Mesoscale Meteorology (6)

Orographic Precipitation: Fundamentals and Challenges

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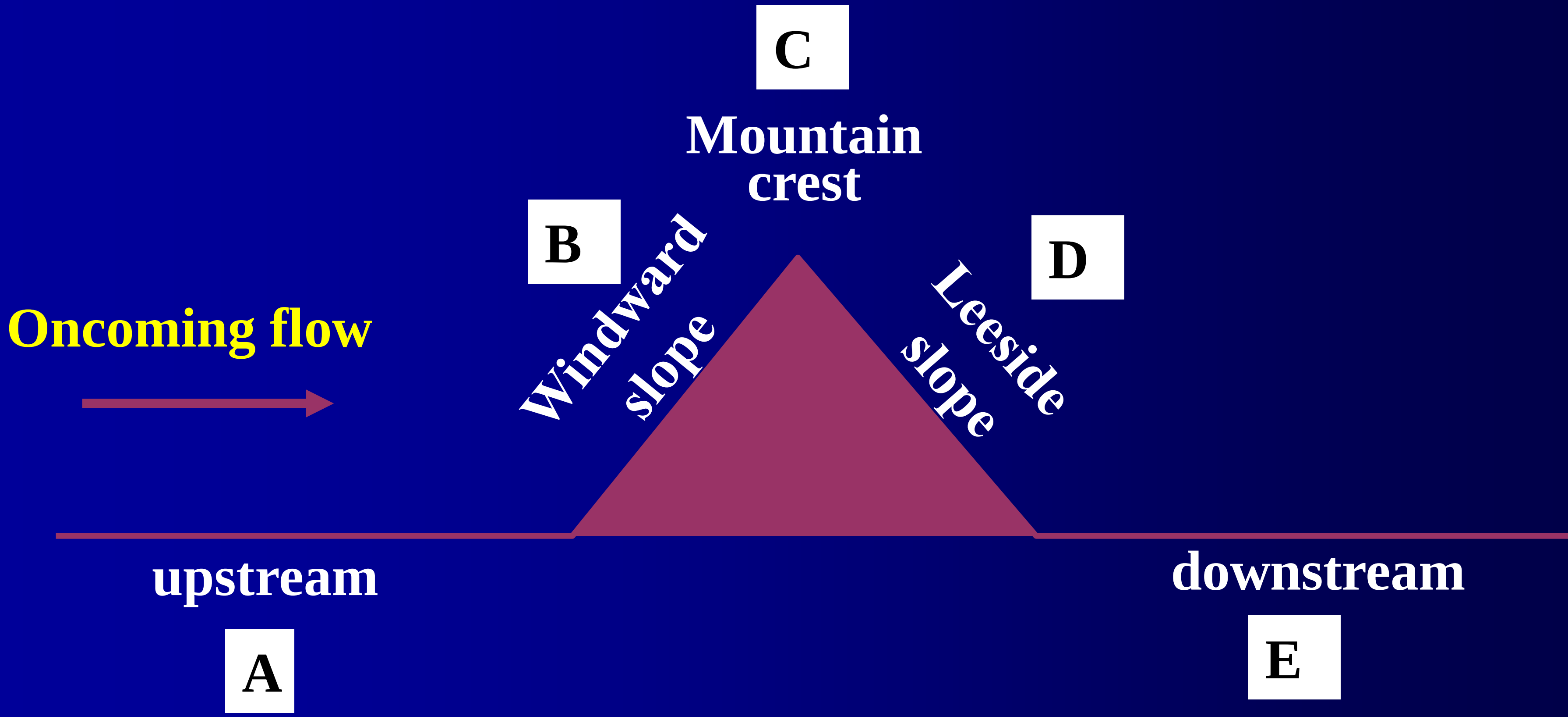
Outline

- Some background
- Froude number (dynamically mountain-induced circulation and precipitation)
- Thermodynamically mountain-induced circulation and precipitation
- Challenges

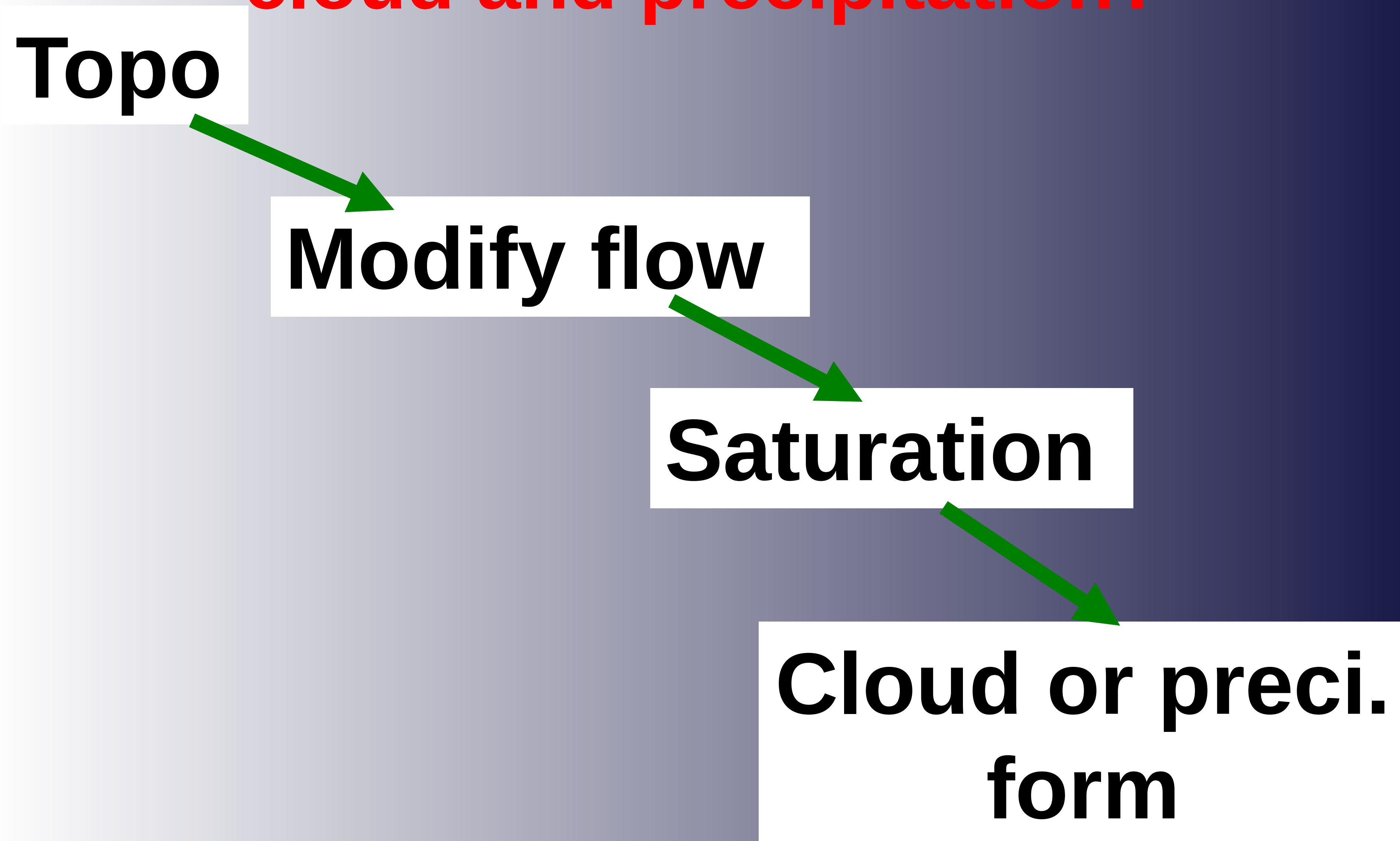



Which location can cloud and precipitation be generated by a mountain barrier ?



Answer: A, B, C, D, E

Why topography can produce cloud and precipitation?



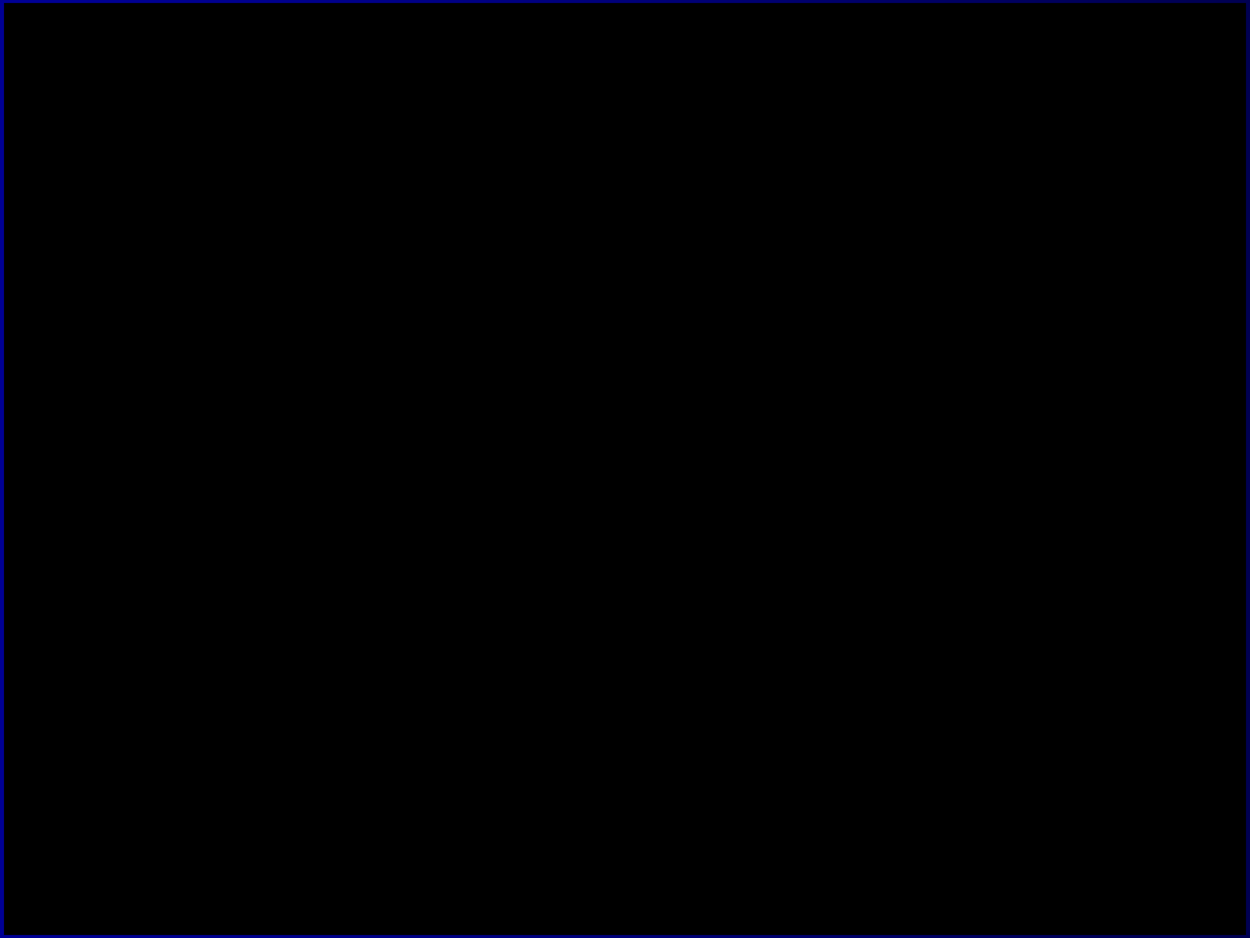
Interaction of incident flow with topography

$$KE = \frac{1}{2} m U^2$$

$$PE = mgH$$

$$Ratio = \frac{KE}{PE} = \frac{\frac{1}{2} m U^2}{mgH} = \frac{U^2}{2gH}$$

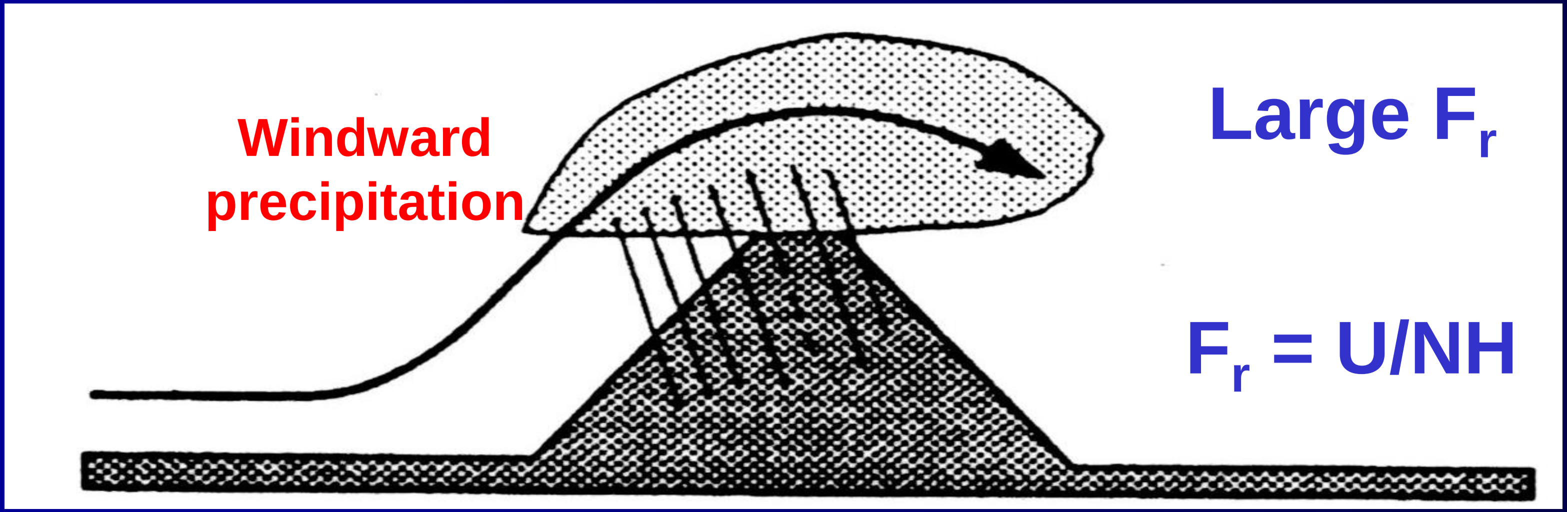
Marble
Speed U
Mass m
Terrain H

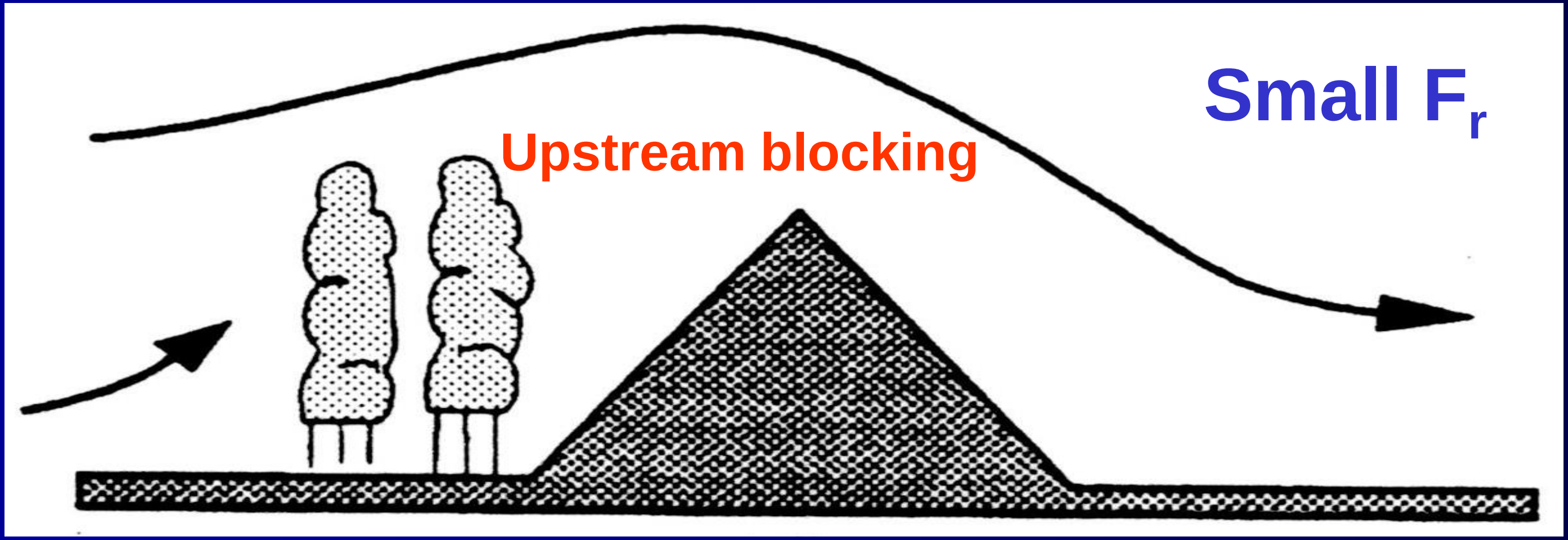


Stratified Atmosphere
Brunt-Väisälä frequency N

$$Froude\ number = \frac{KE}{PE} \propto \frac{U^2}{N^2 \delta z H} \propto \frac{U^2}{N^2 H^2} = \frac{U}{NH}$$

Precipitation location depends on flow regimes

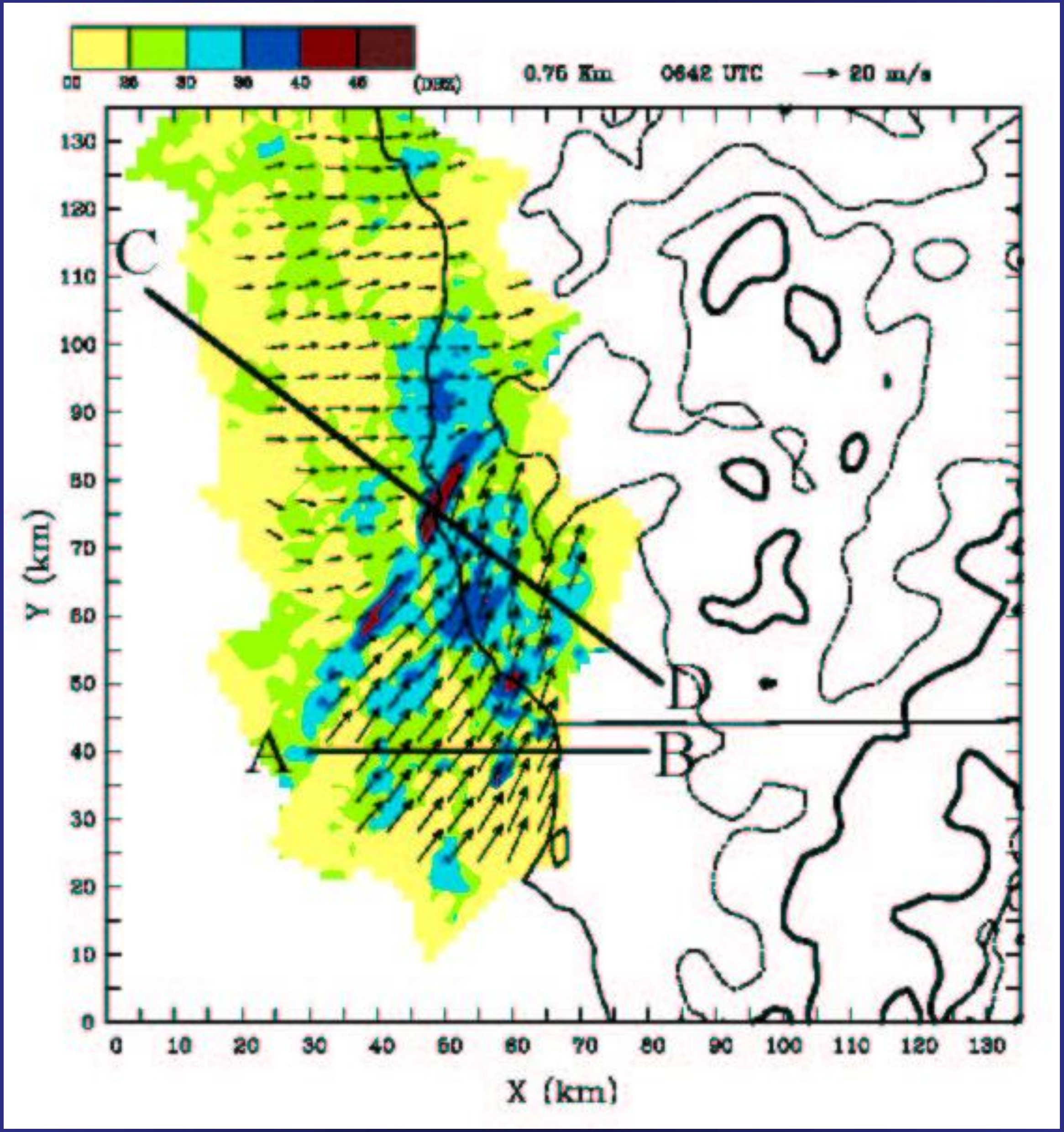




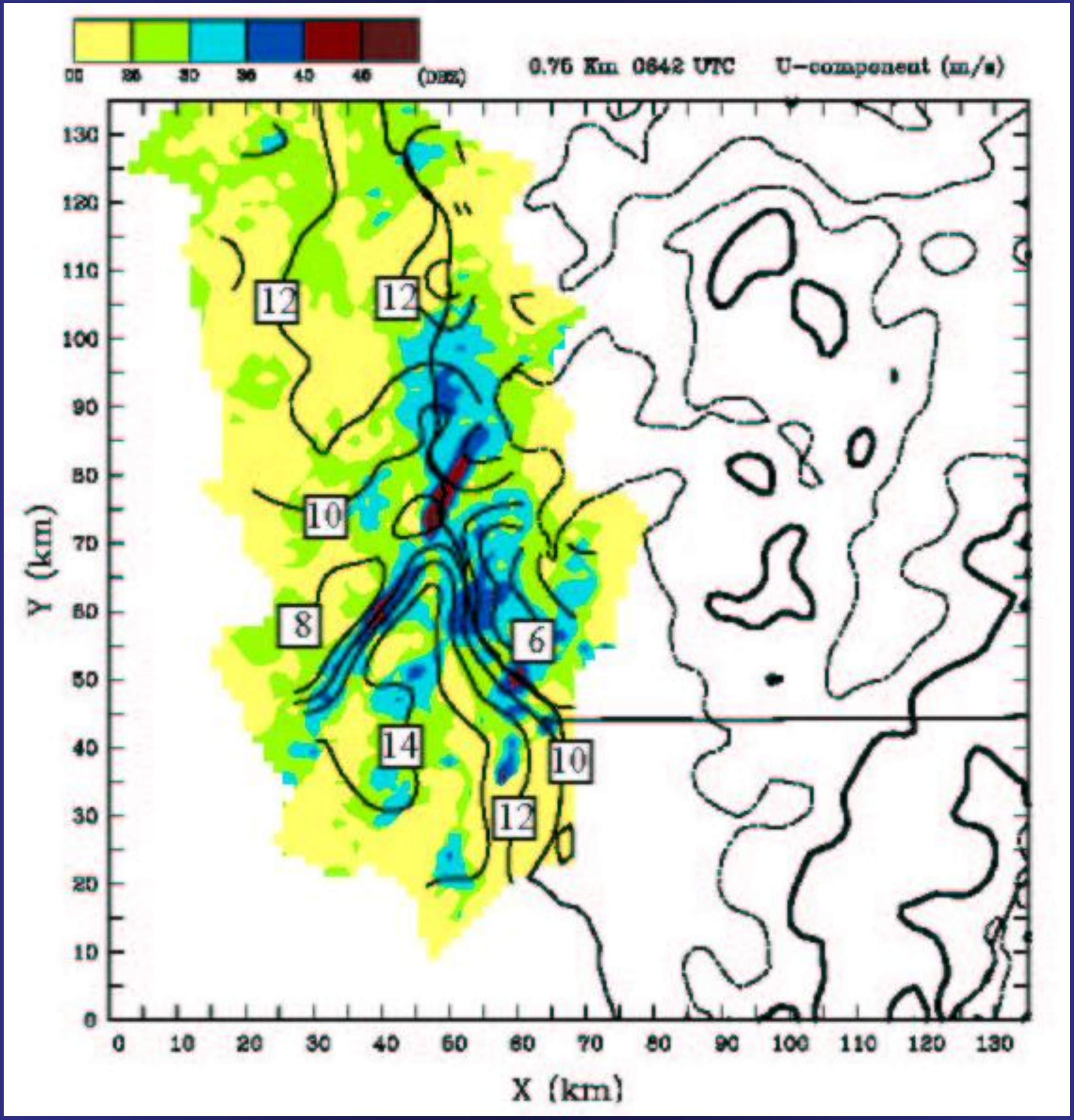
Cloud formation due to orographic lifting

(possible spillover for narrow barrier or strong winds)

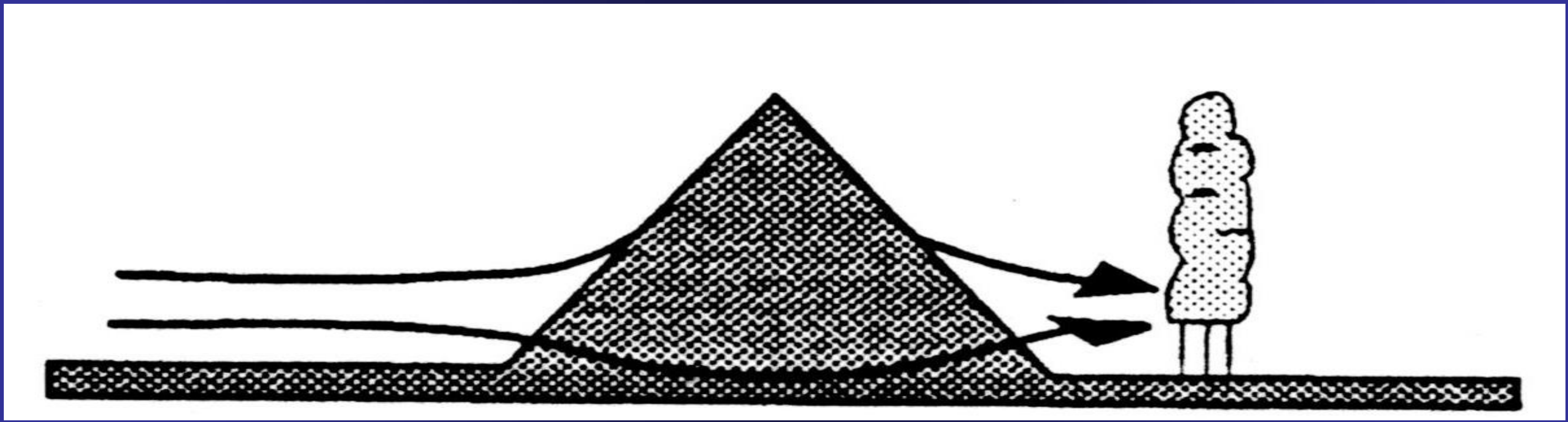
Upstream deceleration of prefrontal southwesterly flow by coastal mountains (Yu and Smull 2000)



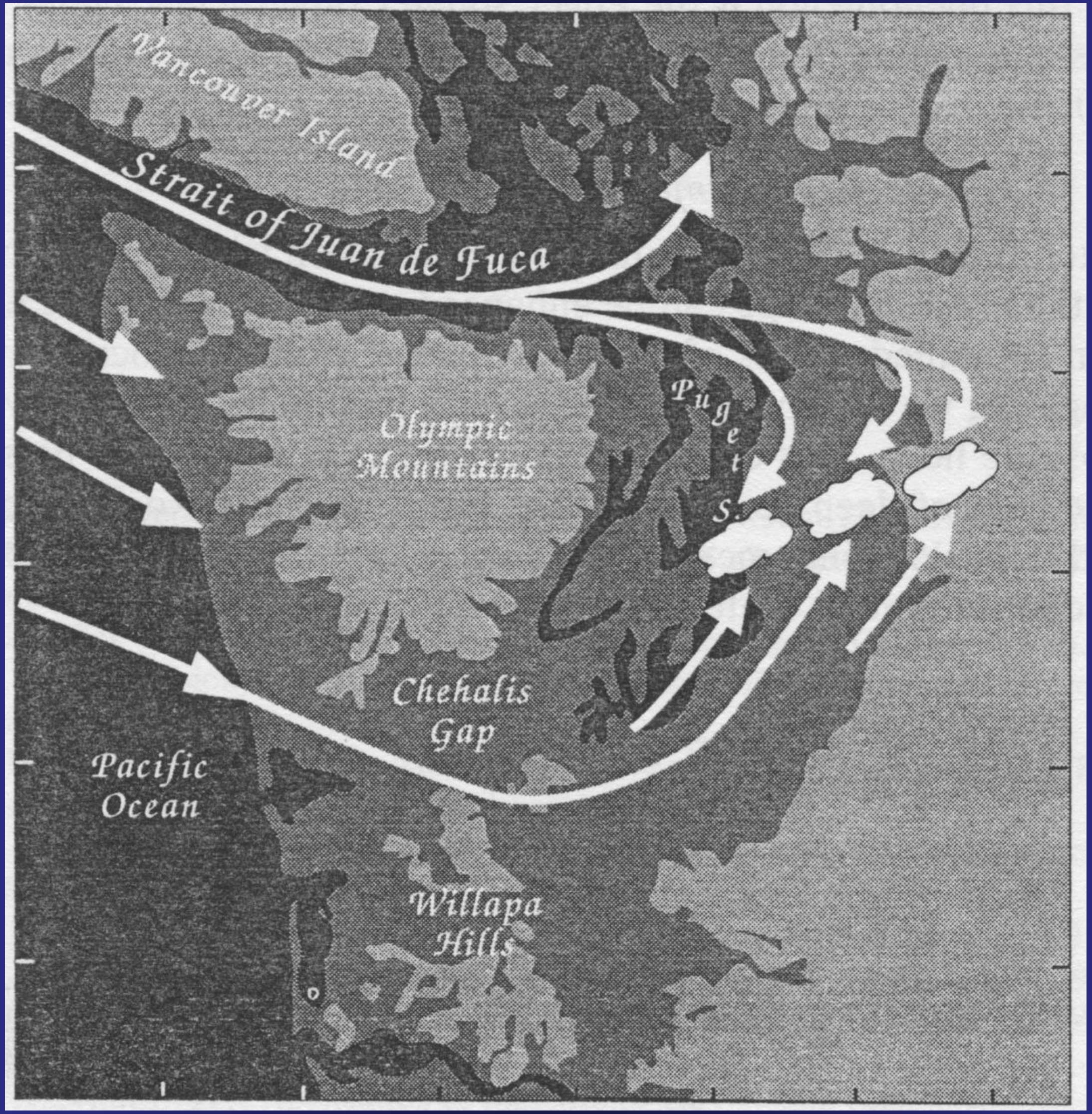
Contours of cross-barrier flow component



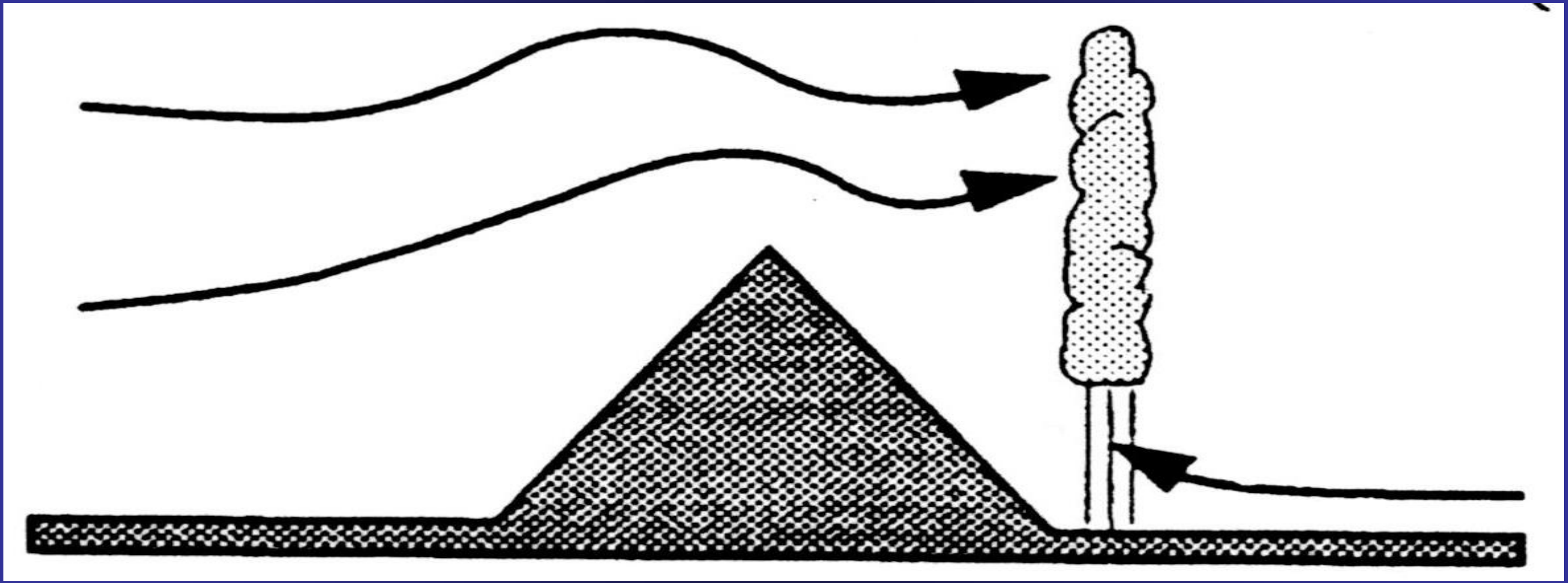
Lee-side triggering



Occurrence of low-level convergence on the leeside of Olympic Mountains under small Froude number flow regime (Mass 1981)



Lee-side enhancement or triggering by gravity waves



Influence of multiple waves on orographic precipitation (Garvert et al. 2007, JAS)

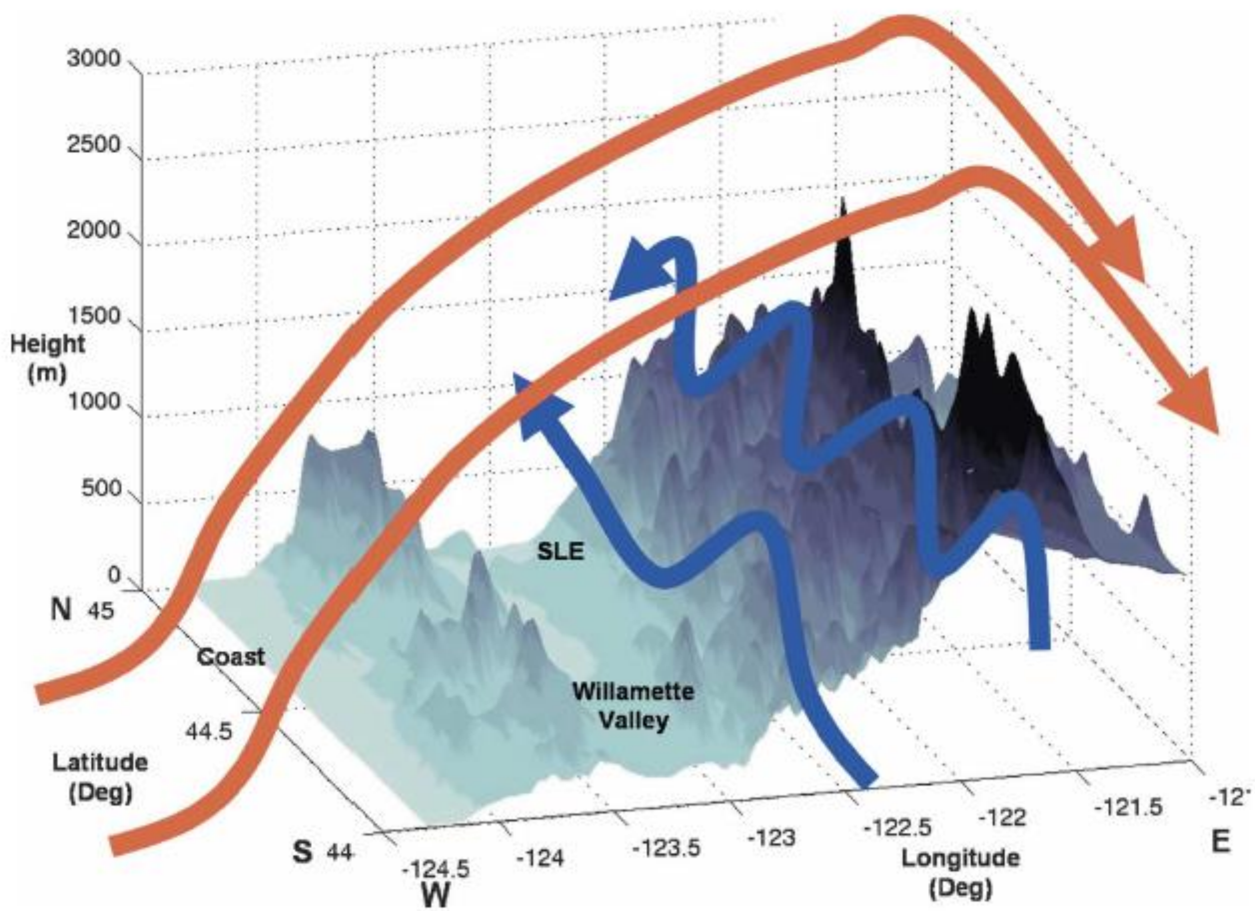
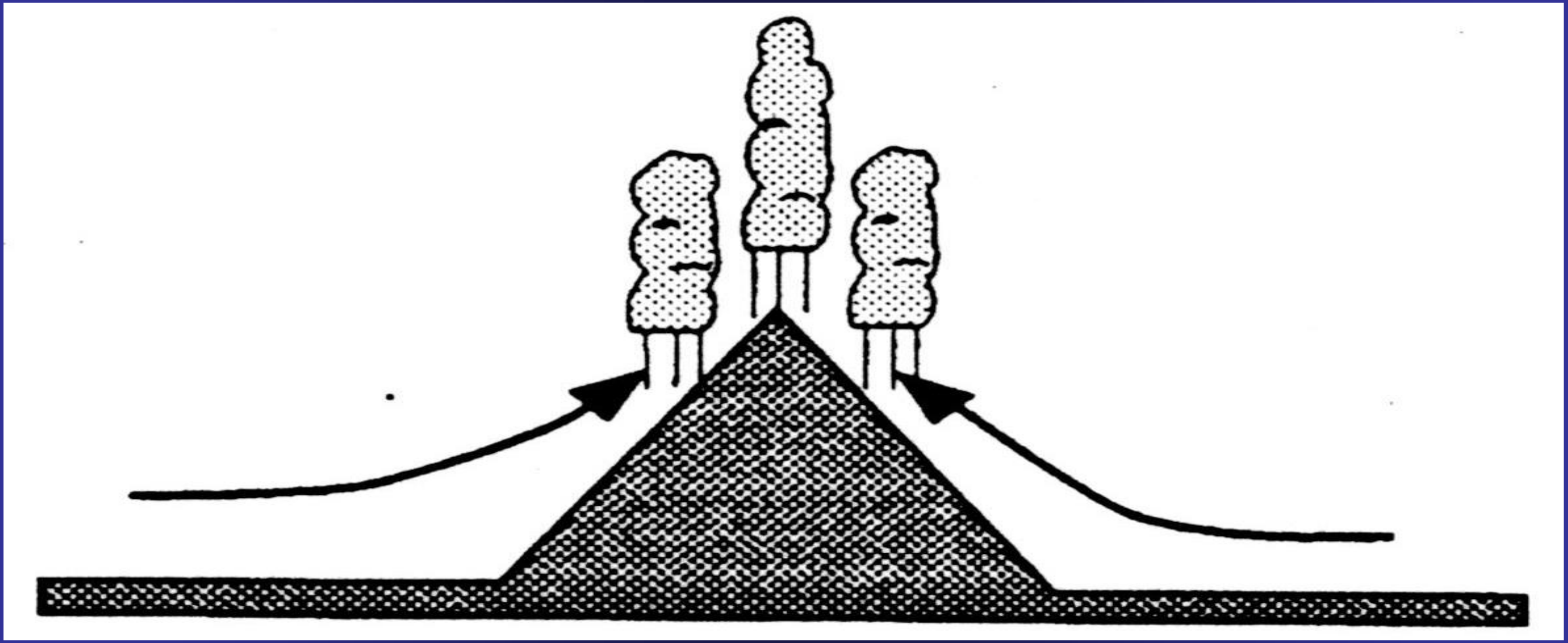


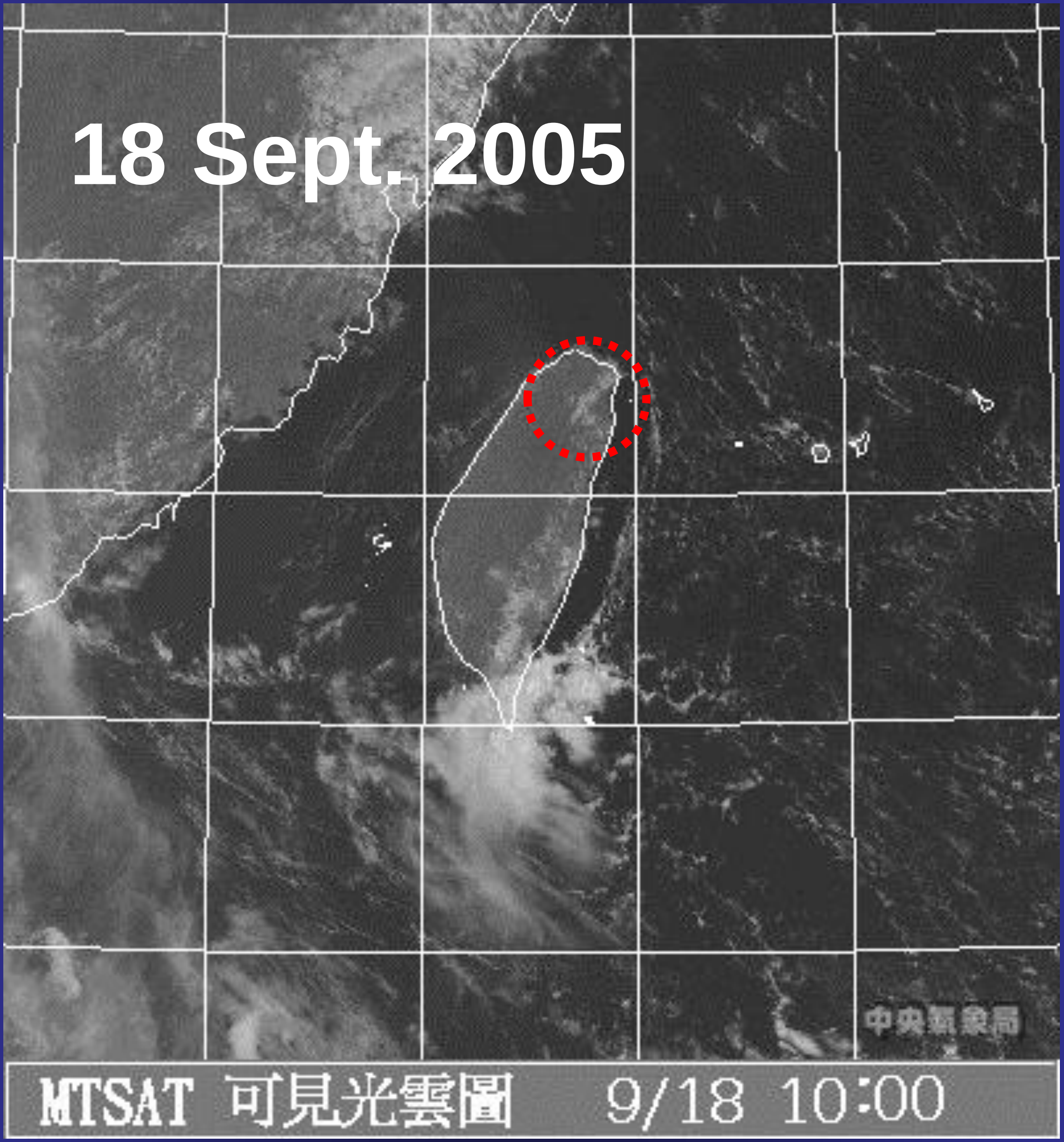
FIG. 19. Three-dimensional idealized schematic of topography and wind flow over the IMPROVE study area from 2300 to 0100 UTC 13–14 Dec 2001. Blue arrows show strong southerly low θ_e airflow at low levels along the windward (west facing) slopes of the Cascade range which was subsequently involved in wave generation over multiple small-scale east–west-oriented ridges–valleys within the Cascade foothills. Red arrows show the high θ_e cross-barrier flow that surmounted the low θ_e air and exhibited a vertically propagating mountain-wave structure anchored to the mean north–south Cascade crest.

In addition to dynamically mountain-induced circulation and precipitation, thermal forcings associated with mountain effects are often observed to produce cloud and precipitation

Thermal triggering



18 Sept. 2005



Development of cumulus cloud along the ridges of SMR near noon

(Car was moving northward on the south of SMR)

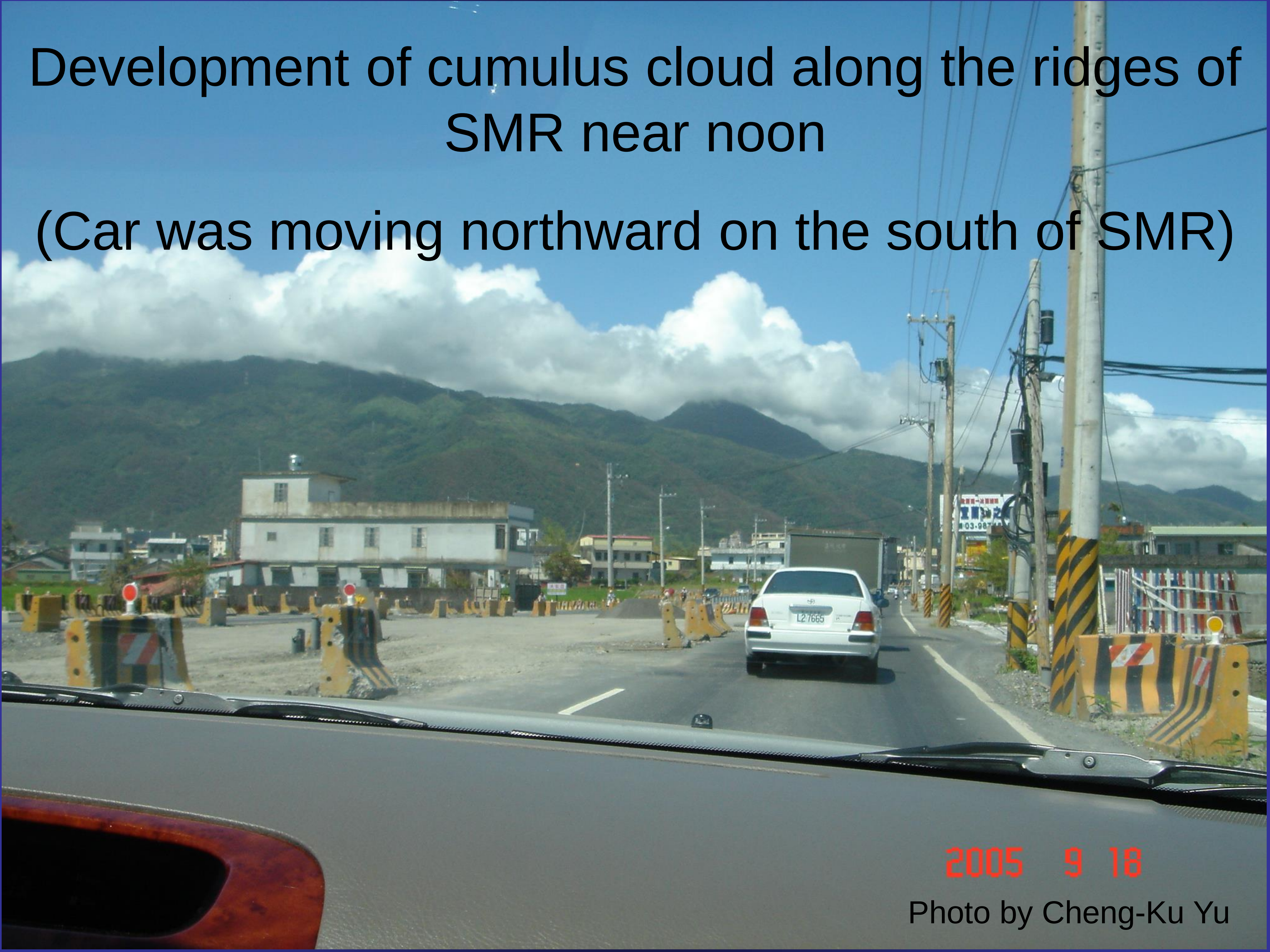
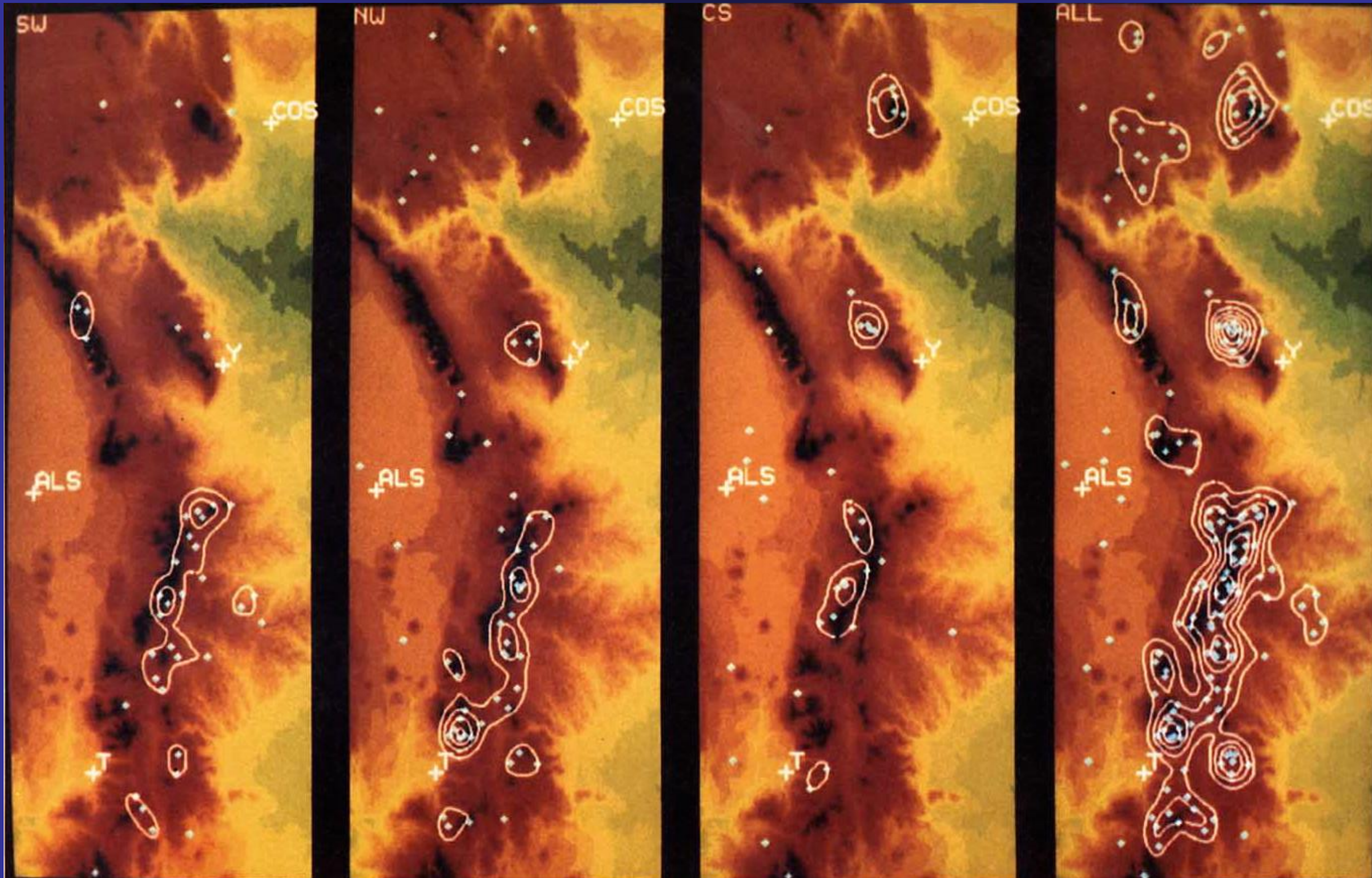
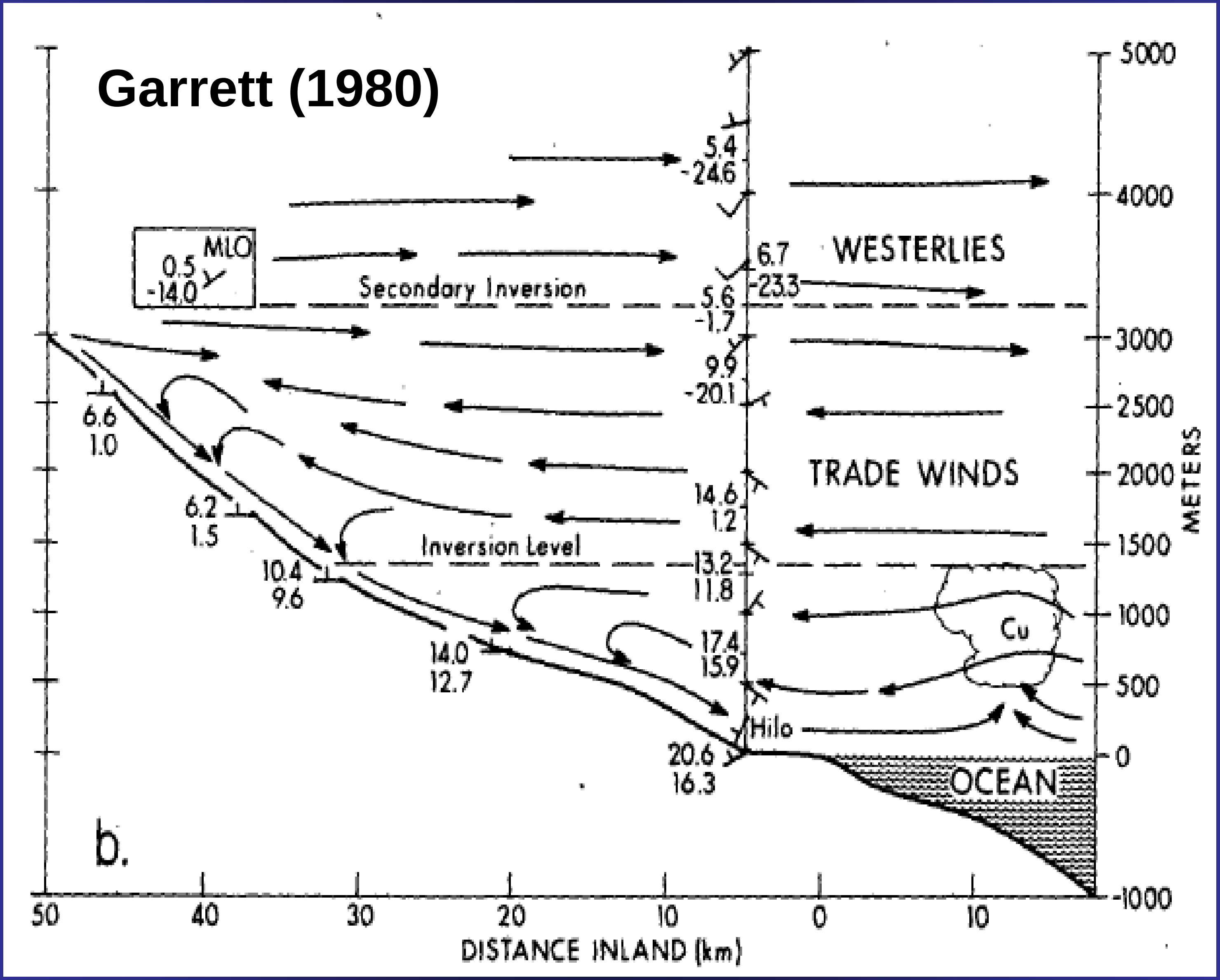


Photo by Cheng-Ku Yu

Summertime thunderstorm initiation over mountains of Colorado and New Mexico over different ridgetop winds (Schaaf et al. 1988)



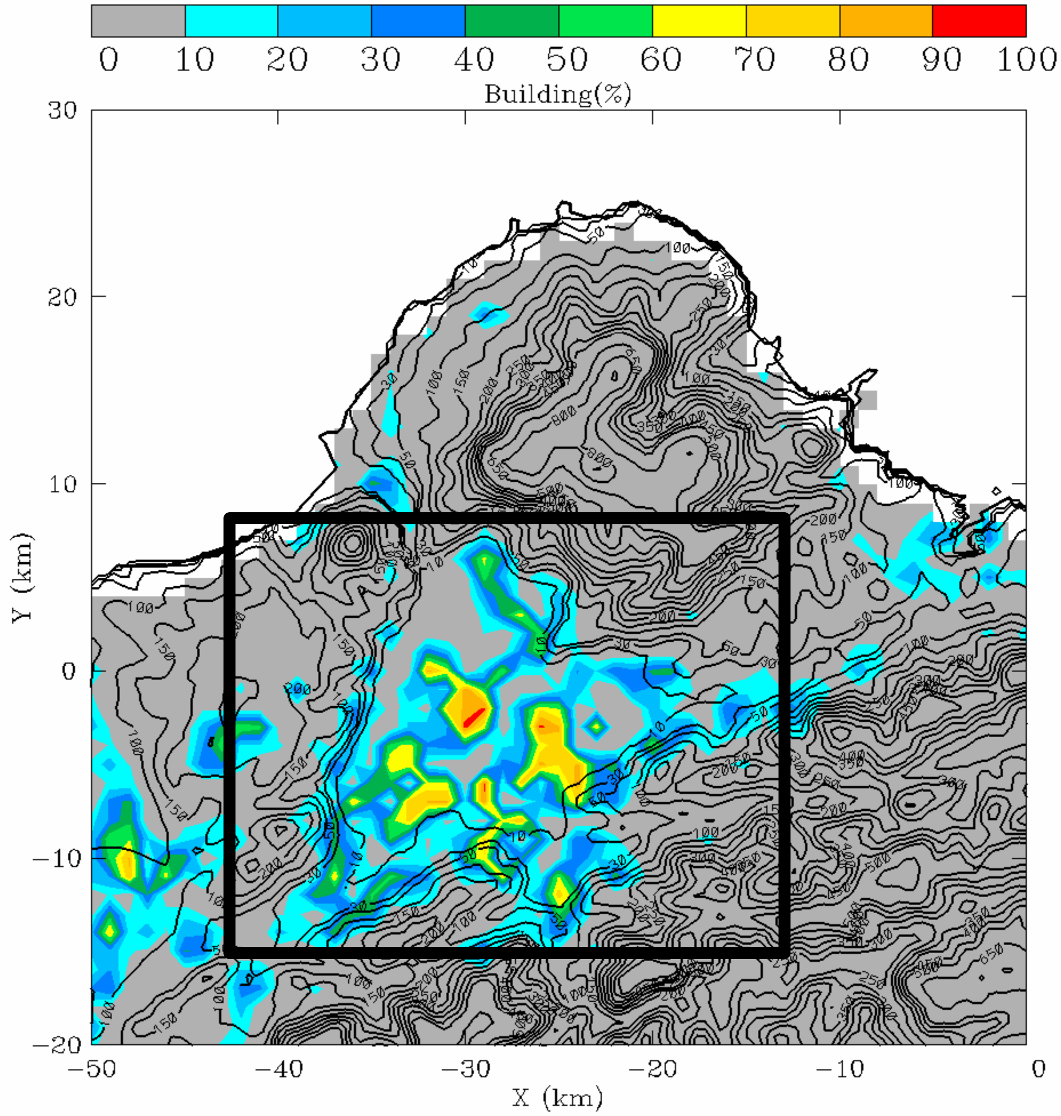
Importance of mountain-land breeze on generating nighttime Cumulus offshore of Hawaii

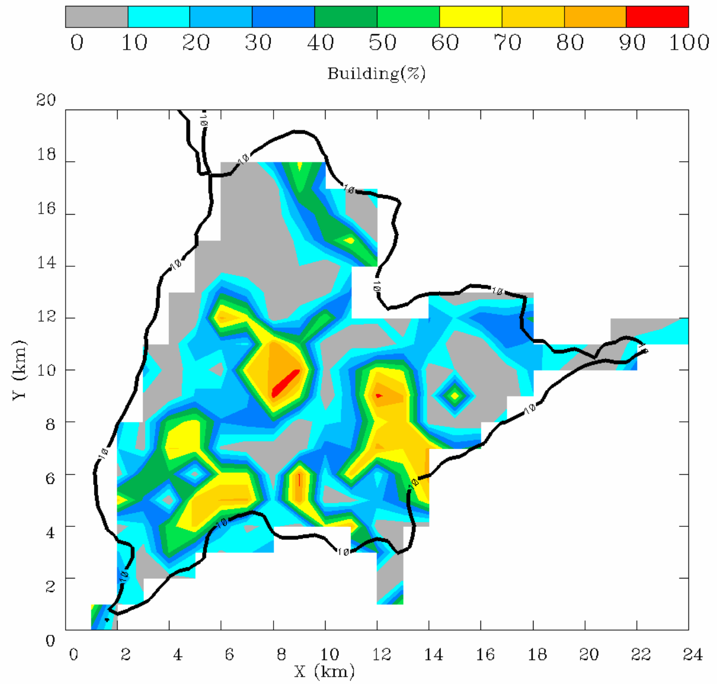


Buildings are some sort of low topography, which can also play a role in modulating precipitation

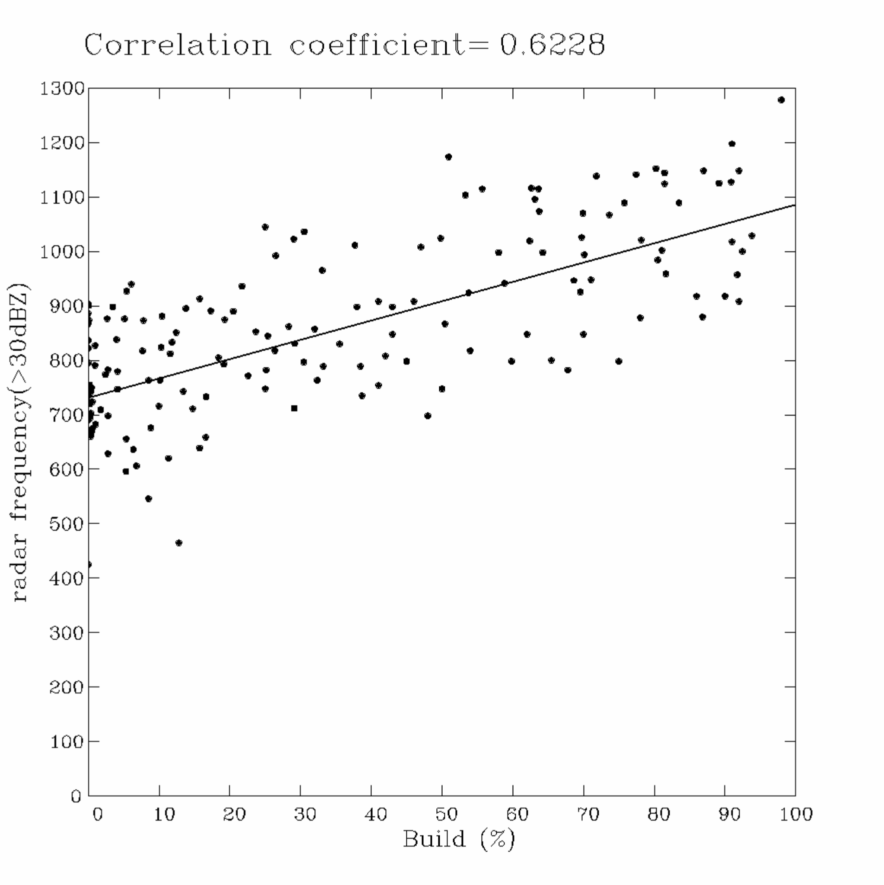
This issue has been largely unexplored

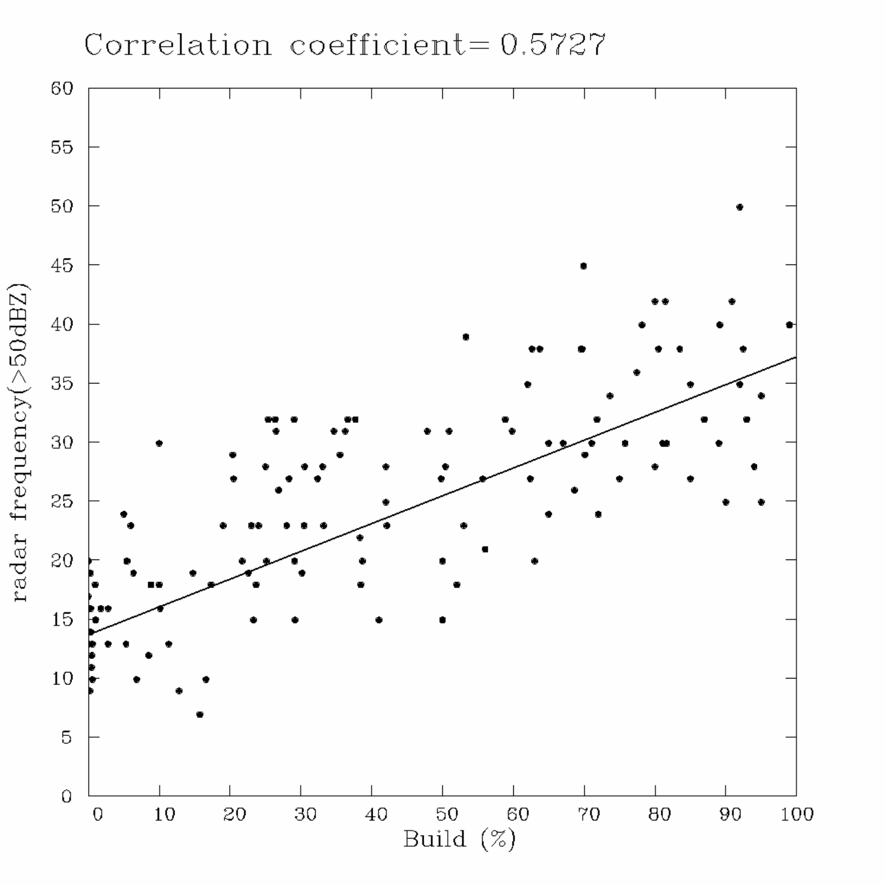
Building percentage over Taipei basin





Scatter plot of building percentage vs. frequency of radar reflectivity





> 30 dBZ

> 50 dBZ

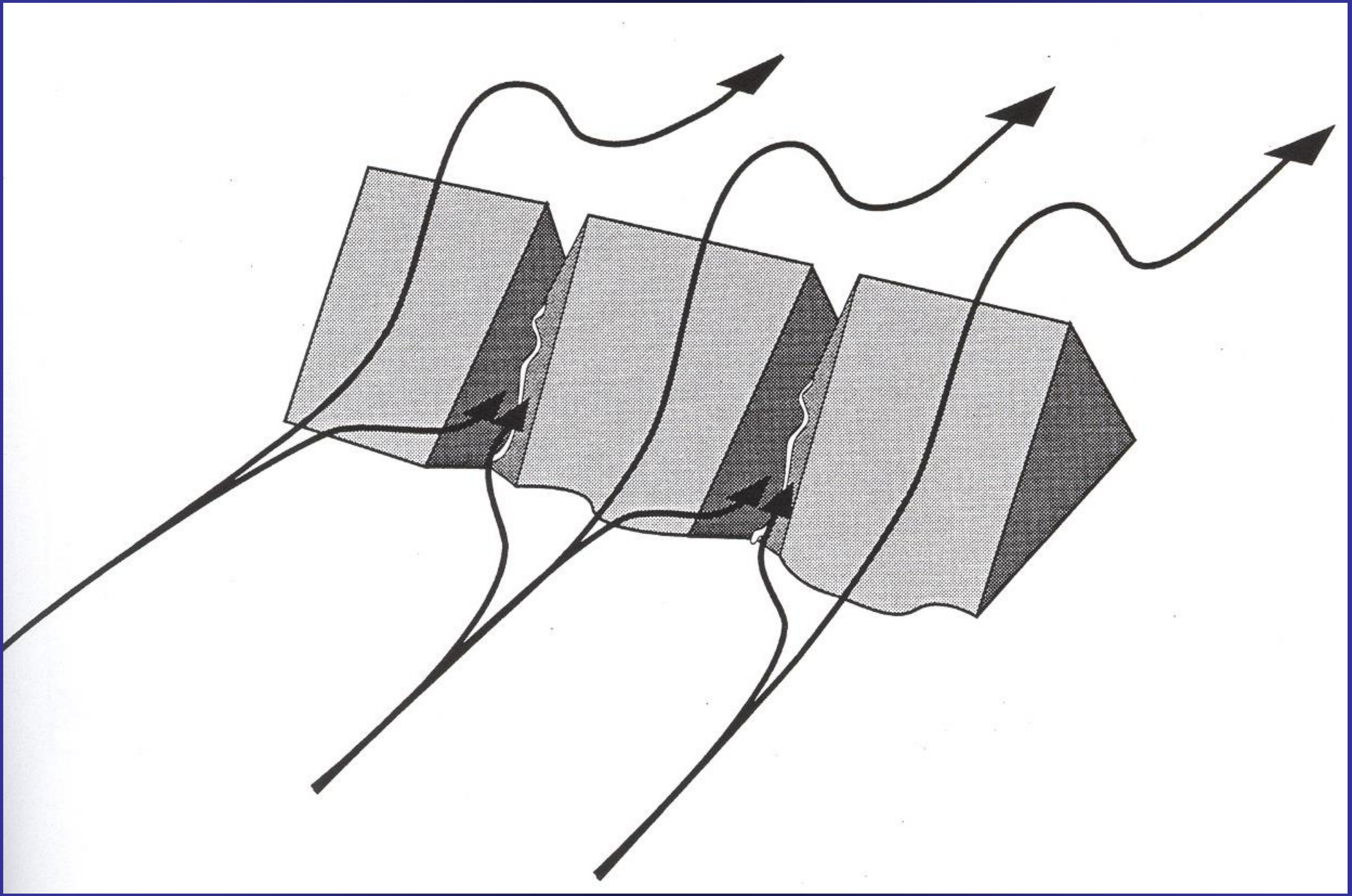
Challenge I

Processes of orographic precipitation are often beyond such a scope of knowledge and usually more complicated

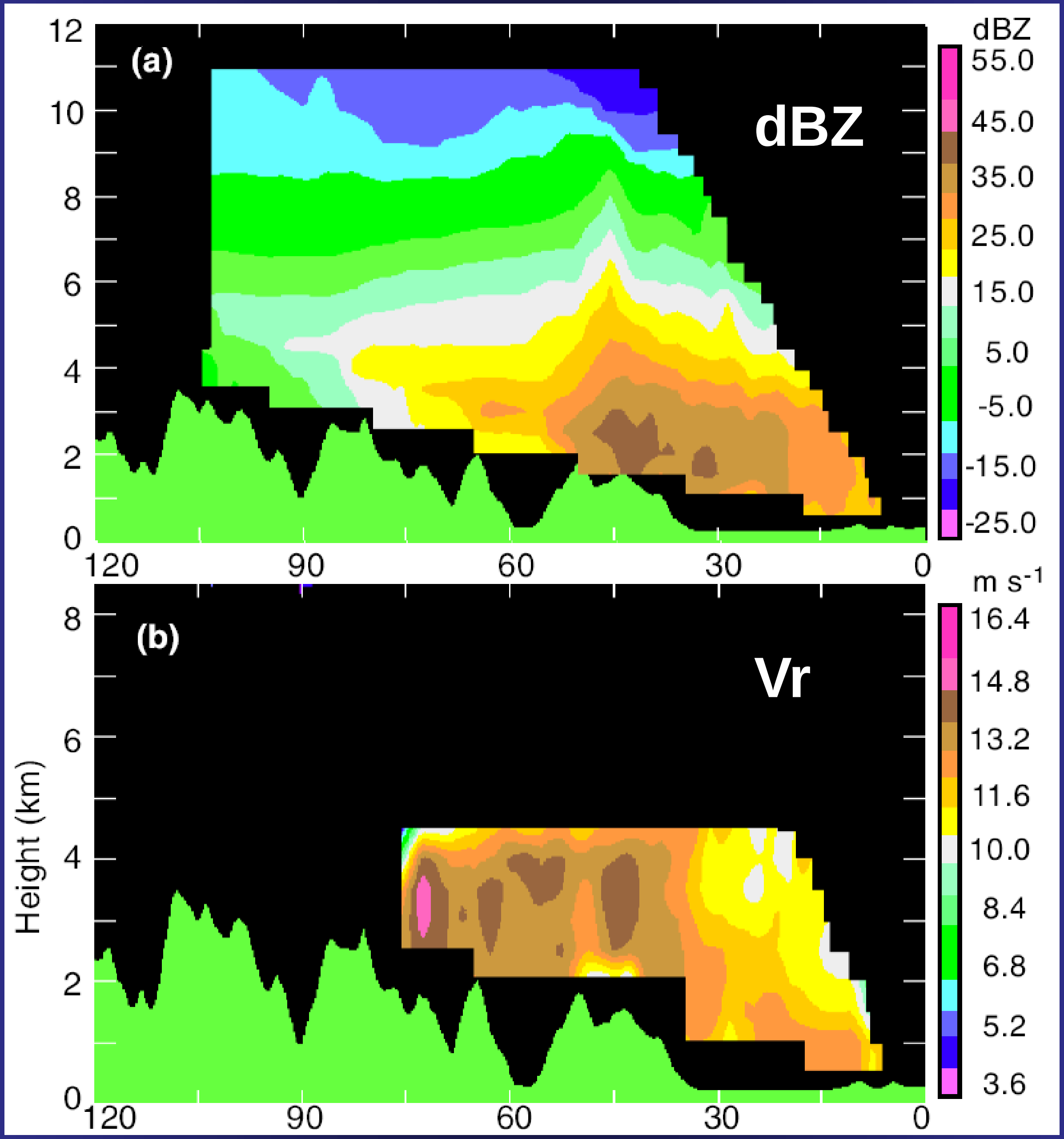
- Inherent complexity of orographic geometries
- High variety of ambient flow and precipitation associated with fronts, typhoons, and other strong synoptic forcings
- Influences of convectively generated circulations
- Interactions among above factors

Convergence of the windward flow into valleys (Houze 1998)

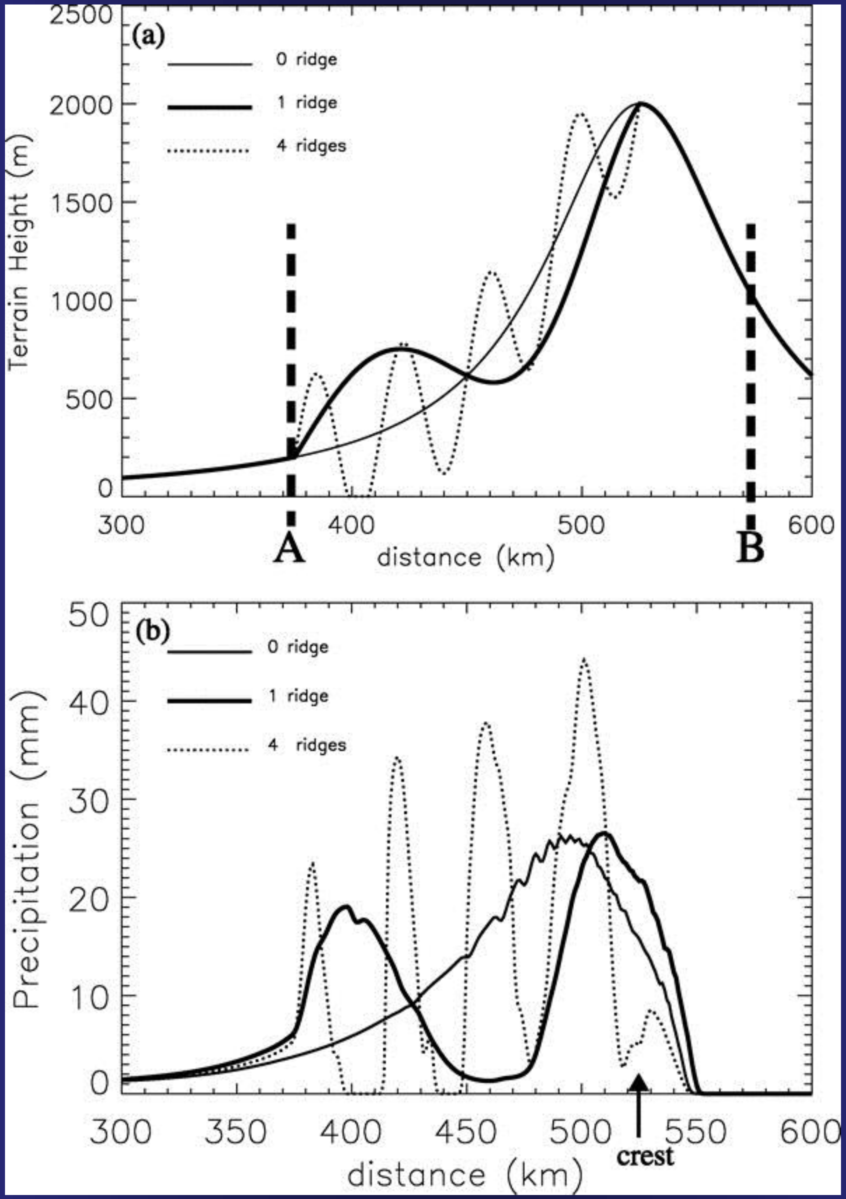
(Three-dimensional nature of airflow over mountains)



MAP IOP2b (Medina and Houze 2003)



Improve understanding for the impact of complicated terrain profiles on precipitation distribution and intensity through modeling efforts



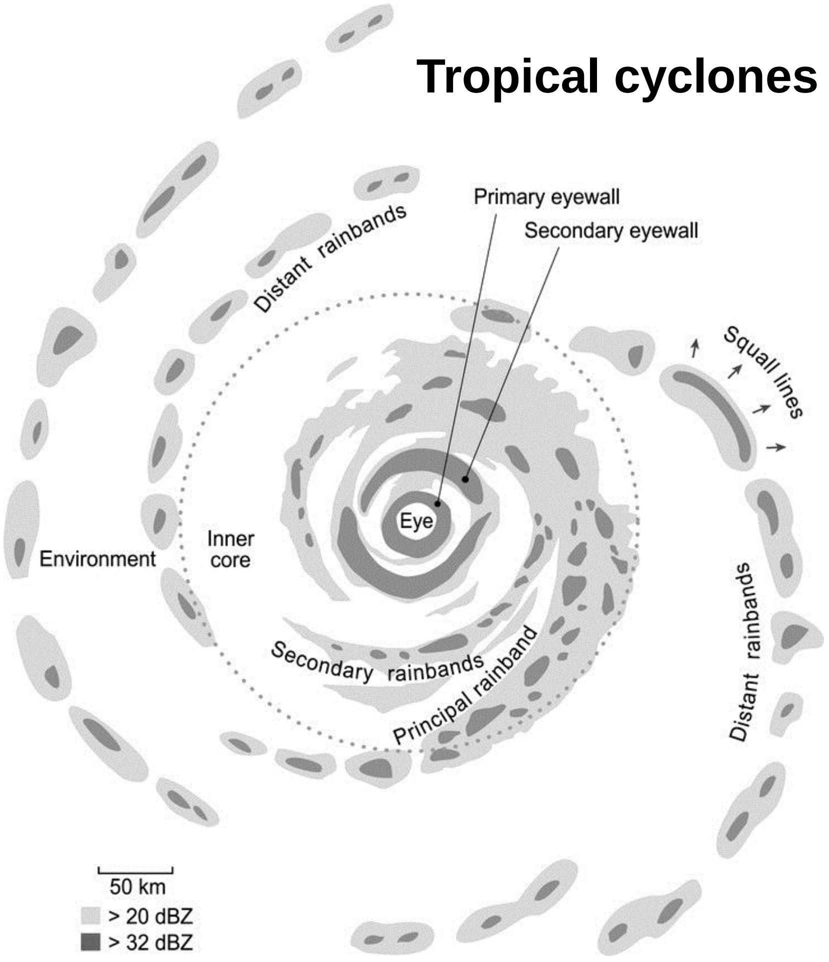
Colle 2008

Important note:

Severe orographic precipitation is usually not caused by simple interactions between incident flow and mountains, and instead, it is more often associated with weather systems as they approach and interact with topography

Considerable preexisting precipitation associated with weather systems (TCs, cyclones, and fronts)

Tropical cyclones



Houze (2010)

Extratropical cyclones

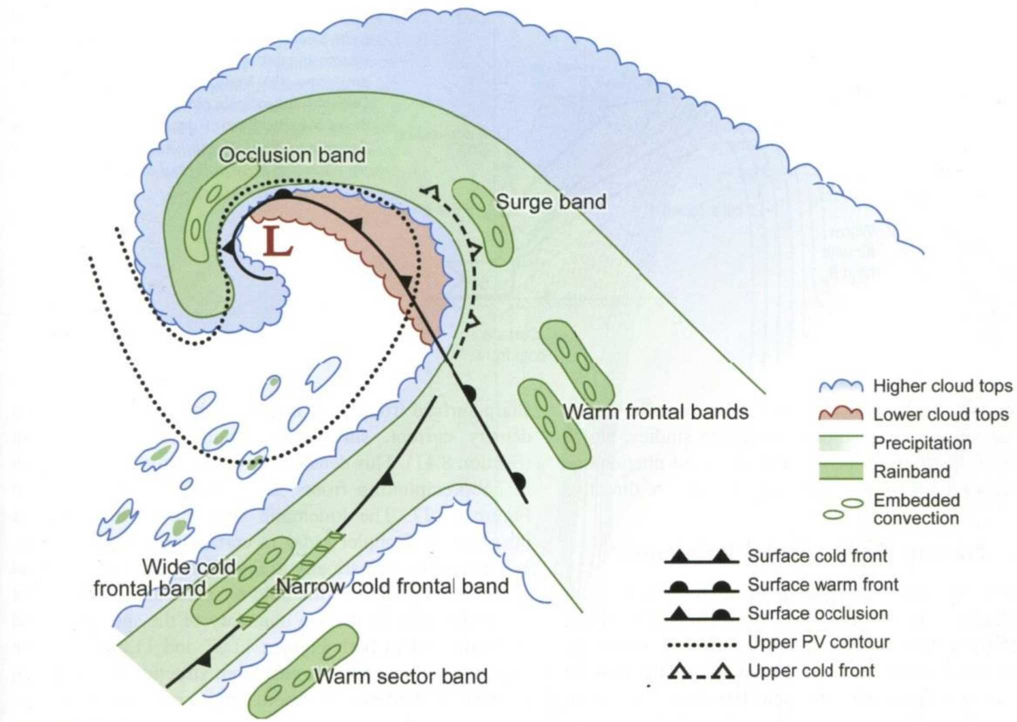
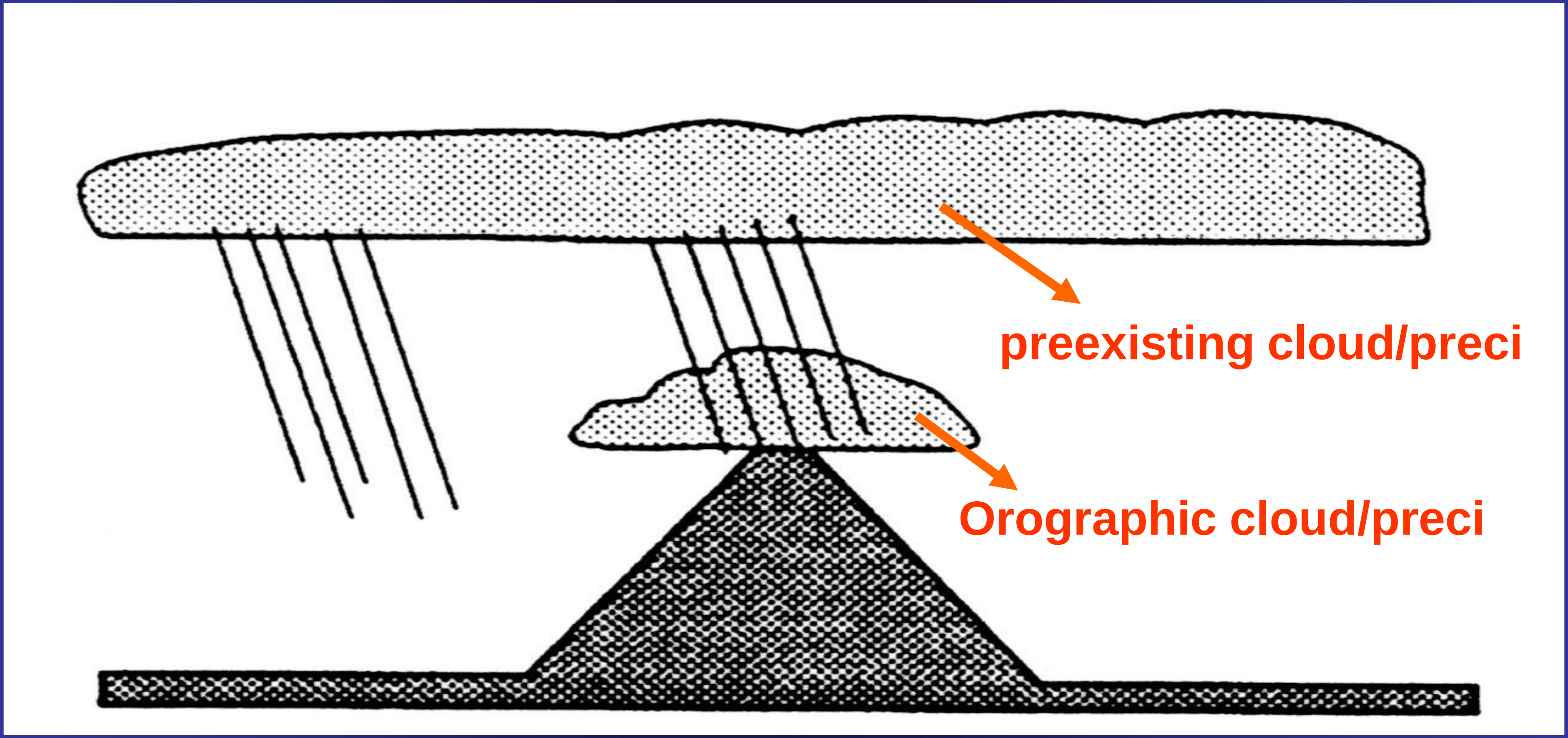


FIGURE 11.24 Idealization of the cloud and precipitation pattern associated with a mature extratropical cyclone.

Houze (2014)

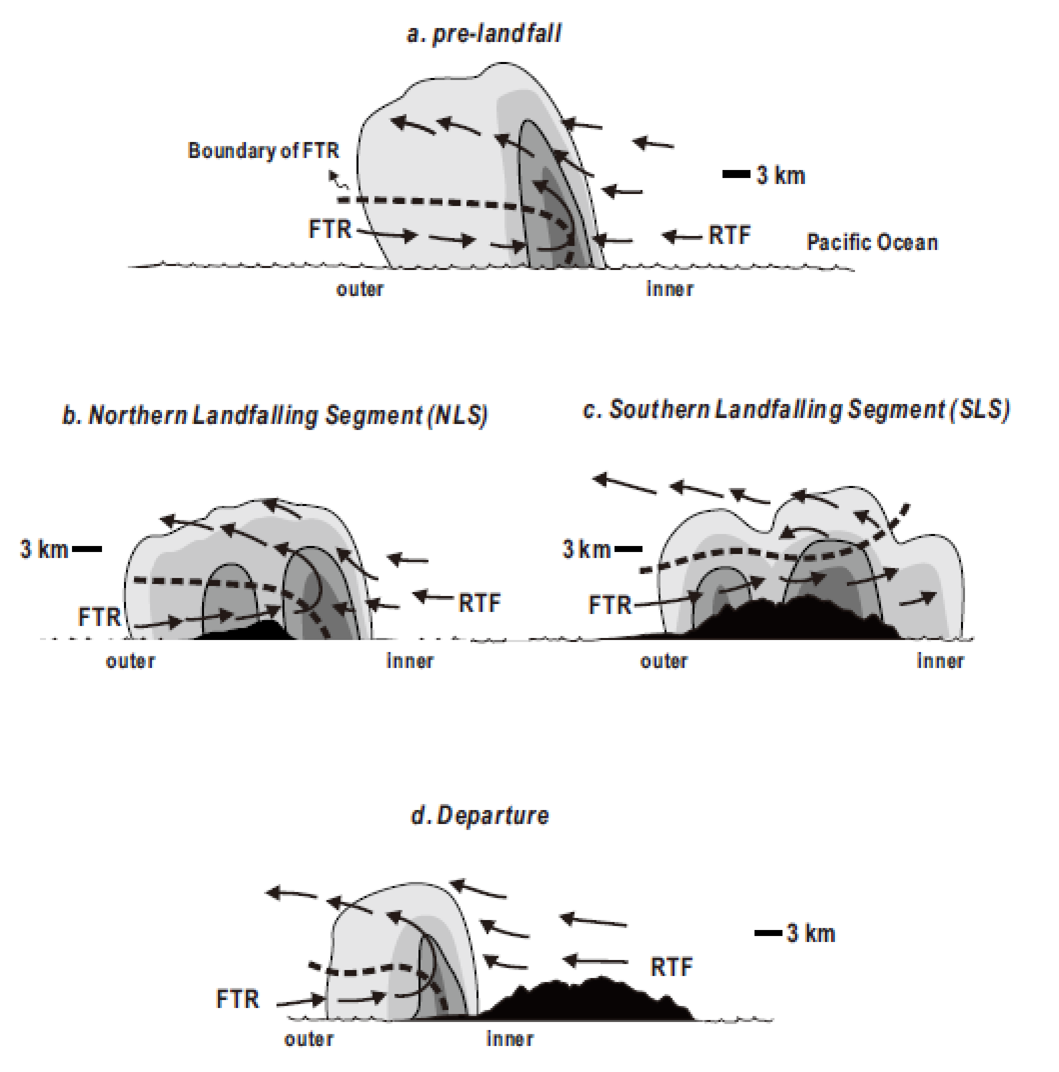
Orographic precipitation is not just a simple "airflow-terrain interaction" problem

Microphysical interaction between preexisting cloud and orographically generated cloud

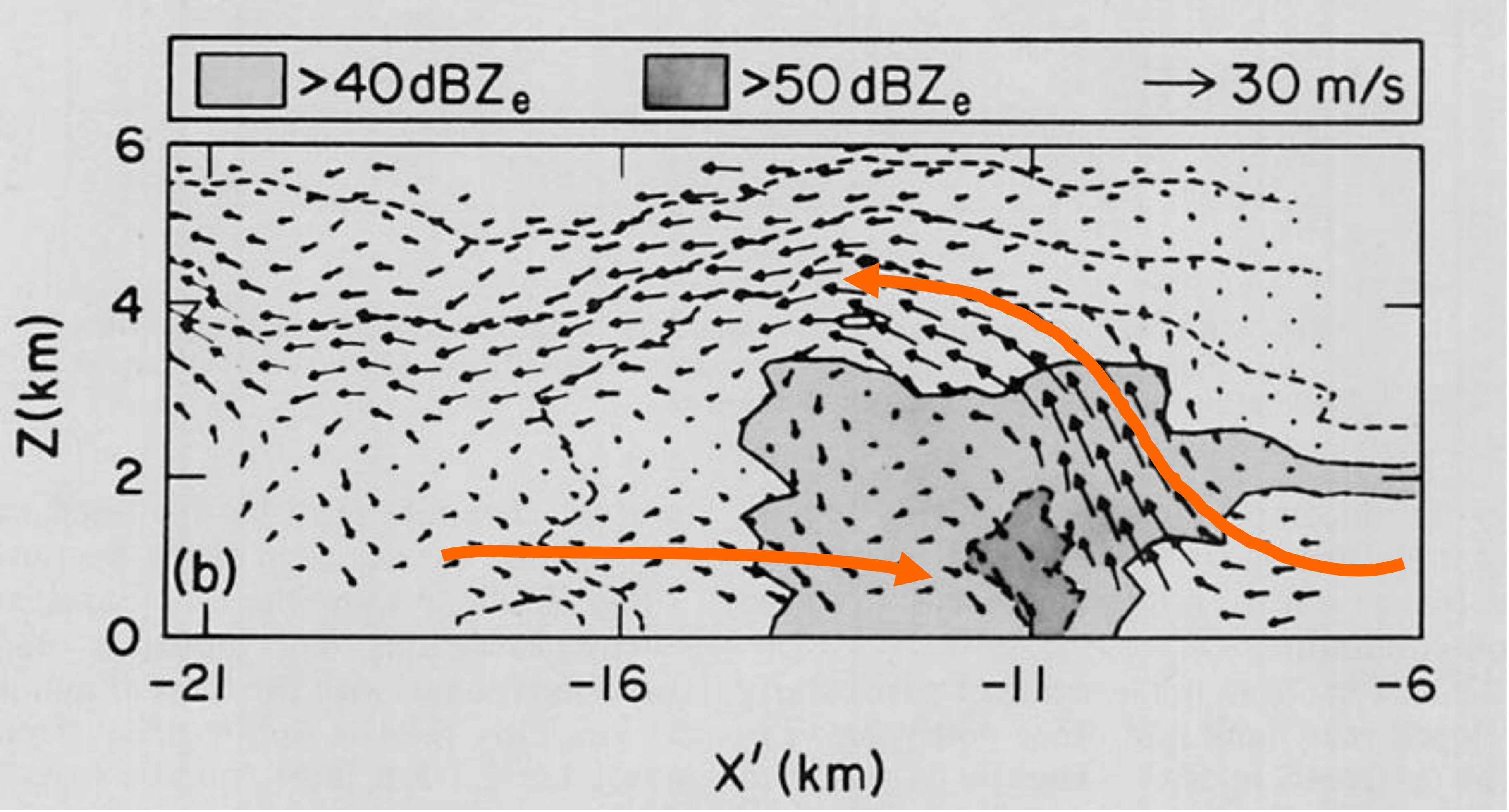


Tropical cyclone rainbands and fronal rainbands are generated as a consequence of internal dynamics of TCs and fronts

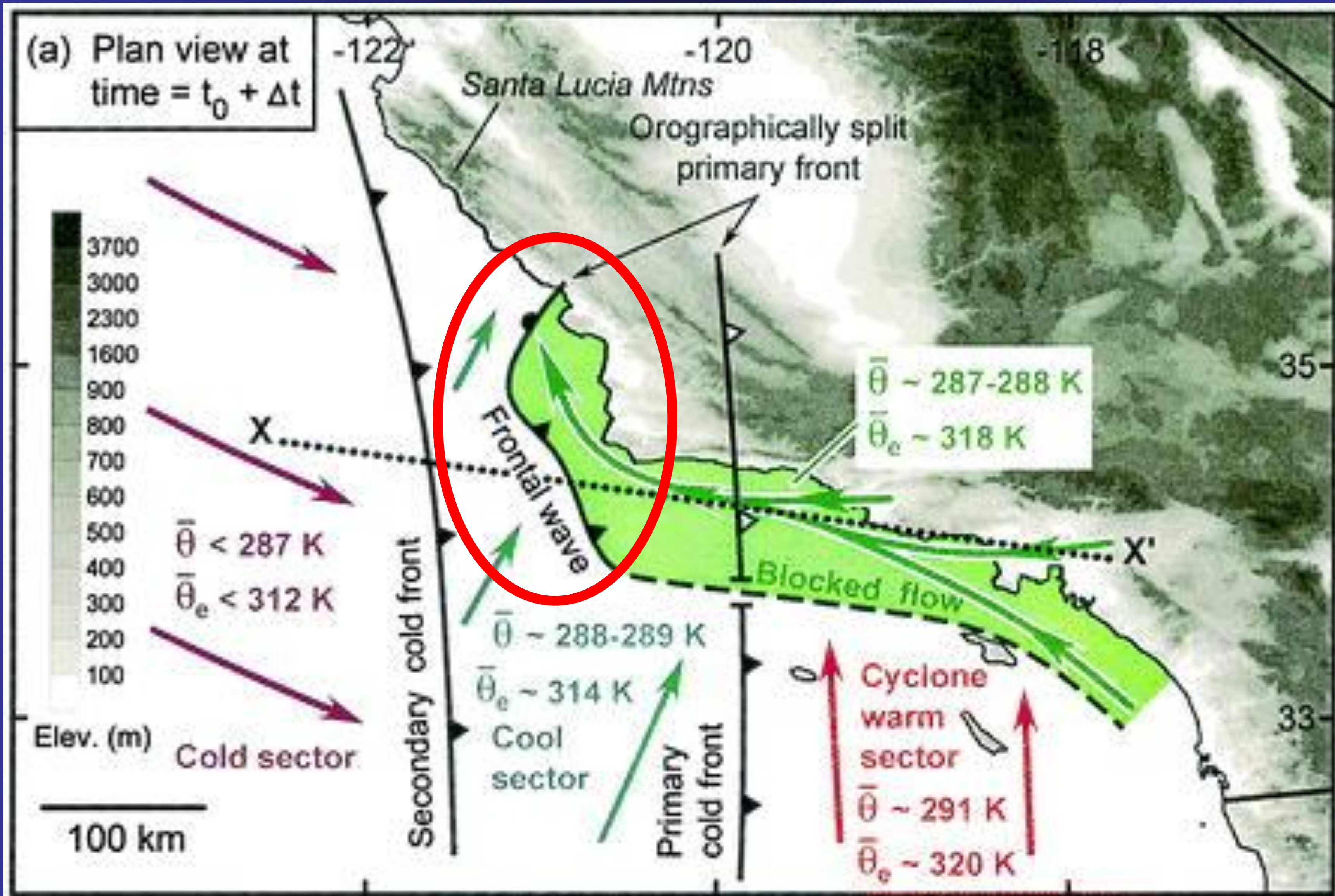
An example showing rapid evolution of a TCR as it passed over complex terrain of northern Taiwan (Yu and Tsai 2015)



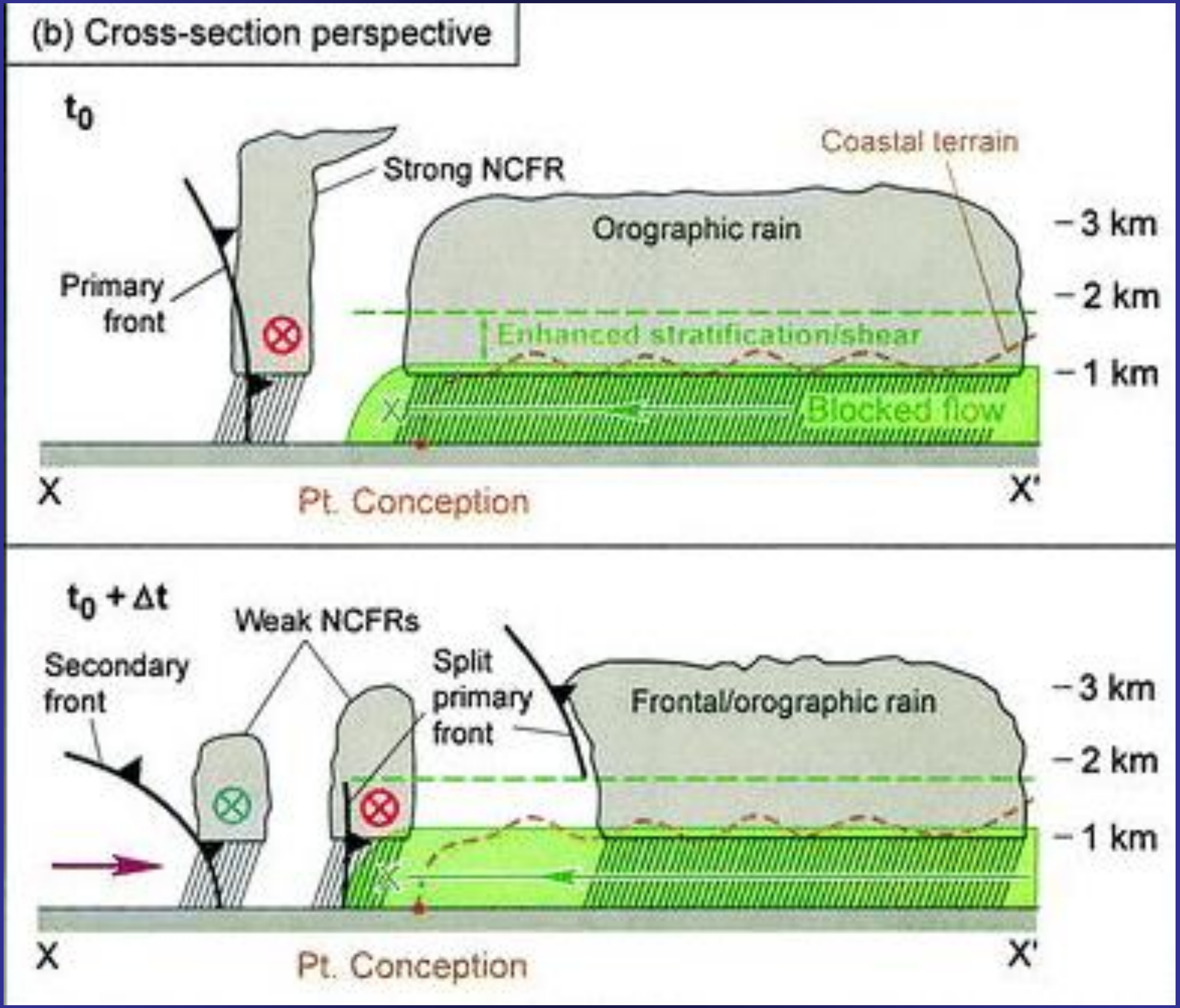
Airflow and precipitation structure of a narrow cold frontal rainband (Carbone 1982)



Strong interaction between the blocked, along-barrier flow and postfrontal flow (Neiman et al. 2004)



Neiman et al. (2004)



Distortion of frontal zone by upstream blocking

Yu and Bond (2002)

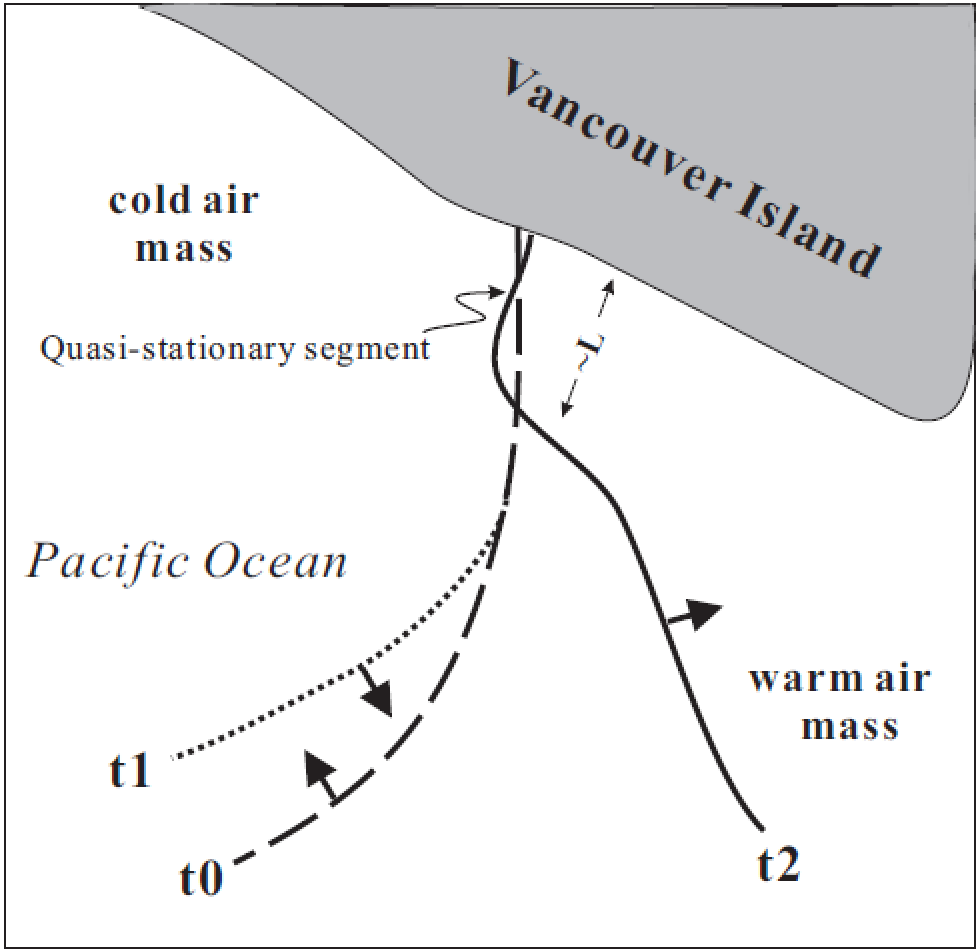
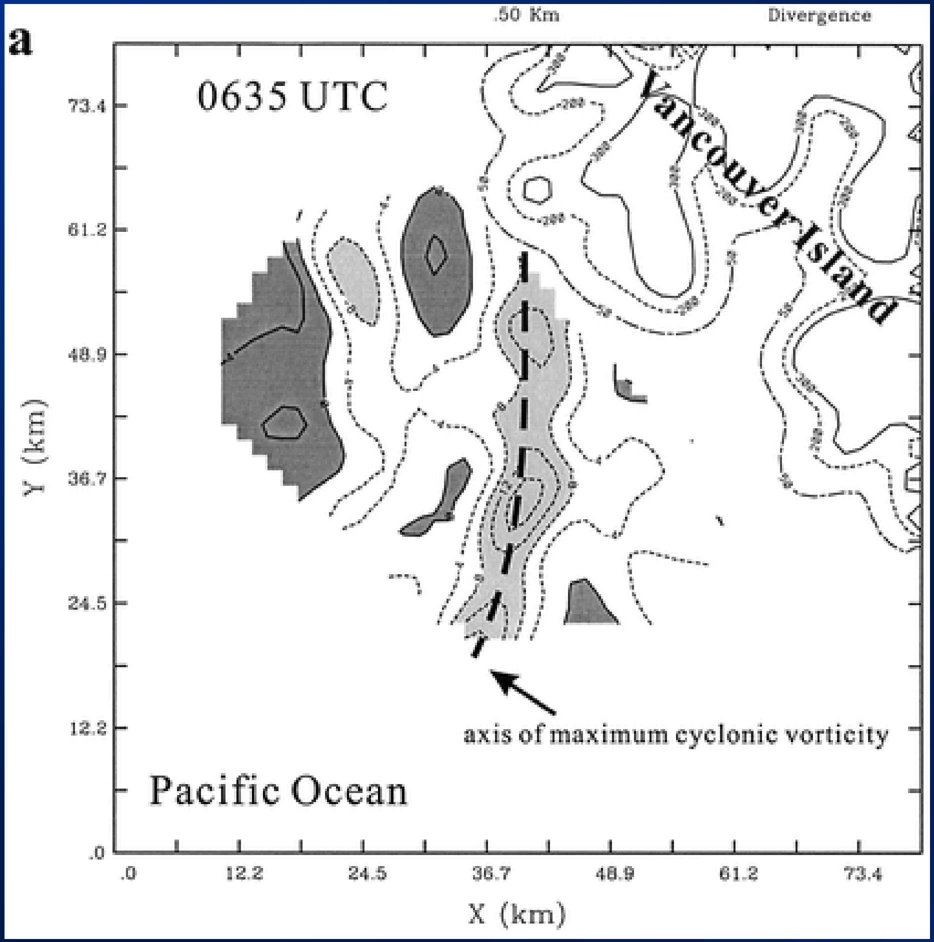


Figure 14. Schematic diagram qualitatively illustrating the movement of the front during the aircraft observation and resulting distortion of the nearshore segment of the front in the latter part of the flight. The positions of the front over Vancouver Island are not indicated due to the lack of aircraft observations. Thick arrows denote the moving direction of the front. L denotes the upstream extent of the terrain blocking.

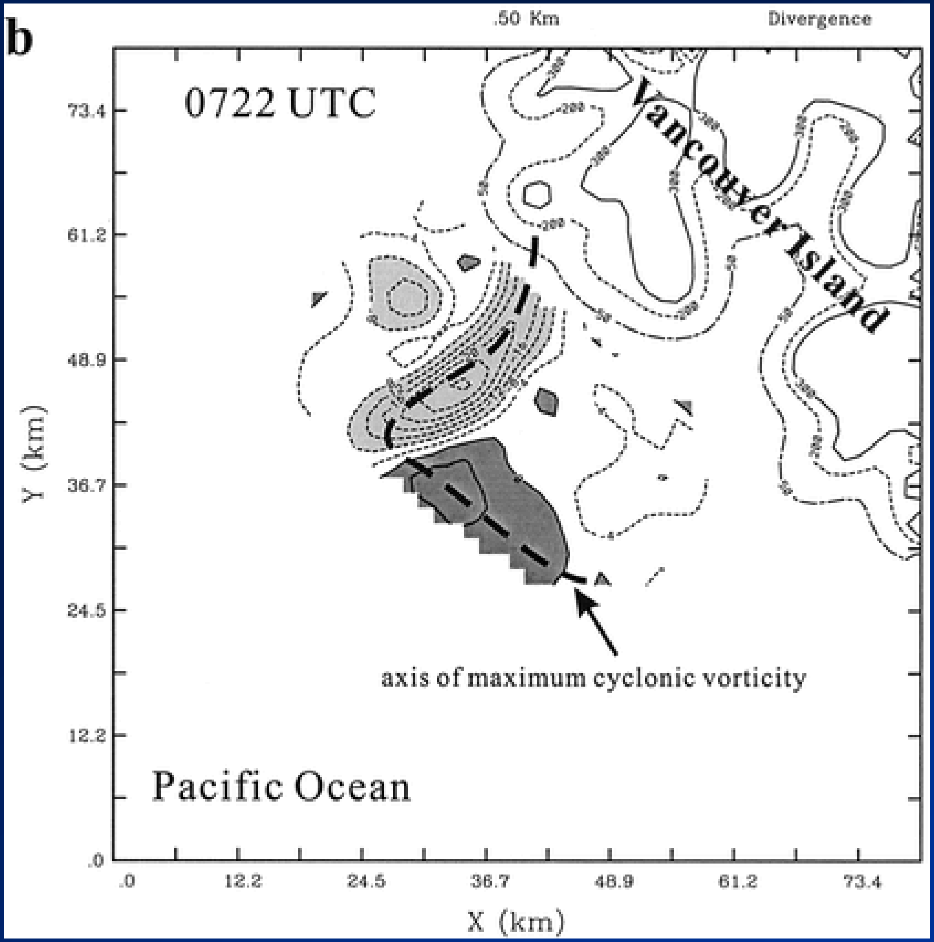
Enhanced convergence associated with frontal distortion

Yu and Bond (2002)

Before distortion

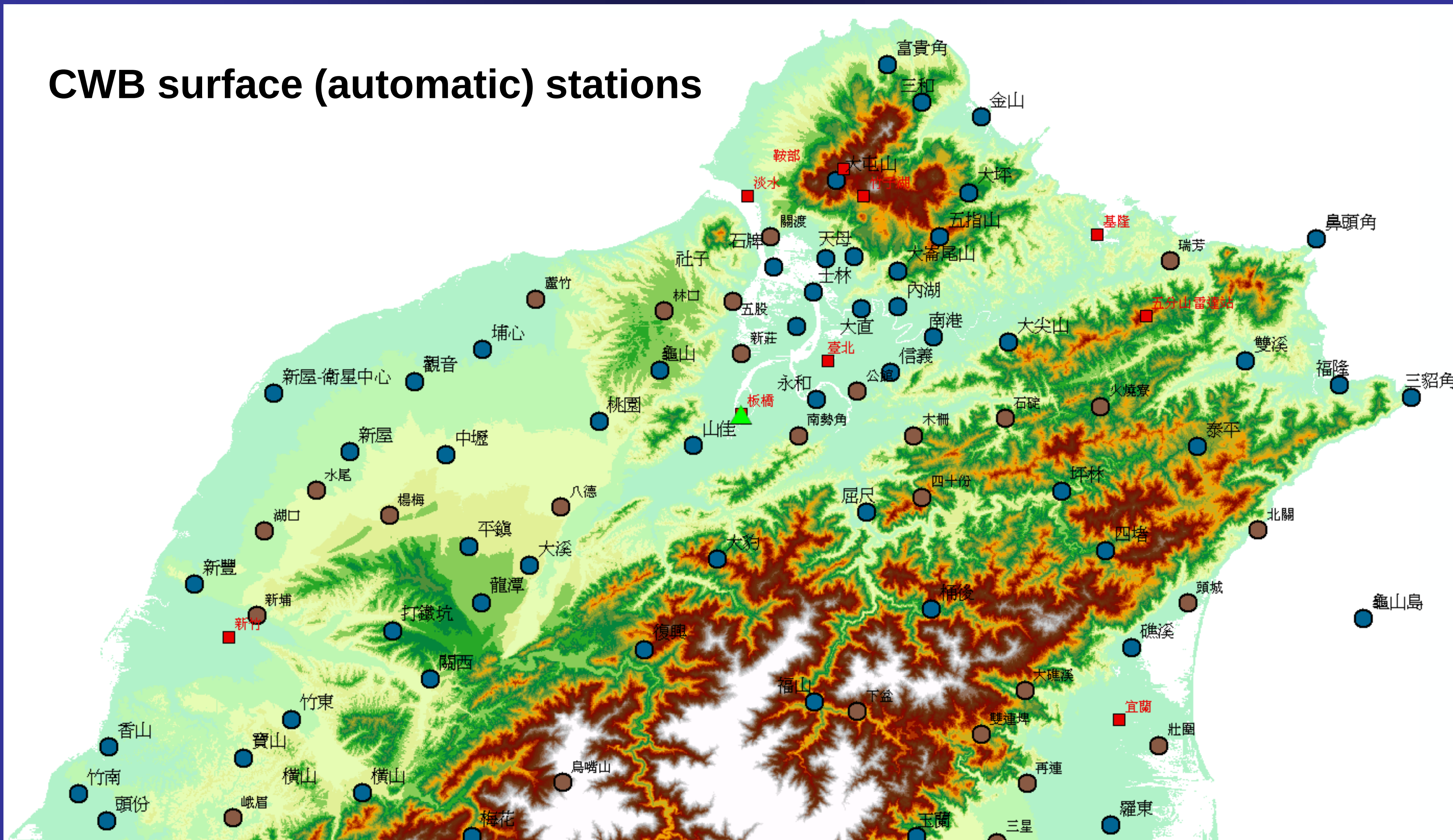


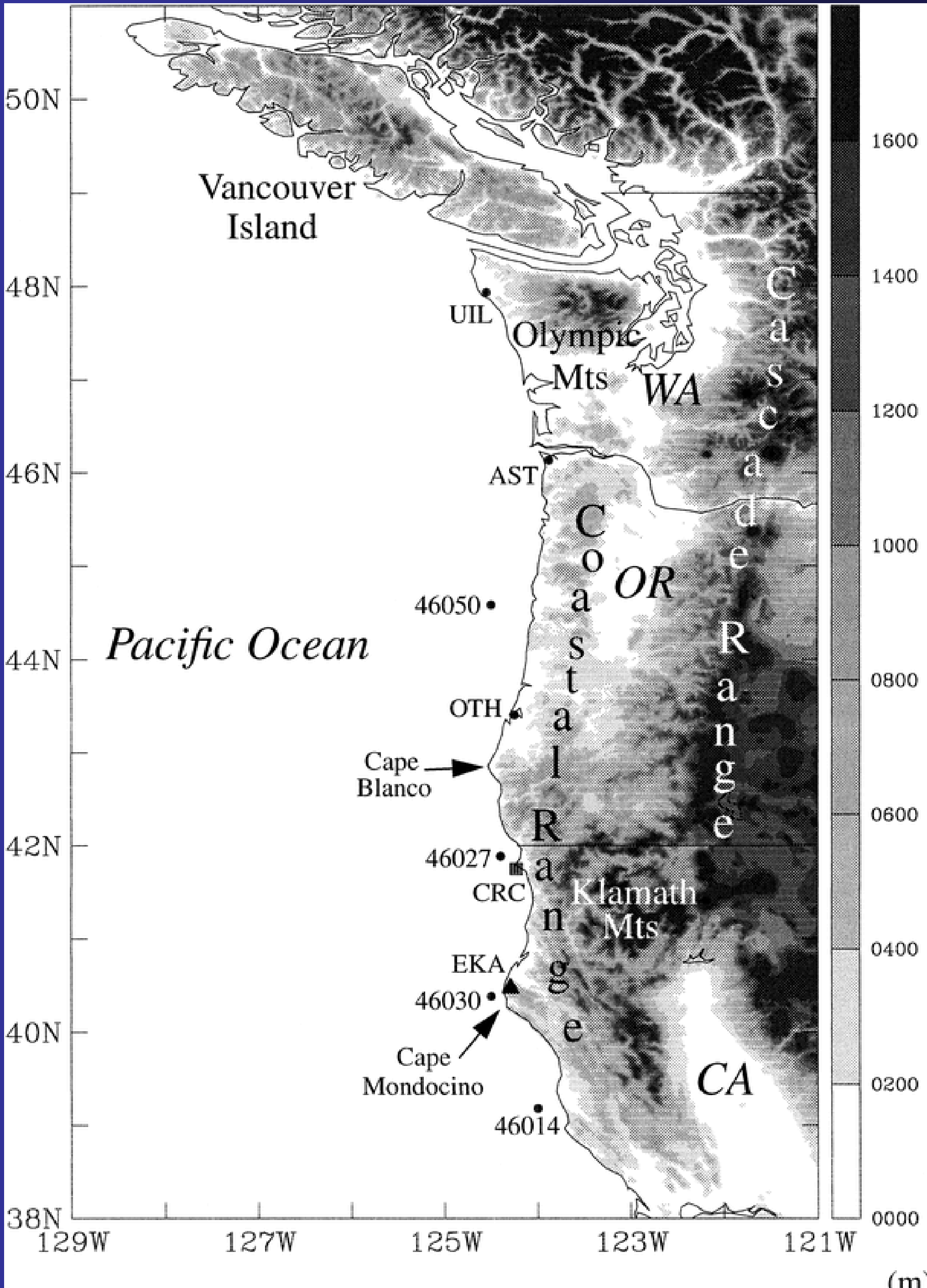
After distortion



Challenge II

Sparse observations over mountains of northern Taiwan

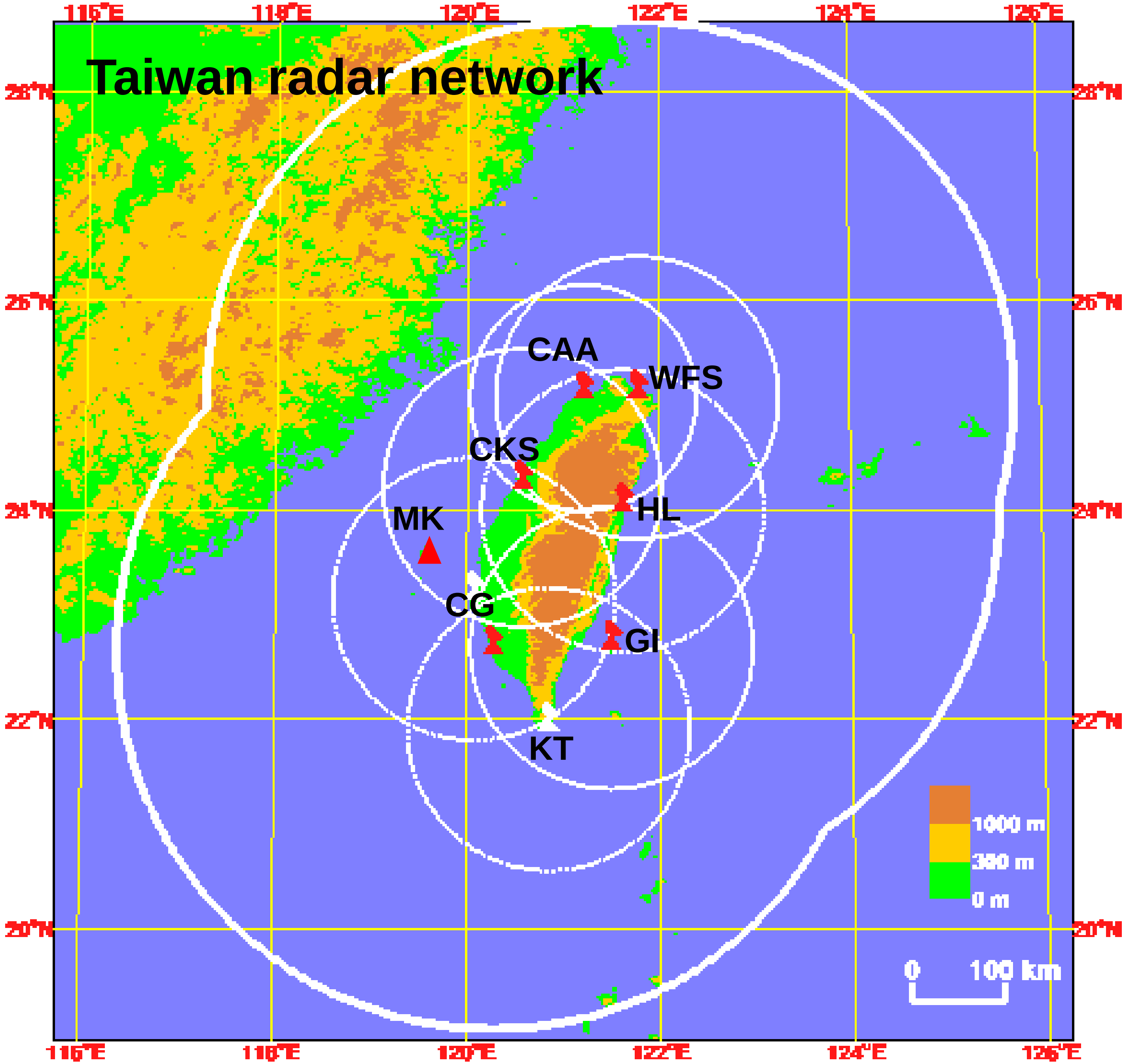




Sparse observations along the coastal zone of western U.S.

Adopted from Yu and Smull (2000)


How to obtain more data over mountains?
?
?
?
2007 7 10

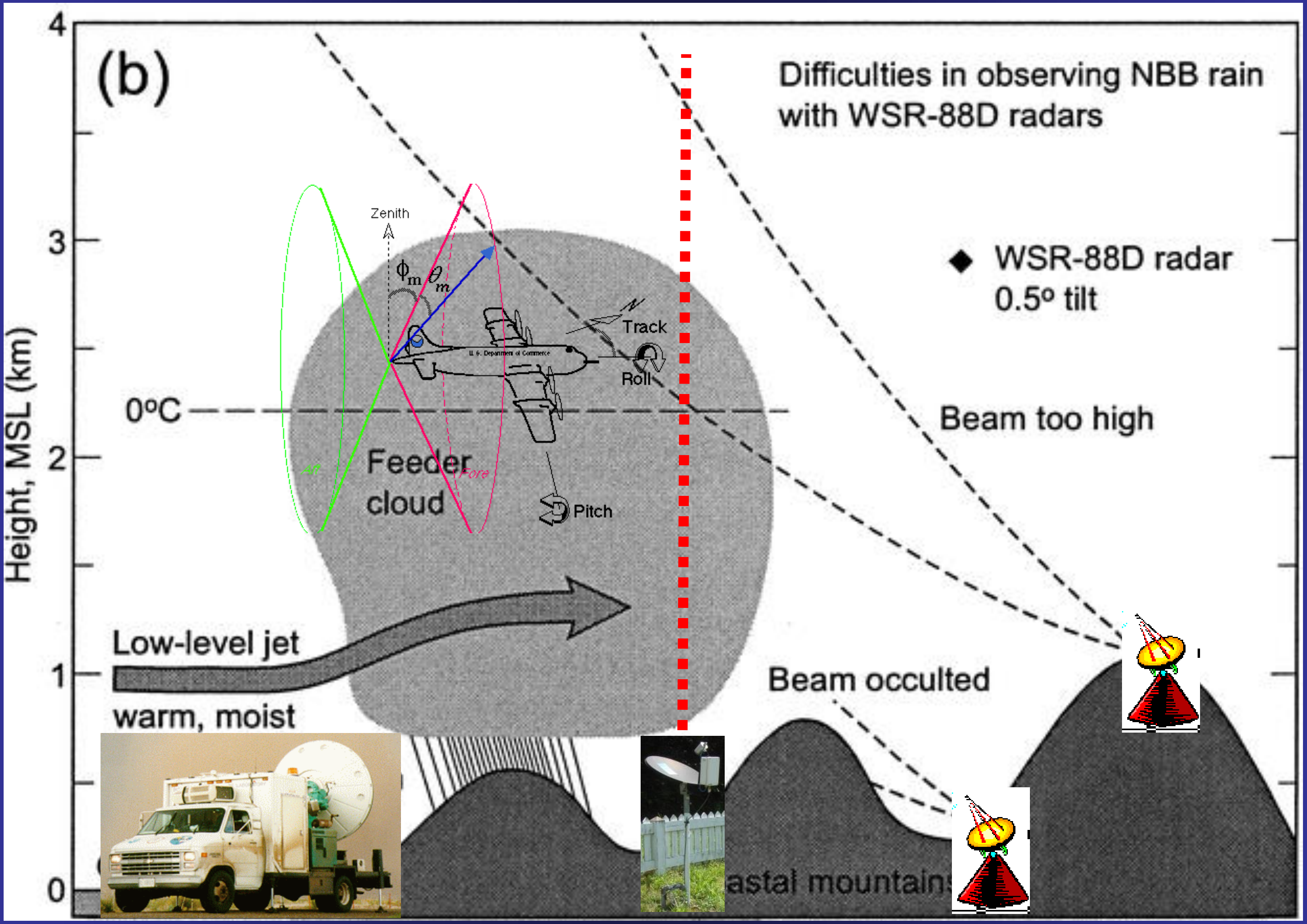


Taiwan radar network
116°E
118°E
120°E
122°E
124°E
126°E
26°N
25°N
24°N
22°N
20°N
CAA
WFS
CKS
HL
MK
CG
GI
KT
1000 m
300 m
0 m
0
100 km

The WFS radar was destroyed by Typhoon Soudelor (2015)

圖片擷取自http://www.cna.com.tw/news/firstnews/201508105018-1.aspx

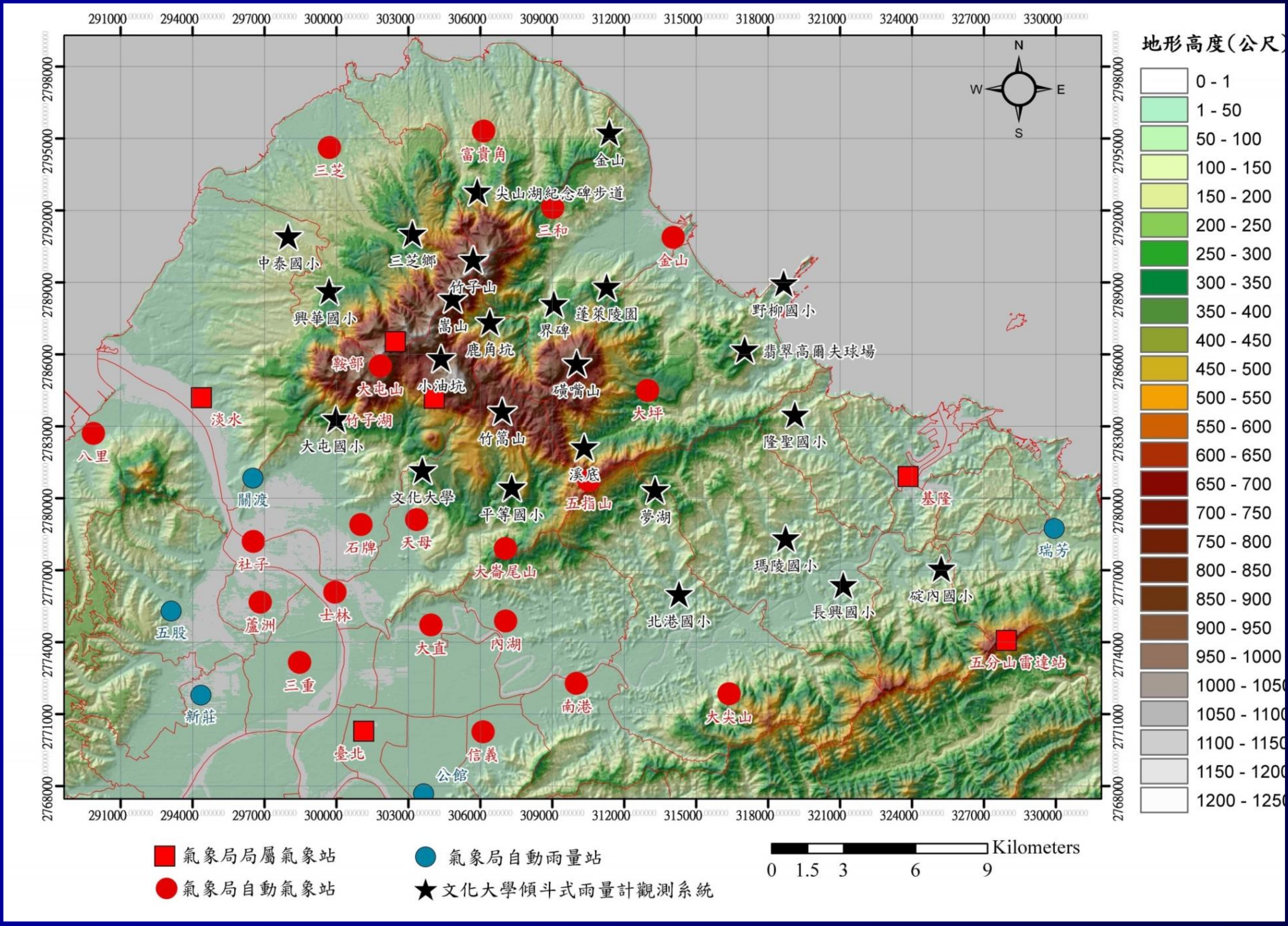
Aircraft and radar observations are important for OP research



Previous field experiments conducted to improve understanding of precipitation processes nearby topography

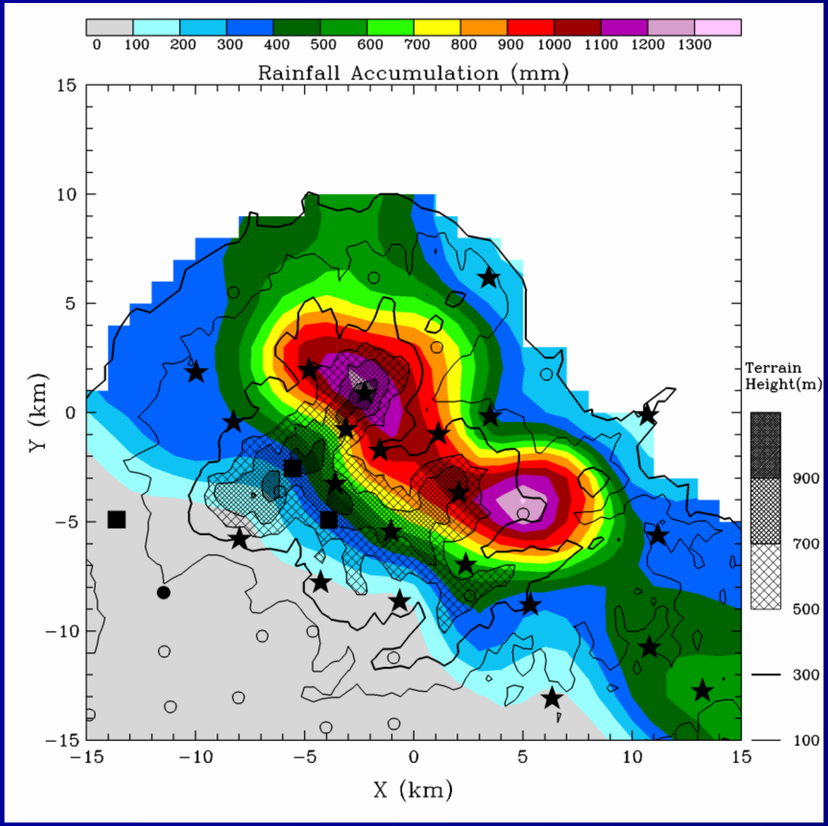
- COAST (Bond et al. 1997)
- CALJET (Ralph et al. 1999)
- MAP (Bougeault et al. 2001)
- IPEX (Schultz et al. 2002)
- IMPROVE-II (Stoelinga et al. 2003)
- TiMREX (2008)

Rain Gauge Network over Da-Tun Mountains (DTRGN)



240-h rainfall accumulation from 18 cases during the northeasterly monsoon (2011-2013)

DTRGN+CWB



CWB