How Linear is Orographic Precipitation?
Insights from Nahuelbulta Mountains in Southern Chile

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Orographic Precipitation

Upstream precipitation enhancement/downstream rain shadow is a very consistent meteorological pattern produced by seemingly simple atmospheric physics.

The quantitative distribution of precipitation over mountainous terrain is, however, a significant challenge in meteorology, especially as one considers shorter time scales (e.g., daily or hourly accumulations). On the other hand, precipitation distribution is a critical input for water resource and risk management over complex terrain.

Several methods have been used to obtain the precipitation distribution over mountains:

• Geo-statistical methods (e.g., PRISM) (need lot of obs.)
• Full meteorological models (e.g., WRF) (expensive to run at high resolution)
• Linear precipitation models (need to tune a few parameters, fast to run)

Widely used to force other models...but is it realistic?
Results from AFEX: Andean frontal Experiment
15 raingauges. 2011-2013. Estimated annual mean precipitation [mm]

∼1000 mm

≤1000 mm

∼4000 mm

20 km
WRF (1 km) continuous run during winter 2011 (May-Sep) forced by GFS
Several weeks of computation in high performance computer...and a lot of pain.
WRF-AFEX Comparison
Winter 2011 precipitation
Rainfall episodes (24 during winter 2011) largely produced by the passage of cold fronts
(a) Meridional wind speed [m/s]

(b) Rainfall

<table>
<thead>
<tr>
<th>Height [m ASL]</th>
<th>Time [hr]</th>
<th>Rainfall rate [mm/30 min]</th>
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<tr>
<td>12000</td>
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**NW Jet**

**Frontal passage**
WRF-AFEX Comparison - Winter 2011 precipitation: 24 events

Observations [blue: MEO1, green: all others]

AFEX Precipitation [mm/30 min]

WRF
For each of the 27 events:

**Orographic modification ratios**

- **Observed**
- **Simulated by WRF full**

*Equations:*

\[
P(\text{ETA+A3P})
\]

\[
P(\text{TES+EOM})
\]

\[
P(\text{MEO+CUR})
\]

\[
P(\text{MEO+CUR})
\]

**Upstream enhancement**

**Downstream suppression**

[Graph showing scatter plot with axes labeled as 'Simulated by WRF full' on the y-axis and 'Observed' on the x-axis. Dashed line indicates 1:1 ratio. Clusters of data points are marked as 'ETA' and 'TES'.]
Simulated 2011 winter (May-Sep) Precipitation [mm]

(a) WRF (Full physics)
(b) LT Model (var. Wind and moisture from WRF)

(*) Linear Theory Model by Smith and Barstad (2004)
\[ \tau_c = \tau_f = 1000 \text{ s}, \; P_\infty = 0 \]

30 min of calculation in domestic PC
Simulated 2011 winter (May-Sep) Precipitation [mm]

Winter 2011 Precip [mm] and Terrain height [m ASL]

LT Model
LT Model scaled to WRF
WRF
How similar are the WRF and LT-Model precipitation pattern at individual events?
How similar are WRF and LT precipitation pattern at individual events?

Full WRF

Prefrontal (20')

Frontal (20')

Postfrontal (20')

Oro. WRF

LT Model

Orographic WRF: Full topo – No topo

\[ r = 0.65 \]

\[ r = 0.40 \]

\[ r = 0.22 \]

\[ r = 0.49 \]
How similar are WRF and LT precipitation extremes? Intense precipitation (>10 mm/hr) restricted to mnt. top in LT Model but widespread in WRF and observations.
Another way to look linearity using WRF

WRF-Oro = \((1-\beta)^{-1}\) \(\cdot\) \([\beta \cdot \text{TopoRun} - 0\text{TopoRun}]\)

WRF Topographic Effect

\[\text{PAcum(topo*1)} - \text{PAcum(topo*0)}\]

\[2 \cdot [\text{PAcum(topo*0.5)} - \text{PAcum(topo*0)}]\]
Another way to look linearity using WRF

Linear range

Orographic precipitation can’t be fully recovered if topography is reduced below 70% (mountain dependent?)
Conclusions

✓ WRF model does a good job in simulating the seasonal mean and event rainfall accumulation. WRF itself partially linear.

✓ Linear model does capture the seasonal rainfall distribution of precipitation over the Nahuelbuta mountains, although it overestimate accumulation in the windward side and produce a too strong rain shadow effect.

✗ Over/under estimations in the LT model can be reduced by tuning their parameters and filtering out many periods of light precipitation that the model produce before actual rainfall began.

✗ LT model can’t resolve intense, short-lived (less than an hour) rainfall episodes that are associated with non-linear effects during frontal passage. This episodes are highly variable in time and space, so they smooth when considering daily or longer periods.