Variability of the Northern Annular Mode…

…and its relationship to momentum and heat fluxes in the troposphere and lower stratosphere

Ich erlerne es sehr schnell

Signature time series of the Northern Annular Mode

- Spatial pattern defined as the leading unrotated EOF of 90-day low-pass filtered geopotential on mandatory pressure levels
- Spatial pattern projected onto unfiltered daily geopotential on each pressure level
- Time series of NAM index at each level is analogous but not identical to principal component time series

GET IT HERE

- Time series of the Northern Annular Mode index are available at the home page of the famous scientist shown at right…

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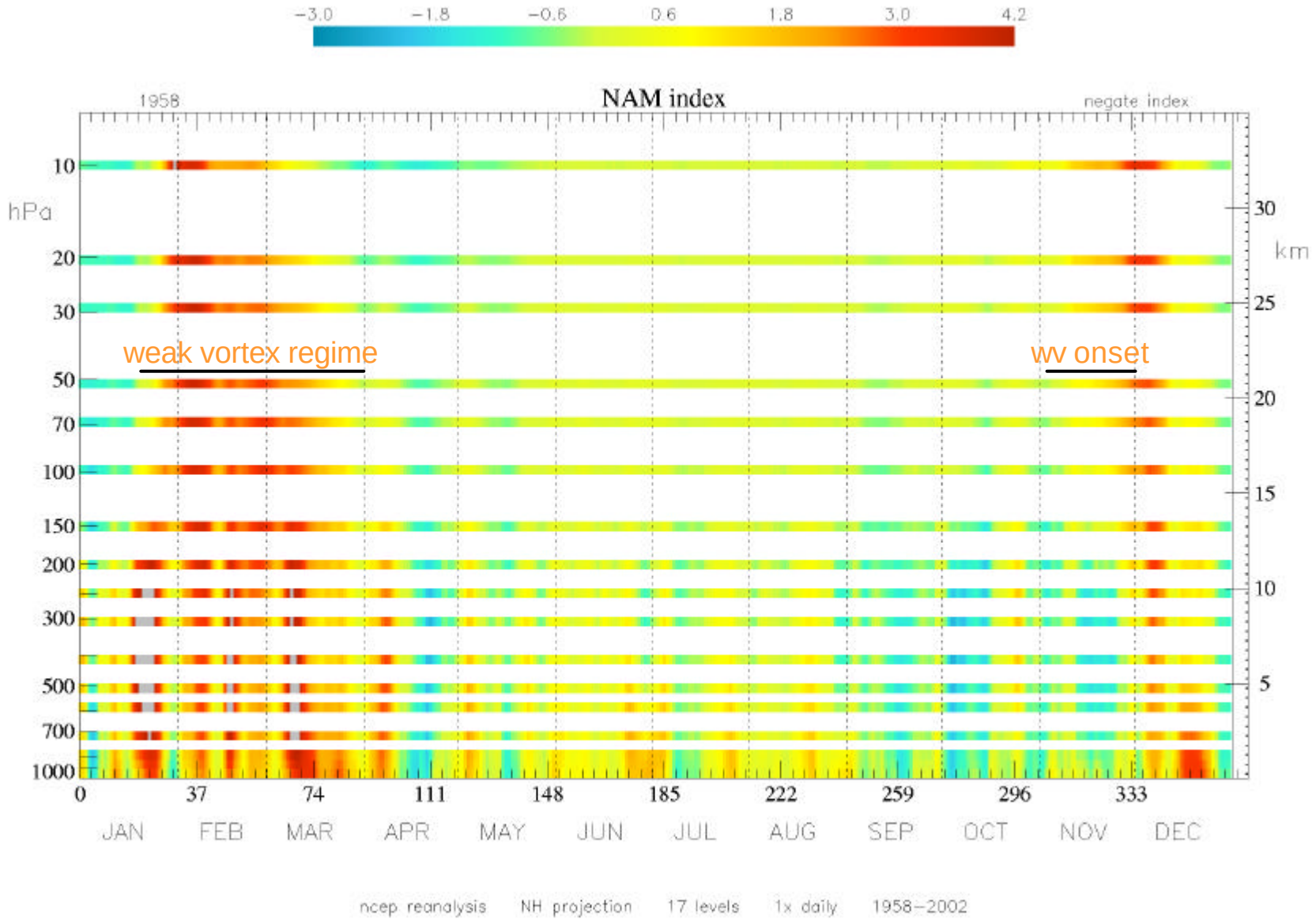
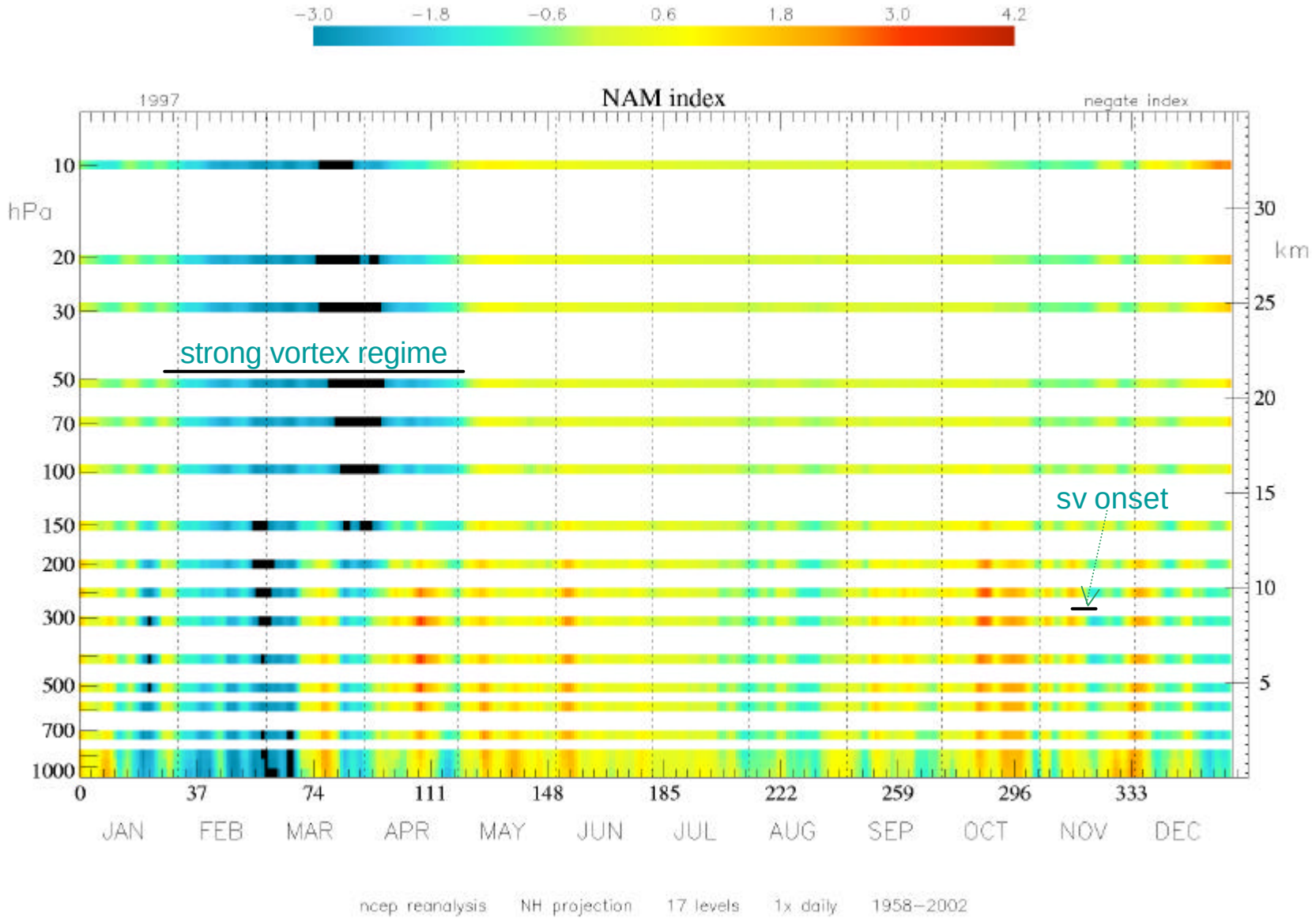

−3.0
−1.8
−0.6
0.6
1.8
3.0
4.2
1958
NAM index
negate index
hPa
km
10
20
30
50
70
100
150
200
300
500
700
1000
30
25
20
15
10
5
weak vortex regime
wv onset
0
37
74
111
148
185
222
259
296
333
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
ncep reanalysis
NH projection
17 levels
1x daily
1958–2002


−3.0
−1.8
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0.6
1.8
3.0
4.2
1997
NAM index
negate index
hPa
km
10
20
30
50
70
100
150
200
300
500
700
1000
30
25
20
15
10
5
strong vortex regime
sv onset
0
37
74
111
148
185
222
259
296
333
JAN
FEB
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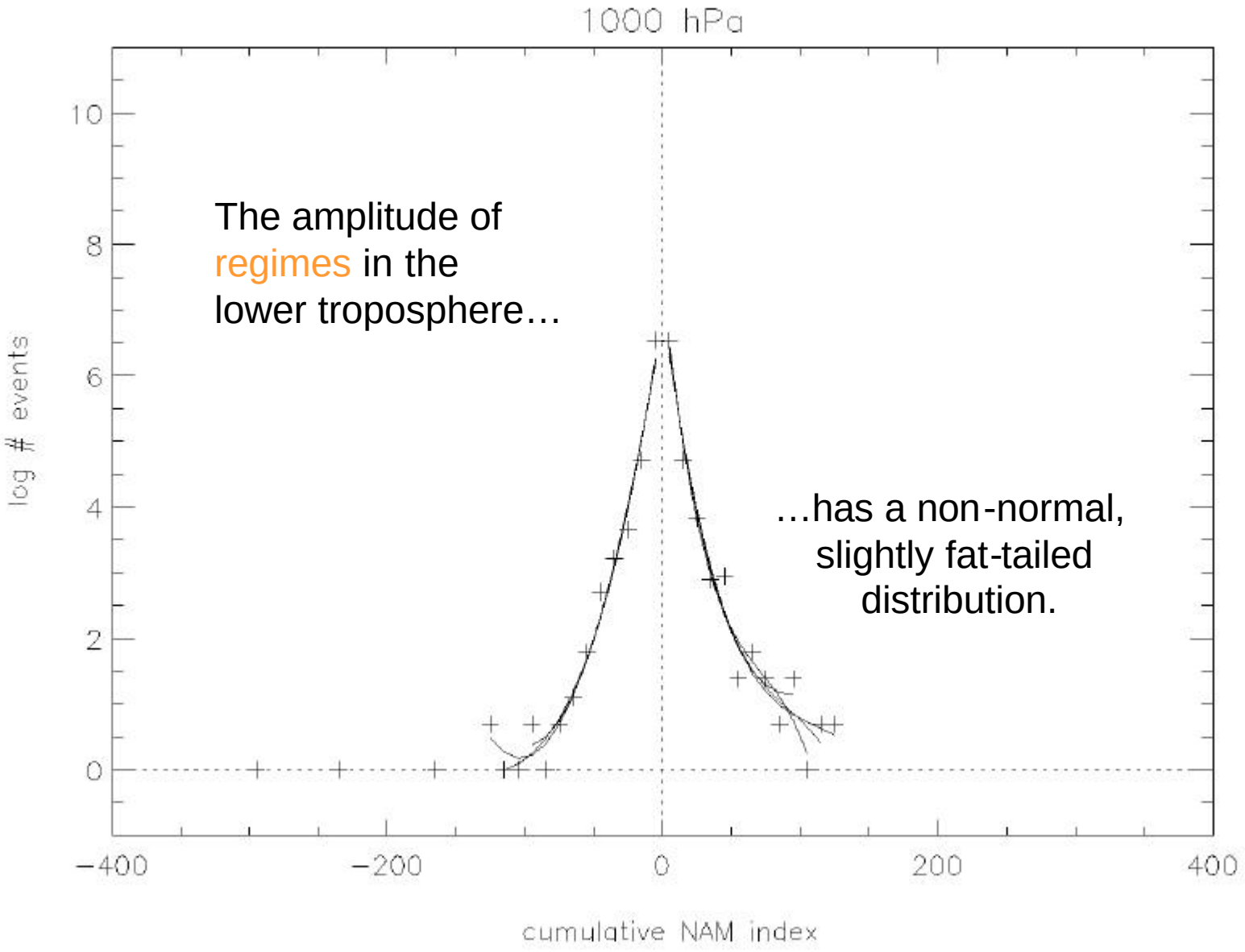
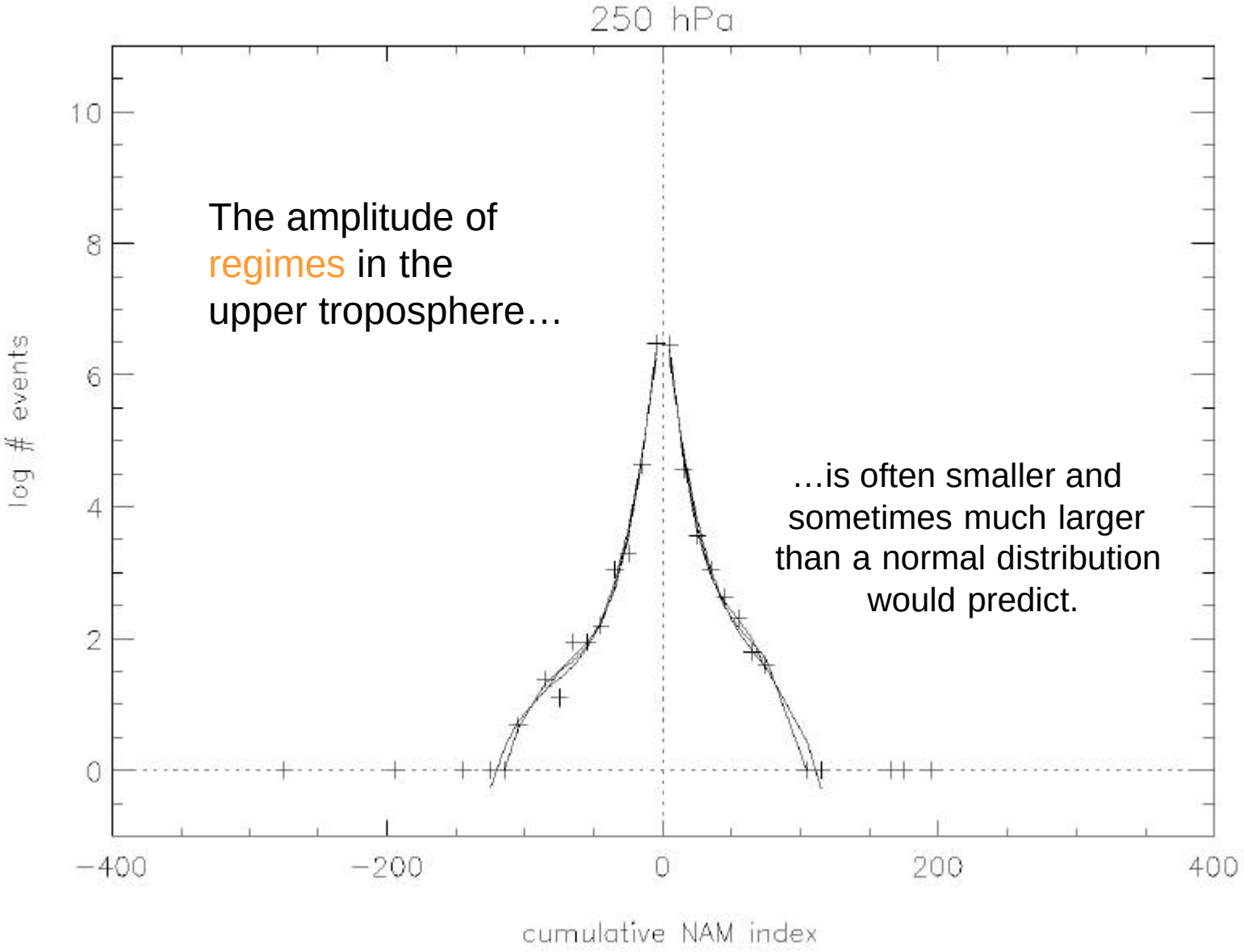
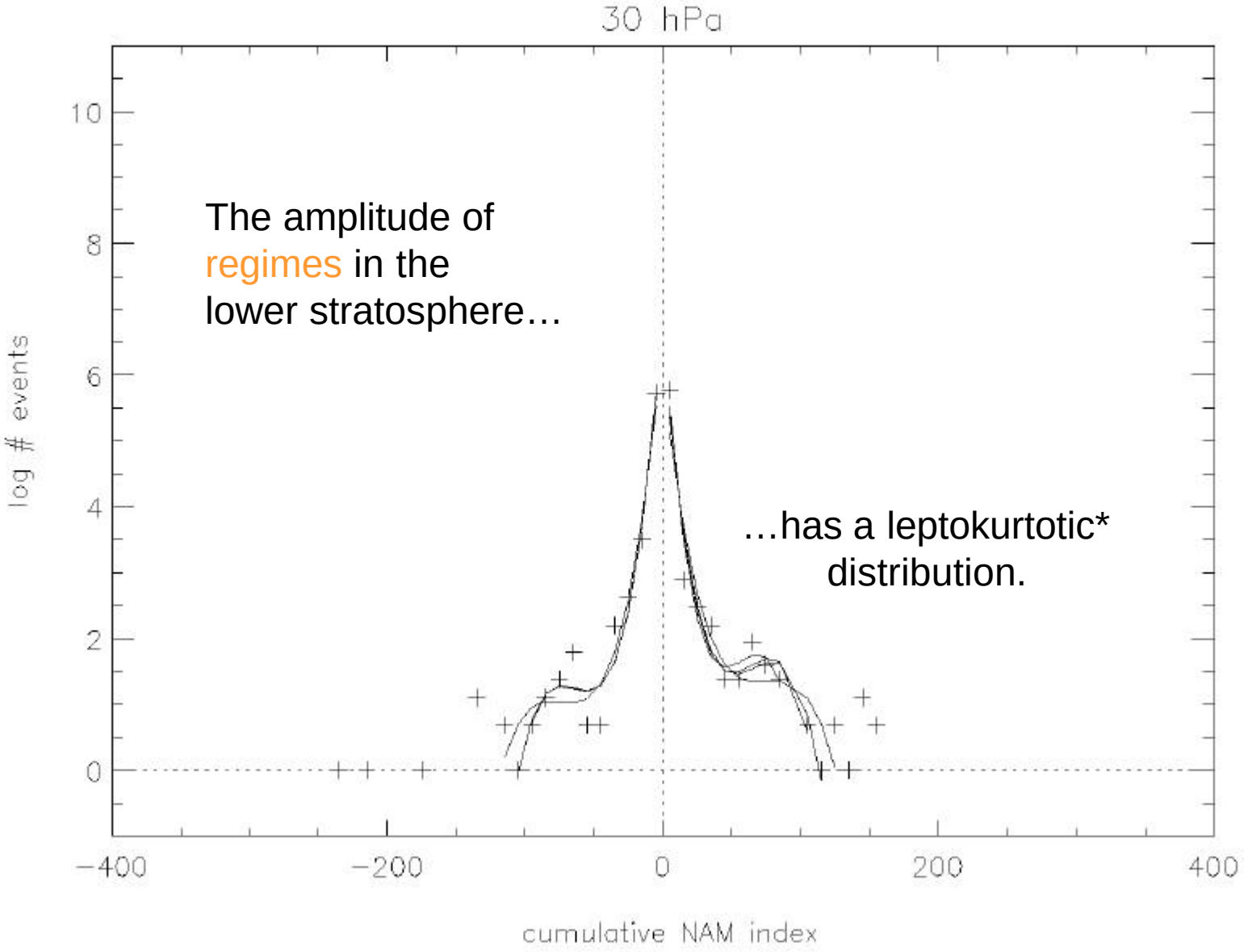
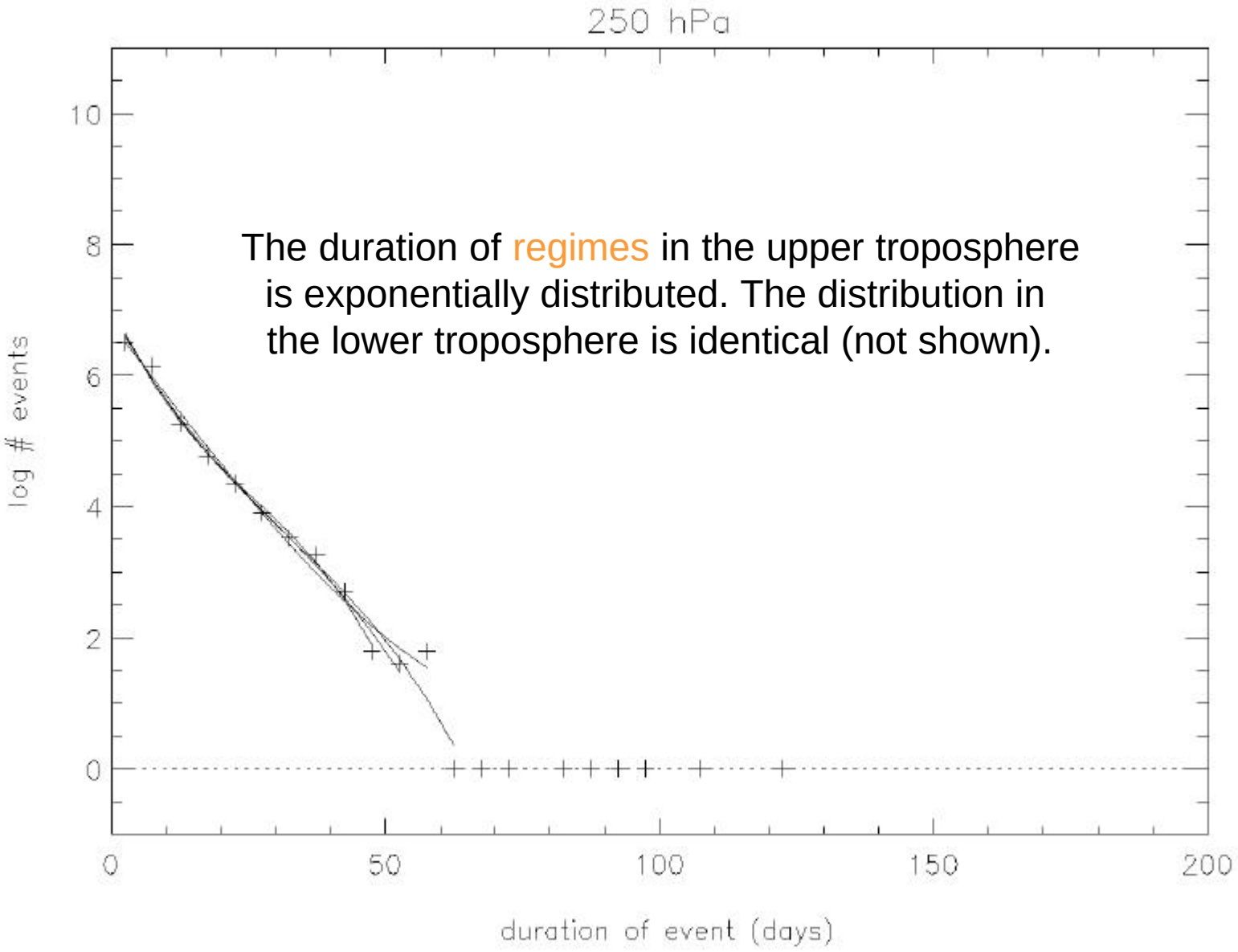
17 levels
1x daily
1958–2002

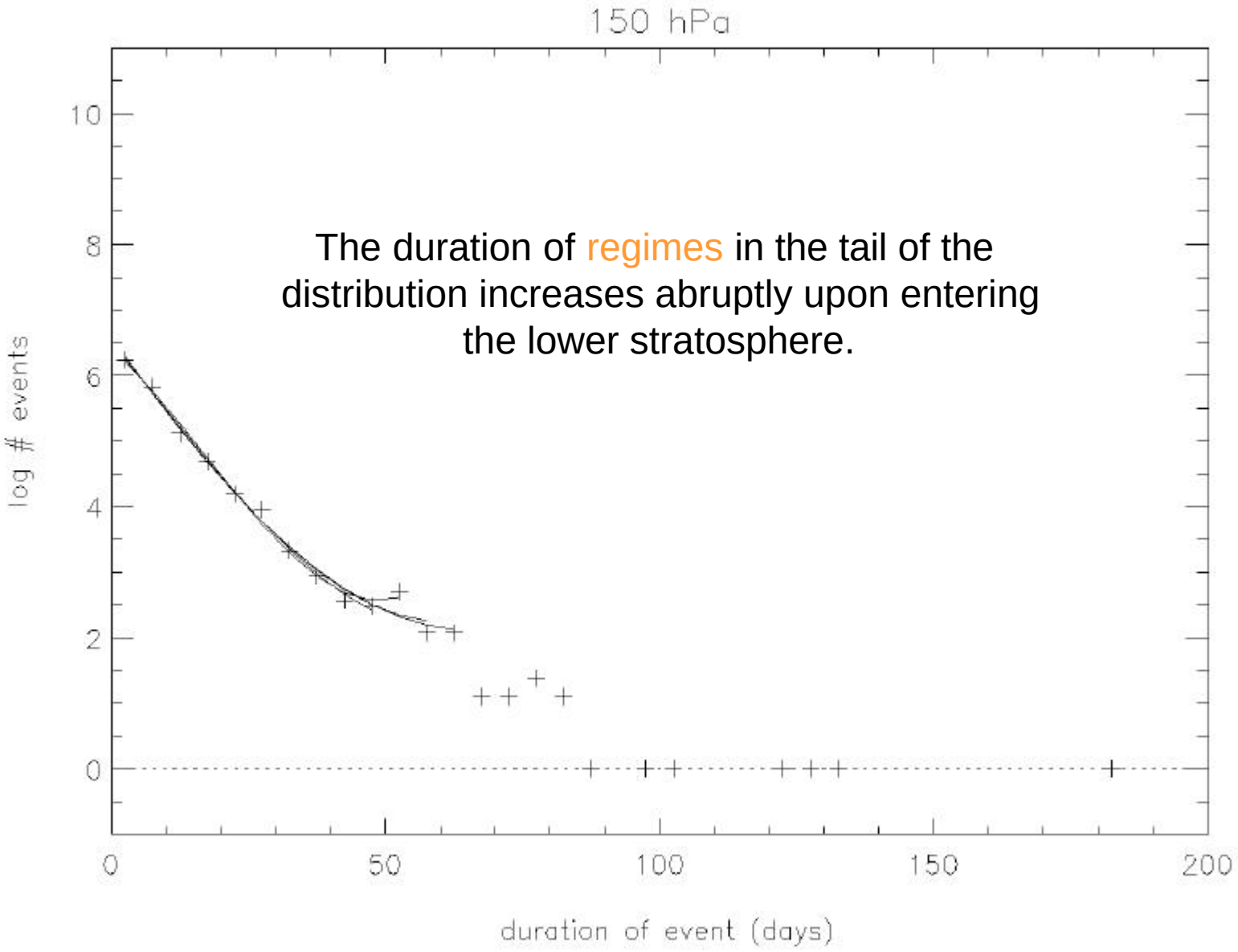

1000 hPa
log # events
10
8
6
4
2
0
−400
−200
0
200
400
cumulative NAM index
The amplitude of regimes in the lower troposphere…
…has a non-normal, slightly fat-tailed distribution.


250 hPa
The amplitude of regimes in the upper troposphere…
…is often smaller and sometimes much larger than a normal distribution would predict.
log # events
10
8
6
4
2
0
−400
−200
0
200
400
cumulative NAM index

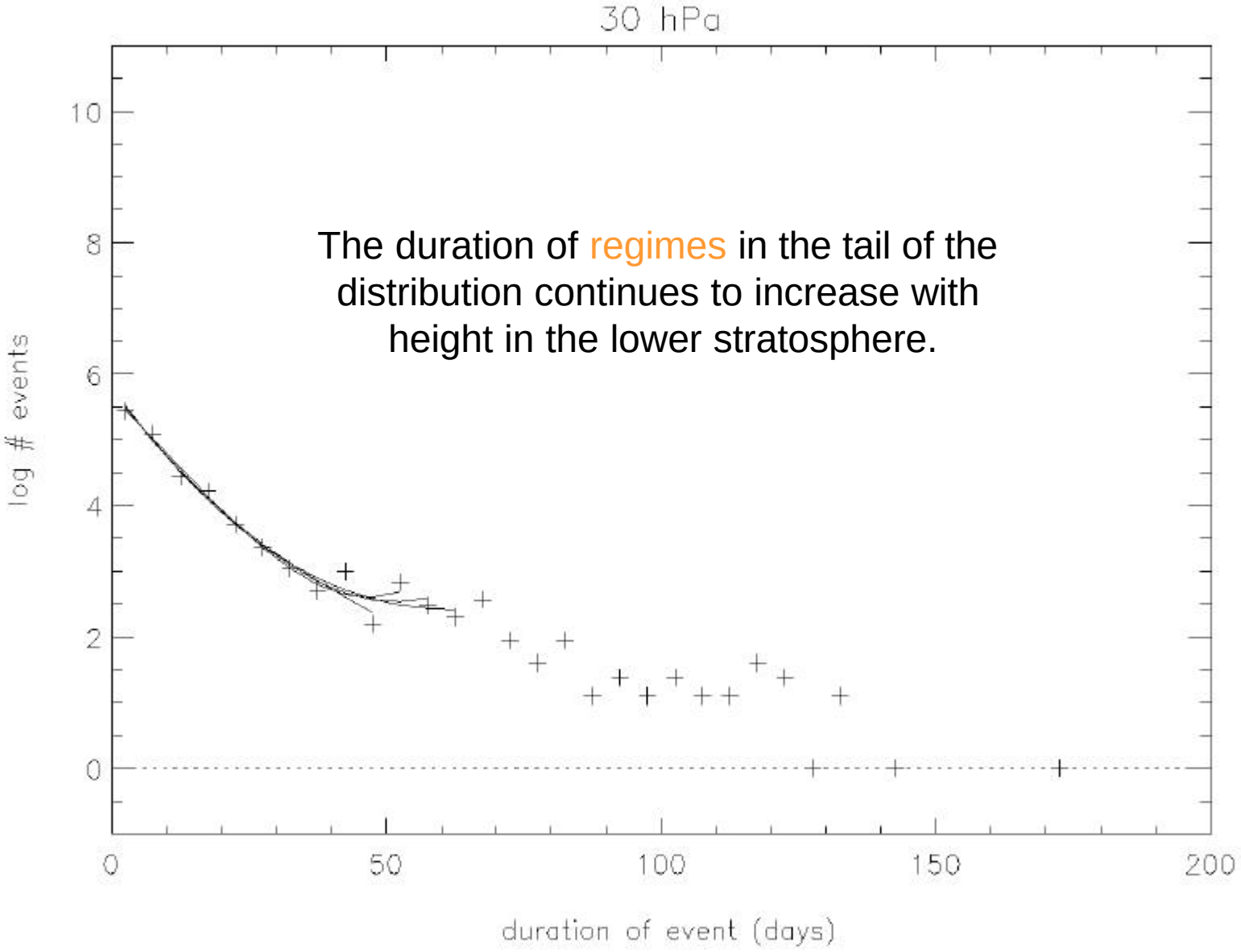


*don't worry if you've already forgotten the definition. So have I.

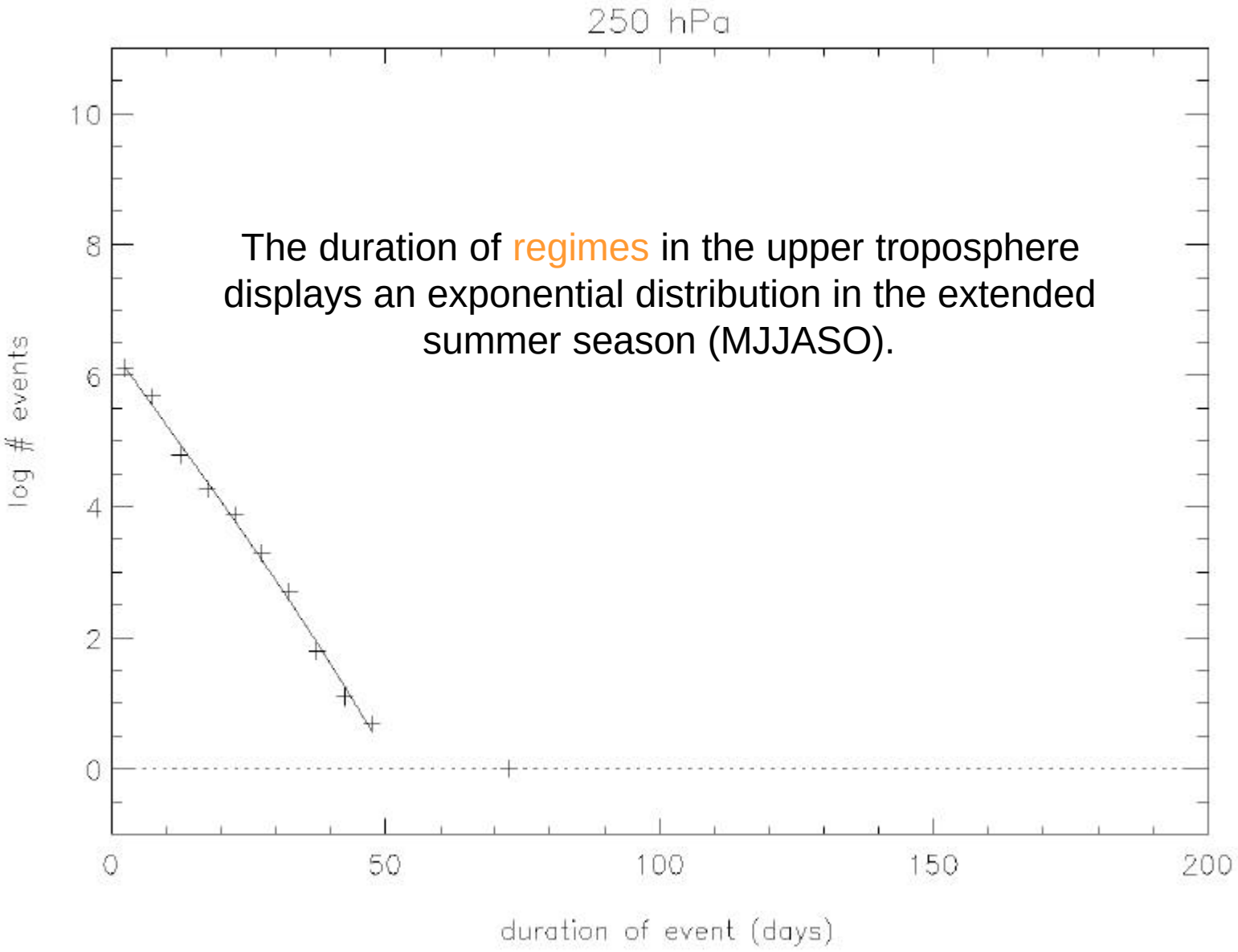

250 hPa
The duration of regimes in the upper troposphere is exponentially distributed. The distribution in the lower troposphere is identical (not shown).
log # events
10
8
6
4
2
0
0
50
100
150
200
duration of event (days)



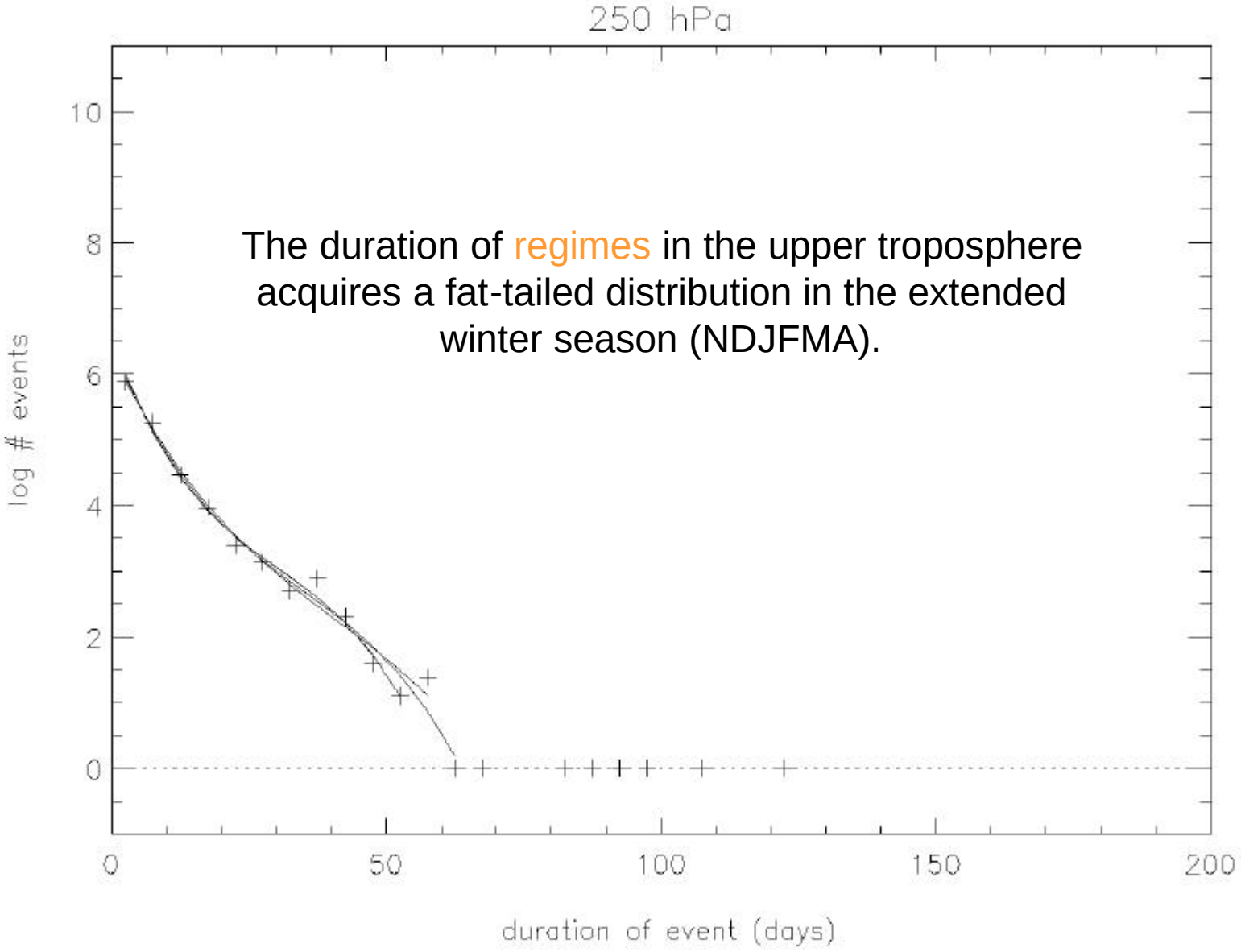
The duration of regimes in the tail of the distribution increases abruptly upon entering the lower stratosphere.



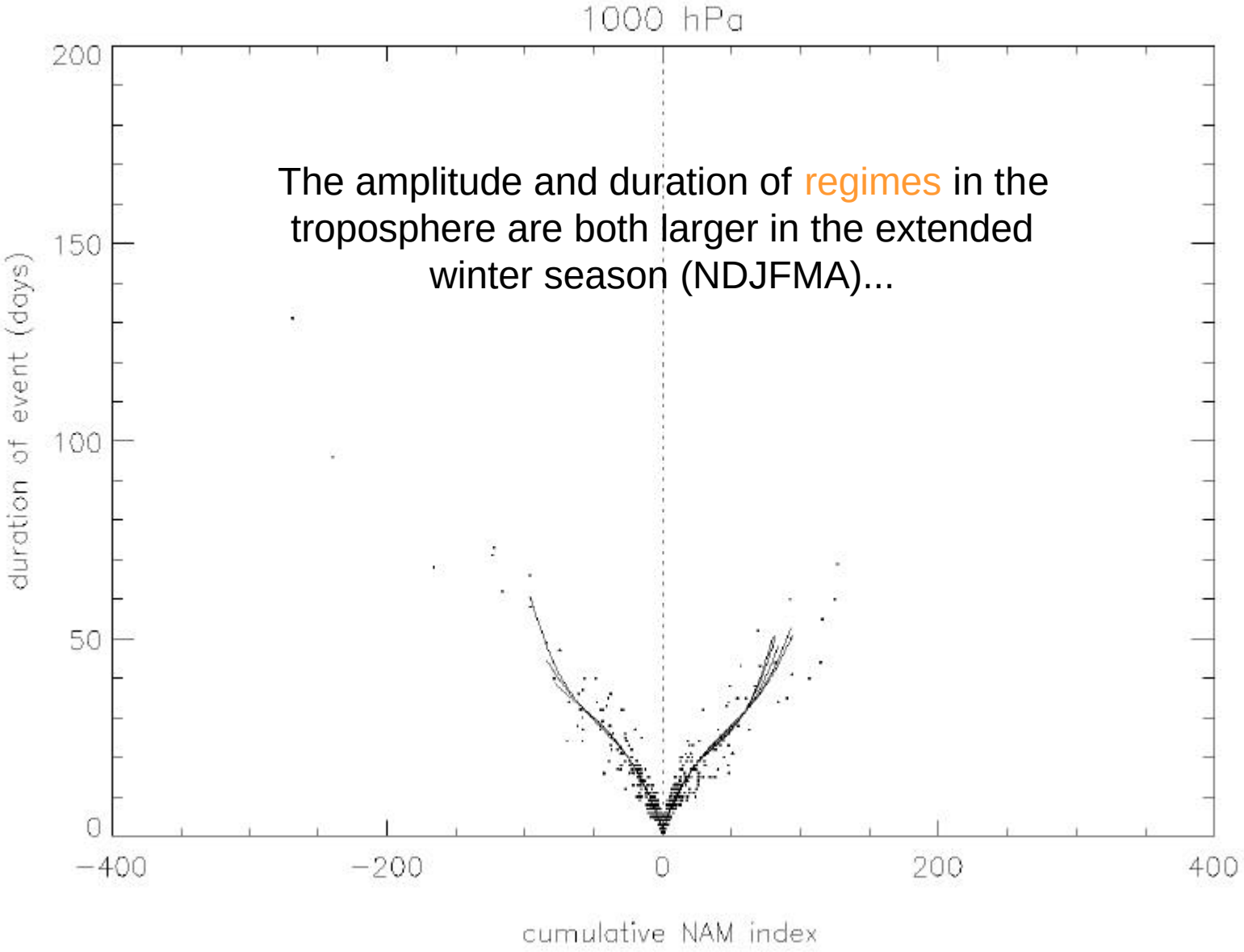
The duration of regimes in the tail of the distribution continues to increase with height in the lower stratosphere.



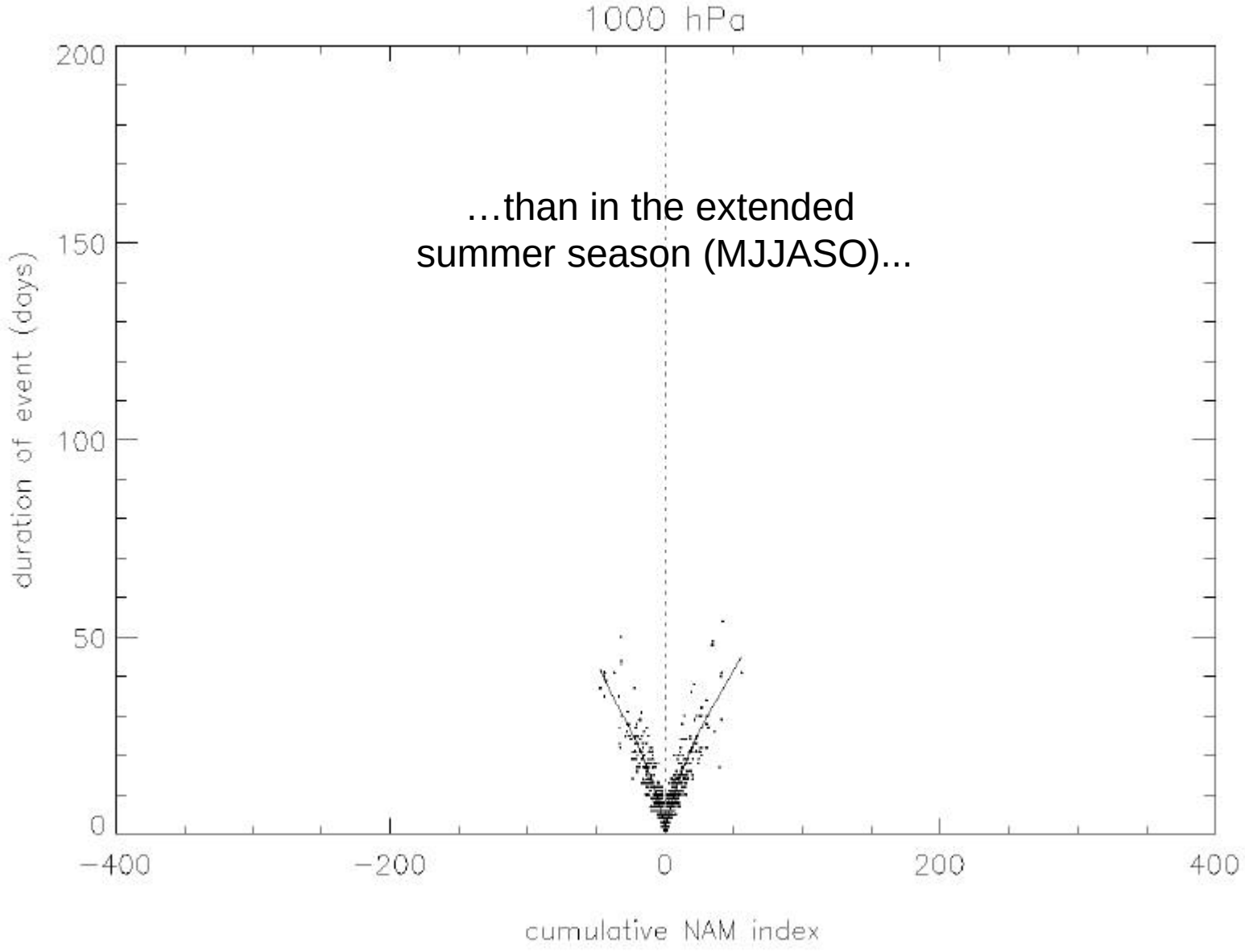
The duration of regimes in the upper troposphere displays an exponential distribution in the extended summer season (MJJASO).

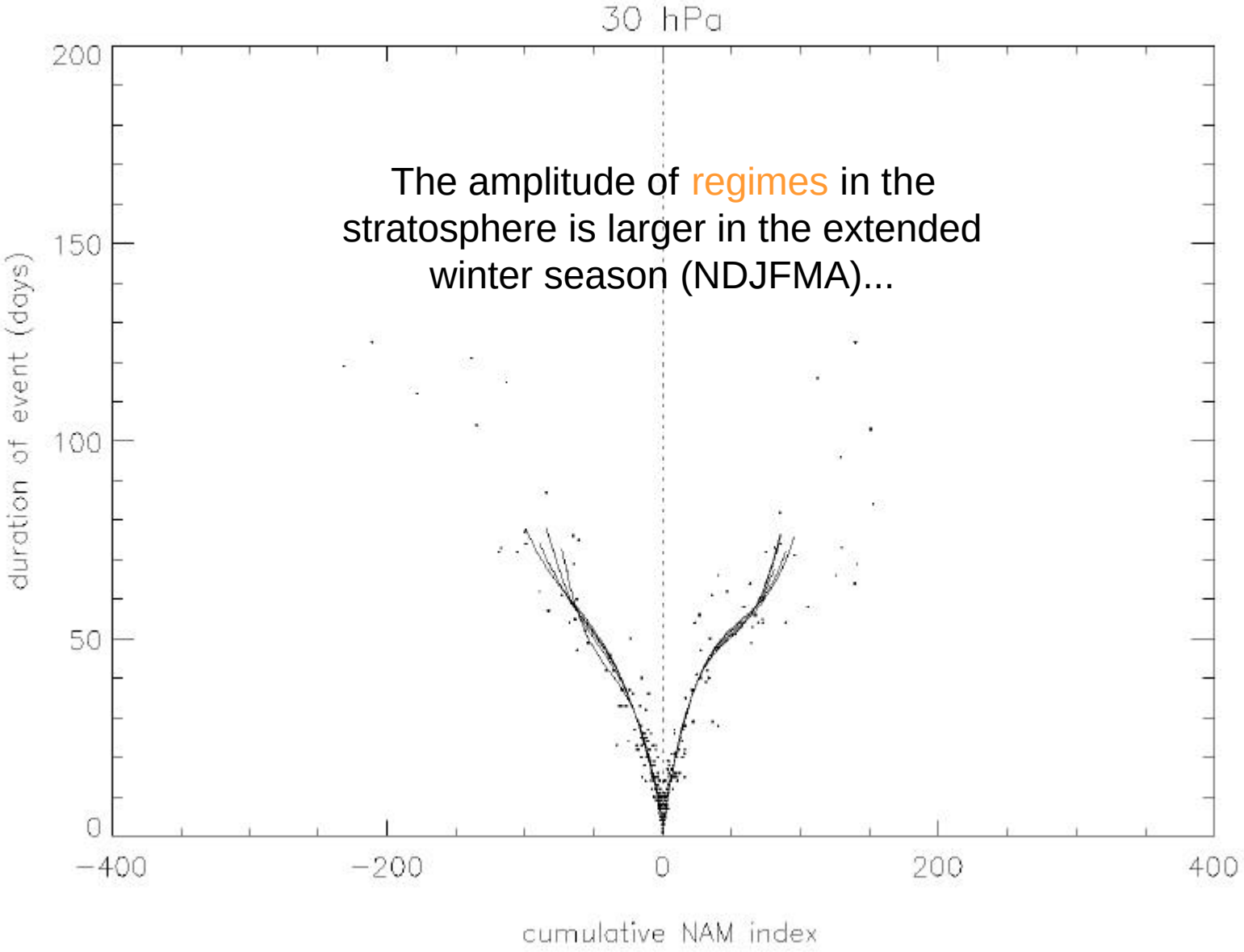


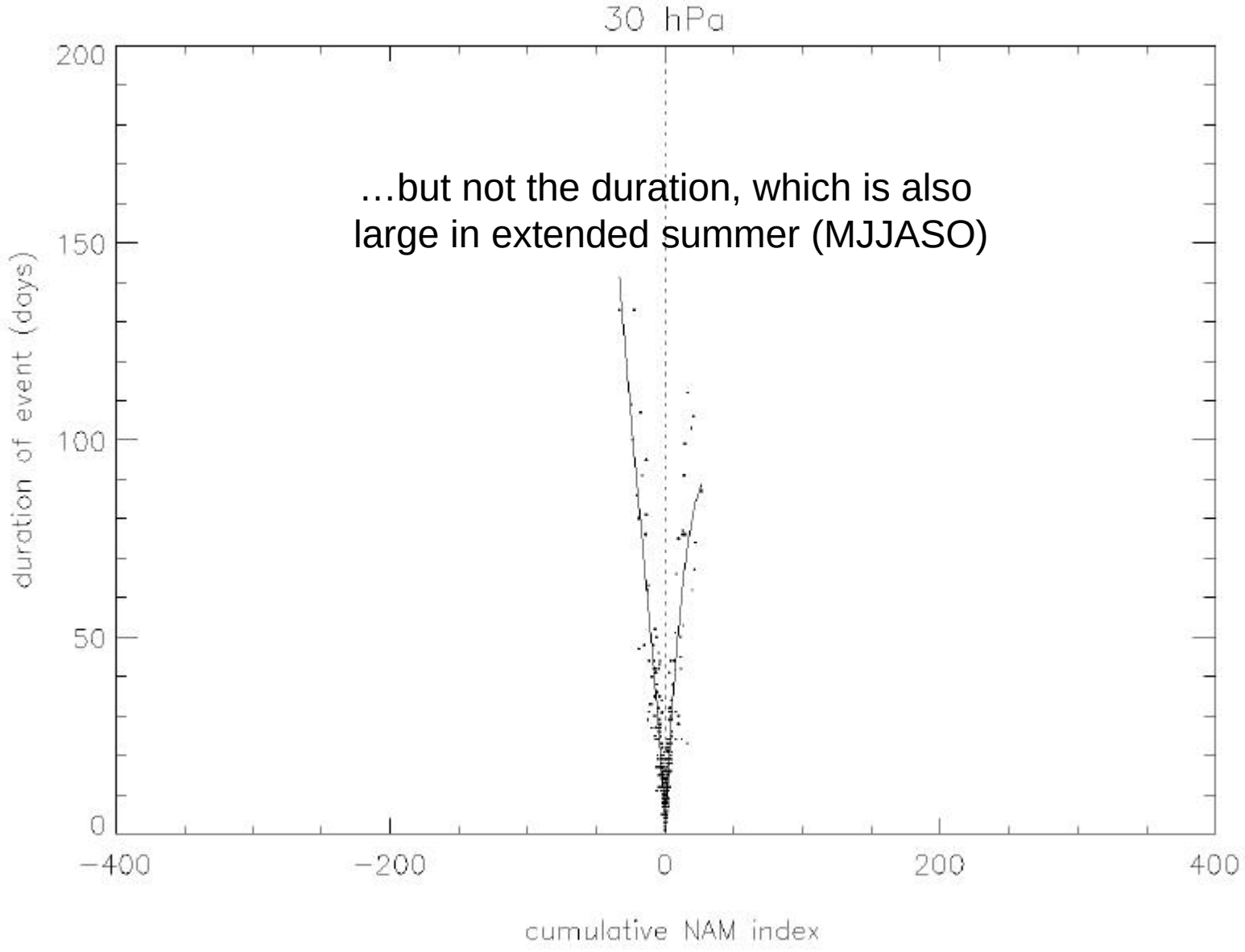
The duration of regimes in the upper troposphere acquires a fat-tailed distribution in the extended winter season (NDJFMA).



The amplitude and duration of regimes in the troposphere are both larger in the extended winter season (NDJFMA)...


1000 hPa
…than in the extended
summer season (MJJASO)...
duration of event (days)
200
150
100
50
0
−400
−200
0
200
400
cumulative NAM index


30 hPa
The amplitude of regimes in the stratosphere is larger in the extended winter season (NDJFMA)...
duration of event (days)
200
150
100
50
0
−400
−200
0
200
400
cumulative NAM index


30 hPa
…but not the duration, which is also
large in extended summer (MJJASO)
duration of event (days)
200
150
100
50
0
−400
−200
0
200
400
cumulative NAM index

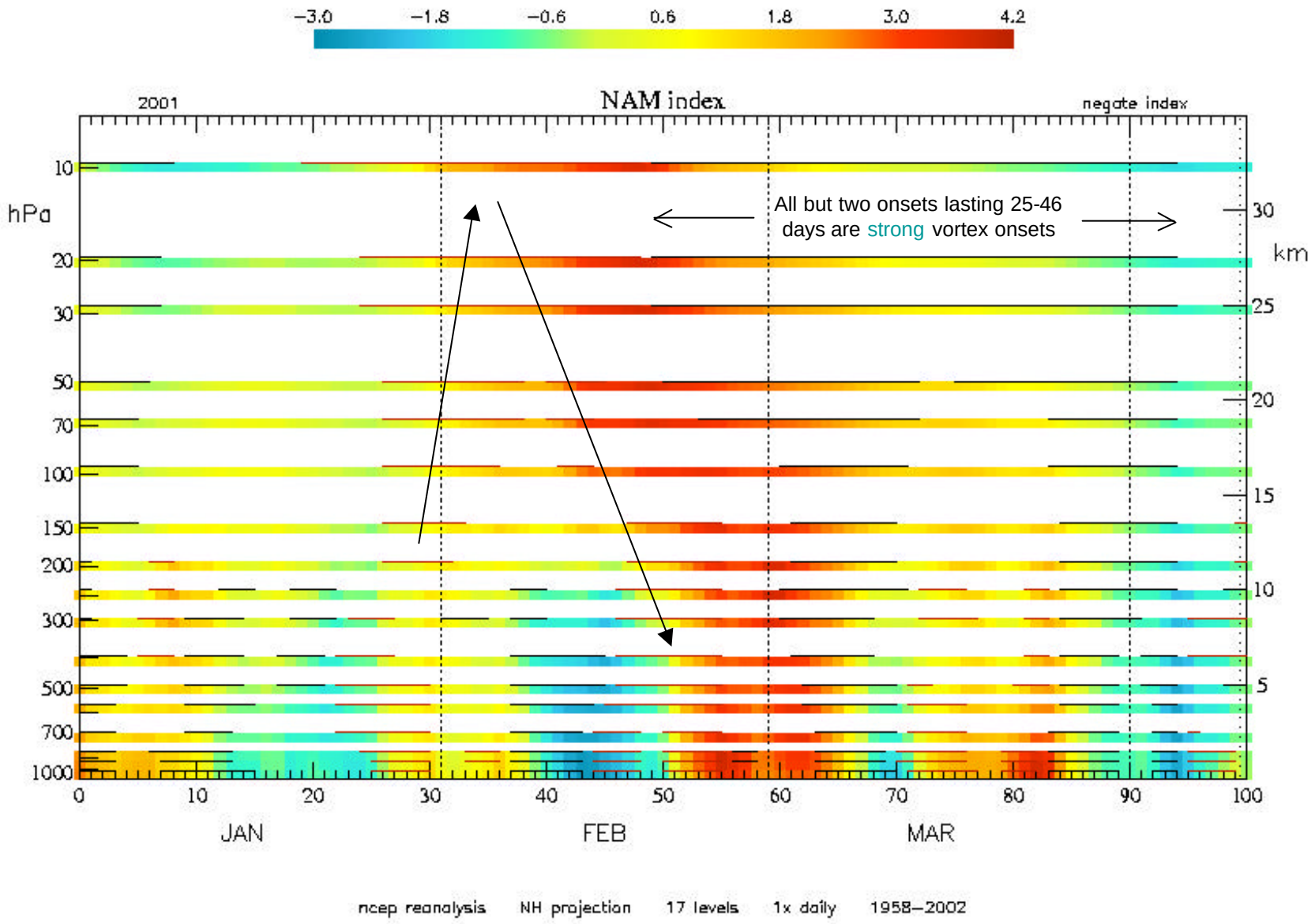
winter vs summer seasons

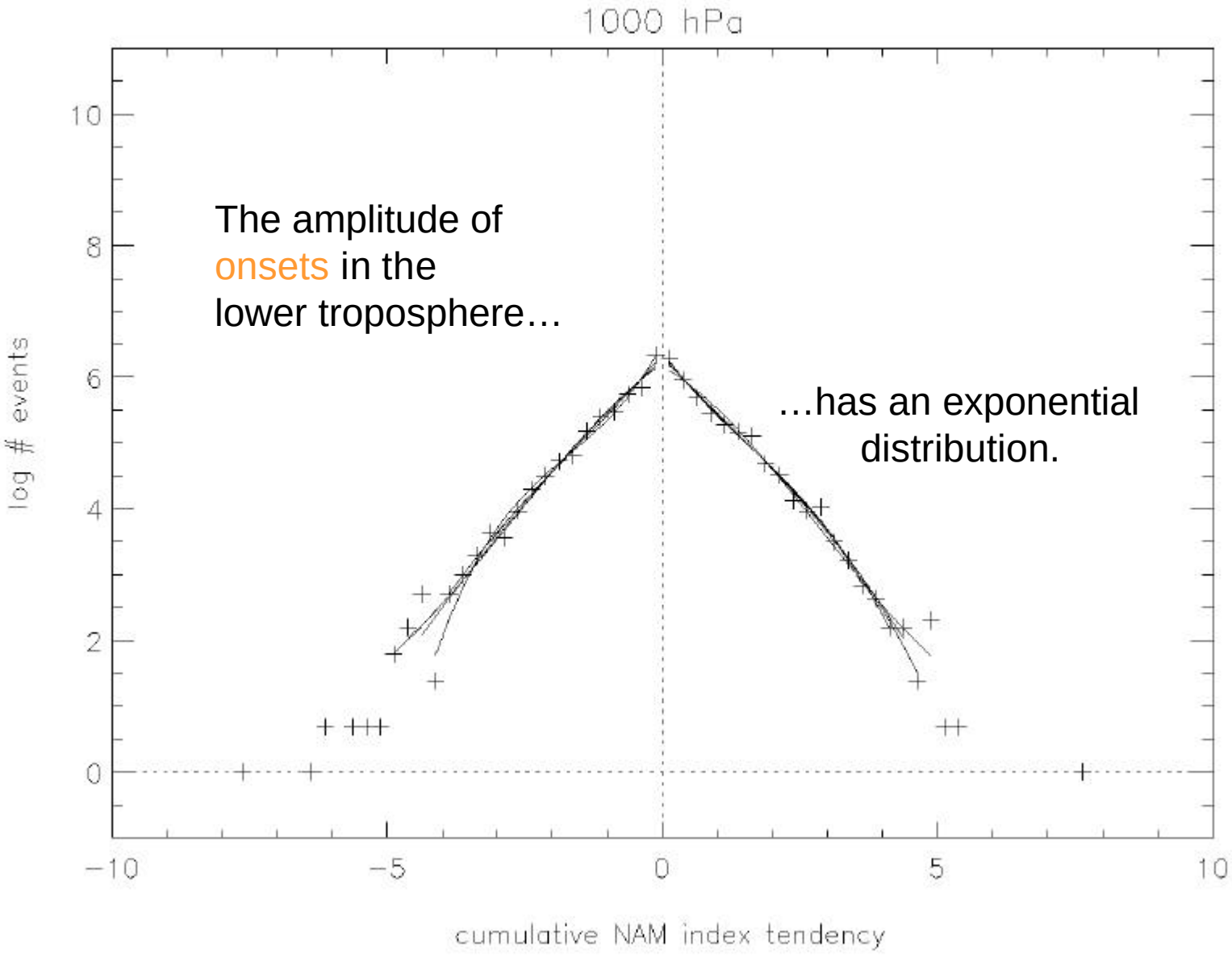
In the troposphere:

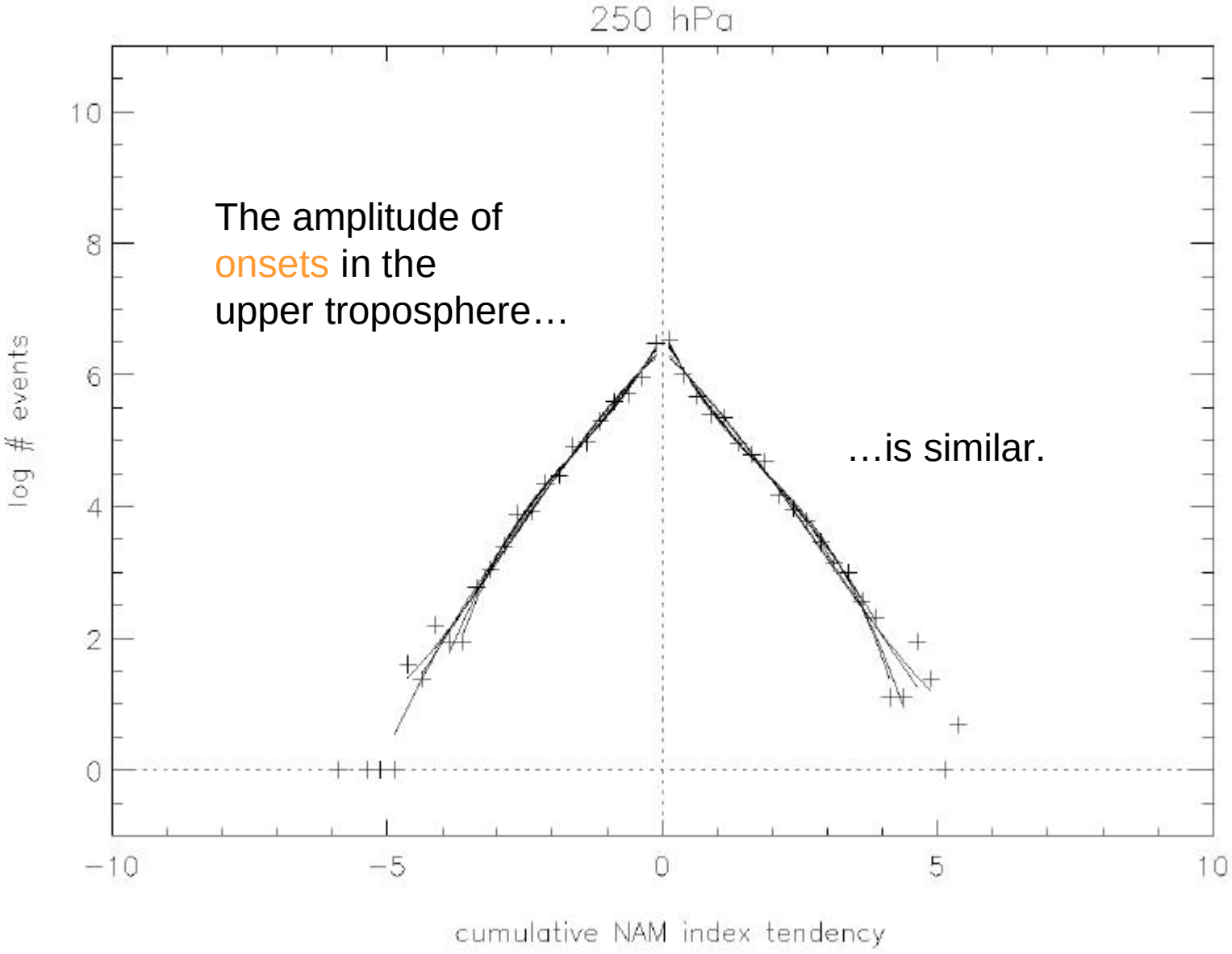
- Large-amplitude regimes occur mainly in extended winter
- Long-duration regimes occur mainly in extended winter

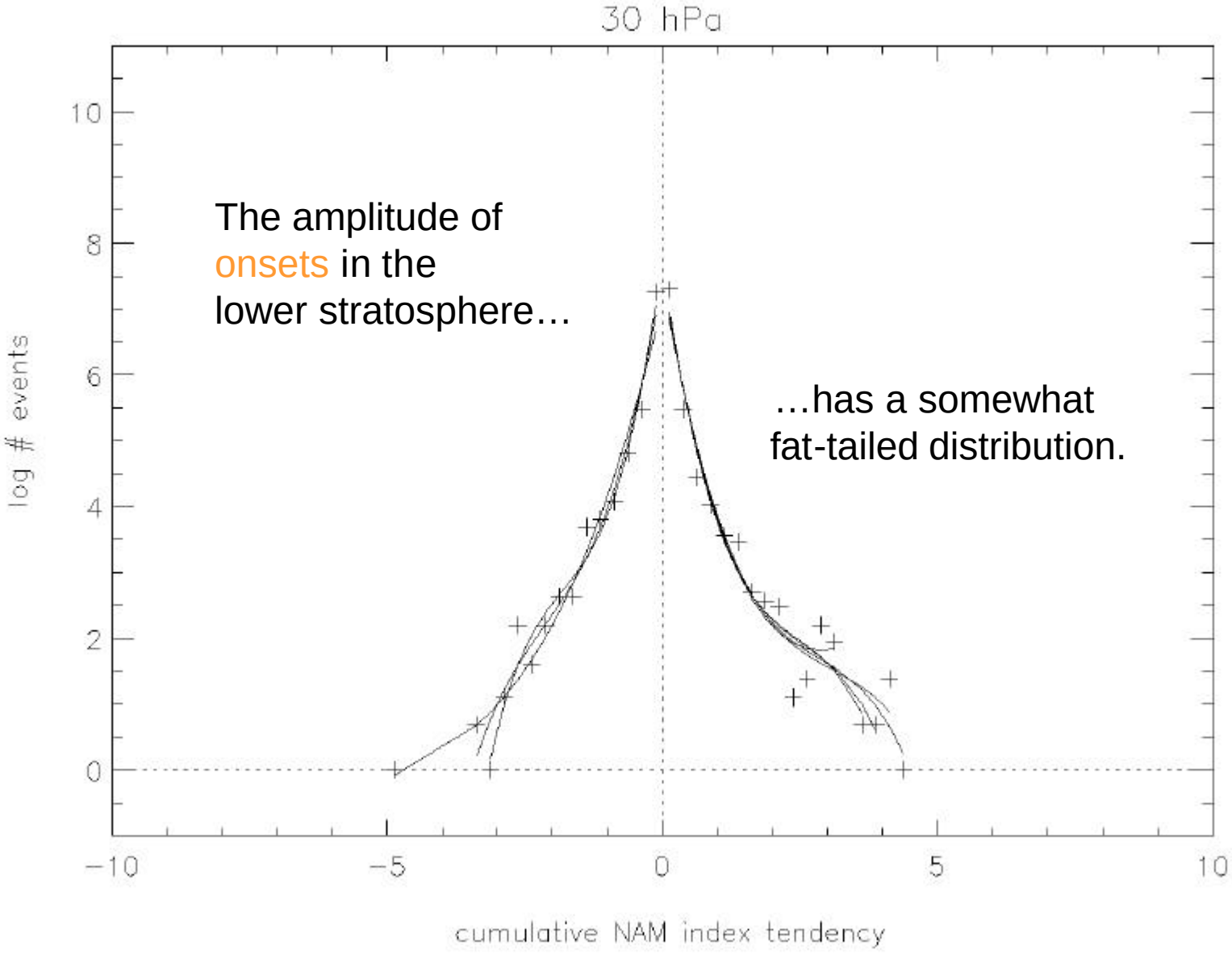
In the stratosphere:

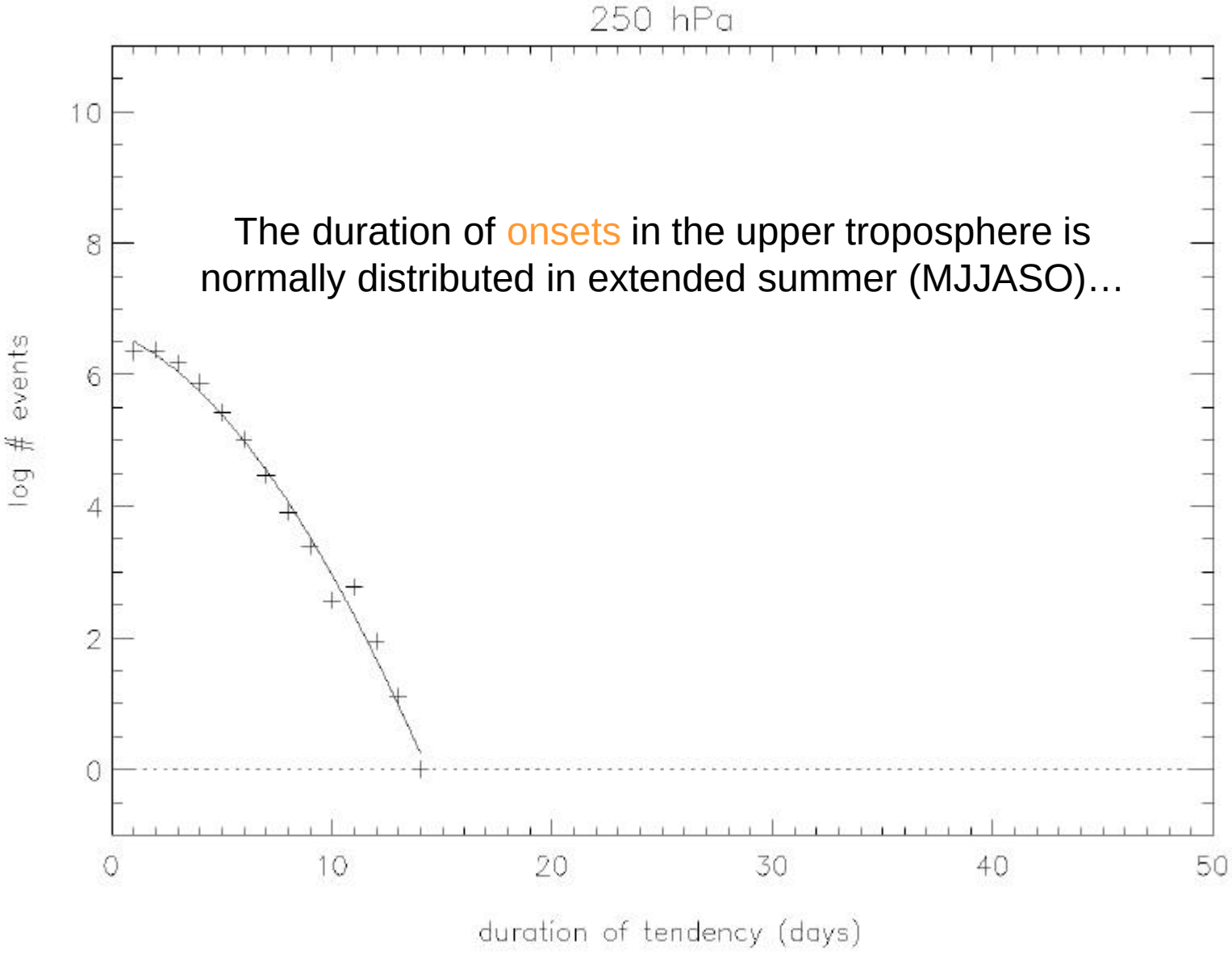
- Large-amplitude regimes occur mainly in extended winter
- Long-duration regimes occur in both seasons but are of small amplitude in extended summer

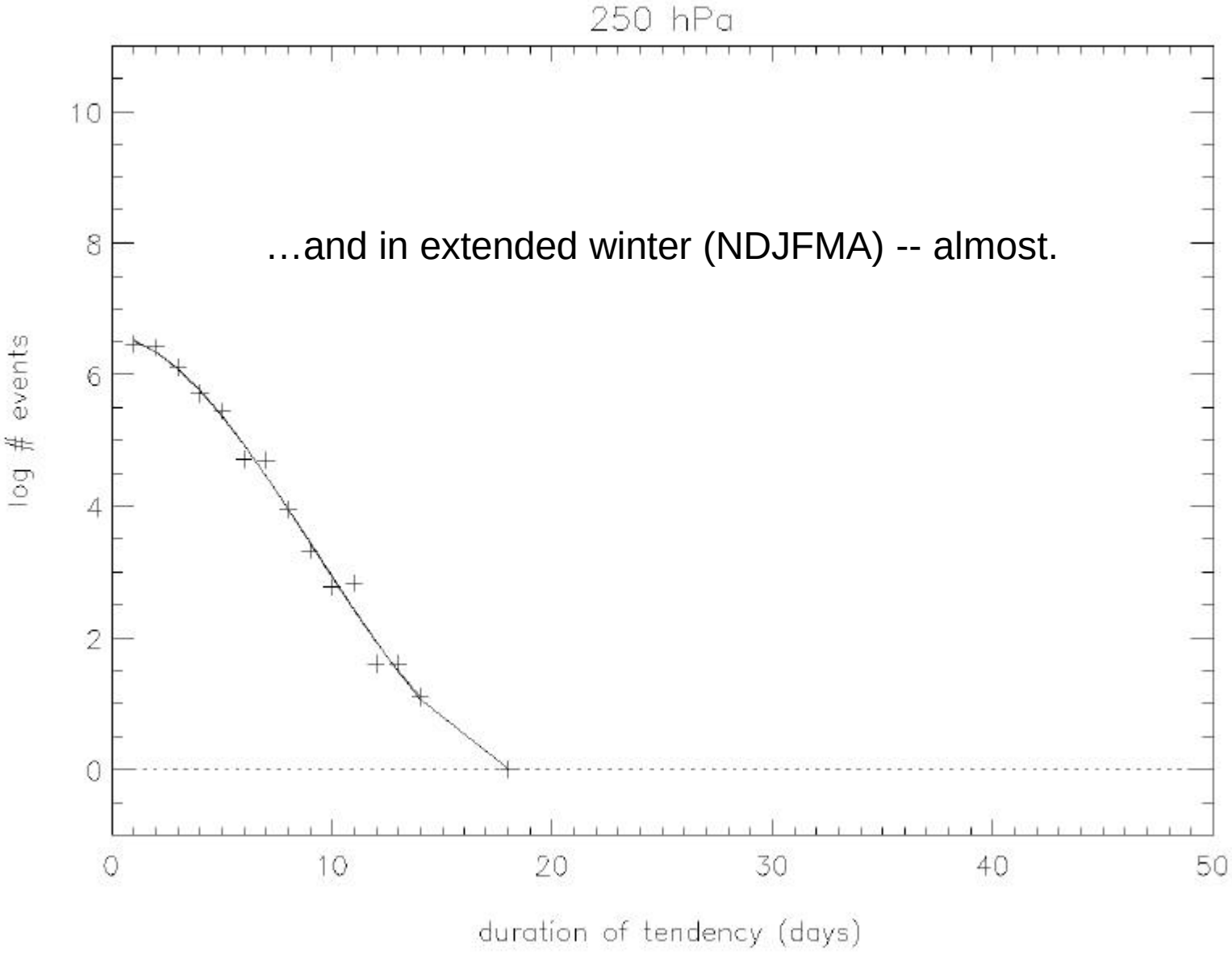

−3.0
−1.8
−0.6
0.6
1.8
3.0
4.2
2001
NAM index
negate index
hPa
km
All but two onsets lasting 25-46 days are strong vortex onsets
10
20
30
50
70
100
150
200
300
500
700
1000
30
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
100
JAN
FEB
MAR
ncep reanalysis
NH projection
17 levels
1x daily
1958–2002

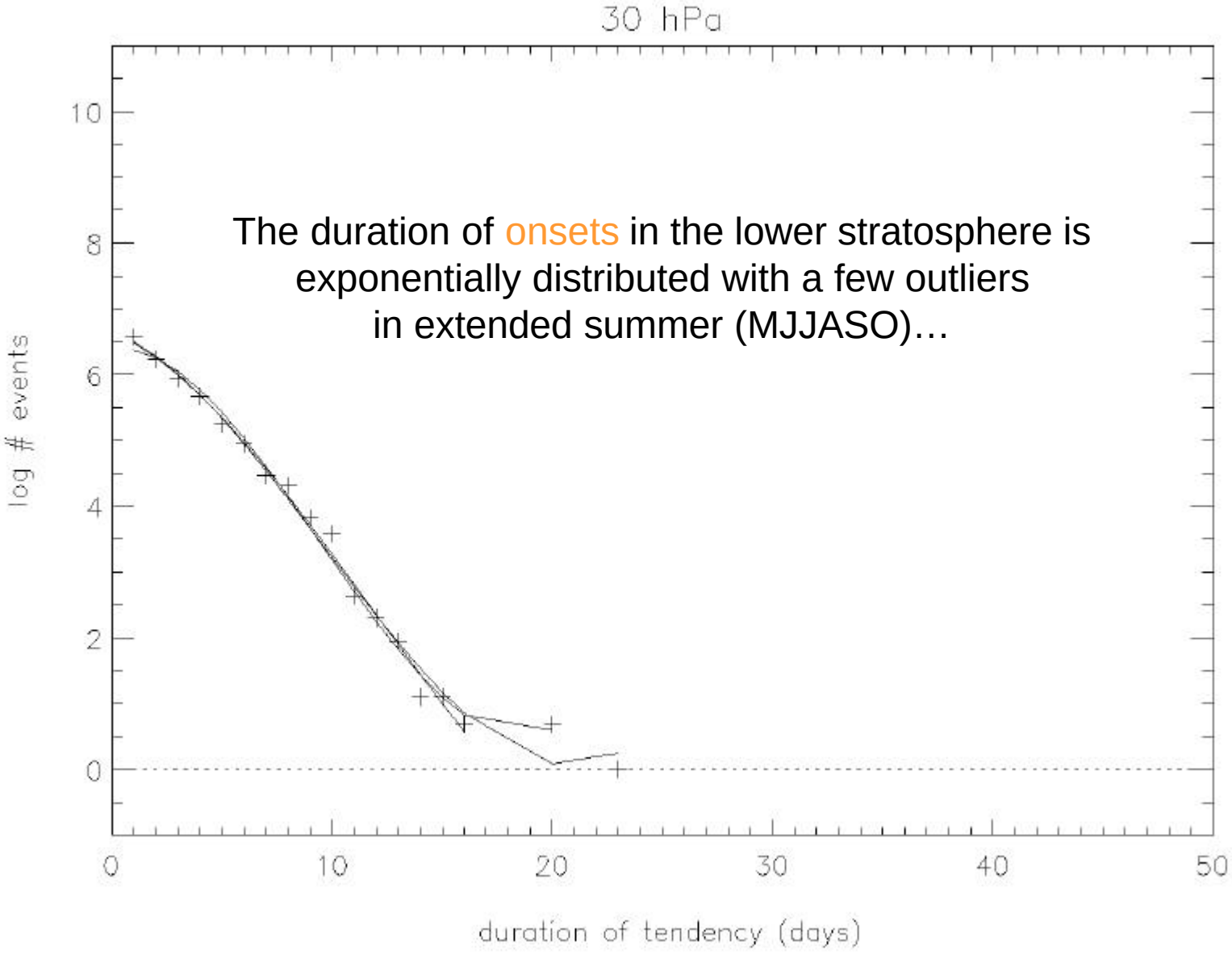

1000 hPa
The amplitude of onsets in the lower troposphere…
…has an exponential distribution.
log # events
10
8
6
4
2
0
−10
−5
0
5
10
cumulative NAM index tendency


250 hPa
The amplitude of onsets in the upper troposphere…
…is similar.
log # events
10
8
6
4
2
0
−10
−5
0
5
10
cumulative NAM index tendency

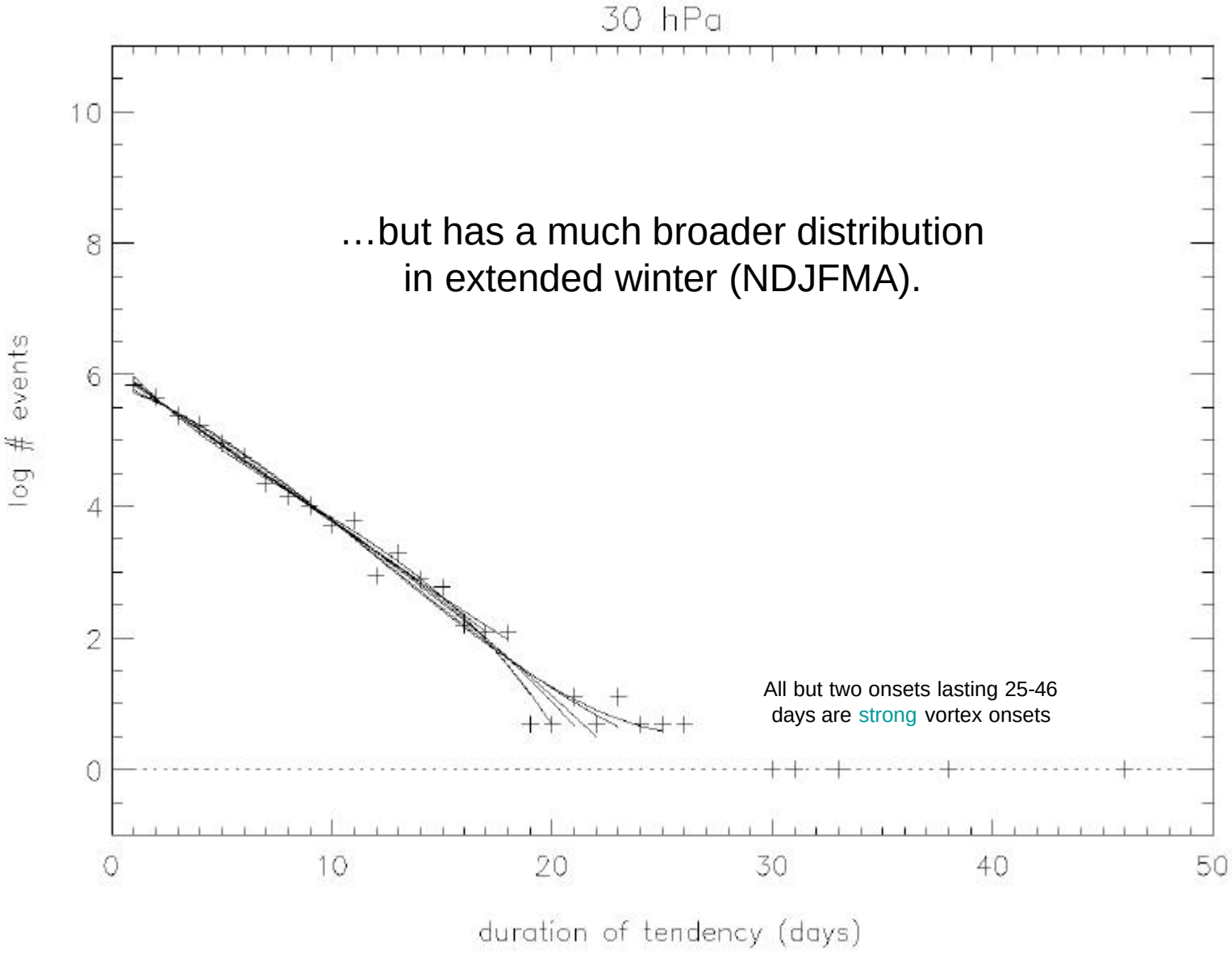

30 hPa
The amplitude of onsets in the lower stratosphere…
…has a somewhat fat-tailed distribution.
log # events
10
8
6
4
2
0
−10
−5
0
5
10
cumulative NAM index tendency

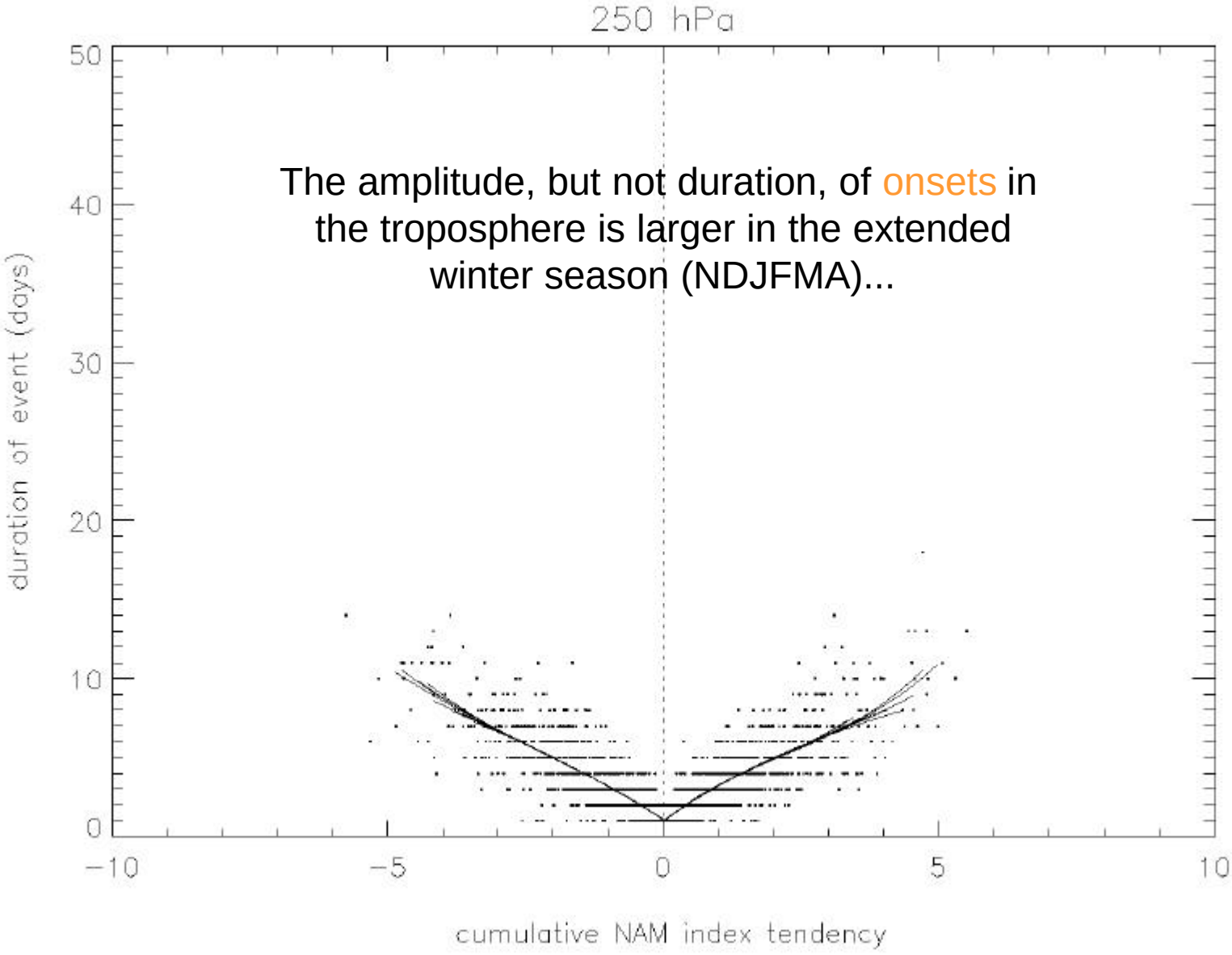

250 hPa
The duration of onsets in the upper troposphere is normally distributed in extended summer (MJJASO)…
log # events
0
2
4
6
8
10
0
10
20
30
40
50
duration of tendency (days)

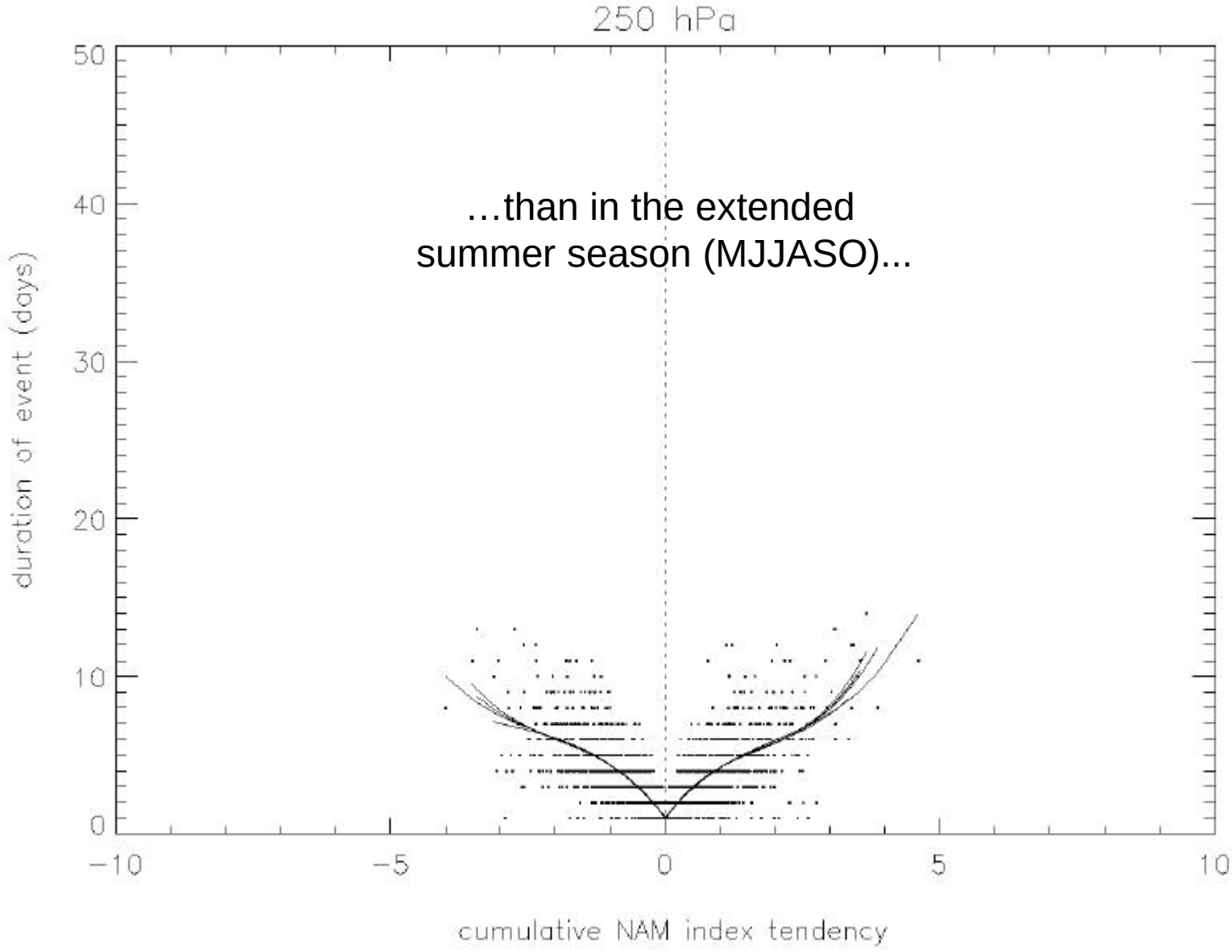

250 hPa
…and in extended winter (NDJFMA) -- almost.
log # events
0
2
4
6
8
10
0
10
20
30
40
50
duration of tendency (days)



The duration of onsets in the lower stratosphere is exponentially distributed with a few outliers in extended summer (MJJASO)…


30 hPa
…but has a much broader distribution
in extended winter (NDJFMA).
All but two onsets lasting 25-46
days are strong vortex onsets
log # events
duration of tendency (days)
0
2
4
6
8
10
0
10
20
30
40
50


250 hPa
The amplitude, but not duration, of onsets in the troposphere is larger in the extended winter season (NDJFMA)...
duration of event (days)
50
40
30
20
10
0
−10
−5
0
5
10
cumulative NAM index tendency


250 hPa
…than in the extended
summer season (MJJASO)...
duration of event (days)
50
40
30
20
10
0
−10
−5
0
5
10
cumulative NAM index tendency

winter vs summer seasons

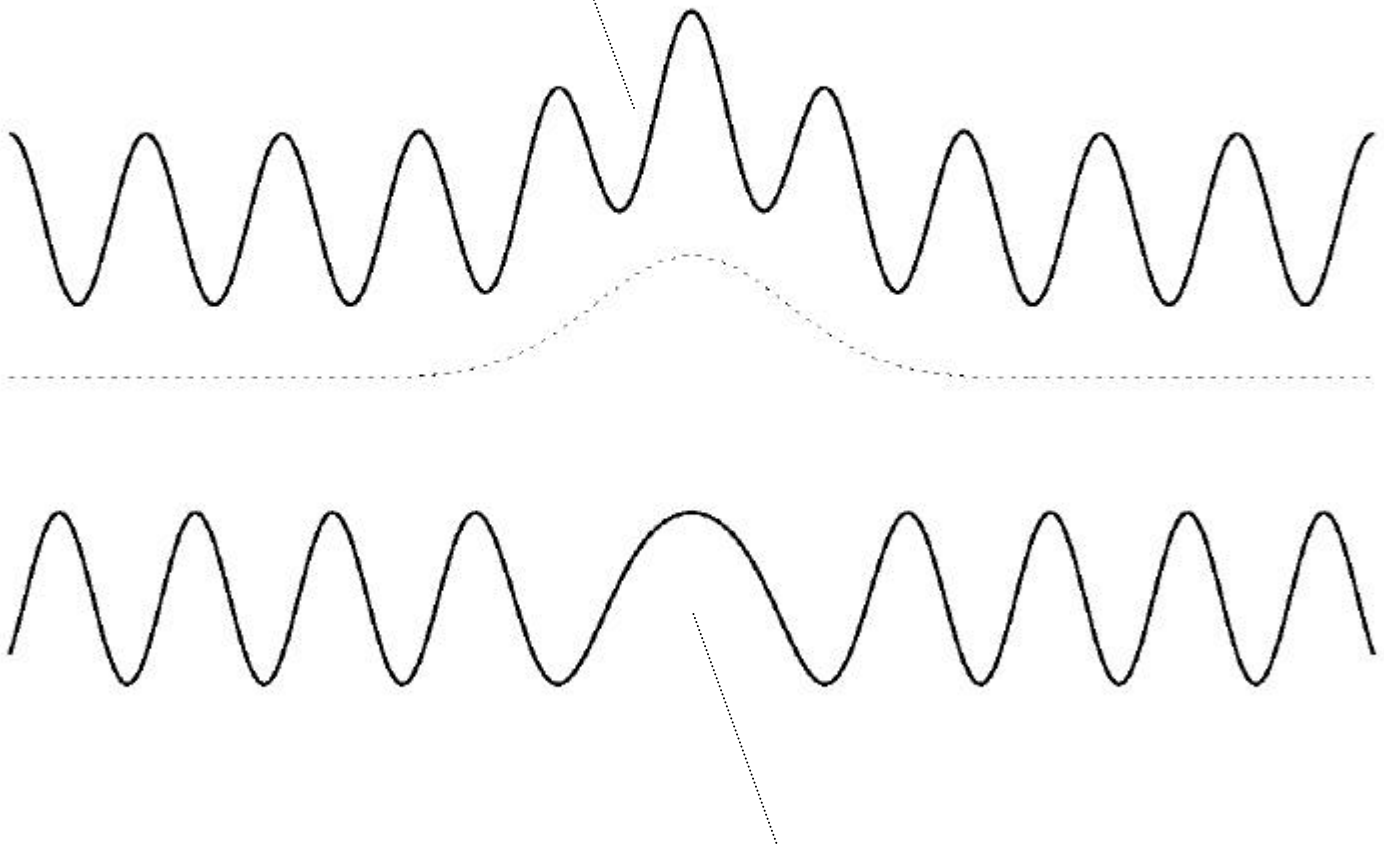
In the troposphere:

- Onsets are somewhat larger in extended winter
- The duration of onsets is similar in both seasons

In the stratosphere:

- Large-amplitude onsets occur mainly in extended winter
- Long-duration onsets occur mainly in extended winter and the longest of these are strong vortex onsets

linear superposition of stratospheric NAM contribution



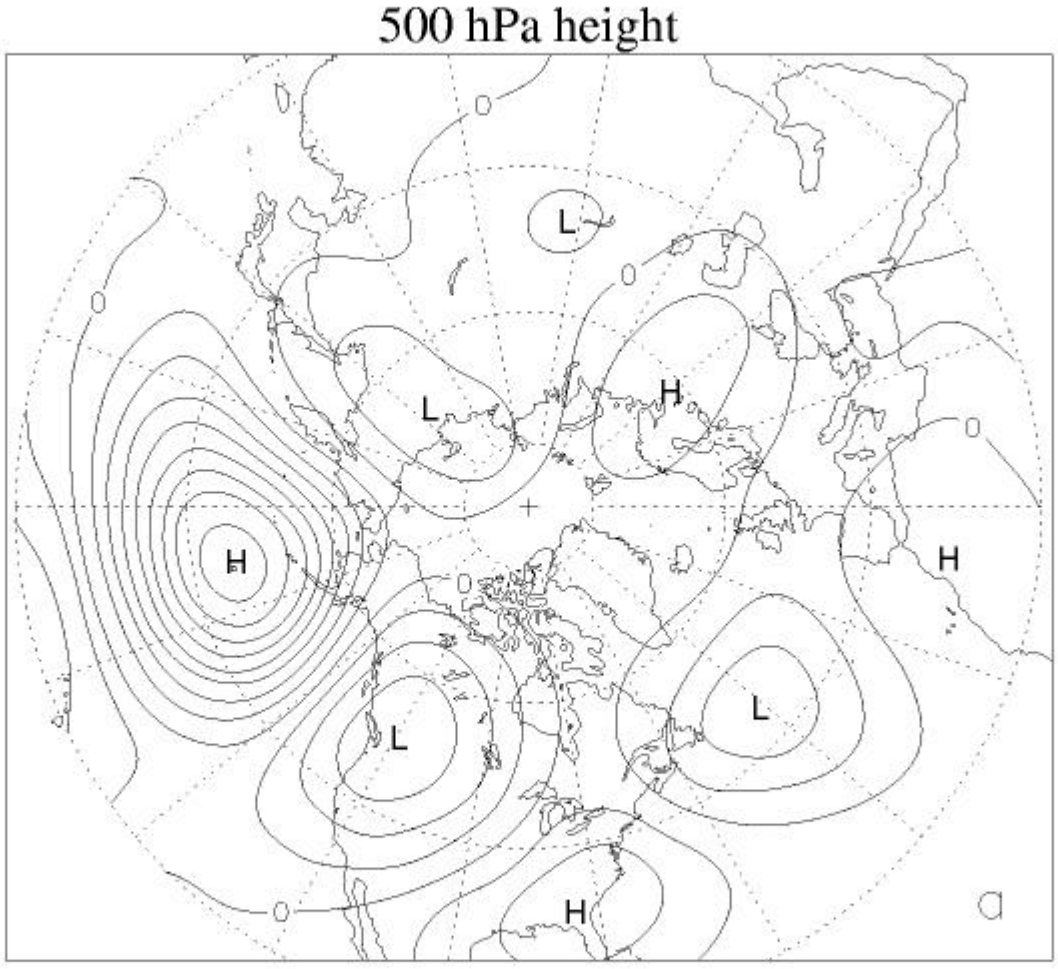
stratosphere modulates tropospheric NAM period

Relation of surface and stratospheric NAM

- No relationship. The tropospheric NAM is driven by synoptic scale waves year-round and the stratospheric NAM is driven by planetary scale waves in extended winter. The two types of wave act more or less independently and their associated NAM anomalies are uncorrelated.
- In-phase relationship. The NAM is maintained by eddy momentum fluxes in the troposphere and stratosphere. The induced mean meridional circulation opposes the wave forcing and creates a surface pressure anomaly in the polar cap of same sign as the anomaly aloft.
- Out-of-phase relationship. The stratospheric NAM is maintained by eddy heat fluxes. Divergence of wave flux in the upper troposphere creates a NAM anomaly of opposite sign in the troposphere. The induced mean meridional circulation opposes the wave forcing and creates a surface pressure anomaly of opposite sign to the anomaly aloft.
- Mixed or time-dependent relationship. The stratospheric NAM has a life cycle involving poleward and downward migration of anomalies. When the near-tropopause environment is altered by the stratospheric NAM anomaly, the tropospheric NAM anomaly is rapidly created or altered from its original state.

Organizing principles for the tropospheric NAM

- The lower stratospheric NAM anomaly induces a mean meridional circulation that enforces a measurable zonal symmetry on the tropospheric circulation (= tropospheric NAM anomaly). The tropospheric NAM anomaly organizes synoptic-scale eddies, which reinforce the original tropospheric NAM anomaly, providing a positive feedback. Hypothesis supported by statistical analysis using rotated SVD (Cheng and Dunkerton, 1995) and observed relationship of eddy flux and mean-flow anomalies (Lorenz and Hartmann, 2002). Walt Robinson's amplification mechanism.
- The upper troposphere acts as a waveguide for low-frequency Rossby wavetrains propagating from the Pacific to Atlantic sector. The PNA pattern undergoes linear or nonlinear reflection at its southernmost point, and bounces northward into the Atlantic to affect the NAO. Hypothesis supported by analysis of persistent anomaly lifecycles (Dole, 1989) and 3D wave activity (Honda et al, 2001). Wallace and Gutzler (1981) two-point correlation of AL/IL seesaw. Recent modeling by Grant Branstator.
- Synoptic eddy activity undergoes downstream development to such a degree that one stormtrack affects another downstream. Any takers…?



Dole (1989)

Wave reflection and induced MMC

- It was stated by Judith Perlwitz and Nili Harnik that the wave forcing itself is needed to establish a downward reflecting basic state in the polar upper stratosphere. Simple modeling suggests that in large warming events the waves temporarily create an over-reflecting basic state with zero-wind line embedded in a region of reversed PV gradient (Dave Ortland). This mechanism causes transient downward bursts of wave activity, some of which are absorbed in the polar troposphere critical layer. Probably cannot explain reflection on > monthly timescale.
- An induced mean meridional circulation explains the lower tropospheric NAM anomaly (AO) in our simulations and its strength may be the most important factor to determine whether or not a stratospheric NAM anomaly approaching the tropopause is able to influence the lower troposphere. Alternatively, modulation of upper tropospheric eddy fluxes by the stratospheric NAM anomaly and the resulting MMC induced by planetary and synoptic-scale waves together may be the most important factor to determine whether a significant NAM anomaly is realized in the lower troposphere.

Eulerian momentum budget