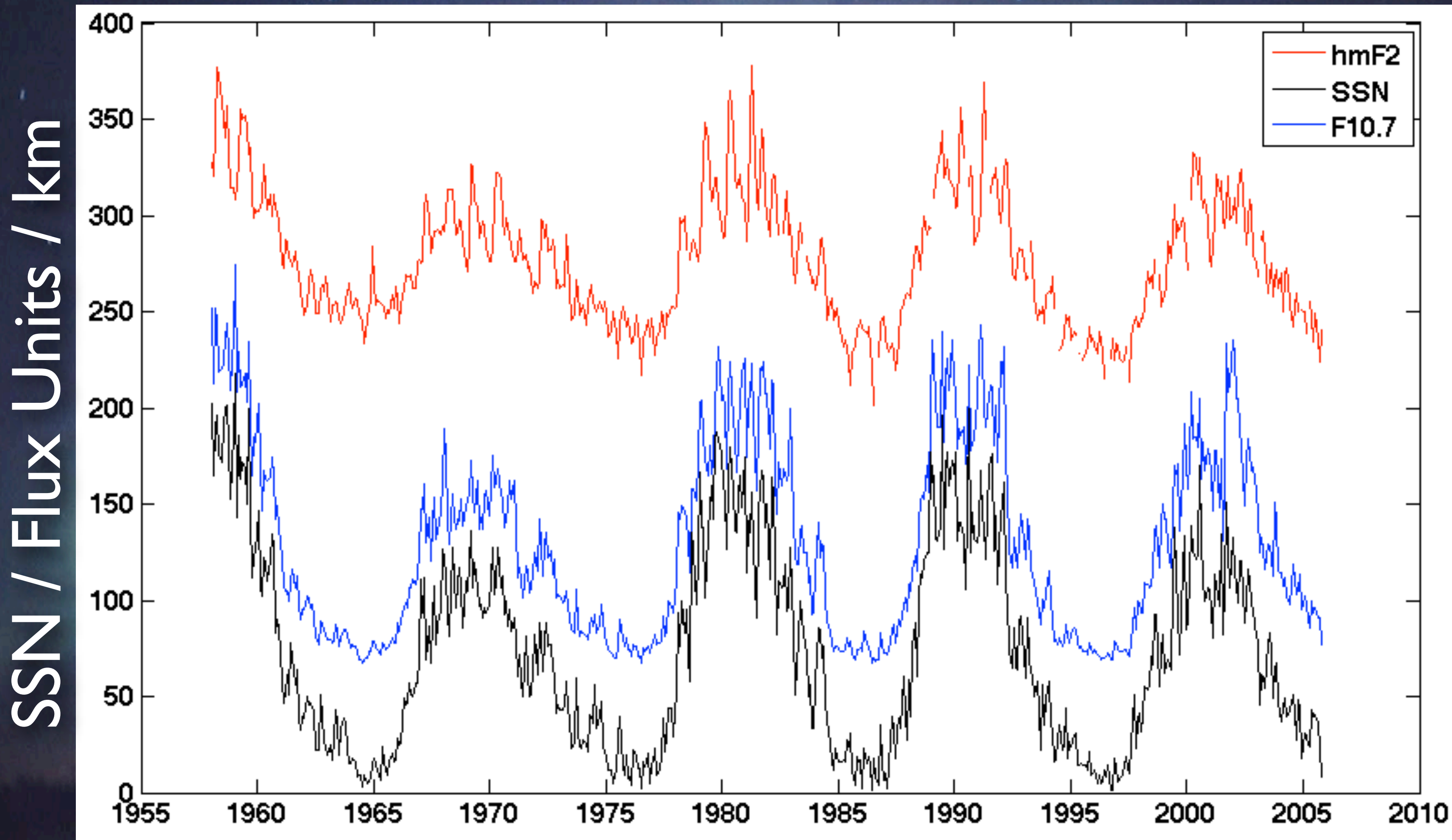
Running Mean Filter



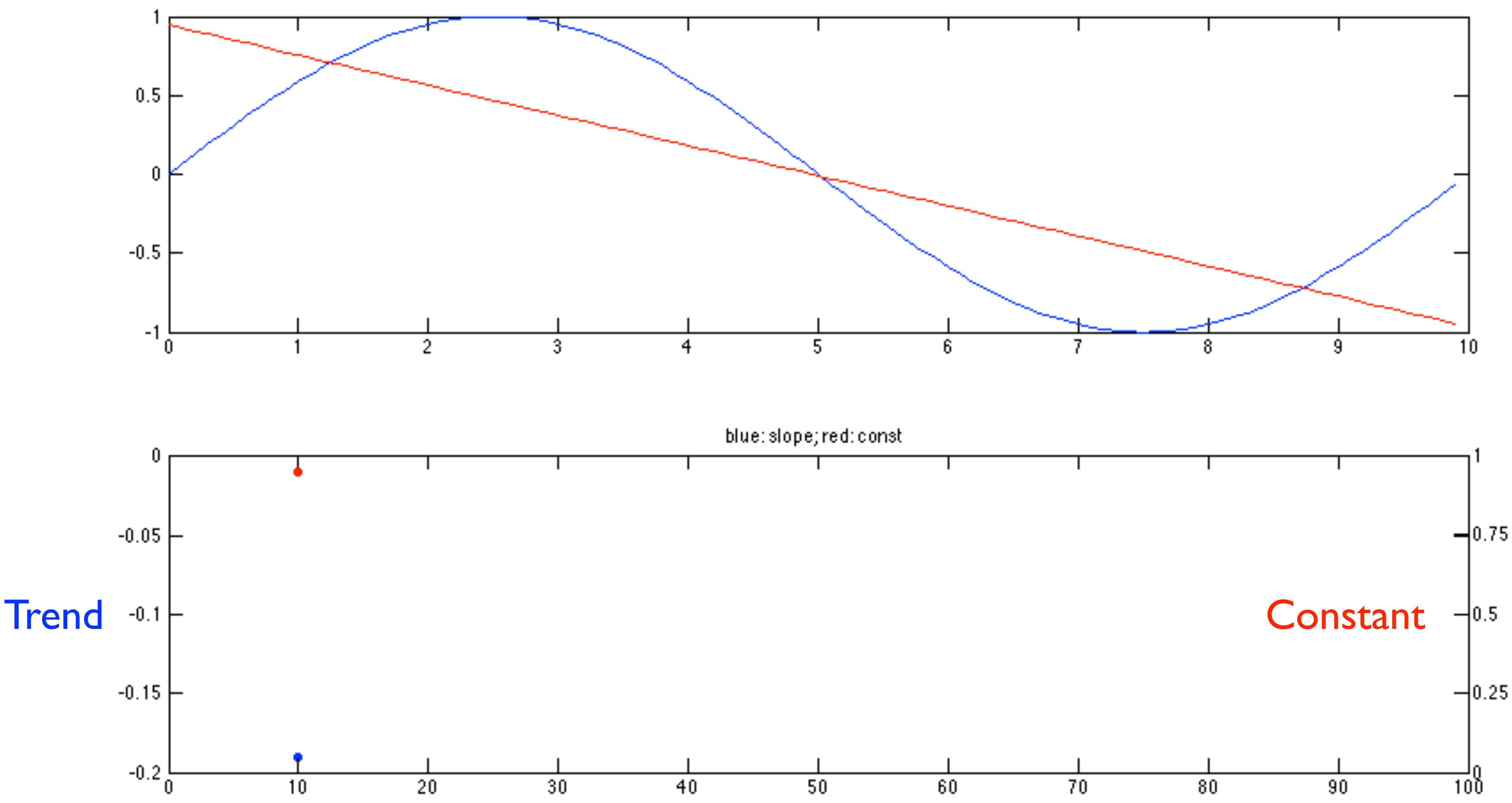
Problems

- Data resolution (h, 3-h, day, month(?), ...)
- Low-pass filtering or polynomial fitting...
- Removal of underlying (cyclic) variability:
  - Choice of proxy (sinusoid, SSN, Group SSN, F10.7 (adj./obs.), Ly-α, Mg II, E10.7, ...)
  - Resolution of proxy: compatibility with data

hmF2 & Solar Activity

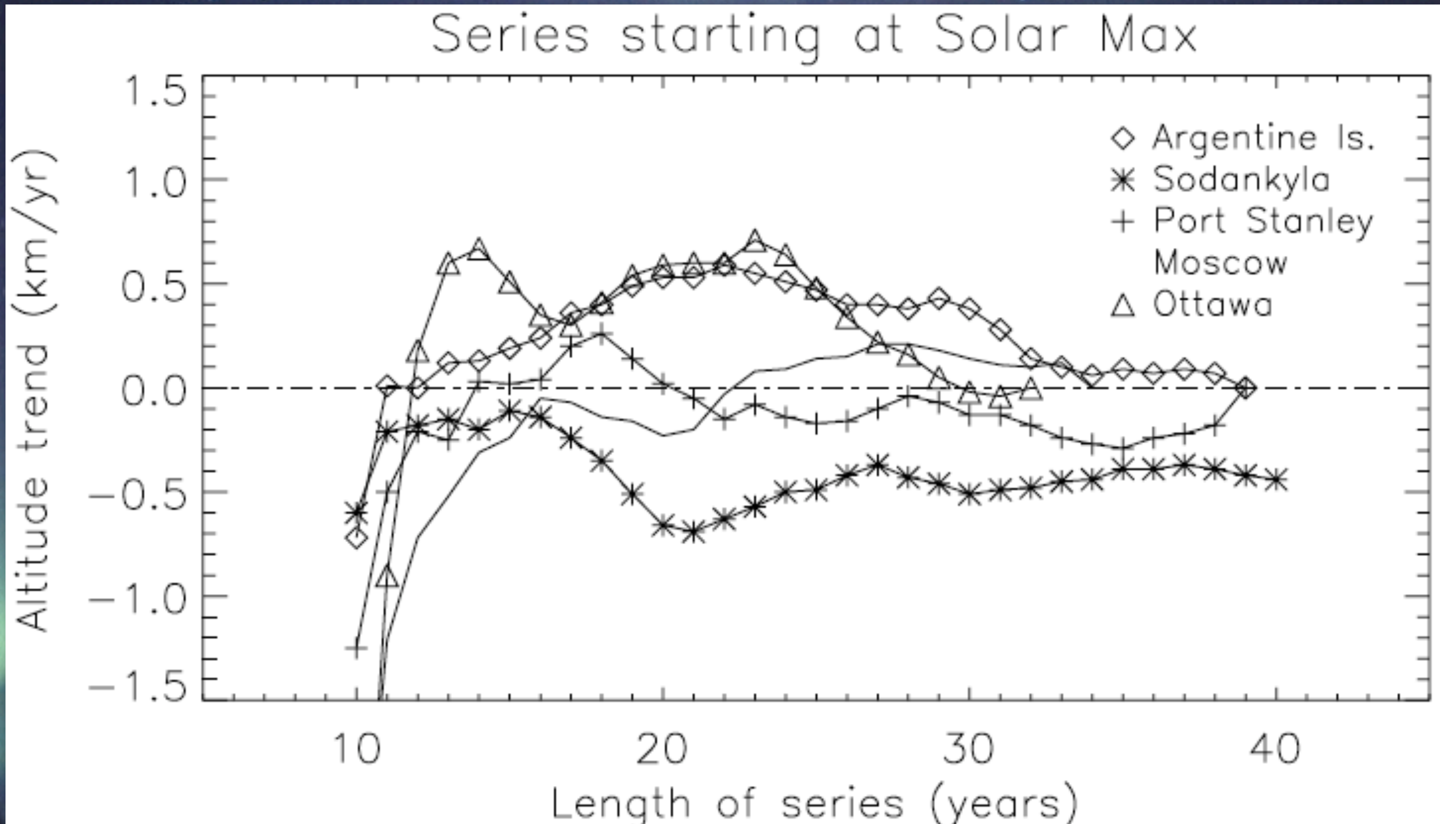


Ringing



1
0.5
0
-0.5
-1
0
1
2
3
4
5
6
7
8
9
10
blue: slope; red: const
0
-0.05
-0.1
-0.15
-0.2
0
10
20
30
40
50
60
70
80
90
100
1
0.75
0.5
0.25
0
Trend
Constant

Ringing



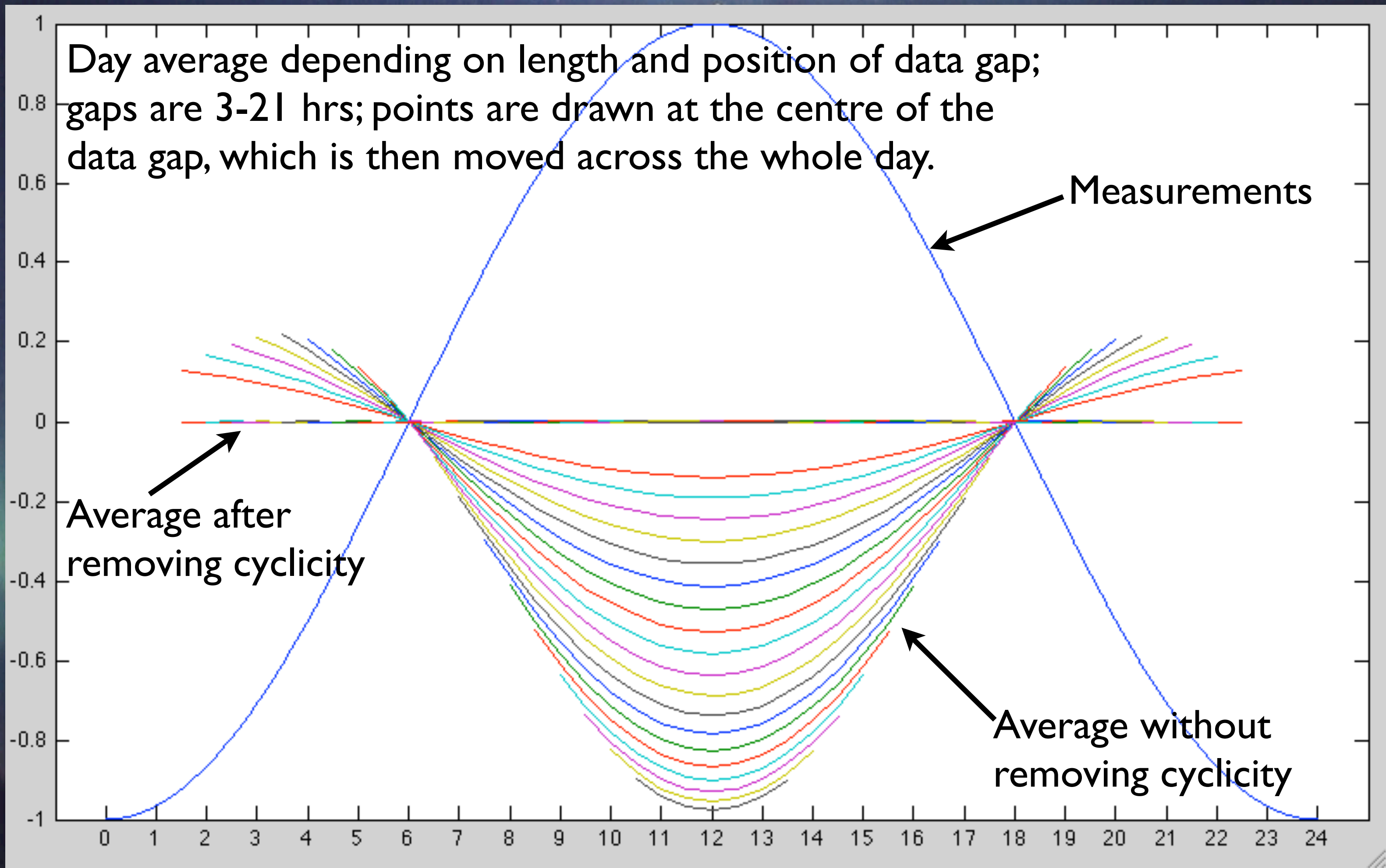
The ringing idea was first introduced by Jarvis et al., 2002. The plots shown here are from a follow-up paper by Clilverd et al., 2003.

Problems

- Data resolution (h, 3-h, day, month(?), ...)
- Low-pass filtering or polynomial fitting...
- Removal of underlying (cyclic) variability: ...
- Data gaps

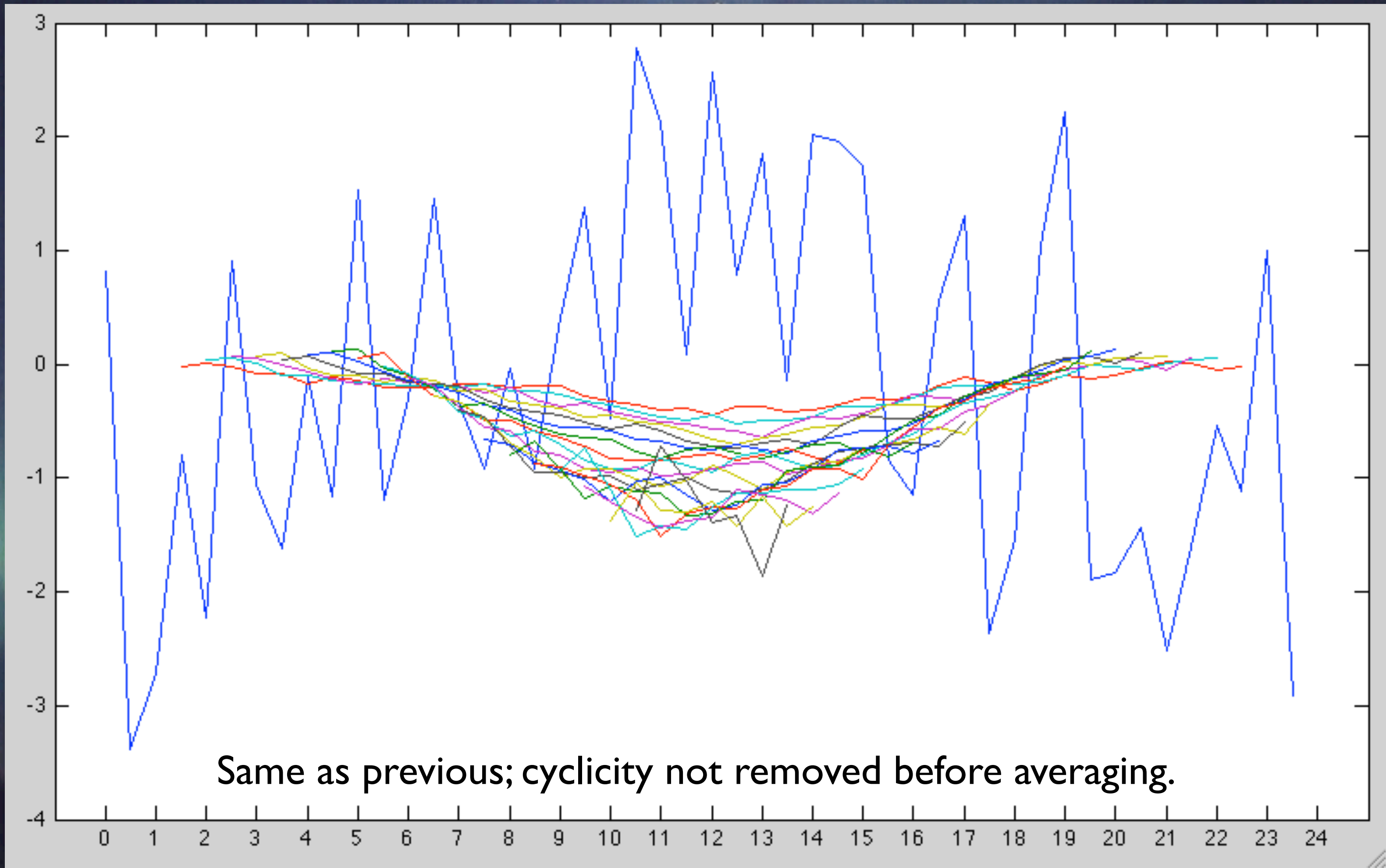
Example: Data Gaps

Data Gaps



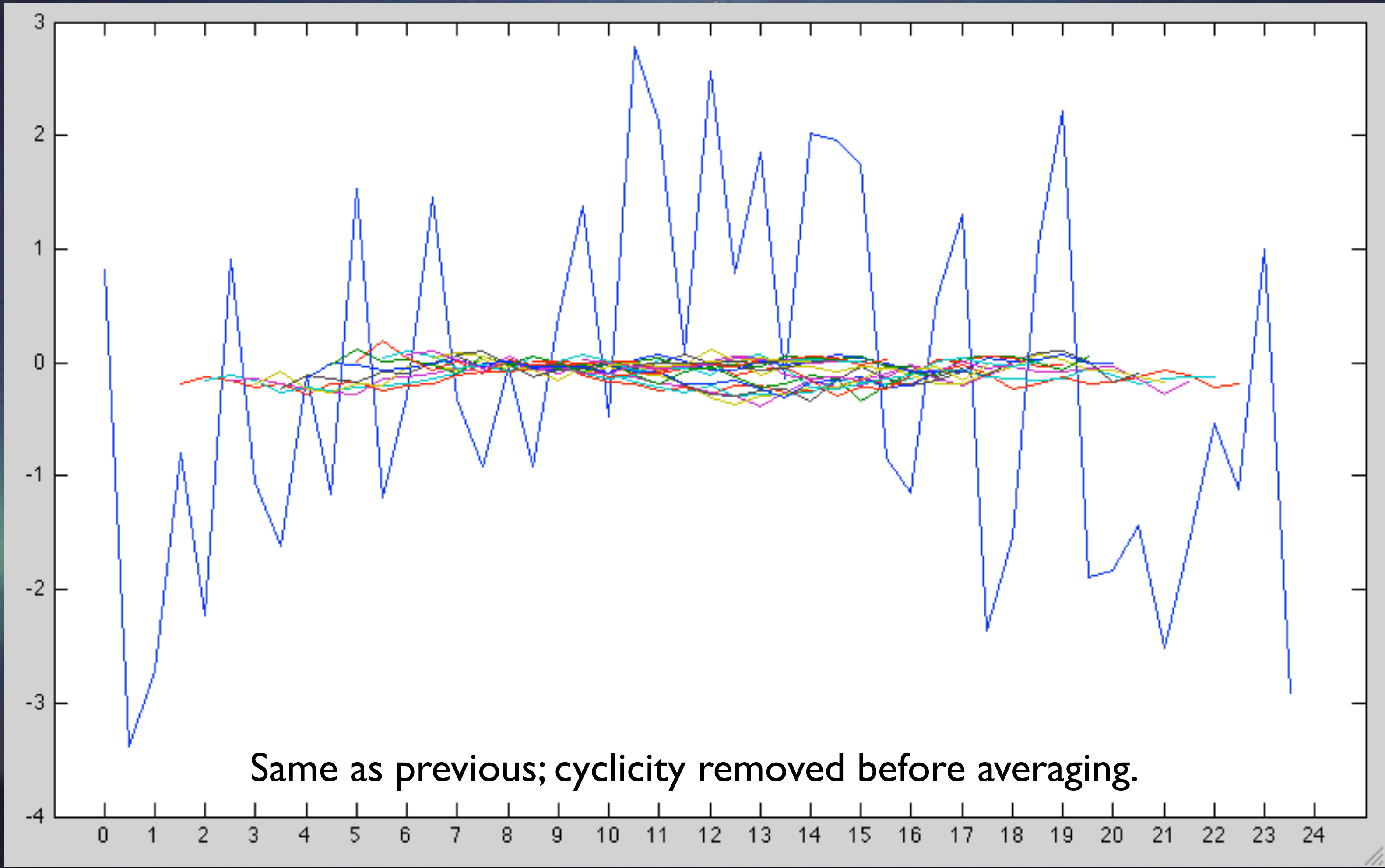
Day average depending on length and position of data gap;
gaps are 3-21 hrs; points are drawn at the centre of the
data gap, which is then moved across the whole day.
Measurements
Average after
removing cyclicity
Average without
removing cyclicity
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Data Gaps



Same as previous; cyclicity not removed before averaging.

Data Gaps



Same as previous; cyclicity removed before averaging.

Problems

- Data resolution (h, 3-h, day, month(?), ...)
- Low-pass filtering or polynomial fitting...
- Removal of underlying (cyclic) variability: ...
- Data gaps
- Measurement errors
- Mathematics of trend detection
  - stepwise or multi-parameter fit
  - error propagation

Making models

- Base functions of the model(s) are, e.g.:

$m_i = \varepsilon_i$	-> measurement errors
$+ x_1$	-> constant
$+ x_2 t_i$	-> sampling times
$+ x_3 F_{10.7}(t_i)$	-> solar activity
$+ x_4 Ap(t_i)$	-> geomagnetic activity
$+ x_5 \sin(2\pi t_i)$	
$+ x_6 \cos(2\pi t_i)$	-> annual variation
$+ x_7 \sin(4\pi t_i)$	
$+ x_8 \cos(4\pi t_i)$	-> semi-annual variation
$+ \ldots$	

Modelling the data

The ionospheric property of interest is function of time and a number of other parameters. The model of the data is therefore

$$m(t) = \mathcal{F}(t, x_1, \ldots, x_M)$$

where

$$\mathcal{F}(t, x_1, \ldots, x_M) = \sum_{i=1}^{M} x_i\, f_i(t)$$

The actual measurements m_i observed at time t_i are equal to the model plus some measurement error ε_i

$$m_i = \mathcal{F}(t_i, x_1, \ldots, x_M) + \varepsilon_i$$

Inverse problem I

This can be expressed as a matrix equation. Usually there are many more data points than unknowns x_i and the problem is over-determined:

$$\begin{pmatrix} m_1 \\ m_2 \\ \vdots \\ m_N \end{pmatrix} = \begin{pmatrix} f_1(t_1) & f_2(t_1) & \cdots & f_M(t_1) \\ f_1(t_2) & f_2(t_2) & \cdots & f_M(t_2) \\ \vdots & \vdots & \ddots & \vdots \\ f_1(t_N) & f_2(t_N) & \cdots & f_M(t_N) \end{pmatrix} \cdot \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{pmatrix} + \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_N \end{pmatrix}$$

In other words:

$$\mathbf{m} = \mathbf{A} \cdot \mathbf{x} + \varepsilon$$

Inverse problem II

Measurements and theory are weighted by the measurement errors:

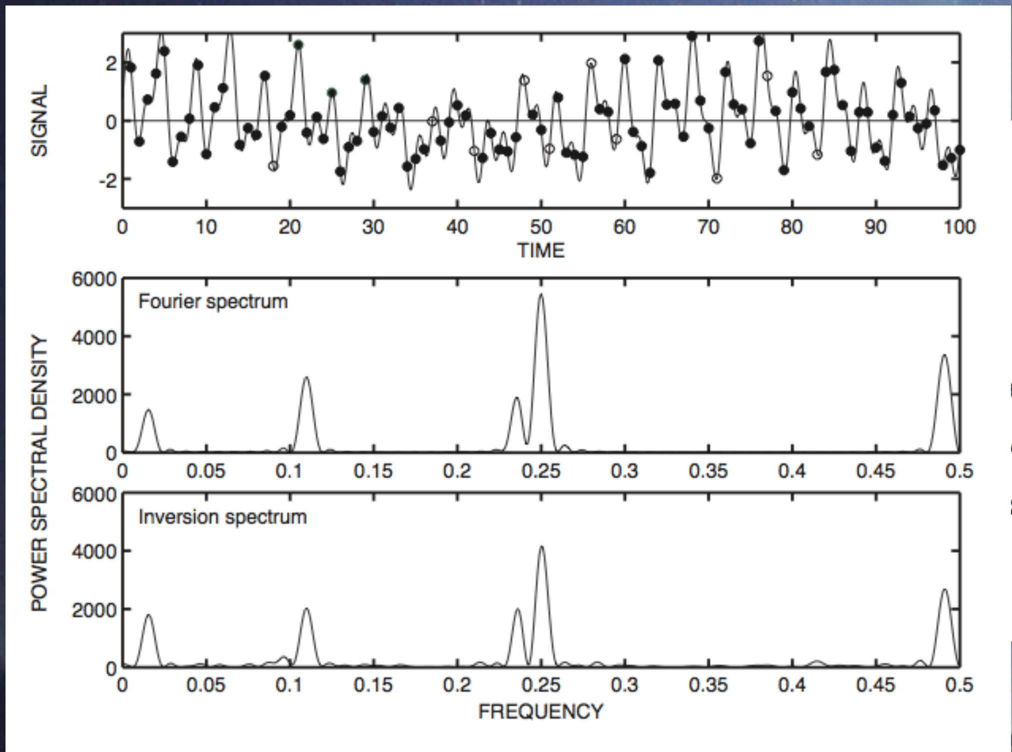
$$B_{ij} := \frac{A_{ij}}{\varepsilon_i} \quad \text{and} \quad b_i := \frac{m_i}{\varepsilon_i}$$

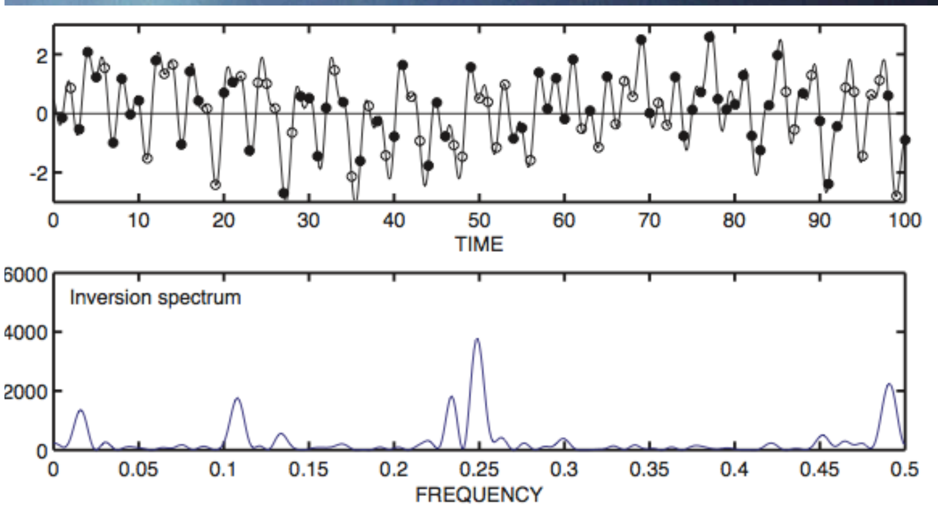
The solution is the vector **x**, which minimises the following expression:

$$\chi^2 = |\mathbf{B} \cdot \mathbf{x} - \mathbf{b}|^2$$

We are left with a general least squares problem. Solving this results in the most probable solution for **x**.

Signal Spectrum by Stochastic Inversion



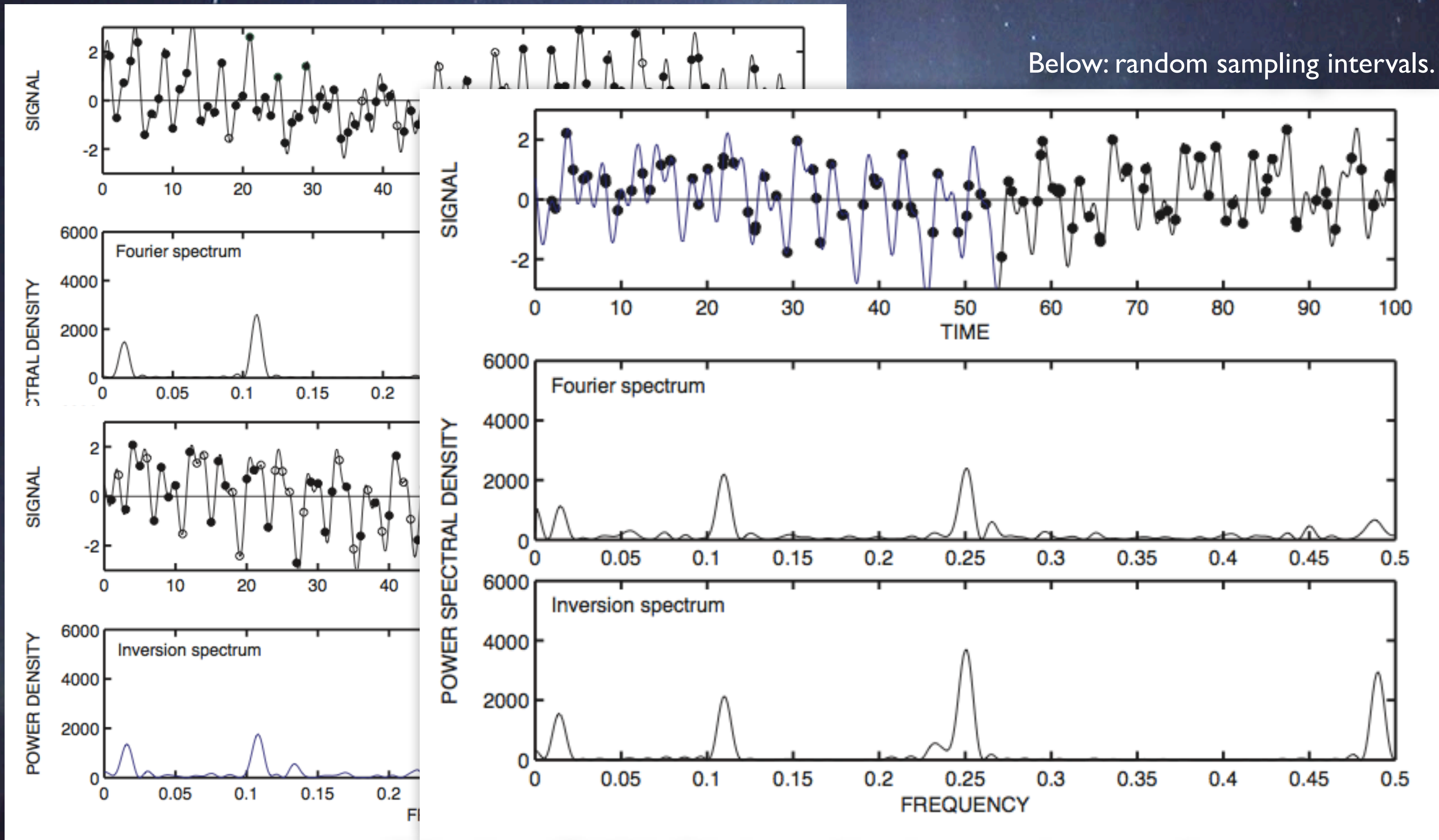


Left: 100 pts for Fourier, 90 for inversion.
Above: 59 pts.

T. Nygrén and Th.Ulich, Calculation of signal spectrum by means of stochastic inversion, Ann. Geophys., 28, 1409-1418, 2010.

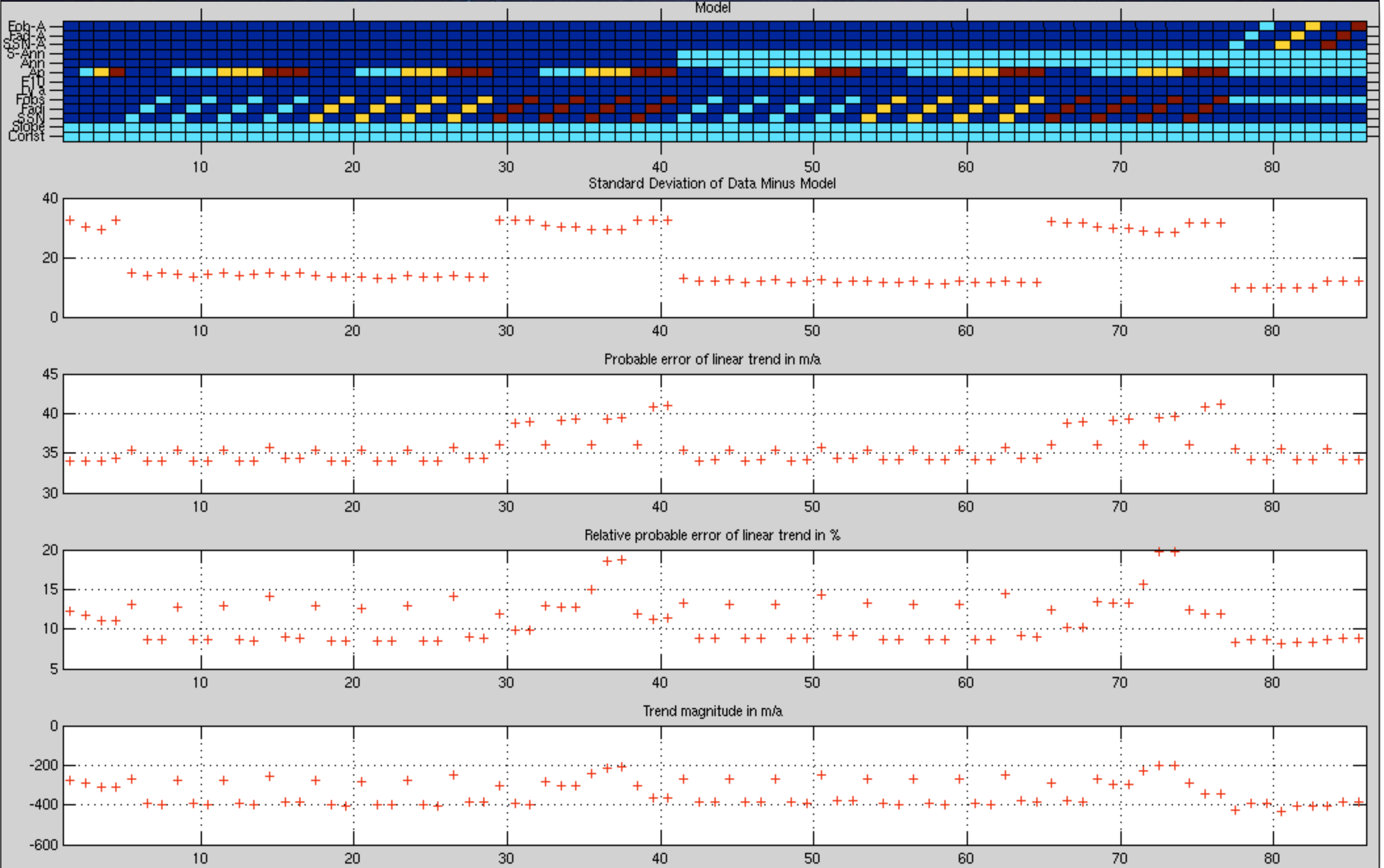
Signal Spectrum by Stochastic Inversion

Below: random sampling intervals.



T. Nygrén and Th.Ulich, Calculation of signal spectrum by means of stochastic inversion, Ann. Geophys., 28, 1409-1418, 2010.

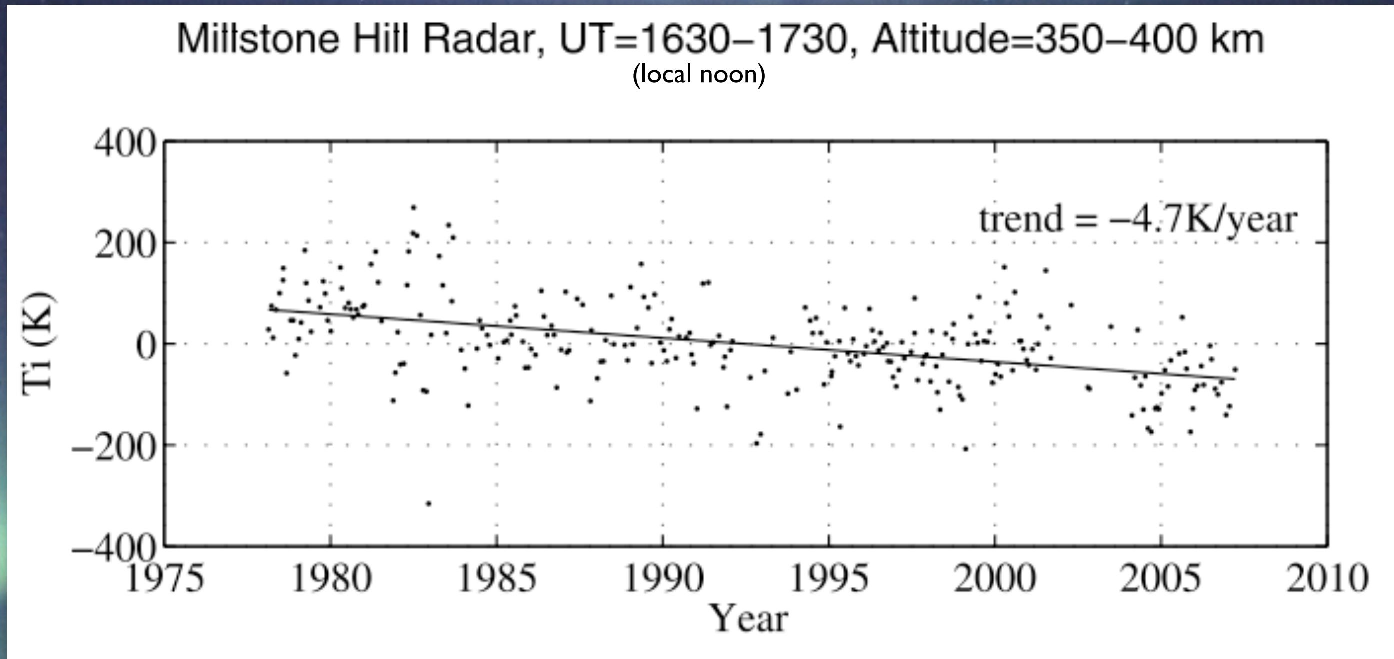
Sodankylä F2-layer peak height hmF2



Trends in other Observations

Height in km	Method	Parameter	Trend per Year	Reference
75	Sounding rocket	Temperature	-0.6 K	Kokin and Lysenko, 1994
70	Sounding rocket	Temperature	-0.7 K	Golitsyn et al., 1996
60-70	Lidar	Temperature	-0.4 K	Hauchecorne et al., 1991
60	Sounding rocket	Temperature	-0.4 K	Golitsyn et al., 1996
60	Sounding rocket	Temperature	-0.33 K	Keckhut et al., 1999
50-60	Lidar	Temperature	-0.25 K	Aikin et al., 1991
50	Sounding rocket	Temperature	-0.25 K	Golitsyn et al., 1996
40	Sounding rocket	Temperature	-0.1 K	Golitsyn et al., 1996
30-60	Sounding rocket	Temperature	-0.17 K	Dunkerton et al., 1998
30-50	Sounding rocket	Temperature	-0.17 K	Keckhut et al., 1999
30	Sounding rocket	Temperature	-0.1 K	Golitsyn et al., 1996
25	Sounding rocket	Temperature	-0.1 K	Golitsyn et al., 1996
25	Sounding rocket	Temperature	-0.11 K	Keckhut et al., 1999

Direct F-Region Temperature



Long-term temperature trends in the ionosphere above Millstone Hill

J. M. Holt[1] and S. R. Zhang[1]

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L05813, doi:10.1029/2007GL031148, 2008

Conclusion

(the last one, I promise!)

- Definitely, there's long-term change in the ionosphere and thermosphere!
- The enhanced greenhouse effect is probably a part of it.
- Other (unknown?) processes are involved.
- Solution in modelling?
- We don't understand what's going on.
- Student exercise: Find out!

Conclusion

(I lied to you!)

Ionsondes, originally deployed for monitoring ionospheric conditions for HF radio communication and for studying short-term events, are becoming useful in an <u>environmental context</u>.

They provide long-term measurements of our environment!

Do not discontinue atmospheric observations at a time of climate change!