WRF-GC: an on-line coupling of WRF & GEOS-Chem model structure and preliminary results

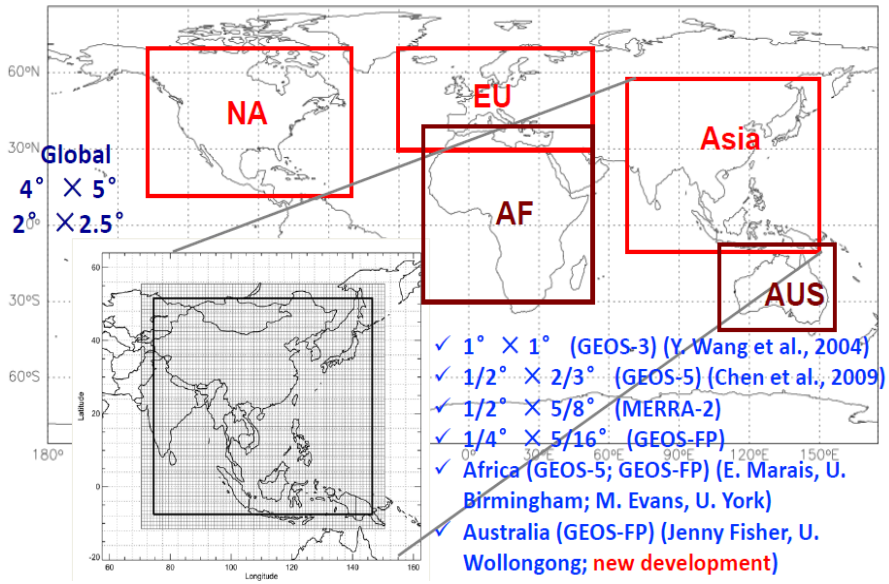
Tzung-May Fu[1] (fuzm@sustech.edu.cn), Haipeng Lin[2], Xu Feng[2], Heng Tian[2], Yaping Ma[2], Lijuan Zhang[2], Robert Yantosca[3], Melissa Sulprizio[3], Elizabeth Lundgren[3], Jiawei Zhuang[3], Daniel J. Jacob[3], Sebastian Eastham[4], Christoph Keller[5]

[1] Southern University of Science and Technology, [2] Peking University, [3] Harvard University, [4] MIT, [5] NASA GMAO

3:15-3:45 Model Clinic 2:
WRF-GC: GEOS-Chem in WRF (Haipeng LIN and Xu FENG, PKU)
Maxwell-Dworkin G115

How can GC users benefit from a WRF-GC coupled model?

Current GC high-resolution simulation: over some areas, some of the time



- **Multi-scale meteorology / chemistry interactions**
- **Flexible grid systems, including nested grids and moving nest grids, at resolutions 100 km to 1 km**
- **Hindcast and forecast capabilities, driven by NCEP, EC, CESM, FGOALS-g2, etc**
- **WRF hindcasts can be nudged with observations to mimic assimilated meteorological fields at high resolution**

- **Atmosphere-land-water-ecosystem studies may be more achievable, because many other models are already coupled to WRF**

What about current WRF / WRF-Chem / other model users?

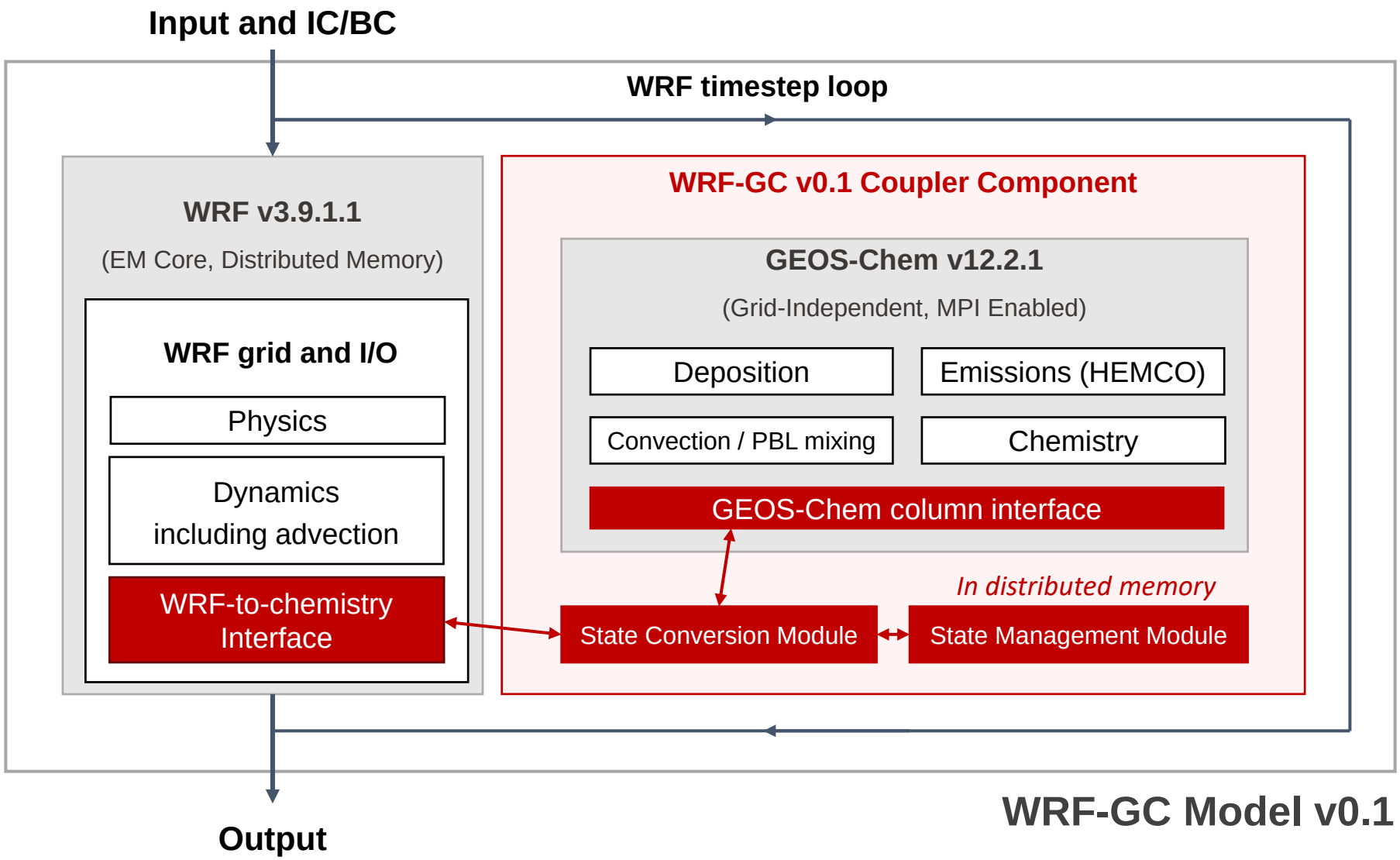
- **GEOS-Chem is a state-of-the-science, well-documented, traceable, benchmarked, GCST-supported chemical module for gases and aerosols, backed by a large atmospheric chemistry community**
- **GEOS-Chem provides a "standard" mechanism that is suitable for most applications, but still customizable**
- **GC as an abstraction layer can provide consistency when coupled to current and future NCAR models from global to local scales**
- **Adoption of WRF / WRF-GC by the large meteorology / AQ communities for AQ applications for both research and operation**

Development guideline: coupling structure that is easy to use, massively parallel, and ready for the future

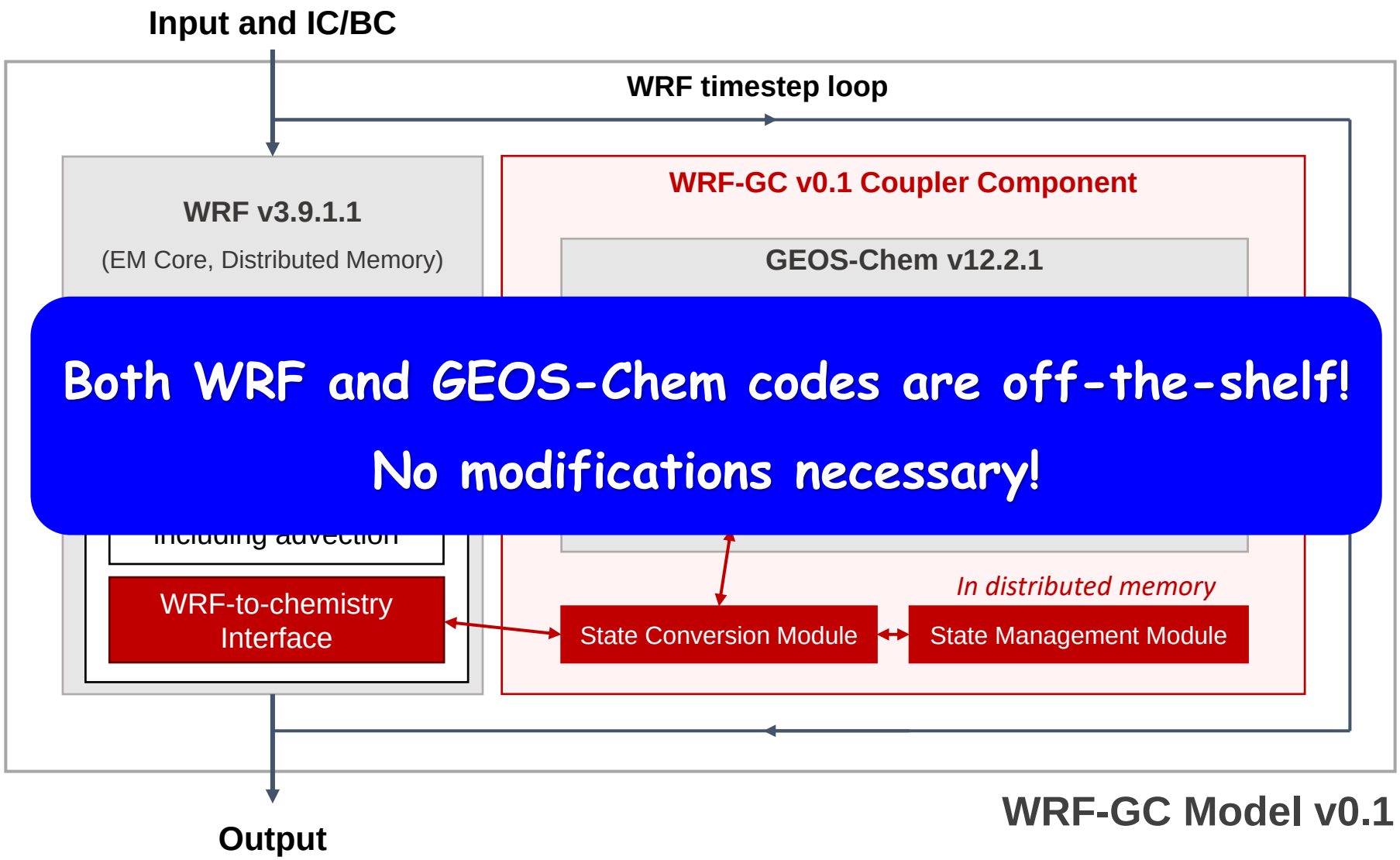
- **Very specific goal: regional GEOS-Chem simulations with online meteorology**
- **A coupling structure with minimal changes to either model, such that *either parent model could be updated independently***

  → WRF-GC can stay state-of-the-science
- **GEOS-Chem High Performance (GCHP) technology is used, allowing WRF-GC to run in *massively parallel architectures* for high performance**
- **We further "columnized" GC so that it can operate as a *stateless, grid-independent column model* that can be fully driven by external models, which will also ease the development of future coupling projects with GC**
- **WRF-GC is free and open-access (wrf.geos-chem.org)**

WRF-GC architectural overview

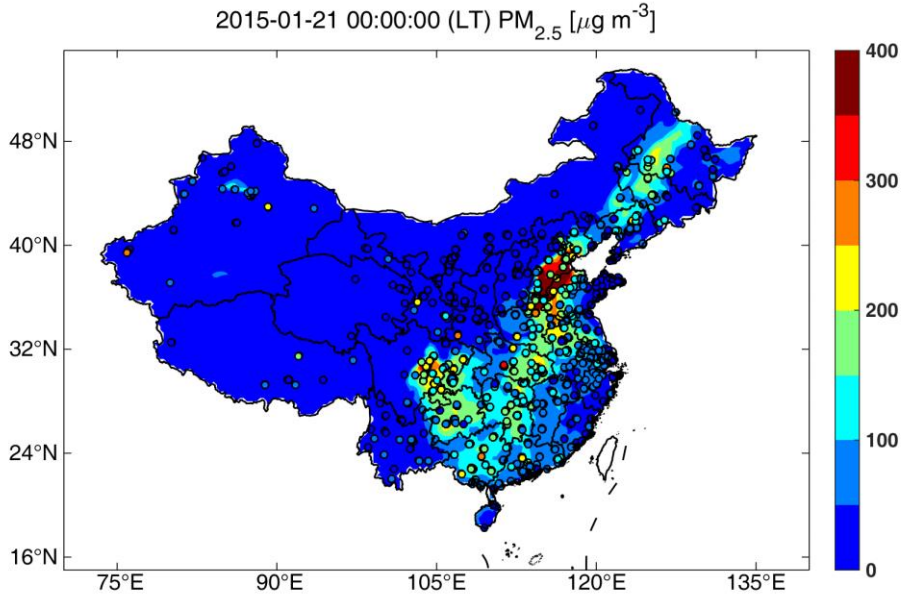


WRF-GC architectural overview



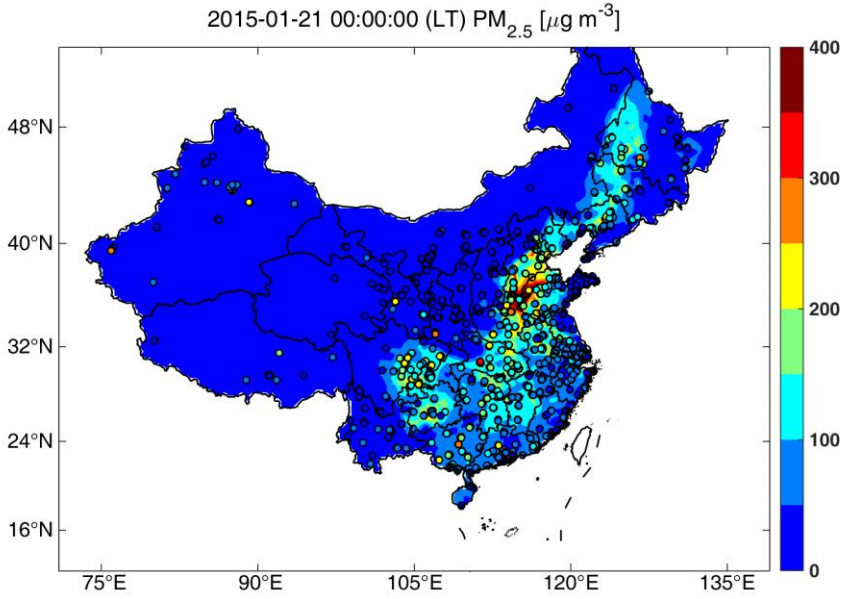
Case: Chinese surface $PM_{2.5}$ Jan 21-28, 2015

GEOS-Chem classic
0.25º x 0.3125º



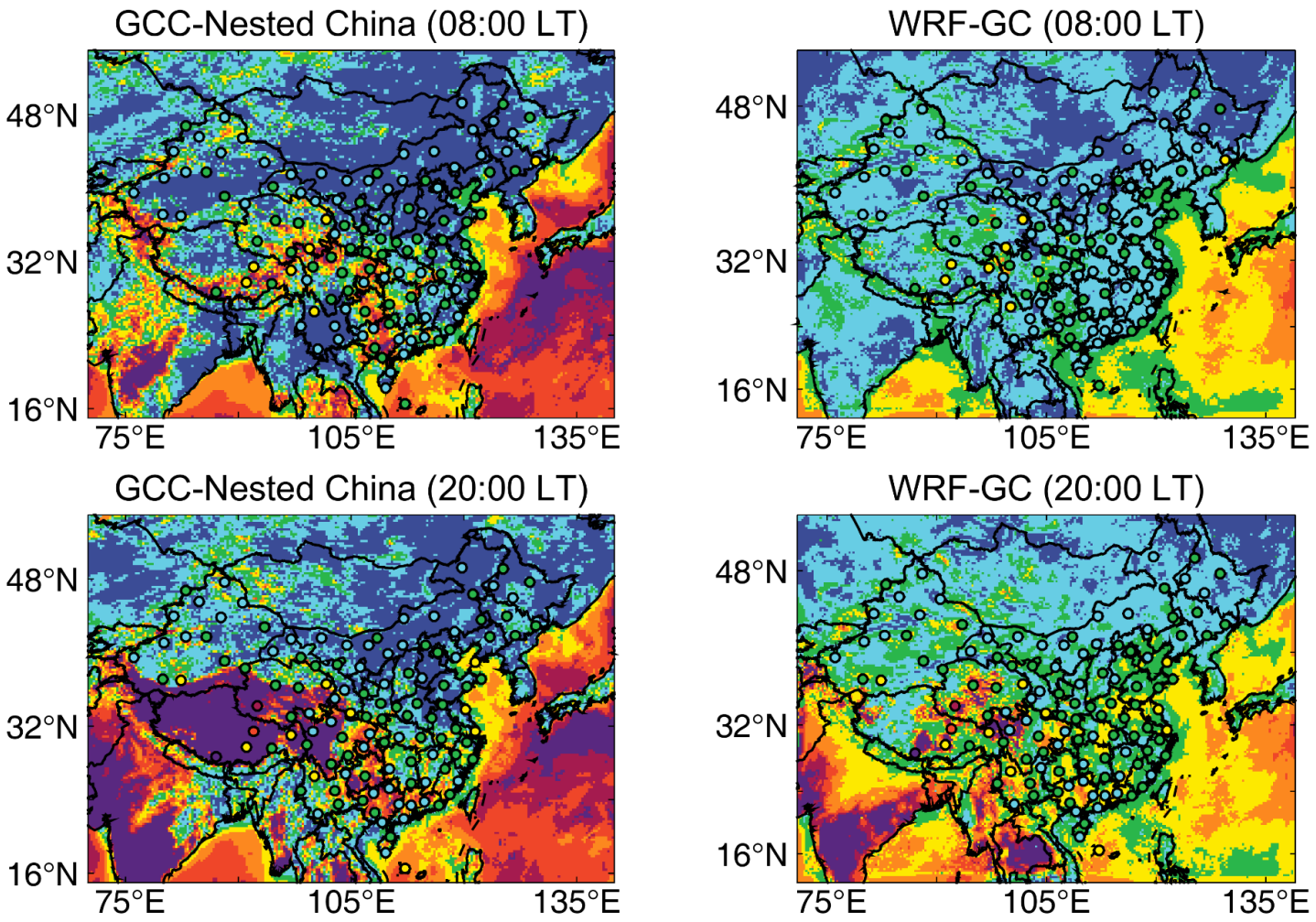
Slope = 1.33
R = 0.75

WRF-GC (nudged)
27 x 27 km



Slope = 1.20
R = 0.71

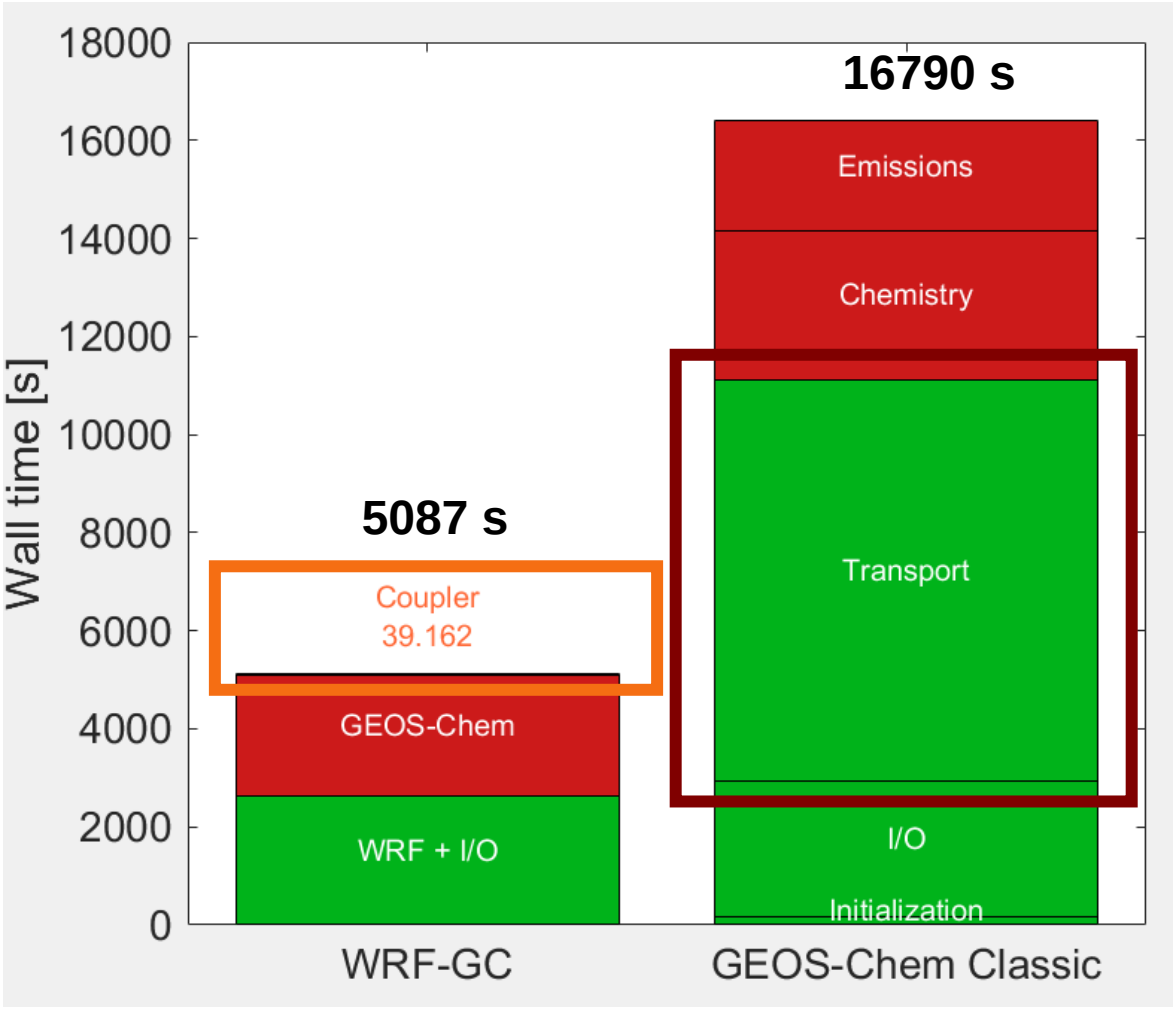
Better representation of PBL height Jan 21-28, 2015



MYNN PBL scheme, nudged with sfc and upper level data

PBLH observation data from Guo et al. (2016)

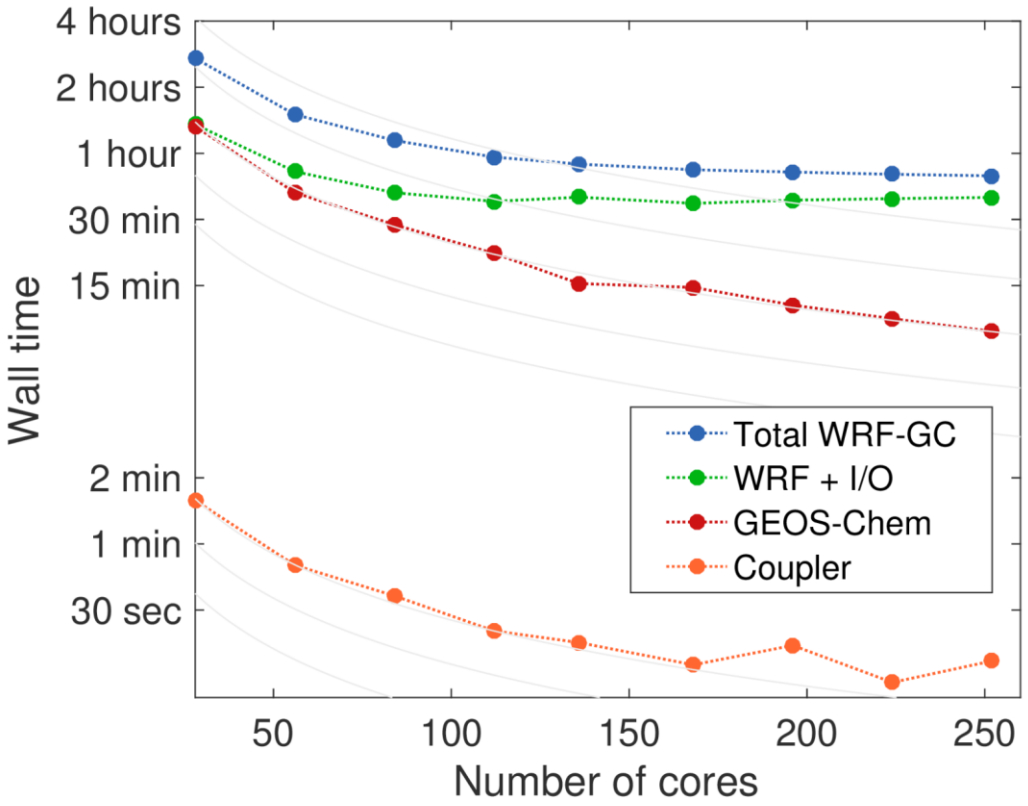
Performance comparison w/ GC-classic (China, 24-h, 32 cores)



Surprisingly, transporting chemicals using archived met data is no longer saving us time!

Coupler is extremely light-weight

Scalability of WRF-GC



- **48-h simulation on Tianhe-1A**
- **GEOS-Chem Column is perfectly scalable**
- **Coupler requires inter-processor communication, dependent on domain decomposition**
- **WRF handles I/O, overhead too high > 150 cores (dependent on domain size)**

Future plans and challenges

- Alpha version release (Jan 4, 2019)
- **WRF-GC can already do what GC-classic can do!**
- **Nested-grid capability (Haipeng Lin + GCST, on-going)**
- **Robust one-way coupling (static nested-grids, limited physical options) (Xu Feng, on-going)**
- **Beta release with nested-grid capability (Late 2019)**
- **Two-way coupling (aerosol feedback based on bulk aerosol mass) by late 2019 (Xu Feng, on-going)**
  - **Binding for aerosol feedbacks will be in the Coupler. Goal is to develop a more general binding for aerosol mass / size / number / composition to connect to WRF (may need to involve WRF developers)**
- **More complex two-way coupling? Size segregated aerosols with APM and TOMAS?**
- **Output / analyses: Python tools developed for WRF-GC (just started)**
- **Compatibility with NCAR model development efforts?**

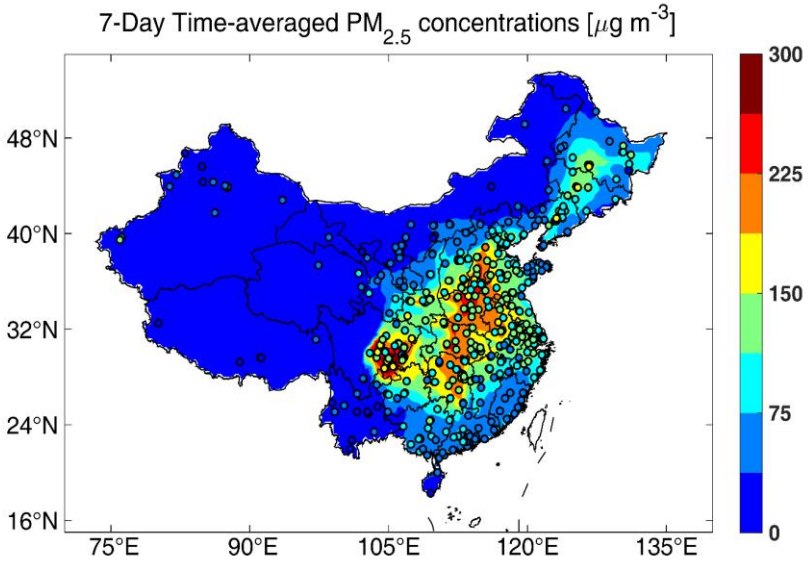
We welcome collaborations

- **Research projects using WRF-GC**
- **Joint effort in model development:**
  - **Direct and indirect effect of aerosols**
  - **Chemical mechanisms for high-resolution simulations**
  - **Representation of small-/meso-scale/boundary layer meteorology**
- **Atmosphere-land-ecosystem studies may be more achievable**
- **We are hiring: 1-2 research scientists, 3-4 postdocs, 1 software engineer**

Try WRF-GC!

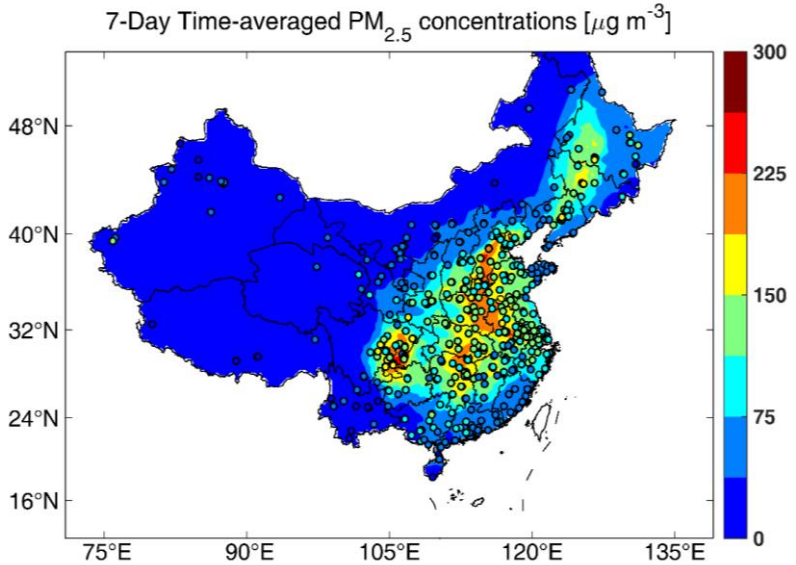
Case: $PM_{2.5}$ during Jan 21-28, 2015

GEOS-Chem classic
0.25º x 0.3125º



Slope = 1.33
R = 0.75

WRF-GC (nudged)
27 x 27 km



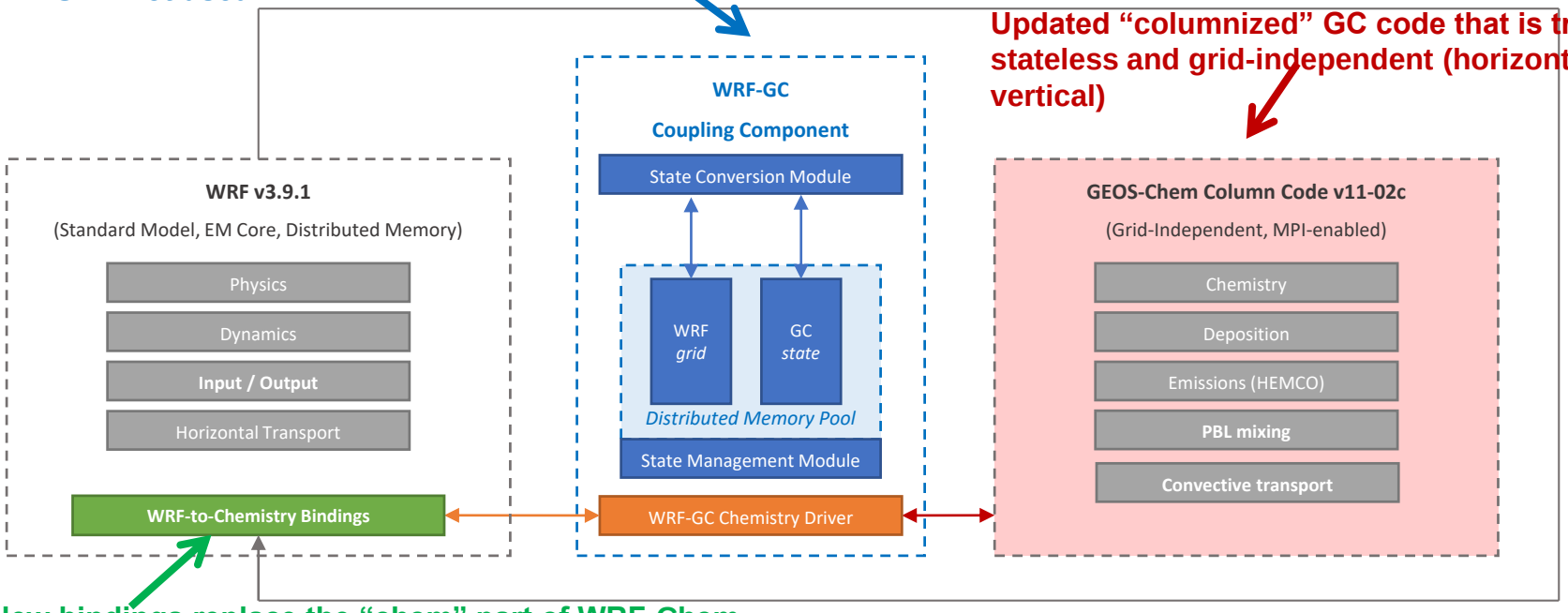
Slope = 1.20
R = 0.71

Review of development efforts

- **Creating a *chemistry abstraction layer* for the WRF Model**
- **Isolating the *GEOS-Chem Column Code* from GCHP:**
  - **Reduced ESMF/MAPL dependencies;**
  - **Stateless, grid-independent operation fully driven by external model;**
- **Conversion of meteorology & chemistry variables between WRF and GC**
- **Creation of a state management module further abstracting WRF and GC data structures into the coupler, allowing for easier development of multi-domain work & coupling of GC with other models**
- **Accepts IC/BC from previous WRF-GC run outputs and MOZART4-GEOS5 output files using the mozbc tool (BC from CESM-GC in the future?)**
- **PBL mixing and vertical convective transport in GC using meteorological data from WRF**

WRF-GC Architectural Overview

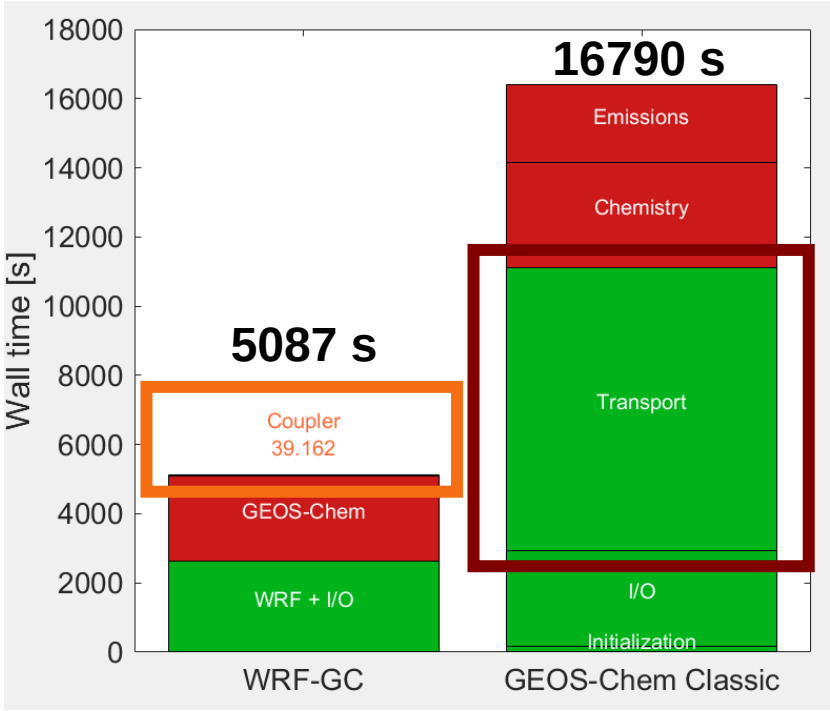
- Data structures managed by the state management module and ingested by the respective parent models (WRF, GC) in their native format
- Conversion performed after each timestep loop by the state conversion module
- ESMF not used



- New bindings replace the "chem" part of WRF-Chem, which is isolated from the rest of WRF
- Chemistry output currently in WRF

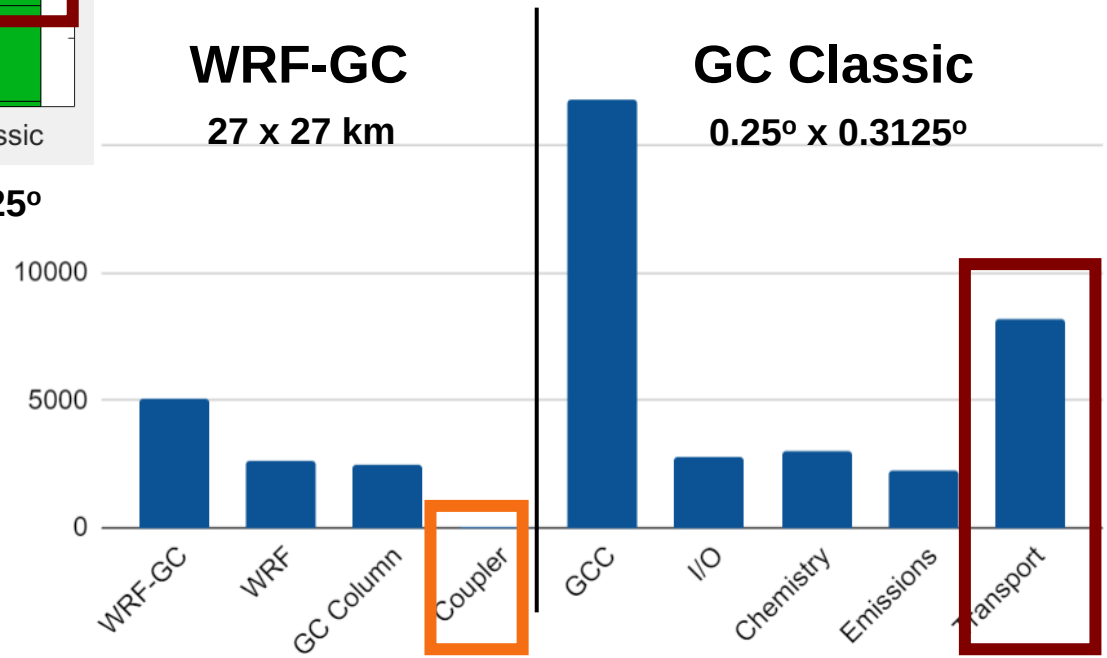
"One-step" compilation of the coupled models

Comparison w/ GC-classic (China domain, 24-h, 32 cores)

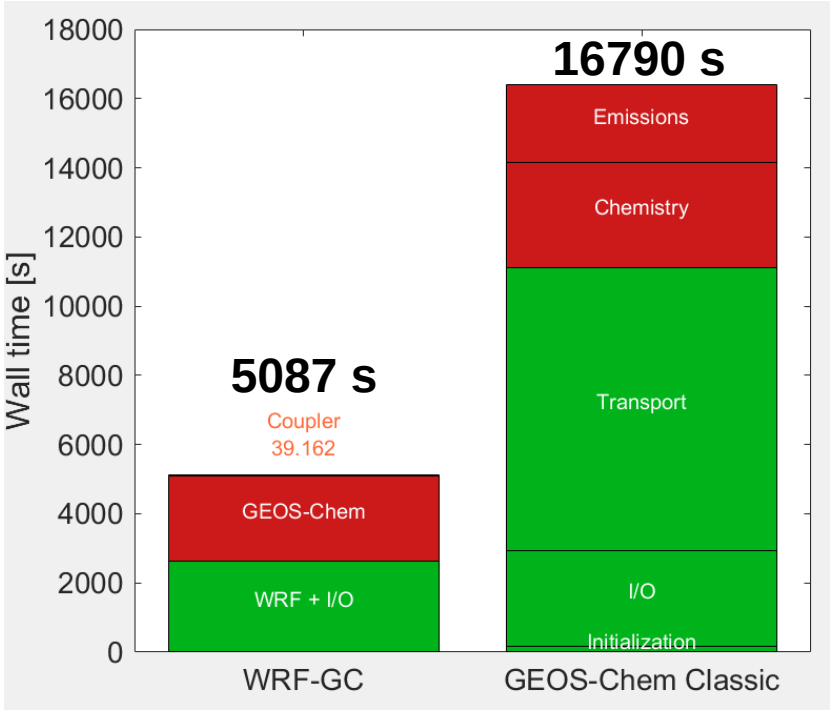


Surprisingly, transporting chemicals using archived met data is no longer saving us time!

Coupler is extremely light-weight!



Comparison w/ GC-classic, nested China 0.25x0.3125



Timer/Cores	16	32	
WRF-GC		**5087.883**	Unit: seconds
WRF		2625.358	
GC Column		*2462.525*	
Coupler		39.162	
GCC		**16789.812**	
I/O		2768.469	I/O, Diags
Chemistry		3031.891	+Deposition
Emissions		2231.594	includes HEMCO input times.
Transport		8192.453	
=> PBL Mixing		1142.531	
=> Convection		694.219