"Do periodic consolidations of Pacific countercurrents trigger global cooling by equatorially symmetric La Niña?" cpd-2010-28 John H. Duke

Author response to review

This paper frames a broad hypothesis that Pacific countercurrent consolidation (PCC) is the common mechanism of global cooling in ENSO, millennial, and Milankovitch timescales. Though the field of paleoclimatology is now largely specialized by timescale, I believe there is utility in a trans-timescale approach, in the sense that simultaneous equations provide solution to each other. It is necessary that change in all timescales play out within the same Earth system. Here, PCC may be the physical mechanism that explains the seminal Cane (1998) observation of La Niña - ice age similarity.

The 23 July review does not mention PCC, which is the unifying idea of the paper, or any part of Sections 4 through 8, which include the proposed millennial and Milankovitch timescale triggers of PCC. I therefore respectfully question whether the review takes a full measure of the paper's integrative merit. I offer this brief summary in a revised order:

(1) PCC occurs when the North Equatorial Countercurrent (NECC) and South Equatorial Countercurrent (SECC) transport merge with the Equatorial Undercurrent (EUC), sometimes breaching the surface. In contrast, the present mean NECC-EUC-SECC system is interconnected within the thermocline at 165°E, forming a 900 km wide largely submerged ribbon of eastward flow. The high specific surface area of this ribbon provides shear friction that maintains the gravitational potential of the western warm pool, which PCC therefore releases. This release is initially El Niño if the warm pool is in its known recharged state. But if not, the same PCC condition then results (Section 5) in what I define as equatorially symmetric La Niña (ESLN), in which the NECC is absent, the ITCZ is shifted south to the equator, and there is a characteristic "cold eye" centered on 140°W (rather than the usual cold tongue further east). The duration of ESLN is not inherently limited because PCC concentrates shear energy at the equator, which acts to steepen east-west thermocline tilt by expansion of the underlying thermostad. ESLN becomes the proposed engine of global cooling (Section 6) in all timescales, largely because water vapor production plummets when the rising branch of the mid-Pacific Hadley cell is over the ESLN cold eye.

(2) ITCZ migration is the proposed long timescale PCC control (Section 4). Sverdrup (1947) explains that the NECC's present mean northward extent results from conservation of planetary vorticity spun up by positive wind curl. But the mean wind state that yields that pattern of wind curl is itself a function of present northward ITCZ bias. So the NECC follows the ITCZ (as it does in the annual cycle). I therefore hypothesize that perihelion between March and September (increasing north-south temperature gradient in northern summer) is the precessional condition that shifts the annual mean ITCZ north to turn PCC off, and vice-versa. Fig. 15 shows that the "fast melt" portion of 31 of the 34 largest interglacial periods in the past two million years occurs in the half precession period between March and September perihelion. But, importantly, this precession effect is also modulated by obliquity (Section 8), so I further propose that (a) glacial termination requires *both* March perihelion and obliquity greater than 23.5°, and (b) obliquity greater than 23.5° also extends warm periods after the fast melt interval (as at present). In this way, orbital control of PCC is the missing external driver in the tropical hypothesis (Chiang 2009 review) that follows Cane (1998). Koutavas and Lynch-Stieglitz (2005) provide evidence of cold phase southward ITCZ migration.

(3) The proposed short and millennial timescale PCC trigger also relates to Sverdrup (1947), but in a different way. Northward NECC drift is due to the vortex stretching term, which presumes conservation of vorticity, so an event that dissipates vorticity would cancel that term. In that circumstance, geostrophic convergence then merges the NECC into the EUC as PCC. I propose that sporadic internal tide resonance (ITR) is that event. For example, Fig. 1(h) shows 8°C semidiurnal temperature excursions in 150 m depth at 0°N 165°E coincident with local meridian passage of the moon and sun during 16-22 February 1997. This rapid subsurface temperature change indicates

semidiurnal thermocline heave of approximately 100m two weeks prior to eastward advection at the 1997 El Niño onset. The Fig. 3(c) timeseries shows that ITR precedes 11 of 12 major upturns in the Niño 3.4 index between 1992 and 2008. There are also distinct pulses of net subsurface southward transport at 0°N 165°E on the same day as distinct peak tide events.

(4) Section 7 presents forcing periodicities that test the above short timescale PCC by ITR hypothesis. Fig. 8 relates the Niño 3.4 series to total daily tidal excursion recorded at the Marshall Islands (9°N 168°E), a record that published tide tables also extend into the future. A first periodicity is noted in the recurring coincidence of proxigee (minimum perigee of Wood (1986)) with the vernal equinox in 1993-94, 1998, 2002, and 2006-07, which are years of maximum equinoctial tidal excursion. A second overlapping periodicity is in the recurrence of vernal eclipses, which repeats in 1997 and 2006. These vernal forcing events corresponds to El Niño years, except 1998 which was ESLN. A third periodicity is in the frequency of extreme close eclipses, which both govern the proxigee cycle and maximize perturbation in the length of the synodic month, which in turn yields five month long periods of minimum length perigee-sysygy intervals (Wood, 1986). In the present epoch this circumstance repeats in 1973, 1982, 1991, 2000, and 2009, which are El Niño years, except 2000 in the extended post-1998 La Niña. I introduce a 586 year cycle in the frequency of this circumstance (Figs. 10-14), with maxima during the mid-eighteenth century La Niña peak (Gergis and Fowler, 2009) and Bond cycles 1-3 (Bond et al., 1999). This cycle is related to the 18.03 year Saros eclipse cycle, whose overlapping perigean series are separated by 86.83 years. In accord with this forcing, Treolar (2000) provides spectral analysis of ENSO that reveals 18.02, 20.295, and 86.795 year cycles. In the millennial domain, 2x and 3x multiples of the 586 year interval (1,172 and 1,758 years, again related to higher commensurabilities with perigee) approach the dual 1,197 and 1,667 year Sulu cave spectral peaks identified by Clemens (2005) and the 1,163 and 1,613 year Greenland periods identified by Hinnov et al. (2002).

The general criticism that the paper is speculative is consistent with its stated objective to "frame a hypothesis" (page 908 line 10). The trans-timescale approach which I attempt may resolve five important questions:

a) If the "10 kyr" duration of the fast melt portion of interglacials is physically determined by the PCC-off half precession interval between March and September perihelion, and ice sheets accrete slower than they melt (in the other half), then continuing precession forcing can only manifest as an overtone, for the length of a complete cycle must exceed one precession period. Precession's 2x overtone is spectrally indistinguishable from that of obliquity. This may resolve the question why the 41 kyr spectral signature of obliquity is greater than that of precession, though the insolation signal of precession is stronger (Raymo and Nisancioglu, 2003).
b) A physically determined half precession fast melt interval also explains apparent skewness in glacial-interglacial durations (Broecker and van Donk, 1970; Lisiecki and Raymo, 2007).
c) The dual necessary condition of March perihelion *and* obliquity greater than 23.5° for glacial termination may explain the late Pleistocene transition to 100 kyr glacial cycles, for that is when the phase relation between precession and obliquity changed from 1:2 to either 3:5 or 2:5 (Fig. 15).
d) The prevalence of millennial climate change during MIS 3 observed by Siddall et al. (2010) may reflect a climate forcing hierarchy in order of timescale. MIS 3 is a skipped obliquity cycle (Huybers, 2009). If this is due to (c), then net long timescale forcing is weakened at MIS 3 because precession and obliquity effects are in conflict, which may be what allows stronger manifestation of the millennial signal. Conversely, Siddall et al. (2010) observe weak millennial forcing when the proposed precession and obliquity effects are in phase.
e) The proposed ITR-PCC mechanism may also play a role in the observed association of low obliquity with cold climate. Fig. 8(f) indicates that Marshall Islands maximum tide excursions

are approximately 30% greater at the equinox than at the solstice (low latitude semidiurnal inequality diminishes with sun and moon declination). Lower obliquity would therefore increase annual mean low latitude tidal energy that drives the proposed ITR-PCC mechanism.

f) The striking observation of ENSO activity in years of maximum tidal excursions near the vernal equinox (Fig. 8) suggests that this may be the key to the so-called spring predictability barrier. If verified, such a predictive tool would have great societal value in agricultural planning and tropical cyclone risk assessment.

In response to the review's detailed comments:

Page 906/Line 13: It is no clear to me what is "a distinct mode of equatorially symmetric La Niña"? It is not a La Niña event to me!

The sentence continues, "characterized by a winter monsoon cell above a "cold eye" that is separated from the South American continent, as in 1998." I should add that equatorially symmetric means the ITCZ is centered over the equator.

Page 911/Line25: "a solar eclipe on 14 December 2001 coincident with another WWB.." A WWB lasts somewhat like 3 to 10 days whereas an eclipse not..!

Change "coincident with" to "occurs in the middle of".

Page 912/ Line 6-23: Interpretation of Fig 3: A definition of WWB is lacking. From Fig. 3d; it is not possible to me to state if a WWB is going on or not.

Insert in line 12, "indicated by positive values greater than 2 m/s".

Note that the interpretation of Fig. 3 omits the contribution of reflected equatorial waves (not related directly to local wind variation) at the western boundary which may also impacts the SST

The purpose of the figure is to relate ITR to El Niño onset. As I understand the present theory, wave reflection at the western boundary is invoked as a negative feedback that terminates El Niño (Wang and Picaut, 2004).

Page 912/Line 25: "There is also evidence of an ITR role in later stages of the ENSO": this sentence is very vague.

This is just a transition sentence introducing Figs 4 and 5, which depict complete ENSO cycles.

Page 913/ Line 6: "This of coarse.."

Thanks.

Page 913/Line 17: "Close examination of the lunar distance plot of Fig. 4(a) shows…": this is not obvious from the inspection of the timeseries...it should be quantified.

Add, "For example, geocentric lunar distance at 7 February 1997 proxigee is 356,847 km, at 29 May 1997 perigee is 369,788 km, and at 16 September 1997 proxigee is 356,966 km.

Page 913/Line 22-23: "The correlation…is evident..": so please provide the values!

Change "correlation" to "association". My purpose is to frame a broad hypothesis (not prove it), so that other researchers may attack its disparate ideas. To that end, I believe that graphic presentation is the best way to convey qualitative understanding necessary to begin thinking about the ideas.

Page 916/Line 14: very obscure. The mean circulation in the tropical Pacific is described and this leads to the definition of an hydraulic model of ENSO…!? Please clarify.

Use of the term “hydraulic” is in reference to the ribbon vs. pipe analogy (high vs. low specific surface area) used earlier.

Page 916/Line 17-18: “ITR triggers PCC by dissipating cyclonic vorticity, which tips Sverdrup balance towards convergence…”..this sentence is incomprehensible to me!”

This idea is described in paragraph (3) above.

To the editors, I respectfully request an extension of time in the discussion phase, to permit both a real exchange of ideas and time to re-edit the paper. Other reviews and more comments are welcome.

References not in paper:

Raymo, M. E., and K. Nisancioglu, The 41 kyr world: Milankovitch’s other unsolved mystery, Paleoceanography, 18(1), 1011, doi:10.1029/2002PA000791, 2003.

Siddall, M., Rohling, E. J., Blunier, T., and Spahn, R.: Patterns of millennial variability over the last 500 ka, Clim. Past, 6, 295–303, 2010.

Wang, C., and J. Picaut, Understanding ENSO physics - A review, in *Earth's Climate: The Ocean-AtmosphereInteraction*, Geophysical Monograph Series, Volume 147, edited by C. Wang, S.-P. Xie, and J. A. Carton, pp. 21-48, AGU, Washington, D. C., 2004)