AOGS
13th Annual Meeting
Asia Oceania Geosciences Society
31 Jul to 5 Aug 2016, Beijing

The Ocean Pole Tide: A Review

Richard Gross

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109–8099, USA

Asia Oceania Geosciences Society
13th Annual Meeting

July 31 to August 5, 2016
Beijing, China

© 2016 California Institute of Technology. U.S. Government sponsorship acknowledged.

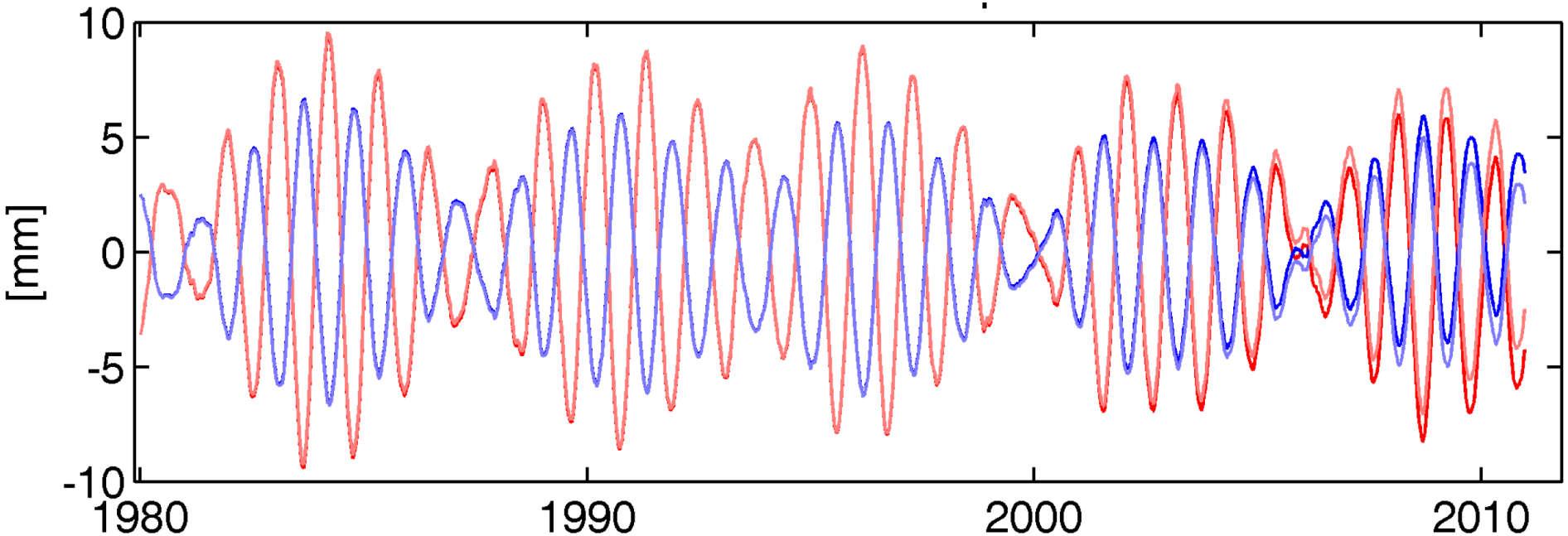
Outline of Presentation

- Theory of pole tides
  - Solid Earth
  - Oceans
- Observations of ocean pole tide
  - Tide gauge
    - Fourier analysis
    - Power spectrum analysis
    - Stacking
  - Satellite altimetry
- Impact of ocean pole tide
  - Oceanography
    - Small, non-astronomically forced ocean tide
  - Geodesy
    - Period and *Q* of Chandler wobble

Theory

- Earth rotation
  - Not constant
    - Rate of rotation changes (length-of-day variations)
    - Earth wobbles as it rotates (polar motion)
- Centrifugal force acting on Earth
  - Changes as Earth rotation changes
  - Deforms elastic solid Earth (solid Earth pole tide)
    - Changes in rotation rate cause size of Earth's rotational bulge to change
    - Polar motion causes solid Earth pole tide
  - Deforms oceans (ocean pole tide)
- Solid Earth pole tide
  - Y_{21} pattern, amplitude of a few centimeters
- Ocean pole tide
  - Y_{21} pattern, amplitude of about 5 mm
  - Frequency same as forcing (polar motion) frequency

Solid Earth Pole Tide at Wetzell & Kokee



(Krásná, 2012)

Primary signals: 12-month annual and 14-month Chandler

Pattern of Ocean Pole Tide

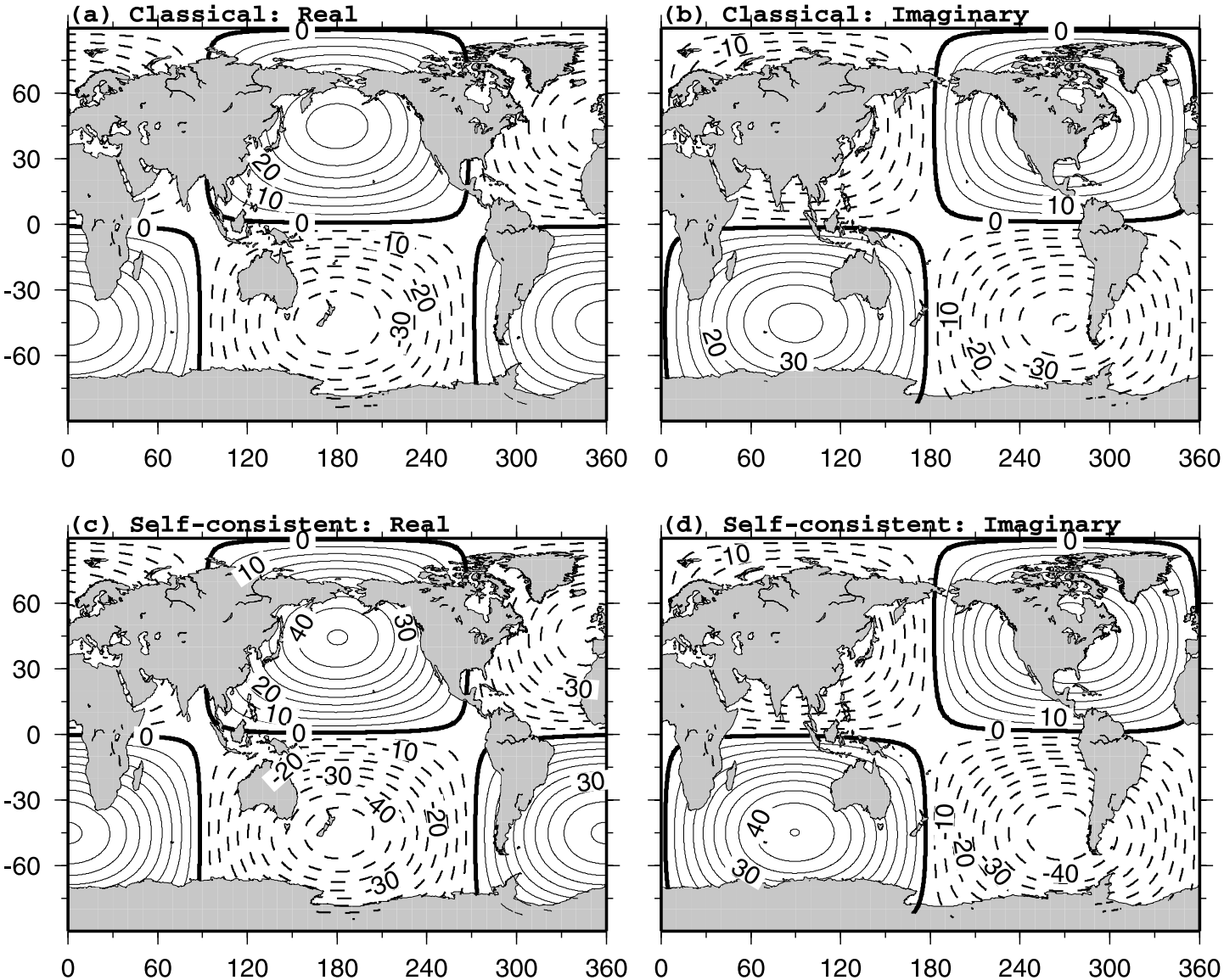


Figure 2. Normalized classical and self-consistent equilibrium ocean pole tide admittance functions with mass conserved, $\bar{E}^c$ and $\bar{E}^s$, respectively. Solid contours are positive, dashed contours are negative, and the units are percent.

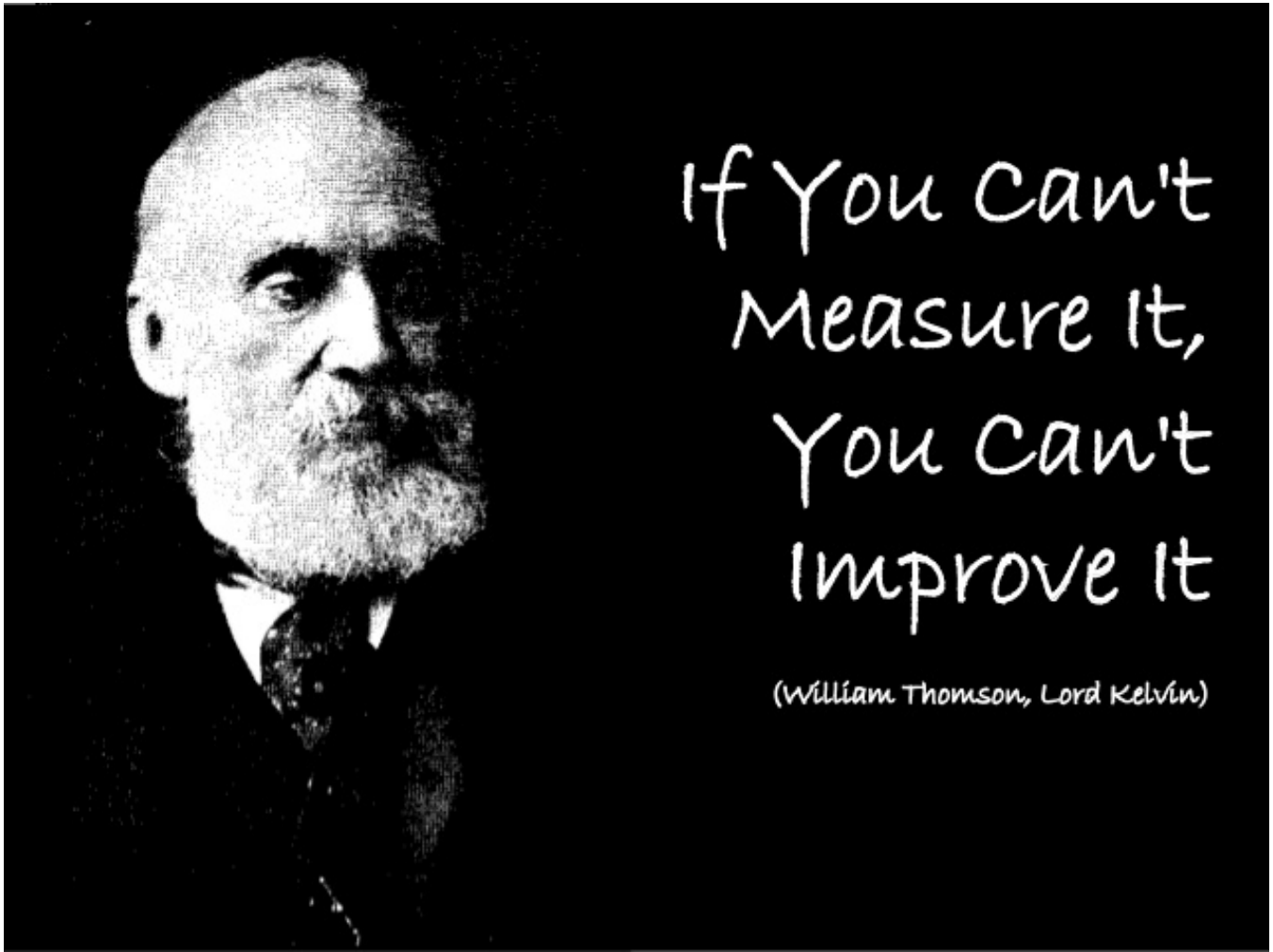
(Desai, 2002)

History of Ocean Pole Tide

- Predicted by Lord Kelvin in 1876

"The sea would be set into vibration, one ocean up and another down …"

(Presidential Address, BAAS, 1876)



source:
likesuccess.com

History of Ocean Pole Tide, cont.

- Early questionable observations
  - Detect 14-month signal in 7-yr segments of tide gauge data
    - A. S. Christie (“The latitude variation tide”, 1900)
    - H. G. Bakhuyzen (“Über die Änderung der Meereshöhe und ihre Beziehung zur Polhöhenschwankung”, 1913)
    - E. Przbyllok (Veröff. des Preuss, Geodäsischen Inst., 1919)
    - J. Baussan (”La composante de Chandler dans la variation des niveaux marins”, 1951)
    - I. Maximov (“The polar tide in the Earth’s ocean”,1956)
- Haubrich and Munk (1959)
  - Applied power spectrum analysis to tide gauge data
  - Questioned earlier claims of detection (data too noisy)

Haubrich and Munk (1959)

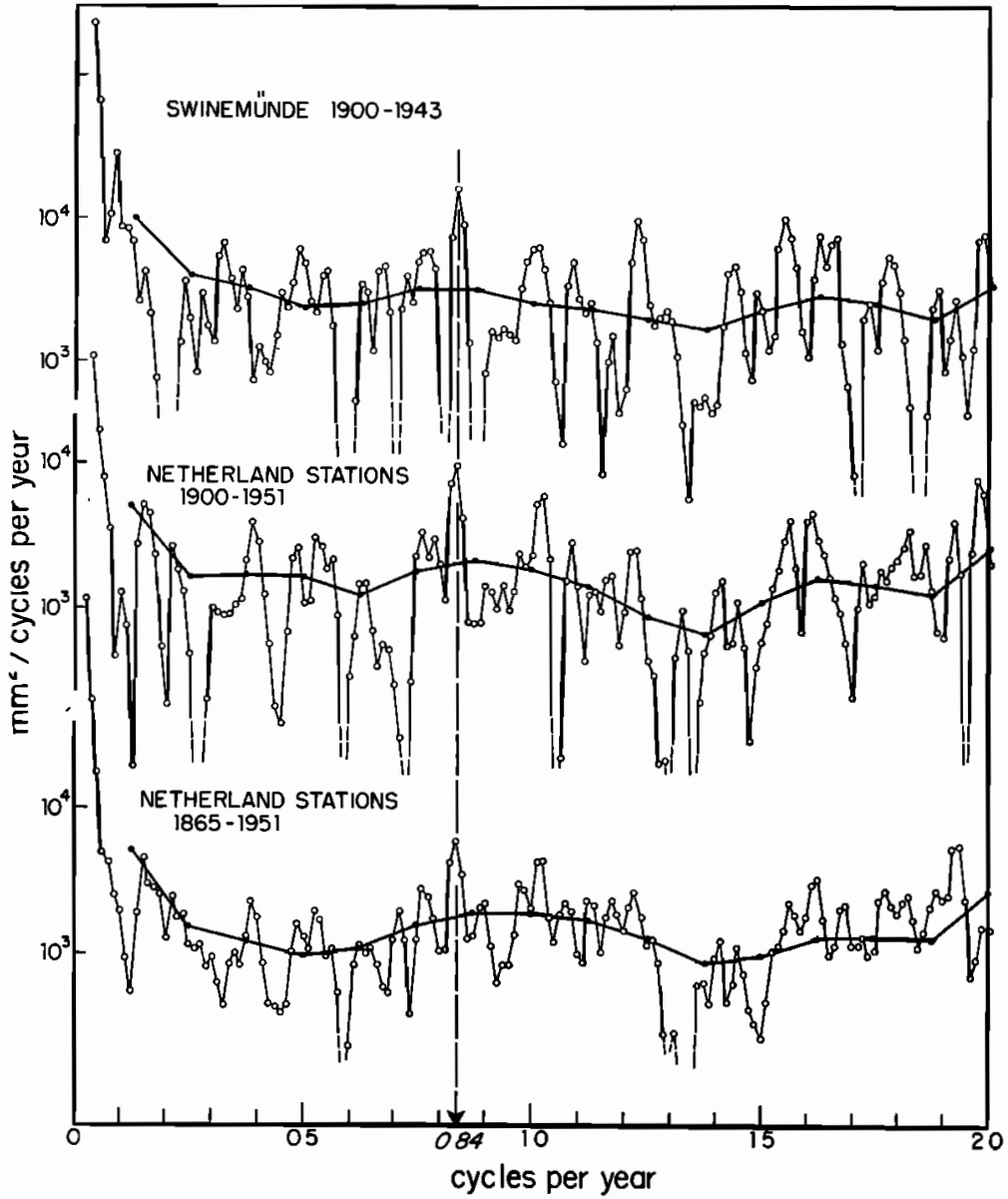


FIG. 1—Power spectra for Swinemünde and the Netherlands stations; solid circles, low-resolution spectra; open circles, high-resolution spectra.

History of Ocean Pole Tide, cont.

- Early questionable observations
  - Detect 14-month signal in 7-yr segments of tide gauge data
    - A. S. Christie (“The latitude variation tide”, 1900)
    - H. G. Bakhuyzen (“Über die Änderung der Meereshöhe und ihre Beziehung zur Polhöhenschwankung”, 1913)
    - E. Przbyllok (Veröff. des Preuss, Geodäsischen Inst., 1919)
    - J. Baussan (”La composante de Chandler dans la variation des niveaux marins”, 1951)
    - I. Maximov (“The polar tide in the Earth’s ocean”,1956)
- Haubrich and Munk (1959)
  - Applied power spectrum analysis to tide gauge data
  - Questioned earlier claims of detection (data too noisy)
- Trupin and Wahr (1990)
  - Stacked tide gauge data (weight data to match Y_{21} pattern)

Trupin and Wahr (1990)

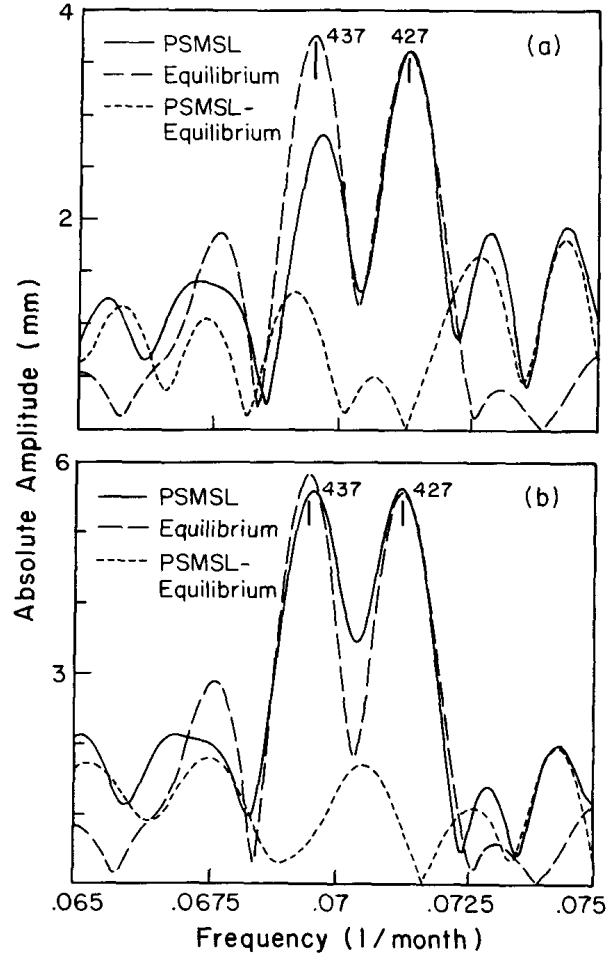


Figure 2. Amplitude spectra at the Chandler wobble frequency band for Y_2^1 stacks of 487 stations. The solid curve is for the PSMSL stack, the long-dashed curve is for the synthetic (equilibrium) data and the short-dashed curve is the spectrum obtained when the synthetic stack is subtracted from the PSMSL stack. The effects of pressure have been subtracted from the PSMSL data, assuming an inverted barometer response. The Chandler wobble is clearly evident in the PSMSL results, and its amplitude is close to equilibrium. Stations in the North and Baltic Seas and in the Gulf of Bothnia are not included in the stacks. (a) Ungridded. (b) $10° \times 20°$ grid.

History of Ocean Pole Tide, cont.

- Early questionable observations
  - Detect 14-month signal in 7-yr segments of tide gauge data
    - A. S. Christie (“The latitude variation tide”, 1900)
    - H. G. Bakhuyzen (“Über die Änderung der Meereshöhe und ihre Beziehung zur Polhöhenschwankung”, 1913)
    - E. Przbyllok (Veröff. des Preuss, Geodäsischen Inst., 1919)
    - J. Baussan (”La composante de Chandler dans la variation des niveaux marins”, 1951)
    - I. Maximov (“The polar tide in the Earth’s ocean”,1956)
- Haubrich and Munk (1959)
  - Applied power spectrum analysis to tide gauge data
  - Questioned earlier claims of detection (data too noisy)
- Trupin and Wahr (1990)
  - Stacked tide gauge data (weight data to match Y_{21} pattern)
- Desai (2002)
  - Detected (solid Earth + ocean) pole tide in altimetry data

Desai (2002)

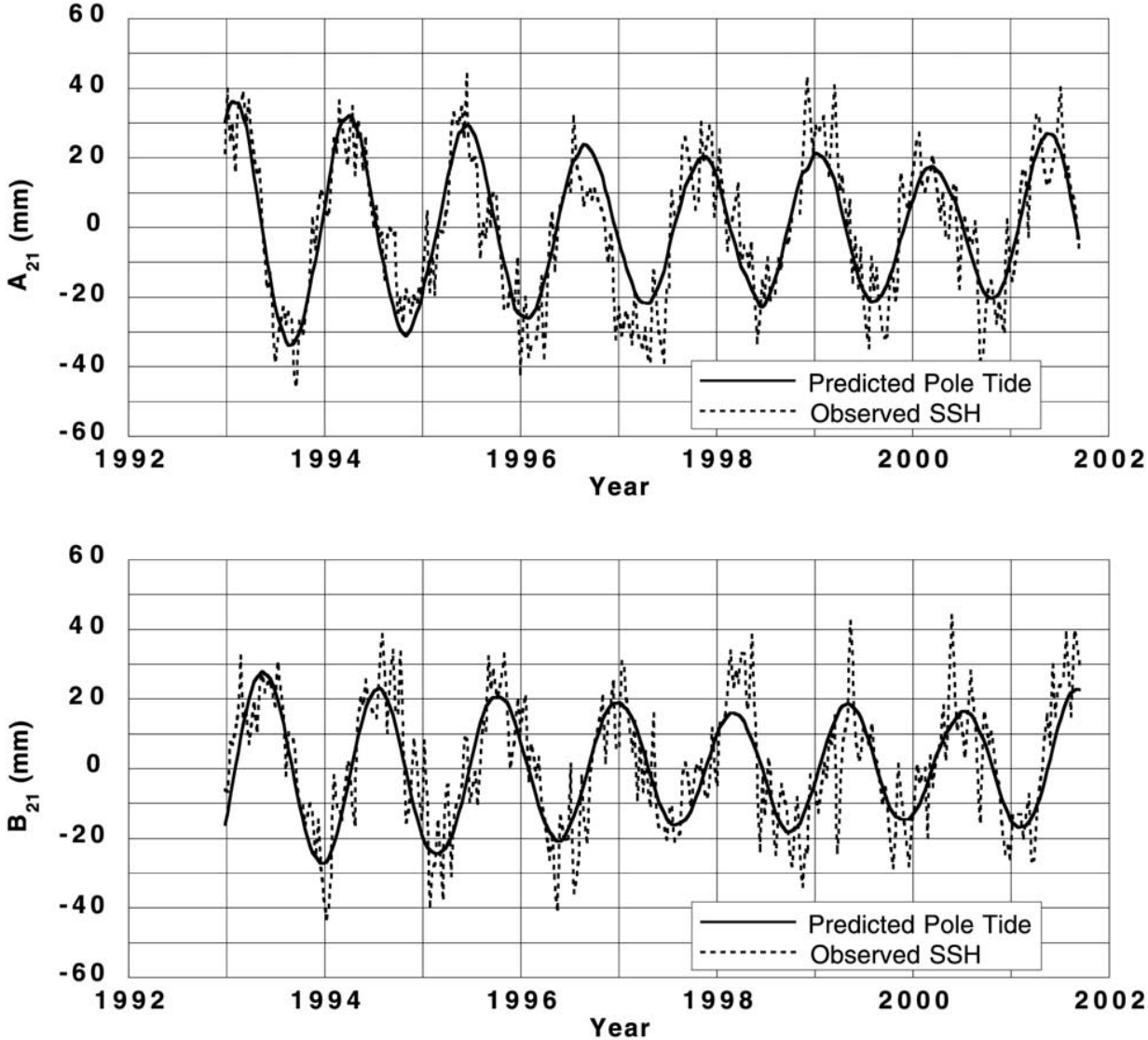


Figure 4. Degree 2, order 1 spherical harmonic coefficients, A_{21} and B_{21}, of the T/P sea surface height (SSH) observations, and the predicted geocentric pole tide deformations of the sea surface height observed by T/P. The predictions are computed with the assumption that the ocean pole tide has a self-consistent equilibrium response.

Desai (2002)

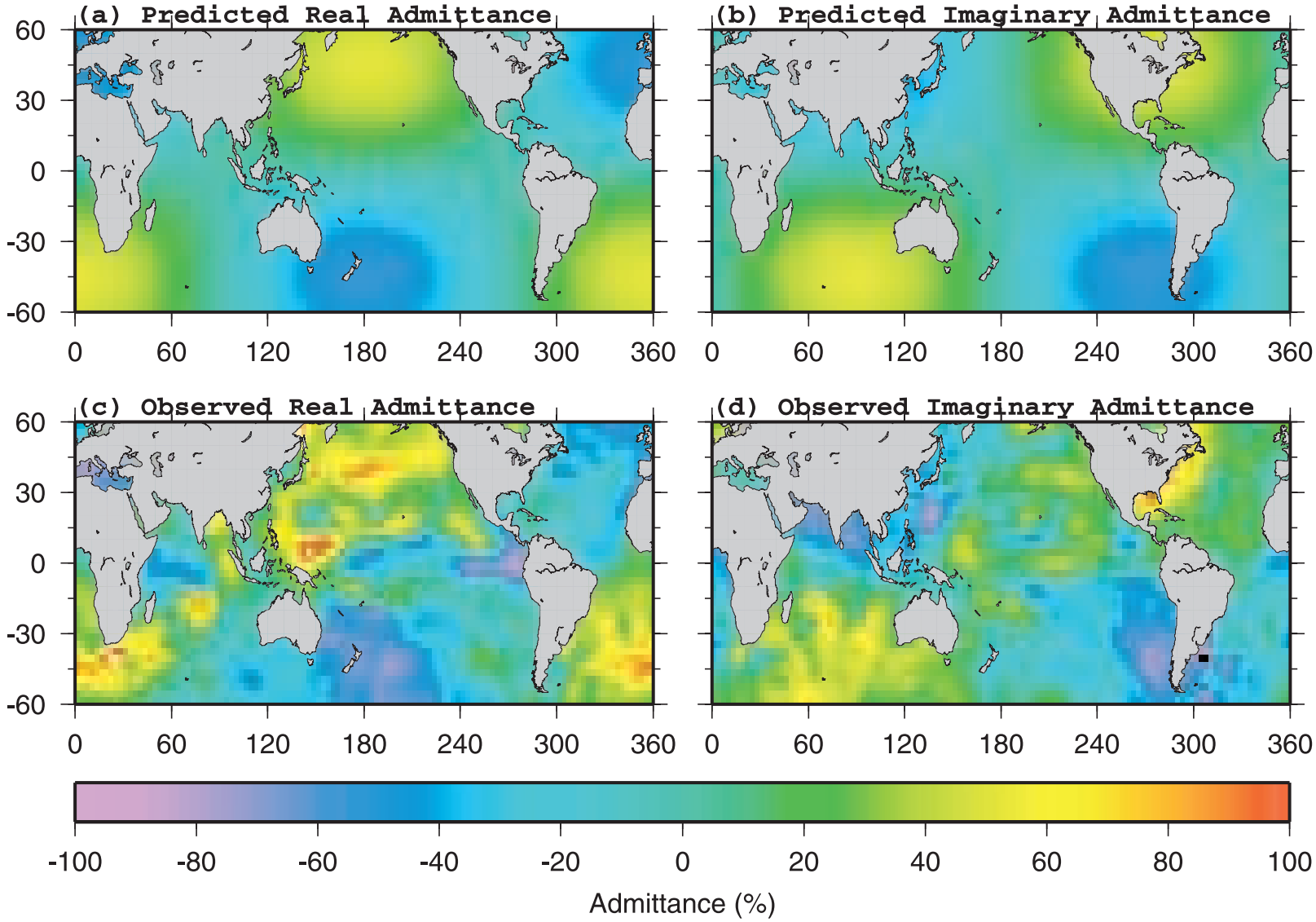


Figure 5. Maps of the geocentric pole tide admittance function, $Z_A(\theta, \lambda)$, that is determined from T/P sea surface height observations, and the corresponding admittance that is predicted with the assumption that the ocean pole tide has a self-consistent equilibrium response.

Passive Influence of Oceans on T_{cw}

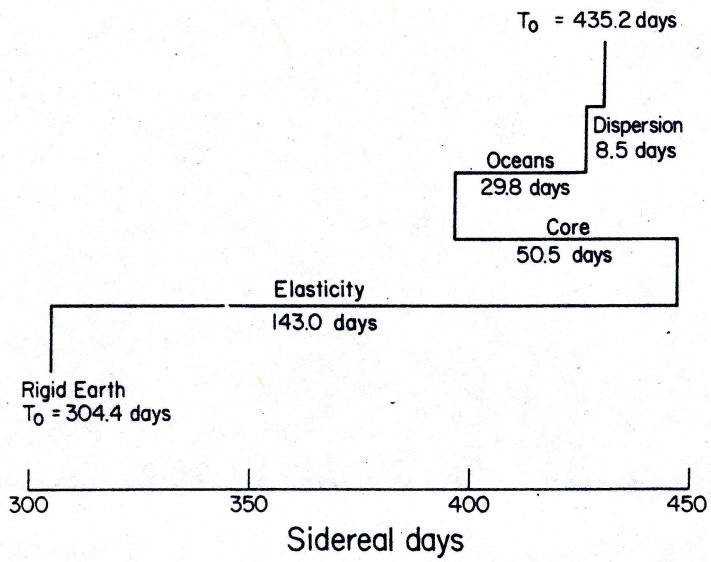


Figure 5. Schematic summary of the extent to which the rigid Earth Chandler period T_0 = 304.4 day is modified by the effects of elasticity, the fluid core, equilibrium oceans and mantle dispersion to its observed value T_0 = 435.2 day.

(Smith and Dahlen, 1981)

- Period of Chandler wobble
  - Presence of oceans increases period of Chandler wobble
    - Oceans deform as result of wobbling motion of solid Earth
  - First suggested by Newcomb (1891, 1892)
    - Explained discrepancy between 427-day period observed by Chandler (1891) and 306-day period predicted by Euler as due to “fluidity of the ocean” and “elasticity of the Earth”
  - If oceans are in equilibrium, Chandler period increases by 29.8 sidereal days (Smith and Dahlen, 1981)
  - If oceans depart from equilibrium by 1%, then period increases by an additional 0.3 sidereal days (Smith and Dahlen, 1981)
    - Uncertainty (1σ) in observed period of Chandler wobble is 1.1 days (Wilson and Vicente, 1990)

Passive Influence of Oceans on Q_{cw}

- Damping of Chandler wobble
  - Due to possible dissipation in oceans
  - No dissipation if oceans wobble with the solid Earth
    - That is, if pole tide is an equilibrium tide
  - Amount of dissipation depends on amount that global oceans are not in equilibrium with Earth's wobbles
    - Impact may be large
    - Departure from equilibrium of only 1%, or a phase lag or 4.5 days, gives $Q_{cw} = 100$ (Smith and Dahlen, 1981)
  - Numerical models indicate negligible departure of pole tide from equilibrium (Carton and Wahr, 1986)
  - Observations are consistent with an equilibrium pole tide
    - Tide gauges (Trupin and Wahr, 1990)
    - Topex/Poseidon sea surface height (Desai, 2002)
  - But observations are uncertain

Summary

- Solid Earth and ocean pole tides
  - Forced by polar motion
    - Amplitude of few cm in solid Earth, order of magnitude smaller in oceans
- Ocean pole tide unambiguously observed
  - Tide gauges and satellite altimetry
- Impact of ocean pole tide
  - Small for oceanography, large for geodesy
  - Equilibrium oceans increases T_{cw} by 29.8 sidereal days
    - Oceans out of equilibrium by 1% increases period by additional 0.3 sid. days
  - Dissipation within oceans may be an important damping mechanism of Chandler wobble
    - In absence of observations to the contrary, ocean pole tide is usually assumed to be in equilibrium based on results of models
  - Better observations of ocean pole tide are needed