Sequentially Estimating and Updating Terrestrial Reference Frames

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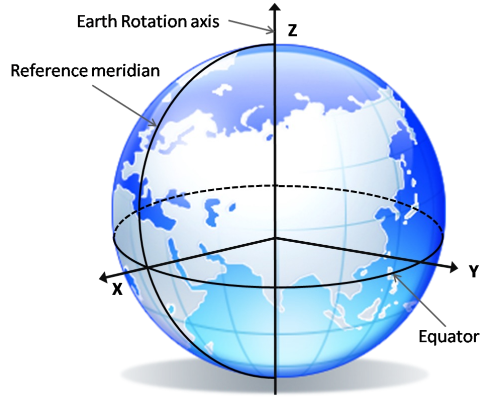
Introduction

- **Terrestrial Reference Frame (TRF)**
  - The TRF is an accurate, stable set of positions and velocities of reference points on the surface of the Earth
  - The TRF provides the stable coordinate system that allows us to link measurements over space & time for numerous scientific and societal applications including climate & sea level change studies
  - The GNSS, VLBI, SLR, & DORIS geodetic networks, along with ground surveys of stations at co-located sites to tie the networks together, provide the data for determining the TRF as well as for direct science investigations



Terrestrial Reference Frame

- **IAG / GGOS goal**

  TRF accurate to better than 1 mm, stable to better than 0.1 mm/yr

- **Pathways to Improving the TRF**
  - Develop next generation ground stations
  - Launch dedicated satellite missions
  - Improve analysis of existing ground and space observations (this presentation)

- **NASA/JPL's IERS ITRS Combination Center**
  - Conduct research into improving combined TRFs
    - Sequential estimation (Square-root information filter / Dyer-McReynolds covariance smoother)
    - TRF represented by time series of smoothed station positions


GNSS


SLR


VLBI


DORIS

NASA/JPL's Unique Approach to TRF Combination

- The traditional approach to the International Terrestrial Reference Frame (ITRF)
  - The frame is the **model** fit to observed station positions
  - Station positions at times beyond the date of the frame creation are based on model predictions alone and not the latest observations

- The JPL Terrestrial Reference Frame (JTRF) approach is different
  - Rather than a model, the JPL Frame is a **set of time series of smoothed, actually observed station positions**
  - An advantage of this approach is that **station positions and predictions can be kept updated** using the latest geodetic observations, sustaining the quality of the TRF and potentially **increasing the time between re-determinations**
    - JPL plans to provide monthly updates to JTRF2020

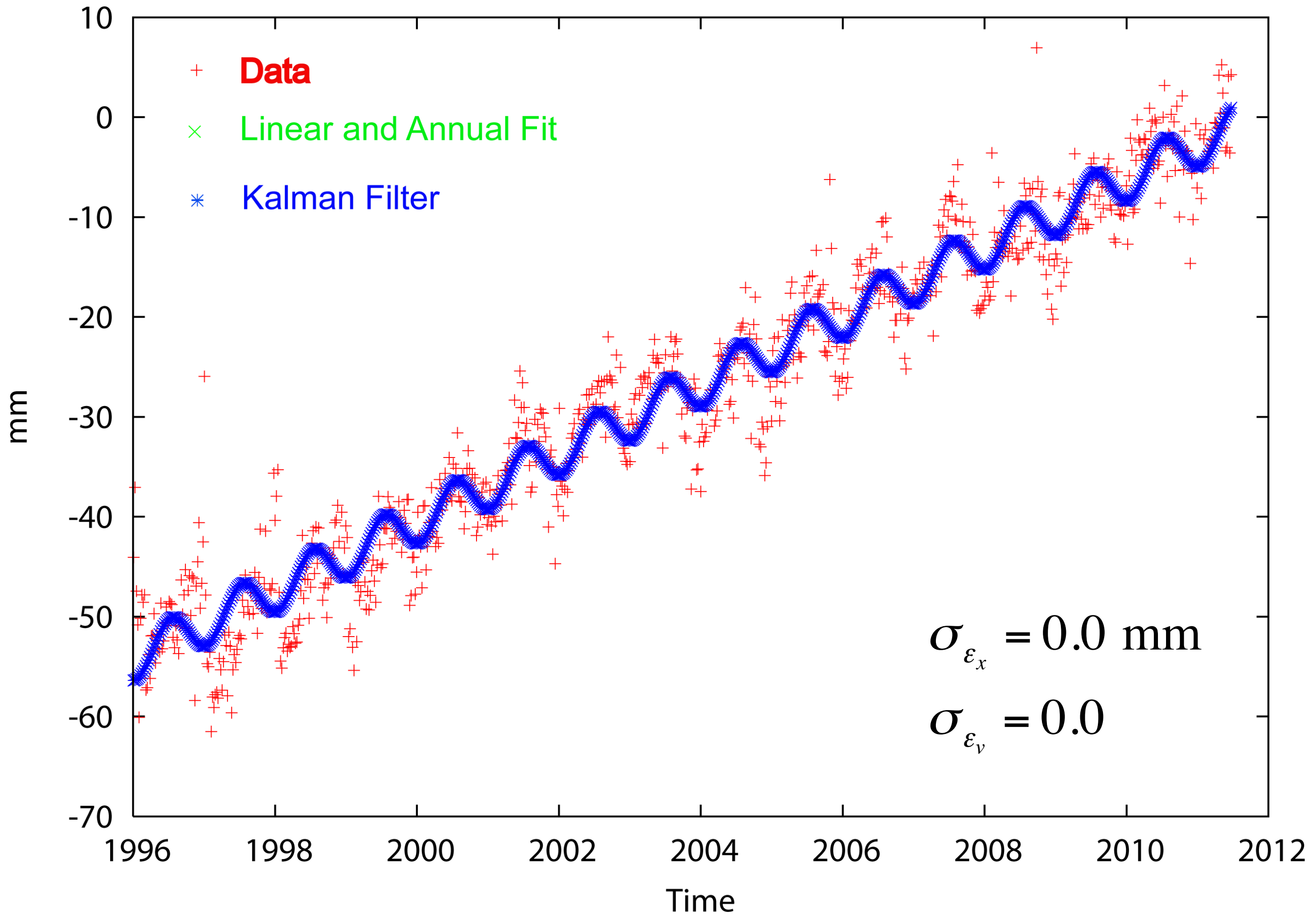
JPL Terrestrial Reference Frame

Sequential Estimation

- Square-root information filter / DMCS Smoother
  - Variable time step
- State vector and full covariance matrix
  - Station positions (at observation epoch)
    - X, Y, Z
  - Earth orientation parameters (daily)
    - Polar motion, polar motion rate, UT1, LOD
  - Helmert transformation parameters (at observation epoch)
    - Translation, rotation, scale (per technique)
  - Parameters of the dynamic model of the process (daily)
    - Linear, periodic, postseismic displacement
- Propagate state to measurement epoch
  - Using dynamic model of process
- Process noise from surface loading models
  - Atmospheric, non-tidal oceanic, hydrologic

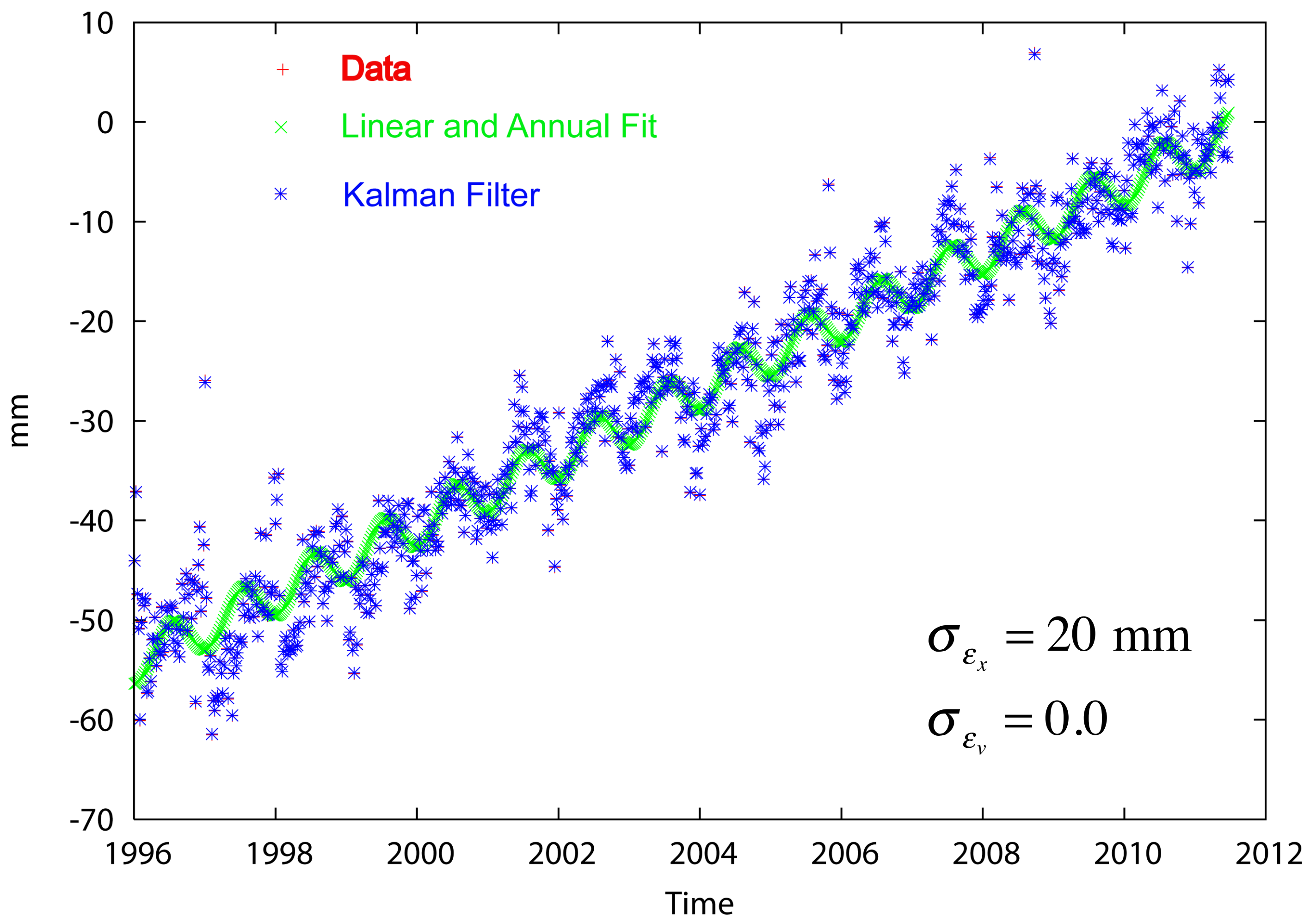
Sequential Filter and Smoother

No Process Noise



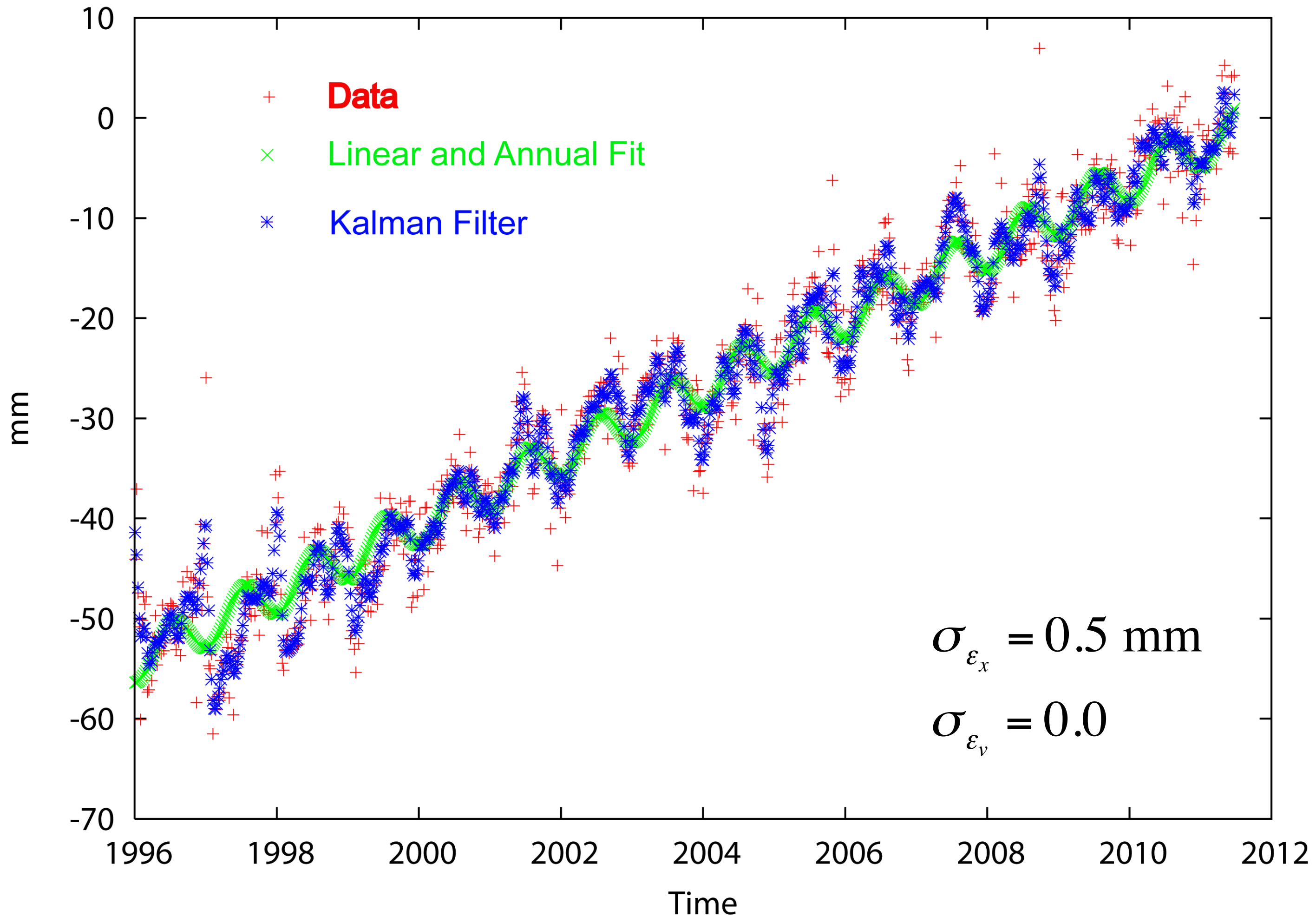
Sequential Filter and Smoother

Large Process Noise



Sequential Filter and Smoother

Intermediate Process Noise

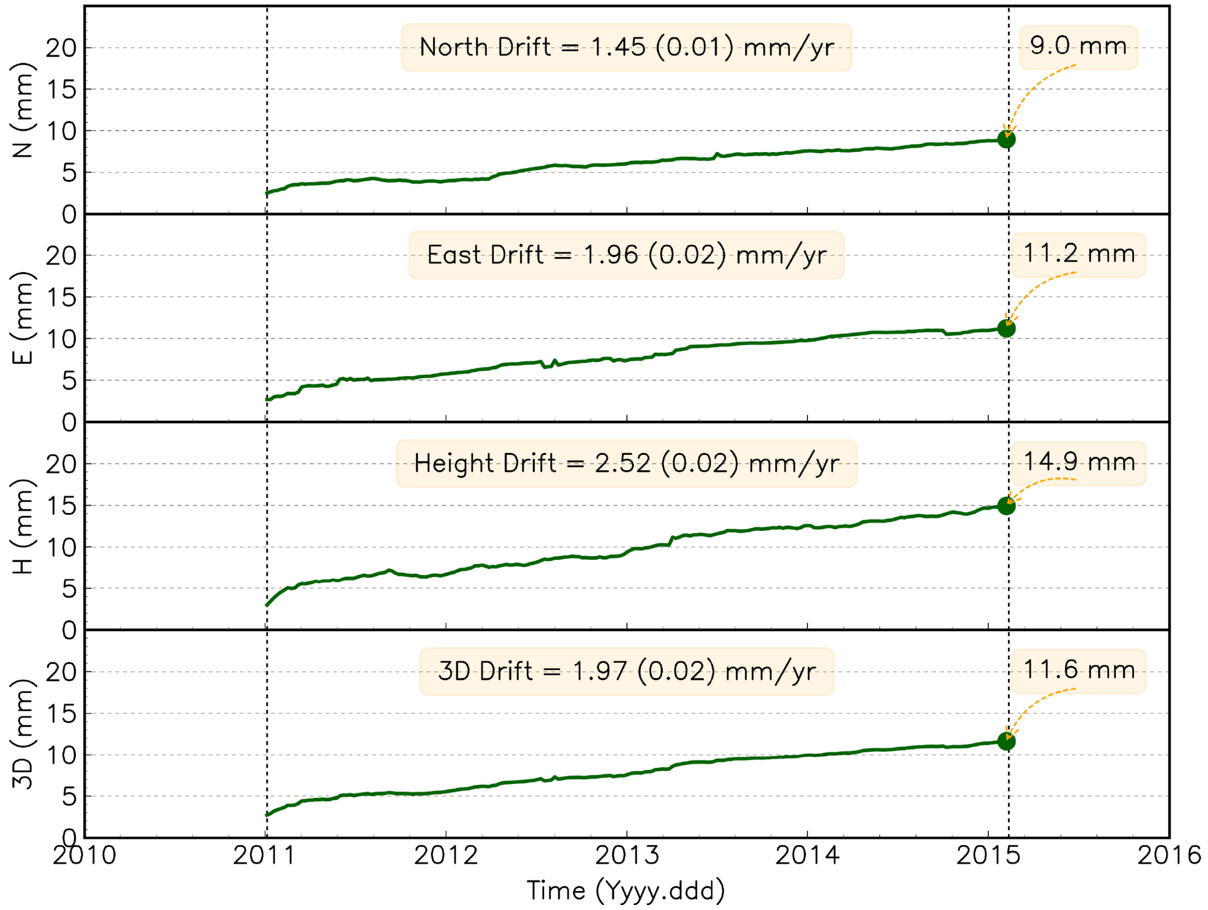


Updating TRFs

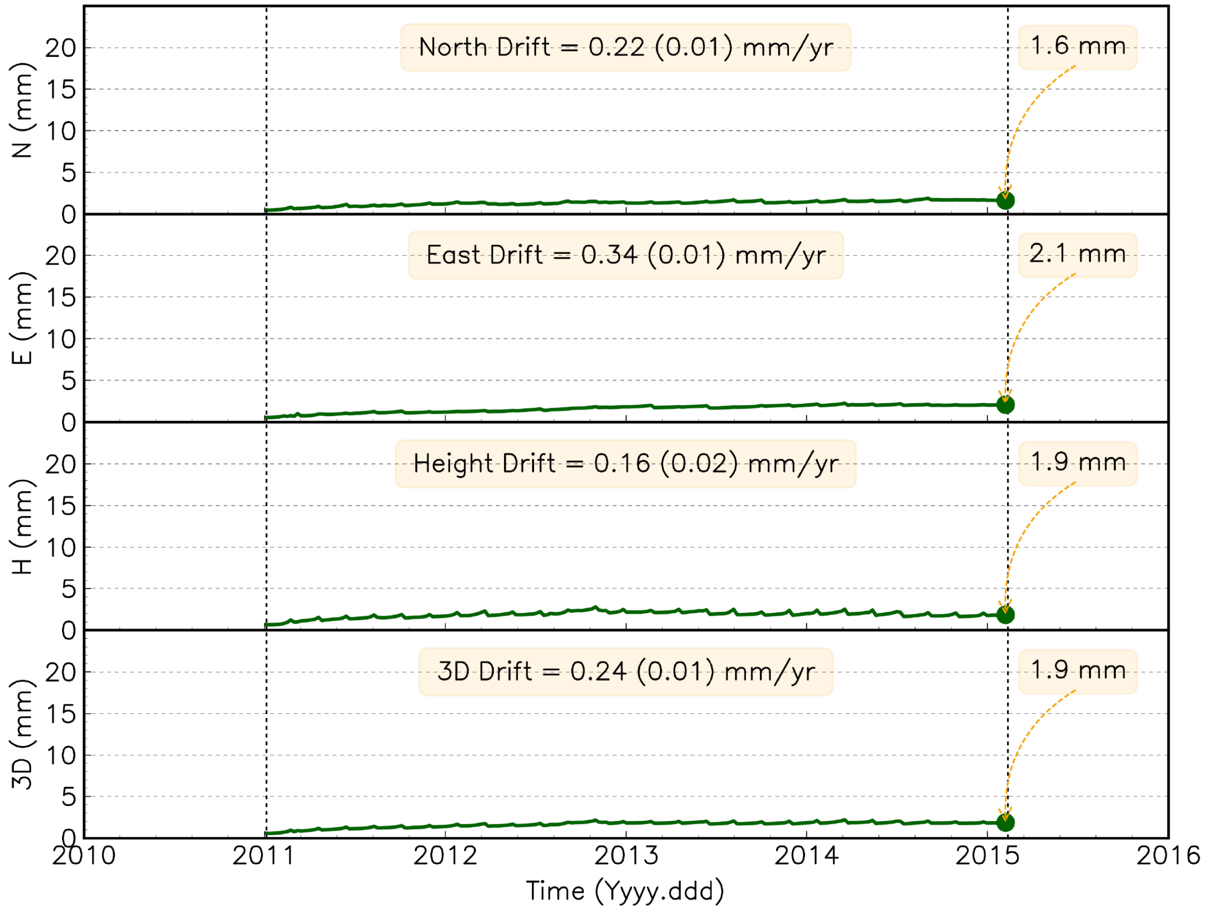
- ITRFs degrade with time
    - Predictions of station positions
        - Rely on model fit to data
        - Model accurate during data interval, degrades after that
    - ITRFs must be re-determined
        - Every 3-5 years to maintain accuracy
- Update TRF
    - By updating predictions of station positions
        - Using new observations as they become available
        - Easily done with NASA/JPL approach
    - Reduces frame degradation
        - Maintains accuracy of TRF (station positions, geocenter)
        - Maintains consistency of EOPs with TRF
        - May extend interval between frame re-determinations
            - Frame still needs to be re-determined to include new stations, new/improved background models, etc.

Growth in Station Position Uncertainty (wrms over 495 stations)

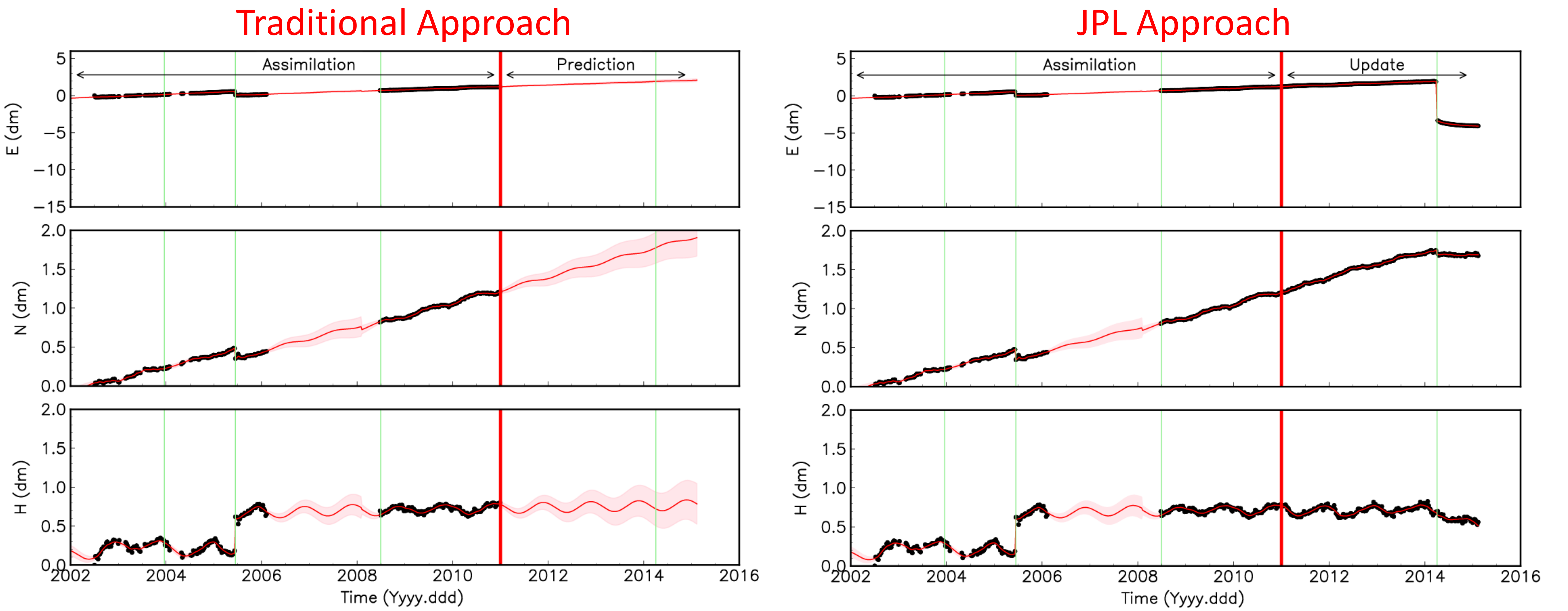
Predicted Station Positions



Updated Station Positions



GNSS station at Iquique, Chile

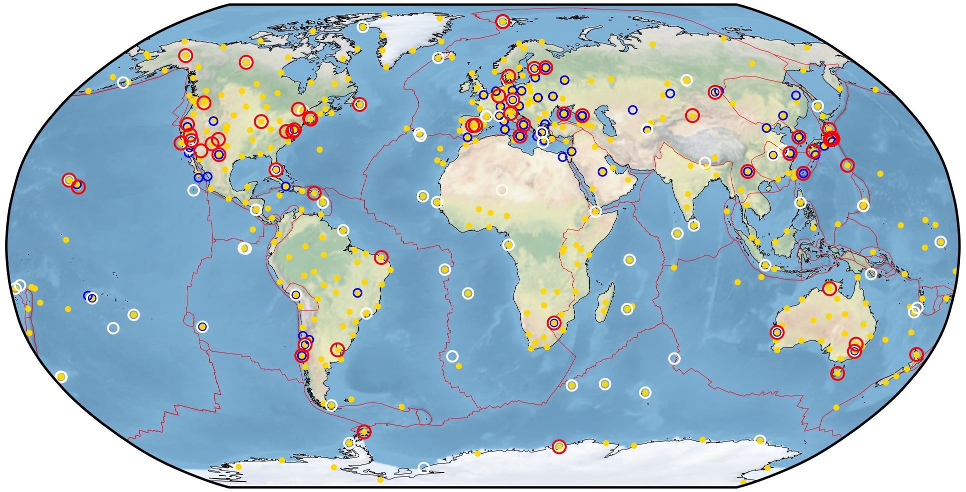


Comparing the predicted position of a frame-defining station (left panel) to its position based on updating the frame using observations that become available after the frame is determined (right panel). The black dots are the observations of the station's position, the thin red line is the smoothed estimate of the station's position, the red shading represents the ± 1-sigma uncertainty in the estimate, the thick vertical red line at 2011.0 marks the epoch of the last measurements used to determine the frame, and the thin vertical green lines mark observed offsets in the station's position including that caused by an earthquake in early 2014.

JTRF2020 Solution Design

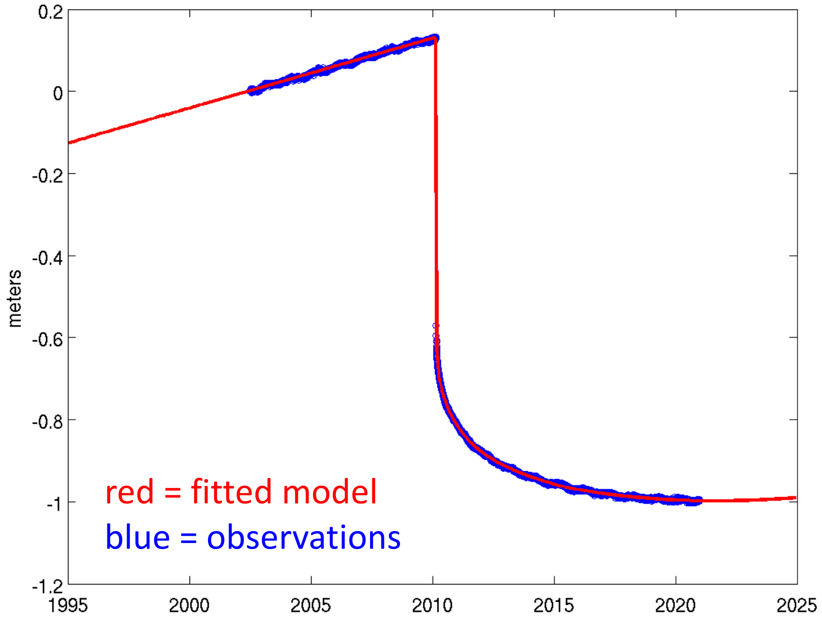
- Time series of daily station positions
  - 525 GNSS + 194 DORIS + 96 VLBI + 116 SLR = 931 Total
  - Nov 26, 1979 to Dec 31, 2020 + 5 years of predictions
- Input data cleaned
  - Stations/sessions selected; outliers detected, downweighted, & decorrelated
  - Breaks determined in position and velocity
- Dynamic model of station motion
  - Trend + annual
  - Postseismic displacement (linear + sum of exponentials)
    - For 34 GNSS stations having exponential amplitudes > ~ 1 cm
      - Transferred to VLBI, SLR, DORIS stations at co-located sites
- Station-dependent process noise model – AR(1)
  - Parameters estimated from detrended IERS GGFC loading models
    - atmospheric + non-tidal oceanic + hydrologic
- Site-dependent vector ties
  - Downweight if rms of (observed – computed) residual > 3-sigma
- Site-dependent co-motion constraints
  - Trend: Downweight if rms of station pair velocity differences > 5-sigma
  - Annual: Downweight if rms of station pair annual differences > 5-sigma
- Origin
  - SLR center-of-mass
- Scale
  - Combination of VLBI and detrended SLR
- Test solutions being estimated
  - Daily / weekly data from reduced 592-station network
  - Weekly data from full 931-station network
- Final solution available autumn 2022
  - Daily data from full 931-station network

JTRF2020 Station Network



525 GNSS 194 DORIS (white) 96 VLBI 116 SLR 931 Total

Antuco, Chile

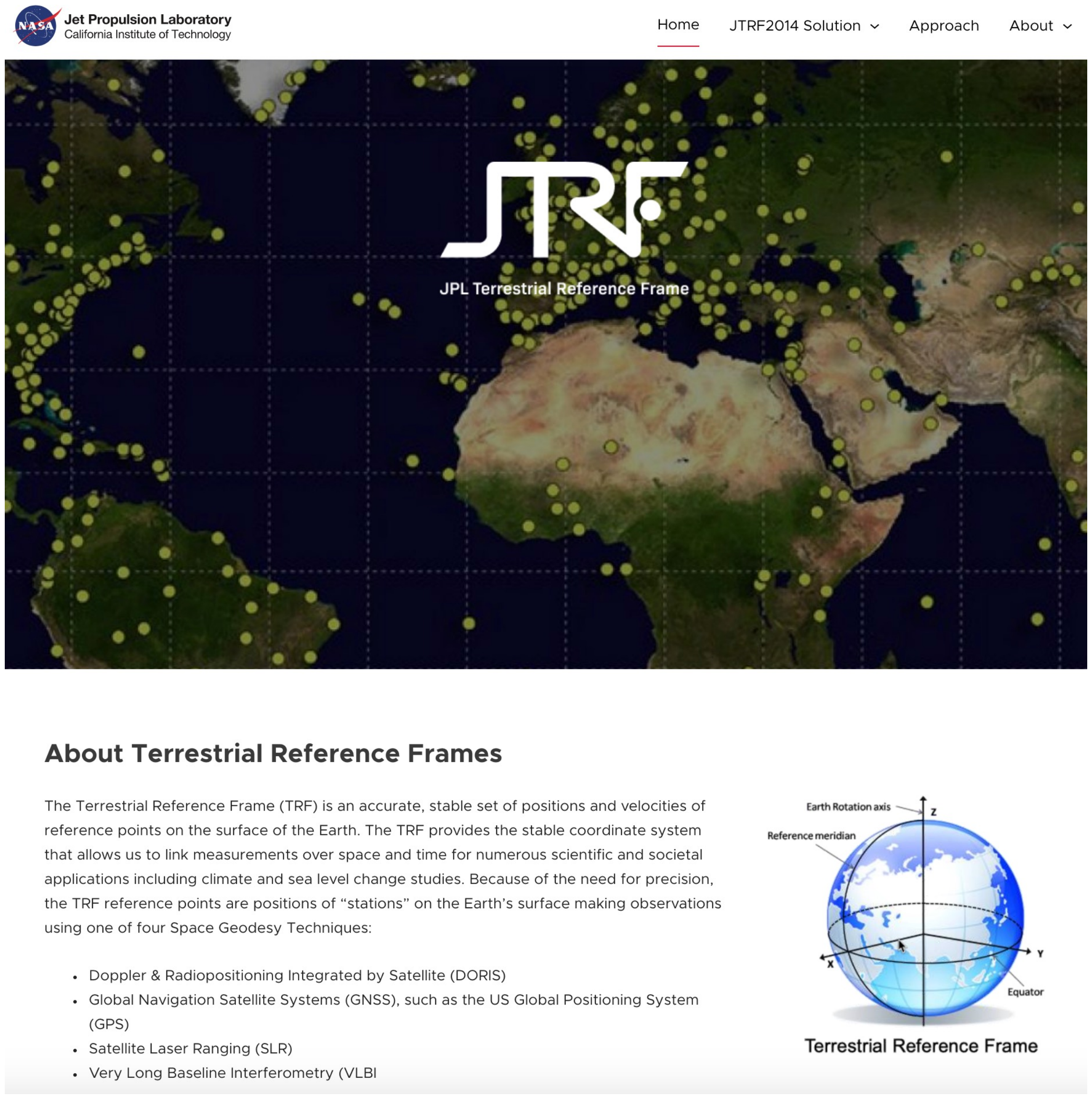


Updating JTRF2020

- Save state vector and full covariance matrix at epoch of last measurement
  - Also save ancillary bookkeeping information
- As new observations become available, re-start filter from saved state
  - Propagate state forward in time assimilating new observations
  - Save state at epoch of last new observation
  - Re-generate predictions
  - Repeat at monthly (?) intervals
- Entire history of observations are not processed
  - So frame is not changed
    - Only new observations are processed to improve predictions
- Would still want to re-determine ITRFs
  - To incorporate re-processed observations, updated models, ...
  - But perhaps less often than every 3-5 years (?)

JTRF Website

- Distribute
  - JTRF2014
  - JTRF2020
  - Monthly updates to JTRF2020
  - Future JTRF solutions and updates
- Describe JPL approach
  - Sequential estimation
    - TRF represented by time series of smoothed station positions
      - Not by model (traditional approach)
- Promote need for sustainable geodetic infrastructure
  - Needed for sustainable TRF



https://jpl.nasa.gov/site/jsgt/jtrf

شكراً جزيلاً

thank you
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
merci
obrigado
спасибо
Баярлалаа
рахмат
bedankt
dziękuję
sukriya
kop khun krap
go raibh maith agat
mochchakkeram
tapadh leat
dank je
arigatô
dakujem
grazie
terima kasih
감사합니다
ありがとう
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