Numerical Weather Prediction (NWP) Issues in Mountainous Western North America

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Aug 2017

Topics:
1. fjord weather & forest fire forecasts
2. Pacific data "void" & rocketsondes
3. grid smoothing & nowcasting
4. ensemble forecasts & wind turbines
5. landfalling cyclones & applications

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Dominique Bourdin
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Kyle Sha
Roland Schigas
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Greg West
Tatjana Zenker

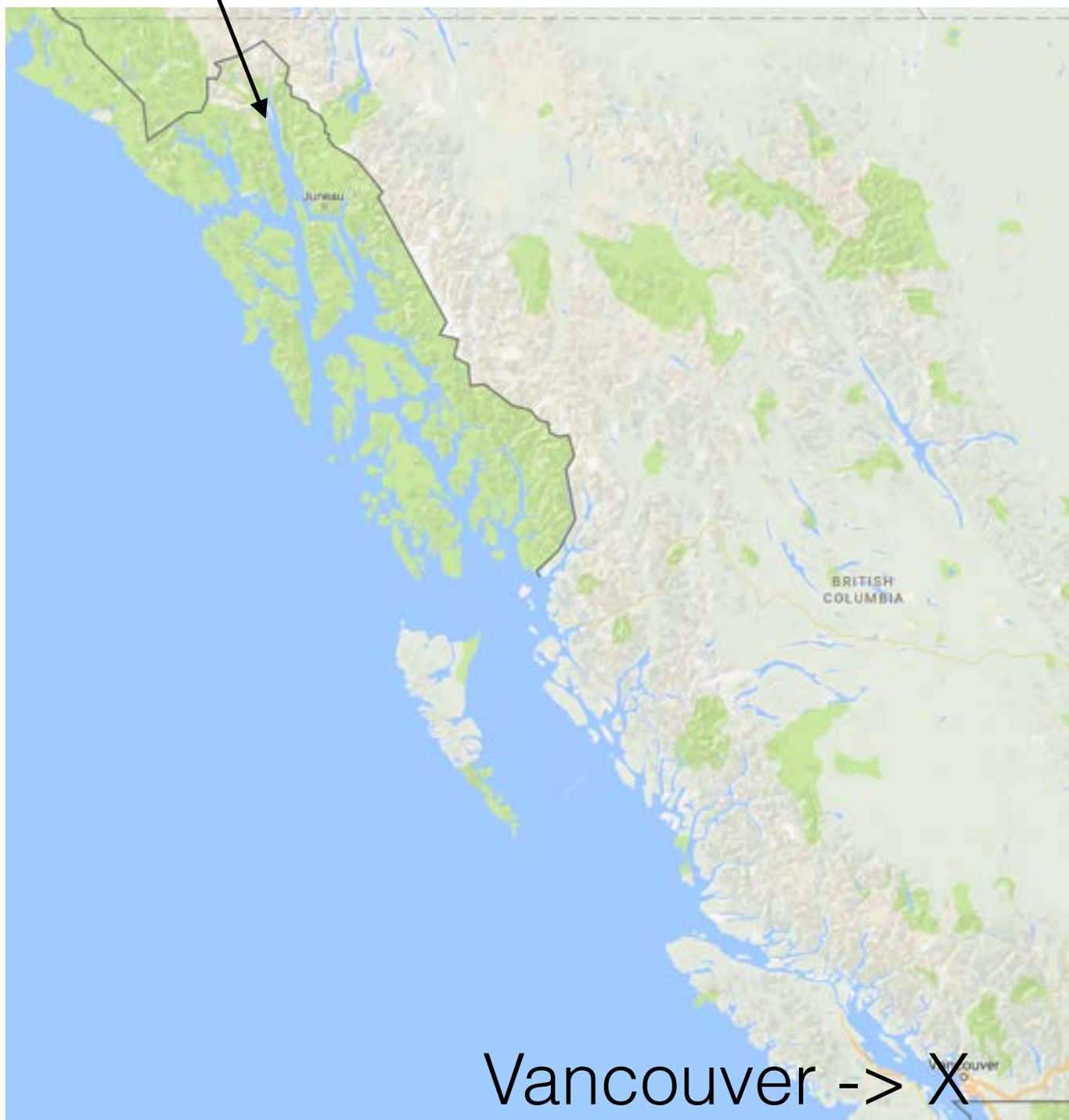
1. Fjord weather & forest fire forecasts

West Coastline changes character at the Canadian border

smooth coastline, few islands

X = Vancouver

fjords & many islands



Vancouver -> X

Similar to Norway

How does forest-fire smoke interact with fjords?

Image courtesy of BC Wildfire Service. https://www.facebook.com/BCForestFireInfo/videos/10155384746680673/

Bishop Bluffs fire in central BC - 13 Aug 2017

Over 65 provincial parks closed.
Dozens of highways closed. Dozens of towns evacuated.

Smoke oozing down the valleys and fjords toward Vancouver and Washington State

(not classic Gaussian plume)

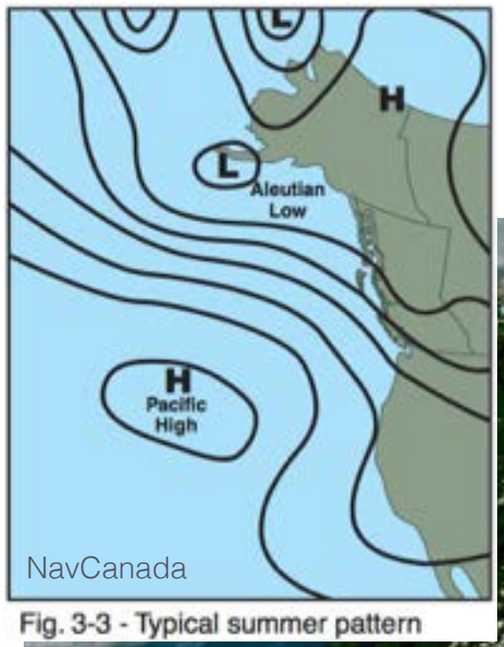


Fig. 3-3 - Typical summer pattern

GOES 16 image on 18 July 2017

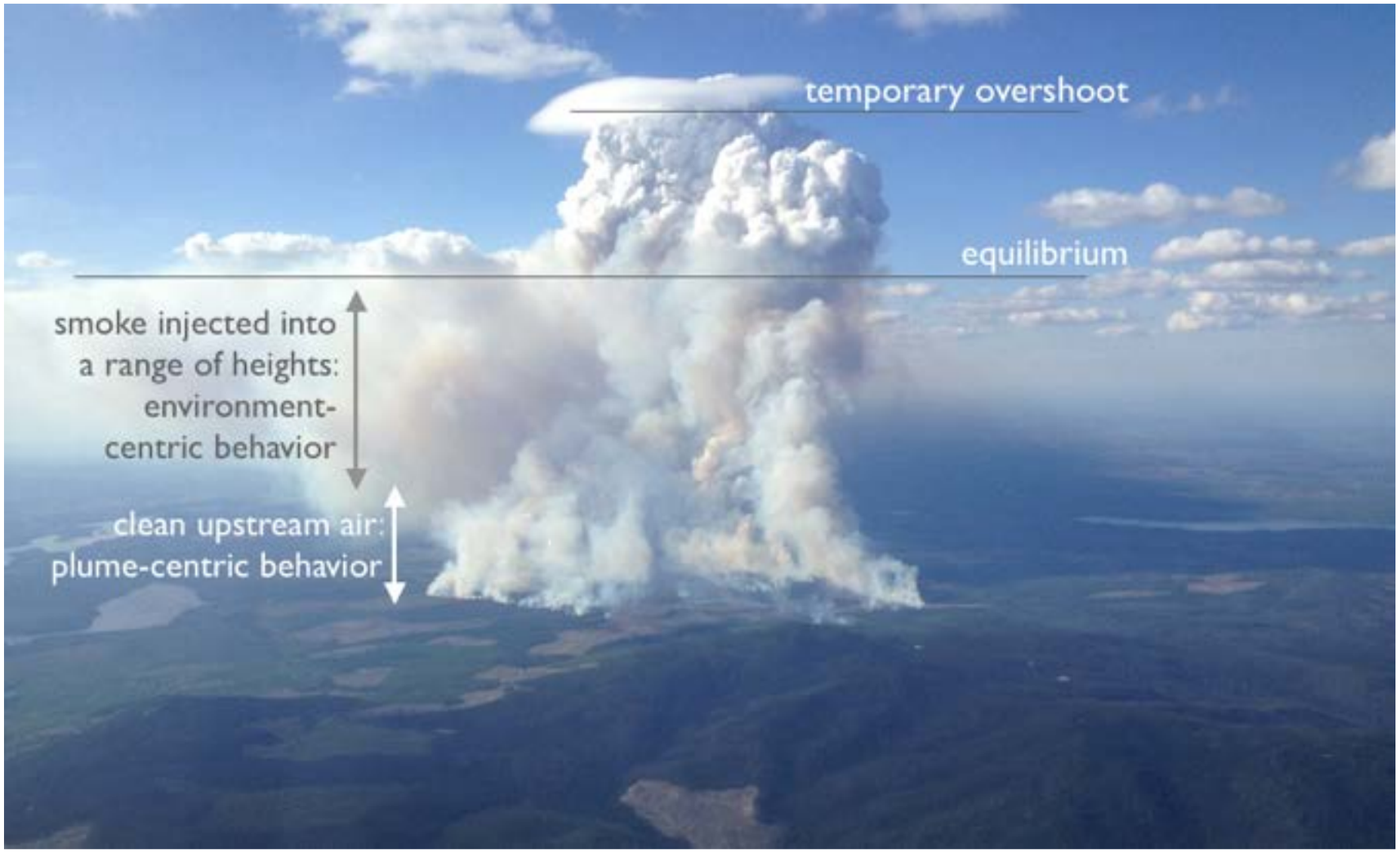
Whistler Ski Resort

BACKGROUND

Plume Rise

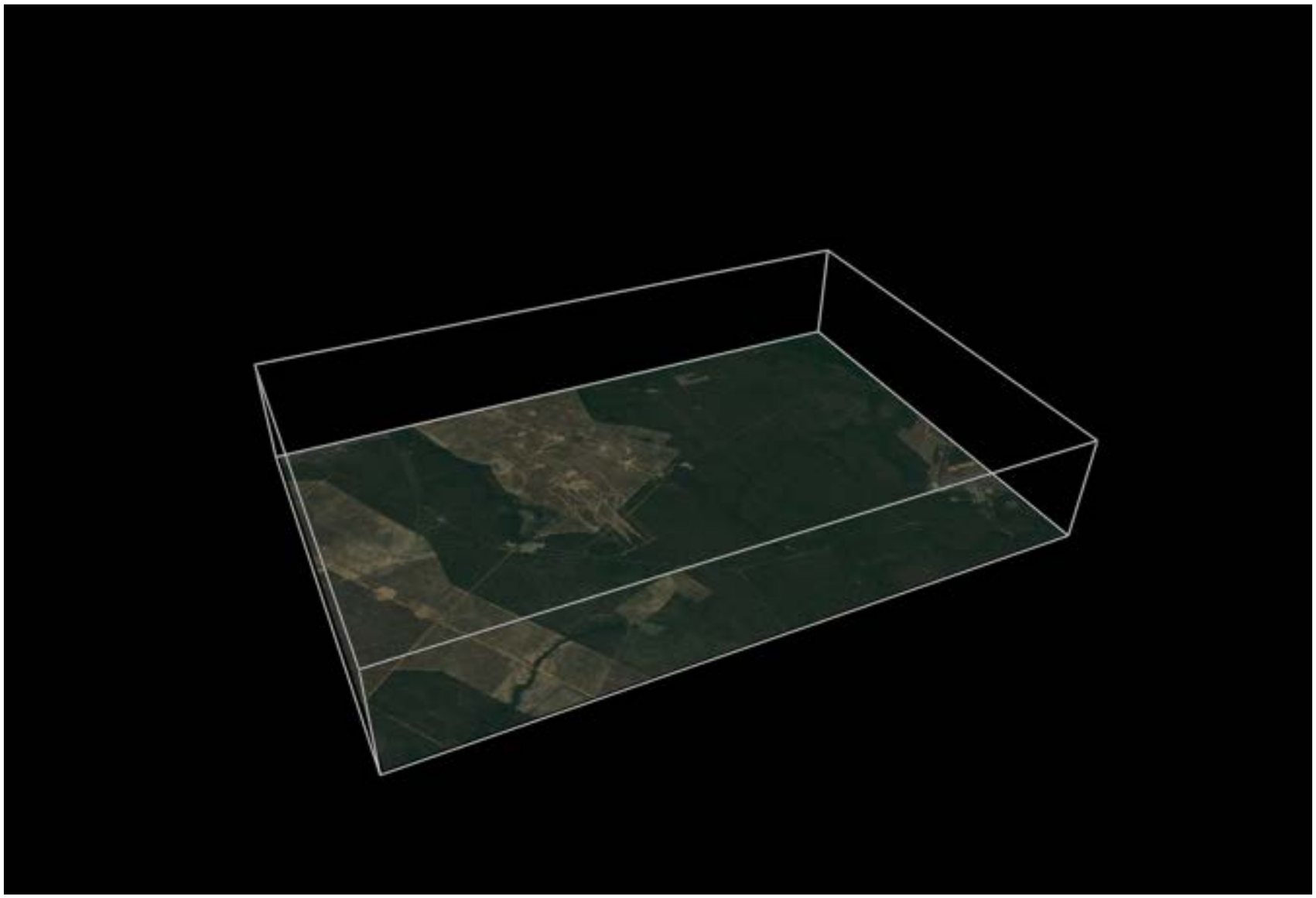
- Biggest challenge = predicting vertical rise and injection height of the smoke
  - small prediction error → potentially devastating downwind effects

- Current models (including BlueSky) use Brigg's (1975) equations for smoke stack plumes. These do a poor job of describing actual injection of smoke vs. altitude.



Can LES (WRF-FIRE) capture plume rise from real fires? - research by Nadya Moisseeva at UBC.

- prescribed burn: RxCADRE 2012 (Nov 10, 2012 – Elgin Air Force Base, Florida)

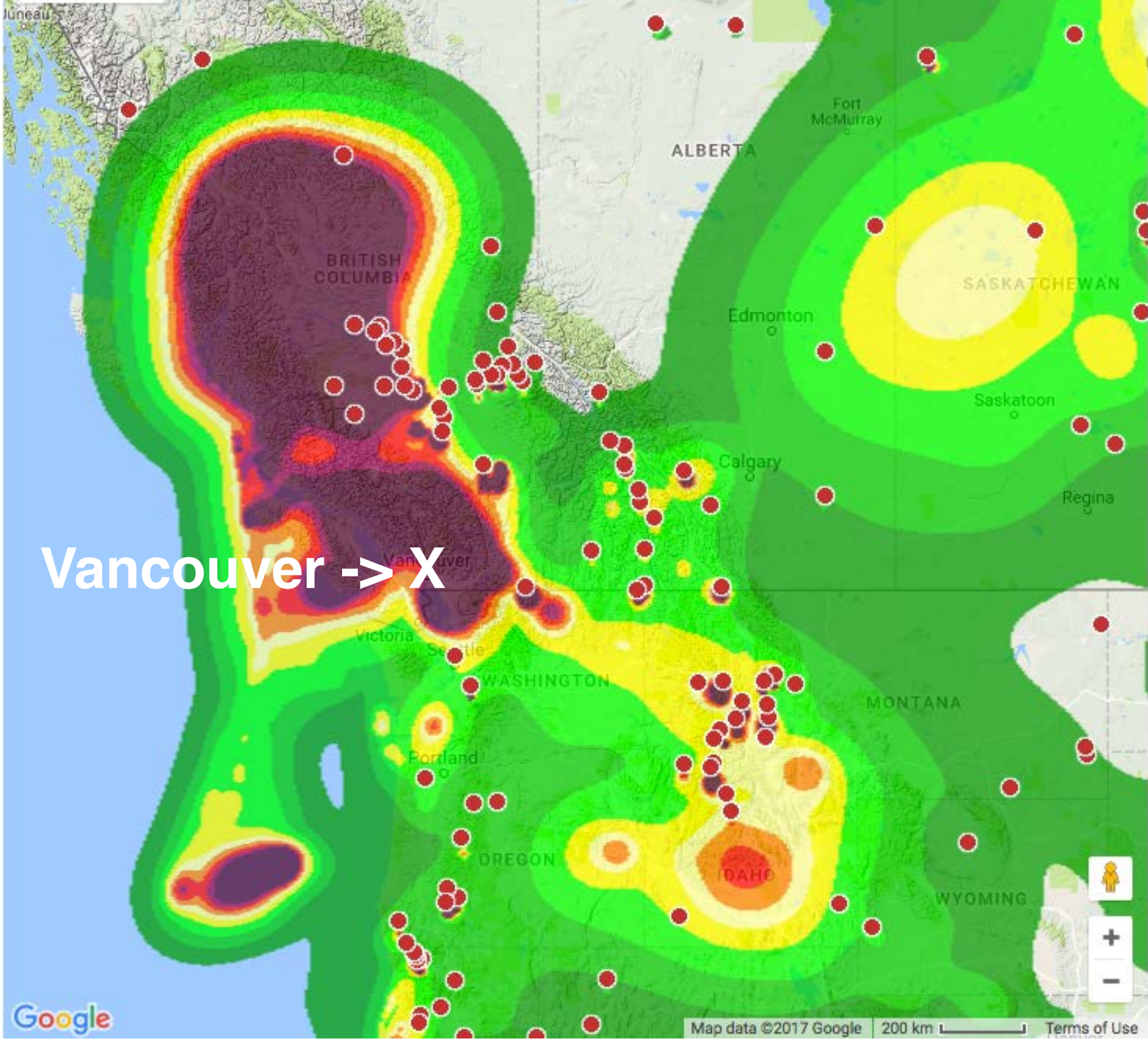


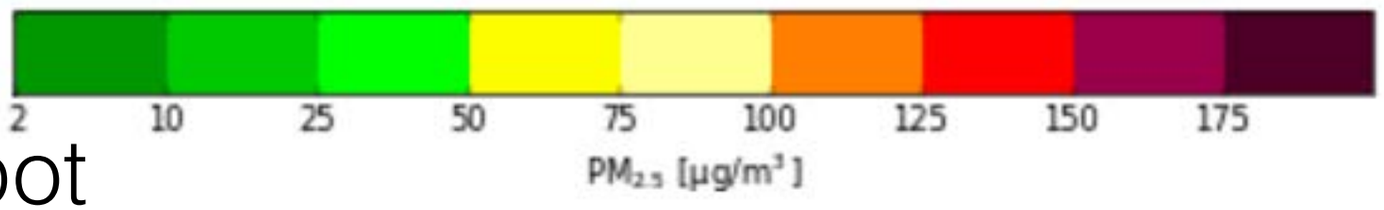
BlueSky-Canada

firesmoke.ca

Run daily at UBC

- hotspots from satellite
- forest/fuel map
- flame energy & propagation
- smoke emissions
- plume rise <== Nadya's research
- meteorology
- dispersion (hysplit model)





- = fire hotspot

2. Pacific data “void” & rocketsondes

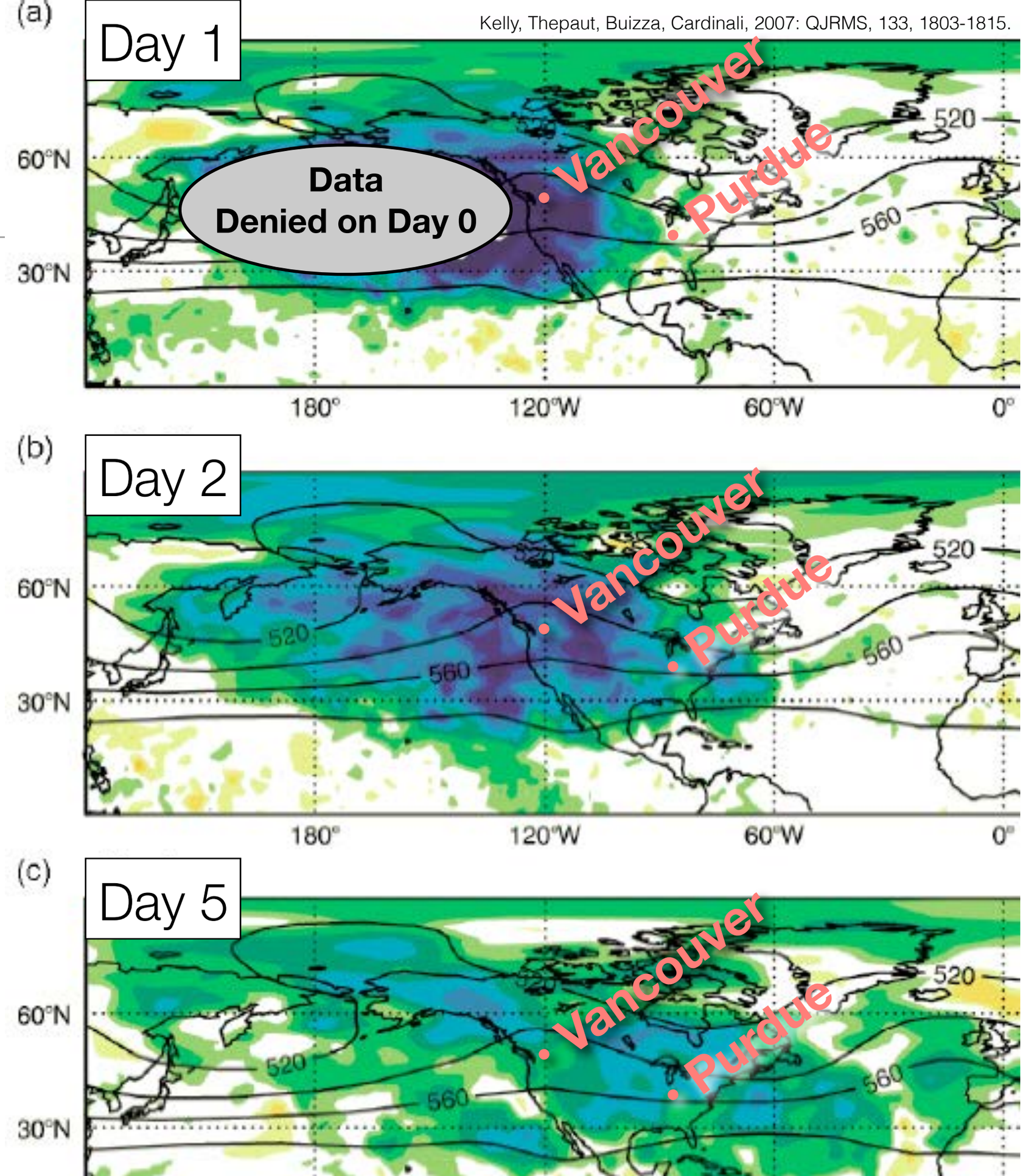
Data Denial Experiment

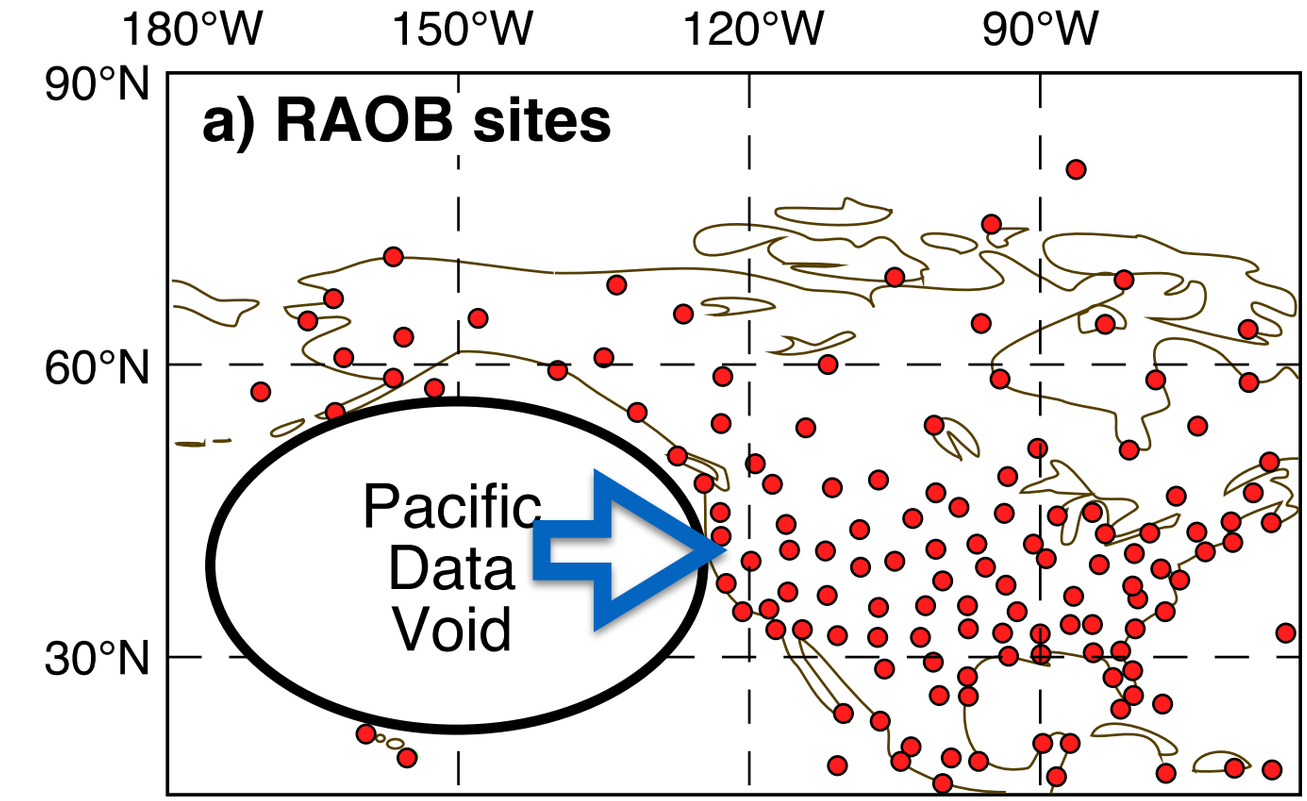
Kelly et al, 2007, QJRMS

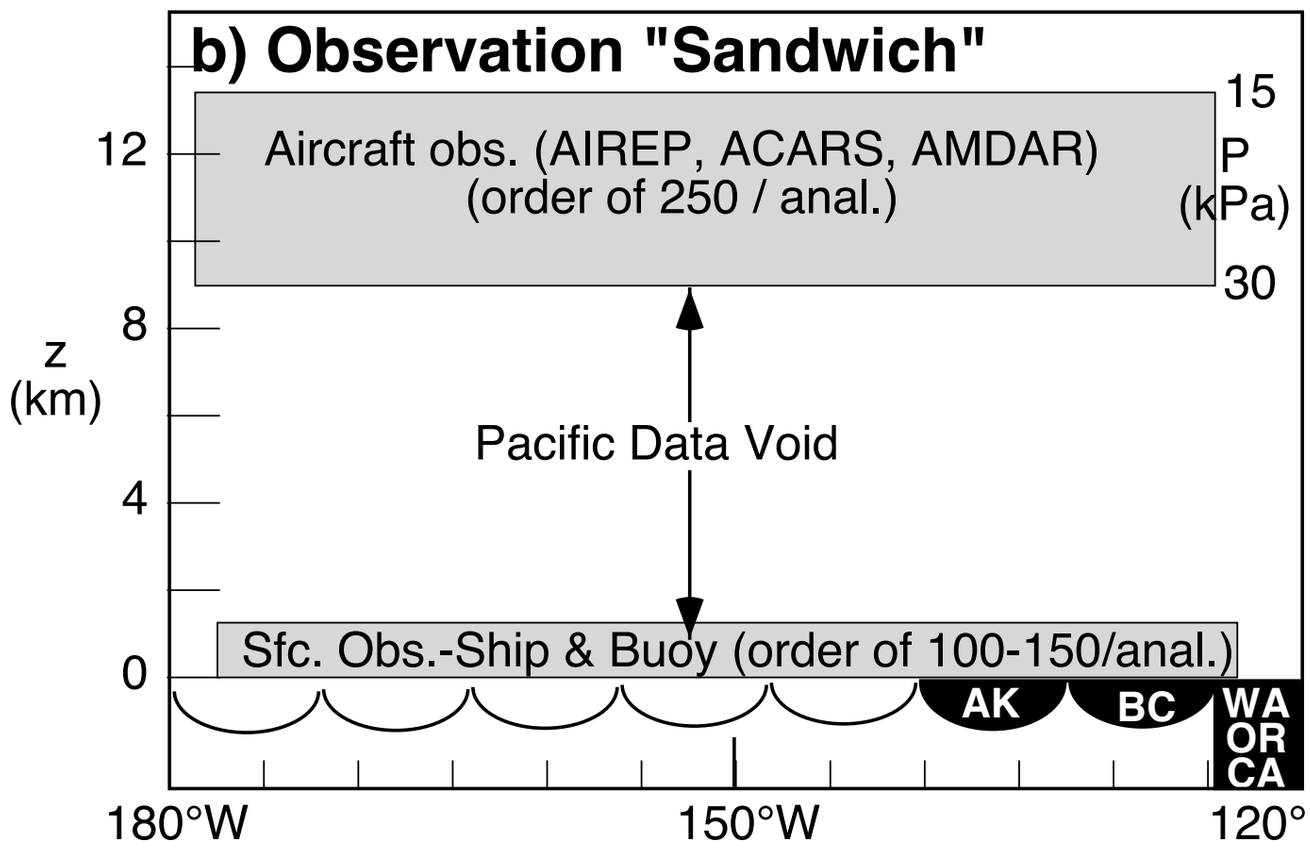
Relative RMS errors in the 50 kPa geopotential heights, when all observations over the Pacific are excluded from the ECMWF data assimilation for Day 0, vs. those normally retained by ECMWF.

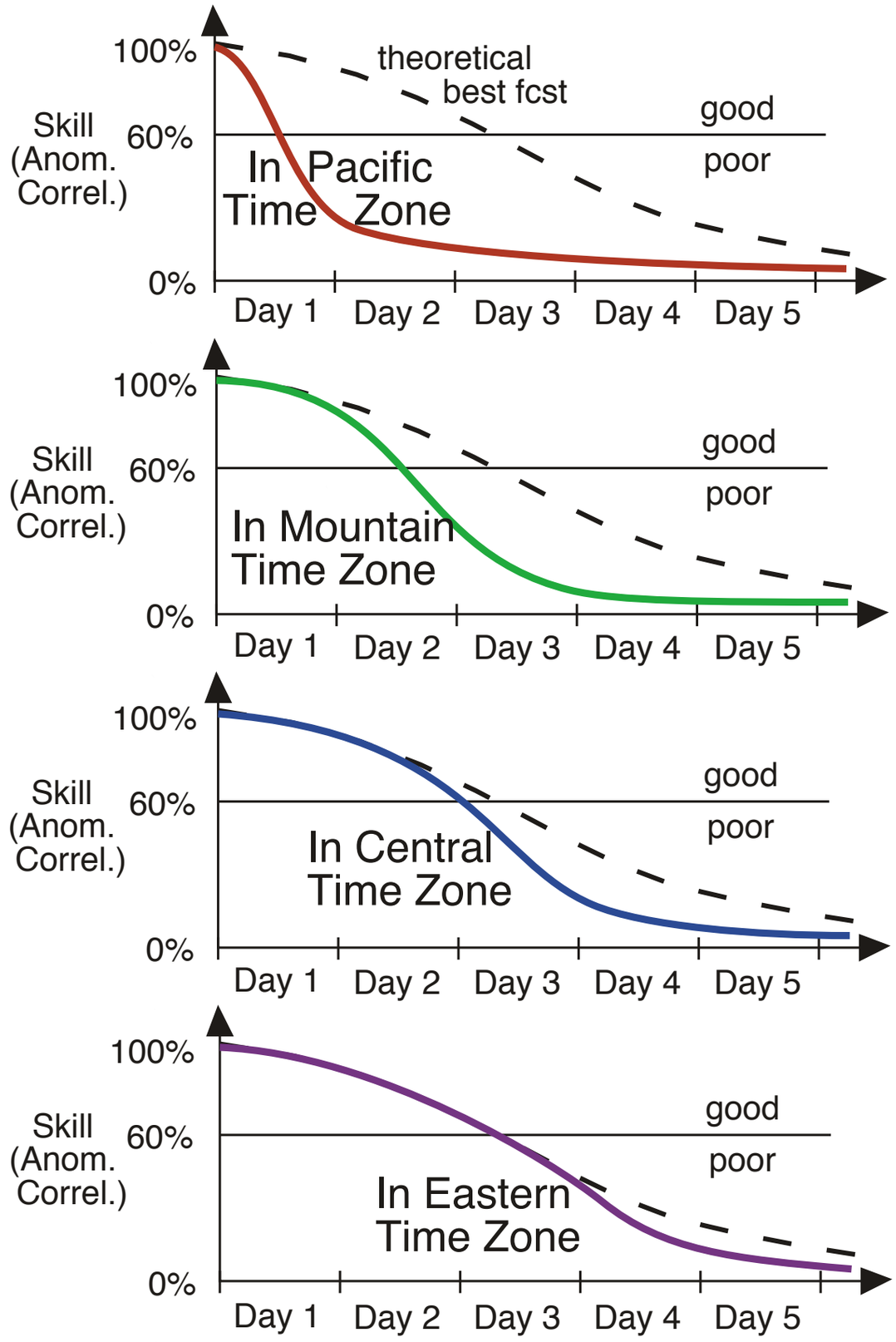
Green, **blue**, **dark purple** show worse forecasts,

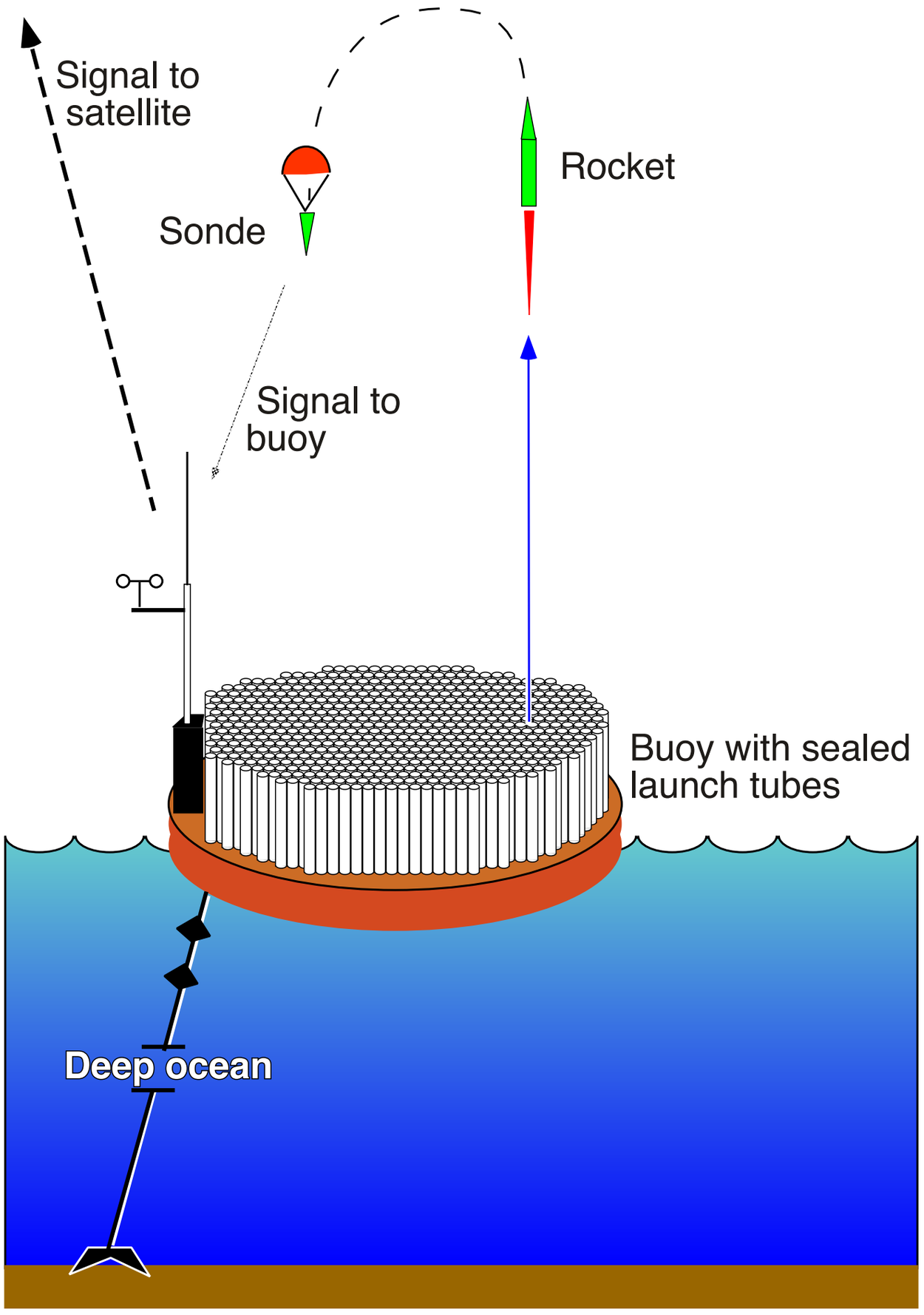
while **yellow** and **red** show positive impact.




180°W
150°W
120°W
90°W
90°N
60°N
30°N
a) RAOB sites
Pacific
Data
Void


b) Observation "Sandwich"
Aircraft obs. (AIREP, ACARS, AMDAR)
(order of 250 / anal.)
15
P
(kPa)
30
12
8
4
0
z
(km)
Pacific Data Void
Sfc. Obs.-Ship & Buoy (order of 100-150/anal.)
AK
BC
WA
OR
CA
180°W
150°W
120°


100%
60%
0%
Skill
(Anom.
Correl.)
theoretical
best fcst
good
poor
In Pacific
Time Zone
Day 1
Day 2
Day 3
Day 4
Day 5
In Mountain
Time Zone
In Central
Time Zone
In Eastern
Time Zone



Solution

Fill the data void with soundings:
rawinsonde,
dropsondes,
driftsondes,
GPS radio occultation,
etc.

Floating gantry on Harrison Lake, BC

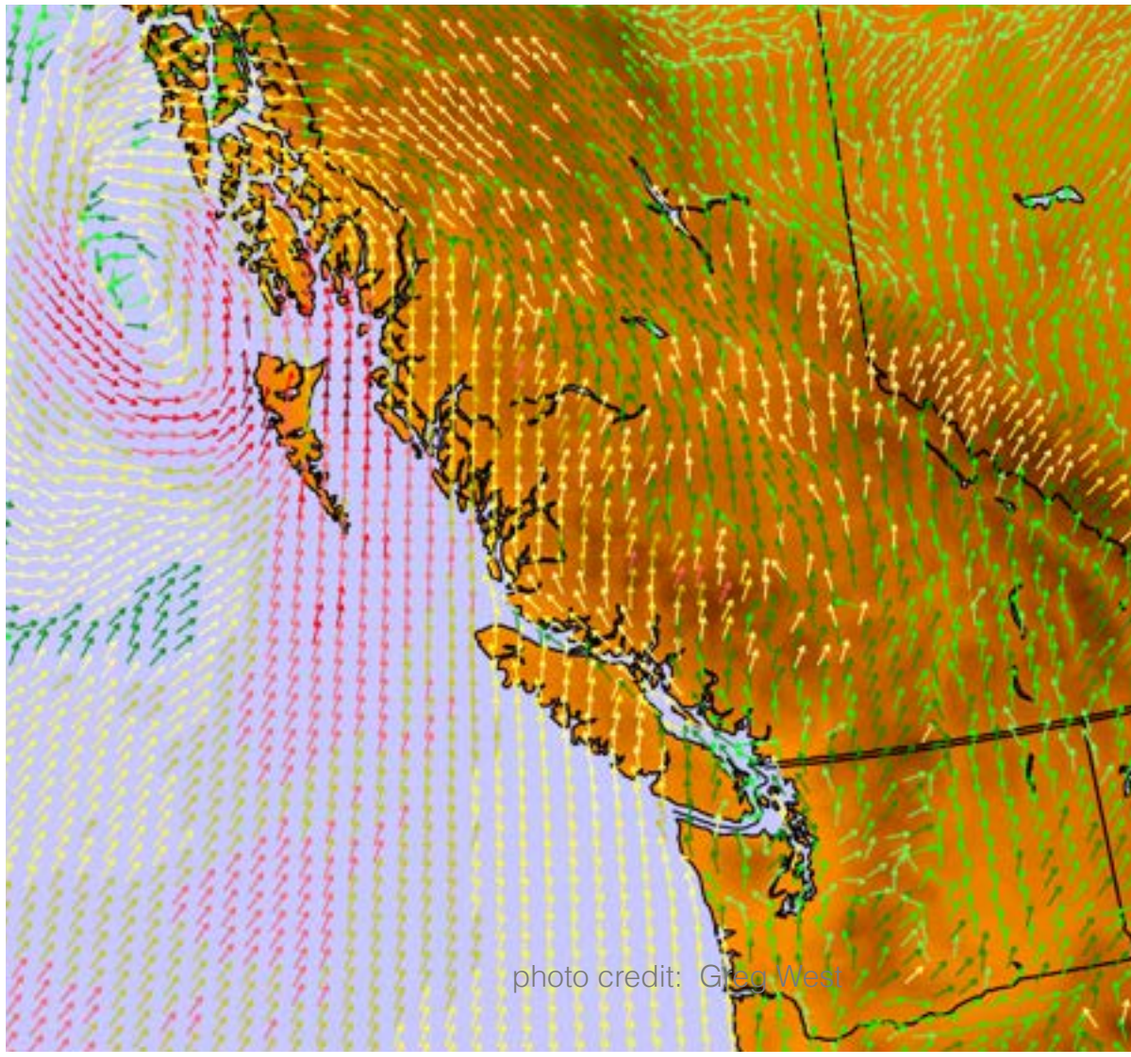
The poor forecast skill motivated my change from PBL to NWP research

Ensemble Forecasts at UBC

Reduces random errors associated with chaotic atmosphere

<u>UBC Example</u>: 42 ensemble members run each day on our 448 core computer cluster + additional members run on cloud computers

- Multi NWP models
  WRF, MM5
- Multi model versions
  WRF-ARW, WRF-NMM
- Multi Initial Conditions (ICs)
  GFS, NAM, GEM, NAVGEM, ARPEGE
- Multi grid sizes
  108, 36, 27, 12, 9, 4, 1.3 km horiz.
- Multi boundary-layer physics
  YSU, ACM2, & more



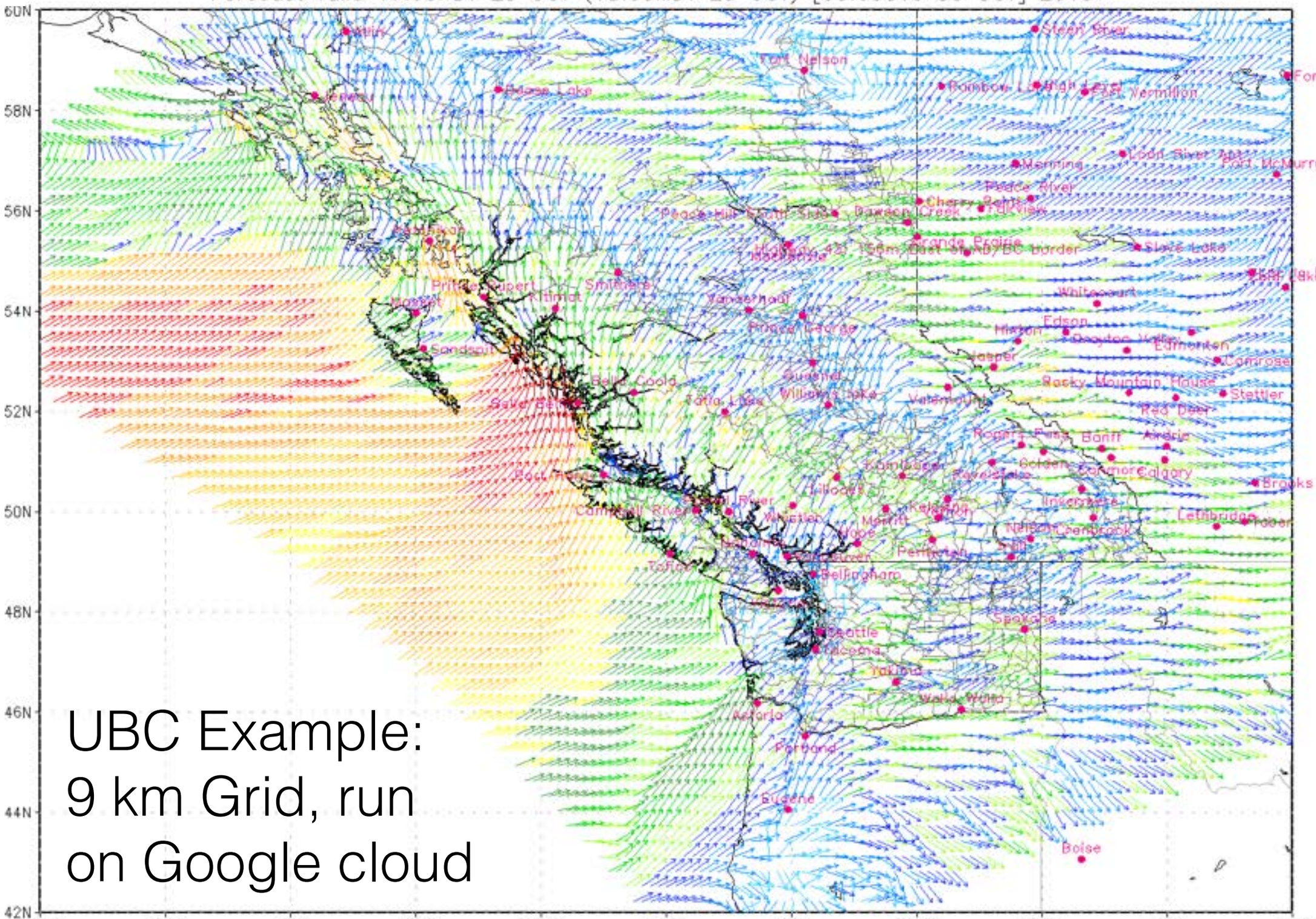
Model/IBC: WRF3/GFSgc01

9 km grid

Coloured Surface Winds

Grid initialized: 3UTC, 29 OCT 2015

Forecast valid 17:00PDT 29 OCT (18:00MDT 29 OCT) [00:00UTC 30 OCT] 2015



UBC Example:
9 km Grid, run
on Google cloud

Forecast valid 17:00PDT 29 OCT (18:00MDT 29 OCT) [00:00UTC 30 OCT] 2015

3 5 8 11 13 16 19 22 24 27 30 32 35 38 43

5 10 15 20 25 30 35 40 45 50 55 60 65 70 80

colour bar: Wind Speed marked in knots above bar and km/hr below bar

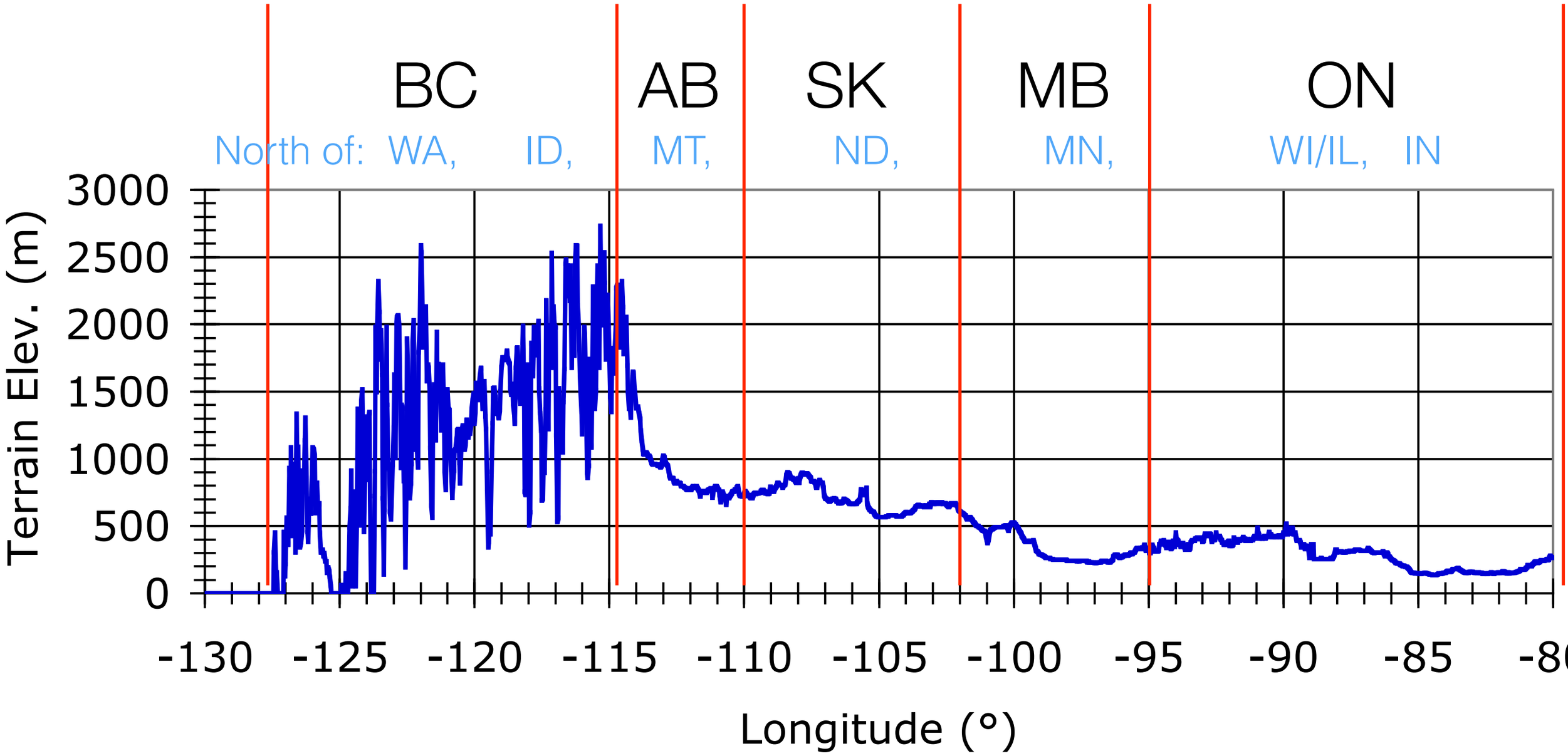
arrows: Wind Direction

2 Degrees Longitude is
128 km at 55 latitude
143 km at 50 latitude
157 km at 45 latitude

photo credit: David Siuta & Henryk Modzelewski

3. NWP terrain grid smoothing & nowcasting

Canadian Terrain Elevation



- West-East terrain cross section through Whistler (50.12°N)

Coast Range Mountains

Columbia Mountains

Rocky Mountains

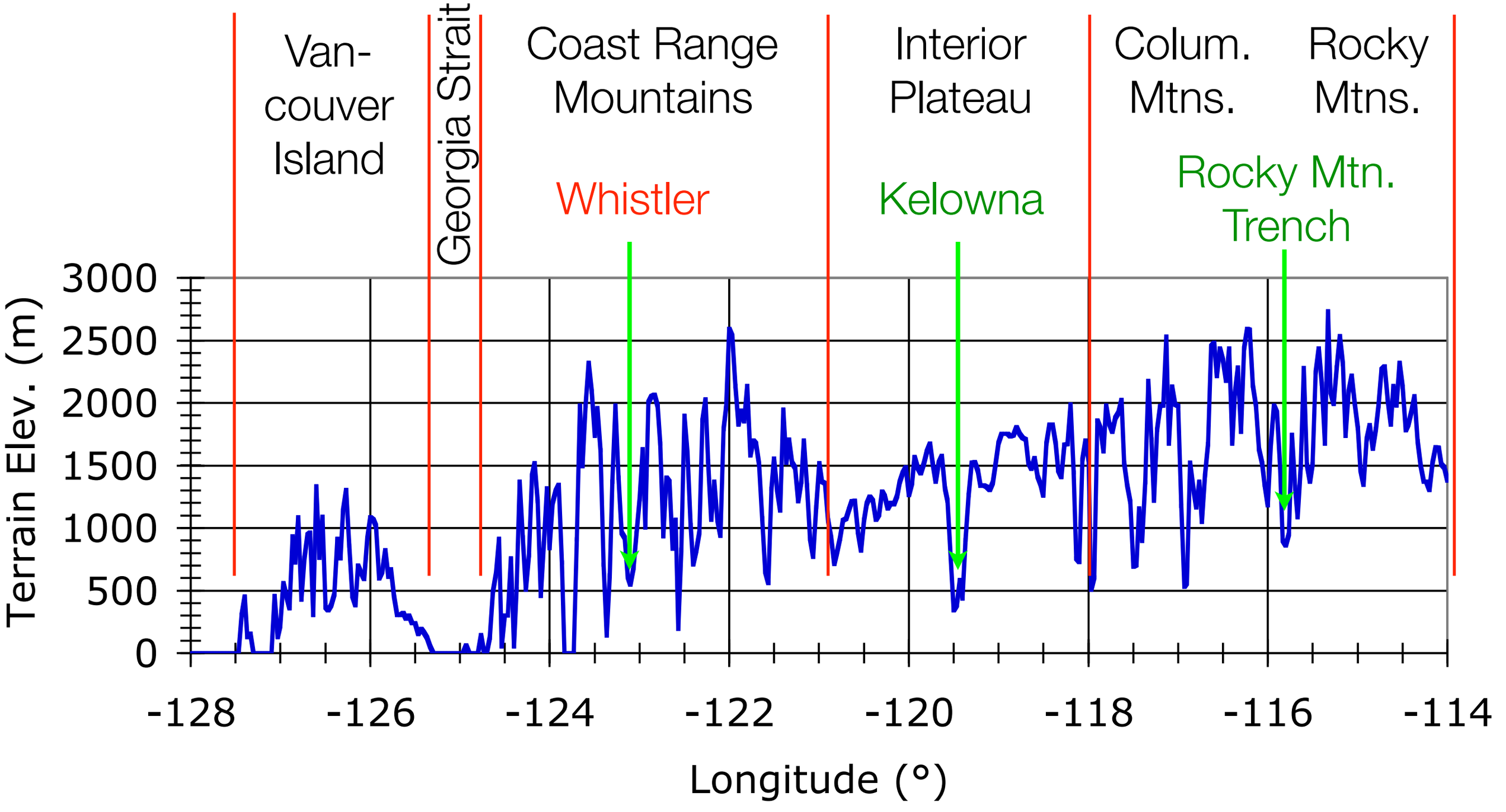
Vancouver Island Mtns.

cross section

Olympic Mountains

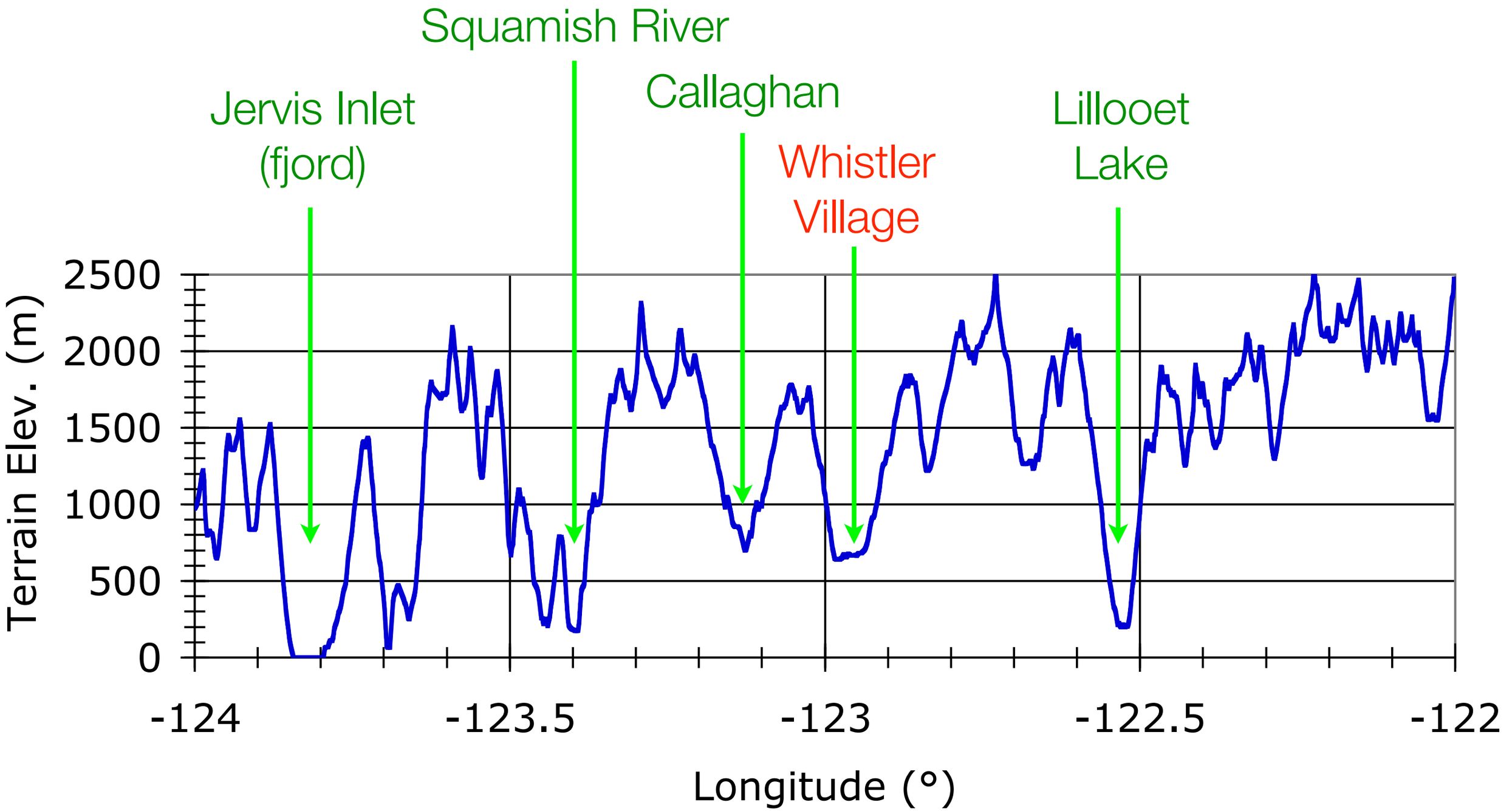
Cascade Mountains

British Columbia Terrain Elevation



- West-East terrain cross section through Whistler (50.12°N)

Zooming in Near Whistler



- West-East terrain cross section through Whistler (50.12°N)

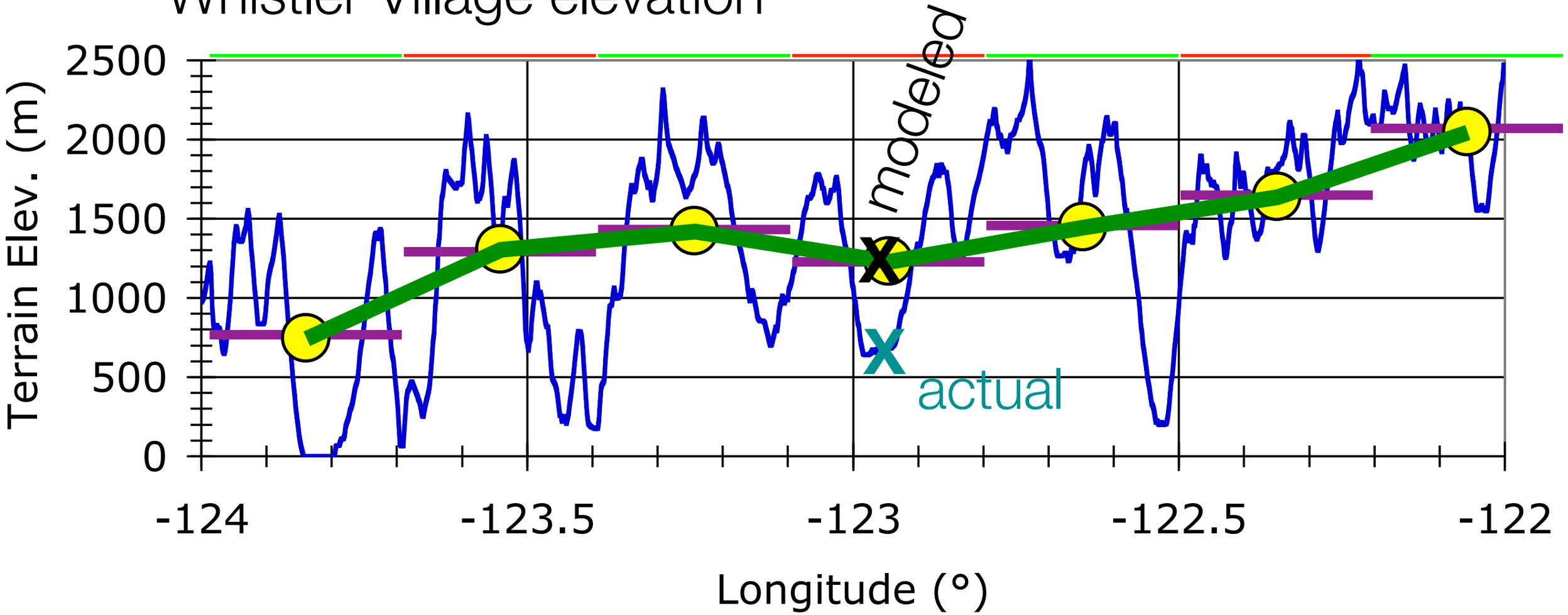
Terrain Elevation vs. Grid Size.

Terrain must be smoothed to match grid resolution.

Example: If grid size is Δx = 21 km

Then smoothed terrain is shown in green.

Whistler Village elevation



- West-East terrain cross section through Whistler (50.12°N), where 0.1°lon ≈ 7 km.

How Fine is Fine Enough?
Many valleys are narrower than 1 km

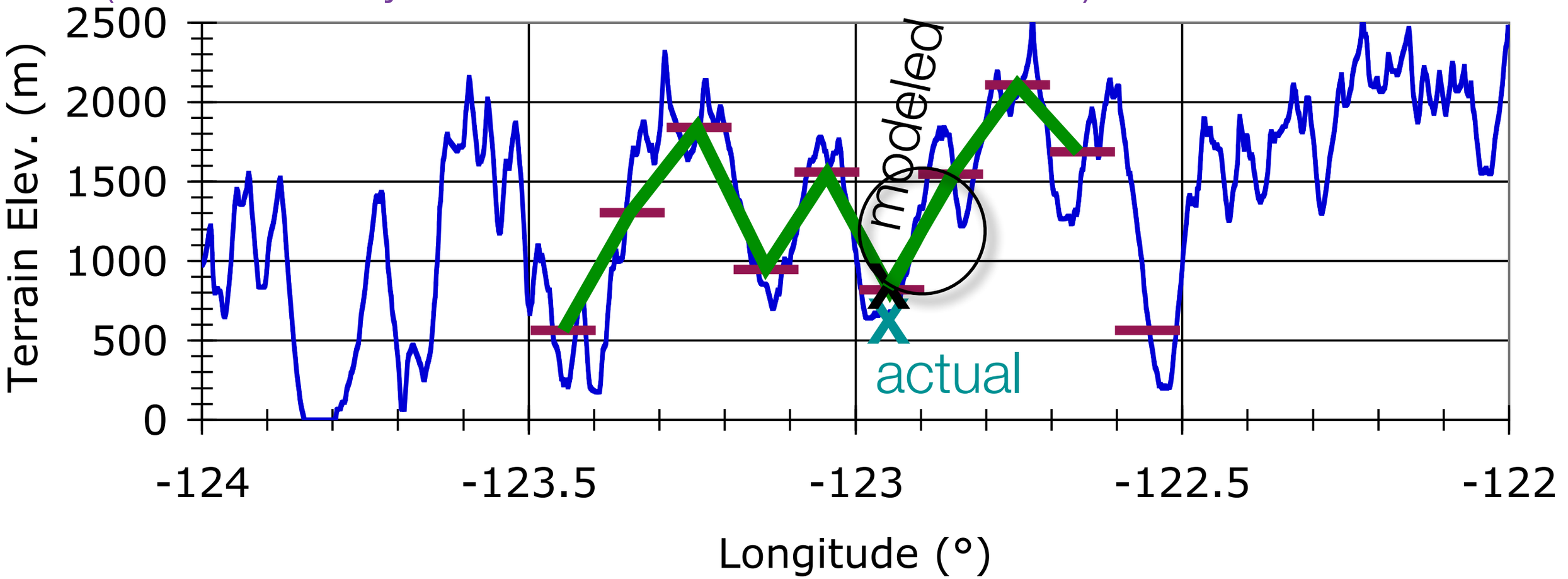
An Obvious Trick: Use finer horizontal grid size

Example: If grid size is Δx = 7 km —

Then the modeled terrain is closer to the actual terrain. **Good.**

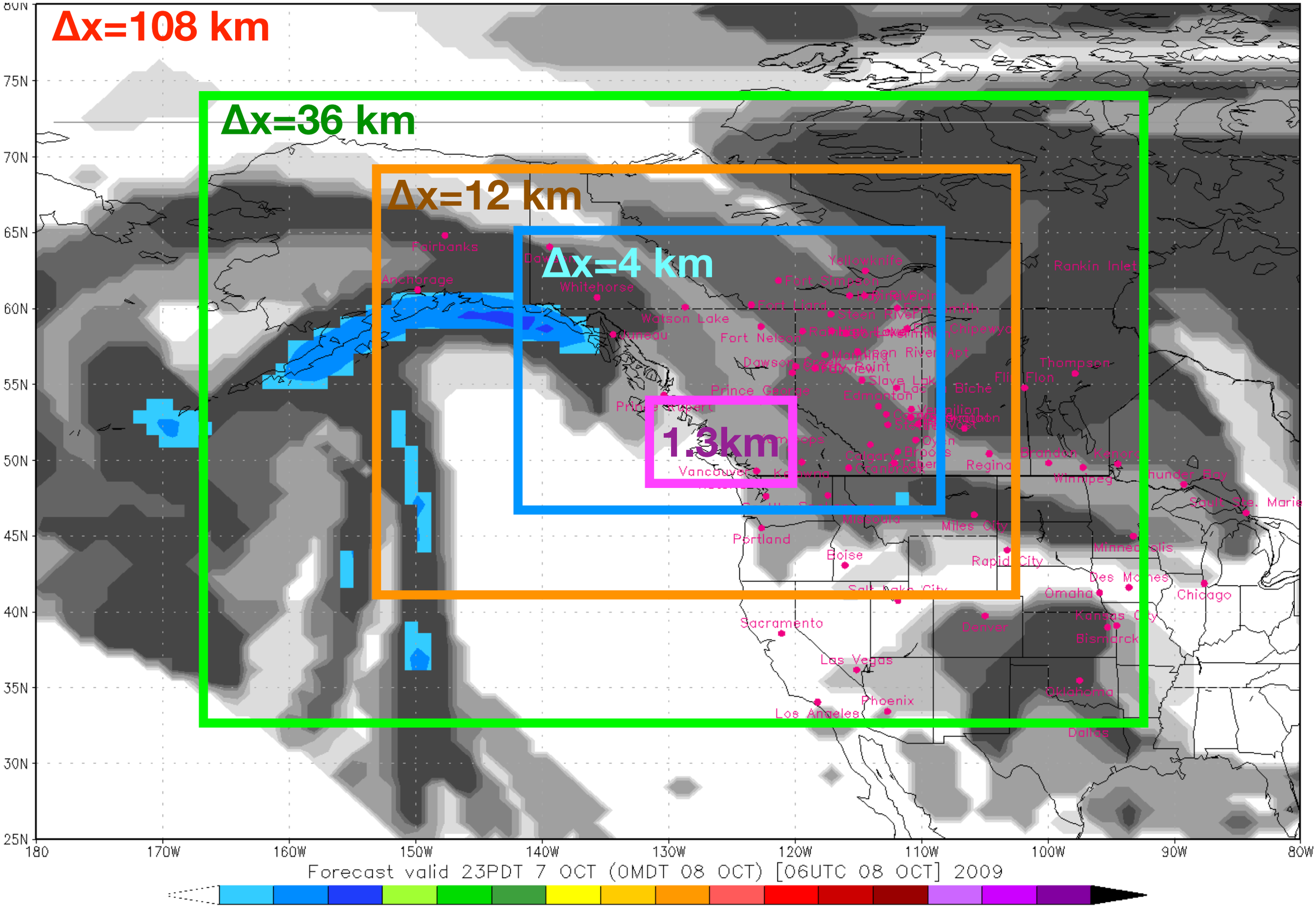
And the modeled slopes become steeper (closer to real). **Difficult**.

(& still have systematic errors due to location.)



- West-East terrain cross section through Whistler (50.12°N), where 0.1°lon ≈ 7 km.

Nested Grids (Coarse mesh to fine mesh)



Forecast Improvement

Large systematic errors due to terrain smoothing

- Systematic error reduction via post processing (Kalman filters, running averages, Gaussian process modeling, gene-expression programming, artificial neural networks, etc.)

- Random error reduction via ensembles.

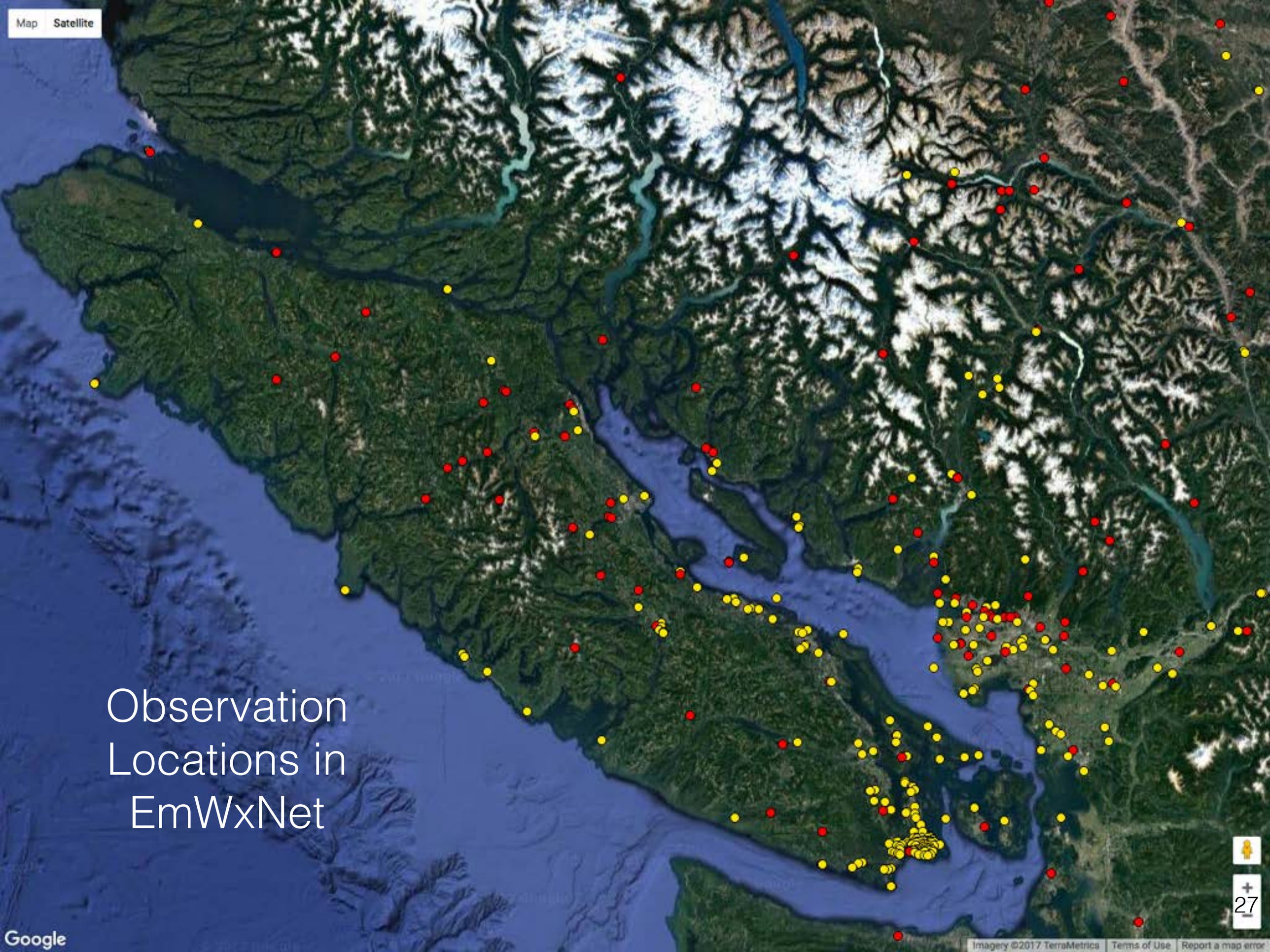
- Probabilistic forecast calibration (Nipen method)

more about these later

Nowcasting in complex terrain

- Combine gridded NWP output (i.e., forecast)
- With sparse irregularly located weather **observations**
- To make an updated “nowcast”.

Observation Locations in EmWxNet

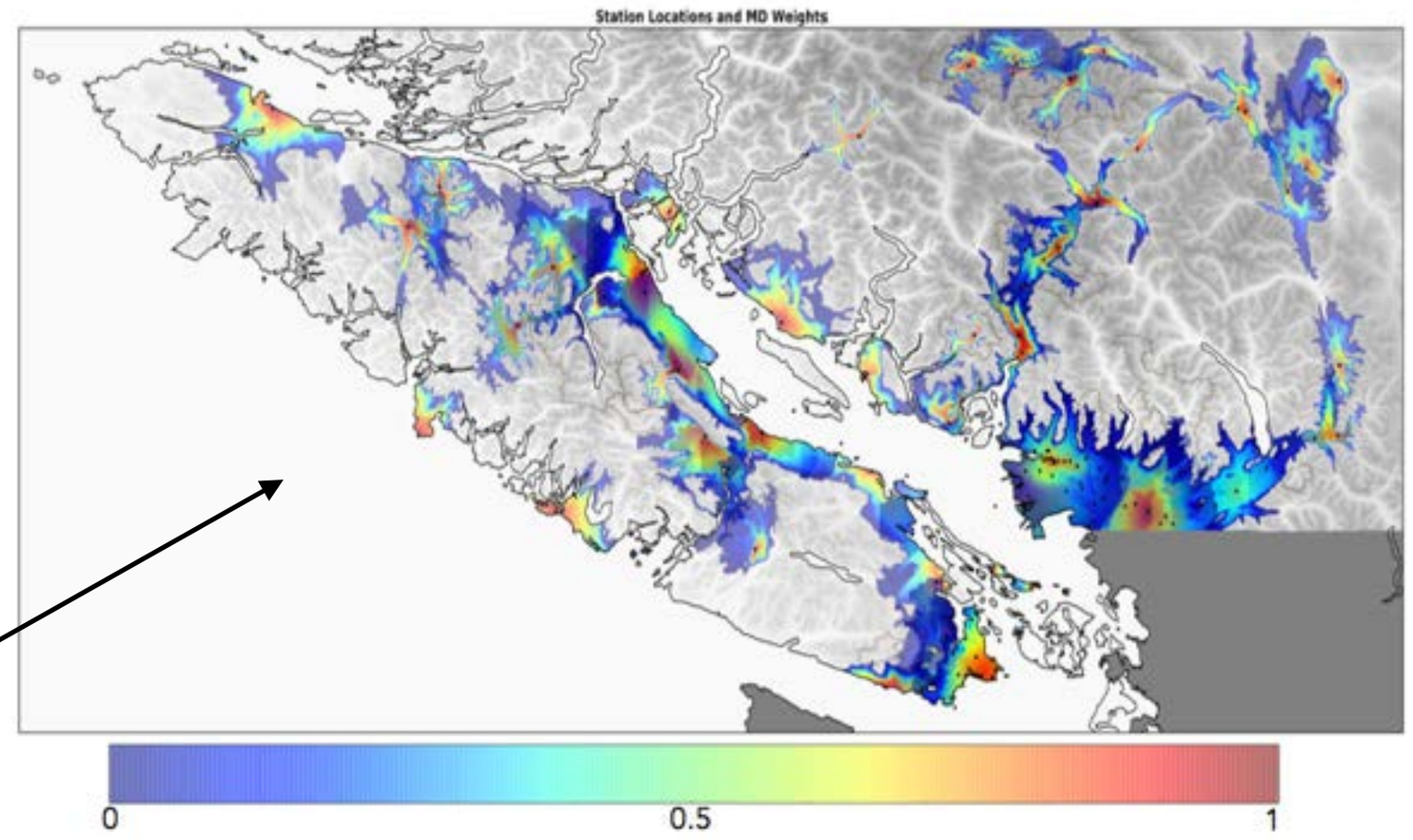


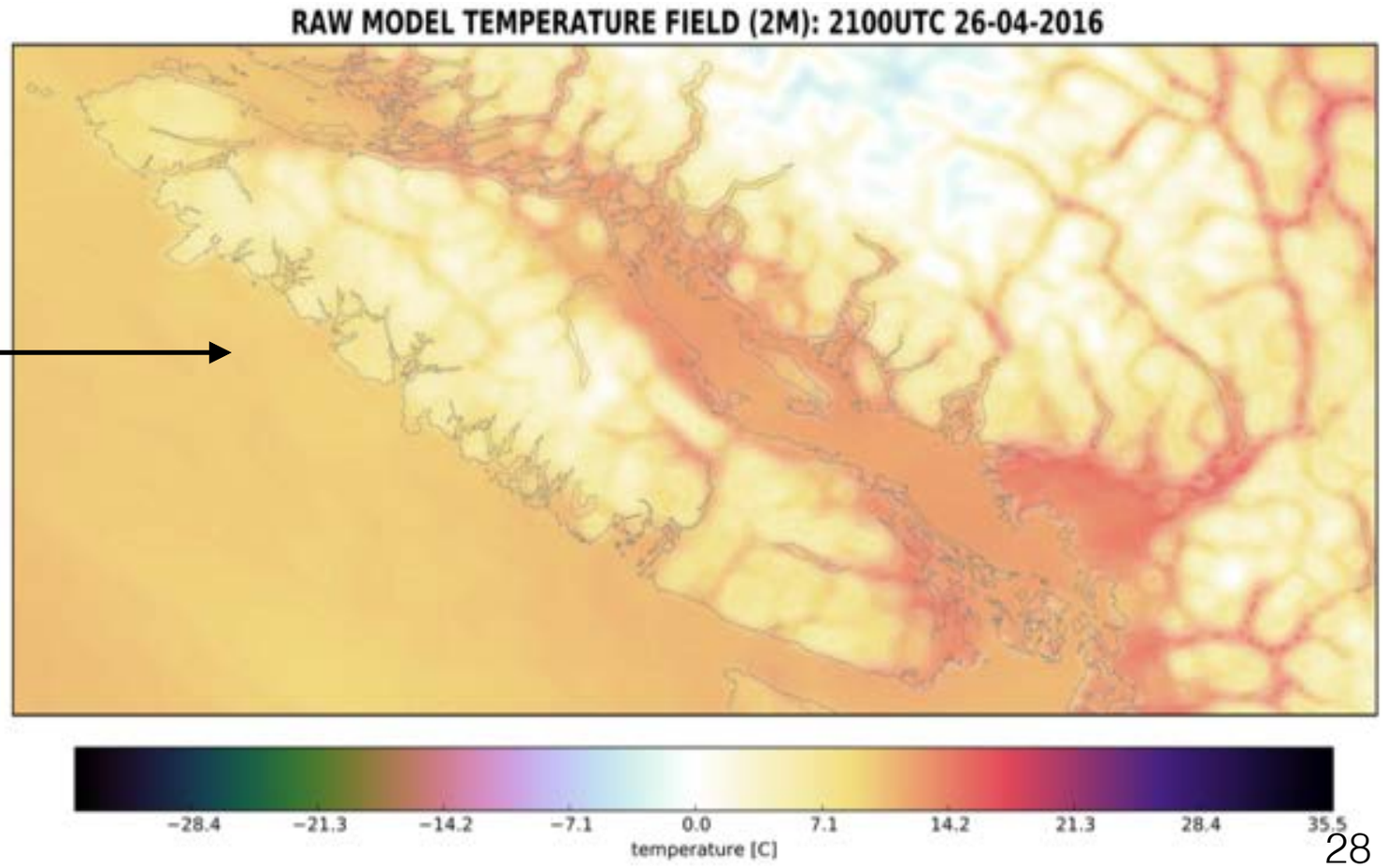
Take the sparse weather observations from EmWxNet,

spread them with due regard to topography,

and combine them with the raw gridded forecast

to yield … (see next slide)





HIGH-RESOLUTION TEMPERATURE ANALYSIS (2M) | 2100UTC 26-04-2016 | MD DA

Resulting Nowcast of Temperature

(running operationally at UBC)

Vancouver

Victoria

-35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35

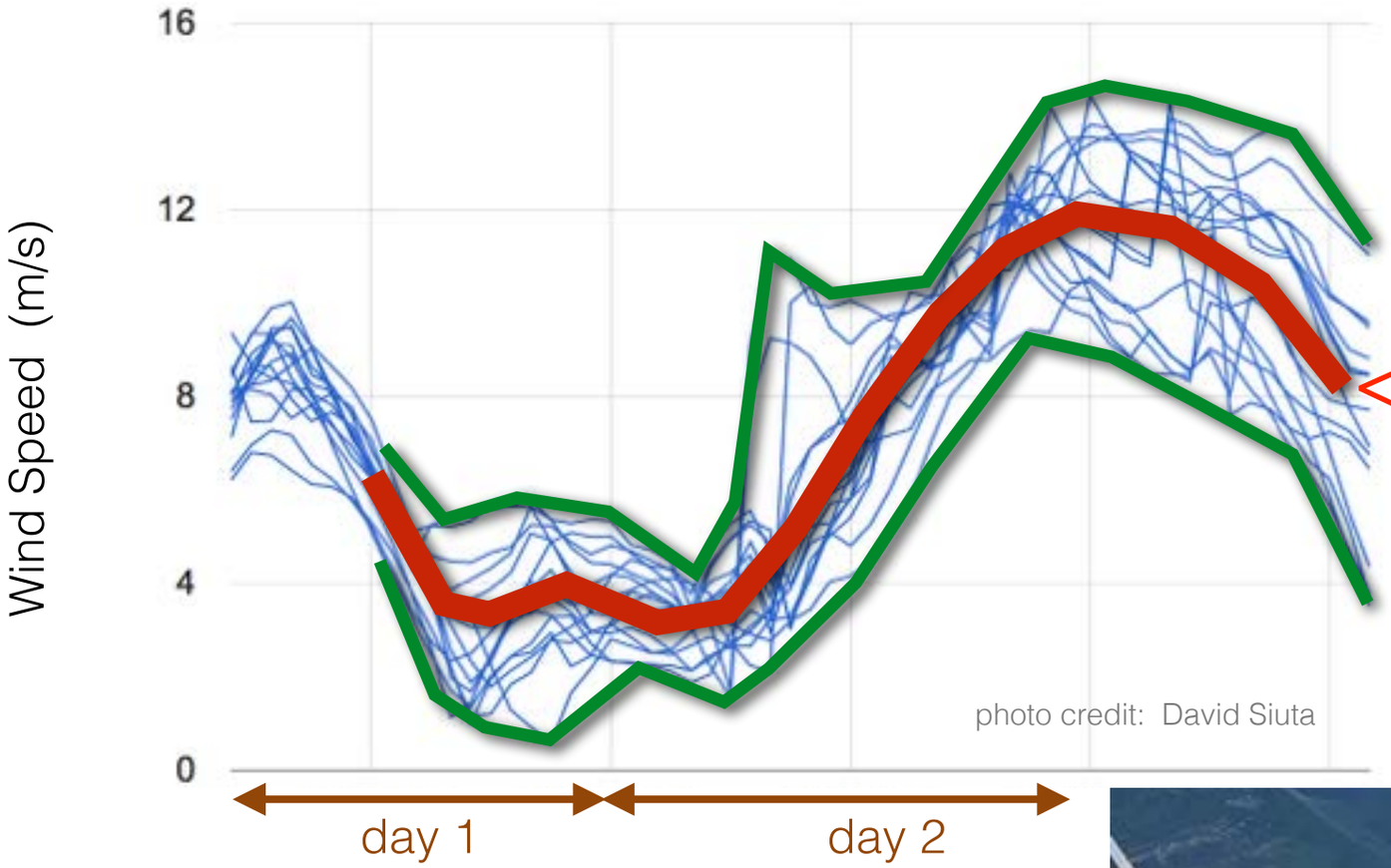
temperature[C]

4. Ensemble forecasts & wind turbines

Ensemble Mean

Gives the best forecast

Generic Methods:



← Ensemble Average

photo credit: David Siuta

Ensemble Verification

Measures skill & identifies potential problems

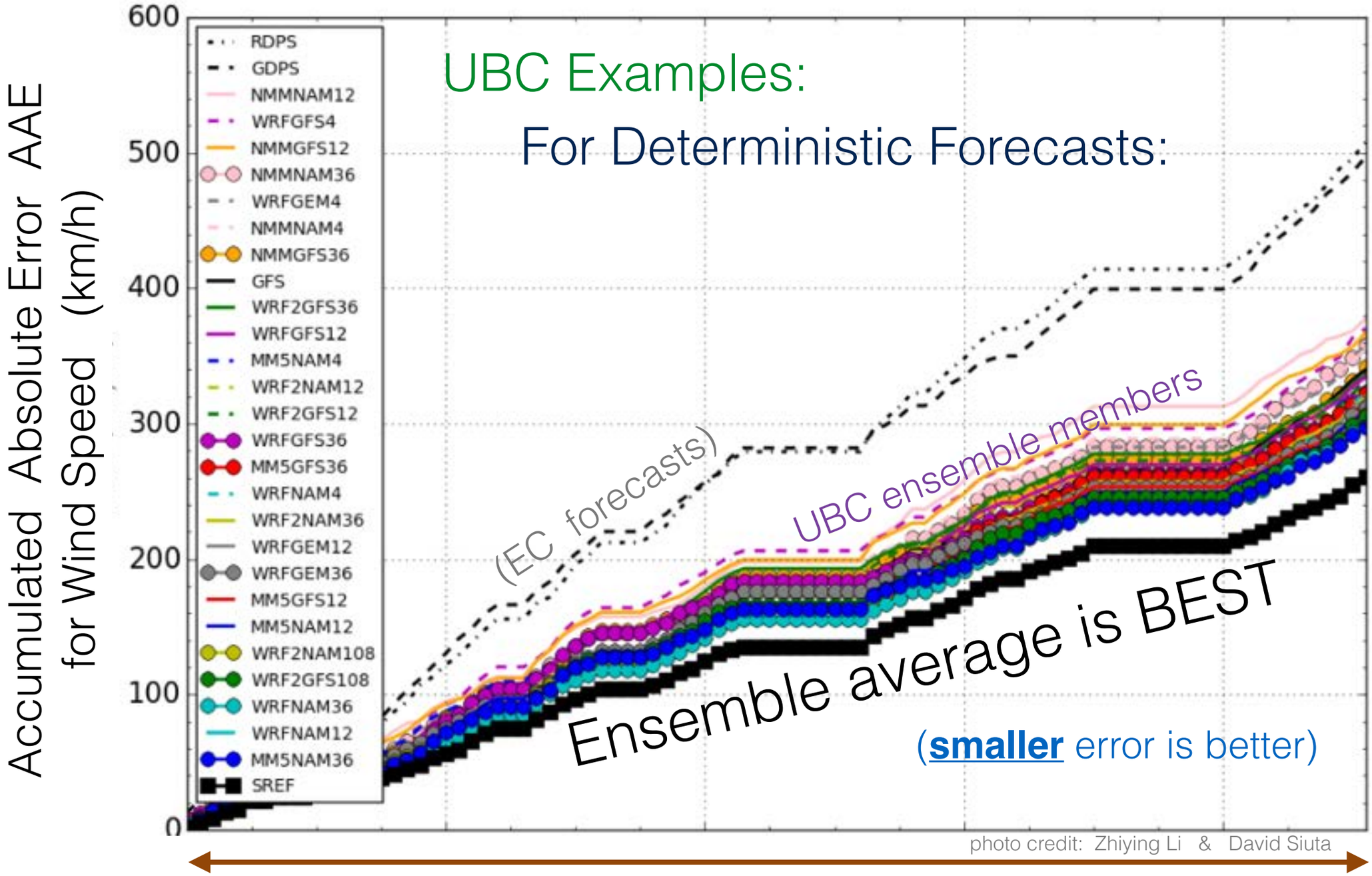


photo credit: Bear Mountain Wind

Ensemble Spread

Gives one estimate of forecast uncertainty.

(But <u>un</u>calibrated spread has little value.)

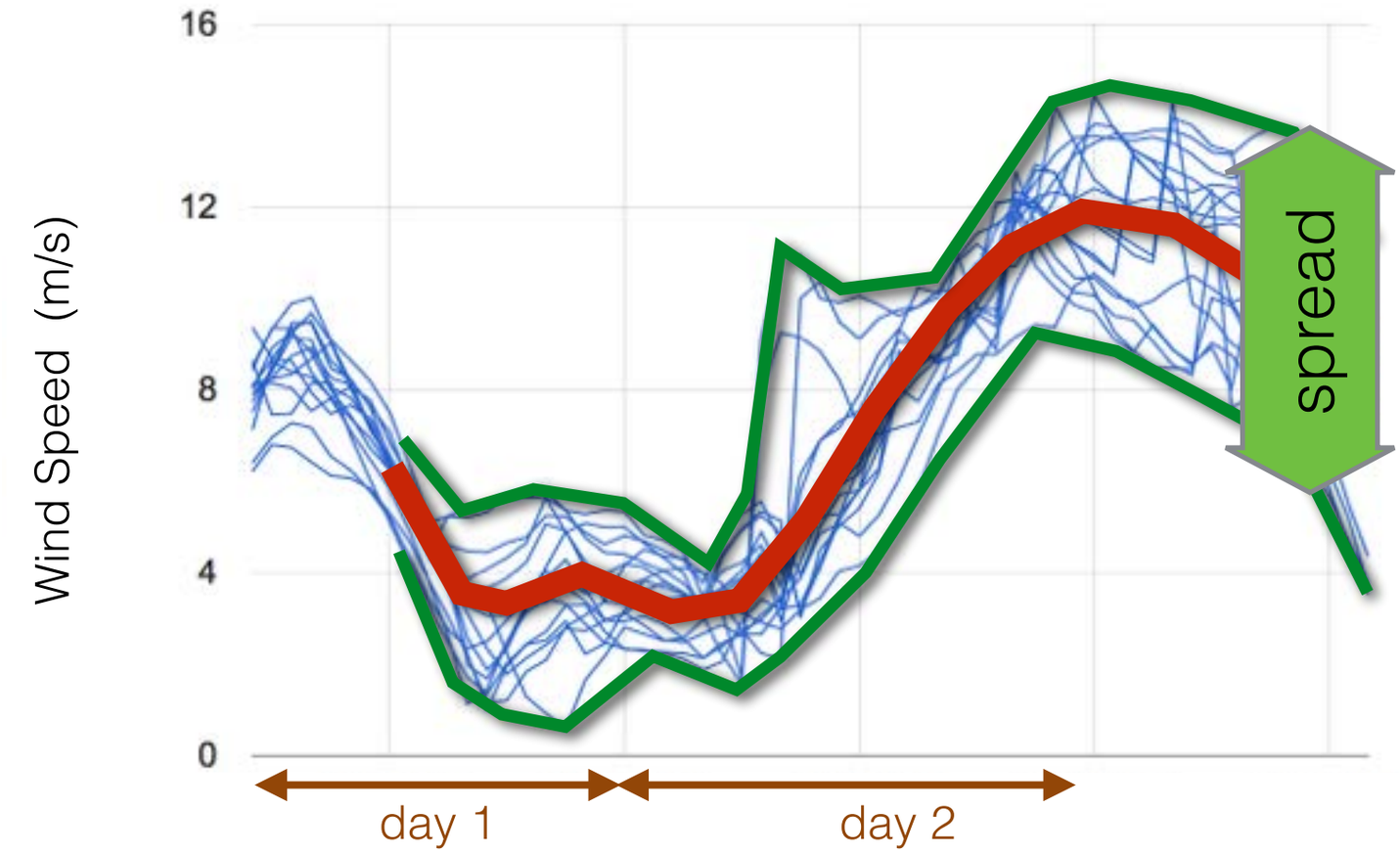


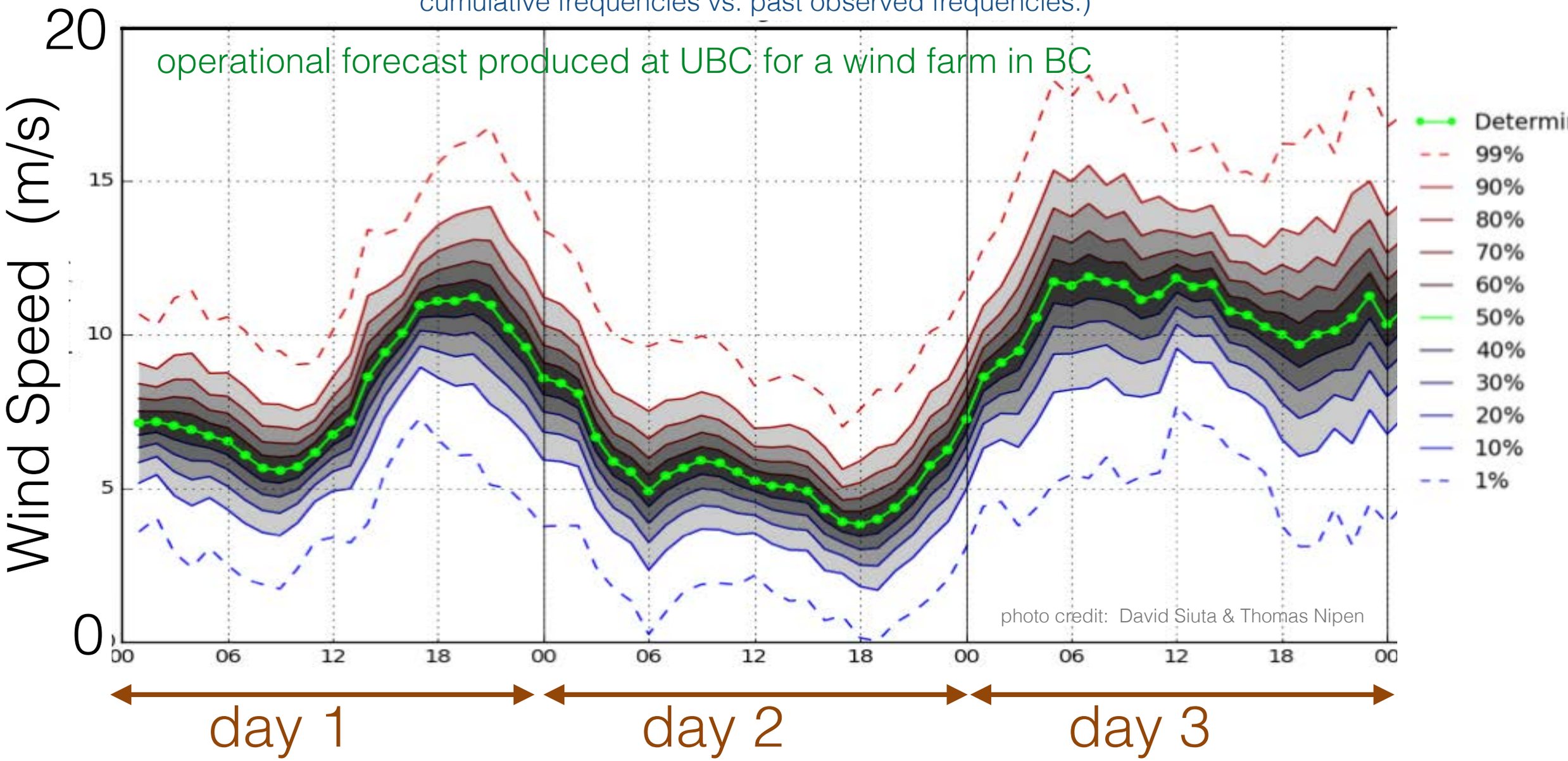
photo credit: David Siuta

Ensemble Probabilities

Finally, calibrate the probabilities:

Calibration means the predicted probability matches the observed frequency.

(Calibrated using the Nipen method: based on a mapping of past forecast cumulative frequencies vs. past observed frequencies.)



Simplified cost / loss **example** for blade-replacement maintenance decision:

<u>Issue</u>: Should you schedule the blade replacement for 18 local time today when 4 m/s winds are predicted deterministically? Next slow winds in 2 days.

Assumptions: 2 MW turbine costs $4M installed. Blades = 18%. Crane rental = $80,000/day. If selling at 5c/kWh, then downtime cost = $2,400/day. Max wind speed for crane safety ~ 5 m/s.

http://www.windustry.org/community_wind_toolbox_8_costs

photo credit: Mark Stull

Simplified cost / loss **example** for blade-replacement maintenance decision:

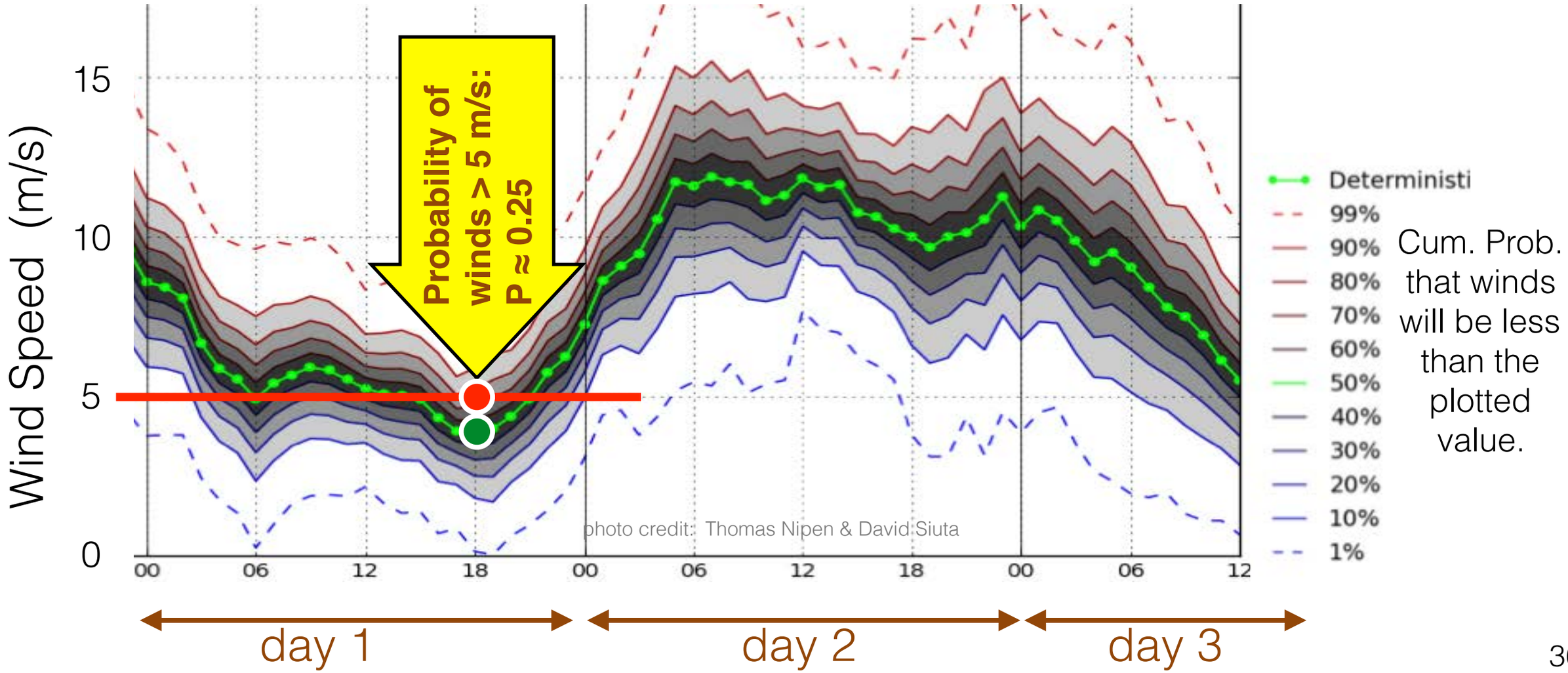
Solution:

Cost to protect the blades (postpone the replacement) ≈ $165k.

Loss if blades damaged during attempt ≈ $970k.

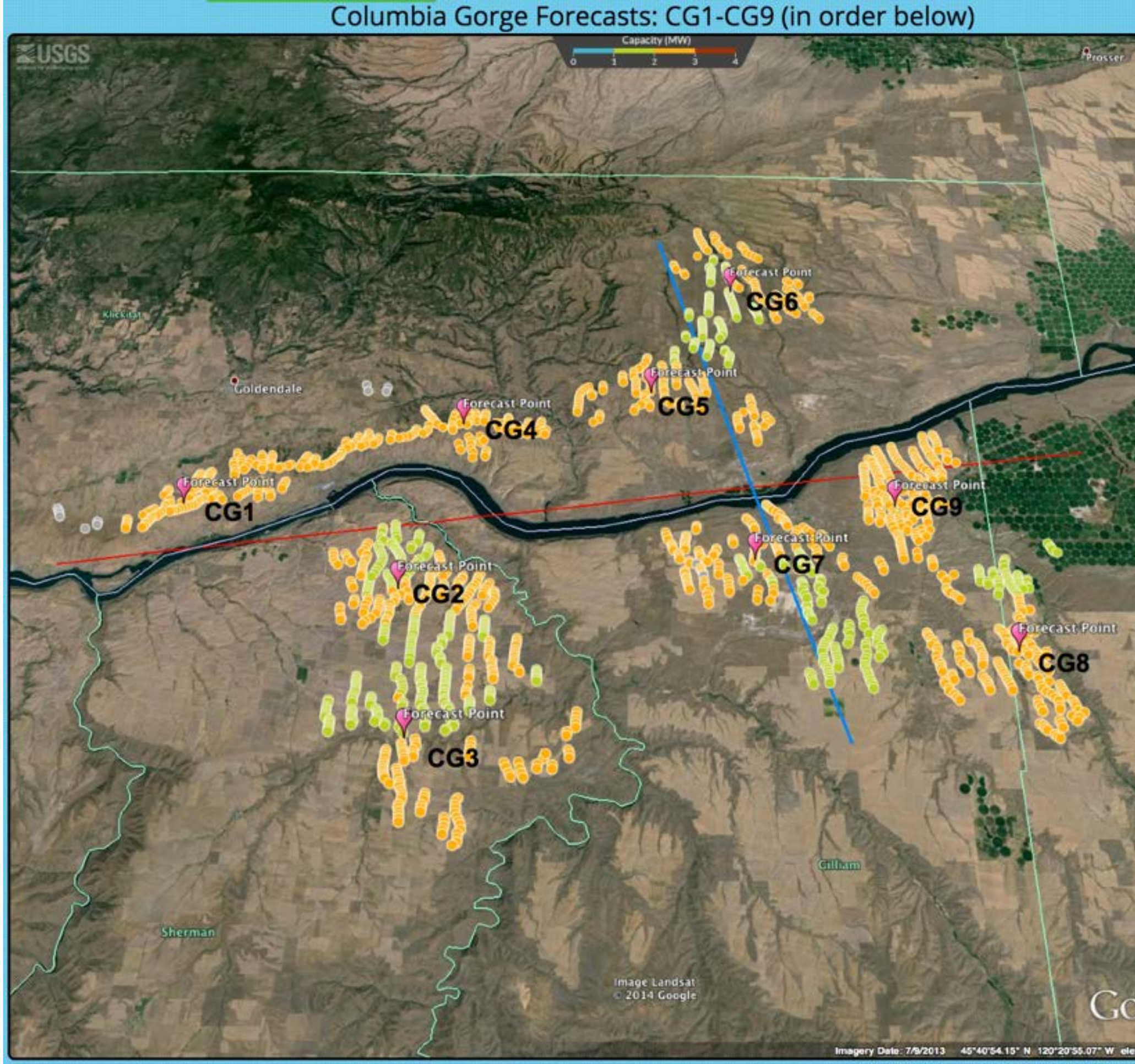
Cost/Loss ratio R ≈ 0.17

P > R, Therefore do not replace today.



UBC also forecasts for hundreds of wind turbines in the Columbia River gorge between WA and OR.

This enables BC Hydro to make better decisions regarding energy trading with the US.



work by David Siuta

Research Goals

1. Quantify the effects of
   - Planetary Boundary Layer (PBL) physics scheme
   - Initial condition (IC)
   - Grid length

   choice on **deterministic** and **probabilistic** hub-height (80 m AGL) wind-speed forecasts (Chapters 2 and 3).

2. Evaluate current surface-layer (SL) similarity theory in complex terrain (Chapter 4).

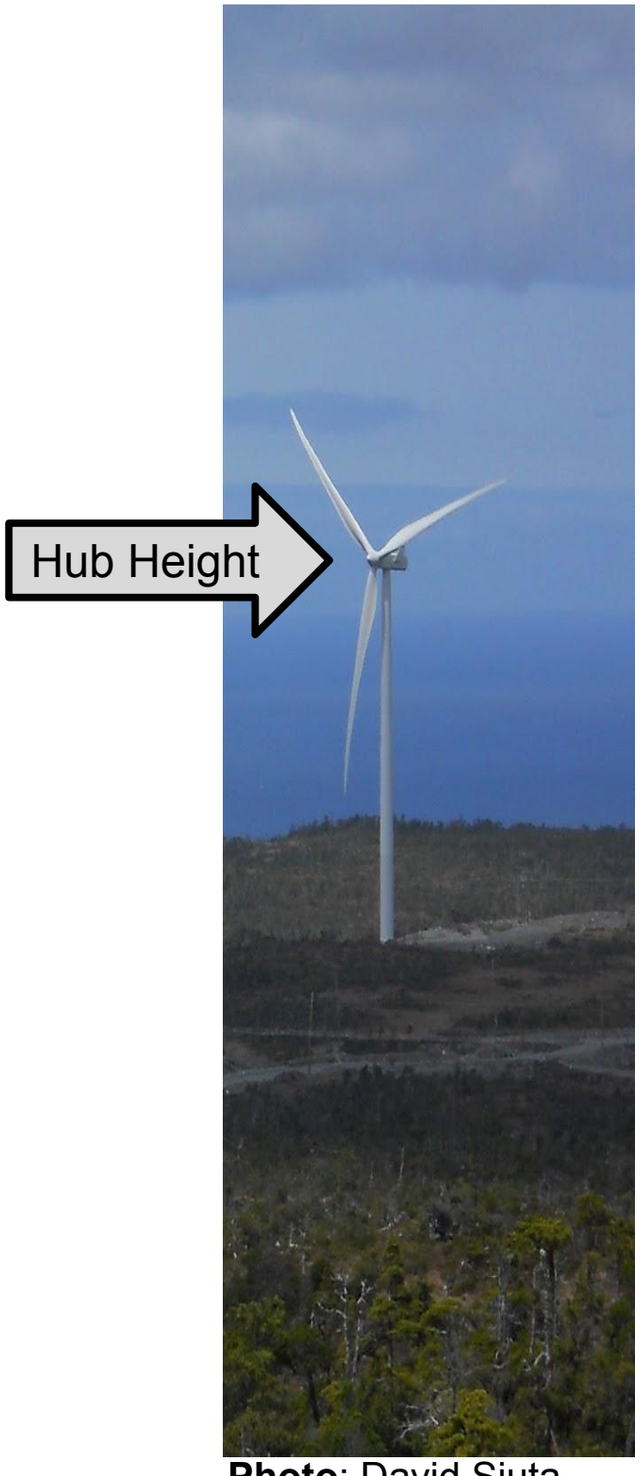
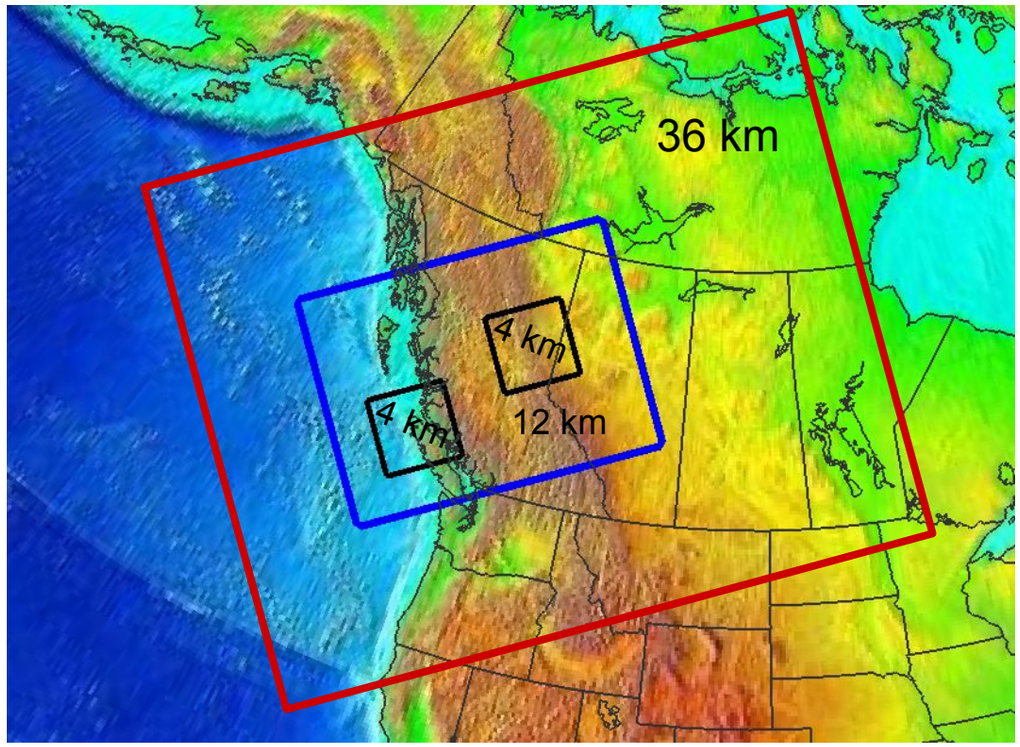


Photo: David Siuta

Methodology: WRF Setup

- 48 WRF forecasts each day for 1 year
- 24-hour forecast horizon

Model Grids



ICs Used
Global Forecast System (**GFS**)
North American Mesoscale Model (**NAM**)

PBL Schemes Used
Yonsei University (**YSU**)
Asymmetric Convective Model v2 (**ACM2**)
Medium Range Forecast (**MRF**)
Mellor-Yamada-Janjic (**MYJ**)
Quasi-Normal Scale Elimination (**QNSE**)
Mellor-Yamada Nakanishi and Niino Level 2.5 (**MYNN**)
University of Washington (**UW**)
Grenier-Bretherton-McCaa (**GBM**)

7

work by David Siuta

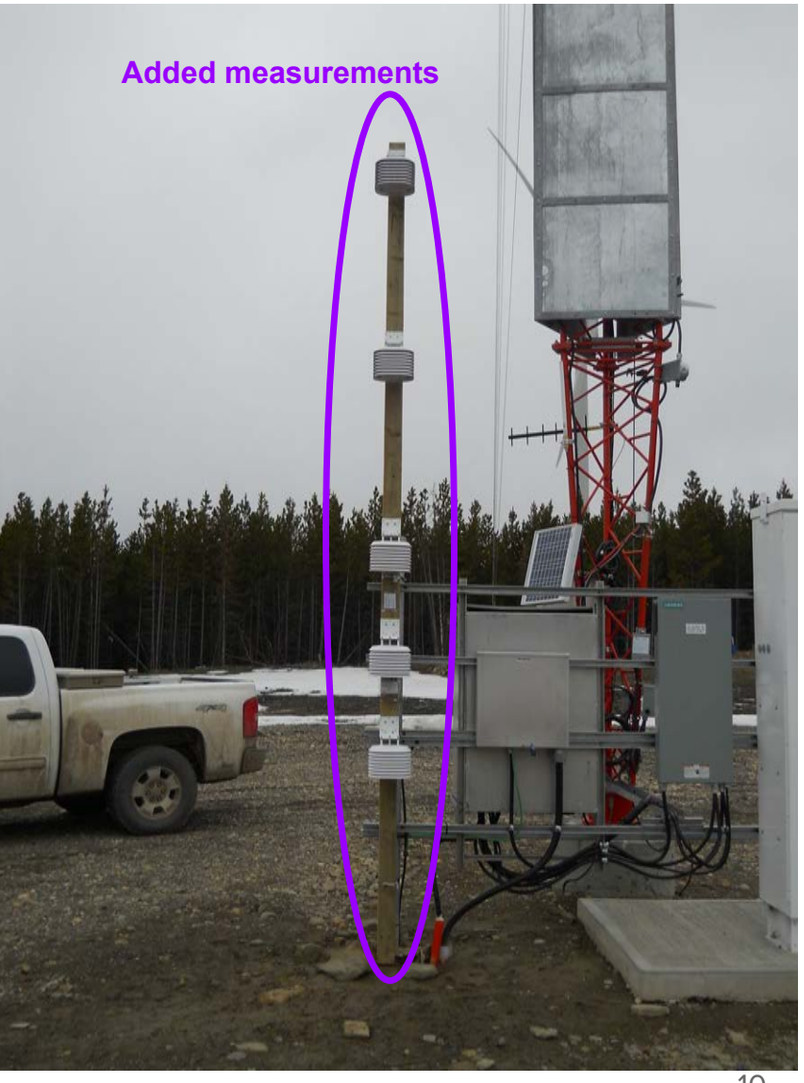


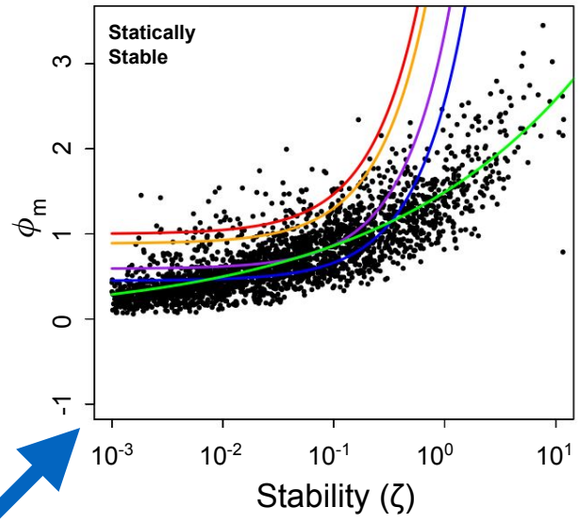
Photo: David Siuta

10

Summary of findings

- The PBL scheme and grid length influence forecast accuracy the most; a 13-29% reduction in error can be achieved by selective configuration (Chapter 2).
- Prescribing a Gaussian probability distribution around a bias-corrected ensemble mean produces calibrated probabilistic forecasts (Chapter 3).
- Observed wind profiles depart substantially from those described by accepted flux-profile relationships when applied over complex terrain (Chapter 4).

Inclusion of canopy effects on BD flux profile



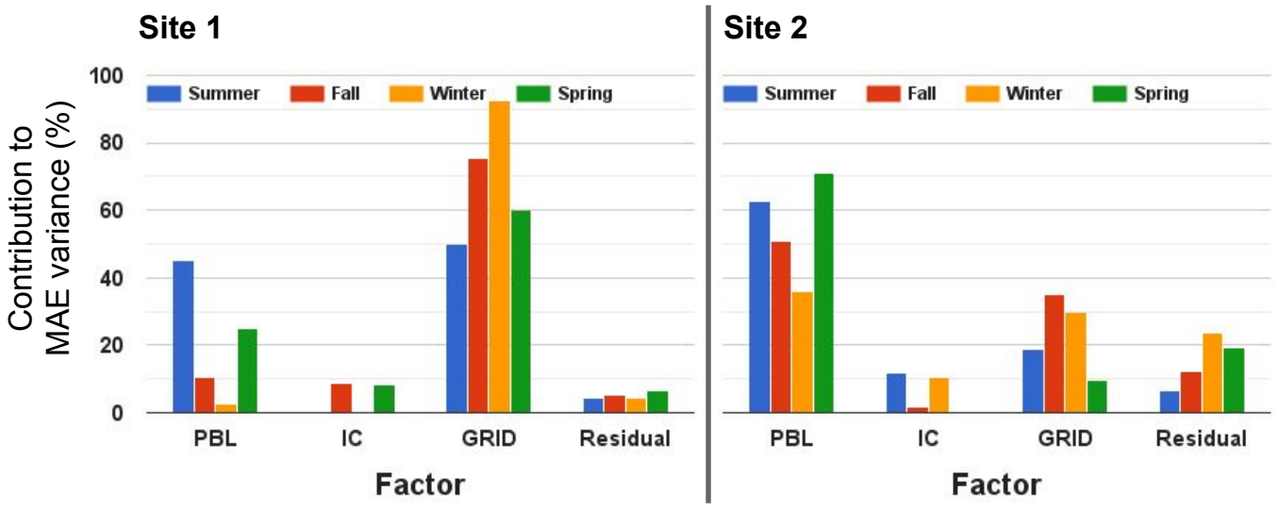
Canopy effects reduce ϕ_m by 12%

Increased transition layer depth (6 times canopy height) a poor fit

Constant 55% reduction independent of transition layer a poor fit

Next step: Test green curve as a new flux-profile relationship at an independent location under statically-stable conditions.

Which factor is most influential in forecast accuracy?



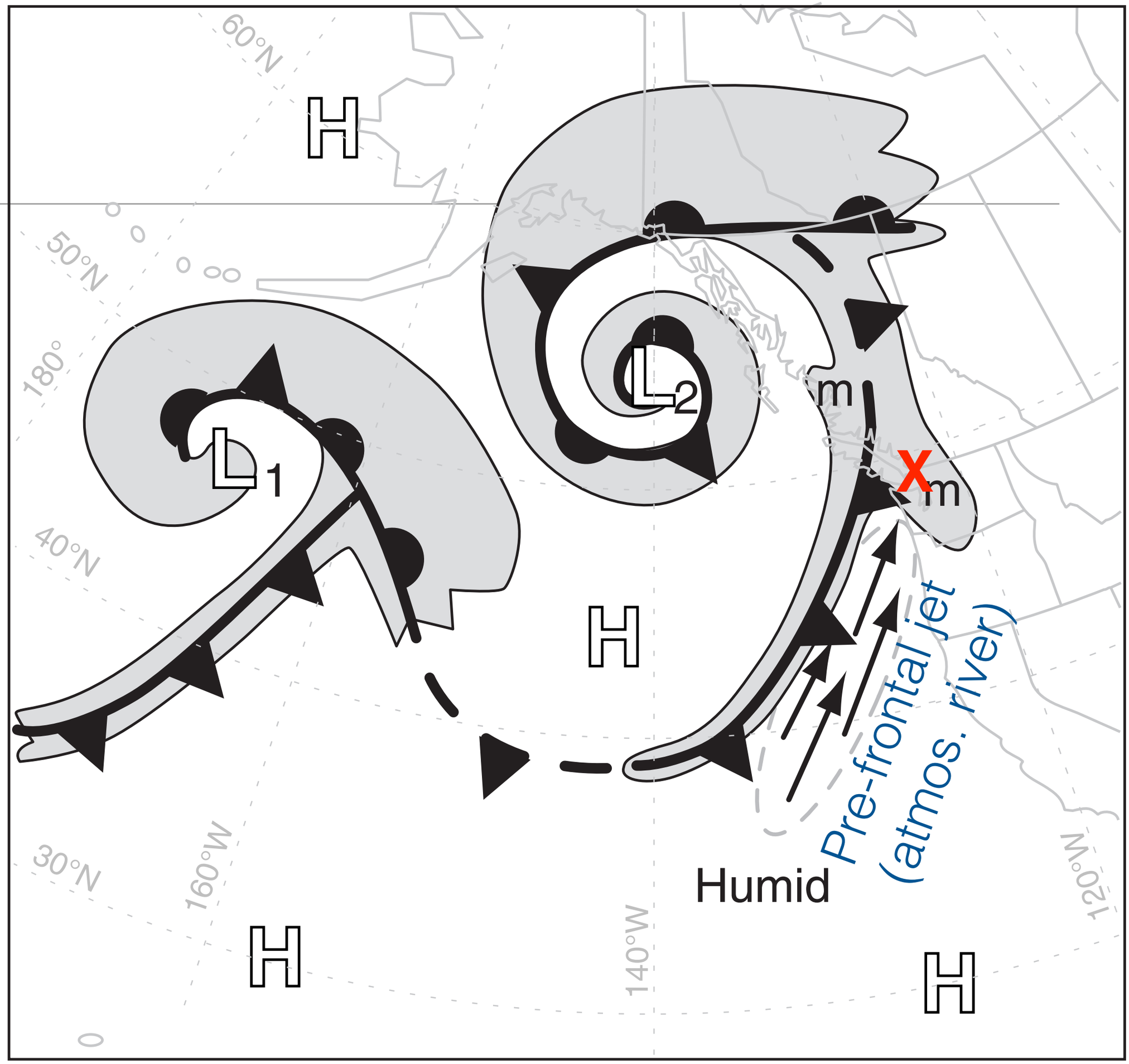
work by David Siuta

Analysis of Variance (ANOVA) explains factor contribution to variance of MAE.

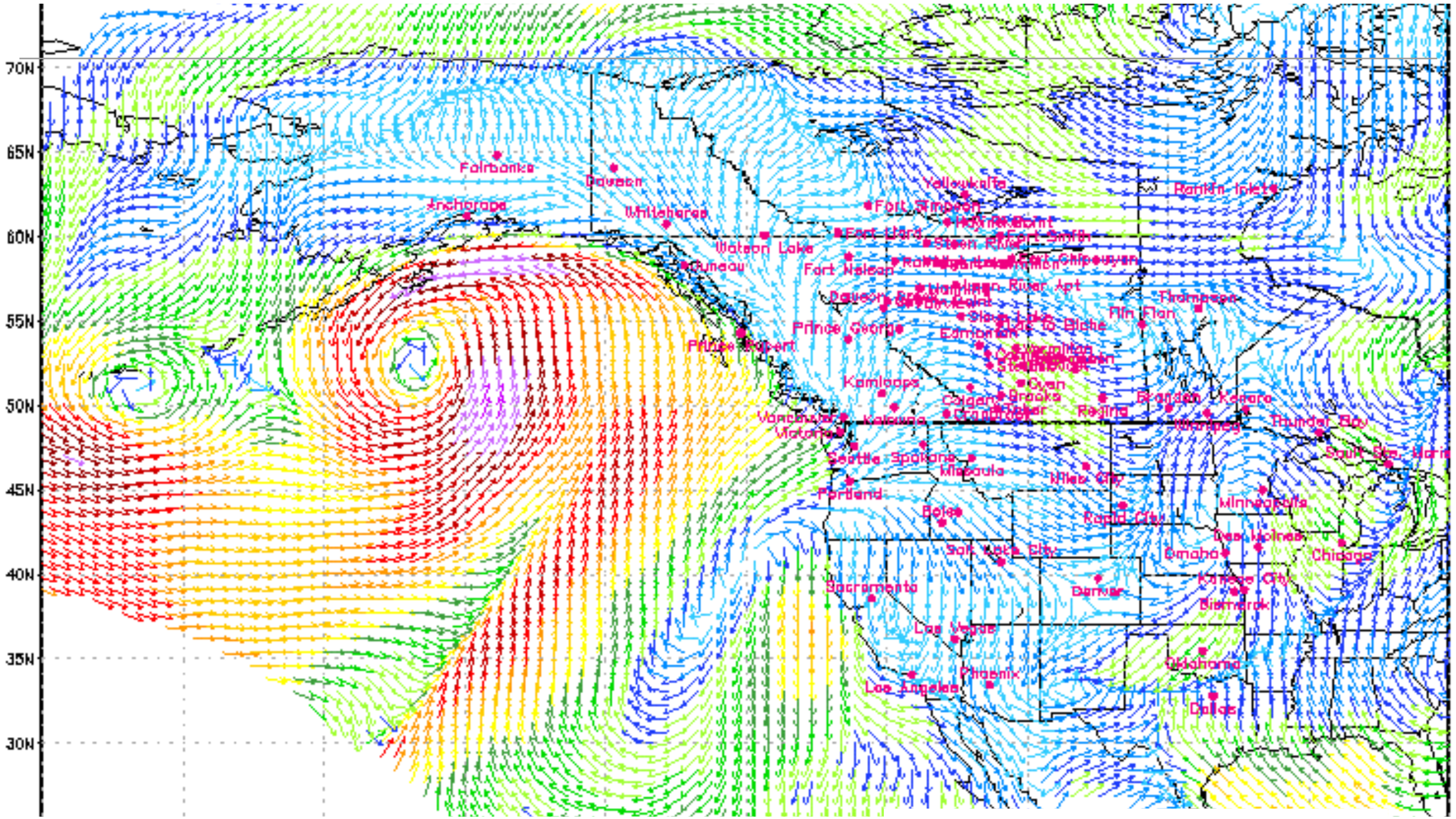
1. PBL scheme or grid length are most influential (location, season dependent).
2. A seasonal cycle often exists.
3. IC choice *may* be less important for short-term wind forecasts.

5. Landfalling cyclones & applications to energy, transportation, hazards

Big Picture: Occluding Cyclones



Pre-frontal Jet -- Onset of Pinapple Express



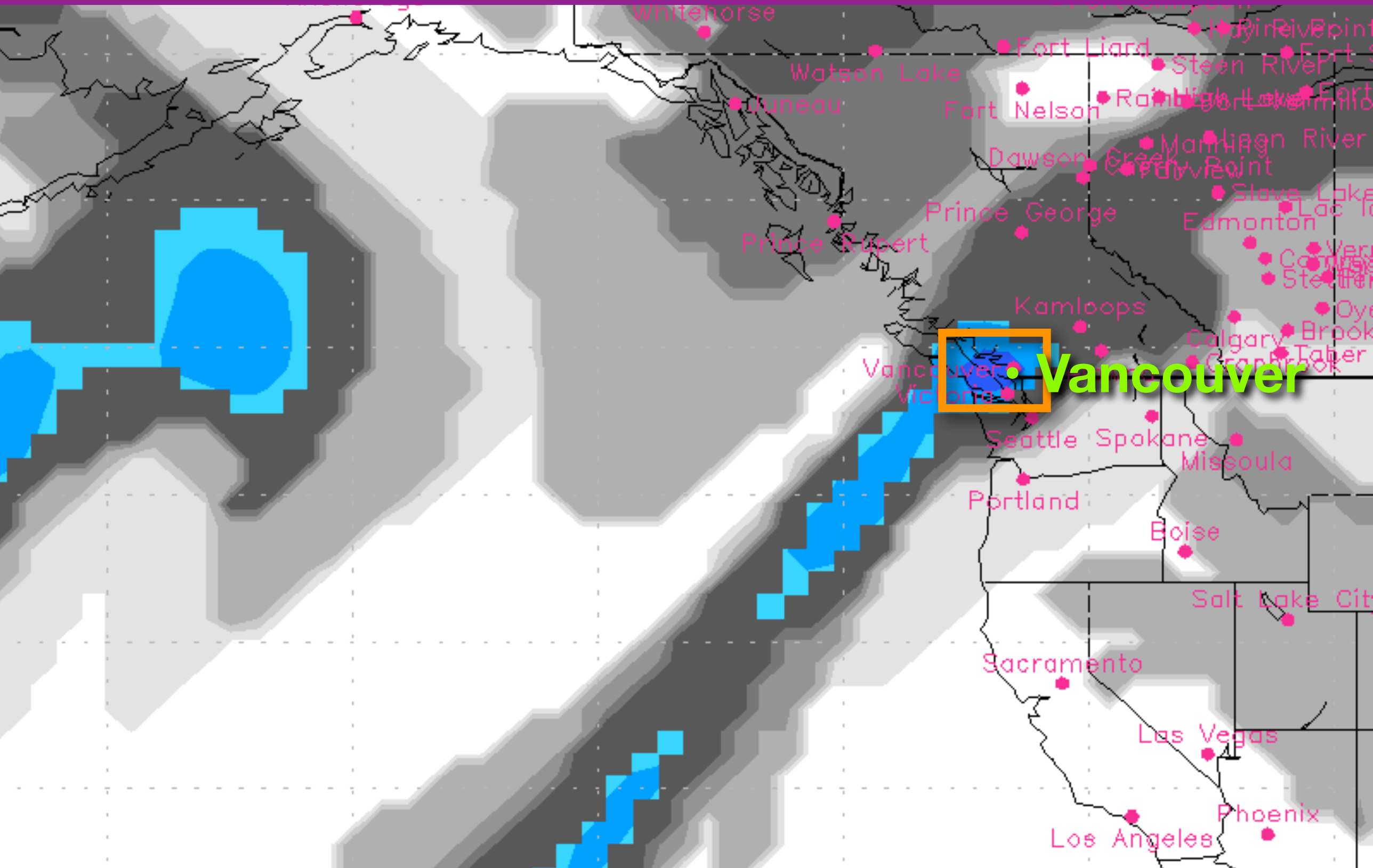
Surface Winds: 13-15 May 08

3 5 8 11 13 16 19 22 24 27 30 32 35 38 43

5 10 15 20 25 30 35 40 45 50 55 60 65 70 80

colour bar: Wind Speed marked in knots above bar and in km/hr below bar

Trick: Use coarse resolution to see what's coming . . .
Example: 14 Jan 2008 MC2 -108 km -
BUT see only stratiform clouds



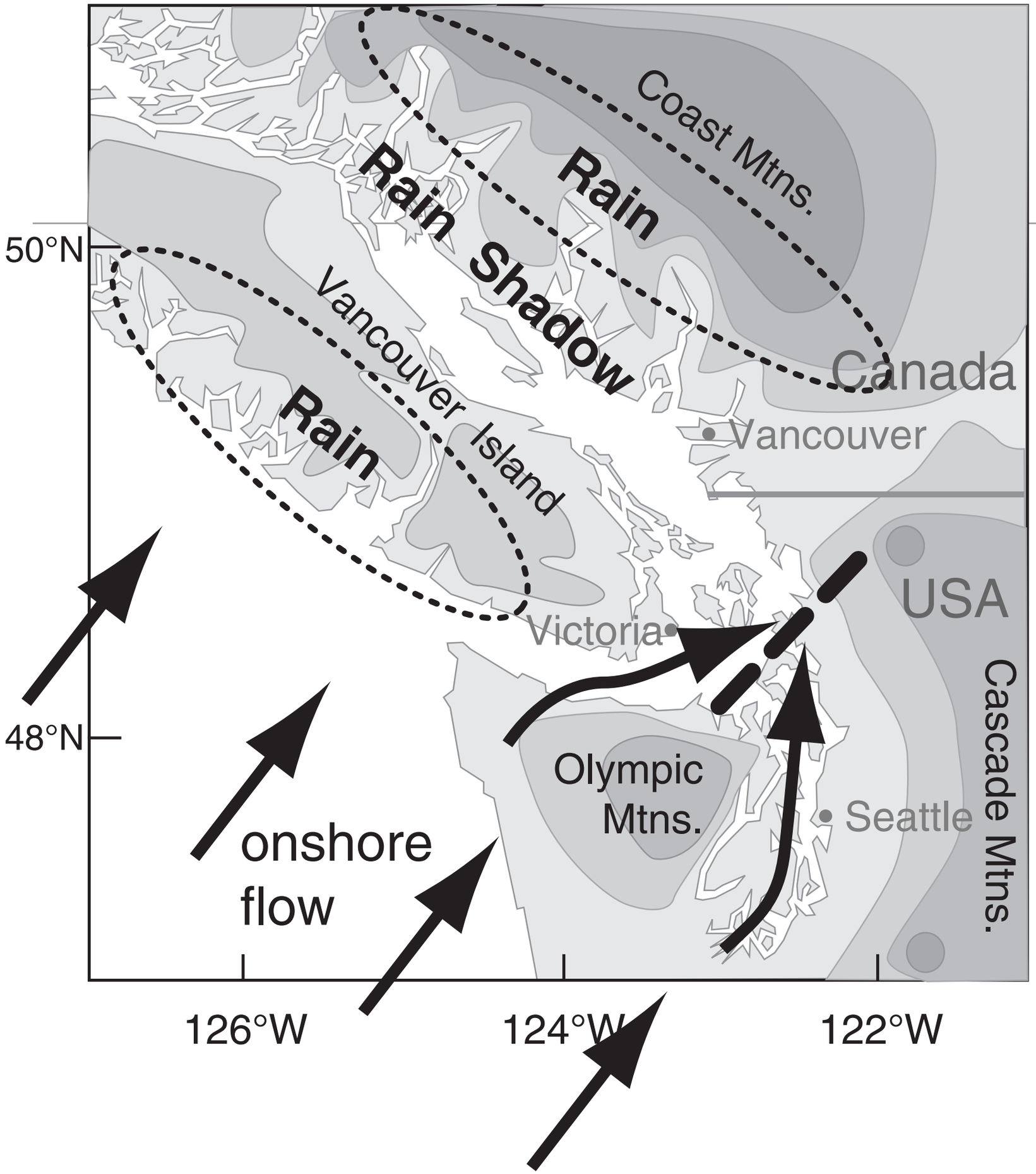
S.W. Canada

Vancouver

Victoria

Courtesy of Google Maps

Zoomed View: Terrain Effects



Typical End Result (12 h accum. precip.) 15 Nov 06

Vancouver •

• Victoria

20 30 40 50 60 70 80 90 100 110 120 130 140 150

12Hr Accumulated Total Precipitation (mm)

Arctic Canada forecasts

for shipping & aviation

http://weather.eos.ubc.ca/arctic/

Possible Sites for Weather Sensors

TA Station
Existing
CC Array Target Areas 85 km (165)
Mackenzie Mountains Stations
BCACS
CN
YGS
TD
NE-BC
NV
RV
YNSN

Recommended Weather Stations
Top 10
Next 10
Next 10
Next 10

Forecast valid 2:30PST 11 FEB (3:30MST 11 FEB) [10:30UTC 11 FEB] 2010

49.7N
49.6N
49.5N
49.4N
49.3N
49.2N

Squamish
Sechelt
Cypress
Vancouver

24-h Accum Snowfall Forecasts for the 2010 Winter Olympics

15 Dec 2006 Windstorm

In Stanley Park, several thousand trees destroyed

1.3 km MC2 forecast

valid 4 am 15 Dec 06

initialized from 4 pm 13 Dec 06 NAM

Stanley Park

Vancouver

Sechelt

Parksville

Nanaimo

Langley

Mission

Abbotsford

White Rock

Duncan

Bellingham

Port Renfrew

Victoria

Sooke

Mount

124.5W 124.2W 123.9W 123.6W 123.3W 123W 122.7W 122.4W

Forecast valid 4PST 15 DEC (5MST 15 DEC) [12UTC 15 DEC] 2006

3 5 8 11 13 16 19 22 24 27 30 32 35 38 43

5 10 15 20 25 30 35 40 45 50 55 60 65 70 80

Geophysical Disaster Computational Fluid Dynamics Center

• University of British Columbia – Vancouver • Dept. of Earth, Ocean & Atmospheric Sciences • Weather Forecast Research Team • Directed by Prof. Roland Stull •

What we do.

Weather Forecasts for Clean Energy

- Hydroelectricity
- Wind power
- Solar power
- Biomass energy

Bennett Dam & Williston Lake photo by R. Stull

Sponsor:
BC Hydro

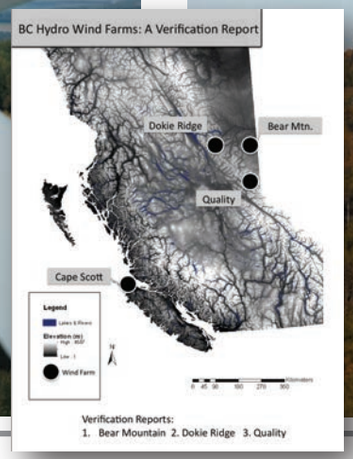
Region:
British Columbia

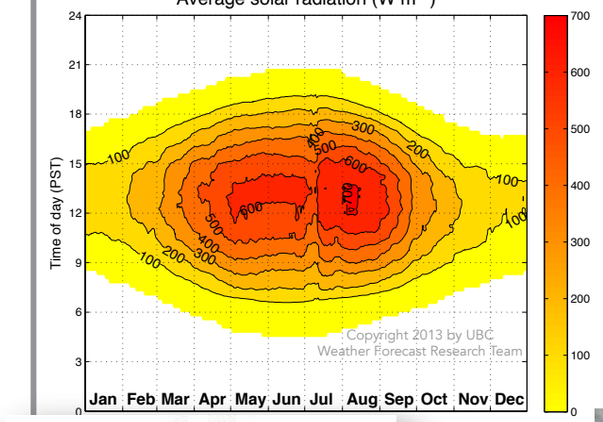
Ensemble forecasts out to 16 days of precipitation, temperature, & freezing level for 30 hydro electric facilities

Sponsor:
BC Hydro

For 4 BC Wind Farms:
- Bear Mountain
- Dokie
- Quality
- Cape Scott

Bear Mountain Wind Park photos by AltaGas

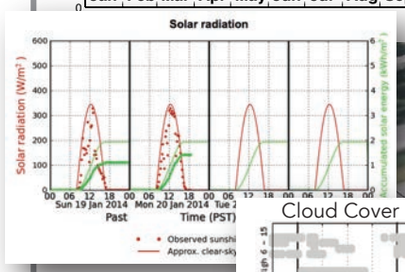




Sponsor: BCIT

Region: Burnaby

Solar-radiation forecasts for GAIT solar-panel oasis.



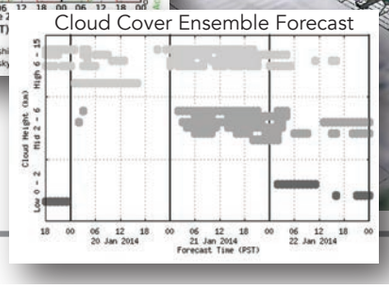


photo by BCIT

For more info, contact:

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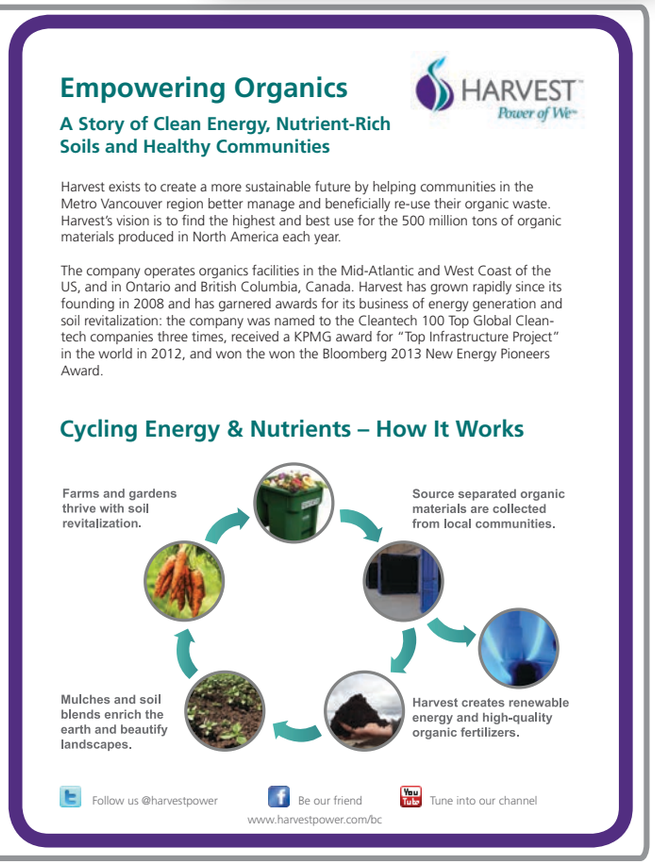
rstull@eos.ubc.ca
604-822-5901

Sponsor:
Harvest Power

Region:
Richmond

Wind and stability (gustiness) fore-casts & email alert messages.



Empowering Organics

A Story of Clean Energy, Nutrient-Rich Soils and Healthy Communities

HARVEST
Power of We

Harvest exists to create a more sustainable future by helping communities in the Metro Vancouver region better manage and beneficially re-use their organic waste. Harvest's vision is to find the highest and best use for the 500 million tons of organic materials produced in North America each year.

The company operates organics facilities in the Mid-Atlantic and West Coast of the US, and in Ontario and British Columbia, Canada. Harvest has grown rapidly since its founding in 2008 and has garnered awards for its business of energy generation and soil revitalization: the company was named to the Cleantech 100 Top Global Clean-tech companies three times, received a KPMG award for "Top Infrastructure Project" in the world in 2012, and won the won the Bloomberg 2013 New Energy Pioneers Award.

Cycling Energy & Nutrients – How It Works

Follow us @harvestpower Be our friend Tune into our channel
www.harvestpower.com/bc

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What we do.

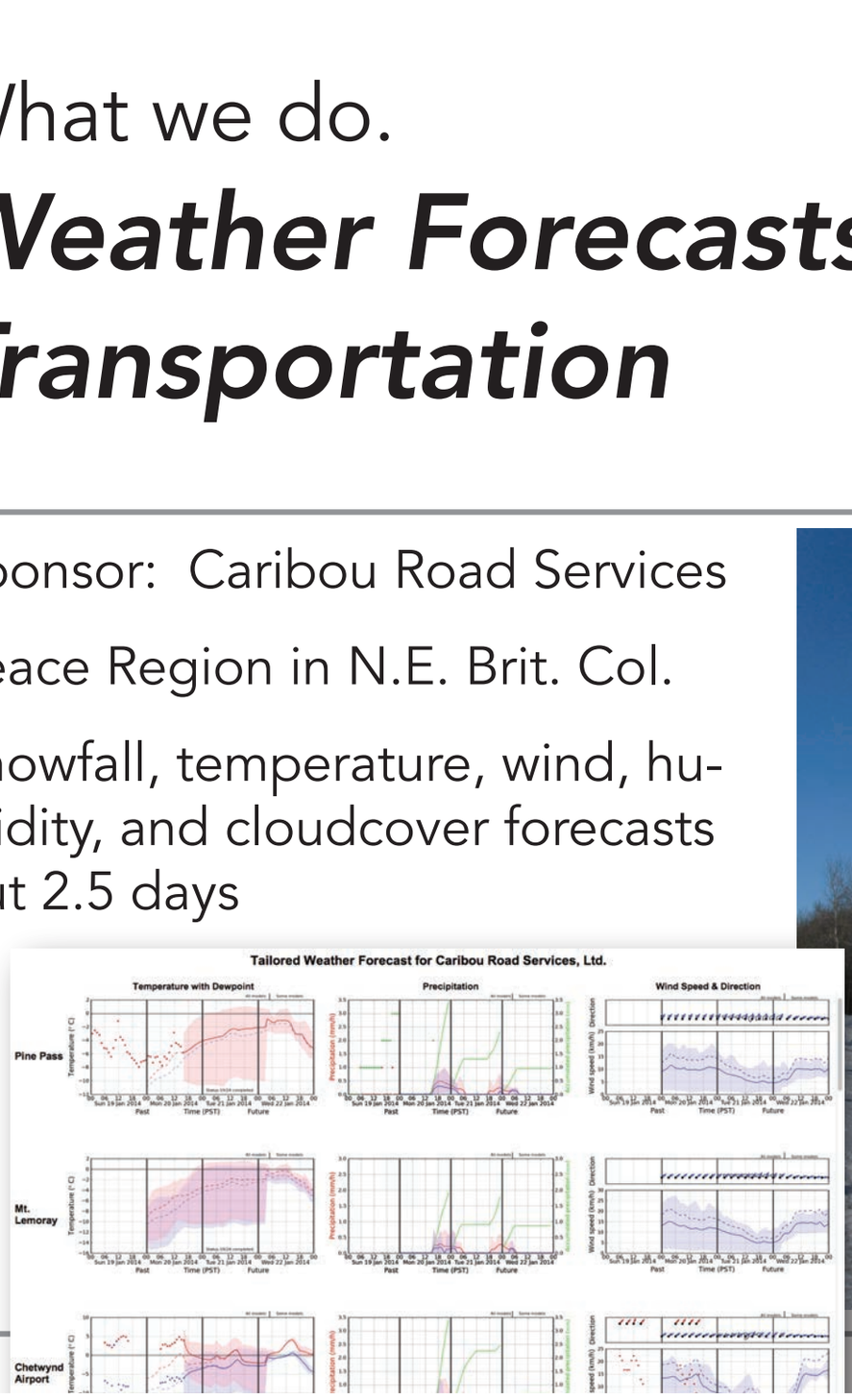
Weather Forecasts for Transportation

- Highway Maintenance
- Electric Bus/Trolley
- Sea Ports
- Railroads

Sponsor: Caribou Road Services

Peace Region in N.E. Brit. Col.

Snowfall, temperature, wind, humidity, and cloudcover forecasts out 2.5 days



photos by Caribou Road Services

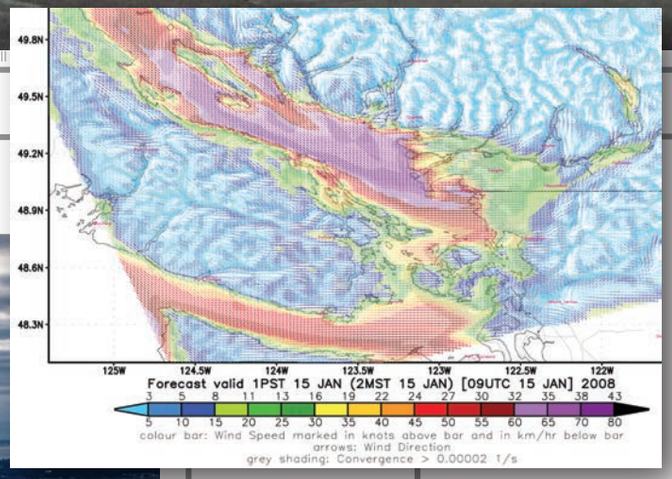
photo by R. Stull

photos by R. Stull

Sponsor: Coast Mountain Bus Co.

Region: Greater Vancouver

Temperature, humidity for frost & ice formation on trolley overhead lines.
Also deployed weather stations.



Sponsors: Deltaport & Westport

Wind & gust forecasts for safer ship loading.

photo by TSI Deltaport

Deltaport is Port Metro Vancouver's largest container terminal, located at Roberts Bank.

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Sponsor: RadHyPS.
Region: W. Canada

Weather-station data in support of Canadian Pacific Railway operations.

http://www.cpr.ca/en/news-and-media/photo-gallery/merchandise/PhotoGallery/Attachments/7/merch_007_hr.jpg

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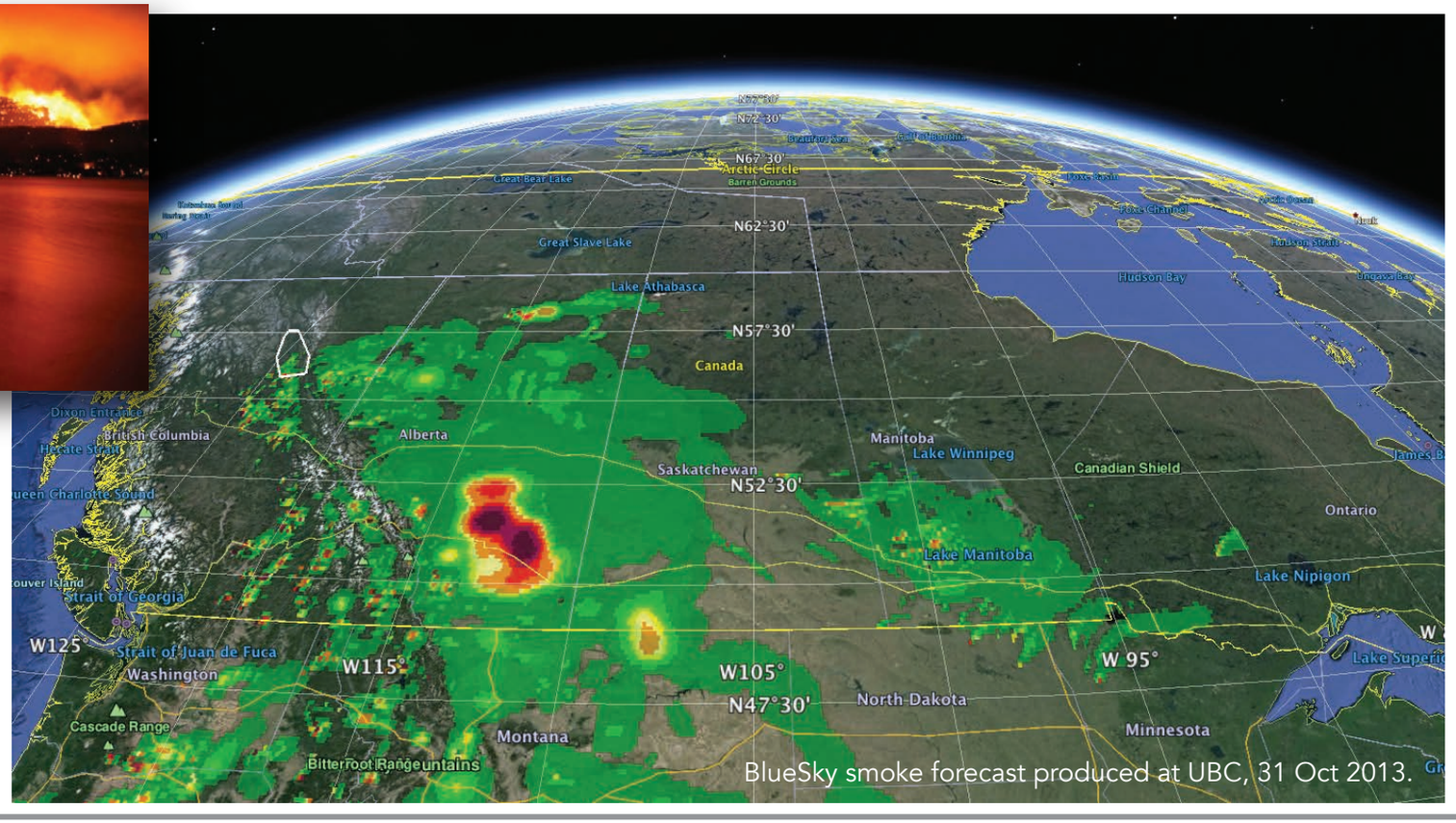
What we do.

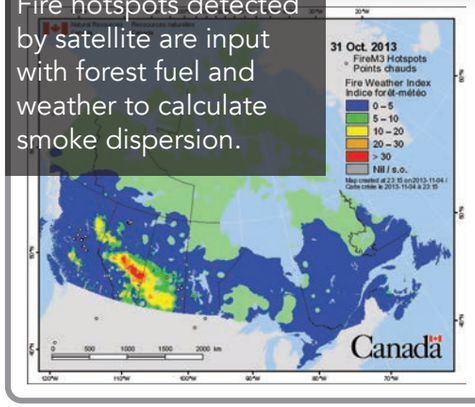
Forecasts for Weather-related Hazards

- Forest Fire Smoke
- Flooding
- Avalanches
- Emergency Weather Net



BlueSky smoke forecast produced at UBC, 31 Oct 2013.

Fire hotspots detected by satellite are input with forest fuel and weather to calculate smoke dispersion.



Sponsors: CSSP & Environment Ministries from many provinces.

Name: BlueSky

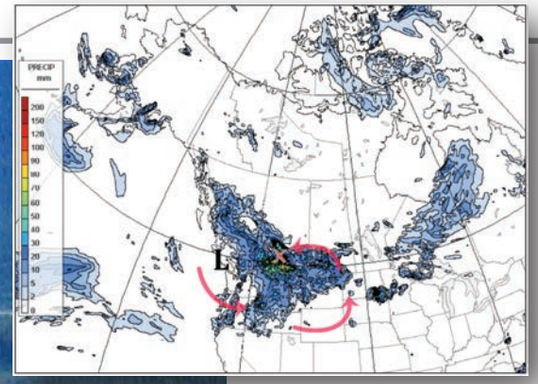
Region: Canada

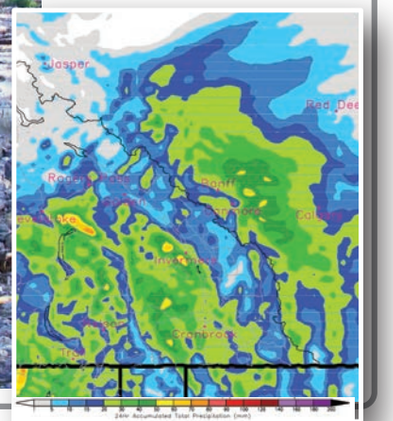
Spread of smoke from wild fires.

Sponsor: Town of Canmore, AB, and BGC Engr.

Region: Alberta

Analysis of storm conditions that caused flooding in 2013.





Sponsor: BC Ministry of Transportation

Region: BC. Avalanche weather data.

photo of Pine Pass cleanup
by Caribou Road Services

photos by BC Min. of Transportation & Infrastructure. East of Revelstoke, 2011.

For more info, contact:

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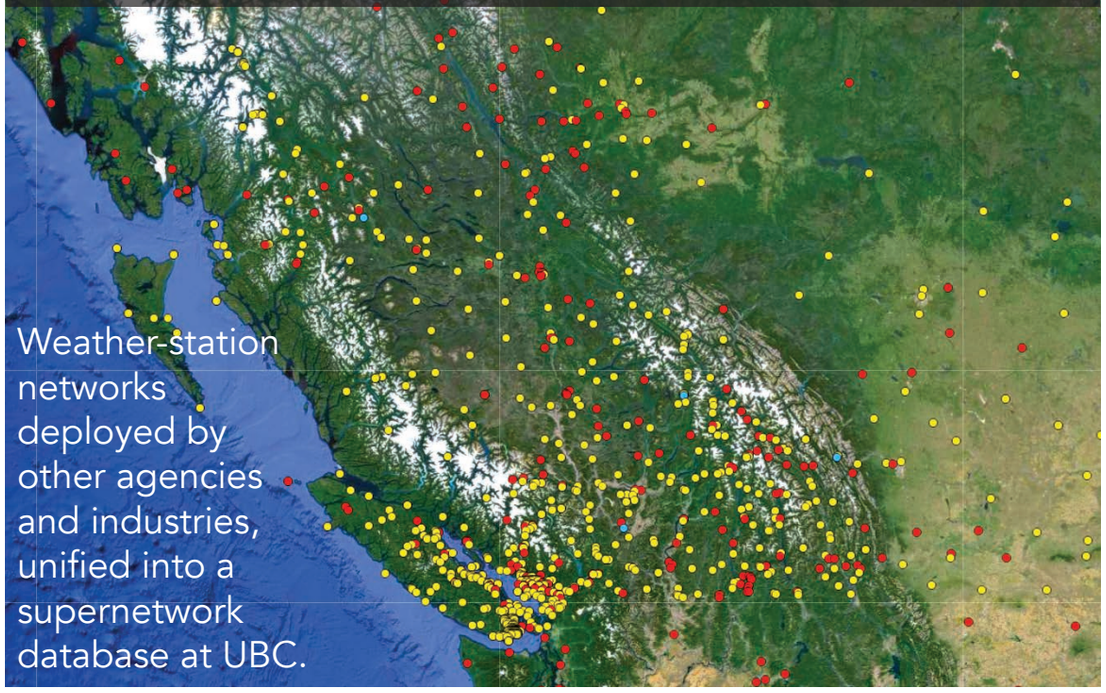
604-822-5901

Emergency Weather Network
Weather support for emergency managers



Weather-station networks deployed by other agencies and industries, unified into a supernetwork database at UBC.

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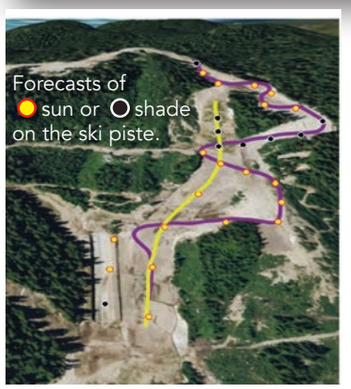
What we do.

Weather Forecasts for Special Events/Projects

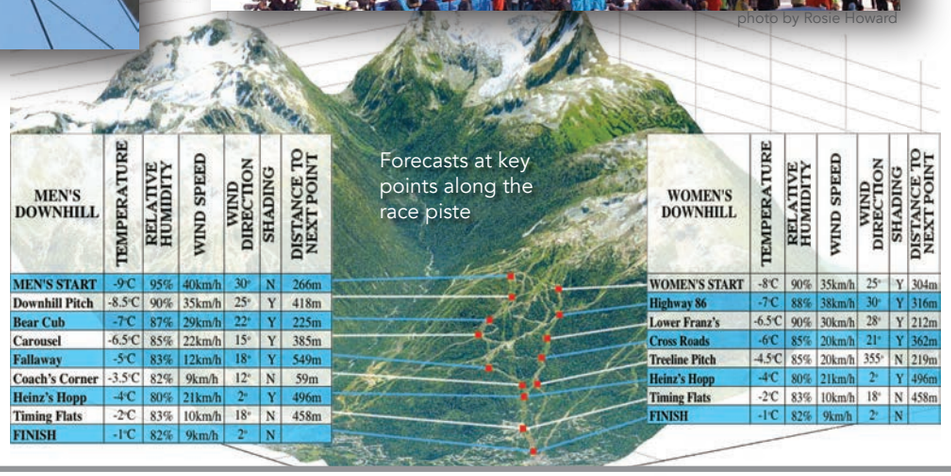
- 2010 Winter Olympics
- Project Firestorm
- Rocketsonde Buoys
- Canadian Arctic

Deployment of sophisticated sensors

photo by Rosie Howard

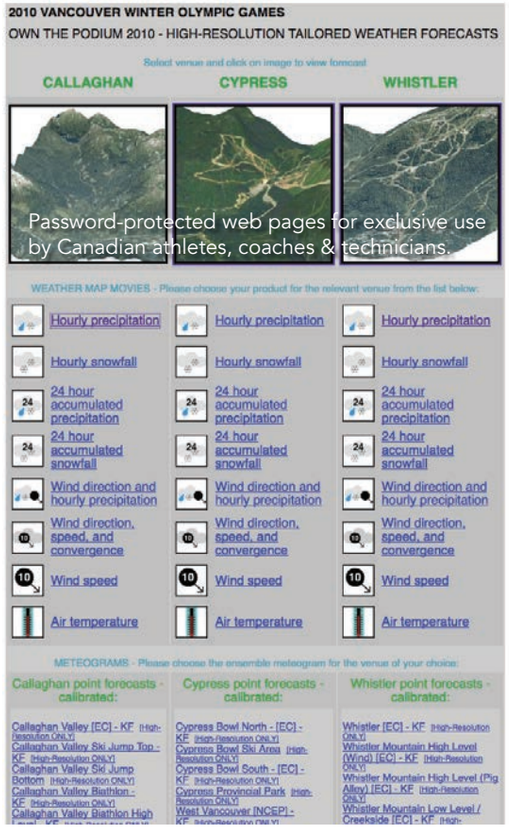


photos by R. Stull



MEN'S DOWNHILL	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED	WIND DIRECTION	SHADING	DISTANCE TO NEXT POINT
MEN'S START	-9°C	95%	40km/h	30°	N	266m
Downhill Pitch	-8.5°C	90%	35km/h	25°	Y	418m
Bear Cub	-7°C	87%	29km/h	22°	Y	225m
Carousel	-6.5°C	85%	22km/h	15°	Y	385m
Fallaway	-5°C	83%	12km/h	18°	Y	549m
Coach's Corner	-3.5°C	82%	9km/h	12°	N	59m
Heinz's Hopp	-4°C	80%	21km/h	2°	Y	496m
Timing Flats	-2°C	83%	10km/h	18°	N	458m
FINISH	-1°C	82%	9km/h	2°	N	

WOMEN'S DOWNHILL	TEMPERATURE	RELATIVE HUMIDITY	WIND SPEED	WIND DIRECTION	SHADING	DISTANCE TO NEXT POINT
WOMEN'S START	-8°C	90%	35km/h	25°	Y	304m
Highway 86	-7°C	88%	38km/h	30°	Y	316m
Lower Franz's	-6.5°C	90%	30km/h	28°	Y	212m
Cross Roads	-6°C	85%	20km/h	21°	Y	362m
Treeline Pitch	-4.5°C	85%	20km/h	355°	N	219m
Heinz's Hopp	-4°C	80%	21km/h	2°	Y	496m
Timing Flats	-2°C	83%	10km/h	18°	N	458m
FINISH	-1°C	82%	9km/h	2°	N	



Password-protected web pages for exclusive use by Canadian athletes, coaches & technicians.

Sponsor: 2010 Vancouver Olympic Committee & OTP

Region: Whistler, Callaghan, Cypress Ski Resorts, BC.

Tailored weather forecasts for athletes & technicians, and research on snow race surfaces.

Numerical Weather Prediction (NWP) Issues in Mountainous Western North America

Roland Stull
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University of British Columbia (UBC)
Vancouver, Canada
Aug 2017

Topics:
1. fjord weather & forest fire forecasts
2. Pacific data "void" & rocketsondes
3. grid smoothing & nowcasting
4. ensemble forecasts & wind turbines
5. landfalling cyclones & applications

The End. Questions?