Modeling the evolution and life cycle of fog

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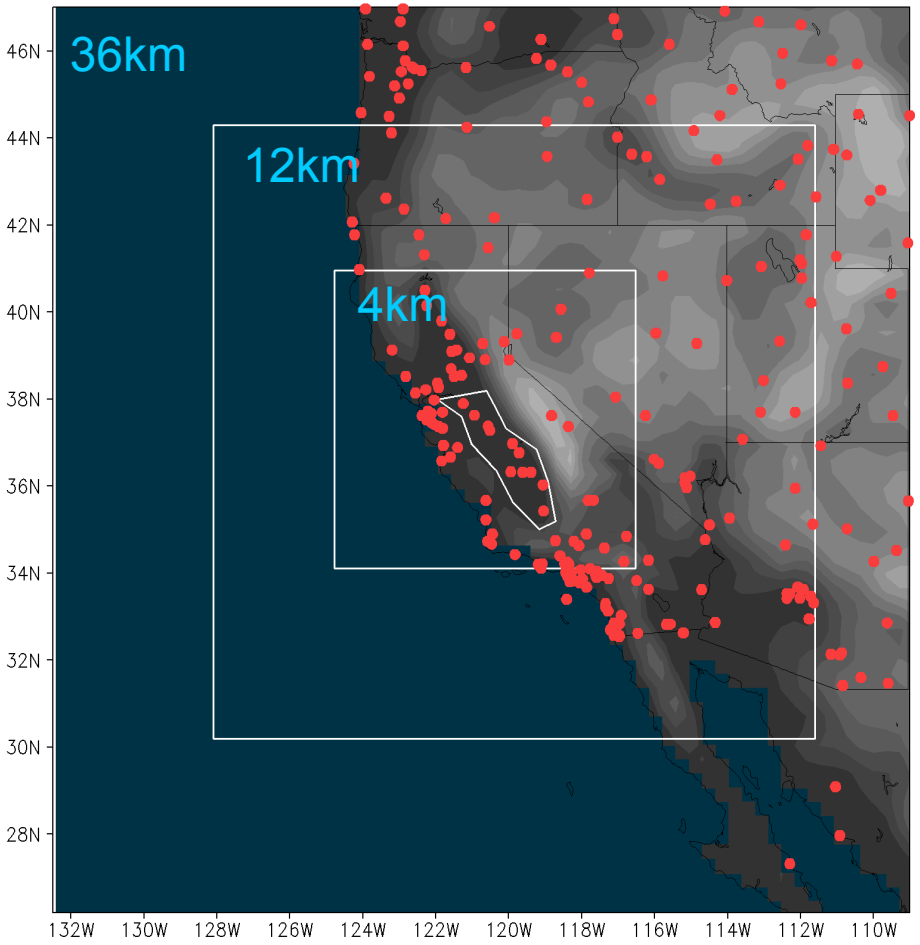
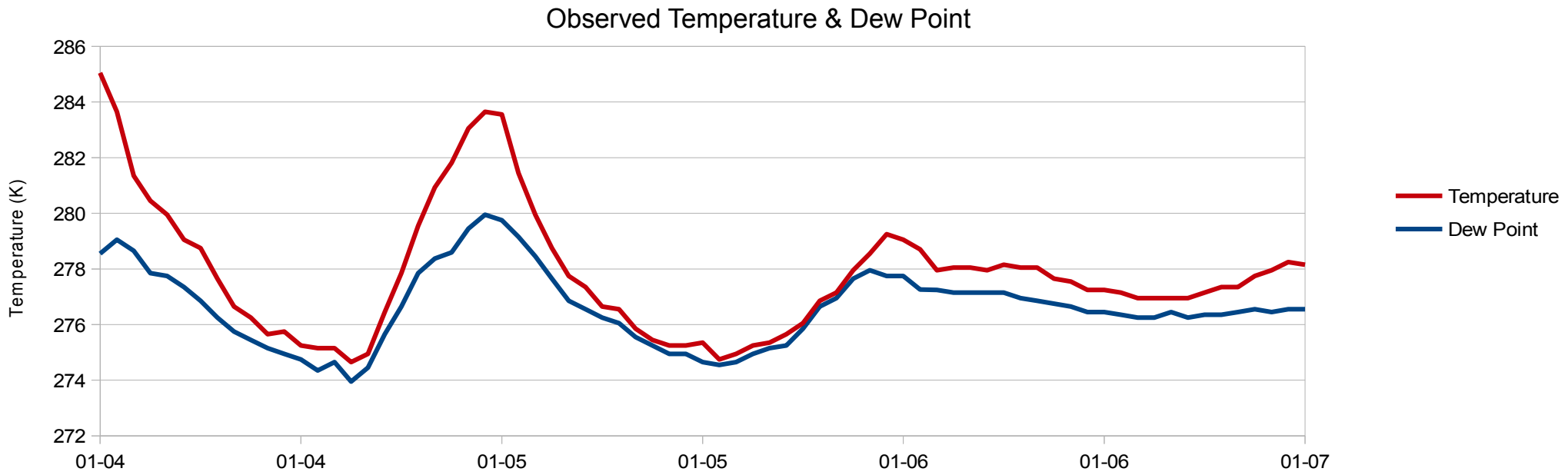
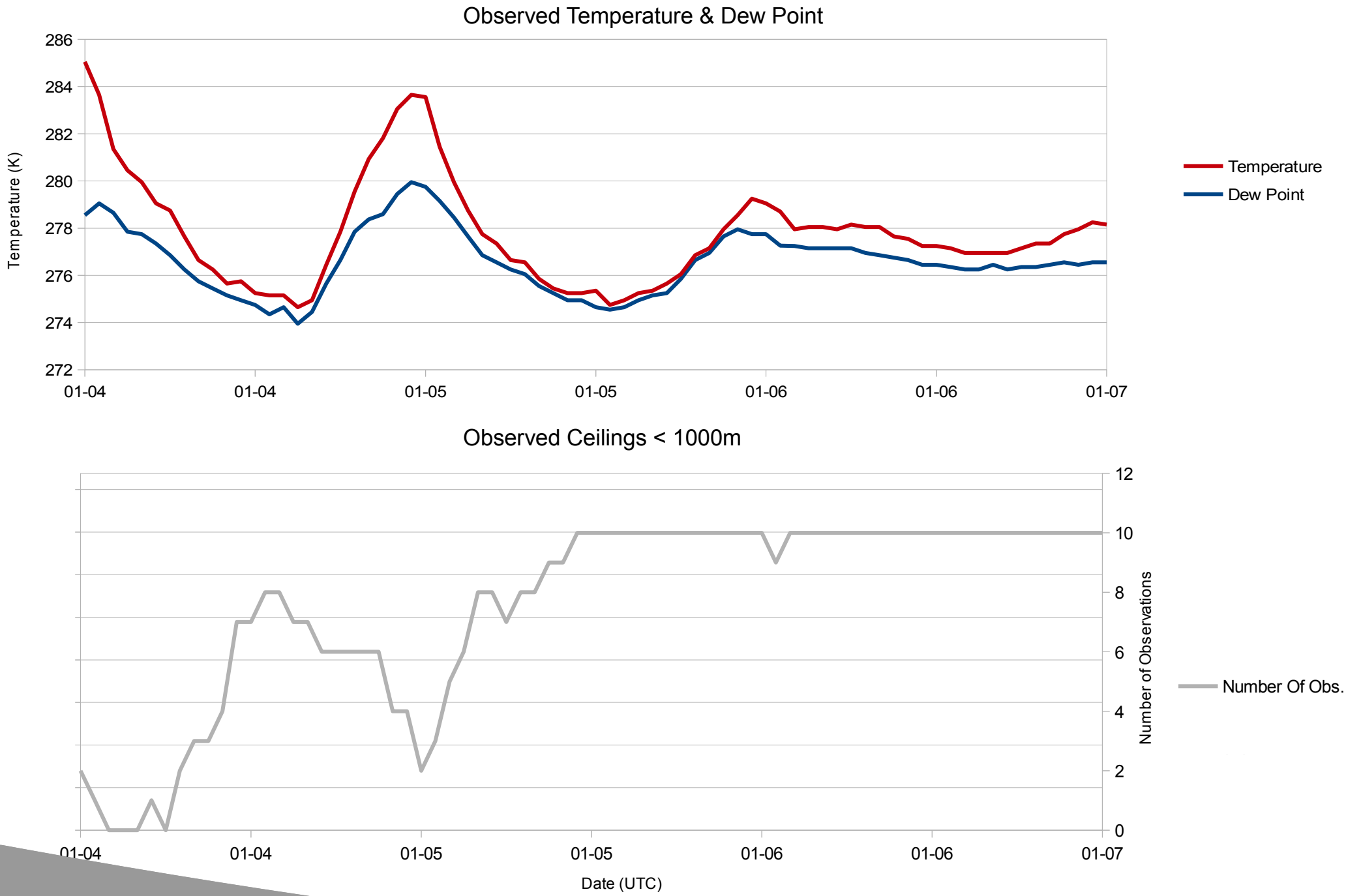
WRF 3.5.1

- 3 domains 36/12/4km
- Statistic computed, then averaged in San Joaquin subset.
- diffopt = 0
- gravitational settling (fixed for this presentation)
- WDM5 (various tested)
- Dudhia/RRTM (various tested)
- Various initialization/initialization times tested
- YSU





Observations – San Joaquin Subset



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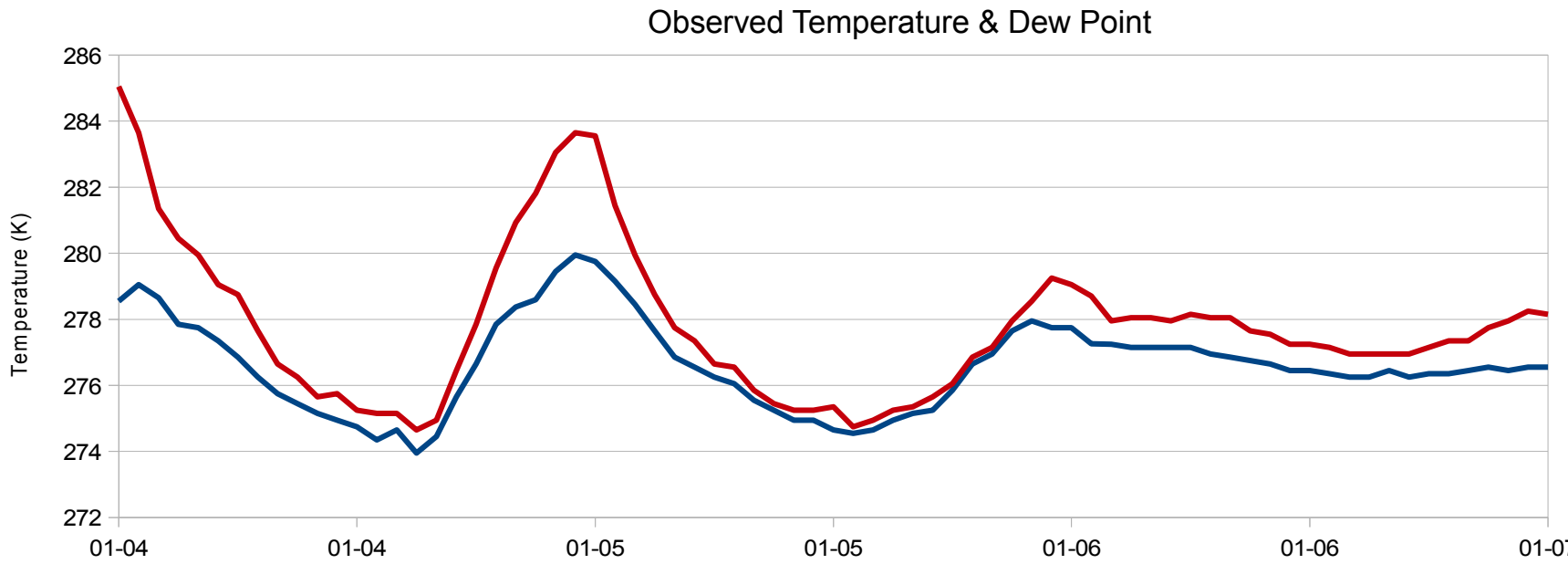

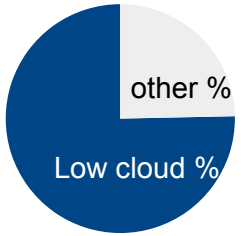

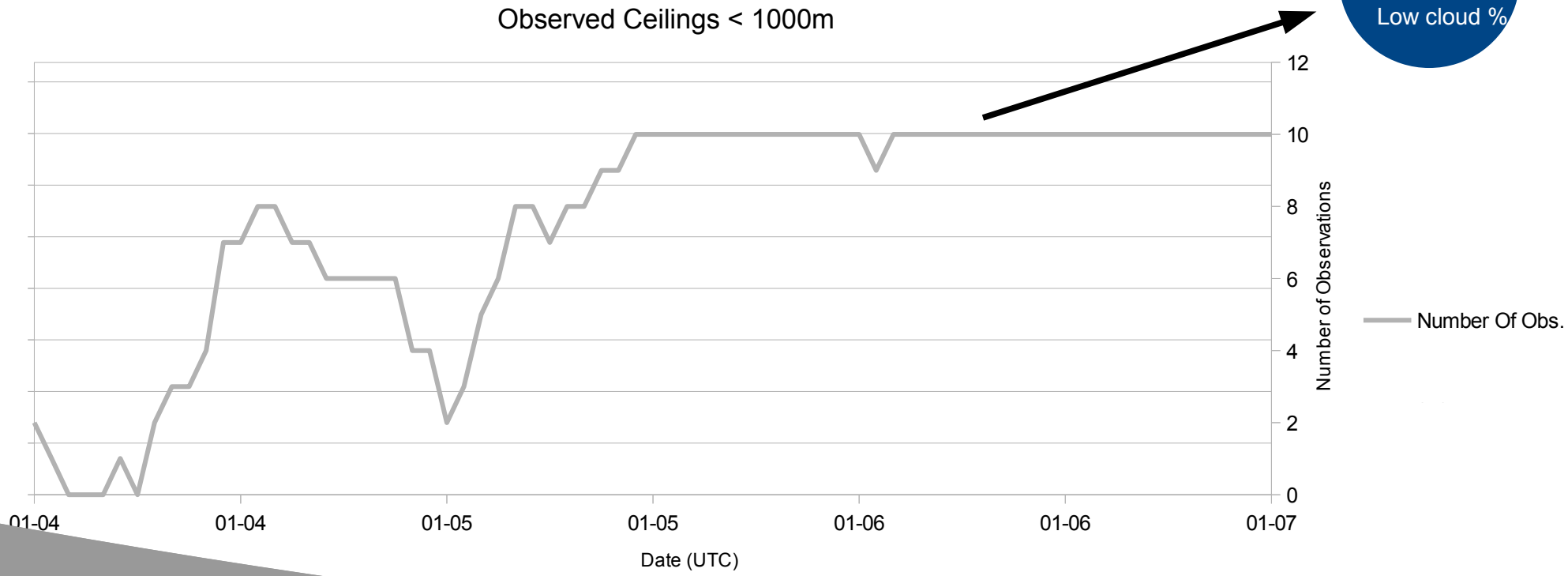

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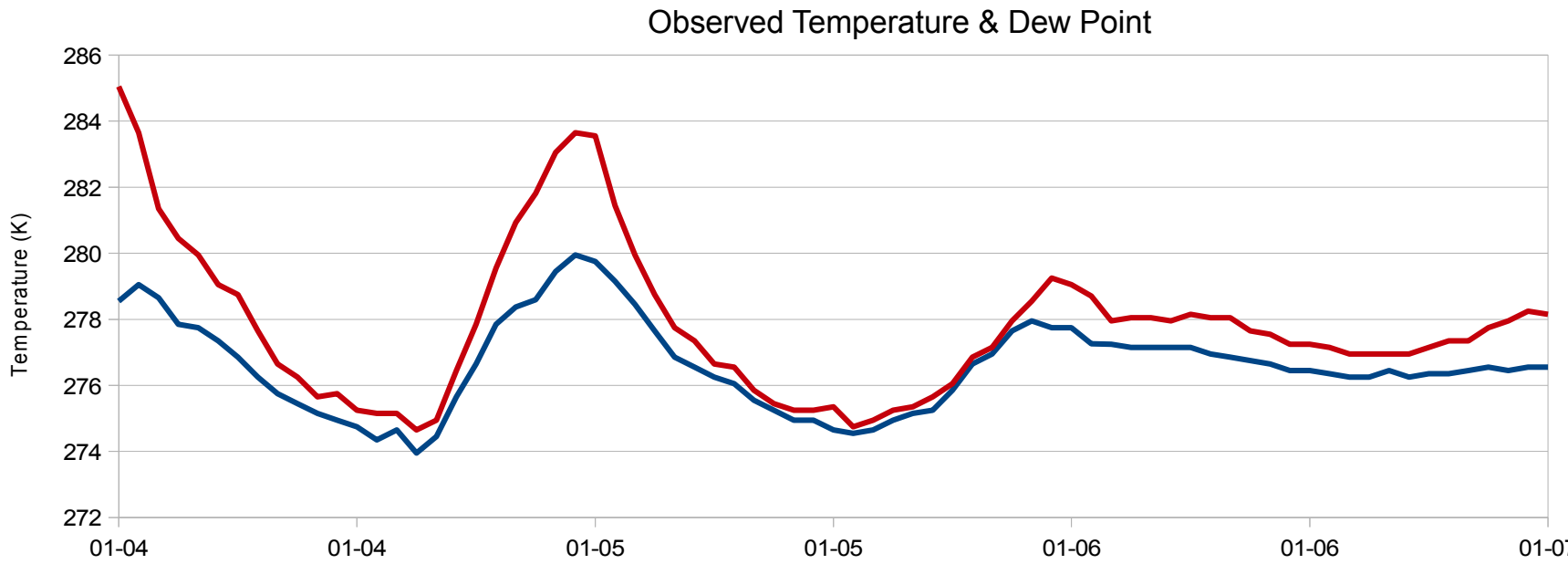
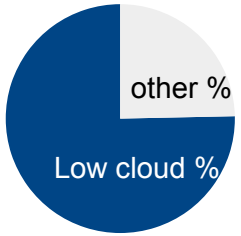
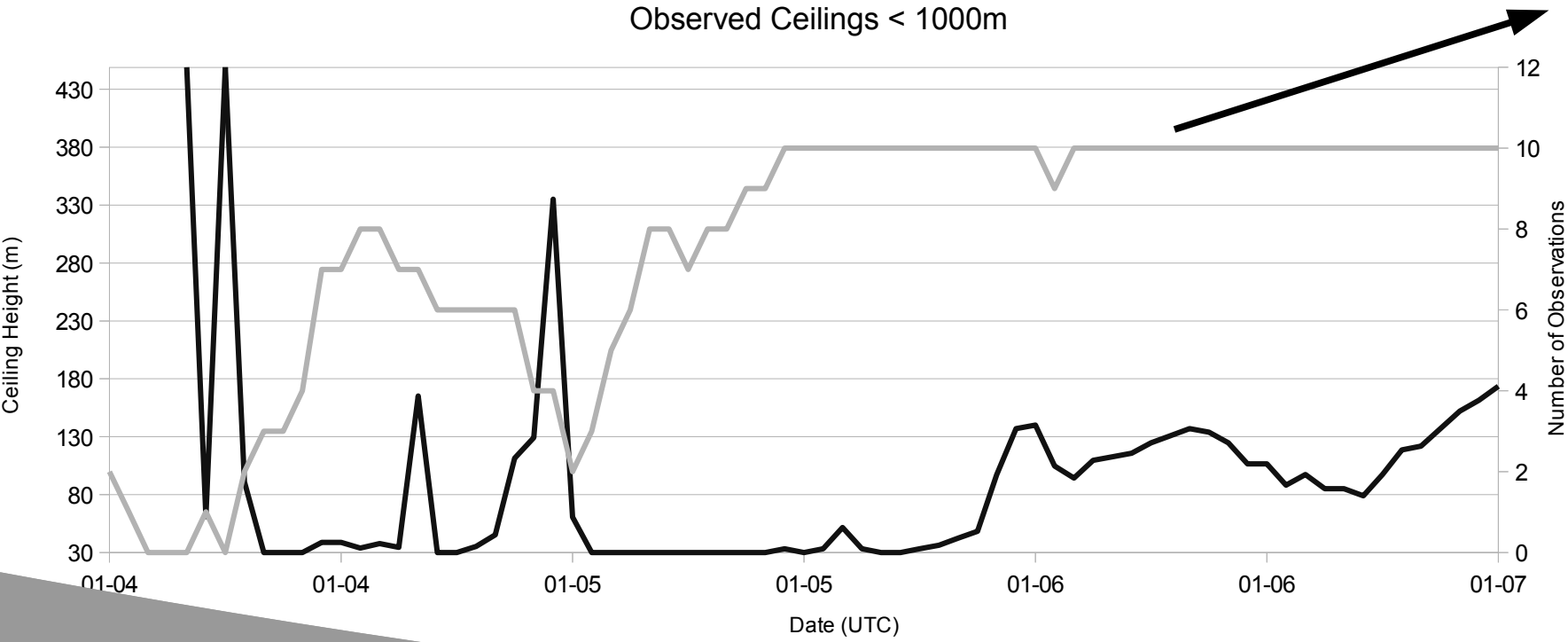
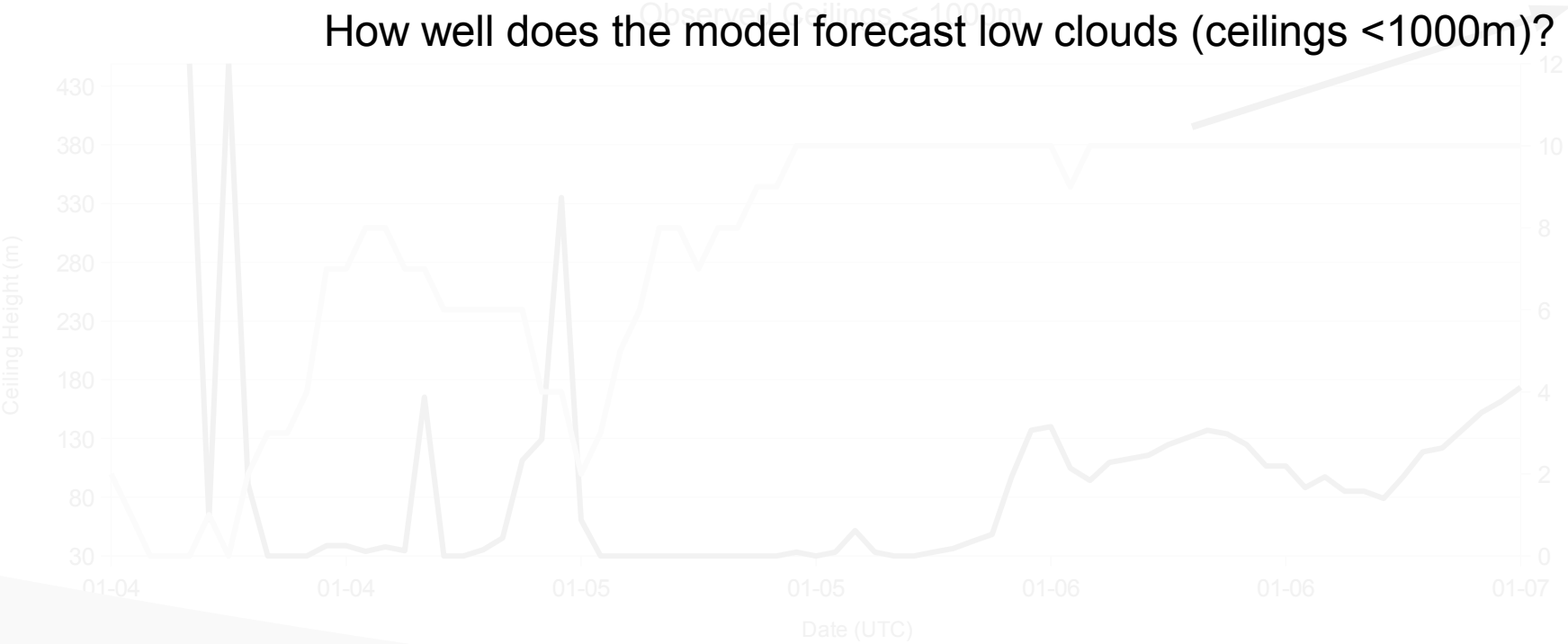




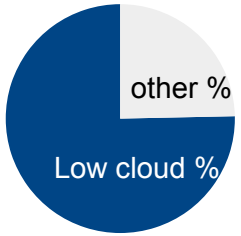


Observations – San Joaquin Subset

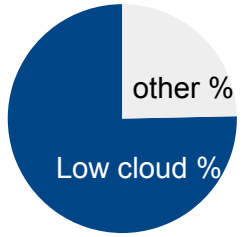
How well does the model forecast low clouds (ceilings <1000m)?



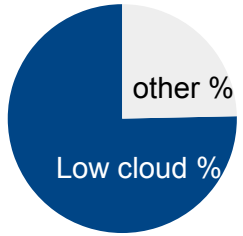
Category threshold: Ceilings < 1000m

	Forecast low clouds Observed low clouds	Forecast none Observed none	Forecast low clouds Observed none	Forecast none Observed Low clouds	Observed
Jan 4-7th 2011 (72 hours)					

Category threshold: Ceilings < 1000m

	Forecast low clouds Observed low clouds	Forecast none Observed none	Forecast low clouds Observed none	Forecast none Observed Low clouds	Observed
Jan 4-7th 2011 (72 hours)	0.87				

Category threshold: Ceilings < 1000m

	Forecast low clouds Observed low clouds	Forecast none Observed none	Forecast low clouds Observed none	Forecast none Observed Low clouds	Observed
Jan 4-7th 2011 (72 hours)	0.87		0.13		

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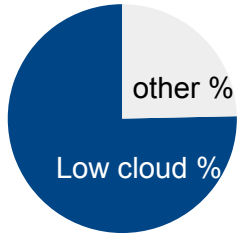
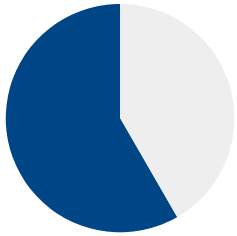
Jan 4-7th 2011 (72 hours)	0.87		0.13		
Jan 13-16th 2011 (72 hours)	0.76		0.24		

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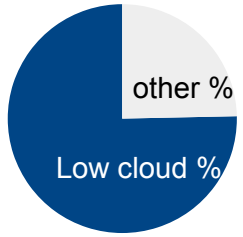
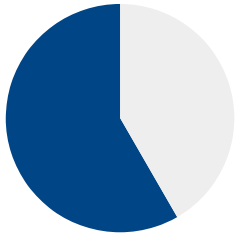
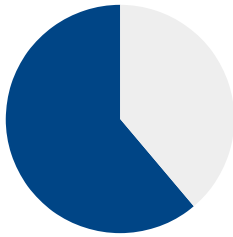
Jan 4-7th 2011 (72 hours)	0.87		0.13		
Jan 13-16th 2011 (72 hours)	0.76		0.24		
Dec. 29 – 2nd 2008/09 (84 hours)	0.91		0.09		

Category threshold: Ceilings < 1000m

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Fog vs. Stratus

Can the model differentiate between the two?

Conditional: forecast and observations have ceilings < 1000m

Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

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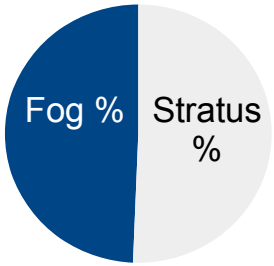
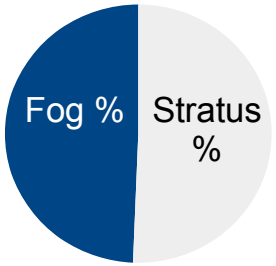
	Forecast fog Observed fog	Forecast stratus Observed stratus	Forecast fog Observed stratus	Forecast stratus Observed fog	Conditional Observations
Jan 4-7th 2011 (72 hours)					

Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

	Forecast fog Observed fog	Forecast stratus Observed stratus	Forecast fog Observed stratus	Forecast stratus Observed fog	Conditional Observations
Jan 4-7th 2011 (72 hours)	0.49	0.03			

Conditional: forecast and observations have ceilings < 1000m
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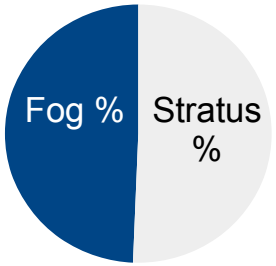
	Forecast fog Observed fog	Forecast stratus Observed stratus	Forecast fog Observed stratus	Forecast stratus Observed fog	Conditional Observations
Jan 4-7th 2011 (72 hours)	0.49	0.03	0.48	0.01	

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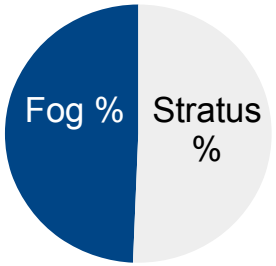
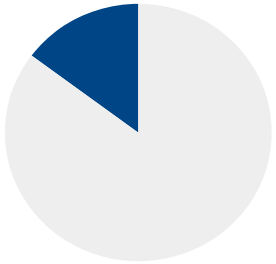
Jan 4-7th 2011 (72 hours)	0.49	0.03	0.48	0.01	
Jan 13-16th 2011 (72 hours)	0.12	0.39	0.46	0.03	

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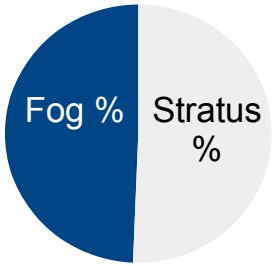
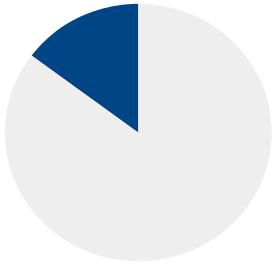
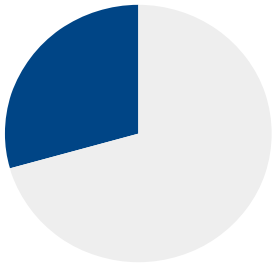
Jan 4-7th 2011 (72 hours)	0.49	0.03	0.48	0.01	
Jan 13-16th 2011 (72 hours)	0.12	0.39	0.46	0.03	
Dec. 29 – 2nd 2008/09 (84 hours)	0.27	0.10	0.60	0.02	

Conditional Categorical Verification – San Joaquin Subset

Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

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Persistent Issues:

1) Model over forecasts fog

2) Surface temperatures are too cold*

3) Boundary layer is too shallow*

*not shown for the sake of time

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Persistent Issues:

1) Model over forecasts fog

2) Surface temperatures are too cold*

3) Boundary layer is too shallow*

*not shown for the sake of time

Could this be a boundary layer problem?

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right) - \overline{(w'c')}_h\left(\frac{z}{h}\right)^3\right]$$

$C = u, v, \theta, q$

$h = pbl\ height$

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right) - \overline{(w'c')}_h\left(\frac{z}{h}\right)^3\right]$$

(1) (2) (3)

$C = u, v, \theta, q$

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1) Local term

2) Counter-gradient

3) Entrainment

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c \left(\frac{\partial C}{\partial z} - \gamma_c \right) - \overline{(w' c')}_h \left(\frac{z}{h} \right)^3 \right]$$

1 2 3

$$C = u, v, \theta, q$$

$$h = pbl\ height$$

1) Local term

2) Counter-gradient

3) Entrainment

$$K_m = k w_s z \left(1 - \frac{z}{h} \right)^p$$

$$w_s = w_s(sfc.\ heat\ flux, \ldots)$$

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right) - \overline{(w'c')}_h\left(\frac{z}{h}\right)^3\right]$$

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$$C = u, v, \theta, q$$

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1) Local term

2) Counter-gradient

3) Entrainment

$$K_m = k w_s z\left(1 - \frac{z}{h}\right)^p \longrightarrow$$

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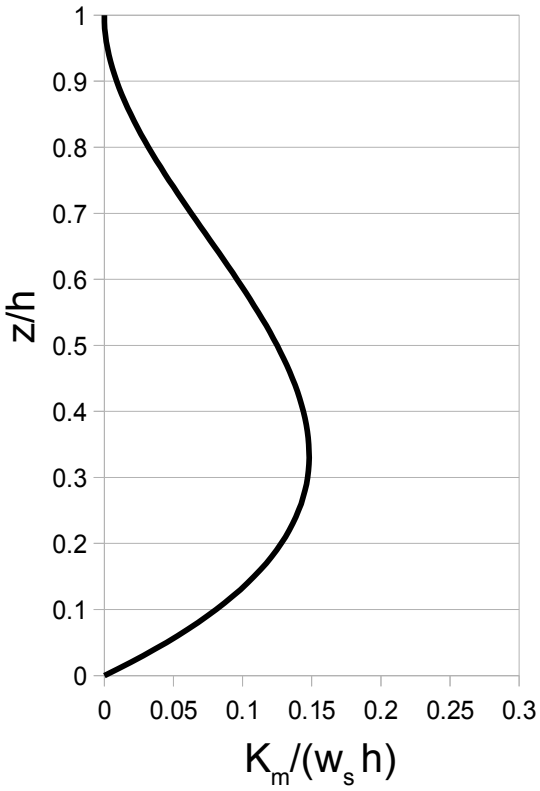

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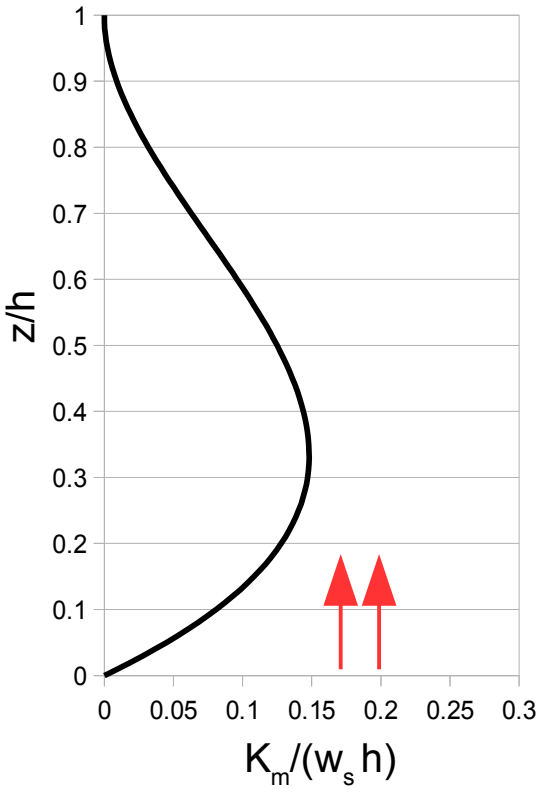

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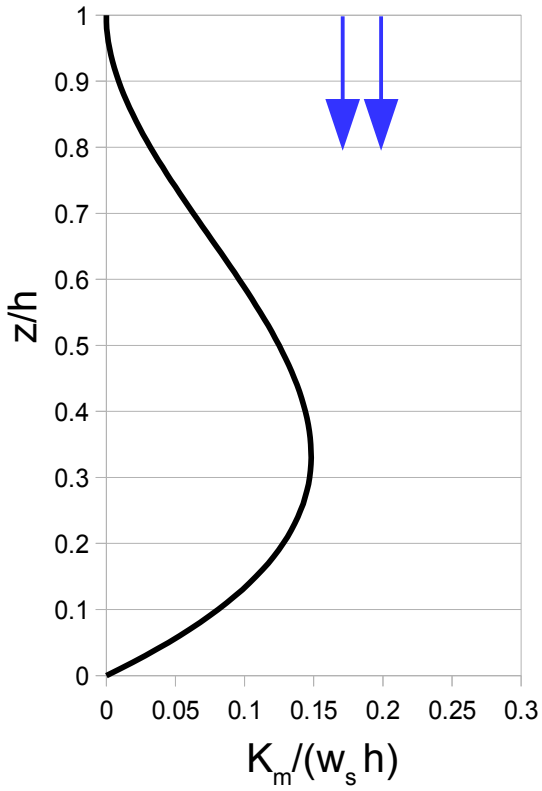

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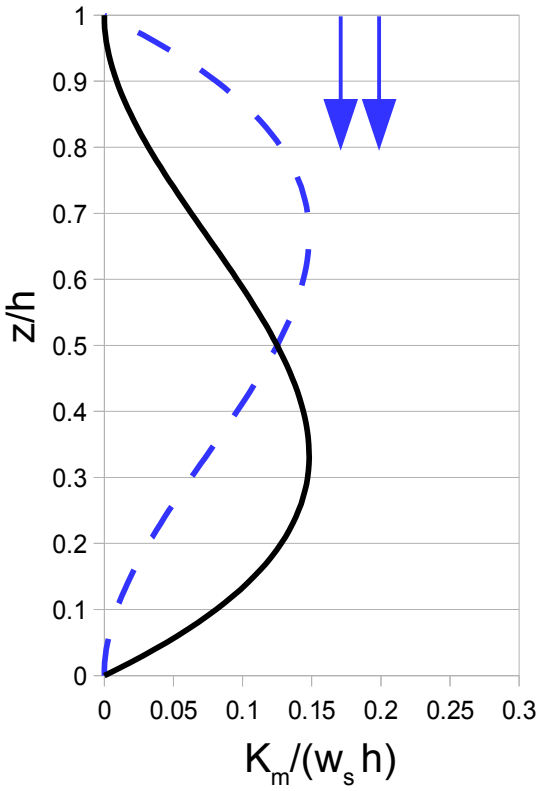

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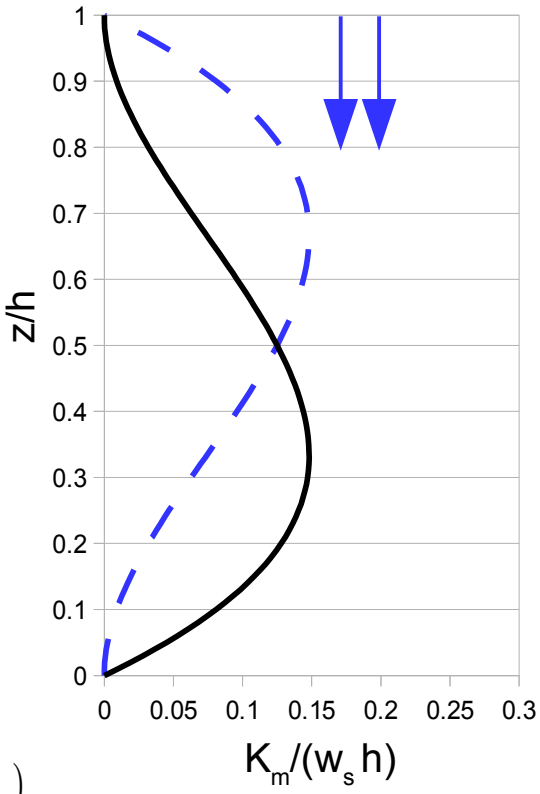
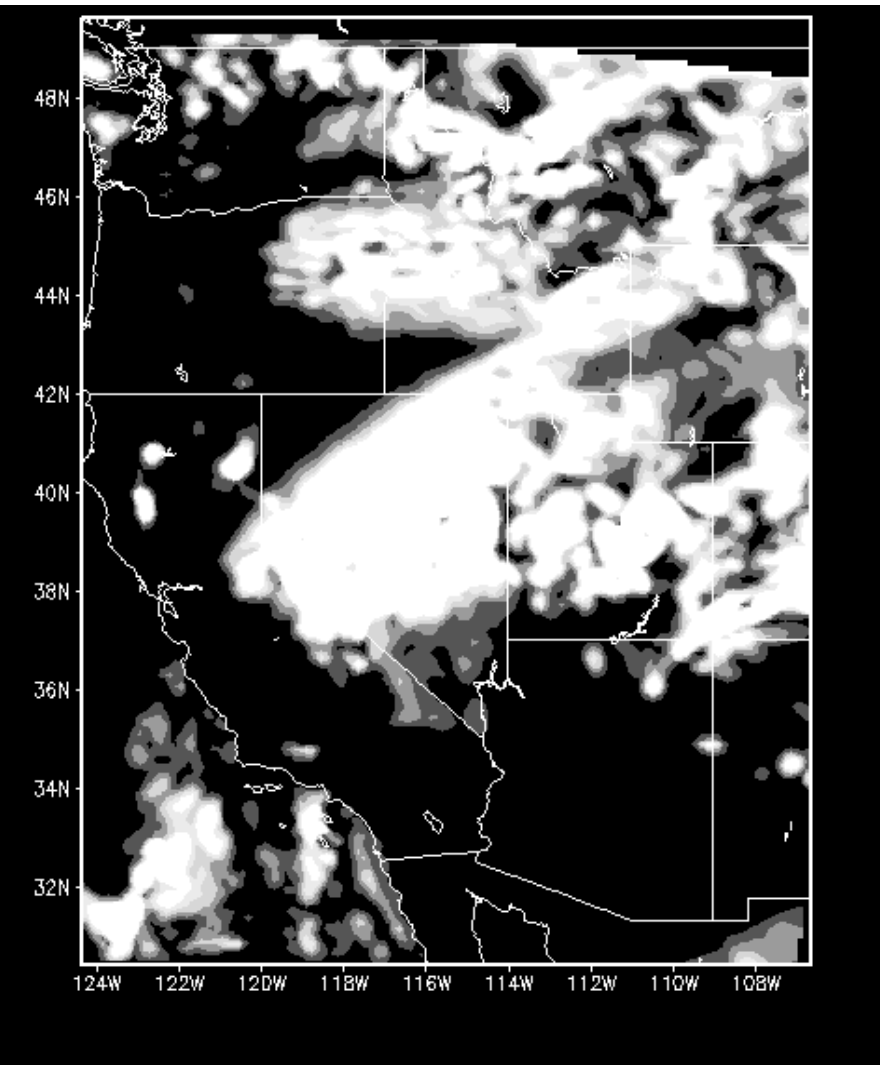


Revised momentum diffusivity

$$K_m = k w_s z \left(1 - \frac{z}{h} \right)^p + k w_{pbl} (h - z) \left(1 - \frac{h - z}{h} \right)^p$$

$$w_{pbl} = w_{pbl}(PBL\ top\ heat\ flux, \ldots)$$

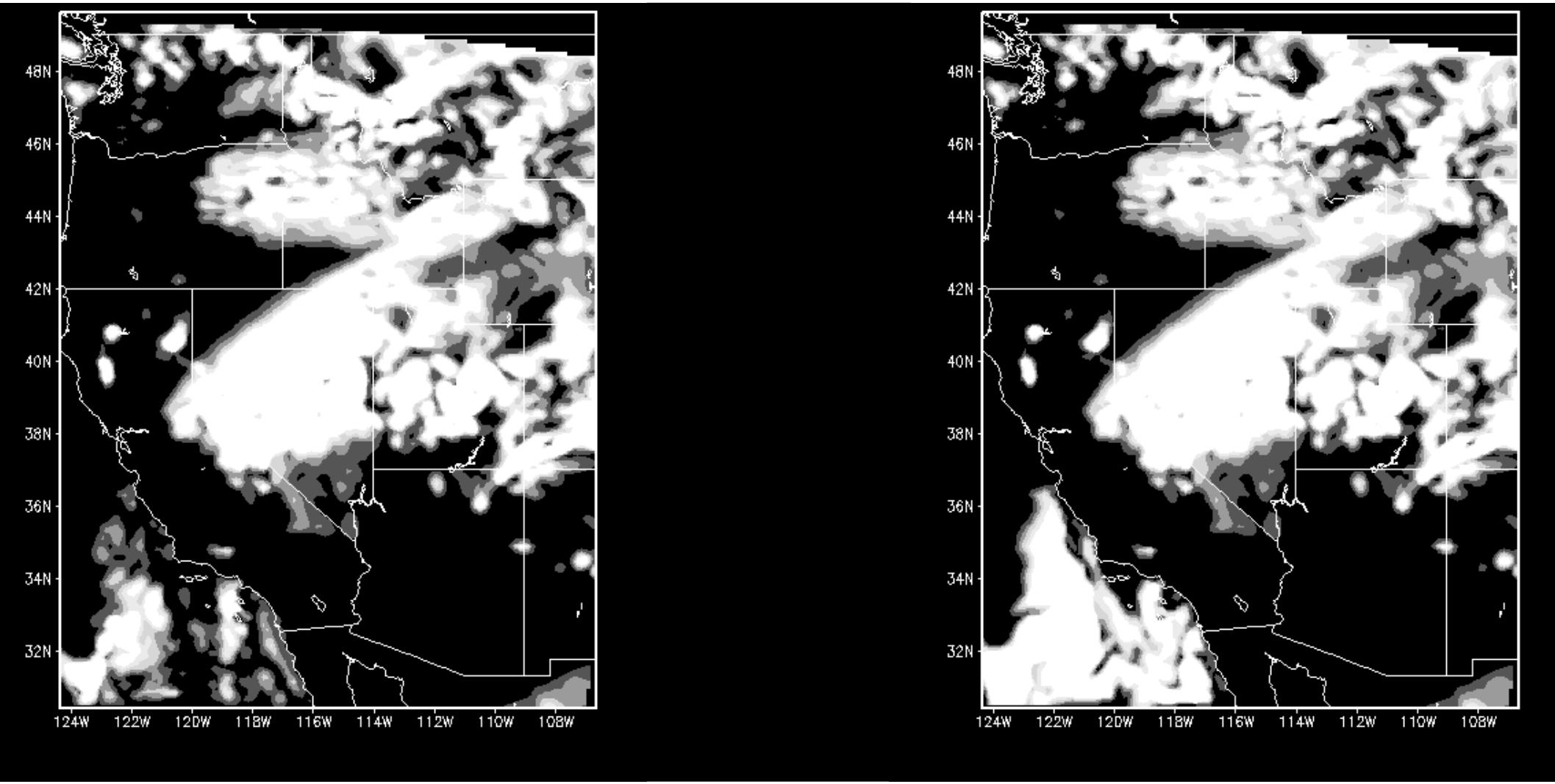
YSU



Total Condensate (white) – 24 hour forecast

YSU

YSU with top down mixing



Total Condensate (white) – 24 hour forecast

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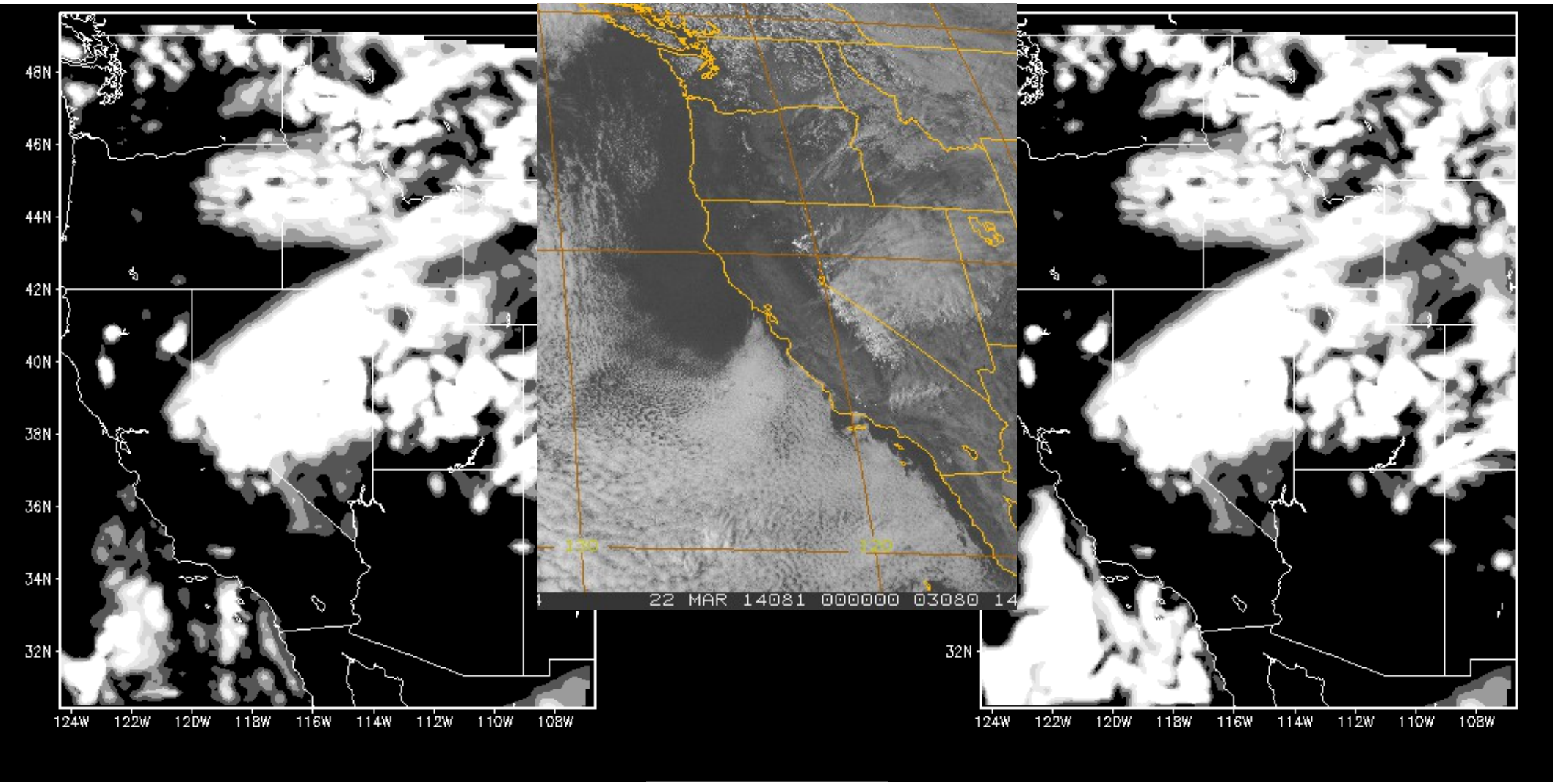

Total Condensate (white) – 24 hour forecast

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right) - \overline{(w'c')}_h\left(\frac{z}{h}\right)^3\right]$$

(1) (2) (3)

$$C = u, v, \theta, q$$

$$h = pbl\ height$$

1) Local term

2) Counter-gradient

3) Entrainment

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c \left(\frac{\partial C}{\partial z} - \gamma_c \right) - \overline{(w' c')}_h \left(\frac{z}{h} \right)^3 \right]$$

(1) (2) (3)

$$C = u, v, \theta, q$$

$$h = pbl\ height$$

1) Local term

2) Counter-gradient

3) Entrainment

$$\overline{(w'\theta')}_h = -0.15 \left(\frac{\theta_v}{g} \right) \frac{w_m^3}{h}$$

$$w_m = w_m(sfc.\ heat\ flux, \ldots)$$

Entrainment is a function of the surface flux.

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right) - \overline{(w'c')}_h\left(\frac{z}{h}\right)^3\right]$$

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$$C = u, v, \theta, q$$

$$h = pbl\ height$$

1) Local term

2) Counter-gradient

3) Entrainment

$$\overline{(w'\theta')}_h = -0.15\left(\frac{\theta_v}{g}\right)\frac{w_m^3}{h}$$

$$w_m = w_m(sfc.\ heat\ flux, \ldots)$$

Entrainment is a function of the surface flux.

$$\overline{(w'\theta')}_h = -0.15\left(\frac{\theta_v}{g}\right)\frac{w_m^3}{h} - 0.3\left(\frac{\theta_v}{g}\right)\frac{w_l^3}{h}$$

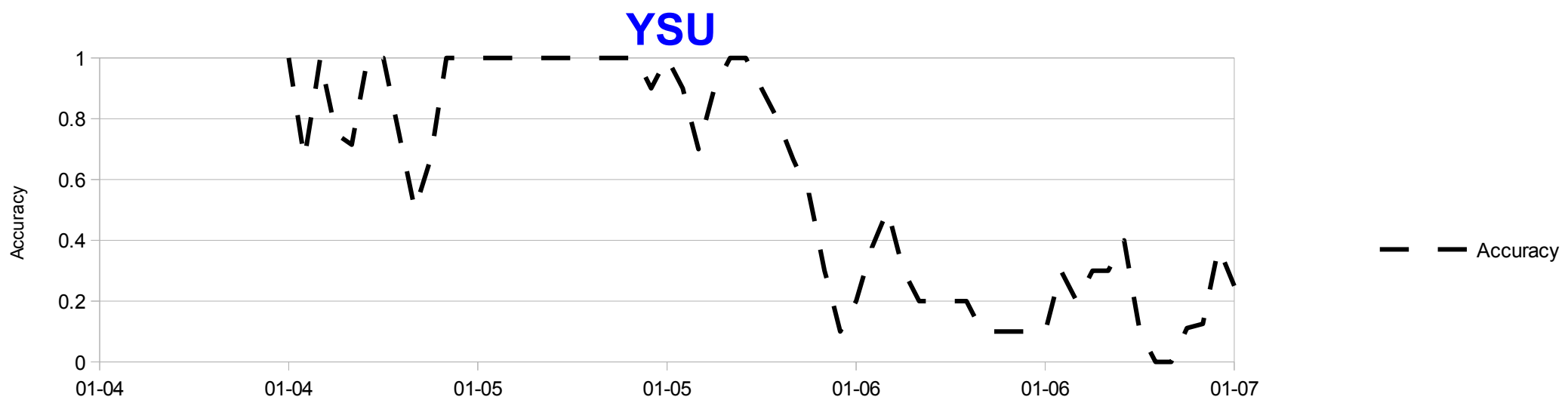
$$w_l = w_l(PBL\ top\ heat\ flux, \ldots)$$

Entrainment now includes the PBL top flux.

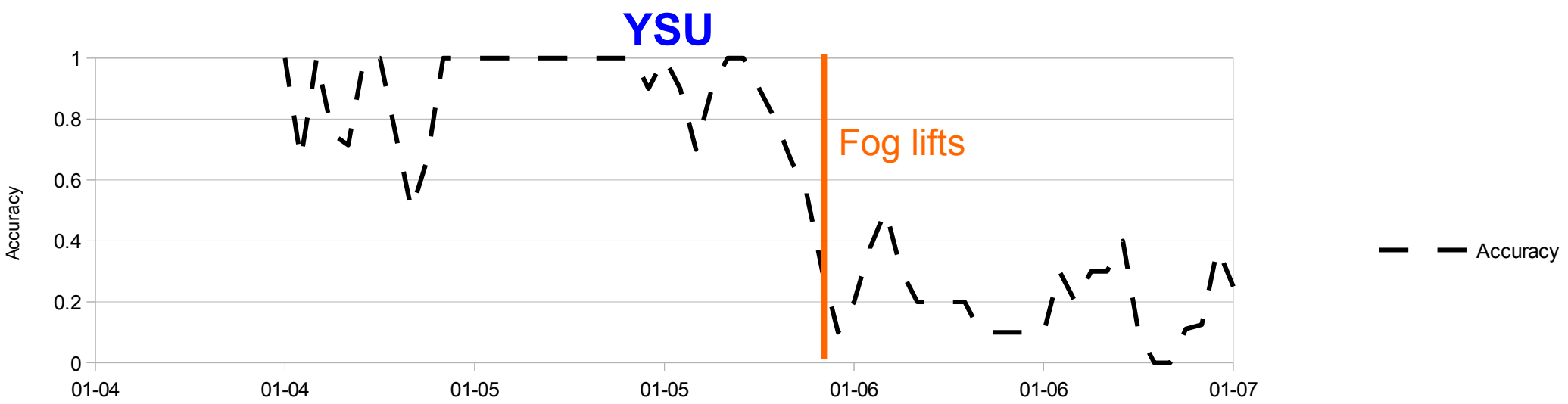
Revised Entrainment

Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

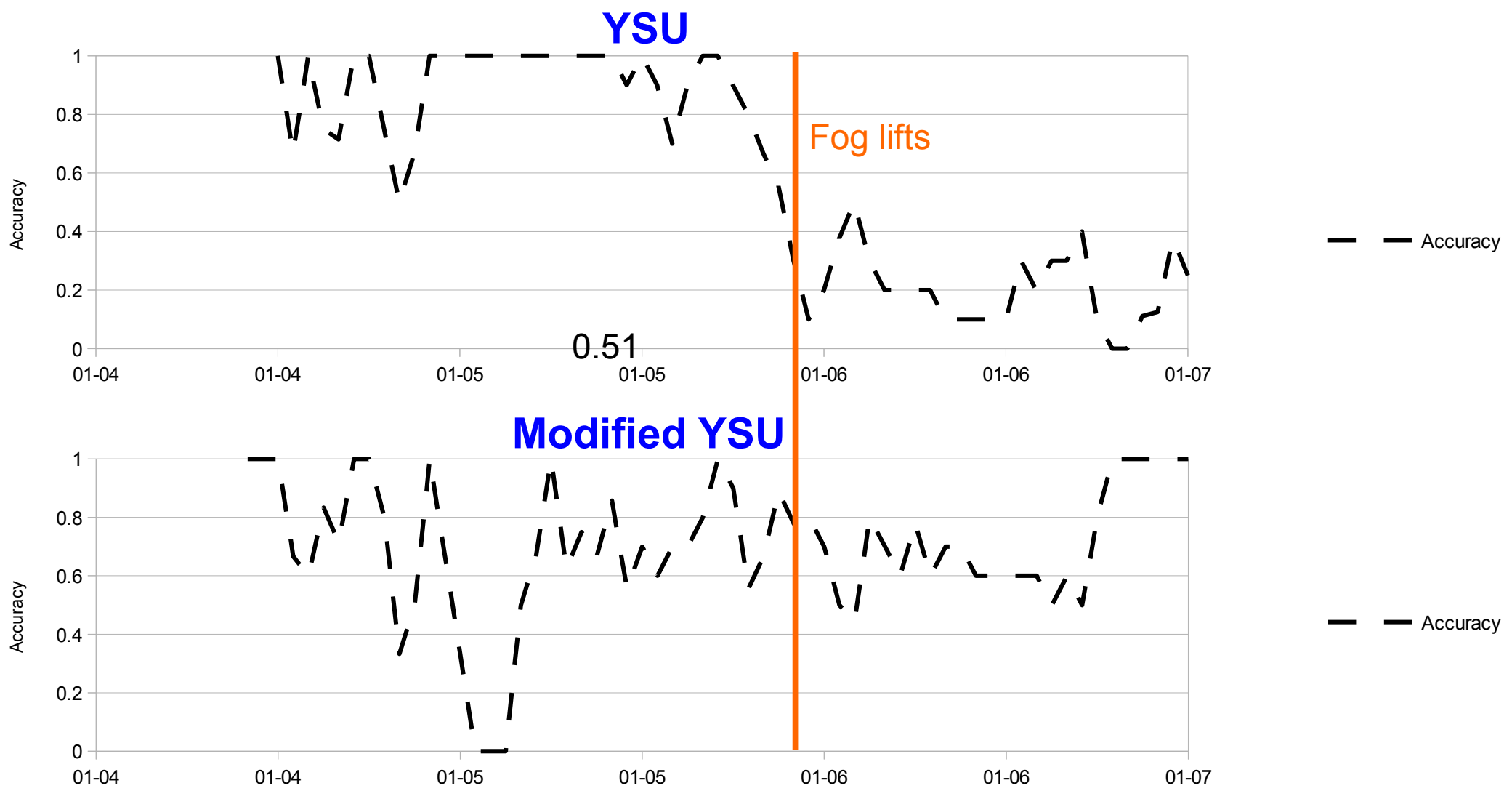
Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m



Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

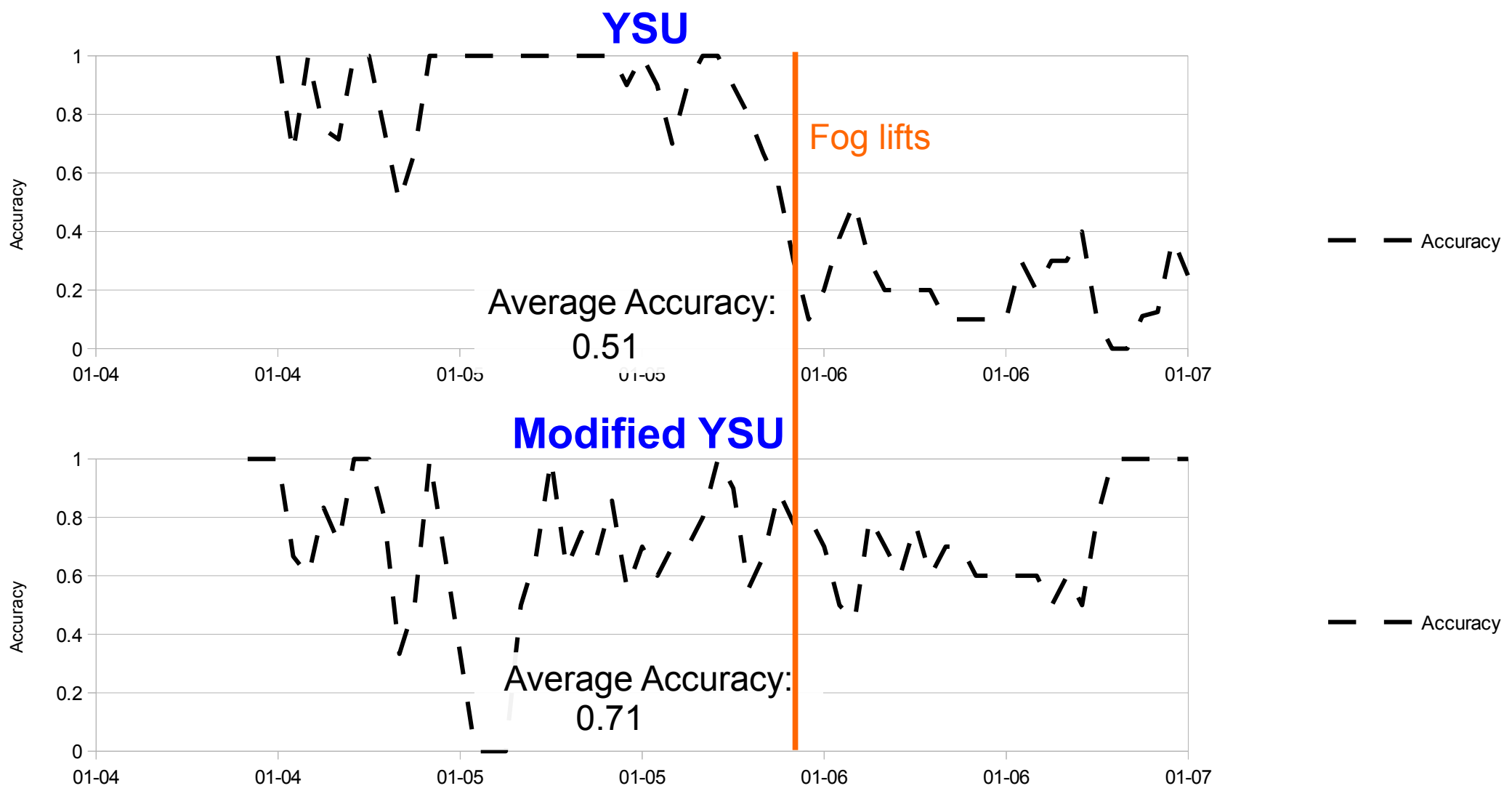


Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m



Fog vs. stratus accuracy - San Joaquin Subset

Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m



Fog vs. stratus accuracy - San Joaquin Subset

Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

	YSU	Modified YSU	MYJ
Jan 4-7th 2011 (72 hours)	0.51	0.71	
Jan 13-16th 2011 (72 hours)			
Dec. 29 – 2nd 2008/09 (84 hours)			

Fog vs. stratus accuracy - San Joaquin Subset

Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

	YSU	Modified YSU	MYJ
	Improvement		
Jan 4-7th 2011 (72 hours)	0.51 --39%-->	0.71	
Jan 13-16th 2011 (72 hours)			
Dec. 29 – 2nd 2008/09 (84 hours)			

Fog vs. stratus accuracy - San Joaquin Subset

Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

	YSU	Modified YSU	MYJ
	Improvement		
Jan 4-7th 2011 (72 hours)	0.51 --39%-->	0.71	0.46
Jan 13-16th 2011 (72 hours)			
Dec. 29 – 2nd 2008/09 (84 hours)			

Fog vs. stratus accuracy - San Joaquin Subset

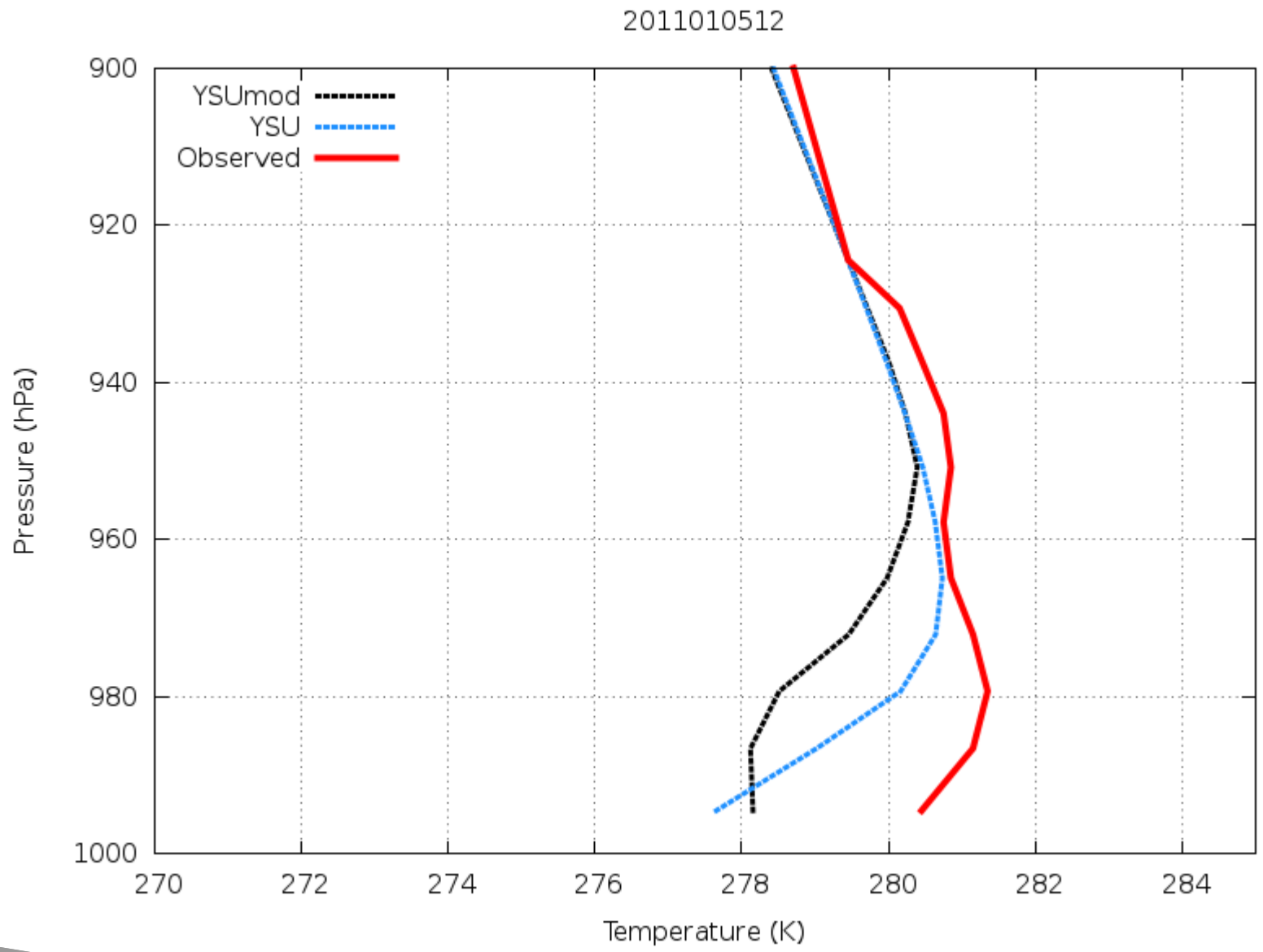
Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

	YSU		Modified YSU	MYJ
		Improvement		
Jan 4-7th 2011 (72 hours)	0.51	--39%-->	0.71	0.46
Jan 13-16th 2011 (72 hours)	0.51	--67%-->	0.85	0.69
Dec. 29 – 2nd 2008/09 (84 hours)				

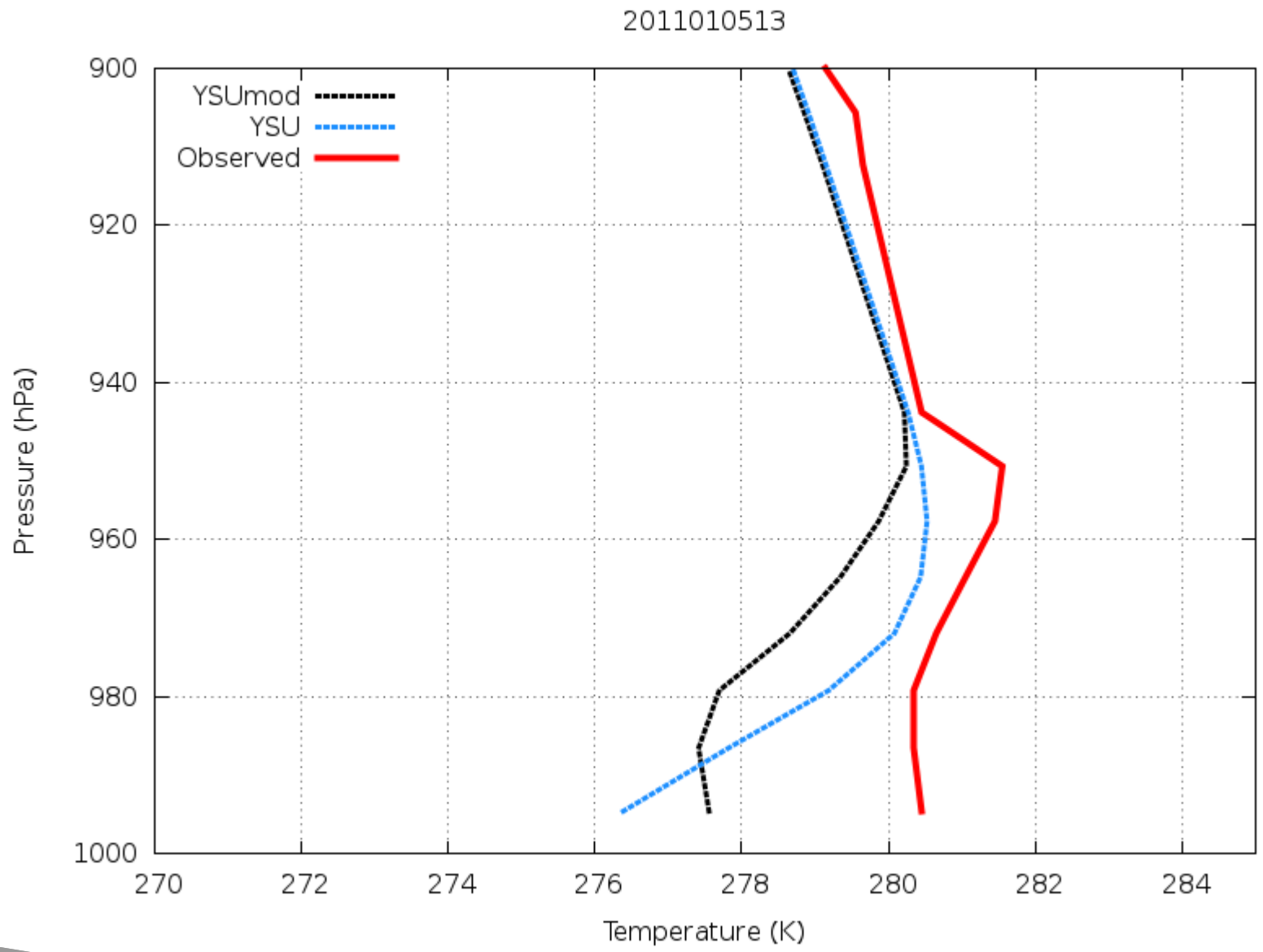
Conditional: forecast and observations have ceilings < 1000m
Category threshold: ceilings < 31m

	YSU		Modified YSU	MYJ
		Improvement		
Jan 4-7th 2011 (72 hours)	0.51	--39%-->	0.71	0.46
Jan 13-16th 2011 (72 hours)	0.51	--67%-->	0.85	0.69
Dec. 29 – 2nd 2008/09 (84 hours)	0.38	--84%-->	0.70	0.64

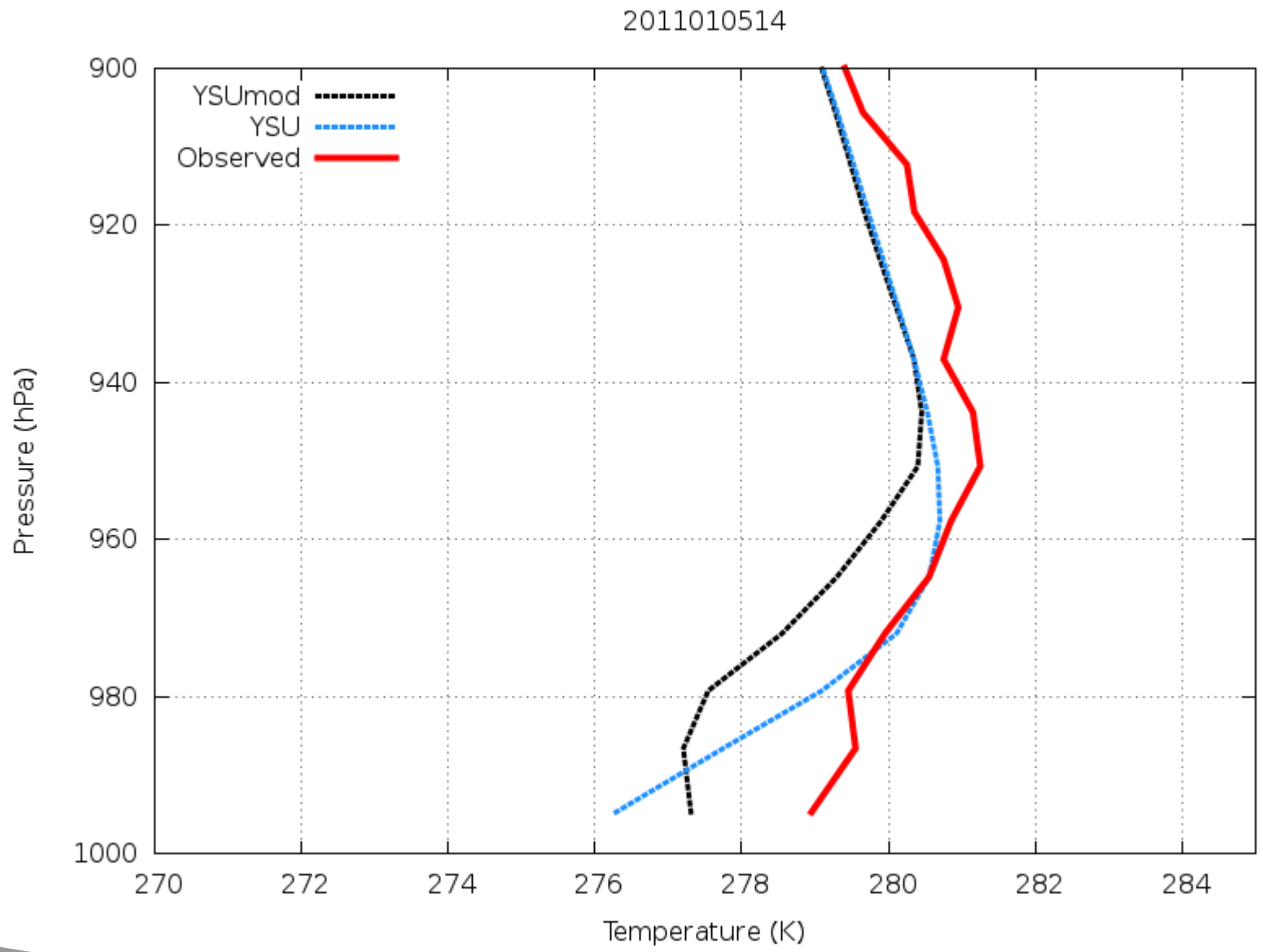
Fog vs. stratus accuracy - San Joaquin Subset



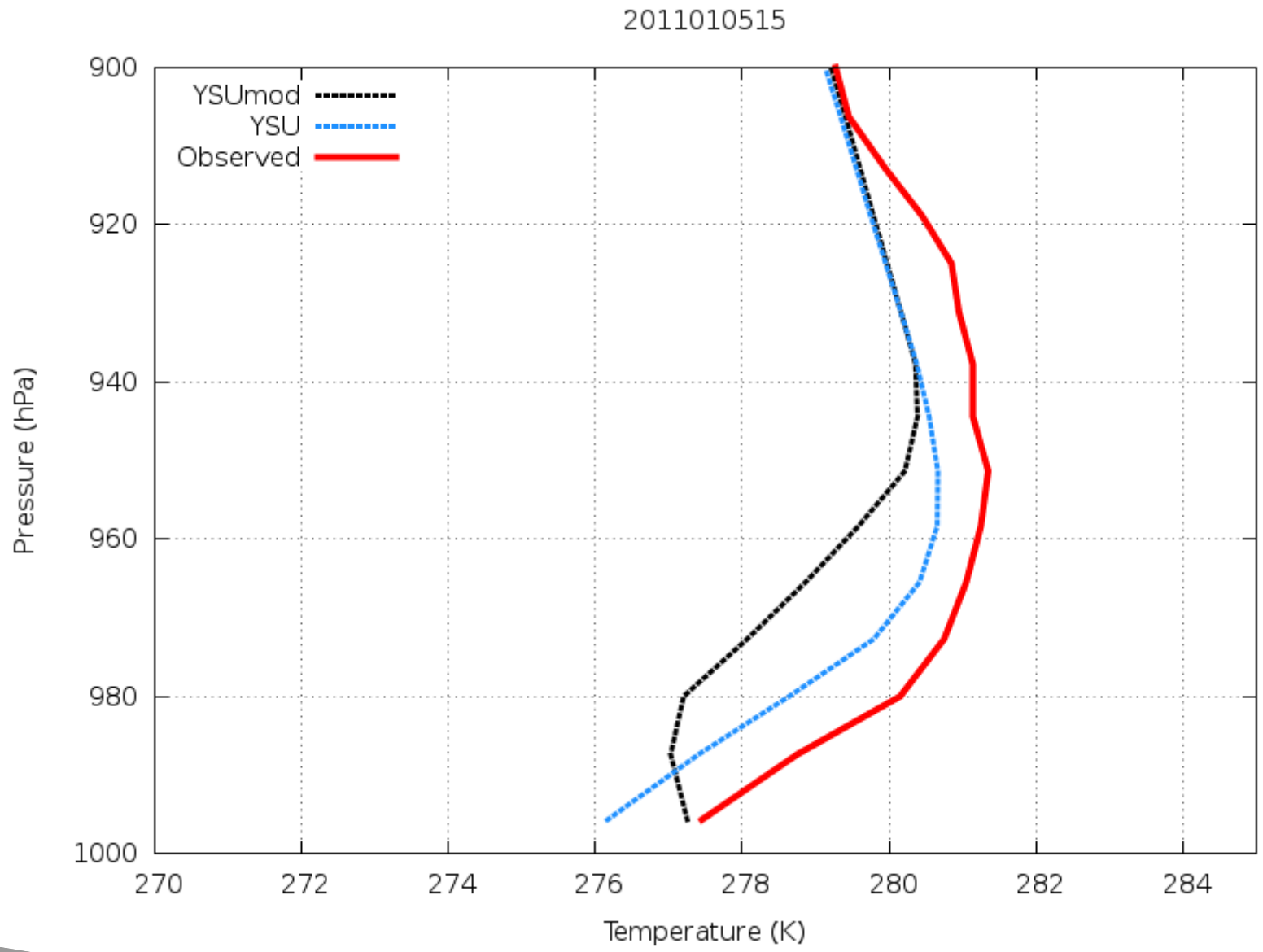
Virtual Temperature – CCLCA (Chowchilla, CA)



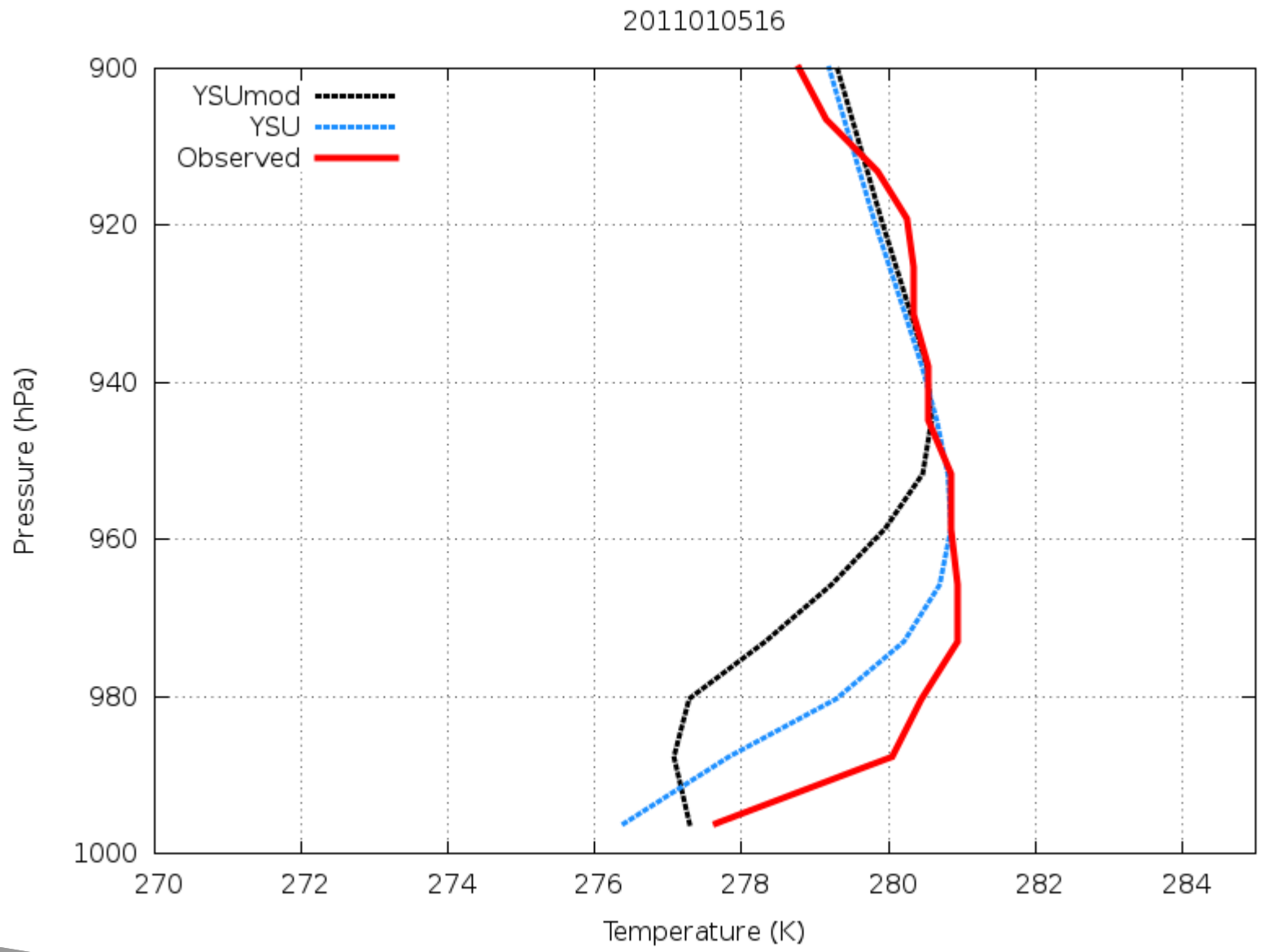
Virtual Temperature – CCLCA (Chowchilla, CA)



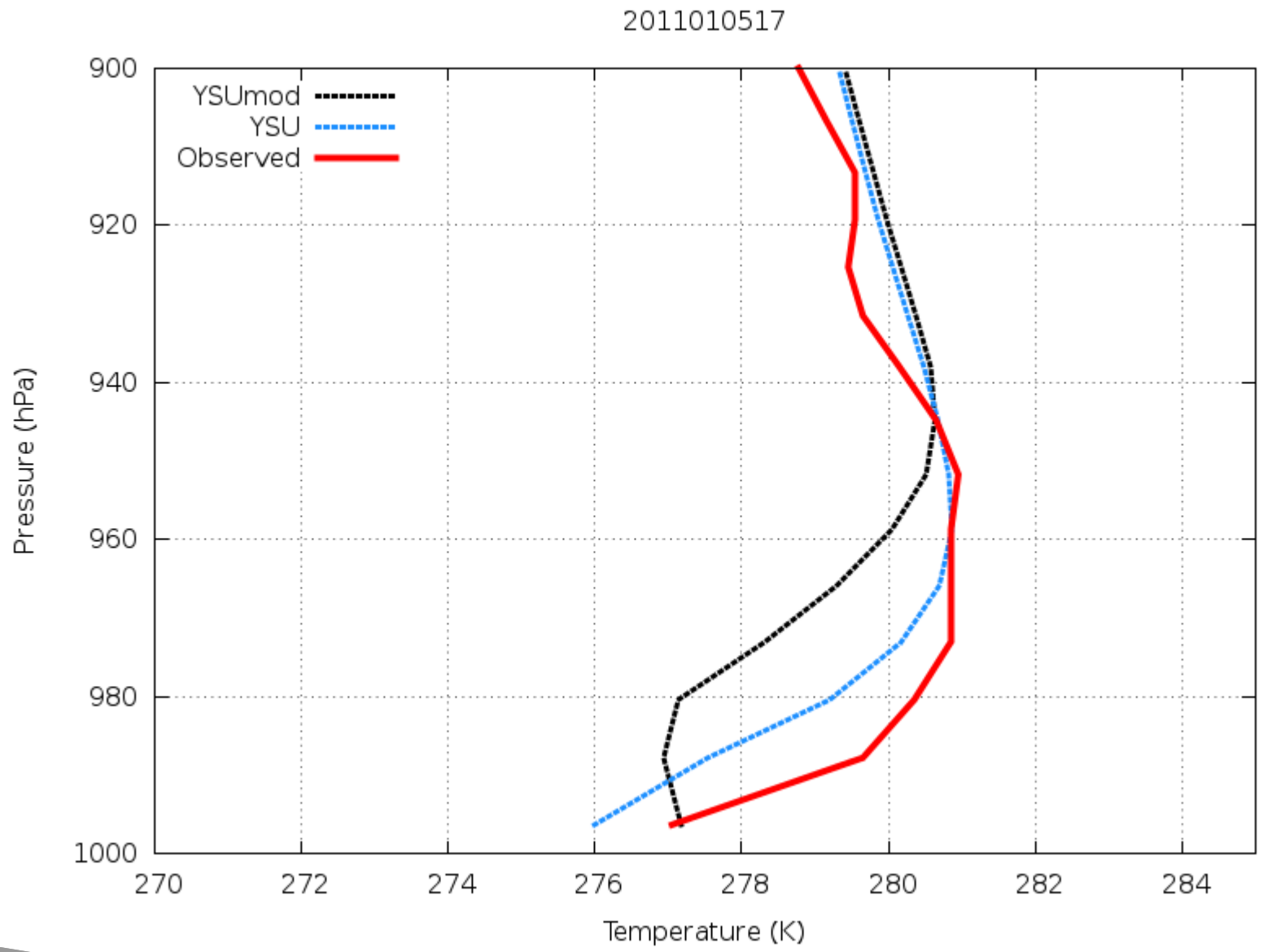
Virtual Temperature – CCLCA (Chowchilla, CA)



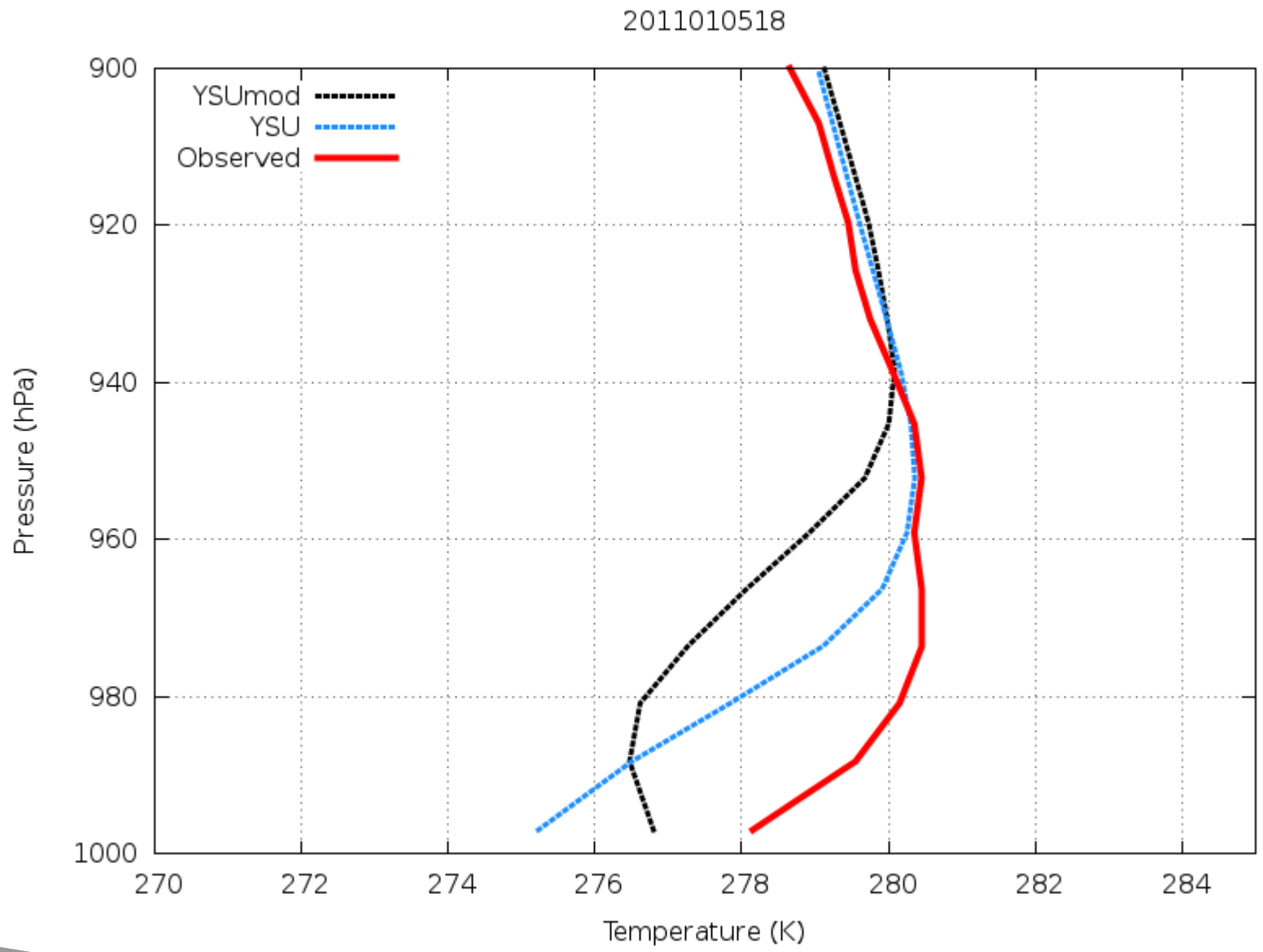
Virtual Temperature – CCLCA (Chowchilla, CA)



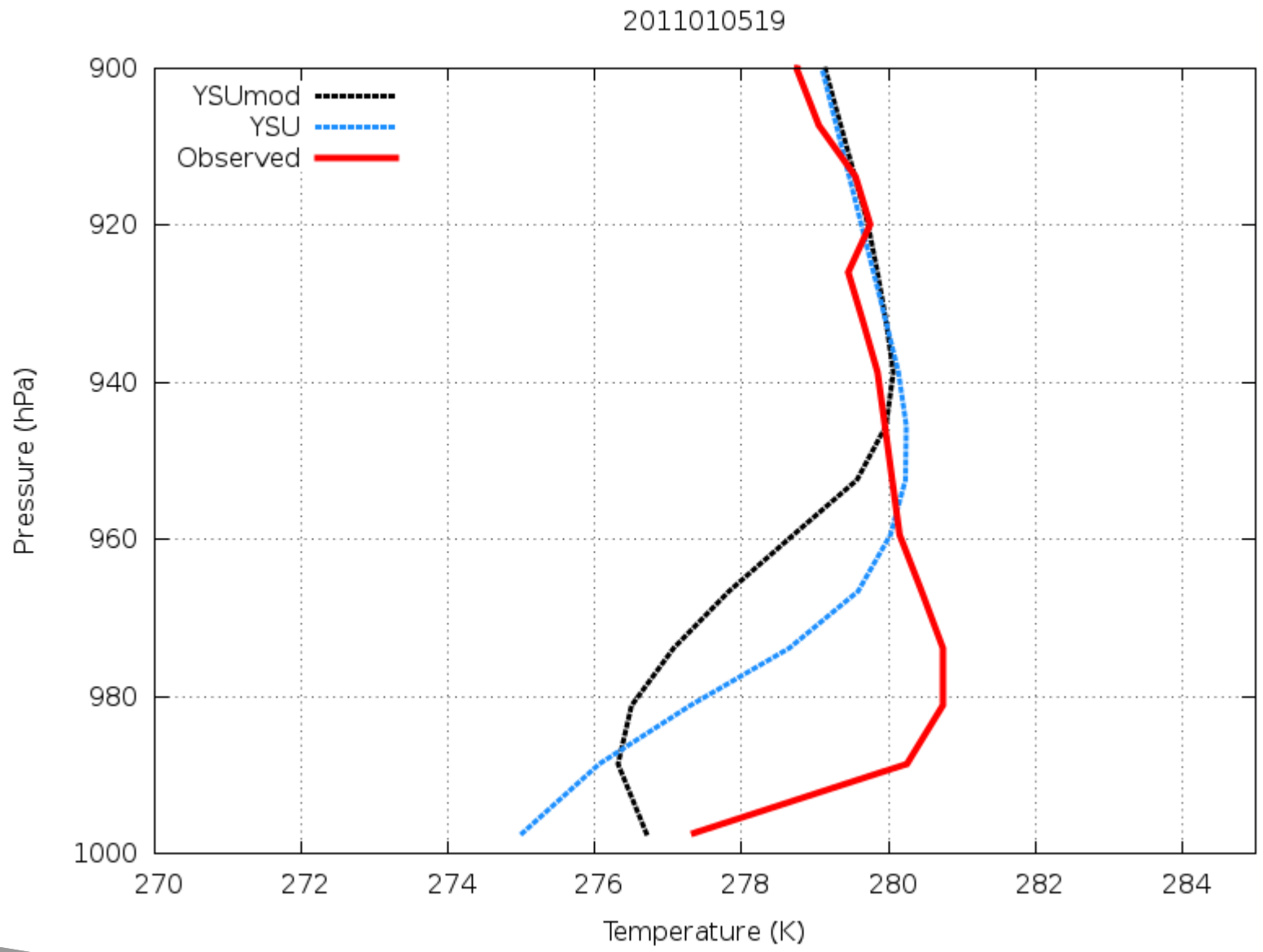
Virtual Temperature – CCLCA (Chowchilla, CA)



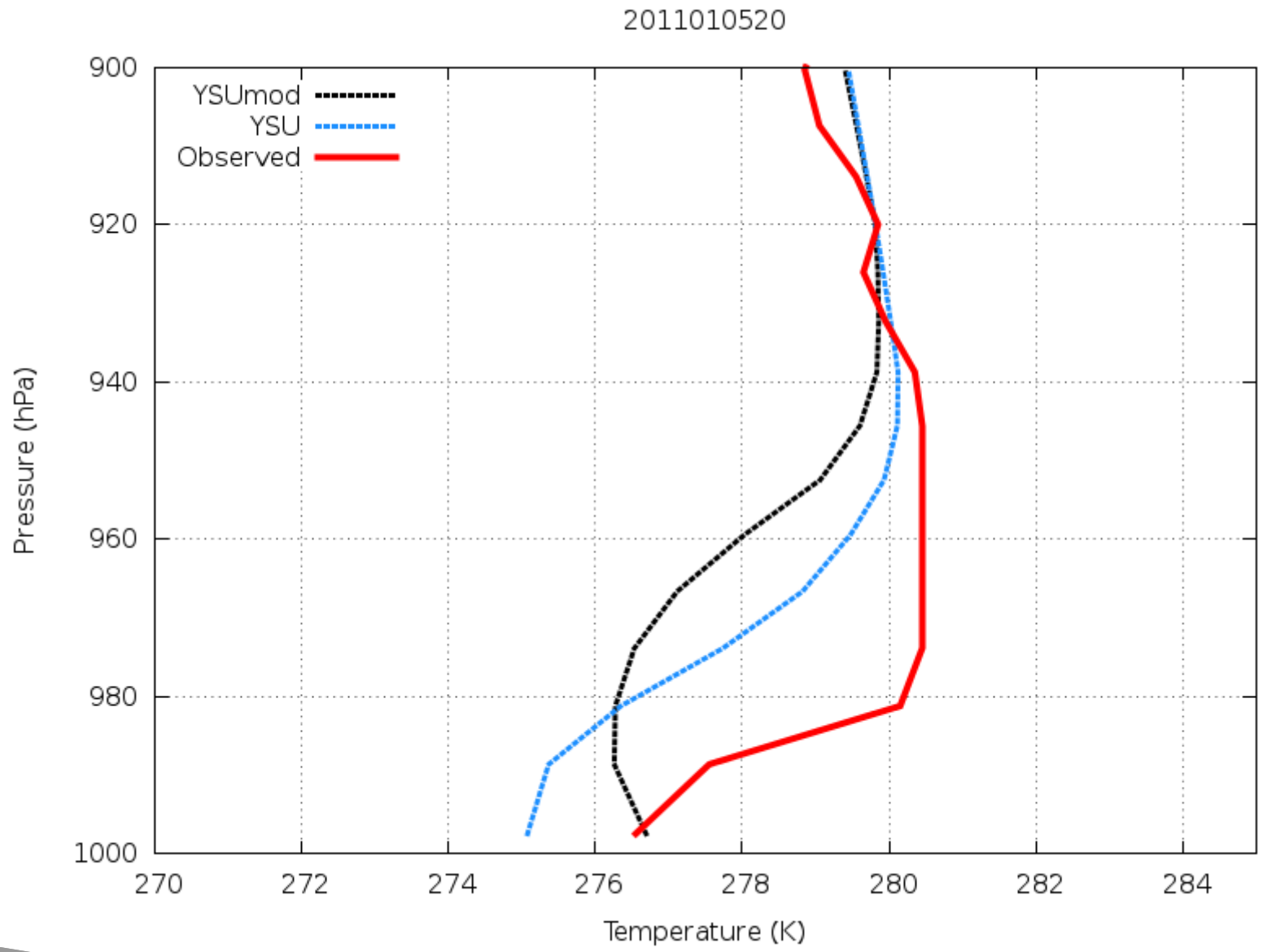
Virtual Temperature – CCLCA (Chowchilla, CA)



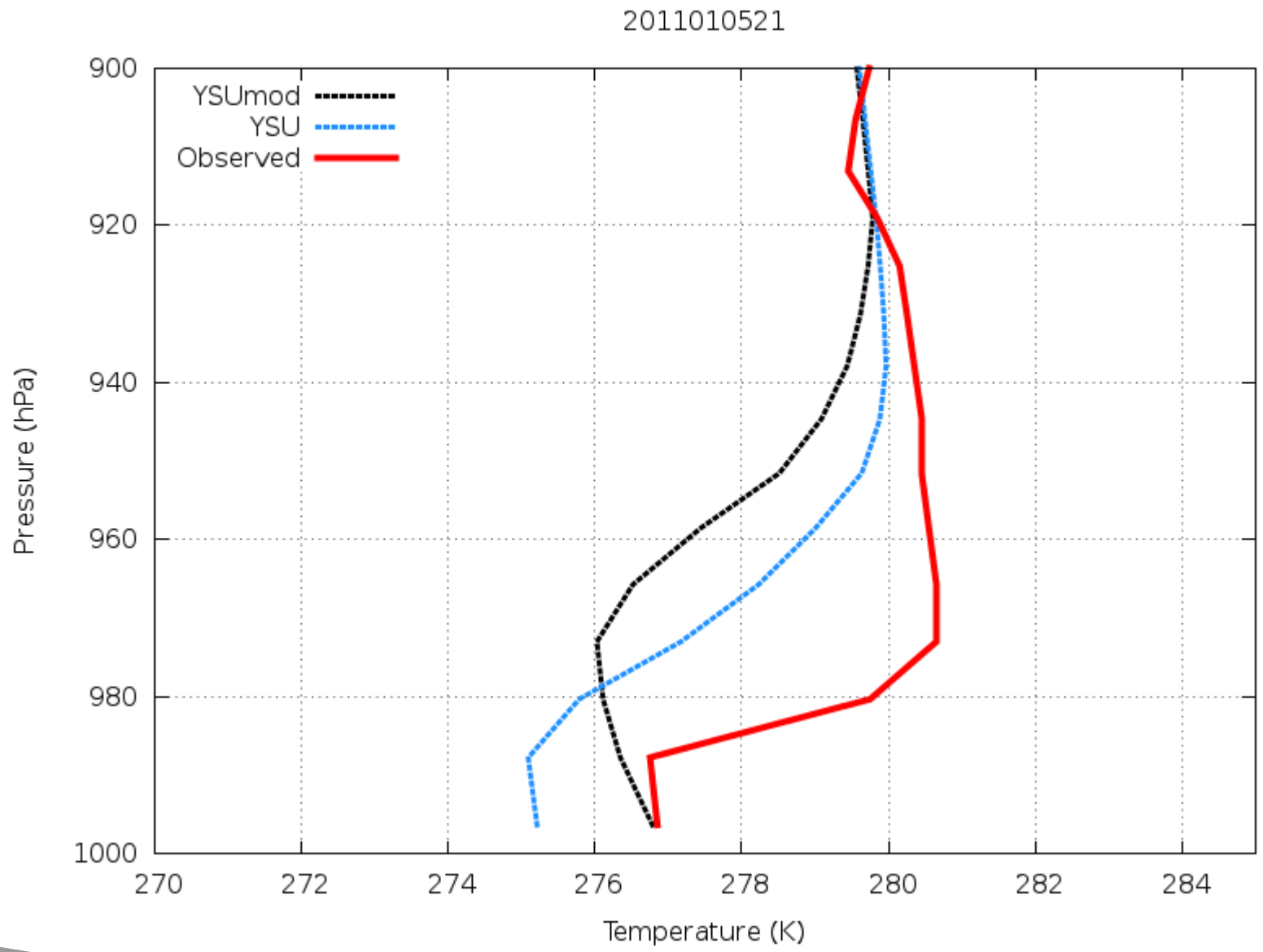
Virtual Temperature – CCLCA (Chowchilla, CA)



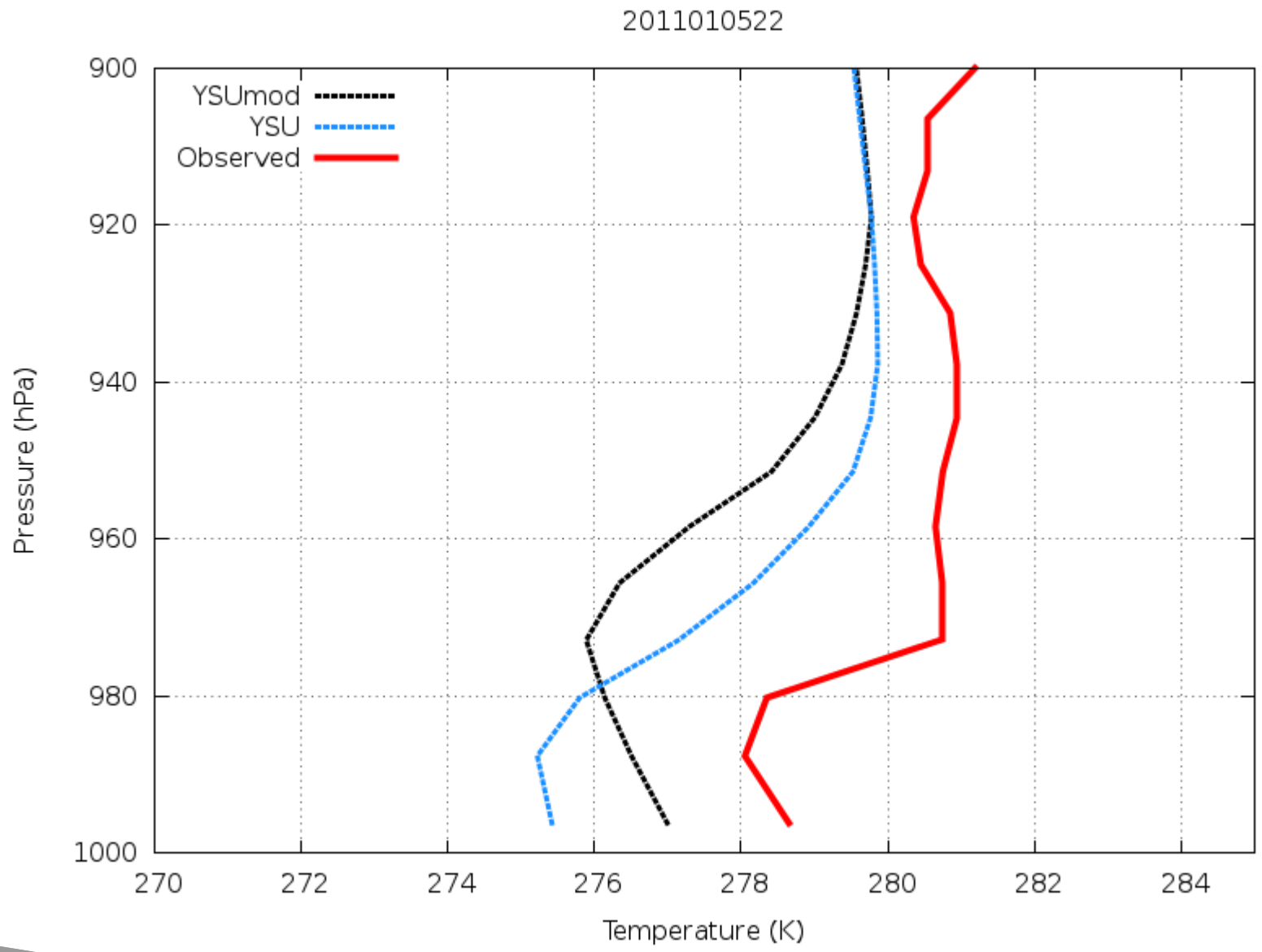
Virtual Temperature – CCLCA (Chowchilla, CA)



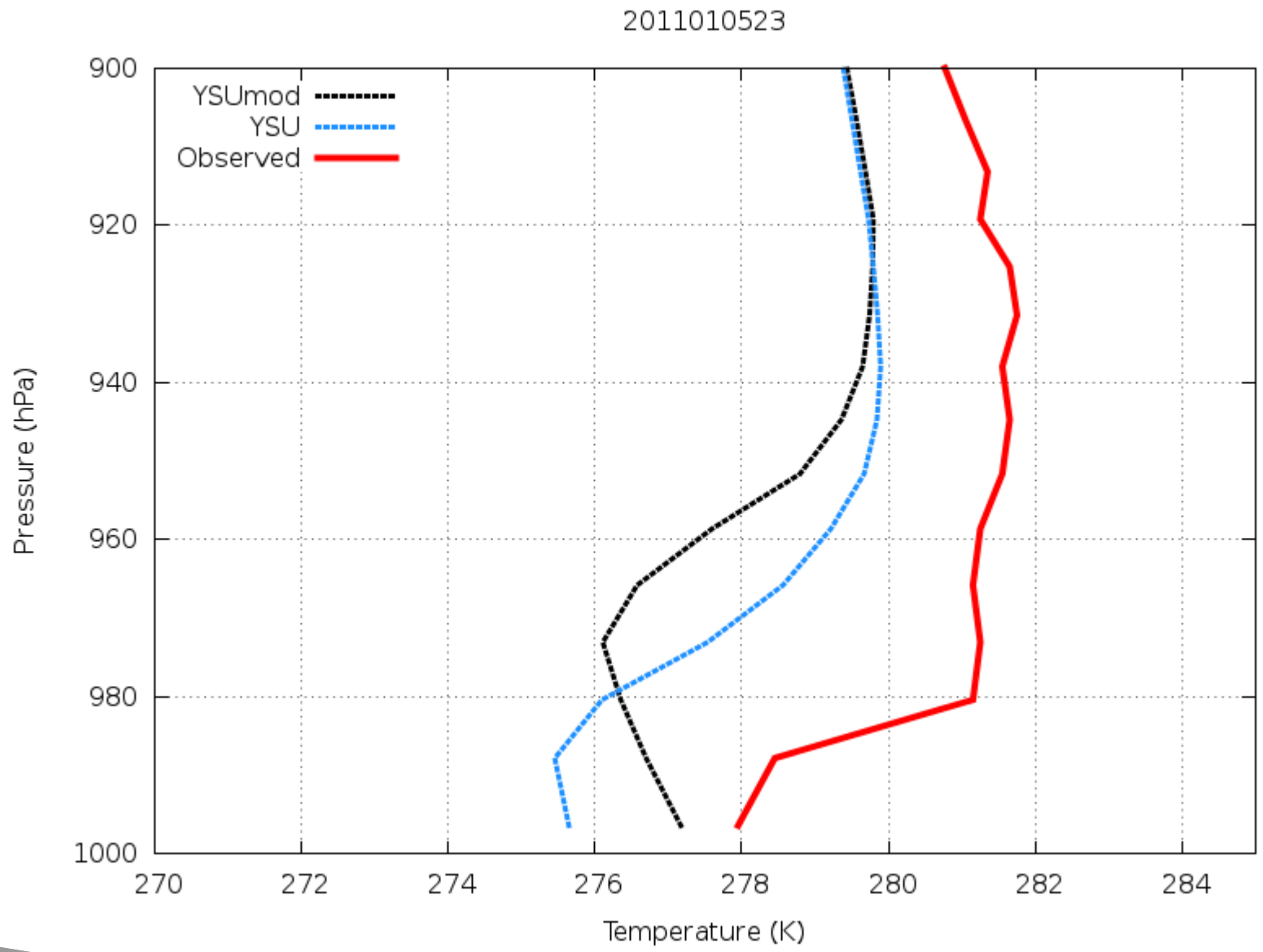
Virtual Temperature – CCLCA (Chowchilla, CA)



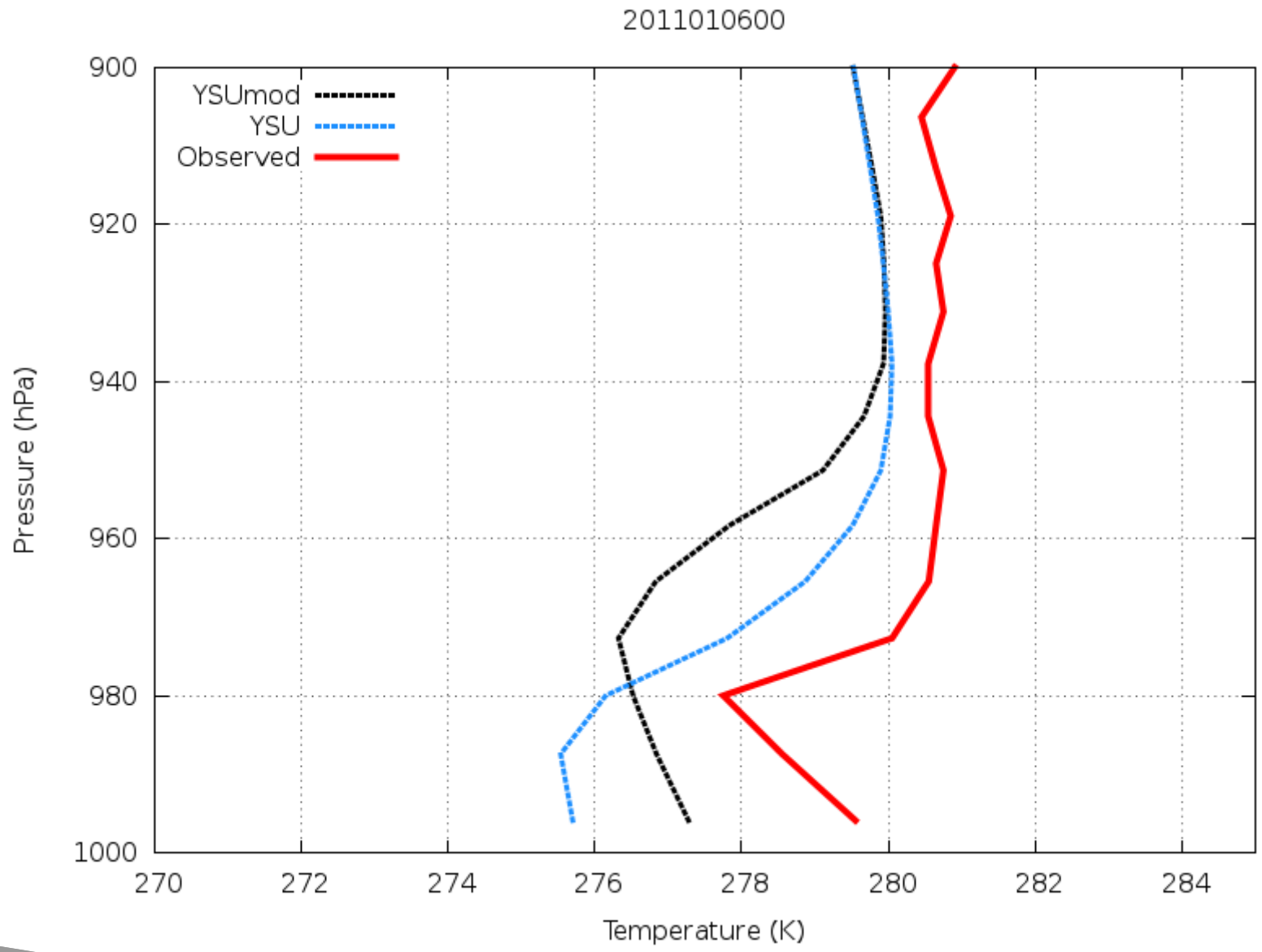
Virtual Temperature – CCLCA (Chowchilla, CA)



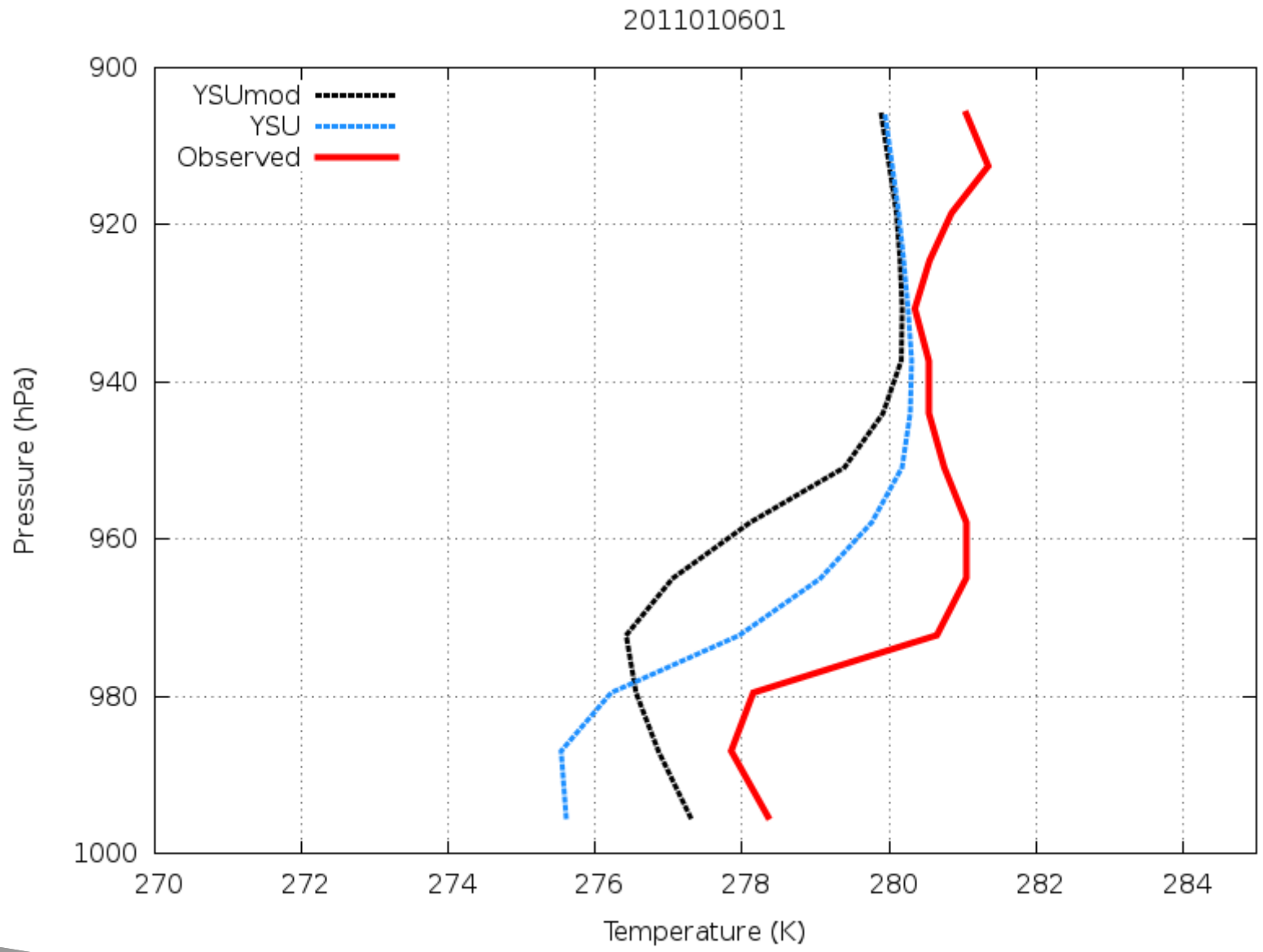
Virtual Temperature – CCLCA (Chowchilla, CA)



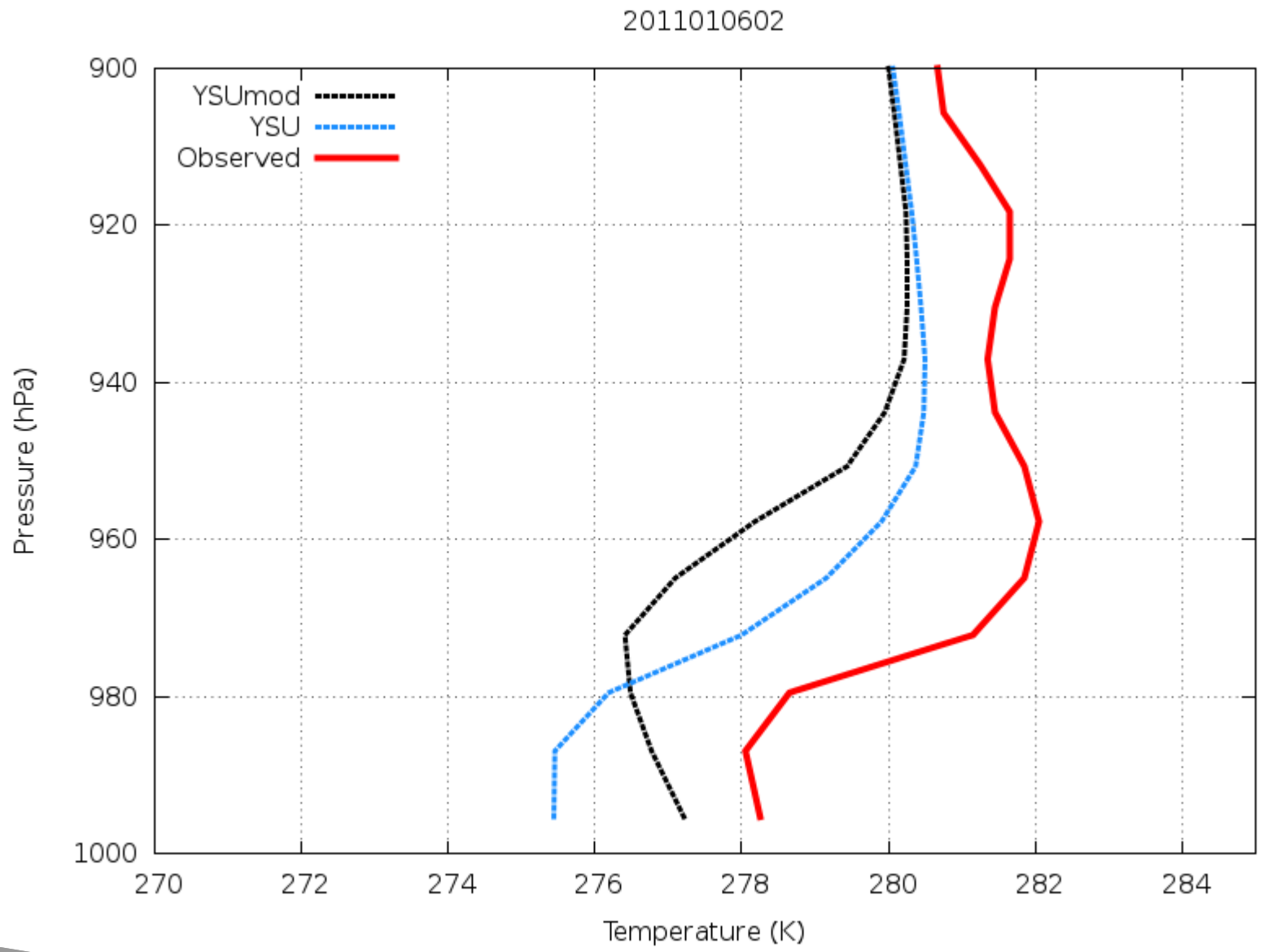
Virtual Temperature – CCLCA (Chowchilla, CA)



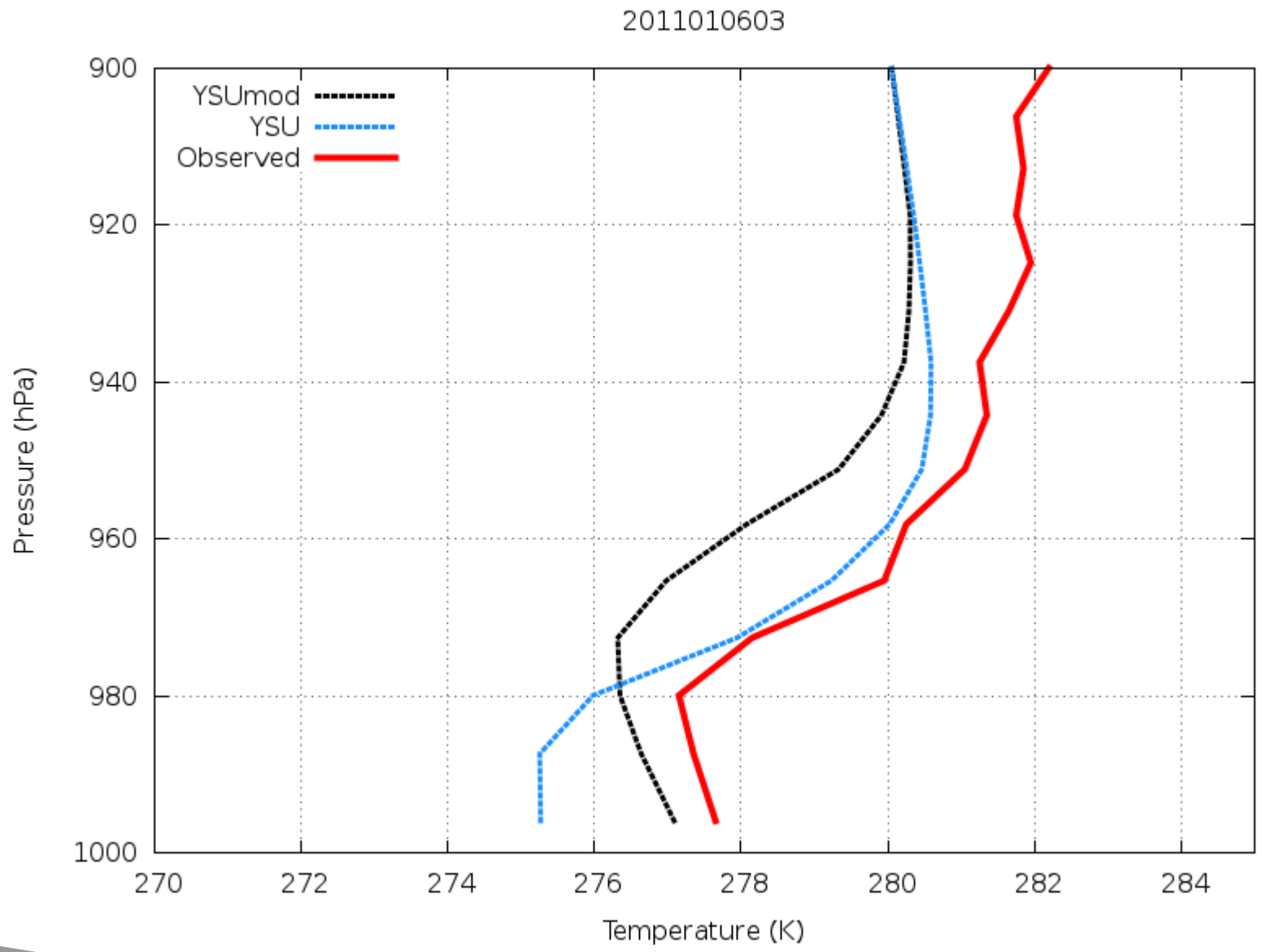
Virtual Temperature – CCLCA (Chowchilla, CA)



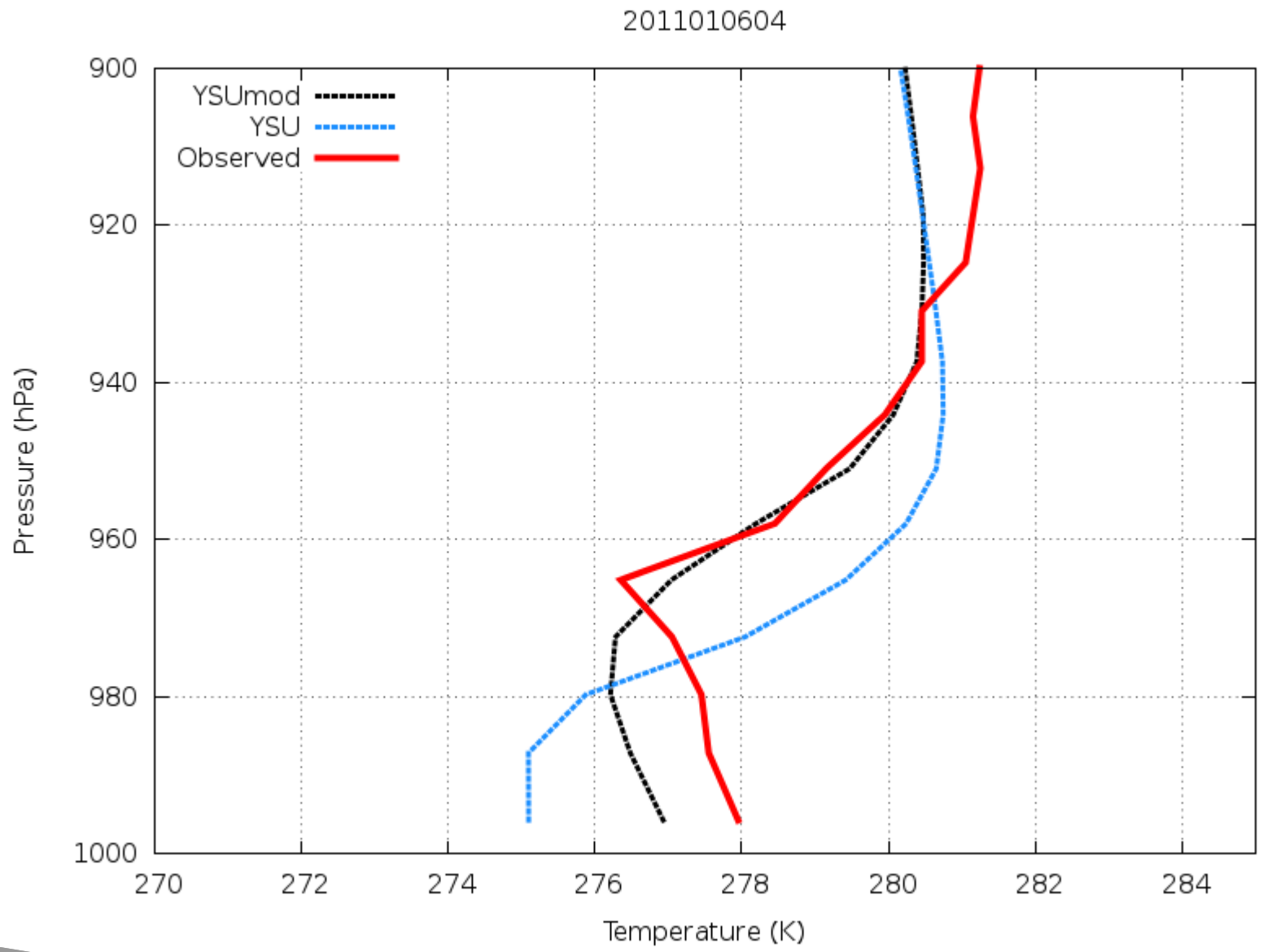
Virtual Temperature – CCLCA (Chowchilla, CA)



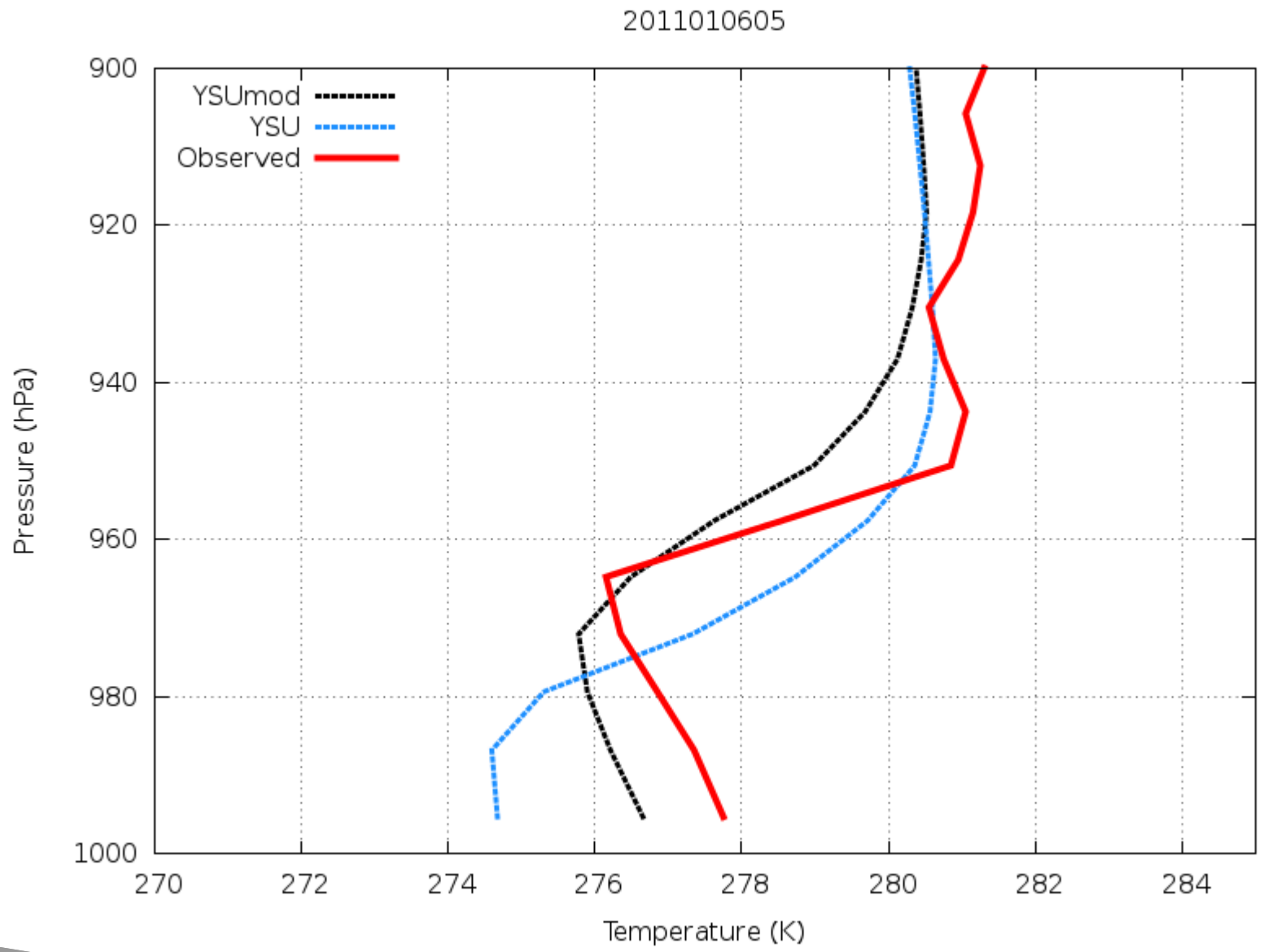
Virtual Temperature – CCLCA (Chowchilla, CA)



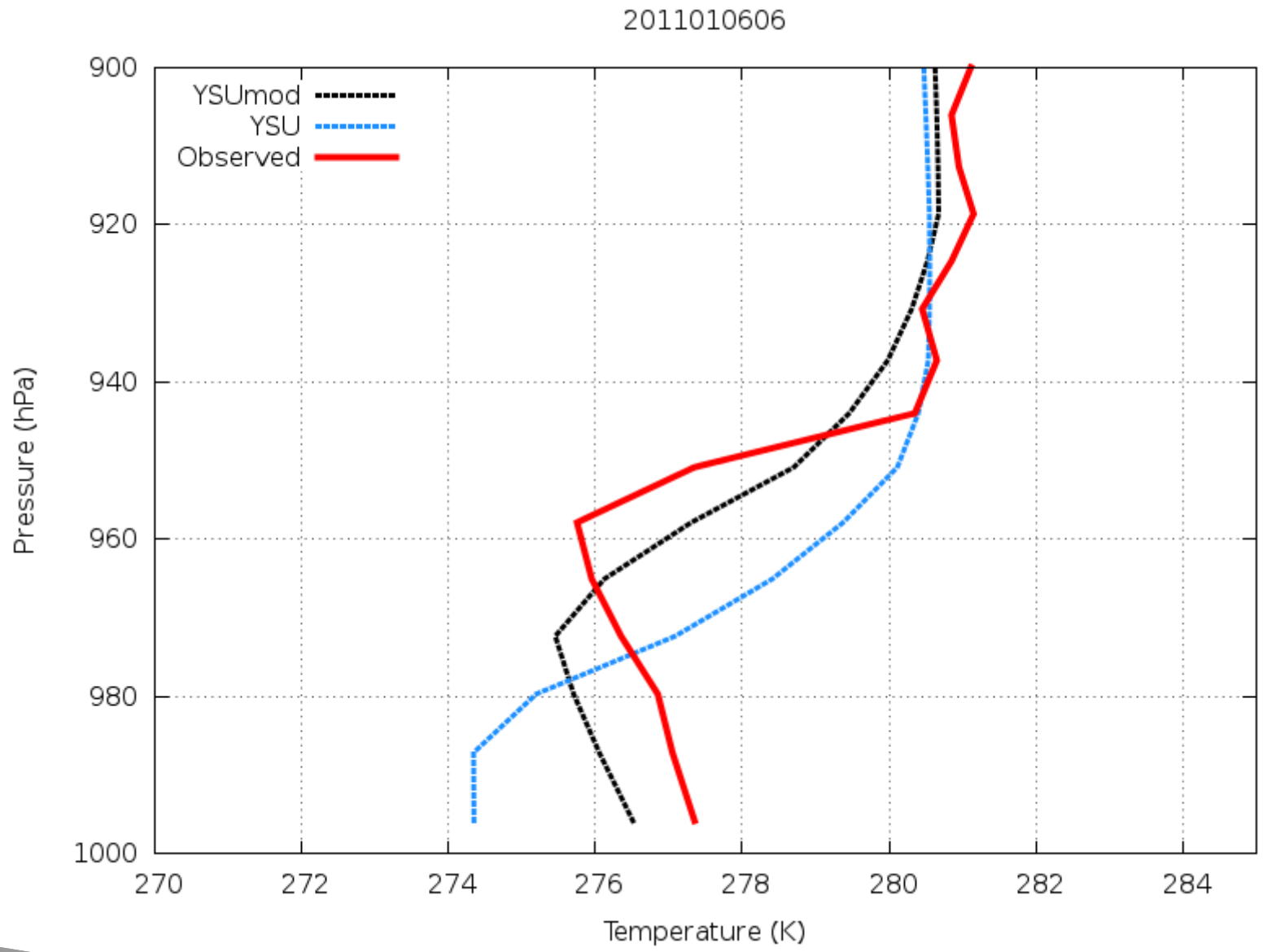
Virtual Temperature – CCLCA (Chowchilla, CA)



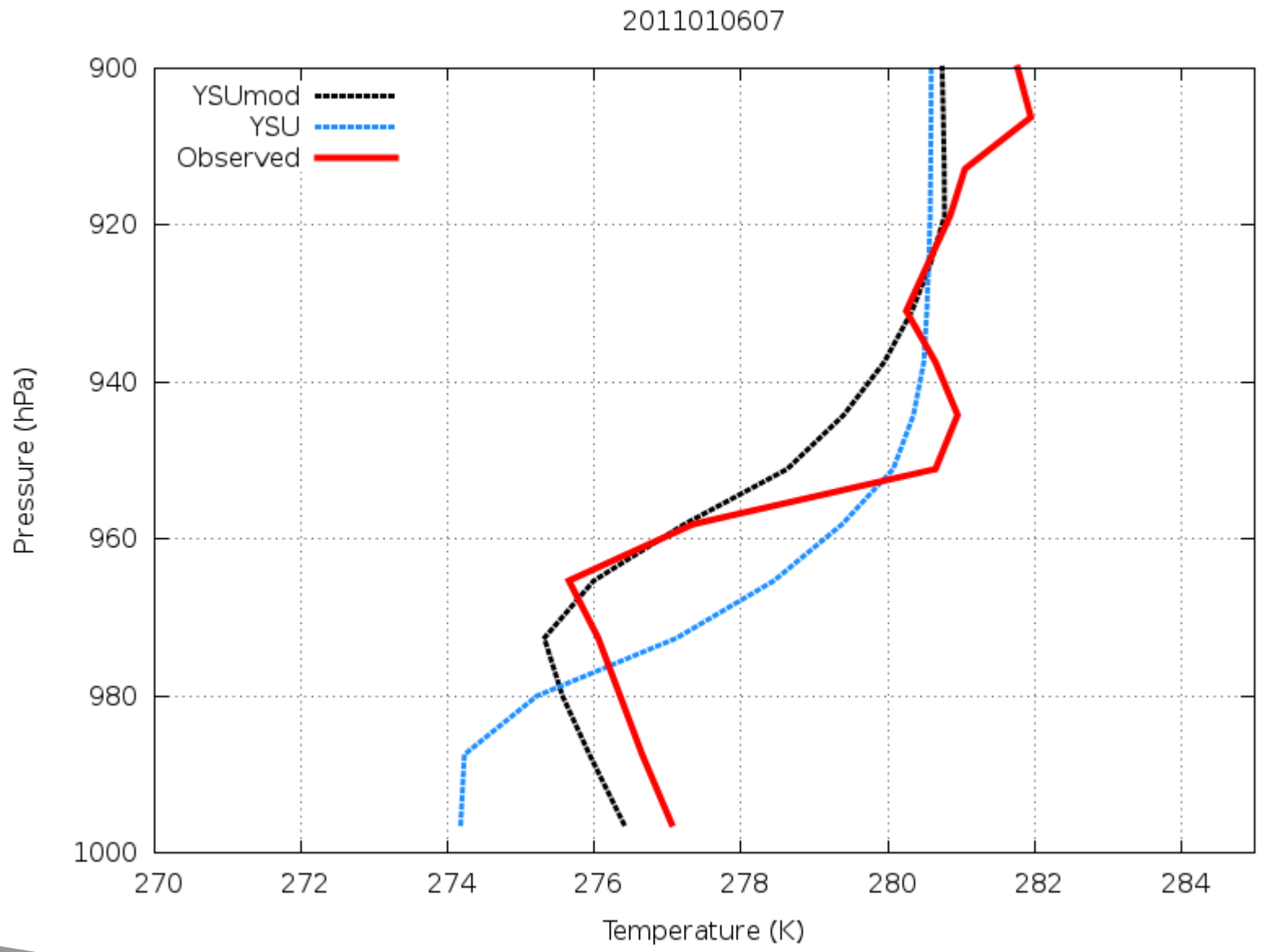
Virtual Temperature – CCLCA (Chowchilla, CA)



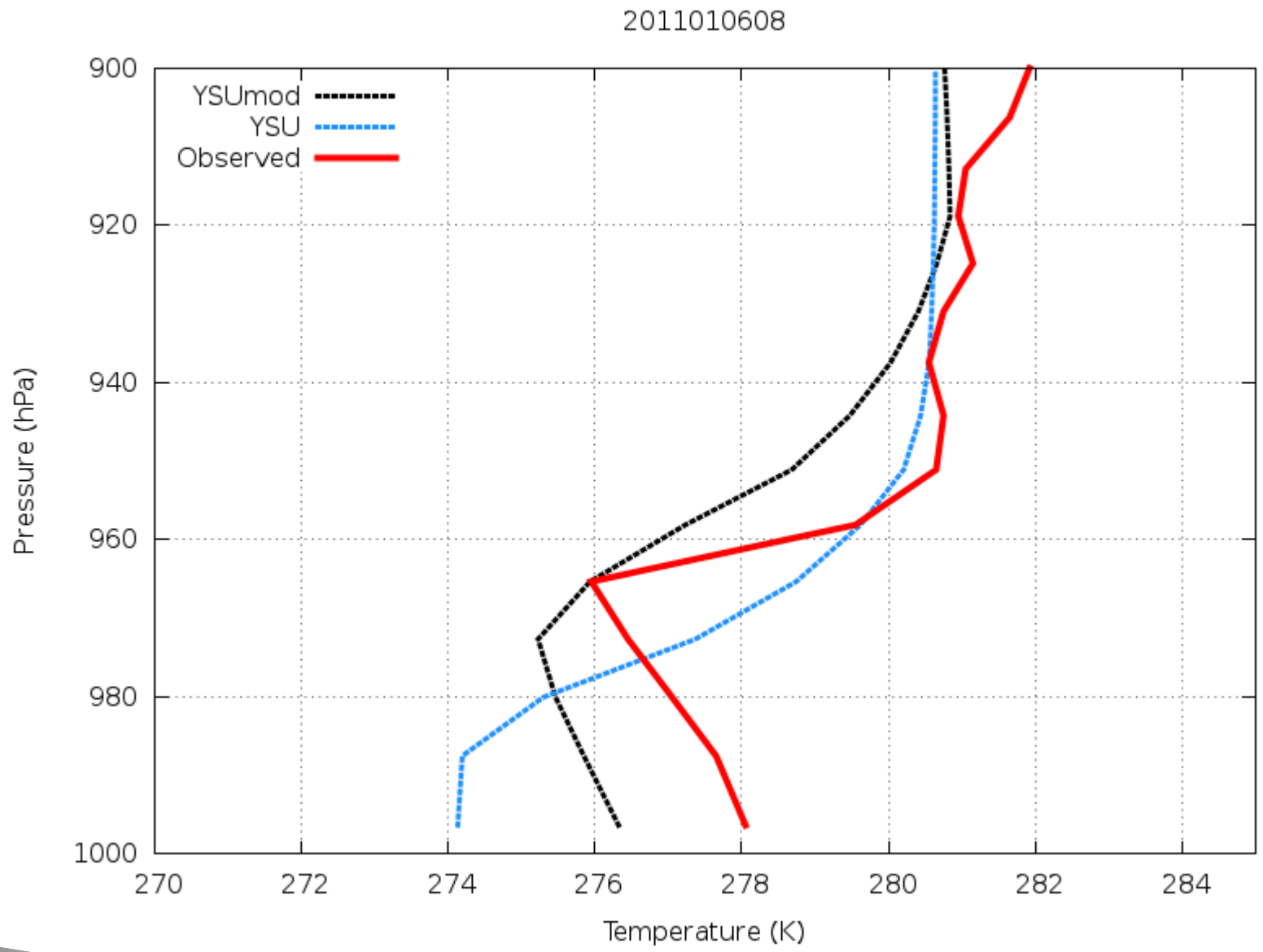
Virtual Temperature – CCLCA (Chowchilla, CA)



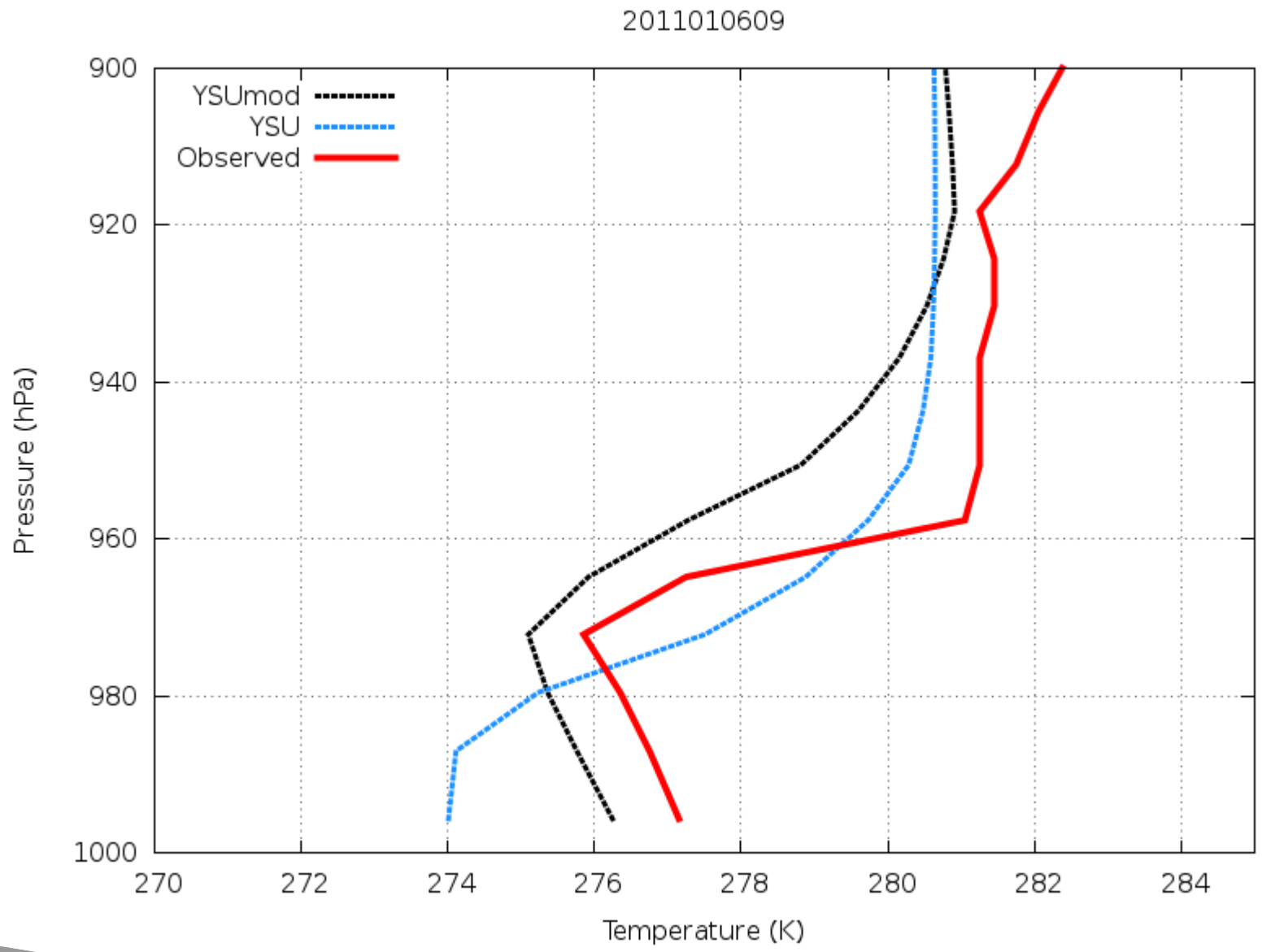
Virtual Temperature – CCLCA (Chowchilla, CA)



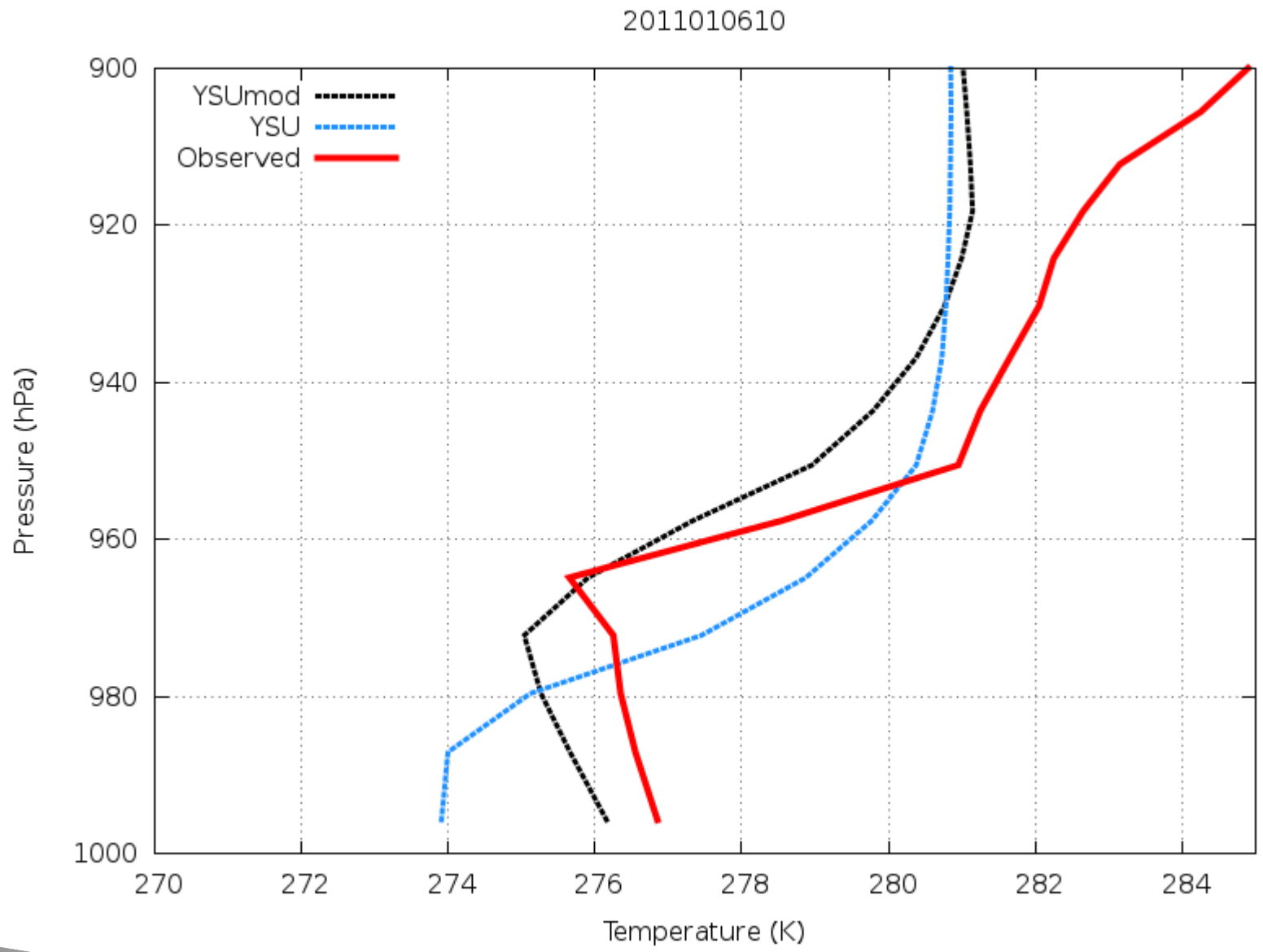
Virtual Temperature – CCLCA (Chowchilla, CA)



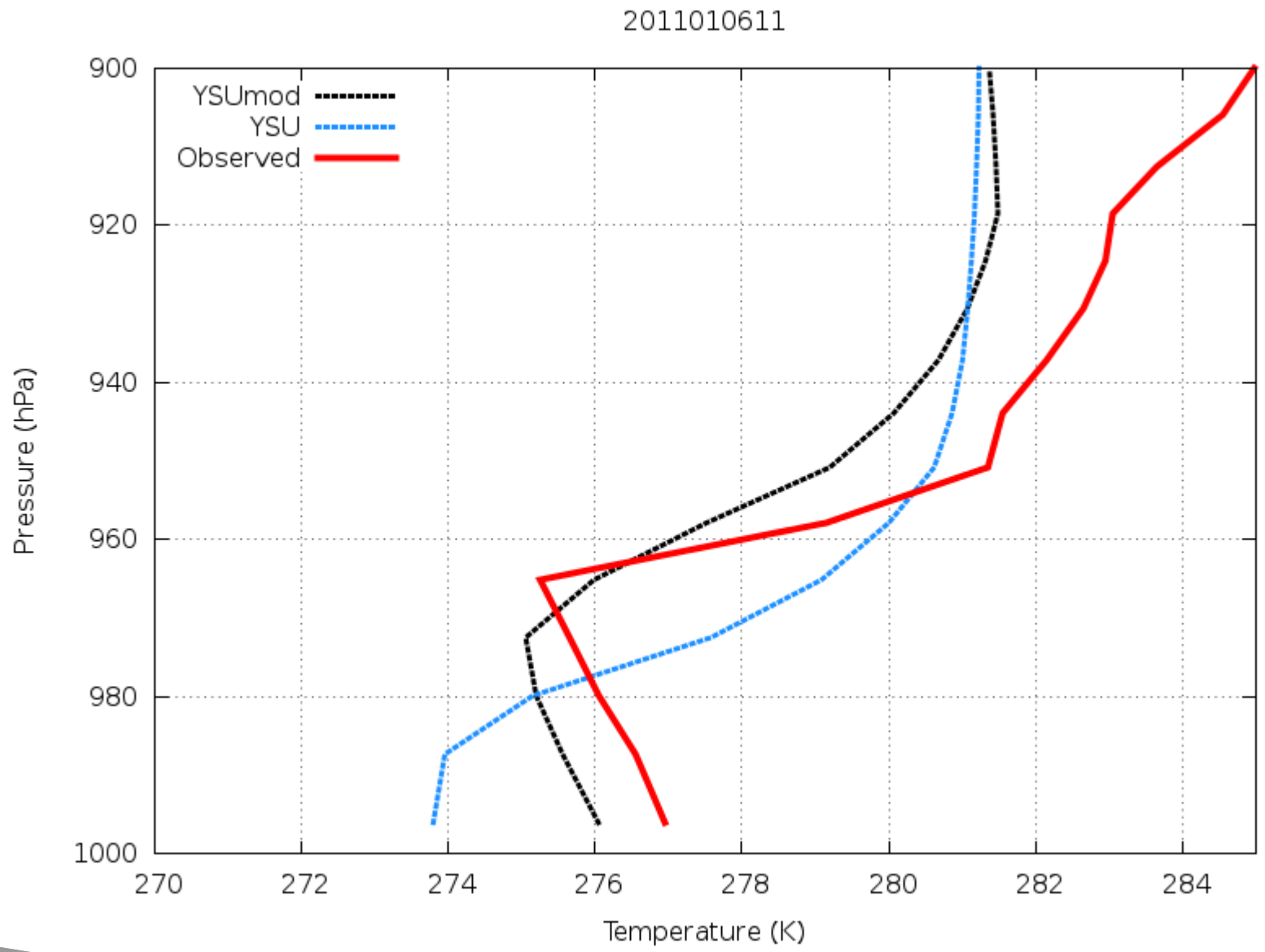
Virtual Temperature – CCLCA (Chowchilla, CA)



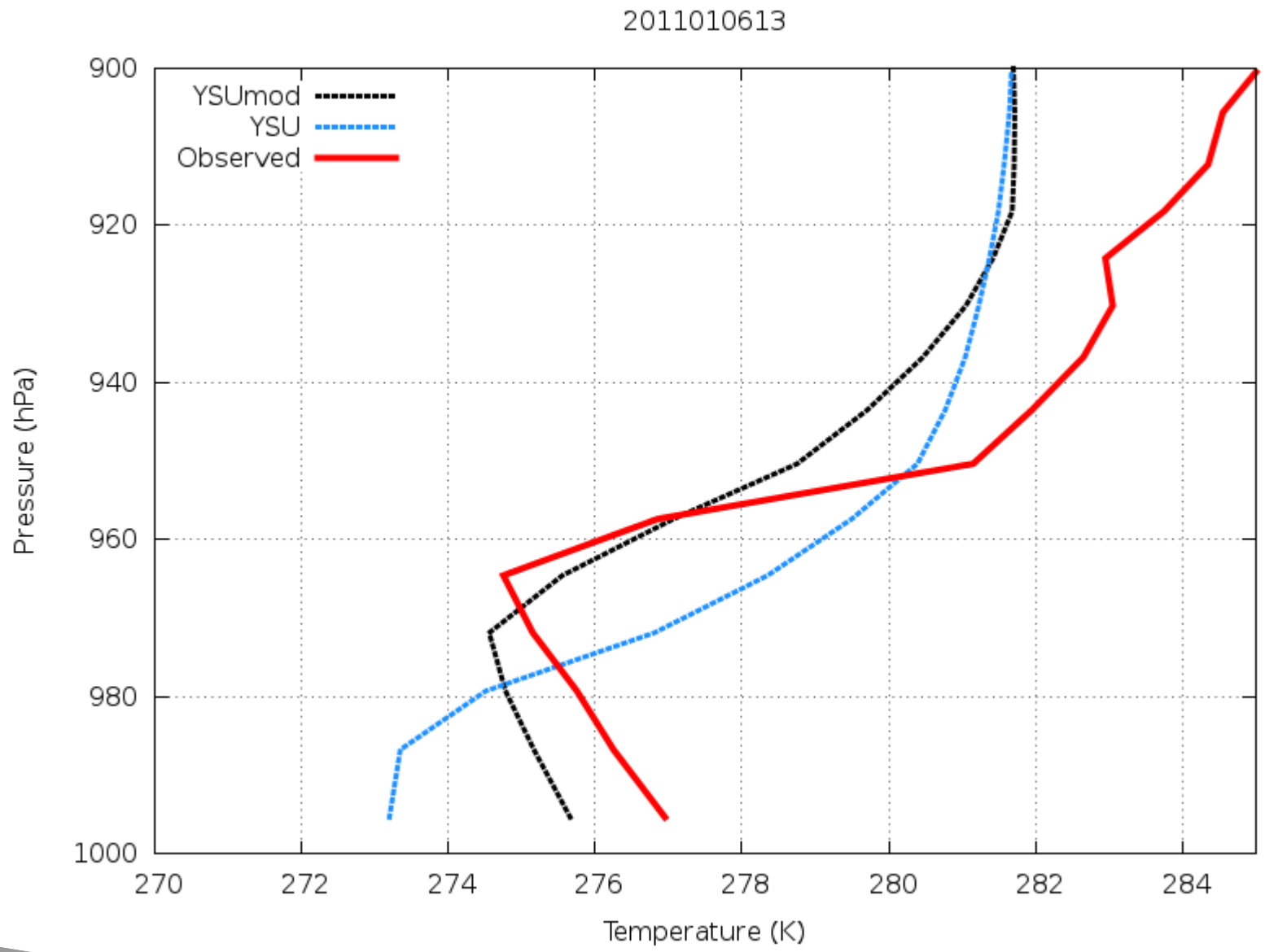
Virtual Temperature – CCLCA (Chowchilla, CA)



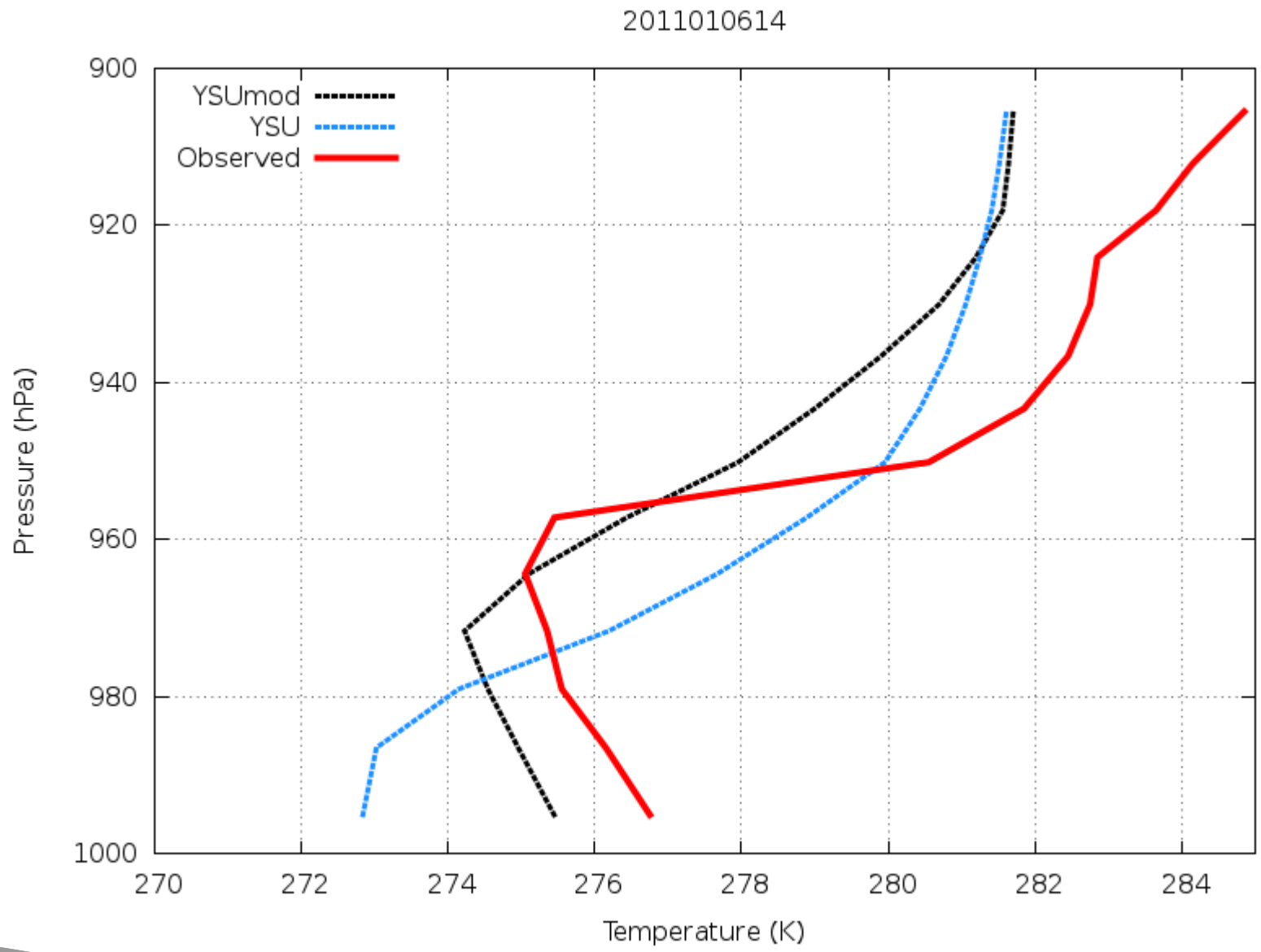
Virtual Temperature – CCLCA (Chowchilla, CA)



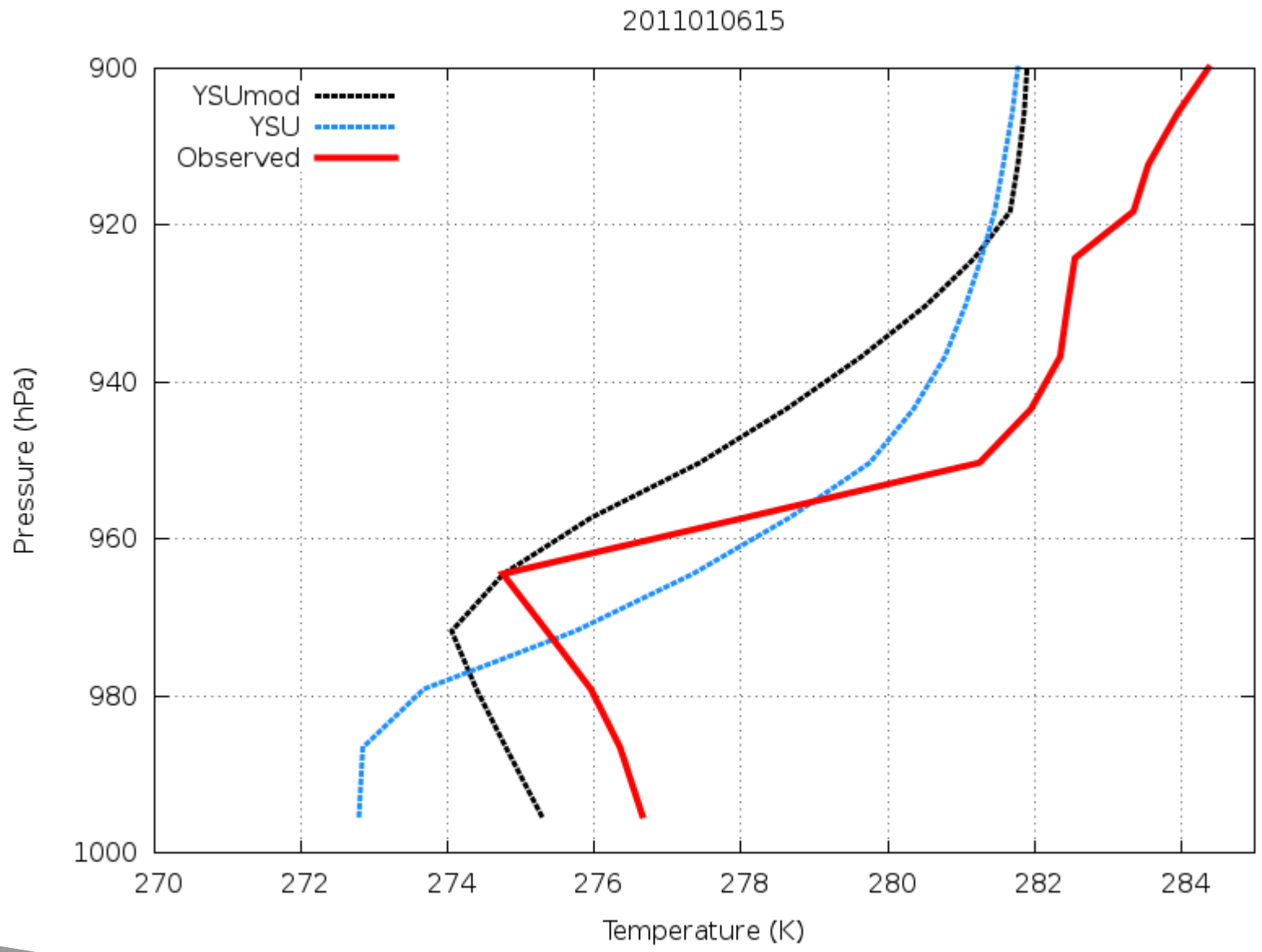
Virtual Temperature – CCLCA (Chowchilla, CA)



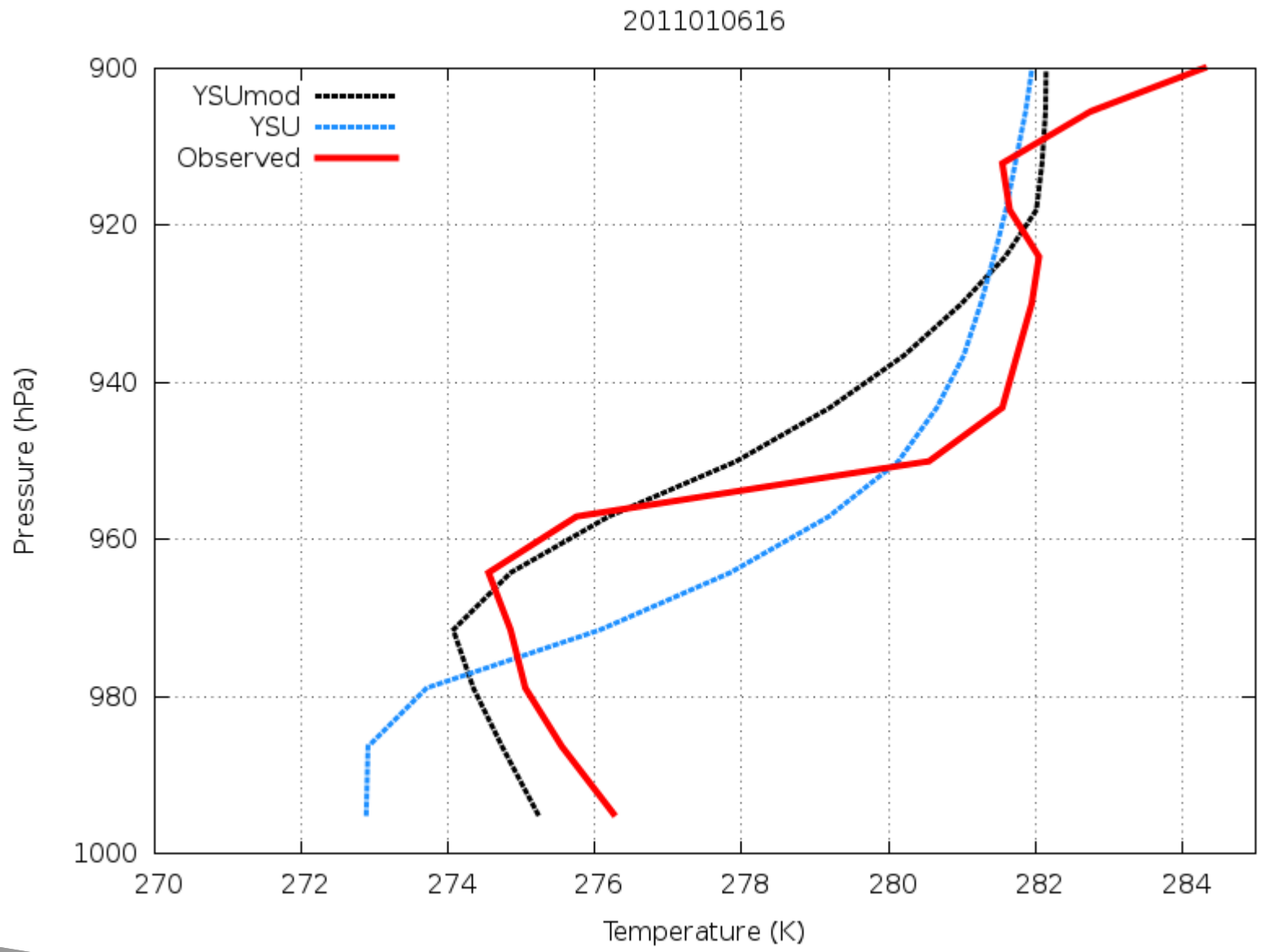
Virtual Temperature – CCLCA (Chowchilla, CA)



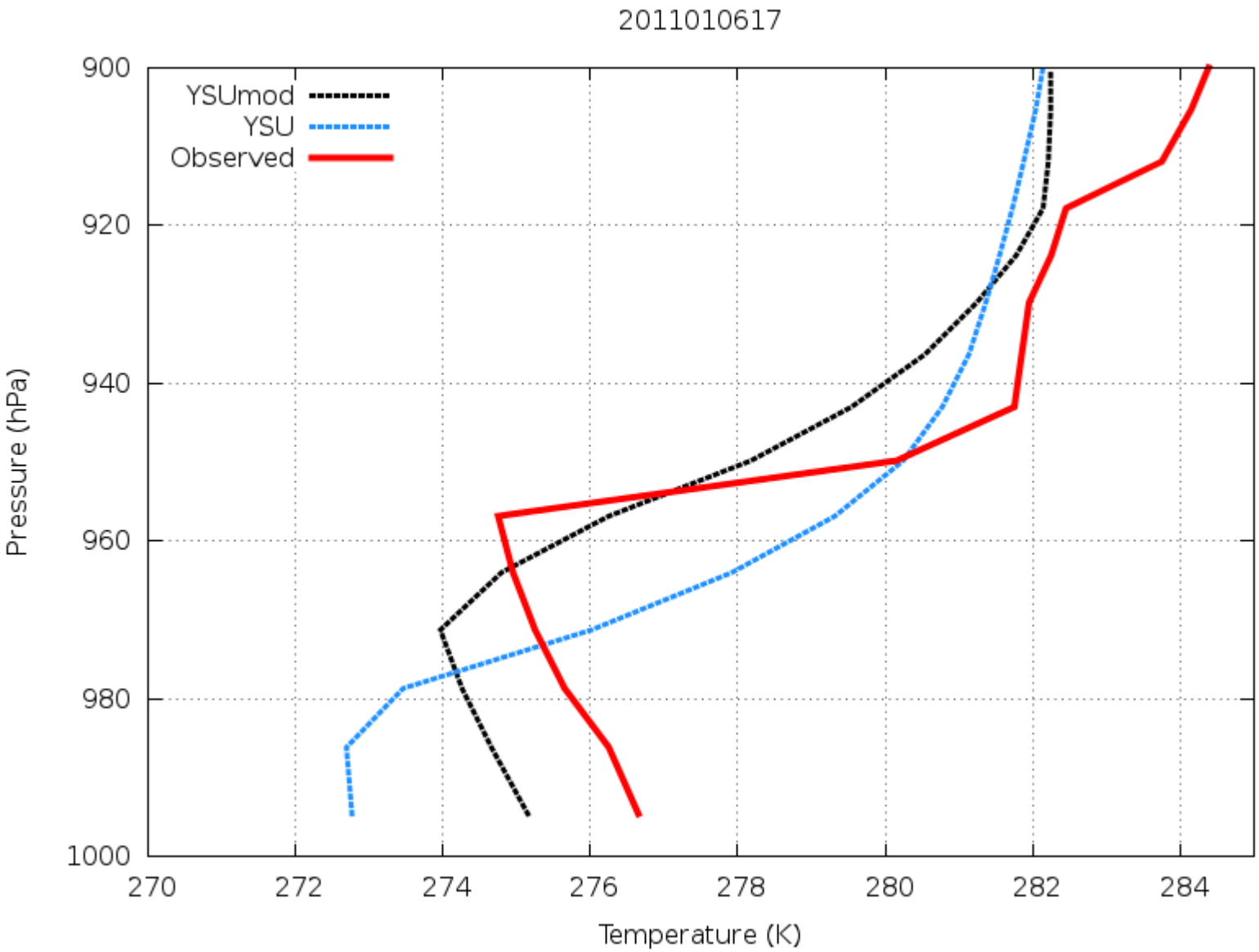
Virtual Temperature – CCLCA (Chowchilla, CA)



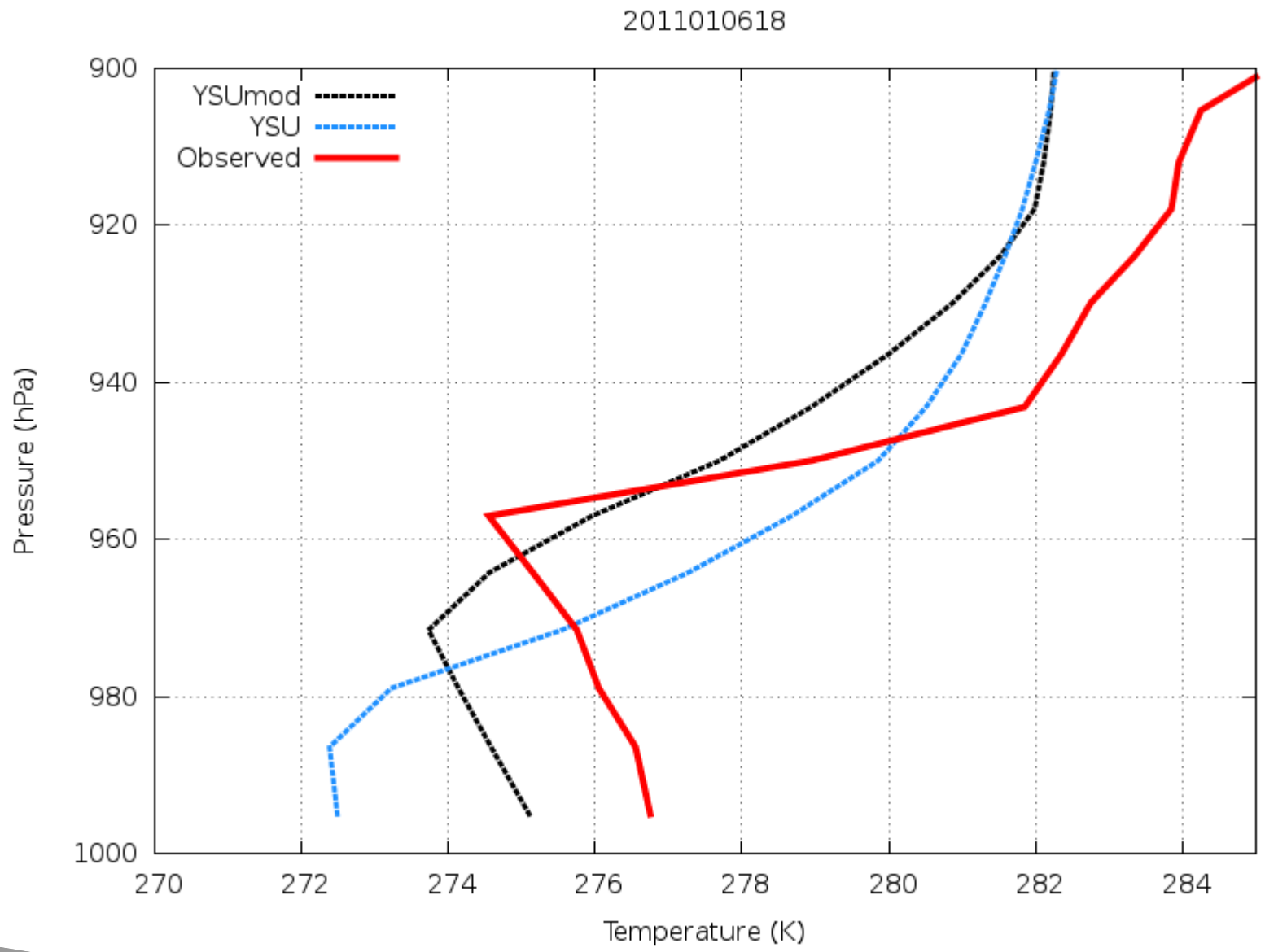
Virtual Temperature – CCLCA (Chowchilla, CA)



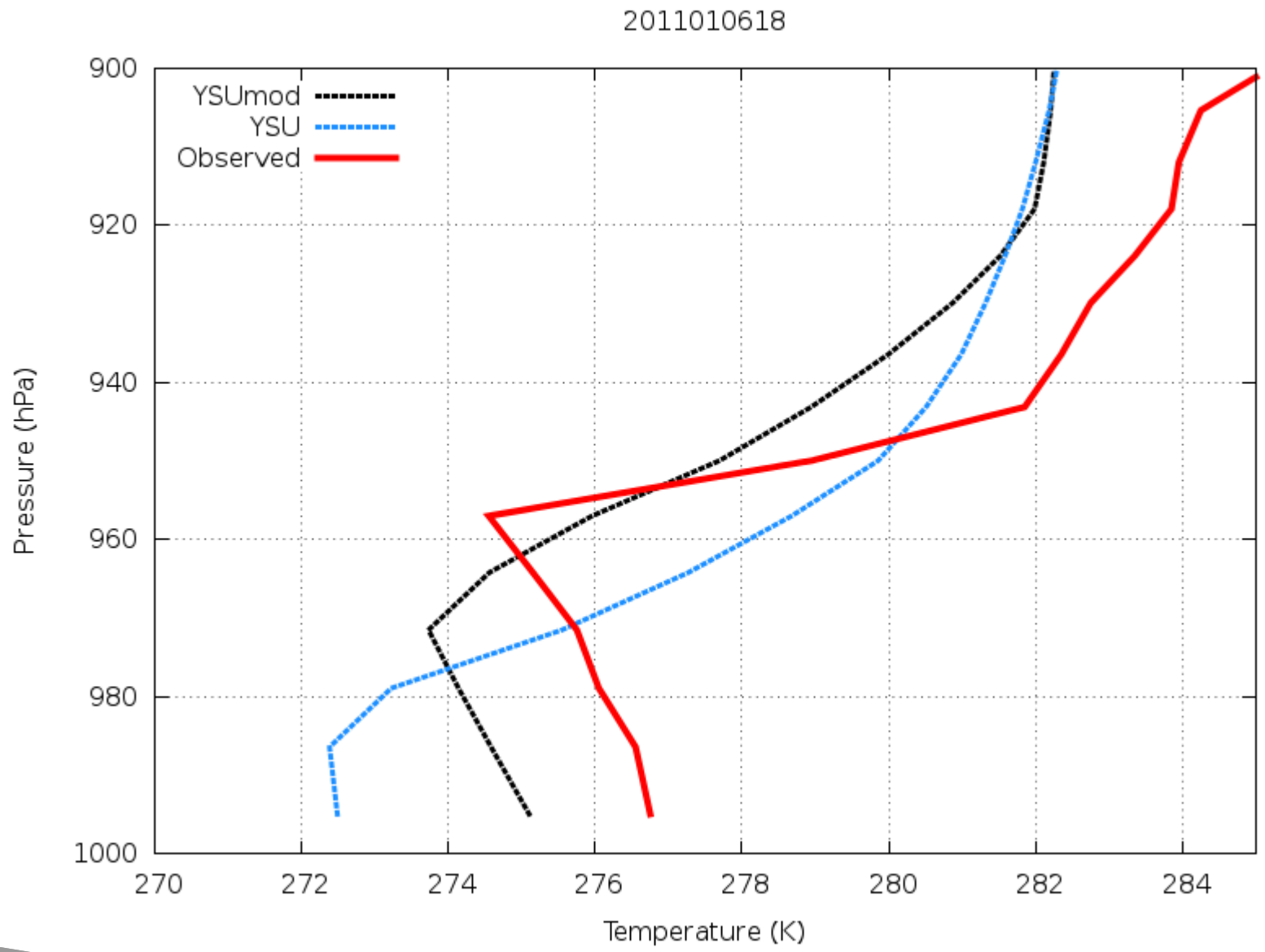
Virtual Temperature – CCLCA (Chowchilla, CA)



Virtual Temperature – CCLCA (Chowchilla, CA)



Virtual Temperature – CCLCA (Chowchilla, CA)



Virtual Temperature – CCLCA (Chowchilla, CA)

- Being able to differentiate between fog and stratus is absolutely critical. Unfortunately, the default WRF model is unable to properly capture this distinction.

-We believe a large part of these errors are tied to the boundary layer which was shown to be too shallow, too cold, and too foggy.

- By making changes to the YSU entrainment and the diffusivity coefficient (along with some other small changes), we have manged to reduce the bias in temperature and PBL height in addition to dramatically improving the fog/stratus forecast.

Contact: twilson@atmos.ucla.edu

Conclusions