# 4th Workshop on Physics-Dynamics Coupling in Weather and Climate Models

Wednesday 01 June 2022 - Friday 03 June 2022

# Book of Abstracts

## Markus Sebastian Gross, 1974-2022

PDC 2022 is dedicated to the memory of Prof. Gross, who unexpectedly passed away from a household accident in January 2022. He founded the PDC workshop series and was a leader in the Physics-Dynamics Coupling community, having published the defining article in the field. His vision brought light to the significance of the coupling problem to a larger community and established it as a field worthy of serious scientific study. Prof. Gross's legacy is carried on by this workshop.

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**Wednesday Morning 1 June: Physics Dynamics Interactions I / 42**

## Alternative Assumptions about Topographic Height Improve Coupled Global Climate Model Simulation Fidelity

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A key boundary condition in global climate models (GCMs) is surface height. Typically, a high-resolution observed topographic dataset is placed on a GCM grid by averaging the observed topography over each model grid cell. This process has the unfortunate effect of smoothing out mountain peaks, such that the model wind is steered less by topography than in reality. Prior work has highlighted the important mechanical effects on atmospheric circulation of thin but high mountains, such as the Himalayas, Andes, and Sierra Madre. We hypothesize that the systematic smoothing of topography contributes to pervasive large-scale biases in GCMs by underrepresenting these mechanical effects. To test this, we perform a suite of experiments with the GFDL GCM CM2.5-FLOR, which has a 50 km atmosphere/land resolution, and with the relatively lower resolution NCAR GCM CCSM4, in which we alter the model topography to allow for a more accurate representation of the effective maximum elevations of mountain ranges. With this alternative topographic assumption, higher Central American topography leads to more realistic East Pacific winds. This in turn yields more accurate spatial distributions of sea-surface temperatures and precipitation. Notably, the double ITCZ bias in the East Pacific is lessened, and the seasonality of ENSO variance is improved. In this presentation, we will document these improvements and their dynamical causes, and discuss how this alternative and arguably improved topography might influence projected future climate.

**Thursday Afternoon 2 June: Physics-Dynamics Interactions II / 28**

## Physics-Dynamics-Chemistry Coupling with components of different resolutions in LFRic

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Can we save computational resources in NWP and climate models without degrading the quality of the solution, by running different parts of the model at different resolutions?

In traditional models, the physics parametrisations, dynamical core and any chemistry components use the same grid. In this talk, I will present an approach to run these components at different resolutions to one another, within the Met Office's new LFRic model.

The talk will focus on a geometric framework for mapping fields between meshes, which preserves certain desirable mathematical properties as the fields are mapped. This will be limited to changes of resolution only in the horizontal direction, and to cases where the cells of the finer mesh are exactly nested within the cells of the coarser mesh. I will also discuss some of the major challenges, such as orography and the positivity of tracer species. I will then demonstrate this framework in action through some idealised tests.

**Friday Morning 3 June: Theory of Coupling / 38**

## Consistent and Flexible Thermodynamics in Atmospheric Models

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Approximations in the moist thermodynamics of atmospheric models can often be inconsistent; different parts of numerical models may handle the thermodynamics in different ways, or the approximations may disagree with the laws of thermodynamics.
To address these problems all relevant thermodynamic quantities may be derived from a defined thermodynamic potential; approximations are then instead made to the potential itself - this guarantees self-consistency, as well as flexibility.
Previous work showed that this concept is viable for vapour and liquid water mixtures in a moist atmospheric system using the Gibbs potential.
However, on extension to include the ice phase an ambiguity is encountered at the triple-point.
To resolve this ambiguity, here the internal energy potential is used instead.
Constrained maximisation methods on the entropy can be used to solve for the system equilibrium state. However, a further extension is necessary for atmospheric systems.
In the Earth's atmosphere many important non-equilibrium processes take place; for example, freezing of super-cooled water, and evaporation into subsaturated air.
To fully capture processes such as these, the equilibrium method must be reformulated to involve finite rates of approach towards equilibrium.
Here the principles of non-equilibrium thermodynamics are used, beginning with a set of phenomenological equations, to show how non-equilibrium moist processes may be coupled to a semi-implicit semi-Lagrangian dynamical core.
A standard bubble test case and simulations of cloudy thermals are presented to demonstrate the viability of the approach for equilibrium thermodynamics, as well as the more complex non-equilibrium regime.

**Wednesday Afternoon 1 June: Coupling Techniques I / 12**

## What timestep do we need… and how do we afford it?

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Most coupling problems result from using an overly long timestep. As an example, numerically accurate microphysics in version 1 of the Energy Exascale Earth System Model (E3SMv1) is shown to require a timestep which is an order of magnitude shorter than what is used in climate models today. Given this, how can we afford to perform accurate simulations? The answer lies at the intersection between physics, numerical analysis, and software engineering. Recent advances in coupling software are shown to be critical for obtaining the right answer fast.

**Thursday Afternoon 2 June: Physics-Dynamics Interactions II / 39**

## iDust - an inline dust prediction system powered by FV3-based SHiELD NWP system

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High-impact dust events affect humans from multi-scale perspectives, including long-range transportation to local Haboobs. High-resolution dust prediction models usually use a regional domain due to computational limitations, and although they resolve small-scale local events with high fidelity, it lacks long predictability skills due to low-accurate lateral boundary conditions. On the contrary, global dust models are good at capturing averaged aerosol dust impact in a more extensive range and at a longer time scale but cannot capture sufficient details and amplitude of local small-scaled hazardous events due to relatively lower resolution and highly uncertain sub-grid physical parameterizations. On the other hand, the offline dust transportation approach, such as GOCART, is still essential in dust-related research but consequently is less accurate and less capable for real-time tasks than traditional NWP applications. This work attempts to fully integrate a set of light-weighted GOCART dust algorithms into the FV3-based SHiELD NWP system at a 12-km global resolution to resolve multi-scale major dust events while maintaining significant predictability for a few days. iDust does not couple costly complete dust/aerosol chemistry packages, keeping only the essential surface-layer dust algorithms, including emission and dry deposition, and achieves high computational efficiency via directly resolving related dynamical processes, including sedimentation and wet scavenging. The new "inline" dust integration treatment is significantly more efficient than the traditional chemistry parameterization packages and more accurate via dynamical-core-powered direct resolving wind-driven processes leveraging the high resolutions of the weather prediction models. This newly developed iDust has been validated using several major dust events from 2020 to 2021. The fully integrated inline dust algorithm only requires less than 10% additional computing power than the original SHiELD system. The transfer of iDust to the GPU platform is also underway.

**Thursday Morning 2 June: Coupling Techniques II / 29**

## Exploring Two Coupling Strategies of the Boundary Layer and Convection Schemes in GFDL AM4

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Most general circulation models (GCMs) represent boundary layer turbulence by eddy-diffusivity (ED) schemes, and convection by mass-flux (MF) schemes. Because boundary layer and convective processes closely interact with each other, the ED and MF schemes should be coupled appropriately. This study explores two coupling strategies of the ED and MF schemes using GFDL AM4, namely, (1) the "ED-then-MF" strategy: the MF scheme is called after the ED scheme and the MF scheme "sees" the atmospheric state updated by ED. The underlying philosophy is that the ED "diffuses" steep gradients arising from surface fluxes and radiative transfer and then the MF scheme acts to reduce remaining instability; and (2) the "ED-and-MF" strategy: both the ED and MF schemes "see" the same atmospheric state, and the MF tendencies are included into the ED tendency calculations. The underlying philosophy is that the ED and MF processes are closely related and interacted, so these two processes should see the same state and be treated simultaneously. To quantify how these two coupling strategies affect the simulated climate, we use GFDL AM4 and carry out parallel 15-year AMIP simulations for each strategy. Preliminary results show that the simulated climate using both strategies exhibit similar features in terms of global mean and spatial patterns. In addition, the Cess climate sensitivity is almost identical. We may conclude that given the same ED and MF schemes, the simulated climate is not sensitive to the coupling strategies of the ED and MF schemes for AM4.

**Wednesday Afternoon 1 June: Coupling Techniques I / 18**

## Correcting a coarse-grid climate model in multiple climates by machine learning from global 25-km resolution simulations

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While counterexamples can be found, running atmosphere models at fine resolution generally leads to better simulation of several aspects of the observed climate, e.g. the spatial distribution of precipitation. This can be attributed in part to tendency errors introduced by physical parameterizations at coarse resolution. At AI2 we have developed an approach that uses nudging to diagnose these errors, and then machine learning (ML) to predict state-dependent corrections at each model timestep. This approach was used successfully to help a 200 km version of NOAA's full-geography FV3GFS model evolve more like a 3 km version of GFDL's SHiELD model over a 40-day period (Bretherton et al., 2022).

Here we will discuss an extension of this work to multiple climates and multi-year ML-corrected simulations. We start from four fine-resolution 25 km two-year reference simulations run using FV3GFS with climatological sea surface temperatures perturbed uniformly by -4 K, 0 K, +4 K, and +8 K. A dataset of state-dependent corrective tendencies is then derived through nudging the 200 km model to the coarsened state of the fine-resolution simulations in each climate. Along with the surface radiative fluxes, the nudging tendencies of temperature and specific humidity are machine-learned as functions of the column state. ML predictions for the fluxes and corrective tendencies are applied in 1+ year 200 km resolution simulations in each climate, and improve the spatial pattern errors of land precipitation by up to 30%. In addition to these results, we will touch on the technical solution we use to couple these ML parameterizations to prognostic simulations, as well as the challenges associated with achieving consistently stable multi-year ML-corrected runs.

**Friday Morning 3 June: Theory of Coupling / 34**

## Multiscale geometric mechanics formulations for GFD parameterization

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Geophysical flows are highly multiscale, without scale gaps and involving upscale and downscale exchanges of energy and entropy. These exchanges are physically consistent: they obey the 1st and 2nd laws of thermodynamics. Unfortunately, computational resources limitations prevent fully resolved simulations and lead to a mismatch of many orders of magnitude between the simulation scales (O(100)m at the very best, and usually much coarser) and the natural scales (O(mm) to O(cm)). This leads to the problem of parameterization: how to represent the effects of the unresolved (subgrid) scales on the resolved scales. Unfortunately, most existing approaches to parameterization often lose physical consistency, and therefore require the use of energy fixers and other artificial, unphysical mechanisms.

In fully resolved models, physical consistent is elegantly encoded in geometric mechanics formulations (variational/Lagrangian, Hamiltonian, metriplectic, etc.). This suggests a new approach towards physically consistent parameterization: develop multiscale geometric mechanics formulations. Indeed, there are two existing physically consistent approaches that do exactly this: mimicking the irreversible parts of the Navier-Stokes-Fourier (NSF) equations (first developed by Almut Gassmann) and Stochastic advection by Lie transport (SALT). However, both of these have limitations: mimicking NSF limits the resolved/unresolved exchanges to behave like irreversible processes, and SALT only supports subgrid variability in the velocity field. Additionally, both approaches have no notion of unresolved reservoirs of energy/entropy.

Instead, we are pursuing a new idea: introduce novel degrees of freedom to represent subgrid variability for all variables, and use those dofs to construct models of both resolved and unresolved reservoirs of energy/entropy within a multiscale geometric mechanics formulation that allow for both reversible and irreversible exchanges. This talk will present progress towards this, with a focus on a multiscale representation of the velocity and the kinetic energy reservoirs.

**Wednesday Afternoon 1 June: Coupling Techniques I / 43**

## Common Community Physics Package: 2022 Update and Future Direction

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The Common Community Physics Package (CCPP) consists of a repository of physics schemes that adhere to a well-defined set of rules governing their data interface and a software framework for auto-generating "caps" that function as drivers for user-selectable collections (or suites) of compliant physics schemes. The intent and design of this package is to allow physics schemes to be "dycore-agnostic" such that physics may easily be shared across atmospheric modeling systems from many institutions. The Unified Forecast System (UFS) has adopted this package for many of its applications for current and future development and it is slated for operational use in the near future. Other partners include NCAR and NRL, whose flagship institutional models such as CESM, MPAS and WRF, and NEPTUNE, respectively, have adopted or are currently adopting the CCPP framework or contributing to CCPP physics in some way. Development of the CCPP thus far has endeavored to maintain as much flexibility for experimenting with physics-dynamics coupling as possible. Through participation in the PDC Workshops, CCPP developers hope to continue to learn of novel methods in the atmospheric modeling community so that their use may not be precluded by the CCPP software design. We will discuss the current status of the CCPP and pose discussion questions to the audience regarding the potential need for new functionality within the framework.

**Friday Morning 3 June: Theory of Coupling / 41**

## Boundedness and Stability of the Primitive Equations Governing Large Scale Atmospheric Behavior

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The primitive equations (PEs) are the core equations governing the events in the atmosphere. The PEs are derived from the Navier-Stokes (NS) and Boussinesq equations in domains which are small in the vertical direction compared to the horizontal ones. This justifies the assumption of a hydrostatic balance in the vertical direction which facilitate the use of the pressure coordinate system instead of the vertical coordinate. The continuity equation in this system takes the same form as for an incompressible fluid, which is an advantage gained by using the pressure coordinate system. Mathematical analysis of the primitive equations has been done in [1, 2].
In this presentation, we prove that the appropriate physical boundary conditions lead to an energy estimate of the solution to the equations. The numerical scheme for the PEs we introduce in this article is based on high order finite difference operators that satisfy a summation-by-parts rule with weak boundary conditions [3]. By mimicking the continuous energy analysis, the resulting discrete scheme is proven to be energy stable. Based on the numerical scheme proposed in this presentation, we test the model on a bounded domain to show the stability of the scheme and the high accuracy of the solution.
As a first step, a linear analysis of the coupling atmosphere-ocean was done in [4]. We are now aiming for a non-linear coupling, which as a second step requires this non-linear analysis of the PEs for atmosphere. Once this is done, we will proceed with the third and final step where we couple the PEs to the non-linear incompressible NS (INS) which describes the events the events in the ocean. The analysis of the INS is already completed [5]. In the later part of this presentation, we will discuss details of the upcoming nonlinear coupling.

References
[1] M. Petcu, R. M. Temam and M. Ziane. Some mathematical problems in geophysical fluid dynamics Handbook of Numerical Analysis vol 14 Special vol Computational Methods for the Atmosphere and the Oceans, Holland Publ.Co. Amsterdam. (2009).
[2] J. L. Lions, R. Temam and S. Wang, New formulations fo the primitive equations of atmosphere and applications, Nonlinearity. 5 (1992) 237-288.
[3] M. Svärd and J. Nordström, Review of summation-by-parts schemes for initial–boundary-value prob- lems , Journal of Computational Physics. 268 (2014) 17-38.
[4] F. Ghasemi and J. Nordström, An energy stable coupling procedure for the compressible and incom- pressible Navier-Stokes equations, Journal of Computational Physics. 396 (2019) 280-302.
[5] J.Nordströom and C.La Cognata, Energy stable boundary conditions for the nonlinear incompressible Navier-Stokes equations , Mathematics of Computation. 88 (2019) 665-690.

**Thursday Morning 2 June: Coupling Techniques II** / **27**

## Impact of shoaling waves on wind stress and drag coefficient in coastal waters

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Understanding of wind stress, or drag coefficient (Cd), in finite depth is important for improving numerical weather and storm surge prediction models. In most applications, Cd is assumed to be the same in open ocean (deep water) and coastal waters (finite to shallow depth). However, if the wind stress is dependent on sea state, Cd is likely different in shallow water compared to that in deep water, because the wave spectrum is significantly modified by decreasing depth (shoaling). This study investigates the impact of shoaling waves on wind stress using the WAVEWATCH III (WW3) model with shallow water physics. Uniform wind speed ranging from 5m/s to 50m/s and tropical cyclones moving normal to the coastline are used as wind forcing. The uniform wind results show that as water depth decreases, the drag coefficient increases gradually to a peak value and then rapidly decreases compared to its deep-water counterpart. The magnitude of Cd increase

can be as large as 30% and is sensitive to the bottom slope, with larger Cd enhancement on a steeper bottom slope. The maximum Cd is reached when depth-induced breaking starts to be significant. In the TC experiments, the drag coefficient is increased in the right-rear and the left-front quadrants and reduced in other quadrants compared to those in deep water. The wind stress direction is also modified compared to that in the deep water. Overall, the results show increased spatial variability of the magnitude and direction of wind stress at finite water depths as the TC approaches the coastline. This study provides support that the shoaling surface gravity waves in the coastal ocean can increase the air-sea momentum exchange outside the surf zone. Incorporating this effect into coastal ocean and atmospheric models can be essential to improve their performance under onshore wind conditions.

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## Multispectral High Resolution Satellite Measurements To Study Dynamical & Morphological Properties Of Meso-Scale Convective Systems & Develop Weather Research and Forecasting Model (WRFM) Over Tropics'.

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The multispectral high resolution satellites measurements intend to examine high resolution Satellite imageries with emphasis on the large scale kinematic and thermodynamic behavior of selected meso scale Convective Systems, e.g. intense Cloud Cluster s, Thunderstorms & Depressions by making use of Aircraft, Doppler Weather Radar and conventional data over the domain. Equipped with horizontal and vertical resolution ,the active Radars on two Satellites (TRMM and GPM) would be employed to investigate three dimensional structure of severe thunderstorms.

The diagnostic & evolutionary aspects of meso-scale convective systems e.g. cloud clusters and severe thunderstorms are to be studied through the new generations of geostationary satellites fitted with Lightning sensors & future constellation of CubeSats (TROPICS) carrying high-frequency passive microwave sensors.

The values of characteristics, e.g. lifetime, distribution, trajectories, size and three dimensional structure, i.e., vertical extent of these systems would be computed in order to develop a Medium Range Thunderstorm Forecasting Model(MRTFM) for South East Asian, Tropical ,Mid-latitudinal and the other regions over the Globe with seasonal & climatologically variations.
Attempt has been made to study Monsoon Energetic over Bay of Bengal by analyzing Cloud and Monsoon Depression fields during Summer Monsoon using TIROS-N Satellite imageries. Kinematic features of Disturbed Phases were studied in a LaGrange an frame to identify the evolutionary features of an associated Monsoon Depression .
The Time Series plot of Surface Pressure Gradient between selected station falling at almost the same longitude were plotted in order to correlate with the Disturbed Phases vis-a-vis evolution features of a Monsoon Depression . Kinematic features of the Disturbed Phases were correlated with the extracted Sea Surface Temperature (SSTs) to bring out a few optimum values of these to develop Depression Model. The same methodology would be repeated to study Morphological and Thermodynamic characteristics of severe Thunderstorms.
Following Cloud Cluster studies of Goswami ; the two plausible models of Monsoon Depression studies have been postulated in terms of Cluster Coalescence Theory (CCT) and Giant Cluster Theory (GCT). Based on this 'Cluster Coalescence Theory' (CCT) & 'Giant Cluster Theory '(GCT);the regional/sub-regional ' Medium Range Thunderstorm Forecasting Model(MRTFM) would be developed by using High Resolution Satellite imageries of Cube Sats (TROPICS), data access, assimilation; HPC and cloud computing for real-time analysis.
Thermodynamic structure of Monsoon Depression & severe Thunderstorms would be developed by computation of deep convective mass transport inside the Cloud Cluster & thunderstorm-cell through Cloud Tracer Analysis .
Next, Morphological and Dynamical properties of other mesoscale convective systems, Thunderstorms in particular & Tele-connection of SH features with the identical features of NH of these

weather systems are to be investigated through Geostationary Satellite Imageries & LIDAR enabling the precipitation and related severe weather hazards forecasting.

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## Enthalphy fluxes in EAM

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We present studies of enthalpy fluxes in the atmospheric model of E3SM (EAM). It is known that to improve water energy transfers within atmosphere and at its interface, it is required to treat thermodynamic processes involving water accurately. It is not exactly the case in EAM. We propose a series of steps that will allow us to gradually improve water energy transfers within E3SM.

**Thursday Morning 2 June: Coupling Techniques II / 24**

## Advances in Physics-Dynamics Coupling in the GFDL SHiELD prediction model

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GFDL has developed the System for High-resolution prediction on Earth-to-Local Domains (SHiELD) as a platform in which to test new ideas in numerical modeling with a focus on seamless modeling on scales from short-range weather prediction to seasonal to subseasonal timescales. The FV3-based SHiELD includes a number of physical innovations, most notably an integrated microphysics energetically consistent with the nonhydrostatic dynamics, as well as very tight and consistent integration with the physical parameterizations. We present results across a range of time and spatial scales, from seasonal-to-subseasonal prediction to short-range severe storm prediction and global cloud-resolving modeling. We find that enhancements in the integrated microphysics and better consistency with radiation and vertical turbulence have shown clear improvement in forecast skill and biases. We also find that SHiELD's simple mixed-layer ocean greatly improves the simulation of the Madden-Julian Oscillation and also further improves forecast skill and hurricane predictions. The integrated microphysics allows data assimilation cycling to take advantage of all-sky radiances within operational global models. We close with discussion of experimental integrated dust processes within FV3 to help further advance physics-dynamics integration within SHiELD.

**Wednesday Morning 1 June: Physics Dynamics Interactions I / 22**

## The role of subgrid winds on precipitation biases in E3SMv1

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Precipitation is an important climate quantity that is critically relevant to society. In spite of intense efforts, significant precipitation biases remain in most climate models. Using the DOE-E3SM model version 1, the inclusion of a missing process, convective gustiness, is shown to reduce a pervasive and persistent bias found in many general circulation models that occurs in the Tropical West Pacific. Convective gustiness increases surface evaporation, which acts as an energy source to invigorate the large-scale circulation. A normalized gross moist stability framework is used to diagnose the impact surface evaporation has on the precipitation response to gustiness. Including the impact of another subgrid-scale process, the large eddy wind variance taken from the Cloud Layers Unified by Binormals subgrid turbulence and shallow convection scheme, shows reductions in the Amazon dry bias. These results highlight the importance of interactions between the resolved and subgrid-scale processes, particularly in regions where the resolved surface winds are weak and convection is favorable.

**Thursday Morning 2 June: Coupling Techniques II / 11**

## Climate and Computational Savings of the Lower Resolution Physics Grid in CESM

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The lower-resolution physics grid option in CESM is evaluated in both an AMIP-style simulation and fully-coupled with active ocean/sea-ice components, and compared against the standard configuration in which the physics and dynamics grids coincide. As topography boundary conditions are on a coarser grid than in the standard configuration, a portion of this talk will focus on model fidelity in mountainous regions. This includes an analysis of the orographic precipitation patterns around the Greenland coasts, and impacts on the surface mass balance of the Greenland Ice Sheet. The fully-coupled simulation is evaluated against the standard configuration, with an emphasis on differences in oceanic mean state. The focus of this talk will then shift to a detailed assessment of the computational savings of the lower-resolution physics grid, which are quite substantial.

**Friday Morning 3 June: Theory of Coupling / 23**

## Assessing the interaction between dissipation and physical processes in FV3-based GCMs via idealized test cases

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The paper explores how the dissipative processes in the FV3 dynamical core interact with physical parameterizations in GCMs. The FV3 cubed-sphere dynamical core has been developed by NOAA's Geophysical Fluid Dynamics Laboratory (GFDL). It is now used as the dynamics driver in GFDL's model framework, in various applications of NOAA's Unified Forecast System (UFS), and has become an optional dynamical core for NCAR's Community Earth System Model (CESM). The research assesses how implicit numerical diffusion and explicitly-added dissipation processes impact the evolution and strengths of weather systems in short deterministic forecasts as well as the properties of waves and precipitation in climate-like simulations. The research is built upon a hierarchy of idealized test scenarios that increase in their complexity. They include dry Held-Suarez configurations, moist baroclinic waves, and aqua-planet assessments with complex physics schemes that utilize the CESM 'Simpler Model' framework. It is found that the FV3 dissipation settings have a profound impact on the physics-dynamics coupling, and a further fine-tuning of the dissipation is needed to guarantee both stability and accuracy of the simulations.

**Friday Morning 3 June: Theory of Coupling** / **33**

## Reconciling and improving formulations for thermodynamics and conservation principles in Earth System Models (ESMs)

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Closing the energy budget in Earth System Models (ESM) is conceptually challenging and hard to achieve in practice without resorting to ad hoc fixers. As a concrete example, the energy budget terms are diagnosed in a realistic climate simulation using a global atmosphere model. The largest total energy errors in this example are spurious dynamical core energy dissipation, thermodynamic inconsistencies (e.g. coupling parameterizations with the host model) and missing processes/terms associated with falling precipitation and evaporation (e.g. enthalpy flux between components). The latter two errors are not, in general, reduced by increasing horizontal resolution. They are due to incomplete thermodynamic and dynamic formulations. Future research directions are proposed to reconcile and improve thermodynamics formulations and conservation principles.

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## Improved Climate Simulation by using a Double-Plume Convection Scheme in a Global Model

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Convective parameterization can drastically regulate the mean climate and tropical transient activity of a general circulation model. In this study, the physics suite of the NCAR Community Atmosphere Model, version 5 (CAM5) was first ported to the GRIST (Global-to-Regional Integrated Forecast System) model. Then, the original convective parameterization of CAM5—with a separate representation of deep convection (Zhang–Mcfarlane; ZM) and shallow convection (University of Washington; UW)—was replaced by a double-plume (DP) scheme. This DP scheme adopts a quasi-unified representation of shallow and deep convection within a single framework. Results demonstrate that the new scheme brings about several improvements in the modeled climate. The differences in the trigger and closure assumptions, lateral mixing rate, and cloud model for the deep convection result in systematic regional differences in the simulated precipitation pattern, cloud vertical structure, and the associated radiative forcing. Compared with ZM-UW, DP reduces the biases in precipitation over the Indian Ocean, ameliorates the "high-frequency and low-intensity" problem of tropical precipitation, and leads to an improved representation of tropical variability, including the Madden–Julian Oscillation. DP reduces low clouds and increases high clouds in the tropics, due to its internal parallel-split convective processes and smaller cumulus cloud fraction. Discussions related to parametric tuning of convective parameterization are also presented.

**Wednesday Morning 1 June: Physics Dynamics Interactions I / 25**

## Design and Performance of a global prediction system based on the "Super Dynamics on the Cube"

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A new generation of global cloud-resolving modeling system is being developed, based on the concept of "Super Dynamics on the Cube" (SD3). SD3 represents a dramatic departure in the model design, by merging the traditional "dynamical core" with "sub-grid physical parameterizations". The sub-grid physics includes all the moist processes (cloud microphysics and 3D gray-zone convective parametrization), sub-grid mountain induced drag (blocking), and upward propagating gravity wave drags. The merger of the dynamics and physics serves dual purposes: 1) it enables fast and more accurate interaction between the adiabatic (dynamical) and non-adiabatic (physical) processes.; 2) it dramatically enhances the computational efficiency on HPC with modern accelerators (e.g., GPU), achieving roughly a ten-fold speed-up versus modeling system with comparable resolution.

Due to the dramatic increase in computational efficiency, it is now operationally affordable to perform real-time weather predictions using the SD3 based global modeling system at cloud-resolving resolution. The computational performance can be further improved by using a smoothly varying global grid that preserves the accuracy of the synoptic scale on the whole sphere, while simultaneously reaching the desired 1-3 km resolution over a very large region (e.g., the whole Asian continent). The NWP skill of this newly developed operational global cloud-resolving system is evaluated using several commonly used NWP metrics. The key metrics being evaluated are the precipitation and the "Anomaly Correlation Coefficients" (ACC) of the 500mb heights, both are found to be highly competitive with the leading NWP centers (ECMWF and NCEP).

**Wednesday Afternoon 1 June: Coupling Techniques I / 31**

## AN EXTREME VARIABLE GRID MODEL FOR LOCAL HIGH-RESOLUTION WEATHER FORECASTS FROM GLOBAL INITIAL DATA

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Global models are desirable in many ways. For example, they do not depend on boundary updating and do not inherit potential inaccuracies from the driving model(s). Also, undesirable artifacts from traditional nested modelling strategies, such as step changes at the boundaries and relatively coarse time sampling, can be avoided. On the other hand, high-resolution models are also desirable, as

local orography and surface types can strongly influence the forecast, especially when local forecasts and not just general trends are sought. However, high-resolution global models are expensive, due to their high demand of computing resources. This is where variable resolution models have an advantage because the grid can be refined at will in the area of interest, whilst keeping it coarse in other areas.
Here we present a global, variable resolution weather forecasting model that has been pushed to the extreme. We have kept the very coarse resolution in most parts of the globe and have refined it to a very fine resolution around the port of Ensenada, Baja California, Mexico. Comparisons of the model predictions with the forecast from the model providing the initial state show that the downscaled model certainly improves on this forecast in most of the local weather stations used for model testing. Where the resolution degrades, so does the forecast, as one would expect. The downscaled model predictions are also compared to a forecast from a collection of analyses from the HRRR, a best-case scenario, as the analysis already includes the most recent observations. The HRRR data as such does not qualify as a forecast, but it is interesting to see how the variable mesh fares compared to it, for example for retrospective or climate studies.

**Wednesday Afternoon 1 June: Coupling Techniques I / 45**

## Resolved gravity waves in the stratosphere: Impact of horizontal resolution increase from O(10 km) to O(1 km)

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Gravity waves (GWs) in the stratosphere contribute to the driving of the quasi-biennial oscillation and to the deceleration of the polar vortices and the subtropical jets. Global ECMWF IFS simulations with horizontal grid-spacings of 1 km, 4 km and 9 km are used to assess resolved gravity wave forcing (GWF) from larger-scale (with horizontal wavelengths 2000-100 km) and smaller-scale (with horizontal wavelengths <100km) GWs in the tropical and extra-tropical stratosphere. Results with implications for GWF parameterizations at high and intermediate resolutions are presented.

In the tropics, deep convection parametrisation is shown to inhibit resolved convectively generated GW generation. When deep convection is represented explicitly, total resolved GWF from convectively generated waves is insensitive to an increase in the horizontal resolution. However, there is no convergence of larger-scale GWF with resolution: Representing deep convection explicitly at 4 km (and 9 km) generates too strong larger-scale GWF in comparison to the 1 km simulation and to the simulations with parametrized deep convection. This is due to too strong latent heating at larger scales. Therefore, a parametrization of deep convection is still required at 4 km, together with a parametrization of non-orographic GWF to account for the missing forcing from the unresolved smaller-scale waves. In the extra-tropics, total resolved GWF increases with an increase in the horizontal resolution. This is due to an increase in smaller-scale GWF over orographic and non-orographic regions. Therefore, parametrizations GWF are still required at 4 km and 9 km grid-spacings.

**Thursday Afternoon 2 June: Physics-Dynamics Interactions II / 19**

## Energetically Consistent Boundary Layer Parameterization for Ocean Climate Models

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Ocean surface boundary layer parameterizations are used to compute vertical turbulent fluxes in the upper ocean for regional and global ocean models. In many cases, the fluxes predicted by the parameterizations are sensitive to choices made by the calling dynamical model, such as the vertical grid and time discretization. This leads to a situation where a parameterization and a particular set of parameterization tunings may give different results if used in different models. For example, regional ocean models typically use short time steps compared to global models and ocean models often make different choices for discretizing the vertical grid, significantly affecting the near surface vertical resolution. As part of the development of GFDL's latest ocean model (MOM6), a new surface boundary layer parameterization, ePBL, has been developed that is specifically constructed to reduce such dependencies on decisions made within the dynamical model. One important component of such design is an emphasis on energetic consistency between the energy available to drive mixing at the base of the boundary layer and the parameterized fluxes. By achieving this goal, ePBL is able to yield reliable answers on the relatively long time steps and coarse vertical grids used in climate models without requiring additional parameter tuning. In this presentation we discuss the details behind the ePBL implementation to avoid sensitivity to time-step and vertical grid and discuss the implications of achieving such independence from the calling model for ocean modeling across various time-scales.

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## The CAMS Climate System Model and a Basic Evaluation of its Climatology and Climate Variability Simulation

**Author:** Xinyao Rong[None]

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A new coupled climate system model (CAMS-CSM) has been developed at the Chinese Academy of Meteorological Sciences (CAMS) by employing several state-of-the-art component models. The coupled CAMS-CSM consists of the modified atmospheric model ECHAM5, ocean model MOM4, sea ice model Sea Ice Simulator (SIS), and land surface model Common Land Model (CoLM). A detailed model description is presented and both the pre-industrial and "historical" simulations are preliminarily evaluated in this study. The model can reproduce the climatological mean states and seasonal cycles of the major climate system quantities, including the sea surface temperature, precipitation, sea ice extent, and the equatorial thermocline. The major climate variability modes are also reasonably captured by CAMS-CSM, such as the Madden-Julian Oscillation (MJO), El Niño-Southern Oscillation (ENSO), East Asian Summer Monsoon (EASM), and Pacific Decadal Oscillation (PDO). The model shows a promising ability to simulate the EASM variability and the ENSO-EASM relationship. Several biases still need further improvement, such as the double-intertropical convergence zone (ITCZ) in the annual mean precipitation map, overestimated

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## Short Biases in Mountains Cause Western U.S.A. Wet Biases in GFDL CM2.5-FLOR

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A common bias in comprehensive Global Climate Models (GCMs) is overestimation of precipitation in the western U.S.A., which limits our confidence in how the climate of this region may change in the future. Prior work has suggested this bias is partially due to SST biases in atmosphere-ocean coupled GCMs. In this work we explore the alternative possibility that GCMs' portrayal of the complex terrain of this region, namely the high elevation Rockies, Cascades, and Sierra Nevada, leads to this wet bias. In GCMs, placing observed topography on a model grid smooths out observed mountain peak heights, which may reduce their impacts on circulation. To investigate the role of mountain peak height on the precipitation biases, we use the GFDL CM2.5-FLOR model (~0.5° res. atmosphere,~ 1° res. ocean) to simulate climate with altered topography. Our simulation, called HiTopo, changes the surface height in every grid cell from the average observed elevation in that cell to the maximum. We find that the HiTopo simulation does a noticeably better job than the Control (standard surface height) simulation at simulating precipitation patterns over the Western U.S.A., especially during northern hemisphere winter (DJF). In our search to determine what causes this improvement, we find the stationary wave pattern associated with the raised surface height causes a weaker westerly flow from the Pacific Ocean, and a southward shift in the jet stream. This in turn reduces moisture coming into the western U.S.A. and precipitation in this region. Additional investigation includes a moisture budget analysis and examination of whether the forcing is driven primarily by local mountains (the Rockies) or by distant ones (the Tibetan Plateau and Himalayas). Possible implications for future projection of western U.S.A. precipitation and snowpack will be discussed.

**Thursday Afternoon 2 June: Physics-Dynamics Interactions II / 44**

## Physics, Dynamics and Coupling in the UK Met Office atmospheric models

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The UK Met Office provides weather forecasts and climate predictions at a range of timescales, for different domains of interest and at varying levels of complexity. For example, global deterministic model forecasts are currently carried out 4 times a day with ~10km horizontal resolution, while more detailed short-to-medium-range forecasts over the UK are run more frequently with regional models using a 1.5km resolution. Seasonal and climate configurations use lower resolutions, but with additional complexity in the physics packages and coupling to ocean and sea ice models.

Underpinning all of these activities is the Unified Model(UM) - designed to be seamless across the range of scales and applications. The UM has served well for several decades, but recently we have been developing a new model, named LFRic, aiming to retain the scientific skill of the UM, but also to provide better computational performance on the next generation of computer architectures. The seamless approach developed in both the UM and LFRic, i.e. retaining a common dynamical core and physics package applicable at all scales, brings with it many benefits and challenges for model development. Consideration must be given to the underlying equation set (e.g. non-hydrostatic, deep), thermodynamic choices (e.g. moist heat capacities), conservation properties, scale-awareness and, of course, efficient time-to-solution. In this talk I will outline the physics and numerics used in the dynamical cores, the subgrid parametrizations and the coupling between them.

**Thursday Morning 2 June: Coupling Techniques II / 9**

## Improving solution accuracy and convergence for stochastic physics parameterizations with colored noise

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Stochastic parameterizations are used in numerical weather prediction and climate modeling to help capture the uncertainty in the simulations and improve their statistical properties. Convergence issues can arise when time integration methods originally developed for deterministic differential equations are applied naively to stochastic problems. (Hodyss et al 2013, 2014) demonstrated that a correction term to various deterministic numerical schemes, known in stochastic analysis as the Itô correction, can help improve solution accuracy and ensure convergence to the physically relevant solution without substantial computational overhead. The usual formulation of the Itô correction is valid only when the stochasticity is represented by *white* noise. In this study, a generalized formulation of the Itô correction is derived for noises of any color. The formulation is applied to a test problem described by an advection-diffusion equation forced with a spectrum of fast processes. We present numerical results for cases with both constant and spatially varying advection velocities to show that, for the same time step sizes, the introduction of the generalized Itô correction helps to substantially reduce time integration error and significantly improve the convergence rate of the numerical solutions when the forcing term in the governing equation is rough (fast varying); alternatively, for the same target accuracy, the generalized Itô correction allows for the use of significantly longer time steps and hence helps to reduce the computational cost of the numerical simulation.

**Thursday Morning 2 June: Coupling Techniques II / 6**

# A unified and Python-based approach to the physics-dynamics coupling in atmopsheric models

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We present a numerical analysis of six strategies to couple the dynamical core with physical parameterizations in atmospheric models. The algorithms are outlined on a generic problem and then applied to two idealized test beds: the two-dimensional viscid Burgers' equations and a hydrostatic model which employs the potential temperature as vertical coordinate. The latter is used for vertical slice simulations of moist airflow past an isolated bell-shaped mountain. Both models are set on Cartesian grids and discretized via finite differences combined with two-time-levels integrators. A grid refinement study is carried out on both applications, holding the ratio between the grid size and the timestep constant. In the mountain flow problem, grid spacings from $\mathcal{O}(10)$ km down to $\mathcal{O}(100)$ m are used. We show that the sensitivity of the prognostic variables to the coupling mechanism may vary. For those variables (e.g. momentum) whose evolution is largely driven by the dry dynamics, the truncation associated with the dynamical core dominates and hides the error due to the coupling. On the other hand, the coupling error on the precipitation rate emerges gradually as the grid resolution increases, with each scheme eventually adhering to the formal order of convergence. Particularly, quadratic convergence is observed for two methods - the so-called full coupling and the Strang splitting. Potential implications for a full-fledged model are discussed with an eye on performance. All the results are obtained in Python using a library intended to ease the development of Earth system models. To overcome the intrinsic slowness of the Python interpreter,

all mathematical operators are implemented on top of a domain specific library (DSL) which generates high-performance stencil kernels for different computer architectures starting from a high-level definition.

**Friday Morning 3 June: Theory of Coupling / 35**

## An Error Analysis Framework for Process Coupling in Atmospheric Models

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The Energy Exascale Earth System Model (E3SM), like many other global system models, consists of modular components that are each responsible for a different subset of processes in the global system. Typically, the system state is advanced in time by sequential splitting: the state is advanced by a single process at a time and then passed to the next process in a predetermined sequence. While sequential splitting is very straightforward to implement with modular components, as one component simply passes the updated state to the next component, the associated splitting error is highly dependent on the ordering of the processes in the sequence. Various other splitting methods have been considered in the atmosphere community, including parallel splitting where all components operate in parallel on the same state and then combine all the resulting states into a single updated state. The presence of subcycling/substepping in one or more components brings the opportunity for even more approaches, including multirate infinitesimal step (MIS) methods and "dribbling" methods that distribute the action/tendency of one process across the subcycles/substeps of another process.
This work introduces an error analysis framework for identifying the splitting error independent of the other temporal discretization errors. Using a semi-discrete approach, the framework avoids requiring details of the internal component time integration schemes by assuming the integration is done exactly. This work uses the framework to evaluate sequential splitting, parallel splitting, "dribbling", and MIS methods applied to a two-process system with subcycling/substepping. The results are interpreted in the context of coupling the cloud processes component of the E3SM atmospheric model (namely, CLUBB and MG2) with the rest of the E3SM atmospheric model components (dynamics, radiation, etc.). This work will compare the costs and benefits of the various methods against the current sequential splitting approach.
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**Thursday Morning 2 June: Coupling Techniques II / 21**

## Improving the numerical accuracy and physical realism of process coupling in an atmospheric general circulation model

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Complex interactions among atmospheric processes like radiation, convection, boundary layer turbulence, cloud microphysics, aerosols, and large-scale dynamics can be an important aspect affecting the evolution of the atmospheric state. These interactions can also be a substantial source of numerical error in atmospheric general circulation models used in numerical weather prediction and climate research. This presentation gives an overview of our recent and ongoing efforts to quantify, attribute, understand, and reduce time integration errors related to process coupling in the atmosphere component of the Energy Exascale Earth System Model (E3SM).

Our methodology consists of multiple components: (1) a strategy for carrying out sensitivity experiments with E3SM to quantify time integration error and attribute it to individual processes and their coupling, (2) an online diagnostic tool with conditional sampling and budget analysis capabilities for revealing process-level characteristics of the E3SM simulations, (3) simplified models that identify key features of the numerical methods and physical mechanisms affecting model behavior, (4) theoretical error analyses that help to explain model behavior from the applied math perspective and identify alternate coupling methods with potentially higher accuracy.

We will show that this suite of tools has helped us to substantially reduce time-step sensitivities in several aspects of the model's long-term climate including, e.g., the subtropical marine stratocumulus and trade cumulus, as well as the aerosol lifecycle. We will also discuss the plans for future work.

**Thursday Afternoon 2 June: Physics-Dynamics Interactions II / 20**

## Modeling the Coupled Cycles of Dust and Water with the NASA Ames Mars Climate Model

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The outstanding problem for simulating the present Mars climate is representing the spatial and temporal variability of aerosols and the feedbacks that connect dust raising and transport with the evolving atmospheric circulation. A particular challenge has been the inability of Mars global climate models (MGCMs) to realistically simulate seasonal and interannual variability, most notably in the occurrence of regional and planetary-scale dust storms.

The current version of the NASA Ames Mars GCM is based on the NOAA/GFDL FV3 finite volume atmospheric dynamical core that has been implemented on a cubed-sphere grid. The modeling has been carried out with resolutions ranging from 4° x 4° (C24) to 0.125° x 0.125° (C768). The MGCM includes surface and subsurface physics, which allow the calculation of realistic surface temperatures and accounts for the reservoirs of dust and water for the planet, which influence where dust has been lifted and deposited on the surface. Water ice clouds on Mars are made of water ice crystals nucleating on airborne dust particles. We represent the water cycle by including water sublimation, water ice cloud nucleation, growth, transport, and gravitational sedimentation. For current day Mars simulations, the North Polar Residual Cap (NPRC) is assumed to be the only source of atmospheric water, though subsurface ice reservoirs likely play an important role in the past climate. We employ both bins and/or moments to represent the evolving spatial distributions of dust and cloud particle sizes. Simulated water ice clouds, particularly those that tend to form over the NPRC during summer, can be quite sensitive to the time step used for the microphysical calculations. To mitigate this issue, we have implemented a time splitting scheme. The radiation code is used to

account for solar and infrared radiative heating by gaseous $CO_2$ and atmospheric aerosols. Aerosol heating rates are calculated using the optical properties of the evolving aerosol size distributions and composition.

There is strong evidence that radiatively active water ice clouds contribute to the thermal structure of the atmosphere, both in the tropics and in the vicinity of the polar hoods that develop along the seasonally-varying $CO_2$ ice caps. Our simulations suggest that radiative cooling by polar hood clouds can influence the structure of the polar vortex during the spring and fall seasons. The resulting changes to the westerly jet embedded in the polar vortex can significantly influence transient wave characteristics and thus dust lifting activity.

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## Understanding Precipitation Characteristics and Sensitivity Over East Asia in AMIP simulations of the GRIST model

**Authors:** Yi Zhang[1] ; Rucong Yu[1] ; Jian Li[1] ; Xiaohan Li[1] ; Xinyao Rong[1] ; Xindong Peng[1] ; Yihui Zhou[1]

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GRIST (Global-to-Regional Integrated forecast SysTem) is a model system designed for unified weather-climate modeling within a single framework. In this presentation, we demonstrate a process of understanding the model behaviors by using a series of sensitivity experiments, with a special focus on the dynamics-physics interaction. The objective for understanding is precipitation characteristics over East Asia. The model shows a reasonable mean state, seasonal variation, frequency–intensity structure, and diurnal phase time. The regional features characterized by "afternoon versus nocturnal-to-early-morning peaks" are properly distinguished. The hourly climatic features have been compared with super-parameterized CAM5 and are overall comparable. Different dynamical configurations demonstrate unique sensitivities related to underling physical mechanisms, which are studied from the perspective of the diurnal cycle for some representative regions. Over South China, the higher-resolution models decrease the weak-precipitation while increase intense rainfall, thus reducing the dry biases. This is contributed by enhanced grid and sub-grid scale motions associated with daytime convection progression. Over central western China, the variable-resolution model better simulates the eastward propagating episodes characterized by a transition from convective to stratiform rainfall along the eastern slope of the Plateau. This reduces the positive biases at the high topography of the Plateau and alleviates the negative biases at the lower foot. Over central eastern China, the model replicates the dominant role of large-scale governing factors in regulating the early morning rainfall peaks, and produces stratiform heating patterns. Meanwhile, at the southern slope of Tibetan Plateau, the precipitation field also shows a sensitivity to advection transport schemes. This is due to the inherent relation between condensation-advection process and sub-grid numerical reconstruction. Some of these model features/sensitivity is specific to the choice of the physics suite. This work demonstrates how interactive dynamics-physics processes change the model behaviors under different configurations.

**Wednesday Afternoon 1 June: Coupling Techniques I / 40**

## Integrated Dynamics-Physics Coupling in GFDL-SHiELD

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Atmospheric models consist of two main parts: dynamical core and physical parameterizations. Traditionally, dynamical cores and physical parameterizations have been engineered in isolation for the

sake of tractability (Gross et al. 2018, and references therein). These two independent components are coupled and are integrated using the same time step, following either parallel splitting or sequential splitting (Ubbiali et al. 2021). Ubbiali et al. (2021) analyzed six strategies of dynamics-physics coupling in atmospheric models. They emphasized that the coupling remained an open problem in atmospheric modeling and were conscious that significantly more effort is required to fully understand the implications for a full-fledged model. Gross et al. (2018) stated that dynamics-physics coupling is challenging from time-stepping of different components to understanding of the role of coupling, from thermodynamics compatibility to further coupling with ocean and land. In summary, Dynamics-physics coupling is complicated, mainly reflected in the three following aspects. 1) Dynamical cores and physical parameterizations have different physical time scales. 2) Thermodynamics definition and conservation between the dynamical core and physical parameterization are usually different. 3) The dynamical core and physical parameterizations have traditionally been separated in models.

We demonstrate a proposed integrated dynamics-physics coupling framework in Geophysical Fluid Dynamics Laboratory (GFDL)'s System for High-resolution prediction on Earth-to-Local Domains (SHiELD), and propose this idea for any weather and climate-scale models. First, each physical parameterization in current models is reconstructed based on their natural time scale, revised to include a moist thermodynamic relationship, and finally integrated into the relevant components of the dynamical core. An example of an integrated cloud microphysics scheme in GFDL-SHiELD is provided to demonstrate the superiority of this concept. Statistics gathered from one year of weather forecast experiments show significantly better prediction skills when the model is upgraded to use the integrated dynamics-physics coupling. This successful development promotes the next step to integrating the convection, boundary layer turbulence, and orographic drag into the dynamical core in GFDL-SHiELD in the coming few years.

**1**

## Registration & Welcome