

Coil Healing Results.

- Changes to selected coil Fourier modes are made to encourage/guarantee that selected resonances vanish in converged PIES free-boundary calculations.
- Results are presented for the m12, 0907 and 0813 coil sets.

The coils are represented using Fourier representation.

- The coils lie on a winding surface :

$$R = \sum_i r_i \cos(m_i \theta + n_i N \phi), \quad (1)$$

$$Z = \sum_i z_i \sin(m_i \theta + n_i N \phi). \quad (2)$$

- Each coil has toroidal variation :

$$\phi_i = \phi_{i0} + \sum_k [\phi_{i,k,c} \cos(k\theta') + \phi_{i,k,s} \sin(k\theta')], \quad (3)$$

$$\theta' = \theta + \sum_j \theta'_j \sin(j\theta). \quad (4)$$

- A subset of the $\phi_{i,k,c}, \phi_{i,k,s}$ modes is chosen to be the independent parameters.
- These parameters will be varied to produce healed configurations.

Resonances eliminated by coil geometry variation.

- The resonant harmonics of the magnetic field normal to the rational surfaces are computed using PIES.
- Changes in these resonant harmonics are related to changes in the independent variables via a coupling matrix \mathbf{C} :

$$\mathbf{B}(\mathbf{r}_0 + \delta\mathbf{r}) = \mathbf{B}(\mathbf{r}_0) + \mathbf{C} \cdot \delta\mathbf{r} + \dots \quad . \quad (5)$$

- Inversion of the coupling matrix using $\mathbf{C} = \mathbf{U}_w \mathbf{V}^T$ allows an iterative Newton procedure which will find the parameter set eliminating resonances :

$$\delta\mathbf{r}_{i+1} = -\mathbf{V}_w^{-1} \mathbf{U}^T \mathbf{B}_i. \quad (6)$$

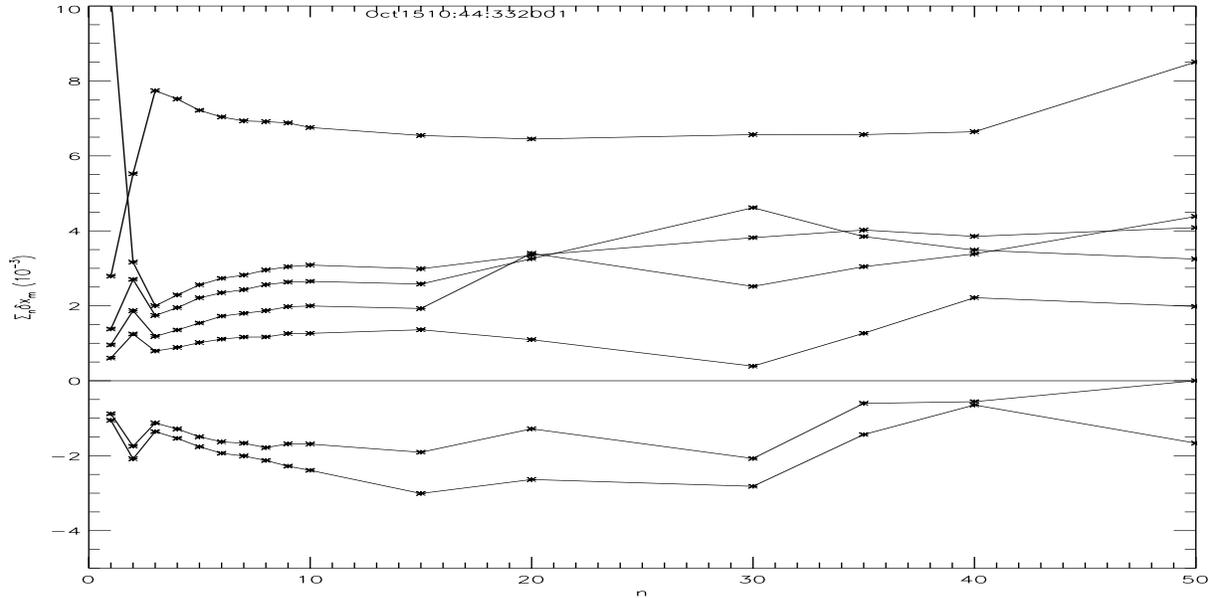
STATIC and DYNAMICAL HEALING : SUMMARY OF RESULTS

- For static healing, the coils are kept fixed for every PIES run : the coil-healing solution is a function of N , where N is the number of PIES iterations used.
 - Do the coil-healing solutions converge as N increases ? **No.**
 - If the N th iteration is healed, does the configuration remain healed as $n \rightarrow \infty$? **No.**
- For dynamical healing, the coils are altered at every PIES iteration to suppress resonances.
 - Do the coil changes tend to zero ? **Yes.**
 - Does PIES initialized with restart remain healed as $N \rightarrow \infty$? **Yes.**
 - Does PIES initialized with VMEC remain healed as $N \rightarrow \infty$? **No.**

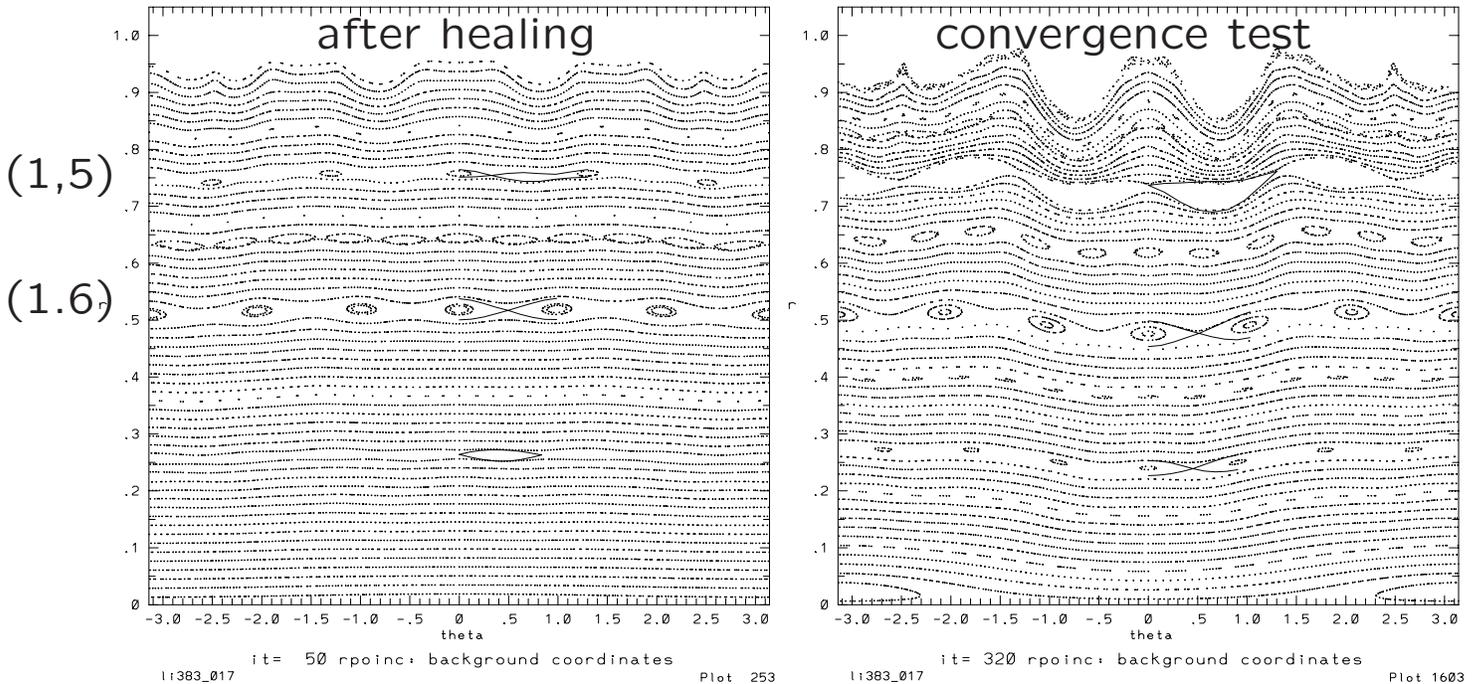
Note the Yes/No answers may be somewhat simplistic.

Static healing fails to converge.

- Below is the coil-healing variation shown against N for $N < 50$. The m_{12} $m = 5$ modes (7 variables) are varied and the (1,5) island is targeted.

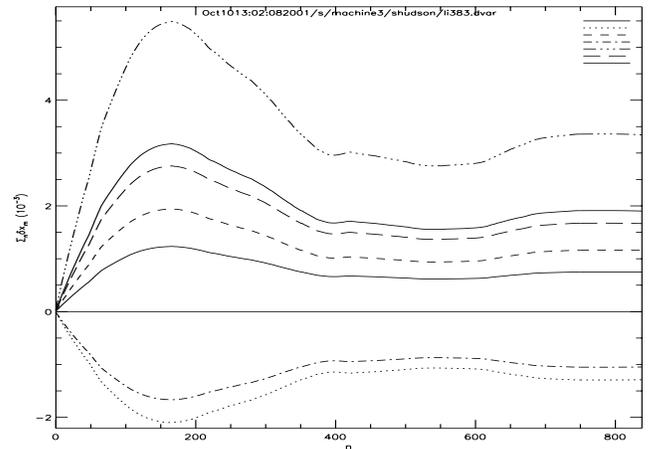
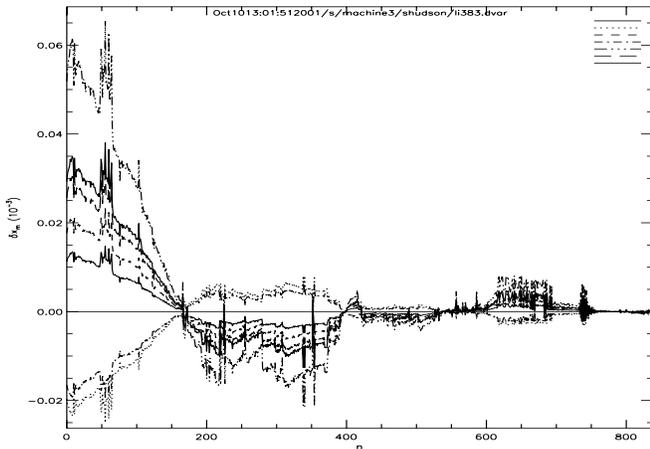


- The lower left plot shows the PIES field at $N = 50$, in which the (1,5) island is insignificant. The lower right plot shows the PIES field at $N = 320$, and the (1,5) island is growing.

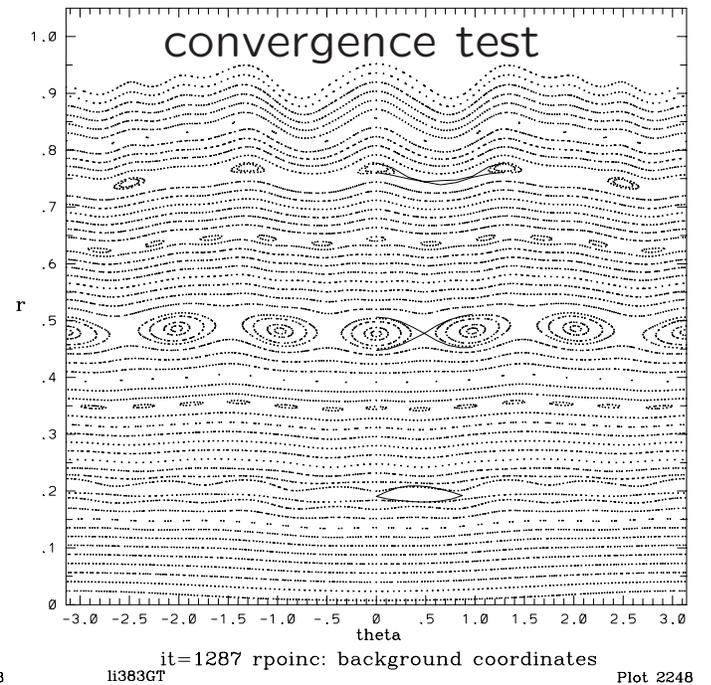
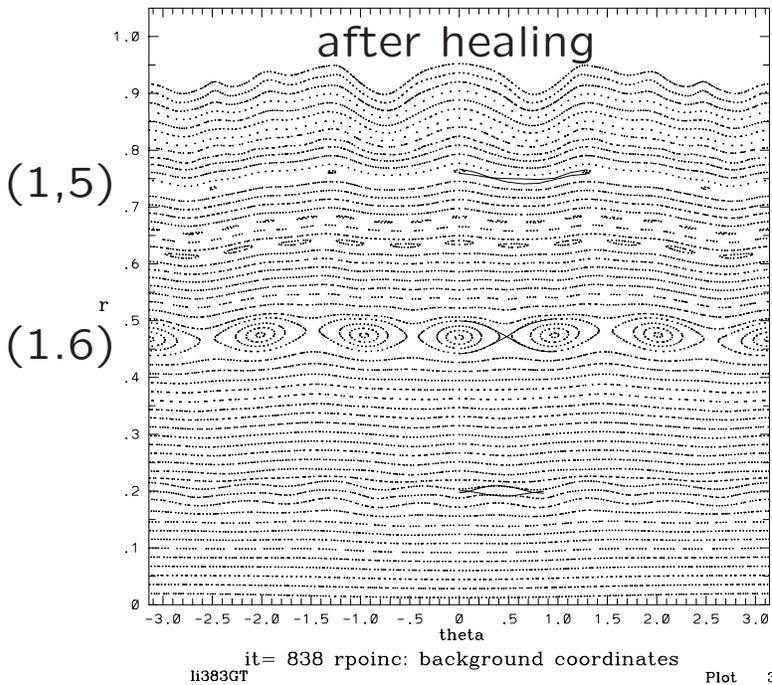


Dynamical healing does converge.

- Using the m12 coils, with li383 initialization, targetting the (1,5) island and varying the $m=5$ coil modes, dynamical healing runs are performed.
- Left plot shows coil change plotted against PIES iteration. Right plot shows summed coil change.

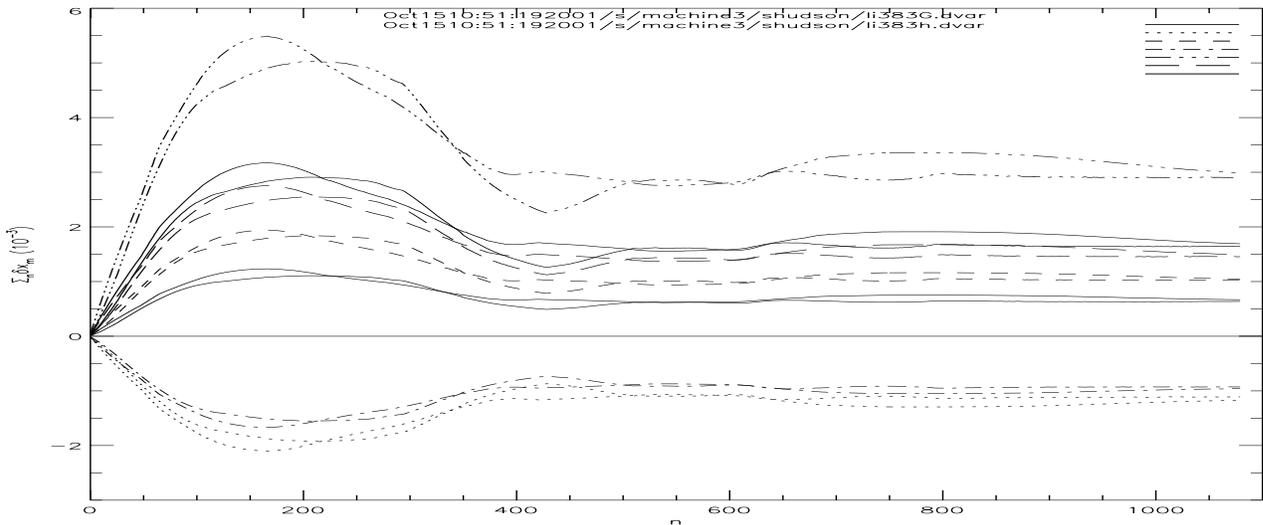


- After the dynamical healing the (1,5) island is small (left plot). This PIES runs is continued for 450 iterations without coil changes and the (1,5) island remains small (right plot).



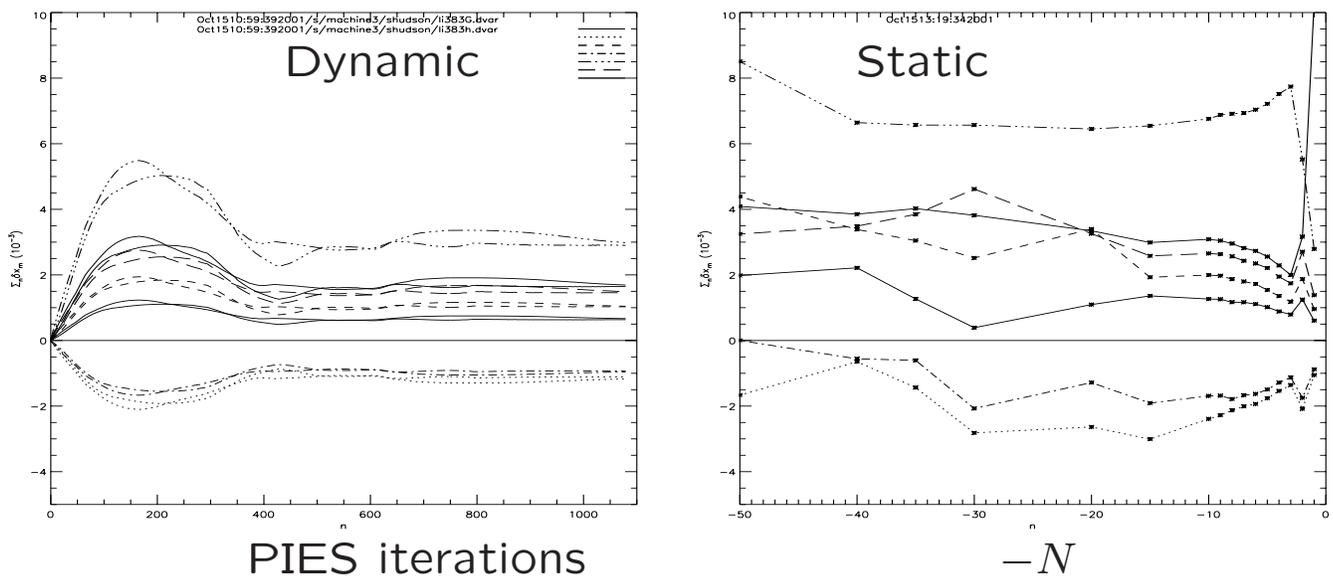
Dynamical healing seems robust to initialization.

- Shown are dynamical healing runs on m12 coils with different VMEC initializations (li383/li383h) targeting the (1,5) island. It appears that the dynamical healing converges to the same coil set.



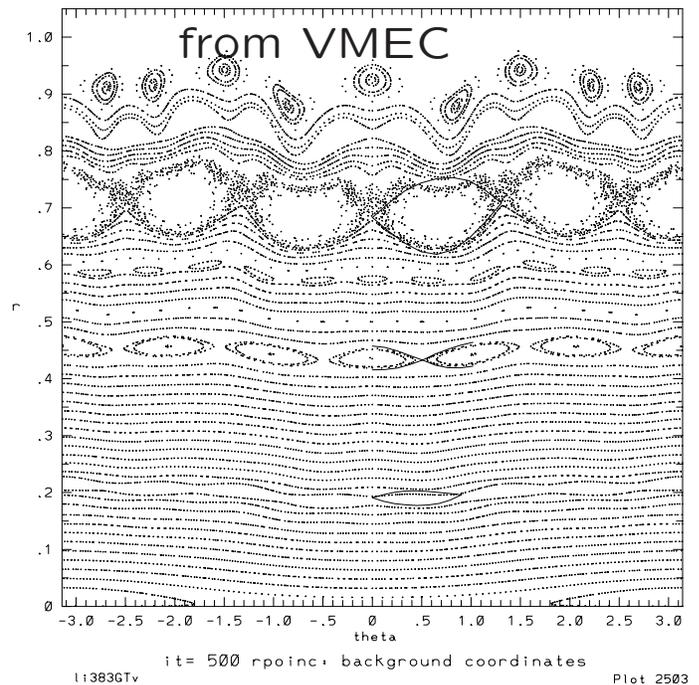
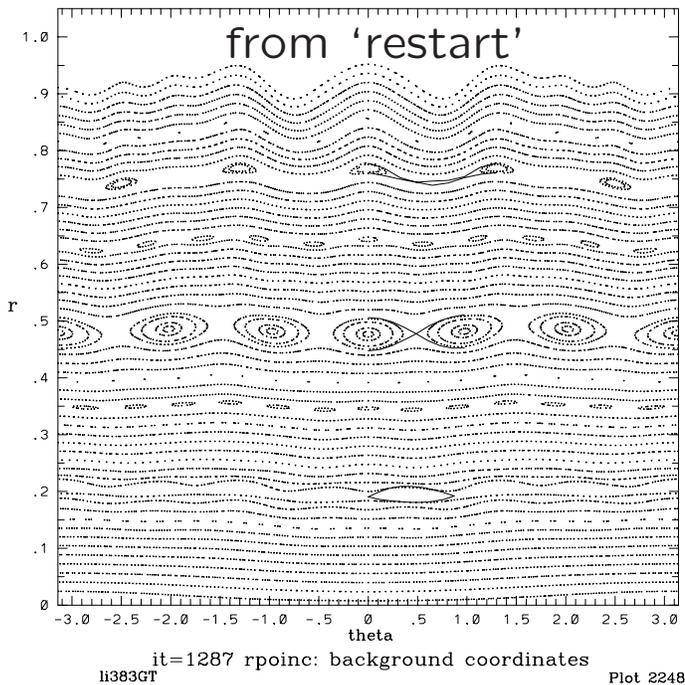
Dynamical Healing and Static Healing disagree

- The dynamical healing results are compared to the static healing results



PIES sensitive to initialization.

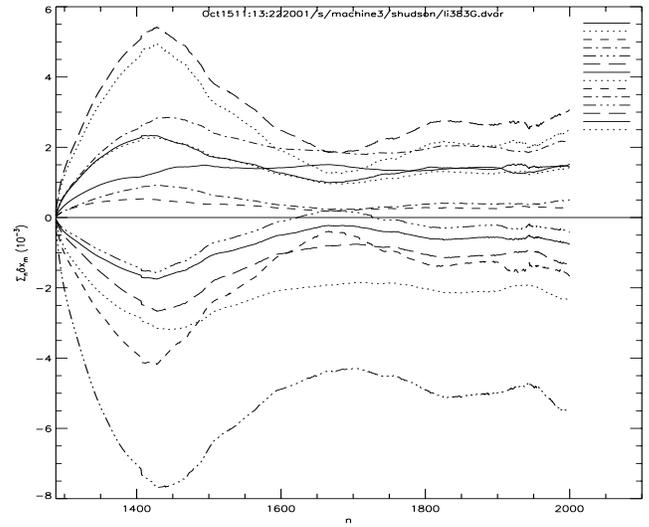
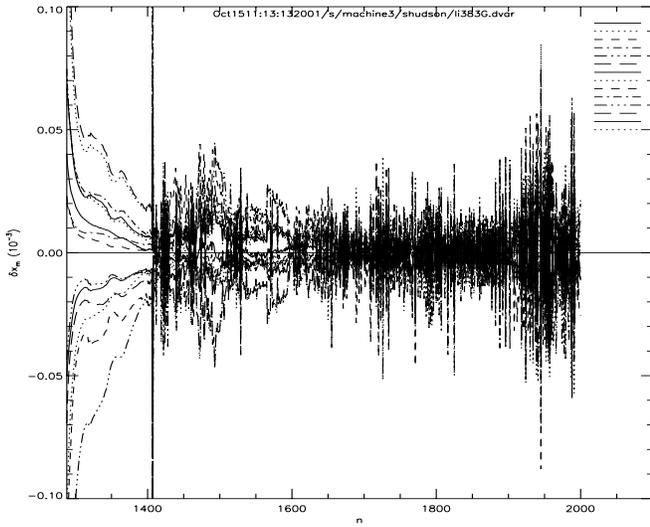
- The same coil set may give different PIES configurations depending on the initialization.
- PIES may be initialized with the 'restart' or with VMEC. The result depends on the initialization.



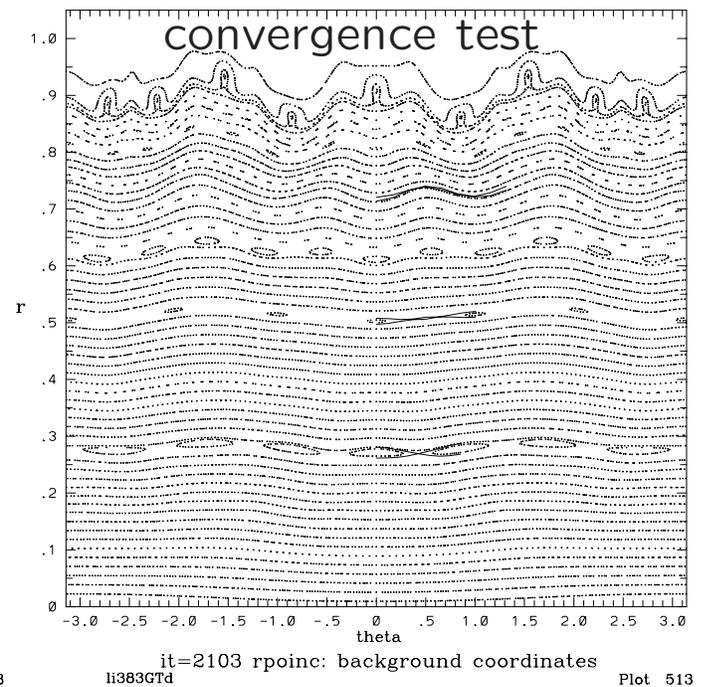
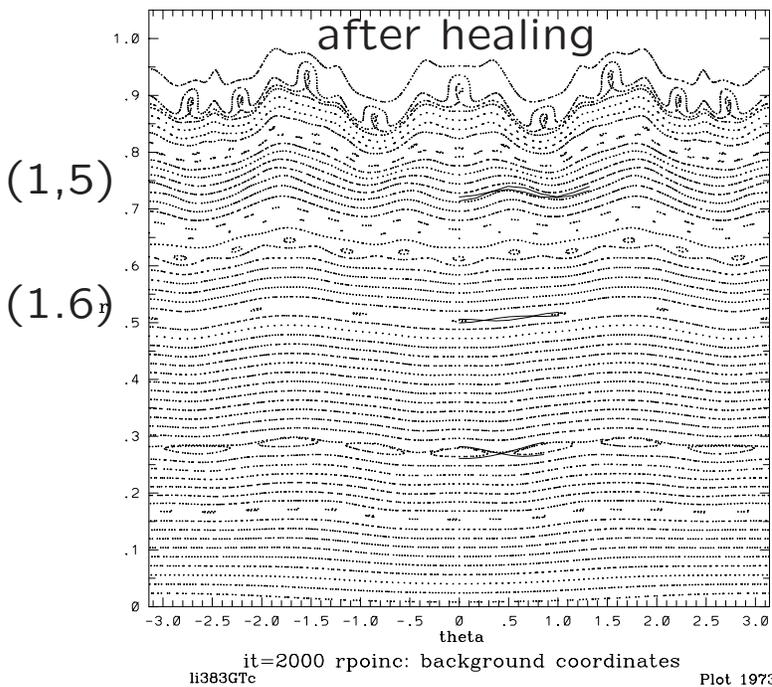
- Perhaps ...
 - multiple solutions;
 - D_R playing a role: resulting in 'meta-stable' configurations;
- Dynamically healing by construction eliminates chosen islands. If present, these islands may affect the dynamics.

The (1,6) island is also eliminated using dynamical healing.

- The previous dynamically healed case is continued now targeting the (1,5) and (1,6) islands. As the (1,6) island is initially large, 10% blending on the coil changes is used until the (1,6) island is small, then 100% blend is used.
- Shown below is the coil changes from when the dynamical healing is restarted. The coil changes are quite noisy.

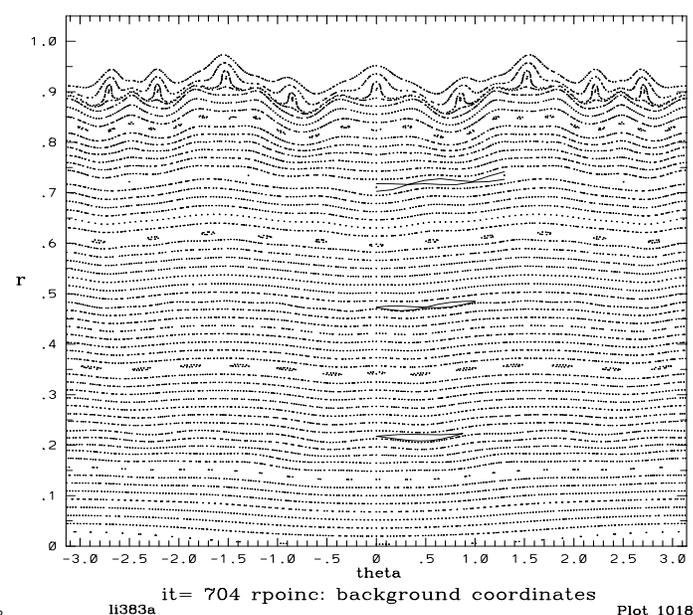
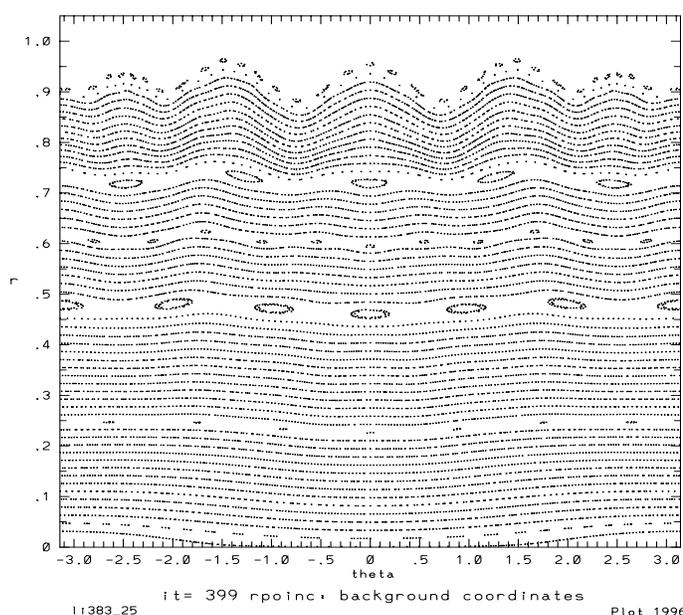


- Shown below is the configuration at the end of the dynamical healing and after 100+ iterations with no coil changes.

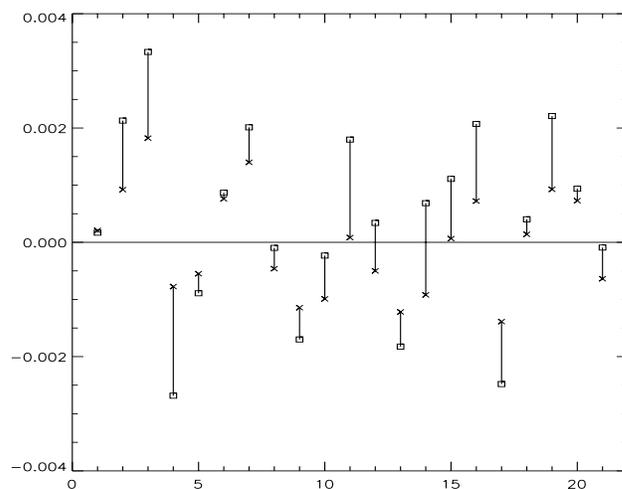
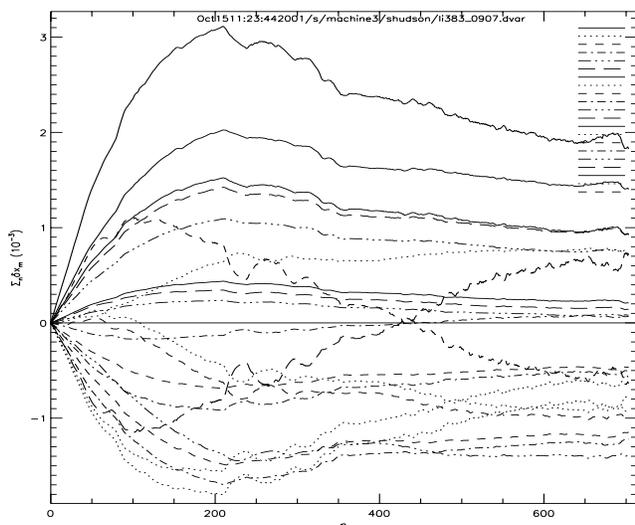


Comparison of static/dynamic healing of 0907.

- The static healing algorithm was used to derive a healed 0907 coil set. For comparison, the 0907 coil set is dynamically healed.
- Note the following : edge targetting, included in static, not included in dynamic; a null-space exists thus some variables are more crucial than others; islands are smaller in dynamically healed case; dynamical healing perhaps not converged.
- The static healed 0907 (left) and the dynamically healed 0907 (right) configurations are shown.

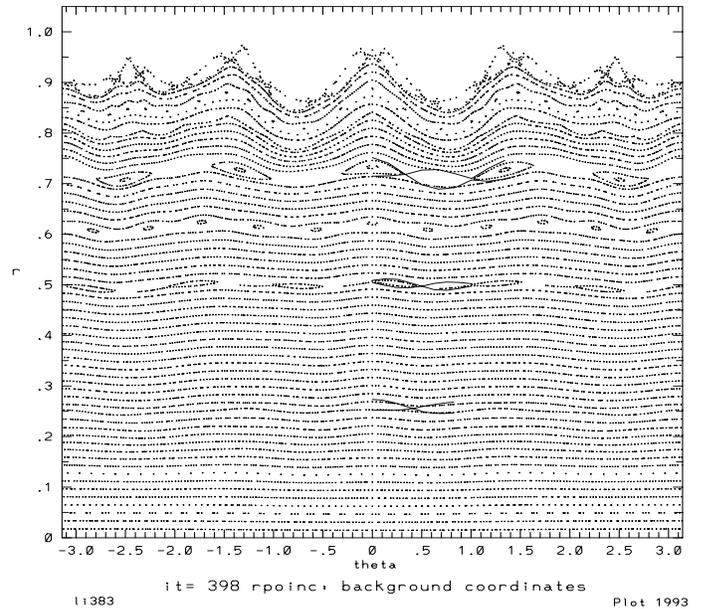
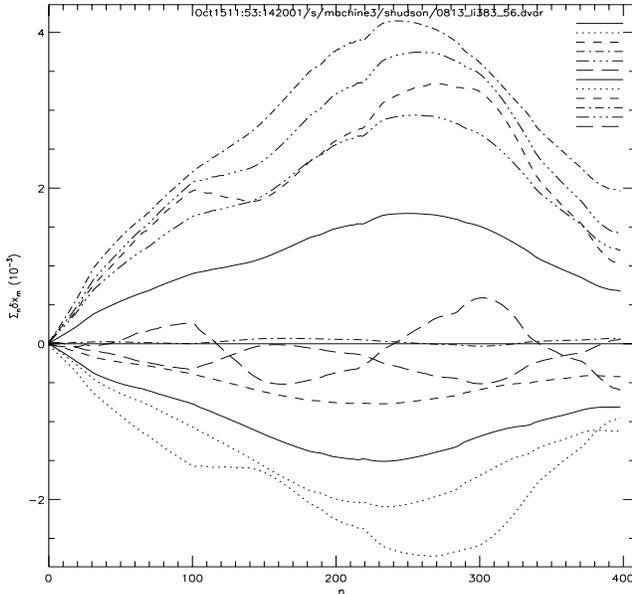


- The dynamical healing coil changes (left) and comparison with results from static healing (right).

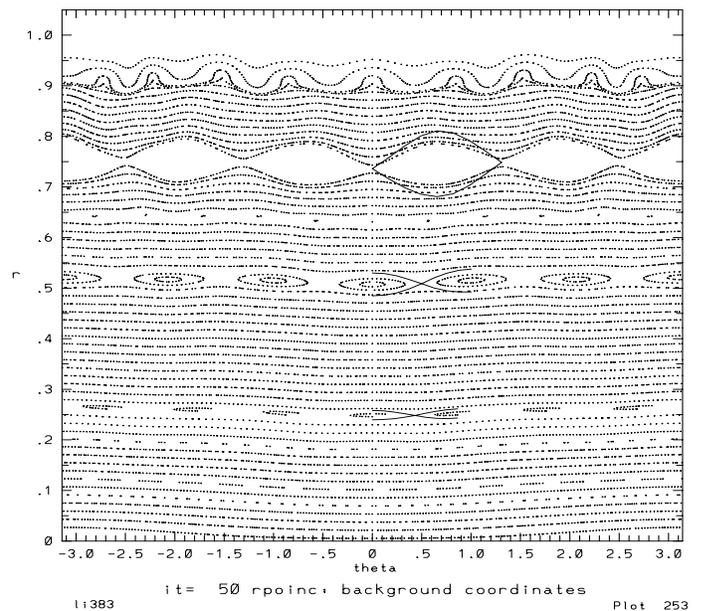
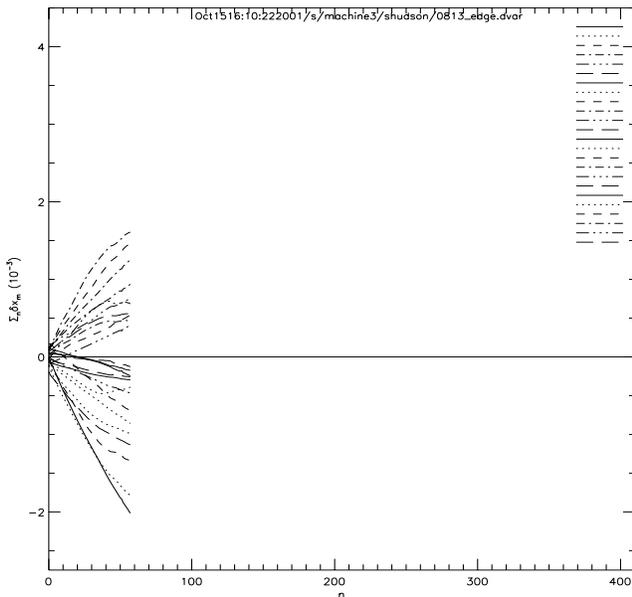


Dynamically healing the 0813 coil set is underway.

- The 0813 coil set is used and the (1,5),(1,6) islands are targeted. The total coil change and the dynamically healed PIES configuration is shown.



- The deformation of the edge is concerning. Edge targeting is included and thus far is working.



- Note that the fixed boundary li383 has significant islands, so a flat edge will probably cause islands.

Discussion / Conclusions.

- Can probably forget about the static healing method. The healing of the 0907 coils was probably lucky. The sole reliable result of this method is the determination of trim coil currents to heal an intermediate plasma state.
- Dynamical healing seems to be working well. Extended convergence tests are required to confirm this.
- The coil changes shows some 'noise' which may be due to the finite radial grid used in PIES.
- Including edge targeting may result in free-boundary PIES reproducing fixed-boundary PIES results. In which case, it is desirable to use fixed-boundary healed configurations to initialize PIES.
- May be the case that a single coil set supports multiple PIES configurations.

Future Work Plan

- to take vacation. R.Hatcher will continue this work;
- to heal final coil set for CDR;
- (determine trim coil currents for Ed);
- present healed m12 coils for D_R /physics/engineering analysis;
- consider monotonic profile;
- consider the various outstanding issues discussed.