Dynamics of the Caribbean and Panama Plates

Steven van Benthem and Rob Govers, Utrecht University, the Netherlands (benthem@geo.uu.nl)

Universiteit Utrecht

OBJECTIVE:

The Caribbean and Panama plates (figure 1) are characterized by a stable interior with, especially in the northeast and southwest corners, deforming plate boundaries. We adress the following questions:

- What causes the deformation at the boundaries of the Caribbean?
- Which tectonic forces are responsable for the observed strain patterns?
- Can we explain the first-order observations with an elastic thin shell model ?

Our approach is to assume different types of forces acting on the Caribbean (Table 1, figure 2) and then to assume no net torque acting on the plate (Wortel et al, 1991). This enables us to solve for the unknown magnitudes of the forces, and to develop a series of elastic models.

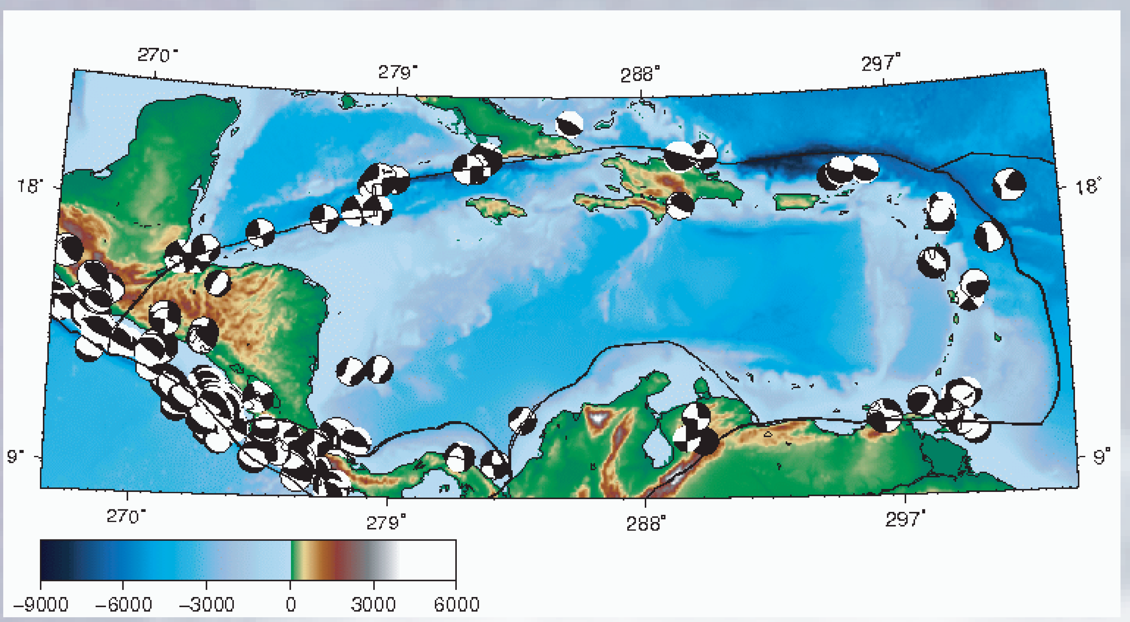


Figure 1a) Bathymetry, focal mechanisms (CMT catalogue) and mayor tectonic elements of the Caribbean and Panama plates.

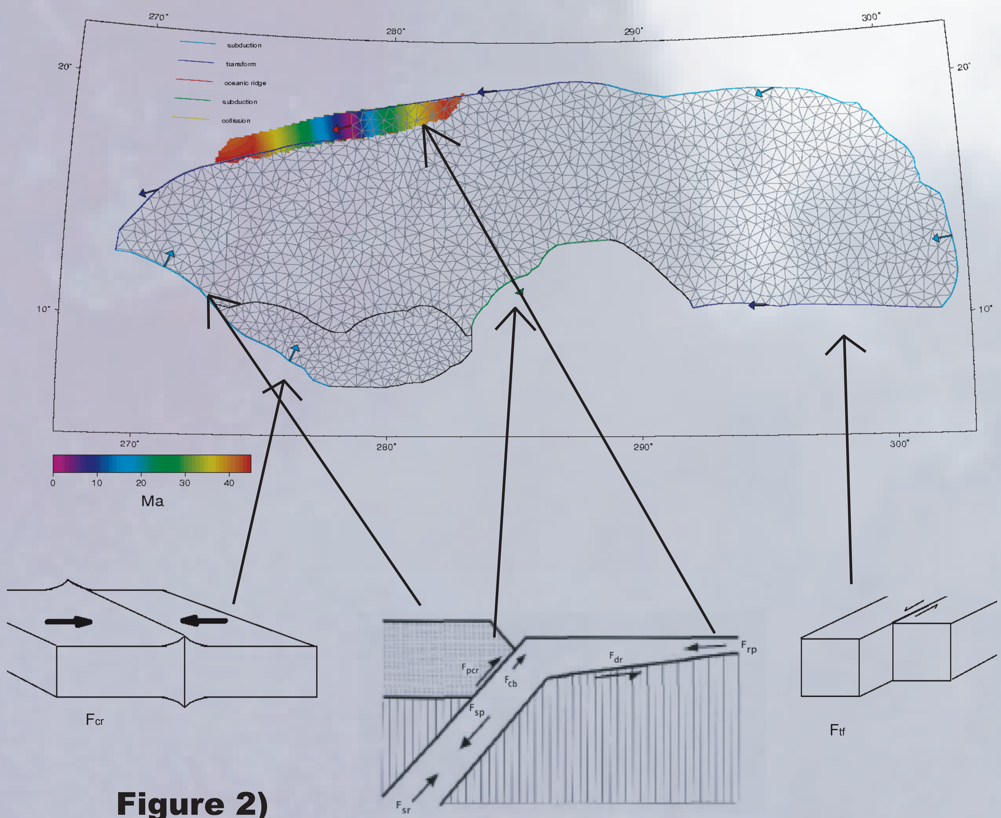


Figure 2)
Major tectonic forces acting on the Caribbean.
A summary of those forces is given in Table 1.

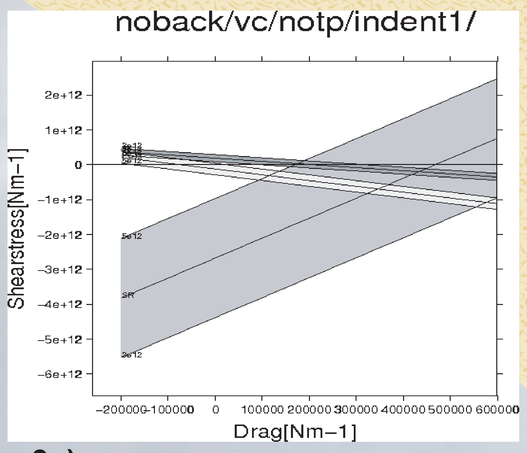
Notation:	Name:	Direction:	Magnitude
F_{SP}	Slab Pull	Perpendicular to plate boundary	Known
F_{RP}	Ridge Push	Into direction of age gradient	Known
F_{RC}	Ridge Collision	Into direction of RPM	1-100*F_{PCR}
F_{TF}	Transform Friction	Into direction of RPM	Not known
F_{PCR}	Plate Contact Resistance	Into direction of RPM	Not Known
F_{SR}	Slab Resistance	Into Direction of RPM or APM	Not Known
F_{CB}	Compositional Buoyancy	Into direction of RPM	Not Known
F_{CF}	Cornerflow	Into direction of RPM	Known
F_{GR}	Gravitational Forces	Into direction of lithostatic stress gradient	Known
F_{DR}	Drag Forces	Into direction of APM	Not known

Table 1
Summary of the tectonic forces that act on the Caribbean and Panama plates

FORCE CONSTRAINTS

Here we show a reference model (figure 2), followed by variations in three of the force types:

1. suction force at the Southern Antilles, simulating trench roll-back
2. F_{pcr} is proportional with the relative plate movement, simulating a subduction channel
3. A model incorporating an extra force, F_{rc} accounting for a possible extra force due to subduction of seamounts.



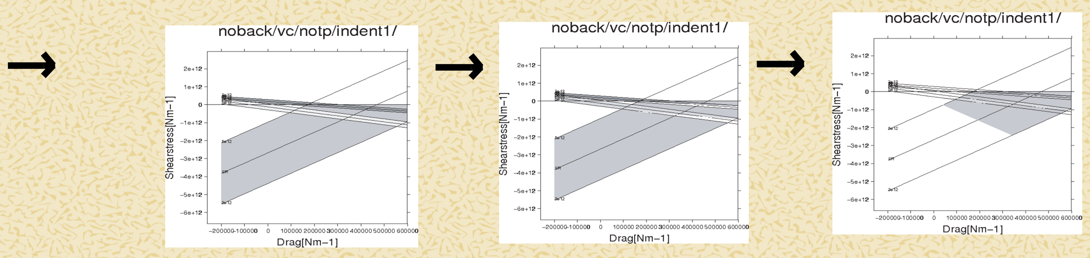
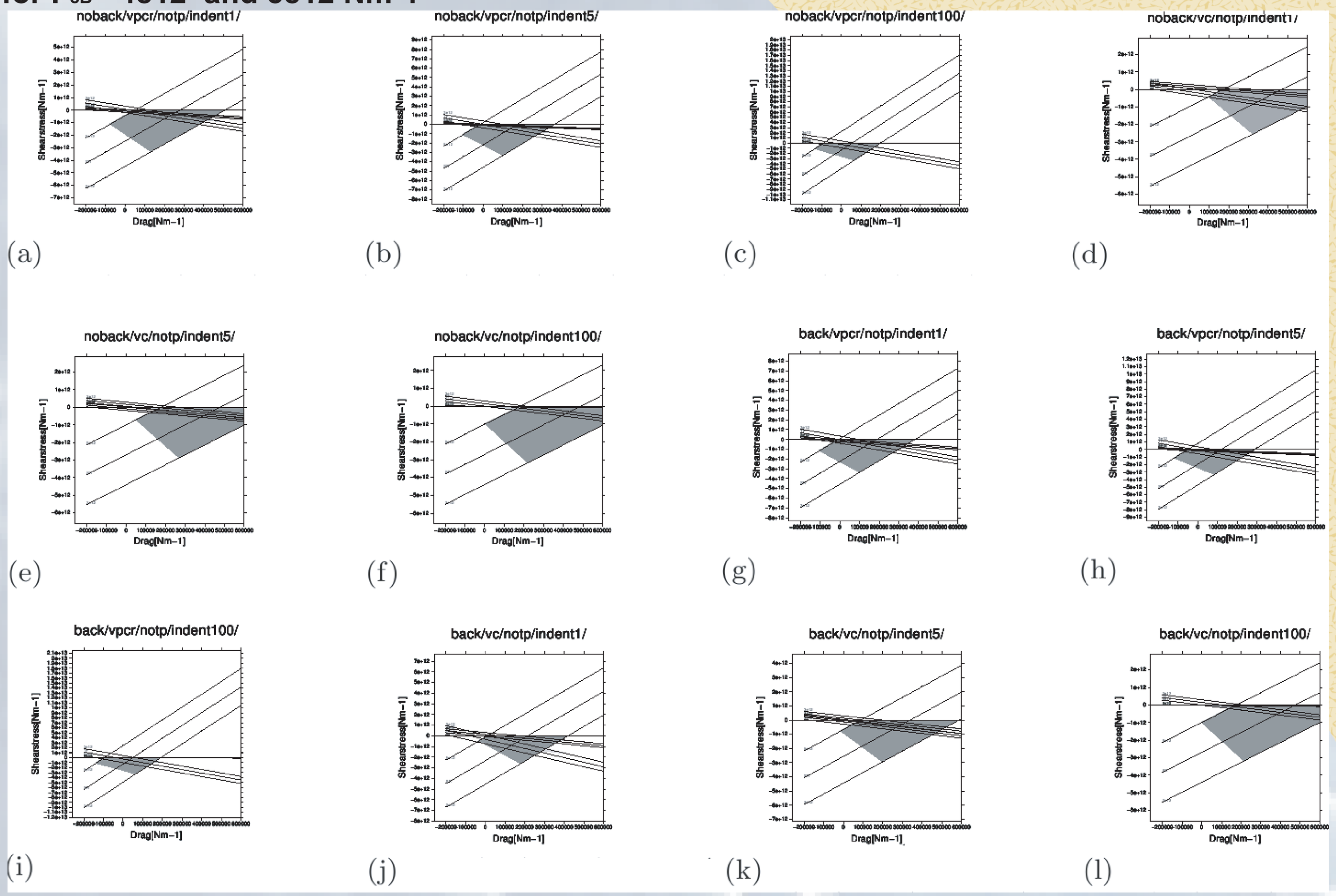


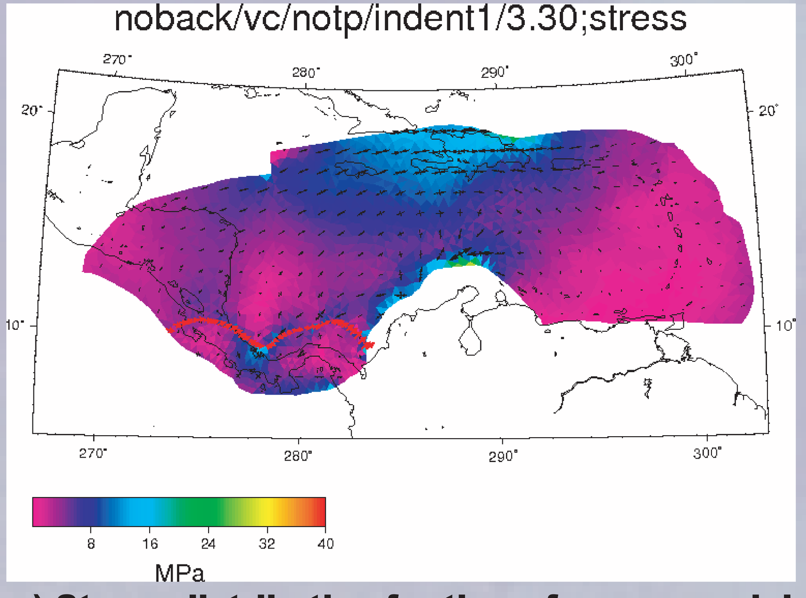
Figure 3a)
All possible solutions for, in this case, the reference model. The F_{dr} has been varied, F_{cb} has been taken constant, 3e12 Nm-1, giving 3 lines with solutions for the other unknown magnitudes. Then the same is done for F_{cB} =4e12 and 5e12 Nm-1

Figure 3b)
Not all solutions are physically sound. For example, we do not allow a driving (positive) resistive force. Figure 3b-d shows how to remove those solutions that have a positive resistive force.

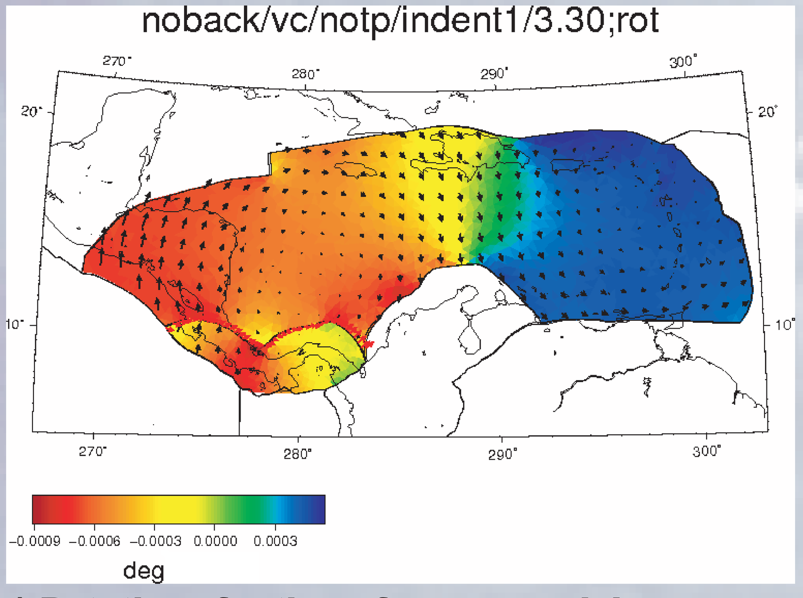


Figures 4 a-l: Solutions for all models mentioned above. Almost all models have solutions centered around F_{dr} = 0, implying that no basal drag is needed to obtain a balanced solution.

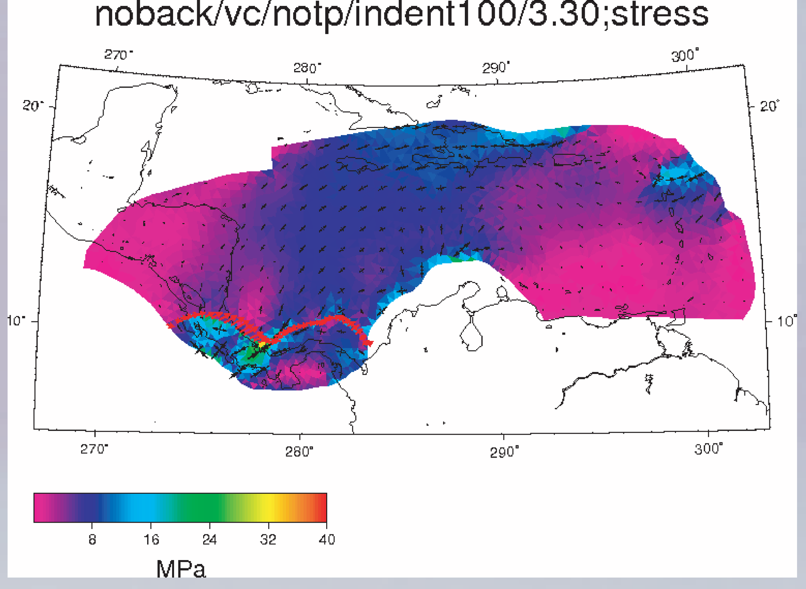
We solve the mechanical equilibrium equation, for all force combinations above, using the finite element code G-Tecton (Govers and Meijer, 2001). However, we choose only to examine the reference model and variations as mentioned above, since all other solutions can be composed as linear combinations of those deviations. The different solutions, share most first-order features, and we show only those solutions that are most representative



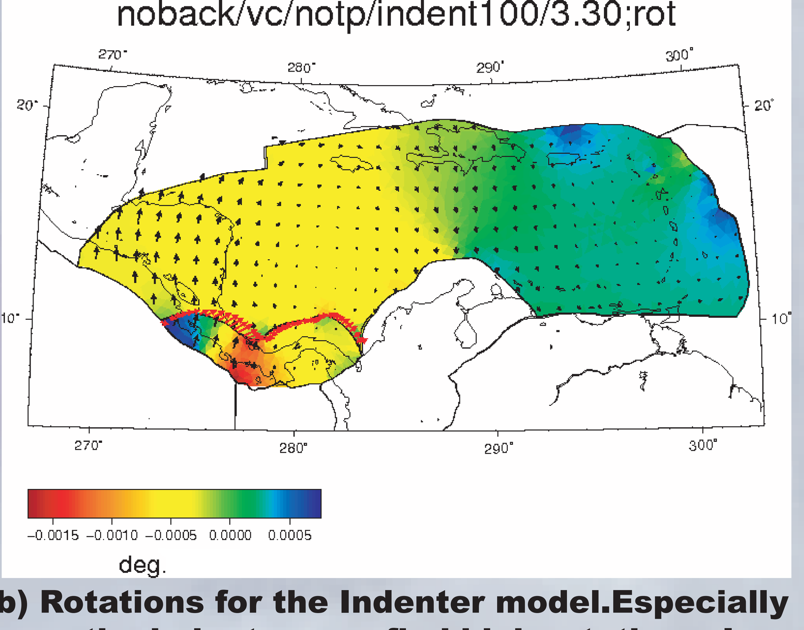
a) Stress distribution for the reference model. Features are high stresses, both in the north - and south centre of the Caribbean.



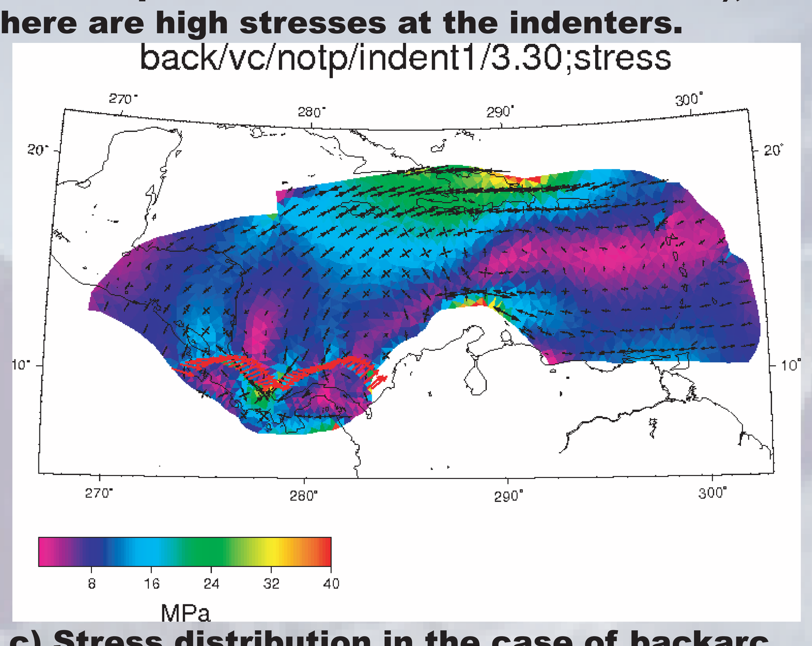
a) Rotations for the reference model. In the east we find counterclockwise rotations, in the west clockwise.



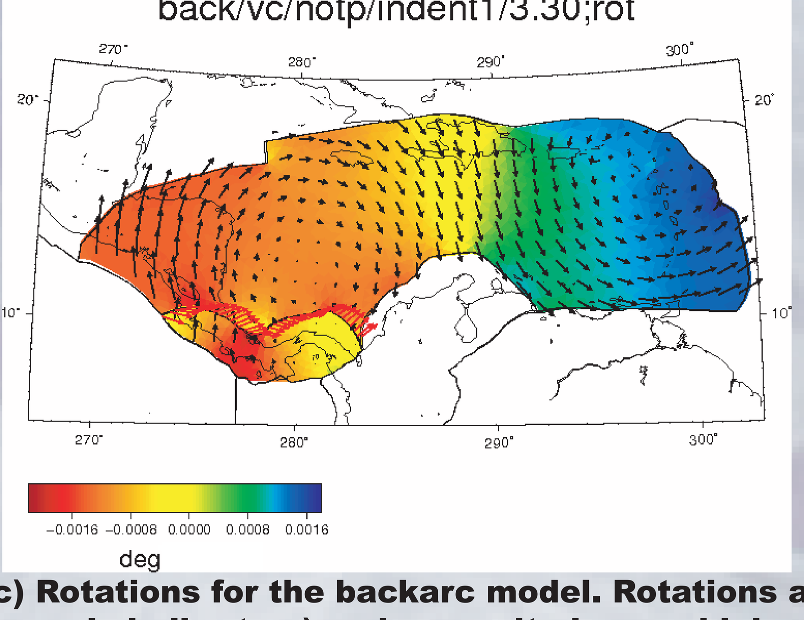
b) Stress distribution for the indenter (factor 100) model. Apart from features mentioned at a), there are high stresses at the indenters.



b) Rotations for the Indenter model. Especially near the indenters we find high rotations. In Panama there's both CW and CCW rotation.



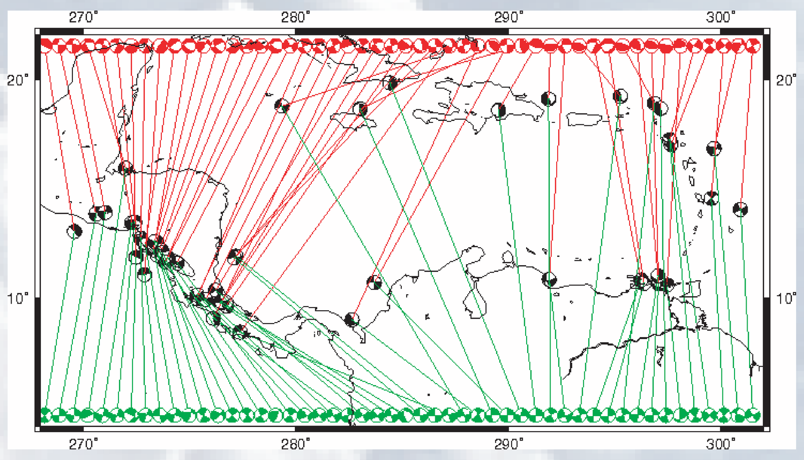
c) Stress distribution in the case of backarc spreading. Stresses are overall much higher.



c) Rotations for the backarc model. Rotations are overal similar to a), only magnitudes are higher.

Figure 5 (left) and 6: Solutions of the equilibrium equation. Figure 5 shows effective stress, and stress crosses. Figure 6 shows the rotation together with the displacement field.

The last step is to compare our results with actual data. As we have modelled the Caribbean as an elastic plate, we cannot use all observations. First we follow the method of Meijer (1995), as shown in figure 7.



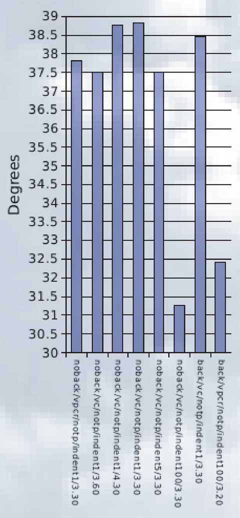
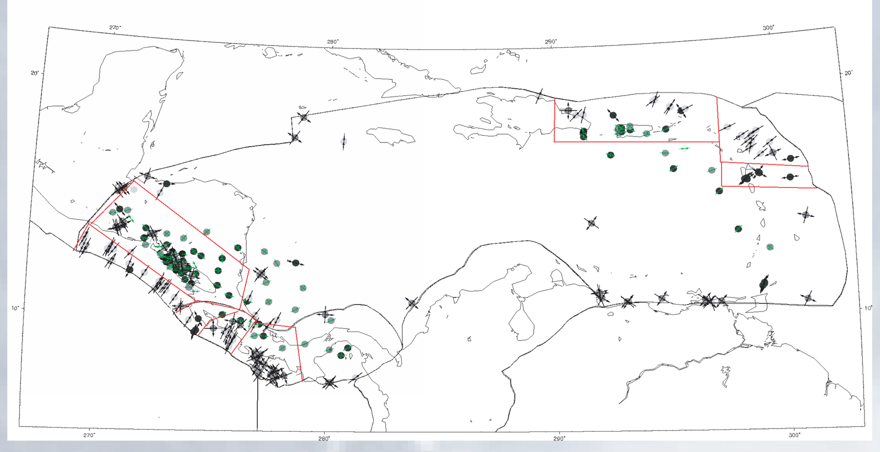


Figure 7a): Focal mechanisms, given by the CMT catalogue. Assuming, that slip occurs on a pre-existing fossil fault, we can, using the stress field from our models, calculate the direction of maximum shearstress on the faultplane. Next we assume, that slip occurs in the direction of maximum shearstress, thus obtaining new focal mechanisms, for both possible fault planes, as shown in the figure (red and green). By summing the squared differences in direction, between observed and calculated slip, we obtain a measure for the fit with the data. This measure is shown in figure 7b for all models.



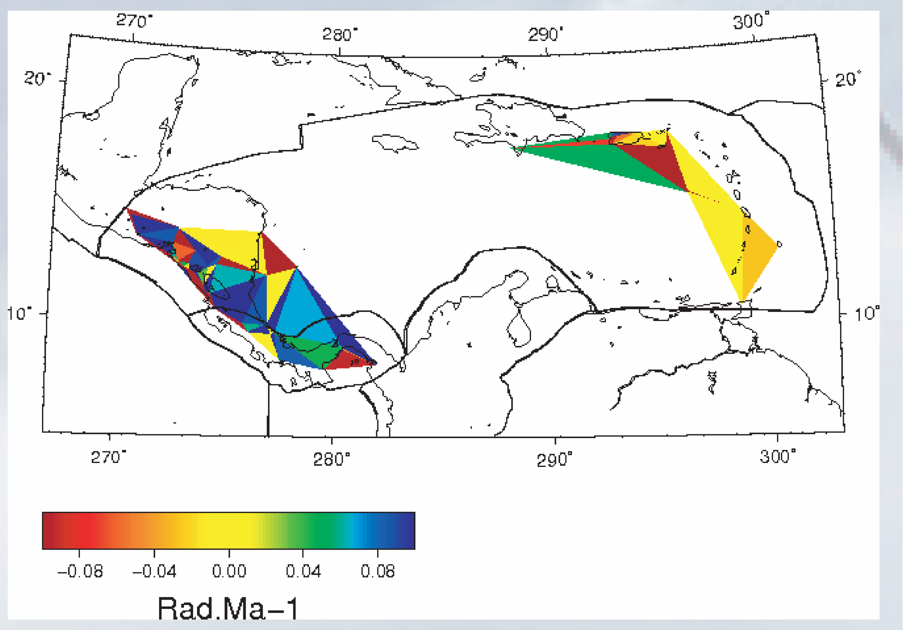


Figure 8a) Relative strainrate directions as obtained from gps measurements, in combination with strain directions from the World Stress Map. We triangulated the areas between the GPS - stations, and calculated the velocity gradients. Next, this can be converted to both rotations (Figure 8b), and strainrates, which are proportional to actual strains. The regime is denoted by a dot, ranging from compression (light), along trans-compression and trans-tension to tension(dark)

CONCLUSIONS:

1. **No basal drag is needed to obtain balanced solutions, contrary to findings by Negredo et al. (2004)**
2. **Consistent features of each model, are high compressive strains near Maracaibo and Hispaniola.**
3. **Slab pull forces are largely compensated in the subduction zone.**
4. **Indenters cause local high stresses. Our preliminary assessment indicates that models with indenters correlate better with observations.**

References:

Wortel, M. J. R., M.J.N. Remkes, R. Govers, S.A.P.L. Cloetingh, and P.Th. Meijer (1991). " Dynamics of the lithosphere and the intraplate stress field." Phil. Trans. R. Soc. A 337: 111-126.
Govers, R., and P.Th.Meijer (2001). "On the dynamics of the Juan de Fuca plate." Earth and Planetary Science Letters 189: 115-131.
Meijer, P. T. (1995). " Dynamics of active continental margins: the Andes and the Aegean region, PhD Thesis." Geologica Ultraiectina 130: 218.
Negredo A.M., I. Jiménez-Munt, A. Villaseñor, 2004, Evidence for eastward mantle flow beneath the Caribbean plate from neotectonic modeling, Geophys. Res. Lett, 31, L06615, doi:10.1029/2003GL019315