Fairfield Public Schools Curriculum Proposal

Grade(s):	10, 11, 12
Discipline/Course:	Science/AP Physics 1
Course Title:	AP Physics 1
Prerequisite(s):	"B" or better in Algebra I and Geometry and concurrently enrolled or successful completion of Algebra II
Course Description: *Program of Studies*	The AP Physics I course is a university level course that focuses on the big ideas typically included in the first semester (and parts of a second semester) of an algebra-based, introductory college-level physics sequence and provides students with enduring understandings to support future advanced course work in the sciences. Through inquiry-based learning, students will develop critical thinking and reasoning skills, as defined by the AP Science Practices. Students will cultivate their understanding of physics and science practices as they explore the following topics: forces and interactions, momentum and energy, circular motion and rotation, harmonic motion and waves (I) and electricity (I). This course requires that 25 percent of the instructional time will be spent in hands-on laboratory work, with an emphasis on inquiry-based investigations that provide students with opportunities to apply the science practices. Students in AP Physics I are learners with demonstrated mathematical and problem-solving ability. Students wishing to prepare for the AP Physics II examination should take AP Physics I and AP Physics II.
Course Essential Questions:	● What are forces? ● How can they describe the interactions between or among objects? ● How do interactions between systems change those systems? ● How are changes that occur as a result of interactions explained by conservation laws? ● What are the constraints of those changes?

Course Enduring Understandings:	Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis. Big Idea 2 - Interactions: Objects and system interactions can be described using concepts such as force and energy. Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system. Big Idea 4 - Conservation: Changes that occur because of interactions are constrained by conservation laws.
AP Science Practices	AP Science Practices Science Practice 1: Creating Representations Create representations that depict physical phenomena. 1.A Create diagrams, tables, charts, or schematics to represent physical situations. 1.B Create quantitative graphs with appropriate scales and units, including plotting data. 1.C Create qualitative sketches of graphs that represent features of a model or the behavior of a physical system. Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena. 2.A Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway. 2.B Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.

	2.C Qualitatively compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario. 2.D Quantitatively predict new values or factors of change of physical quantities when variables are changed using the functional dependence between variables. Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims. 3.A Create experimental procedures that are appropriate for a given scientific question. 3.B Identify and describe possible sources of experimental uncertainty. 3.C Apply an appropriate law, definition, theoretical relationship, or model to make a claim. 3.D Support a claim using evidence from experimental data, physical representations, or physical principles or laws.
Duration:	Full year/1.0 credit
Course Materials/ Resources:	*Proposed Textbook: Knight, Randall D., Brian Jones, and Stuart Field. 2023. College Physics: A Strategic Approach. 4e ed., AP® ed. Boston: Pearson*
FPS Course Academic Expectation(s):	**Synthesizing and Evaluating** **Conveying Ideas**
Year at a Glance (Units)	**Unit 1: Kinematics** **Unit 2: Force and Translational Dynamics** **Unit 3: Work, Energy, and Power** **Unit 4: Linear Momentum** **Unit 5: Torque and Rotational Dynamics** **Unit 6: Energy and Momentum of Rotating Systems** **Unit 7: Oscillations** **Unit 8: Fluids**

Unit Number and Title:	Unit 1: Kinematics
Unit Overview:	The world is in a constant state of motion. To understand the world, students must first understand movement. Unit 1 introduces students to the study of motion and serves as a foundation for all of AP Physics 1 by beginning to explore the complex idea of acceleration and showing them how representations can be used to model and analyze scientific information as it relates to the motion of objects. By studying kinematics, students will learn to represent motion—both uniform and accelerating—in narrative, graphical, and/or mathematical forms and from different frames of reference. These representations will help students analyze the specific motion of objects and systems while also dispelling some common misconceptions they may have about motion, such as exclusively using negative acceleration to describe an object slowing down. Additionally, students will have the opportunity to go beyond their traditional understanding of mathematics. Instead of solving equations, students will use them to support their reasoning and tighten their grasp on the laws of physics. Lastly, students will begin making predictions about motion and justifying claims with evidence by exploring the relationships between the physical quantities of acceleration, velocity, position, and time. This is an important starting point for students, as these fundamental science practices will spiral throughout the course and appear in multiple units
Standard(s):	1.1 Position, Velocity, and Acceleration ● VectorMeasurements of displacement and velocity ● Vector addition and subtraction ● Systems of directional designations ● Acceleration and related quantities ● Relative Velocity 1.2 Representations of Motion ● Gravitational Acceleration ● Vector Addition Using Pythagorean theorem, law of sines and cosine law

	• Projectile motion Science Practices: • Science Practice 1: Creating Representations Create representations that depict physical phenomena • Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena. • Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims.
Essential Question(s):	• What happens when systems of objects interact? • How do we describe the interaction of an object with other objects?
Enduring Understandings	Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis. Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system.
Learning Goal(s): *Students will be able to use their learning to:*	1.1.A Describe a vector or scalar quantity using magnitude and direction, as appropriate. 1.1.B Describe a vector sum in one dimension. 1.2.A Describe a change in an object's position. 1.2.B Describe the average velocity and acceleration of an object. 1.2.C Describe the displacement, instantaneous velocity, and acceleration of an object as functions of time. 1.3.A Describe the position, velocity, and acceleration of an object using representations of that motion. 1.4.A Describe the reference frame of a given observer. 1.4.B Describe the motion of objects as measured by observers in different inertial reference frames. 1.5.A Describe the perpendicular components of a vector quantity. 1.5.B Describe the motion of an object moving in two dimensions.

Unit Number and Title:	Unit 2: Force and Translational Dynamics
Unit Overview:	In Unit 2, students are introduced to the term force, which is the interaction of an object with another object. Part of the larger study of dynamics, forces are used as the lens through which students analyze and come to understand a variety of physical phenomena. This is accomplished by revisiting and building upon the representations presented in Unit 1, specifically the introduction to the free-body diagram. Translation, however, is key in this unit: Students must be able to portray the same object–force interactions through different graphs, diagrams, and mathematical relationships. Students will continue to make meaning from models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change. Alongside mastering the use of specific force equations, Unit 2 also encourages students to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. The skill of making predictions will be nurtured throughout the course to help students craft sound scientific arguments. Further in Unit 2, students will continue to enhance their understanding of the physical world using models and representations to create a more complete and complex model of motion, particularly as it relates to gravitational mass and inertial mass. Specific preconceptions will be addressed in this unit, such as the idea of a centrifugal force. Students will also have opportunities to wrestle with the idea of field models, which will be expanded upon in AP Physics 2.
Standard(s):	2.1: Systems and Center of Mass 2.2: Forces and FreeBody Diagrams 2.3: Newton's Third Law 2.4: Newton's First Law 2.5: Newton's Second Law 2.6: Gravitational Force 2.7: Kinetic and Static Friction 2.8: Spring Forces

	2.9: Inertial and Gravitational Mass 2.10: Circular Motion Science Practices: ● Science Practice 1: Creating Representations Create representations that depict physical phenomena ● Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena. ● Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims.
Essential Questions:	● What are forces? How can they describe the interactions between or among objects? ● How does the Law of Universal Gravitation govern the interaction of objects in the universe?
Enduring Understandings:	Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis. Big Idea 2 - Interactions: Objects and system interactions can be described using concepts such as force and energy. Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system.
Learning Goal(s): *Students will be able to use their learning to:*	2.1.A Describe the collection of objects that will be analyzed as a system. 2.1.B Describe the location of a system's center of mass with respect to the system's constituent parts. 2.1.C Describe the properties of a system based on its substructure. 2.2.A Describe a force as an interaction between two objects and identify both objects for any force. 2.2.B Describe the forces exerted on an object using a free-body diagram. 2.3.A Describe the interaction of two objects using Newton's third law and the representation of paired forces exerted on each object. 2.4.A Describe or identify the conditions under which a system's velocity remains constant.

	2.5.A Describe or identify the conditions under which a system's velocity changes. 2.6.A Describe the gravitational interaction between two objects with mass. 2.6.B Describe situations in which the gravitational force can be considered constant. 2.6.C Describe the conditions under which the magnitude of a system's apparent weight is different from the magnitude of the gravitational force exerted on that system. 2.7.A Describe kinetic friction between two surfaces 2.7.B Describe static friction between two surfaces. 2.8.A Describe the force exerted on an object by an ideal spring. 2.9.A Describe the differences between inertial mass and gravitational mass. 2.10.A Describe the motion of an object traveling in a circular path. 2.10.B Describe circular orbits using Kepler's third law.

Unit Number and Title:	Unit 3: Work, Energy, and Power
Unit Overview:	In Unit 3, students will be introduced to the idea of conservation as a foundational model of physics, along with the concept of work as the agent of change for energy. As in earlier units, students will once again utilize both familiar and new models and representations to analyze physical situations, now with force or energy as major components. Students will be encouraged to call upon their knowledge of Units 1–3 to determine the most appropriate technique and will be challenged to understand the limiting factors of each. Describing, creating, and using these representations will also help students grapple with common misconceptions that they may have about energy, such as whether or not a single object can "have" potential energy. A thorough understanding of these energy models will support students' ability to make predictions—and ultimately justify claims with evidence—about physical situations. This is crucial, as the mathematical models and representations used in Unit 3 will mature throughout the course and appear in subsequent units. As students' comprehension of energy (particularly kinetic, potential, and microscopic internal energy) evolves, they will begin to connect and relate knowledge across scales, concepts, and representations, as well as across disciplines, particularly physics, chemistry, and biology.

Standard(s):	3.1: Translational Kinetic Energy 3.2: Work 3.3: Potential Energy 3.4: Conservation of Energy 3.5: Power Science Practices: ● Science Practice 1: Creating Representations Create representations that depict physical phenomena ● Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena. ● Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims.
Essential Questions:	● How can we use models to illustrate that energy can be accounted for as a combination of energy associated with the motion of particles and the energy associated with the relative position of particles? ● How can we model the change in energy of one component of the system when the change in energy of the other component(s) and of the system are known? ● How can we use energy to predict the motion or displacement of objects?
Enduring Understandings:	Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis. Big Idea 2 - Interactions: Objects and system interactions can be described using concepts such as force and energy. Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system. Big Idea 4 - Conservation: Changes that occur because of interactions are constrained by conservation laws.

Learning Goal(s): *Students will be able to use their learning to:*	3.1.A Describe the translational kinetic energy of an object in terms of the object's mass and velocity. 3.2.A Describe the work done on an object or system by a given force or collection of forces. 3.3.A Describe the potential energy of a system. 3.4.A Describe the energies present in a system. 3.4.B Describe the behavior of a system using conservation of mechanical energy principles. 3.4.C Describe how the selection of a system indicates whether the energy of that system changes 3.5.A Describe the transfer of energy into, out of, or within a system in terms of power

Unit Number and Title:	Unit 4: Linear Momentum
Unit Overview:	Unit 4 introduces students to the relationship between force, time, and momentum via calculations, data analysis, designing experiments, and making predictions. Students will learn how to use new models and representations to illustrate the law of the conservation of momentum of objects and systems while simultaneously building on their knowledge of previously studied representations. Using the law of the conservation of momentum to analyze physical situations gives students a more complete picture of forces and leads them to revisit their misconceptions surrounding Newton's third law. Students will also have the opportunity to make connections between the conserved quantities of momentum and energy to determine under what conditions each quantity is conserved. It's essential that students are not only comfortable solving numerical equations (such as the speed of a system after an inelastic collision) but also confident in their ability to discuss when momentum is conserved and how the type of collision affects the outcome. Threading such connections between physical quantities is fundamental to understanding the broader relationship between this unit and the rest of the course. Students will have more opportunities to apply conservation laws to make predictions and justify claims in Unit 6 when they are introduced to rotational quantities.
Standard(s):	4.1: Linear Momentum 4.2: Change in Momentum and Impulse

	4.3: Conservation of Linear Momentum 4.4: Elastic and Inelastic Collisions Science Practices: ● Science Practice 1: Creating Representations Create representations that depict physical phenomena ● Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena. ● Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims.
Essential Questions:	● How are impulse and momentum related?
Enduring Understandings:	Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis. Big Idea 2 - Interactions: Objects and system interactions can be described using concepts such as force and energy. Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system. Big Idea 4 - Conservation: Changes that occur because of interactions are constrained by conservation laws.
Learning Goal(s): *Students will be able to use their learning to:*	4.1.A Describe the linear momentum of an object. 4.2.A Describe the impulse delivered to a system. 4.2.B Describe the relationship between the impulse given to a system and the change in momentum of the system. 4.3.A Describe the behavior of a system using conservation of linear momentum. 4.3.B Describe how the selection of a system indicates whether the momentum of that system changes. 4.4.A Describe whether an interaction between systems is elastic or inelastic.

Unit Number and Title:	Unit 5: Torque and Rotational Dynamics
Unit Overview:	Units 5 and 6 continue the study of mechanical physics by introducing students to torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same: The content and models explored in the first six units of AP Physics 1 set the foundation for Units 5 and 6. During their study of torque and rotational motion, students will be confronted with different ways of thinking about and modeling forces. As in previous units, students are given opportunities to create and use representations and models to make predictions and justify claims. Students derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. Units 5 and 6 also focus on the mathematical practice of estimating quantities that can describe natural phenomena. For example, students need to be able to estimate the torque on an object caused by various forces in comparison to other situations. Throughout these units, students will have opportunities to compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to make meaning of these concepts as a whole, rather than as distinct and separate units.
Standard(s):	5.1: Rotational Kinematics 5.2: Connecting Linear and Rotational Motion 5.3: Torque 5.4: Rotational Inertia 5.5: Rotational Equilibrium and Newton's First Law in Rotational Form 5.6: Newton's Second Law in Rotational Form Science Practices: ● Science Practice 1: Creating Representations Create representations that depict physical phenomena ● Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena.

	• Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims.
Essential Questions:	• How does circular motion differ from linear motion? • How can we use rotational dynamics to predict rotational motion? • How does exerting a torque affect an object's motion?
Enduring Understandings:	Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis. Big Idea 2 - Interactions: Objects and system interactions can be described using concepts such as force and energy. Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system.
Learning Goal(s): *Students will be able to use their learning to:*	5.1.A Describe the rotation of a system with respect to time using angular displacement, angular velocity, and angular acceleration. 5.2.A Describe the linear motion of a point on a rotating rigid system that corresponds to the rotational motion of that point, and vice versa. 5.3.A Identify the torques exerted on a rigid system. 5.3.B Describe the torques exerted on a rigid system. 5.4.A Describe the rotational inertia of a rigid system relative to a given axis of rotation. 5.4.B Describe the rotational inertia of a rigid system rotating about an axis other than a rotational axis that passes through the system's center of mass. 5.5.A Describe or identify the conditions under which a system's angular velocity remains constant using a dynamics analysis. 5.6.A Describe or identify the conditions under which a system's angular velocity changes using a dynamics analysis.

Unit Number and Title:	Unit 6: Energy and Momentum of Rotating Systems
Unit Overview:	Units 5 and 6 continue the study of mechanical physics by introducing students to torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same: The content and models explored in the first six units of AP Physics 1 set the foundation for Units 5 and 6. During their study of torque and rotational motion, students will be confronted with different ways of thinking about and modeling forces. Students are given opportunities to create and use representations and models to make predictions and justify claims. Students will become comfortable deriving new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. Units 5 and 6 also focus on the mathematical practice of estimating quantities that can describe natural phenomena. For example, students need to be able to estimate the torque on an object caused by various forces in comparison to other situations.
Standard(s):	6.1: Rotational Kinetic Energy 6.2: Torque and Work 6.3: Angular Momentum and Angular Impulse 6.4: Conservation of Angular Momentum 6.5: Rolling 6.6: Motion of Orbiting Satellites Science Practices: ● Science Practice 1: Creating Representations Create representations that depict physical phenomena ● Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena. ● Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims.
Essential Questions:	● How are angular acceleration, angular momentum and torque related?

Enduring Understandings:	Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis. Big Idea 2 - Interactions: Objects and system interactions can be described using concepts such as force and energy. Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system. Big Idea 4 - Conservation: Changes that occur because of interactions are constrained by conservation laws.
Learning Goal(s): *Students will be able to use their learning to:*	6.1.A Describe the rotational kinetic energy of an object or rigid system in terms of the object's or rigid system's rotational inertia and angular velocity. 6.2.A Describe the work done on an object or system by a given torque or collection of torques. 6.3.A Describe the angular momentum of an object or rigid system. 6.3.B Describe the angular impulse delivered to an object or rigid system by a torque. 6.3.C Relate an object's or rigid system's change in angular momentum to the angular impulse given to the object or rigid system. 6.4.A Describe the behavior of a system using conservation of angular momentum. 6.4.B Describe how the selection of a system indicates whether the angular momentum of that system changes. 6.5.A Describe the kinetic energy of a system that has translational and rotational motion. 6.5.B Describe the motion of a system that is rolling without slipping. 6.5.C Describe the motion of a system that is rolling while slipping. 6.6.A Describe the motions of an isolated object system consisting of two objects interacting only via gravitational forces.

Unit Number and Title:	Unit 7: Oscillations

Unit Overview:	In Unit 7, students will continue to use the same tools, techniques, and models that they have been using throughout this course. However, they will now use them to analyze a new type of motion: simple harmonic motion. Although simple harmonic motion is unique, students will learn that even in new situations, the fundamental laws of physics remain the same. Energy bar charts, as well as free-body diagrams, become increasingly important as students work toward determining which model is most appropriate for a given physical situation. Preconceptions—such as the relationship between the amplitude and period of oscillation—will also be addressed to provide students with a more nuanced awareness of simple harmonic motion. Students are expected to use the content knowledge they gained in the first six units to make and defend claims while also making connections in and across the content topics and big ideas. Because Unit 7 is the first unit in which students possess all the tools of force, energy, and momentum conservation, it's important that teachers scaffold lessons to help them develop a better understanding of each fundamental physics principle as well as its limitations. Throughout this unit, students will be asked to create force, energy, momentum, and position versus time graphs for a single scenario and to make predictions based on their representations. Students will enhance their study of motion when they learn about oscillatory motion in AP Physics 2.
Standard(s):	7.1: Defining Simple Harmonic Motion (SHM) 7.2: Frequency and Period of SHM 7.3: Representing and Analyzing SHM 7.4: Energy of Simple Harmonic Oscillators Science Practices: ● Science Practice 1: Creating Representations Create representations that depict physical phenomena ● Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena. ● Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims.

Essential Questions:	● What properties affect the motion of an object in SHM? ● How can SHM be modeled as a wave? ● How do waves interact with each other? ● How are the principles of wave behavior and interactions with matter used to transmit and capture information and energy?
Enduring Understandings:	Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis. Big Idea 2 - Interactions: Objects and system interactions can be described using concepts such as force and energy. Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system. Big Idea 4 - Conservation: Changes that occur because of interactions are constrained by conservation laws.
Learning Goal(s): *Students will be able to use their learning to:*	7.1.A Identify simple harmonic motion. 7.2.A Describe the frequency and period of an object exhibiting simple harmonic motion. 7.3.A Describe the displacement, velocity, and acceleration of an object exhibiting SHM using representations of that motion. 7.4.A Describe the mechanical energy of a system exhibiting SHM.

Unit Number and Title:	Unit 8: Fluids
Unit Overview:	The unit provides a basic algebraic overview of the behavior of non-compressible Newtonian fluids. The unit covers static fluid behavior including buoyancy force calculations as well as hydraulics. It then moves on to dynamic fluid flow centered around the use of Bernoulli's equation as a representation of the conservation of energy of the fluid system.

<table>
<tr><td>Standard(s):</td><td>8.1: Internal Structure and Density
8.2: Pressure
8.3: Fluids and Newton's Laws
8.4: Fluids and Conservation Laws

Science Practices:
Science Practice 1: Creating Representations Create representations that depict physical phenomena
Science Practice 2: Mathematical Routines Conduct analyses to derive, calculate, estimate, or predict physical phenomena.
Science Practice 3: Scientific Questioning & Argumentation Describe experimental procedures and methods, interpret their results, and scientifically support claims.</td></tr>
<tr><td>Essential Questions:</td><td>What is the buoyancy force and how does it act on objects in various liquids?
How can we apply Bernoulli's equation to describe the conservation of energy in fluid flow?
How can we apply the continuity equation to describe conservation of mass in fluid flow?
What classical laws and principles define the behavior of fluids?</td></tr>
<tr><td>Enduring Understandings:</td><td>Big Idea 1 - Systems: A physical system is a portion of the physical universe chosen for analysis.
Big Idea 2 - Interactions: Objects and system interactions can be described using concepts such as force and energy.
Big Idea 3 - Change: Changes in the properties of a system can be used to predict future states of the system.
Big Idea 4 - Conservation: Changes that occur because of interactions are constrained by conservation laws.</td></tr>
<tr><td>Learning Goal(s):
Students will be able to use their learning to:</td><td>8.1.A Describe the properties of a fluid.
8.2.A Describe the pressure applied to a surface by a given force.
8.2.B Describe the pressure exerted by a fluid.</td></tr>
</table>

	8.3.A* Describe or identify the conditions under which an object's or system's velocity changes. 8.3.B Describe the buoyant force exerted on an object interacting with a fluid. 8.4.A Describe the flow of an incompressible fluid through a cross-sectional area by using mass conservation. 8.4.B Describe the flow of a fluid as a result of a difference in energy of the fluid-Earth system between two locations.