Physics-dynamics coupling and task parallelism

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Dynamics Research

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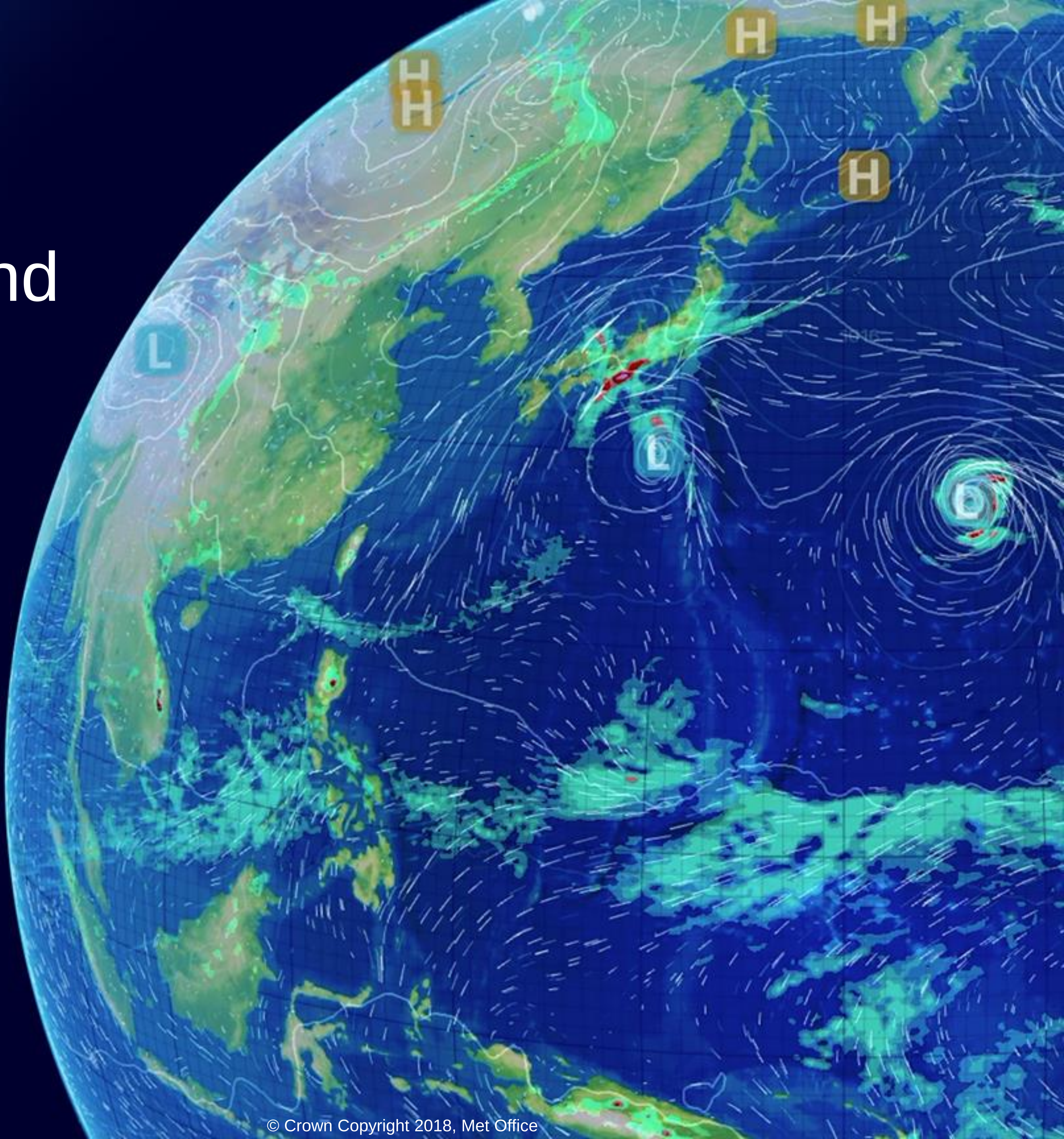


Plan

- History
- Physics-dynamics time stepping
- All physics parallel?
- Physics forcing
- Physics-dynamics coupling

History

- 1990 Split-explicit Hydrostatic UM. Advection + sequential physics, 3 adjustment steps . Option to reduce advection time step if polar night jet was too strong. This led to running with longer (3x) physics time step in regional model, halving the cost and giving the same accumulated rainfall.
- 2002 Non-hydrostatic UM operational. SISL numerics. Used for regional and global NWP and climate modelling.
- Caya et al 1998. Consequences of using splitting method for implementing physical forcings in a semi-implicit semi-Lagrangian model.
- ECMWF Seminars: Recent developments in numerical methods for
- atmospheric modelling September 1998 The origin of noise in semi-Lagrangian integrations. Aidan McDonald
- 2003 Analysis of Parallel versus Sequential Splittings for Time-Stepping Physical Parameterizations, 2005 Mixed Parallel–Sequential-Split Schemes for Time-Stepping Multiple Physical Parameterizations

  Mark Dubal, Nigel Wood, Andrew Staniforth

Non- hydrostatic Unified Model

- New dynamics. Latitude-longitude C-grid staggering. Hybrid-height terrain-following vertical coordinate Charney-Philips vertical staggering. 2TL Semi-Lagrangian advection, semi-implicit time stepping with off-centring. Eulerian forward-backward continuity equation to conserve mass for climate. 3d Helmholtz solver GCR(k).
- Parallel slow physics, sequential fast physics shown to be appropriate time step coupling for long (semi-implicit) time steps.
- Variable resolution option developed for 1.5km UK model (UKV).
- Regional models use rotated latitude-longitude grid and nesting suite used to run LAMs anywhere.
- 2014 ENDGame version to reduce off-centring and cost of the solver.
- V-at-the-poles, semi-Lagrangian treatment of continuity equation, cheaper solver, iterative time-stepping.

Target scheme and time stepping

$$\frac{D\boldsymbol{X}}{Dt} = \boldsymbol{L}in + \boldsymbol{N}on + \boldsymbol{S}low + \boldsymbol{F}ast$$

where $\boldsymbol{S}low$ physics are radiation, microphysics (cloud and precipitation) and sub-grid orography (gravity wave drag and low-level blocking) and where $\boldsymbol{F}ast$ physics are surface exchanges, boundary layer mixing (vertical mixing) and convection (showers).

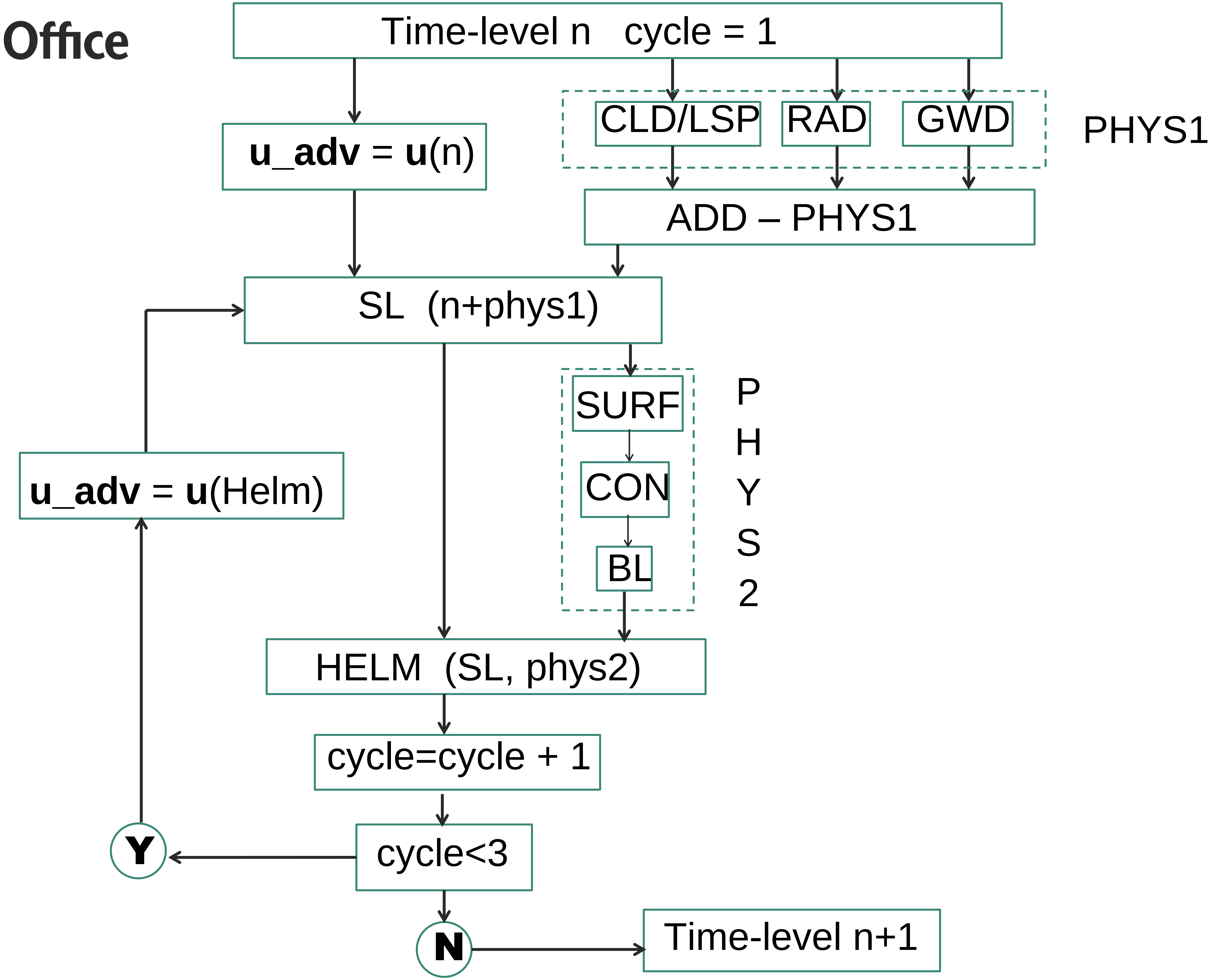
The target scheme is

$$\begin{aligned}\boldsymbol{X}^{\boldsymbol{n+1}} = {} & [\boldsymbol{X} + (1-\alpha)\Delta t(\boldsymbol{L}+\boldsymbol{N})]_d^n + (1-\alpha_S)\Delta t\boldsymbol{S}_d^n + (1-\ \alpha_F)\Delta t\boldsymbol{F}_d^n \\ & + \alpha\Delta t(\boldsymbol{L}+\boldsymbol{N})^{n+1} + \alpha_S\Delta t\boldsymbol{S}^{n+1} + \alpha_F\Delta t\boldsymbol{F}^{n+1}\end{aligned}$$

To reduce non-linear coupling and calculations, a suitable scheme may be written as

$$(\boldsymbol{X} - \alpha\Delta t\boldsymbol{L})^{n+1} = [\ \boldsymbol{X} + (1-\alpha)\Delta t(\boldsymbol{L}+\boldsymbol{N}) + \Delta t\boldsymbol{S}\ ]_d^n + \alpha\Delta t\boldsymbol{N}^* + \Delta t\boldsymbol{F}^{**}$$

where $\boldsymbol{N}^*$ and $\boldsymbol{F}^{**}$ represent appropriate estimates for time-level $n+1$.



Time-level n cycle = 1

u_adv = **u**(n)

CLD/LSP

RAD

GWD

PHYS1

ADD – PHYS1

SL (n+phys1)

SURF

CON

BL

PHYS2

u_adv = **u**(Helm)

HELM (SL, phys2)

cycle=cycle + 1

cycle<3

Y

N

Time-level n+1

Physics time stepping

$$(\boldsymbol{X} - \alpha\Delta t\boldsymbol{L})^{n+1} = [\boldsymbol{X} + (1-\alpha)\Delta t(\boldsymbol{L}+\boldsymbol{N}) + \Delta t\boldsymbol{S}]_d^n + \alpha\Delta t\boldsymbol{N}^* + \Delta t\boldsymbol{F}^{**} \qquad (1)$$

$\boldsymbol{S}low$ physics each operate from time-level n input

input so in theory they could be computed simultaneously, i.e. in parallel.

$\boldsymbol{F}ast$ mixing processes have smaller time-truncation error when they are computed using

the latest model state, i.e. mixing needs to be a sequential process.

If the time step is small enough, can $\boldsymbol{F}ast$ mixing processes also be run in parallel? Does

$$(\boldsymbol{X} - \alpha\Delta t\boldsymbol{L})^{n+1} = [\boldsymbol{X} + (1-\alpha)\Delta t(\boldsymbol{L}+\boldsymbol{N}) + \Delta t\boldsymbol{S} + \Delta t\boldsymbol{F}]_d^n + \alpha\Delta t\boldsymbol{N}^*$$

give similar results as equation (1)?

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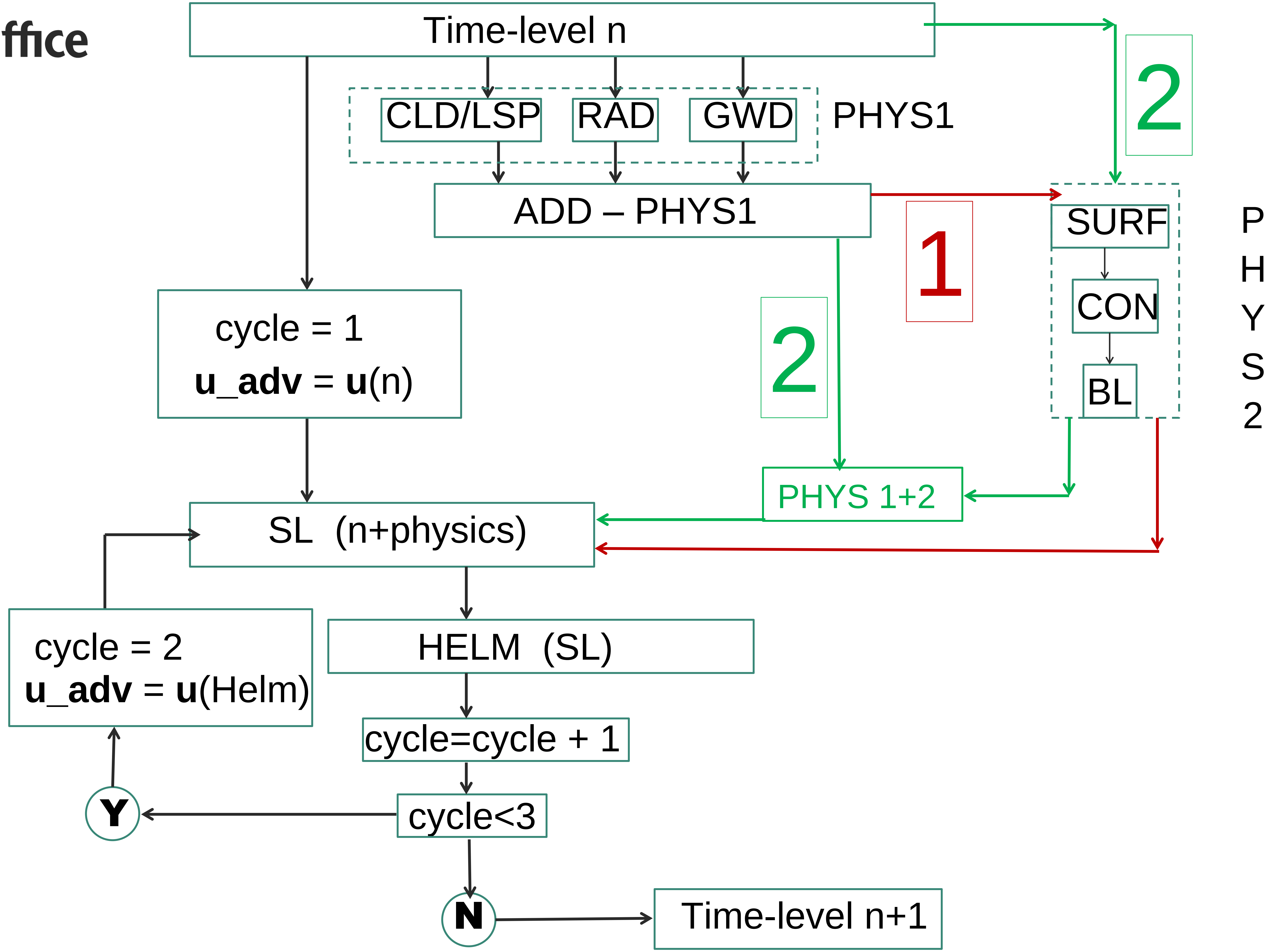

Time-level n

CLD/LSP

RAD

GWD

PHYS1

2

ADD – PHYS1

1

SURF

CON

BL

PHYS2

cycle = 1

u_adv = **u**(n)

2

PHYS 1+2

SL (n+physics)

HELM (SL)

cycle = 2

u_adv = **u**(Helm)

cycle=cycle + 1

cycle<3

Y

N

Time-level n+1

Parallel physics tests in UKV

- Parallel physics 1 > sequential physics2

  > cycle (sequential SL(time-level n + physics) sequential solver
- UKV looks the same and is 15% faster

- Parallel physics 1 > parallel physics2 > add physics

  > cycle (sequential SL(time-level n + physics) sequential solver
- UKV looks the same and is 15% faster

22 hour UKV forecasts of PMSL, rainfall rate and cloud for 22UTC 8/1/2015

Parallel physics tests in UKV

No interpolation of physics to departure points i.e. physics at arrival points.

- Parallel physics1 -> sequential physics2 – cycle (Parallel SL(time-level n), add physics, sequential solver)

- UKV fails after 40 (60 second) steps.

- Parallel physics1, parallel physics2 – cycle (Parallel SL(time-level n), add physics, sequential solver)

Time stepping scheme is inconsistent.
Time-level n quantities MUST be at departure points – target scheme is

$$\boldsymbol{X}^{n+1} = [\boldsymbol{X} + (1-\alpha)\Delta t(\boldsymbol{L}+\boldsymbol{N})]_d^n + (1-\alpha_S)\Delta t\boldsymbol{S}_d^n + (1-\alpha_F)\Delta t\boldsymbol{F}_d^n + \alpha\Delta t(\boldsymbol{L}+\boldsymbol{N})^{n+1} + \alpha_S\Delta t\boldsymbol{S}^{n+1} + \alpha_F\Delta t\boldsymbol{F}^{n+1}$$

Parallel physics tests in Global N512

	Time step	steps	Max w	Run max	step		Time(hr)
Control	600	144	3.0	3.0	129		24
Parallel	600	33	34.7	34.7	33	fail	5.5
	300	40	37.5	37.5	40	fail	3.3
	150	89	52.6	52.6	89	fail	3.7
	120	192	47.6	47.6	192	fail	6.4
	90	480	10.5	31.0	423		12
	75	576	3.1	5.4	364		12
	60	720	2.8	7.0	382		12

Parametrization problems and The End

1. Partially-resolved processes

   No numerical convergence – grey zone.

   Need extra prognostics to provide memory to process and to advect information.

2. Large forcing at grid-scale – mainly due to strong latent heating.
   Dynamics can only represent linear variation or discontinuity/gradient near grid-scale.
   Unbalanced state, grid-scale noise.
   Large vertical velocities in non-hydrostatic models due to forcing (no hydrostatic balance – compare with vertical velocity diagnosed from integrated mass divergence in hydrostatic models).
   Need to apply forcing at filter scale > grid scale.
   Horizontal mixing/diffusion needs to be targeted to avoid weakening gradients.

3. Lower boundary condition/interaction with surface/drag.