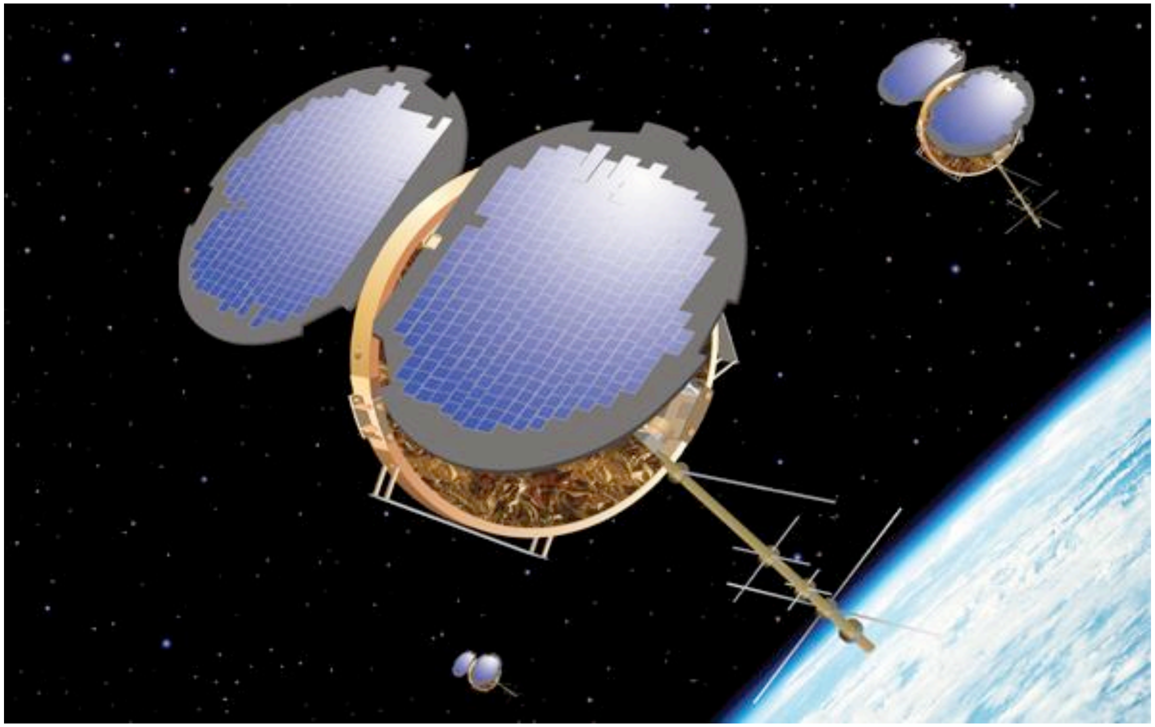
COSMIC Data Analysis and Archive Center Status and Data Product Description



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2nd GPS RO Data Users Workshop, Aug. 22-24, 2005, Lansdowne VA

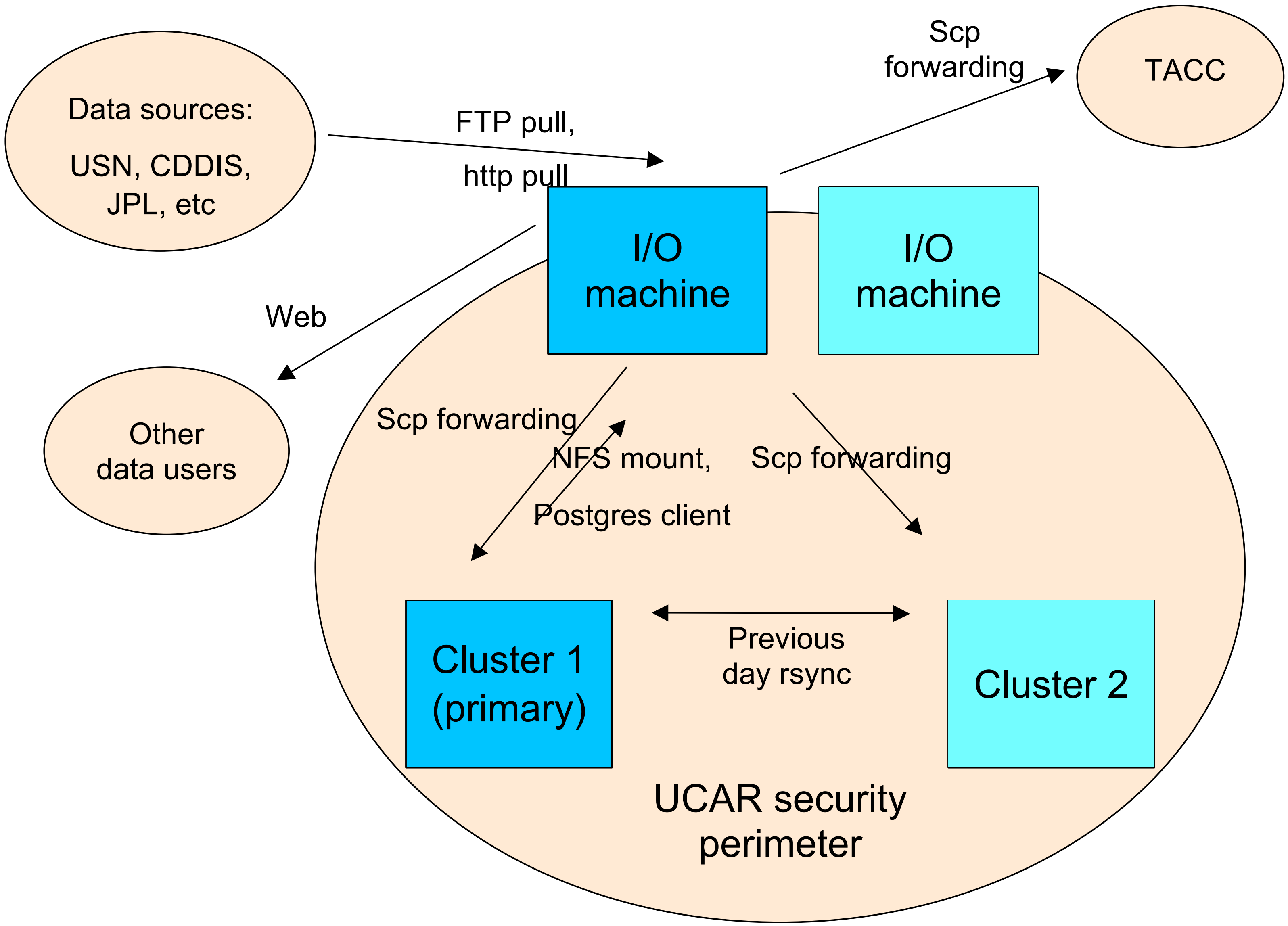
Overview

- CDAAC Summary
  - CDAAC Role
- CDAAC Data Products
  - Neutral atmosphere
    - Overview of Data Processing
    - Data content and format (level 0 to BUFR)
  - Ionosphere
    - Data Products
- Data Distribution Plans
  - Real Time Data
  - Daily data sets

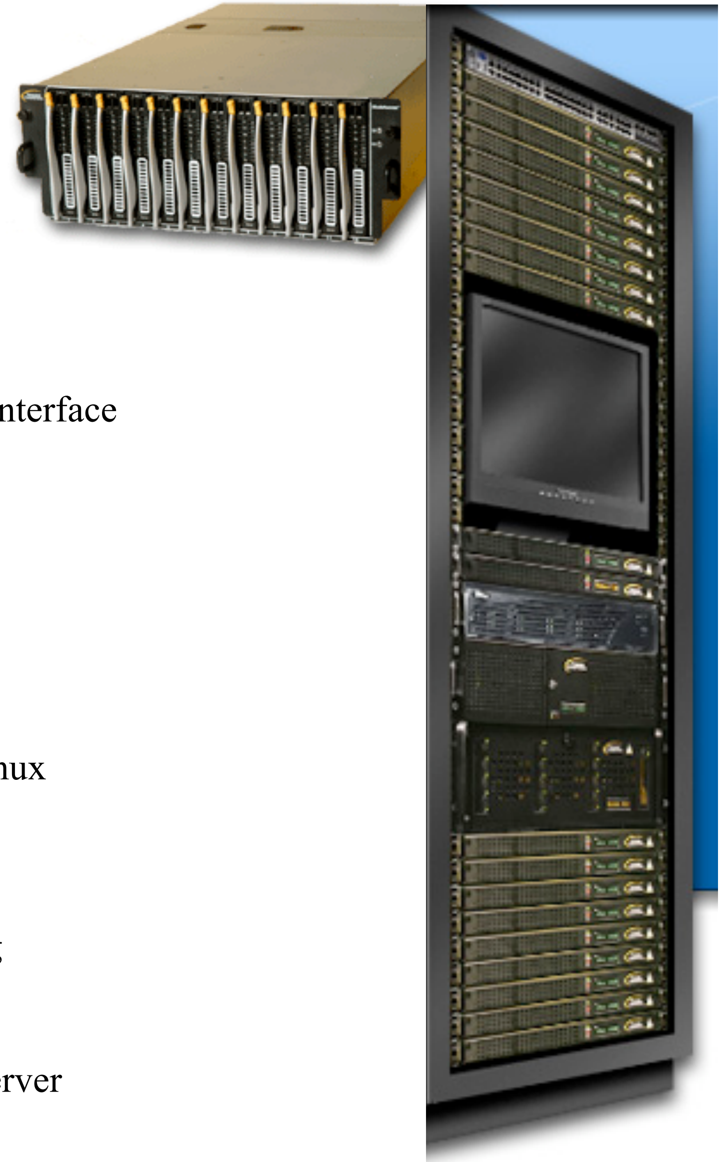
CDAAC responsibilities

- Process all COSMIC observations
  - LEO/GPS orbit determination
  - Atmospheric & Ionospheric profiles
  - Rapid analysis for operational demonstration
  - Post-processed analysis for climate and other research
- Provide data to universities and research laboratories
- Provide data feeds (< 3hr) to operational centers
- Archive data & provide web interface

Dual string processing

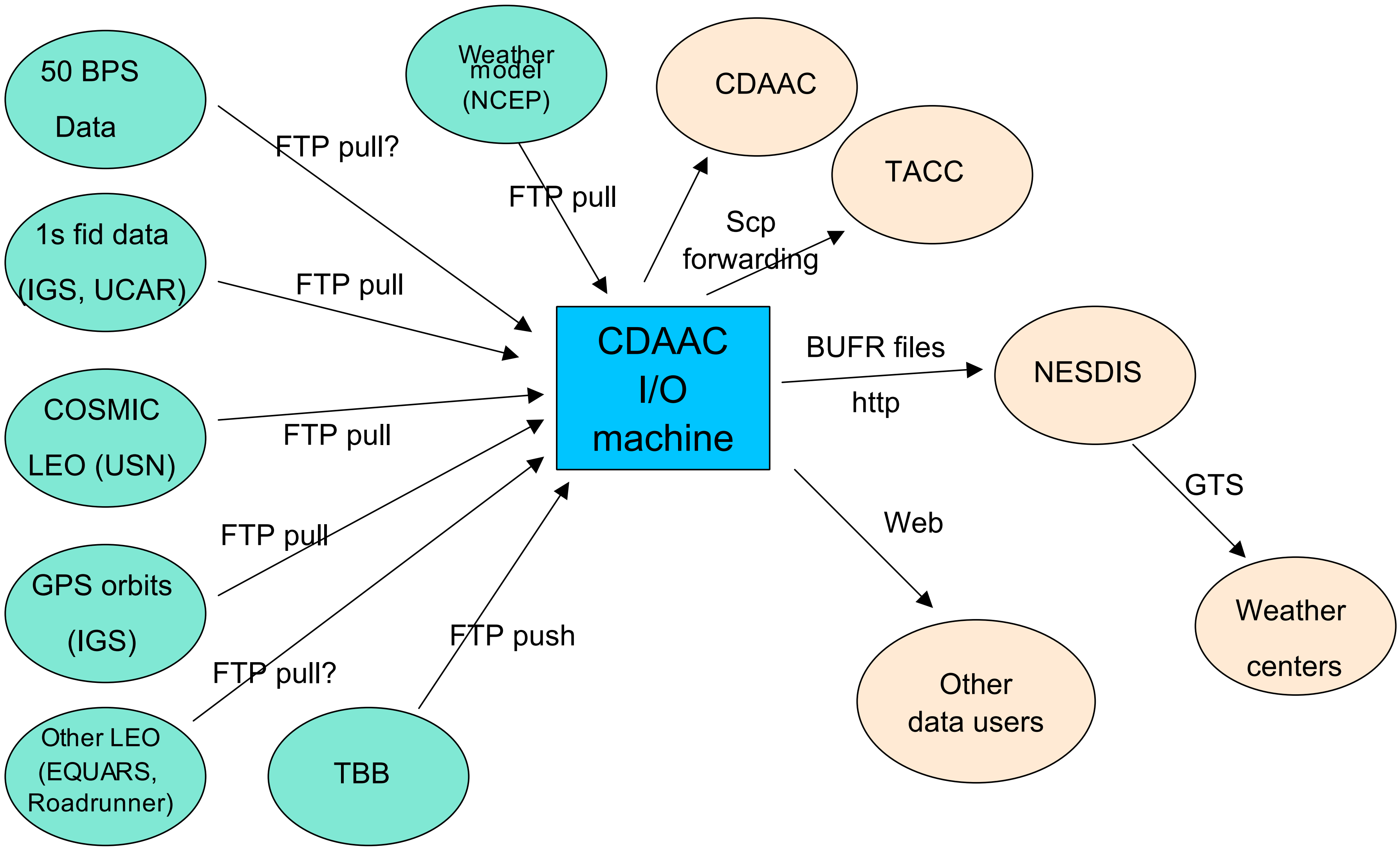


CDAAC Hardware

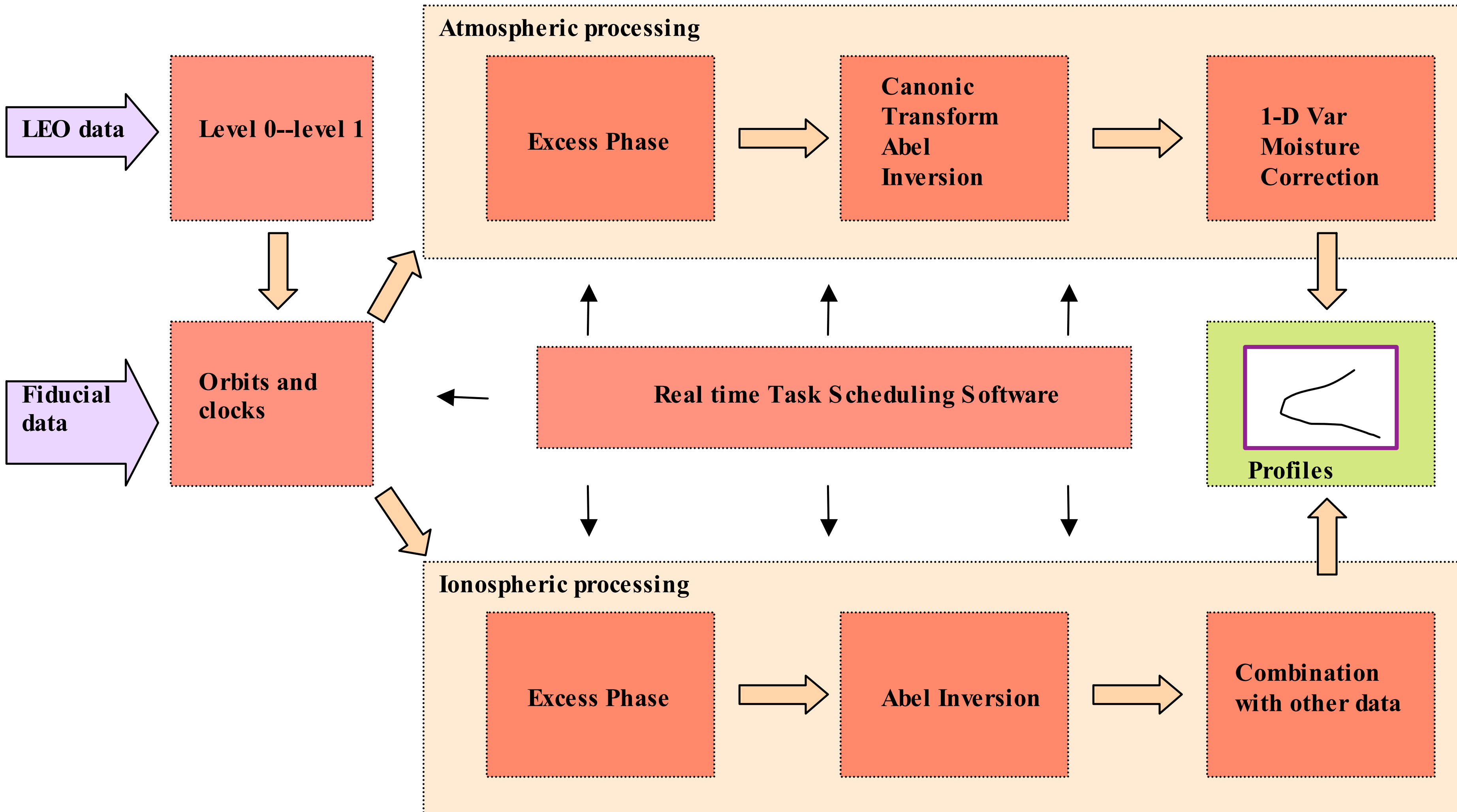


* CDAAC consists of a redundant processing string
  with 2 each I/O, NFS and Blade Server:
  * I/O machine running 64 bit Linux
    * 4 Gig Ram
    * Dual 2 GHz AMD Opteron (64 bit) processors
    * 200 Gig local HD
    * 1 GigE network connection to internet
    * 1 GigE network connection to processing cluster
      ("Iptables Firewall" protects NFS and Cluster)
    * 1 100 BT network connection for administrative interface
  * NFS server running 64 bit Linux
    * 2 Gig RAM
    * Dual 1.6 GHz AMD Opteron (64 bit) processors
    * 200 Gig local HD
    * 4 TeraByte RAID Array
    * Dual GigE connection to processing cluster
      (Aggregate 2 GHz internal network)
  * 1 Master and 6 compute node "Blade Server" running 32 bit linux
    Each Blade has:
    * 4 Gig RAM
    * Dual 2.4 GHz Pentium IV processor (32 bit)
      (Total of 14 P IV CPU's for processing
      in each cluster)
    * Local 40 Gig HD
    * Dual GigE connection between nodes and NFS server

Data Sources / Recipients

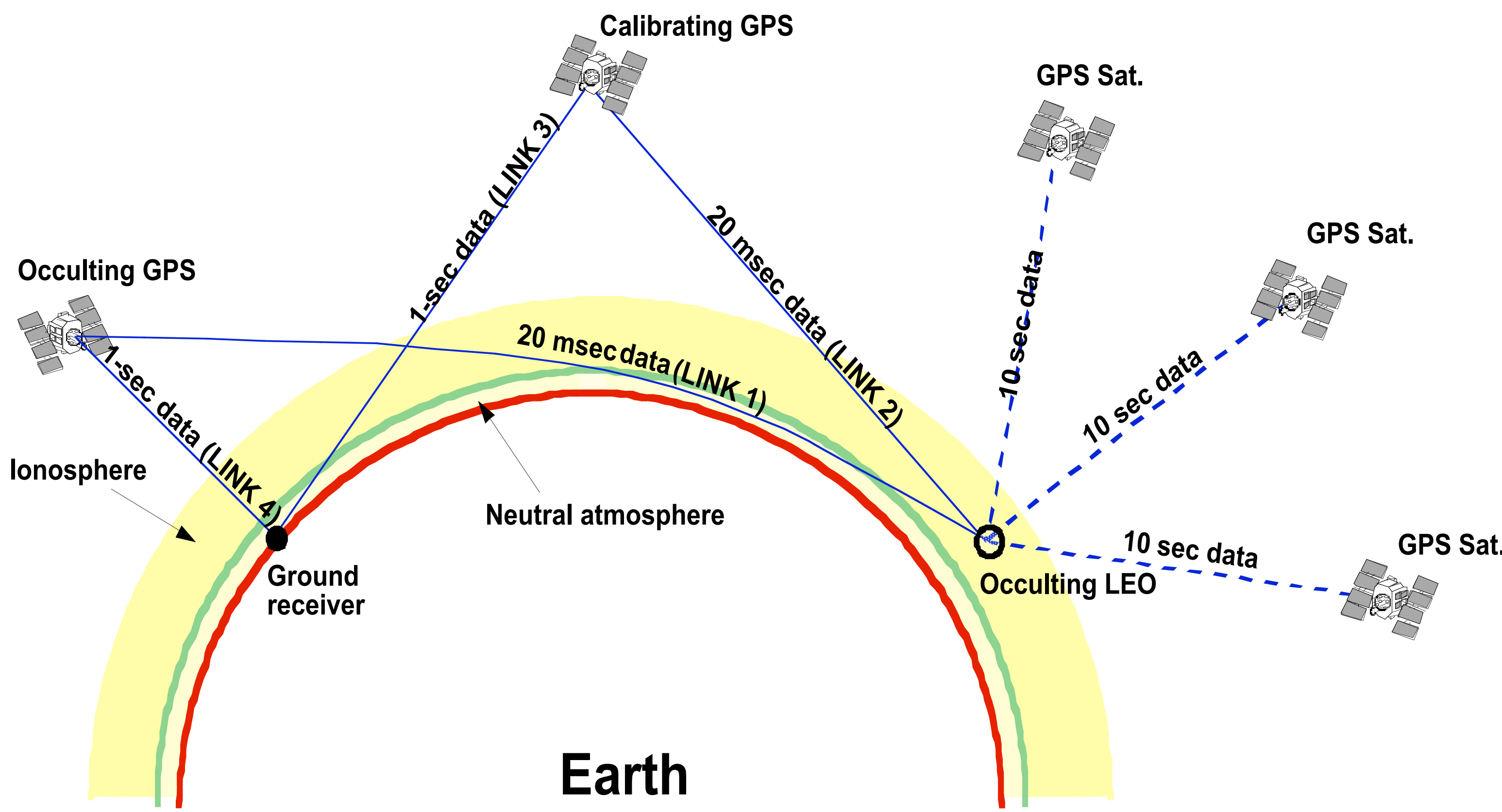


CDAAC overview



Current processing time for 35 occultations + 100 minutes of fid data: ~12 min

POD and Clock Calibration



- GPS Data for Analsyis
  - Link to all satellites in view at 1 Hz at all times (dual frequency phase + range data)
  - Below 120 km (settable) rate increases to 50 Hz (dual frequency phase data)
  - Below 12 km (settable) receiver 50 Hz in open loop (L1 phase data)

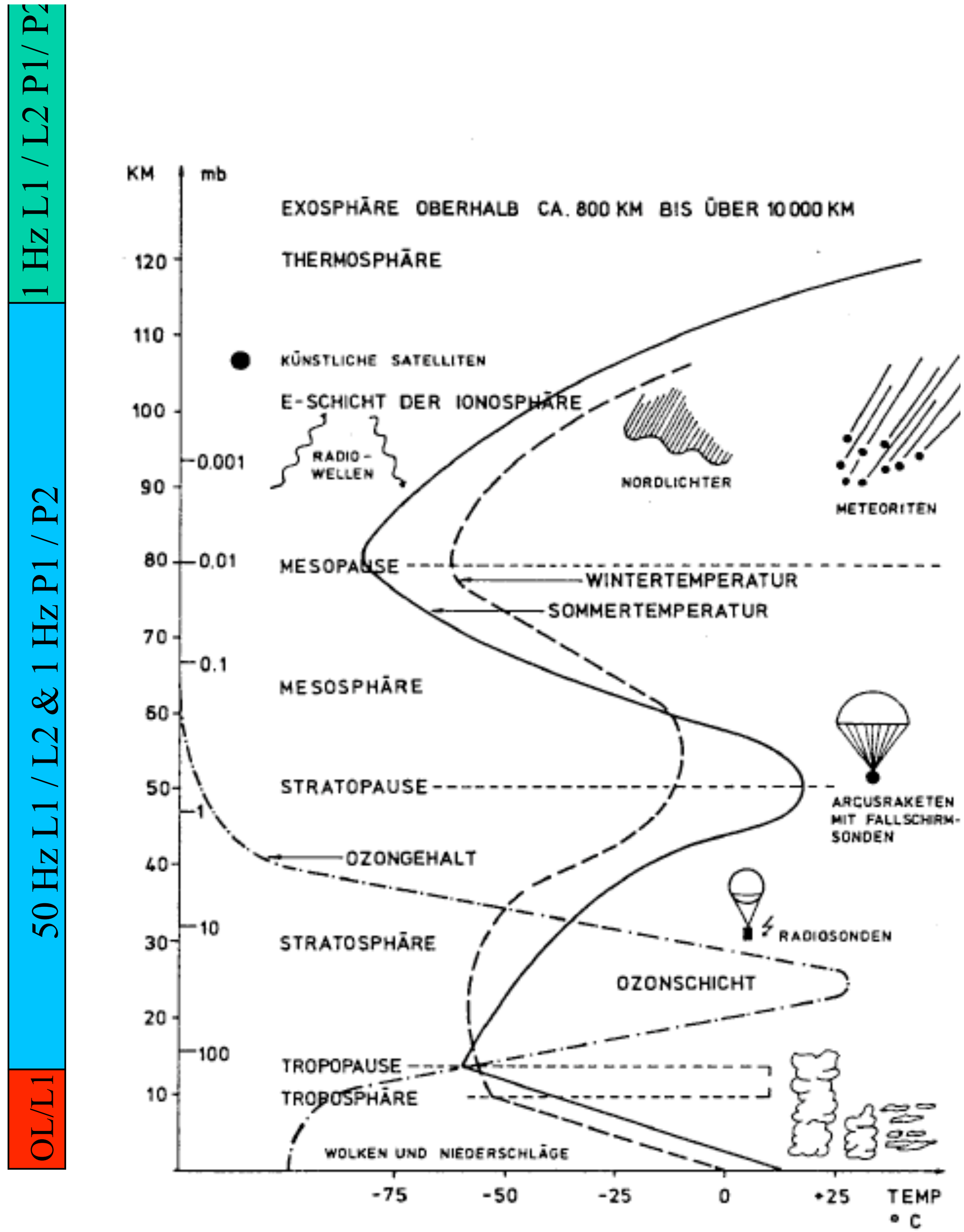
Profile the (sporadic) ionospheric E-layer with ~1-km vertical resolution

Area dominated by noise - used for noise calibration of profile

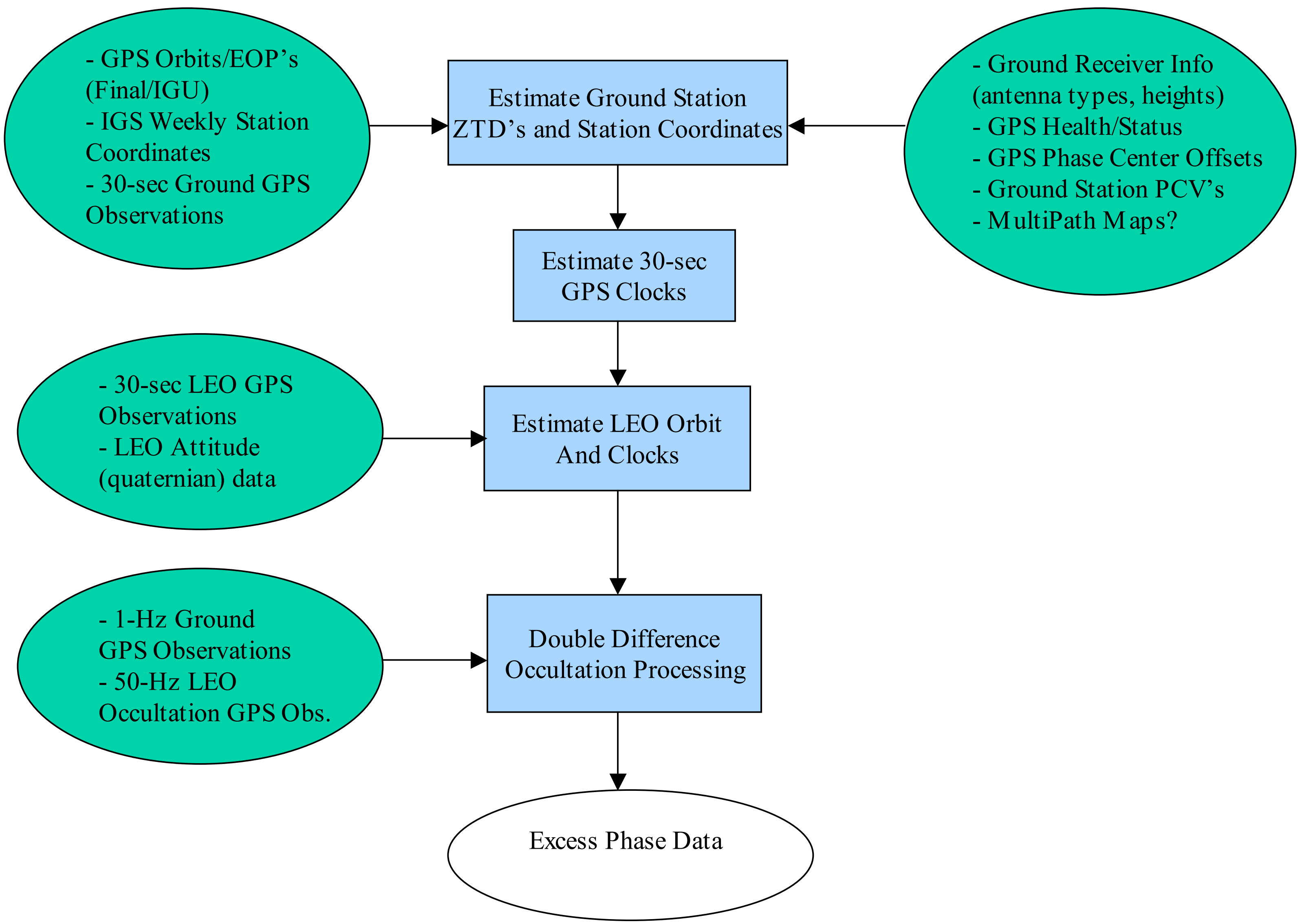
Area affected by iono noise - profiles are noisy and/or affected by climatology

Highest quality profiles 5-30 km

Some profiles affected by boundary layer effects (super refraction)

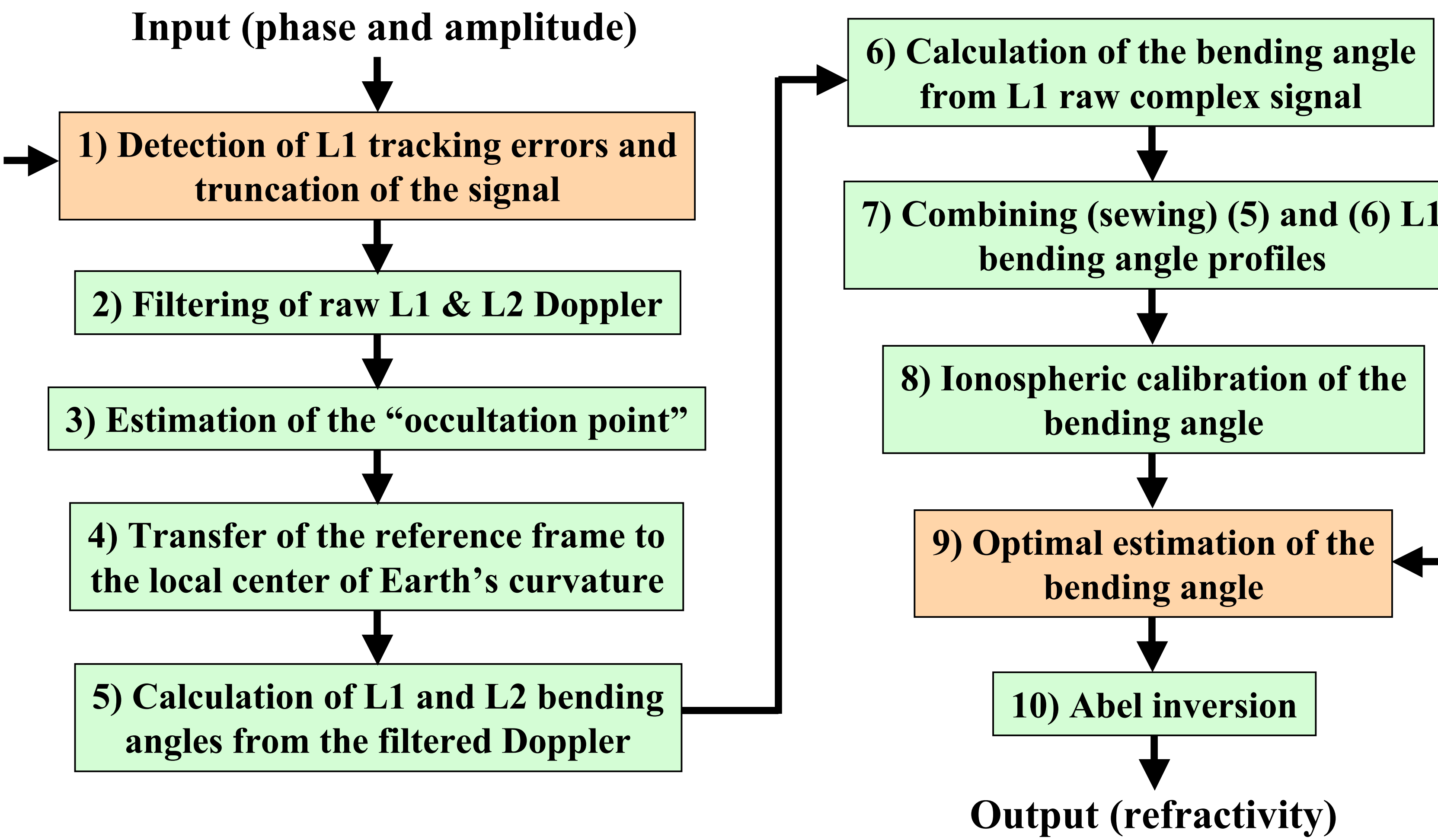


CDAAC Excess Phase Processing



Lay-out of radio occultation data processing at CDAAC

indicates the use of ancillary data (climatology)



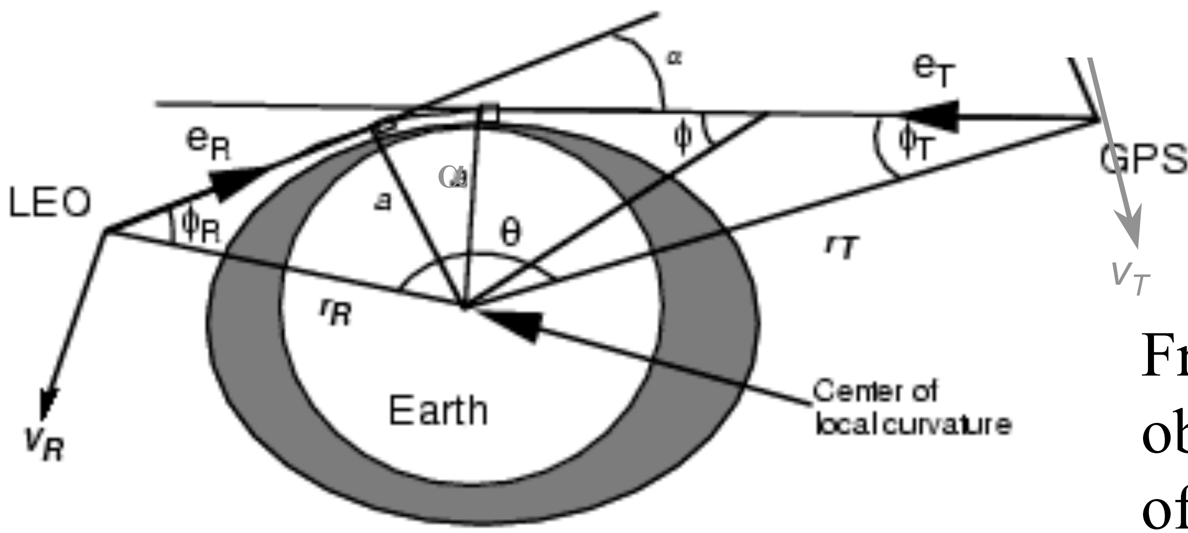
Deriving Bending Angles from Doppler

- The projection of satellite orbital motion along the signal ray-path produces a Doppler shift at both the transmitter and the receiver
- After correction for clock and relativistic effects, the Doppler shift, f_d, of the transmitter frequency, f_T, is given as

$$f_d = \frac{f_T}{c}\left(\vec{V_T} \bullet \hat{e}_T + \vec{V_R} \bullet \hat{e}_R\right) \quad = -\frac{f_T}{c}\left(V_T^r \cos\phi_T + V_T^\theta \sin\phi_T + V_R^r \cos\phi_R - V_R^\theta \sin\phi_R\right)$$

$$\sin(\phi_R) = a / r_R \qquad \sin(\phi_T) = a / r_T$$

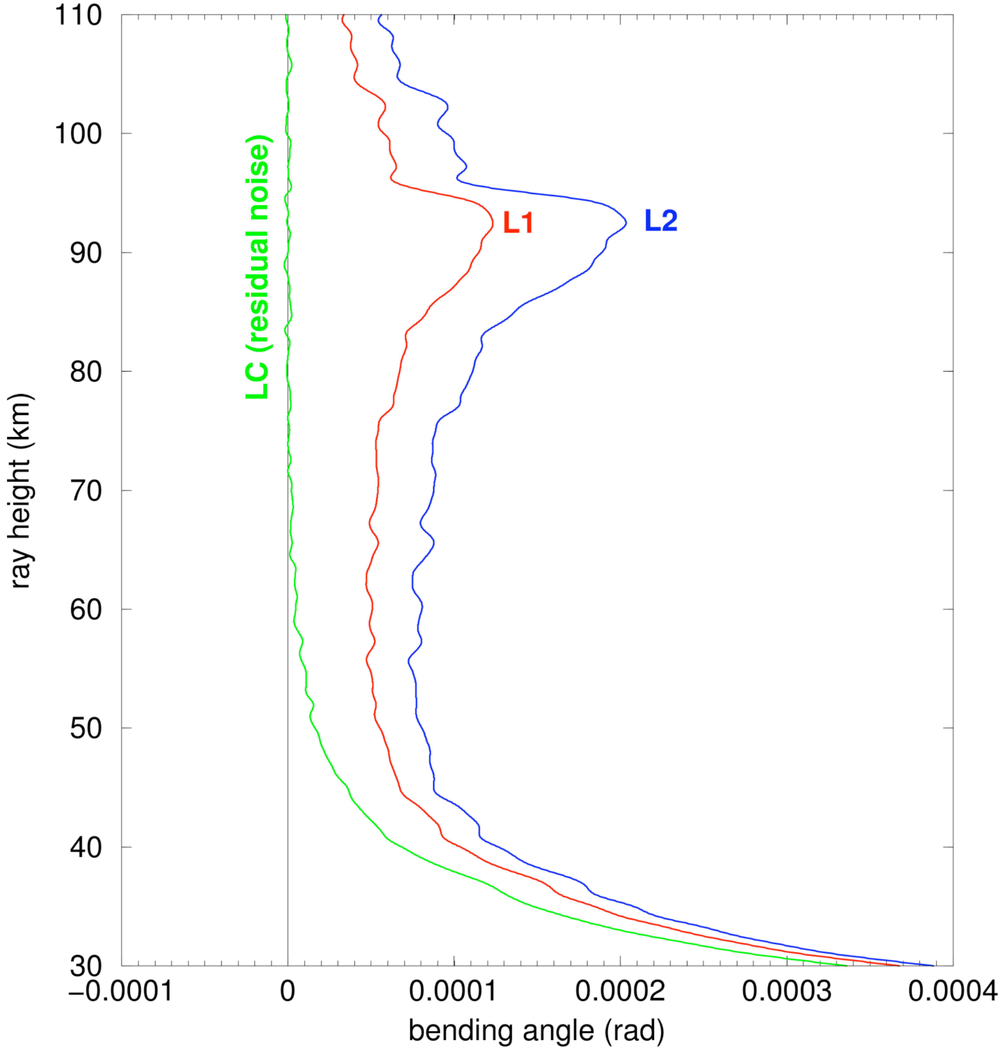
- where: c is the speed of light and the other variables are defined in the figure with V_T^r and V_T^θ representing the radial and azimuthal components of the transmitting spacecraft velocity.



From Doppler + orbits we obtain bending as a function of impact parameter

Ionospheric calibration

Is performed by linear combination of L1 and L2 bending angles at the same impact parameter (to combine rays with minimal separation of ray tangent points).



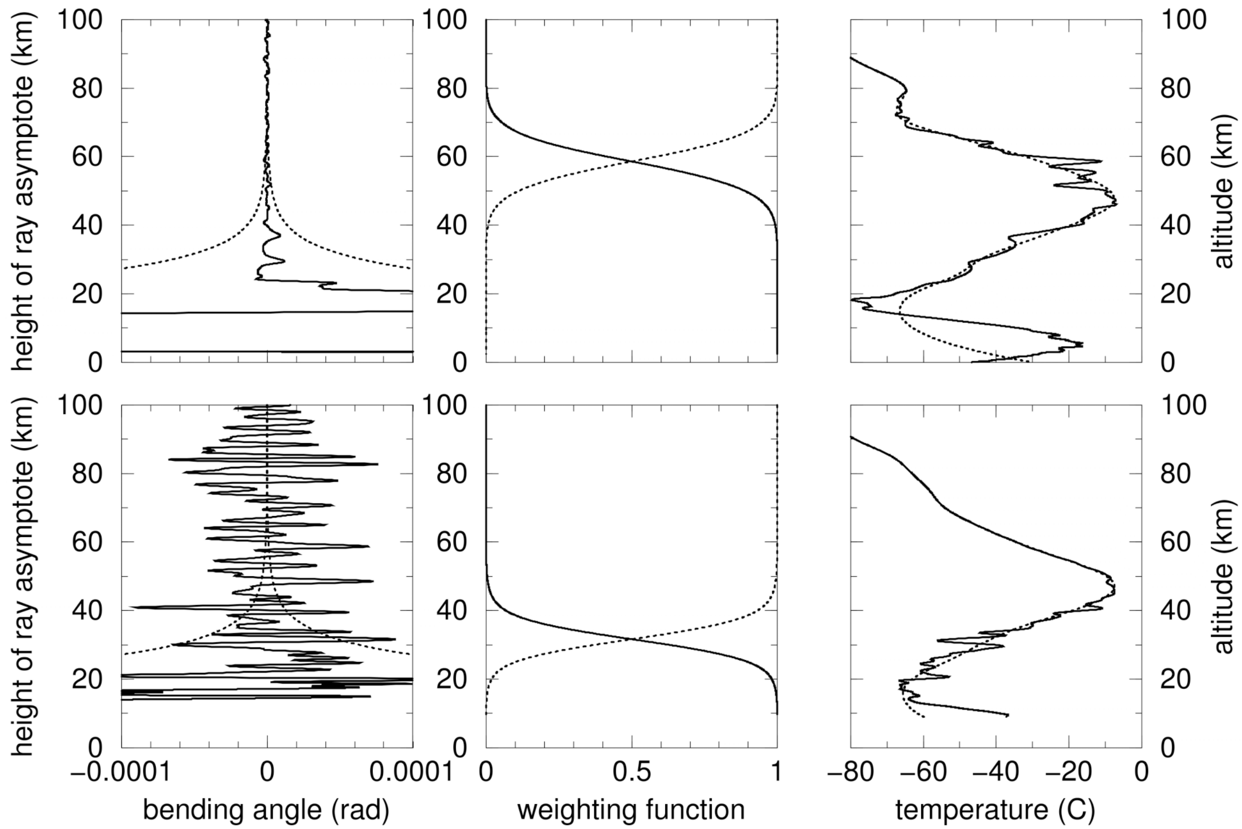
$$\alpha(a) = \frac{f_1^2\alpha_1(a) - f_2^2\alpha_2(a)}{f_1^2 - f_2^2}$$

α bending angle

a impact parameter

Effect of the small-scale ionospheric irregularities with scales comparable to ray separation is not eliminated with this linear combination, thus resulting in residual noise on the ionospheric-free bending angle.

Optimization of the observation bending angle



$$\alpha_{opt} = w\alpha_{obs} + (1-w)\alpha_{clm} \quad \text{where} \quad w = \frac{\sigma_{clm}^2}{\sigma_{clm}^2 + \sigma_{obs}^2}$$

The weighting function is calculated individually for each occultation.

The magnitude of the residual ion noise can be very different for different occultations, but is almost height independent for any given occultation. Above a certain height, climatology provides a better estimate of the atmospheric state than RO observation. The observed bending angle is optimally weighted with climatology. This does not improve the value of the bending angle at large heights, but results in reduction of error propagation downward after the Abel inversion.

Define the refractional radius $x=nr$, where $n=1+N*10^{-6}$

$$\alpha(a) = 2a \int_a^{\infty} \frac{dn}{ndx} \frac{dx}{\sqrt{x^2 - a^2}}$$

$$n(x) = \exp\left[-\frac{1}{\pi} \int_x^{\infty} \frac{\alpha(a)\, da}{\sqrt{a^2 - x^2}}\right]$$

Now we have a profile of refractivity as a function of r

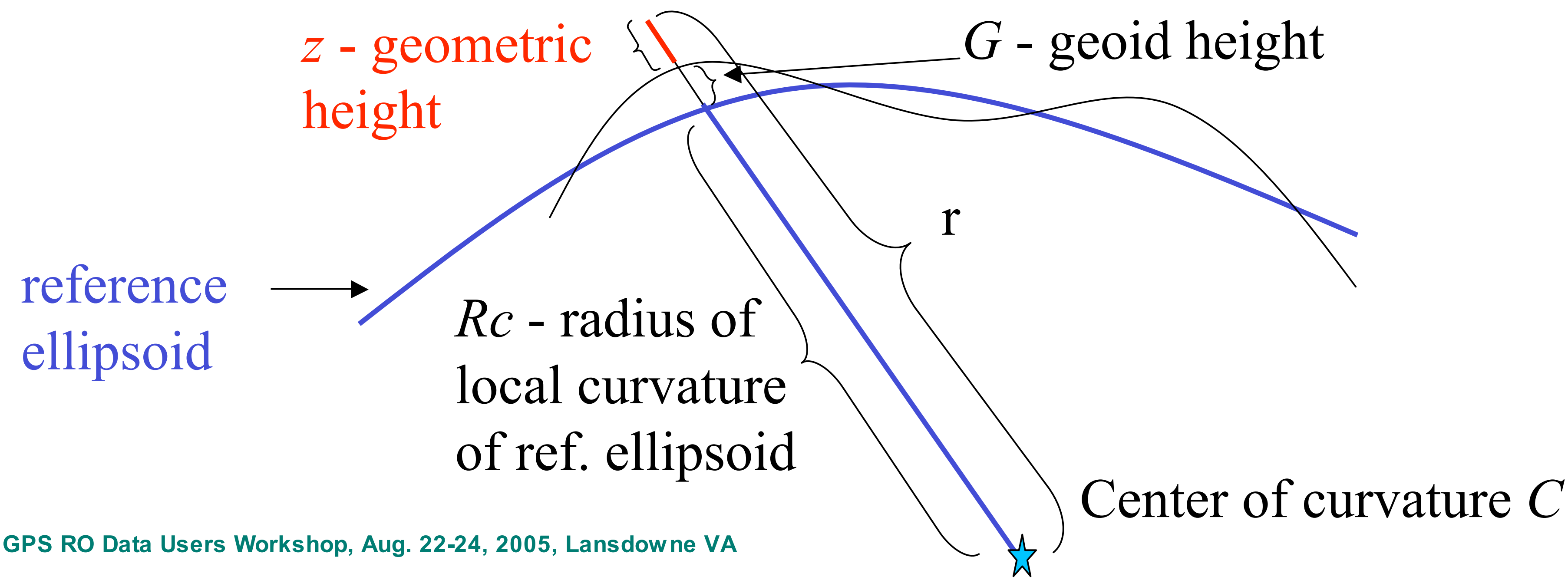
Definition of Altitude in CDAAC Products

Steps taken in determining "MSL" altitude *z*

1. Determine the lat/lon of the ray path perigee at the'occultation point' (that point where the excess phase exceeds 500 meters)
2. Compute the center of sphericity (*C*) and radius of curvature (*Rc*) of the intersection of the occultation plane and the reference ellipsoid at the assigned lat/lon.
3. Do the Abel inversion in the reference frame defined by the occultation plane and *C*.
4. Now height *r* is defined as the distance from the perigee point of the ray path to *C*.
5. *G* is the geoid correction. We currently use the JGM2 geoid.

The geometric height in the atmosphere is computed :

$z = r - Rc - G$



COSMIC

Atmospheric refractivity $N=(n-1)*10^{-6}$

$$N = 77.6\frac{P}{T} + 3.73e^{5}\frac{P_w}{T^2} - 40.3\times10^{6}\frac{n_e}{f^2}$$

Ionospheric term dominates above 70 km

Hydrostatic (dry) wet terms dominates at lower altitudes

Wet term becomes important in troposphere (> 240 k) and
Can be 30% of refractivity in tropics

Liquid water and other aerosols are generally ignored

Deriving Height ,Pressure Temperature Humidity

- After converting *GPS Doppler phase* => $\alpha(a)$ => $n(r)$ => $n(z)$ we have a profile of dry refractivity for altitudes from ~150 km down to the 240K level in the troposphere.
- We use the hydrostatic equation, $dP = -g\,\rho\,dz = -g\,n_d\,\mu_d\,dz$ to derive a vertical profile of pressure versus altitude over this altitude interval.

$$P(z) = \int_z^{z_{top}} g\rho dz + P(z_{top}) = \int_z^{z_{top}} g n_d \mu_d dz + P(z_{top})$$

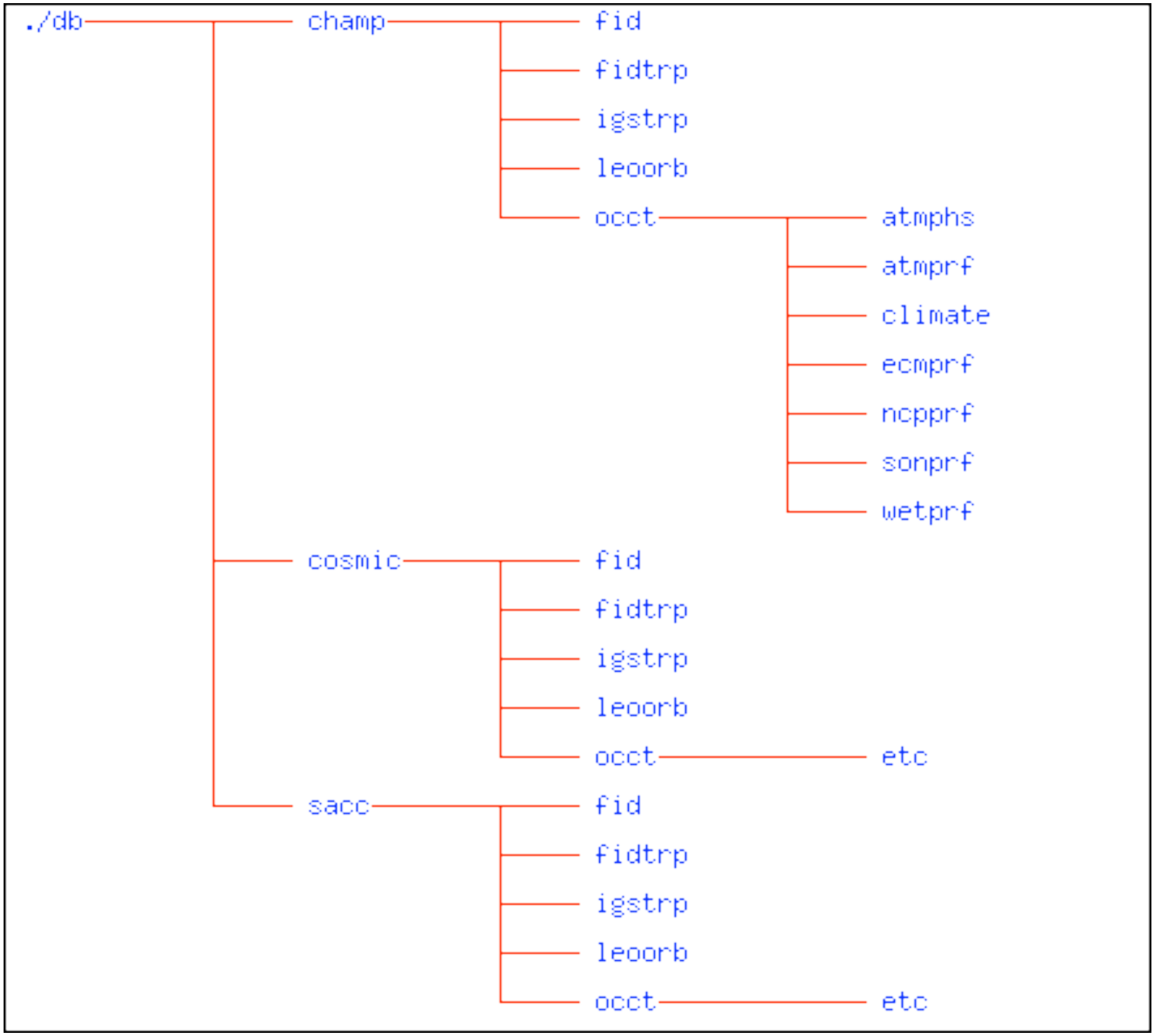
- If we start high enough $P(z_{top})$ =0 with negligible error
- Given P(z) and n_d(z), we can solve for $T(z)$ over this altitude interval using the equation of state (ideal gas law): $T(z) = P(z) / (n_d(z)\,R)$
- Below the 240k level we need additional information (usually temperature from a weather model) to obtain water vapor pressure and humidity. This is done with a 1DVar method.

Data Products

Type	Description	Quality flags	Comments
atmPhs	Atmospheric excess phase and satellite positions and velocities	'bad' flag, set on low SNRs	netCDF format
atmPrf	Full resolution atmospheric bending angle, refractivity, dry pressure and temperature	'bad' flag--0 = OK, 1 = failed QC Scalar data quality indicators, N and α errors	netCDF format
wetPrf	100 meter resolution refractivity, pressure, temperature and moisture	'bad' flag	netCDF format, 1D VAR combination with AVN 12 hour forecast (real time) or ECMWF analysis (post-processed)
bfrPrf	200 meter resolution bending angle, refractivity, P, T and E	'bad' flag, N and α errors, percent confidence vectors	WMO BUFR format. Data Fourier smoothed and then interpolated

Information on data formats available at http://cosmic-io.cosmic.ucar.edu/cdaac/fileFormats/

Database design, illustrated



atmPhs

- netCDF format
- Delta time is the independent variable (time in seconds from the start of the occultation)
  - Corresponding height runs from about 150km to -150km straight line distance
- Excess phase (L1, L2, LC)
- SNR (CA L1, P-code L1 and L2)
- LEO position and velocity (in inertial frame)
- GPS position and velocity (in inertial frame)
- Extra open loop columns:
  - Raw phase model
  - Double differenced phase model
  - Range model
  - Delta phase atan2(I,Q)

atmPrf

- netCDF format
- Mean Sea Level geometric height is the independent variable. Runs from 40km to occultation cutoff (limited by topography or tracking)
- Profile variables:
    - Lat, lon, MSL_alt, N, Azimuth, dry pressure, dry temperature, α (raw), α (optimized with climatology), impact parameter, N error, α error
- Some important quality indicators

s4	40 to 80km amplitude scintillation index
difmaxref	Maximum fractional difference between retrieved and climatological refractivity
difmaxion	Maximum difference of L1 and L2 bending angles
smean	Average difference of climatological and observed bending angles between 60 and 80km
stdv	Indication of variation of 60-80km bending angle differences
znid	Altitude below which L2 noise becomes too great and ionospheric correction is turned off

The ‘bad’ flag is based a comparison of these and other scalar parameters with empirically determined thresholds

wetPrf

- netCDF format
- All variables on standard Mean Sea Level geometric height grid: 0 to 40km in 100m increments
- Profile variables:
    - T, P, e, N (1D VAR), lat, lon, N (occultation)
- Computed from the atmPrf refractivity and model (ECMWF for post-processing or AVN 12 hour forecast for real-time) using a 1D VAR algorithm

bfrPrf

- WMO BUFR format
- All variables on standard Mean Sea Level geometric height grid: 0 to 40km in 200m increments
- Profile variables:
    - lat, lon, azimuth, impact parameter, bending angle (non-optimized)
    - Geometric height, refractivity
    - Geopotential height, P, T, e
- Overall quality indicator based on atmPrf ‘bad’ flag, radius of curvature
- Percent confidence for bending angle and refractivity
    - This is preliminary, based on atmPrf scalar quality indicators. A better PC vector is needed.
- Bending angle, impact parameter, lat, lon, azim and refractivity are smoothed with a window compatible with the output resolution and then interpolated.

CDAAC Data Distribution

- All data and products shared in real-time with TACC (Taiwan Analysis Center for COSMIC)
- Real-time distribution of BUFR files via NESDIS
- All data including Level 0 will be made available on the internet after the end of each day
- Ionospheric data products and distribution to be discussed in a separate presentation (Stig Syndergaard)
- Climate products will be made available weeks after data data collection
- FORMOSAT3/COSMIC Data Policy has been agreed to by NSPO and UCAR

CDAAC Summary

- Hardware is in place
- Software is mostly finished
- Data products and formats mostly finalized (Stig Syndergaard will talk about ionospheric products)
- CDAAC BUFR files are now flowing to NESDIS since Aug.18 05
- CDAAC data/result transfer to NSPO has been tested