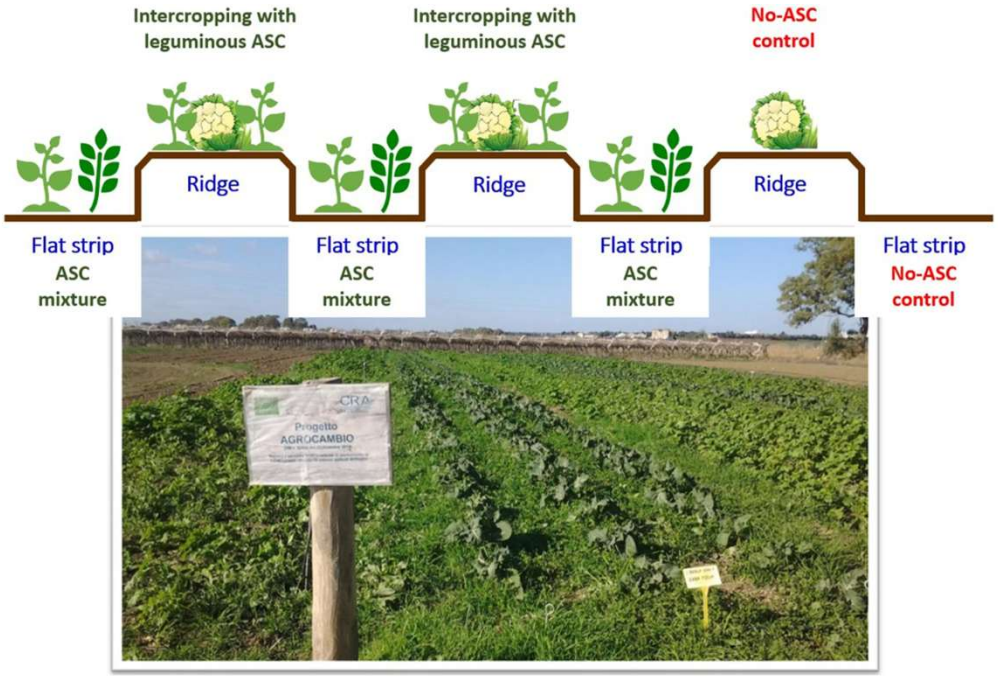
Utilizing HPC for Environmental Modeling

CS-455: Introduction to High Performance Computing

Rohan Charudatt Salvi

Introduction

- Agriculture faces pressure from population and environment change.
- Land resources must be efficiently and sustainably utilized.
- **EPIC [1]** model simulates crop systems in varying conditions.
- Scaling up simulations is slow.
- HPC enables faster and scalable modeling solutions.

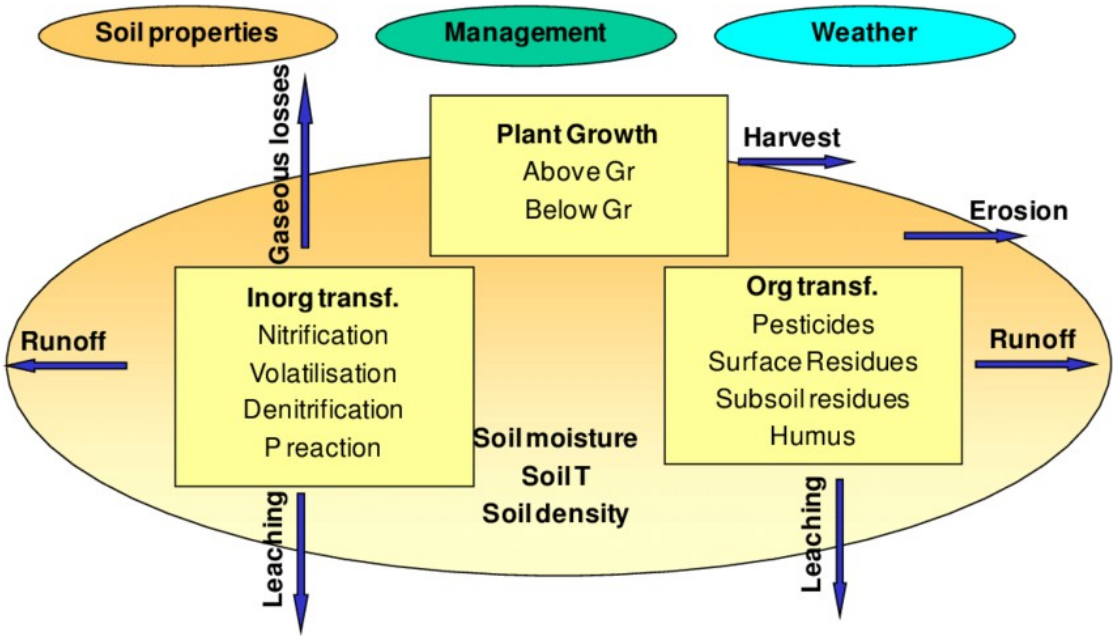


: EPIC model simulation to assess effective agro-ecological practices for climate change mitigation and adaptation

Image Source: Di Bene, C., Diacono, M., Montemurro, F. *et al.* EPIC model simulation to assess effective agro-ecological practices for climate change mitigation and adaptation in organic vegetable system. *Agron. Sustain. Dev.* **42**, 7 (2022). https://doi.org/10.1007/s13593-021-00745-5

Background: Environmental Modeling

- Numerous data parameters
- Duration over 100 years
- Over a million Simulations



: EPIC Model Structure

Image Source: Pistocchi, Alberto & Aloe, Alberto & Dorati, Chiara & Sanz, Laura & Bouraoui, Faycal & Gawlik, Bernd & Grizzetti, Bruna & Pastori, Marco & Vigiak, Olga. (2018). The potential of water reuse for agricultural irrigation in the EU A Hydro-Economic Analysis. 10.2760/263713.

Design & Implementation

- **Nicholas et.al (2011) [2]**
  - 20 nodes HPC cluster
  - Simulation package to enable independent simulation on each node
  - PBS for job scheduling

- **Zhao et al. (2013) [3]**
  - Grid Computing
  - Utilize power of multicore CPUs

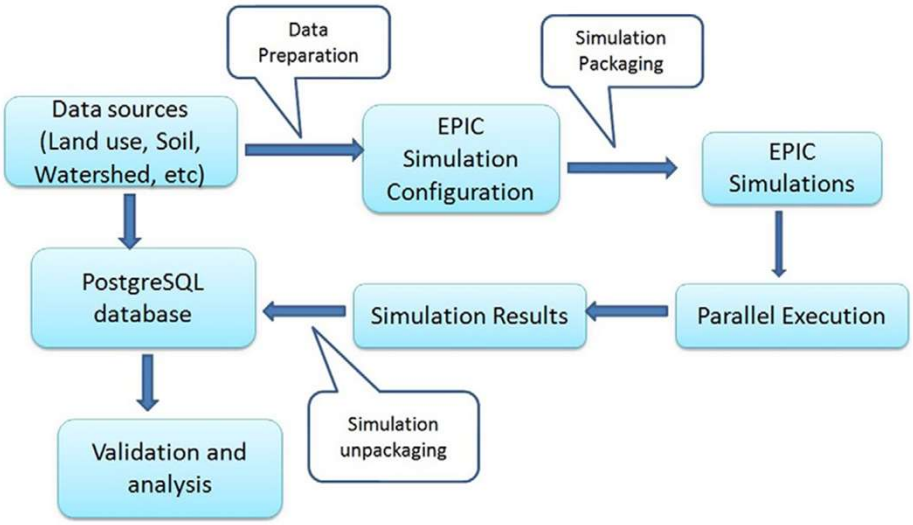


Fig. 2. The workflow design of high-performance computing EPIC (HPC-EPIC).

: Proposed approach by Nicholas et.al [2]

Image Source: Nichols, J., Kang, S., Post, W., Wang, D., Bandaru, V., Manowitz, D., ... & Izaurralde, R. (2011). HPC-EPIC for high resolution simulations of environmental and sustainability assessment. Computers and Electronics in Agriculture , 79 (2), 112-115.

Design & Implementation (2)

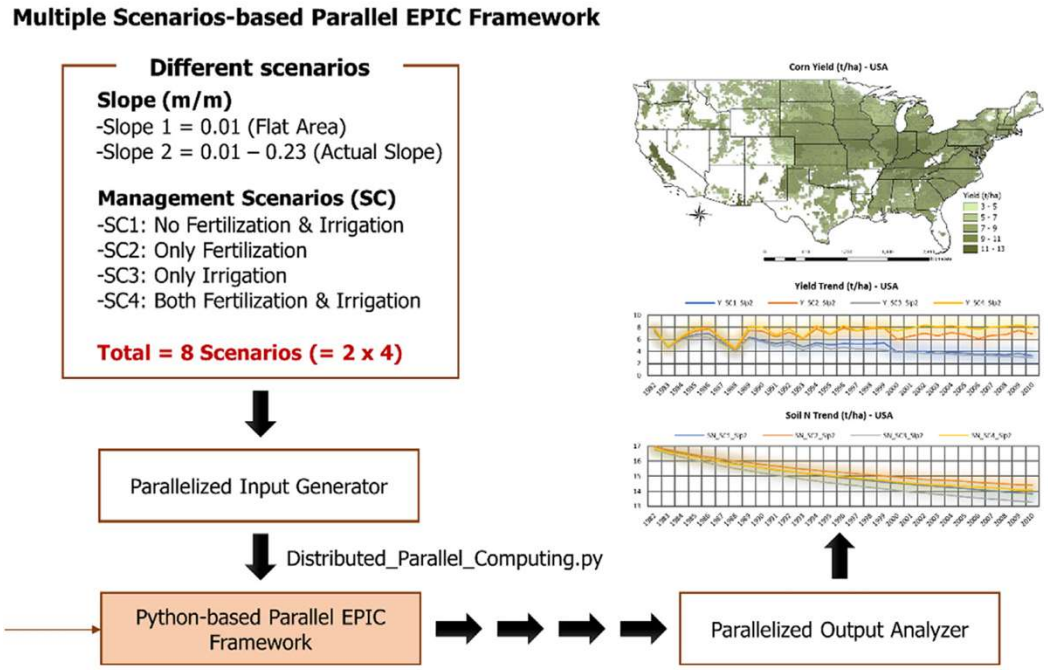
- **Bryan (2013) [4]**
- Assess how software and hardware affect simulation
- Synthetic Dataset
- Three different Implementations:
  1. ESRI's ArcMacroLanguage script
  2. Python/Numpy on 1-256 CPU cores
  3. Python/Numpy on 1-64 GPU cores

Implementation Method	Platform Used	Speedup
GIS script	Single CPU (baseline)	1
Python/NumPy on 1 CPU core	Single CPU	59
PyCUDA GPUArray on 1 GPU	Single GPU	1,473
PyCUDA ElementwiseKernel on 1 GPU	Single GPU	4,881
PyCUDA ElementwiseKernel on 64 GPUs	GPU cluster (64 GPUs)	63,643

: Speedup achieved on the implementation methods

Design & Implementation (3)

- **Jang et.al (2018) [5]**
- Researchers may not have expertise in distributed system
- EPIC parallel computing framework
- Modular Design
- Few additional lines of code to parallelize EPIC simulations



: EPCF Design

Image Source: Jang, W. S., Lee, Y., Neff, J. C., Im, Y., Ha, S., & Doro, L. (2019). Development of an EPIC parallel computing framework to facilitate regional/global gridded crop modeling with multiple scenarios: A case study of the United States. Computers and Electronics in Agriculture , 158 , 189-200.

Results

- Massive speedups
- Diverse implementations
- Support for complex simulations

Research	Methods	Simulation Problem	Speed Up
Nicholas et.al (2011) [2]	Cluster	Agricultural modeling for central wisconsin	40
Zhao et.al (2013) [3]	Cluster, Multiprocessor	Wheat production modeling for Australia	1000
Bryan (2013) [4]	Custer, GPU, ElementwiseKernel	Agriculture economic returns modeling on synthetic data	63643
Jang et.al (2018) [5]	Framework	Corn yield in the corn belt region of the USA	13.5

: Speedups achieved using various HPC techniques in agricultural simulation studies

Discussion

- Embarrassingly parallel design simplifies model scaling.
- Bottlenecks: I/O handling, load balancing, calibration.
- Other Barriers: HPC expertise, cost, and software adaptation.
- Choosing the right hardware and software tools matters!

Conclusion

- As climate issues grow, advanced modeling will play a key role in finding sustainable solutions.
- HPC enables large-scale, high-resolution simulations.
- Quick insights support more data-driven, sustainable agricultural decisions on a global scale.
- Future research can focus on making agricultural modeling more accessible and environmentally sustainable.

References

1. Di Bene, C., Diacono, M., Montemurro, F., Testani, E., & Farina, R. (2022). EPIC model simulation to assess effective agro-ecological practices for climate change mitigation and adaptation in organic vegetable system. *Agronomy for Sustainable Development*, *42*(1), 7.
2. Nichols, J., Kang, S., Post, W., Wang, D., Bandaru, V., Manowitz, D., ... & Izaurralde, R. (2011). HPC-EPIC for high resolution simulations of environmental and sustainability assessment. Computers and Electronics in Agriculture , 79 (2), 112-115.
3. Zhao, G., Bryan, B. A., King, D., Luo, Z., Wang, E., Bende-Michl, U., ... & Yu, Q. (2013). Large-scale, high-resolution agricultural systems modeling using a hybrid approach combining grid computing and parallel processing. Environmental Modelling & Software , 41 , 231-238.
4. Bryan, Brett A. "High-performance computing tools for the integrated assessment and modelling of social–ecological systems." Environmental Modelling & Software 39 (2013): 295-303.
5. Jang, W. S., Lee, Y., Neff, J. C., Im, Y., Ha, S., & Doro, L. (2019). Development of an EPIC parallel computing framework to facilitate regional/global gridded crop modeling with multiple scenarios: A case study of the United States. Computers and Electronics in Agriculture , 158 , 189-200.

Thank You!

Questions?