CMCC WEBINAR

May 29, 2018 - h. 12.30 pm CEST

"Water management: innovative ways to assess precipitation spatial distribution"

Paola Marson - Presenter
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To investigate and model our **climate system** and its interactions with **society** to provide reliable, rigorous, and timely **scientific results**, which will in turn stimulate sustainable growth, protect the **environment**, and **develop science driven** adaptation and **mitigation policies** in a **changing climate**

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Centro Euro-Mediterraneo sui Cambiamenti Climatici

MISSION

NETWORK

ASC
Advanced Scientific Computing

CSP
Climate Simulation and Prediction

ECIP
Economic Analysis of Climate Impacts and Policy

IAFES
Impacts on Agriculture, Forest and Ecosystem Services

ODA
Ocean Modelling and Data Assimillation

OPA
Ocean Predictions and Applications

RAAS
Risk Assessment and Adaptation Strategies

REMHI
Regional Models and Hydrogeological Impacts

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Modelling
Policy
Adaptation
Agriculture
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Predictions
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Q&A session

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Water Management:

Innovative Ways to Assess Precipitation Spatial Distribution

CMCC

Bologna, 29 May 2018

Paola Marson, CMCC

Centro Euro-Mediterraneo sui Cambiamenti Climatici

A Process-Informed Statistical Framework for the Spatial Distribution and Intensity of Orographic Precipitation

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(2) National Center for Atmospheric Research, Boulder , CO, USA
(3) Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy
(4) Università Ca' Foscari Venezia, Italy

Motivation

Accurate estimates of precipitation is crucial for

- **Impact Studies**
  - **Water Management**
  - **RIsk Assessment**

Human activities may be strongly impacted especially downstream of mountainous regions

Challenges

Major challenges modeling precipitation over mountainous regions:

- **High variability in both space and time**
- **Abrupt discontinuities**
- **Complex interaction among atmospheric processes and orography.**

Existing Methods

Focus on modelling precipitation in space

- **Statistical/geostatistical interpolation of precipitation data from weather stations**
    - Rely on information in the observations
    - Geostatistical attributes (e.g. spatial dependence)
    - Auxiliary variables (e.g. elevation)
    - Limitations: data may not be representative

- **Up-slope methods**
    - Analytical models
    - Approximated description of physical processes
    - Limitations: may deviate from the observed precipitation patterns

Objective

Definition of a **Statistical Framework** for inferring the spatial distribution and intensity of precipitation over mountainous regions

- **Describes the variations in space of precipitation fields**

- **Combines information from both**
  - precipitation data
  - description of physical processes causing orographic precipitation

- **Improves numerical climate models usability (downscaling)**

Definition of a **Statistical Framework** for inferring the spatial distribution and intensity of precipitation over mountainous regions

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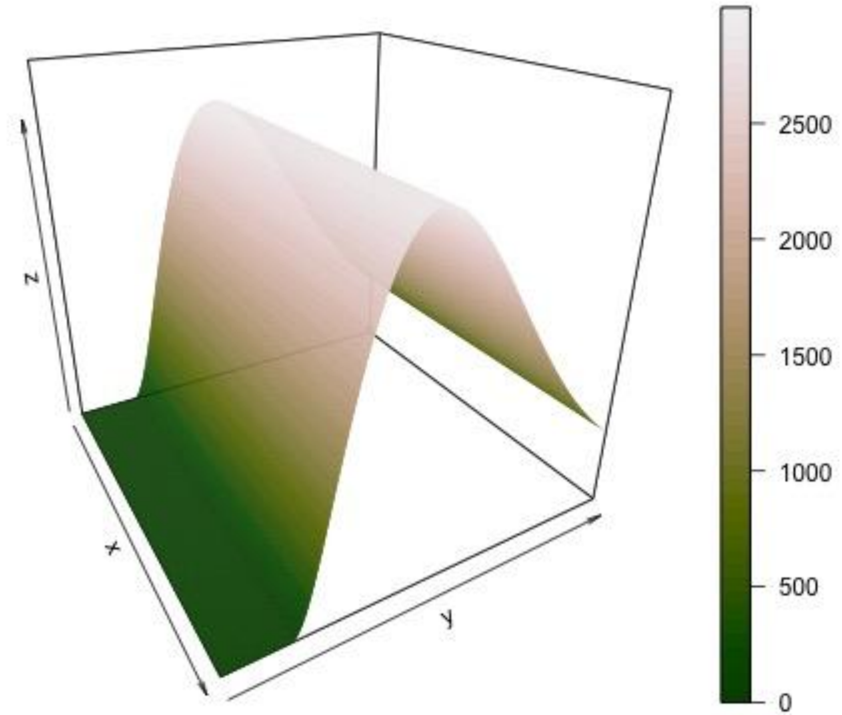
Local Scale Orographic Processes: The Up-slope Mechanism

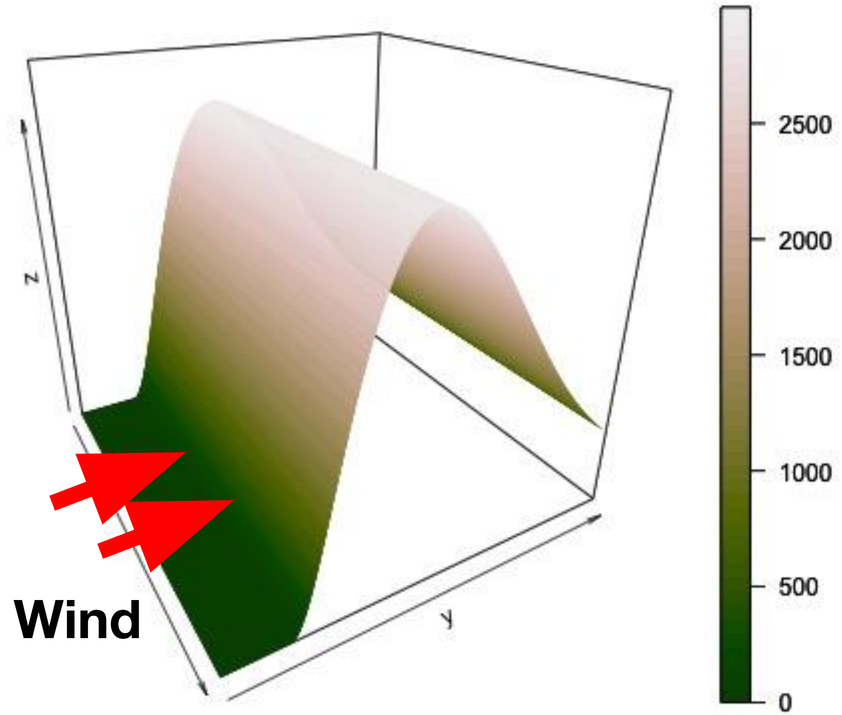
Idealized terrain features: indefinitely elongated ridge;

Resembles real ranges as Cascades, Sierra Nevada, Andes, coastal ridges



Local Scale Orographic Processes: The Up-slope Mechanism

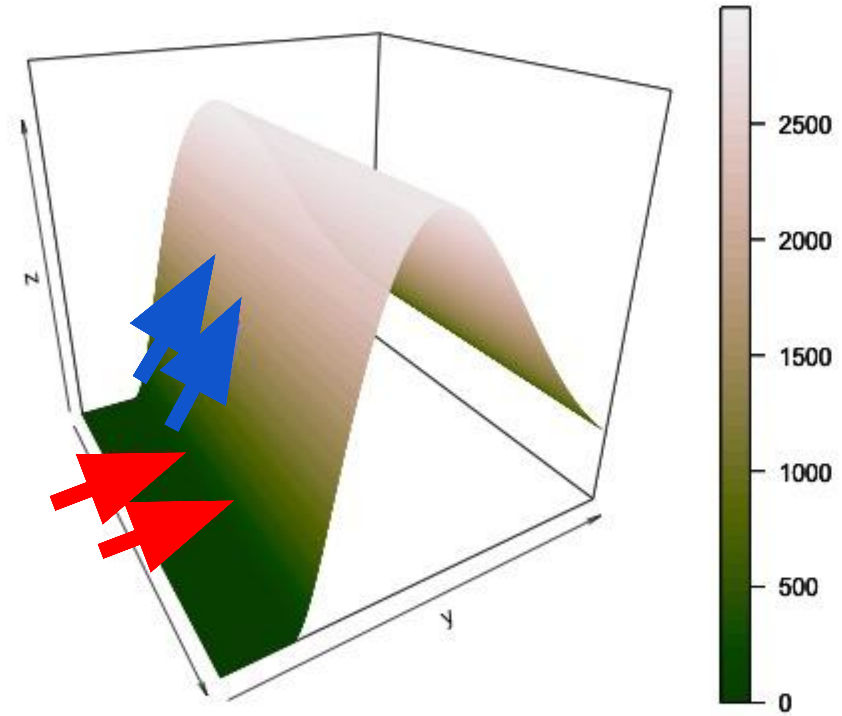
Warm moist flow impinges the topographic obstacle**:**



Local Scale Orographic Processes: The Up-slope Mechanism

Moist flow is forced to raise over the topographic obstacle**;**

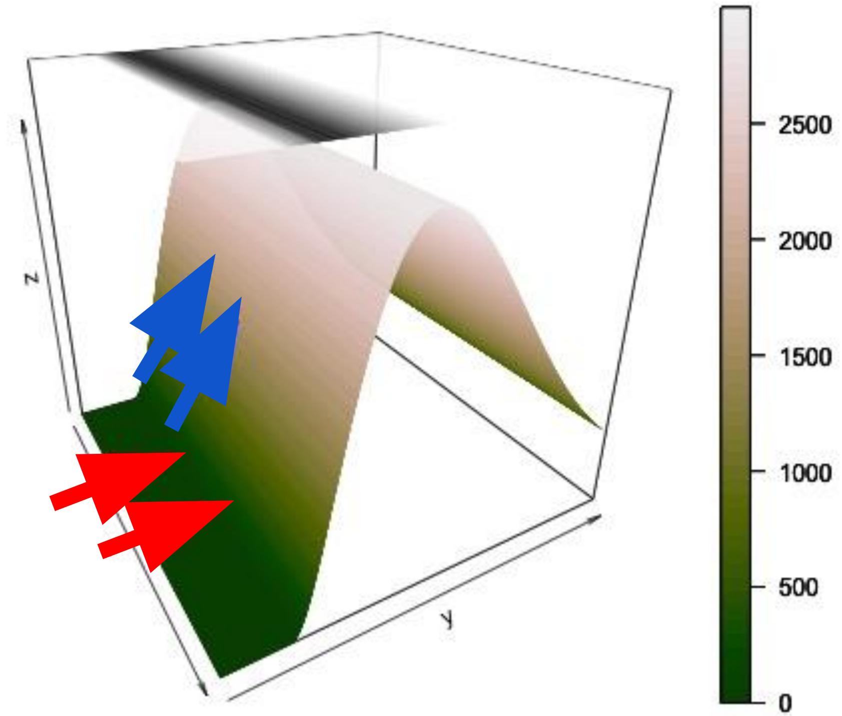
It cools;



Local Scale Orographic Processes: The Up-slope Mechanism

Saturation threshold may be reached → Condensation;

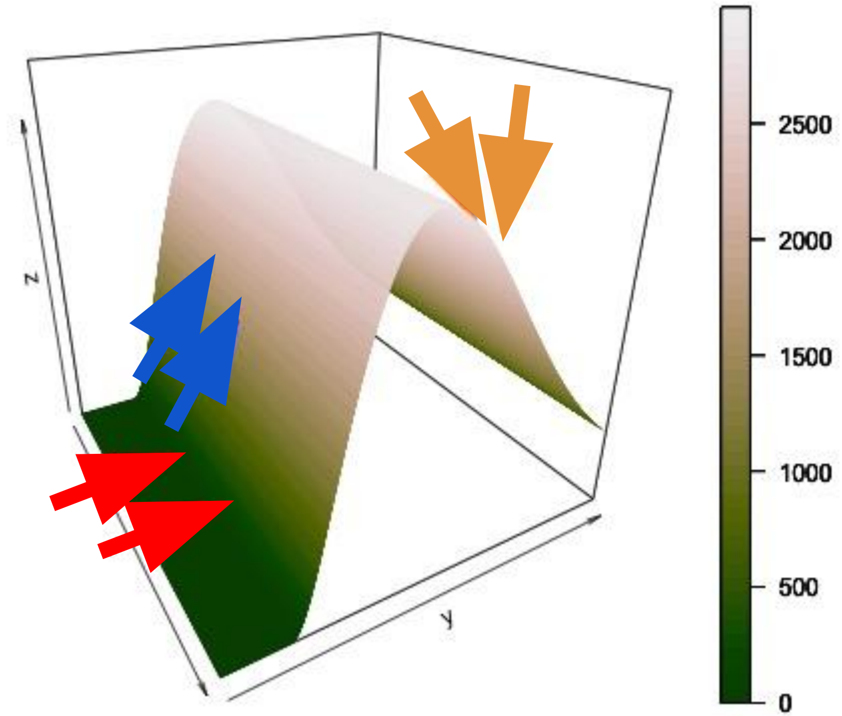
A cloud is formed;



Local Scale Orographic Processes: The Up-slope Mechanism

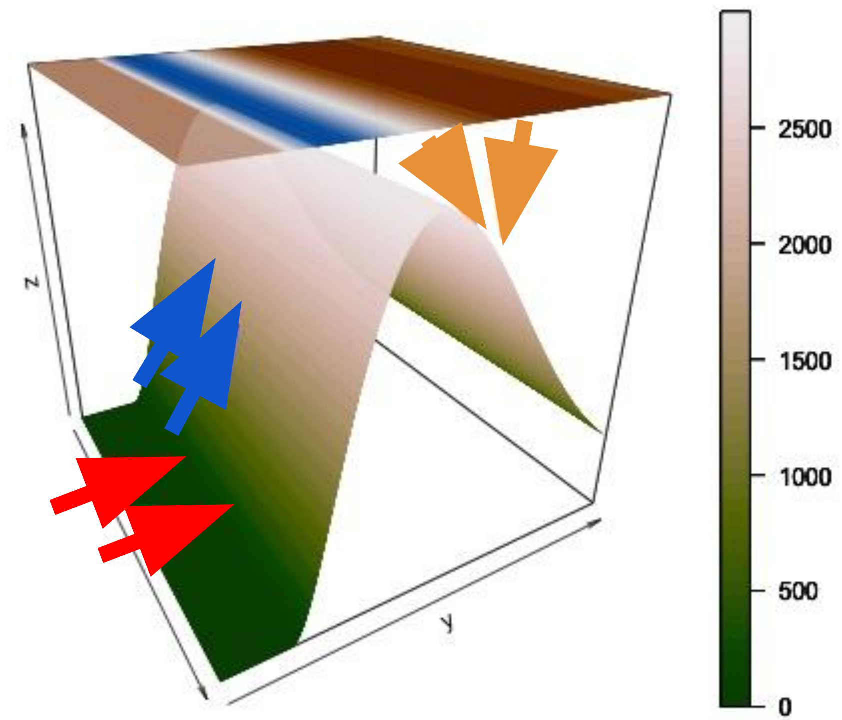
Flow proceeds past the topographic obstacle**:**

Descending it becomes warmer, cloud may evaporate



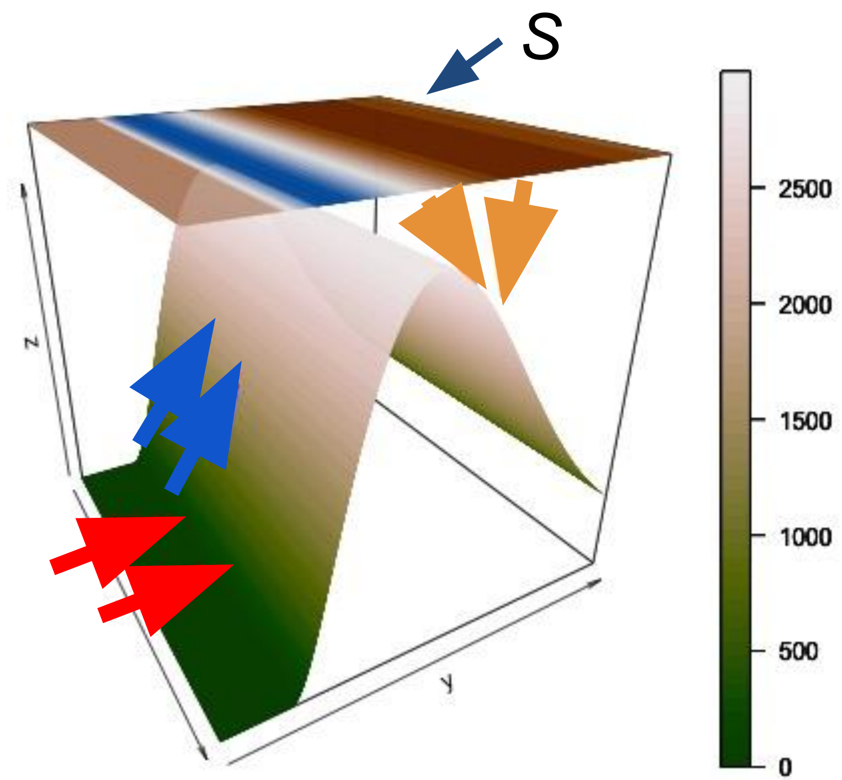
Local Scale Orographic Processes: The Up-slope Mechanism

Both **condensation** and **evaporation** displayed on one surface



Local Scale Orographic Processes: The Up-slope Mechanism

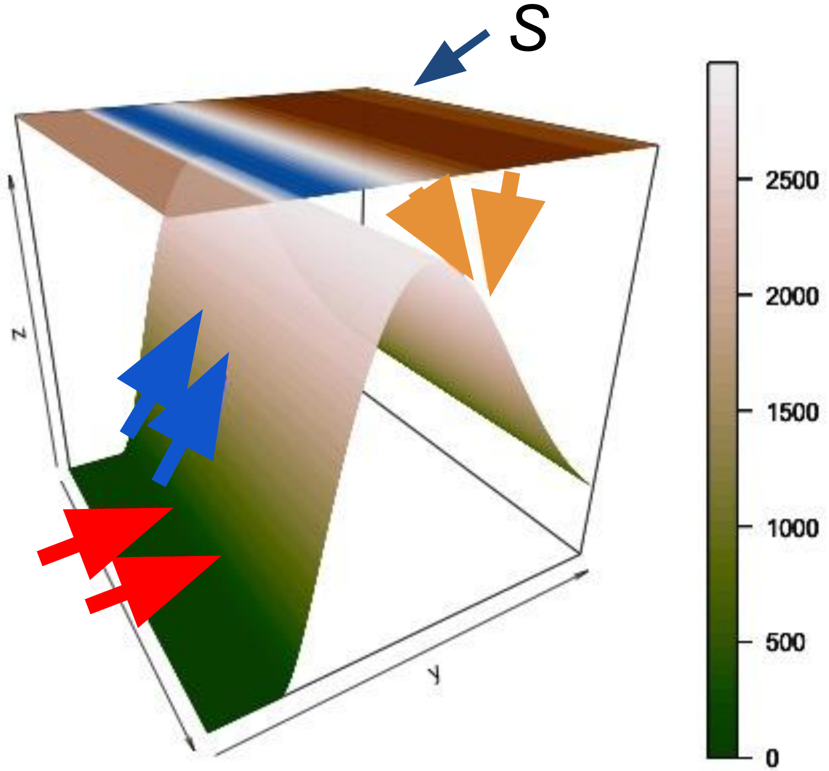
Source of condensation (+ −) (Condensation rate)



Local Scale Orographic Processes: The Up-slope Mechanism

Source S of condensation is proportional to :

- **Impinging Horizontal Wind Velocity**
- **Mountain Slope**
- **Saturation Water Vapor Density**

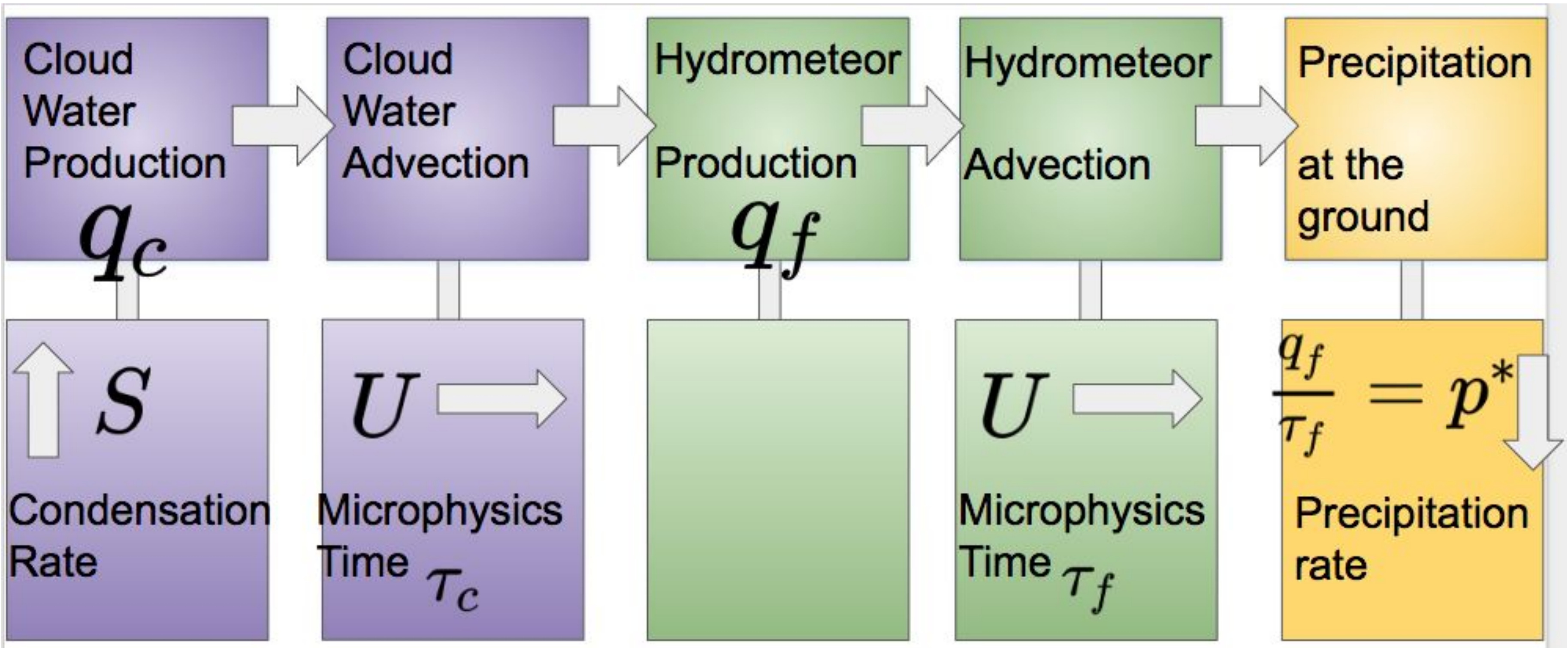


Local Scale Orographic Processes: The Governing Equation

The *up-slope-time-delay model* of Smith,2003

Two **lumped categories** of condensed water (column integrated):

- q_c **Cloud Water (density)**
- q_f **Hydrometeor (density)**



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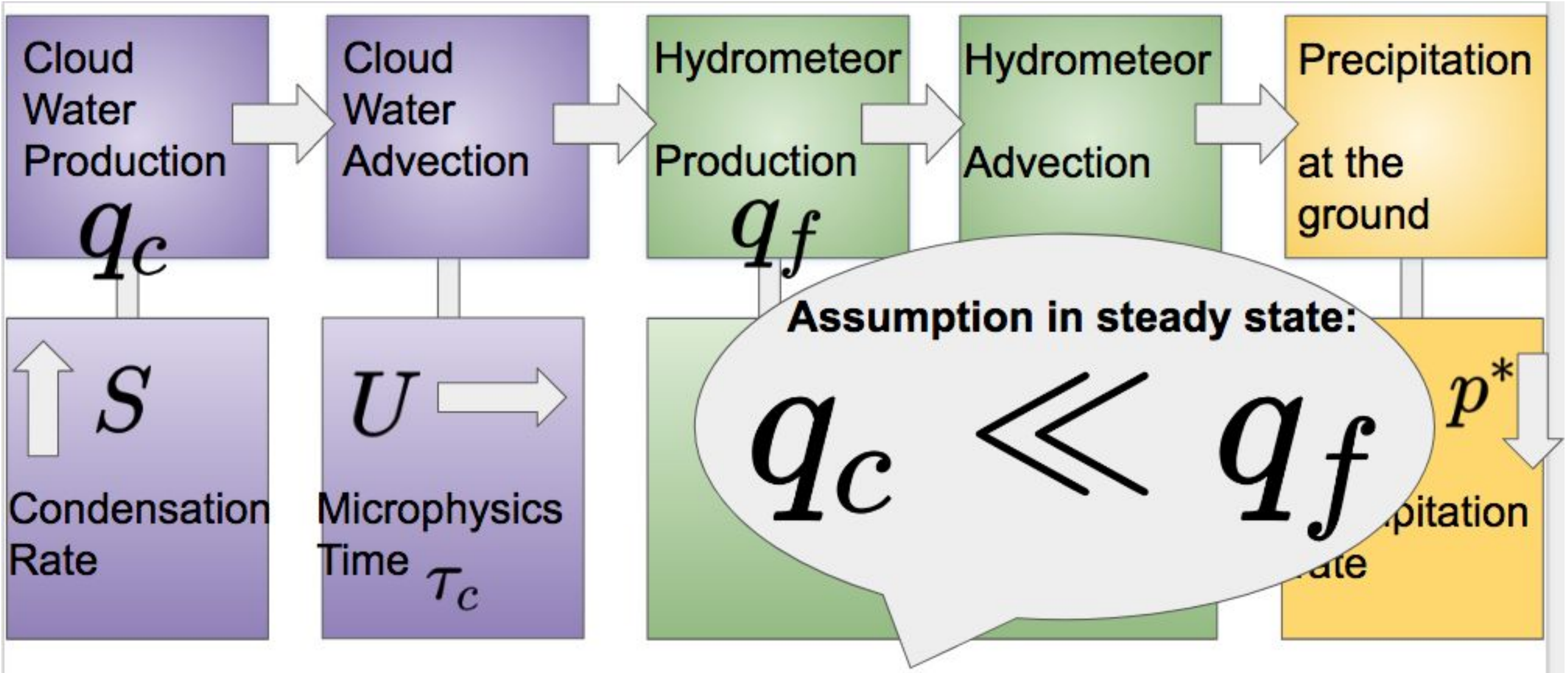
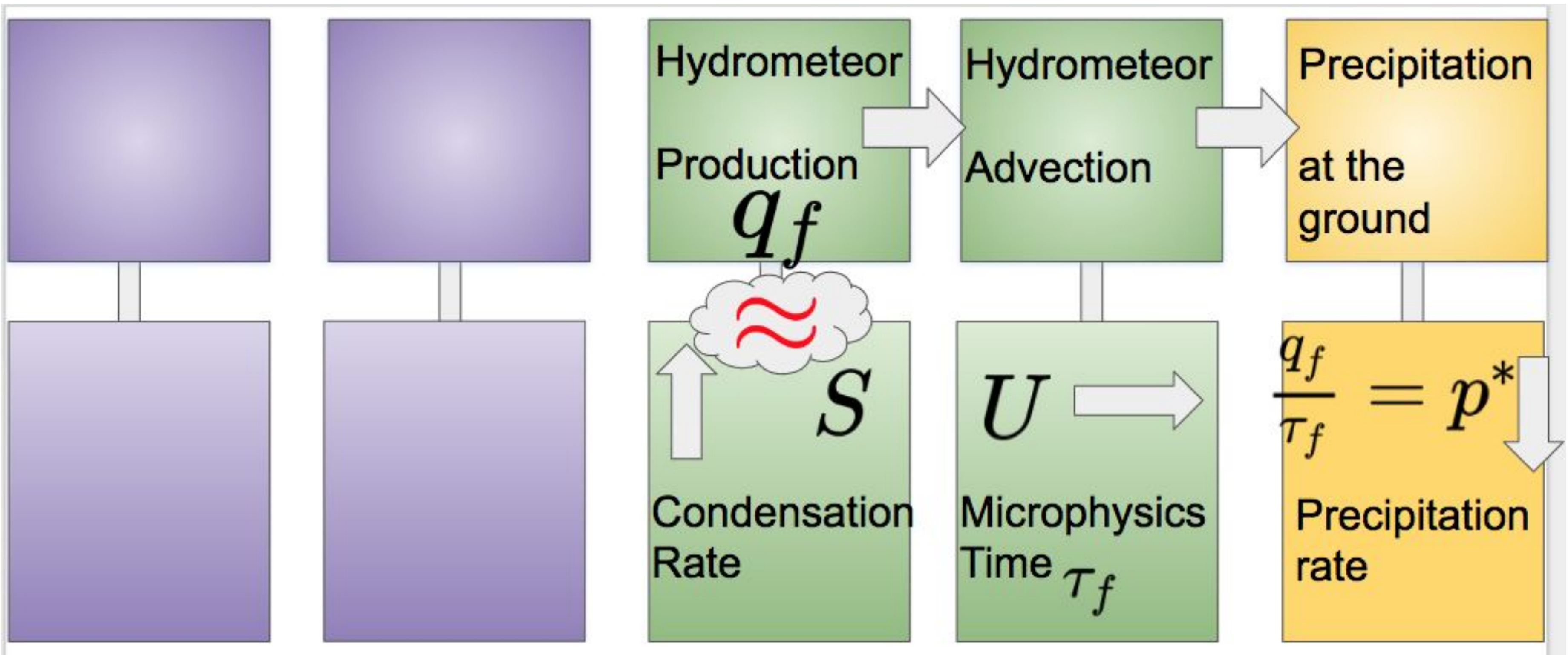


Local Scale Orographic Processes: The Governing Equation

Reducing *up-slope-time-delay model* of Smith,2003

One **lumped category** of condensed water (column integrated):

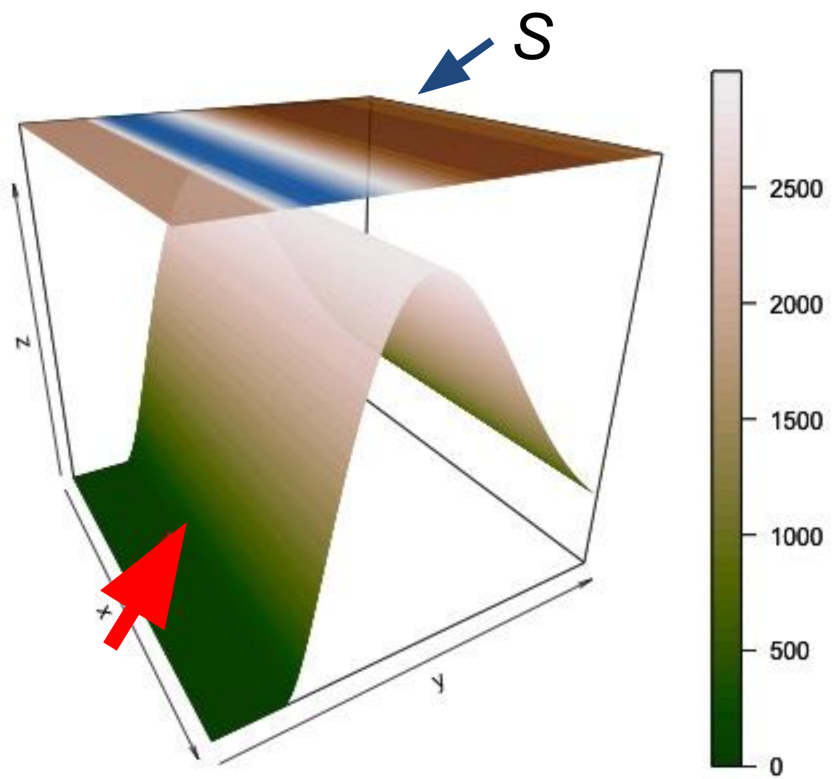
- q_f **Hydrometeor (density)**



Local Scale Orographic Processes: Potential Precipitation Rate

Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s



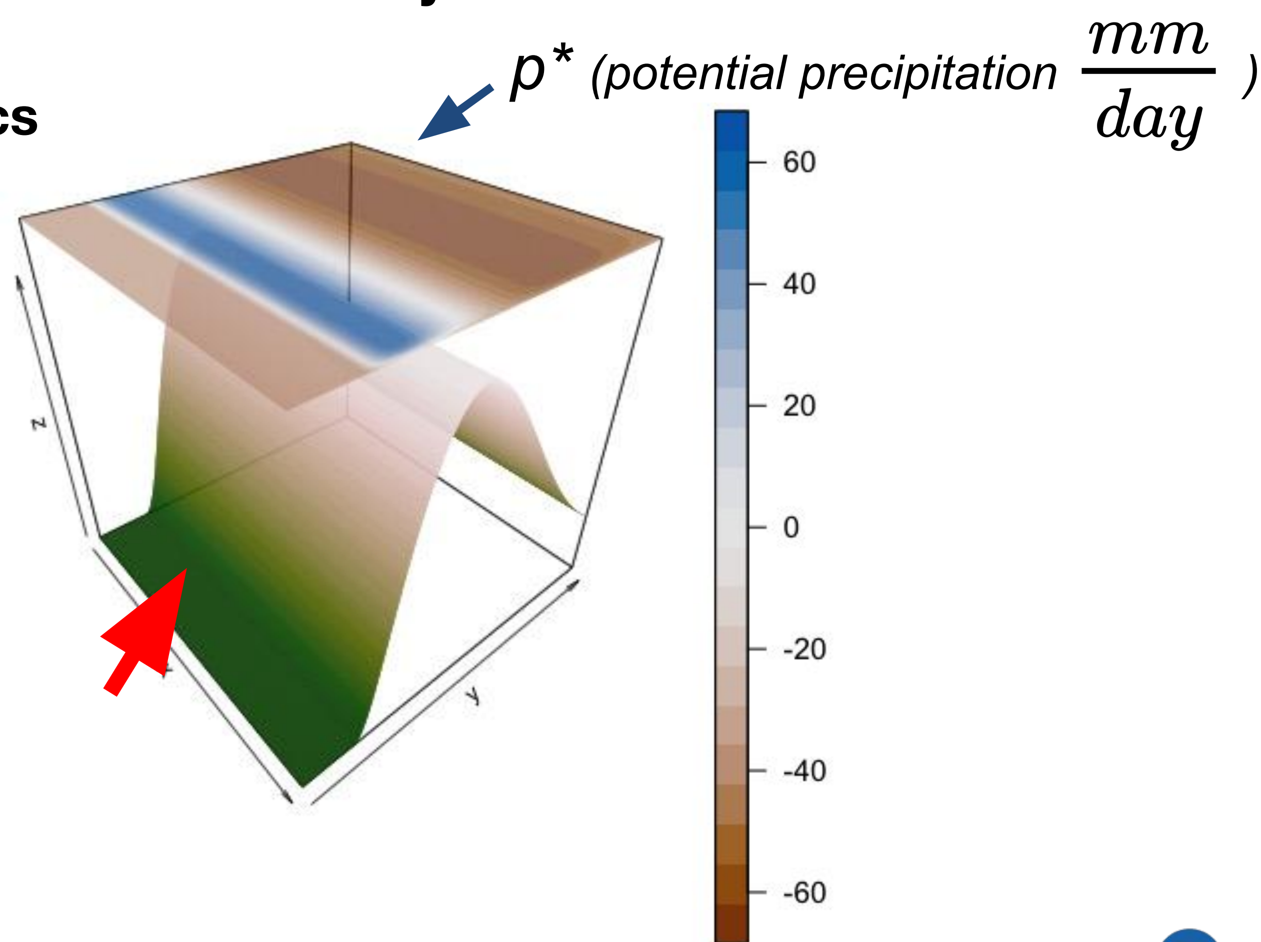
Local Scale Orographic Processes: Potential Precipitation Rate

Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s

- **Time microphysics parameter:**

$$\tau_f = 1000s$$



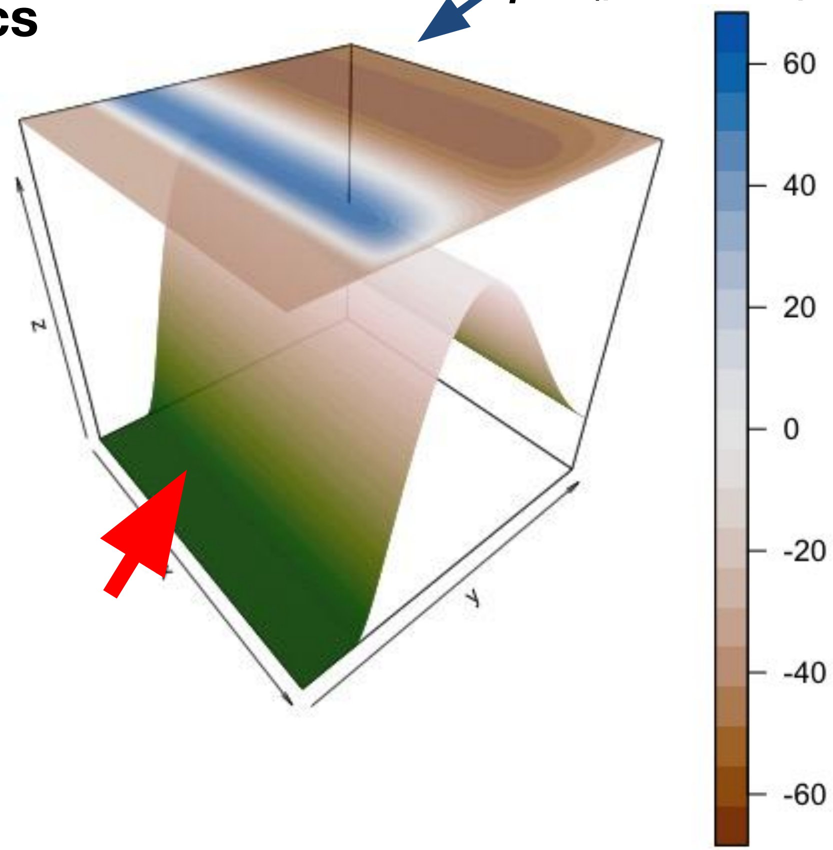
Local Scale Orographic Processes: Potential Precipitation Rate

Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s
- **Time microphysics parameter:**

$$\tau_f = \mathbf{5000}\mathrm{s}$$

p^* *(potential precipitation* $\frac{mm}{day}$ *)*



Local Scale Orographic Processes: Potential Precipitation Rate

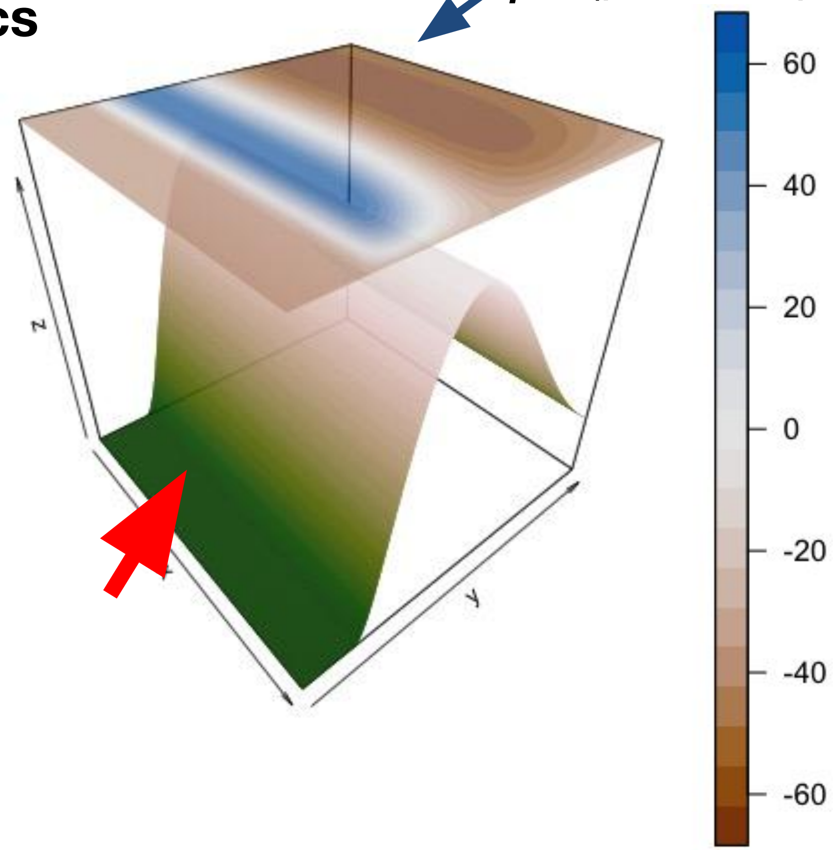
Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s

- **Time microphysics parameter:**

$\tau_f = \mathbf{10000}\mathrm{s}$

p^* *(potential precipitation* $\frac{mm}{day}$ *)*



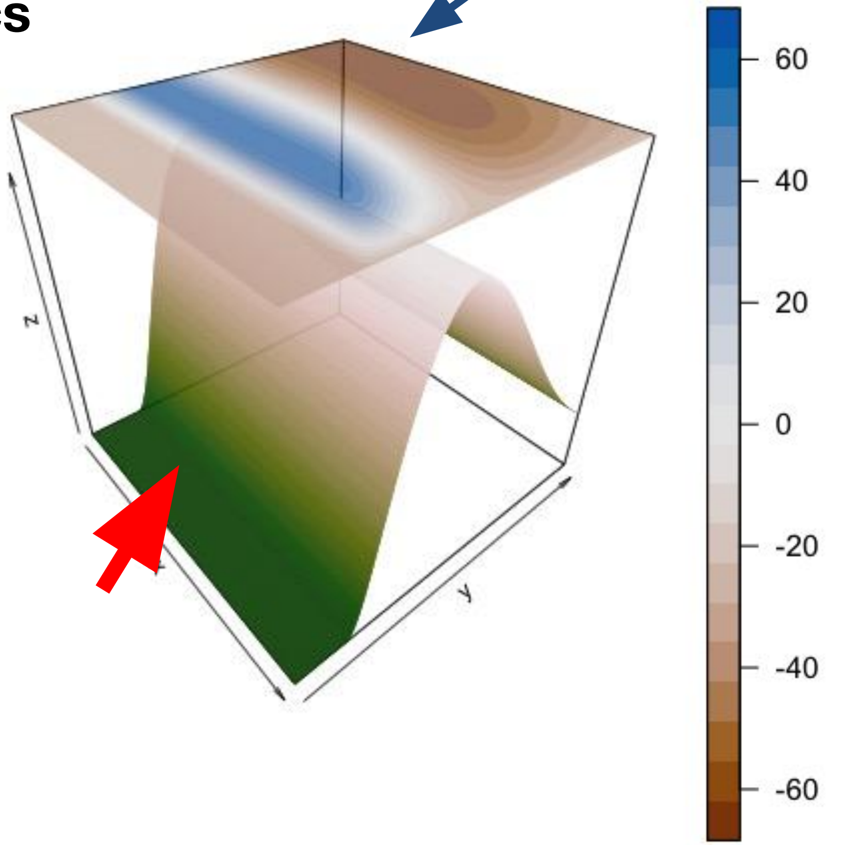
Local Scale Orographic Processes: Potential Precipitation Rate

Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s
- **Time microphysics parameter:**

$$\tau_f = \mathbf{20000}\text{s}$$

p^* *(potential precipitation* $\frac{mm}{day}$ *)*



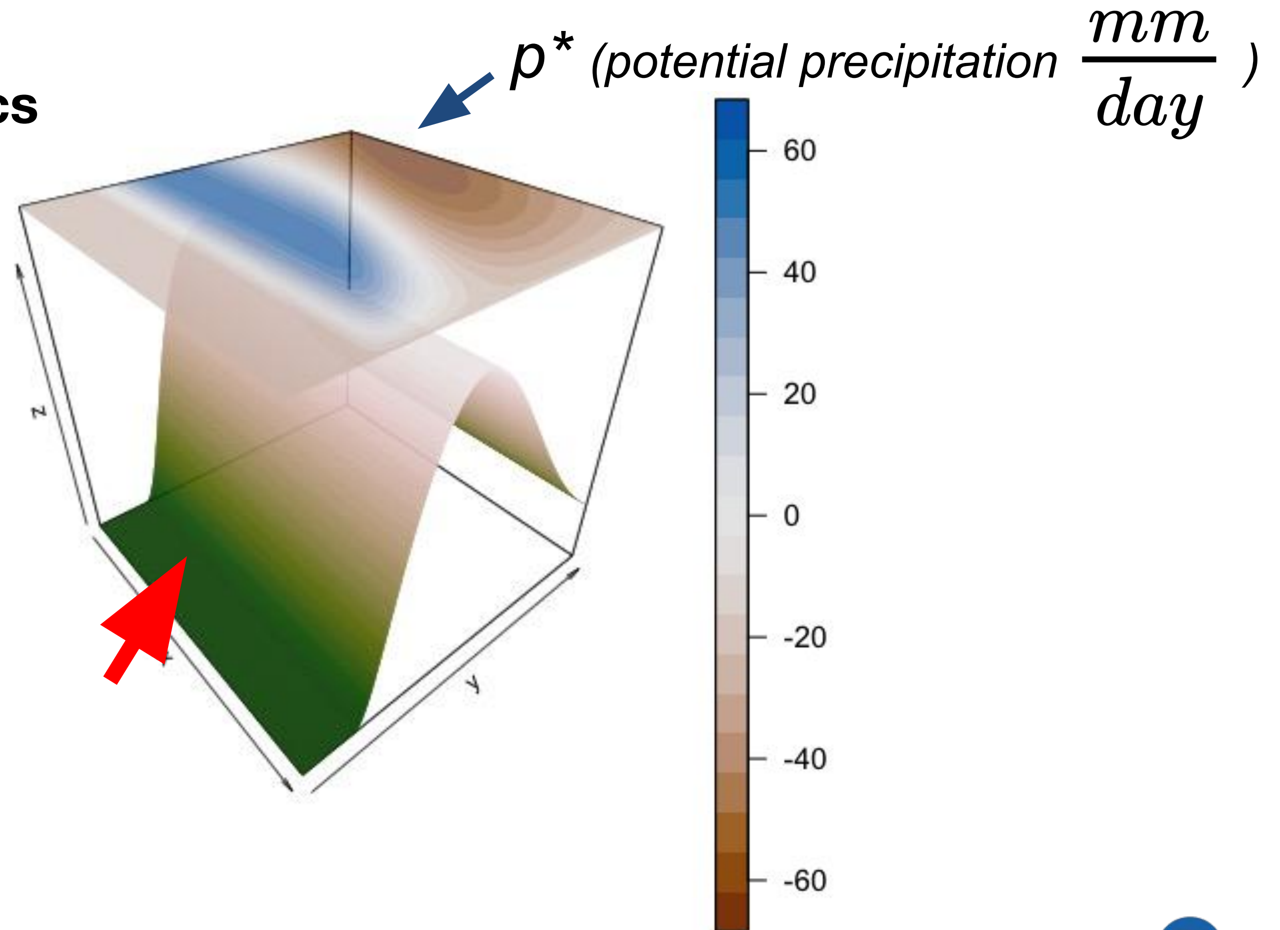
Local Scale Orographic Processes: Potential Precipitation Rate

Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s

- **Time microphysics parameter:**

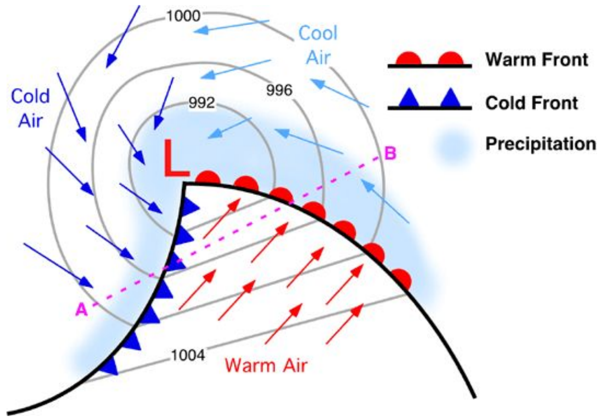
$\tau_f = \mathbf{50000}\text{s}$



Precipitation due to large scale processes:

Majority of precipitation observed in the mid-latitudes attributable to

- **Frontal Systems**
- **Convective Clouds**

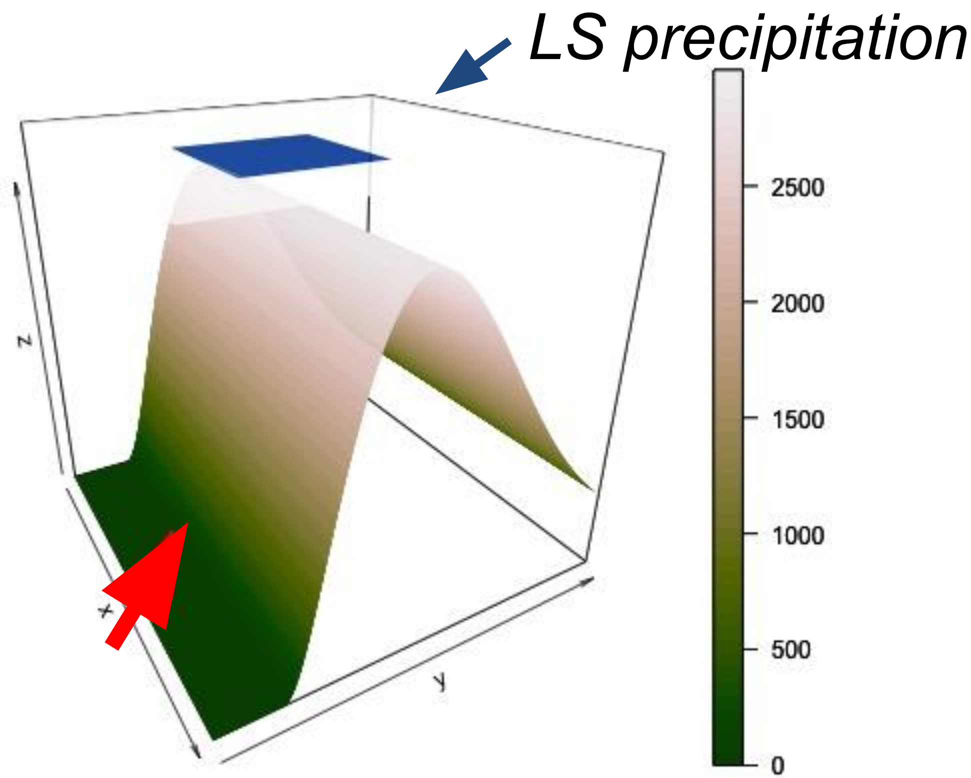


They originate due to mechanisms most often not related to topography.

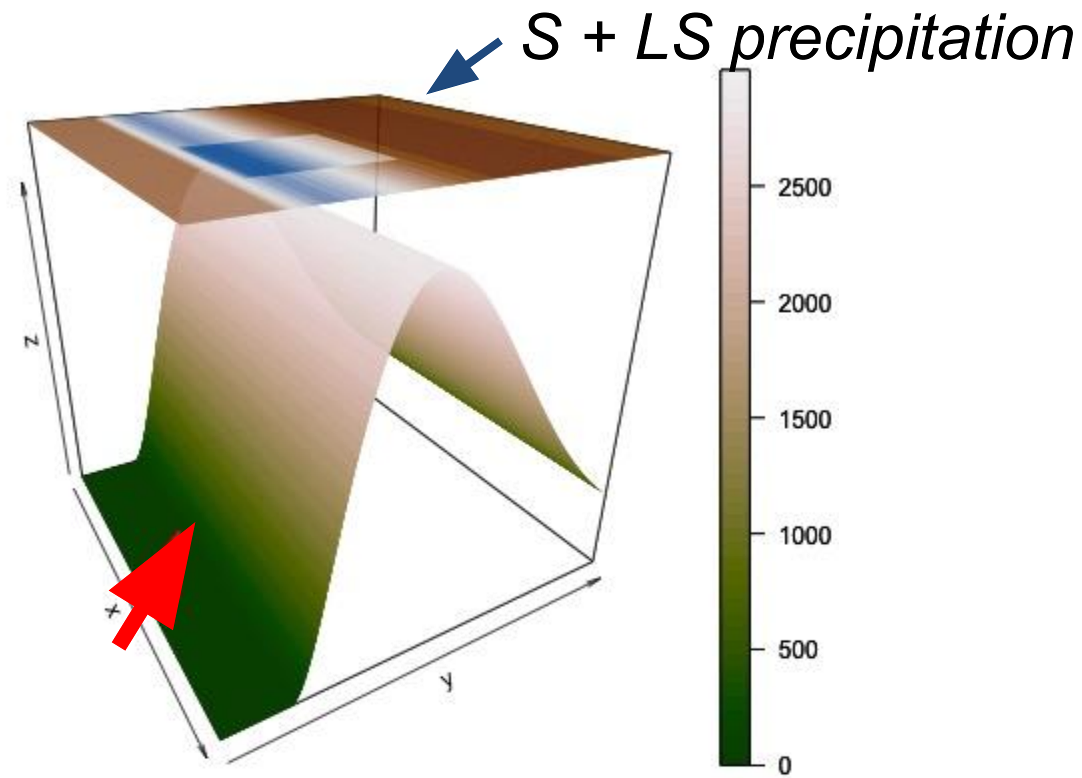
Topography alters their features.

Precipitation due to large scale processes:

Idealized box representing large-scale precipitation over the peak



Precipitation due to large scale processes:



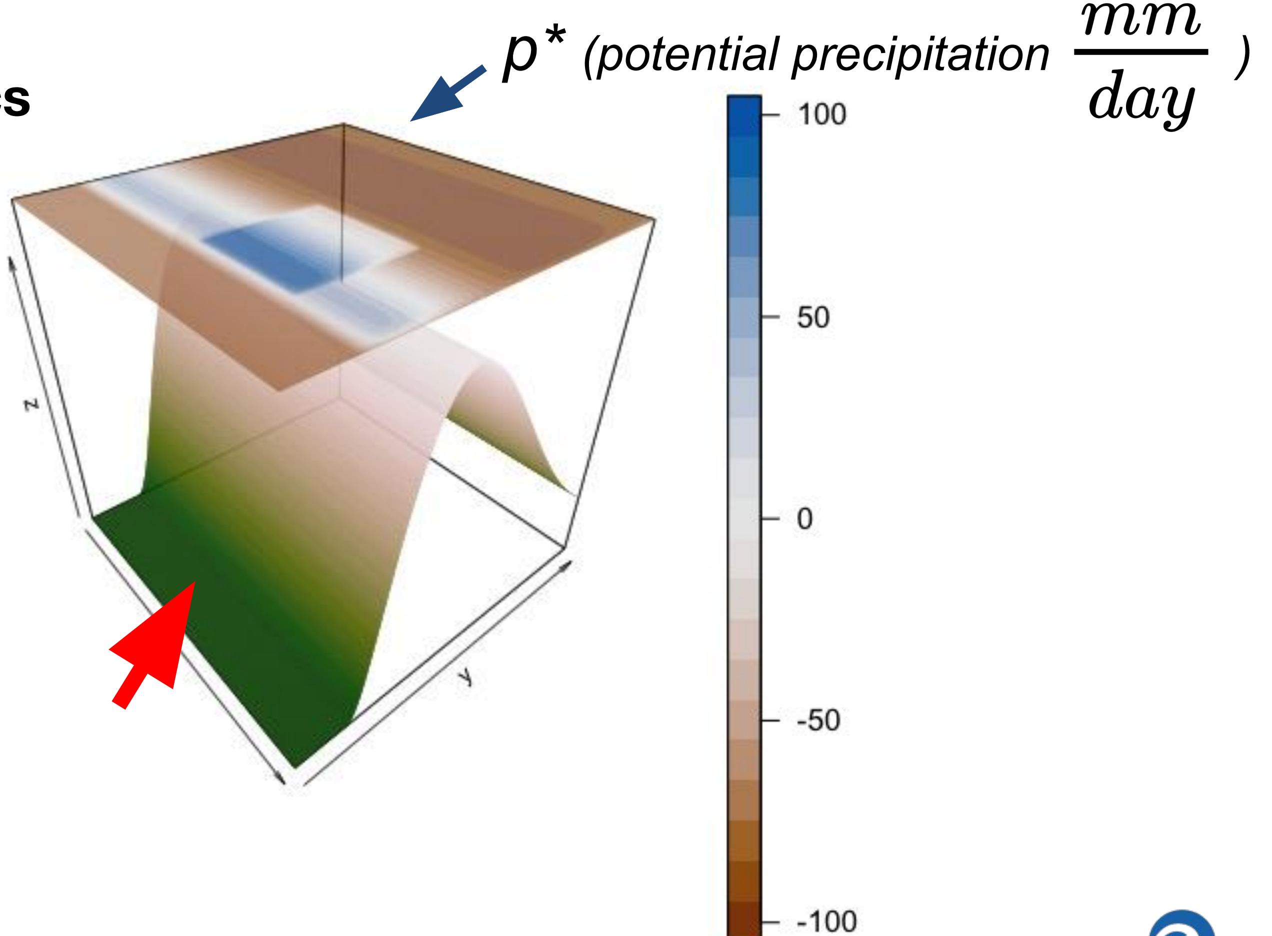
Precipitation due to large scale processes:

Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s

- **Time microphysics parameter:**

$$\tau_f = 1000s$$



Precipitation due to large scale processes:

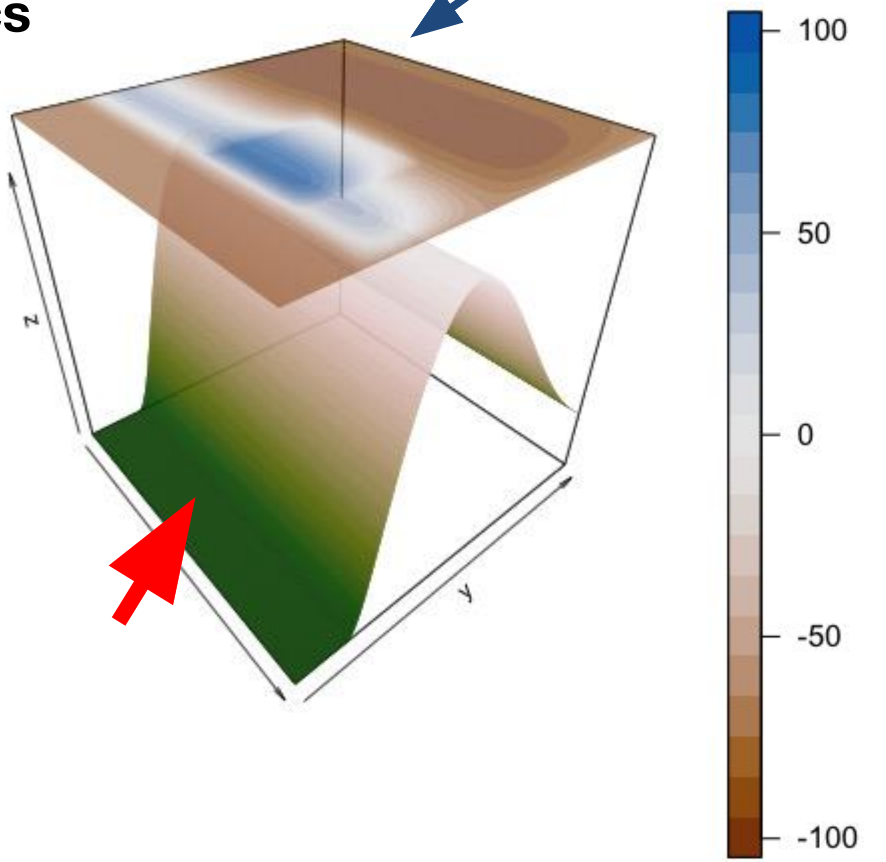
Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s

- **Time microphysics parameter:**

$\tau_f = \mathbf{5000}$s

p^* *(potential precipitation* $\frac{mm}{day}$ *)*



Precipitation due to large scale processes:

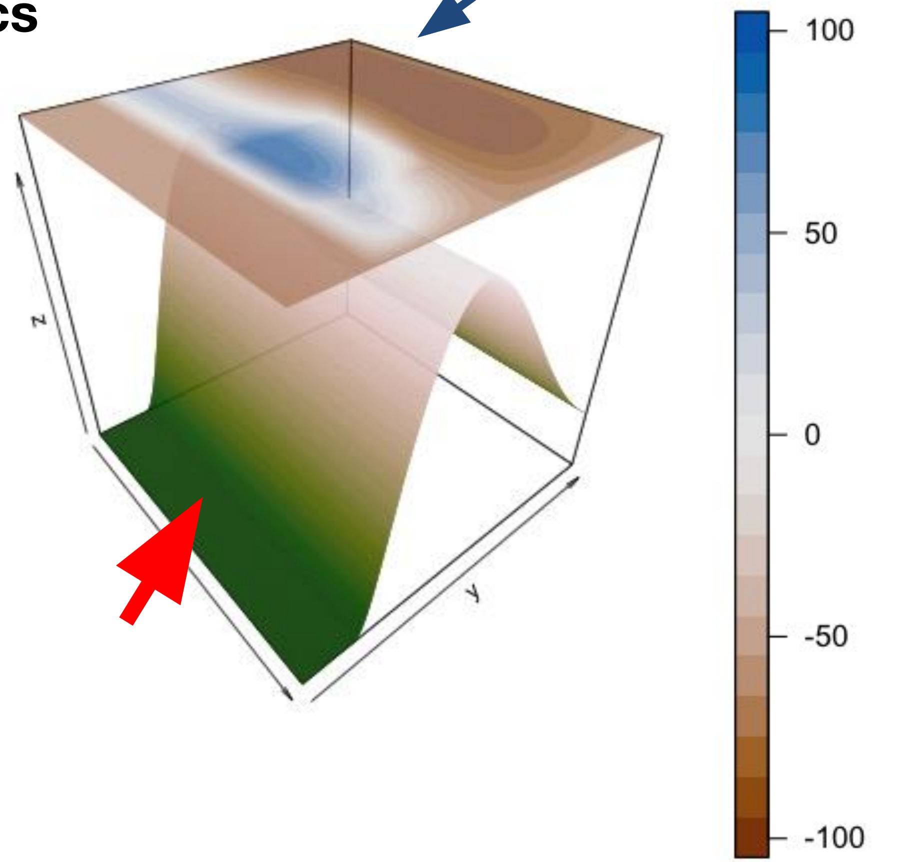
Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s

- **Time microphysics parameter:**

$\tau_f = 10000$s

p^* *(potential precipitation* $\frac{mm}{day}$ *)*



Precipitation due to large scale processes:

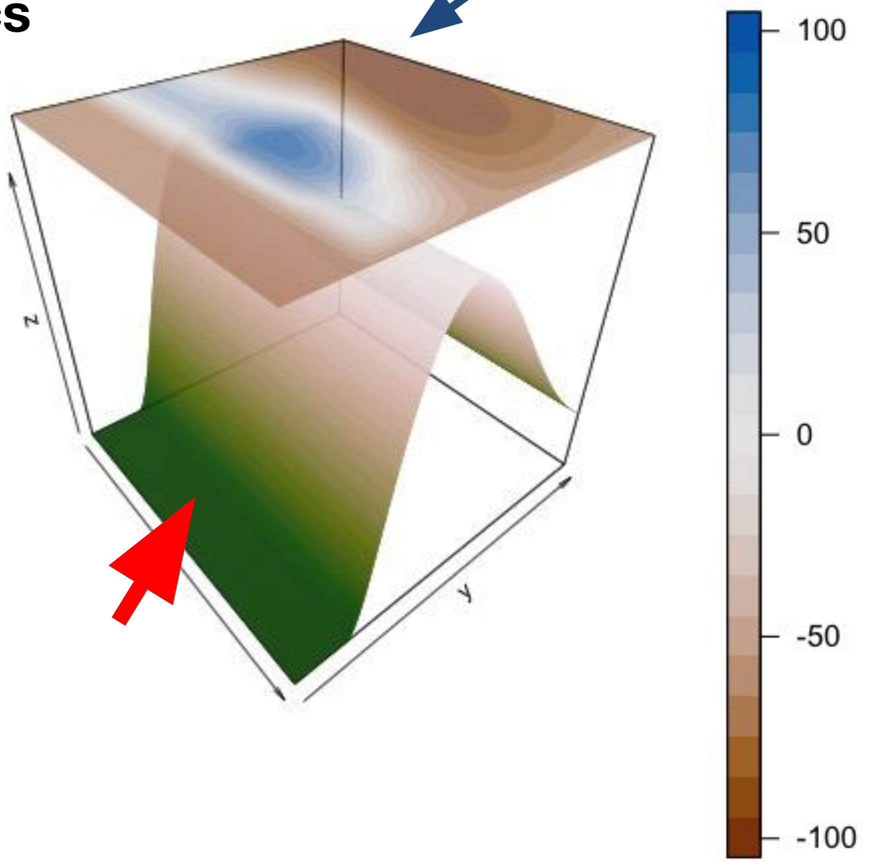
Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s

- **Time microphysics parameter:**

$$\tau_f = \mathbf{2000}\mathbf{0}\text{s}$$

p^* *(potential precipitation* $\frac{mm}{day}$ *)*



Precipitation due to large scale processes:

Environmental Conditions:

- **Impinging Horizontal Wind Velocity** : 15 m/s
- **Time microphysics parameter:**

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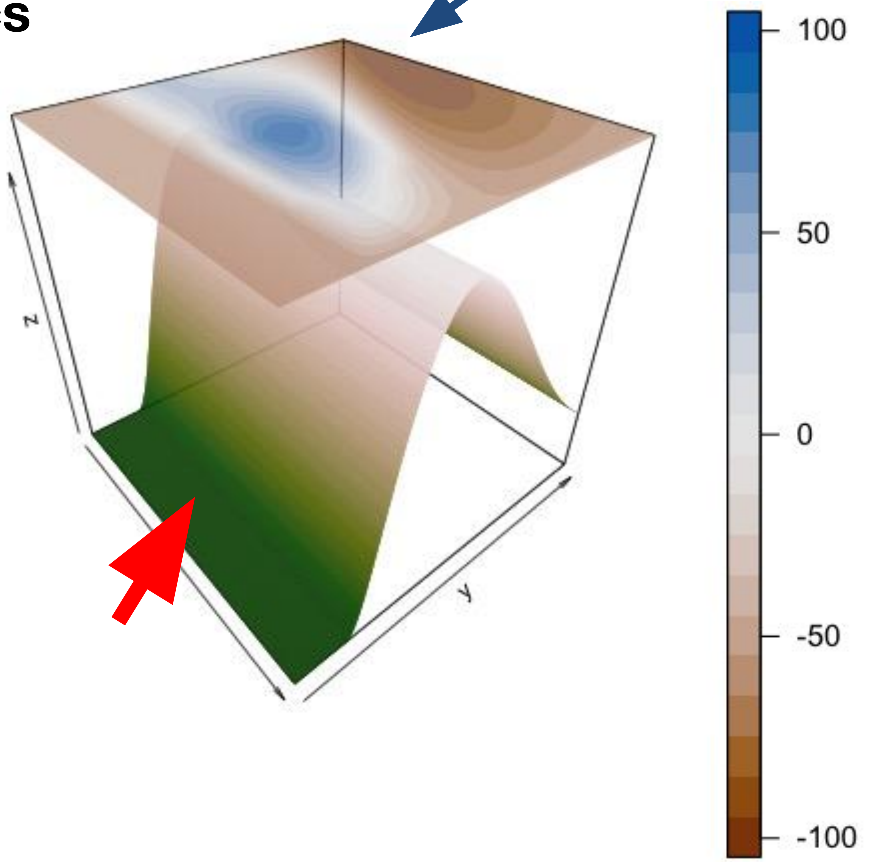
p^* *(potential precipitation* $\frac{mm}{day}$ *)*



Definition of a **Statistical Framework** for inferring the spatial distribution and intensity of precipitation over mountainous regions

- **Describes the variations in space of precipitation fields**

- **Combines information from both**
    - **precipitation data**
    - description of physical processes causing orographic precipitation

- **Improves numerical climate models usability (downscaling)**

Building a Statistical Framework

We build a statistical model that describes how ***p**** varies in space

Analogy with differential/difference equations

$$p^*(x,y) \quad = \quad \underbrace{S + LSP}_{\text{Sources}} \quad + \quad p^* \text{ (upwind)}$$

Building a Statistical Framework

We build a statistical model that describes how ***p**** varies in space

Analogy with differential/difference equations

$p^*(x,y)$ = Sources $S + LSP$ + p^* (upwind)

$$p^*(x,y) = S(x,y) + LSP(x,y)$$

Building a Statistical Framework

We build a statistical model that describes how ***p**** varies in space

Analogy with differential/difference equations

$p^*(x,y)$	=	Sources $S + LSP$	+	p^* (upwind)

$$p^*(x,y) = \lambda_1 S(x,y) + \lambda_2 LSP(x,y)$$

Building a Statistical Framework

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Building a Statistical Framework

We build a statistical model that describes how ***p**** varies in space

Analogy with differential/difference equations

$$p^*(x,y) = \text{Sources } S + LSP + p^*\text{(upwind)}$$

$$p^*(x,y) = \lambda_1 S(x,y) + \lambda_2 LSP(x,y) + W^{\triangle} p^*(\text{upwind})$$

Building a Statistical Framework

We build a statistical model that describes how ***p**** varies in space

Analogy with differential/difference equations

$$p^*(x,y) = S + LSP + p^*\,(\text{upwind})$$

Sources

$$p^*\,(x,y) = \lambda_1 S(x,y) + \lambda_2 LSP(x,y) + W^{\triangle}\,p^*(\text{upwind})$$

$$-\quad p^*(x,y;\ \text{passed downwind})$$

Building a Statistical Framework

We build a statistical model that describes how ***p**** varies in space

Analogy with differential/difference equations

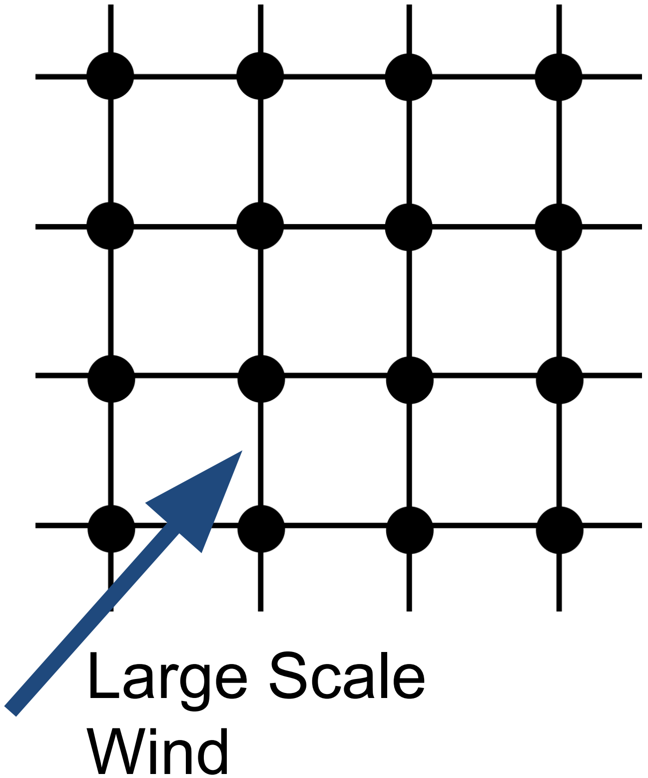
$p^*(x,y)$	=	Sources $S + LSP$	+	p^* (upwind)

$$p^*(x,y) = \lambda_1 S(x,y) + \lambda_2 LSP(x,y) + W^{\triangle} p^*(\text{upwind})$$

$$- W^{\star} p^*(x,y;\ \text{passed downwind})$$

Autoregression: a closer look to W

Grid:



Autoregression: a closer look to W

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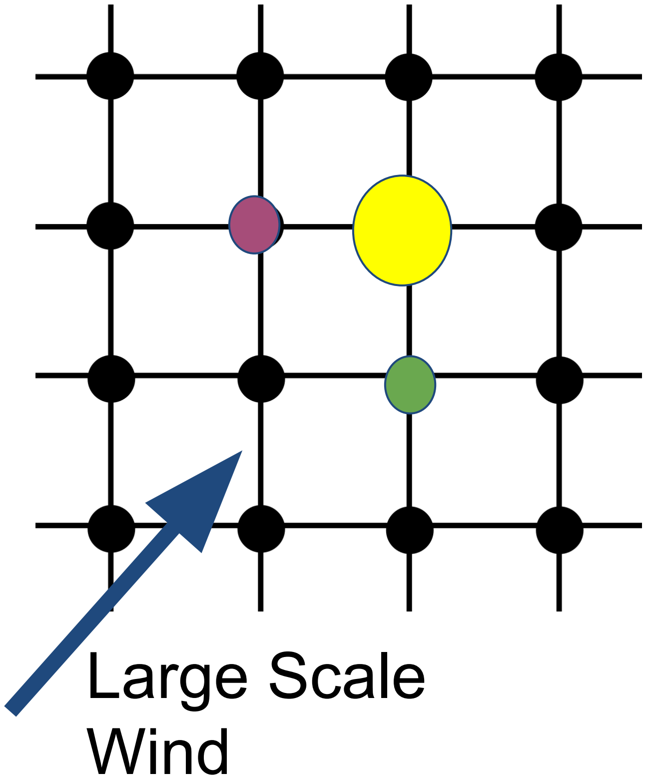

Autoregression: a closer look to W

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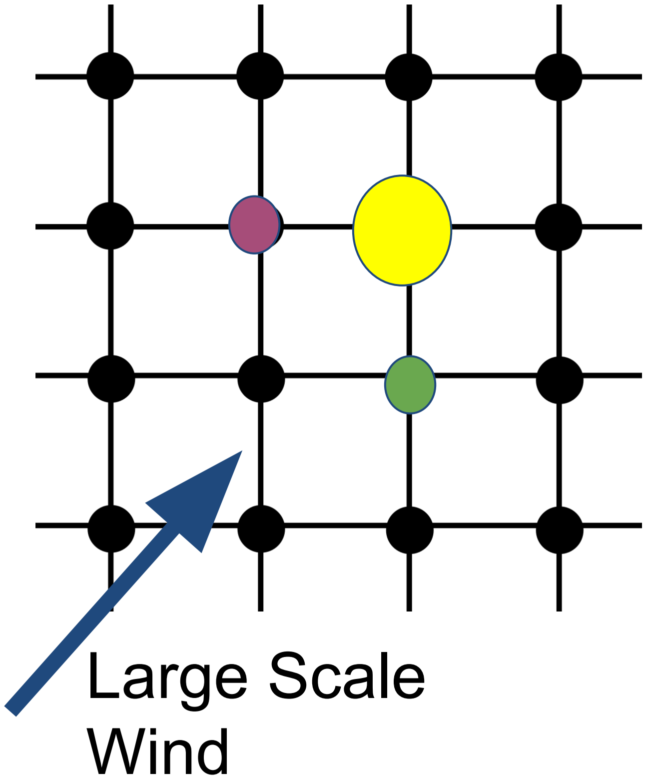
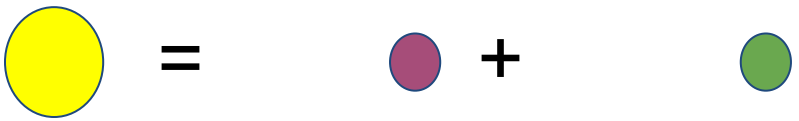
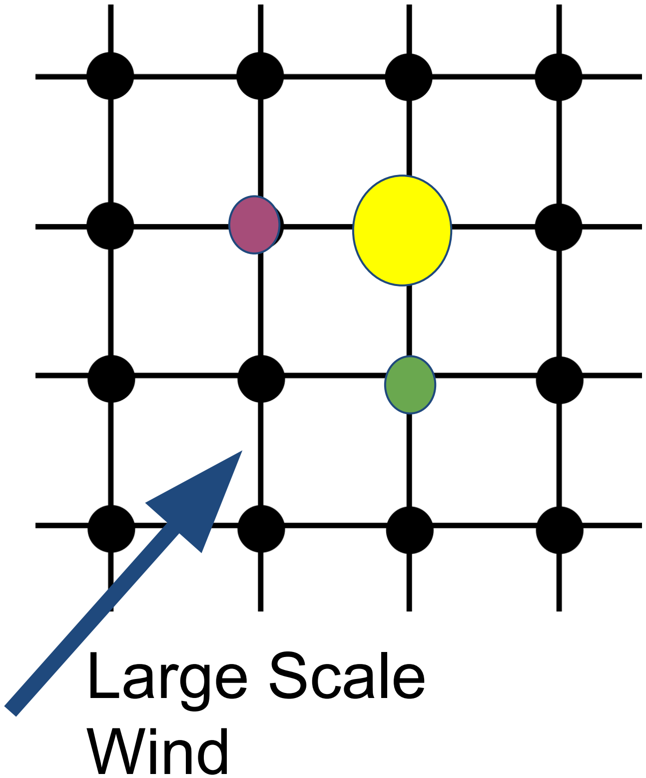




Autoregression: a closer look to W

Grid:

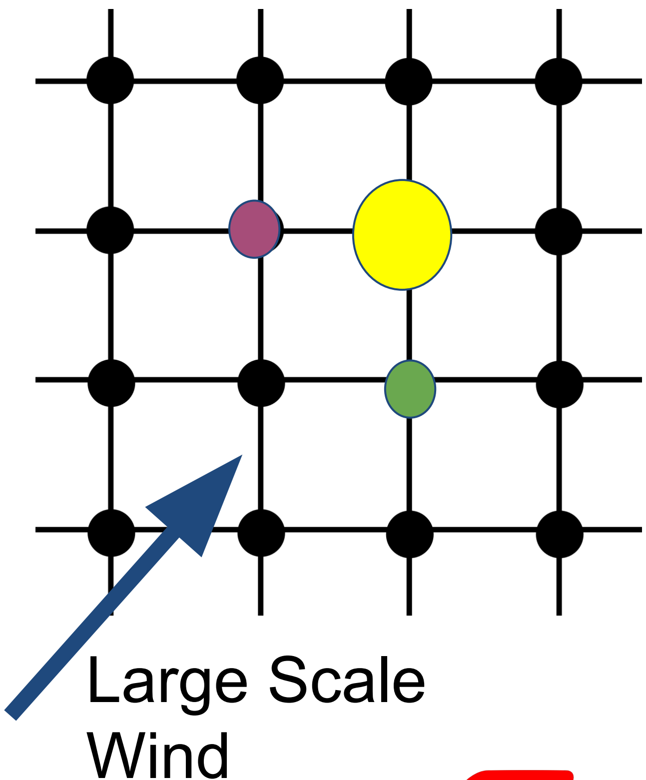


$$= \frac{u\tau_f}{\Delta_x} + \frac{v\tau_f}{\Delta_y}$$

$$\frac{u\tau_f}{\Delta_x} = \frac{Distance\ \ Advected}{Grid\ \ Spacing}$$

Autoregression: a closer look to W

Grid:



$$= \frac{u\tau_f}{\Delta_x} \quad + \quad \frac{v\tau_f}{\Delta_y}$$

$$\frac{u\tau_f}{\Delta_x} = \frac{Distance\ \ Advected}{Grid\ \ Spacing}$$

Analogous of Autoregressive Parameters

τ_f Unknown

Model Summary

$$p^*(x,y) = \lambda_1 S(x,y) + \lambda_2 LSP(x,y)$$

$$+\frac{u\tau}{\Delta x}p^*(x-\Delta x;y) + \frac{v\tau}{\Delta y}p^*(x;y-\Delta y)$$

$$+\left[-\frac{u\tau}{\Delta x} - \frac{v\tau}{\Delta y}\right]p^*(x,y)$$

$$+\eta(x,y)$$

$\lambda_1, \lambda_2, \tau$:Estimated from observed precipitation data

Model Summary

$$p^*(x,y) = \lambda_1 S(x,y) + \lambda_2 LSP(x,y)$$

$$+ \frac{u\tau}{\Delta x} p^*(x - \Delta x; y) + \frac{v\tau}{\Delta y} p^*(x; y - \Delta y)$$

$$+ \left[- \frac{u\tau}{\Delta x} - \frac{v\tau}{\Delta y} \right] p^*(x,y)$$

$$+\eta(x,y)$$

Stochastic Noise

$\lambda_1, \lambda_2, \tau$:Estimated from observed precipitation data

Model Summary

$$p^*(x,y) = \lambda_1 S(x,y) + \lambda_2 LSP(x,y)$$

Simultaneous Autoregressive Model

(SAR model)

$\lambda_1, \lambda_2,$:Estimated from observed precipitation data

Some key points

- **Orographic Processes from the Linear Theory of Orographic Precipitation;**

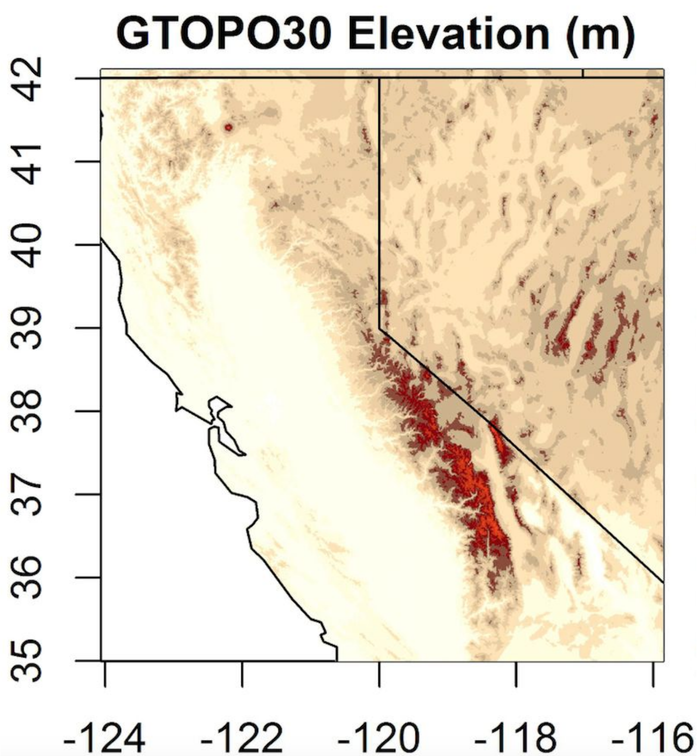
- **Atmospheric fields (U, Humidity, ...) from reanalysis: nesting and sub-grid refinement**

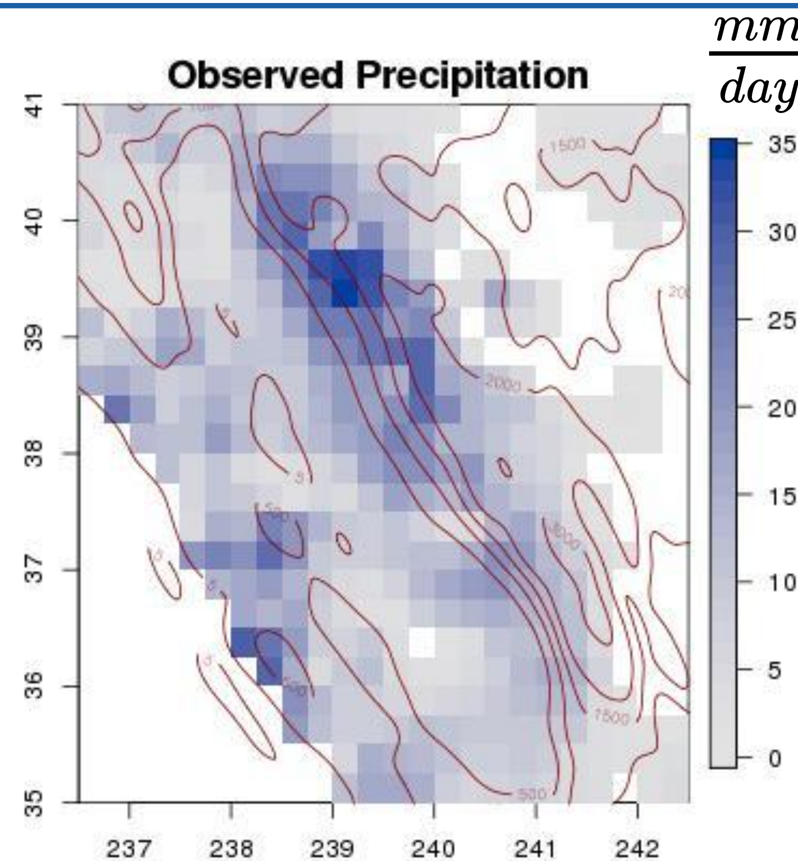
    - process-informed
    - spatially-consistent
    - adjustment from data

- **Gridded observational dataset needed**

Case Study: Winter Storms in California

Domain and Data





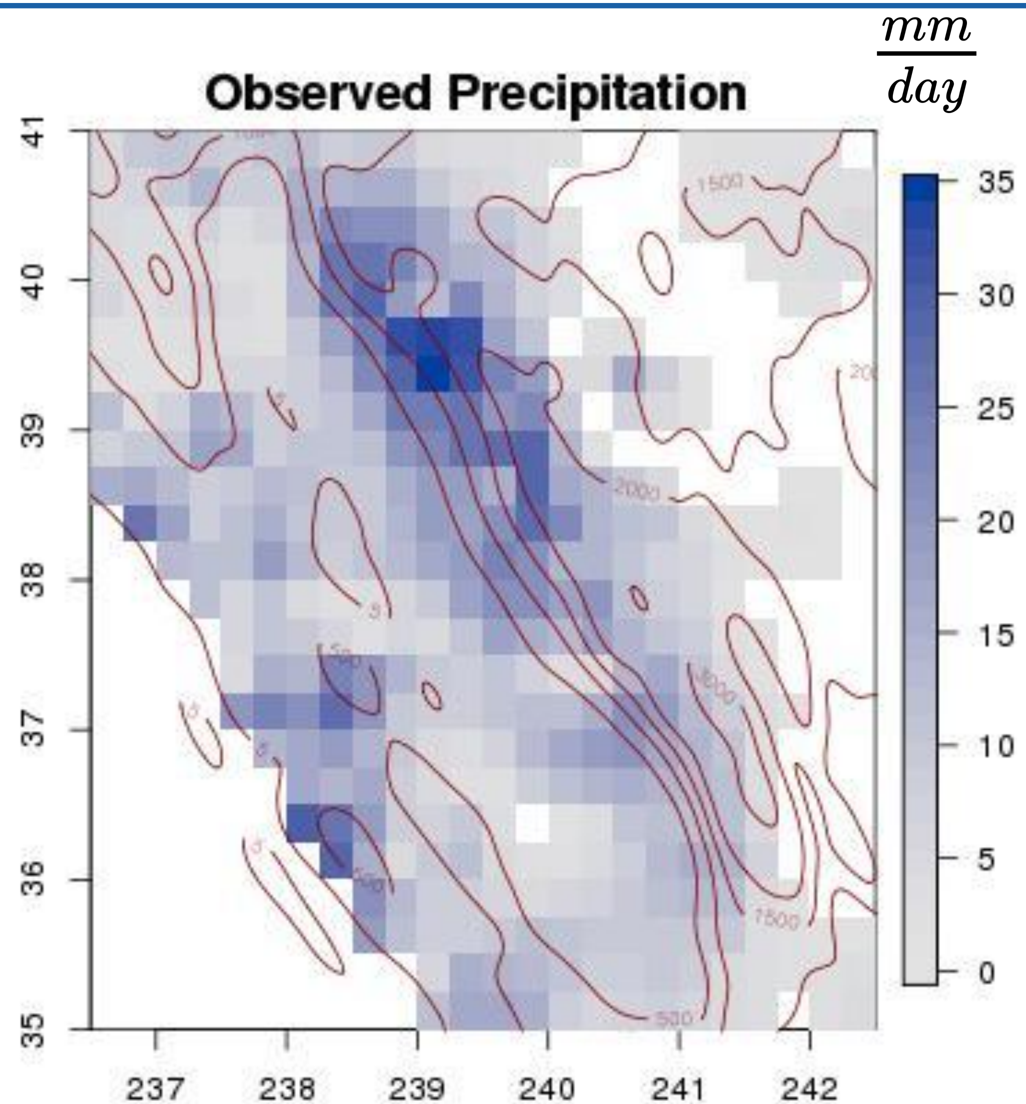
CPC US (NOAA/OAR/ESRL PSD)
.25 x .25 deg Regular Grid

Wind, Temperature, humidity, LS Prec:
ERA-Interim reanalysis

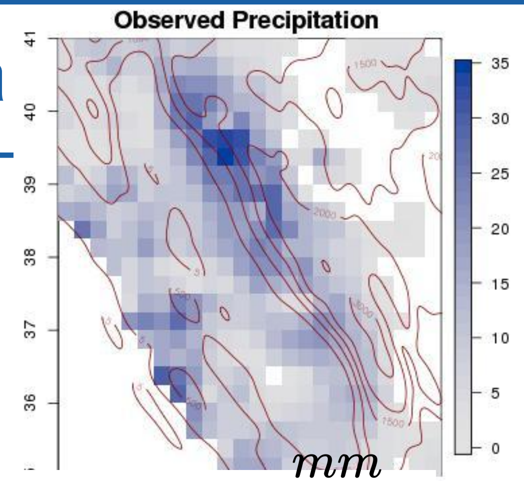
Winter Storm in Central California

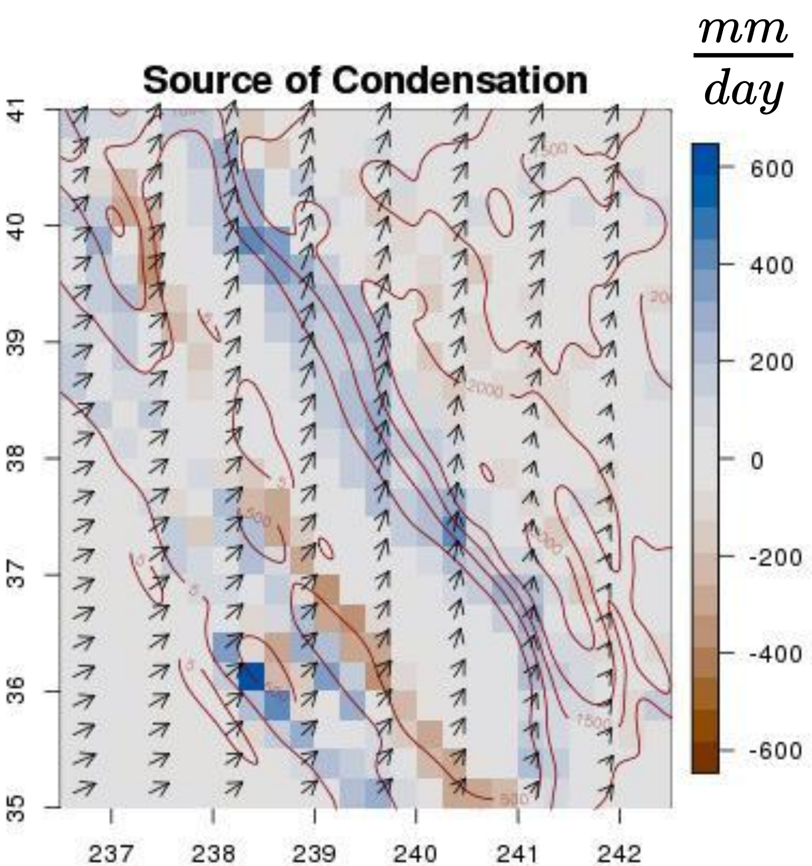
4 February 1990

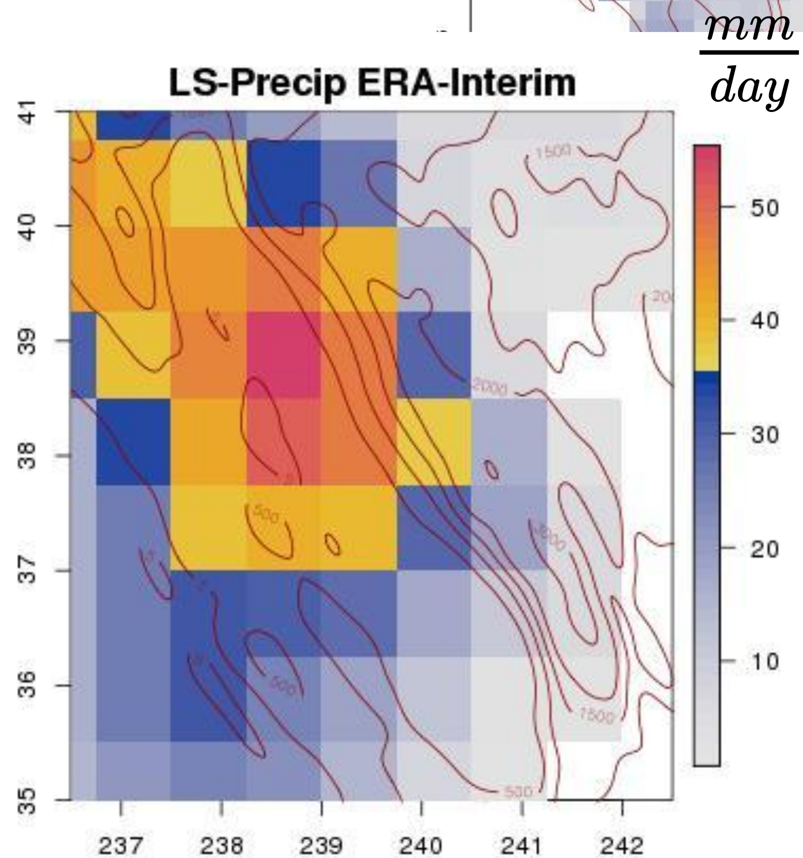
- **Typical Orographic Effect**
- **Medium Intensity Storm**



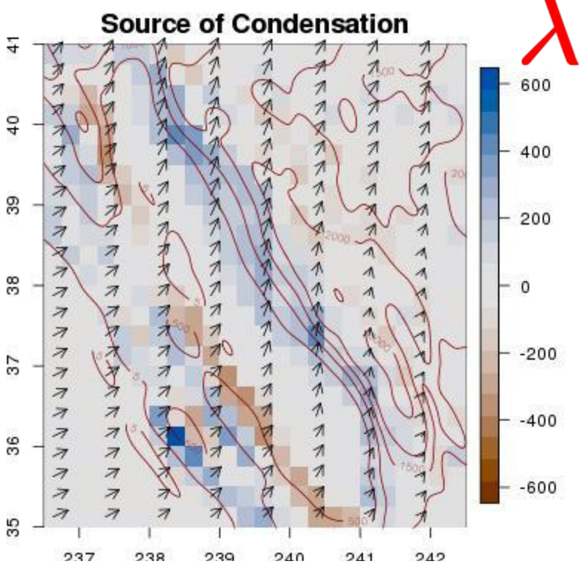
Winter Storm in Central California



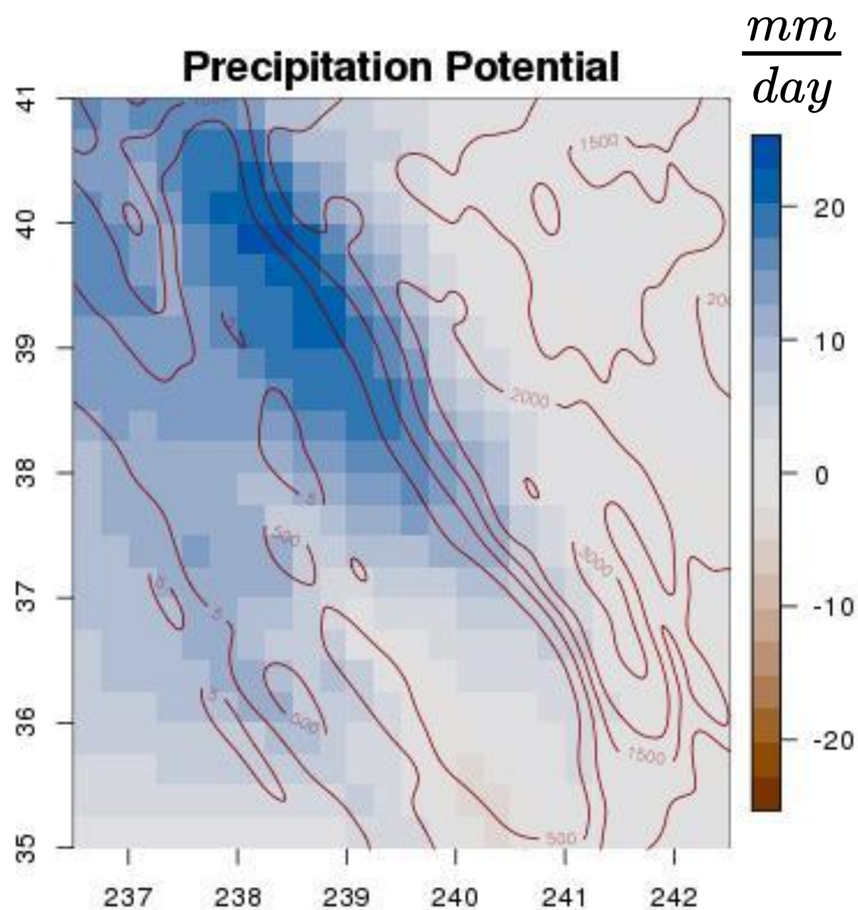


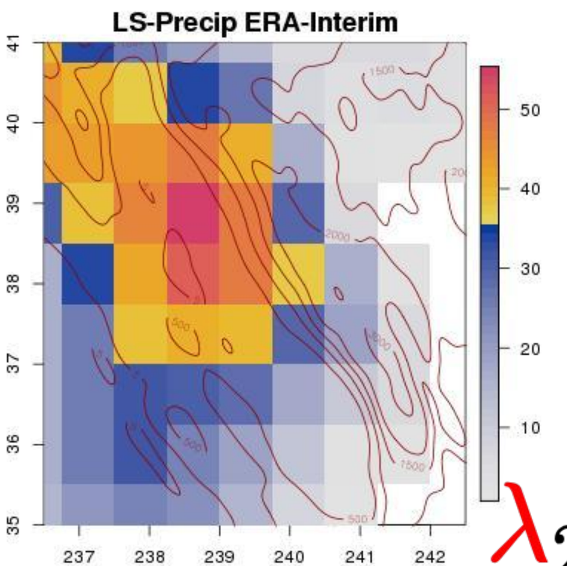


Winter Storm in Central California



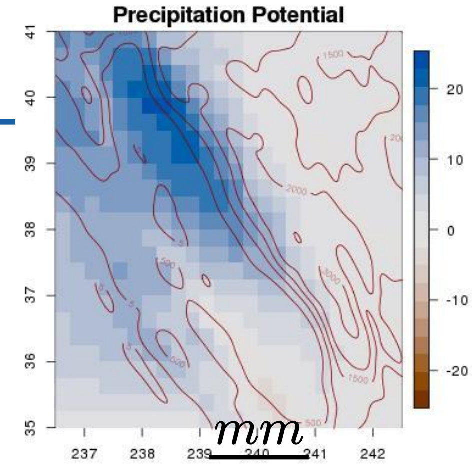
$$\lambda_1 S, (\lambda_1 = 0.052)$$

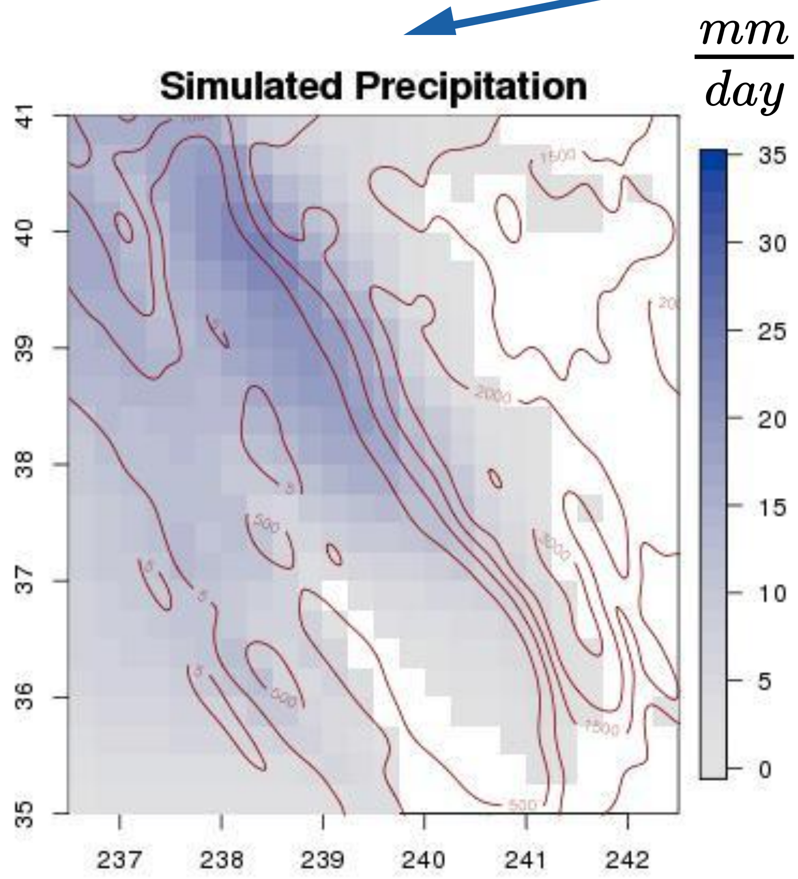


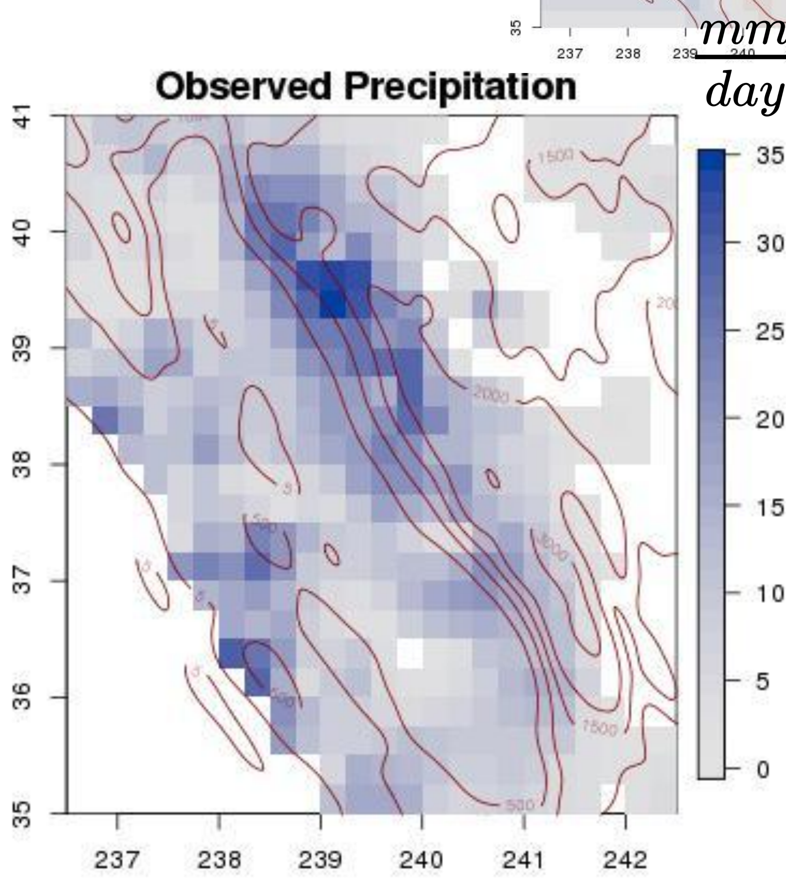


$$\lambda_2 LSP, (\lambda_2 = 0.34)$$

Winter Storm in Central California

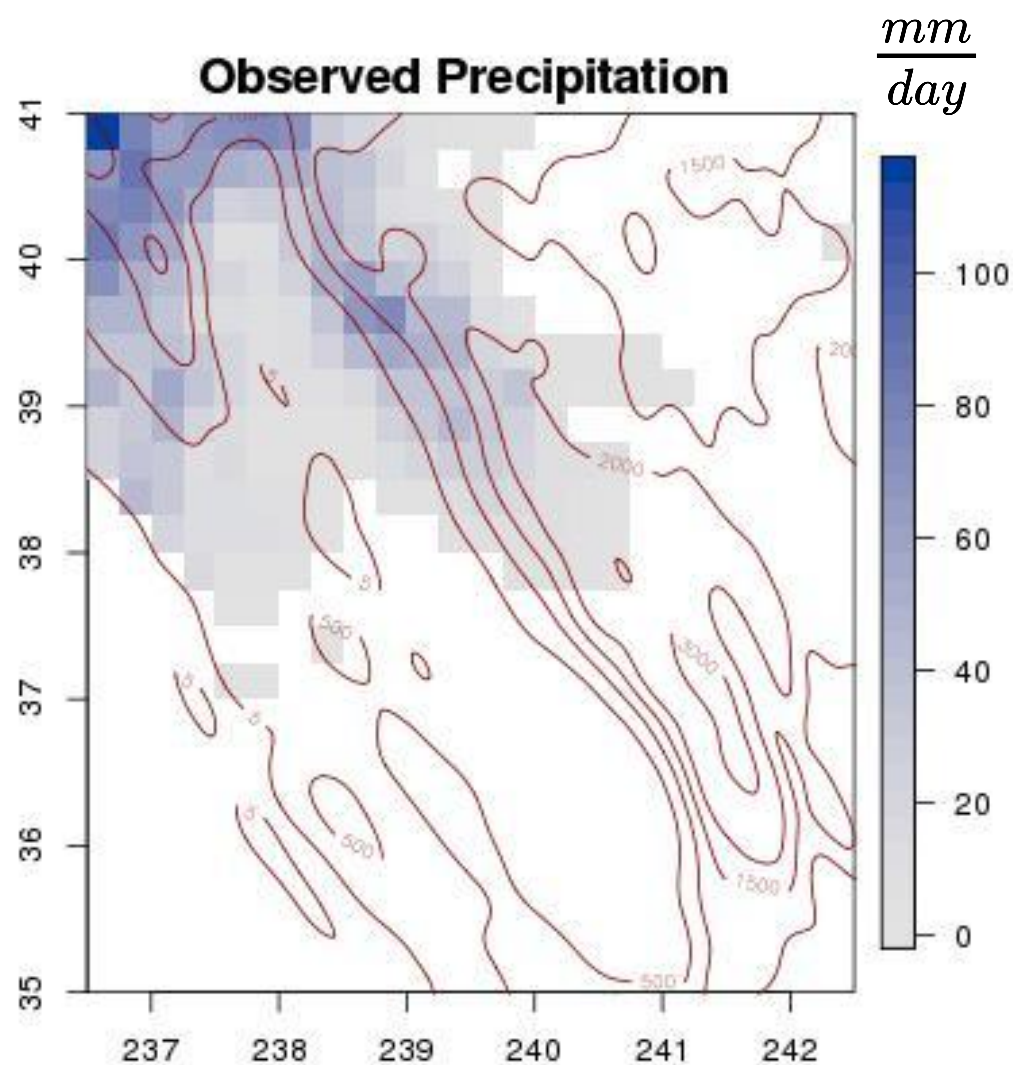




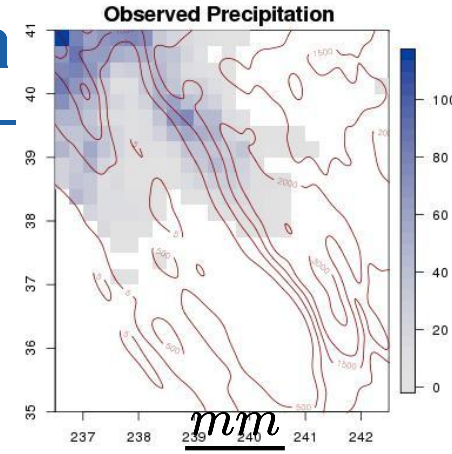


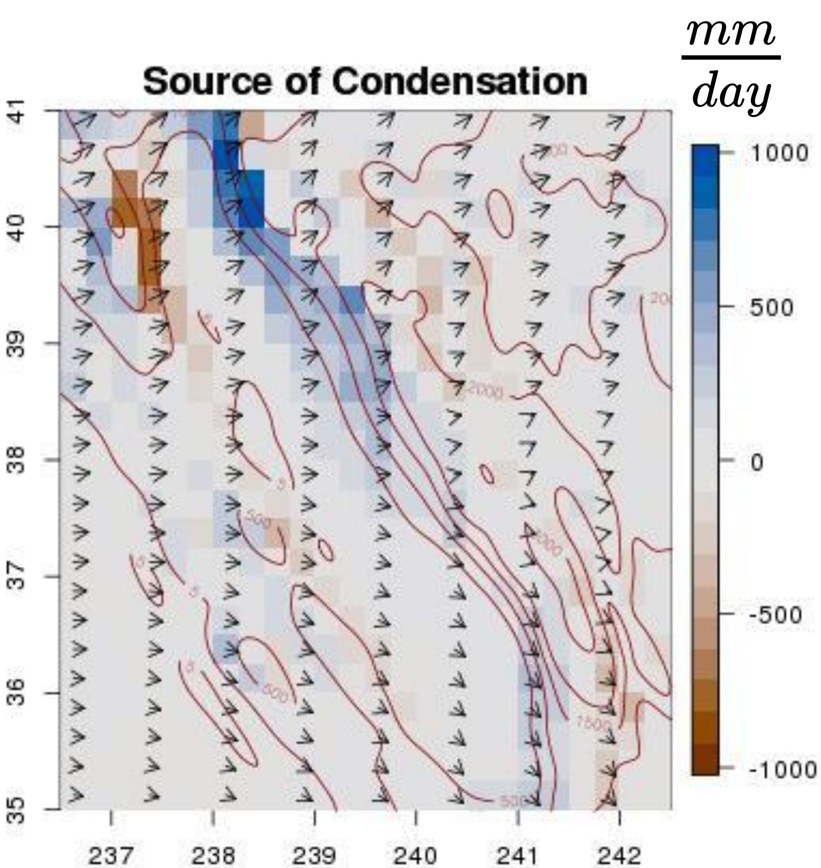
Winter Storm in Northern California

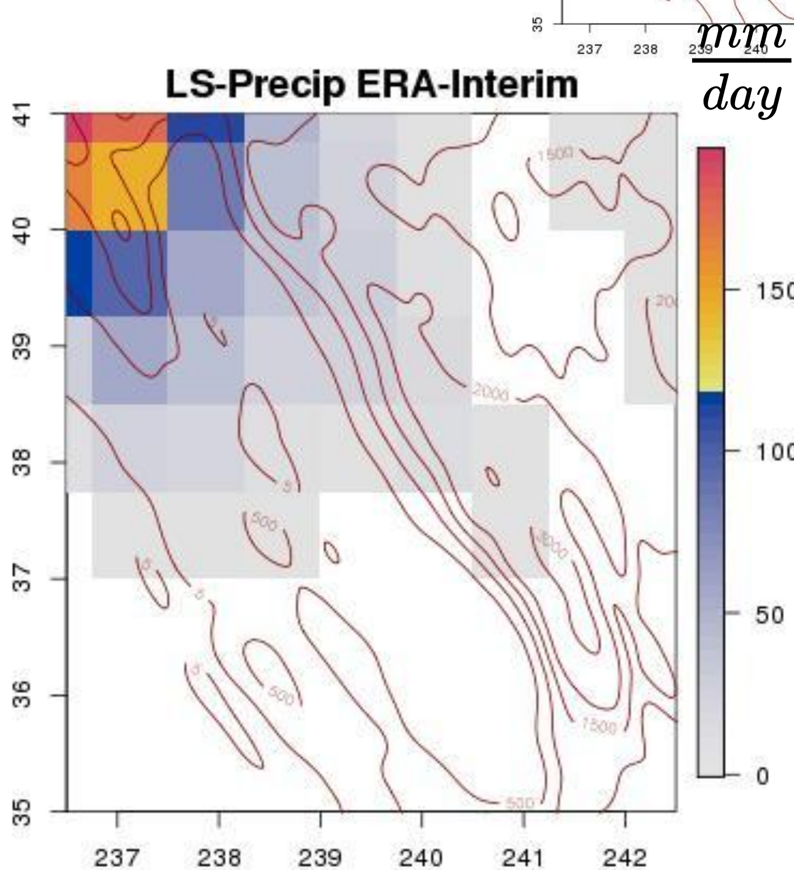
8 January 1990



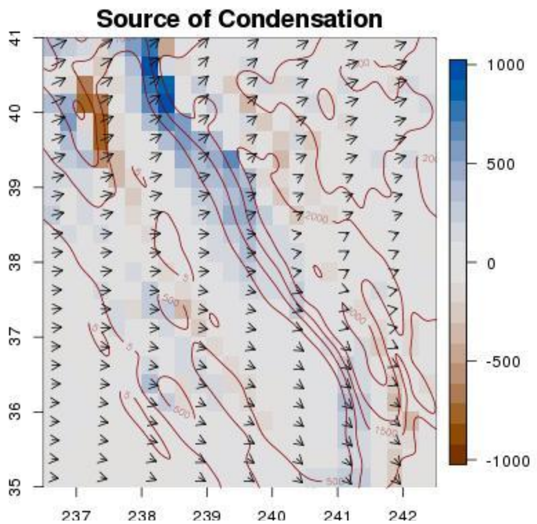
Winter Storm in Northern California



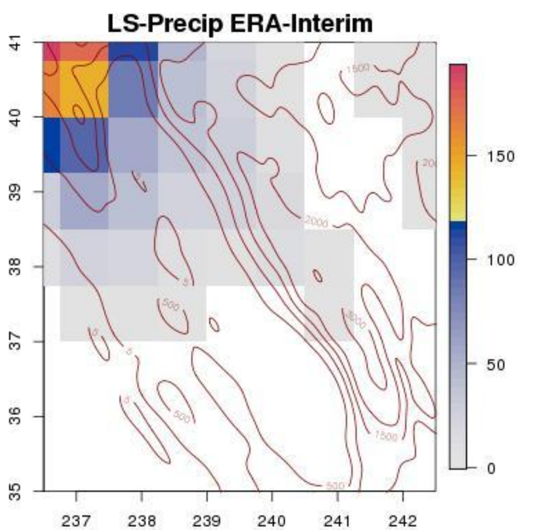


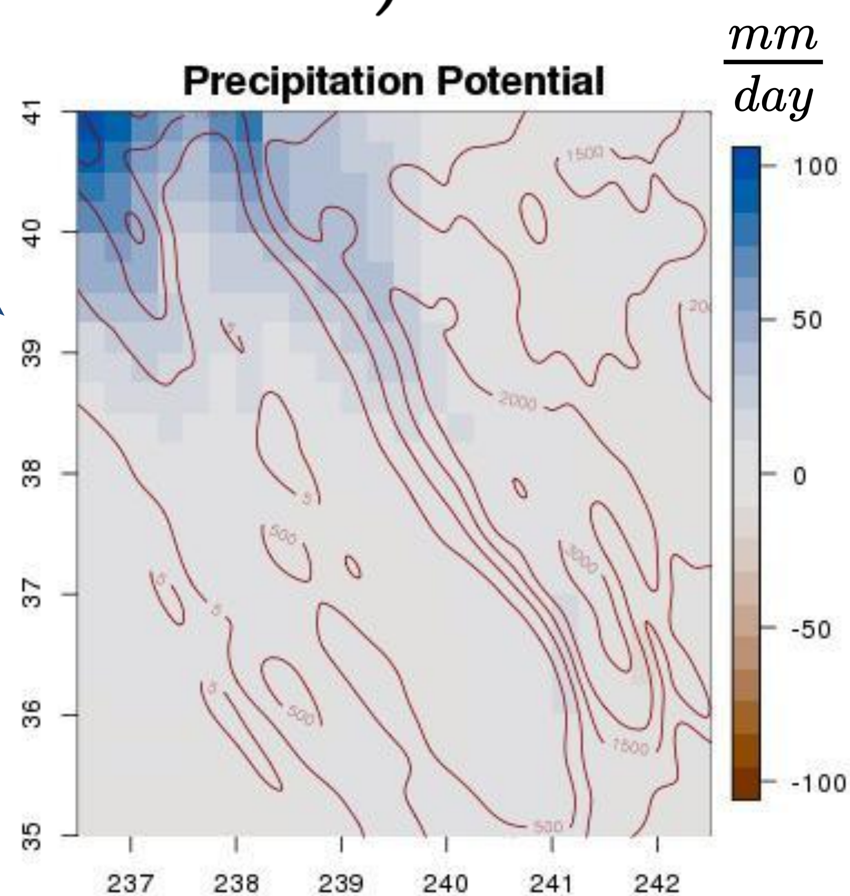


Winter Storm in Northern California



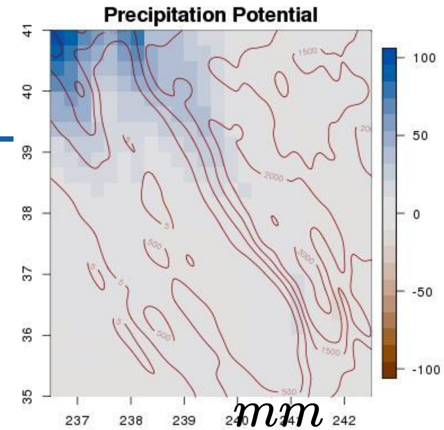
$$\lambda_1 S, (\lambda_1 = 0.087)$$

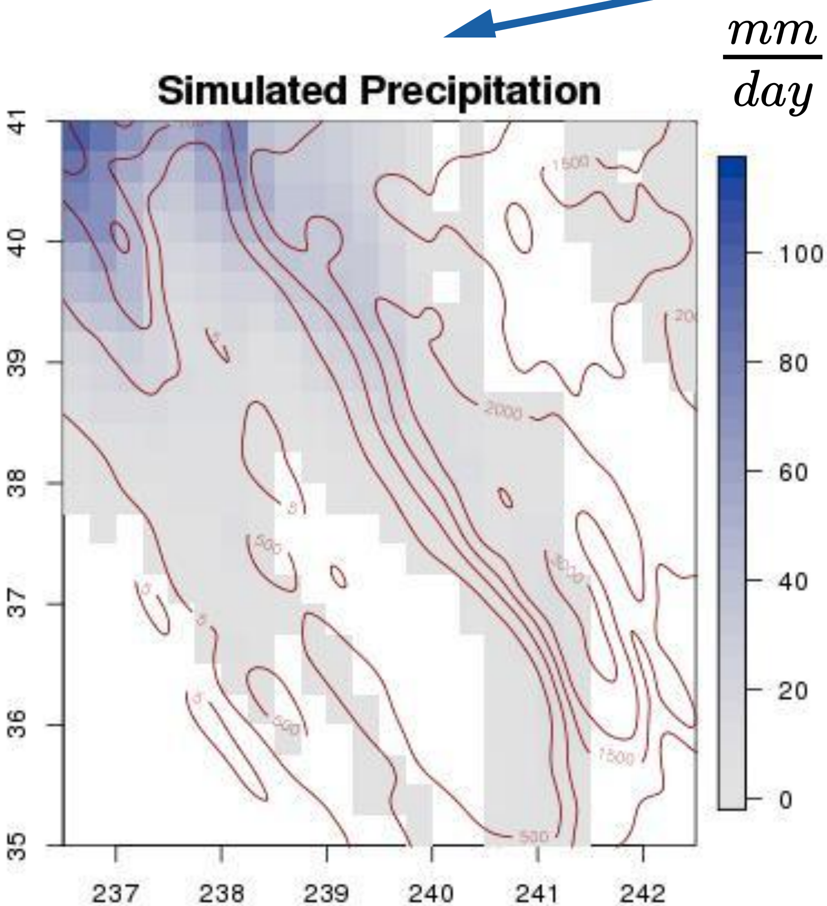


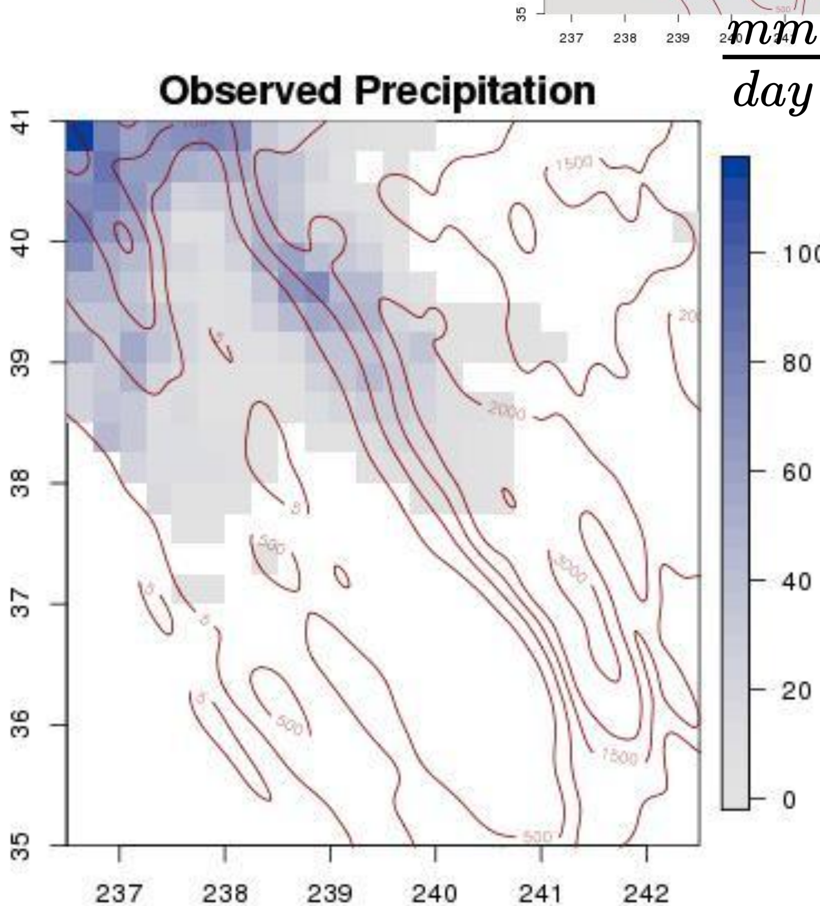


$$\lambda_2 LSP, (\lambda_2 = 0.79)$$

Winter Storm in Northern California

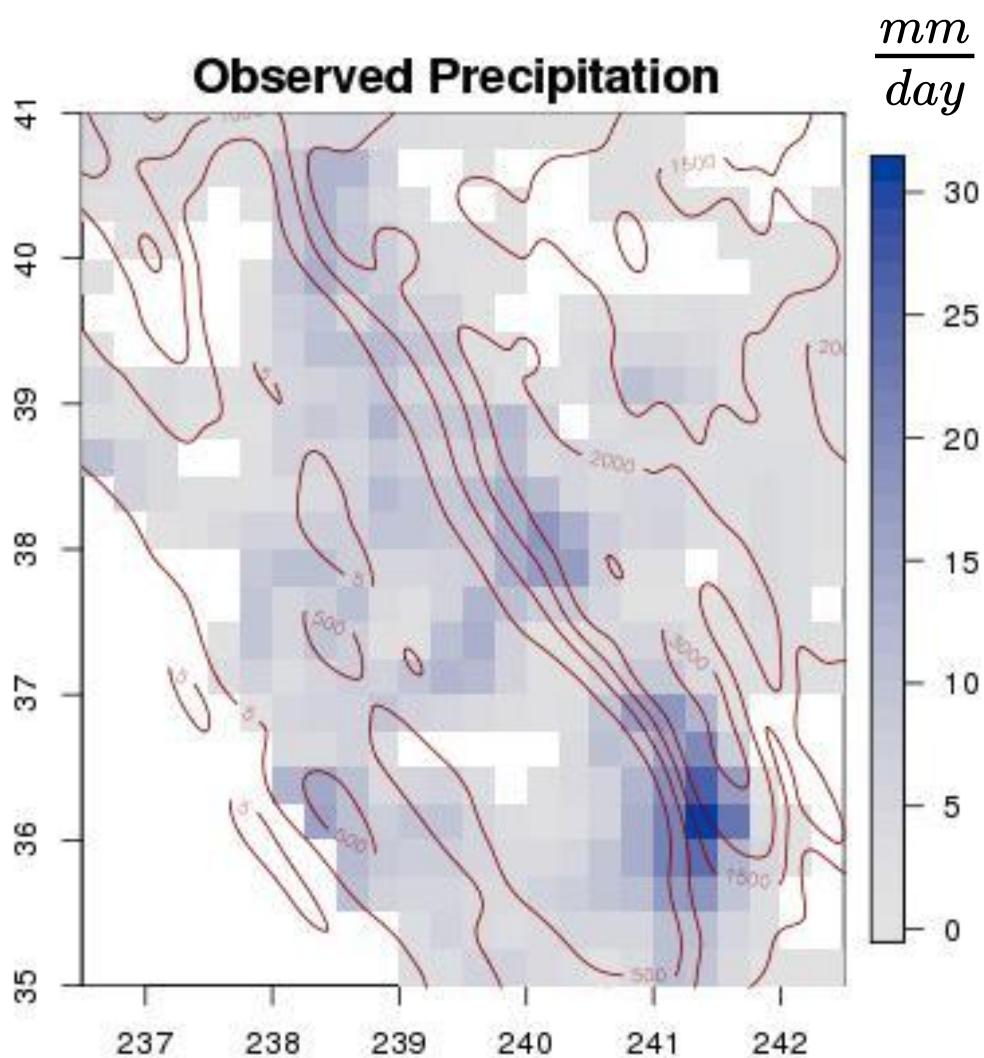




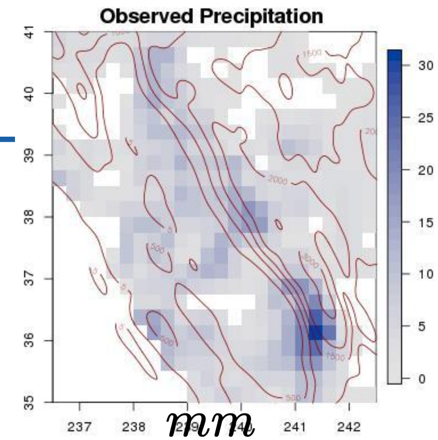


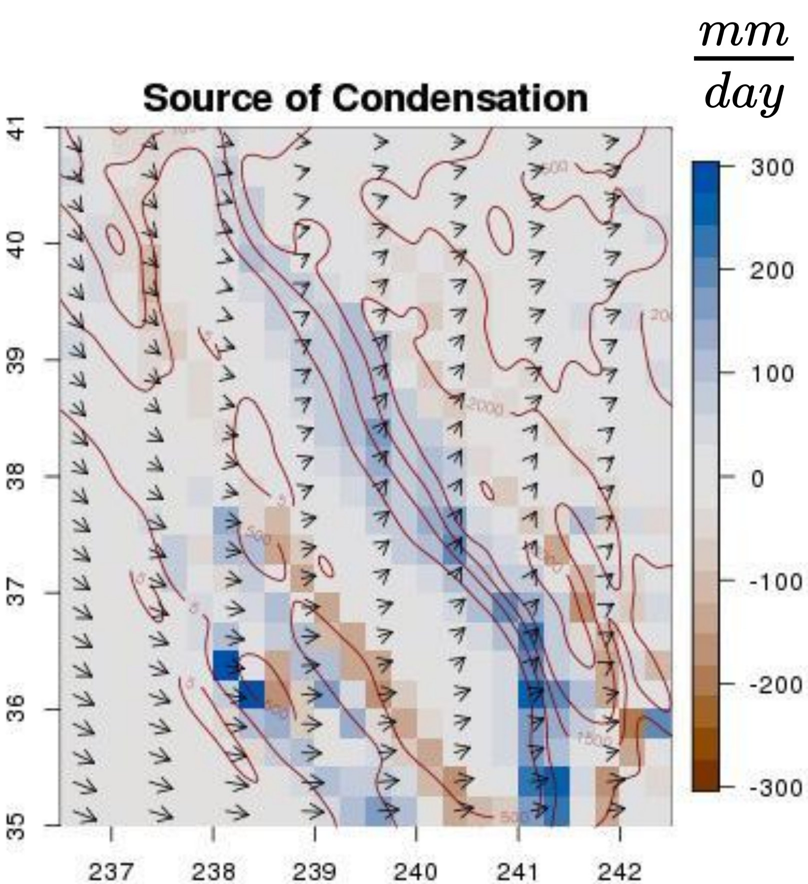
Winter Storm in Southern California

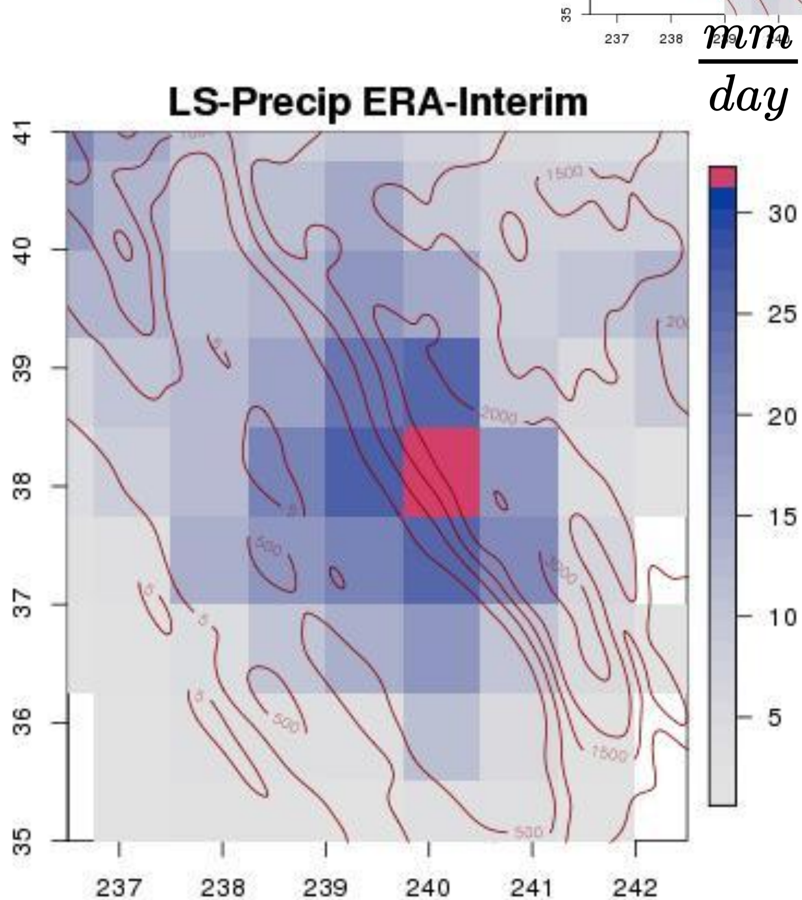
2 January 1990



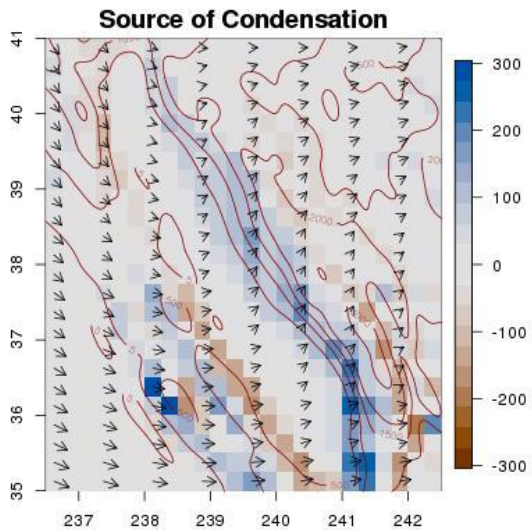
Winter Storm in Southern California





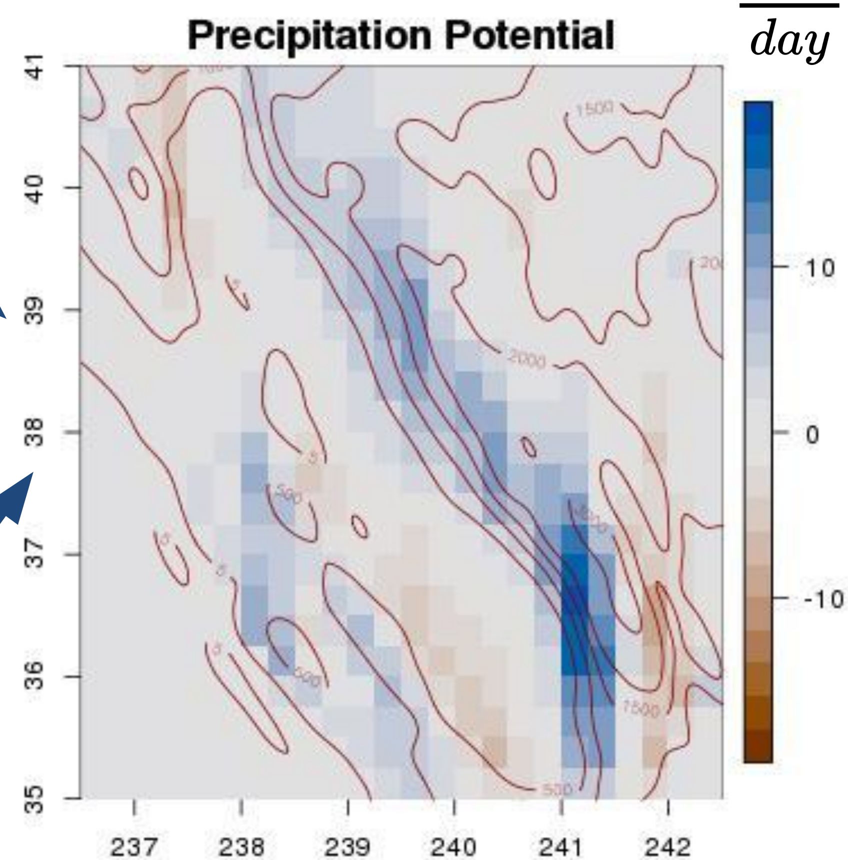


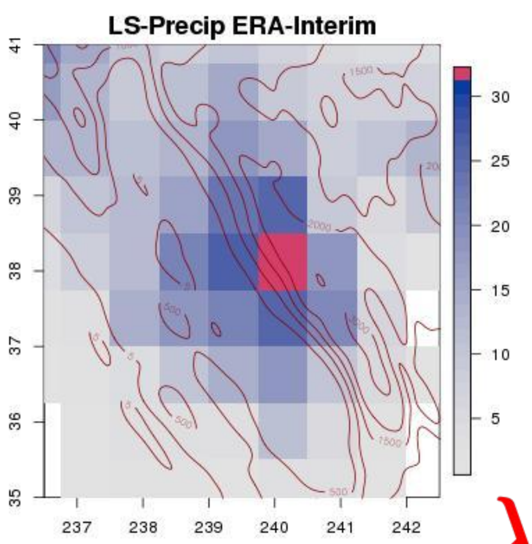
Winter Storm in Southern California



$$\color{red}{\lambda_1} S, (\lambda_1 = 0.12)$$

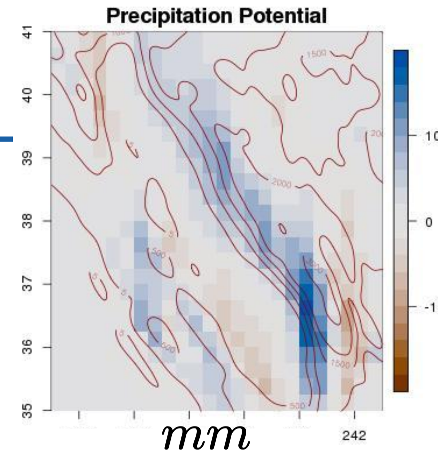
$$\frac{mm}{day}$$

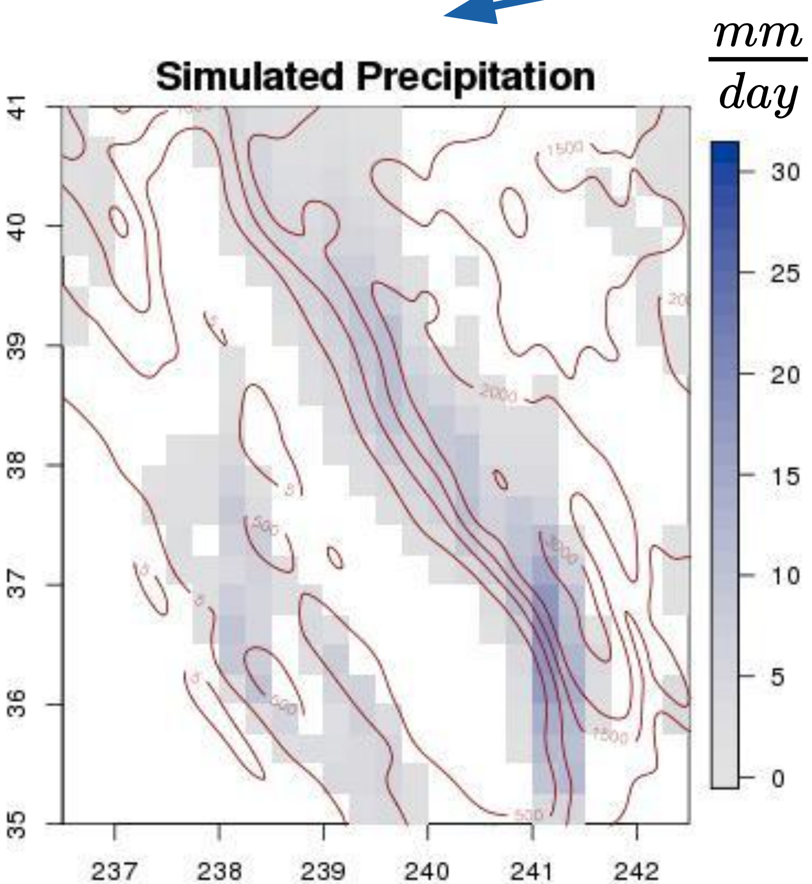


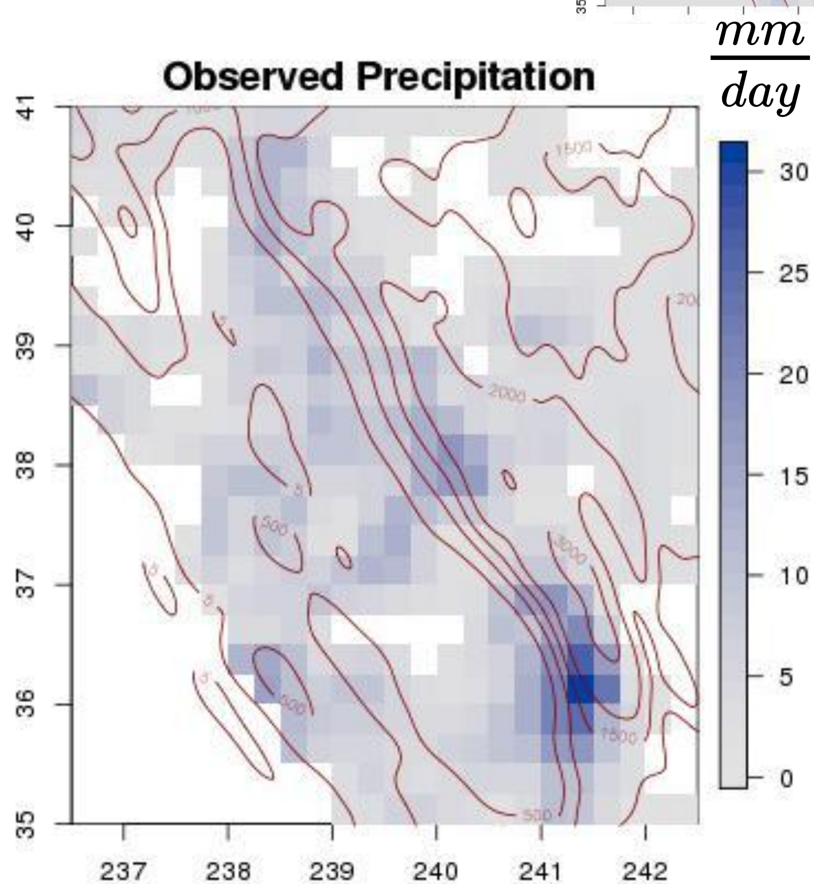


$$\color{red}{\lambda_2} LSP, (\lambda_2 = 0.24)$$

Winter Storm in Southern California







Ongoing Work

Toward a Predictive Downscaling Method

- Evolution in time driven by large-scale processes
- Link $\lambda_1, \lambda_2, \tau$ to atmospheric fields
- Interpretable linkages from a process-perspective

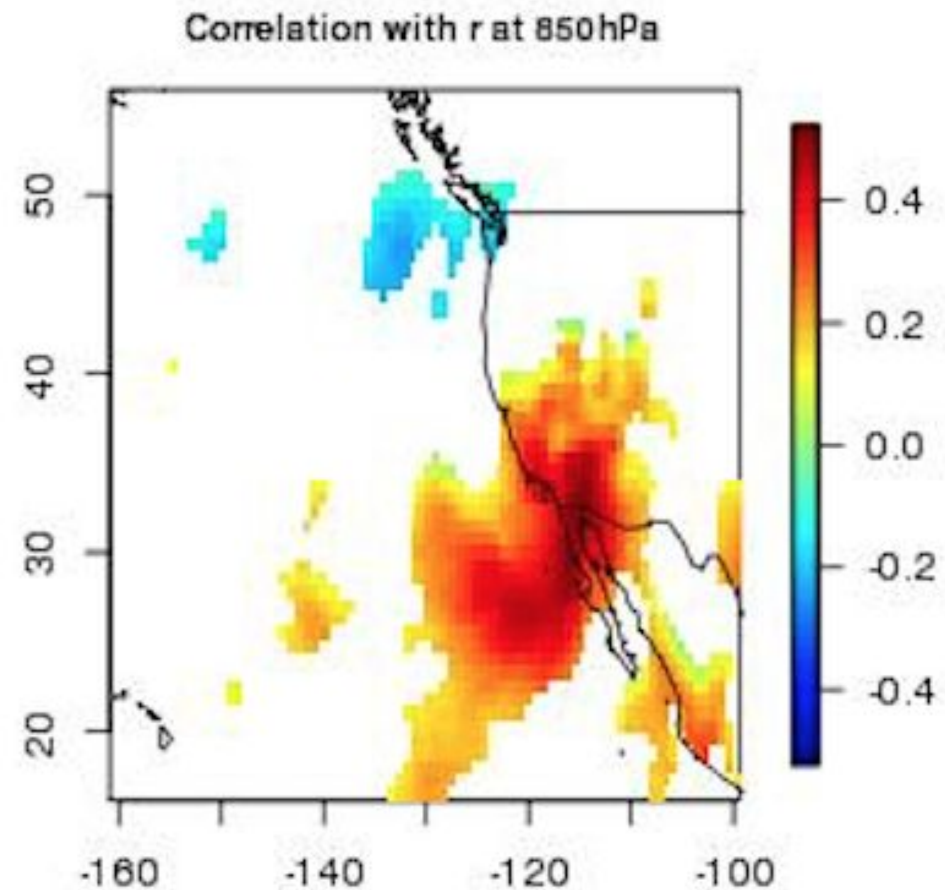
Ongoing Work

Toward a Predictive Downscaling Method

- Evolution in time driven by large-scale processes
- Link $\lambda_1, \lambda_2, \tau$ to atmospheric fields
- **Interpretable linkages from a process-perspective**

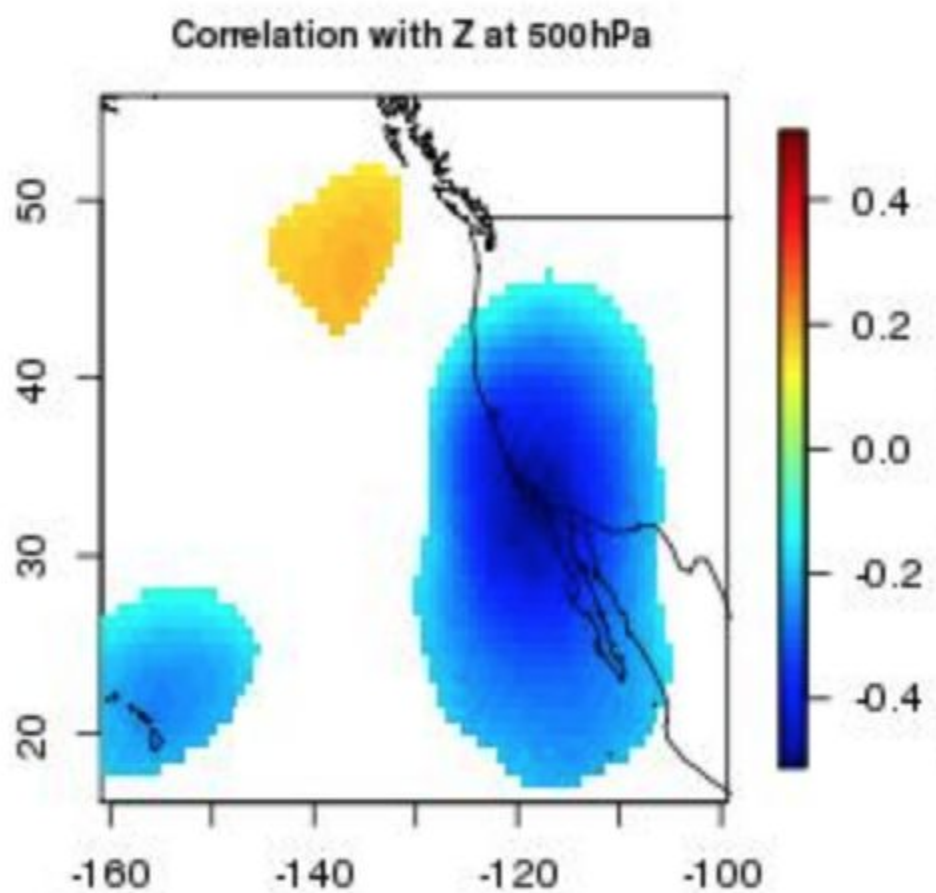
Toward a Predictive Downscaling Method

Linking λ_1 to Actual Relative Humidity



Toward a Predictive Downscaling Method

Linking λ_2 to Geopotential Height



Conclusion

- Orographic up-slope mechanisms
→ Condensation → Precipitation

- Upslope model used to create sub-grid local signal of precipitation

- Local scale source + Large Scale Precipitation

- Adjustment from data in a statistical framework

- Case Studies in California show improved agreement with observations

- Interpretable linkages of model parameters can be found
  Towards a predictive downscaling method

Thanks

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Q&A session

To participate in the Q&A Session, please use the chat room provided by the Go-to-Webinar system

WEBINAR

May 31, 2018 - h. 12.30 pm CEST

Ratcheting up Brazil´s Nationally Determined Contribution (NDC): a consistent roadmap towards the global objective of a 1.5 or 2º C world

Roberto Schaeffer - Presenter
Energy Planning Program, COPPE,
Universidade Federal do Rio de Janeiro

Enrica De Cian - Moderator
CMCC@Ca'Foscari

Thank you for attending this CMCC webinar.

This webinar was recorded and will be uploaded to the CMCC website: www.cmcc.it

If you have any further question about the webinar, please email: webinar@cmcc.it

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