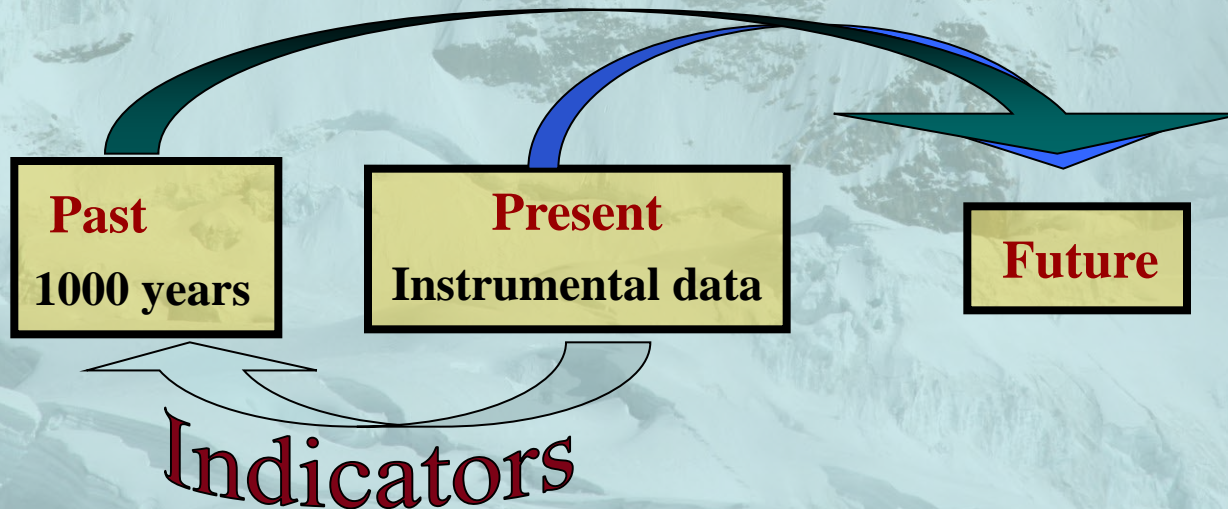


**Climate change, glacier retreat and water resources availability in  
high mountain cities: case of Bolivia**

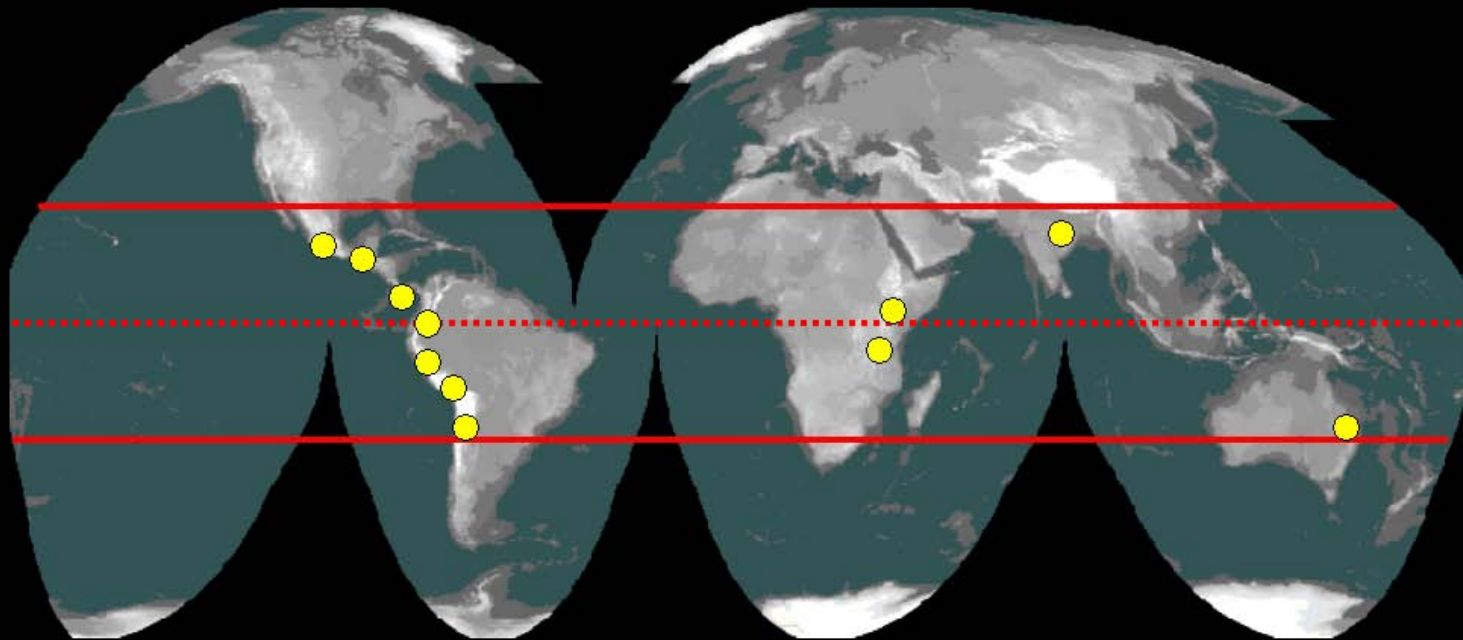
**Edson RAMIREZ Ph.D.**

## Glaciers and Altitude Water Resources Climate and Environmental Indicators

- ✓ The evolution of water resources
- ✓ The variability of the climate - hydrosphere - cryosphere in high altitude regions



# Tropical Glaciers distribution in the world



5% of the world's mountain glaciers

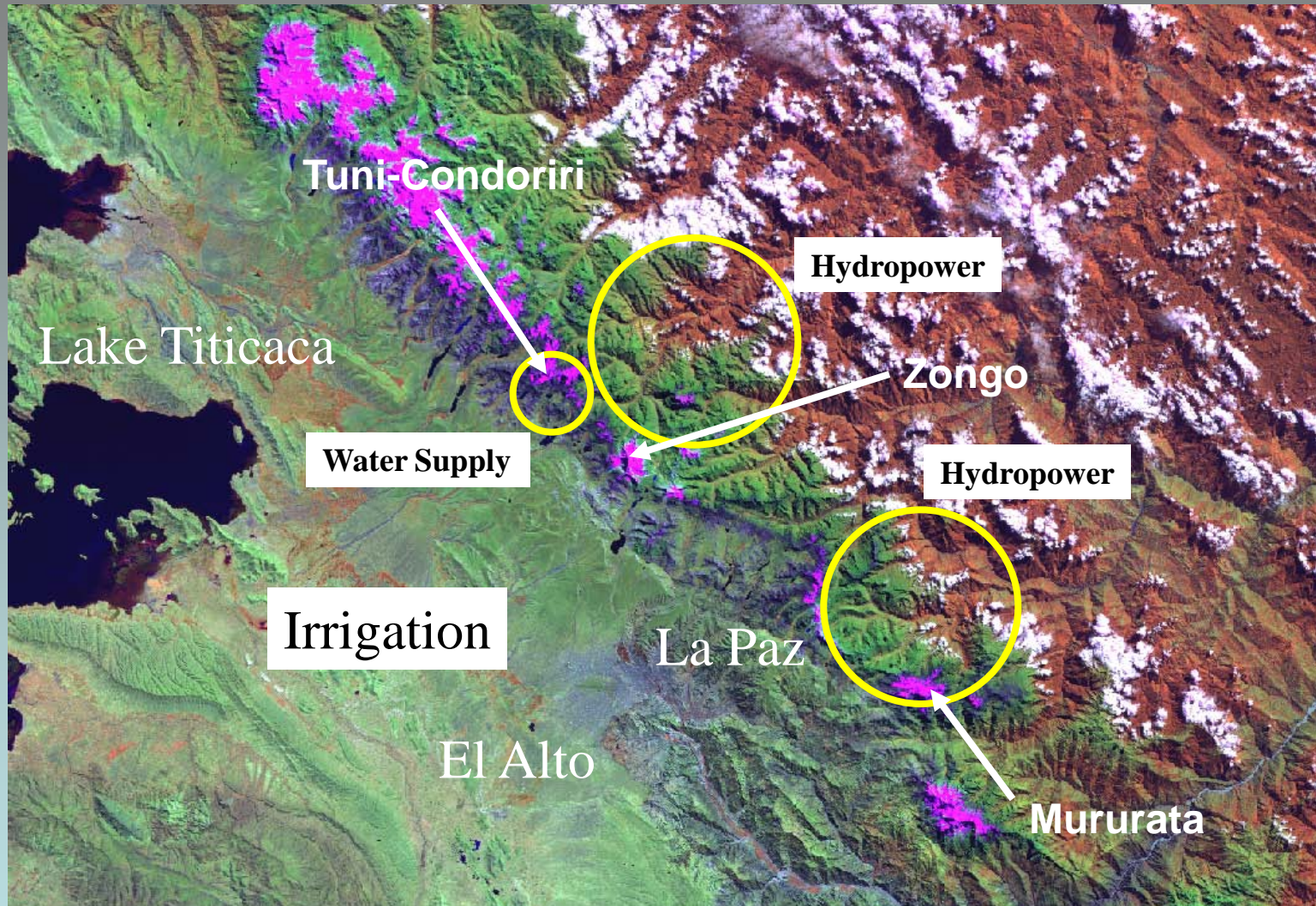
99% are concentrated in the Andes

70% in Perú, 20% in Bolivia, 10% in the rest

# Location of the “Cordillera Real” BOLIVIA



# Water glaciers uses



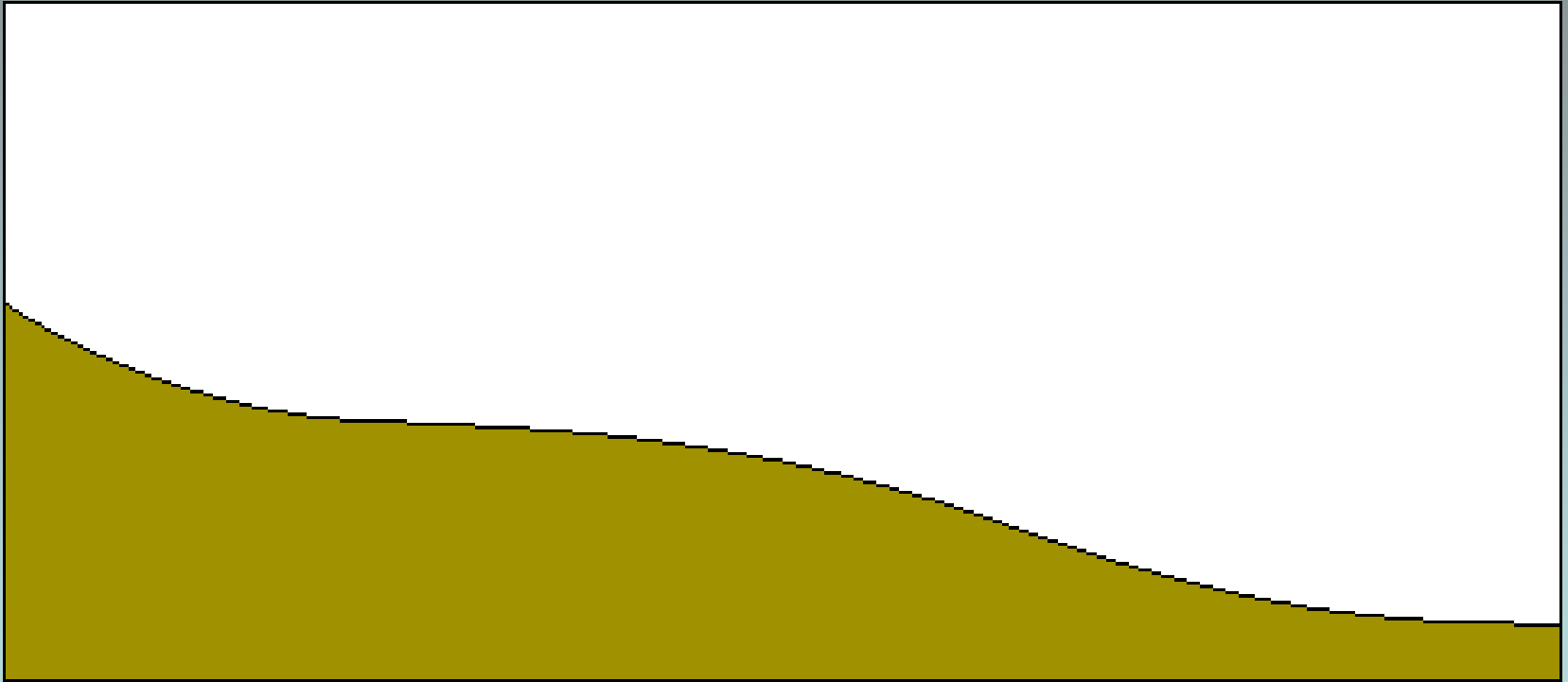
These glaciers were selected mainly because of the influence of ice melting on water resources for human consumption and hydropower generation for the city of La Paz and El Alto.

## Tropical glaciers respond to:

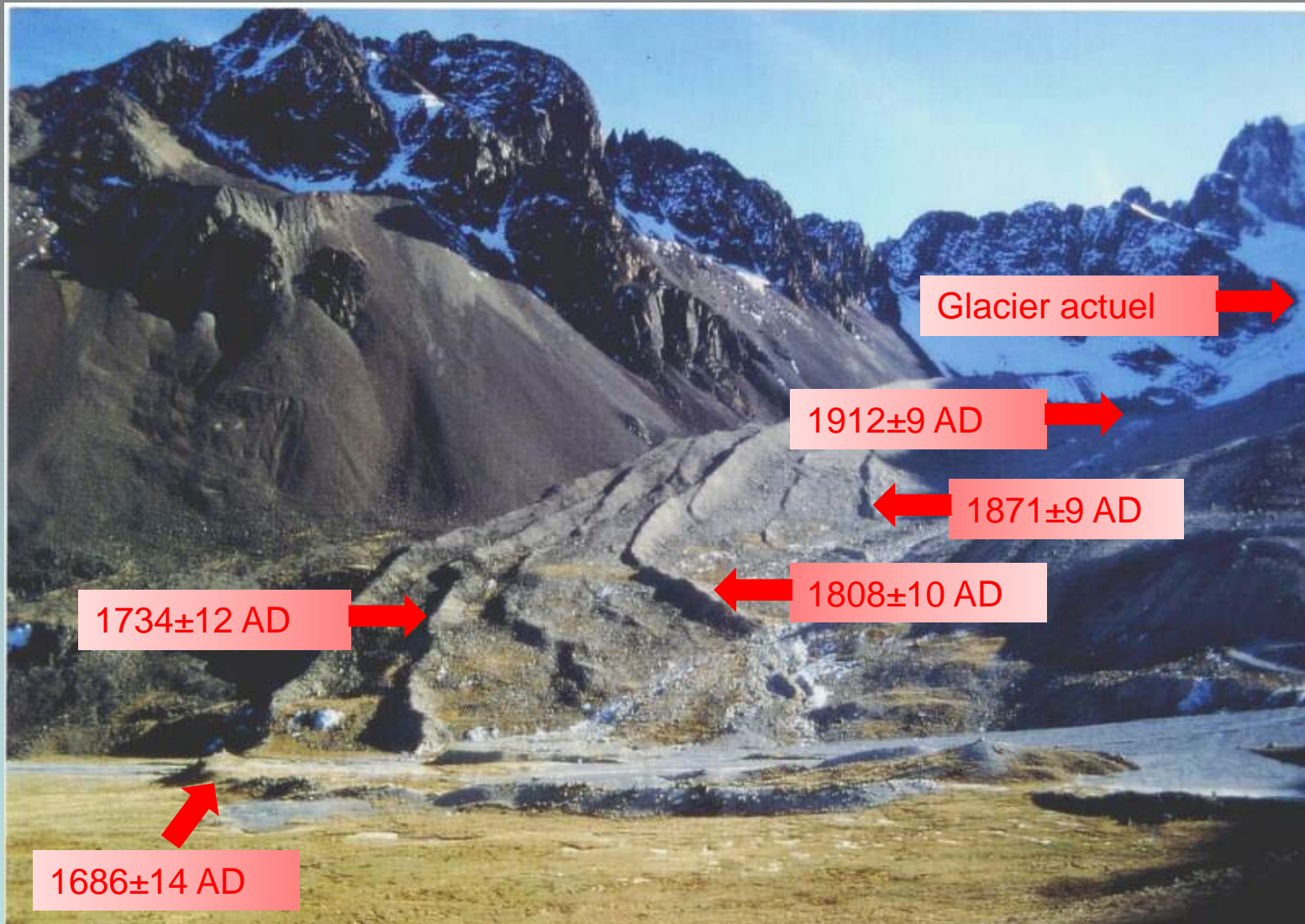
- Precipitation (Snow/Rainfall)
- Temperature
- Humidity
- Cloudiness
- Solar Radiation
- “El Niño” Climatic Events.



# Dynamics of a glacier



# Glacier fluctuation since the Little Ice Age

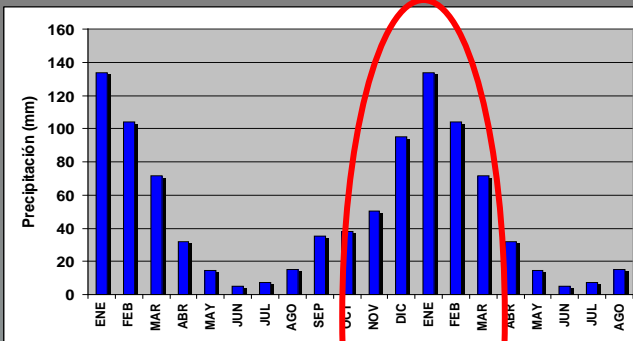


Charquini glacier (Bolivia)

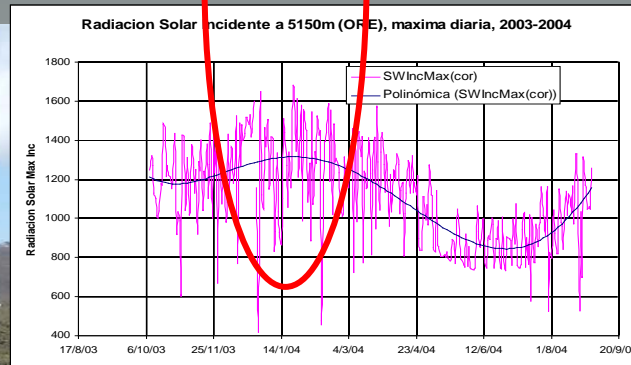
Source:  
Rabatel et al. 2005 (IRD)



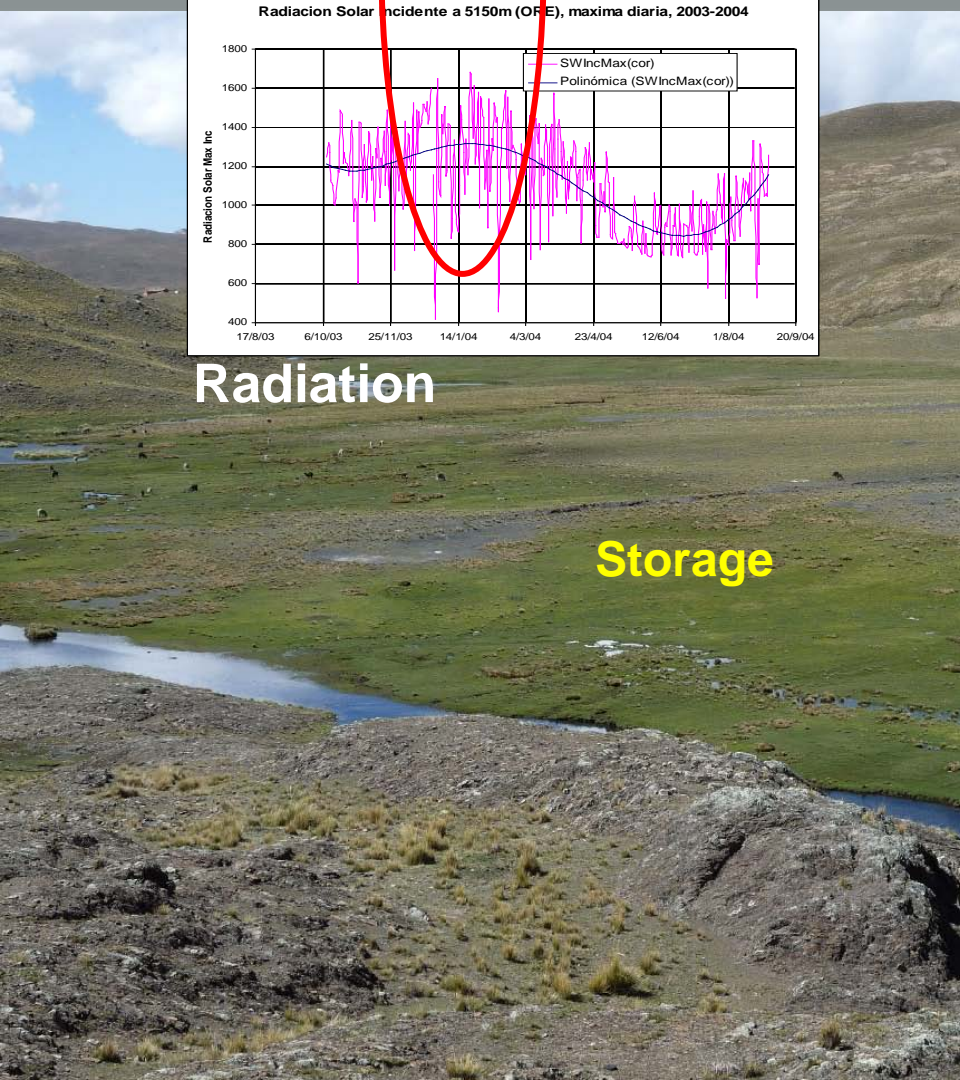
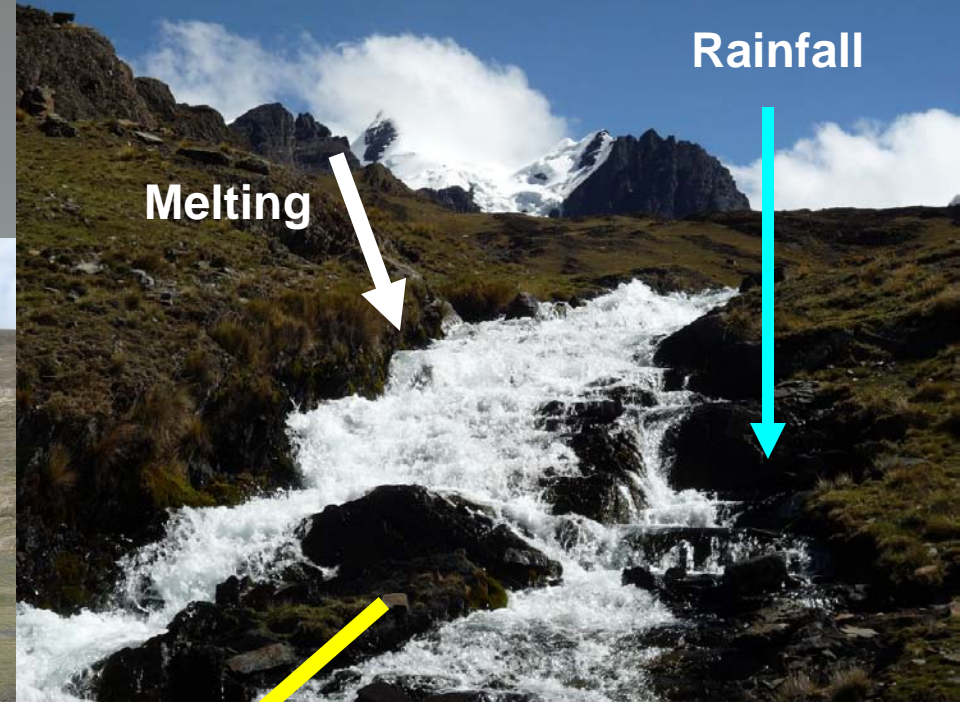
# ¿Why the Bolivian glaciers are sensitive?



Precipitation



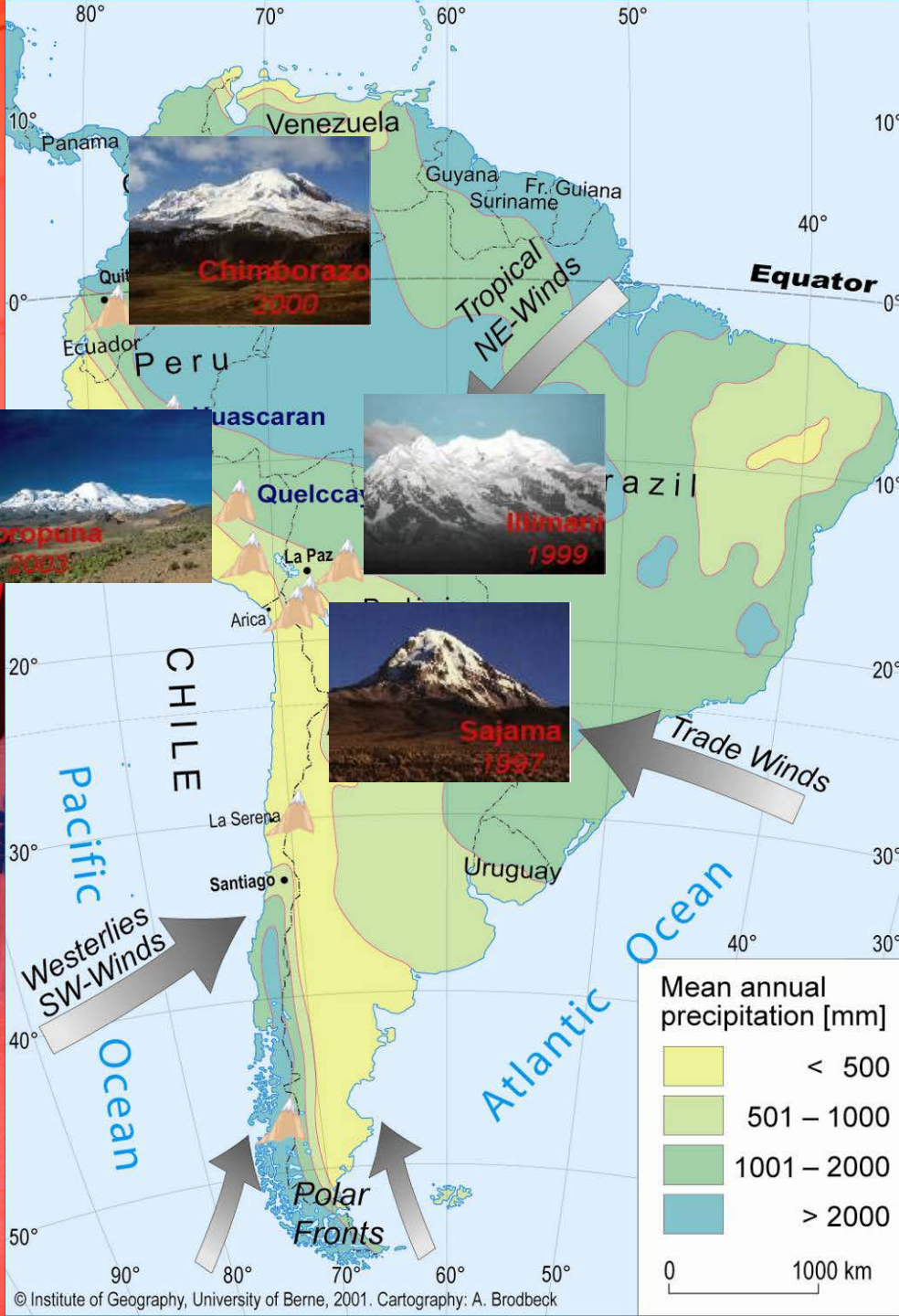
Radiation



During the summer (Rainy season)

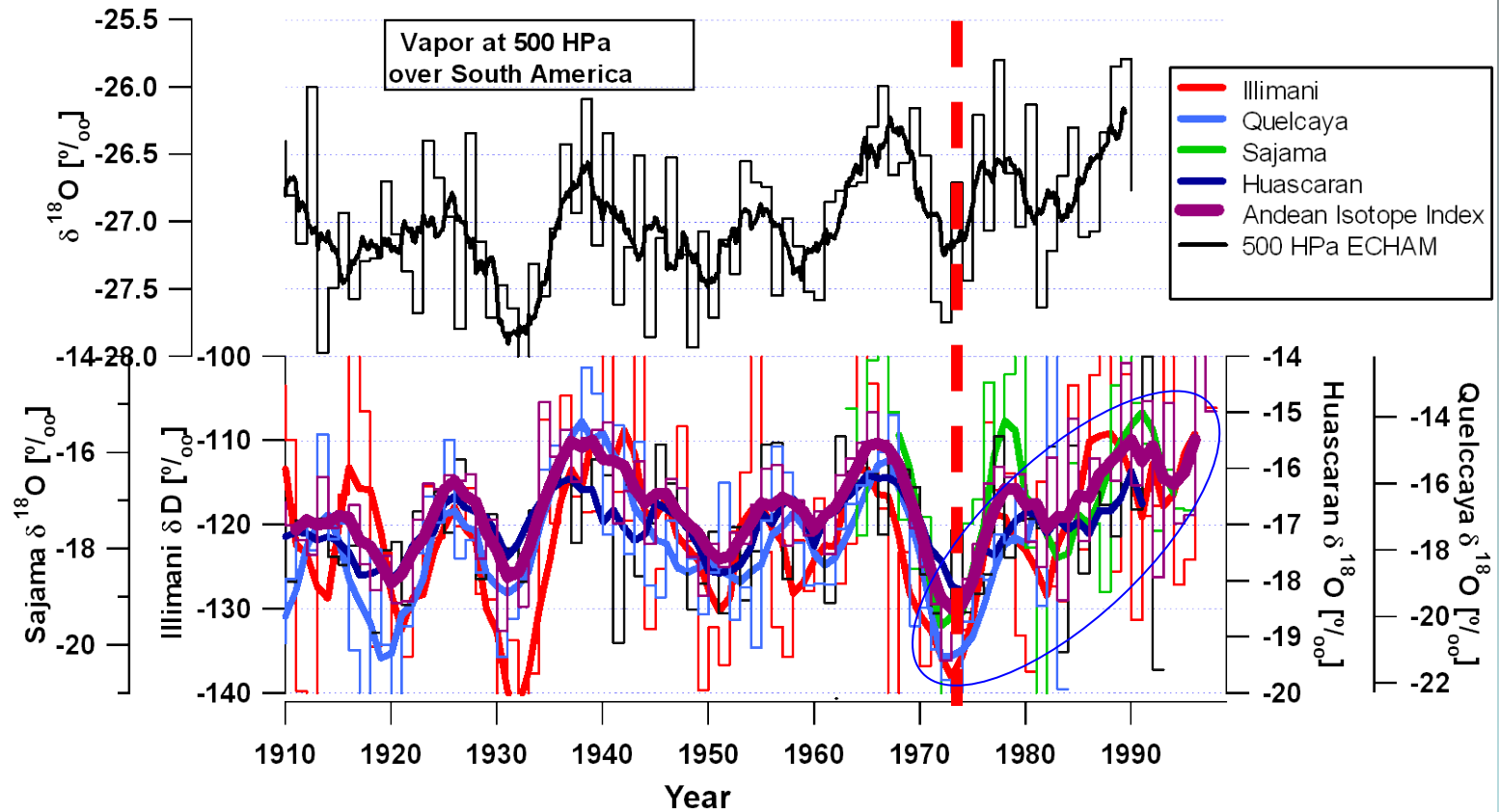
# In the Past

# In the Past: Andean Ice Cores for climate reconstruction



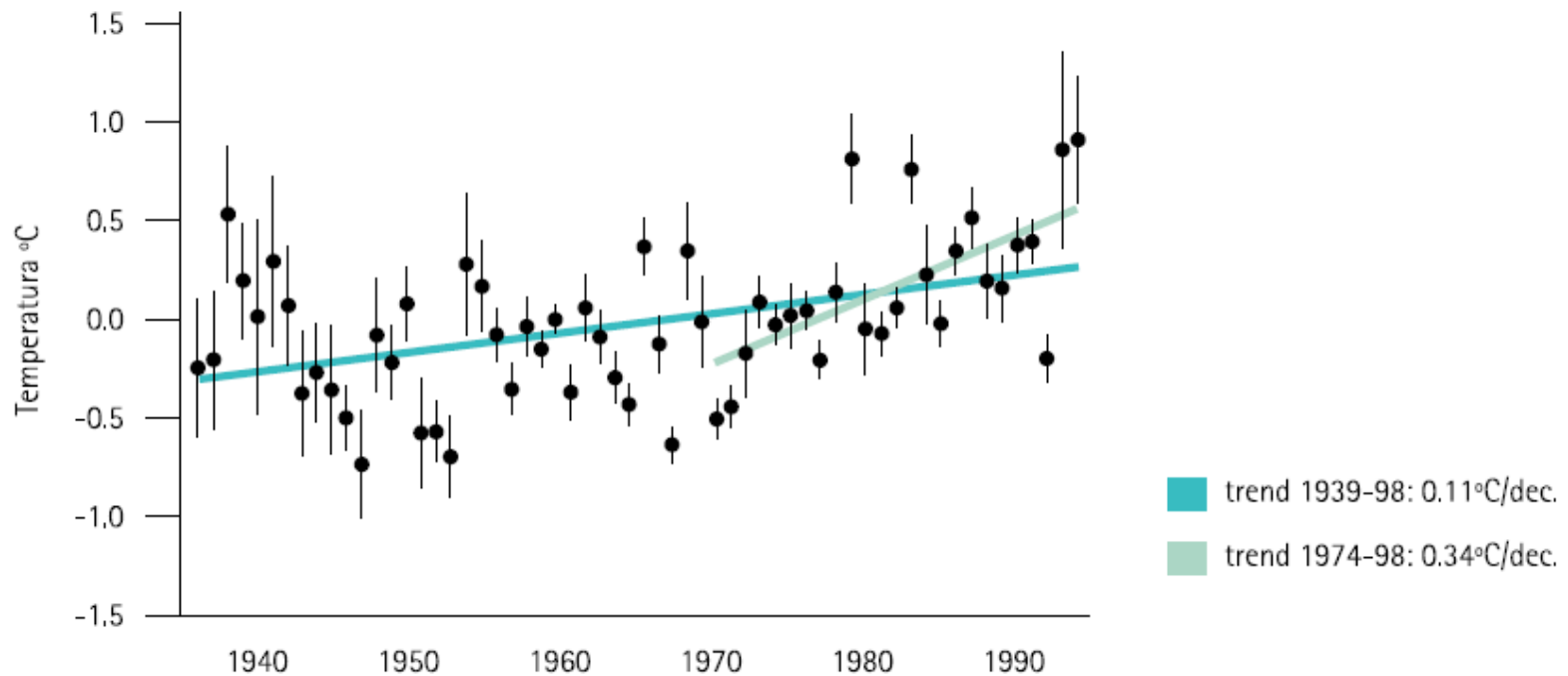
# IN THE LAST CENTURY

Four isotopic Andean drilling records compared with simulated ECHAM model outputs



(Hoffmann, Ramirez et. al. 2003, Geophysical Research Letters)

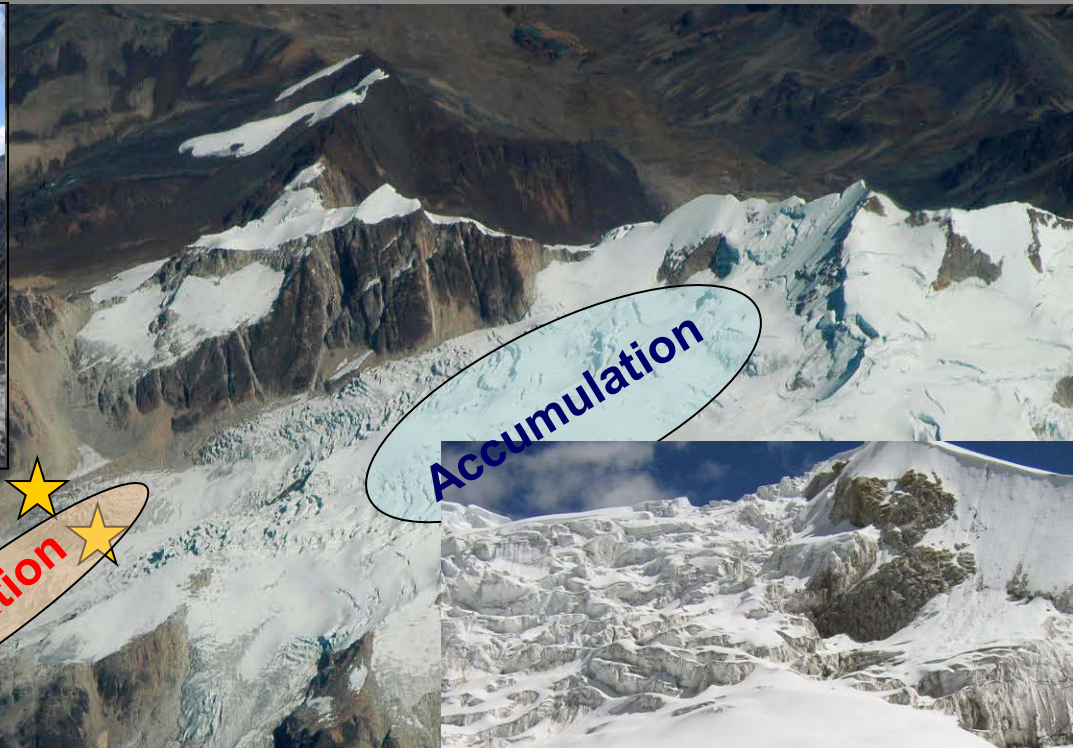
- Temperature in the tropical Andes between 1939 and 1998 -



# In the Present

# Zongo glacier - Bolivia

# Hydrology



## Aerial photogrammetric missions since 1956 to 2009

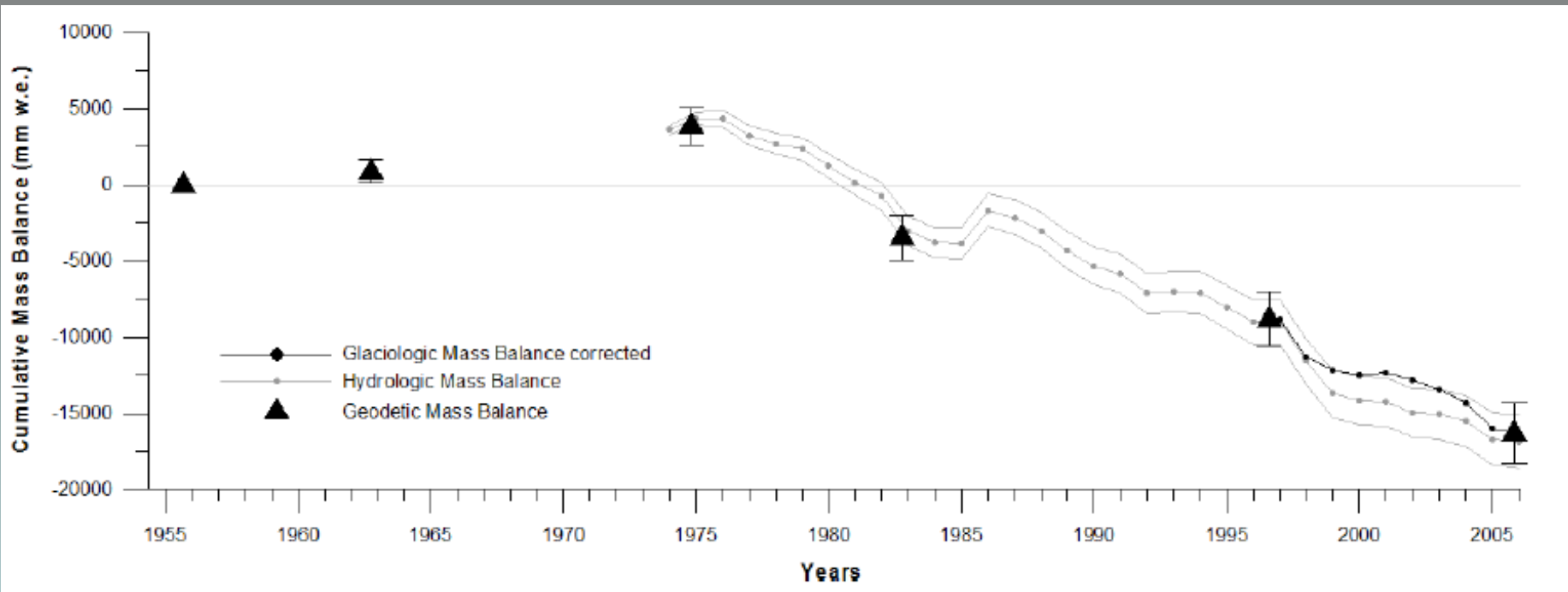


**Photogrammetric mission in 2009**

**Bolivian Air Force & IHH-UMSA**



## Zongo cumulative mass balance reconstruction since 1956

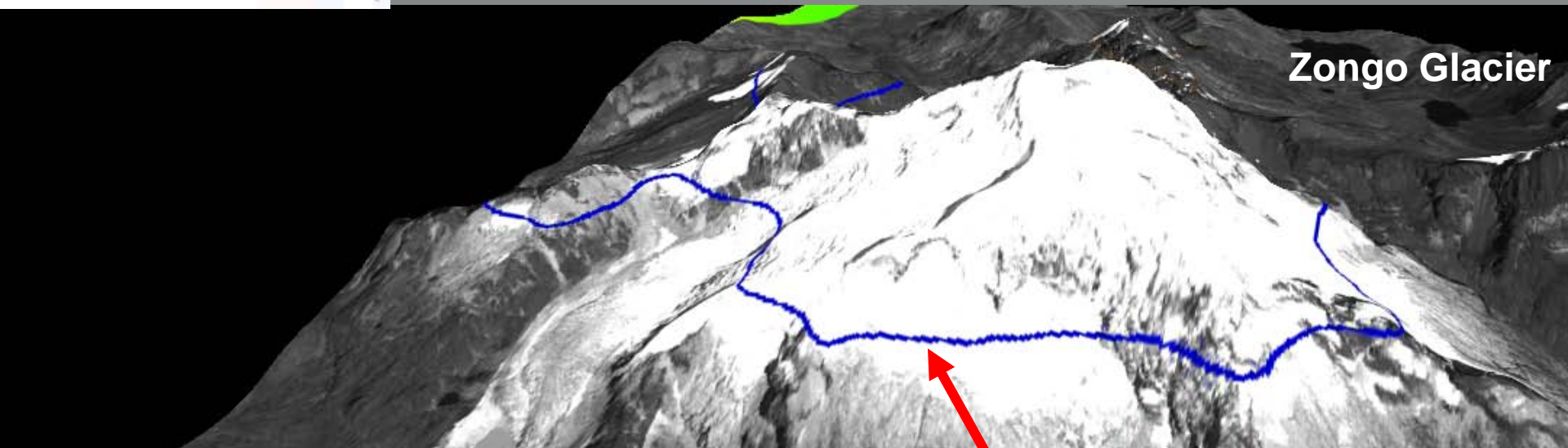


**Recent studies shows the advantage of digital photogrammetric techniques in order to reconstruct glaciological mass balance.**

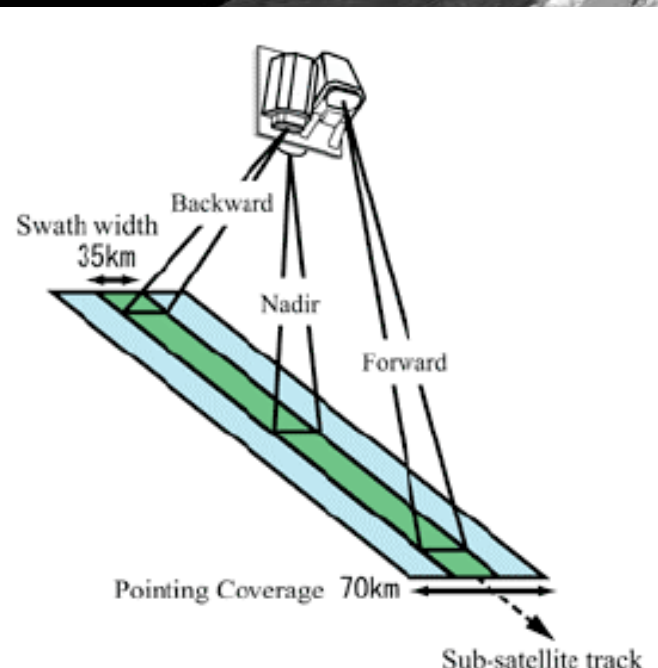
**The glaciological mass balances were calculated using yearly field measurements and adjusted according to photogrammetric data.**



# Advanced Land Observation Satellite (ALOS) JAXA - RESTEC



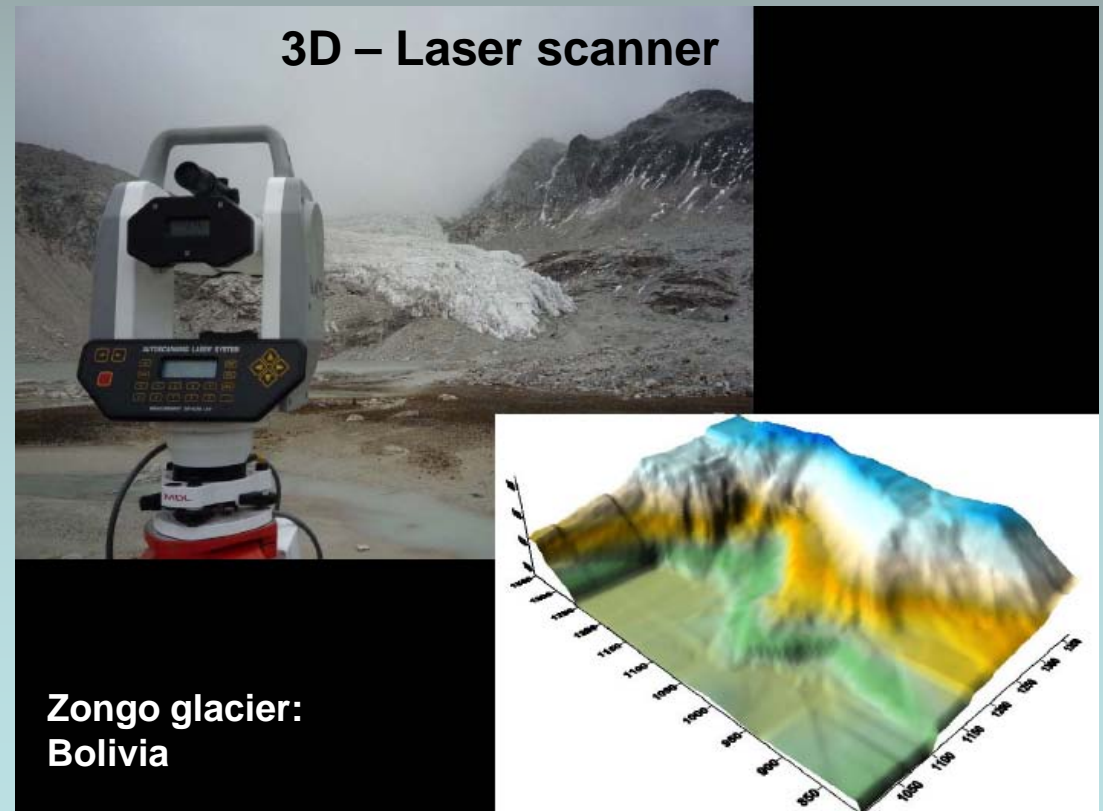
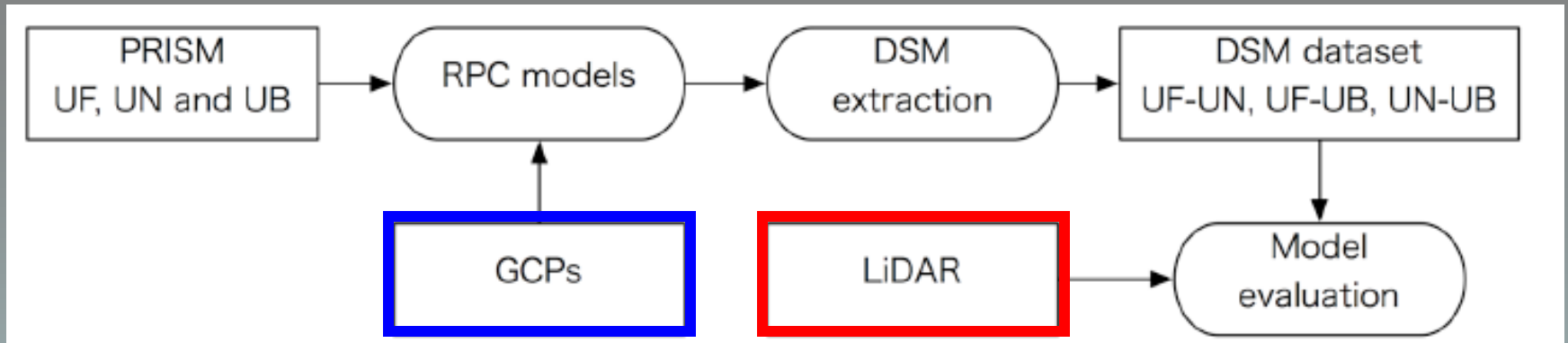
Zongo Glacier



ELA: 5500 m

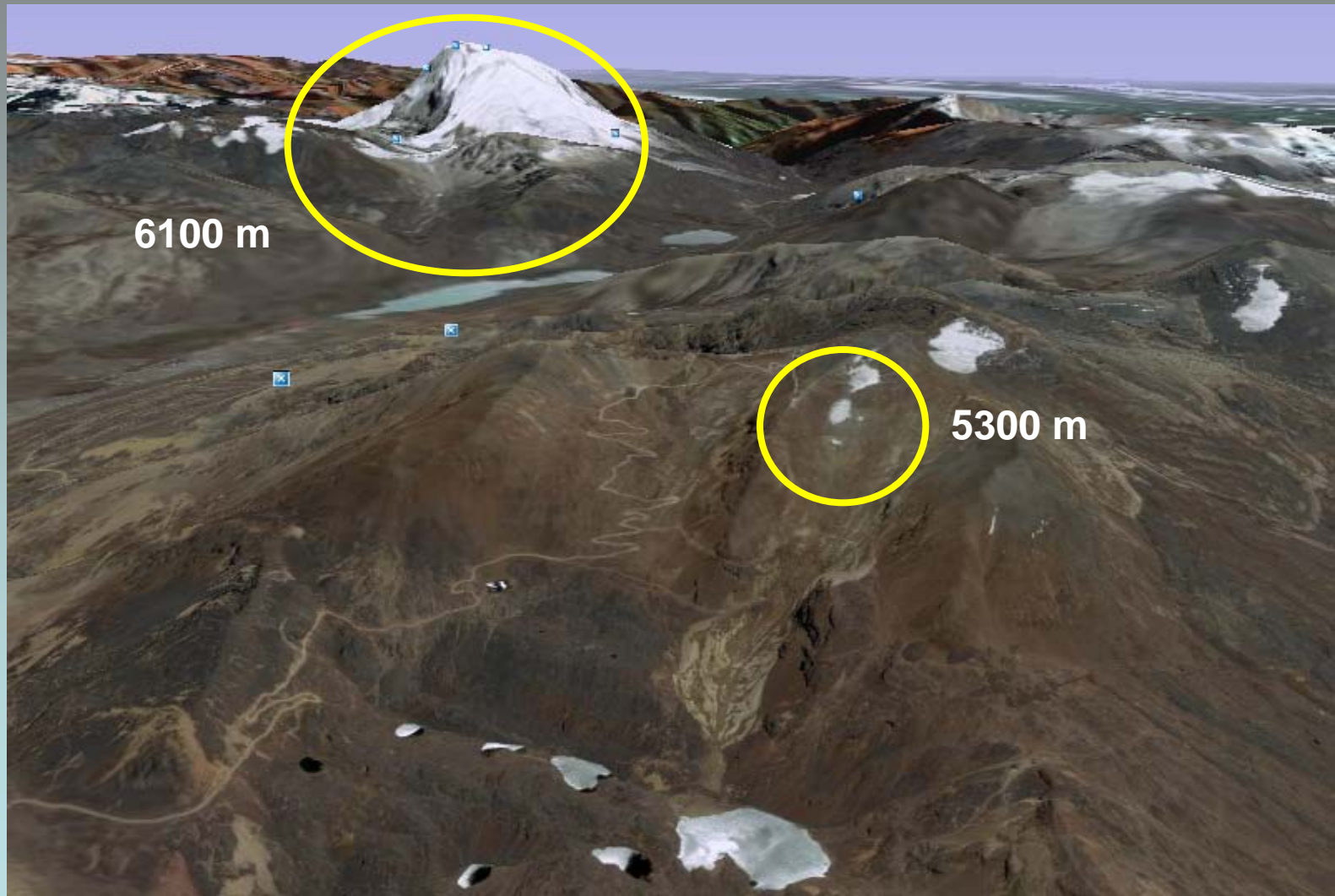
Contacts in RESTEC:  
Dr. Makoto ONO  
Dr. Nobuhiro TOMIYAMA

# COMBINING NEW TECHNOLOGIES: ALOS – DGPS - LIDAR



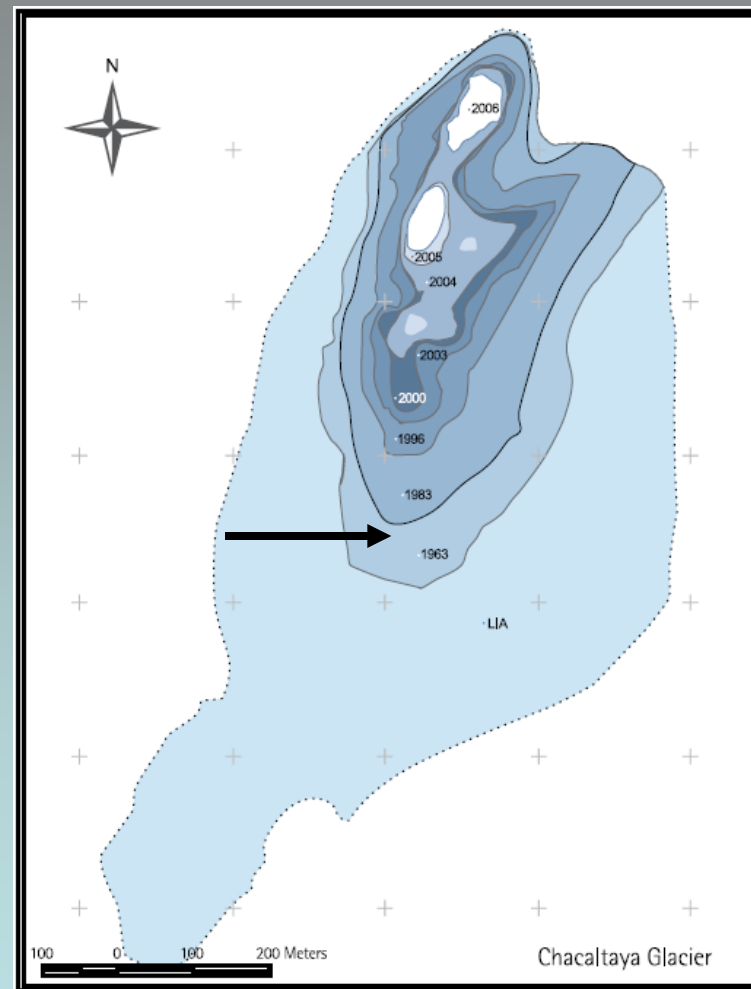
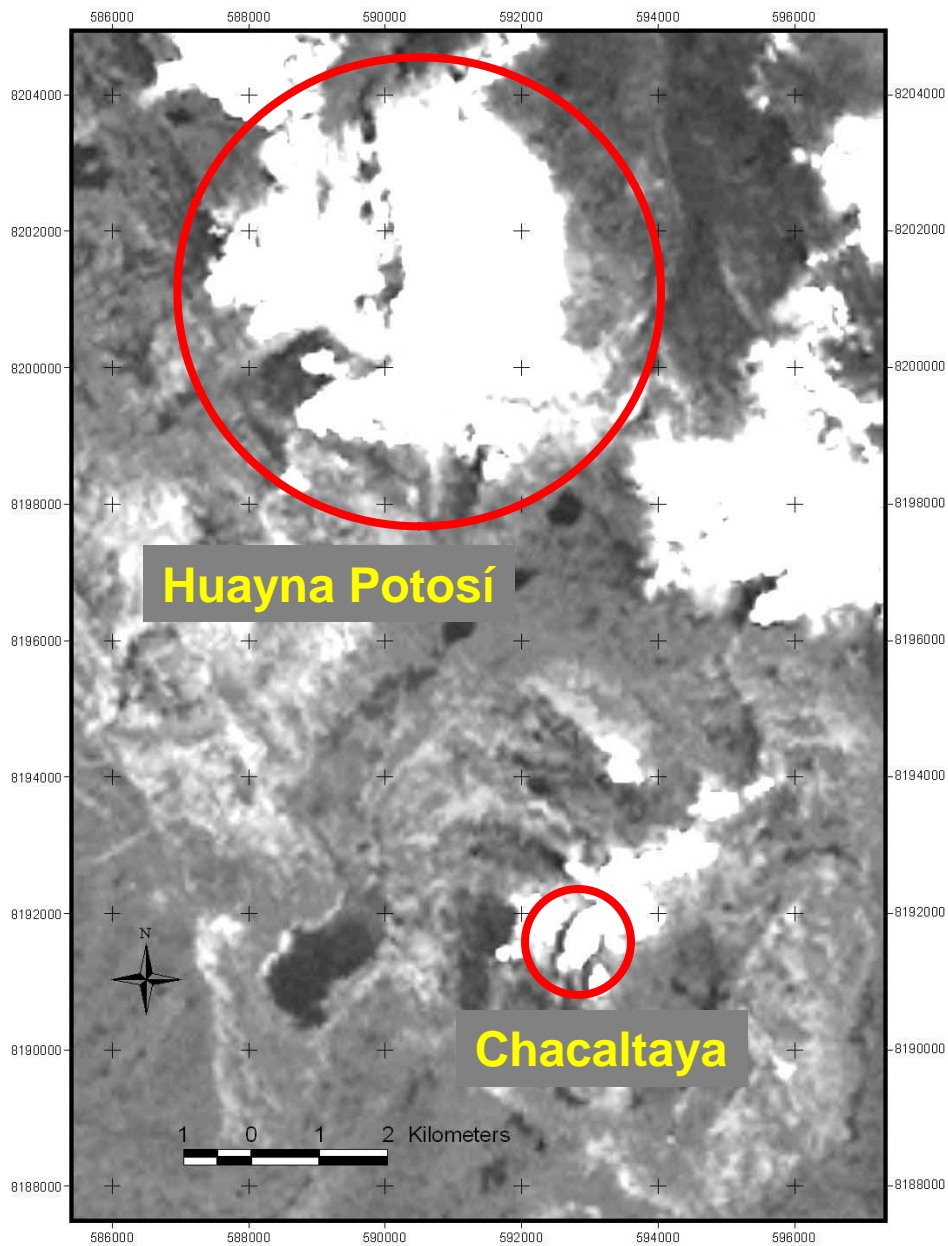
# CASES OF STUDY IN BOLIVIA:

## ZONGO GLACIER (HUAYNA POTOSI) & CHACALTAYA

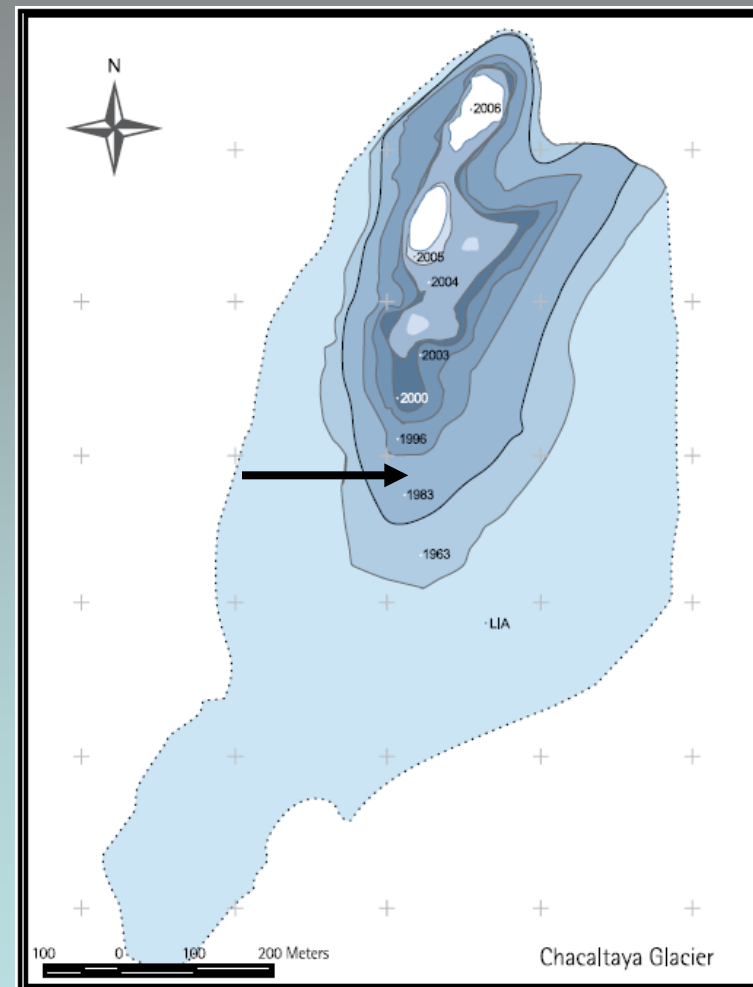
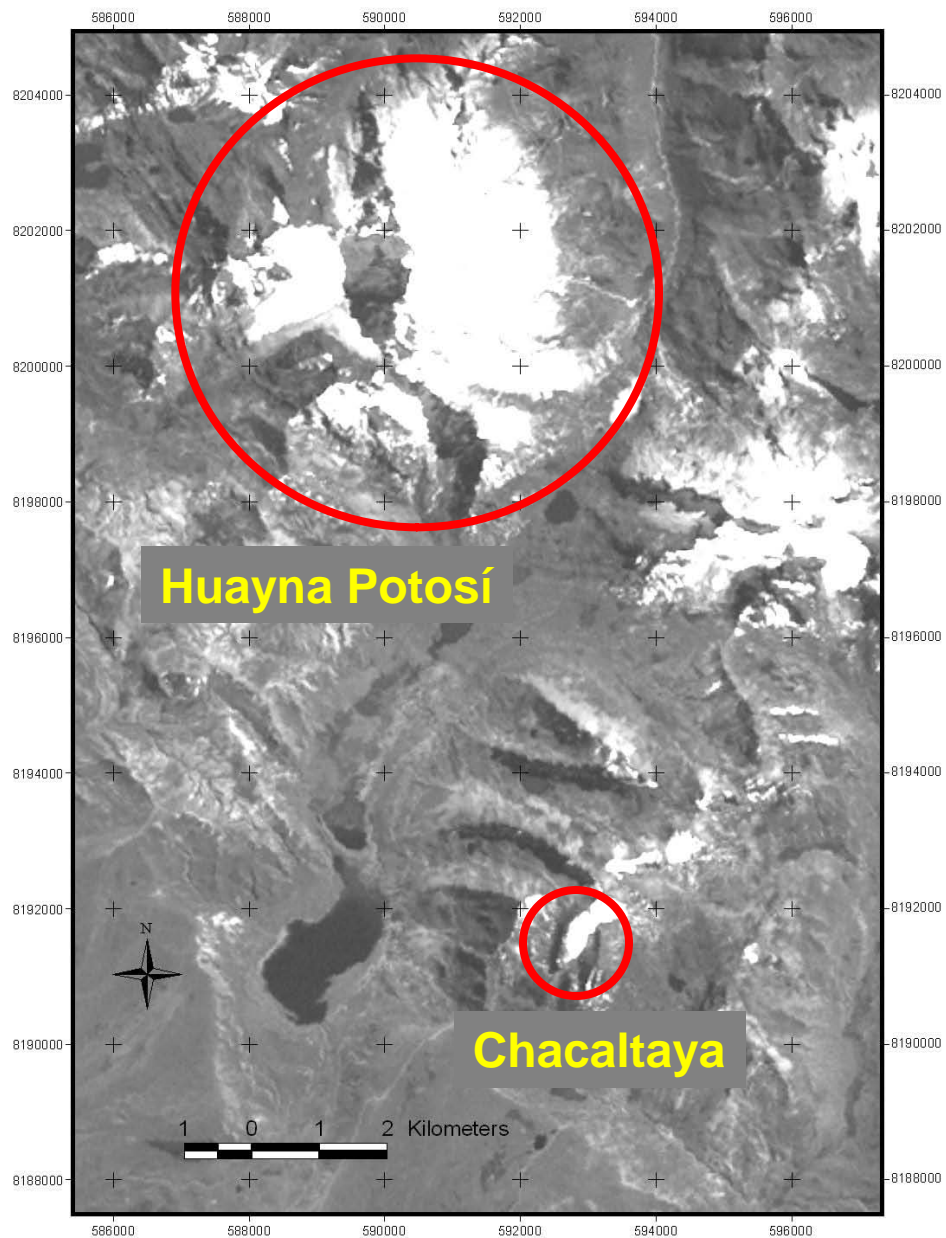


*Beginning of the Glacier Monitoring Program in Bolivia: 1991*

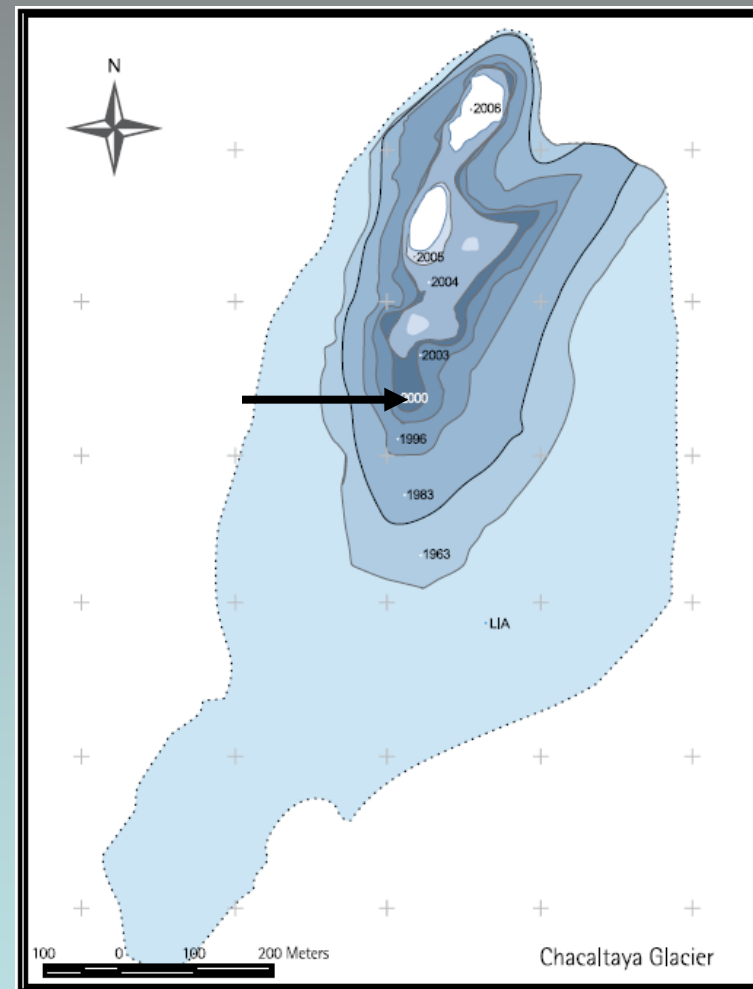
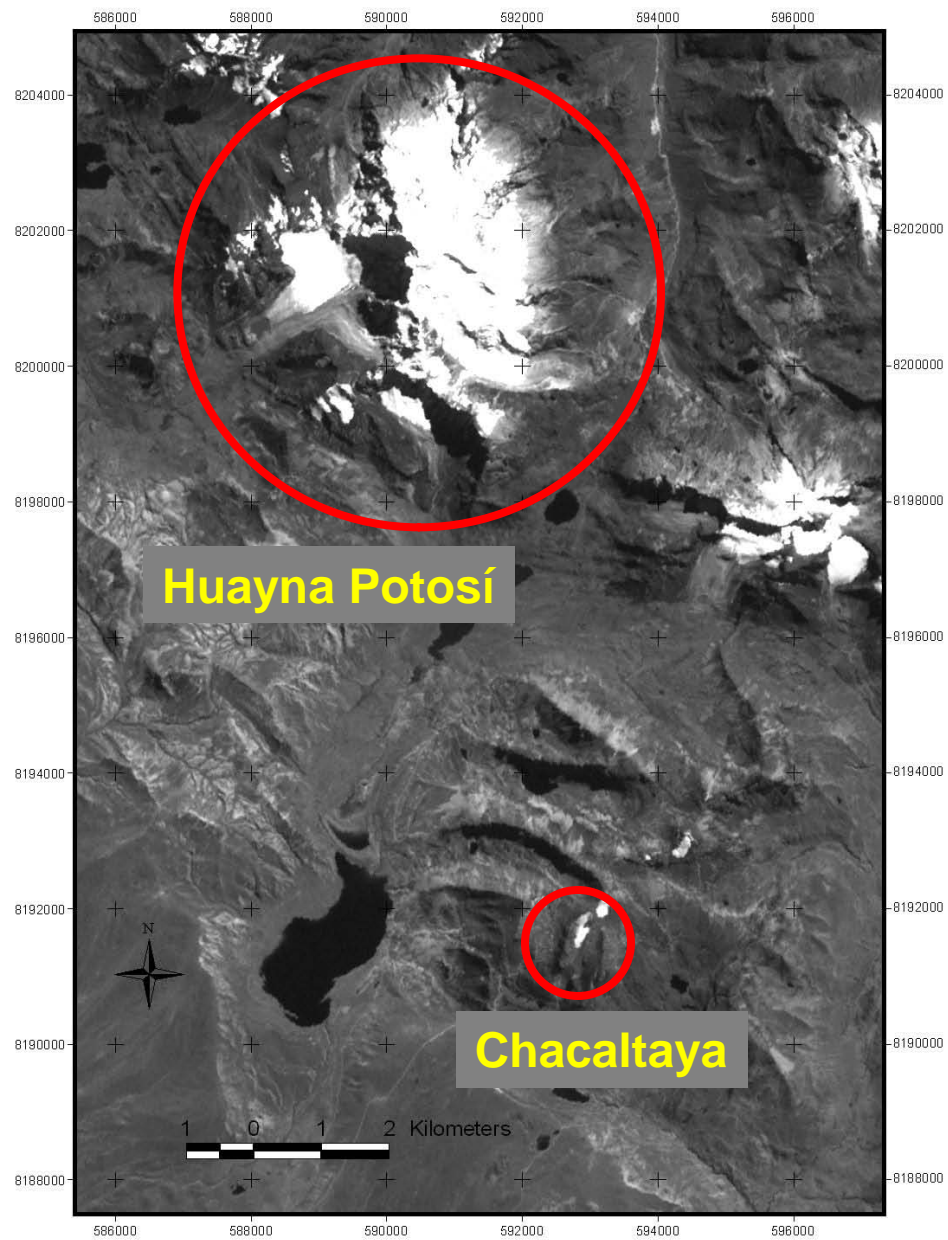
1975



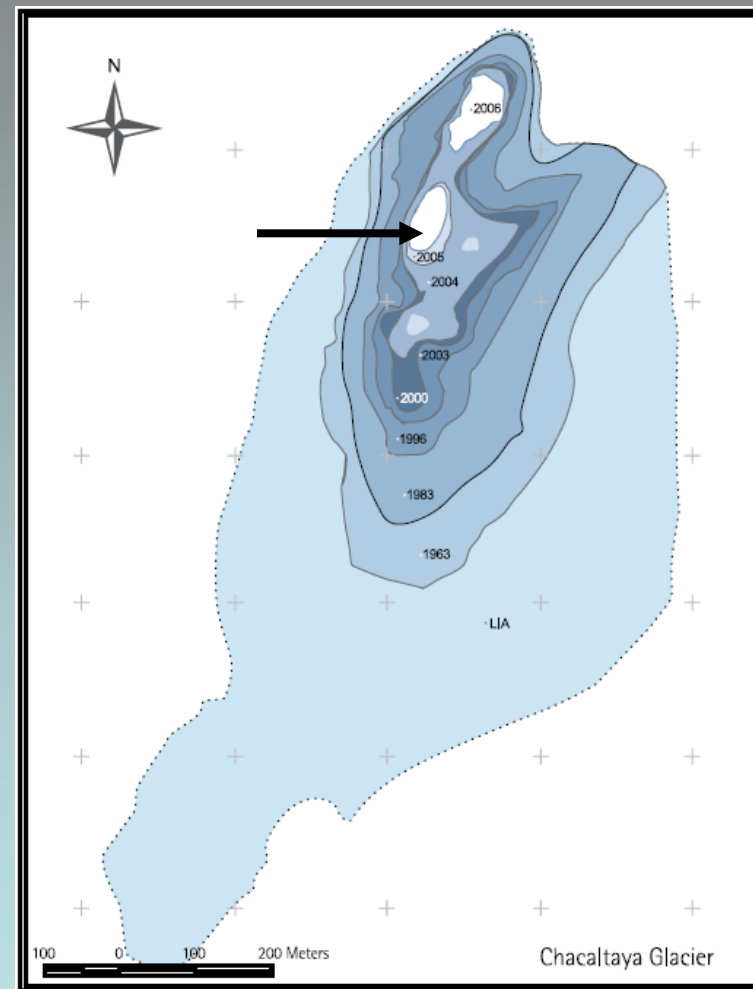
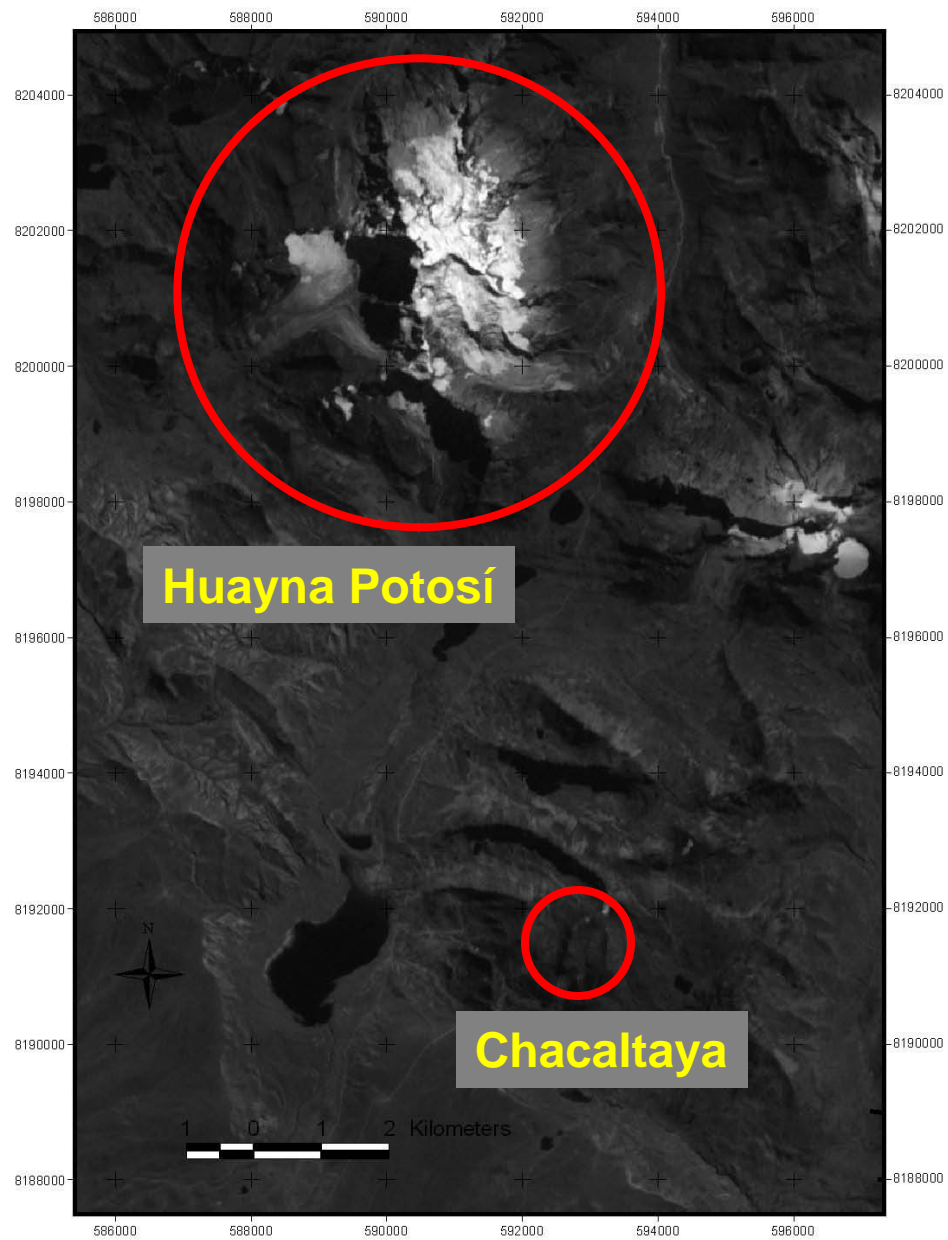
1987



2000



**2009**







1994

Photograph by Bernard Francou

## Chacaltaya Glacier

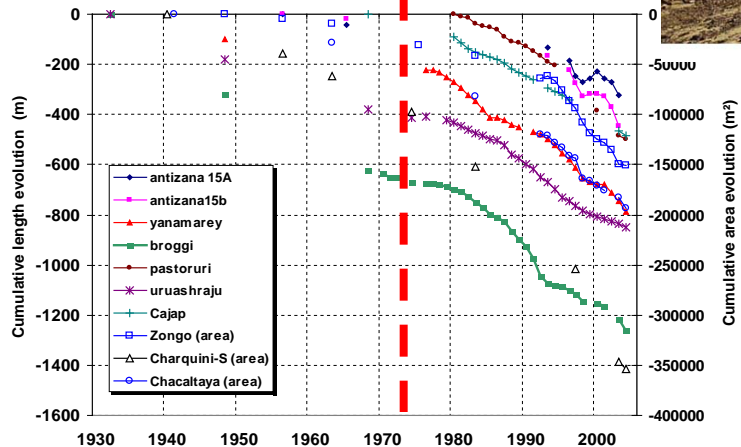
Geographical position: 16°21'S-68°07'W  
 Altitude range: **4700-5396 m**  
 Catchment area: 0.52 km<sup>2</sup>  
 Glacier area in 2007: 0.003 km<sup>2</sup>  
 General exposure: South



2005

Photograph by Bernard Francou

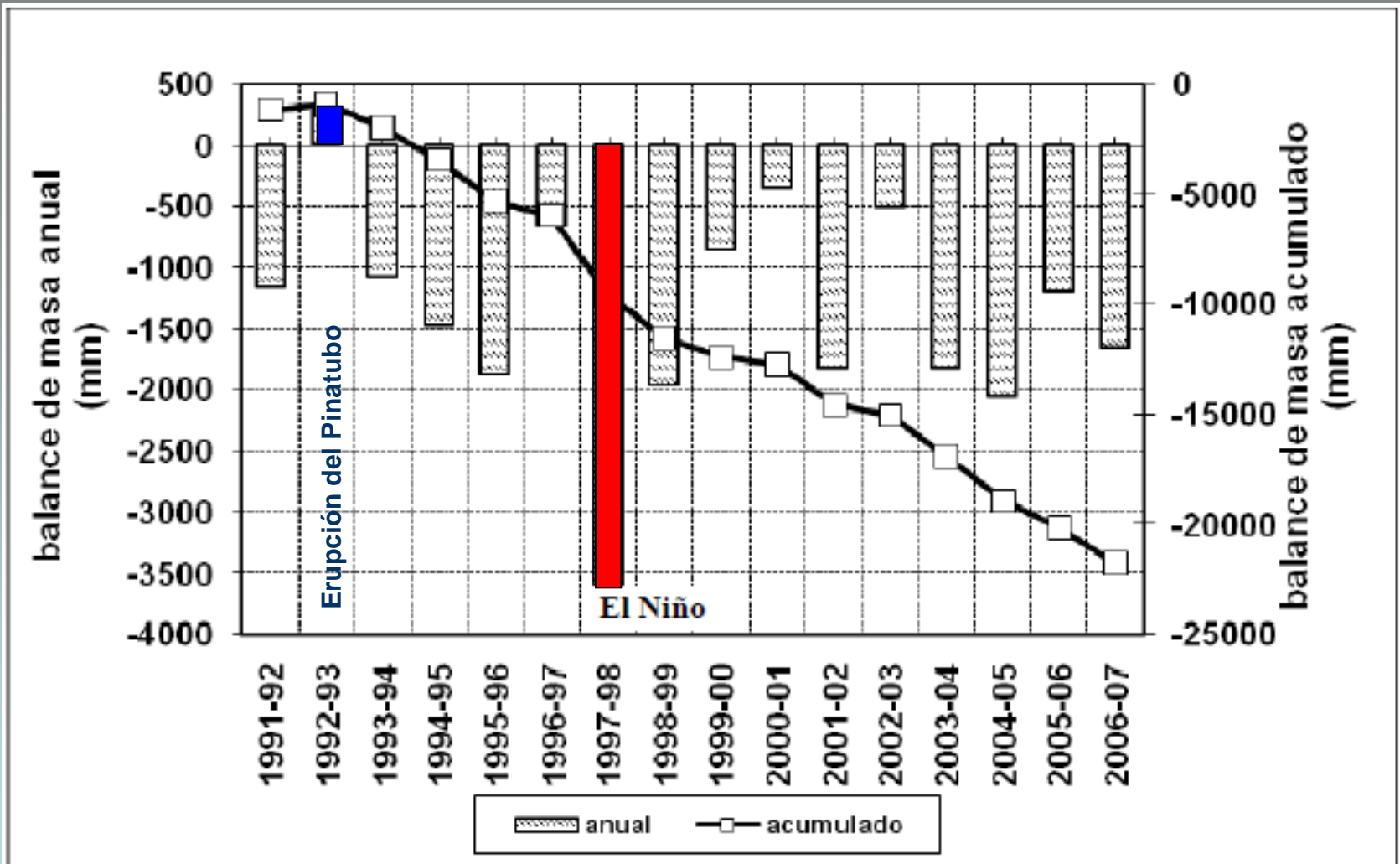
Photos:  
 B.Francou (IRD)©  
 E.Ramirez (IHH-UMSA) ©



2009

Foto: E. Ramirez ©

# MASS BALANCE DE FOR CHACALTAYA GLACIER SINCE 1991



# Water resources in La Paz



**The city of La Paz, administrative capital of Bolivia, is located at 3600 m a.s.l. with a population of one million inhabitants. An increasing migratory flow from the countryside has formed the city of “El Alto” (3800 m a.s.l.), also about one million inhabitants, that borders La Paz.**

Tuni-Condoriri

Huayna Potosi

Tuni

Chacaltaya

Milluni

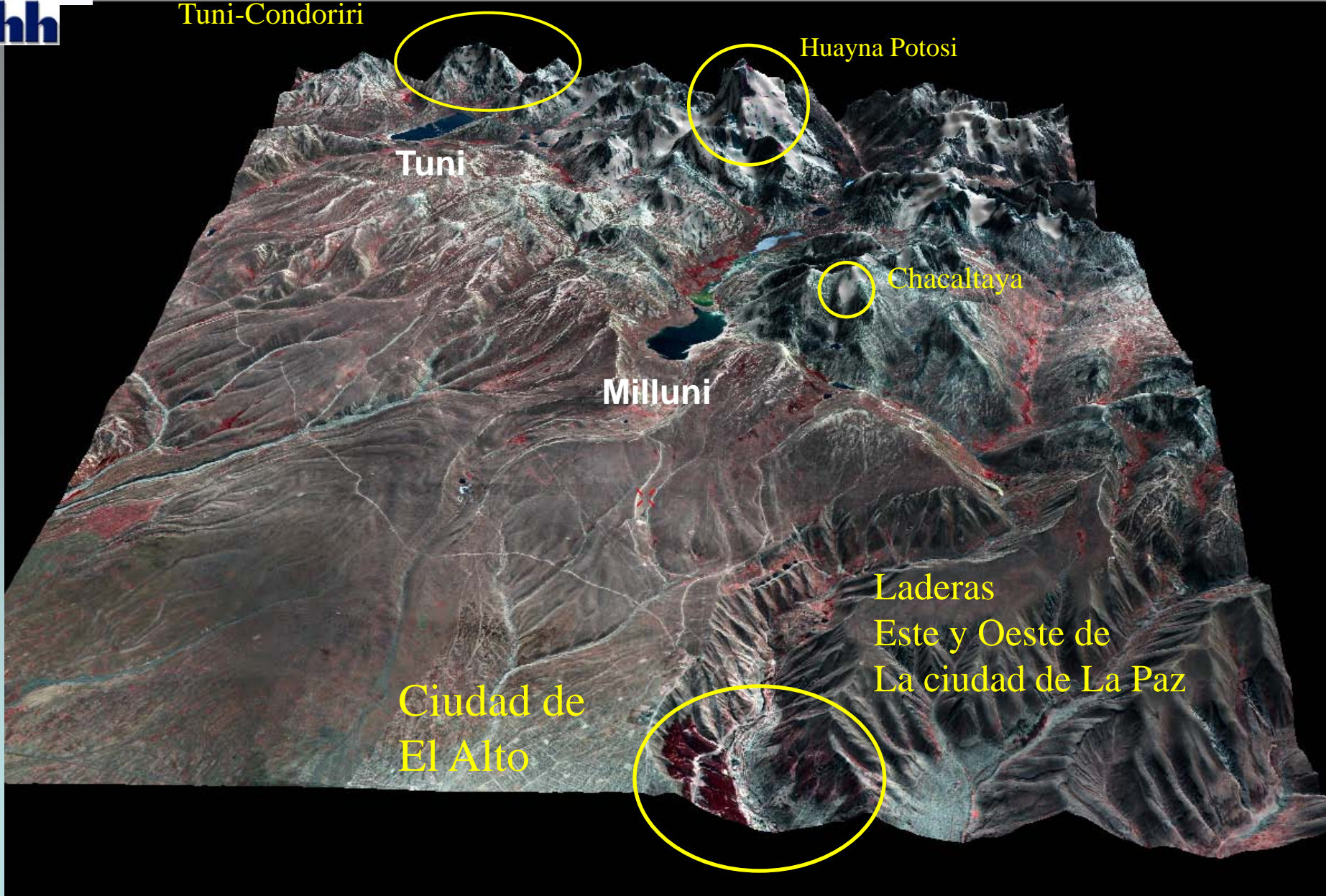
Laderas

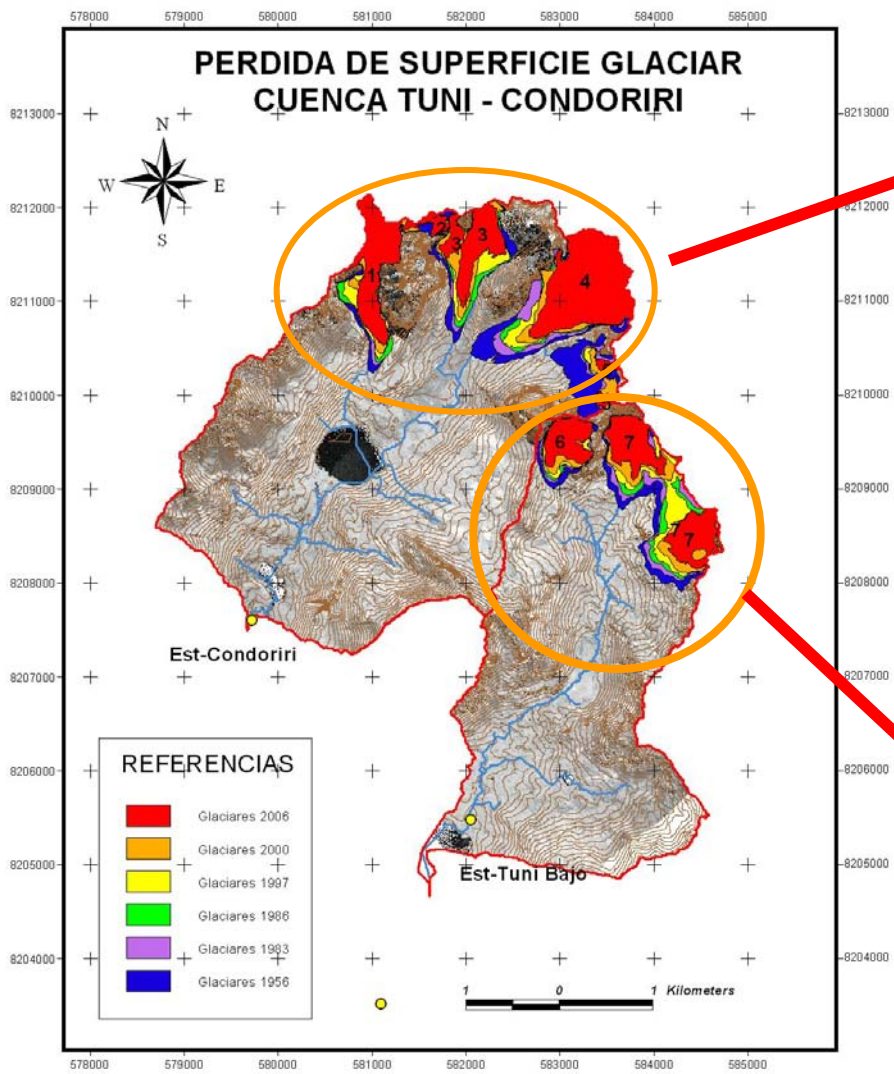
Este y Oeste de

La ciudad de La Paz

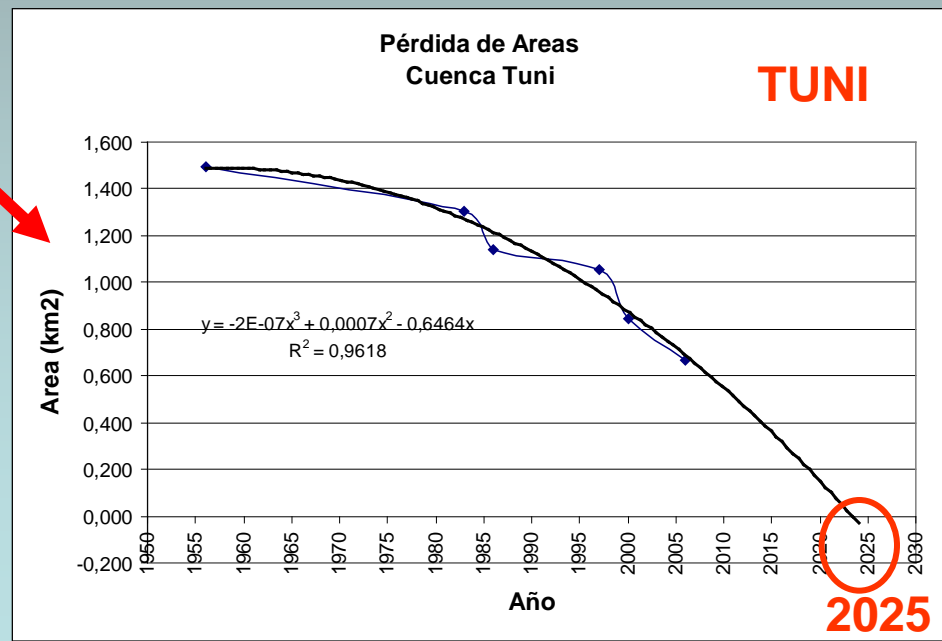
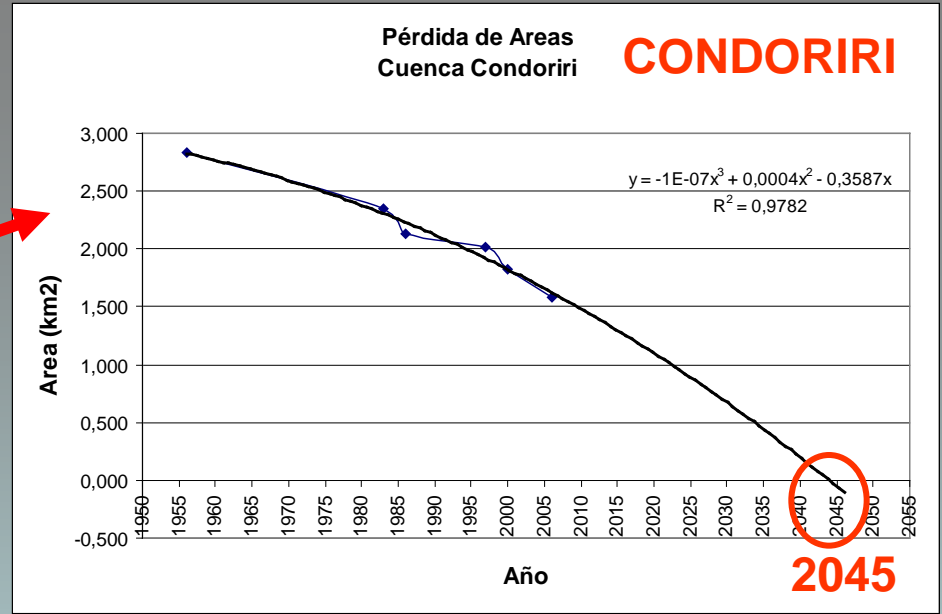
Ciudad de  
El Alto

(Fuente: E. Ramirez)



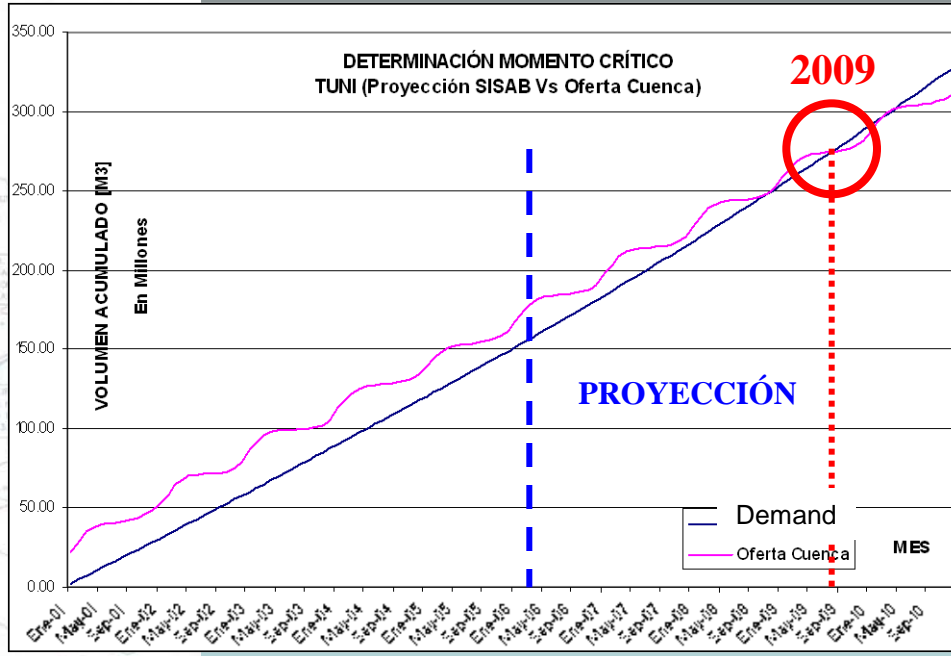
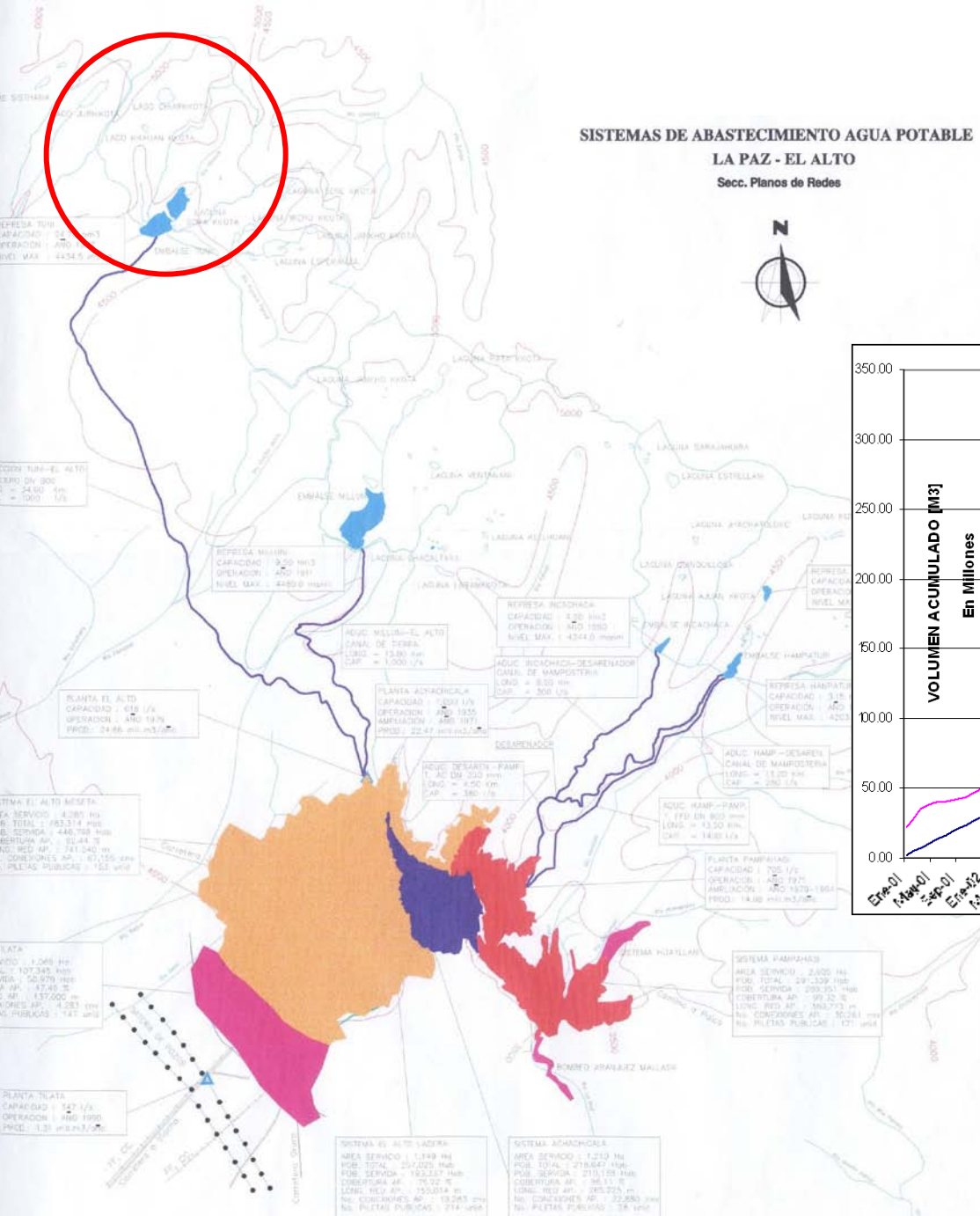


**Glacier surface losses for the period 1956 – 2006**  
**Condoriri: 44%, Tuni: 55%**



Source: IHH-UMSA, IRD

**SISTEMAS DE ABASTECIMIENTO AGUA POTABLE  
LA PAZ - EL ALTO  
Secc. Planos de Redes**



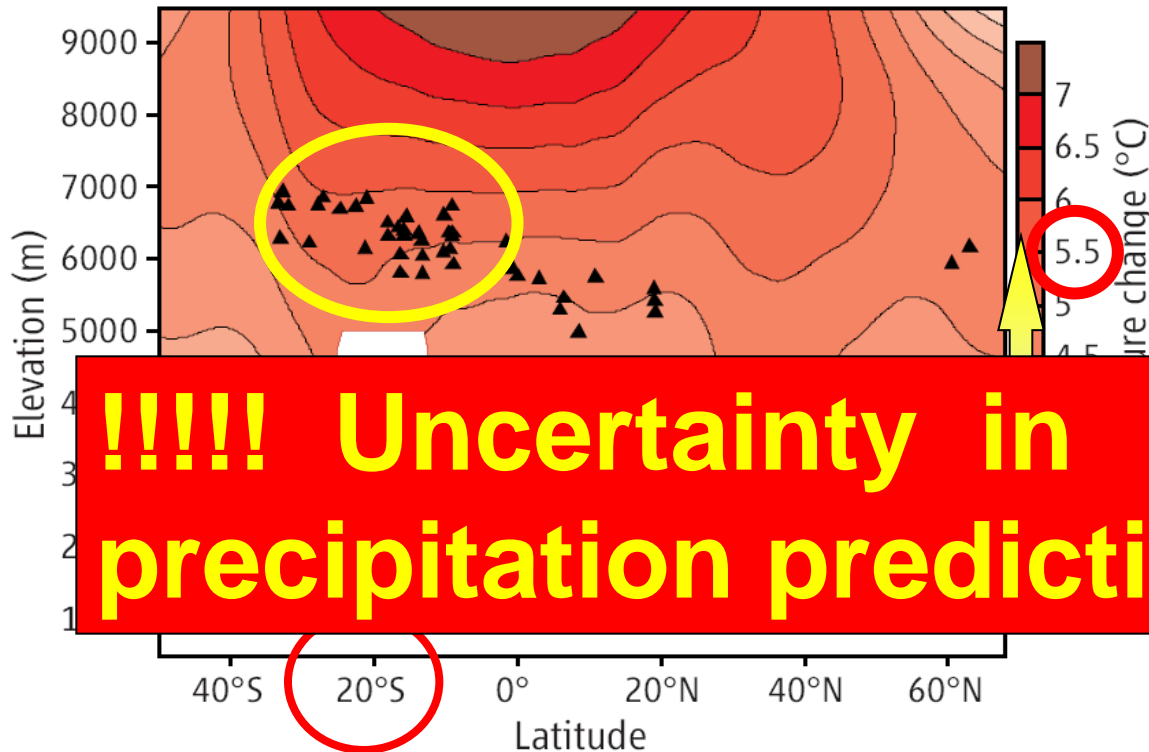
The analysis of the water demands and supplies for “El Alto” shows a break in 2009, where the demand will surpass the water supply.

*(Ramirez & Olmos, 2006)*

¿What about the future?



# Future climate in a world with double the preindustrial carbon dioxide (CO<sub>2</sub>) concentrations, according to general circulation models



**!!!!!! Uncertainty in precipitation prediction !!!!**



The process of adaptation to the impacts of the climatic change will depend besides the water resources management

**Water availability**



**Uses of Water**

- Precipitation
- Melting (Glacier)

- Efficient use of water

(Vulnerable to climatic change)

(Vulnerable to the inefficient use of the water)

**At the present the city of “El Alto” loses in the water supply system even of 50%.**

## References:

- Francou, B., Ramirez, E., Cáceres, B., Mendoza, J., **Glacier Evolution in the Tropical Andes during the Last Decades of the 20<sup>th</sup> Century: Chacaltaya, Bolivia, and Antizana, Ecuador**, *AMBIO a Journal of the human environment*, 29 (7) 416-422, 2000.
- Ramirez, E., Francou, B., Ribstein, P., Descloitres, R., Guérin, R., Mendoza, J., Gallaire, R., Pouyaud, B., Jordan, E., **Small-sized glaciers disappearing in the Tropical Andes, A case study in Bolivia : The Chacaltaya Glacier, 16°S**, *Journal of Glaciology*, 47, 187-194, 2001.
- Hoffmann, G., E. Ramirez, J.D. Taupin, B. Francou, P. Ribstein, R. Delmas, H. Dürr, R. Gallaire, J. Simões, U. Schotterer, M. Stievenard, and M. Werner, **Coherent isotope history of Andean ice cores over the last century** *Geophysical Research Letters*, 30 (4), 1179-1182, 2003.
- Ramirez, E., G. Hoffmann, J.D. Taupin, B. Francou, P. Ribstein, N. Caillon, F.A. Ferron, A. Landais, J.R. Petit, B. Pouyaud, U. Schotterer, J.C. Simoes, and M. Stievenard, **A new Andean deep ice core from the Illimani (6350 m), Bolivia**, *Earth and Planetary Science Letters*, 212 (3-4), 337-350, 2003
- Ramirez, E., B. Francou, C. Olmos, A. Román, C. Ramallo, P. Garreta, T. Berger, F. Ledezma, A. Soruco and R. Fuertes (2007). **Deshielo de la Cuenca del Tuni-Condoriri y su Impacto sobre los Recursos hídricos de las ciudades de La Paz y El Alto. La Paz**, (Final Report) Ministry of Development, Vice-Ministry of Planification : 150.

***Thank you very much for your attention***



Photo: E.Ramirez