C-Coupler2: a Flexible and User-Friendly Community Coupler for Model Coupling and Nesting

Li Liu, Cheng Zhang, Ruizhe Li, Bin Wang, Guangwen Yang, Chao Sun, Xinzhu Yu, Hao Yu

Department of Earth System Science,

Tsinghua University

liuli-cess@tsinghua.edu.cn

Outline

- **Background**
- C-Coupler2
- Future work

C-Coupler (Chinese Community Coupler)?

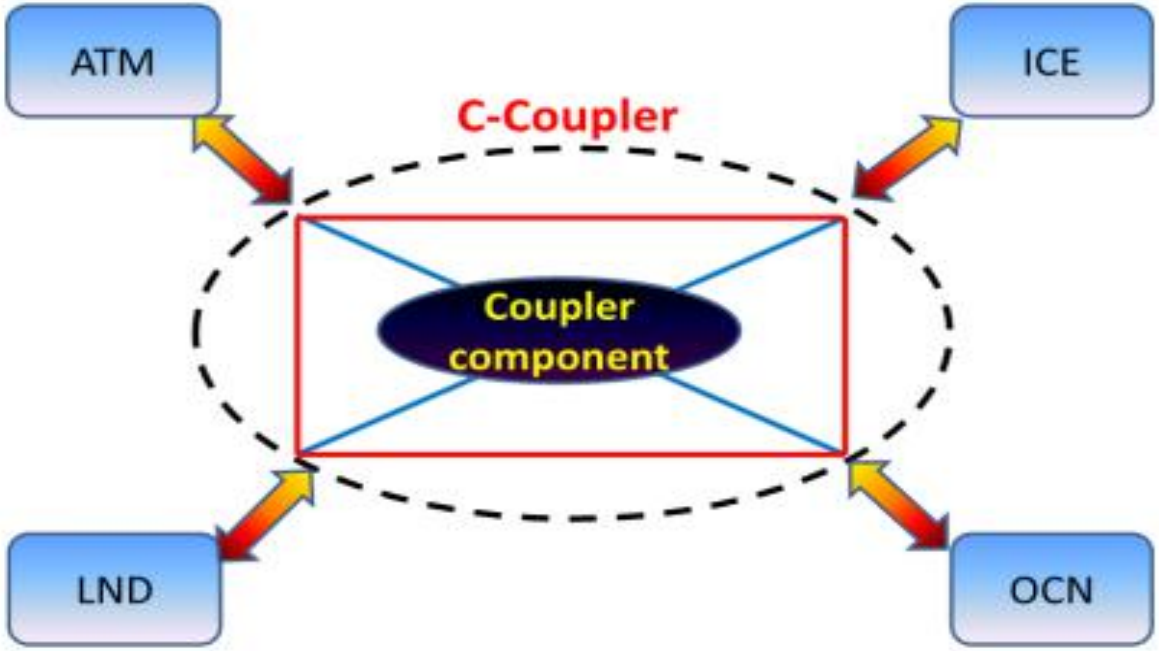
- No coupler team in China before 2010, while there are a lot of coupled models developed in China
- Coupler teams outside of China are generally inconvenient to directly serve Chinese models
- New requirements regarding couplers from Chinese model development

C-Coupler should be able to serve various coupled models developed in China, especially address new requirements

Milestones of C-Coupler development

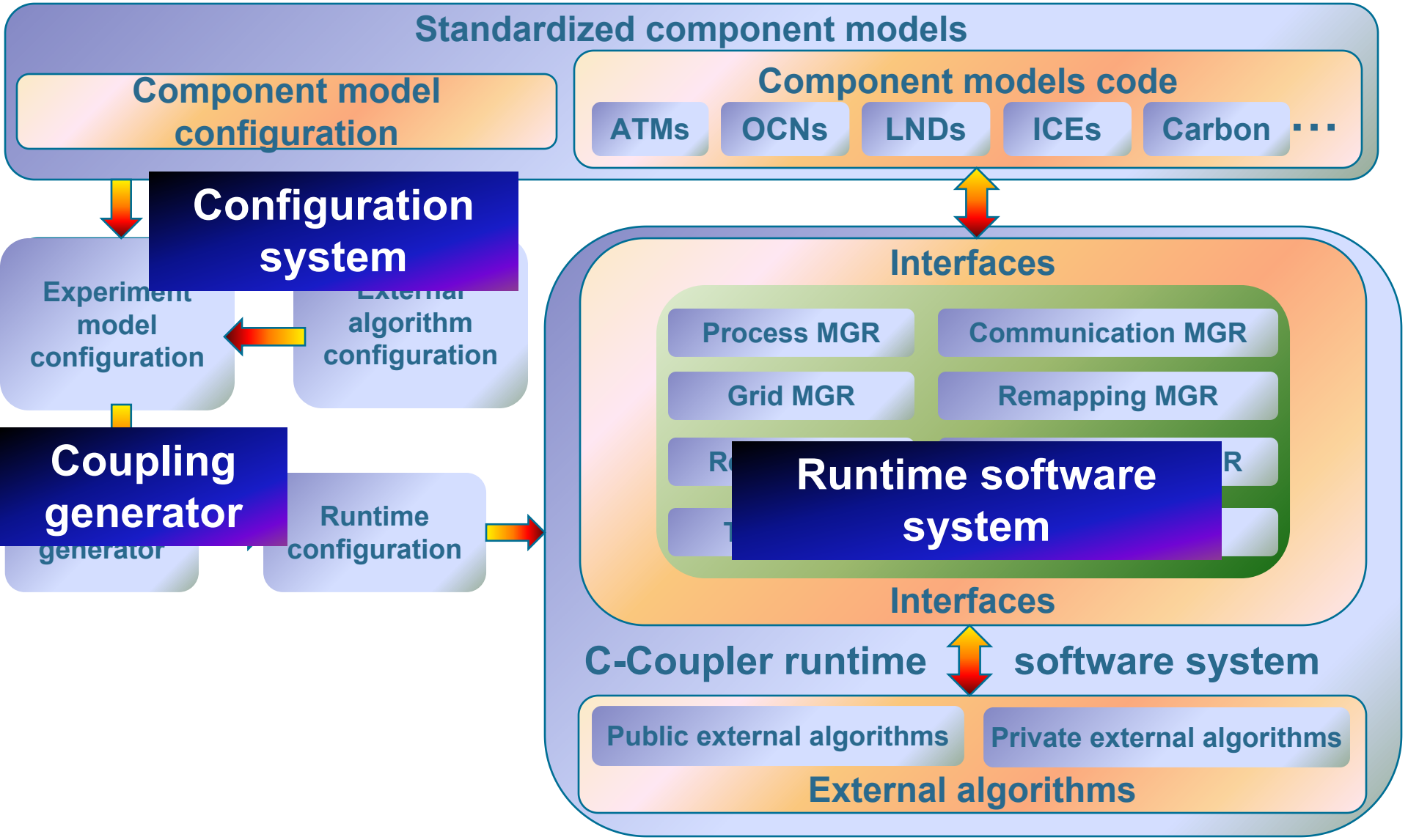
Milestones	Time
Initiation of C-Coupler development	2010.01
Main design of C-Coupler	2010.11
Common multi-dimensional remapping software (CoR)	2012.07
C-Coupler1	2014.06
Initiation of C-Coupler2 development	2016.07
C-Coupler2 released	2018.05
Initiation of C-Coupler3 development	2018.06
C-Coupler3 released	~2022

General architecture of coupled models with C-Coupler



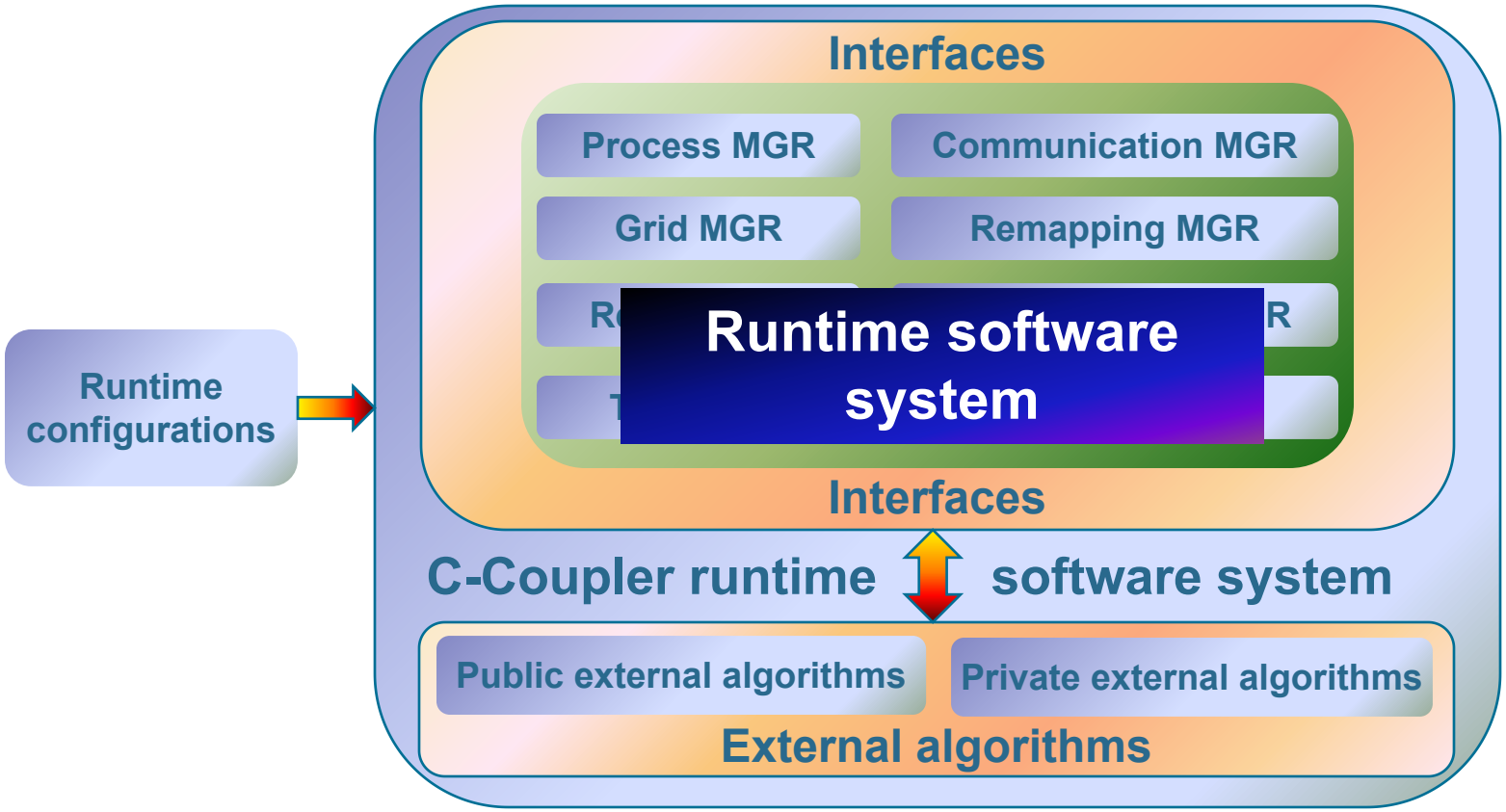
- C-Coupler can serve various coupling configurations in different coupled models
- A component model can have an identical code version in different coupling configurations

General software structure of C-Coupler



C-Coupler1: a parallel 3-D coupler

The first Chinese coupler finished in 2014



Achievements and limitations of C-Coupler1

Achievements

- **First Chinese coupler**
- **New features**: new coupling architecture and static 3-D coupling capability
- **Feasibility** of the overall design of C-Coupler

Limitations

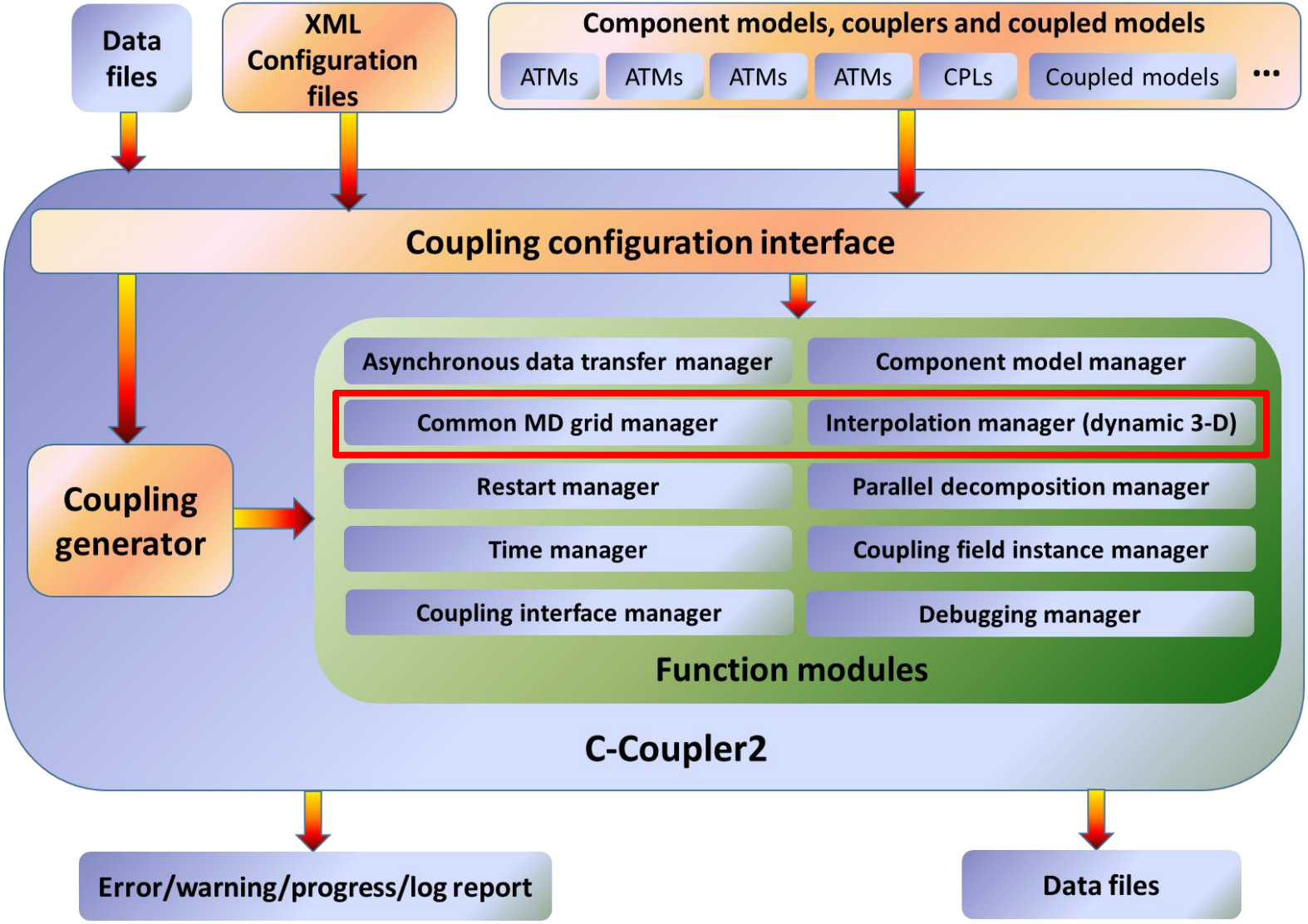
- **Incompatible with other couplers**
- **Unable to couple modules intra the same component model**
- **Unfriendly simplified version**
  - **Incomplete configuration system**
  - **No coupling generator**
- **Low reliability: very limited software testing**
- **High initialization cost, especially in 3-D coupling**
- **Interfaces of C-Coupler1 will not be used by future versions**

Few applications in real model development in China

Outline

- Background
- **C-Coupler2**
- Future work

C-Coupler2 software structure



Development of C-Coupler2

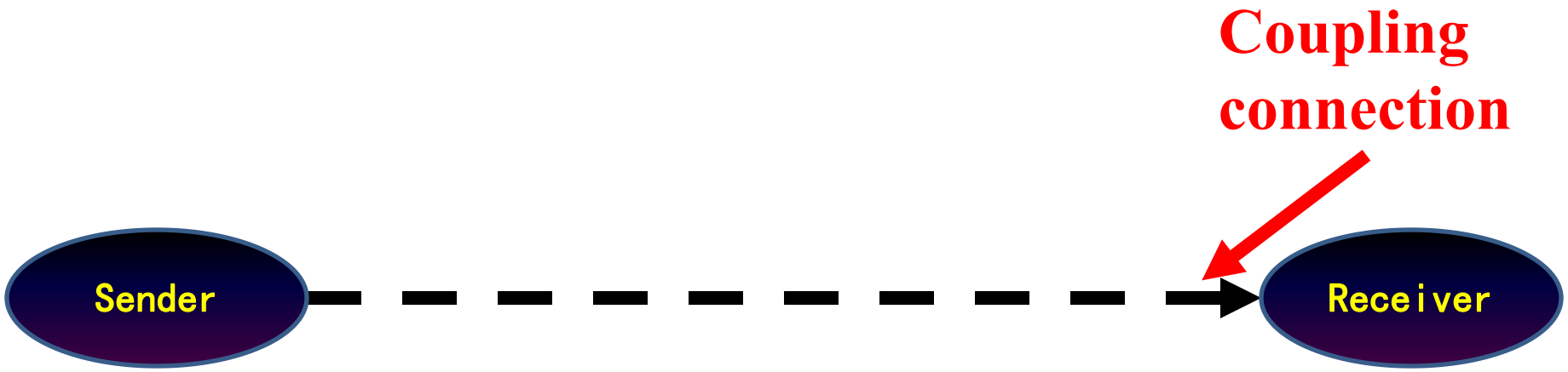
- Started to design and develop C-Coupler2 in 2016.6; finished and open-resource released with a training in 2018.5
- About 40000 lines of source code
  - 3300+ lines of Fortran code: APIs
  - 36700+ lines of C++ code: coupling functionalities
- Documentations
  - C-Coupler2 paper (Liu et al, 2018, GMD)
  - C-Coupler2 user guide (English) and training guide (Chinese)
- Source code **free downloading** from https://github.com/C-Coupler-Group/c-coupler-lib; **free usage** under non-commercial purposes; a bonus for detecting a new bug

New features of C-Coupler2 from C-Coupler1

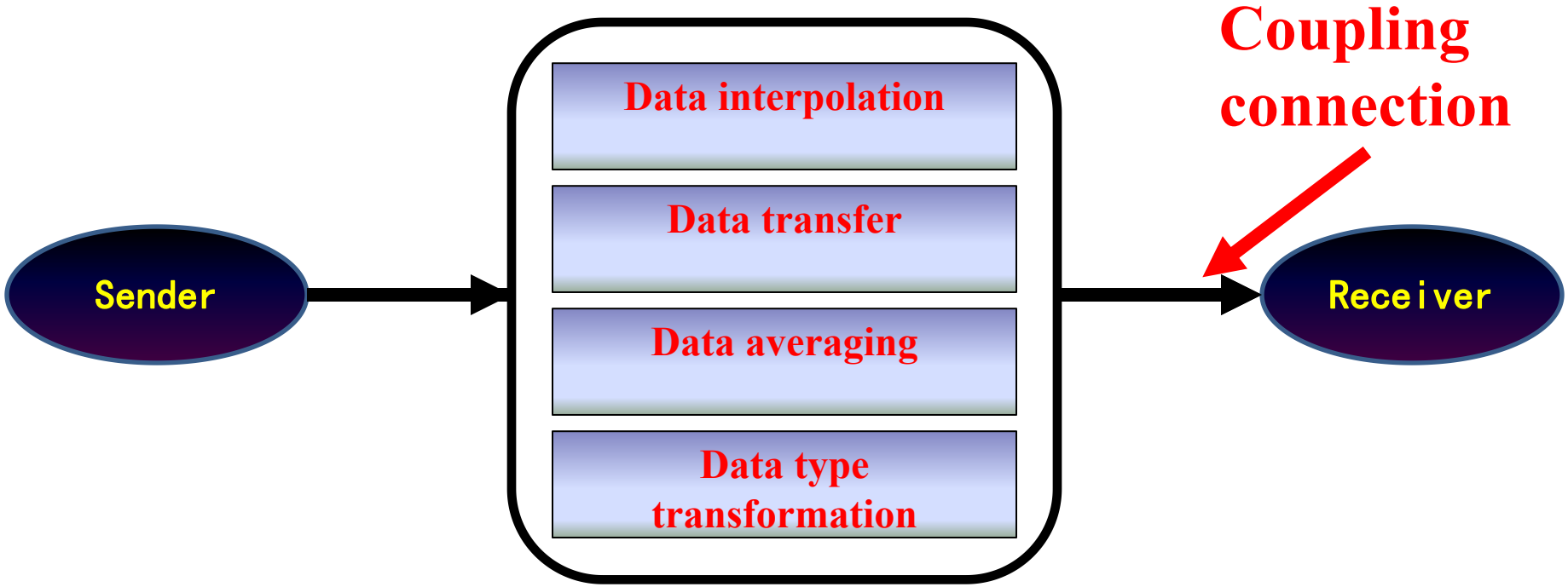
- **Flexible and automatic coupling generation**
- **Dynamic 3-D coupling capability**
- **Facilitation for incremental coupling and model nesting**
- **A common, flexible, and user-friendly coupling configuration interface**
- **Non-blocking data transfer**
- **Adaptive restart capability**
- **Flexible configuration of coupling lags**
- **Parallel online remapping weight generation**
- **Debugging capability**
- **Model coupling within one executable or the same component model**

(Liu et al, 2018, GMD)

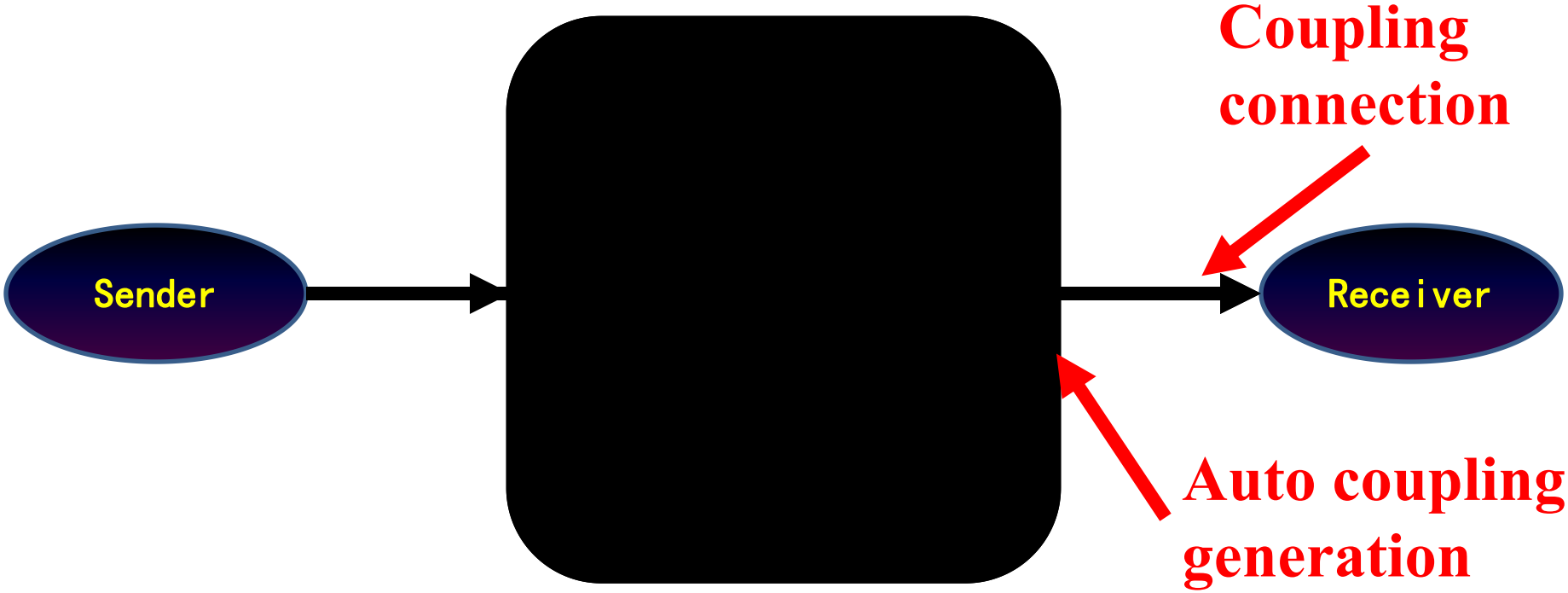
Automatic coupling generation



Automatic coupling generation



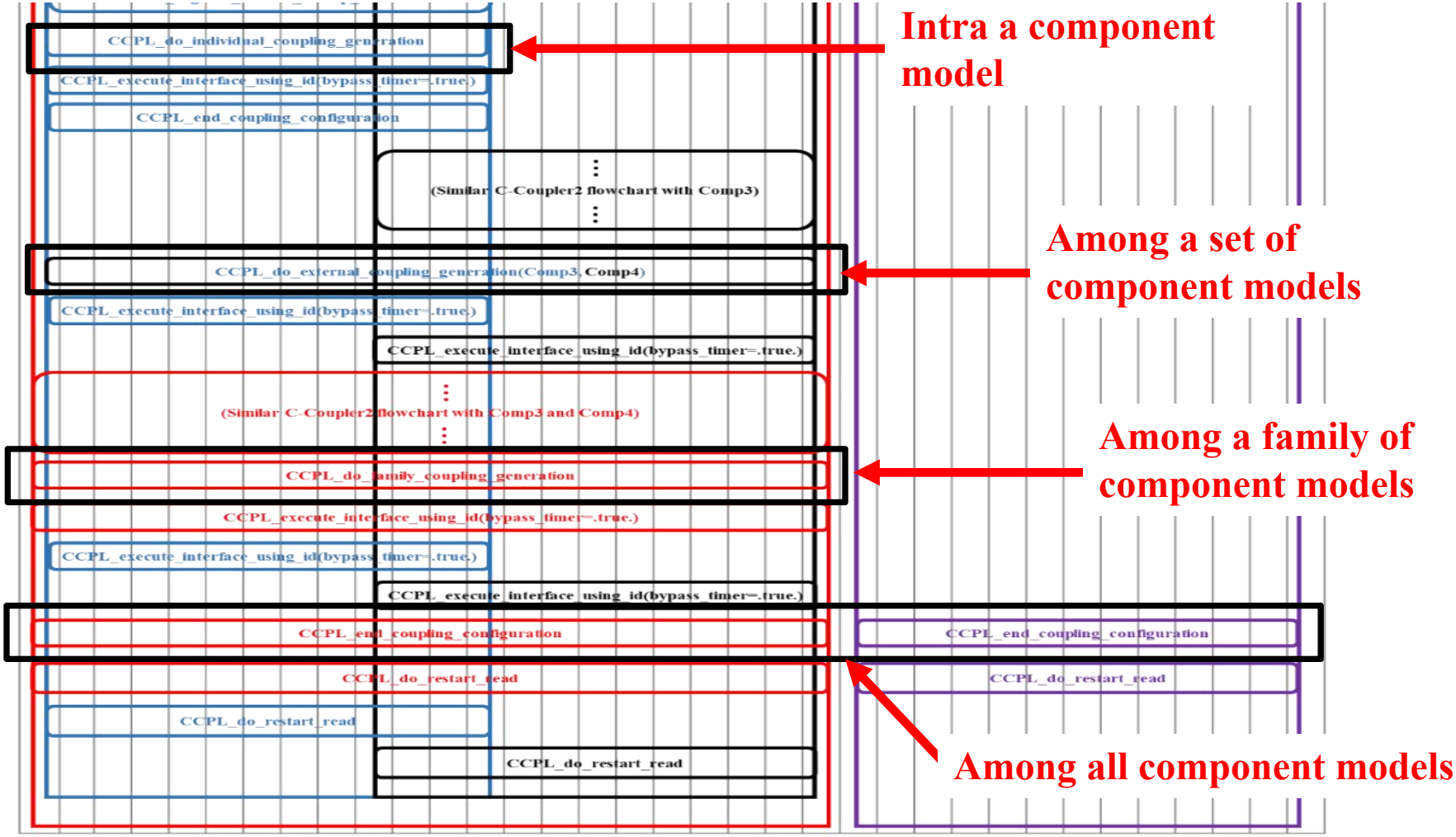
Automatic coupling generation



Coupling flowchart

Auto coupling generation is significant for improving the friendliness and reliability of a coupler

Automatic coupling generation of C-Coupler2



Flexible automatic coupling generation at different levels

Dynamic 3-D coupling

- 2-D coupling related to horizontal grids was enough in the past
- Requirements of 3-D coupling
  - Between ocean model and wave model
  - Between atmosphere model and atmospheric chemistry model
- **Dynamic 3-D coupling**
  - Pressure-based terrain following coordinate makes pressure values (vertical coordinate values) in 3-D grids of atmosphere model and atmospheric chemistry model change with surface pressure in time integration
  - Dynamic 3-D coupling: **coupling between different 3-D grids with variable vertical coordinate values**

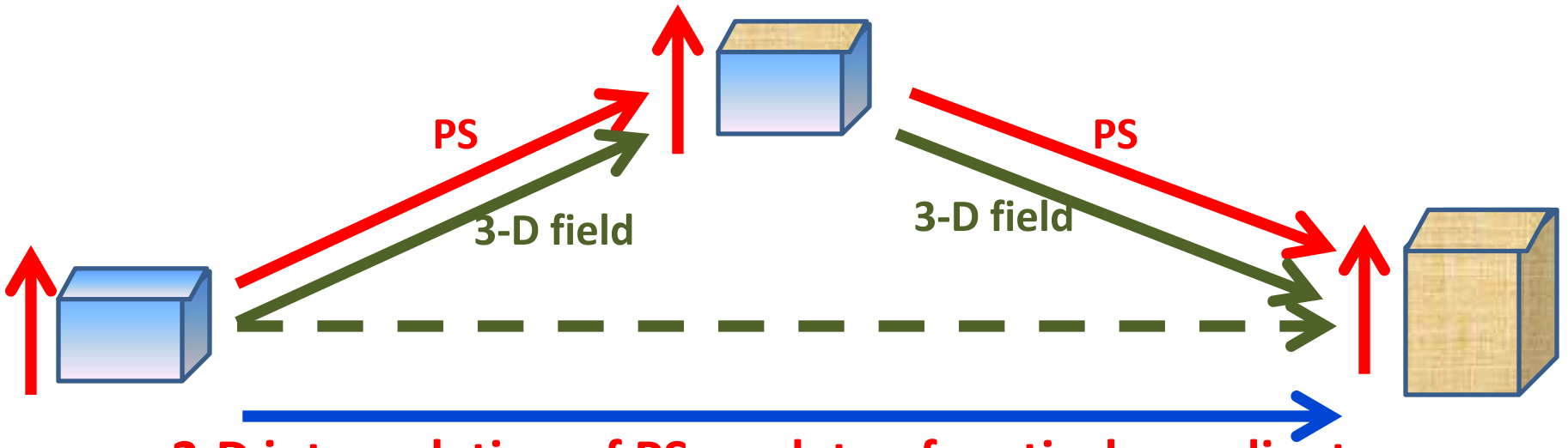
Challenges to support dynamic 3-D coupling in a coupler

How to adaptively calculate pressure (vertical coordinate) values following the dynamic change of surface pressure

How to adaptively update vertical remapping weights after recalculating vertical coordinate values

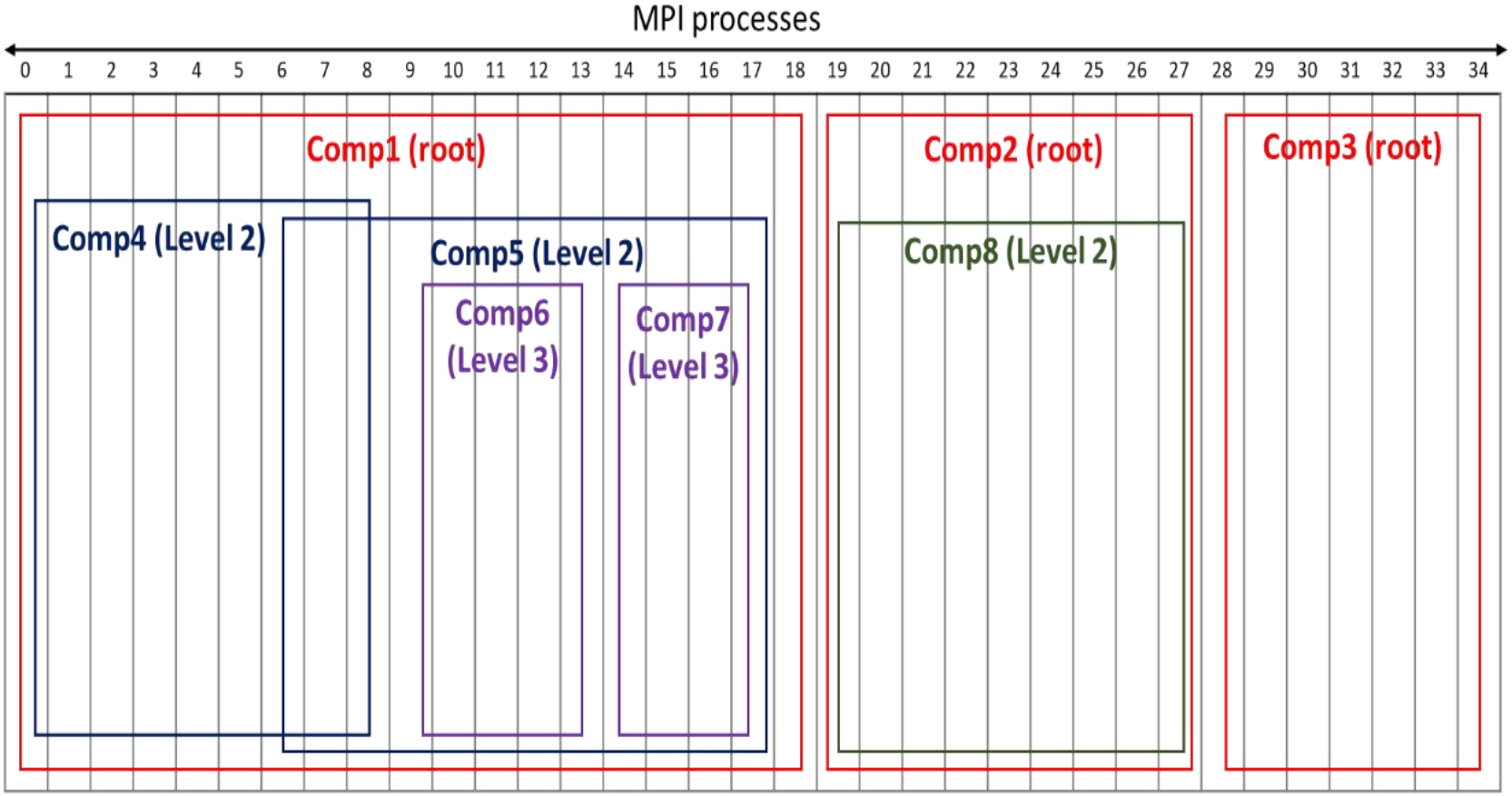
Implementation of dynamic 3-D coupling in C-Coupler2

- "horizontal 2-D + vertical 1-D" implementation
  - 2-D remapping weights keep unchanged constantly
  - Dynamic update of vertical coordinate values and 1-D remapping weights according to surface pressure (PS)

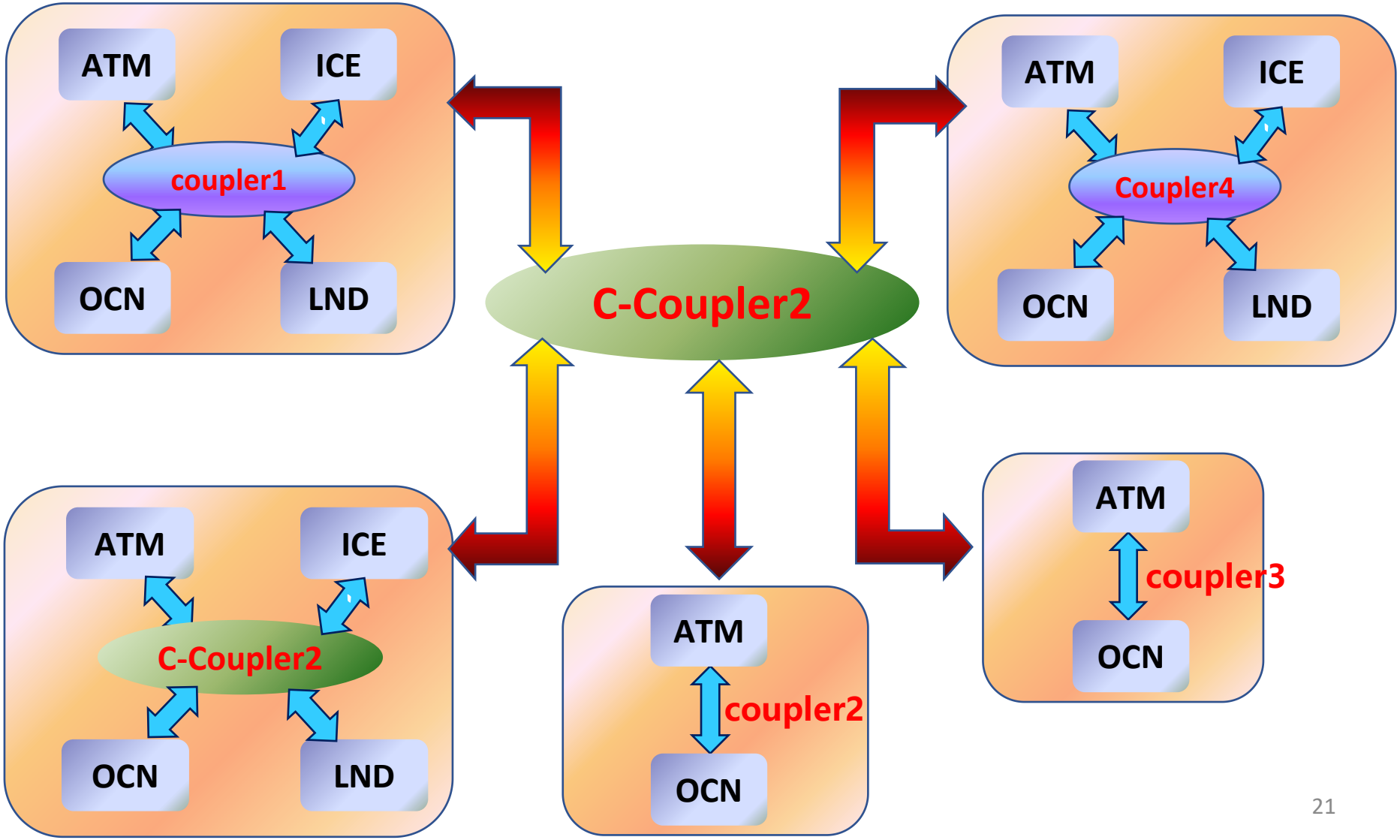


2-D interpolation of PS, update of vertical coordinate values, update of 1-D remapping weights and 3-D interpolation are fully parallelized

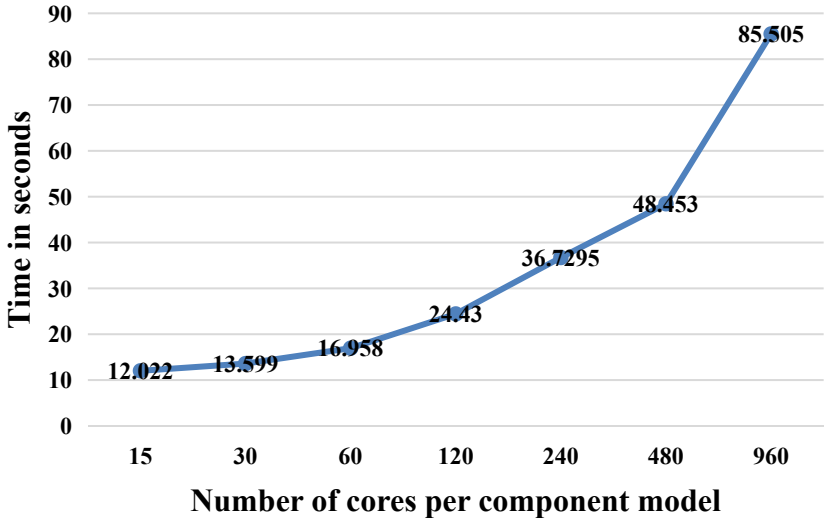
Flexible management of component models



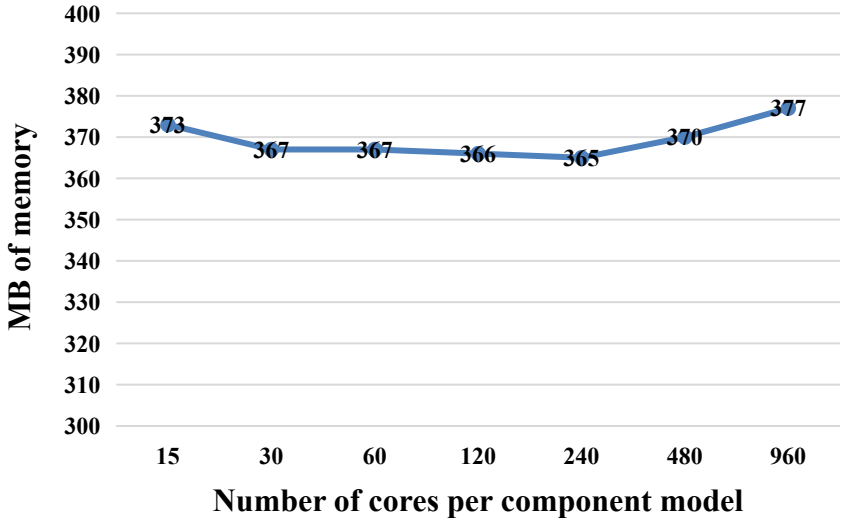
General architecture for incremental coupling



Initialization cost and memory usage



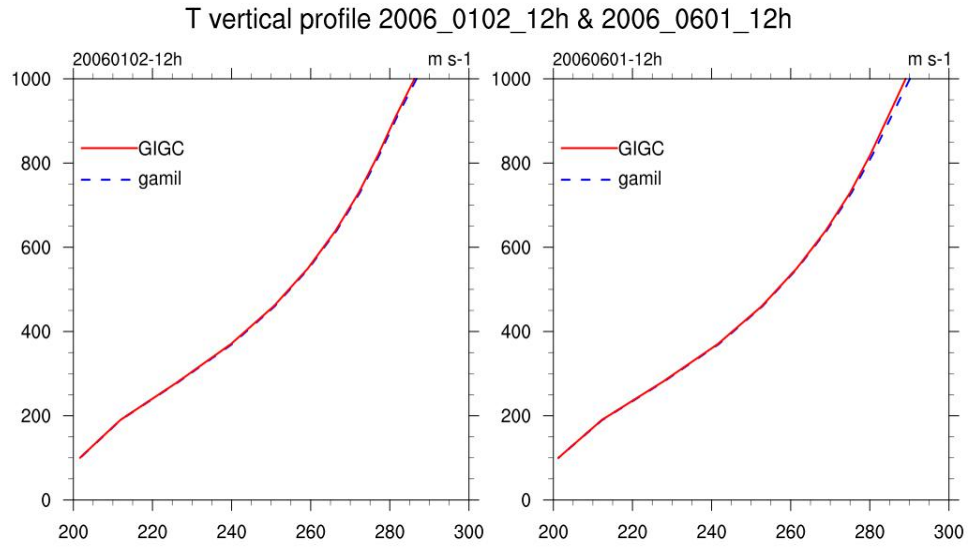
Initialization cost



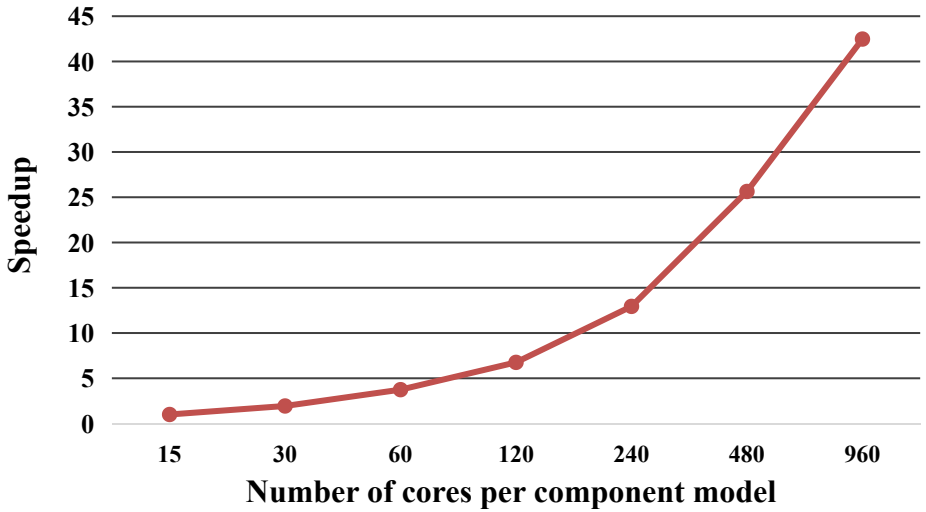
Memory usage

Between two toy component models with a regular longitude–latitude grid of 1440 × 720 grid points and a tripolar grid of 1440 × 1021 grid points respectively

Performance of dynamic 3-D coupling



Global vertical profiles of the temperature from GAMIL2 to GEOS-Chem (GC) at two different model time



Parallel speedup of dynamic 3-D coupling (for 100 ping-pong couplings) between the two toy component models with 50 vertical levels

Existing applications of C-Coupler2

- Coupled models for Chinese institutions
  - First Institute of Oceanography, Ministry of Natural Resources: **FIO-AOW**
  - National Climate Centre: **parallel coupler version of BCC-CSM**
  - National Meteorological Center: **parallel version of a new dynamic core (MCV)**
  - National Marine Environmental Forecasting Center: **MPAS-Wavewatch, WRF-MITgcm**
  - First Institute of Oceanography and National Meteorological Center: **GRAPES-FIOCOM**
  - Institute of Atmospheric Physics, Chinese Academy of Sciences: **a version of CAS-FGOALS-g3**
  - Tsinghua University: **CIESM**
- Coupled models for at least 4 key research projects of China

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- **Future work**

C-Coupler3 progress

- Faster initialization
  - https://gmd.copernicus.org/preprints/gmd-2020-75/
- Remapping weight generation based on triangulation of grids
  - https://gmd.copernicus.org/articles/12/3311/2019/
- Flexible coupling between a model and an external procedure
- Efficient ensemble data assimilation framework
  - https://gmd.copernicus.org/articles/12/3311/2019/

Thanks!