### 1. Evolution of ion upwelling from soft electron precipitation

Cusp neutral density enhancements observed by CHAMP may be associated with ion upwelling from soft electron precipitation. (e.g. Sadler et al. 2012) An accurate time-line of the response of electron and ion response to soft precipitation facilitates understanding the subsequent effects on neutrals.

We distinguish between ion upwelling (lower altitude) and ion outflow (higher altitude) processes as described in the ion outflow literature. (See also Holroyd and Moore (1997) for a review.)

In general, the time evolution of ion upwelling from soft precipitation is described as follows:

- **Sufficiently soft electron precipitation (< ~500 eV)** initiates a strong upward plasma expansion above the F-region which increases with altitude. The precipitation quickly transfers energy to the ambient electron gas resulting in an electron temperature increase. The electron temperature increase is substantial and correlates to both decreasing electron energy and increasing electron energy flux. The electron gas subsequently increases a thermal (upward) expansion, establishing a vertical ambipolar field which pulls the ions upwards through the parallel electric field arising from the need for charge neutrality.

Model predictions of the temporal evolution of electron and ion upwelling response are given below. Published predictions are from Whittaker, 1977 Planet Science and Field, and Su et al. 1999 JGR. Both are one-dimensional, two-fluid, time-dependent models with inertial ion terms. Comparisons are made with model from Sadler et al. 2012, a two-dimensional, three-fluid model.

#### Electron temperature rise: 1.3 minutes

- **Whittaker 1977** shows quick $T_e$ rise to a higher asymptote
- **3-fluid model** shows quicker $T_e$ rise then fall to more typically observed values
- **Both models use “instant-on” electron precipitation (“eP”); full strength at t=0.**

#### Ions upward velocity increases: 3.5 minutes.
- **Su et al. 1999** shows large rise in $v_i$, followed by slower decrease (30 min. ramped eP)
- **3-fluid model** shows similar progression (eP “instant-on” at t=0)
- **Difficult to make direct comparisons due to ramped vs instant-on eP**
- **Su et al. 1999** shows gradual velocity decline: 30-60 minutes

Electron precipitation data from FAST provided input data for a 3D numerical simulation (based on OTTO 2002). Values of 4 mW/m^2 electron precipitation energy flux and 150 eV characteristic energy were used.

Model outputs for ion and neutral response to these inputs are shown in the following figures. Time evolution snapshots begin on the left with the solid line and progress every 22.5 seconds, generally to the right.

The first plot shows a very large ion acceleration, which at 800 km altitude results in a peak upward velocity of 2.35 km/s in only 2.7 minutes. (Average initial acceleration is approximately 15 m/s².) After this peak is reached, the velocity drops somewhat but still remains significant. Lower, at 400 km, the ion velocity rises and stabilizes more quickly to a somewhat modest 500 m/s. (Average initial acceleration is approximately 12 m/s².)

Ions upwelling data from two satellites, CHAMP and FAST, in conjunction over the dayside cusp region. (CHAMP in blue, FAST in red.)

### 2. Effect on Neutrals

The phenomenon of the density increase of thermospheric gas in the Earth’s magnetic cusp was reported by Luih et al. (QRL 2004) and was thought by those authors to be due to small-scale Joule heating in the cusp. Since that report was published, however, several other ideas have emerged which offer plausible explanations for this phenomenon.

Joule heating from the lower ionosphere / thermosphere was one popular idea. Ion upwelling effects from soft electron precipitation was suggested in Sadler et al. 2012, JASTP.

In-situ data was taken from two satellites, CHAMP and FAST, in conjunction over the dayside cusp region. (CHAMP in blue, FAST in red.)

Electron precipitation data from FAST provided input data for a 3D numerical simulation (based on OTTO 2002). Values of 4 mW/m^2 electron precipitation energy flux and 150 eV characteristic energy were used.

Model outputs for ion and neutral response to these inputs are shown in the following figures. Time evolution snapshots begin on the left with the solid line and progress every 22.5 seconds, generally to the right.

The first plot shows a very large ion acceleration, which at 800 km altitude results in a peak upward velocity of 2.35 km/s in only 2.7 minutes. (Average initial acceleration is approximately 15 m/s².) After this peak is reached, the velocity drops somewhat but still remains significant. Lower, at 400 km, the ion velocity rises and stabilizes more quickly to a somewhat modest 500 m/s. (Average initial acceleration is approximately 12 m/s².)

The upward neutral velocities are much smaller than the ions’, as expected, but still reach about 7.5 m/s at altitudes of 425 km and about 22 m/s at higher altitudes. Even though the neutral population generally outnumber that of the plasma, the momentum carried by up-flowing ions is significant and capable of dragging neutral gas upward. In this case, the term “drift” should be taken loosely to mean either elastic or inelastic collisions and include, for example, charge exchange.

The third plot shows the resulting change in neutral density (ratio of time-varying density vs. initial value). Physically, the upward neutral motion shifts the neutral column slightly higher which leads to a moderate density increase, in this case up to 1.5% to 3.5% of the original density in about 7 minutes. Since atmospheric density decreases with altitude on an exponential scale, raising even a small quantity of “dense” neutrals in a vertical column can produce a measurable effect at the higher altitude.

### 3. Future work – e-POP Satellite

Previous investigation of the cusp neutral density enhancement typically required satellite conjunctions to acquire appropriate in-situ measurements. The CHAMP satellite provided magnetometer, neutral density, and electron information within the enhancement event. However, satellite or rocket conjunctions were required to obtain plasma and other detailed information. Combining CHAMP data with FAST or DMRP conjunctions (for example) provided additional in-situ data, but at the expense of spatial impression and a limited selection of events to study.

The recent launch of the e-POP science payload (CASSIOPE satellite), should greatly improve this situation. Simultaneous, single-point measurements from a suite of plasma, neutral, and field instruments will allow study of the anomaly without spatial or temporal separation of the instruments. The elliptical orbit will carry instruments through the region at a range of altitudes where plasma and neutral parameters are theorized to vary considerably.

The e-POP science payload will carry a suite of 8 instruments.