The effect of boundary-layer parameterization schemes on the evolution of an idealized cold front simulated with WRF

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Motivation and Objectives

- Many previous numerical studies have investigated the dynamics of cold fronts
  → Simple models - 2D, coarse resolution, simple parameterizations

- What structure do simulated synoptic-scale cold fronts have in the boundary layer (BL) when complex BL parameterizations are used?

- How significant is the role of the BL scheme compared to adiabatic processes?

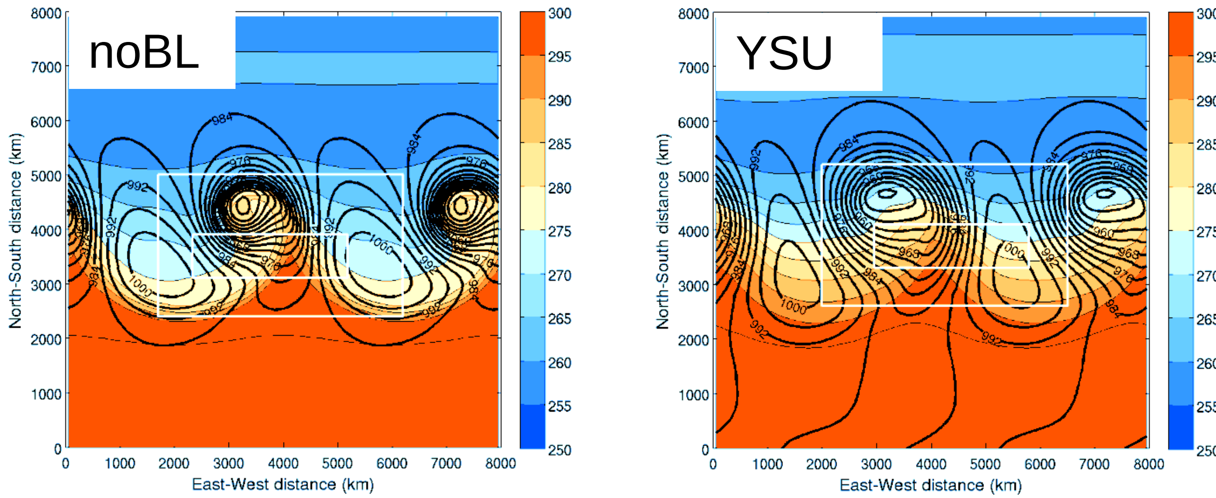
- How does the relative role of the BL parameterization vary between different BL schemes and model grid spacing?

Experiments with WRF (Weather Research and Forecasting) model

Simulate an idealized weather system

- No moisture
- Only physics are PBL scheme and surface layer scheme
- No diurnal cycle
- Three nested with different dx (100km, 20km, 4km)

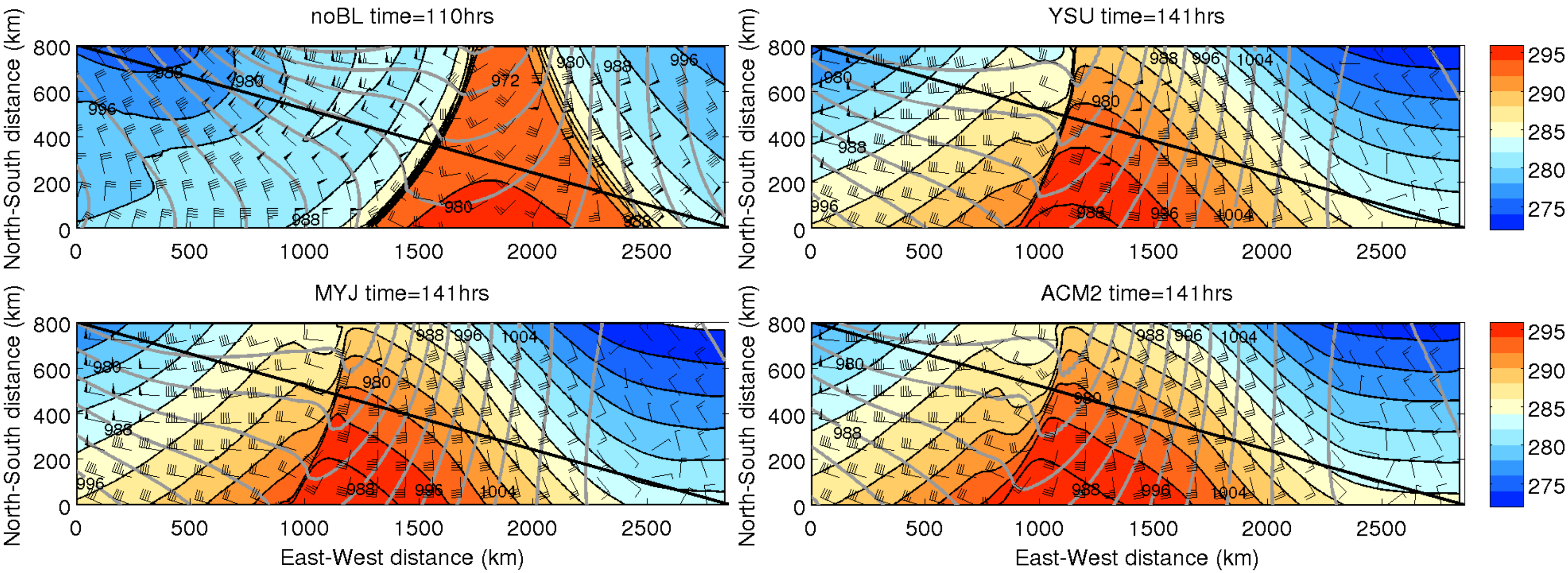
Surface pressure and potential temperature.



Four different PBL schemes

1. No boundary layer (**noBL**)
2. Yonsei University (**YSU)**: 1st order non-local scheme with explicit entrainment
3. Mellor-Yamada-Janjic (**MYJ)**: 1.5 order prognostic TKE (local mixing) scheme
4. Asymmetrical Convective Model version 2 (**ACM2)**: transilient mixing upwards and local mixing downwards.

Effect of PBL on horizontal frontal structure at z=100m



All PBL schemes weaken the thermal gradient and wind speeds compared to noBL

Small differences between PBL schemes at synoptic-scales

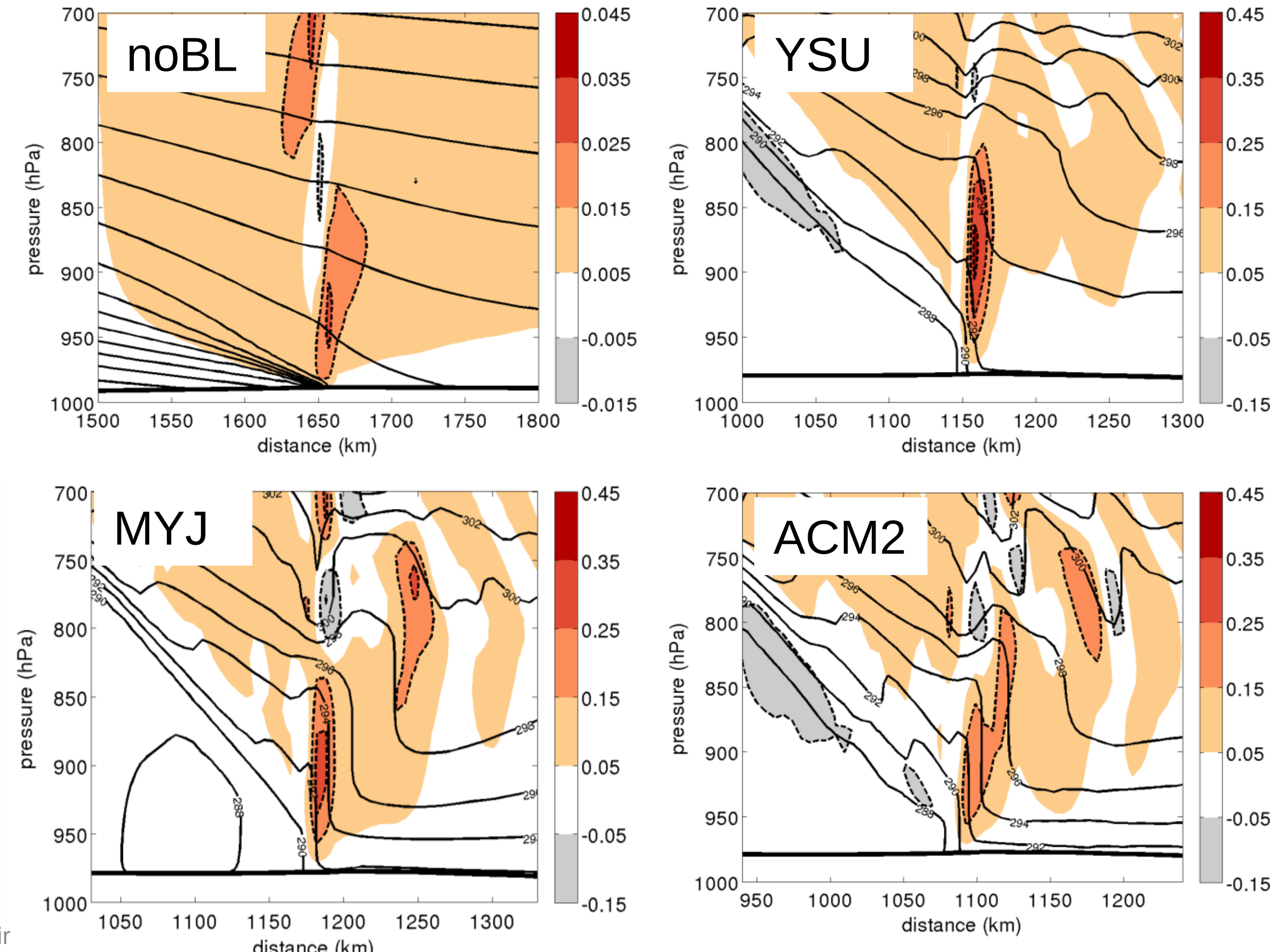
Effect of PBL on potential temperature and vertical motion

Note: color scale in noBL case is 10 times less than in other cases!

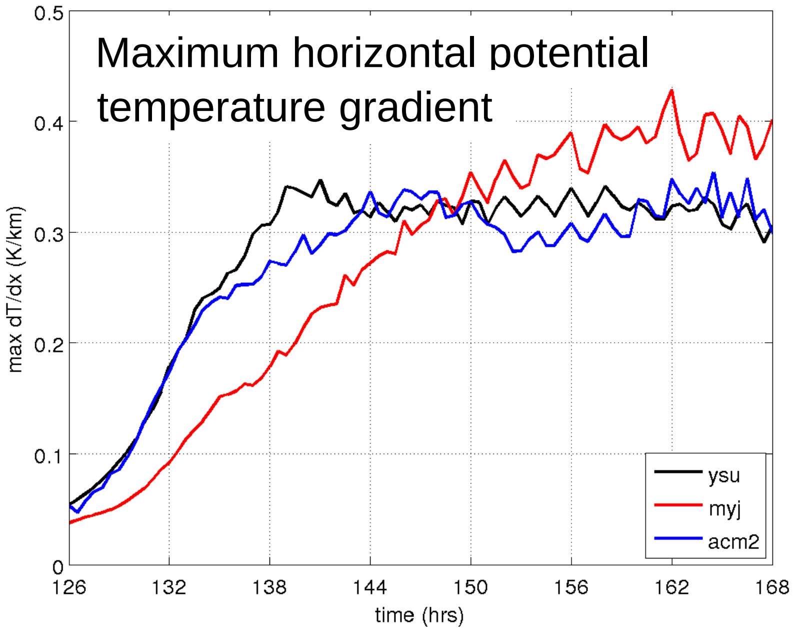
Stability of pre-frontal PBL differs considerably

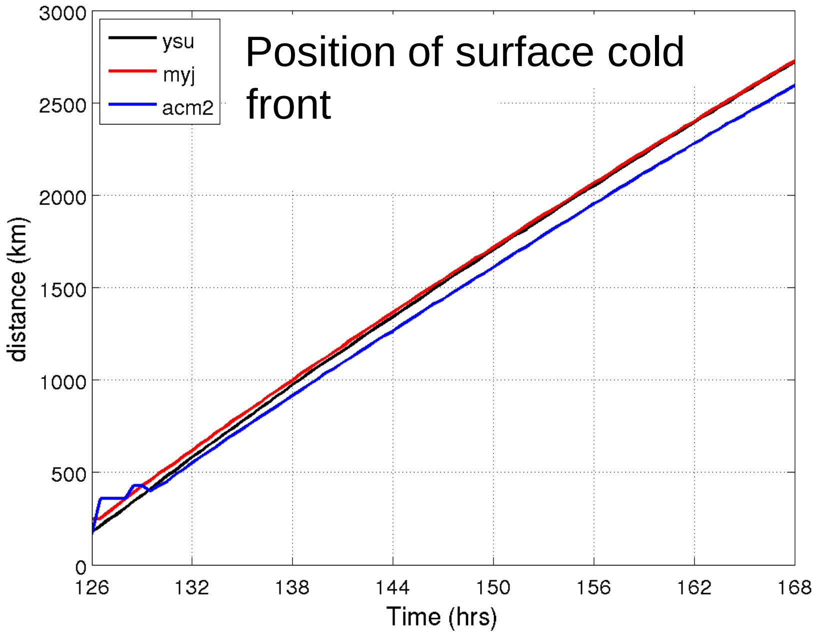
YSU has the most mixing and strongest ascent

ACM2 and MYJ develop a feature above the stable PBL.



Quantitative comparison
YSU MYJ ACM2

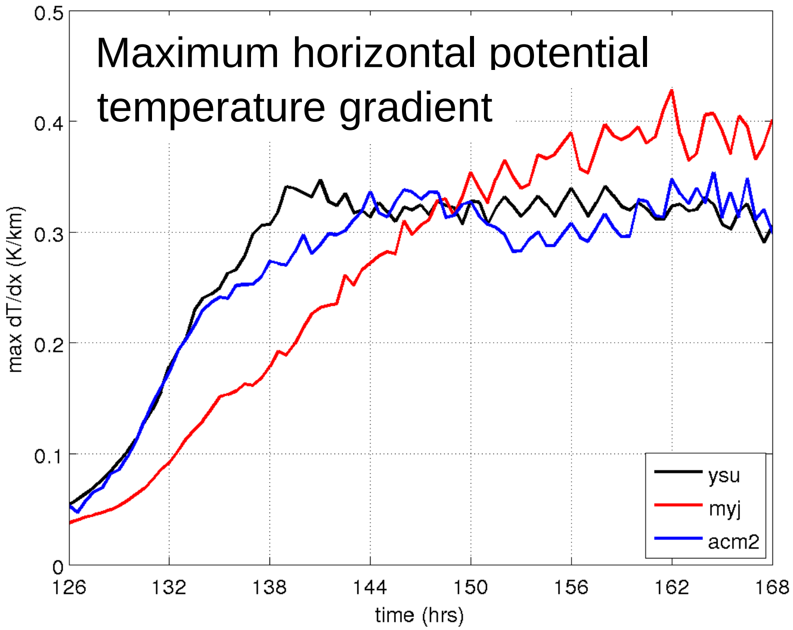


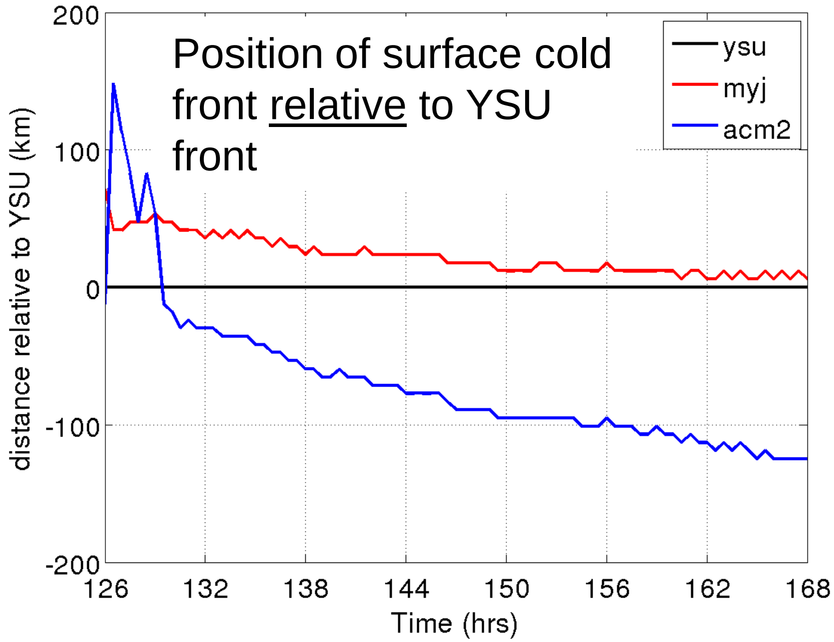


- MYJ has the slowest development but ends up with the strongest front
- After 134 hrs, the thermal gradient differs by a factor of 2
- ACM2 has the slowest moving front
  - ACM2 front is 113km behind MYJ front after 156 hrs.

Quantitative comparison

YSU MYJ ACM2





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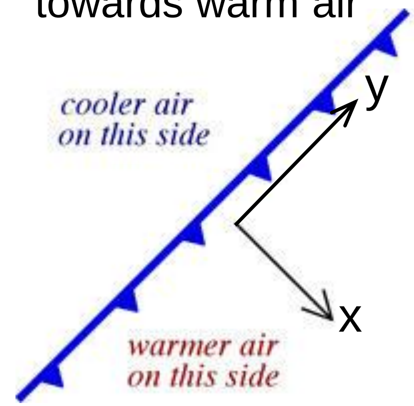
Compare terms in the cross-front horizontal momentum equation

$$\frac{Du}{Dt} - fv + \frac{1}{\rho}\frac{\partial p}{\partial x} = F_u^{bl}$$

Acceleration | Coriolis Force | Pressure gradient force | PBL tendency

Rotate coordinates so that the x-axis is perpendicular to the front and points towards warm air



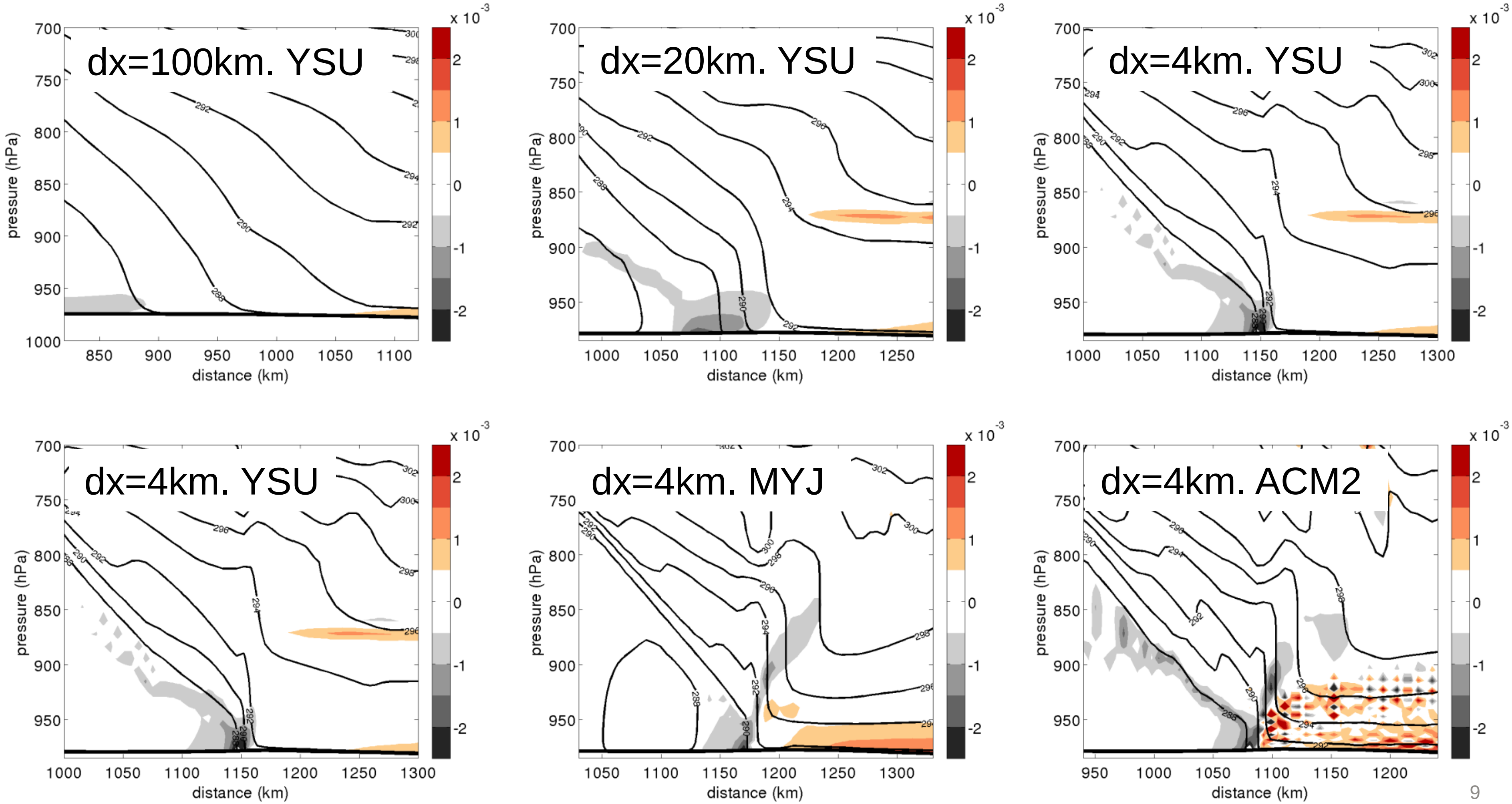
- Output each term directly from WRF
- Compare the relative magnitude of the BL term to the Coriolis term – "Pseudo Ekman number, Ek"
- Identify which model configurations are most sensitive to PBL parameterizations

$$Ek = \left| \frac{\overline{F}_{BL}}{\overline{Cor}} \right|$$

Cross-front BL tendency

different dx (top) and PBL schemes (bottom)

contours show potential temperature, colors show BL tendency



Pseudo-Ekman number

different dx (top) and PBL schemes (bottom)

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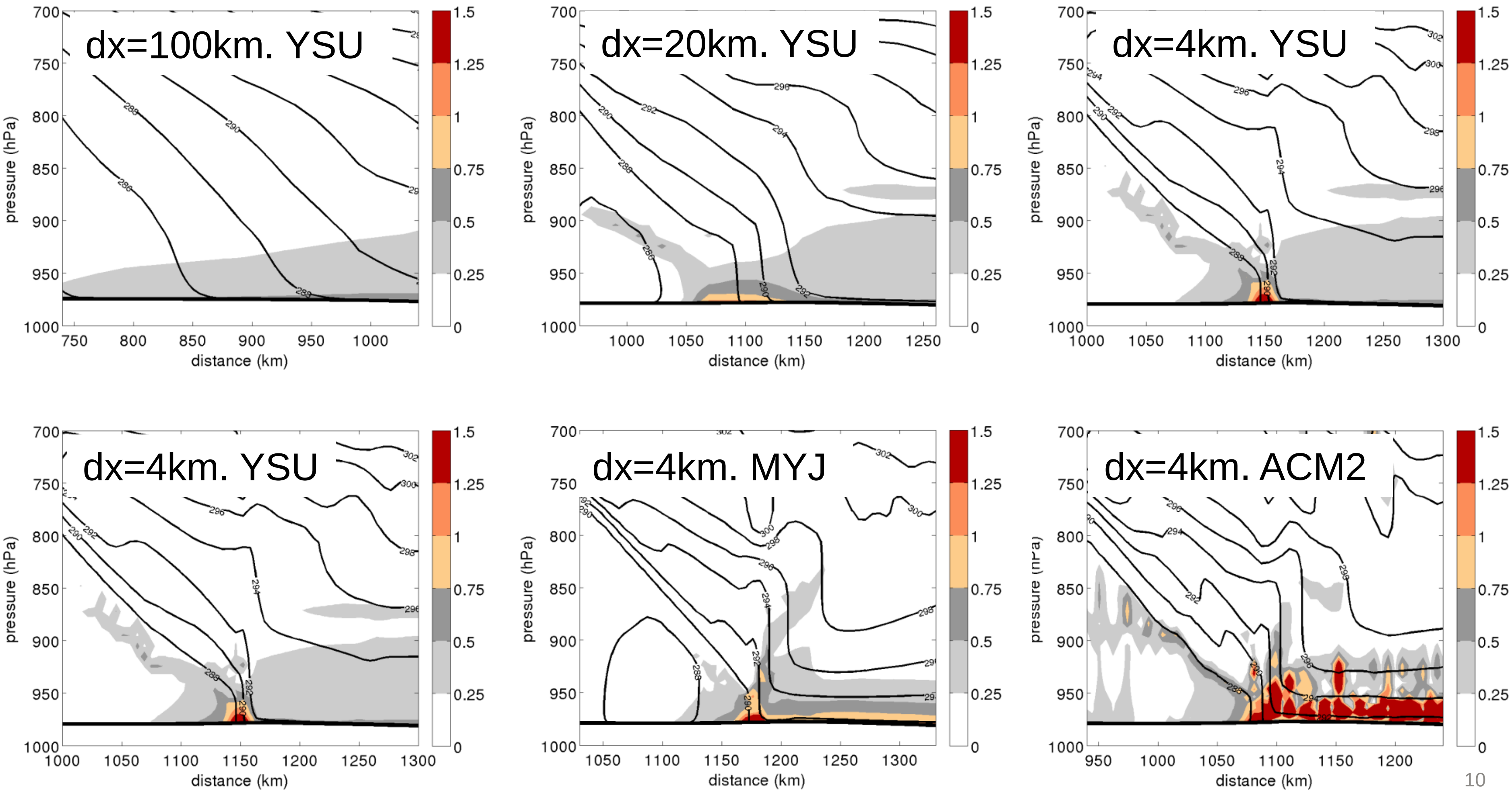
$$Ek = \left| \frac{\overline{F_{BL}}}{\overline{\overline{Cor}}} \right|$$



Conclusions

1. The synoptic-scale structure of the front is not sensitive to the PBL parameterization.
2. The vertical structure of the front and the rate of frontogenesis are sensitive to the PBL parameterization.
3. In the surface frontal zone, the cross front BL tendency is similar in all PBL schemes but large differences exist in the stable pre-frontal BL.
4. For all PBL schemes, the BL tendency in the frontal zone is of equal importance as the adiabatic terms.
5. The magnitude of the cross-front BL tendency and its relative importance compared to the adiabatic terms increases as the grid spacing decreases.

Thank you

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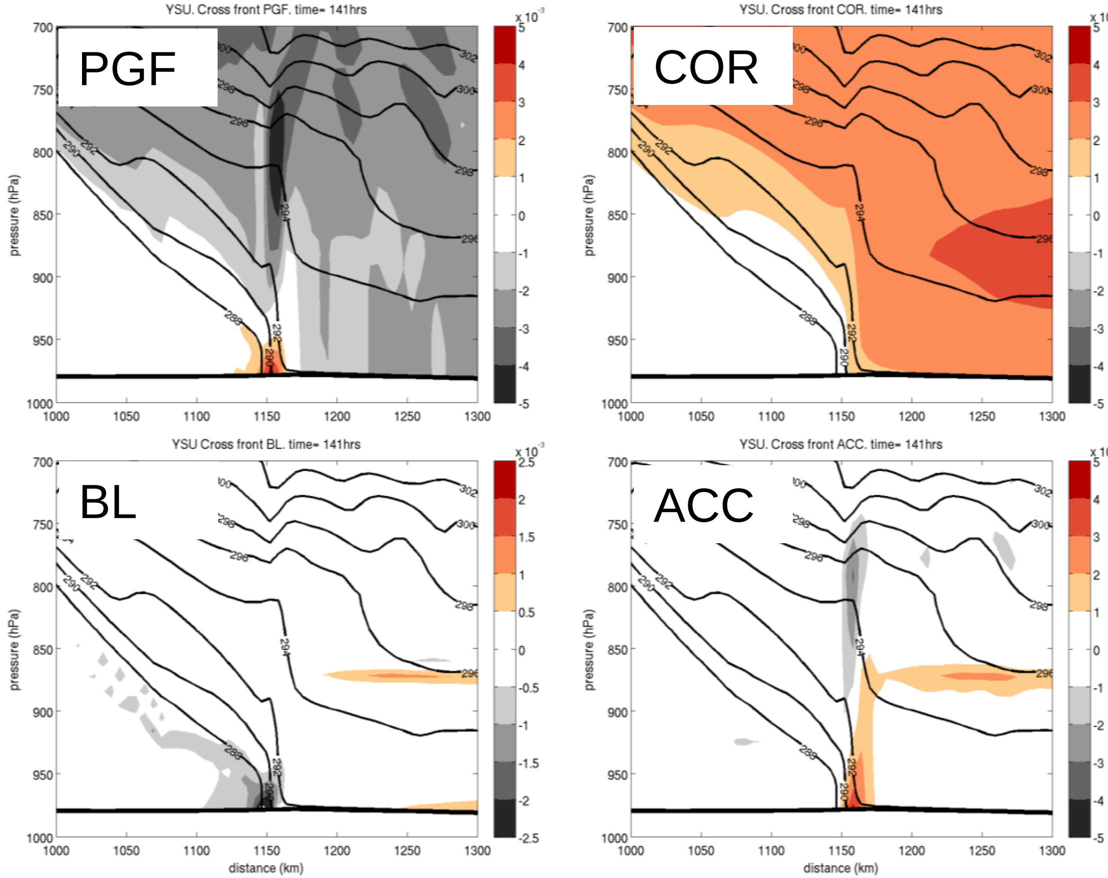
Extra slides

Cross-front momentum balance YSU dx=4km

BL color scale is half that of other panels!

BL tendency is non negligible:

1. on the cold side of the front
2. at the top of pre-frontal BL (explicit entrainment)



Compare terms in the cross-front frontogenesis equation

$$\frac{D}{Dt}\left(\frac{\partial\theta}{\partial x}\right) = -\frac{\partial u}{\partial x}\frac{\partial\theta}{\partial x} - \frac{\partial v}{\partial x}\frac{\partial\theta}{\partial y} + \frac{\partial w}{\partial x}\frac{\partial u}{\partial z} + \frac{\partial}{\partial x}\left(\frac{\partial\theta}{\partial t}\right)_{BL}$$

Lagrangian frontogenesis

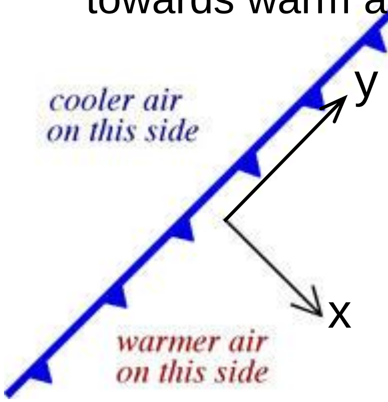
Confluence

Shear

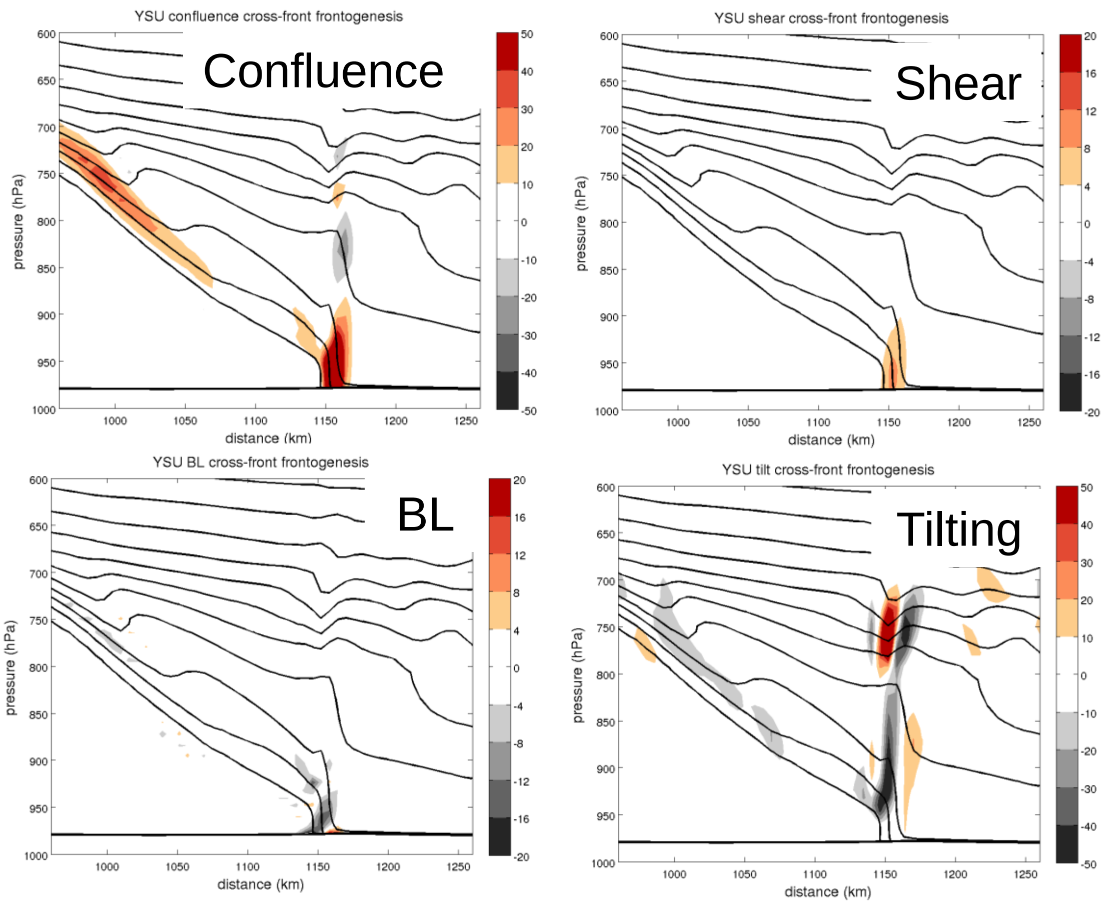
Tilting

PBL tendency

Rotate coordinates so that the x-axis is perpendicular to the front and points towards warm air



YSU terms in cross-front frontogenesis equation



Confluence is the main source of frontogenesis

The PBL term acts to weaken the front

The magnitude of frontolysis due to the PBL is about 25% of the frontogenesis due to shear and confluence combined.