The Dynamics of Heat Lows

Thomas Spengler

thomas.spengler@noaa.gov

Geophysical Institute, University of Bergen, Norway

Atmospheric and Oceanic Sciences, GFDL NOAA, Princeton University

Roger K. Smith

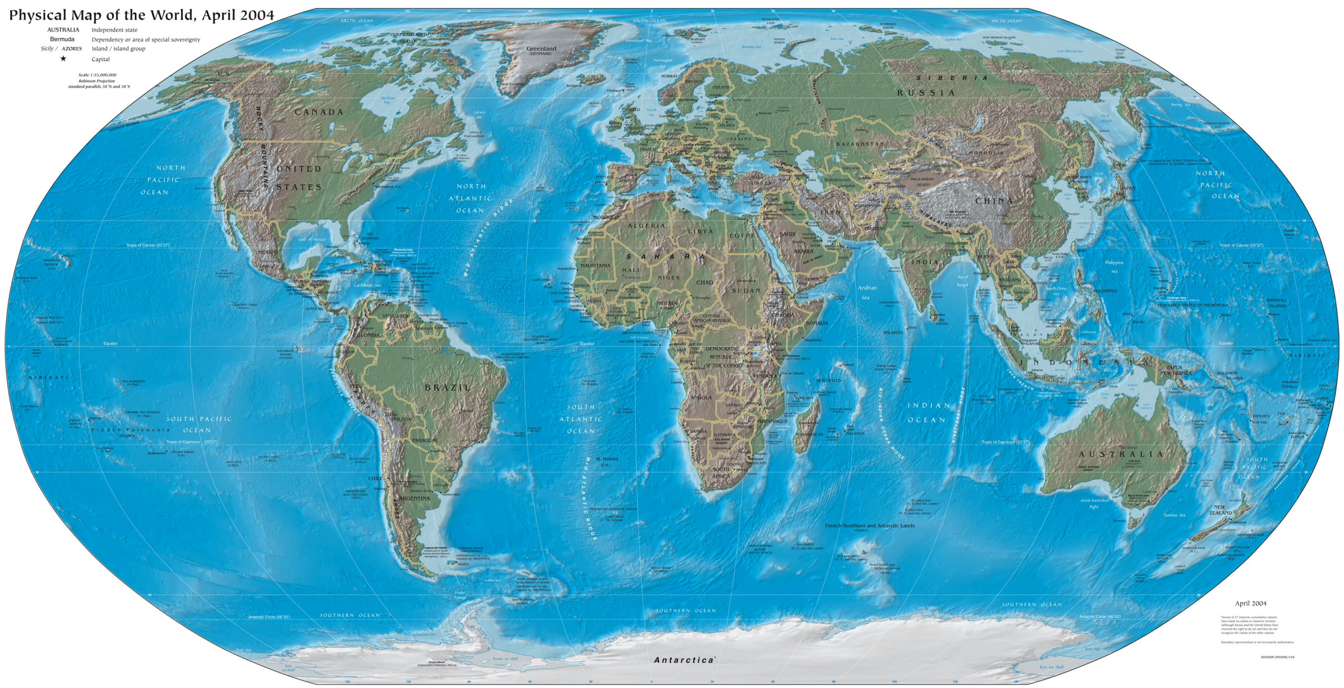
Meteorological Institute, University of Munich, Germany

Michael J. Reeder

Monash Weather and Climate, Monash University, Australia

<u>Why? Where?</u>

- high solar insolation
- arid regions
- sparse vegetation



http://www.printableworldmap.org/printable-world-map-political-wiki.jpg

<u>Subtropical Regions</u>

NW and SW-Africa

SW North America

West Pakistan

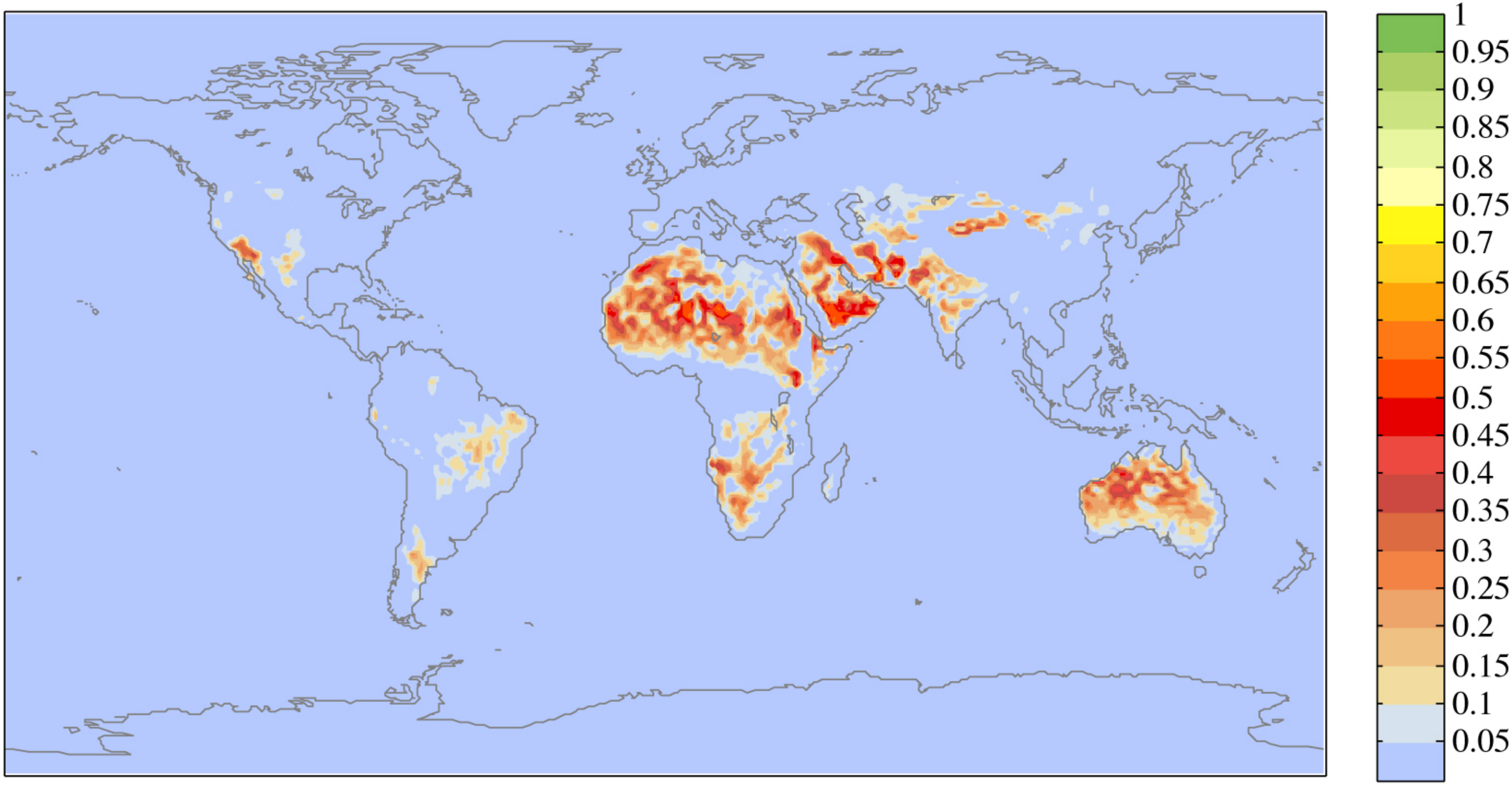
North India

Saudi Arabia

Iberian Peninsula

Australia

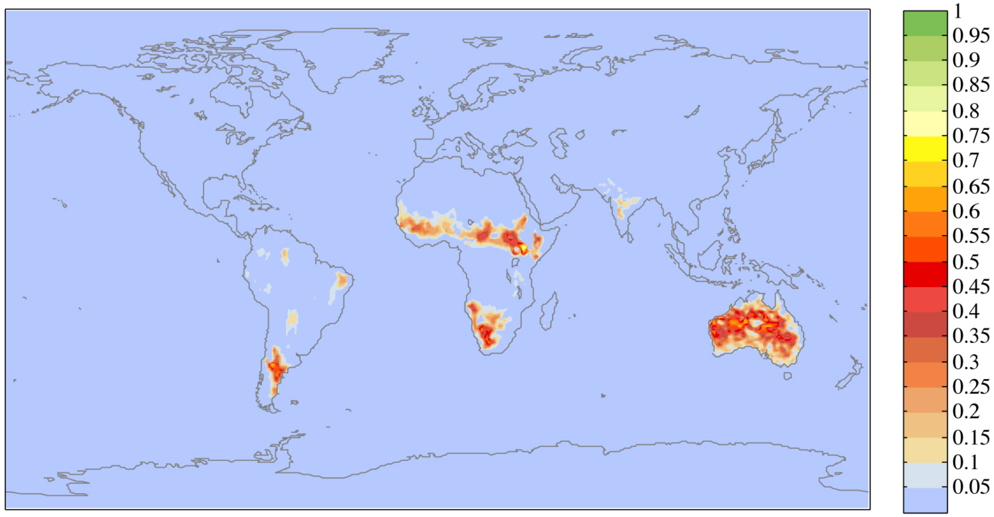
Heat Low Climatology



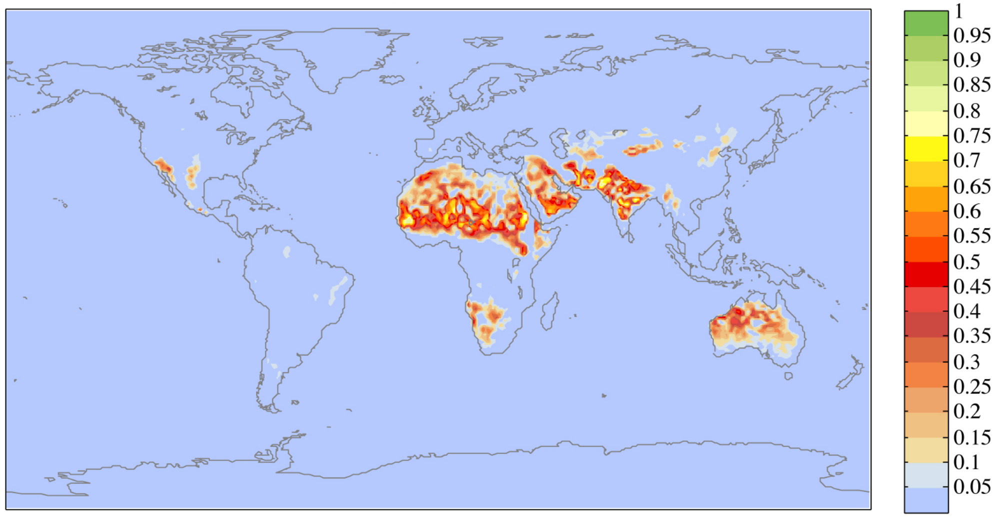
Heat Low frequency for 45 year period in ERA40

Seasonal Climatology

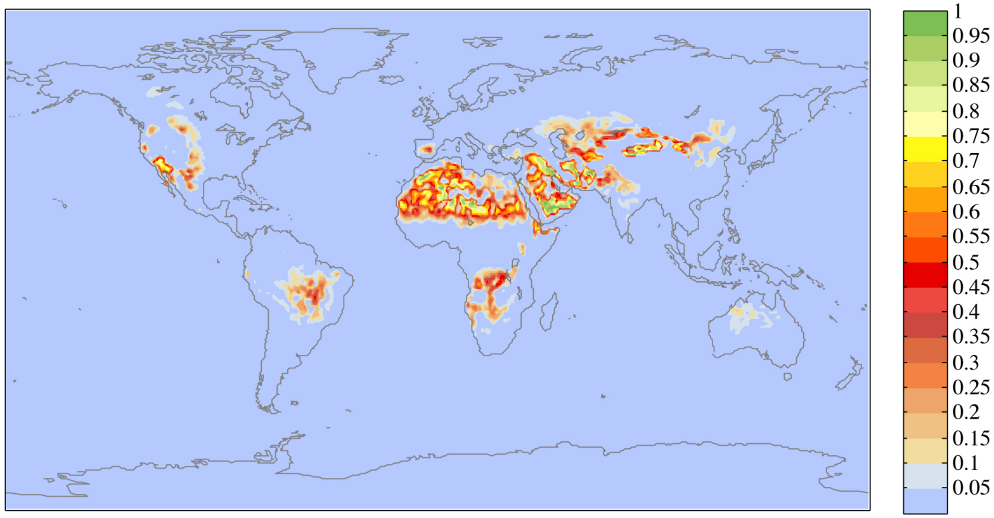
DJF



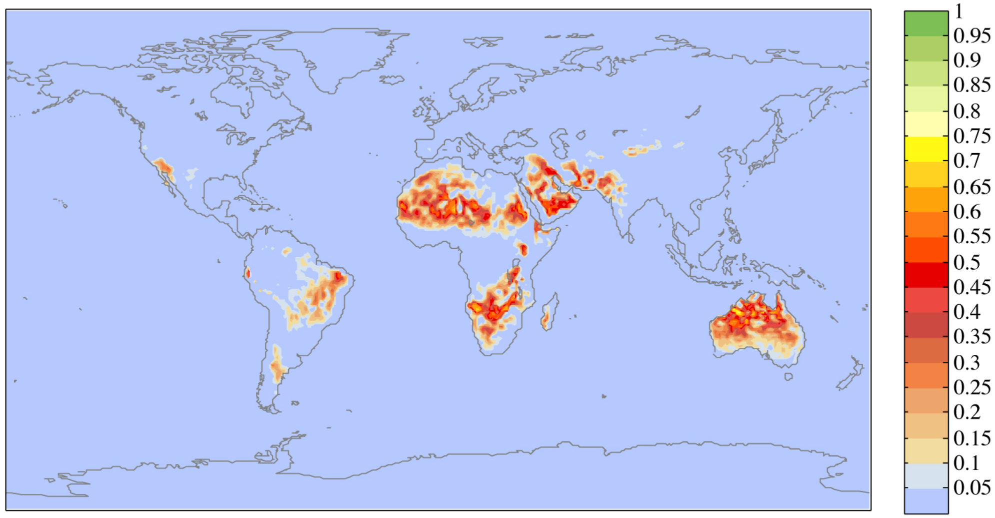
MAM



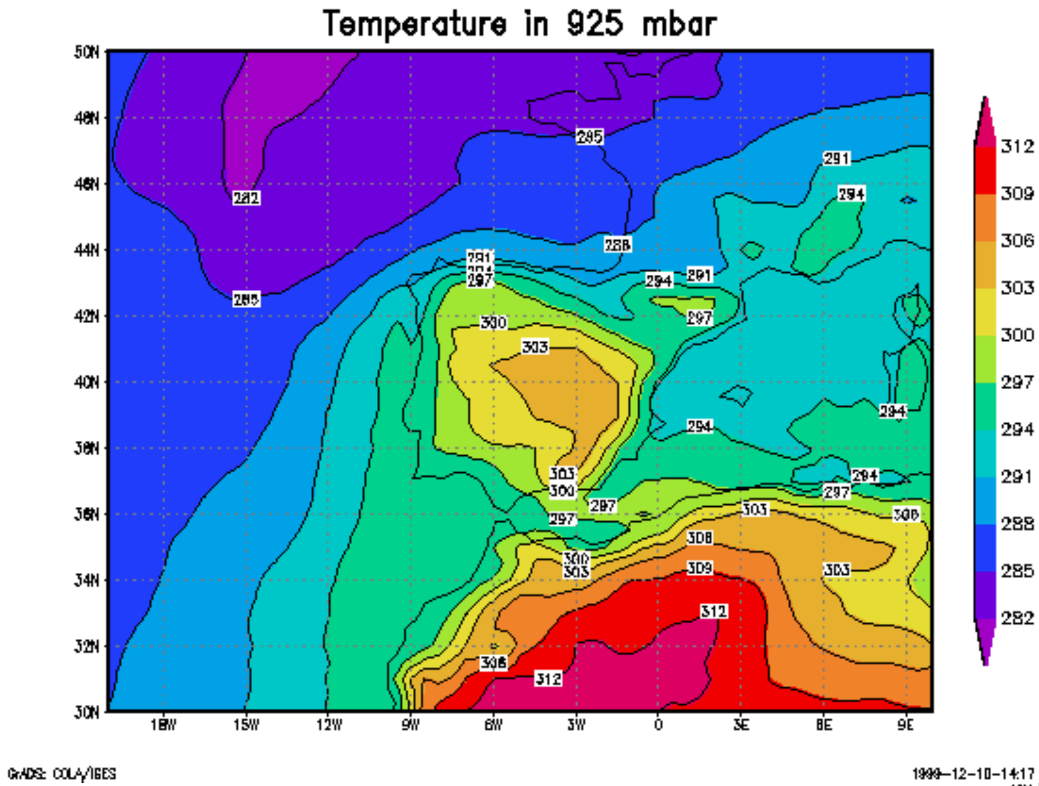
JJA

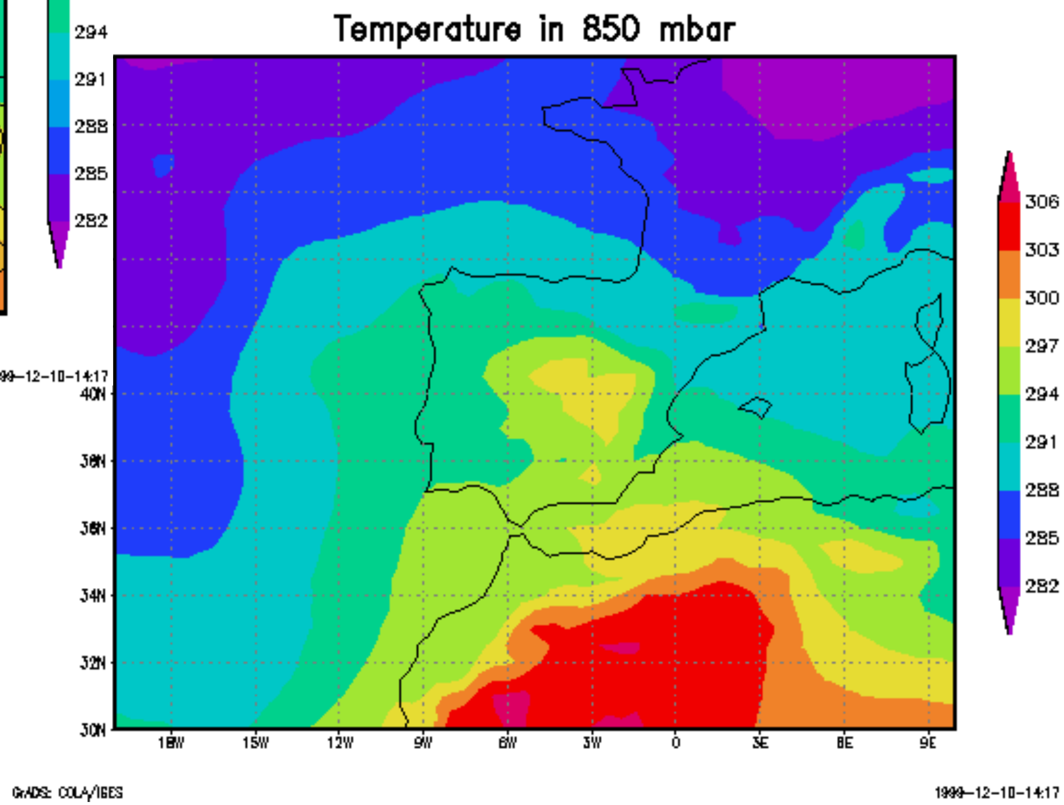


SON

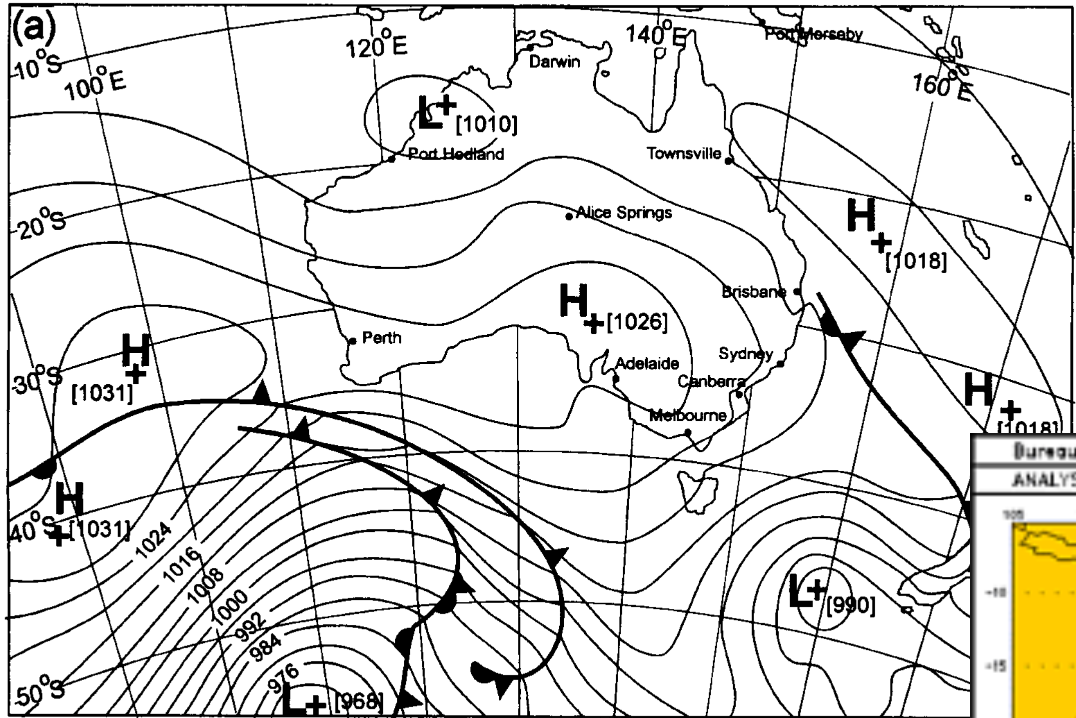


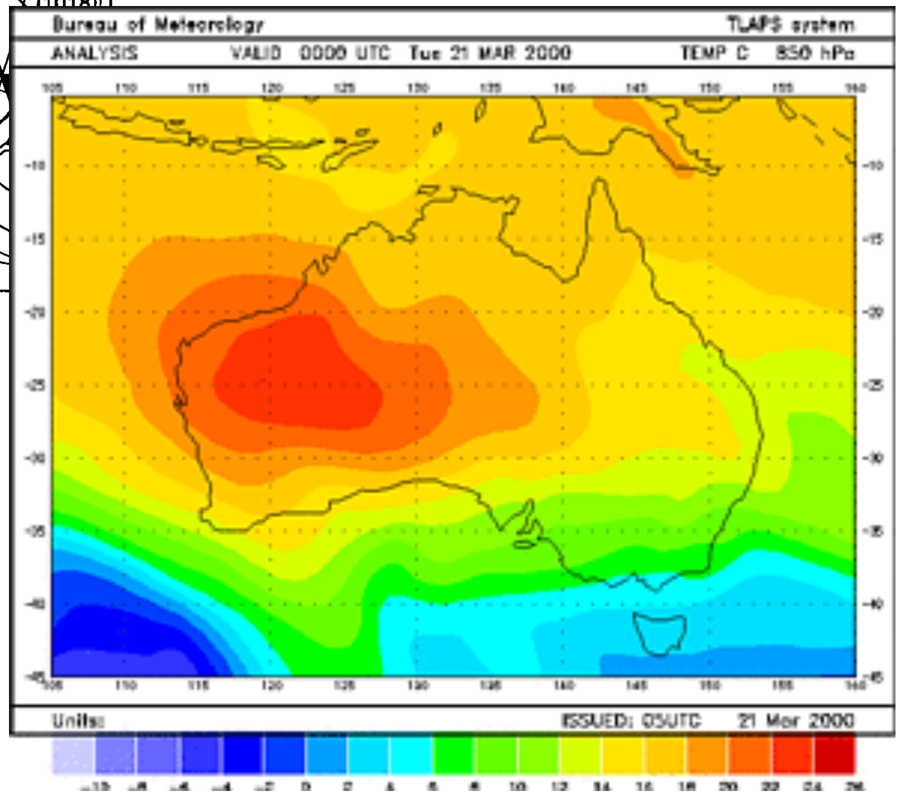
Heat low over the Iberian Peninsula



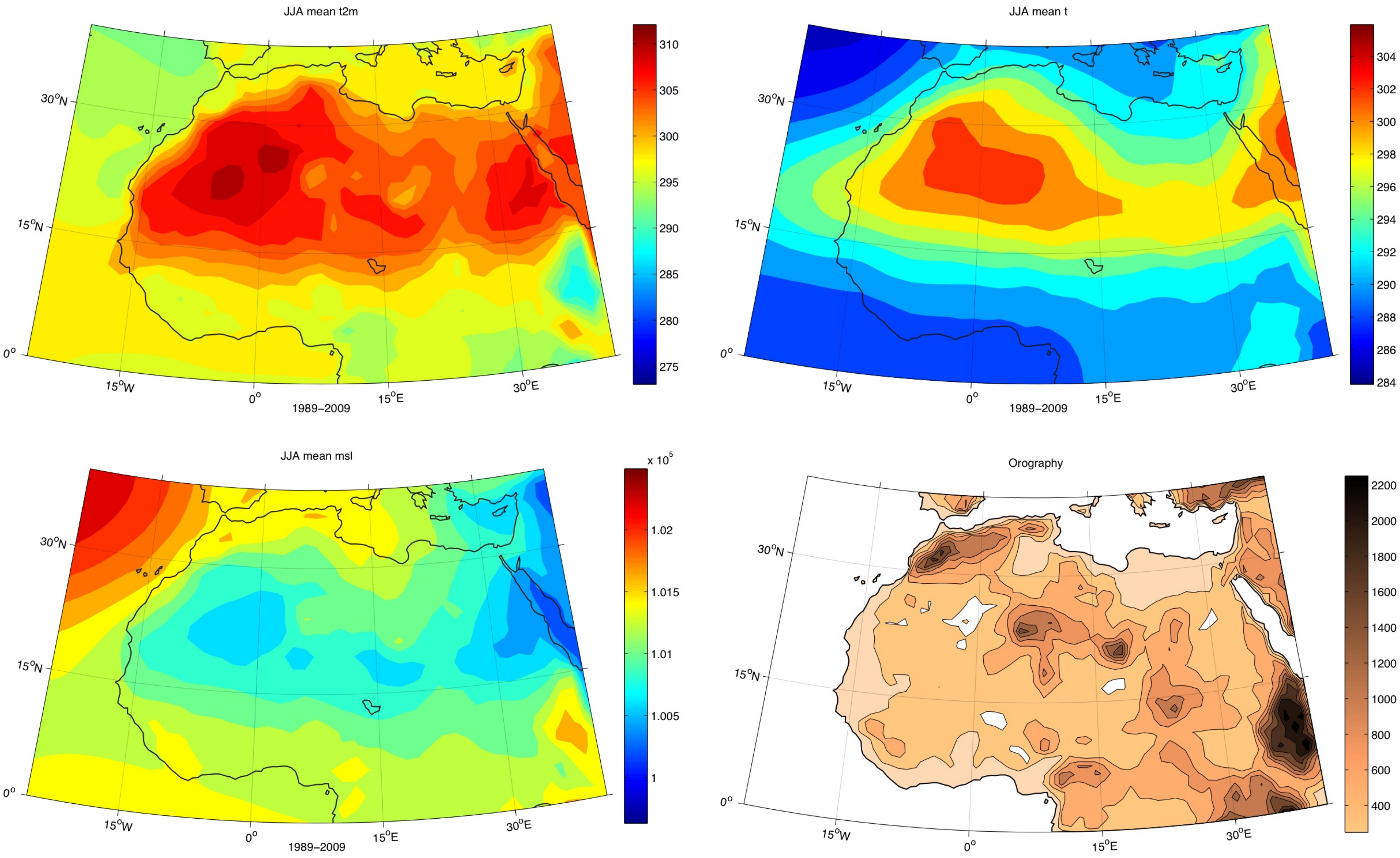


West Coast Trough in Australia

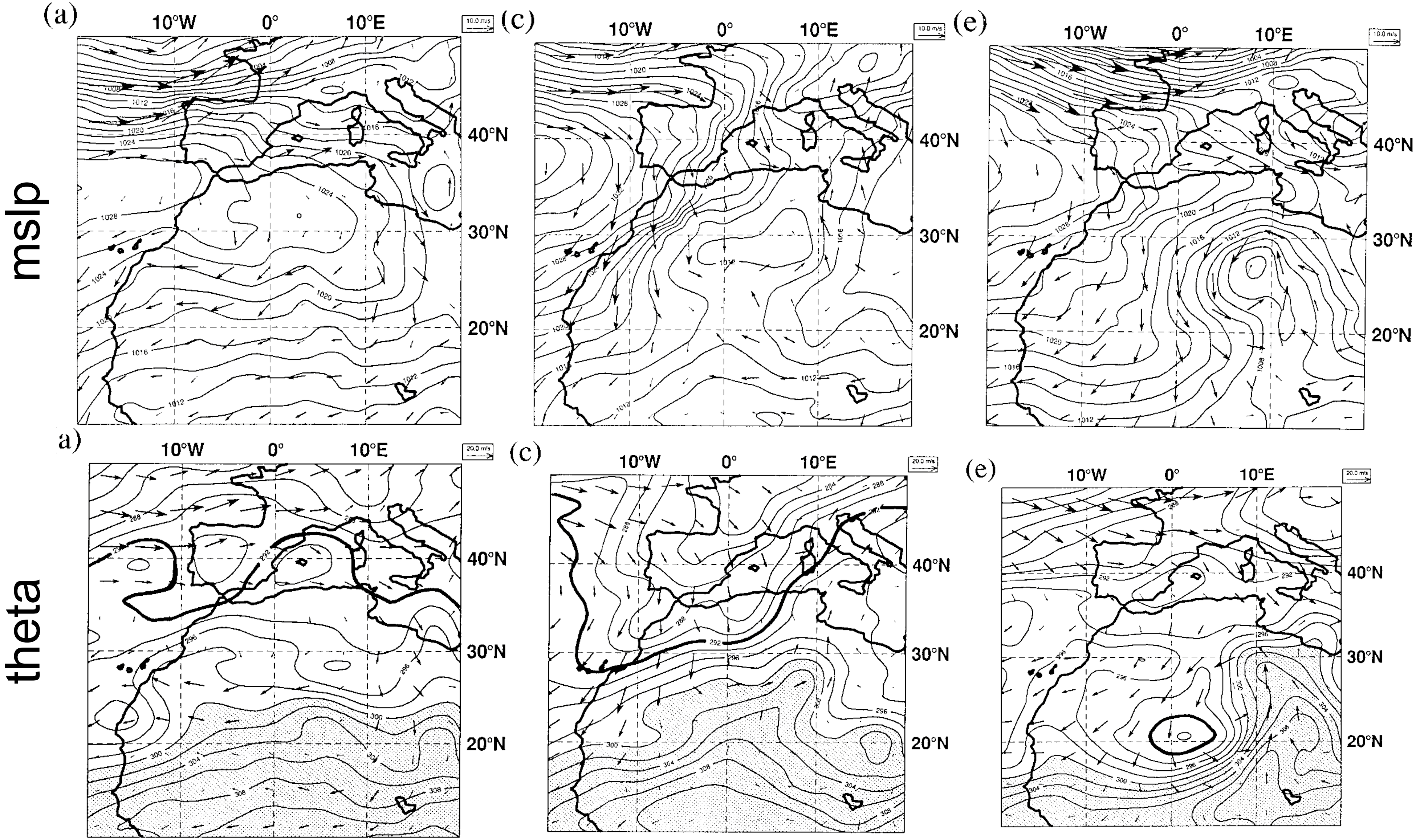




Heat Low over the Sahara

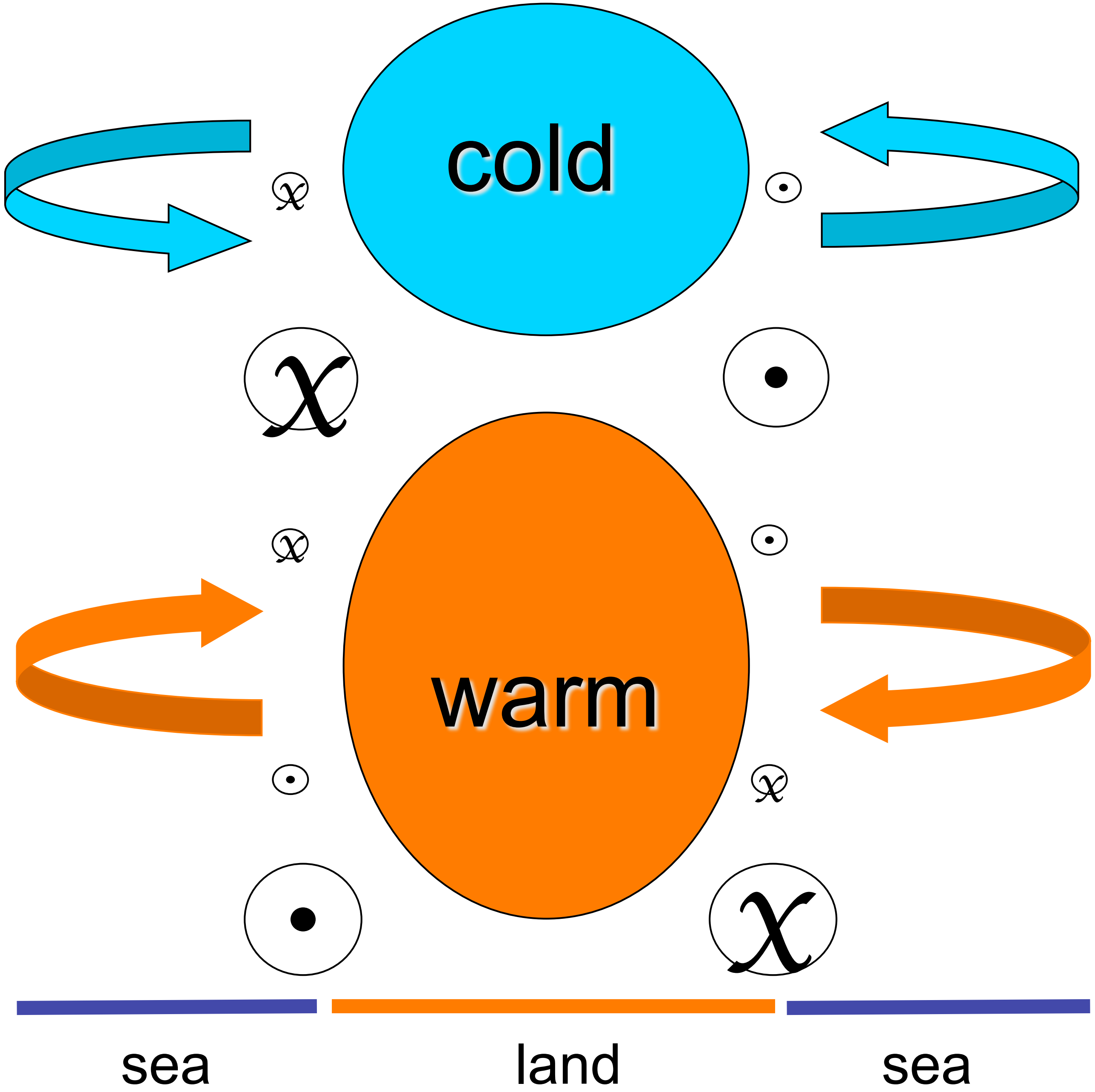


Heat Low over the Sahara



Thorncroft and Flocas (1997)

Heat Lows in general



Motivation

Significant synoptic features in subtropical latitudes:

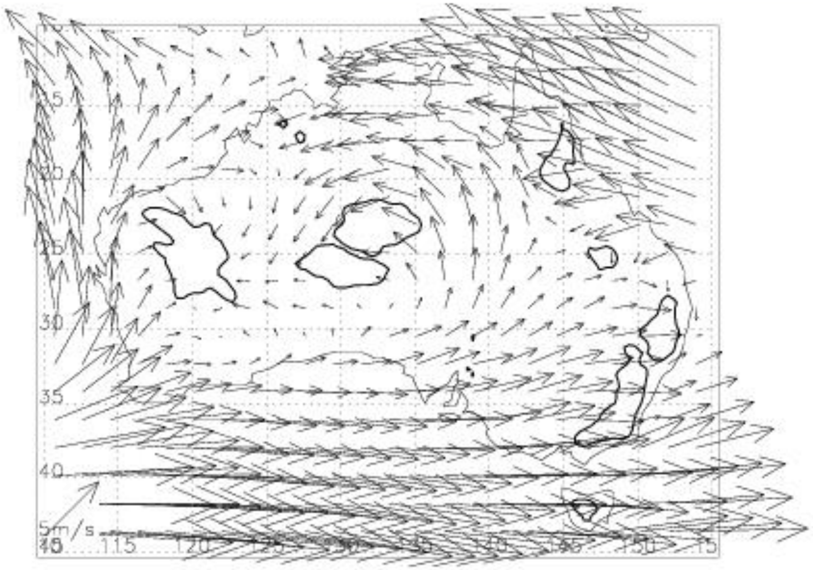
- nocturnal thunderstorm activity
- desertification
- influencing synoptic weather conditions

(Heat Low – subtropical cold front? Heat Trough)

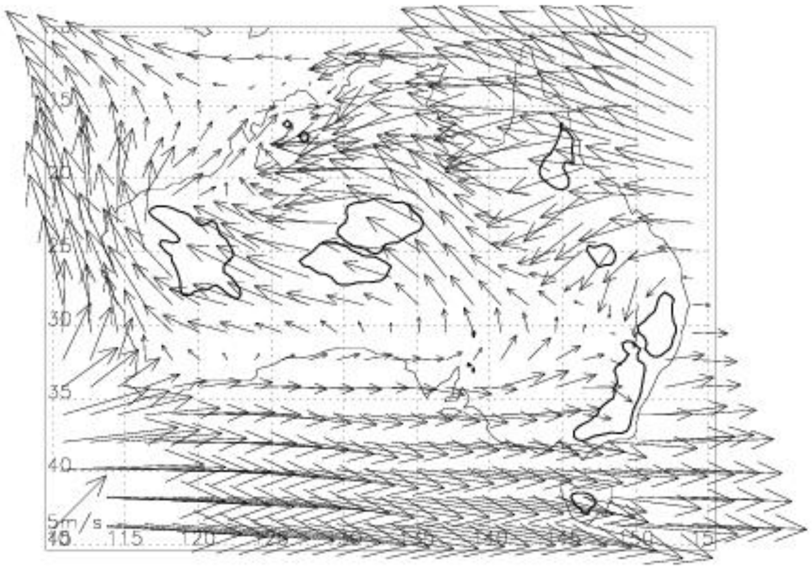
Motivation

Questions:

- Nocturnal Frontogenesis? Trough dynamics?
- Balanced Flow?
- Feedback on longevity of Heat Low system itself?



SON total-wind 4 pm



SON total-wind 4 am

(Spengler *et. al* 2005)

The Model

The Model

- 3D, hydrostatic, sigma coordinates
- primitive equations
- Mellor-Yamada 2.25 BLP
- Sim. theory lowest layer
- Simple radiation scheme (long-short-wave)

Boundary conditions:

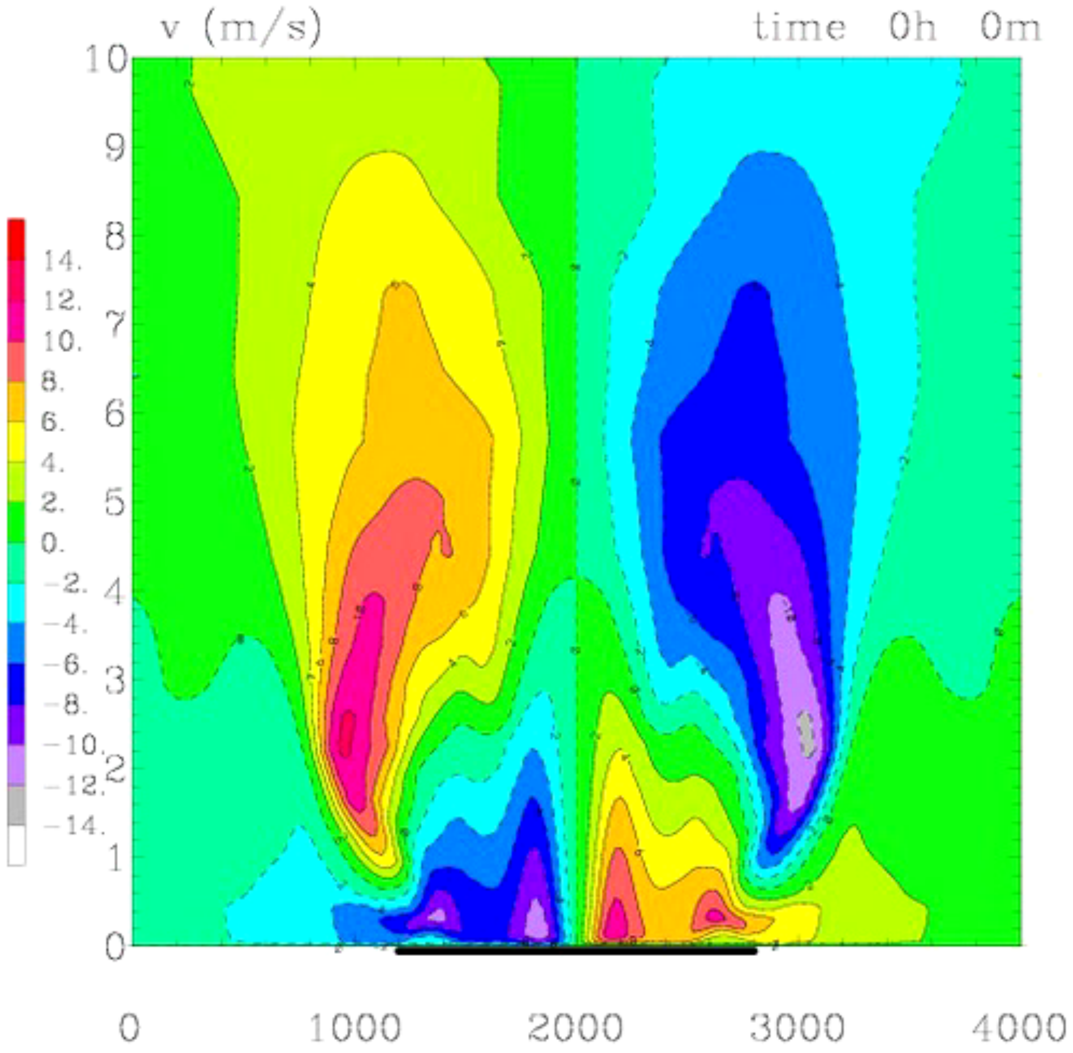
- Relaxation at boundaries in x and y

Initialisation

- Heated island: circular, radius = 800 km
- Domain: 4800 x 4800 km, dx = 25 km
- SST: const (25° C)
- Coriolis: 20° N
- Temperature: radiative equilibrium
- Albedo: 0.3

- **No** moisture
- Integration until quasi-equilibrium: day 11

Results



V component of wind

Anticyclonic at upper levels

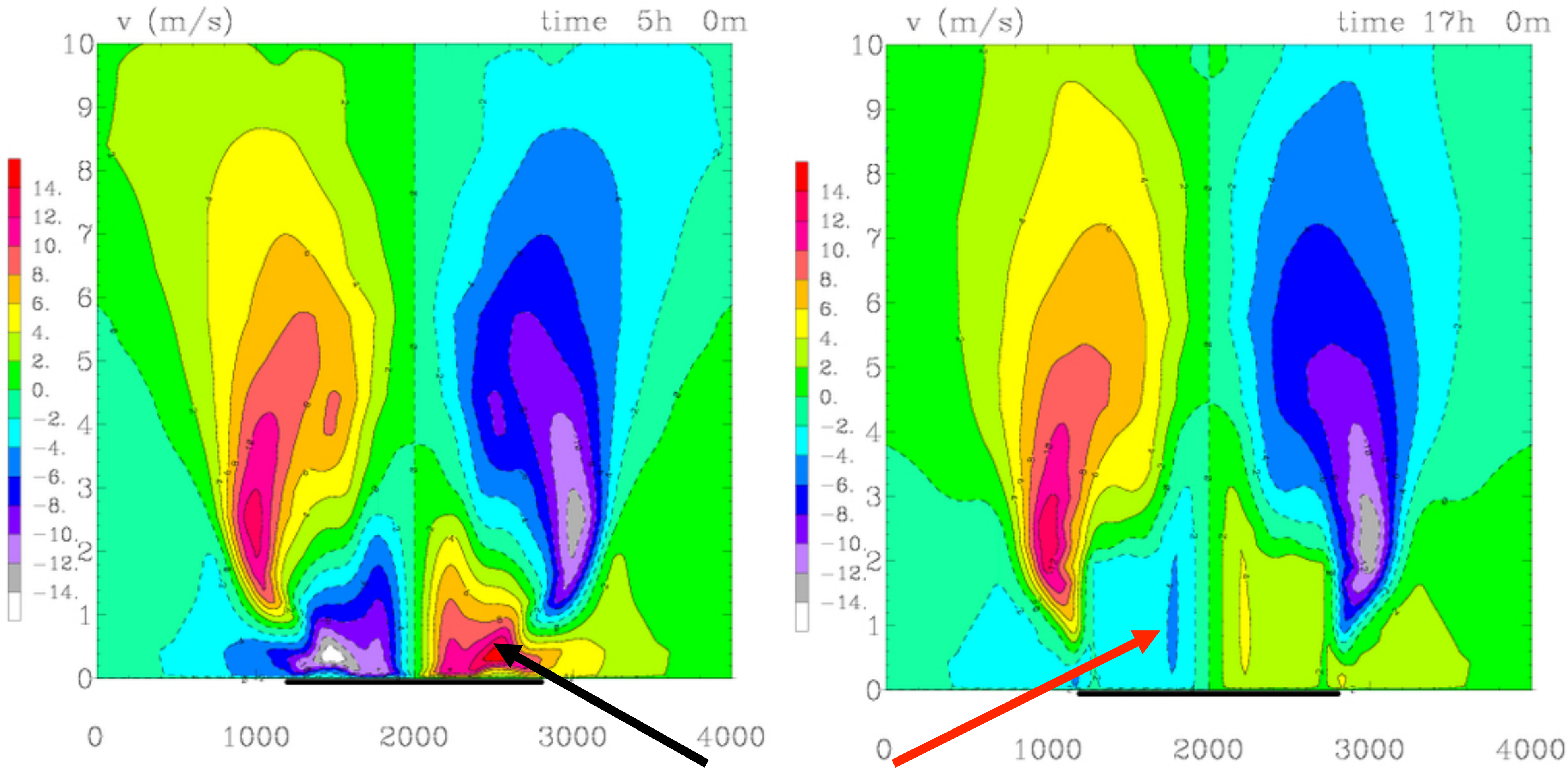
Cyclonic at lower levels

Strong diurnal cycle!

Results

5:00 morning

17:00 afternoon

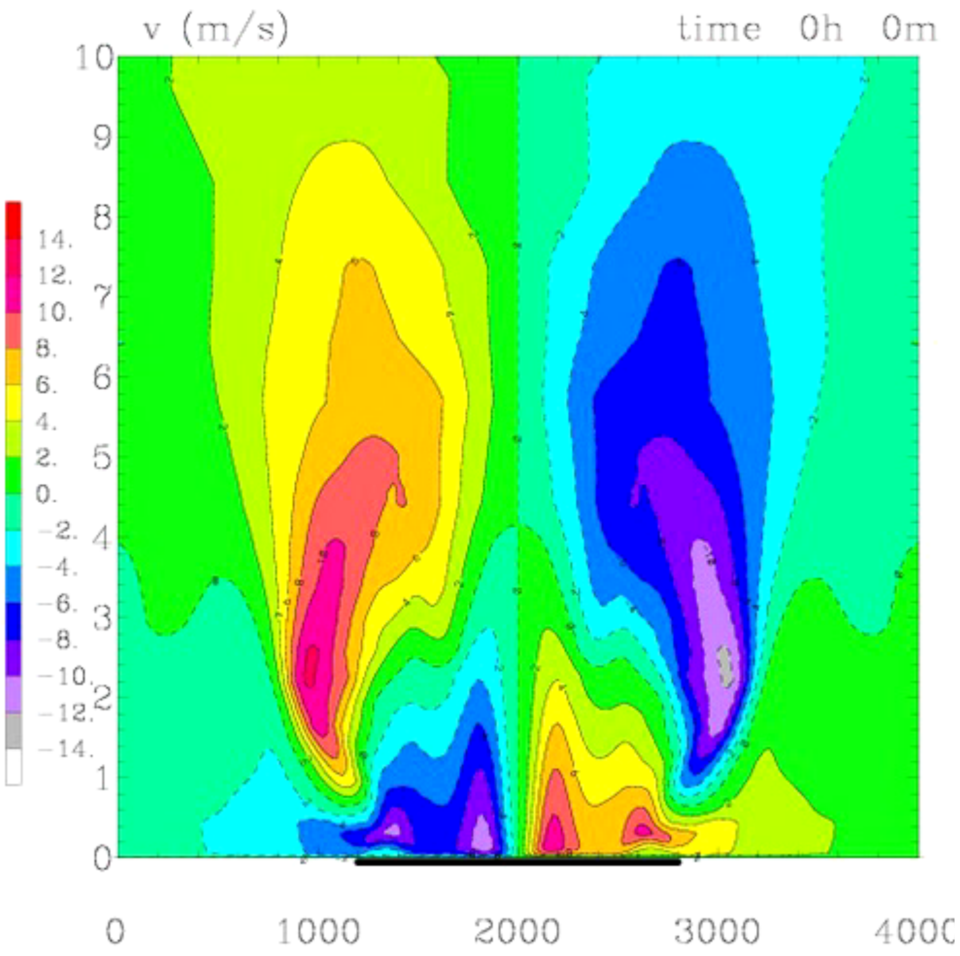


HUGE morning - afternoon contrast!

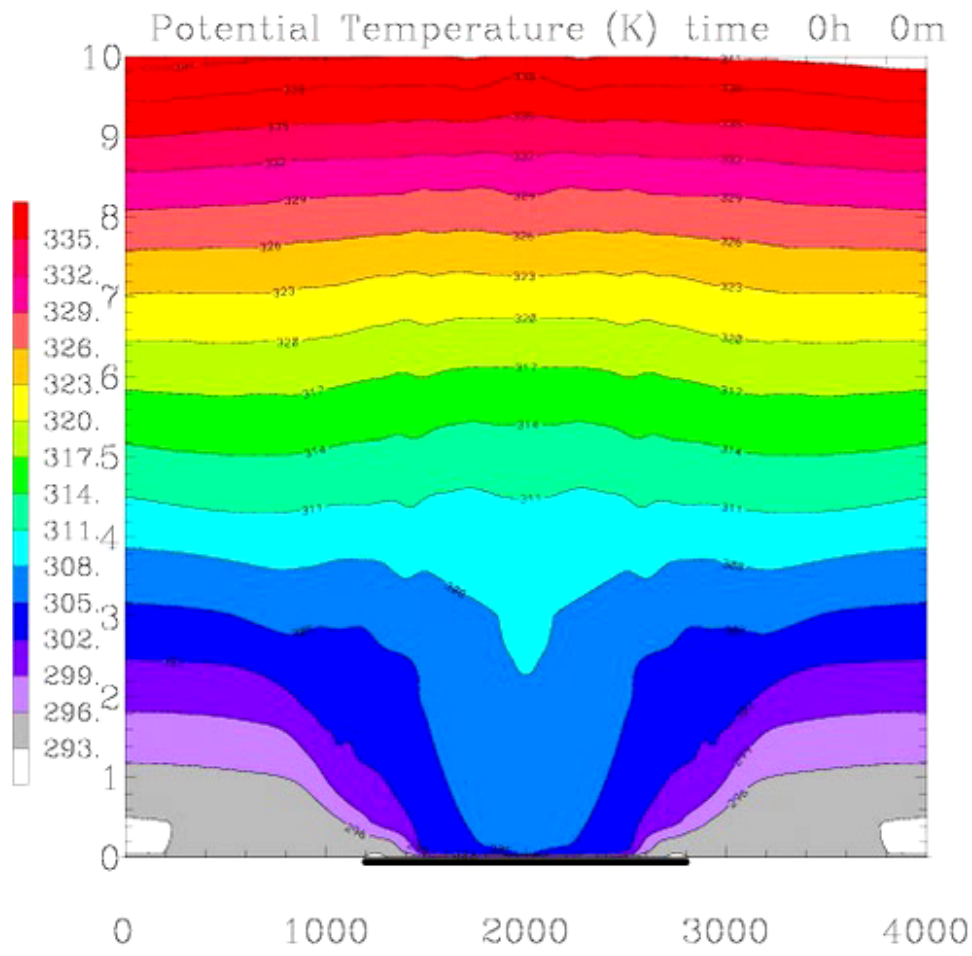
(At low levels only)

Results

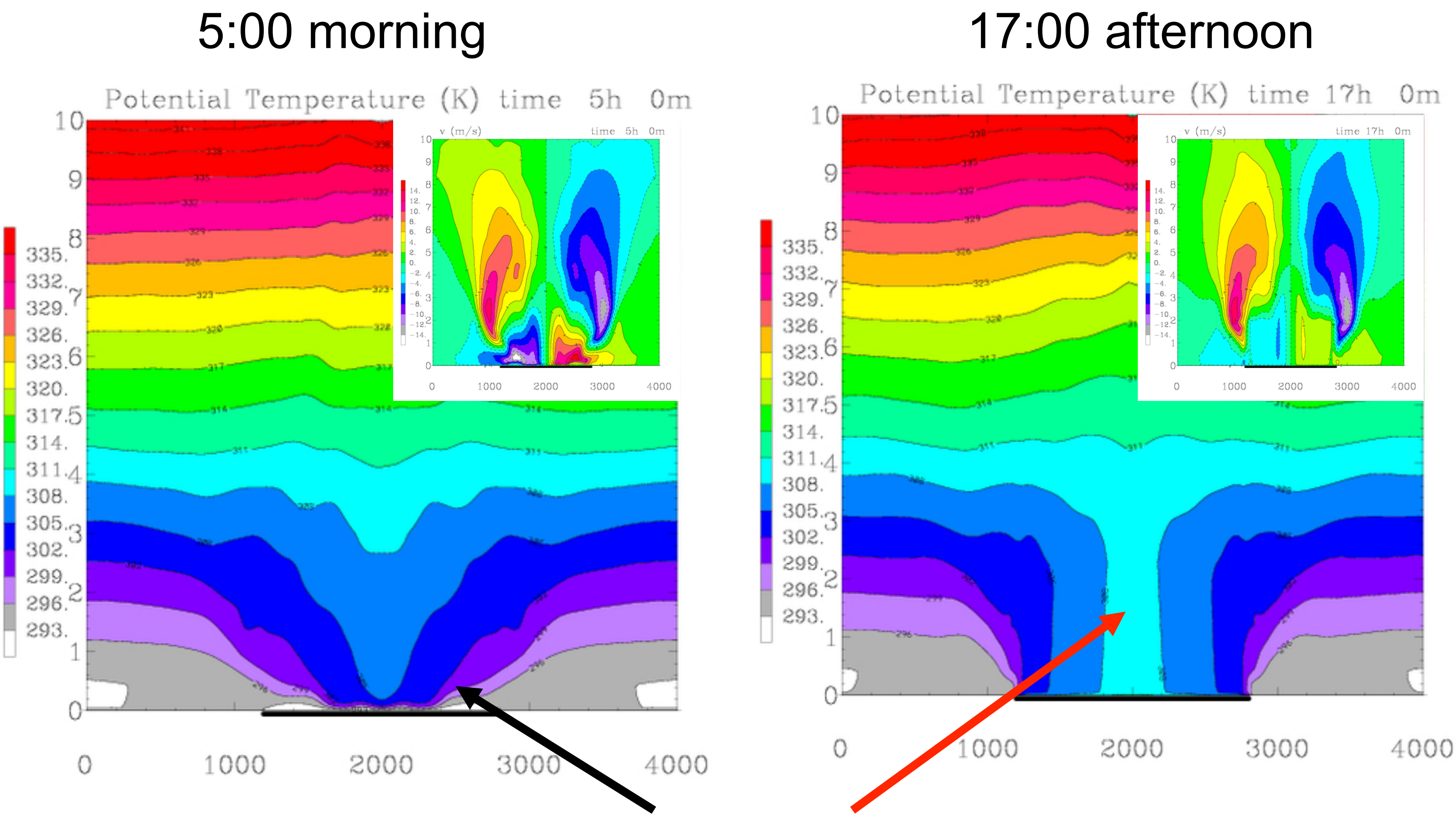
v component of wind



Potential temperature theta



Results



Low level stable at night - deep mixed layer during day

Theory: Inertial wave
(turning of low-level-jet)

Linearised momentum equations with linear drag:

total wind — geostrophic — drag

$$\frac{\partial u}{\partial t} - fv = -fv_g - \mu u$$

$$\frac{\partial v}{\partial t} + fu = fu_g - \mu v$$

$$fk \times \vec{u}_g = -\frac{1}{\rho}\nabla p$$

geostrophic balance

assumption:

basic state geostropic component stationary => initial condition

$$u_0 = \frac{f^2 u_g - \mu f v_g}{f^2 + \mu^2}$$

$$v_0 = \frac{f^2 v_g - \mu f u_g}{f^2 + \mu^2}.$$

After ‘sunset’ => no friction

equation for ageostrophic wind

$$\frac{\partial}{\partial t}\left(u-u_g\right)=f\left(v-v_g\right)$$

$$\frac{\partial}{\partial t}\left(v-v_g\right)=-f\left(u-u_g\right)$$

$$W=\left(u-u_g\right)+i\left(v-v_g\right)$$

$$\boxed{W=W_0 e^{-ift}}$$

$$T=\frac{2\pi}{f}=\frac{24h}{2\sin\Phi}$$

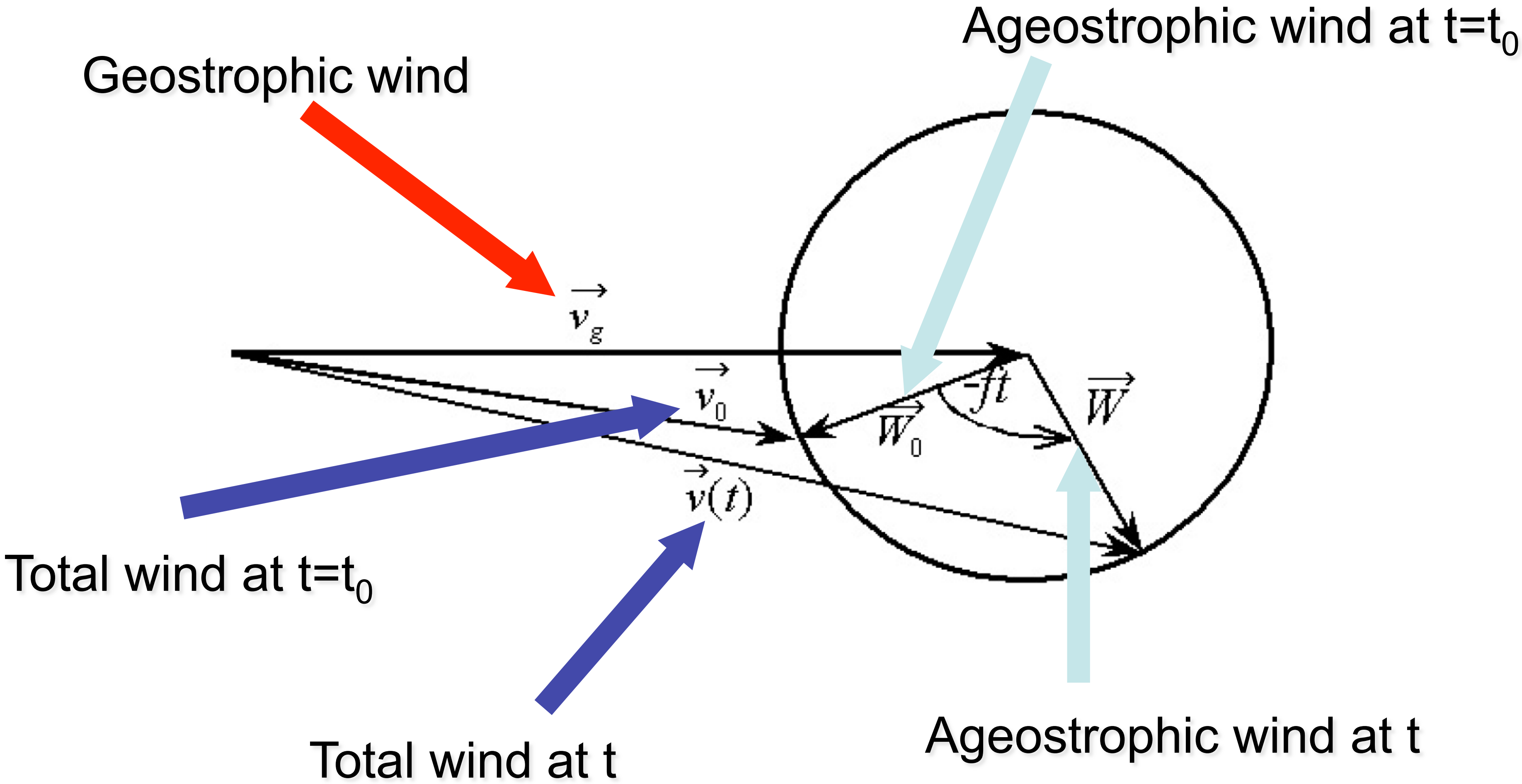
$$T(25,7^\circ)=27,67h$$

$$W_0=\sqrt{\left(u_0-u_g\right)^2+\left(v_0-v_g\right)^2}$$

$$\boxed{\frac{\mu\left|\vec{v}_g\right|}{\sqrt{f^2+\mu^2}}}$$

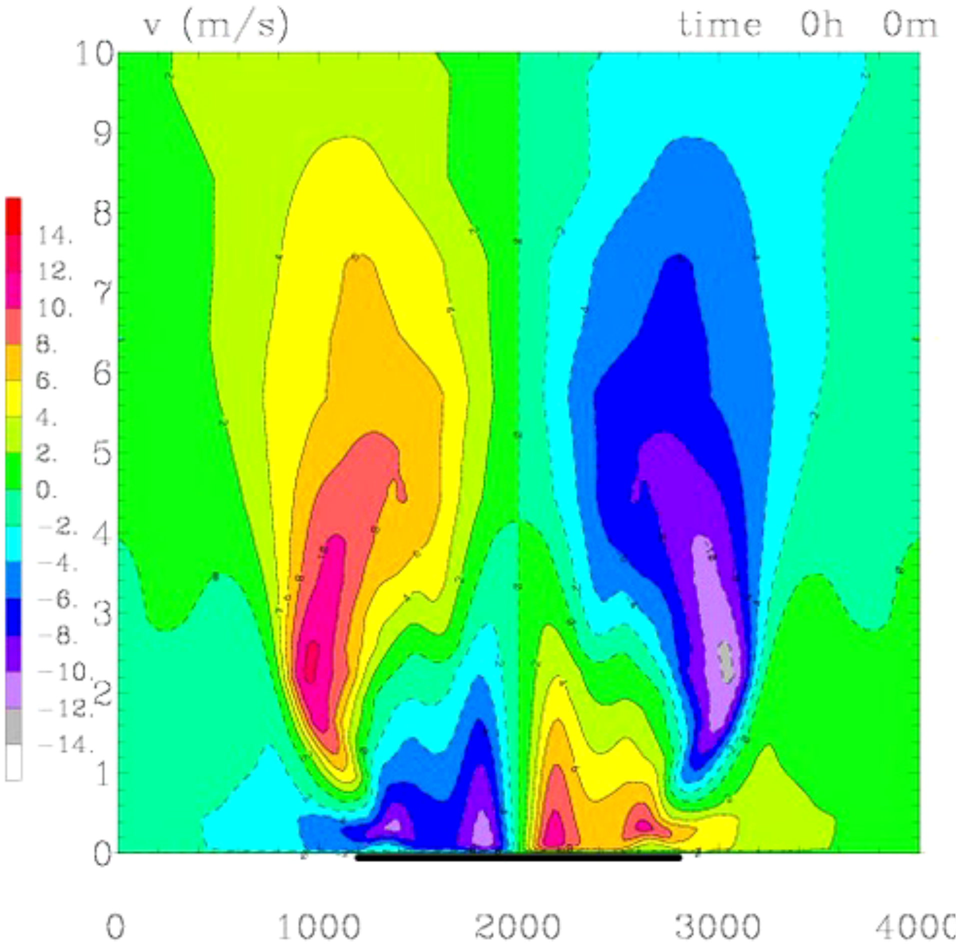
$$T(45^\circ)=16,97h$$

Turning low-level Jet

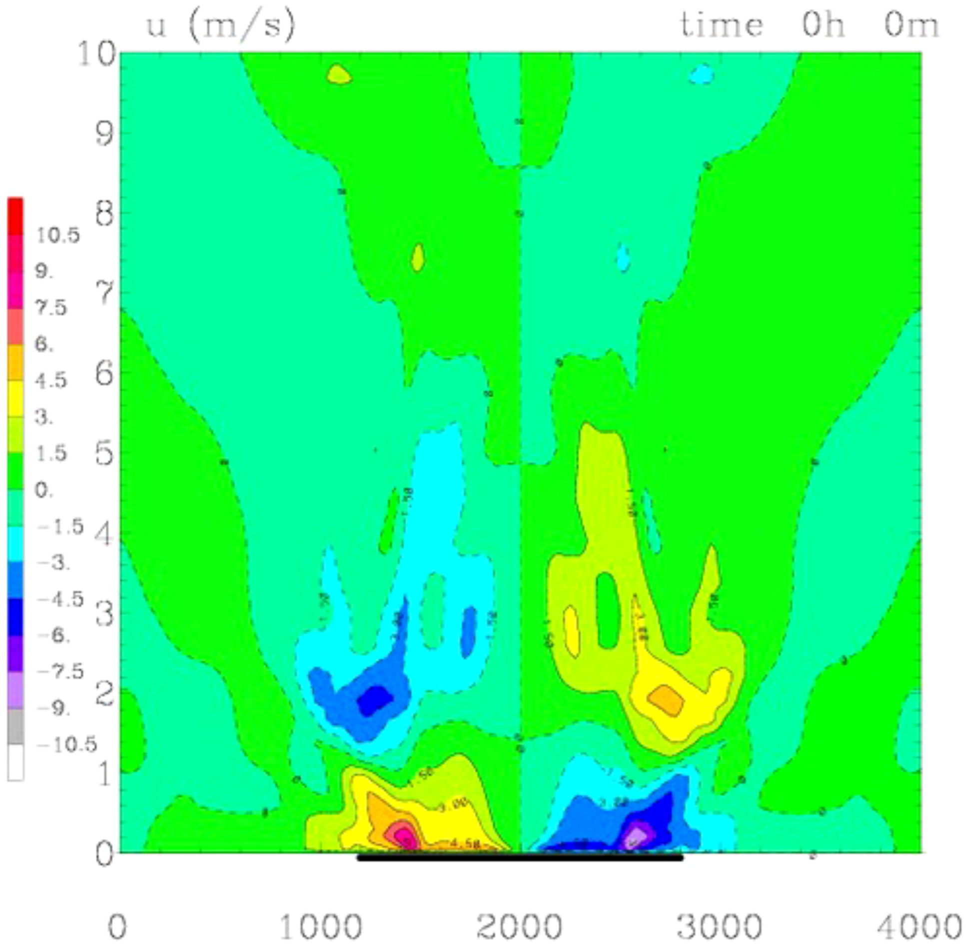


Results

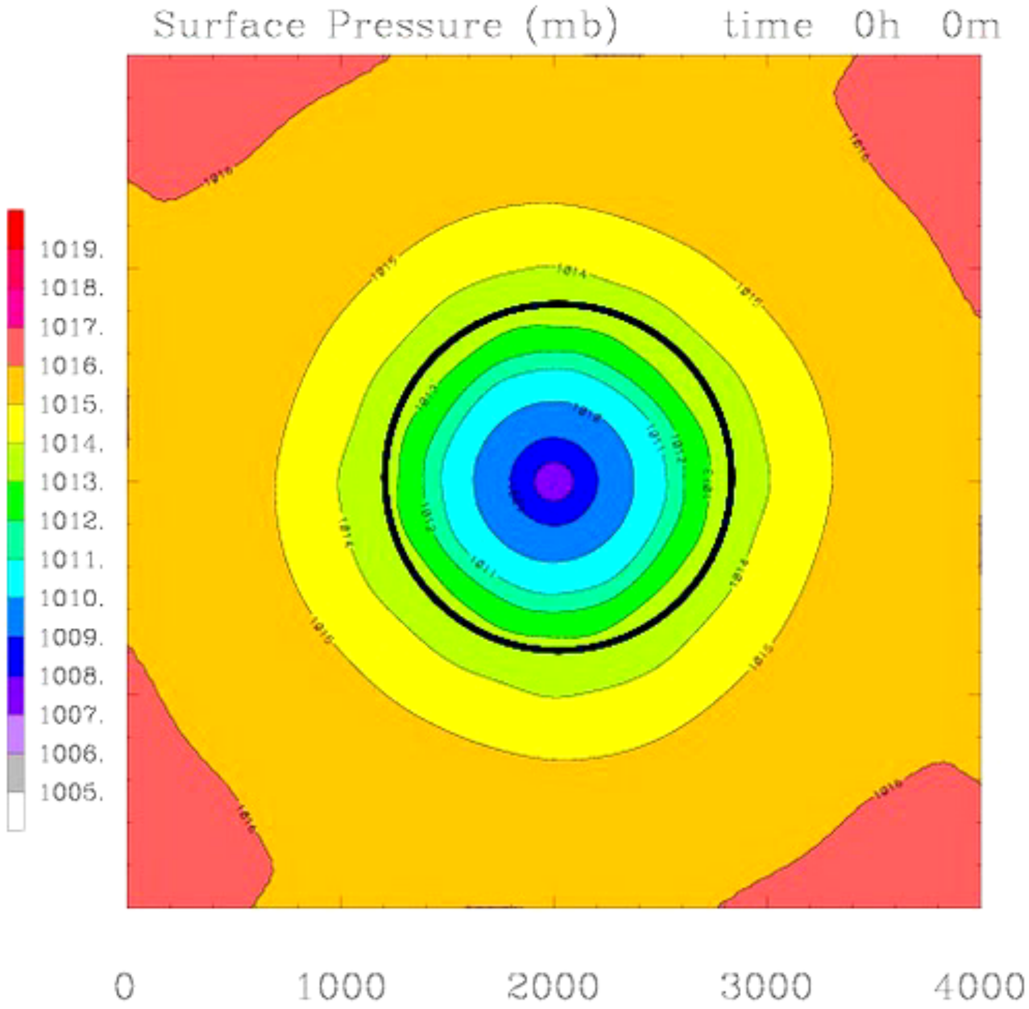
v component of wind



u component of wind



Results



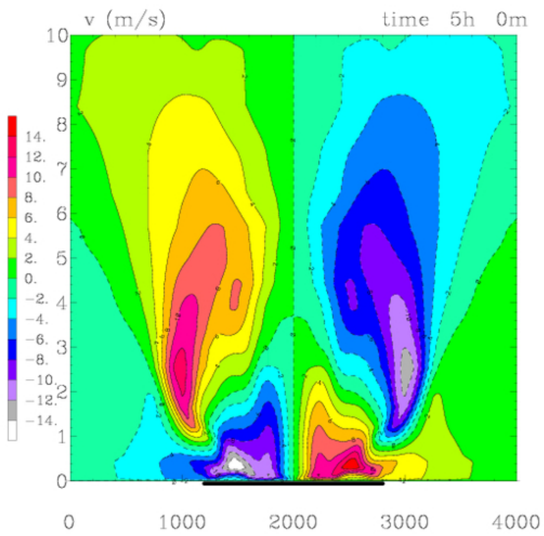
Surface low contracts during the night

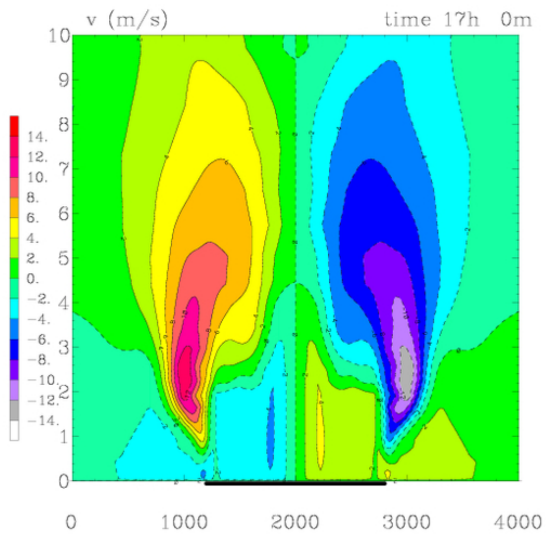
Pressure gradients centered at coast during the afternoon

Summary

- Cyclonic circulation at low levels, anticyclonic aloft
- Late afternoon minimum in surface pressure
- Maximum relative vorticity occurs in the early morning
- Low level relative vorticity is weak during the afternoon when convective mixing is at its peak

5 am



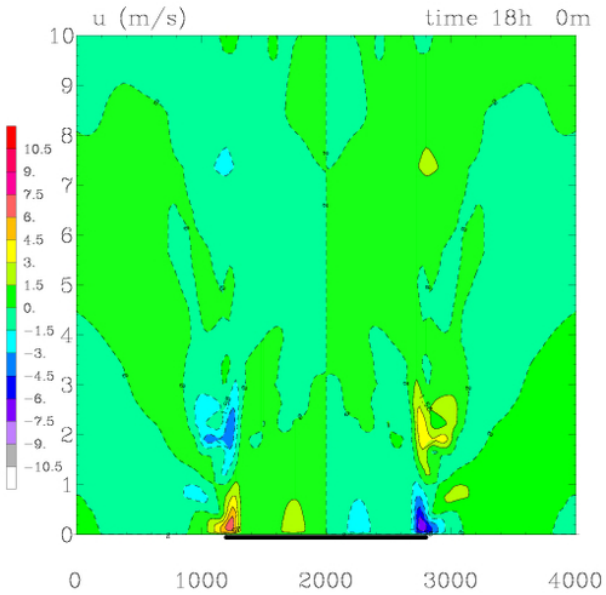


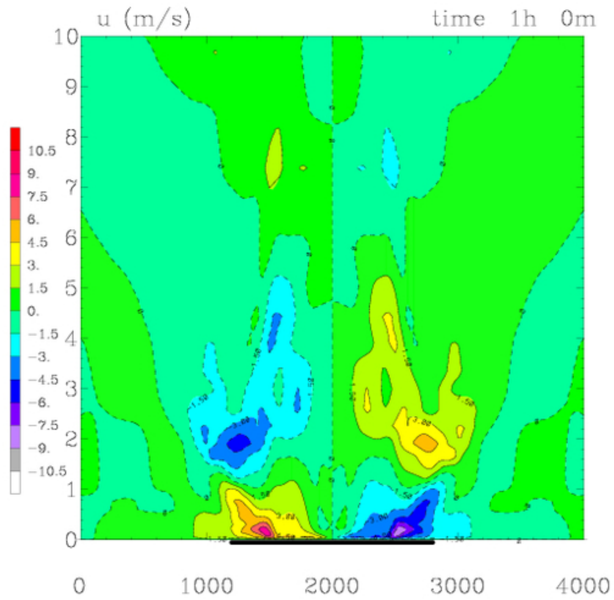
5 pm

Summary

- Sea breeze and low-level jet are key players in generating low-level convergence into the heat low during the late evening and early morning
- Flow has strong diurnal cycle at low levels
- Upper level anticyclone quasi-steady

6 pm

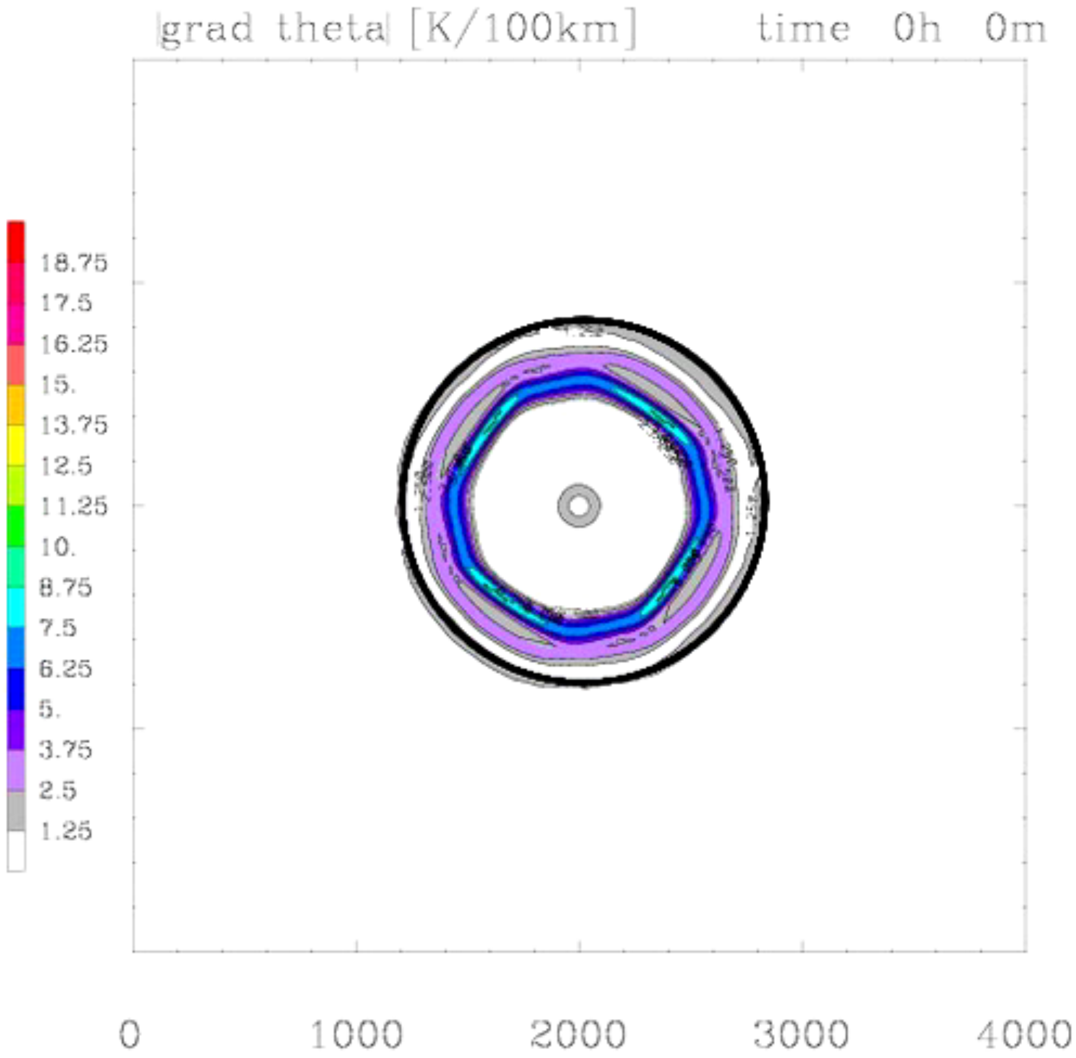




1 am

Nocturnal frontogenesis

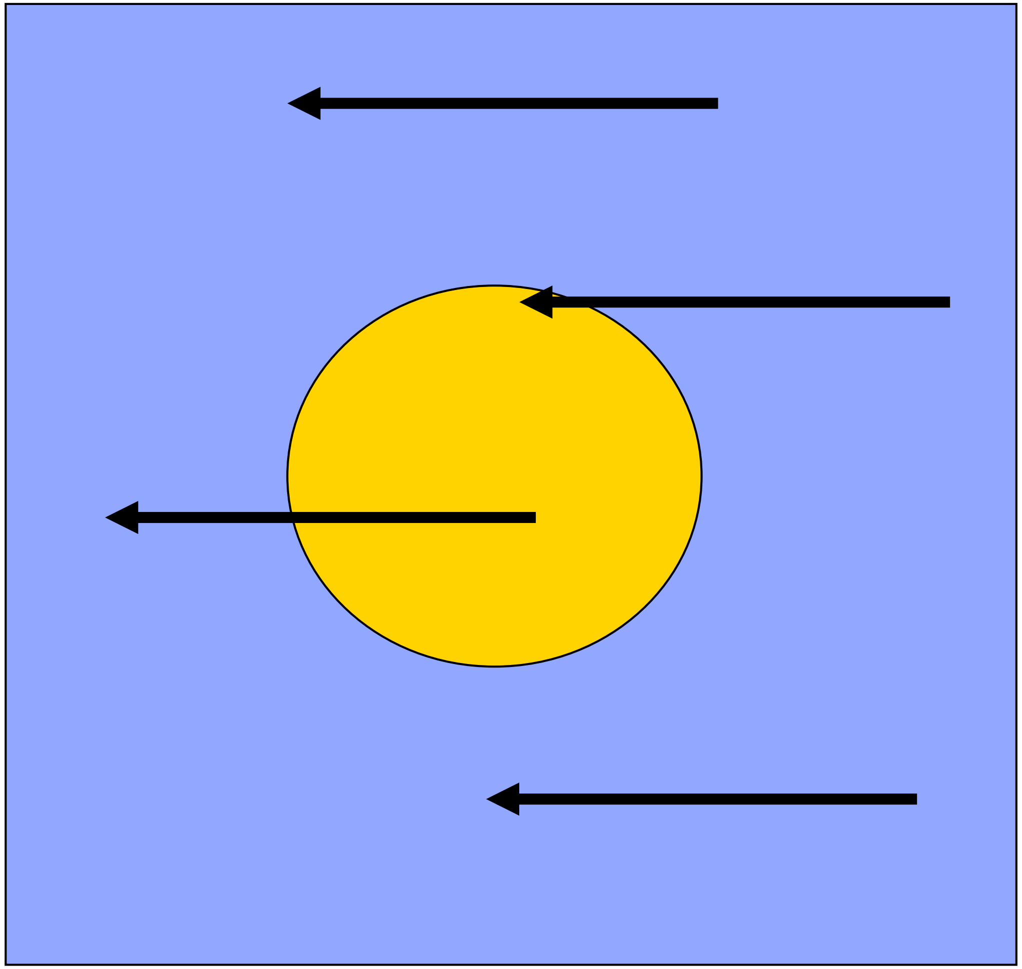
Gradient of theta (K/100 km)



Sea Breeze fronts during daytime

Nocturnal frontogenesis over island (advection/ contraction)

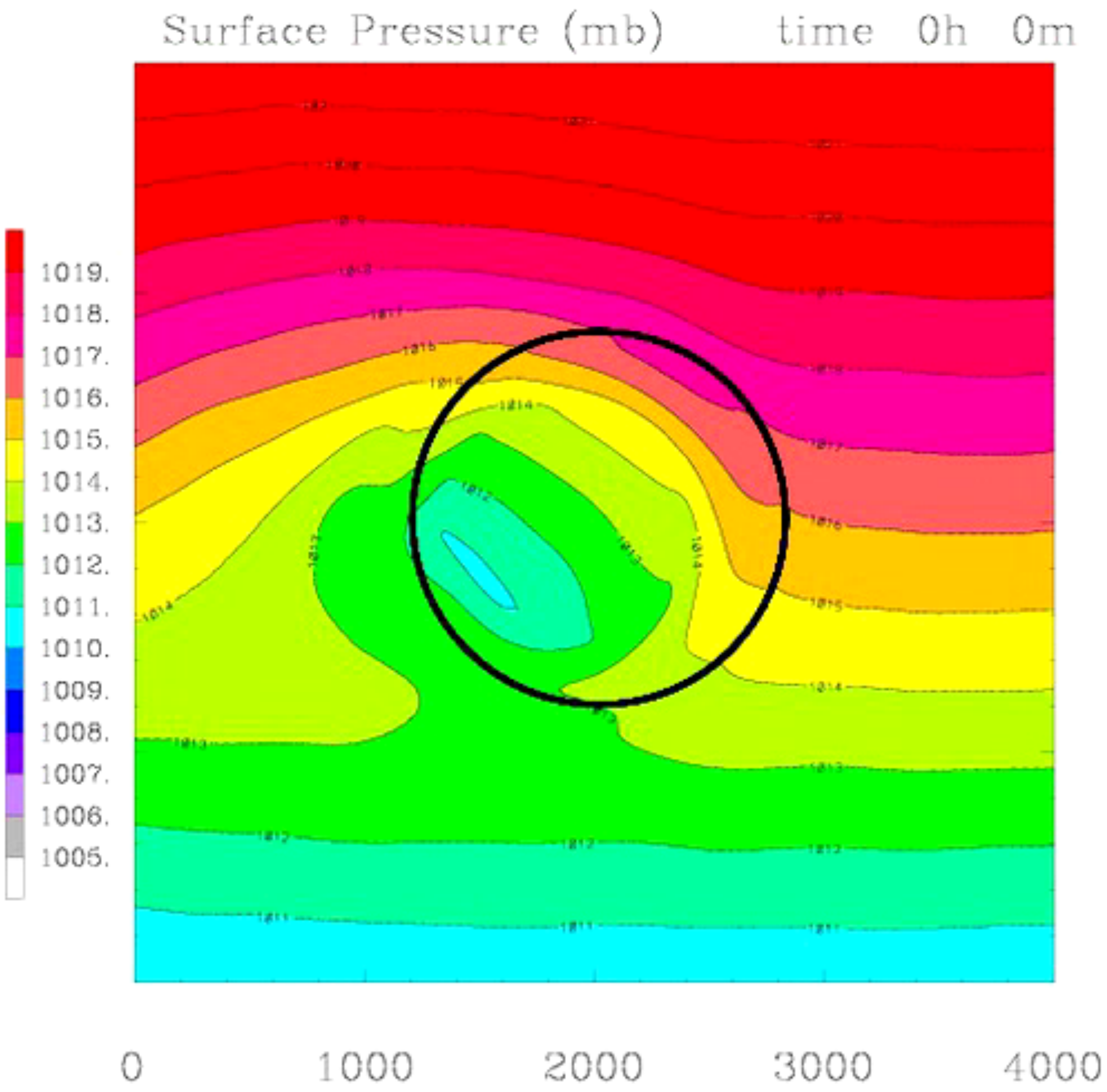
Background Flow



What are the effects on the heat low if a basic state background flow is imposed?

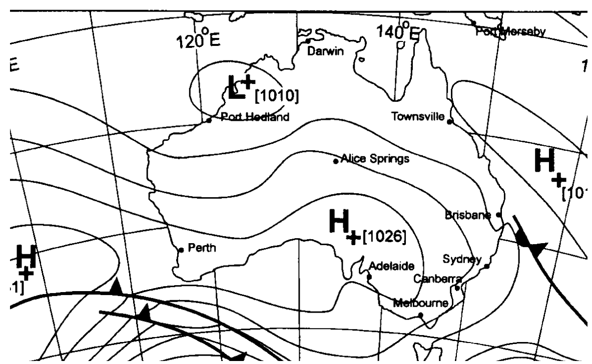
Motivation:
Trade winds in the subtropics

Background Flow

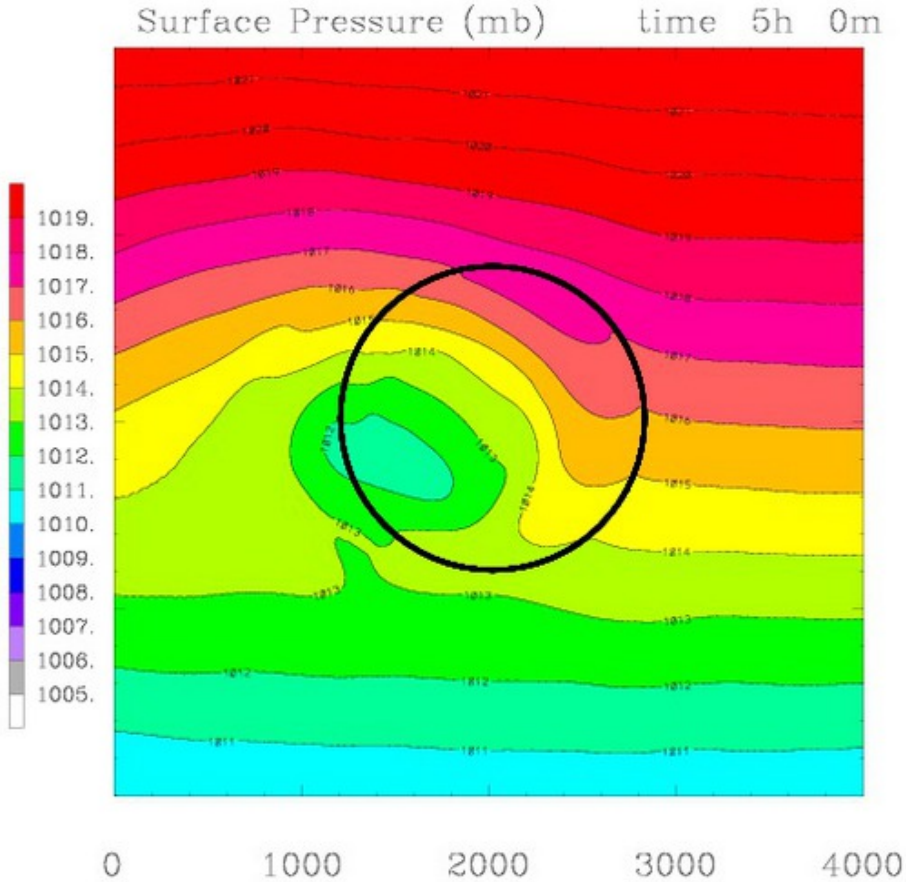


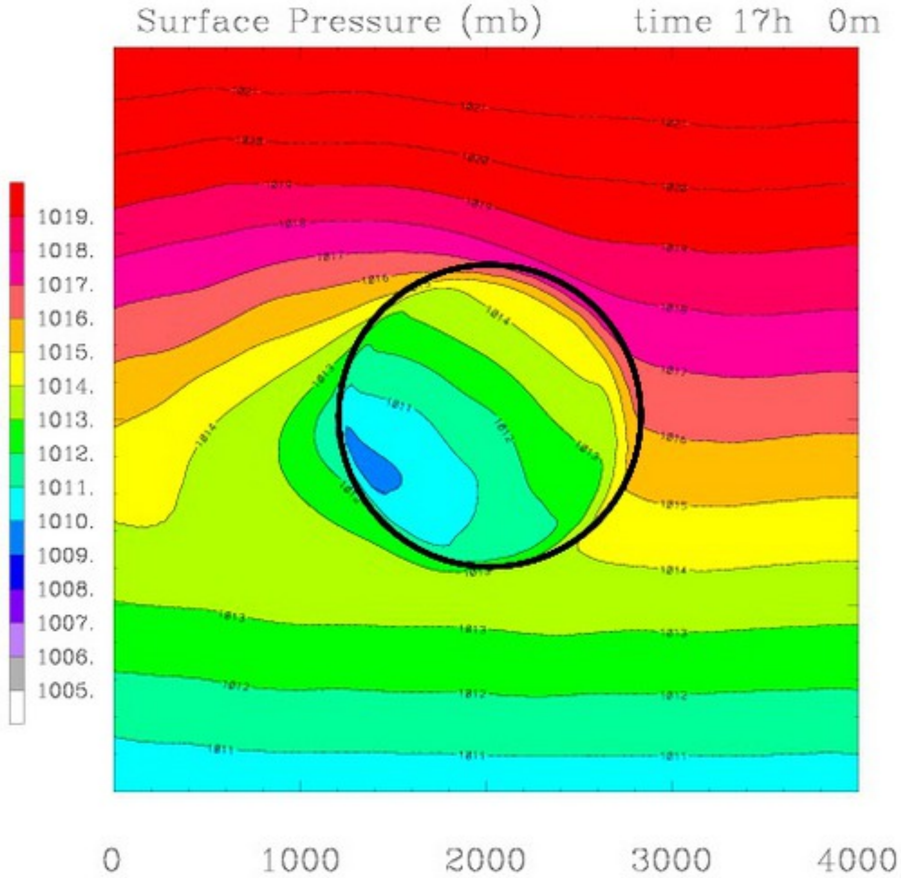
Trough forms on the lee-ward side of the heated island.

<u>See e.g.</u>
Australian West Coast Trough



Background Flow





5 am

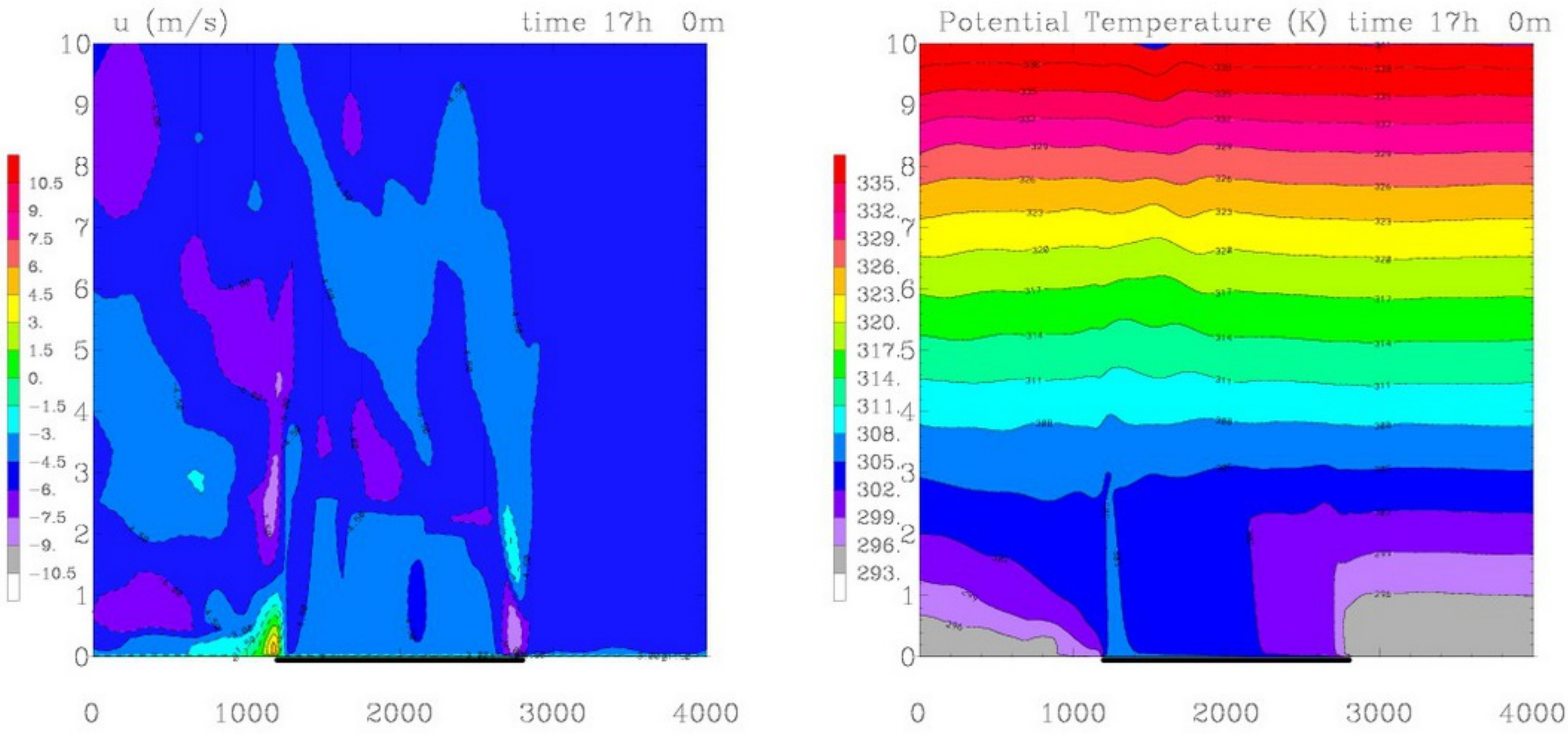
5 pm

tightens during the night

broadens during the day

Background Flow

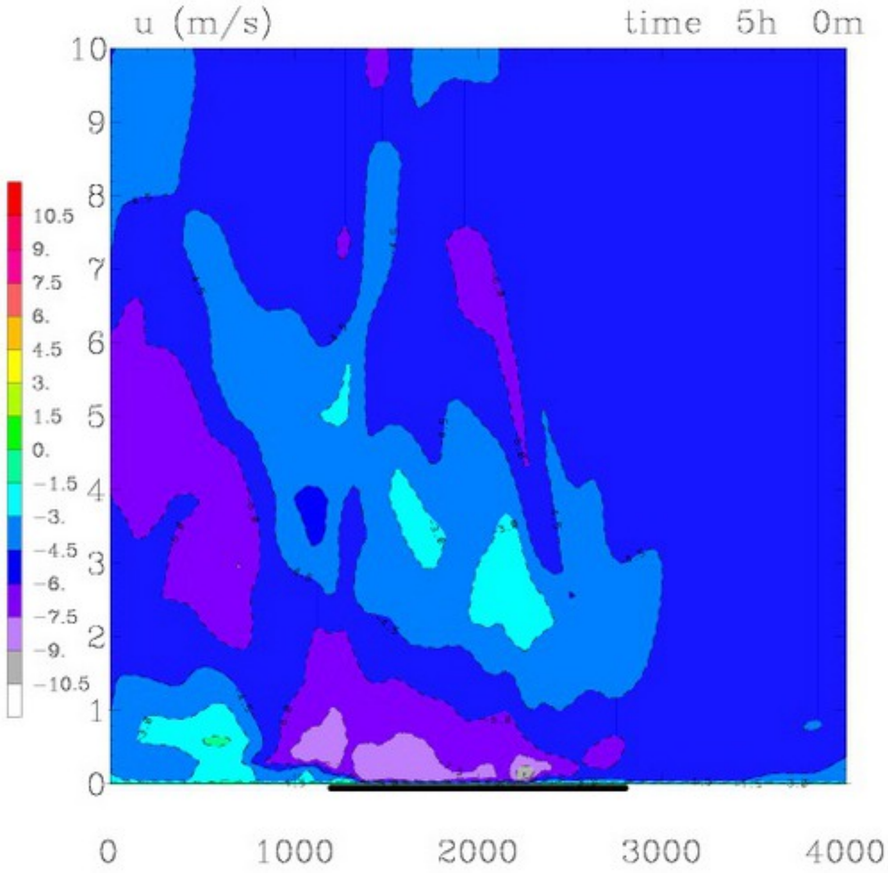
5 pm

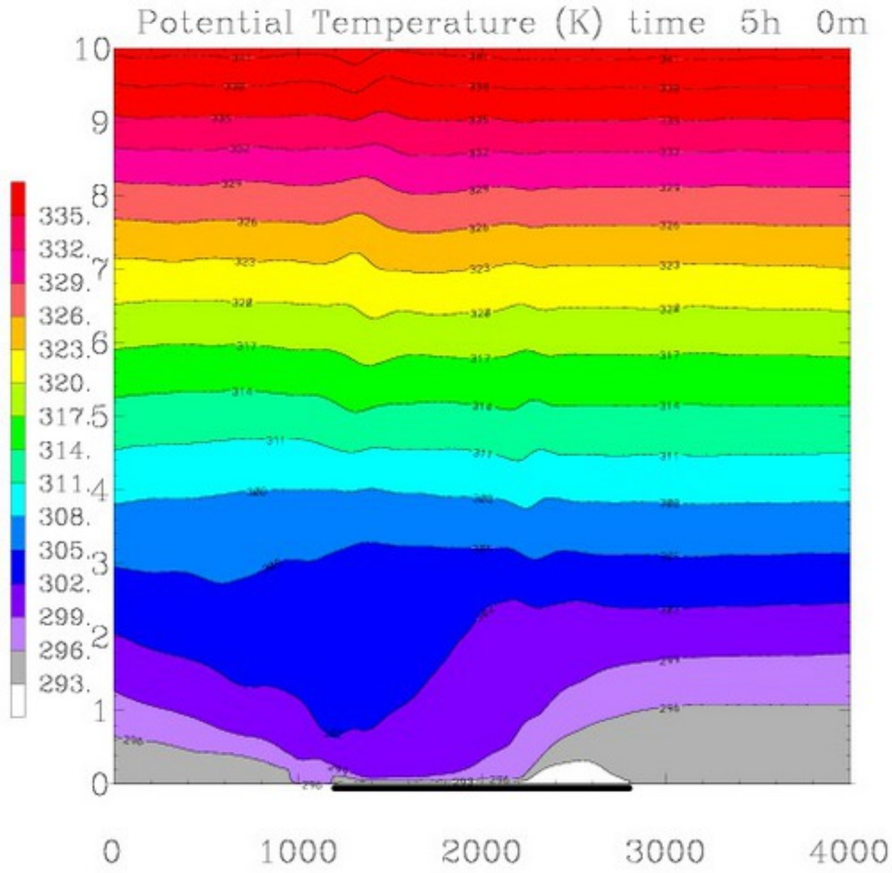


Wind-ward sea breeze circulation and sea breeze front weaker and shallower than lee side sea breeze

Background Flow

5 am

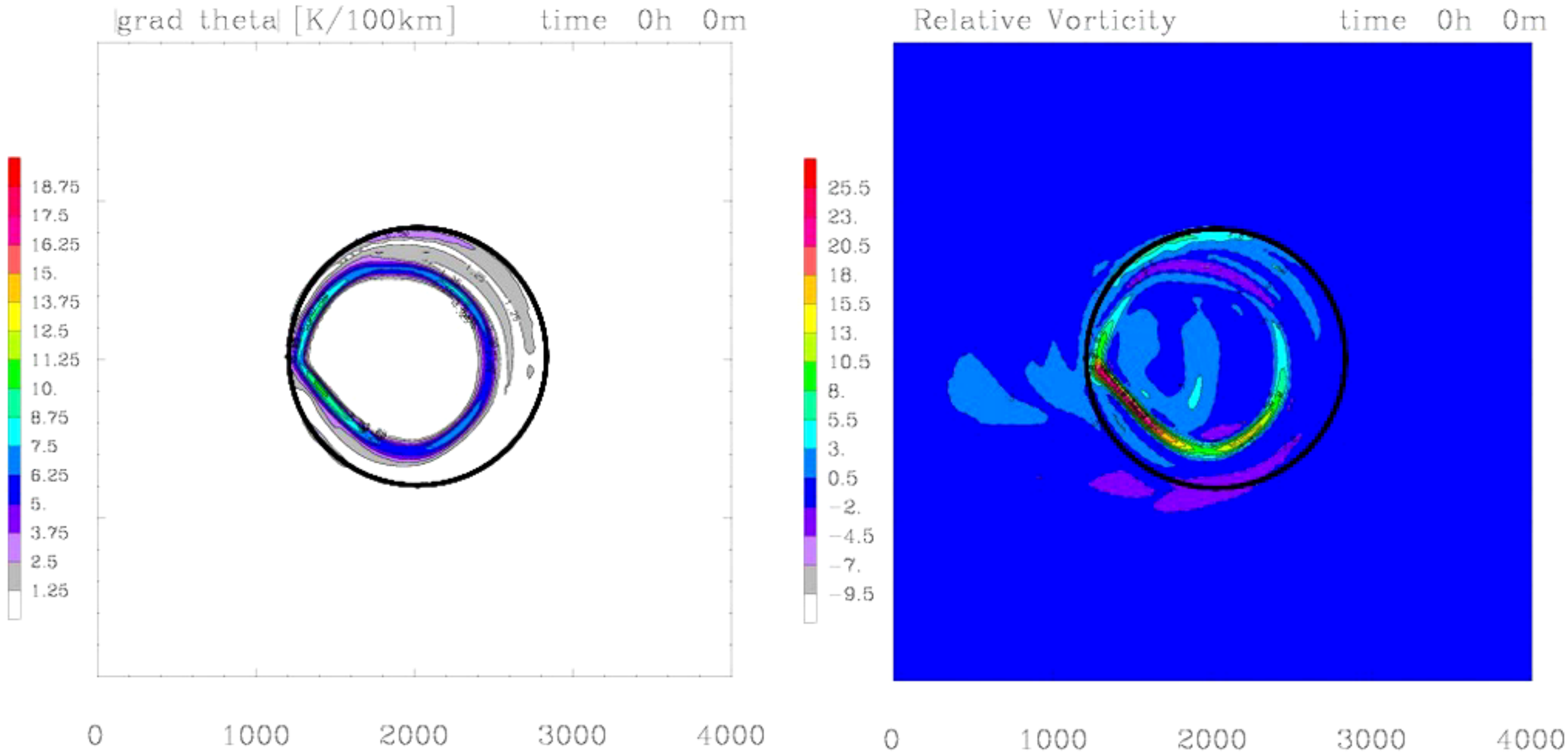




Warm air pushed out over sea during the night by mean easterlies. Warmer east coast breeze rides on west coast cold air.

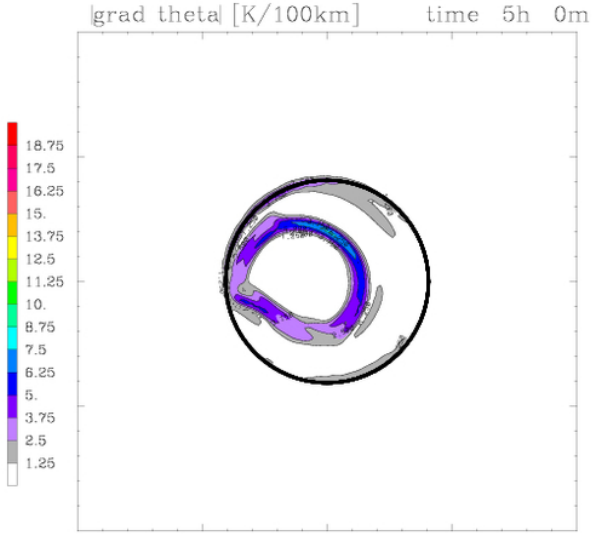
Background Flow

Nocturnal frontogenesis



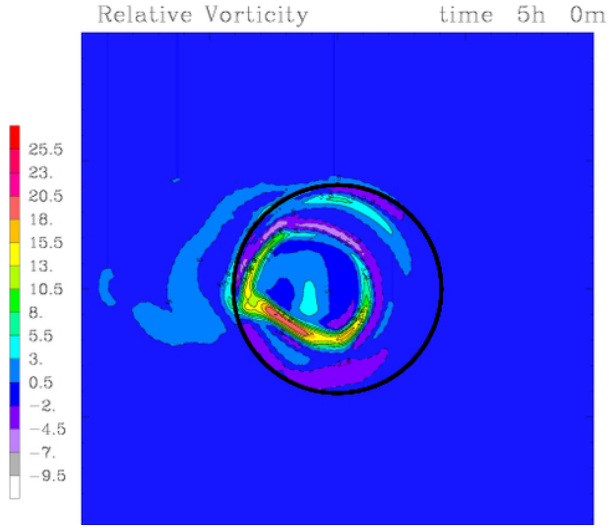
Background Flow

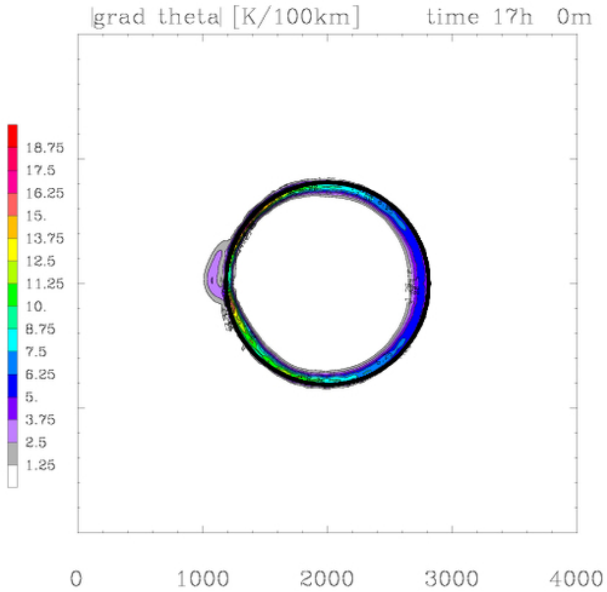
Nocturnal frontogenesis



5 am

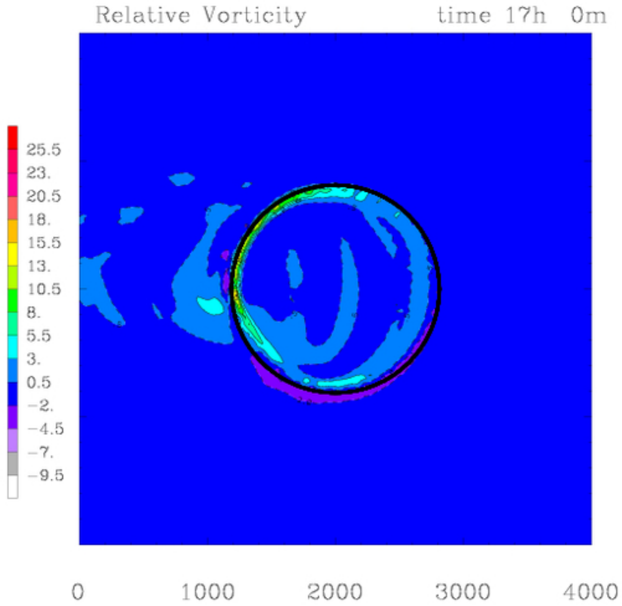
Frontal structures far inland. Dynamics of trough enhance genesis





5 pm

Gradients of theta and vorticity solely related to sea breeze fronts



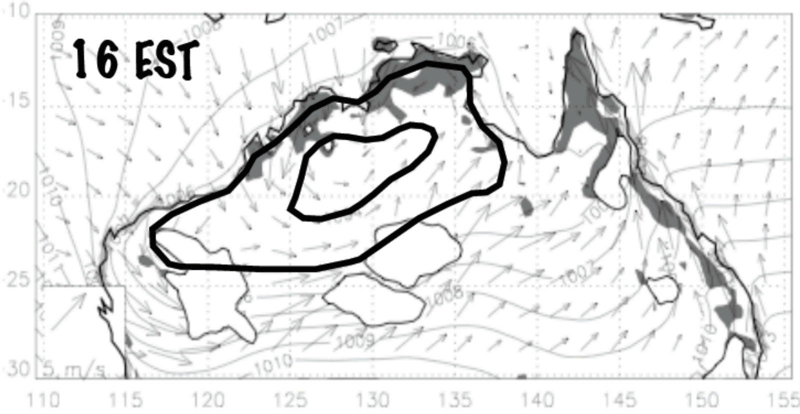
Background Flow

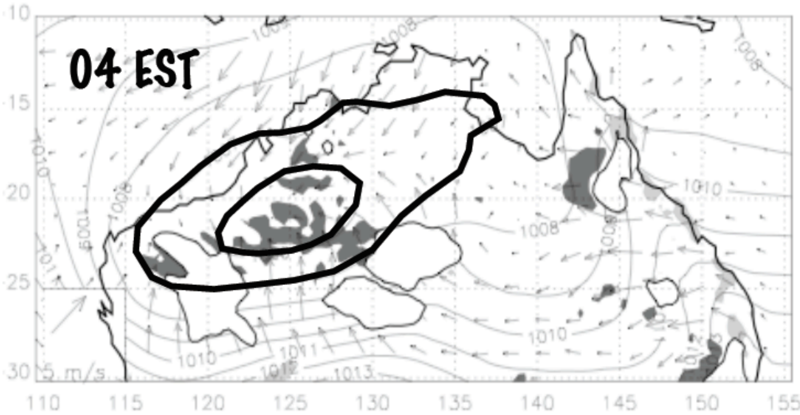
Subtropical cold fronts are difficult to predict
⇒Hazard to light aircrafts

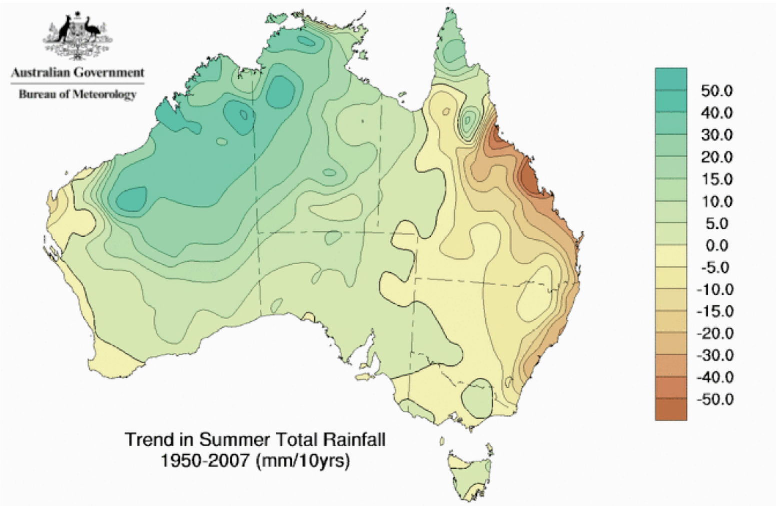
Strong low-level wind can pick up dust and aerosols.
⇒Once airborne they can be transported into the upper troposphere during the daytime mixing

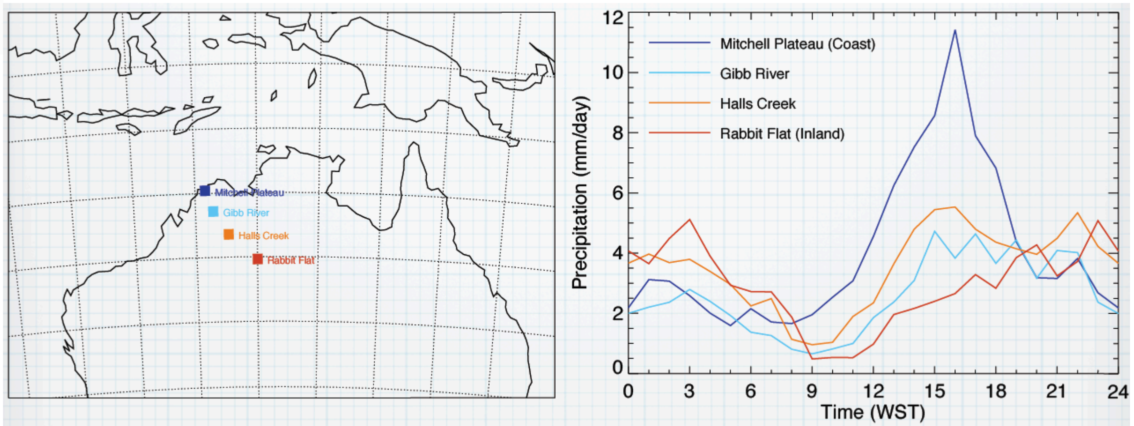
Background Flow

Low level fronts and convergence during the night can yield nocturnal thunderstorm activity (e.g. Northern Australia)



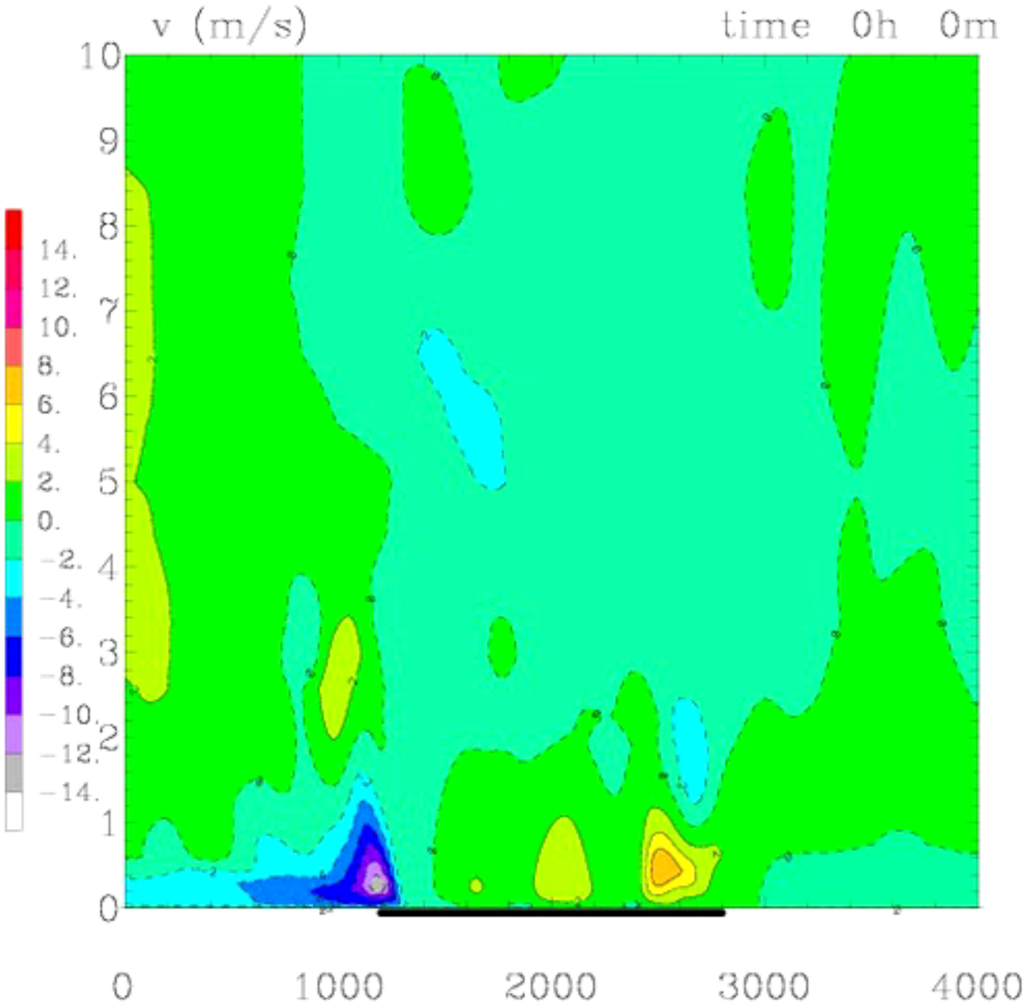






Courtesy:
Michael Reeder and Christian Jakob

Background Flow



No quasi-stationary upper level anticyclone evident!

???

?Why so sensitive?

???

Outlook/Open Questions

Heat Lows and wild fire

Heat Lows and heat wave conditions

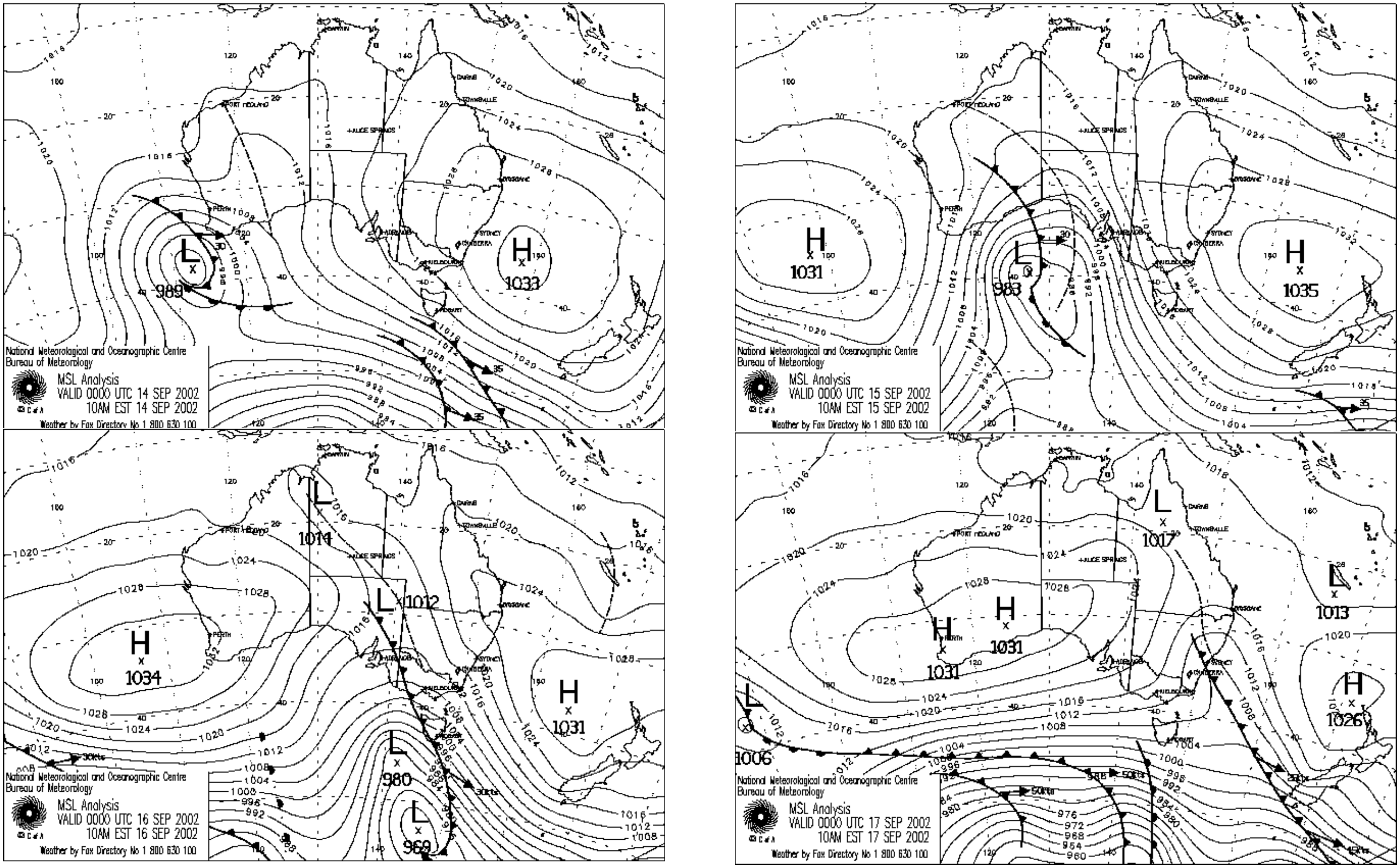
Heat Lows and dust transport

Heat Lows and desertification

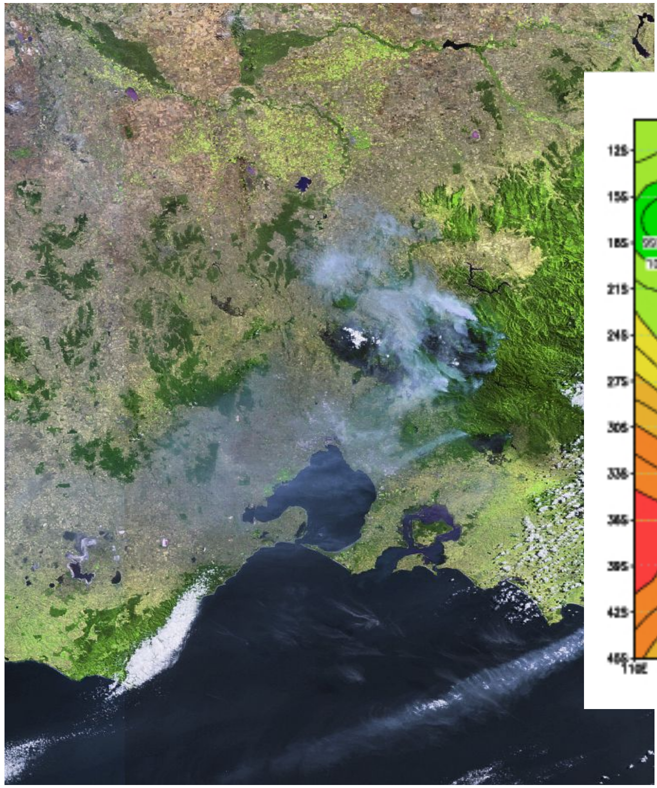
Heat Lows and orography

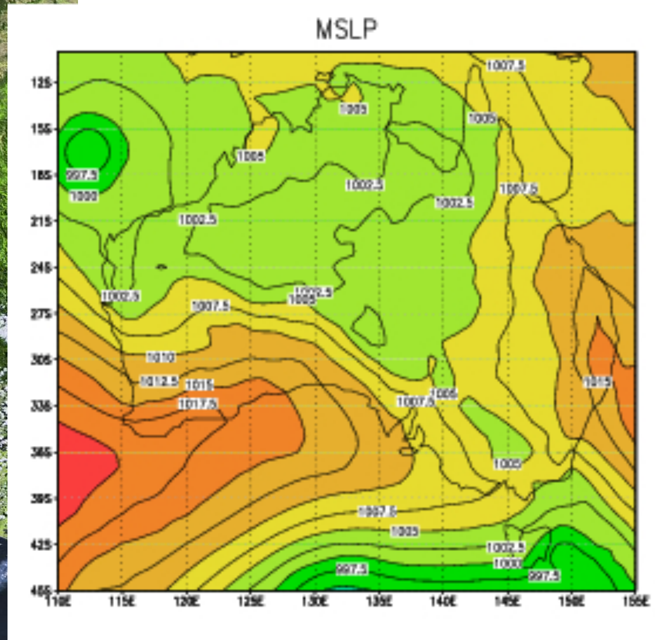
Heat Lows and Climate Change

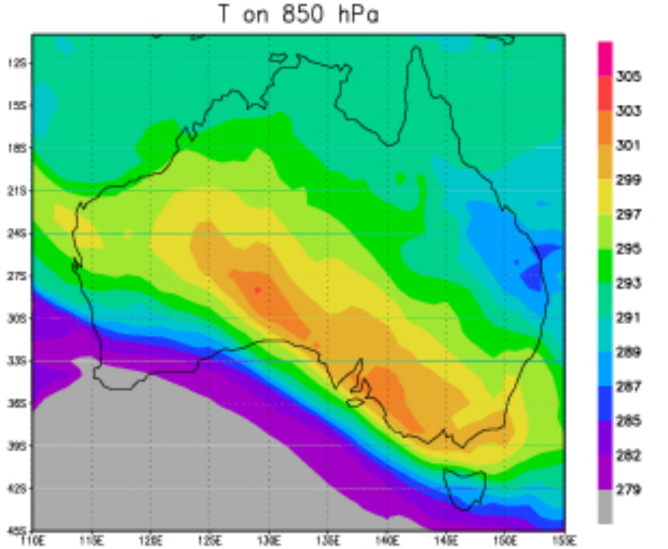
Australian Troughs

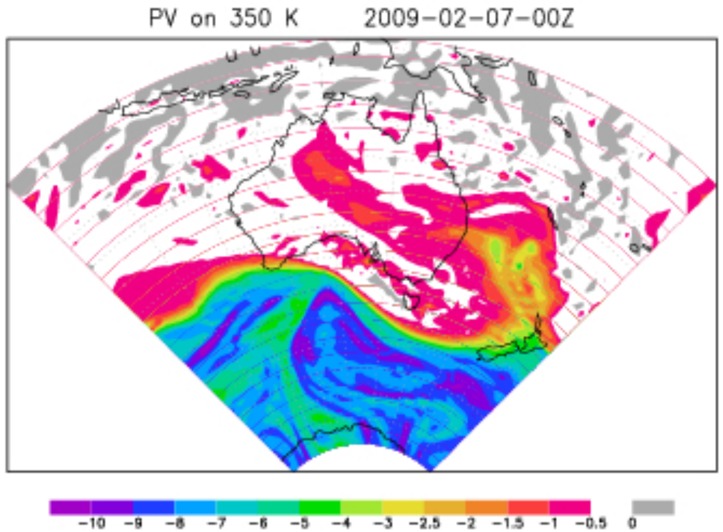


Outlook/Open Questions









Summary

Strong diurnal cycle in the lower levels
⇒ Maximum cyclonic circulation at night/early morning
⇒ Cyclonic circulation absent during daytime (mixing)

Upper level anticyclone quasi-stationary
⇒ In gradient wind balance
⇒ existence rather sensitive to background flow

Nocturnal frontogenesis
⇒ Turning of low level jet yields convergence patterns
⇒ fronts disappear once heating commences
⇒ nocturnal convergence initiating thunderstorms

Deformation of Heat Lows yields troughs
⇒ Subtropical cold fronts (Australia, Africa)