Moist Idealized CAM Assessments with Simplified Physics

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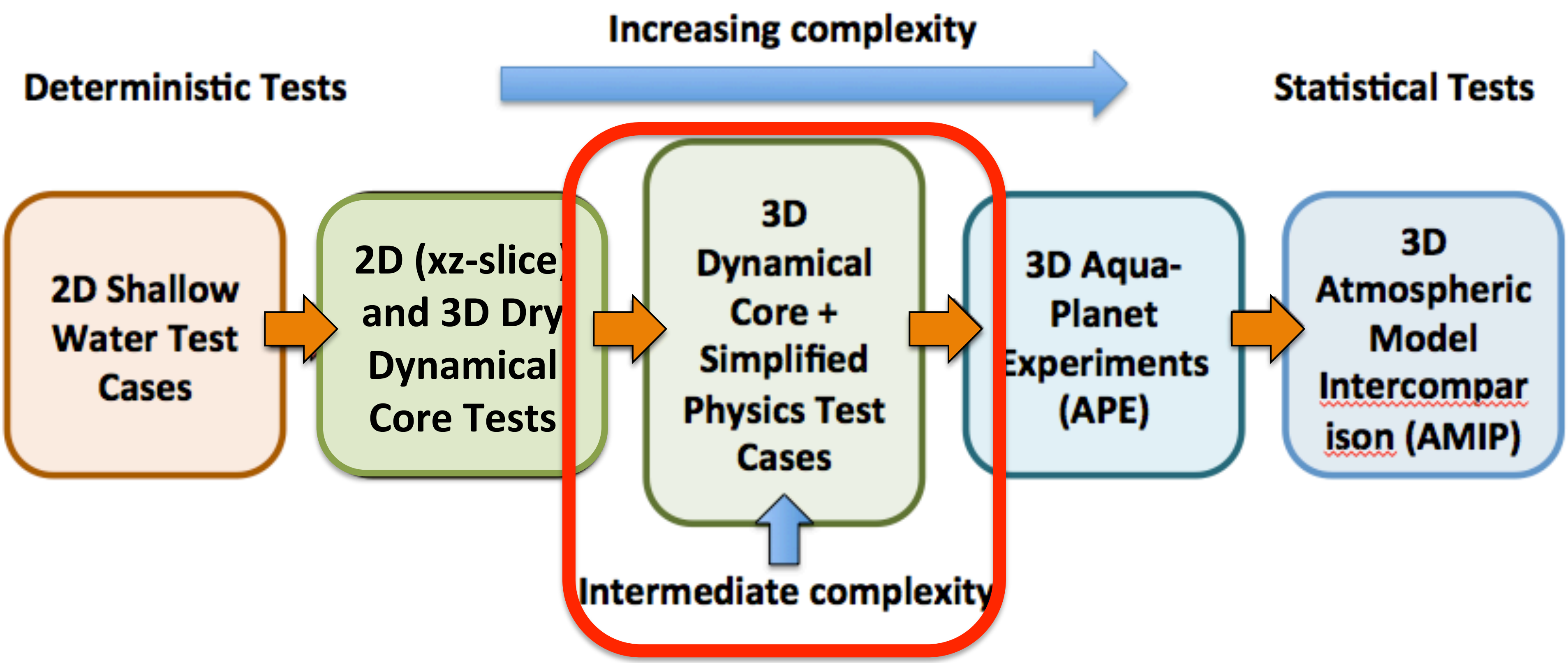
CESM Atmosphere Model Working Group (AMWG) Meeting, NCAR, Boulder, 2/9/2016

Bridging the Gap:
Test Case Hierarchy with Increasing Complexity



Simplified Physics Test Cases:

- Moist baroclinic waves (DCMIP 4.2, Extension of JW (QJ, 2006))
- Tropical Cyclone Test Case (Reed and Jablonowski, MWR 2011, 2012)
- Moist Held-Suarez (Thatcher and Jablonowski, GMDD 2015)
  another approach: Frierson et al. (JAS, 2006)
- Super-Cell Storm (Klemp et al., JAMES 2015)

Moist Held-Suarez Test: All Details are Here

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www.geosci-model-dev-discuss.net/8/8263/2015/
doi:10.5194/gmdd-8-8263-2015

Geoscientific Model Development Discussions
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A moist aquaplanet variant of the Held–Suarez test for atmospheric model dynamical cores

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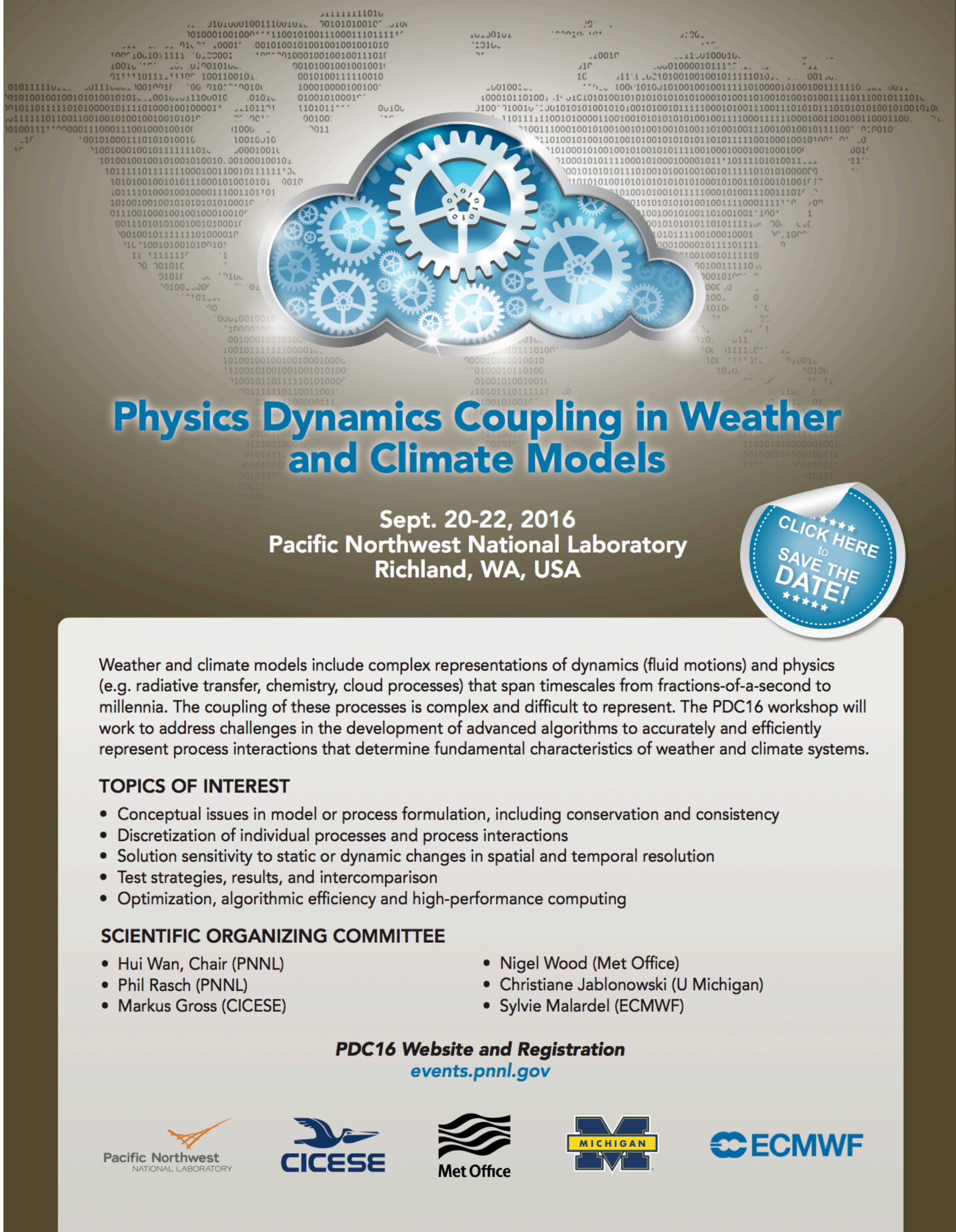
GMDD also provides the Fortran code of the simplified physics package for the moist Held-Suarez test case

Physics-Dynamics Coupling: Workshop Announcement

Sep/20-22/2016
at PNNL

http://events.pnnl.gov/default.aspx?topic=Physics_Dynamics_Coupling_in_Weather_and_Climate_Models



Recent Papers on Physics-Dynamics Coupling

Recent progress and review of Physics Dynamics Coupling in geophysical models

Markus Gross,[1], Hui Wan[2], Philip J. Rasch[2], Peter M. Caldwell[3], David L. Williamson[4], Daniel Klocke[5], Christiane Jablonowski[6], Diana R. Thatcher[6], Nigel Wood[7], Mike Cullen[7], Bob Beare[8], Martin Willett[7], Florian Lemarié[9], Eric Blayo[9], Sylvie Malardel[10], Piet Termonia[11], Peter Bechtold[10], Almut Gassmann[12], Peter H. Lauritzen[4], Hans Johansen[13], Colin M. Zarzycki[4], Koichi Sakaguchi[2], and Ruby Leung[2]

Submitted to JAMES, Jan. 2016

BRIDGING THE (KNOWLEDGE) GAP BETWEEN PHYSICS AND DYNAMICS

BY MARKUS GROSS, SYLVIE MALARDEL, CHRISTIANE JABLONOWSKI, AND NIGEL WOOD

Gross, M., S. Malardel, C. Jablonowski and N. Wood, 2016: Bridging the (knowledge) gap between physics and dynamics. Bull. Amer. Meteor. Soc., Vol. 97, 137-142, doi: 10.1175/BAMS-D-15-00103.1

Questions to Ask & Today's Talking Points (in red)

- What is the **motivation and idea** behind the moist Held-Suarez test?
- Is it **reasonable**: How does a moist Held-Suarez (HS) aqua-planet general circulation compare to a full-physics CAM5 aqua-planet general circulation?
- What do we **learn** about the **physics-dynamics coupling**?
- **Intercomparison**: How do the different CAM5 dynamical cores compare in moist HS and complex aqua-planet experiments?
- Unit testing: How does the moist HS configuration compare to aqua-planet simulations that omit some processes (like the deep convection parameterization)?
- Can we replicate some aspects of the complex physics-dynamics interactions with the moist HS setup?

Motivation:
Results from the Aqua-Planet Experiment (APE)

- Aqua-planet model intercomparison revealed a huge spread in the GCM circulations and precipitation characteristics
- Impossible to tell whether the APE differences are due to physics parameterizations or the dynamical cores or both?
- The most HS test levels the playing field **(identical physics)**.

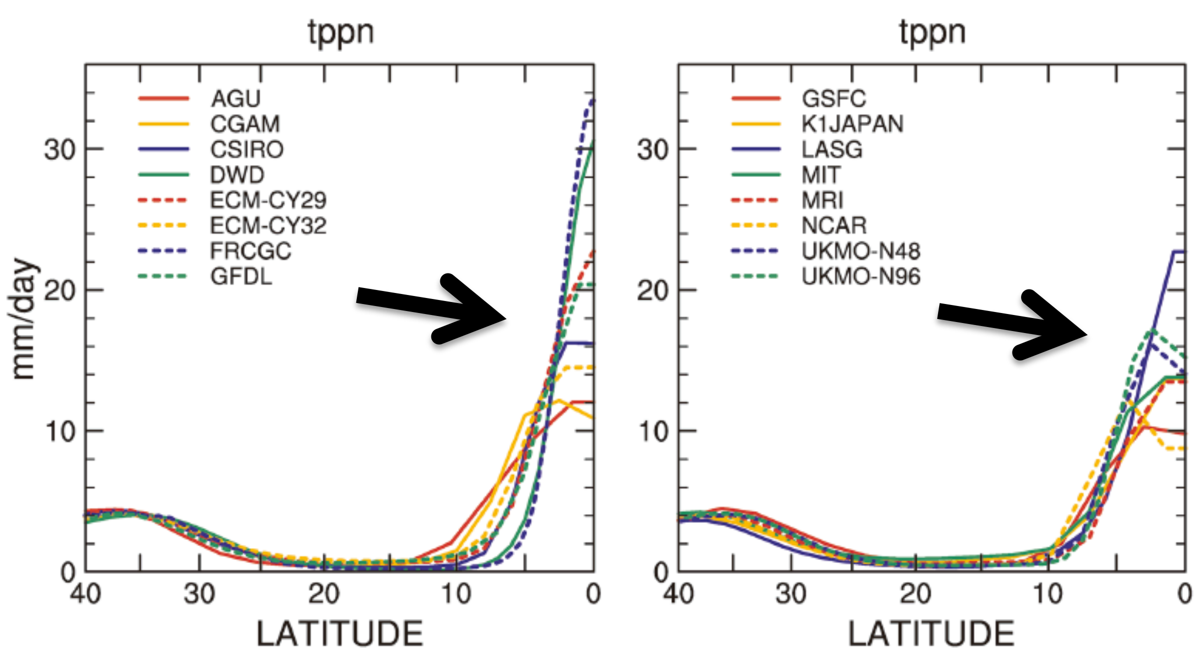


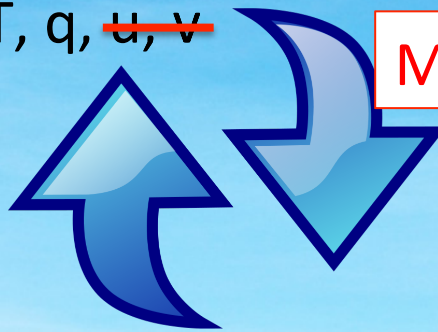
Fig. 4. Zonal-time average total precipitation (tppn) for individual models, mm day^{-1}. The 16 models are split between two panels for clarity.

Zonal-mean time-mean total precipitation rates (hemispherically averaged) in 16 GCMs in aqua-planet mode, see Blackburn at al. (2013)

Design of the Moist Version of the Held-Suarez Test on an Aqua-Planet (prescribed SST)

Large-scale condensation

PBL Mixing of pot. T, q, ~~u, v~~

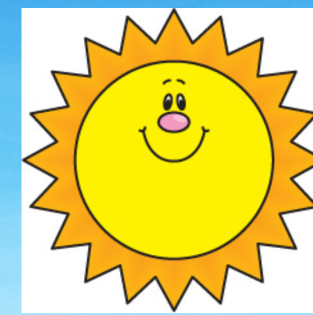


Merge

Surface fluxes of sensible & latent heat, ~~and momentum~~

Simple-Physics (Reed and Jablonowski 2012)

Radiation: Newtonian Temperature relaxation



Surface momentum fluxes and PBL mixing of momentum: Rayleigh Friction between the surface and 700 hPa

Held and Suarez (BAMS, 1994) physics

Moist Held-Suarez Test: Basic Ideas

- Climate test: Run model for 3 years, disregard first 6 months (spinup), analyze the time-mean zonal-mean circulation (2.5 y)
- Prescribe the sea surface temperature with analytic function
- Add a specific humidity field q to the dynamical and transport it as a tracer, introduce moist HS forcing mechanisms
- Compute condensation C tendencies to force q and the temperature T whenever the relative humidity (RH) at a grid point exceeds a threshold (e.g. RH > 100%):

$$C = \frac{1}{\Delta t}\left(\frac{q - q_{sat}(T,p)}{1 + \frac{L}{c_p}\frac{\mathrm{d}q_{sat}(T,p)}{\mathrm{d}T}}\right)$$

- The large-scale precipitation P_{ls} removes the water instantaneously **without a cloud stage, no re-evaporation**
- Kessler warm rain scheme (3 water species) works just as well

Moist Held-Suarez Test: Basic Ideas

- Merge and tune the Reed and Jablonowski (2012) *simple-physics* and the Held and Suarez (1994) *physics* forcings
- The forcing mechanisms are

C_X: increased by factor 4

$$\frac{\partial T}{\partial t} = \frac{L}{c_p} C$$

$$\frac{\partial q}{\partial t} = -C\,.$$

← Condendation & Surface Fluxes →

$$\frac{\partial T_a}{\partial t} = \frac{C_H |\boldsymbol{v}_a| (T_s - T_a)}{z_a}$$

$$\frac{\partial q_a}{\partial t} = \frac{C_E |\boldsymbol{v}_a| (q_{sat,s} - q_a)}{z_a}$$

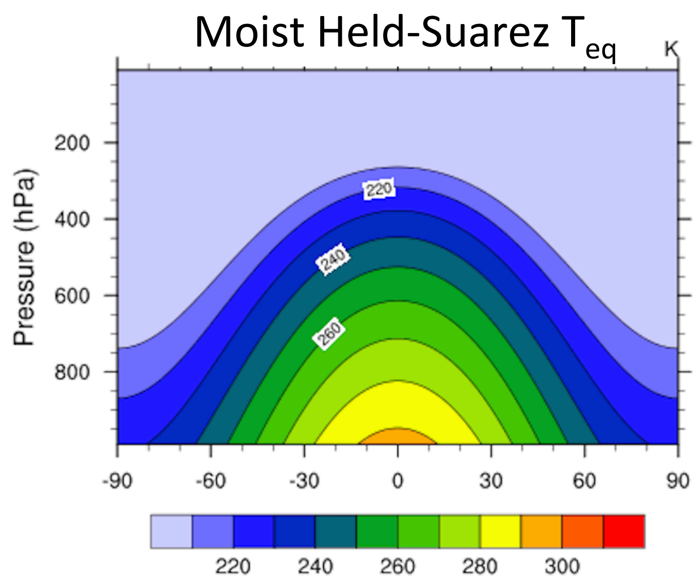
$$\frac{\partial T}{\partial t} = -k_T(\phi,\sigma)\left[T - T_{eq}(\phi,\sigma)\right]$$

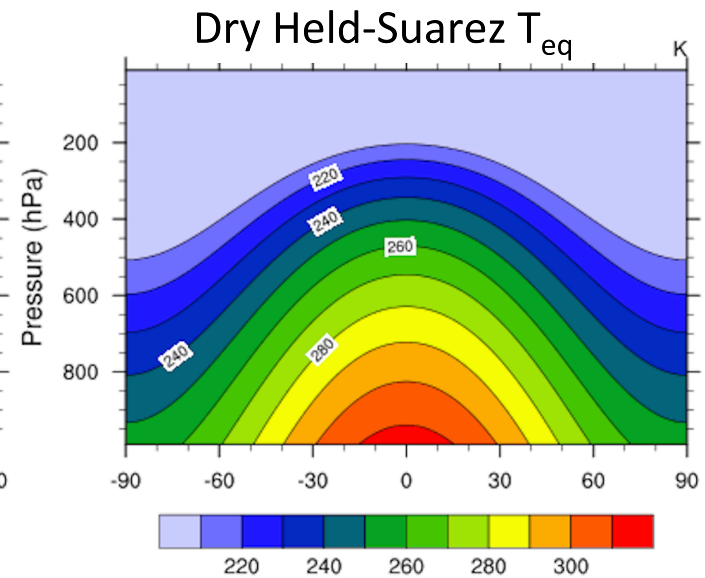
Temperature relaxation

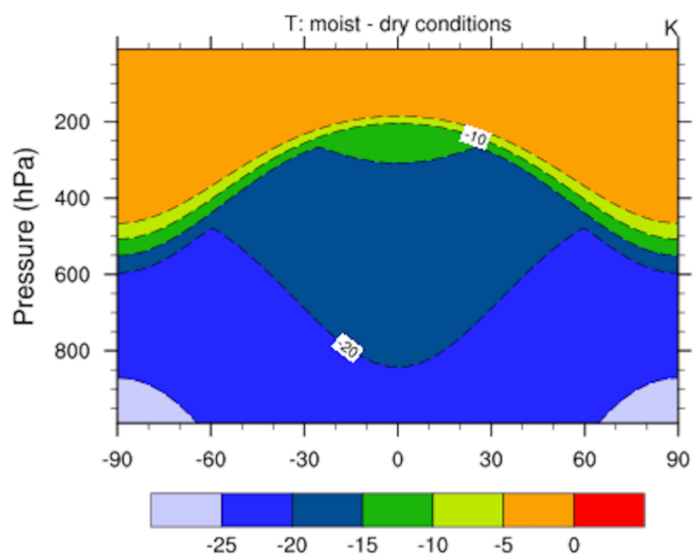
modified

- Plus: PBL mixing
  - HS Rayleigh friction below 700 hPa and 2nd-order diffusion of potential temperature and specific humidity with flow-dependent mixing coefficient.

Why Do We Need a Modification of the Held-Suarez Equilibrium Temperature T_{eq}?







Temperature Difference:
Moist – Dry

Moist T_{eq} is up to 26 K colder than dry $T_{eq,}$ the general circulation was unreasonable with the dry Held-Suarez T_{eq} profile

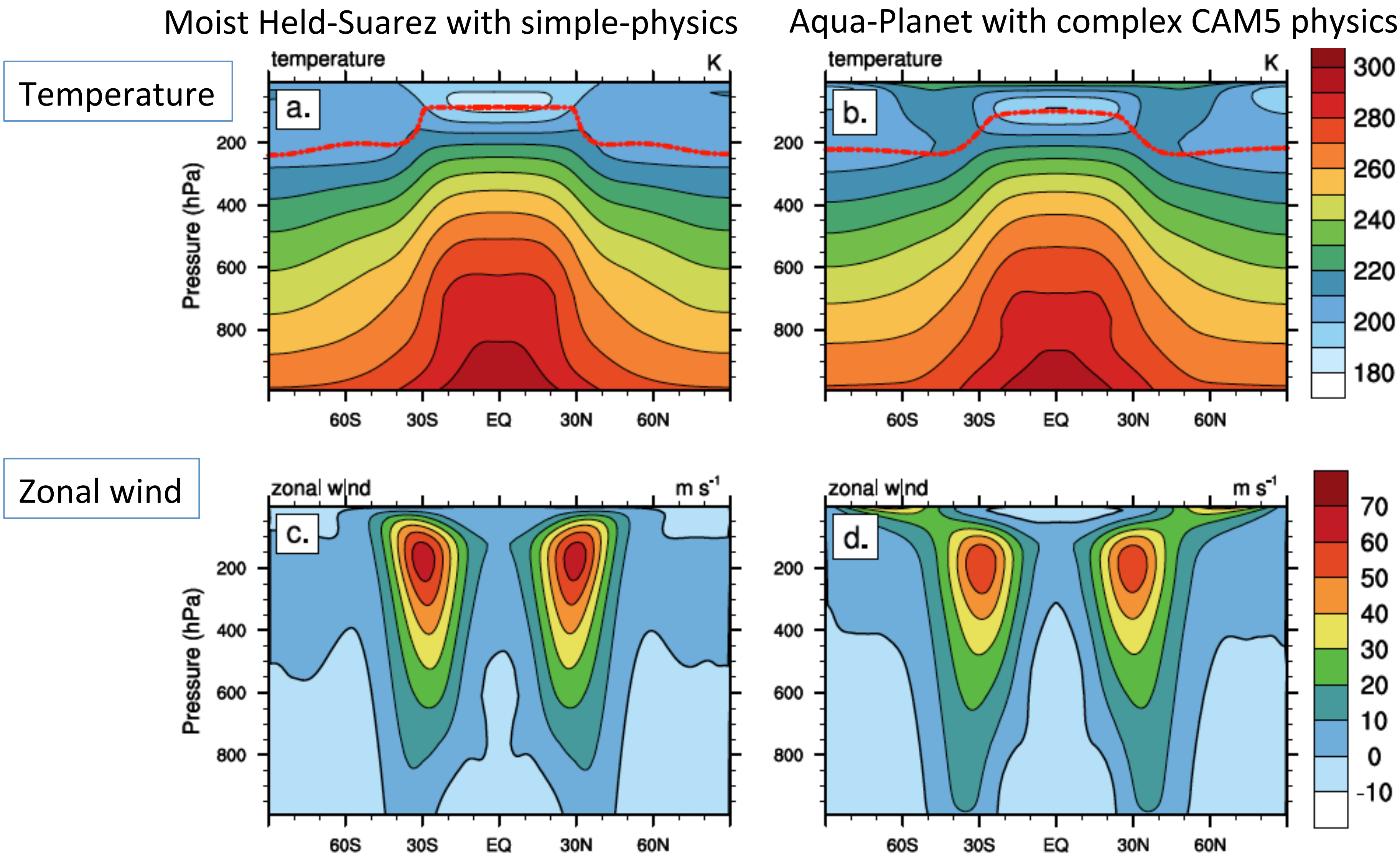
Modeling Framework: CAM5 dynamical cores

The Community Atmosphere Model (CAM) provides four different dynamical cores (based on the primitive equations):

1. **Semi-Lagrangian (SLD)**: two-time-level, semi-implicit semi-Lagrangian spectral transform model, Gaussian grid, 1800 s PDC
2. **Eulerian (EUL)**: three-time-level, semi-implicit Eulerian spectral transform dycore, Gaussian grid, 600 s PDC interval
3. **Finite-Volume (FV)**: default dynamical core in CAM 5 & CAM 5.1, grid-point-based finite-volume discretization, explicit time-stepping scheme, latitude-longitude grid, 1800 s PDC interval
4. **Spectral Element (SE)**: newest dynamical core, based on continuous Galerkin spectral finite element method, designed for fully unstructured quadrilateral meshes (cubed-sphere grid), locally energy- and mass-conserving, explicit time-stepping scheme, 1800 s Physics-Dynamics Coupling (PDC) interval

Moist Held-Suarez and Complex Aqua-Planet

CAM-SE 1° L30: Reasonable - Moist Held-Suarez mimics Aqua-Planet



Thatcher and Jablonowski, GMDD 2015

Moist Held-Suarez and Complex Aqua-Planet

CAM-SE 1° L30: Reasonable - Moist Held-Suarez mimics Aqua-Planet

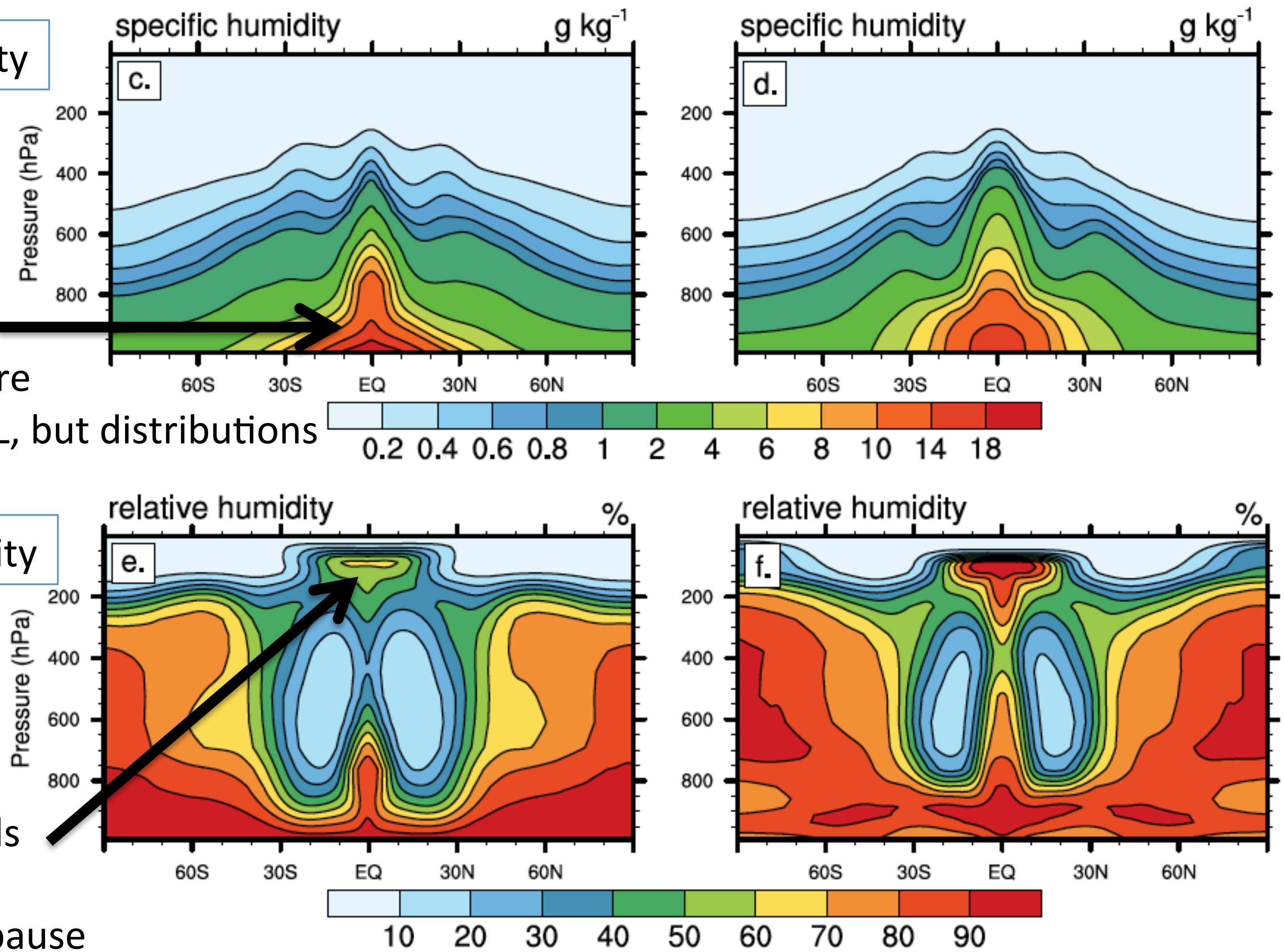
Moist Held-Suarez with simple-physics | Aqua-Planet with complex CAM5 physics

Specific humidity

Less efficient upward moisture transport in PBL, but distributions are similar

Relative Humidity

Lack of deep convection leads to dryer areas near the tropopause



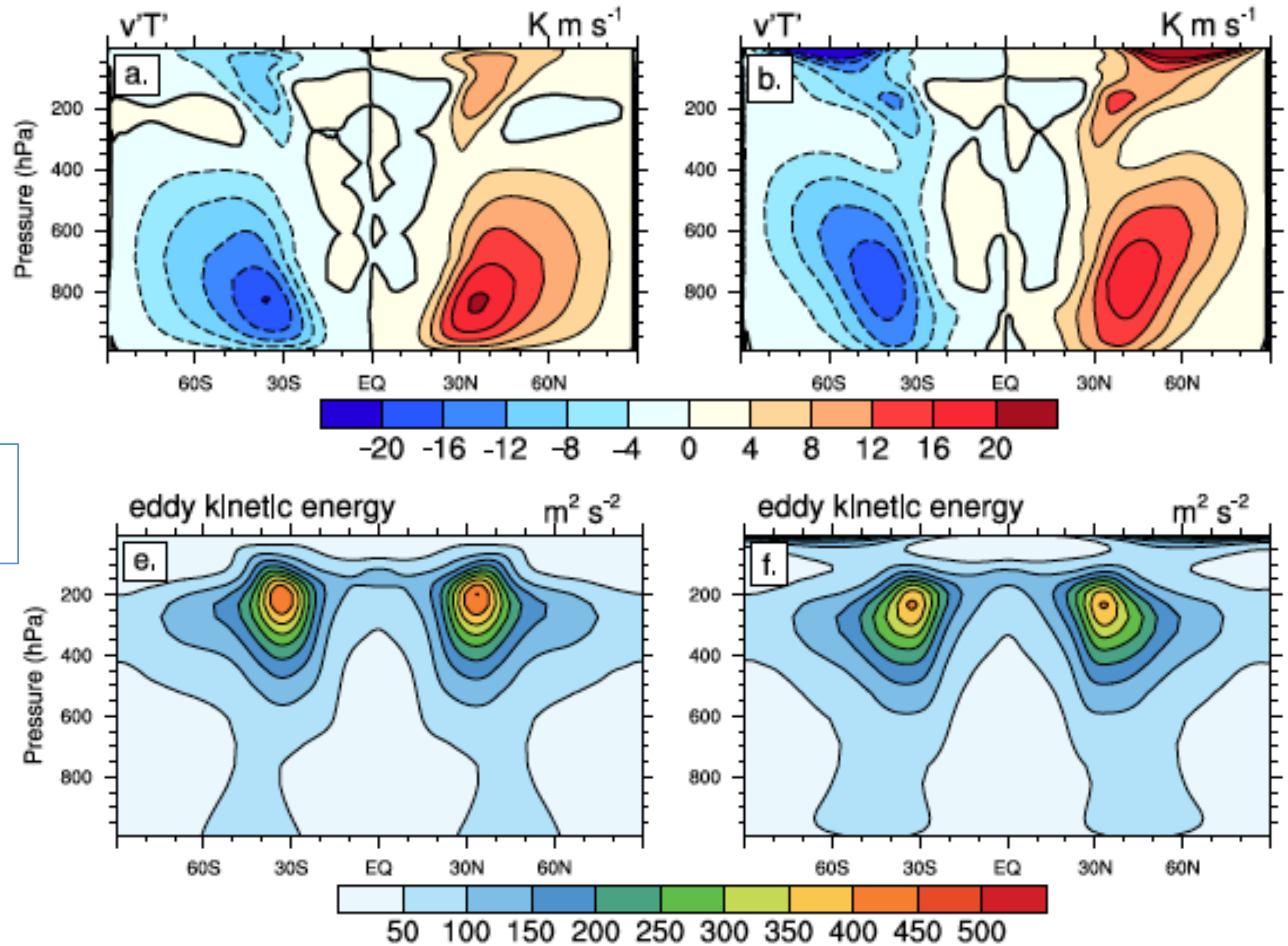
Moist Held-Suarez and Complex Aqua-Planet

CAM-SE 1° L30: Reasonable – Eddy transports are comparable

Moist Held-Suarez with simple-physics | Aqua-Planet with complex CAM5 physics

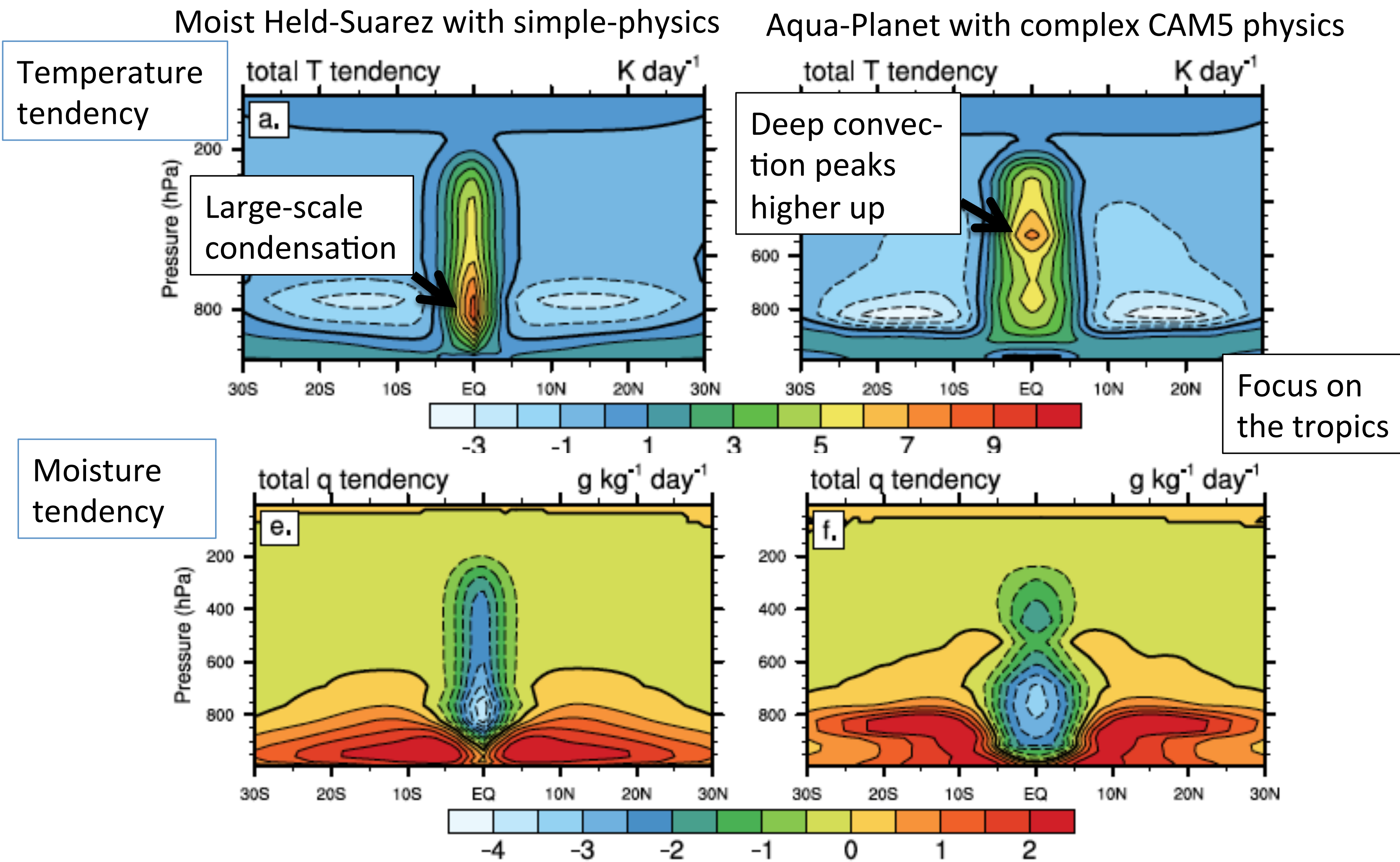
Eddy Heat Flux

Eddy Kinetic Energy



Moist Held-Suarez and Complex Aqua-Planet

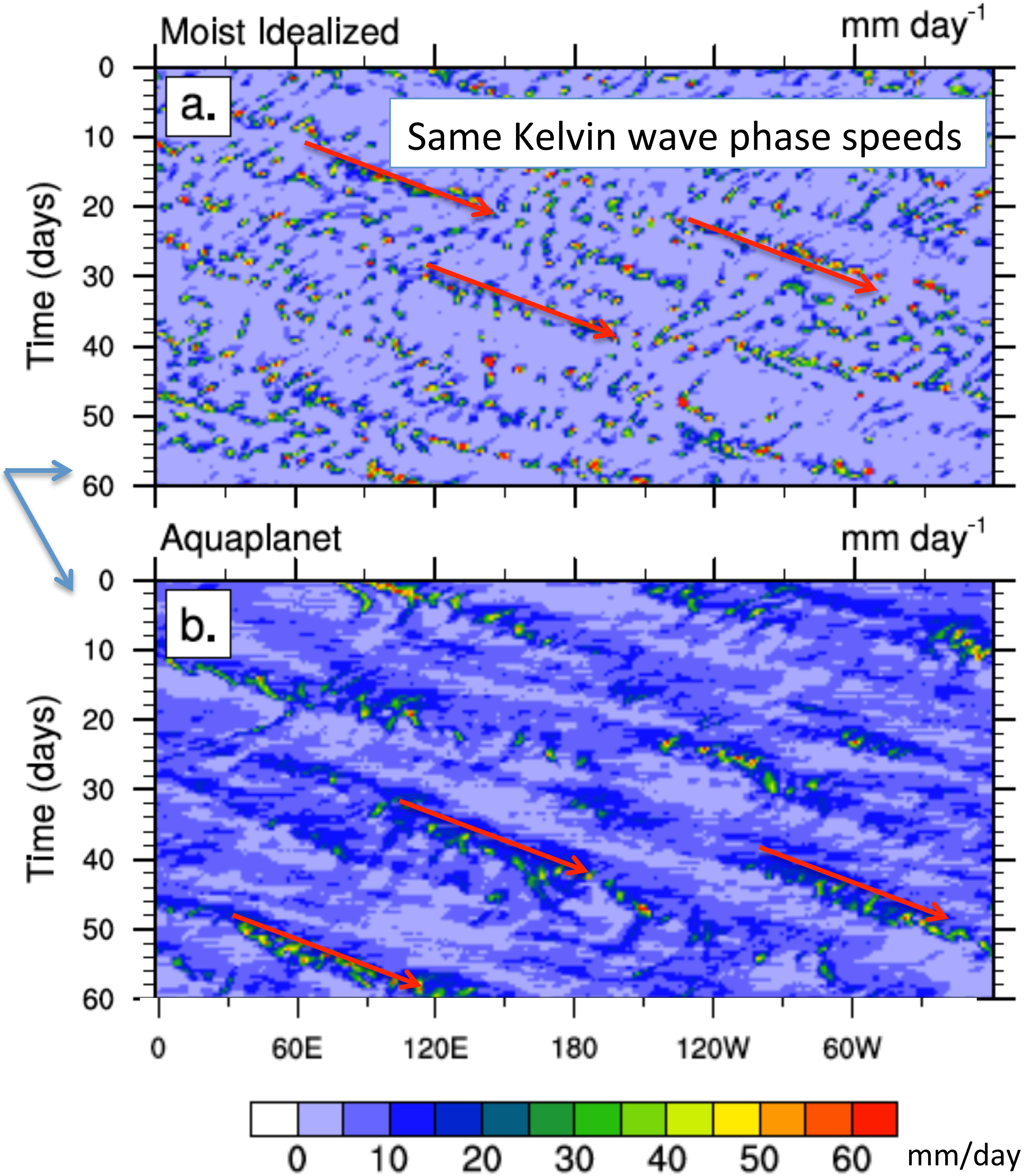
CAM-SE 1° L30: Reasonable – Physics forcing magnitudes comparable



Moist Held-Suarez and Complex Aqua-Planet

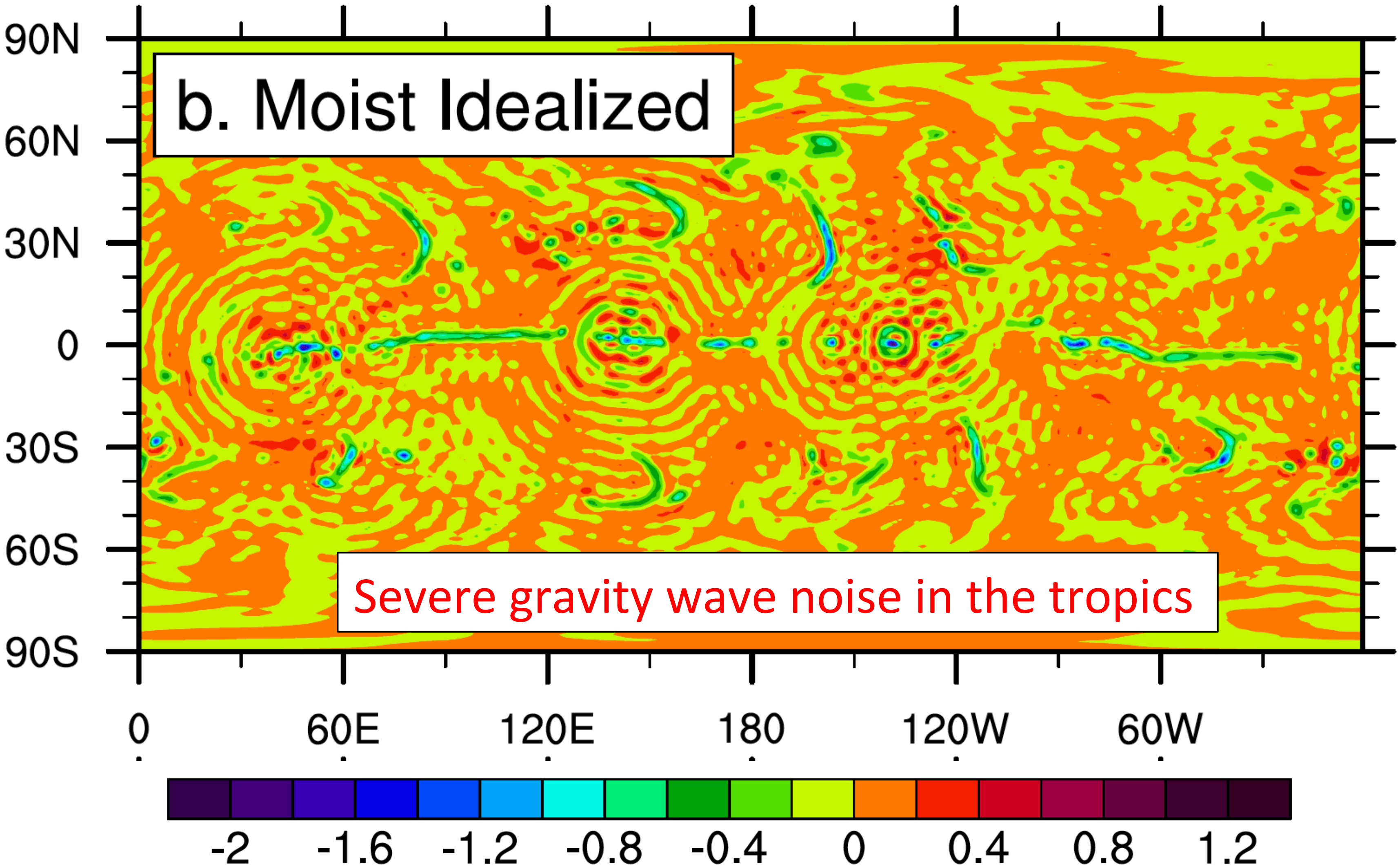
CAM-SE 1° L30:
Similar tropical waves are apparent in **the total precipitation rate (averaged between 5S-5N)** in moist Held-Suarez (top) and Aqua-Planet (bottom) runs (here eastward traveling Kelvin waves)

Precipitation is less organized in the moist HS experiment due to simplicity of precipitation



Moist HS: Physics – Dynamics Coupling

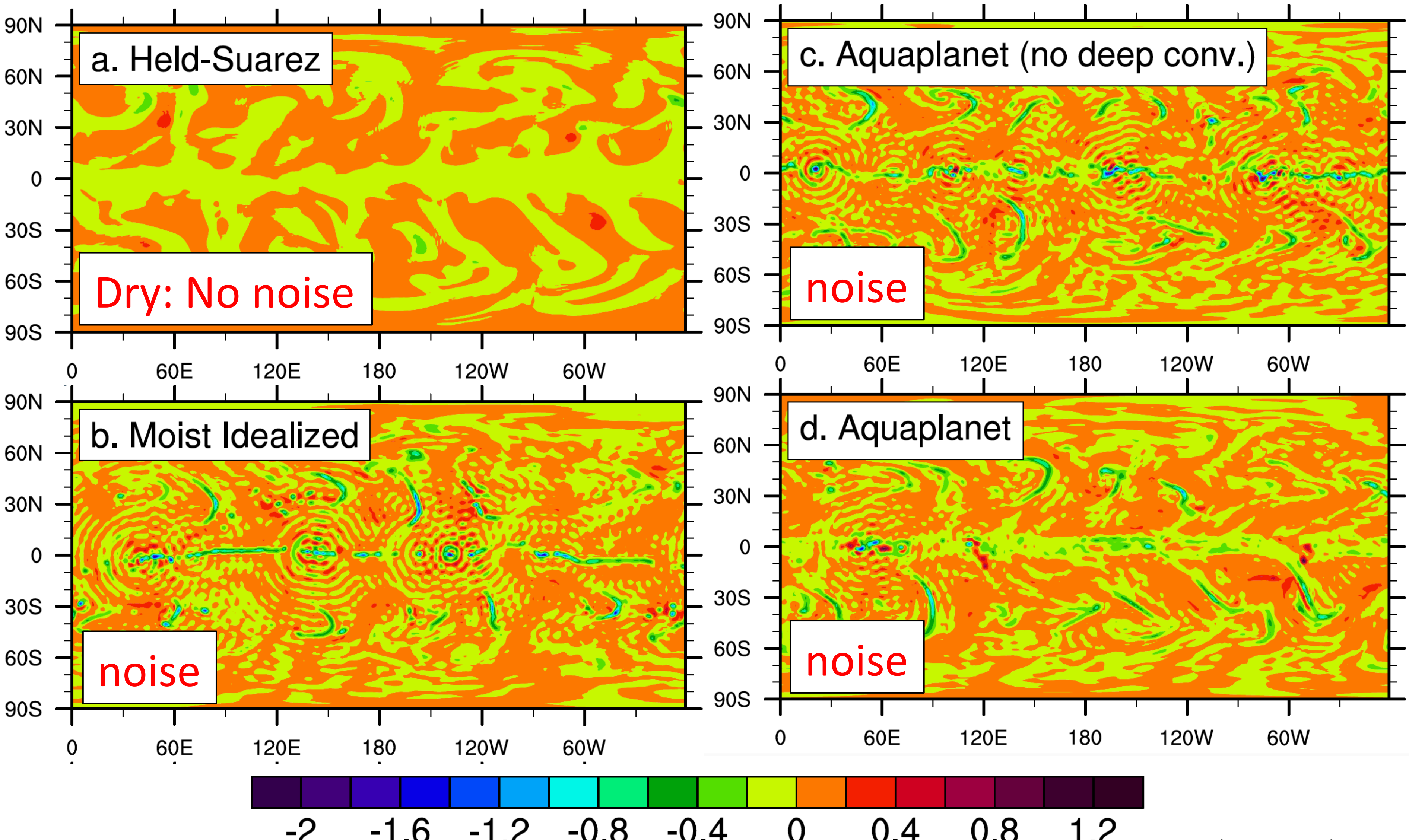
Vertical pressure velocity snapshot at 850 hPa (Pa/s) in CAM-SE



Resolution: 110 km, L30

Moist HS: Physics – Dynamics Coupling

Vertical pressure velocity snapshots at 850 hPa (Pa/s) in CAM-SE



Resolution: 110 km, L30

What Are the Possible Causes for the Gravity Wave Noise in CAM-SE?

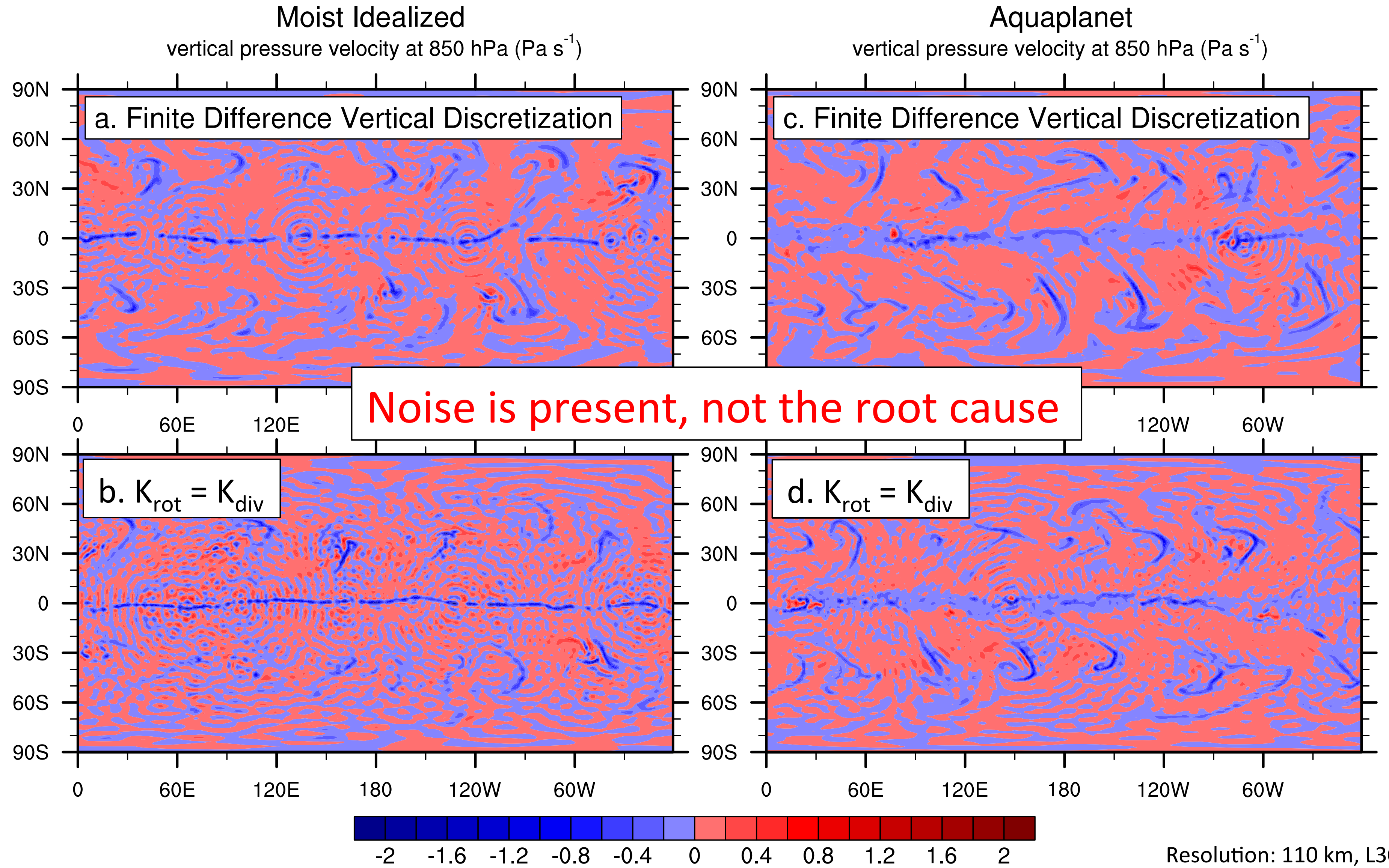
The SE dycore provides various options for

1. Vertical discretization (FD versus vertical floating Lagrangian)
2. Various options for the default floating Lagrangian coordinate (user-defined remap interval)
3. 4th-order hyperdiffusion coefficient for rotational and divergent motions can be different (default: $K_{div} = 2.5^2 \times K_{rot}$)
4. Various Runge-Kutta time stepping variants, complicated subcycling is present
5. Violation of stability constraints? Dynamics time steps too long?
6. Various options for the physics-dynamics coupling interval: sudden adjustment of the physics tendencies after long physics time steps (se_ftype = 1) or gradual application of the physics tendencies in the subcycled dycore (se_ftype = 0)

Moist HS: Physics – Dynamics Coupling

Try: Vertical Finite-Difference Scheme, Identical diffusion coefficients

model variants

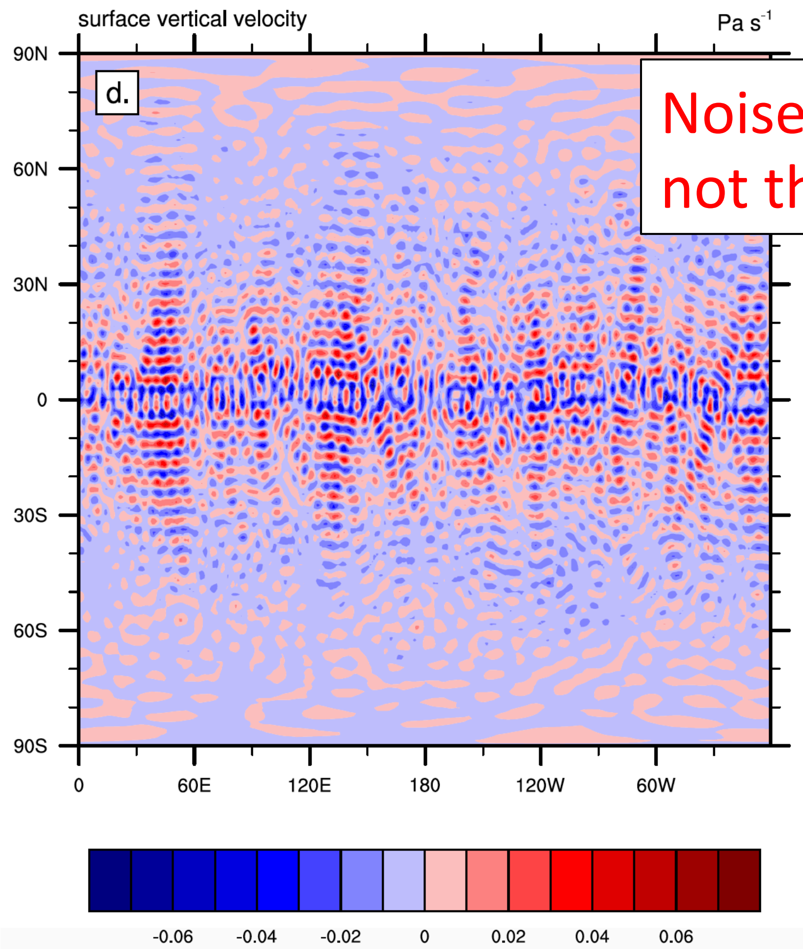


Resolution: 110 km, L30

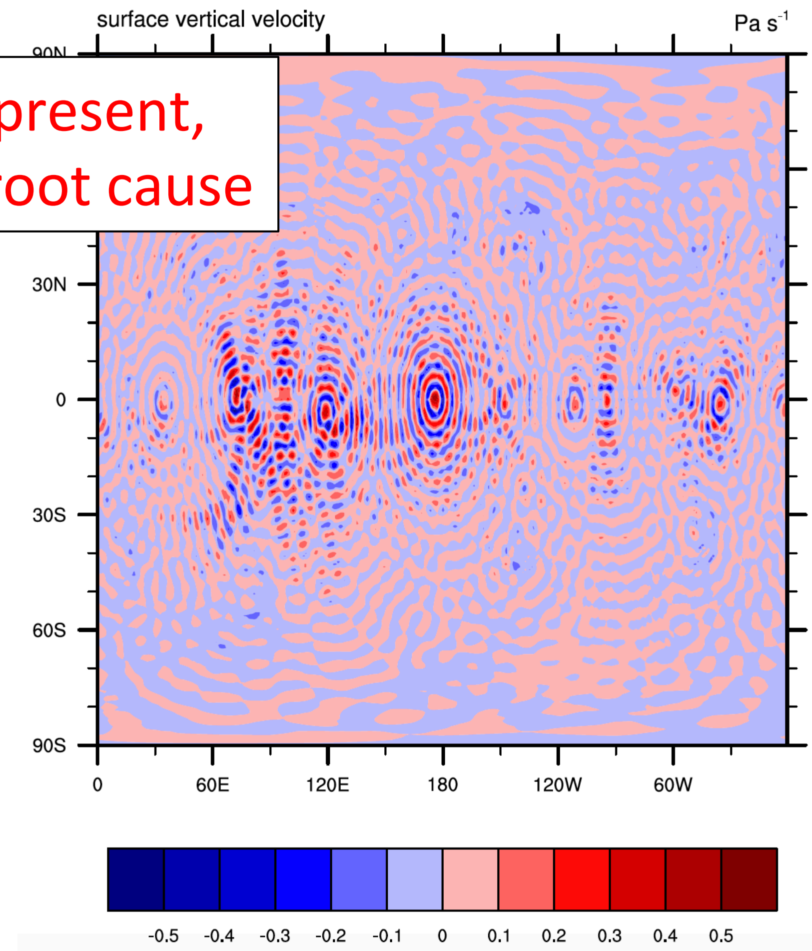
Moist HS: Physics – Dynamics Coupling

Try variants: Different dynamics time steps and vertical remap intervals

Default Time Step Settings
for the dynamics



Shorter dynamics time steps
Shorter remap interval

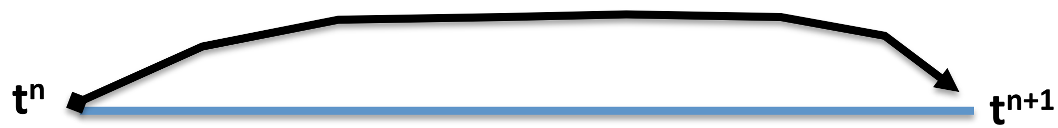


Noise is present,
not the root cause

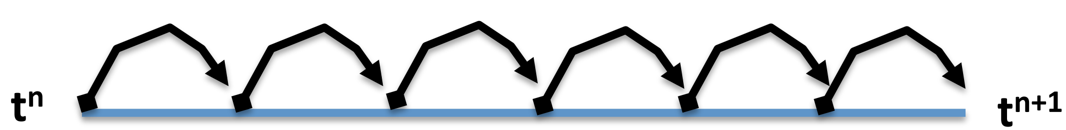
Resolution: 110 km, L30

CAM-SE: Physics – Dynamics Coupling Options

- CAM-SE time-split coupling: means that the physics package receives the updated state variables from the dynamical core.
- The physics and dynamics time steps are different. Dynamics time steps are subcycled (typically shorter by a factor of 6).
- Two available options, both compute the physics tendencies every 1800 s
  - se_ftype=1, sudden adjustment (default)
    Physics tendencies are immediately applied to update the state variables.



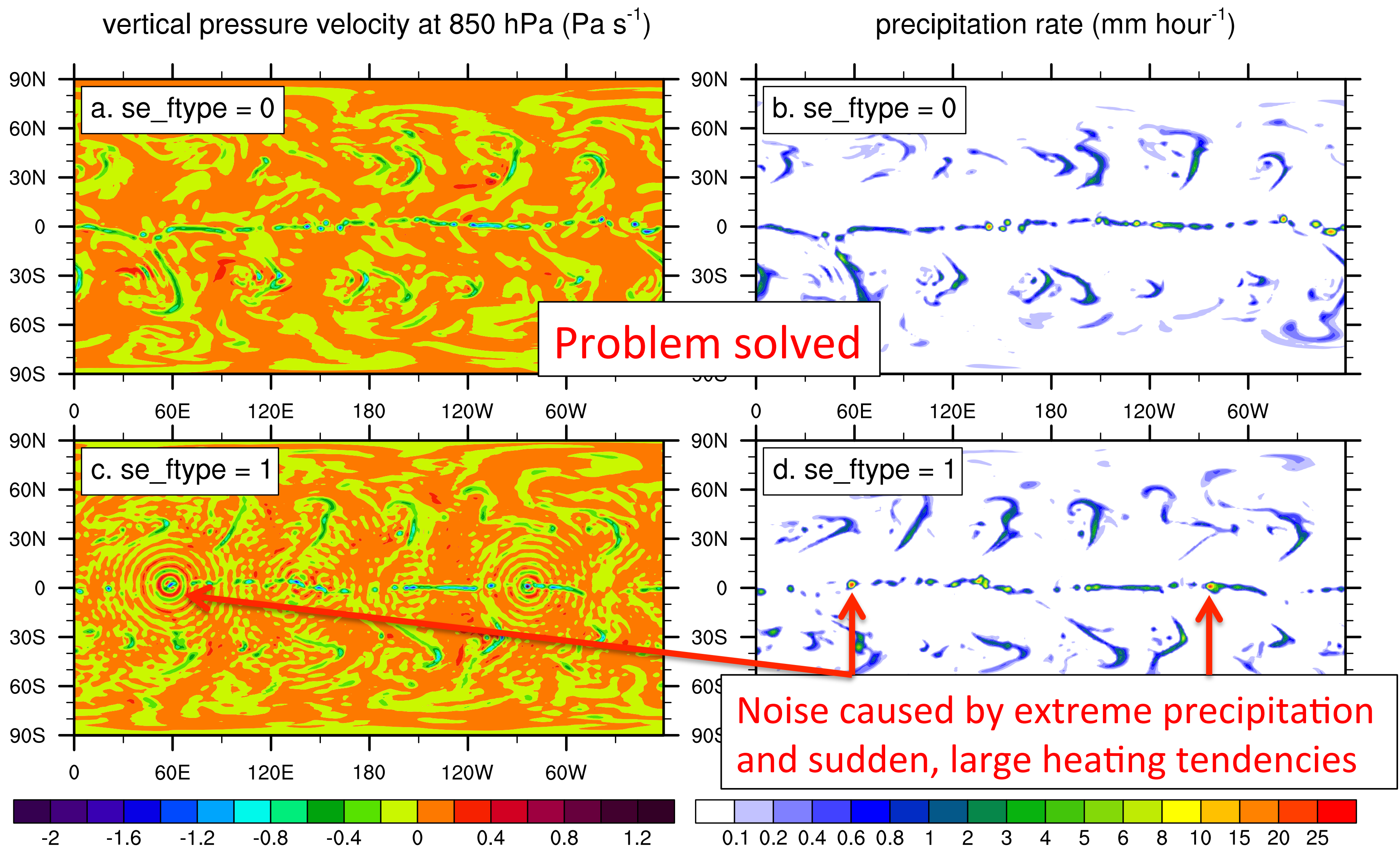
  - se_ftype=0 gradual adjustment
    Physics tendencies are divided by 6. They are not immediately applied but transferred to the dycore. The dycore applies them at each subcycled time step (6 times).



Moist HS: Physics – Dynamics Coupling

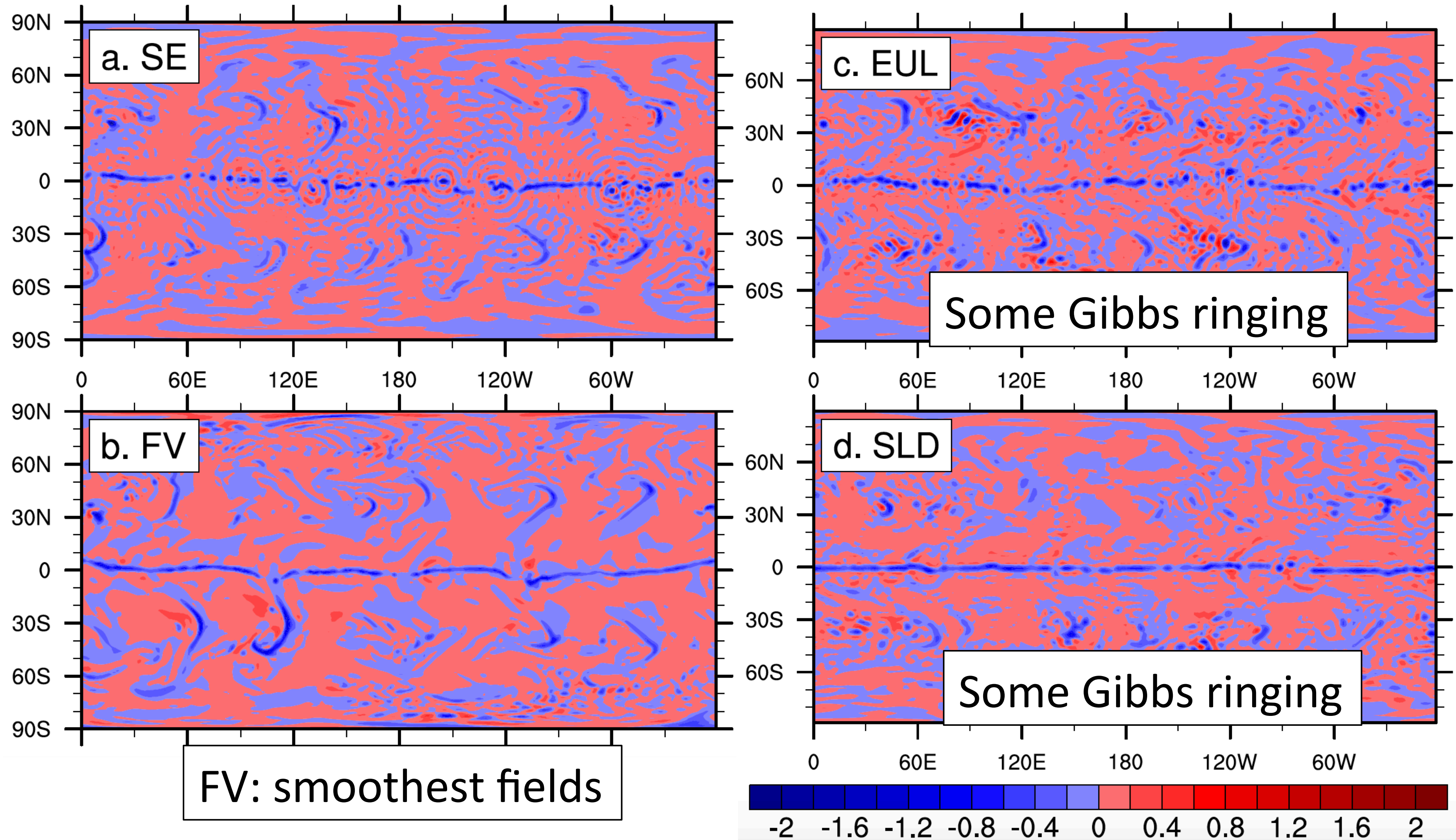
Try: Different physics-dynamics coupling strategy

se_ftype=1, sudden adjustment (default), se_ftype=0 gradual adjustm.



Intercomparison: Physics – Dynamics Coupling

Instantaneous vertical pressure velocity at 850 hPa (Pa/s) in all CAM dycores with moist HS forcing



Intercomparisons: CAM5 dynamical cores

- The kinetic energy (KE) spectra of the moist HS experiments (solid) replicate the KE spectra of the complex CAM5 aqua-planet runs (dashed).

  Here with 110-150 km grid spacing.

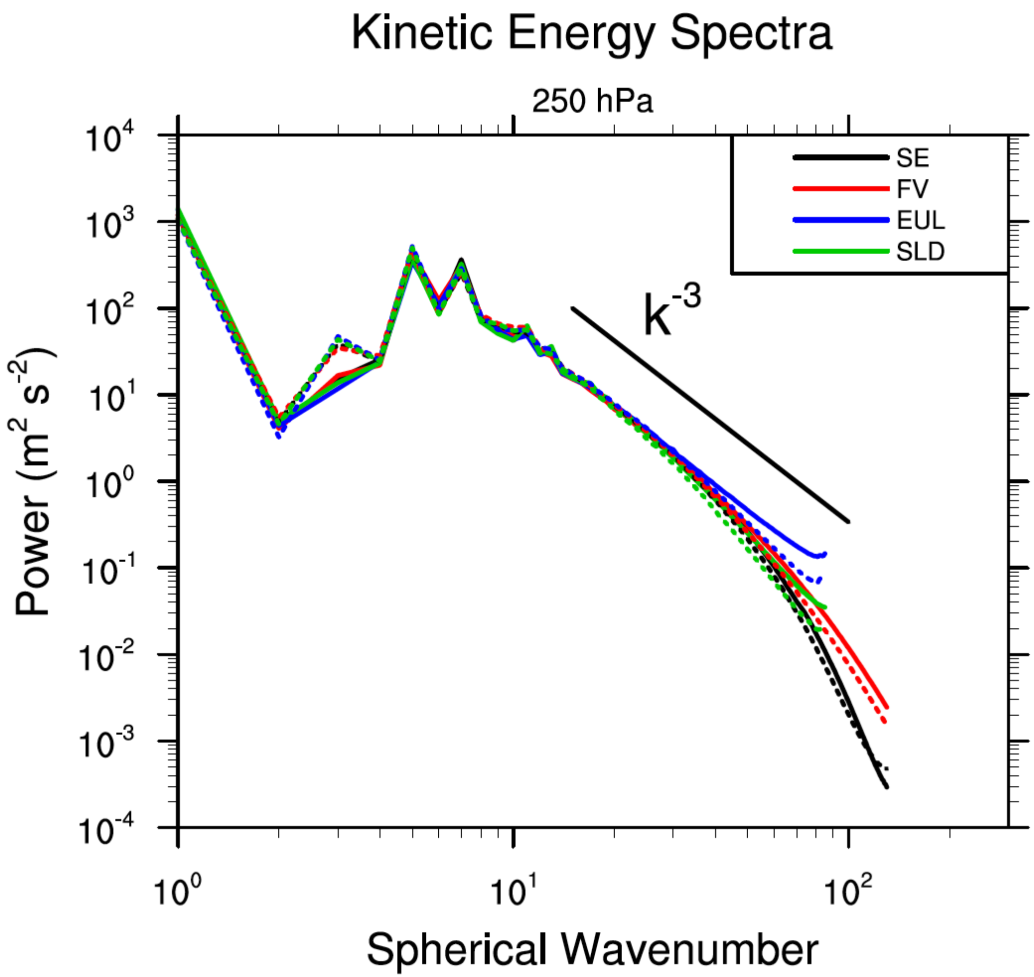
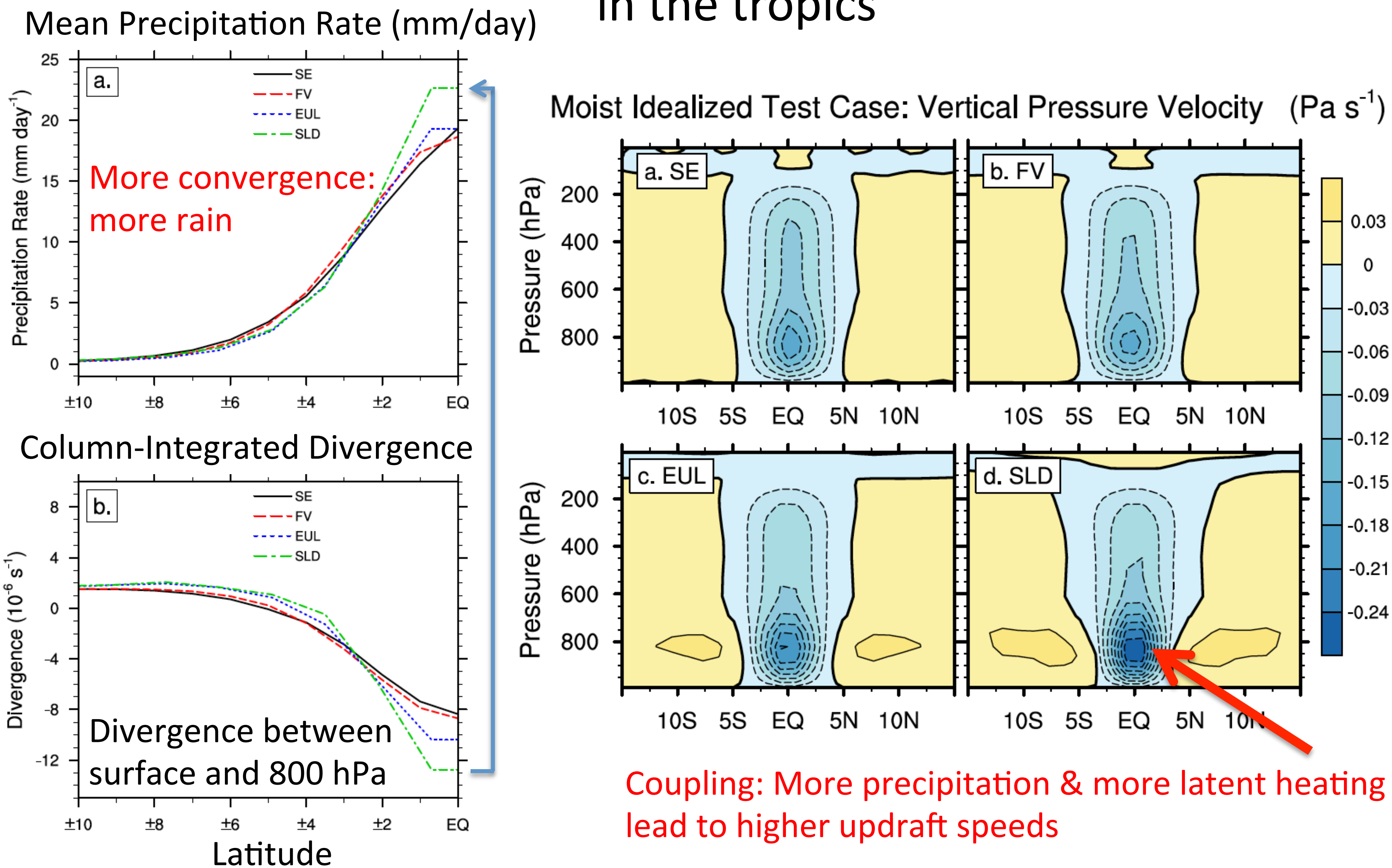


Figure 11. 250 hPa kinetic energy spectra for MITC (solid lines) and APS (dashed lines) simulations with SE (black), FV (red), EUL (blue), and SLD (green). The slopes can be compared to the theoretical k^{-3} slope.

Intercomparisons: CAM5 dynamical cores

- Moist HS experiments highlight dynamical core differences in the tropics



Conclusions

- The interactions between the dynamical core and moisture processes can already be simulated with very simple model configurations, like large-scale condensation, simple-physics, or the moist HS test
- Large-scale condensation can also be replaced with Kessler-like warm rain scheme. Leads to almost identical results.
- Some aspects of the complex GCM behaviors can be replicated with the simplified physics setups.
- Tests give access to an easier understanding of the physics-dynamics coupling.
- Using identical physics for dynamical cores levels the playing field
- Approach allows unit testing of selected parameterizations or tests of the physics-dynamics coupling technique
- Test holds promise to be useful for community use, can also be further modified, e.g. mixed-layer ocean instead of constant SST

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