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(3 Pages)

Quantitative Accuracy in Predicting the Long Time Fate of a Two-Dimensional Decaying Navier-Stokes Turbulence

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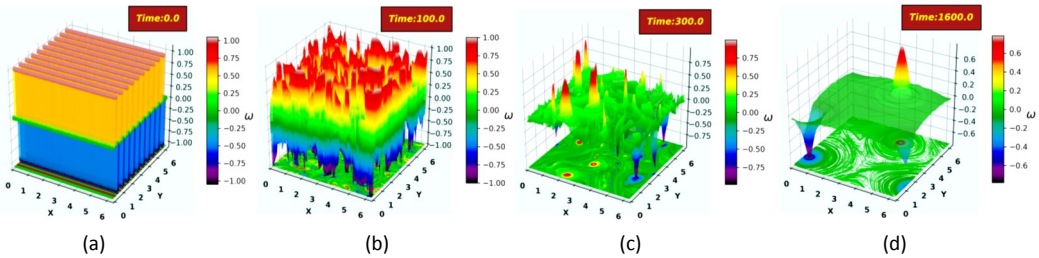


Figure 1: Time evolution of vorticity (3D visualization) for a tightly packed [62.5%] vortex strips.

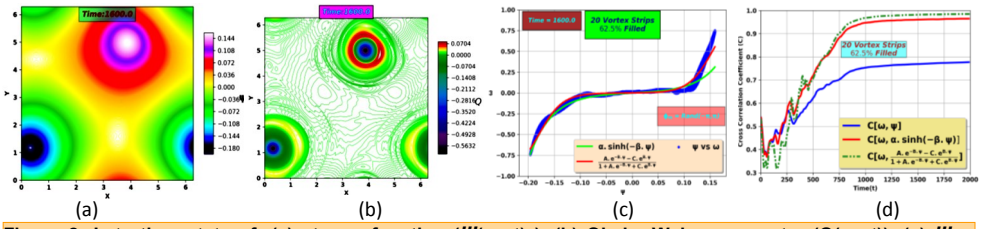


Figure 2: Late time state of: (a) stream function ($\Psi(x,y,t)$), (b) Okubo-Weiss parameter (Q(x,y,t)), (c) Ψ-ω scatter plot, (d) Cross-correlation coefficient (C).

Quantitative prediction of the long time or late time states of two-dimensional incompressible, high Reynolds number, slowly decaying turbulence has been one of the long standing problems. To understand the such turbulence properties, certain macroscopic quantities such as enstrophy (square of vorticity in the volume/area of fluid flow), energy (Kinetic) and Circulation (vorticity contained in a volume/area of the fluid flow) are often invoked as a part of developing extremization principles. For example, in a two-dimensional Navier-Stokes turbulence, it is well known that the ratio of enstrophy to kinetic energy is a decreasing function of time, suggesting that the enstrophy decays significantly "faster" while the energy decays by a relatively negligible amount, for high enough Reynolds number. This "selective decay" process and its generalizations have been introduced as a possible explanation for relaxation and to predict the late time state of "slowly" decaying two-dimensional turbulence, in fluids, plasmas and in magnetofluids, but has not been successful in predicting, not even qualitatively, the late time states of two-dimensional decaying turbulence.

Another school of thought, to predict the late time fate of two-dimensional slowly decaying Navier-Stokes (NS) turbulence, is that of entropy extremization, subject to conservation of kinetic energy and circulation in high Reynolds number Navier-Stokes turbulence. Using "point vortices" as "inviscid" building blocks, but which do not respect incompressibility, statistical mechanical models conserving only total energy and zero total circulation result in the well known sinh-Poisson relation between vorticity and stream function [1]. This relationship has been tested using direct simulation of NS equations. To properly account for "incompressibility" in a statistical mechanical model of two-dimensional NS turbulence, Kuz'min, Miller and later Roberts & Sommeria (KMRS) [2, 3, 4], independently proposed that "patch vortices"' or vortices with finite size, if used as "building blocks", should be able to account for incompressibility effects completely. To address this physics issue, we have recently upgraded an existing incompressible two-dimensional hydrodynamic solver developed in house to GPU architecture [GHD2D] for better performance [5]. We consider 20 tightly packed parallel vortex strips of identical widths keeping the total initial circulation to zero as our initial condition (see Fig. 1a). As there exists a shear between the vorticity layers, the strips are Kelvin-Helmholtz unstable when perturbed. Eventually the vortex configuration evolves towards turbulence and system is dominated by turbulence associated with a rapid mixing of vortex layers. It is well known that in two-dimensional Hydrodynamics, vortices of same sign attract and merge while vortices of opposite sign repeal each other. We observe in our simulation that over the longer time, after all the possible like sign vortex capture occurs, the system ends up with one vortex of either sign in the entire 2-dimensional domain [See Fig. 1].

"High resolution DNS using GHD2D code confirms the suitability of KMRS patch vortex theory to quantitative understanding of incompressible turbulent 2D flows, than sinh-Poission model which is based on point vortex model."

It is also observed that after all the possible vortex mergers occur, the vorticity achieves a particle like character, suggested by late time similarity of the streamlines with Ewald potential contours (with a basic cell containing two point vortices) [See Fig. 2(a)]. We calculate the Okubo-Weiss parameter *(Q(x,y,t))*, which is a measure of rotation vs. deformation for two dimensional turbulence. Using this parameter as a diagnostic, two distinct domains is identified from our numerical simulation namely, "elliptic domain" or "Vortex cores" [$Q(x,y,t)<0$], where rotation dominates deformation and "hyperbolic domain" or Strain cells [$Q(x,y,t)>0$], where deformation dominates rotation [See Fig. 2(b)]. As the quasi-steady structure of two large counter rotating vortices is reached, one may expect a strong correlation to emerge between vorticity $\boldsymbol{\omega}$ and stream function $\boldsymbol{\Psi}$ at late times. Using point vortex model it is showed based on entropy extremization that the stream function $\overline{\boldsymbol{\psi}}$ and vorticity $\overline{\boldsymbol{\omega}}$ obeys a relationship

$$\bar{\omega}_{\mathrm{PV}} = \alpha \times \sinh(-\beta \times \bar{\psi})$$

where as, based on finite size vortices predict KMRS theory [2, 3, 4] the following relationship

$$\bar{\omega}_{\mathrm{KMRS}} = \frac{Aexp(-B\bar{\psi}) - Cexp(B\bar{\psi})}{1 + [Aexp(-B\bar{\psi}) + Cexp(B\bar{\psi})]}$$

Our simulation data shows better agreement with the latter model (i.e. KMRS) than the former (i.e. Sinh-Poisson) which is shown in Fig. 2(c) & Fig. 2(d). Thus, our numerical observation shows quite good agreement with the theoretical prediction obtained by KMRS theory [6]. Our quantitative findings throws light on one of the long standing problems in two-dimensional high-Reynolds number NS turbulence.

References:

1. *D. Montgomery,W. H. Matthaeus,W. T. Stribling, D. Martinez, and S. Oughton, "Relaxation in two dimensions and the 'sinh-Poisson' equation," Phys. Fluids A 4, 3 (1992).*
2. *G. Kuz'min, "Statistical mechanics of the organization into two-dimensional coherent structures," Struct. Turbul. 103, 114 (1982).*
3. *J. Miller, "Statistical mechanics of Euler equations in two dimensions," Phys. Rev. Lett. 65, 2137 (1990).*
4. *R. Robert and J. Sommeria, "Statistical equilibrium states for two-dimensional flows," J. Fluid Mech. 229, 291–310 (1991).*
5. ***S Biswas**, R Ganesh et al. "GPU Technology Conference (GTC-2022)", https://www.nvidia.com/en-us/ondemand/session/gtcspring22-s41199/.*
6. ***S. Biswas** and R. Ganesh , "Long time fate of two-dimensional incompressible high Reynolds number Navier–Stokes turbulence: A quantitative comparison between theory and simulation", Physics of Fluids 34, 065101 (2022) [Selected as Featured article].*

Submitting A Large No. of Jobs using PBS Array in ANTYA

There are times when you need to submit a large number of similar jobs or jobs using multiple similar sets of data. This article introduces Job Arrays, a handy feature of PBS Pro Scheduler available on ANTYA that can help you submit hundreds of similar jobs at once.

What are PBS Array Jobs?

PBS Array Jobs allows submission of N (an environment variable defined with PBS_ARRAY_INDEX) copies of a job using a single jobscript with only one time qsub submission. Each of the subjobs runs independently on a single node as well as multiple nodes and uses the same compute resources.

When to use PBS Array Jobs?

For both serial as well as MPI jobs which are not dependent on each other and you need to submit a lot of such jobs at once, the PBS Array Jobs feature can help you. Array Jobs can significantly ease the load on ANTYA Queuing System (AQS) and is an effortless method to run a large number of jobs simultaneously.

How to Implement in ANTYA?

Example: As an example here, we are calculating the value of pi. The variable parameter here is an iterating number M which goes as an input to the pi code. The pi code we are using, is a serial code that runs on a single CPU core and we want to run 500 pi code calculations/runs simultaneously for different values of M. The following commands along with the script show how to set-up, submit and monitor array jobs in ANTYA.

 # Here is the pi code. Compiled code name is a.out.

```
[user@login1 ~]$ cat pi.c
#include <stdio.h>
main() {
   double x,h,sum = 0; int i,N;
   printf("Input number of iterations: ");
   scanf("%d",&N);
   h=1.0/(double) N;
   for (i=0; i<N; i++) { x=h*((double) i + 0.5);
sum += 4.0*h/(1.0+x*x);
   }
   printf("\nN=%d, PI=%.15f\n", N,sum);
}
```

 # Here is the PBS array jobs script for submitting 100 independent runs as individual jobs for pi calculation. For PBS job script details, refer issue13.

```
[user@login1 ~]$ cat pi_array_job.sh
#!/bin/bash
#PBS -q serialq
#PBS -N array_jobs
#PBS -l select=1:ncpus=1
#PBS -l walltime=00:10:00
#PBS -J 1-100
#PBS -j oe
cd $PBS_O_WORKDIR
```

This is a PBS_ARRAY_INDEX, with values from 1 to 100 to submit 100 independent serial runs of pi calculation each with 1 core.

 # The following lines of script shows setting up of input files and individual directories for each independent runs.

```
mkdir $PBS_O_WORKDIR/Array$PBS_ARRAY_INDEX
cd $PBS_O_WORKDIR/Array$PBS_ARRAY_INDEX
echo 10000*$PBS_ARRAY_INDEX | bc > input
time ../a.out < input > log$PBS_ARRAY_INDEX
echo "All done"
```

 # Submit the batch job using the array job script.

```
[user@login1 ~]$ qsub pi_array_job.sh
```

239968[].ANTYA # Job ID with square bracket shows it is an array job

 # To see the status of all the subjobs, use the following command:

```
[user@login1 ~]$ qstat -atn1
```

ANTYA UPDATES AND NEWS

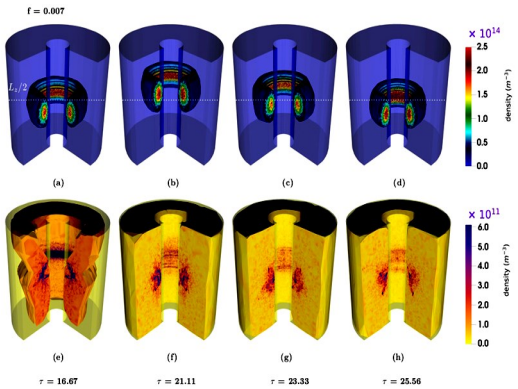
1. New Packages/Applications Installed

⇒ **Intel-2013 suite available on request.**

⇒ **A team from IPR named Basic Simulation (Anjan Paul, Gayatri Barsagade, Sandeep Dalui) participated in NSM GPU Hackathon 2022 at IIT Bombay.**

HPC PICTURE OF THE MONTH

Ion-driven Destabilization of a Toroidal Electron Plasma



Pic Credit: **Swapnali Khamaru**

The figure shows time evolution of primary electron plasma (a-d) and ion plasma (e-h) with respective density values, for f = ratio of ion density to electron density=0.007 at different simulation time periods τ = 16.67, 21.11, 23.33 and 25.56. τ is time normalized by the toroidal Diocotron time period of the electron cloud at f = 0.0.

[Ref: manuscript under review]

This figure is generated in Paraview with data generated from in house developed code **PEC3PIC** on *ANTYA* cluster. The simulation took around 2160 hours to generate the data.

TIP OF THE MONTH

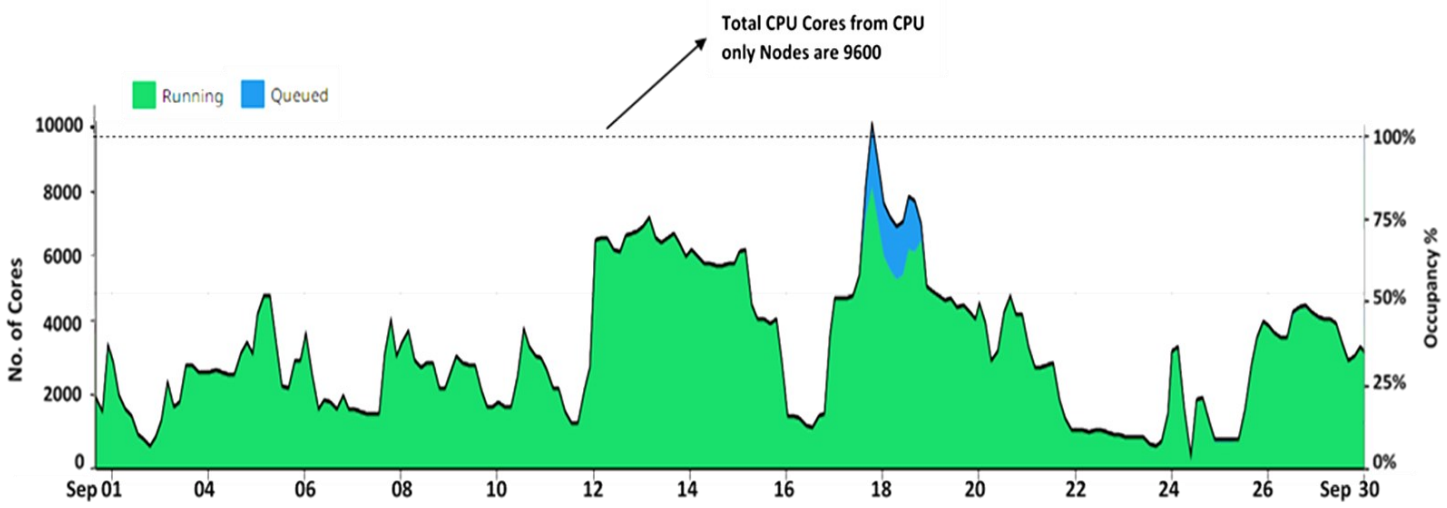
To save your modules environment to application specific custom name:

This helps when you need lot of modules for running your code. You can simply save the modules loaded in your shell and save it to a custom name.

```
[user@login1 ~]$ module list
1)shared 2)intel-2020 3)fftw3/
intel/3.3.8
#To save the modules info in a name
$ module save custom-name
#To restore modules from custom-name
$ module restore custom-name
```

ANTYA Utilization: SEPTEMBER 2022

ANTYA Daily Observed Workload



Other Recent Work on HPC (Available in IPR Library)

Numerical Simulation of Coal Devolatilization Process in Presence of High Power Plasma Arc in Plasma Fuel System	SUNIL BASSI
Neutronic Analysis of Medical Radioisotope Production Using IPR 14-MeV Neutron Generator	ABHISHEK SAXENA
Analysis on linear and nonlinear collective excitations of strongly coupled Yukawa systems within Quasi-localized charge approximation framework	PRINCE KUMAR
Developing Scalable Parallel Applications using Small and Low-Cost Testbed Cluster of Single Board Computers	DEEPAK AGGARWAL
Convection Cells In 2D Yukawa Liquids: Formation, Stability And Role Of Collisions	PAWANDEEP KAUR
Effect Of Velocity Shear On Magnetic Islands In A Compressible Plasma	JAGANNATH MAHAPATRA
Molecular Dynamics Simulation Of Subcritical Turbulence In Stratified 3D Yukawa Liquids	SURUJ JYOTI KALITA
Energy Dispersion Study Of Laser-coupled Clustered Electrons In Ambi-ent Magnetic Field	KALYANI SWAIN
Medium-Z impurity seeding on Aditya-U : inward propagation of impurities and radiation losses	NIRMAL K. BISAI
CFD analysis of water cooled gate valve assembly for safe handling of bio -medical waste inside waste feeding lines of Plasma Pyrolysis system	DEEPAK SHARMA
Collective behavior of soft self-propelled disks with rotational inertia	SOUMEN DE KARMAKAR
A WIDEBAND HYBRID COMBINER DESIGN FOR ITER ION CYCLO-TRON RADIO FREQUENCY SOURCE	AKHIL JHA
Concept Development and Prototyping of End Connections for Flexible Cryostat towards Testing of HTS Cables	MAHESH M GHATE

ANTYA HPC USERS' STATISTICS– SEPTEMBER 2022

- Total Successful Jobs — **4367**
- Top Users (Cumulative Resources):

• CPU Cores	Suruj Kalita
• GPU Cards	Suruj Kalita
• Walltime	Anshika Chugh
• Jobs	Someswar Dutta

Acknowledgement

The HPC Team, Computer Division IPR, would like to thank all Contributors for the current issue of *GANANAM*.

On Demand Online Tutorial Session on HPC Environment for New Users Available
Please send your request to ***hpcteam@ipr.res.in.***

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