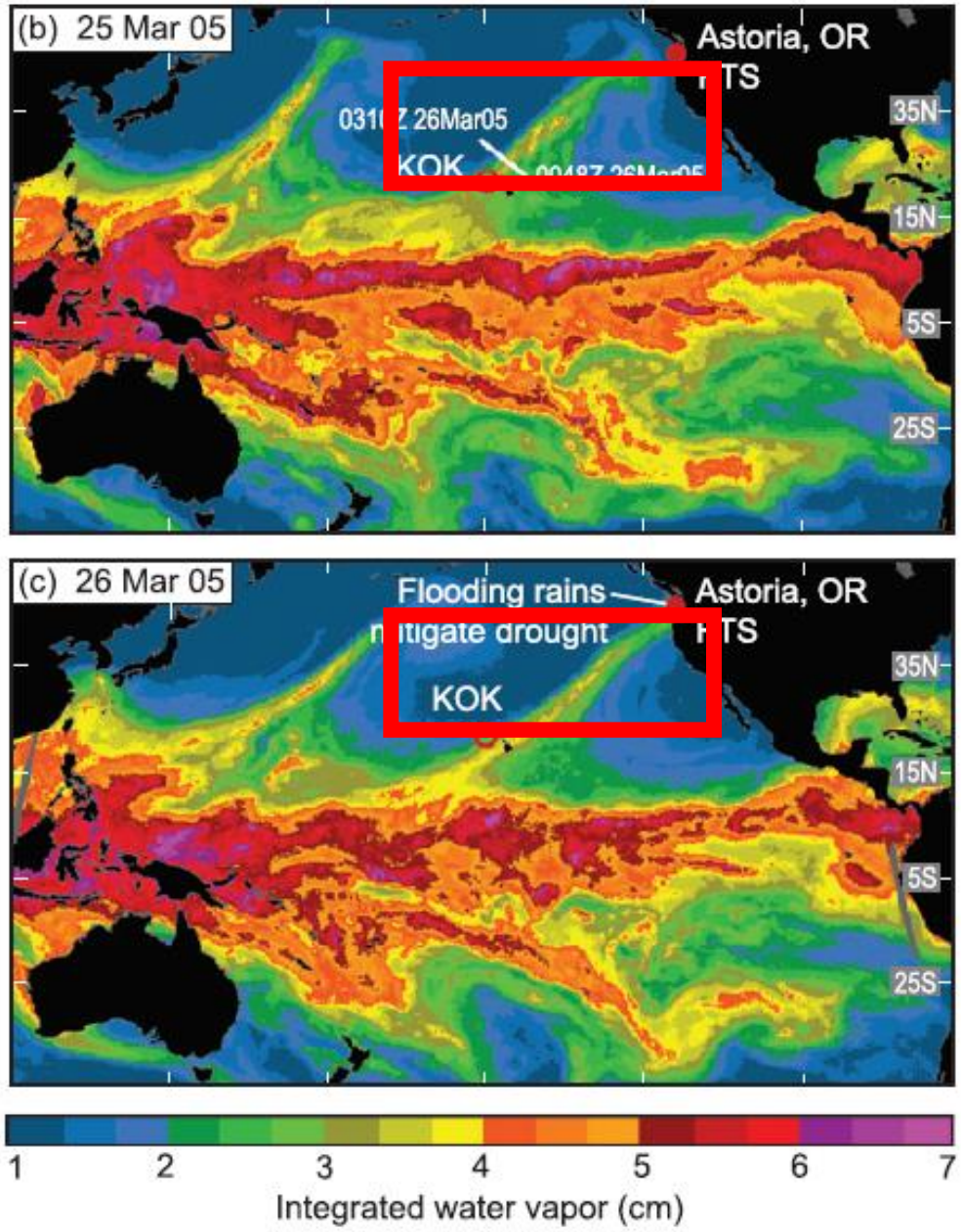
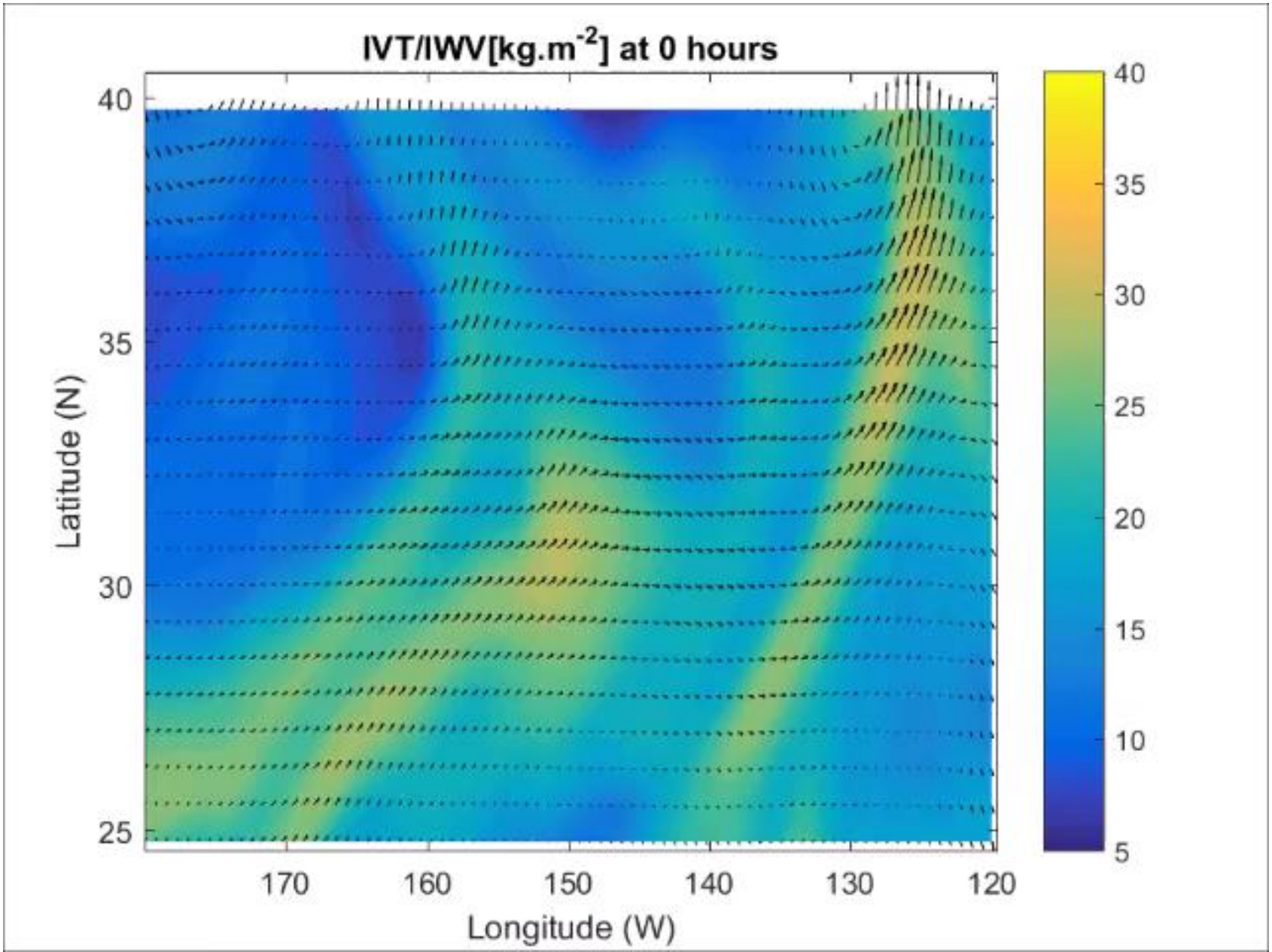
A moist static energy perspective on ARs

Tom BEUCLER

Pacific AR, Mar 05 *(Ralph et al., 2010)*

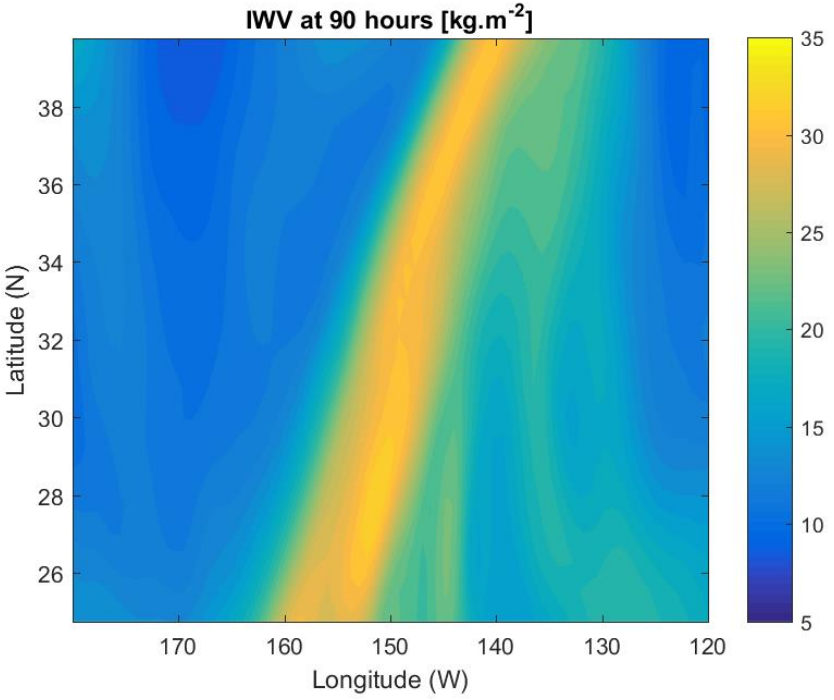


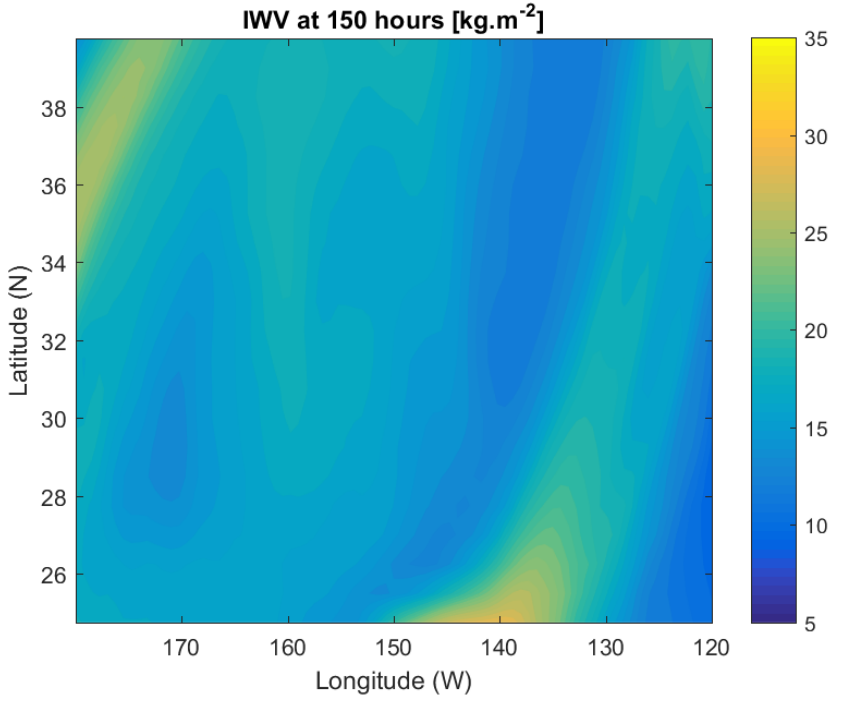
Colors: IWV Arrows: IVT



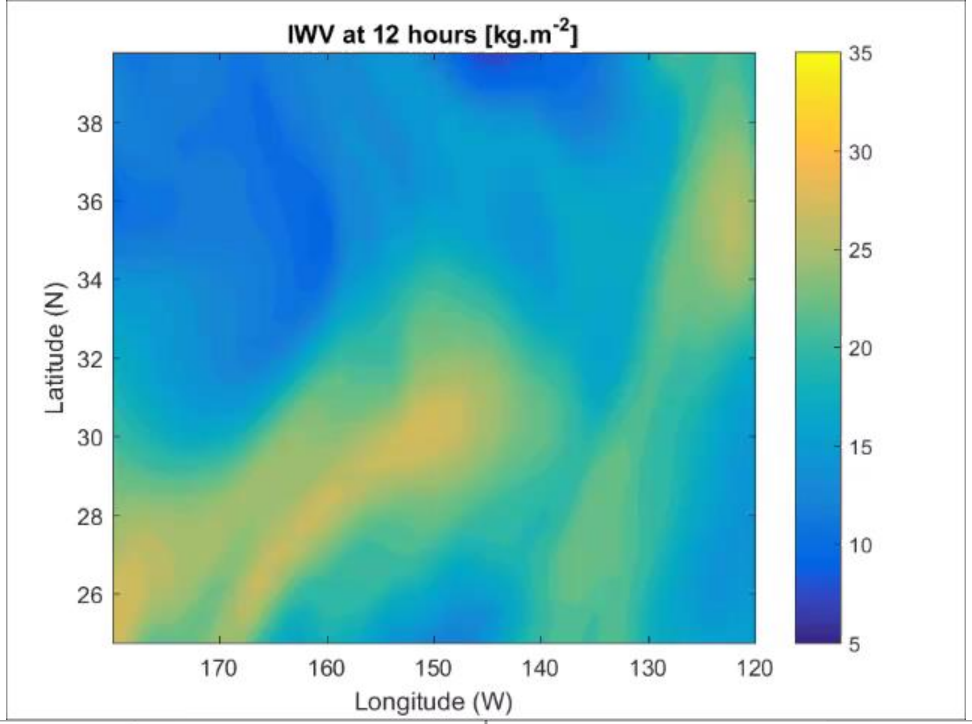
Goal

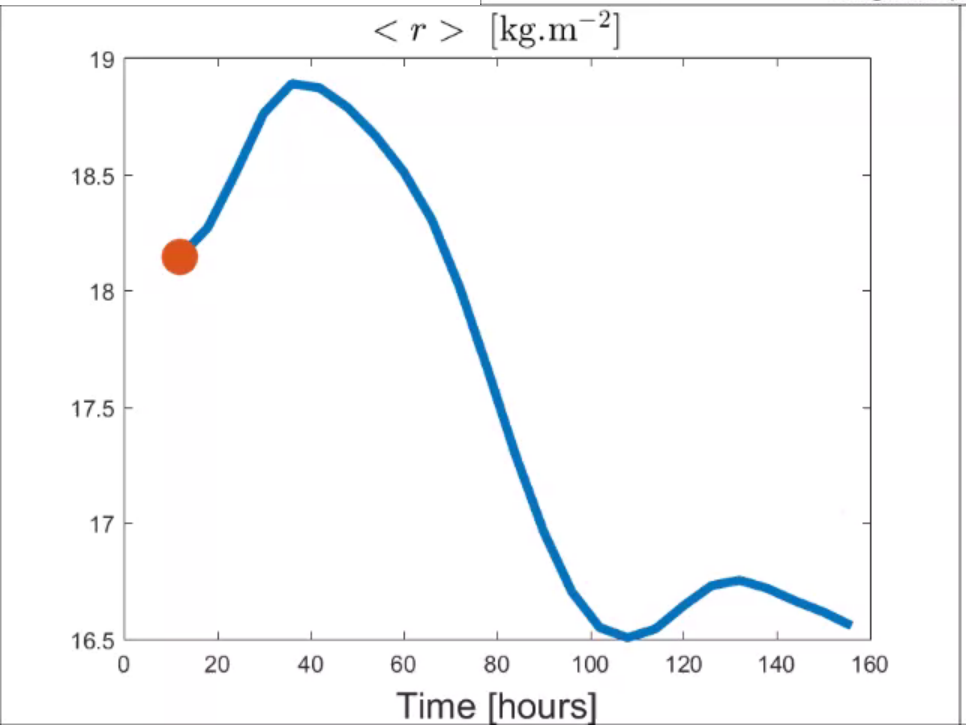
- Can we find simple physical variables to describe the AR structure within our domain?

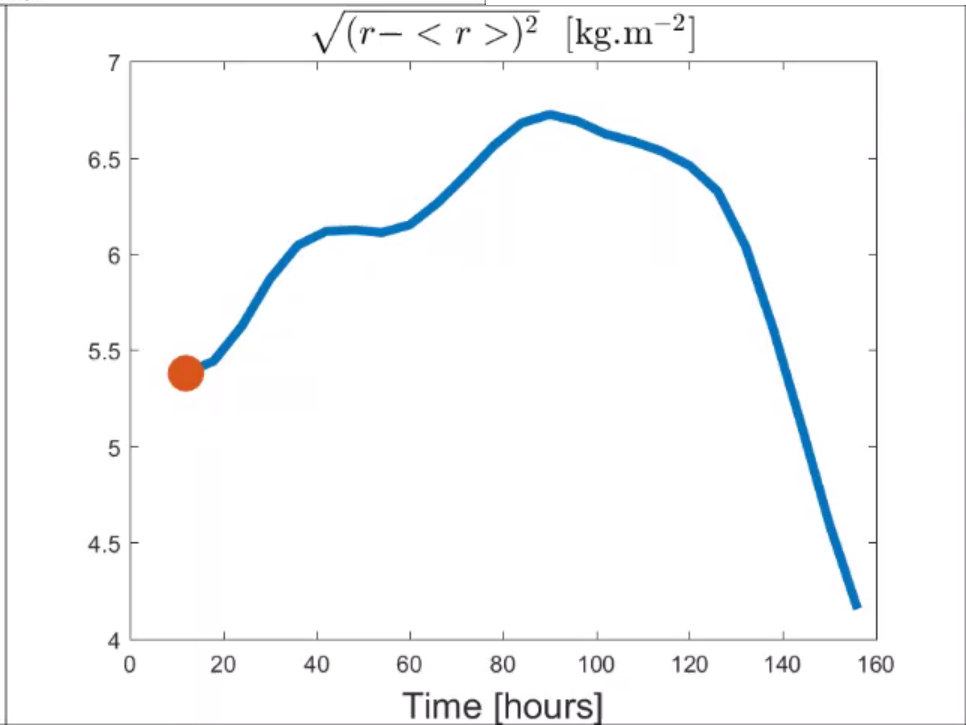




- Domain-averaged IWV: $< r >$
- Spatial standard deviation of IWV: $SD(r)$


IWV at 12 hours [kg.m-2]
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
35
30
25
20
15
10
5


$< r >$ [kg.m^{-2}]
19
18.5
18
17.5
17
16.5
0
20
40
60
80
100
120
140
160
Time [hours]


$\sqrt{(r- < r >)^2}$ [kg.m^{-2}]
7
6.5
6
5.5
5
4.5
4
0
20
40
60
80
100
120
140
160
Time [hours]

Goal

- Can we find simple physical variables to describe the AR structure within our domain?

➢ Domain-averaged IWV: $< r >$
➢ Spatial standard deviation: $SD(r)$

- **Problem**: Water vapor is not conserved

➢ Requires knowledge of evaporation and precipitation at each pressure level
➢ Need cloud resolving model with precise microphysics

- **Solution**: Variable conserved for adiabatic motion with water phase changes → **Moist static energy**

1. Moist static energy

2. Moist static energy variance

3. Comparison between Pacific cases

1. **Moist static energy**

2. Moist static energy variance

3. Comparison between Pacific cases

Definition

$$h = L_v r + c_p T + \Phi$$

Moist static energy | **Latent heat** | **Sensible heat** | **Geopotential**

CONDENSATION

h is **conserved** for adiabatic motion with water phase changes

➢ Unchanged by internal latent heating

Definition

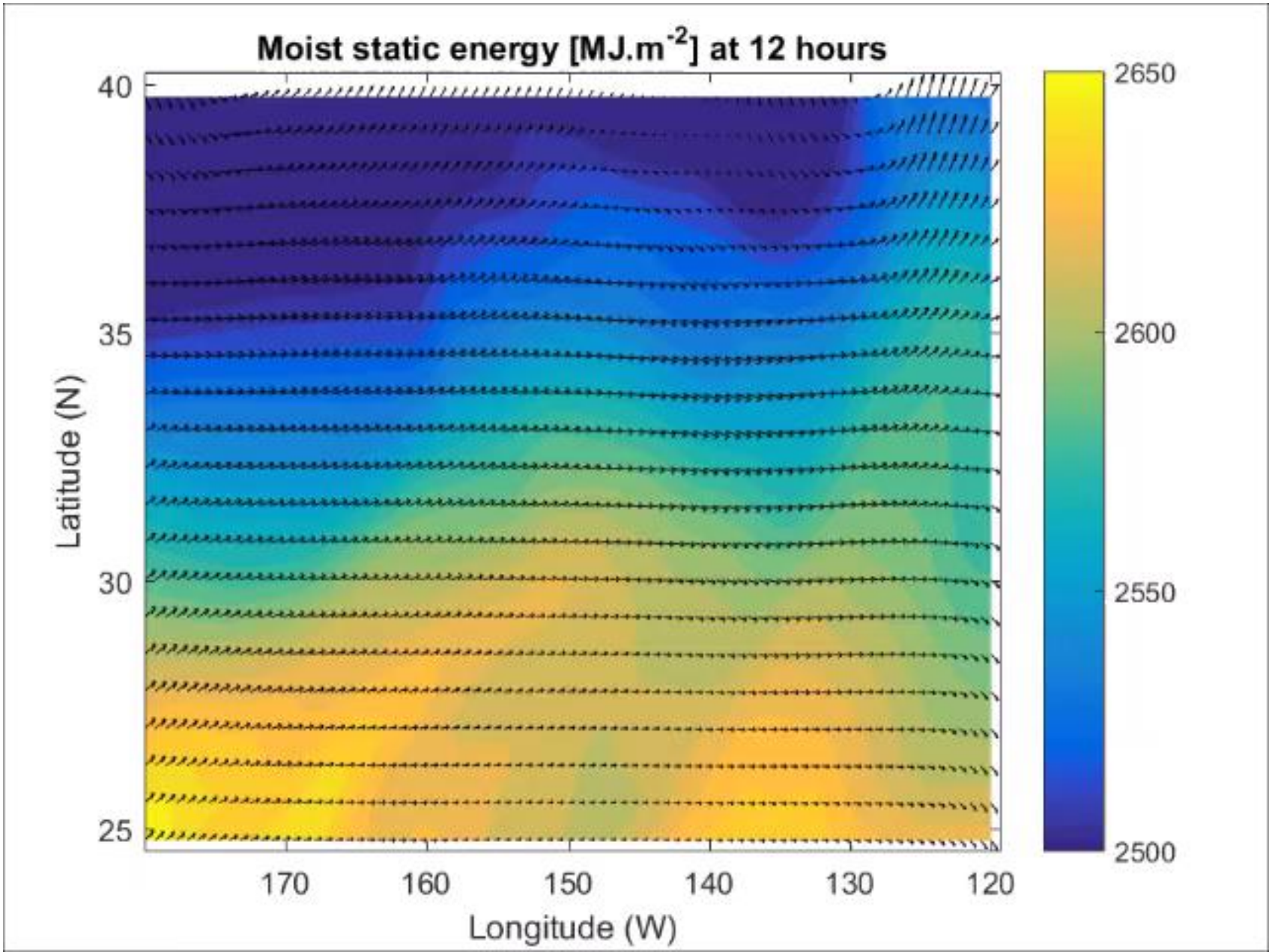
$$h = L_v r + c_p T + \Phi$$

Moist static energy | **Latent heat** | **Sensible heat** | **Geopotential**

Column-integrated moist static energy:

$$\hat{h} \quad (J.m^{-2})$$

Integrated moist static energy



Definition

$$\hat{h} = L_v \hat{r} + c_p \hat{T} + \hat{\Phi}$$

Integrated moist static energy

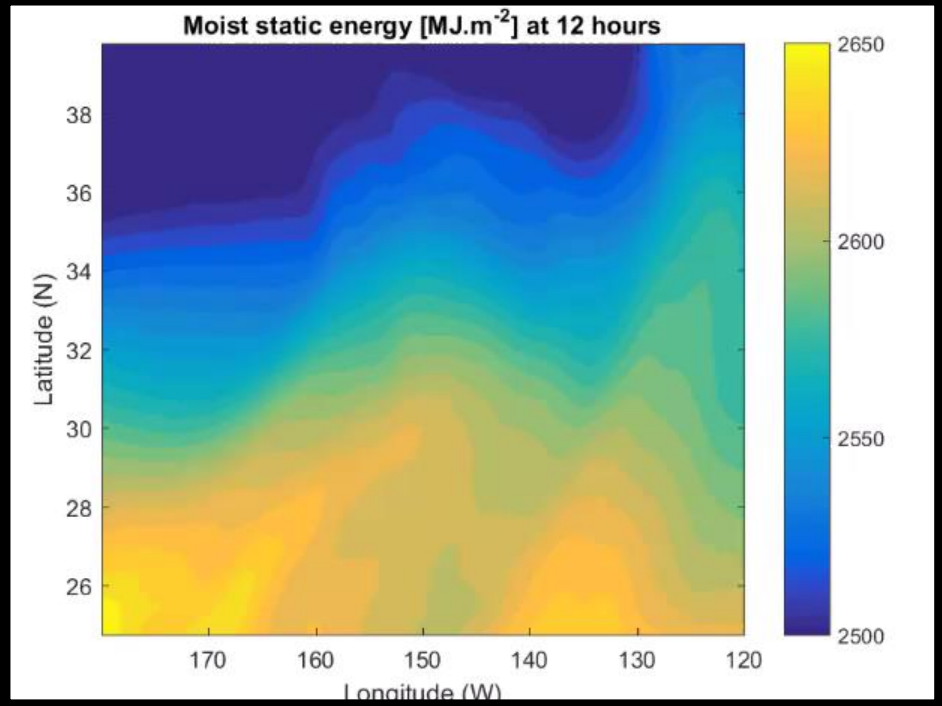
Integrated latent heat

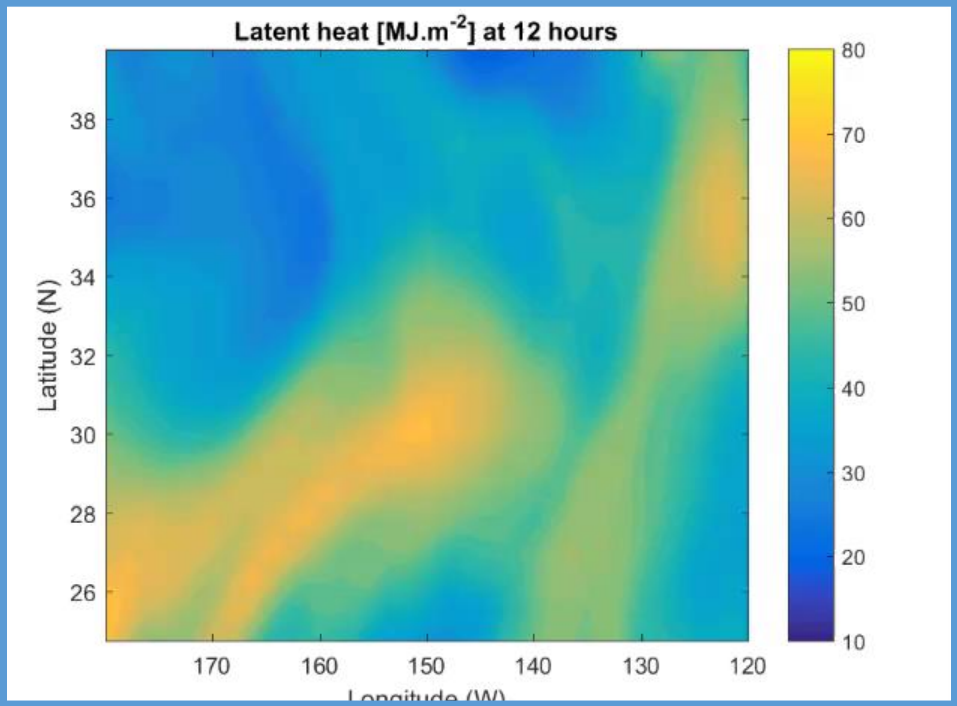
Integrated sensible heat

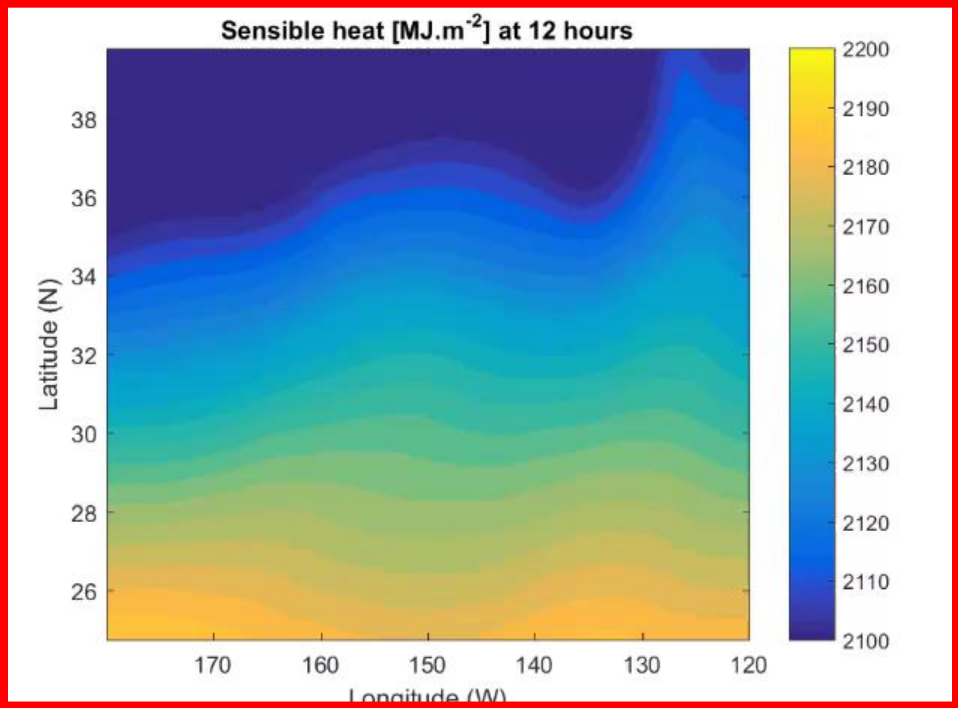
Integrated geopotential

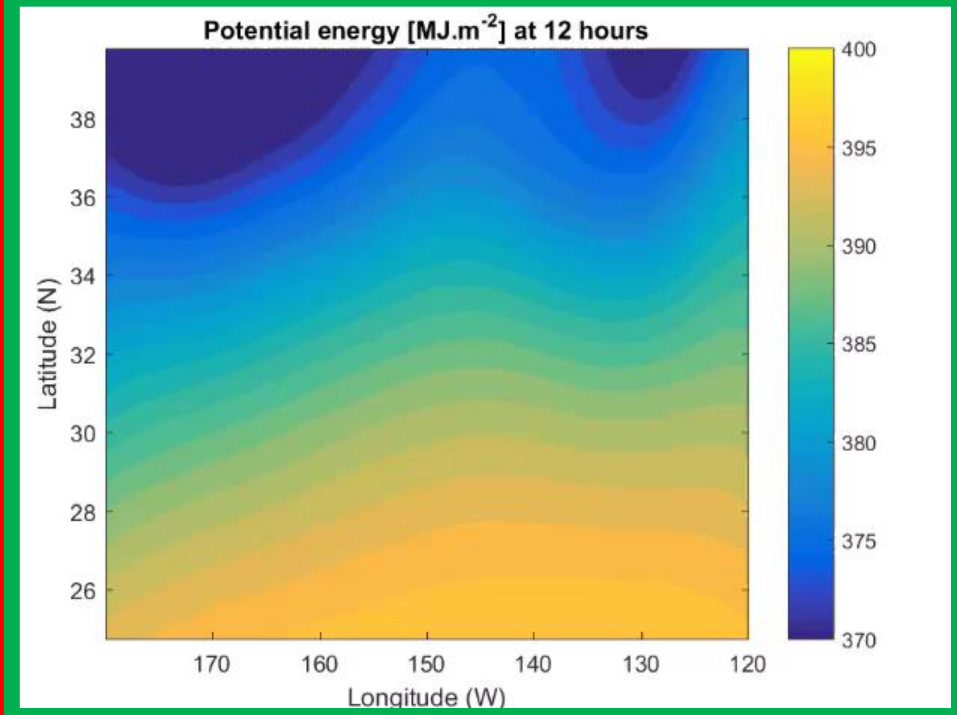
Column-integrated moist static energy:

$$\hat{h} \quad (J.m^{-2})$$


Moist static energy [MJ.m-2] at 12 hours
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
2650
2600
2550
2500

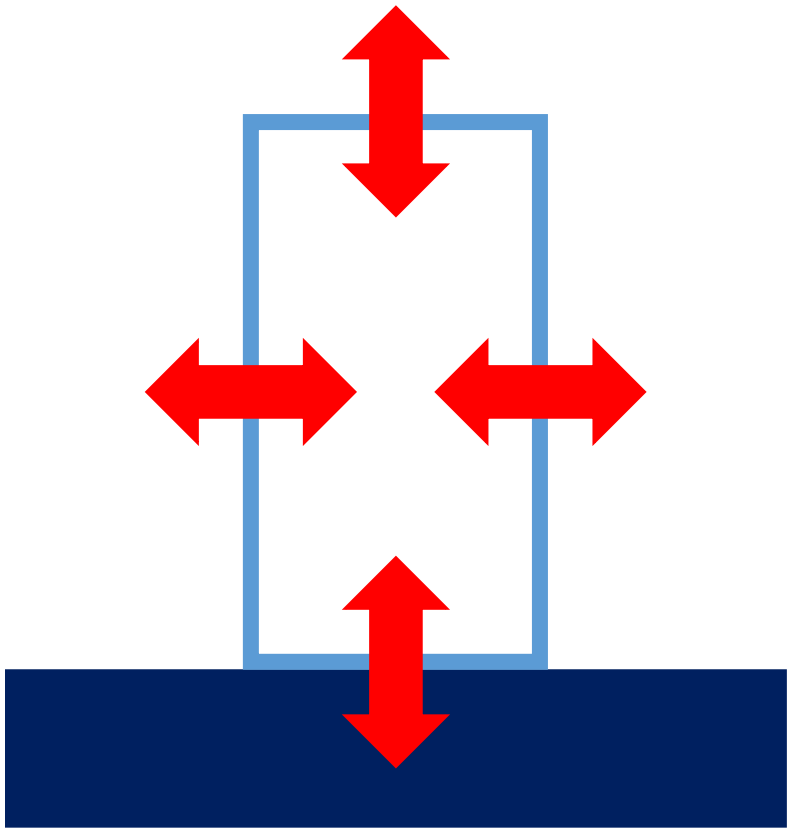

Latent heat [MJ.m-2] at 12 hours
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
80
70
60
50
40
30
20
10


Sensible heat [MJ.m-2] at 12 hours
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
2200
2190
2180
2170
2160
2150
2140
2130
2120
2110
2100


Potential energy [MJ.m-2] at 12 hours
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
400
395
390
385
380
375
370

Integrated MSE budget

What changes $\widehat{h}$ in our domain?



Net radiative fluxes

Lateral advection of moist static energy

Surface turbulent fluxes

Integrated MSE budget

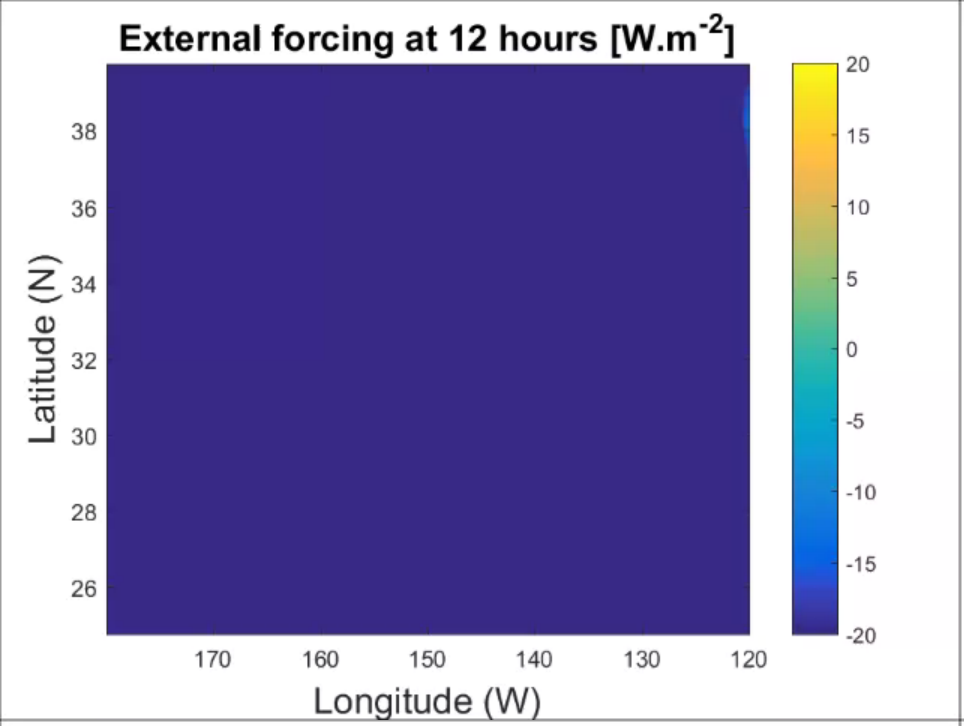
What changes $\hat{h}$ in our domain?

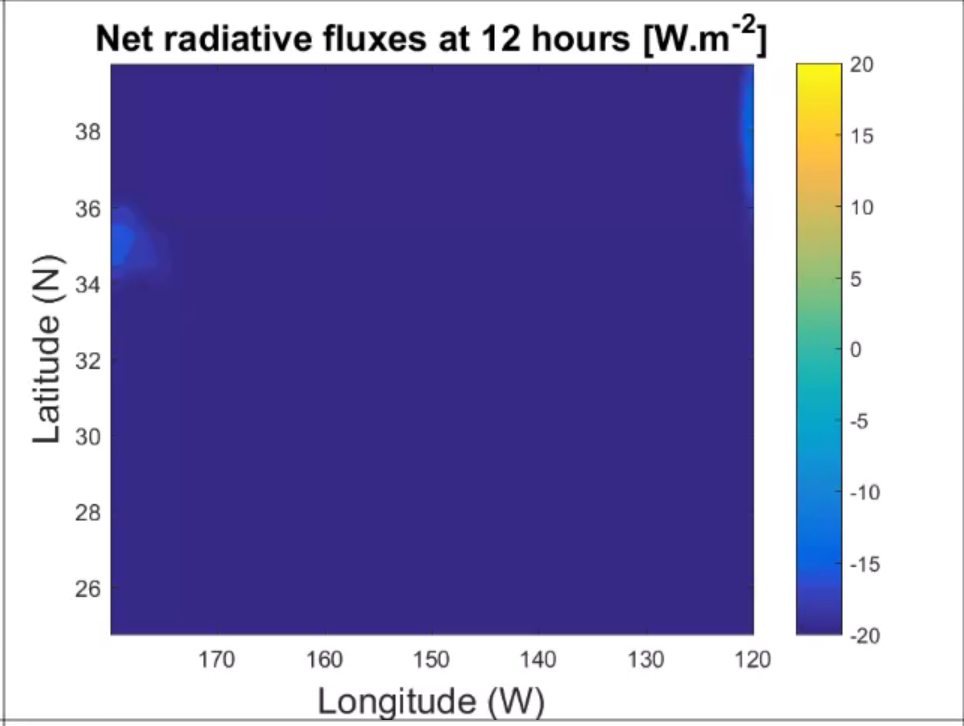
Local variation of MSE

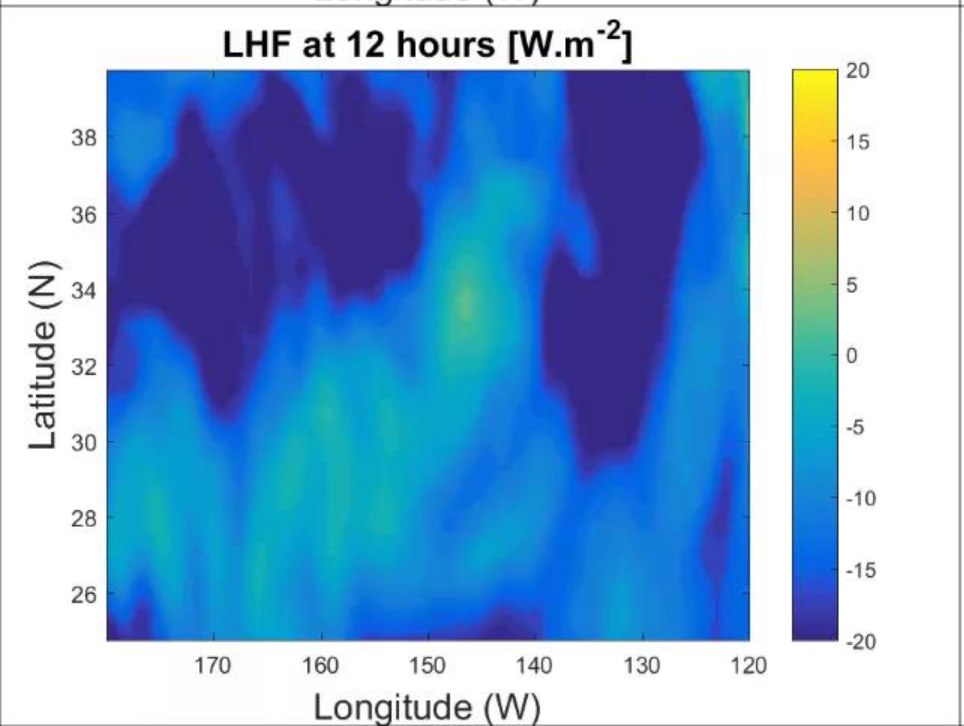
$$\boxed{\frac{\partial \hat{h}}{\partial t}} = \boxed{-\overbrace{\vec{\nabla} \cdot h\vec{u}}} + \boxed{\text{External forcing}}$$

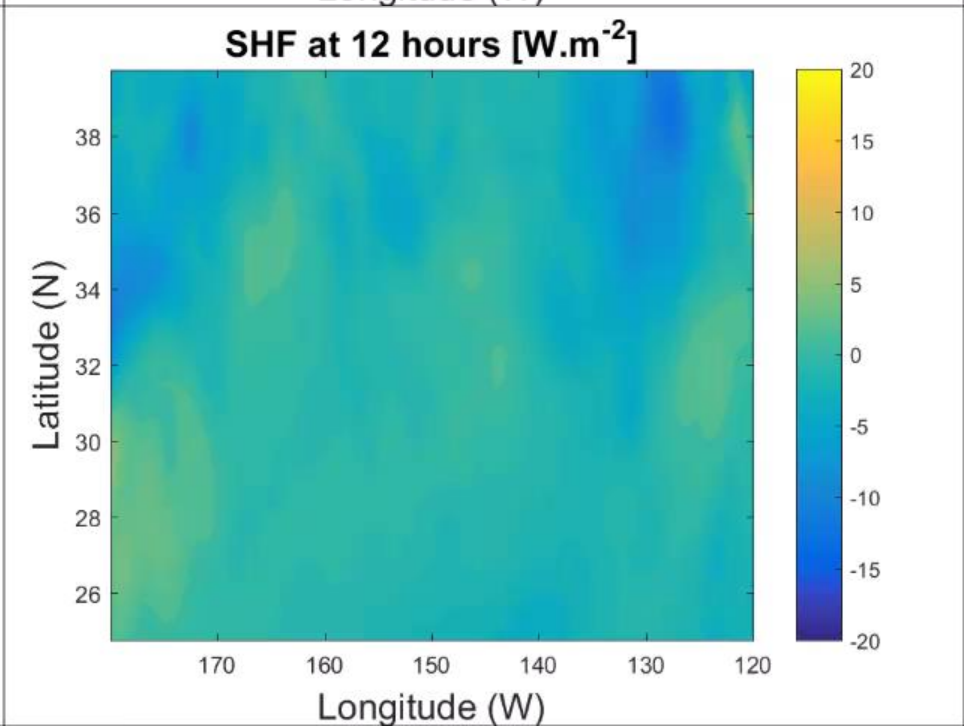
Lateral advection of MSE

External forcing = Latent heat flux + Sensible heat flux + Net radiative cooling


External forcing at 12 hours [W.m-2]
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
20
15
10
5
0
-5
-10
-15
-20


Net radiative fluxes at 12 hours [W.m-2]
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
20
15
10
5
0
-5
-10
-15
-20


LHF at 12 hours [W.m-2]
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
20
15
10
5
0
-5
-10
-15
-20


SHF at 12 hours [W.m-2]
Latitude (N)
38
36
34
32
30
28
26
170
160
150
140
130
120
Longitude (W)
20
15
10
5
0
-5
-10
-15
-20

Integrated MSE budget

What changes $\hat{h}$ in our domain?

Local variation of MSE

$$\boxed{\frac{\partial \hat{h}}{\partial t}} = \boxed{-\overbrace{\vec{\nabla} \cdot h\vec{u}}} + \boxed{\text{External forcing}}$$

Lateral advection of MSE

External forcing = Latent heat flux + Sensible heat flux + Net radiative cooling

Integrated MSE budget

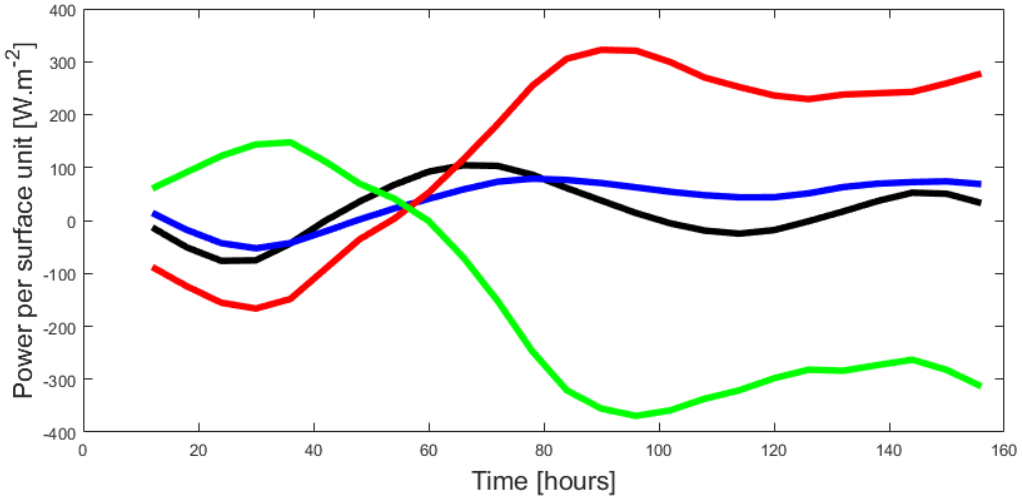
What changes $\hat{h}$ in our domain?

Local variation of MSE

$$\frac{\partial \hat{h}}{\partial t} \approx -\vec{\nabla} \cdot r\vec{u} + F_{ext}$$

Lateral advection of latent heat

External forcing



Sensible heat

Latent heat ≈ MSE

Potential energy

1. Moist static energy

2. **Moist static energy variance**

3. Comparison between Pacific cases

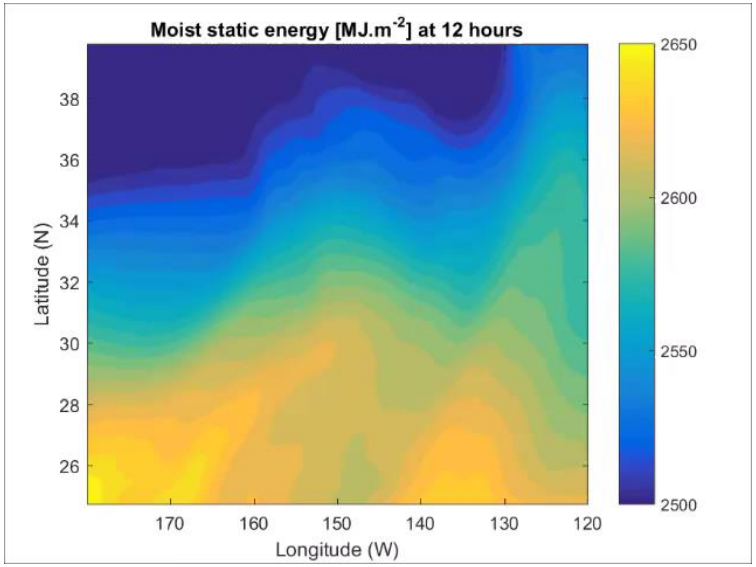
Moist static energy spatial variance

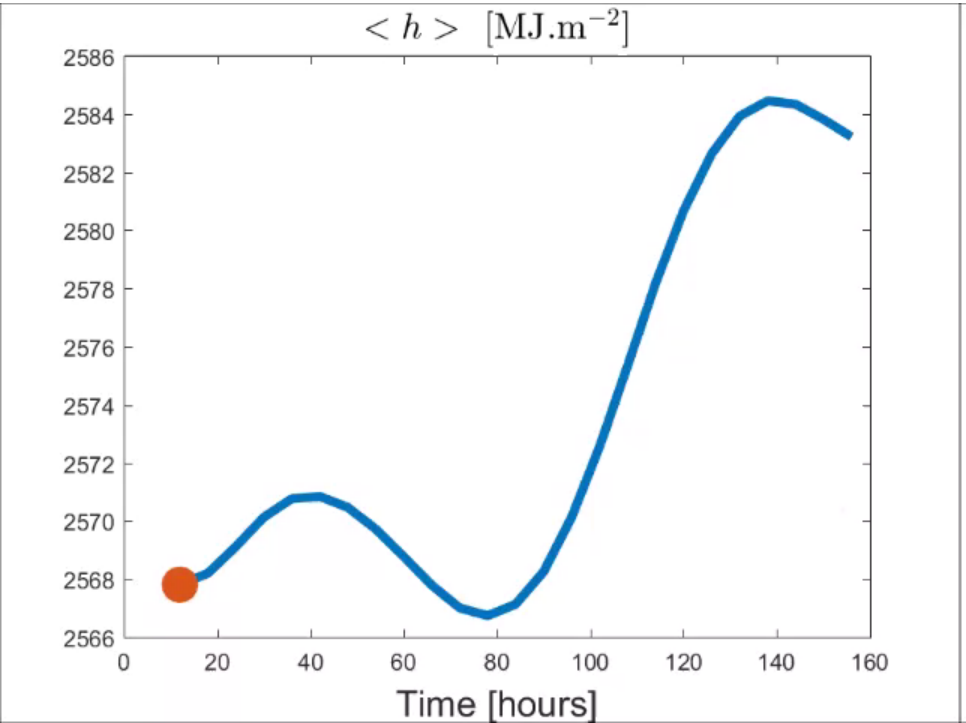
Domain average: $< \hat{h} >$

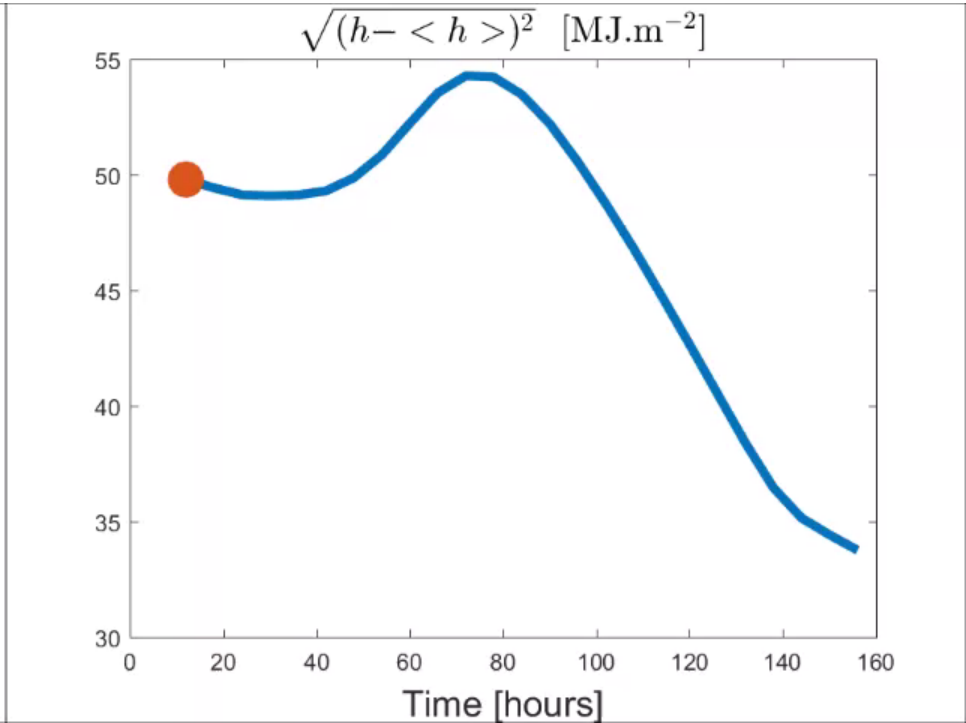
Perturbation: $\hat{h}' = \hat{h} - < \hat{h} >$

Spatial variance: $< \hat{h}'^2 >$

Moist static energy mean & St.Dev.

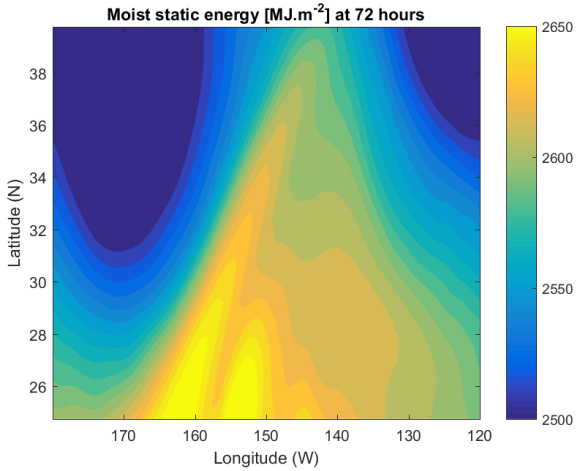


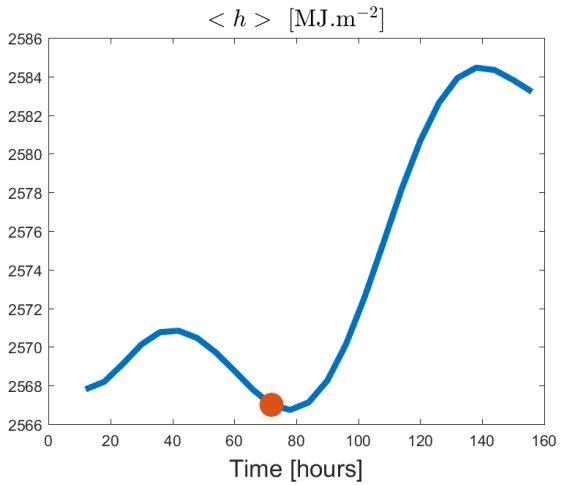


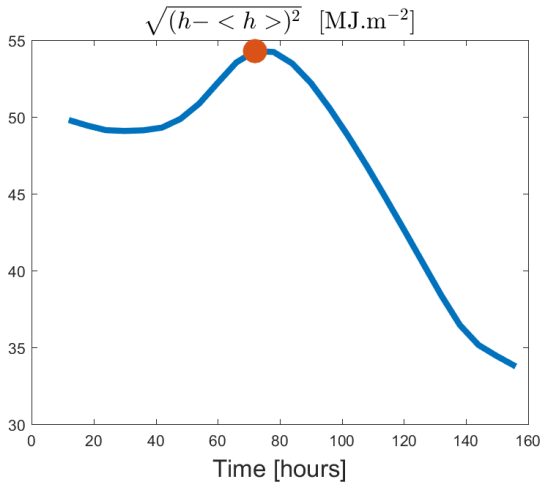


MSE variance is a better metric for AR

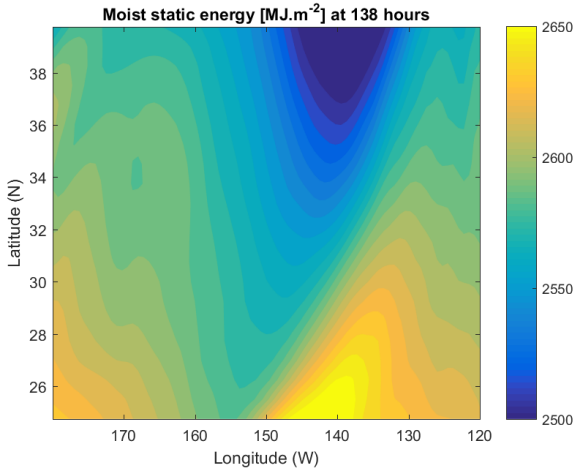
72 hours ↔ Peak AR intensity

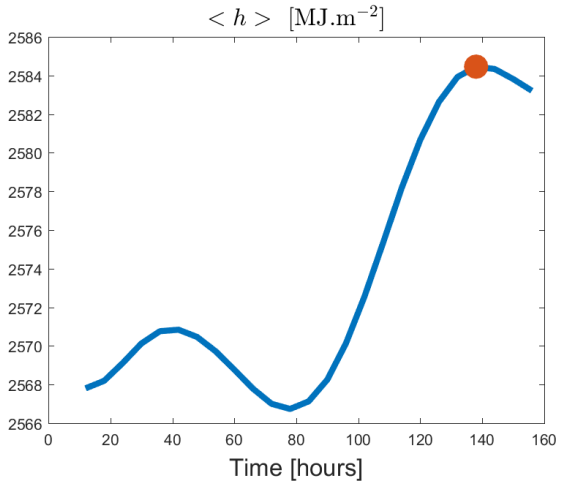


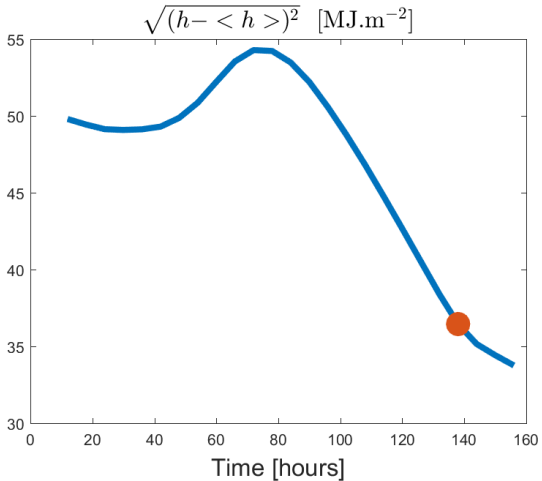




138 hours ↔ End AR life







Budget of MSE variance *(Wing and Emanuel, 2014)*

What changes $< \hat{h}'^2 >$ in our domain?

$$\frac{\partial}{\partial t}\frac{<\hat{h}'^2>}{2} = -<\hat{h}'\widehat{\left(\vec{\nabla}\cdot h\vec{u}\right)}'> + <\hat{h}'\ \ _{rt}>$$

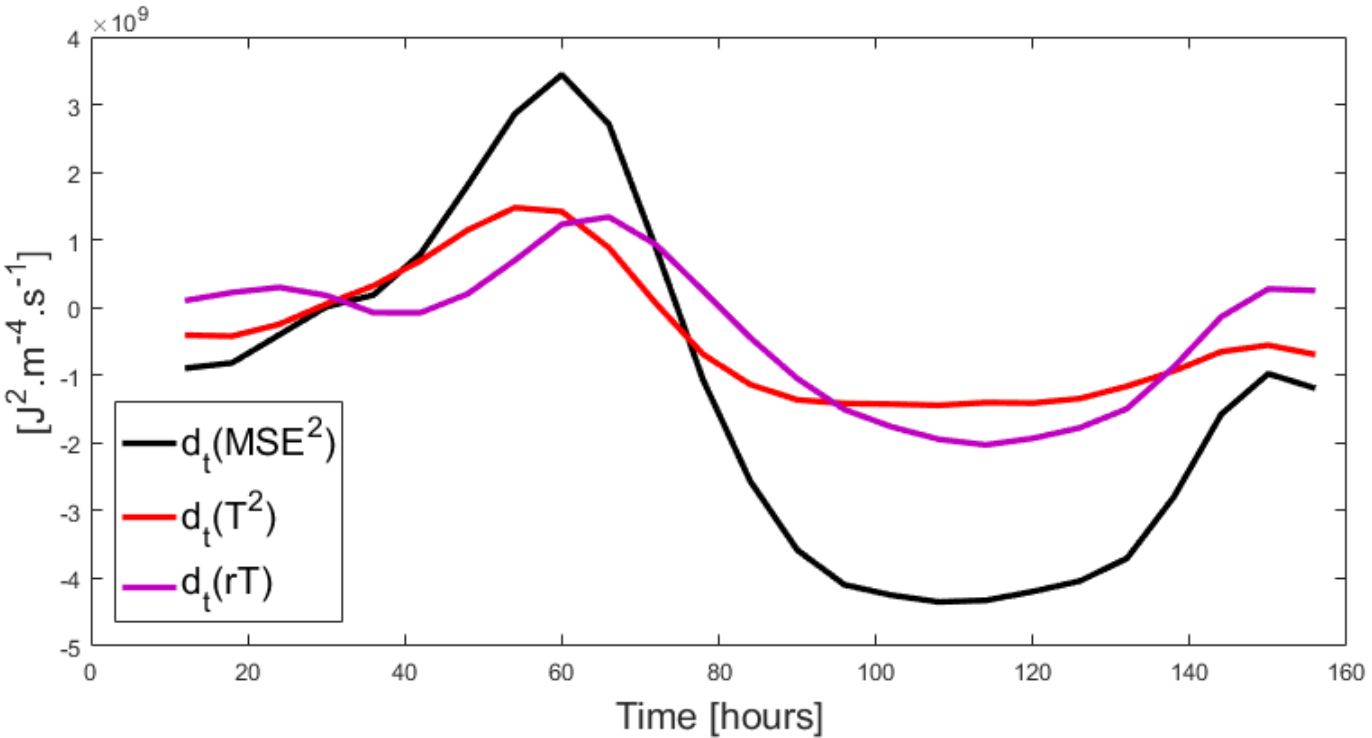
Local variation of MSE variance

Correlation between MSE and MSE advection

Correlation between MSE and ext forcing

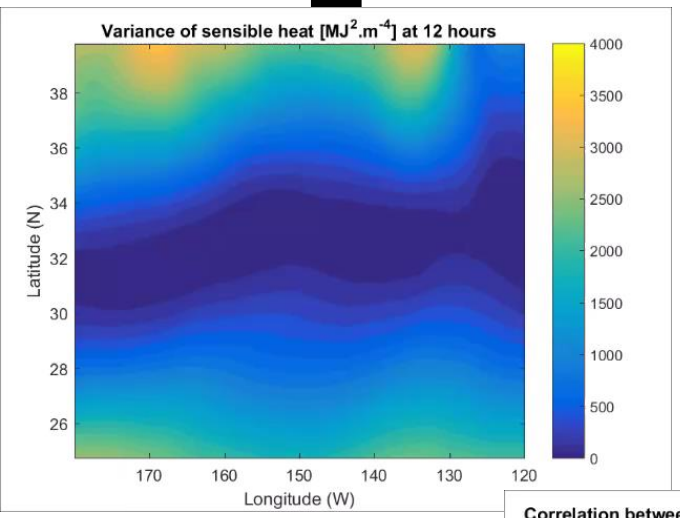
Decomposition of MSE var. tendency

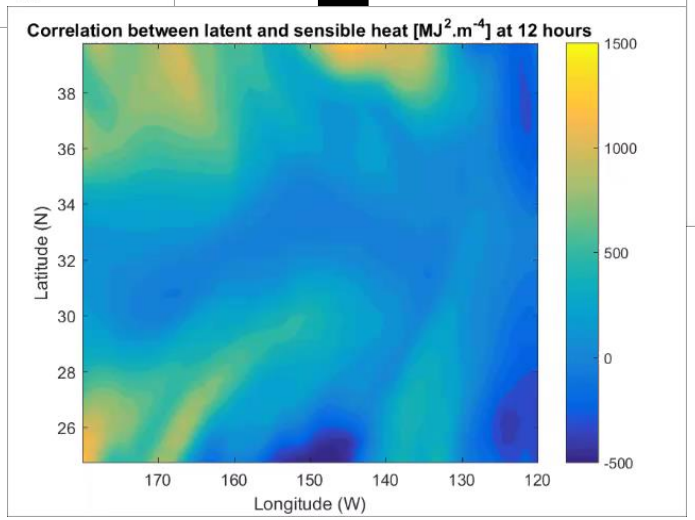
$$\frac{\partial}{\partial t}\frac{<\hat{h}'^2>}{2} = \frac{\partial}{\partial t}<\frac{(L_v\hat{r}')^2}{2} + \frac{(c_p\hat{T}')^2}{2} + \frac{(\hat{\Phi}')^2}{2} + (L_v\hat{r}')(c_p\hat{T}') + (L_v\hat{r}')(\hat{\Phi}') + (\hat{\Phi}')(c_p\hat{T}')>$$

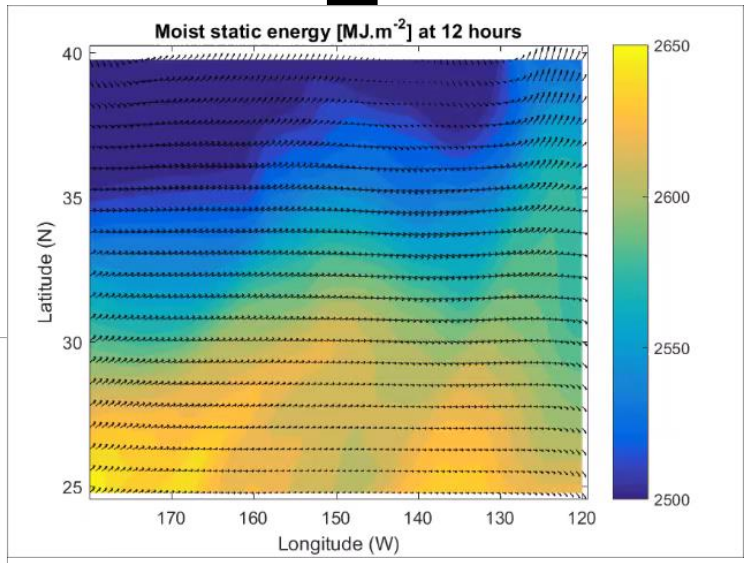


Final AR budget

$$\frac{\partial}{\partial t} < \frac{(c_p \hat{T}')^2}{2} + (L_v \hat{r}')(c_p \hat{T}') > = < \hat{h}' \cdot \left(\widehat{\vec{V} \cdot L_v r \vec{u}} \right)' >$$







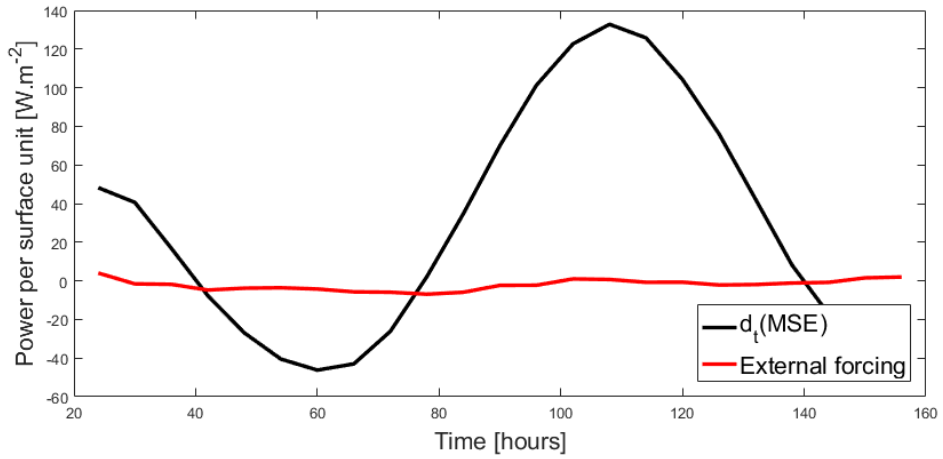
1. Moist static energy

2. Moist static energy variance

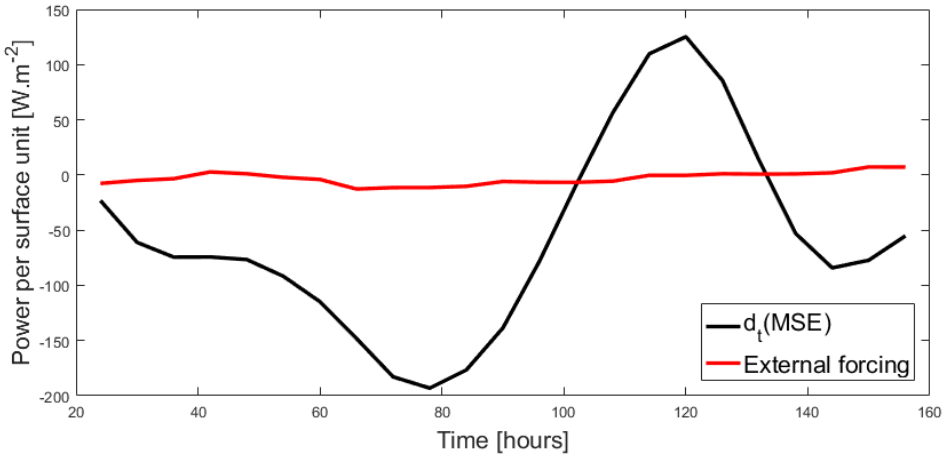
3. **Comparison between Pacific cases**

Summary

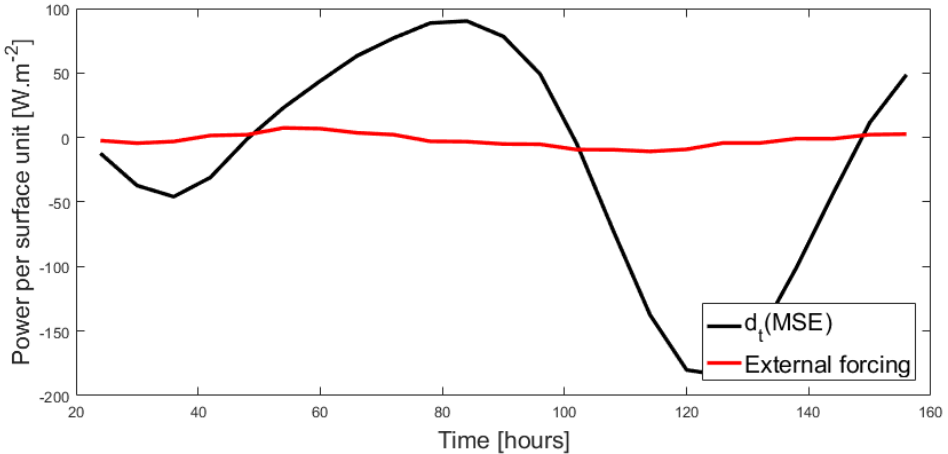
1. The external forcing is small



Mar 22, 2005



Feb 07, 2014

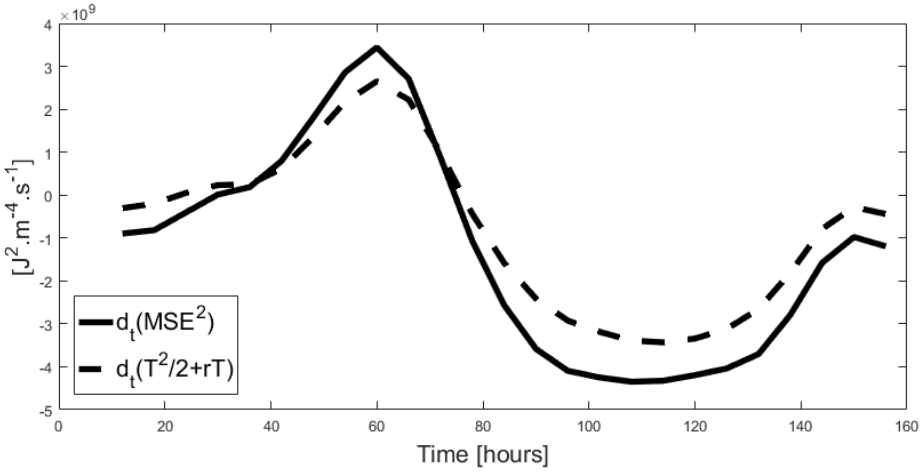


Nov 11, 2014

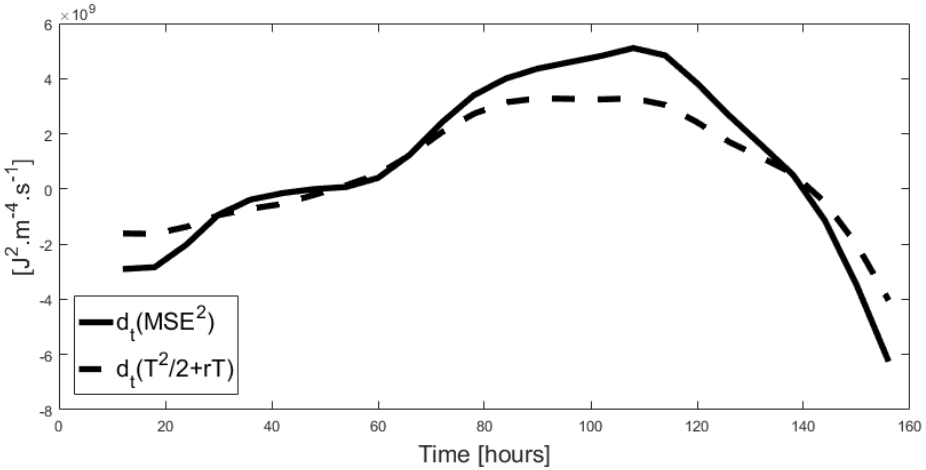
Summary

1. The external forcing is small

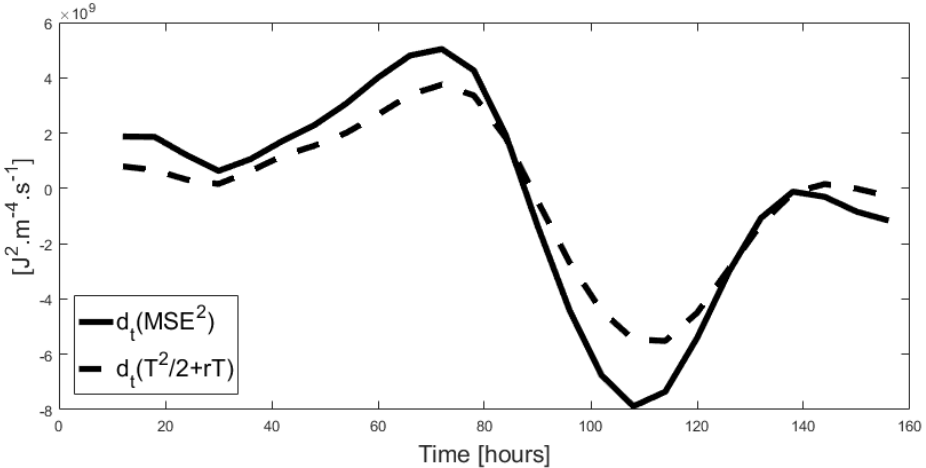
2. MSE var. ≈ Latent/Sensible heat var.



Mar 22, 2005



Feb 07, 2014



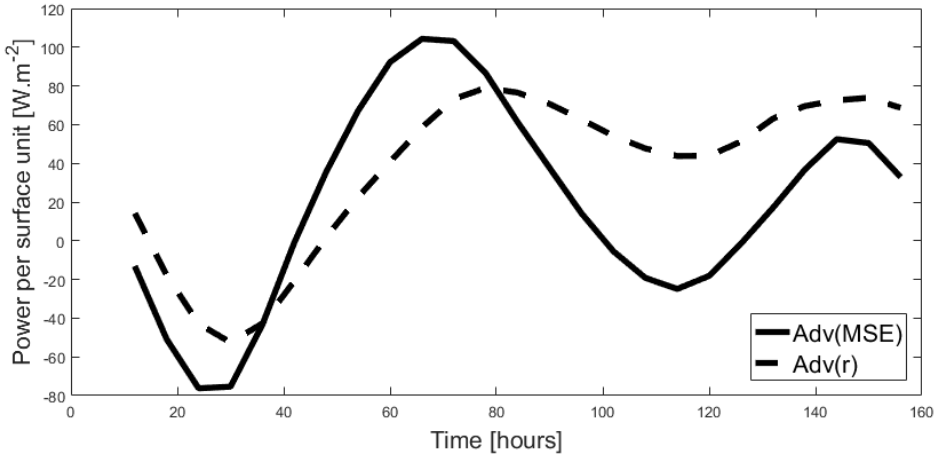
Nov 11, 2014

Summary

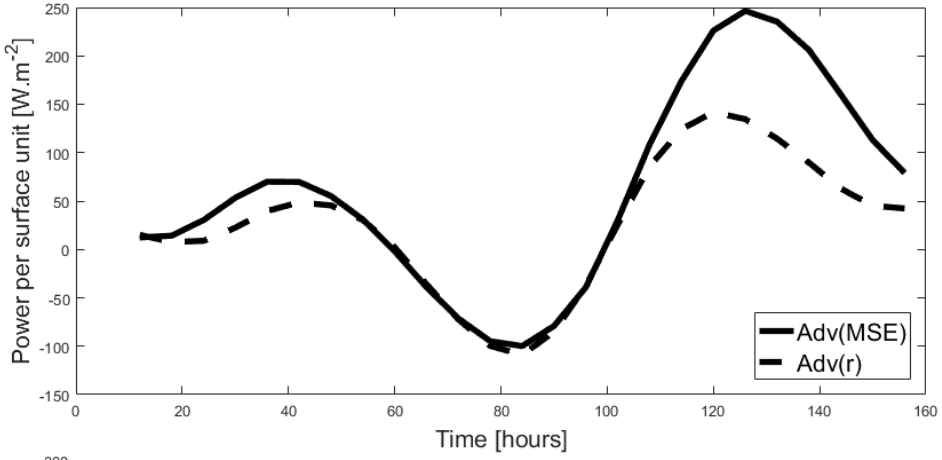
1. The external forcing is small

2. MSE var. ≈ Latent/Sensible heat var.

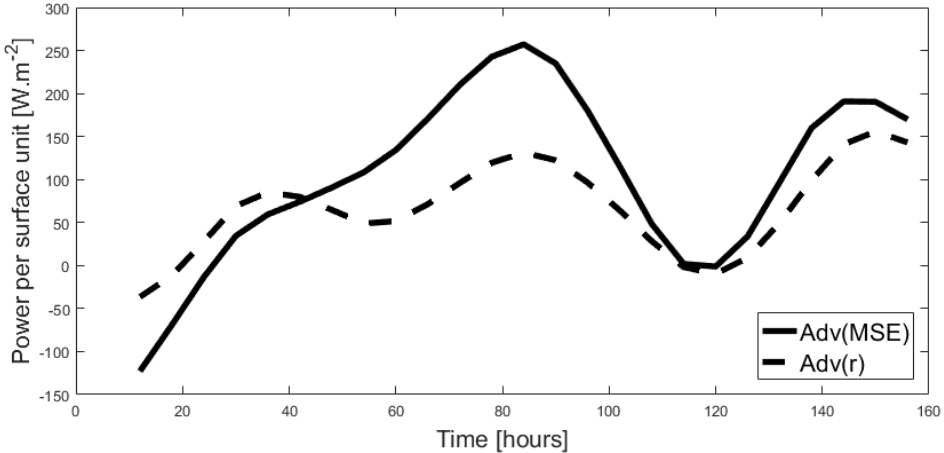
3. MSE adv. ≈ Latent heat advection



Mar 22, 2005



Feb 07, 2014



Nov 11, 2014

Summary

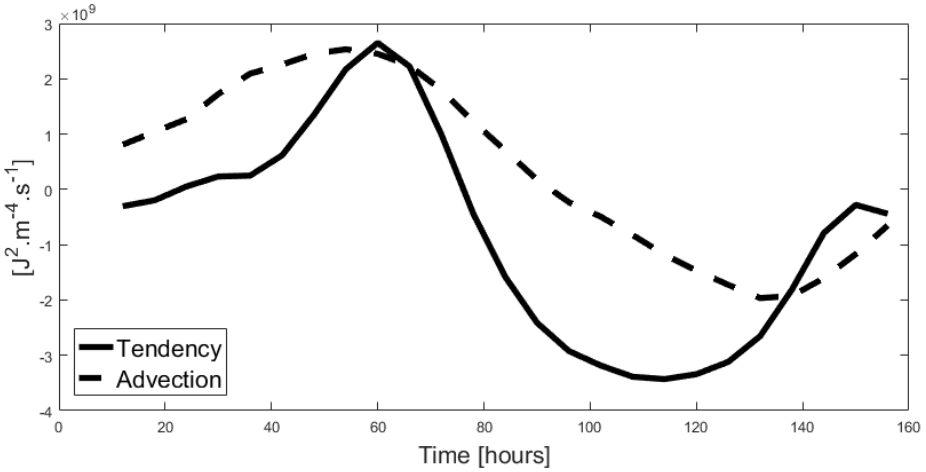
1. The external forcing is small

2. MSE var. ≈ Latent/Sensible heat var.

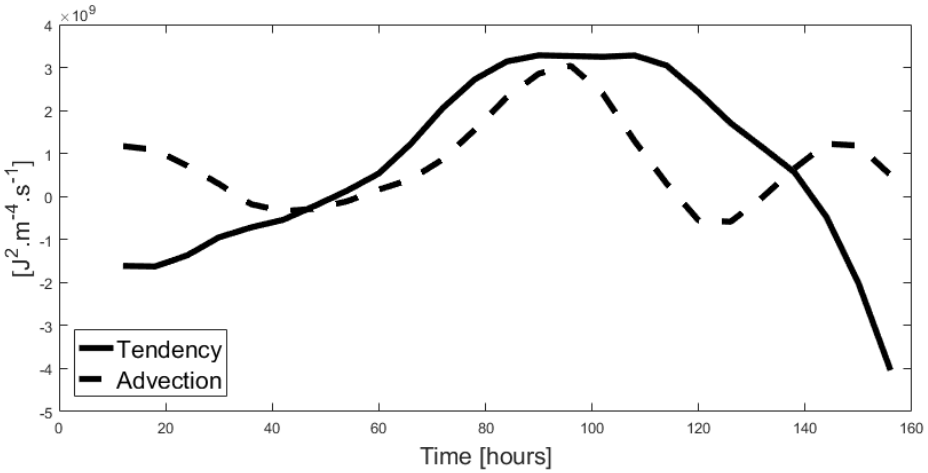
3. MSE adv. ≈ Latent heat advection

4. MSE variance budget:

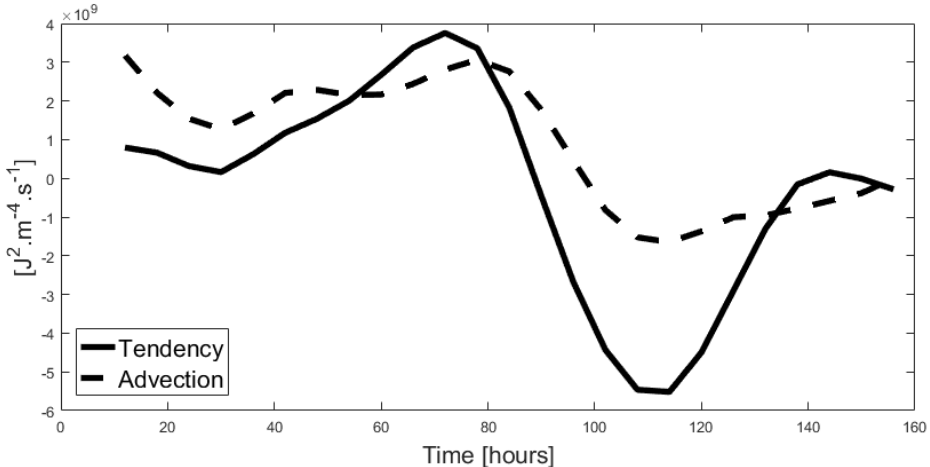
$$\frac{\partial}{\partial t}\frac{<\hat{h}'^2>}{2} = -<\hat{h}'\widehat{\left(\vec{\nabla}\cdot h\vec{u}\right)}'> + <\hat{h}'F'_{ext}>$$



Mar 22, 2005



Feb 07, 2014



Nov 11, 2014

Summary

Center for Western Weather and Water Extremes

1. The external forcing is small

2. MSE var. ≈ Latent/Sensible heat var.

3. MSE adv. ≈ Latent heat advection

4. AR budget:

$$\frac{\partial}{\partial t} < \frac{(c_p \hat{T}')^2}{2} + (L_v \hat{r}')(c_p \hat{T}') > = < \hat{h}' \cdot \left(\vec{V} \cdot \widehat{L_v r \vec{u}} \right)' >$$