A Dynamical Investigation of the May 2004 McMurdo Antarctica Severe Wind Event Using AMPS

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Introduction

- Severe windstorm at McMurdo 15-16 May 2004
- Building 71 maximum wind gust of 71.5 m s^{-1}, Arrival Heights 84 m s^{-1} (Dalrymple 2004)
- Severe damage to base

www.southpolestation.com/mcm/storm.html

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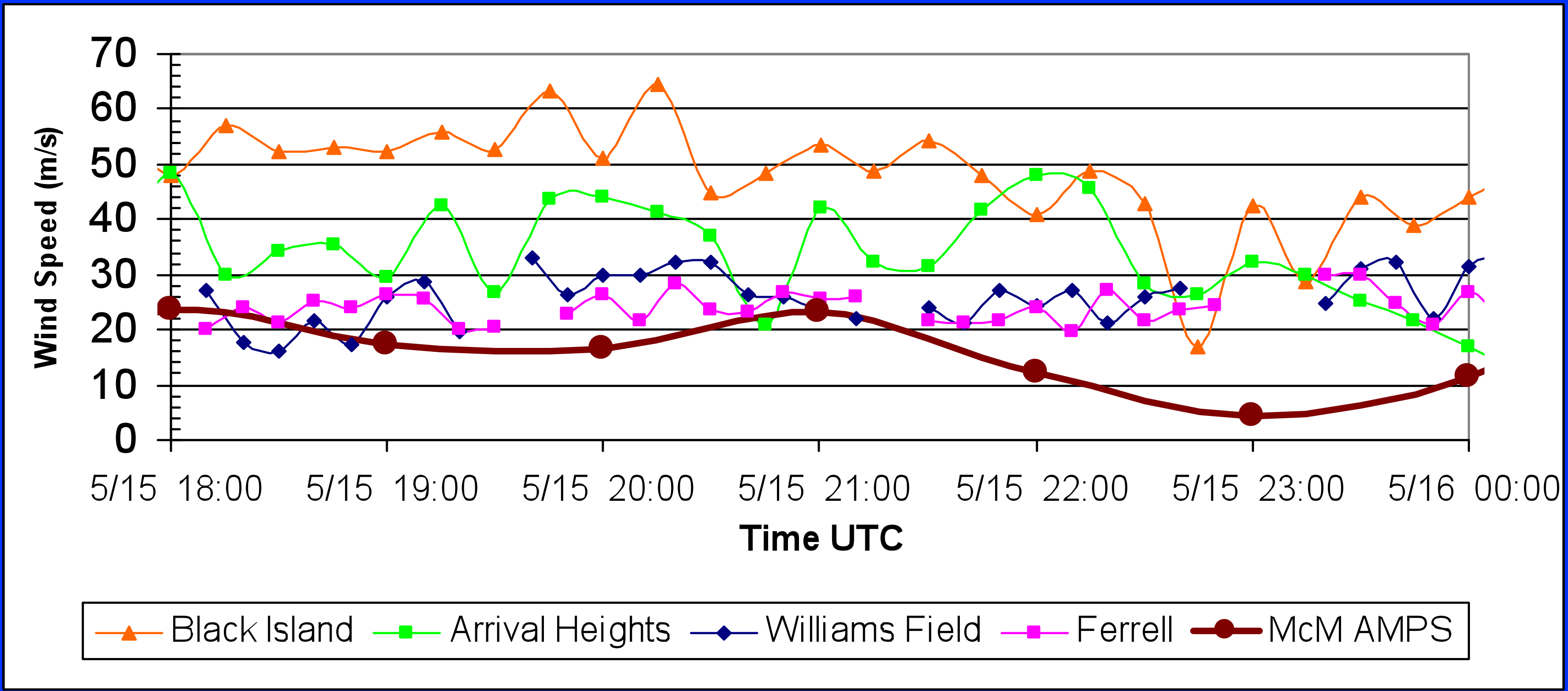
Introduction



- Why are AMPS McMurdo wind speeds so low?
- What localized effects in the Ross Island area cause Black Island and Arrival Heights wind speeds to be higher than Ferrell?
  - And what even smaller scale effects cause them to be higher than Williams Field?

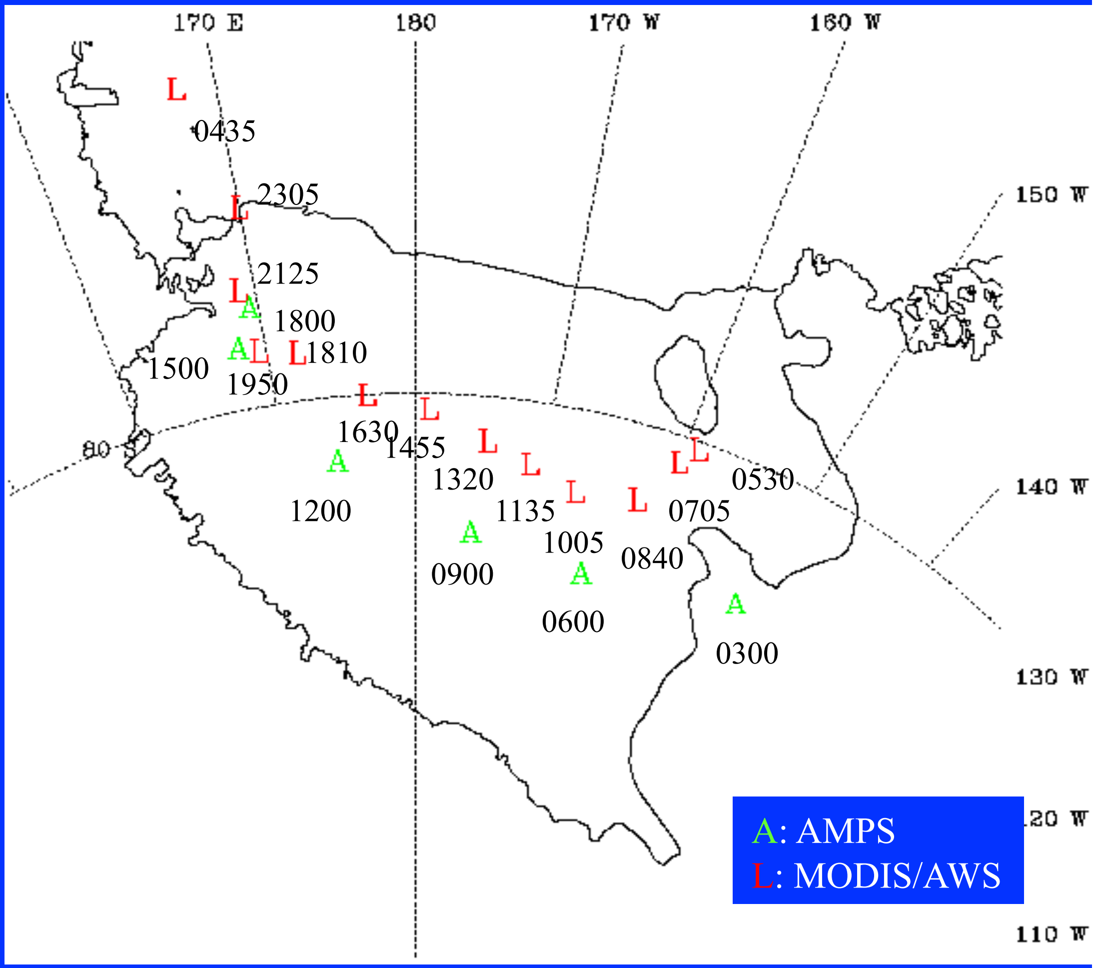
Presentation Outline

- Brief synoptic overview
- Barrier wind forcing
- Mountain wave systems
- Ross Island area flow structure
- Localized effects
- Conclusions

Note: AMPS 12-24 hour forecasts, initialized every 12 hours, are used except from 2100 UTC 15 May to 0000 UTC 16 May, where 9-12 hour forecasts are used.

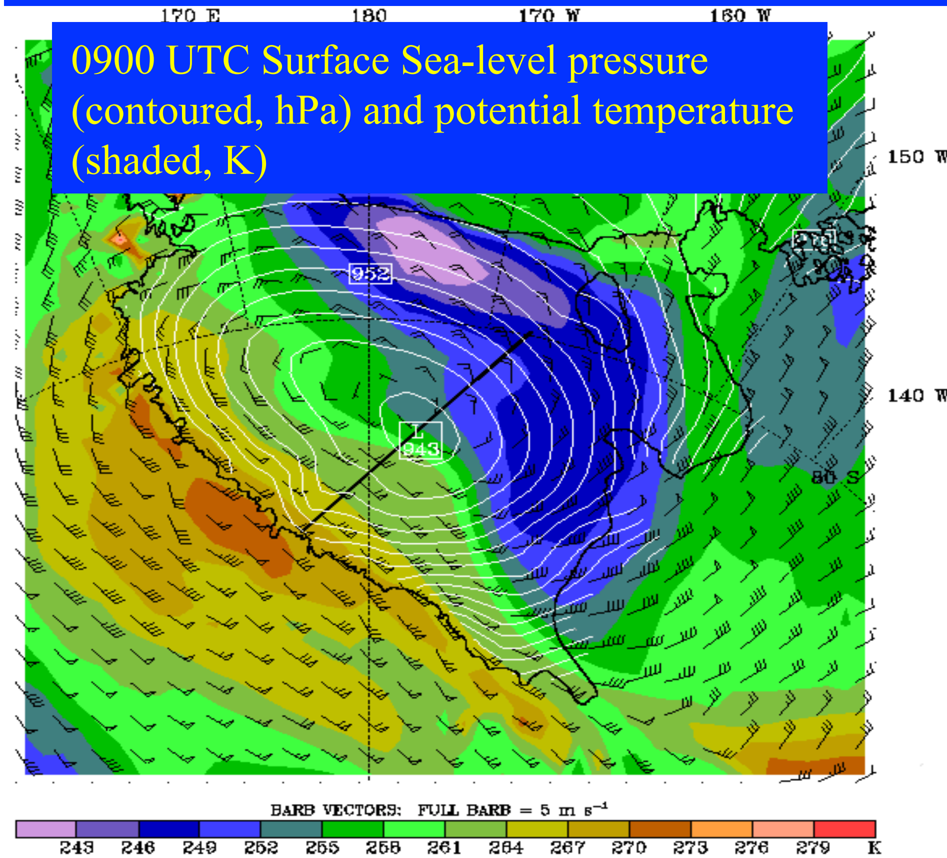
Brief Synoptic Overview

- Minimum central sea-level pressure of cyclone increases by 45 hPa (2.5 hPa/hour) between 0600 UTC 15 May and 0000 UTC 16 May in AMPS, AWS analysis shows similar rate of increase
- No synoptic-scale pressure gradient intensification around the cyclone – it's not the primary component of the McMurdo windstorm

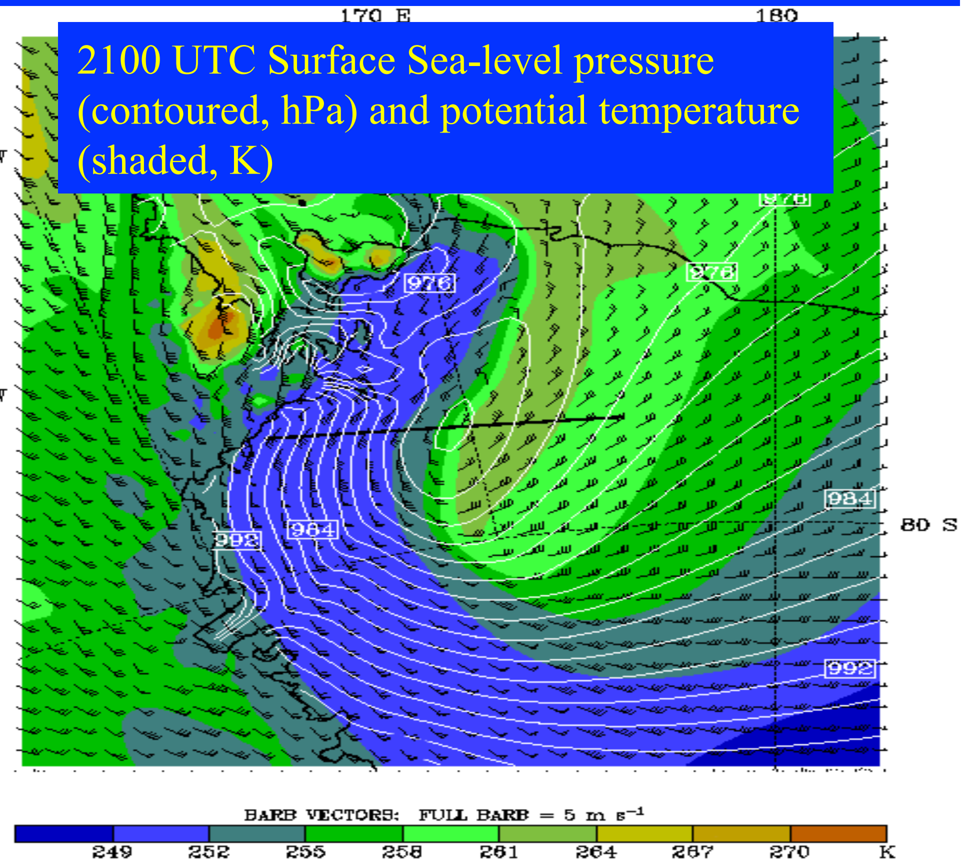


Barrier Wind

- Northerly flow directed into Transantarctic Mountains lacks momentum to traverse the terrain, based on the Froude Number (Fr), setting up barrier jet which increases pressure gradient and wind speeds in western sector of cyclone
- Cold air at surface entrained into cyclone, advected to Ross Island area by barrier wind



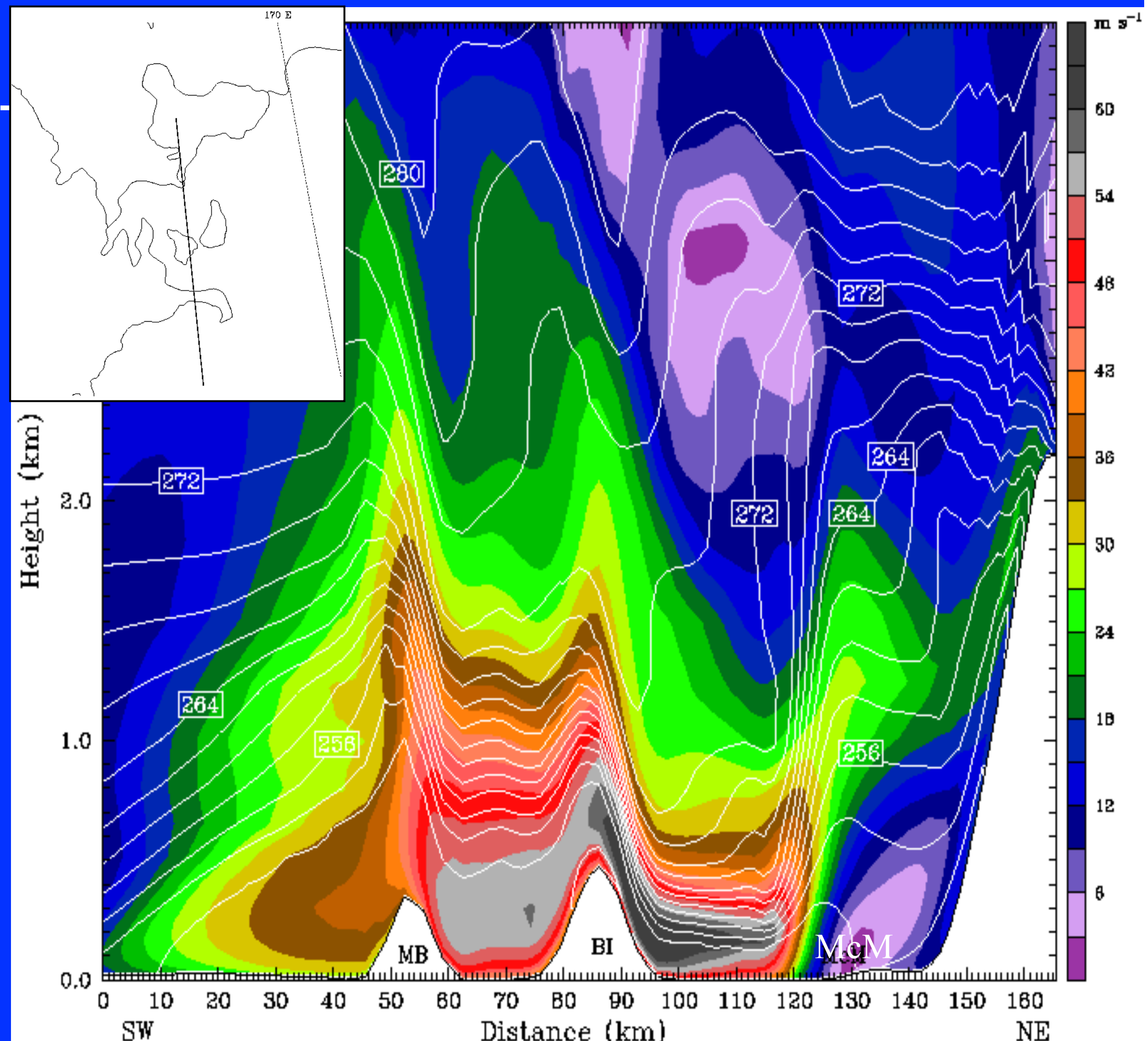
0900 UTC Surface Sea-level pressure (contoured, hPa) and potential temperature (shaded, K)



2100 UTC Surface Sea-level pressure (contoured, hPa) and potential temperature (shaded, K)

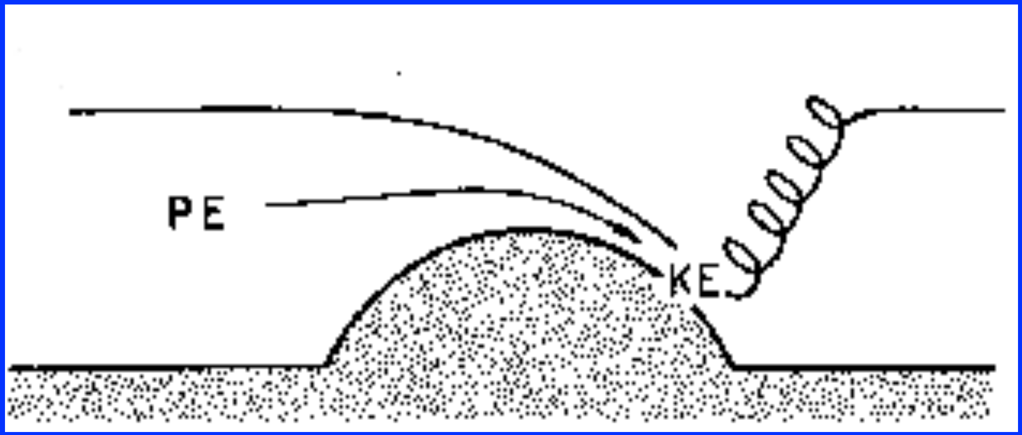
Mountain Waves

- Downslope windstorm on lee slopes from large-amplitude mountain waves
- Hydraulic theory (Long 1953, Durran 1986, 1990): subcritical (Fr < 1) flow transitions to supercritical (Fr > 1) flow at crest, continues to accelerate downslope
- Hydraulic jump downstream as flow adjusts to ambient conditions



2300 UTC Potential Temperature (contoured, K) and horizontal wind speed (shaded, m s^{-1}). MB = Minna Bluff, BI = Black Island, McM = McMurdo

Mountain Waves



From Durran (1986)

- Conversion of Potential Energy (PE) to Kinetic Energy (KE) continues along entire slope (Durran 1990)
- Why are barrier wind effects important? Enhanced wind speeds minimizes terrain blocking, cold air advection at the surface and associated inversion set up hydraulic layer
- Scorer parameter layering and wave-induced critical layers due to wave breaking likely cause wave amplification, transition from subcritical to supercritical flow

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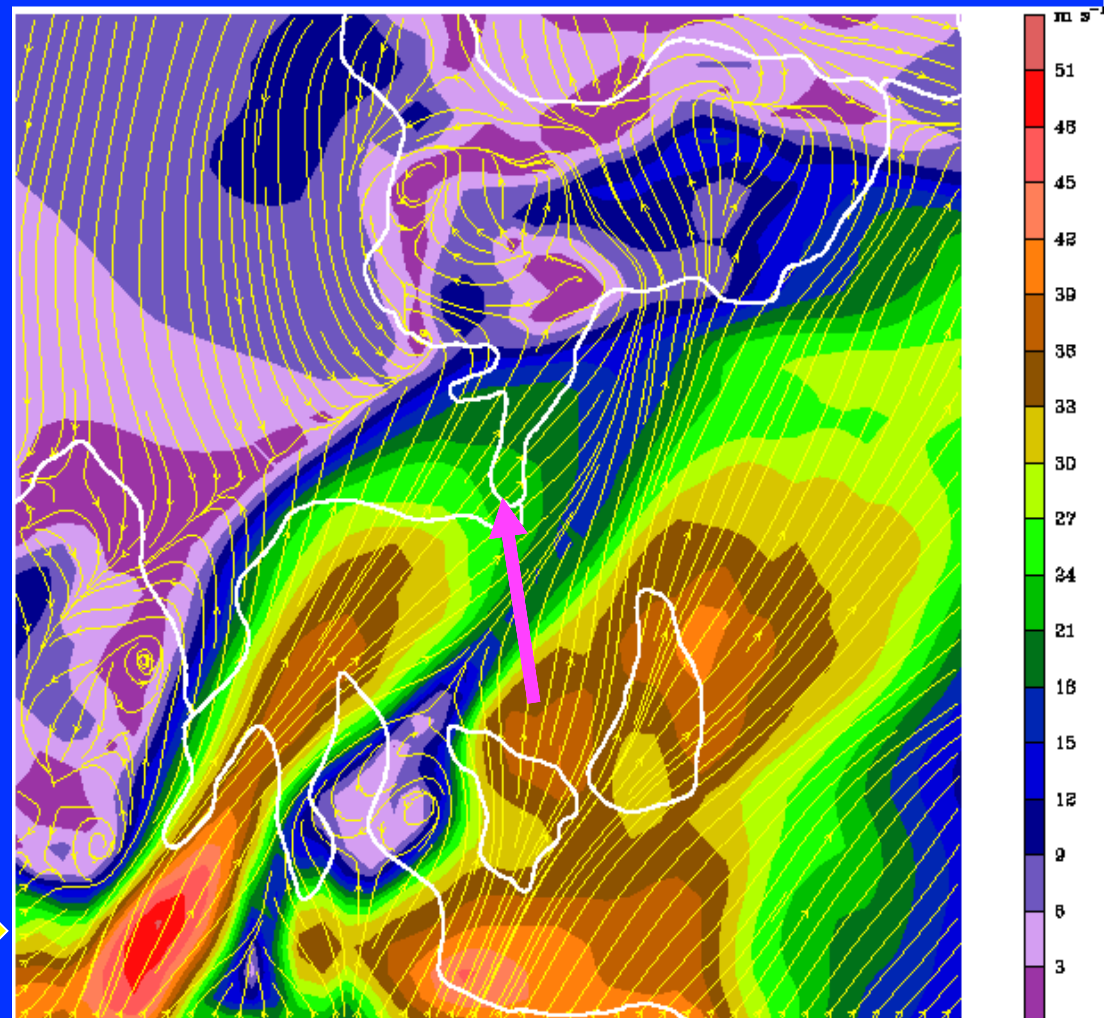
AMPS Mountain Wave Errors

- Why are wind speeds so low at McMurdo?
- No evidence of southwesterly flow in McMurdo area at AWS sites, they show more of a southerly flow

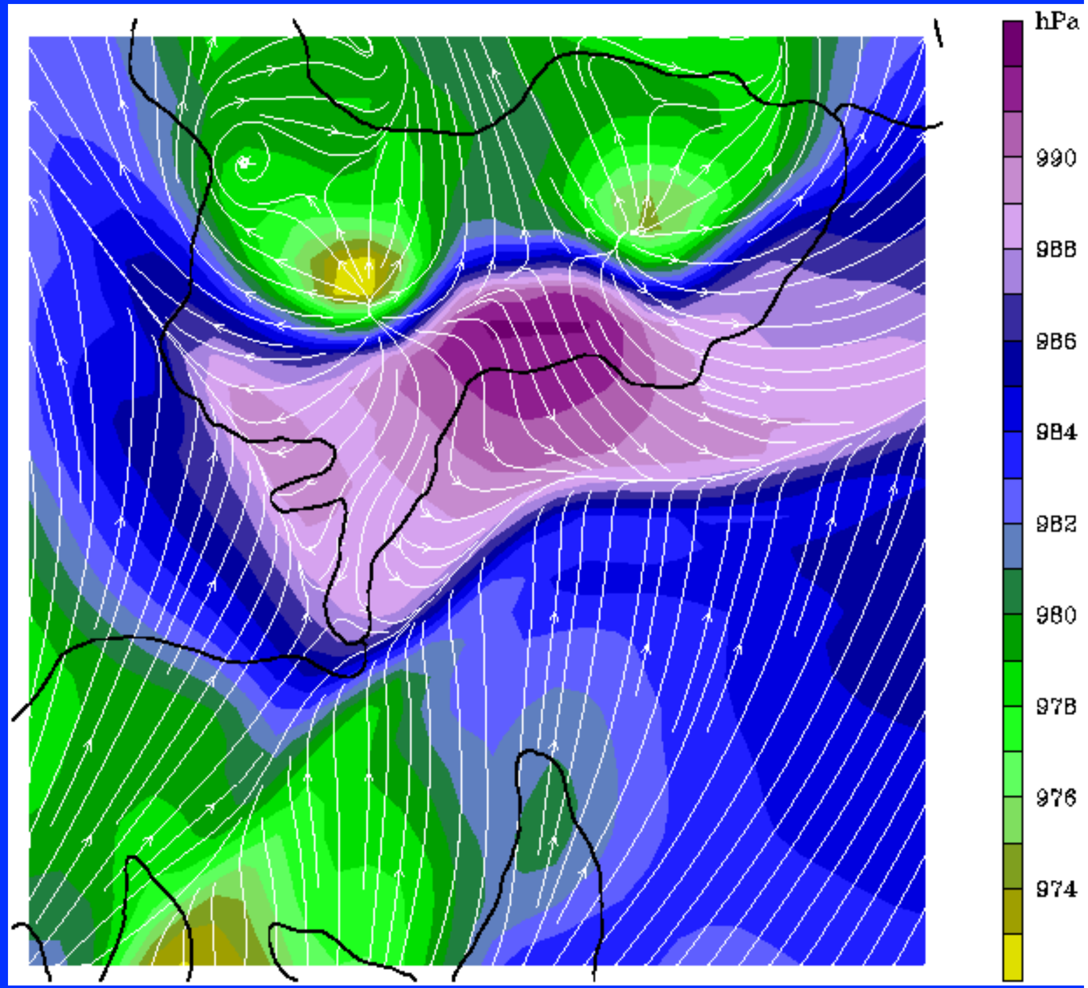


1800 UTC 15 May 2004
surface horizontal wind speed
(m s^{-1}) and surface streamlines

AMPS Mountain Wave Errors

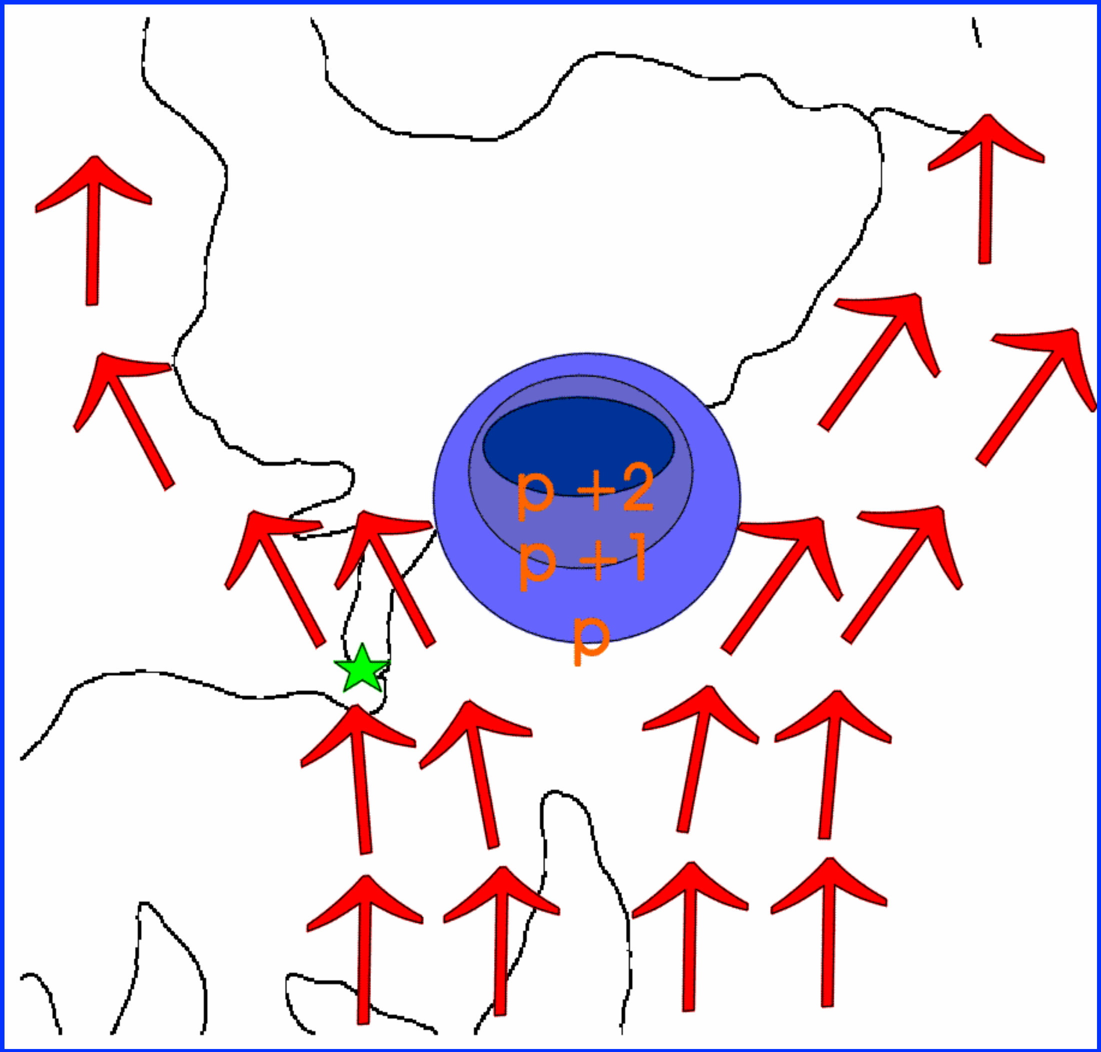
- Incorrect flow pattern sets up a deflection zone over the McMurdo area
- Hydraulic jump located at interface of deflection zone, which is upstream of McMurdo, causing wind speeds to be too low there

0000 UTC 16 May 2004 sea-level pressure (hPa) and surface streamlines.

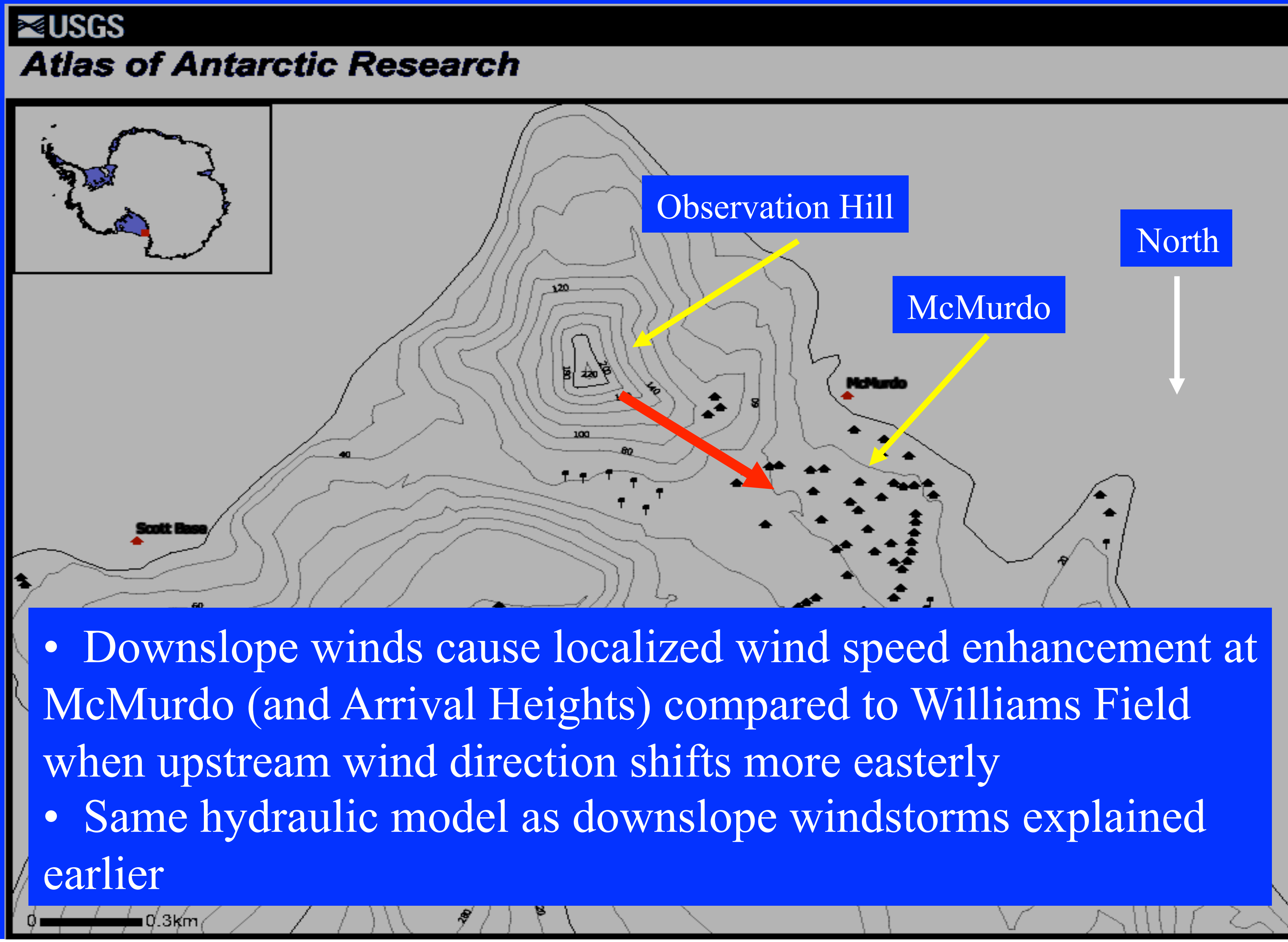


AMPS Mountain Wave Errors

- In reality, flow deflection will occur farther east near Windless Bight, as in Slotten and Stearns (1987), O'Connor and Bromwich (1988), and Seefeldt et al. (2003)
- Hydraulic jump will shift northward, and stronger wind speeds from downslope windstorm will reach McMurdo



Localized Effects



- Downslope winds cause localized wind speed enhancement at McMurdo (and Arrival Heights) compared to Williams Field when upstream wind direction shifts more easterly
- Same hydraulic model as downslope windstorms explained earlier

Conclusions

- Cold air at surface and enhanced southerly winds by barrier wind set up mountain wave system, downslope windstorms
- Additional downslope windstorms off Observation Hill and other terrain features enhance wind speeds at McMurdo and Arrival Heights
- Misrepresented flow structure in Ross Island region leads to displaced hydraulic jump and low wind speeds at McMurdo

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Questions / Comments?

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References (Including extra slides)

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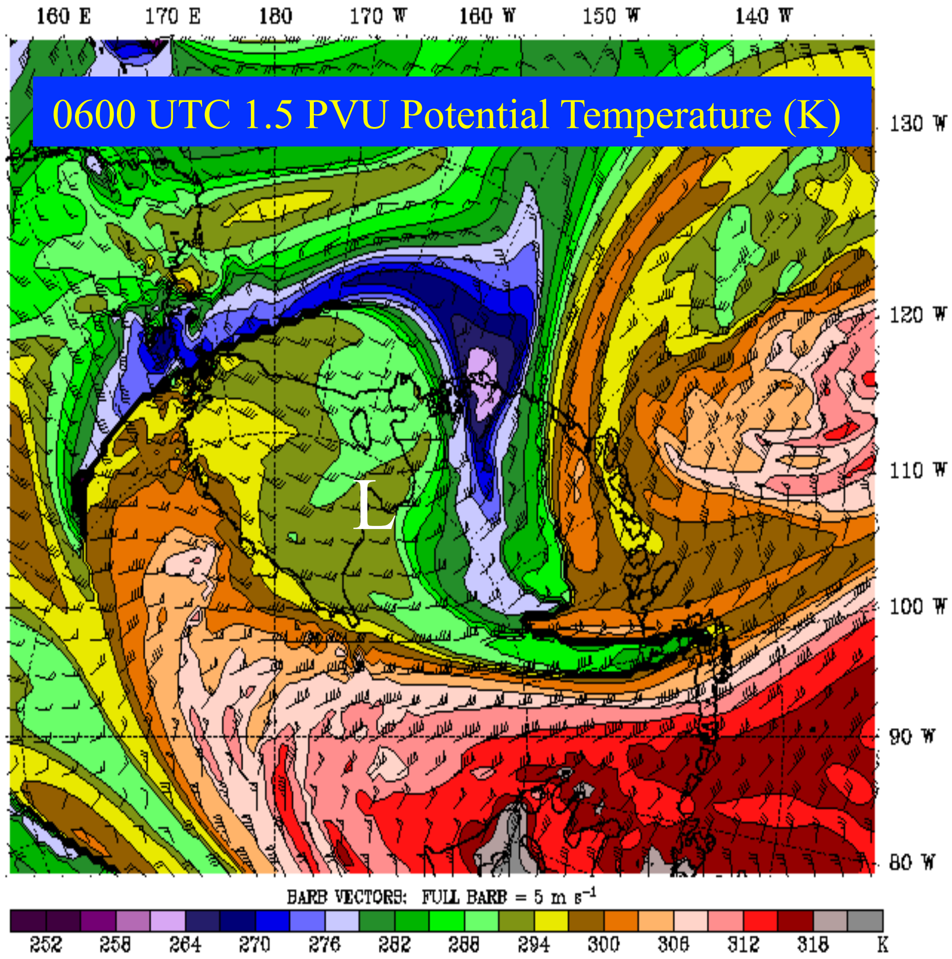
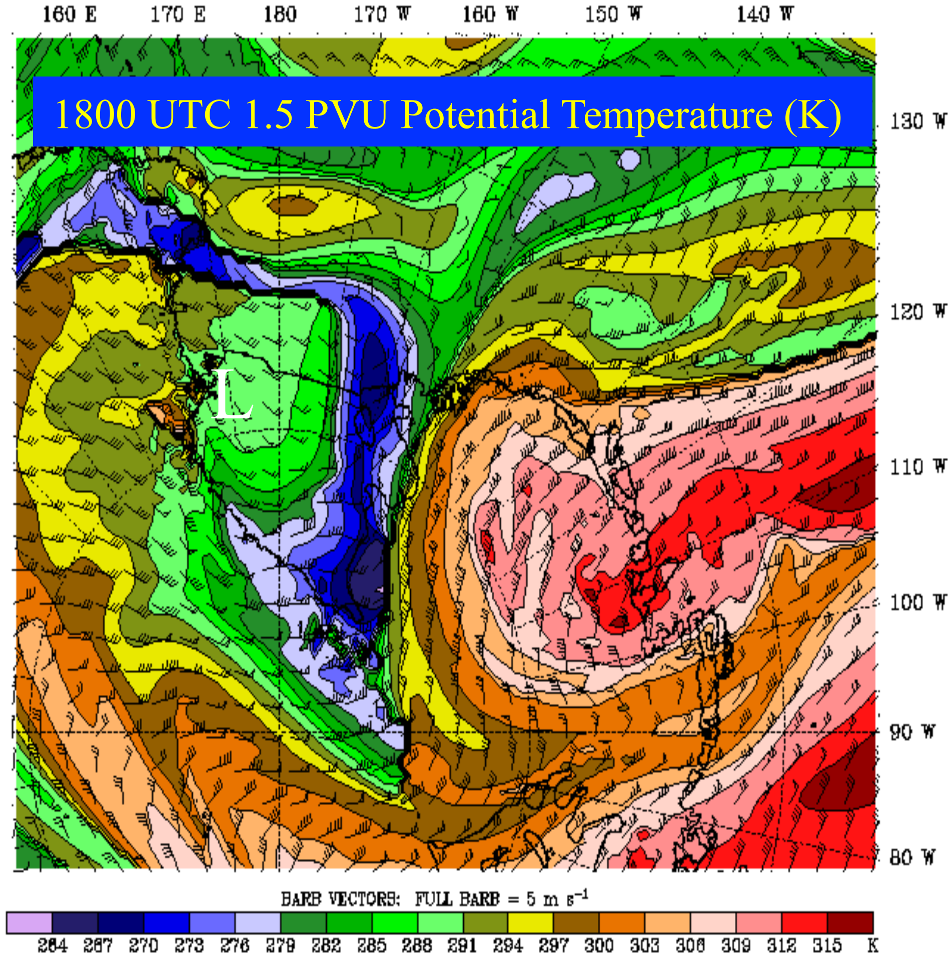
Everything past here is extra!

Synoptic Overview

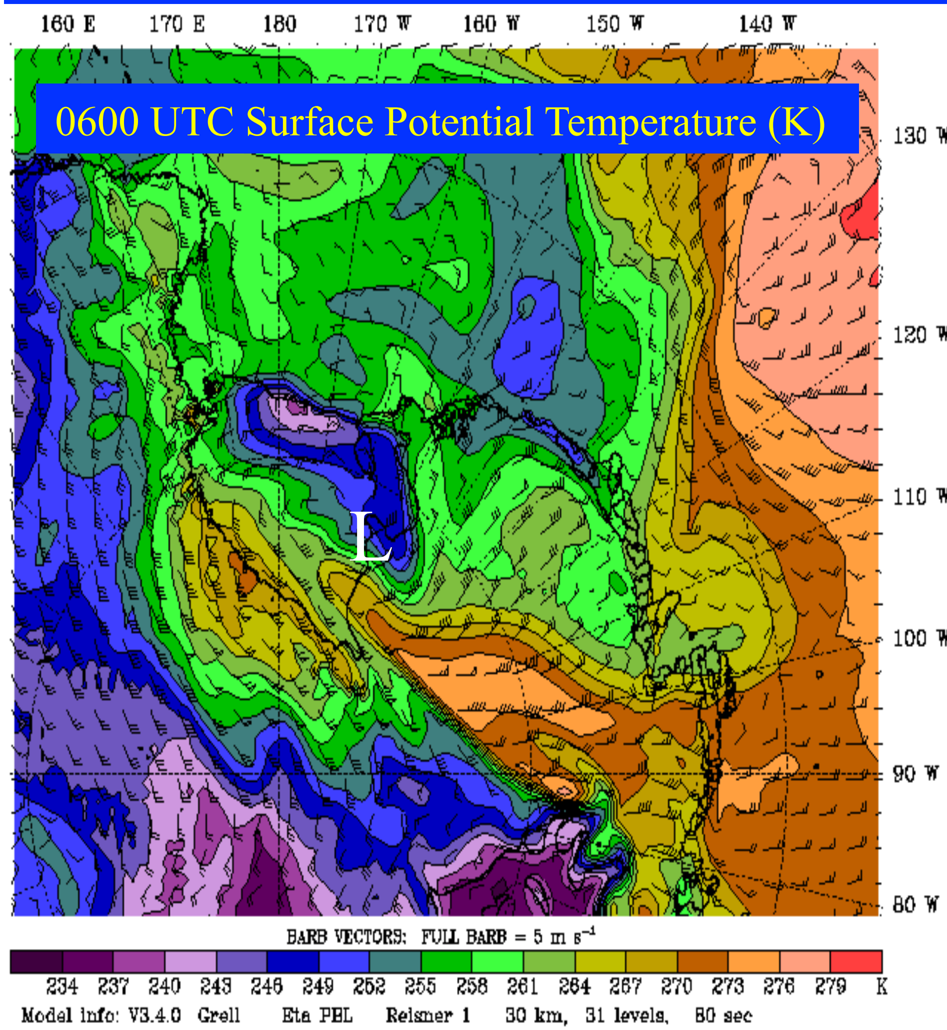
- Potential temperature at the dynamic tropopause (1.5 PVU) shows trough upstream of surface cyclone that provides support for surface cyclone

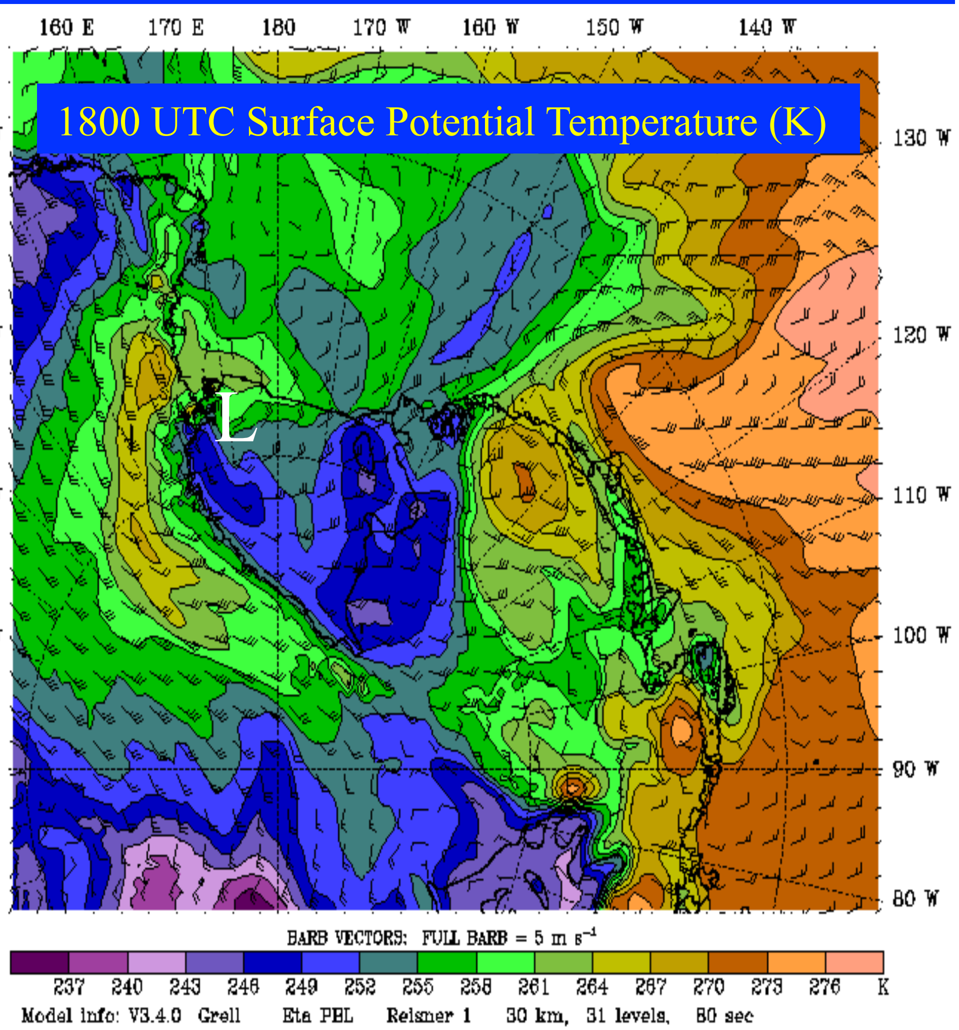




Synoptic Overview

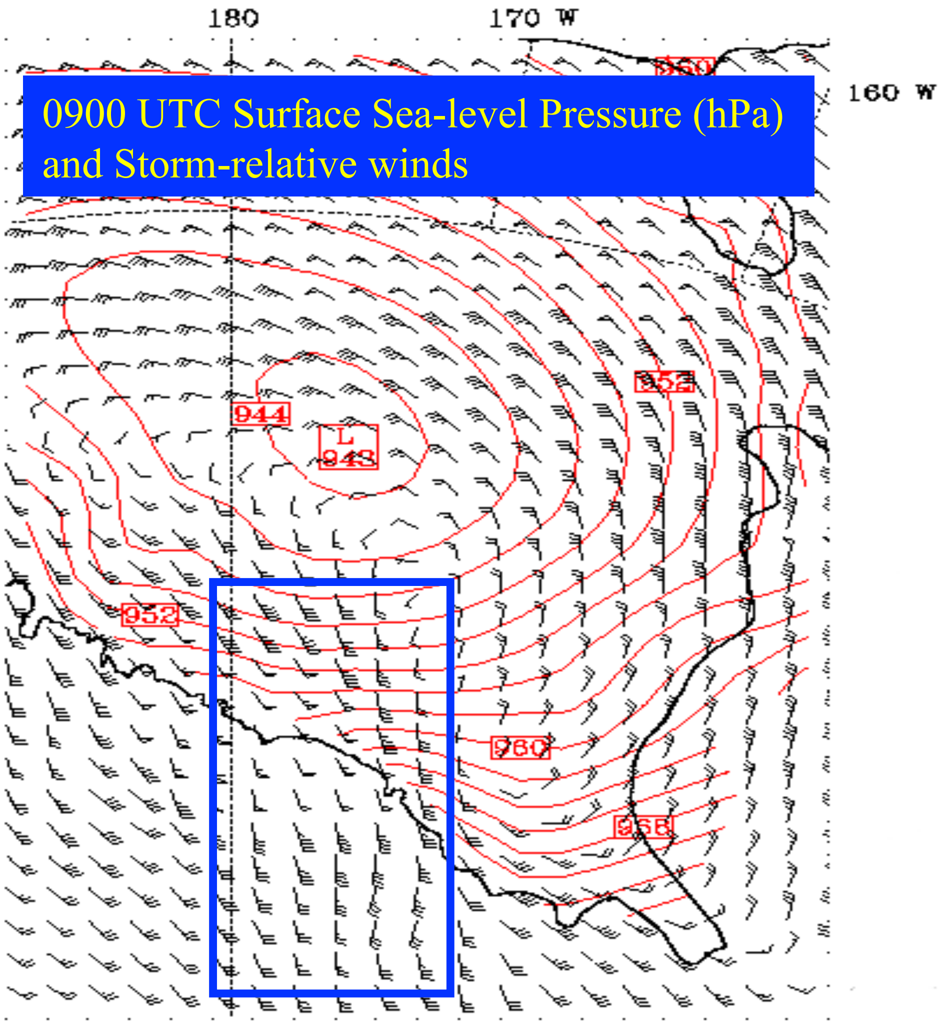
- At surface: warm air advection cut off by Ellsworth Mountains, cold air entrained into cyclone, weakening it

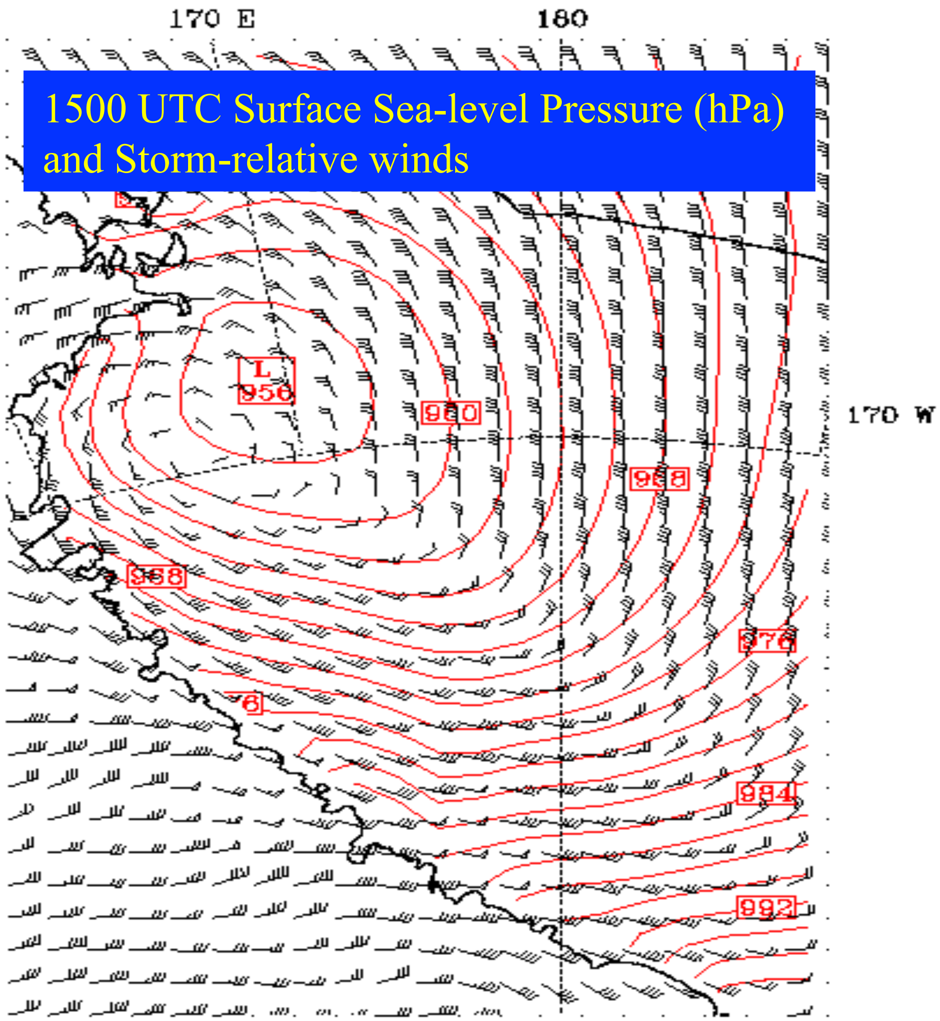




Barrier Wind

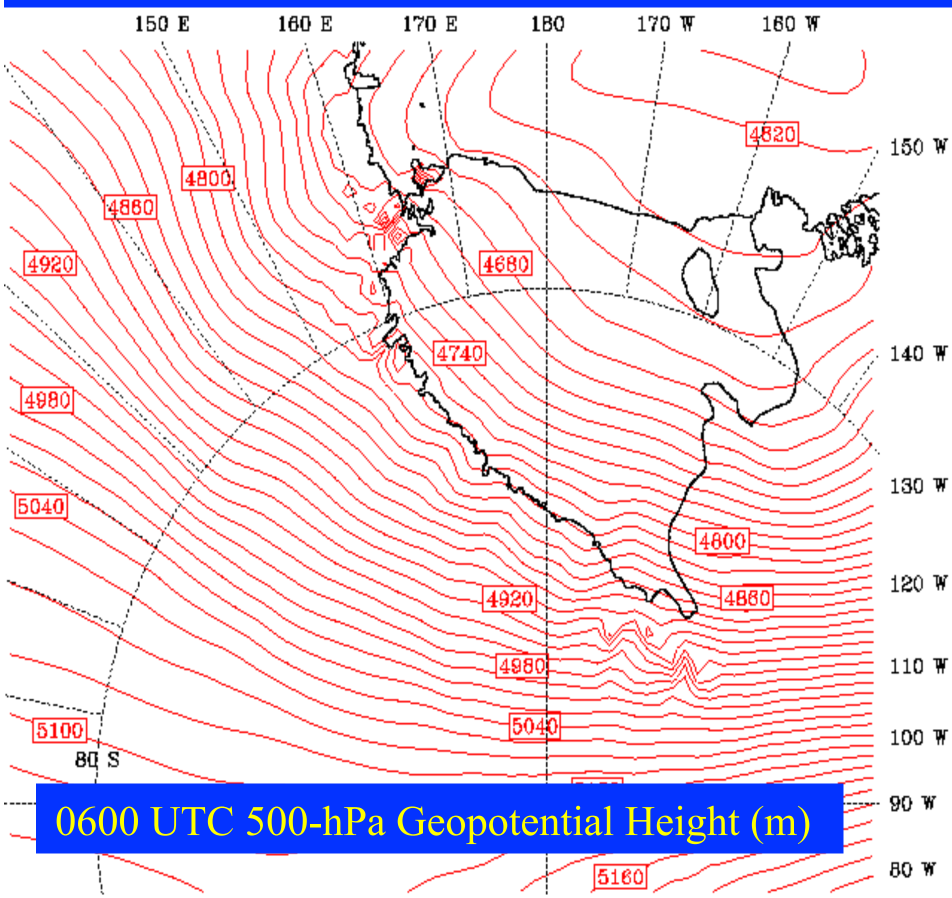
- Storm-relative winds show that downslope winds are forcing for the southeasterly jet at 0900 UTC. By 1500 UTC, downslope winds are shut down and no longer cause the southeasterly jet



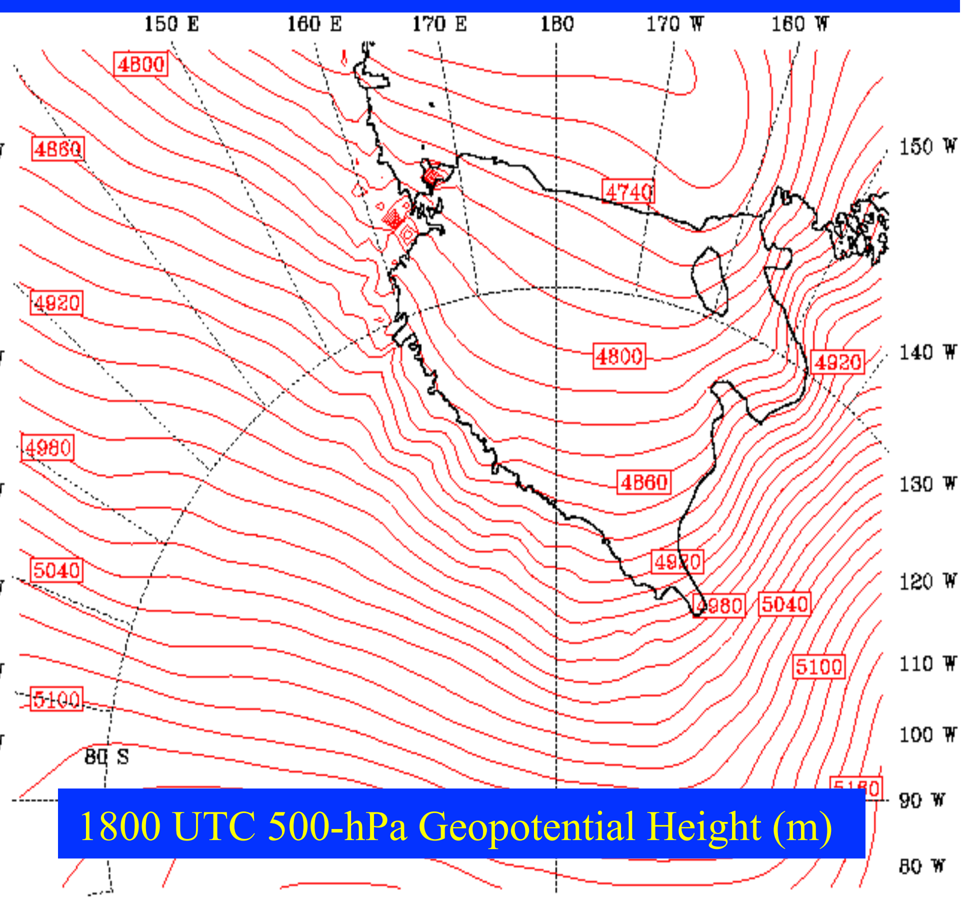


Barrier Wind

- Existing synoptic pressure gradient does not cause increase in pressure gradient in western sector of the cyclone, as the 500-hPa geopotential height gradient over the continental interior decreases in magnitude with time



0600 UTC 500-hPa Geopotential Height (m)



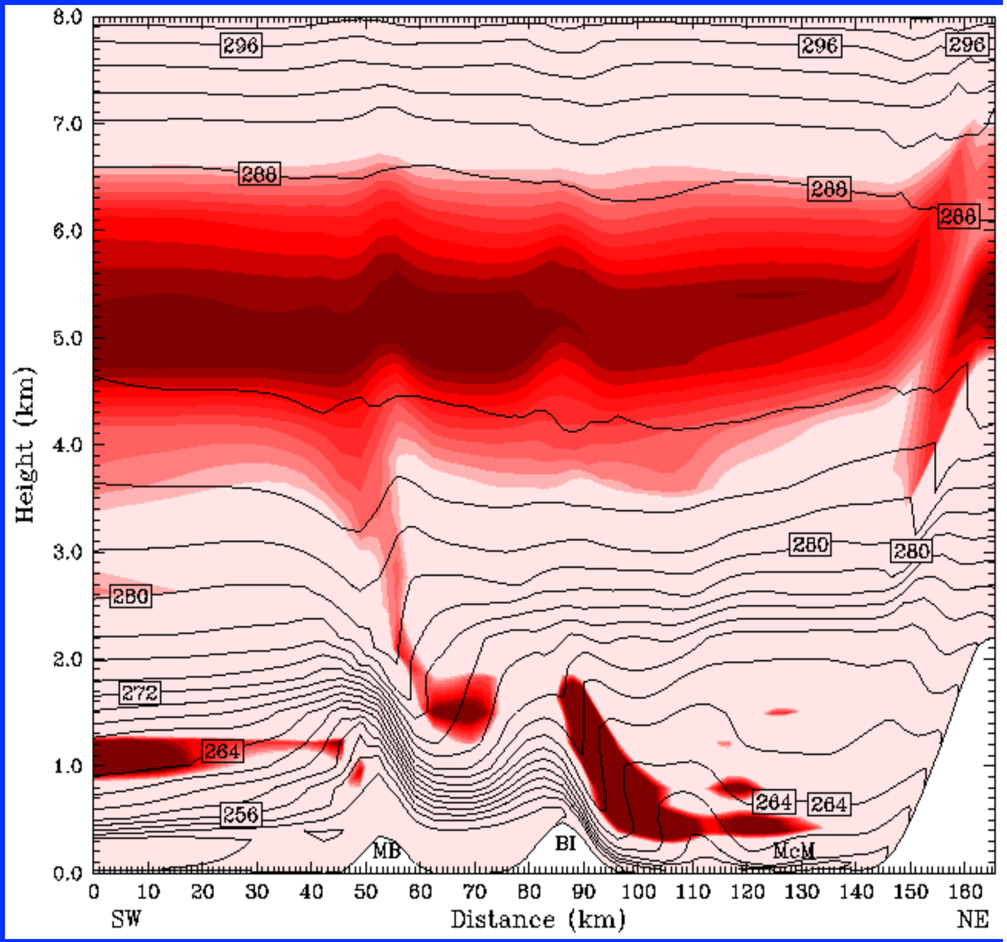
1800 UTC 500-hPa Geopotential Height (m)

Barrier Wind

Time (UTC)	Distance (km)	West (hPa/100 km)	East (hPa/100 km)	Marilyn-Schwerdtfeger Pressure Difference (hPa/100 km)
0900	240	5	5	---
1200	175	6	4	---
1500	140	6	4	7.67
1800	190	10.5	4.5	14.41
2100	120	18	6	---

Mountain Waves

- Possible wave amplification mechanism: Scorer Parameter Layering (Klemp and Lilly 1975)
- A Scorer parameter interface (based on stratification and/or wind speed changes in the vertical) causes a partial reflection of energy, and will amplify a wave system if properly tuned

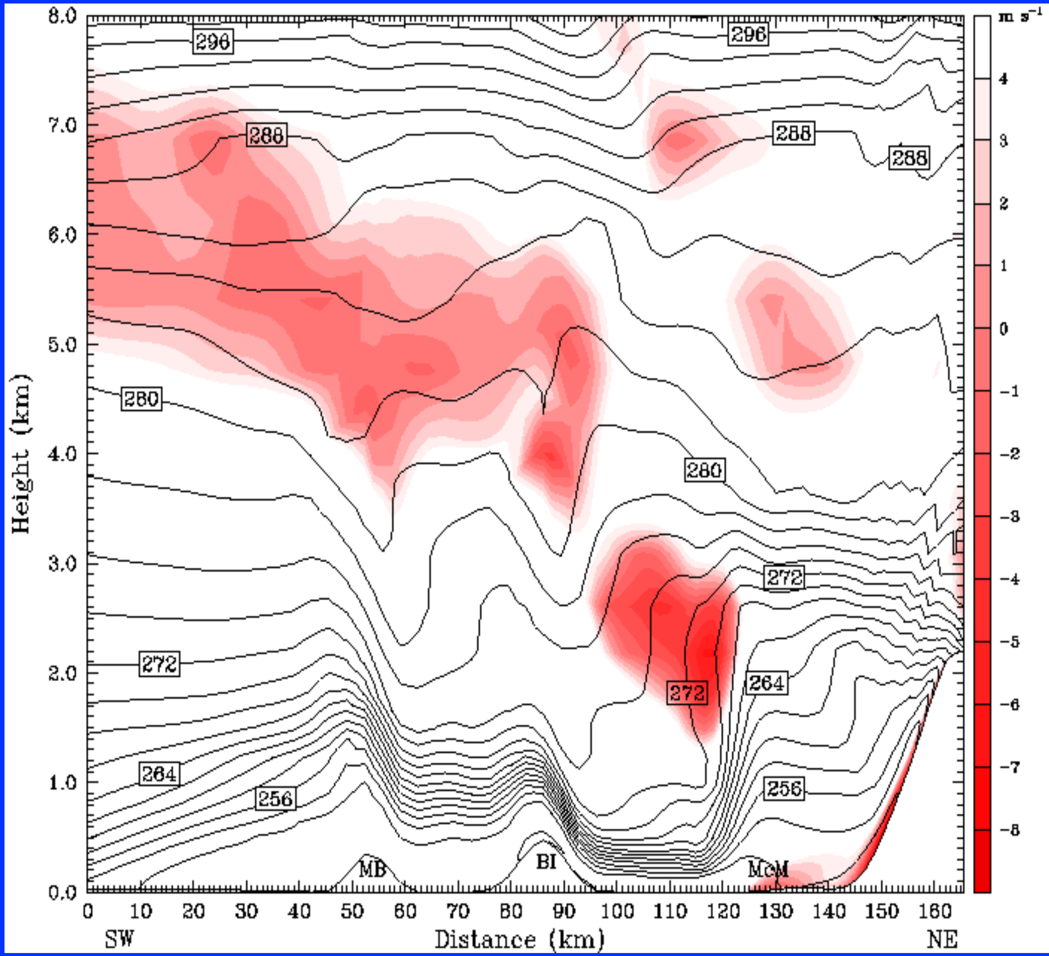


1800 UTC 15 May 2004 potential temperature (contoured, K) and Scorer Parameter (shaded, km^{-2}) between 0 km^{-2} (red) and 1 km^{-2} (white) at 0.1 km^{-2} interval.

Mountain Waves

- Possible wave amplification mechanism: Wave Breaking (Clark and Peltier 1977, 1984, Peltier and Clark 1979, 1983, Clark and Farley 1984)
- Energy associated with wave breaking episodes in the stratosphere propagate into troposphere as regions of slow-to-reversed flow

2300 UTC 15 May 2004 potential temperature (contoured, K) and y-component wind speed (shaded, m s^{-1}) for values < 4 m s^{-1}



Dissipation

- After 0000 UTC 16 May:
  - Ambient wind speeds decrease as barrier wind regime shuts down
  - Low-level inversion conditions, key to development of large-amplitude mountain waves, deteriorate
  - Downslope windstorms no longer impact the McMurdo area after 0300 UTC 16 May

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Barrier Wind

- After the cyclone moves onto Ross Ice Shelf, flow directed orthogonal to the Transantarctic Mountains will either have sufficient momentum to flow over the topography or will be forced around, based upon the Froude Number (Fr)
- At 0900 UTC at the southern end of the Ross Ice Shelf, Fr ≈ 0.55. Since Fr < 1, the flow will not have sufficient kinetic energy to traverse the Transantarctic Mountains
- A mesoscale pressure gradient develops, and a force balance is created between the pressure gradient force and the Coriolis force. The result is a barrier wind that flows with the barrier to the left side (southerly for this case)
- Barrier wind is primary forcing for enhanced pressure gradient and wind speeds in western sector of cyclone

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Localized Effects

- Arrival Heights and McMurdo Building 71 (not shown) wind speeds consistently higher than Williams Field and COSRAY