ASSESSMENT OF FIRE WEATHER DURING A FOEHN EVENT IN SOUTH ISLAND, NEW ZEALAND

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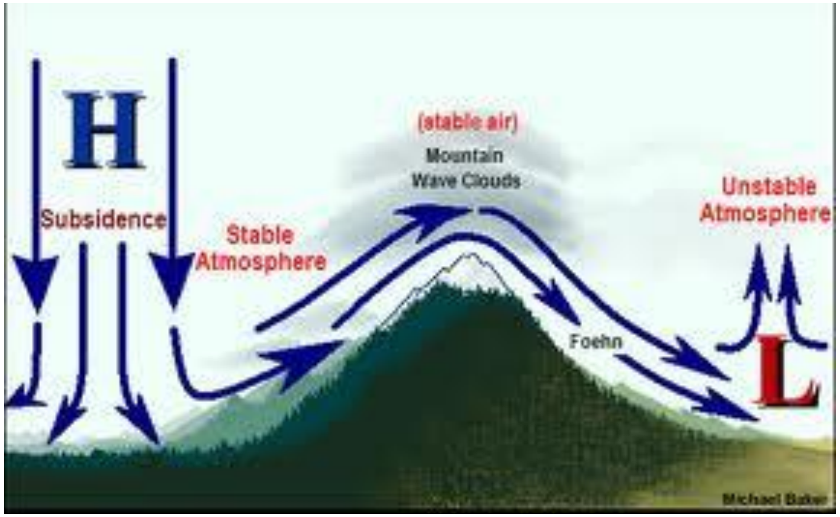
FOEHN WINDS - BACKGROUND

- Foehn winds occur due to interaction between atmosphere and terrain:
  - Occur in lee of substantial terrain features e.g. mountains
  - Synoptic situation driving air over mountains e.g. subsidence associated with high pressure system on windward side
  - Dry, warm air on downwind side of mountains
- Foehn winds occur in many countries:
  - New Zealand - “Canterbury Northwester”
  - USA – “Santa Ana”, “Sundowner”. Europe – “Fohn”
  - Foehn-like winds in southeastern Australia (Sharples 2010)
- Can result in critical fire weather:
  - Rapid variations in fire weather at onset and end of foehn
  - High air temperatures and low relative humidity
  - High wind speeds, mountain waves, hydraulic jumps

THERMODYNAMIC EXPLANATION



Classic foehn mechanism:

- Synoptic winds force air over mountains – adiabatic cooling
- Air reaches LCL and moisture is lost through precipitation
- Latent heat release warms air
- Drier air descends leeward slope and warms adiabatically

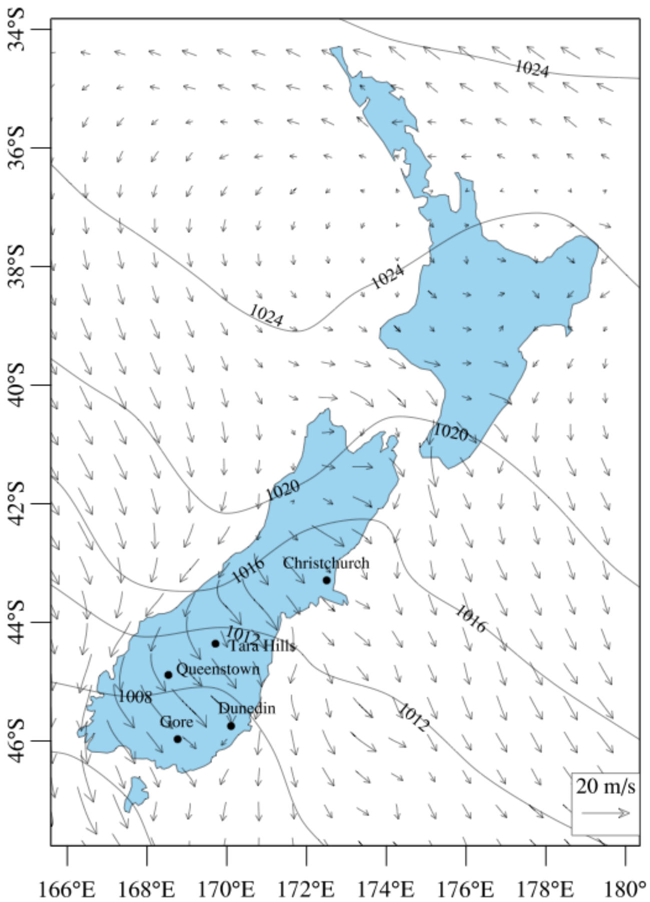
- Difference in upwind and leeward air temperature related to differences in dry and saturated lapse rates
- Additional foehn types e.g. upwind orographic blocking and limited precipitation
- Foehn winds can also be associated with leeward gravity waves

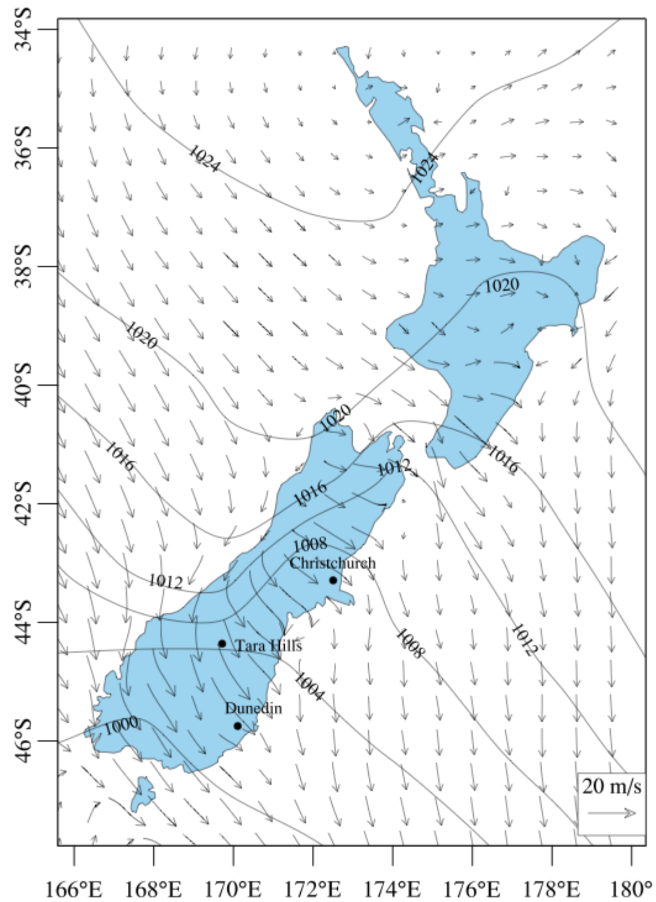
CANTERBURY NORTHWESTER

- Numerous mountain ranges in New Zealand
- Southern Alps extends ~450 km from SW to NE along the South Island:
  - Highest point is Aoraki / Mount Cook at 3,754 m
  - Contains 16 peaks over 3,000 m
  - Considerably influences local weather and climate
- "Canterbury Northwester" affects South Island:
  - Synoptic northwesterly winds interact with Southern Alps
  - Upwind orographic blocking and flow splitting can occur
  - Can get heavy precipitation (> 20 mm hr^{-1}) along west coast
  - High fire weather severity across eastern South Island
  - Can be associated with internal gravity waves

    The Nor'west "Arch"

NORTHWESTERS IN 2009/10 SEASON





CASE STUDY - 6 FEBRUARY 2011

- High air temperatures on 6 February 2011:
  - 40.7˚C recorded at Timaru
  - Compares with NZ record of 42.4˚C set at Rangiora in 1973
  - Widespread “Extreme” fire danger class for South Island
  - High wind speeds and strong gusts observed in parts of South Island
- However, no major wildland fires:
  - Potential existed for high intensity fire behaviour
  - Northwesters associated with other major fires:

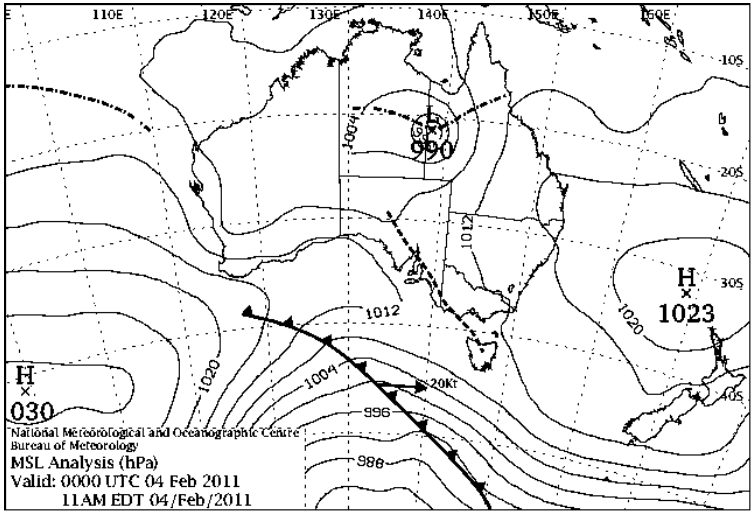
    1973 Ashley Forest fire, 1995 Berwick Forest fire
- Aim to investigate fire weather and atmospheric dynamics using:
  - Weather station data
  - High-resolution NWP modelling

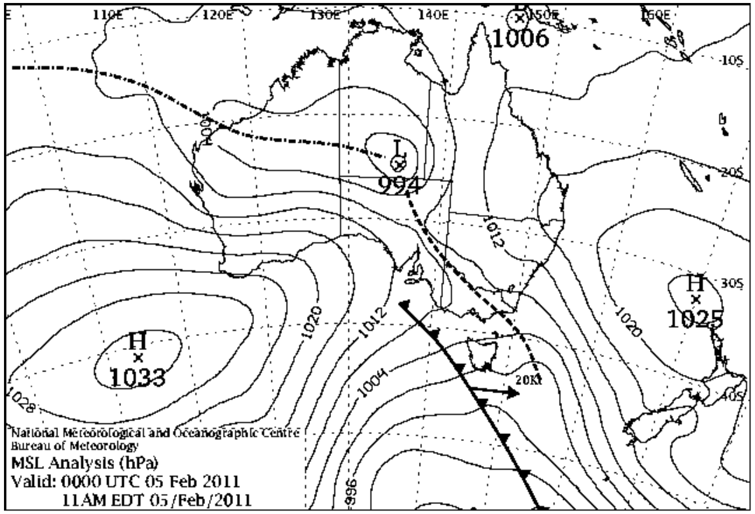
SYNOPTIC SITUATION

bushfire CRC

4 February 2011

5 February 2011

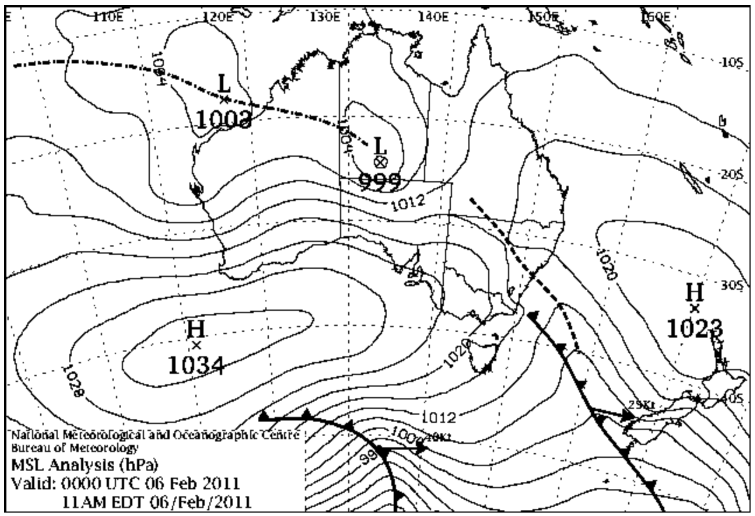




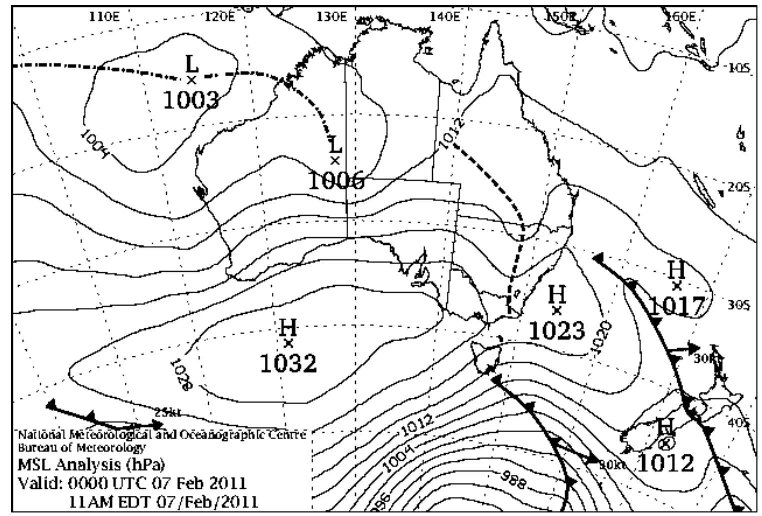
Source: Bureau of Meteorology, Melbourne, VIC

SYNOPTIC SITUATION

6 February 2011



7 February 2011

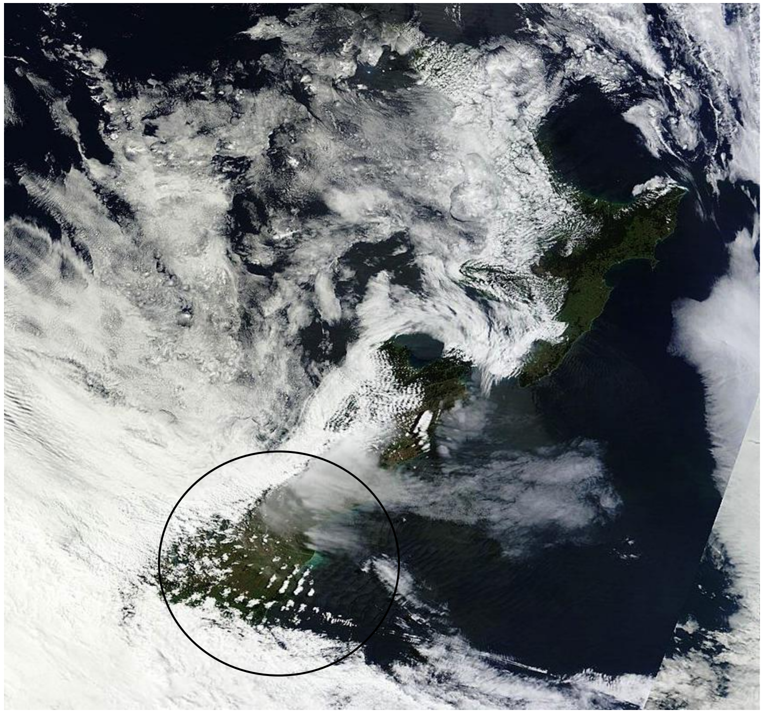


Source: Bureau of Meteorology, Melbourne, VIC

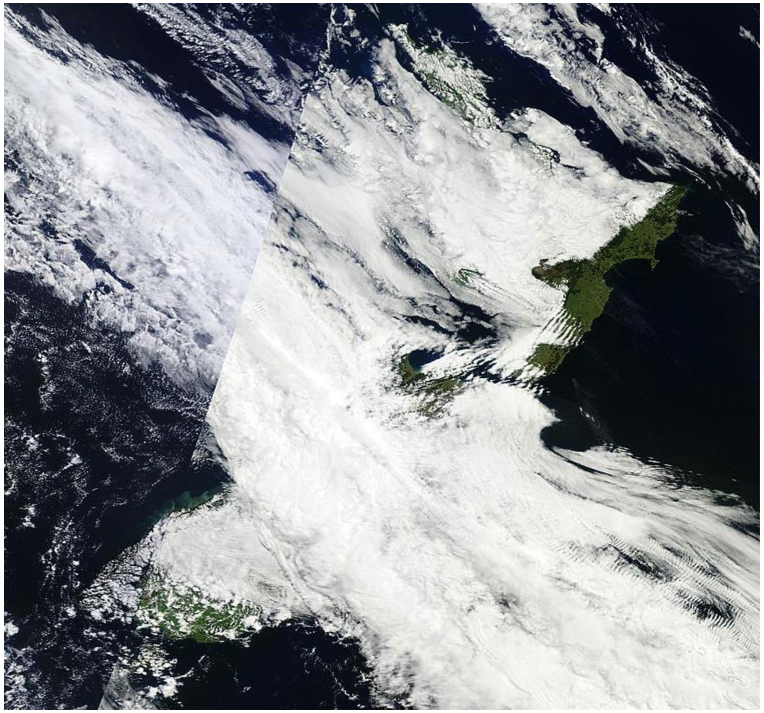
MODIS SATELLITE IMAGERY

bushfire CRC

6 February 2011 Lenticular clouds



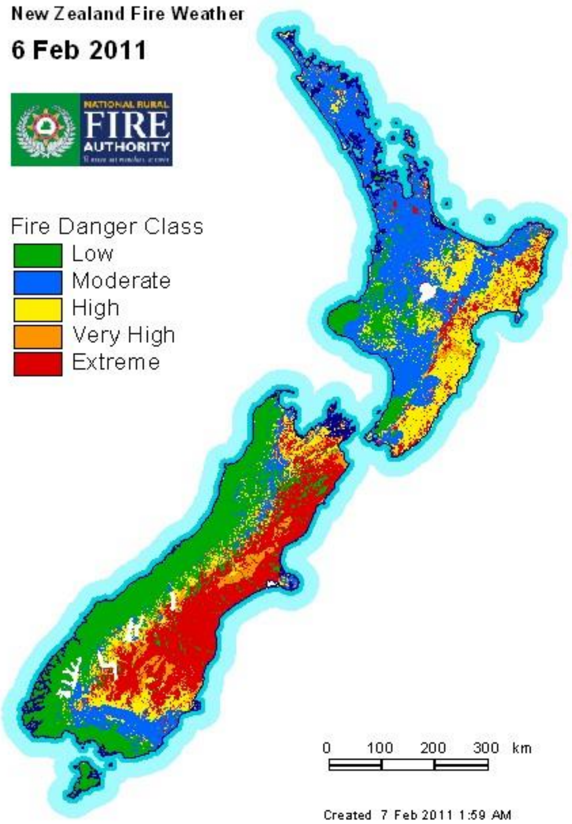
7 February 2011 Cold front passage



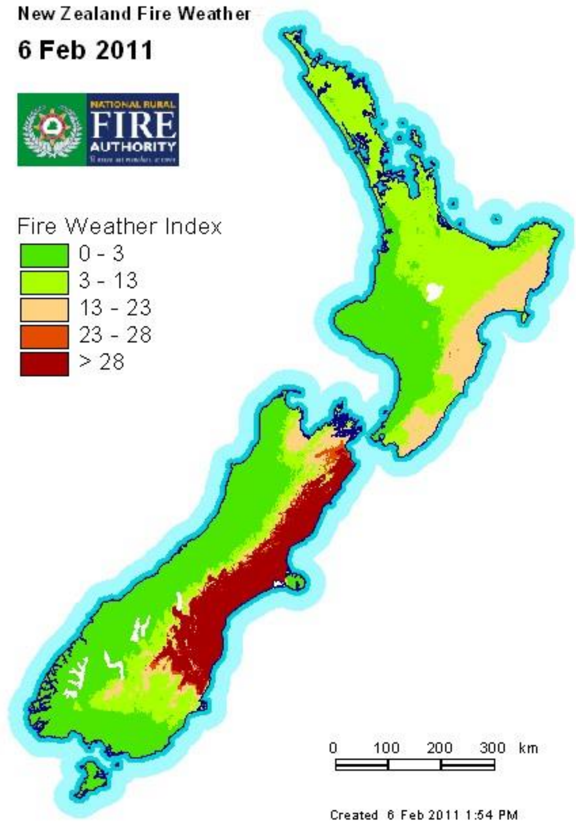
Source: LANCE Rapid Response MODIS images

NRFA – 6 FEBRUARY 2011

Fire Danger Class



FWI



NEW ZEALAND FIRE DANGER RATING

- New Zealand Fire Danger Rating System:
  - Based on Canadian Forest Fire Danger Rating System
  - New Zealand equivalent of Fire Weather Index (FWI)
  - FWI calculated for a reference fuel type
- FWI accounts for fuel moisture and wind on fire behaviour (i.e. fire intensity):
  - Fuel moisture indices: Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), Drought Code (DC)
  - Fire behaviour indices: Initial Spread Index (ISI), Build Up Index (BUI), FWI
  - Dependent on near-surface air temperature, relative humidity, wind speed and rainfall
- Fuel moisture indices calculated cumulatively:
  - Indices calculated at hourly or daily intervals
  - Indices must be initialised with some starting value

FIRE WEATHER CLASSES IN NZ

- Adopt pre-existing FWI thresholds in this study:
  - Low 0 – 7, Moderate 8 – 15, High 15 – 32, Extreme 32+
  - **Not** the same as the fire danger class
  - Only accounts for near-surface weather
  - No account of vertical fire-atmosphere interactions
- Fire danger classes:
  - Combined information on fuel, terrain and weather
  - Low, Moderate, High, Very High, Extreme
  - Correspond to changes in fire management actions

HAINES INDEX AND CONTINUOUS HAINES INDEX

- Haines Index (HI) (Haines 1988) is an upper-air index for atmospheric stability and dryness:
  - Three variants dependent on surface elevation:
    - Low : $T_{950} – T_{850}$ and $T_{850} – D_{850}$
    - Mid: $T_{850} – T_{700}$ and $T_{850} – D_{850}$
    - High: $T_{700} – T_{500}$ and $T_{700} – D_{700}$
  - Calculated using vertical profiles of air and dew point temp.
  - Calculated from NWP model output
- HI takes on integer values from 2 to 6
- Continuous Haines Index (Mills and McCaw 2010) extends HI to continuous number scale:
  - Uses same pressure levels as Mid variant of HI
  - Lower limit of zero, no imposed upper limit
  - CHI rarely exceeds 12 in New Zealand

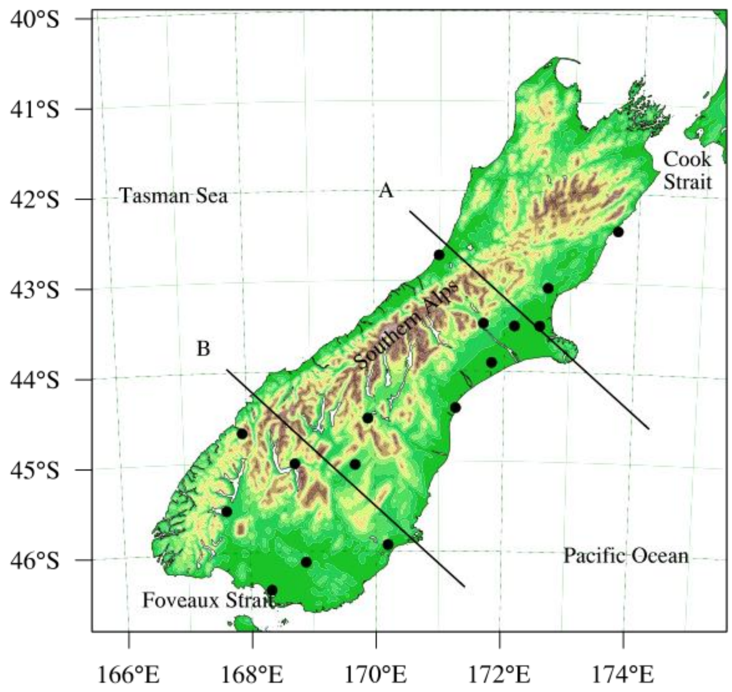
WEATHER STATION DATA

- National Institute of Water and Atmospheric Research (NIWA):
  - Consider 16 of the NIWA stations in South Island
  - West coast: relatively few stations available
  - East coast: mix of coastal and inland locations
  - Hourly measurements of near-surface weather variables
  - Limited upper-air data available:
    - Christchurch, Dunedin, Invercargill

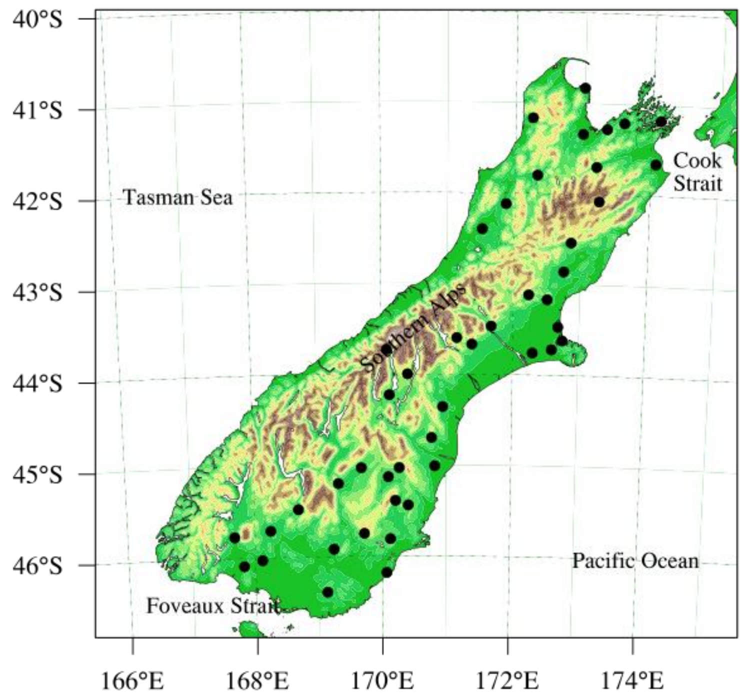
- National Rural Fire Authority (NRFA):
  - Network of 100+ fire weather stations across NZ
  - Measure four weather variables used to calculate FWI
  - Daily FWI and associated variables recorded at each station
  - Consider 45 of the NRFA stations in South Island
  - Data used to initialise WRF modelled FFMC, DMC and DC

WEATHER STATIONS

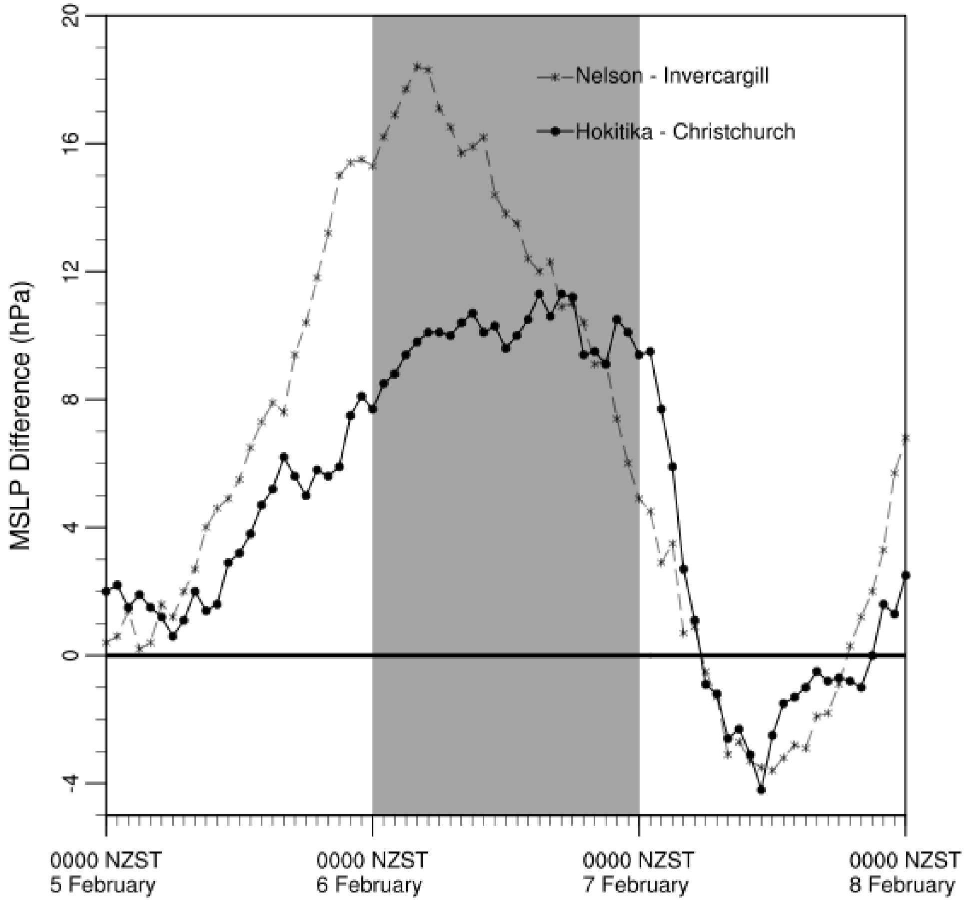
NIWA Stations

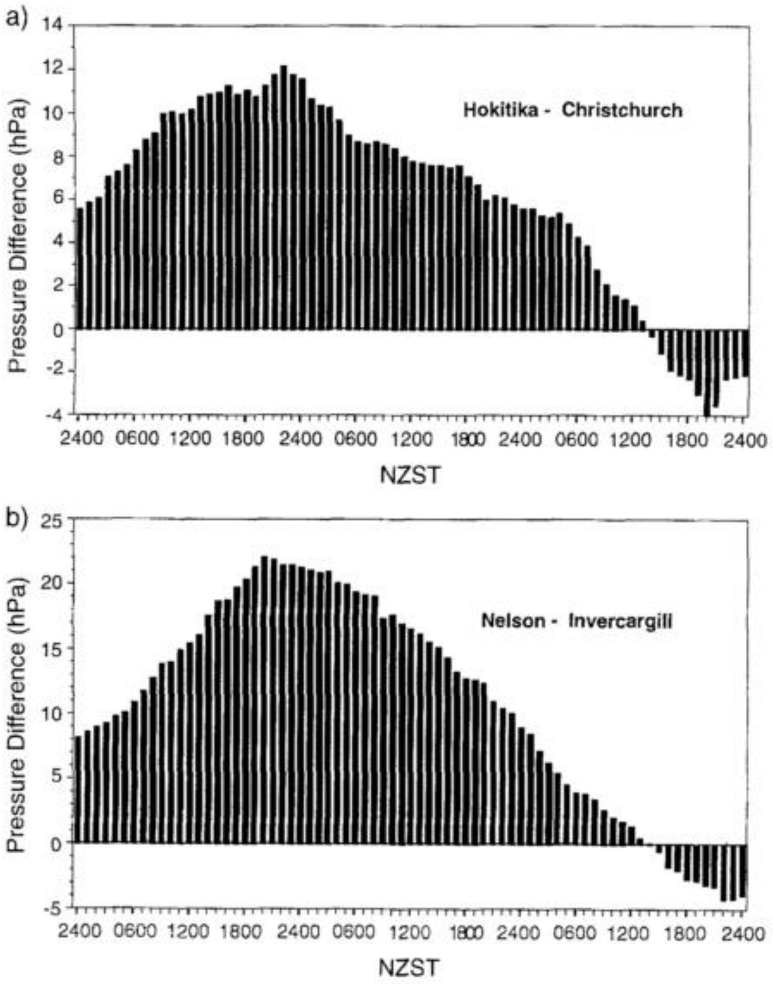


NRFA Stations



PRESSURE GRADIENTS – SOUTH ISLAND





McGowan and Sturman 1996

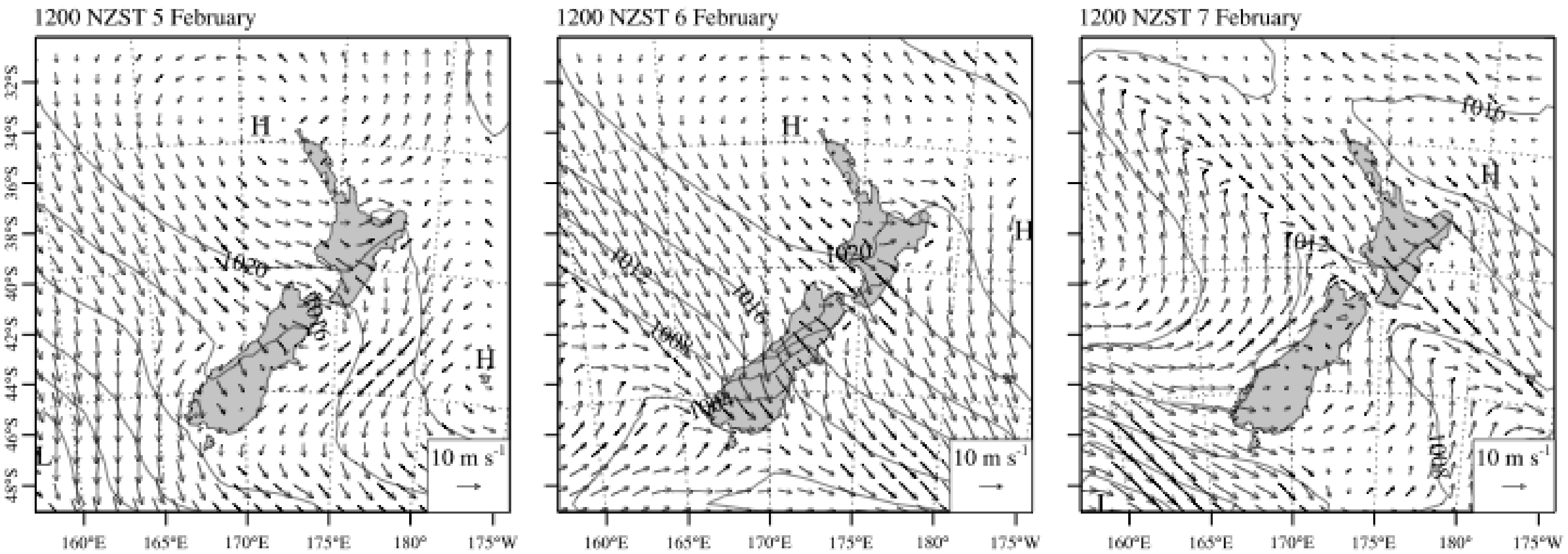
NUMERICAL WEATHER PREDICTION

- Weather Research and Forecasting (WRF):
  - Version 3.4 (3.5 is current)
  - Fully compressible non-hydrostatic equations
  - Terrain-following coordinate system
- Domain configuration:
  - Three domains: 18, 6 and 2 km horizontal grid spacing
  - Two-way nesting between domains
  - Parent domain nudged at six hourly intervals
  - NCEP FNL used as boundary conditions
  - 50 vertical levels up to model top of 10 hPa
  - Gravity wave damping layer in top of model

WRF - VERIFICATION

- Statistical comparison of WRF model output and NIWA weather station data:
  - Under prediction of extremes in air temperature
  - Over and under prediction of RH
  - Wind speeds poorly predicted at some stations
  - Precipitation accurately modelled (i.e. orographic precipitation and cold front passage)
- Improvements could be made to accuracy:
  - May be errors in analyses e.g. SST, temperatures, winds
  - Increase horizontal resolution
  - Employ new set of physical parameterisations:
    - New scheme to adjust wind speeds in and around complex/mountainous terrain)
    - Choice of different PBL, surface layer schemes, etc…

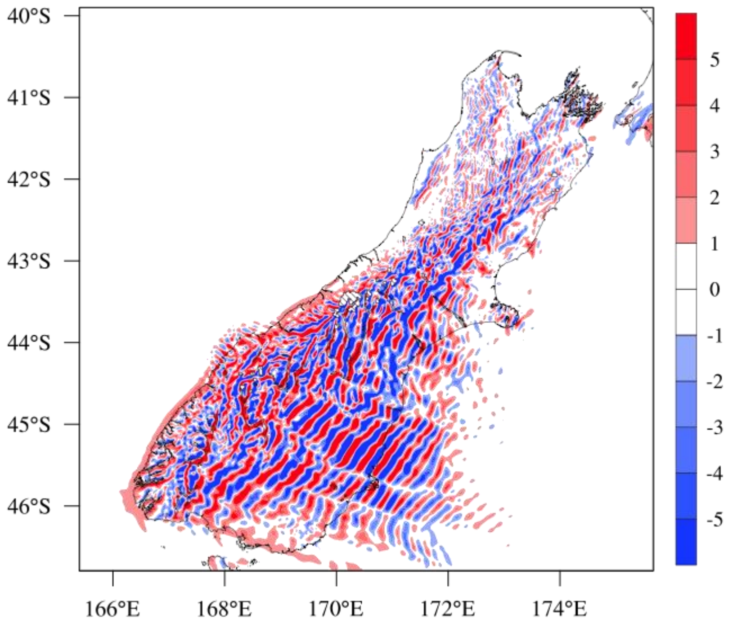
WRF MSLP



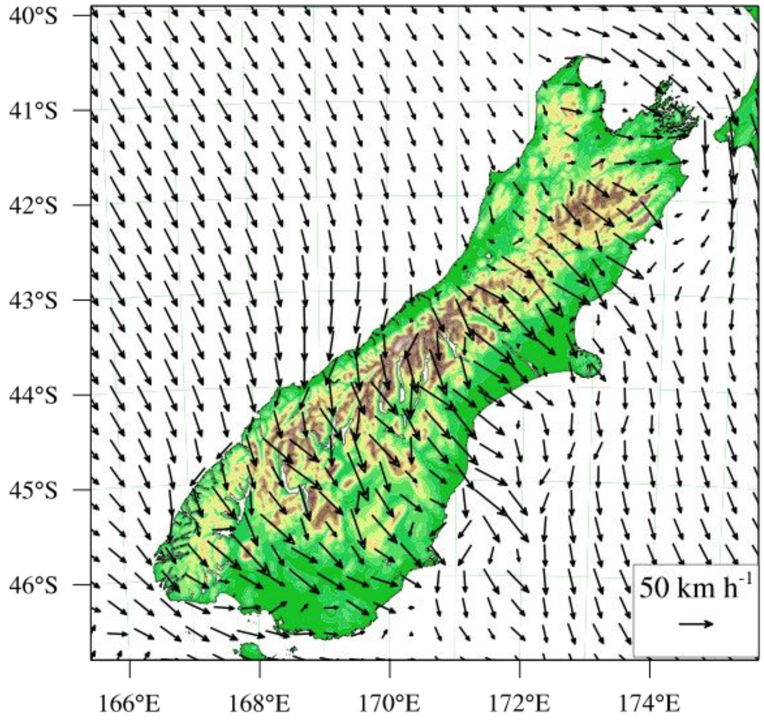
1200 NZST 5 February
1200 NZST 6 February
1200 NZST 7 February
10 m s-1
160°E
165°E
170°E
175°E
180°
175°W
32°S
34°S
36°S
38°S
40°S
42°S
44°S
46°S
48°S

WRF - WINDS DURING FOEHN

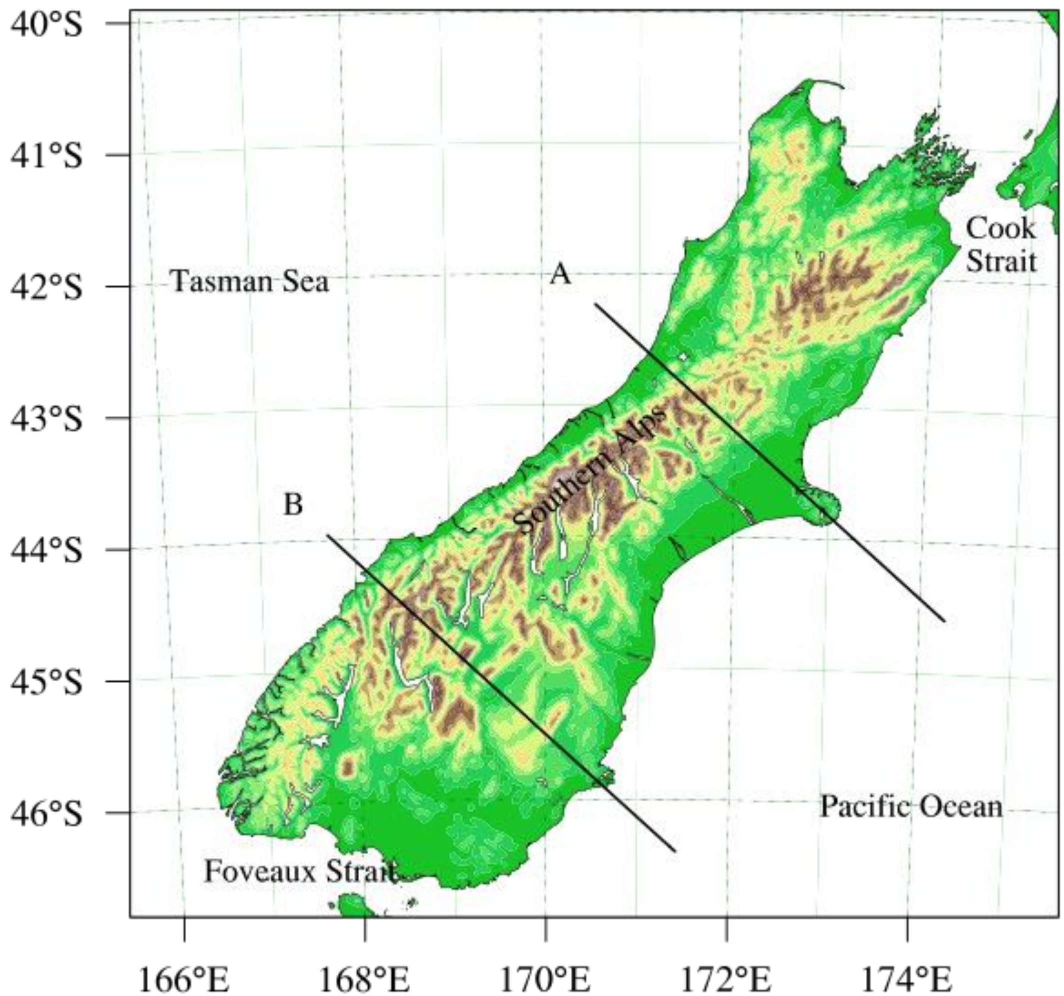
Vertical velocity at 2 km AMSL



10 m horizontal wind vectors



WRF - GRAVITY WAVES



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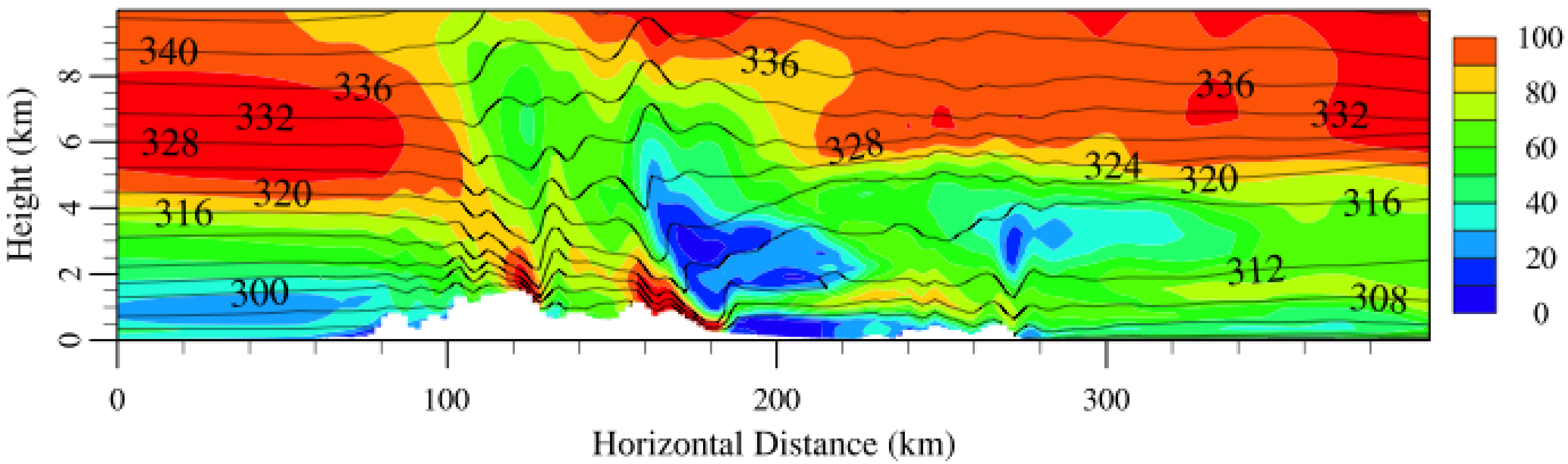
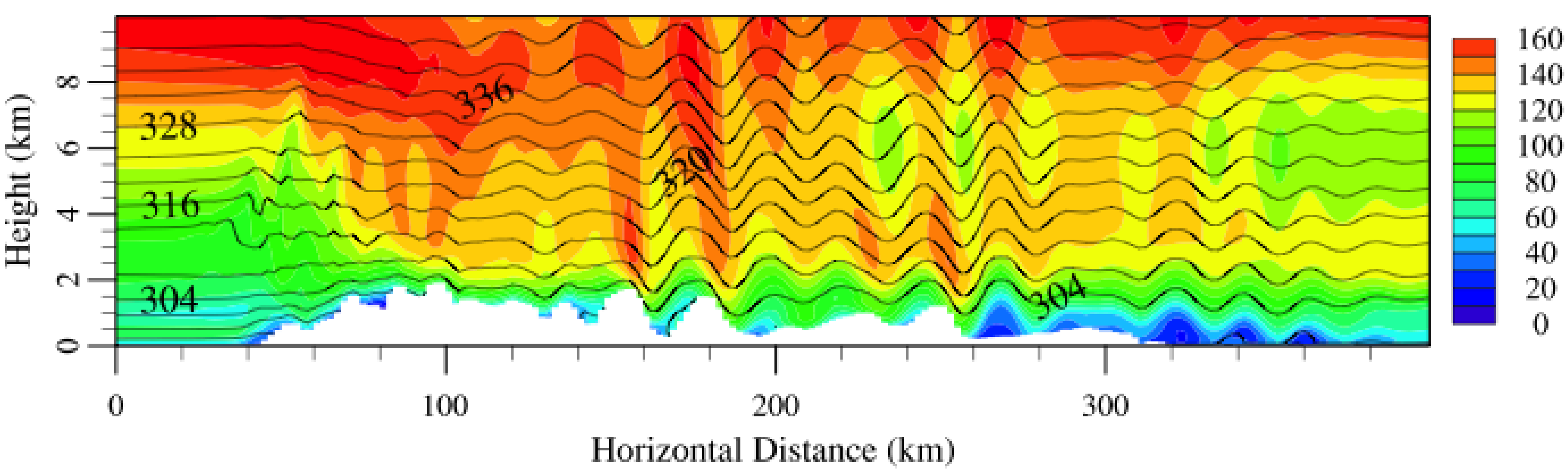
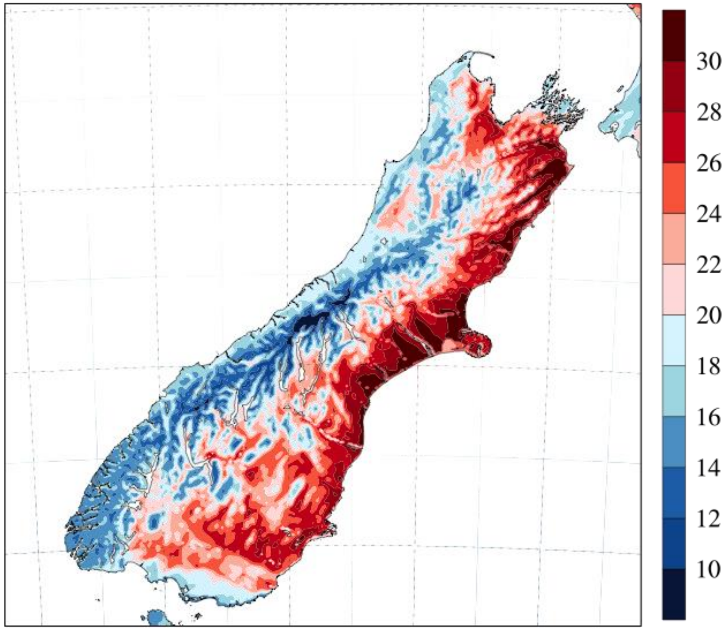


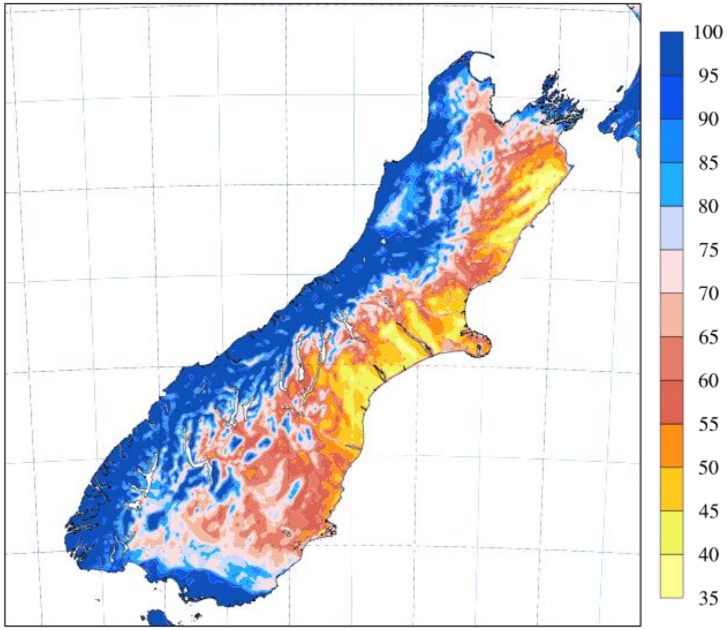


WRF - FIRE WEATHER VARIABLES

Air Temperature (˚C)

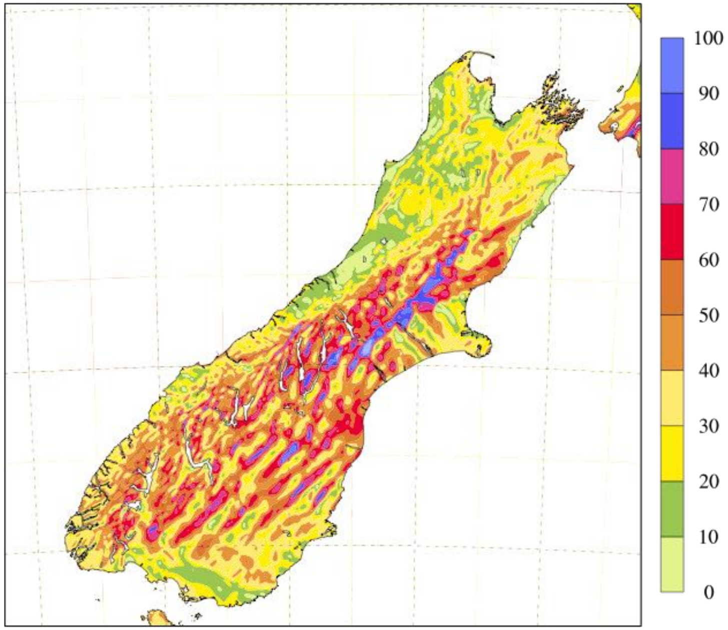


Relative Humidity (%)

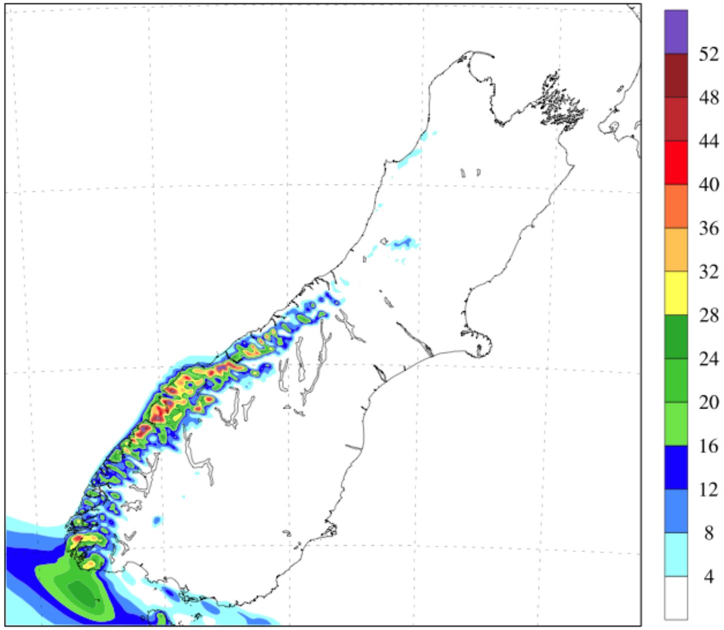


WRF - FIRE WEATHER VARIABLES

Wind Speed (km/h)

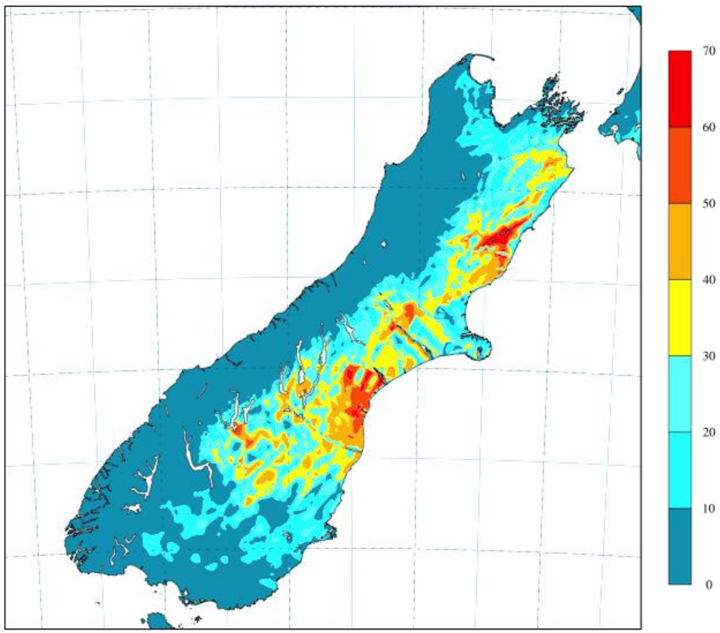


3-hr Rainfall (mm)

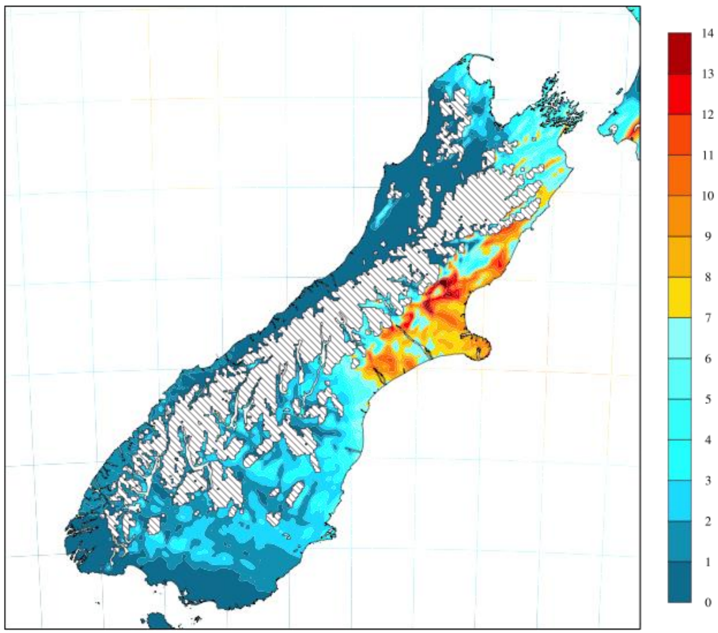


WRF - FIRE WEATHER INDICES

FWI

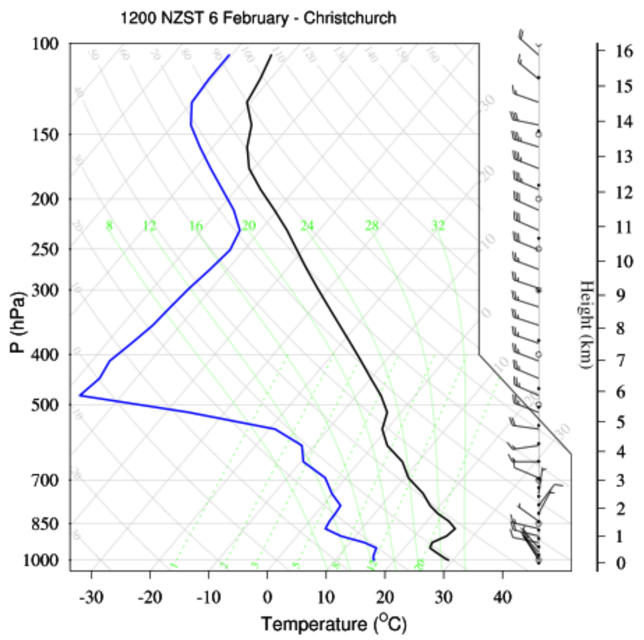


CHI

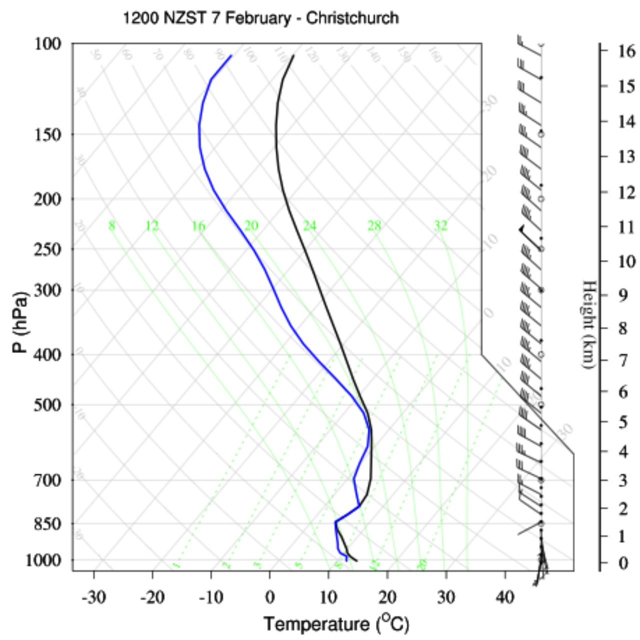


WRF – SKEWT-LOGP CHRISTCHURCH

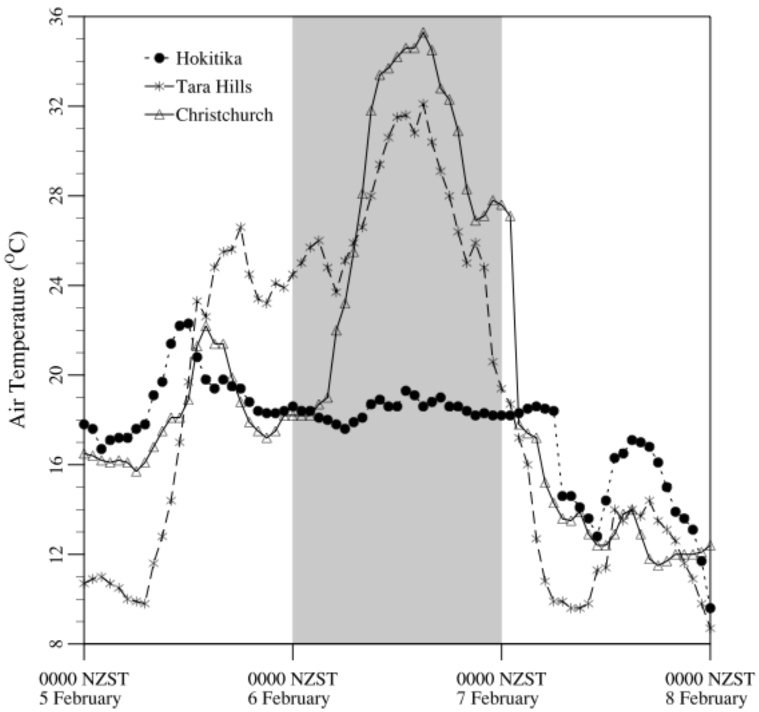
6 February

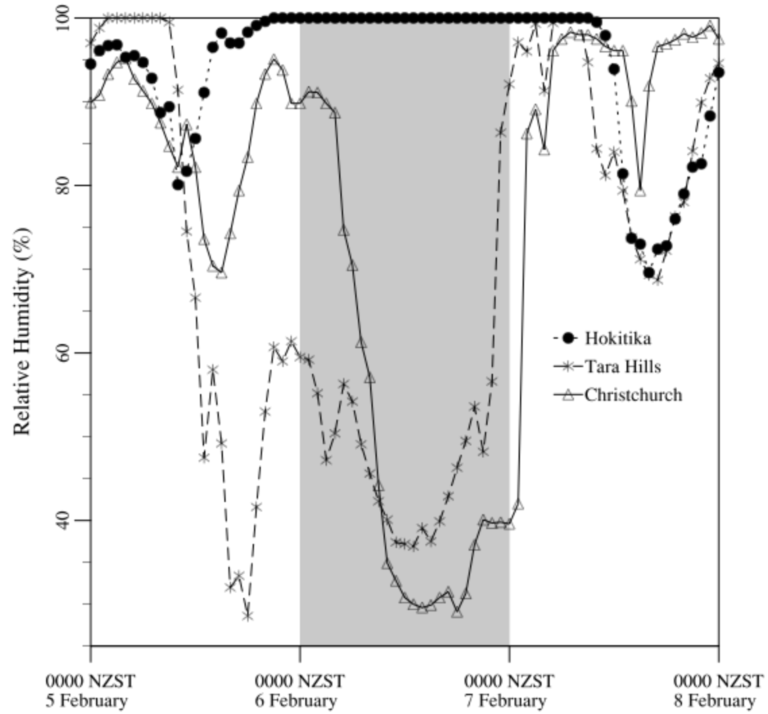


7 February



NIWA – FIRE WEATHER VARIABLES





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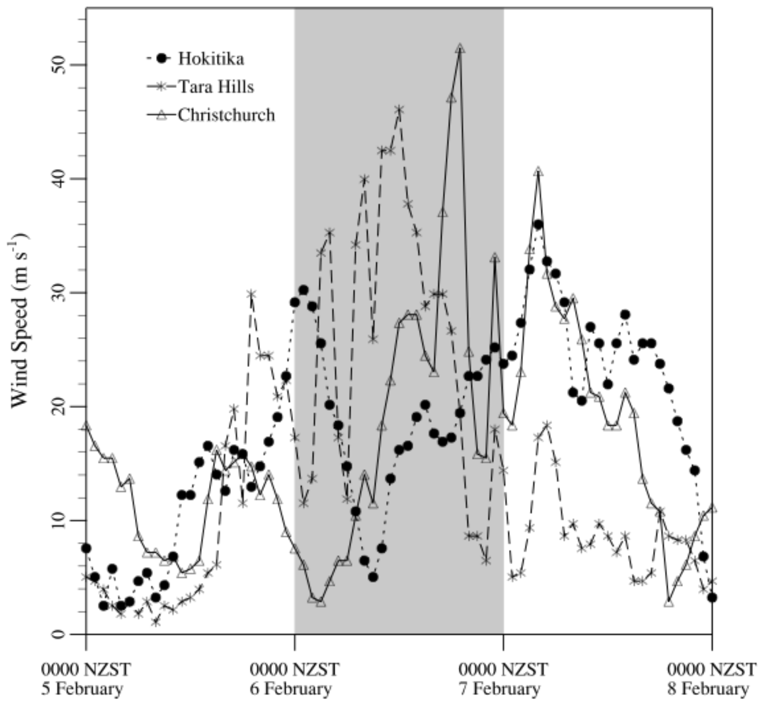

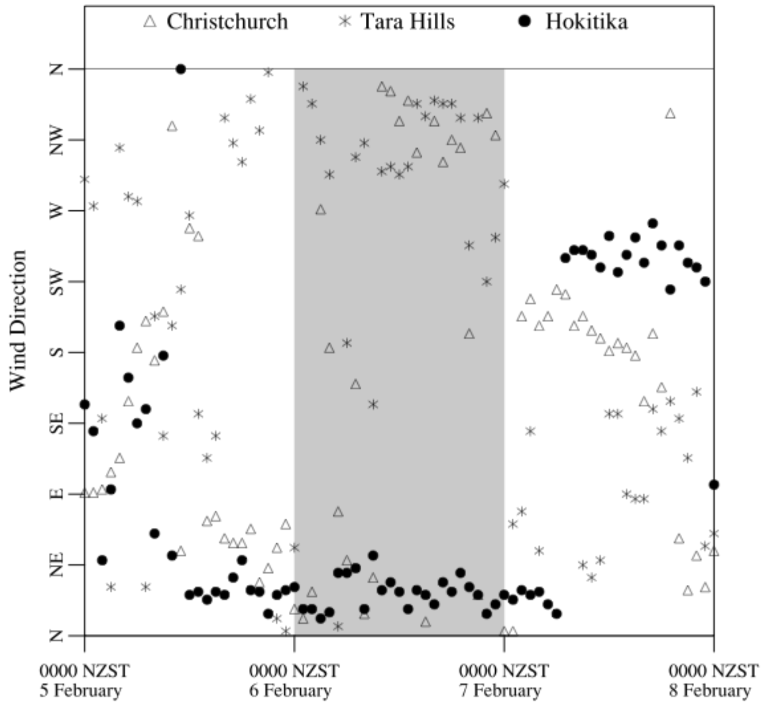

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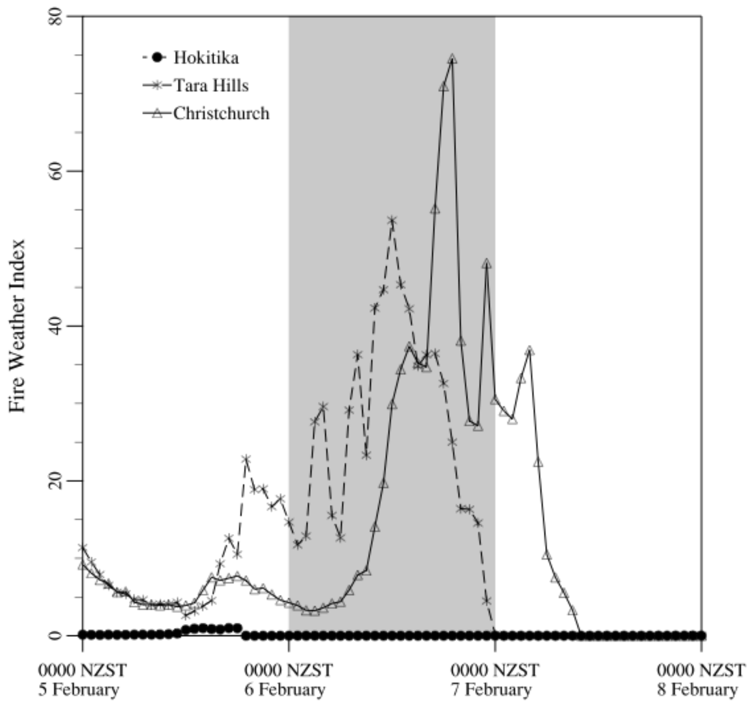
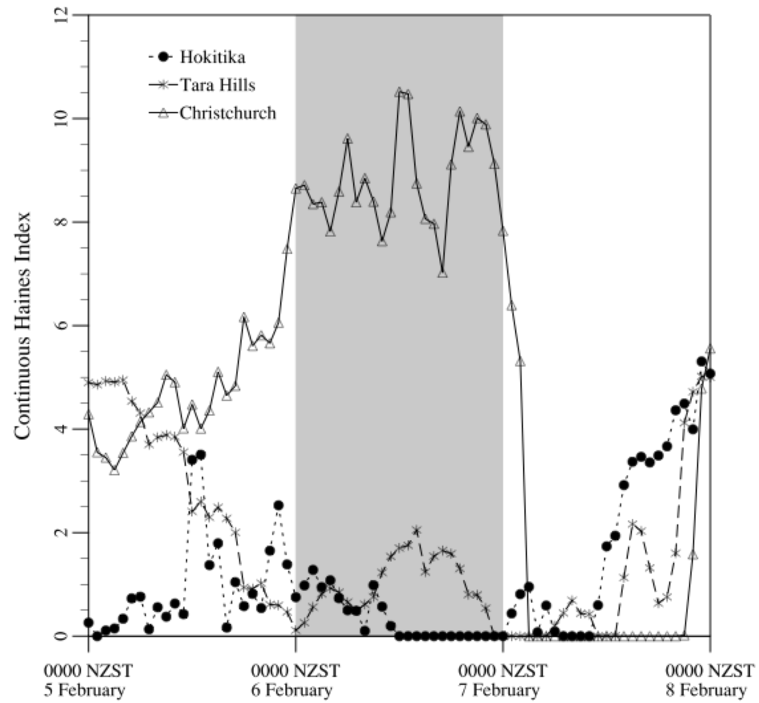
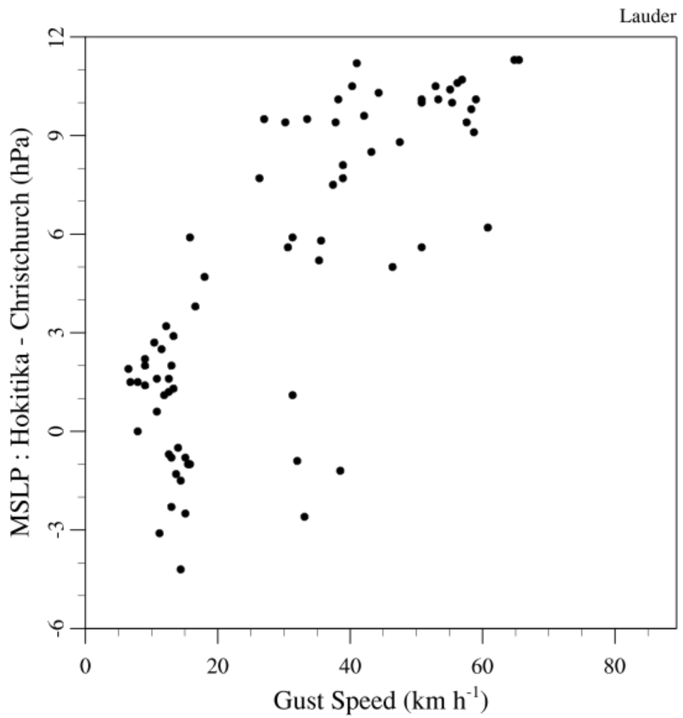
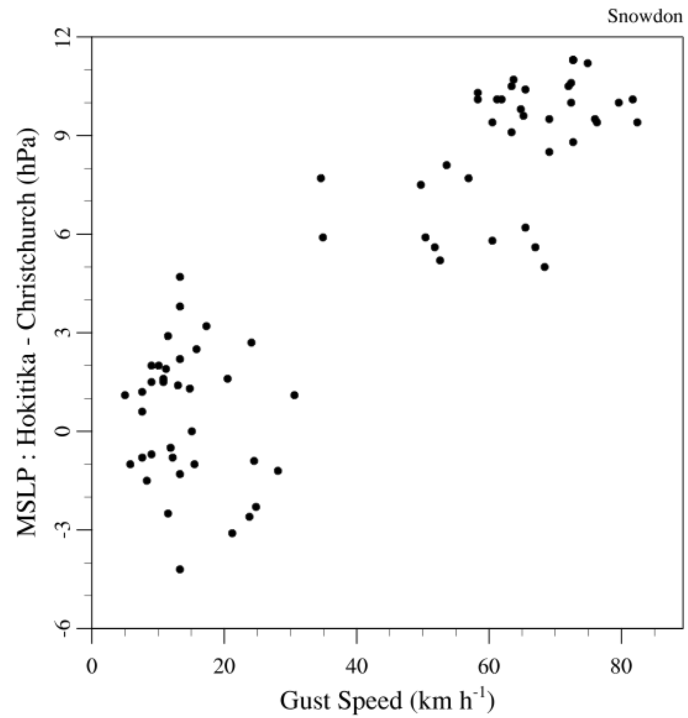


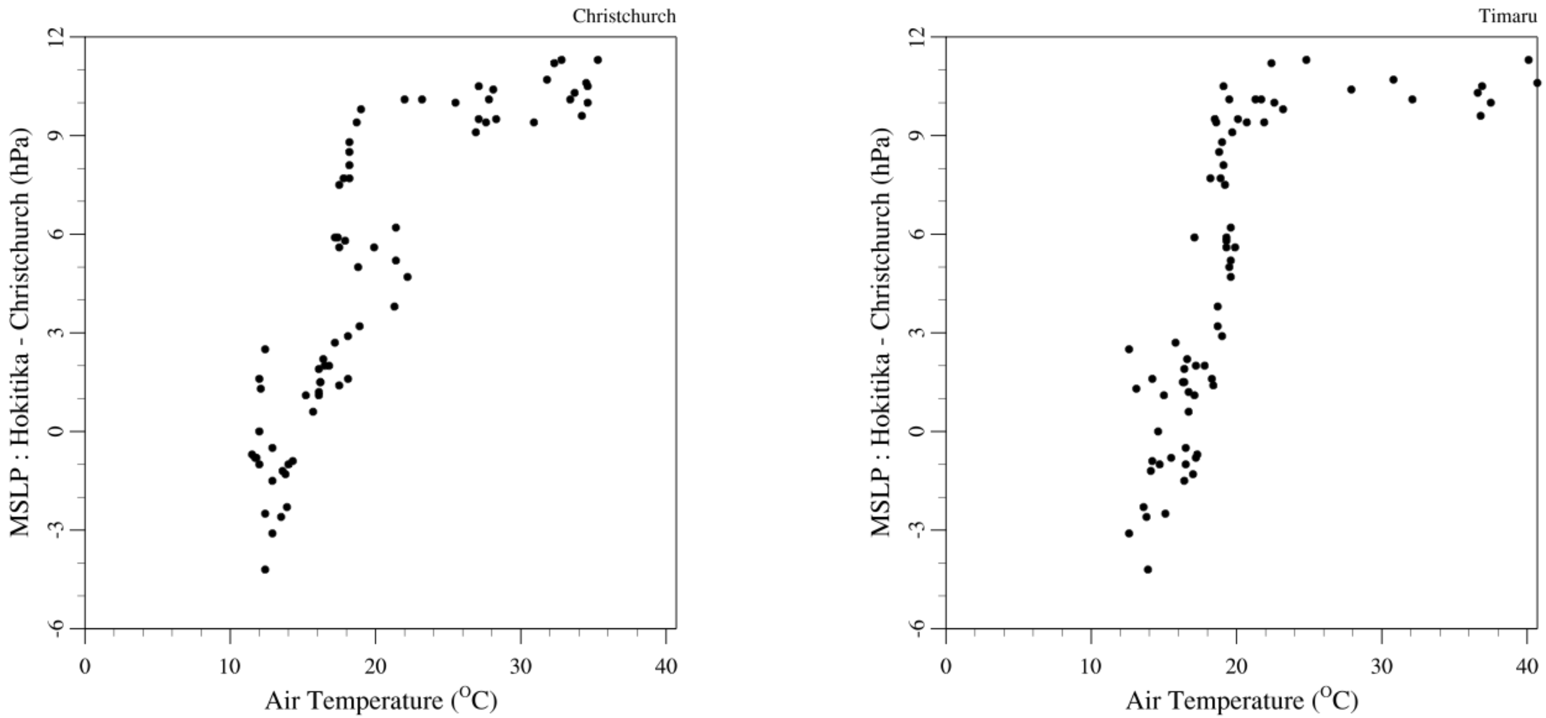


NIWA - PRESSURE GRADIENT AND FOEHN GUST SPEED

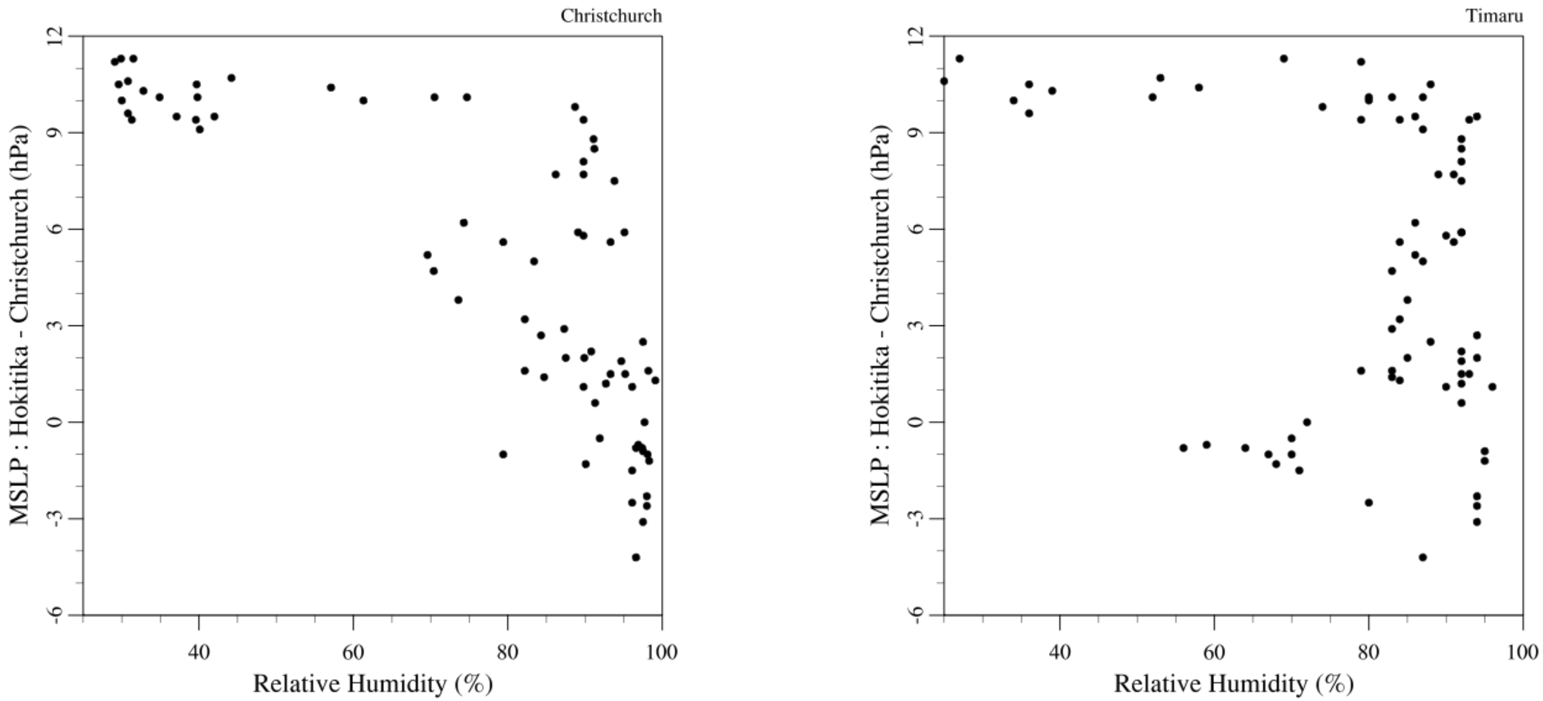




NIWA - PRESSURE GRADIENT AND AIR TEMPERATURE



NIWA - PRESSURE GRADIENT AND RELATIVE HUMIDITY



SUMMARY AND CONCLUSIONS

- Issues with WRF modelled fire weather:
  - Wind speeds were poorly modelled
  - Considerable impact on accuracy of modelled ISI, FWI
  - Known issue in or near mountainous terrain
  - Difficulty in verifying WRF modelled HI, CHI
- Extreme fire weather event in NZ context:
  - FWI exceeded 32 across widespread regions
  - Hourly WRF modelled FWI exceeded 90 in isolated regions
  - Rapid variations in wind conditions, air temperature and RH
- Atmospheric dynamics included:
  - Development of mountain waves
  - Possible hydraulic jump in lee of mountains
  - Further examination of these features required

FUTURE WORK

- Continue analysis of fire weather and atmospheric dynamics:
  - Variations of fire weather conditions at onset/end of foehn
  - Upwind atmospheric stability and orographic blocking
  - Verify existence of hydraulic jump and/or gravity waves
- Develop Northwester climatology:
  - Use climate station data and/or NWP modelling
    e.g. fire weather climatology developed by Pearce et al. 2011
  - Establish criteria for assessing foehn winds
  - Examine relationship with fire weather and behaviour
  - Annual and seasonal variability in Foehn frequency
- Further case studies of fire weather & behaviour:
  - 1973 Ashley Forest Fire
  - 1995 Berwick Forest Fire