Foehn Mechanism in the McMurdo Dry Valleys from Polar WRF

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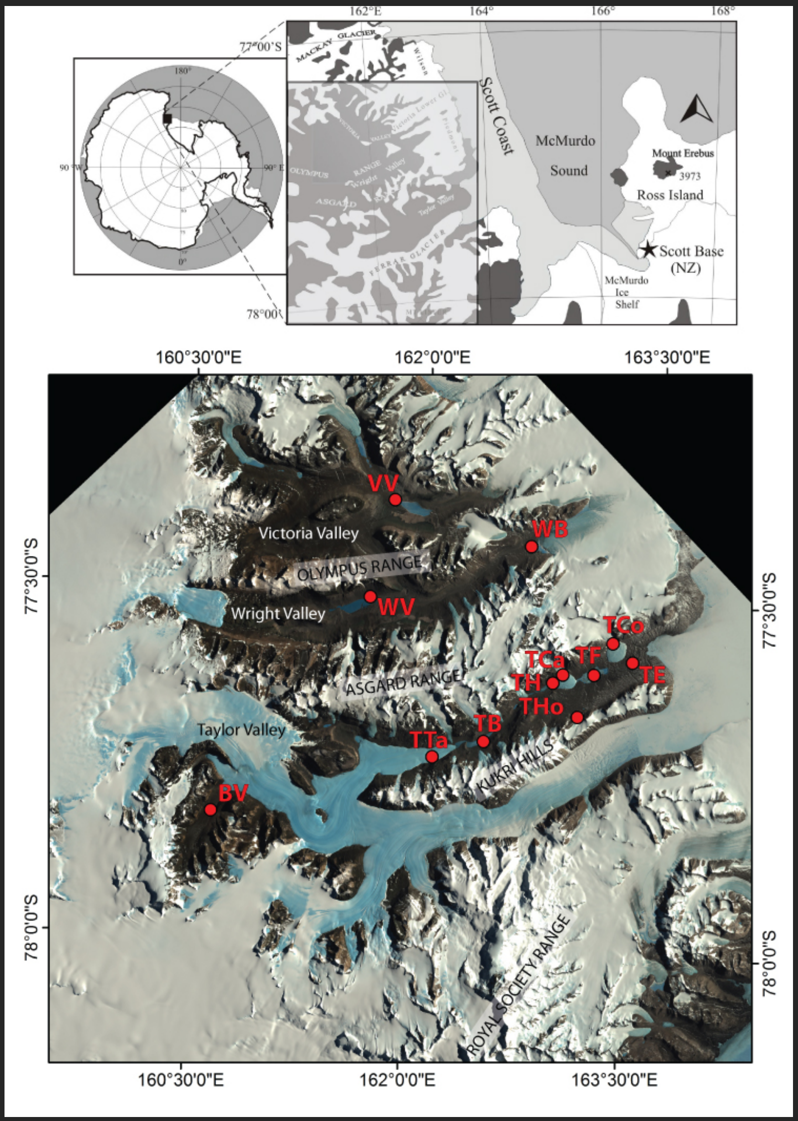
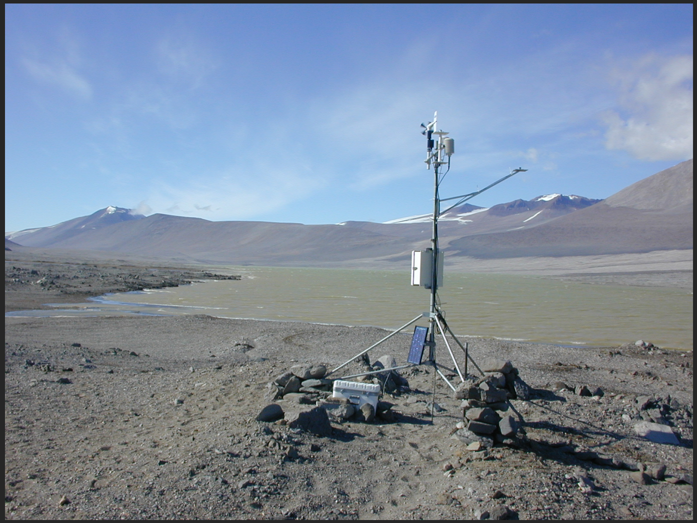
McMurdo Dry Valleys (MDVs): A Complex Environment



- Largest ice-free region in Antarctica (~ 4800 km²), featuring streams and melt lakes
- Located between McMurdo Sound (open water in summer) and East Antarctic Ice Sheet
- Complex terrain – nearby Royal Society Range > 4 km elevation, ranges between valleys > 2 km elevation

Importance of MDVs Meteorology and Climate

- Highly multidisciplinary environment – geochemistry, microbiology, glaciology, hydrology, limnology, soil science, and even a Mars analog!
- Why it matters:
  - The meteorology and climate affect ALL aspects of the MDVs environment
  - Have to get researchers there safely!
  - MDVs have been inferred as a bellwether of climate change: Is this valid?



Lake Vida AWS
Photo credit: Thomas Nylen
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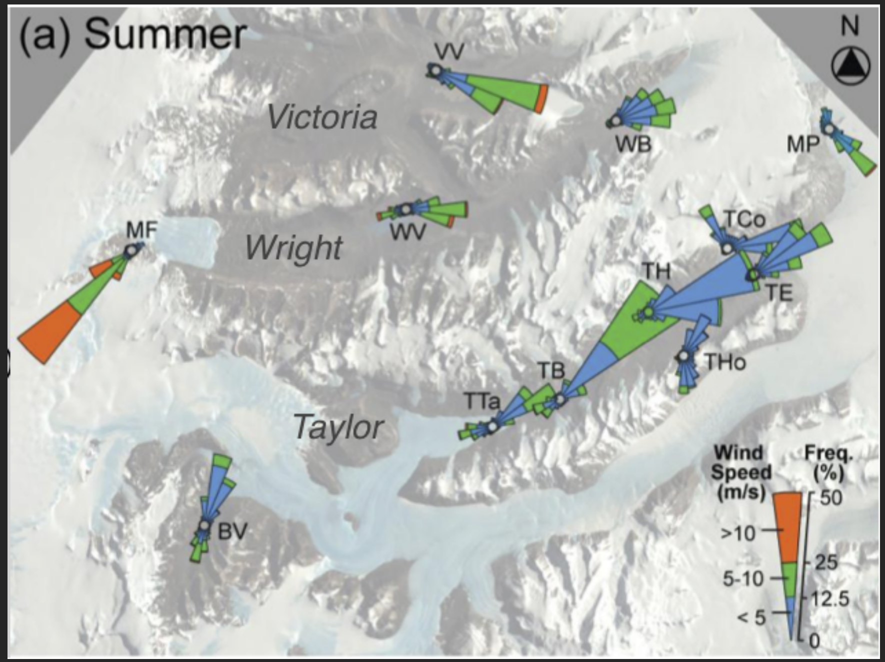
Two Primary Wind Regimes in Summer



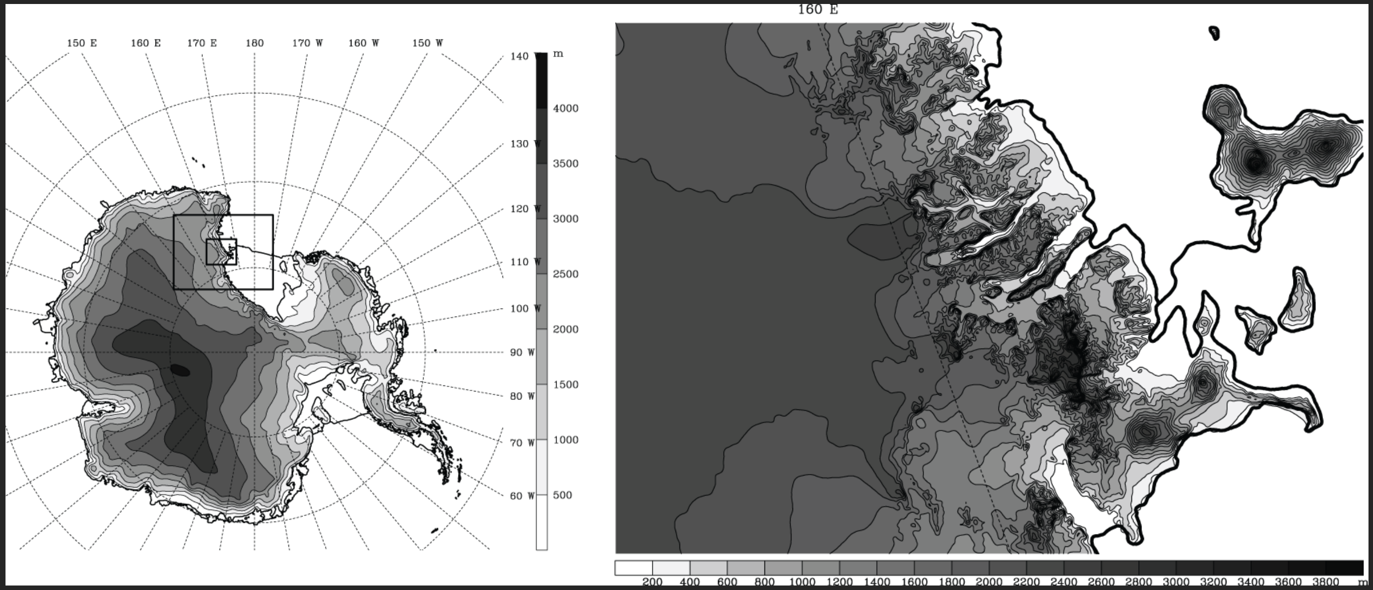
From Speirs et al. (2011), submitted to *Int. J. Climatol.*

- Easterly sea-breeze: dominant summer flow. Occurs during weak forcing. At or below 0°C.
- Strong, warm, dry westerly winds during sporadic episodes. Ablation through blowing snow and melt. Can rise well above 0°C.
- **How do these westerly foehn winds form?**

Polar WRF Simulations

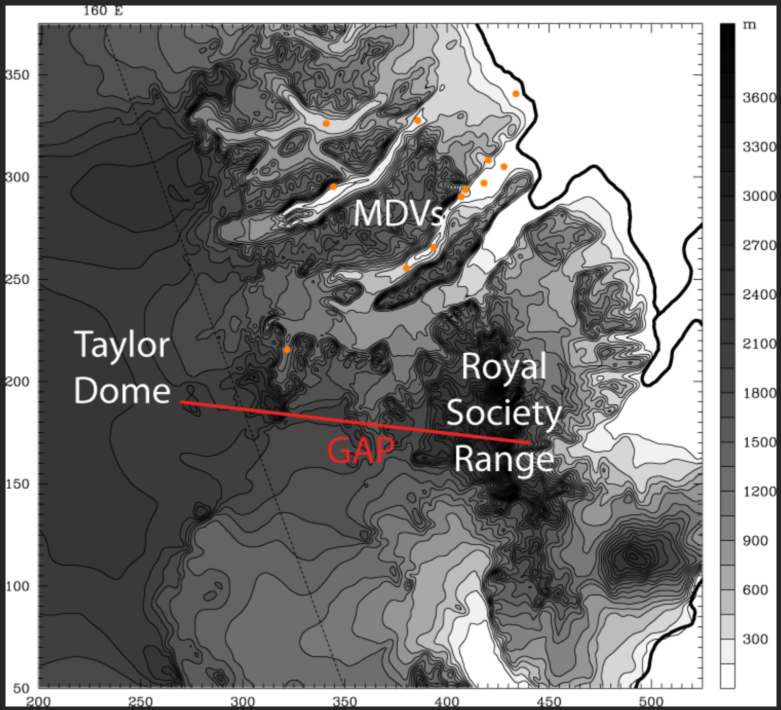
- **Basics:**
  - Polar WRF 3.2.1
  - 500 m grid spacing
  - 55 vertical levels
  - Truly horizontal diffusion
  - Nudging above 1.5 km AGL (outermost domain only)
  - ERA-Interim, NOAA SST, 6 km sea ice (Univ. Bremen), 200 m RAMP DEM

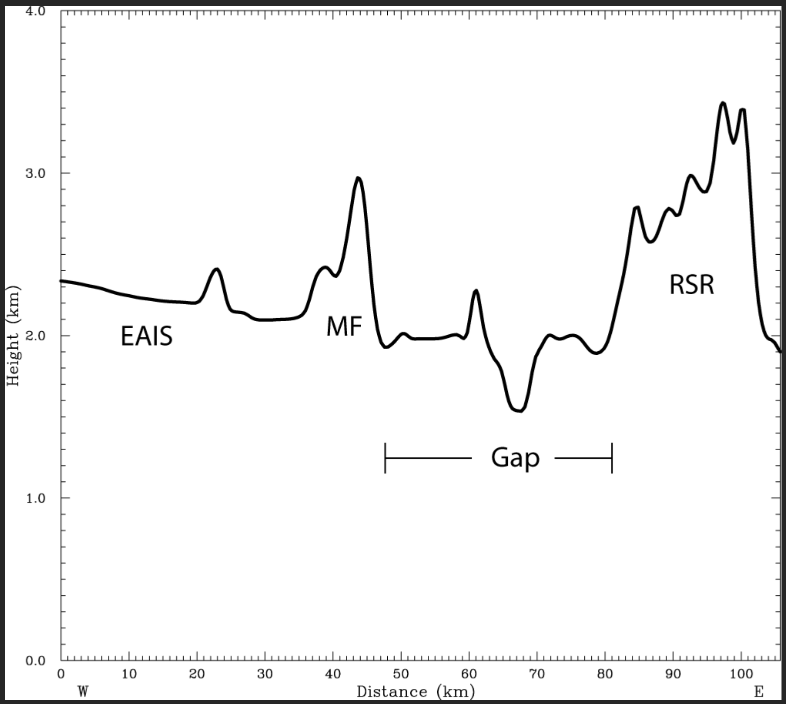
- **Modifications made specifically for MDVs:**
  - Special bare ground land use (courtesy Kevin Manning)
  - Snow cover removed
  - Correct soil specification
  - Additional model code for fractional sea ice
  - One year spinup of land surface state initialized from field study soil observations



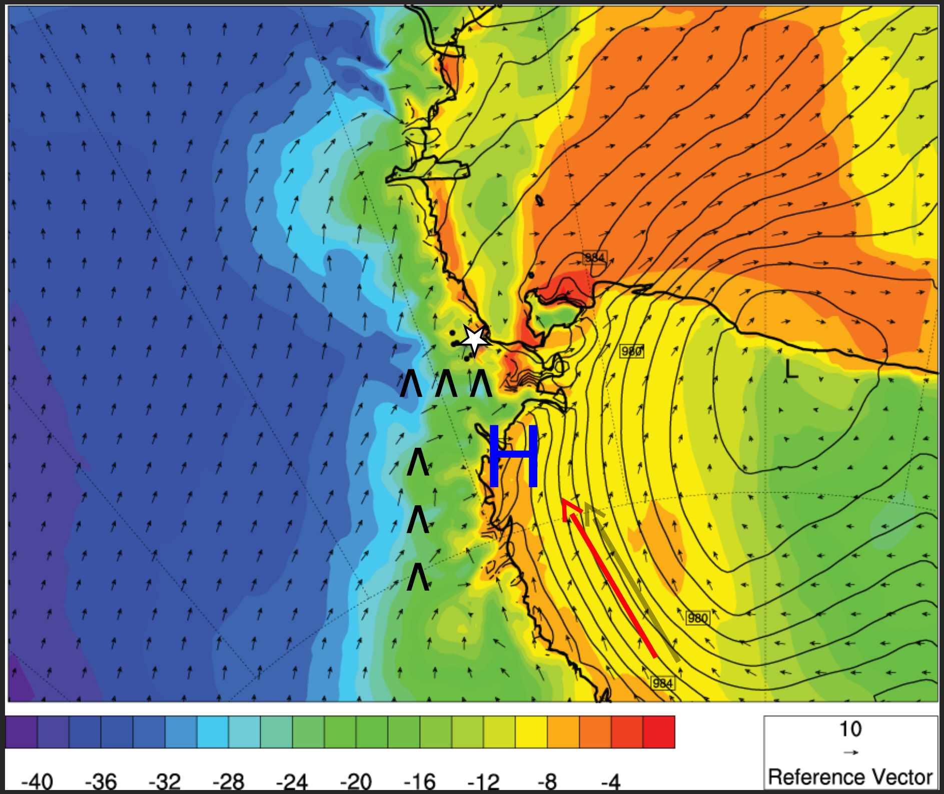
Foehn Components: Gap Flow

- *Gap Flow:* Flow through a gap in a mountain barrier, forced by the cross-gap pressure gradient.
- There is a gap just south of the MDVs, between the Royal Society Range and Taylor Dome





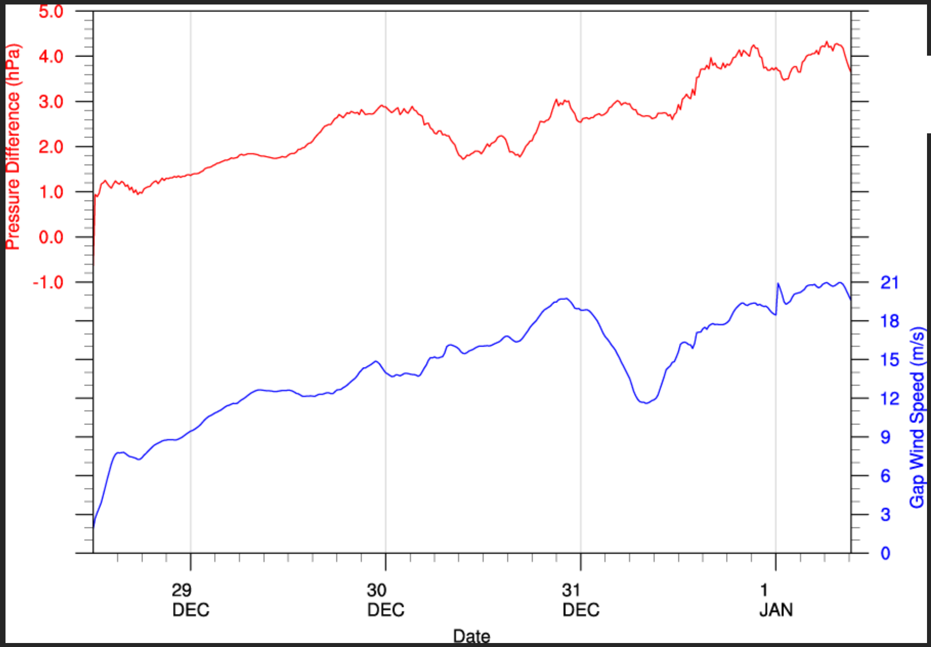
How is Gap Flow Set Up?



Sea Level Pressure (Contours)
Near-surface Temperature (Shaded)
Near-surface Wind Vectors
1800 UTC 29 December 2006

- Terrain blocking effects responsible for pressure differences across gap
  - Associated with cyclonic flow over Ross Ice Shelf – prominent for foehn events (Speirs et al. 2010)
  - Mass accumulates upstream – pressure increases
  - Flow can even be normal to the ridge (i.e., easterly)!

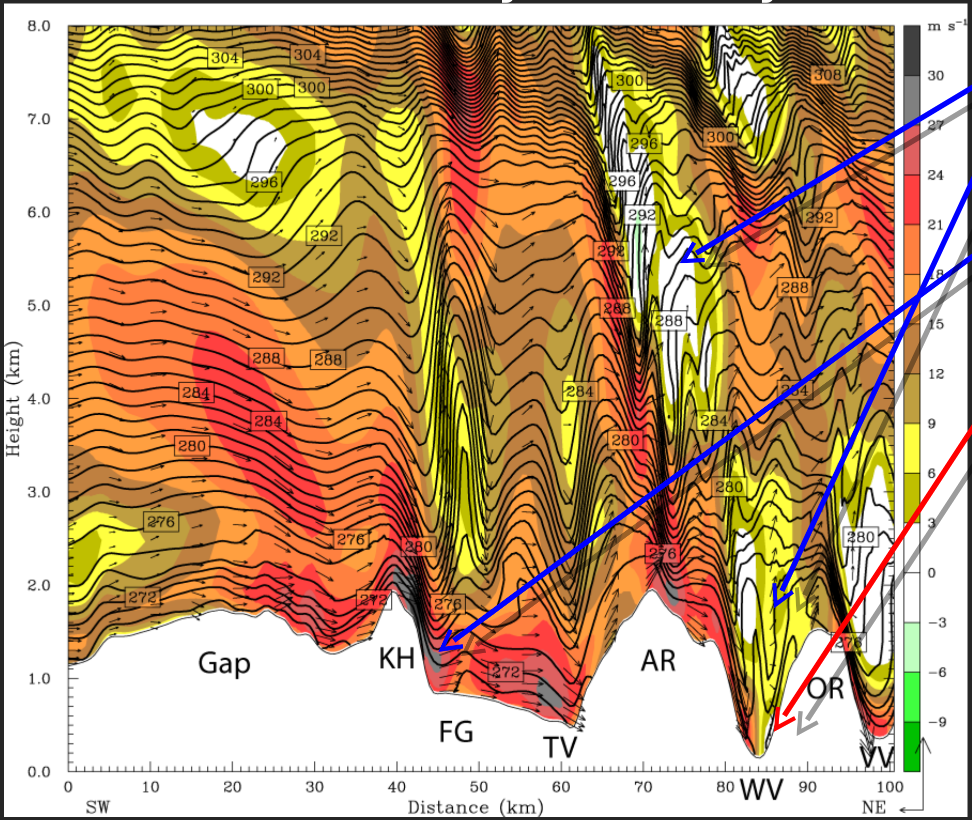
Gap Flow Drives Southerly Winds into MDVs



- Wind speed over gap strongly tied to the cross-gap pressure difference
- There are some deviations to this relationship…

Foehn Components: Mountain Waves

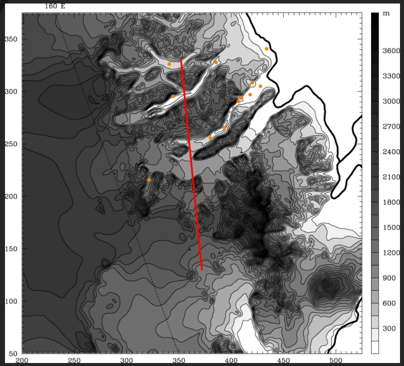
- The gap is elevated and features complex terrain, leading to mountain wave effects that modulate the gap flow
- Primary effect is strong leeside winds extending into western Taylor Valley



Wave-breaking regions

Strong downslope winds into western Taylor Valley

Hydraulic jumps responsible for sharp wind speed cessation

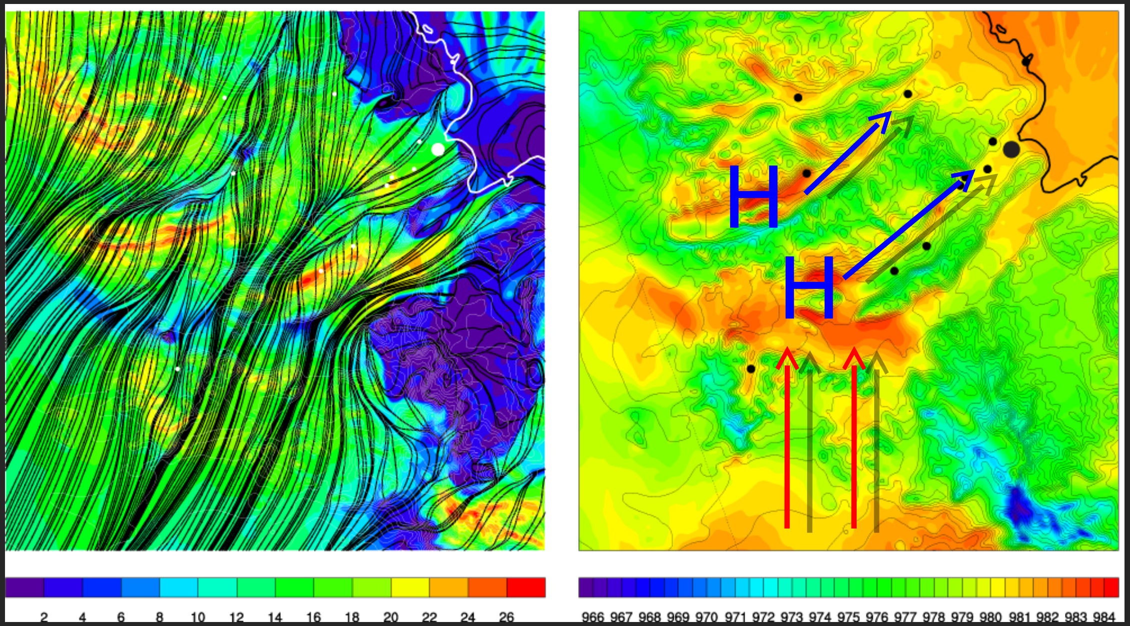


Potential Temperature(Contours) Along-transect Wind Speed (Shaded) 1800 UTC 30 December 2006

Foehn Components: Pressure-driven Channeling

- Ambient flow blocked by Royal Society Range – eastern MDVs do not receive direct foehn flow.
- So how do we get warm, westerly winds down the valleys?
- As flow is blocked or hydraulic jumps occur along valley walls, pressure increases
- Just like gap flow, flow accelerates down the pressure gradient, bringing warm and dry foehn air down valley

Near-surface wind speed and streamlines



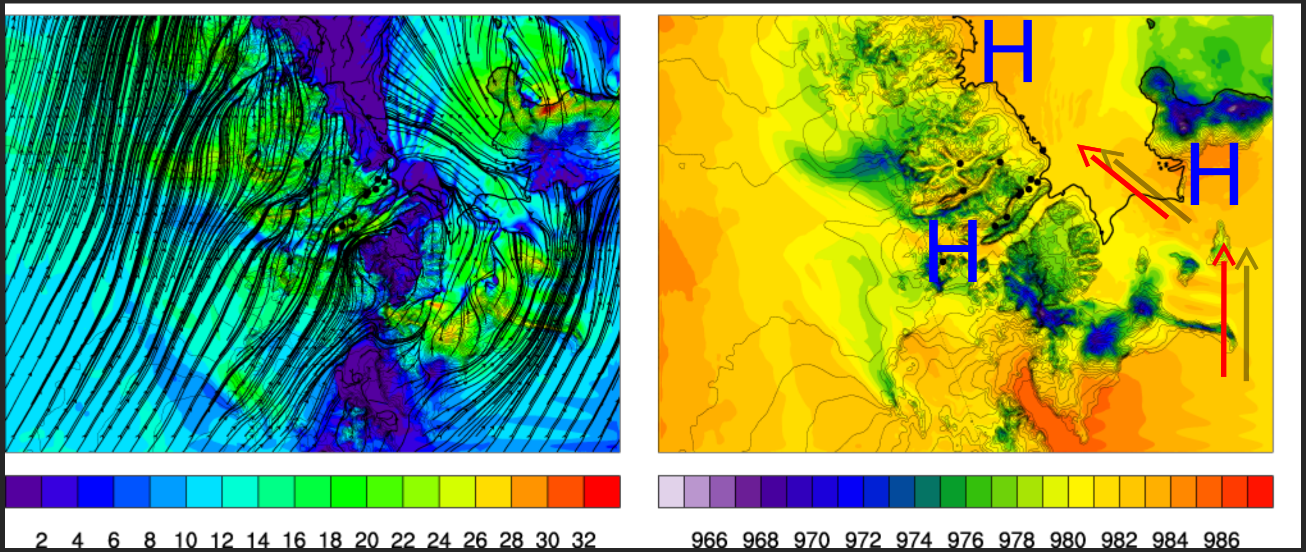
Sea Level Pressure

0900 UTC 30 December 2006

Foehn Components: Easterly Intrusions

- Easterly intrusions of cool, maritime air occur during foehn events – what causes them?
- As flow is blocked by Ross Island (to the east), it is deflected westward towards MDVs, and blocked, increasing pressure along coast
- This provides an *opposing* force to the down-valley warm westerly winds
- Thermodynamic sea-breeze effect negligible during strong forcing

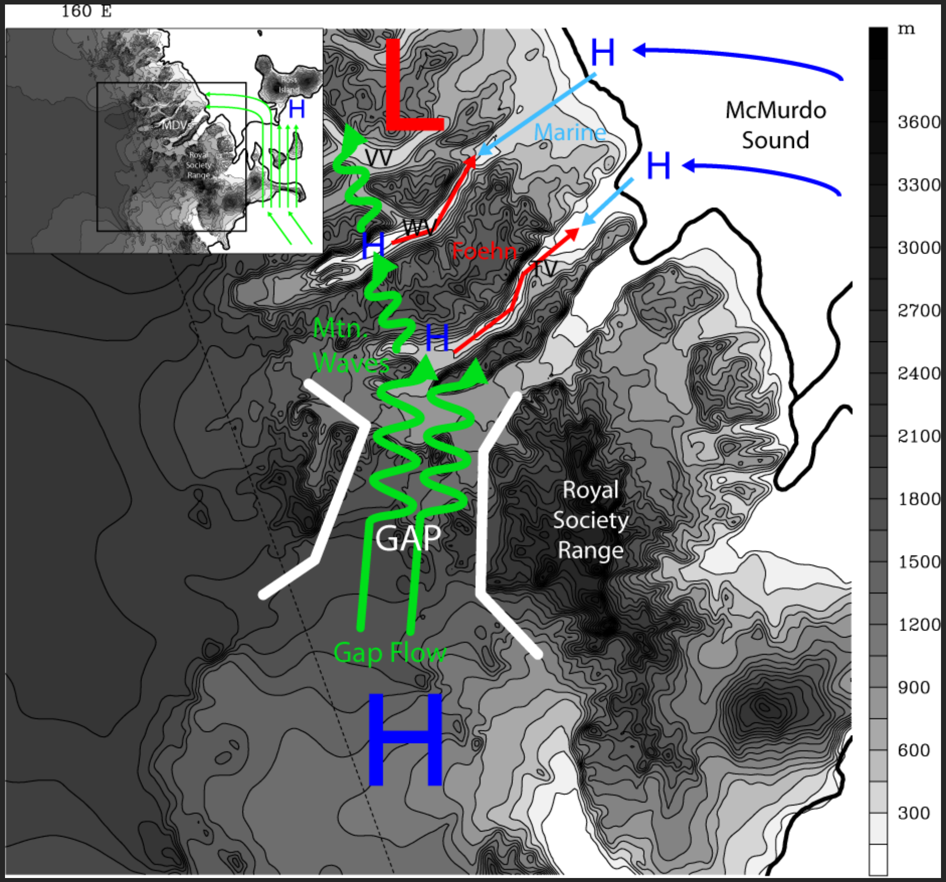
Near-surface wind speed and streamlines



Sea Level Pressure

0900 UTC 30 December 2006

Summary of Foehn Mechanism



- Pre-requisite: Strong winds aloft (either to set up cross-gap pressure difference or flow directly across gap), leading to large-amplitude mountain waves and foehn

One problem: Foehn too strong!

- Positive wind speed bias during foehn events in Polar WRF – hampers foehn mechanism analysis and climatological study
- Suggests model problems with mountain waves. Possible sources:
  - Turbulence / Diffusion (whether calculated on model surfaces or x,y,z space, isotropic or anisotropic mixing lengths, diffusion coefficient values)
  - Distribution of model levels near surface
- Important modeling issues that extend beyond MDVs

Discussion

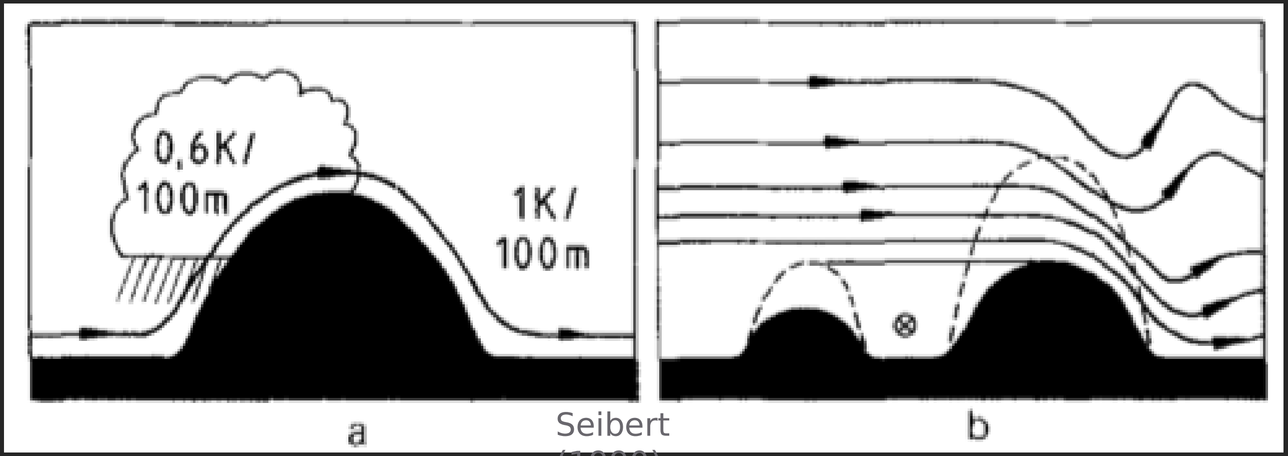
- Strong westerly wind events in MDVs are foehn, and should no longer be referred to as “katabatic”, as there is no katabatic forcing.
- Strong similarities of MDVs meteorology to the Austrian Alps (near Innsbruck) – gap flow through elevated terrain, mountain waves, foehn, blocking effects. MDVs presents opportunity to validate findings from there.
- Many opportunities for mesoscale meteorological research studies in MDVs – both model and observational-based

Extra Slides

The Westerly Winds are *Foehn*

- Katabatic winds: forced by negative buoyancy of diabatically cooled near-surface air
- Foehn winds: warmed through adiabatic descent, regardless of moisture

Thermo-dynamic Foehn



Forced-descent Foehn

Seibert (1990)

- Speirs et al. (2010) present overwhelming evidence for foehn:
  - Forced descent from mountain waves into MDVs
  - MDVs NOT in katabatic wind confluence zone, and katabatic forcing does NOT exist in summer