# Galapagos Islands: Integrated Water Study

## *A trans-disciplinary approach to quantify water resources and their impact on natural ecosystems*

AGENCE NATIONALE DE LA RECHERCHE

ANR

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Ens LETTRES SCIENCES ÉCOLE NORMALE SUPÉRIEURE

irstea

UNIVERSITÉ PARIS-EST Marne-la-Vallée

fundación Charles Darwin foundation

Galapagos National Park

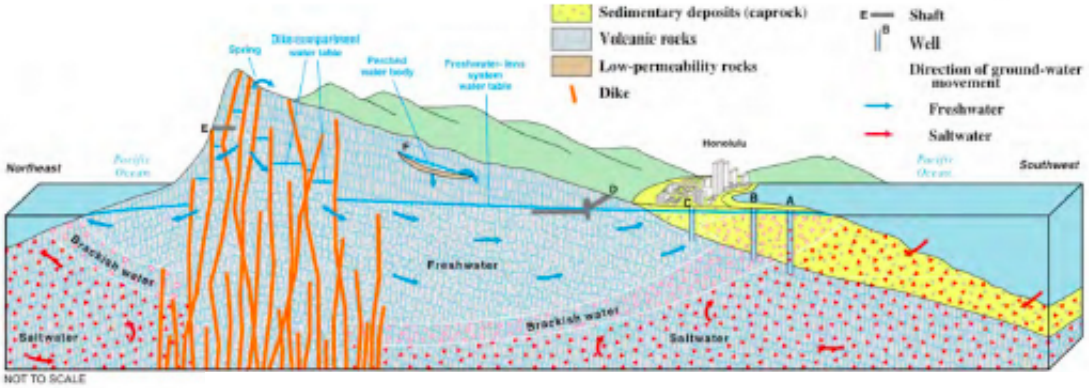
SOLIDUM PETIT IN PROFUNDIS · UNIVERSITAS ARHUSIENSIS



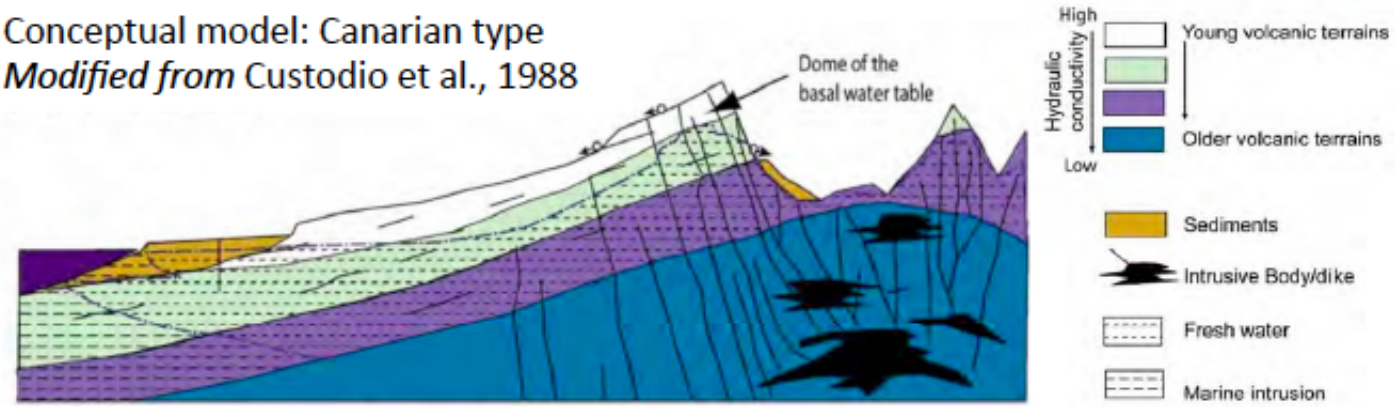
afaq ISO 9001 Qualité AFNOR CERTIFICATION

# Hydrogeological conceptual models for volcanic islands

Conceptual model: Hawaiian type
*Modified from* Mac Donald et al., 1970



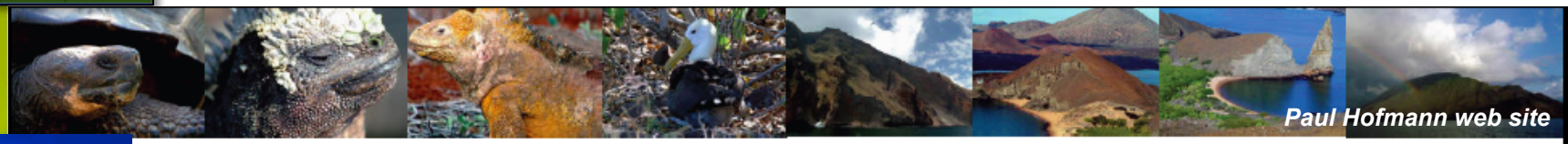

Conceptual model: Canarian type
*Modified from* Custodio et al., 1988

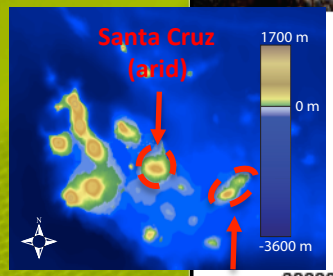



Which relationship exists in between the two models?

⇨ Strong implications in term of water resources management


# A tricky Equation to Ensure Sustainable Water Resources Management!

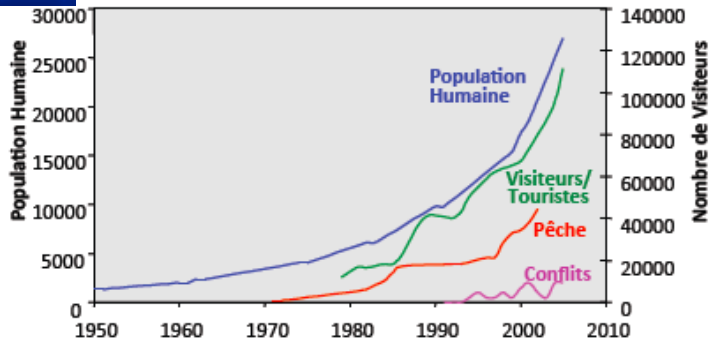



## Pristine and Unique Ecosystem

## +

## Fast Socio-Economic Development




**Population** : 21 500 inhabitants (2010) - vs. 5 000 (1980)

**Economy** : 160 000 tourists / an (2010) – vs. 3 000 (1980)

Fishing / Agriculture

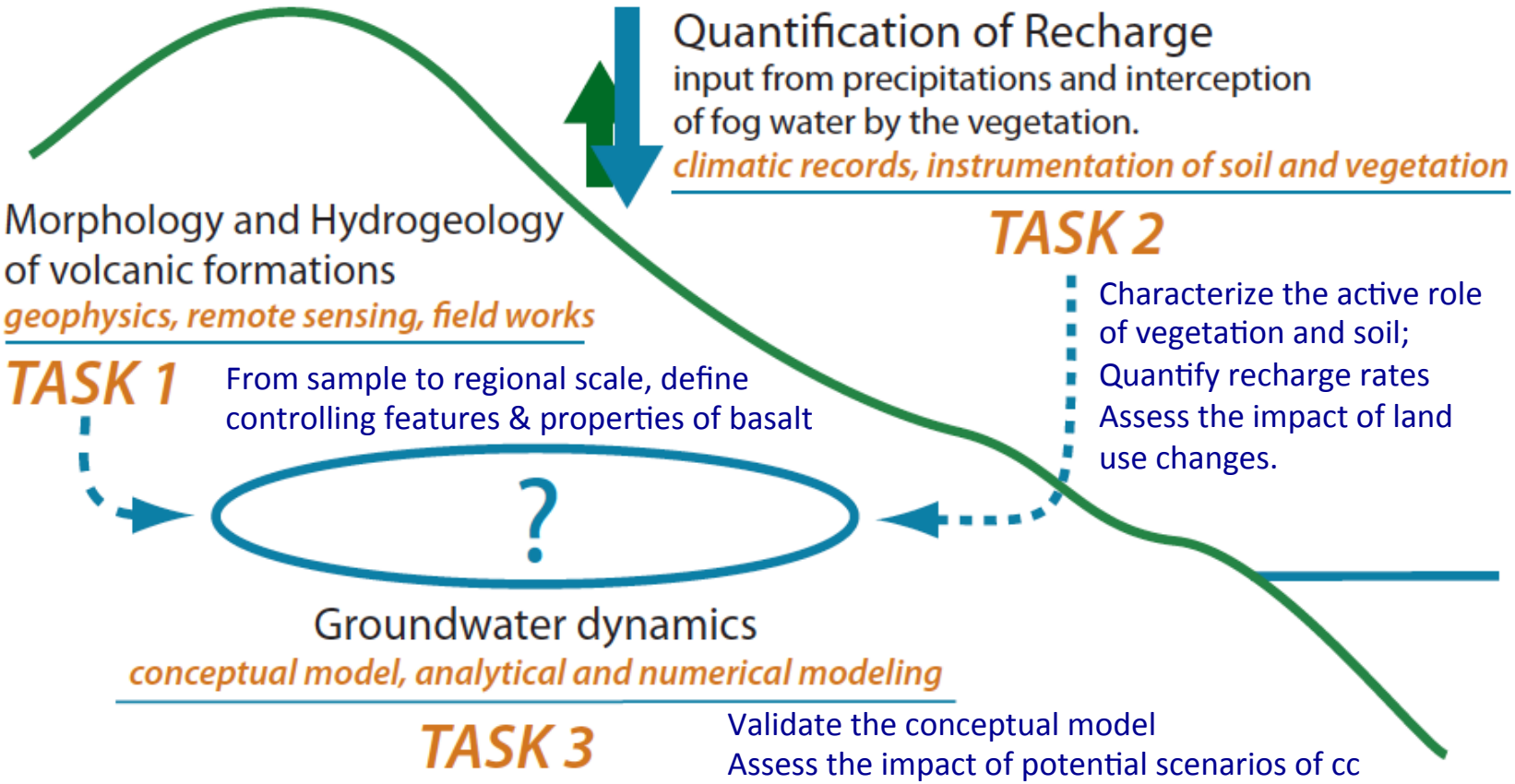
=

## Undergoing increasing stress on ecosystems and natural resources

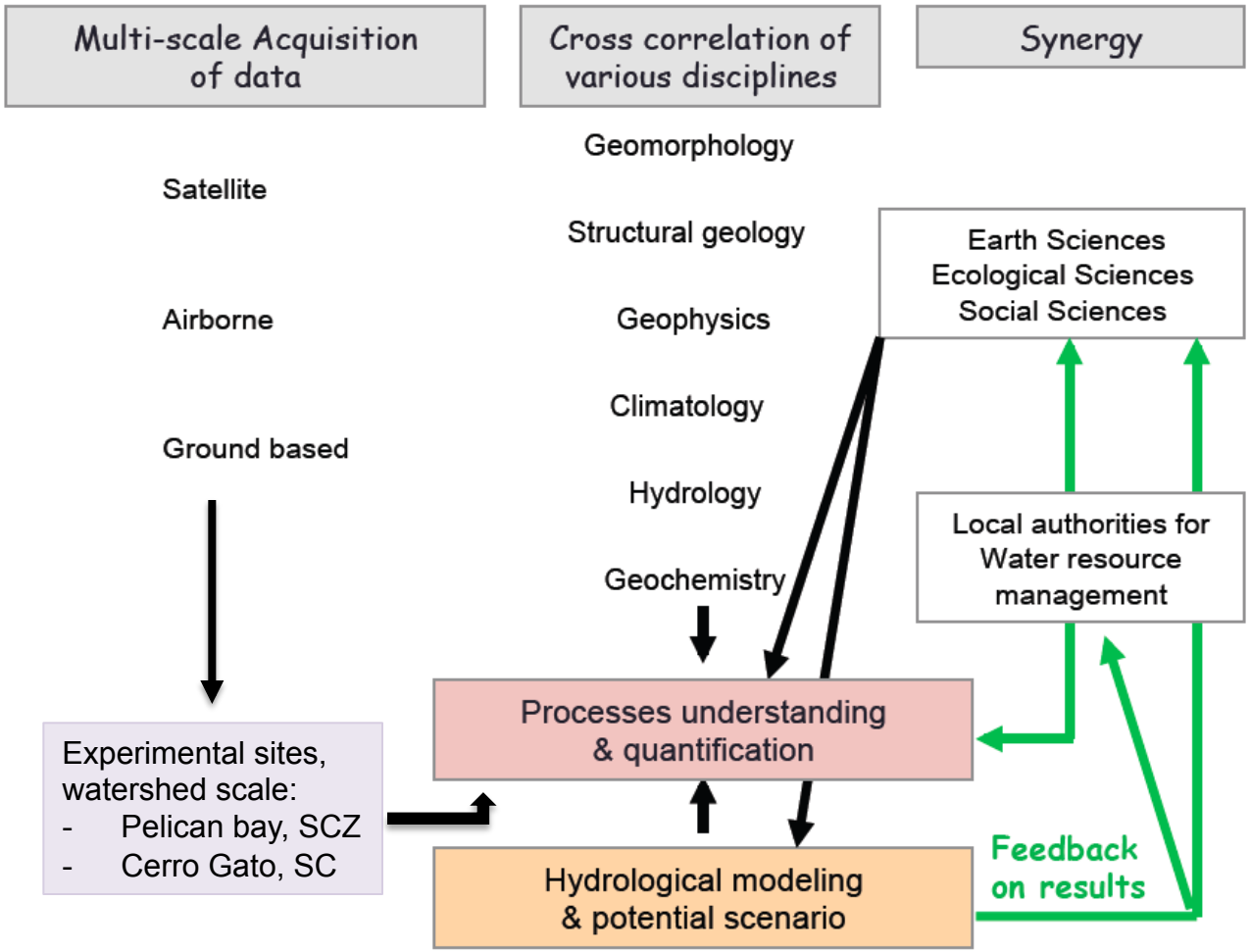
# Galapagos Island: Integrated Water Study (GIIWS)

*Phase I 2003-2009 – Sponsored by Foundations*

*Phase II 2010-2013 – ANR-Blanc 2010 – 601-01*



# Methodology



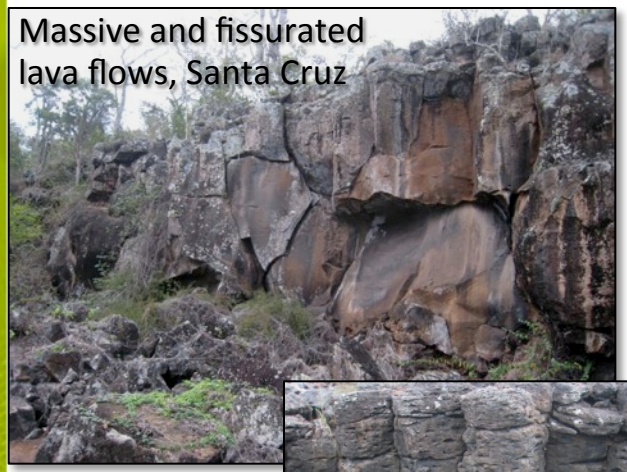



Violette et al., accepted

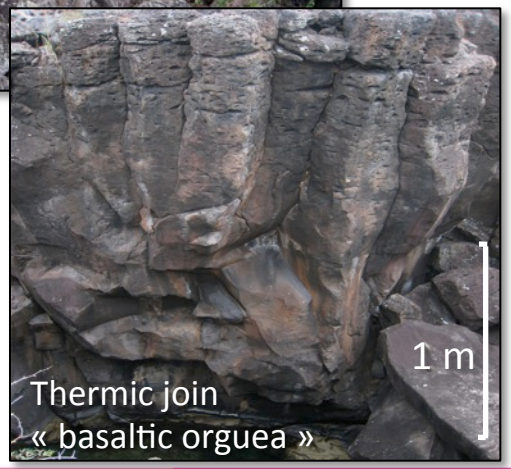
# Task 1 – Morphology and hydrogeology of volcanic formations

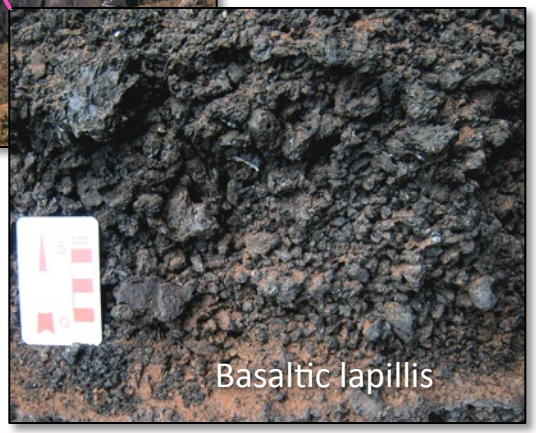
Lava flows
« effusive activity »

Pyroclastic cones,
cinders, lapilli










Photos, Pryet courtesy

# Task 1 – Morphology and hydrogeology of volcanic formations

Permeability Barriers





Volcanic Structure

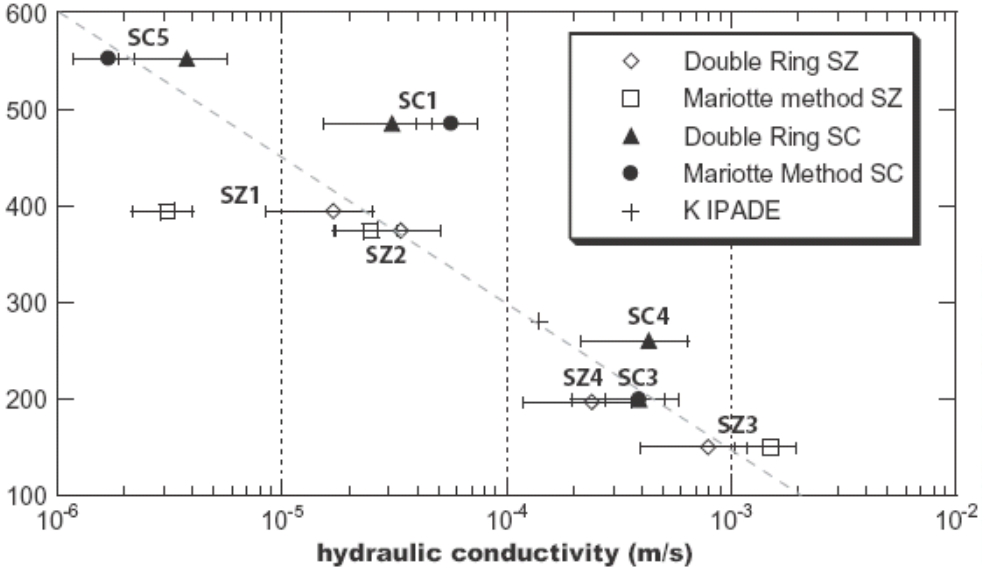


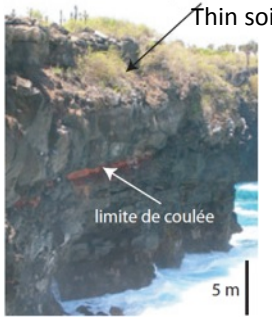
Photos, Pryet courtesy

# Task 1 – Morphology and hydrogeology of soils

Medium elevation
Soil ~1 m

Low elevation
no or very thin soil



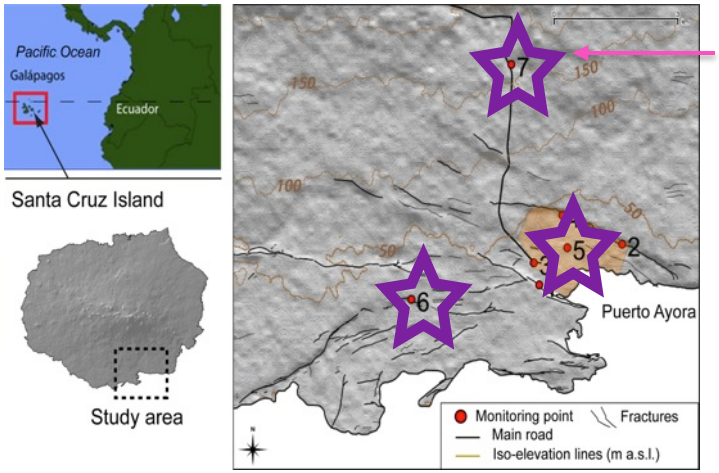




Hydraulic conductivity of soils (SC & SCZ) increases with decreasing elevation

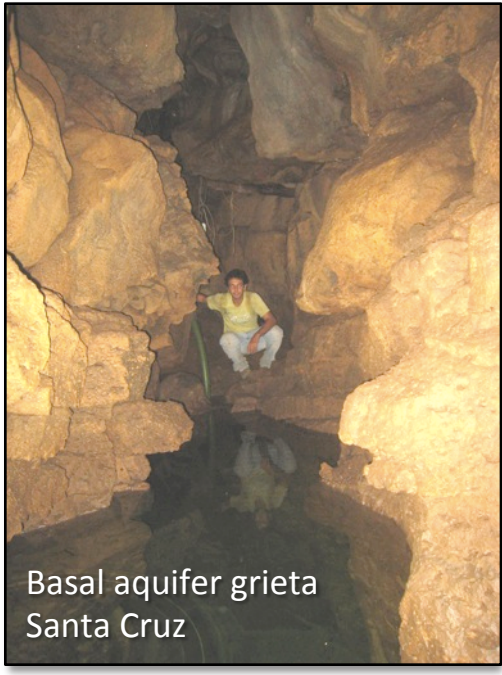


Adelinet et al., 2008

# Task 1 – Basal aquifer properties



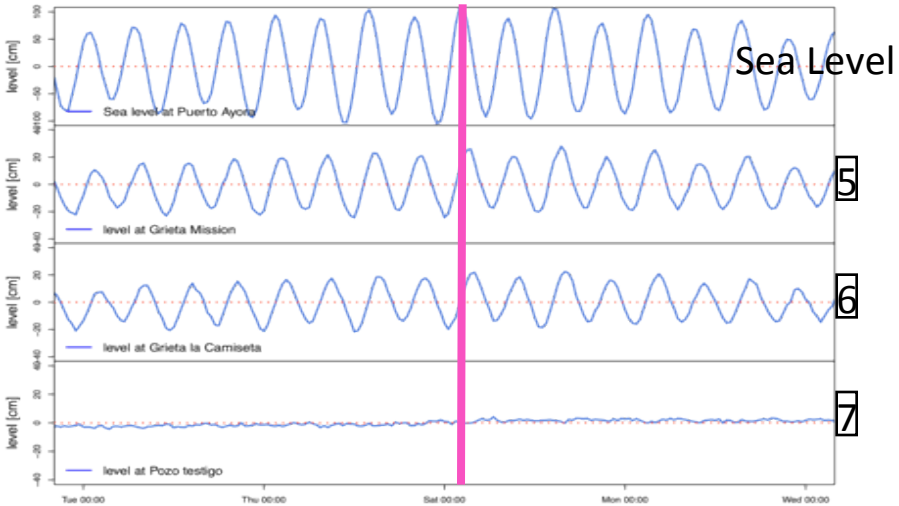

Water level:
+0.20 m amsl




*The low hydraulic gradient is*:

=> confirmed by water level measurement on Pozo Profundo (7), $i=5.10^{-5}$

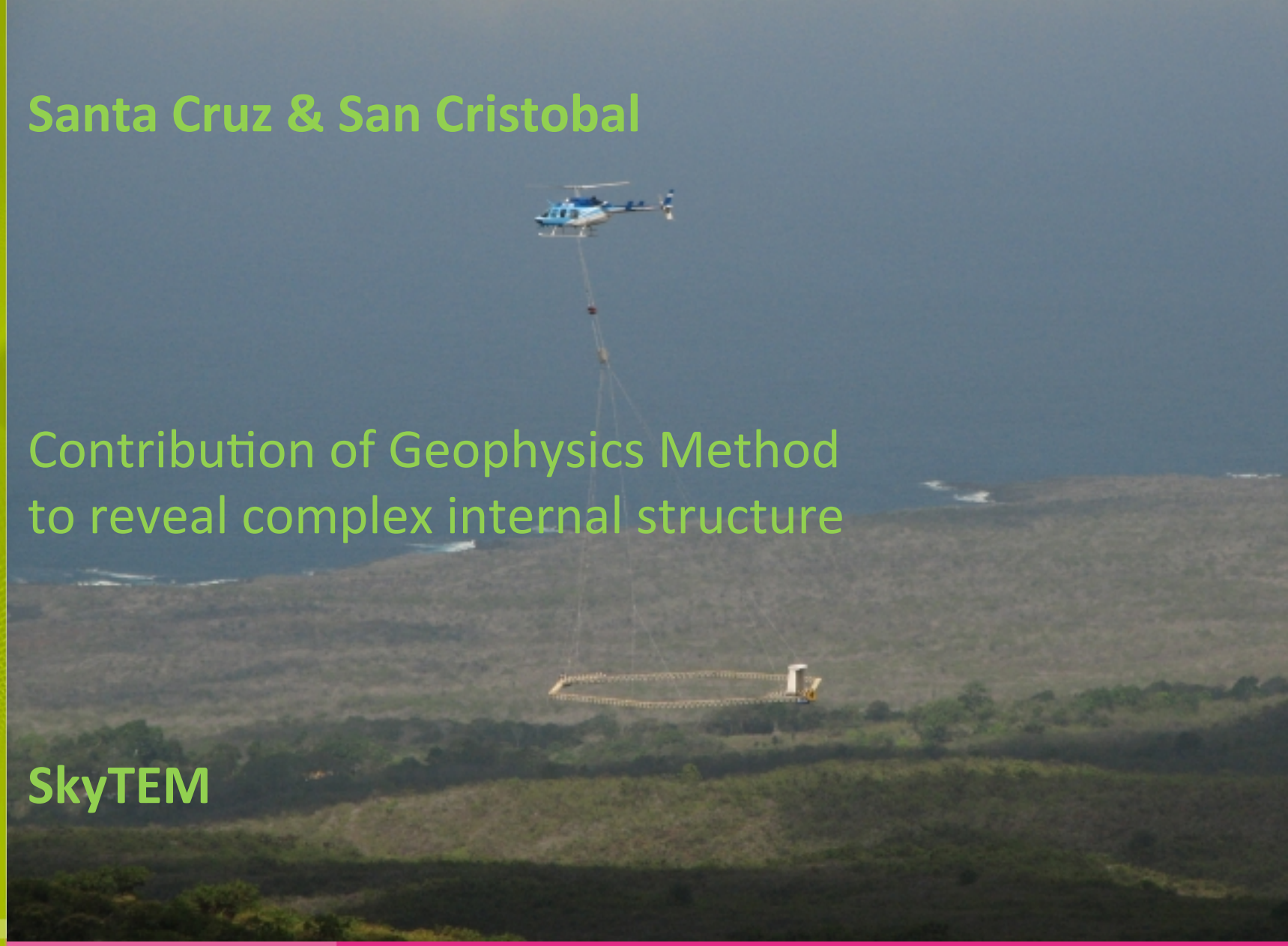
=> characteristic of high hydraulic properties obtained with 1D-analytical tidal wave propagation model, D=140 $m^2/s$ (D=T/S)






d'Ozouville, 2007 & Pryet, 2011
Photos, Pryet courtesy

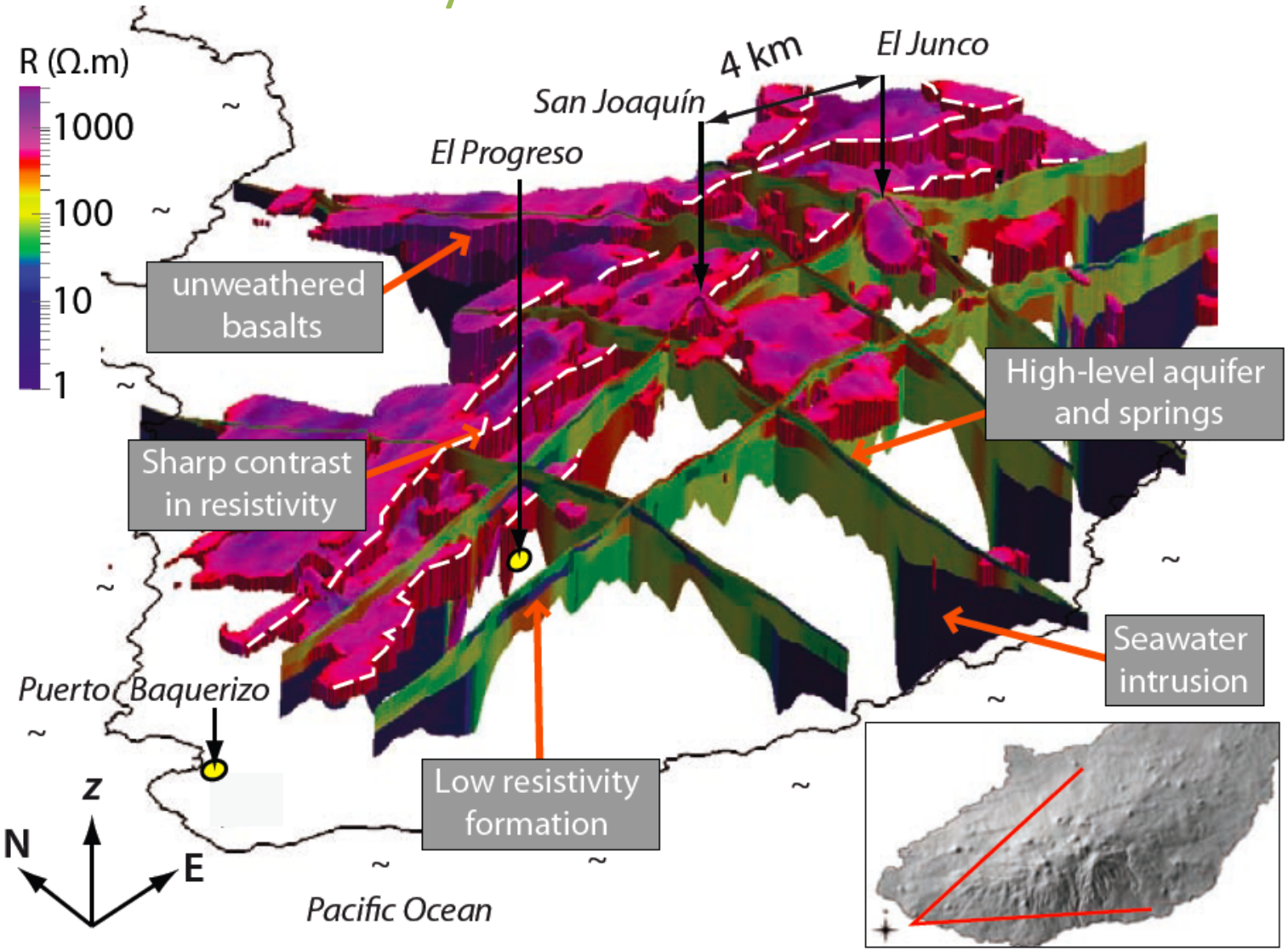
# Santa Cruz & San Cristobal



## Contribution of Geophysics Method to reveal complex internal structure

## SkyTEM

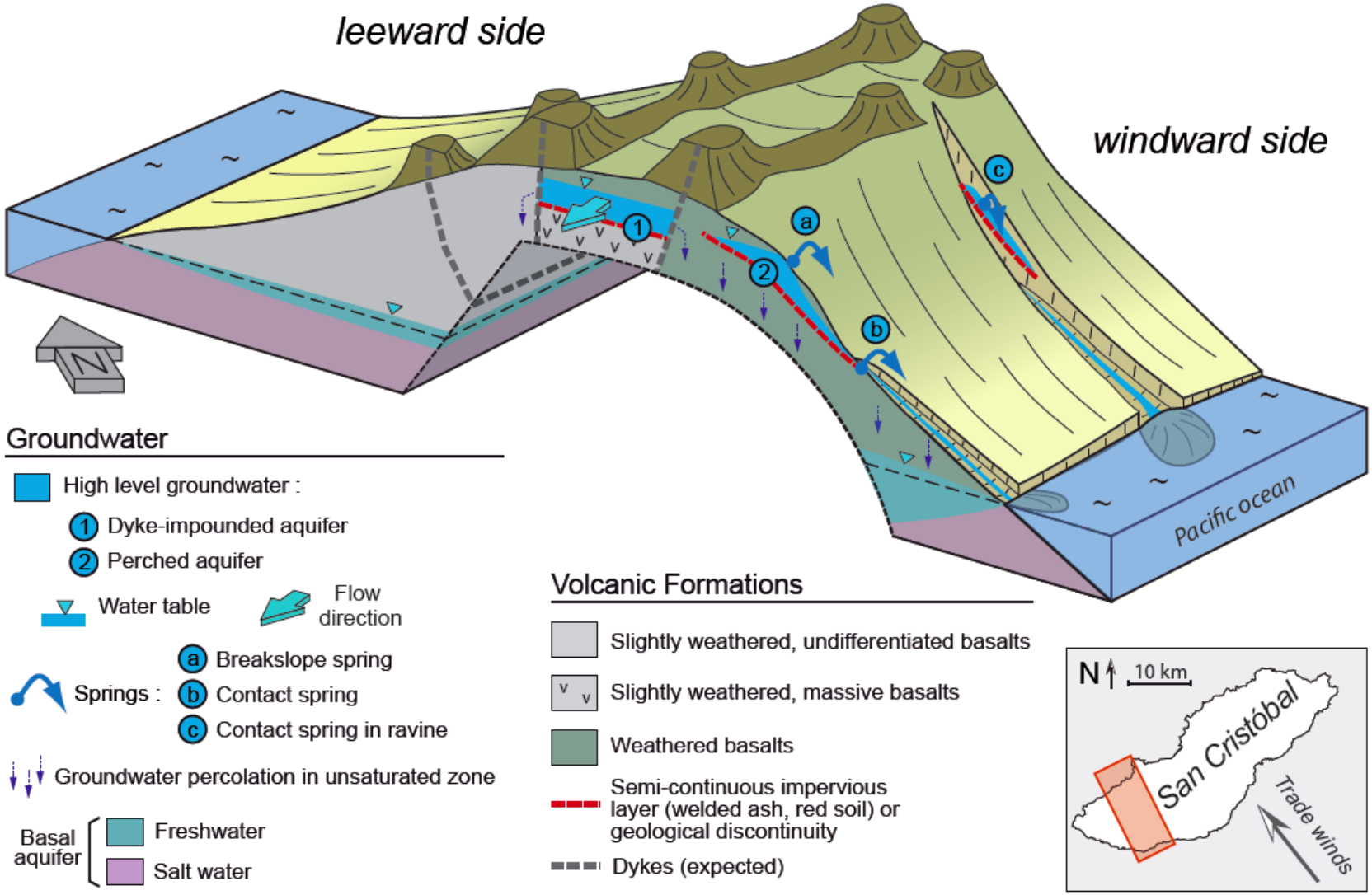
# Task 1 – 3D Resistivity model of San Cristobal






Pryet et al., 2012

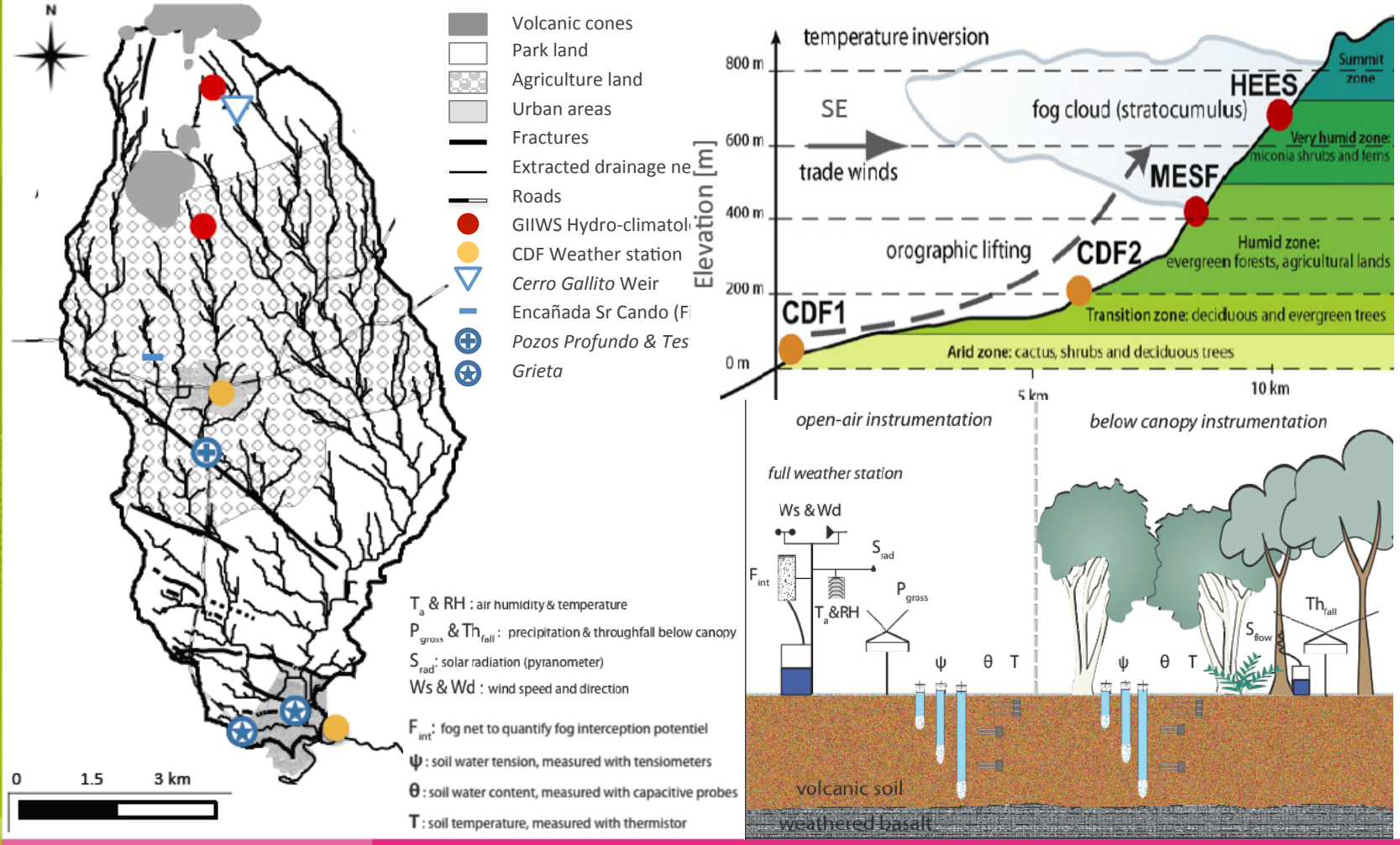
# Task 1 – Hydrogeological structure of San Cristobal






Pryet et al., 2012

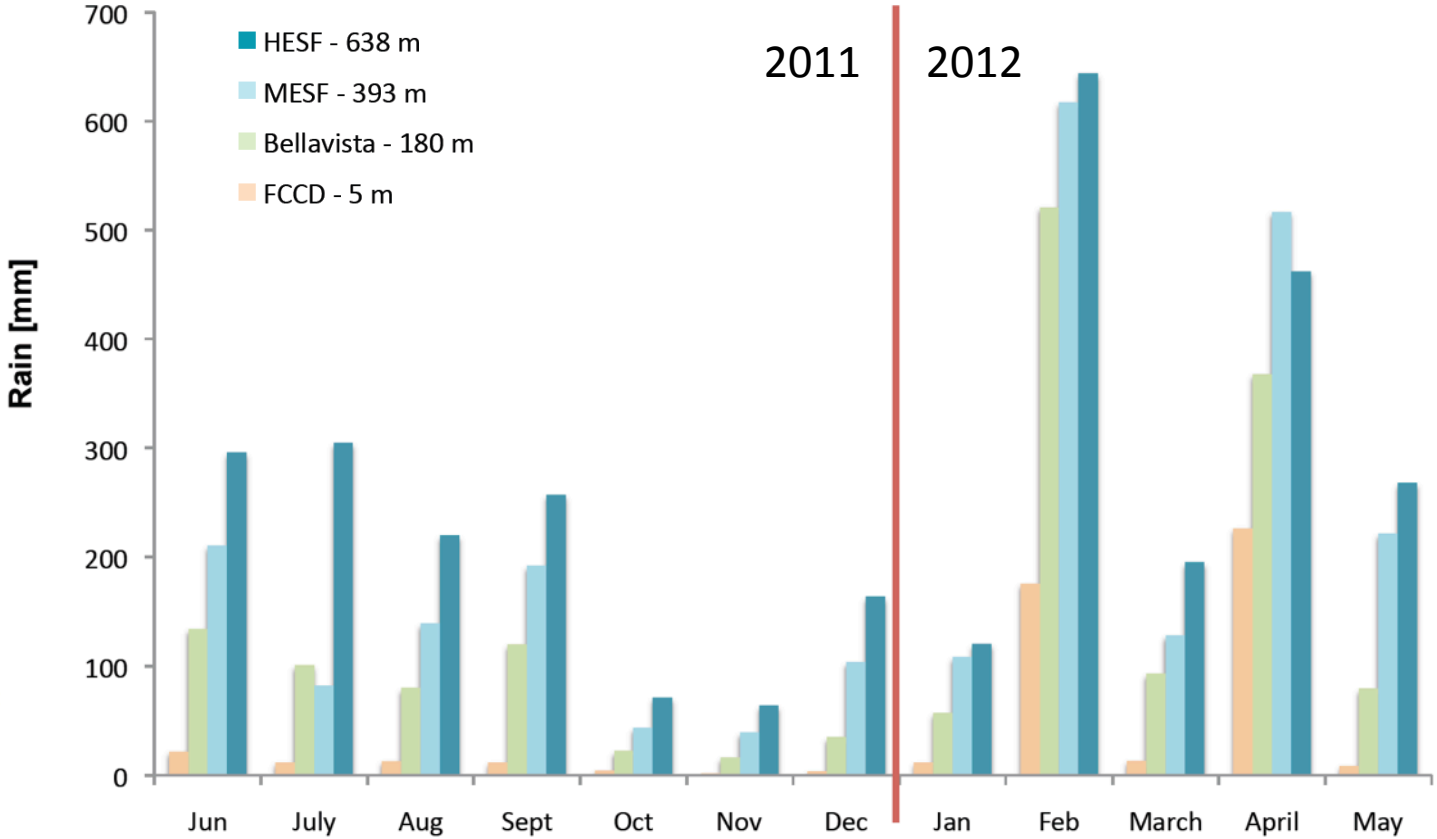
# Task 2 – Boundary condition of the system, i.e.: Recharge – Pelican Bay Watershed






d'Ozouville et al., 2008; Hamann, 1979 completed by Pryet, 2011; Pryet, 2011

# Task 2 – Seasonal and spatial distribution of rainfall




*Garua season*

- Orographic rainfall
- Low intensity rainfall

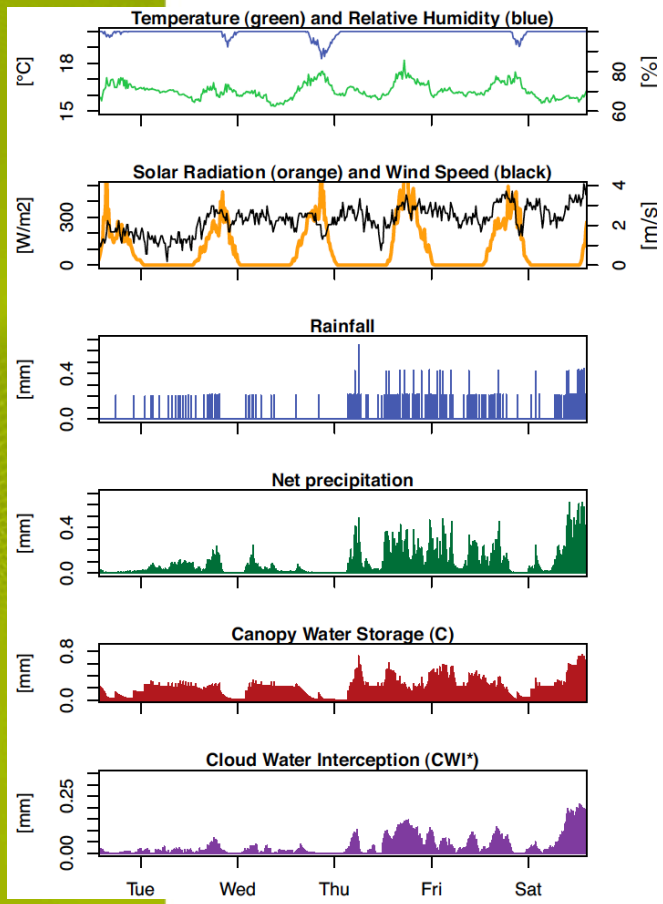
*Invierno season*

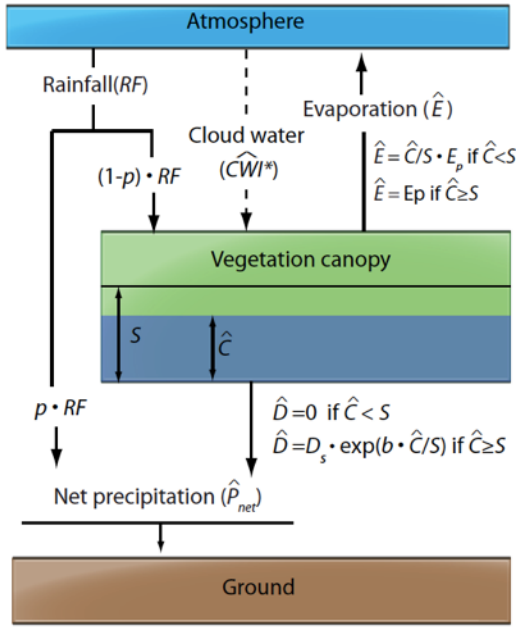
- Convective rainfall
- High intensity rainfall & short duration



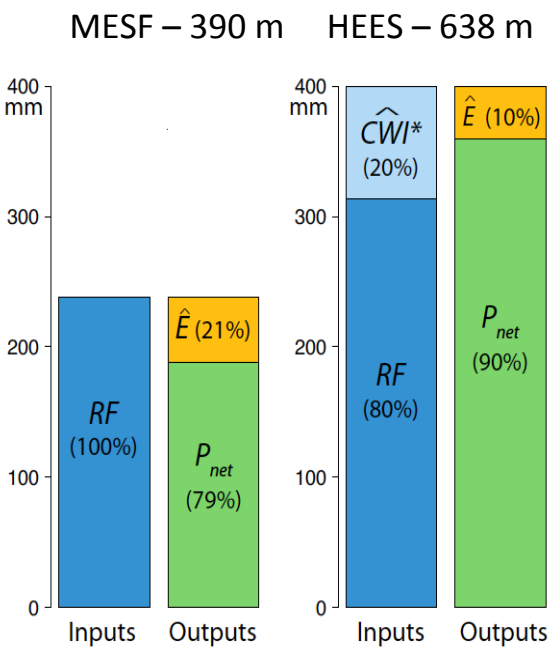
Violette et al., accepted

# Task 2 – « Garua season » Cloud water interception




Modified Interception model,
Rutter et al., 1972, 1975
with drainage function from Gash et Morton, 1978

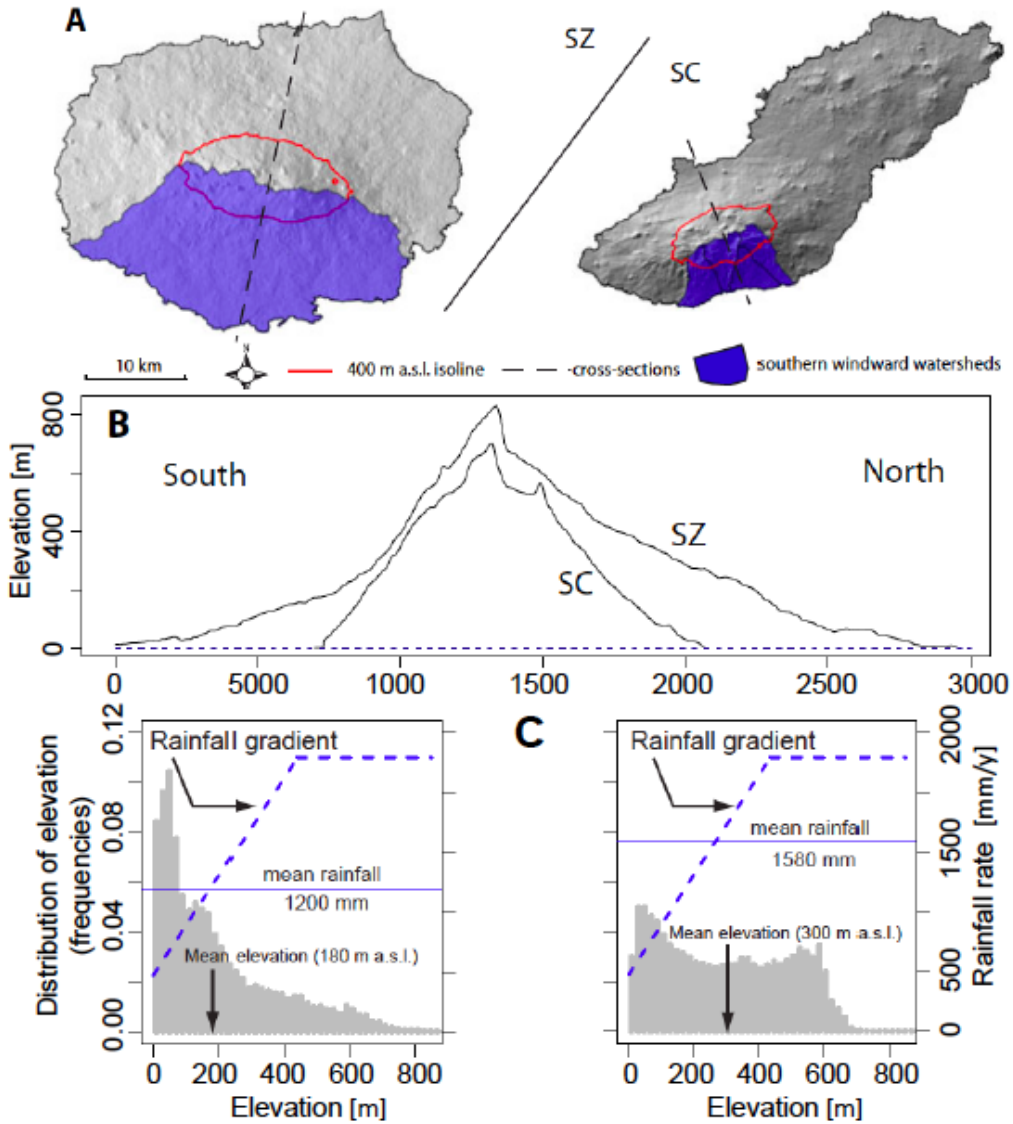



*Measured & calculated climate variables – Interception model – Water balance quantification*



Pryet et al., *2012*

# Task 2 – Rainfall versus Morphology




SC receives 30% more precipitation than SZ



d'Ozouville, 2007, d'Ozouville et al., 2008, Pryet, 2011

# Perspectives

Task 1 - Continue data collection and treatment on experimental sites to quantify the water balance, their spatial and temporal variability, impact of vegetation cover (pasture *vs* forest) and of cloud water (garua season)

Task 2 - Improve the characterization of Galápagos basalt hydro-physical properties from sampling and field investigations

- Valorize results on the assessment of the hydrogeological impact of major discontinuities (faults, dykes…) over regional groundwater flow from remote sensing and field investigations

Task 3 - Test perched aquifer occurrence as revealed by 3D geophysics mapping by numerical simulation of non-saturated and saturated flows and reproduce the dynamic of the basal aquifer (Santa-Cruz)

# Valorisation GIIWS Phase II – ANR blanc 2010

Publications 7 ACL – 2 Invited Seminar – 13 Oral/Poster (EGU, AGU, AGU-Chapman) – 9 Memoirs (2 PhD) – 3 Report (LA)

Training of French and Ecuadorian students (M, D, Post-doc)

Strengthening collaborative actions in between French and Ecuadorian institutions

2 IAC UPMC-Sorbonne Universities/EPN-Quito
& UPMC-Sorbonne Universities/INAMHI *(in progress)*

SENECYT offers 3 grants for Ecuadorian students working on GIIWS (2 PhD – 1 Post-doc)

Inclusion of the GIIWS project in the POA of FCD

Dissemination of scientific results to the local institutions: Municipalities, SENAGUA, PNG…

# GIIWS Publication List (ACL Phases I & II)


Adelinet, M., Fortin, J., d'Ozouville, N., Violette, S., 2008. The relationship betweenhydrodynamic properties and weathering of soils derived from volcanic rocks -Galápagos Islands (Ecuador). Environ. Geol. doi:10.1007/s00254-007-1138-3.

Ozouville d' N., Deffontaines B., Benveniste J., Wegmuller U., Violette S., Marsily G. de, 2008a. DEM generation using ASAR (ENVISAT) for addressing the lack of freshwater ecosystems management, Santa Cruz Island, Galápagos. RSE – Special issue on Monitoring Freshwater Ecosystems, doi:10.1016/j.rse.2008.02.017.

Ozouville d' N., Auken E., Sorensen K, Violette S., Marsily G. de, Deffontaines B., Merlen G., 2008b. Extensive perched aquifer and structural implications revealed by 3D resistivity mapping in Galápagos volcano. EPSL, doi:10.1016/j.epsl.2008.03.011

Auken E., Violette S., Ozouville d' N., Deffontaines B., Sorensen K, Viezzoli A., Marsily G. de, 2009. SkyTEM contribution to hydrogeology of volcanic Islands of Galápagos Archipelago. CRAS-Geoscience, doi: 10.1016/j.crte.2009.07. 006

Trueman, M., and N. d'Ozouville, 2010, Characterizing the Galapagos terrestrial climate in the face of global climate change, Galapagos Research, 67, 26-3.

Pryet A., Ramm J., Chiles J.-P., Auken E., Deffontaines B., Violette S., 2011. 3D resistivity gridding of large AEM datasets: a step toward enhanced geological interpretation. J. App. Geo., doi:10.1016/j.jappgeo.2011.07.006

Loaiza S., Fortin J., Schubnel A., Gueguen Y., Vinciguerra S. and Moreira M., 2012. Mechanical behavior and localized failure modes in a porous basalt from the Azores, GRL, doi :10.1029/2012GL053218, 2012.

Pryet A., Dominguez C., Fuente-Tomai P., Chaumont C., Ozouville d' N., Villacis M., Violette S., 2012. Quantification of cloud water interception along a windward slope of Santa Cruz Island. Agr. For. Met., doi: 10.1016/j.agrformet.2012.03.018

Pryet, A., d'Ozouville, Violette S., Deffontaines B., Auken E., 2012. Hydrogeological settings of a volcanic island (San Cristobal, Galápagos) from joint interpretation of airborne electromagnetics and geomorphological observations. Hydrol. Earth Syst. Sci., doi:10.5194/hess-16-4571-2012, 2012.

Violette, S., d'Ozouville N., Pryet A., Deffontaines B., Fortin J., Adelinet M., (accepted *2013*), Hydrogeology of the Galapagos Archipelago: an integrated and comparative approach between islands. AGU-Monograph Special issue « The Galapagos: A Natural Laboratory for the Earth Sciences ».

Ozouville, d' N., Tournebize, J., Vincent, B., Chaumont, C., Pryet A., Violette S., (*in progress*), Transferts hydrique along the windward side of Santa-Cruz Island, Galapagos. AGU-Monograph Special issue « The Galapagos: A Natural Laboratory for the Earth Sciences ».