Assessing the Added Value of ICAR Without Applying Observation Based Tuning

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Content

Introduction

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A typical research question

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"What is the local impact of a changing global climate?"

   

Introduction

Global Circulation Models

- spatially coarse

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- miss processes relevant for local climate and weather
- $\Rightarrow$ especially problematic in complex topography

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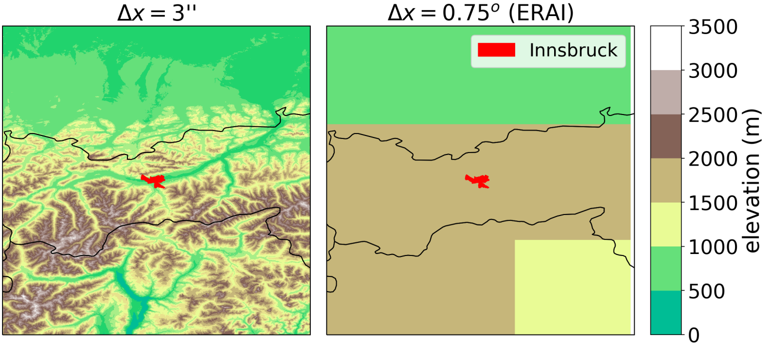

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   - physically consistent fields

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How to obtain atmospheric fields for local impact studies?

1. dynamic downscaling
   - physically consistent fields
   - computationally expensive
   - if tuned to observations: stationarity assumption
2. statistical downscaling
   - computationally cheap
   - require measurements for training

     $\Rightarrow$ data sparse regions?

     $\Rightarrow$ stationarity assumption

Introduction

dynamic downscaling ⟷ statistical downscaling

computationally expensive

physics based

computationally cheap

statistics based

Introduction

dynamic downscaling ⟷ statistical downscaling

computationally expensive

physics based

computationally cheap

statistics based

"intermediate complexity"

Introduction

Sarker 1966
LOP (Smith & Barstad 2004)
ICAR (Gutmann et al 2016)

dynamic downscaling ⟷ statistical downscaling

computationally expensive
physics based

computationally cheap
statistics based

"intermediate complexity"

Introduction

Intermediate **C**omplexity **A**tmospheric **R**esearch Model (ICAR) (Gutmann et al., 2016)

- physics based
- computationally frugal

compared to other intermediate complexity approaches:

- fewer simplifying assumptions
- more general atmospheric model

ICAR

- quantities stored on 3D grid
- numerical advection within wind field
- microphysics

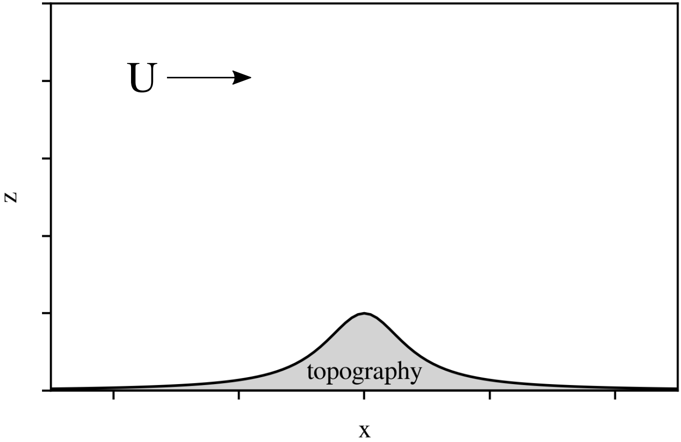
ICAR

- quantities stored on 3D grid
- numerical advection within wind field
- microphysics

Wind field

- calculated analytically
- based in linear theory
- calculated for every forcing time step
  $\Rightarrow$ Sequence of steady states

ICAR - Windfield



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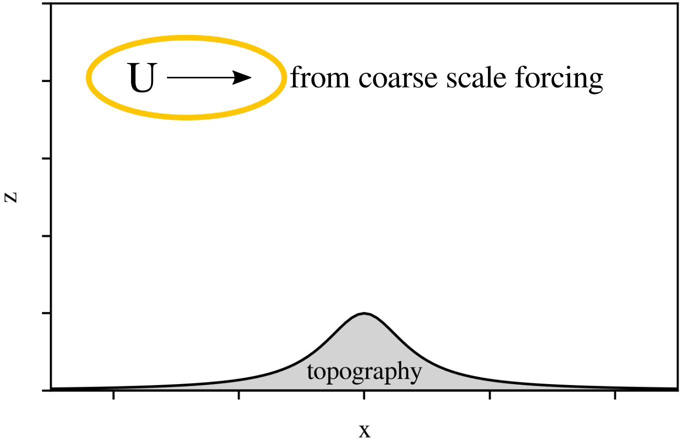

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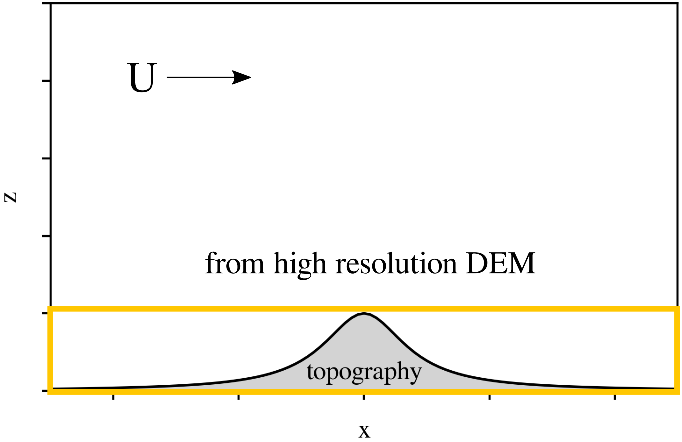

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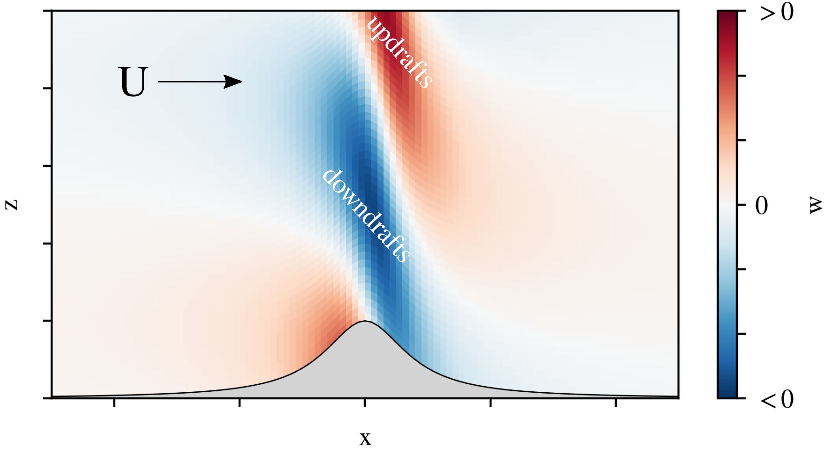
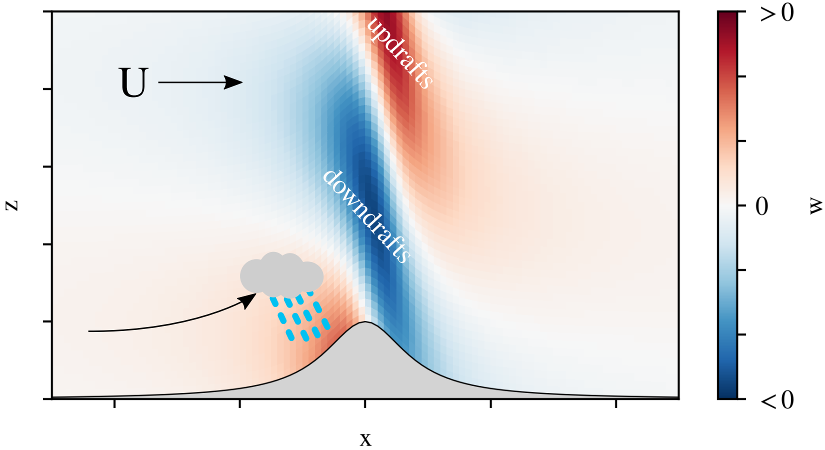


equations: Barstad and Grønås (2006)

ICAR - Windfield



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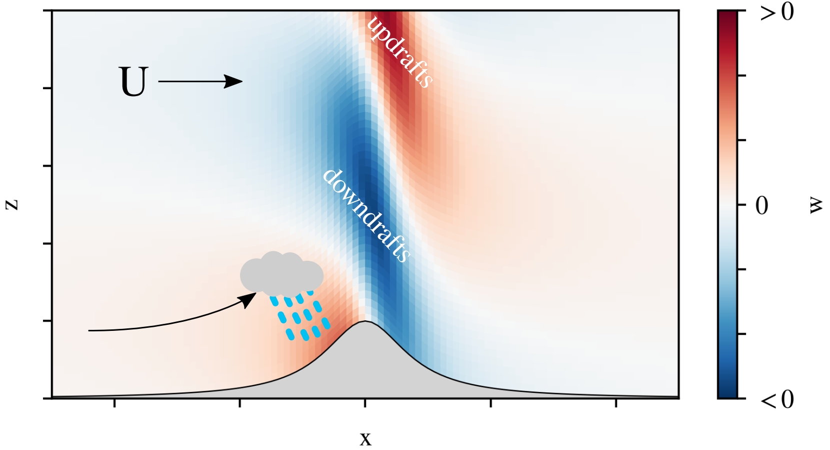
ICAR - Windfield

currently: **no reflection of waves**



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Goal

use ICAR to downscale

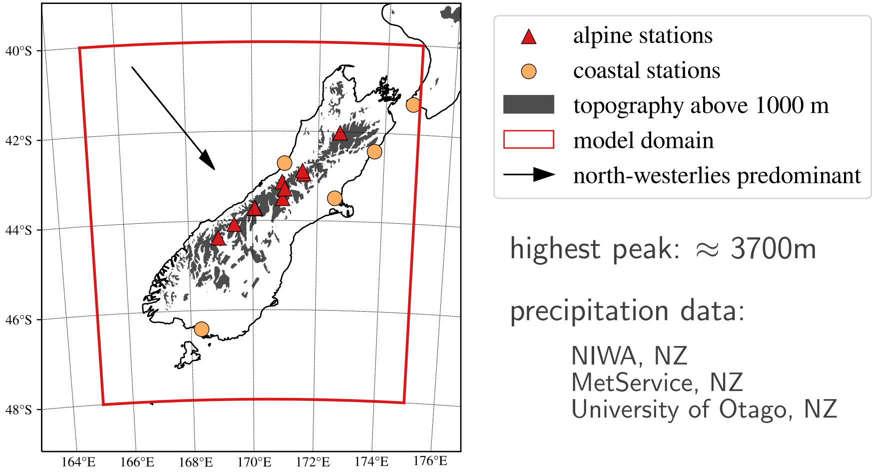
- 24h accumulated precipitation and
- quantify added value over forcing dataset

and investigate

- direct comparison to weather station data over multiple years
- performance in dependence of atm. background state
- performance in dependence of synoptic weather patterns

Study Domain

Domain - South Island of New Zealand

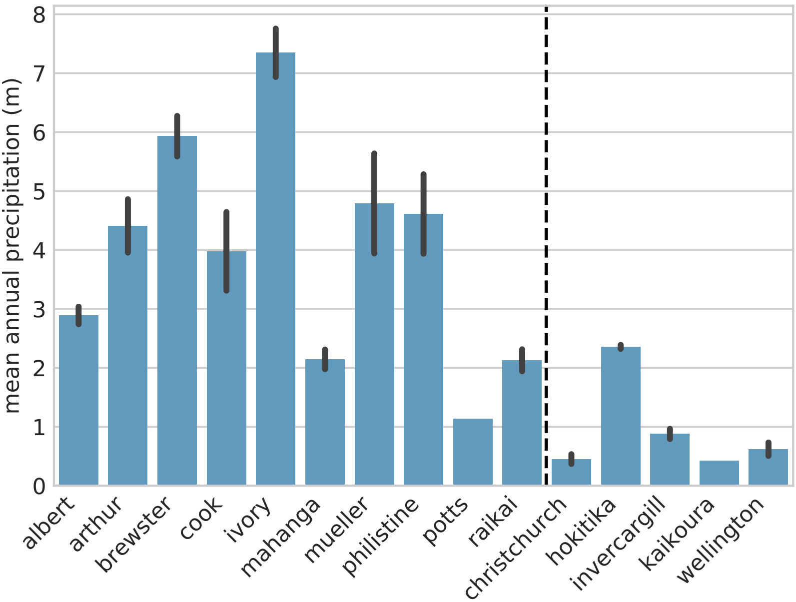


highest peak: $\approx$ 3700m

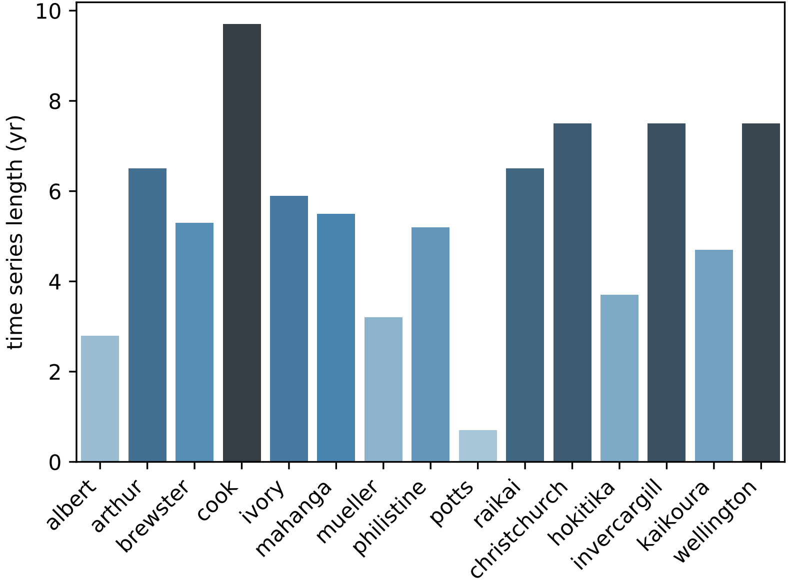
precipitation data:

NIWA, NZ
MetService, NZ
University of Otago, NZ

Mean Annual Precipitation



Observational Data



Setup

ERA-Interim forcing

- $\Delta t = 6\,\text{h} \quad \Delta A \approx 60 \times 83\,\text{km}^2$

Setup

ERA-Interim forcing

- $\Delta t = 6\,\text{h} \quad \Delta A \approx 60 \times 83\,\text{km}^2$

also used as reference model to determine added value

Setup

ERA-Interim forcing

- $\Delta t = 6\,\mathrm{h} \quad \Delta A \approx 60 \times 83\,\mathrm{km}^2$

downscale to

- $\Delta t = 1\,\mathrm{h} \quad \Delta A = 4 \times 4\,\mathrm{km}^2$
- model top at $\approx 5.7\,\mathrm{km}$ above topography

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10 year study period

- 01/2006 to 12/2016

Setup

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10 year study period

- 01/2006 to 12/2016

Settings

- **ICAR standard settings**
- **NO tuning to observations**

Evaluation & Results

Evaluation & Results

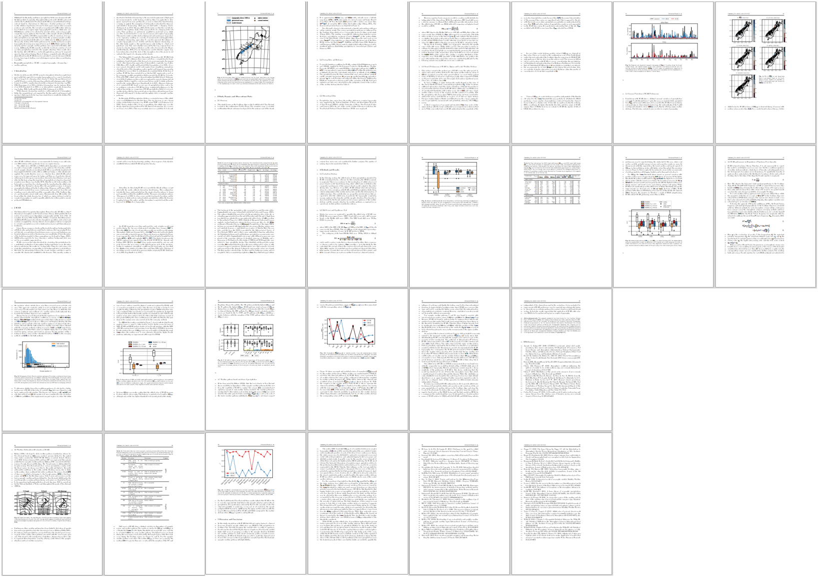
Short intermission:

A small mistake with large consequences

two weeks ago...

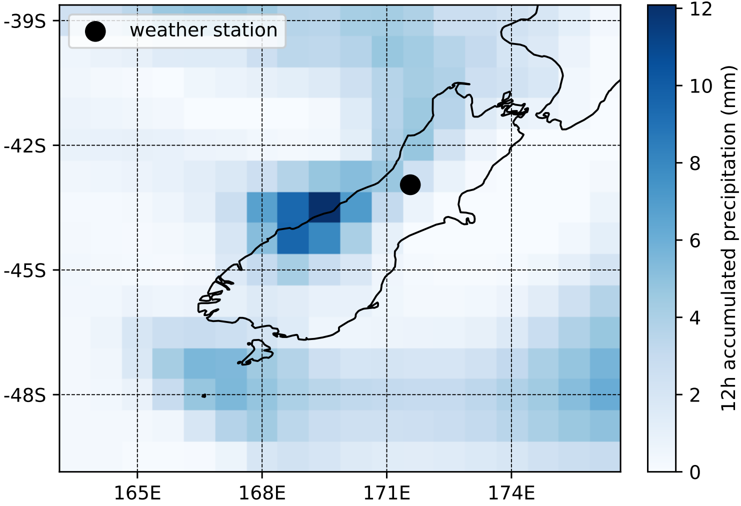
Mistakes

- very advanced paper draft



Mistakes

- found error in self written post-processing tool



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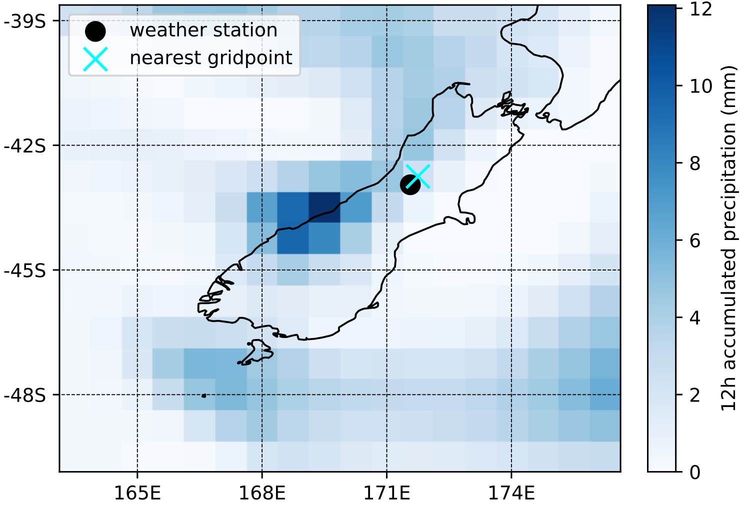

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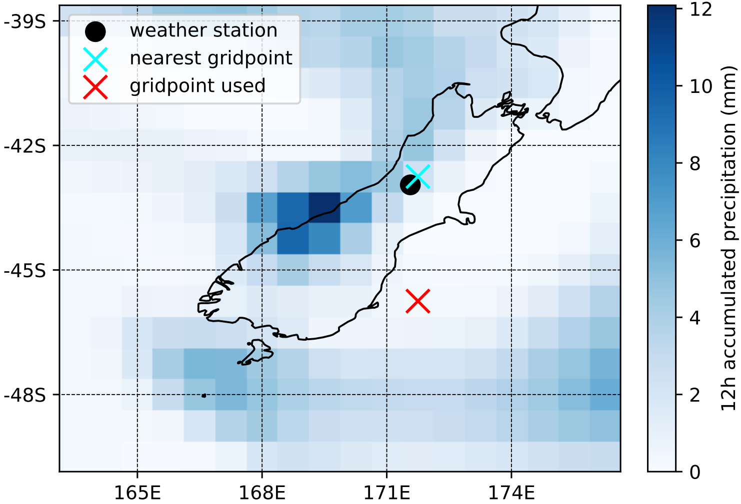


Mistakes

What happened?

ERAI latitude array sorted from highest value to lowest value:

- $[-39, -39.75, -40.5, -41.25, -42, ...]$

equation to find nearest grid point assumed otherwise

- correct index calculated
- started counting from wrong side of array

-39	-40.5	-42	-43.5	-45	-46.5	-48	-49.5
-39	-40.5	-42	-43.5	-45	-46.5	-48	-49.5

$\Rightarrow$ extracted time series from wrong grid point

Consequences

Paper and Evaluation need adaptions

- analysis still relevant
- some results change

$\Rightarrow$ interpretation now obsolete

updated results shown here

Evaluation Strategy

What we can compare

24h accumulated precipitation

$$\begin{array}{ll} \text{ICAR} & : \text{ICAR} \\ \text{ICAR}^{+} & : \text{ICAR} + \text{ERAI} \\ \text{ICAR}^{*} & : \text{ICAR} + \left(\text{ERAI} - \text{ORO}\right) \\ \hline \text{reference} & : \text{ERAI} \end{array}$$

ORO: orographic precipitation already in ERAI

- from ICAR simulations with ERAI topography
- and ERAI wind field (no linear waves)

all interpolated to station coordinates

for now we focus on ICAR^{+} (more work on ICAR* needed)

Evaluation Strategy

determine added value

- Skill scores
  - mean squared error based
  - Heidke skill score

influence of selected criteria on scores

- topographic complexity
- flow linearity
- synoptic situation

significance tests

- moving block bootstrap

Evaluation Strategy

use skill scores to **quantify added value** over ERAI

- **MSE based**
  Model closer to measurements than a reference model?

- **Heidke skill score**
  Model better at forecasting occurrence / non-occurrence of an event than reference is?

  dependent on threshold!

  - 25 mm
  - 50 mm

What is HSS?

- contingency table based
- event occurs or doesn't

Essentially:

$$\frac{\text{prop. correct - reference}}{\text{1.0 - reference}}$$

reference:

prop. correct ERA-Interim

		Observed	
		yes	no
Modelled	yes	hits	false hits
	no	false misses	misses

Evaluation Strategy

$$SS_{\text{MSE}} = 1 - \frac{\text{MSE}}{\text{MSE}_r}$$

$$SS_{\text{HSS}} = \frac{\eta - \eta_r}{1 - \eta_r}$$

where

η	...	proportion correct ICAR$^+$
η_{ref}	...	proportion correct ERAI

score values:

1.0	...	perfect!
0.0	...	as good as reference
< 0.0	...	worse than reference

Significance Tests

moving block bootstrap

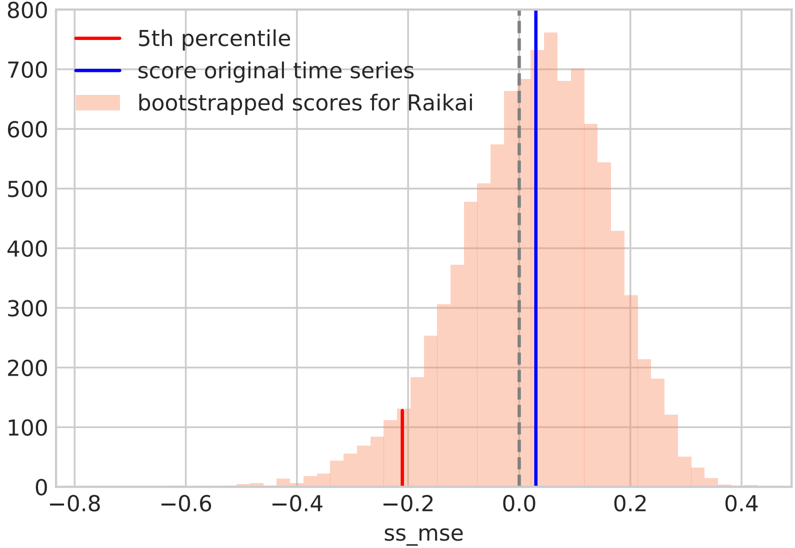
- same algorithm as normal bootstrapping
- preserves autocorrelation structure of time series
- resamples blocks consisting of L observations
- block length $L = L(n, \rho)$

Score significant **if**

- 5th percentile of bootstrapped scores > 0

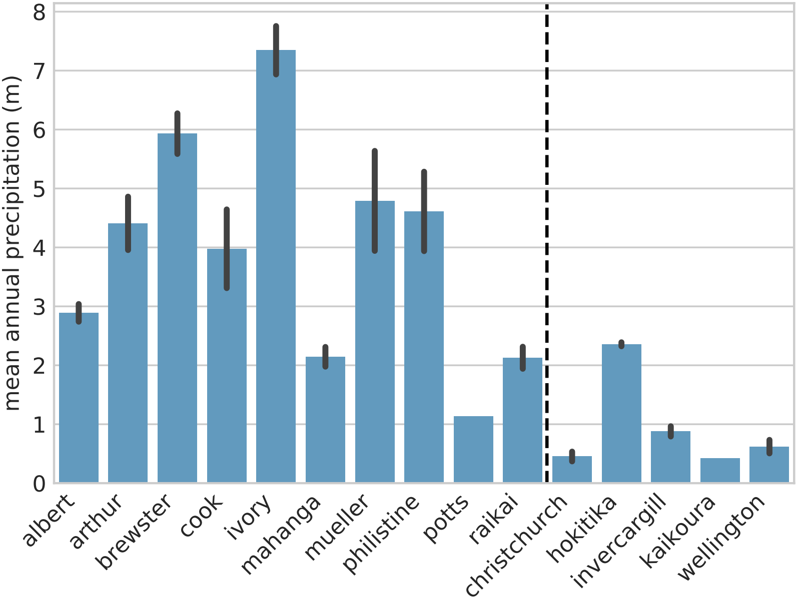
All following plots:
only significant scores included

Significance Tests

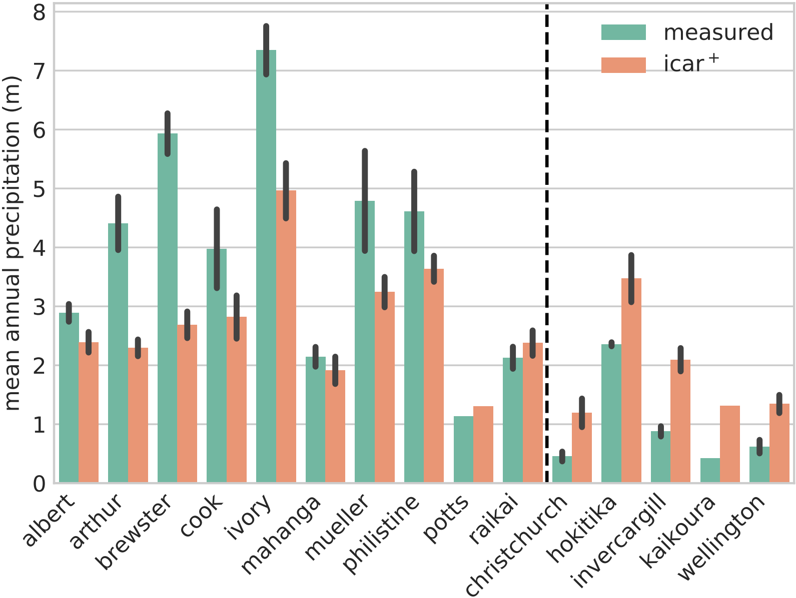


Results

Mean annual precipitation sums



Mean annual precipitation sums



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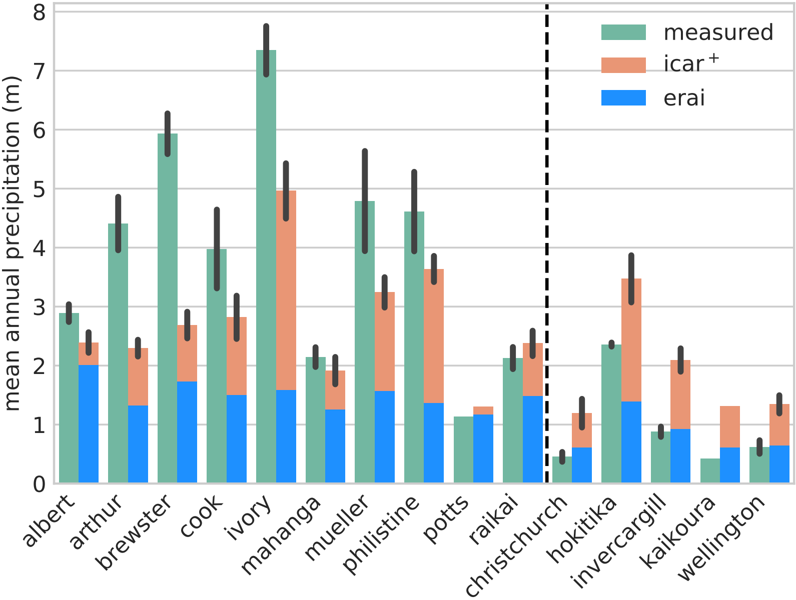
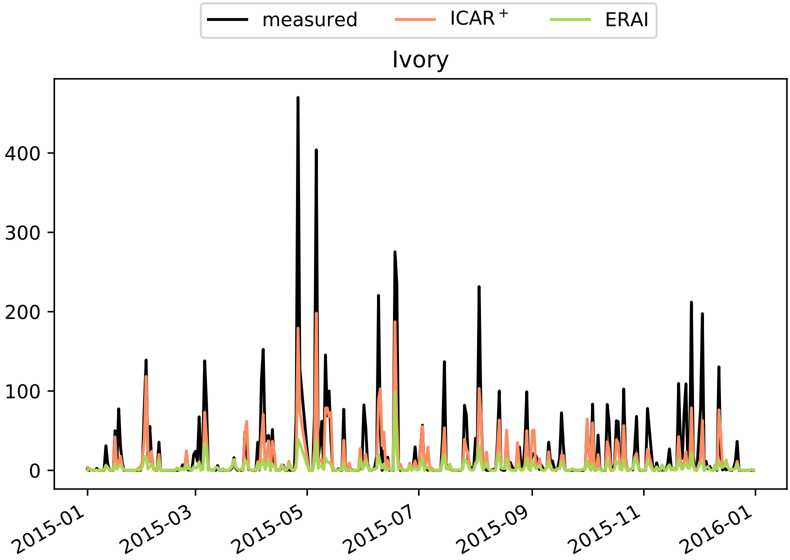
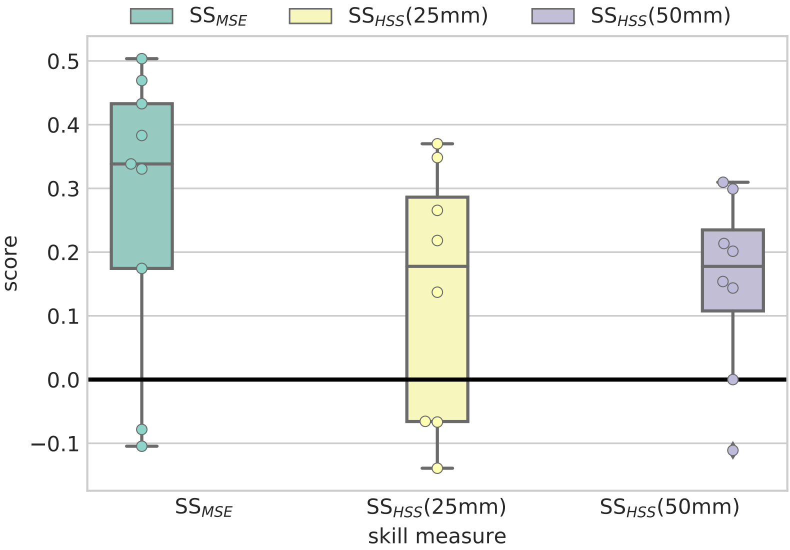


Time Series



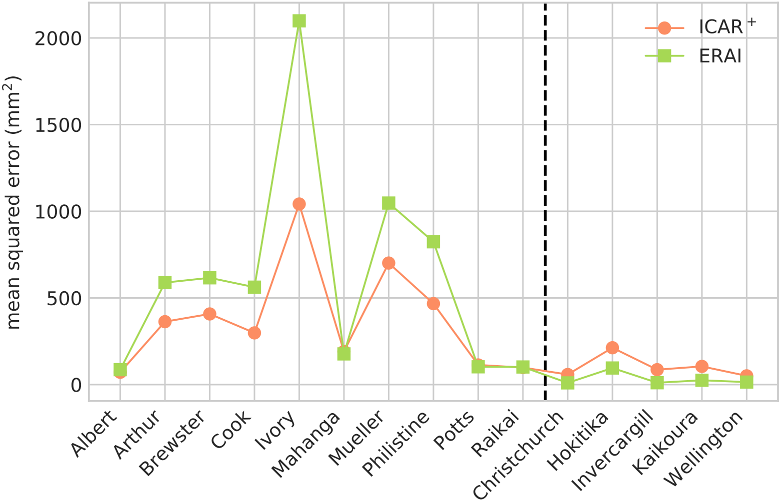
measured
ICAR$^+$
ERAI
Ivory
400
300
200
100
0
2015-01
2015-03
2015-05
2015-07
2015-09
2015-11
2016-01

Scores



SS_{MSE}
SS_{HSS}(25mm)
SS_{HSS}(50mm)
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
score
SS_{MSE}
SS_{HSS}(25mm)
SS_{HSS}(50mm)
skill measure

Mean Squared Error

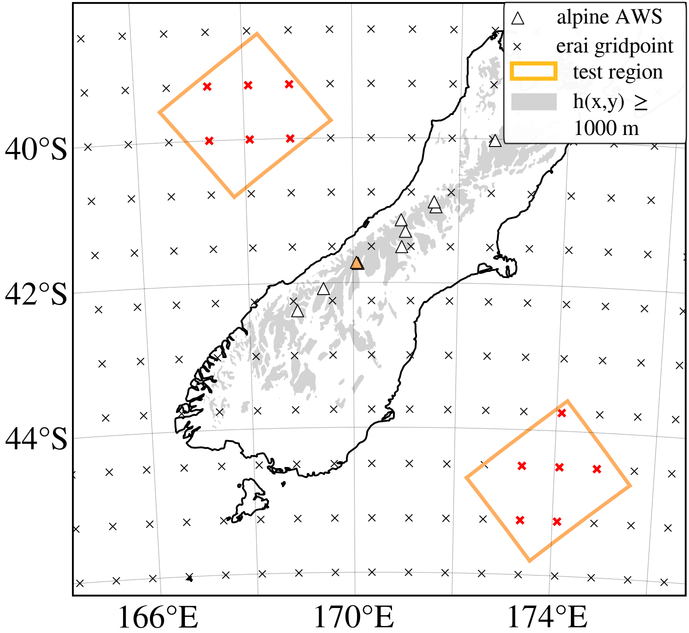


ICAR and linearity of flow upstream

ICAR based on linear theory
$\Rightarrow$ linear flow should increase model performance

1. defined upstream test volumes (per weather station)
2. characterized flow linearity in test volumes with Froude number
$$Fr = \frac{WS}{HN}$$
3. investigated how this affects skill scores

ICAR and linearity of flow upstream



ICAR and linearity of flow upstream

Characterized with Froude Number

$$\mathrm{Fr} = \frac{\mathrm{WS}}{\mathrm{H\,N}} \tag{1}$$

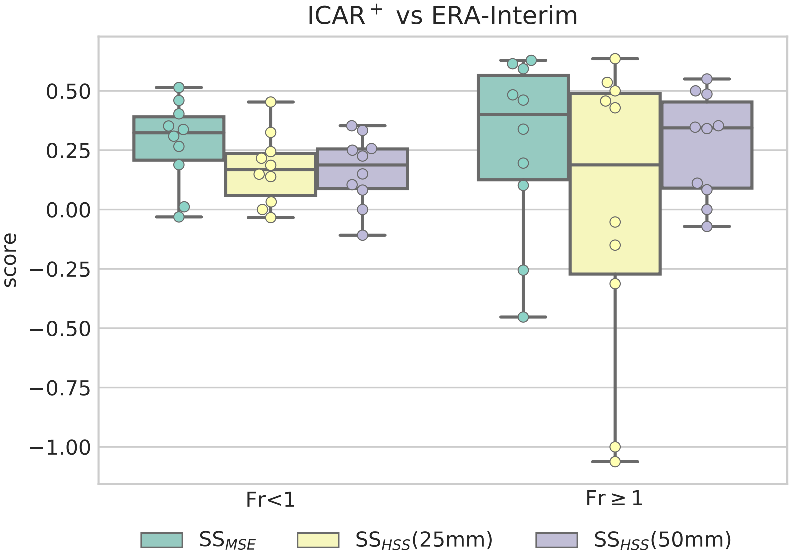
$\mathrm{Fr} < 1$ non-linearity more likely
$\mathrm{Fr} \geq 1$ linear flow

- WS... wind speed perpendicular to alps
- H ... characteristic height
- N ... Brunt Väisälä frequency

Only included days where

- flow $\pm 15^o$ northwest or southeast
- stable stratification

ICAR and linearity of flow upstream



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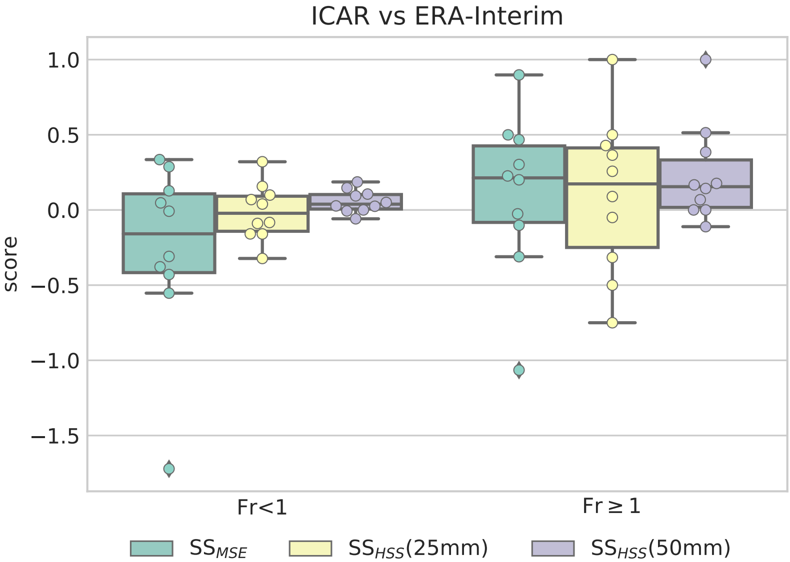

Weather Patterns

- 12 synoptic weather patterns (Kidson, 2000)

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Weather Patterns

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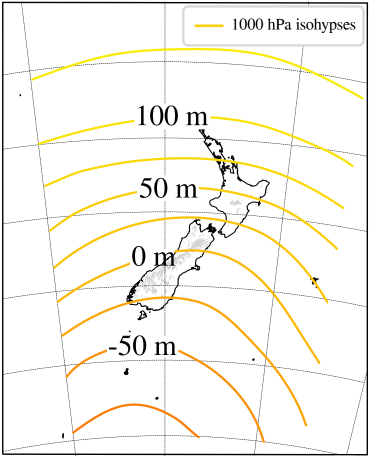
- defined by 24h mean elevation of 1000 hPa lvl
  - example: Trough - pattern
  - on ≈ 12% of days



Trough - pattern

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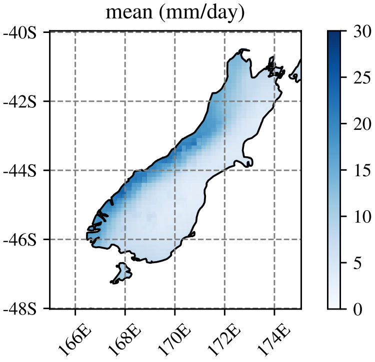

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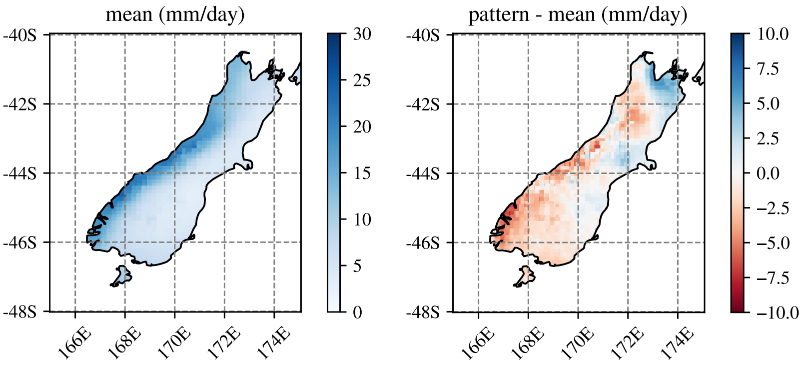

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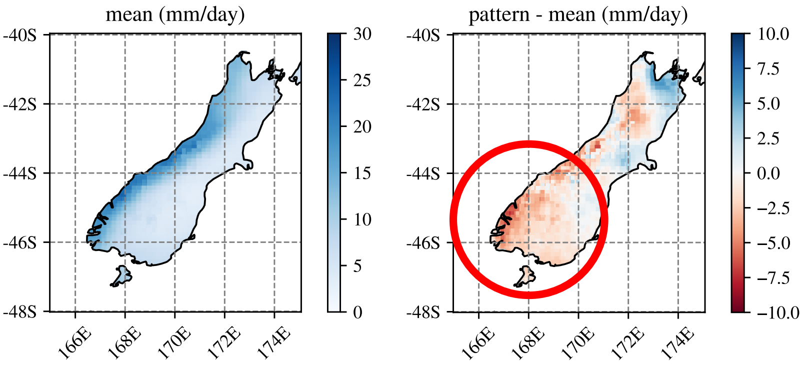

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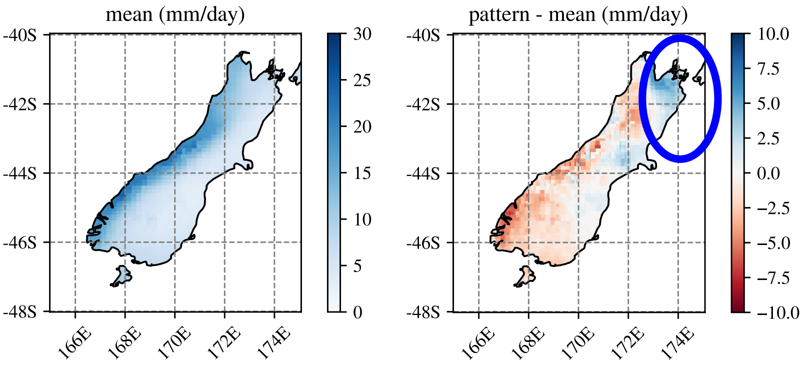

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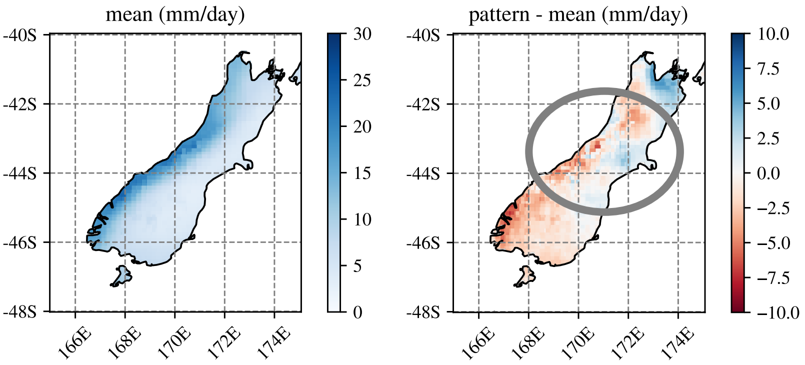

Weather Patterns

Weather patterns - ideal for investigating ICAR

- not part of downscaling method
- indicator of how physics based model is

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Weather Pattern $\Rightarrow$ local moistening and drying

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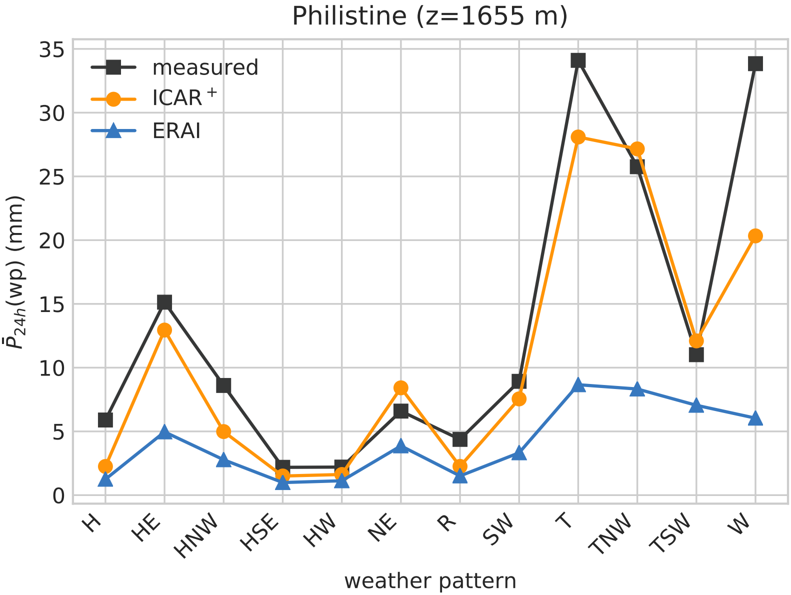
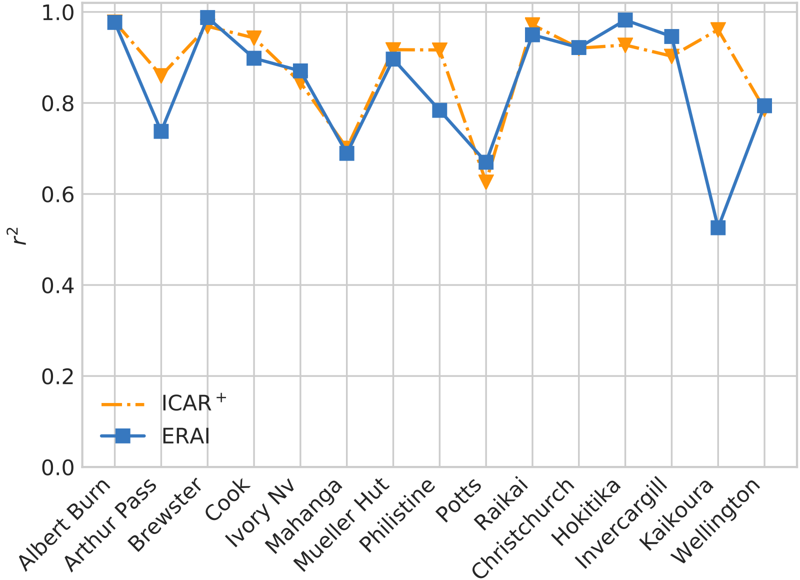
Weather Pattern $\Rightarrow$ local moistening and drying

can ICAR model the measured variation?

Precipitation Variation at an Alpine Station



Coefficient of Determination



Precipitation Variation at an Alpine Station

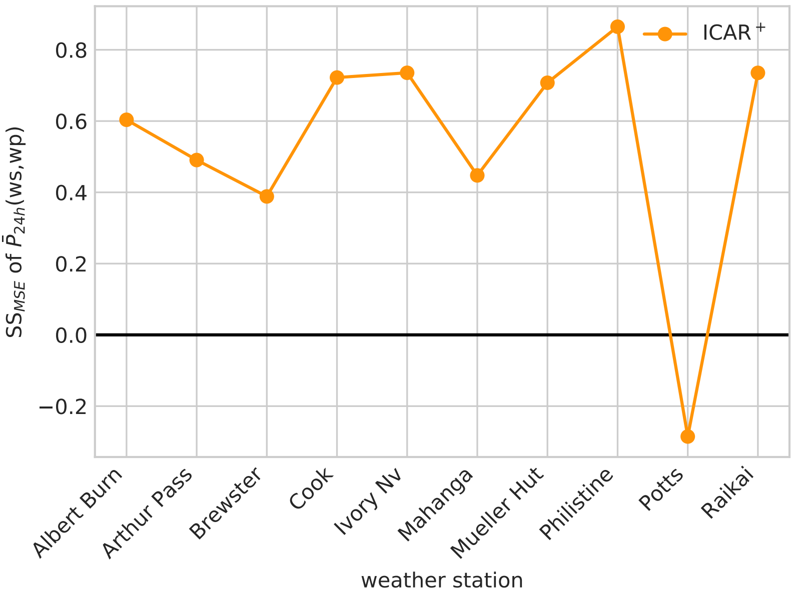
- only small differences
- ICAR^+ very similar to ERAI

- ICAR^+: $r^2 > 0.9$ at 10 of 15 sites

$\Rightarrow$ variability explained equally well by forcing

However, at alpine stations:

local $\bar{P}_{24h}$ precipitation during pattern
more accurate in ICAR^+



ICAR $^+$
0.8
0.6
0.4
0.2
0.0
−0.2
SS_{MSE} of $\bar{P}_{24h}$(ws,wp)
Albert Burn
Arthur Pass
Brewster
Cook
Ivory Nv
Mahanga
Mueller Hut
Philistine
Potts
Raikai
weather station

SS_{MSE} during weather patterns

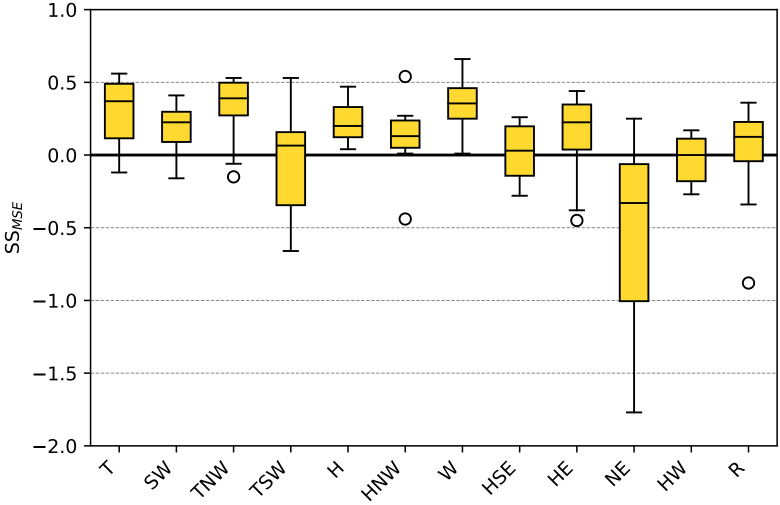
Before:

- looked at average precipitation at a weather station during a pattern
- calculated SS_{MSE} for average precipitations per weather pattern at a weather station

Now:

- calculate SS_{MSE} for all days where weather pattern occurs

SS_{MSE} during weather patterns



Summary and Conclusions

Conclusions

Added value of ICAR^{+} over ERAI in complex topography

- SS_{MSE} - added value at some $7/10$ alpine stations
- SS_{HSS} - added value for 6 alpine stations at every threshold

no added value for coastal weather stations

best 'choice' for complex topography:

- $\text{ICAR}^{+} = \text{ICAR} + \text{ERAI}$

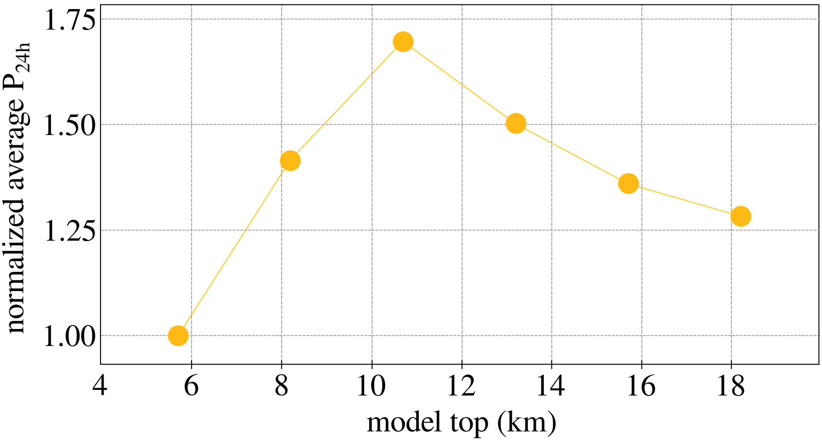
but: ICAR is too dry

ICAR is too dry

Potential reasons

1. no coupling w. surface
2. ERAI too dry?
3. cloud ice water and cloud liquid water
4. seeder/feeder mechanism
5. nonlinear wave amplification
6. model top height

Influence of Model Top



Conclusions

Upstream flow linearity

- slightly improves ICAR$^+$ performance
- however, effect clearer in ICAR only
  ERAI affected as well

Conclusions

Variation of local precipitation

- variability similar to that of forcing (r^2)

However, clear added value found for local $\bar{P}_{24h}(wp)$

- at 9 of 10 alpine stations
  $SS_{MSE} \geq 0.4$

SS_{MSE} in dependence of weather pattern:

- clear added value for 8/12 weather patterns
- 3/12 with no added value (median)
- 1/12 with worse performance compared to ERAI

Conclusions

ICAR shows potential

- added value without observational tuning
- particularly relevant for data sparse regions
- despite low model top

...but has its problems

Clarification needed for

- orographic component of ERAI
  work in progress
- underestimation of precipitation
- physics based argument for choice of model top

Thank you!

Literature I

Barstad, I. and Grønås, S. (2006). Dynamical structures for southwesterly airflow over southern norway: the role of dissipation. Tellus A, 58(1):2–18.

Gutmann, E., Barstad, I., Clark, M., Arnold, J., and Rasmussen, R. (2016). The intermediate complexity atmospheric research model (icar). Journal of Hydrometeorology, 17(3):957–973.

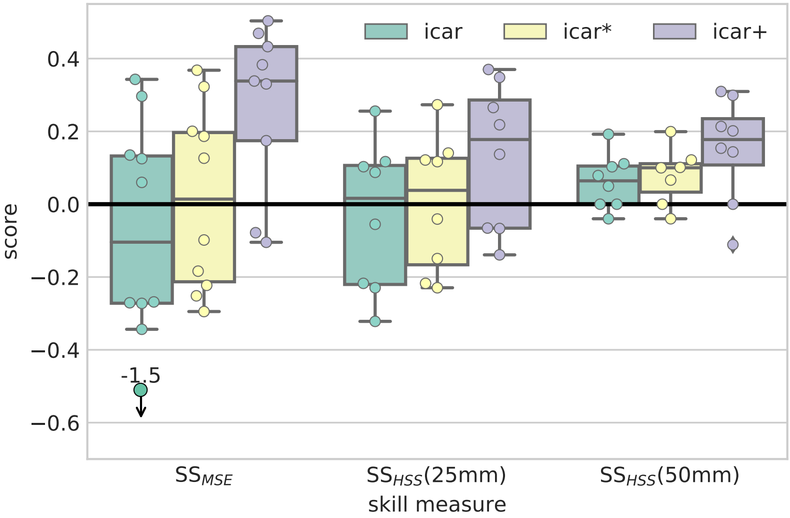
Kidson, J. W. (2000). An analysis of new zealand synoptic types and their use in defining weather regimes. International journal of climatology, 20(3):299–316.

Sarker, R. (1966). A dynamical model of orographic rainfall. Monthly Weather Review, 94(9):555–572.

Smith, R. B. and Barstad, I. (2004). A linear theory of orographic precipitation. Journal of the Atmospheric Sciences, 61(12):1377–1391.

Appendix

Scores



icar* = icar + erai - oro

icar+ = icar + erai