On modelling tropopause polar vortices (TPVs)

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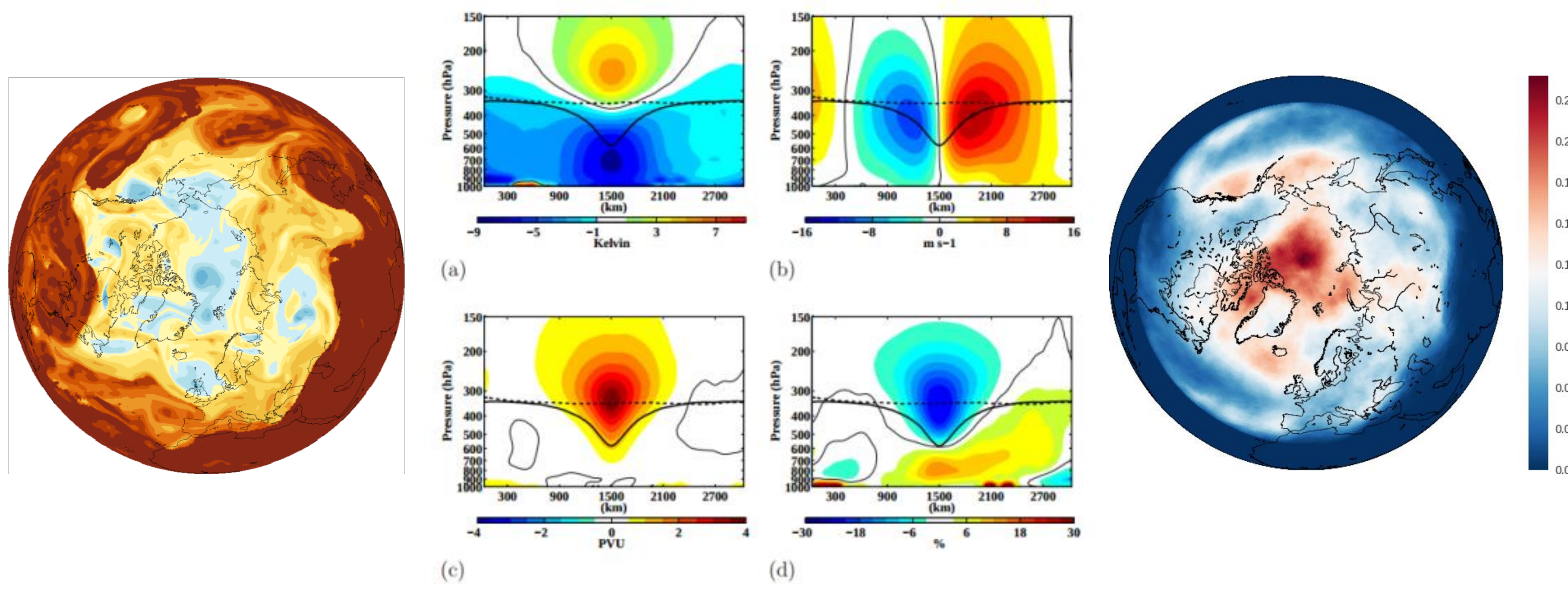
Given mechanisms for TPVs to impact surface cyclones, RWB, water vapor transport, STE, and sea ice loss, can improved representation extend predictions? What impacts dynamics/prediction of TPVs?

TPV structure

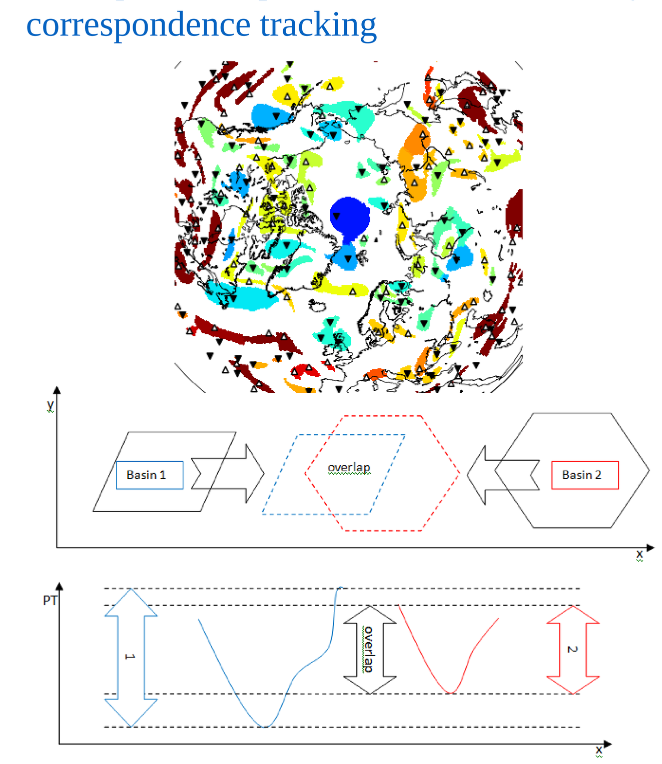
Common, coherent features on dynamic tropopause (DT) poleward of jet with O(100-1000 km, 10 K, days-months)



(Left) Potential temperature on dynamic tropopause Aug 1 2006; (Middle) composite west-east x-sections of anomalous (a-d) T, v, EPV, RH. Mean DT is thick black contour and 0 is thin black curve (Cavallo & Hakim 2010); (Right) mean probability of a TPV August 1979-2014

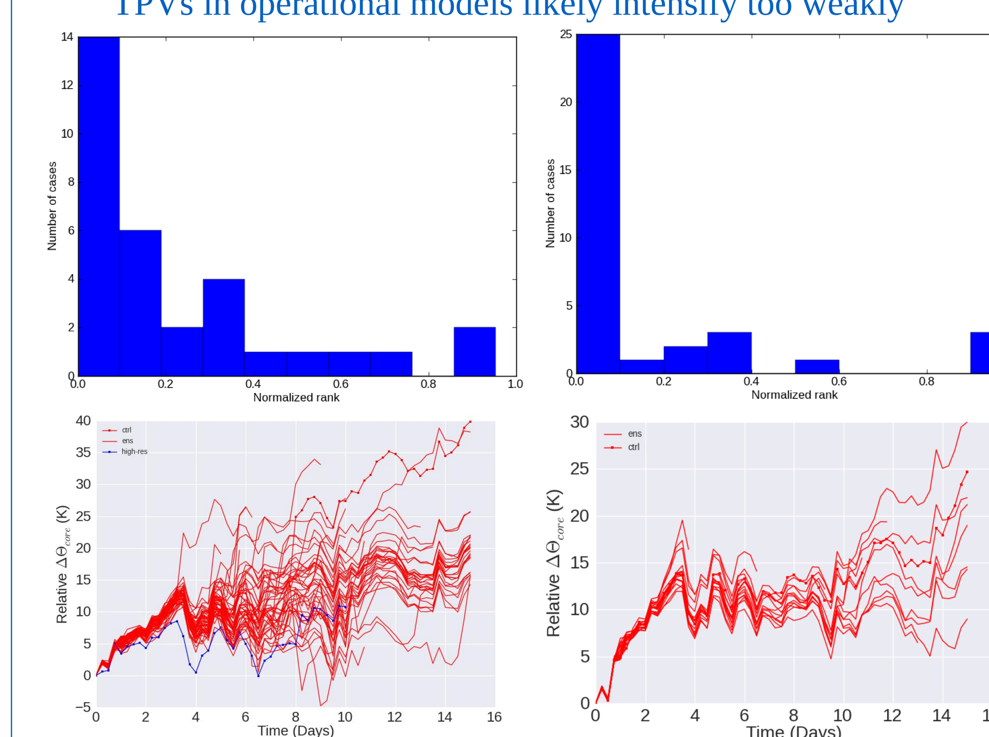
Tracking TPVs

Watershed basin segmentation + PT contour cutoff -> horizontal advection + vertical PT overlap correspondence -> 1-1 major correspondence tracking



TPVs in TIGGE

TPVs in operational models likely intensify too weakly

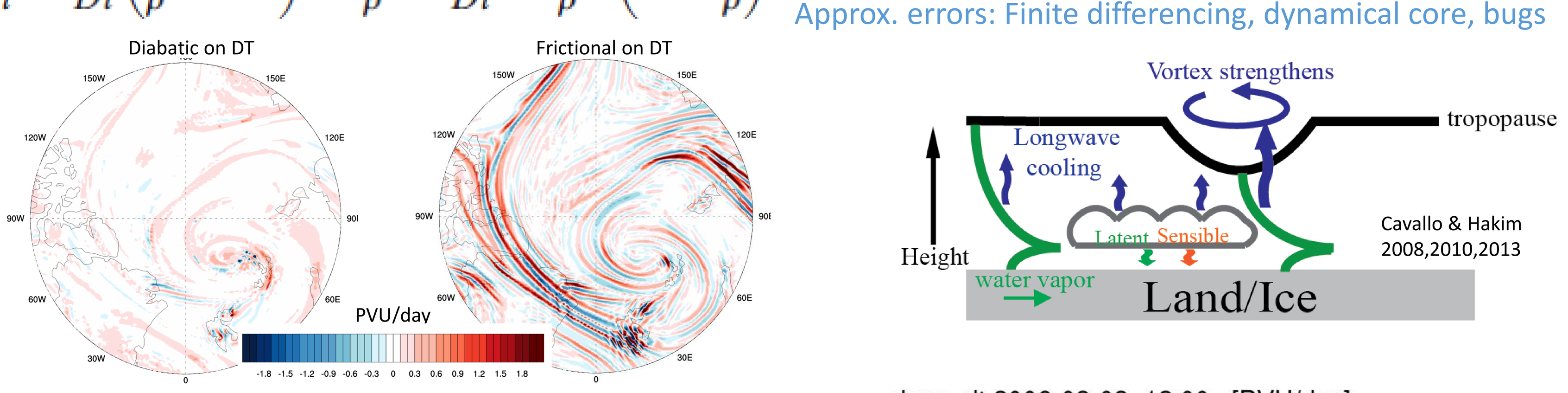


(Top) Rank histograms of 1-day intensification for (left) deterministic in ensemble and (right) ERA-I in ensemble. (Bottom) Intensification error for EC (left) and UKMO (right) ensembles for 2007-07-20 case

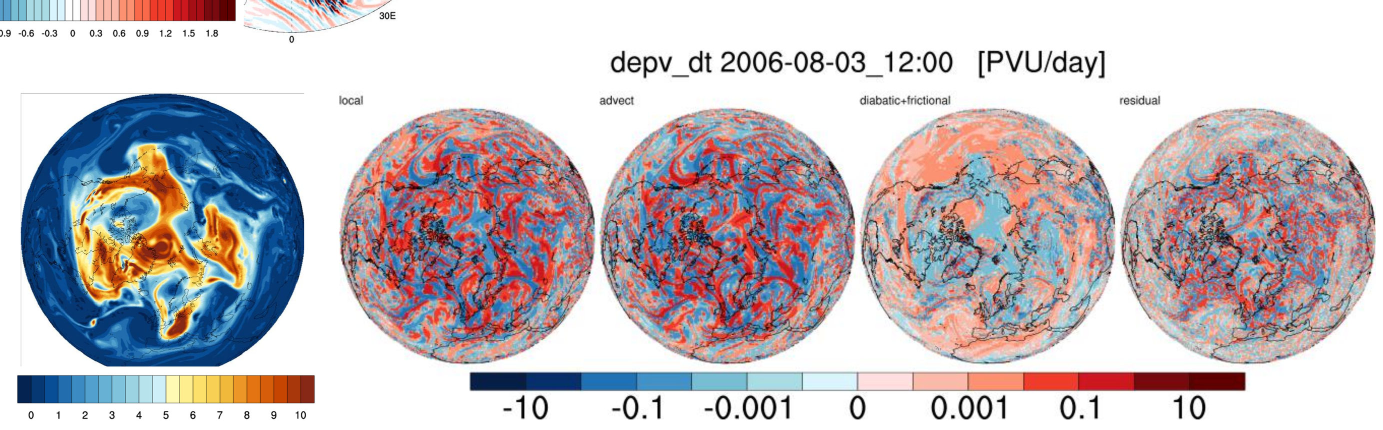
Dynamics: Ertel's potential vorticity (EPV) framework

$$\frac{D\Pi}{Dt} = \frac{D}{Dt}\left(\frac{1}{\rho}\boldsymbol{\omega}_a \cdot \nabla\theta\right) = \frac{\boldsymbol{\omega}_a}{\rho} \cdot \nabla\frac{D\theta}{Dt} + \frac{\nabla\theta}{\rho} \cdot \left(\nabla \times \frac{\mathbf{F}}{\rho}\right)$$

Diab.: Radiation, microphysics, PBL, convection, diffusion
Fric.: PBL (& wave drag), convection, diffusion
Approx. errors: Finite differencing, dynamical core, bugs



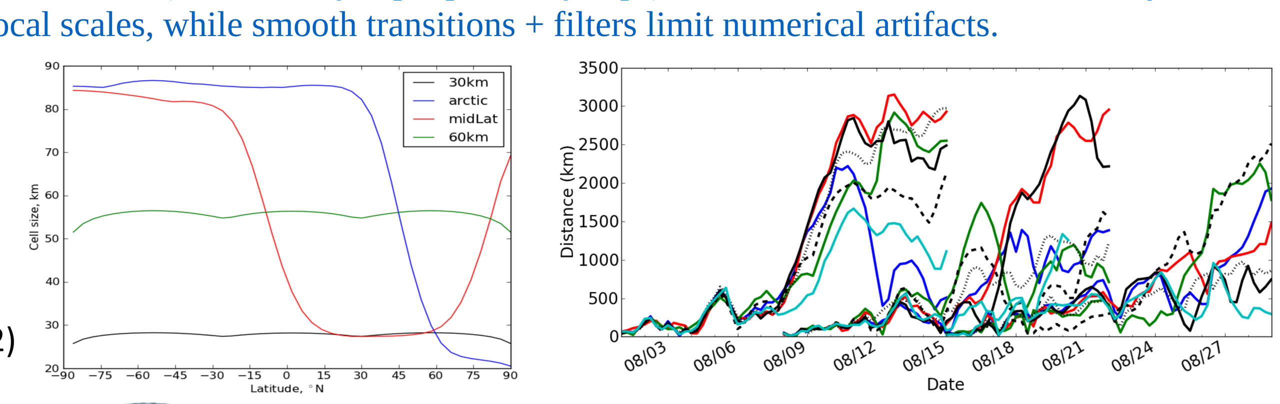
(Top) Diagnosed diabatic & frictional EPV budget terms interpolated to DT at 2006-08-17; (Right) Driving maintenance processes;
(Bottom) EPV & budget terms w/ non-0 residual on model level ~10 km

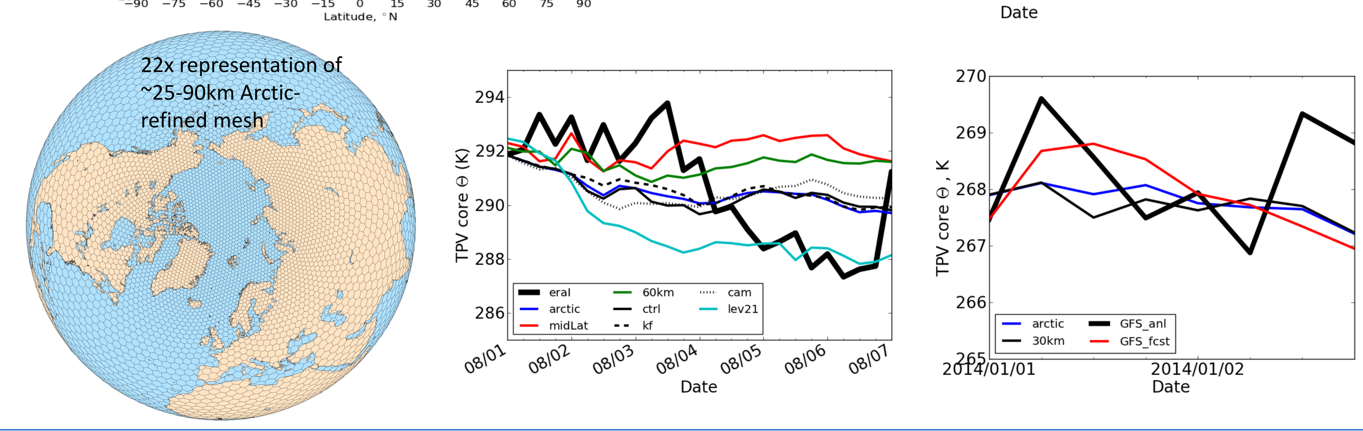


Example MPAS-A setup and evaluation

Scale is fundamental to NWP approximations (e.g., Laprise et al. 2008). GCMs are expensive computationally if not coarse. LAMs are cheaper but inconsistent (BCs, scale jumps, process jumps). Variable meshes allow flexibility in managing costs of representing local scales, while smooth transitions + filters limit numerical artifacts.

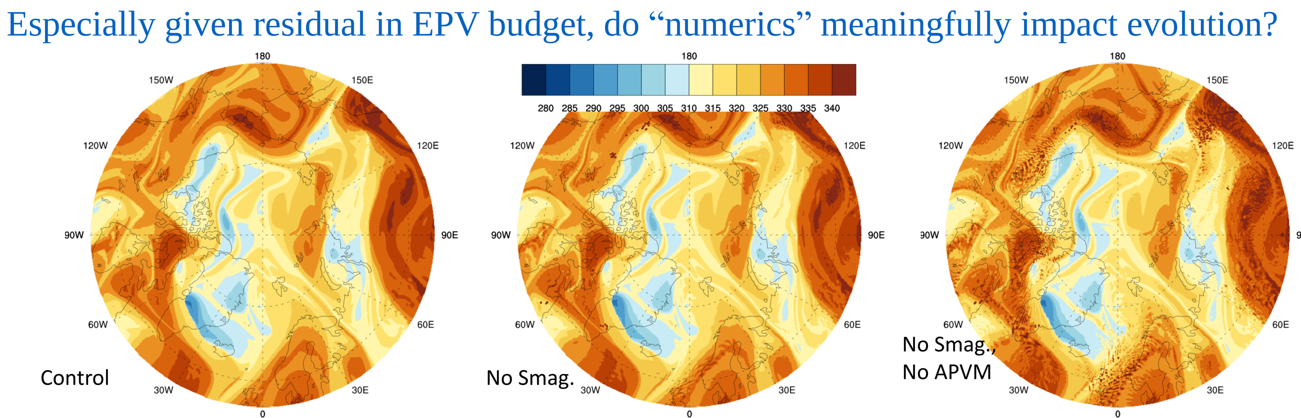
- Physics – WRF NRCM
  - NOAH LSM
  - Monin-Obukhov
  - YSU_PBL (gwdo option)
  - Kessler, WSM6
  - Tiedtke, Kain-Fritsch
  - CAM, RRTMG
- Numerics (Skamarock et al. 2012)
  - 3[rd] order advection
  - 22/30km w-damping
  - APVM, upwind transport, Smagorinsky diffusion
- Mesh
  - 41 levels
  - dt= ~4 min(dx) dtMp = dt/8 dtRad = 20min
- Boundaries
  - ERA-I ICs, xice & SST 6 hourly



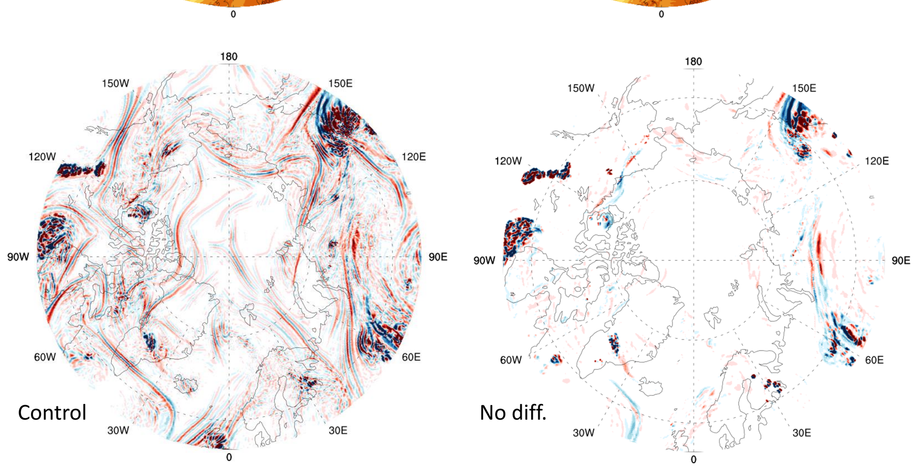


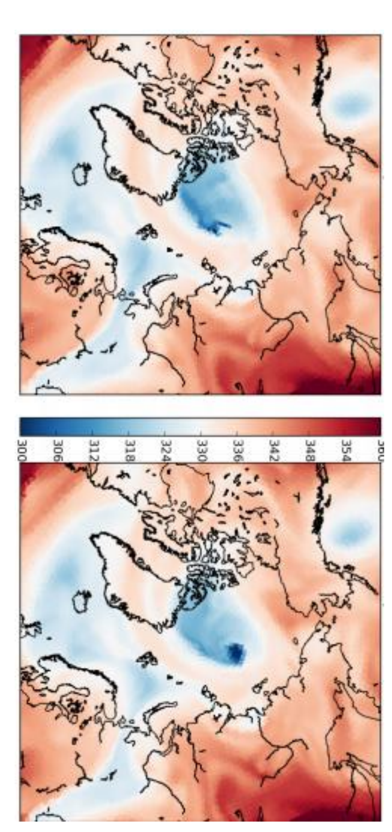
Characteristics of numerical filters

Especially given residual in EPV budget, do "numerics" meaningfully impact evolution?

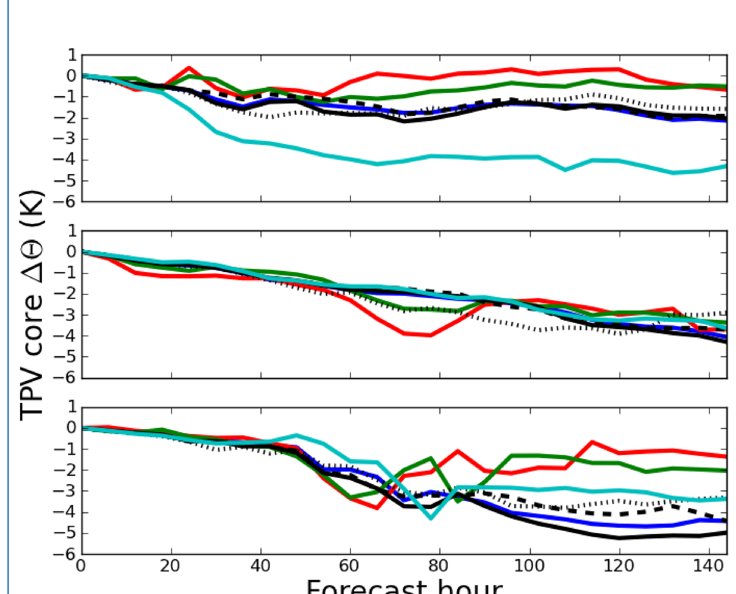


(Top) DT PT for control (left), no Smagorinsky diffusion (middle), no diffusion or APVM (right).
(Bottom) DT frictional EPV for control (left) and no explicit diffusion (right)
(Right) DT PT for TPV crossing pole in CESM-LE lat/lon CAM-FV

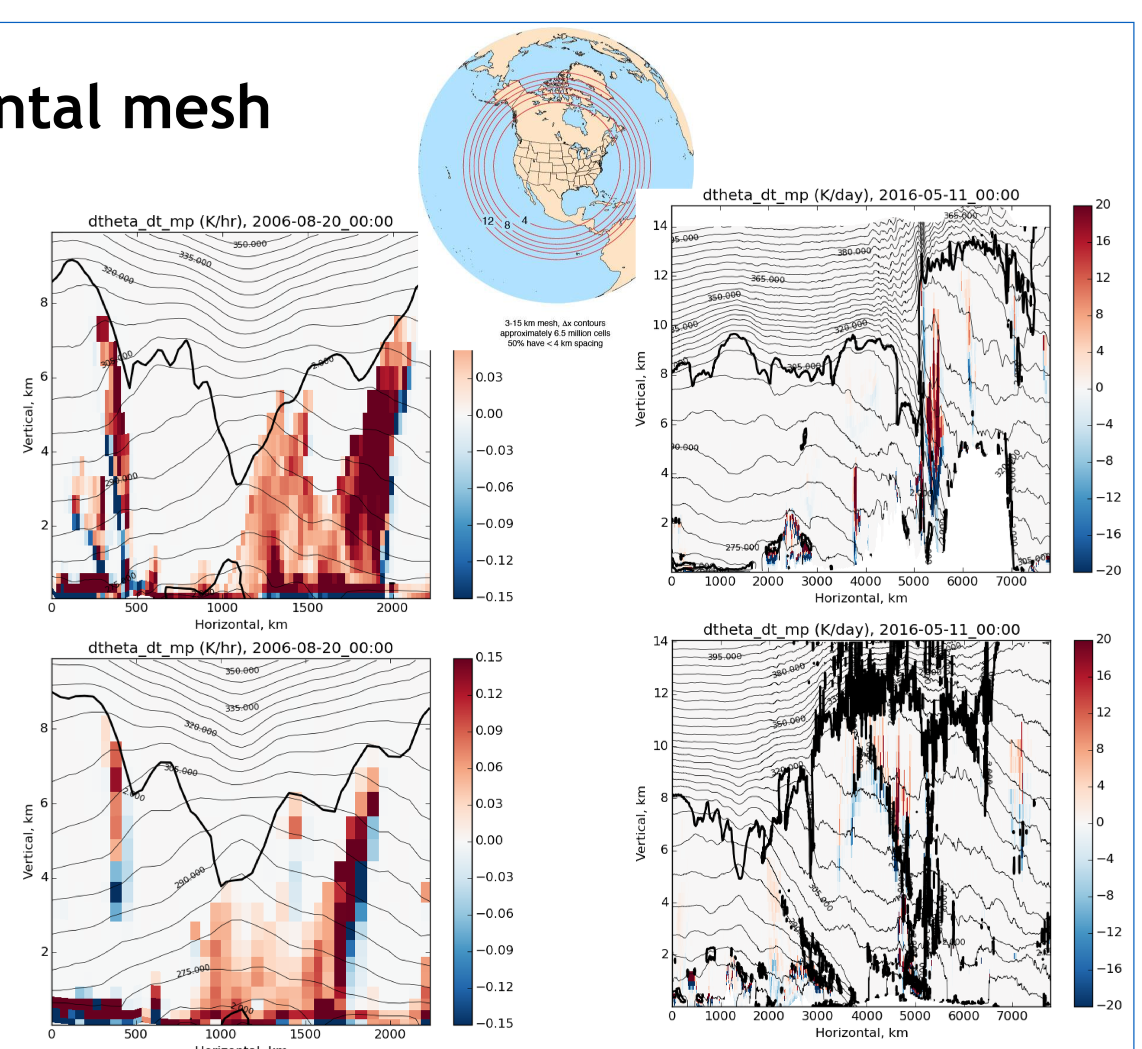




Sensitivities to horizontal mesh

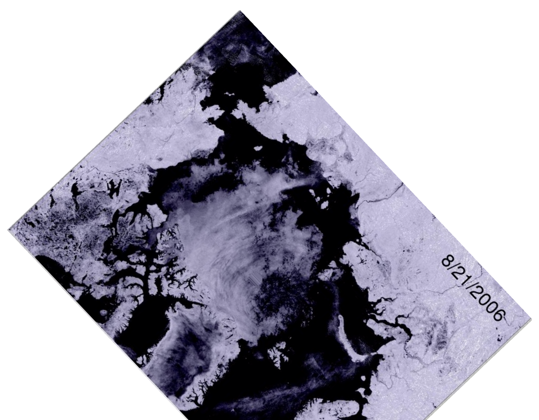


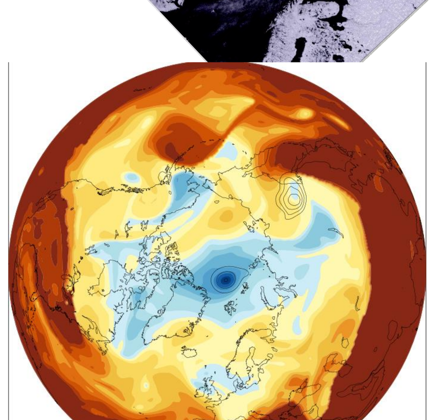
(Left) TPV intensification for MPAS ensemble for August 2006 cases;
(Middle) PT, 2PVU, and mp heating rates for control and midLat meshes;
(Right) x-sections for spring experiment case through 90E and 90W

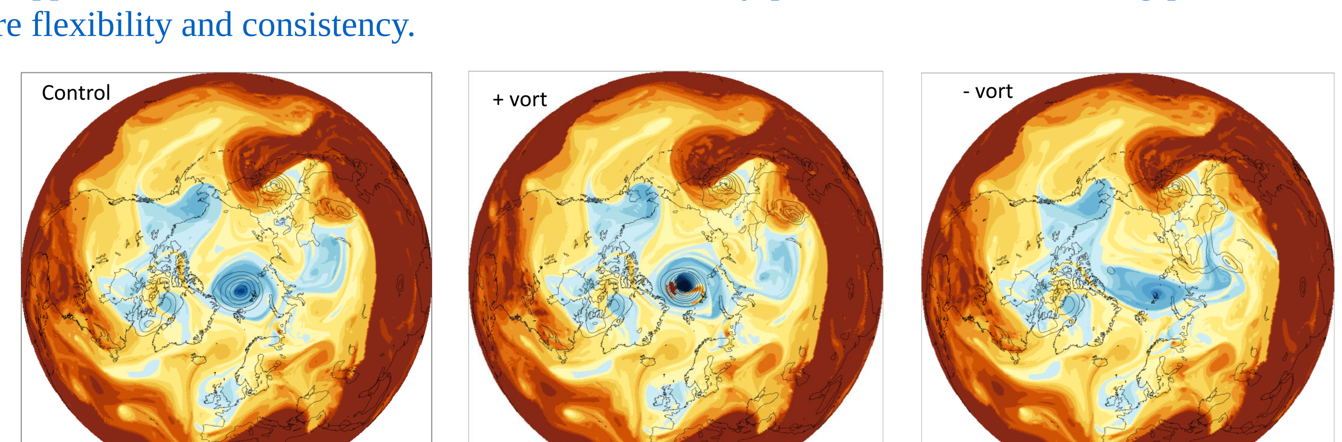


Quantifying TPV impacts (Aug 2006 vorticity TPV mods)

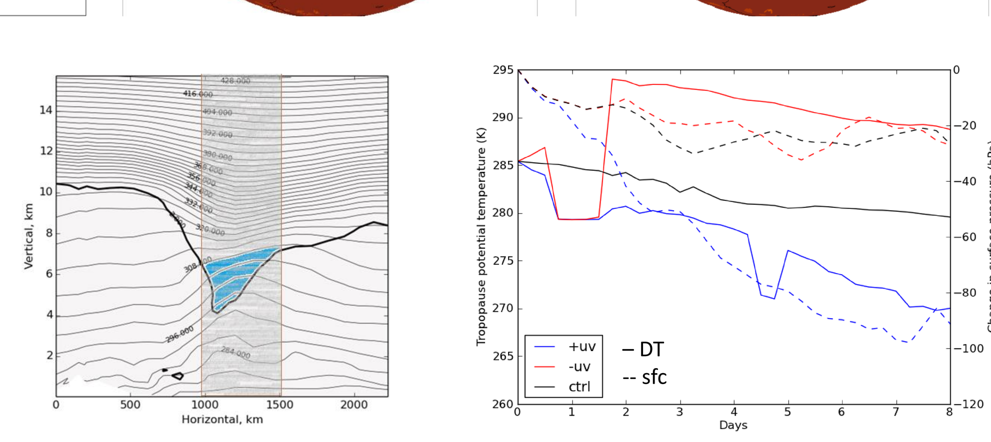
Traditional "PV surgery" relies on questionable approximations and creates inconsistent ICs, likely problematic for evaluating process rates. Targeted flow modifications allow for more flexibility and consistency.







(Left) AMSR sea ice and ERA-I DT PT / MSLP 2006-08-21;
(Right) TPV vorticity modifications 4 days in at 2006-08-19



Conclusions and discussion points

- Intensity sensitivity to mesh driven by diabatic physics (mp) feedbacks
- Track sensitive to advection from lower latitude wave breaking
- Unclear why EPV budget not closed and numerics non-negligible
- TPV dynamics and predictability well framed in terms of EPV but not fully rigorous argument
- How to quantify EPV contributions from dynamical core?
- How should process rates and physics feedbacks be sensitive to local scale?
- Where should the mesh be refined? Are judgments ultimately subjective?
- How accurate do simulations need to be to make claims wrt process rates?
- Other models/questions to explore?

Research project overview

Narrative: For skillful S2S sea ice predictions, the atmospheric forcing needs to be accurate (e.g., Stroeve et al. 2014). Among the multi-scale, coupled processes, TPVs, as slowly changing impactful eddies, may provide "potential predictability" to extend forecasts. Working hypothesis is that MPAS-A can be designed to target processes of interest eventually extending understanding and predictions.

Steps: ID mechanisms for TPV-sea ice interactions. Case studies for MPAS-A configuration. Develop strategies for modifying TPVs. Evaluating coupled MPAS-CESM. Quantifying impact of modified TPVs.