Randomness, symmetry and scaling of mesoscale eddy life cycles

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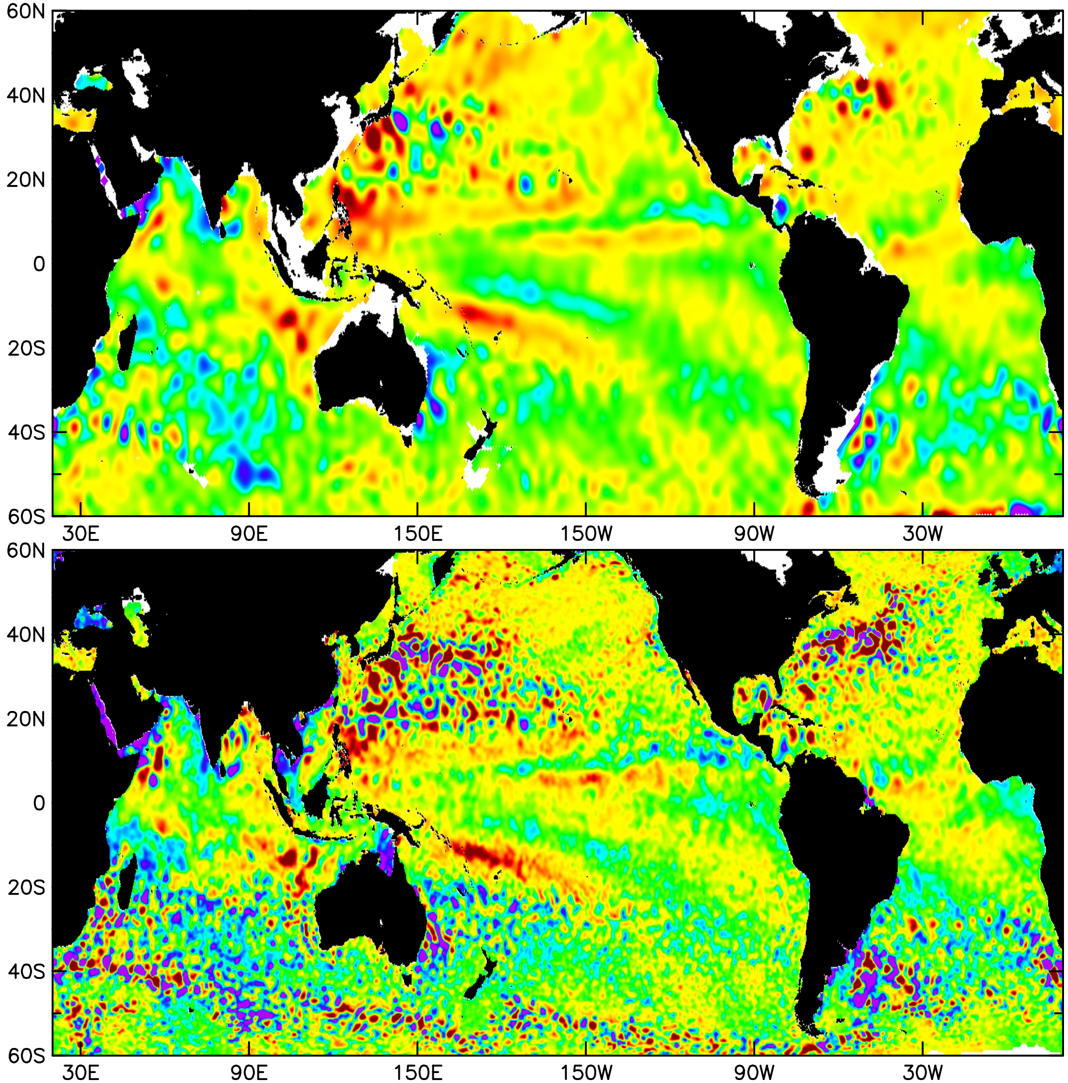
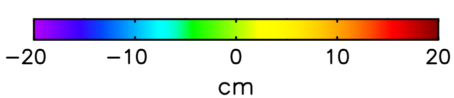
SSH From TOPEX Only and from the Merged TOPEX and ERS-1/2 Data

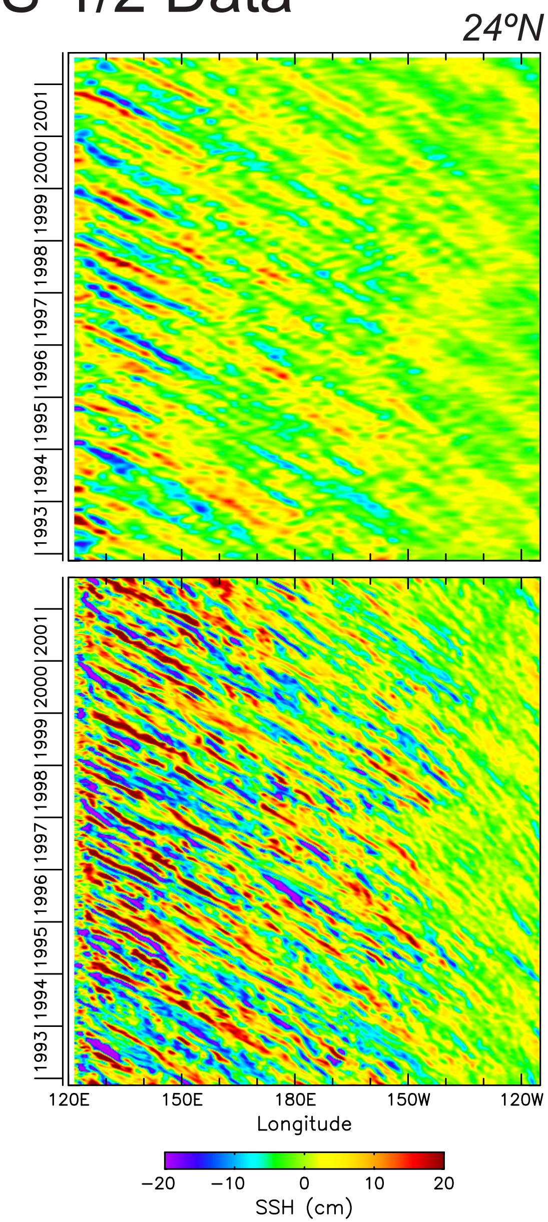


TOPEX Only

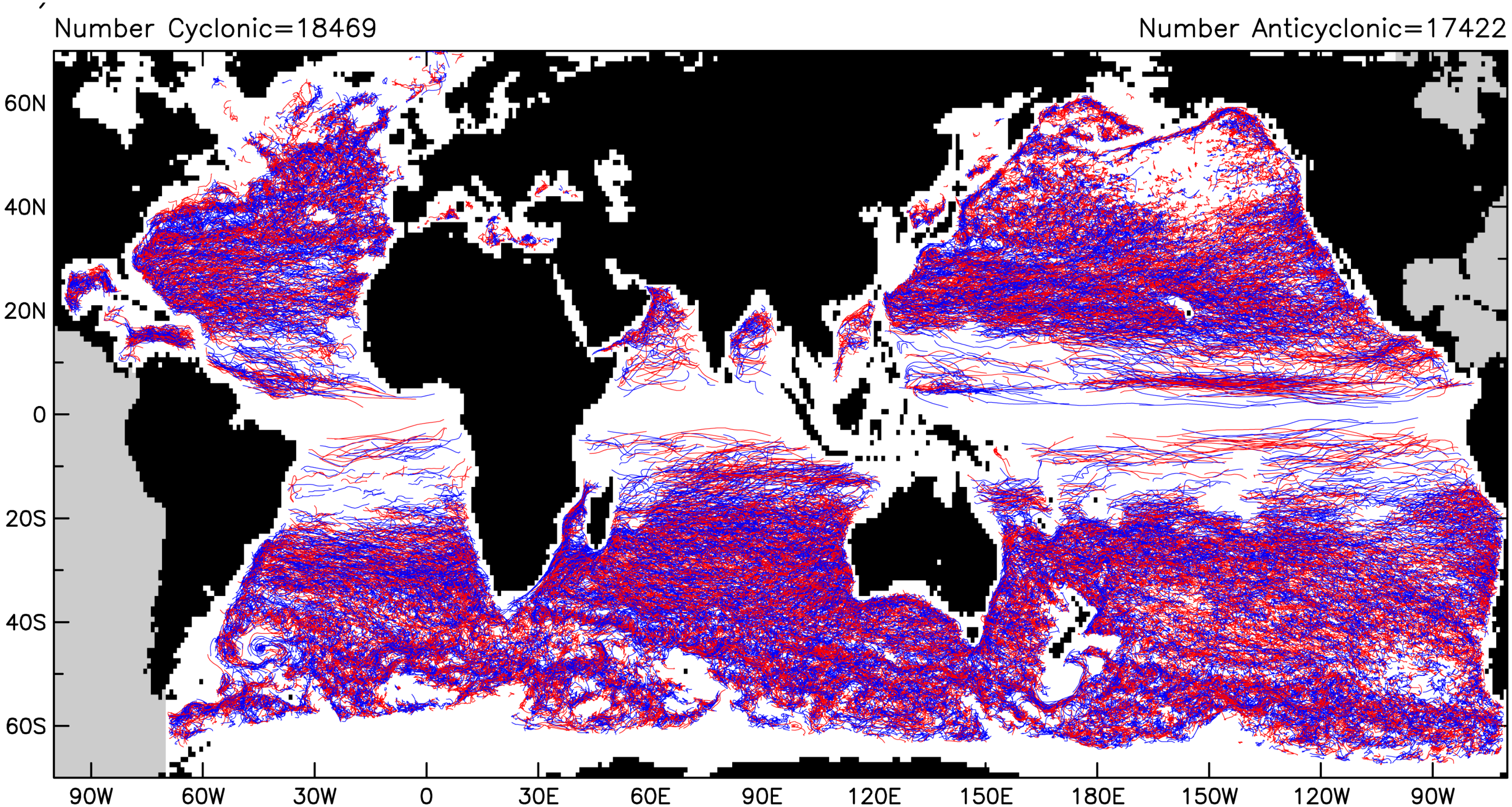
TOPEX + ERS-1/2



There are 2495 eddies in this map



Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 16 Weeks
(35,891 total)



Average lifetime: 32 weeks
Average propagation distance: 550 km
Average amplitude: 8 cm
Average horizontal radius scale: 90 km

Total number of observations: ~1.15 million

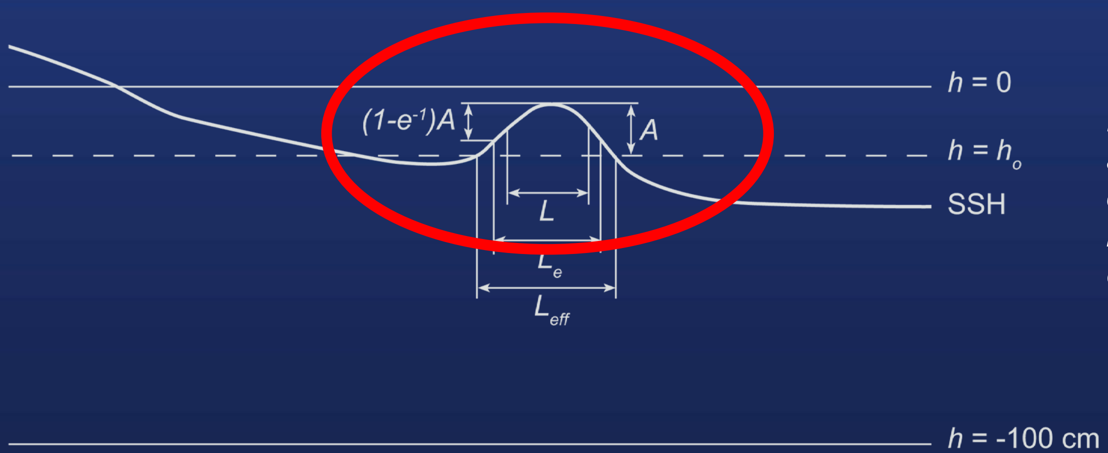
(Chelton et al, 2011)

Details of the Procedure for Identifying Eddies

1) *For <u>anticyclones</u> (concave downward SSH), start with a large negative SSH of -100 cm and step upward in increments of 1 cm until an outermost closed contour of SSH is found.*

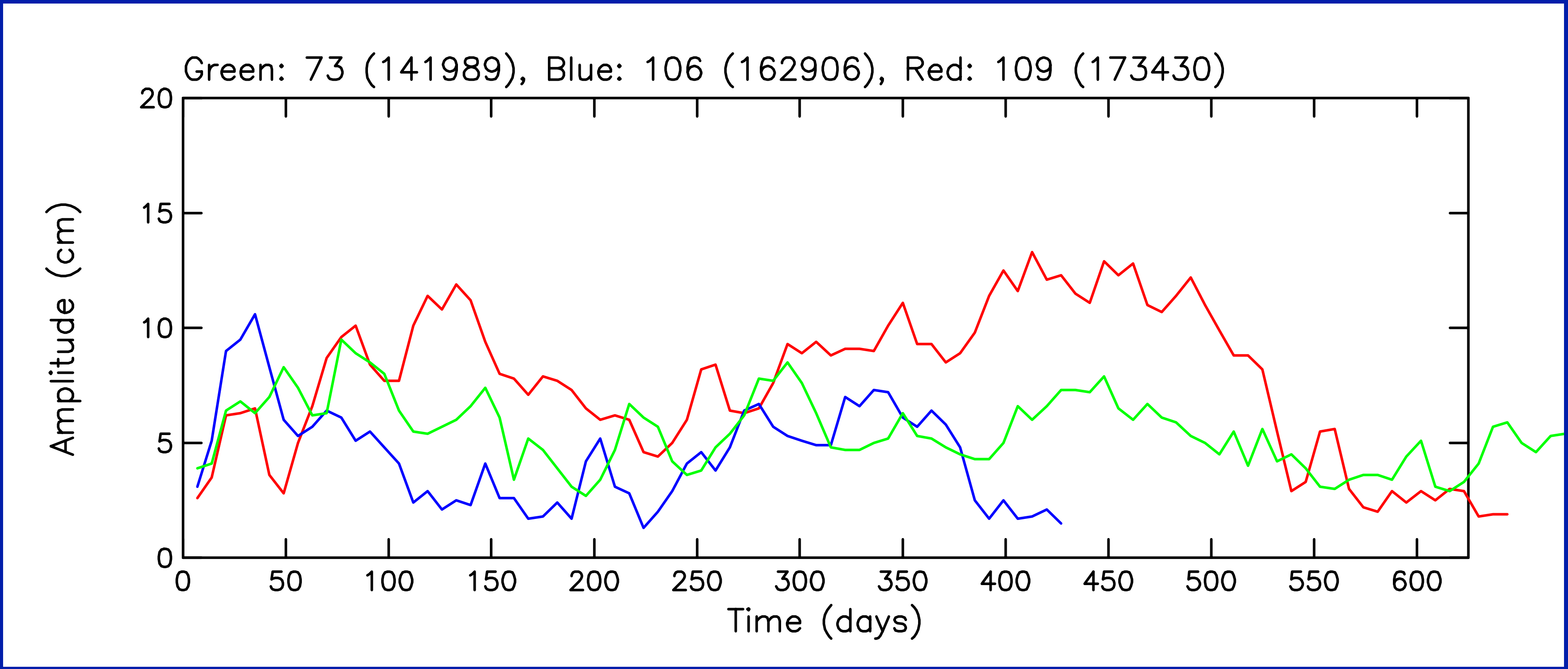
2) *The closed contour of SSH is defined to be the base of an eddy if the following criteria are satisfied:*
   a) *the SSH of all of the pixels inside the closed contour are higher than the base.*
   b) *there are at least 8 pixels and fewer than 1000 pixels comprising the interior.*
   c) *there is at least one local extremum of SSH in the interior.*
   d) *the difference between the extremum and the base is at least 1 cm.*
   e) *the distance between any pair of points within the interior is <400 km, increasing linearly equatorward of 25º to a maximum of 1200 km at the equator.*

3) *The same procedure is applied in reverse to identify <u>cyclones</u> (concave upward SSH), starting with a large positive SSH of +100 cm and stepping upward incrementally until an outermost closed contour of SSH is found.*



Note that this procedure allows for anticyclones that are propagating on a large-scale background of negative SSH, and vice versa for cyclones.

Observed amplitude life cycles: 3 examples



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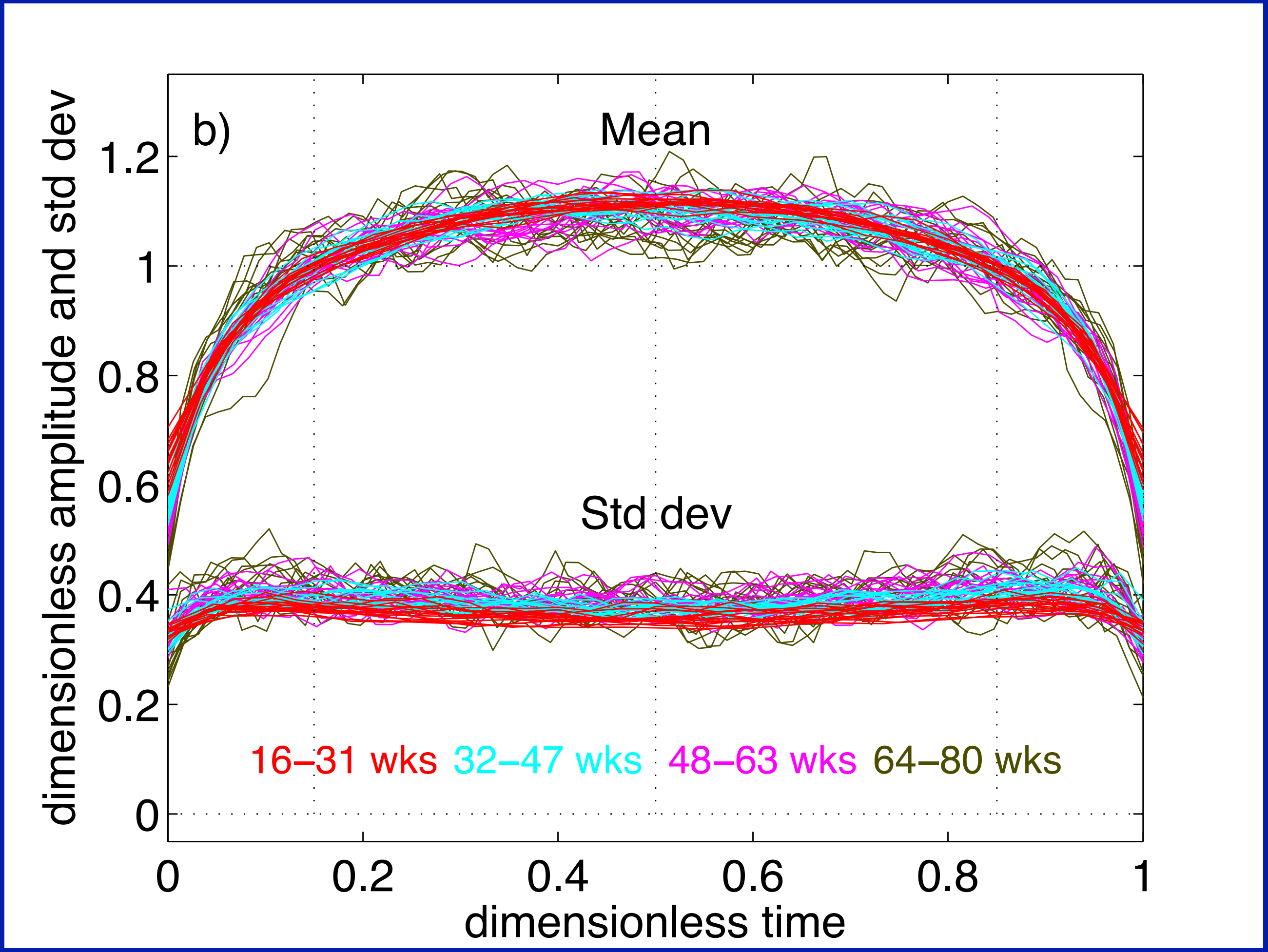
Normalized mean and std dev life cycles from altimeter eddy-tracking analysis

Universality, time-symmetry,….!!!



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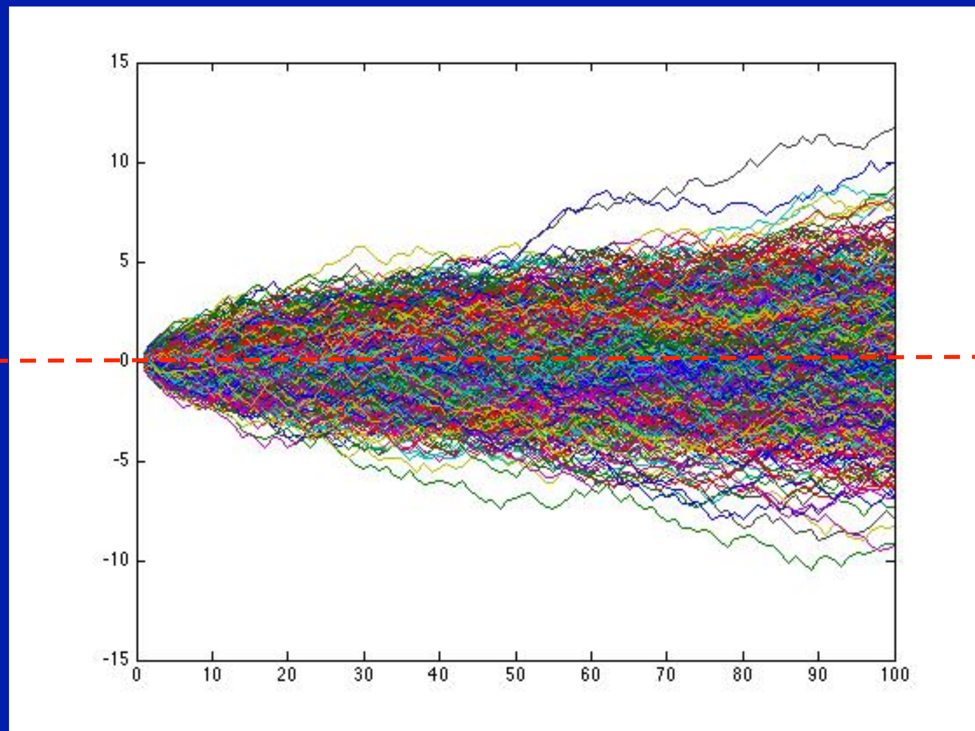
Standard random walk: amplitude $A(t_j) \sim t_j^{1/2}$

$$A(t_{j+1}) = A(t_j) + \delta_j \qquad \delta_j = \pm 1$$

$A(t_j)$



j

$$t_{j+1} = t_j + \Delta t, \qquad \Delta t = 1 \text{ wk}$$

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Gaussian random walk with linear damping

(first-order autoregressive/AR1 process; Markov processs)

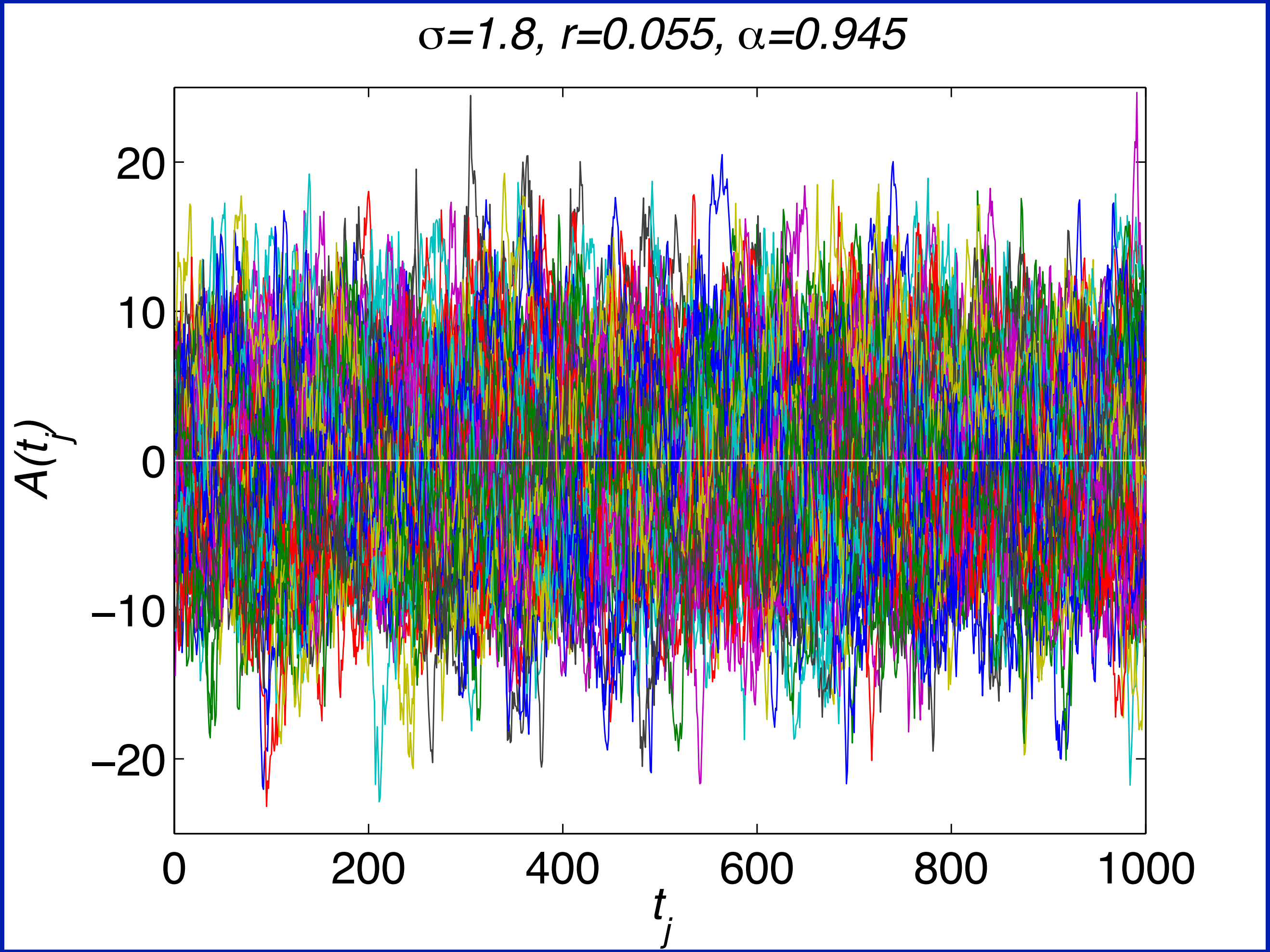
$$
\begin{aligned}
A(t_{j+1}) &= A(t_j) + \delta_j - rA(t_j) \\
&= \alpha A(t_j) + \delta_j, \\
& \quad 0 < \alpha = 1 - r < 1
\end{aligned}
$$

δ_j is a random increment drawn from a zero-mean normal distribution with standard deviation σ.

This gives an asymptotically stationary distribution for A in the limit of large j (i.e., the damping r arrests the $A(t_j) \sim t_j^{1/2}$ growth).

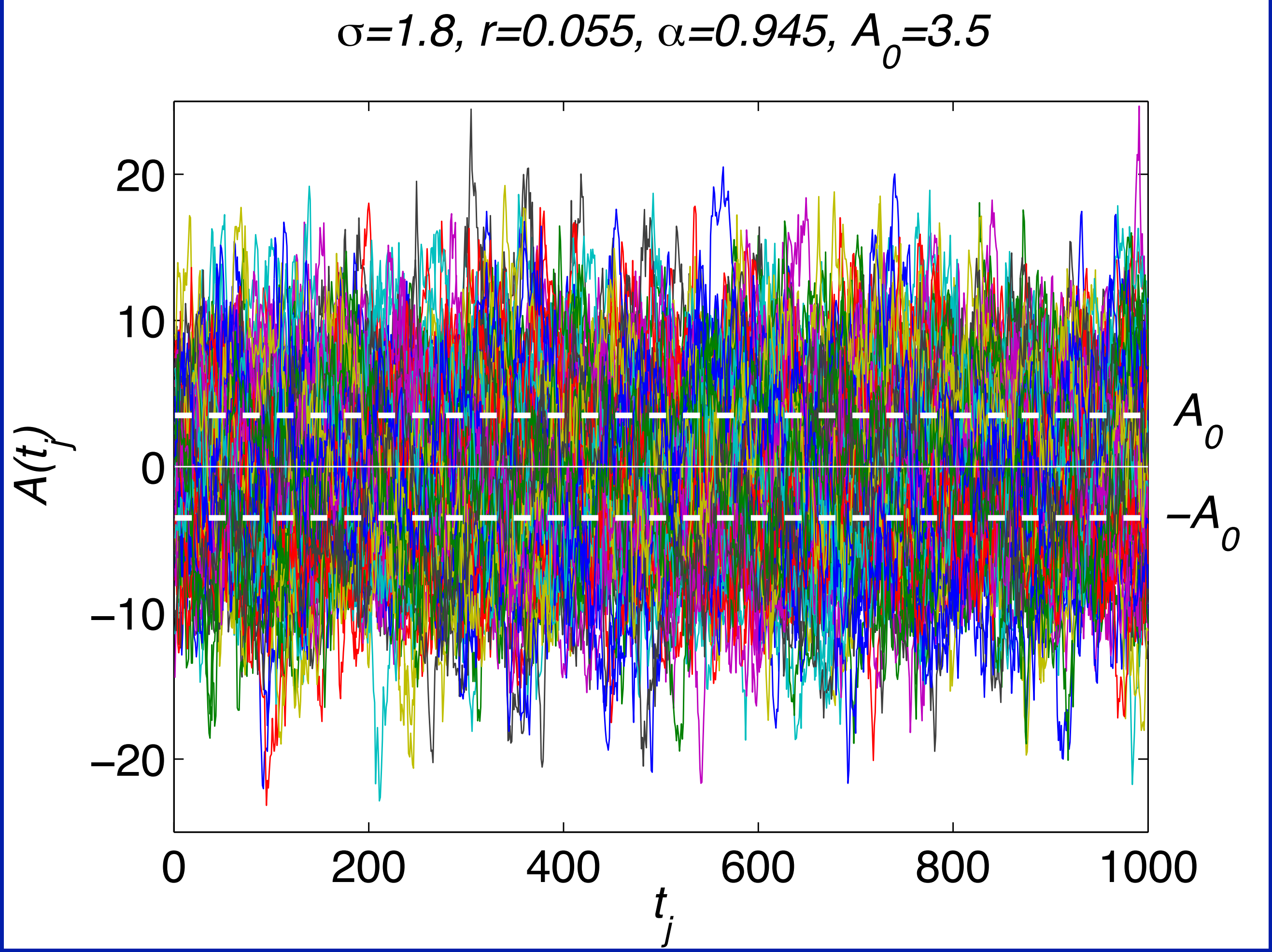
Gaussian random walk with linear damping

(first-order autoregressive/AR1 process; Markov processs)



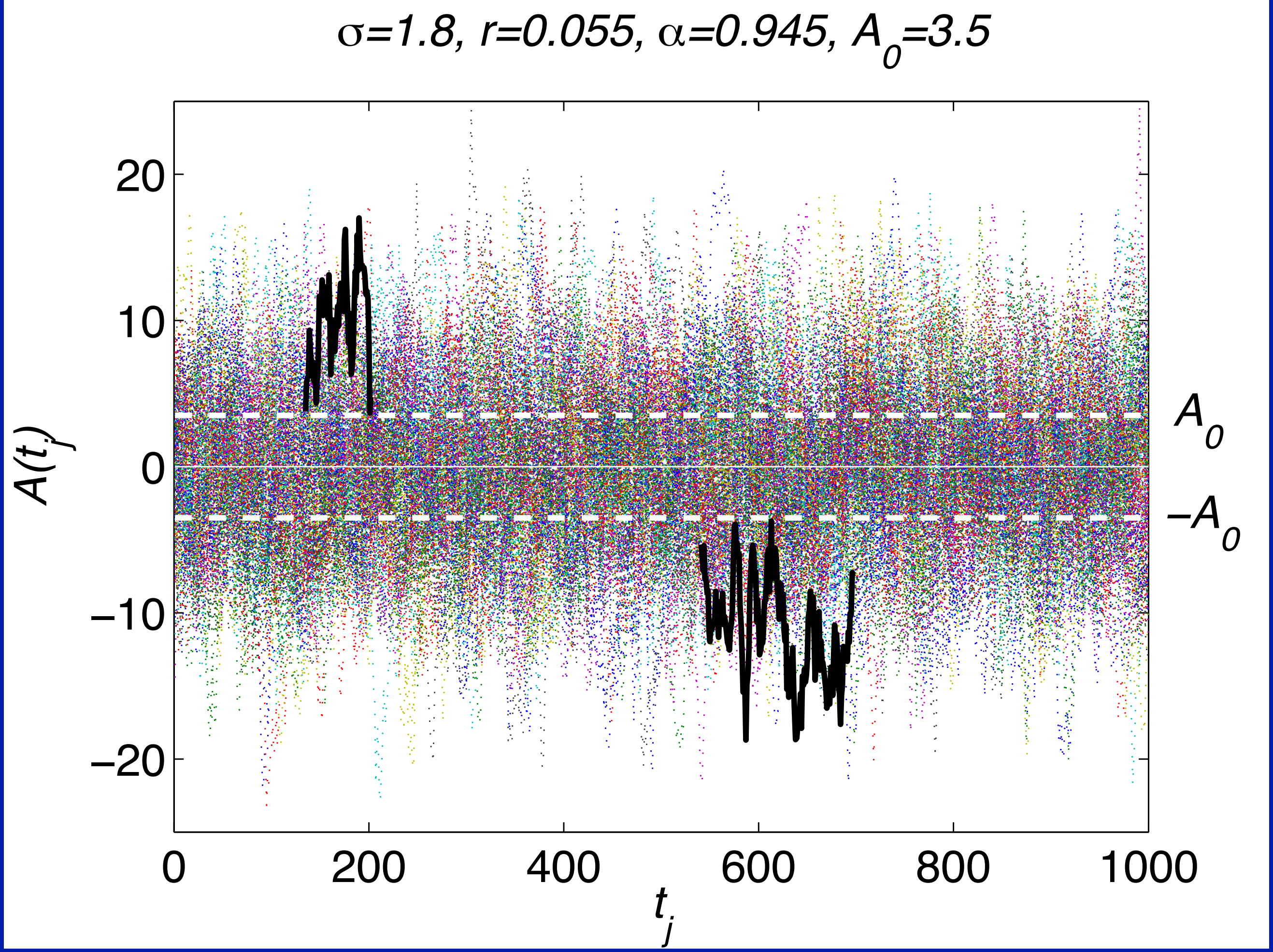
Subsequences of Gaussian random walk with linear damping

1. Threshold amplitude $A_0 > 0$



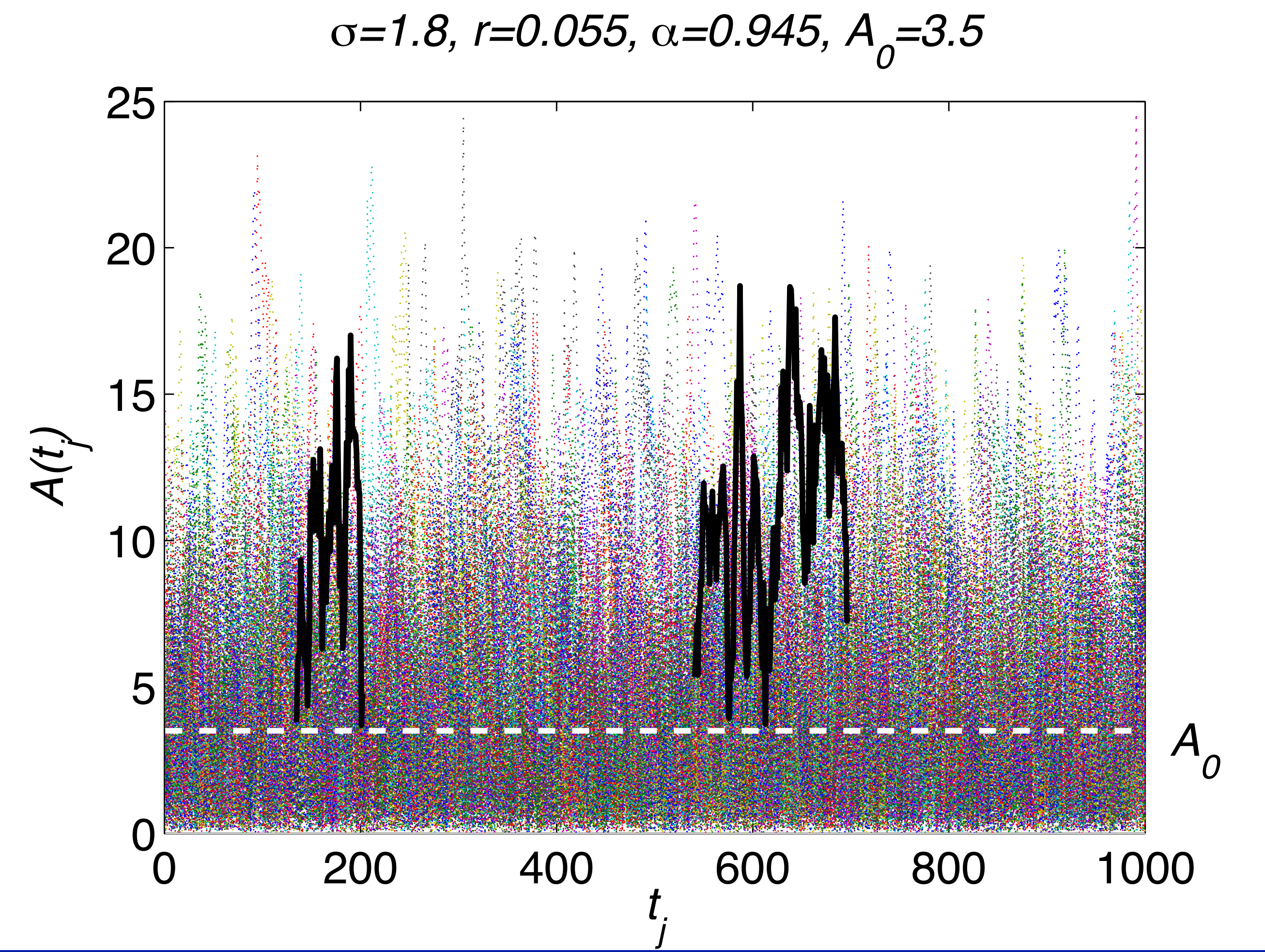
Subsequences of Gaussian random walk with linear damping

2. Identify subsequences $\{A(t_j) > A_0\}$ or $\{A(t_j) < -A_0\}$



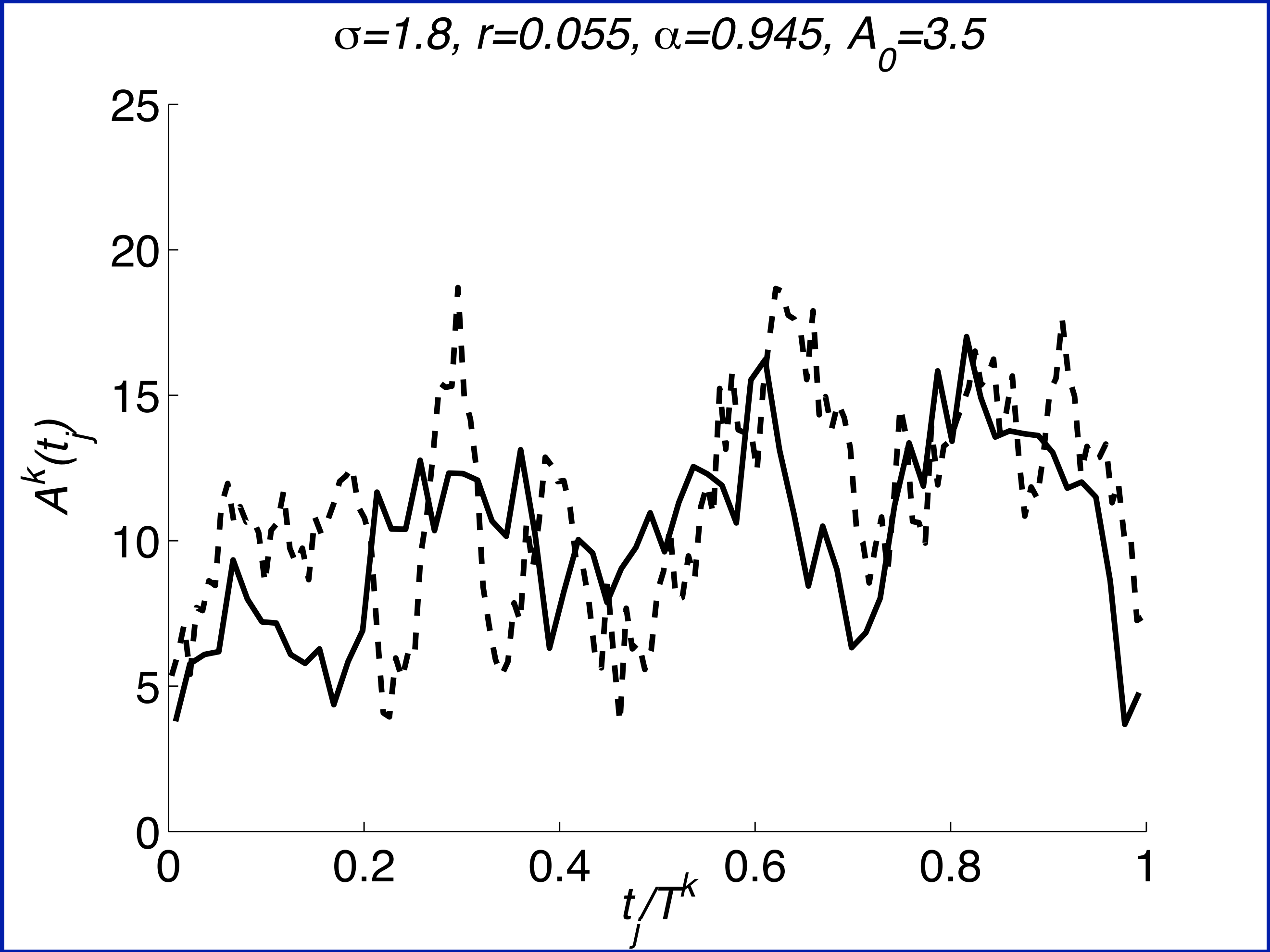
Subsequences of Gaussian random walk with linear damping

3. Take absolute values $\{|A(t_j|\}$



Subsequences of Gaussian random walk with linear damping

4. Normalize time by subsequence length so $0 < t < 1$



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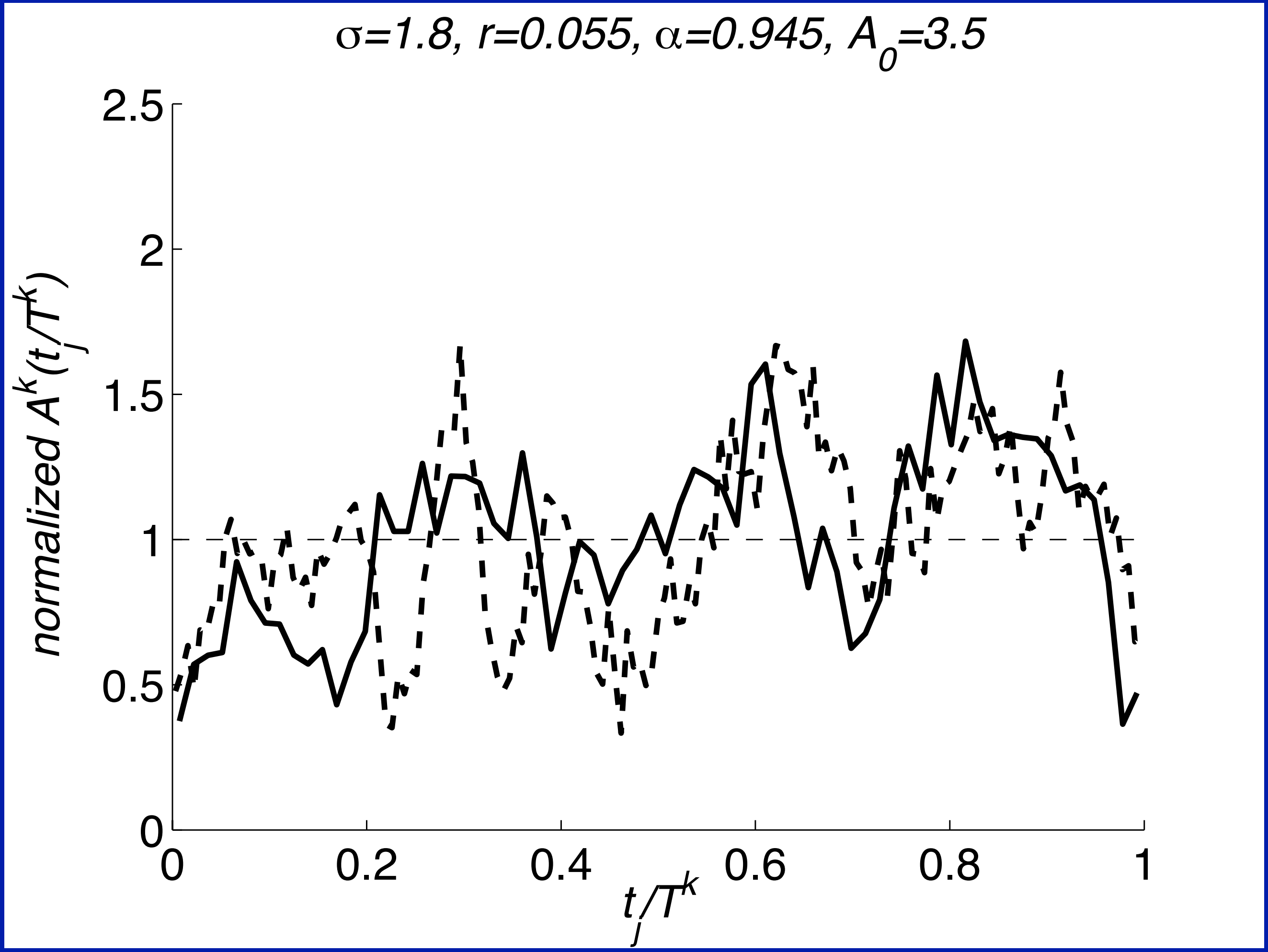
Subsequences of Gaussian random walk with linear damping
5. Normalize amplitude to have unit mean



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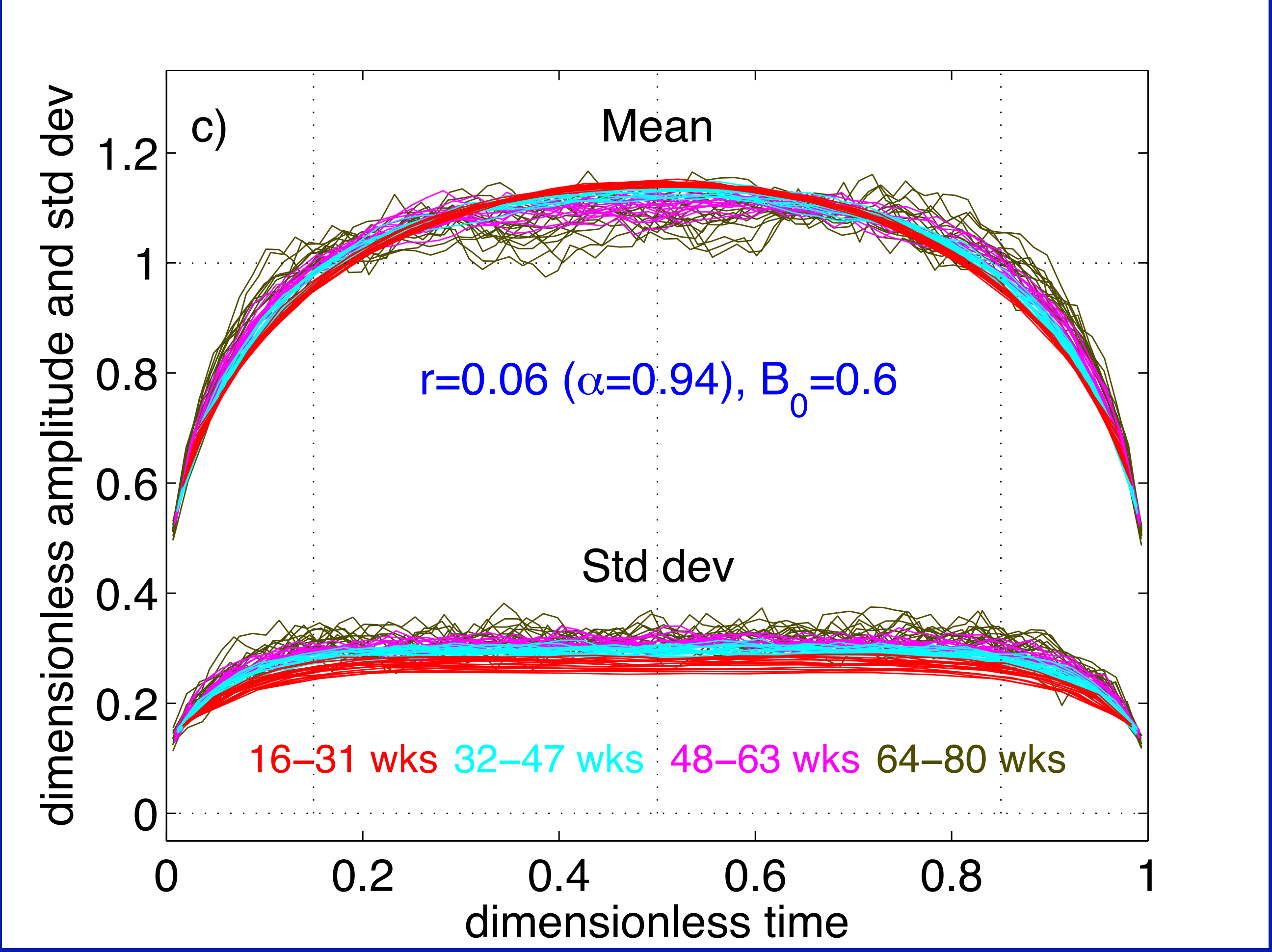
Subsequences of Gaussian random walk with linear damping:

Universal scaling: Normalized life cycle structure is essentially independent of lifetime (and is time-symmetric)!



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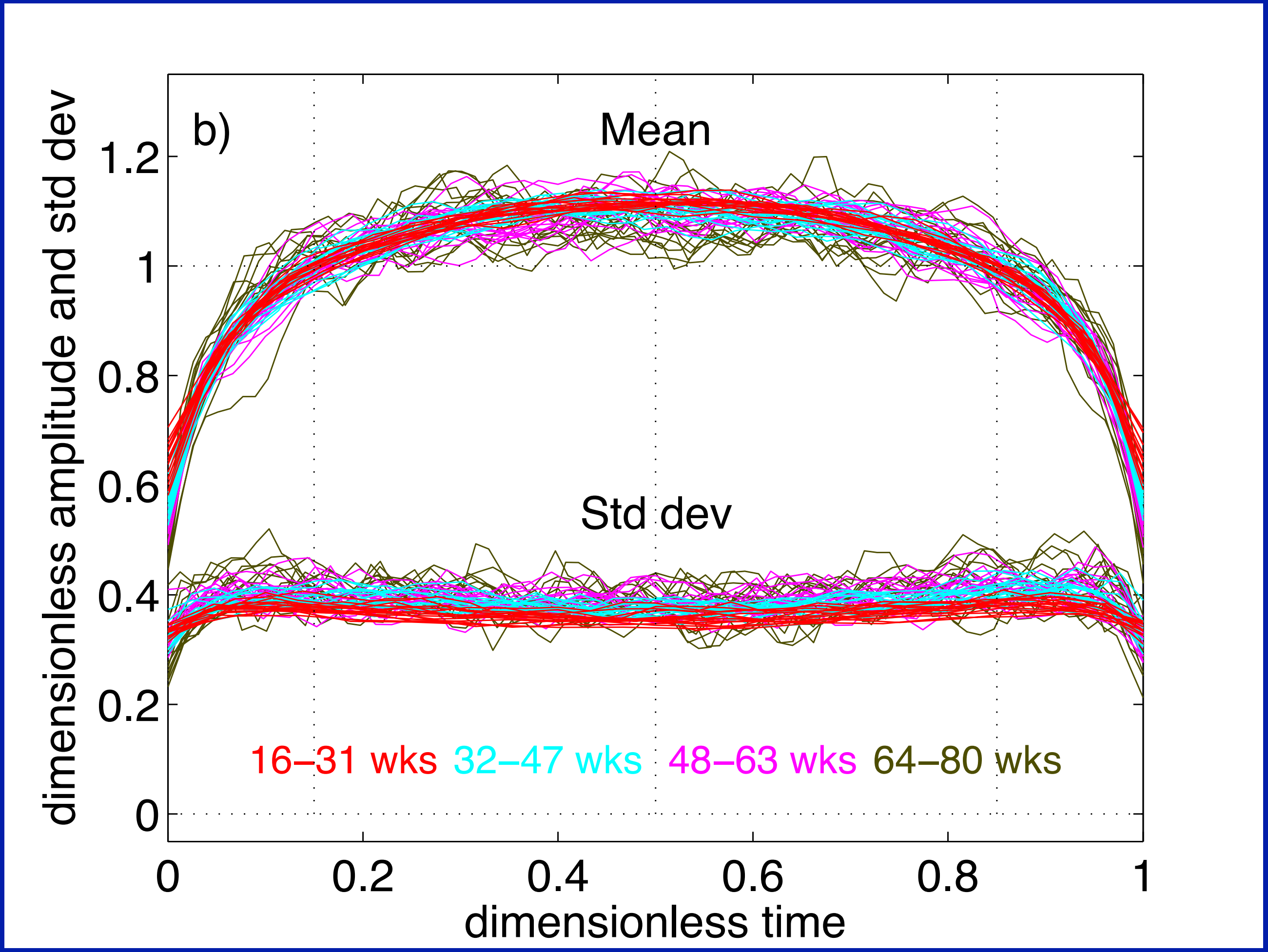
Normalized mean and std dev life cycles from altimeter eddy-tracking analysis

Universality, time-symmetry,….!!!



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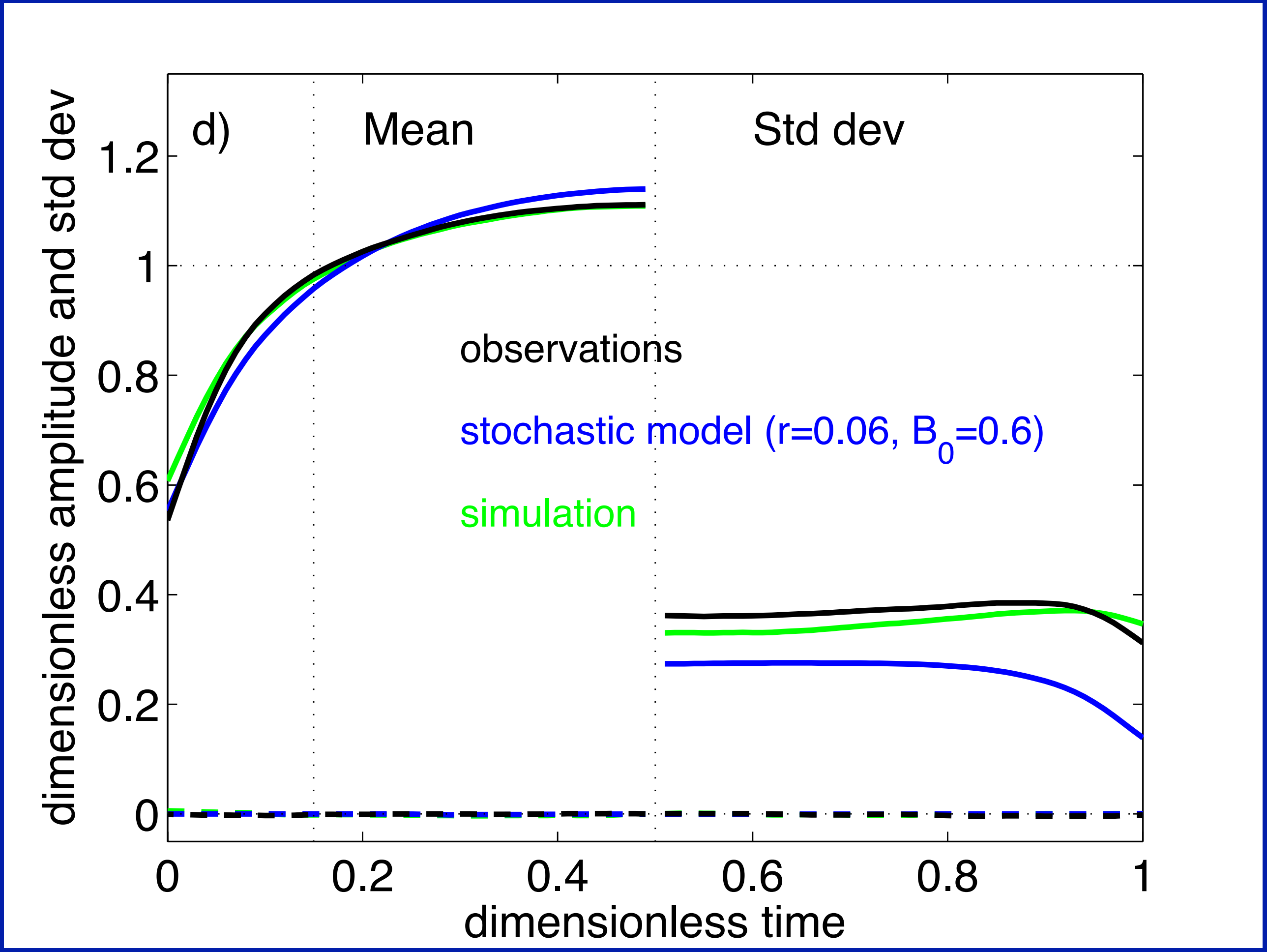
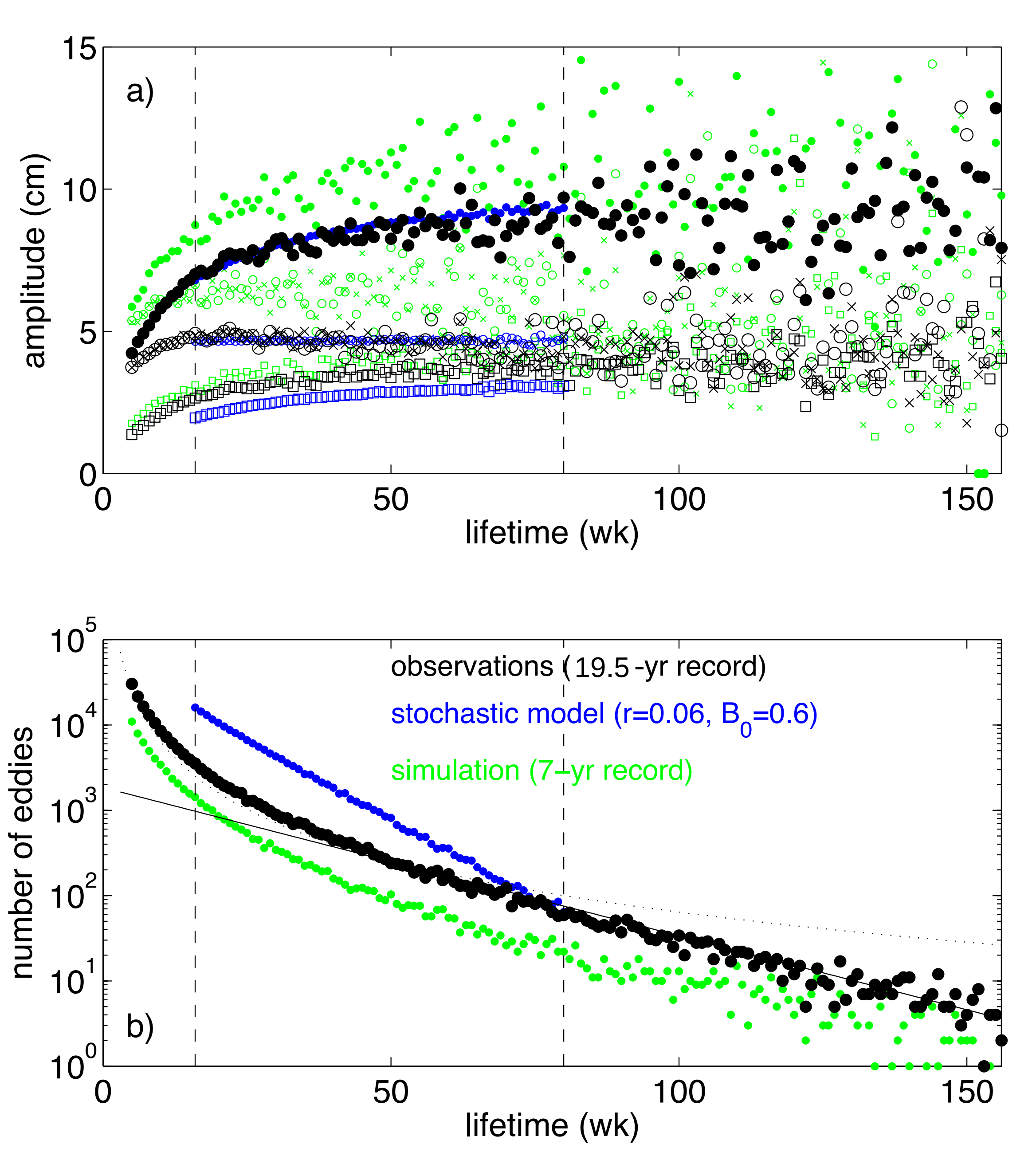
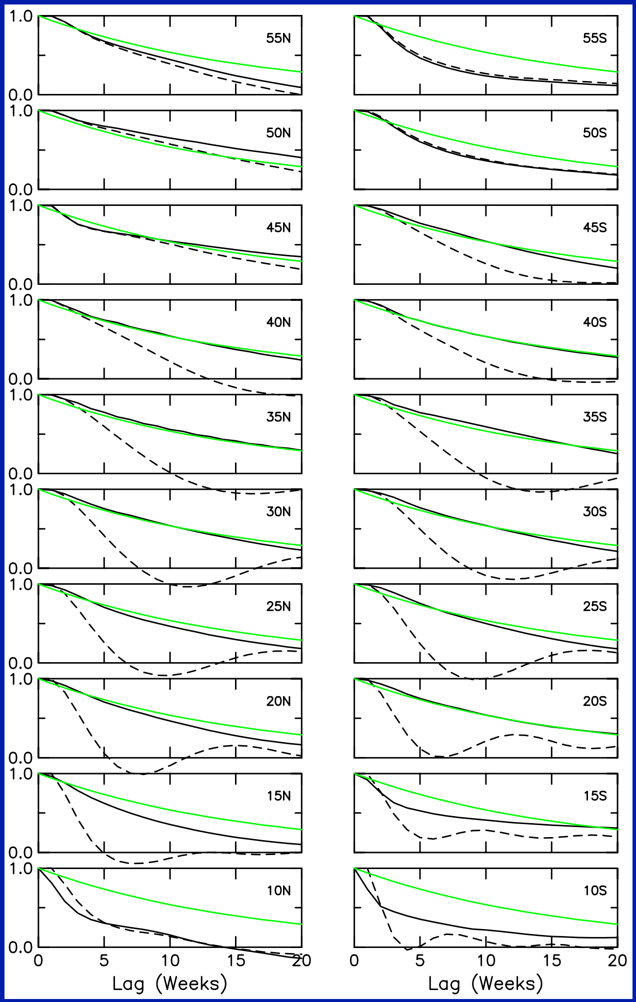
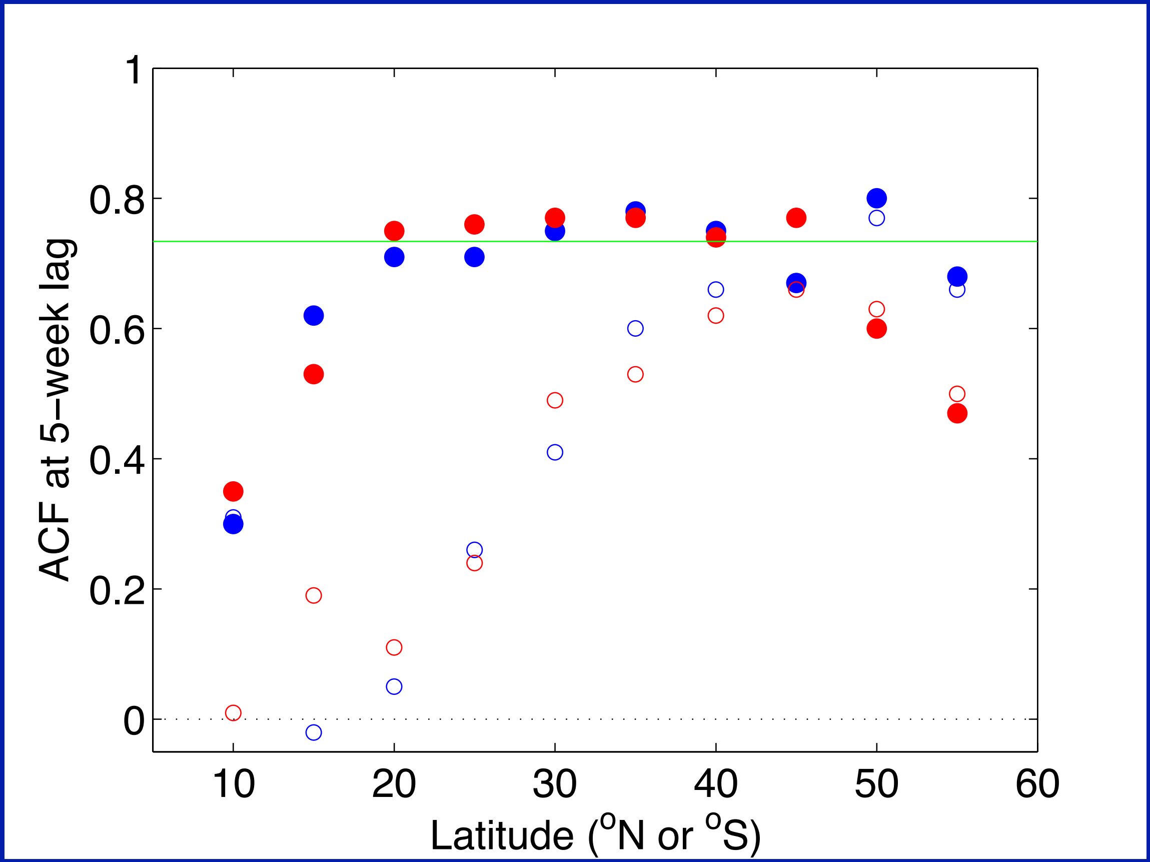


Mean amplitude and number of eddies vs. lifetime



Autocorrelation structure of altimeter SSH field (prior to eddy tracking) is consistent with stochastic model when viewed on long planetary (Rossby) wave characteristics





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The dynamics of random increments

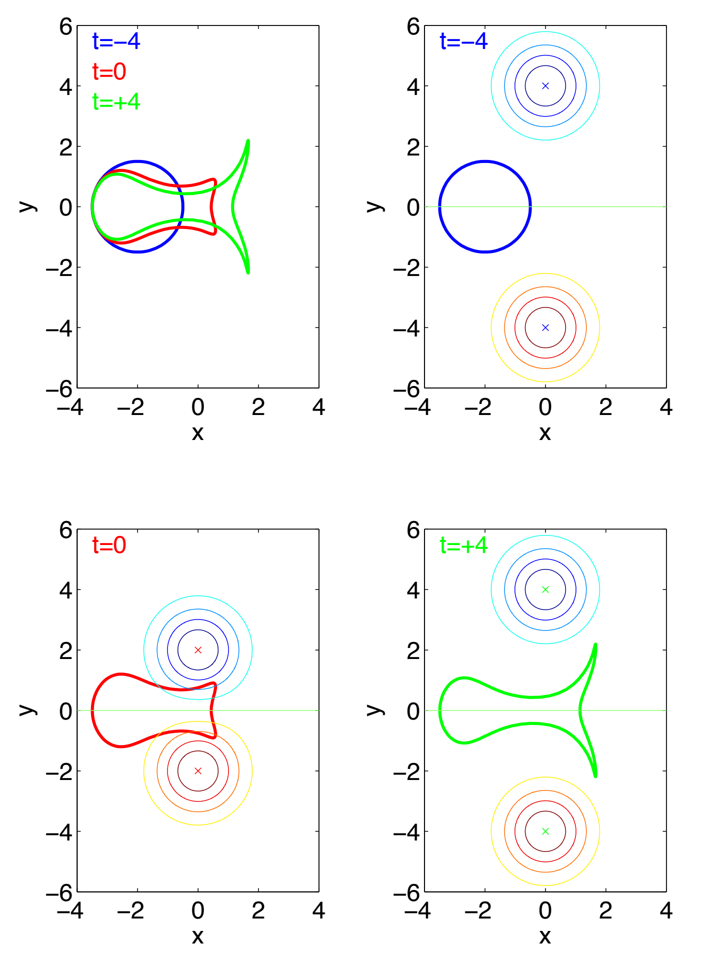
How should the random increments be interpreted physically?

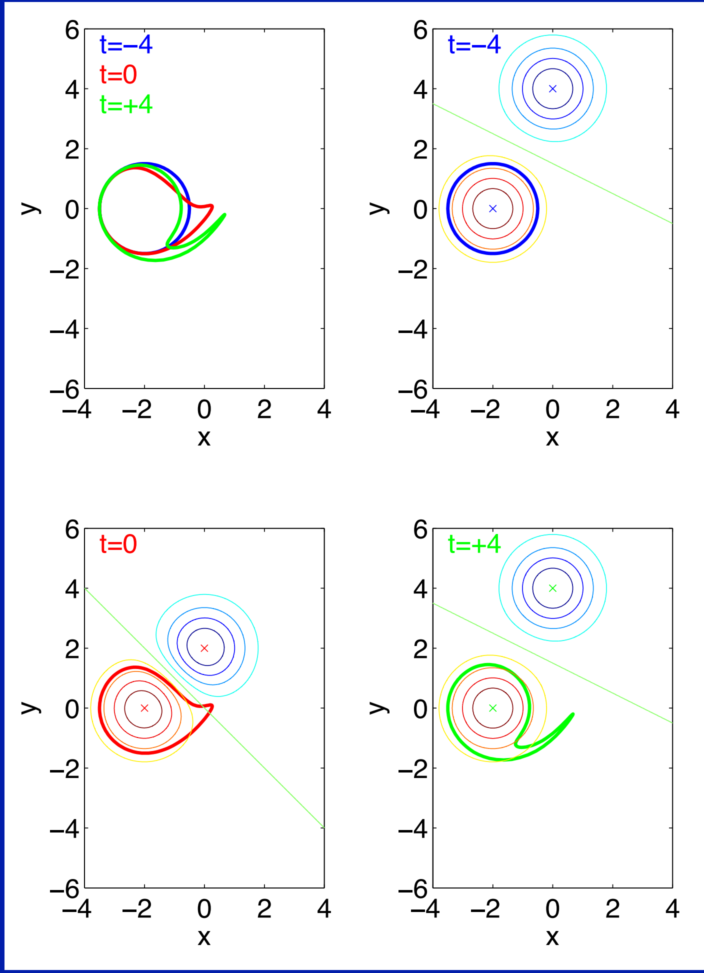
Eddy-eddy interactions (vortex pairs)?
Eddy-mean interactions (mean-flow instability)?
Eddy-whatever interactions (everything and anything)?

What are the implications for theories of mesoscale ocean dynamics (for example, the postulated inverse cascade)?

Work in progress: Correlate observed eddy tracks and eddy amplitude variations to evaluate eddy-eddy interactions.

A candidate mechanism: gain or loss of material through eddy-eddy interaction and filament generation or assimilation





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Conclusions

1. A simple Markov-based model reproduces many basic aspects of observed mean eddy amplitude life cycles from altimeter-based identification and tracking, including time-reversal symmetry and lifetime-independence.

2. Best fit of model results to observations requires inclusion of damping; difficult to reproduce relative magnitude of standard deviations.

3. A “pure” noise model is inconsistent with observations.

4. Physical interpretation of random increments – “forward” or “backward” filamentation?

5. Underlying SSH field autocorrelation structure is consistent with stochastic model when viewed on long planetary wave characteristics

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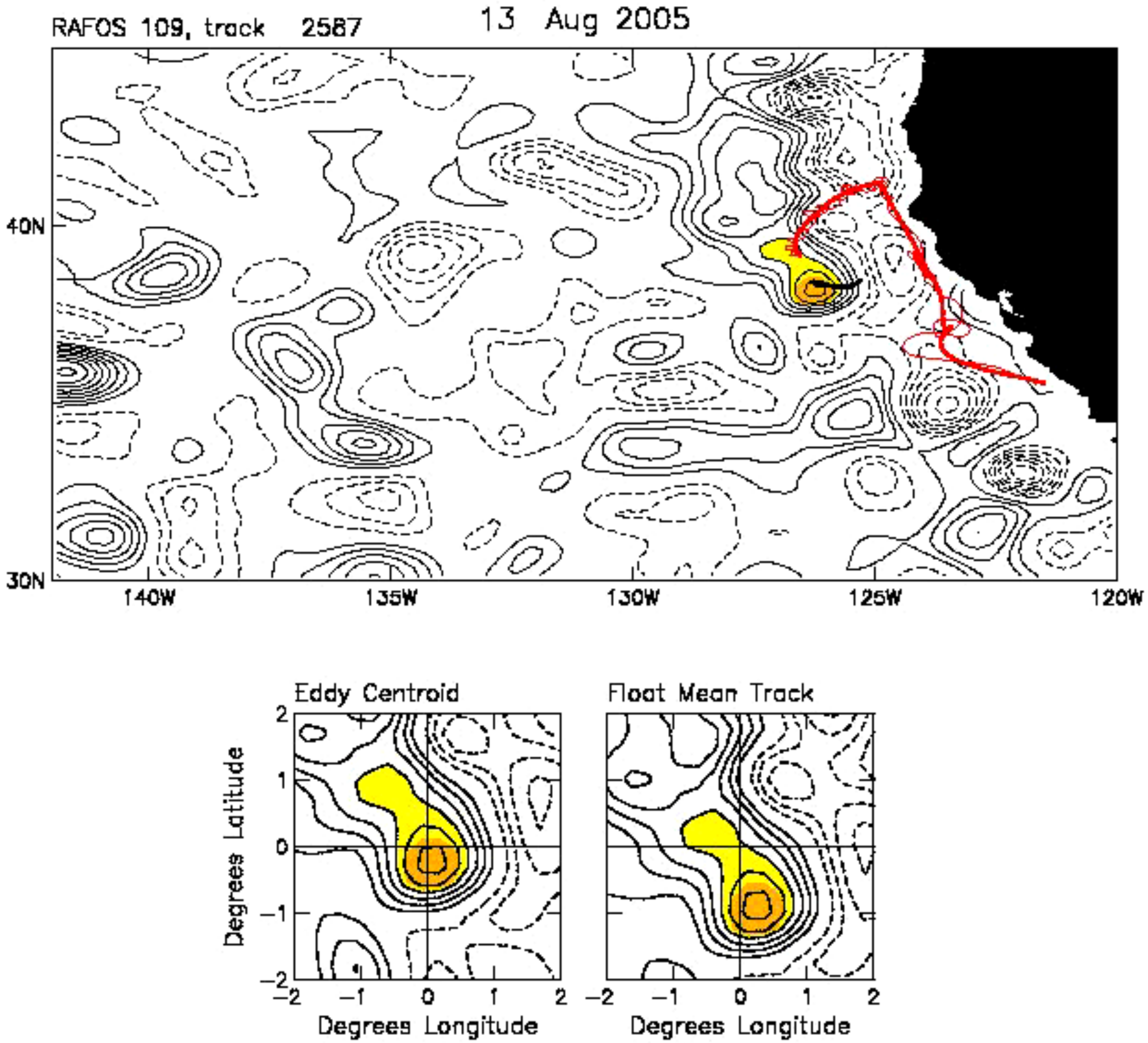
Evidence in Support of an Interpretation of the Observed Westward-Propagating SSH Variability as Nonlinear Eddies

- *the existence of many long-lived coherent structures with symmetric, quasi-Gaussian characteristics.*
- *nearly ubiquitous locations of origin of the eddy-like features, consistent with baroclinic instability as the generation mechanism.*
- *westward propagation with little change in amplitude over long time periods and with very little meridional deflection at approximately the phase speed of nondispersive baroclinic Rossby waves, consistent with theories for large eddies.*
- *preferences for slight poleward deflection of cyclonic eddies and equatorward deflection of anticyclonic eddies, also consistent with theories for large eddies.*
- *broad-banded in wavenumber and frequency (i.e., not dominated by annual or semiannual variability in most regions)*
- *weak dispersion (consistent with propagating coherent structures)*
- *rapid decrease in spectral energy at wavelengths shorter than the Rossby radius of deformation, consistent with nonlinear QG dynamics.*
- *mostly nonlinear by 3 different measures, of which U/c is most relevant to the trapping of fluid within eddies.*
- *regions of trapped fluid estimated from altimetry are consistent with RAFOS float trajectories in the California Current System.*



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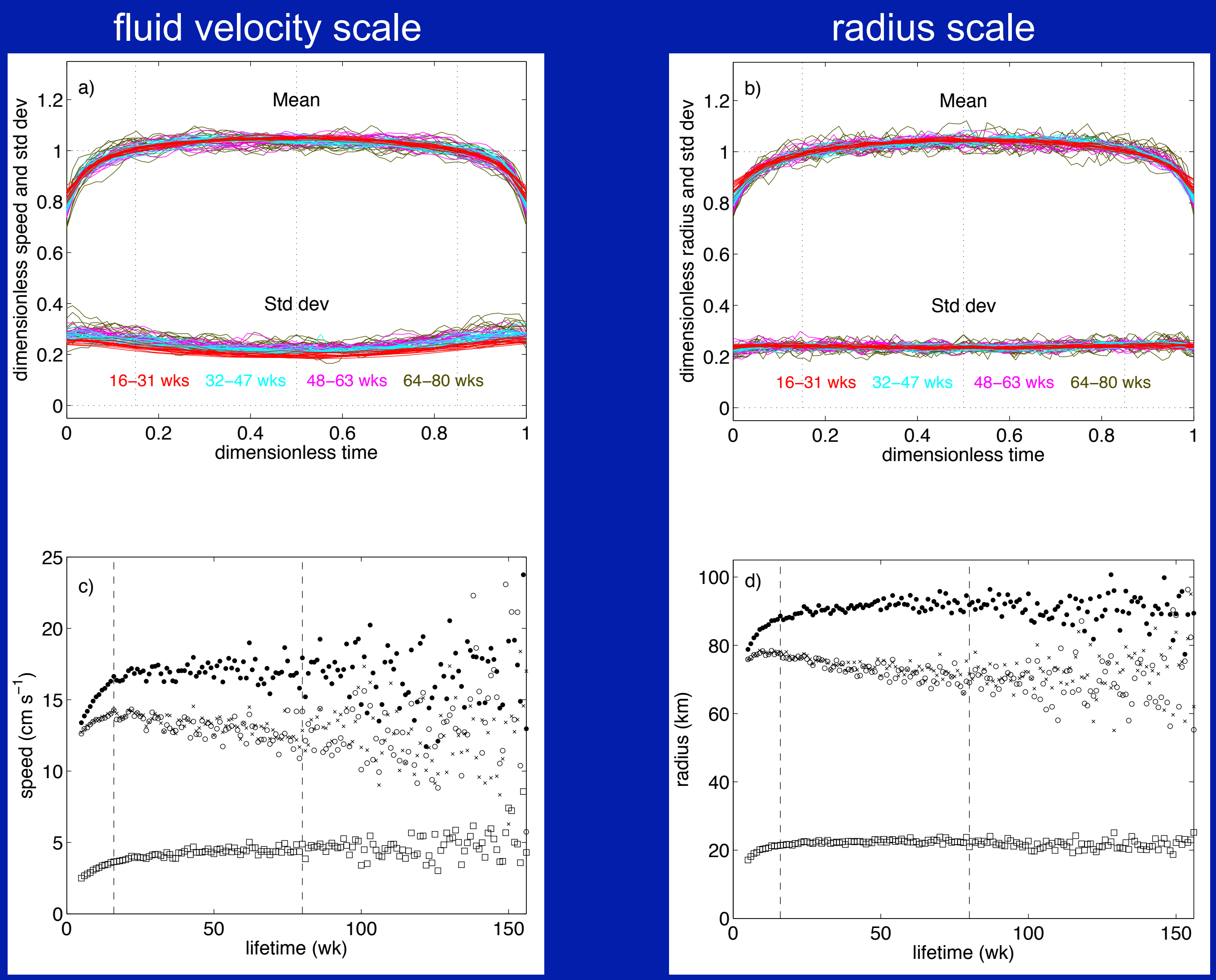
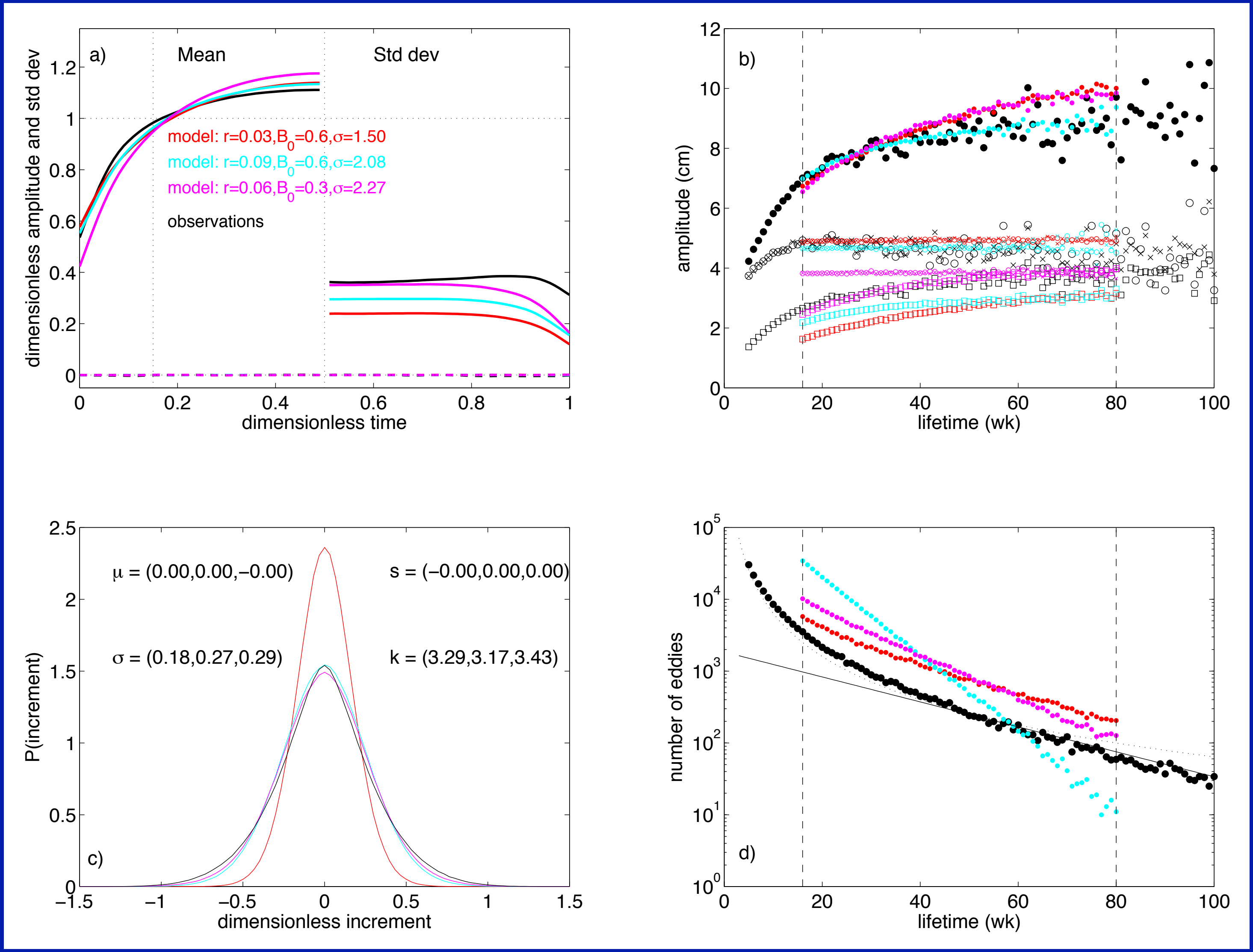
Eddy fluid velocity and radius life cycles

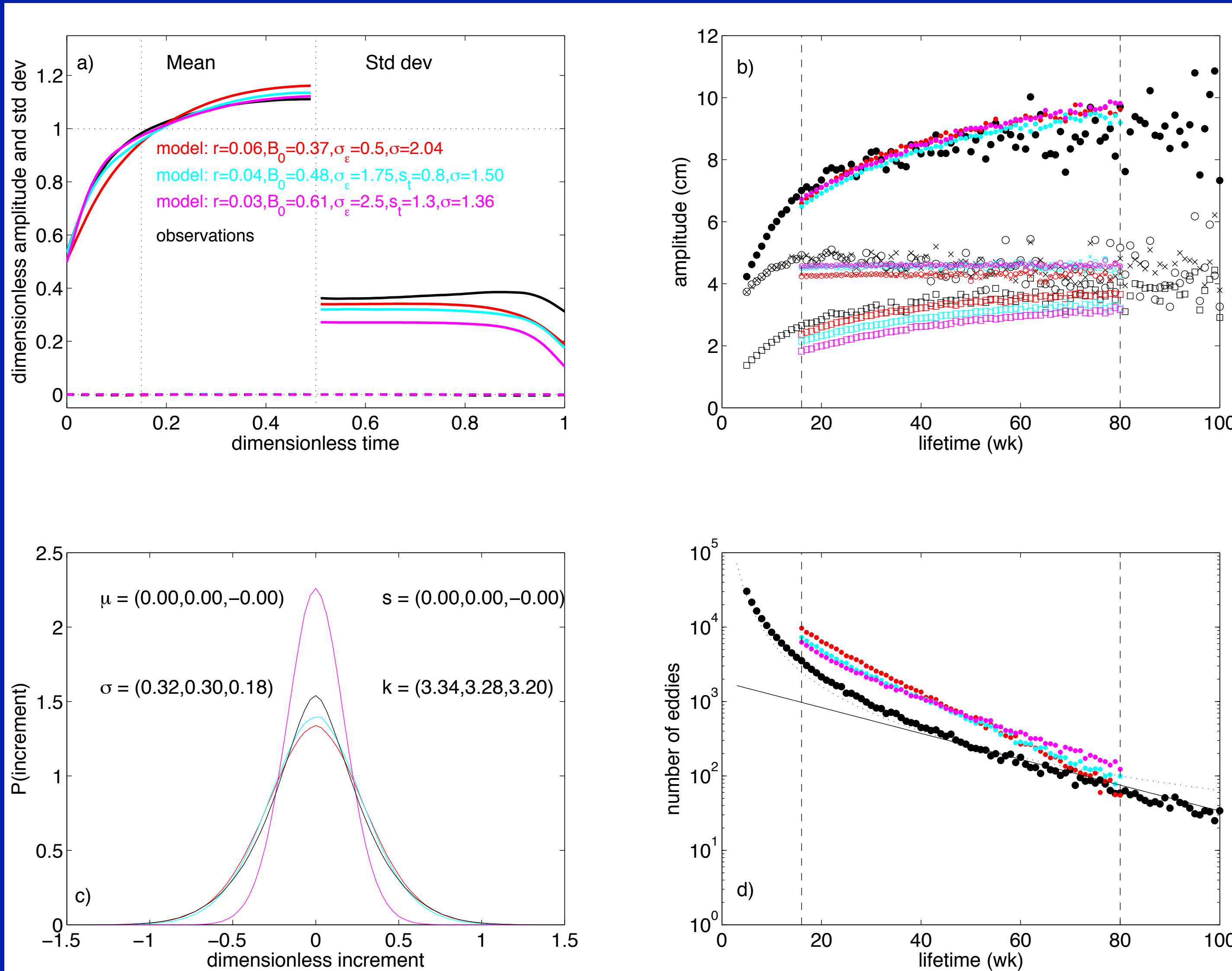
Scales from altimeter-based eddy-tracking



Stochastic model, revisited



Stochastic model, refined



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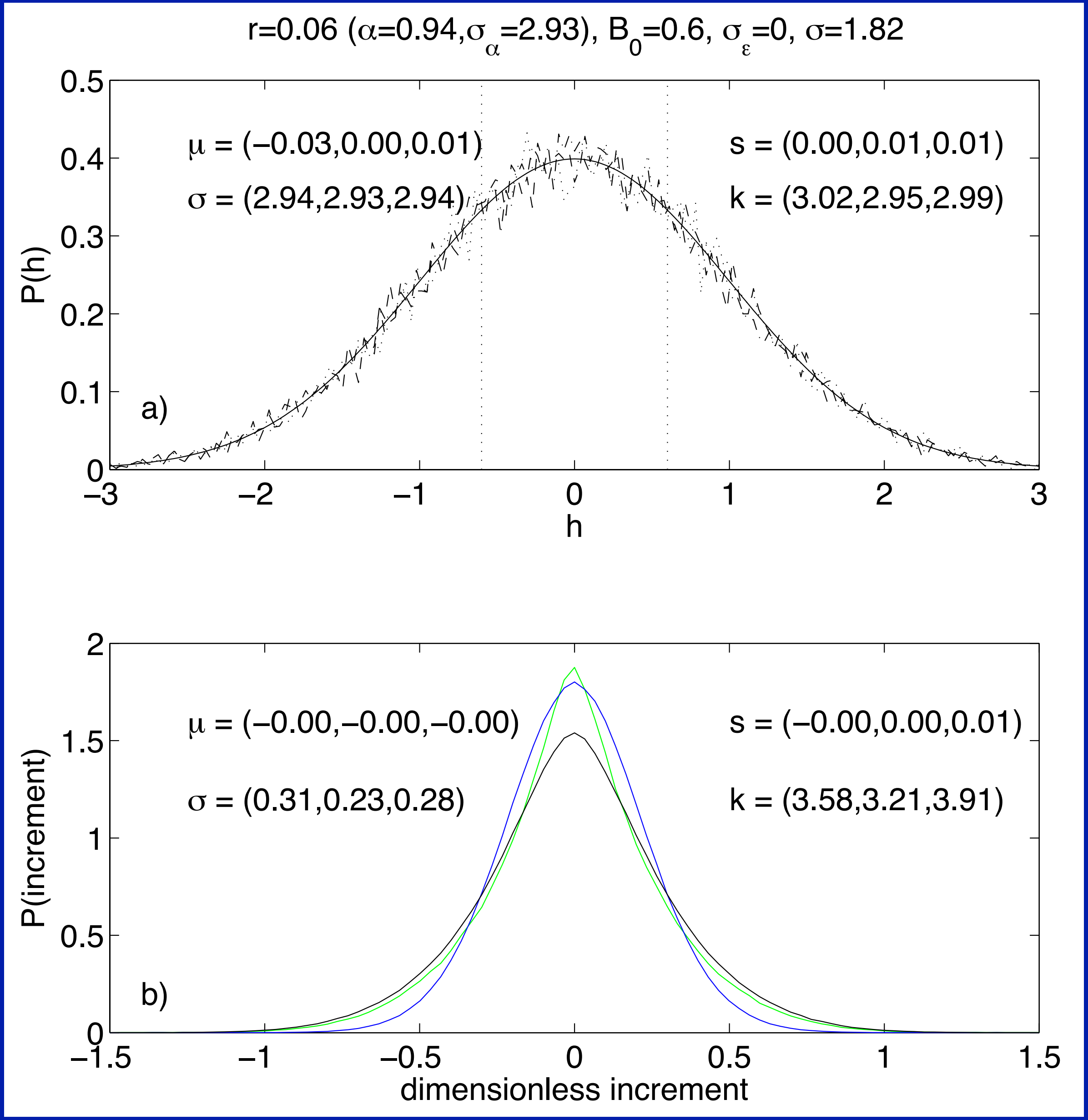
Increment distributions



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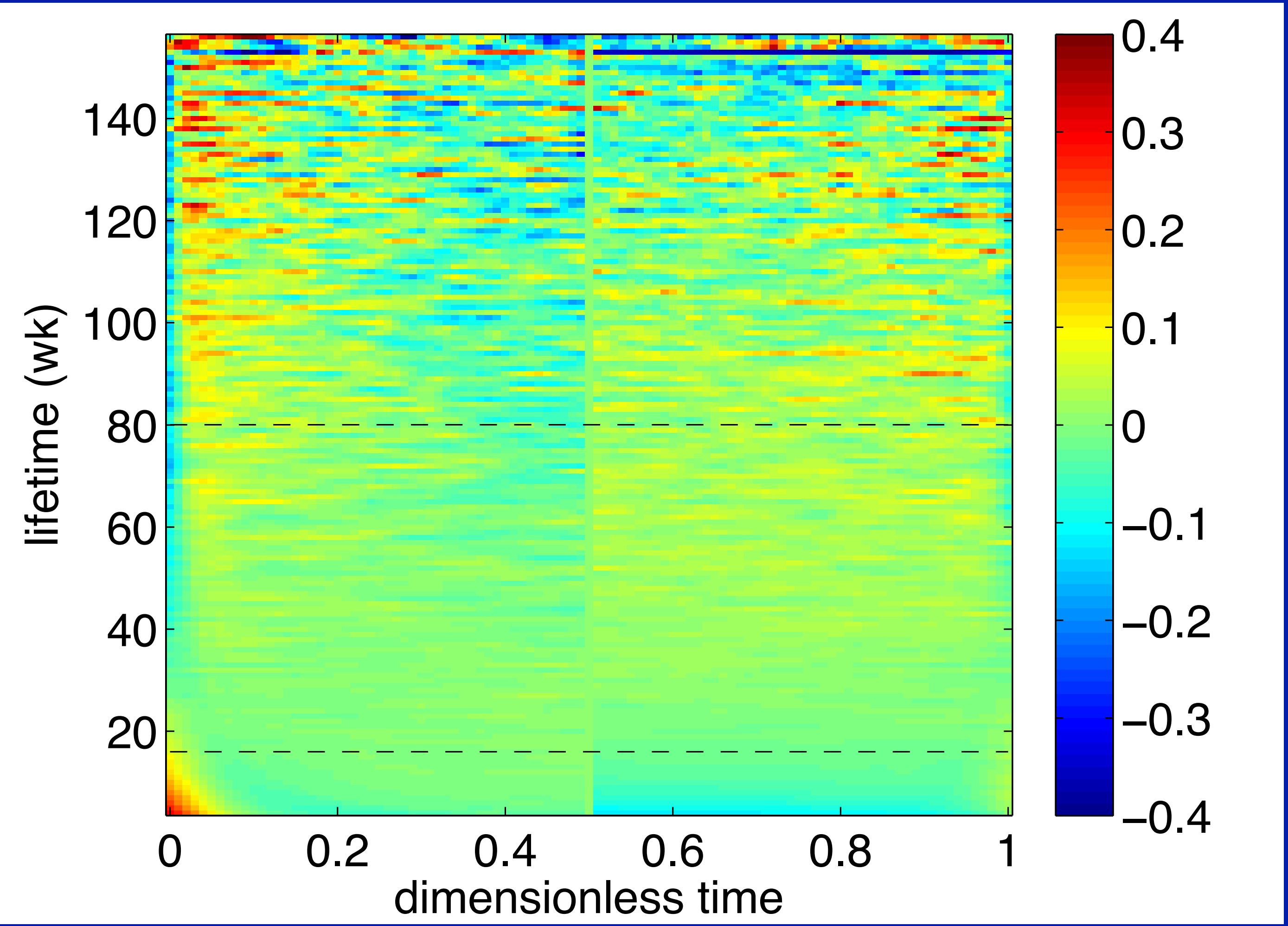
Departures from overall ensemble mean and std dev life cycles vs. lifetime

(symmetric parts only)



Mean

Std Dev

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