Interaction of Turbulence, Clouds and Aerosol Particles

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Turbulence variables calculated from the G-1 Gustprobe

Presently available

Vertical Velocities, w_a

Turbulent Energy Dissipation Rate, ϵ

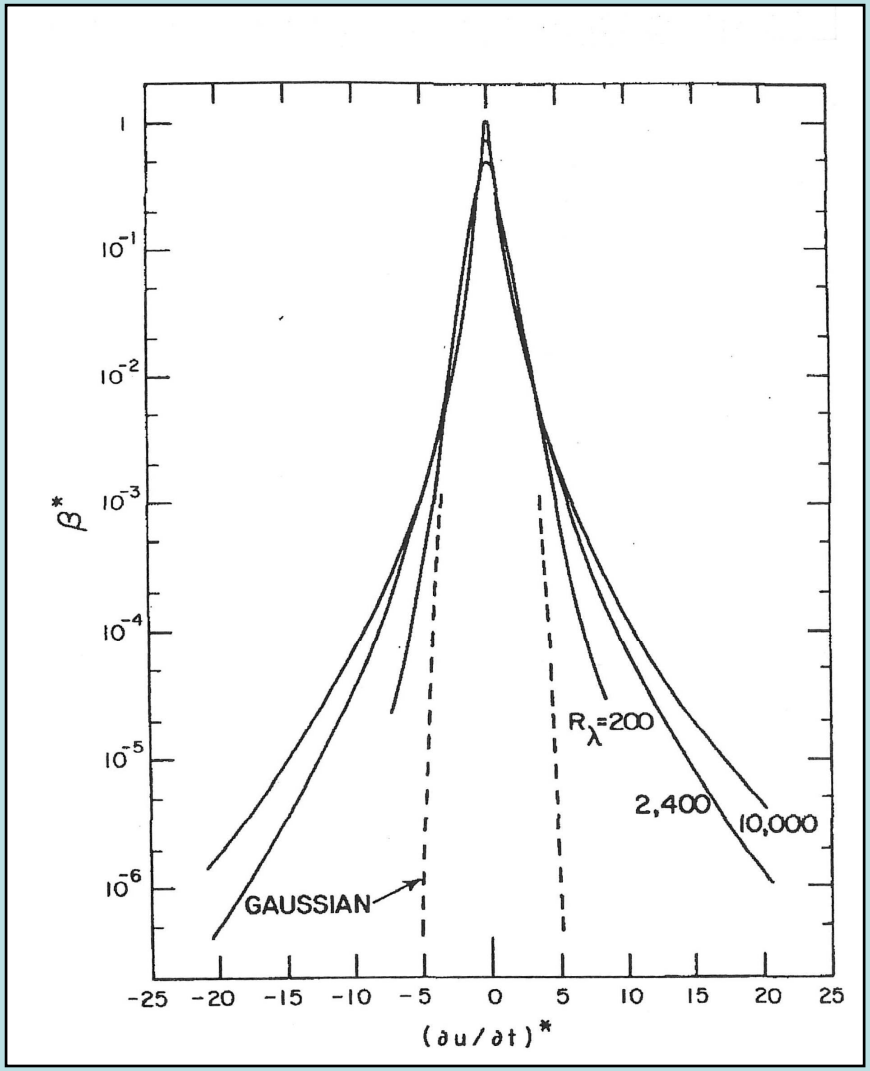
New

Microscale Reynolds Number, Re_λ

Turbulent Eddy Fractal Dimensionality

Motivation for the Microscale Reynolds Number, Re_λ

Probability density



Wyngaard, Annu.Rev.Fluid.Mech. 1992

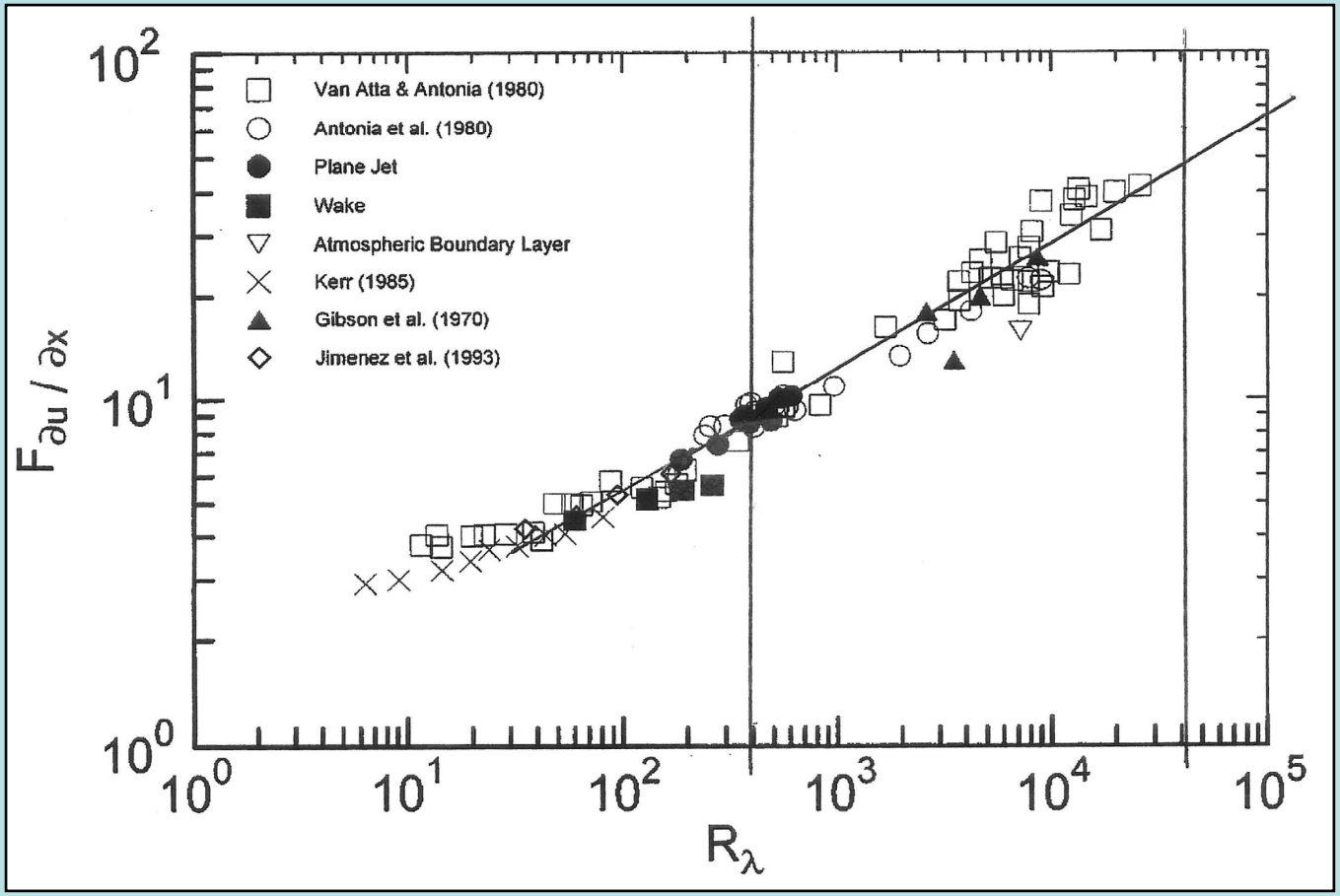
Turbulence is intermittent

The degree on intermittency is proportional to Re_λ

As Re_λ increases, the probability of

1. Very large values of turbulence increases
2. Near zero values of turbulence increases

There is a correlation between Re_λ and the flatness factor (F) of ($\delta u/\delta x$)

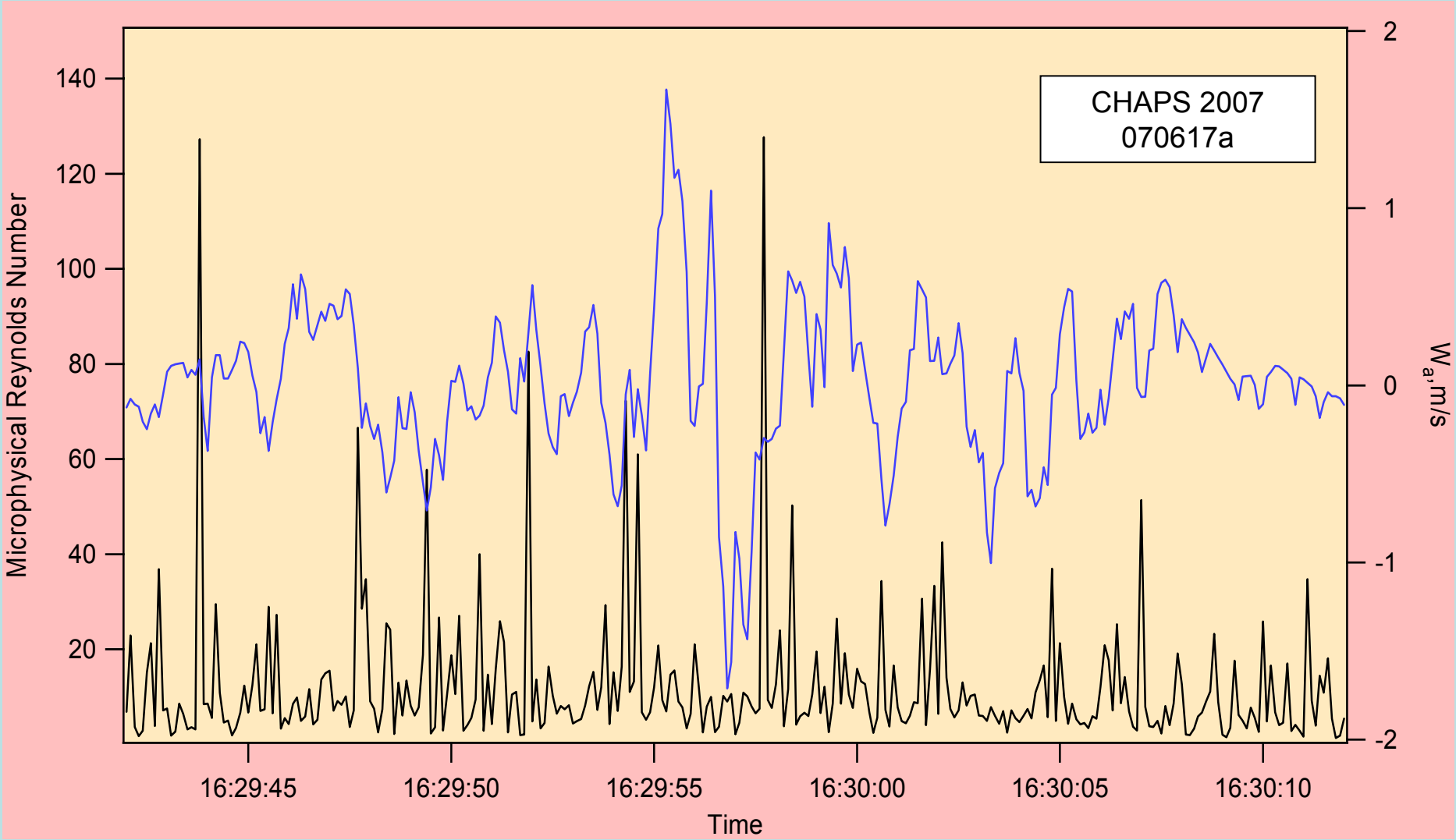


$$F = \frac{\left\langle \left(\frac{\partial u}{\partial x} \right)^4 \right\rangle}{\left\langle \left(\frac{\partial u}{\partial x} \right)^2 \right\rangle^2}$$

Sreenivasan and Antonia, Ann. Rev Fluid Mech., 1997

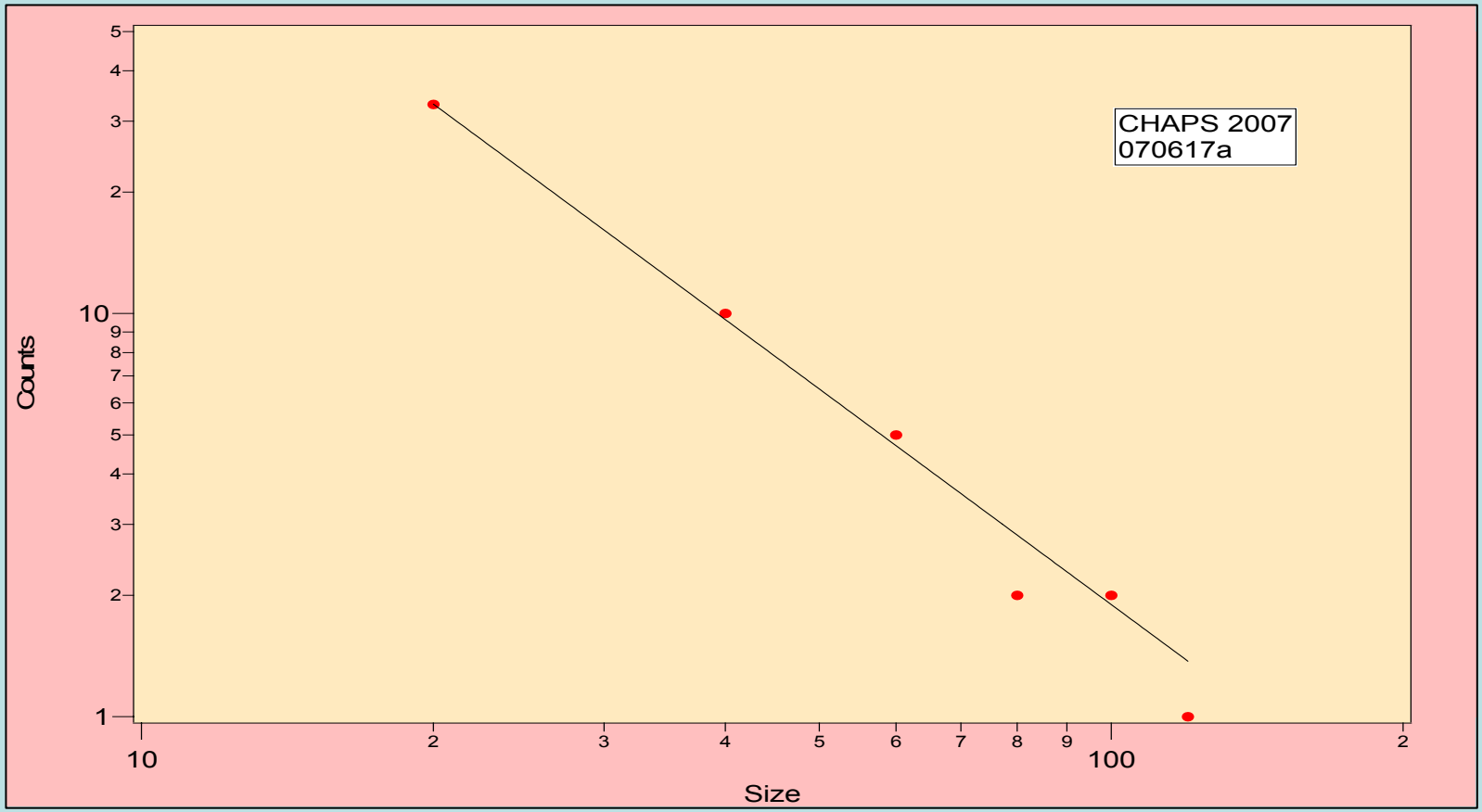
The microscale Reynolds number is calculated from $Re_\lambda = F^{2.86}$ and is averaged to 10 Hz

Re_λ and w_a versus Time



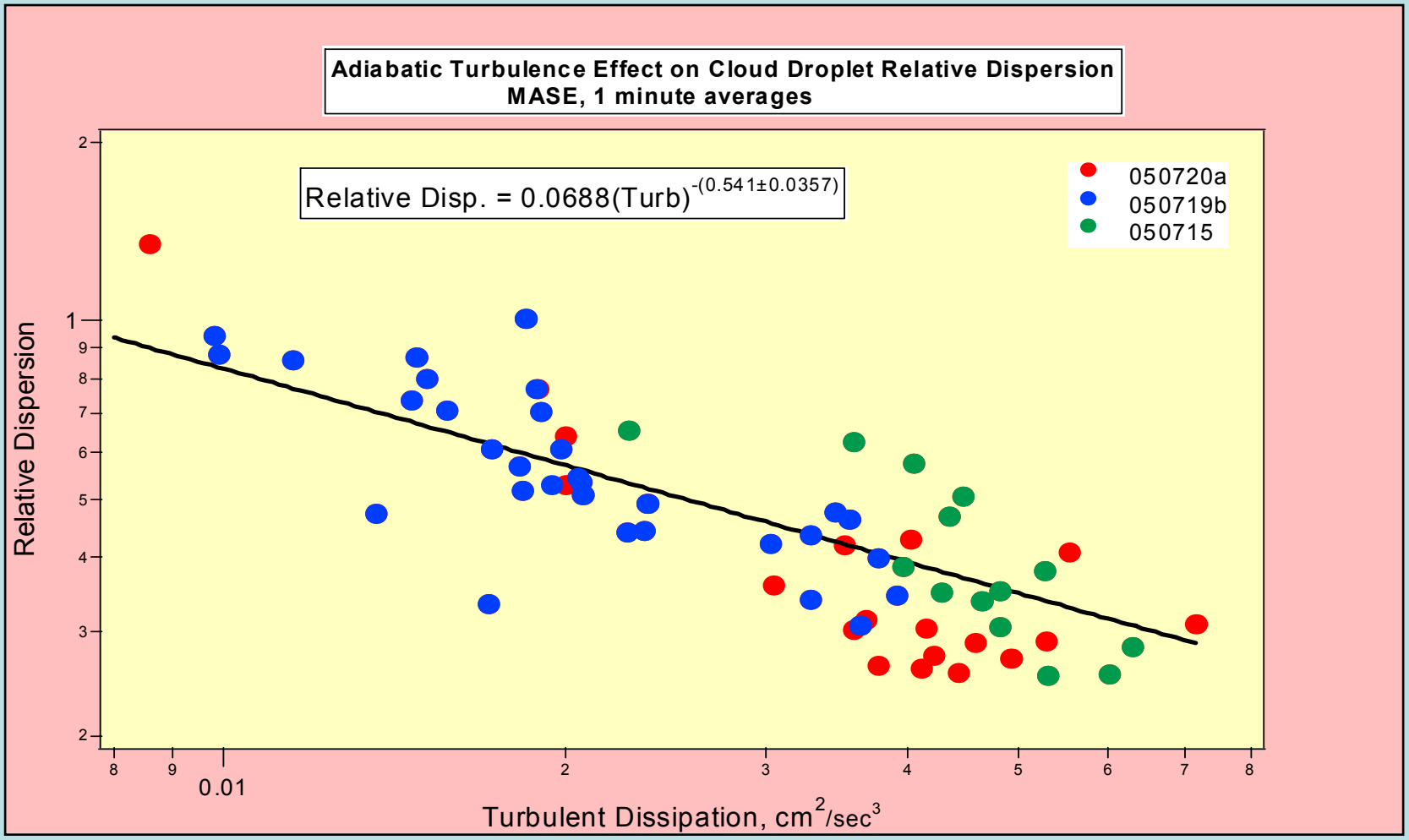
The Re_λ maxima are at the turbulent eddy boundaries.
This was conjectured by Vainstein and Sreenivasan, 1994.

Turbulent Eddy Fractal Dimensionality



$$D = \frac{d\ \ln(\text{counts})}{d\ \ln(1/\text{size})} = 1.78 \pm 0.05$$

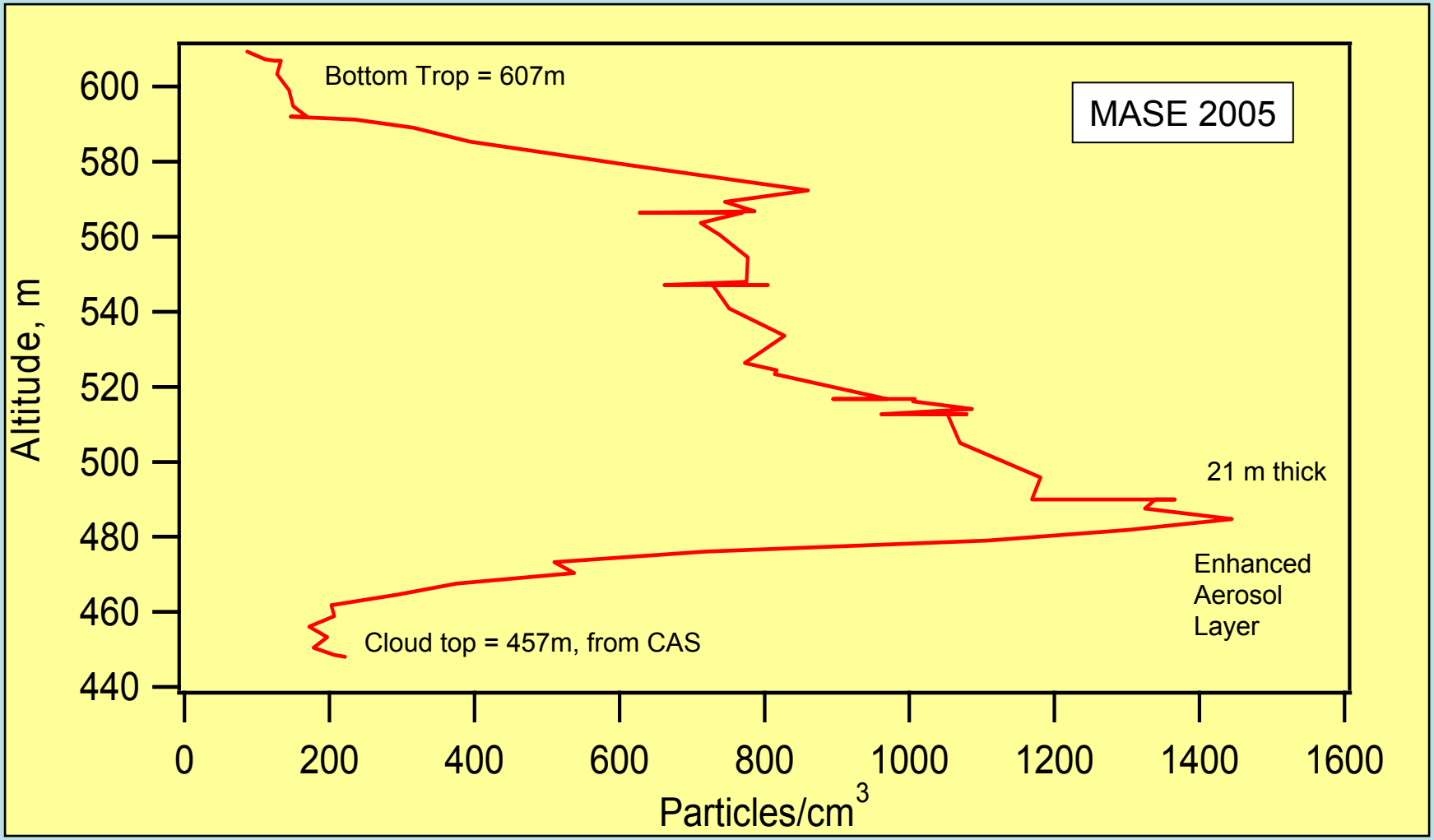
Application of Turbulence to Cloud Studies, MASE 2005



The effect has been shown earlier by Liu and Daum with updraft data.

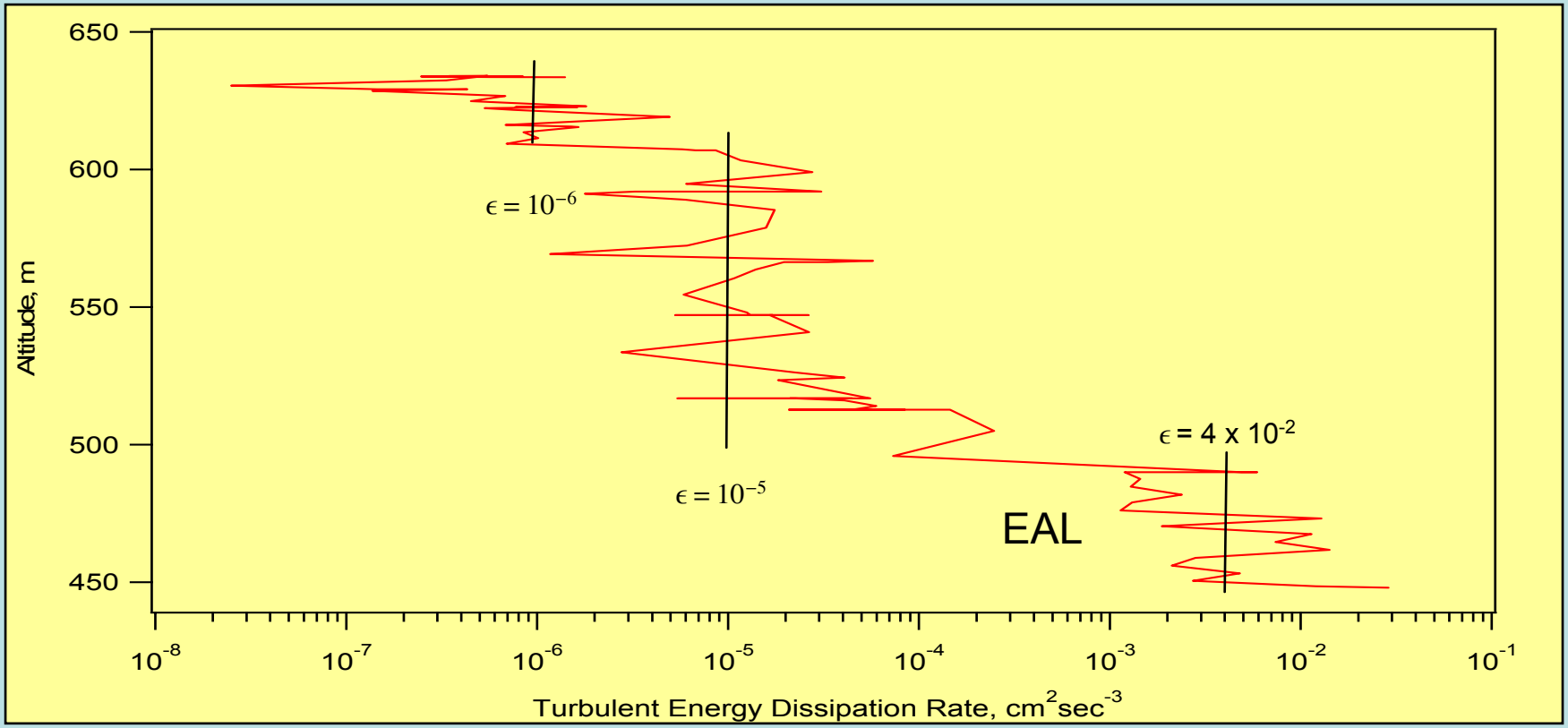
Vaillancourt (2002), in a numerical simulation, explained this as a decreased correlation between droplets and their thermodynamic environment due to turbulence

Interaction of turbulence with aerosol particles above marine stratus clouds: the enhanced aerosol layer.



Plot of the aerosol particle concentration, measured by the SP-200 probe. Particles counts are per cm^3, dry, summed from 0.1 to 0.4 μ diameter.

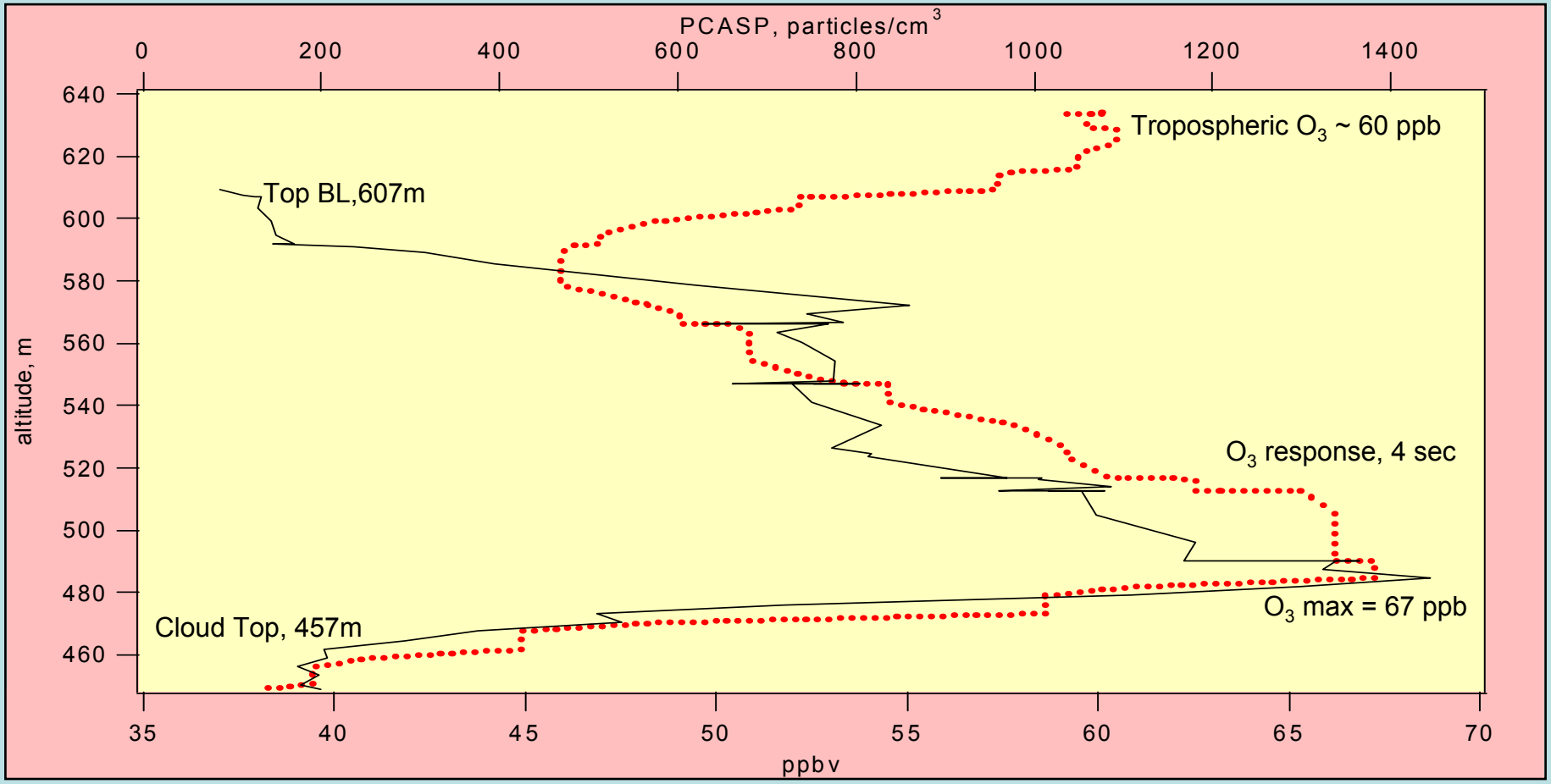
Enhanced aerosol layer is turbulently coupled to the cloud top



Measured turbulent energy dissipation rate versus altitude, with the troposphere bottom at 607 m, and cloud top at 457 m

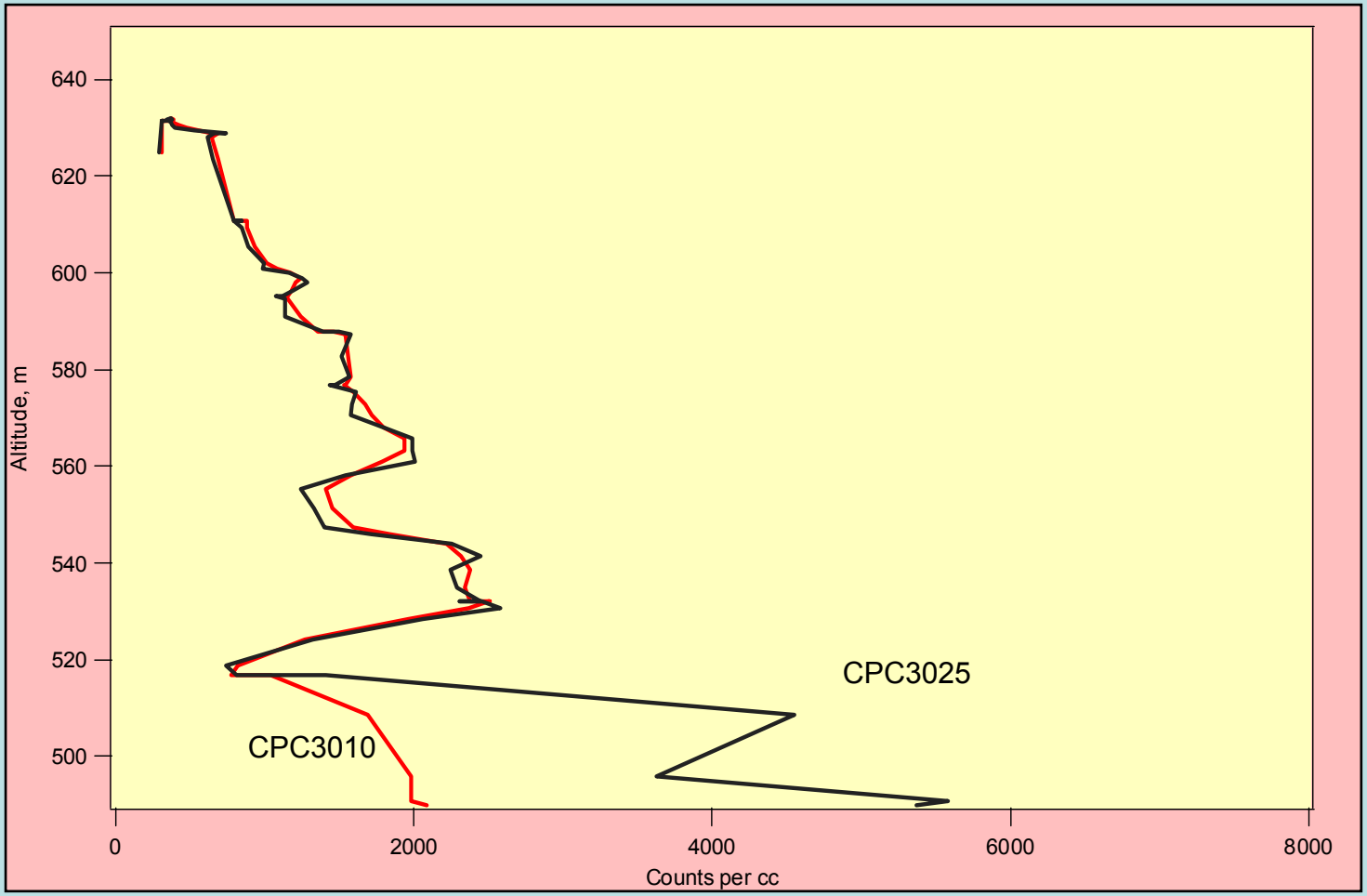
This is the first experimental evidence of this turbulent coupling, though it has been predicted

Chemistry in the Enhanced Aerosol Layer



Ozone is being produced in the enhanced aerosol layer as a result of chemical reactions producing new particles; a similar spike is observed in SO_2 at the same altitude

Excess aerosol particles between 2.5 and 10 nm in the enhanced aerosol layer



The difference between the particles counts of the CPC3025 and CPC3010 is the number of particles between 2.5 and 10 nm

Further evidence for new particle formation in the enhanced aerosol layer

Observed aerosol particle concentrations in the enhanced aerosol layer and the immediate cloud top, Counts/cm^3

	Cloud Top			Aerosol Layer
Sample #	Sum CAS	Sum SP-200	Sum(CAS+SP-200)	Sum SP-200
050719A	120	310	430	1210
050719B	130	220	350	1280
050719C	190	365	555	1440
050719D	280	190	470	1580
050720A	305	350	655	1200
050720B	305	275	580	1410
050720C	280	100	380	1200
050720D	340	110	450	1100
050720E	300	120	420	420

Ratio of aerosol particles in the enhanced aerosol layer to cloud top is 2.8 ± 0.6

Why aren't the particle concentrations equal since there is turbulent transport between the EAL and cloud top??

The higher concentration of aerosol particles in the enhanced layer compared to the cloudtop is due to

rate of new particle formation > rate of turbulent transport back into the cloud top

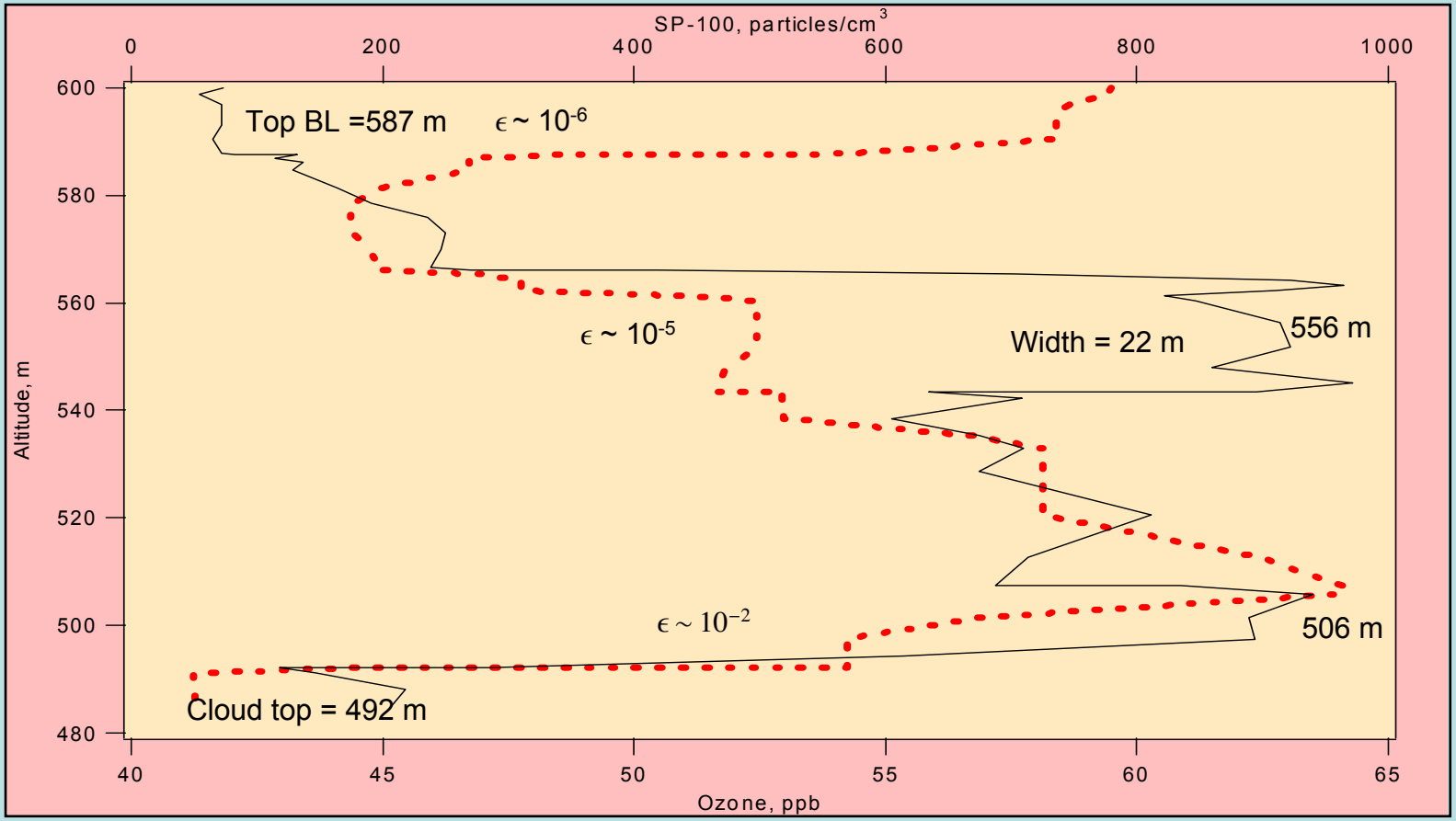
Therefore the new aerosol particles are accumulating in the enhanced aerosol layer

Summary of evidence for new particle formation in the EAL

- Elevated ozone and SO_2 concentrations
- Elevated aerosol particle concentrations between 3 and 10 nm in the EAL
- Elevated concentrations of aerosol particles in the EAL compared to cloud top

This will be pursued further in VOCALS

Secondary aerosol layer above the enhanced aerosol layer



Secondary aerosol layer is not turbulently coupled to the cloudtop, nor is it producing ozone. It is the enhanced aerosol layer from an earlier time, perhaps the previous day.

Summary

The following turbulence quantities can be calculated from the gustprobe

Vertical Velocities, w_a
Turbulent Energy Dissipation Rate, ϵ
Microscale Reynolds Number, Re_λ
Turbulent Eddy Fractal Dimensionality

Turbulence is needed in our understanding of

Cloud particle relative dispersion
The enhanced aerosol layer above marine stratus clouds

Turbulence has to be included in order to understand cloud microphysics