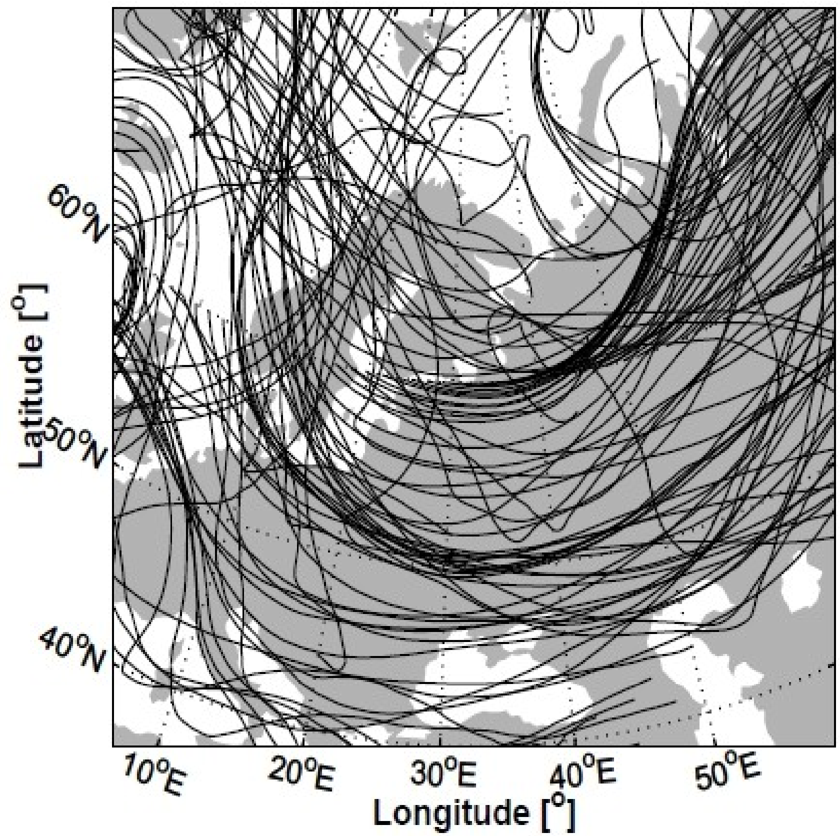
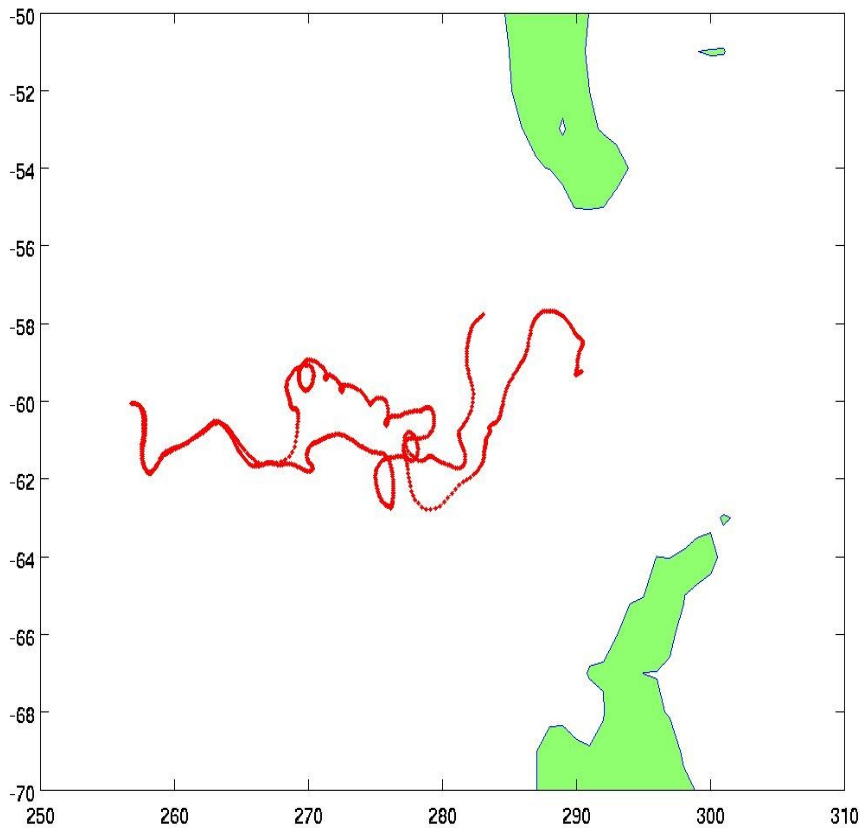
Relative dispersion in the atmosphere



Lise Seland Graff, Sigmund Guttu and Joe LaCasce
Dept. of Geosciences, University of Oslo

Pair dispersion and spectra



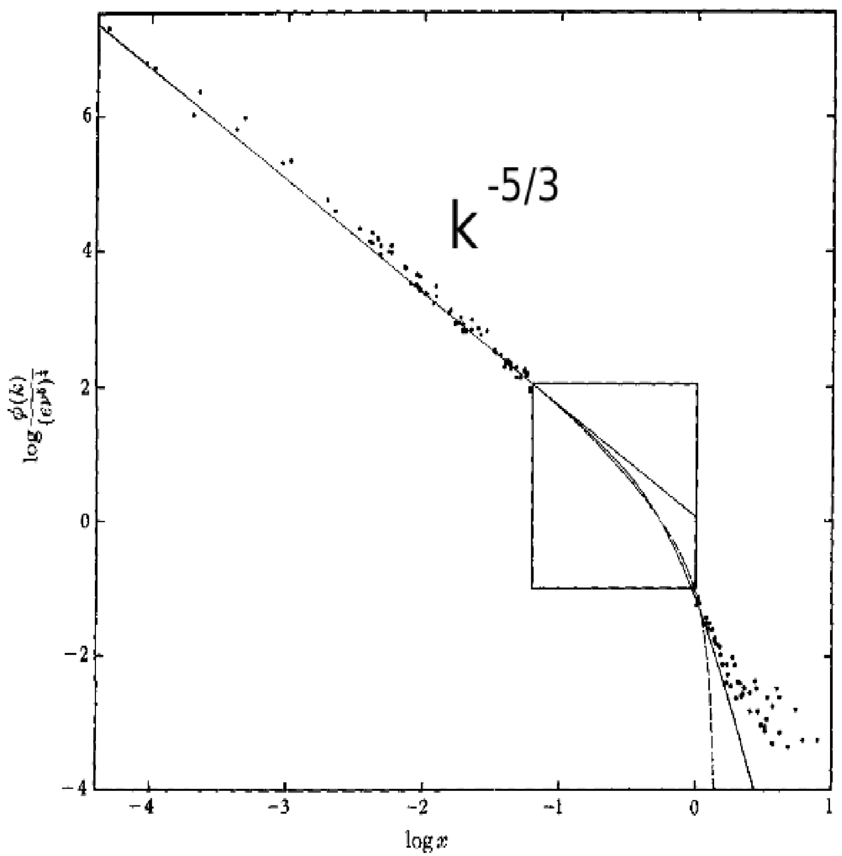
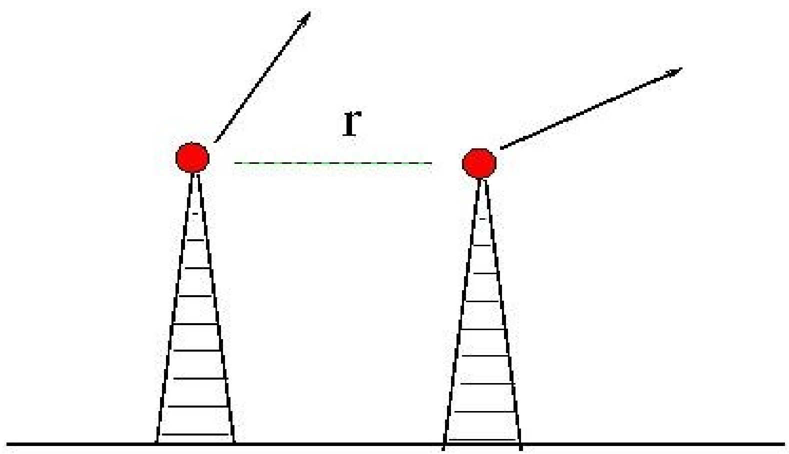
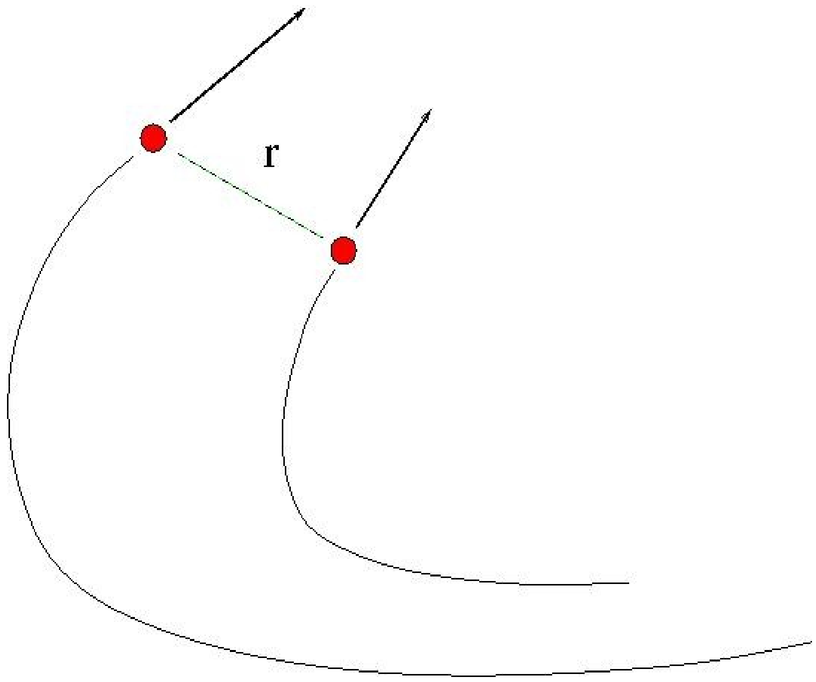


FIGURE 12. Seventeen spectra compared to the theories of Kolmogoroff, Heisenberg and Kovasznay. The straight line has a slope of $-\frac{5}{3}$, the curved solid line is Heisenberg's theory and the dashed line is Kovasznay's theory. Within the square, the observations are too crowded to display on this scale and they are shown in figure 13.

Statistical equivalence





- In homogeneous, isotropic turbulence, Lagrangian and Eulerian velocity differences are equivalent

$$\delta v_E(r) = \delta v_L(r)$$

Structure functions and dispersion

$$< v^2(r) >=< (u(x+r,t)-u(x,t))^2 >= 2\int_0^\infty E(k)[1-J_0(kr)]\,dk$$

$$< v^2(r) >\approx 2\int_0^{1/r} k^{-\alpha}(\frac{1}{4}k^2r^2)\,dk + 2\int_{1/r}^\infty k^{-\alpha}\,dk$$

$$< v^2(r) >= \frac{1}{2}r^2\frac{1}{3-\alpha}k^{3-\alpha}|_0^{1/r} \; + \; \frac{2}{1-\alpha}k^{1-\alpha}|_{1/r}^{\infty}$$

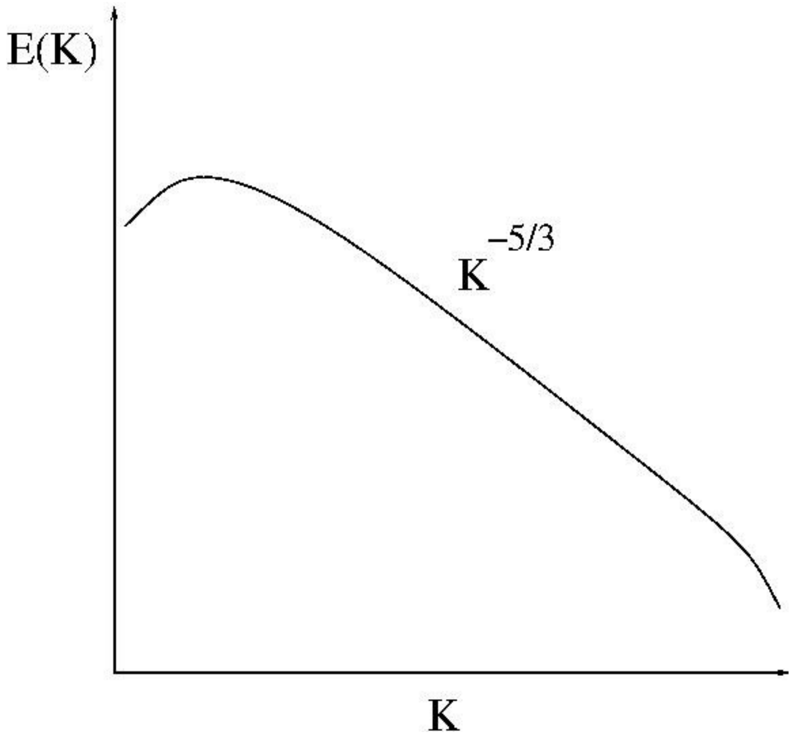
Bennett (1984)

Local dispersion

Intermediate slopes: $1 < \alpha < 3$

$$< v^2(r) > \propto r^{\alpha-1}$$

$$\kappa_2 = \frac{1}{2}\frac{d}{dt} < r^2 > \propto r^{(\alpha+1)/2}$$



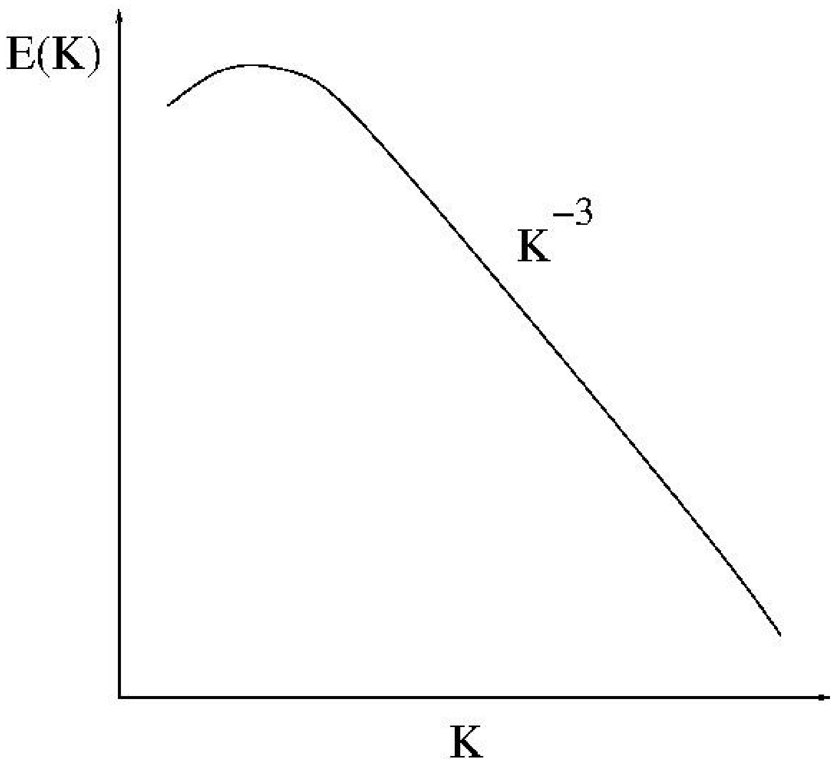
Richardson Regime:

$$< v^2(r) > \propto r^{2/3}$$

$$\kappa_2 = \beta r^{4/3}$$

Non-local dispersion

Steep slopes: $\alpha \geq 3$



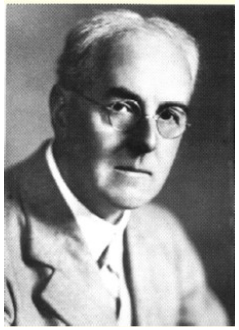
<u>Lundgren regime</u>:

$$v^2(r) > \approx \frac{1}{2} r^2 \int_0^\infty k^2 E(k)\, dk = \frac{1}{2} Z r^2$$

$$\kappa_2 = \frac{C}{T} r^2$$

Pair separation PDFs

- Richardson equation (2D)



$$\frac{\partial}{\partial t}p = \frac{1}{r}\frac{\partial}{\partial r}(\kappa_2\, r\frac{\partial}{\partial r}\, p)$$

- Richardson Regime: $\kappa_2 = \beta r^{4/3}$

$$p(r,t) = \frac{3}{4\pi\beta t(r_0^2 r^2)^{1/3}}\; exp(-\frac{9(r_0^{2/3}+r^{2/3})}{4\beta t})\;\; I_2(\frac{9r_0^{1/3}r^{1/3}}{2\beta t})$$

- Lundgren Regime: $\kappa_2 = r^2/T$

$$p(r,t) = \frac{1}{4\pi^{3/2}(t/T)^{1/2}\, r_0^2}\; exp(-\frac{[ln(r/r_0)+2t/T]^2}{4t/T})$$

Lundgren (1981), LaCasce (2010)

Relative dispersion

- Richardson Regime:

$$< r^2 > \to 5.2675 \beta^3 t^3 \qquad Ku \equiv \frac{< r^4 >}{(< r^2 >)^2} \to 5.6$$

- Lundgren Regime:

$$< r^2 > = r_0^2 e^{8t/T} \qquad Ku = e^{8t/T}$$

Balloon dispersion in the EOLE and TWERLE experiments

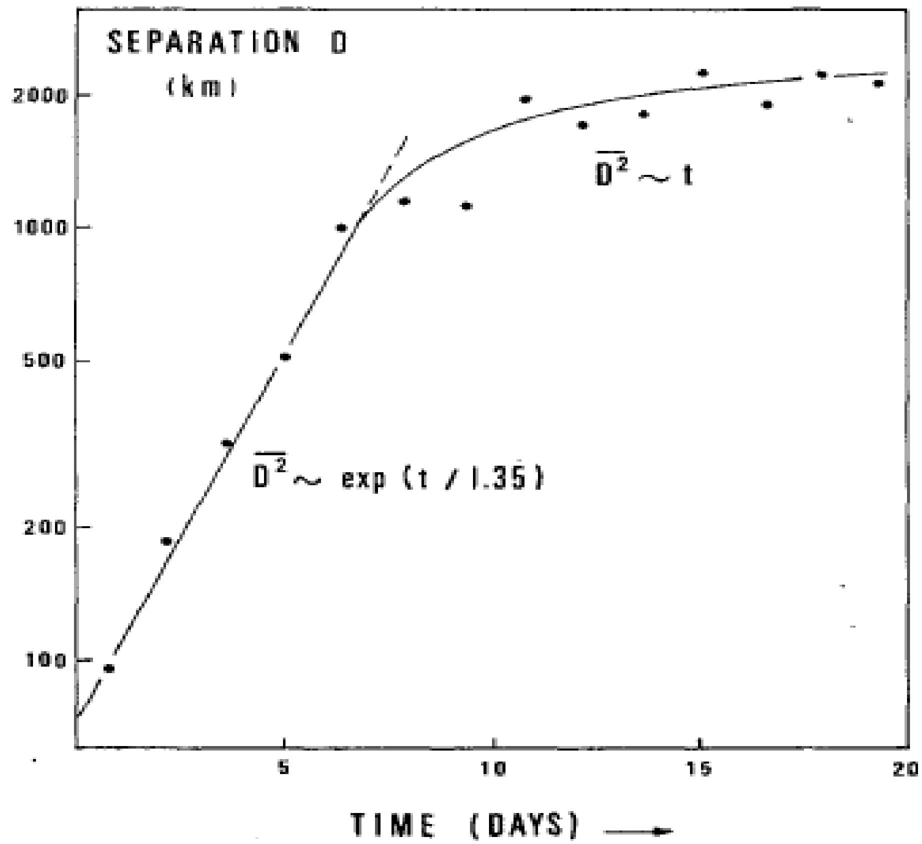


FIG. 8. Root mean square separation of the original pairs of balloons released during the EOLE experiment, as a function of time after launch.

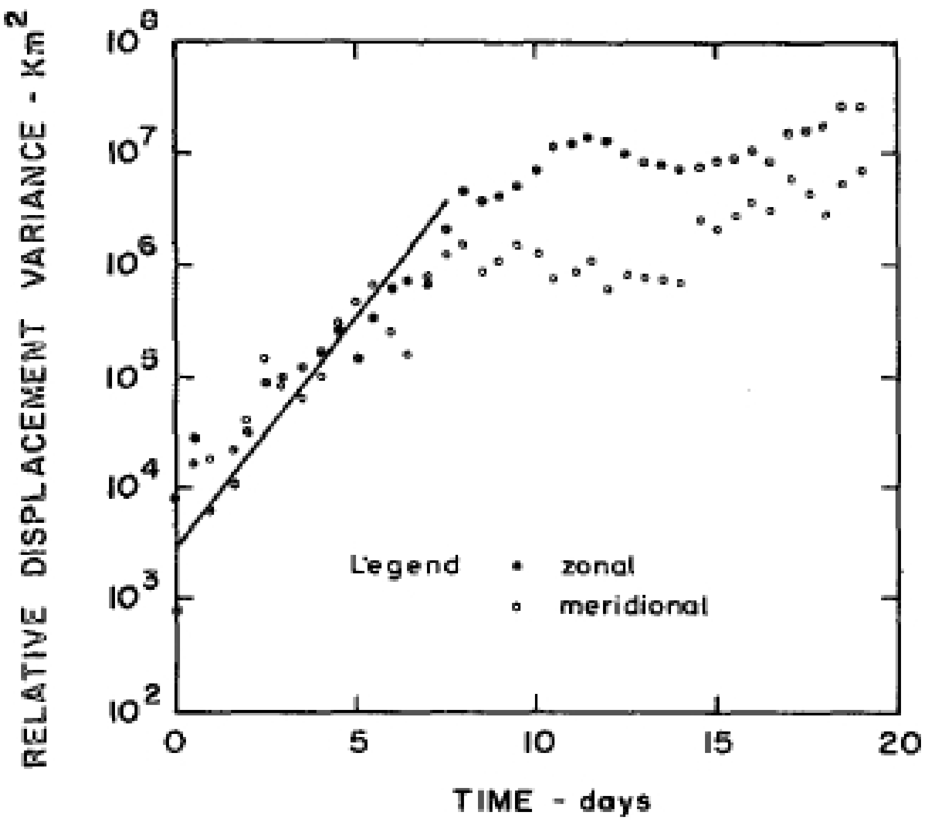
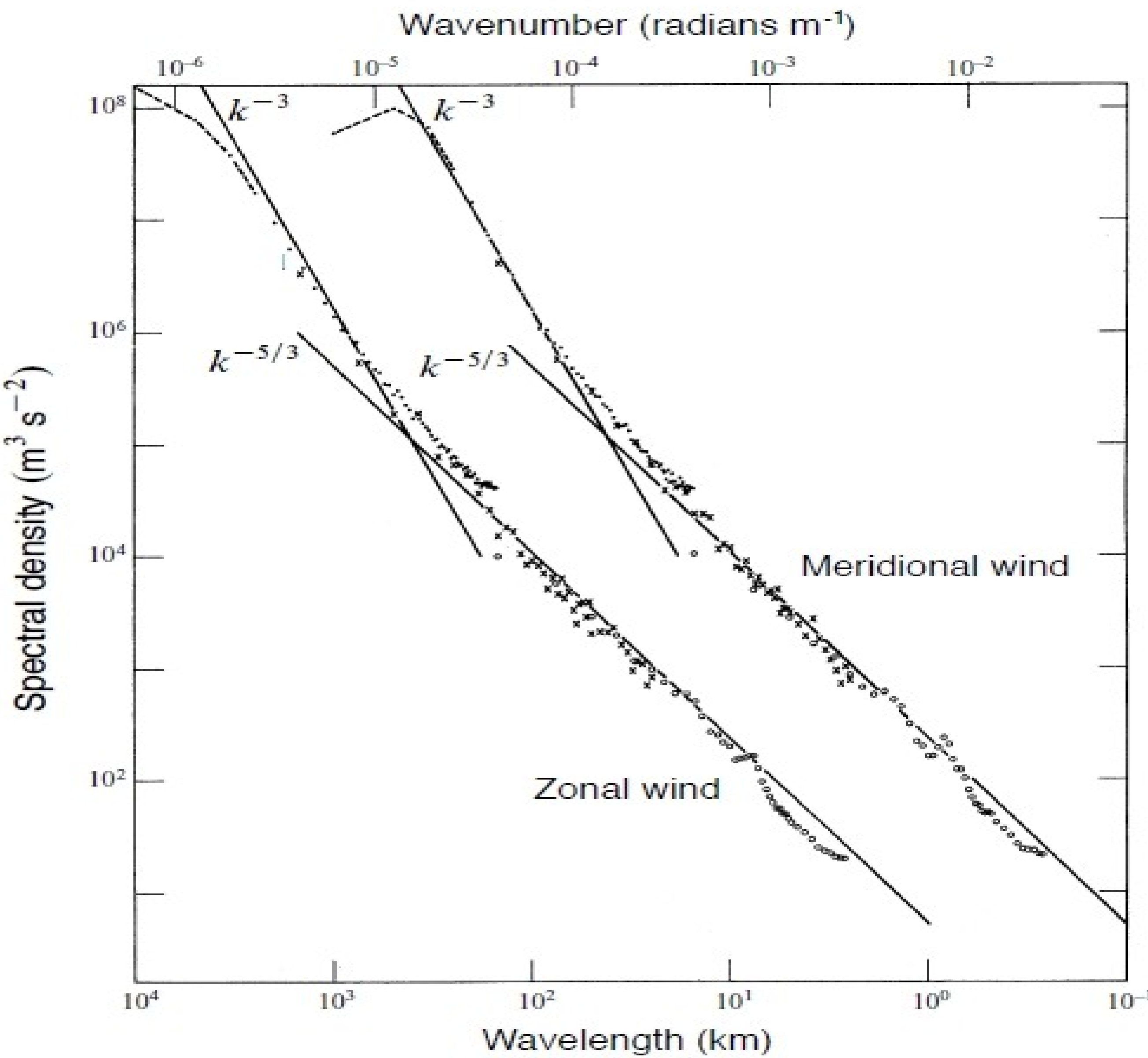


FIG. 6. The mean-square relative displacement components for midlatitudes releases on a log-linear scale. The straight line indicates an exponential region.

Morel and Larcheveque (1974)

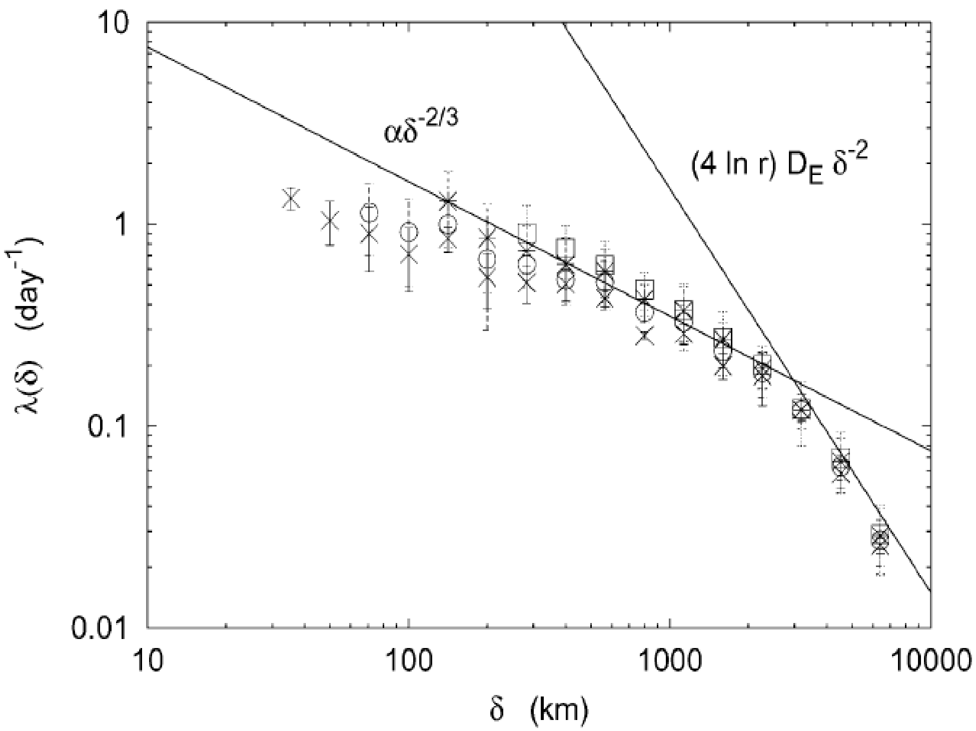
Er-El and Peskin (1981)

Gage and Nastrom (1986) spectra

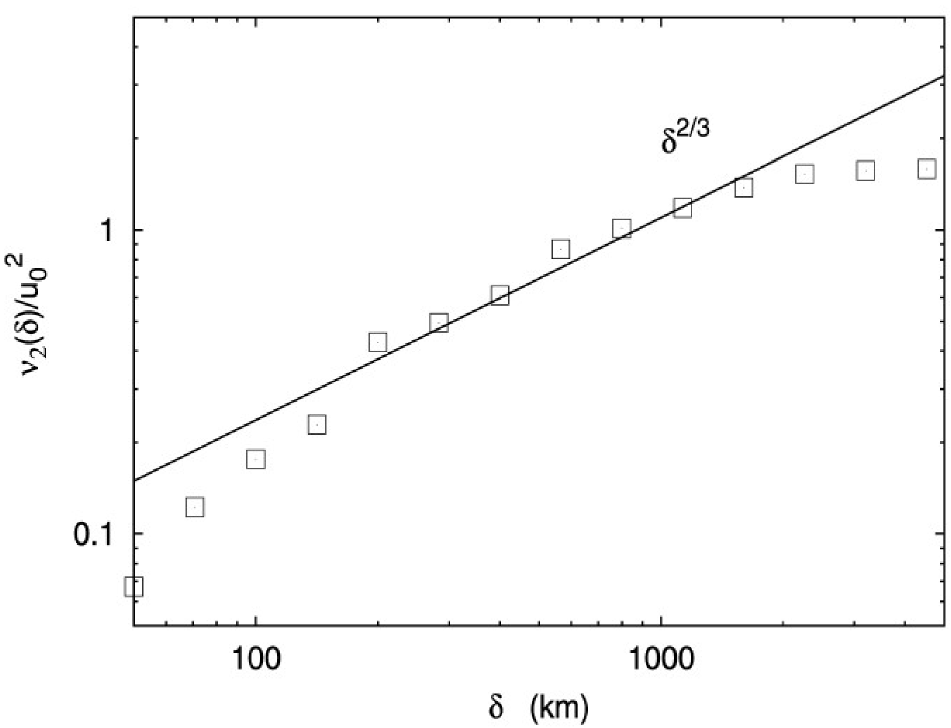


Subsequent analyses

FSLE

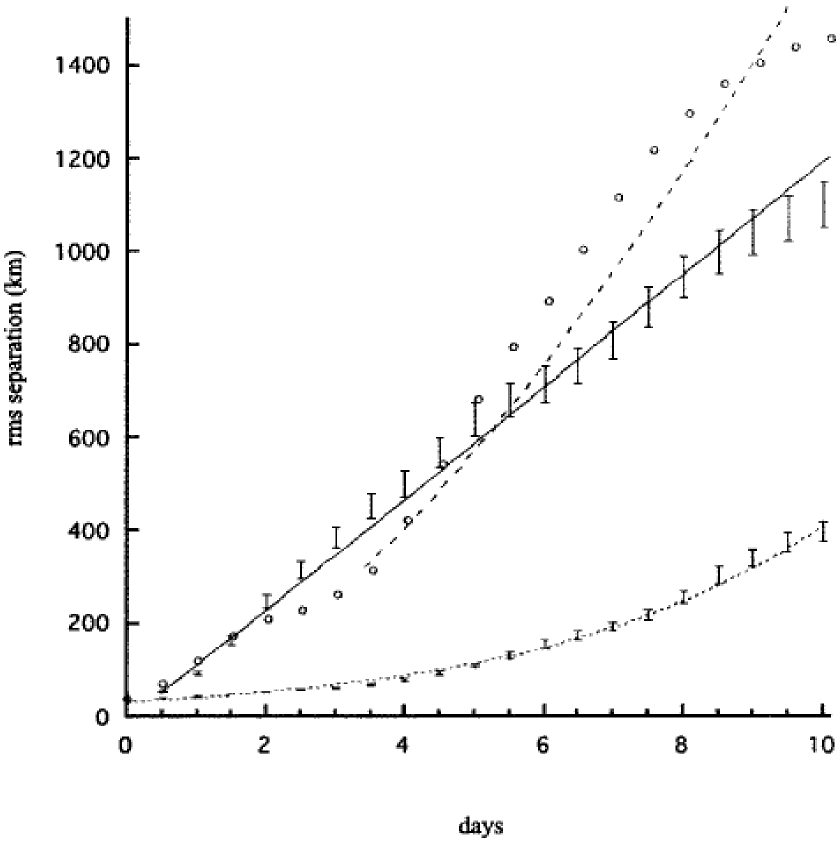


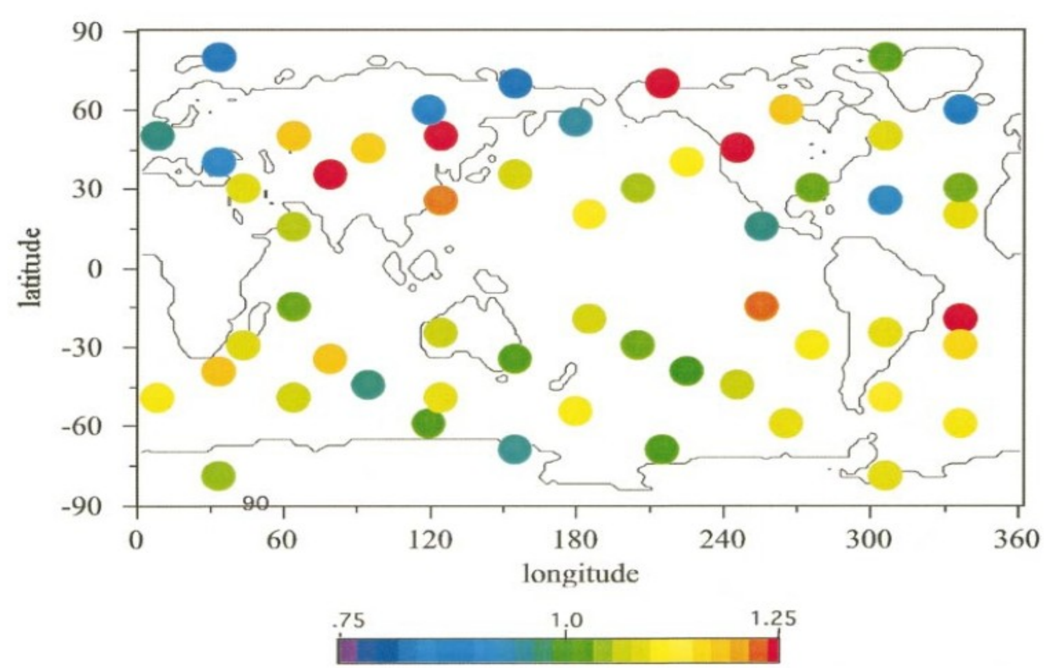
Second order structure function



Lacorata et al. (2004)

Reanalysis-based trajectories





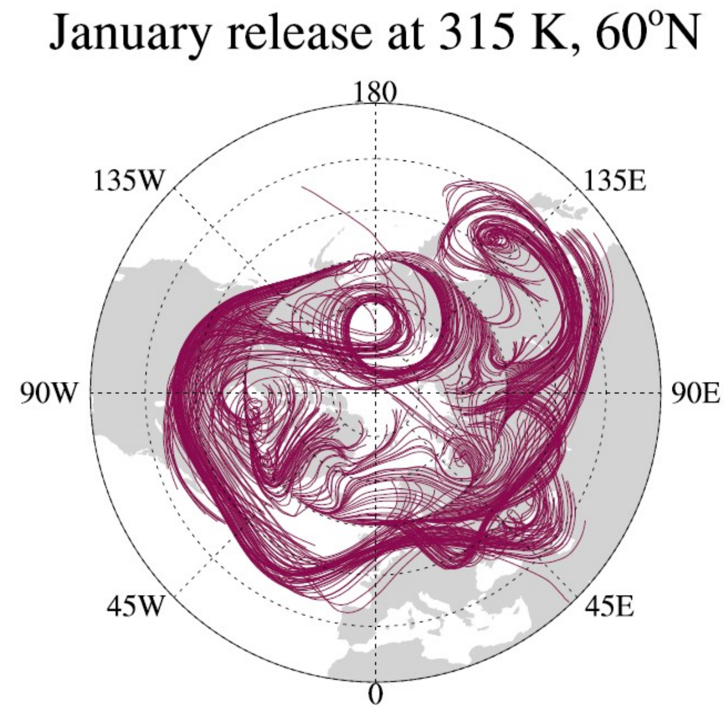
Huber et al. (2001)

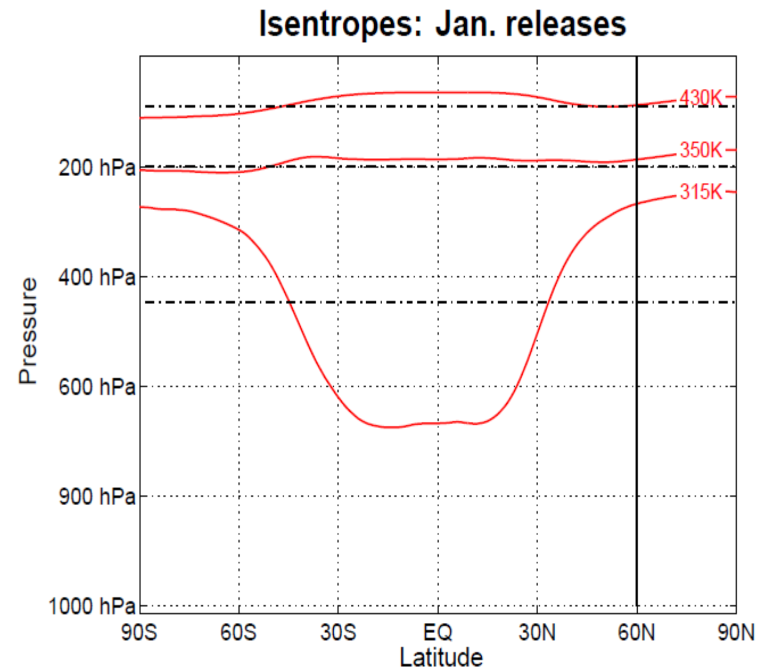
This study

- Advect synthetic “balloons” with reanalysis winds
- Calculate relative dispersion, displacement PDFs, etc.
- Compare with Richardson and Lundgren predictions
- Examine variation with latitude, height and season

Model

- ERA-Interim reanalysis winds (1991-2009)
- 1^{O} x 1^{O} resolution
- 60 vertical levels
- FLEXPART (Stohl et al. '05)
- 360x4 balloons: r_0=100 km
  at 10^{O}, 30^{O}, 60^{O} N/S
  on 315K, 350K, 430K surfaces
  in January and September



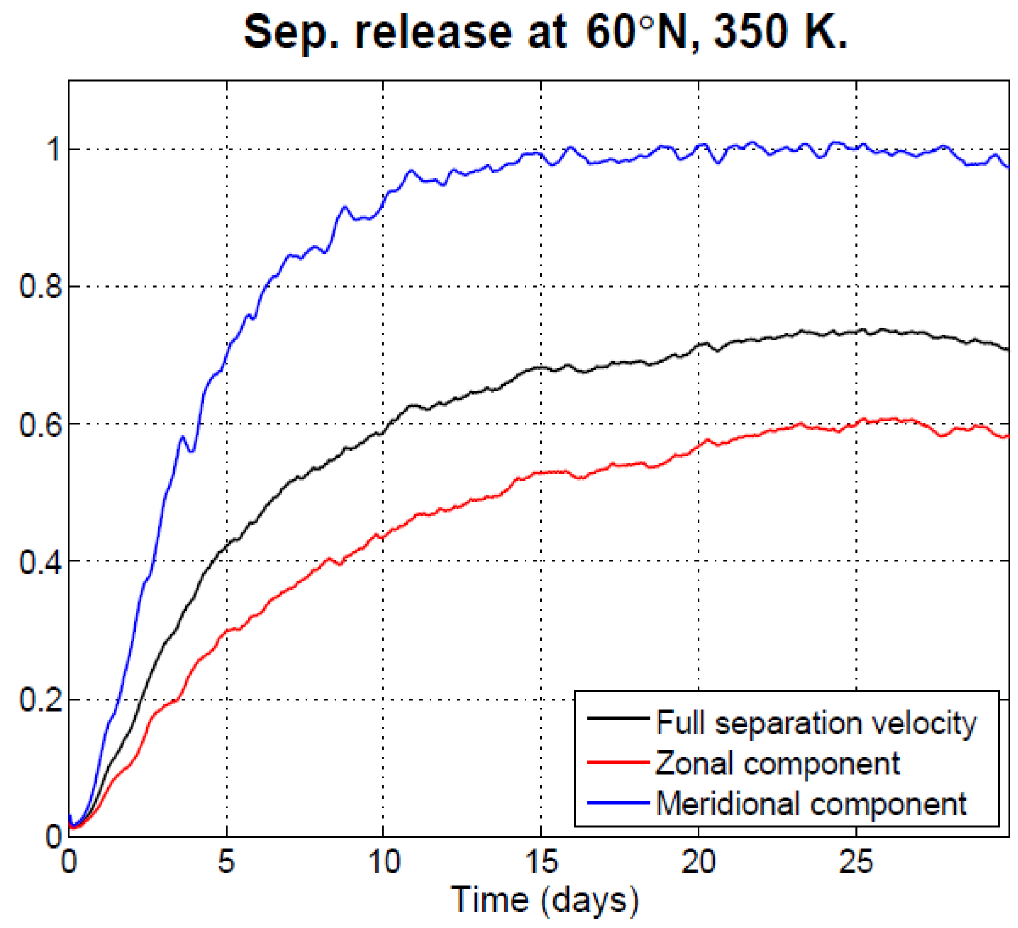


Correlated motion

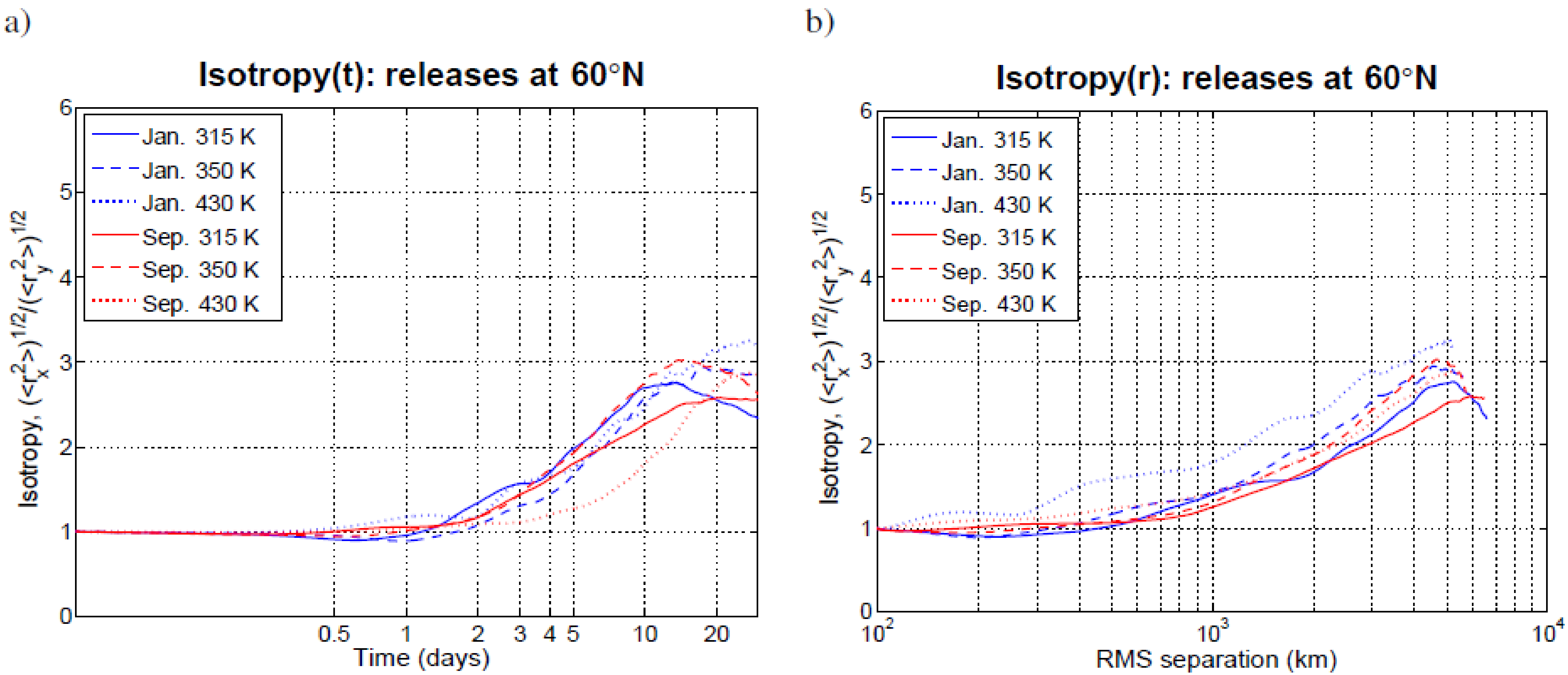
$$< (u_i - u_j)^2 >=$$

$$< u_i^2 > + < u_j^2 > -2 < u_i u_j >=$$

$$2\nu^2 - 2 < u_i u_j >$$



Zonal anisotropy



$$I = \frac{(< r_x^2 >)^{1/2}}{(< r_y^2 >)^{1/2}}$$

Previous studies

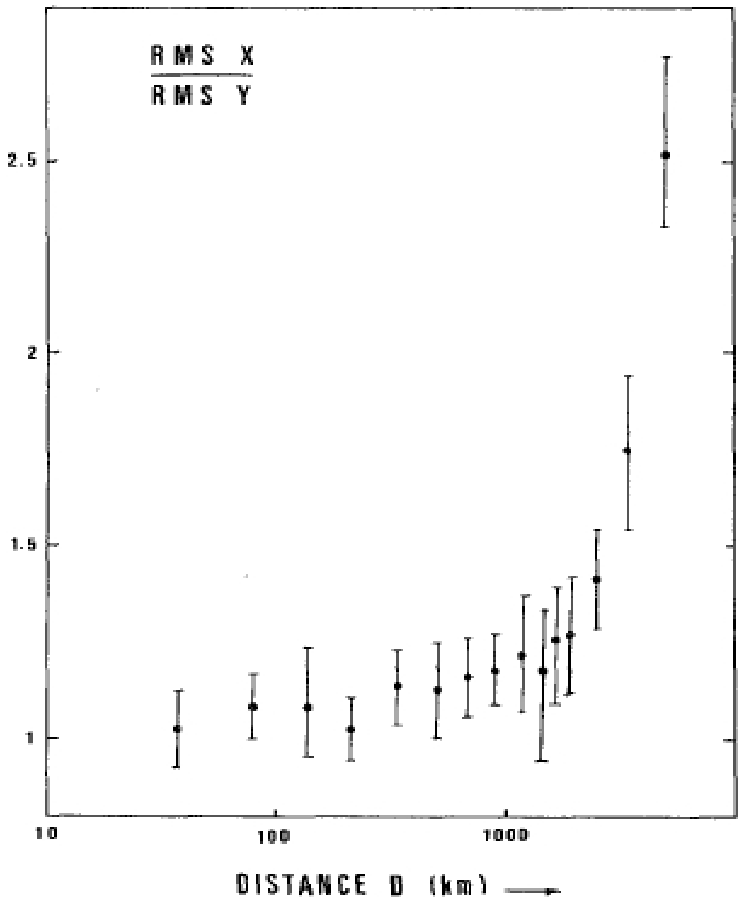


FIG. 7. Ratio of the rms zonal and meridional relative displacements of all chance balloon pairs which formed randomly during the course of the EOLE experiment. Ratio 1 corresponds to a perfect isotropic dispersion process.

Morel and Larcheveque (1974)

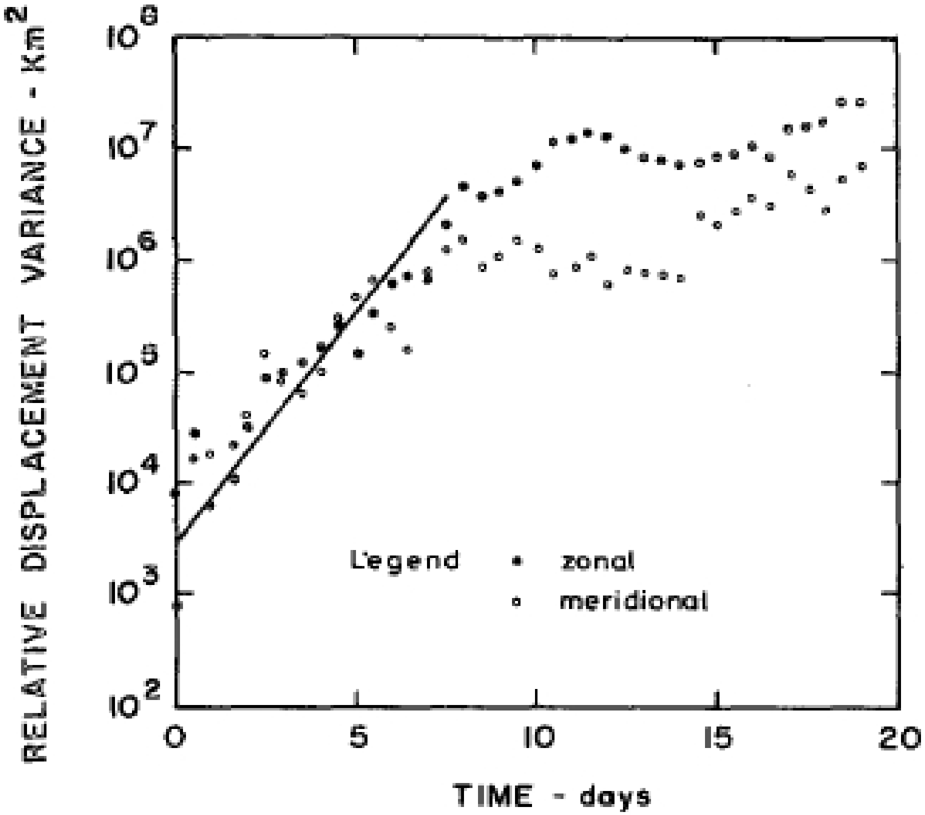
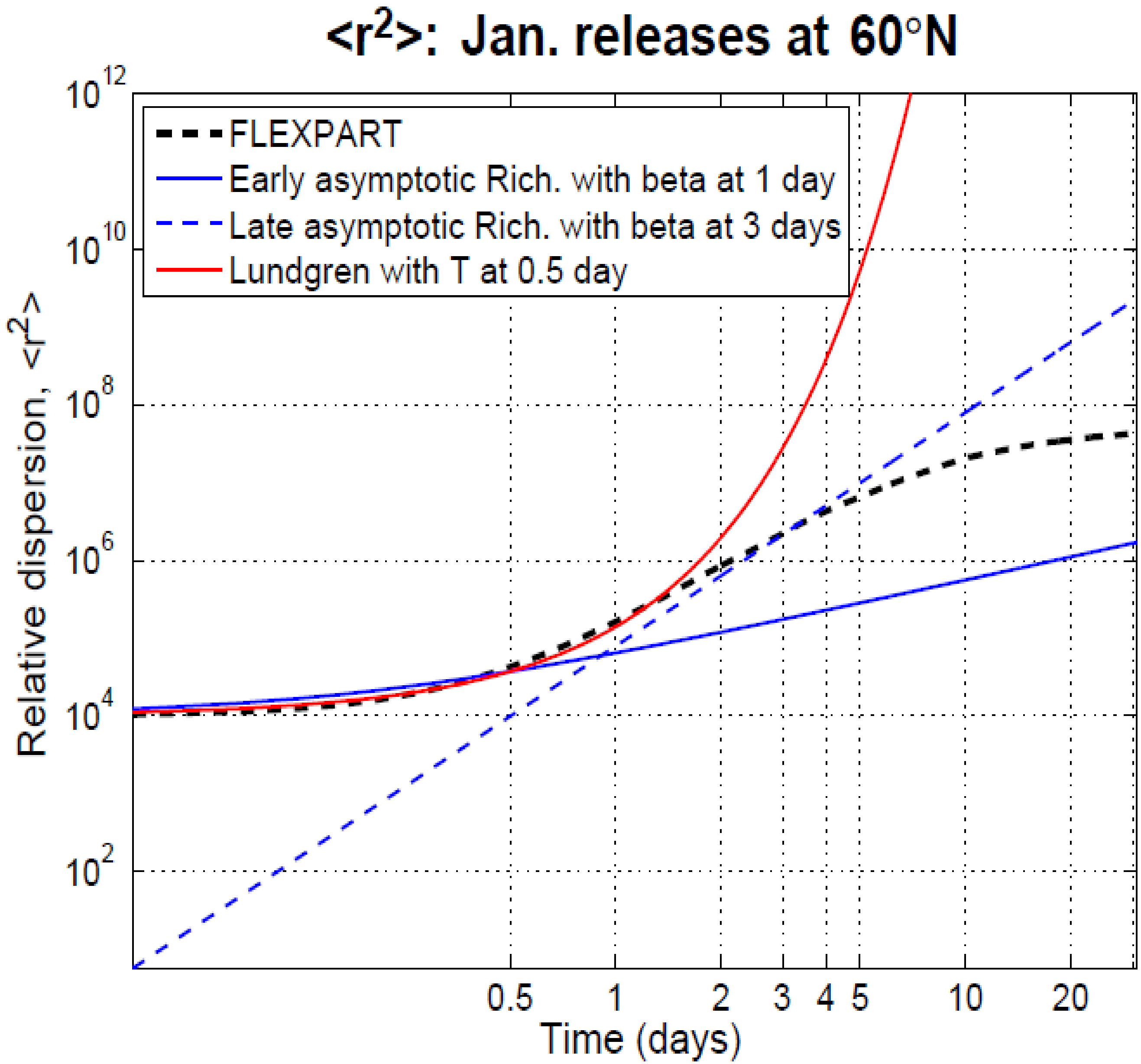


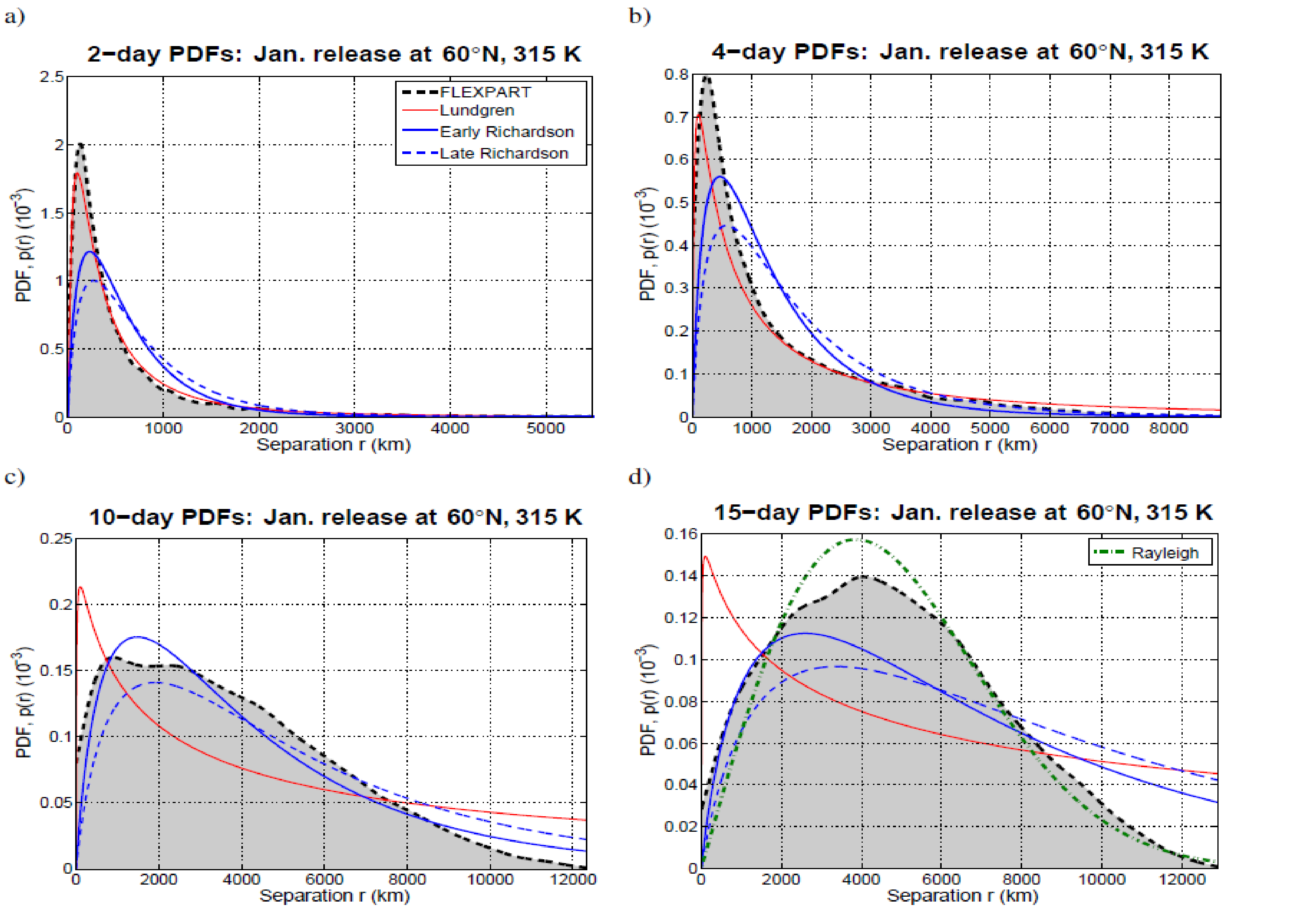
FIG. 6. The mean-square relative displacement components for midlatitudes releases on a log-linear scale. The straight line indicates an exponential region.

Er-El and Peskin (1981)

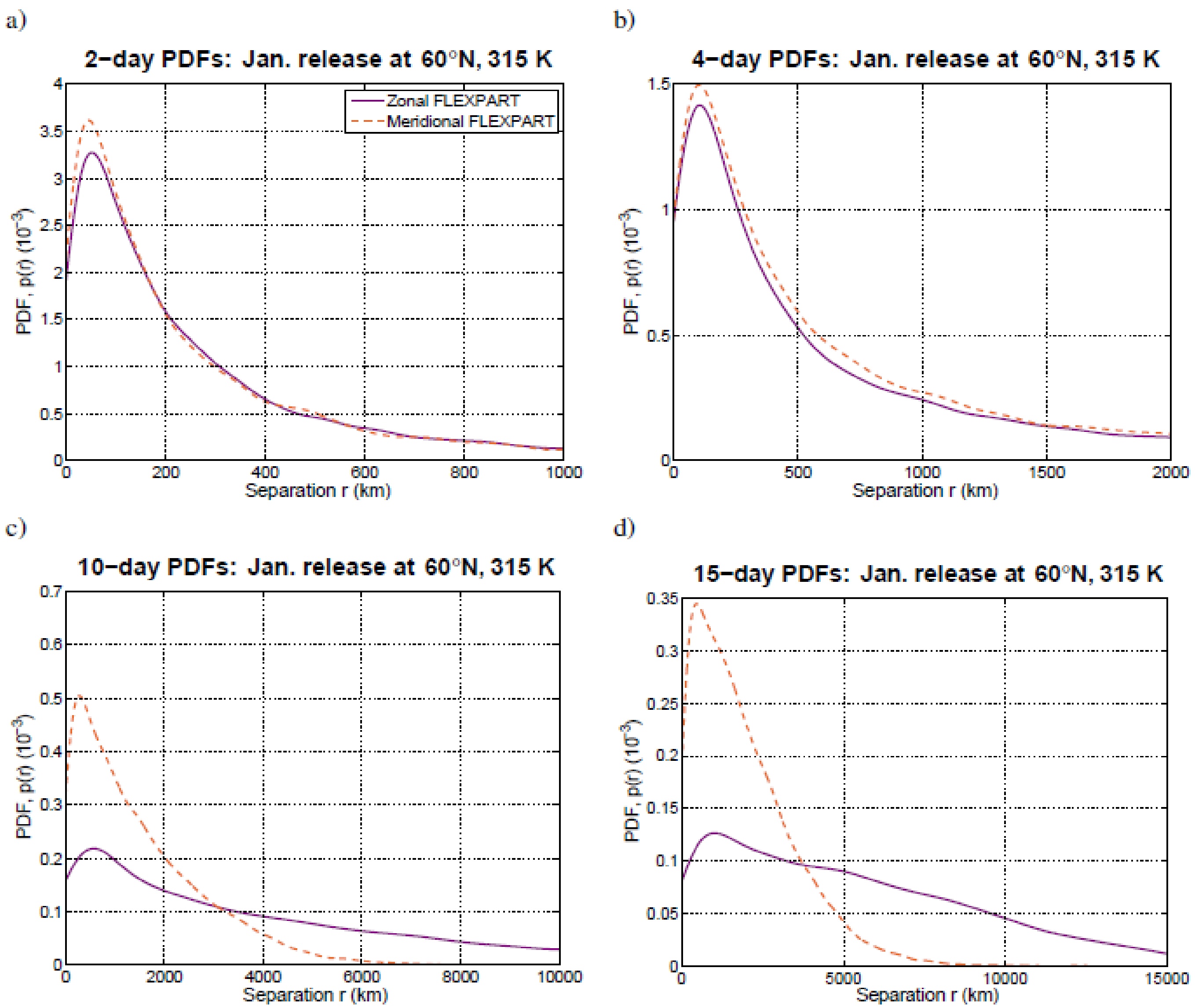
Relative dispersion at 60N



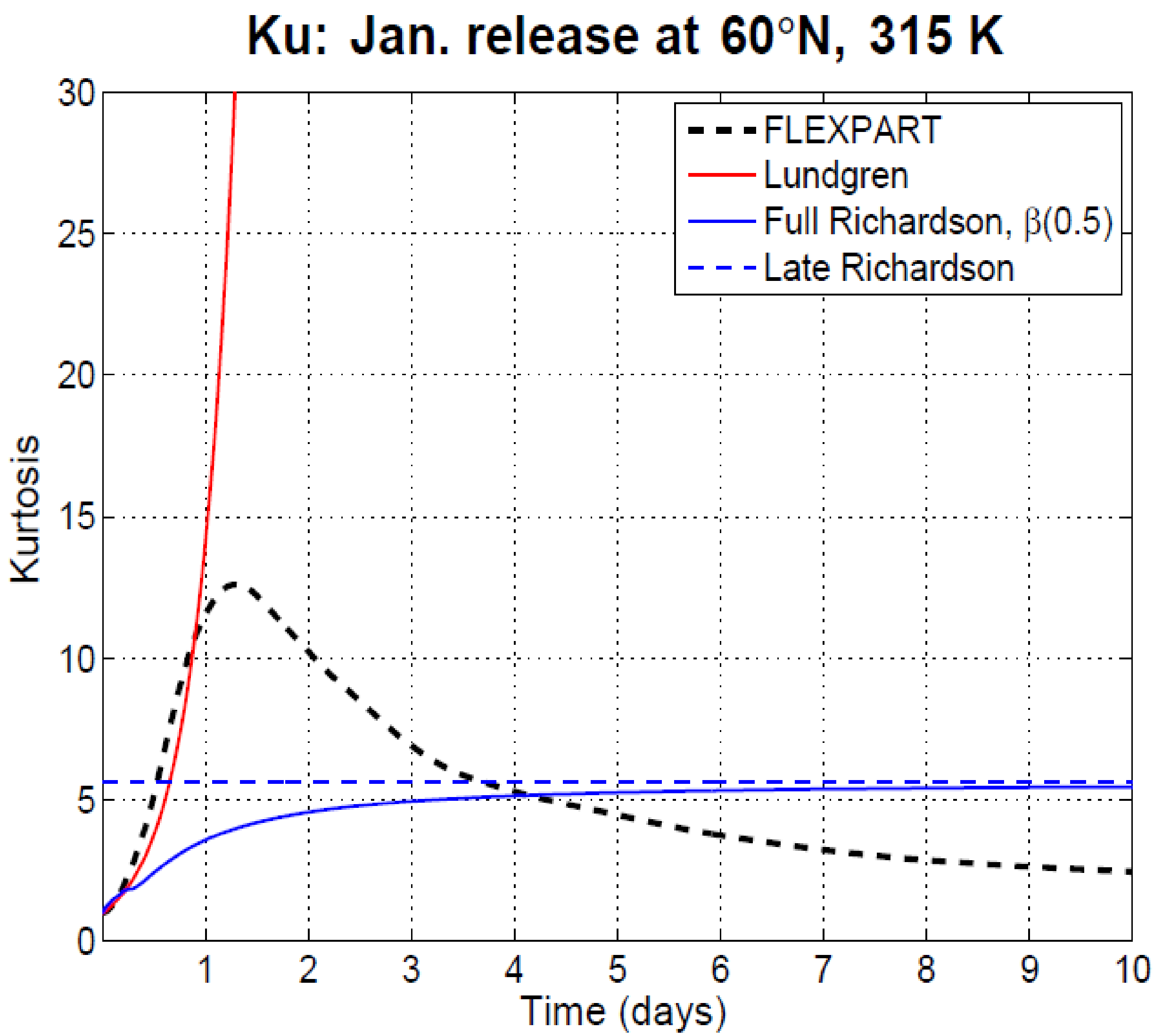
Separation PDFs



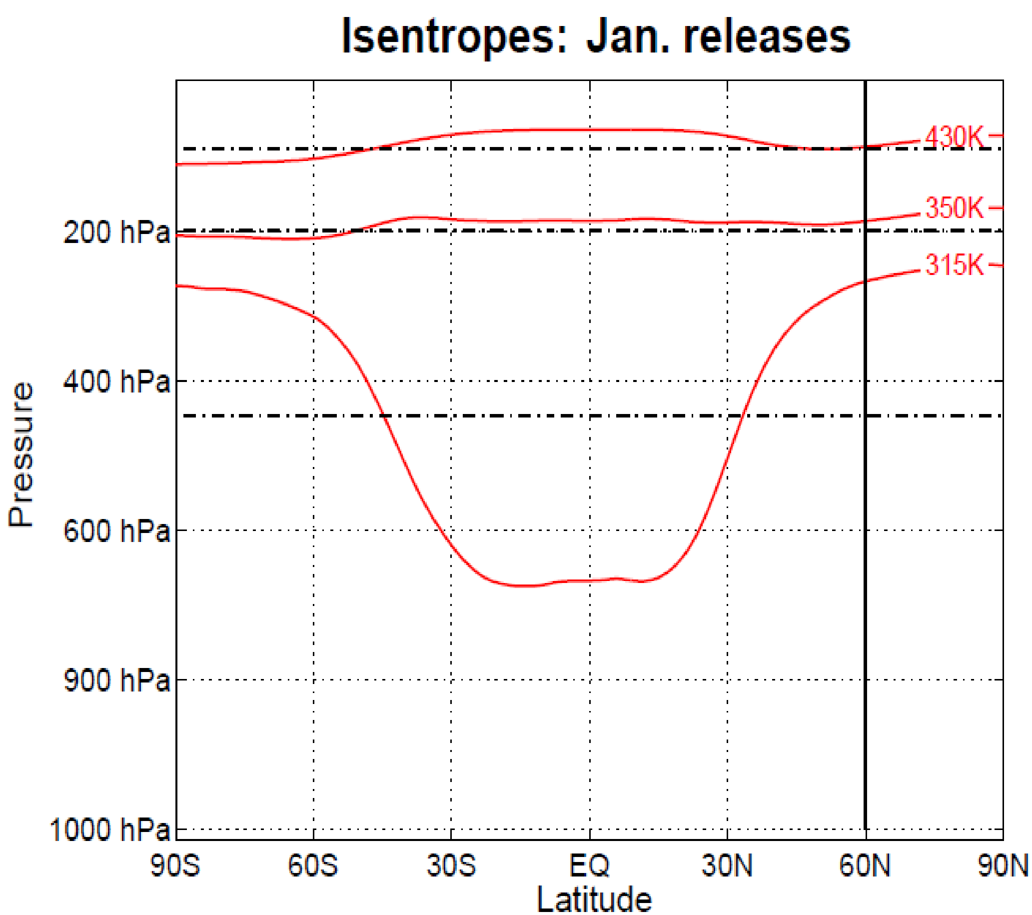
Zonal anisotropy

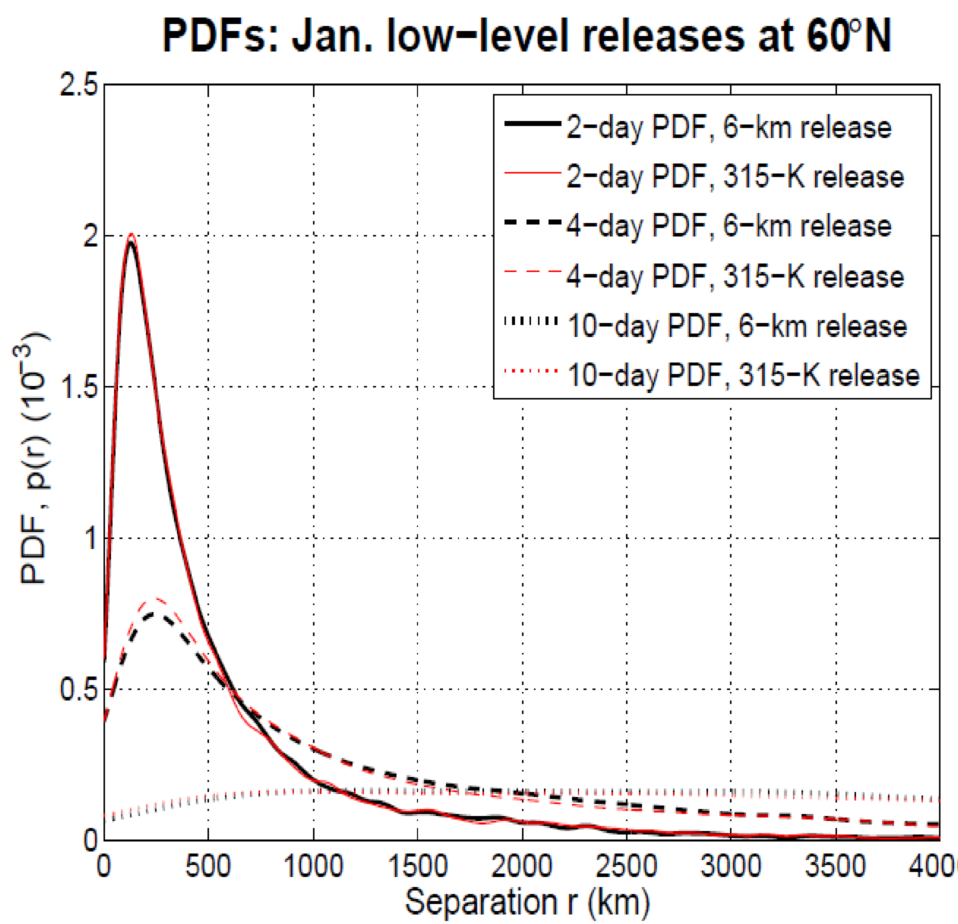


Separation kurtosis

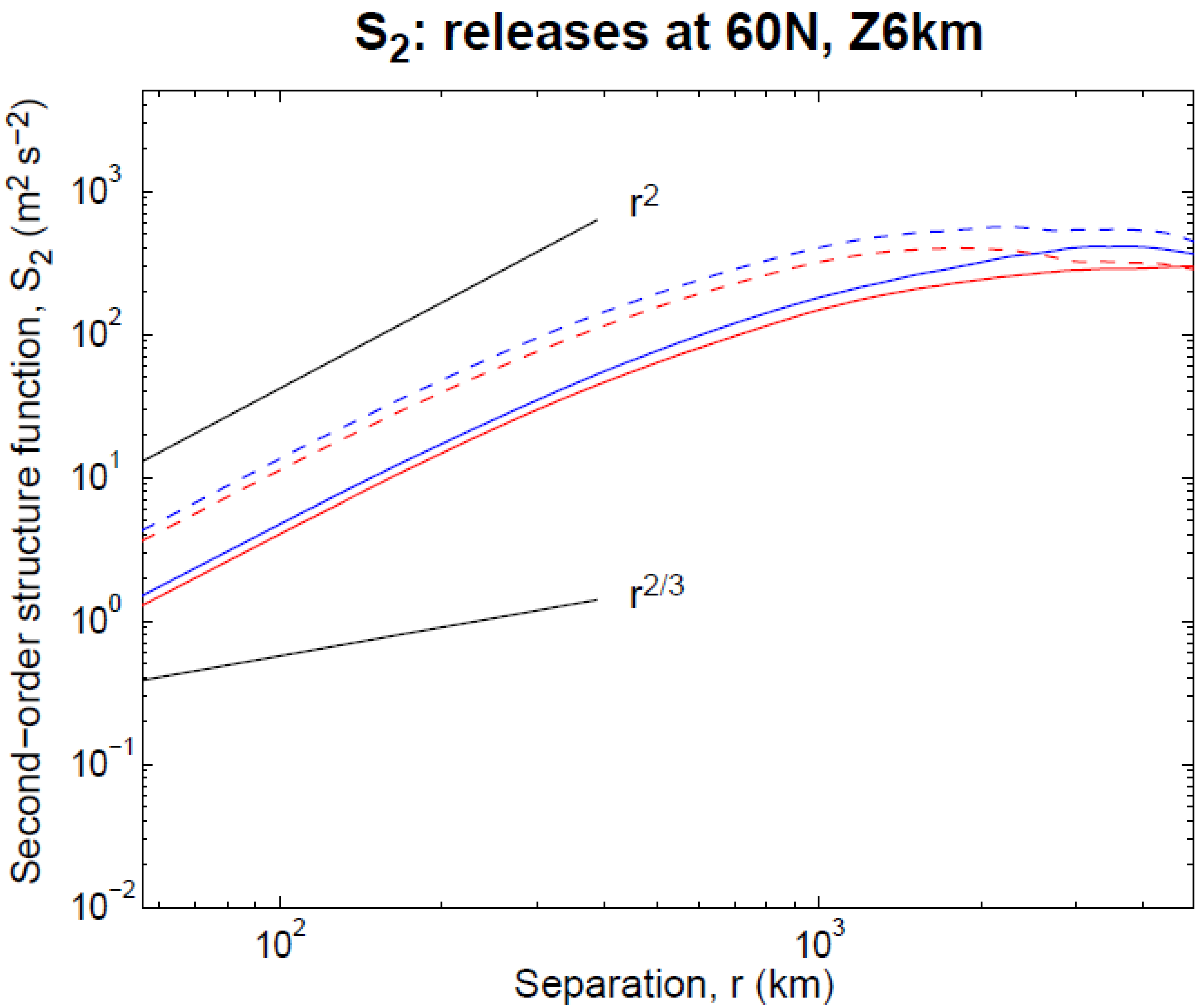


Balloon height

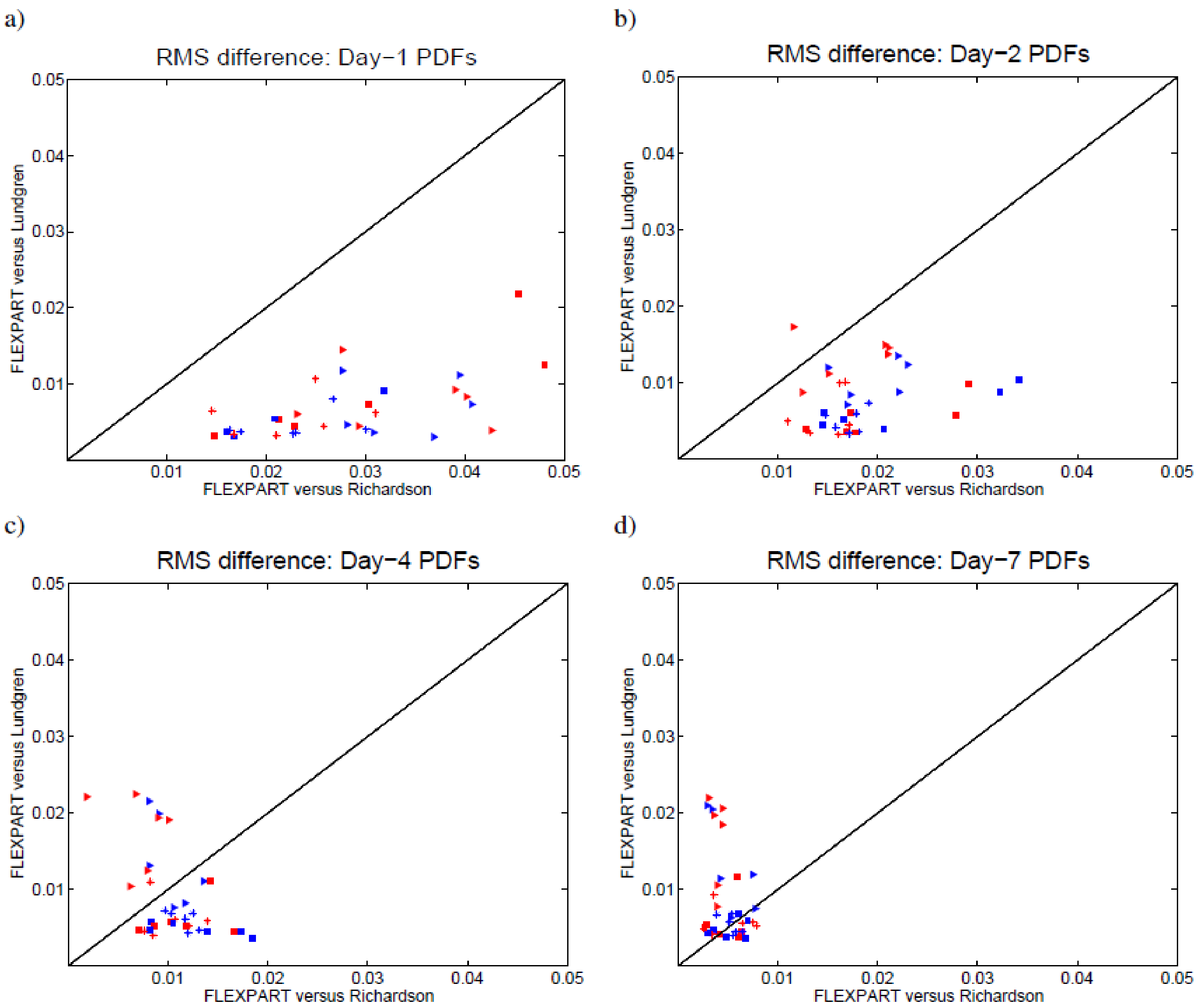




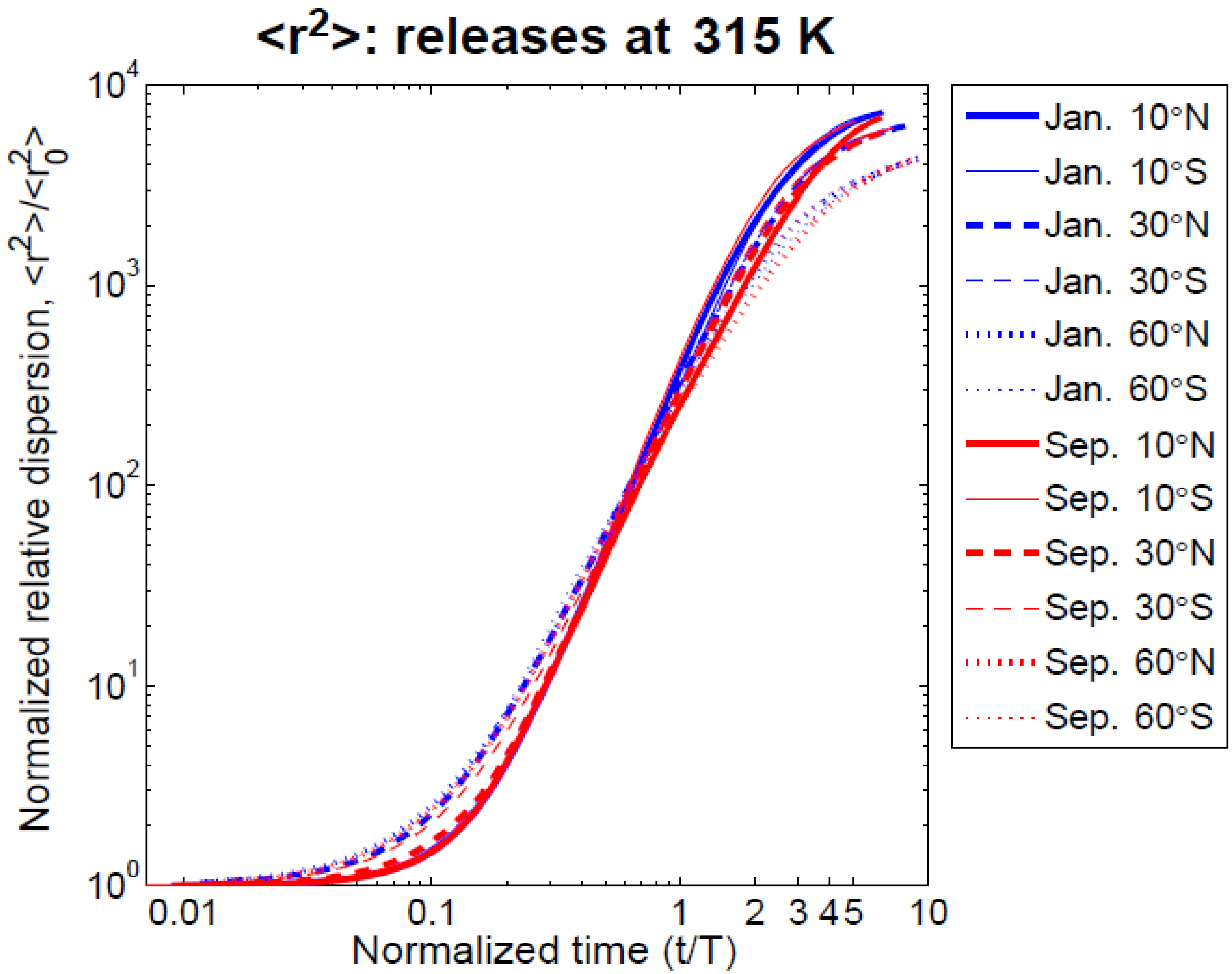
Structure functions



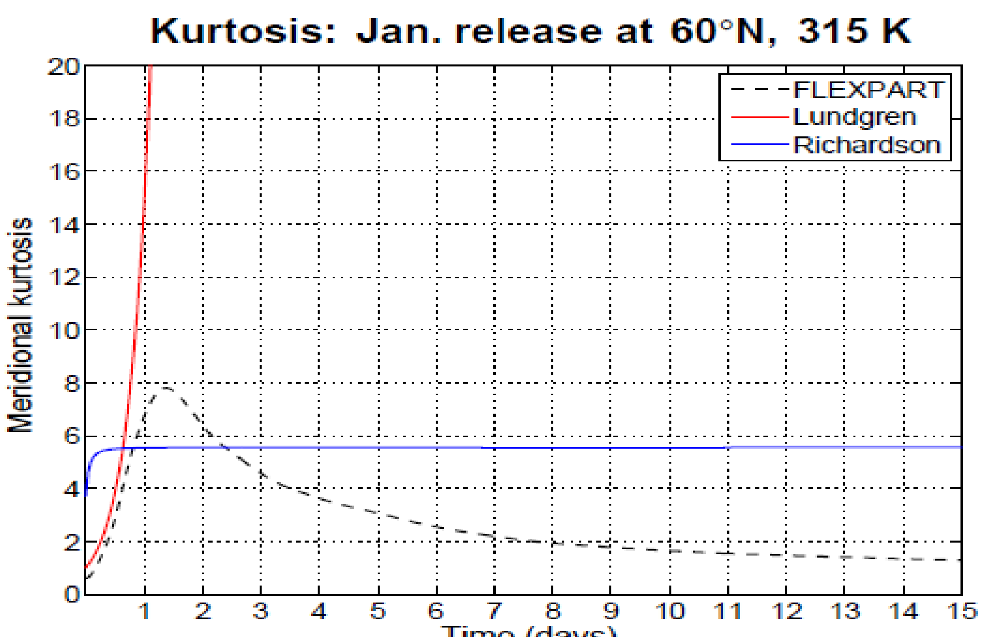
Other latitudes/seasons

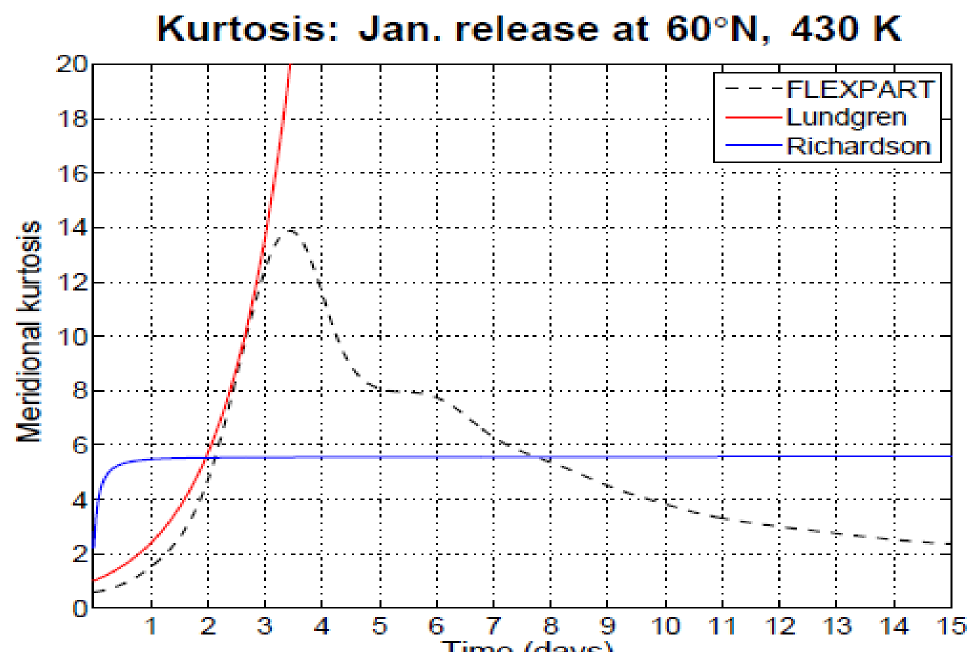


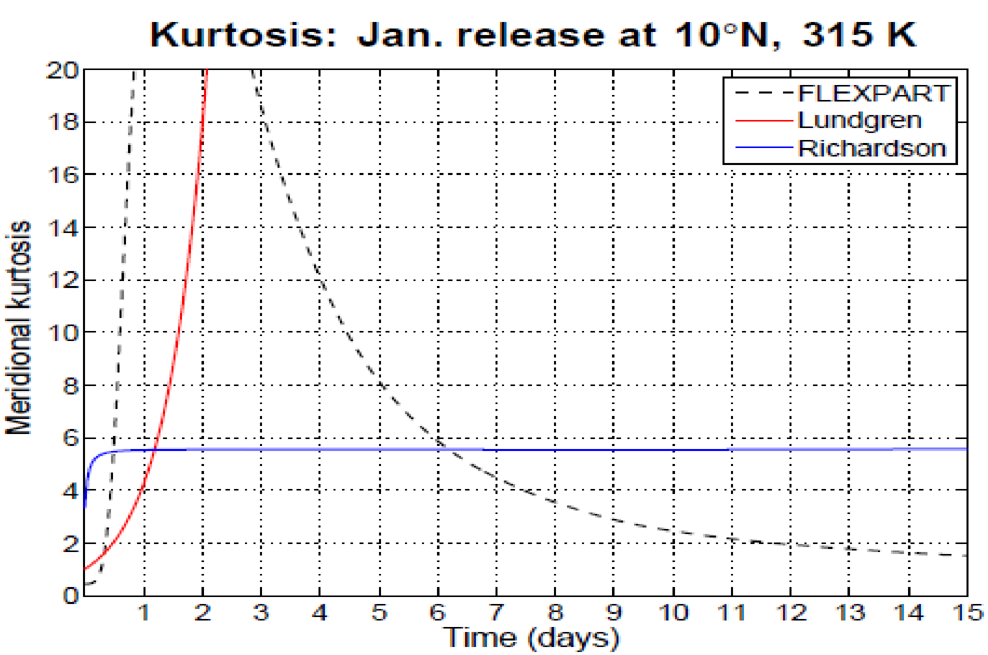
Other latitudes/seasons

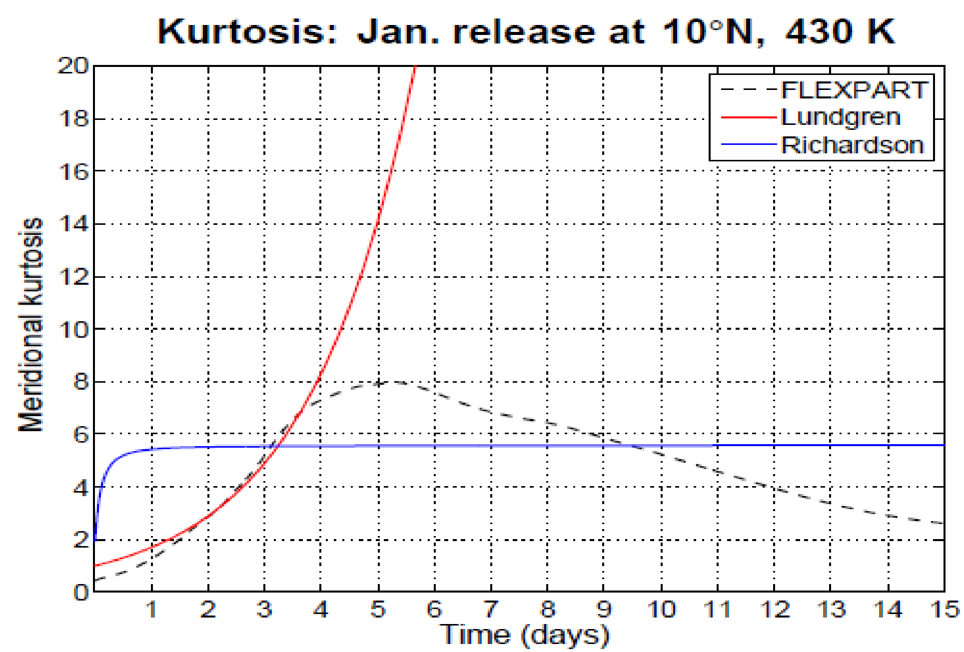


Other kurtoses

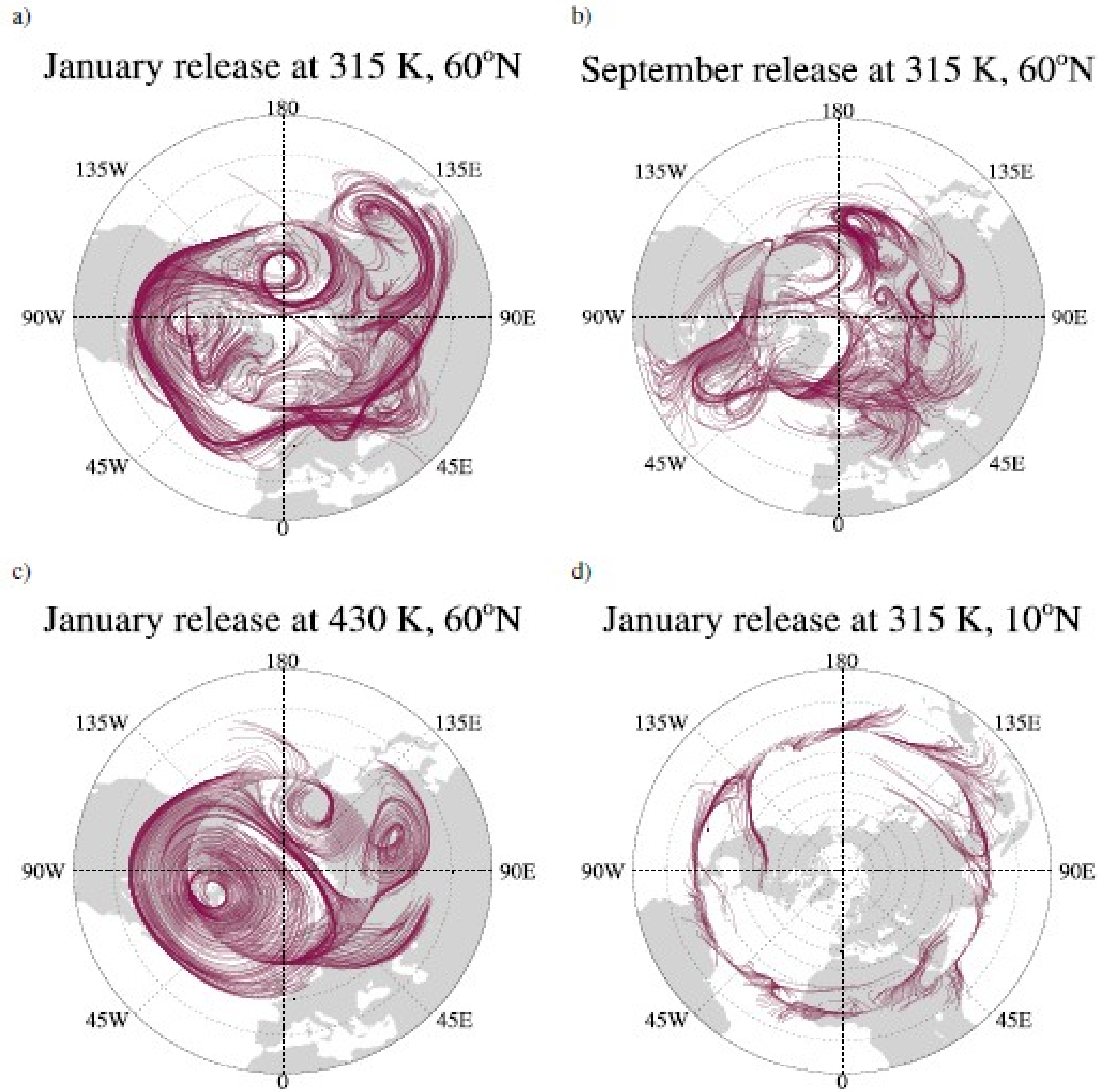




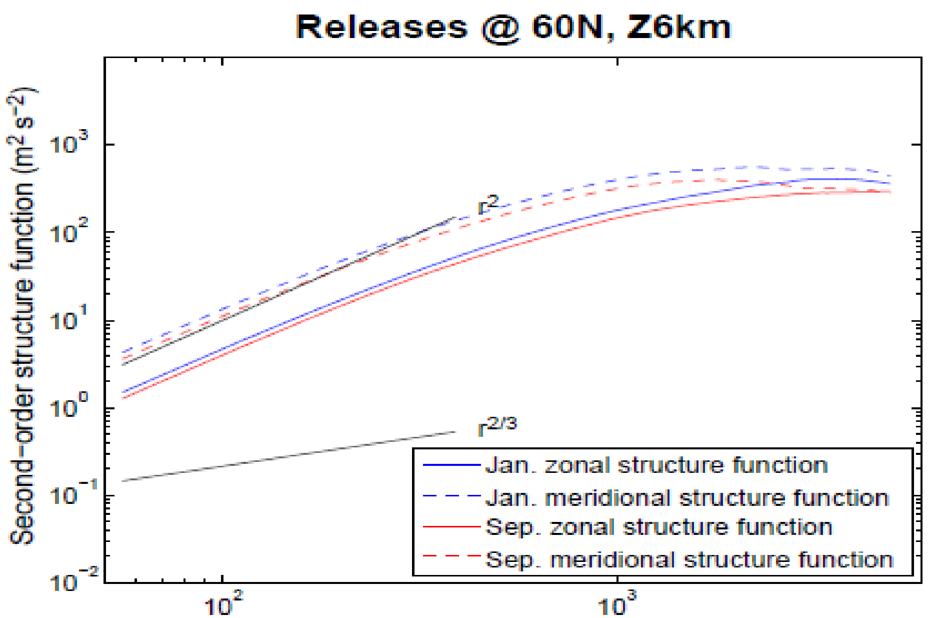


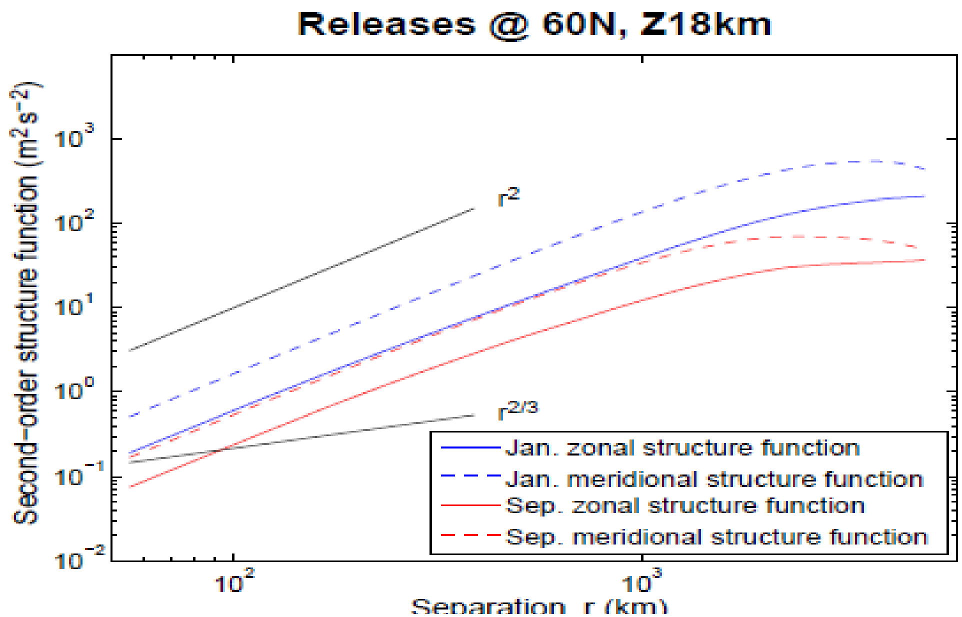


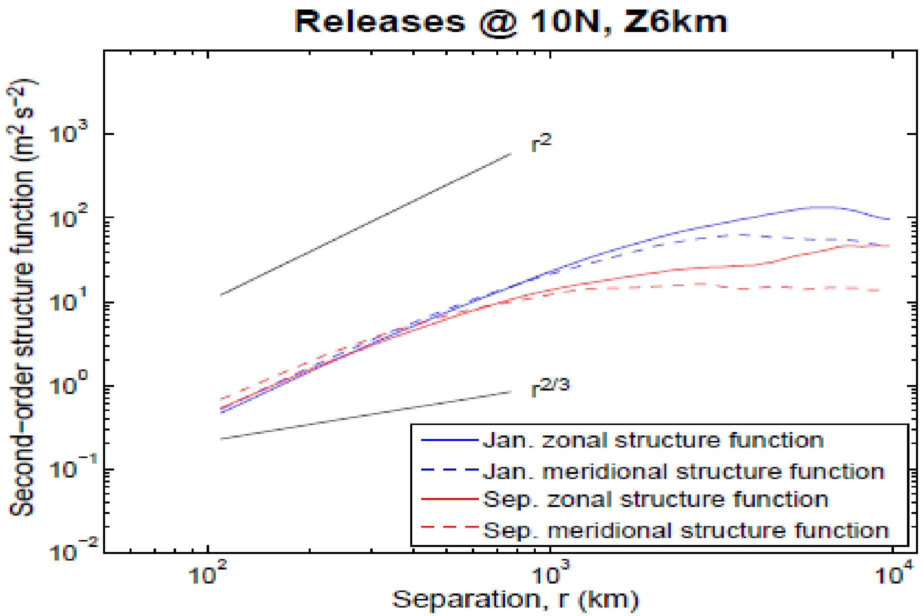
Trajectories

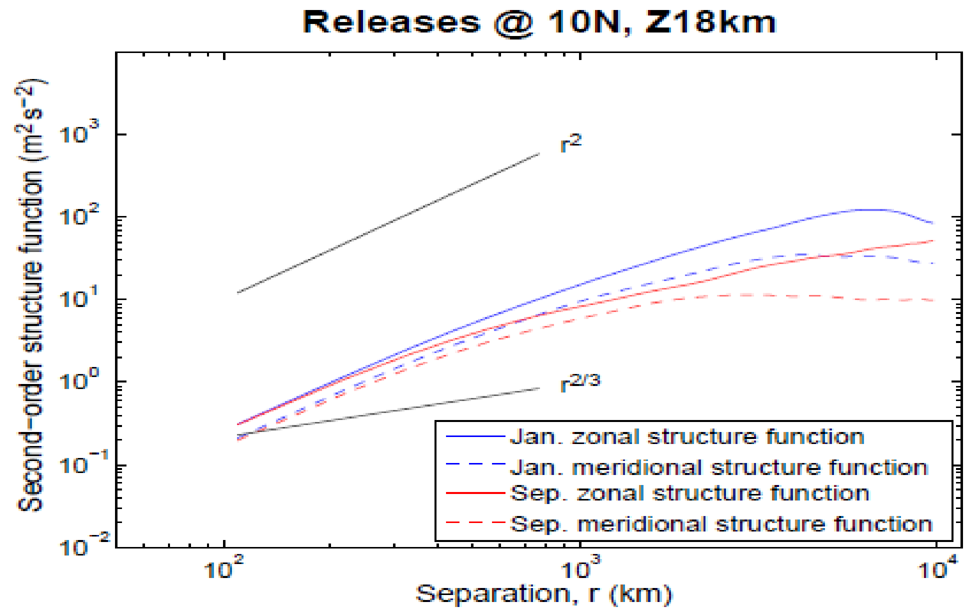


Other structure functions









Summary

- Relative dispersion from 100-1000 km grows exponentially in time
- Shear dispersion at larger scales
- Consistent with Morel and Larcheveque (1974) and Gage and Nastrom (1986)
- Same behavior at different heights and seasons in mid-latitudes
- Low latitude dispersion is more anisotropic, despite also looking exponential
- What varies are the growth time scales and transition scales