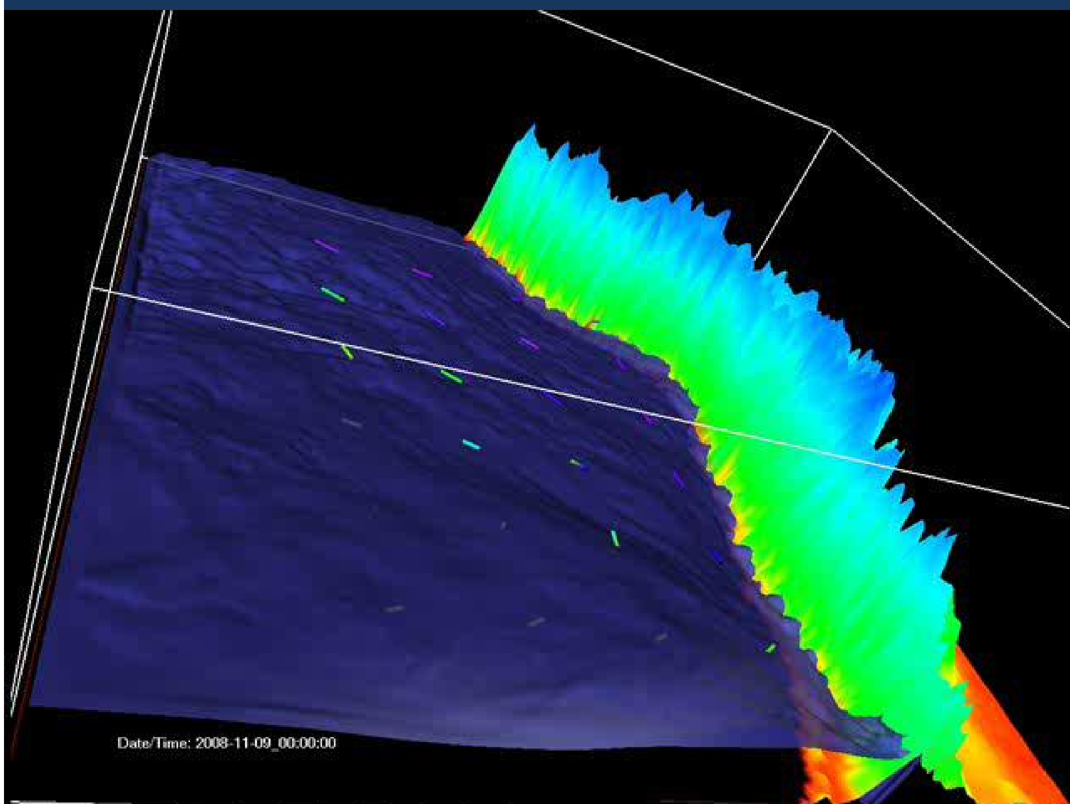
Synoptic variability of the marine boundary layer during VOCALS-REx Spring 2008



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Objectives and Methods

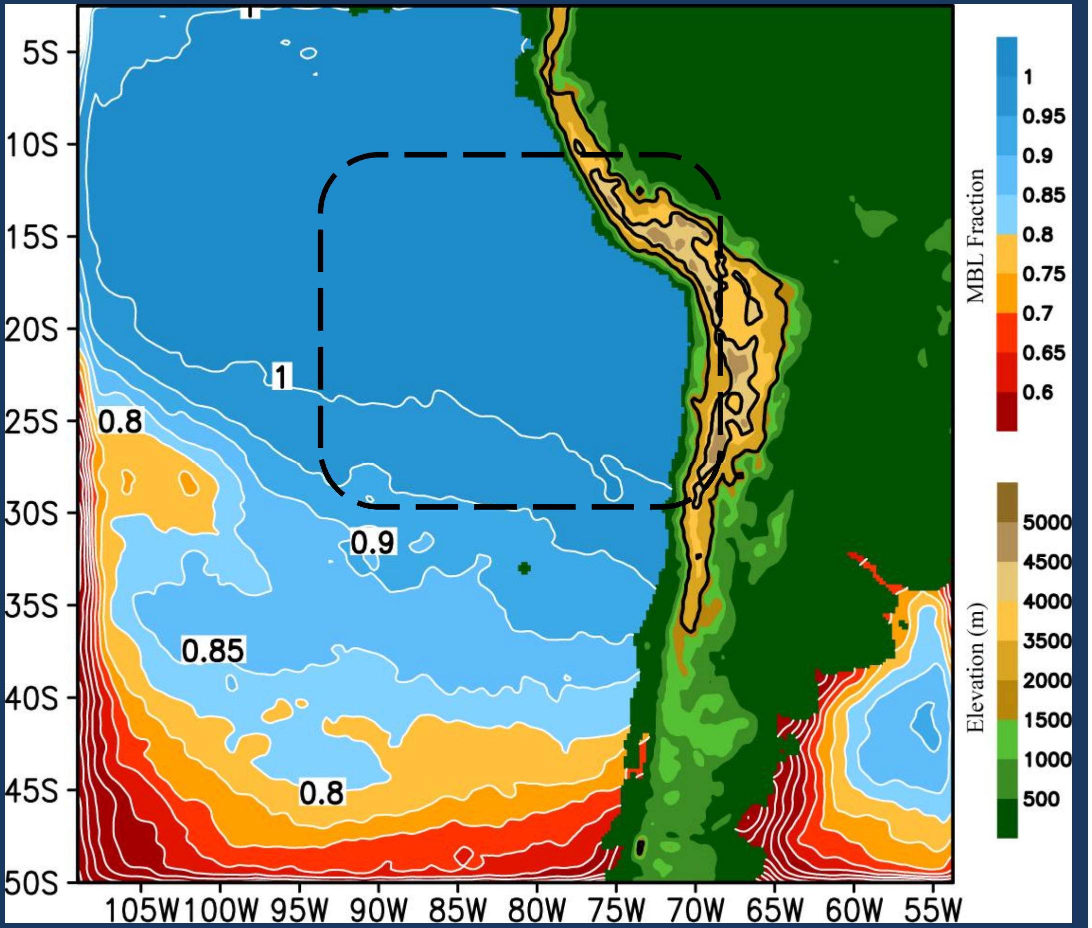
- Characterize variability of the marine boundary layer (MBL) depth over the subtropical southeast Pacific (SEP) during VOCALS-REx (October-November 2008)
  - Use prognostic MBL depth equation to evaluate terms:
    - $\partial H/\partial t$, advection of MBL depth, vertical velocity at MBL top, and entrainment velocity.
  - Mean and standard deviation
  - Correlations
    - Distribution of terms during an increasing, decreasing and stable MBL depth.
    - Time series at 20°S, 80°W

- Dataset from WRF since we need sufficiently high resolution
  - 2-month run over October and November, output every 3-hours
  - 280 x 280 grid at 20-km horizontal resolution
  - 44 sigma levels with telescoping resolution toward the surface (~10 m near the surface).
  - Some parameters: Thompson microphysics, rrtm and Dudhia radiation, Monin-Obukhov (Janjic) surface scheme, Pleim land-surface model, Mellor-Yamada-Janjic boundary layer, Betts-Miller-Janjic cumulus, second-order turbulence and mixing, and a horizontal Smagorinsky first-order closure eddy coefficient.

Fraction of MBL frequency in WRF solution over October and November 2008

- MBL depth found by finding extrema with lowest temperature (throwing out topmost point).
- Check points above, find where temperature is more than 0.5 K, and take the point below as the inversion base.

- North of 25°S a MBL was defined for nearly all times.
- Along southwest borders, MBL is less frequently defined.
- Terms are not incorporated when there is no MBL.
- Developing MBL (transition from no MBL to MBL) does have some impact.

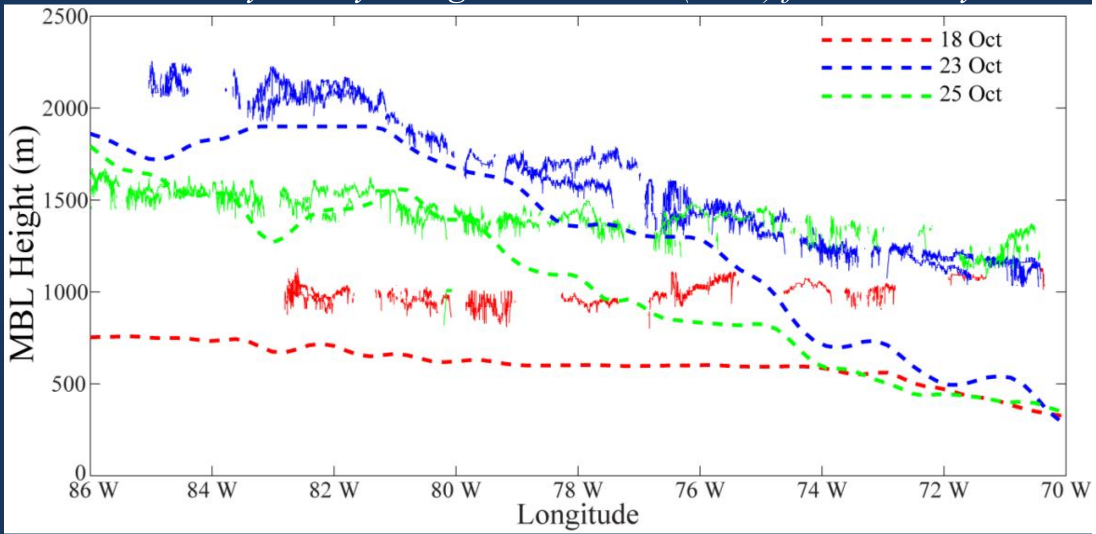


WRF Domain showing terrain elevation (m, bottom color scale and black contours every 2000 m) and fraction of time that a MBL was defined from WRF output (top color scale and white contours every 0.05).

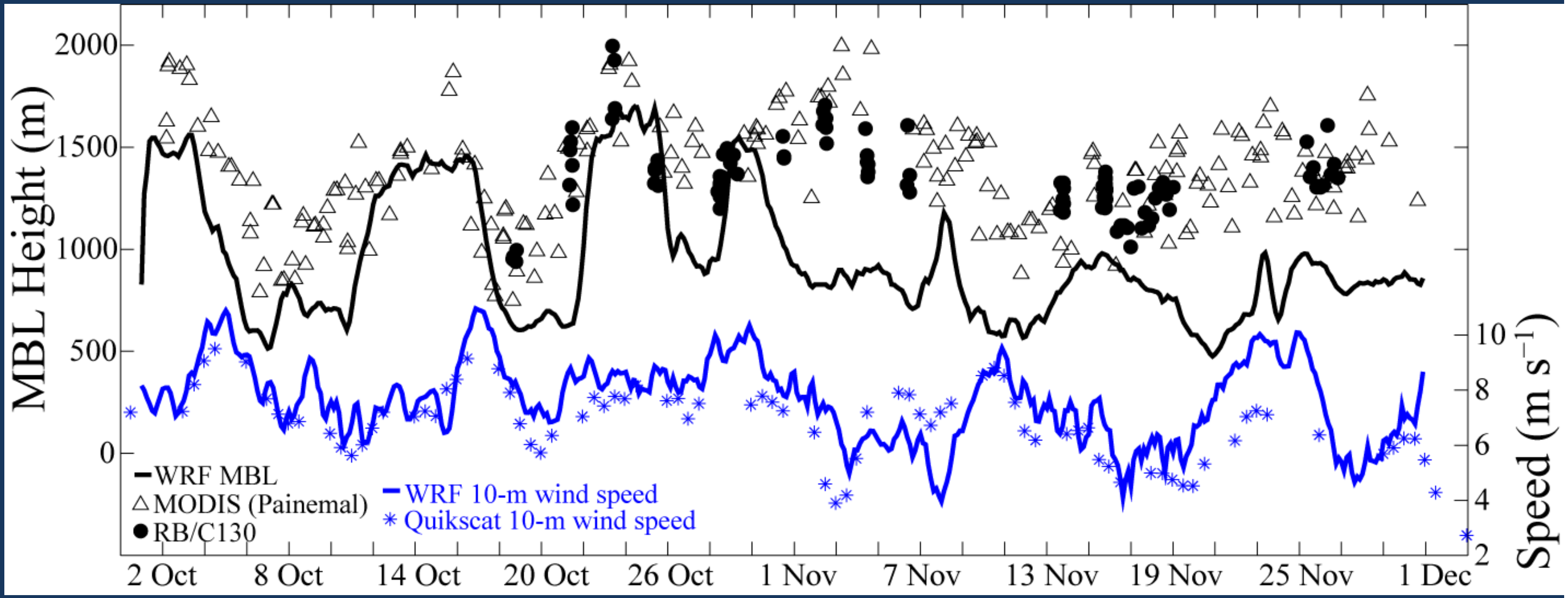
Model Performance

*Below: Examples of MBL height (m) **along 20°S** from WRF (dashed) and from the cloud top heights detected by the Wyoming Cloud Radar (solid) for three days.*

- Simulated MBL depth is typically lower than the observed depth.
- Near the shore, WRF is much lower than observation.
- WRF captures the large variations well during October, but less so during November.



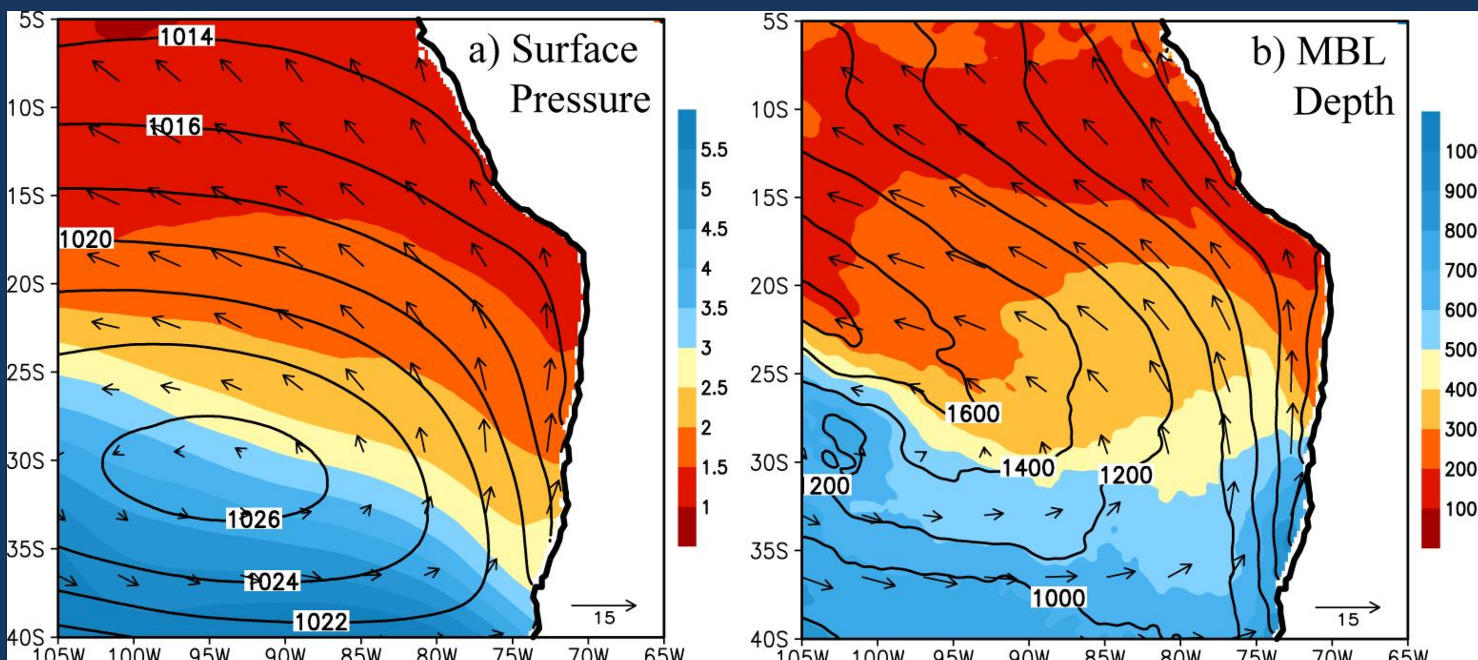
*Right: Time series at **20°S, 80°W** comparing WRF output with observations of MBL depth and surface wind.*



Mean State

- Calculated over the entire months of October and November 2008
- Pacific High centered near 30°S, 95°W on average.
- MBL depth increases offshore.

- Standard deviation of surface pressure and MBL depth have a similar structure, suggesting the importance of the synoptic variation. (Letting surface pressure be a proxy for synoptic variation).
- In MBL depth, can see ‘advection of standard deviations.’



Surface pressure mean (hPa, contours), surface pressure standard deviation (hPa, color), and 10-m wind mean (m s^{-1}, vectors).

MBL height mean (m, contours), MBL height standard deviation (m, color), and mean wind at top of MBL (vectors, m s^{-1}).

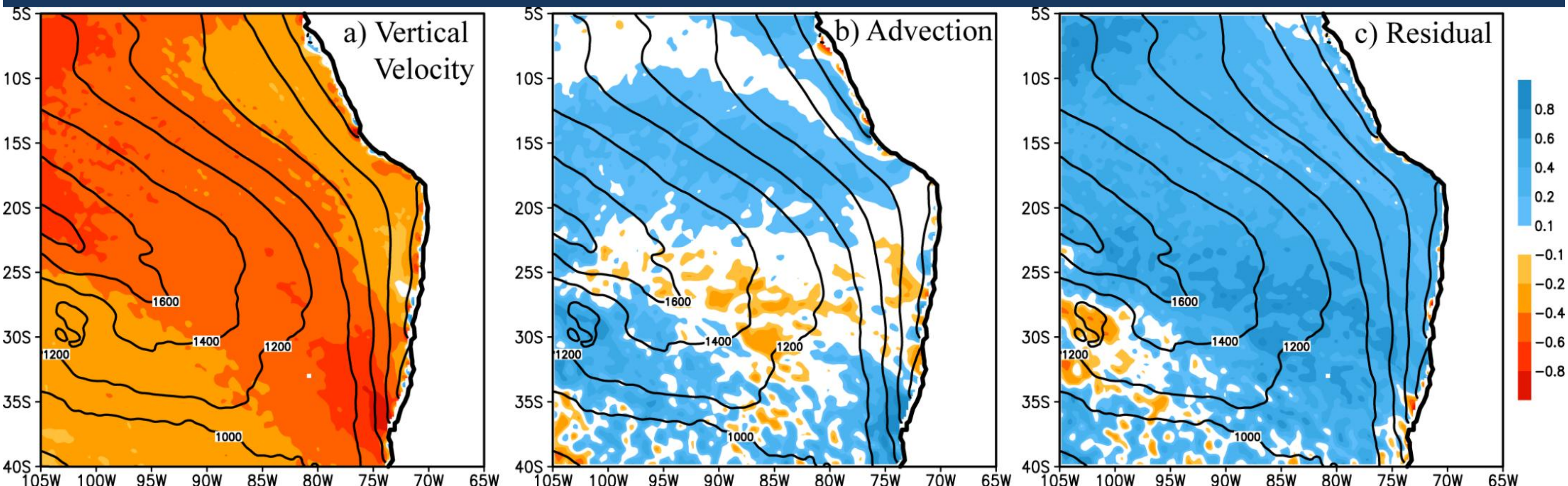
Terms of prognostic MBL depth equation

$$\frac{\partial H}{\partial t} = -V \bullet \nabla H + w_{LS} + w_E$$

- $\partial H/\partial t$ (local change of MBL height) is taken over 3-hours
- $-V \bullet \nabla H$ is the advection of the MBL height by the wind at the top of the MBL. 9-pt smoother applied to both wind and MBL height before calculating.
- w_{LS} is the large scale vertical velocity at MBL top, 9-pt smoother.
- w_E is the entrainment velocity
  - w_E is calculated as the *residual* of the other terms. This term also contains the errors from the other terms.
  - This term is referred to as the "***Residual Term***" to emphasize that it is not strictly the entrainment velocity. Sometimes it is negative. Entrainment velocity should not be negative.

Average Terms

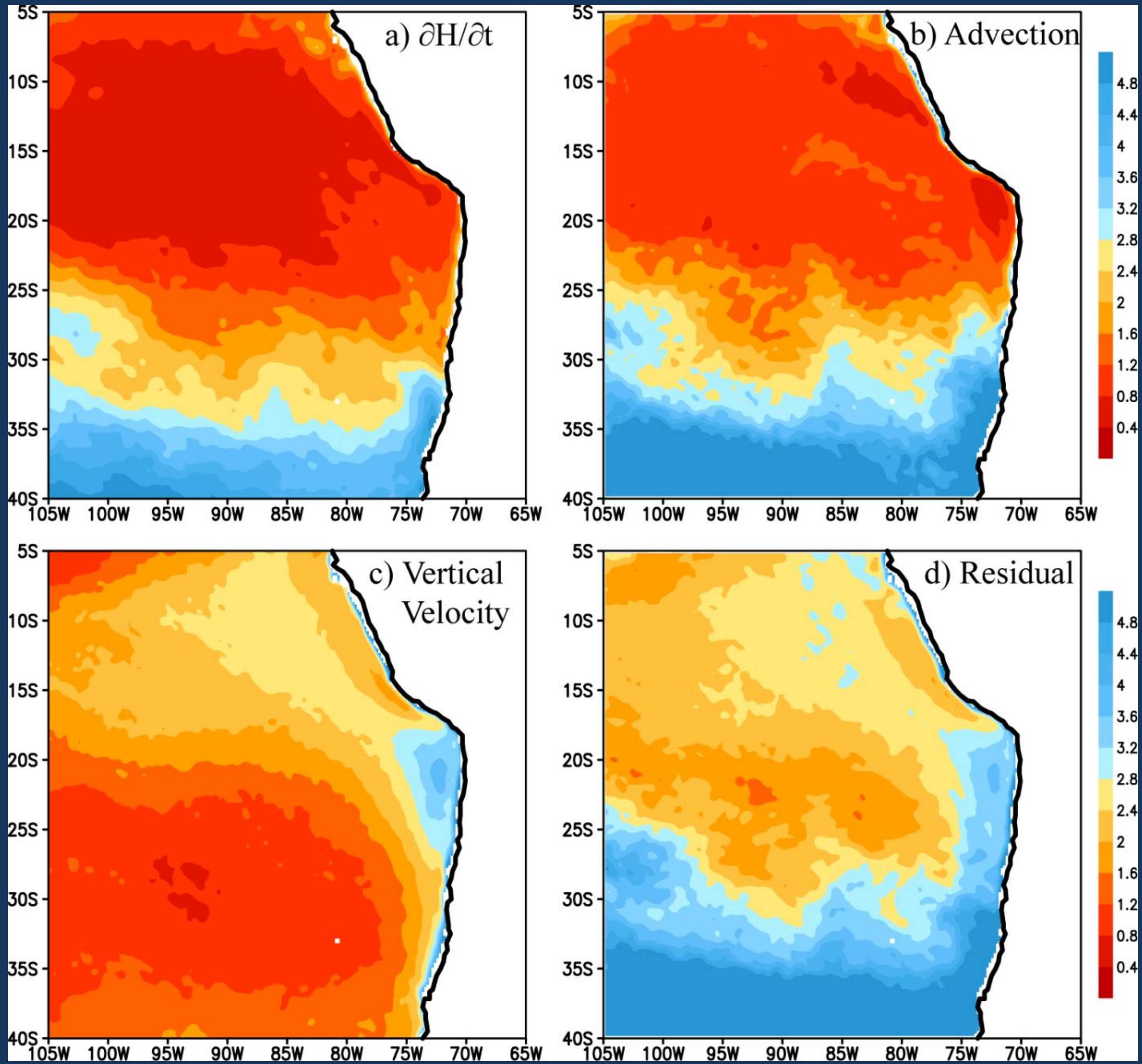
- Vertical velocity and residual are the largest terms and oppose each other.
- Advection is generally smaller and is both negative and positive.
- While averages demonstrate the dominate terms in the equation, they do not address variability nor influence of each term on the change of MBL height.
- Note that residual does have some negative values in the southwest part of the domain. Entrainment velocity should not do this.



Two month averages of (a) vertical velocity at the MBL top, (b) MBL advection by the wind at the top of the MBL, and (c) the residual (cm s^{-1}).

Normalized Standard Deviation

- Standard deviation (σ) normalized by height of the MBL (km) since lower MBL inherently has less variation.
- ∂H/∂t and advection have higher σ in the south associated with mid-latitude systems.
- Vertical velocity has higher σ to the north likely due to trade cumulus, and near the Peruvian Bight due to the upsidence wave.
- Residual has high variability in most locations, result of variability in other terms.



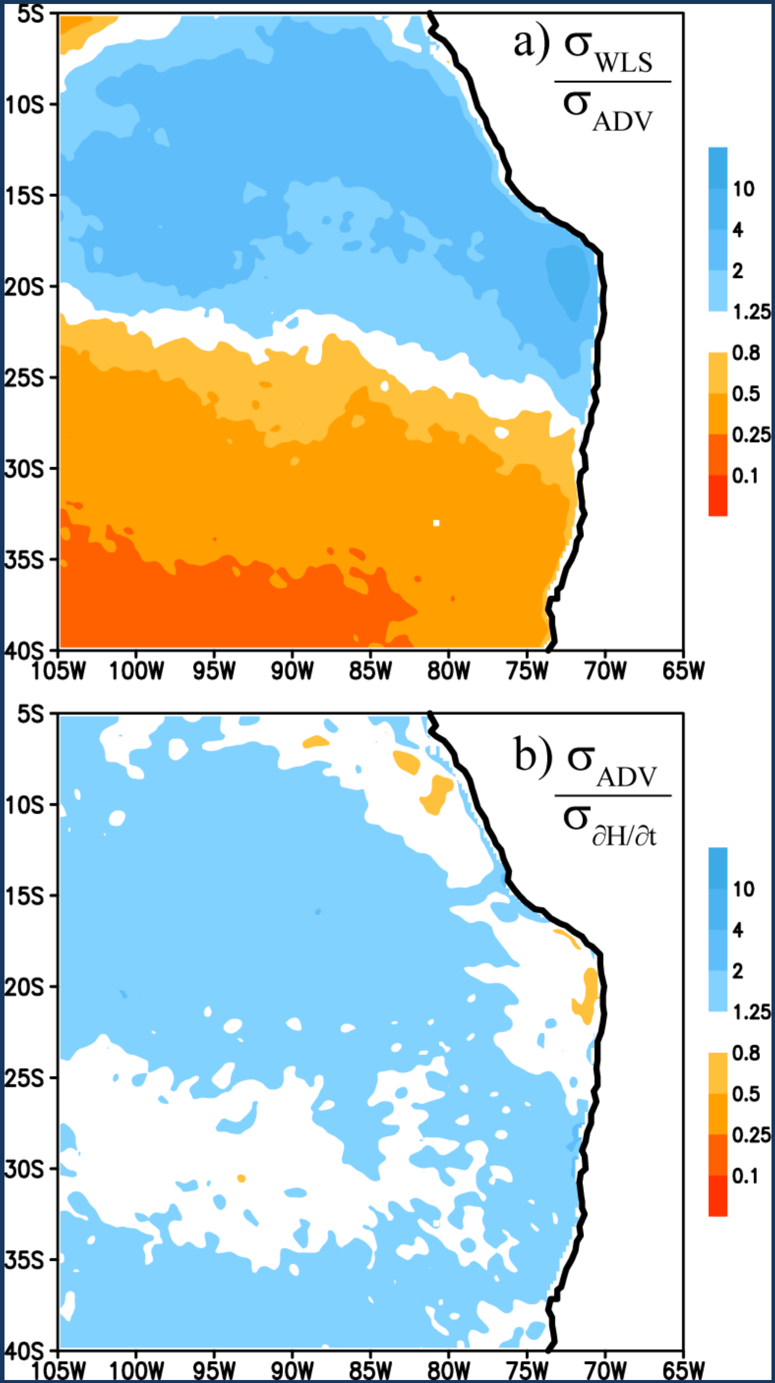
Normalized standard deviation (cm s^{-1} km^{-1}) over October and November 2008 of (a) ∂H/∂t, (b) MBL advection, (c) vertical velocity, and (d) residual.

Ratios of σ

- w_{LS} to Advection:
  - σ of w_{LS} dominates north of 20°S and into the Peruvian Bight region.
  - σ of advection dominates south of 25°S.
  - Between 20°S and 25°S they are on the same order.
  - Really shows a transition between mid-latitudes and the subtropics.

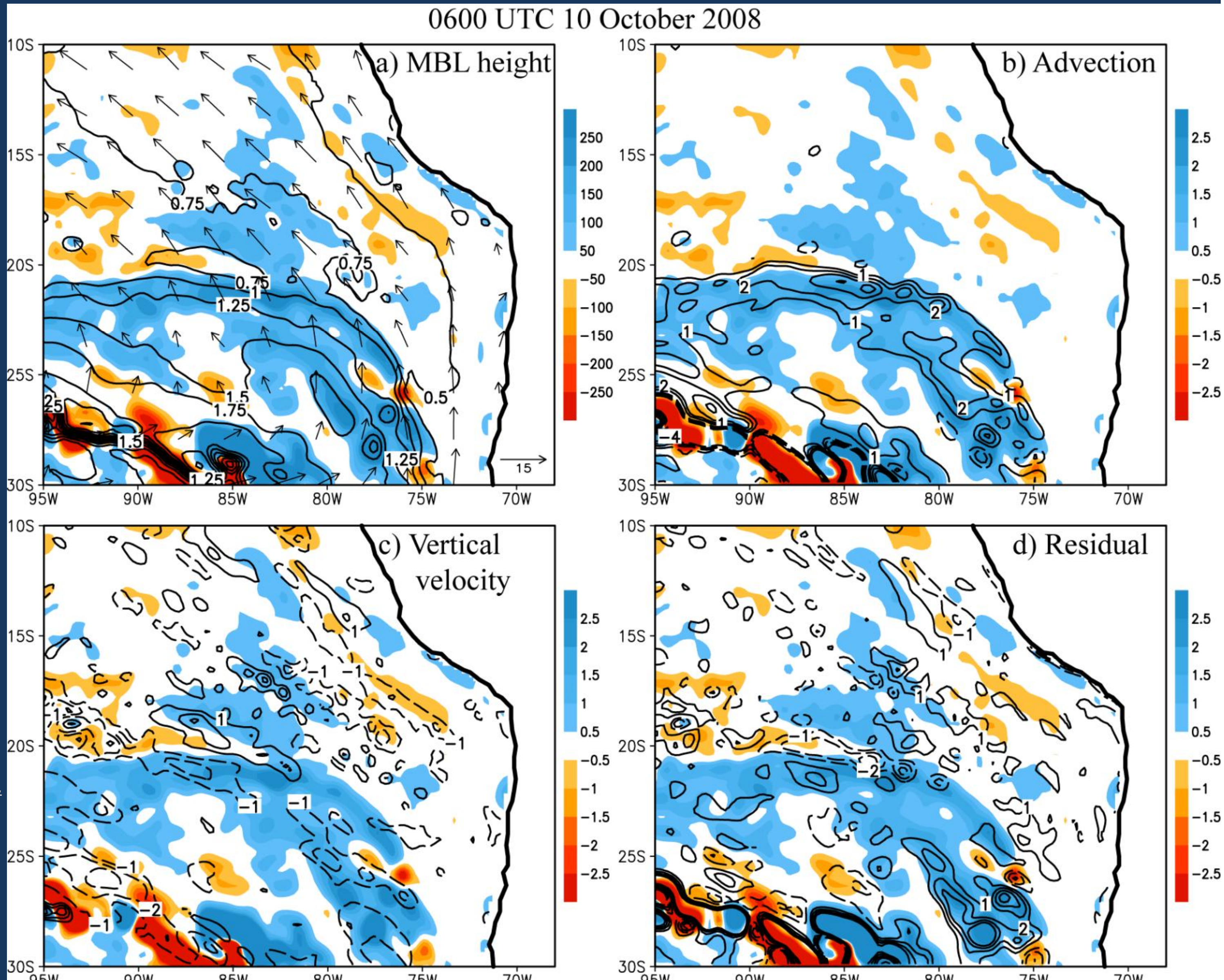
- Advection to ∂H/∂t
  - Similar, suggesting that there is some correlation between the two.
  - Advection is between 1.25 and 2 times as large as ∂H/∂t in most locations.

- Look at individual times and then time series to investigate this apparent correlation.



Example of increasing MBL depth

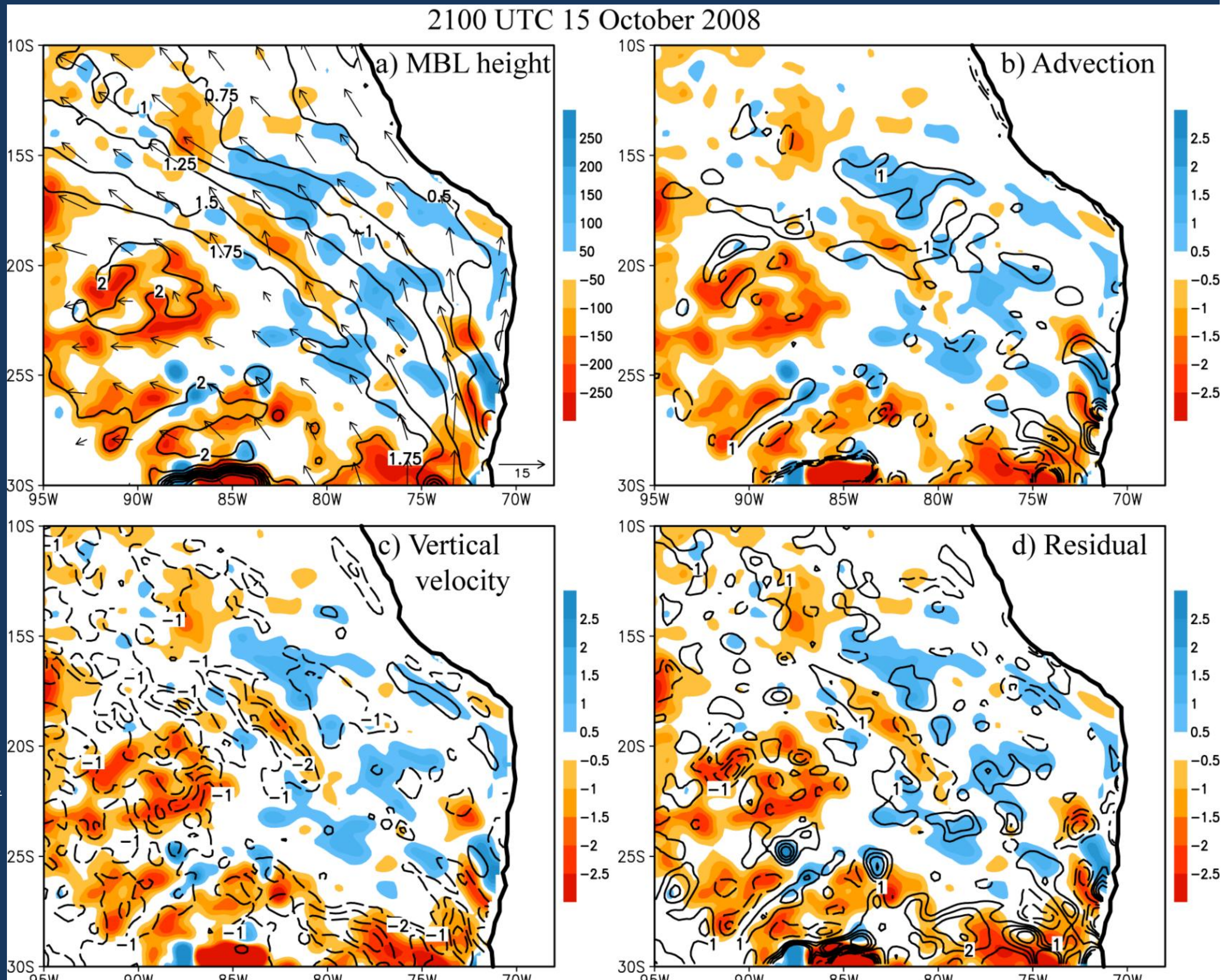
- Correlation between changes of MBL height and advection strong.
-Vertical velocity less so, but is tied to upsidence in Peruvian Bight.
- Residual diffuse.



Right: On 0600 UTC 10 October (a) MBL depth (km, contours) and three-hour change of MBL depth (m, color), (b) advection (cm s^{-1}, contour) and ∂H/∂t (cm s^{-1}, color), (c) vertical velocity (cm s^{-1}) and ∂H/∂t (cm s^{-1}, color), and (d) residual (cm s^{-1}, contour) and ∂H/∂t (cm s^{-1}, color).

Example of ‘stable’ MBL depth

- Smaller correlation between changes of MBL height and advection.
-Vertical velocity driving MBL depth down west and south.
- Residual diffuse.

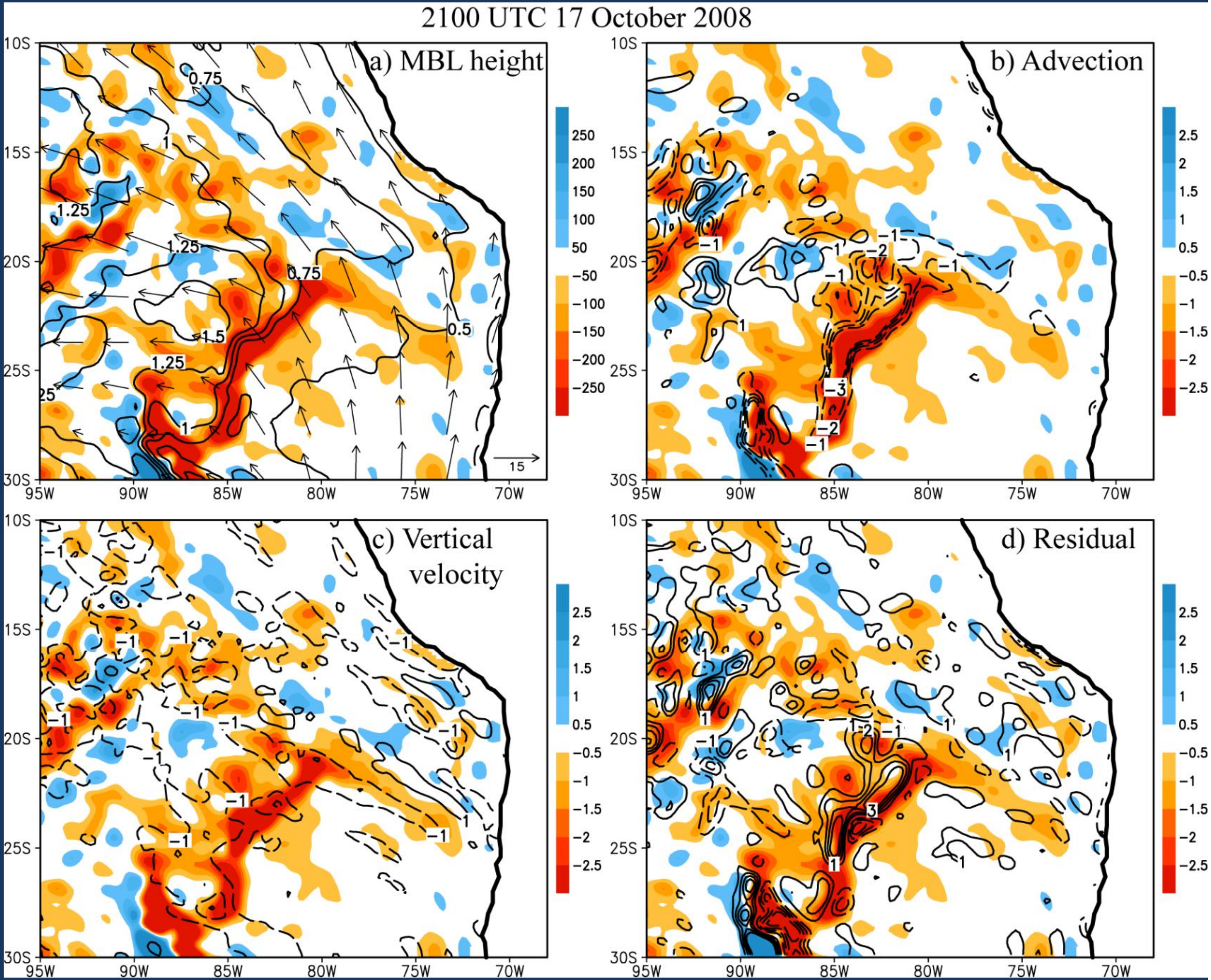


Right: On 2100 UTC 15 October (a) MBL depth (km, contours) and three-hour change of MBL depth (m, color), (b) advection (cm s^{-1}, contour) and ∂H/∂t (cm s^{-1}, color), (c) vertical velocity (cm s^{-1}) and ∂H/∂t (cm s^{-1}, color), and (d) residual (cm s^{-1}, contour) and ∂H/∂t (cm s^{-1}, color).

Example of decreasing MBL depth

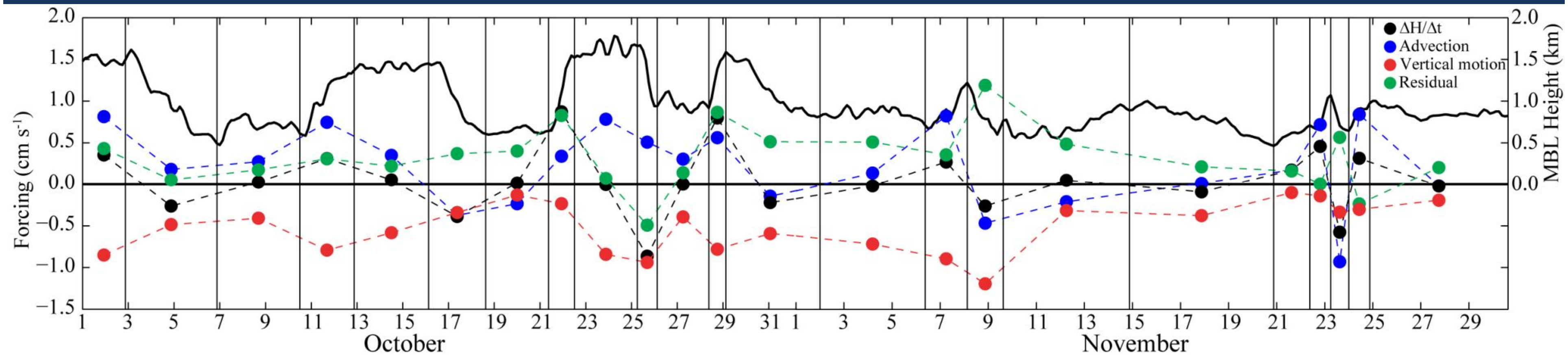
- Strong correlation between changes of MBL height and advection.
-Vertical velocity also exerts influence.
- Residual generally diffuse, but acts against vertical velocity and advection.

Right: On 2100 UTC 17 October (a) MBL depth (km, contours) and three-hour change of MBL depth (m, color), (b) advection (cm s^{-1}, contour) and ∂H/∂t (cm s^{-1}, color), (c) vertical velocity (cm s^{-1}) and ∂H/∂t (cm s^{-1}, color), and (d) residual (cm s^{-1}, contour) and ∂H/∂t (cm s^{-1}, color).



Time series at 20°S, 80°W

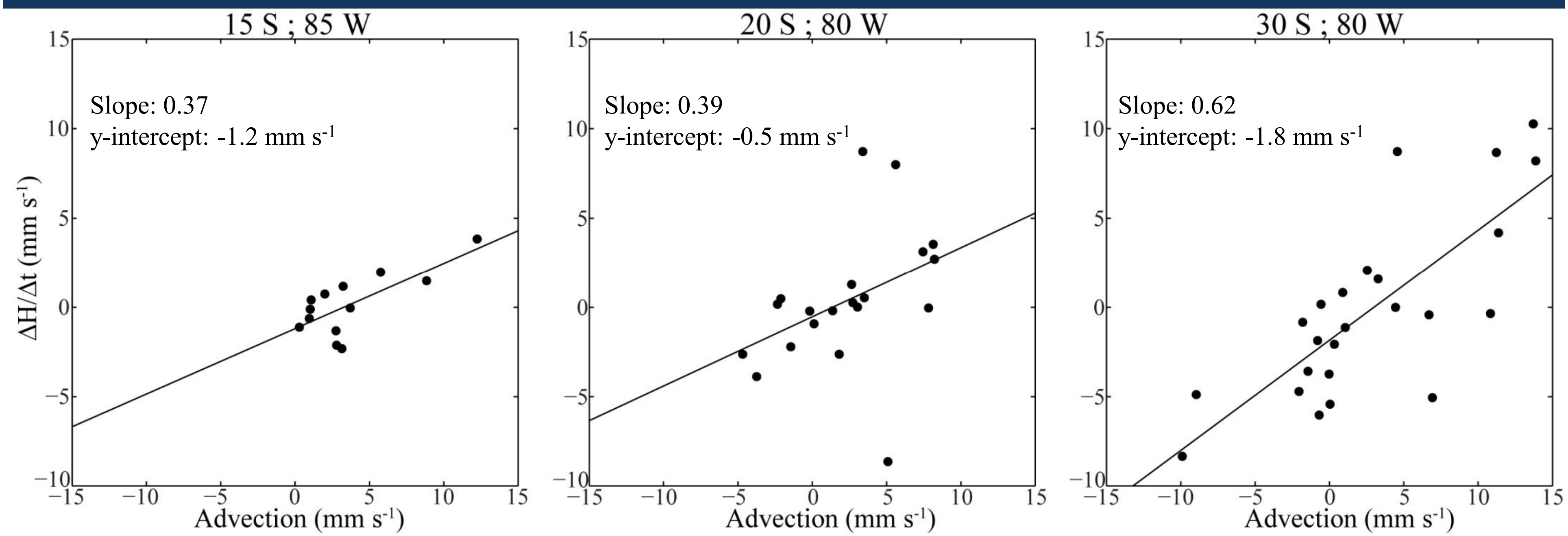
- Terms in the time series are averaged over periods of rising, falling, and steady height.
- October is generally more variable than November.
- Subsidence and residual are on average the largest, opposing terms.
- Advection and ∂H/∂t are more variable and appear to be related.



Time series of MBL height (m, solid contour) at 20°S, 80°W, and averages of three-hour change of height (cm s^{-1}, black), advection (cm s^{-1}, blue), vertical motion at MBL top (cm s^{-1}, red), and residual (cm s^{-1}, green). Time range of averages indicated by vertical lines.

Relationship between ∂H/∂t and Advection

- Same method has been done for 15°S, 85°W and also 30°S, 80°W. (individual time series in 'extra slides' section).
- Standard deviation of both terms increases from north to south.
- Simple linear regression applied to data.
- Slope is about 0.4 for 15°S and 20°S, and 0.6 for 30°S.
  - Suggests a damped response of the MBL change to advection.
- Y-intercept is between -1.8 and -0.5 mm s^{-1}.
- Other terms do not show any significant relationship.



Summary

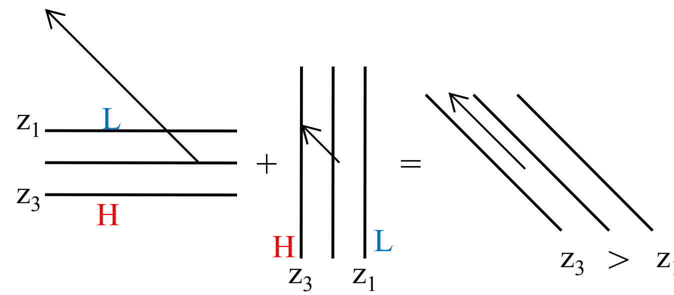
- Comparison with MBL observations demonstrates
  - WRF captures the MBL fairly well in October, but not so well in November.
  - MBL heights in WRF are lower than observed, but variation is consistent.

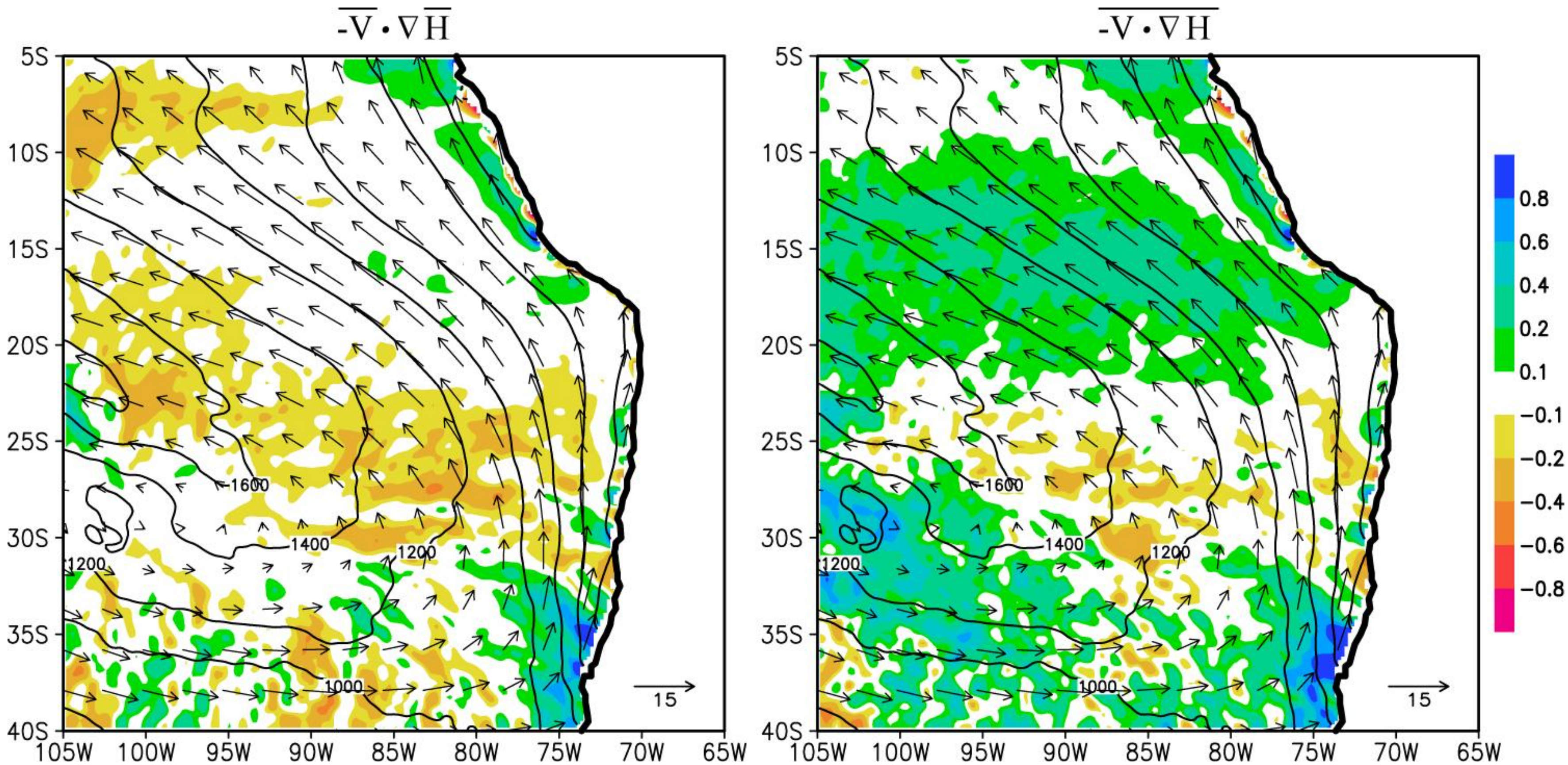
- While the vertical velocity and residual tend to be the dominant opposing terms, variability of MBL depth appears to be tied closely to the variability in advection.
- Extent of the synoptic influence from the mid-latitudes is shown and can greatly impact the subtropical region.
- Generalization of these findings requires analysis over much longer time periods.

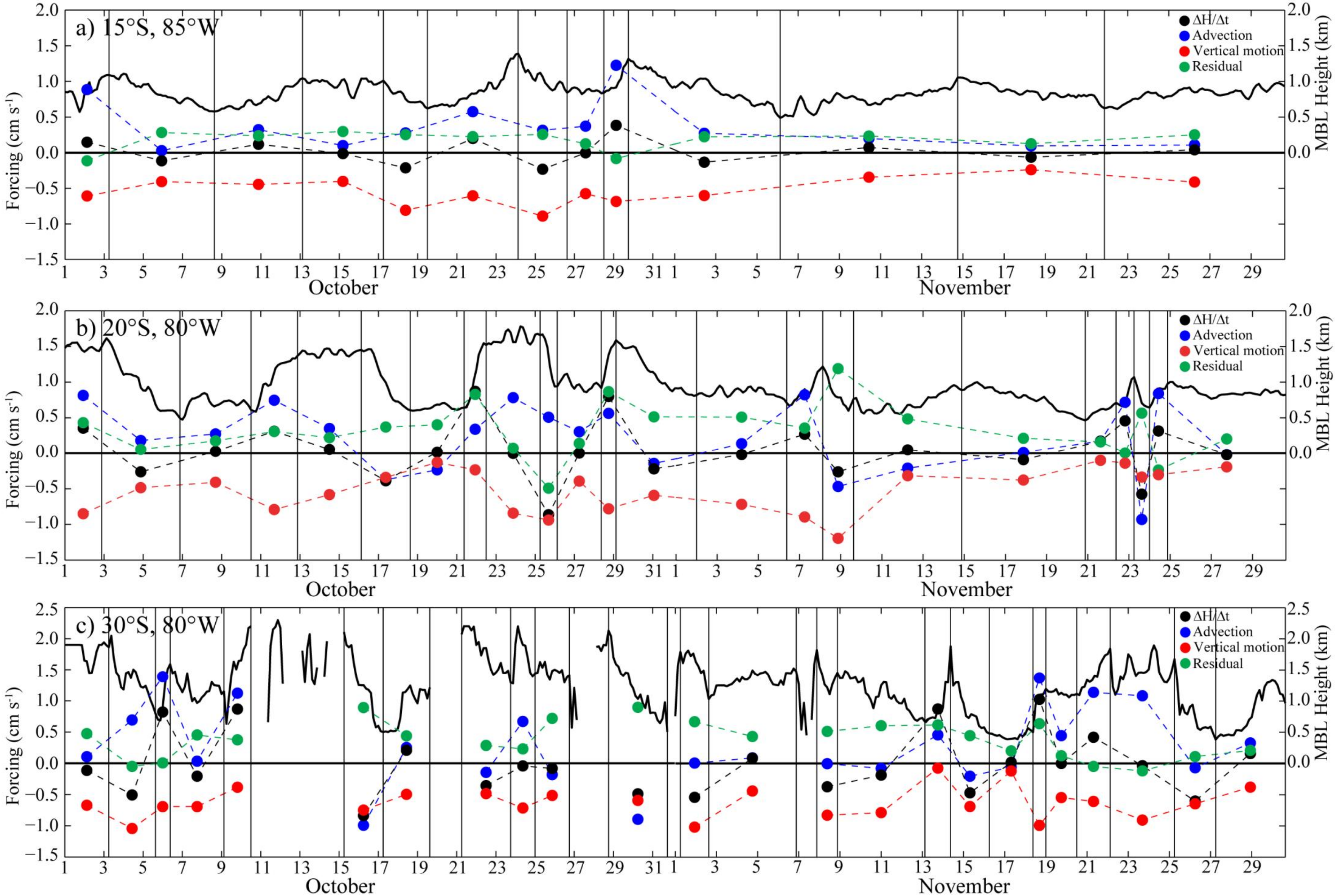
- *Acknowledgments: I would like to thank René Garreaud and José Rutllant for illuminating conversations.*

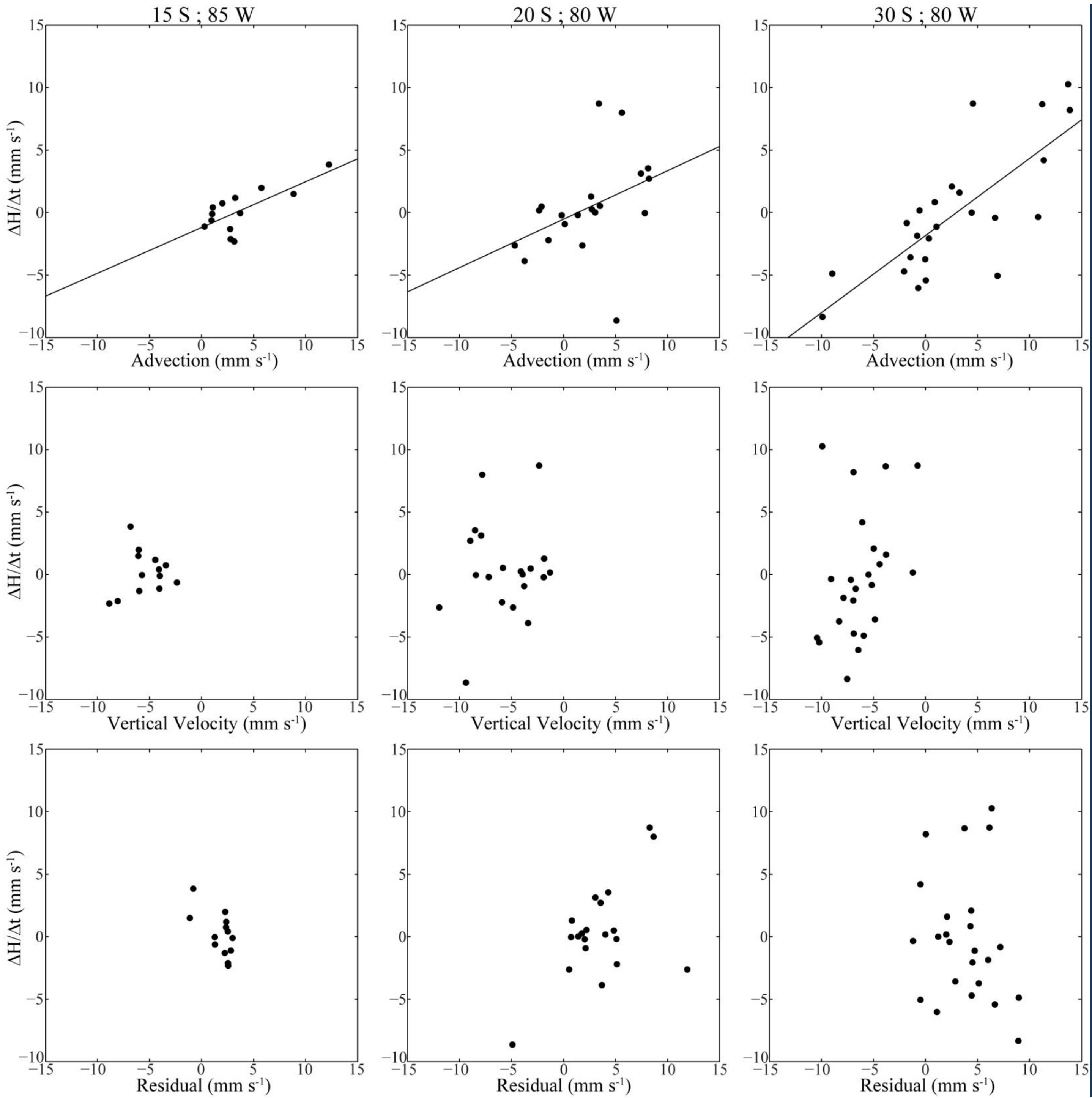
Average Advection

- It is important how average advection is calculated:
  - Advection from average velocity and average height
  - -or- Average of individual advection terms
- Why?
  - Perturbations from the average state.

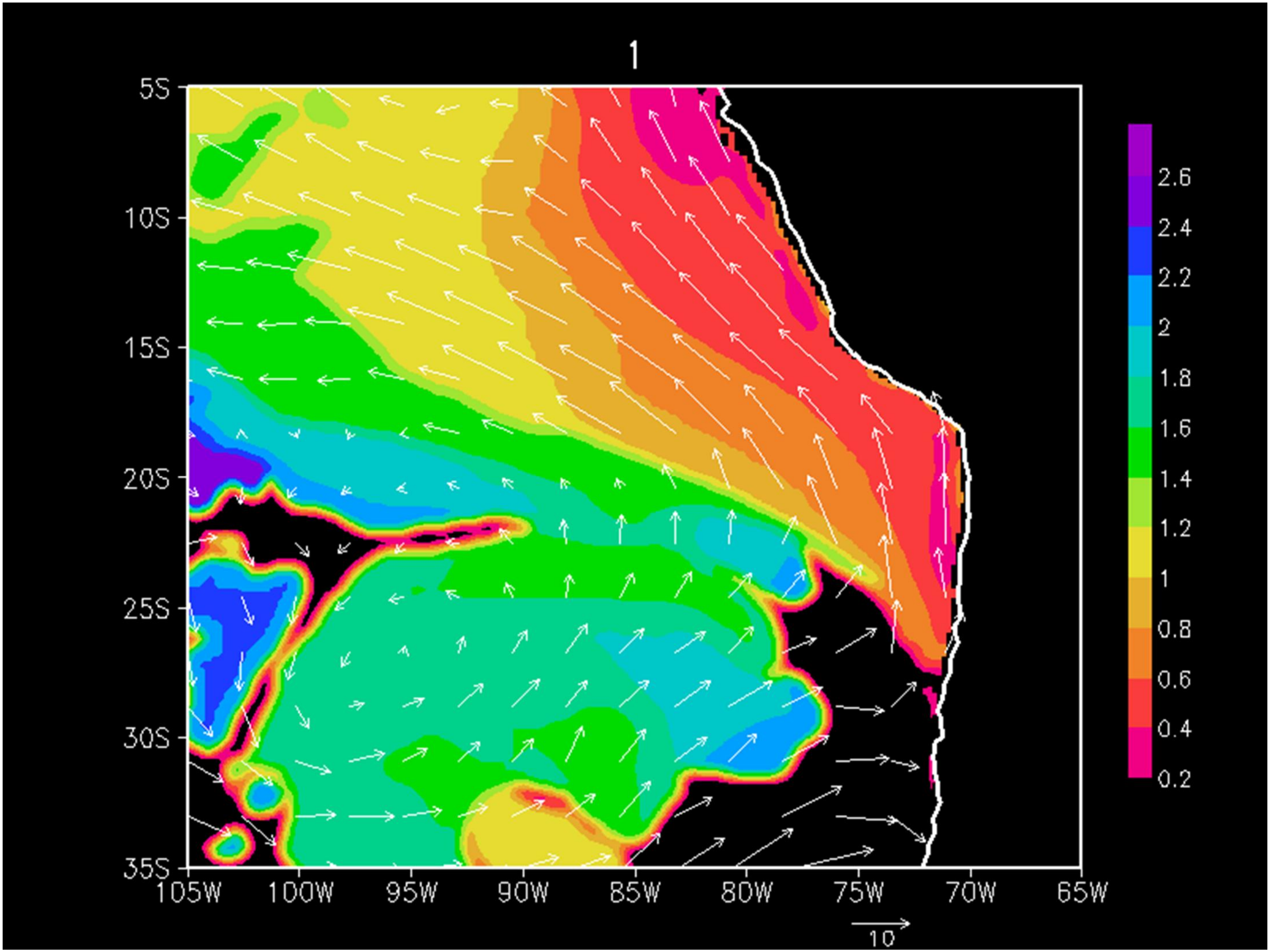





a) 15°S, 85°W
b) 20°S, 80°W
c) 30°S, 80°W
ΔH/Δt
Advection
Vertical motion
Residual
Forcing (cm s-1)
MBL Height (km)
October
November



15 S ; 85 W
20 S ; 80 W
30 S ; 80 W
ΔH/Δt (mm s-1)
Advection (mm s-1)
Vertical Velocity (mm s-1)
Residual (mm s-1)



1
5S
10S
15S
20S
25S
30S
35S
105W
100W
95W
90W
85W
80W
75W
70W
65W
10
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2