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Edge Turbulence, Blob Generation, and Interaction with Sheared Flows*

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There has been a great deal of experimental and theoretical work devoted to the study of convection of coherent objects (blobs and ELMs) in the scrape-off-layer (SOL) of toroidal and linear machines (see the review in [1] and references therein). SOL convection driven by toroidal curvature appears to be a universal phenomenon that can "short-circuit" the particle flow to the divertor, increase plasma interaction with the first wall, and enhance impurity transport into the core. These effects could cause significant degradation of performance in ITER or in a tokamak fusion reactor. On the other hand, turbulent convection of momentum from the core to the wall may induce rotation of the core plasma [2] that can improve the magnetohydrodynamic stability of ITER. The goal of the simulations and experimental comparisons reported here is to identify the important physics issues determining the scaling of the convective transport.

In this paper, we summarize the results of recent simulations using the Lodestar SOLT turbulence code which address a number of related questions: nonlinear saturation mechanisms for edge instabilities, the role of sheared flow in regulating turbulence and blob generation, the turbulent transport of poloidal momentum across the last closed surface by both Reynold's Stress and blob convection, and the role of dissipation in all of these processes. Also, we discuss a comparison of the simulations with NSTX gas puff imaging (GPI) data using a new synthetic GPI diagnostic in the code.

Simulation model – Previous work with the SOLT code used a two-region model that coupled two simulation planes (midplane, divertor) to permit variation of the curvature-driven turbulence along the field line due to collisional effects (reduced parallel conductivity) and by magnetic geometry effects (X-points and magnetic shear). It was shown that the turbulent flux (and blob transport) increased with collisionality and decreased due to X-point effects [3]. Poloidal (binormal) flow was suppressed in these simulations. In the present work, the code has been modified to treat flows and momentum transport. We solve a reduced set of equations numerically for the evolution of vorticity, density, temperature and zonal fluid momentum, in the two dimensions orthogonal to the magnetic field in the edge and SOL of a tokamak. Only a single (midplane) region is employed and the physics model is generalized to include drift-wave terms (to provide directionality and drive flows in the edge plasma) and a momentum-conserving treatment for the zonally-averaged flows. The input profiles are chosen to model the edge-SOL boundary, with drift-wave physics inside the LCS and sheath dissipation outside the LCS. A new diagnostic has also been added to the SOLT code which calculates the GPI intensity for given density, temperature, and neutral profiles.

Poloidal momentum transport – It has been suggested that turbulence transports plasma momentum out of the core region and towards the wall, providing a momentum "source" that can induce net core plasma rotation as well as sheared flows in the edge [2]. Motivated by this idea, preliminary results on turbulent momentum transport were reported at the last IAEA meeting [4]; a more complete analysis [5] has since been carried out for "poloidal" momentum transport, i.e. momentum in the binormal direction, perpendicular to both the radial (x) and magnetic field (z) directions. It was shown that turbulence in the vicinity of the last closed surface transports plasma momentum away from the core region towards the wall, and hence provides a momentum "source" that can induce net core plasma rotation as well as sheared flows in the edge. The net momentum transferred to the core is influenced by a number of physical effects: dissipation, the competition between momentum transport by Reynolds stress and passive convection by particles, intermittency (the role of blobs carrying momentum), and velocity shear regulation of turbulence. A significant result is that the edge momentum source adjusts to match the rate of momentum transfer into the core, keeping the edge velocity shear nearly constant. This result suggests the importance of the sheared flow in regulating the turbulence.

Turbulence saturation and role of sheared flow – Another series of simulations was carried out to investigate the physical mechanism responsible for nonlinear saturation of the turbulence. A damping term $(-\nu\,\bar{p}_y)$ was included in the zonally-averaged momentum equation, and the parameter ν was varied from 0 to ∞. (Here, the overbar denotes a zonal average.) It was found that there are two regimes. In the limit $\nu \to \infty$, the flow is weak, the turbulence saturates at a relatively high level and produces convecting objects that look more like radial streamers than blobs. The time-history of the turbulent flux shows *quasi-periodic* oscillations, and it appears to saturate by *wave-breaking*, i.e. the condition $< \nabla \delta n_{rms} / \nabla \bar{n} > \sim 1$ is satisfied near the surface of maximum growth rate, where $<\ldots>$ denotes a time average. In the limit $\nu \to 0$, the zonal flow is strong, the turbulence saturates at a lower level and produces convecting objects that look blob-like. The time-history of the turbulent flux shows *intermittent* bursts, and the turbulence saturates as a result of the stabilizing effect of the *sheared flow*s. For the parameters of this simulation, there is a smooth transition from the sheared-flow to the wave-breaking regime as ν increases.

NSTX modeling – Generic features of boundary turbulence seen in NSTX and other experiments are reproduced qualitatively by the simulations, including statistical quantities (skewed PDFs, power law frequency spectra, correlation lengths, skewness vs. radius) and qualitative features seen in the GPI and probe data. Preliminary work shows that quantitative agreement for a given shot is sensitive to the width of the region influenced by the separatrix, and further sensitivity studies will be carried out.

Summary – Intermittent transport is an important issue for ITER. Simulations show that there is a subtle interplay between edge turbulence, sheared flows, and dissipation (both in the edge and in the SOL sheaths) which controls intermittent transport of particles and momentum. Preliminary agreement with 2D imaging data in NSTX is encouraging.

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