The Scattering Characteristics of PMSE at 33 cm with the Poker Flat Incoherent Scatter Radar

M. J. Nicolls, C. J. Heinselman, M. C. Kelley, and R. H. Varney

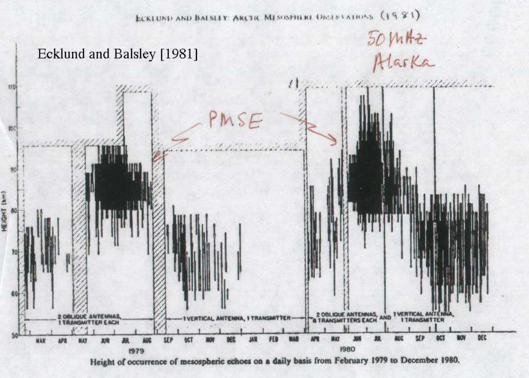
URSI, 15 August 2008

Outline

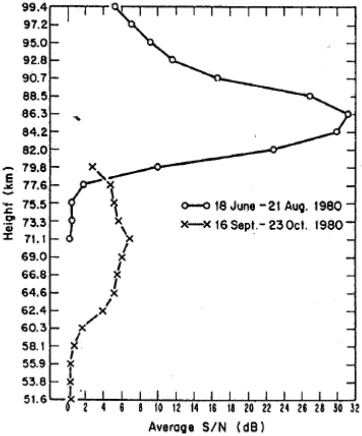
- PMSE Review
- PFISR Experiments
- Observations
- Comparison to Turbulence Theories
- Future Work / Unkowns

Early Observations of PMSE

- Coherent irregularities with time scales (milliseconds) much longer than thermal fluctuations due to incoherent scatter
- Enhanced returns in cold summer mesopause region
- Associated with ice particles and neutral turbulence

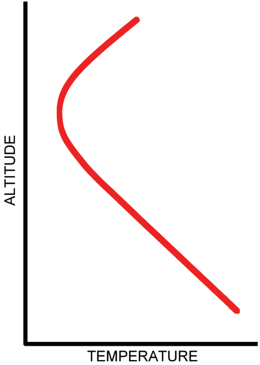


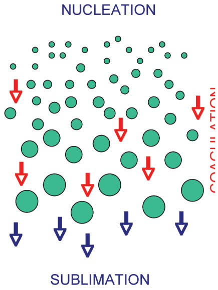
Height of occurrence of mesospheric echoes on a daily basis from February 1979 to December 1980.

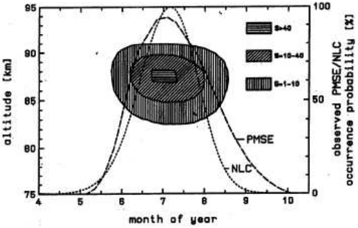


Link to ice / NLCs / PMCs, Basic Phenomenology

- Ice particles sediment and grow 87-89 km (mesopause)
- ~85 km, ice particles are large enough to be seen optically
- Particles are immersed in *D* region - electron attachment
- Turbulence leads to electron density fluctuations

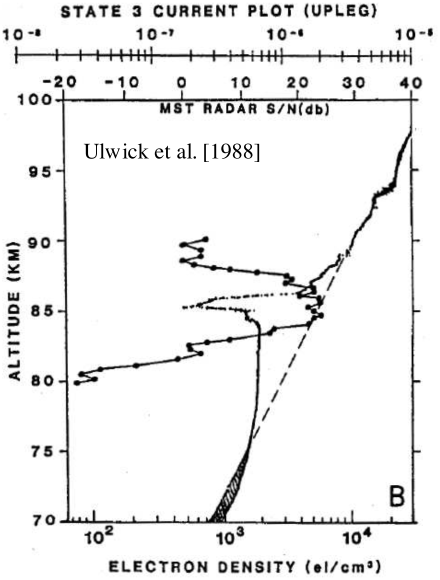




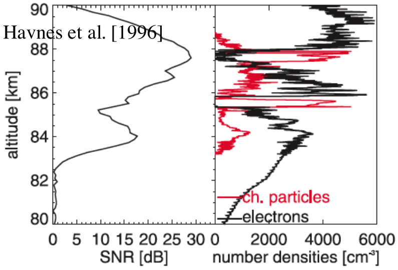


N_e Biteouts / Negatively Charged Particles

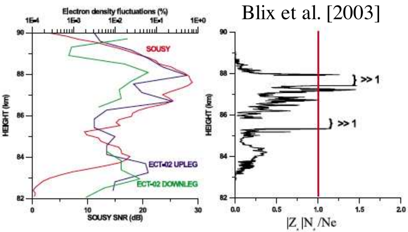
Electron density biteouts within PMSE



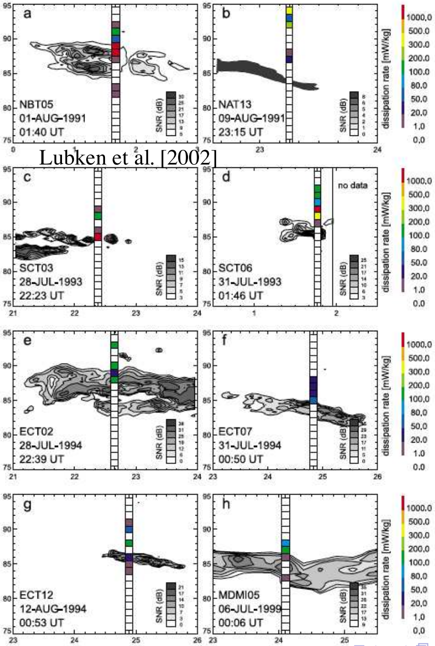
Evidence for negatively charged particles



But don't always carry that much charge



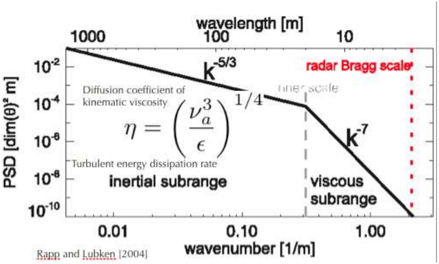
Evidence for direct link to neutral turbulence is dubious



Lubken et al. [2002]

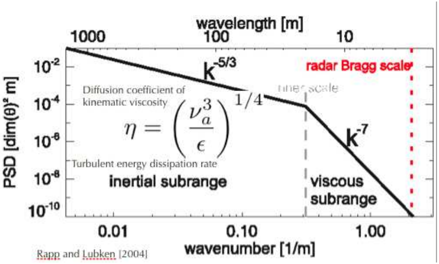
Turbulence Inertial Range

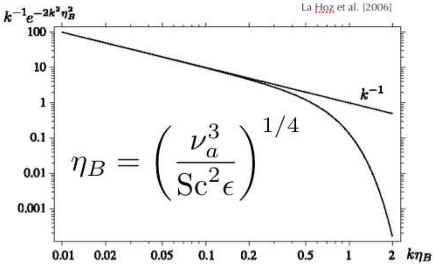
- Extremely high turbulent energy dissipation rate would be required to explain observations at sub-meter wavelengths
- Max value implies that only HF radars could see PMSE



Turbulence Inertial Range

- Extremely high turbulent energy dissipation rate would be required to explain observations at sub-meter wavelengths
- Max value implies that only HF radars could see PMSE

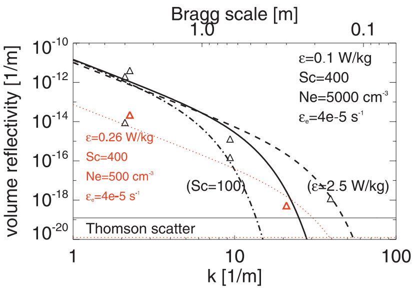




- Electron irregularity dissipation rate may be slower than dissipation of energy (Kolmogorov), because of the braking effects of massive (multiply?) charged ions (ice particles)
- Ratio of the diffusion rates is $\mathrm{Sc} = \nu_a/D_e$ (diffusion coefficient of kinematic viscosity to particle diffusion rate of electrons)
- Dissipation is Batchelor - particle density squared rather than energy (velocity squared)

What can an ISR measure?

1. Absolute volume reflectivity, η - related to turbulence and Schmidt number, as well as background densities, gradients, etc.
2. Doppler velocities - motion of irregularities
3. Spectral widths - related to turbulence dissipation rate, $\epsilon \approx C\sigma_v^2\omega_B$
4. Spatial / aspect sensitivity information



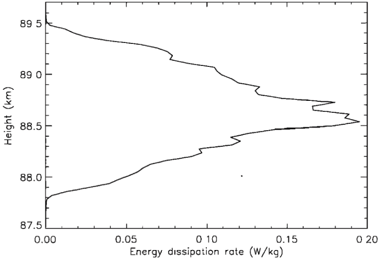
The Poker Flat ISR

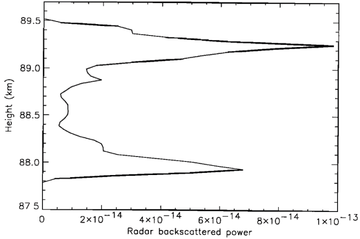
- 128-panel AMISR system (upgraded from 96 in Sep. 07)
- Pulse-to-pulse steering capability
- $\sim$1.6 MW peak Tx
- $\sim$10% max duty cycle
- 4 reception channels
- Tx band 449-450 MHz
- 3.5 MHz max Rx bandwidth
- 4 μs min pulsewidth (freq. allocation limitation)
- Fully programmable, remotely operable/ted
- Graceful degradation - reliable operations

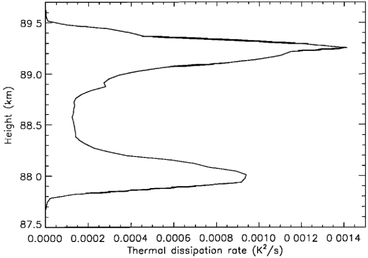
Why a higher frequency is useful

Gibson-Wilde et al. [2000]

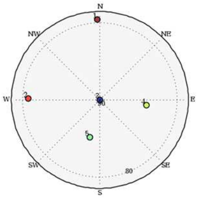
1. Beam broadening effects reduced
2. Measurement of background parameters
3. Scatter may better represent index of refraction variations due to energy dissipation
4. Aspect-insensitive scatter suggests well into the dissipation range

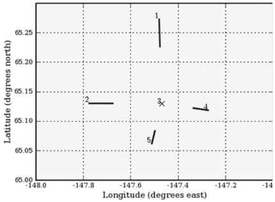


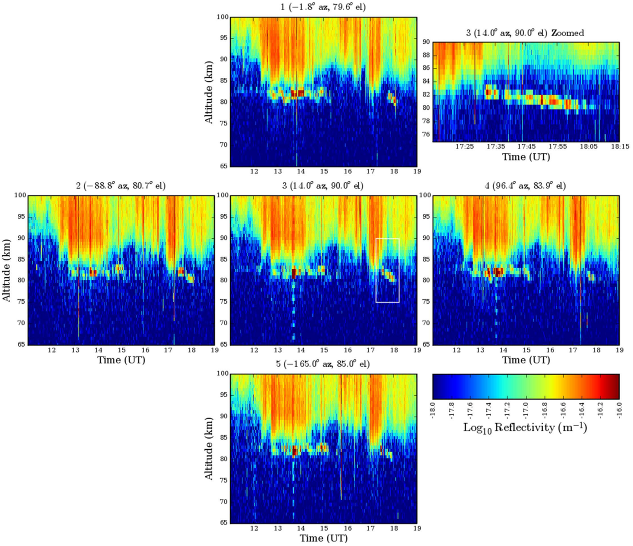




Observations - Absolute Reflectivity

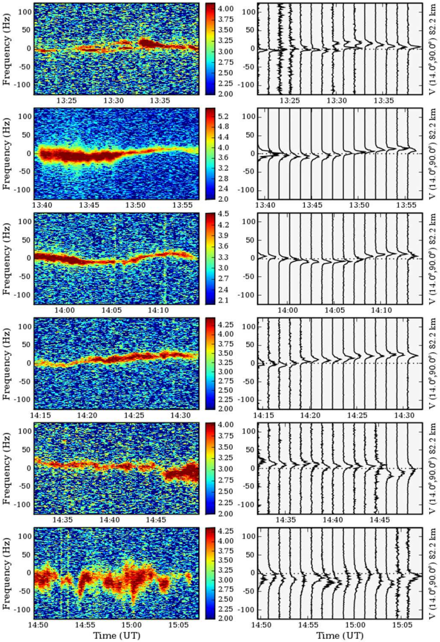






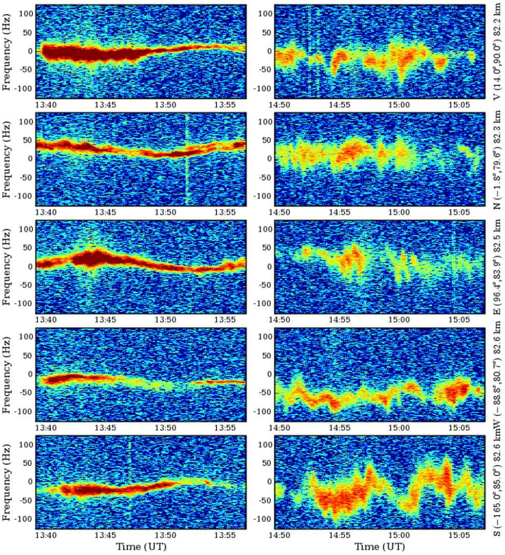
- Absolute reflectivity in line with expectations
- Aspect insensitive (down to at least $\sim 55^\circ$)

Spectral Observations - Vertical Beam



- 5-second, single altitude spectra from vertical beam
- 5 consecutive 20-minute windows
- $\pm \sim 10$ m/s vertical velocities
- Transition from extremely narrow spectra (well-behaved) to extremely broad spectra (more dynamic)
- Perhaps several regions of active turbulence
- Split echoes - evidence for unresolved features

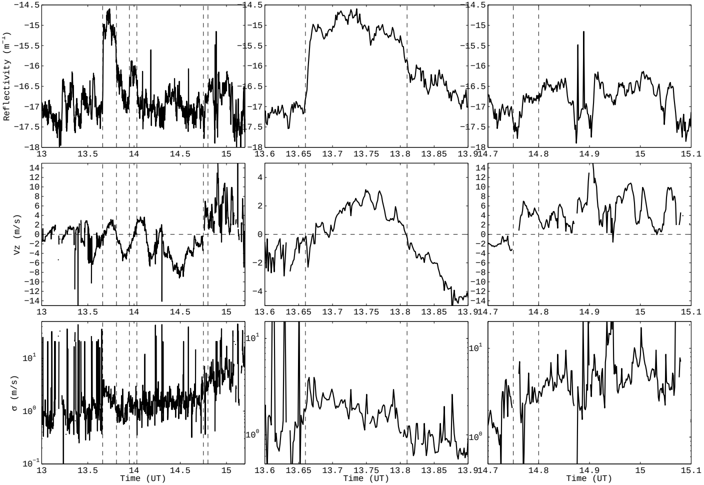
Spectral Observations - All Beams



- Echoes from all beams during two 20-minute windows
- Spectra during "non-turbulent" and "turbulent" time periods show dramatically different characteristics
- Non-turbulent echoes show consistency from beam-to-beam and with motion with a background wind field; turbulent echoes do not
- Non-turbulent echoes show a period of enhanced power and spectral width which decays into narrow returns - fossilization of echoes?
- Non turbulent echoes - spectral widths of $\sim$3 m/s ($\sim 10^{-1}$ W/kg) , decay to widths of $\sim$1-2 m/s ($\sim 10^{-2}$ W/kg)
- Turbulent echoes - spectral widths of $\sim$5-7 m/s ($\sim$ 0.5 W/kg)
- Role of vertical velocity is clear

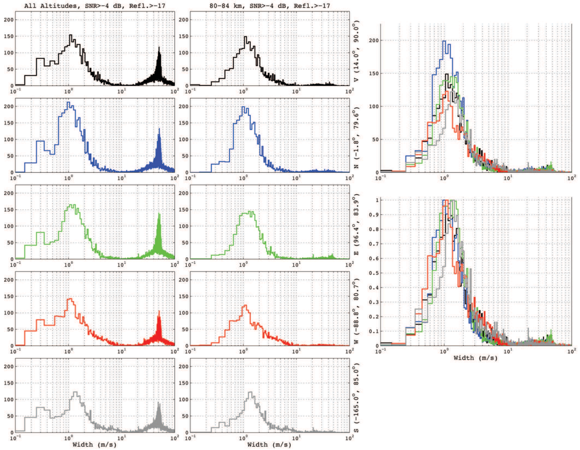
Gravity Wave and Vertical Velocity

- Reflectivity, vertical velocity, and spectral width during the two time periods
- Clear evidence of a $\sim$20-minute wave
- Spectral widths larger during upward phase of wave - larger turbulence dissipation rate
- GWs are more convectively/dynamically unstable during their upward phase
- Enhanced turbulent region logically due to breaking of wave



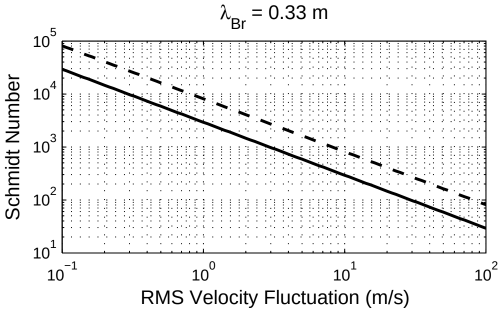
Spectral Width Distributions

- Spectral widths histograms show dominant peak of 1-1.5 m/s
- Relatively consistent from beam-to-beam - no evidence for beam broadening effects



Schmidt Numbers

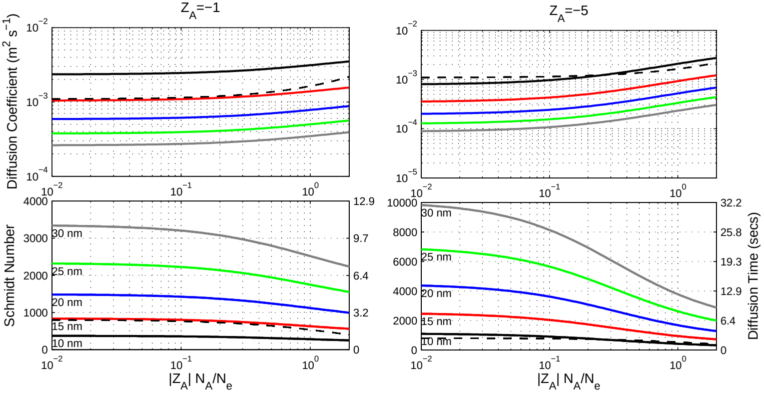
Schmidt number as a function of spectral width, assuming Batchelor shape, $\eta_B = \left(\frac{\nu_a^3}{\mathrm{Sc}^2\epsilon}\right)^{1/4}$



- Spectral widths of ~1-2 m/s imply Schmidt numbers of 3000-8000 **(but, it is unlikely that this is active turbulence)**
- Spectral widths of 5-7 m/s imply Schmidt numbers of 500-1200
- Are these numbers reasonable for particle sizes and charge numbers in the mesopause?

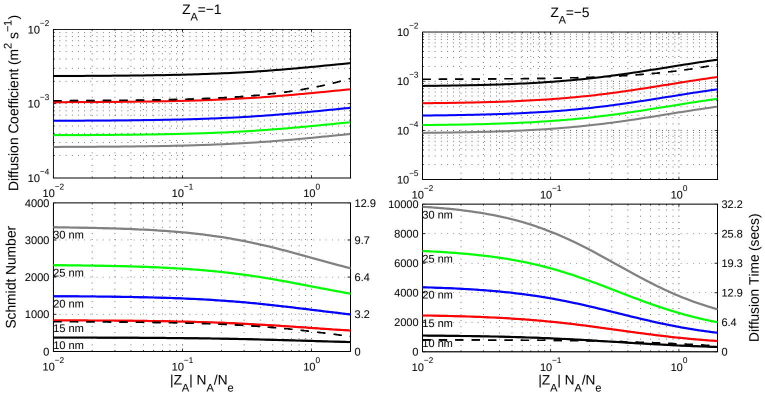
Diffusion in the Vicinity of Charged Ice - 1

- Multi-component plasma (electrons, positive ions, aerosol particles)
- Each satistifies a continuity equation $\frac{\partial N_j}{\partial t} + \nabla \cdot \Gamma_j = 0$
- Two diffusion modes - one (D_1) due to electrons + positive ions, the other (D_2) due to electrons + charged aerosols
- $\Lambda = |Z_A| N_A / N_e$ is the abundance ratio and is critically important
- D_1 - fast diffusion mode, varies strongly with Λ but independent of aerosols
- D_2 - slow diffusion mode, system diffuses as D_A for Λ small
- Real case is some combination - Simulations (Rapp and Lubken, 2003) show decay at D_1 to amplitude of around ∼0.5



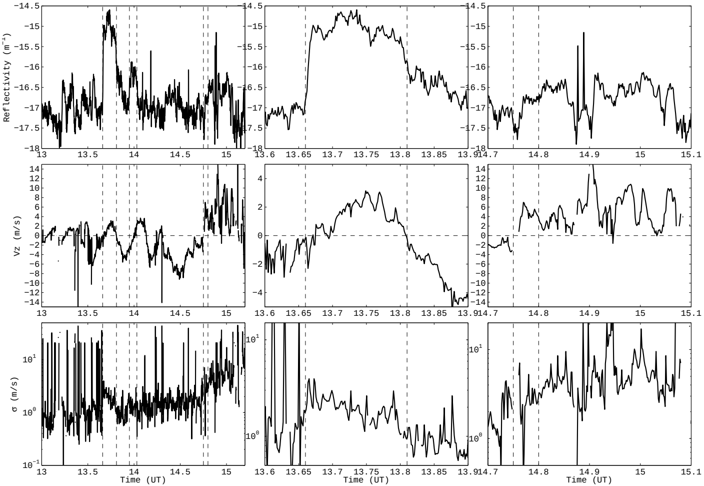
Diffusion in the Vicinity of Charged Ice - 2

- Schmidt numbers of several thousand can be obtained for all values of Λ
- PMSE at UHF is likely associated with large particles $> 20 - 30$ nm (D_2 goes as particle radius squared)
- Large Schmidt numbers are associated with long diffusion times
- If narrow echoes are associated with weak turbulence, but exist in the presence of strongly enhanced Schmidt numbers, they will persist for longer times - explains their predominance



Diffusion Time

- Diffusion time of $\sim$30 seconds is not inconsistent with observations



Summary and Future Work

- Observed reflectivities are in line with expectations of turbulence theories
- Schmidt numbers to explain even narrowest spectral widths can be obtained given typical particle radii and charge numbers in mesopause region
- Diffusion times are somewhat worrisome - "narrow" echoes persist much longer than tens of seconds - may be some physics missing here - calculations are extremely sensitive to background parameters
- Need common volume UHF/VHF measurements - VHF systems likely probe edges of turbulent structures, UHF are likely more direct measure of turbulent region