LA-UR--83-2997

DE84 001709

Conf-8310204--1

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TITLE: MICROINSTABILITIES IN THE HIGH LATITUDE F REGION:
A BRIEF REVIEW

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SUBMITTED TO: Proceedings of the DNA Hilar/Late Time Meeting,
Palo Alto, CA, October 5-8, 1983

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MICROINSTABILITIES IN THE HIGH LATITUDE F REGION: A BRIEF REVIEW

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October 1983

ABSTRACT

This is a review of the theory of plasma microinstabilities that may arise in the high latitude F region ionosphere below 1000 km. Three free energy sources are considered: a density gradient perpendicular to the ambient magnetic field $\underline{B}$, a current parallel to $\underline{B}$ and a steady electric field perpendicular to $\underline{B}$. The BGK model for charged-neutral collisions is used, and the short wavelength properties of the universal density drift, current convective and $\underline{E} \times \underline{B}$ gradient drift instabilities are compared. At sufficiently high altitudes and sufficiently steep gradients, the universal instability is the short wavelength mode most likely to grow and, through wave-particle diffusion, to cause relatively steep wavenumber dependences in power spectra.

I. INTRODUCTION

Several reviews of the theory of ionospheric structure have recently been published [Ossakow, 1979; Fejer, 1979; Fejer and Kelley, 1980; Ossakow, 1981]. This review differs from each of these in that its emphasis is on short wavelength, kinetic instabilities. The F region of the ionosphere below 1000 km is considered, and free energy sources appropriate to the high latitude ionosphere are examined.

A complete description of the evolution of a plasma generally involves both large scale and small scale physics. In a magnetized plasma such as the earth's ionosphere, a thermal ion gyroradius a_i is a convenient boundary between these two scales. Here the prefix "micro-" will denote fluctuations with wavenumbers satisfying $ka_i \geq 1$; the prefix "macro-" will denote phenomena at $ka_i \ll 1$.

Plasma macrophenomena are often described by a set of fluid equations in which densities, flow speeds, pressures, etc. are functions of position and time. Plasma microphysics is usually associated with a kinetic equation which describes the evolution of species distributions which are functions of velocity as well as position and time.

One may formulate macroscopic descriptions of plasma phenomena without reference to microphysics and obtain a limited picture of the long wavelength physics. However, as experimental diagnostics have become more sophisticated and theoretical analyses have probed models more carefully, macrophysics has become less adequate to explain the variety and detail of ionospheric plasma phenomena. In particular, the growth and convection of ionospheric structures are generally well described by fluid models, but a full description of the wavenumber spectra and the dissipation of these irregularities may sometimes require the use of microscopic kinetic theory.

Recent experiments have demonstrated a relatively clear demarcation between macro- and micro-regimes in equatorial spread F at sufficiently high altitudes. Figure I-1 represents density fluctuation power spectra similar to those reported by Rino et al. (1981); Kelley et al. (1982) and Basu et al. (1983). At macroscopic wavelengths, the power spectra are proportional to $k^{-\alpha}$; at microscopic wavelengths, to $k^{-\beta}$ where $\alpha < \beta$. The transition from one regime to the other occurs at a relatively sharp "break," labeled k_c in the figure.

We offer the following explanation for this "break". At sufficiently high altitudes and sufficiently steep background density gradients, microinstabilities can grow in the F region. This leads to enhanced levels of ion-gyroradius-scale fluctuating electric fields which can scatter the plasma particles and lead to wave-particle diffusion. Gary (1980) has derived a closed-form expression for the diffusion coefficient due to the universal instability, and Bernhardt et al. (1982) has used this in a simple diffusion model to obtain one dimensional k^{-4} power spectra. We therefore argue with Kelley (1982) that the short wavelength part of observed "broken" spectra are manifestations of this wave-particle process.

The purpose of this review is to examine the linear theory of short wavelength instabilities which are driven by free energy sources likely to be found in the high latitude F region. Among the various possible instabilities, we find that the universal density drift instability is the mode most likely to produce enhanced fluctuations at the ion gyroscale, and is thus a likely source of wave-particle diffusion and "broken" spectra at high latitudes.

The fundamental kinetic equation appropriate for plasma instability analysis in the ionosphere is

$$\frac{\partial f_j(\underline{x}, \underline{v}, t)}{\partial t} + \underline{v} \cdot \frac{\partial f_j(\underline{x}, \underline{v}, t)}{\partial \underline{x}} + \frac{e_j}{m_j} \left[\underline{E}(\underline{x}, t) + \frac{\underline{v} \times \underline{B}(\underline{x}, t)}{c} \right] \cdot \frac{\partial f_j(\underline{x}, \underline{v}, t)}{\partial \underline{v}} = C_j(f_j) \quad (I-1)$$

where $f_j(\underline{x}, \underline{v}, t)$ represents the distribution function of the j th species particle and $C_j(f_j)$ represents a collision operator.

At sufficiently high altitudes, the ionospheric plasma is so tenuous that particle-particle interactions are not important and one may take $C_j(f_j) = 0$. In this regime the plasma is termed "collisionless"; the associated kinetic equation is the Vlasov equation.

At lower altitudes, the plasma becomes more dense and collisional effects become more important. One popular model for collisions is the BGK operator:

$$C_j(f_j) \equiv -\nu_j \left[f_j(\underline{x}, \underline{v}, t) - \frac{n_j(\underline{x}, t)}{n_j} f_j^{(M)} \right] \quad (I-2)$$

where ν_j is a collision frequency and $f_j^{(M)}$ is a Maxwellian distribution. This model is generally regarded as a reasonable approximation for relatively short-range interactions, and is frequently used to represent charged-neutral collisions. The linearized form of Equation (I-1) with Equation (I-2), coupled to Poisson's equation, is the theoretical basis for the results reported here. Thus throughout this paper ν_j will represent the collision frequency of the j th charged species with neutrals.

A charge neutral plasma with a uniform magnetic field $\underline{B} = \hat{z}B$ is assumed. The following symbols are defined for the j th species: The plasma frequency, $\omega_j \equiv (4\pi n_j e_j^2 / m_j)^{1/2}$; the cyclotron frequency, $\Omega_j \equiv e_j B / m_j c$; the thermal speed $v_j \equiv (T_j / m_j)^{1/2}$ and the (signed) gyroradius $a_j \equiv v_j / \Omega_j$. The Boltzmann factor k_B is understood to multiply the temperatures T_j throughout this paper.

II. LINEAR MICROINSTABILITIES

The results that follow are derived from the linearized kinetic equation (I-1) with the BGK collision term and Poisson's equation. All first order quantities are assumed to vary in time as $\exp(-i\omega t)$ where a complex frequency $\omega = \omega_r + i\gamma$ with positive growth rate is assumed. These fluctuating fields and distributions are Fourier transformed in the directions perpendicular to the direction of any inhomogeneities (which here will be assumed to point in the x-direction). Thus the wavevector is $\underline{k} = \hat{y}k_y + \hat{z}k_z$ and θ represents the angle between $\underline{k}$ and $\underline{B}$. The subscript "m" denotes the maximum growth rate γ_m and the wavevector at maximum growth $\underline{k}_m$.

Then the kinetic dispersion equation may be derived by means of the local approximation and integration over unperturbed orbits. The result is a dispersion equation of the form

$$1 + \sum_j K_j(\underline{k}, \omega) = 0 \quad (\text{II-1})$$

where $K_j(\underline{k}, \omega)$ is the susceptibility of the jth species. Its derivation and detailed form depend upon the zeroth order plasma properties and especially on the type of free energy under consideration. We will not discuss such details here, but merely cite appropriate references; our concern is primarily with the solutions of Equation (II-1).

The illustrations of this section have been obtained from linear dispersion computer codes which provide exact solutions of Equation (II-1). For purposes of making contact with the literature on collisionless drift instabilities, we here use hydrogen mass ratios and exaggerated values of v_e/v_i . Section III reports results using more realistic ionospheric parameters.

We will now consider several sources of free energy and their associated plasma instabilities.

1. $\nabla n \perp \underline{B}$. The first free energy source we consider is a density gradient perpendicular to $\underline{B}$ which can arise in the ionosphere, for example, due to the long wavelength $\underline{E} \times \underline{B}$ gradient drift instability. An important parameter for characterizing the resultant density drift microinstabilities is $\epsilon_n \equiv (1/n)(dn/dx)$, the inverse density gradient scale length. Here and throughout this review we assume weak density gradients, i.e. $\epsilon_n a_i \ll 1$. In the model of a uniform gradient used in this paper, the density gradient drift velocity of the j th species is $v_{nj} = \epsilon_n v_j^2 / \Omega_j$.

The universal density drift instability is driven by the electron density gradient drift velocity. This permits a drift wave, $\omega \approx k_y v_{ne}$, $0 < k_z \ll k_y$, to exist in the plasma. This mode can arise in density gradients that are very broad compared to an ion gyroradius, so $v_{ne} \ll v_i$; since for this instability $k_y a_i \lesssim 1$, it follows that $\omega_r \ll \Omega_i$. Ionospheric applications of the universal in the collisionless limit have been discussed by Costa & Kelley (1978a,b), Thomsen & Gary (1982) and Bernhardt, Thomsen & Gary (1983). The role of ionospheric collisions on this instability has been treated by Huba & Ossakow, 1979b, Gary, Bernhardt & Cole (1983) and Gary (1983).

Very weak electron-neutral collisions ($\nu_e \ll \Omega_i$) damp the universal at very short wavelengths [Huba and Ossakow, 1979b], but do not significantly affect the maximum growth rate until $\nu_e / \Omega_i \approx 100 \epsilon_n a_i$. Figure II-1 shows a dispersion plot for this mode with a modest electron-neutral collision frequency; Figure II-2 shows, in contrast, that relatively weak ion-neutral collisions can reduce the maximum growth rate of and eventually stabilize the universal instability.

Note that charged-neutral collisions do not significantly alter the wavenumber at maximum growth; the implication of Huba and Ossakow (1979b) is that charged-charged collisions also do not affect k_{ma1} . Thus, although collisions may damp the universal density drift instability, they do not alter its short wavelength, kinetic character.

Another class of density drift instabilities is driven by the ion density gradient drift velocity, v_{ni} . These generally correspond to much shorter wavelength modes commonly given the name lower hybrid drift instability. The ionospheric applications of this instability have been studied by Huba et al. (1978), Huba and Ossakow (1979a), Sperling and Goldman (1980), Huba and Ossakow (1981a and b) and Gary, Bernhardt and Cole (1983). The wave-particle dissipation due to this mode is generally much smaller than that of the universal [Gary, 1980], and we will not address this mode further here.

2. $\mathbf{J} \parallel \mathbf{B}$. The next free energy source we consider is an electron drift velocity v_{oe} parallel to $\mathbf{B}$. In the context of the auroral ionosphere, this corresponds to a field-aligned current carried by the entire electron distribution function. The origin of such currents has recently been reviewed by Stern (1983). In a collisionless plasma, this free energy source leads to two unstable electrostatic modes, the ion acoustic and the ion cyclotron current instabilities. Under typical ionospheric conditions, Kindel & Kennel (1971) have shown that the latter has the lower threshold. However, for F region parameters of interest ($v_{oe} \approx v_i$, $T_e \approx T_i$) plasma conditions are far below the threshold of this instability in the collisionless limit. And since collisions do not significantly lower the threshold drift speed of the ion cyclotron current instability (Kindel and Kennel, 1971), it is clear that these modes play no role in the evolution of auroral ionospheric structure.

3. $\mathbf{J} \parallel \mathbf{B} + \mathbf{n} \perp \mathbf{B}$. Now consider a cross-field density gradient as well as a field-aligned current. Given these sources of free energy in a collisional plasma, Kadomtsev (1965, p. 102) used a fluid model to derive the properties of the current convective instability with $|\omega_r| \ll \gamma \ll \Omega_i$ and $0 < k_z \ll k_y \ll a_i^{-1}$. Ossakow & Chaturvedi (1979) first showed how this instability may be applied to the auroral ionosphere. More recent theoretical work on the linear aspects of this instability in the fluid approximation has included Huba & Ossakow (1980) and Chaturvedi & Ossakow (1981).

Gary (1983) has recently examined this configuration using kinetic theory with a BGK collision model. In the absence of collisions, an electron drift speed of the order of the ion thermal speed makes no appreciable change in the universal density drift instability. However, for sufficiently large v_e , there is an important change in the dispersion properties; the universal density drift instability with maximum growth rate at $ka_i \approx 1$ becomes the current convective instability with γ_m at $ka_i \ll 1$. Figure II-3 shows a representative dispersion plot for this mode in the absence of ion-neutral collisions.

Figure II-4 shows the effects of ion-neutral collisions on this instability; as with the universal, increasing v_i reduces the growth rate of this instability. Unlike the universal, the stabilizing effects of ion-neutral collisions are greater at shorter wavelength, so that at sufficiently large values of v_i/v_e the growth of the mode is confined to $ka_i \ll 1$ and the mode may be described by a fluid theory.

The effect of ion-neutral collisions on the universal--current convective transition is illustrated in Figure II-5. The universal with γ_m at $ka_i \approx 0.5$ appears to the left of the dashed line; to the right is the current convective instability with maximum growth in the long wavelength limit. For the latter mode, Equation (8) of Ossakow and Chaturvedi provides a good estimate of γ_m at

$v_i = 10^{-1} v_e$; at smaller values of v_i/v_e this equation tends to overestimate the maximum growth rate.

Another possible effect of field-aligned currents would be that the associated magnetic shear might reduce the growth rate of or stabilize density drift microinstabilities. This is a subject for future research.

4. E ⊥ B. A third potential free energy source in auroral ionospheric plasmas is an electric field perpendicular to B. If one considers a uniform E and a collisionless plasma, the consequent E × B drift velocity v_E is the same for all plasma species, and no free energy is present. However, as one descends in the F region, collision frequencies increase and the combination of a perpendicular E and collisions can lead to new sources of free energy.

The effect of a relatively weak electric field ($v_E \ll v_i$) is to produce Pedersen drift velocities, $v_{pj} = \hat{E} v_j v_E / \Omega_j$. Since these drifts correspond to a net current, they constitute a potential source of free energy. However, it appears that, in the F region, Pedersen drifts alone are not sufficient to cause an instability.

If the electric field becomes sufficiently strong so that v_E exceeds the thermal speed of the neutral gas, ion-neutral collisions can produce a highly anisotropic ion distribution [Barakat et al., 1983, and references therein]. Ott & Farley (1975) pointed out that such distributions, which become toroid-shaped for sufficiently strong electric fields, could drive a variety of ion anisotropy instabilities, and identified the Post-Rosenbluth instability with $\Omega_i < \omega_r < \Omega_{ih}$ as the mode most likely to grow in the auroral ionosphere. St-Maurice (1978) carried out a detailed linear stability analysis of this mode and showed, in particular, that increasing density enhances the growth of this instability. The mode is expected to be unstable in the altitude range 150-400

km, but at present there are no clear identifications of enhanced microfluctuations associated with this instability.

5. $\underline{E} \perp \underline{B} + \nabla n \perp \underline{B}$. If, in addition to a cross-field $\underline{E}$, a density gradient perpendicular to $\underline{B}$ is also present, another mode can grow at considerably smaller values of E . This long wavelength mode, variously called the gradient drift instability, the $\underline{E} \times \underline{B}$ instability or the $\underline{E} \times \underline{B}$ gradient drift instability, has maximum growth rate at $k_z = 0$. Various fluid theories of this instability have been reviewed by Ossakow (1979) and Fejer & Kelley (1980).

Gary and Cole (1983) have examined the short wavelength properties of this mode, which is unstable when $\underline{v}_E$ is parallel to ∇n . Although this instability, like the current convective, has maximum growth in the long wavelength limit and is properly regarded as a fluid instability, it can have appreciable growth at $ka_1 \approx 1$ if v_E is sufficiently large and v_e/v_i is sufficiently small. Figure II-6 illustrates the dispersion properties of this mode under such conditions; in general this mode satisfies $\omega_r \approx kv_{ni}$. Figure II-7 shows how the growth rate at short wavelengths is a sensitive function of v_e/v_i . This mode is driven unstable by the combination of an ion Pedersen drift and an ion density gradient drift so, in contrast to the universal and current convective instabilities, it is strongly damped by electron-neutral collisions.

Fluid calculations [Huba et al. (1983)] have shown that an inhomogeneity in $\underline{E}$ can stabilize this instability, and that short-wavelength modes are preferentially stabilized over longer-wavelength modes. This suggests that a sheared $\underline{E}$ may stabilize kinetic modes, but that has not yet been demonstrated.

6. Other Sources of Free Energy. Instabilities due to other sources of free energy may also arise in the auroral ionosphere. Collisionless linear kinetic theories have been constructed for temperature drift instabilities [Gary & Abraham-Shrauner, 1981] and a field-aligned flow shear instability

[Gary & Schwartz, 1980]. However, these modes are not directly associated with the cross-field density gradients and fields of ionospheric structures, and are not likely to play an important role in irregularity dissipation.

The Table summarizes linear properties of plasma instabilities which may contribute short wavelength fluctuations to the high latitude F region.

TABLE

SELECTED INSTABILITIES IN THE HIGH LATITUDE F REGION

<u>Name</u>	<u>Driven by</u>	<u>Damping</u>	<u>Approximate Frequency</u>	<u>Wavevector at maximum growth rate</u>	
Universal density drift	v_{ne}	Ion Landau, v_i	kv_{ne}	$ka_1 < 1$	$0 < k_z \ll k_y$
Lower hybrid density drift	v_{ni}	Electron Landau, v_e	$kv_{ni}/3$	$k^2 a_e^2 \sim \frac{T_e}{T_i}$	$k_z = 0$
Ion cyclotron current	v_{oe}	Ion Landau, v_i	Ω_i	$ka_1 < 1$	$0 < k_z \ll k_y$
Post-Rosenbluth	ion loss cone	Electron Landau	Lower hybrid	$a_i^{-1} \ll k < a_e^{-1}$	$0 < k_z \ll k_y$
Current convective	$v_{ne} + v_{oe}$	v_i	0	$ka_1 \ll 1$	$0 < k_z \ll k_y$
<u>ExB</u> gradient drift	$v_{pi} + v_{ne}$	v_e	kv_{ni}	$ka_1 \ll 1$	$k_z = 0$

III. AN IONOSPHERIC MODEL

To place the above results into an F region context, we use the collision frequency model of Gary and Cole (1983). The model assumes $T_e = T_i = T_{\text{neutral}}$, an ion mass of 16 times the proton mass and a magnetic field of 0.5G.

Figure III-1 shows curves of constant maximum growth rate as a function of the inverse density gradient scale length ($v_{ni}/v_i = \epsilon_n a_i$) and the altitude for both $v_{oe} = 0$ (the dashed lines) and $v_{oe} = v_i$ (the solid lines). The former case corresponds to the universal density drift instability; these curves are similar to those of Figure 7 of Gary, Bernhardt and Cole (1983) for the equatorial F region. The latter case also represents the universal at $\gamma_m > 10^{-3}\Omega_i$; the solid line at $\gamma_m = 10^{-4}\Omega_i$ shows the transition from the universal to the current convective instability at the "knee" near 320 km. Below this "knee", the increases in collision frequencies do not appreciably change γ_m because $v_i/v_e = 1/12$ at all altitudes in the model, but they do increase the damping of short wavelength modes so that below about 280 km, the current convective mode is damped at $ka_i \geq 0.10$.

Figure III-2 shows curves of constant growth rate at $v_E = 0.10v_i$ for the $\underline{E} \times \underline{B}$ gradient drift instability as a function of ionospheric altitude. The solid lines represent the $ka_i \ll 1$ instability; these are independent of v_e and should be valid as long as $v_{ii} \ll v_i$. The dashed lines represent contours of constant growth rate at $ka_i = 1$, and are subject to the more stringent condition $v_{ei} \ll v_e$. The implication here is that if the short wavelength $\underline{E} \times \underline{B}$ gradient drift instability is to arise for weak electric fields in the auroral ionosphere, it will be in the vicinity of 200 km altitude and only under the restrictive condition of small plasma densities, $n_e \leq 10^4 \text{ cm}^{-3}$.

In summary, we may draw the following conclusions from our recent research on short wavelength instabilities in the high latitude F region:

1) The increased collision frequencies at lower altitudes favor long wavelength, fluid instabilities.

2) Neither field-aligned currents nor $\underline{E} \times \underline{B}$ drifts give rise to new microinstabilities in the F region. The associated fluid instabilities may have weak growth at $ka_1 \approx 1$, but the universal density drift instability remains the important microinstability, confined to altitudes above about 300 km.

3) Thus, at sufficiently high altitudes, we expect the universal instability to be present and to produce the same "broken" wavenumber spectra that have been observed in equatorial spread F.

REFERENCES

Barakat, A. R., R. W. Schunk and J. P. St-Maurice, Monte Carlo calculations of the O^+ velocity distribution in the auroral ionosphere, J. Geophys. Res., 88, 3237, 1983.

Basu, S., S. Basu, J. P. McClure, W. B. Hanson and H. E. Whitney, High resolution topside in situ data of electron densities and VHF/GHz Scintillations in the Equatorial Region, J. Geophys. Res., 88, 403, 1983.

Bernhardt, P. A., M. B. Pongiatz, S. P. Gary and M. F. Thomsen, Dissipation of ionospheric irregularities by wave-particle and collisional interactions, J. Geophys. Res., 87, 2356, 1982.

Bernhardt, P. A., M. F. Thomsen and S. P. Gary. The nonlocal theory of periodic density drift instabilities, J. Geophys. Res., 88, 938, 1983.

Chaturvedi, P. K. and S. L. Ossakow, The current convective instability as applied to the auroral ionosphere, J. Geophys. Res., 86, 4811, 1981.

Costa, E., and M. C. Kelley, On the role of steepened structures and drift waves in equatorial spread F, J. Geophys. Res., 83, 4359, 1978a.

Costa, E., and M. C. Kelley, Linear theory for the collisionless drift wave instability with wavelengths near the ion gyroradius, J. Geophys. Res., 83, 4365, 1978b.

Fejer, J. A., Ionospheric instabilities and fine structure, J. Atm. Terr. Phys., 41, 895, 1979.

Fejer, B. G. and M. C. Kelley, Ionospheric irregularities, Revs. Geophys. Space Phys., 18, 401, 1980.

Gary, S. P., Wave-particle transport from electrostatic instabilities, Phys. Fluids, 23, 1193, 1980.

Gary, S. P., Current and density drift instabilities with weak BGK collisions, J. Geophys. Res., (Submitted), 1983.

Gary, S. P. and B. Abraham-Shrauner, Three electrostatic temperature drift instabilities, J. Plasma Phys., 25, 145, 1981.

Gary, S. P., P. A. Bernhardt and T. E. Cole, Density drift instabilities and weak collisions, J. Geophys. Res., 88, 2103, 1983.

Gary, S. P. and T. E. Cole, Pedersen density drift instabilities, J. Geophys. Res., 88, xxxx, 1983.

Gary, S. P. and S. J. Schwartz, An electrostatic flow shear instability, J. Geophys. Res., 85, 2978, 1980.

Huba, J. D., P. K. Chaturvedi, S. L. Ossakow and D. M. Towle, High frequency drift waves with wavelengths below the ion gyroradius in equatorial spread F, Geophys. Res. Lett., 5, 695, 1978.

Huba, J. D. and S. L. Ossakow, Destruction of cyclotron resonances in weakly collisional, inhomogeneous plasmas, Phys. Fluids, 22, 1349, 1979a.

Huba, J. D. and S. L. Ossakow, On the generation of 3-m irregularities during equatorial spread F by low frequency drift waves, J. Geophys. Res., 84, 6697, 1979b.

Huba, J. D. and S. L. Ossakow, Influence of magnetic shear on the current convective instability in the diffuse aurora, J. Geophys. Res., 85, 6874, 1980.

Huba, J. D. and S. L. Ossakow, On 11-cm irregularities during equatorial spread F, J. Geophys. Res., 86, 829, 1981a.

Huba, J. D. and S. L. Ossakow, Physical mechanism of the lower-hybrid-drift instability in a collisional plasma, J. Atmos. Terr. Physics, 43, 775, 1981b.

Huba, J. D., S. L. Ossakow, P. Satyanarayana and P. N. Guzdar, Linear theory of the ExB instability with an inhomogeneous electric field, J. Geophys. Res., 88, 425, 1983.

Kadomtsev, B. B., Plasma Turbulence, Academic Press, New York, 1965.

Kelley, M. C., Nonlinear saturation spectra of electric fields and density fluctuations in Drift Wave Turbulence, Phys. Fluids, 25, 1002, 1982.

Kelley, M. C., R. Pfaff, K. D. Baker, J. C. Ulwick, R. Livingston, C. Rino and R. Tsunoda, Simultaneous rocket probe and radar measurements of equatorial Spread F--transitional and short wavelength results, J. Geophys. Res., 87, 1575, 1982.

Ossakow, S. L., Ionospheric irregularities, Revs. Geophys. Space Phys., 17, 521, 1979.

Ossakow, S. L., Spread F theories - a review, J. Atm. Terr. Phys., 43, 437, 1981.

Ossakow, S. L. and P. K. Chaturvedi, Current convective instability in the diffuse aurora, Geophys. Res. Lett., 6, 332, 1979.

Ott, E. and D. T. Farley, Microinstabilities and the production of short-wavelength irregularities in the auroral F region, J. Geophys. Res., 80, 4599, 1975.

Rino, C. L., R. T. Tsunoda, J. Petriceks, R. C. Livingston, M. C. Kelley and K. D. Baker, Simultaneous rocket-borne beacon and in situ measurements of equatorial spread F--intermediate wavelength results, J. Geophys. Res., 86, 2411, 1981.

St-Maurice, J-P, On a mechanism for the formation of vlf electrostatic emissions in the high latitude F region, Planet. Space Sci., 26, 801, 1978.

Sperling, J. L. and S. R. Goldman, Electron collisional effects on lower hybrid drift instabilities in the ionosphere, J. Geophys. Res., 85, 3494, 1980.

Stern, D. P., The origins of Birkeland currents, Revs. Geophys. Space Phys., 21, 125, 1983.

Thomsen, M. F. and S. P. Gary, A nonlocal theory of an electrostatic sinusoidal density drift instability, J. Geophys. Res., 87, 3551, 1982.

FIGURE CAPTIONS

Figure I-1. A schematic representation of fluctuating density power spectra observed at short wavelengths and sufficiently high altitudes in certain equatorial spread F experiments.

Figure II-1 The real frequency (solid line) and growth rate (dotted line) of the universal density drift instability as a function of wavenumber at the angle of maximum growth $\theta_m = 89.9938^\circ$. Here $v_{n1} = -10^{-3}v_1$, $v_{oe} = 0$, $v_e = 0.05\Omega_1$ and $v_1 = 0$. Also, for all figures in section II, $m_1 = 1836m_e$, $T_e = T_1$, $\omega_e = 10|\Omega_e|$ and $\beta_1 = 0$.

Figure II-2. The growth rate of the universal density drift instability as a function of wavenumber at $\theta = 89.9938^\circ$ for two different values of the ion-neutral collision frequency. Except for v_1 , parameters are as given in the caption of Figure II-1. At $v_1 = 10^{-2}v_e$, the mode is stable.

Figure II-3. The real frequency (solid line) and growth rate (dotted line) of the current convective instability as a function of wavenumber at the angle of maximum growth $\theta_m = 89.996^\circ$. Here, as in Figure II-1, $v_{n1} = -10^{-3}v_1$, $v_e = 0.05\Omega_1$ and $v_1 = 0$; in contrast to Figure II-1, $v_{oe} = v_1$.

Figure II-4. The growth rate of the current convective instability as a function of wavenumber at $\theta = 89.996^\circ$ for three different values of the ion-neutral collision frequency. Except for v_1 , parameters are as given in the caption of Figure II-3.

Figure II-5. The maximum growth rate of density drift instabilities as a function of the electron-neutral collision frequency for four different values of v_i/v_e . Except for v_i and v_e , parameters are as given in the caption of Figure II-3.

Figure II-6. The real frequency (solid line) and growth rate (dotted line) of the $\underline{E} \times \underline{B}$ gradient drift instability as a function of wavenumber at the angle of maximum growth, $\theta = 90^\circ$. Here $v_{ni} = 0.01v_i$, $v_E = 0.10v_i$, $v_i = 0.01\Omega_i$ and $v_e = 0.10\Omega_i$.

Figure II-7. The growth rate of the $\underline{E} \times \underline{B}$ gradient drift instability as a function of wavenumber at $\theta = 90^\circ$ for three different values of the electron-neutral collision frequency. Except for v_e and $v_i = 0.10\Omega_i$, parameters are as given in the caption of Figure II-6.

Figure III-1. Curves of constant growth rate as a function of ionospheric altitude and the ion density gradient drift speed. The dashed curves describe the growth rate at $v_{oe} = 0$ and the solid curves correspond to $v_{oe} = v_i$; the two curves are essentially the same at $\gamma_m = 10^{-2}\Omega_i$. The parameters are: $T_e = T_i = T_n$, $m_i = 16m_p$, $B = 0.5G$, $n_e = 10^3 \text{ cm}^{-3}$ and T_n and the collision frequencies are taken from Table 1 of Gary & Cole (1983). These results assume $v_{ii} \ll v_{in}$ and $v_e \ll v_{en}$ and may be extended to larger electron densities at altitudes such that these conditions are satisfied.

Figure III-2. Curves of constant growth rate of the $\underline{E} \times \underline{B}$ gradient drift instability as a function of ionospheric altitude and the ion density gradient drift speed for $v_E = 0.10v_i$. The solid curves describe the growth rate in the zero wavenumber limit and the dashed curves correspond to the growth rate at $ka_i = 1$. The parameters are as given in the caption of Figure III-1. These results are strictly valid only for electron densities sufficiently low such that $v_{ii} \ll v_i$ and $v_{ei} \ll v_e$.