2024 CEDAR Workshop
Student Day Tutorial

Introduction to TIEGCM

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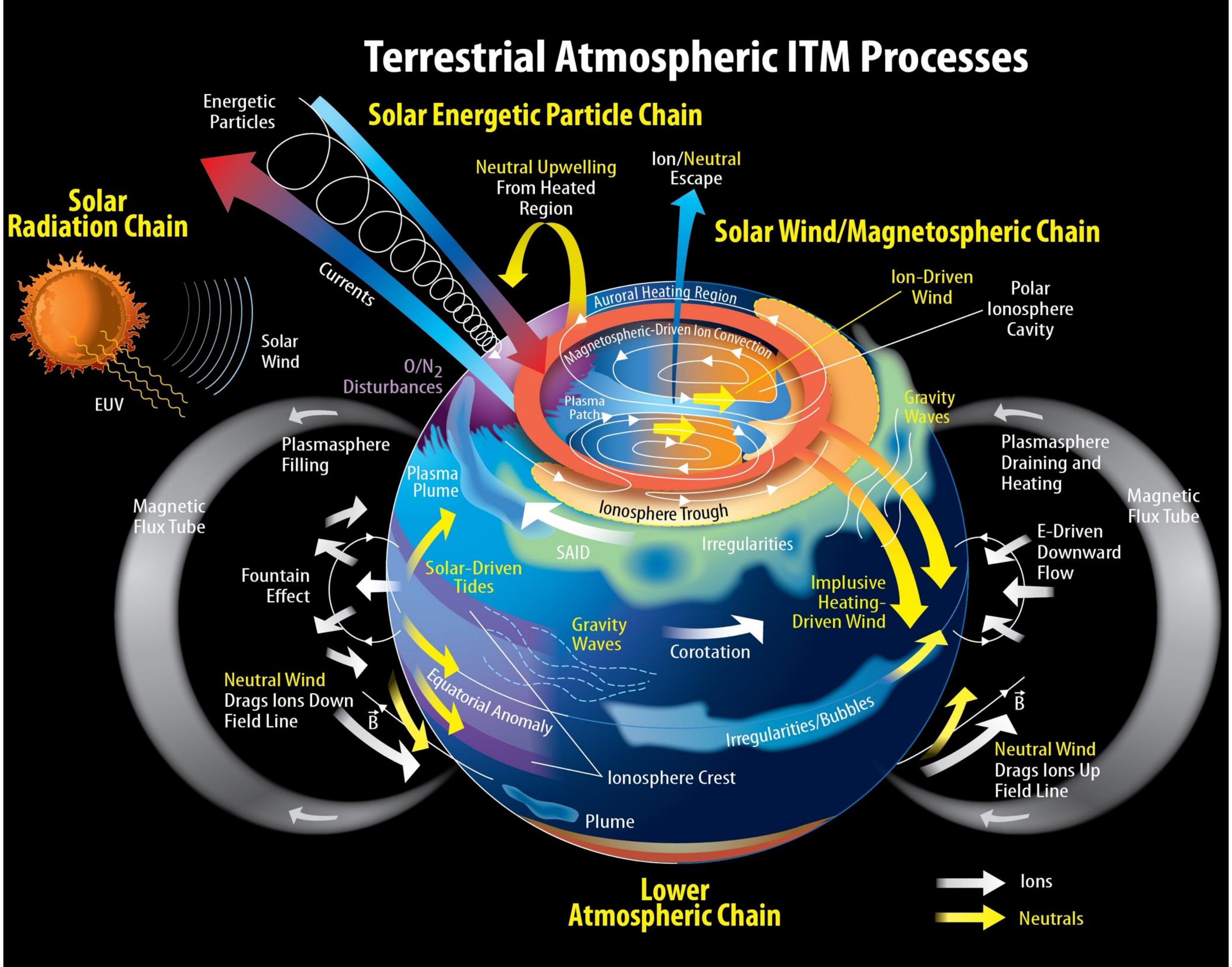


Credit: NASA GSFC

Solar Wind/Interplanetary Magnetic Field

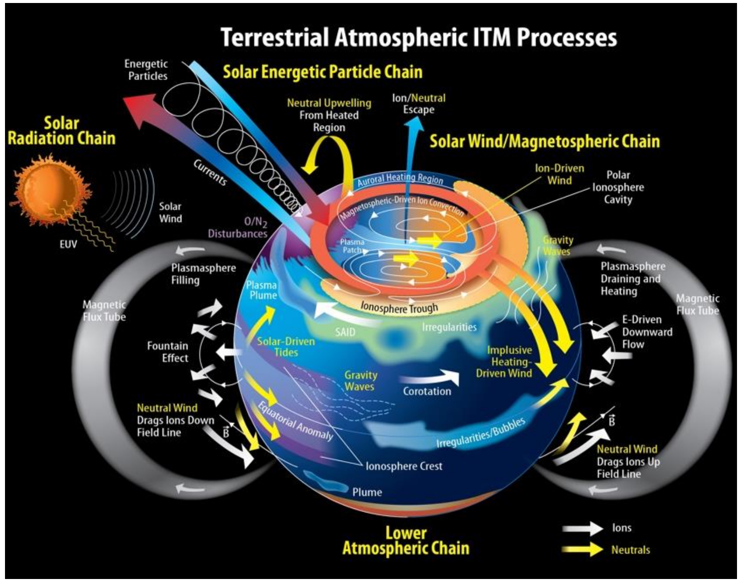
Magnetosphere

Aurora,
Electric Field,
Joule Heating

Ion Outflow

This is what
TIEGCM studies

Thermosphere-Ionosphere

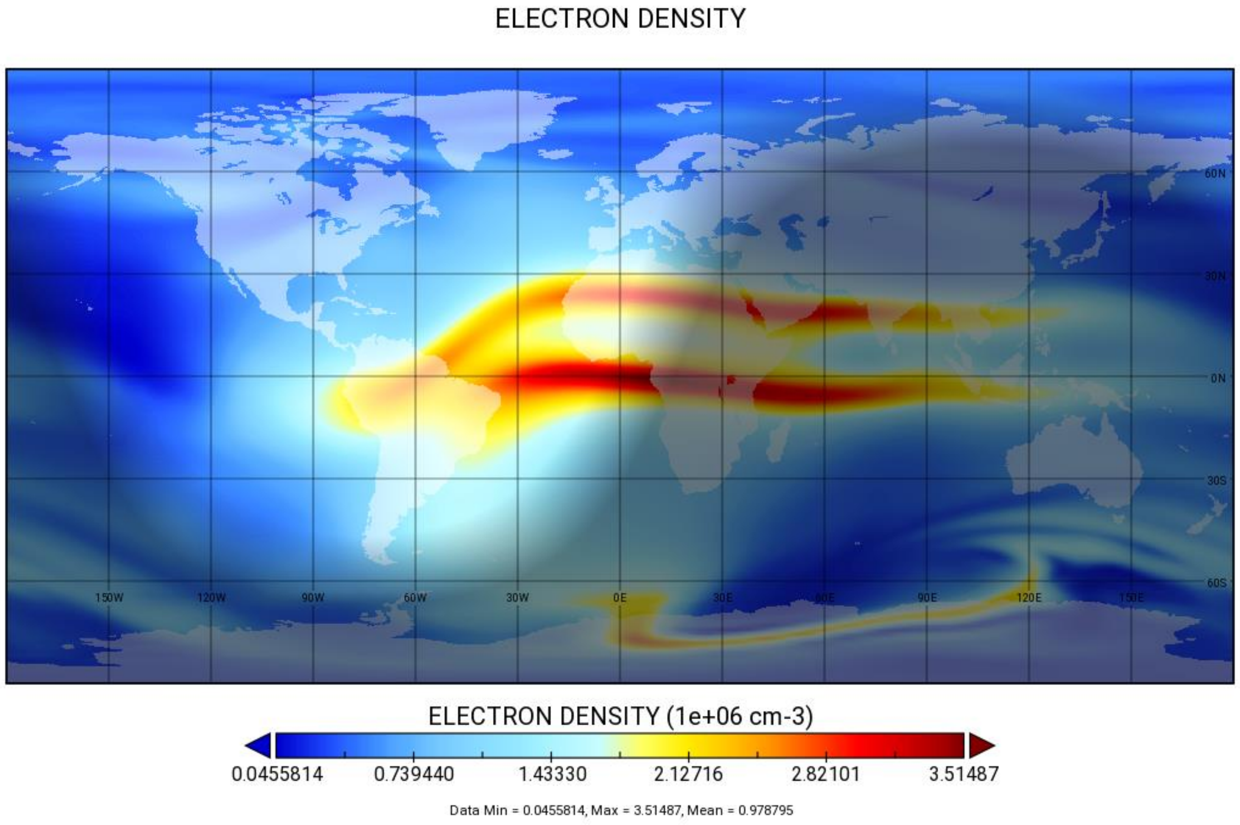


Waves: Planetary waves/tides/gravity waves

Middle and Lower Atmosphere

What is TIEGCM?

Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) computes self-consistently the coupled thermospheric/ionospheric dynamics, the associated dynamo electric fields and currents, and the electrodynamic feedback on the neutral and plasma motions and thermodynamics.



Richmond et al. (1992)

What does TIEGCM solve?

- Neutral Thermodynamics (Energy)

$$\frac{\partial T}{\partial t} = \frac{ge^{z}}{p_0 c_p}\left[\frac{K_T}{H}\frac{\partial T}{\partial z} + K_E H^2 c_p \rho \left(\frac{g}{c_p} + \frac{1}{H}\frac{\partial T}{\partial z}\right)\right] - \boldsymbol{v}_n \cdot \nabla T - w\left(\frac{\partial T}{\partial z} + \frac{RT}{c_p \overline{m}}\right) + \frac{Q_e - e^{z} L_e}{c_p} - L_i T$$

- Neutral Dynamics (Momentum)

$$\frac{\partial u_n}{\partial t} = \frac{ge^{z}}{p_0}\frac{\partial}{\partial z}\left(\frac{\mu}{H}\frac{\partial u_n}{\partial z}\right) + f v_n + \lambda_{xx}(u_i - u_n) + \lambda_{xy}(v_i - v_n) - \boldsymbol{v}_n \cdot \nabla u_n + \frac{u_n v_n}{R}\tan\lambda - \frac{1}{R\cos\lambda}\frac{\partial \Phi}{\partial \phi} - w\frac{\partial u_n}{\partial z} - d_u$$

$$\frac{\partial v_n}{\partial t} = \frac{ge^{z}}{p_0}\frac{\partial}{\partial z}\left(\frac{\mu}{H}\frac{\partial v_n}{\partial z}\right) - f u_n + \lambda_{yy}(v_i - v_n) + \lambda_{yx}(u_i - u_n) - \boldsymbol{v}_n \cdot \nabla v_n + \frac{u_n v_n}{R}\tan\lambda - \frac{1}{R}\frac{\partial \Phi}{\partial \phi} - w\frac{\partial v_n}{\partial z} - d_v$$

- Continuity equation (Diffusion)

$$\frac{\partial \Psi}{\partial t} = -e^{z}\tau^{-1}\frac{\partial}{\partial z}\left[\frac{\overline{m}}{m_{N2}}\left(\frac{T_{00}}{T}\right)^{0.25}\alpha^{-1}L\Psi\right] + e^{z}\frac{\partial}{\partial z}\left(Ke^{-z}\frac{\partial \Psi}{\partial z}\right) - \left(\boldsymbol{v}_n \cdot \nabla \Psi + w\frac{\partial \Psi}{\partial z}\right) + S - R$$

What does TIEGCM solve?

- Plasma Thermodynamics

$$\frac{3}{2}n_e k\frac{\partial T_e}{\partial t} = -n_e k T_e \nabla\cdot\boldsymbol{u}_e - \frac{3}{2}n_e k\boldsymbol{u}_e\cdot\nabla T_e - \nabla\cdot(-\beta_e\boldsymbol{J} - K_e\nabla T_e) + Q_e - L_e$$

$$\frac{\sin^2 I}{H}\frac{\partial}{\partial z}\left(\frac{2K_e}{7H}\frac{\partial T_e^{7/2}}{\partial z}\right) - \frac{(L_n + L_i)T_e^{7/2}}{T_e^{5/2}} = -L_n T_n - L_i T_i - Q_e$$

- O^+ continuity equation

$$\frac{\partial n}{\partial t} - Q + Ln = -\nabla\cdot(n\boldsymbol{v}_i)$$

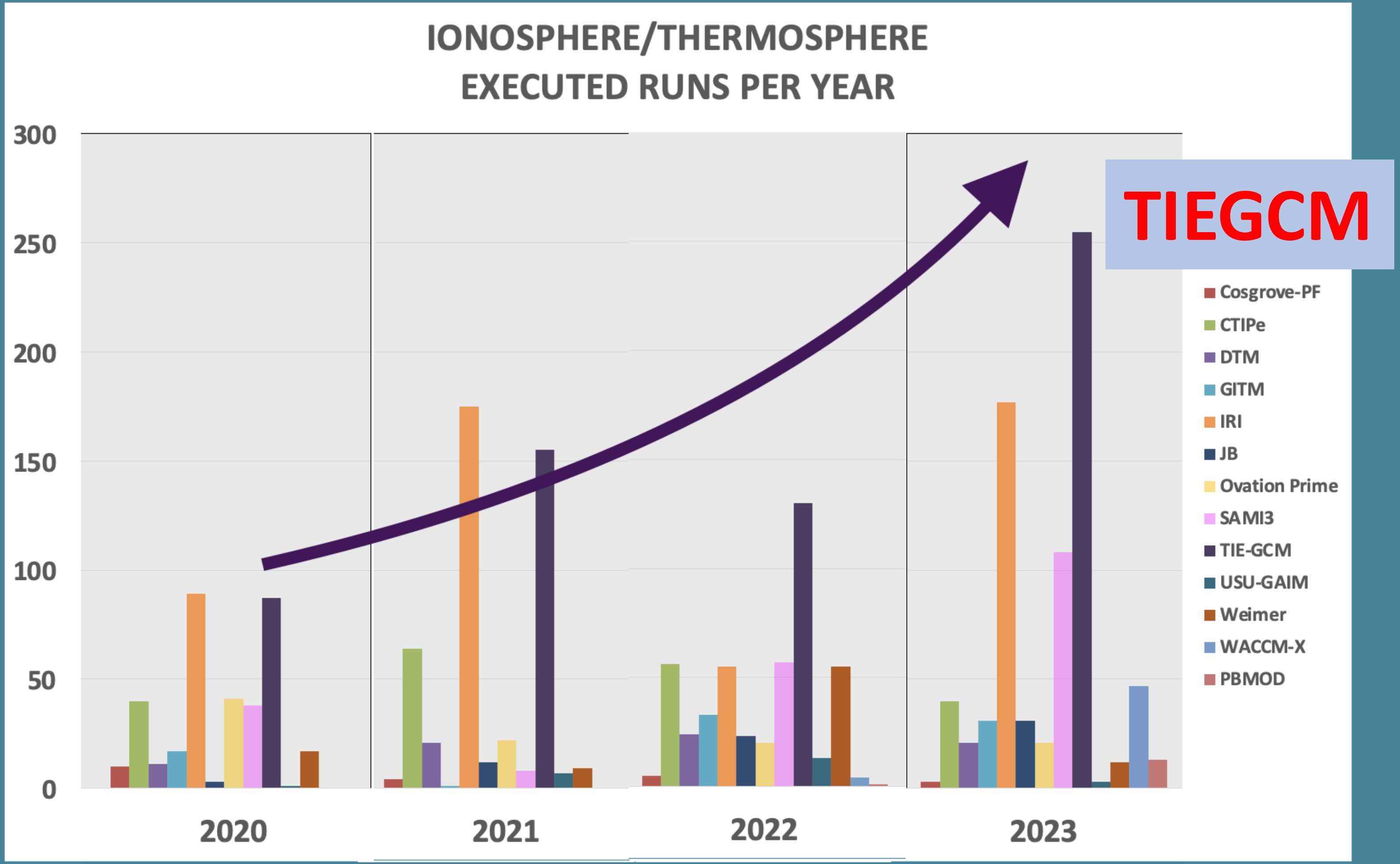
$$\boldsymbol{v}_i = \left\{\frac{\boldsymbol{b}}{\nu}\cdot\left[\boldsymbol{g} - \frac{\nabla(p_i + p_e)}{\rho}\right] + \boldsymbol{b}\cdot\boldsymbol{v}_n\right\}\boldsymbol{b} + \frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2}$$

- Electrodynamics

$$\frac{\partial}{\partial\phi}\left(\frac{\Sigma_{\phi\phi}}{\cos\lambda}\frac{\partial\Phi}{\partial\phi} + \Sigma_{\phi\lambda}\frac{\partial\Phi}{\partial\lambda}\right) + \frac{\partial}{\partial\lambda}\left(\Sigma_{\lambda\phi}\frac{\partial\Phi}{\partial\phi} + \Sigma_{\lambda\lambda}\cos\lambda\frac{\partial\Phi}{\partial\lambda}\right) = R\left[\frac{\partial K_\phi}{\partial\phi} + \frac{\partial(K_\lambda\cos\lambda)}{\partial\lambda}\right] + R^2\cos\lambda J_r$$

- Chemistry/ionospheric processes …

Who uses TIEGCM?



Year	Cosgrove-PF	CTIPe	DTM	GITM	IRI	JB	Ovation Prime	SAMI3	TIE-GCM	USU-GAIM	Weimer	WACCM-X	PBMOD	NAIRAS	TOTAL
2023	3	40	21	31	177	31	21	108	255	3	12	47	13	377	1139
2022	5	56	24	33	55	23	20	57	130	13	55	4	1	49	525
2021	4	64	21	1	175	12	22	8	155	7	9	0	0	9	487
2020	10	40	11	17	89	3	41	38	87	1	17	0	0	0	354
TOTAL	22	200	77	82	496	69	104	211	627	24	93	51	14	435	2505

Publications in 2024 mentioning TIEGCM: ~40

Inputs to TIEGCM

- Solar radiation: F10.7 (EUVAC)
- Lower boundary:
  - GSWM tides
  - Lower boundary forcing driven by SD-WACCM-X
- Magnetosphere:
  - Empirical particle precipitation: Roble and Ridley 1987
  - Empirical electric field: Heelis 1982, Weimer 2005
  - High-latitude inputs from coupled magnetosphere models

Standard Outputs from TIEGCM

- Neutral Temperature (Tn)
- Neutral Wind (Un, Vn, ω)
- Mass mixing ratio of compositions (O_2, O_1, He, N_2, $N(^2D)$, $N(^4S)$, NO, Ar)
- Plasma Densities (O^+, O_2^+, N^+, N_2^+, NO^+, e^-)
- Plasma Temperatures (Ti, Te)
- Ion Drift (Ui, Vi, Wi)
- Geopotential Height (Z)
- Geometric Height (Z_G)

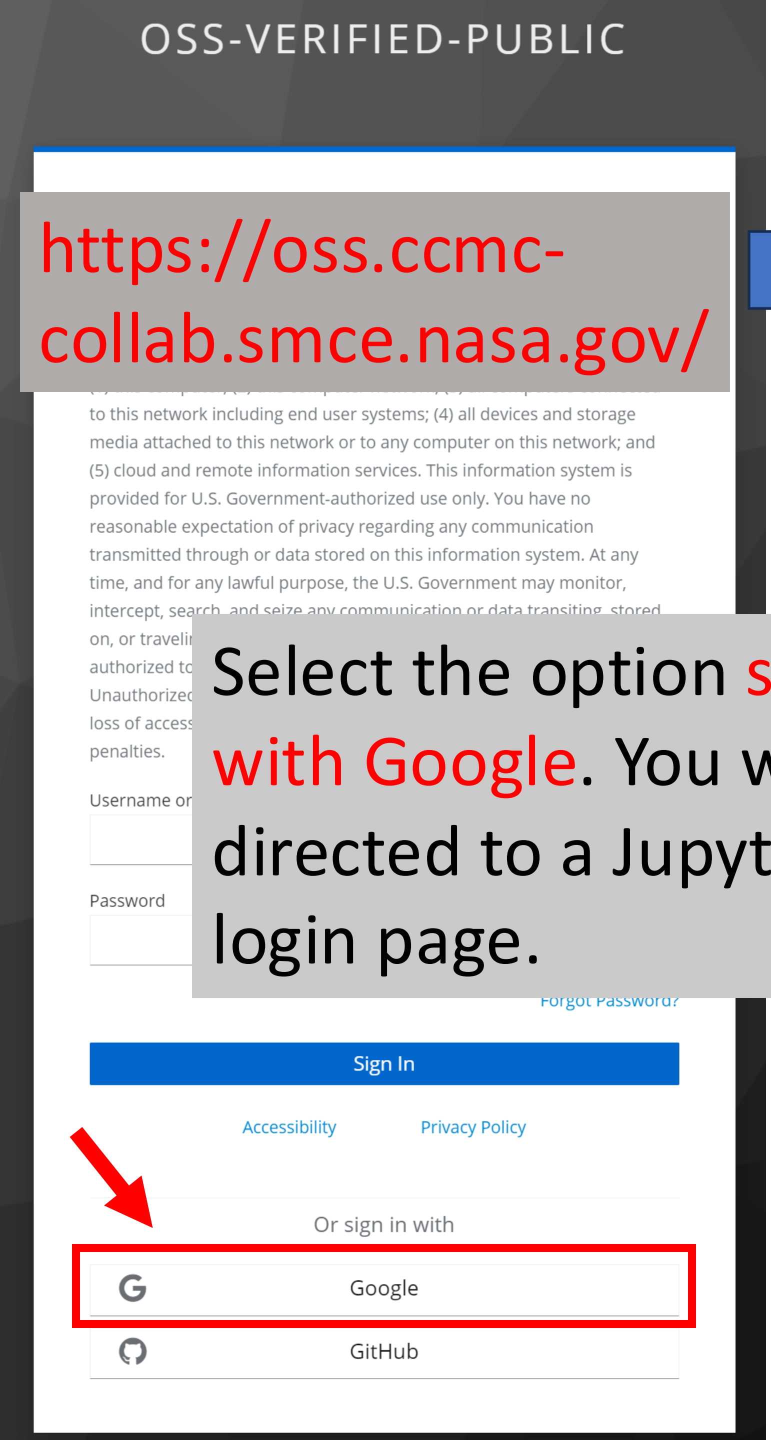
There are a lot more diagnostic fields that can be written out!

Hands-on Tutorial

How to Run the Model?

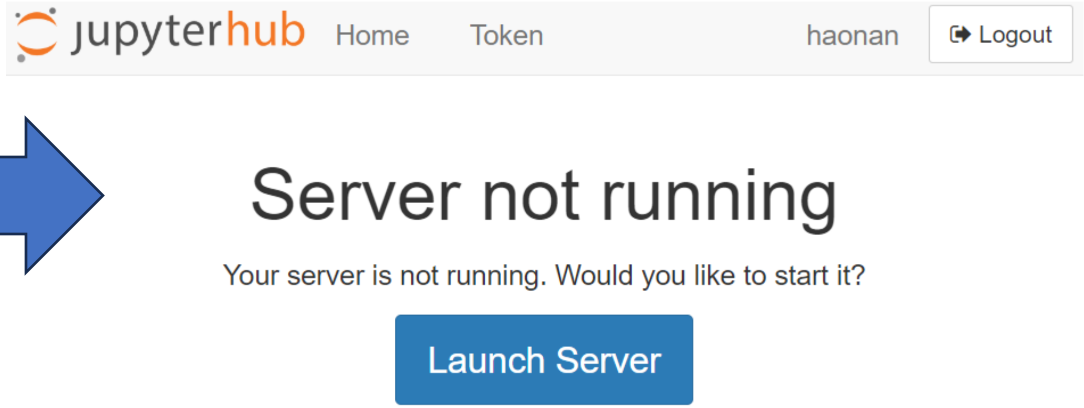
- We will use the Open Science Studio (OSS) platform provided by NASA GSFC/CCMC to demonstrate how to run model.
- When you register, if your email address are not linked to Google or GitHub, you will not be able to access OSS.

- Notice: OSS should only be used during the CEDAR workshop for demonstrative purposes but not production runs. For scientific productions, please set up your runs on supercomputers which you have access to.

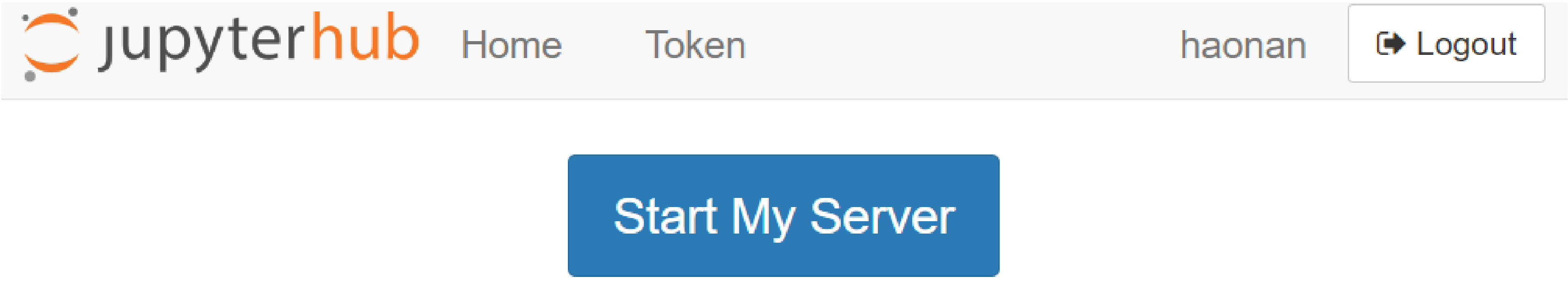


https://oss.ccmc-collab.smce.nasa.gov/

Select the option sign in with Google. You will be directed to a JupyterHub login page.



If you see Server not running, click Launch Server. Or if you see Start My Server, click it.



Server Options

◉ CCMC TIEGCM Open Science Studio

Images: Multiuser Earth Science Server

Server Type: Standard - Up to 4GB RAM/4 CPU

Enter selections as Standard – Up to 4GB RAM/4 CPU

Start

You will see Your server is starting up. Please wait while it sets up everything for you.

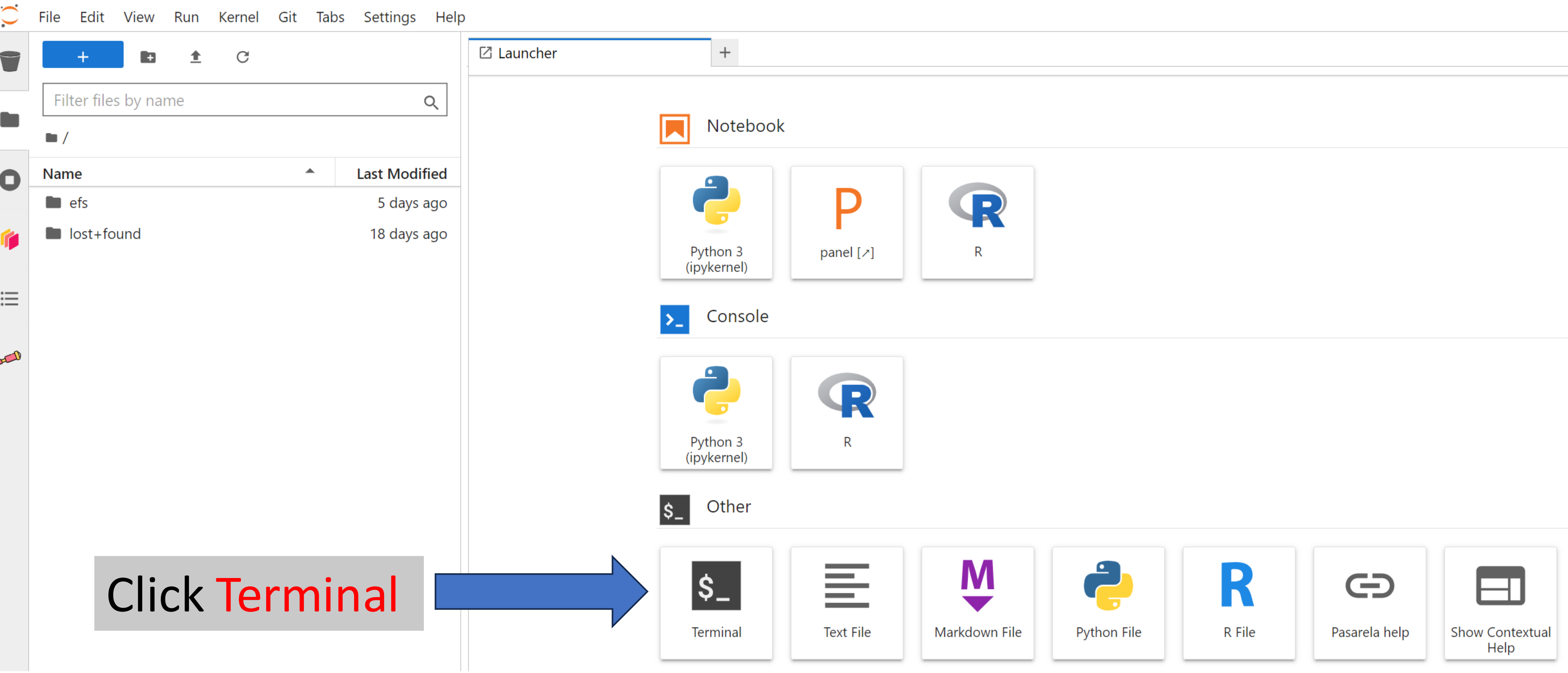
Your server is starting up.

You will be redirected automatically when it's ready for you.

2024-06-04T19:17:55Z [Normal] Started container notebook

Event log

After you logged in, you should see an interface like this.



Click Terminal

It will open a command line interface for you.

Refer to OSS TIEGCM Instructions following on.

Terminal 1

```
(notebook) haonan@jupyter-haonan:~$ conda deactivate
haonan@jupyter-haonan:~$ source /efs/spack.develop/share/spack/setup-env.sh
haonan@jupyter-haonan:~$ spack unload --all
haonan@jupyter-haonan:~$ spack env activate TIEGCM
haonan@jupyter-haonan:~$ export PROJ_DATA=/srv/conda/envs/notebook/share/proj
haonan@jupyter-haonan:~$
```

Note: You don’t get any prompt return if everything goes well. In another word, no sign is good sign.

What you Do to Compile

- Load pre-installed packages:
  - conda deactivate
  - source /efs/spack.develop/share/spack/setup-env.sh
  - spack unload --all
  - spack env activate TIEGCM
- These will set up a general computing environment for compilation and visualization.
- In the visualization part, we will also need this:
  - export PROJ_DATA=/srv/conda/envs/notebook/share/proj

What you Do to Compile

- Create new directories:
  - mkdir source
  - mkdir run
  - cd source
- These help preserve the structure of the home directory. The home directory doesn’t get screwed up during compiling.

What you Do to Compile

- TIEGCM code repository is hosted on GitHub and is published. Obtain code using git:
  - git clone https://github.com/NCAR/tiegcm.git
- This will create a local copy of the code.

What you Do to Compile

- Set up TIEGCM environment:
  - export TIEGCMDATA=/efs/tiegcm3.0/tiegcm_data
  - export TIEGCMHOME=/home/$USER/source/tiegcm
- These environment variables will be used during compiling.

What you Do to Compile

- Install python environment for compiling:
  - pip install -r $TIEGCMHOME/tiegcmrun/requirements.txt
  - cd run
- Compiling:
  - python $TIEGCMHOME/tiegcmrun/tiegcmrun.py –c
- A prompt command line interface will start that guide you through each step.

TIEGCM Specific Input Parameters

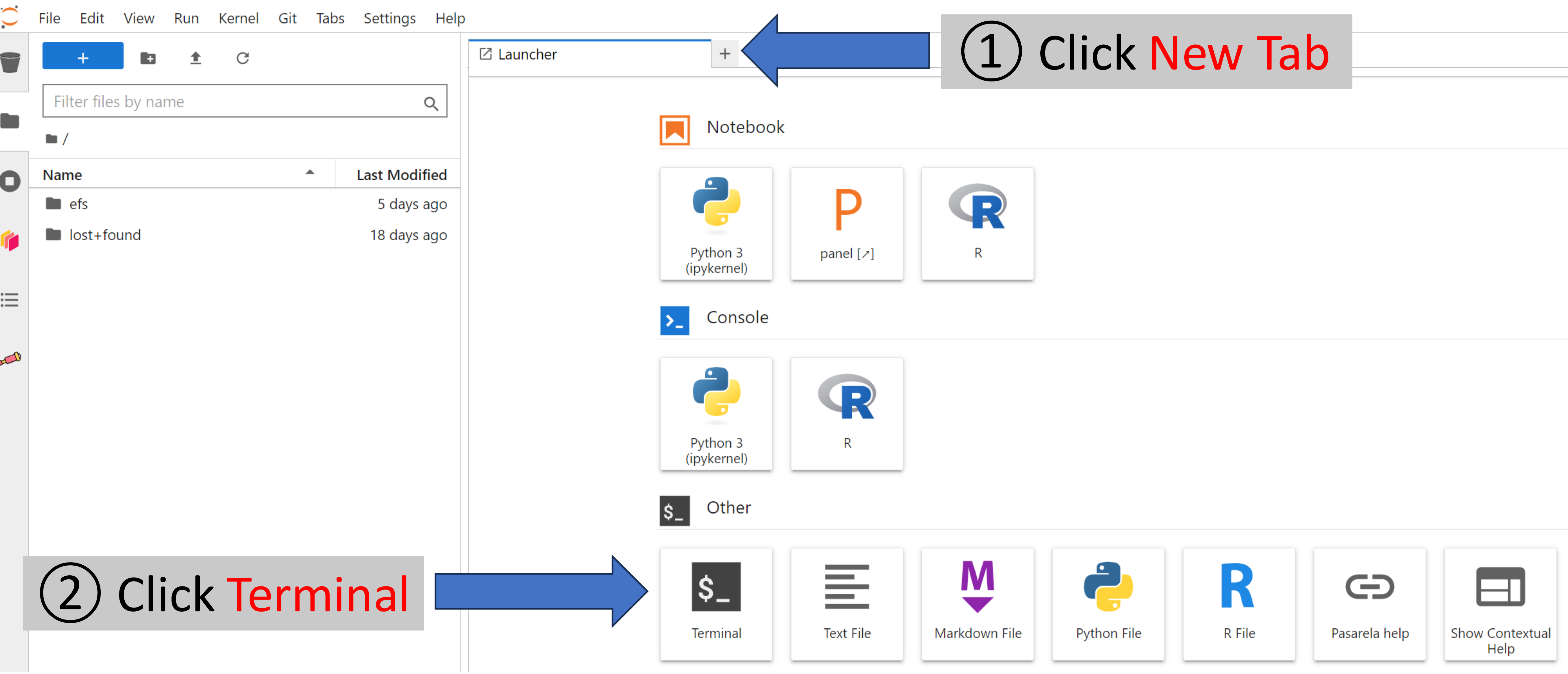
- Horires: 5.0°
- Vertres: 1/2 scale height
- Source File: /efs/nikhilr/tiegcm3.0/tiegcm_data/prim/decsol_f200.nc
- Start Date: 2002-12-21T00:00:00
- Stop Date: 2002-12-22T00:00:00
- POWER: 40 GW
- CTPOTEN: 60 V
- F107: 200 sfu
- F107A: 200 sfu

When you are prompted for those information, enter as in this page.

What you Do to Run

- Start your run:
  - cd stdout
  - mpirun --np 4 --use-hwthread-cpus ./tiegcm.exe tiegcm_5x0.5.inp
- Now you should see a lot of diagnostic outputs screwing on the screen.
- This will take about 15 minutes to finish.

While we wait, let's move on to visualization.



A new command line interface will show up.

Refer to OSS TIEGCM Instructions for more information.

Terminal 1

```
(notebook) nikhilr@jupyter-nikhilr:~$ pip install tiegcmpy
```

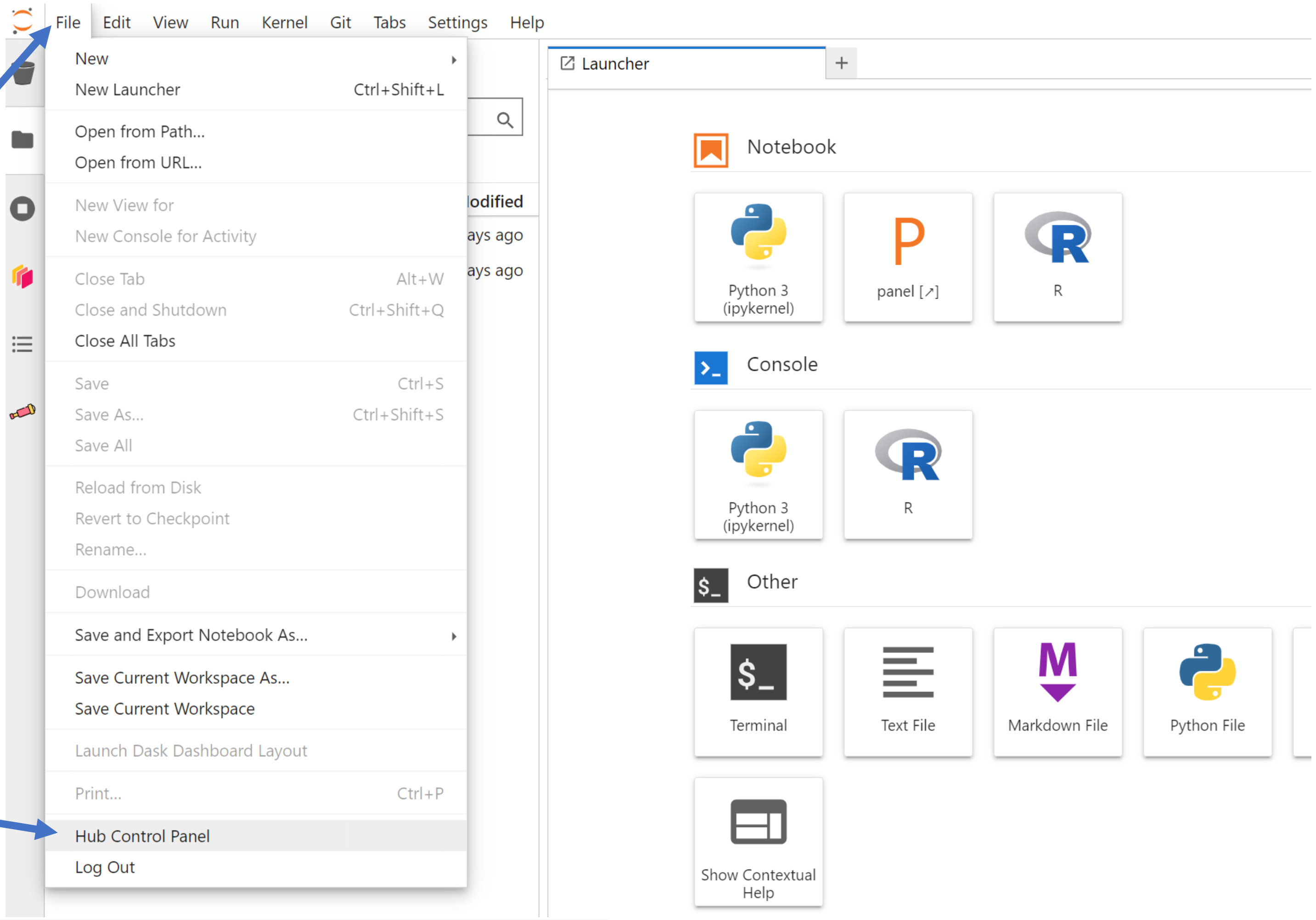
Note: Wait for the prompt to say “Successfully installed tiegcmpy-1.3.0”

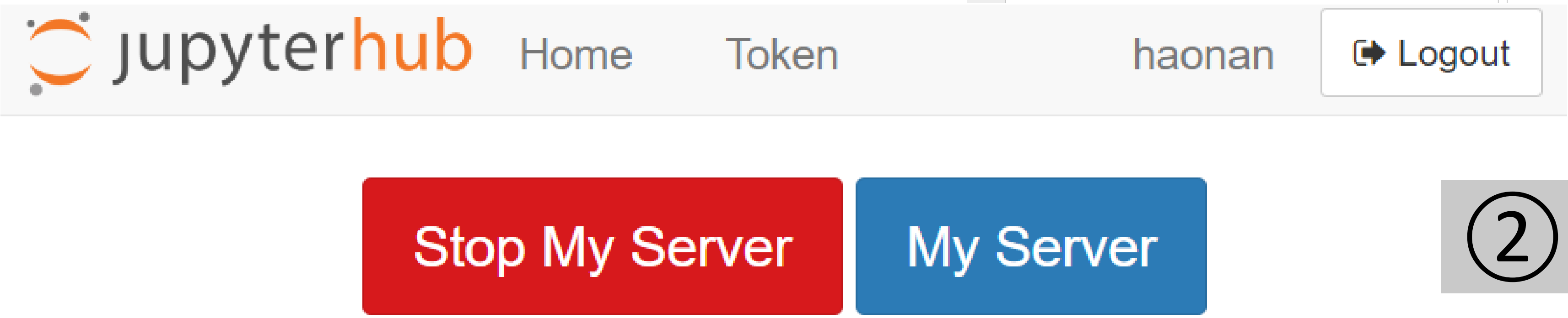
Visualization

- Use this command to copy the Jupyter Notebook over to your directory
  - cp /efs/nikhilr/tiegcm3.0/TIEGCM_CEDAR.ipynb .
- Open it using the left side navigation panel

To help clean up the unused resources when you log out, please do as following:

① Click File → Hub Control Panel





② Click Stop My Server