UNH-CCMC Collaboration

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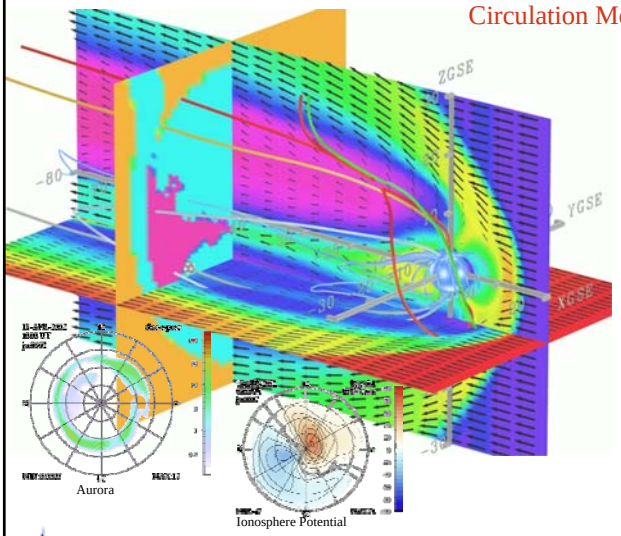
CCMC Workshop, Key Largo, FL, January 25, 2010

Overview

- What is OpenGGCM, where does it come from?
- OpenGGCM at CCMC.
- OpenGGCM use:
  - Tail instability (Siscoe et al.)
  - Ionosphere currents (Vennerstroem et al.)
  - THEMIS support.
  - Metrics.
  - Other science.
- Development under LWS / Strategic Capabilities.
- Development under NSF/PetaApps.
- Other Developments.
- Future Releases (v4.0).

penGGCM: Global Magnetosphere Modelir

The Open Geospace General Circulation Model:



- Coupled global magnetosphere - ionosphere - thermosphere model.
- 3d Magnetohydrodynamic magnetosphere model.
- Coupled with NOAA/SEC 3d dynamic/chemistry ionosphere - thermosphere model (CTIM).
- Coupled with inner magnetosphere / ring current models: Rice U. RCM, NASA/GSFC CRCM.
- Model runs on demand (>300 so far) provided at the Community Coordinated Modeling Center (CCMC at NASA/GSFC). http://ccmc.gsfc.nasa.gov/
- Fully parallelized code, real-time capable. Runs on IBM/datastar, IA32/I64 based clusters, PS3 clusters, and other hardware.
- Used for basic research, numerical experiments, hypothesis testing, data analysis support, NASA/THEMIS mission support, mission planning, space weather studies, and Numerical Space Weather Forecasting in the future.
- Funding from NASA/LWS, NASA/TR&T, NSF/GEM, NSF/ITR, NSF/PetaApps, AF/MURI programs.

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Heritage

- (early 80's) First global magnetosphere MHD models: LeBouef, Ogino @UCLA, Lyon, Brecht, Fedder @NRL.
- (~1993) First parallelized global MHD magnetosphere model (UCLA-MHD).
- (~2000) UCLA global MHD model + NOAA/CTIM model ==> OpenGGCM.
- (2002) Second model to be implemented at the CCMC. >300(?) runs on demand at CCMC to date.
- (2005) Start RC coupling with RCM (NASA SR&T).
- (2006) NASA/NSF "Strategic Capabilities" funding for CTIPe/RB/RCM/CRCM coupling and V&V.
- Current uses: mission planning (THEMIS, Swarm, Mag-Con), complement data analysis, study fundamental processes, numerical experiments.
- >30 data comparison studies in the refereed literature since 1995: tail physics, magnetopause, ionosphere, ground mags …
- Real-time capable with modest resources.

Example of OpenGGCM use: Investigation of tail instability by George Siscoe

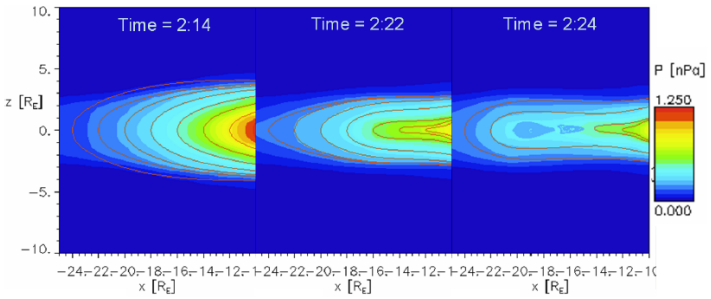


Fig. 1. Three frames from the output of CCMC run UCLA2_UCLA2_060105_3 showing magnetic field lines and contours of plasma pressure in the midnight meridian plane from 10 R_E to 25 R_E down the tail. The contours and field lines are changing in time in response to an IMF flip from south to north, which reached the magnetopause at time 2:06. Magnetic reconnection in this plane commenced between 2:22 and 2:24. In the last frame, blue blobs are coiled-up plasmoid field lines. Solar wind conditions for the run are density = 5 n/cc, speed = 400 km/s, temperature = 100 000 K, and field strength = 5 nT.

Siscoe et al., Annales Geophys., 27, 3141, 2009

Example of OpenGGCM use: Investigation of tail instability by George Siscoe

Imbalance of grad(p) and JxB forces occurs before substorm onset. Points to an ideal MHD instability such as bollooning.

Siscoe et al., Annales Geophys., 27, 3141, 2009

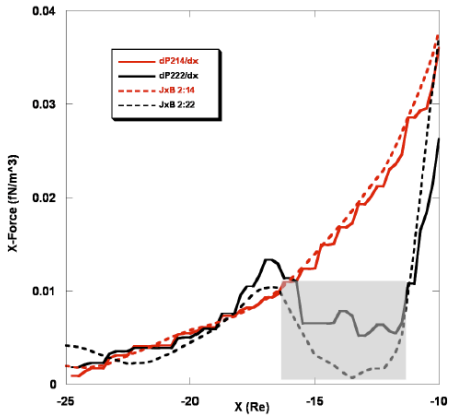
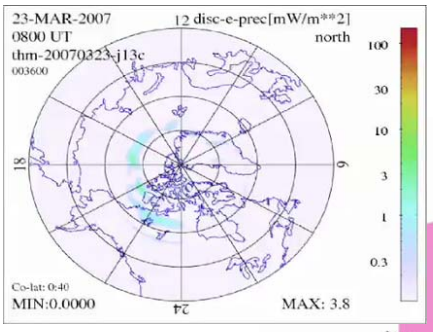
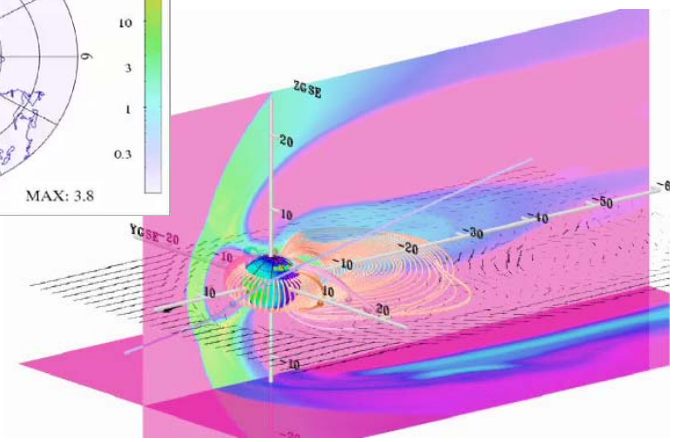


Fig. 2. Corresponding to Fig. 1, this figure shows profiles along the tail axis of the magnetic force ($J \times B$) and the pressure-gradient force (with signed changed for easier comparison) nine minutes prior to reconnection onset (red) and one minute prior to reconnection onset (black). In the gray region the pressure gradient force, which is pushing the plasma away from the Earth, is greater than the magnetic force pulling the plasma toward the Earth.

Follow-up with study of observed THEMIS substorm of March 23, 2007



Aurora and Westward Traveling Surge

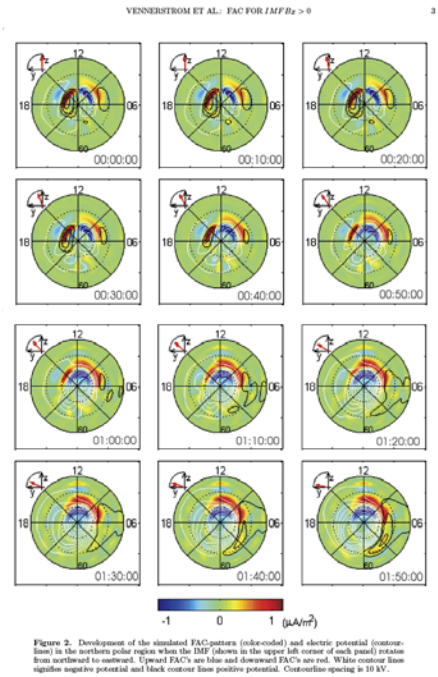


Force balance breakdown before tail reconnection onset

Example of OpenGGCM use: Field-aligned currents by Susanne Vennerstrom

How do FACs react to changes in the IMF direction?

Vennerstrom et al., JGR, 110, A06205, 2005



THEMIS Support

- THEMIS has an OpenGGCM modeling component.
- THEMIS researchers bring problems forward and we run the model.
- Example: Plasma entry into magnetosphere under northward IMF:

Li et al., JGR, 114, A00C15, 2009:

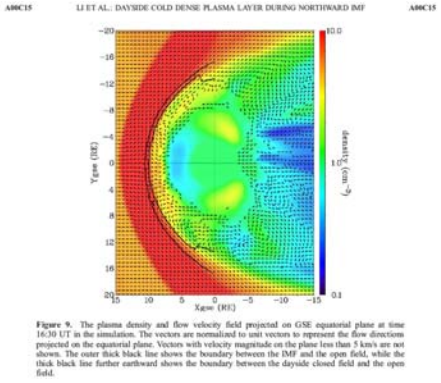
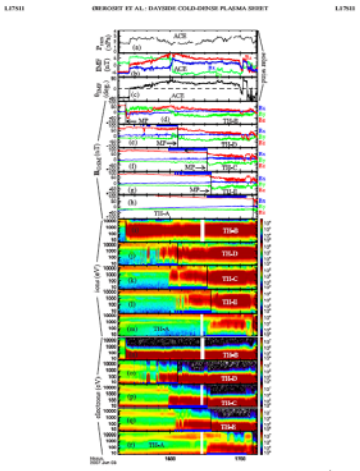


Figure 9. The plasma density and flow velocity field projected on GSE equatorial plane at time 16:30 UT in the simulation. The vectors are normalized to unit vectors to represent the flow directions projected on the equatorial plane. Vectors with velocity magnitude on the plane less than 5 km/s are not shown. The outer thick black line shows the boundary between the IMF and the open field, while the thick black line further earthward shows the boundary between the dayside closed field and the open field.

Oieroset et al., GRL, L17S11, 2009:



Metrics

- We participate in CCMC's metrics and evaluation efforts.
- Antti will say more….

Lpulkkinen et al., JGR, in press, 2010:

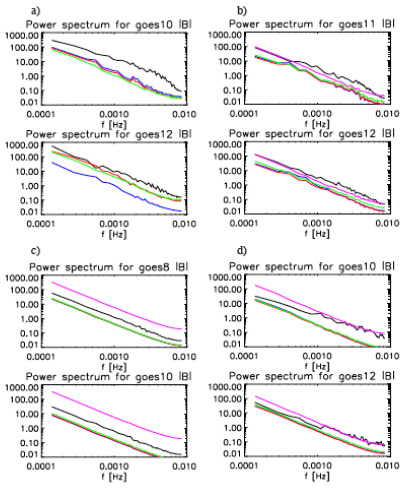
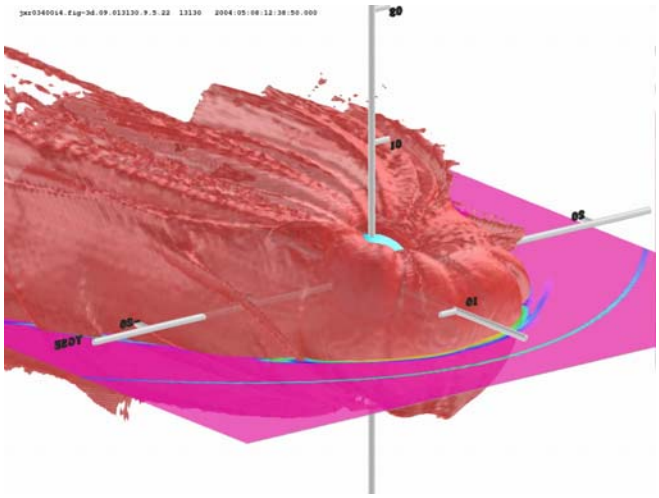


Figure 6. Spectra of the modeled and the observed geostationary magnetic field fluctuations in Fig. 5 for storm events (panels a-d corresponding to events 1-4) given in Table 1. Different colors indicate the power associated with different models. Black curves indicate the observed spectra. The color codes corresponding to different models are given in Table 3.

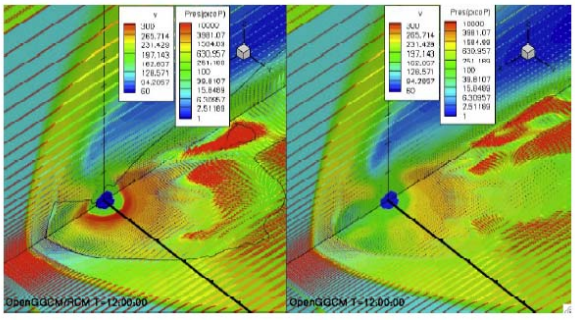
Other science: FTEs

- Flux Transfer Events during east-west IMF, May 8, 2004 Cluster event.
- FTEs for in subsolar region, only move towards dawn, observed at dawn MP.
- OpenGGCM predicts dawn-dusk asymmetry depending on IMF By sign and tilt.

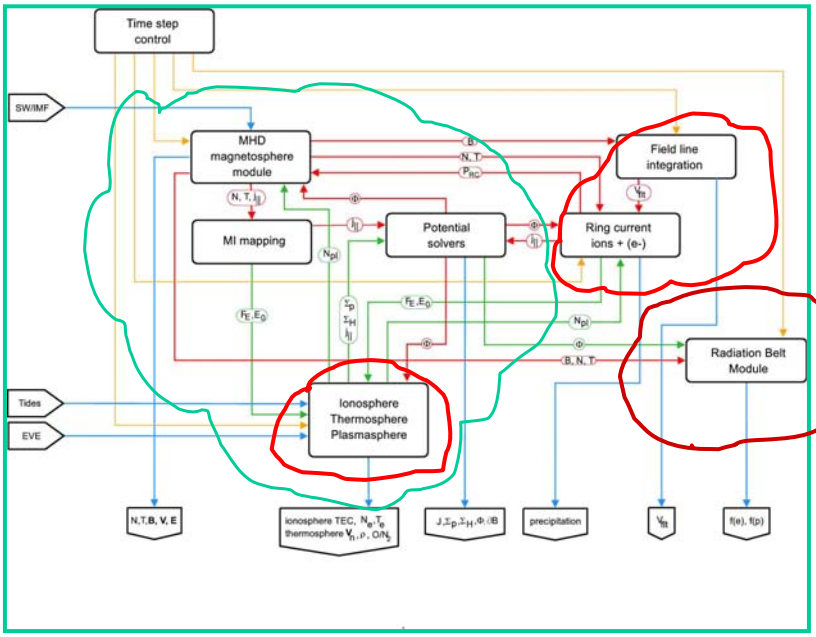


OpenGGCM development under LWS/SC

- Collaboration with:
  - NASA/GSFC (M.-C. Fok, A. Glocer): CRCM/RBM coupling.
  - Rice U. (F. Toffoletto, B. Hu, A, Chan): RCM coupling, RB diffusion.
  - U. Colorado (T. Fuller-Rowell, N. Maruyama): CTIPe/GT-GIP coupling.
  - NCAR/HAO (A. Richmond, A. Maute): Asymmetric potential solver.
- Runs through 09/2011, just passed mid-term review.
- Accomplishments:
  - RCM coupling basically finished.
  - CRCM coupling basically finished.
  - Potential solver tested.
  - ….



Model Data Flow



Development under PetaApps: Tuning for CBE

Computing: The Old Days…

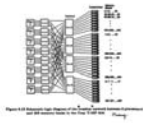
15 years ago one would have needed something like a Cray Y/MP:

- 8 processors
- ~ 1 GB memory
- ~ 8 x 0.2 Gflops
- ~ $10M
- ~ 200 kW power/cooling
- ~ $1M/y operations.

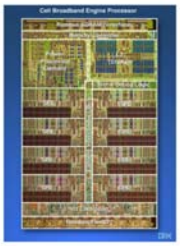
First global models ran on such machines.

Computing: Enter the Cell Chip

1992 Y/MP block diagram:



2006 Cell Broadband Engine (CBE) chip (IBM/Sony/Toshiba):



Computing: Cray on a Chip

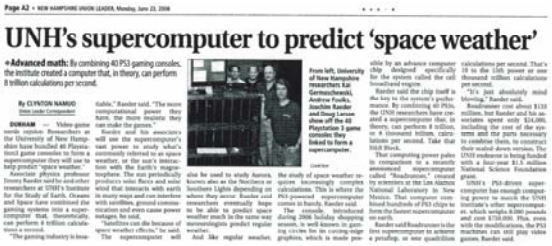
Cell chip versus Y/MP processor board (2 ft wide)

Computing: Comparing the Vitals

	Y/MP	Cell chip
Processors:	8	1+8(6)
Memory:	0.25-1.0 GB	0.25 GB
Peak speed:	~ 2 Gflops	~ 256 Gflops
Memory bw:	2 GB/s	25.6 GB/s
Clock:	0.333 GHz	3.2 GHz
Power:	100 kW	200 W
OS:	UNICOS	Linux
Price:	$10M	599.00 @Walmart
Compilers:	Crap back then	Crap now

Development under PetaApps: 40 PS3 Cluster

- 40 PS3 from Best Buy + GB Ethernet switch + PC head node + cables + monitor – games ~$24k.
- New firmware, Linux, MPI libs etc.
- Uses 5 kW of power, though.
- Motivates middle-schoolers, newspaper writers.



Page A2 • NEW HAMPSHIRE UNION LEADER, Monday, June 23, 2008

UNH's supercomputer to predict 'space weather'

+Advanced math: By combining 40 PS3 gaming consoles, the institute created a computer that, in theory, can perform 8 trillion calculations per second.

By CLYNTON NAMUO
Union Leader Correspondent

DURHAM — Video-game nerds rejoice. Researchers at the University of New Hampshire have hijacked 40 Playstation 3 game consoles to form a supercomputer they will use to help predict "space weather."

Associate physics professor Jimmy Raeder said he and other researchers at UNH's Institute for the Study of Earth, Oceans and Space have combined the gaming systems into a supercomputer that, theoretically, can perform 8 trillion calculations a second.

"The gaming industry is insatiable," Raeder said. "The more computational power they have, the more realistic they can make the games."

Raeder and his associates will use the supercomputer's vast power to study what's commonly referred to as space weather, or the sun's interaction with the Earth's magnetosphere. The sun periodically produces solar flares and solar wind that interacts with earth in many ways and can interfere with satellites, ground communication and even cause power outages, he said.

"Satellites can die because of space weather effects," he said. The supercomputer will also be used to study Aurora, known also as the Northern or Southern Lights depending on where they occur. Raeder said researchers eventually hope to be able to predict space weather much in the same way meteorologists predict regular weather.

And like regular weather, the study of space weather requires increasingly complex calculations. This is where the PS3-powered supercomputer comes in handy, Raeder said.

The console, introduced during 2006 holiday shopping season, is well known in gaming circles for its cutting-edge graphics, which is made possible by an advance computer chip designed specifically for the system called the cell broadband engine.

Raeder said the chip itself is the key to the system's performance. By combining 40 PS3s, the UNH researchers have created a supercomputer that, in theory, can perform 8 trillion, or 8 (insound) billion, calculations per second. Take that Irish Block.

That computing power pales in comparison to a recently announced supercomputer called "Roadrunner," created by scientists at the Los Alamos National Laboratory in New Mexico. That computer combined hundreds of PS3 chips to form the fastest supercomputer on earth.

Raeder said Roadrunner is the first supercomputer to achieve a petaflop, or one quadrillion calculations per second. That's 10 to the 15th power or one thousand trillion calculations per second.

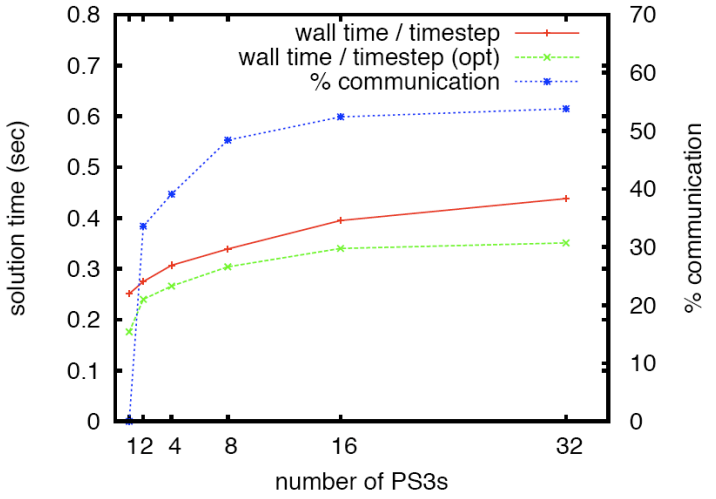
"It's just absolutely mind blowing," Raeder said.

Roadrunner cost about $133 million, but Raeder and his associates spent only $24,000, including the cost of the systems and the parts necessary to combine them, to construct their scaled-down version. The UNH endeavor is being funded with a four-year $1.5 million National Science Foundation grant.

UNH's PS3-driven supercomputer has enough computing power to match the 5760 Institute's other supercomputer, which weighs 8,000 pounds and cost $750,000. Plus, even with the modifications, the PS3 machines can still play video games, Raeder said.

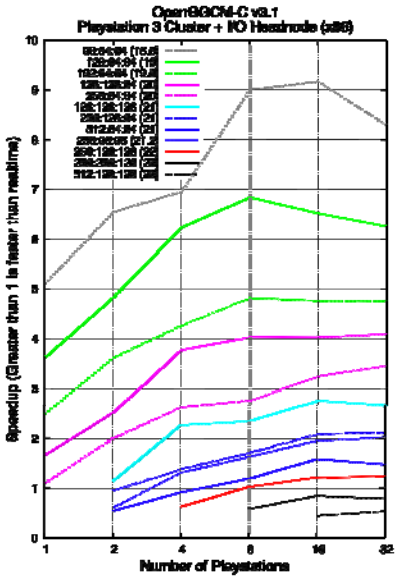
From left, University of New Hampshire researchers Kai Germaschewski, Andrew Fowlie, Joachim Raeder and Doug Larson show off the 40 Playstation 3 game consoles they linked to form a supercomputer.

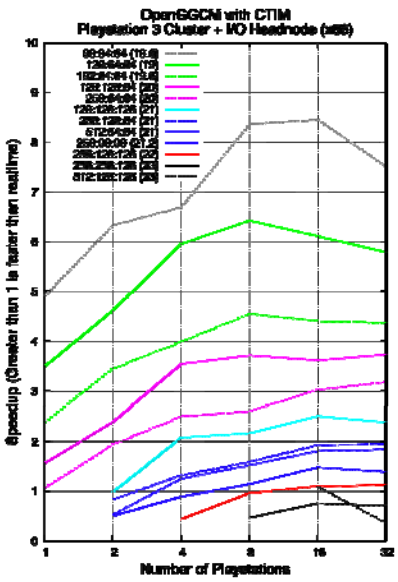
Scaling with number of PS3's



Weak scaling on 40 PS3 cluster: Not perfect. Too much time spent on inter-node communication (GB Ethernet switch). New QS22 IBM Cell blade cluster should be much better. Cluster (42 nodes / 84 CBE, NSF CISE funding + IBM donation) delivered November 2009.

Scaling for PS3 cluster: Event of 31 August, 2001





Latest results: ~ factor 1.8 better!

Other developments

- Code now completely under subversion control.
- Bug reporting system: http://fishercat.sr.unh.edu/trac/openggcm
- Compiling with autoconf/make.
- Ultra-high resolution runs for ballooning (1200x600x600, Ping Zhu, U. Wisconsin).
- Include Hall physics (LWS grant, Bhattacharjee).
- Particle tracing / reconstruction of f(v) (for now cusp ion structures, grad student project).
- Calculating proton aurora (grad student project).
- Moving dipole (grad student project).
- Version 4.0: not so soon. Still many loose ends that need to be tied up.