A Transport Validation Pilot Project

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Motivation

- FSP proposal states the project goal as development of an "experimentally validated predictive simulation capability"

- I interpret validated to mean that
  - A set of metrics have been developed for quantifying the fidelity of individual FSP physics modules to reality as well as integrated FSP predictions

  - That for a given class of physics modules/effects, one or more metric "scores" have been defined as indicating sufficient agreement with experiment that the predictions of a specific module obtaining that score can be assigned a corresponding level of confidence

- Therefore, need to develop a workflow for developing these metrics

- Also important to remember that validation is a continuous process- as models are updated and refined, the metric scores/confidence levels are updated in turn

- Throughout this presentation, I use the phrase transport model to denote both reduced/quasilinear models and nonlinear turbulence simulations

Validation of Turbulent Transport Models

- For turbulent transport, key questions for establishing model fidelity are whether the model
  - Reproduces the magnitudes and scalings of particle, energy, and momentum fluxes determined via independent power-balance modeling
  - Reproduces essential statistics and scalings of the underlying turbulence (e.g. spectra, cross-phases, correlation lengths, etc.)

- Because the direct comparison to turbulence statistics is a more fundamental one than to the power balance calculations (which is a model-model comparison), need to design a suite of metrics which
  - assign the highest score to a model which successfully reproduces both fundamental turbulence statistics and fluxes,
  - but still allows us to assess confidence in reduced models which are only intended to accurately model the fluxes

Workflow for a Transport Model Validation Pilot Project

- Identify a particular parametric dependence which is predicted to strongly vary transport in easily accessible plasmas, and/or would discriminate between competing transport models
  - Includes identification of key experimental measurements and acceptable uncertainties such that a discriminating set of metrics can be designed at this stage

- Design and conduct an experiment to obtain necessary measurements identified in step 1 within specified tolerances

- Given a specified input data set (e.g. equilibrium geometry, profiles and corresponding uncertainties), an analyst performs a series of simulations corresponding to the parameter variations

- Synthetic diagnostics are applied to the simulation output, with the results fed into the metrics designed in step 1 along with the corresponding experimental measurements (which have been analyzed independently by the experimentalists) to perform a "blind" model-experiment comparison

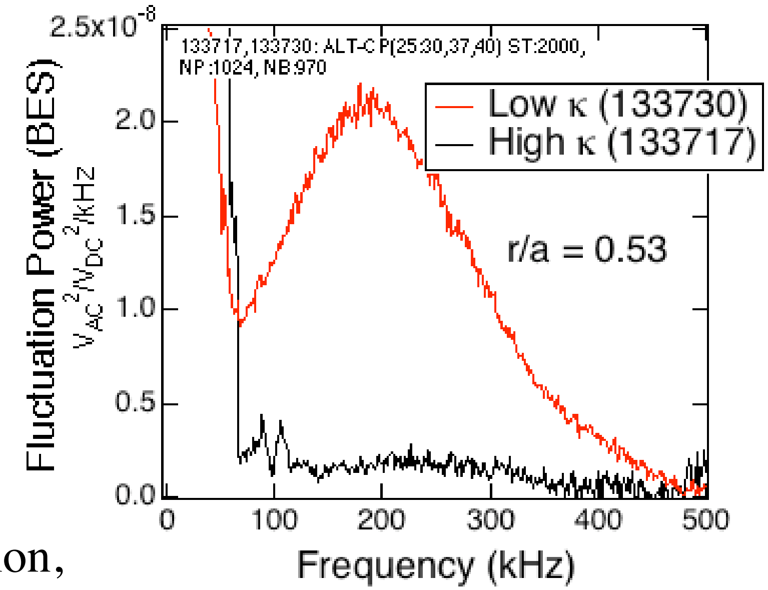
Goals of Project (in Increasing Importance)

- Begin building linkages and collaborations between FSP validation work and experimental groups
- Familiarize FSP with current state of experimental diagnostic capabilities and analysis tools
  - Identify any additional gaps in e.g. equilibrium reconstruction from a validation perspective
- Obtain sufficient information to examine different metric structures within a MFE/FSP context
  - What does and doesn't work from validation exercises in other fields?
- Test a workflow which could be extended to validation of other FSP components, or whole FSP
  - Demonstrate we have a process (or development path to it) for validating FSP predictions <u>at a level sufficient for the intended users</u>

Experimental Example: Elongation Scaling of Transport

- Kinsey et al [2007 PoP] found that use of Miller geometry representation led to GYRO and TGLF turbulent diffusivities roughly scaling as $\chi \propto \kappa^{-1/3} s_\kappa^{-2/3}$

  $$s_\kappa = r d \ln\kappa / dr$$



- Since this was a strong effect not included in other models using a simple s-α representation, an experiment was designed in 2008 to measure a broad spectrum of turbulence quantities in three different plasma configurations (to separate κ and s_κ effects)
  - Follow-up experiments were performed in 2009 to obtain measurements in all three shapes, and improve plasma stationarity and parameter matching

- Initial examination of turbulence measurements indicated order of magnitude increase in fluctuation amplitudes
  - Modeling and metric design still need to be done

Simple Metric Examples

- Calculate 1 global and 2 local metrics:
  - Global reduced χ^2 of different profiles to measurement points

$$M_{prof} = \frac{1}{3}\left(\chi^2_{E_r} + \chi^2_{T_i} + \chi^2_{T_e}\right)$$

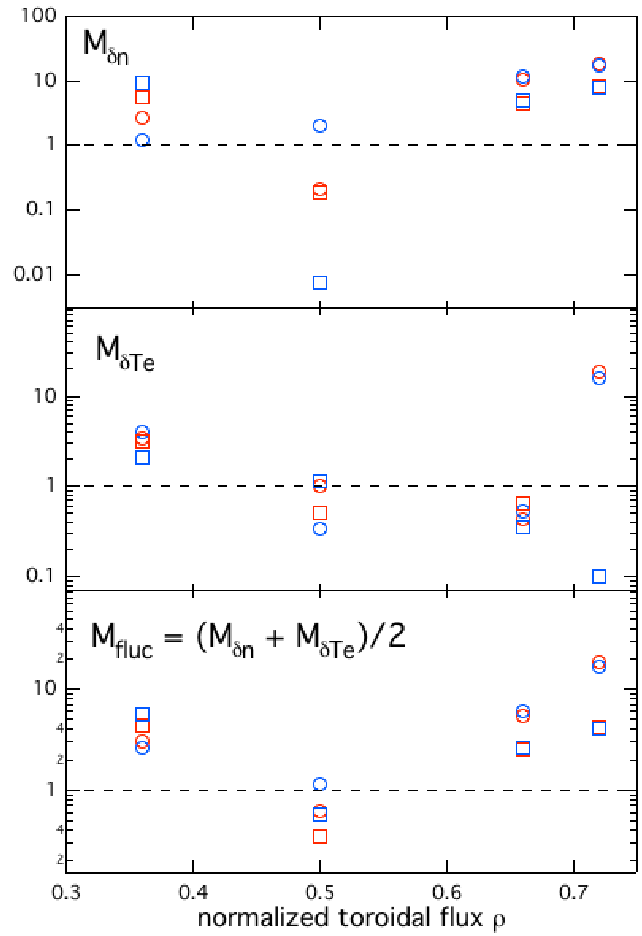
  - A set of local "normalized" errors in RMS density and temperature fluctuation levels ($\delta X = \delta n$ or δT_e)

$$M_{\delta X}(r) = \frac{\left(\delta\overline{X}_{\text{sim}} - \delta\overline{X}_{\text{expt}}\right)^2}{\sigma^2_{\text{sim}} + \sigma^2_{\text{expt}}}$$

- By comparing M_{prof} calculated for different models (quasilinear or nonlinear), can quantify relative model-model performance, as well as to a baseline value corresponding to direct fits (often used in power balance calculation)

- Calculate of $M_{\delta X}$ allows us to independently assess nonlinear simulation performance versus minor radius. Key limitation: how to propagate experimental uncertainties through simulations?

- Next step: what is best way to combine M_{prof} and $M_{\delta X}$ into a single composite metric?



(different symbols correspond to different input profiles)