National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL
University of Reading

Identification of low static stability layers from radiosonde profiles

Ben Harvey

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Outline

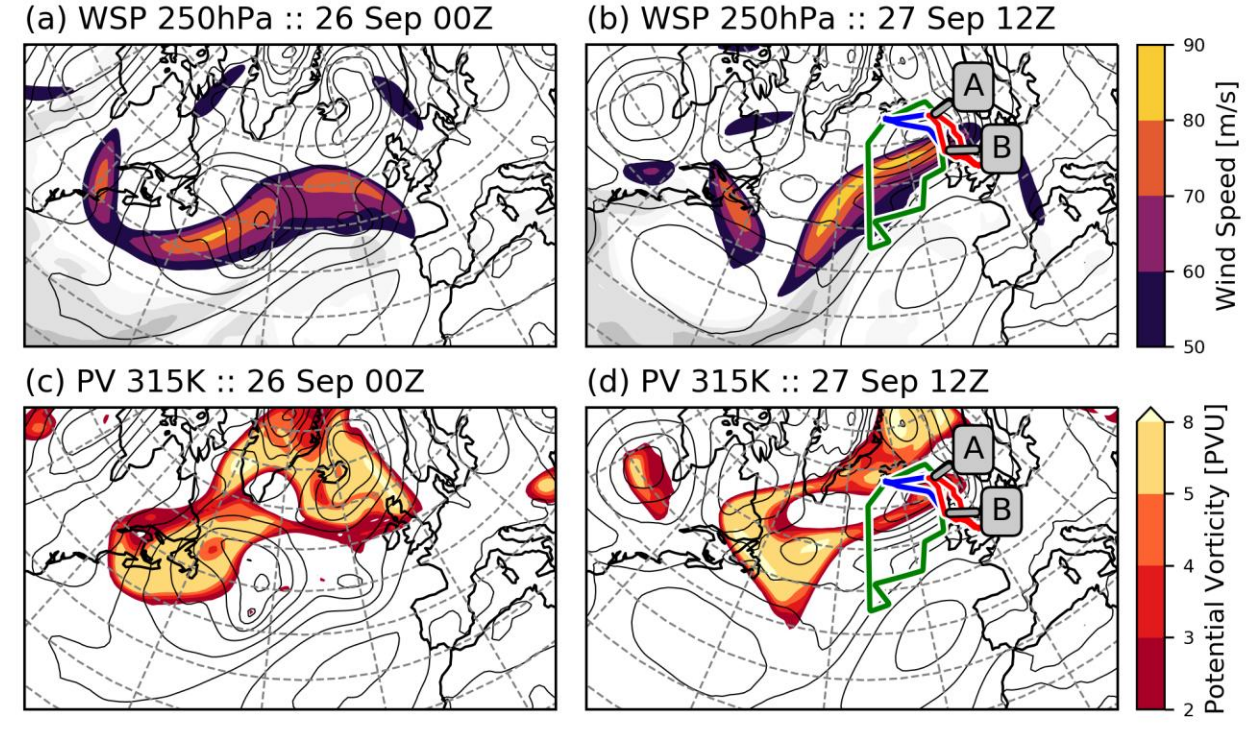
- Negative PV regions: observations, theory, models
- Low stability layers diagnostic
- Case study – Thor Ridge (IOP10)
- Statistics over the whole NAWDEX period

IOP4:
Ex-Tropical
Storm Karl

Negative PV: observations

Wind speed at 250 hPa

PV at 315 K



[data = ERA-Interim]

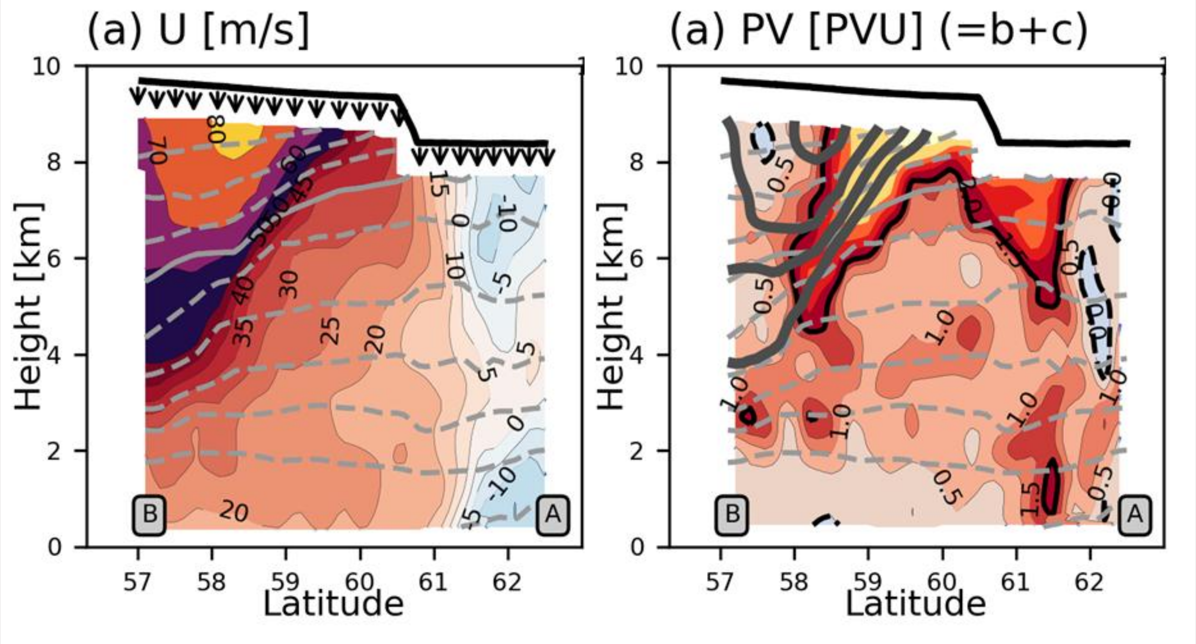
IOP4:
Ex-Tropical
Storm Karl

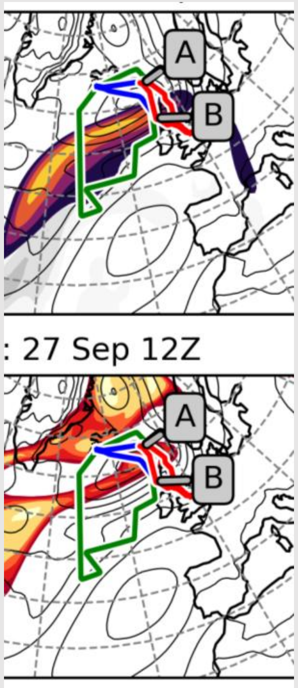
Negative PV: observations

Dropsonde observations

from

FAAM flight B981





$$\rho P = \boldsymbol{\zeta} \cdot \nabla \theta = (f - u_y)\theta_z + u_z \theta_y$$

Negative PV: theory

Lagrangian PV equation:

$$\rho \frac{DP}{Dt} = \boldsymbol{\zeta} \cdot \nabla H$$

Negative PV: theory

- Isentropic advection:

$$\frac{\tilde{D}}{Dt} = \frac{\partial}{\partial t} + (\boldsymbol{u} - \boldsymbol{u}_D) \cdot \nabla$$

- Diabatic mass flux:

$$\rho \boldsymbol{u}_D = \frac{\rho \boldsymbol{n}}{|\nabla \theta|} H$$

- Normal to θ surfaces: $\boldsymbol{n}$
- Projection of absolute vorticity onto isentropic surface: $\boldsymbol{\zeta}_{//}$

Non-advective flux: $\boldsymbol{J}_{NA} = -\boldsymbol{\zeta}_{//} H$
(scales as: Ro)

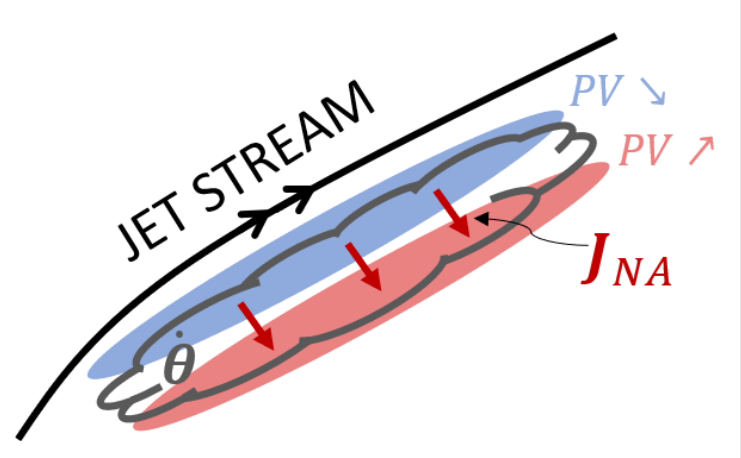
Isentropic PV equation:

E.g. Haynes & McIntyre (1990)

Dilution/concentration
(scales as: $1 + Ro$)

$$\rho \frac{\tilde{D} P}{Dt} = \boxed{P \nabla \cdot (\rho \boldsymbol{u}_D)} - \boxed{\nabla \cdot (\boldsymbol{\zeta}_{//} H)}$$

$\boldsymbol{J}_{NA}$ always directed "down the isentropic slope"



Negative PV: models

'PV tracers' diagnostics allow the PV field to be split as

$$P = P_{adv} + \sum_n P_n$$

Where P_n represents the accumulated PV due to

- each physics parametrization
- an estimate of the non-conservation of PV by the dynamical core

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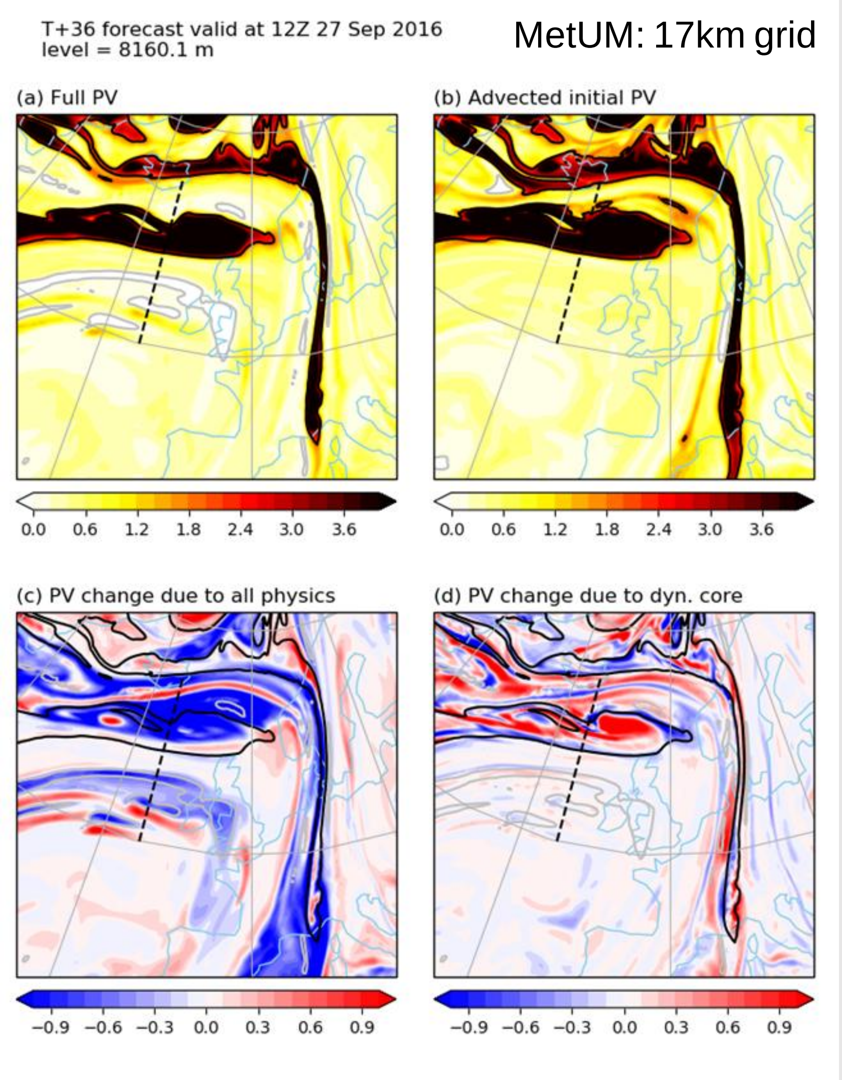


Questions

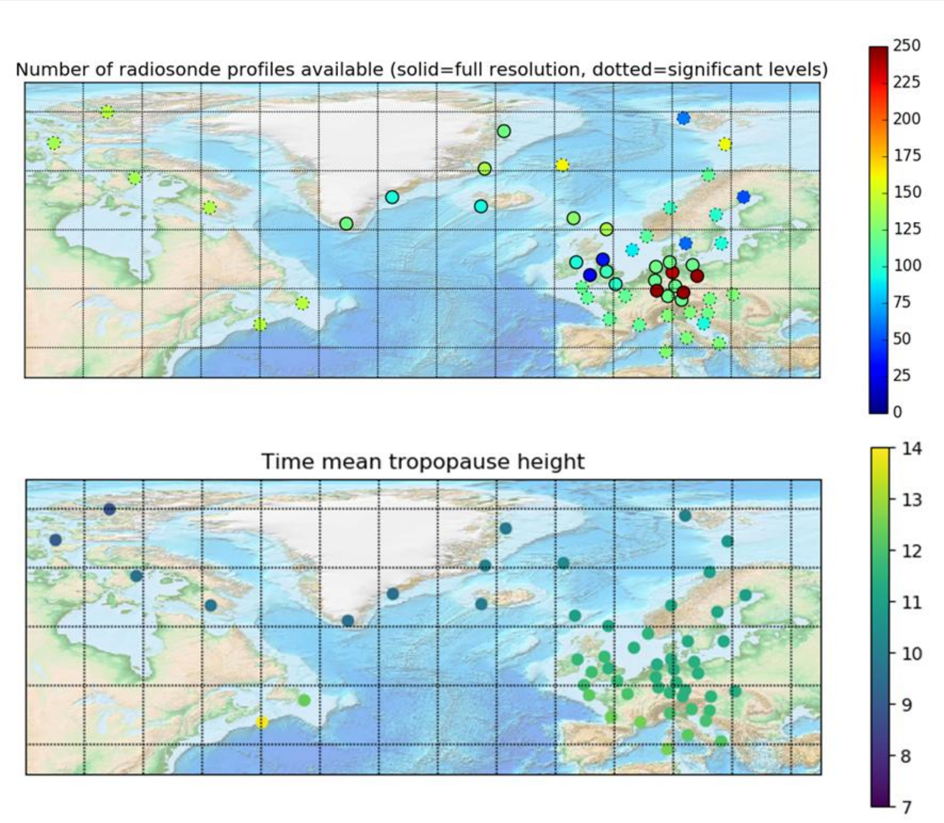
- Do models have a good representation of negative PV features associated with WCBs?
  - Generation process (timing, position, structure)
  - Lifetime / destruction process
- Can we assess this with observations?

  This talk:

  Attempt to do this using the statistics of static stability as measured by radiosondes

NAWDEX radiosondes

- ~7000 radiosonde profiles during Sep/Oct 2016
- About half are full resolution profiles ($dz \approx 10$ m) – the rest are `significant levels' only
- All data is available on the NAWDEX wiki
- Have extracted corresponding profiles from UKMO operational forecasts – out to T+5 days



Low Stability Layers (LSLs)

- Define LSLs based on their bulk static stability value:

$$\Lambda(z_0, z_1) = \frac{\theta(z_1) - \theta(z_0)}{z_1 - z_0}$$

- For a given profile, the deepest layers $z_0 < z < z_1$ satisfying $\Lambda(z_0, z_1) < \Lambda_{thres}$ are identified and successively removed
- Only need to choose one parameter: Λ_{thres}

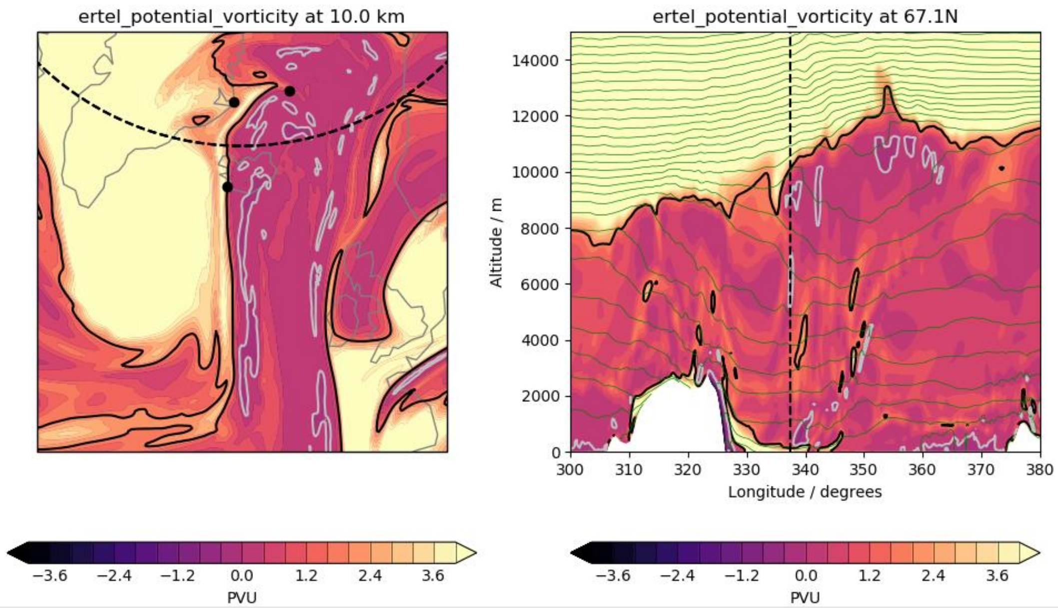
→ Look at $\Lambda_{thres} = 2$ K/km and 1 K/km here

- In practice, also specify a minimum layer depth (here use $\Delta z_{min} = 200$ m)

Case study – Thor Ridge

- Poleward-extending ridge of low PV air east of Iceland
- Grey lines are PV=0 (indicative of recent diabatic heating)
- Cross section shows bulging θ contours in the ridge (= low static stability)

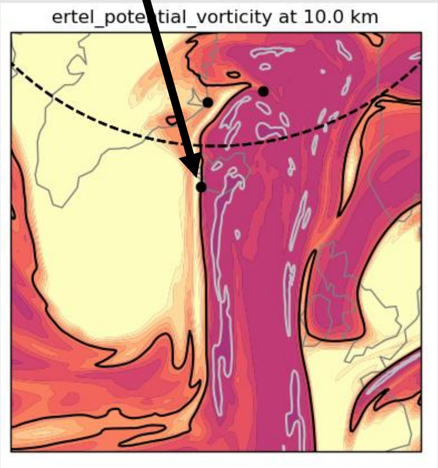
MetUM analysis: 00Z 13 Oct

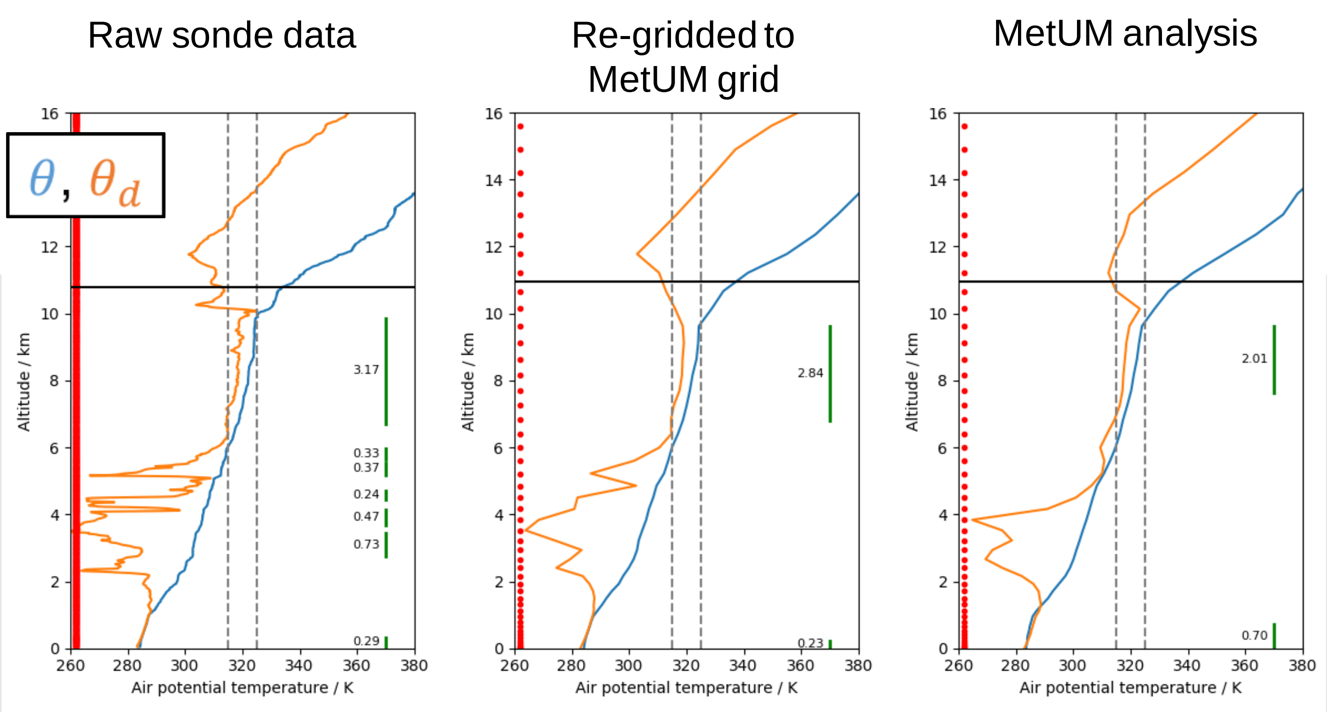


IOP10:
Thor Ridge

An example profile

Keflavik
(hi-res sonde)
00Z 13 Oct



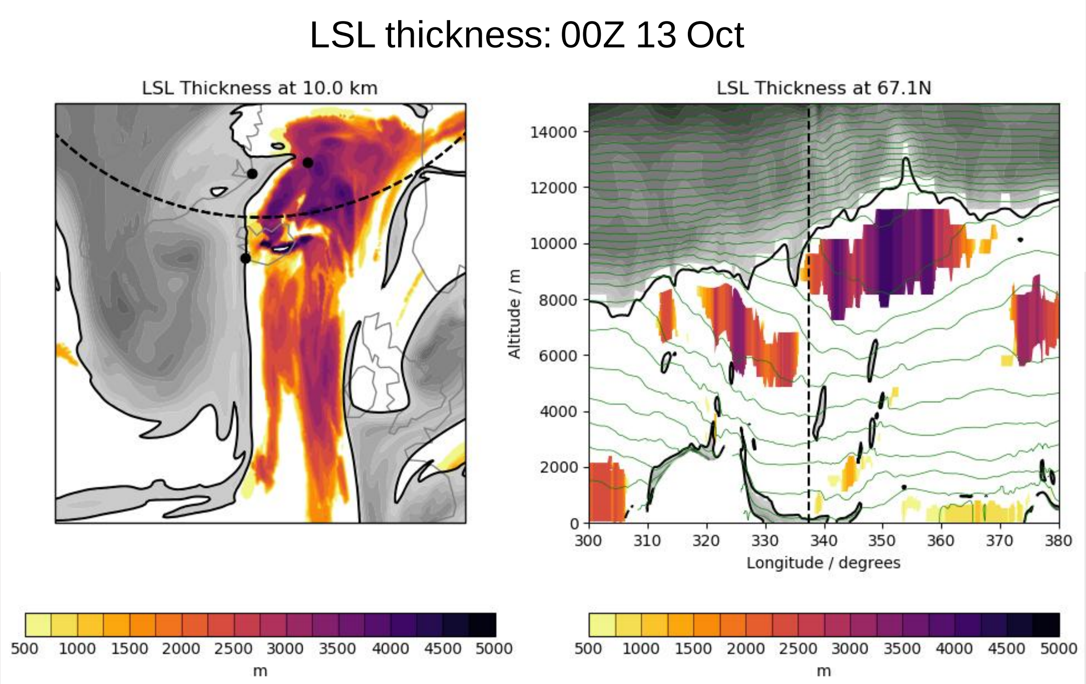


Low stability layers (number = thickness)

IOP10:
Thor Ridge

LSLs in the analysis: 2 K/km

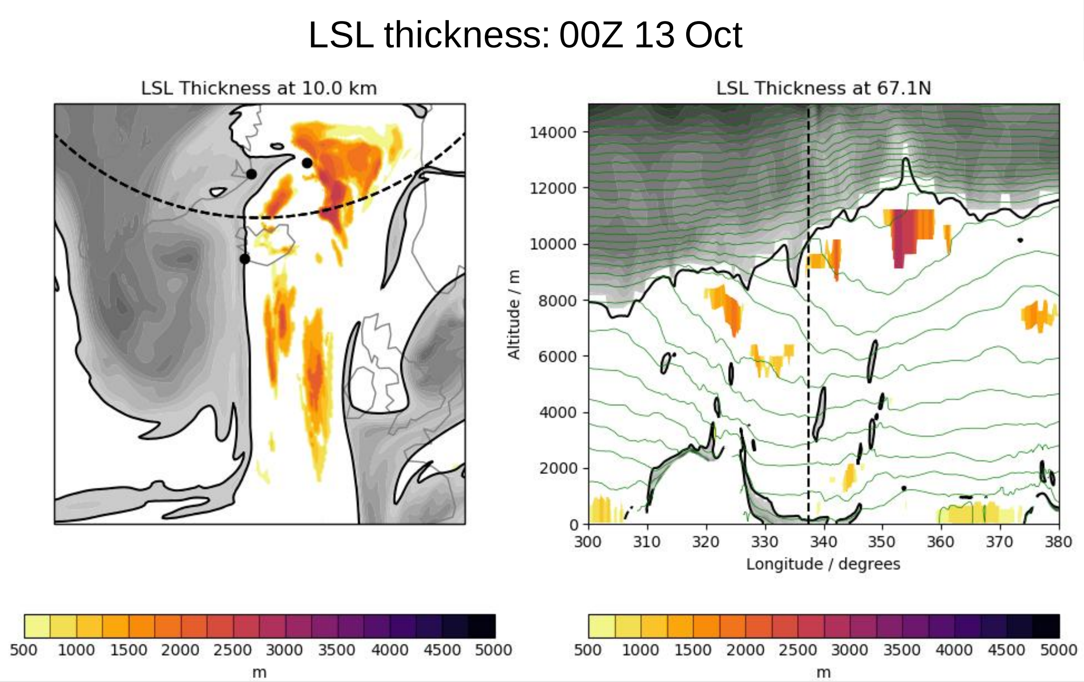
- LSLs with: $\Lambda_{thres} = 2\,K/km$
- Low stability layer forms a coherent structure throughout the ridge
- Also some other features identified, e.g. well-mixed boundary layers



IOP10:
Thor Ridge

LSLs in the analysis: 1 K/km

- LSLs with: $\Lambda_{thres} = 1\,K/km$
- LSLs are still identified, but are much less coherent
- This more stringent criteria gives LSLs that map more closely to the regions of PV<0



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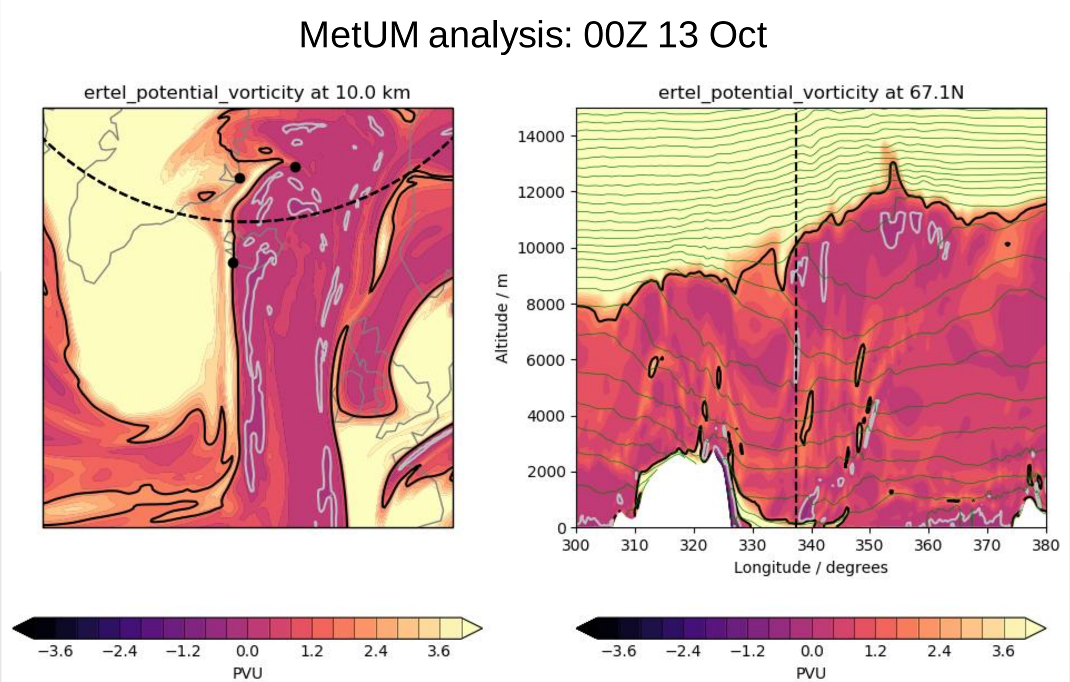
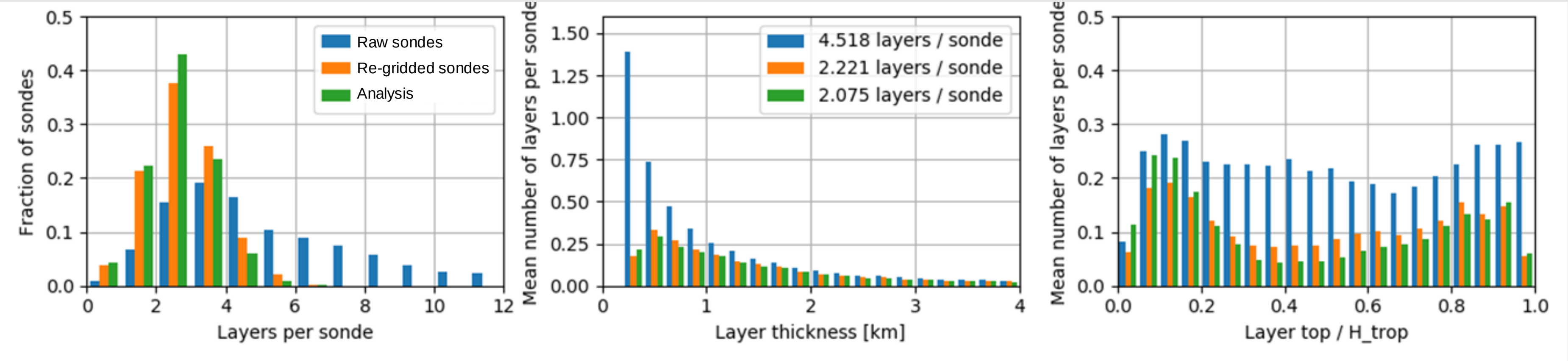


Statistics over all the NAWDEX sondes

How do the sonde statistics compare with the analysis?

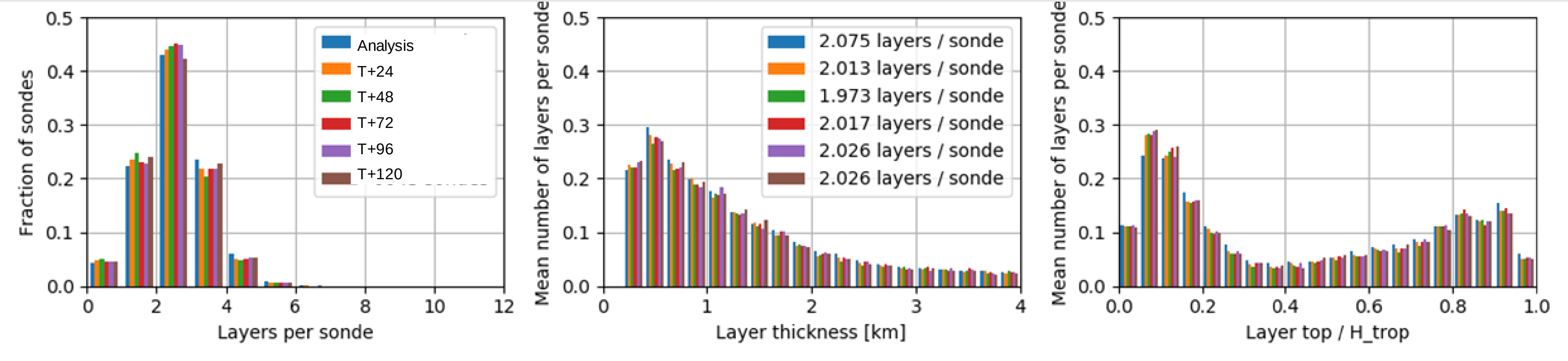
- Re-gridding removes about half of the layers (most < 1 km thick), but re-gridded data still has ~10% more layers than the analysis
- Bias varies with altitude: analysis has more BL layers than sondes, but fewer free-troposphere layers



Statistics over all the NAWDEX sondes

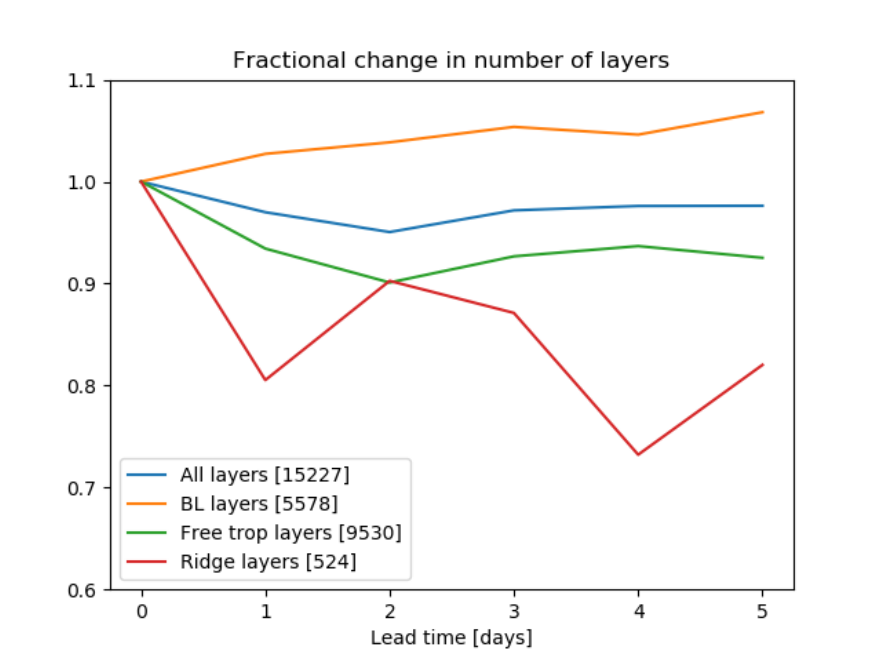
Do the statistics change with forecast lead time?

- Total number of layers reduces with lead time to T+48
- Again there is compensation in the vertical – number of BL layers increases with lead time and the number of tropospheric layers decreases



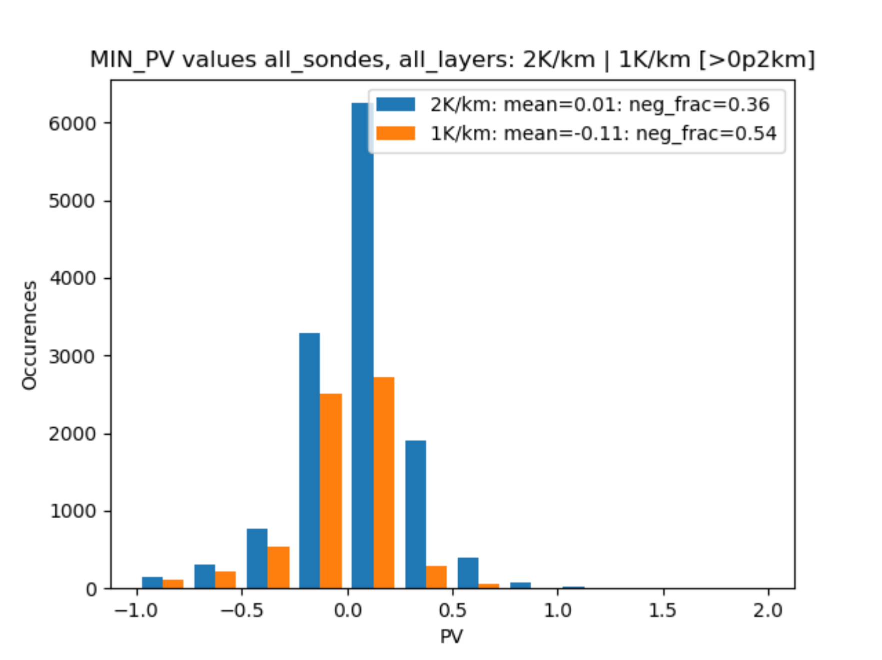
Statistics over all the NAWDEX sondes

- Compensation between BL and free trop layers grows with lead time
- Substantial decrease of ridge layers with lead time
- Associated with reduced amplitude ridges?



Are these LSLs an indicator of negative PV?

- $\Lambda_{thres} = 2$ K/km picks out many of layers not containing negative PV (in the model at least)
- $\Lambda_{thres} = 1$ K/km does better:
  - Mean min(PV) in layers is negative
  - Over 50% of layers contain negative PV points

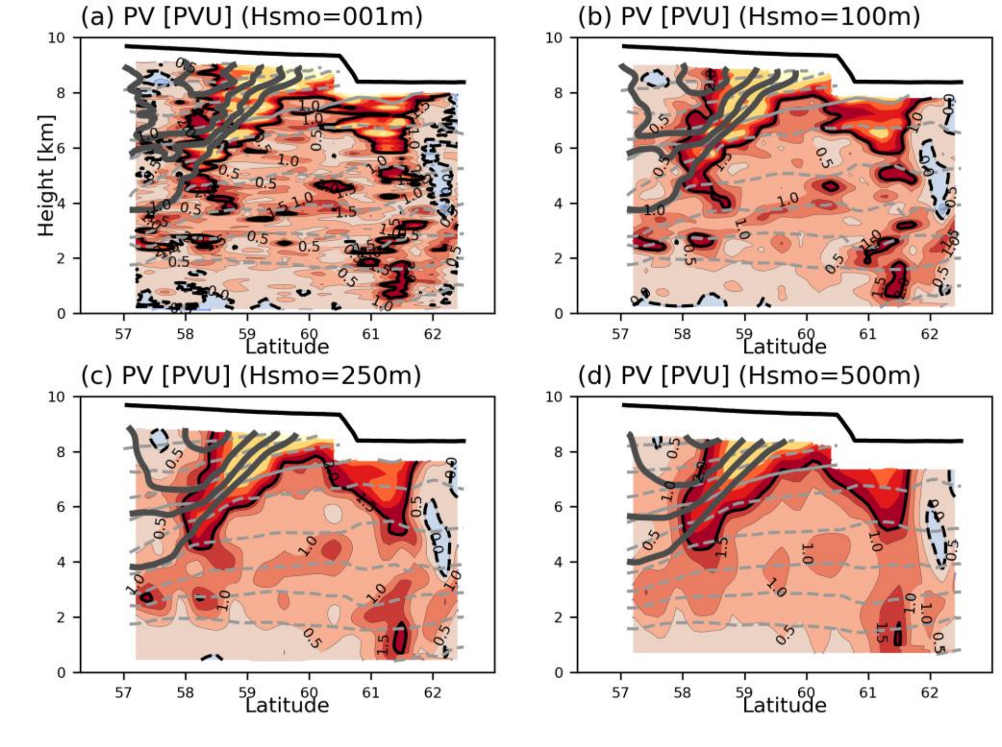


Summary

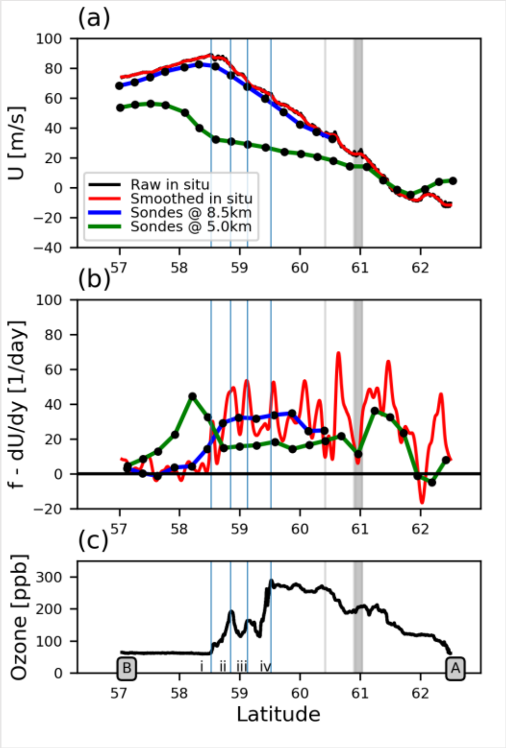
- The isentropic form of the PV equation gives insight into the conditions under which negative PV forms and its structure
- The LSL diagnostic is a proxy for regions of low PV
  - Depending on the threshold used, it can identify the large-scale coherent structure of ridges, or smaller-scale low PV regions within them
- Comparing the MetUM analysis to the NAWDEX radiosondes, find on average the analysis has:
  - Fewer and thinner LSLs then the observations
  - Too many BL layers and too few tropospheric layers
  - A strong reduction in the number of layers in upper-tropospheric ridges with lead time

Spare slides

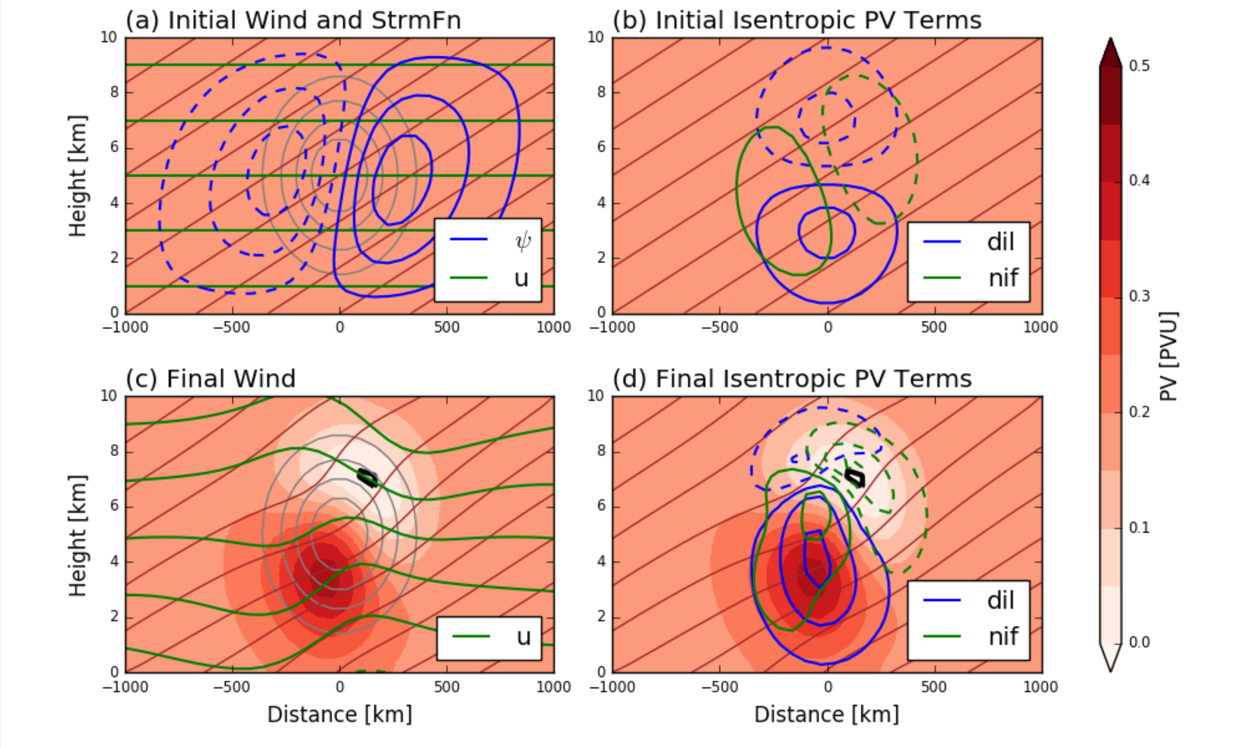
Robustness of observed negative PV



Robustness of observed negative PV



Frontal-geostrophic simulations



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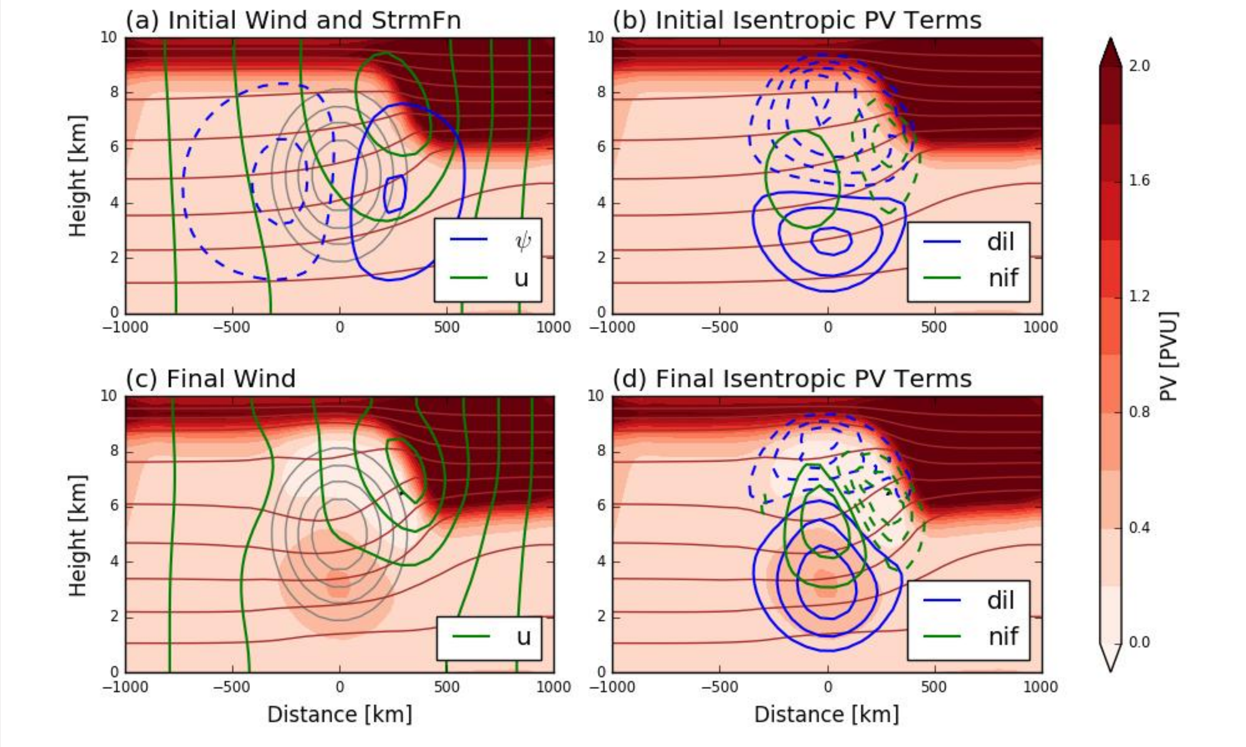

Negative PV: models

'PV tracers' diagnostics allow the PV field to be split as

$$P = P_{adv} + \sum_n P_n$$

Where P_n represents the accumulated PV due to

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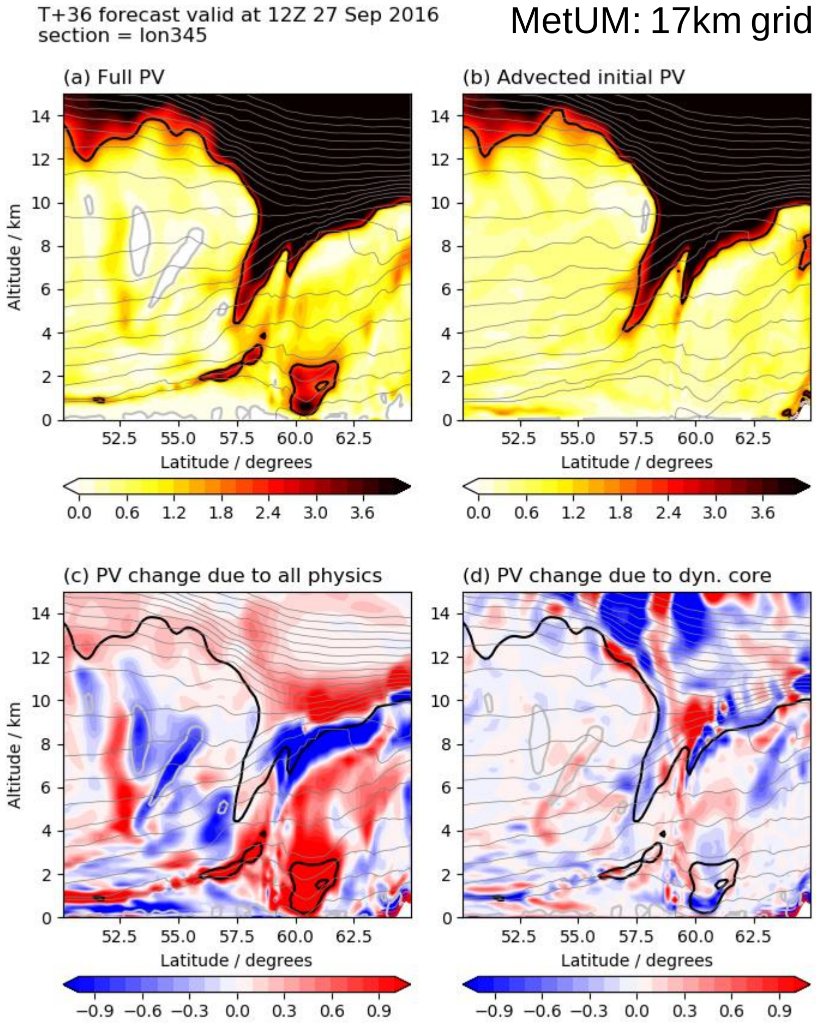
IOP4:
Ex-Tropical
Storm Karl

MetUM: 17km grid



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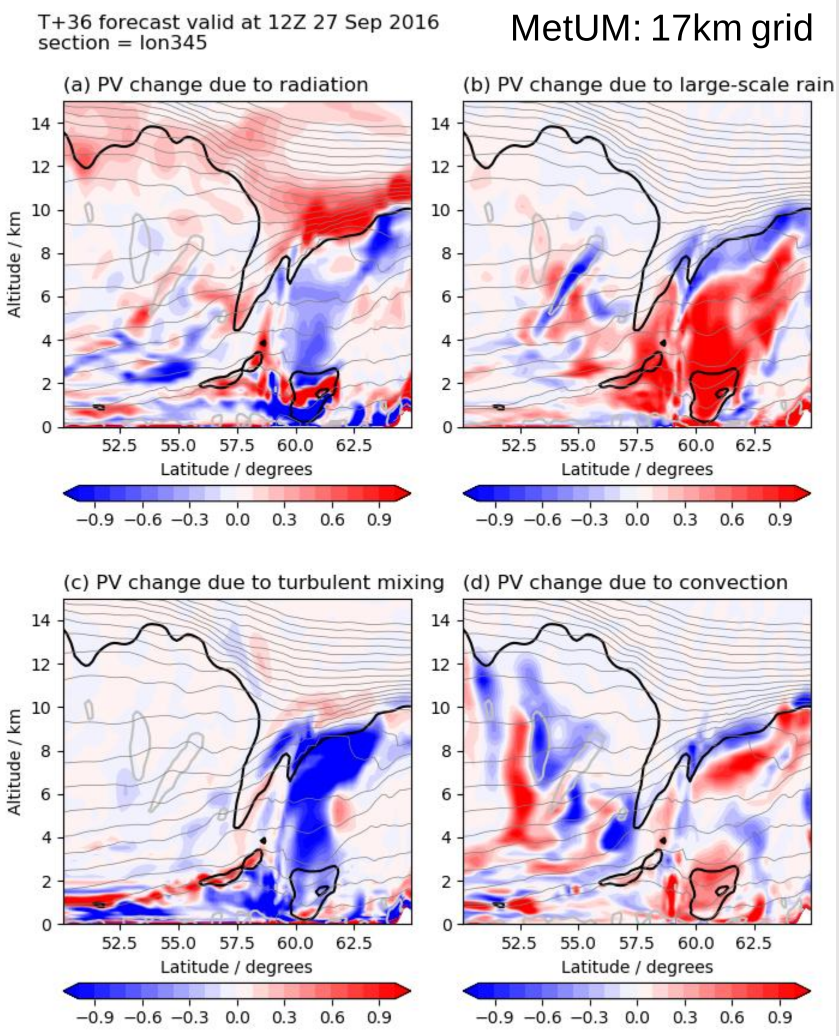
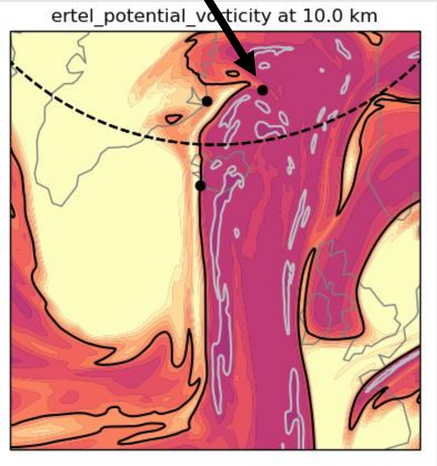
IOP4: Ex-Tropical Storm Karl

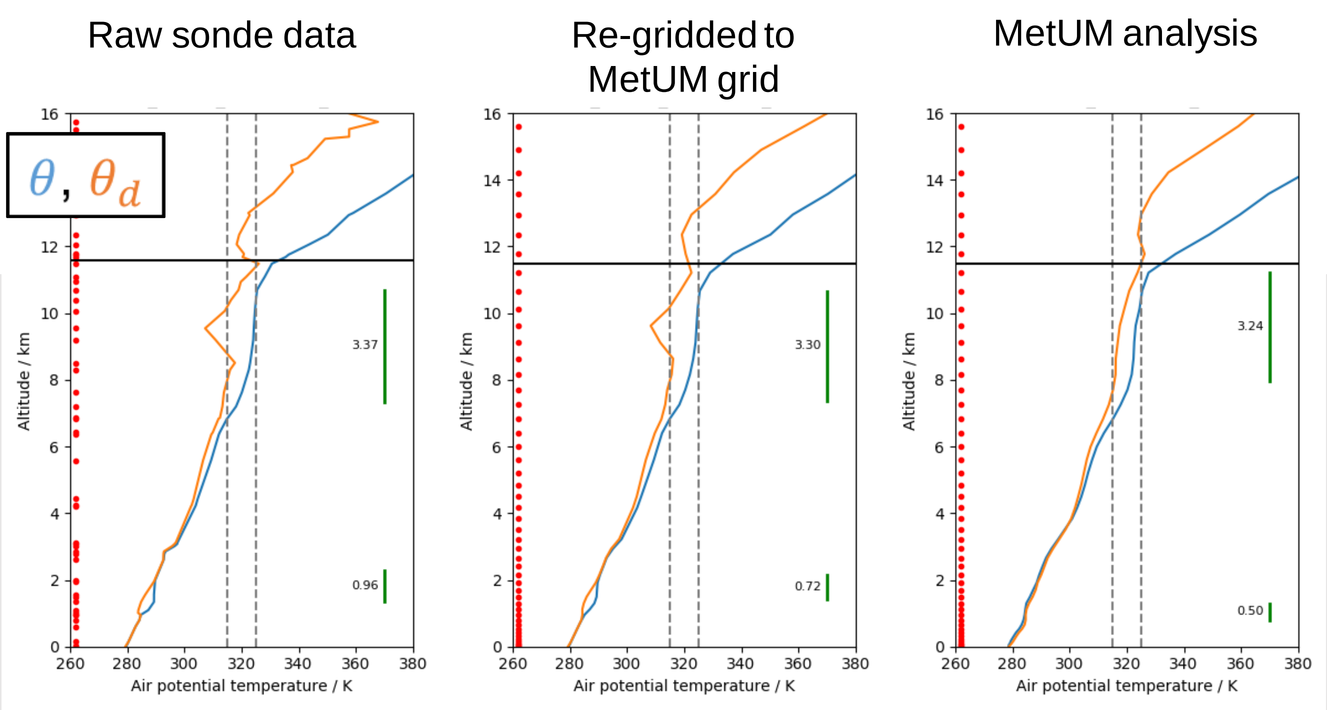


IOP10:
Thor Ridge

Some example profiles

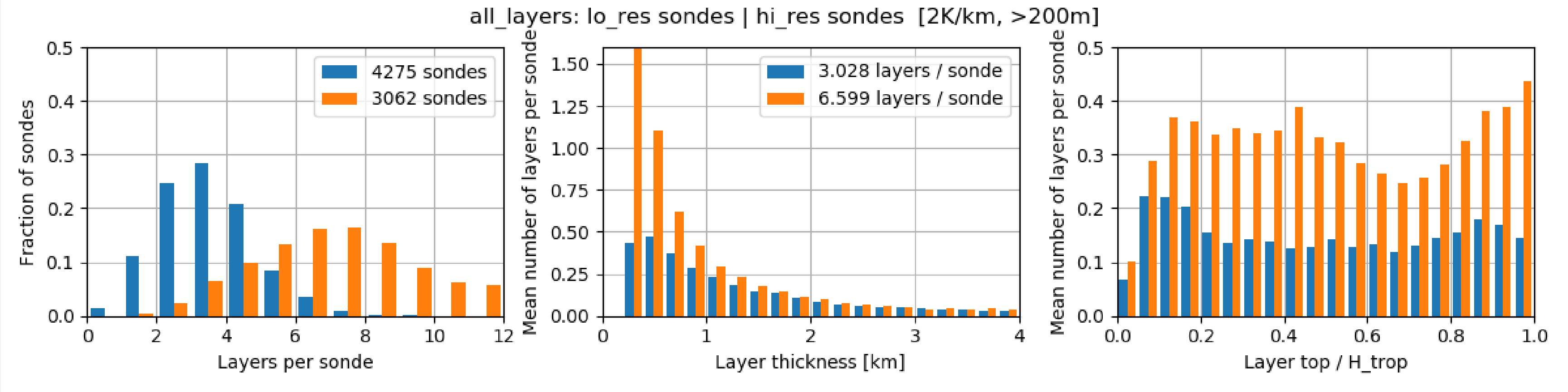
Jan Mayen
(lo-res sonde)
00Z 13 Oct





Low stability layers (number = thickness)

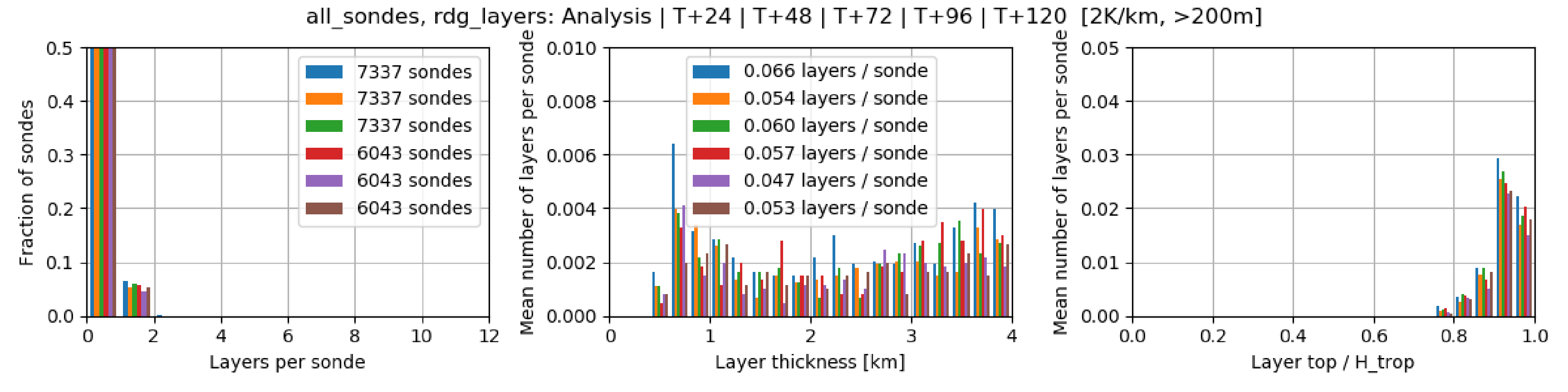
Statistics over all the NAWDEX sondes



Does sonde resolution matter?

- Over twice as many layers per sonde on average in full resolution sondes compared to significant-levels sondes
- Most of the extra layers are shallower than 1km

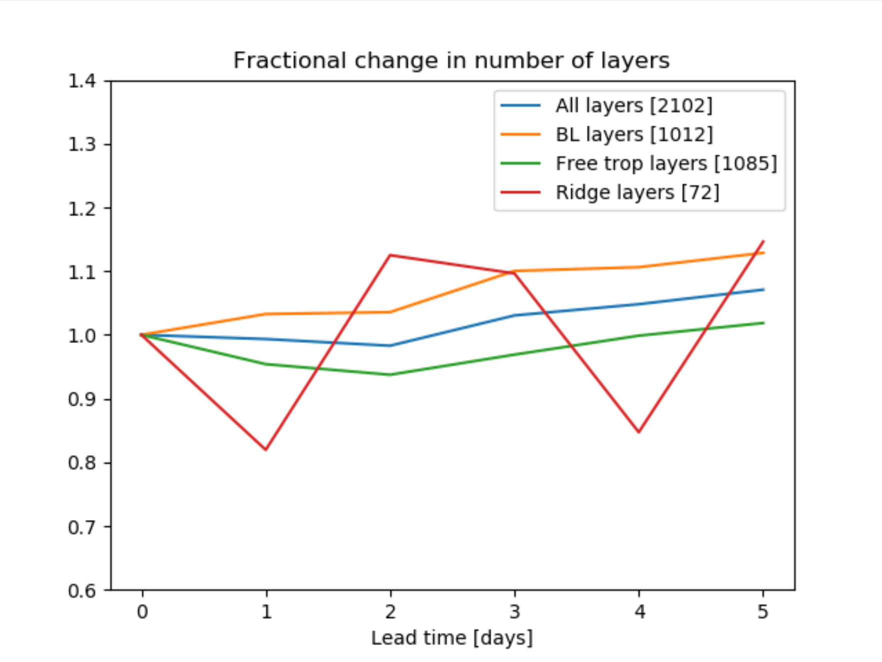
Statistics over all the NAWDEX sondes



- Subset to ridge layers: layer top > mean tropopause height
  - Clear reduction of ridge LSLs with lead time – see also next slide
  - Have tried other definitions of 'ridge layers', find large sensitivity in the rate of decline with the definition used

Are these LSLs an indicator of negative PV?

- $\Lambda_{thres} = 1$ K/km (deep layers) shows a different trend in ridge layers than before – suggestive that model is producing and/or maintaining negative PV too favourably – despite fact overall ridge layers are decreasing…



Statistics over all the NAWDEX sondes

So far, have only counted layer occurrences in each dataset.

How well do the layers match up between the datasets?

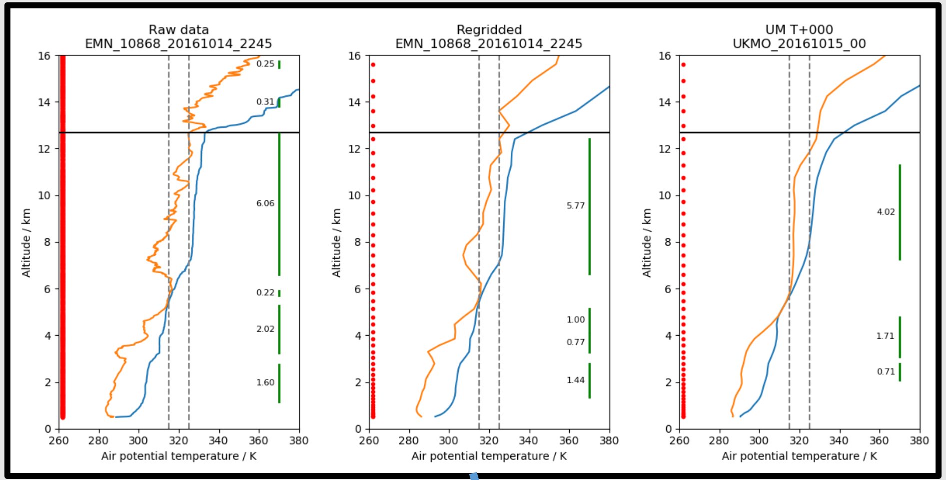
Could devise an objective method for matching all of the layers. For now, just look at the ridge layers. There is rarely more than one in a given profile, so can just check if there is a ridge layer present in each profile or not.

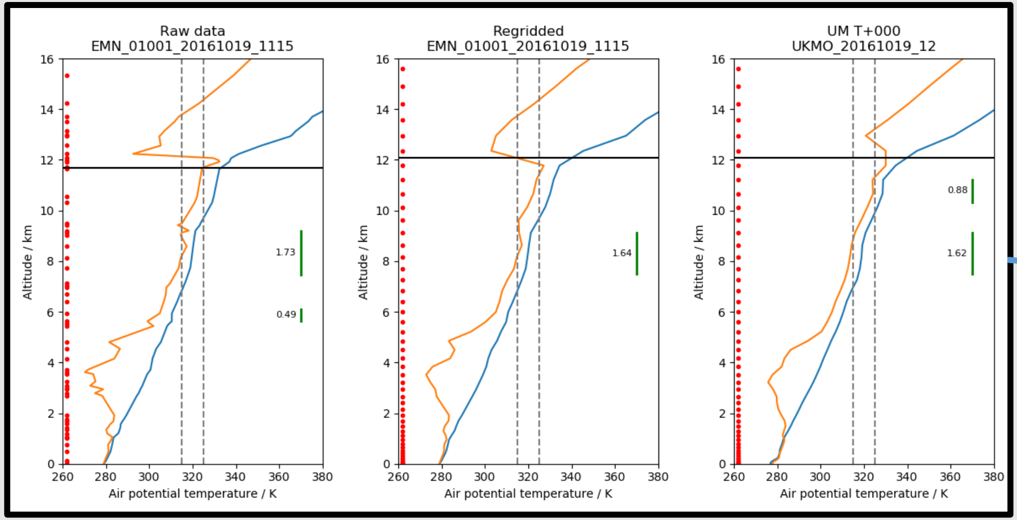
Contingency tables

<table>
<tr><td colspan="2" rowspan="2">Ridge layer present in sonde?</td><td colspan="2">Raw sonde data</td></tr>
<tr><td>Yes</td><td>No</td></tr>
<tr><td rowspan="2">Re-gridded sonde data</td><td>Yes</td><td>482</td><td>28</td></tr>
<tr><td>No</td><td>1181</td><td>5646</td></tr>
</table>

<table>
<tr><td colspan="2" rowspan="2">Ridge layer present in sonde?</td><td colspan="2">Re-gridded sonde data</td></tr>
<tr><td>Yes</td><td>No</td></tr>
<tr><td rowspan="2">Analysis</td><td>Yes</td><td>339</td><td>142</td></tr>
<tr><td>No</td><td>171</td><td>6685</td></tr>
</table>

Examples of false positives and true negatives in sonde/analysis comparison





Ridge layer present in sonde?		Re-gridded sonde data	
		Yes	No
Analysis	Yes	339	142
	No	171	6685