Introduction

In Scrape-Off Layer (SOL) of tokamaks, magnetic field lines intersect the walls of the fusion device
Heat and particles flow along magnetic field lines and are exhausted to the vessel

The Global Braginskii Solver (GBS) code:
- Two-fluid Drift-reduced Braginskii equations
- Mitigation of turbulence by $\Delta'$, $\kappa$, and negative $\delta$: enhancement of turbulence by positive $\delta$

Development and achievements of GBS

System completed with a set of first-principles boundary conditions applicable at the magnetic pre-sheath entrance where the magnetic field lines intersect the limiter [Liu et al., PoP 2012]

mitigation of turbulence of $\Delta'$, $\kappa$, and negative $\delta$: enhancement of turbulence by positive $\delta$
- Linear scan over $\kappa$ and $\delta$ confirms the trend observed for the non-linear simulations
- Preliminary study indicates the curvature as the most important operator in setting $L_p$

The magnetic geometry allows to compute GBS operators
$[\delta, A] = b \left( \nabla \times \nabla \phi \right) = 0$
$\nabla \cdot A = 0$
$\nabla \times A = 0$

The toric coordinate system $(r, \varphi, z)$, general axisymmetric magnetic field $B = F(r, \varphi, z) \nabla \phi + \sqrt{r} \nabla \times \nabla \phi$.
GBS uses the $(r, \varphi, z)$ coordinate system, where $\delta = \int 0 \int \frac{\partial}{\partial r} \int \frac{\partial}{\partial \varphi} \int \frac{\partial}{\partial z} \int B \cdot \hat{n}$ is the straight-field-line angle

The Grad-Shafranov equation is solved in the $r \rightarrow R_b$ domain to obtain $R(r, \varphi, z)$, $Z(r, \varphi, z)$, and $F(r, \varphi, z)$ as function of $\varphi, \delta$, and $\chi(t)$ [L. P. Graves, PoP 2013]

Non-linear simulations

Fully-turbulent non-linear simulations with same physical parameters, in different magnetic geometries
Mitigation of turbulence by $\Delta'$, $\kappa$, and negative $\delta$; enhancement of turbulence by positive $\delta$

Gradient removal saturation mechanism

- The radial gradient of the perturbed plasma pressure comparable to the radial gradient of the background plasma pressure
- Leading order term of the pressure equation gives the perturbed potential
- Balance between radial flux $j_p \sim \nabla (p_b)$ and parallel losses

Assuming $\kappa - \gamma_n \theta_p$ and choosing linear growth rate $\gamma$ and wavenumber $k_p$ to maximize the transport

Non-linear turbulent regimes

- Investigation of the turbulent regimes to understand the mitigation of turbulence by $\kappa$ and negative $\delta$
- Resistive ballooning modes mitigated by $\kappa$ and negative $\delta$
- Resistive drift waves slightly affected by shaping effects

Non-linear simulations that confirm that turbulence is dominated by drift waves for negative $\delta$
Why are $\kappa$ and negative $\delta$ mitigating ballooning modes?
- Shafraanov shift, elongation and negative triangularity stretch magnetic field lines near the outer midplane
- Positive triangularity compress magnetic field lines near the outer midplane
- Curvature less effective with Shafraanov shift, elongation and negative triangularity, and more effective for positive triangularity
- Ballooning modes strongly mitigated by Shafraanov shift, elongation and negative triangularity, enhanced by positive triangularity

Conclusion

- Simulations of SOL turbulence in shaped plasmas
- Scan of $L_p$ and $\gamma$ over $\kappa$ and $\delta$, showing how ballooning modes and drift waves are affected by different magnetic configurations
- Qualitative understanding of the mechanism mitigating enhancing the ballooning character of turbulence

Effects of plasma shaping on tokamak scrape-off layer turbulence

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The magnetic field geometry

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